STAR Offline Simulations and Analysis Software Design

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STAR Collaboration

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R. Bossingham,[1] W. Christie,[2] T. LeCompte,[3]

M. Lisa,[1,4] W. J. Llope,[5] S. Margetis,[1]

C. Pruneau,[6] L. Ray,[7] I. Sakrejda,[1]

W. K. Wilson[6] and P. Yepes[5]

[1]Lawrence Berkeley National Laboratory
[2]Brookhaven National Laboratory
[3]Argonne National Laboratory
[4]Ohio State University
[5]Rice University
[6]Wayne State University
[7]University of Texas at Austin

Abstract

The STAR detector at the Relativistic Heavy-Ion Collider (RHIC) is a complex, multi-component detector system designed to study the hadronic particle production and electromagnetic energy production from high energy, nucleus + nucleus, proton + nucleus and proton + proton collisions. In support of the project a significant amount of online and offline software must be developed. This document describes the general design of the offline simulations, event reconstruction and calibration software. The offline software functions asynchronously with the experiment and its data acquisition (DAQ), hardware control (HC) and experiment control systems. Information is, of course, transmitted in both directions between offline computing and DAQ, HC and experiment control.

The purposes of the offline software described in this document are to provide the necessary functionality and data interfaces in order to carry out the following computations: (1) simulated event multiplicity generation, (2) simulated particle propagation, decay and secondary production, and energy deposition, (3) simulated detector response, (4) event reconstruction, (5) calibration, (6) software performance evaluation, (7) efficiency and acceptance calculations, (8) trigger simulation, and (9) physics analysis. The design of the latter four will be completed at a later date. The offline infrastructure software necessary for the efficient functioning of the large scale, offline computing system (*e.g.* event servers, data catalogs, production control, production monitoring, etc.) is not part of the software design presented here. The general hardware model for the offline computing system has been described in other reports (*e.g.* the RHIC Computing Facility Proposal - 1996). This document should be regarded as a living document that will evolve from a description of the general software design to an overview documentation of the actual, implemented software.

Contents

1 Introduction

Prototype development of simulation and event reconstruction offline software for STAR has been underway for several years and an impressive library of software has been developed and used in designing the detectors and in determining the detection and reconstruction capabilities of STAR for each of the many, predicted signals of quark-gluon plasma (QGP) formation and/or chiral symmetry restoration (CSR) that might occur in ultrarelativistic heavy-ion collisions. The purpose of the present document is to specify the basic requirements of the offline software for STAR, to describe in a general way the essential functionality of the software algorithms, and to identify and define the major data structure interfaces. The design results presented here draw heavily on the considerable experience gained during the past few years using the prototype software.

The goal of the present design effort is to develop a framework to which existing software can be readily adapted and in which new software tasks are readily identified and described, such that the STAR software effort is facilitated and such that the physics goals of the STAR experiment can be more readily achieved given the limited manpower resources for STAR software development. While the authors of this report have made every effort to identify all essential functionality of the offline software, it is inevitable that additional functionality and data information will be required as the software continues to develop. The present design framework is intended to be flexible and amenable to change. Also, in specifying the required functionality of the software we have not, as the reader will see, fully described the actual algorithms, data objects or runtime control scripts which constitute the actual implementation of this design plan. We have, of necessity, left plenty of room for original contributions.

It is intended that this document will evolve in parallel with the actual software, both guiding its development and documenting its overall structure. Upon completion, this document will provide an overview and top-level description of the actual offline software for STAR.

The purposes of the offline software described here are:

1. To simulate the particle production from nucleus + nucleus, proton + nucleus, and proton + proton collisions, as well as that from background sources and from special calibration procedures.

2. To simulate the propagation, scattering, energy deposition, decay and secondary particle production throughout the detector from all the preceding sources of particle production, in both the active and inactive parts of the detector.

3. To simulate the physical (ionization, charge drift and collection, light production and propagation, photo-electron production, etc.) and electronic (pre-amp, shaper, analog-to-digital conversion (ADC), time sampling, etc.) response of each detector to the passage of ionizing particles and energy deposition in the active portions of the detectors.

4. To realistically simulate fluctuations and non-uniformities in order to facilitate the development of calibration and correction procedures and software.

5. To reconstruct the collision event from either the simulated or real data to a sufficient extent that the physics goals of STAR and the physics capabilities of the subdetectors can be realized.

6. To analyze calibration and correction data, both simulated and real, in order to provide corrections which remove the effects of instrumental fluctuations and non-uniformities from the data.

7. To sufficiently evaluate and visualize the results to determine the adequacy and correctness of the simulation, event reconstruction, calibration and physics analysis software.

8. To simulate, analyze, evaluate and develop trigger algorithms which can be used in the on-line trigger system.

9. To generate acceptance and reconstruction efficiency tables.

10. To extract physics results from the reconstructed, corrected collision event data suitable for publication and reporting.

The requirements of the offline software are driven by the physics goals of STAR and by the performance capabilities of the various detectors. However, detailed specification of the required performance of a given software component is quite difficult. For example, the performance of the TPC event reconstruction software can be measured in terms of track finding efficiency, tracking purity, momentum resolution, impact parameter resolution, particle identification accuracy and efficiency, two-track resolution, etc. For each performance criteria the requirements vary considerably depending on the physics issue being considered. Temperature and mean p_T determination, for example, is not particularly demanding of the tracking software whereas strange particle reconstruction (V0 decays) and Hanbury-Brown and Twiss (HBT) interferometry analyses are very demanding of the software and place high performance criteria on most aspects of TPC tracking. The varied physics goals of STAR impose a wide range of performance requirements on the software.

In general, the goal of the offline software development is to achieve the full performance capabilities of the detector hardware. However, given the limited manpower of the STAR software group and the inevitable limitation in computing resources that will be available, we will be forced to specify the minimum acceptable criteria for the software algorithms and work to achieve this level consistently throughout the system. Minimum performance criteria and requirements will be discussed in each of the following sections.

2 Description of the Document

The design and description of the offline software presented here is in the form of functional model or data flow diagrams, supplemented where necessary with traditional execution sequence diagrams (*i.e.* flow charts). The diagrams indicate the necessary computational processes, data flows and data stores (generalized data structures). The diagrams contain a unique list of all the essential computational processes we envision being required for the STAR offline software. Data objects are often repeated throughout the document. Unique data object diagrams are not included in this document at this time. The functional diagrams indicate the computational processes and the data input, output and update for each process. It is important for the reader to understand that these diagrams are *not* flow charts. The latter, when needed for clarity, are shown in separate diagrams.

To organize the substantial amount of software involved, the essential functionality has been separated into six separate branches with each sub-detector appearing as a separate sub-level under most of the main branches. The purpose is to collect similar functionality among the different detectors into the same branch. This also helps keep the lowest level design diagrams uncluttered and less confusing. The six branches are:

1. **Simulations** – includes event generators, GEANT, GEANT to data structure translation, detector specific microscopic (slow) and parametrized (fast) response simulations, and direct or very fast simulators.

2. **Event Reconstruction** – includes all detector specific space point reconstruction, tracking, dE/dx, particle identification (PID), energy determination, and global event summary with calibration and corrections input.

3. **Calibration and Corrections** – includes calculation and determination of all calibration and correction quantities used in the offline analysis.

4. **Evaluation and Visualization** – includes Monte Carlo evaluation of simulation, event reconstruction, calibration, physics analysis and offline trigger software; also includes generation of acceptances and efficiency tables, event displays, offline monitoring and event visualization software.

5. **Physics Analysis** – includes software which acts on DSTs to produce final, publishable physics results.

6. **Offline Trigger** – includes the offline version of the trigger software that runs online.

The naming convention adopted for the main branches and all sub-branches is the standard UNIX hierarchical path notation. The present software in the STAR library does not completely follow this hierarchical structure. The naming convention presented in this document applies, at present, only to this document. The hierarchy for the organization of the offline software is shown in Tables I - V.

The software design is presented as follows. Each branch section begins with a general description and list of requirements, followed by a top level functional model diagram, with an accompanying glossary which defines the processes, data stores and data flows. Similar organization is followed for the sub-branches, where much more specific description, requirements and glossaries are included. In many instances the sub-branches listed in Tables I - V are further subdivided. For the lowest level diagrams an optional flow chart may also be given.

We have adopted the design methodology and notation of Rumbaugh *et al.* [1] for the functional model diagrams. The main symbols used in the diagrams are:

1. *Computational Process* – represented by an ellipse.
2. *Data Store* – represented by two, parallel horizontal lines.
3. *Data Flow* – represented by a solid line with arrow head indicating the direction of data flow; read/write capability indicated by solid lines with arrow heads at both ends.

The STAR offline software implementation now, and as envisioned for the final version, consists of (1) **analysis modules** which carry out the computational processes indicated in the diagrams, (2) **managed data structures** or **tables** which contain the information shown by the data store symbols on the diagrams, (3) **local variables** within analysis modules which include the data shown in the diagrams by the data flow lines, and (4) **run-time procedural scripts** (*e.g.* in the KUIP or TCL command languages) which control the flow of execution of the modules, handles data I/O, connects tables to HBOOK, fills histograms, etc. The latter are partially indicated in (optional) flow charts with each section or on the functional model diagrams, by dashed lines with arrows which indicate the order of execution. Branching points in the execution sequence are indicated by the usual 'diamond' symbol.

For this application to the STAR offline software we define "data stores" as being those data which are kept in managed data structures (tables), held in a data base, or loaded in a storage media (tapes, disks, etc.). Data flow lines between two processes, in this application, indicate data passed within a module via local variables defined within a module at run time. Data stores in the diagrams do not necessarily correspond one-to-one with defined data structure tables, either at present or in the final implementation. However, as the software evolves and as many of the data stores are realized as actual data structures, this documentation should also evolve to match the real data structure definitions.

The computational processes, symbolized by "bubbles," are to be carried out by user written analysis modules. The processes in the diagrams do not necessarily correspond, one-to-one, with the analysis modules that currently exist or with those in the final implementation. In some cases the essential functionality that is, or will be, carried out by one module is represented by several process bubbles. In other cases the opposite situation occurs.

The details of the offline software functional model and data flow model design are presented in sections 4, 5 and 6. At present these include simulation, event reconstruction and calibration offline software only. Evaluation, physics analysis and offline trigger software branches will be included at a later date. Each section begins with a general description and discussion of requirements, followed by the detailed detector specific model, according to the outline presented in Tables I-V.

Table I: Offline software hierarchy for /sim branch.

Main Branch	Sub-Branch	Description
/sim	/geometry	STAR Geometry and Materials
	/magnet	STAR Magnetic Field
	/evg	Event Generators
	/geant/gstar	STAR GEANT
	/det/tpc	Fast and Slow TPC Simulators
	/det/svt	Fast and Slow SVT Simulators
	/det/ctf	CTB and TOF simulators
	/det/emc	Fast and Slow Barrel and End Cap EMC Simulators; Towers and Shower Maximum Detector
	/det/ftpc	Fast and Slow Forward TPC Simulator
	/det/mwc	MWC Simulator
	/det/vpd	VPD Simulator
	/det/vtc	Zero-degree Calorimeter Simulator
	/vfs	Very Fast Simulators

Table II: Offline software hierarchy for /ana branch.

Main Branch	Sub-Branch	Description
/ana	/tpc	Event Reconstruction for TPC
	/svt	Event Reconstruction for SVT
	/ctf	Event Reconstruction for CTB and TOF
	/emc	Event Reconstruction for EMC Barrel and End Cap; Towers and Shower Maximum Detector
	/ftpc	Event Reconstruction for FTPC
	/mwc	Event Reconstruction for MWC
	/vpd	Event Reconstruction for VPD
	/vtc	Event Reconstruction for VTC
	/global	Global Event Reconstruction

Table III: Offline software hierarchy for /cal branch.

Main Branch	Sub-Branch	Description
/cal	/magnet	Calibration and Corrections for Magnetic Field
	/tpc	Calibration and Corrections for TPC
	/svt	Calibration and Corrections for SVT
	/ctf	Calibration and Corrections for CTB and TOF
	/emc	Calibration and Corrections for EMC Barrel and End Cap; Towers and Shower Maximum Detector
	/ftpc	Calibration and Corrections for FTPC
	/mwc	Calibration and Corrections for MWC
	/vpd	Calibration and Corrections for VPD
	/vtc	Calibration and Corrections for VTC
	/global	Calibration and Corrections for Global Event Reconstruction

Table IV: Offline software hierarchy for /evl branch.

Main Branch	Sub-Branch	Description
/evl	/tpc	Evaluation for TPC
	/svt	Evaluation for SVT
	/ctf	Evaluation for CTB and TOF
	/emc	Evaluation for EMC Barrel and End Cap; Towers and Shower Maximum Detector
	/ftpc	Evaluation for FTPC
	/mwc	Evaluation for MWC
	/vpd	Evaluation for VPD
	/vtc	Evaluation for VTC
	/global	Evaluation for Global Event Reconstruction
	/trigger	Evaluation for Offline Trigger
	/viz	Event Displays and Visualization

Table V: Offline software hierarchy for /trg branch.

Main Branch	Sub-Branch	Description
/trg	/L0	Level 0 Offline Trigger
	/L1	Level 1 Offline Trigger
	/L2	Level 2 Offline Trigger
	/L3/tpc	Level 3, TPC Offline Trigger
	/L3/svt	Level 3, SVT Offline Trigger
	/L3/ctf	Level 3, TOF Offline Trigger
	/L3/emc	Level 3, Barrel and End Cap Offline Trigger
	/L3/ftpc	Level 3, Forward TPC Offline Trigger
	/L3/global	Level 3, Global Offline Trigger

3 Overview

An overview of the data flow model in which the offline software discussed in this document exists is shown in Fig. 1. Raw event data, online calibration constants and simulations data are stored at the processor farm. An event selector/server extracts the set of events for analysis and puts these data into hierarchical data structures which are accessed by the offline calibration, event reconstruction and trigger software. In general the area of software addressed in this design document is that part shown below the horizontal, dotted line in Fig. 1. However, the description of physics analysis, DST content, Micro-DST production and data are not very well known at present. The data interfaces between the offline software discussed here and the outside world are contained in the two data stores labelled 'Selected Raw Data' and 'Simulations Data.' The six branches of offline software are shown in the lower portion of Fig. 1.

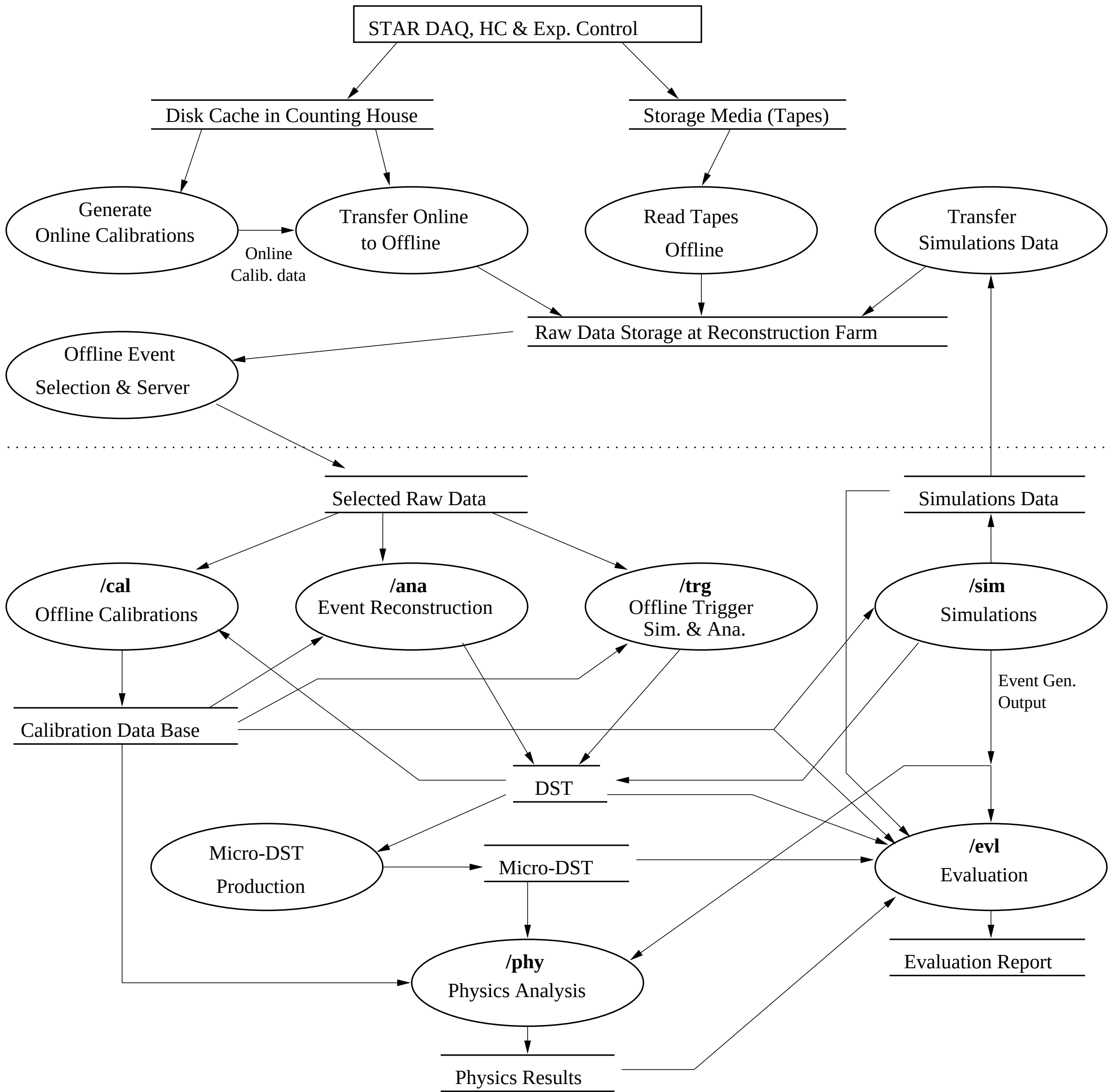

Figure 1: Data flow model and context diagram for STAR Offline Software.

4 Simulation Software (/sim)

The simulation software for STAR describes event generation, particle propagation in the detector, and detector response. The first category includes stand-alone event generator codes written by experts in the field as well as phenomenological multiplicity generators used to study detector sensitivity and efficiency and trigger algorithms. Simulation software in the second category describes particle propagation, secondary production including delta-electrons, particle decays, multiple Coulomb scattering, hadronic interactions, energy deposition and loss, etc. occurring as the particles produced in collisions and from background sources propagate through the detector. This software is embodied in the STAR implementation of GEANT [2], called GSTAR [3]. The third category is the sole responsibility of the STAR software group and will be discussed in detail for each sub-detector in the following subsections.

The STAR detector simulation software is required to simulate the physical and electronic response of each active detector in STAR to all types of particle production processes anticipated during the development and operation of STAR. These include: (1) particle production from pp, pA and AA collisions for many events, with possibly multiple collision vertices for pA and AA and with very many vertices for pp collisions, (2) cosmic rays both as background and for development testing and calibration procedures, (3) beam-gas particle production background, (4) radioactive sources for calibration, (5) laser sources for calibration, (6) charge injection and wire pulsing for testing electronics, and other calibration procedures described in section 6.

The response of the entire STAR detector to particle production from pp, pA and AA collisions, from stray backgrounds, and from calibration procedures must be calculated and understood in order to provide simulated data with which to develop event reconstruction software, optimize detector design, test and develop DAQ, test and develop calibration procedures and software, test and develop trigger algorithms and software, compute detector efficiencies and acceptances, and develop physics analysis software.

The detector simulation software is required to match the actual detector in both its physical and electronics characteristics as the design evolves and finalizes, since evaluation of detector performance and calculation of efficiencies and acceptances are ongoing tasks which will continue well after the detector construction phase is complete. The level of detail to which the software should simulate the detectors is determined by its ultimate effect on deduced physics results.

The following subsections include the functional model designs for STAR geometry (/geometry), magnetic field (/magnet), event generators (/evg), STAR GEANT (/geant/gstar), and detector specific simulation (/det/tpc, etc.).

4.1 STAR Geometry (/sim/geometry)

This section contains a description, list of requirements, functional model diagram (Fig. 2), glossary of terms, and status of software report. A detailed document describing the GSTAR geometry description, as implemented in the Advanced Geometry Interface (AGI) meta-language of Pavel Nevski, will be provided in the near future.

Description:

The definitions and descriptions of the STAR detector geometry for use in GSTAR simulations, detector response simulations, event reconstruction, calibration, physics analysis and event visualization will be stored in a common data base which is maintained in agreement with engineering design documentation, with the actual engineering measurements and surveys, and with current alignment software corrections. Since the specific needs of GSTAR simulations and the analysis codes are different, intermediate processes are required to translate the data base information into suitable format for use by GSTAR and the user developed simulation and analysis codes.

Geometry and materials information for STAR resides in (1) engineering design documents, (2) survey measurements and (3) calculated position and orientation corrections from alignment software analyses. All of these data sources are accessed by the processes described in this section with appropriate updating of the STAR Geometry Data Base. Processes which generate the software alignment corrections are described in various subsections of the Calibrations and Corrections (/cal) section of this document.

In order to describe the geometrical configuration of STAR with its many detector subsystems, a number of coordinate systems are required. Each tracking detector (TPC, SVT and FTPC) has its own local coordinate system (*e.g.* TPC Internal Coordinate System) defined with respect to physical reference points (*i.e.* survey marks) on the support structure. The global, STAR Coordinate System will be defined with respect to the magnet. Alignment analyses for each tracking detector will be carried out internally in each respective local coordinate system. Global alignment software will correct the position of the tracking detector's local coordinate system as well as the positions of the CTF slats, EMC towers and SMD grids.

Requirements:

The STAR geometry software is required to:

1. Make avaiable to a widely accessible STAR Geometry Data Base accurate descriptions (to within engineering tolerances) of the geometry and composition of the physical detector and relevant surrounding environment for a variety of design versions and for a variety of actual implementation scenarios.

2. Provide actual, survey measurement data to both simulations and analysis software.

3. Make available up-to-date position and orientation corrections from software alignment calibration analyses to the simulation software.

4. Handle a variety of detector and hardware configurations.

5. Provide the same geometry and materials information for both simulations and analysis software.

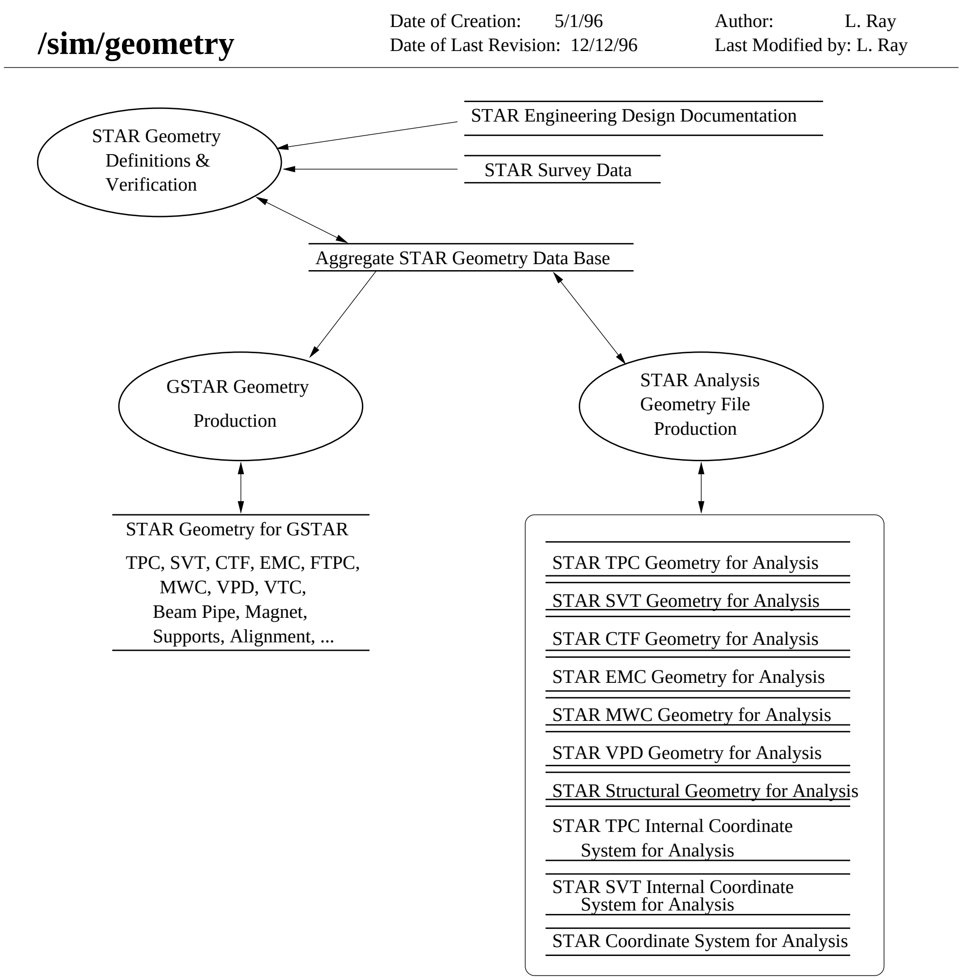

Figure 2: STAR Geometry and Materials Software

Glossary of Terms:

Processes:

STAR Geometry Definitions and Verification – Process by which the geometry and materials parameters of the various engineering designs and the actual construction scenarios as well as the survey data are stored and/or updated in the data base. Nominal and survey values are both handled.

GSTAR *Geometry Production* – Process by which the STAR Geometry Data Base is accessed and used to generate or update geometry files for input into GSTAR. Currently this is being implemented using the Advanced Geometry Interface (AGI) meta-language of Pavel Nevski; details will be reported elsewhere. Nominal design, actual surveyed, and alignment software corrected position and orientation data may be used.

STAR Analysis Geometry File Production – Processes by which the STAR Geometry Data Base is accessed and used to generate or update appropriately formatted geometry data structures for use in detector simulation, event reconstruction, calibration, physics analysis, evaluation and event visualization. These are likely to be implemented as separate codes for each subsystem. Geometry definitions for each detector and structural component are included as well as definitions of the internal coordinate systems for each tracking detector plus the STAR Coordinate System. Software alignment corrections may be loaded or updated into the STAR Geometry Data Base.

Data Stores:

STAR Engineering Design Documentation – Design drawings, materials specifications and other documents which specify the nominal design values for the STAR structural geometry and composition. Alternate design versions are handled as well as different installation scenarios (*e.g.* with or without SVT, with or without full EMC or EMC end cap, full or partial TOF, with or without FTPCs, partial or full TPC electronics, etc.) The position information will most likely be hierarchical where smaller pieces are located with respect to larger, inclusive volumes. Global coordinates for an individual TPC pad, for example, will not necessarily be stored here.

STAR Survey Data – Similar to the preceding except for the actual, measured geometries, positions, orientations and composition.

Aggregate STAR Geometry Data Base – Data Base storage of the engineering design and survey information, as well as the alignment software position and orientation corrections.

STAR Geometry for GSTAR – Input geometry files for GSTAR. See GEANT manual [2] and section /sim/geant/gstar.

STAR TPC Geometry for Analysis – Geometry and material information suitable for the simulation and analysis codes; pad positions in each respective sector; nominal positions and orientations with tolerances for active and structural components in the TPC Internal Coordinate System; surveyed positions and orientations with errors for active and structural components in the TPC Internal Coordinate System; TPC alignment software corrected positions and orientations with errors for the active components in the TPC Internal Coordinate System. See also subsection /ana/tpc/tcl.

STAR SVT Geometry for Analysis – Geometry and material information suitable for the simulation and analysis codes; nominal positions and orientations with tolerances for SDD and structural components in the SVT Internal Coordinate System; surveyed positions and orientations with errors for SDD and structural components in the SVT Internal Coordinate System; SVT alignment software corrected positions and orientations with errors for the SDDs in the SVT Internal Coordinate System.

STAR CTF Geometry for Analysis – Geometry and material information suitable for the simulation and analysis codes; nominal positions and orientations with tolerances for active TOF/CTB slats and structural components in the STAR Coordinate System; surveyed positions and orientations with errors for active and structural components in the STAR Coordinate System; Global/CTF alignment software corrected positions and orientations with errors for the active components in the STAR Coordinate System.

STAR EMC Geometry for Analysis – Geometry and material information suitable for the simulation and analysis codes; nominal positions and orientations with tolerances for active EMC towers and SMD wire grids as well as structural components, all in the STAR Coordinate System; surveyed positions and orientations with errors for active and structural components in the STAR Coordinate System; Global/EMC alignment software corrected positions and orientations with errors for the active components in the STAR Coordinate System.

STAR MWC Geometry for Analysis – Geometry and material information suitable for the simulation and analysis codes; wire positions in each respective sector; nominal positions and orientations with tolerances for active and structural components in the TPC Internal Coordinate System; surveyed positions and orientations with errors for active and structural components in the TPC Internal Coordinate System; TPC alignment software corrected positions and orientations with errors for the active components in the TPC Internal Coordinate System.

STAR VPD Geometry for Analysis – Geometry and material information suitable for the simulation and analysis codes; nominal positions and orientations with tolerances for active Cherenkov counters and structural components in the STAR Coordinate System; surveyed positions and orientations with errors for active and structural components in the STAR Coordinate System; VPD alignment software corrected positions and orientations with errors for the active components in the STAR Coordinate System.

STAR Structural Geometry for Analysis – Beam pipe, magnet, supports, etc. geometry and material information suitable for the simulation and analysis codes; both nominal and surveyed positions and orientations in the STAR Coordinate System.

STAR TPC Internal Coordinate System for Analysis – Parameters, such as the positions of survey points and axis defintions, which define the TPC Internal Coordinate System. Nominal (with tolerances), surveyed (with errors) and global alignment software corrected (with errors) position and orientation in the STAR Coordinate System.

STAR SVT Internal Coordinate System for Analysis – Parameters, such as the positions of survey points and axis defintions, which define the SVT Internal Coordinate System. Nominal (with tolerances), surveyed (with errors) and global alignment software corrected (with errors) position and orientation in the STAR Coordinate System.

STAR Coordinate System for Analysis – Parameters, such as the positions of survey points and axis defintions, which define the STAR Coordinate System. Nominal (with tolerances) and surveyed (with errors) position and orientation with respect to the STAR Magnet.

Data Flows:

None

Status:

GSTAR *Geometry Production (Advanced Geometry Interface)*: At the first release of GSTAR in the Spring of 1996, the geometries were input to GSTAR via namelist reads of ASCII files. Program shells (called nml_create_XXXX) were provided to be revised by each sub-system SAS group to produce the namelist geometry definitions and simple kumacs to be used to debug the geometry definition in GEANT. By the Summer of 1996, roughly half of the STAR subsystems provided namelist geometry files for their detectors, which allowed the careful testing of GSTAR to begin.

The Advanced Geometry Interface (AGI) was added to the front of GSTAR by Pavel Nevski during the Summer of 1996. This is a dedicated GEANT parser (a Fortran preprocessor) that converts Fortran-like ASCII files ("XXXXgeo.g") into shared library files ("XXXXgeo.sl") which are readable by AGI routines ("agstar.g") that are compiled into the GSTAR executable. The shared library files contain the GEANT volume and hits definitions for each of the STAR GEANT sub-systems ("XXXX" = CAVE, MFLD, PIPE, SVTT, TPCE, BTOF, CALB, ECAL, FTPC, VPDD, and MAGP).

The AGI insures the internal consistency of the GEANT volume, media, and hits definitions, and it significantly reduces the amount of information that users need to worry about. The basic parameters that describe the geometry of each subsystem are loaded by AGI into the Zebra bank /DETM, which is written to the GSTAR output file and to disk just after the geometry is loaded at the start of each simulations run. At the same time the AGI creates the appropriate documentation banks for DZDOC package. For each bank in the DETM structure contain the creation date, author information, the variable names and comments, as well as the full information on the Zebra bank relationships. All this information is maintained in the file "detm.rz" which can be analysed by the DZDOC package. Running its interactive version DZEDIT, users can get the full information on the created banks as well as to print a hardcopy of the current STAR input data structure description. As the documentation RZ file is updated automatically each time the program has been changed, this description is always up-to-date.

In addition to defining the physical volumes of particular media that represent each detector, AGI is also used to define the contents of the arrays that contain the hit information recorded as GEANT steps particles through the apparatus. The manner by which AGI can be instructed to define the hits information has two very useful features. First, software sub-divisions of the volumes defined in GEANT can be done in the hits definition. This can both simplify and make more "horizontal" the tree of GEANT volumes, which increases the speed of GEANT's particle propagation. Second, there are flags that can be used in the hits definition to control the manner in which the hits information is recorded. This largely eliminates the need for detector-specific "GUSTEP" routines in the GSTAR code, which simplifies the structure of this code and reduces the amount of software that each subsystem must maintain.

The ASCII files containing the Fortran-like AGI instructions (XXXXgeo.g) to define the GEANT volumes and hits information in GSTAR exist for all eleven STAR sub-systems. Initial versions were released during the Summer of 1996. Since then, these files have been revised by each sub-system SAS group to make the definitions more accurate and to instruct GSTAR provide the information needed by the analysis modules presently being ported from TAS to STAF.

The ASCII XXXXgeo.g files are converted to shared library files (XXXXgeo.sl) by an AGI parser called "geant3." These shared library files are platform dependent. At present, all eleven of the shared library geometry files for STAR sub-systems are available under the platforms IRIX (Silicon Graphics computers) and Solaris (Sun computers). A beta-version of the geometry input for the AIX platform (IBM computers) has also been released. A near-term goal includes the parsing of shared library geometry files on the imminent Pentium Pro farm at BNL.

See the following STAR Library Packages:

ctg – CTB/TOF Geometry table filling
emg – EMC Geometry table filling
mwg – MWC Geometry table filling
svg – SVT Geometry table filling
tpg – TPC Geometry table filling
vpg – VPD Geometry table filling

4.2 STAR Magnetic Field (/sim/magnet)

This section contains a description, list of requirements, functional model diagram (Fig. 3), glossary of terms, and status of software report.

Description:

The STAR magnet group will map the STAR magnetic field for the nominal 0.5 T and 0.25 T field settings using an array of Hall probes on a discrete grid in cylindrical coordinates ρ (radial distance from magnet symmetry axis), ϕ (azimuthal angle) and z (distance along magnet axis). The magnetic field vector (cylindrical components) will be measured at each grid point. Perturbations to the field arising from small variations in the small end coil and end cap trim coil currents will also be measured. The latter information is necessary in order to calculate perturbations to the field if the main or trim coil currents drift from their nominal, design values. The magnet group will fit these measured field values at the measured grid points using analytic expansions and provide the software group with field values interpolated to a fixed grid with equally spaced mesh points. The expansion coefficients will also be provided.

The magnetic field map information required for GSTAR simulation, for detector simulation (charge cloud drift), and for track reconstruction may require different grid sizes than that provided by the magnet group. Also integrated values of radial or azimuthal field components may better serve the detector simulation (charge cloud drift) calculations than just a grid of field vectors. Thus some further processing of the magnetic field measurements will probably be required as well as separate data structures for GSTAR and for the analysis software. The magnetic field maps for GSTAR and Analysis will be supplied in the global STAR Coordinate System.

Requirements:

1. The magnetic field map information should be measured on a sufficiently fine grid with respect to the scale of the field non-uniformities. Special care must be taken to provide adequate determination of the field in the regions occupied by the forward TPCs. Field measurements out to and inbetween the coils may be required for simulation of cosmic ray tracks.

2. The magnetic field software must provide magnetic field map information in a suitable format and with sufficient granularity to ensure optimum performance of the detector simulations and event reconstruction software.

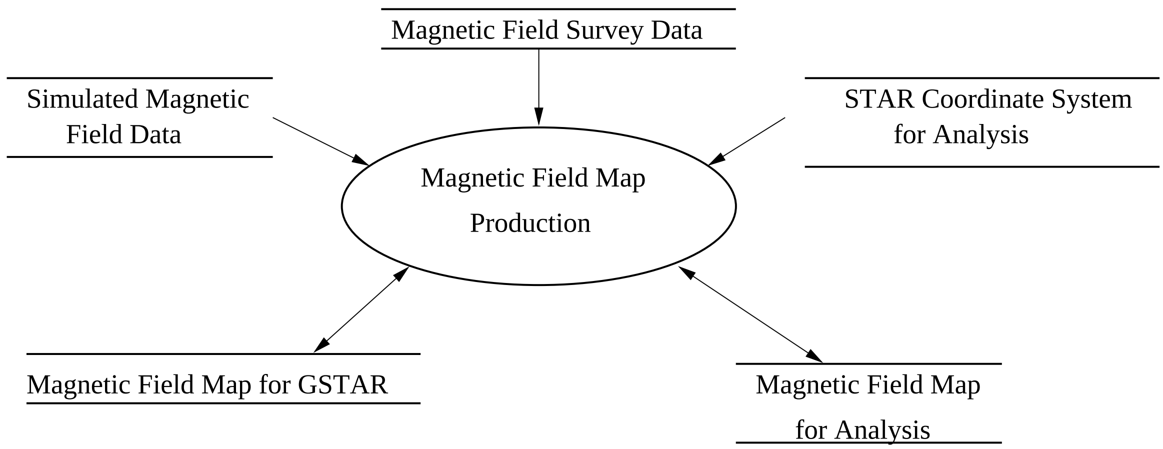

Figure 3: STAR Magnetic Field Map Software

Glossary of Terms:

Processes:

Magnetic Field Map Production – Interpolation and/or integration of measured or simulated magnetic field map as required by GSTAR, detector response simulation, and track reconstruction. Values are supplied in the STAR Coordinate System.

Data Stores:

Magnetic Field Survey Map – Measured vector components of magnetic field over a cylindrical coordinate system (ρ, ϕ, z) for various field configurations as provided by the STAR Magnet group and as discussed in the preceding.

Simulated Magnetic Field Data – Simulated vector components of magnetic field as calculated by the code POISSON for example.

STAR Coordinate System for Analysis – see /sim/geometry.

Magnetic Field Map for GSTAR – Interpolated magnetic field map for use by GSTAR.

Magnetic Field Map for Analysis – Interpolated magnetic field map for use in detector response simulation, event reconstruction, calibration, evaluation, trigger and physics analysis. This contains three cylindrical components or integrated components of the magnetic field on a pre-defined grid. Grid size depends on the scale of the field non-uniformities. Corrections to the nominal field values determined by calibrations (see /cal/magnet) are included in this data store and may be used by any of the offline software.

Data Flows:

None

Status:

The default description of the STAR magnetic field is a 0.5T solenoidal field with no distortions, "off-axis" components, or fringe fields. This is clearly an optimistic description. A beta-version of a new AGI magnetic field source file (mfldgeo.g) is presently being tested, which can be controlled via flags from the GSTAR prompt to produce either the perfect solenoidal field, no field, or a "Ross-III" map read from a file.

It is simple to add the capability to read other kinds of maps. When measured magnetic field maps become available, the software necessary to input these maps into GSTAR via AGI will be written. This involves only simple revisions to the AGI magnetic field file, mfldgeo.g.

4.3 Event Generators (/sim/evg)

This section contains a description, list of requirements, functional model diagram (Fig. 4), glossary of terms, and status of software report.

Description:

Event generator simulation software for STAR includes numerous theoretical reaction codes written by theorists in the field. Presently this list includes FRITIOF [4], HIJING [5], VENUS [6], RQMD [7], and the parton cascade model (PCM) [8]. In addition, phenomenological multiplicity generator codes have been developed for specialized studies of trigger algorithms and for studies of peripheral nucleus + nucleus two-photon exchange collisions.

Software will also be needed to simulate background particles from cosmic rays, beam-gas interactions, beam-collimator collisions due to beam halo, and DC beam-beam interactions in the experimental hall area as well as particle production from radioactive sources used in calibration procedures.

This area of software also includes user developed code which simulates the effects of final state interactions (not usually included in the preceding list of event generators). This includes resonant and non-resonant two-body scattering, particle + medium scattering, and many-body quantum mechanical exchange processes (HBT) which occur when the produced identical particles propagate from the microscopic source outward to the macroscopic detector, where GEANT takes over.

The event generator output is in either an ASCII text format or in a compressed data format (*e.g.* ZEBRA, Dataset Library (DSL), xdf, etc.). At present both types can be input to the STAR implementation of GEANT. However, in the final implementation this may be restricted to only a single data compressed format. A detailed description of the proposed implementation of the text format output files and the general information content output by the STAR event generators is given in Ref. [3].

Requirements:

The STAR event generators are required to:

1. Produce output in a suitable format which can be directly input to the STAR implementation of GEANT (called GSTAR).

2. Produce reasonable estimates of particle multiplicity production from pp, pA and AA collisions for the full range of target masses, collision energies, detector acceptances and impact parameters. This includes peripheral, two-photon exchange collisions.

3. Produce multi-strange particles, charmed mesons, jets, exotic and other rare particles on demand, which can then be mixed with standard events for efficient simulation studies of such processes.

4. Produce multiplicity distributions in support of trigger development.

5. Handle massive event generator production runs for statistically significant comparisons between theoretical models and data, of order 10^7 events per year.

6. Produce realistic background and calibration events as described in the preceding.

7. Provide particle parentage history, fragmentation histories, decay vertices and collision vertices which occur in the dynamical evolution of the collision cascade, as needed for physics analysis of simulated events.

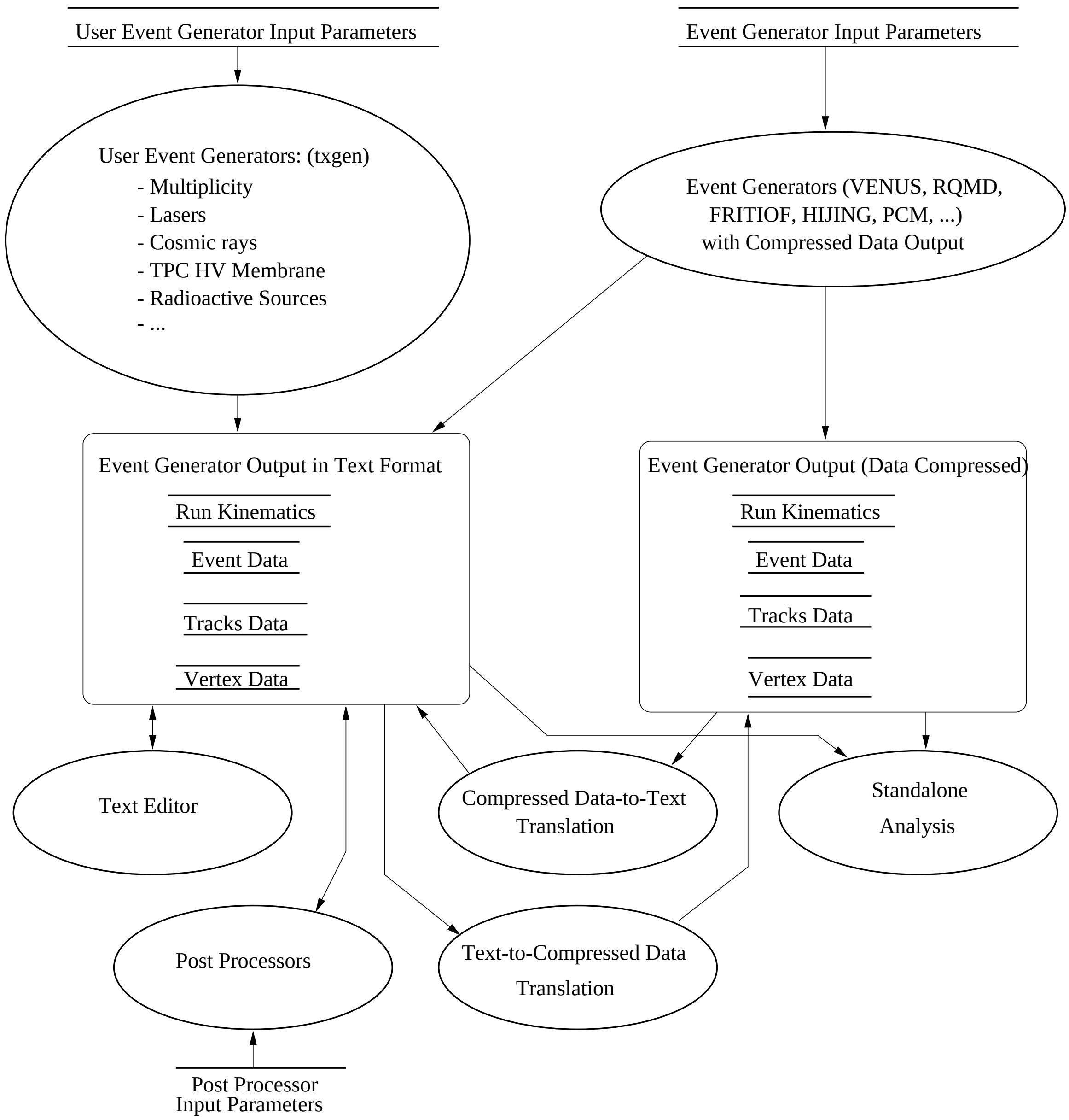

Figure 4: STAR Event Generator Software Functionality

Glossary of Terms:

Processes:

User Event Generators (txgen) – User written, standalone particle multiplicity generator code, background tracks generator, calibration event particle generator, rare particle generator, etc.

Event Generators – Standalone theoretical collision model codes as listed above.

Text Editor – Direct user modification of event generator particle list using standard text editors.

Compressed Data-to-Text Translation – Conversion of compressed data format output into ASCII text format.

Text-to-Compressed Data Translation – Conversion of ASCII text format into a suitable compressed data format.

Standalone Analysis – Separate, Monte Carlo or physics analysis of event generator results.

Post Processors – User developed codes which apply (if necessary) final state resonant and non-resonant scattering, particle + medium interactions, identical particle exchange effects, and other correlations to the event generator output in text format. Also mixes requested rare particles with event generator output, for example.

Data Stores:

User Event Generator Input Parameters – Input parameters, controls, thresholds, cuts, etc. for user event generator codes.

Event Generator Input Parameters – Input parameters, controls, thresholds, cuts, etc. for event generator codes.

Event Generator Output in Text Format – This is described in detail in Ref. [3].

Event Generator Output (Data Compressed) – Data compressed version of the preceding data store.

Post Processor Input Parameters – Input parameters, controls, thresholds, cuts, etc. for Post Processors.

Data Flows:

None

Status:

A variety of methods are available to input events to GSTAR. The basic file format can be either free-form ASCII text, or compressed by ZEBRA. The ASCII text files can be in either of two formats. The first is the so-called 'Old' format (option "TXOLD"), which provides only the ID and three vector momentum for every primary. The so-called 'New' format (option 'TX') includes header, vertex, and track information for each event. This allows one to control which particles are decayed by GEANT, and which can be realistically decayed by the user in a way that makes the parent information readily available to the analysis shell.

It is also possible to combine events written in different formats. The most common example is the embedding of a particular rare particle in a 'generic' Au+Au central event. The two most common combinations of formats are available as GSTAR input options. These are the 'FZTX' option (Zebra format for Au+Au event, 'New' text format for the embedded particles), and the 'TXOTX' ('Old' text format for Au+Au event, 'New' text format for the embedded particles). Also available are several kinds of 'random' event generators that can be controlled entirely from the GSTAR prompt. These are very useful for studying the response of the simulated detectors, and comparing the response of simulated detectors to that measured in prototype or production components of STAR detectors with test beams, sources, lasers, or cosmic rays.

A near term goal is to eliminate the profusion of GSTAR input options by revising GSTAR so that it accepts only one kind of event format - the same Dataset Library (DSL) format that is used by STAF. A standalone program that converts event files in either the Zebra, Old, or New formats into this format will be made available shortly. This is being done in a collaborative effort between the SAS and SOFI Groups. The main motivation of this change is to synchronize the formats input to GSTAR and STAF for simplicity, and to provide the capability to input the event generator output directly into STAF for analyses of simulated data from "the perfect detector."

See the following STAR Library Packages:

egt – Event Generator Tables; text format.
egz – Event Generators, ZEBRA interface.
evz – Event Generator with BNL ZEBRA I/O interface.
fri – Event Generator, FRITIOF.
hij – Event Generator, HIJING.
mrc – Event Generator, fast multiplicity generators.
stl – Event Generator, two-photon processes.
ven – Event Generator, VENUS.

4.4 STAR GEANT (/sim/geant/gstar)

This section contains a brief description, list of requirements, functional model diagram (Fig. 5), special flow chart for EMC applications (Fig. 6), glossary of terms, and status of software report. A detailed document describing the STAR implementation of GEANT is available elsewhere [3]. Many further details are given in the GEANT manual [2].

Description:

Starting with the momentum distribution of particles from collisions and background sources and the vertices of origin in the STAR coordinate system, the STAR implementation of GEANT (called GSTAR) must propagate the particles through the active and inactive portions of the detector. Multiple sources of particles must be accounted for which arise from event pileup during the drift times of the tracking detectors and from background sources which are superimposed on the collision events. Collision vertices can be located anywhere throughout the beam bunch intersection region; background sources may occur anywhere in the STAR detector volume, in the Wide Angle Hall, or in the nearby portions of the RHIC storage ring.

The propagation of particles through the active and inactive portions of the detector are described in the GEANT manual [2]. The user may select the level of realism in the simulation with respect to decays, secondary production, delta electrons, and other interaction mechanisms with the bulk material of the detector.

The mixed events might include, for example, different collision vertices from the same or different beam bunch crossings which occur during the drift time of the detector for the triggered event, mixing background tracks with collision events, mixing tracks from several radioactive sources for simulation of calibration procedures, and mixing a few tracks from rare processes with standard event simulation results. In the present design event mixing occurs after GSTAR and Data Structure Translation (g2t) processing (see Fig. 5).

The final output from the GSTAR/g2t/event mixing processing contains all requested energy depositions in active detector volumes (hits), tracks, vertices, decays, parentage histories, event generator microscopic vertices and parentage information, run data and event mixing information. The user must supply magnetic field information, STAR geometry and materials descriptions, reaction control parameters, and detector configuration parameters.

Requirements:

The STAR implementation of GEANT and Data Structure Translation (g2t) processing is required to:

1. Simulate the propagation of particles through the detector with sufficient realism such that adequate event reconstruction, calibration, physics analysis and trigger software can be developed.

2. Provide simulations of sufficient quality such that appropriate detector design choices can be made.

3. Be able to use realistic, detailed geometry and materials information as well as detailed magnetic field maps.

4. Provide the final output in a suitable data structure format to smoothly interface to the analysis, calibration and physics analysis software.

5. Handle massive production runs (of order 10^6 fully simulated events per year).

6. Provide particle parentage history, decay vertices and decay processes for the simulated macroscopic propagation and to also pass the microscopic particle parentage history, decay vertex and decay process information from the event generators to the final output for physics analysis studies.

In addition the software in this section is required to handle event mixing for minimum bias event pileup, as well as background and rare particle superposition with collision events.

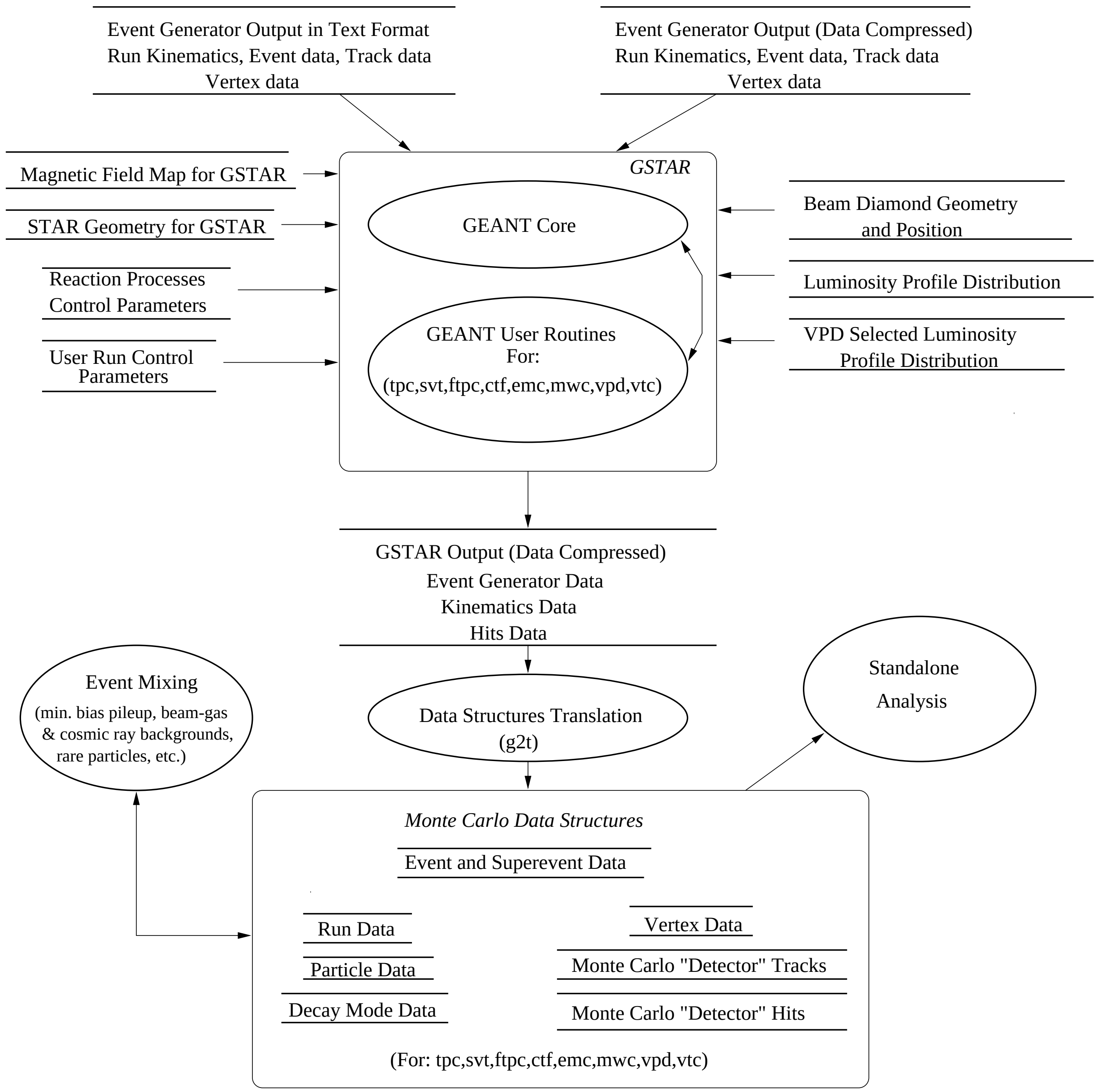

Figure 5: Overview of GSTAR and Monte Carlo data structures

Glossary of Terms:

Processes:

GEANT *core* – Library of CERN developed routines (see GEANT manual [2]).

GEANT *User Routines* – Detector specific, user developed routines to control stepping and showering.

Event Mixing – Combines particle tracks from multiple collision vertices, calibration and/or background events into, so called, superevents and sets appropriate links (Foreign Keys) in the final, output data structures.

Data Structure Translation (g2t) – Converts compressed data output from GSTAR into data structure format for interface to analysis software.

Standalone Analysis – Separate, Monte Carlo or physics analysis of GEANT results.

Data Stores:

Event Generator Output in Text Format – as described in detail in Ref. [3].

Event Generator Output (Data Compressed) – Data compressed version of the preceding.

Magnetic Field Map for GSTAR - STAR magnetic field map in suitable format for GSTAR, see /sim/magnet.

STAR Geometry for GSTAR – vast collection of geometry files, generated from data base reference for input to GSTAR, specifying the physical size, shape, location, composition, radiation length, active status, etc. of all the relevant volumes in the STAR detector and its surrounding environment. See GEANT manual [2].

Reaction Processes Control Parameters – Standard set of physics control parameters for GSTAR.

User Run Control Parameters – User controlled run parameters.

Beam Diamond Geometry and Position – see /cal/vpd.

Luminosity Profile Distribution - see /cal/vpd.

VPD Selected Luminosity Profile Distribution – see /cal/vpd.

GSTAR *Output (Data Compressed)* – Data compressed GSTAR output.

Monte Carlo Data Structures – Collection of several, distinct data structures containing the event, superevent, run, particles, decays, vertices, tracks and hits, information for both the event generator and for each active detector. These are described in detail in Ref. [3]. These are referred to repeatedly throughout the remainder of this document where, for example, "*Monte Carlo 'detector' Tracks*" appears as "*Monte Carlo TPC Tracks*" when referring to the simulated Monte Carlo tracks within the TPC.

Data Flows:

None

Status:

It remains important to study events with multiple sources of primary particles, i.e. event pile-up during drift times, multiple collisions in events in high-luminosity proton running, etc. At an early stage of discussions on this, the consensus was that the study of multiple source events would proceed by revising g2t so that it could add together several independently processed GSTAR events. However, as all of the detector fast and slow simulators are STAF modules, it is equivalent and more convenient to superimpose events in the analysis shell, downstream of GSTAR and g2t. Revisions to g2t are no longer seen as necessary to study this topic.

It is fair to say that the present status of AGI/GSTAR and g2t already fulfills requirements 1, 2, and 4. Requirement 3 is half done - detailed geometry and materials information is presently in use, while work in presently underway to provide more options for the magnetic field maps that can be simulated. Requirement 6 is fulfilled as this requirement goes deep into the philosophy used when the GSTAR code was written, although the SAS group is still acclimating to the proper storage and retrieval of this information.

Of the six, requirement 5 is undoubtedly the most difficult to fulfill. This requirement essentially places upper limits on the CPU time and disk space needed to process an event through GSTAR and g2t. It is therefore important to make GSTAR as realistic and fast as possible, and to make sure that superfluous information is not calculated and saved in the output file. Recent work in this regard is described in the following.

Detailed simulations are presently being performed by each sub-system In these calculations, AGI/GSTAR is instructed to record all information on the parentage and kinematics of all of the primaries and secondaries produced by all possible physical mechanisms anywhere in the detector (in GEANT language, "permanent stacking"). These "full" simulations are very effective for shaking out the software and understanding the detector response, but they are also the most costly in terms of CPU-time and disk space. On the machine rsgi00 (IRIX was the platform supported in the initial release of GSTAR and g2t), the processing of one central HIJING Au+Au event in this way through STAR including all eleven subsystems takes 12 CPU-hours and results in 500 MB of output. Clearly, these numbers rule out the production of thousands to millions of events with permanent stacking.

Realistic production runs, however, can ignore the recording of a large fraction of this information. In this configuration ("temporary stacking") only the kinematics information for primaries or secondaries that leave hits in sensitive media are recorded. In this configuration, a central HIJING Au+Au event takes 4 hours/event on rsgi00 and results in about 30-40 MB of output. The output file size is consistent with that of the GEANT implementation in the previous simulations framework (gxintX11/mct/TAS), even though the present geometrical and hits definitions are far more detailed than that used in the previous framework.

While the output file size problem is essentially under control (20improvements may still be possible), the CPU-times still prohibit the study of thousands of central Au+Au events, or millions of p+p events. Recent work has therefore concentrated on porting the simulation codes to platforms other than SGI, and on optimizing the geometries and GEANT parameters.

GSTAR was ported to Solaris in October, 1996, which opens up for STAR simulations the PDSF farm at LBNL-NERSC and the Suns at several SAS institutions. The considerably more difficult port to the AIX platform is nearly complete.

Any worth-while simulation using on the GEANT package must be based on a solid understanding of the effects that the numerous GEANT parameters (thresholds, cut-offs, step sizes, etc.) can have on the accuracy and speed of the simulation. At present, investigations of the effects related to particular choices for the basic GEANT parameters are underway. In some media, for example, the GEANT tracking cut-offs may be set far lower than those necessary to realistically describe the media in a simulation. Modest CPU-time savings are therefore possible via judicious choices for these basic parameters.

See the following STAR Library Packages:

g2t - GSTAR to Tables conversion.
gst – Implementation of GSTAR.
mcg – Old STAR GEANT.
mct – Old STAR GEANT to Tables conversion.

EMC Specific Particle Propagation Method (/sim/geant/gstar/emc):

Description:

In the new EMC simulations framework, the user will have two choices for the kind of simulation to be performed. These are the so-called "slow" and "fast" simulations. The information needed from GEANT for these two simulations options is entirely different.

The first strategy involves the new EMC Slow Simulator (ESS) (see /sim/det/emc-/ess). This module will be used to study the relationship between particular decisions made on the EMC design and the performance of the device for physics analyses. In ESS, GEANT describes the shower development. Some attempt to tune the GEANT tracking parameters and thresholds so that the GEANT showers are in reasonable agreement with those seen in the two SPEMC (small prototype EMC) test beam runs will be necessary.

It is sensible to instruct GEANT to save the total energy depositions in geometrical blocks (*i.e.* $\sim$0.5cm^3 "cells") that are smaller than the physical size of individual calorimeter read-out channels but larger than the typical GEANT step sizes. This is done using the GEANT routine GSCHIT, and will lead to significantly smaller output files from the GEANT step of the simulation. The most important advantage of this method[1] is the capability to make changes to the size and position of the individual read-out channels in the (faster) analysis stage of the simulation.

It is desirable to be able to disentangle the contribution of any track to any of these calorimeter cells. Thus each cell should have a list of tracks that contributed to it, and each track should have a list of cells to which it contributed. This is a many$\rightarrow$many mapping, and cannot be done as simply as with the TPC GEANT hit pointing to the track responsible (track$\rightarrow$hit is a one$\rightarrow$many mapping). An elegant solution was obtained for the analogous problem[2] in NA49. The essential point is to define a set of "matching tables", which are basically nodes with pointers in and out to the cell and track to which a given table entry belongs, plus the next cell for the given track, the next track for the given cell, et cetera. The node would also contain the contribution of that track to each cell. To get the total cell or track contributions one follows the appropriate pointers from node to node. Further discussion on the links from GEANT to the simulations and analysis software via the GSTAR and g2t implementations can be found in Ref. [3].

The EMC Fast Simulator (EFS) is the second simulations option available to the user (see /sim/det/emc/efs). It will use parametrizations for the lateral and longitudinal profiles of EM and hadronic shower development in EM calorimeters to generate, via Monte Carlo methods, the tower, depth, and SMD signals for each track

[1]That is, besides the savings in memory, disk space, and CPU usage as compared to what is presently being done.

[2]In NA49, this was for the matching of simulated tracks before and after the slow simulator+reconstruction, where an input MC track may be reconstructed as more than one track by the tracking software, tracks will merge at high densities, et cetera.

incident on the EMC stack.

In principle, the particles that strike the EMC in a given EFS-based simulation can be stopped as soon as they enter the EMC envelope. This leads to huge savings in output file sizes and CPU usage, as GEANT's microscopic showering (used for ESS) is replaced by fast parametrizations of the shower development (in EFS). Thus, the simplest implementation of the fast simulation option in GEANT would involve saving the incident particle kinematics, once for each incident track for that step at which the particle enters the EMC front plate. GEANT would then be instructed to stop propagating these particles after saving this kinematic and position information.

There is an important distinction between the EFS and ESS strategies that relates to the effects that the presence of the EMC in STAR has on the CTB, TOF, and TPC. The only GEANT information that the EFS needs is the kinematics of the particles that enter the EMC envelope. The ESS requires the microscopic description of the showering by GEANT, using the default or tuned thresholds, step sizes, et cetera. The fastest EFS-based simulation would therefore stop the incident particles upon entrance to the EMC, as EFS generates the energy deposition patterns in the showers anyway. However, this kind of simulation will by definition not result in any albedo in the inner detectors. The EMC albedo in the inner detectors is however generated in GEANT's microscopic description.

It should be noted that even if EFS is to be used to describe the shower development and hence all of the EMC signals, the incident particles need not be stopped just when they enter the EMC front plate. One could allow these to propagate to some safe depth in the stack (producing secondaries and albedo), then stop them there. This option will not be quite as fast as when EFS is used and the particles are stopped at incidence, but it will be faster and less disk space intensive than ESS. In such an approach, one would expect the best possible reproduction of the showers (as they come from EFS), and some description of albedo, although at some cost of CPU time and disk space.

A new flag, set via a card in the initialization of GSTAR, is necessary to control which of the two simulation strategies is to be performed. This is because the information needed out of GUSTEP and the way this information is accumulated depends on the choice of the analysis strategy.

For the fast simulations, another new flag inside the GSTAR implementation of GUSTEP controls whether a track entering the EMC is stopped in the step at which it enters the EMC stack. This allows the simulation of albedo in the inner detectors.

The procedural flow for the various possibilities is depicted in the following flow chart, /sim/geant/gstar/emc. The conditions and the general kinds of information that are saved by GSTAR are labelled in this chart. The processes are self explanatory. The data store "*Monte Carlo EMC Hits*" is defined in Sec. 4.8.

Flow Chart

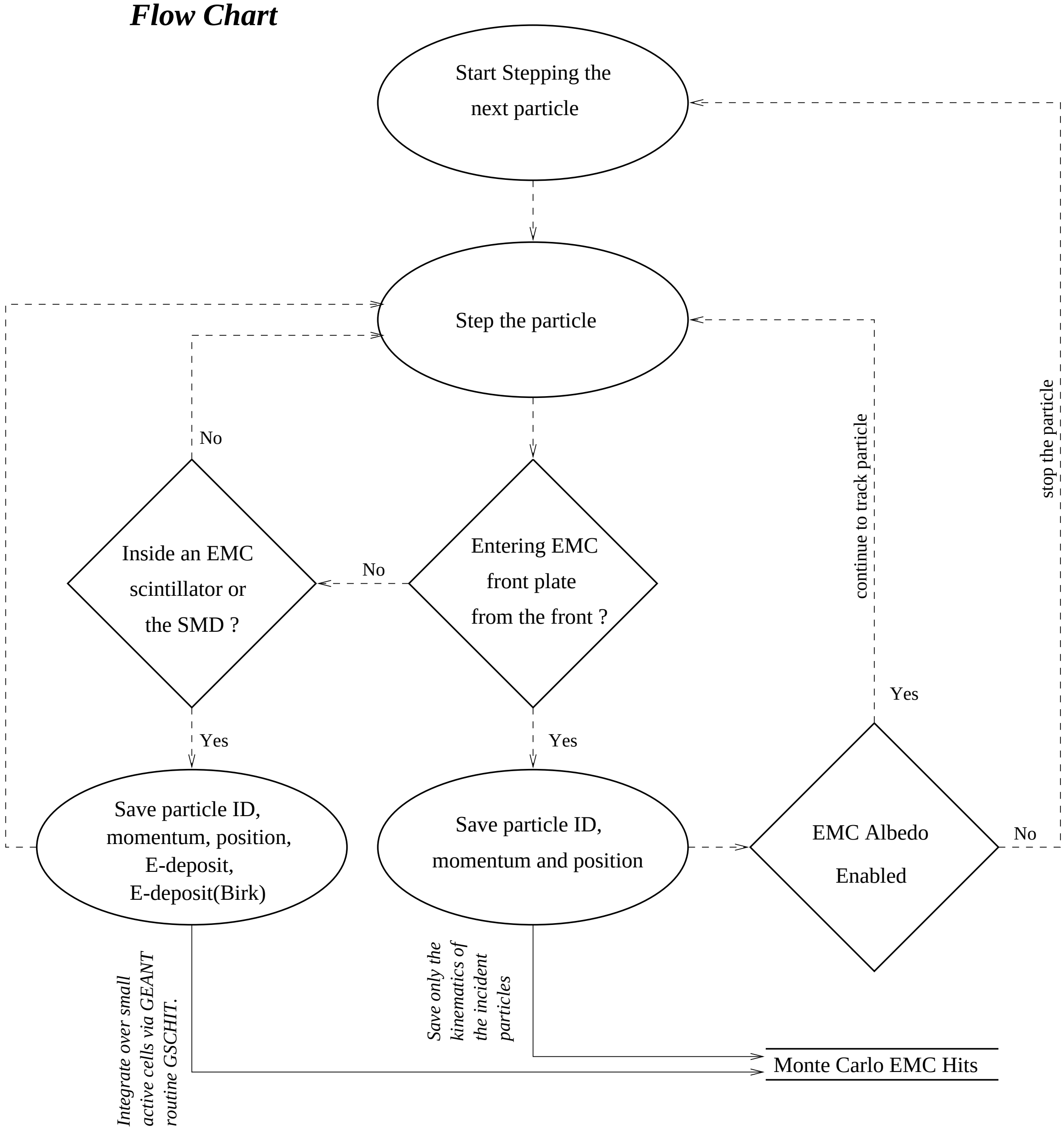

Figure 6: Flow Chart for Track Propagation in EMC with GSTAR.

4.5 TPC Simulation (/sim/det/tpc)

This section contains a description, list of requirements, functional model diagrams for the top level (/sim/det/tpc, Fig. 7) and for two sub-levels, one for the slow simulator (/sim/det/tpc/tss, Fig. 8) and one for the fast simulator (/sim/det/tpc/tfs, Fig. 9), three glossaries, and a status of software report. Detailed descriptions of the present implementation of the TPC fast and slow simulators are available in Ref. [9].

Description:

The TPC detector simulation software generates simulated data corresponding to the real TPC data at various stages of analysis (raw data, reconstructed space points, or reconstructed tracks). These data are subsequently used to optimize the detector design, assist in the development of DAQ and online software, and facilitate development of the reconstruction and analysis software.

The TPC detector simulation software may generate the full event or just a portion of the event (*e.g.* background tracks, rare particles and decays, etc.). In the latter case it is assumed that the output data stores (pixels, space points, or tracks) have already been filled with data from an external source (either from a previous simulation or eventually from actual data) and that these data stores are to be updated.

Requirements:

1. The TPC detector simulation software is required to simulate the response of the TPC detector gas volume and electronics to the passage of ionizing energy through the TPC volume, including that from pp, pA and AA collisions, beam-gas interactions, cosmic rays, radioactive sources and laser beams. This is needed in order to develop hit reconstruction and tracking software, test and develop DAQ, test and develop calibration procedures, and to allow computation of detector efficiencies and acceptances.

2. The TPC is sensitive to the passage of ionizing particles all the time, so all the particles that traverse the gas volume produce drifting charge that superimpose their image on that from the tracks of the event that is read out. Also the triggered event is superimposed on the ionization that was left by particles passing the chamber at an earlier time. In order to understand the background, these features must be reproduced in the simulations.

   The TPC detector simulation software is therefore required to account for the passage of ionizing particles through the TPC active volume before and after the triggered event. The time the detector simulation has to take into account equals the time needed for a drift across the TPC volume from the central membrane to the endcap. Particles from minimum biased, "out-of-time" collisions should be included in these simulations.

3. The TPC detector simulation software must simulate the response of the TPC electronics to wire pulsing and direct charge injection. Wire pulsing and direct charge injection into the electronics are important parts of the calibration procedures, yet processing of such events is different from processing events that generate signal by ionizing the TPC gas. So it is necessary to simulate them in order to properly test and debug the calibration software.

4. The TPC detector simulation software must simulate such realistic effects as non-uniform drift velocities, distortions in drift path due to $\vec{E} \times \vec{B}$ effects and electric field distortions, fluctuations and systematic variations in gas gain, electron attenuation, anode response and electronics gain, dead or malfunctioning channels, etc. Simulation of these effects are necessary in order to develop correction procedures and calibration software.

5. The TPC detector simulation software must simulate both the nominal magnetic field and the zero magnetic field cases. Many processes in the TPC and many gas parameters are different in the absence of the magnetic field and STAR is going to run a large part of its calibration procedures with no magnetic field.

6. The TPC detector simulation software must produce simulated data in the same format to be used by the actual data acquisition system for real data. This is necessary in order to develop and debug the raw data unpacking software.

7. The TPC detector simulation software must provide simulated, raw ADC data output for loading into the TPC front end electronics (FEE) read-out boards for DAQ development and testing in order to test the HDLC link.

8. The TPC detector simulation software must be able to directly generate the reconstructed TPC space points, thus bypassing the slow TPC simulator and the cluster finder/space point reconstruction analysis. This is necessary because in physics analyses a very large number of Monte Carlo events are needed to understand and give a statistically meaningful interpretation of the physics results. Generation of a large number of Monte Carlo events with the slow simulator is extremely CPU intensive. This can be circumvented by directly generating TPC space points which have characteristics identical to those hits reconstructed from simulated pixel data.

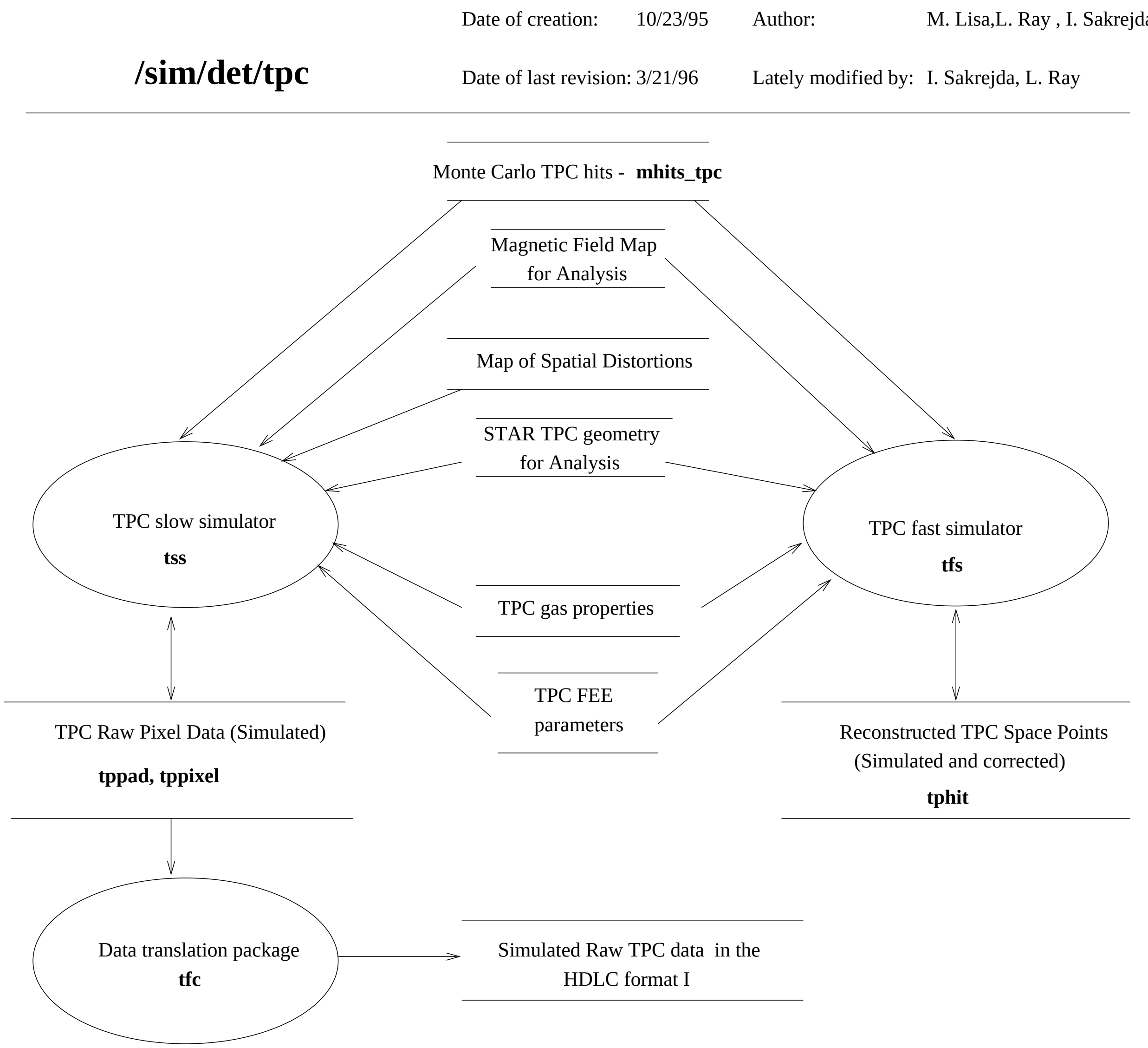

Figure 7: TPC Simulation Software – Top Level

Glossary of Terms:

Processes:

TPC Slow Simulator – Process which calculates the raw TPC pixel data directly from the Monte Carlo (GEANT) crossings.

TPC Fast Simulator – Process which calculates the reconstructed TPC space points directly from the Monte Carlo (GEANT) hits.

Data Translation Package – Process which extracts simulated raw data from the data structures and writes them out in the format suitable for DAQ and the Slow Controls HDLC link.

Data Stores:

Monte Carlo TPC Hits – Space points generated in the GEANT based Monte Carlo detector simulation package. They correspond to points where tracks cross planes that are normal to the padrows and positioned at the middle of every padrow. They also carry information about the average energy loss across padrows and particle momentum.

Magnetic Field Map for Analysis – Map of values of the magnetic field within the TPC volume on a grid that depends on the field gradients, see /sim/magnet.

Map of Spatial Distortions – Data which describes distortions in drift path of electron clouds, which eventually lead to distortions in apparent position of the ionization. This must be calculated from electric and magnetic field maps and calibration procedures on a grid determined by gradients of the distortions. This is either an assumed input or may be an actual map from calibrations.

STAR TPC Geometry for Analysis – Data storage containing descriptions of the detector geometry and materials, see /sim/geometry.

TPC Gas Properties – Data store containing the TPC gas composition, gas gain, pressure and temperature, drift velocity, longitudinal and transverse diffusion constants, etc.

TPC FEE Parameters – Parameters that describe the performance of the STAR TPC front end electronics.

TPC Raw Pixel Data (Simulated) – TPC raw data (ADC information) together with the addressing information packed into data structures.

Reconstructed TPC Space Points (from fast simulator) – Reconstructed space points including hit merging, position resolution, position displacement, false points, lost hits, and energy deposition errors.

Simulated Raw TPC Data in the HDLC Format – Simulated raw TPC pixel data packed in a format readable by the Slow Controls link to the FEE.

Data Flows:

None

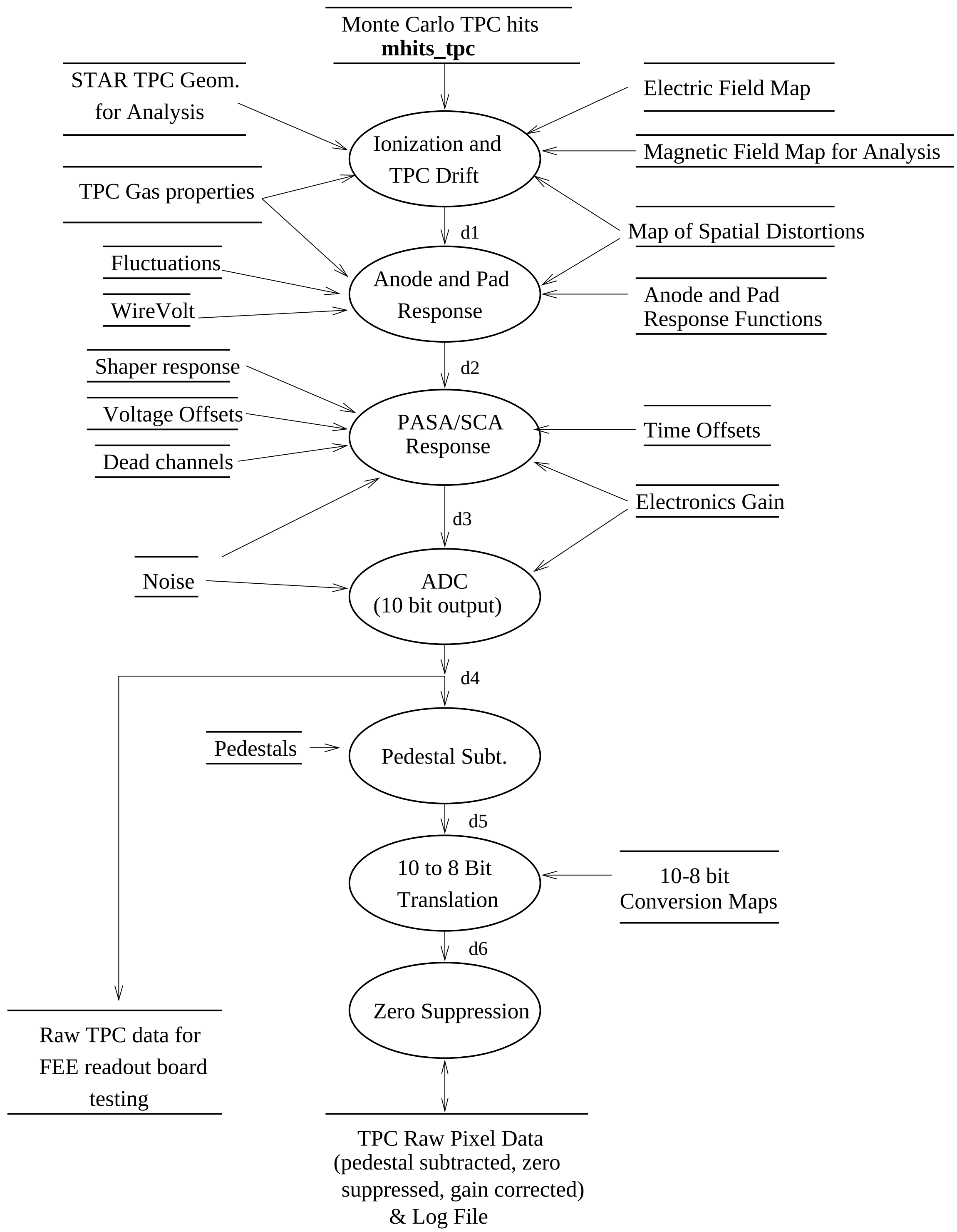

Figure 8: TPC Slow Simulator Software Functionality

Glossary of Terms:

Processes:

Ionization and TPC Drift – Process which calculates the spatial distribution of gas ionization as the particle passes over the padrow, and calculates the electron cloud drift, diffusion and attenuation in the given $\vec{E}$ and $\vec{B}$ fields of the TPC gas volume.

Anode and Pad Response – Process which calculates the anode current using empirical anode response function, wire voltages, and gain fluctuation parametrizations. It also calculates signal on the pads using measured coupling between the anode wires and pads.

PASA/SCA Response – Process which calculates the response of the TPC FEE pre-amp, shaper and SCA. Includes noise, shaper response, voltage offsets, dead or bad channels, timing offsets, and amplifier and SCA gains.

ADC (10 Bit Output) – Process which simulates the conversion of analog signals to 10 bit digital data. Includes ADC gain factors and possible ADC noise.

Pedestal Subtraction – Process which simulates the first stage of ASIC processing using stored pedestal data and subtracting from ADC data.

10 to 8 Bit Translation – Process which simulates second stage of ASIC processing, compressing 10 bit ADC data to 8 bits using nonlinear map depending on overall electronics gain.

Zero Suppression – Process which simulates the last stage of ASIC processing and early function of the i960 cpu, removing from the data stream pedestal subtracted pixels which fall below zero, and building pointers to the beginning and end of non-zero pixel sequences. Updates pixel information in the final output data store.

Data Stores:

Monte Carlo TPC Hits – see /sim/det/tpc.

STAR TPC Geometry for Analysis – see /sim/det/tpc.

TPC Gas Properties – see /sim/det/tpc.

Fluctuations – Parameters controling the simulated random fluctuations in the anode and pad response; parameters for the Polya gas gain distribution function.

Wire Volt – Voltages for the field and anode wires, sector by sector.

Shaper Response – Contains the shape of the preamp/shaper output signal corresponding to a step function input.

Voltage Offsets – Contains channel by channel offsets in voltage that eventually lead to pedestal offsets.

Dead Channels – Assumed list of dead, hot, noisy or otherwise bad channels.

Noise – Contains amplitude and power spectrum of the noise in the PASA, SCA and ADC components.

Pedestals – Simulated ADC values for each channel with no TPC hits; mean and rms values for many events.

Raw TPC Data for FEE Readout Board Testing – Simulated 10 bit ADC values without pedestal subtraction or zero suppression, to be used for FEE readout board tests.

Electric Field Map – Nominal electric field map plus perturbations due to space charge accumulation and field cage anomalies, shorts, etc.

Magnetic Field Map for Analysis – see /sim/det/tpc and /sim/magnet.

Map of Spatial Distortions – see /sim/det/tpc.

Anode and Pad Response Function – Contains wire-to-pad coupling and channel gain information derived from wire pulser calibrations.

Time Offsets – Contains the channel by channel time offsets relative to the triggered event for the SCA conversion of analog signals to time bins.

Electronics Gain – Contains gains for each of the electronic components: PASA, SCA and ADC, including assumed fluctuations.

10-to-8 Bit Conversion Maps – 10 bit to 8 bit nonlinear translation tables for each channel, including assumed electronic gains; or 10 to 8 bit algorithm plus channel by channel gain correction function parameters.

TPC Raw Pixel Data – see /sim/det/tpc.

Data Flows:

d1 – Charge distributions at each anode wire.

d2 – Analog current for each pad.

d3 – Analog voltage for each channel and time bucket.

d4 – 10 bit digital ADC value for each pixel.

d5 – 10 bit pedestal subtracted ADC value for each pixel.

d6 – 8 bit translated, pedestal subtracted ADC value for each pixel.

Date of creation: 10/23/95 Author: D. Weerasundara

/sim/det/tpc/tfs

Date of last revision: 3/21/96 Lately modified by: L. Ray

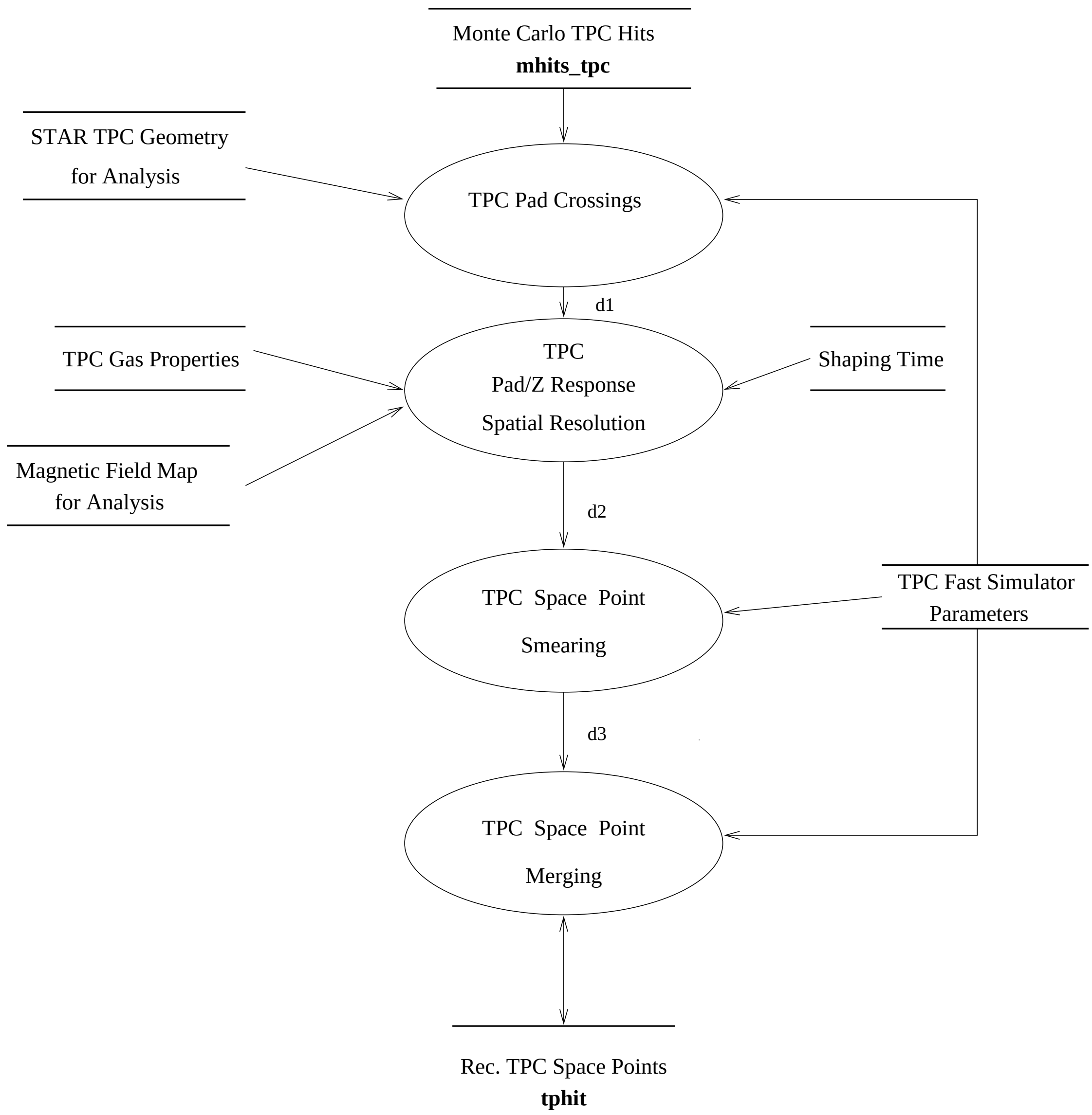

Figure 9: TPC Fast Simulator Software Functionality

Glossary of Terms:

Processes:

TPC Pad Crossings – Process which relates Monte Carlo hits with TPC pads.

TPC Pad/Z Response Spatial Resolution – Process which assigns transverse and longitudinal spatial widths to a TPC hit.

TPC Space Point Smearing – Process which randomly shifts the spatial coordinates of TPC hits according to a Gaussian distribution with widths as defined in TPC Pad/Z Response.

TPC Space Point Merging – Process which merges those TPC hits which are within a predefined merging window in pad and time directions. Updates space point information in final output data store.

Data Stores:

Monte Carlo TPC Hits – see /sim/det/tpc.

STAR TPC Geometry for Analysis – see /sim/det/tpc.

TPC Gas Properties – see /sim/det/tpc.

Magnetic Field Map for Analysis – see /sim/det/tpc.

Shaping Time – Sigma of longitudinal pulse due to electronics shaping time.

TPC Fast Simulator Parameters – Contains the control parameters for the TPC fast simulator (for generating the pp events, switches for hit smearing and hit merging).

Reconstructed TPC Space Points – see /sim/det/tpc.

Data Flows:

d1 – Pad assignments for each Monte Carlo hit.

d2 – List of transverse and longitudinal widths for each hit.

d3 – Shifted positions for each hit.

Status:

See the following STAR Library Packages:

tfs – TPC Fast Simulator.

tss – TPC Slow Simulator.

4.6 SVT Simulation (/sim/det/svt)

This section contains a description, list of requirements, and functional model diagrams for the top level (/sim/det/svt, Fig. 10) and for eight sub-levels. The sub-level diagrams include the following: (1) slow simulator (/sim/det/svt/raw_data, Fig. 11), (2) fast space point simulator (/sim/det/svt/space_points, Fig. 12), (3) fast track simulator (/sim/det/svt/track, Fig. 13), (4) pedestal and voltage offset simulator (/sim/det/svt/ped_volt, Fig. 14), (5) geometry and alignment simulator (/sim/det/svt/geometry, Fig. 15), (6) time offset simulator (/sim/det/svt/time, Fig. 16), (7) gain variation simulator (/sim/det/svt/gains, Fig. 17), and (8) drift time to position map simulator (/sim/det/svt/drift, Fig. 18). Each diagram is followed by a glossary of terms. The status of software is given at the end. A detailed description of the present implementation of the SVT simulation software is available in Ref. [10].

Description:

The principle components of the SVT simulation software are shown in Fig. 10. These include the Raw Data Simulator or Medium Simulator, the Space Point Simulator or Fast Simulator, a Track Simulator, together with several service packages which generate input for these simulators. These include software for simulating the following effects: (1) pedestal and voltage offset fluctuations, (2) detector misalignment, (3) time offsets and fluctuations, (4) gain fluctuations and (5) drift speed nonuniformities. Each of these are explained in greater detail in the following paragraphs.

The SVT detector simulation software may generate the full event or just a portion of the event (*e.g.* background tracks, rare particles and decays, etc.). In the latter case it is assumed that the output data stores (pixels, space points, or tracks) have already been filled with data from an external source (either from a previous simulation or eventually from actual data) and that these data stores are to be updated.

SVT Raw Data Simulator: The raw data simulator is meant to simulate raw data to be produced by the SVT with beam-beam, and beam-gas collisions. The Raw Data Simulator uses simulated SVT hits generated for instance with GSTAR to produce raw SVT data. The medium simulator includes components to simulate the effect of charge drift and noise, the response of the anode readout, the preamp-shaper (PASA) and the switch-capacitor-array (SCA) response, as well as the ADC response and the ASIC zero suppression algorithm. The components of the Medium Simulator are shown in Fig. 11.

SVT Space Point Simulator: The SVT Space Point Simulator simulator uses simulated SVT hits, produced for instance by GSTAR, to produce simulated reconstructed SVT Space Points. The Space Point Simulator, also called "fast simulator," accounts for the finite position resolution of the Silicon Drift Detectors (SDD) and for hit merging when hits are too close to one another. The components of the Space Point Simulator are shown in Fig. 12.

SVT Track Simulator: The SVT Track simulator is used to study the intrinsic performance of the SVT detector. It uses SVT hits, produced for instance by GSTAR, and assumes knowledge of which points belong to which tracks to reconstruct the tracks and calculate their kinematics. It thus neglects effects due to the finite resolution of the SDD but includes effects due to the finite acceptance of the detector and multiple scattering. The elements of the track simulator are shown in Fig. 13.

SVT Pedestal and Voltage Offset Simulator: The SVT Pedestal and Voltage Offset Simulator is meant to simulate the noise of the SDD and electronics signals in order to evaluate the impact of the noise on the detector position resolution and energy deposition (dE/dx) resolution, and to study or test the robustness of the pedestal calibration procedure under various realistic data taking conditions. The components of the SVT Pedestal and Voltage Offset Simulator are shown in Fig. 14.

SVT Geometry and Alignment Simulator: The SVT Geometry and Alignment Simulator is a simple code to generate small but coherent position shifts or offsets of the SDD wafer positions. The position and orientation of the SDD wafers is needed to reconstruct the space point positions. The knowledge of the position and orientation of the wafers is primarily based on a series of detector surveys. However, the positional information will need to be corrected for small offsets. These corrections will be determined on the basis of a study, among other things, of straight tracks produced in the absence of a magnetic field with the alignment calibration software. The purpose of the geometry calibration simulator is to generate, given nominal SDD wafer positions, small position and orientation offsets. These offsets can be used with the space point or raw data simulators to generate simulated SVT raw pixel data or simulated reconstructed space points including detector geometry calibration effects. It thus becomes possible to evaluate the performance of a "mis-aligned" detector and to study the alignment calibration software performance. The components of the SVT Geometry and Alignment Simulator are shown in Fig. 15.

SVT Time Offset Simulator: This is used to simulate the timing jitter in the SCA electronics, systematic timing offsets between each hybrid board, and overall timing shifts relative to the RHIC clock and/or event time. This is needed in order to study the effects on position resolution and to allow testing and development of calibration software. The components are shown in Fig. 16.

SVT Gain Simulator: The gain simulator is meant to simulate random (but slowly varying) gain variations. These variations or deviations must eventually be identified and corrected for by the gain calibration software. The components of the SVT Gain Simulator are shown in Fig. 17.

SVT Drift Time to Position Map Simulator: In the ideal case the drift speed is uniform across the detector. It is however possible to envision conditions by which the drift speed varies globally or even locally. It is the purpose of the SVT Drift Time to Position Map Simulator to generate arbitrary drift speed maps taking into account the actual detector bias, temperature and including miscellaneous defects. The components are shown in Fig. 18.

Requirements:

1. The SVT detector simulation software is required to simulate the response of the SVT detector and electronics to the passage of ionizing particles through the Silicon Drift Detector wafers. These particles may be cosmic rays traversing the detector or particles produced in pp, pA, AA, or in beam-gas interactions. The simulation software also includes components to simulate the response of the SDD wafer detectors to ionization via laser beams and to direct charge injection via capacitive coupling to implanted cathode injection lines in the SDDs. The response simulation software must take into account a proper description of charge transport in the drift detector. It must also include an appropriate description of the response of the analog and digital electronic components. The software must permit the study of various adverse effects such as temperature variations, bias fluctuations, electric field distortions, detector mis-alignment, variations of the response of the electronics, dead or malfunctioning channels, etc.

2. The SVT is sensitive to the passage of ionizing particles all the time, so all the particles that traverse the SDD wafers produce drifting charge that superimpose their image on that from the tracks of the event that is read out. Also the triggered event is superimposed on the ionization that was left by particles passing the SDD wafers at an earlier time. In order to understand the background, these features must be reproduced in the simulations. For the SVT this is mainly an issue for the high luminosity pp spin physics program.

   The SVT detector simulation software is therefore required to account for the passage of ionizing particles through the SVT active wafer volumes before and after the triggered event. The time the detector simulation has to take into account equals the time needed for a drift across the full SDD. Particles from minimum biased, "out-of-time" collisions should be included in these simulations.

3. The SVT detector simulation software must simulate such realistic effects as non-uniform drift velocities which could be caused by temperature gradients and distortions in the electric field, fluctuations and systematic variations in electron attenuation, anode response and electronics gain, dead or malfunctioning channels, etc. Simulation of these effects are necessary in order to develop correction procedures and calibration software.

4. The SVT detector simulation software must produce simulated data in the same format to be used by the actual data acquisition system for real data. This is necessary in order to develop and debug the raw data unpacking software.

5. The SVT detector simulation software must provide simulated, raw ADC data output for loading into the SVT front end electronics (FEE) read-out boards for DAQ development and testing, specifically the HDLC link.

6. The SVT detector simulation software must be able to directly generate the reconstructed SVT space points, thus bypassing the medium SVT simulator and the cluster finder/space point reconstruction analysis. This is necessary because in physics analyses a very large number of Monte Carlo events are needed to understand and give a statistically meaningful interpretation of the physics results. Generation of a large number of Monte Carlo events with the medium simulator is CPU intensive. This can be circumvented by directly generating SVT space points which have characteristics identical to those hits reconstructed from simulated pixel data.

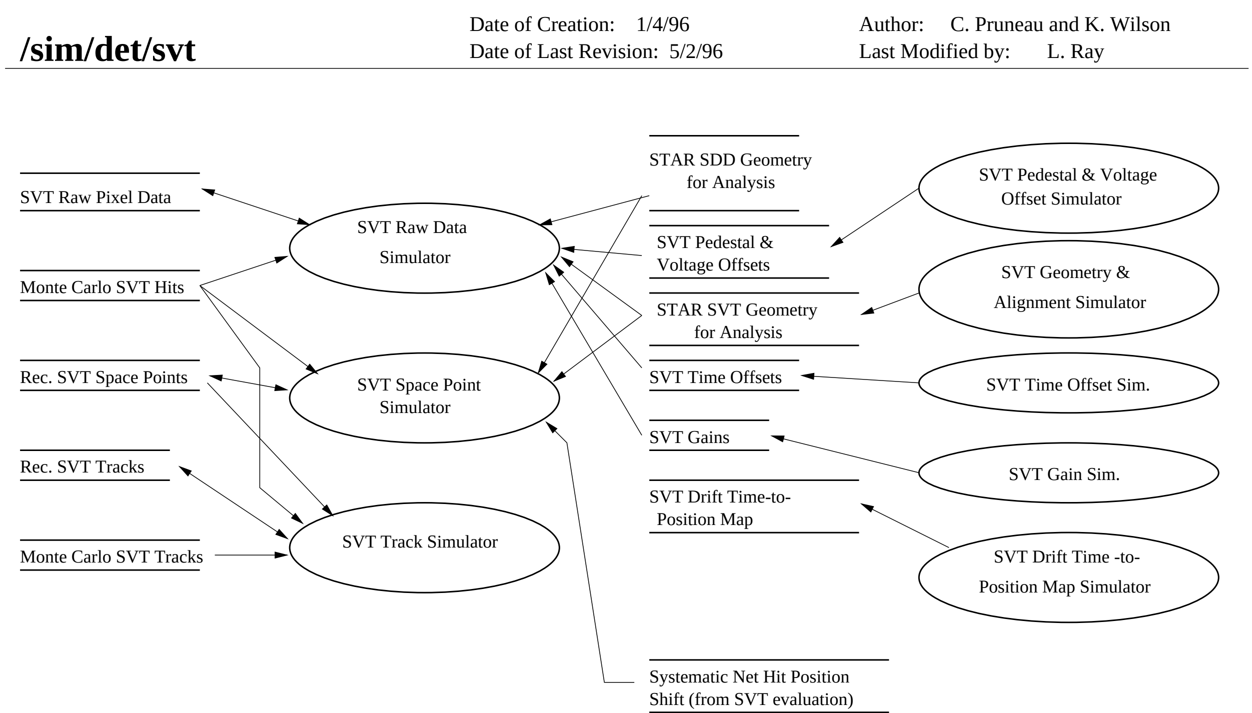

Figure 10: SVT Simulation Software - Top Level

Glossary of Terms:

Processes:

SVT Raw Data Simulator – Full simulation of the SVT SDDs and electronics to all ionizing energy depositions. Referred to as the SVT Medium Simulator. The process outputs simulated ADC pixel data.

SVT Space Point Simulator – Direct simulation of reconstructed SVT space points accounting for hit finding efficiencies and acceptance and hit merging. The process outputs simulated SVT space points.

SVT Track Simulator – Ideal tracking simulation for studying detector acceptance and multiple Coulomb scattering effects. The process outputs simulated SVT tracks.

SVT Pedestal and Voltage Offset Simulator – Simulates noise in the SDD and electronics as well as fluctuations in the electronics bias voltages.

SVT Geometry and Alignment Simulator – Simulates bulk shifts in the SDD wafer positions and/or ladder positions; used to test and develop alignment calibration software.

SVT Time Offset Simulator – Simulates time jitter and offsets.

SVT Gain Simulator – Simulates fluctuations in the electronic gains.

SVT Drift Time to Position Map Simulator – Simulates nonuniformities in the SDD drift time to position mapping.

Data Stores:

SVT Raw Pixel Data – SVT raw data (ADC information) together with the addressing information (see /ana/svt).

Monte Carlo SVT Hits – The simulated SVT hits, produced for instance by GSTAR, consisting of the coordinates of track crossing points through the detector planes, the angles of such crossings inside and outside the plane of the detectors, as well as the energy deposited by the passage of the charged particles.

Reconstructed SVT Space Points – Reconstructed space points including hit merging, position resolution, position displacement, false points, lost hits and energy deposition and position errors (see /ana/svt).

Reconstructed SVT Tracks – Reconstructed tracks through the SVT. This contains a list of points associated with a track as well as the reconstructed kinematic parameters of the track such as its momentum, pitch and azimuthal angles.

Monte Carlo SVT Tracks – Simulated tracks through the active region of the SVT generated, for example, by GSTAR. Includes a list of associated Monte Carlo SVT hits, track kinematics, particle ID, energy deposited, etc.

STAR SDD Geometry for Analysis – The SDD Geometry describes the shape and size of the Si Drift Detector active region, the number, position and size of the anodes, the number, duration, and time interval between samples.

SVT Pedestal and Voltage Offsets – Simulated ADC values for each channel and time bin, with no SVT hits; mean and rms values for many events. Also includes a list of "arbitrary" voltage offsets used to simulate the baseline offsets of the signal output by the PASA chain. Ideally there should be only one such offset for all SCAs. In practice, one may have to use different values for each SCA. These voltage offsets lead to pedestals.

STAR SVT Geometry for Analysis – see /sim/geometry. Simulated offsets to the nominal detector positions can be included here in the software alignment correction variables.

SVT Time Offsets – Channel by channel time offsets relative to the triggered event for the SCA conversion of analog signals to time bins.

SVT Gains – Parameters which define the nominal and fluctuating gains of all SVT electronics channels.

SVT Drift Time to Position Map – A lookup table that establishes a one-to-one correspondence between drift time and position for each SDD.

Systematic Net Hit Position Shift (from SVT evaluation) – Net space point position offsets that remain after nonuniformities in the simulated drift time to position mapping are corrected using calibrations.

Data Flows:

None

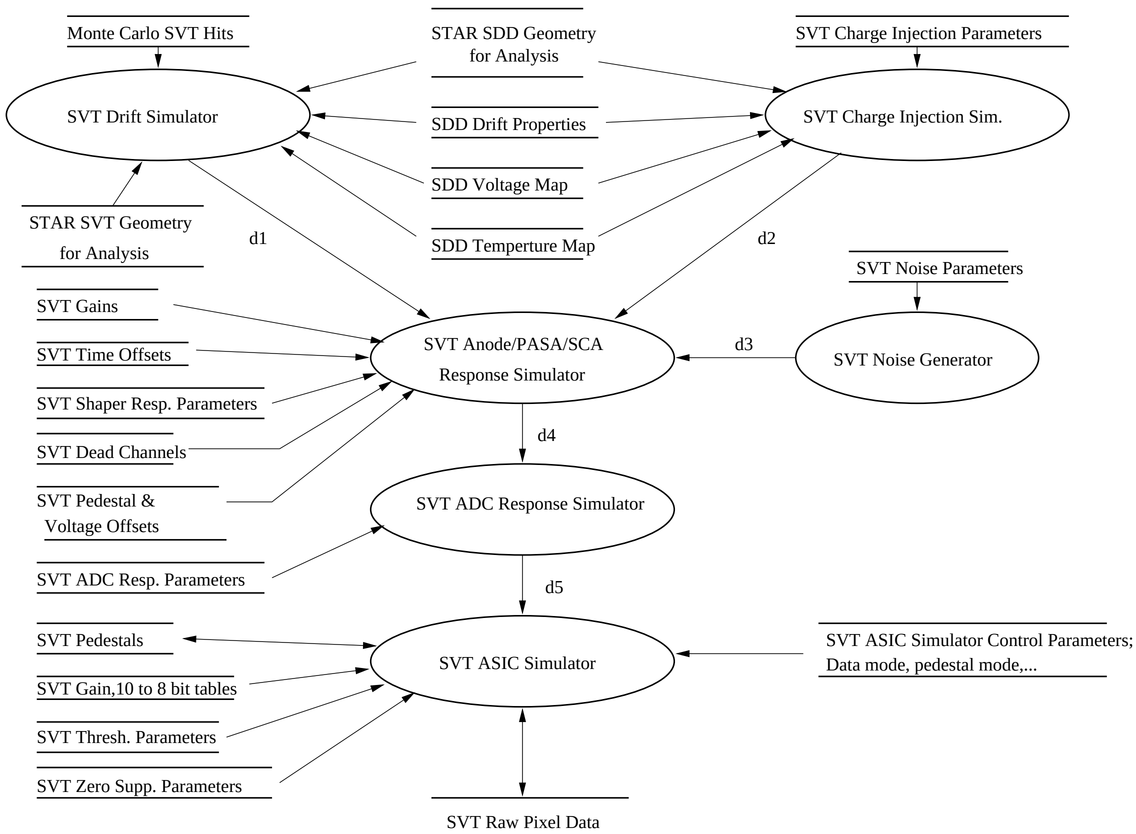

Figure 11: SVT Medium Simulator Functionality

Glossary of Terms:

Processes:

SVT Drift Simulator – The drift simulator generates anode signals on the basis of the position, orientation and charged deposition of the Monte Carlo SVT hits. It takes into account effects of diffusion, Coulomb repulsion, and the shape of the transport field, temperature gradients, etc.

SVT Charge Injection Simulator – The SVT Charge Injection Simulator describes the injection of charge in the bulk of the SDD by capacitive coupling to develop and evaluate the tools necessary for the detector drift speed calibration.

SVT Noise Generator – The noise generator is used to generate realistic noise to be added to the simulated signals produced by the passage of charged particles. The noise generator is also used with the pedestal and line injection simulators.

SVT Anode/PASA/SCA Response Simulator – This process transforms the simulated anode signal output by the drift simulator to produce simulated SCA output consisting of voltage values sampled at regular intervals.

SVT ADC Response Simulator – The SVT ADC Response Simulator transforms the simulated analog signals output by the Anode/PASA/SCA Simulator to produce simulated ADC values. It takes into account the finite range of the actual ADCs, the number of bits (10) used in the conversion, the actual sensitivity of the ADC, offsets and possible nonlinear distortions of the signals.

SVT ASIC Simulator – This process simulates the pedestal subtraction, thresholding, and zero suppression of the ADC values to produce a reduced volume of SVT raw pixel data. Updates pixel information in final output data store.

Data Stores:

Monte Carlo SVT Hits – see /sim/det/svt.

SVT Gains – see /sim/det/svt.

SVT Time Offsets – see /sim/det/svt.

SVT Shaper Response Parameters – The shaper response parameters include all parameters needed to specify the response of the PASA chain. They specify the nominal gain, the shaper time, and its response to a delta function.

SVT Dead Channels – A list of dead or malfunctioning channels that produce no, or bad readout.

SVT Pedestal and Voltage Offsets – see /sim/det/svt.

SVT ADC Response Parameters – The ADC Response Parameters include all necessary parameters to specify the response of the ADC. In the ideal case of a distortion free ADC, these consist of the voltage range, the number of bits used in the conversion, the gain or sensitivity (Volts/ADC Channel), and an offset. One may optionally consider the inclusion of nonlinear effects or distortions at the low and high ends of the ADC range.

SVT Pedestals – Simulated ADC values for each pixel with no SVT hits; mean and rms values obtained for many events are stored here.

SVT Gain, 10 to 8 Bit Tables – 10 bit to 8 bit, nonlinear translation table for each channel, including assumed electronics gains; or 10 bit to 8 bit algorithm plus channel by channel gain correction function parameters.

SVT Threshold Parameters – Minimum and maximum threshold parameters for ASIC simulation of hit finding.

SVT Zero Suppression Parameters – Includes minimum number of consecutive time bins in sequence and other parameters used to determine time sequences.

STAR SVT Geometry for Analysis – see /sim/geometry and /sim/det/svt.

STAR SDD Geometry for Analysis – see /sim/det/svt.

SDD Drift Properties – The SDD Drift Properties include all properties pertinent to the description of the charge drift in the detector such as electron mobility, Si dielectric constant, the Si diffusion constant, the nominal drift velocity, the nominal detector bias, etc.

SDD Voltage Map – The SDD Voltage Map consists of a detailed description of the electric field magnitude in the drift plane of the SDD at various/many locations inside the detector.

SDD Temperature Map – The SDD Temperature Map consists of a detailed description of the temperature at different points in the SDD which will affect the mobility of the charge carriers.

SVT Raw Pixel Data – see /sim/det/svt.

SVT Charge Injection Parameters – Contains all parameters necessary for the definition of the charge injection such as the injection position, duration, and amplitude.

SVT Noise Parameters – Contains all parameters necessary for the definition of the noise such as the electronics bandwidth and the noise amplitude.

SVT ASIC Simulator Control Parameters – Contains control parameters which determine the computation mode; *i.e.,* normal data simulation or simulated pedestal run.

Data Flows:

d1 – Calculated anode response (currents) for each anode from simulated particle tracks.

d2 – Calculated anode response (currents) for each anode from simulated charge injection.

d3 – Analog noise signal for each channel.

d4 – Analog output signals for each channel and time bin.

d5 – Simulated, raw ADC pixel data before ASIC operation.

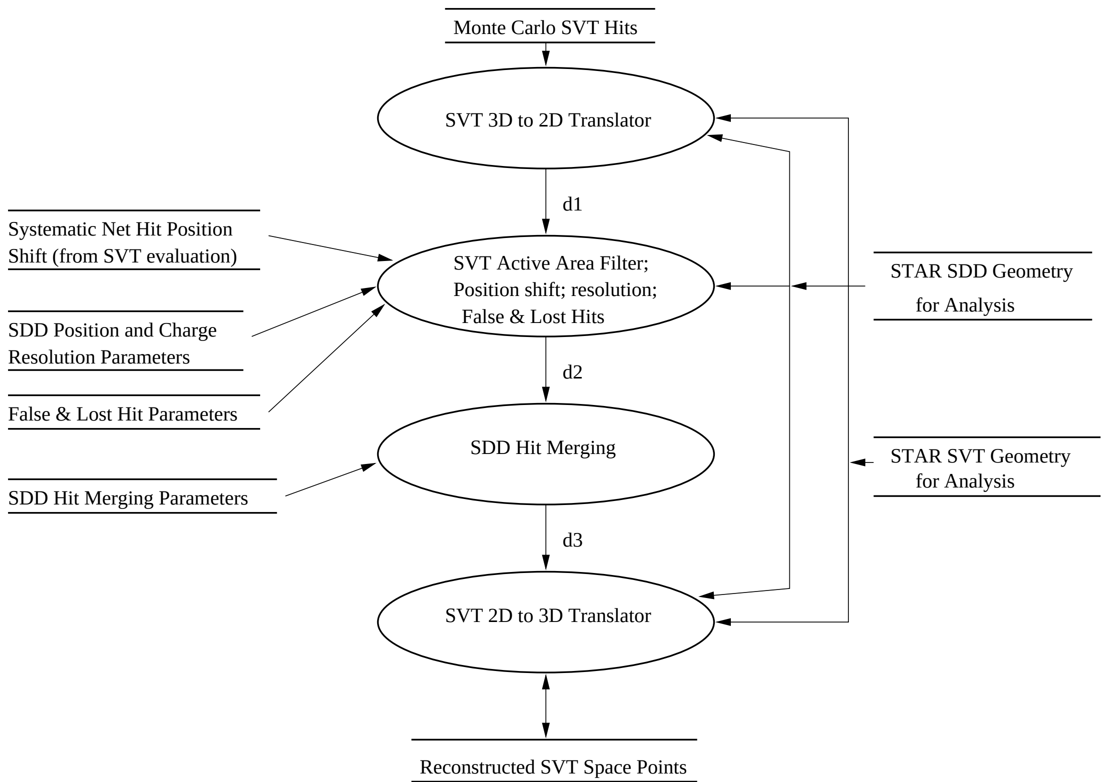

Figure 12: SVT Fast Simulator Functionality

Glossary of Terms:

Processes:

SVT 3D to 2D Translator – The 3D to 2D translator uses the SVT geometry information to transform the 3 dimensional hit coordinates into 2 dimensional coordinates in the drift plane on the SDD.

SVT Active Area Filter; Position Shift; Resolution; False and Lost Hits – The position filtering and smearing procedure first determines if an input hit is within the active region of the SDD. If not the hit is discarded, if yes, the hit position is smeared, *i.e.* shifted in the drift plane of the SDD by an arbitrary offset whose magnitude is determined on the basis the resolution prescribed. False hits may be introduced; some hits may be discarded to simulate the medium simulator or actual SDD performance.

SDD Hit Merging – The hit merging procedure examines the hits and merges those that are considered too close to each other to be resolved.

SVT 2D to 3D Translator – The 2D to 3D translator uses the SVT geometry information to transform the 2 dimensional hit coordinates expressed in the local reference frame of specific SDD wafer into 3 dimensional SVT coordinates. Updates space point information in final output data store.

Data Stores:

Monte Carlo SVT Hits – see /sim/det/svt.

Systematic Net Hit Position Shift – see /sim/det/svt.

SDD Position and Charge Resolution Parameters – The SDD Position and Charge Resolution Simulation Parameters include all necessary parameters to specify the finite position and charge (energy deposition) resolution of the SDDs.

False and Lost Hit Parameters – Parameters obtained from the Medium Simulator and space point reconstruction results (or real SDD data analysis) which determine the hit reconstruction efficiency as well as the purity and amount of false hit contamination.

SDD Hit Merging Parameters – These consist of selection cuts, mainly based on the hit separation, which determine if close hits should be merged into one.

STAR SDD Geometry for Analysis – see /sim/det/svt.

STAR SVT Geometry for Analysis – see /sim/geometry and /sim/det/svt.

Reconstructed SVT Space Points – see /sim/det/svt.

Data Flows:

d1 – SDD wafer ID and local 2D coordinates for each Monte Carlo SVT hit along with all other associated hit information.

d2 – This includes data flow *d1* but with flags set which indicate hits in active or inactive areas of the SDDs; shifted 2D coordinates and charge deposition; additional, false hit information; lost hits are flagged.

d3 – Data flows *d1* and *d2* inclusive plus hit merging flags.

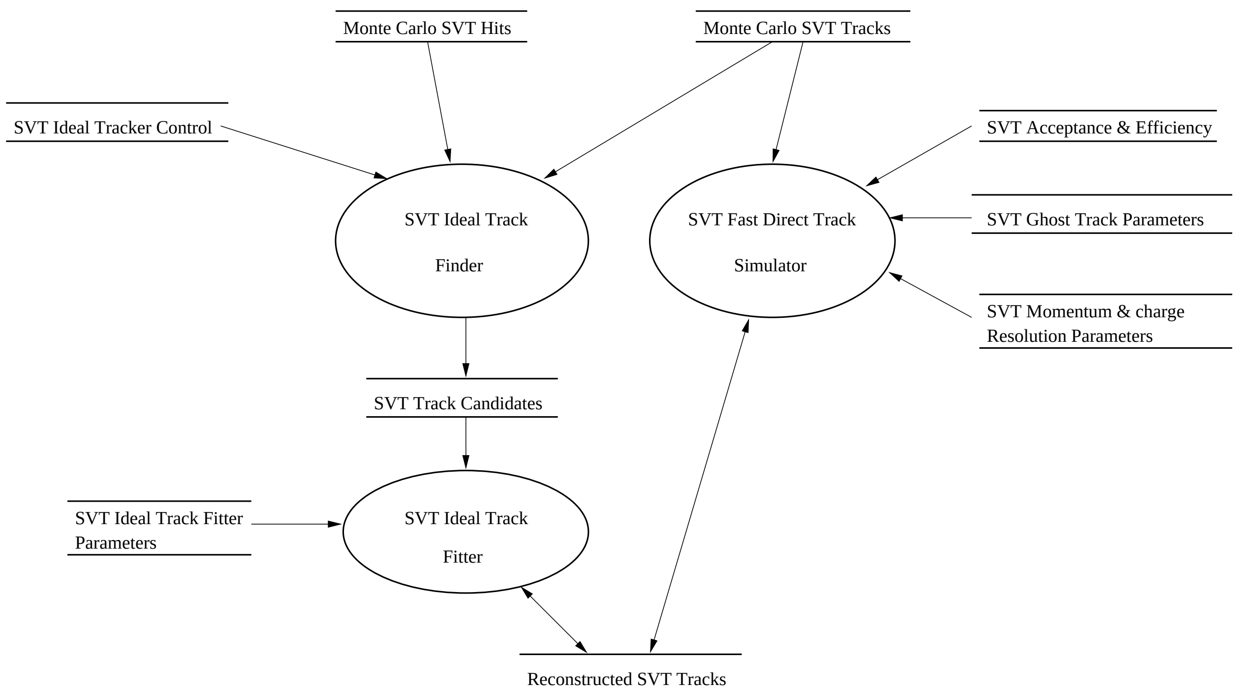

Figure 13: SVT Tracking Simulator Functionality

Glossary of Terms:

Processes:

SVT Ideal Track Finder – The SVT Ideal Track Finder uses the Monte Carlo information about the SVT Hits to reconstruct all tracks, *i.e.* to assign all SVT hits to their proper track.

SVT Ideal Track Fitter – The SVT Ideal Track Fitter uses a helicoidal track model to fit the space points assigned to a track and determine the kinematic parameters of the tracks. Updates track information in final output data store.

SVT Fast Direct Track Simulator – This process does direct tracking from Monte Carlo SVT tracks using calculated acceptance, efficiencies, ghost track contamination, momentum and charge resolution, and two-track resolution criteria. Updates track information in final output data store.

Data Stores:

Monte Carlo SVT Hits – see /sim/det/svt.

SVT Ideal Tracker Control – Control parameters for the SVT ideal track finder.

SVT Ideal Track Fitter Parameters – Fitting parameters for the SVT Ideal Track Fitter.

SVT Track Candidates – List of space points associated with a candidate track.

Monte Carlo SVT Tracks – see /sim/det/svt.

Reconstructed SVT Tracks – see /sim/det/svt.

SVT Acceptance and Efficiency – Calculated SVT tracking acceptance and efficiencies from SVT tracking evaluation.

SVT Ghost Track Parameters – Parameters defining the tracking purity.

SVT Momentum and Charge Resolution Parameters – Contains parameters defining the SVT track momentum resolution and associated charge (dE/dx) resolution.

Data Flows:

None

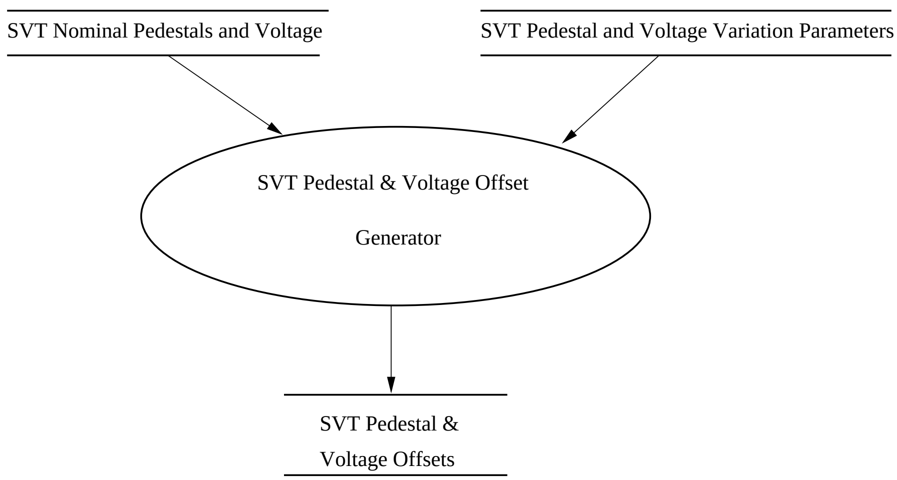

Figure 14: SVT Pedestal and Voltage Offset Simulator

Glossary of Terms:

Processes:

SVT Pedestal and Voltage Offset Generator – This process calculates SVT pedestals and input voltage offsets based on nominal values and including fluctuations.

Data Stores:

SVT Nominal Pedestals and Voltage – Nominal pedestal mean and rms for each ADC pixel; voltage bias mean and rms for each channel.
SVT Pedestal and Voltage Variation Parameters – Parameters defining the input voltage bias fluctuations.
SVT Pedestal and Voltage Offsets – see /sim/det/svt.

Data Flows:

None

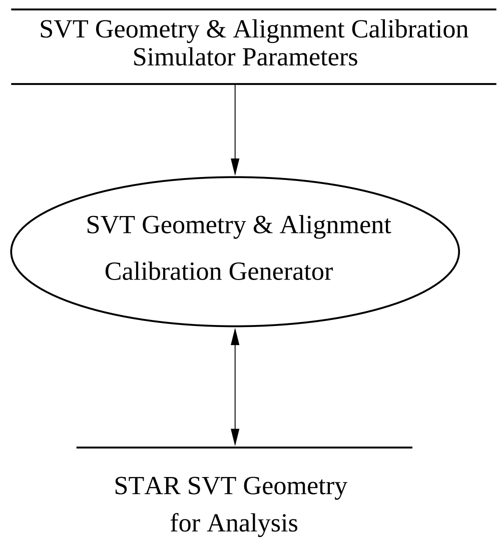

Figure 15: SVT Geometry and Alignment Software

Glossary of Terms:

Processes:

SVT Geometry and Alignment Calibration Generator – The SVT Mis-align procedure calculates position and orientation offsets on the basis of the geometry calibration selection parameters and loads/updates them to the position and orientation software alignment correction. For use in simulations only.

Data Stores:

SVT Geometry and Alignment Calibration Simulator Parameters – The geometry calibration selection parameters consists of position and angular offset ranges to be used to generate random position and angular offsets.
STAR SVT Geometry for Analysis – see /sim/geometry and /sim/det/svt.

Data Flows:

None

/sim/det/svt/time

Date of Creation: 1/4/96
Date of Last Revision:

Author: C. Pruneau and K. Wilson
Last Modified by:

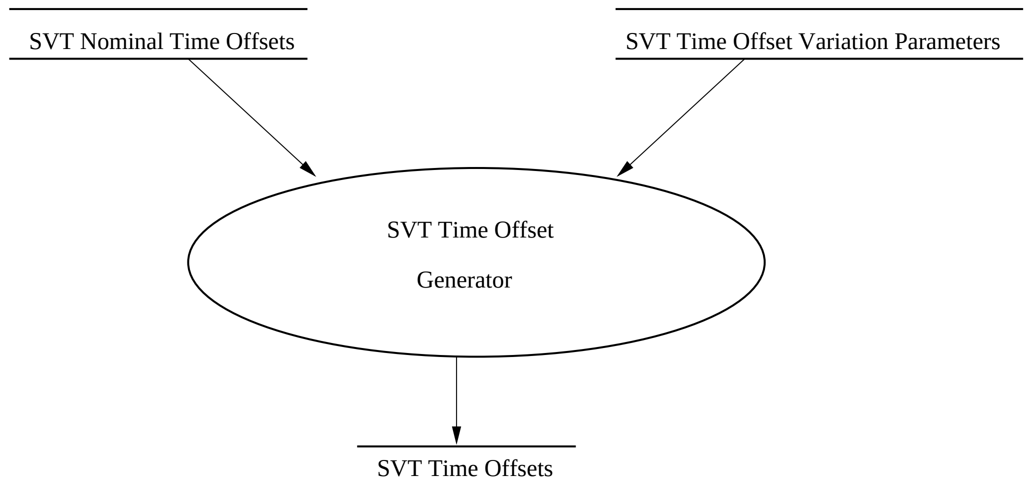

Figure 16: SVT Time Offset Simulator Software

Glossary of Terms:

Processes:

SVT Time Offset Generator – Calculates timing jitter in each channel, systematic timing offsets for channels on a given hybrid board, plus overall timing offsets relative to the triggered event.

Data Stores:

SVT Nominal Time Offsets – Expected time offsets for each channel.
SVT Time Offset Variation Parameters – Parameters which determine the time jitter, systematic and overall time offsets.
SVT Time Offsets – see /sim/det/svt.

Data Flows:

None

/sim/det/svt/gains

Date of Creation: 1/4/96
Date of Last Revision:

Author: C. Pruneau and K. Wilson
Last Modified by:

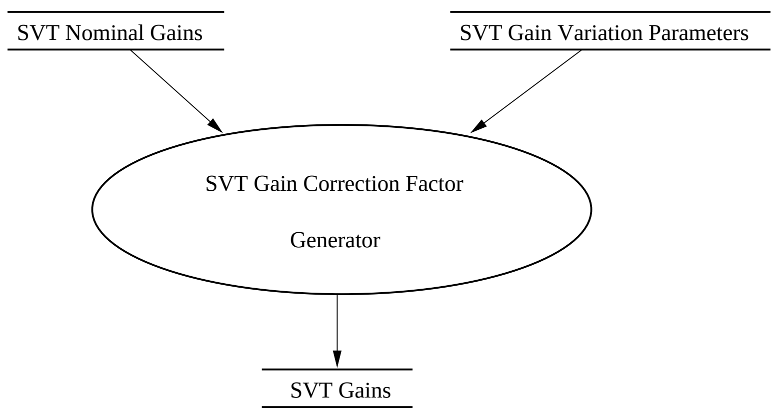

Figure 17: SVT Gain Correction Simulator Software

Glossary of Terms:

Processes:

SVT Gain Correction Factor Generator – This procedure calculates on the basis of the nominal gains and the gain simulator parameters a set of gain factors for all SVT electronics channels.

Data Stores:

SVT Nominal Gains – A minimal set of parameters used to define the nominal gain of the PASA/SCA chain.

SVT Gain Variation Parameters – These parameters consist of gain ranges to be used to generate gain factors with arbitrary (random) fluctuations about the SVT nominal gains.

SVT Gains – see /sim/det/svt.

Data Flows:

None

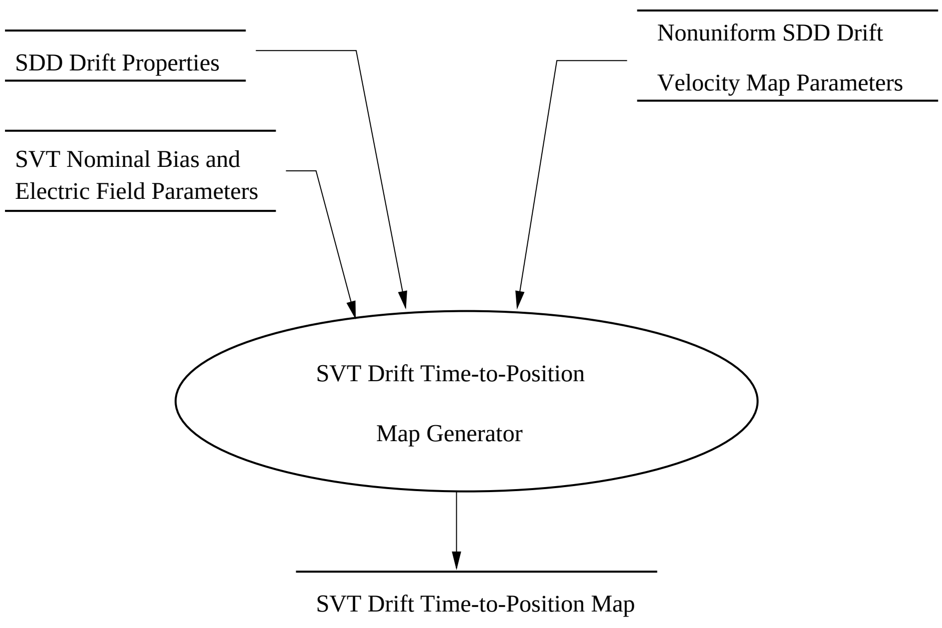

Figure 18: SVT Drift Time to Position Map Simulation Software

Glossary of Terms:

Processes:

SVT Drift Time to Position Map Generator – This procedure calculates a drift velocity map on the basis of the nominal biasing parameters plus the specifications of distortions selected by the user.

Data Stores:

SDD Drift Properties – see /sim/det/svt/raw_data.

SVT Nominal Bias and Electric Field Parameters – Nominal values of all the parameters that determine the drift speed.

Nonuniform SDD Drift Velocity Map Parameters – All parameters necessary to describe field nonlinearities or other sources of nonlinear drift response.

SVT Drift Time to Position Map – see /sim/det/svt.

Data Flows:

None

Status:

See the following STAR Library Packages:

srs – SVT Fast Simulator.
ssf – SVT electronics simulation.
sss – SVT Slow Simulator.

4.7 CTF (CTB and TOF) Simulation (/sim/det/ctf)

This section contains a description, list of requirements, functional model diagram in Fig. 19, glossary of terms and status of software report.

Description:

The CTF detector simulation code transforms the GEANT or GSTAR Monte Carlo hits into ADC and TDC signals with the same format as DAQ real data. The first step consists in looping over all the hits produced by charged particles in the scintillators of the CTB and TOF. The code is flexible enough to handle different configurations of the TOF: a device replacing completely the CTB or a partial patch. The total charged deposited in each scintillator is then converted into a number of photoelectrons produced by the corresponding photo-multiplier (PMT). Scintillator and PMT properties are taken into account in this calculation. In addition the time jitter and smearing of the PMT signal are also simulated. Light propagation in the scintillator and PMT time resolution are taken into account in this step. The code concludes the simulation by emulating the Analog-to-Digital converter function. In addition to digitized amplitudes and times, offset signals and different types of noise are introduced.

The CTF detector simulation software may generate the full event or just a portion of the event (*e.g.* background tracks, rare particles and decays, etc.). In the latter case it is assumed that the output data stores (raw ADC and TDC values) have already been filled with data from an external source (either from a previous simulation or eventually from actual data) and that these data stores are to be updated.

Requirements:

1. The CTF detector simulation software is required to simulate the response of the CTB and/or TOF detector volume and electronics to the passage of ionizing energy through the CTF volume, including that from pp, pA and AA collisions, beam-gas interactions and cosmic rays. This is needed in order to develop hit reconstruction and overall event reconstruction software, test and develop DAQ, test and develop calibration procedures, allow computation of detector efficiencies and acceptances, and test and develop trigger software.

2. The CTF simulation software must produce simulated data in the same format to be used by the actual DAQ in order to test DAQ and develop the unpacking procedures.

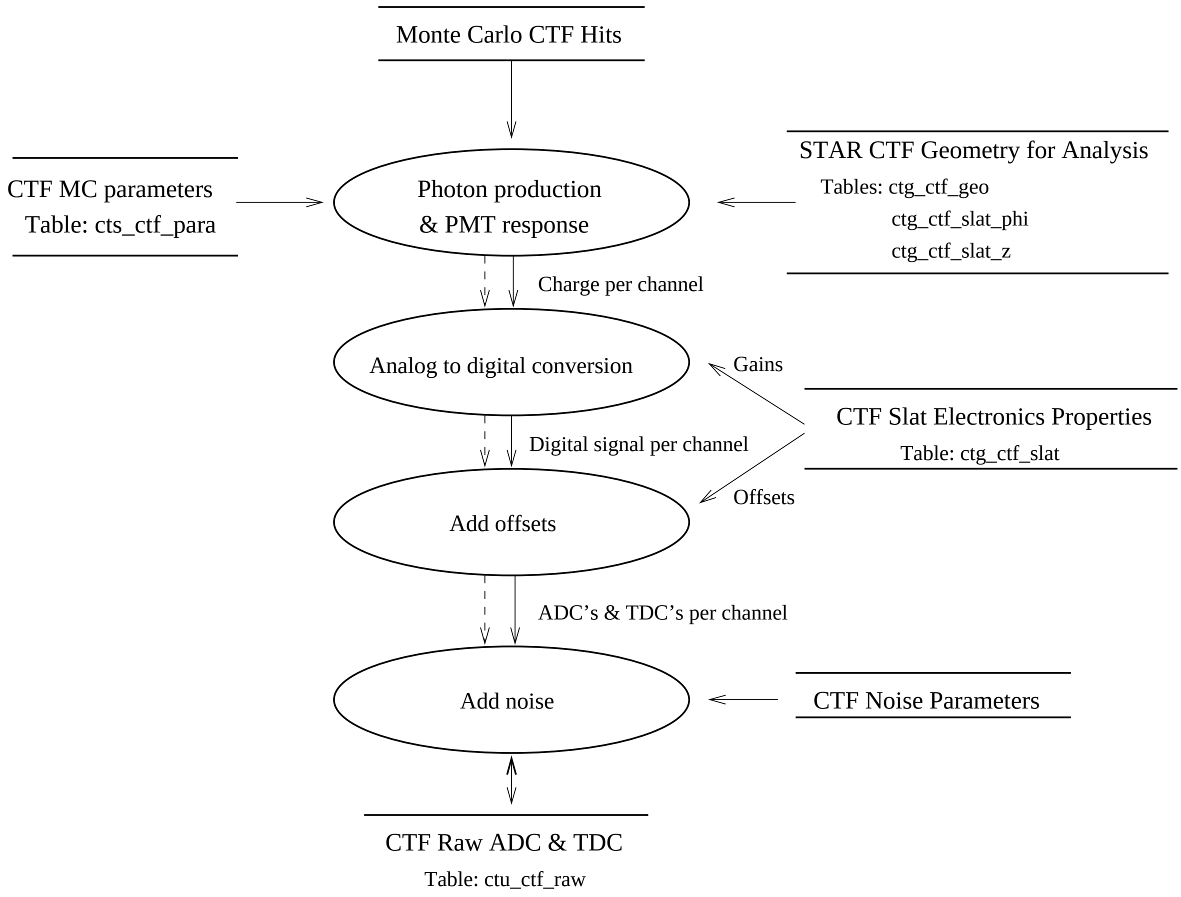

Figure 19: CTF (CTB and TOF) Simulation Software

Glossary of Terms:

Processes:

Photon Production and PMT Response – The scintillator light emission is simulated along with the light conversion into an electric pulse.

Analog to Digital Conversion – Emulates ADCs and TDCs including gain corrections; bad channels are tagged or removed.

Add Offsets – The signal produced by ADCs and TDCs when the input is zero is incorporated in the simulation. This includes simulated gain fluctuations, simulated PMT time jitter, systematic timing offsets between PMTs, and overall timing offsets relative to the triggered event.

Add Noise – Electronic and instrumental background is included in the simulation. Updates information in final output data store.

Data Stores:

Monte Carlo CTF Hits – Contains information about hits of charged particles crossing the CTF scintillators.

CTF MC Parameters – Set of variables with scintillator and PMT characteristics controlling the package operation (see table cts_ctf_para).

STAR CTF Geometry for Analysis – see /sim/geometry; implemented via tables ctg_ctf_geo, ctg_ctf_slat_phi, ctf_slat_z.

CTF Slat Electronics Properties – Offsets and gains for all channels are stored here as well as the assumed list of bad channels. Also parameters determining timing jitter and offsets are included here (see table ctg_ctf_slat).

CTF Noise Parameters – Parameters to steer the addition of electronic or instrumental background noise are kept in this data store.

CTF Raw ADCs and TDCs – Simulated raw ADC and TDC CTF output data in DAQ format (see table ctu_ctf_raw).

Data Flows:

Refer to labels on functional model diagram in Fig. 19.

Status:

See the following STAR Library Packages:

cts – CTB/TOF Detector Simulation.

4.8 EMC Simulation (/sim/det/emc)

This section contains a description, list of requirements, functional model diagrams for the top level (/sim/det/emc, Fig. 20) and for three sublevels including the slow simulator (/sim/det/emc/ess, Fig. 21), the fast simulator (/sim/det/emc/efs, Fig. 22), and signal processing simulation (/sim/det/emc/esp, Fig. 23). Four glossaries and a status of software report follow. Detailed descriptions of the present implementation of the EMC fast and slow simulators are available in Ref. [11].

Description:

The simulation of the EMC as an integral part of STAR involves calculating the response of both the EMC stack (towers and depth sections) and the EMC Shower Maximum Detector (SMD), for both the Barrel and Endcap. The output of the simulation chain should include all known effects in the performance of the device, including shower development and the properties of the optical readout chain, as well as descriptions of all of the algorithms used to process the data in the on-board electronics. The EMC simulations chain should produce output that looks exactly the same as that which will be delivered to the STAR DAQ system. Questions concerning the mechanical design, the optical read-out chain, the electronics signal processing, and calibration systems can, and should, be addressed using the simulation model described in this section.

Two methods for the kind of EMC simulation to be performed are described. These strategies will be referred to as "slow" (/sim/det/emc/ess) and "fast" (/sim/det/emc/efs) simulations. Each strategy may have particular advantages and disadvantages for a particular simulations topic. The EMC simulation codes will be developed with care being taken to allow many avenues for cross-checking between these strategies.

The first strategy involves the EMC Slow Simulator (ESS), /sim/det/emc/ess, which will be used to study the relationship between particular decisions made on the EMC design and the performance of the device for physics analyses. In ESS, GEANT or GSTAR describes the shower development. In the second approach the EMC Fast Simulator (EFS), /sim/det/emc/efs, will use parametrizations for the lateral and longitudinal profiles of EM and hadronic shower development in EM calorimeters to generate, via Monte Carlo methods, the tower, depth, and SMD signals for each track incident on the EMC stack. The available SPEMC test beam data can be used to insure that the parameters used in the shower descriptions are realistic, and that appropriate statistical fluctuations are included.

An important distinction between the EFS and ESS strategies relates to the effects that the presence of the EMC in STAR has on the CTB, TOF, and TPC. The only GEANT information that EFS needs is the kinematics of the particles that enter the EMC envelope (at that step in which they enter). This kind of simulation will by definition not result in any albedo in the inner detectors. However, even if EFS is to be used to describe the shower development and hence all of the EMC signals, the incident particles need not be stopped just when they enter the EMC. One could allow the incident particles to propagate to some depth in the stack, producing secondaries and albedo, then stop all outward-going tracks at that point. This option will not be quite fast as when EFS is used and the particles are stopped at incidence. In such an approach, one would expect the best possible reproduction of the showers (as they come from the test beam data via EFS), and a description of the majority of the albedo. [3]

The EMC detector simulation software may generate the full event or just a portion of the event (*e.g.* background tracks, rare particles and decays, etc.). In the latter case it is assumed that the output data stores (raw ADCs) have already been filled with data from an external source (either from a previous simulation or eventually from actual data) and that these data stores are to be updated.

Requirements:

1. The EMC detector simulation software is required to simulate the response of the Barrel, End Cap and SMD parts of the EMC detector volume and electronics to all incident charged and neutral particles from pp, pA and AA collisions, beam-gas interactions, cosmic rays, radioactive sources, other background sources, and various calibration methods. This is needed in order to develop energy deposition reconstruction and analysis software, test and develop DAQ, test and develop calibration procedures, and allow computation of detector efficiencies and acceptances.

2. The EMC detector simulation software must simulate light injection PMT calibration procedures.

3. The EMC detector simulation software must produce simulated data in the same format to be used by the actual data acquisition system for real data.

4. The EMC detector simulation software must provide simulated, raw ADC data output for loading onto the EMC onboard electronics for development and testing.

[3] This is of course to the extent that GEANT's microscopic showering leads to an accurate simulation of albedo. As for the ESS-based simulations, some attempt to tune the GEANT showers to match the test beam data will be necessary.

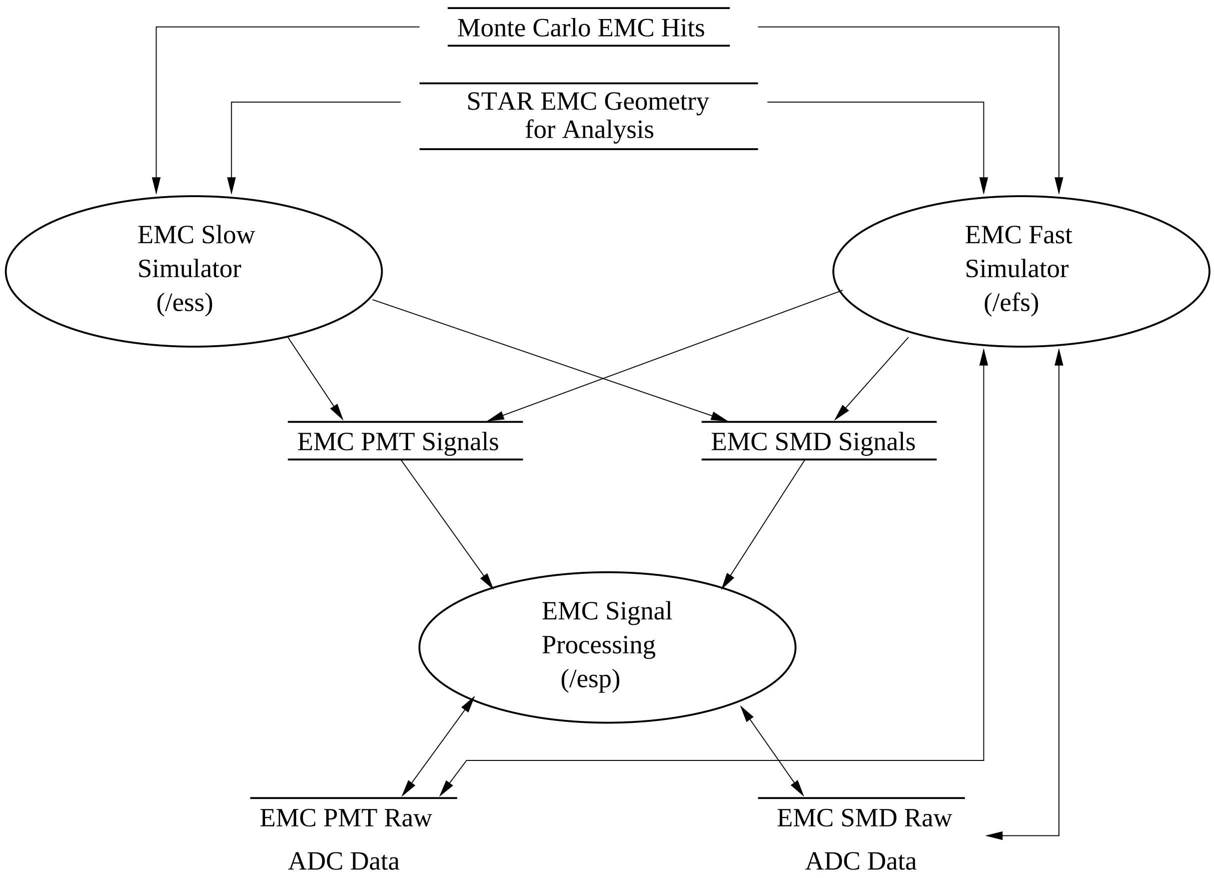

Figure 20: EMC Simulation Software Functionality – Top Level

Glossary of Terms:

Processes:

EMC Slow Simulator (/ess) – Slow simulator using full GEANT or GSTAR shower development.

EMC Fast Simulator (/efs) – Fast simulator using parametrized shower profiles.

EMC Signal Processing (/esp) – On-board EMC electronics response simulation.

Data Stores:

Monte Carlo EMC Hits – Incident particles and/or shower information from GEANT, depending on "slow" or "fast" simulation mode. For "slow" simulations this data store contains the PID, coordinates, and integrated energy depositions in small ($\sim$0.5mm^3) cells inside the scintillators of the stack and the fiducial volume of the SMD. This allows considerable flexibility in the definition of the pixelization of the detector and possible decreases in the GEANT output file sizes. Foreign keys are used to look up the information on the tracks contributing to each cell and the cells contributed to by each track. In the "fast" simulation mode this data store contains particle position and kinematic information at the entrance point of the EMC front plate or EMC volume.

STAR EMC Geometry for Analysis – Data store containing description and parameters of the detector (barrel, end cap and shower maximum) geometry and materials, including active elements, shower material, support structures, voids (gaps) between active detector elements, and pixelization in the SMD. See /sim/geometry.

EMC PMT Signals – EMC PMT output analog signals for each channel prior to any onboard electronics processing. For simulation of light injection calibration procedures the simulated PMT output signals are loaded into this data store.

EMC SMD Signals – EMC SMD output analog wire/strip signals for each channel prior to any onboard electronics processing.

EMC PMT Raw ADC Data – Processed EMC PMT ADCs for each channel after onboard electronics simulation; same data format as DAQ.

EMC SMD Raw ADC Data – Processed EMC SMD ADCs for each channel after onboard electronics simulation; same data format as DAQ.

Data Flows:

None

EMC Slow Simulator (ESS):

Description:

The EMC Slow Simulator (ESS) converts the energy depositions in scintillator plates to PMT signals for each fiber and/or fiber bundle, and the energy depositions in the SMD to the SMD signals. This module reads the Monte Carlo EMC hits data structure. At the output, ESS writes the PMT and SMD channel signals that would be obtained in the absence of any electronic processing of the signals in the onboard or platform electronics. There are two options for how ESS generates the PMT and SMD signals. The EMC geometry information is needed by both of these options.

In the first approach, a response function is used with a parametrization of the facial dependence to produce light at the scintillator/WSF (wave length shifting fiber) interface. The scintillator/WSF and WSF/CF (clear fiber) optical transmission efficiencies and the fiber core and cladding attenuation lengths are applied for each scintillator/WSF/CF combination, producing light at the fiber/PMT interface. The PMT quantum efficiency and gain are used to produce the number of photoelectrons for each PMT, including fluctuations from photoelectron statistics. The EMC geometry data structures define which plates go to which PMT, etc.

In the second approach (a much simpler one), the number of photoelectrons/mip-/plate is multiplied by the number of times minimum ionizing that each particle is, and summed for each plate to produce the PMT signals including the photoelectron statistics. The integrated number of photoelectrons/cell is saved by GEANT during the showering, and integrated to form the number of photoelectrons/PMT in the EMC Summations process. An example of this type of slow simulation can be found in Ref. [12].

The scintillator response function describes the amount of light produced for a given energy deposition. Commonly used forms for this function can probably be applied directly. The facial function describes the position dependence of the signal on the distance from the hit to a nearby WSF, which results in a 20% increase in the plate signal when the hit is close to the WSF edges. A cladding attenuation length for the CFs is not necessary, as the CFs are an order of magnitude longer than this length.

Examples of the topics open for study by the ESS involve the effects arising from the plate facial response (which is affected by the plate wrapping methods), the plate photoelectron response (cheaper scintillators put out less light), and the efficiencies of the Scint/WSF and WSF/CF couplings (to understand the coupling methods and if fiber splicing is necessary). Also, the SMD response will be parametrized, allowing studies of the drift and gain, the pulse height and position resolution, etc.

ESS thus adjusts the raw GEANT shower information to account for the properties of the optical readout chain. The parameters of this description will be adjustable, so that the effects that particular optical read-out chain benchmarks have on the physics analyses can be explored.

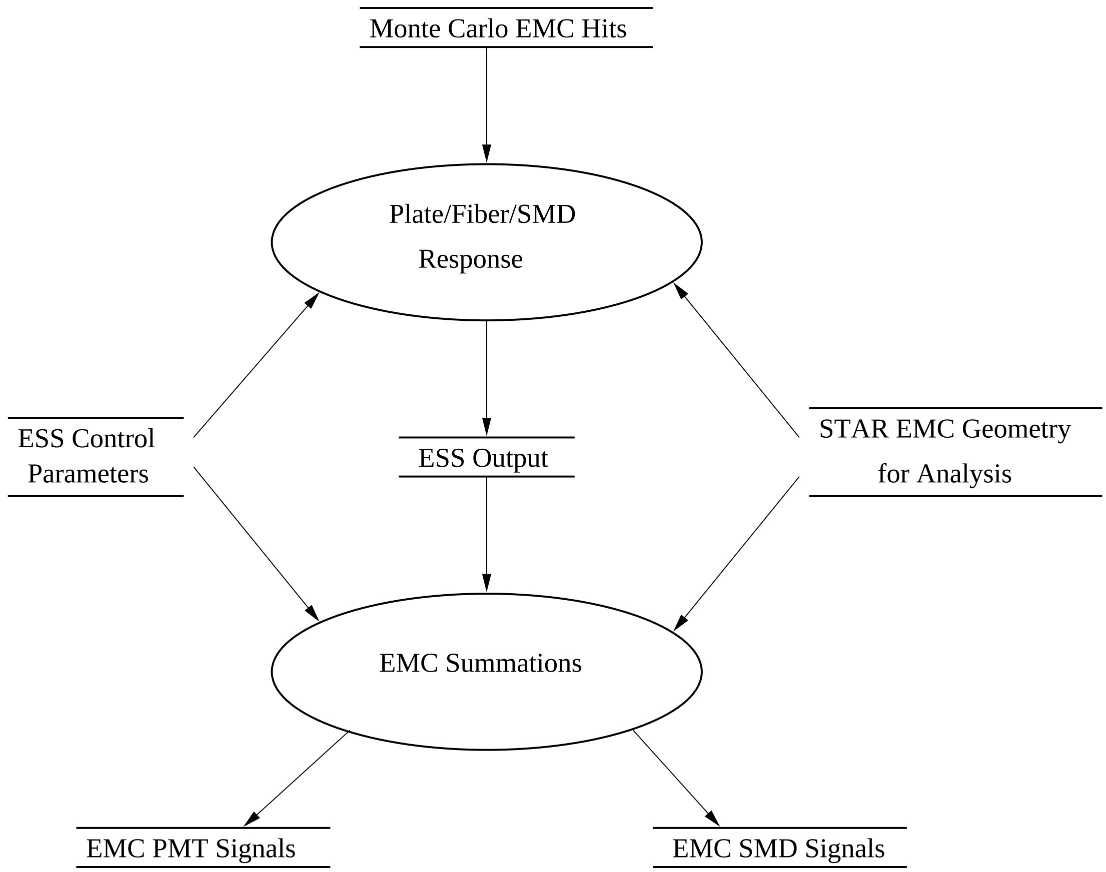

Figure 21: EMC Slow Simulator Software Functionality

Glossary of Terms:

Processes:

Plate/Fiber/SMD Response – Calibration of the scintillator plate, fiber and SMD wire/strip output as described in the preceding.

EMC Summations – This process produces the integrals of the signals in particular towers, depth sections, and SMD channels. The pixelization of the SMD and the definition of the towers and depth segmentation of the stack are obtained from the EMC Geometry for Analysis data store. The resulting sums in individual read-out channels are written to the EMC PMT Signals data store and the EMC SMD Signals data store.

Data Stores:

Monte Carlo EMC Hits – see /sim/det/emc.

ESS Control Parameters – This data store contains the parameters needed to control ESS. Two different kinds of slow simulations will be possible inside the ESS Module (as discussed in the preceding). This data store contains the input parameters necessary for both of these options. These include the value of Np.e./mip/plate (number of photo-electrons per minimum ionizing particle per plate), parameters for the functional form of the position dependence of the plate response, the scint/WSF and WSF/CF interface optical efficiencies, etc. Parameters for the slow simulation of the SMD response, and to control the EMC Summations process are also included.

ESS Output – This data store contains the ESS output. The energy depositions from GEANT showers are modified to include the effects from the properties of the optical read-out chain. The information obtained at several stages within ESS are also saved here. This makes the intermediate signal information available both for diagnosing problems and to allow studies of the importance of the individual effects simulated by ESS. Such a definition for this table also makes it possible to pass the information from either of the two ESS options into the same ESS output data store.

STAR EMC Geometry for Analysis – see /sim/det/emc and /sim/geometry.

EMC PMT Signals – see /sim/det/emc.

EMC SMD Signals – see /sim/det/emc.

Data Flows:

None

EMC Fast Simulator (EFS):

Description:

The EMC Fast Simulator (EFS) uses the known aspects of shower development in electromagnetic calorimeters to generate, via Monte Carlo methods, the lateral and longitudinal profiles of the deposited energy for each particle striking the EMC. The functional forms of the parametrizations for shower development will be fit to the known performance of the SPEMC (Small Prototype EMC) measured in two intensive and systematic test beam runs. Data on the performance of the LPEMC (Large Prototype EMC) will also be used when available.

Three classes of particles are treated in different ways. These classes are EM particles (*e.g.* electrons and photons), hadronic particles (*e.g.* charged pions and nucleons), and muons. The device does not respond in exactly the same way to electrons and photons, which will be reflected in the output of the EFS.

The shower profile parameters sampled for each track by EFS, the incident coordinates of each track, and the known relative positions of tower cracks, cuts, and SMD channels, are used to calculate the energy depositions in the towers, depth sections, and SMD channels. Thus, EFS writes directly to the PMT and SMD signals data stores.

EFS will also operate in a mode in which the PMT and SMD Raw ADC data output are produced directly, thus including the effects of onboard electronics and by-passing the EMC Signal Processing Simulation. This capability will be based on parametrizations of the LPEMC test data in which the final, onboard communications electronics will be attached.

The EMC Fast Simulator is important for the following reasons: (1) it provides statistically sufficient backgrounds for W and Z measurements and for jet finding simulations in a reasonable amount of cpu time, (2) it allows member institutions in STAR with limited computing capabilities to contribute to EMC simulations and development, and (3) the EFS description of the real EMC response may actually be more realistic than that of the ESS because the EFS response is “fitted” to actual test beam data from the SPEMC and LPEMC.

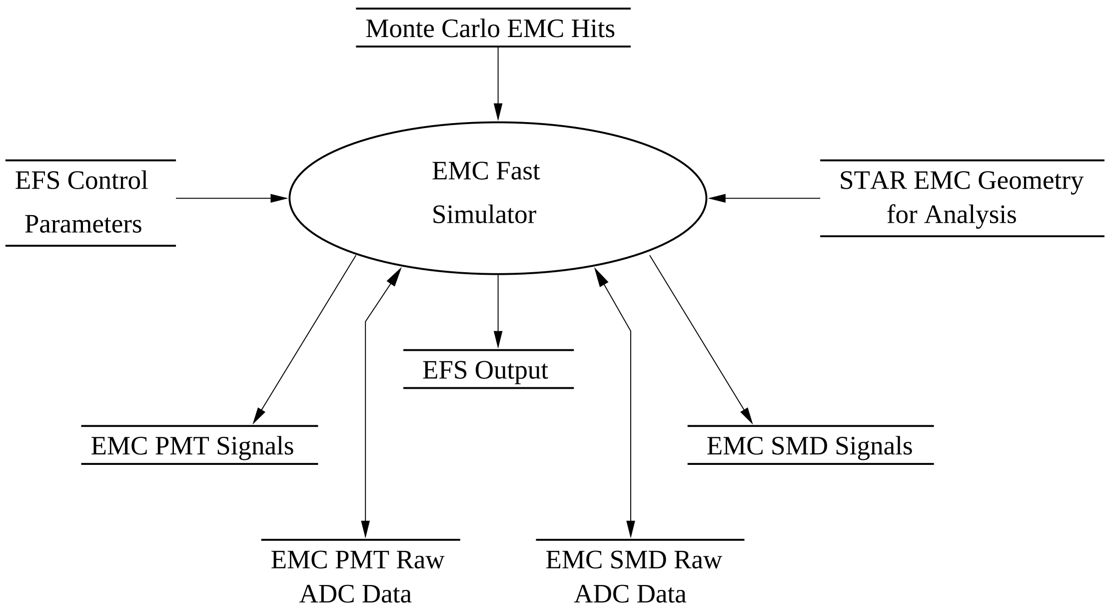

Figure 22: EMC Fast Simulator Software Functionality

Glossary of Terms:

Processes:

EMC Fast Simulator – Computational process described in the preceding. Updates ADC information in final output data stores.

Data Stores:

Monte Carlo EMC Hits – see /sim/det/emc.

EFS Control Parameters – This data store contains the parameters needed to control the fast simulator EFS. These include the overall energy resolution constants, as well as the parameters needed to simulate the lateral and longitudinal profiles of the energy depositions for various particles, including fluctuations. The profile parameters can depend on the particles type (*e.g.* $e^{\pm}$, γ, $\mu^{\pm}$, $\pi^{\pm}$, p, n), energy, angle of incidence, and so on. The shower parametrizations will also depend on the EMC geometry (*i.e.* the number of scintillator planes in each depth section, the dimensions of the SMD channels, etc.).

STAR EMC Geometry for Analysis – see /sim/det/emc and /sim/geometry.

EFS Output – Contains the parameters that were sampled to describe the shower for each track incident on the EMC. The primary key is used to cross-reference the entries in this data store with the entries in the Monte Carlo EMC Hits data store, which contains the true kinematics of each particle as it enters the EMC. These parameters can be different even for particles of the exact same incident kinematics due to the sampled energy resolution and the fluctuations in the (Gaussian) lateral and (exponential) longitudinal profiles of the shower development.

EMC PMT Signals – see /sim/det/emc.

EMC SMD Signals – see /sim/det/emc.

EMC PMT Raw ADC Data – see /sim/det/emc.

EMC SMD Raw ADC Data – see /sim/det/emc.

Data Flows:

None

EMC Signals Processing (/sim/det/emc/esp):

Description:

The EMC Signals Processing (/sim/det/emc/esp) reads the EMC PMT Signals and EMC SMD Signals along with assumed input voltage offsets, electronics gains, bad channels, noise, ADC parameters and other electronic response parameters and simulates all electronic processing algorithms that will be applied to the PMT and SMD signals before going to DAQ. This includes fluctuations. The effects considered will include the ADC dual-range integration, pedestal subtractions, data compression, zero suppression, gain corrections, multiplexing, demultiplexing, etc. The output of this module includes all known effects, giving a realistic simulation of the digitized signals that will be delivered to DAQ.

Simulation of collision and background events as well as light injection calibration events (for the PMTs) are all handled by this process. PMT signals for simulations of light injection calibration events are directly input into the EMC PMT Signals data store.

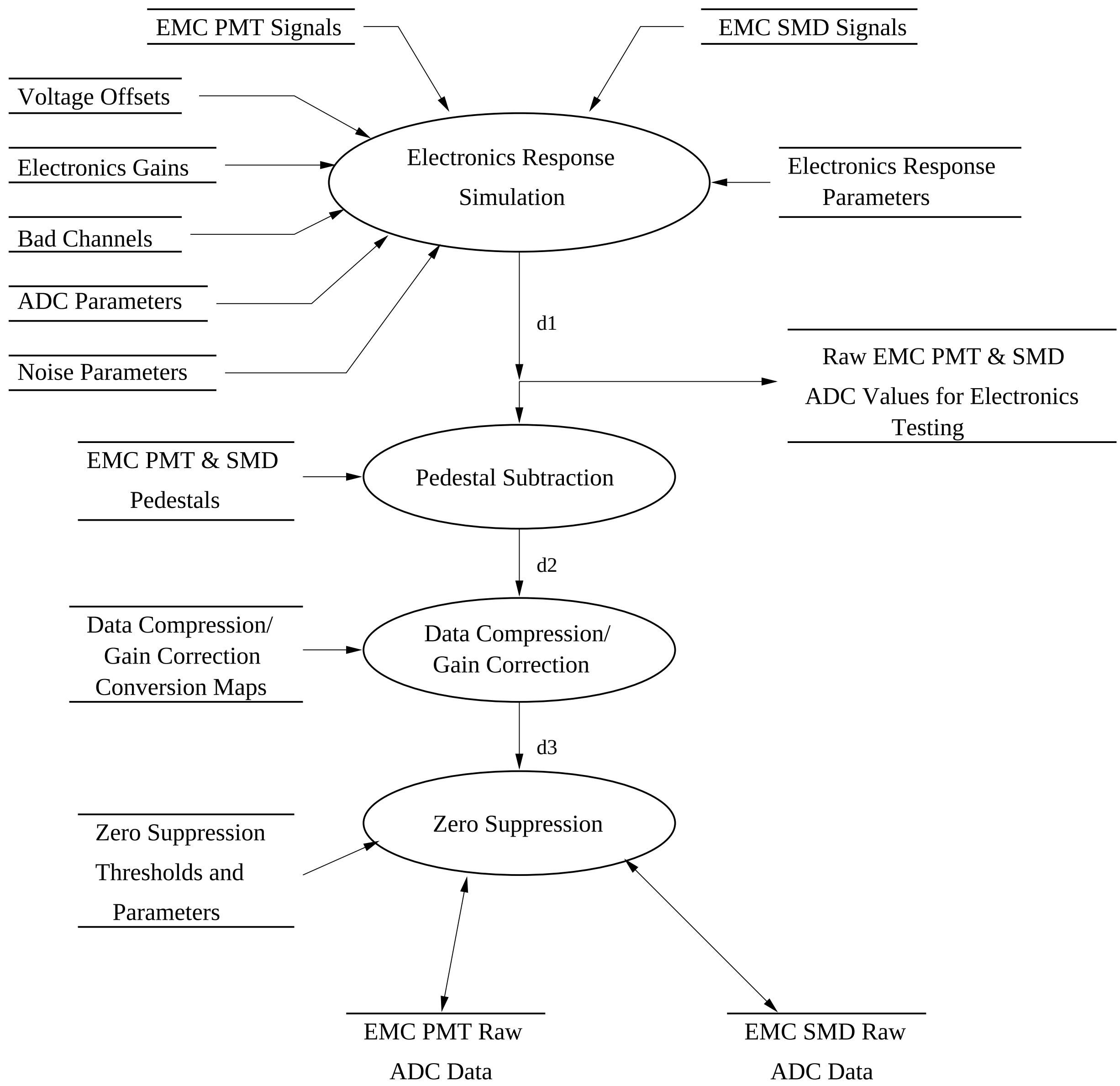

Figure 23: EMC Signal Processing Software Functionality

Glossary of Terms:

Processes:

Electronics Response Simulation – Process which applies input voltage offsets, electronic gains, bad channels, ADC, noise and any other necessary electronic response effects to the input PMT and SMD signals for each channel.

Pedestal Subtraction – Process which subtracts pedestals from the raw ADC values for each PMT and SMD channel.

Data Compression/Gain Correction – Process which simulates data word size translation (*e.g.* 10 bit to 8 bit) and channel by channel gain corrections using nonlinear mapping functions. This applies to both the PMT and SMD data.

Zero Suppression – Process which simulates removal of PMT and SMD data from the event data for those channels which, for example, fall below a specified threshold. Updates ADC information in final output data stores.

Data Stores:

EMC PMT Signals – see /sim/det/emc.

EMC SMD Signals – see /sim/det/emc.

Voltage Offsets – Contains assumed channel by channel offsets and fluctuations in voltage that eventually lead to pedestal offsets. This applies to both PMTs and the SMD.

Electronic Gains – Contains the assumed electronic gains for each PMT and SMD channel, including fluctuations.

Bad Channels – Contains a list of bad, dead, hot or noisy PMT and SMD electronic channels.

ADC Parameters – Dual range ADC parameters.

Noise Parameters – Contains the amplitude and power spectrum parameters of the electronic noise from the pre-amps and ADCs.

Electronics Response Parameters – Data store containing the remaining parameters needed to simulate the processing of the PMT and SMD signals in the onboard and platform electronics. This includes, for example, flags to turn on or off the simulation of various algorithms.

Raw EMC PMT and SMD ADC Values for Electronics Testing – EMC PMT and SMD output ADC values for each channel after Electronics Response Simulation, but prior to pedestal subtraction, data compression and gain corrections, zero suppression, etc. This can be used for testing onboard electronics.

EMC PMT and SMD Pedestals – ADC values for each PMT and SMD channel with no EMC hits; mean and rms values for many "empty" events. Used for both simulated and real pedestals (see /cal/emc).

Data Compression/Gain Correction Conversion Maps – Data word size compression (*e.g.* 10 bit to 8 bit) nonlinear translation look-up table for each channel, including electronic gains. Or data compression algorithm description plus channel by channel gain correction function parameters.

Zero Suppression Thresholds and Parameters – Threshold values for suppressing "empty" PMT signal output and SMD wire/strip signals prior to DAQ.

EMC PMT Raw ADC Data – see /sim/det/emc.

EMC SMD Raw ADC Data – see /sim/det/emc.

Data Flows:

d1 – Raw digital signal for each PMT and SMD channel.

d2 – Pedestal subtracted digital signal for each PMT and SMD channel.

d3 – Pedestal subtracted, data word size compressed and gain corrected digital signal for each PMT and SMD channel.

Status:

See the following STAR Library Packages:

ems – EMC towers and SMD wire grid simulation.

4.9 MWC Simulation (/sim/det/mwc)

This section contains a description, list of requirements, functional model diagram in Fig. 24, glossary of terms and status of software report.

Description:

The MWC detector simulation code converts the GEANT Monte Carlo hits to multiplicity information with the same format as DAQ real data. The first step consists of estimating the energy deposited in each anode wire of the endcap of the TPC. Then the wires with signal above threshold in each section of the detector are counted. Those digital sums constitute the data provided by the MWC.

The MWC detector simulation software may generate the full event or just a portion of the event (*e.g.* background tracks, rare particles and decays, etc.). In the latter case it is assumed that the output data store has already been filled with data from an external source (either from a previous simulation or eventually from actual data) and that this data store is to be updated.

Requirements:

1. The MWC detector simulation software is required to simuate the response of the MWC detector and electronics to the passage of ionizing energy through the MWC, including that from pp, pA and AA collisions, beam-gas interactions, and cosmic rays. This is needed in order to test and develop DAQ, test and develop calibration procedures, allow computation of detector efficiencies and acceptances, and test and develop trigger software.

2. The MWC simulation software must produce simulated data in the same format to be used by the actual DAQ in order to test DAQ and develop the data unpacking procedures.

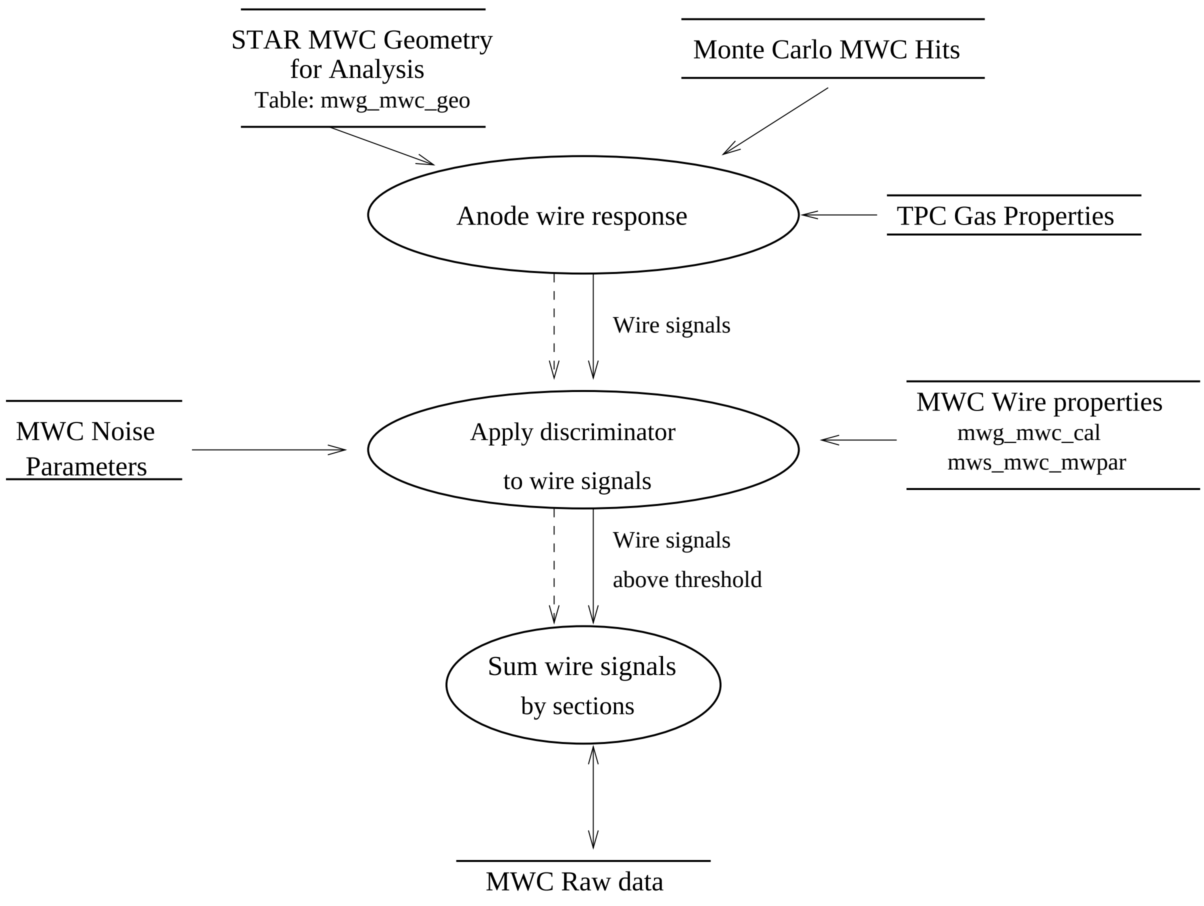

Figure 24: MWC Simulation Software

Glossary of Terms:

Processes:

Anode Wire Response – The charge induced in the wires by the passage of ionizing particles is simulated, including variations in the TPC gas gain.

Apply Discriminator to Wire Signals – After including electronic gain corrections only wires with an induced charge above a certain threshold are kept.

Sum Wire Signals by Sections – Digital summation of number of wires per section with signal above threshold. Updates final output data store.

Data Stores:

Monte Carlo MWC Hits – Contains hits of charged particles crossing the endcaps of the TPC.

STAR MWC Geometry for Analysis – See /sim/geometry and implementation via table mwg_mwc_geo.

MWC Wire Properties – Contains MWC electronic gains and offsets for each wire, list of bad channels and assumed thresholds (see tables mwg_ctf_cal, mws_mwc_mwpar).

MWC Noise Parameters – Parameters to steer the addition of electronic and instrumental backgrounds are kept in this data store.

MWC Raw Data – Digital count of number of wires with signal above threshold for each TPC sector (see tables mwu_mwc_raw, mwu_mwc_sector).

TPC Gas Properties – see /sim/det/tpc.

Data Flows:

As labelled on diagram.

Status:

See the following STAR Library Packages:

mws – MWC detector simulation.

4.10 VPD Simulation (/sim/det/vpd)

This section contains a description, list of requirements, functional model diagram in Fig. 25, glossary of terms and status of software report.

Description:

The VPD detector simulation code transforms the GEANT Monte Carlo hits into ADC and TDC signals with the same format as DAQ real data. The first step consists in looping over all the hits produced by ionizing particles in the Cherenkov counters of the VPD. The total number of photons produced in each unit is then converted into a number of photoelectrons produced by the corresponding photo-multiplier (PMT). Cherenkov radiator and PMT properties are taken into account in this calculation. In addition the time jitter and smearing of the PMT signal is also simulated. Light propagation in the counter and PMT time resolution are also taken into account in this step. The code concludes the simulation by emulating the Analog-to-Digital converter function. In addition to digitized amplitudes and times, offset signals and different types of electronic and instrumental backgrounds are introduced.

The VPD detector simulation software may generate the full event or just a portion of the event (*e.g.* background tracks, rare particles and decays, etc.). In the latter case it is assumed that the output data store (TDCs) has already been filled with data from an external source (either from a previous simulation or eventually from actual data) and that this data store is to be updated.

Requirements:

1. The VPD detector simulation software is required to simulate the response of the VPD detector and electronics to the passage of ionizing energy through the VPD, including that from pp, pA and AA collisions, beam-gas interactions, and cosmic rays. This is needed in order to test and develop DAQ, test and develop calibration procedures, allow computation of detector efficiencies and acceptances, and test and develop trigger software.

2. The VPD simulation software must produce simulated data in the same format to be used by the actaul DAQ in order to test DAQ and develop the data unpacking procedures.

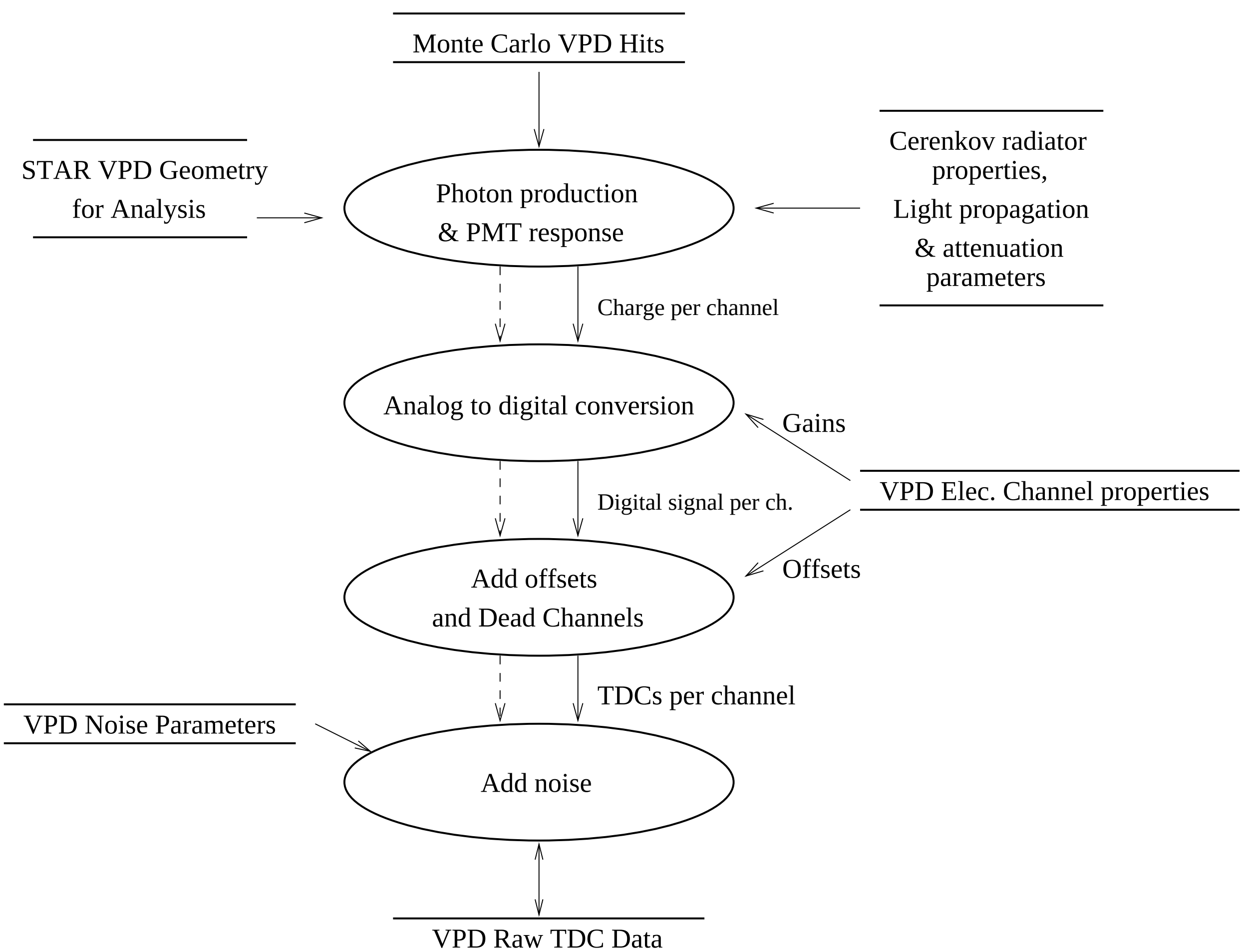

Figure 25: VPD Simulation Software

Glossary of Terms:

Processes:

Photon Production and PMT Response – The Cherenkov counter light emission is simulated along with the light conversion into an electric pulse.

Analog to Digital Conversion – Emulates the ADC and TDC function, including electronic gains and gain fluctuations in each channel.

Add Offsets and Dead Channels – The signals produced by the ADCs and TDCs when the input is zero are incorporated in the simulation. This includes simulated PMT time jitter, systematic timing offsets between PMTs and overall timing differences between the East and West VPDs. Bad channels are tagged or removed.

Add Noise – Electronic and instrumental backgrounds are included in the simulation. Updates final output TDC data store.

Data Stores:

Monte Carlo VPD Hits – Contains list of hits of charged particles crossing the VPD counters.

Cherenkov Radiator Properties, Light Propagation and Attenuation Parameters – Contains values for each Cherenkov counter.

STAR VPD Geometry for Analysis – see /sim/geometry.

VPD Electronic Channel Properties – Voltage offsets and PMT/electronic gains for all channels, time jitter and timing offset parameters, East versus West VPD time differences, bad PMT/electronic channels list, etc.

VPD Noise Parameters – Parameters to steer the addition of electronic and instrumental backgrounds are kept in this data store.

VPD Raw TDCs – Simulated or real VPD TDC data for each Cherenkov PMT counter in both VPD East and West subdetectors in the DAQ data format.

Data Flows:

As indicated on diagram.

Status:

See the following STAR Library Packages:

vps – VPD response simulator.

5 Event Reconstruction (/ana)

The event reconstruction software for STAR includes the following essential functionality: (1) space point and track reconstruction for the three tracking detectors SVT, TPC and FTPC, (2) particle velocity determination, (3) neutral and charged energy determination, (4) particle identification and (5) global event reconstruction in which all the sub-detector specific information is merged into a comprehensive reconstruction of the triggered event. The event reconstruction software is expected to function equally well for analysis of both real and simulated data for either collision events, backgrounds or calibration runs. The event reconstruction software utilizes calibration and corrections data.

The STAR event reconstruction software is required to convert the raw input pixel data from either simulations or from the real experiment into a reconstructed version of the particle production from pp, pA, and AA collisions and from the simulated or real calibration data runs. The output of the event reconstruction software is a list of particles corresponding to the triggered event and includes the momentum, energy, charge and/or particle identification (PID) of the individually identified tracks. The output also contains information about the charged, neutral and total energy production, as well as the reconstructed momentum vectors of hard scattered partons which resulted in reconstructed jets. The software must be able to identify stray background particle tracks from cosmic rays, beam-gas interactions and minimum biased, "out-of-time" events which occur during the drift times of each "slow" detector (*i.e.* SVT, TPC and FTPC) for the triggered event. The event reconstruction software must be able to handle calibration data (both real and simulated) from lasers, cosmic rays, straight tracks from collision data taken with zero magnetic field, and other forms of light injection into the photo-multiplier tubes.

In the following sections we present the functional model design for the event reconstruction software for each detector and for the global software.

5.1 TPC Event Reconstruction (/ana/tpc)

This section contains a description, list of requirements, functional model diagrams for the top level (/ana/tpc, Fig. 26) and for five sublevels including space point reconstruction (/ana/tpc/tcl, Fig. 27), tracking (/ana/tpc/tpt, Fig. 28), raw pixel correction (/ana/tpc/pxc, Fig. 29), dE/dx calculations (/ana/tpc/tde, Fig. 30), and high luminosity pp track selection (/ana/tpc/tpp, Fig. 31), glossaries for each diagram, and a status of software report. Detailed descriptions of the present implementation of the TPC space point reconstruction and tracking software are given in Ref. [13].

Description:

The task of the TPC event reconstruction software is to reduce the raw data taken in a physics event (about 7 million ADC values) to physically meaningful quantities such as a list of particle identities and momenta. Besides the raw data itself, the software utilizes geometry and calibration information, which are stored in a database.

The "standard" method (used by other collaborations) of performing this data reduction is to examine pixel patterns on a padrow-by-padrow basis, finding locations where charged particles crossed the row; these positions are often called "hits." A tracking algorithm then links these hits together to find particle trajectories through the TPC. The particles are then identified by the characteristics of the tracks.

However, alternative methods of data reduction have been proposed, including tracking on pixel information directly. Also, alternative methods for doing *parts* of the data reduction exist, for example performing Hough transforms on the hits to find track segments. These methods, and those that are yet to be proposed, must be able to be tested in the framework of the TPC analysis software. Therefore, the software must be modular, so that new and better ideas can easily replace older ones. Also, provisions must be made in these methods for calibration corrections. For example, if one tracks on pixel data, one will want the spatial positions of the pixels to be corrected for, field distortions for example. Therefore, we envision a software process to do this (see /ana/tpc/pxc in the following).

Requirements:

1. The TPC reconstruction software is required to convert raw TPC pixel data from either simulations or experiment into reconstructed tracks, with accurate corrections being included which account for electronics and gas gains, attenuation of drifting electron clouds, $\vec{E} \times \vec{B}$ field effects on the electron cloud drift, variations in TPC gas properties, variations in TPC drift velocity, dead or malfunctioning electronics channels, timing offsets between various channels, and internal and global position alignment shifts. The identical software must be used for either real or simulated data analysis and must be capable of handling data from pp, pA and AA collisions, cosmic rays, beam-gas background tracks, radioactive sources, laser beams and spots, and wire pulsing.

2. TPC event reconstruction software performance, as measured by such quantities as tracking efficiency, tracking purity, momentum resolution, impact parameter resolution, particle ID and two-track resolution is required to achieve a performance level necessary to reach the main physics goals of STAR. The most demanding physics goals, with respect to TPC event reconstruction software performance, include determination of neutral strange mesons, strange baryon production, and HBT analyses. Global event-by-event physics quantities, such as temperature, mean p_T, K/π ratios, etc. are less demanding of the TPC software. A detailed description of performance requirements versus physics objectives is well beyond the scope of this report, as each entry constitutes a substantial simulation project.

3. The identical software must be used for both real and simulated data analysis in order to fully test and evaluate (via simulations) the actual software to be used for real data.

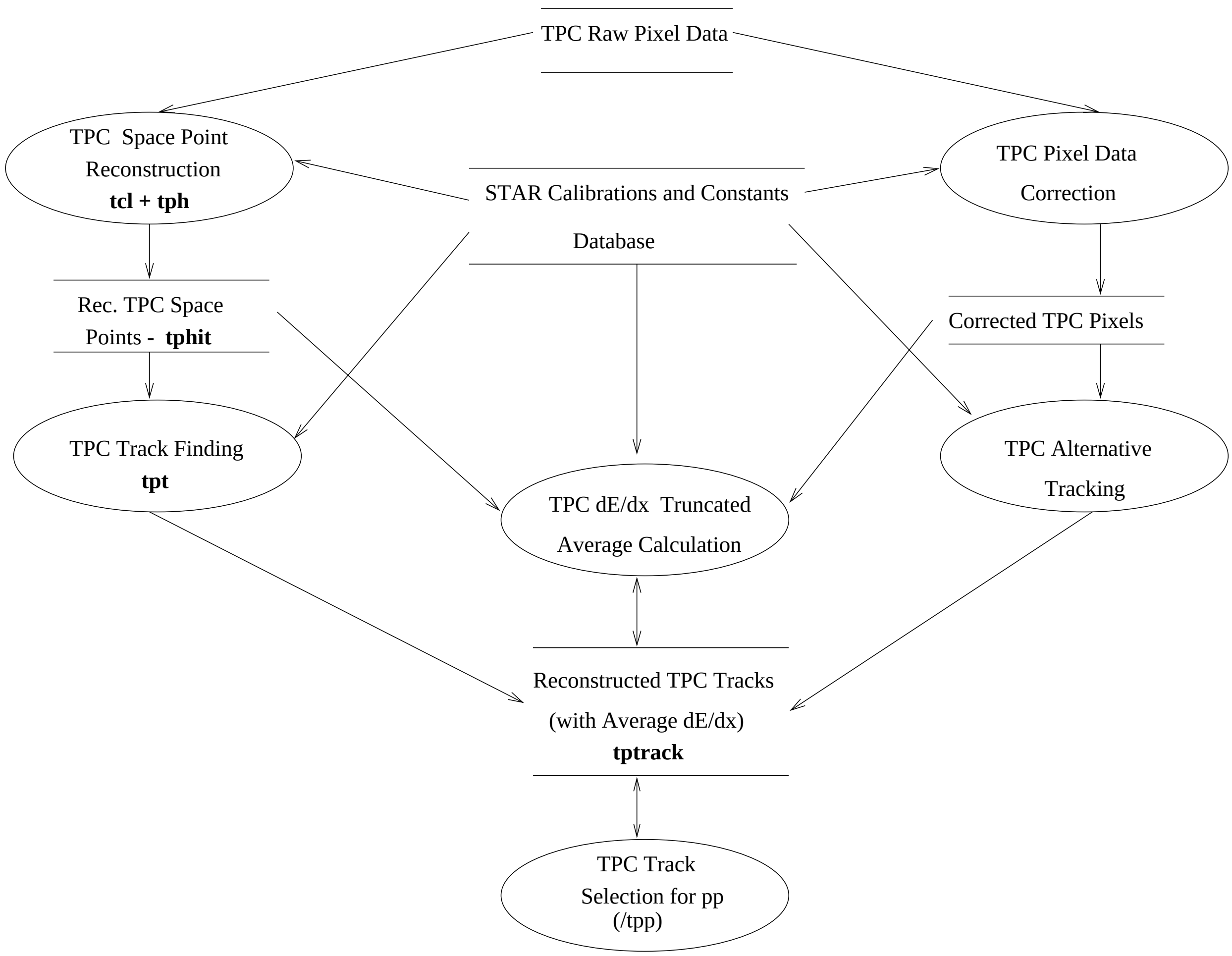

Figure 26: TPC Event Reconstruction Software - Top Level

Glossary of Terms:

Processes:

TPC Space Point Reconstruction – Process that converts the raw TPC pixel data into corrected space points.

TPC Track Finding – Process that links together corrected space points that were generated by the same particle and assigns momentum.

TPC Pixel Data Correction – Process that corrects the raw TPC data on a pixel by pixel basis.

TPC Alternative Tracking – A process that reconstructs the trajectories of the particles that cross the chamber without going through the intermediate stage of cluster/hit finding.

TPC dE/dx Truncated Average Calculation – Process that calculates energy loss per 1 cm of tracks across each row and then assigns a truncated average value to each track.

TPC Track Selection for pp – Process that selects tracks for a specific triggered event from among those in the TPC drift time, mainly intended for the high luminosity pp analysis.

Data Stores:

TPC Raw Pixel Data – Real or simulated, uncorrected data in a format as delivered by DAQ.

Reconstructed TPC Space Points – Points that correspond to track crossings across the midplanes of the TPC pad rows. They are corrected for spatial distortions and information about the energy loss is corrected for gain variations. The dead, noisy and saturated channels are removed. Space points are given in the global STAR Coordinate System.

Corrected TPC Pixels – Raw TPC data corrected for spatial and gain distortions. Dead, noisy and saturated channels are removed. Pixels are given in the global STAR Coordinate System.

STAR Calibrations and Constants Database – Generic data storage that contains all the auxiliary information that is necessary to extract physics information from the raw data.

Reconstructed TPC Tracks – Linked lists of corrected crossings that were assigned by tracking software to the same track, together with a parametrization assigned by a track fitting procedure and a truncated dE/dx average assigned by the energy loss evaluation module. Track parameters are expressed in the global STAR Coordinate System.

Data Flows:

None

TPC Space Point Reconstruction (/ana/tpc/tcl):

Description:

TPC Space Point Reconstruction (/ana/tpc/tcl) offline software must be capable of handling data from pp, pA and AA collisions, cosmic rays, beam-gas background tracks, radioactive sources and laser beams. The goals of the STAR physics program require the capability to analyze events from pp, pA and AA collisions in a consistent manner, so the same software must be able to handle all such data. Also, calibration procedures will make use of cosmic rays, radioactive sources, and laser beams. For reliable and consistent calibration, the same software should be able to analyze this data as well.

The TPC hit reconstruction offline software converts raw TPC pixel data into reconstructed space points, with accurate corrections being included which account for electronics and gas gains, attenuation of drifting electron clouds, $\vec{E} \times \vec{B}$ field effects on the electron cloud drift, variations in TPC gas properties, variations in TPC drift velocity, dead, malfunctioning or saturated electronics channels, timing offsets between various channels, and internal and global position alignment shifts. Reconstructed space points are given in the global STAR Coordinate System.

The TPC hit reconstruction offline software should be capable of deconvoluting multi-hit clusters provided these satisfy the Rayleigh criteria. The TPC hit reconstruction software should also utilize the results of TPC tracking and global SVT-TPC track-to-track matching to facilitate two-track separation and deconvolution of merged TPC hits. The study of source sizes in heavy-ion collisions at RHIC is one of the basic physics goals of the project; this study in turn depends on accurate separation and momentum difference determination for close tracks. Therefore two-track separation and multiple hit deconvolution needs to be done as well as possible.

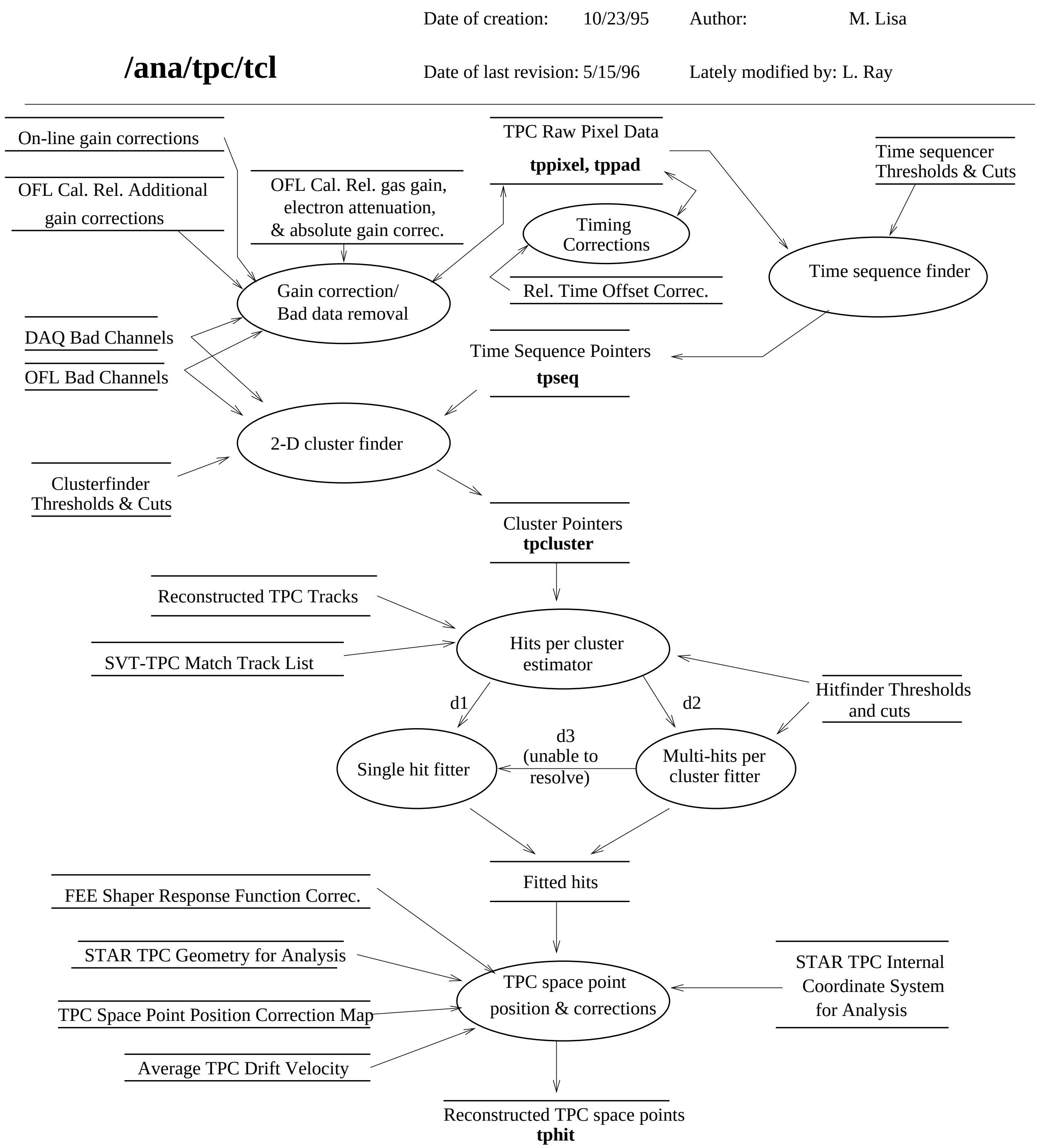

Figure 27: TPC Space Point Reconstruction Software

Glossary of Terms:

Special Definitions:

Pixel – Digital (integer) signal for one pad and one time bin.

Time sequence – Set of contiguous pixels for one pad which are above a predetermined threshold and which contain a sufficient (also predetermined) number of time bins.

Cluster – Set of overlapping (in time bins) time sequences on a predetermined number of adjacent pads, all on one pad row.

Hit – Set of activated pixels which result from passage of one ionizing particle, laser beam or laser spot through the region in the TPC from which the drifting electron cloud will produce a signal in the given pad row.

Space point – Ideally the reconstructed position and energy deposition of one hit, but in actuality may include several merged hits.

Processes:

Gain Correction and Bad Data Removal – Process which removes channel-by-channel gain variations still present after on-line corrections have been applied (if any). Also, data from "dead" channels (including "hot" ones) are removed from the data structure.

Timing Corrections – Process that shifts the time coordinate of each pixel by the appropriate offset in time.

Time Sequence Finder – Process which builds pointers to the beginning and end of time sequences on each channel. In the simplest case, this may involve no more than filling a table of pointers that are taken directly from the on-line ASIC zero-suppression/sequence-defining chip. However, if an offline threshold is desired that is higher than that used in the ASIC, then some processing is required; this capability must be available.

2-D Cluster Finder – Process which identifies cluster in the 2-dimensional space of pads versus drift time for a given padrow.

Hits per Cluster Estimator – Process which estimates the number of space points that may be found in a cluster. This estimate is based on cluster shape information, or, if the cluster/hitfinder is being re-run after tracking software, it is based on local track extrapolations across the padrow.

Single Hit Fitter – Process which determines the position, in local coordinates, of the crossing of a track, assuming only one track contributed to the cluster.

Multi-Hits per Cluster Fitter – Process which finds local peaks in the cluster pattern and determines the positions, in local coordinates, of the track crossings that contributed to the cluster. Deconvolution of the clusters into individual hits may also be done.

TPC Space Point Position and Corrections – Process which converts local space point information into global STAR Coordinate System, based on geometry, calibration and alignment information.

Data Stores:

Online Gain Corrections – Channel by channel nonlinear gain correction functions and parameters that were applied to the raw ADC values online.

Offline Calibration Relative Additional Gain Corrections – Data store which contains (in general, non-linear) corrections for each channel's ADC values to remove variations not removed by on-line corrections.

Relative Time Offset Corrections – Data store containing pad-by-pad time offsets which correct the relationship between time bucket number and global z-position of the pixel, determined by offline calibrations. Timing accuracies of a few nanoseconds are needed.

Offline Calibration, Relative Gas Gain, Electron Attenuation and Absolute Gain Corrections – Data store which contains corrections to account for run-to-run (not channel-to-channel) variations in gas gain and electron attenuation, determined by offline calibrations. Well understood dependences on gas properties are factored out of the parametrizations.

TPC Raw Pixel Data – TPC raw data (ADC information) together with the addressing information packed into data structures.

Time Sequencer Thresholds and Cuts – A data store containing parameters that modify the operation of the offline time sequence finder. This includes an ADC threshold such that a pixel with ADC value less than this threshold is "zero-suppressed." Clearly, to be meaningful, this threshold must be equal to or greater than the on-line ASIC zero-suppression threshold. A second threshold may be included such that a sequence that does not contain a pixel with ADC value above this threshold is discarded. Also, minimum and maximum sequence length cuts would be found in this data store.

DAQ Bad Channels – Data store which identifies those channels for which the data should not be used. The decision for these channels is made by an on-line process.

Offline Bad Channels – Data store which identifies further channels (compared to online) for which the data should not be used. The decision for these channels is made by off-line calibration/evaluation software after processing some data.

Time Sequence Pointers – Index information for the first and last pixels in a time sequence of ADC values.

Clusterfinder Thresholds and Cuts – A data store containing parameters that modify the action of the 2-dimensional clusterfinder. This includes such parameters as the maximum cluster size.

Cluster Pointers – Index information listing the time sequences to be associated with a cluster.

Reconstructed TPC Tracks – see /ana/tpc.

SVT-TPC Match Track List – List of matched SVT and TPC tracks from global event reconstruction, see /ana/global/tracking.

Hitfinder Thresholds and Cuts – A data store containing parameters that modify the action of the hitfinder. This includes cuts that quickly identify, based on cluster shape, those clusters which warrant (time-consuming) hit deconvolution. Also included are peak:valley cuts, minimum peak heights (in ADC counts), and maximum and minimum hit widths.

FEE Shaper Response Function Corrections – Space point position corrections along drift direction due to FEE signal shaper response.

STAR TPC Geometry for Analysis – Data store containing a description of the detector geometry and materials. Also contains information that links each pixel in the TPC to a nominal position. This information includes nominal run-by-run drift velocity, sector and pad positions in global coordinates, and trigger time offset. Includes nominal values and corrections. See /sim/geometry.

TPC Space Point Position Correction Map – Data store which contains position- and run-dependent corrections to the nominal maps given in the geometry store. These corrections come from calibration of the B and E field distortions and drift velocity.

Average TPC Drift Velocity – Computed TPC drift velocity throughout data acquisition period and discrepancies (if any) with nominal, regulated values.

Fitted Hits – Integrated charge, position in pad plane and second moments for identified hits.

STAR TPC Internal Coordinate System for Analysis – see /sim/geometry.

Reconstructed TPC Space Points – see /ana/tpc.

Data Flows:

d1 – ADCs for pad rows and time buckets for each found, single hit cluster.

d2 – ADCs for pad rows and time buckets for each found, multi-hit cluster.

d3 – Control parameter to "single hit fitter" indicating a multi-hit cluster could not be deconvoluted.

TPC Track Reconstruction (/ana/tpc/tpt):

Description:

The TPC offline track reconstruction software converts the reconstructed space points or corrected pixel data into particle tracks and determines the momentum of these tracks for pp, pA and AA collisions. The momentum should be determined as well as can be done given the inherent limitations due to finite position resolution, finite track length and MCS. This is driven by the need to carry out efficient tracking with good momentum resolution since these performance criteria are fundamental to the physics goals of STAR. Removal of backgrounds and use of the tracking codes for calibration are both necessary to achieving efficient tracking and good momentum resolution. In addition, the following features are important aspects of TPC tracking: (1) average energy loss effects should be accounted for; (2) the TPC offline track reconstruction software should provide information to the TPC hit resonstruction software with respect to possible merged hits and merged tracks; and (3) the TPC tracking software must reconstruct tracks in absence of the magnetic field since STAR will be run without the magnetic field for calibration purposes and track reconstruction is an essential part of these calibration procedures. Parameters of reconstructed tracks are given in the global STAR Coordinate System.

Date of creation: 10/23/95 Author: L. Ray

/ana/tpc/tpt

Date of last revision: 11/17/95 Lately modified by: I. Sakrejda

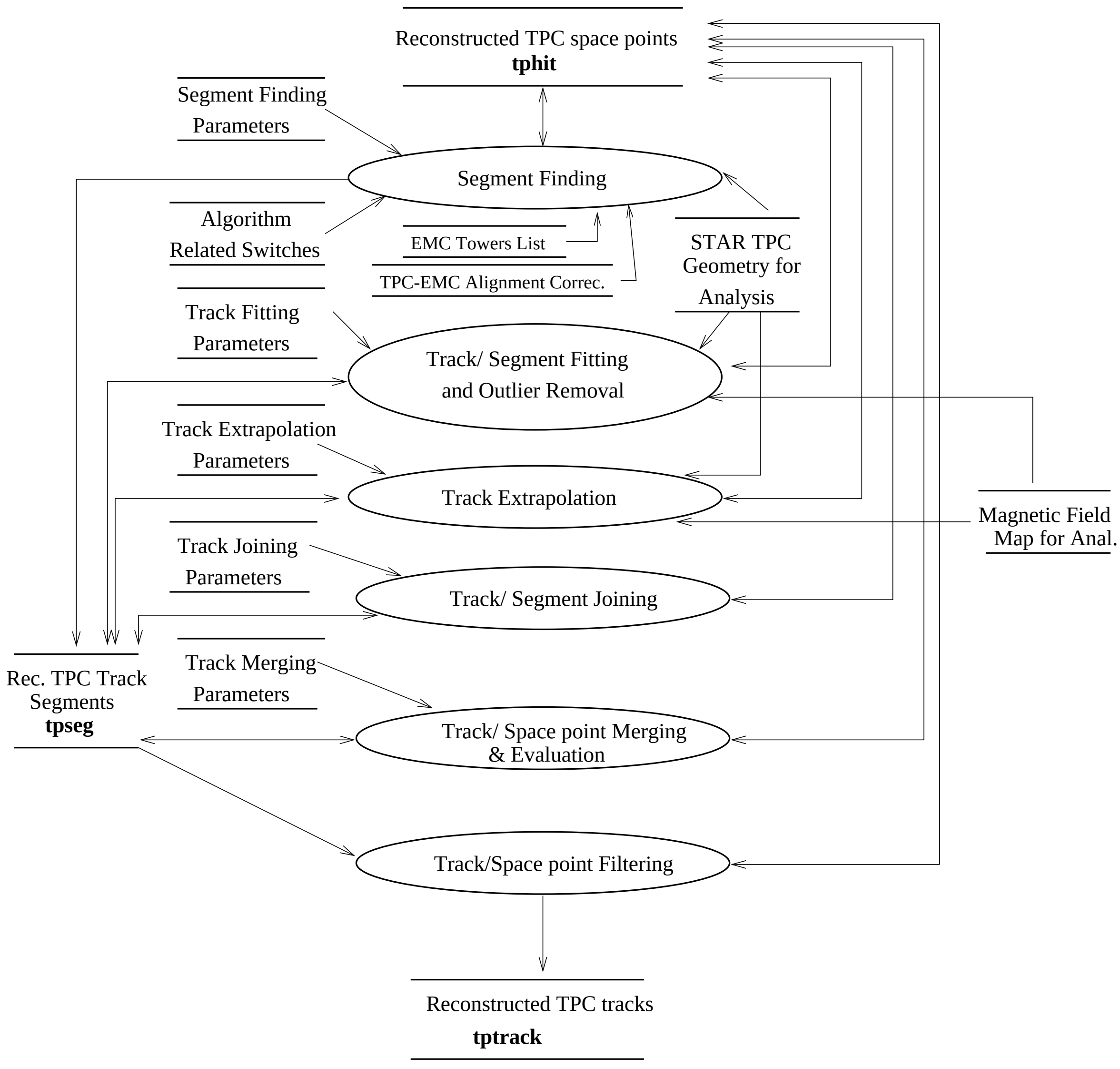

Figure 28: TPC Track Reconstruction Software

Glossary of Terms:

Processes:

Segment Finding – Process of finding space points associated with a charged particle track, either complete or partial.

Track/Segment Fitting and Outlier Removal – Complete TPC track or partial track segment fitting using analytic track models with or without multiple Coulomb scattering, energy loss and non-uniform magnetic field effects. Outlier space points found by 'Segment Finding' may be de-assigned from the track's set of space points.

Track Extrapolation – TPC track extrapolation with or without multiple Coulomb scattering, energy loss and non-uniform magnetic field effects being included. Extrapolation is done within the TPC for purposes of track finding and segment joining.

Track/Segment Joining – TPC track and track segment joining based on track extrapolations and fitting criteria.

Track/Space Point Merging and Evaluation – Improved tracking results for merged tracks or merged space points on tracks.

Track/Space Point Filtering – Final track, track fragments, space point to track assignment clean-up and filtering based on consistency checks.

Data Stores:

Segment Finding Parameters – Tolerances that decide about the space point acceptance/rejection during the segment formation phase.

Algorithm Related Switches – Switches that allow for use of different track finding algorithms.

Track Fitting Parameters – Parameters that define "goodness" of the fit.

Track Extrapolation Parameters – Tolerances that decide about the space point acceptance/rejection during the track extrapolation phase.

Track Joining Parameters – Tolerances that define the segment joining criteria during the track joining phase.

Track Merging Parameters – Parameters used in determining track and space point merging.

Reconstructed TPC Track Segments – List of TPC space points on track segment, track parameters, energy deposition values, etc.

Reconstructed TPC Space Points – see /ana/tpc.

EMC Towers List – List of struck EMC towers above specified threshold for triggered event. Mainly for use in high luminosity pp mode (see /ana/emc).

TPC-EMC Alignment Corrections – Data store containing corrections to the nominal TPC-EMC relative position maps in the geometry data base. These corrections come from the global alignment calibration procedures.

STAR TPC Geometry for Analysis – see /sim/geometry and /ana/tpc/tcl.

Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.

Reconstructed TPC Tracks – see /ana/tpc.

Data Flows: None

TPC Pixel Data Correction (/ana/tpc/pxc):

Description:

Several potentially promising and powerful alternatives to the "standard" method of data reduction have been proposed, which skip hit finding altogether, and reduce directly from pixels to tracks. The TPC Pixel Data Correction software must therefore correct raw pixel data into "spacepoints" corresponding to each pixel without clustering and include all the corrections mentioned in the preceding TPC hit reconstruction chain (/ana/tpc/tcl). It is assumed that the gain correction and bad data removal process described in /ana/tpc/tcl functions also in this mode and acts initially on the raw pixel data. Corrected TPC pixels are given in the global STAR Coordinate System.

	Date of creation: 1/31/96	Author: M. Lisa
/ana/tpc/pxc	Date of last revision: 5/15/96	Lately modified by: L. Ray

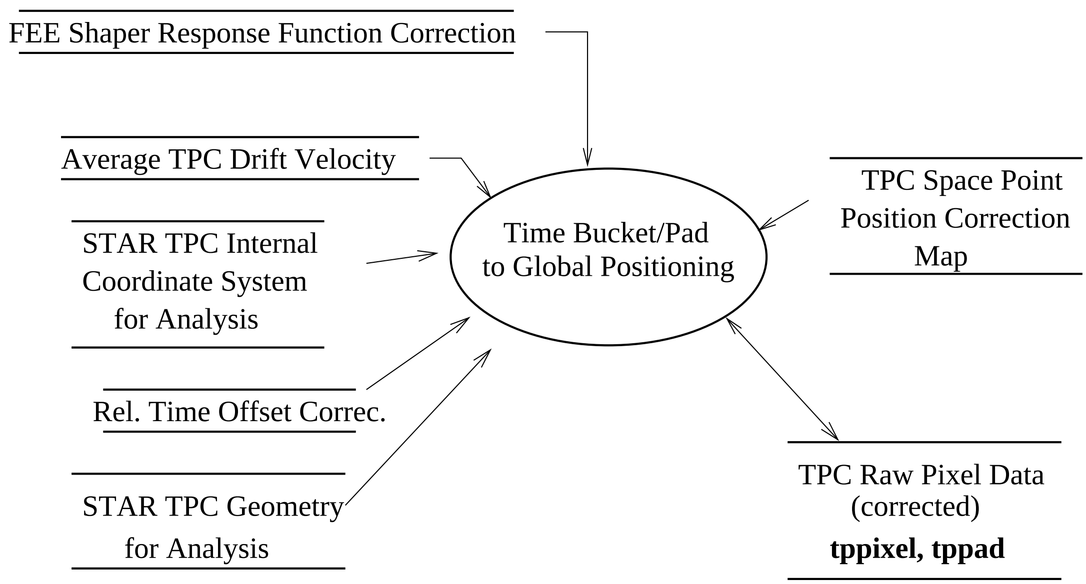

Figure 29: TPC Pixel Correction Software

Glossary of Terms:

Processes:

Time Bucket/Pad to Global Positioning – Process which maps each pixel to a three dimensional coordinate in the TPC expressed in the global STAR Coordinate System.

Data Stores:

FEE Shaper Response Function Correction – see /ana/tpc/tcl.
Average TPC Drift Velocity – see /ana/tpc/tcl.
STAR TPC Internal Coordinate System for Analysis – see /sim/geometry.
Relative Time Offset Corrections – see /ana/tpc/tcl.
STAR TPC Geometry for Analysis – see /sim/geometry and /ana/tpc/tcl.
TPC Space Point Correction Map – see /ana/tpc/tcl.
TPC Raw Pixel Data – see /ana/tpc.

Data Flows: None

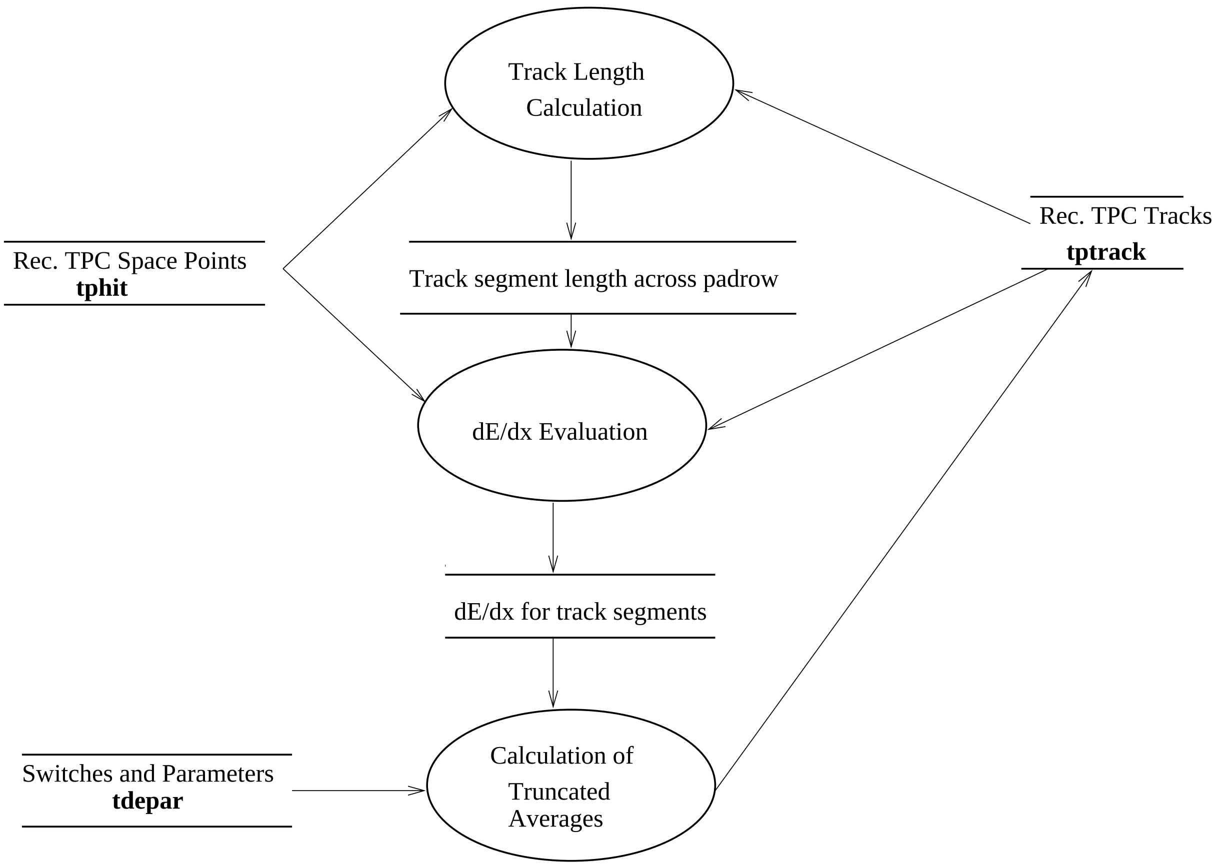

Figure 30: TPC dE/dx Calculation Software

Glossary of Terms:

Processes:

Track Length Calculation – Calculation of actual track length of crossing the TPC pad planes for that portion to be used for calculating dE/dx.

dE/dx Evaluation – Calculation of dE/dx for each pad crossing.

Calculation of Truncated Averages – Calculate mean and rms of dE/dx values for all pad crossings for each, given track where the high dE/dx values may be truncated.

Data Stores:

Reconstructed TPC Space Points – see /ana/tpc.

Switches and Parameters – Contains options and truncation parameters for calculating truncated dE/dx averages, see table tdepar.

Track Segment Length Across Padrow – Contains track lengths for each padrow crossing for each track.

dE/dx for Track Segments – Contains corrected energy deposition for individual pad plane crossings divided by track segment length across the pad rows.

Reconstructed TPC Tracks – see /ana/tpc.

Data Flows:

None

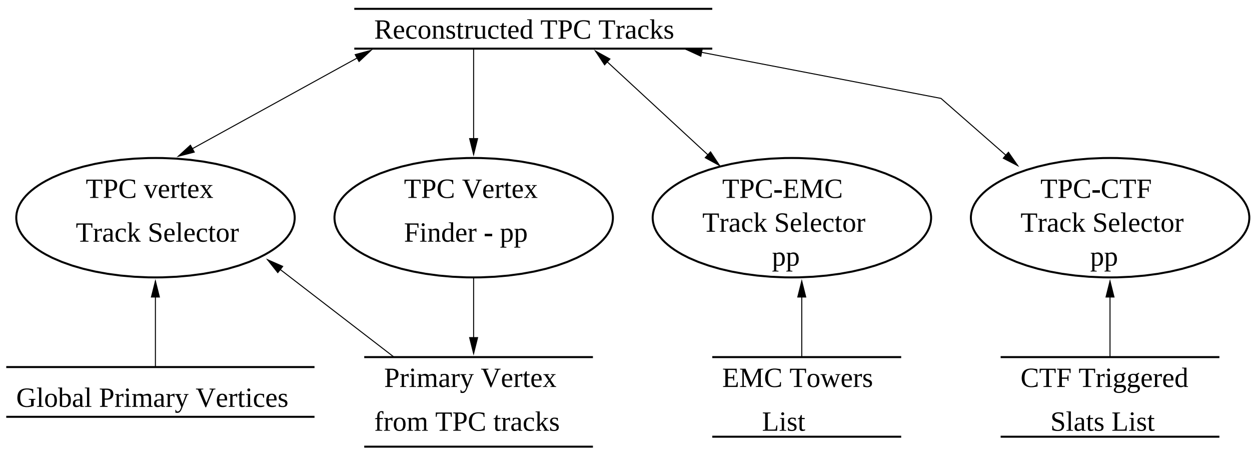

Figure 31: TPC Track Selector Software for High Luminosity pp Analysis

Glossary of Terms:

Processes:

TPC Vertex Track Selector – Process that selects and flags reconstructed TPC tracks that extrapolate inward to the primary vertex of the triggered event, either determined from TPC tracks or globally.

TPC Vertex Finder pp – Primary vertex finder process that uses a set of TPC tracks flagged by the EMC or CTF detectors; mainly for high luminosity pp analysis.

TPC-EMC Track Selector pp – Process that selects and flags reconstructed TPC tracks that extrapolate outward to the struck EMC towers above a selected threshold.

TPC-CTF Track Selector pp – Process that selects and flags reconstructed TPC tracks that extrapolate outward to the struck CTF (TOF and/or CTB) slats.

Data Stores:

Reconstructed TPC Tracks – see /ana/tpc.

Global Primary Vertices – Primary collision vertex location in 3D for triggered event, determined by the global primary vertex finder.

Primary Vertex from TPC Tracks – Primary collision vertex determined from extrapolations of EMC and/or CTF flagged reconstructed TPC tracks.

EMC Towers List - see /ana/tpc/tpt.

CTF Triggered Slats List – List of hit CTF slats (above specified threshold) for triggered event, mainly for use in high luminosity pp mode.

Data Flows:

None

Status:

See the following STAR Library Packages:

tfc – TPC DAQ data to STAF interface; TPC slow simulator output data format.
tcl – TPC cluster finder and space point reconstruction
tct – TPC alternate track finder
tdh – TPC fast cluster finder and space point reconstruction to be used on-line.
tev – TPC Monte Carlo hit and reconstructed space point evaluation.
tht – TPC alternate track finder - Hough transforms.
tid – TPC dE/dx calculation and PID.
tma – TPC alternate track finder and fitter using template matching method for close tracks.
tpt – Main TPC track finding, fitting and filtering.
tte – Main TPC tracking evaluation.

5.2 SVT Event Reconstruction (/ana/svt)

This section contains a description, list of requirements, functional model diagram for the top level (/ana/svt, Fig. 32), and two sublevels including space point reconstruction (/ana/svt/space_points, Fig. 33) and tracking (/ana/svt/tracking, Fig. 34), glossaries for each diagram, and a status of software report. Detailed descriptions of the present implementation of the SVT space point reconstruction and tracking software are given in Ref. [14].

Description:

The SVT event reconstruction is foreseen to proceed in two steps. In the first step the SVT Raw Pixel Data are analyzed to determine the particle's crossing points through the detector. These crossing points, also called space points, are then used in the second stage of the analysis to identify the particle trajectories and determine the particle kinematics, *i.e.* their momenta and emission angles.

The top level functional model of the SVT Event Reconstruction Software is shown in Fig. 32. The two principle components of the SVT event reconstruction software are the SVT Hits or Space Points Reconstruction (SVT Pixel to Space Point) and the SVT Track Reconstruction. These two components are described separately in the following.

Requirements:

1. The SVT reconstruction software is required to convert raw SVT pixel data from either simulations or experiment into reconstructed tracks, with accurate corrections being included which account for electronic gains, attenuation of drifting electron clouds, variations in the SDD properties, variations in SDD drift velocity, dead or malfunctioning electronics channels, timing offsets between various channels, and internal and global position alignment shifts. The identical software must be used for either real or simulated data analysis and must be capable of handling data from pp, pA and AA collisions, cosmic rays, beam-gas background tracks, radioactive sources, laser beams and cathode strip charge injection calibration data.

2. SVT event reconstruction software performance, as measured by such quantities as tracking efficiency, tracking purity, momentum resolution, impact parameter resolution, particle ID and two-track resolution is required to achieve a performance level necessary to reach the main physics goals of STAR. The most demanding physics goals, with respect to SVT event reconstruction software performance, include determination of neutral strange meson and strange baryon production, detection of multiply strange baryons, low p_T spectra, and HBT analyses. A detailed description of performance requirements versus physics objectives is well beyond the scope of this report, as each entry constitutes a substantial simulation project.

3. The identical software must be used for both real and simulated data analysis in order to fully test and evaluate (via simulations) the actual software to be used for real data.

/ana/svt

Date of Creation: 5/16/96 Author: L. Ray
Date of Last Revision: Last Modified by:

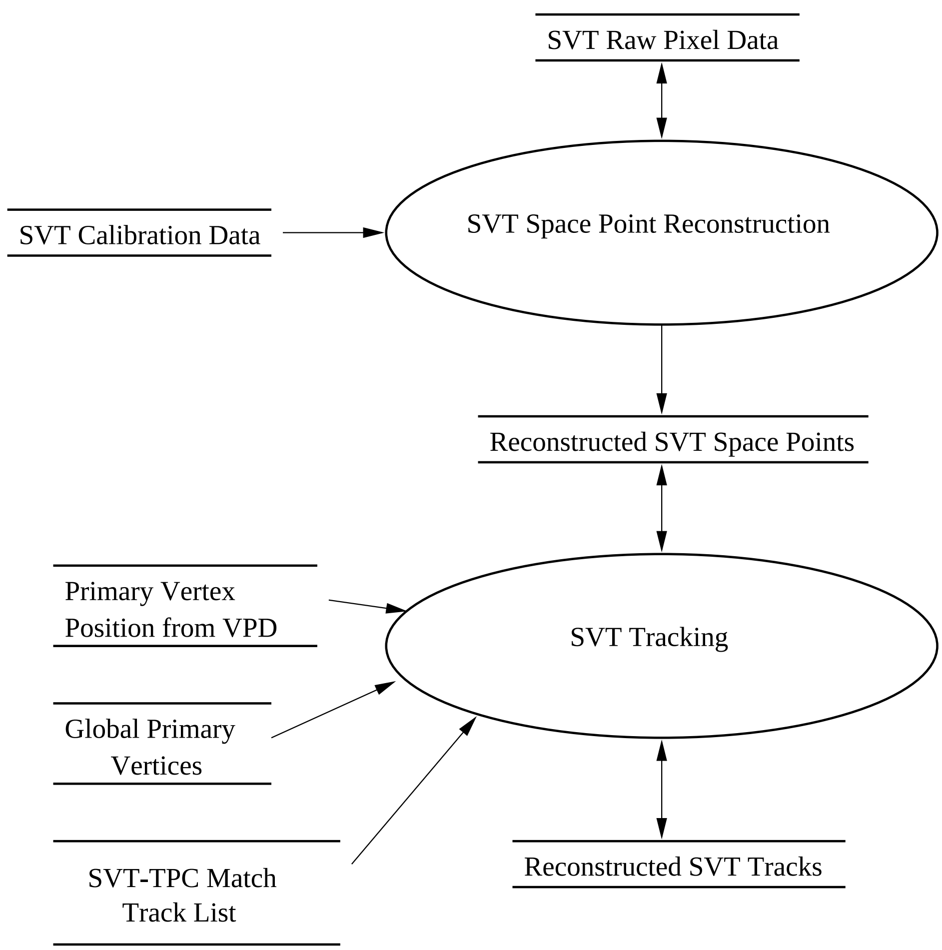

Figure 32: SVT Event Reconstruction Top Level Functional Model Diagram

Glossary of Terms:

Processes:

SVT Space Point Reconstruction – Process that converts the raw SVT pixel ADC data into corrected space points.

SVT Tracking – Process that links together corrected space points that were generated by the same particle, assigns track parameters including momentum, and calculates average dE/dx.

Data Stores:

SVT Raw Pixel Data – The raw SVT pixel data consists of real or simulated SVT raw data in the form of sequences of non-zero ADC values plus addressing information in the format as delivered by DAQ (see /sim/det/svt).

SVT Calibration Data – Generic data store representing all the calibration and corrections necessary to correct the raw space point information.

Reconstructed SVT Space Points – The Reconstructed SVT Space Points consists of a list of all reconstructed particle crossing points through the detector wafers. One space point consists of the 3 dimensional coordinates of the crossing point, the total energy deposition associated with this crossing point, estimates of the angle of crossing (in the drift plane), and estimates of the errors on the above quantities (see /sim/det/svt). Space points are given in the global STAR Coordinate System.

Primary Vertex Position from VPD – Approximate location along the beam axis of the triggered event's primary vertex as determined by the VPDs.

Global Primary Vertices – Primary collision vertex location in 3-D for triggered event, determined by the global primary vertex finder.

SVT-TPC Match Track List – List of matched SVT and TPC tracks from global event reconstruction, see /ana/global/tracking.

Reconstructed SVT Tracks – Includes all kinematical properties of each charged particle track such as momentum, pitch and azimuthal angle, most probable dE/dx, a point of reference on the track, and estimates of the error on the above quantities. Track parameters are expressed in the global STAR coordinate system.

Data Flows:

None

SVT Space Point Reconstruction (/ana/svt/space_points):

Description:

The SVT Pixel to Space Point software converts the raw SVT data from either simulations or the actual experiment into reconstructed space points. The reconstruction of the space points involves a number of operations illustrated schematically in the functional model diagram shown in Fig. 33.

The raw pixel data are first corrected for pedestal offsets and gain non-uniformities. The data thus corrected are then scanned to search for 2 dimensional clusters of energy deposition (time sequence and 2-D Cluster Finder). The clusters found are examined to determine if they can be reliably assumed to be a single cluster or if they instead result from 2 or more merged hits (Hits per Cluster Estimator). The single and double clusters identified are then analyzed to determine their total charge (energy deposition) and centroid position in both the detector anode and drift directions (Single Hit and Multi-Hit Fitters). The centroids are then mapped to 2D coordinates (in the drift plane of the SDD). The mapping requires an accurate knowledge of the detector time offset, the drift velocity (both the average value and the detailed drift velocity profile across the detector), the current temperature of the wafer (*i.e.* the temperature at the time the event was recorded), and the current detector bias (*i.e.* the detector bias at the time the event was recorded). The temperature and biasing voltage are assumed to be available through the hardware control readout system. The 2D coordinates, expressed in the reference frame of each wafer, are finally mapped onto 3D space points expressed in the global STAR Coordinate System (2D to 3D Space Point Mapping). This last mapping involves detailed and accurate knowledge of the position and orientation of each detector wafer, as well as global alignment corrections.

/ana/svt/space_points

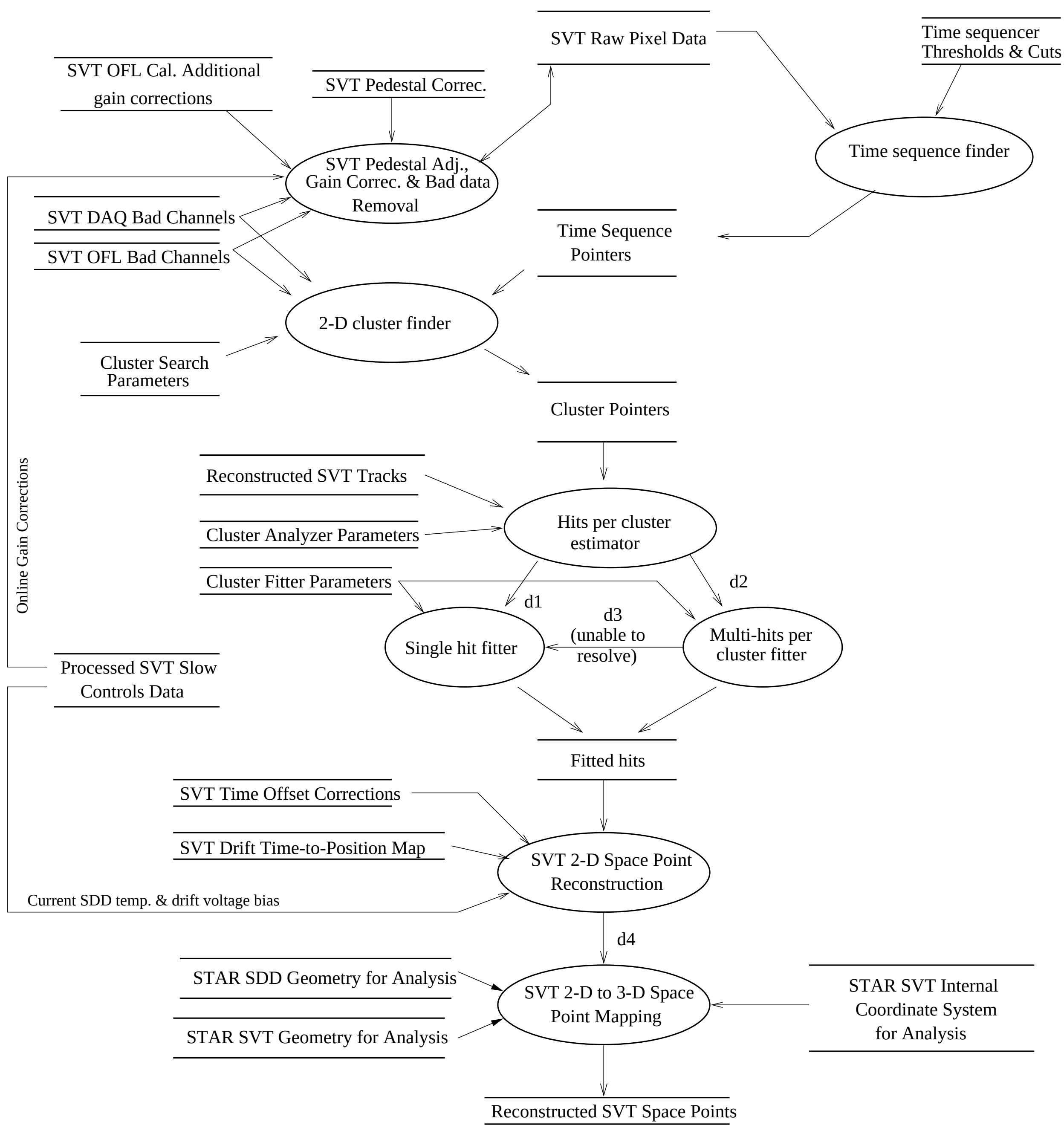

Figure 33: SVT Space Point Reconstruction Software

Glossary of Terms:

Special Definitions:

Pixel – Digital (integer) signal for one anode and one time bin.

Time sequence – Set of contiguous pixels for one anode which are above a predetermined threshold and which contain a sufficient (also predetermined) number of time bins.

Cluster – Set of overlapping (in time bins) time sequences on a predetermined number of adjacent anodes, all on one SDD wafer.

Hit – Set of activated pixels which result from passage of one ionizing particle through the SDD active region.

Space point – Ideally the reconstructed position and energy deposition of one hit, but in actuality may include several merged hits.

Processes:

SVT Pedestal Adjustment, Gain Corrections and Bad Data Removal – Process which removes channel by channel pedestal and gain variations still present after on-line corrections have been applied (if any). Also, data from "dead" channels (including "hot" or noisy channels) are removed from the data structure.

Time Sequence Finder – Process which builds pointers to the beginning and end of time sequences on each channel. In the simplest case, this may involve no more than filling a table of pointers that are taken directly from the ASIC zero-suppression/sequence-defining chip. However, if an offline threshold is desired that is higher than that used in the ASIC, then some processing is required; this capability must be available.

2-D Cluster Finder – This procedure scans the corrected pixel data and time sequences wafer by wafer to identify charge deposition clusters corresponding to the passage of charged particles. It produces a list of cluster candidates.

Hits per Cluster Estimator – Process which estimates the number of space points that may be found in a cluster. This estimate is based on cluster shape information, or, if the cluster/hitfinder is being re-run after tracking software, it is based on local track extrapolations across the wafer.

Single Hit Fitter – Process which determines the centroid positions along the SDD drift and anode directions and the total energy deposition of single hit clusters.

Multi-Hits per Cluster Fitter – Process which finds local peaks in the cluster patterns, deconvolutes the individual hits, and determines the centroid positions along the SDD drift and anode directions and the total energy deposition (if possible) of the individual, resolved hits within the cluster.

SVT 2-D Space Point Reconstruction – This procedure transforms the time and anode centroid positions into an in-SDD plane 2-D position.

SVT 2-D to 3-D Space Point Mapping – This procedure transforms the 2D in-SDD-plane hit positions (space points) to 3-dimensional coordinates expressed in the global STAR Coordinate System. The calibrated positions/orientations of the SDD wafers are used for this operation as well as the overall position and orientation alignment corrections for the SVT Internal Coordinate System in the global STAR Coordinate System. Minor corrections based on online position sensor information can also be applied.

Data Stores:

SVT Offline Calibration Additional Gain Corrections – see /cal/svt.

SVT Pedestal Corrections – see /cal/svt.

SVT Raw Pixel Data – see /ana/svt.

Time Sequencer Thresholds and Cuts – A data store containing parameters that modify the operation of the offline time sequence finder. This includes an ADC threshold such that a pixel with ADC value less than this threshold is "zero-suppressed." Clearly, to be meaningful, this threshold must be equal to or greater than the on-line ASIC zero-suppression threshold. A second threshold may be included such that a sequence that does not contain a pixel with ADC value above this threshold is discarded. Also, minimum and maximum sequence length cuts would be found in this data store.

Time Sequence Pointers – Index information for the first and last pixels in a time sequence of ADC values.

SVT DAQ Bad Channels – Data store which identifies those channels for which the data should not be used. The decision for these channels is made by an online process.

SVT Offline Bad Channels – Data store which identifies further channels (compared to online) for which the data should not be used. The decision for these channels is made by an offline process after processing some data (see /cal/svt/ped and /cal/svt/rel_gain).

Cluster Search Parameters – The cluster search parameters consist of all the analysis parameters necessary for the proper recognition of charge clusters.

Cluster Pointers – Index information listing the time sequences to be associated with a cluster.

Reconstructed SVT Tracks – see /ana/svt.

Cluster Analyzer Parameters – The cluster analyzer parameters consist of all the necessary parameters for the recognition of single and merged clusters.

Cluster Fitter Parameters – The cluster fitter parameters include all parameters involved in the determination of the centroid position and total cluster charge.

Processed SVT Slow Controls Data – This data store includes the following: (1) online gain corrections in the form of channel by channel nonlinear gain correction functions and parameters applied to the raw ADC values online, (2) current SDD temperatures and drift voltage bias corresponding to a list of the estimated temperature of all SDD wafers at the time the event was recorded and a list of the estimated drift voltage bias on all SDD wafers at the time the event was recorded (see /cal/svt).

Fitted Hits – List of fitted hits in all SDD wafers including centroid locations and total energy deposition.

SVT Time Offset Corrections – see /cal/svt.
SVT Drift Time to Position Map – see /cal/svt.
STAR SDD Geometry for Analysis – see /sim/det/svt.
STAR SVT Geometry for Analysis – See /sim/geometry.
STAR SVT Internal Coordinate System for Analysis – See /sim/geometry.
Reconstructed SVT Space Points – see /ana/svt.

Data Flows:

d1 – ADCs for anodes and time buckets for each found, single hit cluster.

d2 – ADCs for anodes and time buckets for each found, multi-hit cluster.

d3 – Control parameter to 'Single Hit Fitter' indicating a multi-hit cluster which could not be decomposed.

d4 – Corrected 2-D centroids for each fitted hit in all SDDs.

SVT Tracking (/ana/svt/tracking):

Description:

The SVT Track Reconstruction software assigns the reconstructed space points to charged particle tracks and determines the momentum of these tracks for pp, pA, and AA collisions. The reconstruction of the SVT tracks requires a number of operations which are illustrated schematically in the functional model diagram shown in Fig. 34.

The track reconstruction of SVT tracks first requires the determination of the primary collision vertex (Primary Vertex Finder). Once the primary or main collision vertex is known, it becomes feasible to search for all tracks emerging from this vertex beginning with tracks with the highest momenta. A list of track candidates is built (Track Finder) and examined to select the best track candidates (Track Filter/Selector). The tracks selected are fitted to determine their momenta and emission angles. They are also analyzed to determine the energy deposition of the charged particle (dE/dx Calculation). Parameters for the reconstructed tracks are given in the global STAR Coordinate System.

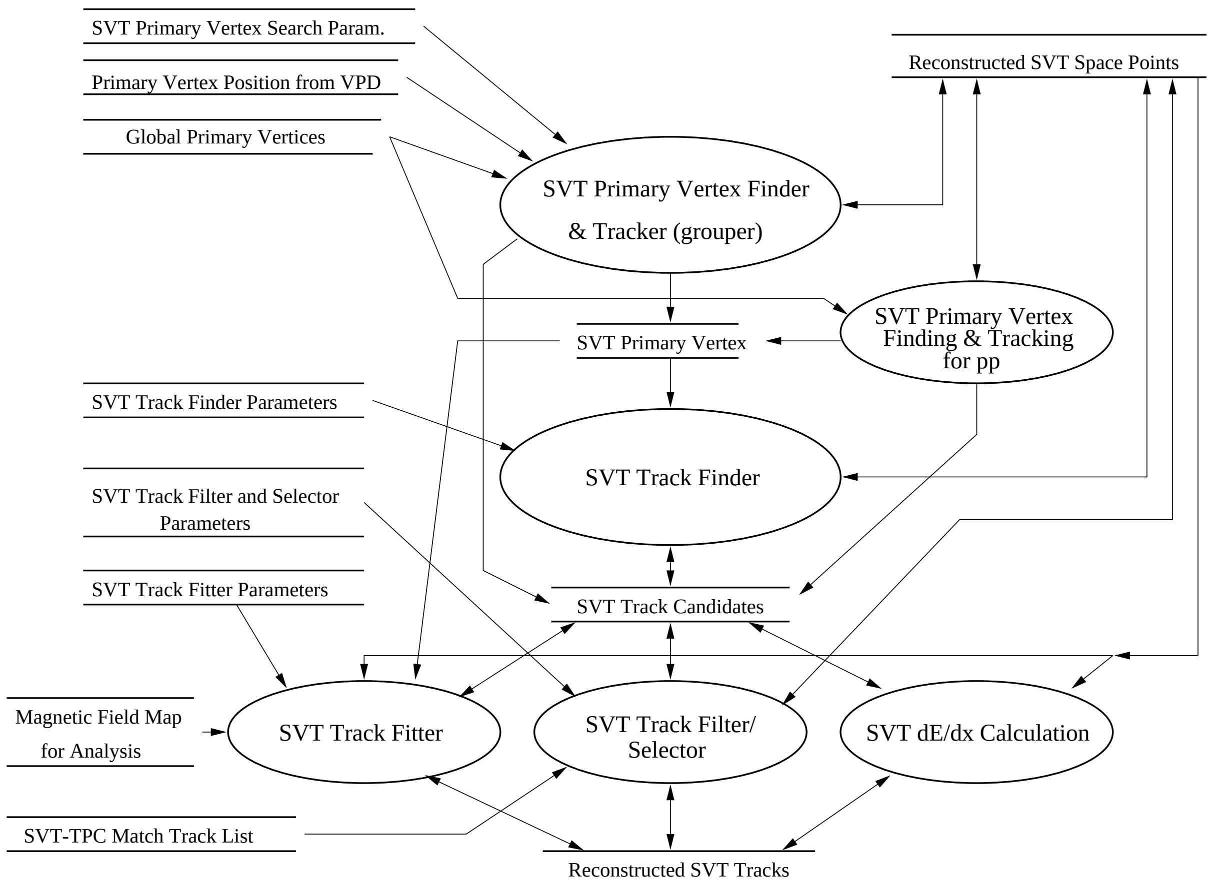

Figure 34: SVT Track Reconstruction Software

Glossary of Terms:

Processes:

SVT Primary Vertex Finder and Tracker (Grouper) – A procedure or a collection of procedures used to determine the position of the primary or main collision vertex on the basis of SVT tracks only. There are currently a number of methods existing and envisioned to perform this operation. Some track finding also occurs at this stage when using pattern recognition algorithm (referred to as the 'Grouper' method).

SVT Primary Vertex Finding and Tracking for pp – A procedure or collection of procedures used to determine the position of the primary, triggered collision vertex using high p_T SVT tracks only for the special tracking environment expected in the high luminosity pp program. Track finding (for high p_T) is also done at this stage.

SVT Track Finder – A procedure or a collection of procedures used to analyze the SVT space points and find track candidates.

SVT Track Fitter – A procedure or a collection of procedures used to analyze the track candidates and determine their kinematical parameters such as momentum and emission angles.

SVT Track Filter and Selector – A procedure or a collection of procedures used to reject false or ghost tracks on the basis of various selection criteria such as the track chi-square, etc.

SVT dE/dx Calculation – A procedure or a collection of procedures used to determine the most probable energy deposition associated with a track.

Data Stores:

SVT Primary Vertex Search Parameters – The primary vertex search parameters include all necessary parameters to define the search range and method. In particular, it includes all parameter cuts necessary for clean identification of the vertex position.

Primary Vertex Position from VPD – see /ana/svt.

Global Primary Vertices – see /ana/svt.

Reconstructed SVT Space Points – see /ana/svt.

SVT Primary Vertex – The reconstructed primary vertex consists of the position and estimated errors on the position determined on the basis of the SVT data.

SVT Track Finder Parameters – The track finder parameters include all necessary selection and cut parameters needed for the track search and recognition.

SVT Track Filter and Selector Parameters – The filter and selector parameters include all parameters needed to reject false tracks and clean the track data sample.

SVT Track Fitter Parameters – The fitter parameters include all necessary cuts and control variables needed to determine the track momentum vectors.

SVT Track Candidates – The track candidates consists of a list of indices of space points likely to form a track.

Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.

SVT-TPC Match Track List – see /ana/global/tracking.

Reconstructed SVT Tracks – see /ana/svt.

Data Flows:

None

Status:

See the following STAR Library Packages:

scs – SVT cluster finding and space point reconstruction.
sgr – SVT grouper method primary vertex finding and tracking.
spr – SVT dE/dx calculation and PID.
ste – SVT tracking evaluation.
stk – Main SVT track finding and fitting.
svd – SVT event display.
svr – SVT primary vertex reconstruction.
szs – SVT zero suppression.

5.3 CTF Event Reconstruction (/ana/ctf)

This section contains a description, list of requirements, functional model diagram (/ana/ctf, Fig. 35), glossary of terms, and a status of software report. Detailed descriptions of the present implementation of the CTF [Time-of-Flight (TOF) and/or Central Trigger Barrel (CTB)] event reconstruction software are presented in Ref. [15].

Description:

The initial operations in the CTF event reconstruction program include subtracting the channel offsets from the ADC and TDC signals, then applying gain corrections to obtain the corrected variables: multiplicity and time of flight.

Requirements:

The TOF offline event reconstruction software is required to obtain the velocity of each particle which produced both a track in the TPC (and possibly also in the SVT) and an isolated hit in the TOF scintillators. The velocity determination, in combination with the momentum resolution, should be of sufficient quality to significantly extend the momentum range for PID well beyond that attainable with dE/dx methods. This initial event reconstruction software must use calibration corrections for PMT gain variations and timing offsets in order to permit accurate PID information to be obtained. The software is only required to provide particle velocity information for particles originating near the primary vertex.

Physical Justification: Accurate particle identification for pions, kaons and protons over the full p_T range expected for the bulk of the multiplicity production at RHIC is necessary in order to determine global event by event properties of the collisions in order to distinguish events having anomalous pion or kaon temperatures, mean p_T, K/π ratios, etc.

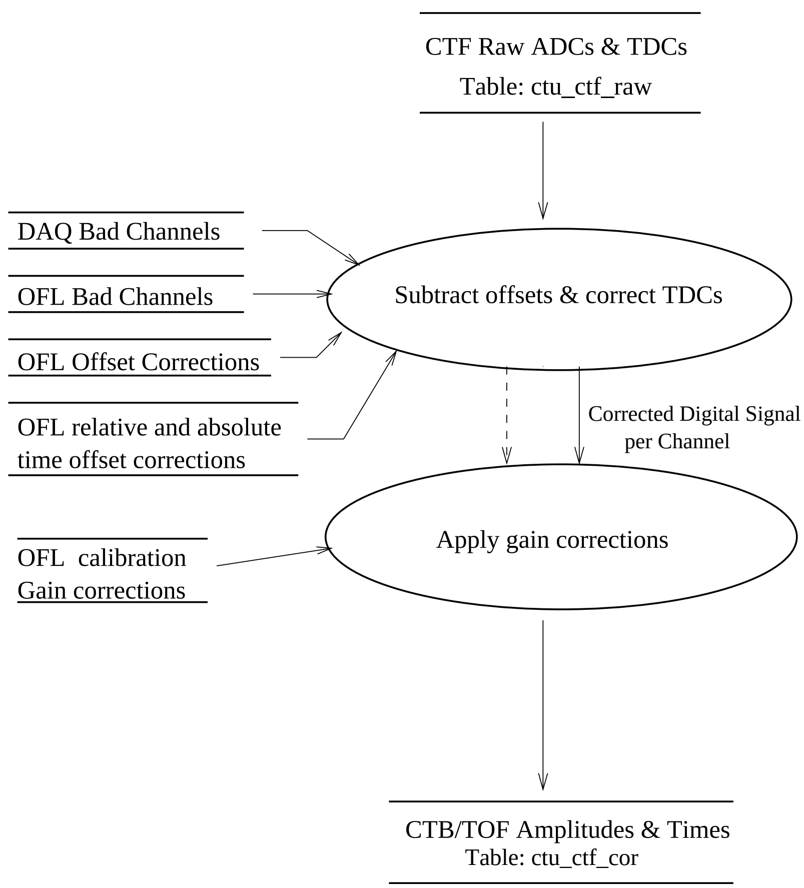

Figure 35: CTF Event Reconstruction Software Functional Model Diagram

Glossary of Terms:

Processes:

Subtract Offsets and Correct TDCs – Raw ADC data from DAQ (or simulations) are corrected for voltage offsets; bad channels determined from online and/or offline analysis are removed from the sample. Relative channel to channel timing corrections as well as absolute, overall timing corrections are applied to the TDC data.

Apply Gain Corrections – Process which applies channel by channel gain corrections determined by offline calibration and evaluation analyses.

Data Stores:

CTF Raw ADCs and TDCs – Simulated or real TOF and/or CTB ADC and TDC values for each channel in the format used by DAQ.

DAQ Bad Channels – DAQ reported TOF and/or CTB dead, hot or problematic PMT and electronic channels.

Offline Bad Channels – Dead, hot or problematic TOF and/or CTB PMT and electronic channels determined by offline analyses of inclusive data sums.

Offline Offset Corrections – Corrections for ADC offsets in each PMT and electronics channels when no signal is present, obtained from offline analysis of inclusive data sums.

Offline Relative and Absolute Time Offset Corrections – Relative channel by channel and overall absolute TDC offset corrections determined by offline analysis of inclusive data sums using high p_T tracks.

Offline Calibration Gain Corrections – Gain corrections for each PMT and electronics channel determined by offline analysis of inclusive data sums.

CTB/TOF Amplitudes and Times – Corrected CTB and/or TOF ADC and TDC values.

Data Flows:

As defined on the diagram.

Status:

See the following STAR Library Packages:

cpi – TOF reconstruction and PID analysis.
ctu – DAQ data to Table interface; data unpacking.

5.4 EMC Event Reconstruction (/ana/emc)

This section contains a description, list of requirements, functional model diagrams for the top level (/ana/emc, Fig. 36) and for two sublevels including gain corrections and absolute energy conversion for the EMC PMT and SMD data (/ana/emc/energy, Fig. 37) and first pass physics analysis (/ana/emc/analysis, Fig. 38) which occurs prior to DST production, glossaries for each diagram, and a status of software report. Detailed descriptions of the present implementation of the EMC offline reconstruction software is presented in Ref. [16].

Description:

The EMC event reconstruction offline software has two principle functions. First, starting with the raw PMT and SMD ADC values from DAQ, pedestals are subtracted (if necessary), additional channel by channel gain corrections from the offline calibration data base are applied, and the corrected ADC values are converted into quantities representing the amount of energy deposition using energy calibration constants. Second, preliminary physics analysis is done in combination with tracking and PID information in order to provide event by event sorting and cataloging information with respect to EMC related physics goals. Included in these preliminary physics analysis quantities are the following: (1) high p_T electrons, (2) charged versus neutral energy deposition in (η,ϕ) space, (3) high p_T photons, (4) jets, (5) missing E_T, and (6) $W^{\pm}$.

Requirements:

1. The EMC event reconstruction software is required to convert the raw ADC values from DAQ into energy depositions in the calorimeter stacks and energy deposition distributions in the shower maximum detector (SMD).
2. The input ADC values must be corrected for channel by channel variations in the light propagation and PMT efficiencies, SMD wire/strip responses, and onboard electronics gains.
3. The energy conversions must be sufficiently accurate and stable throughout the lifetime of the detector such that the physics goals of the STAR-EMC program can be achieved. As with other detectors in STAR, the event reconstruction software performance requirements vary with the physics objectives.
4. Tracking information must be used to estimate the amount of energy deposition in the EMC towers which result from charged hadrons. This is necessary for determining the amount of neutral energy deposition and for physics goals (*e.g.* studies of disoriented chiral condensates) which involve studies of anomalous charged:neutral energy production ratios.

5. The identical software must be used for both real and simulated data analysis in order to fully test and evaluate (via simulations) the actual software to be used for real data.

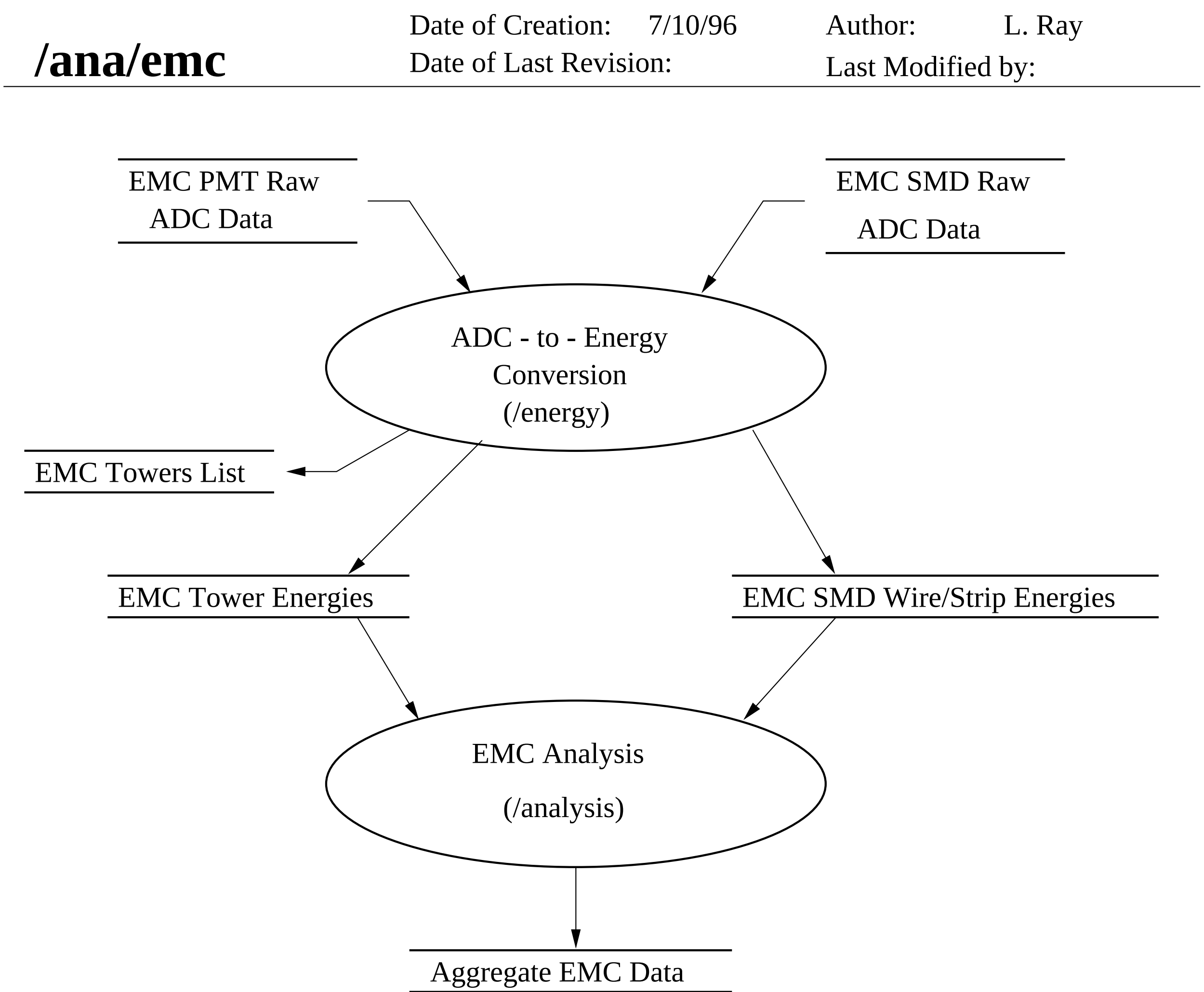

Figure 36: EMC Event Reconstruction Software Top Level Diagram

Glossary of Terms:

Processes:

ADC to Energy Conversion (/energy) – Top level process which includes pedestal subtraction, bad data removal, gain corrections, and ADC to energy deposition conversions for both the PMT and SMD data.

EMC Analysis (/analysis) – Top level process which includes preliminary physics analysis which occurs prior to DST production.

Data Stores:

EMC PMT Raw ADC Data – EMC PMT output ADC values for each channel after onboard electronics signal processing in the same format as that which will be used by DAQ for the real data (see /sim/det/emc).

EMC SMD Raw ADC Data – EMC SMD output ADC values for each channel after onboard electronics signal processing in the same format as that which will be used by DAQ for the real data (see /sim/det/emc).

EMC Towers List – List of struck EMC towers above specified threshold for triggered event. Mainly for use in high luminosity pp mode.

EMC Tower Energies – Corrected and calibrated energy depositions for each EMC tower including depth segmentation (if applicable).

EMC SMD Wire/Strip Energies – Corrected and calibrated energy depositions for each SMD wire or strip.

Aggregate EMC Data – Generic data store representing all the pre-DST physics analysis results, including lists of electrons, photons, jets and W candidates, as well as charged and neutral energy distributions in (η,ϕ).

Data Flows:

None

/ana/emc/energy

Date of Creation: 7/10/96 Author: L. Ray
Date of Last Revision: Last Modified by:

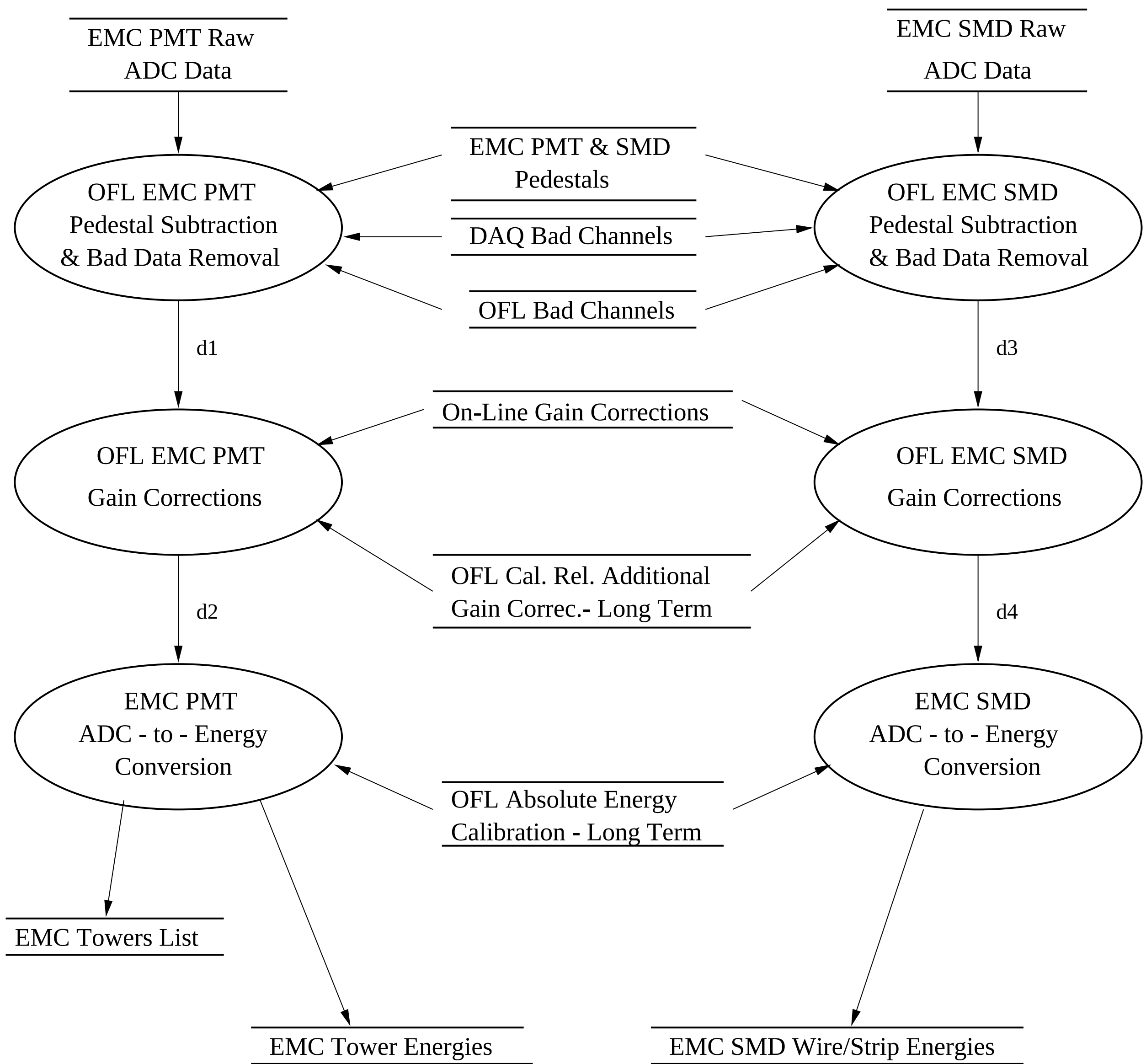

Figure 37: EMC Energy Conversion Software

Glossary of Terms:

Processes:

Offline EMC PMT Pedestal Subtraction and Bad Data Removal – This process subtracts pedestals (if required) and flags bad data channels for each PMT/electronics channel.

Offline EMC PMT Gain Corrections – This process corrects each PMT channel for gain variations which are in addition to that used in the online electronics.

EMC PMT ADC to Energy Conversion – This process converts the corrected PMT data into energy deposition in the EMC towers, with depth segmentation if applicable.

Offline EMC SMD Pedestal Subtraction and Bad Data Removal – This process subtracts pedestals (if required) and flags bad data channels for each SMD/electronics channel.

Offline EMC SMD Gain Corrections – This process corrects each SMD channel for gain variations which are in addition to that used in the online electronics.

EMC SMD ADC to Energy Conversion – This process converts the corrected SMD wire/strip data into energy deposition distributions on the SMD grid.

Data Stores:

EMC PMT Raw ADC Data – see /ana/emc.

EMC SMD Raw ADC Data – see /ana/emc.

EMC PMT and SMD Pedestals – ADC values for each PMT and SMD channel with no EMC hits; mean and rms values for many "empty" events. Used for both simulated and real pedestals (see /cal/emc).

DAQ Bad Channels – List of bad EMC PMT and SMD channels reported by DAQ (see /cal/emc).

Offline Bad Channels – List of bad EMC PMT and SMD channels determined by offline calibration software (see /cal/emc).

Online Gain Corrections – Channel by channel gain corrections for each PMT and SMD wire/strip used in the online ADC data processing (see /cal/emc/esl).

Offline Calibration Relative Additional Gain Corrections - Long Term – Channel by channel additional gain corrections for each PMT and SMD wire/strip to be used in addition to the online gain corrections. These are computed by offline calibration software (see /cal/emc/energy).

Offline Absolute Energy Calibrations - Long Term – Channel by channel ADC to energy deposition conversion factors for the PMTs and SMD wire/strips from offline calibrations (see /cal/emc/energy).

EMC Towers List – see /ana/emc.

EMC Tower Energies – see /ana/emc.

EMC SMD Wire/Strip Energies – see /ana/emc.

Data Flows:

d1 – EMC PMT pedestal subtracted ADC values for each channel with bad data channels flagged.

d2 – Same as *d1* but also including relative channel by channel gain corrections which are in addition to those applied in the online ADC data processing.

d3 – EMC SMD wire/strip pedestal subtracted ADC values for each channel with bad data channels flagged.

d4 – Same as *d3* but also including relative channel by channel gain corrections which are in addition to those applied in the online ADC data processing.

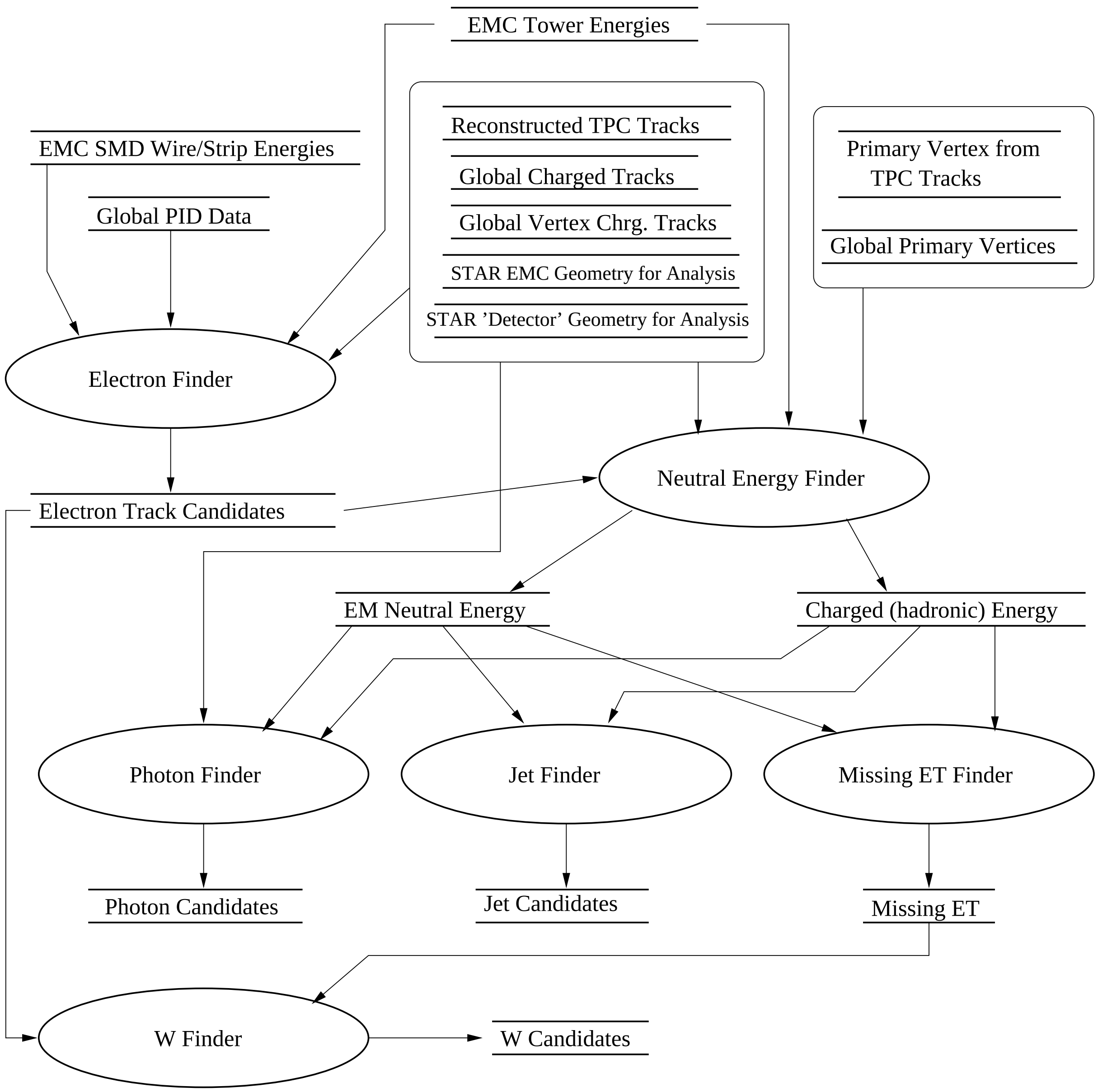

Figure 38: EMC pre-DST Physics Analysis Software Functional Model Diagram

Glossary of Terms:

Processes:

Electron Finder – Process which uses the EMC tower energies and SMD energy distributions along with TPC and/or global tracking and PID results to produce a list of electron ($e^{\pm}$) track candidates. Charged particle tracks in the TPC are extrapolated to the front plate of the EMC and expected tower and SMD energy distributions are compared with the data. Isolation cuts are invoked to identify electrons. Particle ID information, if available, is used to eliminate hadrons from among the electron candidates. Global position alignment information for the EMC towers and SMD wire grids are used.

Neutral Energy Finder – This process uses the total energy deposited in the EMC towers together with TPC and/or global tracking information and the electron track candidates to determine the (η,ϕ) distribution of charged hadronic and neutral energy production. Acceptable tracks are projected outward toward the EMC barrel or end cap front plates and if these appear to hit the EMC then a parametrized amount of energy is subtracted from the struck tower. Primary vertex information is used to enable calculations of transverse energy, E_T. Care is taken not to double count electron energies. After all the accepted tracks have been processed in this manner, the energy remaining in the EMC towers is multiplied by the sampling fraction to give the deduced neutral energy in the (η,ϕ) grid. Global position alignment information for the EMC towers and SMD wire grids are used.

Photon Finder – This process identifies candidate high p_T photons using the EMC neutral energy with isolation cuts and the charged track information (absence of charged tracks with sufficient p_T). The primary vertex location is used to determine the photon's E_T. Global position alignment information for the EMC towers and SMD wire grids are used.

Jet Finder – Jet finding algorithms using only the charged (hadronic) and neutral energy depositions. Examples include modified versions of the UA1, CDF and ISA jet finder codes.

Missing E_T Finder – Process which identifies missing E_T in (η,ϕ) based on the charged and neutral energy distributions. This is important in the high luminosity pp analysis where $W^{\pm}$ production results in very large $e^{\pm}$ energy deposition accompanied with absent $(\nu_e,\bar{\nu}_e)$ opposite side energy deposition. This is also useful as a diagnostic tool for monitoring hardware performance.

W Finder – Process which combines high p_T electrons and missing E_T information to identify $W^{\pm}$ candidates in the high luminosity pp analysis mode.

Data Stores:

EMC SMD Wire/Strip Energies – see /ana/emc.
EMC Tower Energies – see /ana/emc.
Global PID Data – see /ana/global/pid.
Reconstructed TPC Tracks – see /ana/tpc.

Global Charged Tracks – see /ana/global.

Global Vertex Charged Tracks – see /ana/global.

STAR EMC Geometry for Analysis – see /sim/det/emc and /sim/geometry.

STAR 'Detector' Geometry for Analysis – Mainly TPC, CTF and Structural; see /sim/geometry.

Primary Vertex from TPC Tracks – see /ana/tpc/tpp.

Global Primary Vertices – see /ana/global.

Electron Track Candidates – Contains the EMC energy and track kinematics information for global or TPC tracks identifed as electron candidates.

EM Neutral Energy – Calculated neutral energy deposited in the EMC barrel and end cap towers, with depth segmentation if applicable, in the (η,ϕ) grid.

Charged (Hadronic) Energy – Calculated energy deposition in the EMC barrel and end cap towers, with depth segmentation if applicable, for charged tracks (identified electrons are excluded) in the (η,ϕ) grid.

Photon Candidates – Total and transverse energy for photon candidates in the (η,ϕ) grid for the barrel and end cap of the EMC.

Jet Candidates – List of jet candidates with neutral and charged hadronic energy distribution parameters and jet kinematics information.

Missing E_T – (η,ϕ) map of identified regions of missing E_T.

W Candidates – List of $W^{\pm}$ candidates and kinematic information.

Data Flows:

None

Status:

See the following STAR Library Packages:

ems – EMC reconstruction and analysis.
erj – EMC jet finding and energy determination.

5.5 MWC Event Reconstruction (/ana/mwc)

This section contains a description, list of requirements, functional model diagram (/ana/mwc, Fig. 39), glossary of terms, and status of software report. Detailed descriptions of the present implementation of the MWC offline reconstruction software is presented in Ref. [18].

Description:

The MWC event reconstruction software corrects the digital wires above threshold count, from either simulations or real data, in order to obtain a refined estimate of the actual charged track multiplicity in the MWC acceptance. These corrections involve geometrical effects and Poisson statistics.

The geometrical correction depends on the wire position. Particles at large pseudorapidities produce signals in fewer wires than particles at low pseudorapidities. The nominal η coverage of the MWCs is from -2 to -1 and from +1 to +2.

Depending on multiplicity some wires will be fired by two or more particles. To obtain a better estimate of the actual multiplicity, corrections for Poisson statistics must be applied.

Requirements:

The MWC offline event reconstruction software must correct the raw data for geometrical and Poisson statistics with sufficient accuracy and reliability so as to eliminate false triggers which were based either on total multiplicity from $|\eta| = 1$ to 2 or on multiplicity distributions which depend on that part covered by the MWCs.

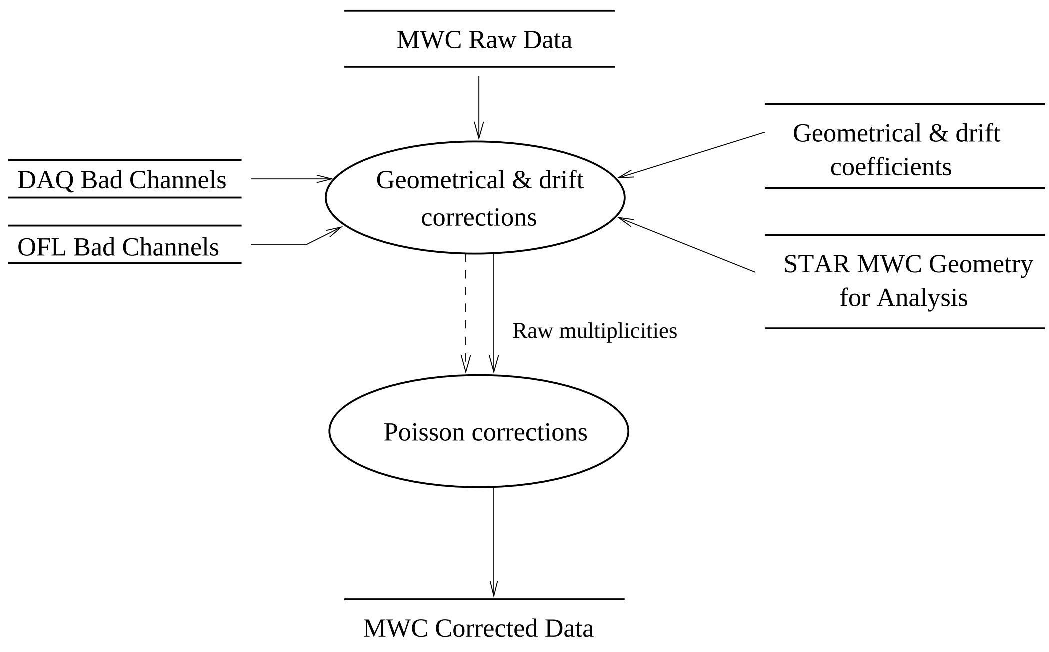

Figure 39: MWC Event Reconstruction Software

Glossary of Terms:

Processes:

Geometrical and Drift Corrections – The number of wires fired by an ionizing particle depends on its pseudorapidity. These effects are corrected in this operation.

Poisson Corrections – This step corrects for effects due to single wires being fired by more than one particle. Since rescattering is not a big effect in this detector, multiple hits are uncorrelated and Poisson statistics can be used.

Data Stores:

MWC Raw Data – Simulated or real MWC wire counts above threshold for each MWC in the DAQ format. See /sim/det/mwc.

DAQ Bad Channels – List of DAQ reported dead or problematic wires or channels.

Offline Bad Channels – List of dead or problematic MWC channels determined by offline analysis of inclusive data sums.

Geometrical and Drift Coefficients – Wire dependent multiplicity correction coefficients based on pseudorapidity and anode response function. Multiple hit corrections based on Poisson statistics and observed multiplicity.

STAR MWC Geometry for Analysis – See /sim/geometry.

MWC Corrected Data – Multiplicities in the different sectors of the device, corrected for geometry and multiple hit effects.

Data Flows:

None

Status:

See the following STAR Library Packages:

mwu – MWC ADC to multiplicity event reconstruction.

5.6 VPD Event Reconstruction (/ana/vpd)

This section contains a description, list of requirements, functional model diagram (/ana/vpd, Fig. 40), glossary of terms, and status of software report. Detailed descriptions of the present implementation of the VPD offline reconstruction software is presented in Ref. [17].

Description:

The VPD event reconstruction program transforms the TDC data of each of the Cherenkov counters into a time of flight. By taking the earliest time in each one of the two subsystems (East and West side VPDs), an interaction point can be determined. The system also has the capability of detecting multiple interactions within a single beam bunch crossing if they occur far enough apart.

Requirements:

The offline VPD event reconstruction software is required to obtain refined primary vertex position information (along the beam axis) for use in SVT tracking and for primary vertex location. Analysis of the VPD TDC data is also required to report multiple collision vertices occurring within the same beam bunch crossing to the remainder of the offline event reconstruction software.

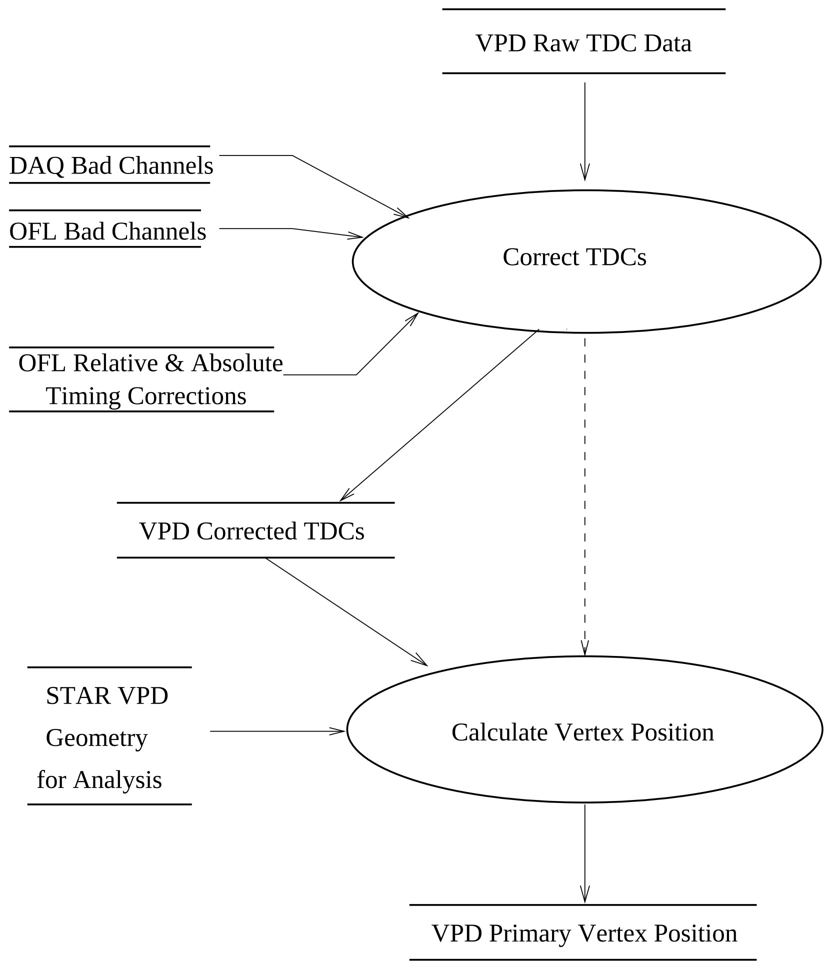

Figure 40: VPD Event Reconstruction Software

Glossary of Terms:

Processes:

Correct TDCs – Bad channels are removed and TDC values are corrected for relative counter to counter variations and for relative VPD East versus VPD West timing differences.

Calculate Vertex Position – The counter with the shortest time is selected in each of the two VPD detectors. By comparing them a vertex position along the beam direction is estimated.

Data Stores:

VPD Raw TDC Data – See /sim/det/vpd.

DAQ Bad Channels – List of DAQ reported dead or problematic channels.

Offline Bad Channels – List of dead or problematic channels determined by offline analysis of inclusive data sums.

Offline Relative and Absolute Timing Corrections – Relative channel to channel timing corrections for TDC values and absolute VPD East versus VPD West timing difference correction determined by offline calibration analysis of inclusive data sums.

VPD corrected TDCs – Corrected TDCs for each channel used.

STAR VPD Geometry for Analysis – See /sim/geometry.

VPD Primary Vertex Position – Calculated position and error of primary, triggered vertex (or multiple vertices) along beam axis in STAR coordinates. Obtained from the comparison between the shortest times in each of the VPD detectors.

Data Flows:

None

Status:

See the following STAR Library Packages:

vpm – VPD minimum time analysis and reconstruction.
vpu – VPD DAQ data unpacking.
vpv – VPD triggered vertex position location.

5.7 Global Event Reconstruction (/ana/global)

This section contains a description, list of requirements, top level functional model diagram (/ana/global, Fig. 41) and run scenarios figure (Fig. 42), followed by nine sublevel diagrams, including that for global tracking (/ana/global/tracking, Fig. 43), global primary vertex finding (/ana/global/primary_vertex, Fig. 44), global track refitting (/ana/global/refitter, Fig. 45), global V0 finding (/ana/global/V0, Fig. 46), kink finding and fitting (/ana/global/kinks, Fig. 47), global track filtering (/ana-/global/filter, Fig. 48), global particle ID (/ana/global/pid, Fig. 49), global Time-of-Flight particle ID (/ana/global/pid/tof, Fig. 50) and flow chart (Fig. 51), and DST event summary (/ana/global/summary, Fig. 52). Each diagram is followed by a glossary of terms. A status of software report is given at the end of this section. More detailed information describing the global event reconstruction software may be found in Ref. [19].

Description:

The global event reconstruction offline software correlates all the tracking, timing and energy deposition information from each detector in STAR and produces the final, overall reconstruction of the pp, pA and AA event, selected by the STAR Trigger system, at the collision vertex, in both the global STAR Coordinate System and in the center-of-momentum (CM) frame of the collision. The problem we are facing at this level is to find the best way of combining the detector-specific pieces of information so that the resulting event summary closely resembles the actual particle production. In this spirit, the actual implementation of this level might include an iterative interaction between the various tasks, *i.e.* the use of PID information in Global tracking and vice versa.

The functionality needed at this level of integration can be divided into two parts: one is the need for **correlating information from different detectors**, and the other a set of **service-routines** which this level should provide to other tasks within the event reconstruction and/or calibration processes. It is apparent that in order for this global reconstruction software to work properly a close interaction with the central geometry and material data base is essential. In the first group we identified the need of the following tasks:

- **Global tracking:** This comprises two functions: Track and hit matching between different detectors, as well as refitting the matched points with or without the vertex hypothesis. The use of the event vertex as an extra point on the refitted track is important as it is going to improve the overall momentum resolution. At the same time the tracking input used in *e.g.* V0 reconstruction routines should not include the event vertex while refitting the SVT and TPC points.

- **Event vertex determination:** Global tracks are the best input to a primary vertex finding routine. In general the resulting event vertex should be of better quality to the one determined by the TPC or the SVT alone. Special attention should be paid in the case of multiple event vertices (pile-up), as in p–p collisions.

- **PID assignment:** Timing (TOF) as well as energy deposition in the TPC, SVT and EMC is combined and a probability of a PID is assigned to each reconstructed track.

- **V0 finder:** Secondary vertices like V0s are reconstructed at this level using reconstructed global tracks. Although part of the V0 search clearly belongs to the physics analysis level, the initial steps of V0 finding and fitting should take place during the event reconstruction since no reconstructed space-points are written on the DSTs, something a V0 fitting routine needs as input.

- **Kink finder:** Charged kaon and pion one prong decays inside the TPC volume are reconstructed at this level using reconstructed global tracks. As with the V0 search this analysis is completed at the physics analysis level.

- **Global filter:** This offline software acts as a track filter flagging all background tracks as well as tracks which are not related to the triggered event.

- **Event Summary:** This comprises the function of producing the event DST as well as the transformation of the tracking information into a form more adequate for physics analysis (rapidity, p_T, CM frame, etc.).

- **Evaluation software:** This includes all the routines and data stores needed for the evaluation of the performance of all the above software. This is an essential step in verifying that a particular module complies with the design specifications (see /evl/global in later versions of this document).

The services include:

- **refitter:** This is a general purpose fitting routine.

- **track propagator:** It will return the track parameters and the associated error matrix of any given track at any point along its trajectory. Since detector boundaries are crossed in these projections, energy loss as well as multiple scattering should be incorporated in the tracking model.

- **Global alignment:** It is apparent that any systematic misalignment between the various detectors (*e.g.* between SVT and TPC) can be best detected and studied by using the primary vertex and global track residuals information, especially using straight tracks taken without magnetic field. This information can be provided by the global event reconstruction software.

Requirements:

This section attempts to set the performance specifications for the software of this level. Ideally this is exclusively driven by the physics goals of STAR. This would require the precise knowledge of the sensitivity of, more or less, all STAR physics observables to the various resolutions and efficiencies of all involved software. This multi-dimensional correlation information has not, as yet, been studied and in many cases the software goal was designed to do the best it could without any compromises (like CPU time and/or disk space). Therefore, our everyday experience running the software together with the uncompromised or 'best' performance from the individual detectors sets the specifications of this level. At a later stage, CPU time and disk space considerations might put some extra constraints.

The following parameters are considered at this level:

- **tracking efficiency:** This is the overall STAR tracking efficiency of the combined central tracking detectors, the SVT and the TPC, and it is the product of the individual tracking efficiencies and the **matching efficiency** as it is performed at this level. The individual tracking efficiencies have a strong momentum dependence [20] which rises sharply for momenta up to 150–200 MeV/c and which then becomes constant at the 90–95% level. A similar behaviour is shown by the matcher [21]. Thus the product of all three currently results in an overall efficiency which is slightly lower than 90%, which is the lowest acceptable efficiency. Some work has been already planned in order to achieve this goal.

  Another issue related to tracking efficiency is the percentage of so-called 'ghost' tracks in the final sample. These are tracks which are created either artificially or through segmentation of a single track. Our goal is to have less than 10% (close to 5%) of these tracks in our final sample. So far the simulations show that this goal is achievable with the current software but some work is also in progress. This is the main function of the 'filter' module.

- **momentum resolution:** The momentum resolution is greatly enhanced at this level mainly due to the extended track length the combined track pieces have. For most momenta it has been shown to be at the 2% level which is adequate for almost all STAR observables. The only exceptions are the very high p_T probes where the determination of steeply falling exponential slopes in p_T might be compromised by low momentum resolution [20]. The construction characteristics of the detectors set the limit in this matter and not software considerations.

- **particle identification:** The performance of the global PID software (which is nothing else but a mere combination of information from the individual detectors) is determined by hardware parameters as well as performance of the individual detectors and therefore all performance specifications are addressed at the individual detector level.

Δp/p	tracking effic.	PID effic.	vertex resolution	V0 effic.
$< 4\%$	$> 90\%$	N/A	$< 500\mu$m	S/N>10:1

- **event vertex resolution:** The current performance is transverse and longitudinal resolutions of less than 100μm for heavy ion events and for the combined TPC+SVT detectors and about 200μm for the TPC alone ([20],[22]) which is much better than the average single point resolution of the individual detectors and adequate for the STAR flavor physics program.

- **V0, $K^{\pm}$ efficiency:** These are inclusive measurements and therefore the main concern is the reconstruction of a reasonable size of signal (in a certain number of events, usually being several thousands) with low levels of background. It has been demonstrated that these goals are achievable with the current software using the right set of cuts [23]. The only exception is the K_s^0 interferometry which requires a reconstructed clean signal of more than one particle per event. Simulations have shown that this is also achievable using the current software although some work is still in progress in this area.

The above table summarizes the current performance specifications for global event reconstruction software.

Global Event Reconstruction – Top Level (/ana/global):

Description:

Fig. 41 shows the top-level diagram of the analysis part of the global event reconstruction software. This functional diagram is adequate for A-A and p-A program of STAR. Special software would be needed for the high luminosity p-p program in which many of the listed modules (V0, kink finder etc.) are obsolete. The listed sequence of modules does not imply sequence of execution. At this level iterative execution sequences are needed which are described as 'run scenarios' in the following.

Run Scenarios

There are two places (so far) where an iteration is needed. One is between the global tracker and the PID modules. The other is the primary vertex finder and the propagator/refitter modules. Figure 42 shows the logic for both of them. In the first case the need for an iteration arises from the fact that the track momentum at the global level is going to be much superior to that which each individual detector determines and thus more appropriate to use in the SVT/TPC PID modules. On the other hand it would be helpful to have PID information available at the tracking level (matching), since this will increase the so much needed overall tracking efficiency and purity. That is why the tracker has to run twice.

In the second case the propagator has to run twice. This is because the event vertex fitter works best if the track parameters are given at points in the proximity of the real vertex (in the transverse direction). This is done by running the track propagator targeting first the (predetermined) beam position in the transverse direction. Then the event vertex finder reconstructs the event vertex which then can be used by the refitter to determine the vertex tracks (see below).

/ana/global

Date of creation:	10/23/95	Author: S. Margetis & L. Ray
Date of last revision:	3/6/96	Last author: S. Margetis & L. Ray

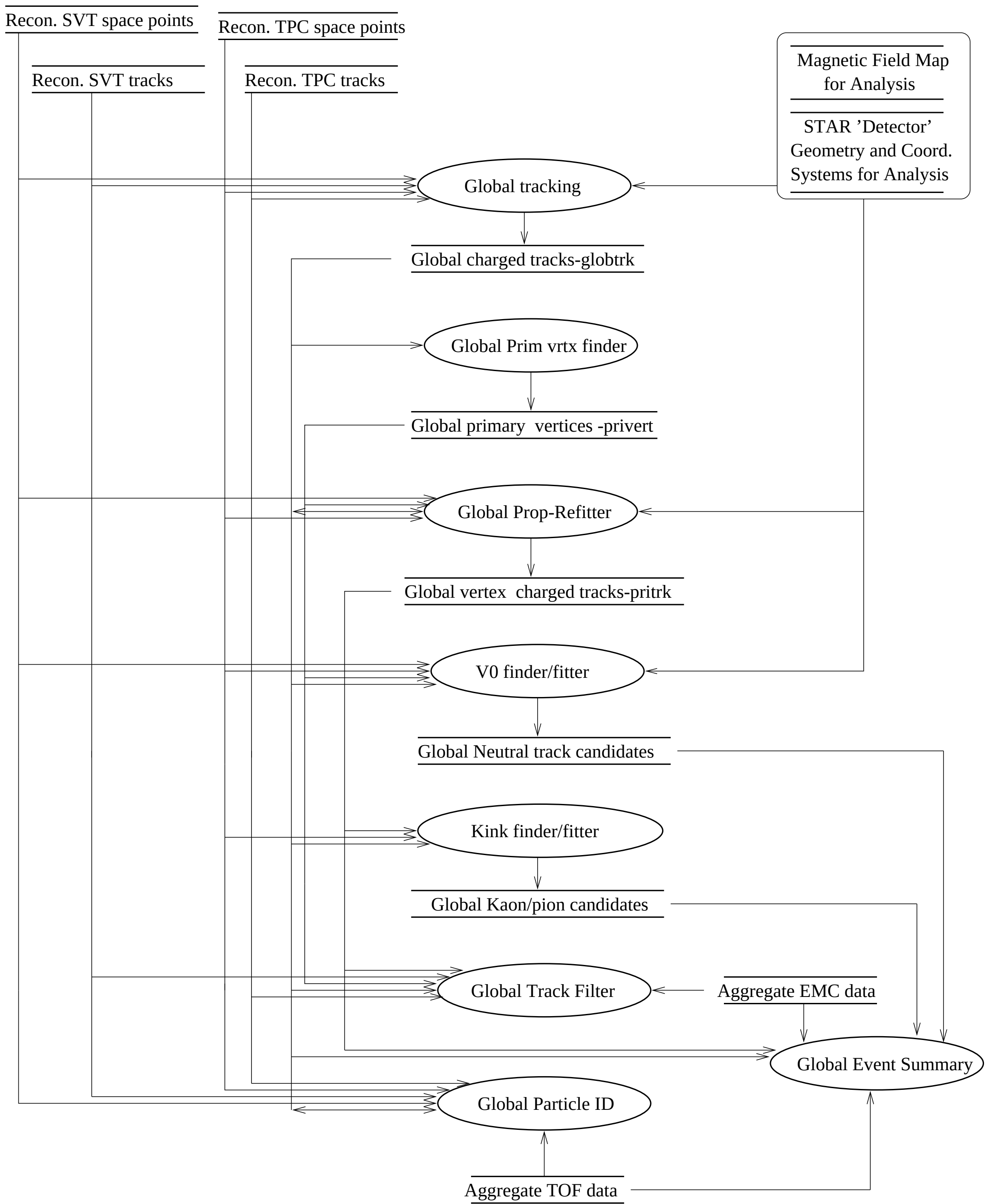

Figure 41: Global Event Reconstruction Software – Top Level

Global tracking - PID:

Run Global tracker - SVT & TPC matching

Run SVT & TPC PID modules using global track momentum

Check SVT & TPC matching - ‘filter’

Primary vertex finder - refitter:

Run propagator/refitter - propagate tracks to beam line

Run Primary vertex finder - reconstruct event vertex

Run propagator/refitter - propagate tracks to reconstructed vertex

Figure 42: Global Event Reconstruction Run Scenarios

Glossary of Terms:

Processes:

Global Tracking – SVT and TPC track to track and track to space point matching plus track filtering and selection.

Global Primary Vertex Finder – Process which determines the location of the primary collision vertex of the triggered event based on global tracks and using SVT and TPC determined primary vertex information, if available.

Global Propagation and Refitter – Generic track propagator service software plus global track refitter using SVT and TPC space points and/or the primary vertex.

V0 Finder and Fitter – Neutral parent candidate finder and decay vertex and daughter tracks fitter.

Kink Finder and Fitter – Single prong decay candidate finder with decay vertex fitting and decay classification.

Global Track Filter – Filtering and selection of fitted charged and neutral tracks for DSTs.

Global Particle ID – This process includes SVT, TPC and TOF particle ID plus global PID assignments.

Global Event Summary – Event summary and DST building in relevant kinematic variables in the beam particle - beam particle CM system.

Data Stores:

Reconstructed SVT Space Points – see/ana/svt.

Reconstructed SVT Tracks – see/ana/svt.

Reconstructed TPC Space Points – see/ana/tpc.

Reconstructed TPC Tracks – see/ana/tpc.

Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.

STAR 'Detector' Geometry and Coordinate Systems for Analysis – Generic data store representing the subsystem specific geometry data stores and local and global coordinate systems for analysis, see /sim/geometry.

Global Charged Tracks (globtrk) – This is a tracking table for the global (refitted) tracks. It also includes important foreign key information to all involved tables. Track parameters are given in the global STAR Coordinate System. Also includes global track fitting residuals.

Global Primary Vertices (privert) – This is the event vertex table. It has more than one row since the event vertex can be also determined at the individual detector level (*e.g.* SVT). Vertices are expressed in the global STAR Coordinate System.

Global Vertex Charged Tracks (pritrk) – This is again a tracking table for the global (refitted) tracks which are compatible with the event vertex and therefore they are refitted with the vertex point included in the fit. This is done for improved tracking parameters and momentum resolution. Track parameters are given in the global STAR Coordinate System.

Global Neutral Track Candidates (ev0out) – This is a table holding all necessary information of reconstructed V0 candidates which is needed for further physics analysis. All tables regarding secondary particle reconstruction (kinks, V0, cascades, D-mesons etc.) might merge at a later time into a few non-overlapping table types, a practice also followed by other experiments. Track parameters are given in the global STAR Coordinate System.

Global Kaon/Pion Candidates (tkfout) – The same as the ev0out table but for charged kaons and pions. Track parameters are given in the global STAR Coordinate System.

Aggregate TOF Data – Generic TOF data store (see /ana/ctf).

Aggregate EMC Data – Generic EMC data store (see /ana/emc).

Data Flows:

None

Global Tracking (/ana/global/tracking):

Description:

The purpose of the global tracking software is to extract the best possible information on any track by correlating the information from different STAR detectors. Since the central STAR detector has two major tracking devices, the SVT and the TPC, the major task at this level is the correlation (matching) of their tracking information (Fig. 43). There are three major types of matching: a) SVT-track to TPC-track, b) TPC-track to SVT-points or SVT-track to TPC-points and c) SVT-track to TPC-track where a decay may have occurred in the region between the two detectors. Obviously most of this task is performed by a), the track-to-track matcher, which should run first in order to clean up the space for the subsequent matchers. The TPC-track to SVT-points matcher can be viewed as an extension of the TPC tracker where new points (in another detector this time) are tried on the existing tracks (*i.e.* those not already matched to SVT tracks). This is useful mainly for tracks leaving only 2 hits in the SVT where there is no corresponding SVT track. The SVT-track to TPC-point is the same function but now an SVT track is matched to TPC points not assigned to any track. This might be useful especially for low momentum tracks reconstructed properly in the SVT which leave only a few hits in the inner TPC sectors. The last matcher is the 'decay' or kink matcher which is a subtask of the track-to-track matcher. It is listed as a separate function because it is algorithmically completely different.

All matchers write their results into a matching table which in turn is used by a global track (re)fitting routine. Global track parameters are given in the global STAR Coordinate System. The only exception is the kink matcher; its results cannot be used by the refitter. Some of the refitter functionality is needed in the track-to-point matchers (outlier rejection). The 'selector' function comes from the need to evaluate the performance or to disentangle conflicts between the matchers (a single track participates in more than one match etc.). Also its functionality is important after PID information becomes available and therefore an extra constraint can be used.

All modules at this level closely interact with the geometry and material data base because accurate knowledge of all detector positions as well as intervening scattering material is required at this integration level.

/ana/global/tracking

Date of creation: 11/21/95 Author: S. Margetis & L. Ray
Date of last revision: 3/6/96 Last author: S. Margetis & L. Ray

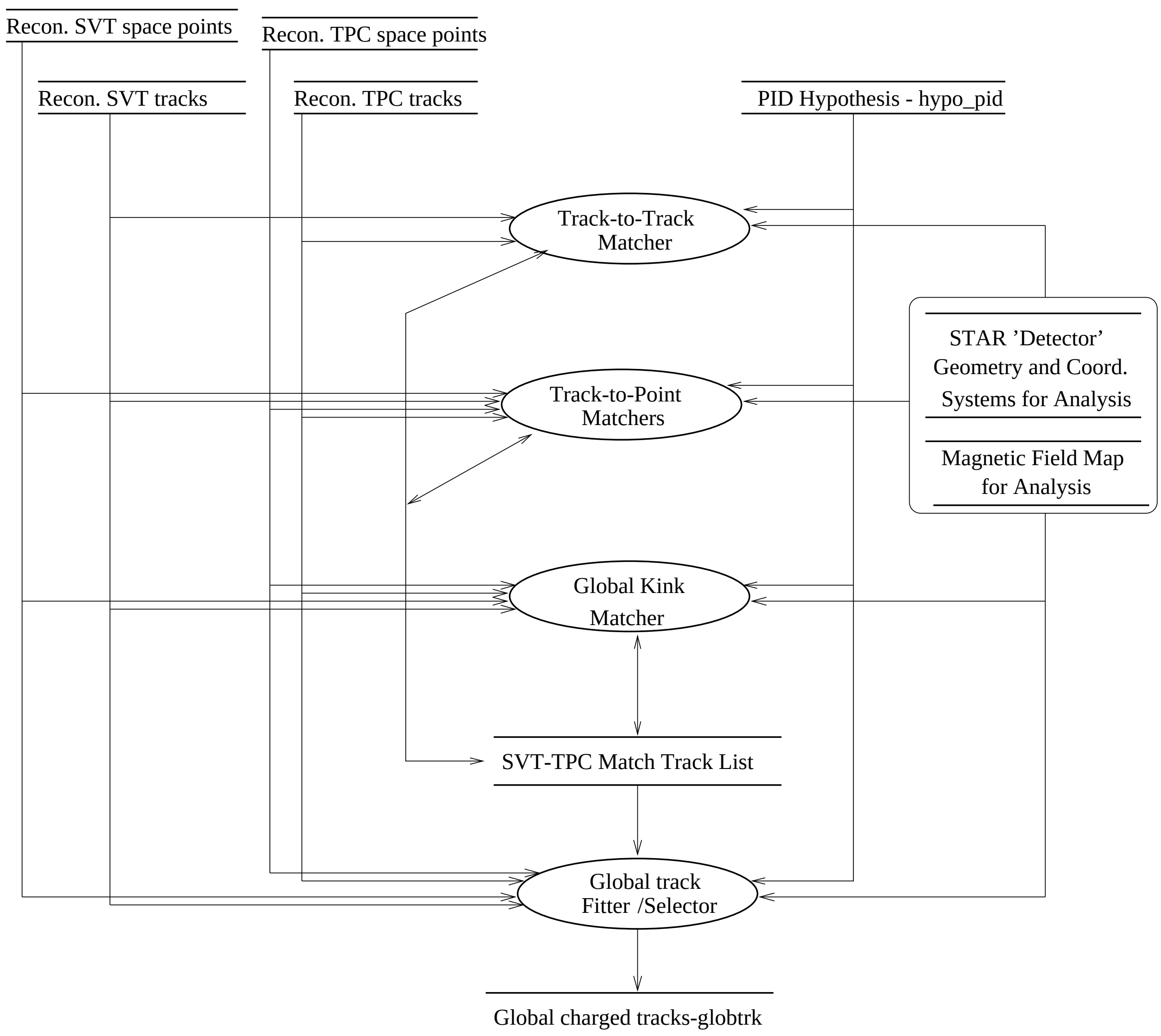

Figure 43: Global Tracking Event Reconstruction Software

Glossary of Terms:

Processes:

Track to Track Matcher – Constructs list of pairs of matched SVT and TPC reconstructed tracks. Particle ID information may be used as well.

Track to Point Matcher – Constructs list of matching relationships between TPC tracks and SVT space points and vice versa. Previously determined matching relationships are quered. Particle ID information may be used as well.

Global Kink Matcher – Constructs list of matched, single prong decay parent-daughter relationships after checking any previously determined matching relationships. Particle ID information may be used as well.

Global Track Fitter and Selector – Limited global track fitting for outlier removal in track-to-point matching; global track selection criteria imposed.

Data Stores:

Reconstructed SVT Space Points – see /ana/svt.

Reconstructed SVT Tracks – see /ana/svt.

Reconstructed TPC Space Points – see /ana/tpc.

Reconstructed TPC Tracks – see /ana/tpc.

PID Hypothesis (hypo_pid) – see /ana/global/pid.

STAR 'Detector' Geometry and Coordinate Systems for Analysis – Generic data store representing the subsystem specific geometry data stores and local and global coordinate systems for analysis, see /sim/geometry.

Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.

SVT-TPC Match Track List – List of matched SVT and TPC track pairs together with matching information such as criteria, chi-square, etc. Also includes the list of matched reconstructed detector tracks and reconstructed detector space points. Also includes the list of matched parent - daughter single prong decays.

Global Charged Tracks (globtrk) – see /ana/global.

Data Flows:

None

/ana/global/primary_vertex

Date of Creation:	3/7/96	Author:	L. Ray
Date of Last Revision:	3/7/96	Last Author:	L. Ray

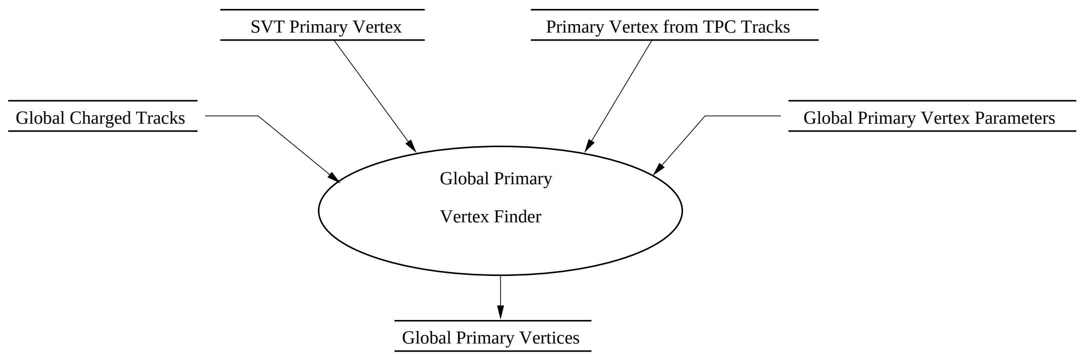

Figure 44: Global Primary Vertex Finding Software

Glossary of Terms:

Processes:

Global Primary Vertex Finder – Process which determines the location of the primary collision vertex based on global track extrapolations, but also uses vertex information found from detector specific (SVT and TPC) tracks. It is assumed that this process acts on global tracks that have already been extrapolated to the beam axis (see /ana/global/refitter). The current vertex finder uses a least squares method combined with a simple mechanism for outlier removal as the basic 'fitting' strategy [22]. It works satisfactorily for A-A and p-A collisions but it is expected to fail in reconstructing the triggered vertex in p-p events. For the latter case another module would be required. Also some work on techniques less sensitive to the presence of outliers ('robustness' [24]) are planned for development. Vertices are expressed in the global STAR Coordinate System.

Data Stores:

Global Charged Tracks – see /ana/global.
SVT Primary Vertex – see /ana/svt/tracking.
Primary Vertex from TPC Tracks – see /ana/tpc/tpp.
Global Primary Vertex Parameters – Parameters defining the track selection criteria and cuts necessary for the vertex determination.
Global Primary Vertices – see /ana/global.

Data Flows:

None

Global Track Refitter (/ana/global/refitter):

Description:

The track propagator and refitter are both service routines that are available to other tasks, but are also standalone modules. The function they serve as part of the global event reconstruction software is to isolate the event primary tracks and refit them with the vertex hypothesis thus improving their tracking parameters. Figure 45 shows the straightforward functionality of the modules. The track propagator returns the tracking parameters at the reconstructed event vertex and at the same time calculates the individual track impact parameters, updating the globtrk table. A track selector flags all tracks which are compatible with the vertex and the fitter refits them putting the new track parameters into the Global Vertex Charged Track data store. Track parameters are given in the global STAR Coordinate System.

/ana/global/refitter

Date of creation: 11/21/95 Author: S. Margetis & L. Ray
Date of last revision: 3/7/96 Last author: S. Margetis & L. Ray

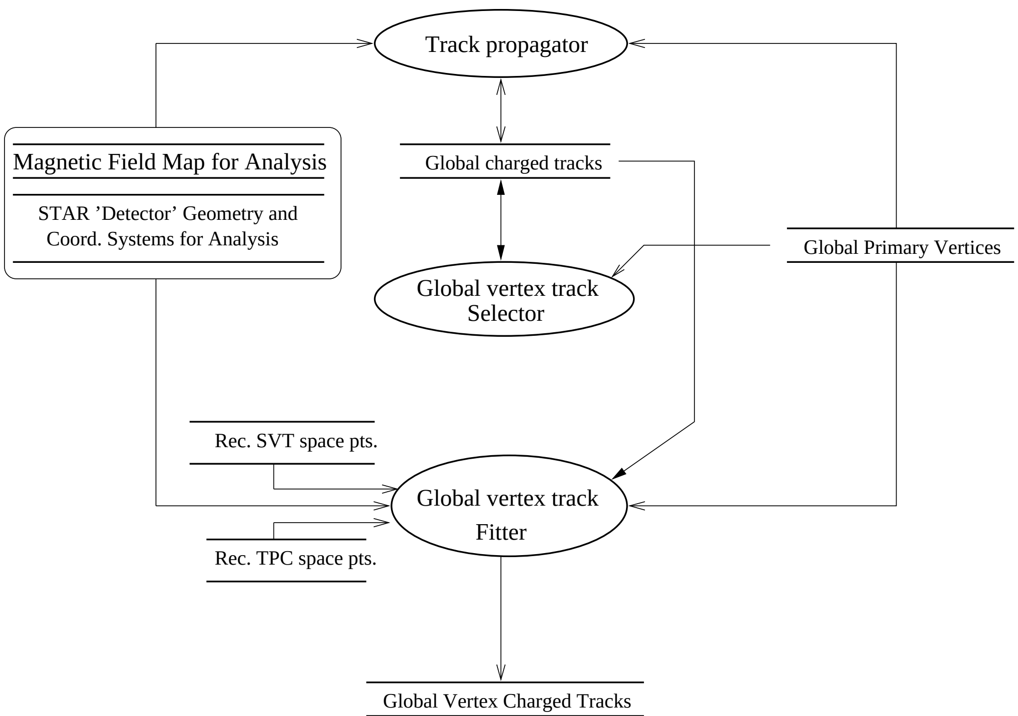

Figure 45: Global Track Refitting Software

Glossary of Terms:

Processes:

Track Propagator – Generic track propagator which, in general, can account for magnetic fields, multiple Coulomb scattering and energy loss in the STAR detector material. Track extrapolation parameters specified from beam axis, TOF slats, EMC tower entry points, etc.

Global Vertex Track Selector – Selects global charged tracks eminating from the primary vertex within specified impact parameter and other cuts.

Global Vertex Track Fitter – This process refits global tracks using the SVT and/or TPC space points accounting in general for the magnetic field and multiple Coulomb scattering and energy loss in the STAR detector material, where the global primary vertex may also be used in the fitting.

Data Stores:

Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.

STAR 'Detector' Geometry and Coordinate Systems for Analysis – Generic data store representing the subsystem specific geometry data stores and local and global coordinate systems for analysis, see /sim/geometry.

Global Charged Tracks – see /ana/global.

Reconstructed SVT Space Points – see /ana/svt.

Reconstructed TPC Space Points – see /ana/tpc.

Global Primary Vertices – see /ana/global.

Global Vertex Charged Tracks – see /ana/global.

Data Flows:

None

Global V0 Finder and Fitter (/ana/global/V0):

Description:

This software refers to the reconstruction of secondary vertices (and consequently strange particles) for the so called V0 topology. Part of this software belongs to the physics analysis branch but the geometrical as well the 'kinematical' reconstruction is part of this level. Figure 46 shows, in a generic way, the basic functions this module should perform. The first task is to reject tracks which emerge from the primary vertex. This is done for CPU time economy reasons since a blind loop over all pairs of tracks results in prohibitive cpu times ($>$ 10 minutes/event on rsgi00). This selection is based on track impact parameter information and it is a common practice. After this the geometrical reconstruction takes place and the pairs passing the cut values are sent to a vertex fitter. Then the parameters (*e.g.* impact parameter, momentum, mass etc.) for the reconstructed parent candidate are estimated and the ones passing the cuts are written in the ev0out table. Kinematical fitting, although not explicity shown (because it is not a standard practice in the community), can be done as a first step in the parameter estimation module.

/ana/global/v0

Date of creation: 11/27/95 Author: S. Margetis & W.K. Wilson
Date of last revision: 3/7/96 Last author: S. Margetis & L. Ray

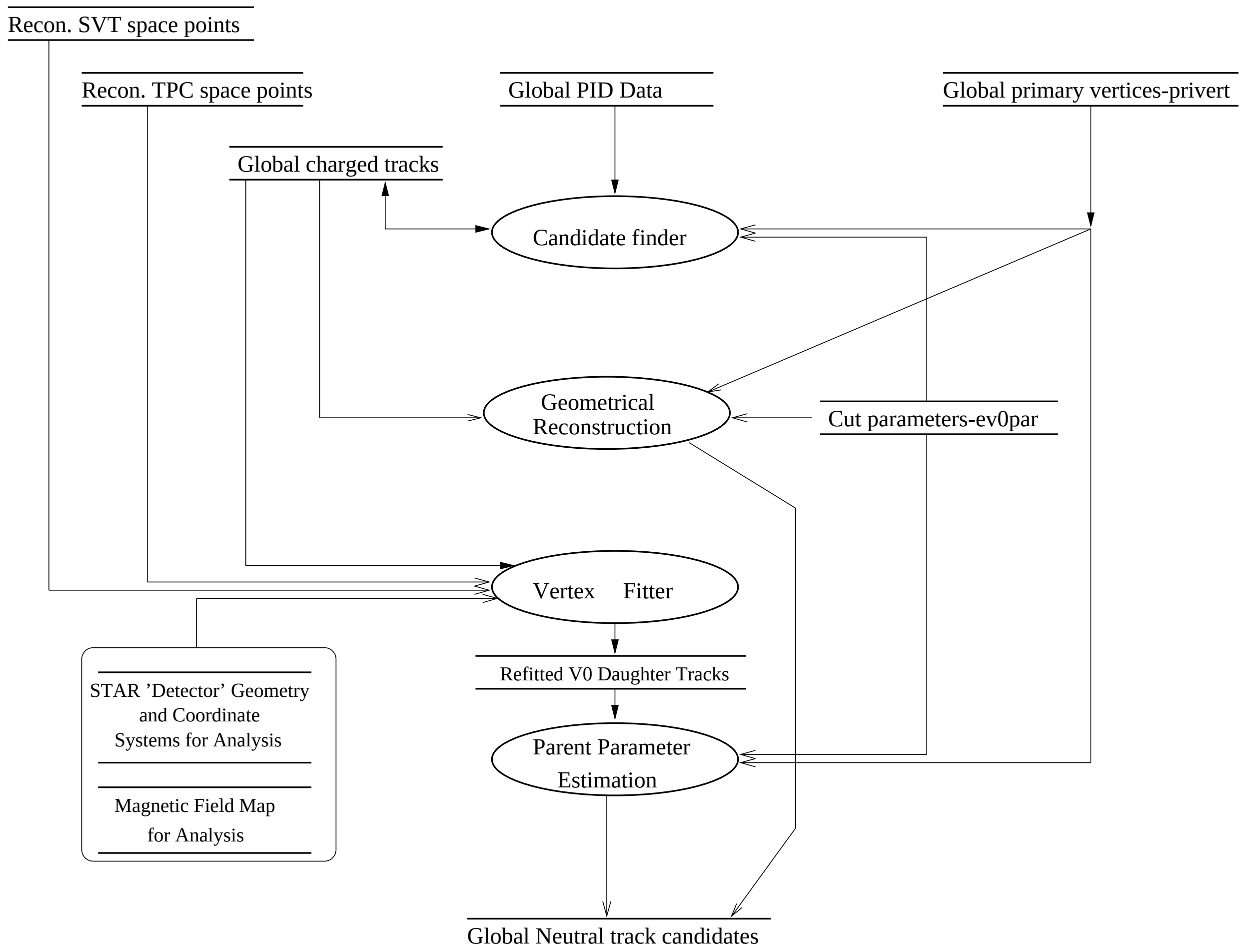

Figure 46: Global V0 Event Reconstruction Software

Glossary of Terms:

Processes:

Candidate Finder – Finds candidate daughter track pairs for neutral particle decays from among the global charged tracks and updates the Global Charged Track data store.

Geometrical Reconstruction – Calculation of geometrical and kinematic quantities associated with the candidate V0 decay vertex including the following: (1) distance of closest approach between daughter tracks, (2) distance of closest approach between reconstructed neutral parent track and the primary vertex, and (3) distance of secondary vertex from primary vertex. These quantities are output to the Global Neutral Track Candidates data store.

Vertex Fitter – Simultaneous fit to reconstructed space points for daughter global tracks with secondary vertex constraints.

Parent Parameter Estimation – Initial (pre-DST) calculation of neutral parent track kinematics.

Data Stores:

Reconstructed SVT Space Points – see /ana/svt.

Reconstructed TPC Space Points – see /ana/tpc.

Global Charged Tracks – see /ana/global.

Global PID Data – see /ana/global/pid.

Global Primary Vertices – see /ana/global.

STAR 'Detector' Geometry and Coordinate Systems for Analysis – Generic data store representing the subsystem specific geometry data stores and local and global coordinate systems for analysis, see /sim/geometry.

Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.

Cut Parameters (ev0par) – V0 finder and fitter; control and cut parameters (*e.g.* upper cut-off of acceptable distance of closest approach between daughter track candidates).

Refitted V0 Daughter Tracks – Adjusted charged global tracks and associated track parameters for decay daughter tracks with secondary vertex constraint.

Global Neutral Track Candidates – see /ana/global.

Data Flows:

None

Global Kink Finding and Fitting (/ana/global/kinks):

Description:

The kink finder module is very similar, as expected, to the V0 module. Figure 47 shows the basic steps of this task. The candidate finder has exactly the same functionality as the one in the V0 finder, as discussed in the previous section. So also do the geometrical reconstruction, the vertex fitter and the parameter estimation modules. The only difference is the specific way this functionality is implemented in the two modules, which, in reality, is indeed very different. The specific decay kinematics of these 'one prong' or 'kink' decays of charged kaons and pions allows the possibility of classification of the decay mode (*e.g.* K$\rightarrow \mu\nu$ or K$\rightarrow \pi\pi^0$ etc. or $\pi \rightarrow \mu\nu$). This is done at the Decay Classification step. After this is done all the different types of candidates are put in the tkfout table for further analysis. One has to pay attention so that the short track segments inside the TPC volume (daughter particles) do not get flagged or eliminated as 'bad' tracks at any matching or track selection levels.

/ana/global/kinks

Date of creation:	11/21/95	Author:	S. Margetis & S. Tooker
Date of last revision:	3/7/96	Last author:	S. Margetis & L. Ray

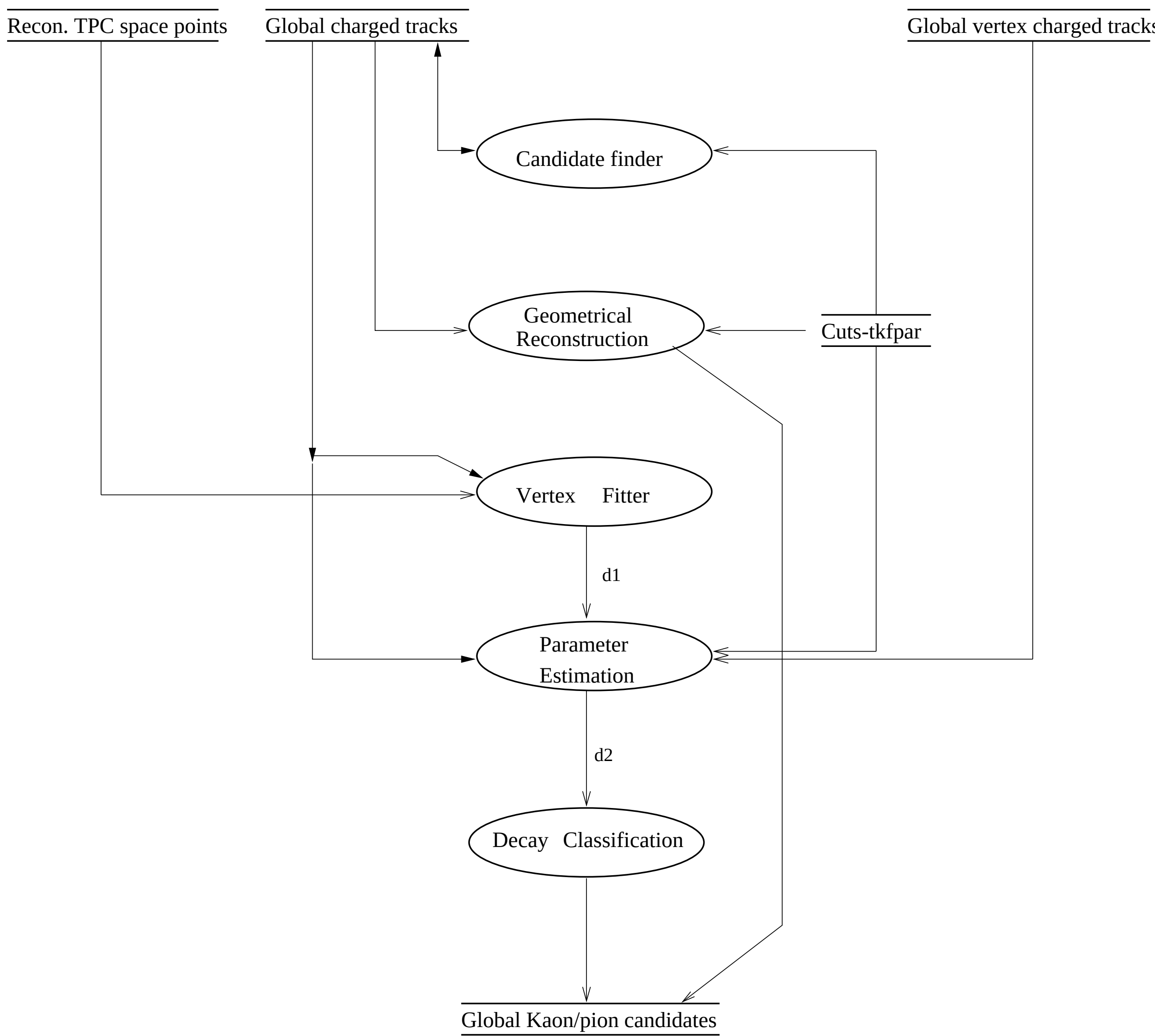

Figure 47: Global Event Reconstruction Kink Finding Software

Glossary of Terms:

Processes:

Candidate Finder – Finds candidate parent - daughter track pairs for single prong, charged particle decays from among the global charged tracks and updates the Global Charged Track data store.

Geometrical Reconstruction – Calculation of geometrical quantities associated with the kink candidate including the following: (1) distance of closest approach between the parent and daughter tracks, and (2) kink angle. These quantities are output to the Global Kaon/Pion Candidates data store.

Vertex Fitter – Simultaneous fit to parent and daughter track space points with secondary vertex constraint.

Parameter Estimation – Initial (pre-DST) calculation of decay kinematics.

Decay Classification – Preliminary (pre-DST) classification of kink candidate's decay mode.

Data Stores:

Reconstructed TPC Space Points – see /ana/tpc.

Global Charged Tracks – see /ana/global.

Global Vertex Charged Tracks – see /ana/global.

Cuts - (tkfpar) – Kink finder and fitter control and cut parameters, *e.g.* upper cut-off for acceptable distance of closest approach between parent and daughter tracks.

Global Kaon/Pion Candidates – see /ana/global.

Data Flows:

d1 – Refitted, adjusted charged global tracks and associated track parameters for parent - daughter charge decays with secondary vertex constraint; also secondary vertex position.

d2 – Candidate charge decay kinematics and geometrical quantities, new values of parent and daughter momenta, kink angle, etc.

/ana/global/filter

Date of Creation: 3/7/96 Author: L. Ray
Date of Last Revision: 3/7/96 Last Author: L. Ray

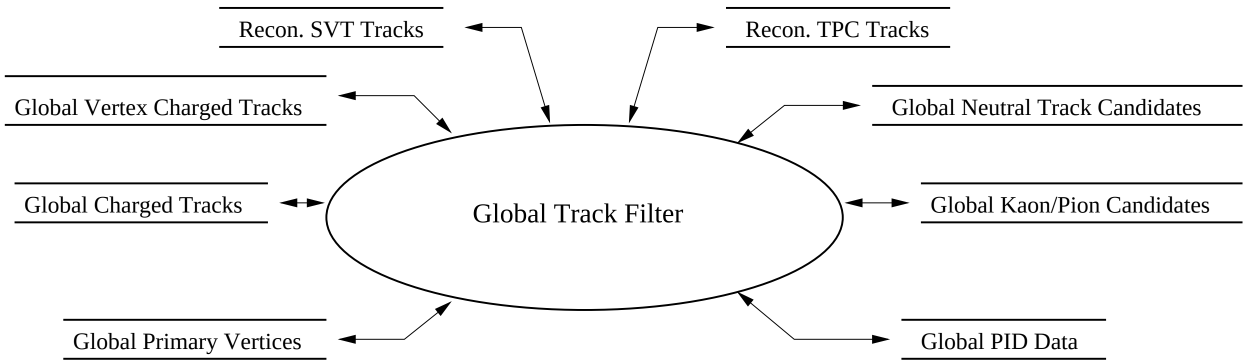

Figure 48: Global Event Reconstruction Track Filter Software

Glossary of Terms:

Processes:

Global Track Filter – Charged and neutral track selection and filtering. May include, for example, photon conversion ($\gamma Z \rightarrow e^+e^-Z$) identification and flagging, track matching with PID consistency checks, etc. Parts of this function are dispersed among several other modules of this level such as the global tracker, global PID, and global refitter. All data stores are updated by this process.

Data Stores:

Reconstructed SVT Tracks – see /ana/svt.
Global Vertex Charged Tracks – see /ana/global.
Global Charged Tracks – see /ana/global.
Global Primary Vertices – see /ana/global.
Reconstructed TPC Tracks – see /ana/tpc.
Global Neutral Track Candidates – see /ana/global.
Global Kaon/Pion Candidates – see /ana/global.
Global PID Data – see /ana/global/pid.

Data Flows:

None

Global Particle ID (/ana/global/pid):

Description:

Particle identification at this level involves the correlation of individual detector PID information. This includes PID information from the SVT (dE/dx), the TPC (dE/dx), and the TOF (timing/path length). The only exception is p-p and perhaps light ion collisions where the EMC detector should be able to contribute some useful PID information. Fig. 49 shows the needed functionality. The SVT/TPC and TOF modules are summarized (although they do not belong functionaly) here for clarity. All detector PID modules output to an intermediate data table, named 'hypo-pid'. The global-PID module then decides on a statistical basis on what is the best pid assignment for the specific track and puts it in the global_pid table for further use.

Data stores containing the relative, not absolute, silicon and TPC gas dE/dx versus momentum reference bands are used as input in the individual detector dE/dx-PID modules. This is because, so far, no experiments have managed to succesfully determine an absolute normalization for their dE/dx bands. The use of parametrizations and the use of the minimum ionizing point to enable the relative adjustment of the spectra has only been done so far. The use of the global tracking results (see table globtrk) is mainly because it contains the best momentum information available.

/ana/global/pid

Date of creation:	11/28/95	Author: S. Margetis & L. Ray
Date of last revision:	3/7/96	Last author: S. Margetis & L. Ray

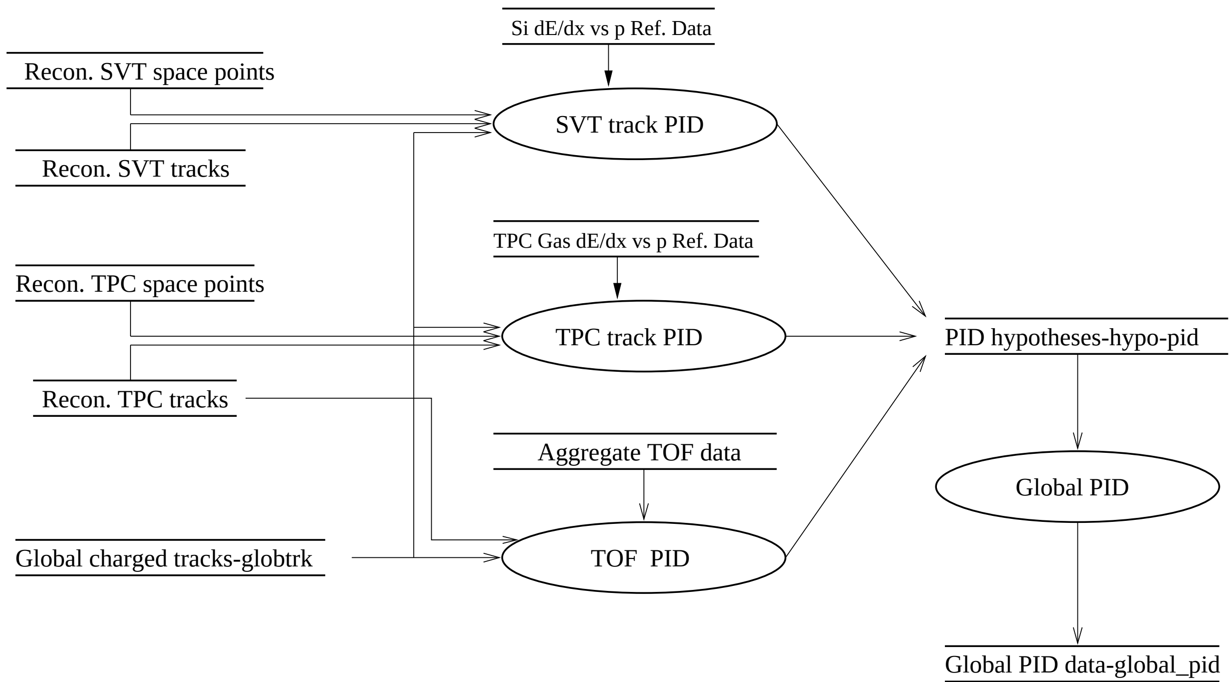

Figure 49: Global Event Reconstruction Particle ID Software

Glossary of Terms:

Processes:

SVT Track PID – PID assignment for SVT specific tracks or SVT portions of global tracks that include SVT space points using average dE/dx information from /ana/svt/tracking and relative dE/dx versus momentum bands obtained from data analysis.

TPC Track PID – PID assignment for TPC specific tracks or TPC portions of global tracks that include TPC space points using average dE/dx information from /ana/tpc/tpt and relative dE/dx versus momentum bands obtained from data analysis.

TOF PID – Time of Flight particle ID, see /ana/global/pid/tof.

Global PID – Global PID assignment based on weighted PID input information from one or more of the STAR PID detectors: SVT, TPC and/or TOF.

Data Stores:

Reconstructed SVT Space Points – see /ana/svt.

Reconstructed SVT Tracks – see /ana/svt.

Reconstructed TPC Space Points – see /ana/tpc.

Reconstructed TPC Tracks – see /ana/tpc.

Global Charged Tracks – see /ana/global.

Si dE/dx Versus Momentum Reference Data – dE/dx versus momentum bands for e, π, K, protons, etc. for silicon determined by analysis of actual data using nominal gain corrections.

TPC Gas dE/dx Versus Momentum Reference Data – dE/dx versus momentum bands for e, π, K, protons, etc. for the TPC gas (P10, He-Ethane) determined by analysis of actual data using nominal gain corrections and for nominal TPC gas properties (*i.e.* temperature, composition, pressure, etc.).

Aggregate TOF Data – Generic TOF data store, see /ana/global/pid/tof.

PID Hypothesis - (hypo_pid) – PID information for each global track from each available detector.

Global PID Data - (global_pid) – Final (pre-DST) PID assignment for each global track.

Data Flows:

None

Global TOF Particle ID (/ana/global/pid/tof):

Description:

Tracks reconstructed by tracking detector software are extrapolated out to the Time of Flight barrel. Tracks crossing TOF counters are matched to those counters with signals. The length of the track from its production vertex to the TOF slat is calculated. By combining the length of the trajectory and the corrected time provided by the TOF the mass may be determined. This value is used to identify the particle species.

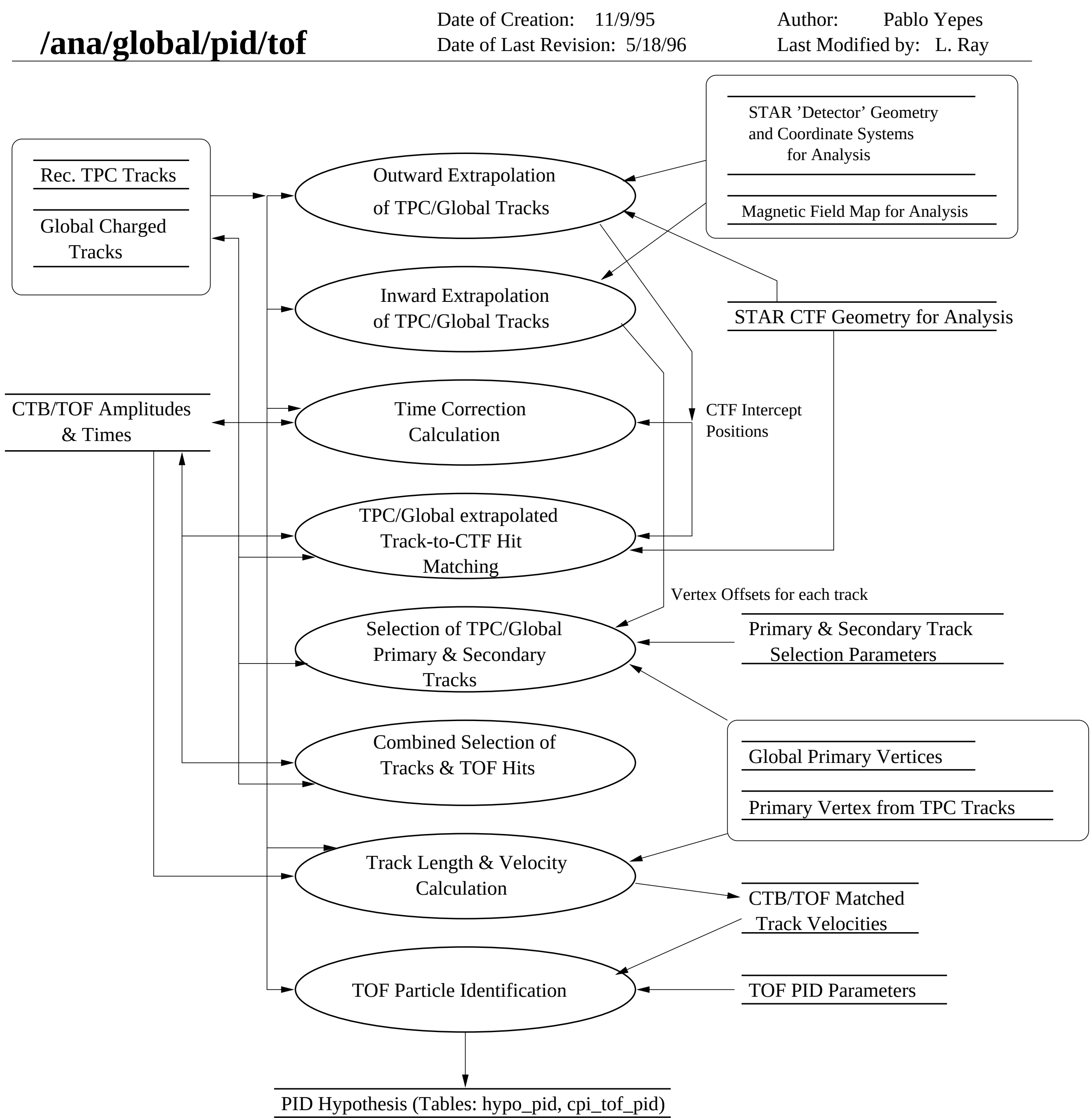

Figure 50: Global TOF Particle ID Software

Flow Chart

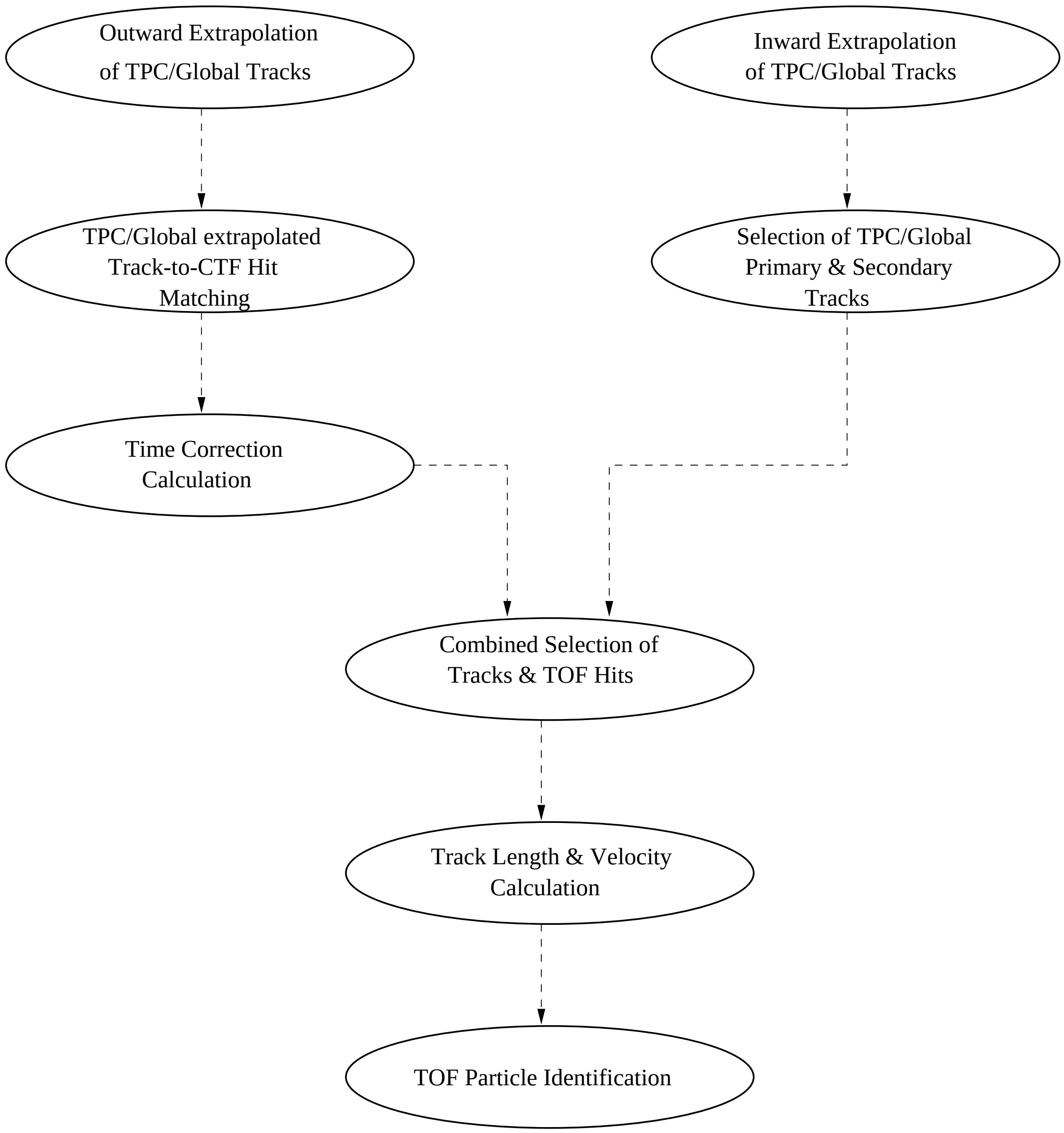

Figure 51: Global TOF Particle ID Software Flow Chart

Glossary of Terms:

Processes:

Outward Extrapolation of TPC/Global Tracks – Tracks are extrapolated to the TOF scintillator radius.

Inward Extrapolation of TPC/Global Tracks – Tracks are extrapolated to the interaction point.

Time Correction Calculation – The time from TOF is corrected taking into account the track extrapolation position relative to the counter photo-multiplier.

TPC/Global Extrapolation Track to CTF Hit Matching – Track extrapolations are matched to TOF counters.

Selection of TPC/Global Primary and Secondary Tracks – By comparing the interaction point coordinates with the inward track extrapolation, tracks are classified as primary or secondary.

Combined Selection of Tracks and TOF Hits – Selection of primary tracks that match to TOF hits.

Track Length and Velocity Calculation – Track length is calculated from track parameters and primary vertex location; velocity is calculated using corrected, elapsed time.

TOF Particle Identification – By comparing the track momentum and velocity the mass is calculated and a particle species is selected if possible.

Data Stores:

Reconstructed TPC Tracks – see /ana/tpc.

Global Charged Tracks – see /ana/global.

CTB/TOF Amplitudes and Times – see /ana/ctf.

STAR 'Detector' Geometry and Coordinate Systems for Analysis – Generic data store representing the subsystem specific geometry data stores and local and global coordinate systems for analysis, see /sim/geometry.

Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.

STAR CTF Geometry for Analysis – See /sim/geometry.

Primary and Secondary Track Selection Parameters – Impact parameter cuts to distinguish primary and secondary tracks.

Global Primary Vertices – see /ana/global.

Primary Vertex from TPC Tracks – see /ana/tpc/tpp.

CTB/TOF Matched Track Velocities – Computed particle velocities for each selected track that was matched to a TOF scintillator hit.

TOF PID Parameters – PID selection criteria parameters and inverse velocity versus momentum acceptance bands for particle species mass determination.

PID Hypothesis – see /ana/global/pid.

Data Flows:

See descriptions on diagram.

/ana/global/summary

Date of Creation: 3/7/96 Author: L. Ray
Date of Last Revision: 12/13/96 Last Author: L. Ray

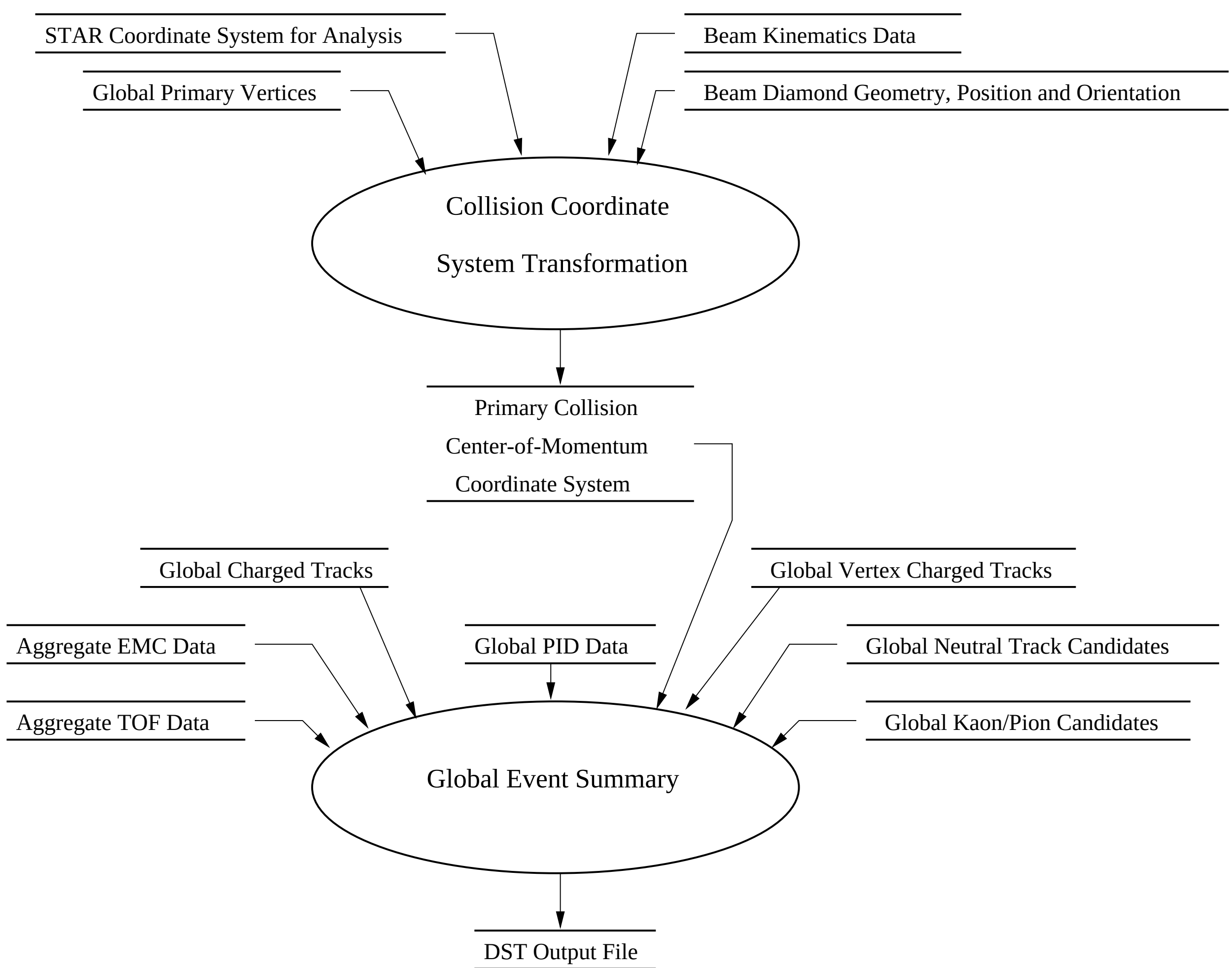

Figure 52: Global Event Reconstruction - Event Summary Software

Glossary of Terms:

Processes:

Collision Coordinate System Transformation – Transformation from LAB - STAR Coordinate System to the collision CM reference frame.

Global Event Summary – The event summary function is currently envisioned as the final organizer of all event information available as well as the track into physics parameter translator. Final event output (4-vectors) are expressed in the global STAR Coordinate System and in the collision CM reference frame. Some other functionality might be added later.

Data Stores:

Global Charged Tracks – see /ana/global.
Aggregate EMC Data – Generic EMC data store, see /ana/emc.
Aggregate TOF Data – Generic TOF data store, see /ana/ctf.
Global PID Data – see /ana/global/pid.
Global Vertex Charged Tracks – see /ana/global.
Global Neutral Track Candidates – see /ana/global.
Global Kaon/Pion Candidates – see /ana/global.
DST Output File – This is part of the final DST which the Global Event Summary module writes out and contains particle physics parameters (*e.g.* rapidity) rather than tracking (helix) variables. Particle track parameters are expressed in the global STAR Coordinate System (in the LAB frame) and in the collision CM reference frame.
Beam Diamond Geometry, Position and Orientation – see /cal/vpd.
Beam Kinematics Data – Beam particle type, momenta, directions at intersection point and intersection crossing angle (if any).
STAR Coordinate System for Analysis – see /sim/geometry.
Global Primary Vertices – see /ana/global.
Primary Collision CM Coordinate System – Boost vector, position and orientation of collision center-of-momentum reference frame and coordinate system at primary collision vertex with respect to the global STAR Coordinate System, which is in the LAB frame.

Data Flows:

None

Status:

See the following STAR Library Packages:

dst – Global Event Reconstruction - event summary.
egr – Global Track Refitting.
epi – Global Particle ID.
ev0 – Global V0 finder and fitter.
evr – Global Primary Vertex Reconstruction.

exi – Global Cascade minus decay finder and reconstruction.
svm – Global SVT-TPC track-to-track matching.
tkf – Global kink finder and fitter for TPC tracks.

6 Calibrations and Corrections (/cal)

The offline calibration and corrections software for STAR is responsible for producing all the necessary calibration constants and correction factors involved in reconstructing the pp, pA and AA collision events from the raw data. The sources of input for the calibration and corrections software are the raw data from special calibration runs, slow controls information from the calibration runs, nominal STAR geometry and magnetic field parameters, nominal STAR detector material properties, and sets of reference data for comparison with actual detector responses. The calibration and correction software processes generally correspond to the online procedures used to calibrate the detector. These include determination of, and corrections for channel by channel variations in gains and timing, energy deposition, hit position reconstruction, etc. in each subsystem detector for STAR.

The procedures which the calibration and corrections software must support include: (1) laser tracks, (2) cathode charge emission, (3) direct charge injection into the FEE, (4) tracking from radioactive sources, (5) direct light injection into the PMTs, (6) no magnetic field, straight track data, (7) cosmic ray data, (8) wire pulsing and (9) gas monitor chamber drift data. The offline calibration and corrections software must provide sufficient information to enable accurate and stable signal strengths, signal shapes, relative and absolute timing, and coordinate space hit locations to be obtained from the raw data throughout the course of a data acquisition period.

In the following sections we present the functional model design for the calibration and corrections software for the magnetic field, for each subdetector in STAR, and for the global detector alignment.

6.1 Magnetic Field (/cal/magnet)

This section contains a description, list of requirements, functional model diagram (/cal/magnet, Fig. 53), glossary and status of software report.

Description:

The STAR magnet group will map the STAR magnetic field for the nominal 0.5 T and 0.25 T field settings using an array of Hall probes on a discrete grid in cylindrical coordinates ρ (radial distance from magnet symmetry axis), ϕ (azimuthal angle) and z (distance along magnet axis). The magnetic field vector (cylindrical components) will be measured at each grid point. Perturbations to the field arising from small variations in the small end coil and end cap trim coil currents will also be measured. The latter information is necessary in order to calculate perturbations to the field if the main or trim coil currents drift from their nominal, design values. The magnet group will fit these measured field values at the measured grid points using analytic expansions and provide the software group with field values interpolated to a fixed grid with equally spaced mesh points. The expansion coefficients will also be provided.

During a run the magnetic field will be monitored with a combination of NMR and Hall probes. In addition, the main coil, end coil and trim coil currents will be monitored. The /cal/magnet software uses this information together with the nominal field map to produce a corrected magnetic field map for a specified run period. The corrected field map is generated in the global STAR Coordinate System (see /sim/geometry).

Requirements:

The magnetic field map correction software must produce sufficiently accurate field maps in order that the tracking detectors achieve their most stringent momentum resolution goals. The same software must be used for both simulations and analysis of real data.

/cal/magnet

Date of Creation: 5/28/96 Author: L.Ray
Date of Last Revision: Last Modified by:

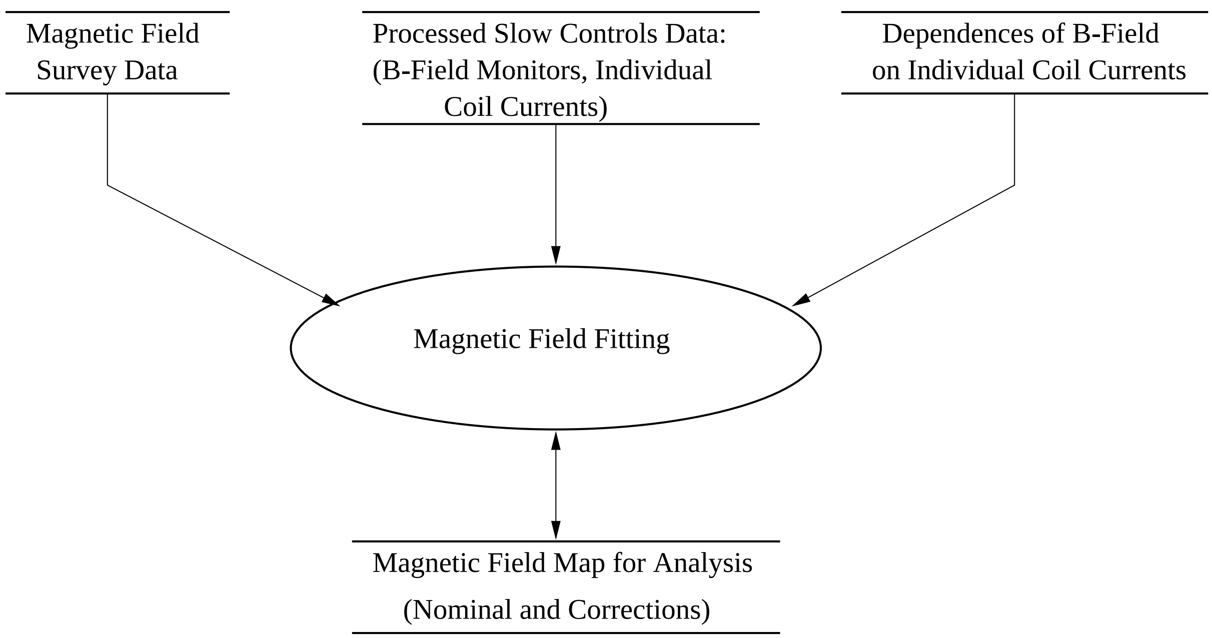

Figure 53: Magnetic Field Calibration Software

Glossary of Terms:

Processes:

Magnetic Field Fitting – Information from the magnetic field monitors and individual coil currents are compared to those values from the nominal field map in order to calculate corrections to the magnetic field vector at each grid point in the magnetic field volume consistent with Maxwell's equations. The corrected magnetic field map is output on the appropriate grid and in a suitable format for the event reconstruction software.

Data Stores:

Magnetic Field Survey Data – see /sim/magnet.

Processed Slow Controls Data (B-Field Monitors, Individual Coil Currents) – These are expected to consist of a number of NMR probes (about 5) at different locations and the five independent coil currents. Temperature information (cooling water input and output; ambient temperature, etc.) might also prove to be significant. These must be recorded when the magnetic field is mapped, as well as when any tracking data is taken.

Dependences of B-Field on Individual Coil Currents – The magnetic field is determined by five independent coil currents (including trim coils). Perturbations in the magnetic field due to small changes in the trim and small end coil currents, relative to the main coil currents, will be obtained by the magnetic field map survey. This information may also be supplemented with calculations (using the code POISSON) of the field perturbations due to small changes in the currents. As an approximation, one could construct a new field from the measured one by adding perturbative fields representing the contributions from the small variations in the coil currents.

Magnetic Field Map for Analysis (Nominal and Corrections) – see /sim/magnet.

Data Flows:

Status:

6.2 TPC Calibration and Corrections (/cal/tpc)

This section contains a description, list of requirements, functional model diagrams for the top level (/cal/tpc, Fig. 54) and for nine sublevels including slow controls data processing (/cal/tpc/tsl, Fig. 55), gain corrections overview (/cal/tpc/gains, Fig. 56), gas gain and attenuation corrections (/cal/tpc/gains/tat, Fig. 57), gain corrections from wire pulse calibrations (/cal/tpc/gains/tpa, Fig. 58), gain corrections from direct charge injection calibration (/cal/tpc/gains/tch, Fig. 59), pedestal checks (/cal/tpc/tpe, Fig. 60), position distortion corrections (/cal/tpc/tdt, Fig. 61), drift velocity corrections (/cal/tpc/tdv, Fig. 62), and internal geometrical alignment corrections (/cal/tpc/tge, Fig. 63), glossaries for each diagram, and a status of software report. Detailed discussion of TPC calibration procedures and of the present implementation of the software may be found in Ref. [25]. Only succinct summaries will be given here.

Description:

The TPC calibration and correction software is designed to provide position correction maps, and gain and attentuation corrections such that accurate and stable space point positions and energy depositions may be determined throughout the TPC volume. The sources of systematic error in determining these quantities are variations in magnetic field strength and direction, $\vec{E} \times \vec{B}$ effects due to space charge accumulation and other sources of field nonuniformities, variations in the stabalized drift velocity from run to run, variations in gas gain and electron cloud attenuation (recombination) due to changes in gas pressure, temperature and composition, variations in electronics gain, voltage offsets, timing and shaper function profiles, electronic noise, and misalignment between sectors of the TPC.

A variety of methods for detecting and monitoring these effects have been developed. These include magnetic field monitors (see /cal/magnet), patterns of laser tracks at known positions, laser induced central membrane electron emission, cosmic ray tracks, no magnetic field straight tracks, ground wire pulsing, direct charge injection into the FEE, radioactive sources at known positions, external gas monitor chambers, and gas property monitors for pressure, temperature and composition.

Requirements:

The TPC calibration and correction software is required to provide all the correction data needed by TPC event reconstruction software in order that the physics capabilities of the detector may be realized. This includes corrections for electronics and gas gains, attenuation of drifting electron clouds, $\vec{E} \times \vec{B}$ field effects on the electron cloud drift, variations in TPC gas properties, variations in TPC drift velocity, dead or malfunctioning electronics channels, timing offsets between various channels, and internal position alignment shifts. The identical software must be used for either real or simulated data analysis.

/cal/tpc

Date of Creation: 3/21/96 Author: L. Ray
Date of Last Revision: 5/02/96 Last Modified by: R.Bossingham

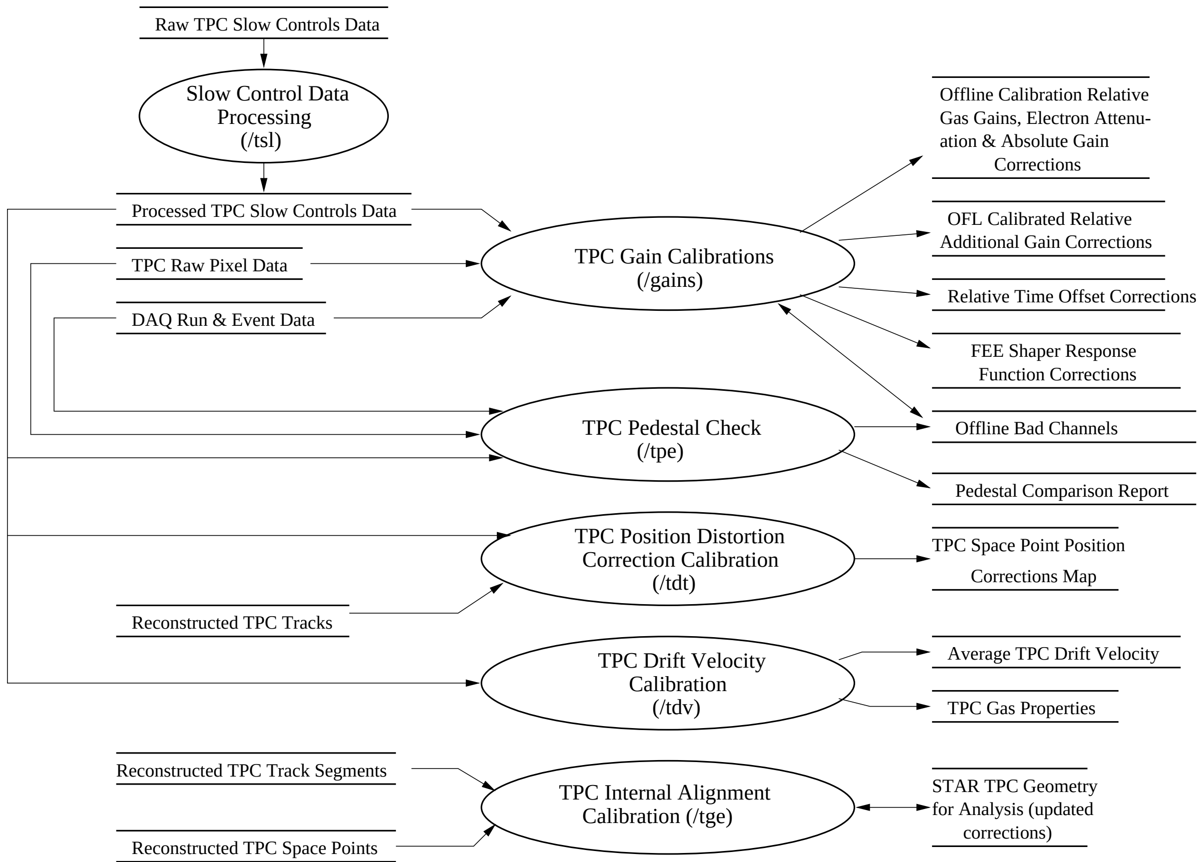

Figure 54: TPC Calibration and Corrections Software – Top Level

Glossary of Terms:

Processes:

Slow Control Data Processing – Raw TPC Slow Controls data are time averaged and smoothed into a more compact and useful form for the remaining calibrations software. Outliers are rejected and data are combined. Derived parameters, such as TPC drift velocity, are monitored throughout a run or other data acquisition period. Periods of validity and problematic values are identified.

TPC Gain Calibrations – This process calculates corrections to the ADC values due to variations in gas gain, electronics gain and linearity, voltage offsets and electron attenuation. Also included here are calculations of the relative time offset corrections and FEE shaper response function corrections as well as a determination of dead, hot or problematic channels.

TPC Pedestal Check – This process calculates the pedestals (mean and rms) for each TPC pixel and checks the adequacy of the online algorithm. Correlated noise (if any) between channels is also evaluated.

TPC Position Distortion Correction Calibration – This process uses reconstructed tracks from laser events to check for systematic deviations from the known positions and to tabulate space point position corrections throughout the TPC volume. Each laser event provides 252 nearly straight tracks; for each group of seven, the relative angles will be known, as will the approximate origin. Since a first estimate of the TPC spatial distortions will already exist based on the magnetic field map and field cage studies, one has a good chance of quickly converging to a good approximation for the distortion map. The deviations can be fit as a linear combination of Hypothetical Distortion Maps.

TPC Drift Velocity Calibration – This process verifies the proper regulation of the TPC drift velocity. This is then checked against an independent (scaled) measurement in the monitor drift chamber, and calculated drift velocities in the TPC and monitor drift chamber. The database is updated with the best estimates for the TPC and monitor chamber drift velocities, and with discrepancies with respect to the values expected. Problems with the drift velocity regulation, or the gas composition, are reported to the On-line State.

TPC Internal Alignment Calibration – The basic process here is to construct track segments across individual inner and outer subsectors, associate them across boundaries in unambiguous cases using the nominal survey, then to iterate, exploiting the continuity (and, when applicable, the straightness) of the tracks. One rejects outlier tracks and relaxes the geometry in a controlled way toward convergence. TPC subsectors are aligned relative to one another where it is assumed that the geometry within a subsector will be well-controlled during production and temperatures are controlled during operation. This is an iterative procedure and probably also requires iteration of the drift distortion corrections. Ideally, the survey geometry could be slowly relaxed to minimize the track residuals; a real survey, though, often contains "non-Gaussian errors" (*i.e.* mistakes), that may require human problem-solving skills. Laser tracks and cosmic rays should be able to tie together several sectors simultaneously; cosmic rays should also be able to tie together sectors across the central membrane. Tracks from RHIC events, on the other hand, will provide more local information. Internal alignment determines position and orientation corrections in the TPC Internal Coordinate System. Alignment of the TPC within the global STAR Coordinate System is handled by global alignment procedures, see /cal/global.

Data Stores:

Raw TPC Slow Controls Data – Slow Controls or Hardware Control information acquired during the relevant data acquisition period. Included are quantities related to the physical condition of the TPC including gas pressure and temperature, drift voltage and regulated drift velocity, monitor chamber pressure, temperature and drift time, wire voltages, FEE temperature, voltages and digitization frequency, pulser amplitude and wave form, laser amplitudes, etc. This also includes ASIC gain function parameters, ADC algorithm and parameters, 10 to 8 bit conversion algorithm and parameters, online time sequence and cluster finder parameters, and ASIC pedestals. For a more detailed description see Ref. [25].

Processed TPC Slow Controls Data – A time averaged, smoothed and more compact version of the Raw TPC Slow Controls Data which is in a suitable format for the offline calibration software.

TPC Raw Pixel Data – see /ana/tpc.

DAQ Run and Event Data – Run and event by event information from DAQ including: (1) trigger type, parameters, thresholds, pre-scalers, etc., (2) bad channels and saturated channels list, and (3) DAQ status and error conditions (if any).

Reconstructed TPC Tracks – see /ana/tpc.

Reconstructed TPC Track Segments – see /ana/tpc/tpt.

Reconstructed TPC Space Points – see/ana/tpc.

Offline Calibration Relative Gas Gain, Electron Attenuation and Absolute Gain Corrections – Data store which contains corrections to account for run to run (not channel to channel) variations in gas gain and electron attenuation. Well understood dependences on gas properties are factored out of the parameters. See /ana/tpc/tcl.

Offline Calibrated Relative Additional Gain Corrections – Data store which contains (in general nonlinear) corrections for each channel's ADC values to remove variations not removed by online corrections (see /ana/tpc/tcl).

Relative Time Offset Corrections – Data store containing pad by pad time offsets which correct the relationship between time bucket number and global z-position of the pixel. Timing accuracies of a few nanoseconds are wanted (see /ana/tpc/tcl).

FEE Shaper Response Function Corrections – Space point position corrections along drift direction due to FEE signal shaper response (see /ana/tpc/tcl).

Offline Bad Channels – Data store which identifies further channels (compared to online) for which the data should not be used. The decision for these channels is made by offline calibration software after processing some data (see /ana/tpc/tcl).

Pedestal Comparison Report – Pedestal mean and rms values from online are compared to that determined in offline analysis of special pedestal (no signal) runs. Correlated noise, if any, is identified.

TPC Space Point Position Corrections Map – Data store which contains position and run dependent corrections to the nominal maps given in the geometry data store. These corrections come from calibration of the B and E field distortions and drift velocity (see /ana/tpc/tcl).

Average TPC Drift Velocity – Computed TPC drift velocity throughout data acquisition period and discrepancies (if any) with nominal, regulated values (see /ana/tpc/tcl).

TPC Gas Properties – see /sim/det/tpc; these values are updated here.

STAR TPC Geometry for Analysis – See /sim/geometry and /ana/tpc/tcl.

Data Flows:

None

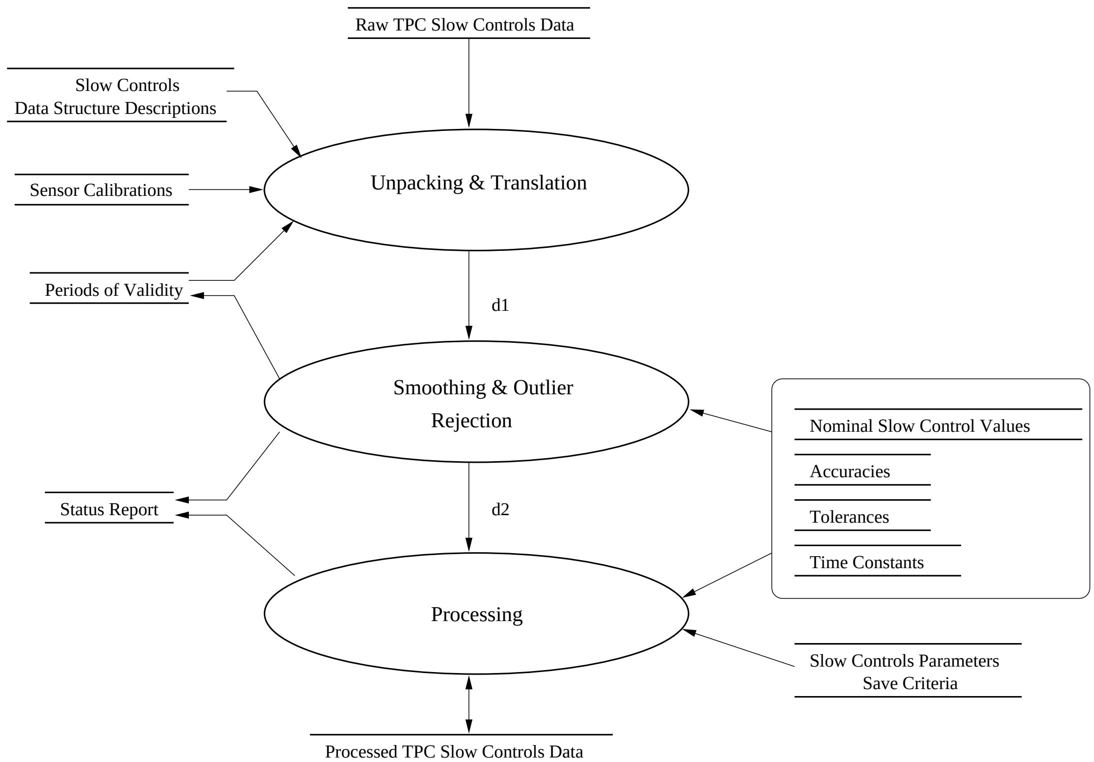

Figure 55: TPC Slow Controls Data Processing Software

Glossary of Terms:

Processes:

Unpacking and Translation – Raw TPC Slow Controls Data are deciphered into individual, calibrated components according to the prescriptions in the data structure description.

Smoothing and Outlier Rejection – Out-of-tolerance values are rejected, with appropriate notification to Online. Spurious values not consistent with a physical time constant may be rejected also. Surviving values are time averaged.

Processing – Essentially redundant values are averaged together and any other necessary calculations are performed. The resulting derived values are then handled in the same way as values directly read by slow controls.

Data Stores:

Raw TPC Slow Controls Data – see /cal/tpc.

Slow Controls Data Structure Description – Definition and description of slow controls raw data format and structure.

Sensor Calibrations – Sensor calibration parameters, including non-linearities and any dependencies on other parameters.

Periods of Validity – Periods during which a given sensor or processed slow controls data are deemed to be valid. This list might be edited by /cal/tpc/tsl, by Slow Controls, or by hand.

Status Report – Results of time averaging, outlier removal, periods of validity, and anomalous parameters are noted. This information is used for offline monitoring of event data throughout a data acquisition period and may be used to notify online of problematic hardware behavior.

Nominal Slow Control Values – Nominal, expected values for slow control parameters to serve as a reference for comparing actual values. These may be used offline if no other valid information is available.

Accuracies – Expected rms error of a sensor, together with its instrumentation.

Tolerances – Allowed deviation of sensor from the nominal value.

Time Constants – Physical time constants expected for various parameters; used to smooth measurements and to detect spurious values.

Slow Controls Parameters Save Criteria – List of processed slow controls information and other criteria which determine what processed slow controls data will be recorded in the Processed TPC Slow Controls data store.

Processed TPC Slow Controls Data – see /cal/tpc.

Data Flows:

d1 – Computed raw slow controls information.

d2 – Smoothed (time averaged) and filtered slow controls data.

/cal/tpc/gains

Date of Creation:	3/21/96	Author:	L. Ray
Date of Last Revision:	5/03/96	Last Modified by:	R. Bossingham

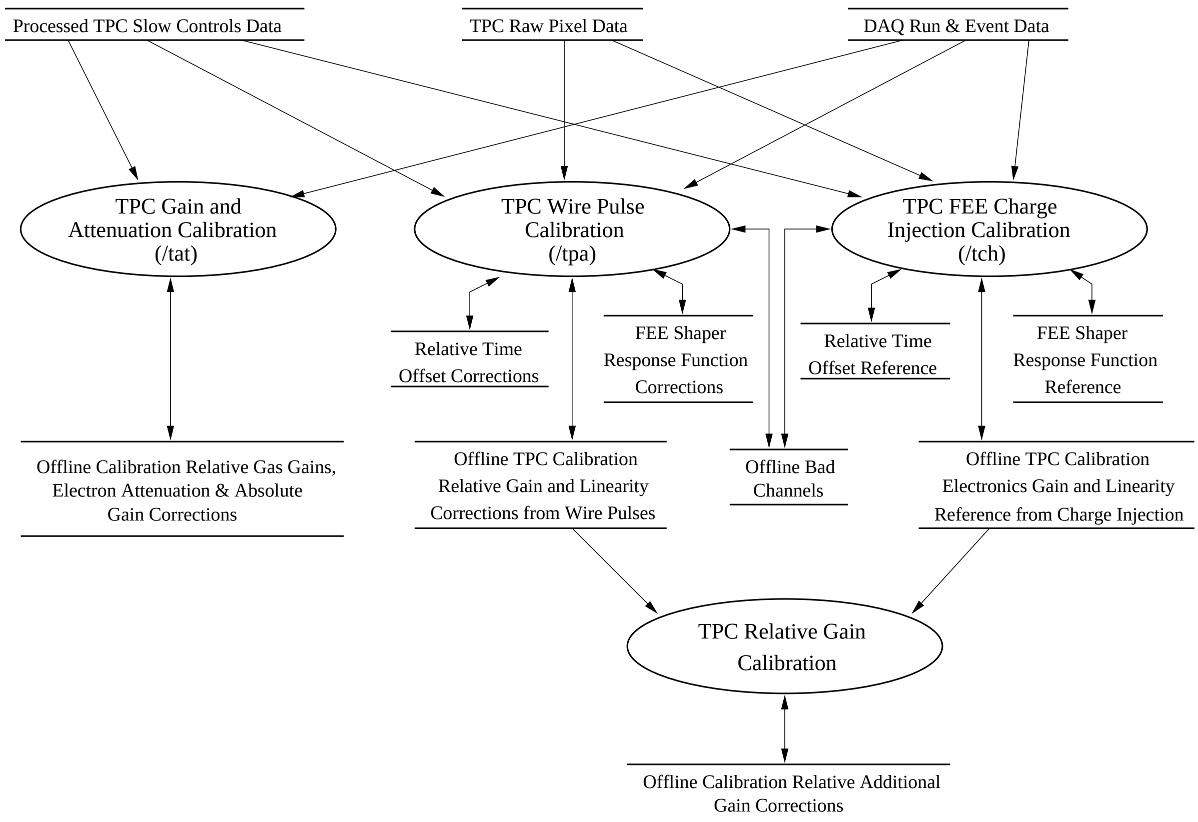

Figure 56: TPC Gain Calibration Software - Top Level

Glossary of Terms:

Processes:

TPC Gain and Attenuation Calibration – This process calibrates overall gain in the TPC, as well as electron attenuation in the gas. Charged pions from 300 - 500 MeV/c can be separated from kaons and protons, providing a dE/dx calibration using ionization values from the literature. This allows one to find corrections to the values used in the original dE/dx calculation. (If large changes are seen, iteration is necessary, of course.) This can be checked against independent measurements, using a gain cell and reference sources in the TPC at two or more drift distances, and the monitor drift chamber (from which values would have to be scaled). The database is updated with the best estimates of gain and attenuation in the TPC and monitor chamber. Abnormal gains or gas attenuations are reported to the On-line State.

TPC Wire Pulse Calibration – This process analyzes the Pad-Pulsing events to extract, for each pad, its Relative Time Offset, FEE Shaper Response, Gain and Linearity. It may also add entries to the Off-line Bad Channels list. The algorithm is intended to be robust against noise or occasional beam-related signal by rejecting outliers.

TPC FEE Charge Injection Calibration – This process analyzes the direct FEE charge injection events to determine, for each channel, the relative time offsets, FEE shaper response, gain and linearity. It can also update the offline bad channels list. Outliers are rejected by the algorithm. Results from this process may or may not be used in subsequent event reconstruction; the data is mainly to be used for offline monitoring of the electronics throughout a data acquisition period and as an alternative calibration method to the wire pulse method.

TPC Relative Gain Calibration – Combines and/or selects the TPC relative gain and linearity corrections available from the wire pulse and FEE charge injection methods for subsequent use in event reconstruction.

Data Stores:

Processed TPC Slow Controls Data – see /cal/tpc.

TPC Raw Pixel Data – see /ana/tpc.

DAQ Run and Event Data – see /cal/tpc.

Offline Calibration Relative Gas Gains, Electron Attenuation and Absolute Gain Corrections – see /cal/tpc.

Relative Time Offset Corrections – see /cal/tpc.

FEE Shaper Response Function Corrections – see /cal/tpc.

Relative Time Offset Reference – Data store containing time offsets for each channel based on analysis of FEE charge injection events which could be used to correct the relationship between time bucket number and global z-position of each pixel.

FEE Shaper Response Function Reference – Response function parametrization of the FEE shaper as determined by direct FEE charge injection events.

Offline TPC Calibration Relative Gain and Linearity Correction from Wire Pulses

– Data store which contains (in general nonlinear) corrections for each channel's ADC values to remove variations not removed by online corrections. These corrections are determined through analysis of wire pulse events.

Offline Bad Channels – see /cal/tpc.

Offline TPC Calibration Electronics Gain and Linearity Reference from Charge Injection – Data store for each channel containing the reference gain corrections (in general nonlinear) determined through analysis of direct FEE charge injection events.

Offline Calibration Relative Additional Gain Corrections – see /cal/tpc.

Data Flows:

None

/cal/tpc/gains/tat

Date of Creation: 2/01/96 Author: R. Bossingham
Date of Last Revision: 5/06/96 Last Modified by: R.Bossingham

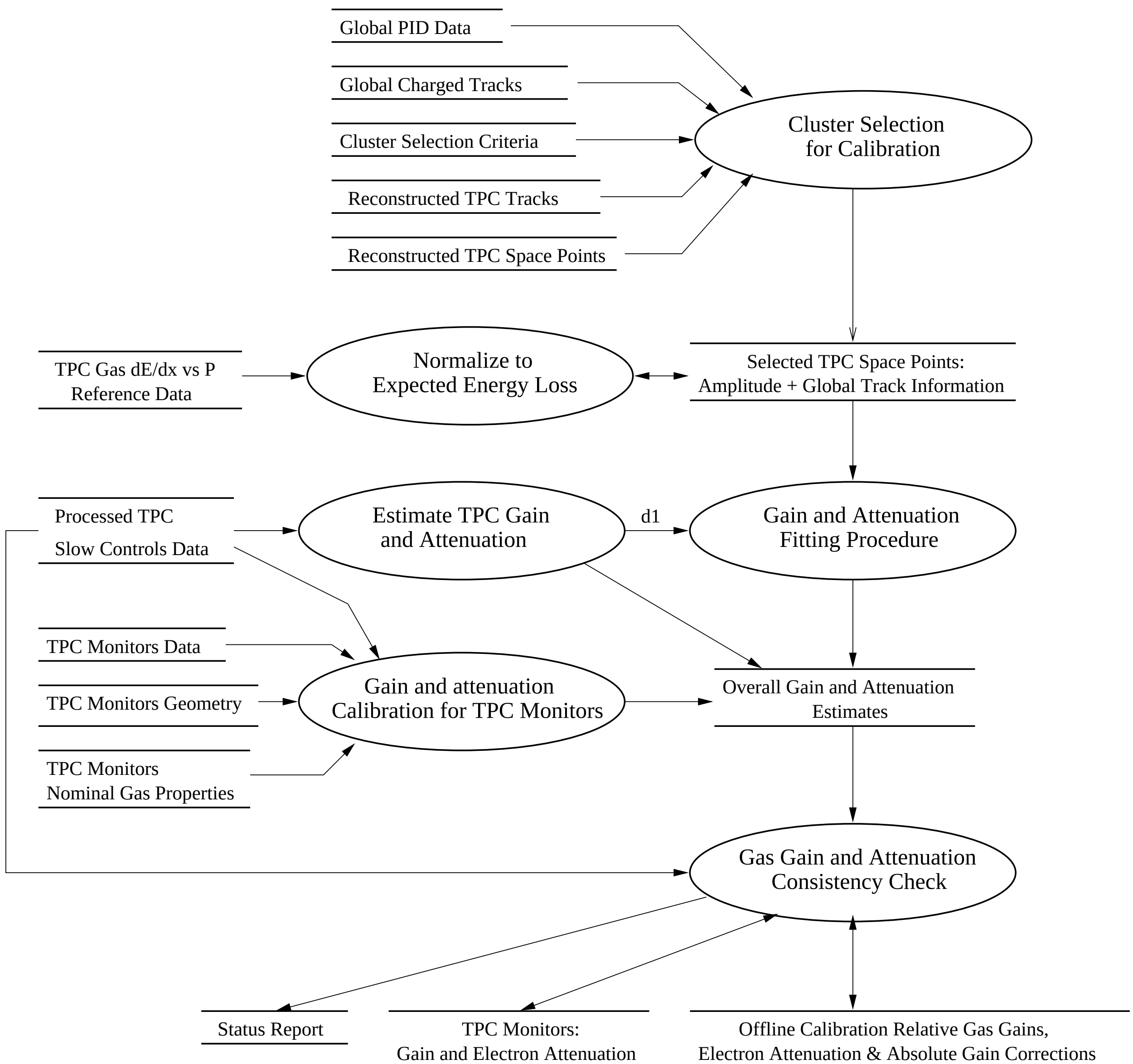

Figure 57: TPC Gain and Attenuation Calibration Software

Glossary of Terms:

Processes:

Cluster Selection for Calibration – Process which selects tracks and corresponding TPC space points for specified particle type and momentum range (*e.g.* 300 - 500 MeV/c pions) using global tracking information and for which the tracks are cleanly separated.

Normalize to Expected Energy Loss – Histograms of dE/dx versus momentum are constructed for selected tracks and space points; outliers are removed; results are normalized to the expected energy loss. The analysis spans the drift distances of both halves of the TPC and over the relevant data acquisition period.

Estimate TPC Gain and Attenuation – TPC gas gain and electron attenuation are estimated based on measured TPC gas properties from the processed slow controls data.

Gain and Attenuation Fitting Procedure – Process computes gain corrections due to relative changes in TPC gas properties and electronics performance; consistency with current TPC gas properties is checked and results throughout the data acquisition period and for varying drift distances are obtained. The results are parametrized such that well understood dependences on TPC gas properties are factored out in order to reduce the data volume.

Gain and Attenuation Calibration for TPC Monitors – Process computes gain and attenuation corrections due to relative changes in TPC monitor chamber gas properties.

Gas Gain and Attenuation Consistency Check – Gas gain, attenuation and absolute gain corrections obtained from analysis of selected tracks, TPC gas properties and TPC monitor chamber data are compared, the consistency between each is checked, and final, relative gas gains, electron attenuation and absolute gain corrections computed for both the main TPC and the TPC monitor chamber. Results are made available to online via a status report.

Data Stores:

Global PID Data – see /ana/global/pid.

Global Charged Tracks – see /ana/global.

Cluster Selection Criteria – Selection parameters used to specify track type, particle type, momentum range, minimum distance from neighboring tracks, radial distance in TPC, etc.

Reconstructed TPC Tracks – see /ana/tpc.

Reconstructed TPC Space Points – see /ana/tpc.

TPC Gas dE/dx Versus Momentum Reference Data – see /ana/global/pid.

Processed TPC Slow Controls Data – see /cal/tpc.

TPC Monitors Data – ADC values from monitor chamber due to ionization from reference source.

TPC Monitors Geometry – Includes information about the source and anode wire positions.

TPC Monitors Nominal Gas Properties – Nominal temperature, pressure, composition, etc. for the TPC monitor chamber(s). Also includes dependence of gain on anode wire voltages.

Selected TPC Space Points: Amplitude and Global Track Information – Global or TPC track parameters, energy deposition and corresponding space point information for selected tracks.

Overall Gain and Attenuation Estimates – Relative attenuation and absolute gain corrections determined by selected track dE/dx, TPC gas properties and TPC monitor chamber data analysis.

Status Report – Results of gas gain and attenuation consistency check for monitoring and for online usage.

TPC Monitors: Gain and Electron Attenuation – Deconvoluted gain and attenuation measured in the TPC monitors; well understood dependences on gas properties are factored out of the reported parametrization.

Offline Calibration Relative Gas Gains, Electron Attenuation and Absolute Gain Corrections – see /cal/tpc.

Data Flows:

d1 – Gain and attenuation estimates based on current TPC gas properties.

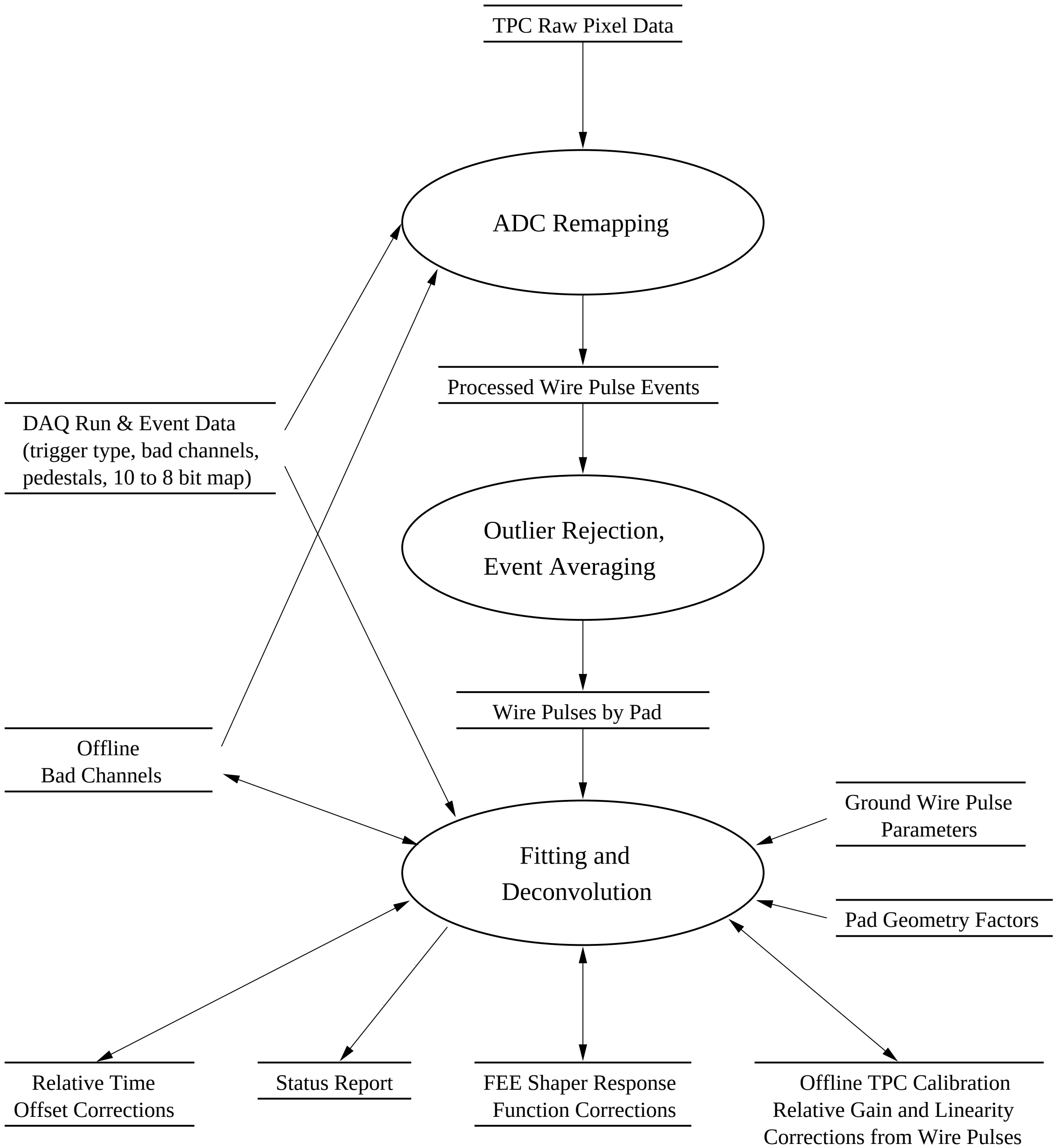

Figure 58: TPC Gains and Time Offset Calibration Software from Wire Pulse Data

Glossary of Terms:

Processes:

ADC Remapping – Pixels from wire pulsing events are corrected for pedestals and 10 to 8 bit mapping. The pulses within a class are then histogrammed by pixel and event.

Outlier Rejection, Event Averaging – Elimination of the non-Gaussian tail, if any, from the event distribution. Remaining events within a class are then averaged.

Fitting and Deconvolution – From the recorded events for a pad, the Shaper Response, Electronics Gain and Relative Time Offset are fit, so as to produce the observed signals. From the variation of gain with input amplitude, the electronics linearity is obtained.

Data Stores:

TPC Raw Pixel Data – see /ana/tpc.

DAQ Run and Event Data – see /cal/tpc.

Offline Bad Channels – see /cal/tpc.

Processed Wire Pulse Events – Histogram of corrected ADC values for wire pulse events of given class for each TPC pixel.

Wire Pulses by Pad – Filtered and event averaged ADC values for wire pulser events of given class for each TPC pixel.

Ground Wire Pulse Parameters – Pulse waveform and amplitude parameters and trigger delay for each TPC sector.

Pad Geometry Factors – Individual corrections due to pad size variations (at ends of pad rows).

Relative Time Offset Corrections – see /cal/tpc.

Status Report – Results of wire pulse analysis for monitoring and online usage.

FEE Shaper Response Function Corrections – see /cal/tpc.

Offline TPC Calibration Relative Gain and Linearity Corrections from Wire Pulses – see /cal/tpc/gains.

Data Flows:

None

# /cal/tpc/gains/tch	Date of Creation: 3/21/96 Date of Last Revision: 5/02/96	Author: L. Ray Last Modified by: R. Bossingham

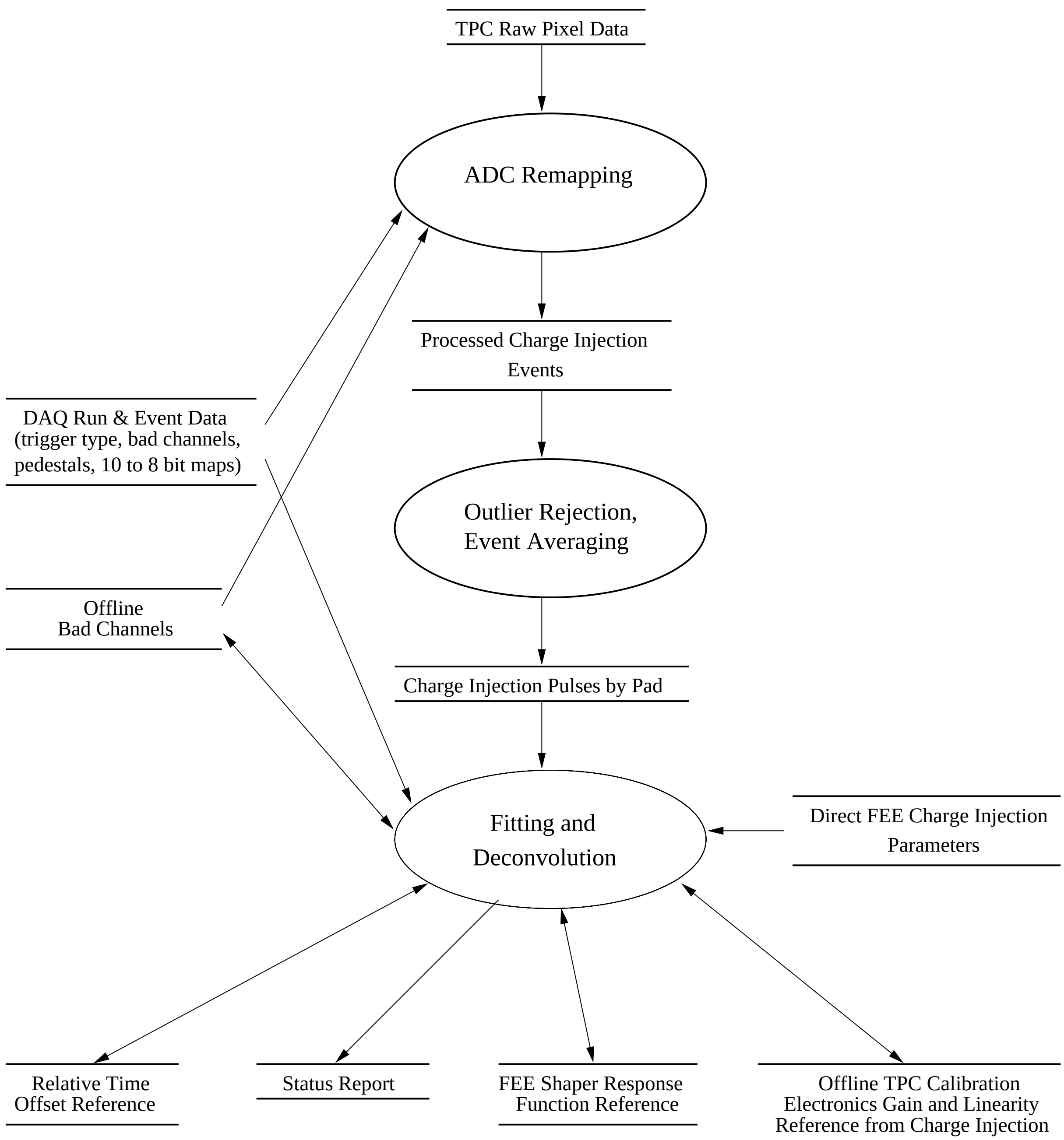

Figure 59: TPC Gain and Time Offset Calibration Software for Direct Charge Injection

Glossary of Terms:

Processes:

ADC Remapping – Pixels from direct FEE charge injection events are corrected for pedestals and 10 to 8 bit mapping. The pulses within a class are then histogrammed by pixel and event.

Outlier Rejection, Event Averaging – Elimination of the non-Gaussian tail, if any, from the event distribution. Remaining events within a class are then averaged.

Fitting and Deconvolution – From the recorded events for an electronics channel, the Shaper Response, Electronics Gain and Relative Time Offset are fit, so as to produce the observed signals. From the variation of gain with input amplitude, the electronics linearity is obtained.

Data Stores:

TPC Raw Pixel Data – see /ana/tpc.

DAQ Run and Event Data – see /cal/tpc.

Offline Bad Channels – see /cal/tpc.

Processed Charge Injection Events – Histogram of corrected ADC values for charge injection events of given class for each TPC pixel.

Charge Injection Pulses by Pad – Filtered and event averaged ADC values for charge injection events of given class for each TPC pixel.

Direct FEE Charge Injection Parameters – Charge injection current waveform and amplitude parameters and trigger delay for each TPC FEE board.

Relative Time Offset Reference – see /cal/tpc/gains.

Status Report – Results of charge injection analysis for monitoring and online usage.

FEE Shaper Response Function Reference – see /cal/tpc/gains.

Offline TPC Calibration Electronics Gain and Linearity Reference from Charge Injection – see /cal/tpc/gains.

Data Flows:

None

/cal/tpc/tpe	Date of Creation: 1/30/96	Author: R. Bossingham
	Date of Last Revision: 5/02/96	Last Modified by: R. Bossingham

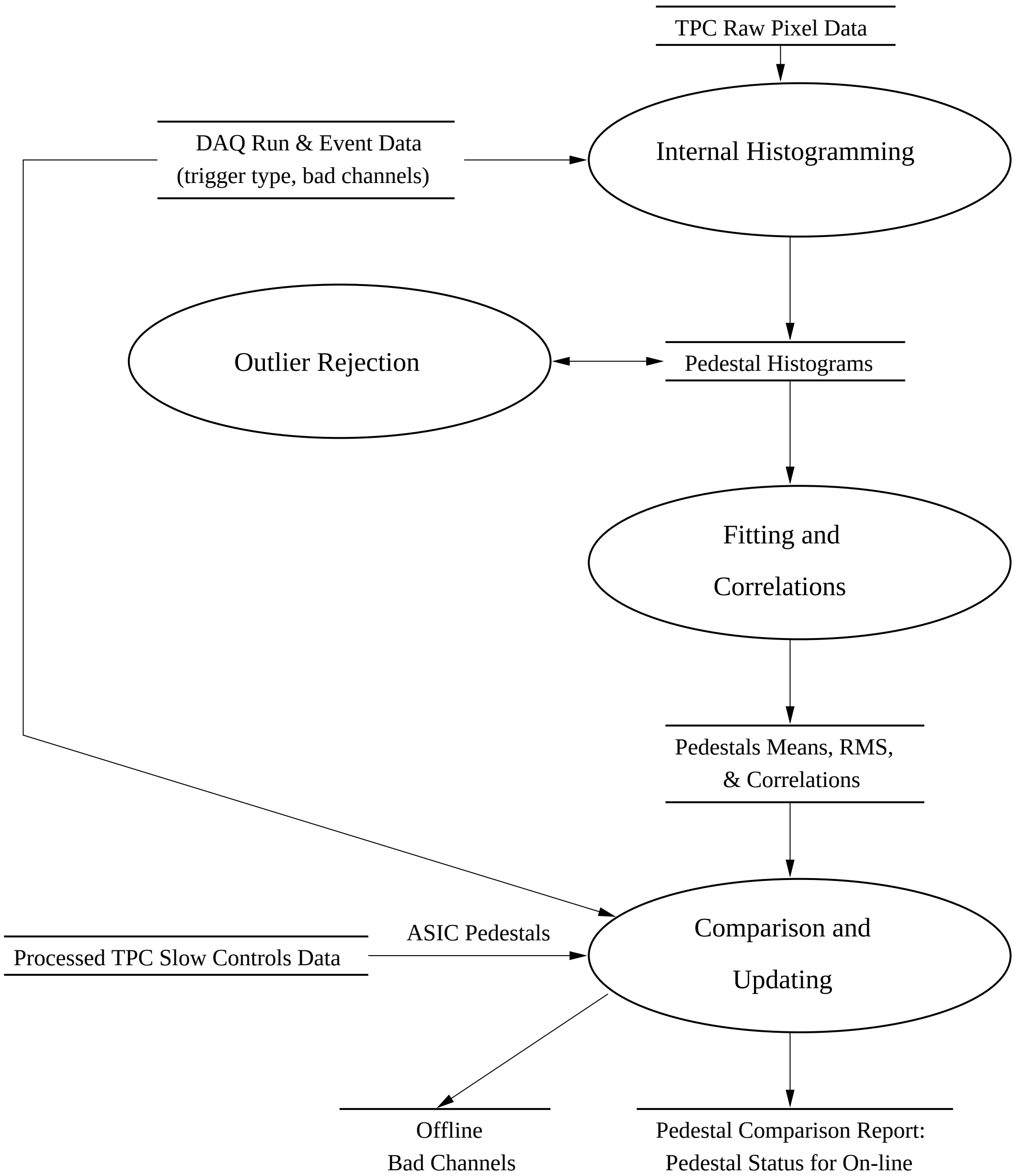

Figure 60: TPC Pedestal Check and Calibration Software

Glossary of Terms:

Processes:

Internal Histogramming – Measured pedestal distributions are histogrammed for each pixel, allowing outlier rejection without iteration.

Outlier Rejection – Elimination of the non-Gaussian tail, if any, from the pedestal distributions.

Fitting and Correlations – Determines the mean and rms width of the (possibly truncated) pedestal histograms. Correlated noise can be checked at various levels.

Comparison and Updating – Pedestals, noise and the bad channels list are compared to the existing data base entries; the data base is updated if there are significant differences.

Data Stores:

TPC Raw Pixel Data – see /ana/tpc (non-pedestal subtracted, full pixels).

DAQ Run and Event Data – see /cal/tpc.

Pedestal Histograms – Pedestal histograms for each TPC pixel for a given class of pedestal events.

Pedestal Means, RMS and Correlations – Pedestal mean and rms values for each pixel for a given class of pedestal events; correlated noise identification if any.

Processed TPC Slow Controls Data – see /cal/tpc.

Offline Bad Channels – see /cal/tpc.

Pedestal Comparison Report – see /cal/tpc.

Data Flows:

None

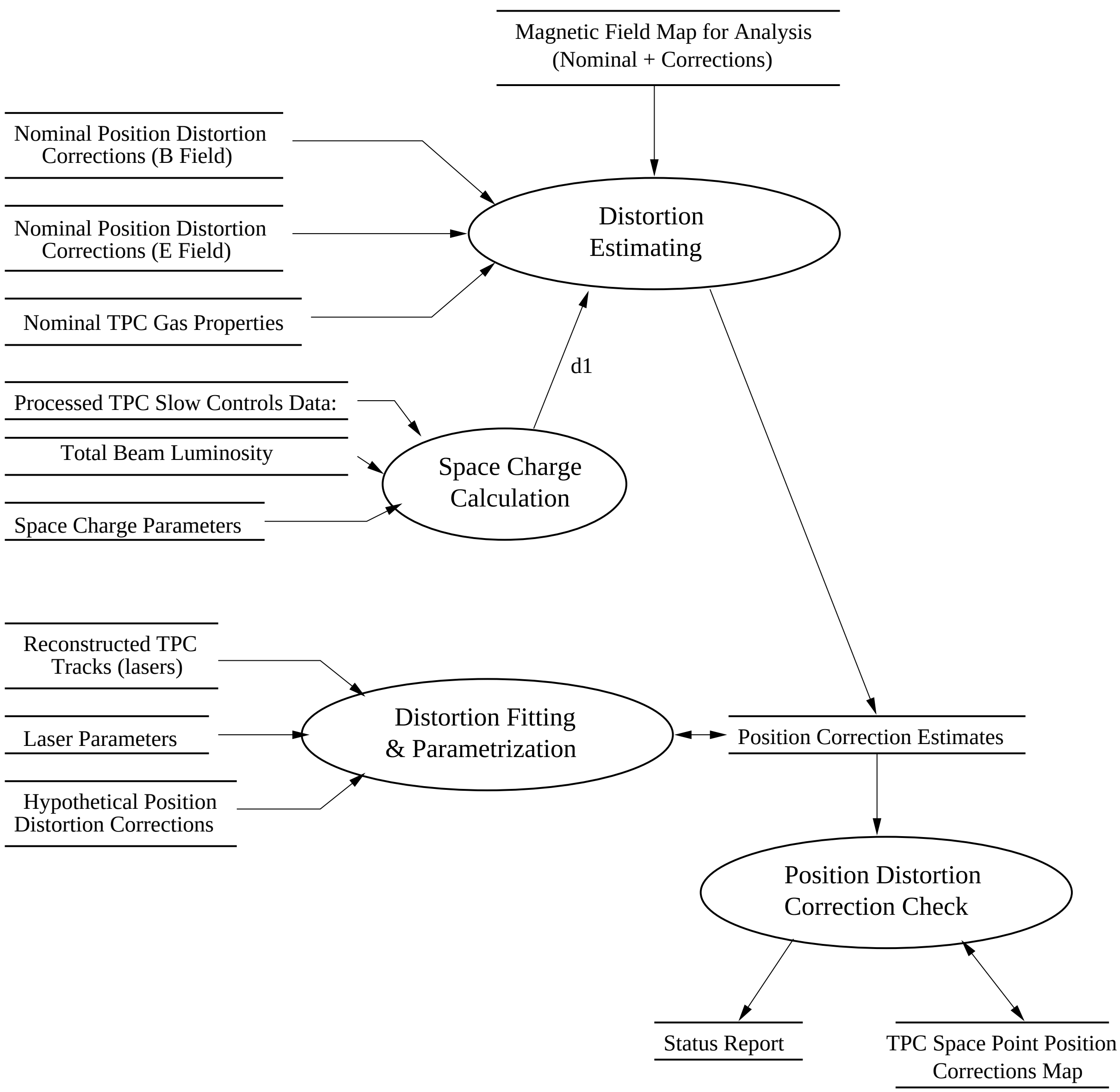

Figure 61: TPC Space Point Distortion Correction Software

Glossary of Terms:

Processes:

Distortion Estimating – Process which estimates position distortions using actual magnetic field map, electric field distortions and space charge effects.

Space Charge Calculation – Process which calculates the accumulated positive ion space charge in the TPC gas volume as a function of beam luminosity. The resulting perturbations to the electric field are calculated.

Distortion Fitting and Parametrization – After correcting the laser track fits and residuals for the difference between the estimated distortions and those used to fit the laser events, we can fit a linear combination of additional distortions, as needed to make the fitted laser tracks straight and at the correct relative angles. The net distortions, integrated along the electron drift paths, are parametrized.

Position Distortion Correction Check – Position distortion corrections from laser track analysis and from E and B field distortion estimates are compared and if these are found to be in suitable agreement the TPC Space Point Position Correction Map is updated.

Data Stores:

Magnetic Field Map for Analysis (Nominal and Corrections) – see /sim/magnet.

Nominal Position Distortion Corrections (B Field) – Map of TPC space point distortions due to the TPC magnetic field distortions. These are expected to be from 3000 to 7000 μm.

Nominal Position Distortion Corrections (E Field) – Map of TPC space point distortions due to the TPC electrostatic field cage alone. Under normal conditions, these should be small.

Nominal TPC Gas Properties – Nominal values for the TPC gas temperature, pressure, composition, etc. These also include information with which to calculate $\omega\tau$ for the gas.

Processed TPC Slow Controls Data – see /cal/tpc.

Total Beam Luminosity – Processed slow control information about beam-beam luminosity throughout the data acquisition period.

Space Charge Parameters – Parameters needed for calculating the accumulated positive ion space charge in the TPC volume.

Reconstructed TPC Tracks (Lasers) – see /ana/tpc.

Laser Parameters – Laser positions, amplitudes, relative firing times for the two independent laser systems, central membrane photoelectron emission pattern, etc.

Hypothetical Position Distortion Corrections – Many of the likely TPC space point distortions can be calculated in advance, if one assumes azimuthal symmetry (distortions due to a shorted field cage resistor, for example). If these maps span a roughly orthogonal and complete set, one should be able to find a linear combination which corrects an observed distortion.

Position Correction Estimates – Estimated space point position corrections from

E and B field distortions and from laser track analysis.

Status Report – Results of comparison of position distortion corrections from E and B field non-uniformities and from laser track analyses are reported for monitoring and for online.

TPC Space Point Position Corrections Map – see /cal/tpc.

Data Flows:

d1 – Electric field distortions due to accumulated positive ion space charge in the TPC gas volume.

/cal/tpc/tdv				
	Date of Creation: 1/30/96		Author:	R. Bossingham
	Date of Last Revision: 5/03/96		Last Modified by:	R. Bossingham

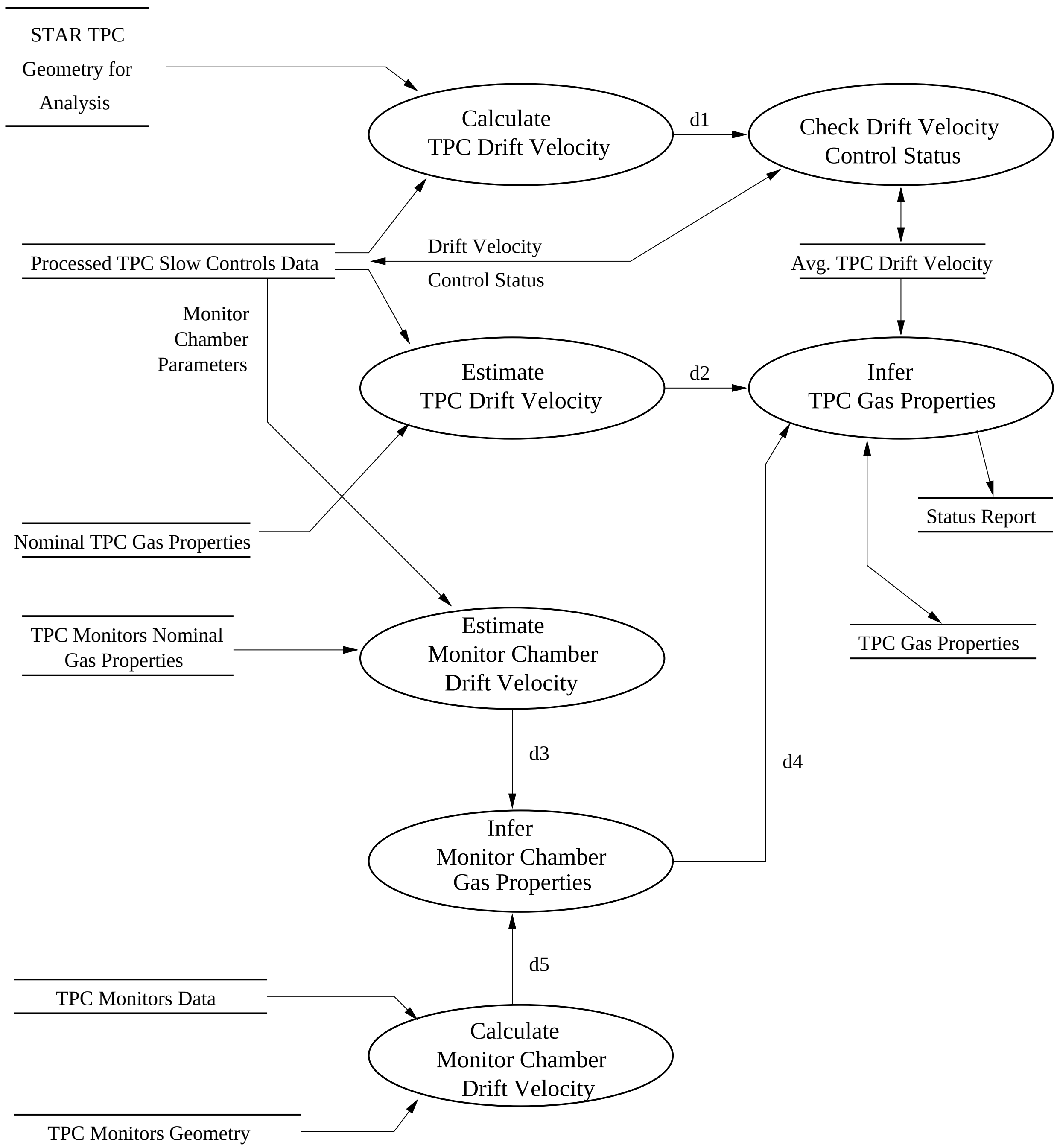

Figure 62: TPC Drift Velocity Calibration Software

Glossary of Terms:

Processes:

Calculate TPC Drift Velocity – At the simplest level, this uses the electron drift time and distance to find the drift velocity (drift speed, strictly speaking). Corrections may be needed for variations in the drift velocity after the gating grid; for timing walk due to gas gain variations; or for non-ideal geometries.

Check Drift Velocity Control Status – Checks the internally calculated TPC drift velocity against that found by the field cage voltage regulation system; this replaces the nominal velocity if the field cage system is out of regulation.

Estimate TPC Drift Velocity – Predicts drift velocity from the electric field, gas density and nominal gas composition in the TPC.

Infer TPC Gas Properties – Compares the TPC drift velocity deduced from the electric field strength and assumed gas properties in the TPC and TPC monitor chamber with the actual TPC drift velocity to infer corrections to the TPC gas properties.

Estimate Monitor Chamber Drift Velocity – Predicts drift velocity from the electric field, gas density and nominal gas composition in the monitor chamber.

Infer Monitor Chamber Gas Properties – Compares the Monitor Chamber drift velocity deduced from the electric field strength and assumed gas properties in the monitor chamber with the actual drift velocity to infer corrections to the monitor chamber gas properties.

Calculate Monitor Chamber Drift Velocity – The monitor drift chamber will have electrons drifting over short and long distances to a single sensor; the drift time difference and geometry give the drift velocity as a check on the gas properties.

Data Stores:

STAR TPC Geometry for Analysis – see /ana/tpc/tcl and /sim/geometry.

Processed TPC Slow Controls Data – see /cal/tpc.

Nominal TPC Gas Properties – see /cal/tpc/tdt.

TPC Monitors Nominal Gas Properties – see /cal/tpc/gains/tat.

TPC Monitors Data – see /cal/tpc/gains/tat.

TPC Monitors Geometry – see /cal/tpc/gains/tat.

Average TPC Drift Velocity – see /cal/tpc.

Status Report – Contains the results of checking the TPC drift velocity, monitor chamber drift velocity, and the inferred TPC and monitor chamber gas properties for offline monitoring and for reporting to online.

TPC Gas Properties – see /sim/det/tpc.

Data Flows:

d1 – Calculated TPC drift velocity from processed TPC Slow Controls data.

d2 – Estimated TPC drift velocity from processed TPC Slow Controls gas properties data.

d3 – Estimated Monitor Chamber drift velocity from processed Slow Controls Monitor gas properties data.

d4 – Inferred Monitor Chamber gas properties.

d5 – Calculated Monitor Chamber drift velocity from processed Monitors Slow Controls data.

/cal/tpc/tge

Date of Creation: 2/23/96 Author: R. Bossingham
Date of Last Revision: 5/02/96 Last Modified by: R.Bossingham

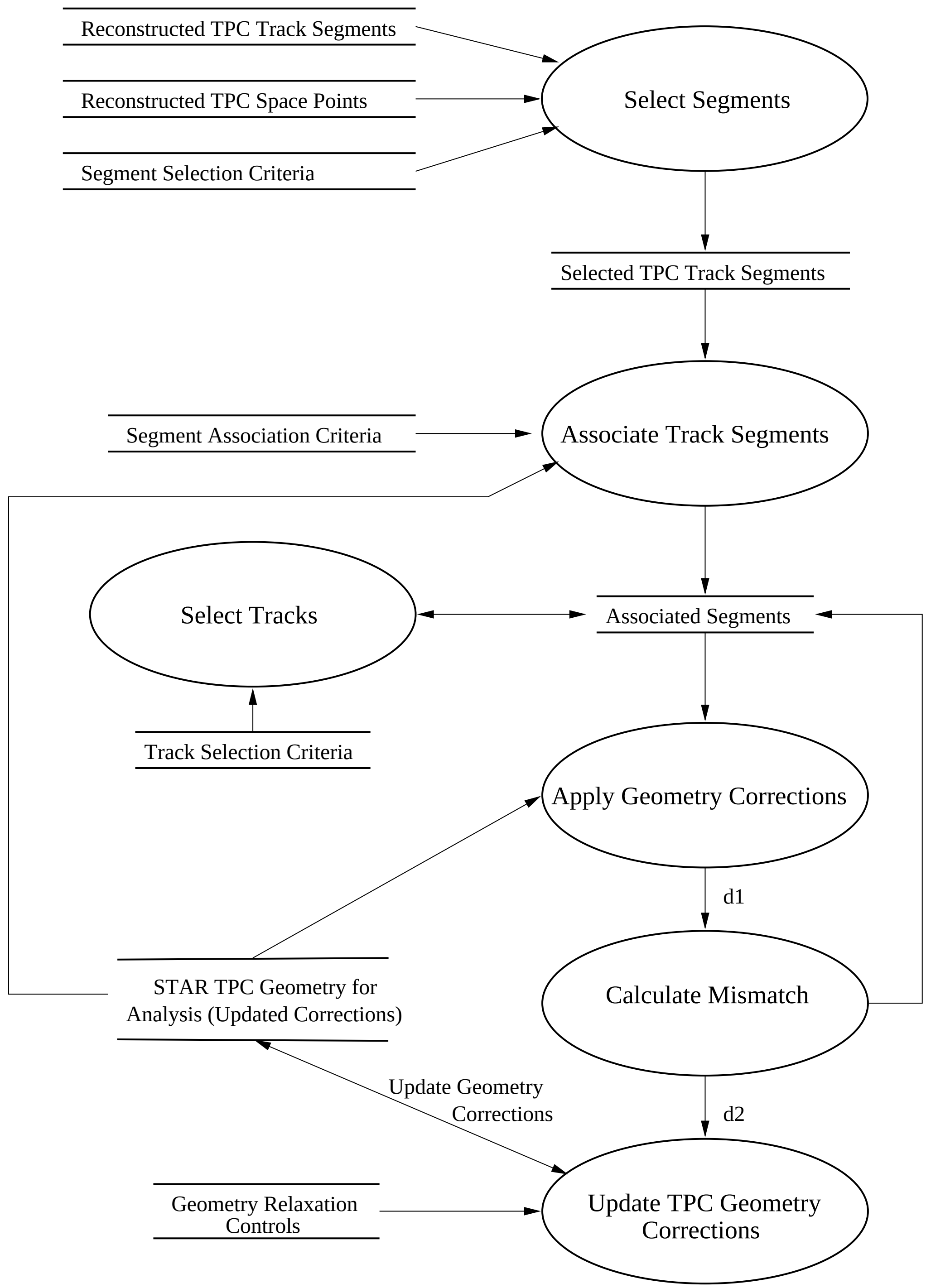

Figure 63: TPC Internal Alignment Calibration Software

Glossary of Terms:

Processes:

Select Segments – Clean, well separated track segments in the inner and outer TPC sectors are selected according to specified criteria.

Associate Track Segments – Based on the current iteration of the geometry and applying only moderately tight cuts, subsector track segments are associated to form inter-sector tracks.

Select Tracks – The inter-sector track sample is culled to eliminate unassociated segments, poorly fit tracks (due to decays or hard scatters) and tracks which are not well defined (due to missing channels, detector 'cracks,' δ-rays).

Apply Geometry Corrections – Updated sector alignment parameters (if any) are used to correct the space point positions.

Calculate Mismatch – Based on the track fit residuals, the relative mismatches between subsectors are determined.

Update TPC Geometry Corrections – The TPC geometry is relaxed to reduce the mismatches between subsectors. The relaxation allowed per iteration should be controlled to avoid oscillation in the fitted geometry. The TPC Geometry data store is updated iteratively throughout this procedure. Position and orientation corrections are applied in the TPC Internal Coordinate System.

Data Stores:

Reconstructed TPC Track Segments – see /ana/tpc/tpt.

Reconstructed TPC Space Points – see /ana/tpc.

Segment Selection Criteria – Parameters and cuts used to select clean, well separated TPC track segments.

Selected TPC Track Segments – Selected TPC track segment parameters and associated space points.

Segment Association Criteria – Parameters and cuts used to associate (match) selected track segments across sector boundaries, or across the entire TPC (for laser and cosmic ray tracks).

Associated Segments – Matched track segments, fitted track parameters, corresponding space points and fitted track residuals.

Track Selection Criteria – Parameters and cuts used to select clean inter-sector tracks.

STAR TPC Geometry for Analysis – see /ana/tpc/tcl and /sim/geometry.

Geometry Relaxation Controls – Control parameters and limits on the magnitude of the allowed sector alignment shifts per iteration and the total allowed shifts for each sector.

Data Flows:

d1 – Corrected space point position coordinates for selected, associated track segments based on updated geometry.

d2 – Track segment matching information and track fit residuals.

Status:

See the following STAR Library Packages:

tfc – TPC pedestal calculation and gain corrections. (Package tfc is a temporary location for this software).

6.3 SVT Calibrations and Corrections (/cal/svt)

This section contains a description, list of requirements, functional model diagrams for the top level (/cal/svt, Fig. 64) and for seven sublevels including Slow Controls data processing (/cal/svt/ssl, Fig. 65), pedestal calibration (/cal/svt/ped, Fig. 66), relative gain calibrations (/cal/svt/rel_gain, Fig. 67), absolute gain calibrations (/cal/svt-/abs_gain, Fig. 68), average drift velocity calibrations (/cal/svt/avg_drift, Fig. 69), drift velocity profile calibration (/cal/svt/profile_drift, Fig. 70), and SVT internal position and alignment calibration (/cal/svt/geometry, Fig. 71), glossaries for each diagram, and a status of software report. Detailed discussion of SVT calibration procedures is given in Ref. [26].

Description:

The SVT calibration and correction software is designed to provide position correction maps and gain and attenuation corrections such that accurate and stable space point positions and energy depositions can be determined for each SDD wafer of the SVT. The sources of systematic error in determining these quantities are variations in the temperature of the SDDs, impurities in the silicon, nonuniformities in the electric field gradient, fluctuations in the drift voltages, variations in the PASA gains, timing offsets in the SCAs, and misalignment or position shifts of the SDDs and/or ladders of the SVT. A variety of methods for detecting, monitoring and correcting for these effects have been proposed. These include temperature probes, cathode line injection implants at several drift distances on each SDD wafer, no B field straight track analysis, laser induced ionization, etc.

Requirements:

The SVT calibration and correction software is required to provide all the correction data needed by SVT event reconstruction in order that the physics capabilities of the detector can be realized. This includes corrections for voltage offsets (pedestals), time offsets for each channel, electronic gain variations for each channel, drift time to spatial position nonuniformities, and internal misalignments, as well as identification of dead, hot or problematic electronic channels. The identical software must be used for either real or simulated data analysis.

/cal/svt

Date of Creation: 1/4/96
Date of Last Revision: 5/31/96

Author: C. Pruneau & W. K. Wilson
Last Modified by: L. Ray

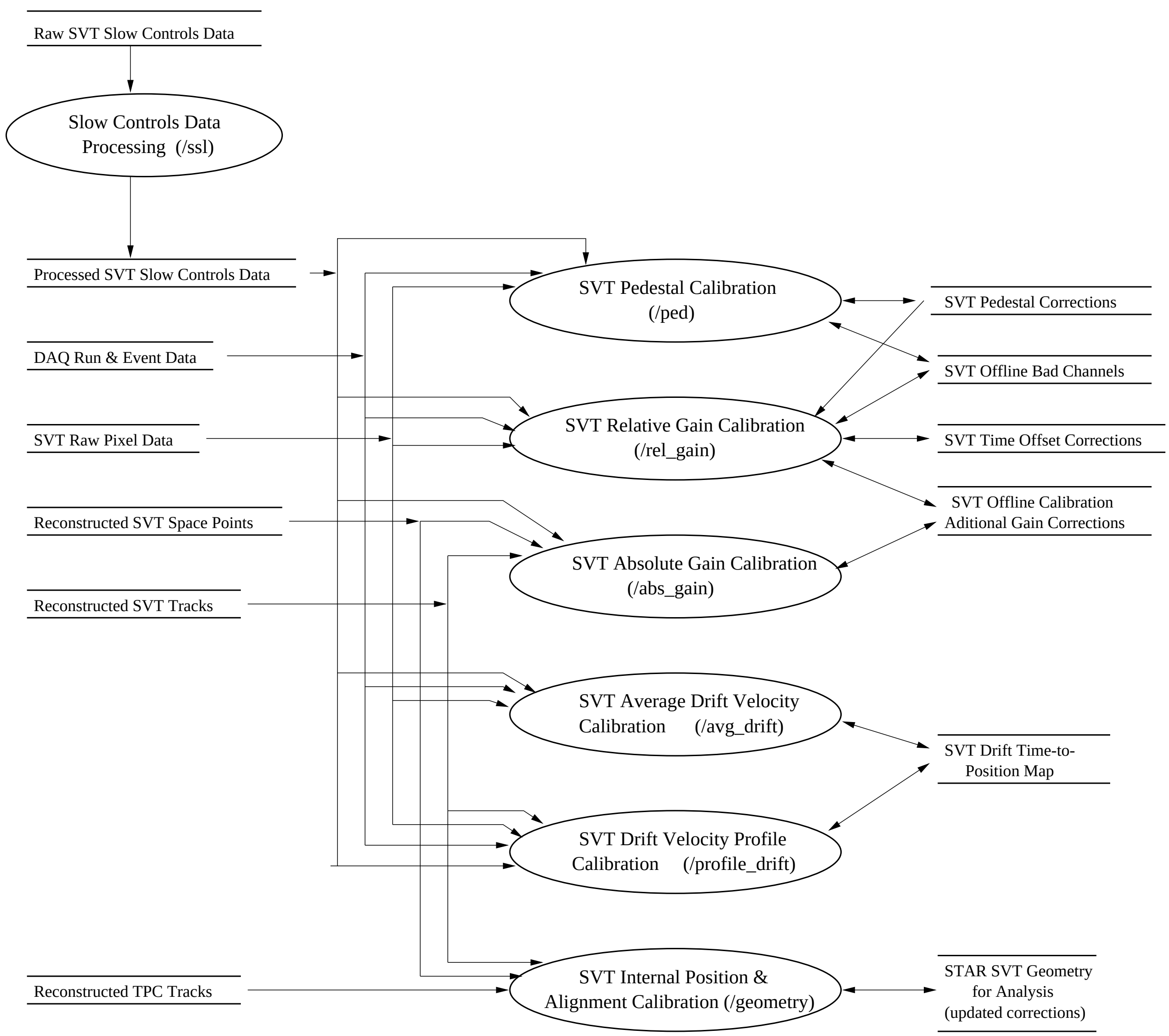

Figure 64: SVT Calibration and Corrections Software – Top Level

Glossary of Terms:

Processes:

Slow Control Data Processing – Raw SVT Slow Controls data are time averaged and smoothed into a more compact and useful form for the remaining calibrations software. Outliers are rejected and data are combined. Derived parameters, such as SVT drift velocity, are monitored throughout a run or other data acquisition period. Periods of validity and problematic values are identified.

SVT Pedestal Calibration – The pedestal determination is necessary to subtract ADC zero offsets while analyzing the SVT pixel data. The pedestals are evaluated by accumulating SVT pixel data with no beam or incoming signals in the detector ("empty events"). The pedestal average is evaluated for each pixel by averaging the ADC values over many empty events.

SVT Relative Gain Calibration – The determination of the relative gains of all channels (anodes) is necessary to correct the pixel and insure signal uniformity across the detector. Although the corrections are foreseen to be small (a few per cent difference from channel to channel), they are considered important for optimizing the energy deposition and position reconstruction. The relative gain determination will be performed on the basis of the signals measured with line injectors.

SVT Absolute Gain Calibration – The determination of the absolute gain of the SVT PASA/SCA chain is required to unambiguously link the strength of the signal to the energy deposition expected from Minimum Ionization Particles traversing the detector at normal incidence. As the PASA gains are not adjustable, but can however vary (most likely decrease) in time for a number of reasons, a comparison of the signal strength to a chosen reference (such as MIPs) insures not only the proper reconstruction of the signals but also provides useful information to evaluate the performance of the detector after years of running/operation.

SVT Average Drift Velocity Calibration – The average drift velocity is likely to fluctuate slowly with varying operational and ambient conditions such as the biasing voltage, the ambient temperature, the water cooling system temperature, etc. It is thus required to evaluate the average drift velocity on a regular basis. This is accomplished by means of line charge injection at 4 locations on each SDD wafer.

SVT Drift Velocity Profile Calibration – A number of factors can alter the drift speed locally and must thus be compensated for in the analysis. Also, as simulations have shown, with a finite number of samples and a shaping time comparable to the signal width achieved with the shortest drift time, a finite position offset or bias is introduced by virtually any method of signal centroid determination. As these offsets depend both on the analysis method and the actual drift time, detailed corrections will need to be applied to properly translate the drift time centroids into positions along the drift direction. These corrections will in part be deduced from a Monte Carlo analysis of the signal shape and in part from line injection data and from actual data signals.

SVT Internal Position and Alignment Calibration – The accurate translation of the coordinates of a track's crossing points in the reference frame of each SDD wafer to 3 dimensional coordinates expressed in the global STAR Coordinate System requires a detailed and precise knowledge of the position and orientation of each SDD wafer relative to the SVT Internal Coordinate System and the position and orientation of the SVT with respect to the global STAR Coordinate System. The former alignment procedure is done here, while the latter is handled by global calibration software, see /cal/global. The primary basis for the determination of the orientation and position of the wafers will be the initial position surveys performed during and after the installation of the SVT inside the STAR TPC. It is unlikely that the position/orientation determined by survey will provide enough accuracy to reach the optimal position resolution of the SVT. It is thus foreseen that complementary methods will be needed to determine the positions more accurately. These complementary methods involve the usage of straight tracks under zero magnetic field and helicoidal tracks under nominal magnetic field. Various approaches are envisioned which involve track residue minimization and vertex size minimization.

Data Stores:

Raw SVT Slow Controls Data – Slow controls or hardware control information acquired during the relevant data acquisition period. Includes quantities related to the physical condition of the SVT including SDD temperatures, drift voltages, anode voltages, PASA gains and linearity, SCA digitization frequency, line injection amplitudes and wave forms. Also includes the ASIC gain function parameters, ADC algorithm and parameters, 10 to 8 bit conversion algorithm and parameters, online time sequence and cluster finder parameters and ASIC pedestals.

Processed SVT Slow Controls Data – A time averaged, smoothed and more compact version of the Raw SVT Slow Controls Data, which is in a suitable format for the offline calibration software.

DAQ Run and Event Data – Run and event by event information from DAQ for the SVT including: (1) trigger type, parameters, thresholds, pre-scalers, etc., (2) bad channels and saturated channels lists, and (3) DAQ status and error conditions (if any).

SVT Raw Pixel Data - see /ana/svt.

Reconstructed SVT Space Points - see /ana/svt.

Reconstructed SVT Tracks - see /ana/svt.

Reconstructed TPC Tracks - see /ana/tpc.

SVT Pedestal Corrections – Pedestal mean and rms values from offline analysis are compared to that assumed in online processing; corrections for offline analysis are recorded. Correlated noise (if any) is identified.

SVT Offline Bad Channels – Data store which identifies further channels (compared to online) for which the data should not be used. The decision for these channels is made by offline calibration software after processing some data (see /cal/svt/ped and /cal/svt/rel_gain).

SVT Time Offset Corrections – Data store containing anode by anode time offsets which correct the relationship between time bucket number and local SDD drift direction position of the pixel, see /cal/svt/rel_gain.

SVT Offline Calibration Additional Gain Corrections – Data store which contains (in general nonlinear) corrections for each channel's ADC values to remove variations not removed by online corrections. Also may include drift distance dependent gain corrections to account for attenuation effects.

SVT Drift Time to Position Map – A lookup table that establishes a one-to-one correspondence between drift time and position for each SDD.

STAR SVT Geometry for Analysis – See /sim/geometry.

Data Flows:

None

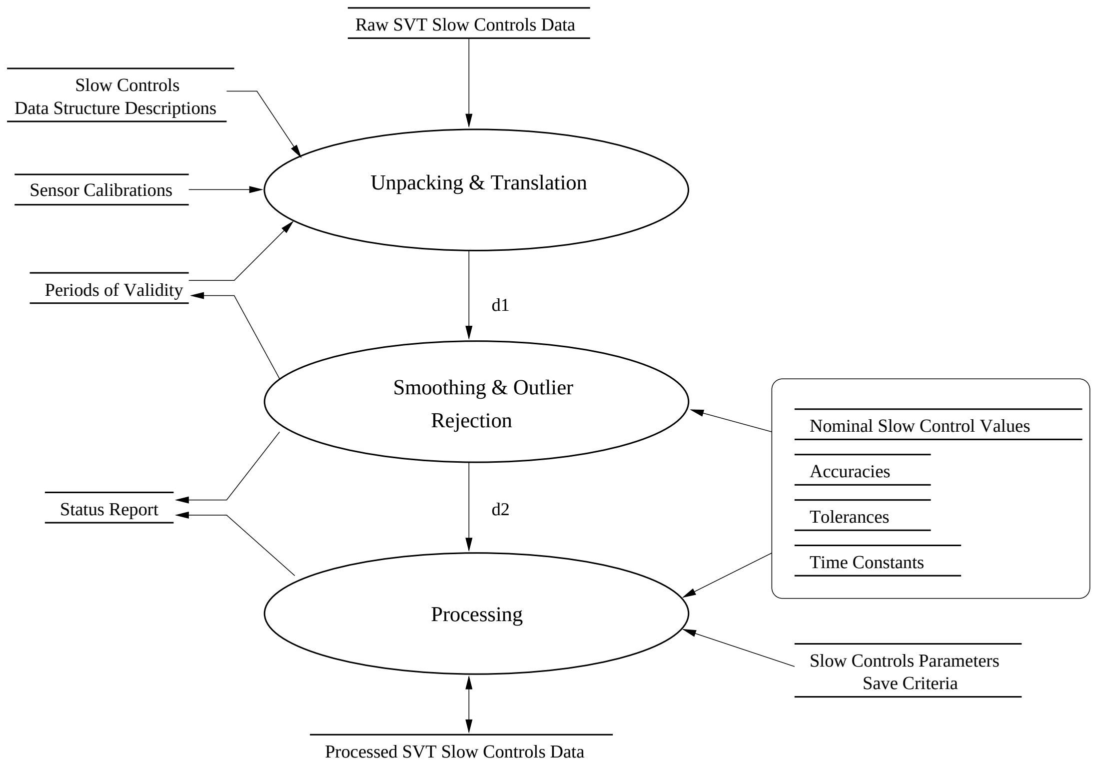

Figure 65: SVT Slow Controls Data Processing Software

Glossary of Terms:

Processes:

Unpacking and Translation – Raw SVT Slow Controls Data are deciphered into individual, calibrated components according to the prescriptions in the data structure description, specialized for the SVT.

Smoothing and Outlier Rejection – Out-of-tolerance values are rejected, with appropriate notification to Online. Spurious values not consistent with a physical time constant may be rejected also. Surviving values are time averaged. The results are specialized for the SVT.

Processing – Essentially redundant values are averaged together and any other necessary calculations are performed. The resulting derived values are then handled in the same way as values directly read by slow controls. The results are specialized for the SVT.

Data Stores:

Raw SVT Slow Controls Data – see /cal/svt.

Slow Controls Data Structure Description – Definition and description of slow controls raw data format and structure for the SVT.

Sensor Calibrations – Sensor calibration parameters, including non-linearities and any dependencies on other parameters for SVT.

Periods of Validity – Periods during which a given sensor or processed slow controls data are deemed to be valid. This list might be edited by /cal/svt/ssl, by Slow Controls, or by hand.

Status Report – Results of time averaging, outlier removal, periods of validity, and anomalous parameters are noted for the SVT. This information is used for offline monitoring of event data throughout a data acquisition period and may be used to notify online of problematic hardware behavior.

Nominal Slow Control Values – Nominal, expected values for slow control parameters to serve as a reference for comparing actual values. These may be used offline if no other valid information is available. Specialized for the SVT.

Accuracies – Expected rms error of a sensor, together with its instrumentation, for the SVT.

Tolerances – Allowed deviation of sensor from the nominal values, for the SVT.

Time Constants – Physical time constants expected for various parameters; used to smooth measurements and to detect spurious values for the SVT.

Slow Controls Parameters Save Criteria – List of processed slow controls information and other criteria which determine what processed slow controls data will be recorded in the Processed SVT Slow Controls data store; specific for the SVT.

Processed SVT Slow Controls Data – see /cal/svt.

Data Flows:

d1 – Computed raw slow control information for the SVT.

d2 – Smoothed (time averaged) and filtered Slow Controls data for the SVT.

/cal/svt/ped

Date of Creation:	5/30/96	Author:	L. Ray
Date of Last Revision:		Last Modified by:	

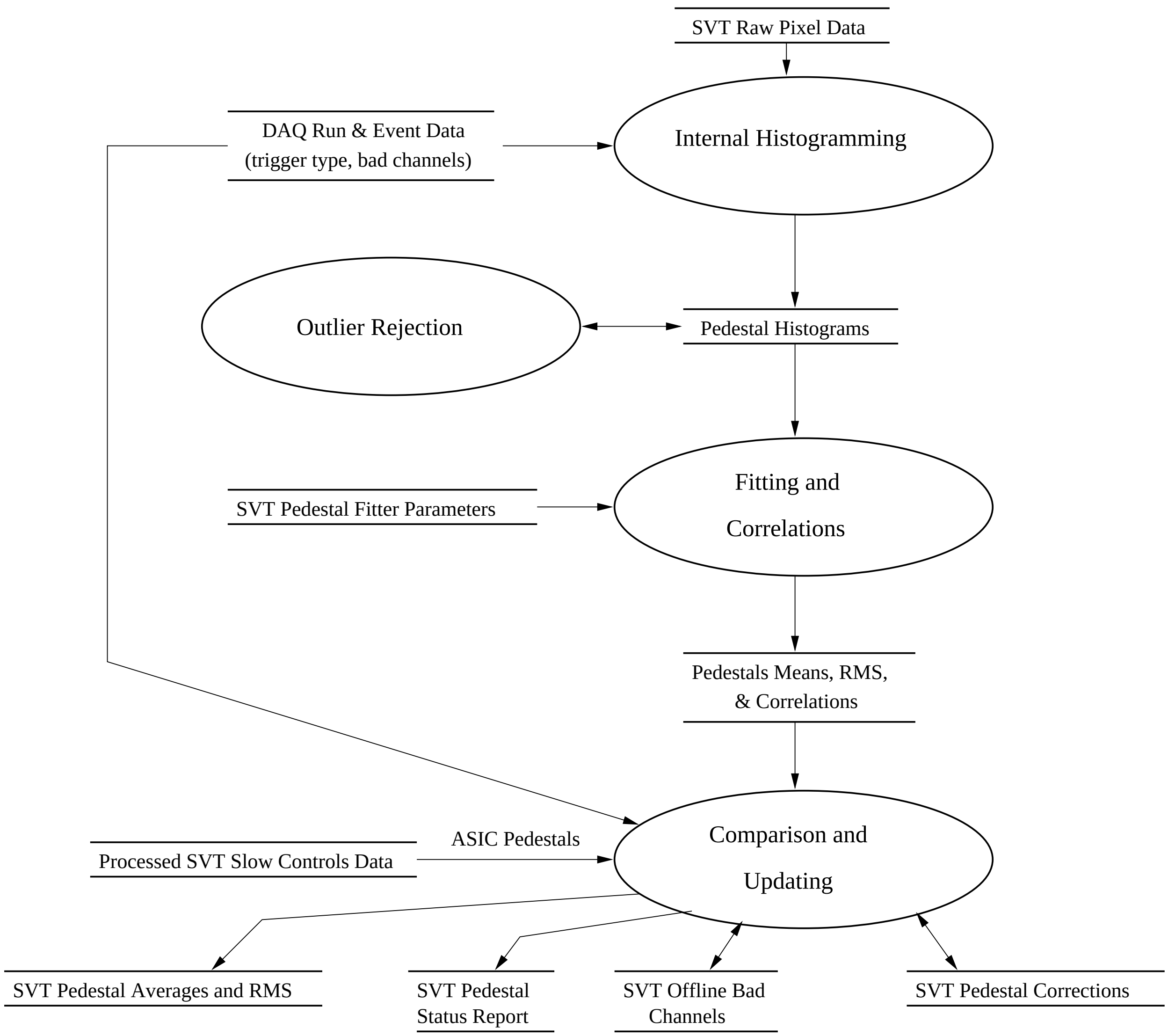

Figure 66: SVT Pedestal Check and Calibration Software

Glossary of Terms:

Processes:

Internal Histogramming – Measured SVT pedestal distributions are histogrammed for each pixel, allowing outlier rejection without iteration.

Outlier Rejection – Elimination of the non-Gaussian tail, if any, from the pedestal distributions.

Fitting and Correlations – Determines the mean and rms width of the (possibly truncated) SVT pedestal histograms. Correlated noise among the SVT channels can be checked at various levels.

Comparison and Updating – SVT pedestals, noise and the bad channels list are compared to the existing data base entries; the data base is updated if there are significant differences.

Data Stores:

SVT Raw Pixel Data – see /ana/svt (non pedestal subtracted, full pixels).

DAQ Run and Event Data – see /cal/svt.

Pedestal Histograms – Pedestal histograms for each SVT pixel for a given class of pedestal events.

SVT Pedestal Fitter Parameters – Parameters of assumed pedestal distribution function and other fitting criteria.

Pedestal Means, RMS and Correlations – SVT pedestal mean and rms values for each pixel for a given class of pedestal events. Correlated noise identification also included, if any.

Processed SVT Slow Controls Data – see /cal/svt.

SVT Pedestal Averages and RMS – SVT pedestal mean and rms for each SVT pixel for a class of pedestal events, determined by offline analysis.

SVT Pedestal Status Report – SVT pedestal mean and rms values from online are compared to that determined in offline analysis of special pedestal (no signal) runs. Correlated noise (if any) are identified. This report is used for offline monitoring and for notification of online of any detector problems or anomalies.

SVT Offline Bad Channels – see /cal/svt.

SVT Pedestal Corrections – see /cal/svt.

Data Flows:

None

/cal/svt/rel_gain

Date of Creation: 1/4/96
Date of Last Revision: 5/31/96

Author: C. Pruneau & W. K. Wilson
Last Modified by: L. Ray

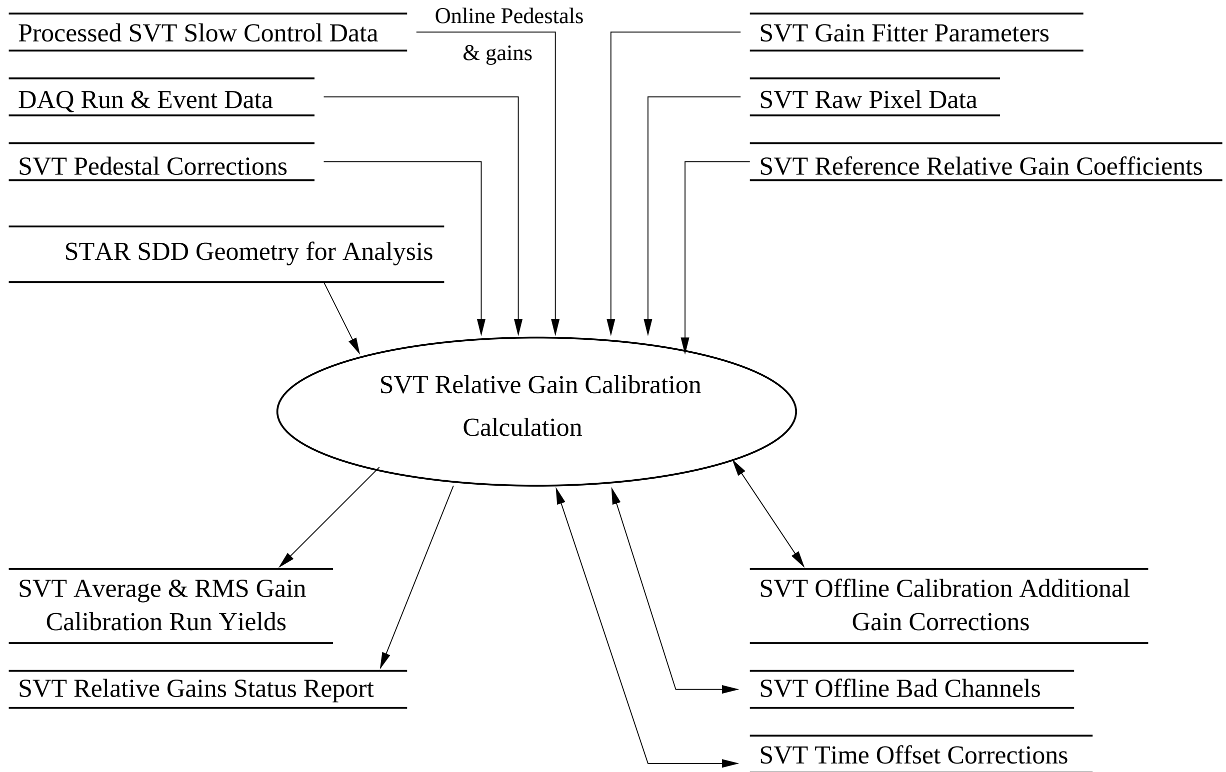

Figure 67: SVT Relative Gain Calibration Software

Glossary of Terms:

Processes:

SVT Relative Gain Calibration Calculation – Relative anode to anode gain variations, time offsets and bad electronics channels are detected and corrections evaluated based on cathode line injection data. Some drift distance dependent gain corrections are also computed by comparing signal strengths from the several injection lines on each SDD wafer. These correct for electron attenuation effects in the silicon.

Data Stores:

Processed SVT Slow Controls Data – see /cal/svt.

DAQ Run and Event Data – see /cal/svt.

SVT Pedestal Corrections – see /cal/svt.

STAR SDD Geometry for Analysis – See /sim/det/svt.

SVT Average and RMS Gain Calibration Run Yields – Mean and rms values for all calibration run yields during relevant data acquisition period for each pixel.

SVT Relative Gains Status Report – Deduced relative gains, bad channels and time offsets for each anode on each SDD; summarized for offline monitoring and for reporting problems and anomalies to online.

SVT Gain Fitter Parameters – Parameters of assumed line injection yields for the gain calibration events and other controls.

SVT Raw Pixel Data – see /ana/svt.

SVT Reference Relative Gain Coefficients – Nominal gain coefficients for each channel.

SVT Offline Calibration Additional Gain Corrections – see /cal/svt.

SVT Offline Bad Channels – see /cal/svt.

SVT Time Offset Corrections – see /cal/svt.

Data Flows:

None

/cal/svt/abs_gain	Date of Creation:	5/31/96	Author:	L. Ray
	Date of Last Revision:		Last Modified by:	

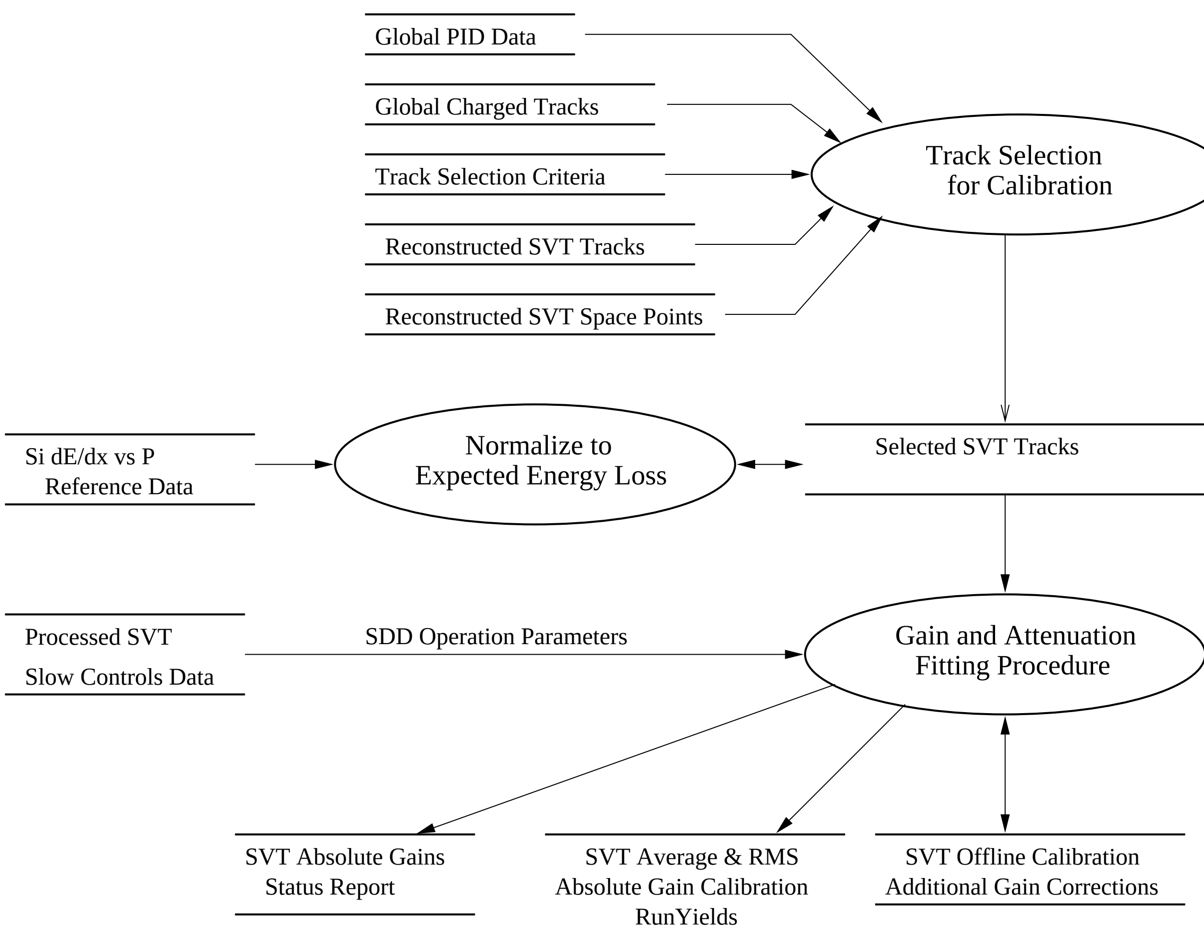

Figure 68: SVT Absolute Gain Calibration Software

Glossary of Terms:

Processes:

Track Selection for Calibration – Process which selects tracks and corresponding SVT space points for specified particle type and momentum range (*e.g.* 300 - 500 MeV/c pions) using global tracking information and for which the tracks are cleanly separated from neighboring tracks.

Normalize to Expected Energy Loss – Histograms of dE/dx versus momentum are constructed for selected tracks and space points; outliers are removed; results are normalized to the expected energy loss. The analysis spans the drift distance of the SDDs and over the data acquisition period.

Gain and Attenuation Fitting Procedure – Process computes gain corrections due to long time scale variations in the SDDs and/or electronics throughout the relevant data acquisition period. The results are parametrized such that well understood dependencies on SDD properties are factored out in order to reduce the data volume.

Data Stores:

Global PID Data – see /ana/global/pid.

Global Charged Tracks – see /ana/global.

Track Selection Criteria – Contains the selection parameters used to specify track type, particle type, momentum range, minimum distance from neighboring tracks or space points, etc.

Reconstructed SVT Tracks – see /ana/svt.

Reconstructed SVT Space Points – see /ana/svt.

Silicon dE/dx Versus Momentum Reference Data – see /ana/global/pid.

Selected SVT Tracks – Global or SVT track parameters, energy deposition and corresponding SVT space point information for selected tracks.

Processed SVT Slow Controls Data – see /cal/svt.

SVT Absolute Gains Status Report – Deduced absolute gains for each anode (and possibly for each pixel) on each SDD; summarized for offline monitoring and for reporting problems and anomalies to online.

SVT Average and RMS Absolute Gain Calibration Run Yields – Mean and rms values for all absolute gain calibration run yields during relevant data acquisition period for each pixel.

SVT Offline Calibration Additional Gain Corrections – see /cal/svt.

Data Flows:

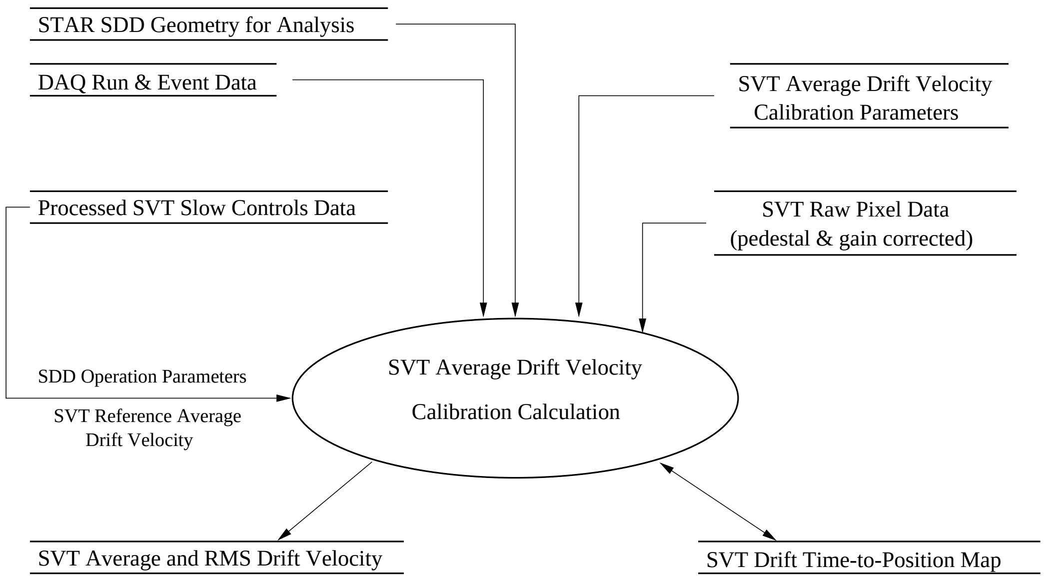

Figure 69: SVT Average Drift Velocity Calibration Software

Glossary of Terms:

Processes:

SVT Average Drift Velocity Calibration Calculation – Average drift velocity in each SDD calculated using corrected SVT pixel data from the cathode line injection events.

Data Stores:

DAQ Run and Event Data – see /cal/svt.
STAR SDD Geometry for Analysis – See /sim/det/svt.
Processed SVT Slow Controls Data – see /cal/svt.
SVT Average and RMS Drift Velocity – Mean and rms values for all calibration events during the relevant data acquisition period are included for the average drift velocities for each SDD in the SVT.
SVT Average Drift Velocity Calibration Parameters – Selection, fitting and control parameters.
SVT Raw Pixel Data – see /ana/svt.
SVT Drift Time to Position Map – see /cal/svt.

Data Flows: None

/cal/svt/profile_drift

Date of Creation: 5/31/96 Author: L. Ray
Date of Last Revision: 12/16/96 Last Modified by: L. Ray

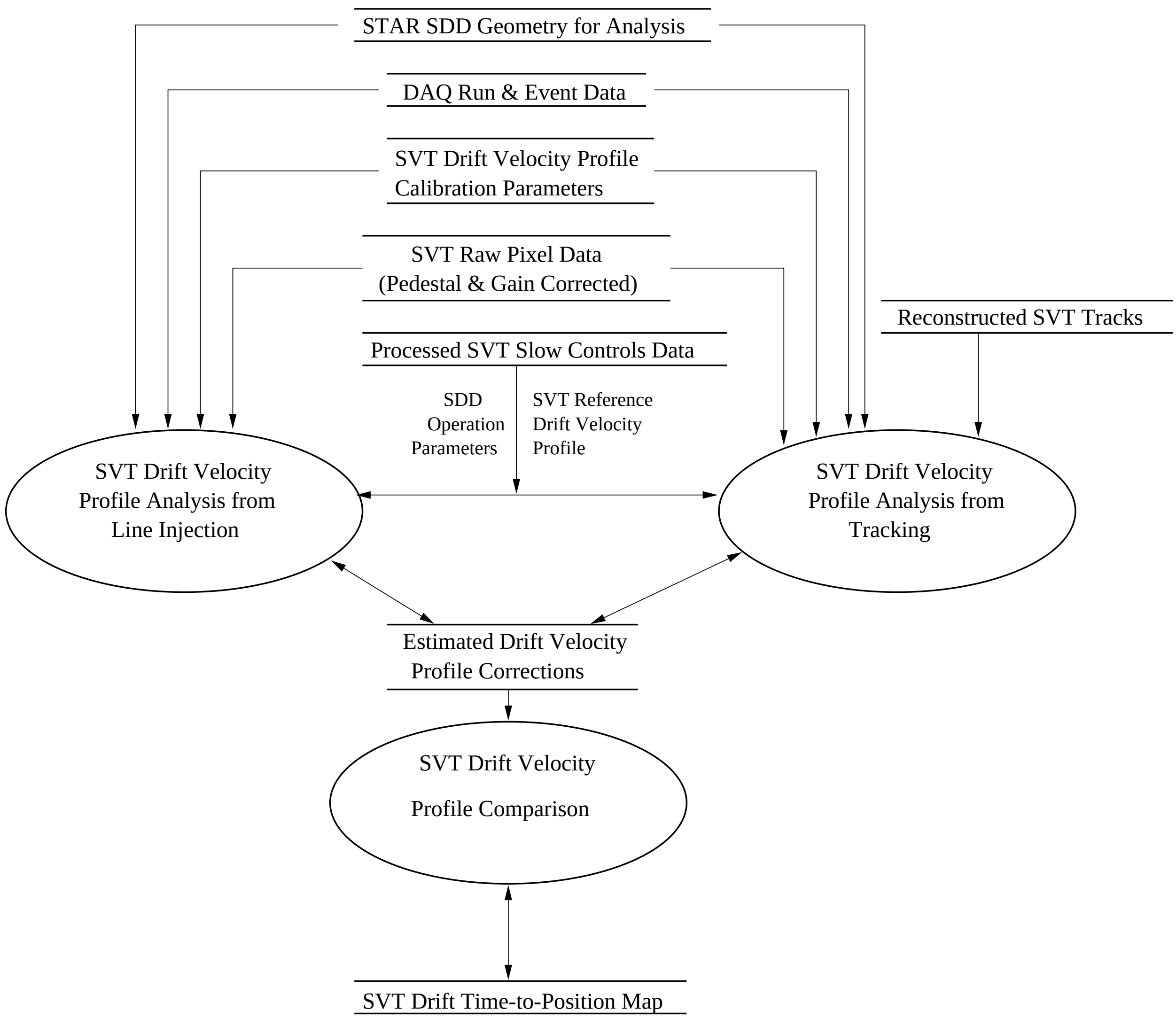

Figure 70: SVT Drift Velocity Profile and Position Correction Map Software

Glossary of Terms:

Processes:

SVT Drift Velocity Profile Analysis from Line Injection – Cathode line injection data are analyzed to determine nonuniform drift velocities across the anodes for each SDD during the relevant data acquisition period.

SVT Drift Velocity Profile Analysis from Tracking – Systematic variations in pixel ADC values for many data events during the relevant data acquisition period are analyzed. Nonuniform drift speeds are expected to result in greater or lesser averages for each pixel value. The results are used to update the SVT Drift Time to Spatial Position Map.

SVT Drift Velocity Profile Comparison – The results of the preceding two processes are compared and the final SVT Drift Time to Position Map is updated.

Data Stores:

STAR SDD Geometry for Analysis – See /sim/det/svt.

DAQ Run and Event Data –see /cal/svt.

SVT Drift Velocity Profile Calibration Parameters – Selection, fitting and control parameters.

SVT Raw Pixel Data – see /ana/svt.

Processed SVT Slow Controls Data – see /cal/svt.

Reconstructed SVT Tracks – see /ana/svt.

Estimated Drift Velocity Profile Corrections – Corrections to the nominal drift velocity for each anode and SDD from either or both methods are stored here.

SVT Drift Time to Position Map – see /cal/svt.

Data Flows:

None

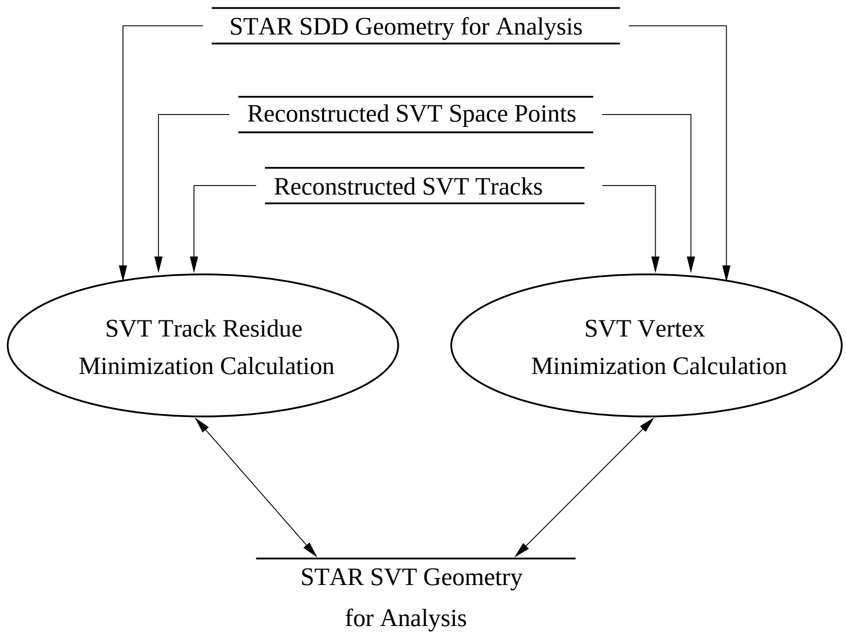

Figure 71: SVT Internal Geometry and Alignment Calibration Software

Glossary of Terms:

Processes:

SVT Track Residue Minimization Calculation – The positions and orientations of each SDD on each ladder, and that for each ladder in the SVT are relaxed such that the SVT track fit residues are minimized. Alignments in the SVT Internal Coordinate System are computed.

SVT Vertex Minimization Calculation – The positions and orientations of each SDD and ladder are relaxed in order to minimize the primary track impact parameter dispersion. Alignments in the SVT Internal Coordinate System are computed.

Data Stores:

STAR SDD Geometry for Analysis – See /sim/det/svt.
Reconstructed SVT Space Points – see /ana/svt.
Reconstructed SVT Tracks – see /ana/svt.
STAR SVT Geometry for Analysis – see /sim/geometry.

Data Flows:

None

Status:

6.4 CTF Calibrations and Corrections (/cal/ctf)

This section contains a description, list of requirements, functional model diagram (/cal/ctf, Fig. 72), glossary of terms, and a status of software report. Further information related to the calibration of the TOF/CTB is given in Ref. [27].

Description:

The CTF calibration program is intended to provide the gain and offset coefficients to obtain the multiplicity of MIP particles crossing each counter. This is achieved by using the tracks reconstructed in the TPC. These tracks are extrapolated to the CTF and matched to hits using reconstruction software (see /ana/ctf). Then the ADC signal in every counter is compared with the number of tracks crossing it. Variations in offsets and gains thus detected are removed using correction coefficients for each CTB/TOF slat. Dead, hot and problematic channels are identified and recorded. Finally, the velocity of the very high momentum tracks from event reconstruction are accumulated and compared to the speed of light to obtain relative and absolute timing offset corrections.

Requirements:

1. The gain and offset corrections must provide sufficiently stable CTF multiplicity determinations such that level 0, 1 and 2 triggering of physics events based on CTF multiplicity distributions, asymmetries, correlations, etc. are not affected and such that false triggers for these multiplicity scenarios do not occur at an unacceptable level.
2. The relative and absolute timing corrections must be sufficiently accurate to produce stable PID determination over the momentum range accessible to the STAR TOF detector.
3. The TOF calibration software is required to provide relative and absolute timing corrections at an accuracy comparable to the timing resolution of the slat-PMT system.

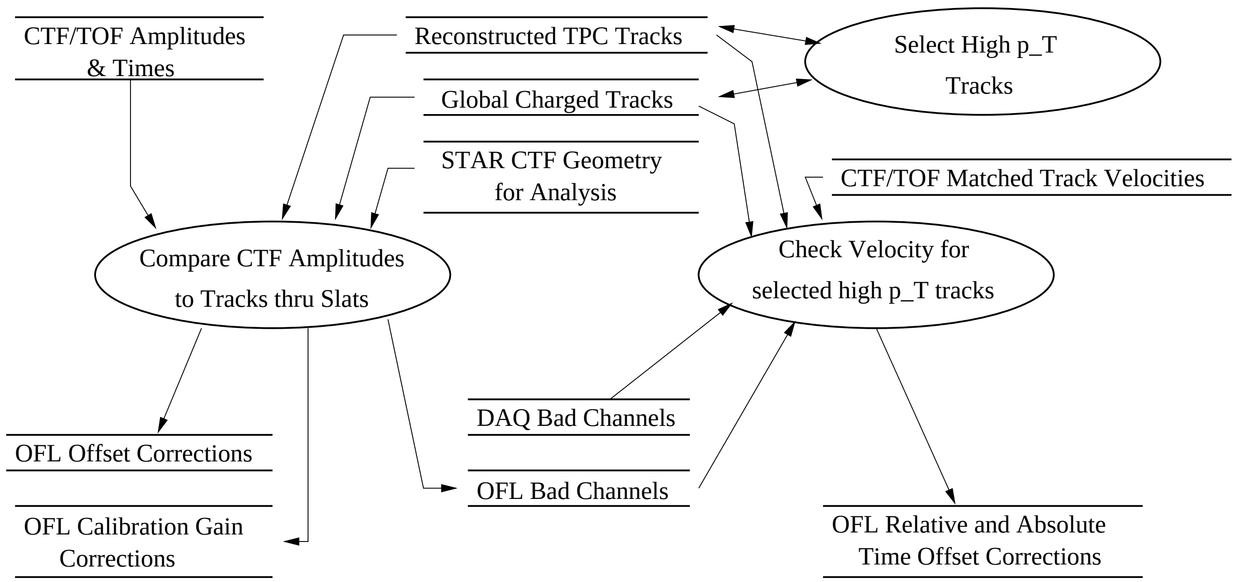

Figure 72: CTF Calibration Software

Glossary of Terms:

Processes:

Compare CTF Amplitudes to Tracks Through Slats – The number of tracks reaching each slat is counted and compared to the ADC signal in order to extract gains. Offsets are obtained when no tracks hit the counters.

Select High p_T Tracks – TPC and/or global charged tracks are selected based on momentum, pseudorapidity, azimuthal angle, separation from neighboring tracks, etc. and flagged for later use.

Check Velocity for Selected High p_T Tracks – Computed velocities for selected TPC and/or global tracks (from /ana/global/pid/tof) are histogrammed and compared channel to channel for relative timing corrections and are also compared to the speed of light for absolute timing corrections.

Data Stores:

CTF/TOF Amplitudes and Times – see /ana/ctf.
Reconstructed TPC Tracks – see /ana/tpc.
Global Charged Tracks – see /ana/global.
STAR CTF Geometry for Analysis – See /sim/geometry.
CTF/TOF Matched Track Velocities – see /ana/global/pid/tof.
Offline Offset Corrections – see /ana/ctf.
Offline Calibration Gain Corrections – see /ana/ctf.
DAQ Bad Channels – see /ana/ctf.
Offline Bad Channels – see /ana/ctf.
Offline Relative and Absolute Time Offset Corrections – see /ana/ctf.

Data Flows:

None

Status:

6.5 EMC Calibrations (/cal/emc)

This section contains a description, list of requirements, functional model diagrams for the top level (/cal/emc, Fig. 73) and for two sublevels including slow controls data processing (/cal/emc/esl, Fig. 74) and gain and energy calibration (/cal/emc/energy, Fig. 75), glossaries for each diagram, and a status of software report.

Description:

The EMC PMT and SMD calibration and correction software is designed to provide offline checks and/or calculation of pedestals for each channel, determine a list of dead, hot or problematic channels for the relevant run period, obtain relative channel by channel gain corrections to be applied in addition to that used in the onboard electronics data processing prior to DAQ, and determine absolute ADC signal to actual energy deposition conversion factors for each EMC tower, with or without depth segmentation, and for each SMD wire or strip.

A number of calibration methods are possible for determining the relative gains and the overall energy calibration. Direct charge injection into the onboard electronics will be used by experiment control to determine channel by channel gain corrections to be used during each data acquisition period. However, variations in light propagation and PMT efficiencies are not regulated in this way and must be monitored and the data corrected offline. Direct light injection (*e.g.* via photo emitting diodes, xenon flashers) and movable radioactive source data when analyzed during offline calibrations can be used to correct for these additional, channel by channel variations.

Absolute ADC signal to energy deposition conversion factors can be obtained by analyzing radioactive source data and from inclusive sums of E/p measurements for electrons using the calorimeter and TPC (or global) tracking. SMD energy deposition can be monitored and corrected by analyzing inclusive sums of electrons and photons into the EMC SMD grid. The latter input information derives from post-DST physics analysis.

Finally, the relevant slow controls data for the EMC PMT and SMD are processed for the relevant data taking period to obtain interpolation tables of corrections, determine periods of validity for each channel, and to monitor detector performance with respect to previously determined operating tolerances and time constants.

Requirements:

1. The EMC offline calibration software is required to provide channel by channel corrections for electronic gains and PMT efficiencies such that stable, uniform (nominally $\sim$1%) energy deposition measurements across the full (η,ϕ) domain is achieved.

2. The EMC offline calibration software is required to provide channel by channel corrections for SMD wire/strip responses and electronic gains such that stable,

uniform (nominally $\sim$1%) energy deposition measurements across the full SMD (η,ϕ) grid is achieved.

3. The EMC offline calibration software is required to provide overall, absolute energy deposition conversion factors. This is necessary in order to determine neutral particle energy production in the collision by subtracting the energy deposition from charged particles (from TPC tracking) from the total measured amount. This requirement is also driven by invariant mass resolution for meson (ϕ, J/ψ, ψ', etc.) decay studies.

4. The same EMC offline calibration software must be used for both real data and simulations.

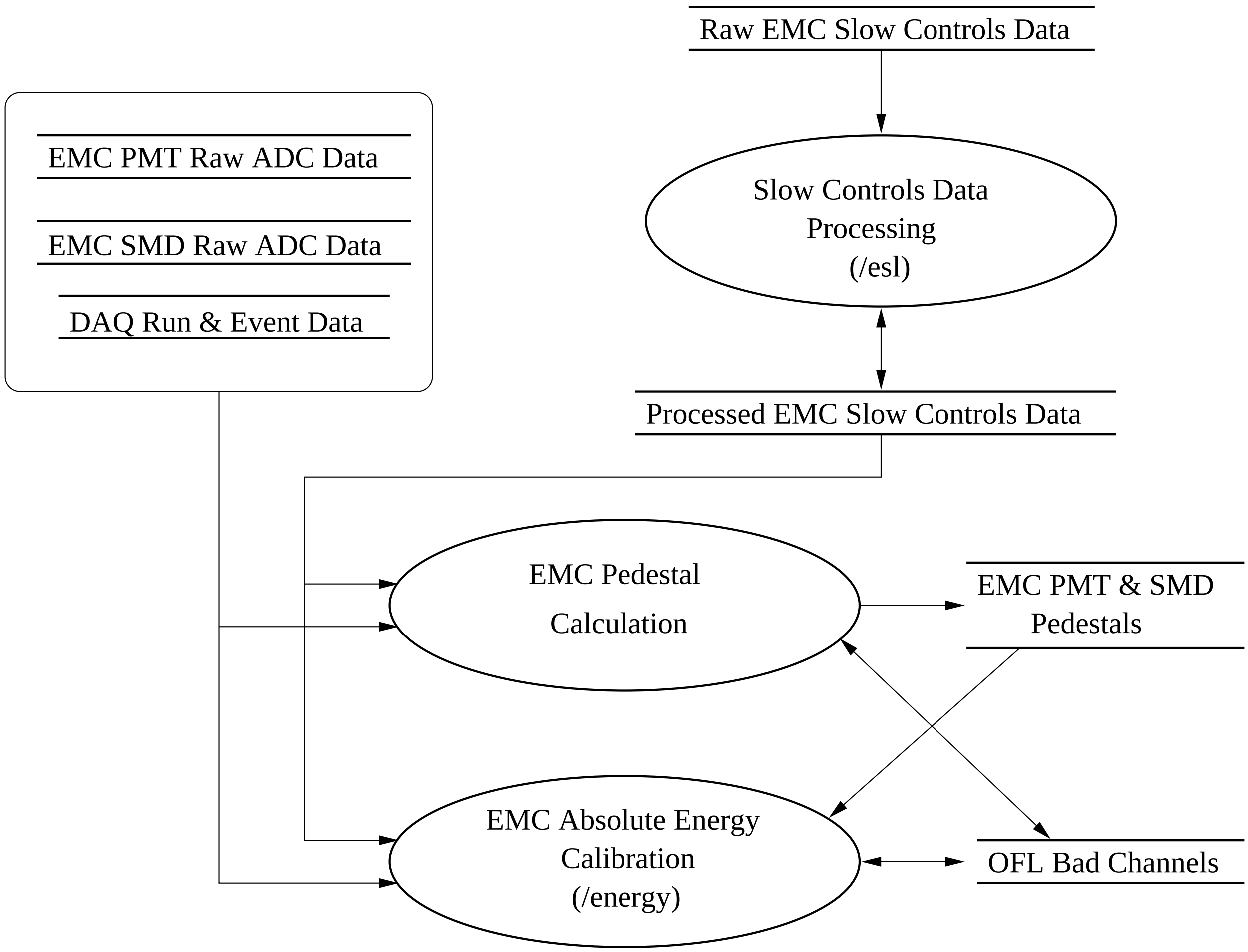

Figure 73: EMC Calibration Software – Top Level

Glossary of Terms:

Processes:

Slow Controls Data Processing (/esl) – Raw EMC Slow Controls data are time averaged and smoothed into a more compact and useful form for the remaining calibration software. Outliers are rejected and data are combined. Derived parameters, such as PMT gains, are monitored throughout the relevant data acquisition period. Periods of validity and problematic values are identified.

EMC Pedestal Calculation – This process calculates the pedestals (mean and rms) for each EMC PMT and SMD channel and checks the adequacy of the online algorithm. Correlated noise between channels (particularly the SMD) are also evaluated.

EMC Absolute Energy Calibration (/energy) – A variety of calibration data (*e.g.* light injection, radioactive sources, inclusive sums of electrons and photons) are analyzed in order to produce ADC signal to energy deposition conversion factors for the barrel and end cap EMC as well as the SMD.

Data Stores:

EMC PMT Raw ADC Data – see /sim/det/emc.

EMC SMD Raw ADC Data – see /sim/det/emc.

DAQ Run and Event Data – Run and event by event information from DAQ including: (1) trigger type, parameters, thresholds, pre-scalers, etc., (2) bad channels and saturated channels list, and (3) DAQ status and error conditions (if any).

Raw EMC Slow Controls Data – Slow Controls or Hardware Control information acquired during the relevant data acquisition period. Included are PMT voltages, SMD wire/strip voltages, electronic gains, relevant operating temperatures, PMT light injection data, radioactive source type and location information, etc. This also includes gains, pedestals and zero suppression thresholds used in the online data analysis.

Processed EMC Slow Controls Data – A time averaged, smoothed and more compact version of the Raw EMC Slow Controls Data which is in a suitable format for the offline calibration software.

EMC PMT and SMD Pedestals – ADC values for each PMT and SMD channel with no EMC hits; mean and rms values for many "empty" events. Used for both simulated and real pedestals. Obtained from slow controls readout or from offline calibration.

Offline Bad Channels – List of bad EMC PMT and SMD channels (dead, hot, jittery or otherwise problematic) determined by offline analysis of inclusive sums of events.

Data Flows:

None

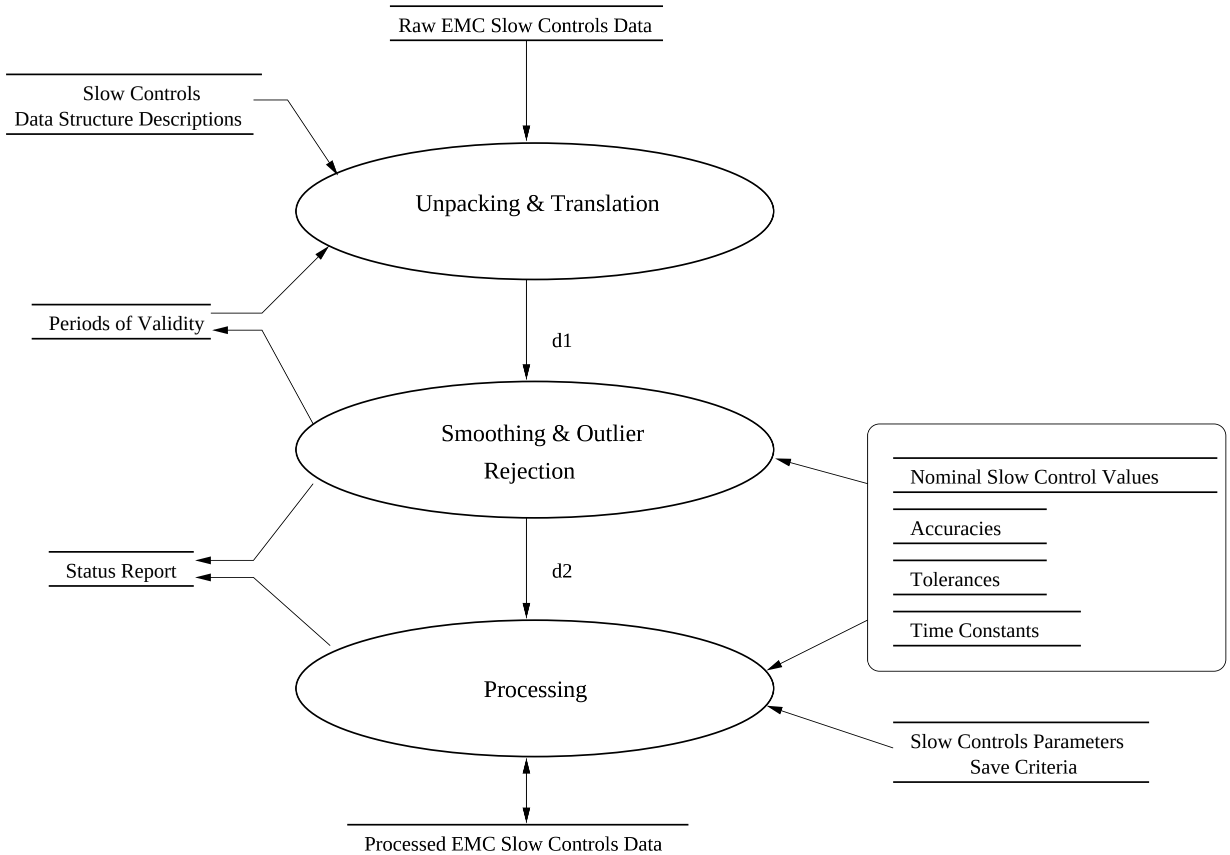

Figure 74: EMC Slow Controls Data Processing Software

Glossary of Terms:

Processes:

Unpacking and Translation – Raw EMC Slow Controls Data are deciphered into individual, calibrated components according to the prescriptions in the data structure description.

Smoothing and Outlier Rejection – Out-of-tolerance values are rejected, with appropriate notification to Online. Spurious values not consistent with a physical time constant may be rejected also. Surviving values are time averaged.

Processing – Essentially redundant values are averaged together and any other necessary calculations are performed. The resulting derived values are then handled in the same way as values directly read by slow controls.

Data Stores:

Raw EMC Slow Controls Data – see /cal/emc.

Slow Controls Data Structure Description – Definition and description of EMC Slow Controls raw data format and structure.

Periods of Validity – Periods during which processed EMC Slow Controls data are deemed to be valid. This list might be edited by /cal/emc/esl, by Slow Controls, or by hand.

Status Report – Results of time averaging, outlier removal, periods of validity, and anomalous parameters are noted for the EMC Slow Controls data. This information is used for offline monitoring of event data throughout a data acquisition period and may be used to notify online of problematic hardware behavior in the EMC.

Nominal Slow Controls Values – Nominal, expected values for EMC Slow Controls parameters to serve as a reference for comparing actual values. These may be used offline if no other valid information is available.

Accuracies – Expected rms errors of EMC sensors (voltage monitor, temperature gauge, etc.), together with their instrumentation.

Tolerances – Allowed deviation of EMC sensor from the nominal value.

Time Constants – Physical time constants expected for various EMC parameters; used to smooth measurements and to detect spurious values.

Slow Controls Parameters Save Criteria – List of processed EMC Slow Controls information and other criteria which determine what processed slow controls data will be recorded in the Processed EMC Slow Controls Data Store.

Processed EMC Slow Controls Data – see /cal/emc.

Data Flows:

d1 – Computed raw EMC Slow Controls information.

d2 – Smoothed (time averaged) and filtered EMC Slow Controls data.

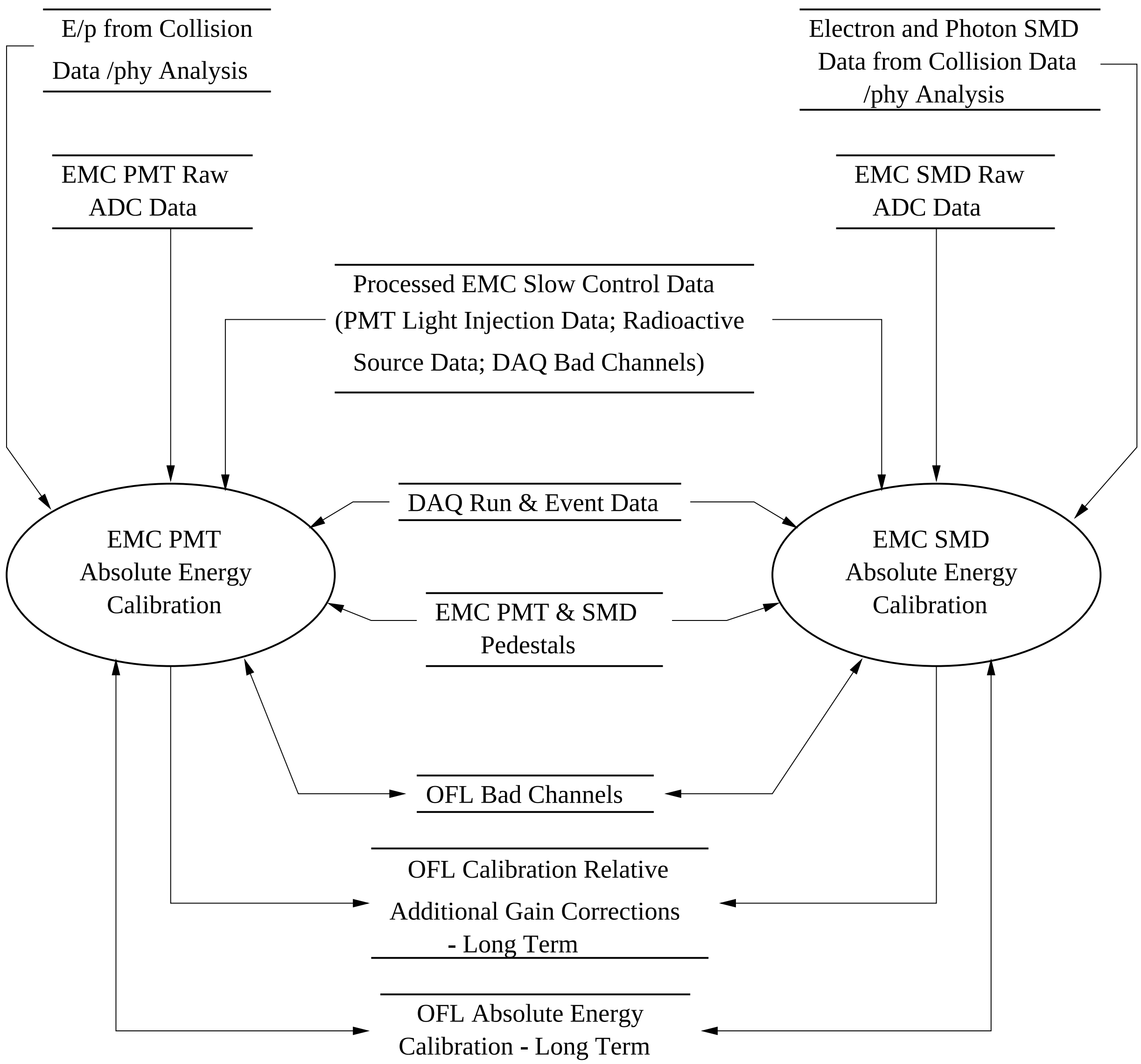

Figure 75: EMC Absolute Energy Calibration Software

Glossary of Terms:

Processes:

EMC PMT Absolute Energy Calibration – Analysis of light injection and radioactive source data and evaluation of E/p inclusive data for electrons. Results include offline bad channels list, additional, relative channel by channel PMT gain corrections and absolute energy calibration constants.

EMC SMD Absolute Energy Calibration – Analysis of radioactive source data and electron versus photon shower patterns from inclusive sums of collision data. Results include offline bad channels list, additional, relative channel by channel SMD wire/strip gain corrections and absolute energy calibration constants.

Data Stores:

E/p from Collision Data Physics Analysis (/phy) – Total energy (E) divided by total momentum (p) for reconstructed electrons from EMC energy deposition and TPC or global tracking analysis for inclusive sums over many collision events. Obtained over long time period by post-DST physics analysis of reconstructed events.

EMC PMT Raw ADC Data – see /sim/det/emc.

Electron and Photon SMD Data from Collision Data Physics Analysis (/phy) – Inclusive SMD energy deposition distributions on the SMD (η,ϕ) grid for electrons and photons determined over a long time period by post-DST physics analysis of reconstructed events.

EMC SMD Raw ADC Data – see /sim/det/emc.

Processed EMC Slow Controls Data – see /cal/emc.

DAQ Run and Event Data – see /cal/emc.

EMC PMT and SMD Pedestals – see /cal/emc.

Offline Bad Channels – see /cal/emc.

Offline Calibration Relative Additional Gain Corrections - Long Term – Channel by channel additional gain corrections for each PMT and SMD wire/strip to be used in addition to the online gain corrections.

Offline Absolute Energy Calibration - Long Term – Channel by channel ADC to energy deposition conversion factors for the PMTs and SMD wire/strips.

Data Flows:

None

Status:

6.6 MWC Calibrations and Corrections (/cal/mwc)

This section contains a description, list of requirements, functional model diagram (/cal/mwc, Fig. 76), glossary of terms, and a status of software report.

Description:

The MWC calibration program is intended to provide geometrical and drift correction coefficients. In addition TPC off-line calibrations with a radioactive source can be a good way to localize dead or inefficient channels.

Requirements:

The geometrical and drift corrections must provide sufficiently stable MWC multiplicity determinations such that level 0, 1 and 2 triggering of physics events based on MWC multiplicity distributions, asymmetries, correlations, etc. are not affected and such that false triggers for these multiplicity scenarios do not occur at an unacceptable level.

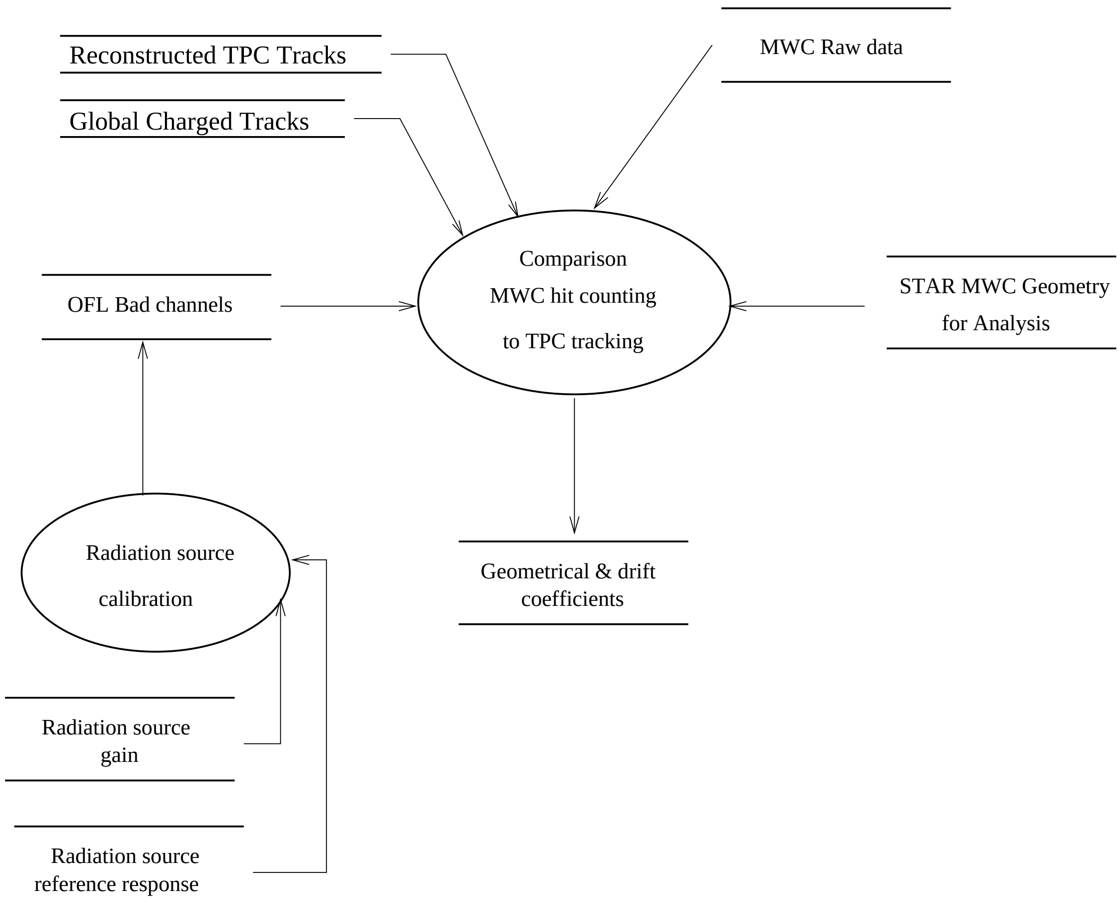

Figure 76: MWC Calibration Software

Glossary of Terms:

Processes:

Comparison MWC Hit Counting to TPC Tracking – The signal in each MWC sector is compared with the number of reconstructed tracks crossing it. When TPC tracks are used only wires at low rapidities can be calibrated.

Radiation Source Calibration – Data taken with a radiation source are analyzed to determine dead or inefficient channels.

Data Stores:

Reconstructed TPC Tracks – see /ana/tpc.

Global Charged Tracks – see /ana/global.

MWC Raw Data – see /ana/mwc and /sim/det/mwc.

Offline Bad Channels – see /ana/mwc.

STAR MWC Geometry for Analysis – see /sim/geometry.

Radiation Source Gain – Nominal gains for radioactive source excitation of MWC wire/channels.

Radiation Source Reference Response – Nominal MWC wire signal response for specified radioactive sources.

Geometrical and Drift Coefficients – see /ana/mwc.

Data Flows:

None

Status:

6.7 VPD Calibrations and Corrections (/cal/vpd)

This section contains a description, list of requirements, functional model diagram (/cal/vpd, Fig. 77), glossary of terms, and a status of software report.

Description:

The VPD calibration software determines relative timing corrections for each Cherenkov-PMT, absolute VPD East versus VPD West timing corrections, beam-beam intersection diamond geometry and position, the beam-beam luminosity profile distribution for a given run period, and the luminosity profile distribution for the VPD selected region of the beam diamond for the given run period. These quantities are computed for inclusive sums of many events for a given run period.

The VPD calibration program compares the on-line vertex position with that obtained with the tracking detector off-line. By calculating the vertex position with a selected Cherenkov-PMT counter the time constants of that counter can be calibrated.

The beam diamond geometry and position as well as the luminosity profile distribution (along the beam direction) and the luminosity profile distribution of the VPD selected region of the intersection diamond are determined by inclusive sums of primary vertices for many events during a run period using both the results of tracking analyses and analyses of corrected VPD TDC data. The beam diamond and luminosity information may apply to each beam bunch crossing and/or the average over all bunch crossings and will be evaluated during each beam storage period throughout the several hours of useful storage in the RHIC rings. These results are also useful for offline monitoring throughout a run period.

Requirements:

The VPD channel by channel timing corrections should provide accurate and stable determination of the primary event vertex location along the beam axis, using any one of the VPD counters, to an accuracy comparable to that attainable given the intrinsic time resolution of the Cherenkov counter/PMT system.

/cal/vpd

Date of Creation: 11/9/95
Date of Last Revision: 12/16/96

Author: Pablo Yepes
Last Modified by: L. Ray

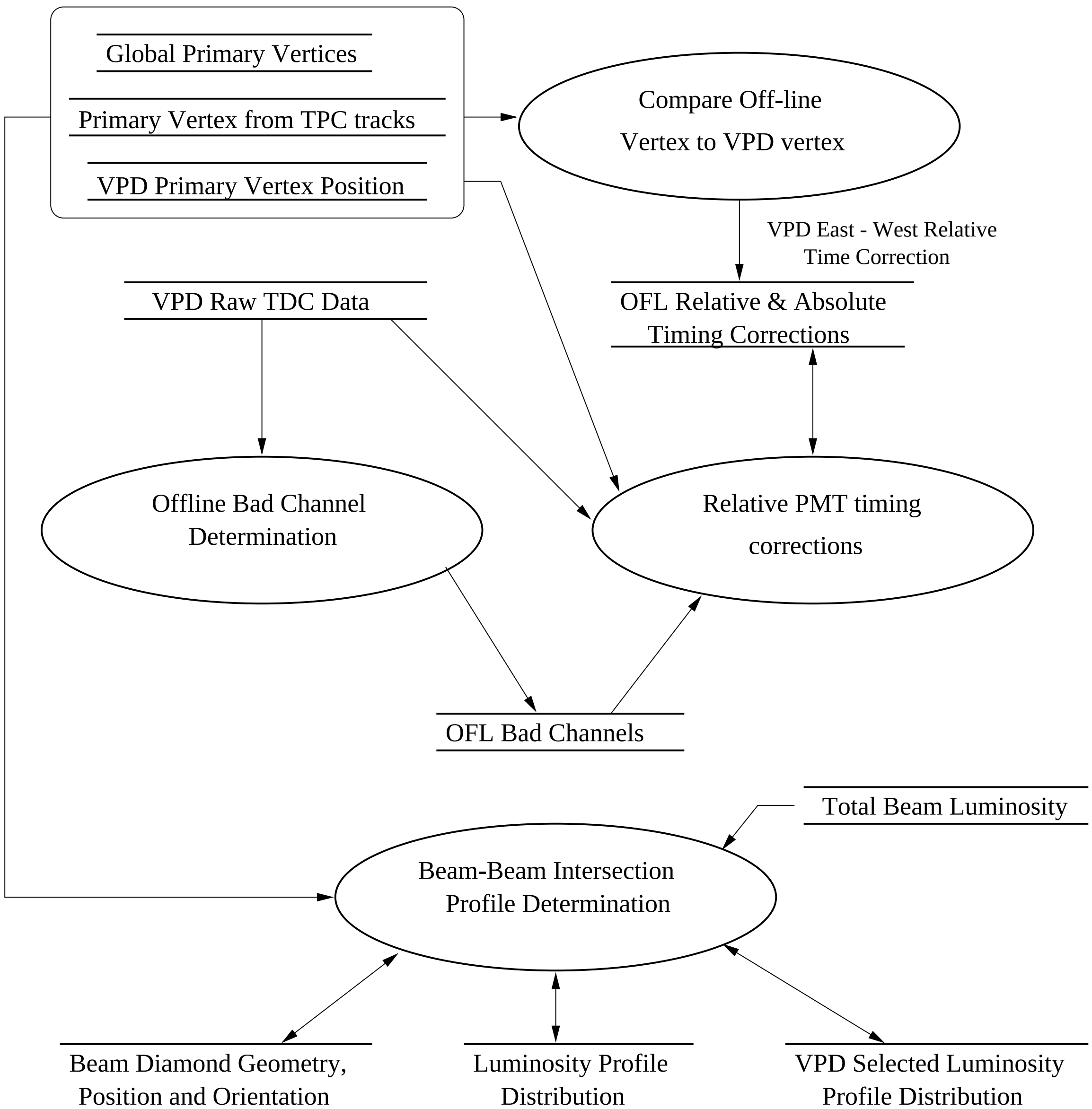

Figure 77: VPD Calibration Software

Glossary of Terms:

Processes:

Compare Offline Vertex to VPD Vertex – Primary vertices determined by offline TPC and/or global tracking are compared with that determined by analysis of the VPD timing to obtain overall, absolute VPD East versus VPD West timing corrections.

Offline Bad Channel Determination – Raw VPD TDC histograms are collected. Dead, hot or problematic channels are identified and reported.

Relative PMT Timing Corrections – Primary vertices from the VPD detectors and from TPC and/or global tracking and vertex finding software are compared for many events for cases where the leading time signal occurred for each successive Cherenkov/PMT counter for both the East and West end VPDs. Relative channel to channel timing corrections are thus obtained.

Beam-Beam Intersection Profile Determination – Primary collision vertex positions from tracking analysis and from analysis of corrected VPD TDC data are compared and analyzed to determine and/or update the beam diamond geometry and position (in the STAR Coordinate System), the full luminosity profile distribution, and the luminosity profile distribution in the VPD selected region.

Data Stores:

Global Primary Vertices – see /ana/global.
Primary Vertex from TPC Tracks – see /ana/tpc/tpp.
VPD Primary Vertex Position – see /ana/vpd.
VPD Raw TDC Data – see /sim/det/vpd.
Offline Relative and Absolute Timing Corrections – see /ana/vpd.
Offline Bad Channels – see /ana/vpd.
Total Beam Luminosity – see /cal/tpc/tdt.

Beam Diamond Geometry, Position and Orientation – Data store containing nominal values and updated values or corrections for the beam-beam intersection region geometrical shape, position and orientation (*i.e.* beam axis direction) in the global STAR Coordinate System throughout the run period. Both average values and individual bunch crossing values may be included.

Luminosity Profile Distribution – Data store containing nominal values and updated values or corrections for the total beam-beam luminosity profile distribution along the beam axis throughout the run period. Both average values and individual bunch crossing values may be included.

VPD Selected Luminosity Profile Distribution – Data store containing nominal values and updated values or corrections for the luminosity profile for the VPD selected events along the beam axis throughout the run period. Both average values and individual bunch crossing values may be included.

Data Flows: None

Status:

6.8 Global Calibrations and Corrections (/cal/global)

This section contains a description, list of requirements, top level functional model diagram (/cal/global, Fig. 78), and four sublevel diagrams including that for global SVT-TPC alignment (/cal/global/svt_tpc_align, Fig. 79), global CTB/TOF alignment (/cal/global/ctf_align, Fig. 80), global EMC/SMD alignment (/cal/global/emc_-align, Fig. 81), and global magnetic field and alignment calibration check (/cal/global-/magnet, Fig. 82). Each diagram is followed by a glossary of terms. A status of software report is given at the end of this section.

Description:

The global alignment software is responsible for adjusting the overall positions and orientations of the tracking detectors (TPC, SVT and eventually the FTPC) relative to each other [28] as well as the relative positions and orientations of the CTB/TOF slats, the EMC towers and the SMD wires with respect to the TPC. Global track residuals, primary vertex positions, survey measurements, TPC track to CTB/TOF hit projections, and TPC track to EMC shower projections are used to make the alignment corrections. The adjustments are included as updates to the TPC and SVT Internal Coordinate Systems and the CTF and EMC geometry data stores, all with respect to the global STAR Coordinate System.

An overall check of the magnetic field is possible by looking at the reconstructed masses of K_s^0 and Λ particles. Any shift of the reconstructed mass from its nomimal value would indicate a poor knowledge of the momentum of the decay products. This involves physics analysis software but since its purpose is to check the field, it is included in this branch, and it is more of a task rather than a specific correction algorithm.

A final consistency check of the overall detector alignment in the global STAR Coordinate System is possible by using the reconstructed V0 decay vertices from $\gamma Z \to e^+e^-Z$ conversion. These occur throughout the detector but mainly within the bulk structural members and the beam pipe and should provide a three-dimensional outline of the major structural components in the inner part of the detector and of the beam pipe. Comparison between these reconstructed positions and that obtained from survey measurements provides an independent test of the global alignment procedures.

Requirements:

1. Relative detector alignment corrections should be obtained which allow accurate and stable determination of particle tracks such that the intrinsic momentum resolution, impact parameter resolution, and secondary vertex reconstruction capabilities of STAR are achieved and are not compromised by uncorrected global detector misalignments.

2. The overall magnetic field strength should be independently checked and verified

based on physics reconstructed quantities, *e.g.* reconstructed invariant masses of parent particles.

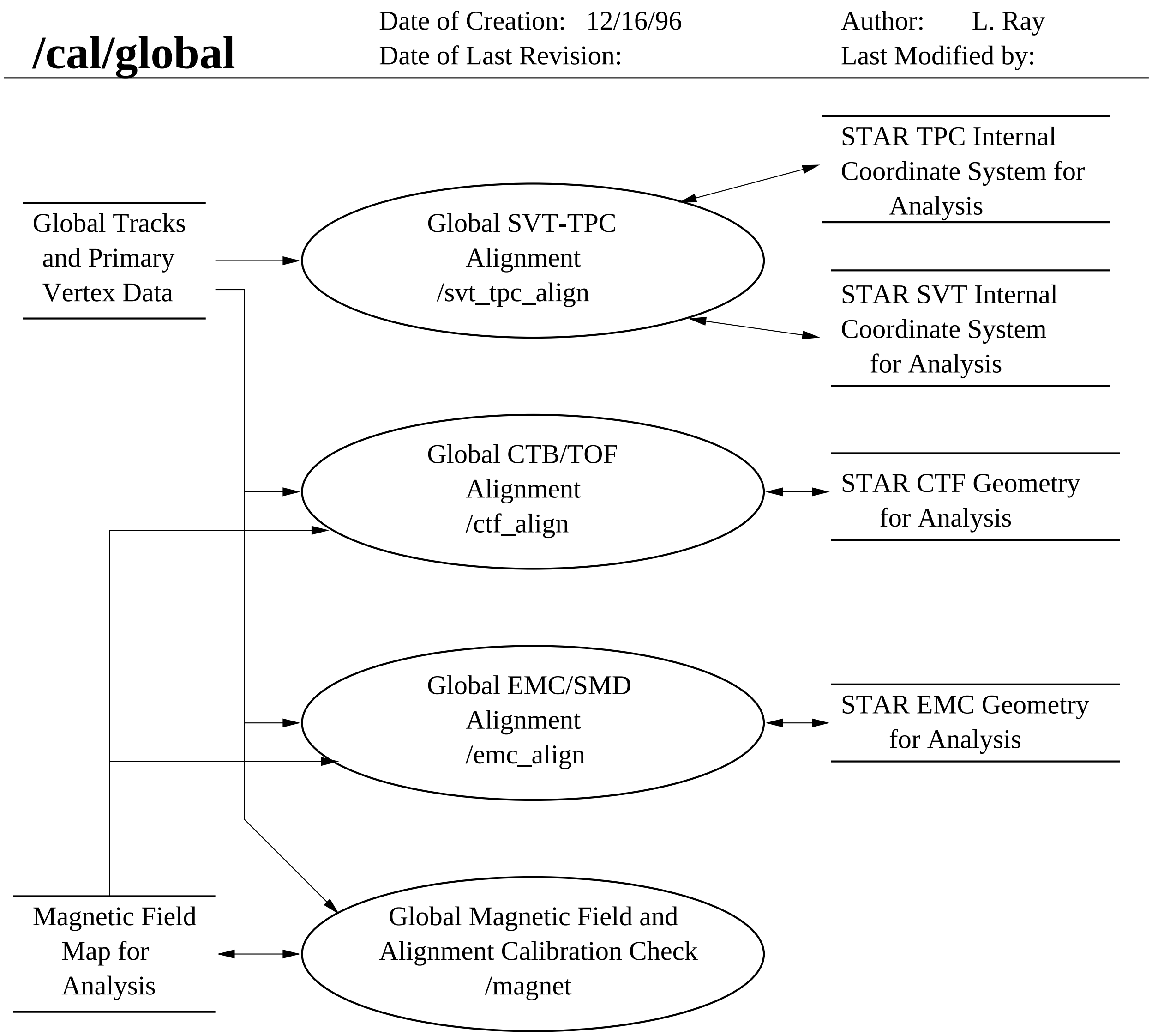

Figure 78: Global Calibration and Alignment Software - Top Level

Glossary of Terms:

Processes:

Global SVT-TPC Alignment – Process which computes small adjustments to the overall locations of the SVT and/or TPC detectors with respect to each other and the global STAR Coordinate System.

Global CTB/TOF Alignment – Process which computes small adjustments to the locations of the CTB/TOF slats with respect to the TPC and the global STAR Coordinate System.

Global EMC/SMD Alignment – Process which computes small adjustments to the locations of the EMC towers and SMD wire grids with respect to the TPC and the global STAR Coordinate System.

Global Magnetic Field and Alignment Calibration Check – Process which checks the overall value of the magnetic field by analyzing V0 decays and invariant mass reconstruction for K_s^0 and Λs, etc. This also provides an independent, consistency check of the overall alignment of the tacking detectors by way of $\gamma Z \rightarrow e^+e^-Z$ vertex reconstruction.

Data Stores:

Global Tracks and Primary Vertex Data – Generic data store representing reconstructed tracking and vertex information.

Magnetic Field Map for Analysis – See /sim/magnet and /cal/magnet.

STAR TPC Internal Coordinate System for Analysis – see /sim/geometry.

STAR SVT Internal Coordinate System for Analysis – see /sim/geometry.

STAR CTF Geometry for Analysis – See /sim/geometry.

STAR EMC Geometry for Analysis – See /sim/geometry and /sim/det/emc.

Data Flows:

None

/cal/global/svt_tpc_align

Date of Creation: 12/16/96 | Author: L. Ray
Date of Last Revision: | Last Modified by:

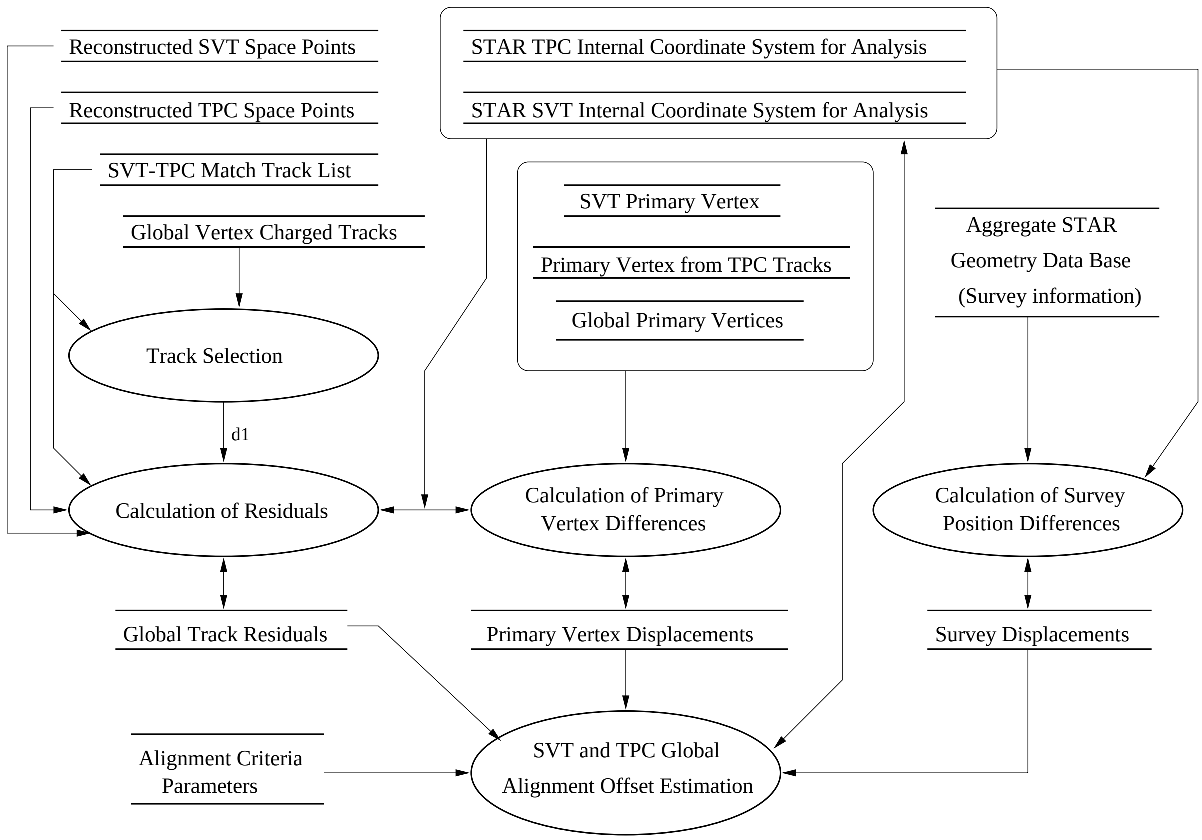

Figure 79: Global SVT and TPC Alignment Correction Software

Glossary of Terms:

Processes:

Track Selection – Matched and refitted SVT and TPC tracks are selected based on momentum, pseudorapidity, azimuthal angle, separation from neighboring tracks and space points, for any given TPC sector and SVT wafer (or octant) combination.

Calculation of Residuals – Selected SVT-TPC matched tracks are refitted (if STAR SVT or TPC Internal Coordinate Systems have been updated) and global track fit residuals calculated.

Calculation of Primary Vertex Differences – The displacement and error between the reconstructed primary vertex found using SVT tracks and TPC tracks separately are computed for the same event using the current SVT and TPC locations in the global STAR Coordinate System. The mean and rms values of these displacements are calculated for many events in the calibration event sample. The location of the global primary vertex is checked for consistency.

Calculation of Survey Position Differences – The displacements and errors between the measured locations of various SVT and TPC survey marks and the corresponding positions obtained from the software adjusted positions are computed. The positions are computed with respect to the global STAR Coordinate System, *i.e.* the magnet.

SVT and TPC Global Alignment Offset Estimation – Calculation of overall SVT and/or TPC detector shifts based on global track residuals, primary vertex displacements, survey mark displacements, and various alignment criteria options selected by the user. The STAR SVT and/or TPC Internal Coordinate Systems are shifted with respect to the global STAR Coordinate System (magnet) as needed.

Data Stores:

Reconstructed SVT Space Points – see /ana/svt.

Reconstructed TPC Space Points – see /ana/tpc.

SVT-TPC Match Track List – see /ana/global/tracking.

Global Vertex Charged Tracks – see /ana/global.

STAR TPC Internal Coordinate System for Analysis – see /sim/geometry.

STAR SVT Internal Coordinate System for Analysis – see /sim/geometry.

SVT Primary Vertex – see /ana/svt/tracking.

Primary Vertex from TPC Tracks – see /ana/tpc/tpp.

Global Primary Vertices – see /ana/global.

Aggregate STAR Geometry Data Base – Survey position information, see /sim/geometry.

Global Track Residuals – Computed global track residuals for selected tracks; possibly for many events; including values for several assumed SVT and/or TPC positions and orientations in the global STAR Coordinate System.

Primary Vertex Displacements – Computed displacements and errors between the positions of the primary vertex determined with SVT and TPC tracks separately; includes mean and rms displacement results for many events; includes values for several assumed SVT and/or TPC positions and orientations in the global STAR

Coordinate System.

Survey Displacements – Computed displacements and errors between the measured positions of various survey marks and the adjusted positions; includes values for several assumed SVT and/or TPC positions and orientations in the global STAR Coordinate System.

Alignment Criteria Parameters – Parameters which control the alignment relaxation; weights for residuals, vertex displacements and survey mark displacements; selection options for SVT adjustment only, or simultaneous SVT and TPC adjustment, etc.

Data Flows:

d1 – List of selected global, matched SVT-TPC tracks and the global track parameters.

/cal/global/ctf_align

Date of Creation: 12/16/96 | Author: L. Ray
Date of Last Revision: | Last Modified by:

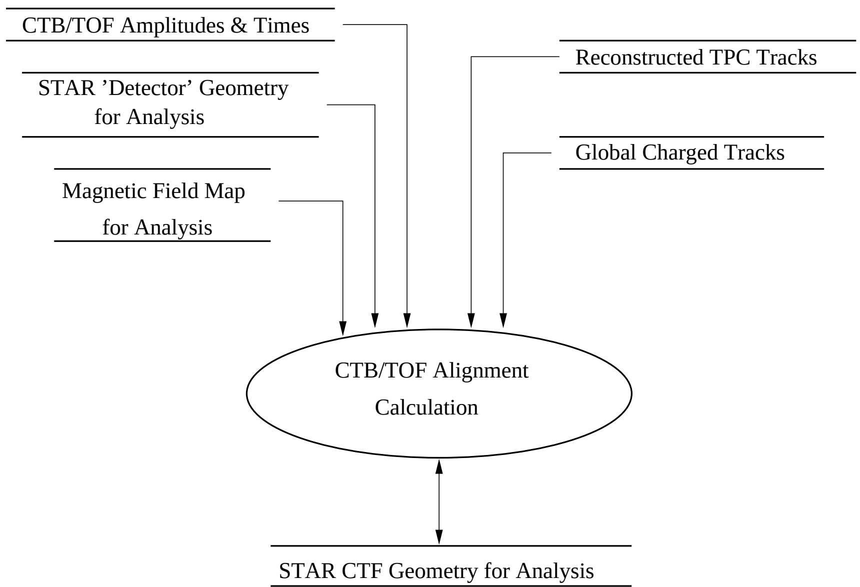

Figure 80: Global CTB/TOF Detector Alignment Calibration Software

Glossary of Terms:

Processes:

CTB/TOF Alignment Calculation – This process compares the expected hits in the CTB/TOF slats based on extrapolations of the TPC and/or global charged tracks, assuming nominal slat positions, with that actually measured for many inclusive collision events. Position and orientation corrections are determined which align the CTB/TOF slats with respect to the TPC. The positions are located with respect to the global STAR Coordinate System. The CTF Geometry data store is updated if necessary. See also /ana/global/pid/tof.

Data Stores:

CTB/TOF Amplitudes and Times – see /ana/ctf.
STAR 'Detector' Geometry for Analysis – Inclusive data stores where 'Detector' mainly includes TPC and Structural parts, see /sim/geometry.
Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.
Reconstructed TPC Tracks – see /ana/tpc.
Global Charged Tracks – see /ana/global.
STAR CTF Geometry for Analysis – see /sim/geometry.

Data Flows: None

/cal/global/emc_align

Date of Creation: 7/17/96 Author: L. Ray
Date of Last Revision: 12/16/96 Last Modified by: L. Ray

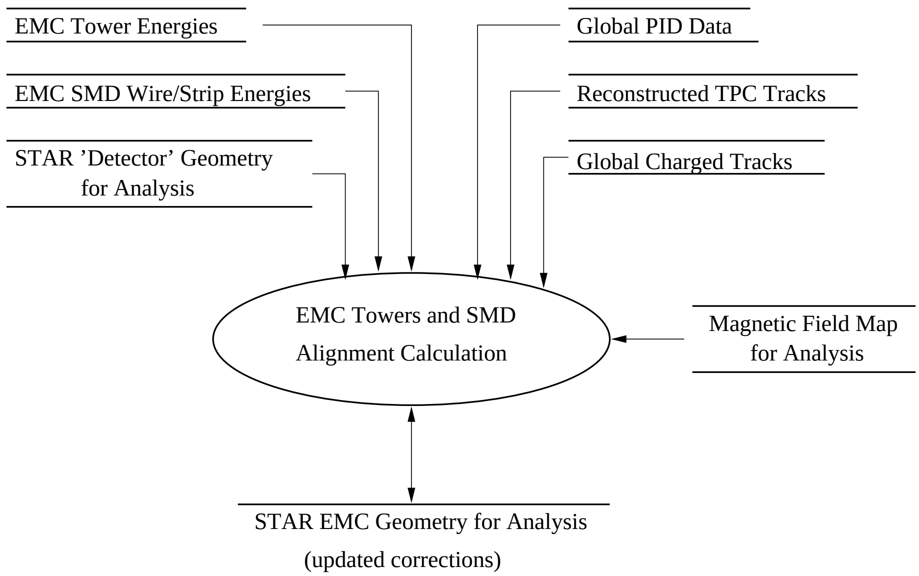

Figure 81: Global EMC Detector Alignment Calibration Software

Glossary of Terms:

Processes:

EMC Towers and SMD Alignment Calculation – This process compares the EMC Tower and SMD shower distributions expected from the reconstructed TPC and/or global tracks with the reconstructed energy depositions to check and possibly correct the individual EMC barrel and end cap towers and the SMD wire/strip sections. The STAR EMC Geometry position and alignment data base is updated if necessary.

Data Stores:

EMC Tower Energies – see /ana/emc.
EMC SMD Wire/Strip Energies – see /ana/emc.
STAR 'Detector' Geometry for Analysis – Inclusive data stores where 'Detector' mainly includes TPC, CTF and Structural parts, see /sim/geometry.
Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.
Global PID Data – see /ana/global/pid.
Reconstructed TPC Tracks – see /ana/tpc.
Global Charged Tracks – see /ana/global.
STAR EMC Geometry for Analysis – see /sim/det/emc and /sim/geometry.

Data Flows: None

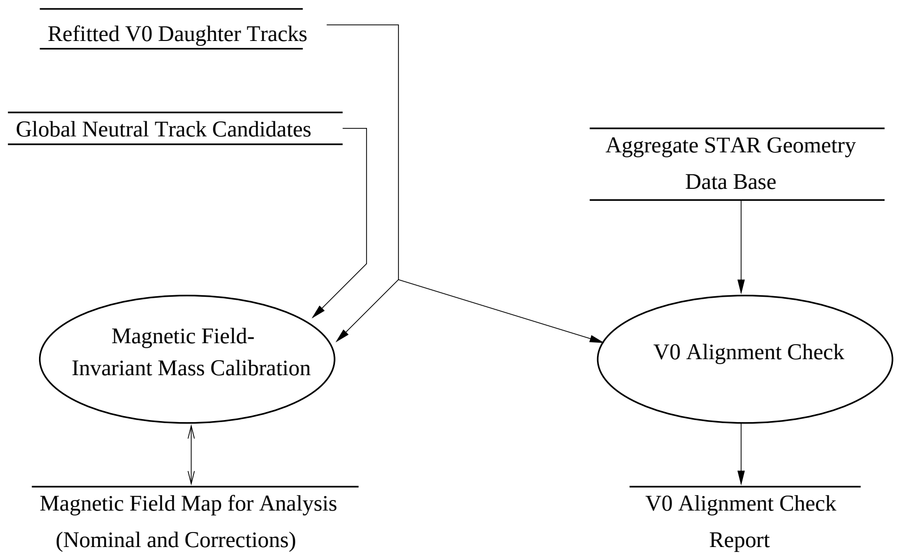

Figure 82: Global Event Reconstruction Magnetic Field and Alignment Calibration Check Software

Glossary of Terms:

Processes:

Magnetic Field - Invariant Mass Calculation – V0 decays are analyzed as a function of overall magnetic field strength to determine K_s^0, Λ, etc. invariant masses. Systematic displacements in the mean reconstructed invariant masses are used to check, and if necessary correct, the magnetic field map data store.

V0 Alignment Check – The locations of reconstructed V0 decay vertices are obtained for many events. The clustering of decay vertices (mainly electron-positron pairs from γ conversion in bulk material) should outline the structural members of the detector and the beam pipe. These locations are compared with the surveyed positions as an overall consistency check on the global alignment procedures.

Data Stores:

Refitted V0 Daughter Tracks – see /ana/global/V0.
Global Neutral Track Candidates – see /ana/global.
Magnetic Field Map for Analysis – see /sim/magnet and /cal/magnet.
Aggregate STAR Geometry Data Base – see /sim/geometry.
V0 Alignment Check Report – Results of V0 alignment check; systematic discrepancy for the location of the beam pipe, SVT support frame, etc.

Data Flows:

None

Status:

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[18] See STARLIB Software documentation for the following packages: **mwg, mws, mwu**.

[19] See STARLIB Software documentation for the following packages: **svm, evr, egr, epi, ev0, exi, tkf, dst**.

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