TOFp Functional Requirements

STAR TOFp Group
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1 The Prime Directive

To achieve the physics goals, the system must measure the flight time of tracks reconstructed in the STAR TPC with an overall time resolution on the order of 100 picoseconds. This requirement is conservative based on the performance of numerous similar TOF systems in other experiments.

It must be recognized that this requirement is also extremely generic. Strictly speaking, it makes no sense to attempt to quote a single number that summarizes the time resolution of the TOFp system. The time resolution for a single-ended TOFp slat varies by tens of picoseconds depending on the distance along the slat from the hit to the PMT. The finite propagation speed of scintillation light implies that the PMT rise time, and hence the resolution weakly, depends on the angle with respect to the slat normal defined by the path of the particle through the plastic. The larger the energy deposition for a particular hit, either from the "Landau tail" or if the particle is more heavily ionizing, then the larger the number of photoelectrons, N_{pe}, which improves the time resolution like $1/\sqrt{N_{pe}}$. Alternatively, tracks striking slats near the edges, especially those that do not pass through the full thickness, may result in lower than normal numbers of photoelectrons and hence somewhat poorer time resolution. All of these effects can be isolated track-by-track and corrected offline using the information from the global tracking and the TOFp ADCs.

Full simulations described in the TOFp Proposal [1] include correctly all of these effects, their correction offline, in the presence of all GEANT physics "on" and the application of the public track reconstruction and extrapolation software. They imply the proposed TOFp system should have an *average* time resolution, including all effects and after all corrections, near 80 ps. Including all effects in the simulations track by track results *on average* in clean π/K identification of at least the 2σ level for track momenta up to $\sim$1.7 GeV/c, and π+K/p identification up to $\sim$3 GeV/c.

The aspects of the TOF system, and its interfaces to other STAR subsystems, that are required to meet this performance goal are outlined here. Familiarity with the TOFp proposal will be assumed.

Table 1 provides a general summary of system parameters and requirements. Shown in Figure 1 is a schematic overview of the major connections requirements. For more details, see below and Ref. [1].

2 Executive Summary

Table 1: A summary of the requirements.

Requirement	Specification	Comments
Tray Interior		
Scintillator	41	Bicron BC420, 2×4×20 cm^3
PMTs[†]	41	Hamamatsu R5946, Mesh Dynode, 1.5" diameter
Bases	41	Cockroft-Walton, "HVSys" from Astakhov *et al.*
Tray[†]	1	Welded Aluminum
Foam[†]		Last-A-Foam, 3 lbs/ft^3
FEE Boards	10	Custom, N. Adams version 5, one per slat row
Geometry		
Configuration	1×5 + 9×4	number of slat rows in $(\eta \times \phi)$
Slat angle	5.5°-12°	optimized near $\eta \sim 0$
Envelope I.R.[†]	207.75 cm	
Envelope O.R.[†]	219.5 cm	
Connections		
Signal cables	82	Coaxial, 400 ns
Max Cable Attn	20 dB/100m @ 200 MHz	
Max Ampl X-talk	1%	
Max Time X-talk	20ps	
HVSys Bus	10 posn	simple ribbon cable, ~100 ft
Low voltage	few conductors	
Thermocouple R/O	6	3 in tray, 3 along cable path
Heat removal	TPC Water	tray "T's" into TPC water supply
Digitization		
ADC/TDC modules	CAMAC	Commercial, LRS or Phillips
ADC resolution	≥10 bits	
TDC resolution	≥10 bits	
TDC conversion	≤50 ps/bin	
TDC full scale	100 ns	
Digitization time	$\leq 100\ \mu s$	
Power, Total	<56W	
Power, Bases	<16W	req. <0.4 W/cell for 40 cells
Power, FEE	<40W	req. <4 W/board for 10 boards
Disc. Time resn.	<40ps	(meas. under specific conditions)

[†] Same as in the STAR-CTB.

3 Major connections schematic

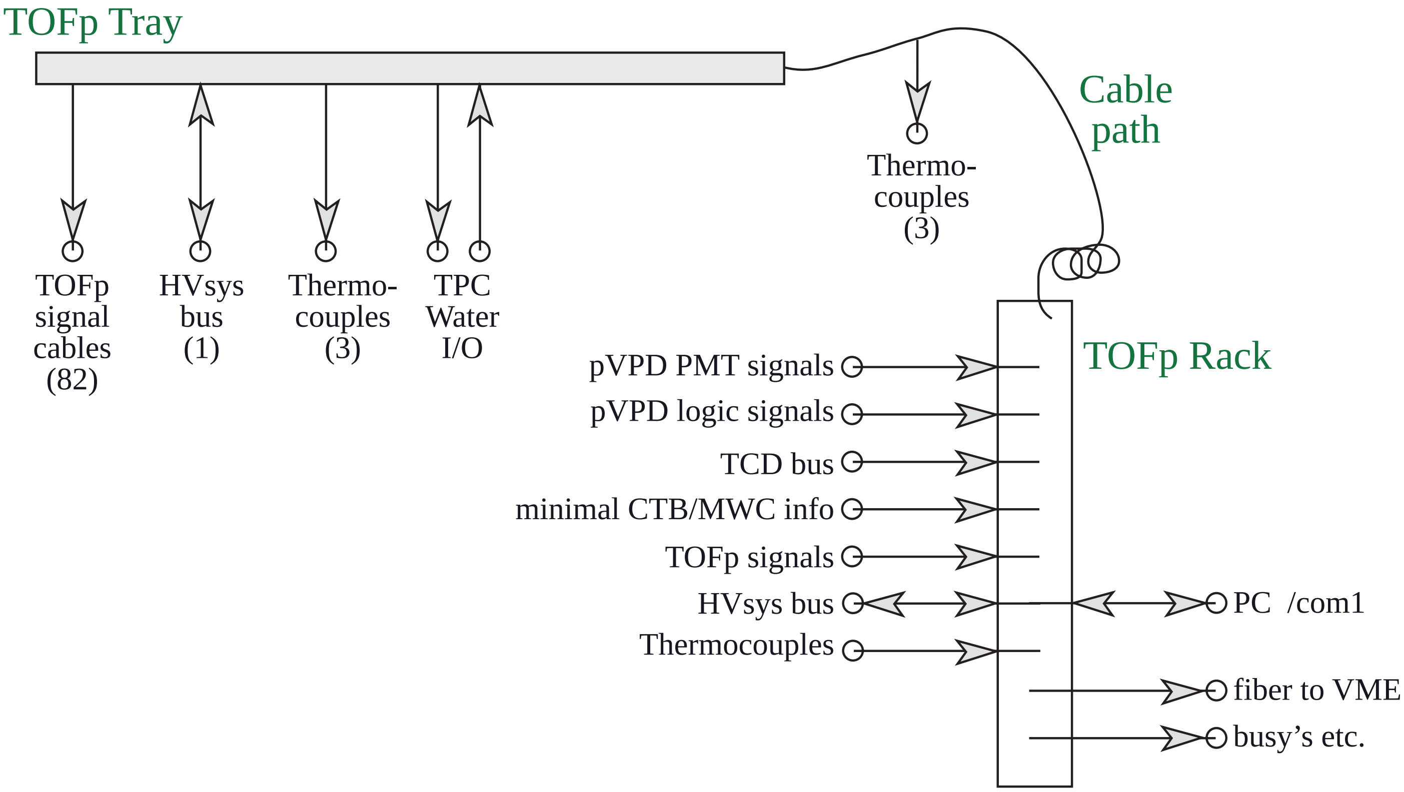

Figure 1: A schematic overview of the connections requirements.

4 In-Tray Requirements

4.1 Safety

Requirement: All in-tray components will meet all BNL Safety standards.
Justification: These standards were implemented to insure the safety of all equipment and experimenters.
Comments: The big sister of TOFp is the STAR CTB, which exists. Many aspects of these are the same, and hence already approved as meeting BNL Safety requirements. The tray itself, active elements, wrapping, PMTs, foam, and other in-tray hardware are all the same type as was already approved for the STAR CTB. The TOFp cabling requirements are considerably decreased compared to the CTB, as CW bases and low voltage are used for the TOFp tray, as compared to resistive bases and high voltage in the CTB. Two other aspects of the TOFp tray interior differ from the CTB - the need for heat removal via an in-tray cooling loop, and FEE boards, which are also driven by low voltage.

4.2 Slats

Requirement: The scintillator slats will be Bicron BC-420.
Justification: These provide the fastest and brightest performance at the lowest cost.
Comments: This is the formulation being used throughout TOFp SysTest-I.

Requirement: The slat dimensions will be 4cm×2cm×20cm.
Justification: Given the physics goals of TOFp are primarily on singles spectra, there is no requirement on a minimum total geometrical efficiency of the counters within the tray. Rather, the size of the TOFp slats is driven more by the occupancy. Slat sizes of 4cm×2cm×20cm and somewhat longer are conservative for all light-A collisions, conservative for Au+Au events at impact parameters larger than $\sim$3fm, conservative in central Hijing events, and tolerable in central Venus events (all fully simulated).
Comments: This is the slat size being used throughout TOFp SysTest-I.

4.3 Channel count

Requirement: There will be no less than 36, and no more than 45, slat assemblies in the TOFp tray.
Justification: Mechanically conservative configurations of slats in the tray that maximize the geometrical efficiency under the slat size constraint imposed by the maximum tolerable occupancies imply a channel count per tray in the range from 36 to 45. With the slat size fixed by occupancy considerations, the largest TOFp singles rates per event are obtained as large a TOFp channel count as is feasible mechanically. Simply maximizing the total channel count inside the tray is the best first step towards the high-

est possible integrated luminosities. The use of ∼40 slats per tray is still large enough to allow TOFp-based start time corrections which could possibly improve the overall resolution beyond that obtained using the pVPD starts.

Comments: An real CTB tray and 45 wooden slat+PMT+base assemblies, i.e. a fake TOFp, are being used to study the tray layout and interior cable routing. Forty-one (41) slats, *i.e.* one row of five slats near $\eta\sim0$ and then nine rows of four slats out to $\eta\sim0.95$, are conservative mechanically. This 41 slat design has been adopted for TOFp. The present studies being done with the fake TOFp concern the foam dimensions and positioning, as well as the cable routing.

4.4 Slat positioning

Requirement: The slats shall be placed in ten rows ("η-rows"), where there are four or five slats ("ϕ-rows") in each row. The rows in η are spaced projectively by 2cm. The rows in ϕ are spaced to span the full width of the tray, implying a slat spacing of ∼3 mm in ϕ.

Justification: The row spacings in η and ϕ are intended to insure that single tracks do not leave hits in two slats. Such tracks would complicate the analyses unnecessarily by increasing the occupancy. As there is no requirement on the minimum total geometrical efficiency of the slats inside the tray, there is no reason not to space the slats conservatively to fully suppress these.

Comments: Such an arrangement is presently being studied with the fake TOFp. In the 41 slat arrangement, there is a comfortable amount of space inside the tray for the cabling and, at the high-η end, for all of the feedthroughs.

Requirement: The angle subtended between the long axis of a slat and the STAR Z-axis shall be optimized (as possible under a tray height constraint) for the average particle angles of incidence for collisions with primary vertices at X=Y=Z=0.

Justification: An additional component to the slat time resolution contributes for tracks that strike TOFp slats at finite angles with respect to the long axis the slat. This is an artifact of the finite velocity of propagation of the scintillation light in the slats, which is ∼80 ps/cm for the present BC-420 slats. If a track strikes a (2cm thick) TOFp slat with an angle relative to the slat's long axis of 20°, scintillation light is produced over a range of distances from the PMT that span ∼7 mm, which smears the time distribution of scintillation light reaching the photocathode by ∼54 ps between the two extremes. The internal reflectivity of the slats and wrapping allow near-direct light to contribute to the leading edge, which softens this degradation. Nonetheless, such angle of incidence effects should be minimized as much as possible by placing each TOFp slat at the most appropriate angle inside the tray.

Comments: By reducing the length of the voltage bases, the adoption of the HVSys system improves the performance of the system overall by allowing this maximum possible slat angle to increase by ∼5°. The tests being performed with the fake TOFp, and AutoCAD drawings, indicate that the first row of slats near $\eta\sim0$ will be at an angle near 5.5°, the second row will be near 11°, and the remaining seven rows out to $\eta\sim1$ are at the maximum angle of just over 12°. Thus, the first few slat rows see primary tracks from collisions at $Z=0$ striking very nearly normally on average. The average angle of track incidence the outer rows increases smoothly up to approximately 35°-12° $\sim$ 23° for the slat row near $\eta\sim 1$. This contributes an additional component to the time resolution in these slats ranging from zero for the first few slat rows to up to at most ~50ps in the highest-η row, giving in this last row an overall resolution degraded from ~80ps to ~94 ps. Thus, this arrangement of the slat angles inside the tray both does not require a different tray geometry (although one is possible!) and does not cause a significant degradation of the resolution with increasing slat-η.

4.5 PMTs

Requirement: The PMTs will be Proximity Mesh Dynode 1.5" diameter Hamamatsu R5946.

Justification: The PMTs must operate in a 5 kG magnetic field. The photocathode area is dictated by the available space and the goal of maximizing the overlap area of the photocathode and the ends of the slats. The largest possible overlap area results in the largest possible number of photoelectrons per hit and hence improves the performance. A 1.5 inch-diameter PMT can be fit five across inside the tray, and is well matched to the 4 cm (1.57 inch) width of the slats.

Comments: These are the PMTs used in the STAR CTB, and they have been used throughout TOFp SysTest-I.

4.6 Scintillator/PMT coupling

Requirement: The Scintillators and PMTs are glued using Epotek-301 spectrally transparent epoxy.

Justification: This glue is designed for this purpose, and has used successfully in the E896 TOF System as well as the STAR CTB. It is very strong, and ~100% efficient for wavelengths above ~300nm. Cookie/spring assemblies would add unnecessary mass and mechanical complexity to the tray.

Comments: This is the glue being used throughout TOFp SysTest-I. Valuable experience exists on the minimum requirements on the shipping container necessary to preserve such glue joints during commercial ground transport from Houston to Upton.

4.7 Slat wrapping

Requirement: The scintillator slats will wrapped in two layers of unpainted fine-grain Tyvek 1055 or equivalent, which is surrounded by a layer of black Photographers Plastic and sealed by 3M Super 33+ electrical tape.

Justification: This wrapping makes each slat assembly light tight, is approximately 1mm thick per side, and, given this particular type of Tyvek's amazing reflectivity for

~400 nm light, results in the best possible photoelectron response for particle hits. This is exactly the wrapping scheme used both in the STAR CTB and the two side walls of E896 TOF System. Aluminum foil and aluminized mylar are less reflective, higher mass density, and tend to cause microscratches in the surface of the scintillator, which over time degrade the slat's total internal reflectivity.
Comments: Tests comparing different wrapping schemes were performed during TOFp SysTest-I. The best performance was obtained with the by now obvious dual-Tyvek wrapping scheme. There were indications that wrapping the first ~5cm of the slat closest to the PMT with non-glossy black construction paper would make a slight improvement to the uniformity of the slat response for hits close to the PMT. Similar masks were used near the light guides in the STAR CTB slats.

4.8 PMT bases

Requirement: The high voltage distribution for the dynodes of the PMTs will be provided by a Cockroft-Walton (CW) type bases.
Justification: The tray is a closed metal box. To minimize the heat generated inside the box, the choice of CW bases helps greatly by reducing the power dissipation from ~50W for resistive HV bases (~1W/base) to ~10W for CW bases (~0.2W/base). Also, remotely controlled high voltage generated from low voltage supplies reduces significantly the cabling requirements.
Comments: The system adopted for TOFp is the "HVSys" of Astakhov *et al.* of JINR-Dubna. This is the voltage system being used throughout TOFp SysTest-I. The sustem consists of small "cells" which are simply daisy-chained inside the tray on a single 10posn ribbon cable, called the "HVSys bus." The HVSys bus is driven by a small 6U VME-sized "System Module," which connects only to AC power and the serial port of a PC (and the HVSys bus of course). The adoption of this system considerably simplifies the tray layout, as the HVSys cells are very small. This adoption of this system also very much simplifies the electronics and control interfaces, as all cells are controlled and read back via the HVSys bus and System Module. There is no no longer any need for a TOFp to STAR Slow Controls interface and its associated hardware, such as the Radstone board, HDLC Mother and Mezzanine boards, and VME crate.

4.9 Front end electronics

Requirement: Each row of four or five slat assemblies will be connected to a single custom circuit board of the same width as the tray, a length (parallel to Z) of ~2 inches, and a minimized thickness, that has the following functions: Split the input PMT signal into two, pass one half directly to an output connector, and pass the other half to the input of a custom fast discriminator circuit, which also sits on this board.
Justification: The mechanical arrangement of ten rows of slat assemblies inside the tray naturally implies ten TOFp FEE boards, each serving a single row of slats.
Comments: The latest two versions, *i.e.* versions 4 and 5, of the TOFp FEE

are of the final minimized dimensions for mounting inside a tray. Five Lemo connectors, and ten Lemo connectors, are used for the boards' signal I/O, respectively. This board is trivial except for the fast discriminator circuit, so we have defined separately specific requirements for this "first discriminator" below.

4.10 "First" discriminator

Requirement: A Leading Edge (LE) discriminator with an intrinsic resolution of 40 ps, or better, as measured under specific controlled conditions, is required inside the tray.
Justification: There is no requirement that TOFp must provide fast timing information to early levels of the STAR trigger. Thus, there is no requirement that TOFp's first discriminator not slew. Hence, we originally proposed LE discriminators instead of Constant Fraction (CF) designs, as the overall resolution of LE+slew corrected systems is generally better than can be obtained from CF discriminator-based systems.
Comments: There have been five product cycles for the FEE including this discriminator circuit. While a LE was proposed, many variants of both LE and CF discriminators have been developed at Rice. All of the discriminators so produced have been compared to each other, and to commercial discriminators, under controlled conditions throughout TOFp SysTest-I. The performance of the latest custom discriminators meets or exceeds this 40 ps requirement, as well as the performance of the best commercial discriminators, *e.g.* the 300 MHz Phillips Scientific 70x series.

Requirement: The rise time of the logic signal output by the first discriminator shall be less than 1 ns.
Justification: RG-58 and equivalent cable has a rise time per 250 ft of $\sim$5 ns. Minimizing the rise time of the discriminator output minimizes slightly the rise time of the logic signals seen on the platform, which improves the timing performance slightly.
Comments: The rise time from TOFp Discriminator Version 1 is 750 ps, Versions 2 and 3 are 650 ps, and Version 4 is 610 ps.

Requirement: The first discriminator's LE threshold shall be common to all TOFp channels and adjustable remotely.
Justification: The slat gains will be matched to the same pulse height (note not to the same pulse area), so a single threshold common to all slats is the simplest approach that is appropriate. The ability to vary this threshold is needed for flexibility.
Comments: The setting of this threshold does not require an interface to Slow Controls, as it can be defined via a single LV line from the platform to the tray.

4.11 Tray power dissipation

Requirement: The total power dissipation in the tray will be 60 W or less
Justification: The power dissipation in the tray must be minimized, as such implies elevated temperatures inside the tray. Temperatures near 140 ° can result in mechanical

instability in plastic scintillators, *i.e.* they can melt. Bench tests described in Ref. [1] indicated 200W of power dissipation results in less than a 10° rise in the tray interior temperature given an the proposed cooling loop. The present requirement this allows a safety factor of approximately four. This which would be expected to keep the temperature rise inside the tray to less than 5° above the ambient temperature.
Comments: The actual power spec for the HVSys cells is 0.2 W/cell, while the power measured for the version 4 FEE boards is 0.6 W/ channel, or 3 W per board. Thus, we expect the actual tray power will be of order 8+30=38 W, which is ~70% of the requirement.

4.12 Tray mass thickness

Requirement: The total mass thickness of the tray will be minimized.
Justification: The less dense the TOFp tray, the smaller the probabilities for the production of secondaries inside the tray that may then produce (unwanted) hits in the TPC or RICH.
Comments: The use [1, 2] of a very detailed TOFp geometry in GSTAR implies that the TOFp has total interaction and radiation lengths that are, averaged over the tray, only ~20% larger than the same quantities for the CTB. This increased thickness is not distributed, rather it is concentrated to specific regions near the PMT+base assemblies, which are at known and constant absolute positions. The overall size and mass thickness of these bases has been significantly decreased since these simulations by adopting the HVSys voltage system.

4.13 Interior cabling

Requirement: The interior signal cables must be coaxial, and with attenuation specs near or exceeding that for RG-58. Space-efficiency is necessary in order to minimize inactive and dense regions inside the tray.
Justification: Coaxial cable results in the lowest possible signal degradation and cross talk of any cable type.
Comments: Each row of N slats results in 2N signal cables that all must be routed to the end of the tray at $\eta\sim1$. RG-174 is very thin but as the interior cable runs can be up to 12' in length, the attenuation performance of RG-174 is not acceptable. The most space-efficient cable with attenuation specs near RG-58 is the Amphenol FlatCoax. This is the type adopted for the interior cabling for TOFp. Much longer (250') lengths of FlatCoax have been studied in detail in the TOFp SysTest-I. Ten Flat Coax assemblies of varying lengths would simply be purchased for the final interior cabling.

4.14 Heat removal

Requirement: An interior loop of $\leq$3/8" diameter aluminum pipe is thermally connected to each of the ten FEE boards in side the tray. Water circulated through this pipe

is required to remove the heat generated inside the tray by the HVSys cells and the FEE boards.
Justification: The power dissipation inside the tray is expected to be $\sim$38 W, and the requirement (above) is a maximum of $\sim$60W. This heat so produced must be removed. PMTs and electronics work better and last longer at lower temperatures.
Comments: Bench tests [1] of the performance of actual cooling loops inside a heated tray indicate that 200 Watts of power dissipation can be effectively removed from inside the tray with such a design. This is a factor of four more power than expected inside the TOFp tray.

Requirement: The tray cooling loop simply "T's" into the TPC cooling water system.
Justification: The heat removal requirements are very modest, so a separate water system for the TOFp is not necessary.
Comments: This interface is not yet designed. In principle it requires only the appropriate choice of a handful of pipe connectors and small sections of piping, and then watching the TPC Group plug us into their water.

4.15 Tray interior temperature measurement

Requirement: The measurement of the temperature at several locations inside the tray is required.
Justification: The PMT dark currents, the PMT timing performance, and the FEE performance may depend on the tray interior temperature. Searches for these effects, and corrections for them if they are significant, require the availability of the relevant instantaneous temperature information.
Comments: We expect the ambient temperatures seen by the tray to be stable to a few degrees in general, and hence in general temperature effects should be small and slowly varying. A small commercial thermocouple system that is most appropriate for readout into a CAMAC-based DAQ system should simply be purchased.

5 Cable requirements

5.1 Safety

Requirement: The TOFp signal cables will meet all BNL Safety standards.
Justification: These standards were implemented to insure the safety of all equipment and experimenters.
Comments: The cables for TOFp are standard types as can be purchased from stock at BNL.

5.2 Length

Requirement: The length of the signal cables connecting the TOFp tray to the platform must be no shorter than ~200 ft, and no longer than 500 ft.
Justification: Signal delay is needed to allow time for the formation of the TOFp master start signal, which is based on the information from different subsystems in STAR and must be obtained before or near the time the TOFp signals arrive at the platform. Longer cables allow more time to form the TOFp master start, but they would require inordinate amounts of storage space on or near the TOFp rack. Also the raise time attenuation for a 500 ft long cable is twice that for 250 ft of the same cable - approaching 10 ns for 500 feet of RG-58.
Comments: Both RG-58 and FlatCoax cables that are 250 ft long are being used in TOFp SysTest-I.

Requirement: The time required for signals to travel along the TOFp signal cables from the tray to the TOFp rack on the platform shall be 400ns.
Justification: This allows for a gap of approximately 200 ns between the time the 32 pVPD signals arrive at the TOFp rack and the time the 78 TOFp signals arrive at the TOFp rack. During this 200ns period, the TOFp master start is formed in NIM logic, so that is is ready to fire the digitization of the TOFp signals when they arrive.
Comments: 250 ft of RG58 has a total signal propagation time of approximately 380 ns; such cables and lengths are being used successfully during TOFp SysTest-I. RG-58 cables that are approximately 550 ns long have been used successfully in the E896 TOF system.

5.3 Attenuation

Requirement: The attenuation of the TOFp signal cable will be ~20 dB/100m or less at 200 MHz.
Justification: Such an attenuation spec leads to reasonably low rise time attenuation after 250-350 ft lengths of cable.
Comments: The "standard" signal cable is one of the RG58 series, such as RG-58A/U or RG-58/U, which has an attenuation spec of 18-23 dB/100m at 200 MHz. Cables

such as RG-62 are attractive in that their attenuation and hence their rise time degradation, is much lower. However, they are also much larger diameter cables and their signal propagation speed is much faster. To obtain 400ns of delay, $\sim$20% more RG-62 would be needed compared to RG-58, which offsets somewhat the improved attenuation characteristics of the RG-62. The optimal choice of the long TOFp cable thus appears to be RG-58/U, as it also requires no special impedance matching on the platform. The 250ft RG-58 cables studied in detail in SysTest-I are RG-58C/U, which has an attentuation of 23 dB/100m at 200 MHz, *i.e.* a 25% high attenuation than for the proposed RG-58/U cables.

5.4 Impedance

Requirement: The impedance of the signal cables shall be matched one one end to the FEE output and at the other end to the CAMAC input.
Justification: Matching the impedences suppresses reflections. These would in general have little effect on the timing performance, although they could compromise the ADC measurements unnecessarily.
Comments: The TOFp FEE is at present designed to drive 93 Ω cable, such as the FlatCoax. In this case, the TOFp patch panel would include for each signal cable a 43 Ω resistor to result in a 50 Ω input impedance at the face of the TOFp second discriminators and ADCs. Specific commercial high-pass filter chips are being studied both to match the impedences and to suppress low frequency (*i.e.* correlated noise) components of the propagated signals. The choice of RG-58/U obviates the need for such resistors or filters at the patch panel, as these cables are 50 Ω and hence are already matched to the input impedences in the TOFp rack. Of course the output impedance of the FEE boards would need to be revised, but this is a trivial adjustment to the already solid TOFp FEE version 5 design.

5.5 Amplitude cross-talk

Requirement: The nearest-neighbor amplitude cross talk in the bundle of signal cables shall be 1% or less, as defined using logic signals.
Justification: Amplitude cross-talk increases with decreases in the rise time of the signal. Thus, logic signal propagation leads to larger amplitude cross-talk than analog signal (*i.e.* the PMT signal itself) propagation. A 1% level of amplitude cross talk for standard logic signals implies less than 8 mV signals at the input of the second discriminators. Thus, the neighbor signals will not fire the second discriminators, which will have thresholds certainly no less than 50 mV. Such a 1% level of amplitude cross talk also leads to neighbor signals that are small compared to the same-channel signals for hits. Hence, the effects of such amplitude cross-talk are small compared to the $\sim$10% ADC resolution for hits.
Comments: The amplitude cross-talk has been studied during TOFp SysTest-I. The amplitude cross-talk for the 250 ft 93 Ω FlatCoax cable is approximately a factor of

ten larger than for an equivalent bundle of RG-58 cable, although tolerably so.

5.6 Timing cross-talk

Requirement: The nearest-neighbor timing cross talk in the bundle of signal cables shall be 20ps or less, as defined using logic signals.
Justification: The presence of signals in neighboring channels cannot be allowed to affect the signal delay time in a specific cable channel. This would significantly and unnecessarily complicate the offline analyses.
Comments: The timing cross-talk has been studied during TOFp SysTest-I. The timing cross-talk for the 250 ft 93 Ω FlatCoax cable can, for two logic signals separated by 50 ps, be as much as few hundred picoseconds. This is equivalent to a difference in flight path for β=1 particles of ∼10cm. This is unacceptable. This is strongest statement in favor of the adoption of separately stranded RG-58/U cable, instead of FlatCoax, for the long signal cables. These tests are still in progress.

5.7 Cable path temperature measurement

Requirement: The measurement of the temperature at several locations along the cable path is required.
Justification: The signal cable timing offsets can depend on the local temperatures along the cable path. Searches for these effects, and corrections for them if they are significant, require the availability of the relevant temperature information.
Comments: We expect the ambient temperatures seen by the cables to be stable to a few degrees in general, and hence in general temperature effects will be small and slowly varying. Nonetheless, it should be possible to inexpensively implement a commercial approach here.

6 Platform Requirements

6.1 Safety

Requirement: The TOFp platform equipment will meet all BNL Safety standards.
Justification: These standards were implemented to insure the safety of all equipment and experimenters.
Comments: All TOFp equipment on the platform is conventional. The electronics there are commercial and are used in numerous AGS and RHIC experiments.

6.2 Rack space

Requirement: Space on the platform is required to house the TOFp electronics. The total space required is one full sized rack.
Justification: The TOFp platform electronics include one NIM bin, one CAMAC crate, one patch panel, and two low voltage power supplies. The remaining space is used to store any remaining length of TOFp signal cable.
Comments: A single rack presently houses the TOFp SysTest-I set-up with room to spare.

6.3 The psuedo-VPD (pVPD)

Requirement: The TOFp detector requires that there exist a detector, referred to here as the pseudo-VPD (pVPD), in STAR positioned close to the beam-pipe and with a good time resolution, to provide high-resolution trigger signals needed to digitize the TOFp detector data.
Justification: The detector is needed to provide the signals used for the TOFp ADC gate and the TDC time reference. Without such a detector, the TOFp can work only for the most central collisions, and then only after a complicated offline analysis [1, 2] using the TOFp information to effectively correct the start resolution from some lower resolution detector. The ZDC is the only available alternative, and it is not at all attractive given its time resolution is at best ~250 ps.
Comments: It is not sensible to construct a "stop" detector without an appropriate source of "stops". Such a detector should cost less than 10 k$ as we expect that most of the necessary parts could be borrowed. John Mitchell (NASA-GSFC) has expressed interest in constructing the detector elements. Aspects of the electronics needed to provide the STAR Level-0 Trigger with the primary vertex location have been studied by Pandey and Bellwied *et al.* Note that the TOFp system requires *only* the 2^*N_{ch} raw analog and logic signals from the N_{ch}-channel detector itself. Updated simulations on the positioning and performance or a pVPD are in progress by M. Kaplan's group at CMU.

Requirement: The pVPD shall exist on both sides of STAR.
Justification: This is needed to form electronic indications of the primary vertex

location, and to form electronically primary vertex-independent master start signals.
Comments: As the cost per detector element is expected to be less than 1 k$, there is no significant reason not position pVPD elements on both sides of STAR. If the SVT or Trigger people in STAR decide a L0 measurement of the primary vertex position using the pVPD would be useful, then this possible only if the pVPD exists on both sides of STAR.

Requirement: The pVPD must have at least a 20% efficiency for firing in extremely peripheral Au+Au collisions, *i.e.* for impact parameters near ~10 fm.
Justification: Simulations [4] of the original VPD detector indicate that a 2ch VPD, *i.e.* one VPD channel per side, is negligibly efficient in peripheral Au+Au collisions. Given the low channel count and the low cost per channel for the detector elements, and everything else is borrowed, there is no reason of cost or mechanical complexity motivating one to consider anything less than a 16 channel pVPD, with 8 channels per side.
Comments: Renewed simulations on the efficiency of a pVPD for large impact parameter Au+Au collisions are in progress at CMU. At this point the possible locations for a pVPD are much better defined, as actual STAR hardware now exists, and certain aspects of the simulations, *e.g.* the STAR fringe fields, are presently more accurately defined.

Requirement: The intrinsic time resolution of the pVPD elements for neutral or charged particle hits shall be no worse than 50 ps.
Justification: Such a time resolution would lead to the required overall TOFp timing, and can easily be obtained from detector elements composed of a Pb converter plus an active layer, either quartz or scintillator, followed by a shielded "normal" PMT in a "flashlight" arrangement.
Comments: Similar detectors are highly conventional and common.

Requirement: Each pVPD signal will be split in two very close to the pVPD elements, one leg to be used to obtain pVPD pulse area information in specific pVPD elements, and the other to provide the timing information.
Justification: This is the conventional design of TOF signal paths. The pulse area information is needed to study and correct for any slewing effects in the pVPD signals.
Comments: Two commercial NIM Linear Fan units could be easily borrowed to perform this function on each side of STAR.

Requirement: There will also exist a discrimination of each pVPD signal after a cable run from the detector that is no longer than 10 ft.
Justification: Like the TOFp signals, the pVPD signals must to be discriminated close to the pVPD itself, as the timing signals are sent long (~100 ft) cables to the STAR platform.
Comments: This is the conventional design of the timing signal path. Space should exist close to the pVPD elements to position on each side of STAR a minicrate with a 1 commercial NIM Linear Fan unit and one commercial 8-channel NIM discriminator. The 300 MHz Phillips Scientific 708 Discriminator is appropriate and can easily be borrowed from any equipment pool.

It should be stressed that the TOFp FEE are *highly* appropriate *as is* for use in the pVPD. If space within ∼10 feet of the pVPD detectors (on each side) is too precious to allow mini-NIM bins to be located there, the TOFp FEE boards are an excellent alternative. A single TOFp FEE board does both the signal split and the discrimination for five detector channels much better than is possible with commercial NIM components. Two TOFp FEE boards would service up to 10 pVPD elements (leaving two spares per side for an 8+8 channel pVPD) in perhaps a quarter of the space required for a NIM bin.

Requirement: The discriminated signal from each near-pVPD discriminator, and the raw PMT signal from each pVPD channel, shall be delivered to the TOFp rack via coaxial cables.
Justification: We require no processing of the pVPD signals other than that performed very close to the detector elements themselves (split and discriminate). The earliest pairs of the 8+8 logic signals from the 8+8 pVPD elements are used in the TOFp rack to define the TOFp master start, which is used to generate the TOFp ADC gates and the timing reference signal for the TDCs.
Comments: Simple NIM logic is used to form the master TOFp start signal from the earliest pairs of pVPD logic signals from each side for each collision. The digitization of both the pVPD ADC and TDC in the TOFp crate (see below) allows one to determine which detectors on each side were the ones used event by event for the trigger, and hence allowing any pVPD detector-dependent corrections.

Requirement: The 16 logic and 16 analog signals shall arrive at the TOFp rack no later than 300 ns after the collision.
Justification: This allows at least 100ns for the formation of the TOFp master start and ADC gates before the arrival of the TOFp signals from the detector.
Comments: This is understood at present to be a very conservative requirement. There can be ∼20 ns of flight time from the primary vertex to the pVPD elements. The present understanding is that pVPD-to-platform signal cables would be ∼100 ft long, so that the pVPD signals should be available at the a STAR Trigger rack on the platform near ∼200 ns after the collision. This is consistent with the arrival times on the platform of other fast detectors in STAR such as the ZDC and CTB. The present requirement thus leaves 100ns of headroom for the arrival of the pVPD signals at the TOFp crate and the formation of the TOFp master starts once the pVPD signals arrive at the TOFp rack. If more headroom is warranted, we would simply increase the length of the TOFp signal cables by ∼30 feet with no discernible loss of performance.

Requirement: The pVPD logic signals will be digitized in ADCs and TDCs read by the TOFp DAQ system, whether or not these signals are also digitized elsewhere in STAR.
Justification: Having the TOFp start information digitized in the TOFp crate is the best possible design, as there are no relative gains/offsets et cetera between the two absolute start and stop measurements to worry about. This increases the number of detector channels to be digitized in the TOFp DAQ, but insignificantly so - this adds sixteen additional ADCs and 16 TDCs to the (low) number of ∼40 each for TOFp channels.

Comments: The local digitization of the start signals themselves in the same TDCs digitizing the TOFp detector stops is a common design feature for all high performance TOF systems. Such a trick allows the effective elimination of any noise intrinsic to the digitization itself, although such noise is common only in Fastbus-based TOF systems and hence is not expected for the present CAMAC-based system. The ADC digitization of the pVPD signals allows the investigation of, and correction for, any (pVPD detector channel-dependent) slewing effects in the start timing. Having the start and stop information in the same tables also simplifies the data I/O in the offline analyses.

6.4 Patch panel

Requirement: A rack-mounted panel will be built to distribute the TOFp analog and logic signals to the appropriate locations in the TOFp rack.
Justification: This allows convenient and conventional short RG-174 coaxial cables to connect each TOFp signal cable to the appropriate ADC or second discriminator.
Comments: This panel is, at least, simply a correctly-isolated plate holding ~100 lemo bulkhead connectors and, if necessary, the resistors to impedance-match the 93 Ω signal cables to the 50 Ω input impedance of either the TOFp ADCs or the TOFp second discriminators. At most, it is such a simple plate with lemo bulkhead connectors and, if necessary, 1.4:1 high-pass filters to match the impedences and to eliminate low-frequency (noise) components. In the case of 50 Ω signal cable, this patch panel is nothing more than a simple plate with ~100 bulkhead connectors.

6.5 Tray power supplies

Requirement: The low voltage power supplies must be located away from the detector. There will be 1-2 commercial power supplies to deliver ±5 and -2.2V to the tray for the FEE power. One additional low voltage line carries the (common) discriminator threshold. Power cables must be of sufficient size to limit the voltage drop and heat dissipation to reasonable values.
Justification: There is no space allocation for power supplies on the detector.
Comments: The power requirements are very modest. We will simply purchase 2 standard commercial LV supplies. Commercial three-conductor power cables are common and inexpensive. The LV cable run is expected to be ~100 ft long. If the TOFp FEE are used for the pVPD FEE, these same power supplies could drive the pVPD FEE as well, removing the need for low voltage power supplies near the pVPD detectors.

6.6 "Second" discriminator

Requirement: The logic signals from the TOFp tray shall be re-discriminated on the platform just before the TOFp TDC digitization.
Justification: This is the conventional and proven design of all TOF systems that

include long signal cables. One pays ~10 ps per discrimination in overall resolution by adding another discriminator, but the second discrimination presents to the TOFp TDCs a timing signal with a rise time reduced from ~6-8 ns to ~2 ns, which greatly suppresses the importance of TDC baseline jitter.
Comments: These discriminators are to be borrowed from an equipment pool at no cost.

Requirement: The nearest-neighbor timing cross talk in the second discriminators shall be 20ps or less, as defined using logic signals.
Justification: The presence of signals in neighboring channels cannot be allowed to affect the time at which a specific discriminator channel fires. This would significantly and unnecessarily complicate the offline analyses.
Comments: The timing cross-talk in numerous discriminators applicable to TOFp has been studied in detail during TOFp SysTest-I. The timing cross-talk for the Phillips Scientific 7106 discriminator can, for two logic signals separated by 200 ps, be as much as 600 ps! This is unacceptable. This is a strong statement that fully loaded P/S 7106 discriminators are not appropriate for the TOFp second discriminator. NIM discriminators such as the P/S 70x series show no timing cross talk at all.

6.7 Interface to the STAR Trigger

Requirement: The TOFp system shall receive from the STAR Trigger a fast "pre-trigger" less than 400ns after the collision.
Justification: The formation of a full STAR Level-0 trigger and the token assignment for this crossing requires 1.5 μs, which is at least 1 μs longer than the time at which the TOFp signals arrive at the TOFp rack. At least preliminary pre-trigger information must be available earlier than this to insure reasonable live-times of the TOFp system.
Comments: There is considerable experience in STAR now on the definition and distribution of such pre-triggers, as one is presently being used by the RICH detector.

Requirement: The fast pre-trigger shall, either in the TOFp rack or somewhere in a STAR Trigger rack, be "anded" with minimal particle multiplicity requirements before being used to issue TOFp master starts.
Justification: Given its (intentionally) extremely forward location, the pVPD is much more likely to fire on a given crossing than is the full STAR trigger system, which may include additional requirements such as on, *e.g.*, the centrality. Thus, if the existence of a pair of pVPD signals (one on each side of STAR) was the only requirement for firing the TOFp DAQ, it is likely that the TOFp DAQ would commonly be dead for that subset of these collisions that includes both a valid pretrigger and valid higher level STAR triggers. The coincidence with minimal CTB (and/or MWC) multiplicity information before the issuance of the TOFp master starts is intended to enhance the probability that a valid Level-0 and later STAR triggers follow a given pretrigger ~1.5 μs after the collision in question.
Comments: This functionality has met preliminary approval of the STAR Trig-

ger group. [5] It is performed as follows (as in the RICH). The raw CTB information arrives at the Trigger racks on the platform approximately 150 ns after a collision. The information from the first layer of DSMs is the "minimal CTB/MWC" information that we are referring to here. One layer of DSM processing costs 160ns. Thus, the pretrigger plus first layer DSM information is expected to be available ~310 ns after the collision.

Requirement: The STAR Trigger information for valid Level-O, 1, and 2 triggers, *i.e.* valid tokens and subsequent accepts/aborts, shall be passed from the TOFp-dedicated Trigger TCD board to the TOFp CAMAC crate via a twisted pair cable and a commercial CAMAC I/O register.
Justification: This the design preferred by the STAR Trigger group. [5] A similar interface, although to an I/O register in a VME crate, exists for the RICH.
Comments: The TCD board for TOFp is the STAR standard design and will be simply be purchased by the TOFp group and connected appropriately by the Trigger group.

6.8 Fast TOFp multiplicity information

Requirement: The TOFp shall make available to the STAR Trigger system information indicating the number of TOFp slats struck by particles in a given crossing well before the STAR Level-0 decision.
Justification: Such information could be used in the STAR Level-0 decision. It could also be useful in later STAR Trigger levels as the hit multiplicity information exists from TOFp in ten small bins in η and 4-5 small(er) bins in ϕ.
Comments: The complete ignorance of the multiplicity of hits in the TOFp tray cannot significantly affect the multiplicity resolution of the STAR Level-0 trigger. One tray is $1/120^{th}$ of the full CTB coverage, yet the overall CTB resolution on the particle multiplicity in any Au+Au given event is more like ~3%. However, it is not difficult for the TOFp electronics to provide this multiplicity information to the STAR Trigger anyway.

Each of the (16 channel) Phillips 7106 discriminators originally proposed for the second discrimination can provide a signal that is proportional to the number of channels in this discriminator that fired. Given the substantial timing cross talk in these units seen during SysTest-I, however, we now know that these units are inappropriate for TOFp. The second discriminators will thus be PS708 NIM. The multiplicity information will thus be obtained from separate NIM logic. The multiplicity sums from the TOFp platform discriminators and the two discriminators looking at pVPD are sent via a few cables to the STAR Trigger racks for use in Level-0 or later decisions. These TOFp and pVPD multiplicity signals would be available at the Trigger racks ~500ns after the collision.

Note the TOFp rack is providing to Level-0 both the TOFp multiplicity information, and the pVPD multiplicity information. This would allow the TRG or other STAR groups to base Level-0 or higher triggers on either or both quantities in the same way.

6.9 TOFp Digitization

Requirement: The TOFp signals will be digitized in a CAMAC crate.
Justification: This standard is so conventional that the necessary components can all be borrowed from equipment pools. CAMAC is far more dependable than Fastbus, and CAMAC results in simpler systems as compared to VME. Present commercially available VME TDCs involve "time stretching" techniques, which for the present system unnecessarily extend the digitization time per event.
Comments: CAMAC digitization for TOFp is the standard preferred by the STAR DAQ group. [6]

Requirement: The TOFp pulse area and timing information will be obtained via commercial ADC and TDC units.
Justification: This is the most conventional and inexpensive approach.
Comments: Throughout the TOFp SysTest-I, 50ps 10bit Lecroy TDCs and 10 bit LeCroy ADCs were used and performed as expected. ADCs and TDCs constructed by Phillips Scientific, specifically the 7166H ADC and the 7186H TDC, have a number of advantages compared to the equivalent LeCroy models. In hand at present are a number of appropriate CAMAC ADC and TDC units, which are being using via a CAMAC/GPIB interface during the TOFp SysTest-I.

Requirement: The ADC resolution will be 10 bits or larger.
Justification: This resolution is comfortably larger than both the intrinsic ADC resolution of the slats for hits, and the ADC resolution needed to perform sufficient slewing corrections.
Comments: The LeCroy ADCs are 10 bits, the Phillips ADCs are 11 bits.

Requirement: The TDC bin width per count shall be 50 ps or less and the full scale will be $\sim$100ns.
Justification: Time distributions with variances as low as $\sim$30 ps can be measured reasonably by TDCs with an intrinsic resolution of 50 ps/count. Such variances are comfortably smaller than the intrinsic time resolutions of both the (pVPD) starts and the (TOFp) stops, which are in the range from 50-80 ps. A full scale of 100ns is comfortably more than the range of particle arrival times, which is at most $\sim$40 ns after the collision.
Comments: The best resolution in the TOFp system will be for hits striking slats near normally and close to the PMT ends. The full simulations and the SysTest-I data imply the time resolution for these hits could be as low as 60 ps. TDCs with a 50 ps/bin calibration are still capable of accurately measuring such distributions, as 3σ here is $\sim$180ps, so such a Gaussian spans 7-8 TDC bins depending on the centroid location relative to any bin. LeCroy CAMAC TDCs with 50ps/count are readily available from equipment pools. The Phillips 7186H TDC has the much better time resolution of 30 ps/count. Three Phillips 7186H and two Phillips 7186 TDCs are presently in hand.

Requirement: The digitization time of the ADC and TDC units shall be $\sim$100 μs or less.

Justification: This the spec for the available units and appropriate.
Comments: LeCroy ADC and TDC units have a digitization time of 100 μs. The Phillips units have a digitization time of $\sim$7 μs. The requirement has little actual impact on the TOFp performance, as 100 μs is still very much smaller than the 5 ms it takes to read out the TPC, and there is no reason to read out the TOFp for any event without TPC data.

Requirement: The TOFp digitization shall allow for fast clears.
Justification: The live time of the TOFp system will be greatly increased by allowing one to abort the digitization of events with a valid pretrigger but not a valid Level-0 trigger.
Comments: Both the LeCroy and Phillips ADCs and TDCs allow fast clears. The Phillips ADCs and TDCs also allow one to delay the digitization by up to 750 ns.

6.10 TOFp DAQ Actions

Requirement: The TOFp CAMAC crate controller shall be programmed to recognize when valid ADC and TDC data exists in TOFp crate (i.e. "LAMs"), and then read/clear these data into local memory.
Justification: This is the natural first action per event needed to obtain the TOFp data.
Comments: The TOFp data can be stored in 8 MB list memory of the Kinetics CAMAC "Grand Interconnect Crate Controller," or 32 MB of memory on the VME side. The connection between CAMAC and VME in the TOFp DAQ is performed by connecting the Grand Interconnect Crate Controller to the sibling Kinetics "Host Adapter for the Grand Interconnect" via an optical fiber. The two are designed for exactly such a connection between CAMAC and VME. In 32 MB of memory, one could store 32,000 TOFp events of 1 kB each.

Requirement: The digitized TOFp data will be stored locally in memory for up 1s of real time after the collision.
Justification: It takes 5ms in order to read out the TPC should the event pass all trigger levels. The TOFp data must be available to be read by DAQ at any time up to or after this 5 ms period.
Comments: At an event rate of 1 kHz, which is that expected asymptotically in minimum-bias Au+Au running. In 32 MB of local memory, as in a Motorola 2306 CPU, one could store 32000 1 kB events, implying 32 real-time seconds of data can be stored locally, which is much larger than 10ms.

Requirement: The STAR token must be assigned to each block of event data that is stored locally in TOFp memory.
Justification: The token is the standard and sole event identifier for all interactions between the STAR detectors and the STAR TRG and DAQ systems.
Comments: The token arrives 1.5 μs after the collision. The TOFp Crate Con-

troller must be programmed to periodically look at the I/O register in the TOFp crate which is connected to the Trigger's TCD bus. If a Level-0 is seen, the token for this event obtained from the bus must be attached to the block of (already stored) TOFp data corresponding to this same crossing. The TOFp Crate Controller also must be programmed to periodically look for higher-level trigger aborts/accepts.

Requirement: Events stored locally in TOFp memory are to be flushed if no valid Level-0 trigger is seen for this event, or if subsequent higher level trigger aborts are seen later.
Justification: There is no reason to keep TOFp data if the TPC is not read out. The TPC isn't going to be read out unless all trigger levels are satisfied.
Comments: Just lose the pointer and release the memory for this block of TOFp data.

Requirement: The TOFp DAQ must be able to read certain technical monitor data, such as from thermocouples, and save this information for readout with the TOFp ADC and TDC data in every event.
Justification: Monitor information is needed to evaluate the stability of the system on both long and short terms. Having these data in the same table as the TOFp ADC and TDC data would make the analysis codes simpler. As there are only perhaps 20 words too be read out from the thermocouples, adding these words to the TOFp data in each event is only a small (20%) increase to an already small number (<1 kB/event, see below).
Comments: Any appropriate commercial system that can easily be configured for readout into a CAMAC crate controller should simply be purchased.

6.11 Interface to STAR DAQ

Requirement: The TOFp DAQ system must be connected to the STAR DAQ system via optical fiber.
Justification: This is the STAR standard.
Comments: The two major components of the TOFp DAQ system are a Kinetics CAMAC crate controller and a Kinetics VME host adapter, which are designed to be connected by optical fiber.

Requirement: The TOFp event size shall be as small as possible.
Justification: Allows one to store more events locally, and reduces time to transmit the data to DAQ.
Comments: If there are 100 TOFp data words of 4 bytes each, and including a generous amount of space for tokens and other event identifiers, then a TOFp event is less than 1 kB of data.

Requirement: If the TOFp DAQ logic determines that a block of TOFp event data exists in local memory, and it has assigned a valid token, and was not aborted by higher

level STAR triggers, then the TOFp DAQ will generate a VME interrupt in a crate seen by the STAR DAQ.
Justification: This tells DAQ that, when they're ready, we want to be read into into the main STAR data stream.
Comments: This design was suggested by the DAQ Group. [6] The Kinetics Host adapter for TOFp generates this interrupt.

Requirement: This VME interrupt will be "accompanied" somehow by a small header table to indicate basic aspects of the TOFp event that is now available, in particular the token number.
Justification: We need to tell STAR DAQ not only that we have data, but also what the token number is for the event(s) being held in local memory, *i.e.* there is a nonzero table of TOFp information "with the proper papers." The STAR DAQ then reads out this properly referenced event when it is convenient for STAR DAQ to do so.
Comments: This header and other details of the VME interrupt are not yet defined.

Requirement: There will be some signal obtained from the STAR DAQ that alerts the TOFp DAQ that the event has been successfully read by STAR DAQ.
Justification: This is needed so that the local memory holding this TOFp event can be released.
Comments: The details of this handshake have also not yet been defined.

6.12 Interface to STAR Online

Requirement: It will be possible to display the values of certain TOFp monitors such as the various thermocouple values.
Justification: It is important to monitor the conditions inside the tray and along the cable path throughout the data collection.
Comments: This data should be attached to the table containing the TOFp ADC and TDC data before DAQ reads this data, so that DAQ and online can get all of the TOFp data for each event from a single source.

Requirement: It will be possible to display the raw ADC and TDC distributions and their correlations separately for each TOFp slat in a given STAR event.
Justification: This is needed to evaluate the stability of the gains and timing offsets.
Comments: These are simple 1- and 2-dimensional histograms of the TOFp data itself.

Requirement: It will be possible to display certain standard summary histograms, such as the ADC and TDC hit patterns over many events.
Justification: These are needed to look for pathologies in the behavior of individual channels of the detector.

Comments: These are simple 1- and 2-dimensional histograms of simple variables calculated from only the TOFp information.

Requirement: It will be possible to obtain at least minimal track information for use by TOFp software to make the matching of TPC tracks to TOFp hits online.
Justification: The availability of tracking information allows the online formation of the canonical $1/\beta$ versus momentum plots. These are excellent indicators of the performance of the system.
Comments: These are simple 1- and 2-dimensional histograms of variables calculated using both the TPC tracking and extrapolation and the TOFp information.

References

[1] TOFp Proposal, http://bonner-mac8.rice.edu/~TOF/default.html (Nov. 17, 1998).

[2] W.J. Llope for the STAR TOFp Group, STAR Collaboration Meeting, plenary session, BNL, January, 1999.

[3] W.J. Llope for the STAR TOFp Group, STAR Collaboration Meeting, plenary session, BNL, August, 1999.

[4] Z. Milosevich, available below STAR Trigger WWW page.

[5] H. Crawford, private communication.

[6] M. Levine, private communication.