Brief Introduction to the VPD & the TOF Start-Side

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☆ Analysis Meeting
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1. STAR L-0 Triggering...
   ...including Zvtx selection
2. TOF Start Timing...
3. Polarimetry...

Outline:
- Mechanics & Acceptance
- Electronics & Digitization
- Offline Calibrations
- Outlier Rejection
- Vertex Consistency
- Resolution
- Triggering

What's the idea here?

two very forward detector assemblies on each side of STAR, each with many sub-detectors, and each sub-detector has a good time resolution

Exploit the fact that very forward particles are typically very fast (v~c) to measure:

START TIME

TOF = Tstop - Tstart

Teast: ...time from the east detector assy,   Twest: ...time from the west detector assy

Tstart = (Teast + Twest)/2   ...pushes an offset of d/c to the stop-side

Tstart = (Teast + Twest)/2 - d/c   ...gives Tstart at the primary vertex

ZVTX from timing -

a 2nd opinion to the Zvtx from tracking...

can also be measured very quickly, allowing constraints on Zvtx at Level-0...

ZvtxVPD = (c/2)(Teast - Twest)

TOF PRO: TOF extends the momentum intervals allowing direct PID!

TOF CON: The resolution track-by-track is much more complicated than for dE/dx...

Nsigma-type cuts and trivial PID-efficiency corrections are generally approximate...

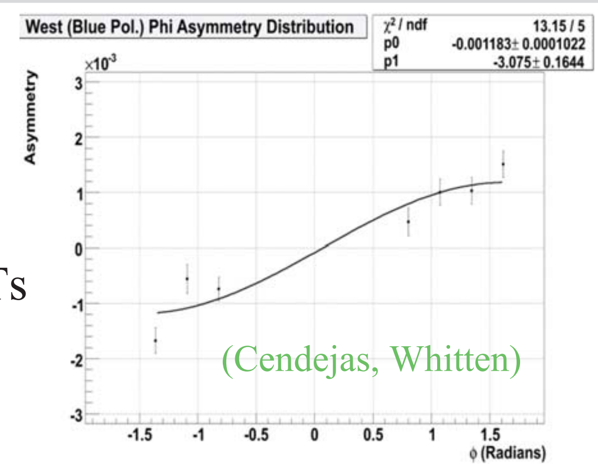
A lot of this more complicated resolution dependence is coming from the start-side!

This is a main theme of this brief introduction to the TOF start-side....

I'll come to the resolution on Tstart and ZvtxVPD later...

POLARIMETRY

look at L/R asymmetries of the lit PMTs



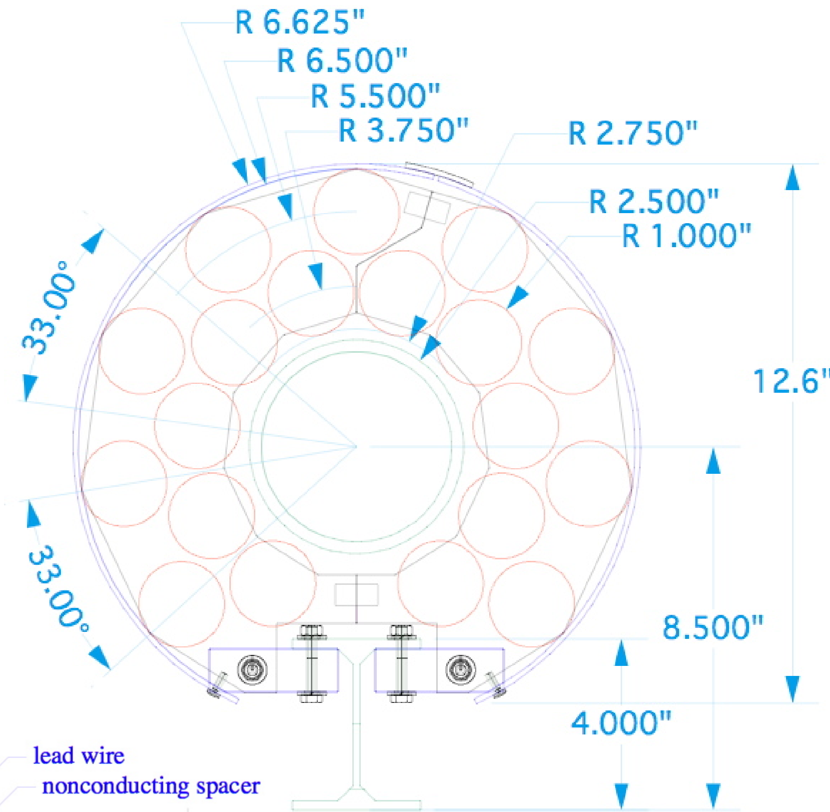
(Cendejas, Whitten)

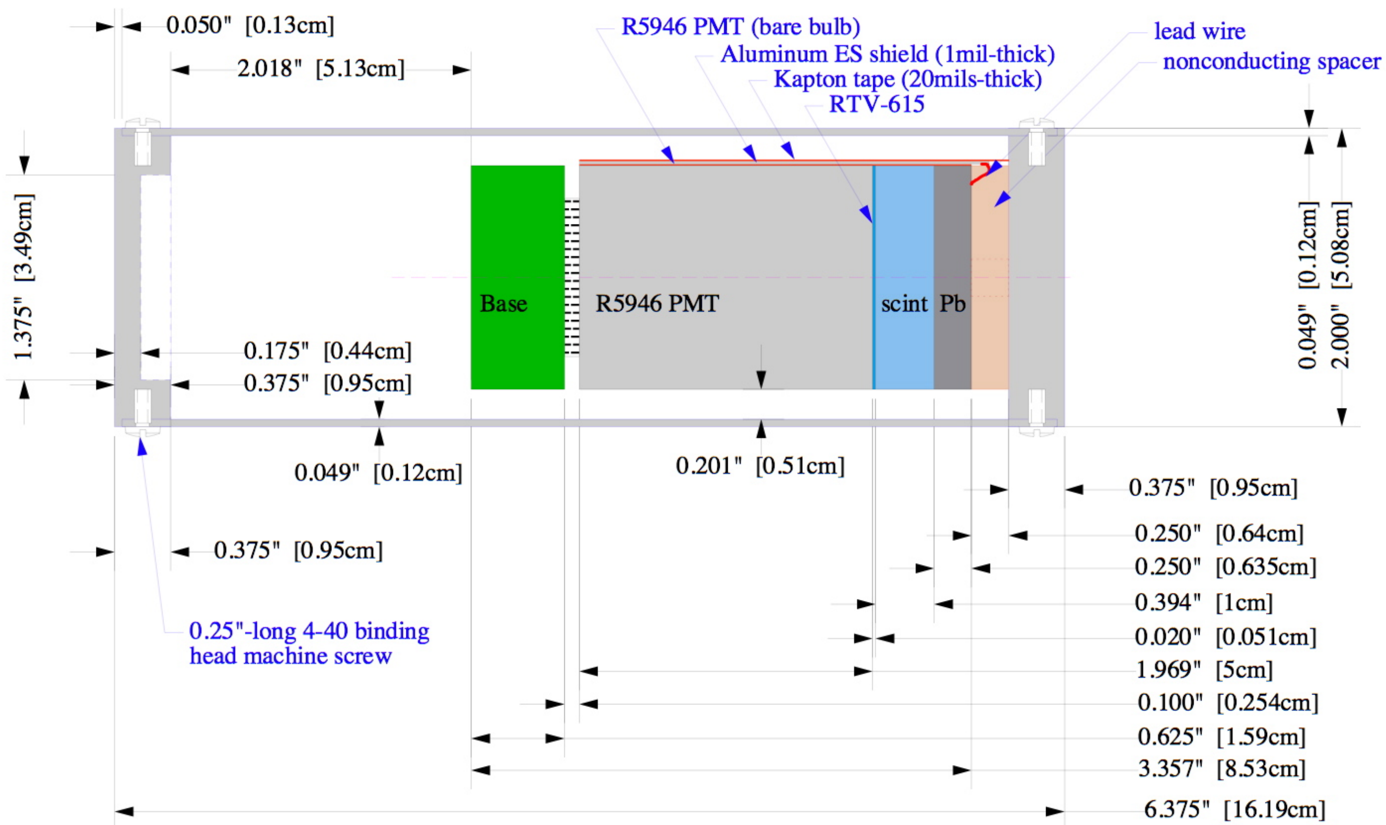
upVPD Mechanical Details

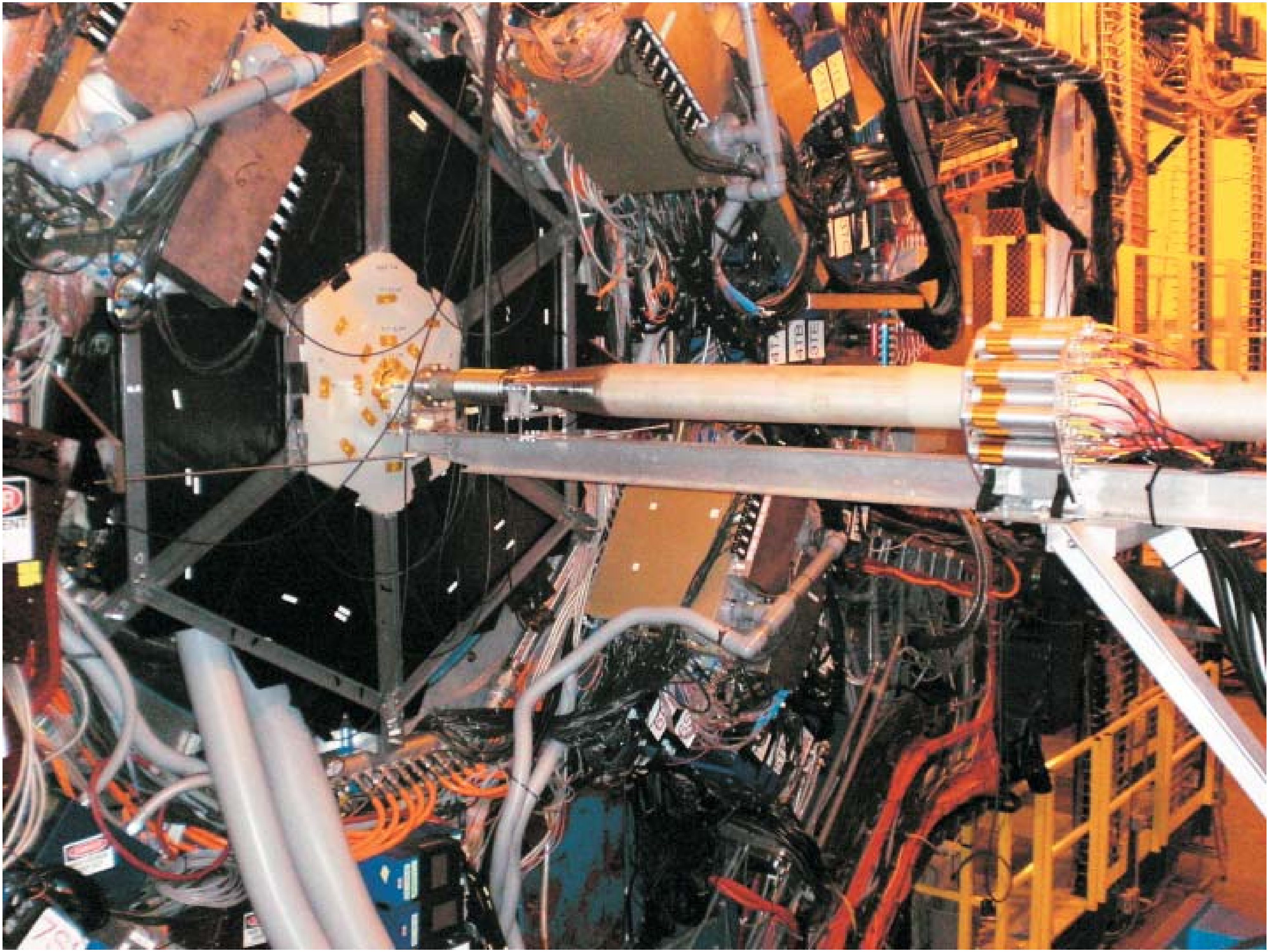
19 detector channels per side, 2.0” OD
in same integration volume as pVPD
no Steel or magnetic shielding, light-weight

Inner radius ~ 2.75” = 6.98cm
Outer radius ~ 6.50” = 16.51cm
STAR |Z| ~ 570 cm
$4.24 < |\eta| < 5.10$

Pb converter, 1.5” OD, 1/4”-thick (1.13 radiation lengths)
inner ring converter min $|\eta| = 4.60$
inner ring converter middle $|\eta| = 4.79$
outer ring: ~1/3 of azimuth covered, $4.2 < |\eta| < 4.6$

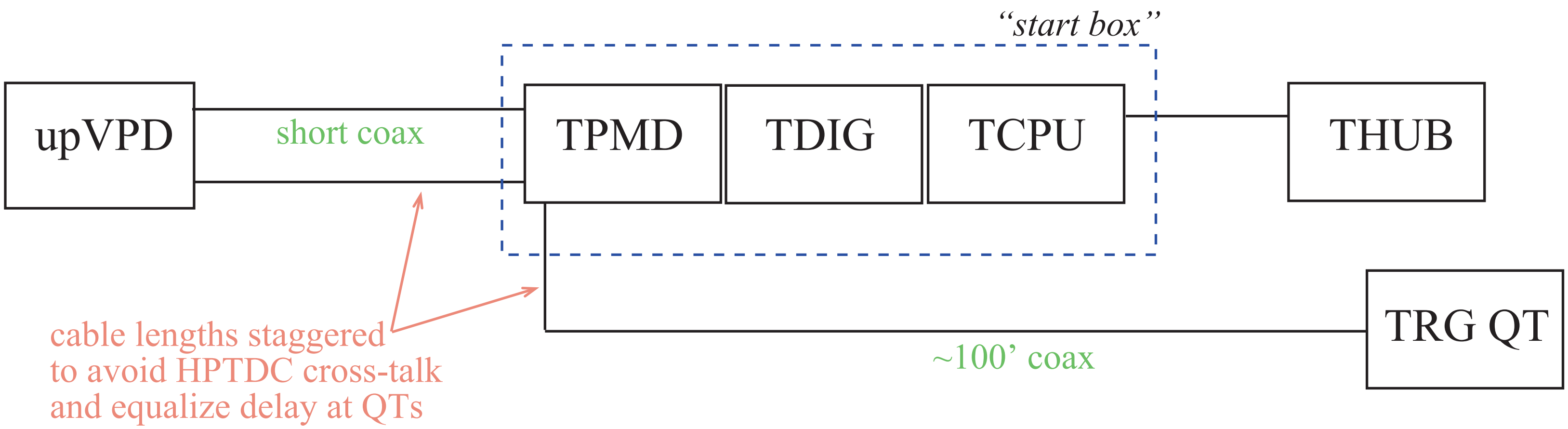






Electronics & Digitization

The upVPD signals are digitized by two different sets of electronics in the same event.

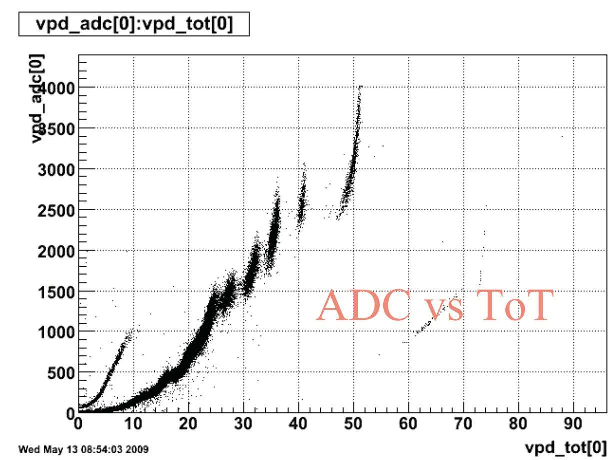


TOF Digitization: "Absolute timing"

- 21 bit time values w.r.t. revolving 40 MHz clock
  - Time-stamps within ±2.5 μs of the L0 trigger are sent to DAQ.
  - Earlier times are smaller numbers
- Signal size metric is the Time-over-Threshold ("ToT") = pulse width

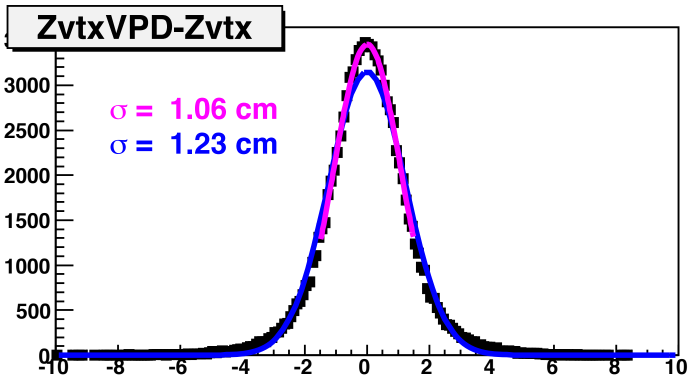
TRG Digitization: "Start-stop timing"

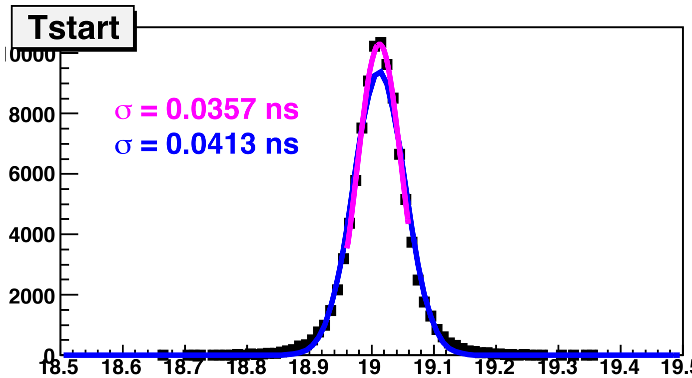
- 12 bit time values w.r.t. a common start from the RHIC clock
  - Times available for the triggered crossing only.
  - Timing common-stop - earlier times are larger numbers
- Signal size metric is an ADC value = pulse area



Let's calculate Tstart = (Te+Tw)/2 and ZvtxVPD = (c/2)*(Te-Tw) from a Toy Model

```
event loop:
    generate Gaussian-distributed Zvtx, σ_z = 50cm
    set random number of lit PMTs on each side, Ne and Ne in range [1,19]
    calculate time for each lit PMT as (570cm±Zvtx)/c smeared with σ_t = 150ps
    calculate average time on each side → Te and Tw
```

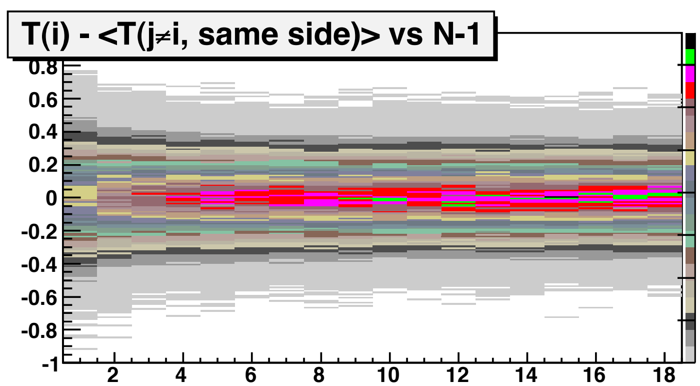


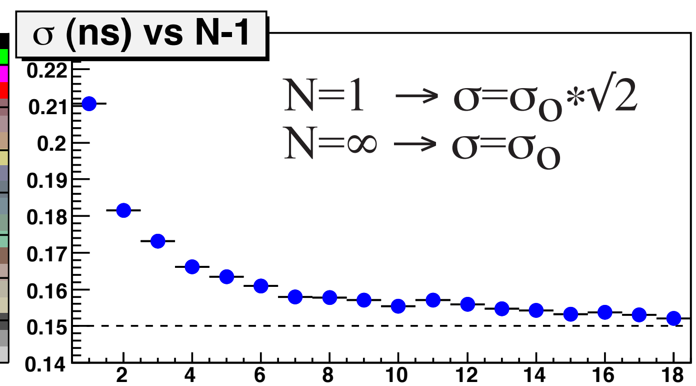


Resulting distributions are not Gaussian!

...and here's why

$\sigma \sim \sigma_O/\sqrt{N}$





This is the Averaging Effect, and it is both a blessing and a curse

PRO: resolution improves as N increases... (& is much better than the single-detector resolution)...

CON: in a given event sample w/in which Ne & Nw can vary
(and depend on trigger ID, centrality, etc...)
then the start time (and hence the TOF PID), and ZvtxVPD measurements are not Gaussian...

So,

p+p: Ne~Nw~1-2, and if σ_o~140ps

→ σ(Tstart) ~ $\sigma_o/\sqrt{2}$ ~ 85ps

→ σ(ZvtxVPD) ~ $\sigma_o*\sqrt{2}*(c/2)$ ~ 3cm

"Differences Cost, Averages Earn"

Resolution in Au+Au is much much better...

multiparticle timing (huge signals)

Ne ~ Nw ~ 19

TOF PID resn is complicated by the complicated start-side resn!

At least can make σ_o as small as possible! → **Calibrations**

On both the start and stop sides: Slewing and Offsets

Offsets: PMT transit time, cable & trace lengths, etc etc

Slewing: Large pulses cross a threshold earlier than small pulses

"Define a quantity that would be zero if there was no slewing and no offsets..."

Iterative procedure

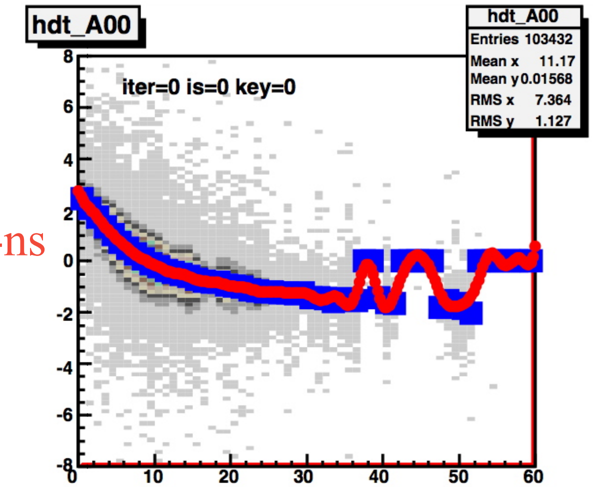
Plot time(i) minus average of other times on the same side vs the signal size

Fit it

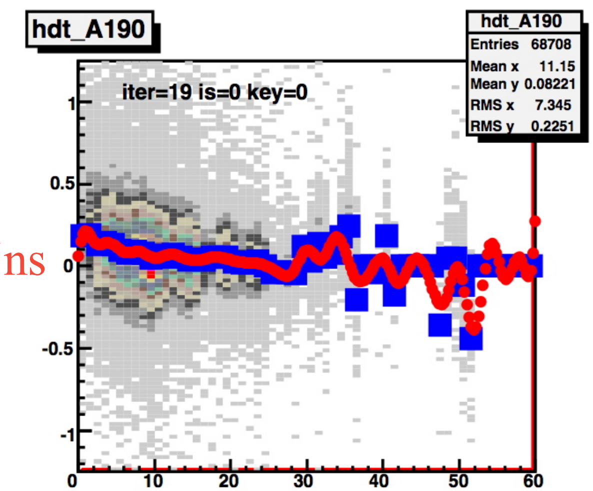
Use the correction in subsequent passes

Stop when the resn no longer improves

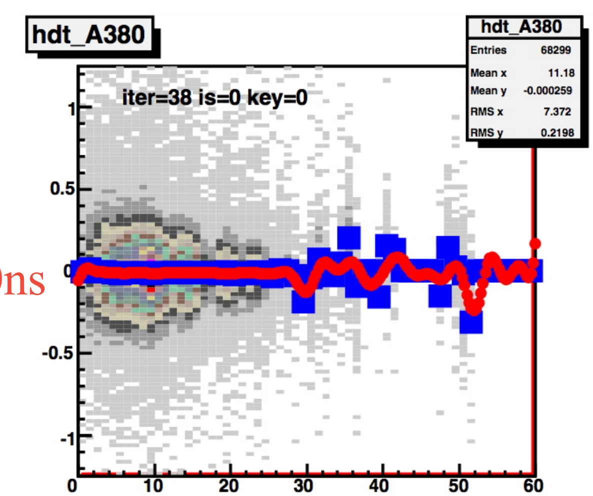
~4ns



~0.5ns



~0ns



Start-side Single Detector Resolution

Evaluate the resolution in a way that avoids the smearing from the Averaging Effect....

Plot
t(i) - <T(i!=j, same side)>
versus
N-1
where i runs over all 19chs/side

Then FitSlicesY these 38 plots...

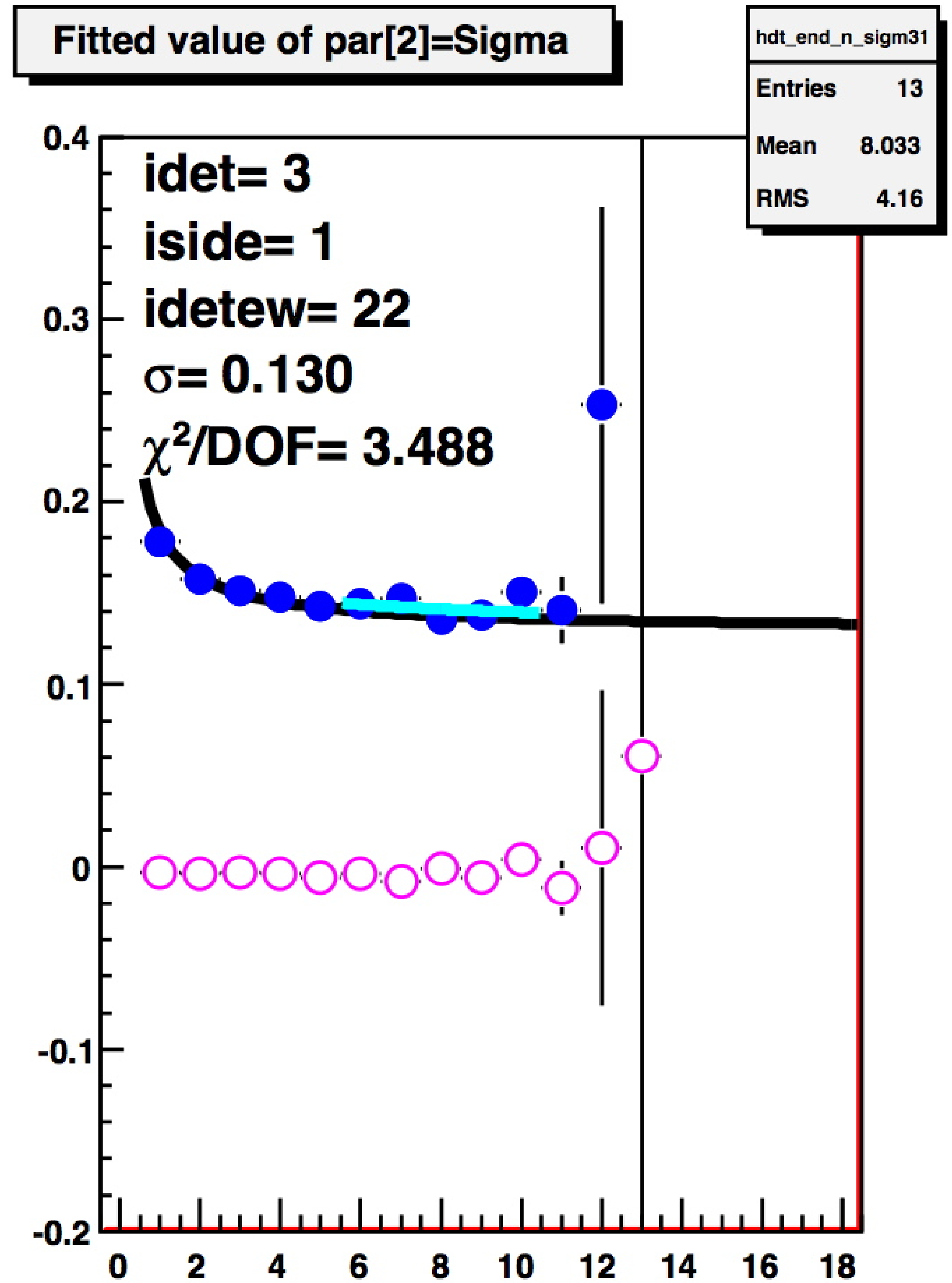
Plot mean vs N-1 (magenta points)
Plot sigma vs N-1 (blue points)

Fit sigma vs N-1 with the function:
$F(x) = par[0] * Sqrt((x+1) / x)$

par[0] = asymptotic resn (N=∞)
"Single Detector Resolution"

If Magenta points not all near 0
→ problem!

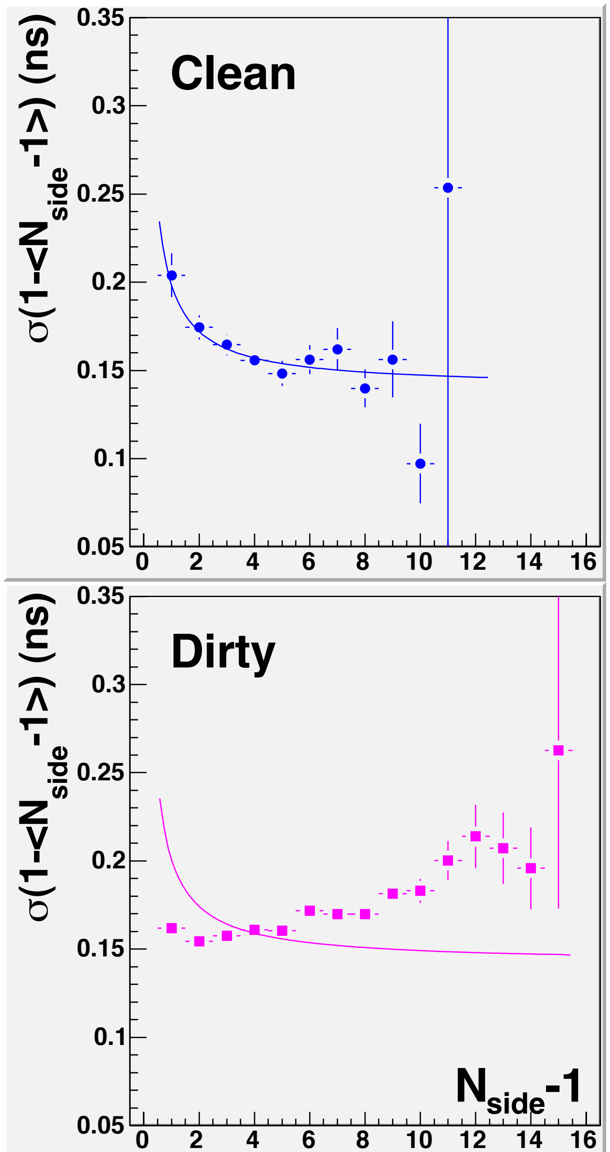
cf. BES "Sawtooth"
http://www.star.bnl.gov/HyperNews-star/get/startof/2256/1/1.html



Outlier Rejection

Not all start-side hits are “in-time” and those that aren’t need to be rejected!

Best Indicator: Resn vs N-1 does not follow the expected function
i.e. adding more hits makes the resolution *worse*.

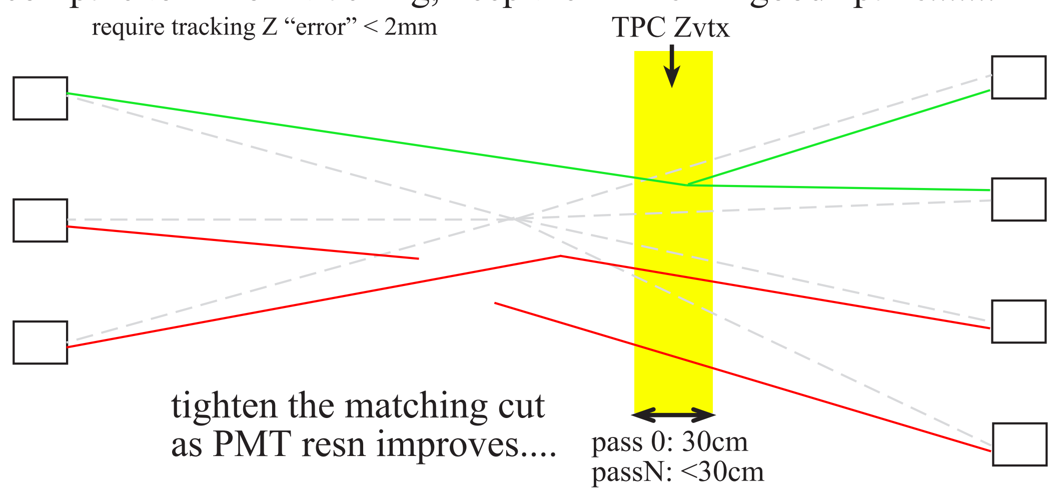


Two Outlier Rejection Algorithms presently in use:

Zebo-style:
require t(i) - <t(i!=j, same side)> below a Δt cut.

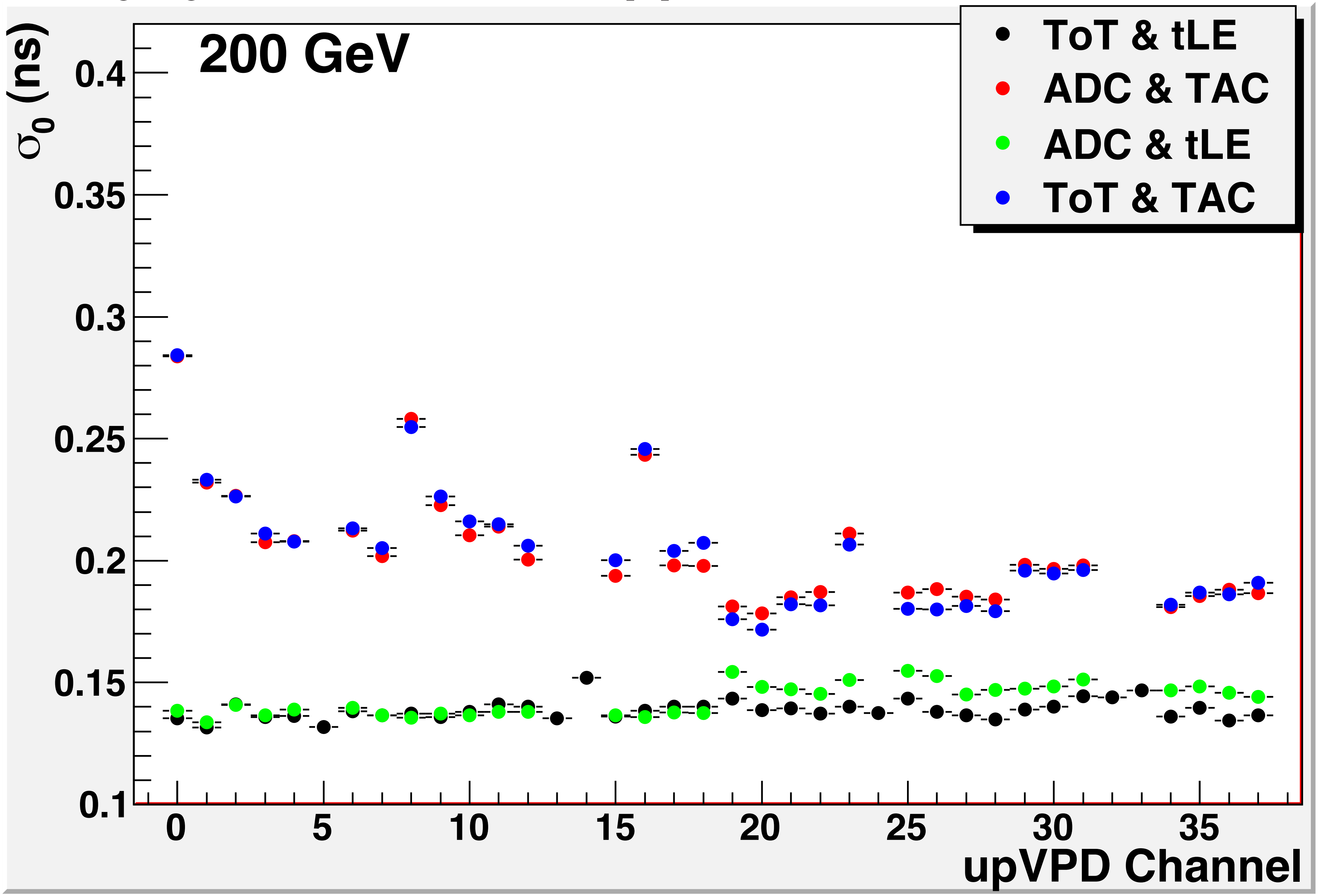
My Style:
use the TPC track/vertex information

measure Z from timing for all pairs of lit PMTs
compare to Z from tracking, keep the PMTs in “good” pairs.......



with calibrated times, a 6cm cut is appropriate in p+p

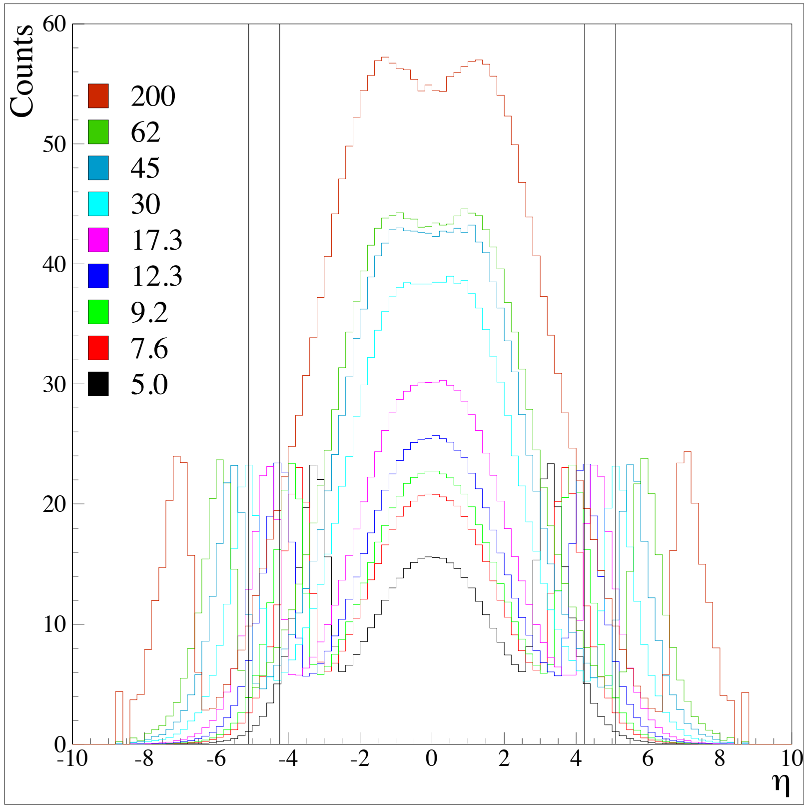
Resulting Single-Detector Resolution in Run-9 p+p

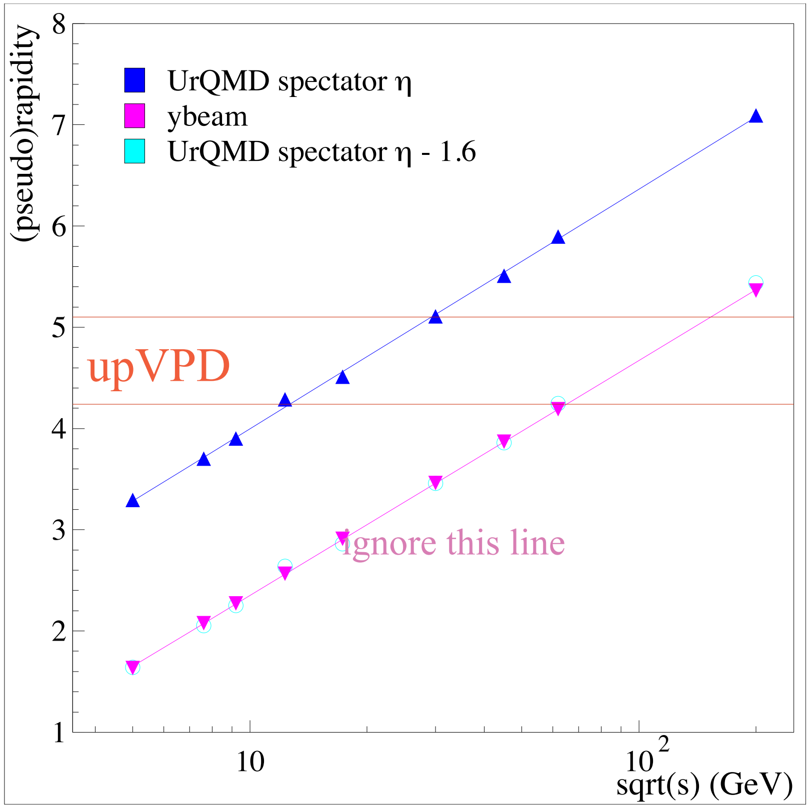


Blue Sky, Rice, LBL, UT SBIR in progress: improve time resolution of TRG time digitization....

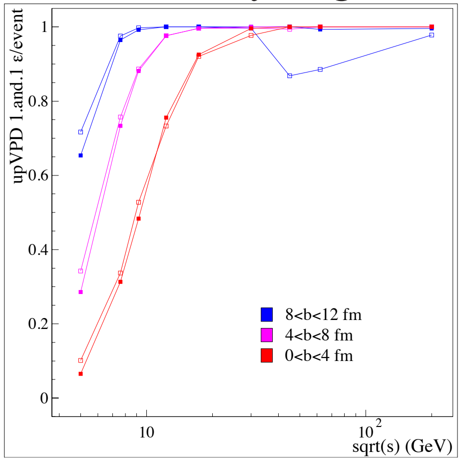
Beam Energy Scan Data..... upVPD “acceptance” is a strong function of the beam energy...

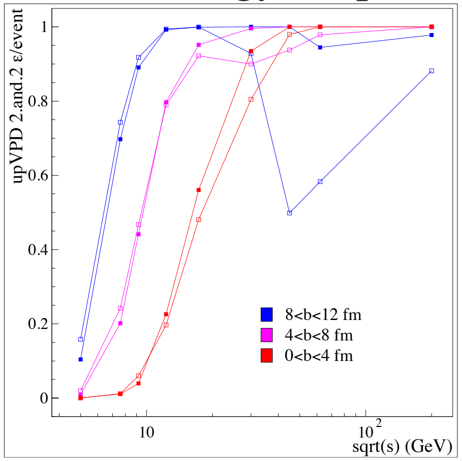
from a UrQMD simulation:

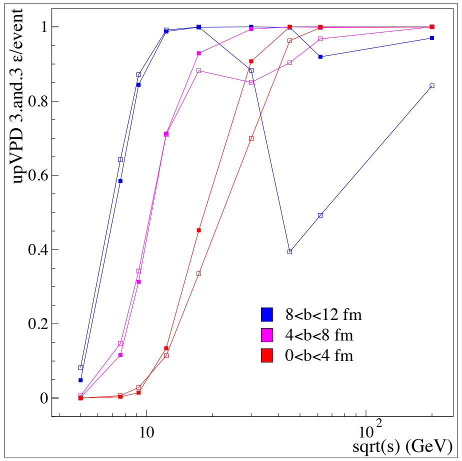




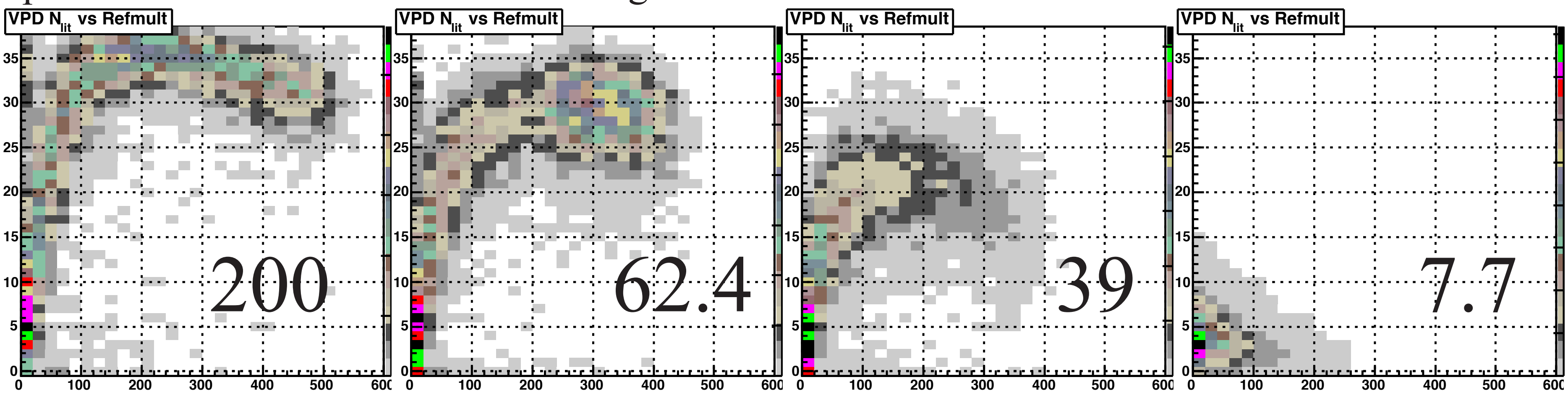
Efficiency degrades as the beam energy drops...

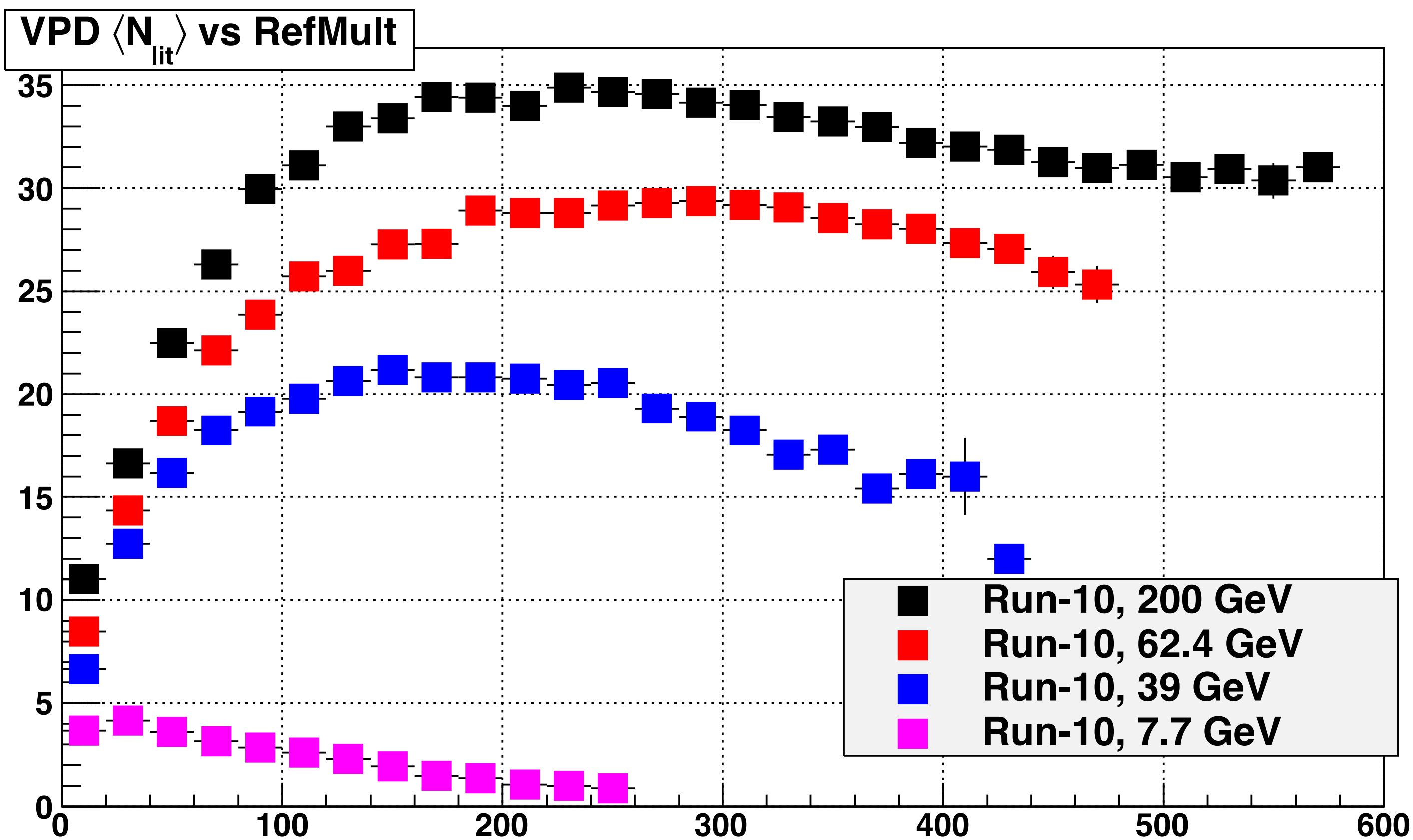






upVPD Lit Channels vs RefMult during the BES...





Beam/Energy	σ_0
Au+Au 200	~100
Au+Au 62.4	~130
Au+Au 39	~140
Au+Au 7.7	~200*
p+p 200	~140

* all triggers....
vpd_mon in progress

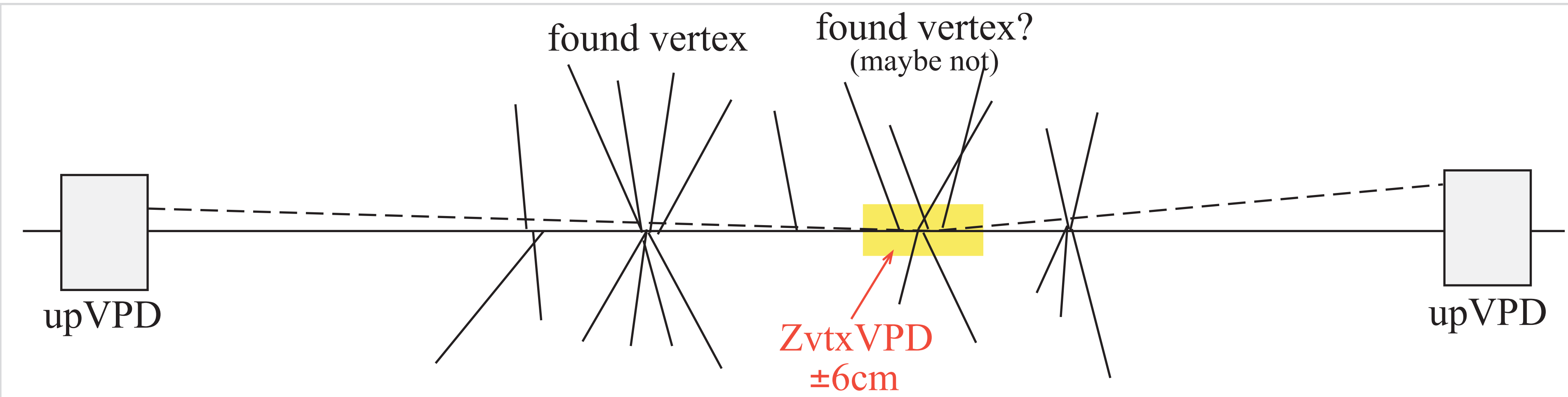
http://www4.rcf.bnl.gov/~llope/files/

Vertexing in Analyses....

In Run-9, the choice was made to avoid the VertexFinder results.

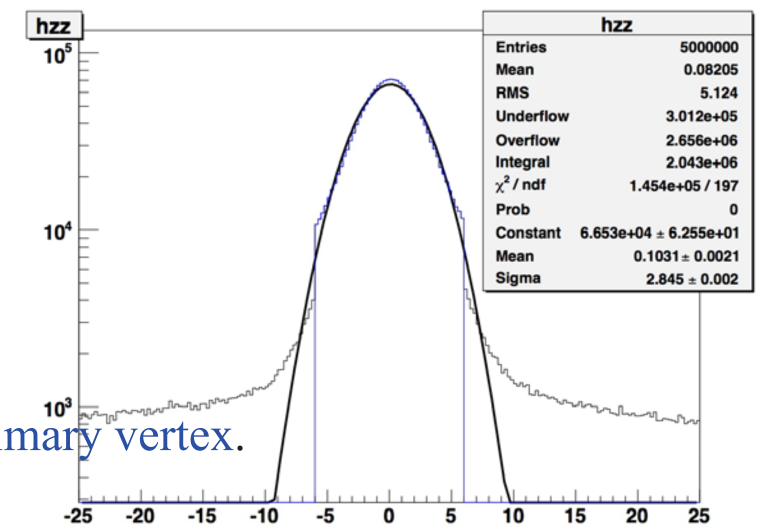
→ Calculate ZvtxVPD. (as σ_O is ~150ps, and Ne~Nw~1, then σ(ZvtxVPD)~3cm)
Extrapolate a Global Track to the beam line.
if Z value of the track at the beam line is w/in ±6cm of ZvtxVPD, keep the track!

insures the Start time from the VPD is appropriate for these tracks (because ZvtxVPD matches!)
This is the default option for Run-9 in BTofCalibMaker



Fine for singles-type analyses, well-defined efficiency....
Does not play nice w/ other Makers (*e.g.* JetFinders)
have own DCA cuts and use found vertices....

http://www.star.bnl.gov/HyperNews-star/protected/get/jetfinding/1003.html



Option B:
→ Calculate ZvtxVPD as before...
Loop over found Primary Vertices
if |ZvtxTPC[i] - ZvtxVPD| < 6cm, set Vertex[i] as the Primary vertex.
Now globals from this vertex become primaries...

http://www.star.bnl.gov/HyperNews-star/get/startof/2287.html

The VPD and Level-0 Triggering

No time to apply a full slewing correction

But there's a trick!

Take the earliest hit on each side

Form Zvtx = (c/2)*(Twest - Teast)

This can be done very quickly...

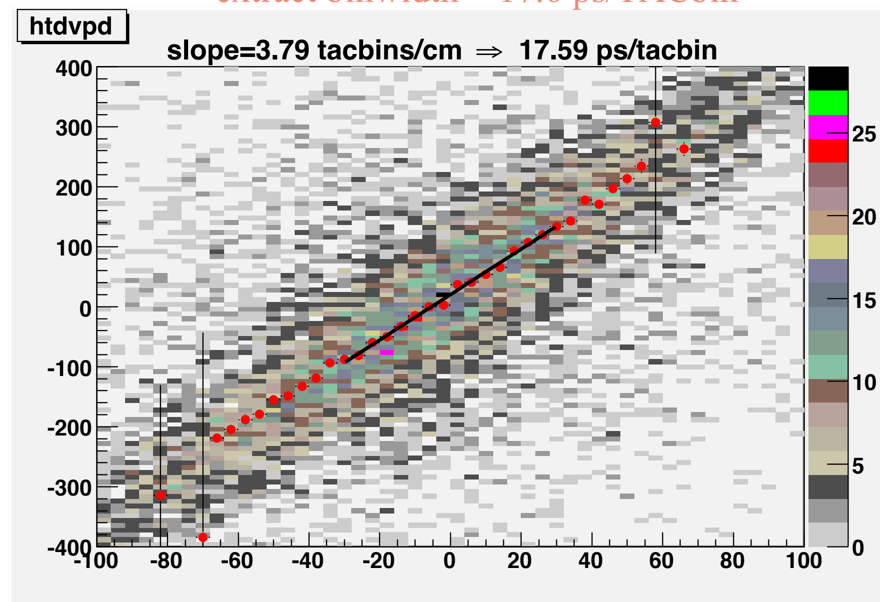
Selection of earliest hit in Au+Au results in an equivalent σ_0 ~ 240ps in all but the most peripheral collisions

→ σ(Zvtx) ~ 5cm

ZvtxVPD = (TACwest-TACeast)*(binwidth)*(c/2)

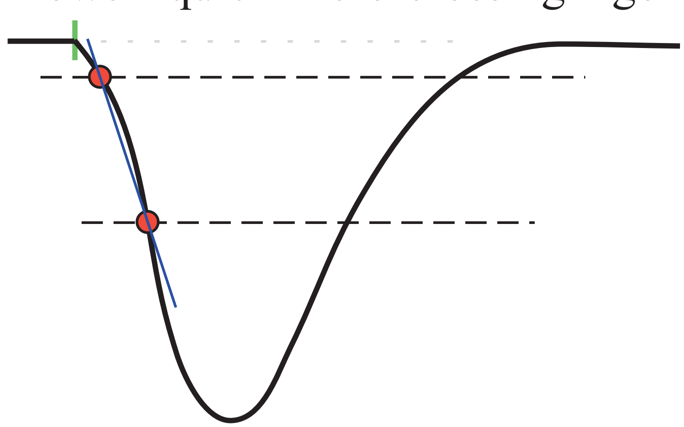
plot ZvtxVPD vs ZvtxTPC

→ extract binwidth ~ 17.6 ps/TACbin



New in Run-10 is Dual Discrimination

allows a quick "zero-crossing algorithm"



only modest improvement (~50ps) in Au+Au due to huge dynamic range of VPD signals

but it will work a lot better in p+p!