TOF Performance

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Outline of Talk

- TOF Calibration Procedure
- TOF Performance
- TOF Issues
- To Do List

TOF timing calibration procedure

Developed by Benni Zihlmann **see GlueX-Doc-2767**

There are 6 steps in TOF timing calibration:

1) **Event selection**: Prepare root tree with TOF hits.

2) **Time-walk correction**: Correction of time shift due to varying pulse amplitudes with Respect to the discriminator threshold.

3) **Mean Time Calibration:** Determine relative Mean Time for all double ended modules.

$$MT = \frac{t_L + t_R}{2}$$

4) **Time Difference Calibration:** Determine relative Time Difference for all double ended modules.

$$TD = \frac{t_L - t_R}{2}$$

5) **Double Ended Paddle Timing Offsets:** Obtain timing offsets for each individual PMT channel from the module's Mean Time and Time Difference.

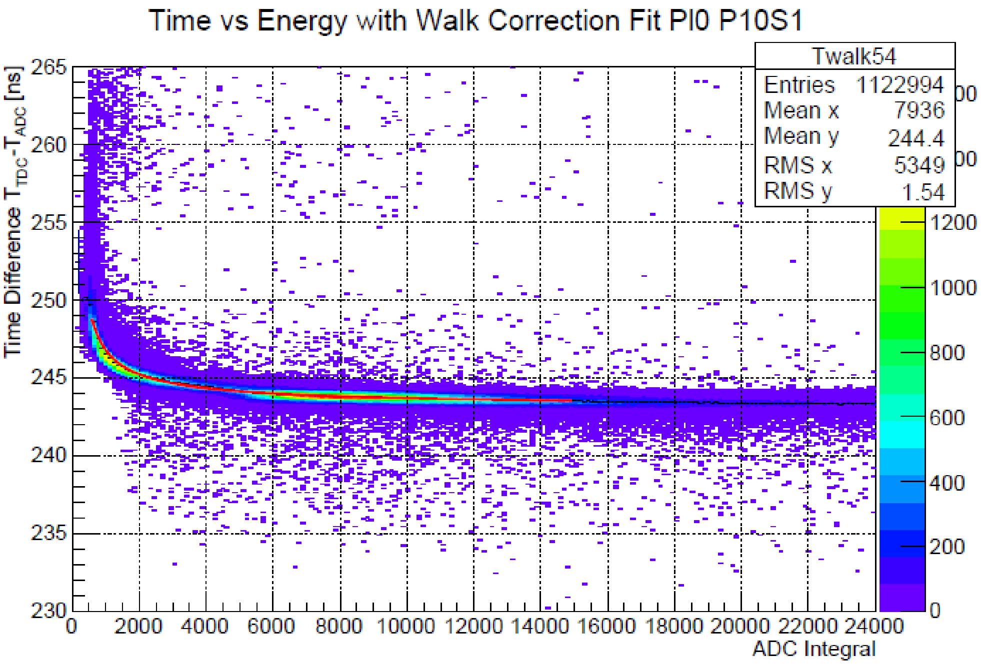
6) **Single Ended Paddle Timing Offsets**: Determine relative timing offsets for single-ended paddles using calibrated double ended modules.

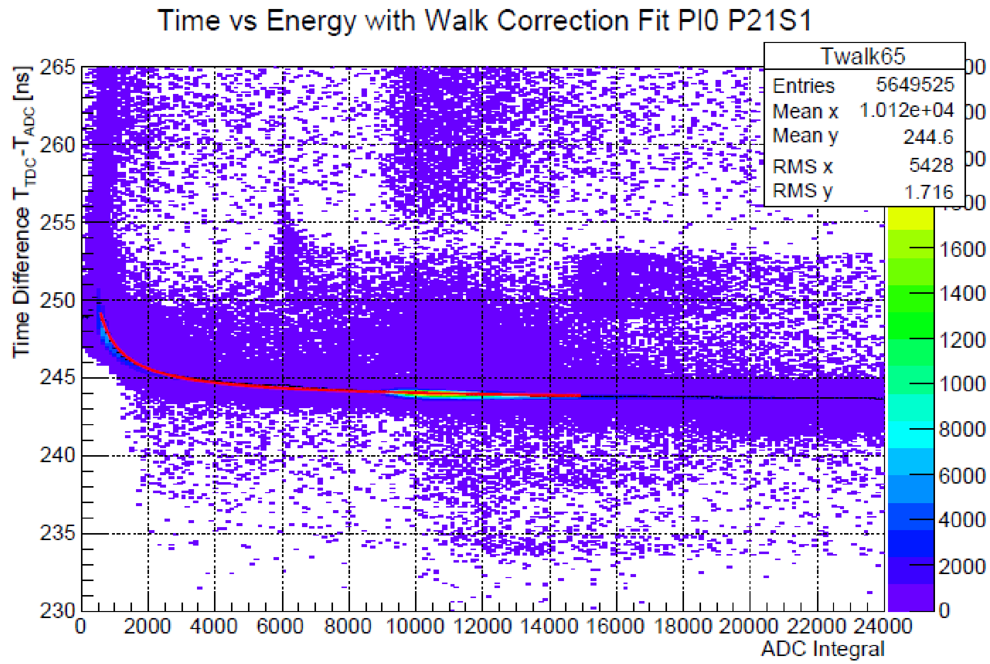
Beni wrote a fully automated calibration toolkit which we have used successfully.

1) **Event Selection**

- Only events with ADC and TDC hits
- Create separate root trees for both ADC and TDC data
- Create separate root trees for double and single ended paddles
- Some of the information we collect is: Number of Hits, Paddle and Plane location, MT, TD, and ADC integral.

2) Time-walk calibration





- ADC hit time is used as t_0 for TDC time
- Characteristic dependence of $\Delta(t_{TDC}-t_{ADC})$ on the pulse integral is clearly seen;
- It is fitted with a functional form: $f(x) = A + B * x^C$
- Important parameter C is typically in the range from -0.75 to -0.85, i.e.,
- A much steeper dependence than 1/sqrt(ADC).

Investigation of alternative t_0

ADC time is determined as a crossing of a fixed threshold. It should have its own time-walk

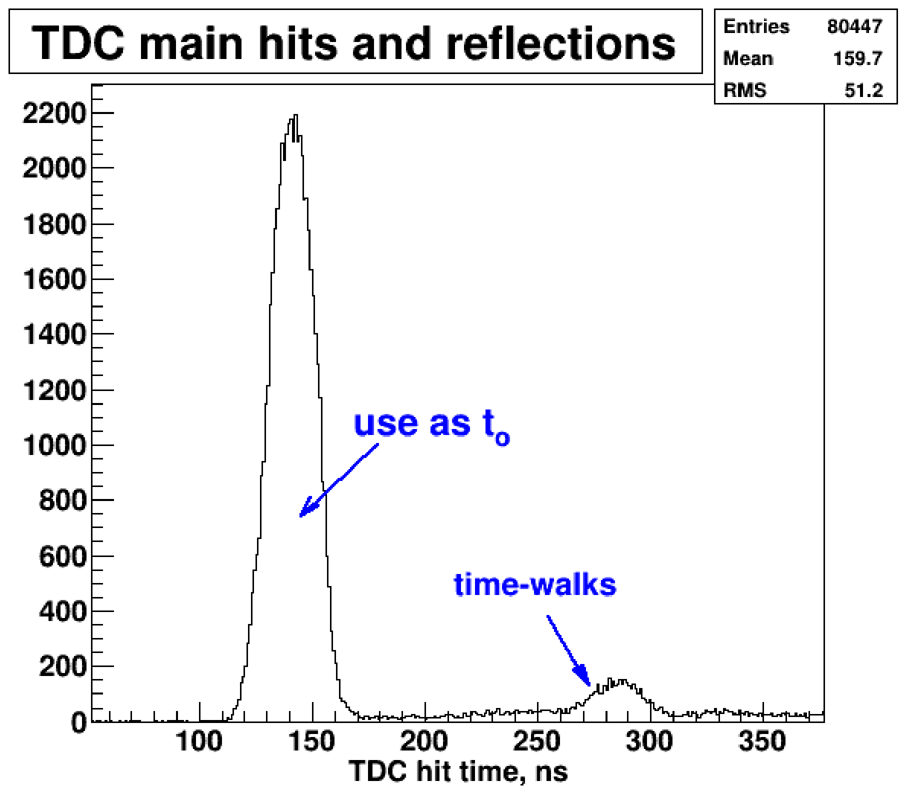
Possible alternatives:

1. Use $6x6cm^2$ intersection region with the other plane (as per GlueX-doc-1719).

- A single fit with ~350 parameters did not converge well
- 6cm uncertainty in position translates into >0.4 ns uncertainty in t_0

2. Use signal reflections.

- Assume that reflection time is constant (twice the cable length at ~170 ns)
- Assume that a huge first pulse (which is needed to observe the reflection) has no time walk
- Study the timing of the reflection a function of its magnitude (more on next slide)



Using reflections to correct time-walks

Events with 2 hits in the same channel (both TDC and ADC) have been selected

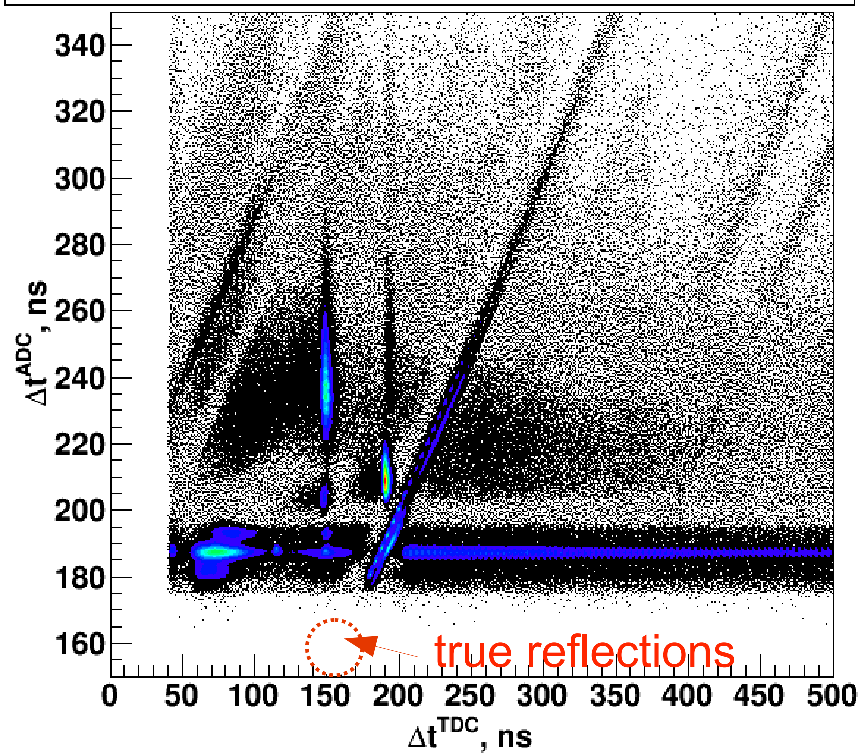
fADC Mode 7 with Npeaks=3

- We set NSA to 45 samples (or 180ns)
- This window was too long and caused the ADC to miss the reflection

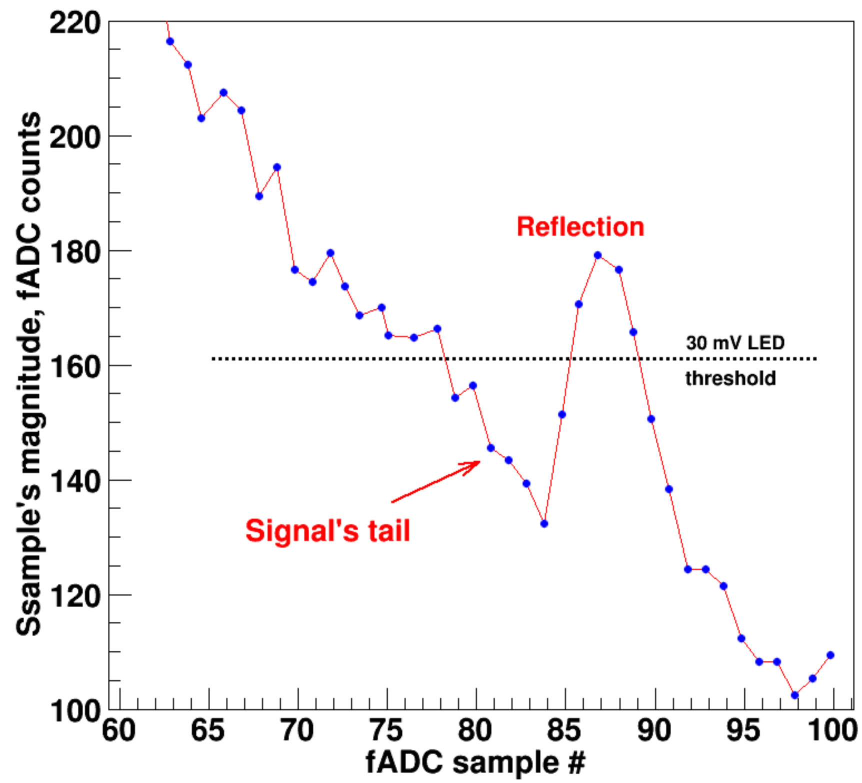
fADC Mode 8

- Reflections which trigger TDC-registered are sitting on top of the signal's tail and therefore have different time-walk shape

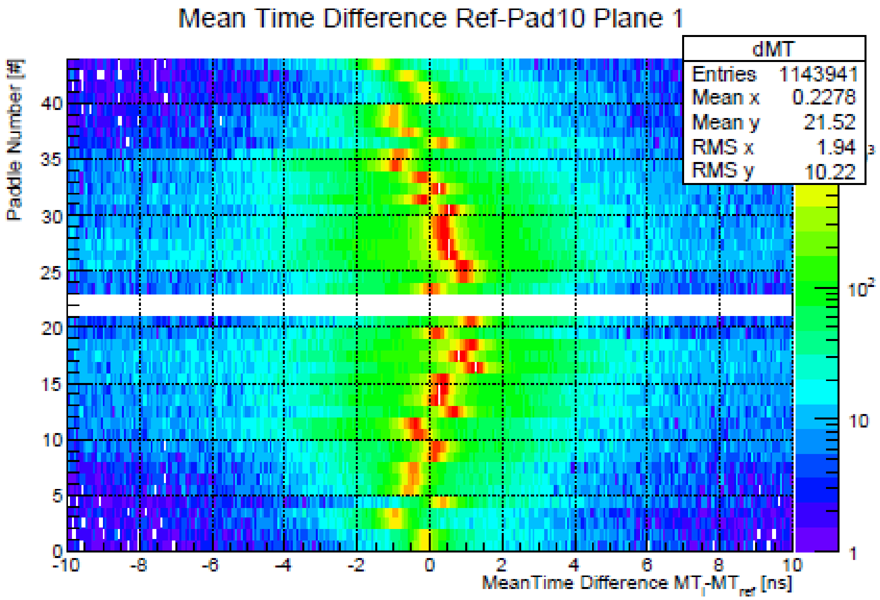
2 pulses: Time differrence of TDC vs ADC

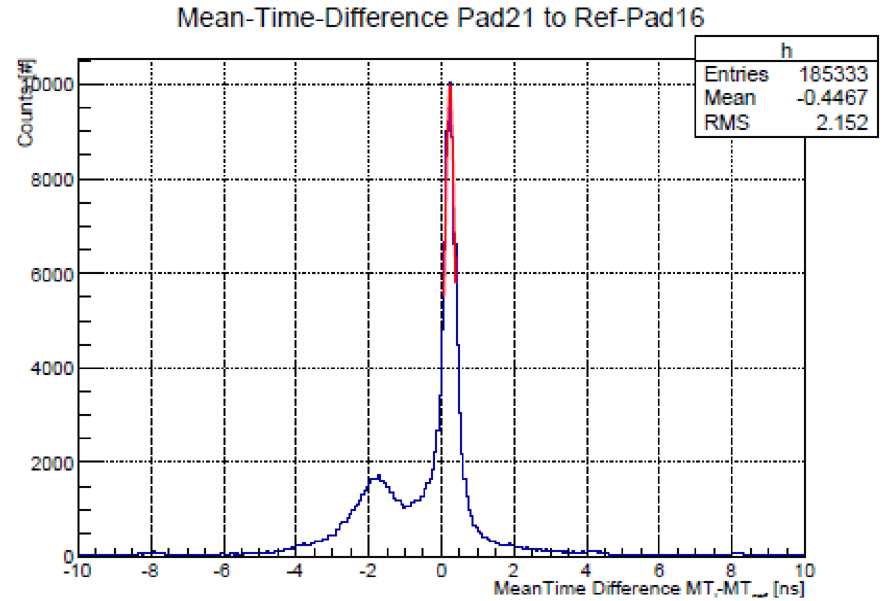


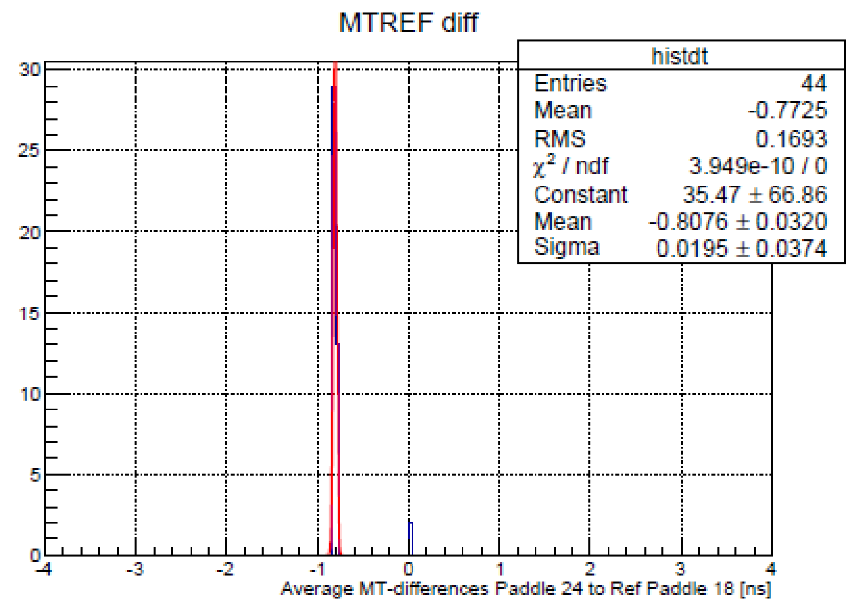
fADC: reflection on top of the signal's tail



3) Mean Time Calibration

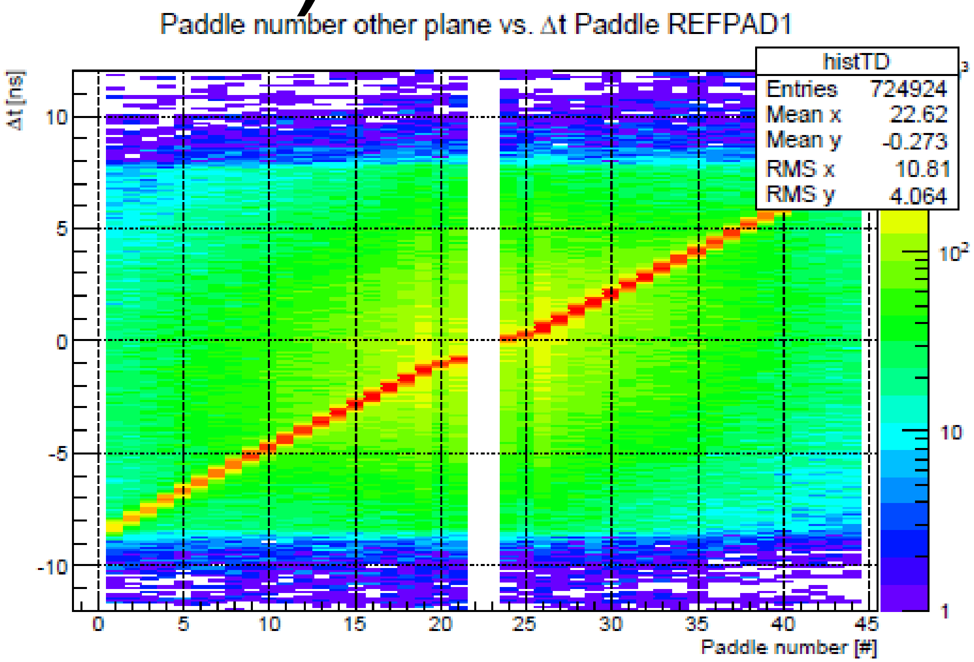


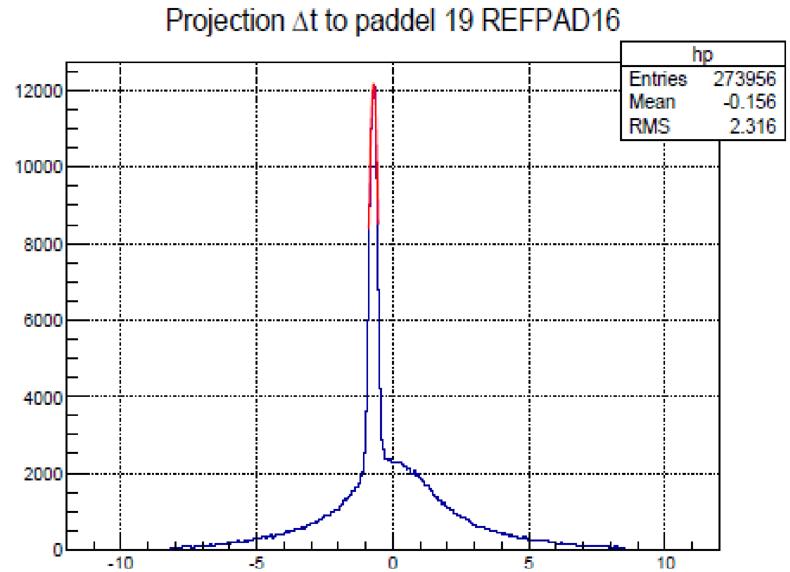


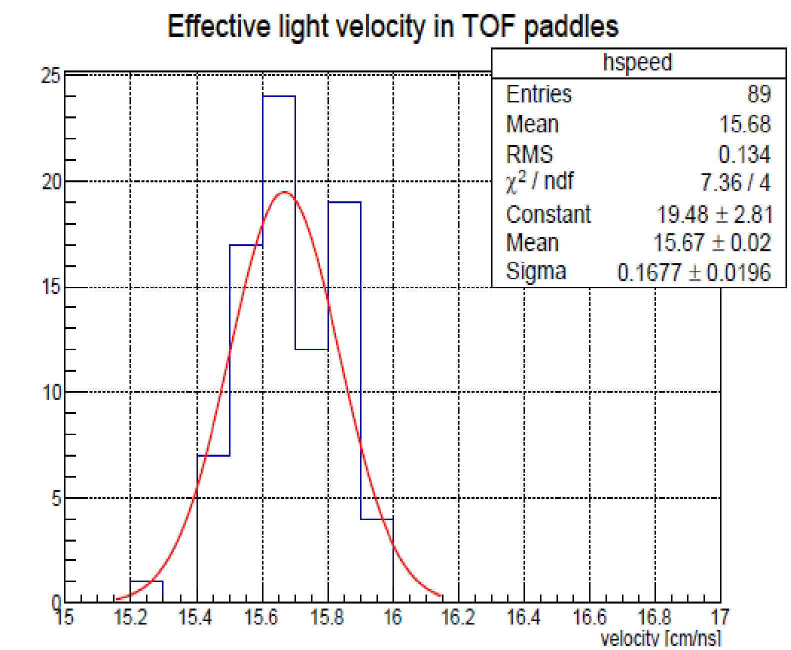


1) Calculate the difference in MT for a reference paddle in plane A with all double ended paddles in plane B
2) Plot the MT difference versus paddle number
3) Select a paddle number and project onto the x-axis
4) Fit the resulting peak to get the timing offset between the two paddles
5) Repeat steps 1-4 for all paddles in plane A
6) Select paddle 18 as a reference paddle for plane A
7) Calculate the difference in MT for paddle 18 with all other double ended paddles in plane A
8) Plot the MT difference versus paddle number
9) Select a paddle number and project onto the x-axis
10) Fit the resulting peak to get the timing offset between the two paddles

4) Time Difference Calibration







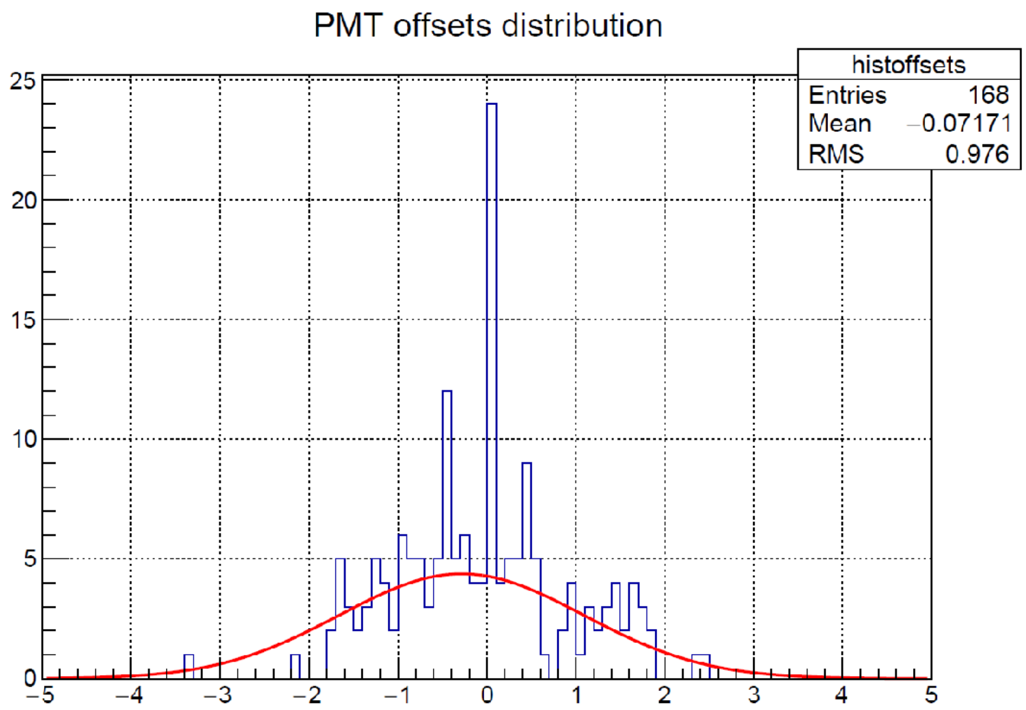
- Same procedure as MT, except we use TD instead
- After we collect the TD peak positions, we can convert a paddle number into its geometric position on the TOF
- This result of this plot gives us a slope which is inversely proportional to the effective velocity of light inside the paddle
- Average c_{eff} = 15.7 cm/ns

5) Double Ended Paddle Timing Offsets

- Knowing the MT and TD offsets for each module allows us to get the timing offsets for individual PMT's by adding/subtracting the MT and TD equations

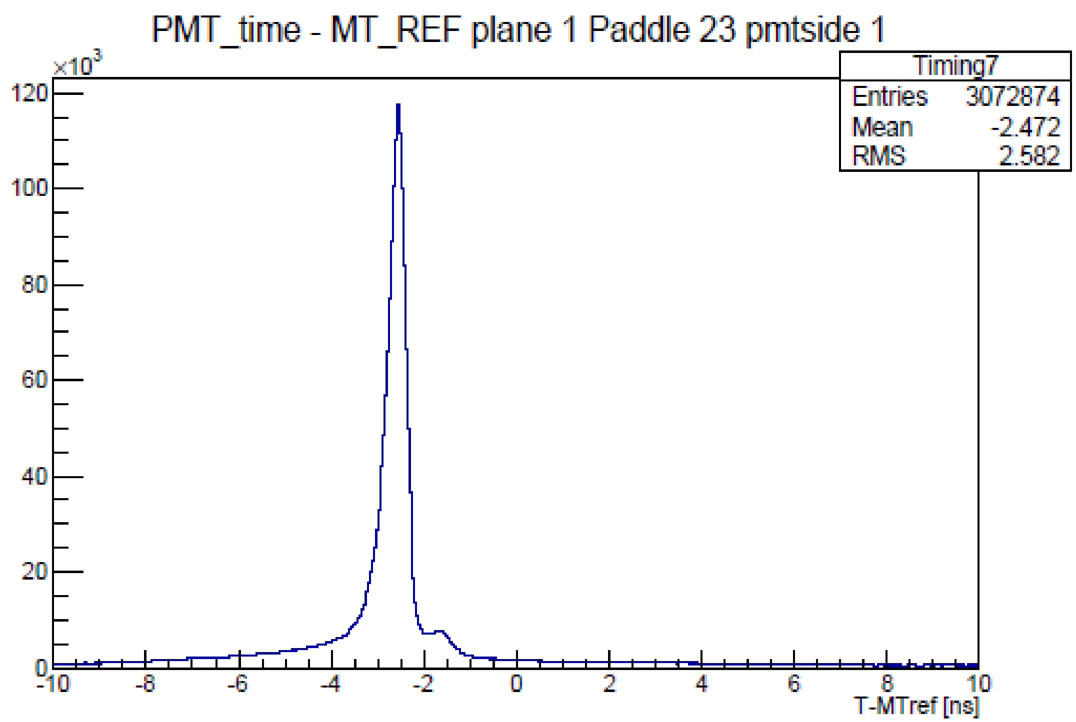
$$MT = \frac{t_L + t_R}{2} \qquad TD = \frac{t_L - t_R}{2}$$

- On average, the timing offset is about 1 ns, with max offsets of 3.5 ns

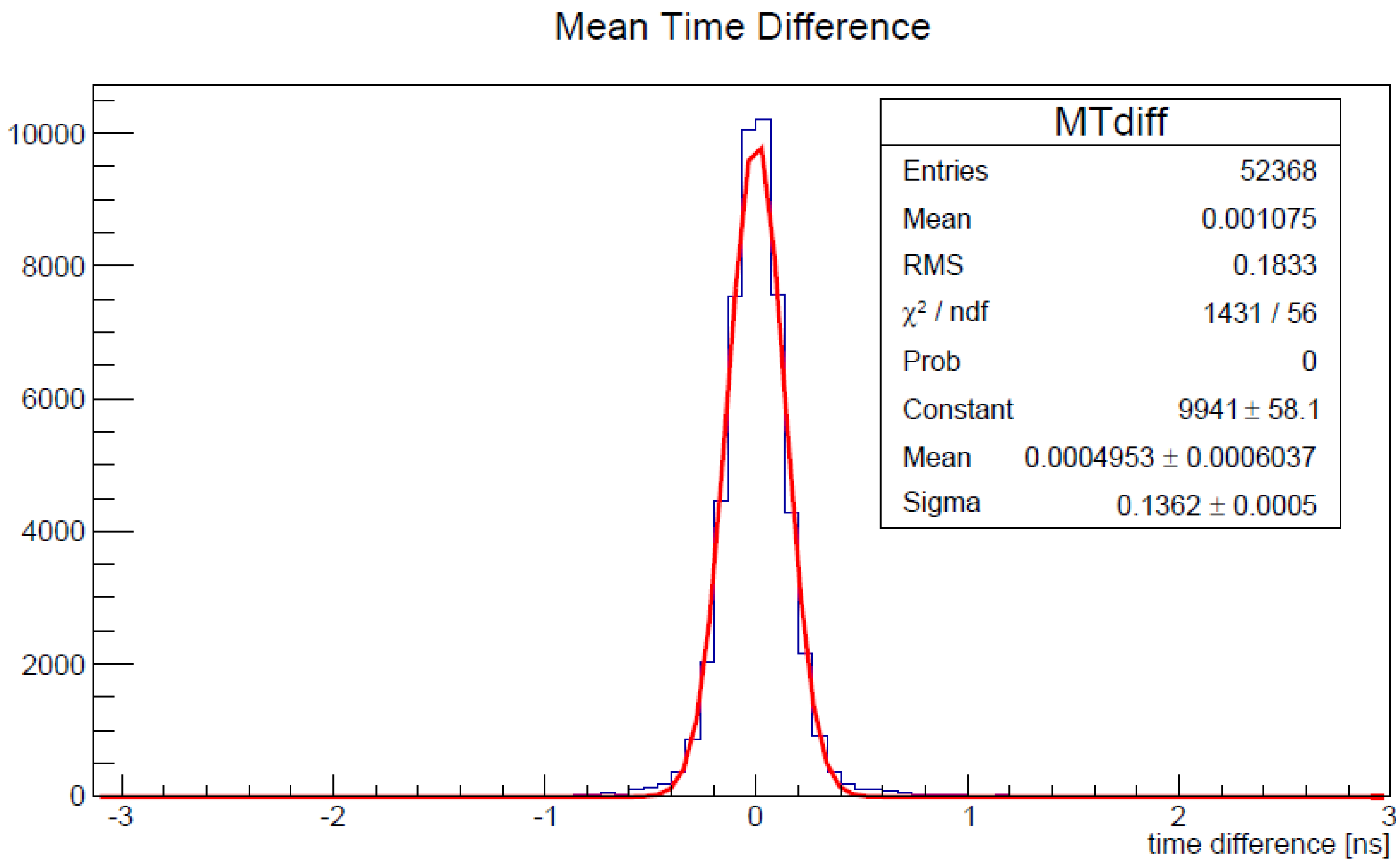


6) **Single Ended Paddle Timing Offsets**

1) Apply walk corrections and timing offset corrections to all full length paddles
2) Select events with a TD < 0.5 ns so that the hit took place near the middle of the double ended paddles, and thus overlapping with the single paddles
3) Calculate MT for all double ended paddles that geometrically overlap with a single paddle
4) Calculate timing offset of the single paddle by subtracting the MT of a double ended paddle with the recorded time of single paddle



Timing Resolution Estimate



1. Select tracks with TOF hits in both planes
2. Compare measured t_{mean} (aka t_{TOF}) times in both planes.
3. The difference of 2 independent t_{TOF} measurements has a width of 136.2 ps.

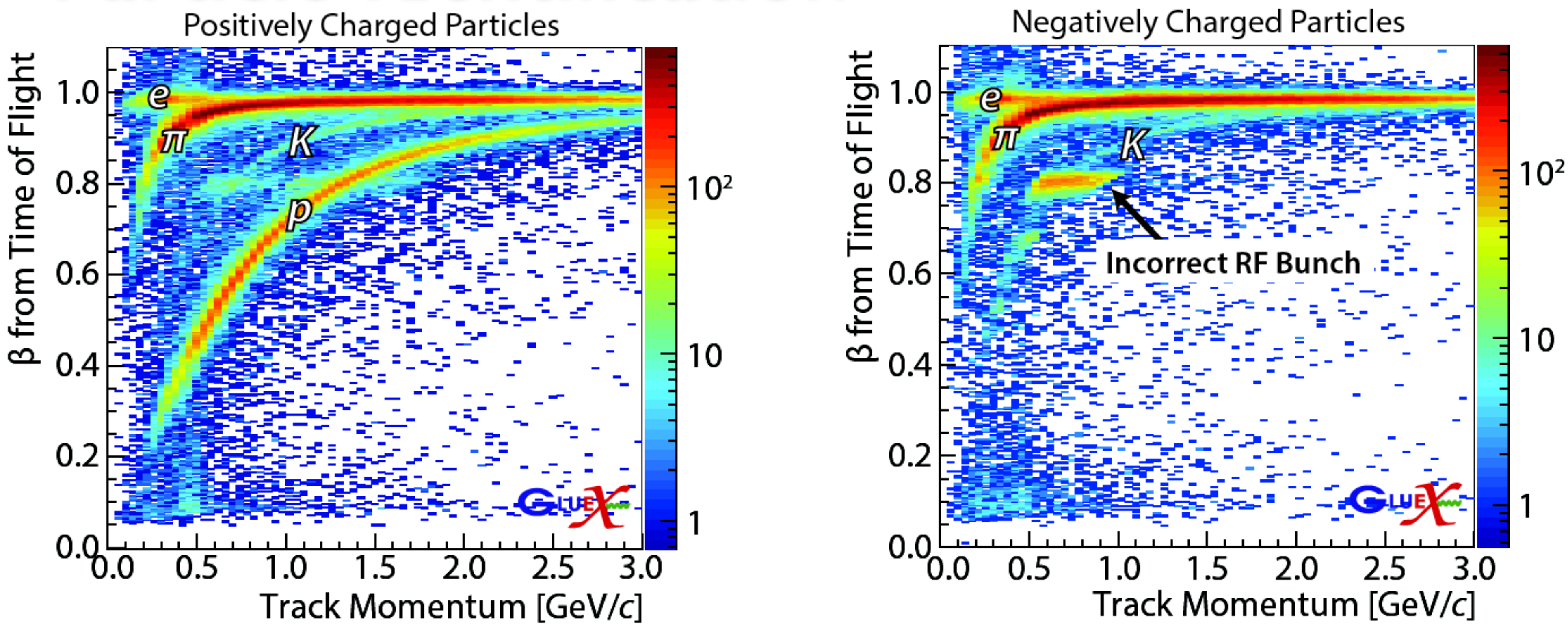
This translates into per-plane timing resolution of 136.3/√2 = **96 ps**

We are almost at the design goal!

TOF performance: the bottom line

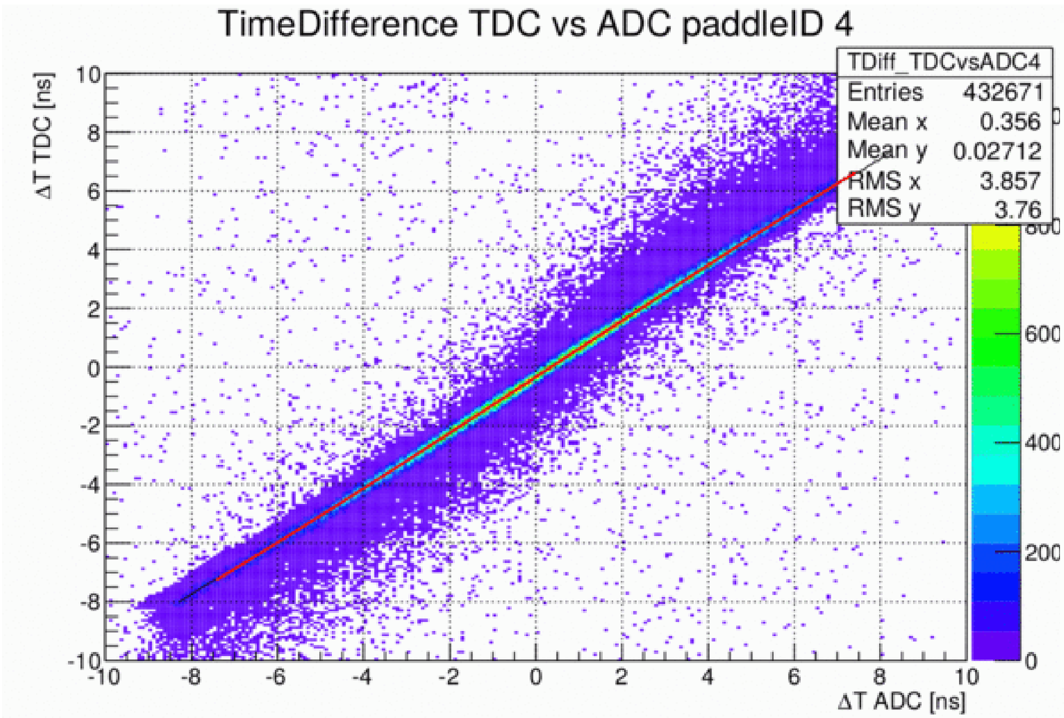
Particle Identification

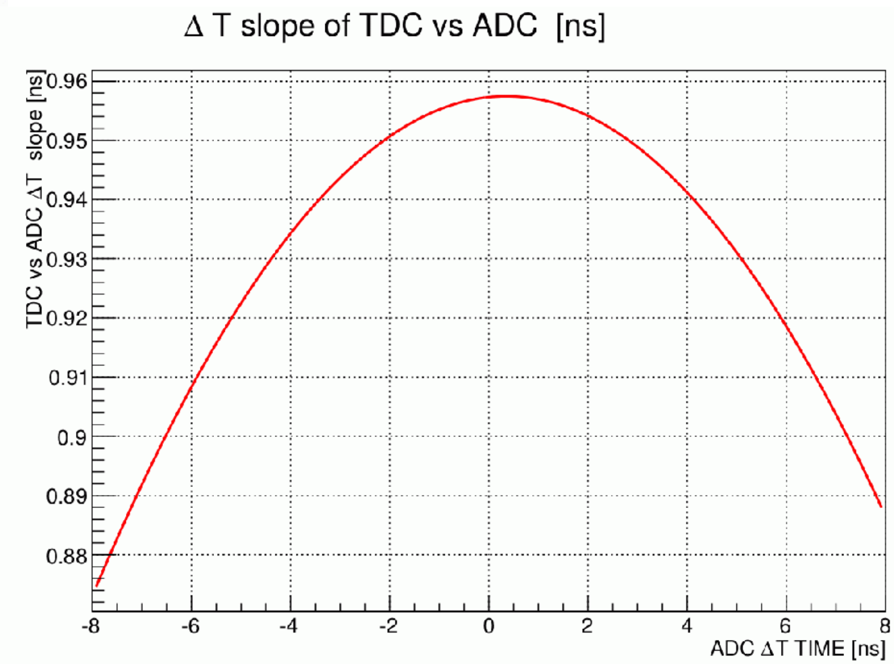
C.Meyer **Hadron 2015 presentation**



- Proton band is clearly separated all the way to 3 GeV/*c*
- Pion and Kaon bands are distinguishable upto 1.5 – 2 GeV/*c*

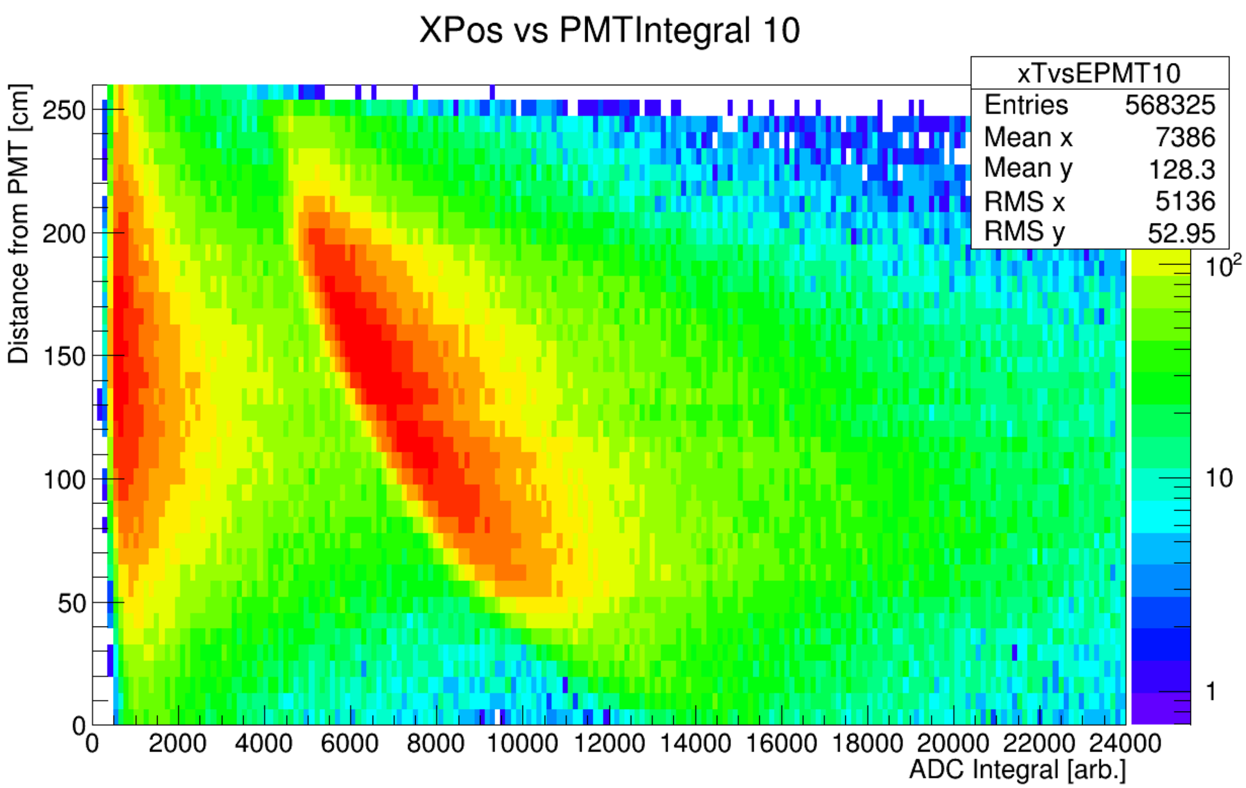
Issue #1: TDC vs ADC timing



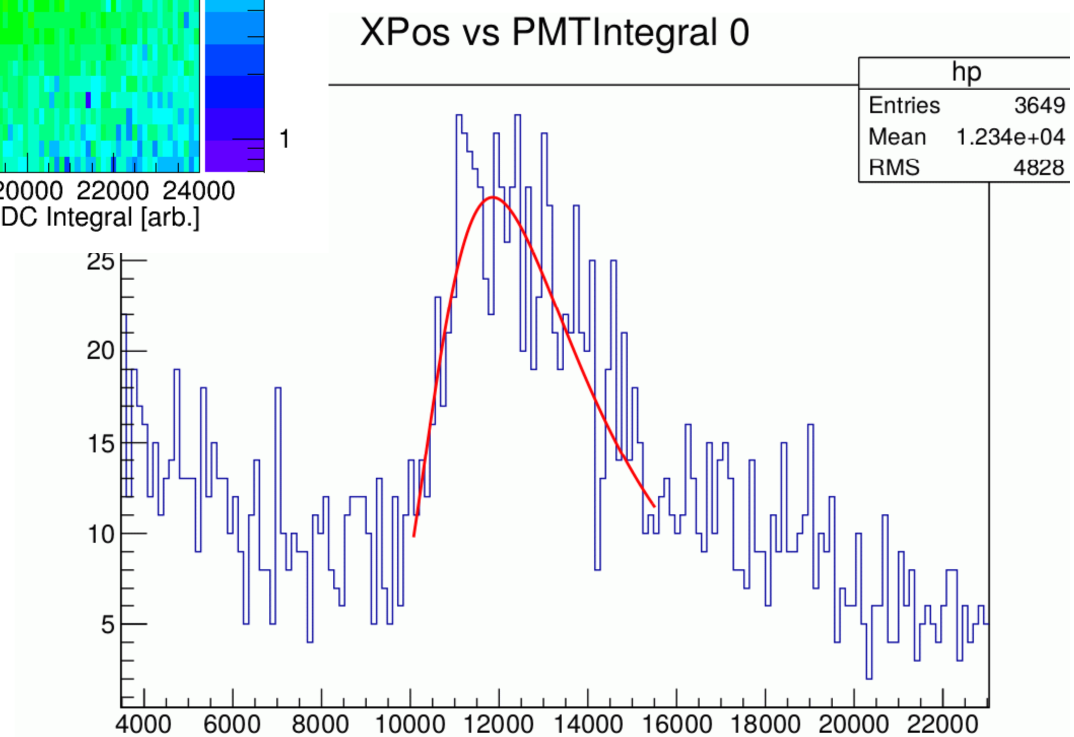


- Hit location along module's length can be determined both from TDC and ADC Δt.
- TDC times are calibrated; ADC times are as is.
- At first glance, there is a good linear correspondence of TDC and ADC time differences.
- Closer inspection reveals a slight curvature, with a *Cosine*-like behavior of the slope.
- Near the center, hits locations are in agreement. Near the edges, they differ by ~7cm.
- The origin of this effect is still mysterious.

Issue #2:ADC data: Attenuation length



ADC pulse integral vs. TDC-determined hit position along the module length. Minimum-ionizing particles are clearly seen



Taking slices at different locations and fitting them with a Landau convoluted with a Gaussian provides the dependence of the observed MIP peak on the location of the hit.

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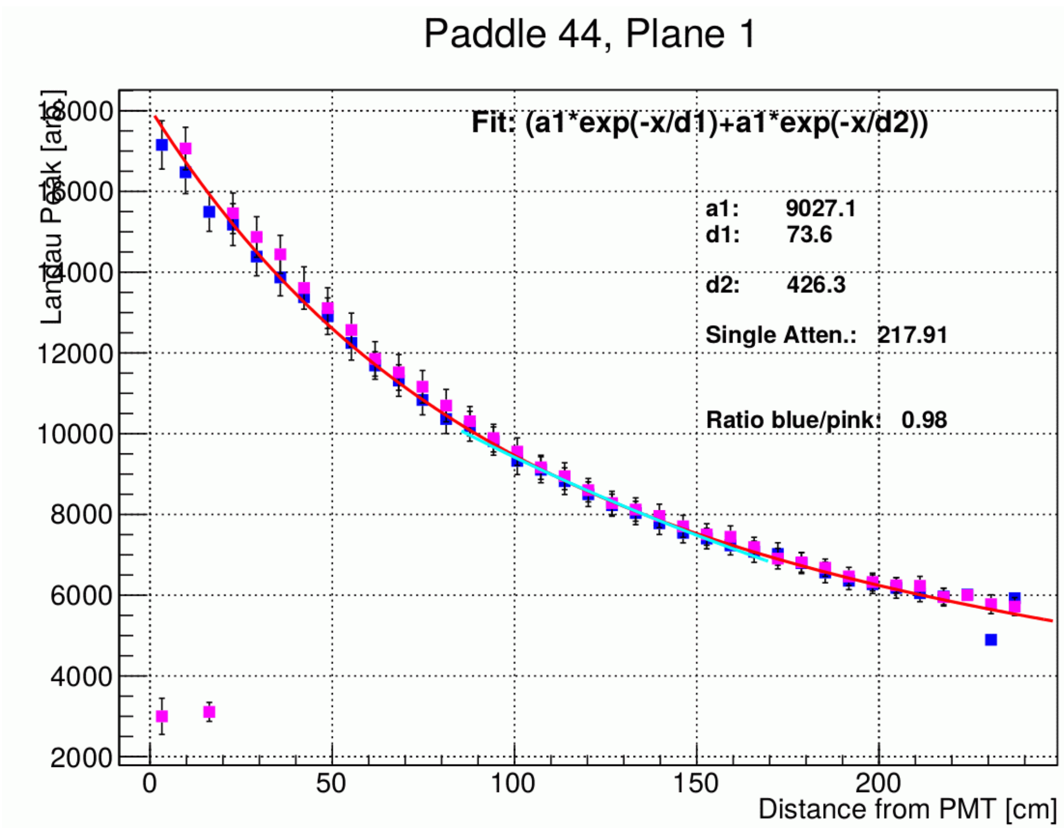
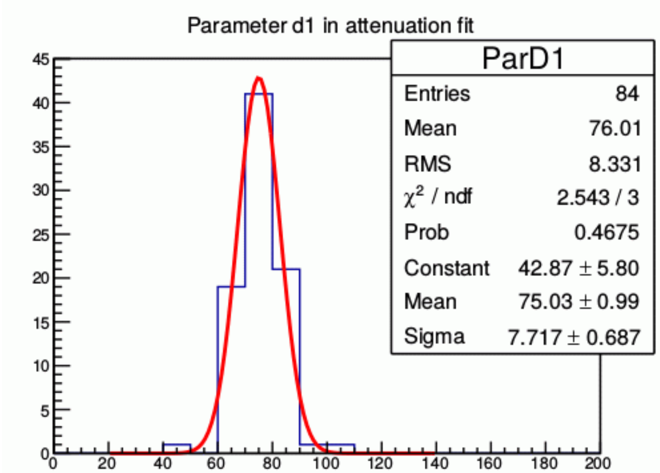
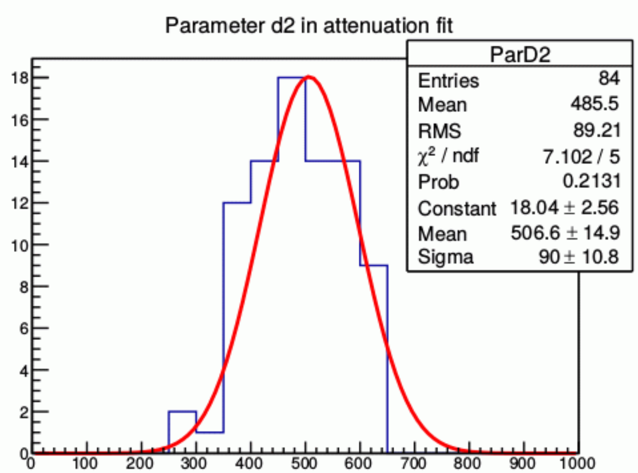


MIP peak vs location fit

- Blue and pink points are from left and right PMTs of the same module.
- Two exponents with different att.lengths (73 cm and 426 cm here) are required.
- Central area is also fitted with a single exponent (cyan) giving 218 cm length.

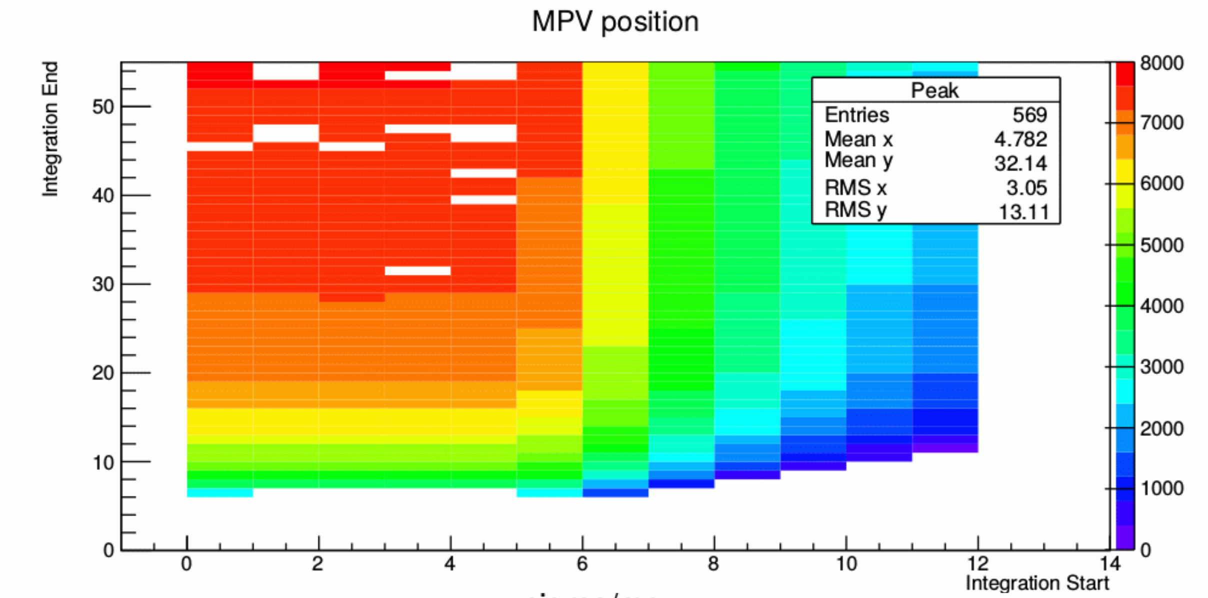
- For all modules, the fitted attenuation lengths are 75±8 cm and 506±90 cm.

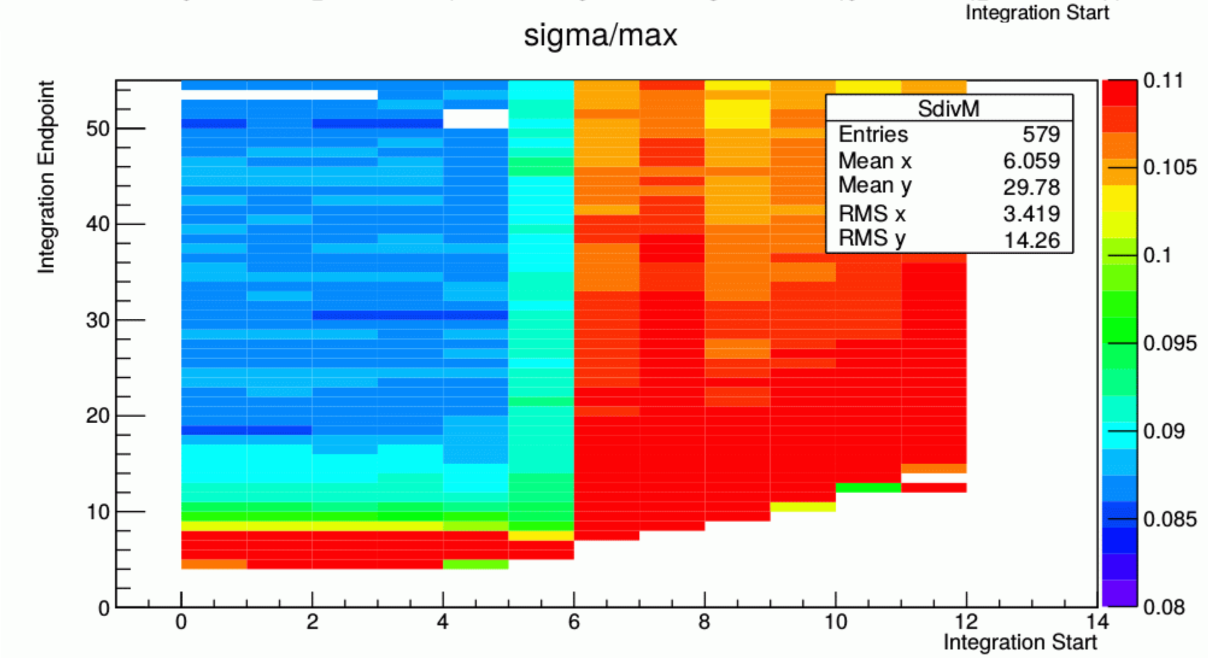




- Mean value for single attenuation fit is 225 cm
- Past lab measurements (unwrapped modules in the black box with UV LED) had 307±51 cm average length.

Issue #3: FADC250 integration range

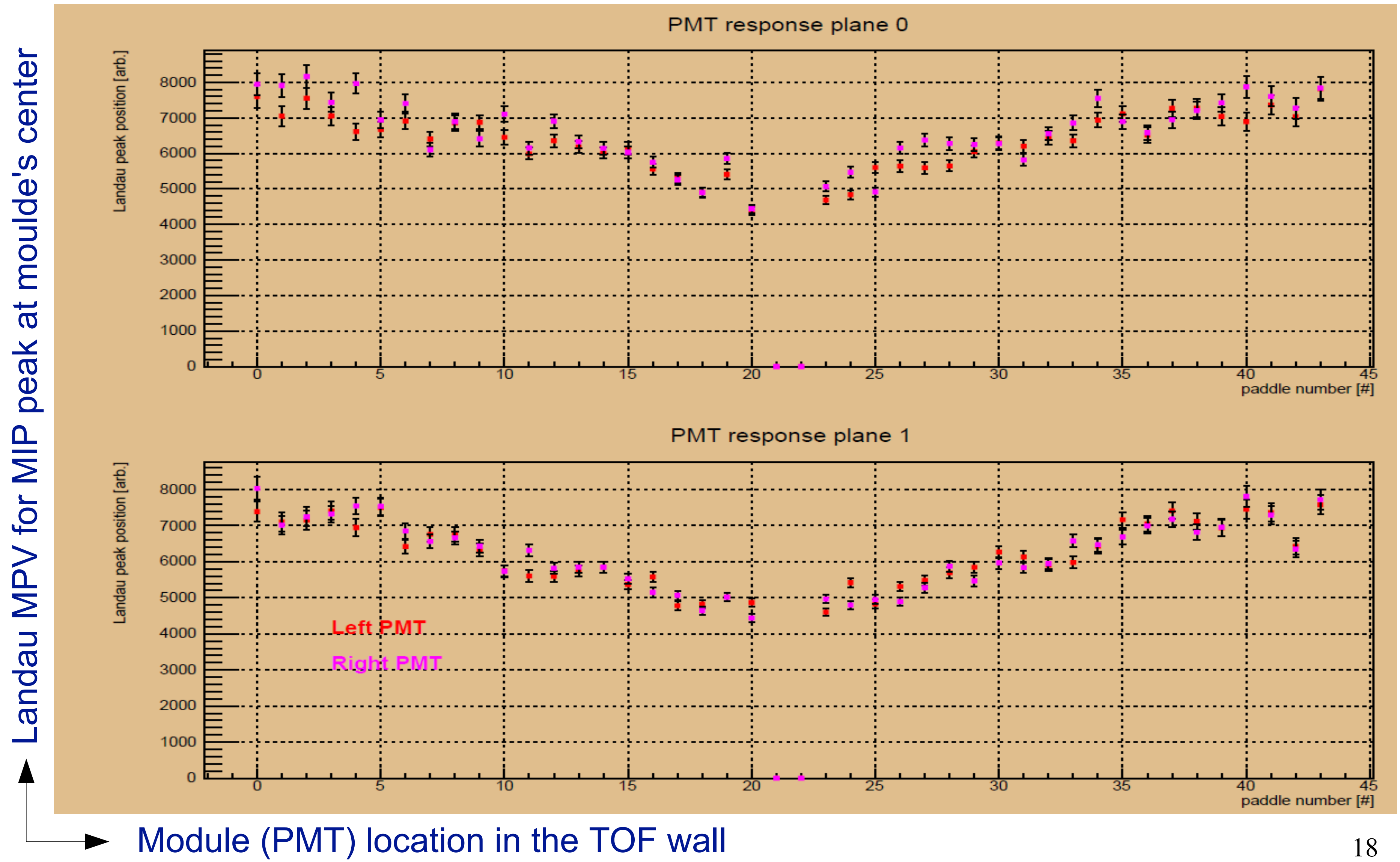




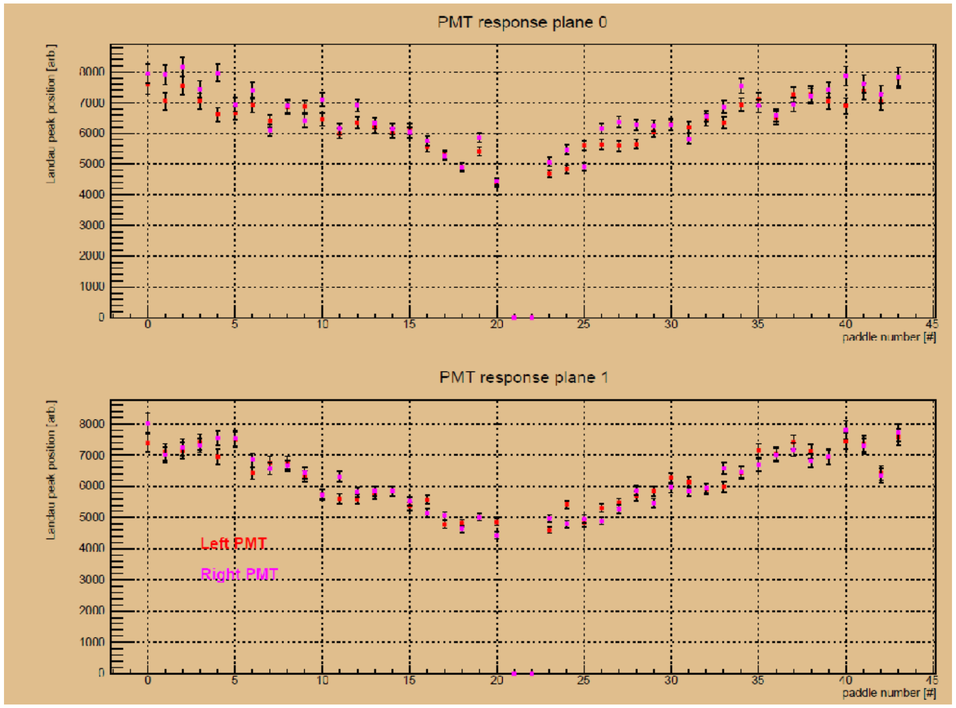
- Most TOF data were obtained with FADC250 integration range values of NSB/NSA at 10/45 samples.
- In this study, actual waveforms of MIP hits at a fixed location have been integrated within varying range.
- The distribution of such integrals is then fitted with a Landau.
- First plot shows fit's MVP value for different NSA/NSB combinations.
- The second plot is Landau's width to max ratio. The best integration resolution (blue) is for any NSB below 5 and any NSA above 20.
- Therefore, using too high NSB is not necessary.

Issue #4: PMT Gain Balancing

Observed MIP energy deposition as a function of module's location (both PMTs)



Issue #4: PMT Gain Balancing



- Observed energy deposition from minimum ionizing particles shows an apparent variation of PMT gains up to 30% from module to module.

- At FSU labs, the gains were balanced with 10% accuracy.

- The variation is not random:
  a) Left/Right PMTs seems to be balanced;
  b) The farther a PMT from TOF center, the higher its gain appears to be.

<u>Why 10% balanced became 30% unbalanced? Why unbalanced in an orderly fashion?</u>

Hardware-related "theories": a) "jitter" of different HV PS at FSU and JLAB; b) fringe magnetic field effect on PMT; c) something else.
Beam-related causes: a) average path-length through scintillator variations due to angles; b) average momentum variations with MIP change per Bethe formula.

Short-term plan: use cosmic data to confirm the effect. If it's real then re-adjust HV.

To-do list for the near future

- Collect TOF cosmic data to: a) verify PMT gains; b) independently check timing calibration (i.e., how straight are cosmic tracks after calibration).

- Study TOF efficiencies with collected beam data.

- Work on CAEN TDC calibration by B.Moffit is in progress.

- Improve TOF code in hdview2 (use of calibrations, TOFPoint in addition to TOFHit, etc.).

- ADC-to-energy calibration of TOF hits (requires Monte Carlo studies).