Svt Hit Reconstruction

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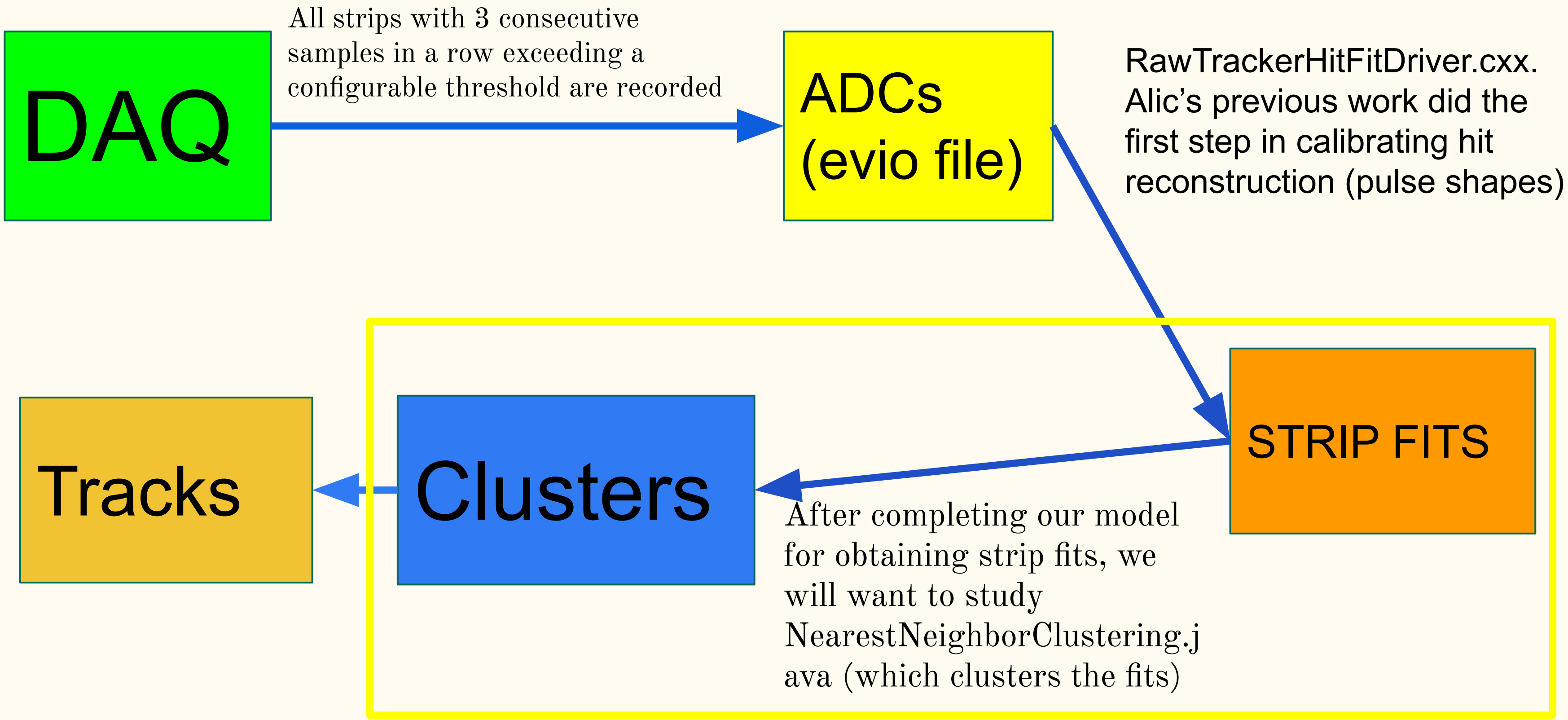
Analysis Workshop 4/12/23

Introduction

Outline of the Reconstruction Process



Calibration of Pulse Shapes

The APV25 has preamplifier and shaper chain which are empirically observed to be best modeled by a 4-pole function with 1 single-pole and 1 triple-pole

Using the UCSC testboard, and calibration pulse procedure in rogue, the internal calibrated charge injection circuit is used to read out 6 samples at 25 ns time interval with several different delays on the arrival time of the pulse

Alic used this data to calibrate the shapes of each strip; the next step in the reconstruction chain is characterizing the performance of fitting these calibrated shapes to data collected during physics runs

$$\mathcal{F}\left(\frac{1}{(1-j\omega\tau_1)(1-j\omega\tau_2)^3}\right) = \frac{\tau_1^2}{(\tau_1-\tau_2)^3}\left(e^{-\frac{t}{\tau_1}} + \left(\sum_{i=0}^{2}\left(t\frac{\tau_1-\tau_2}{\tau_1\tau_2}\right)^i\right)e^{-\frac{t}{\tau_2}}\right)$$

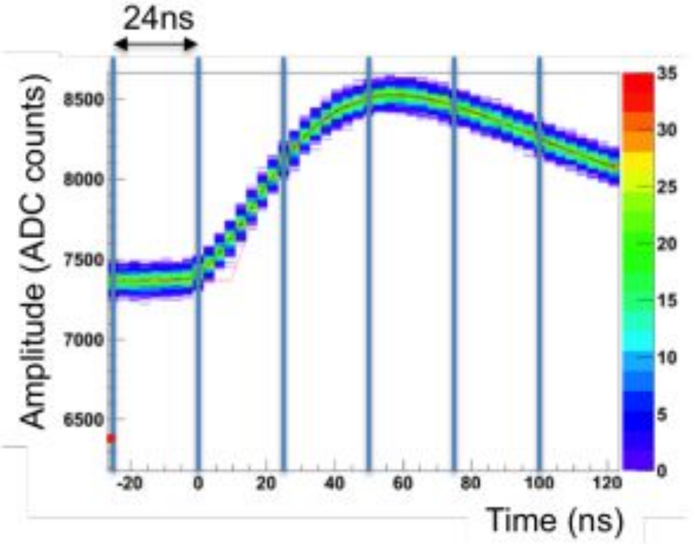
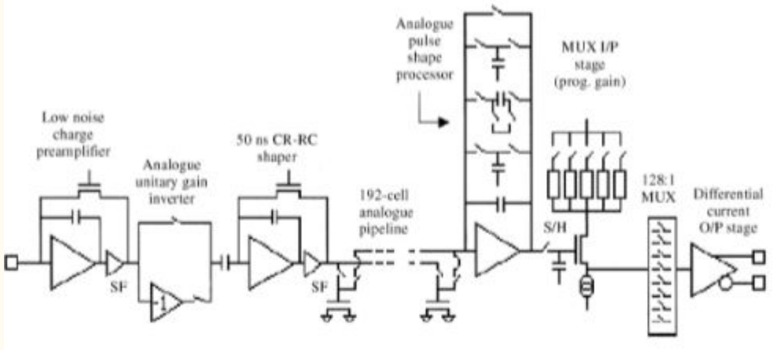


Fig. 4. Pulse shape of the APV25 ASIC.



The Function Minuit Minimizes (doLinFit_ejml)

The pulse fitting algorithm ShaperLinearFit can implement an arbitrary amount of pulses.

It reduces the # of free parameters in half so Minuit only minimizes a function of the pulse times.

For each set of pulse times, doLinFit_ejml uses a least squares fit to obtain amplitudes which minimizes χ^2 for pulses at that set of times. This χ^2 is then returned to Minuit.

After getting its input pulse time guess, doLinFit_ejml solves the over constrained system of equations to the right to fit the amplitudes of the pulses for that set of times.

The idea is the baseline subtracted profile is a linear superposition of Four-Pole pulse shapes, so the fit can be linearized over the calibrated shape for that APV25 channel

$$N_{amp}(t_i, t_p) = \frac{\text{Four Pole}(t_i - t_p, \tau_1, \tau_2)}{\text{max(Four Pole)}}$$

$$\begin{pmatrix} N_{amp}(t_0, t_{p1}) & N_{amp}(t_0, t_{p2}) \\ N_{amp}(t_1, t_{p1}) & N_{amp}(t_1, t_{p2}) \\ N_{amp}(t_2, t_{p1}) & N_{amp}(t_2, t_{p2}) \\ N_{amp}(t_3, t_{p1}) & N_{amp}(t_3, t_{p2}) \\ N_{amp}(t_4, t_{p1}) & N_{amp}(t_4, t_{p2}) \\ N_{amp}(t_5, t_{p1}) & N_{amp}(t_5, t_{p2}) \end{pmatrix} \begin{pmatrix} A_{p1} \\ A_{p2} \end{pmatrix} = \begin{pmatrix} ADC[0] \\ ADC[1] \\ ADC[2] \\ ADC[3] \\ ADC[4] \\ ADC[5] \end{pmatrix}$$

$$N_{amp} * \vec{Amplitude} = \vec{ADC}$$

PF recently implemented the ejml libraries to increase solving speed.

A Table of SVT Hit Reconstruction Terminology

Fit Parameters		
	Amp	Amplitude of a pulse (if PileUp we will have one for each)
	T0	The time translation w.r.t the triggering time (-9 ns for layer 1,2, -27 for later layers)
	AmpErr	The Error in the Amplitude Fit given by FitMinuit for a pulse component
	T0Err	The Error in the Time translation Fit given by FitMinuit for a pulse component
	$P(\chi^2)$	Chi Squared Probability returned by fit.
DataBase Values		
	$\boldsymbol{\tau}_{1,}\boldsymbol{\tau}_2$	Channel specific rising and falling edge times for four pole pulse profile
	B	Baseline values; run specific baselines to be subtracted from ADCs during fitting
	Ch_{err}	Channel specific error (comes with baseline dat file).
Reconstruction Variables		
	$P(\chi^2_{thresh})$	The χ^2 probability threshold used by Pulse Fitting to determine when to check pileUp
	$Clu_{seed,}Clu_{cluster}$	Seeding threshold and Clustering threshold used for associating hits to cluster.

The way we framed the problem: Finding a better way of performing reconstruction

We showed why Hit Reconstruction the earliest step in reconstruction where we can improve hit efficiency and time resolution.

In previous slides we reviewed the current hit reconstruction algorithm with PF's improvements and Alic's calibrations. We can separate it into three parts

- doLinFit_ejml
- doRecursiveFit
- Pulse Number Decision

The point is that these first two are conceptually 'correct'; future improvements in them are unlikely to do anything to improve performance beyond sw runtime.

It is in this last portion of hit reconstruction where the Pulse Number decision should be studied systematically. Needed a new analysis toolkit to study this.

Details of samples used

Over this talk we used the following events from 2021 and 2019:

- 2021:

  14552 for high lumi

  14166 for low lumi

  I used HPS_Run2021Pass0_v1 and HPS_Run2021FEE2 for my detectors here

- 2019:

  10420 for DAQ sync good

  10442 for DAQ sync bad

  I used HPS-PhysicsRun2019-v1-4pt5-3mm

Numbers for raw OneFit and PileUp Fits

Here is a table of pileUp number decision per layer for one among 39 (roughly equivalent) run 14552 files. There were a total of 6.8 million hits in a track with 383 thousand (5 percent) of them being pileUp

	A single pulse	pileUp
Layer 0A (top/bottom)	532776	68783
Layer 0S (top/bottom)	561686	72634
Layer 1A (top/bottom)	657276	44520
Layer 1S (top/bottom)	665914	45039
Layer 2A (top/bottom)	690021	47103
Layer 2S (top/bottom)	724744	50518

In 14166 we have a negligible number of pileUp ($<.1$ percent) in all the layers.

OneFit and PileUp Plots

In the coming plots, we were looking to characterize when the Pulse Decision was made improperly.

One way to do this was to see which features in OneFit pulses were accentuated when $P(\chi^2_{thresh})$ was lowered.

Another was to probe regions in parameter space which were unlikely to result in physical hits, (i.e. in the 2d Pile-Up T0 plots)

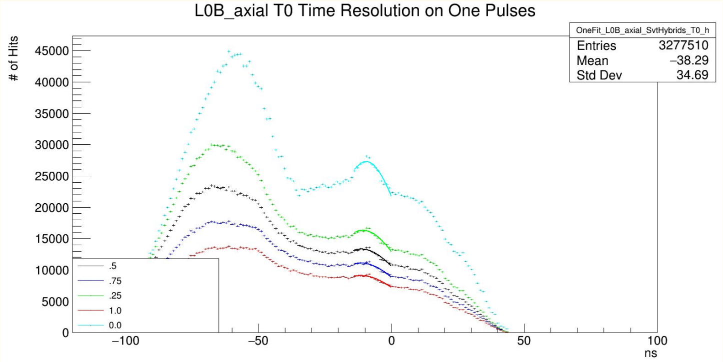
We will show these plots, and some of the conclusions we made on raw hits alone. It will be clear that we will need to condition on hits on tracks to obtain consequential handles for our DT.

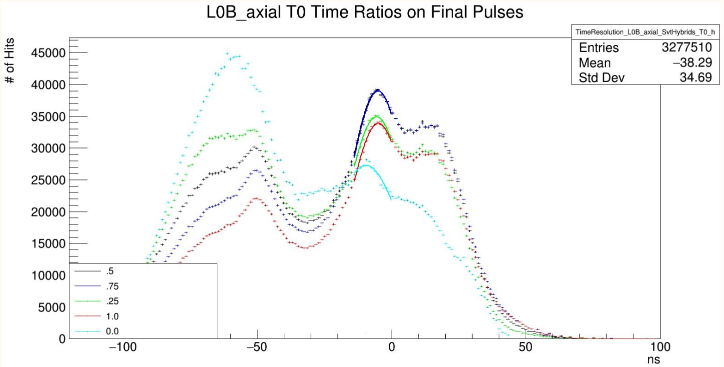
A First Distribution: T0 For All Hits In Early Layers

To obtain handles on the Pulse DT, we needed to identify issues histograms of Fit Parameters.

This is the hit time distribution of all hits (not on track), and we see a large peak that reduces with pileUp parameter.

This could help determine the chi2 hyperparameter optimal value of .75





Timing Distribution for OneFit Pulses and All Candidate Pulses

Hit Fit Values

Here are a table of hit fit parameters. The constant is a rough estimate of our signal (and is weakly associated to signal efficiency)

If we sum up the constants, we note that .75 seems to be where our signal peak is highest

	Mean	Sigma	Constant
0	-9.545	14.135	27269.7
.25	-10.708	16.303	16303.0
.5	-11.35	16.7668	13321.2
.75	-11.585	17.198	11085.8
1	-11.6302	17.09	9092.75
.25	-4.008	9.26	19817.0
.5	-4.156	9.48	26842.0
.75	-4.148	9.768	28854.2
1.0	-4.106	9.92	25625.9

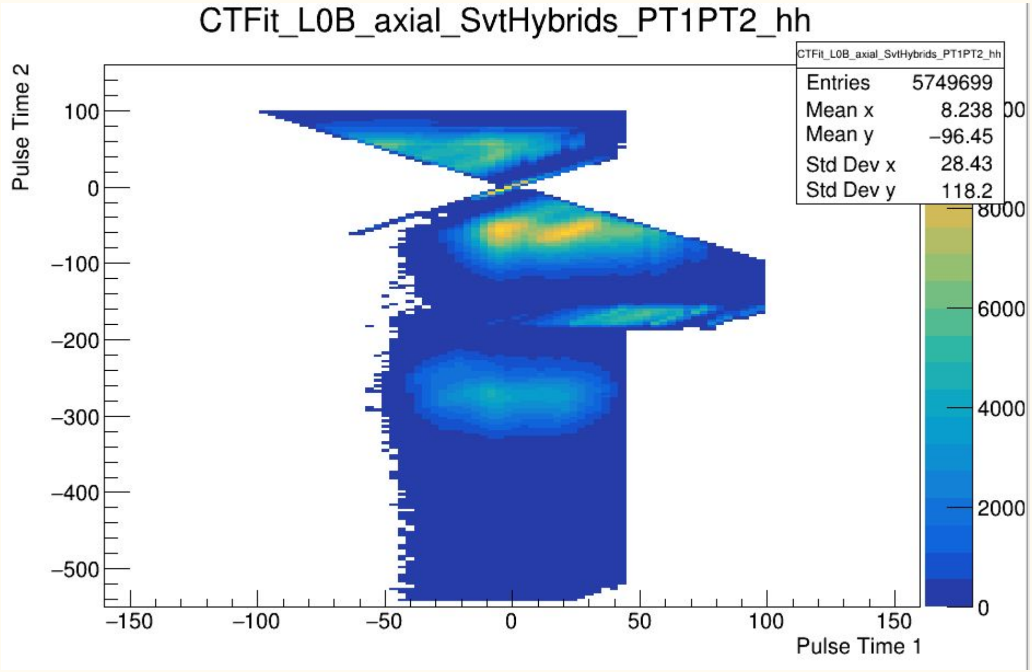
A more important pileUp plot

This is a plot of the closest time to zero on x, vs. the farthest.

We would prefer to see a bright line along t=0, but we instead see a peak at -9 ns

We also see a large line of degenerate fits when the closest and farthest times are near.

We aimed to explain all of these features.

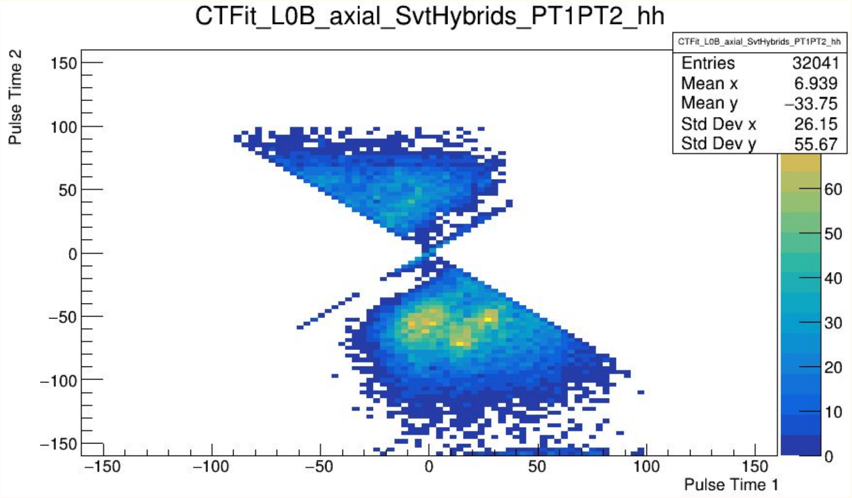


Isolating the Degenerate Region and Changing the DT

For our off track studies, we focused on regions of high number count which had off time contributions.

This occurs with a rate more than 1 percent in the lower triangular region and the region w/ high degeneracy of fits.

As will become clear later, other regions where we saw large off time contributions are cleaned when you condition on on track hits.

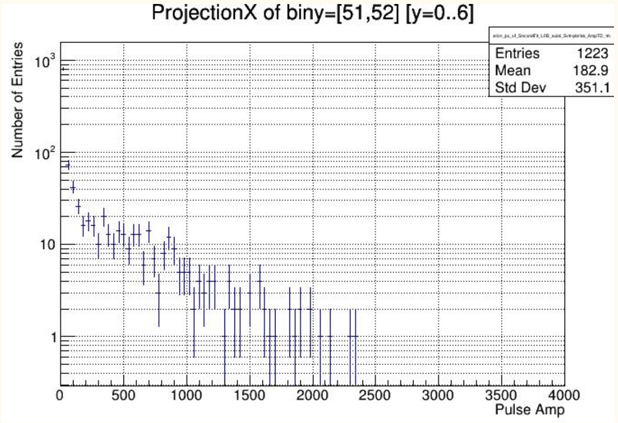


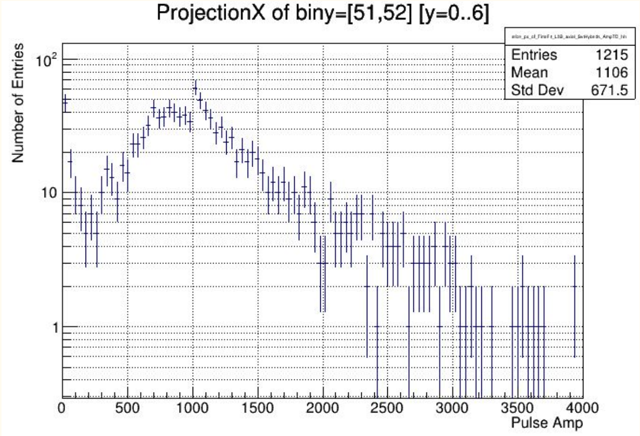
A Look at PileUp Pulses in the Delta T=0 Regime

If we condition on hits falling on the diagonal stripe in the plot in slide 13, and plot hit amplitude as a function of first fitted pulse (instead of closest pulse) we see the two plots here.

The first fitted pulse gets the lion's share of the amplitude, meaning hits in this region have zero amplitude at a fairly high frequency.

This would indicate that a change in the DT to one fit would be appropriate in this region.



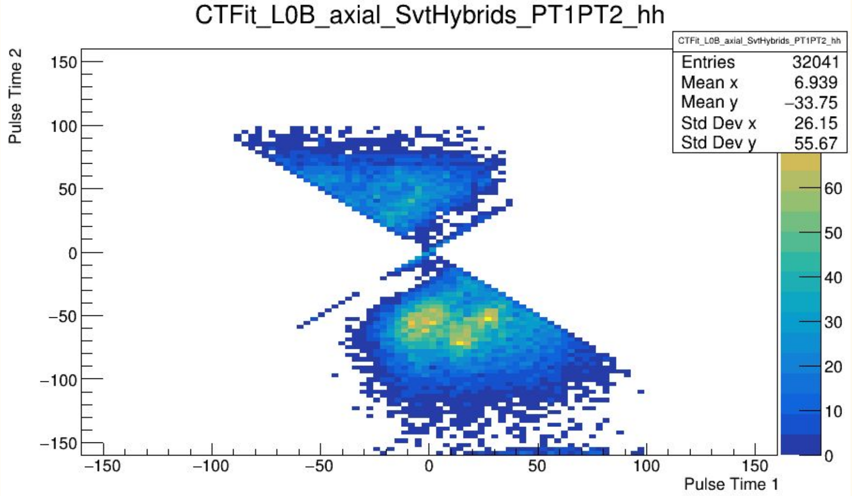


The Issue with Some Plot Features

We were going to move towards isolating regions in the plot on slide 13 and characterizing them like the degenerate region, but we paused.

Some regions, like the bright peaks in the plot, did not correspond to features we would see on a real track.

These hits would be filtered out by latter steps in reconstruction anyway, so we determined to make more headway in hits on triggered tracks.

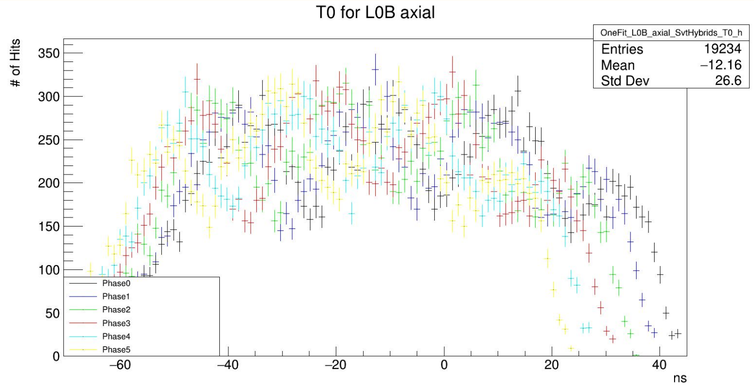


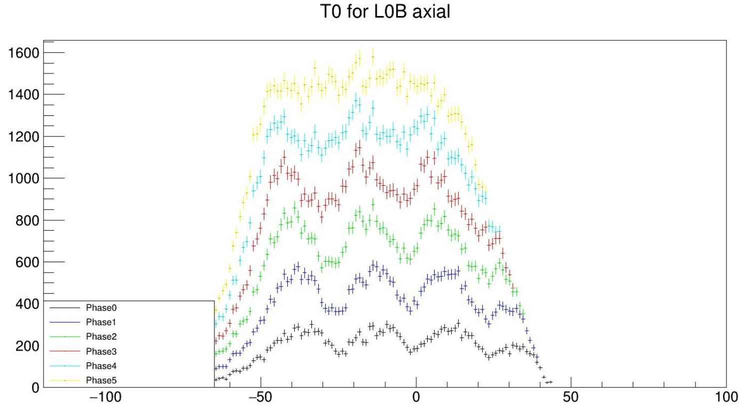
Checking out the Phase Dependence for Random Triggers

In order to understand what some features of on time on track hits, its relevant to consider the features of random hits.

Here are the T0 distributions for hits on tracks (conditioned on a random trigger).

There is a clear phase dependance for random trigger hits; you shall continue to see this for this that are not timed in with the trigger.





Random Triggers w/ and w/out THStacks for 14552

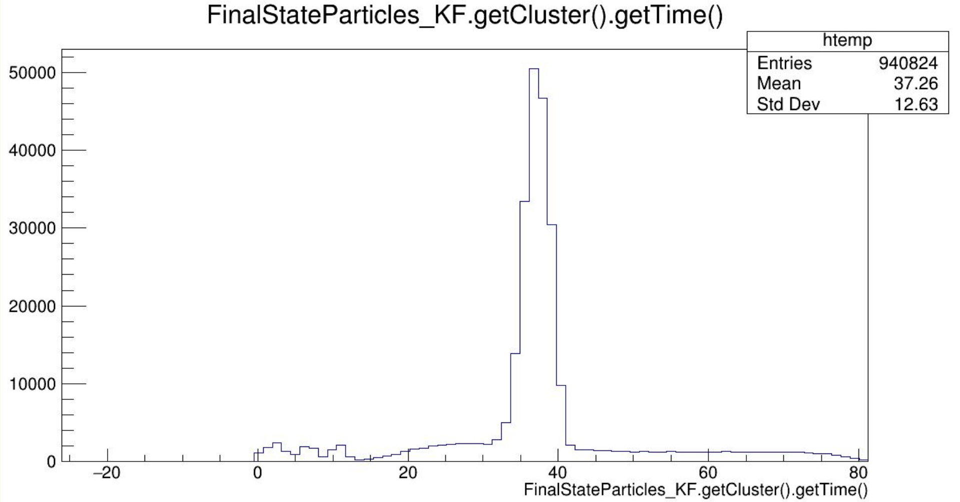
Performing Analysis with Hits On Track

Motivation for the FSP Processor

The plot to the right here is the time distribution of ECal Clusters; there is a clear signal peak at 36-40 ns.

When we can associate a track to this ECal cluster, we can more certain that the track is from the event that induced the trigger.

Therefore we developed a processor which, from a cut on ECal times, obtains our hits on track



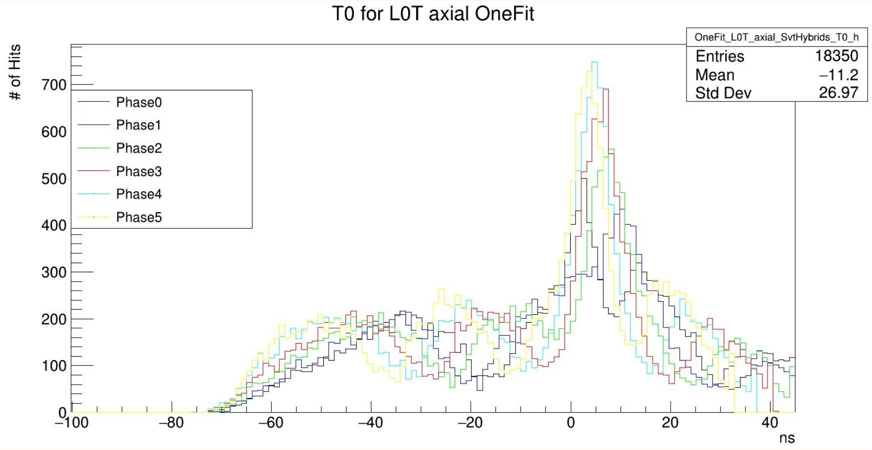
Alignment fixes and improvements to signal

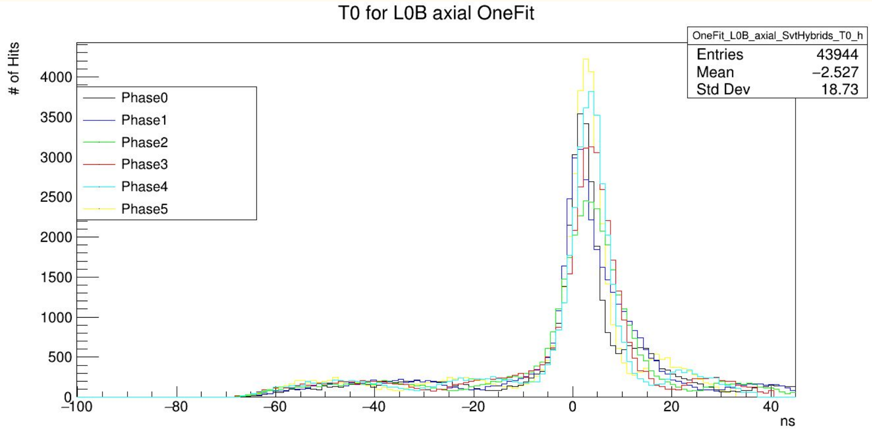
There are two geometries we used in our studies: HPS_Run2021Pass0_v1 and HPS_Run2021FEE2

Upon opening the time window for hits in Kalman Tracking, we see that originally we had a-lot of off time tracks

With Cam's gradual alignment fixes, many of these off time hits are fixed.

Some coming plots are aimed at addressing those issues that remain in OneFit T0





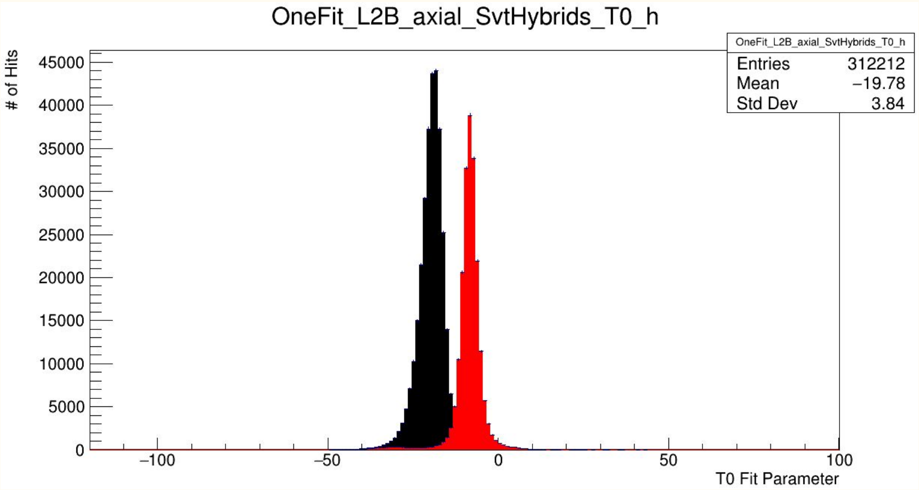
Aligning the Forward and Backwards Layers

As a first modification before we proceed with further studies, we want to align to forward and back layers.

Forward layers usually occur at -9 ns while the back at -20; these differences are due to wiring difference between the two sets of layers

We eyeballed each peak for all layers; luckily in the new alignment a phase dependent shift seems largely unnecessary.

With this we can rule out forward and backward layers inducing wrong hit choices



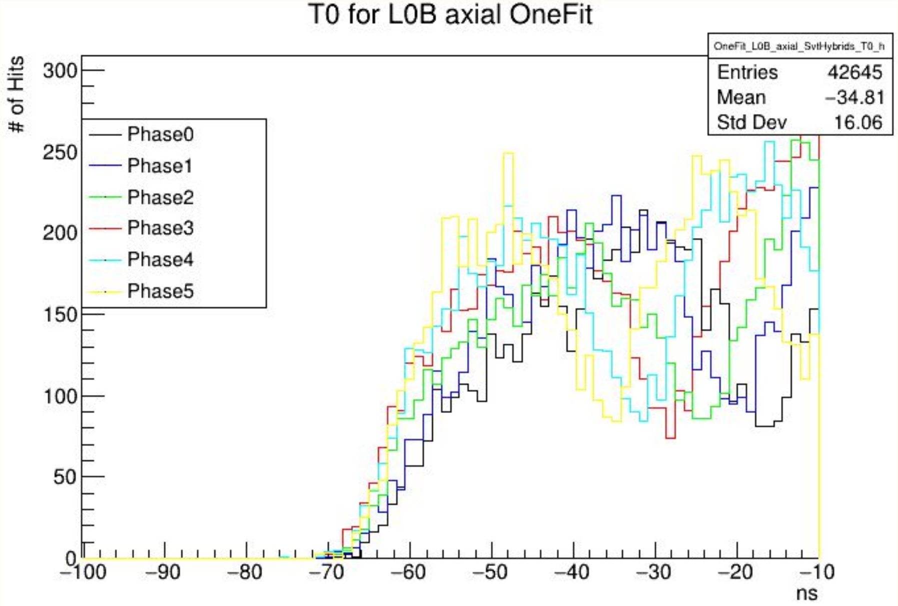
T0 distribution for 14166 (a low lumi 2021 detector). In this case the distribution is insensitive to detector model because of the low event count.

Possible Handles for Hit Reco Optimization: Off Time Prominences and Phase Dependances

While much more prominent in the older detector, the new detector also shows off time oddities and unexpected phase dependence

~72,000 out of the 250,000 events found in T0 over all phases are out of time.

These out of time hits display the features characteristic of random triggers (w/out on track cuts) in terms of phase dependance.



Off time phase dependent peak.

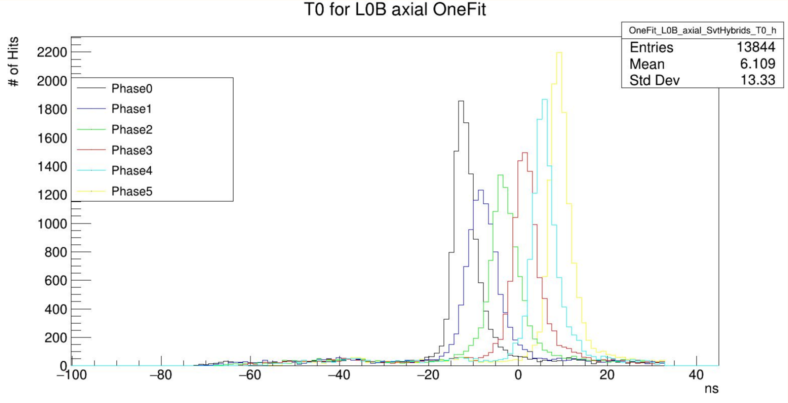
Good and Bad Daq Sync in 2019 Data

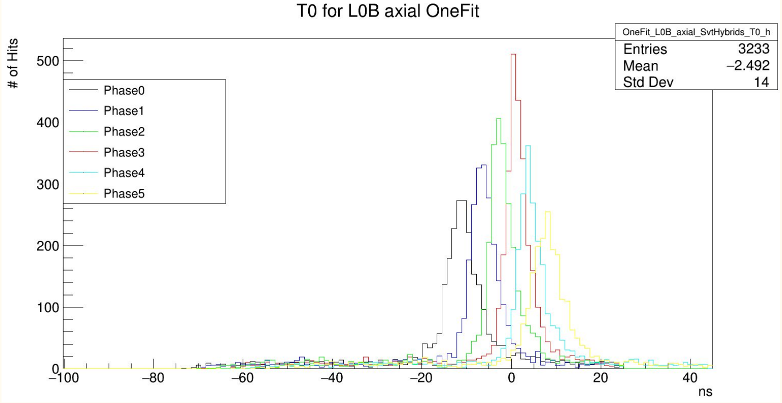
There are no good daq syncs in 2021, so we tried some study with 2019

These were high lumi 10420 and 10442 for the 2019 run with good and bad sync respectively. An artificial phase displacement is introduced

The point here is that good and bad sync swap phase hits around, but you don't get a ton of off trigger time hits nor do the shapes deform from gaussian.

So for some reason 2021 has a decent rate of out of time window hits (even with a good alignment) and its features in phase are not entirely explained by the daq sync.



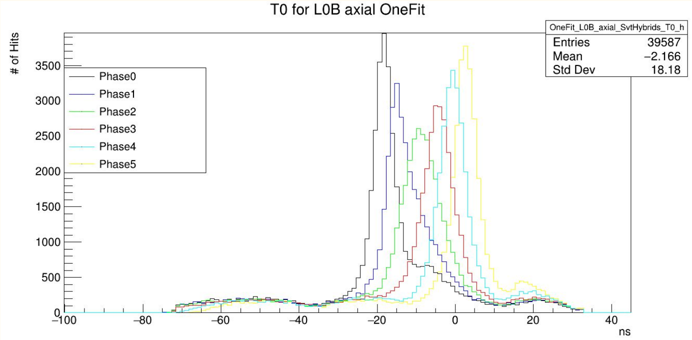


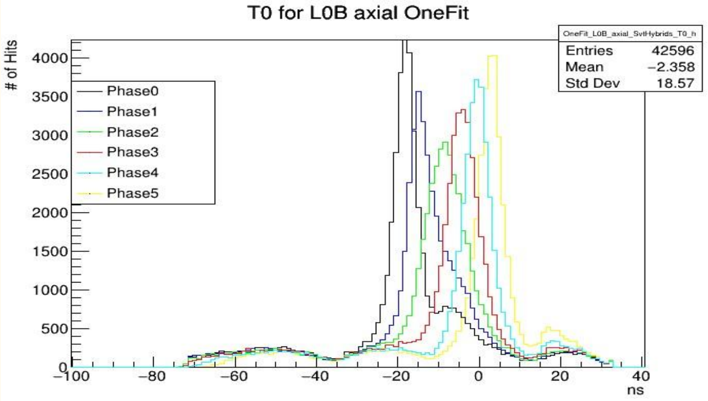
High Lumi 2021 Offline and Online Baselines

to check in 2019 data where we had good and bad daq syncs.

It seems that 2019 is especially clean in terms of of time peaks, without good/bad daq syncs. This suggested that out of time hits we see in 2021 may be there due to offline/online baselines.

To the right are plots (phase shifted) for online and offline baselines. We induced a shift in the peaks, and it became easier to see if there were tighter peaks.

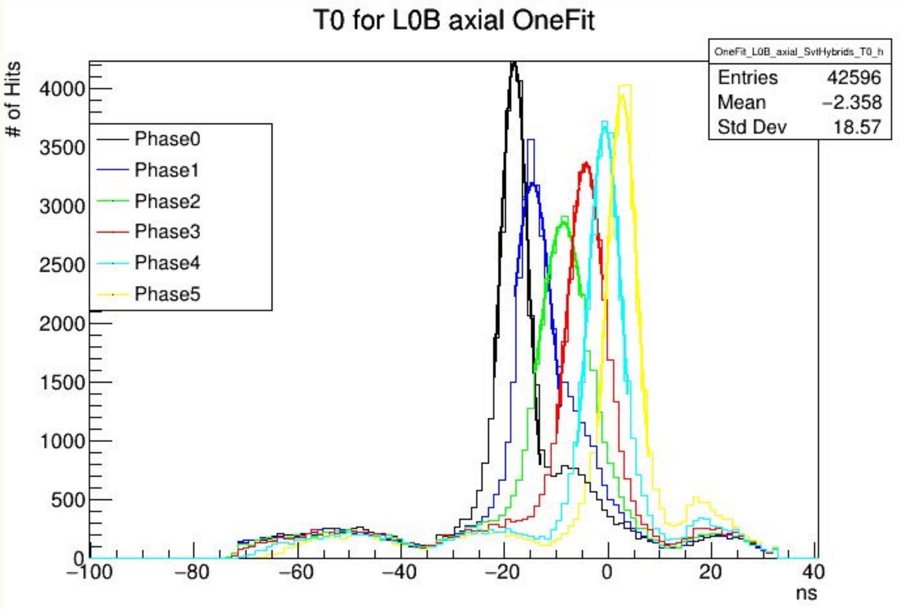




Bottom is Offline Baselines, Top Online, You get more events and sharper time resolutions.

Fit Values for Offline Baselines

```
 EXT PARAMETER                                          STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     4.22113e+03   3.84573e+01   1.02202e-01   1.96357e-06
  2  Mean        -1.80573e+01   2.33080e-02   8.51798e-05   4.28223e-04
  3  Sigma        2.73667e+00   2.89870e-02   1.07034e-05   6.16024e-02
FCN=111.355 FROM MIGRAD    STATUS=CONVERGED      97 CALLS          98 TOTAL
                     EDM=9.80394e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                          STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.18670e+03   3.06977e+01   1.14653e-01   4.49228e-06
  2  Mean        -1.45236e+01   6.37387e-02   2.42041e-04  -2.28616e-04
  3  Sigma        4.06864e+00   9.10139e-02   3.06335e-05   1.61306e-02
FCN=3.39345 FROM MIGRAD    STATUS=CONVERGED     104 CALLS         105 TOTAL
                     EDM=1.14474e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                          STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     2.85366e+03   2.73019e+01   1.97646e-02  -1.86471e-06
  2  Mean        -8.58161e+00   7.40960e-02   6.34369e-05   4.48814e-04
  3  Sigma        5.00158e+00   1.26090e-01   7.71748e-06  -2.28987e-03
FCN=2.76489 FROM MIGRAD    STATUS=CONVERGED      87 CALLS          88 TOTAL
                     EDM=1.63428e-07    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                          STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.36092e+03   3.06855e+01   2.19577e-02   1.97110e-05
  2  Mean        -4.21452e+00   6.15263e-02   3.83421e-05   2.21677e-03
  3  Sigma        3.78628e+00   7.30665e-02   4.44125e-06   5.46253e-02
FCN=17.418 FROM MIGRAD    STATUS=CONVERGED      78 CALLS          79 TOTAL
                     EDM=6.05907e-07    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                          STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.66524e+03   3.31390e+01   4.98529e-02  -2.47334e-05
  2  Mean        -5.84813e-01   2.81628e-02   5.90094e-05  -7.64011e-03
  3  Sigma        3.25268e+00   3.64219e-02   6.60846e-06   7.61389e-02
FCN=73.5413 FROM MIGRAD    STATUS=CONVERGED      78 CALLS          79 TOTAL
                     EDM=4.50599e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                          STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.93780e+03   3.52654e+01   1.06866e-01  -2.11261e-06
  2  Mean         2.76287e+00   2.39771e-02   1.01062e-04  -2.46492e-05
  3  Sigma        2.96650e+00   2.91004e-02   1.12579e-05   7.15722e-03
```



Fit Values for Online Baselines

```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     3.73703e+03   3.62169e+01   1.10315e-01   1.41732e-05
  2  Mean        -1.81849e+01   2.53313e-02   1.05328e-04  -6.88487e-04
  3  Sigma        2.76017e+00   3.16940e-02   1.32649e-05   1.85346e-01
FCN=157.56 FROM MIGRAD    STATUS=CONVERGED      91 CALLS          92 TOTAL
                    EDM=3.32374e-11    STRATEGY= 1  ERROR MATRIX UNCERTAINTY
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     2.82979e+03   2.84018e+01   5.31742e-03  -4.30999e-07
  2  Mean        -1.47736e+01   8.83210e-02   4.71933e-05  -1.56899e-04
  3  Sigma        4.47296e+00   1.26341e-01  -1.28251e-05  -1.10247e-03
FCN=6.00515 FROM MIGRAD    STATUS=CONVERGED      95 CALLS          96 TOTAL
                    EDM=1.02594e-06    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     2.57400e+03   2.64072e+01   2.37721e-02  -3.46037e-05
  2  Mean        -8.88221e+00   6.66860e-02   7.95591e-05   1.48637e-02
  3  Sigma        4.79969e+00   1.18702e-01   9.91282e-06  -2.36432e-03
FCN=17.1118 FROM MIGRAD    STATUS=CONVERGED      93 CALLS          94 TOTAL
                    EDM=1.78778e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     2.88740e+03   2.88080e+01   4.42511e-02  -1.84979e-06
  2  Mean        -4.31054e+00   6.61114e-02   9.52366e-05   1.02395e-03
  3  Sigma        3.89842e+00   8.53328e-02   1.14852e-05  -5.17086e-03
FCN=12.8907 FROM MIGRAD    STATUS=CONVERGED      75 CALLS          76 TOTAL
                    EDM=3.85524e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     3.35954e+03   3.16050e+01   4.12626e-02   6.68743e-07
  2  Mean        -6.88493e-01   3.01369e-02   5.47690e-05   2.64084e-03
  3  Sigma        3.30586e+00   3.94365e-02   6.14350e-06  -3.30190e-03
FCN=27.7376 FROM MIGRAD    STATUS=CONVERGED      69 CALLS          70 TOTAL
                    EDM=8.2858e-07    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     3.69077e+03   3.38920e+01   6.43576e-02  -2.26384e-05
  2  Mean         2.67415e+00   2.45784e-02   6.43089e-05  -2.78822e-02
  3  Sigma        2.94918e+00   2.91611e-02   7.09411e-06  -3.86706e-01
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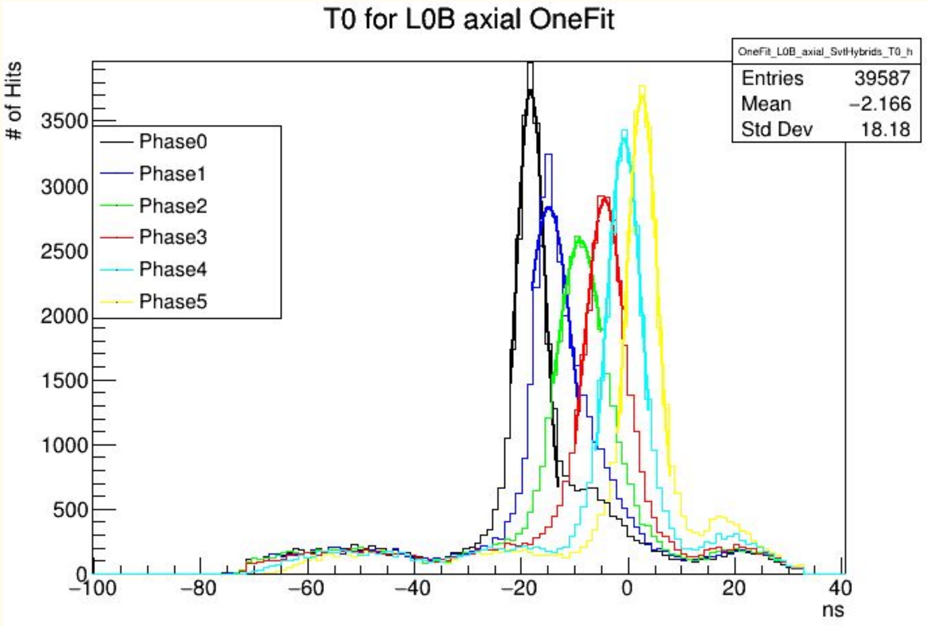


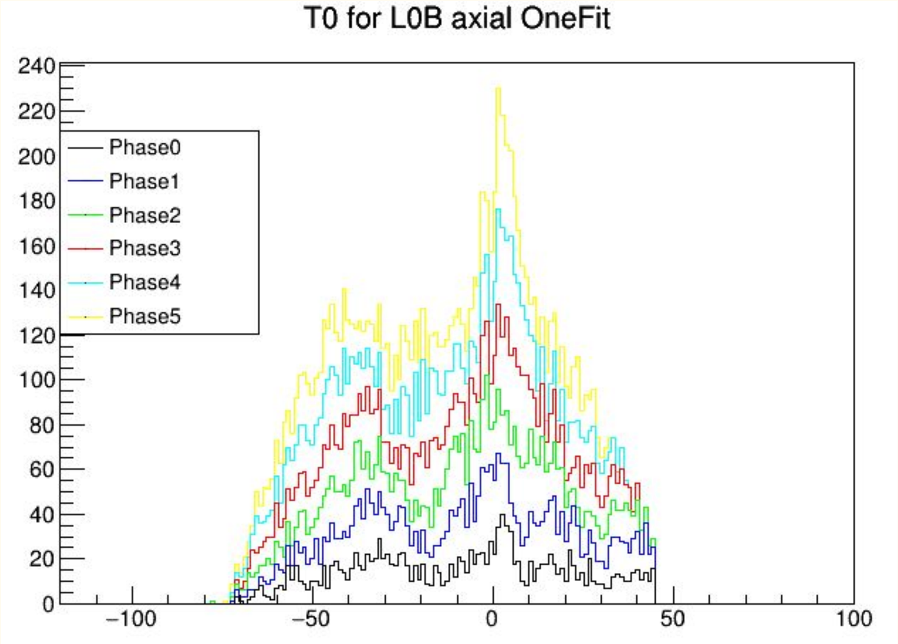
Studying More Directly the Source of out-of-time Hits

For the next study, we inspected out of time hits.

Conditioning on our hits having t0<-30 ns (~40,000 events or so) we plotted all other hits in layers and modules for said hit.

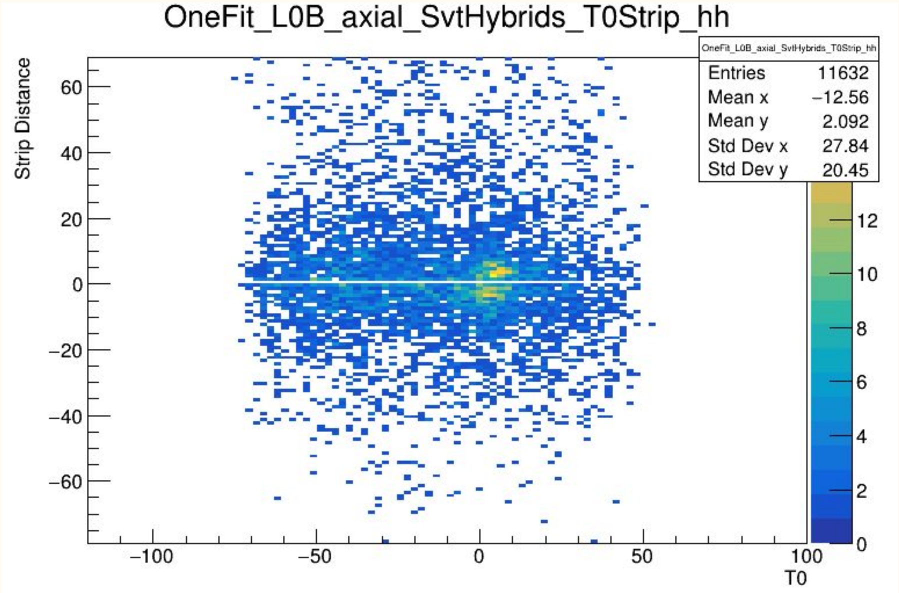
In those events we have ~13,000 that have other hits in the same module, and of these 4,000 that have a those hits on time

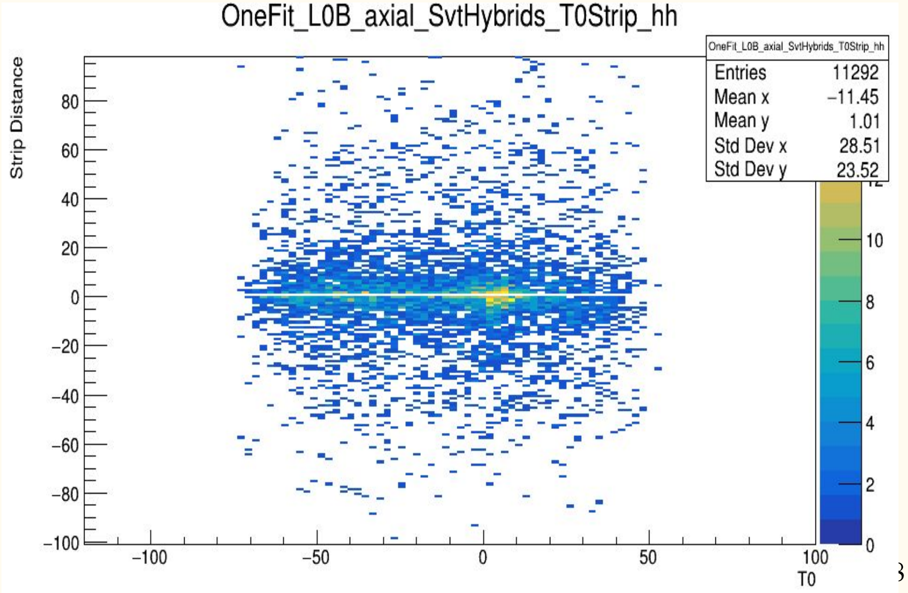
We have some room for improvement in tracking, but his is not something we would address on the DT level.



The spread (in terms of hit strips) of this distribution

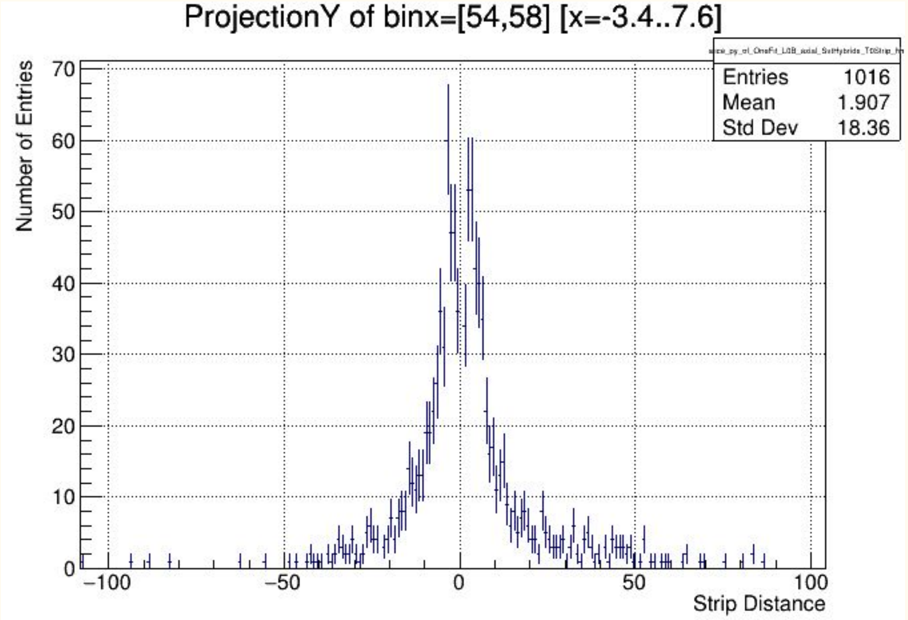
In this plot we plot the same ‘mischosen’ hits’ T0 distribution in 2D Histogram with the strip distance from it and the original hit in our track. The two plots correspond to the 2FEE (bad alignment) detector on the left and most recent detector geometry on the right

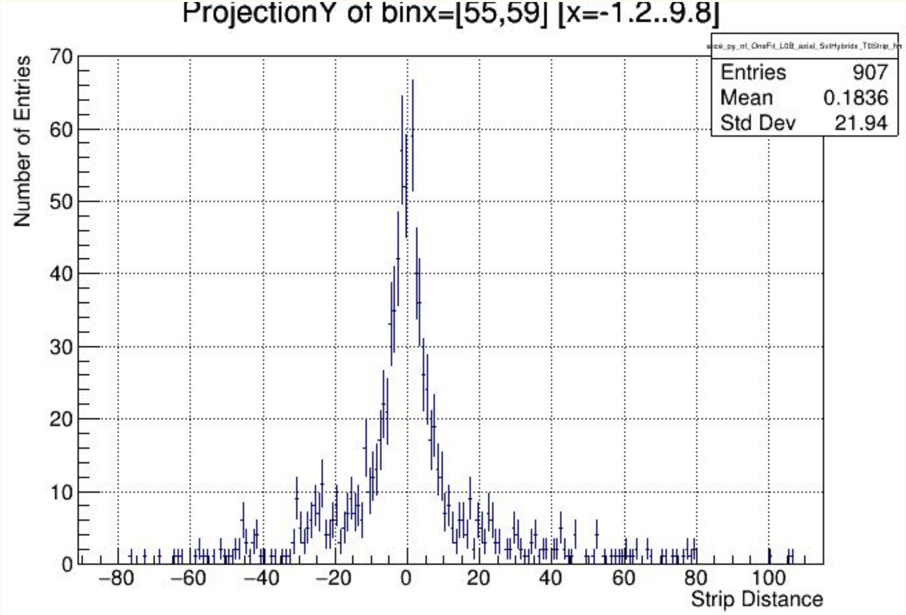




Projecting on the Strip Distance Axis

The alignment improvement in this strip makes mayber a meagre improvement in the standard strip deviation for hits on the same layer and module as a mis-managed hit.





Moving to looking at another potential issue with hit reconstruction

With the fixed alignment, unexplained phase dependent issues in on track hit reconstruction (and off time hits) became fixed. Those issues we had identified, however, are still present:

- Degenerate Fit Region
- Misalignment between forward and back layers
- Misidentification of hits for hit times $<$-30 ns.

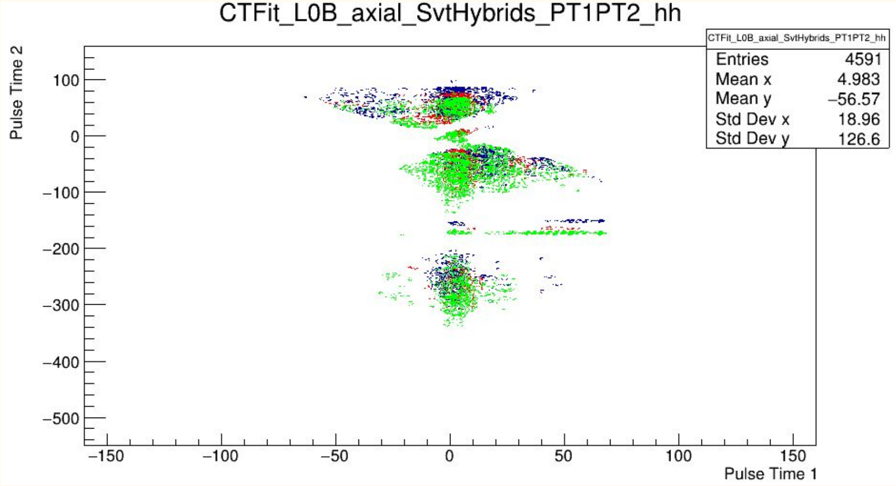
Otherwise we now have pretty decent time distributions in T0. In order to explore one further improvement, we return back to our CT Fit plot

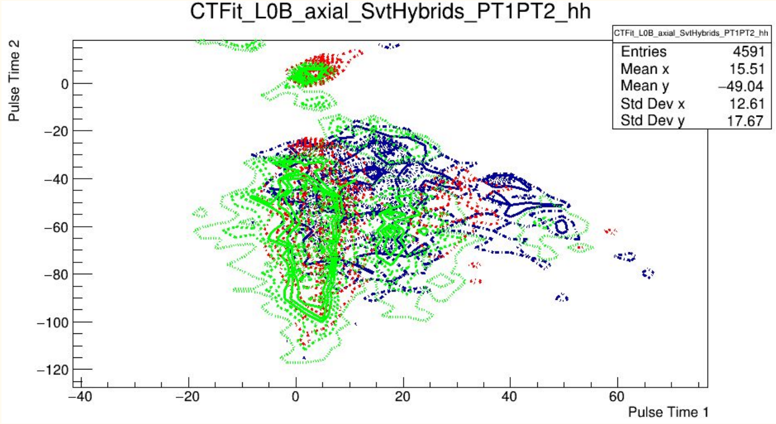
Possible Sources of these Hit Reconstruction Issues

This plot is the closest vs. farthest time plot for pileUp separated by phase.

Before the new alignment, we say a phase drift by ~4 ns in the closest pulse essentially everywhere; now we only see it in this middle most region.

Furthermore, we may color in blue phase 0, red phase 3, and green phase 5. The phase which displays the lion share of out-of-time hits is Phase 0 (we had seen this in even the misaligned detector).



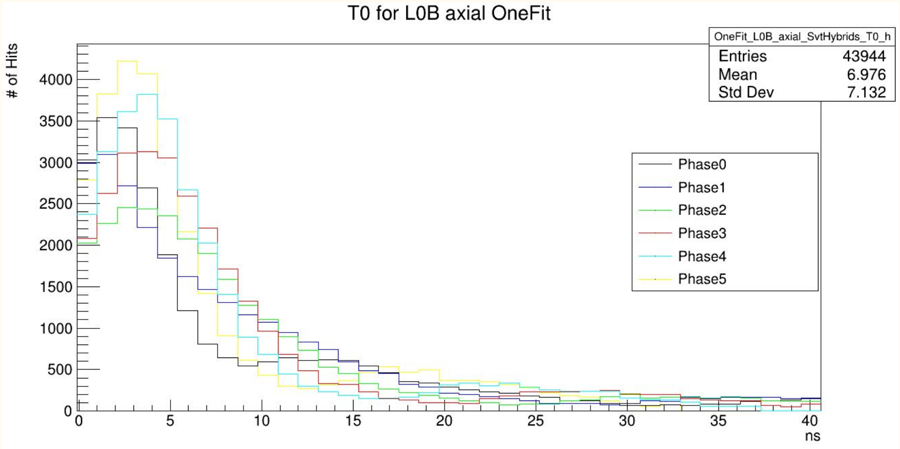


Possible Handles for Hit Reco Optimization: Phase Dependances

In most phases, you see an asymmetric (broad) tail to the right of the T0 distribution.

In Phase 0, this tail has a significant divet at 10 ns.

That Phase-0 has a strange out of time peak (and that it holds true in pileUp as well) begs for further inspection.



What Should Be Done Before the Next Pass

List of things that need fixing.

Before the next pass, we would like to correct any issues we can identify w.r.t. wrong pulse decision that exceed 1 percent of events. Here is a list:

- Optimal Hyperparameter of P($\chi_{sthresh}$) of .75
- Degenerate Pulses (just use one fit)
- Feature Alignment in Phases (for PileUp) and first and later layers.
- Identifying the issue with OneFit Phase 0 and resolving it
- Track Reconstruction and Misidentification of Hits (include time-error in Hit addition)

There are two last issues that should be addressed, both to do with clustering reconstruction parameters (one found by Norm).

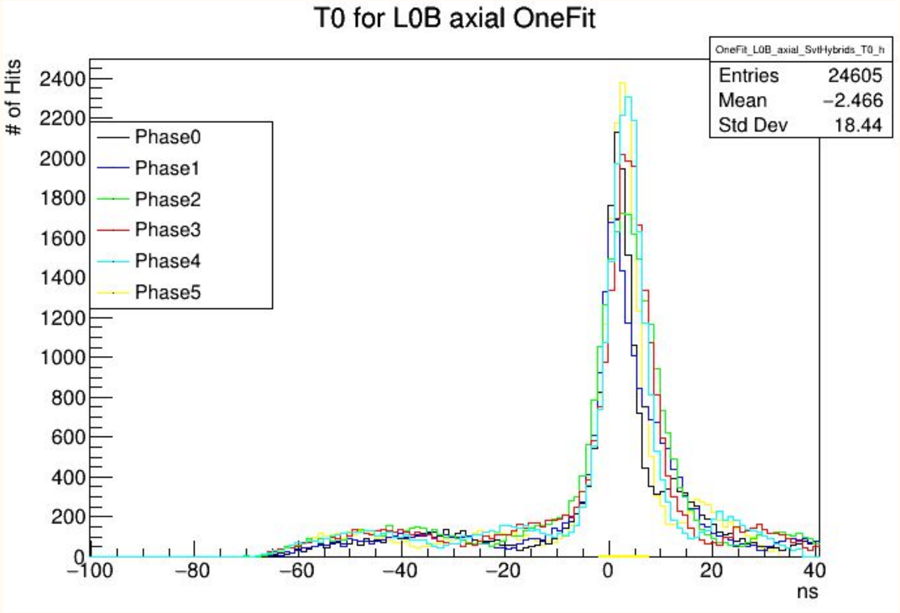
Clustering Threshold Lowered

In this case only 32/40 files from 14552 didn't get booted from the queue.

If its roughly linear in event number (and I believe it is) then we would still see ~30,000 events

This is a significant reduction in tracks found than with the cluster threshold unlowers.

It seems the shoulders also increase in proportionality, to 40 percent of the total event number.



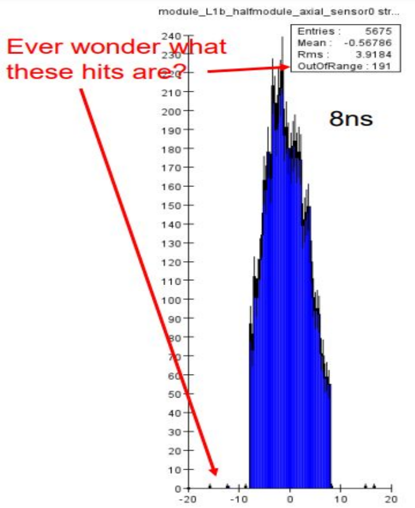
The Cluster Time Cut Window

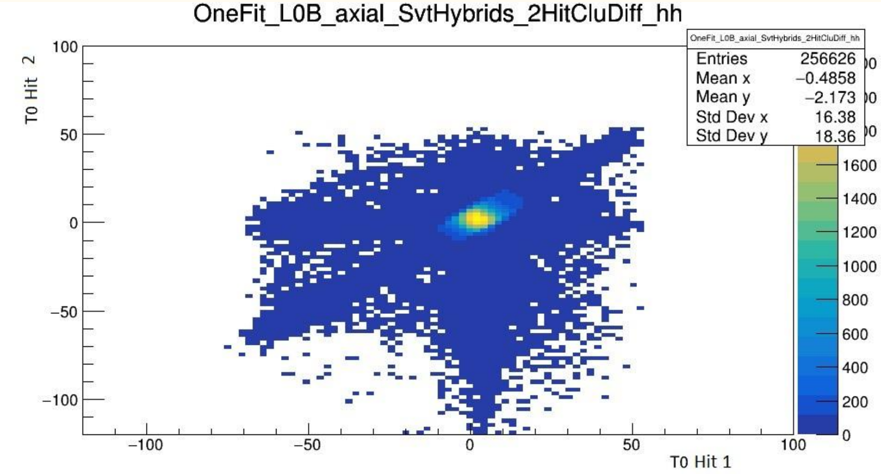
Norm had showed the abrupt cut-off in cluster times, and that opening the time acceptance window for clustering should be appropriate.

I ran the same analysis for a high luminosity run (without the window increase) and also found the same bug in analysis.

When you have very high luminosity,

The problem of pileUp becomes much more severe, and warrants care in clustering Studies. This would still be something nice to address in the near future.





What Should Be Done Longer Term

Plotting Hit Efficiency and Track Information

The framework developed in these previous slides. As of yet there are a couple things that could be explored and are not fully utilized.

Matt Graham has a nice hit efficiency script that we used along with chi-sqr thresholds. We found that hit efficiency was largely invariant w.r.t this parameter. This needs to be returned to.

We have not explored the effect of our changes on tracking parameters (though having access to them). As we want to tie a bow on this, a comprehensive exploration of track parameters and changes to the reconstruction algorithm ought to be performed.

With the analysis tools we have devised, we should be able to do all of this. Work needs to be expended to speed this up (valgrind for memory leaks, etc) as each study takes almost half a day.

Conclusion and Next Steps.

We have found a number of things that have a >1 percent contribution to the total hits on track that probably need to be solved before the next pass

For a couple of these, we have found a way we could solve them, with the exception of the Phase 0 prominences.

We will want to identify the issue there (and implement other specified changes) before the next run.

Most of our changes in our detector geometry have been shown to improve our hit reconstruction (i.e. alignment, off/online baselines).