Proposing a new method for lightless t0 calculations compatible with the dE/dx model

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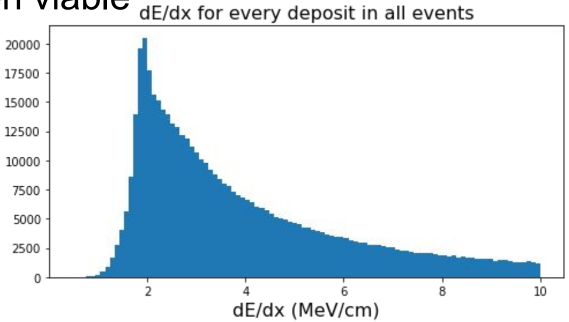
Overview

- The Problem
- Trying a Simple Solution
- Proposed Next Steps
- Summary, Thoughts and Conclusions

The Problem

Q_PIX_RTD v0.0 made energy deposits in discrete points. Q_PIX_RTD v0.1.1 now has the energy deposits spread out with a dE/dx model. While this is more realistic, it makes the reconstruction harder. Specifically, the number of resets for a pixel goes way down, so the previous algorithms are struggling to get a good measurement of RMS (and thus, Z and t0 for the event).

Said differently, the number of pixels with an adequate number of resets in a clean Gaussian distribution is very limited so we are starting from scratch to see if this method is even viable

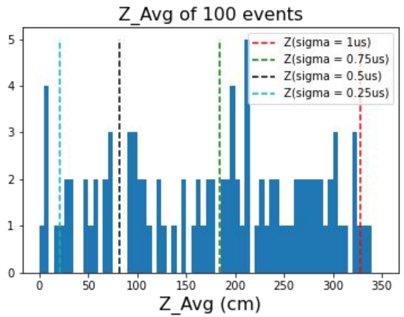


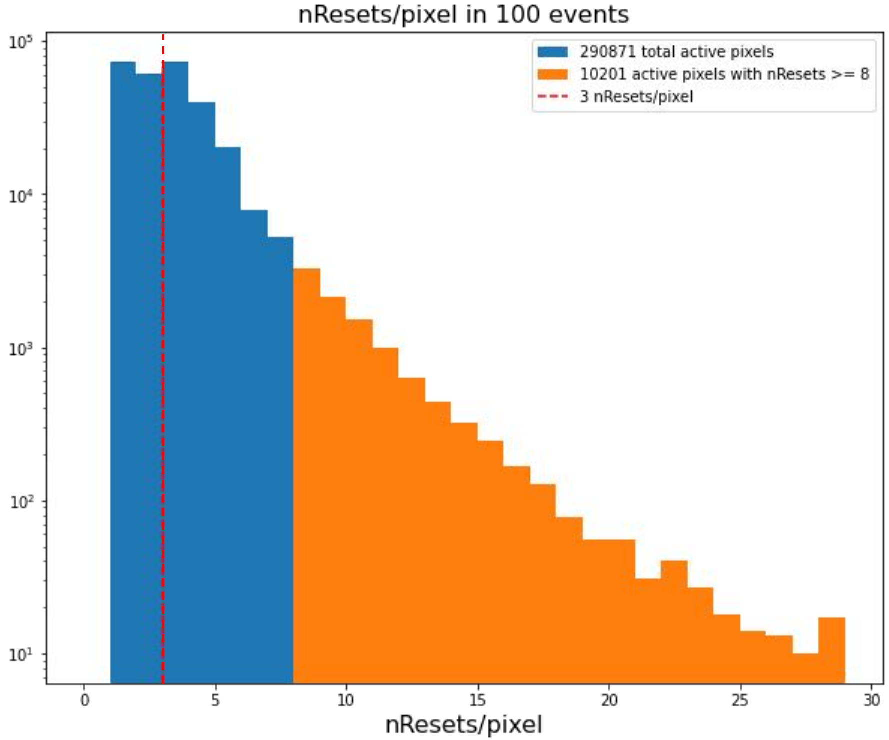
At an average dE/dx of ~2 MeV per cm, a 4mm pixel can expect to get an average of 0.8 MeV deposited over its length. That will result in 5 resets, which will diffuse into neighboring pixels, decreasing the number of resets we see to ~3ish.

nHits/pixel

Sample:

- Simulation v0.1.1
- 100 events
- 10 GeV muons
- Traversing ~6m LAr, only for small Z





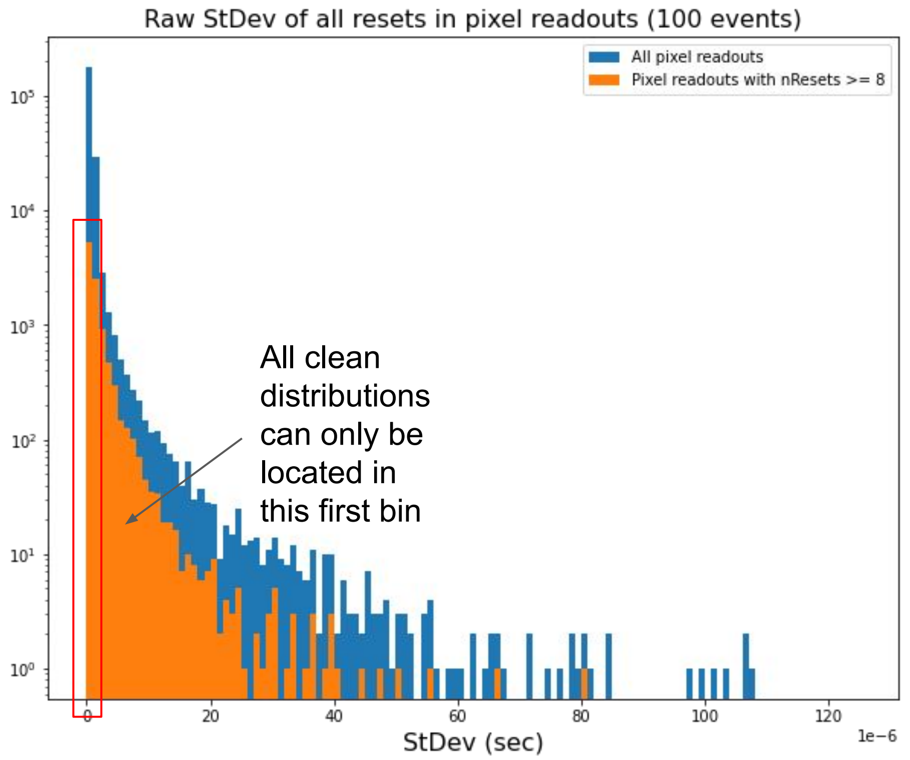
Only ~3% of pixels have at least 8 resets which is what we've decided was a minimum number of resets needed to get a good measurement

Raw StDev of pixel readouts

Since what we are interested in is a Z measurement (and the old method doesn't work with a smaller number of resets) we allow all resets and just look at the RMS for all hits in a Pixel

Since we have only simulated 0 < Z < 350cm, clean pixels should have an RMS <1us

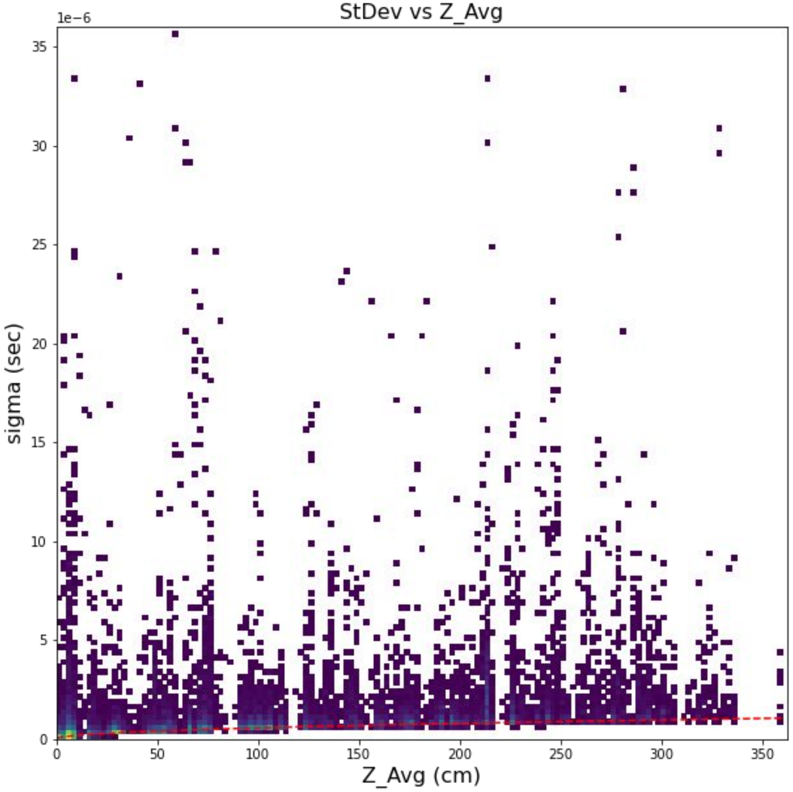
See that about half of them have StDev>1 so those are ones with multiple deposits on them. Will come back to them. Start by seeing what we can do with the ones with StDev<1

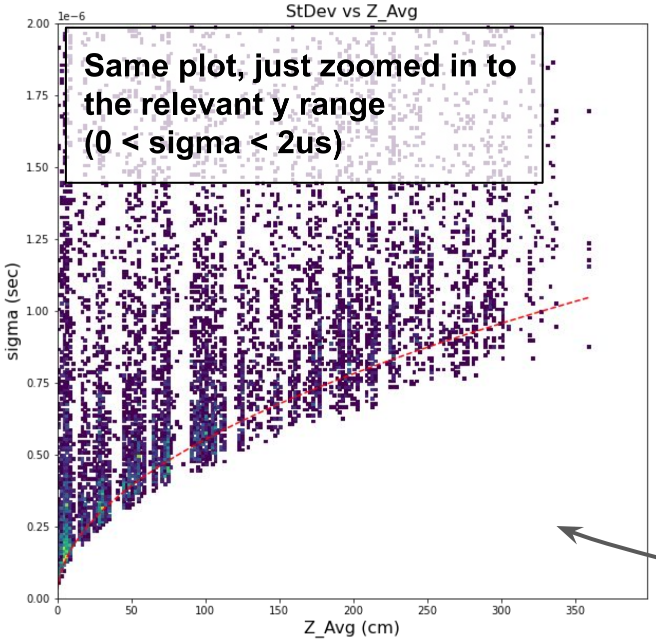


- 5237 active pixels with nResets ≥8 have StDev < 1us
  - Comes out to ~52 pixels/event
- 4964 active pixels with nResets ≥8 have StDev > 1

*Z_LocalAvg is determined by looking at all energy deposits with start and stop points in the 3x3 grid around a pixel. If none are found, grid is expanded to 7x7.

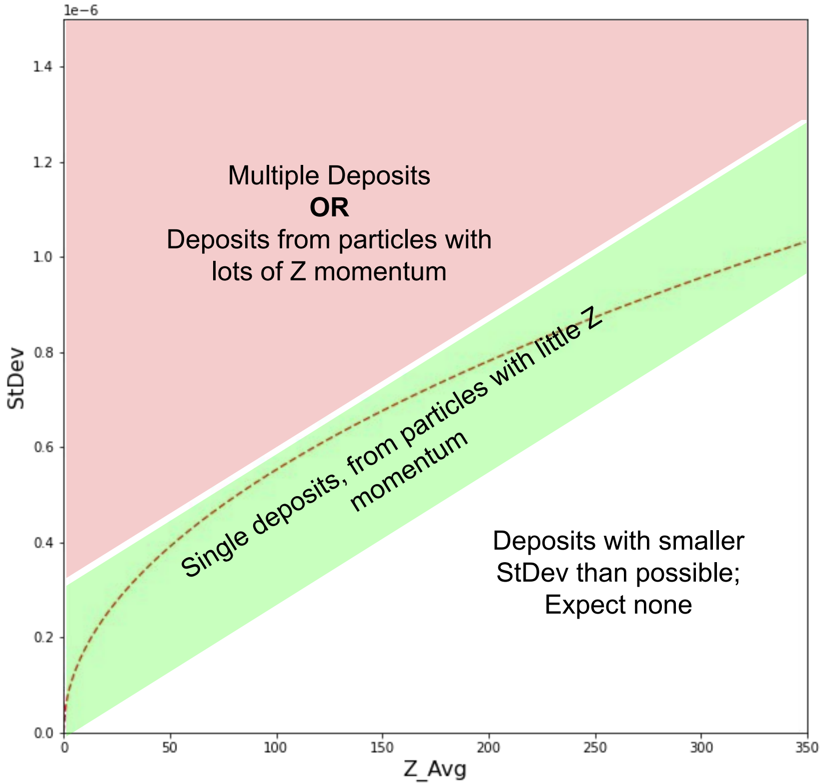
StDev vs Z_LocalAvg (for active pixels with nResets ≥ 8)





- No visible clean separation between single deposits and multiple deposits.
- Do see some statistical deviations around the theoretical projection, but clean below that as expected

Understanding the Variation



There are a mix of pixel readouts in every event, but in principle they can be differentiated by

- A single, good deposit
- Multiple Deposits, or deposits spread out in Z

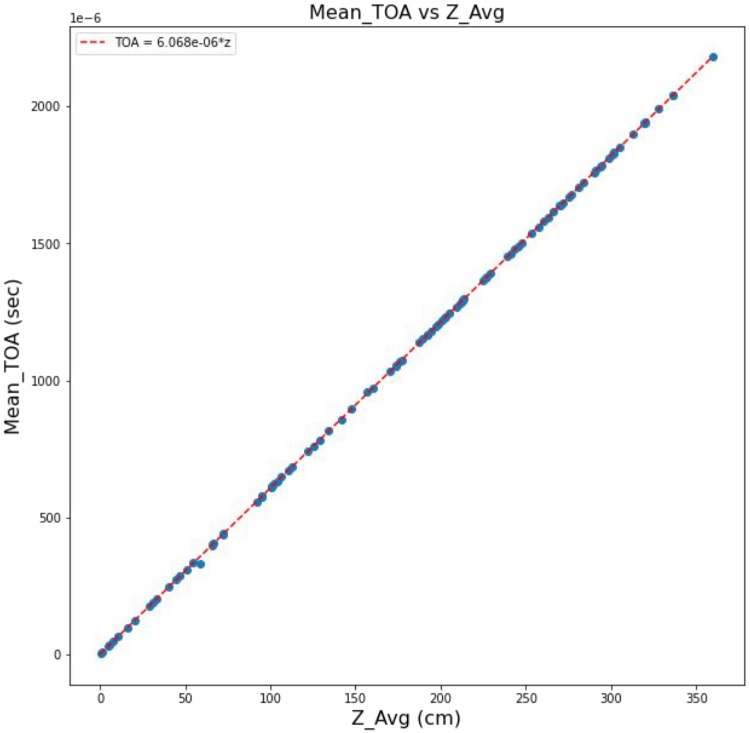
First attempt to separate

A (should be) simple method to separate the clean pixels from the multi-deposit pixels is to compare the chi squared of the fit of the resets in the pixel readout to a Gaussian

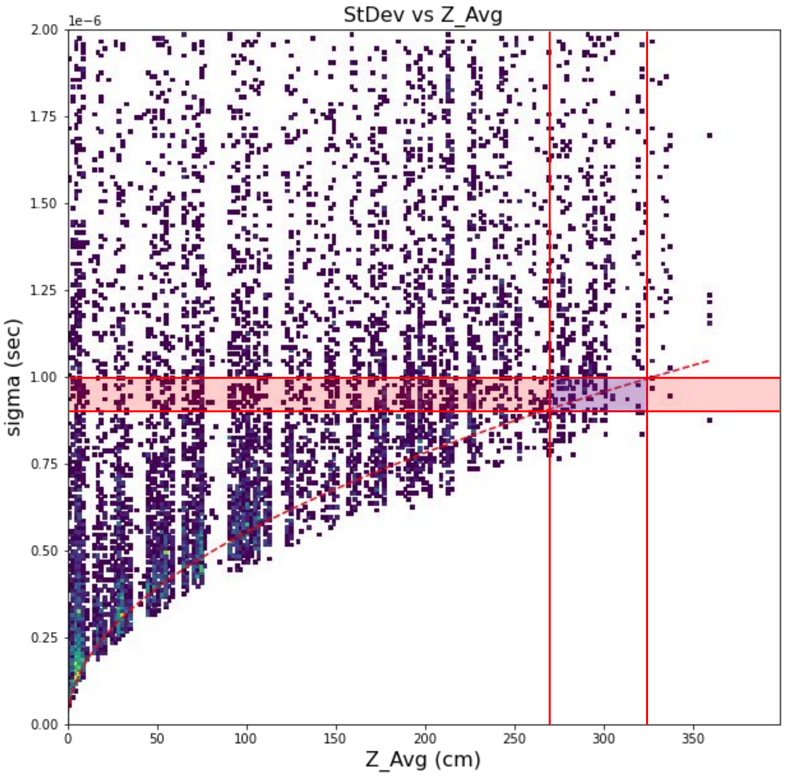
- A charge swarm from a clean deposit should be a clean Gaussian distribution, therefore so should the resets
- A clean Gaussian function fit to a clean Gaussian distribution should have a small chi squared
- A single Gaussian function fit to a non-Gaussian distribution, or a distribution with multiple Gaussians, will be a poor fit and the chi squared will be large

Quick Note: Mean_TOA and Z_Avg relationship

In the upcoming slides, we will start using Mean_TOA instead of Z_Avg. This is because Mean_TOA and Z_Avg are related linearly and we will actually be able to measure Mean_TOA in experiment and Z_Avg is an MC-only quantity (and much harder to get from the data over a single pixel).



Putting the Chi Square test to practice



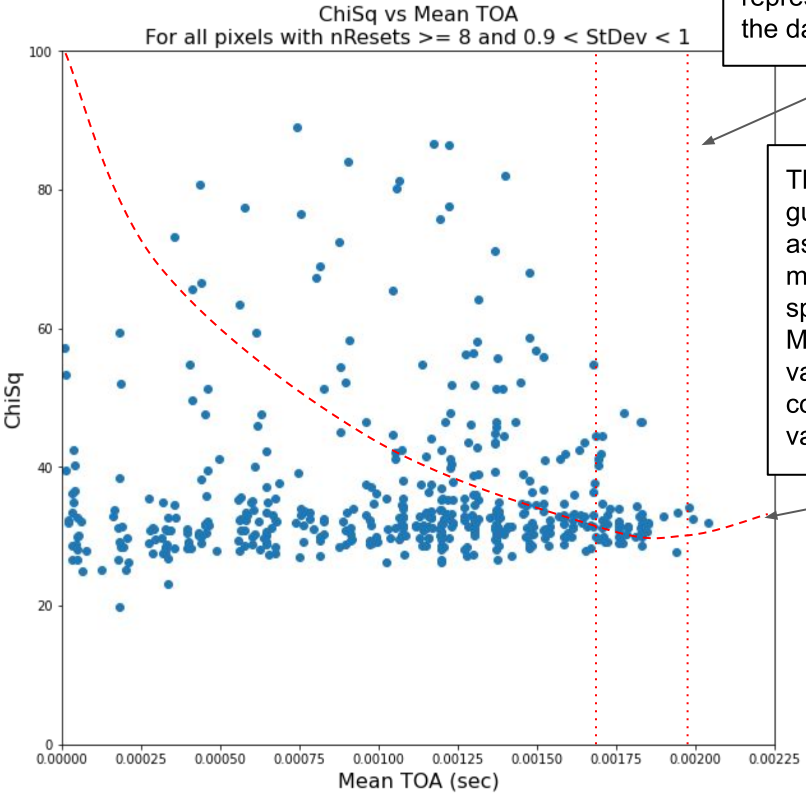
By this way of thinking, in simulation where t0 = 0, every sigma should map to a TOA and Z_Avg. For example the following 3 values should theoretically describe the same set of pixels (see blue shaded box):

- sigma = 0.9-1.0us
- z_avg = 265.7-328.0cm
- Mean_TOA = 1612.3-1990.5us

BUT as we can see in the red shaded box, there are many more pixels that fall into the
sigma = 0.9-1us range than just that theoretical set.

When we plot the chi squared values of all pixels in the range of sigma = 0.9-1us (everything in the light red box), we expect the pixels that are best fit by a Gaussian with that RMS to have the lowest values, and all the pixels outside the blue box (primarily low Z) to have much higher values, increasing with distance from the theoretically correct range

Goodness of fit: Expectation vs Reality



The dotted lines represent the edges of the dark red box

The dashed line roughly shows a guess at values of chi squared as a function of Mean_TOA. The minimum values occur within the specified range, and as the Mean_TOA (and therefore Z) values get further from the correct values, the chi squared value increases drastically

The fact that the chi squared shows no trend across the entire Z range suggests that there is going to be no real method for accurately fitting the distributions.

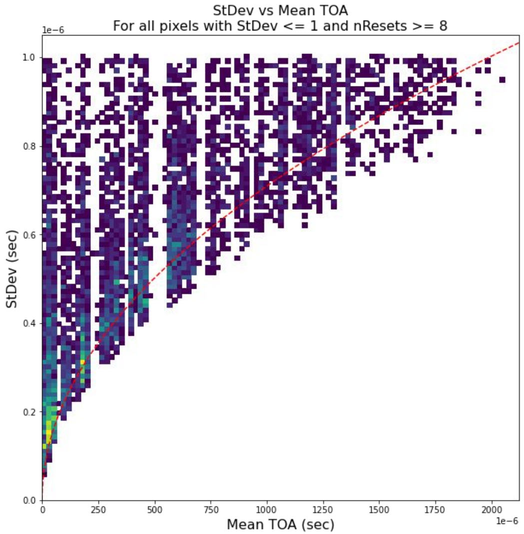
Said differently, there are few if any clean gaussian distributions with 8+ resets that we can use to get t_0.

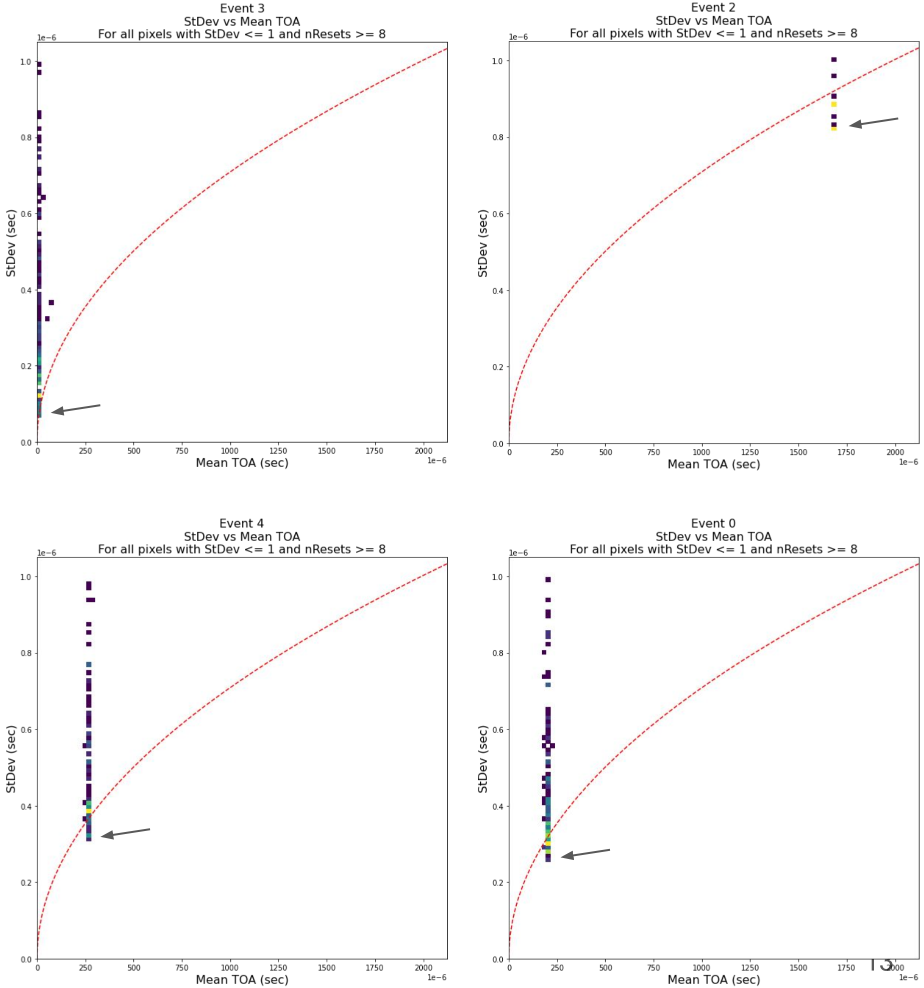
Bottom line, chi squared is useless when it comes to testing for good fits

Trying a Simple Solution

Since we know that there are a multitude of factors that can increase the StDev, but nothing that can decrease it other than a statistical bias, it makes sense that the minimum StDev of a 8+ reset pixel could be a good way to find the least messy looking grouping of deposits.

Looking at single events





If we break up this plot by event, we see that all the 8+ reset pixels are generally grouped by Mean_TOA (aka Z), which is expected because the events are muons with only y initial momentum.

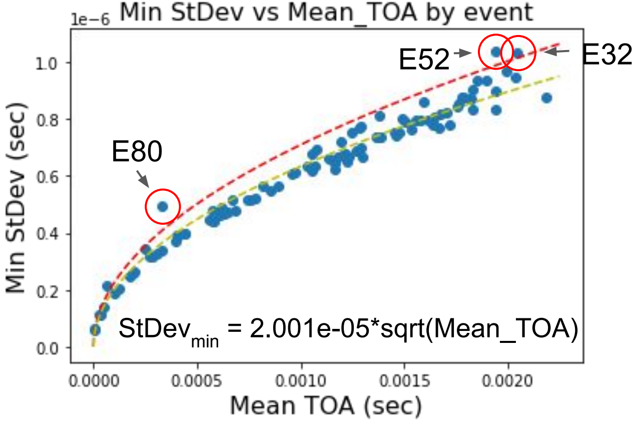
- ***What if we look at all the 8+ reset pixels in an event and then just choose the pixel with the minimum StDev that fluctuates low?***

Plotting StDev_Min vs Mean_TOA

- For each event, find the pixel with 8+ resets that has the StDev_Min
- Use the Mean_TOA of that specific pixel

- Red dashed line is the theoretical relation
- Data looks like fluctuation low of each pixel (the cleanest Gaussian is picked for each event, but the RMS fluctuates low in a systematic way)
- Yellow dashed line is the fit
- Fit is remarkably good, but does have some outliers (will look at these in a little bit)

- Since t0 = 0 in simulation, we can invert the fit function to get expressions for Z_est and t0_est

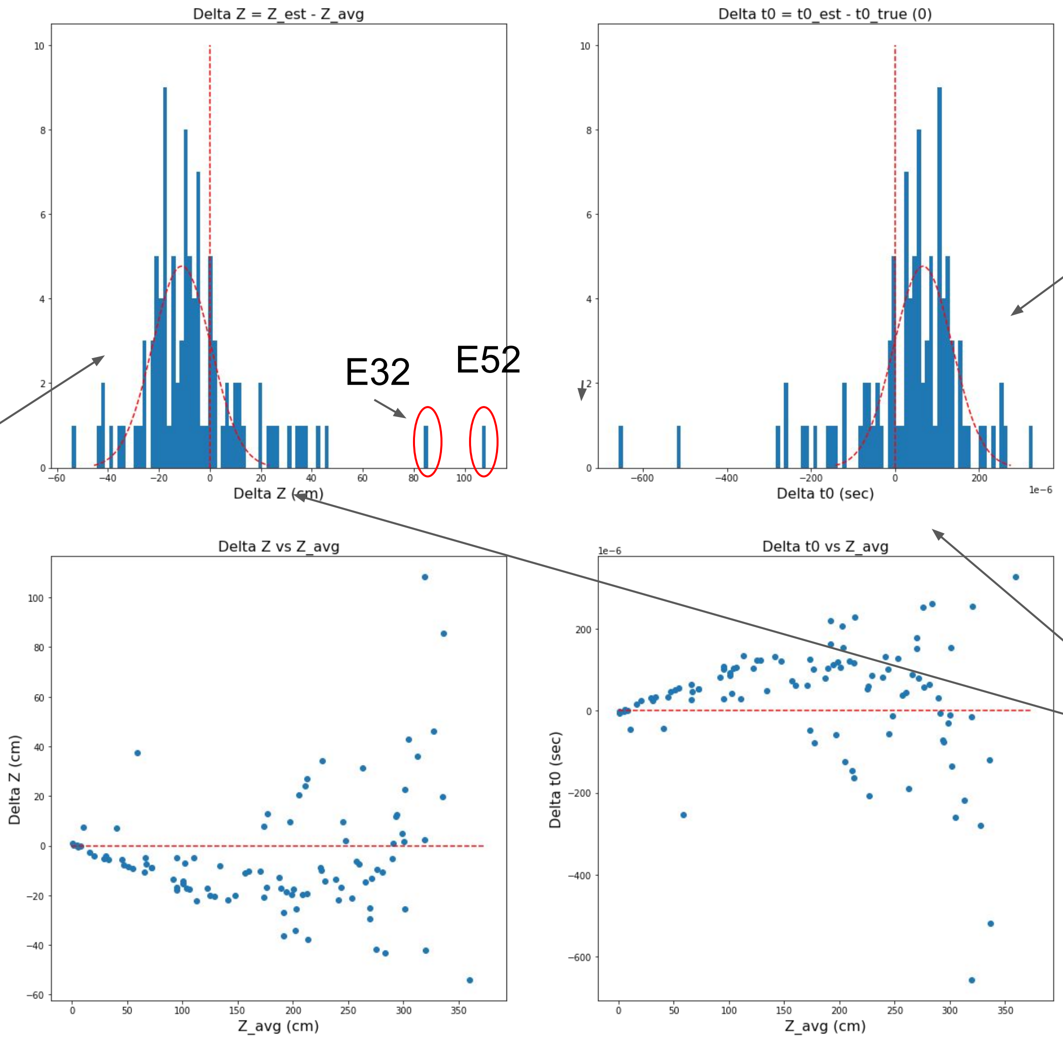


TOF_{est} = 2.496e09 * $StDev_{min}^{2}$

Z_{est} = 4.114e+14 * $StDev_{min}^{2}$

$T0_{est}$ = Mean_TOA - TOF_{est}

How well does it do?



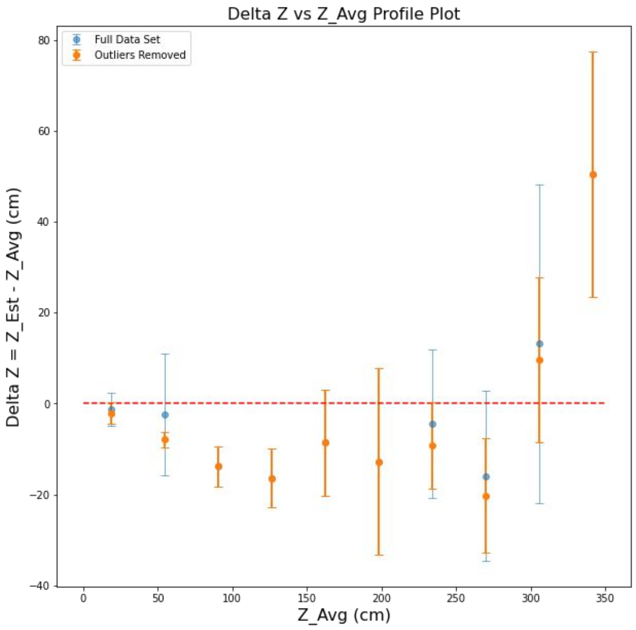
μ = -11.03 cm
σ = 11.47 cm

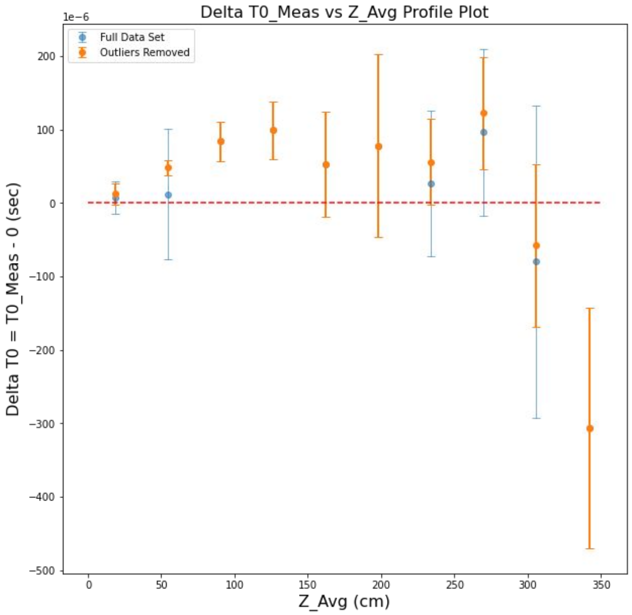
μ = 67.1 μsec
σ = 69.6 μsec

Plots shows the difference between the "measured" quantity and the MC quantity. It's very Gaussian, also shows a bias as well as some tails

Gaussian, but have tails that will affect our resolution method

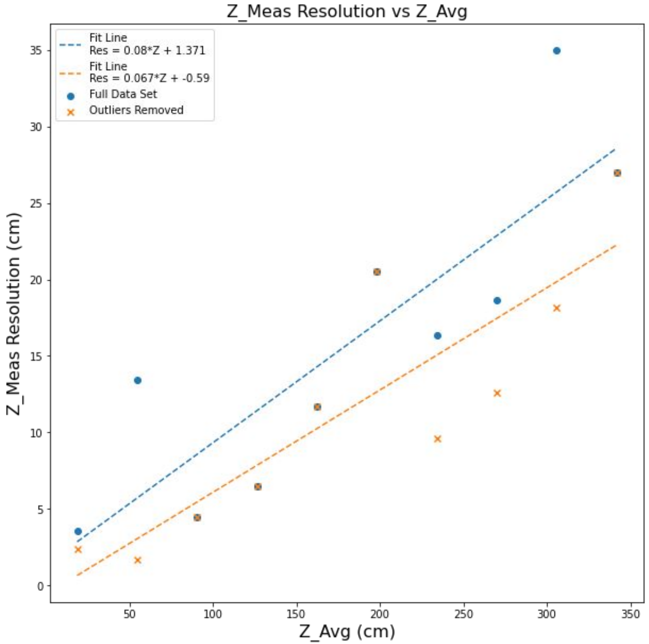
Z Resolution vs Z

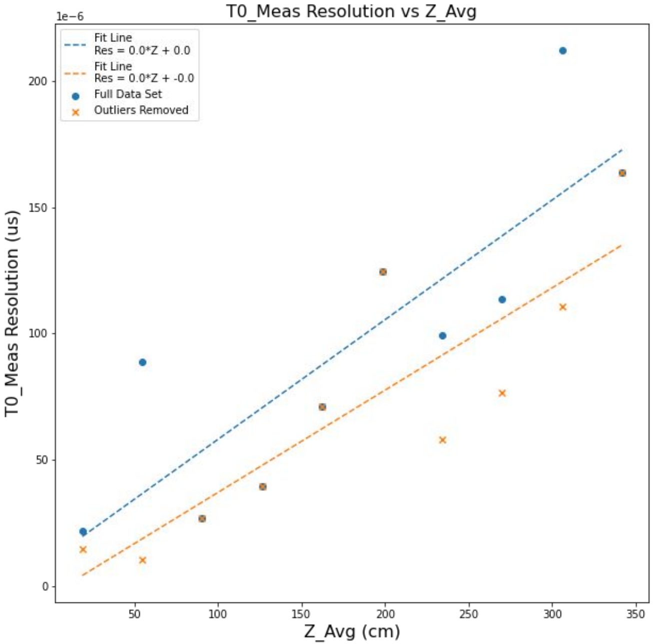




- Error bars are the RMS of each distribution
- Blue shows the distribution of full data set
- Orange shows what it would be if we could remove outliers

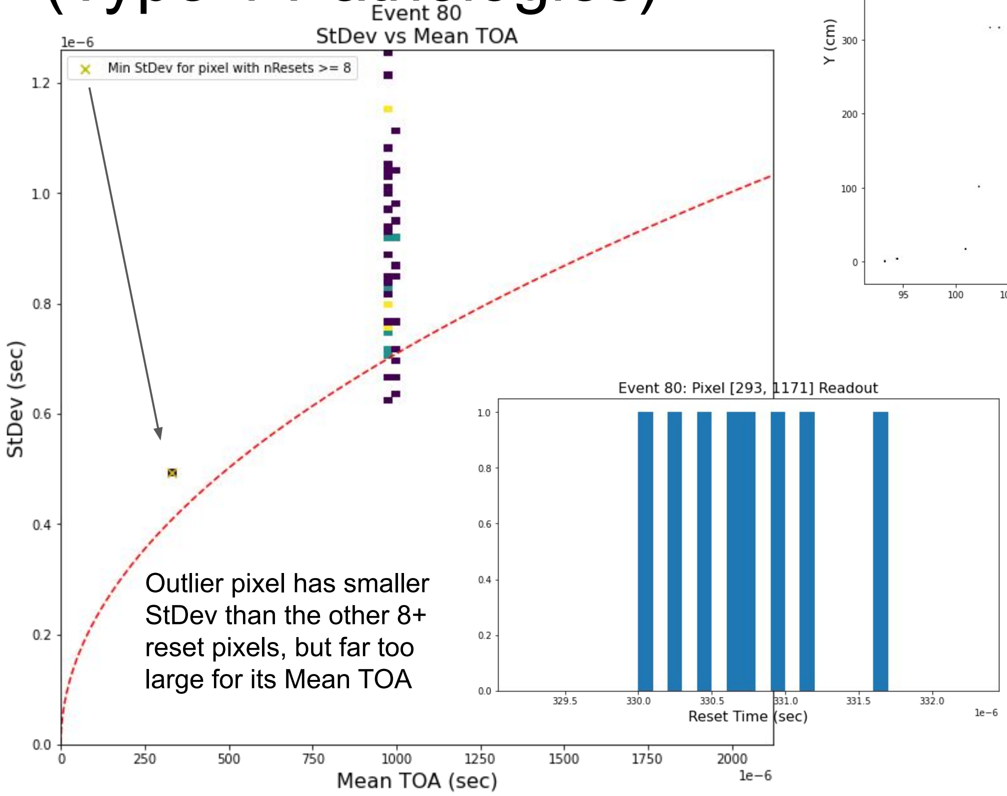
Resolution as function of Z

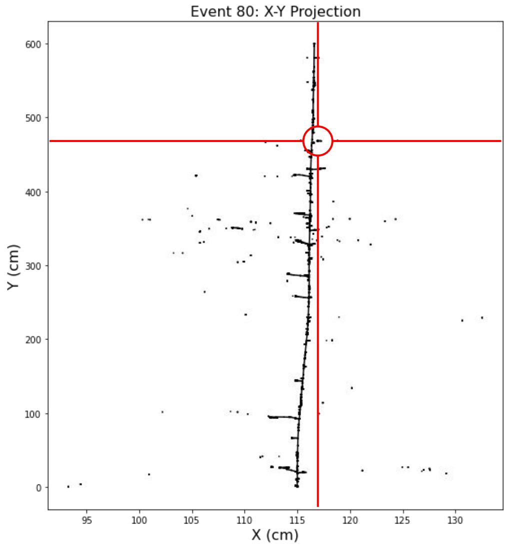


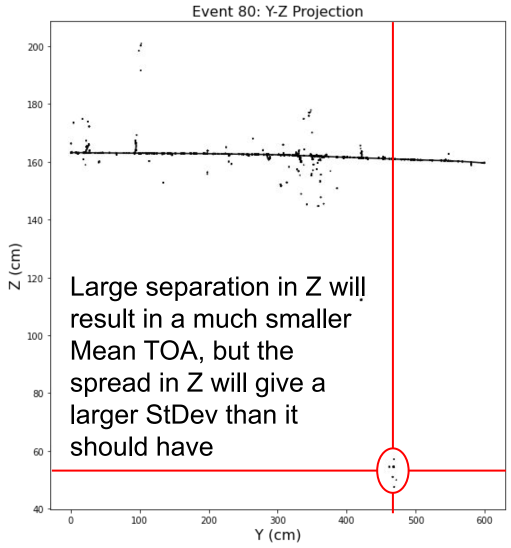


The orange points and line is an estimate of how well we hope to do by the time we're done (i.e. at Z=300cm, the resolution is about 17cm in Z and 100us in t0)

Looking at outliers to see if they can be removed (Type 1 Pathologies)

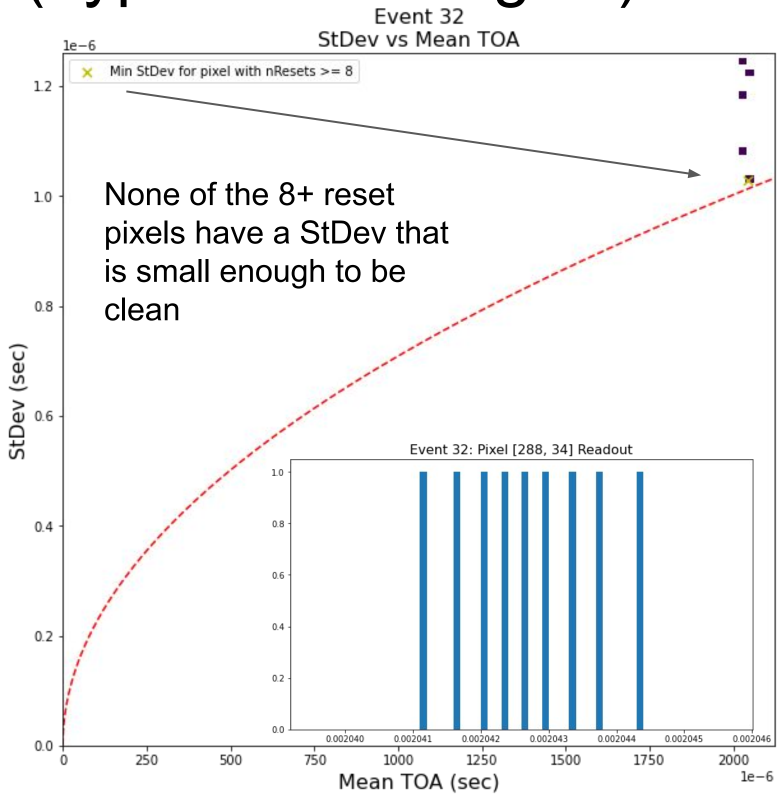




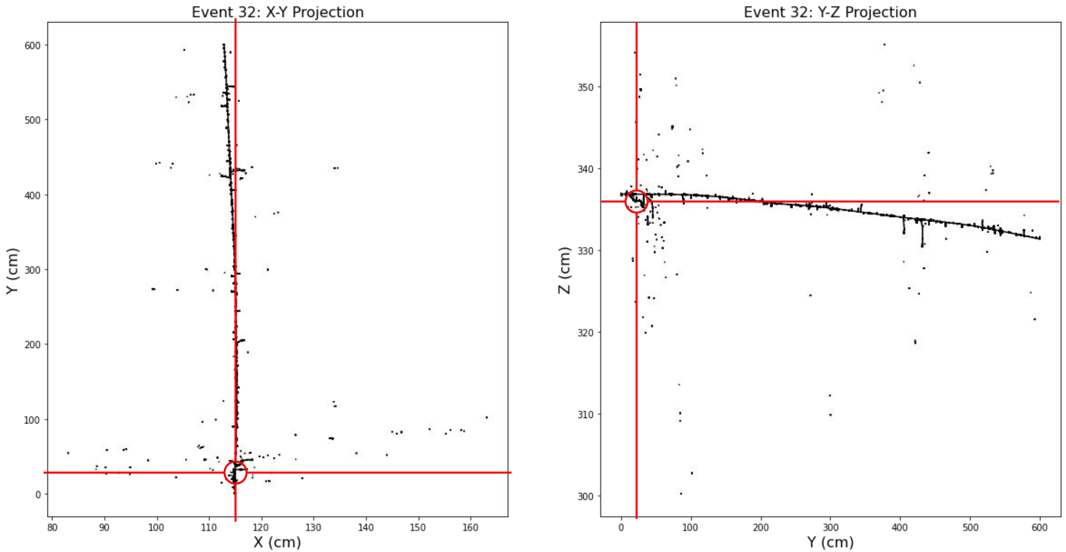


In this event, a particle branched off from the main path and made a significant deposit at a much lower Z, which should, and does, get a lower StDev. Because of the vast difference in Z_Avg, the spread out pixel readout has a smaller StDev than the other pixels corresponding to the main part of the event. Call this a **Type 1 Pathology**, where outlier pixels cause small, but misleading StDev_Mins.

Looking at outliers to see if they can be removed (Type 2 Pathologies)



None of the 8+ reset pixels have a StDev that is small enough to be clean



This is an event where very few deposits resulted in 8+ resets in any single pixel, and none of them “fluctuated to be clean”. While there are many pixels with lower StDev, they all have < 8 resets, leaving the smallest 8+ reset pixel as one under multiple deposits with some non-negligible delta Z. We will call this a **Type 2 Pathology**, where no clean part of the event produced 8+ resets for a single pixel

*Event 52 shows similar behavior

Proposed Next Steps

Describing perceived shortcomings and possible solutions

Deposits at multiple Z locations (Type 1 pathologies)

There is more information than just the RMS. We can look at the Mean_TOA and identify cases where particles are deposited with very different Z. Can use this known correlation to do better and tell which is the StDeV_Min relative to how low it traveled. This way we can separate misleading pixels corresponding to small Z and large RMS from clean pixels corresponding to small RMS at large Z.

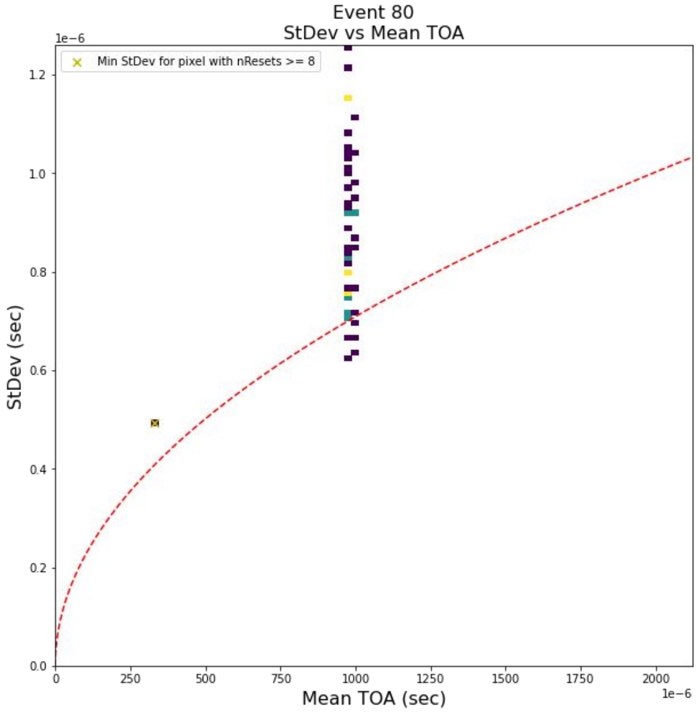
Small number of pixels with large energy deposits makes us vulnerable to not getting a clean pixel with 8+ resets (Type 2 pathology)

One possibility is to increase the number of resets seen by each pixel (decrease reset threshold from 6250 e^- → 3125 e^-)

Making the algorithm more robust to type 1 pathologies - Part 1

1) We saw that the current algorithm is susceptible to outlier pixels as shown ***to the right.***
2) Once we start introducing z momentum into the equation, we will no longer have all pixels grouped by TOA, will need to have a way to compare all pixels without confusing poorly measured outliers for smaller z pixels.

Suggestion: Can compare each 8+ reset pixel to the theoretical relation (red dashed line), shifting the largest Mean_TOA to correspond with the max drift time and see which pixel is furthest below the red line at its given arrival time. Outliers would be shown to be "small in absolute value but large in terms of expectation and not considered to be the StDev_min"



Potential solution to type 2 pathologies: decreasing the reset threshold to get more pixels with 8+ resets

Currently, any pixel with 8+ resets is probably going to have resets from 2-3+ deposits, OR from deposits that are primarily travelling in the Z direction.

- By requiring enough resets to get a good rms measurement, we are confining ourselves to looking at messy pixels (pixels in booms)

By decreasing the reset threshold to 3125 e^-, we are turning a 3ish reset deposit into a 6-7 reset deposit.

- We may be able to start looking at sticks, which we know are much cleaner and probably more reliable than booms
- Currently sticks only have 2 or 3 resets per pixel and while we may get some with the correct rms, the uncertainty on the rms is extremely high rendering them not useful

More in next talk

Summary, Thoughts and Conclusions

- The amount of energy deposited in dE/dX processes, as shown in Q_PIX_RTD 0.1.1, illustrates that the trajectory of a muon doesn't deposit enough energy above a pixel to make lots of resets
- With many fewer resets the previous method of measuring Z and t0 longer works
- We have shown that by looking at the minimum standard deviation of all pixels with 8+ resets in an event seems to be a good start, but it’s an imperfect method for predicting a Z and t0, susceptible to outliers and more complex topology
- Efforts are underway to make the algorithm more robust and less susceptible to cases where there are multiple deposits with very different Z.
- Currently studying the effect of lowering the reset threshold by 50%
- A combination of the above two changes shows promise of improving the results from the first rudimentary attempts (Will show preliminary results in the next talk)