Run 4 Analysis

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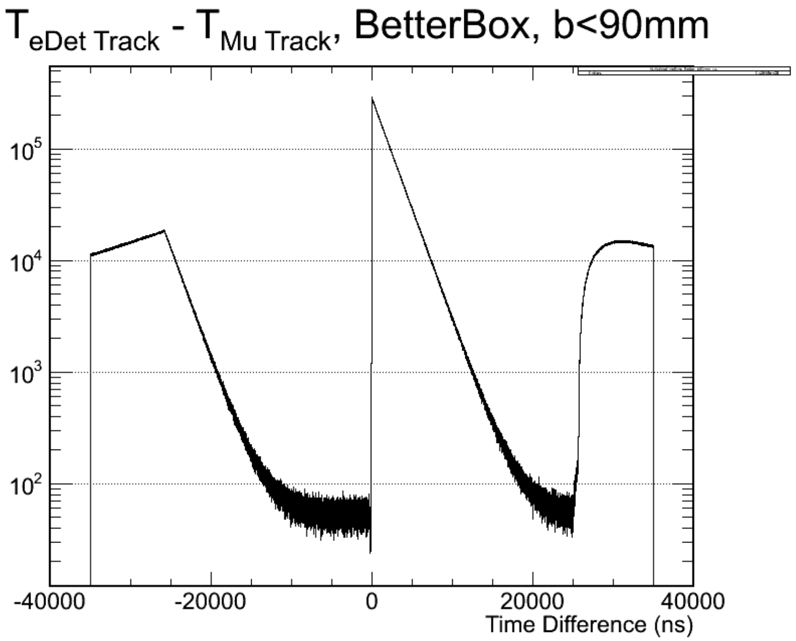
MTA Lifetime Histograms

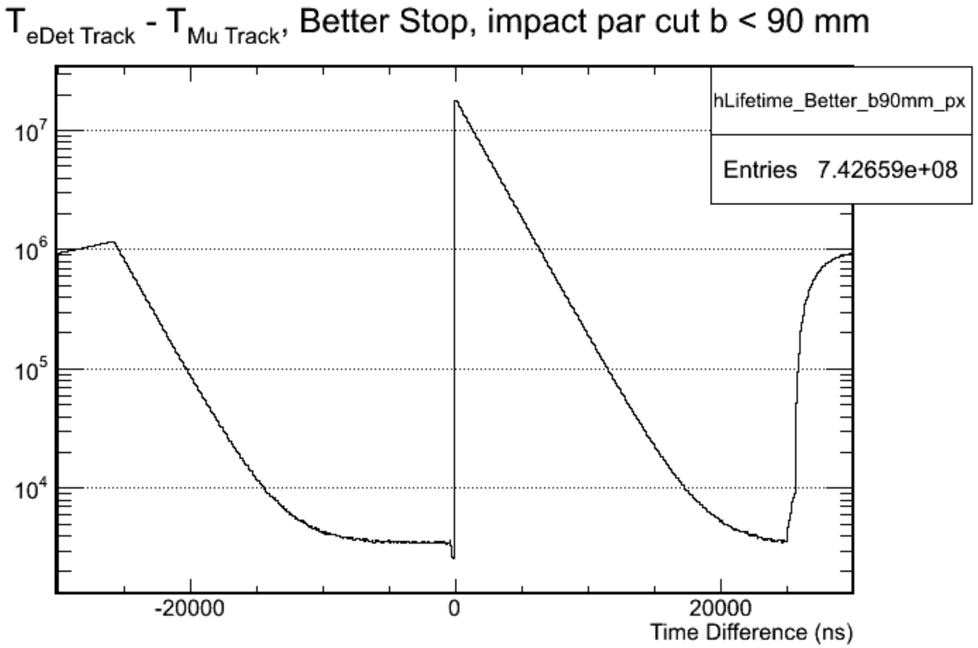
Histogram binning can be 1.25ns or 40ns

The CAEN TDC has a 40ns external clock period, but this is subdivided into 1.25ns bins.

However, MuCap found that the interpolator is non-linear, which can inflate the Chi^2 of the fit.

Thus, 40ns bins or a multiple should be used.



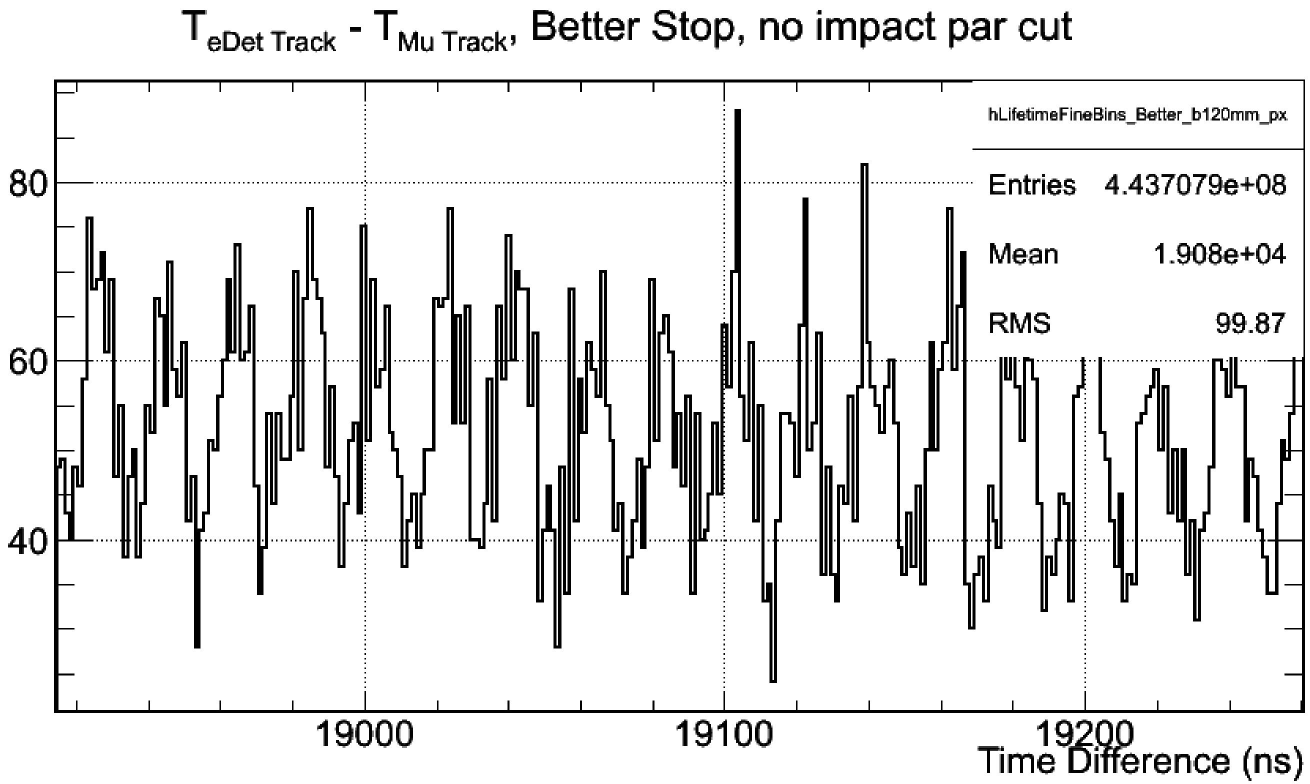


Residual Cyclotron RF

We see a residual component of the cyclotron RF in the electron background.

The frequency seen in the 40ns binned histograms is close to 1500ns.

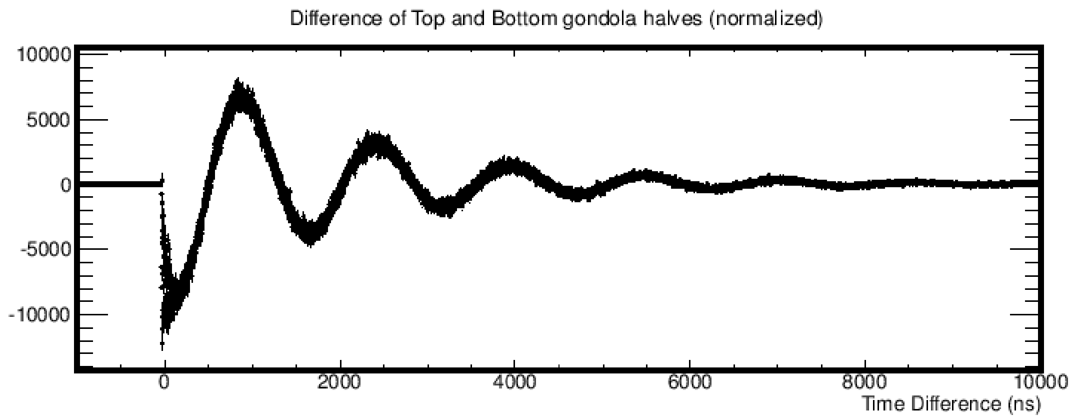
In the 1.25ns bins, the frequency is ~51MHz.



Mu+ Lifetime Scans

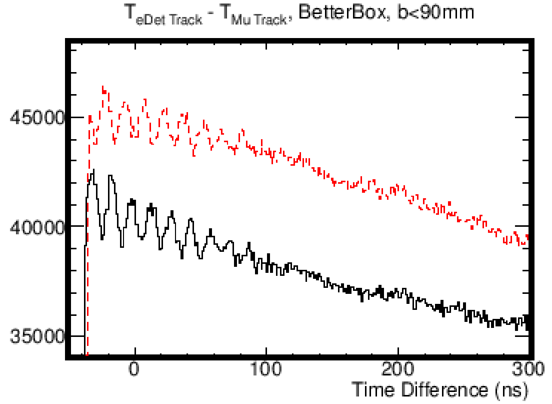
Mu+ does show stability with the geometric scans.

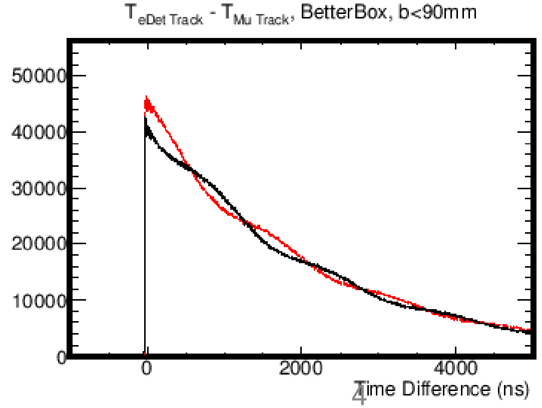
For all of these studies, I used the Mini pulse template fitter, and the basic clustering tracking algorithm (explained later).



Standard cuts are

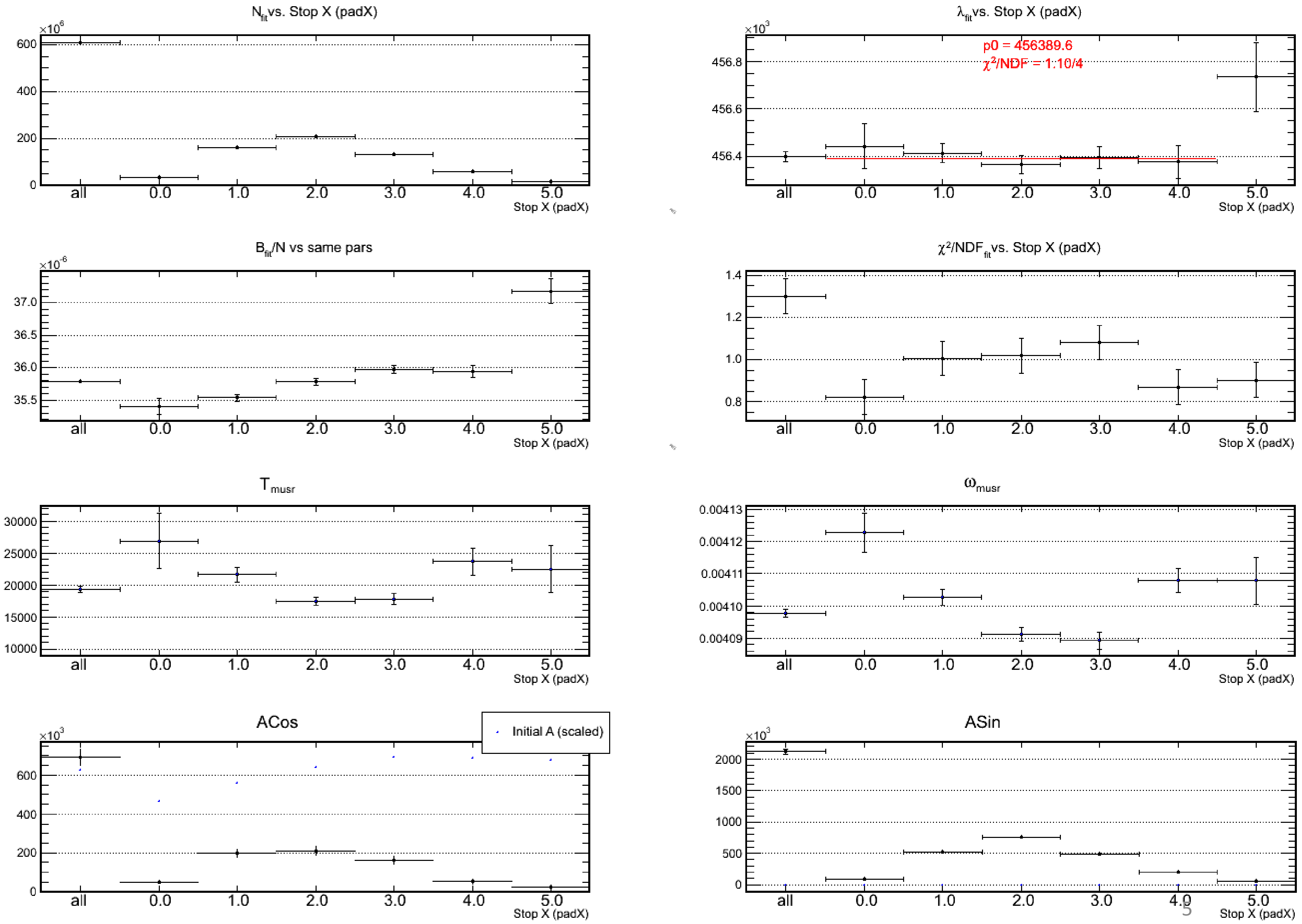
- Track length >= 3 pads
- Track S-Energy > 450 keV (or 300 ch)
- Track stop is in fiducial volume (exclude border pads, 15mm < Y < 55mm)
- Impact parameter < 90mm



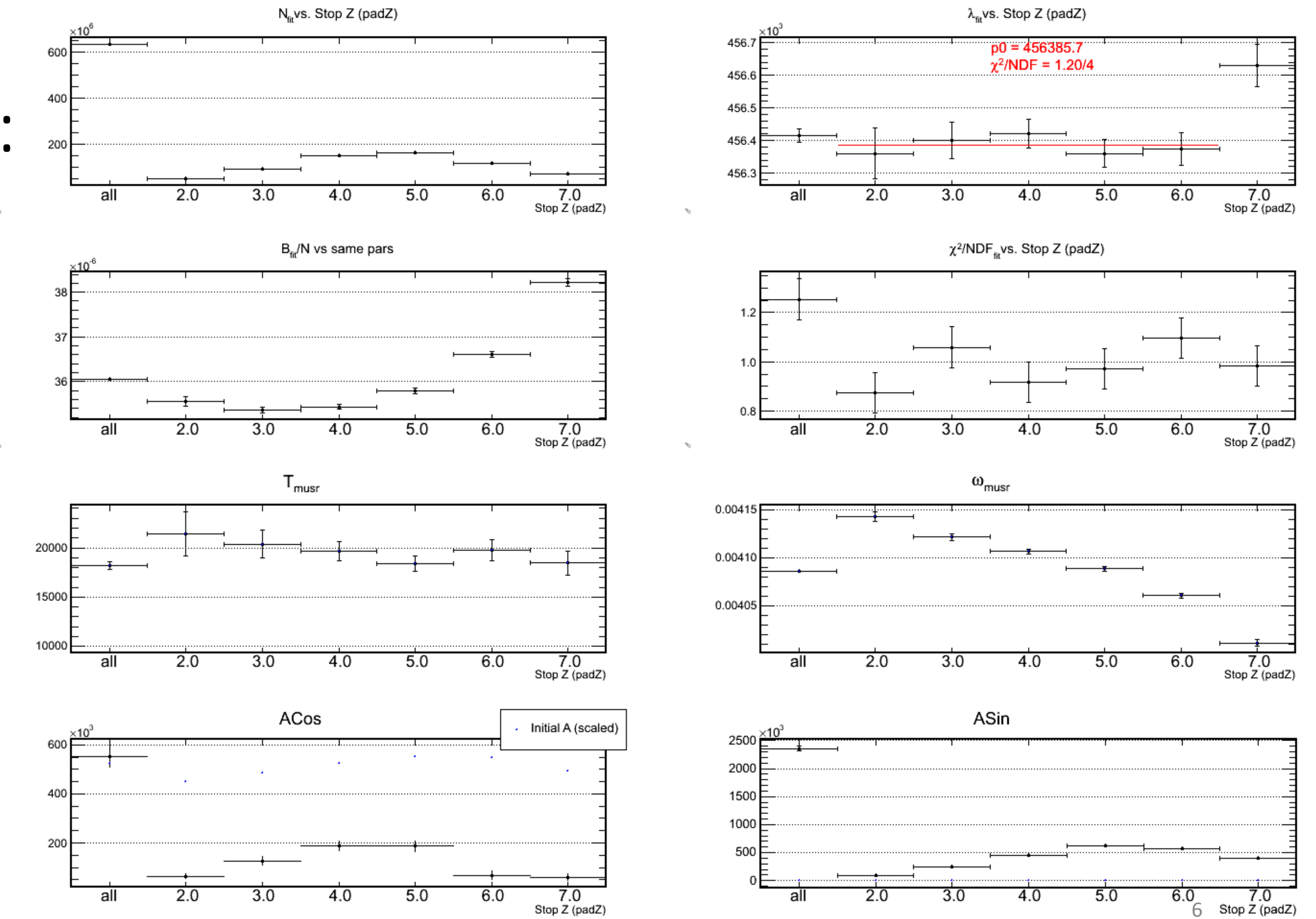


Fit start time 160ns, stop time 24000ns

Mu+ fitting : Lifetime vs Stop X

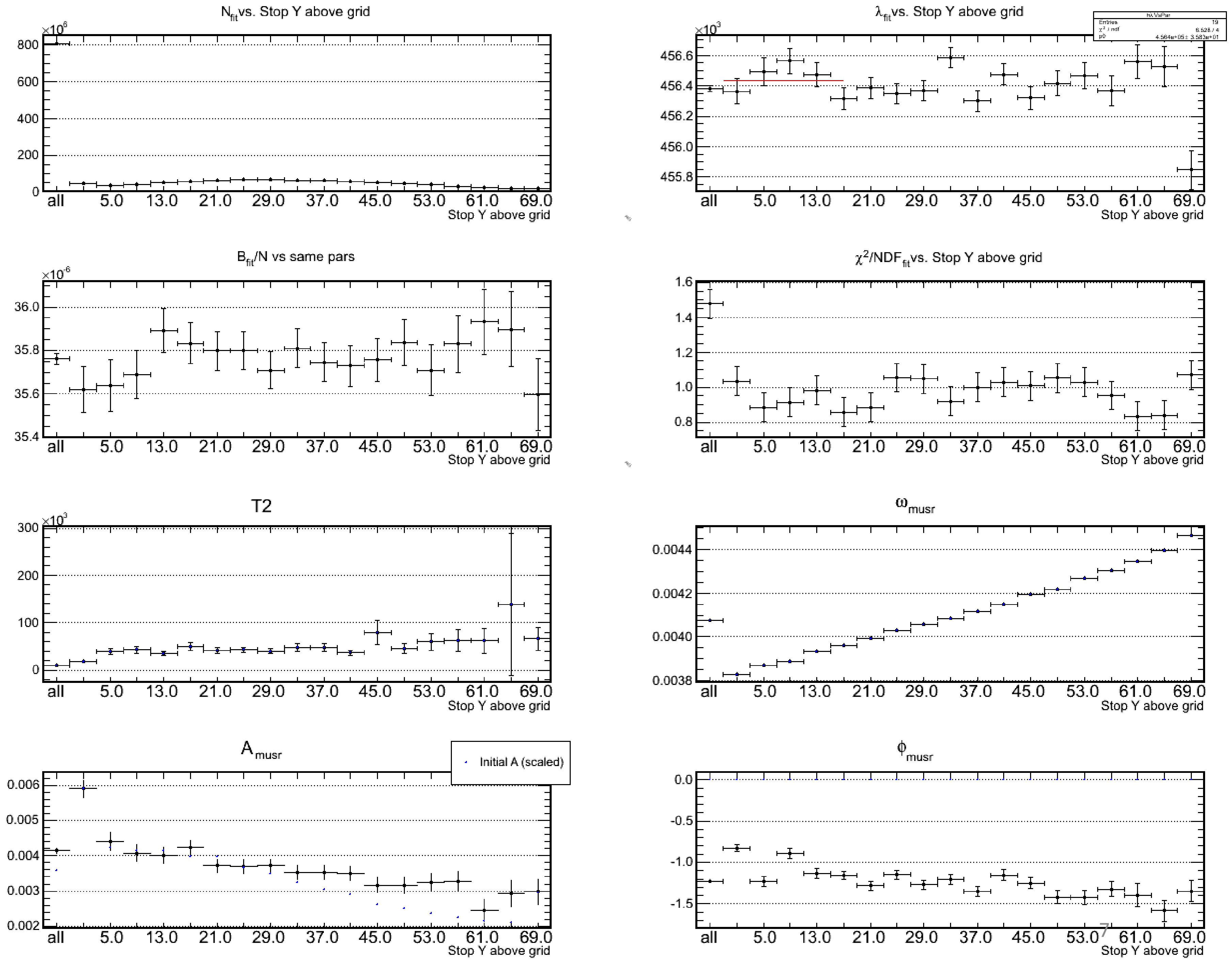


Mu+ fitting : Lifetime vs Stop Z



Mu+ fitting Lifetime vs Stop Y

Changing omega_musr showed us that we mounted the magnet incorrectly in Run 4.

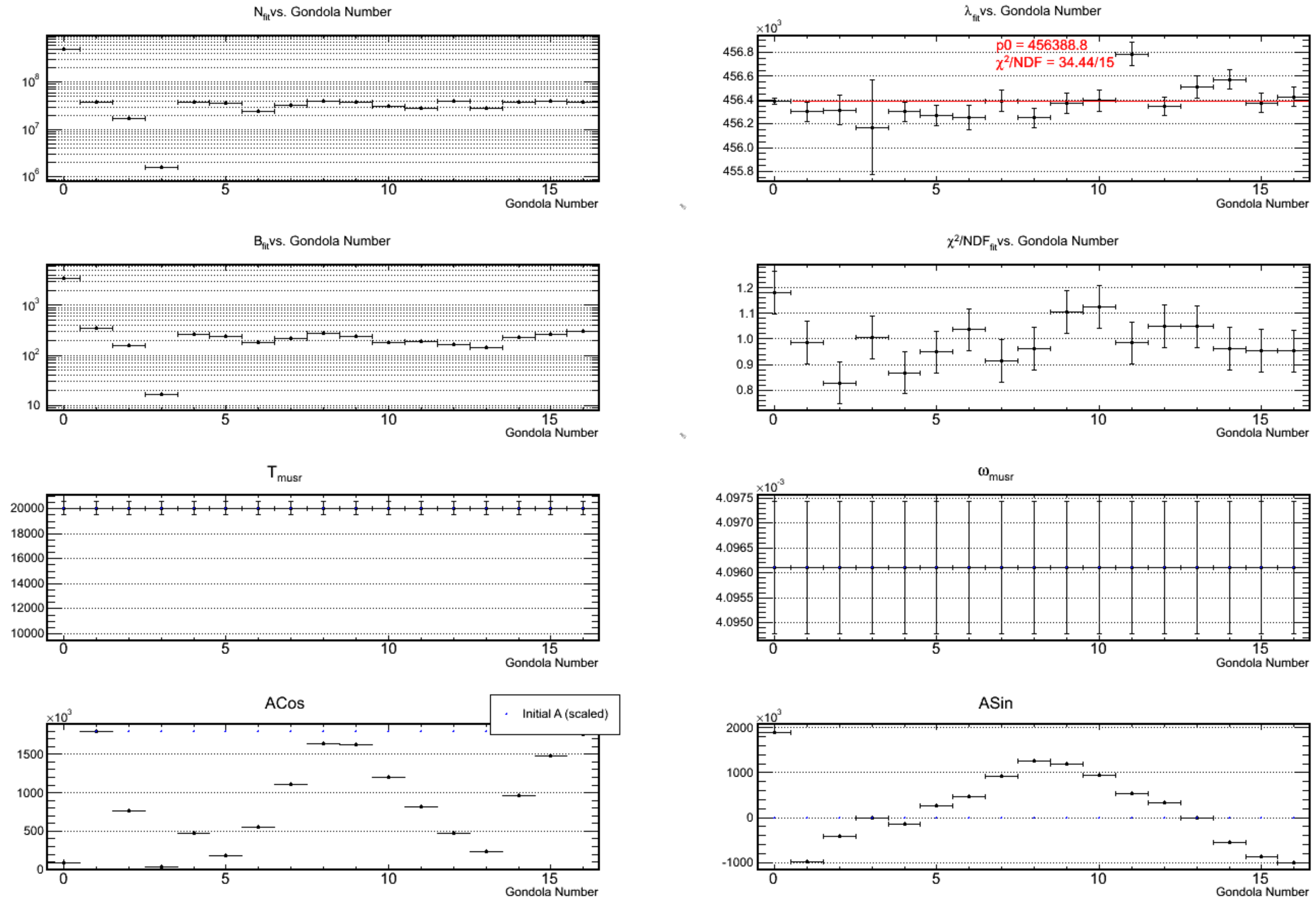


Mu+ fitting : Lifetime vs Gondola

Fixed omega and Tmusr, unlike the other fits.

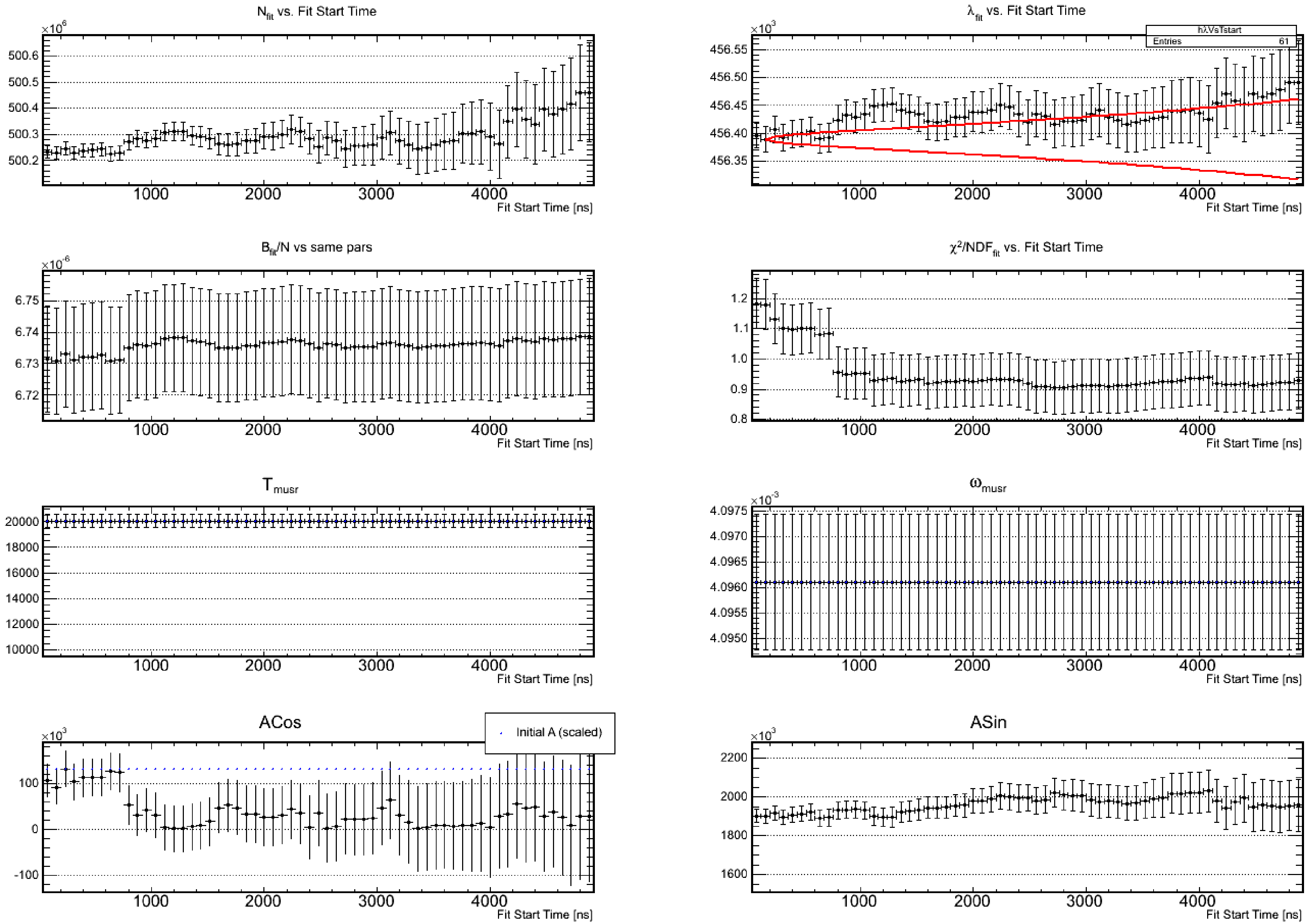
Individual gondolas have 100 s^-1 error bars

What's going on with gond11?

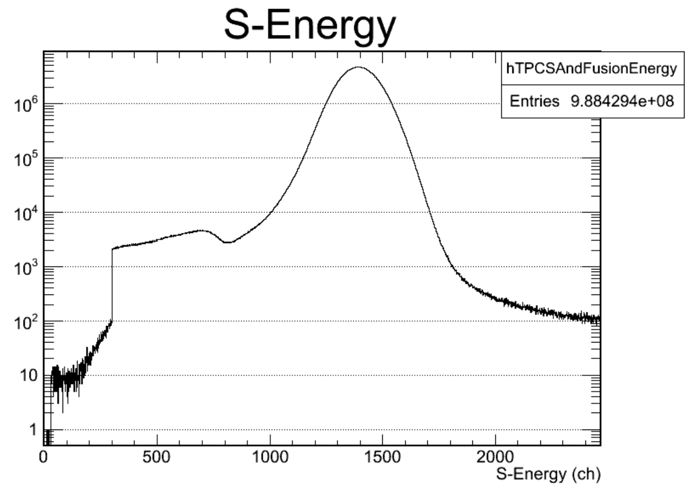


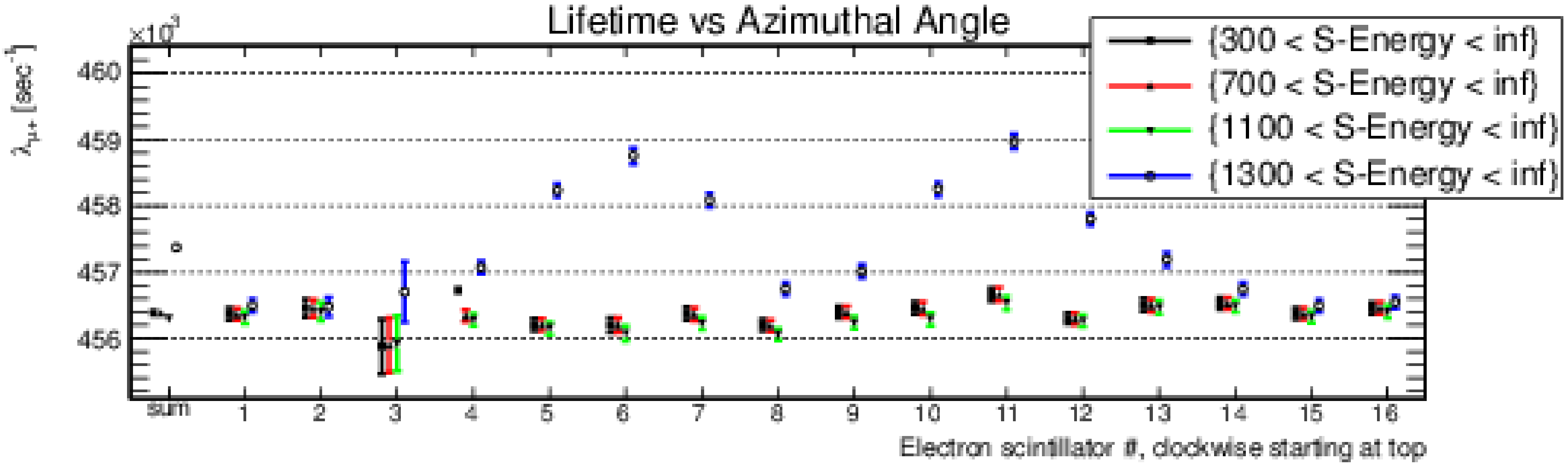
Mu+ fitting : Start time scan

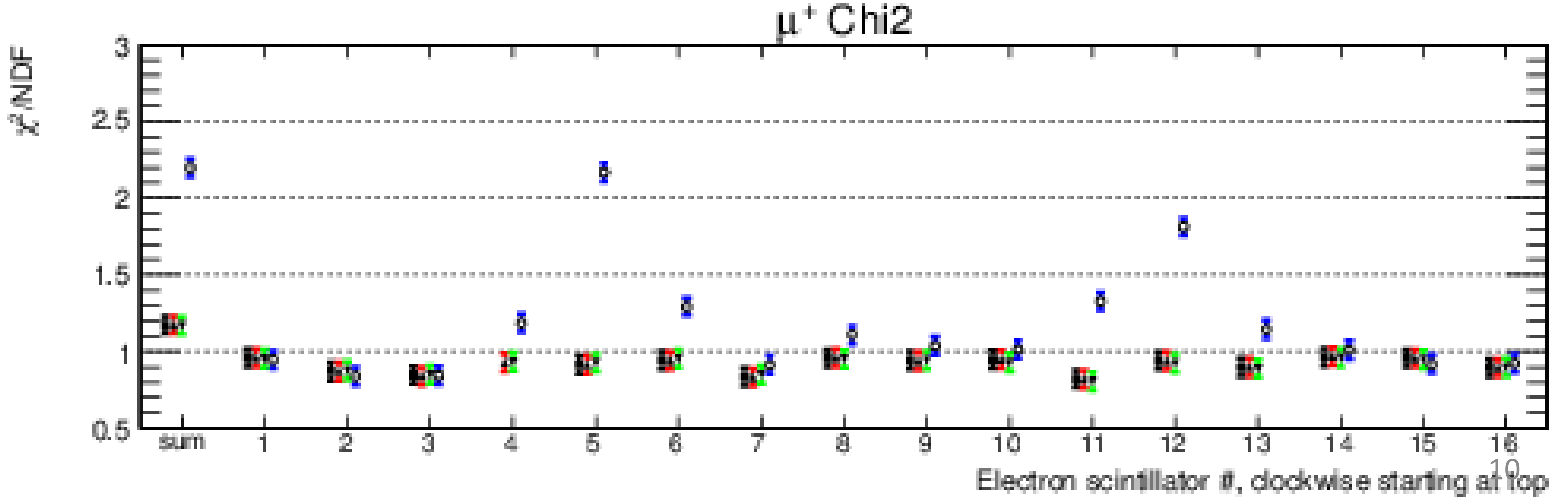
Is early bad chi^2 due to oscillation effect <1us?



Mu+ Electron Interference

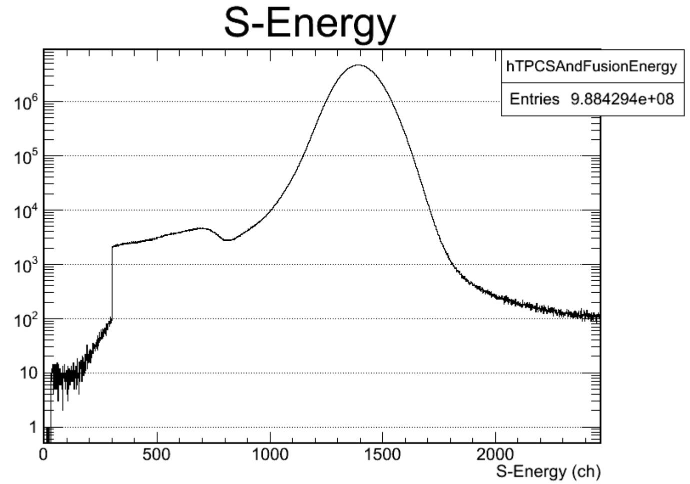


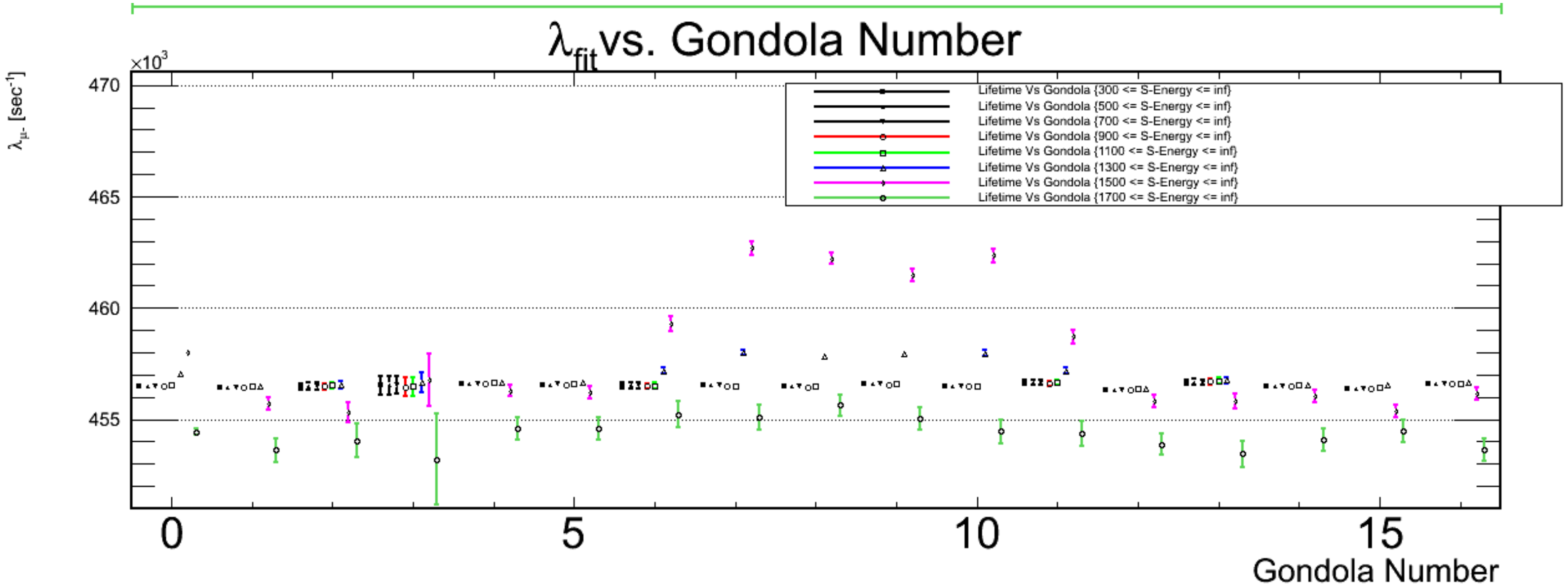




If the electron interferes with the muon stop threshold, we see a “gondola effect”, where the lifetime is enhanced for horizontal electrons and suppressed for up- or down-going electrons.

Mu+ Electron Interference

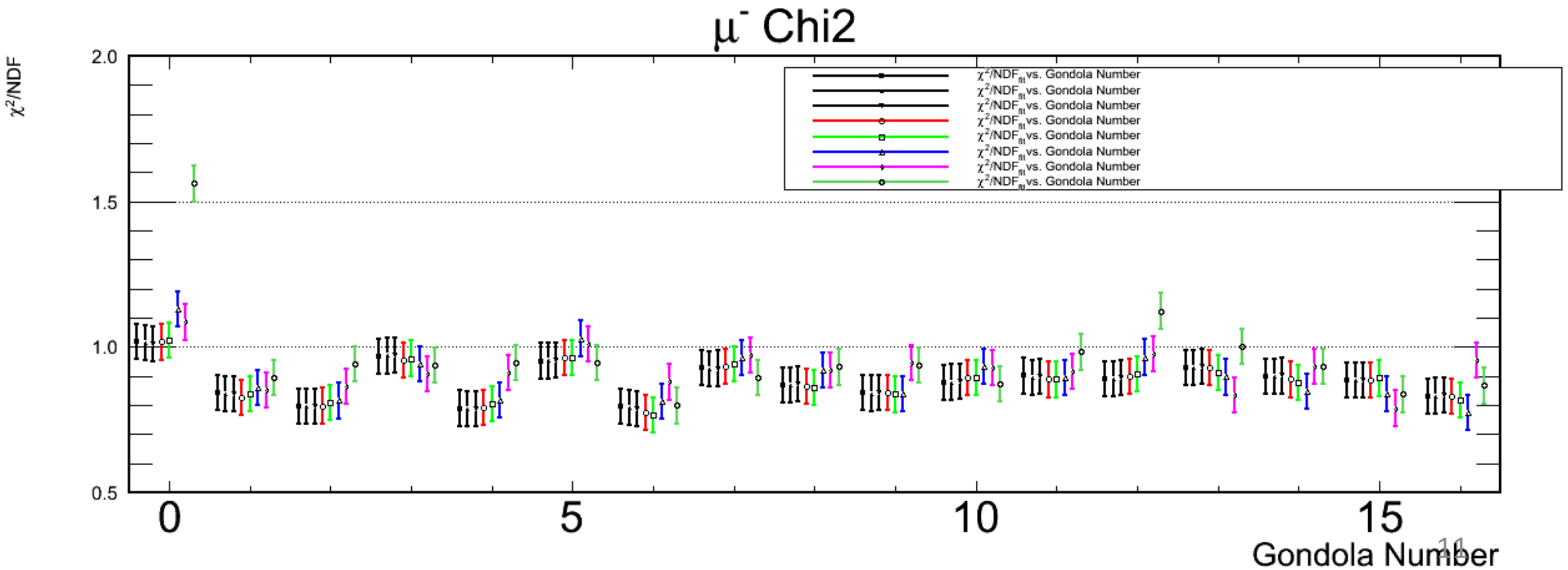




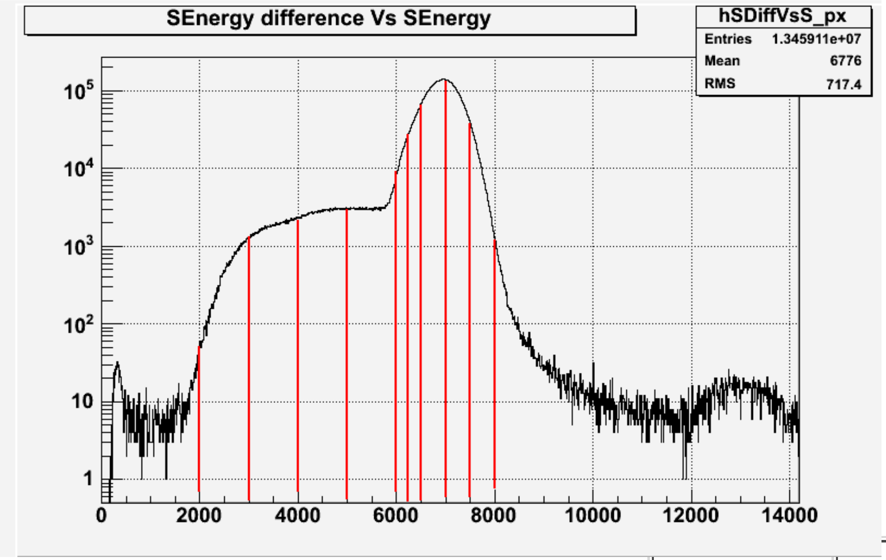
If we use a later start time, the effect is confined to downward-going electrons.

Start time 2000ns

(gondolas 6-11)



Mu+ Electron Interference



However, Xiao looked at MC data with the electron energy deposition turned off and on, comparing the lifetime shift.

These shifts could matter for mu-, but not so much for the 30 s^-1 error bar on mu+.

(Xiao uses run6 data for this, so the Senergy gain is different)

S cut (ch)	**WI Lambda (Hz)**	Chi2/NDF	error (Hz)	**WO Lambda (Hz)**	Chi2/NDF	error (Hz)	**delta lambda (Hz)**	**error(Hz)**
2000	**454605.5**	165.4	1.098	**454606.2**	164.8	1.100	**-0.6**	**13.5**
3000	**454614.6**	165.2	1.103	**454611.2**	165.2	1.105	**3.4**	**0.7**
4000	**454617.6**	166.3	1.113	**454610.9**	166.3	1.117	**6.7**	**0.7**
5000	**454595.5**	168.0	1.094	**454586.3**	168.0	1.097	**9.3**	**1.1**
6000	**454618.4**	170.3	1.088	**454582.7**	170.3	1.091	**35.7**	**2.2**
6250	**454778.1**	173.4	1.096	**454626.5**	173.3	1.101	**151.6**	**2.9**
6500	**455176.0**	182.3	1.065	**454758.5**	182.4	1.076	**417.6**	**4.7**
7000	**457346.6**	263.8	1.123	455338.0	265.4	1.122	**2008.6**	**29.7**
7500	**463553.0**	763.7	1.148	**458938.9**	779.3	1.143	**4614.1**	**155.1**
8000	**480382.1**	382.3	0.813	**473339.1**	402.2	0.801	**7043.0**	**1248.0**

Mu+ Electron Interference

Summary

- S-Energy cut scan can “turn on” the gondola effect from electron interference
- With mu+, the shifts are undetectable for all but the highest cuts, indicating that the electron interference is small. (For mu+ error bars of 30-100 sec^-1 per gondola bin)
- This is only considering the energy of the track. In principle, electrons could extend tracks to pass other cuts (eg. length) with higher probability.
- Xiao’s studies indicate that the effect is small but not necessarily negligible. A more in-depth study is warranted.

Mu- Lifetime Scans

Mu+ does **not** show stability with the geometric scans.

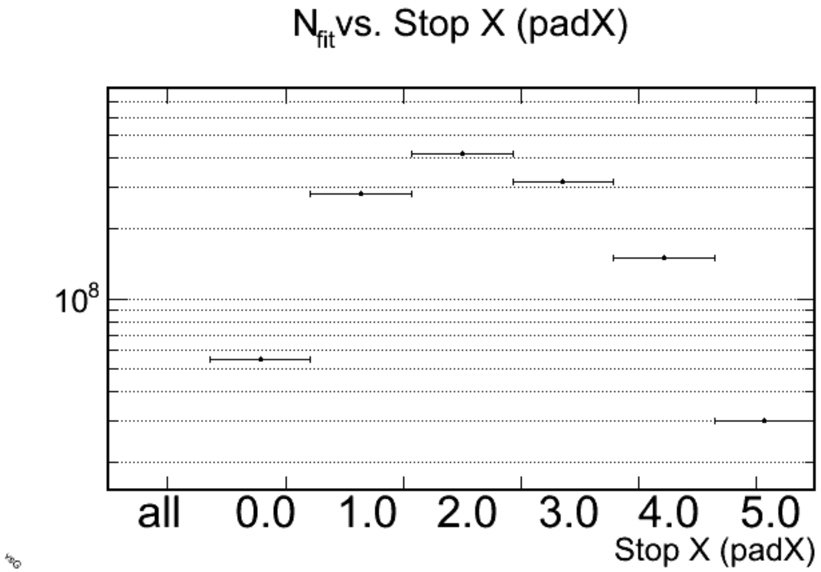
Mini pulse template fitter, and the basic clustering tracking algorithm (explained in a few slides).

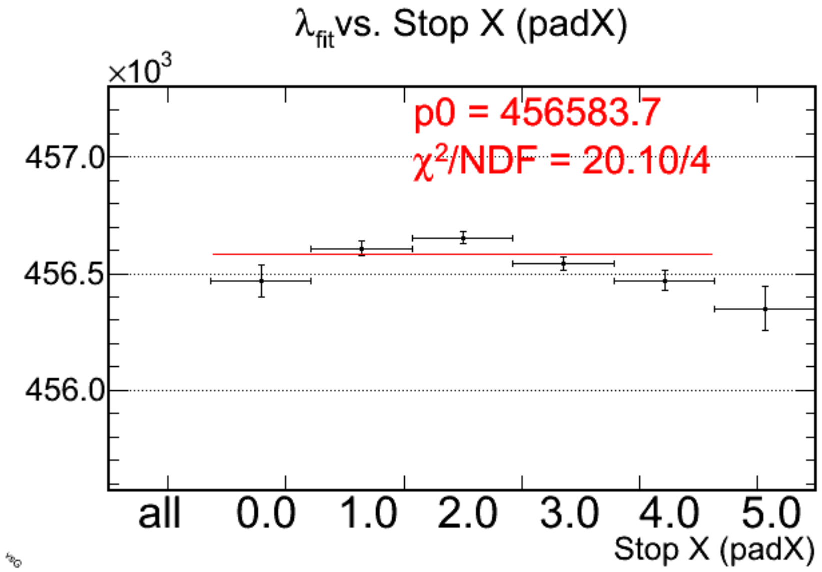
Standard cuts are

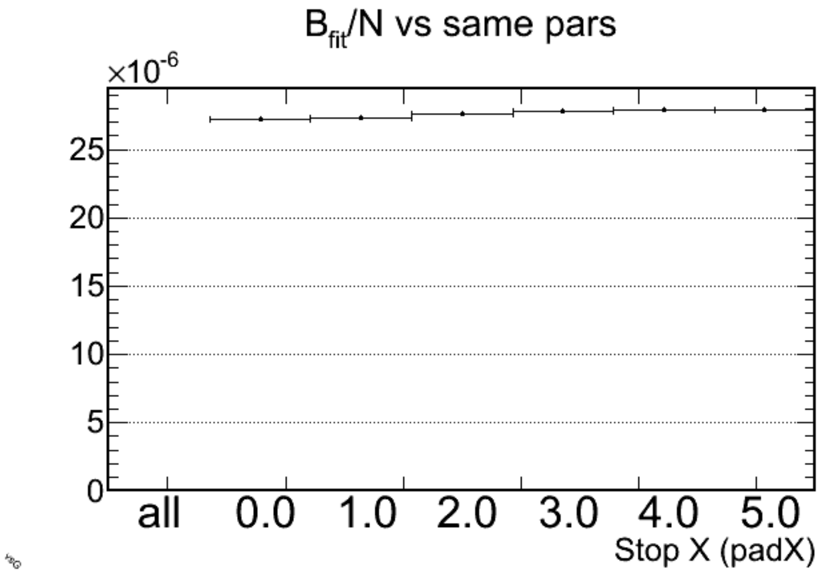
- Track length >= 3 pads
- Track S-Energy > 450 keV (or 300 ch)
- Track stop is in fiducial volume (exclude border pads, 15mm < Y < 55mm)
- Impact parameter < 90mm

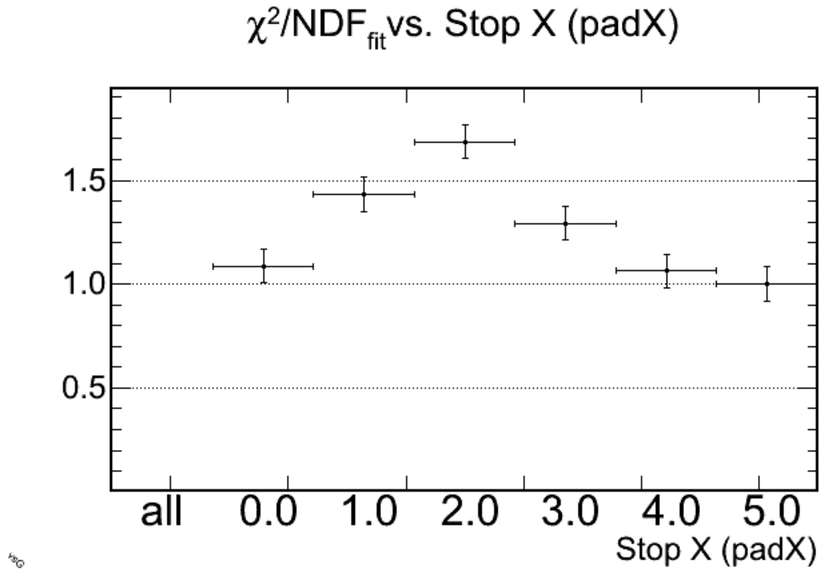
Fit start time 160ns, stop time 24000ns

Mu- fitting : Lifetime vs Stop X

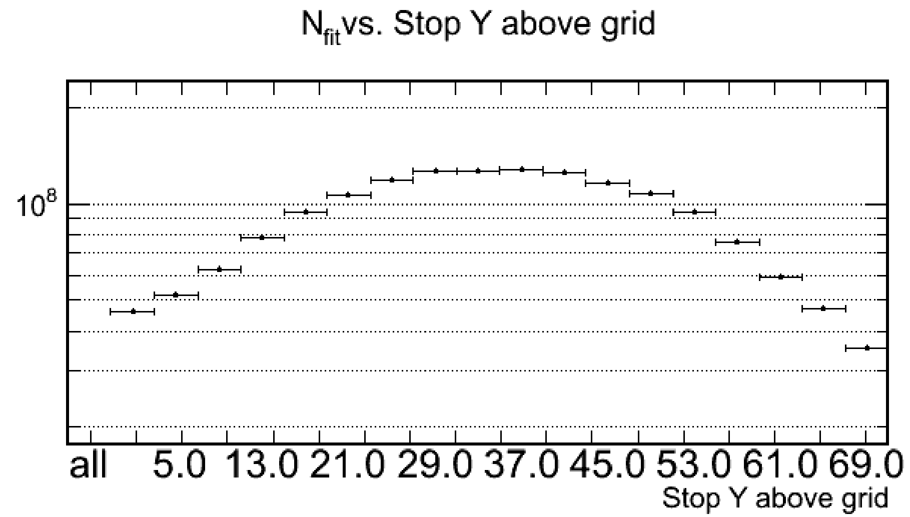


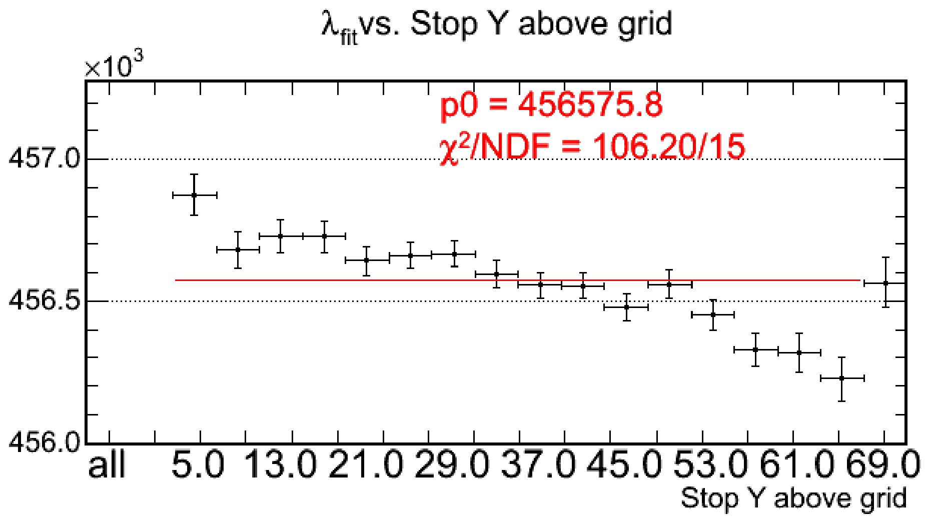


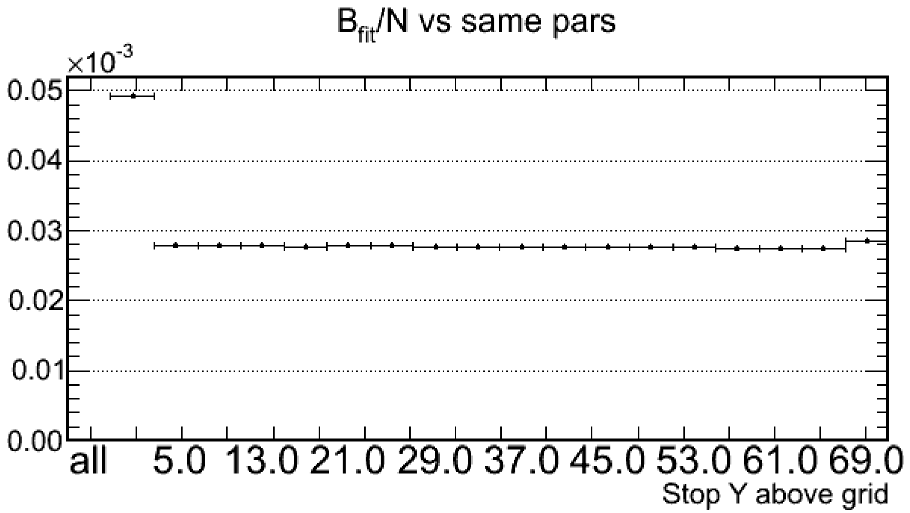


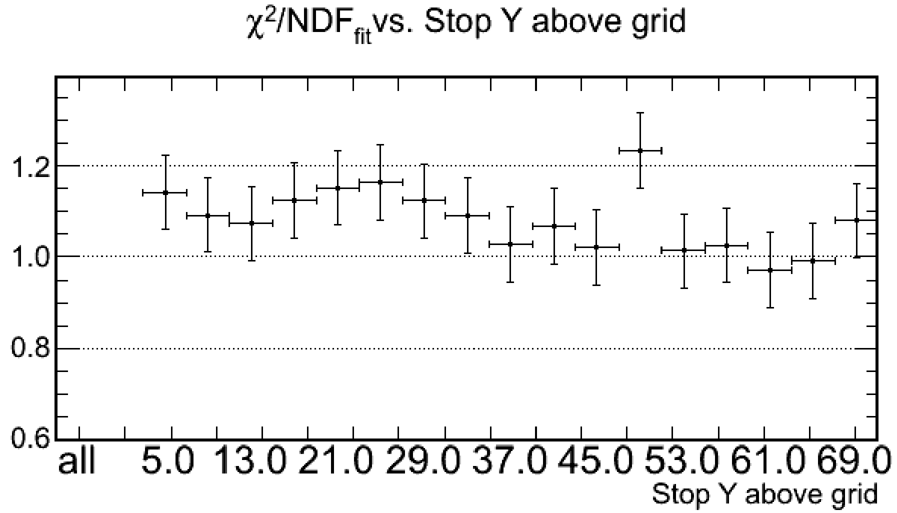


Mu- fitting : Lifetime vs Stop Y

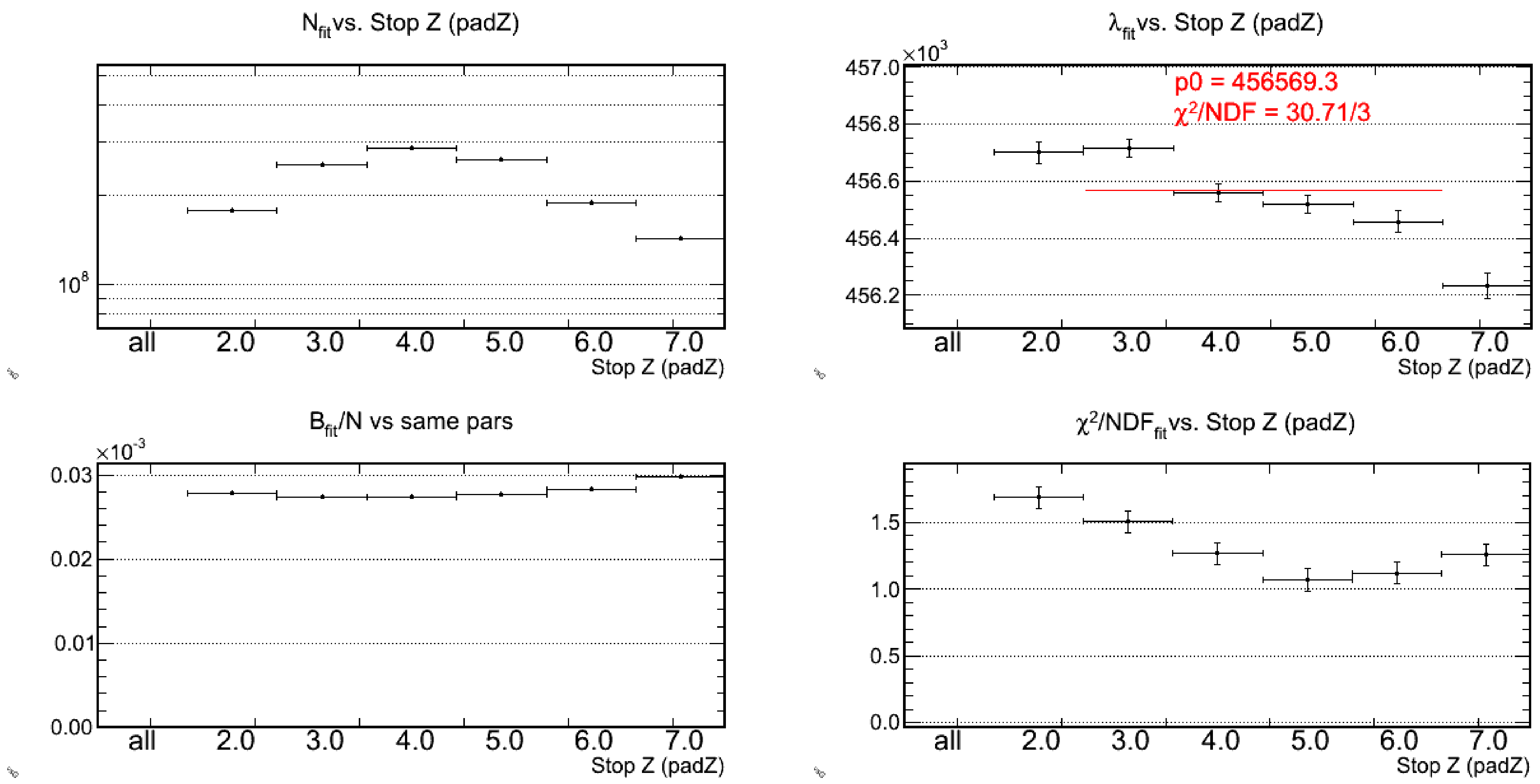




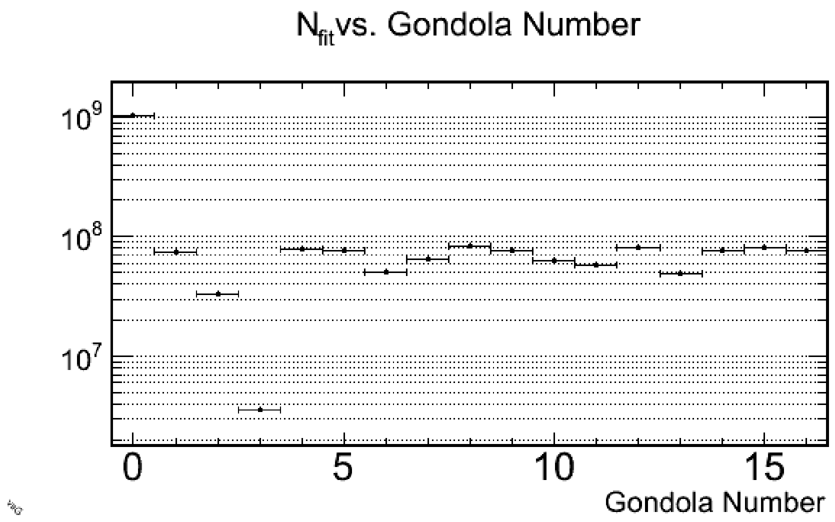


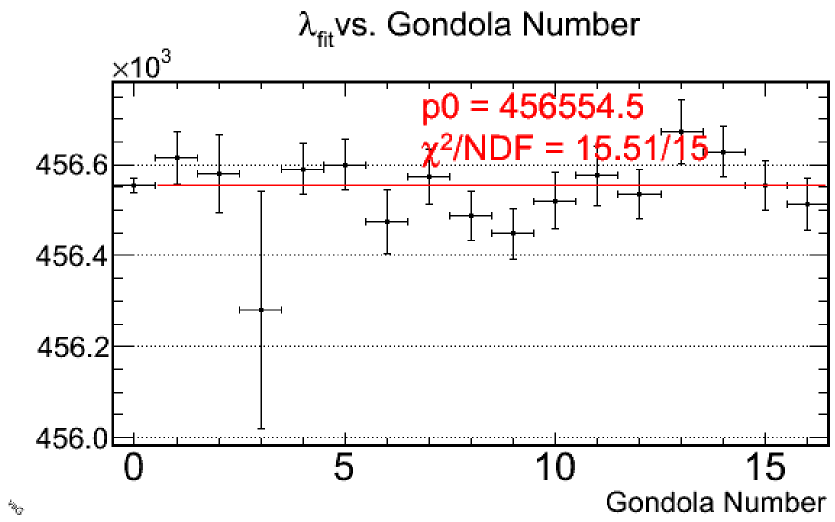


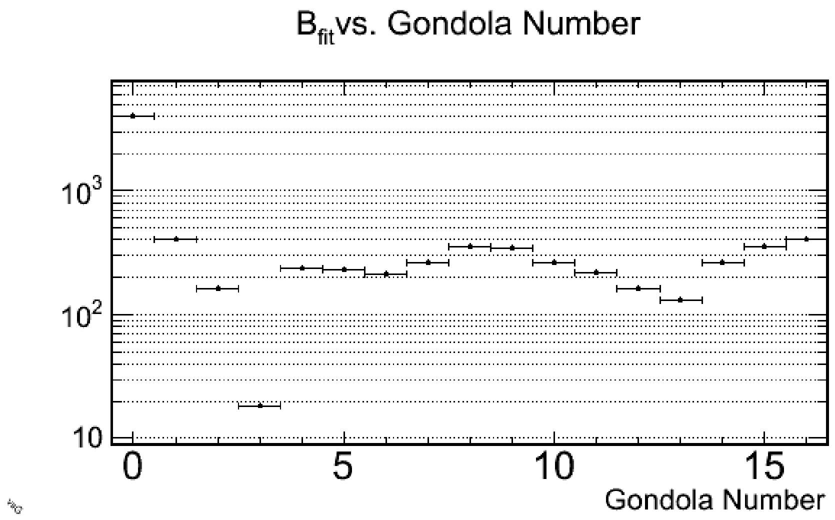
Mu- fitting : Lifetime vs Stop Z

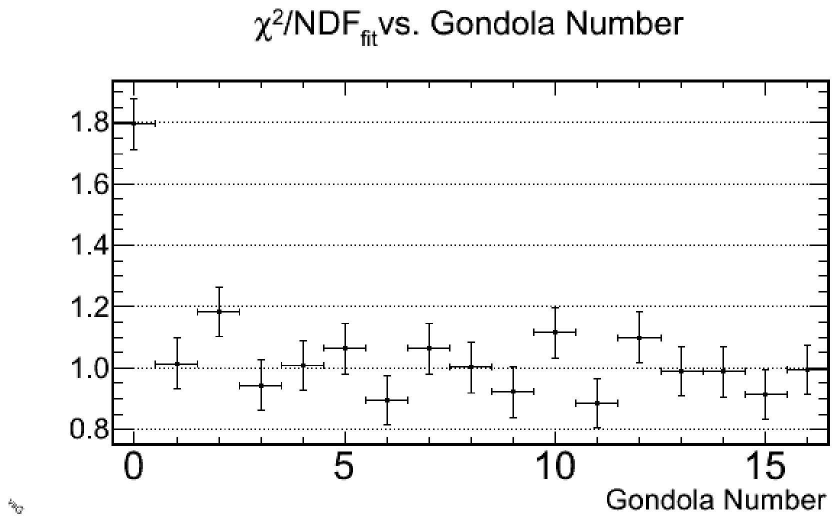


Mu- fitting : Lifetime vs Gondola

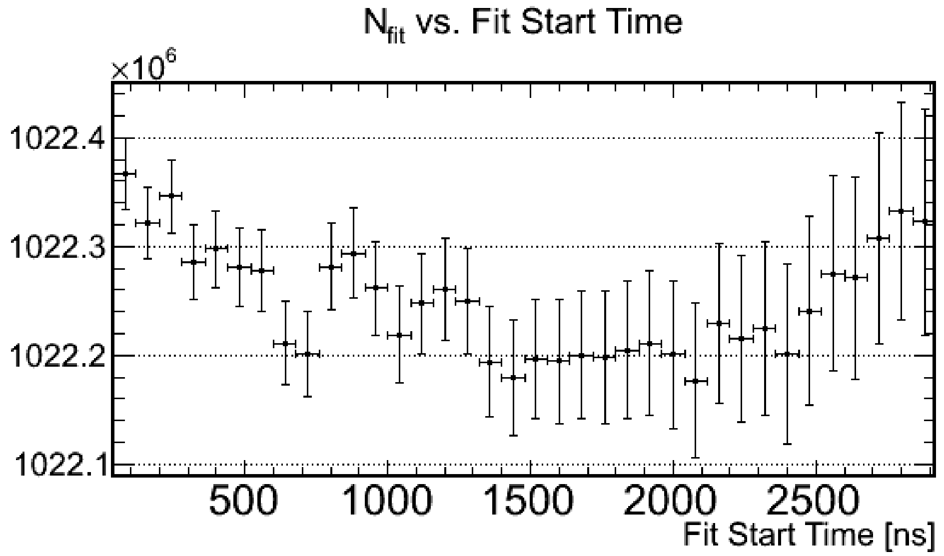


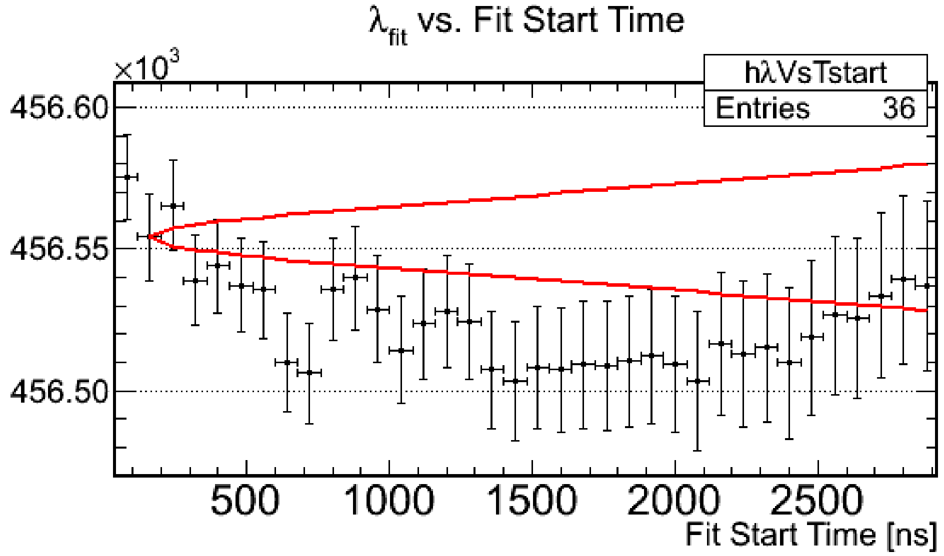


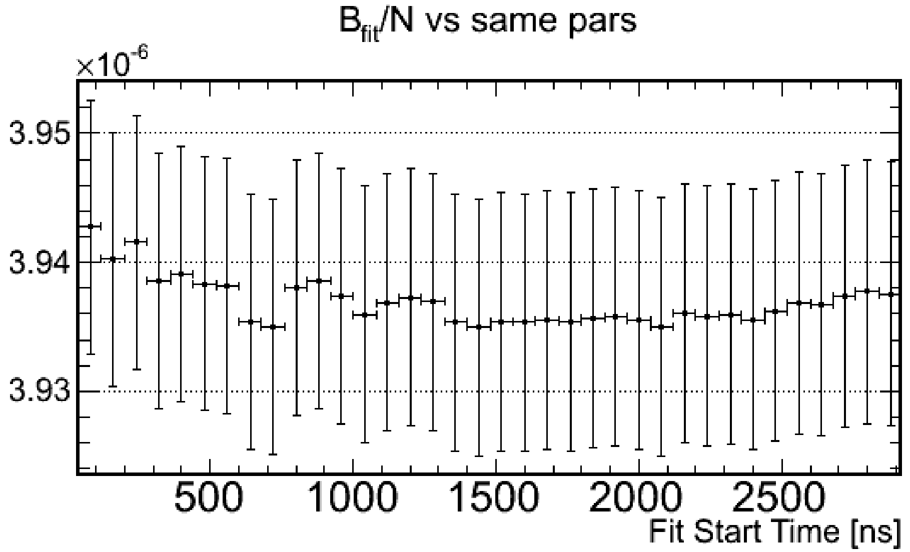


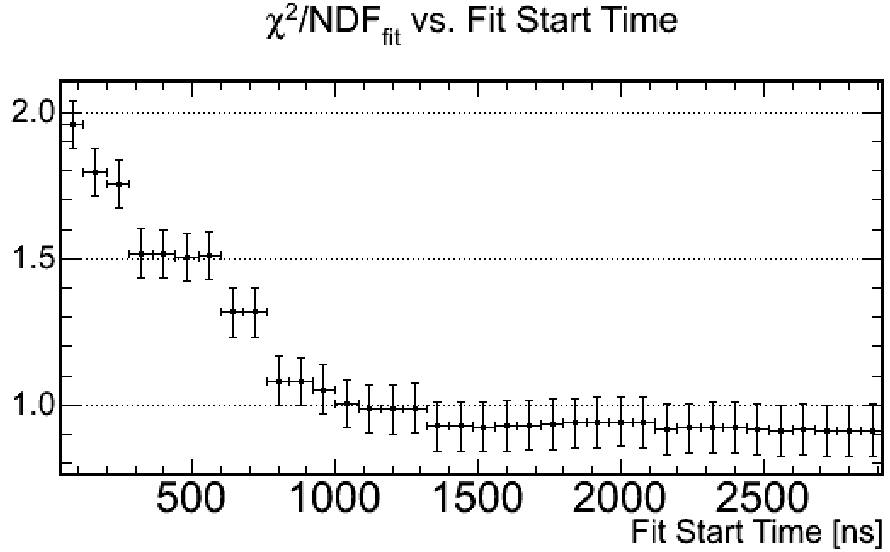


Mu- fitting : Start time scan



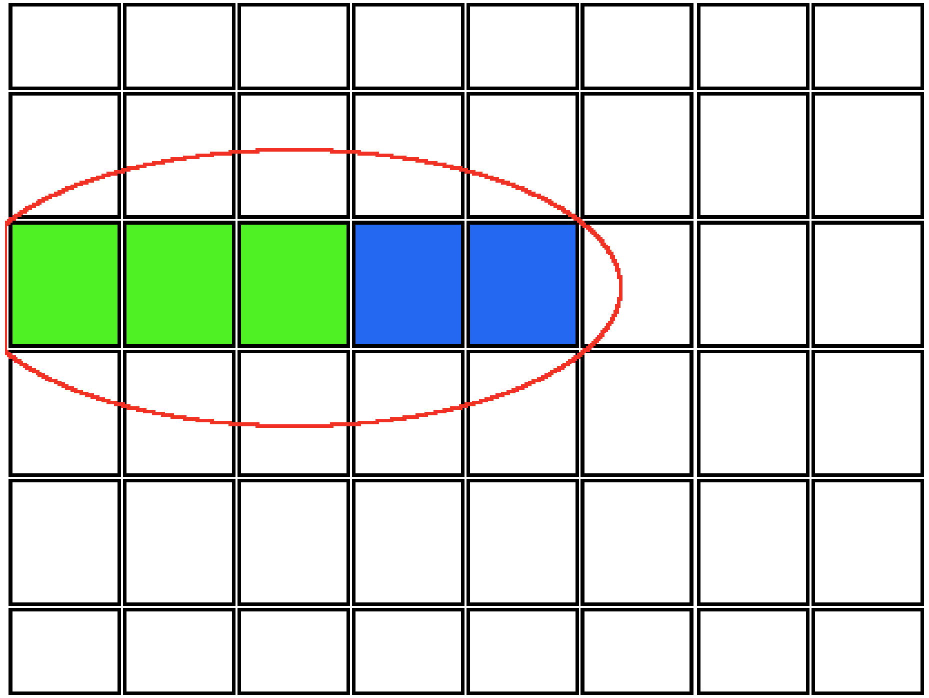




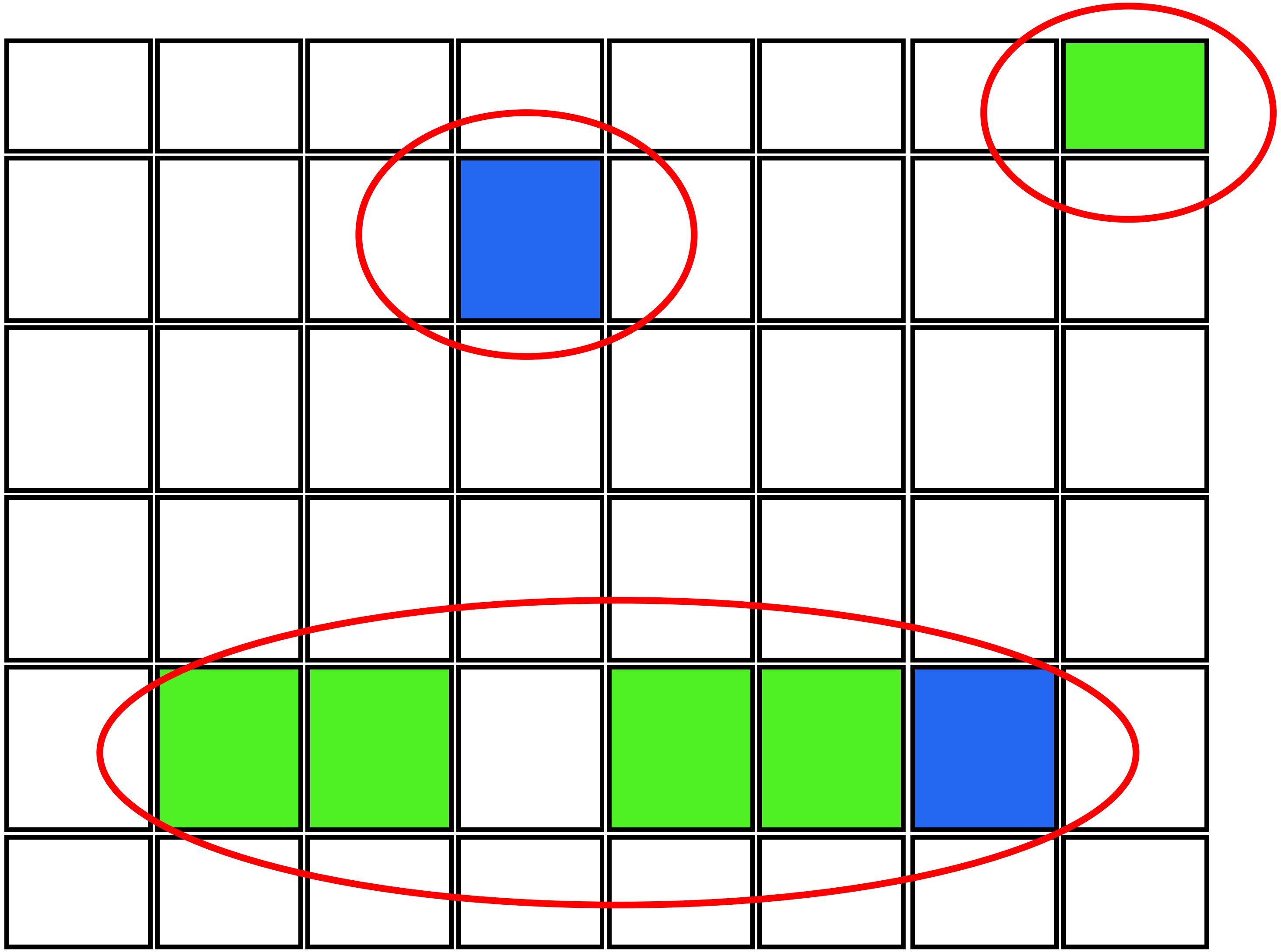


TPC Basic Cluster Tracking

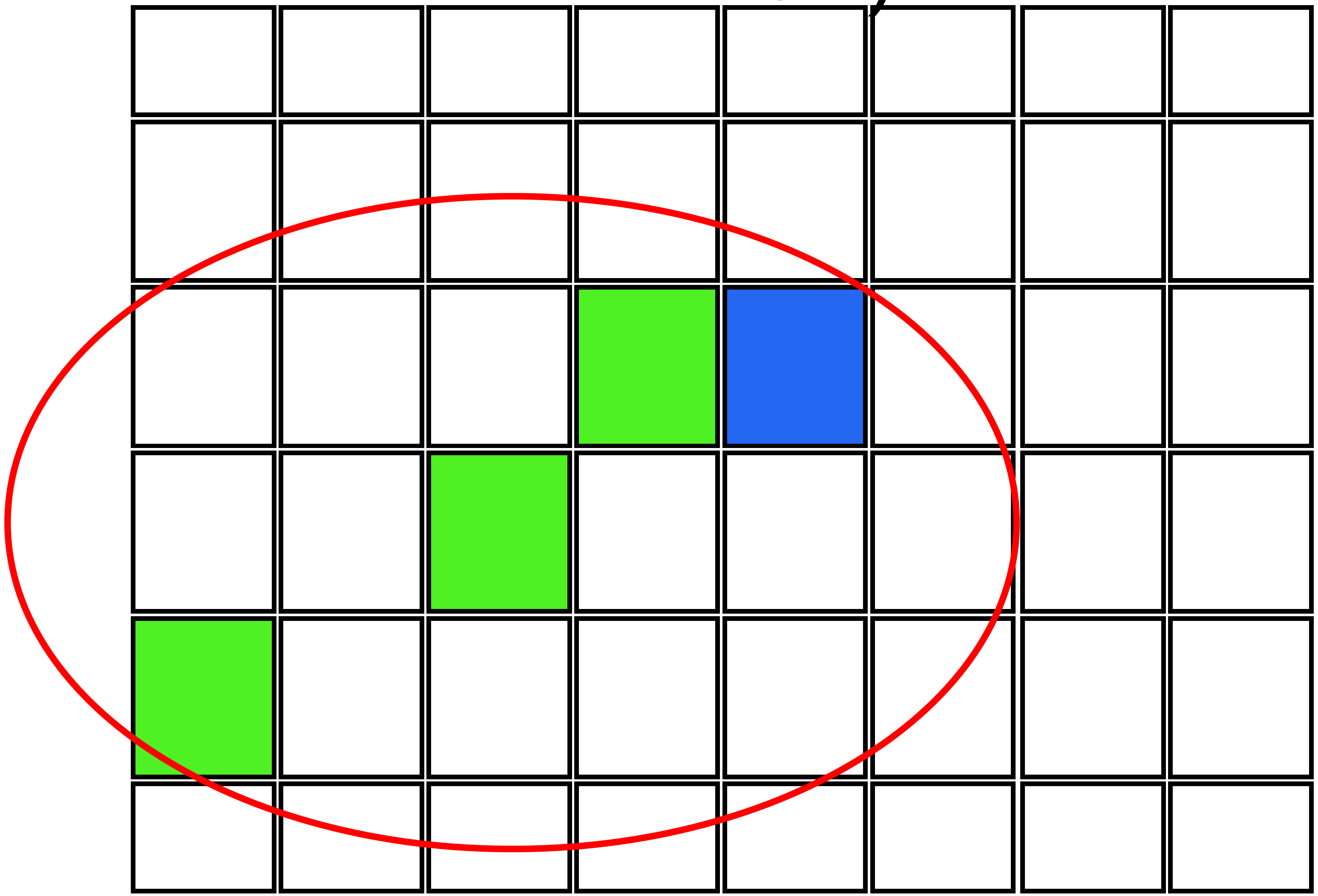
- Form **clusters** from TTPCMiniPulses (or other pulses)
  - Distance to nearby pulses
    - $\Delta X \leq 1$ pad
    - $\Delta Z \leq 2$ pads (one gap allowed)
    - $\Delta Y \leq 2\mu s$ (= 1cm)
  - S-Energy > 440 keV
  - Length >= 3 pads



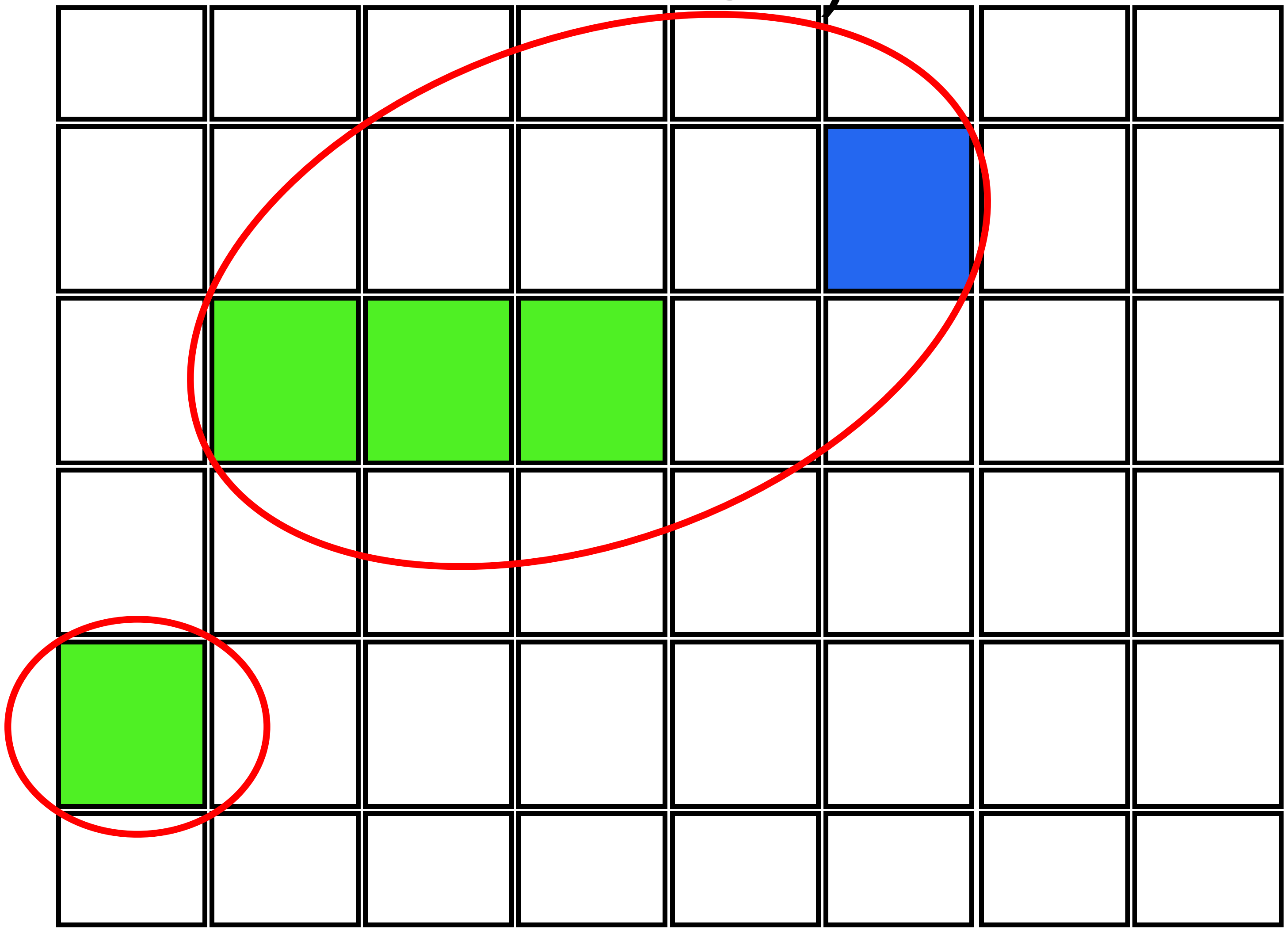
$\Delta X \leq 1 \quad \Delta Z \leq 2 \quad \Delta Y \leq 2\mu s\ (= 1cm)$



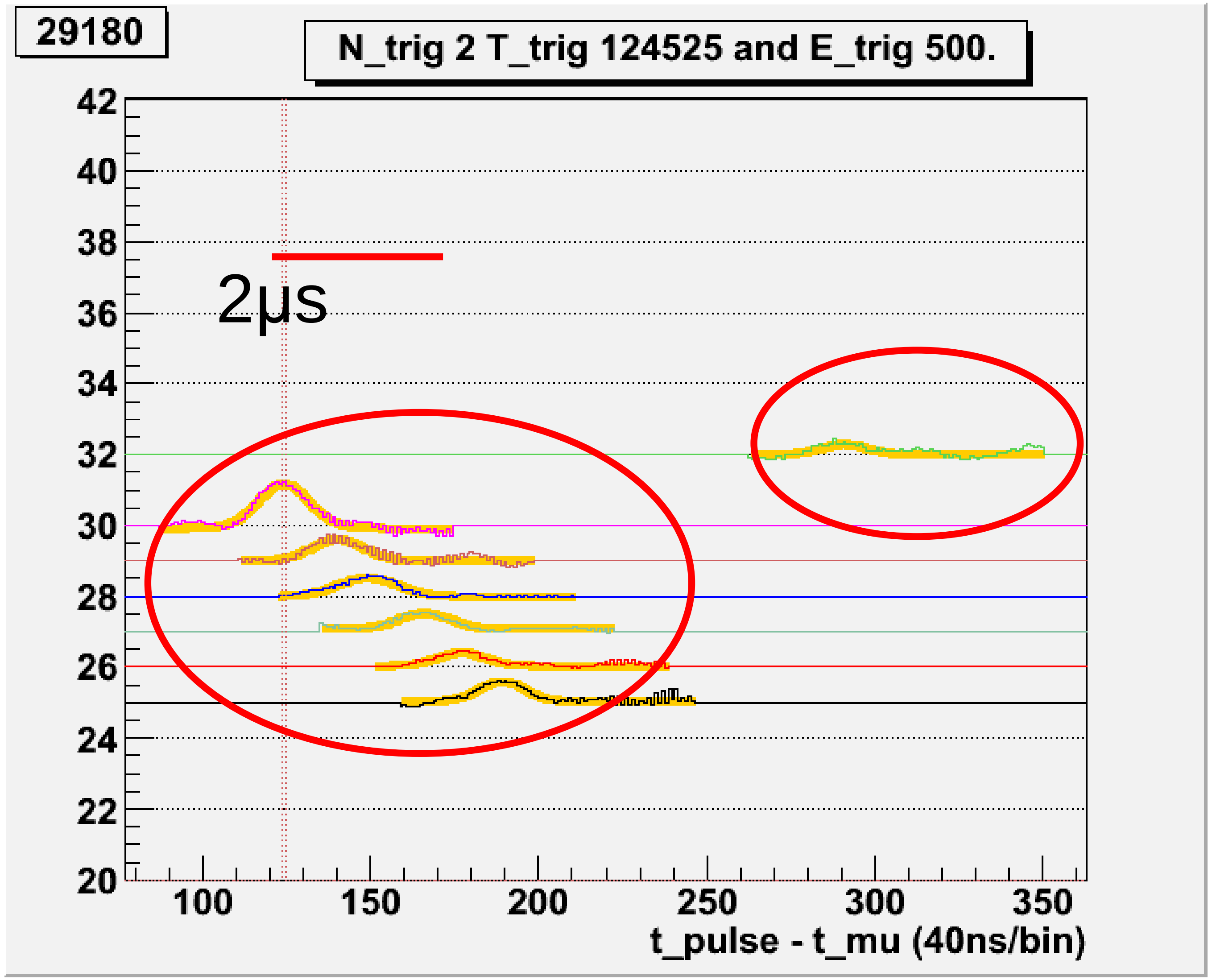
□$\Delta X \leq 1 \quad \Delta Z \leq 2 \quad \Delta Y \leq 2\mu s$ (= 1cm)



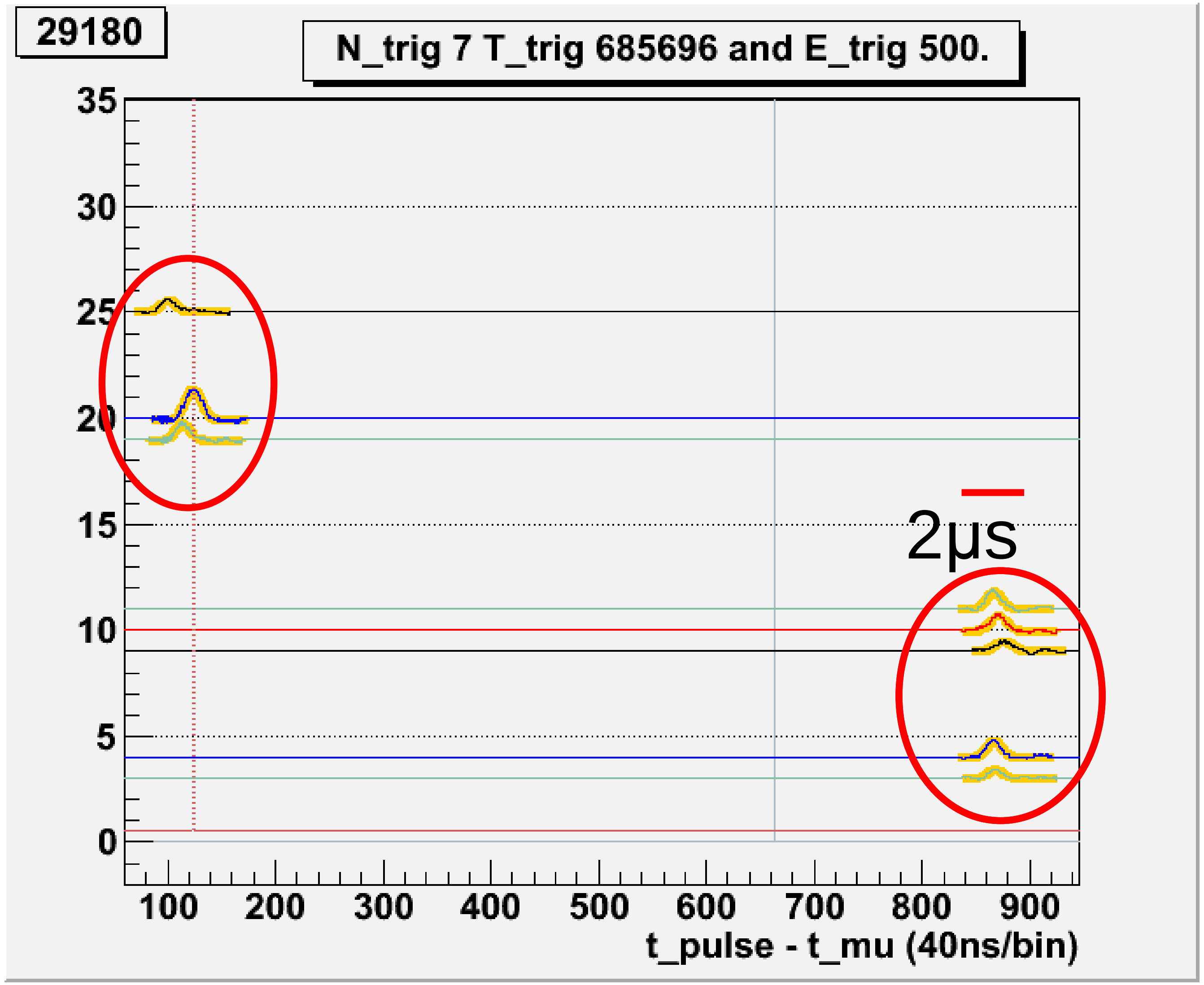
□ΔX ≤ 1   ΔZ ≤ 2   ΔY ≤ 2μs (= 1cm)



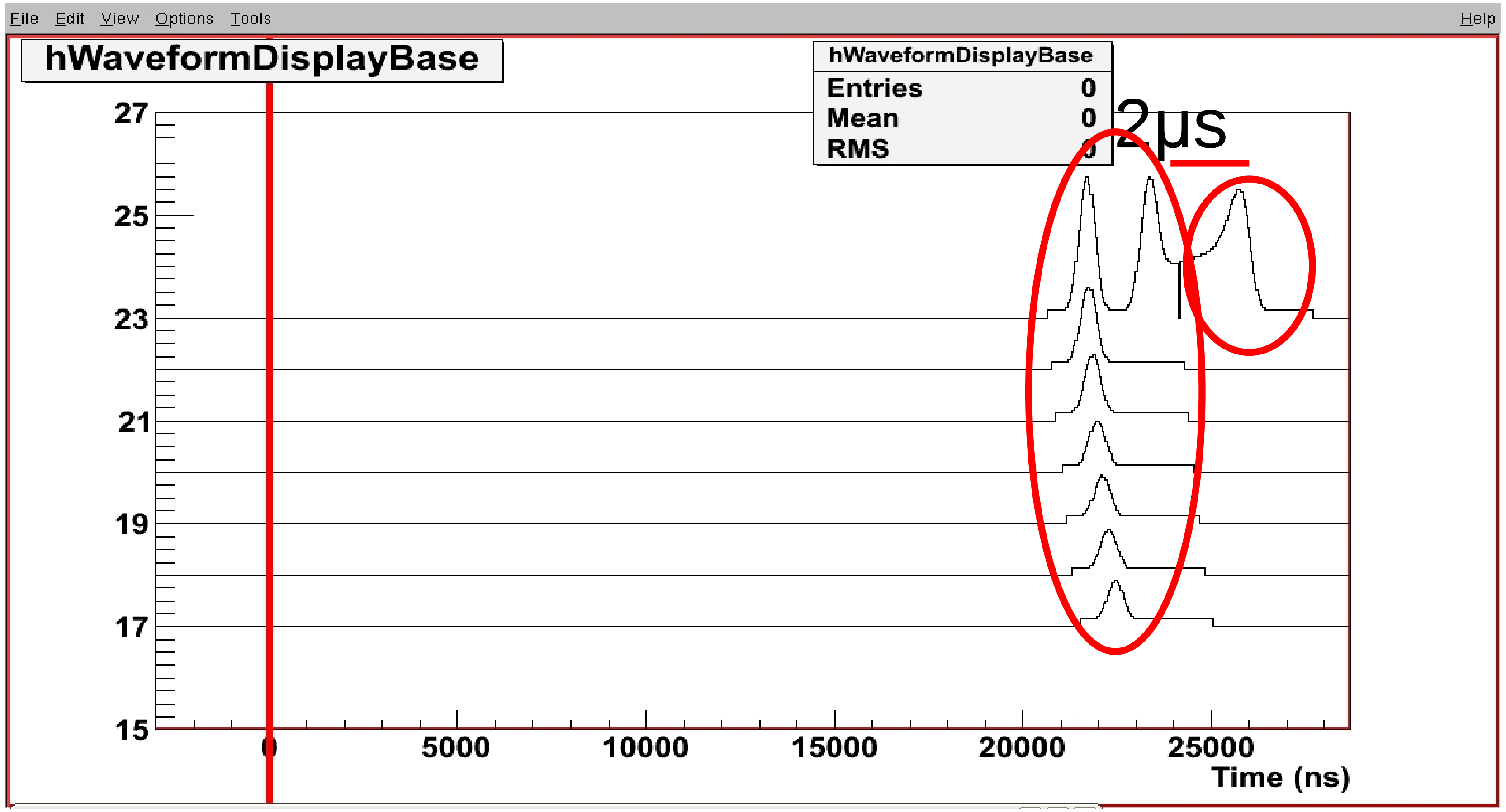
$\Delta X \leq 1 \quad \Delta Z \leq 2 \quad \Delta Y \leq 2\mu s$ (= 1cm)



ΔX ≤ 1 ΔZ ≤ 2 ΔY ≤ 2μs (= 1cm)

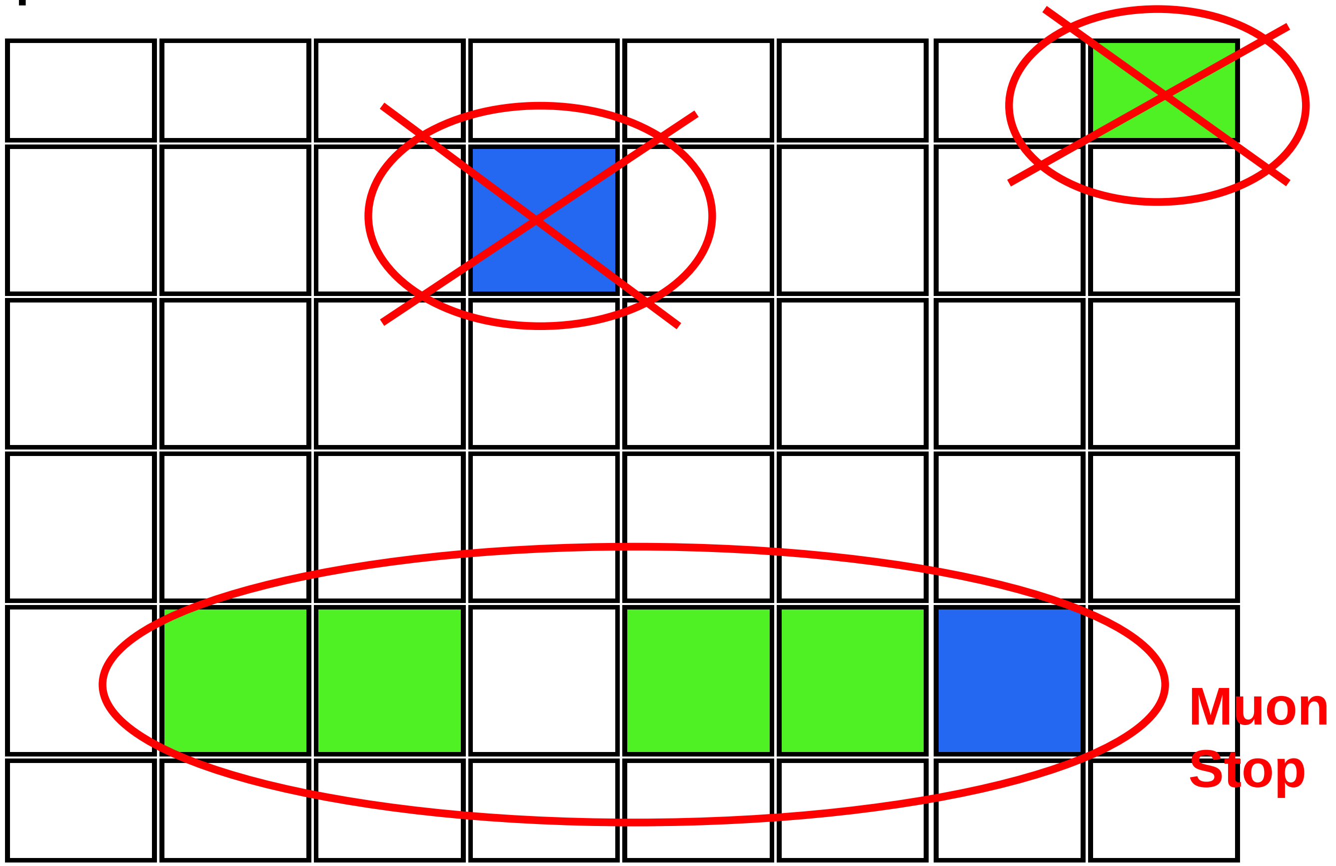


$\Delta X \leq 1 \quad \Delta Z \leq 2 \quad \Delta Y \leq 2\mu s\ (= 1cm)$

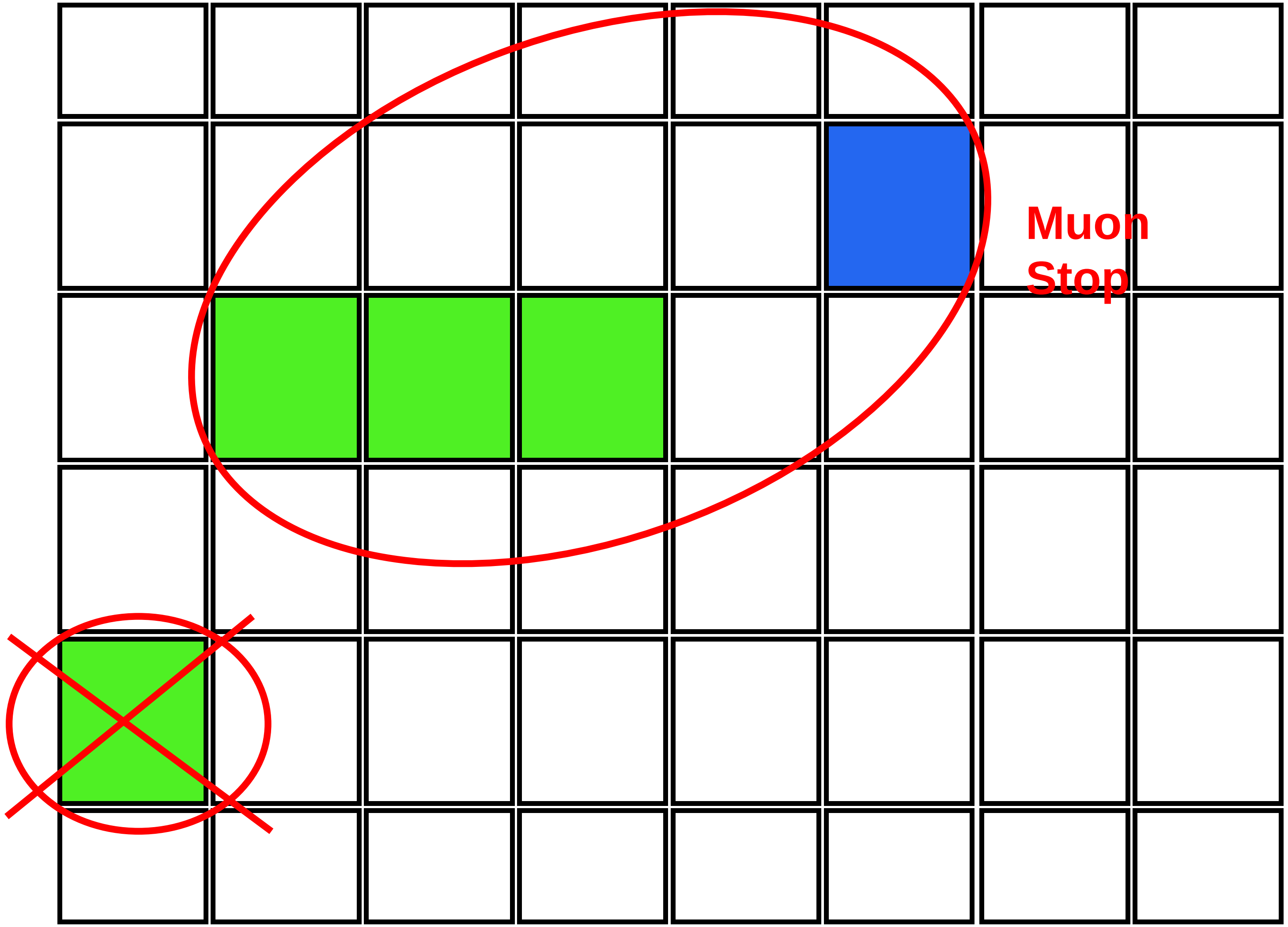


TPC Muon Stop

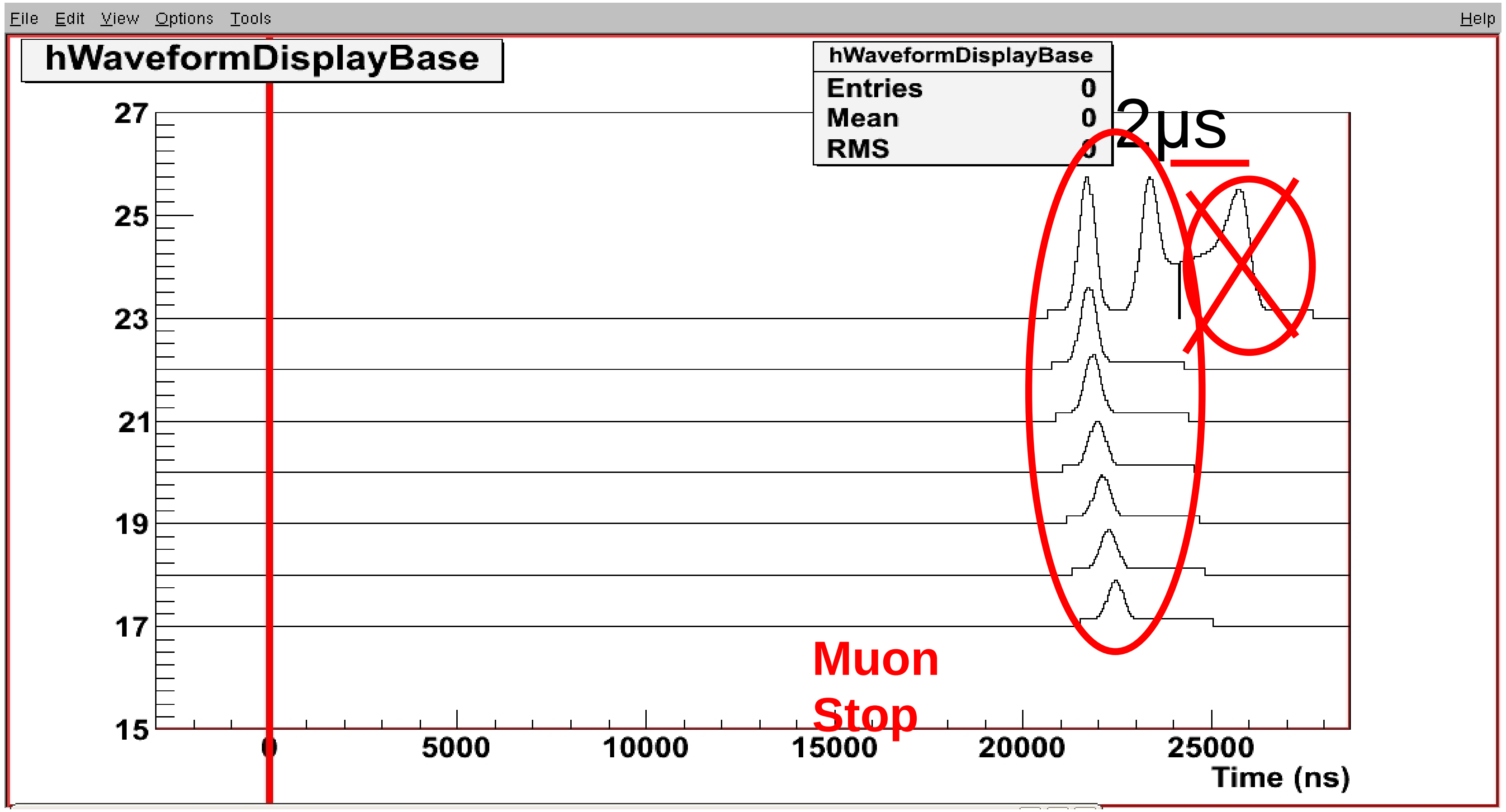
- **Stops** are a more fluid definition. Currently:
- A cluster with (Length in Z) > 2 is defined as a muon stop.



Muon Stop = Length in Z > 2

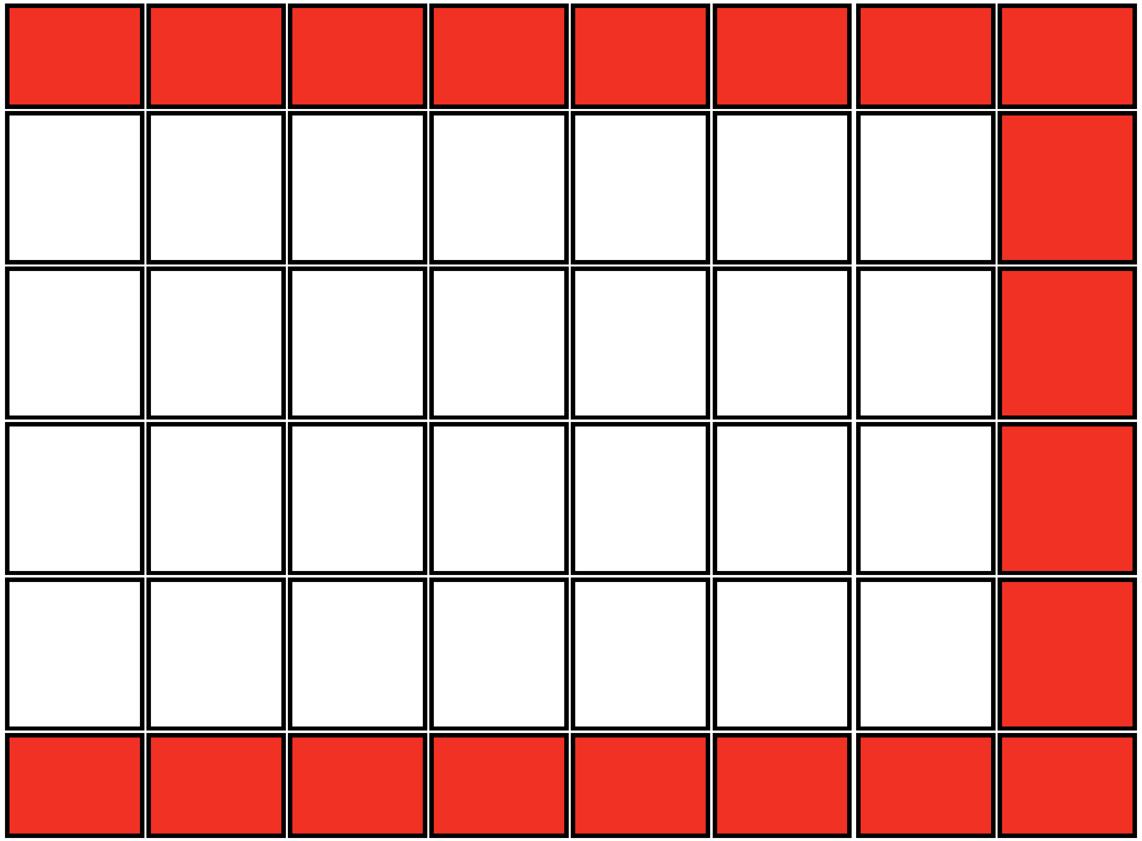


Muon Stop = Length in Z > 2



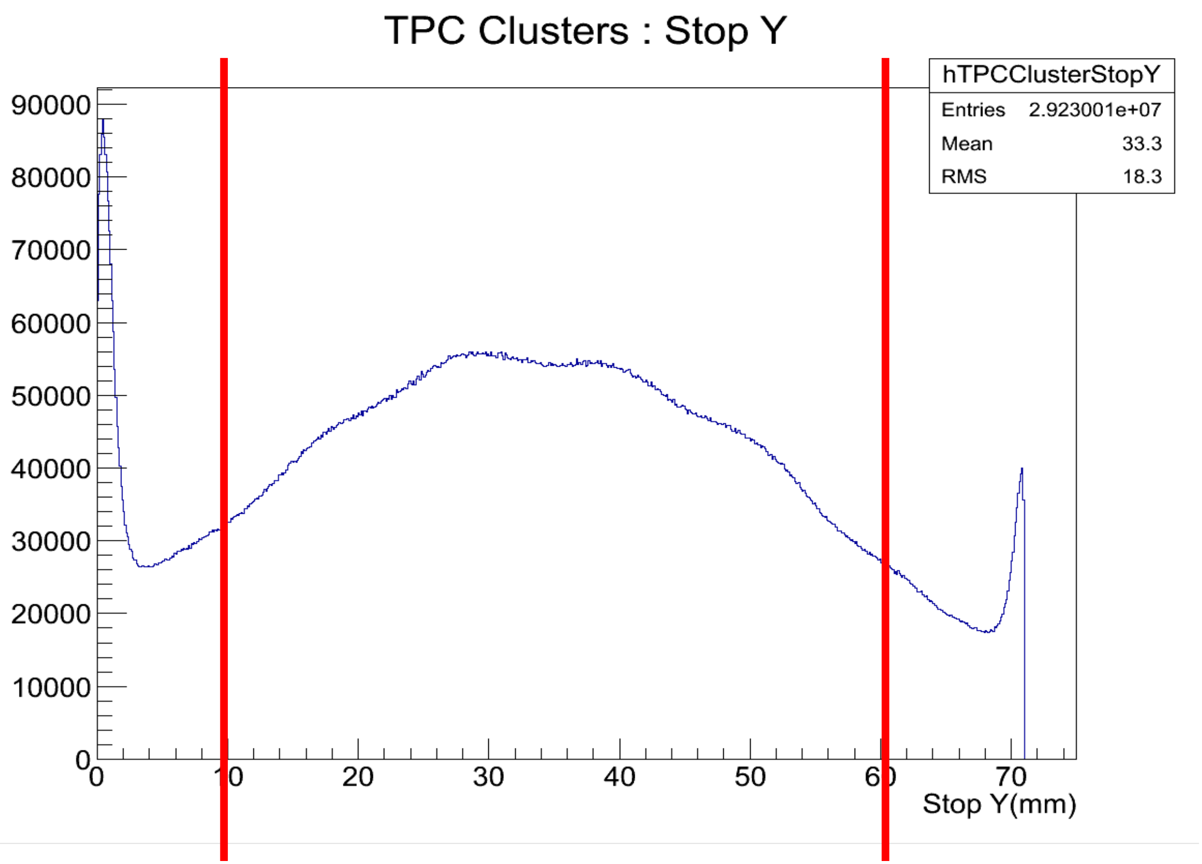
TPC Fiducial Volume

- The **fiducial volume** cut is given by the border pads in X and Z.



TPC Fiducial Volume

- Drift times between 2us and 12us (10mm and 61mm) are the fiducial volume Y-cut
- This cut is much easier to scan, since our resolution is better.

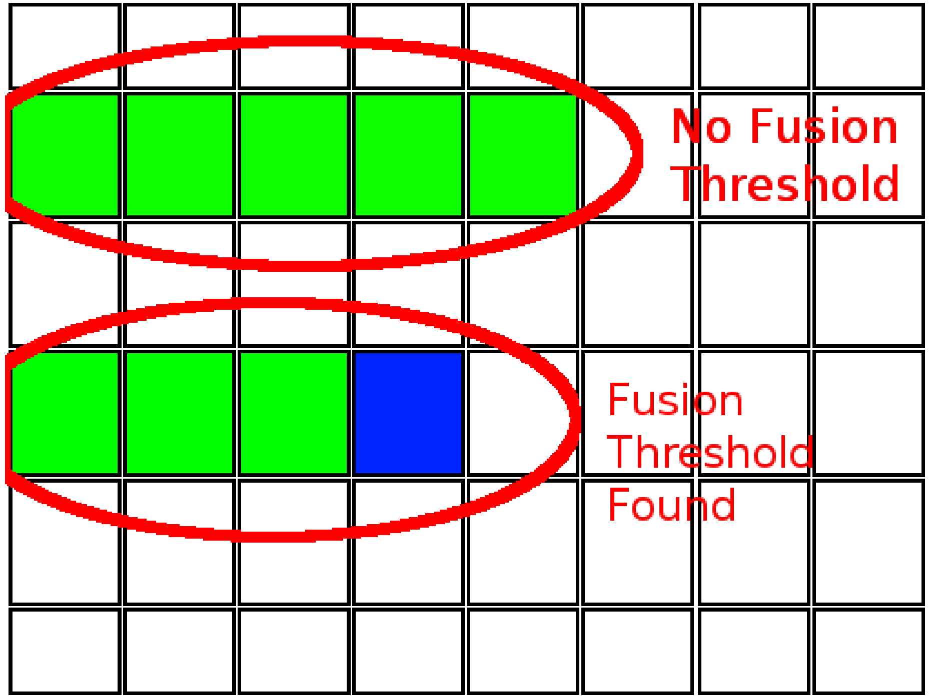


Alternate tracking: TPC Road Tracking

- Form **clusters** from TPC Pulses (TTPCTOTPulse)
  - Distance to nearby pulses
    - ΔX ≤ 1 pad
    - ΔZ ≤ 2 pads (one gap allowed)
    - ΔY ≤ 1μs (edge-matching)
  - S-Energy > 440keV
  - Length >= 3 pads

  - Edge-matching : the leading (trailing) edge must be <1us from the trailing (leading) edge of the neighboring pulse.

Two Road tracks, one with the fusion threshold (blue pad), one without the fusion threshold.

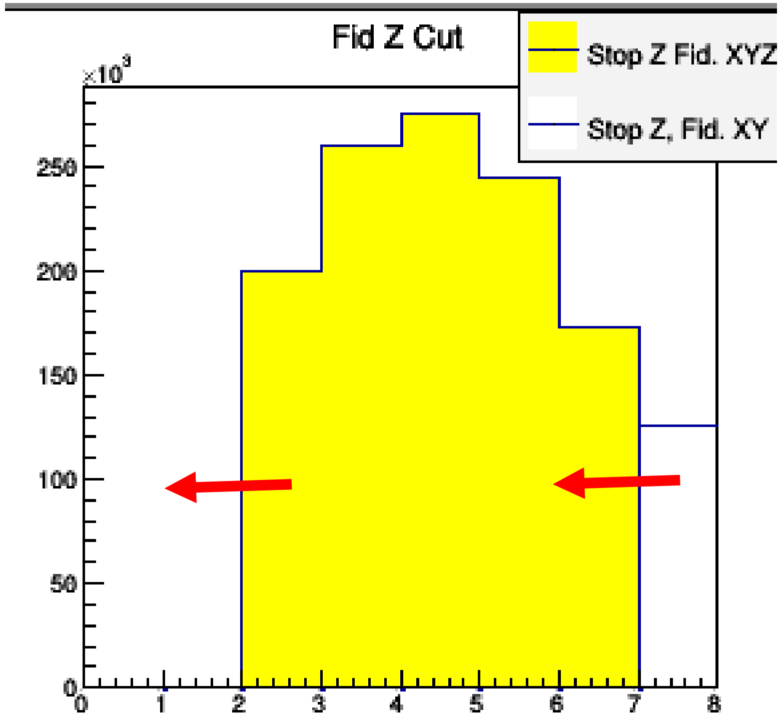


Motivation : Proton migrates one way

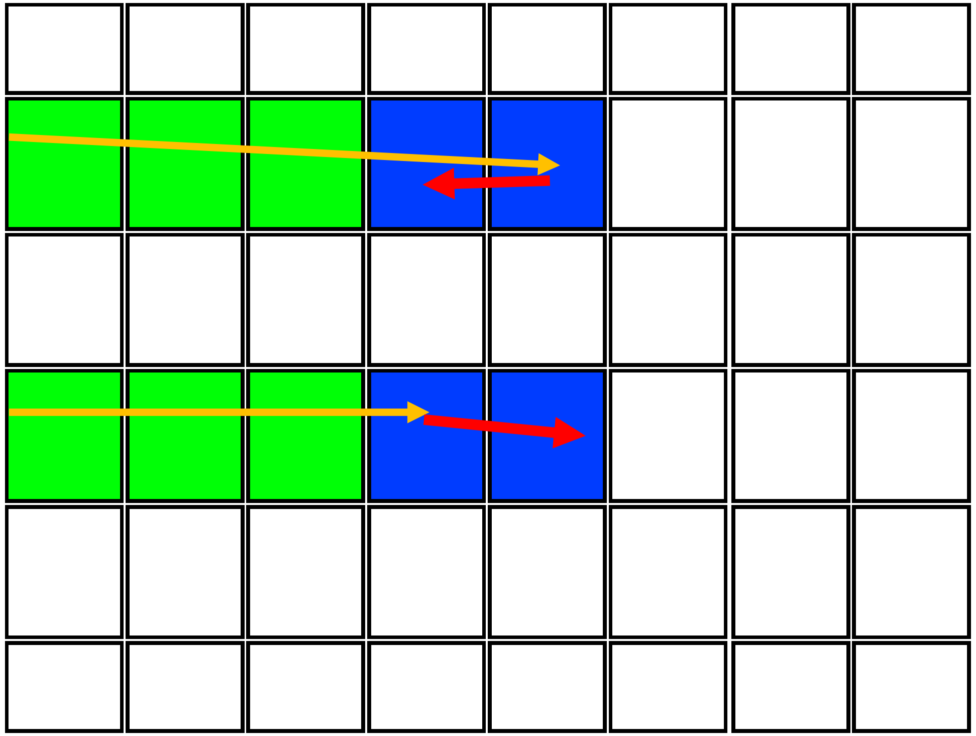
A proton can go forward or backward to confuse the stopZ.

The road tracker makes the stop Z determined from these situations identical (4th row in the diagram)

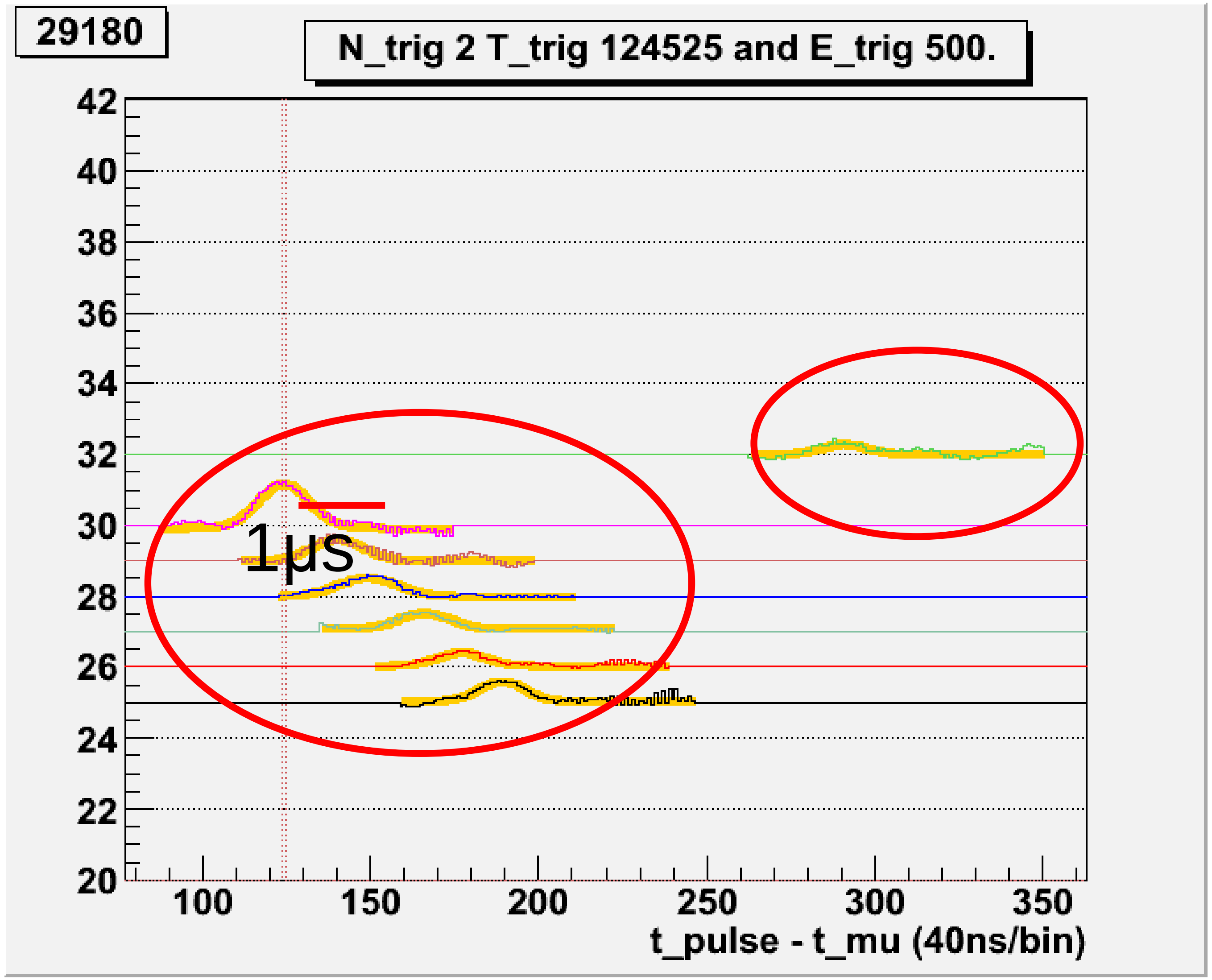
By managing the populations of events, we can balance the number of stops that migrate in and out of the fid. vol.



Two tracks with a p-t, triggering threshold, but with different stop Z. Proton in red, muon in orange.

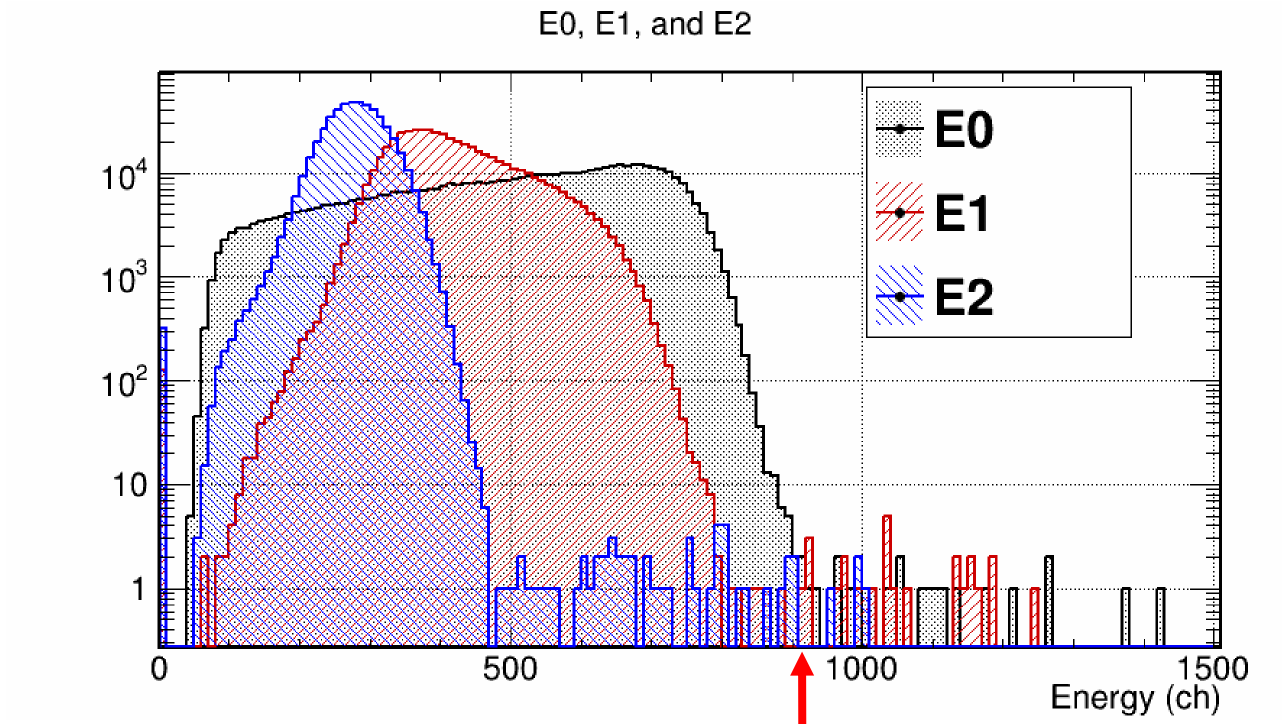


$\Delta X \leq 1 \quad \Delta Z \leq 2 \quad \Delta Y \leq 1\mu s$ (= 0.5cm)



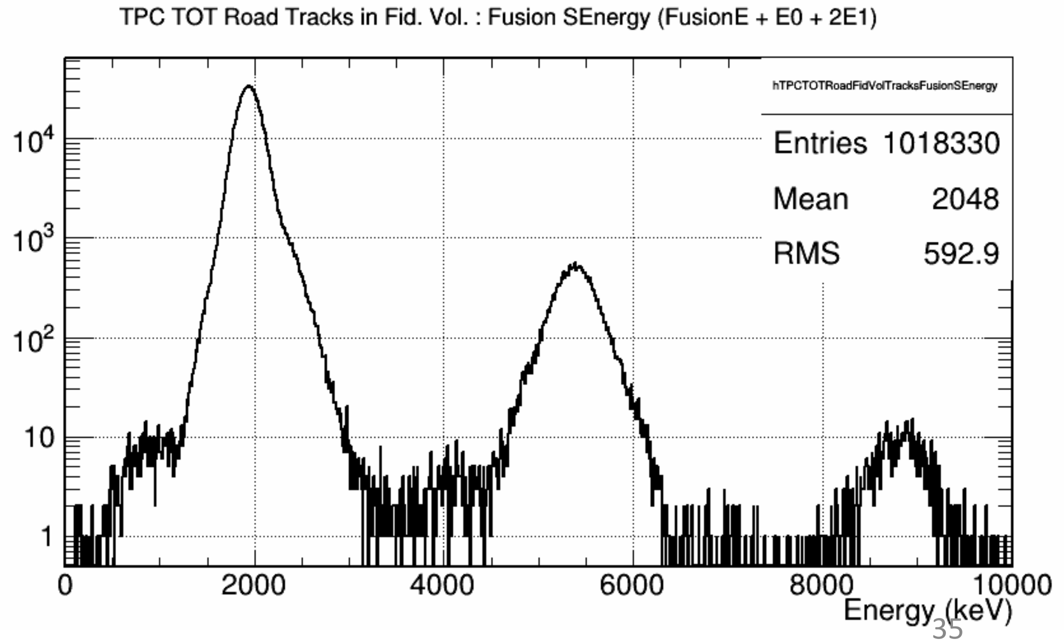
Road Track : Fusion Energy threshold

Upstream energies, mu+



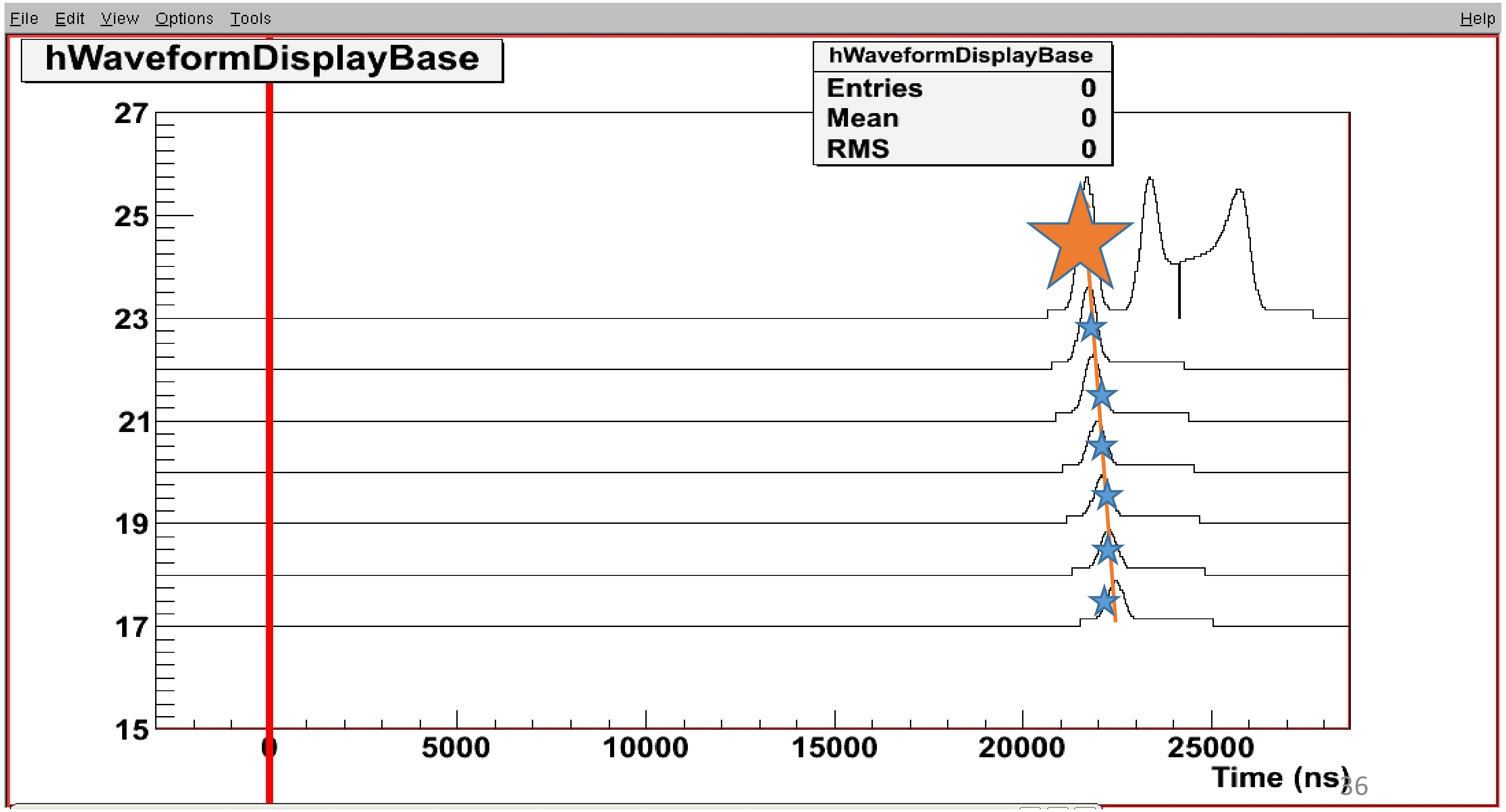
Fusion threshold

- The “fusion” energy threshold is chosen to be larger than the largest possible E0 for mu+.
- Ideally, only events with fusion products hit this threshold.
- In practice, pileup might sneak in, and fusion products might alter E0 but stay under threshold.



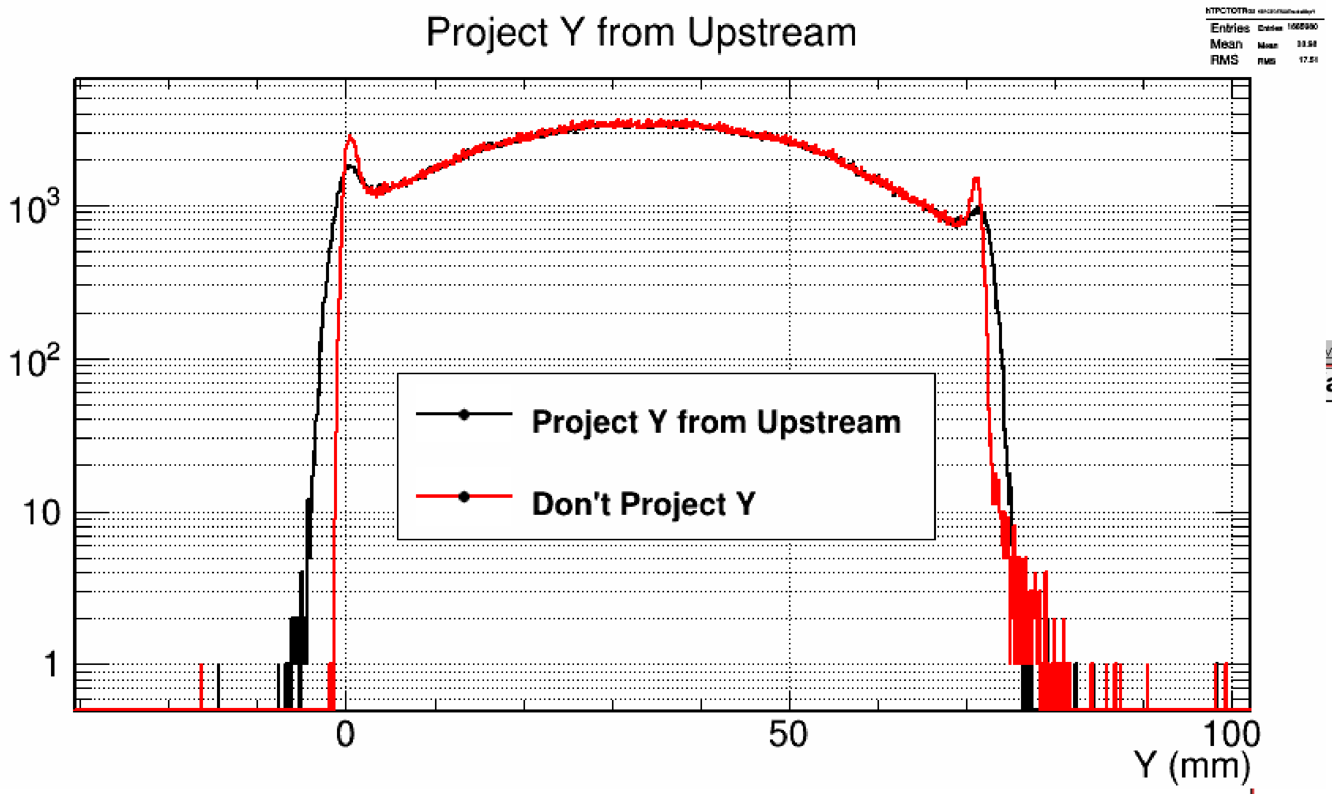
Road tracking : Projection for Y coord.

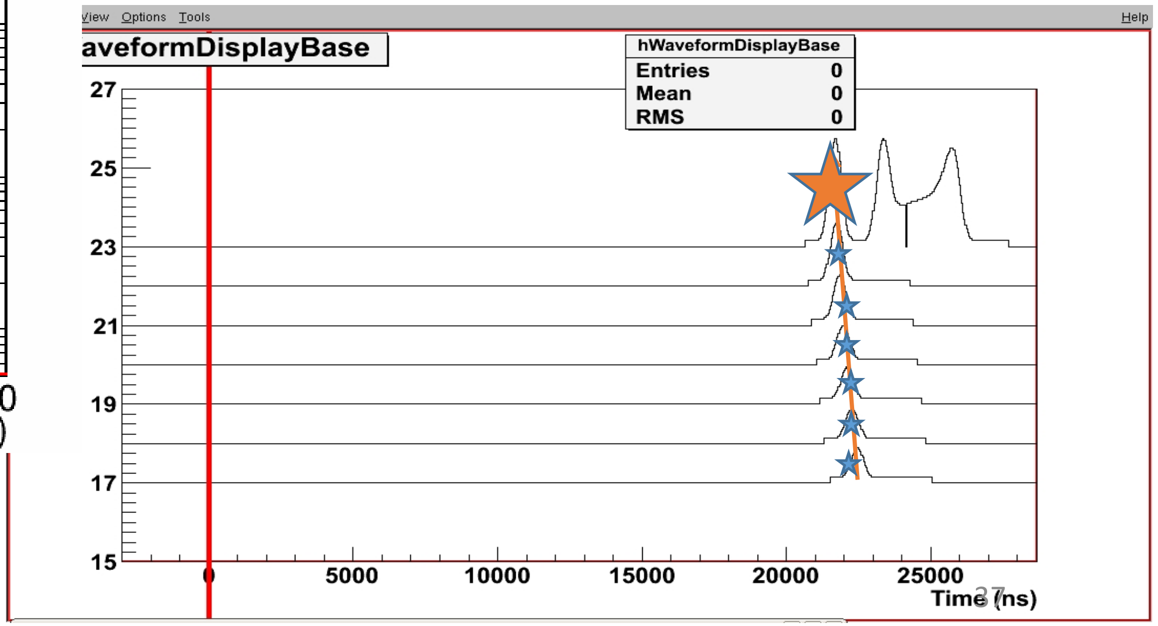
Project the upstream pads into the fusion row to get the Y coordinate. The pulses on the “fusion” row are ignored, and only the “road;



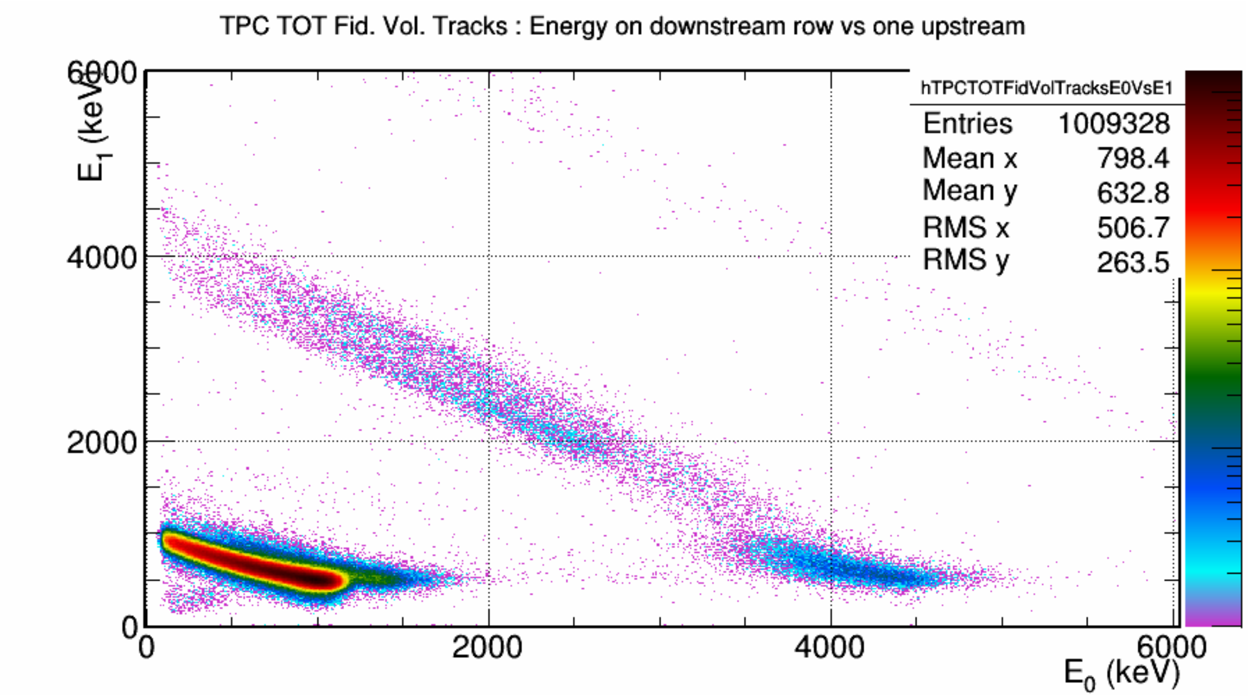
Variant: Use projection for all tracks, not just fusions

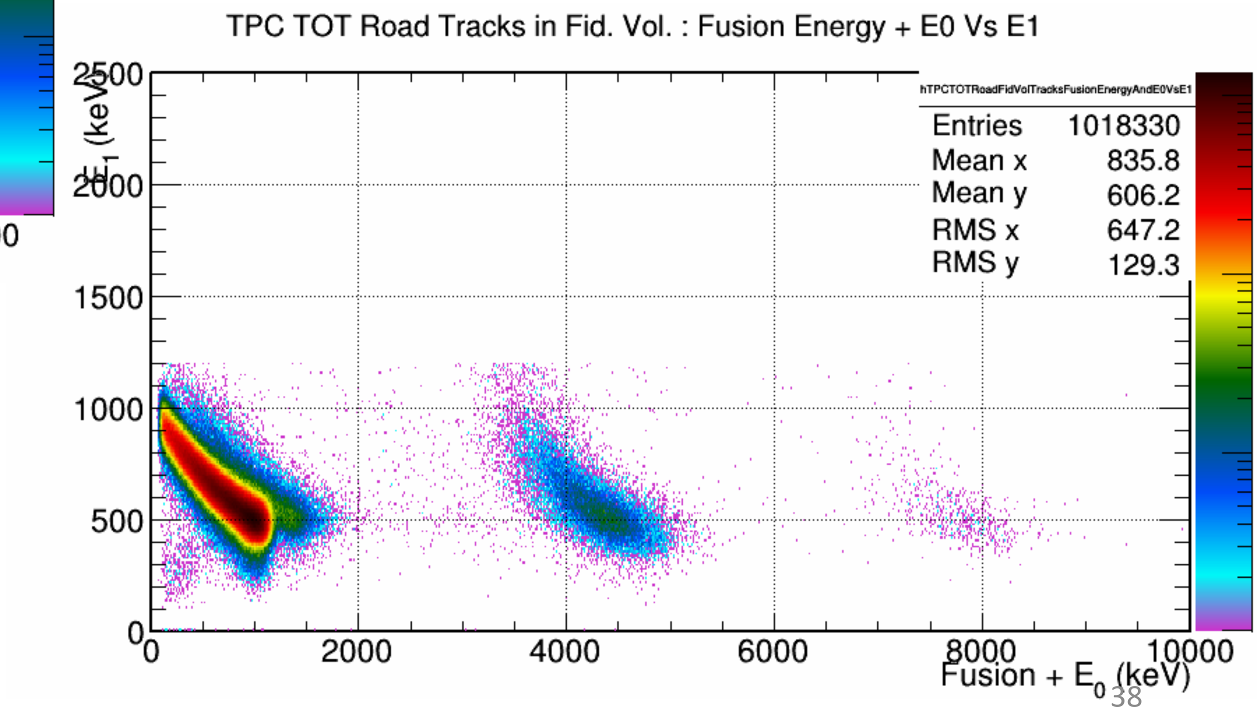
To treat events without the fusion threshold in a similar manner to the fusion events, use the projection method for all tracks. This decreases Y resolution, of course.





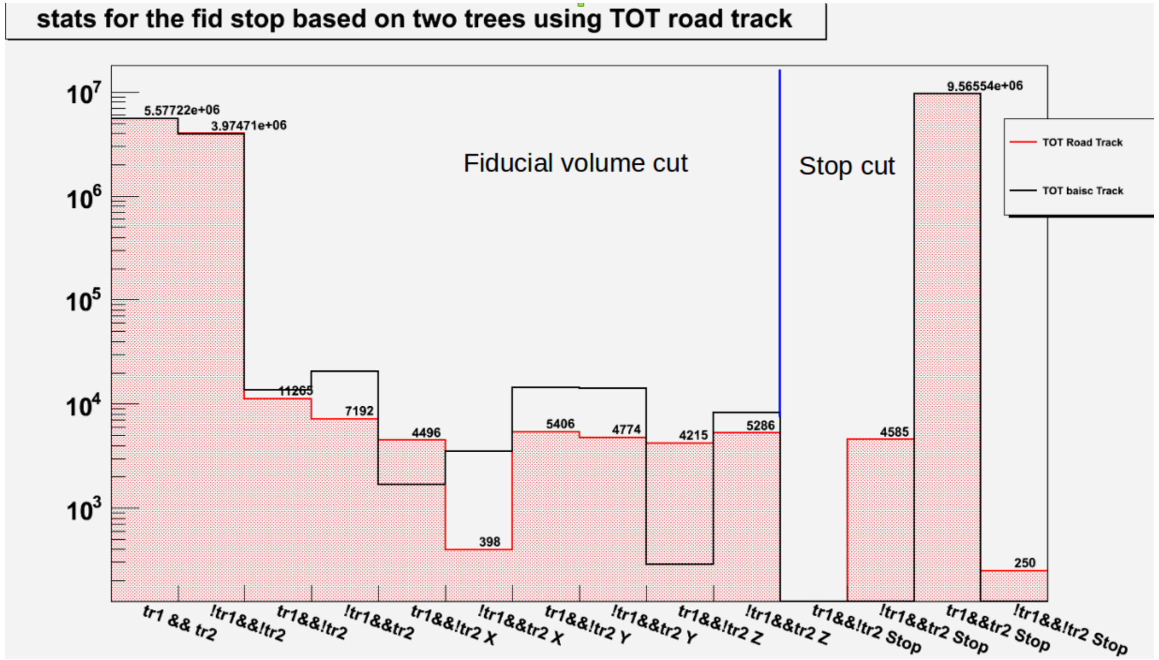
E1 vs E0 for Basic and Road Tracks





TPC Muon Stop : The future

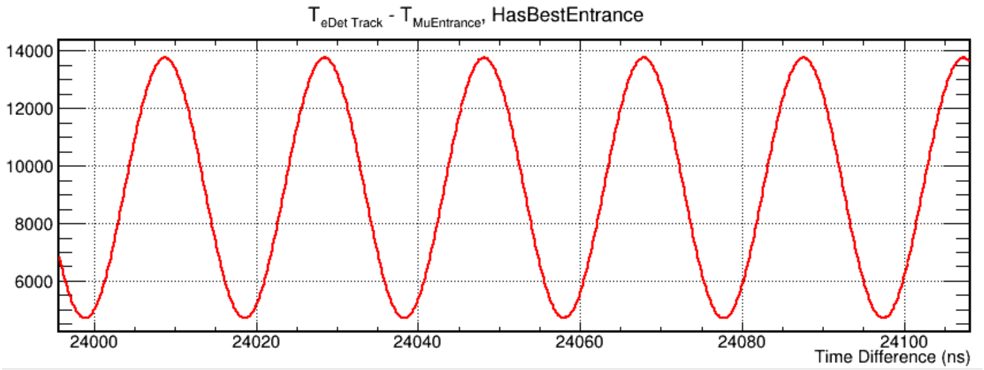
- Analyze full data set with Road tracker, compare to Basic tracker. (MU pass ongoing on Lonestar, half-way done 12 Aug 2014)
- (Also incorporates new TOT pulse finder)
- For Road tracker, try different "fusion" thresholds
- Try projection variants, as discussed. Also variants for Stop X.
- Study the migration of events using MC



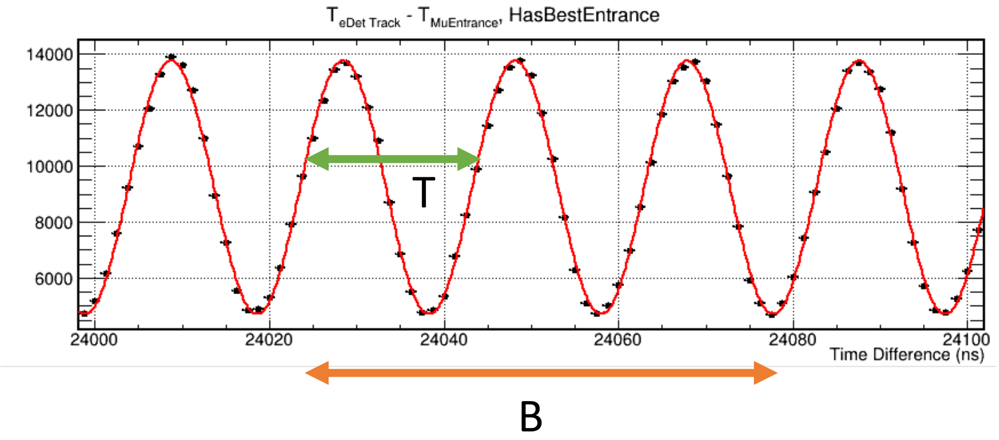
Backup

Rebinning an oscillatory signal

<u>The data has a periodic additive component</u>



<u>This is sampled by an ADC</u>



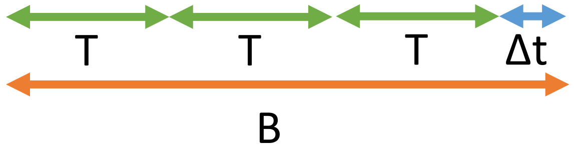
<u>What happens to the period when we rebin the ADC samples?</u>

Properties of our signal, f(t).

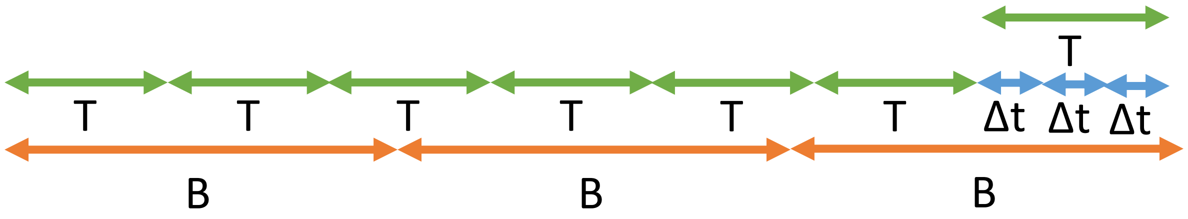
$$f(t+T) = f(t)$$

$$\int_{t'}^{t'+T} dt\, f(t) = 0$$

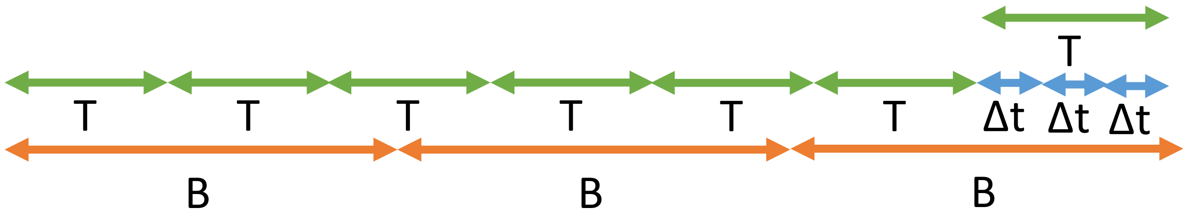
where T is the period. Rebinning to a bin width B (in ns), where B > T, we accumulate an extra bit of the signal, Δt.



Since the integral of the oscillatory signal is zero over one period, only the portion Δt contributes to the new bin content. The period of these new bins is set by how many Δt pieces it takes to get to a whole new period, T.



Rebinning an oscillatory signal



Calculating the new period

Remember that T and B are times in ns. Δt is given by

$$\Delta t = B \bmod T$$

And the rebinned signal reaches zero after N bins, where

$$N = \frac{T}{\Delta t} = \frac{T}{B \bmod T}$$

This translates to a period, T_B in ns of

$$T_B = NB = \frac{BT}{B \bmod T}$$

This works even if T is not an integer multiple of Δt.

Some numbers for MuSun

Assume the cyclotron RF determining the correlation of electron background counts to the muon has a period of T=19.7 ns, which is close to the real value.

Our CAEN TDC samples times at 1.25ns, so we can only rebin such that B is an integer multiple of this. For now, consider B=40ns, B=50ns, and B=100ns

T=19.7ns	T=19.7ns	T=19.7ns
B=40.0ns	B=50.0ns	B=100.0ns
Δt = B mod T = 0.6ns	Δt = B mod T = 10.6ns	Δt = B mod T = 1.5 ns
N = T/(B mod T) = 32.8	N = T/(B mod T) = 1.81	N = T/(B mod T) = 13.1
T_B = NB = 1310ns	**T_B = NB = 90.5ns**	**T_B = NB = 1310ns**

Notice that for B=40.0ns and B=100.0ns, we get the same T_B. This is a general property for bin sizes B_1 and B_2 as long as B_1 mod T = (B_1 / B_2) * B_2 mod T. This will be the case when (B_1 mod T) and (B_2 mod T) are small compared to T.