Measurements with the 35-ton Prototype

Tom Junk

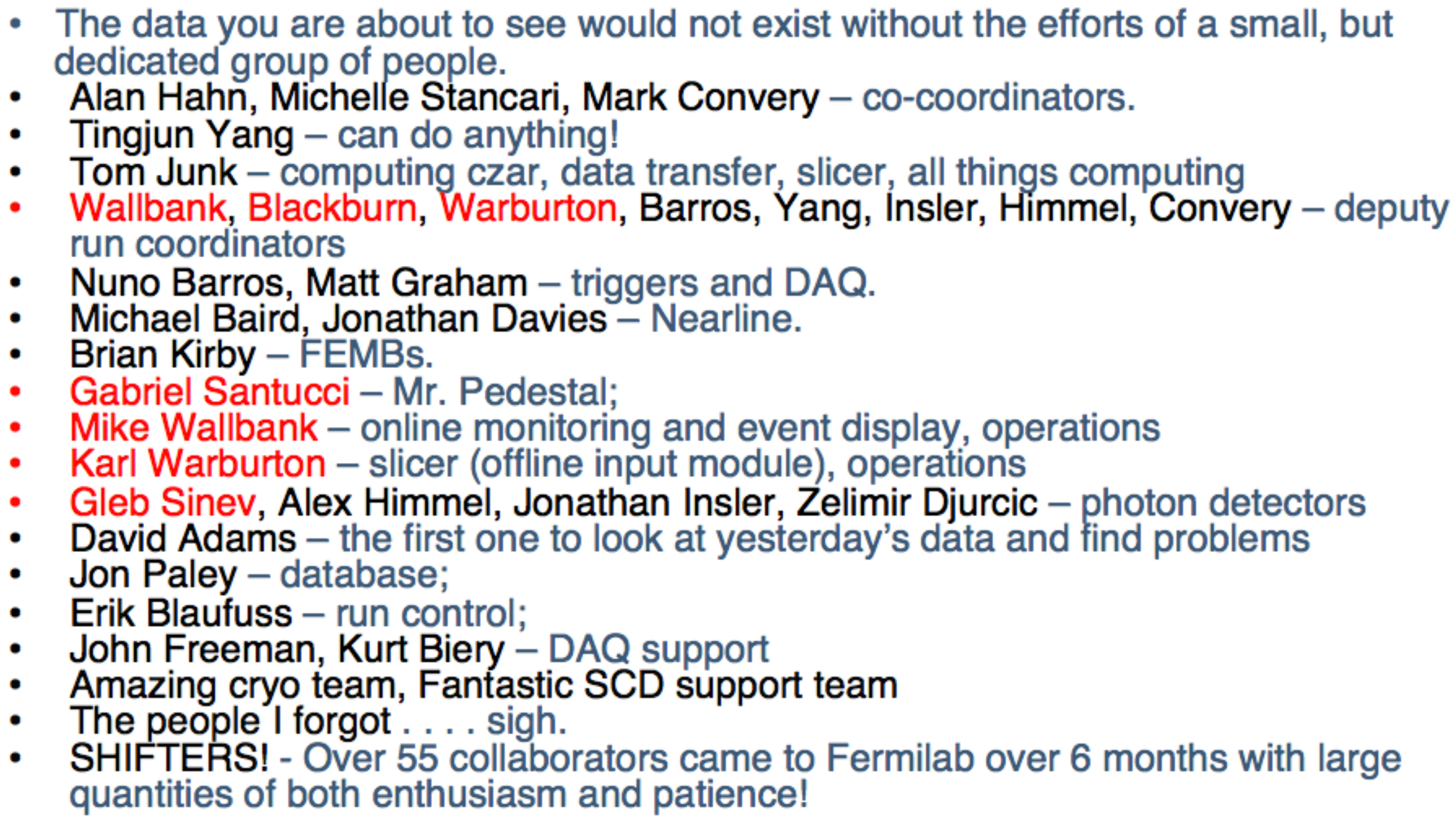
Joint DUNE/SBN Meeting: Lessons Learned

May 15, 2017

The status of all plots and analyses is "Work in Progress"

Lessons Learned Documents (DUNE DocDB)
DocDB 1315
DocDB 913
DocDB 281

The Operations and Analysis Team



- The data you are about to see would not exist without the efforts of a small, but dedicated group of people.
- Alan Hahn, Michelle Stancari, Mark Convery – co-coordinators.
- Tingjun Yang – can do anything!
- Tom Junk – computing czar, data transfer, slicer, all things computing
- Wallbank, Blackburn, Warburton, Barros, Yang, Insler, Himmel, Convery – deputy run coordinators
- Nuno Barros, Matt Graham – triggers and DAQ.
- Michael Baird, Jonathan Davies – Nearline.
- Brian Kirby – FEMBs.
- Gabriel Santucci – Mr. Pedestal;
- Mike Wallbank – online monitoring and event display, operations
- Karl Warburton – slicer (offline input module), operations
- Gleb Sinev, Alex Himmel, Jonathan Insler, Zelimir Djurcic – photon detectors
- David Adams – the first one to look at yesterday's data and find problems
- Jon Paley – database;
- Erik Blaufuss – run control;
- John Freeman, Kurt Biery – DAQ support
- Amazing cryo team, Fantastic SCD support team
- The people I forgot . . . . sigh.
- SHIFTERS! - Over 55 collaborators came to Fermilab over 6 months with large quantities of both enthusiasm and patience!

slide from K. Warburton & M. Stancari

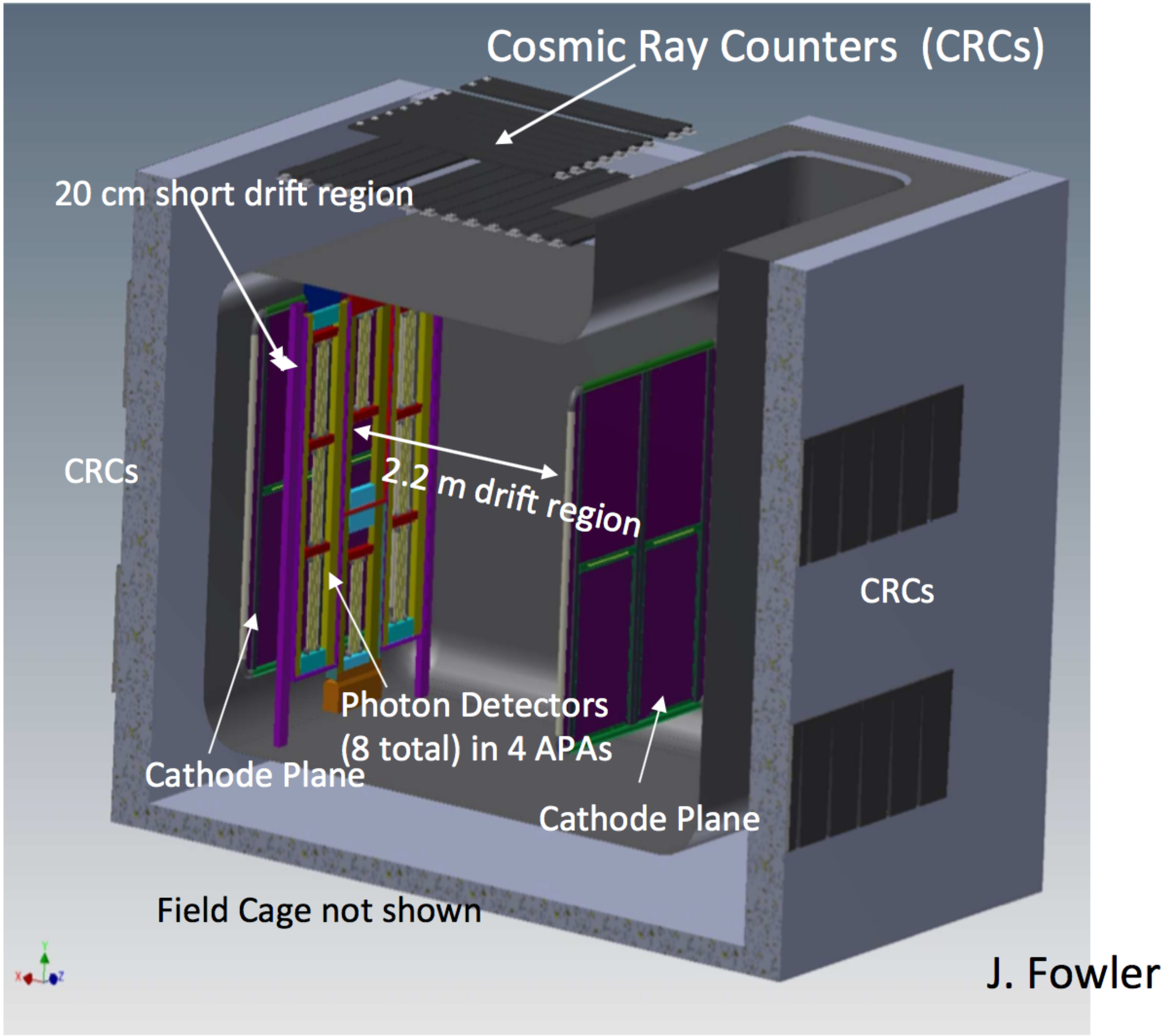
Faces to go with some of the names

The 35-ton Prototype

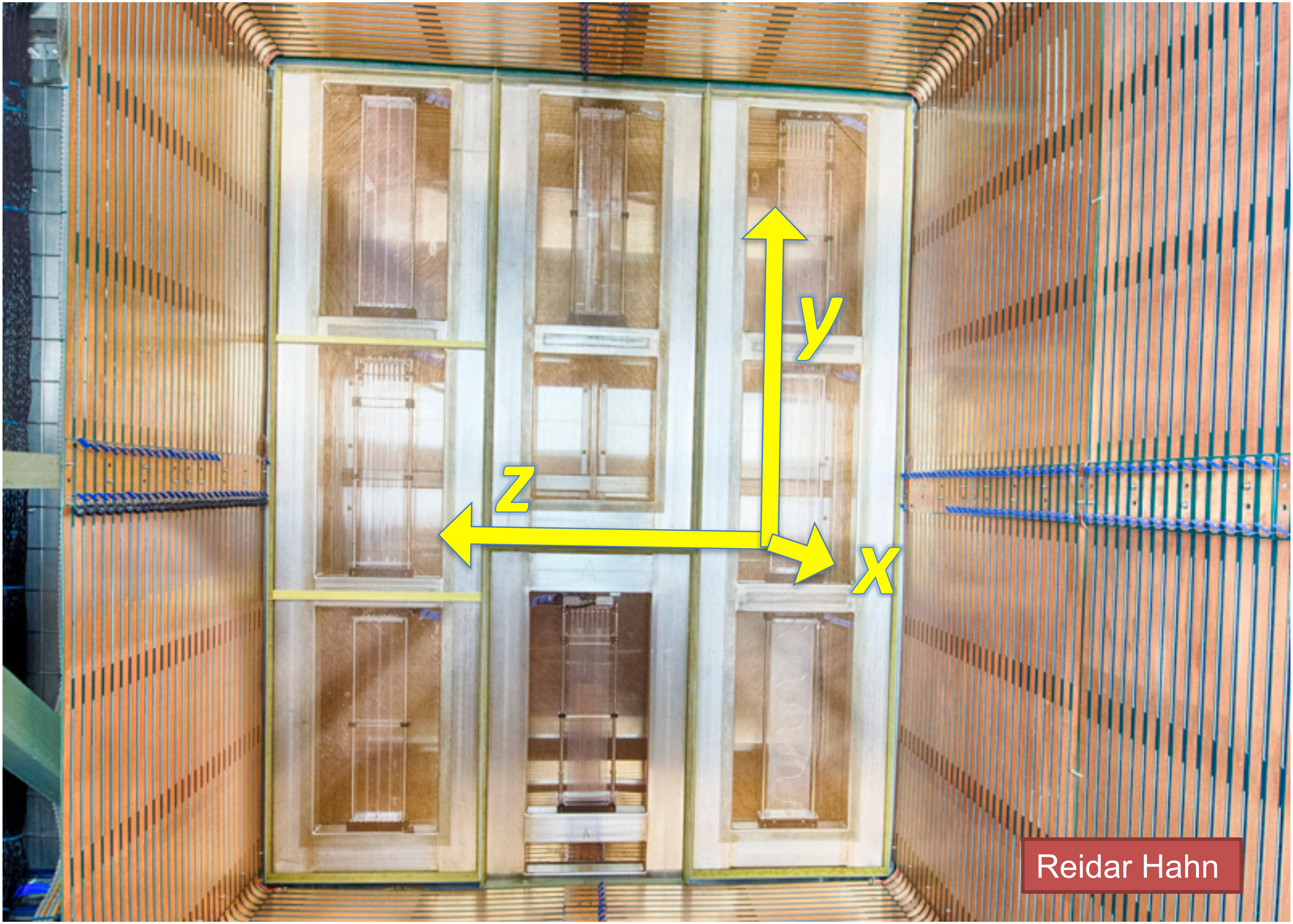
- Tested many of the design features of the DUNE far detector.
  - Membrane Cryostat – the first one with a LArTPC!
  - Modular Anode Planes
  - Double-Sided Anode Plane Assemblies with Wrapped Induction-Plane Wires
  - Photon detectors inside the wire planes
  - Cold Electronics
- Analyses target performance aspects specific to these unique features.
- Due to the high noise levels, innovative analysis techniques had to be developed. These may be of use even when noise is less of a problem.

Two Operations Phases

- Phase I (~December 2013—February 2014):
  - Test cryostat concept and purification system.
  - Purity monitors but no TPC or photon detectors.
  - Electron lifetime of 3 ms.
- Phase 2 (January — March 2016) – This Talk!
  - Data run with detector (TPC, photon detectors, external muon counters).
  - 3 ms electron lifetime sustained with detector equpment installed and running
  - Data analysis nearly finished.
  - Two papers in preparation: Photon Detectors, and TPC Performance/Analysis. Target Journals: JINST and/or NIM A

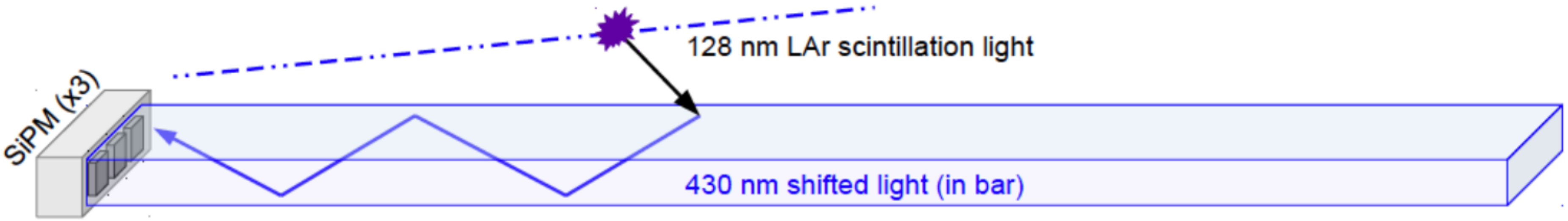

Cosmic Ray Counters (CRCs)
20 cm short drift region
CRCs
2.2 m drift region
CRCs
Photon Detectors
(8 total) in 4 APAs
Cathode Plane
Cathode Plane
Field Cage not shown
J. Fowler

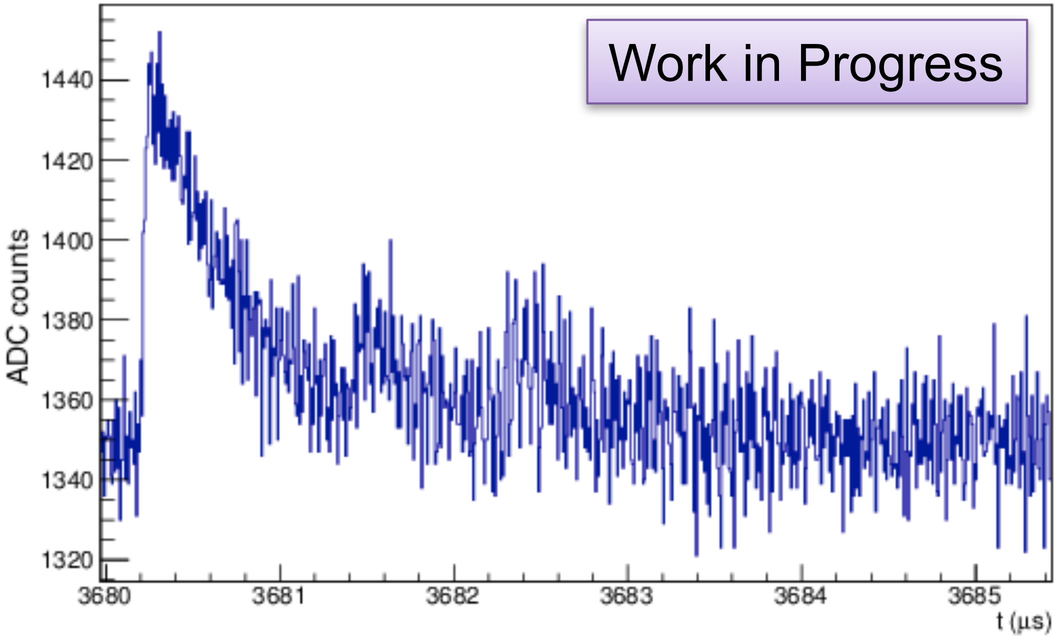

Reidar Hahn



Reidar Hahn

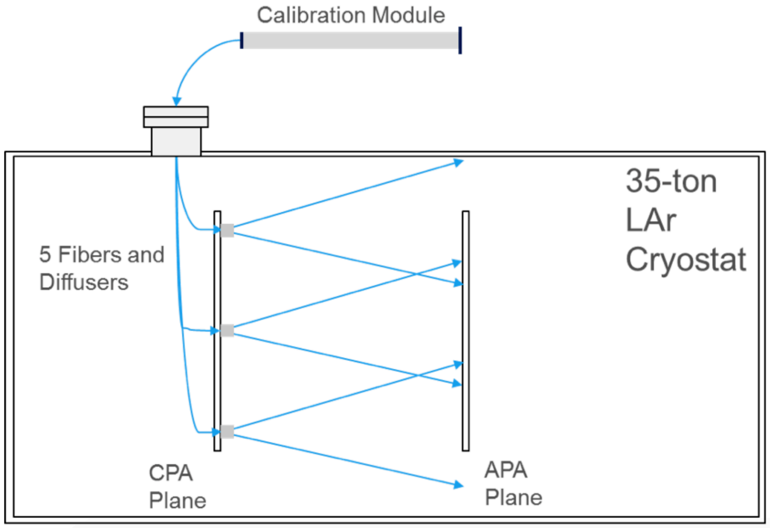
Photon Detection System

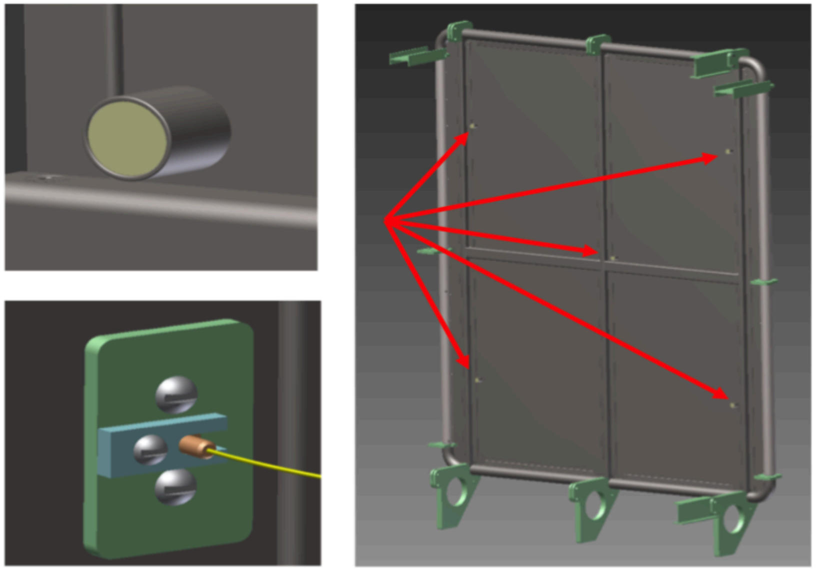


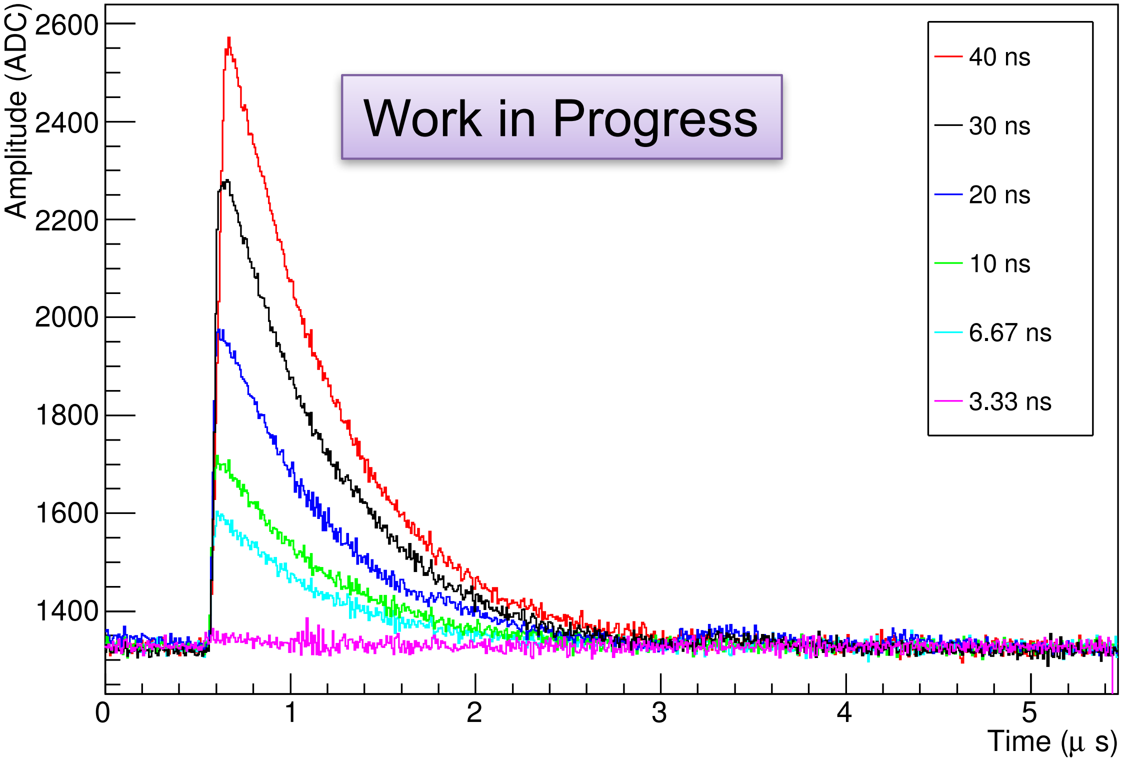


A waveform with a signal corresponding to about 4 PE

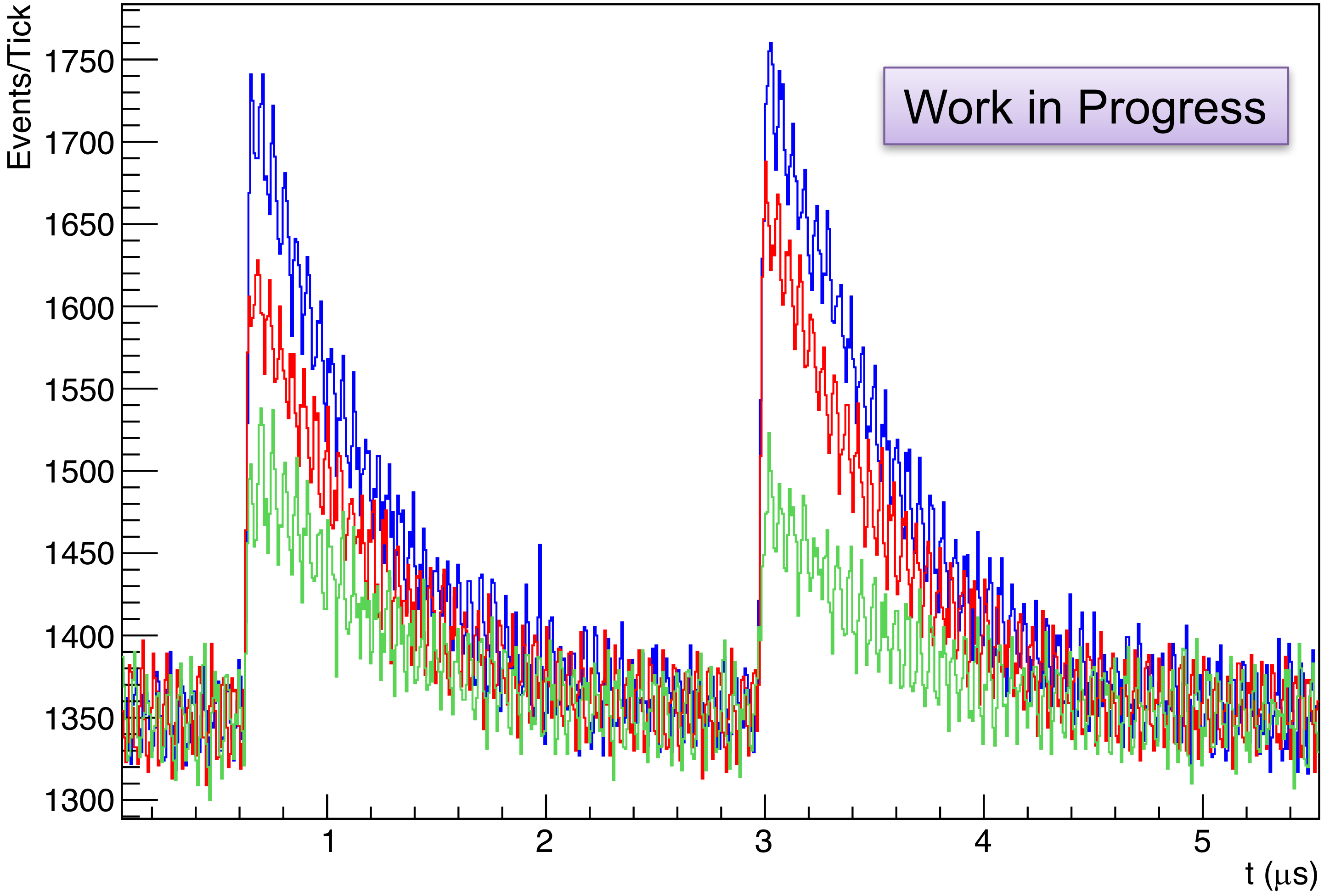
Photon Detector Calibration System







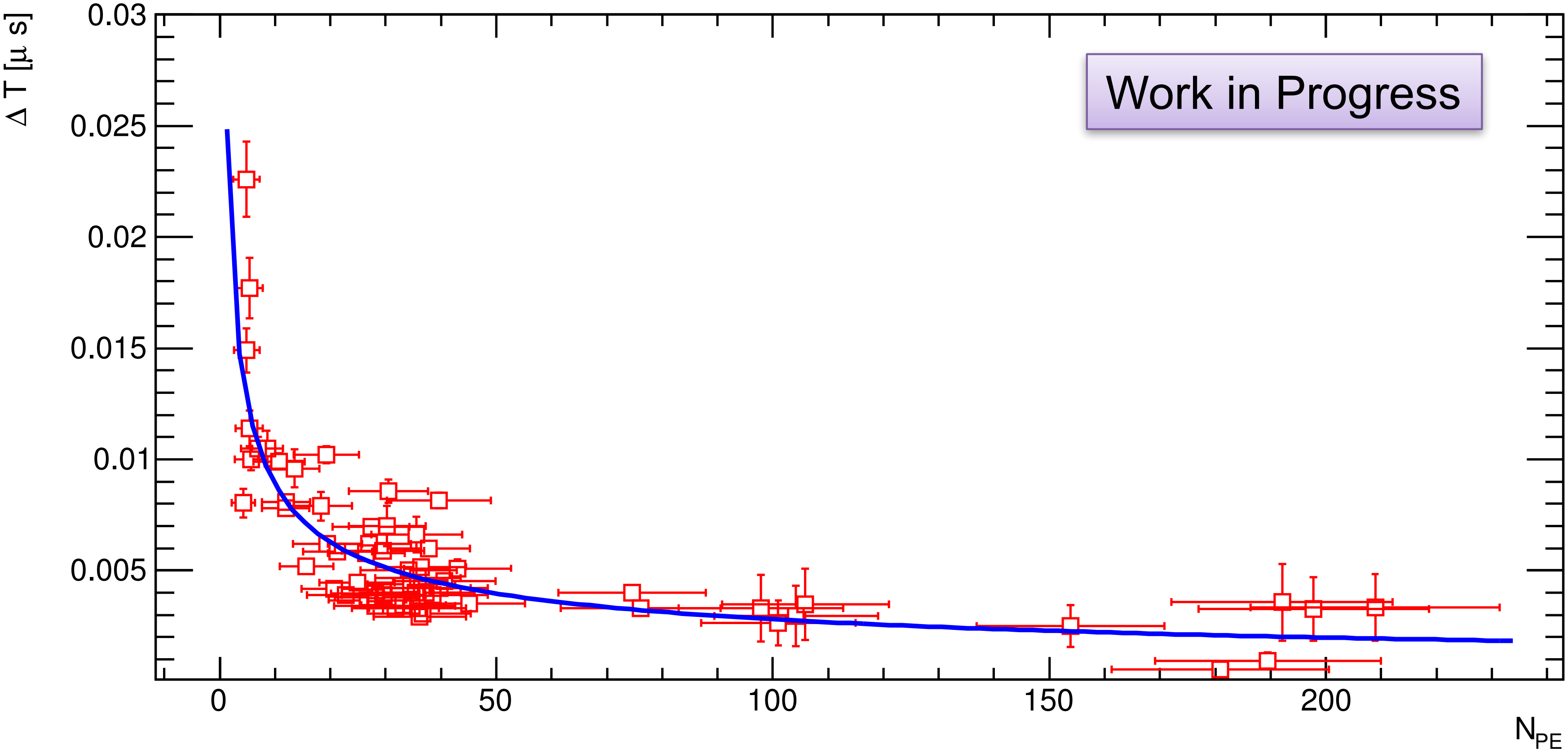
Double-Pulse Timing Measurements



A. Himmel
Z. Djurcic
J. Insler
G. Sinev

Timing Resolution vs. Signal Strength

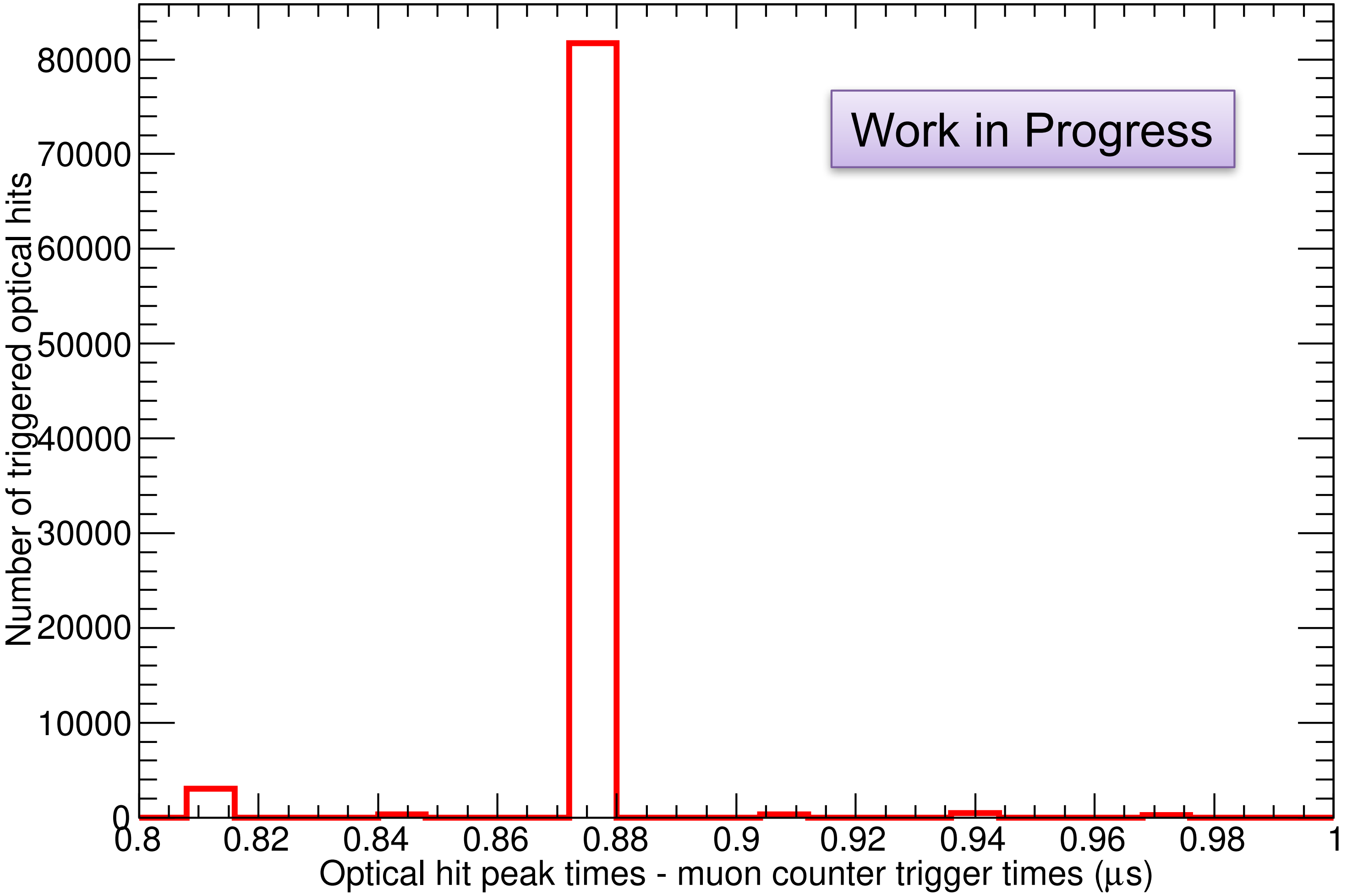
- Determined with double pulses on the calibration system



Resolution is better than 30 ns at 1 PE. Just detector: does not include physics effects such as selecting a late photon instead of a prompt one

A. Himmel
Z. Djurcic
J. Insler
G. Sinev

Timing Resolution: PD/Counter Time Differences



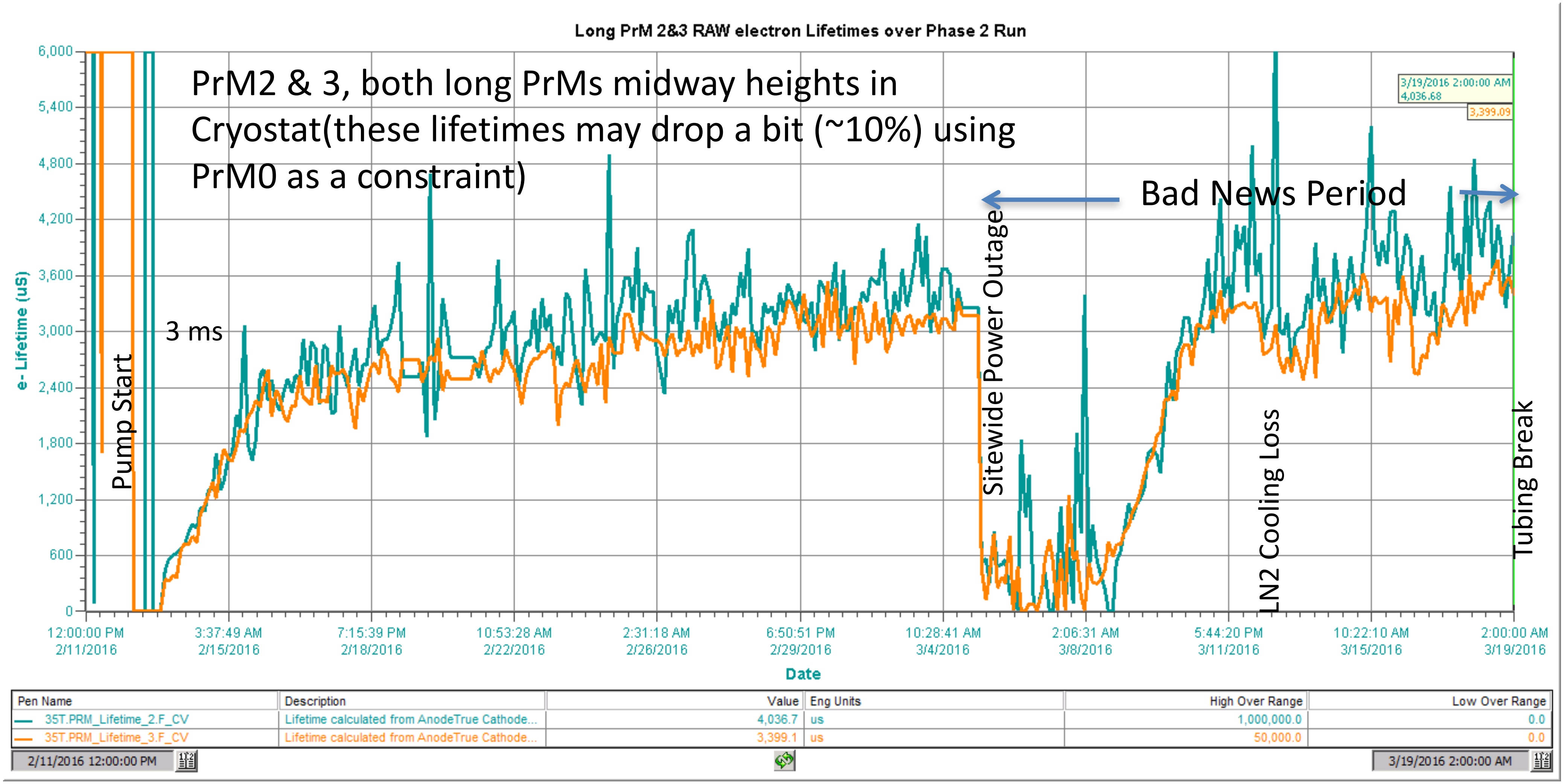
Resolution is better than the 30 ns bins

overbinned at 10 ns, but data are discretized by the trigger board

A. Himmel
Z. Djurcic
J. Insler
G. Sinev

Run: e$^-$ Lifetime

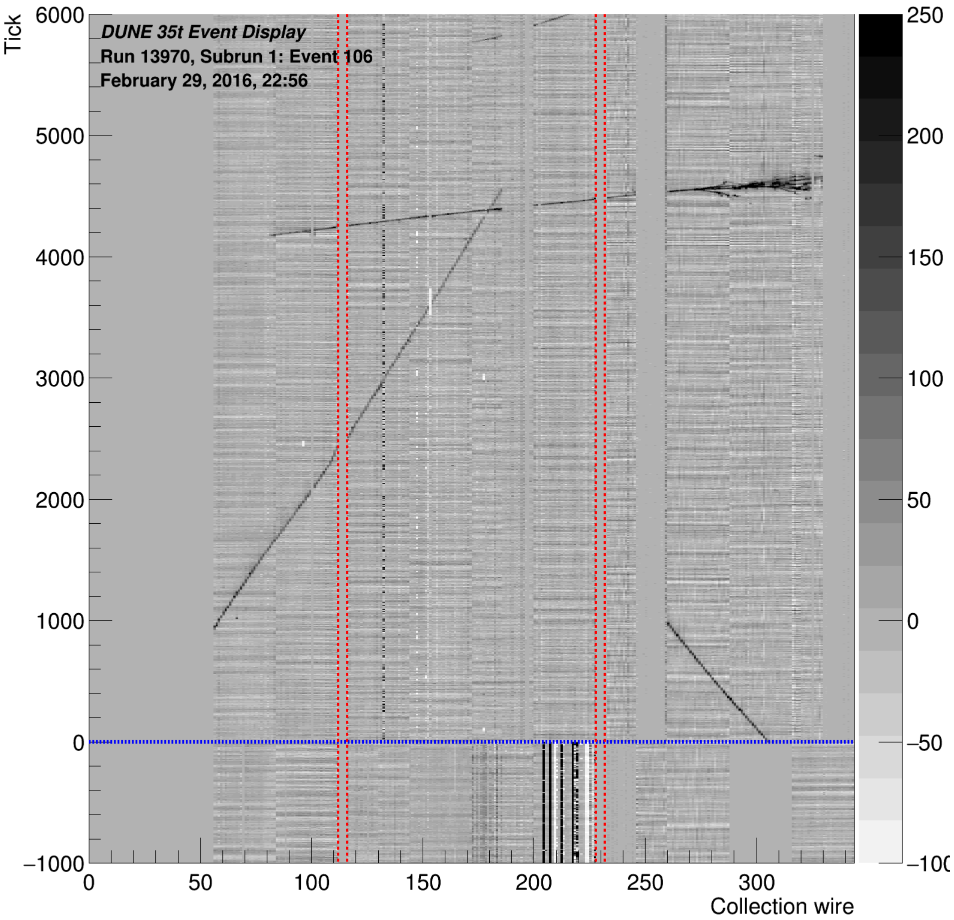
A. Hahn



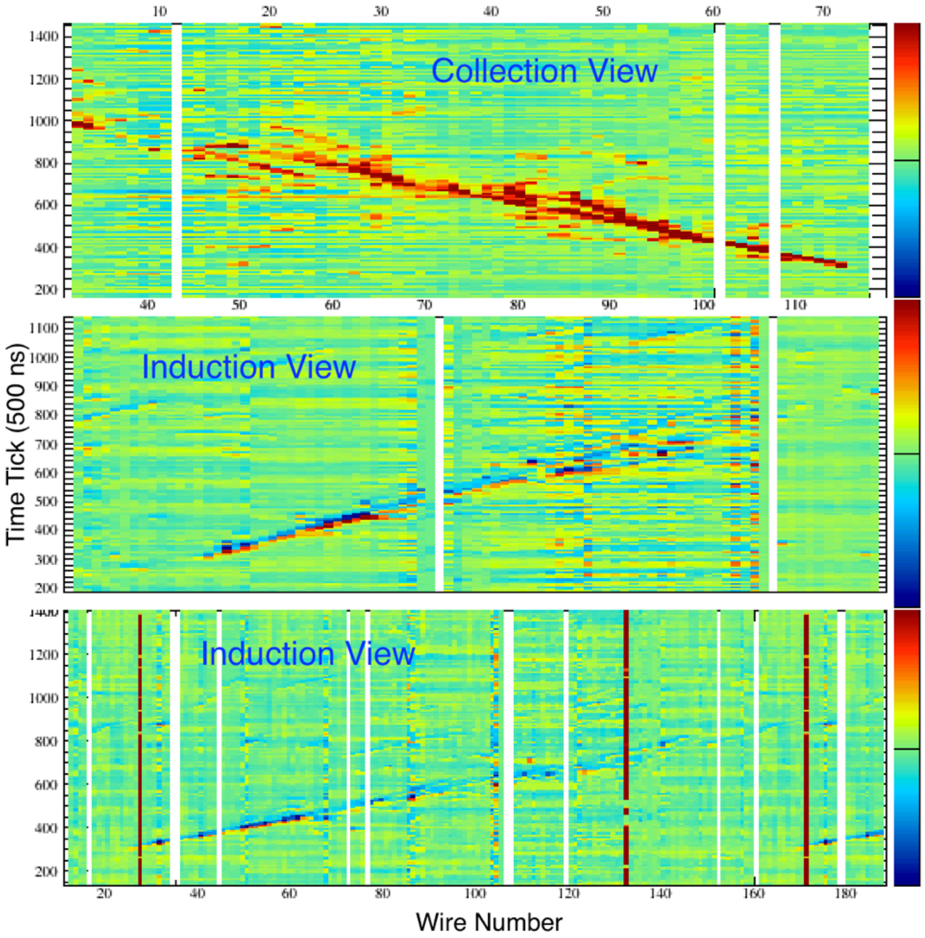
PrM2 & 3, both long PrMs midway heights in Cryostat(these lifetimes may drop a bit (~10%) using PrM0 as a constraint)

Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
35T.PRM_Lifetime_2.F_CV	Lifetime calculated from AnodeTrue Cathode...	4,036.7	us	1,000,000.0	0.0
35T.PRM_Lifetime_3.F_CV	Lifetime calculated from AnodeTrue Cathode...	3,399.1	us	50,000.0	0.0

35-Ton Data



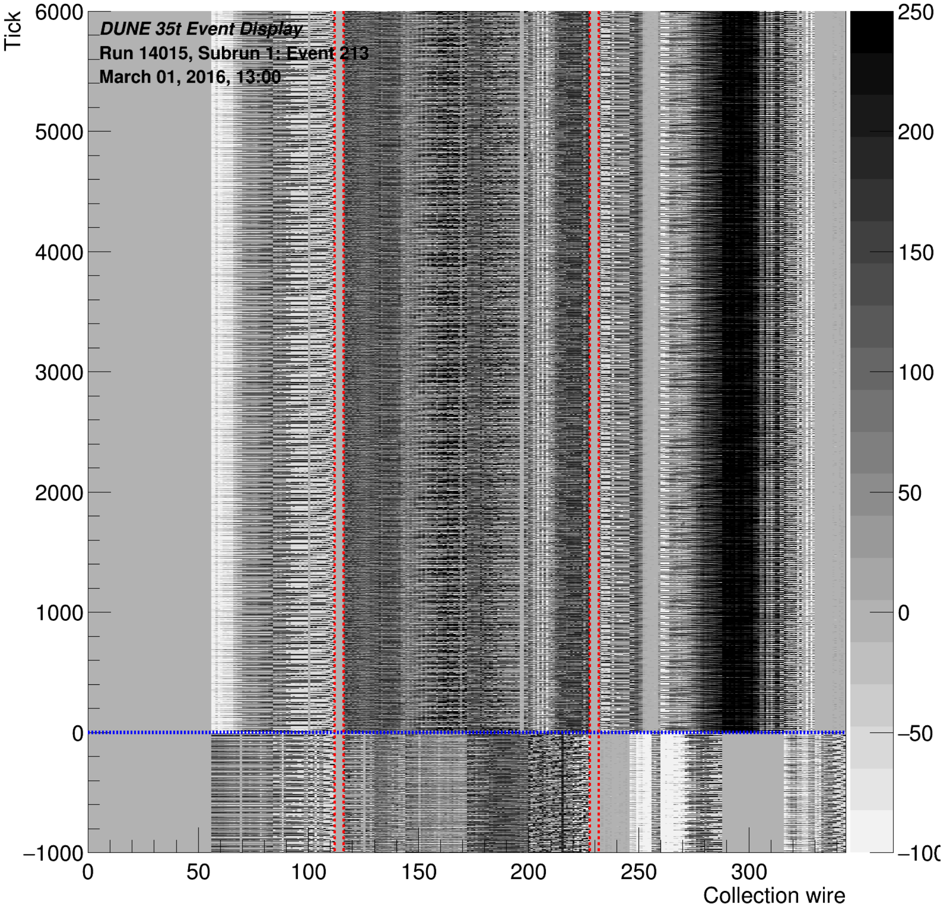
Mike Wallbank's online event display – collection view



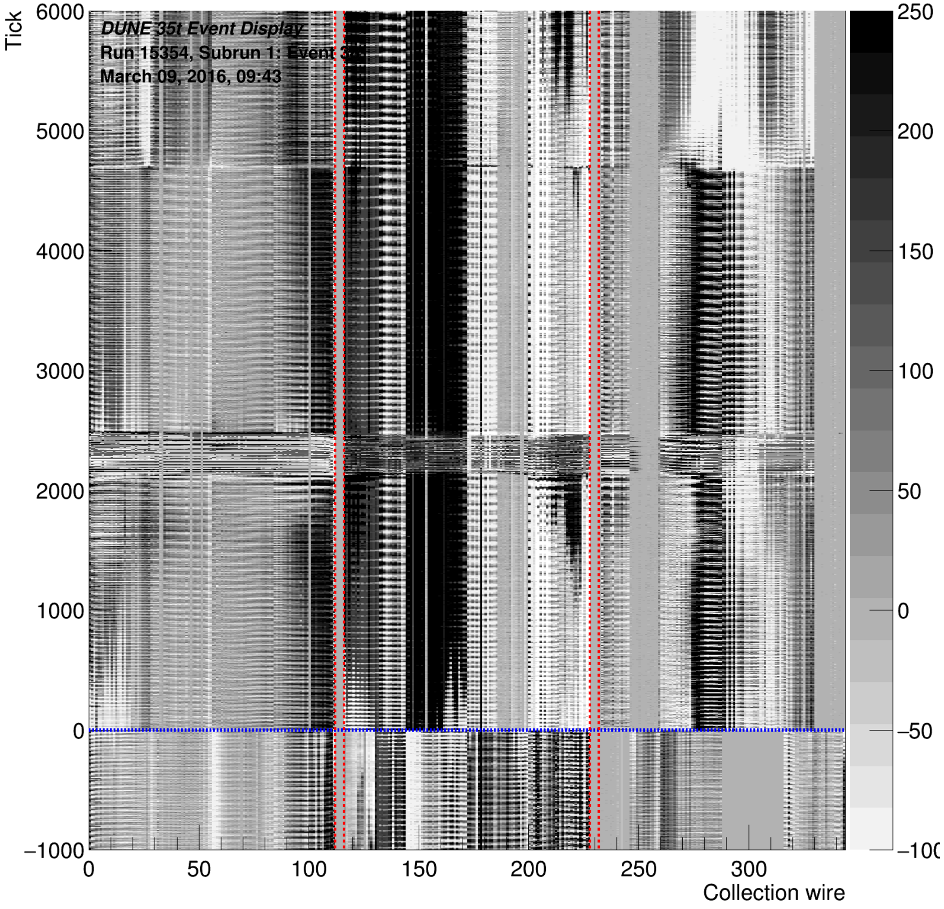
Electron Shower seen in three views in the LArSoft event display.
Stuck codes and noise filtering applied.

High-Noise State(s)

Oscillatory noise

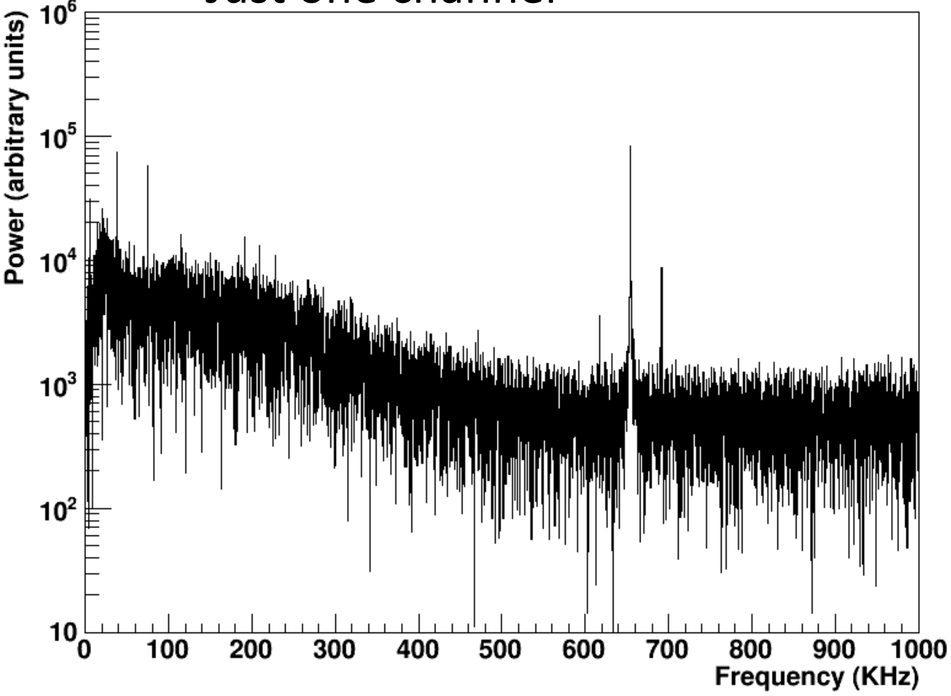


Transients

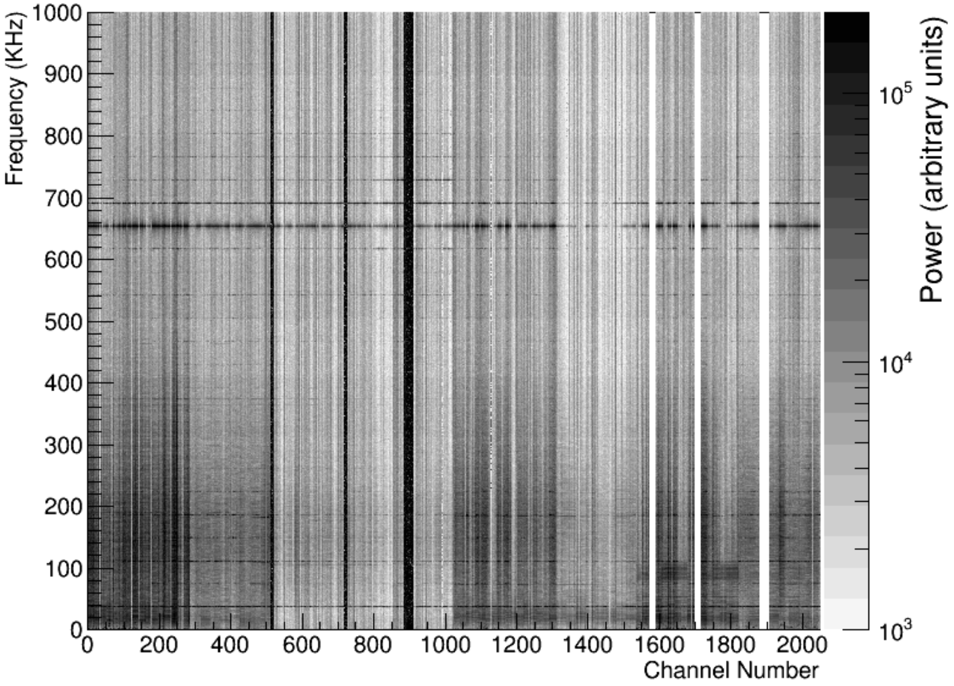


Noise Frequency Spectrum

As quiet as it got: ~30 counts of noise on most channels



Just one channel



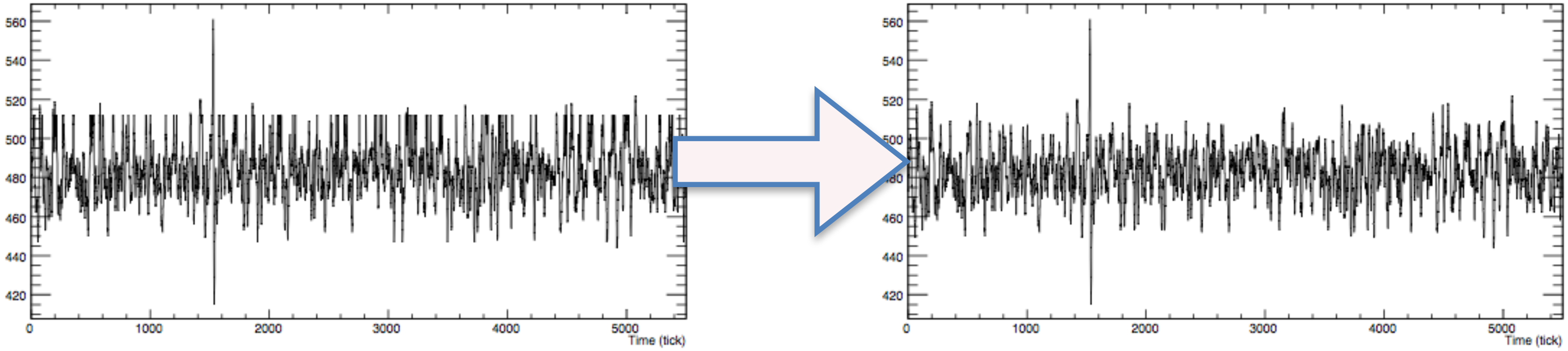
All channels

Work in Progress

Preparing 35-ton Data

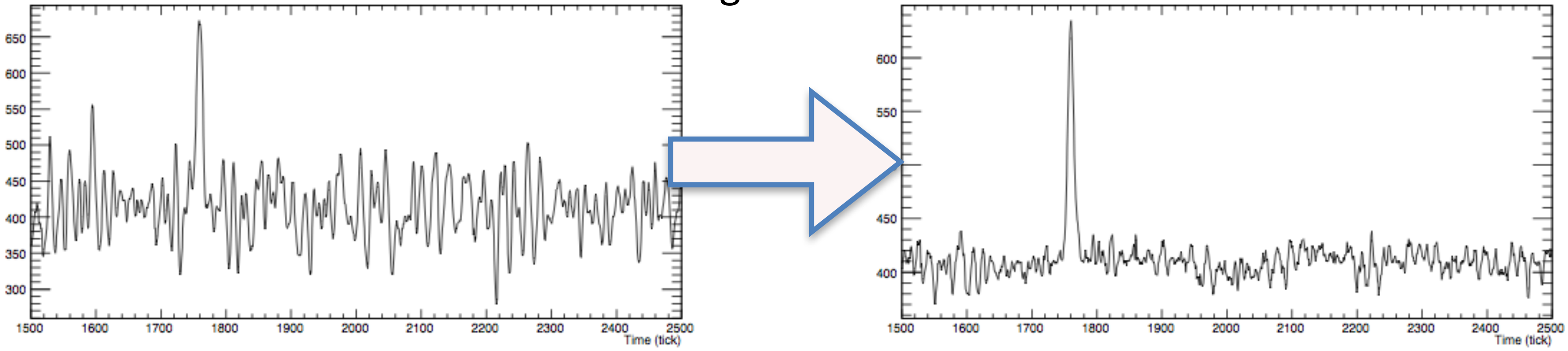
Brian Kirby
David Adams
Jonathan Insler

- Stuck code mitigation: Low six bits would stick at 0x00 or 0x3F. Interpolate nearby samples



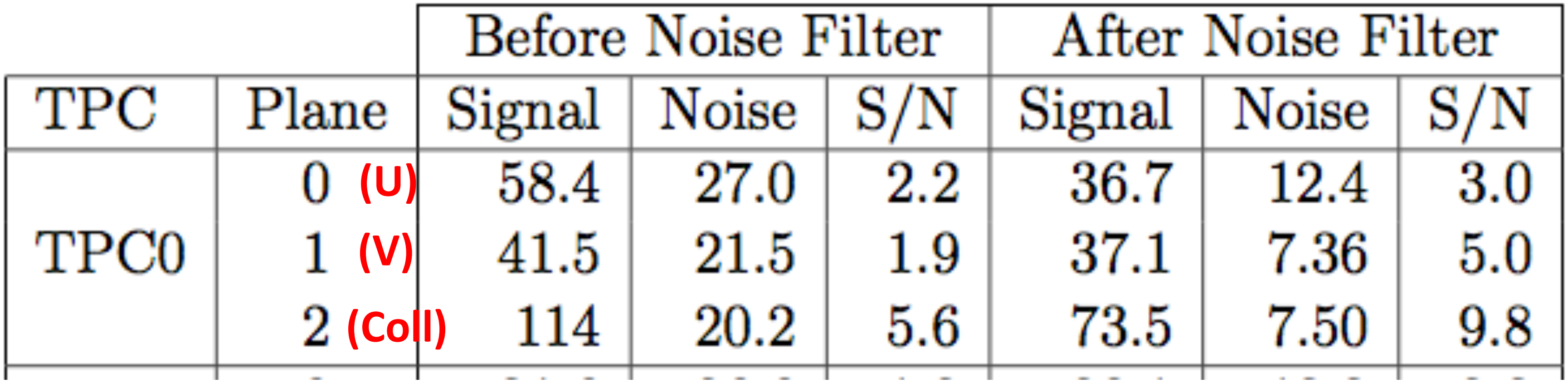
- Coherent noise removal:

Applied across channels sharing FE voltage regulator. Subtract the median of all channels.



TPC Signal and Noise Performance

Tingjun Yang



		Before Noise Filter			After Noise Filter		
TPC	Plane	Signal	Noise	S/N	Signal	Noise	S/N
TPC0	0 (U)	58.4	27.0	2.2	36.7	12.4	3.0
	1 (V)	41.5	21.5	1.9	37.1	7.36	5.0
	2 (Coll)	114	20.2	5.6	73.5	7.50	9.8

Units: ADC counts

Work in Progress

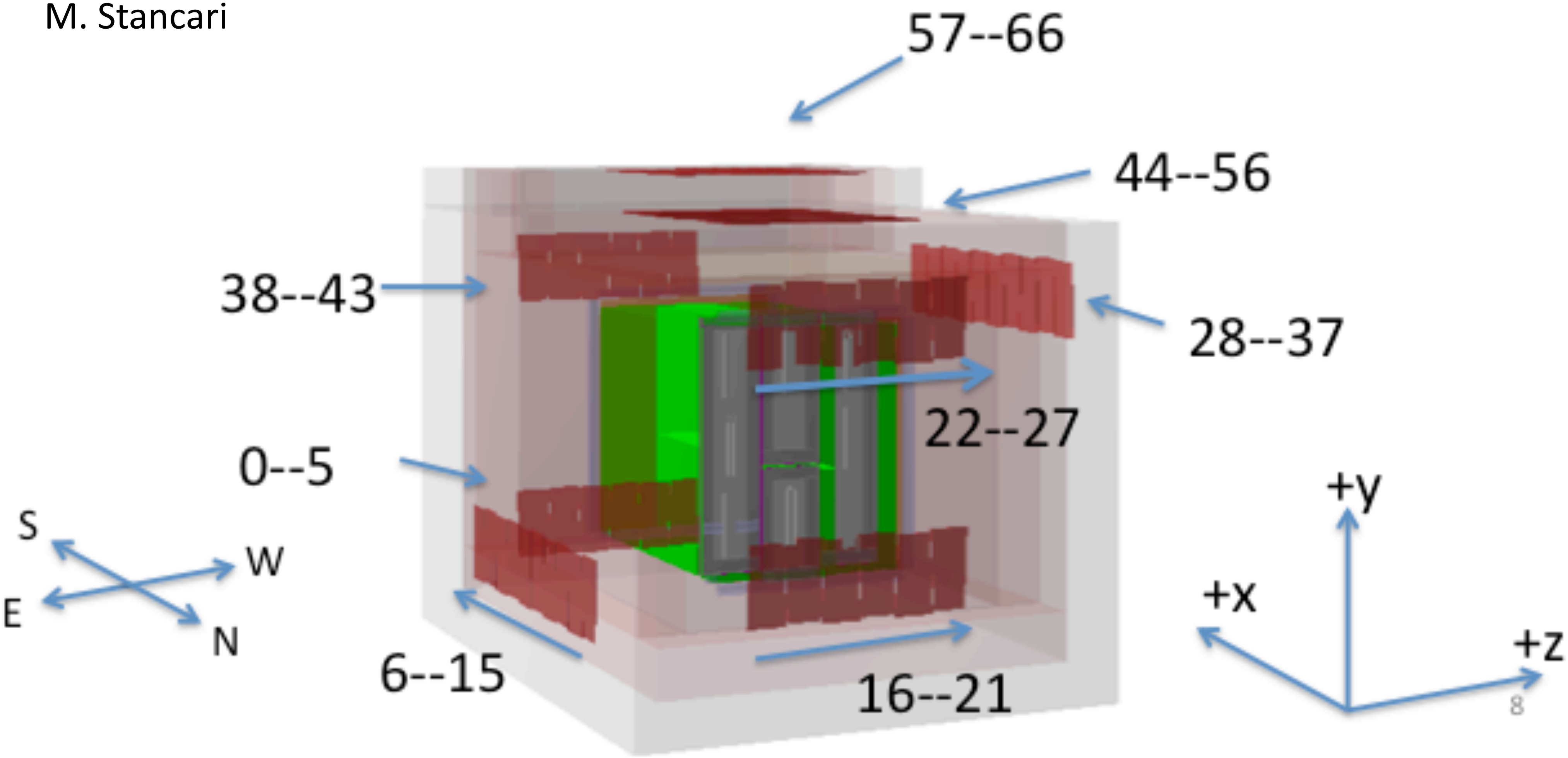
Results are for MIPs at the *anode*

Other TPC's similar – short APA has a bit less noise in this run

Track angle helps, but you cannot have a favorable angle in both induction views.

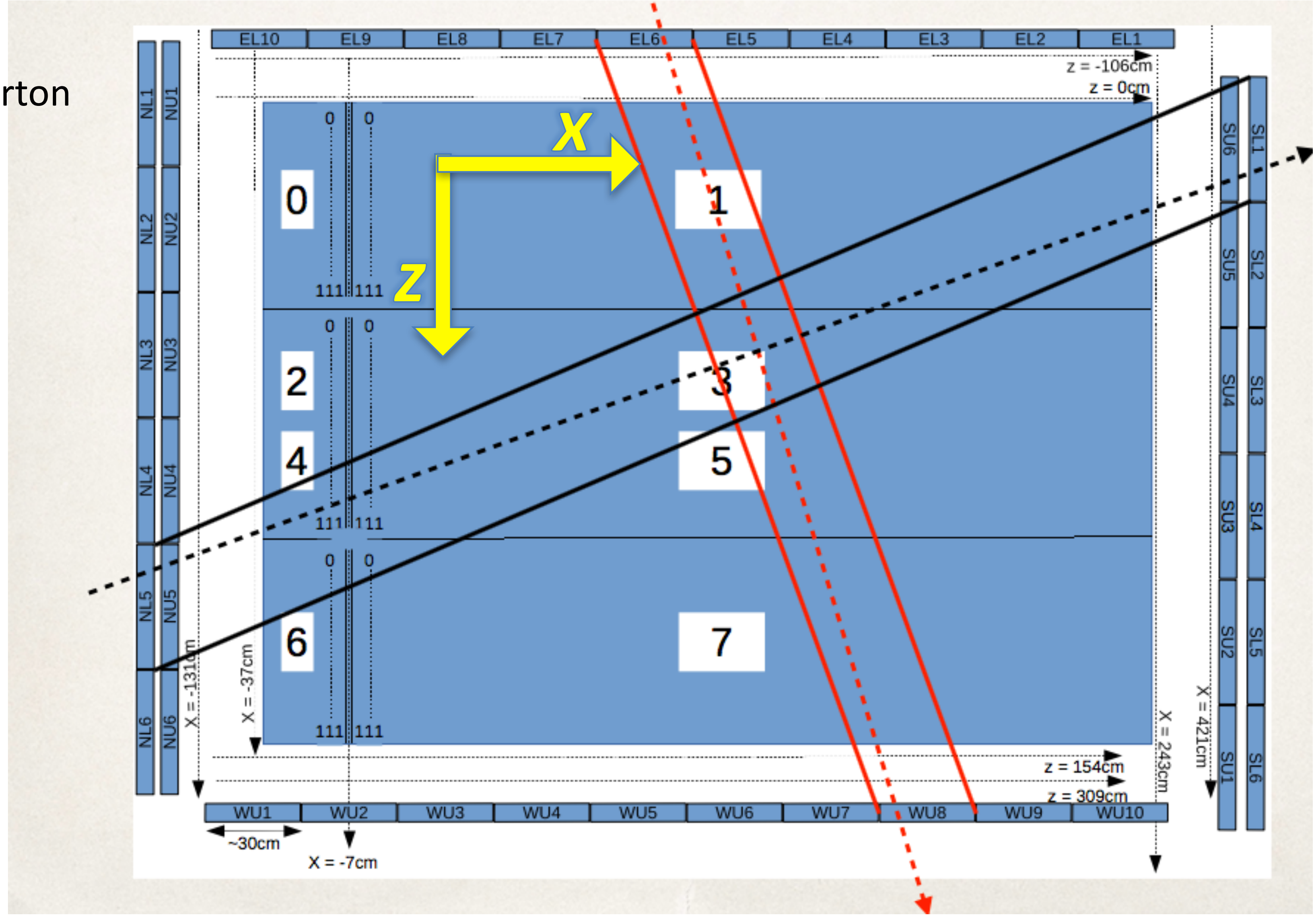
Muon Counter Locations

M. Stancari



East-West and North-South Counters

K. Warburton

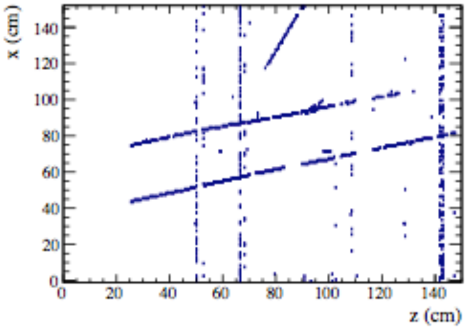


Slide from K. Warburton

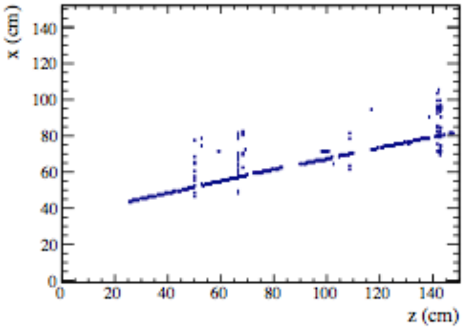
Selecting Hits on E-W Counter Triggers

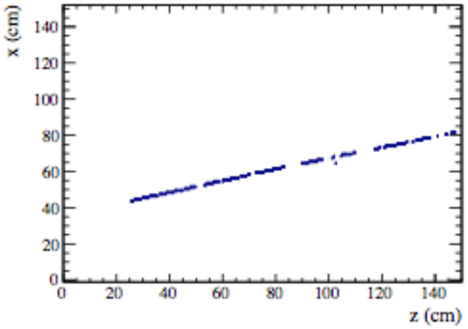
- A lot of data taken using the EW counter trigger.
- This provides a subset of the data which is used in many of the analyses shown.
  - Can select tracks with known track angles and interaction times.
  - ”The 35 ton selection.”
- Can select:
  - Hits with them being fitted to tracks by the user.
  - Fully reconstructed tracks.

Reconstructed Gaus hits

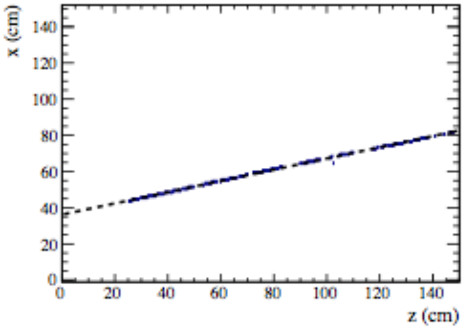


Hits in counter shadow





Only 1 hit on wire

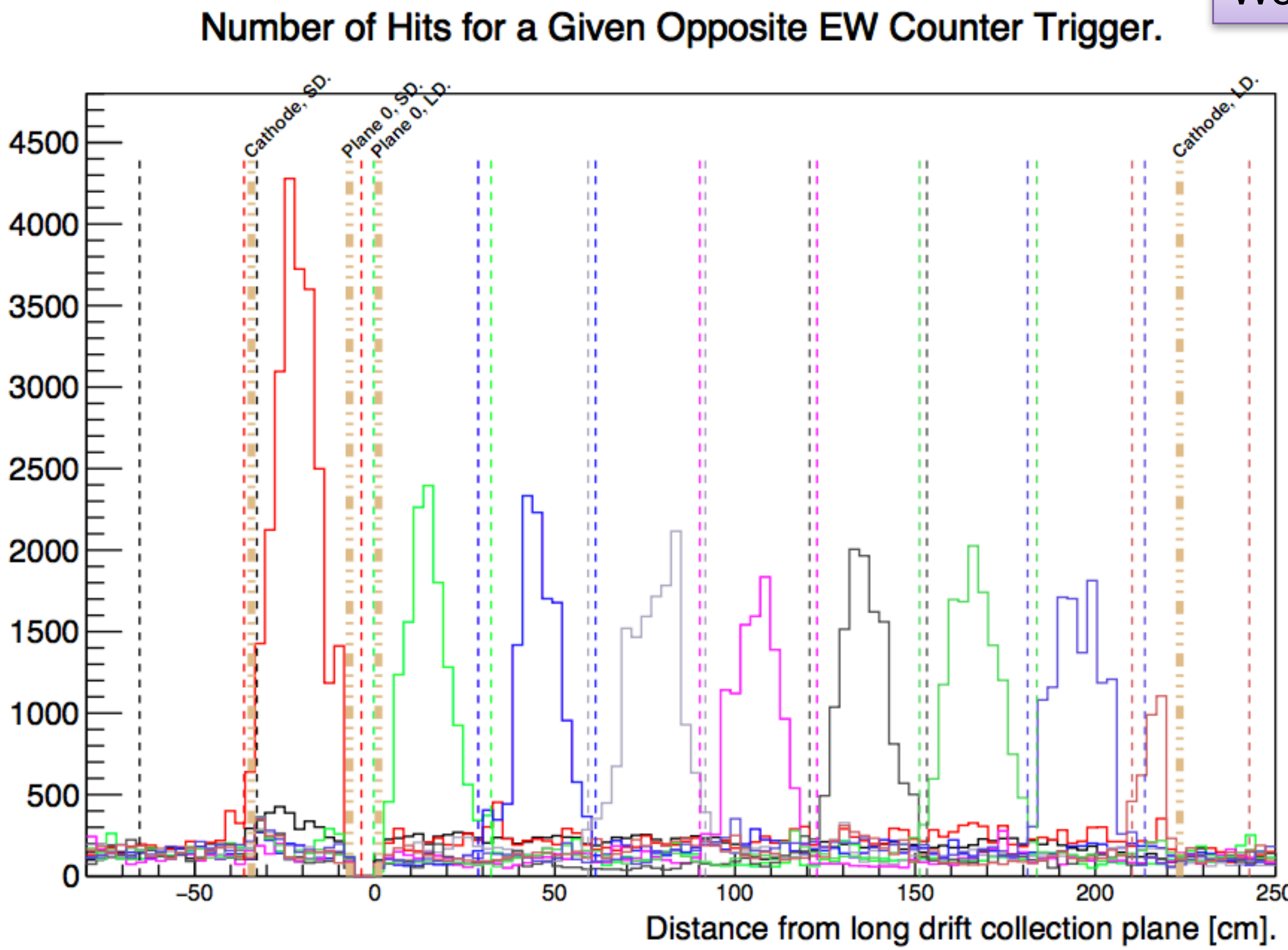


Least sq. resid. per d.o.f < 1 cm

Dominic Brailsford, Lancaster

East-West Counter Alignment

Work in Progress



A. Booth
D. Braisford
M. Stancari

E-W Counter Position Fits

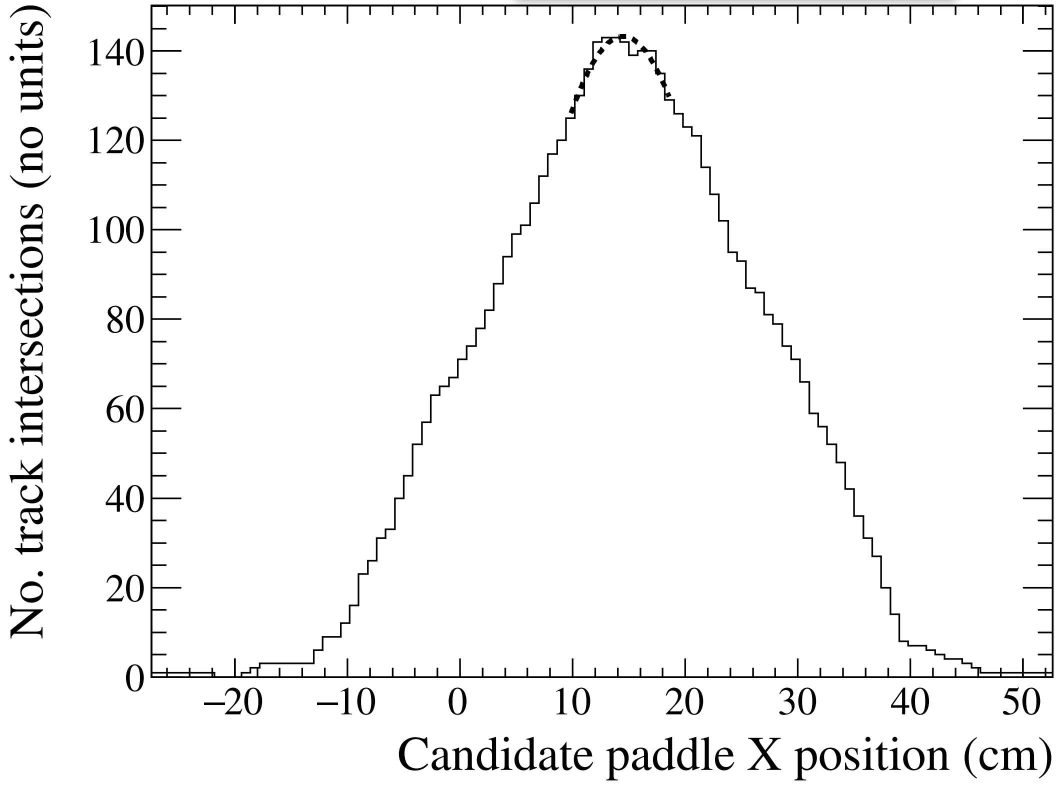
Extrapolate tracks to the Z location of the counter.

Count how many tracks intersect the counter location as a function of hypothesized counter position

Update detector geometry for downstream analyses.

Y positions not measured (requires 3D tracking)

Work in Progress



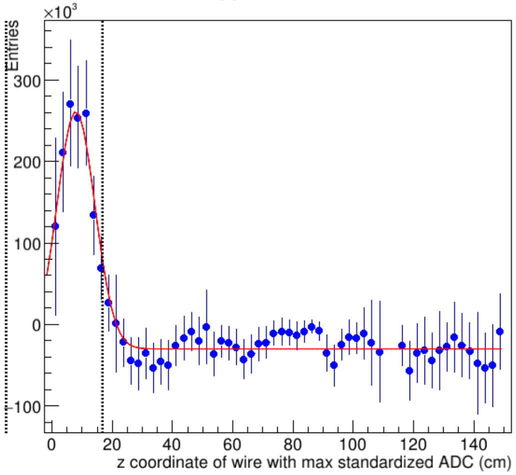
Cross-check of N-S Counter Alignment

Matt Thiesse

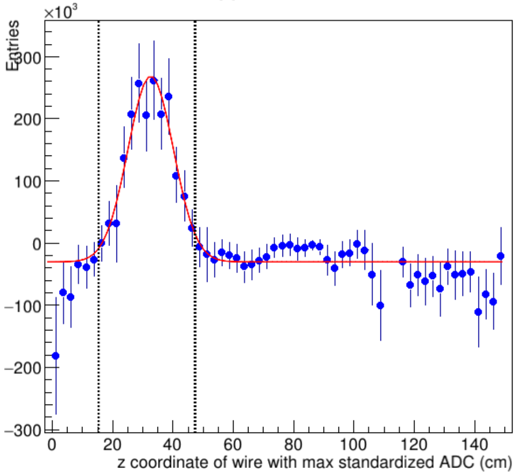
For N-S triggered events, look at the Z of the collection wire with the largest hit, for each tick.

Work in Progress

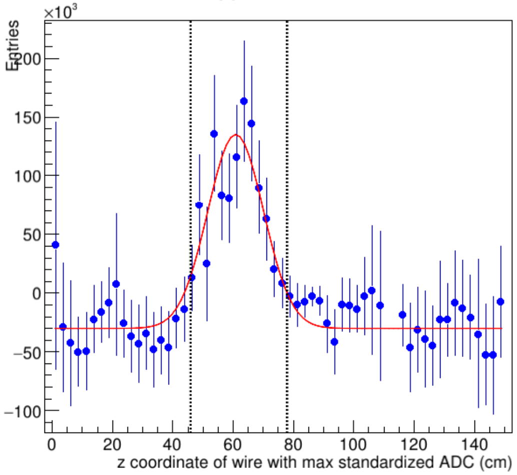
Counters Triggered: 0/27 & 38/21



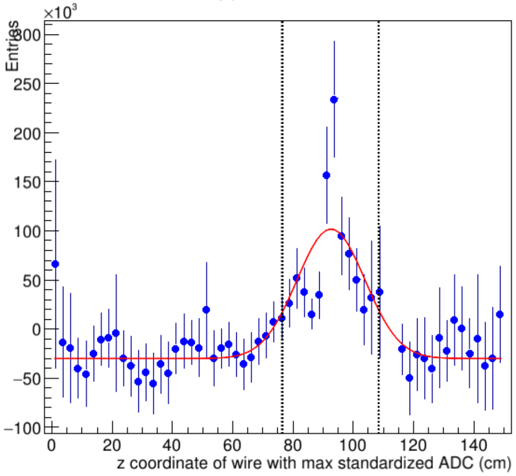
Counters Triggered: 1/26 & 39/20



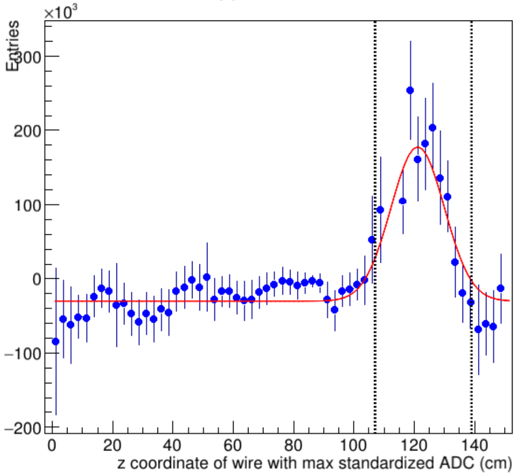
Counters Triggered: 2/25 & 40/19



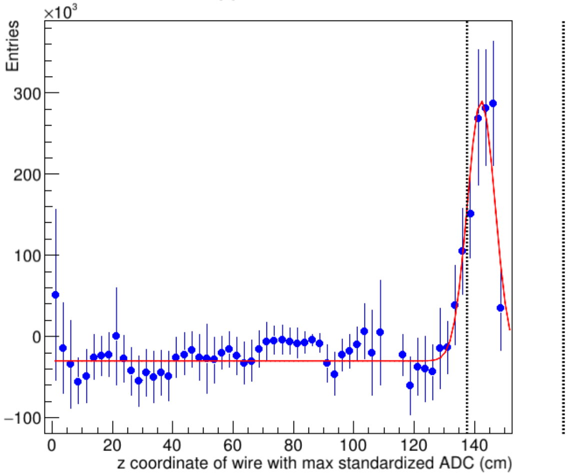
Counters Triggered: 3/24 & 41/18



Counters Triggered: 4/23 & 42/17



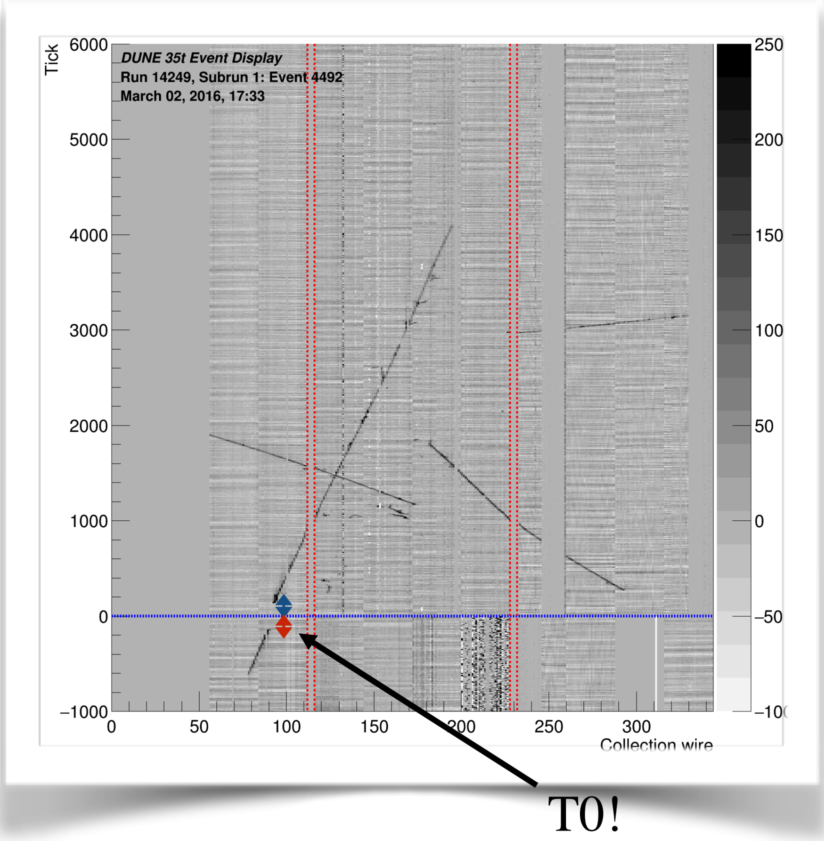
Counters Triggered: 5/22 & 43/16



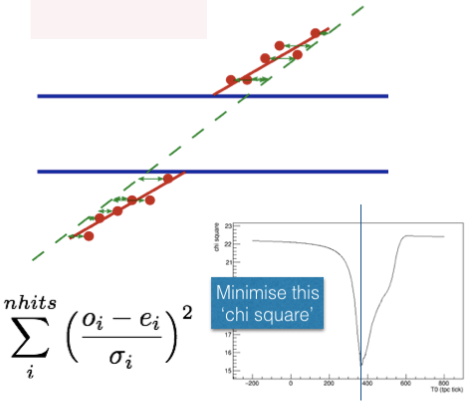
M Wallbank

APA-Crossing Muons: t_0 Measurement

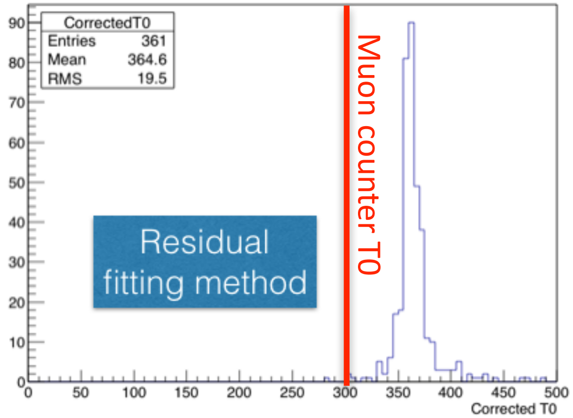
- Only planned LArTPC experiment before the final DUNE far detector utilising APAs reading out multiple drift regions simultaneously.
- Can give unique handle on the event t_0 directly from TPC data.
- Determined by minimising the residuals of a linear fit across the gap, as a function of various t_0 hypotheses.
- Found timing offset between the counters and TPC data of ~64 TPC ticks (32 μs).



T0!



$$\sum_{i}^{nhits}\left(\frac{o_i - e_i}{\sigma_i}\right)^2$$

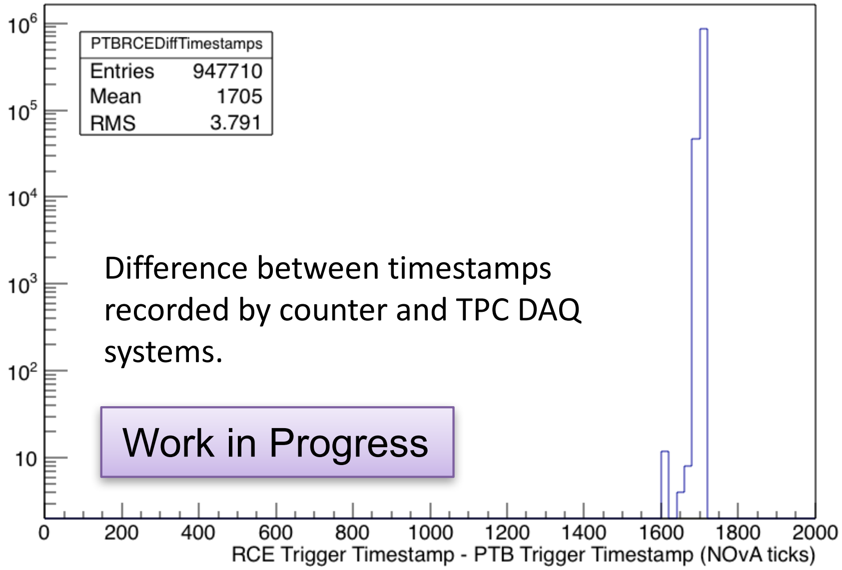


Residual fitting method

M Wallbank

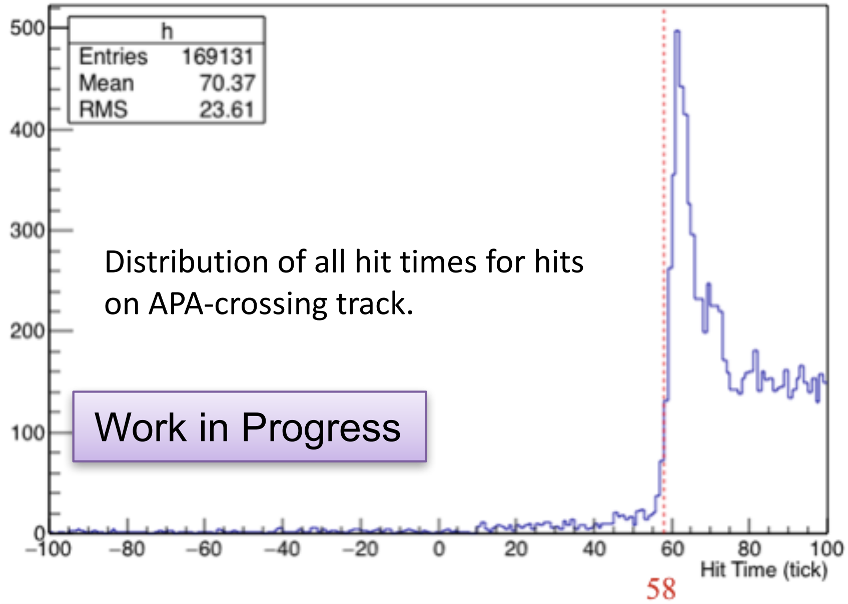
APA-Crossing Muons: t_0 Measurement

- Compare the timestamps of the trigger as recorded by the counters (PTB) and the TPC (RCE) (top plot):
    - 1705 NOvA ticks ~ 26.6 μs (~ 55 TPC ticks).
- Agrees with the leading edge of the distribution of all hit times on the APA-crossing track (bottom plot).
- Difference of ~ 6 μs between the two measurements:
    - If this were a geometry error, there would be a 6 mm offset in the APA width.
    - Measurements from PSL checked against software geometry with much tighter tolerances



Difference between timestamps recorded by counter and TPC DAQ systems.

Work in Progress



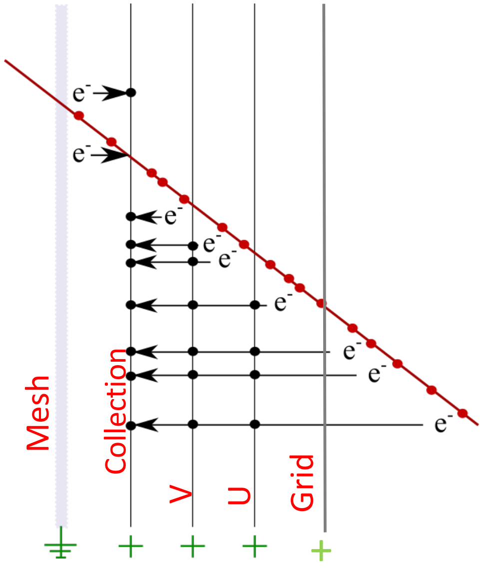
Distribution of all hit times for hits on APA-crossing track.

Work in Progress

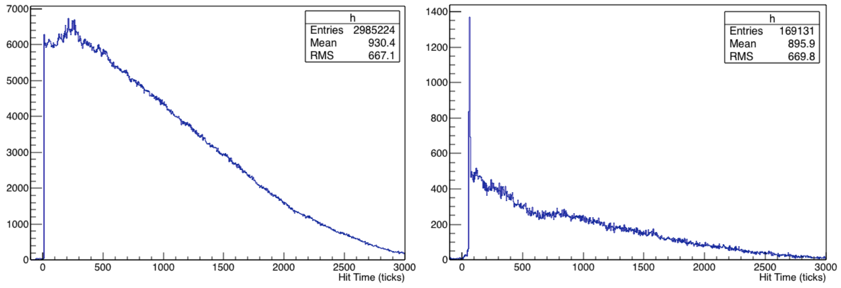
M Wallbank

APA-Crossing Muons: Deposited Charge

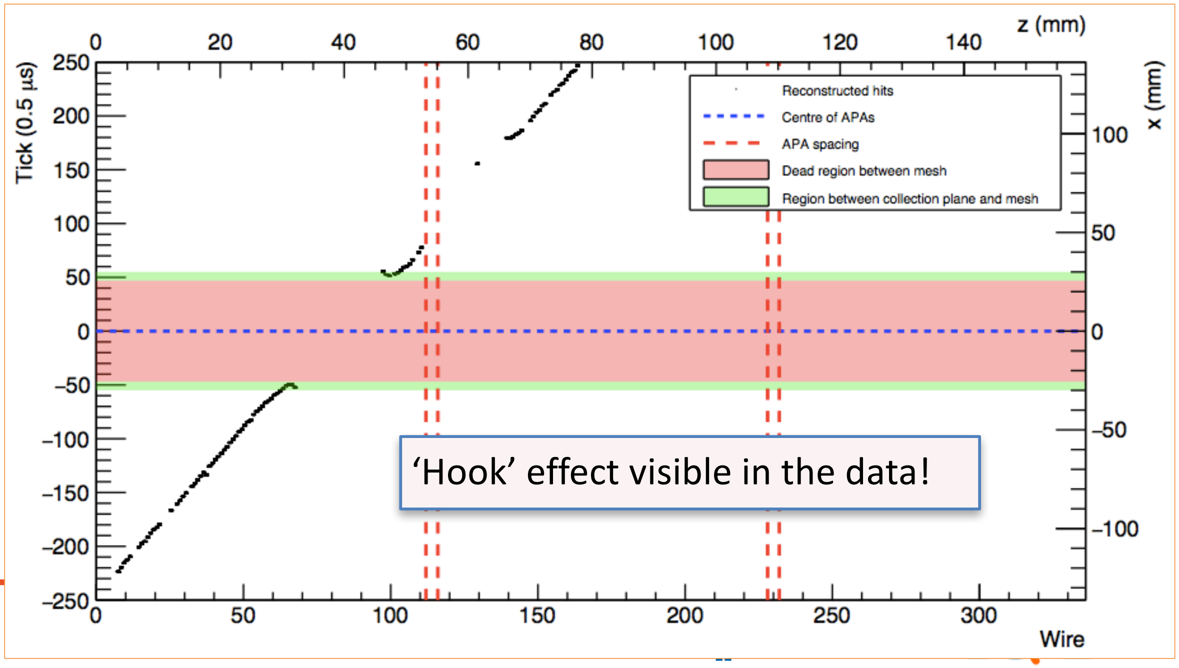
- Electric field changes direction on other side of the collection plane.
- Drift times are positive but distance is negative.
- Hits pile up at the minimum drift time.
- "Hooks" seen in event display
- Not yet simulated in the Monte Carlo
- Effect not seen in APA 3 collection wires over regions with no mesh. We still like the mesh, though.



Work in Progress



Hit time distributions for simulation (left) and data (right)

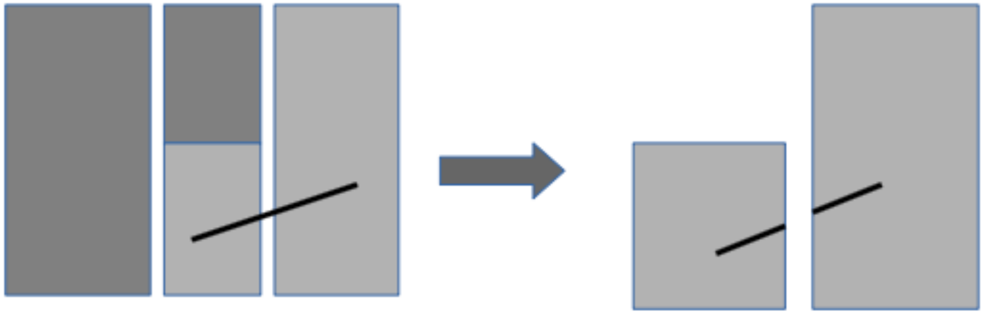


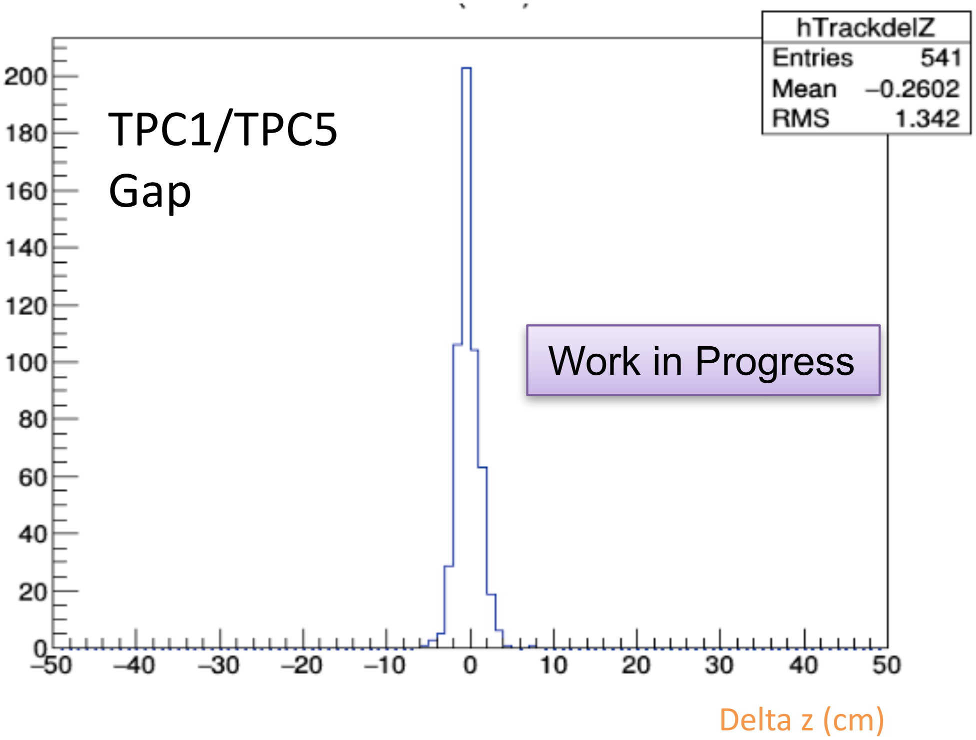
‘Hook’ effect visible in the data!

A Chatterjee

z-Gap-Crossing Muons

- Want to measure the gap in between the APA planes using crossing tracks.
- Similar analysis to Wire-Plane crossers
- Would expect delta z of zero if the gap is as assumed — looks like it's very close.
- Can measure each gap separately.



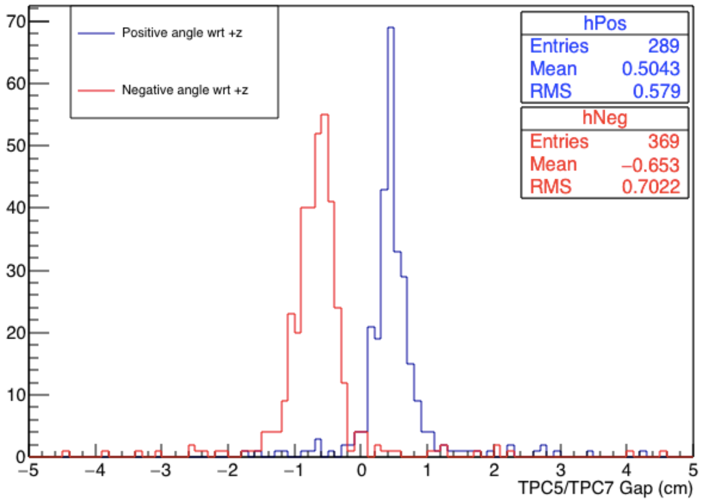


M Wallbank

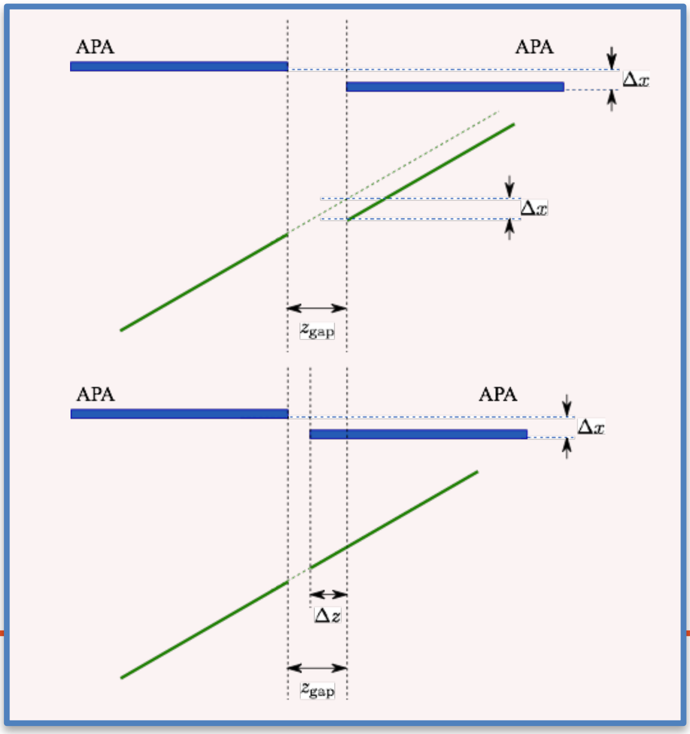
APA Gap Crossing Muons

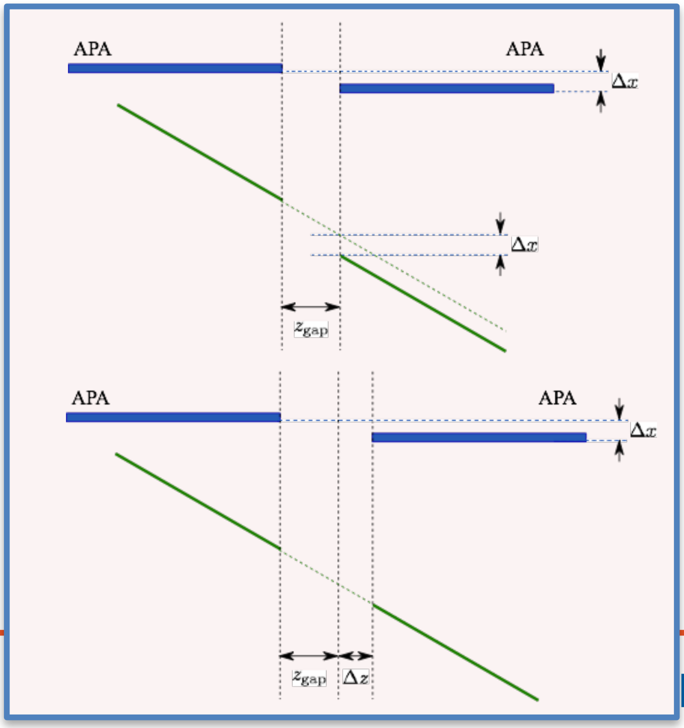
Work in Progress

- Noticed a strange ‘double peak’ effect, with the measured *z*-offset dependent on the angle the track makes wrt the APAs.
- Could be due to an *x*-offset (or equivalently a timing offset) between the APAs.
- Need tracks at several angles, but both offsets can be constrained



Positive track angle: measure negative *z*-offset



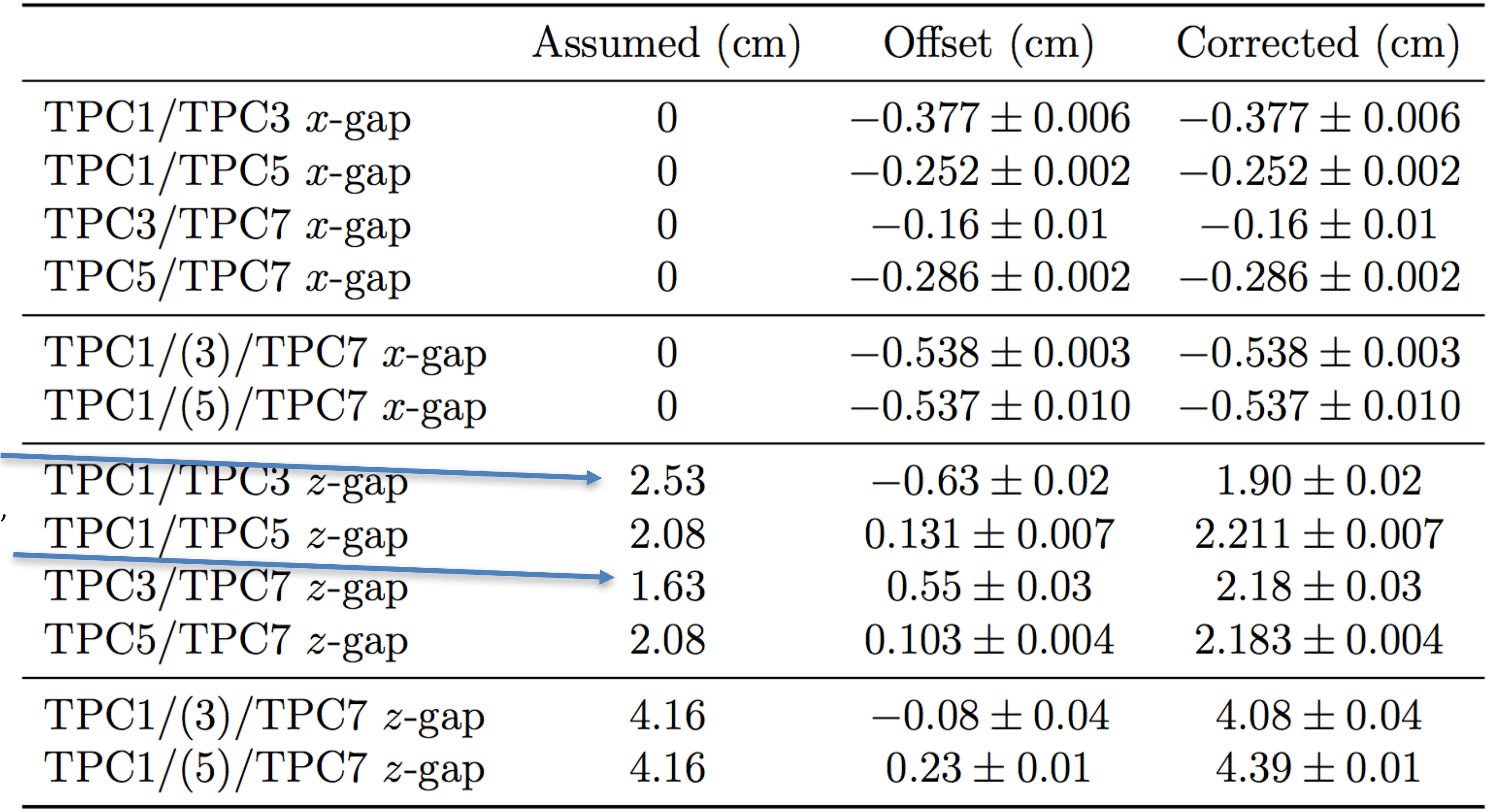


Negative track angle: measure positive *z*-offset

Measured *x* and *z* offsets

Work in Progress

M. Wallbank



	Assumed (cm)	Offset (cm)	Corrected (cm)
TPC1/TPC3 x-gap	0	-0.377 ± 0.006	-0.377 ± 0.006
TPC1/TPC5 x-gap	0	-0.252 ± 0.002	-0.252 ± 0.002
TPC3/TPC7 x-gap	0	-0.16 ± 0.01	-0.16 ± 0.01
TPC5/TPC7 x-gap	0	-0.286 ± 0.002	-0.286 ± 0.002
TPC1/(3)/TPC7 x-gap	0	-0.538 ± 0.003	-0.538 ± 0.003
TPC1/(5)/TPC7 x-gap	0	-0.537 ± 0.010	-0.537 ± 0.010
TPC1/TPC3 z-gap	2.53	-0.63 ± 0.02	1.90 ± 0.02
TPC1/TPC5 z-gap	2.08	0.131 ± 0.007	2.211 ± 0.007
TPC3/TPC7 z-gap	1.63	0.55 ± 0.03	2.18 ± 0.03
TPC5/TPC7 z-gap	2.08	0.103 ± 0.004	2.183 ± 0.004
TPC1/(3)/TPC7 z-gap	4.16	-0.08 ± 0.04	4.08 ± 0.04
TPC1/(5)/TPC7 z-gap	4.16	0.23 ± 0.01	4.39 ± 0.01

Geometry
had a mistake
(1 wire). Animesh
Chatterjee found it,
and we sought to
measure it.

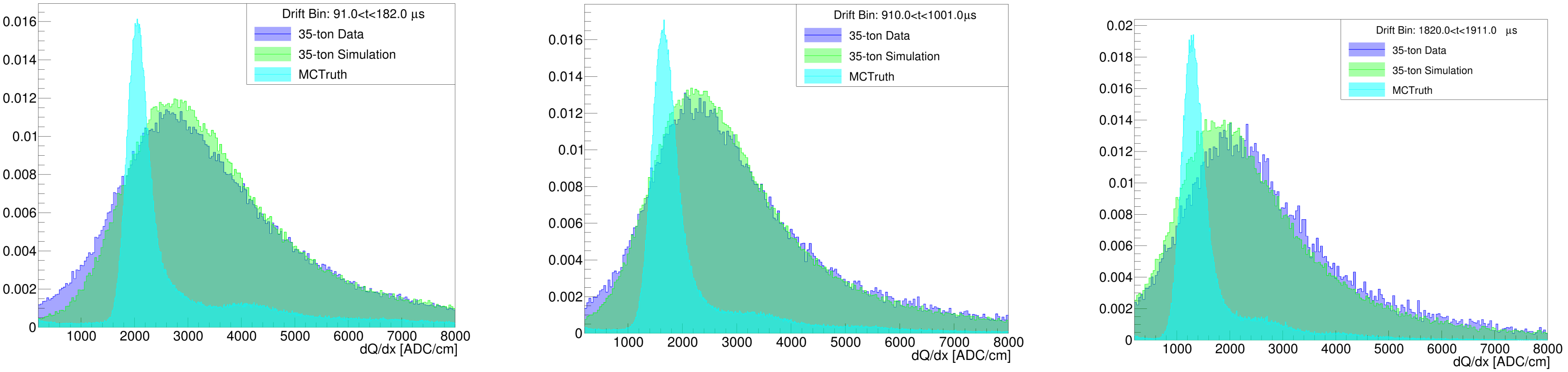
Uncertainties are statistical only

Measuring Lifetime from Tracks

Work in Progress

Matt Thiesse

dQ/dx Distributions from a Robust Hit Finder, corrected for track angle



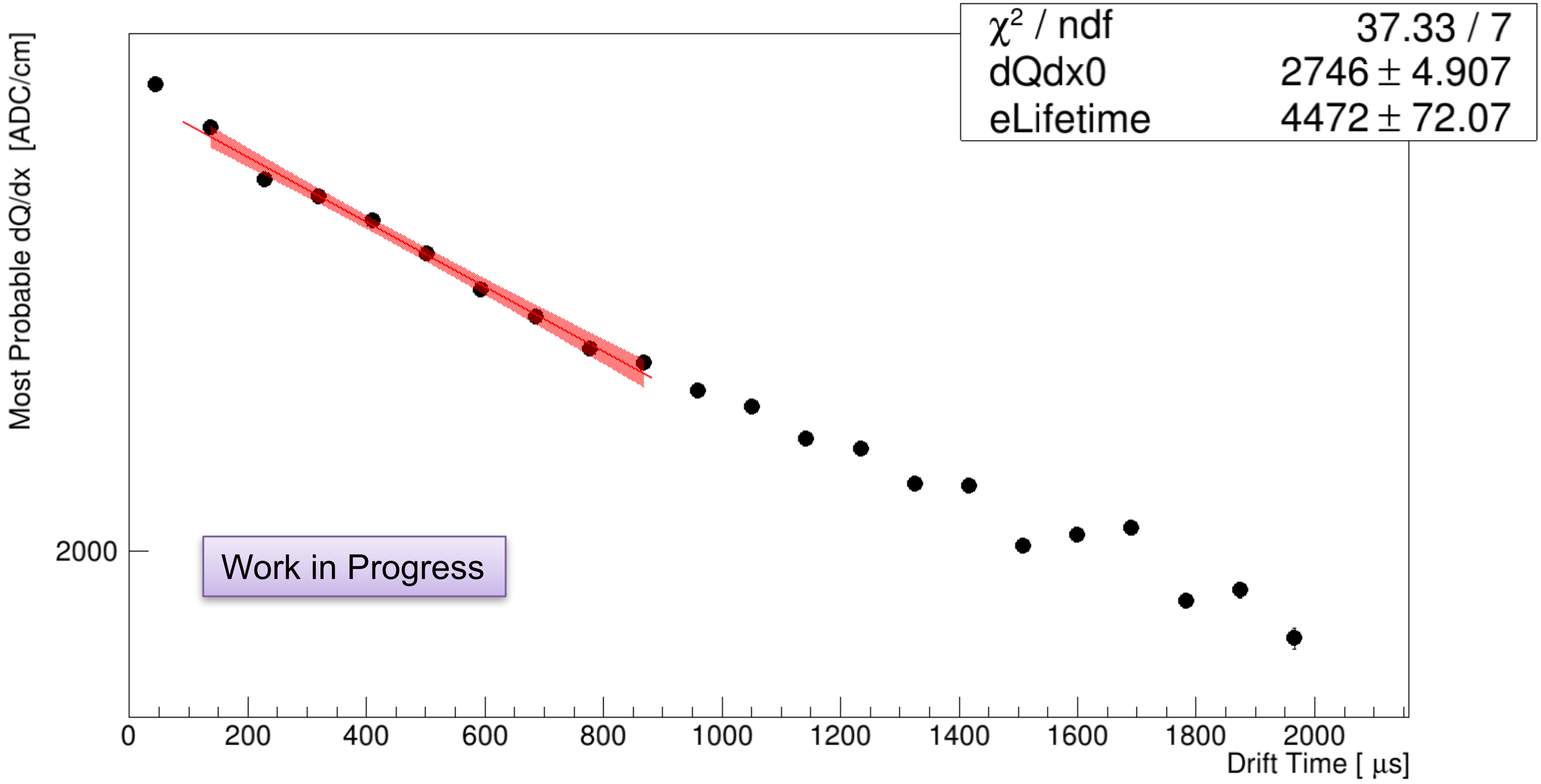
Short Drift lengths

Medium Drift lengths

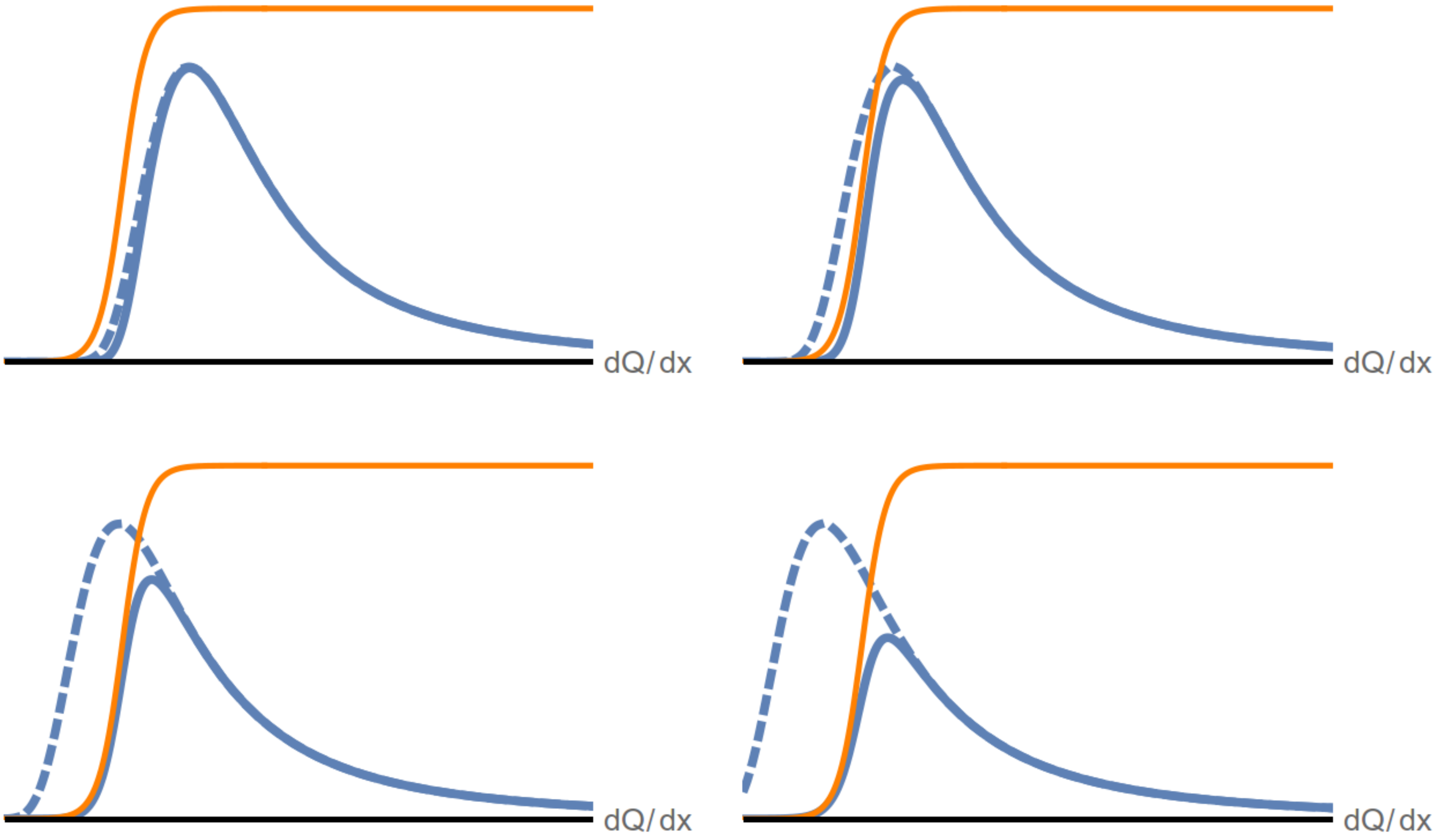
Long Drift lengths

Measuring the Lifetime with Tracks

Matt Thiesse



Biases due to Hit-Finding Thesholdds



Landau distribution (solid blue) is sculpted by the hit-finder efficiency threshold (orange curve)

Tends to make lifetime look too long at small signal sizes.

Worse with higher noise.

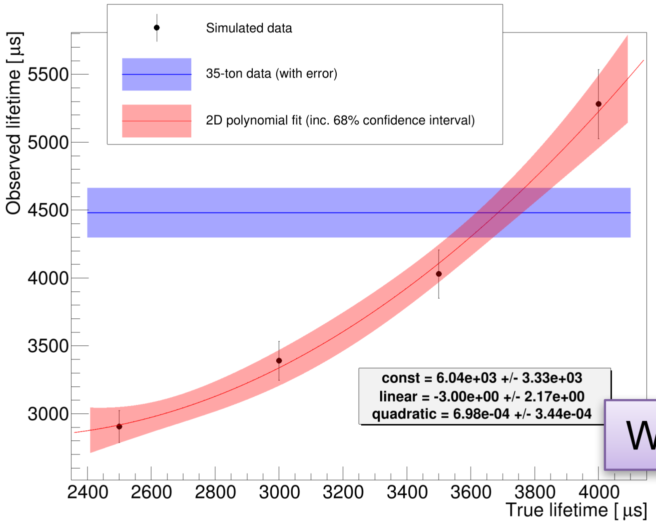
Two effects of noise – need higher threshold, and noise adds randomness to the hits.

Correcting for the Bias

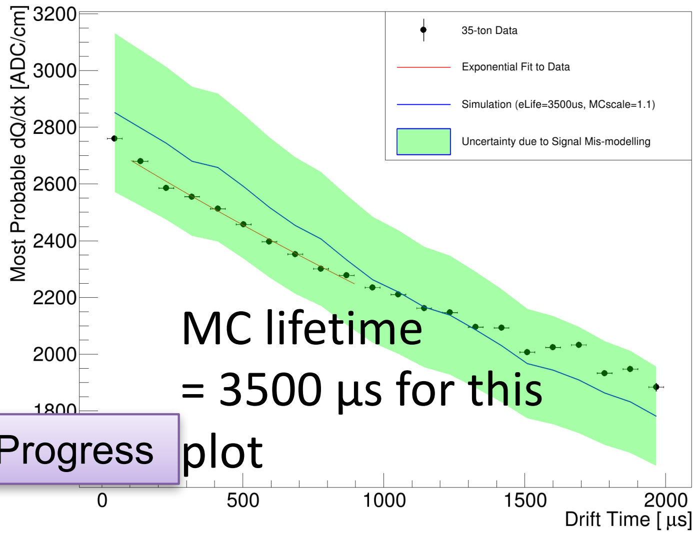
Matt Thiesse

- Data events overlaid on MC to simulate noise.
  - MC signal scales are varied and tuned to the data
  - Analysis is repeated in MC with data overlay at different lifetimes to see what the measured lifetime is as a function of input lifetime.
  - Used as a calibration curve for the analysis.
  - Check to see of dQ/dx modeling is good for entire drift time.

Measured Lifetime = $3683^{+169}_{-160}\ (\text{stat.})\ \pm 789\ (\text{syst.})\ \mu s$



Work in Progress



MC lifetime = 3500 µs for this plot

Measuring Event Time from Diffusion

K. Warburton
M. Stancari

- Diffusion broadens the signal both in
  - arrival time: "longitudinal diffusion"
  - wire on which signal appears "transverse diffusion"
- Diffusion scales with the square root of the drift time, differently for longitudinal and transverse cases.
- Can measure diffusion coefficients if the detector is quiet and the signals are large
- An idea from Michelle, 2015, when devising the analysis plan for 35t. Alternatively, you can use the width of the signal pulses to compute the drift time, assuming diffusion coefficients measured elsewhere
- The drift time analysis is possible even when the noise is high

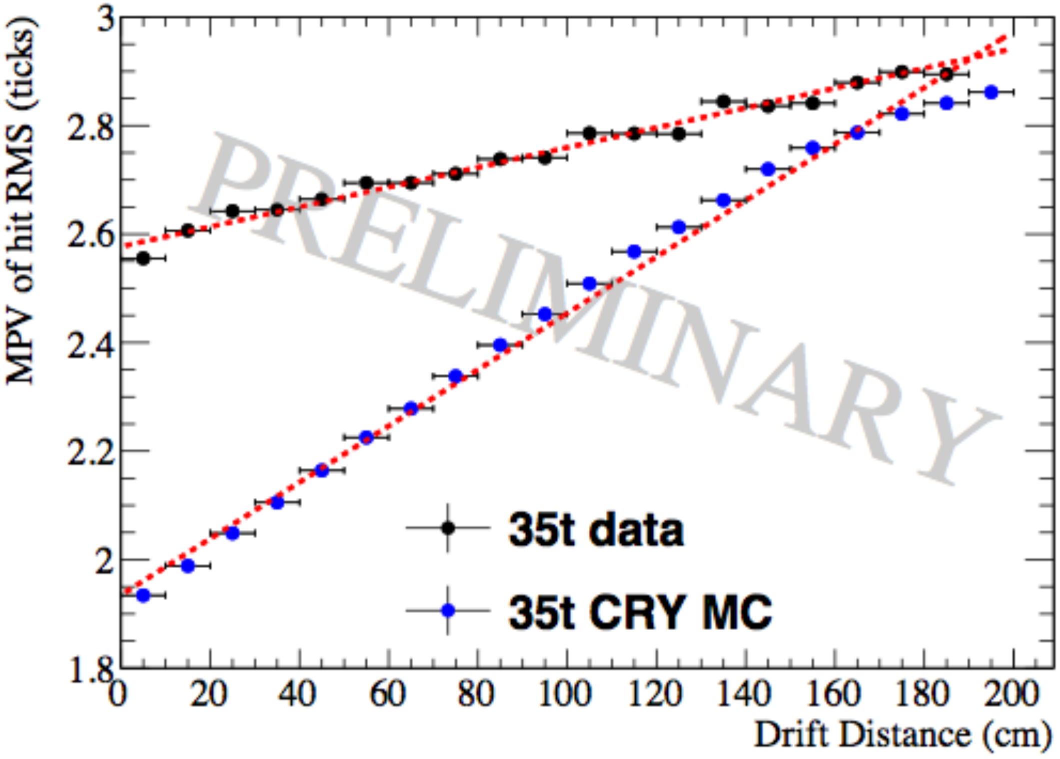
Lookup Tables For Distance

K. Warburton
M. Stancari

Transverse diffusion is difficult to measure – tracks naturally share charge among neighboring wires.

Use longitudinal diffusion –
hit width in time (RMS) increases with drift distance.

Transpose plot for the lookup table



Apply lookup to each hit on a track.
Average the inferred interaction time.

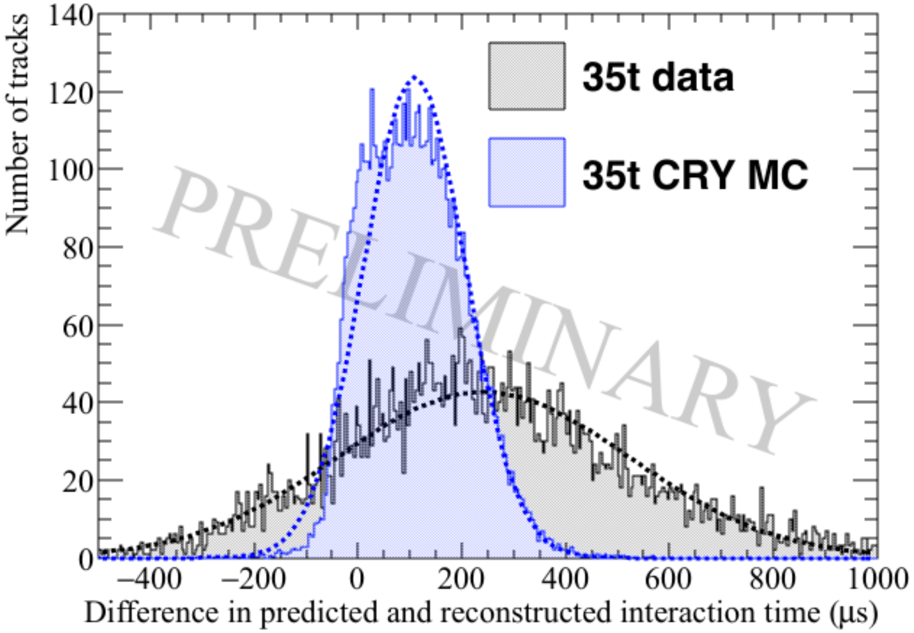
Distance Resolutions

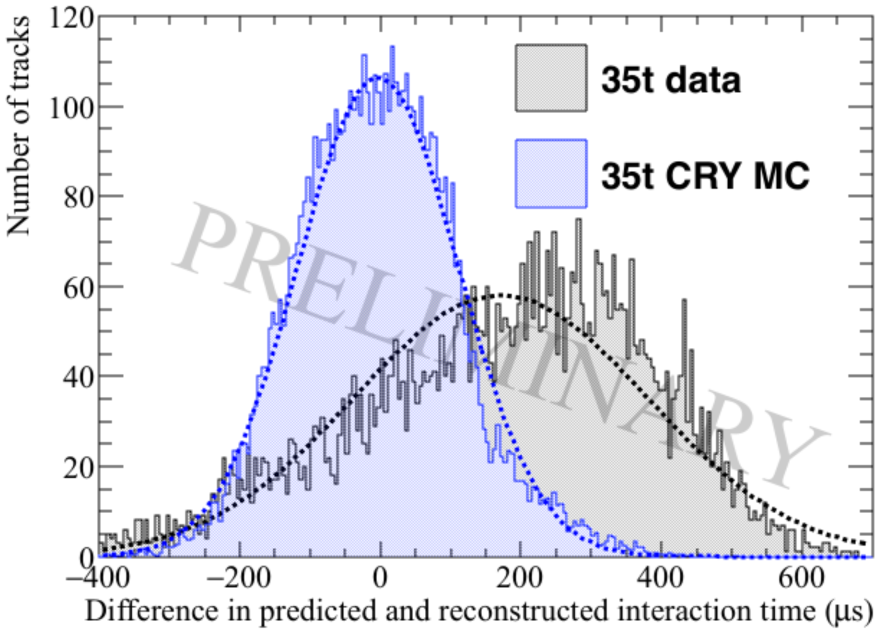
K. Warburton
M. Stancari

Using hit RMS as the metric

Using hit RMS/Q

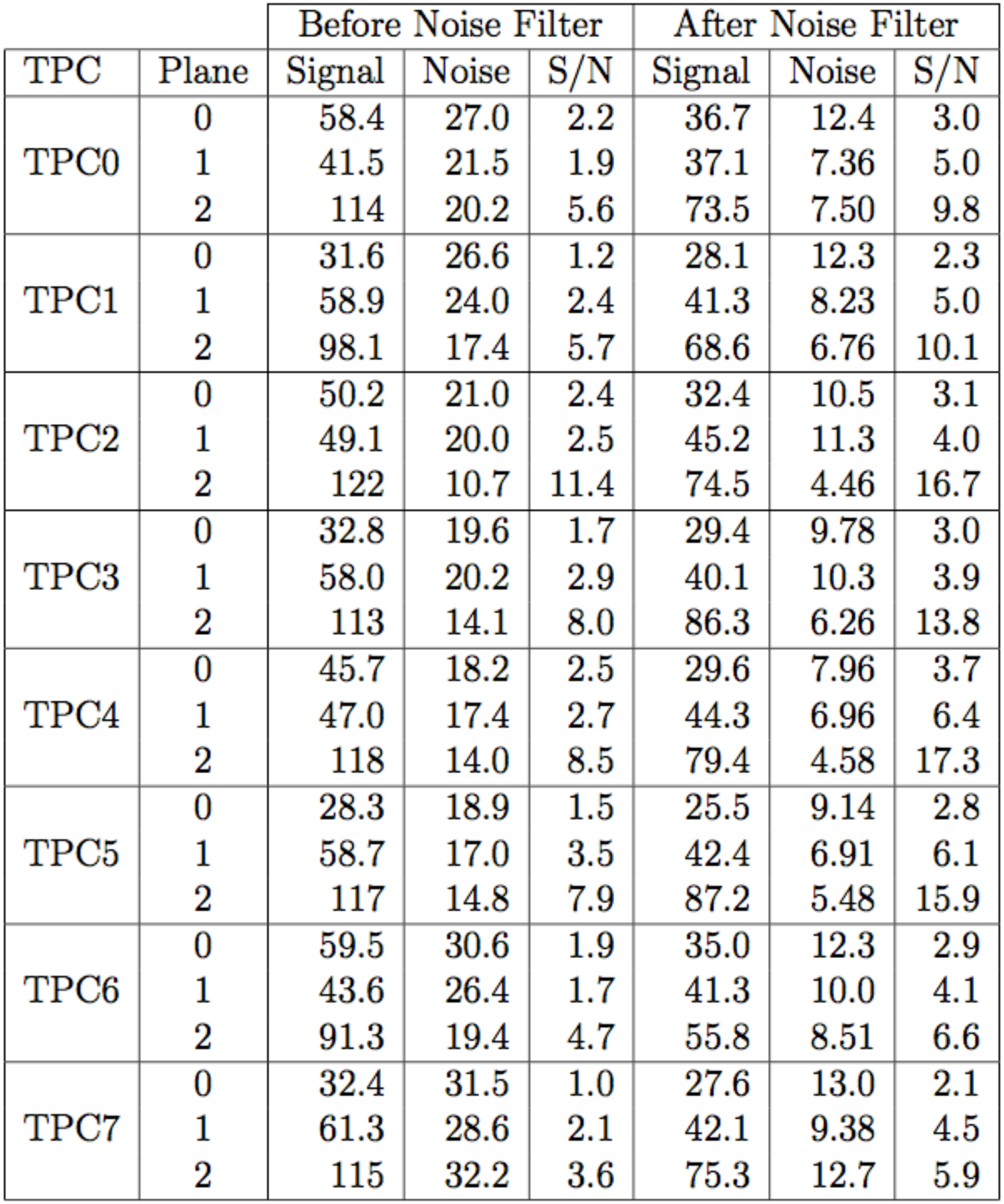
Advantage: less sensitive to track angle.
Better resolution in time.





Offsets and larger widths also seen in the MC when noise is increased.

Extra Slides

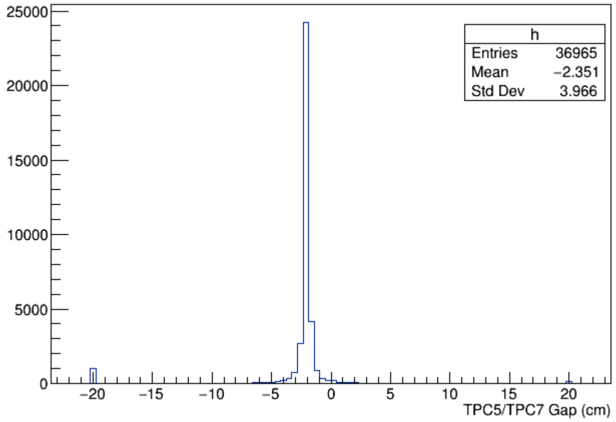


		Before Noise Filter			After Noise Filter		
TPC	Plane	Signal	Noise	S/N	Signal	Noise	S/N
TPC0	0	58.4	27.0	2.2	36.7	12.4	3.0
	1	41.5	21.5	1.9	37.1	7.36	5.0
	2	114	20.2	5.6	73.5	7.50	9.8
TPC1	0	31.6	26.6	1.2	28.1	12.3	2.3
	1	58.9	24.0	2.4	41.3	8.23	5.0
	2	98.1	17.4	5.7	68.6	6.76	10.1
TPC2	0	50.2	21.0	2.4	32.4	10.5	3.1
	1	49.1	20.0	2.5	45.2	11.3	4.0
	2	122	10.7	11.4	74.5	4.46	16.7
TPC3	0	32.8	19.6	1.7	29.4	9.78	3.0
	1	58.0	20.2	2.9	40.1	10.3	3.9
	2	113	14.1	8.0	86.3	6.26	13.8
TPC4	0	45.7	18.2	2.5	29.6	7.96	3.7
	1	47.0	17.4	2.7	44.3	6.96	6.4
	2	118	14.0	8.5	79.4	4.58	17.3
TPC5	0	28.3	18.9	1.5	25.5	9.14	2.8
	1	58.7	17.0	3.5	42.4	6.91	6.1
	2	117	14.8	7.9	87.2	5.48	15.9
TPC6	0	59.5	30.6	1.9	35.0	12.3	2.9
	1	43.6	26.4	1.7	41.3	10.0	4.1
	2	91.3	19.4	4.7	55.8	8.51	6.6
TPC7	0	32.4	31.5	1.0	27.6	13.0	2.1
	1	61.3	28.6	2.1	42.1	9.38	4.5
	2	115	32.2	3.6	75.3	12.7	5.9

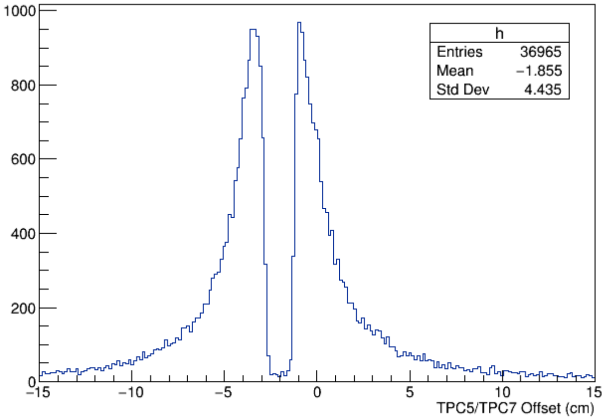
M Wallbank

APA Gap Crossing Muons

- In simulation, try introducing offsets between the APAs, in *x* and *z*.



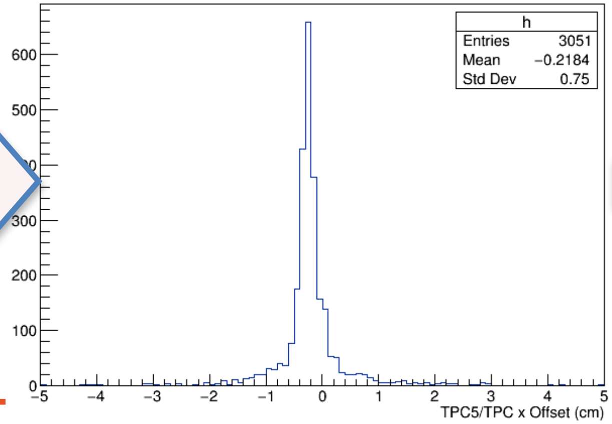
z-offset: 2 cm



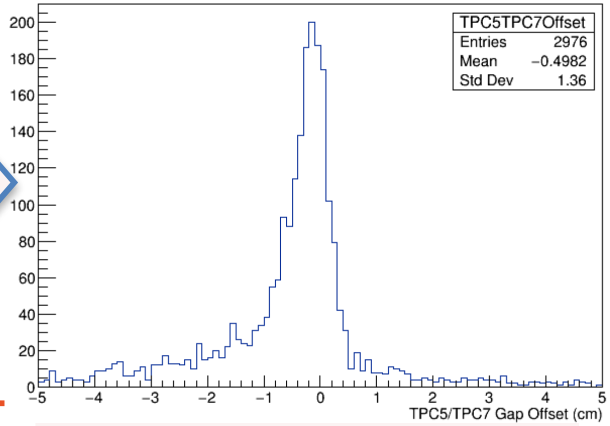
z-offset: 2 cm, *x*-offset: 0.5 cm

- Can measure *z*-offset from the minimum of the full distribution, then measure *x*-offset by aligning the tracks across the gap.

z-offset: -1 mm (from plot on previous page)



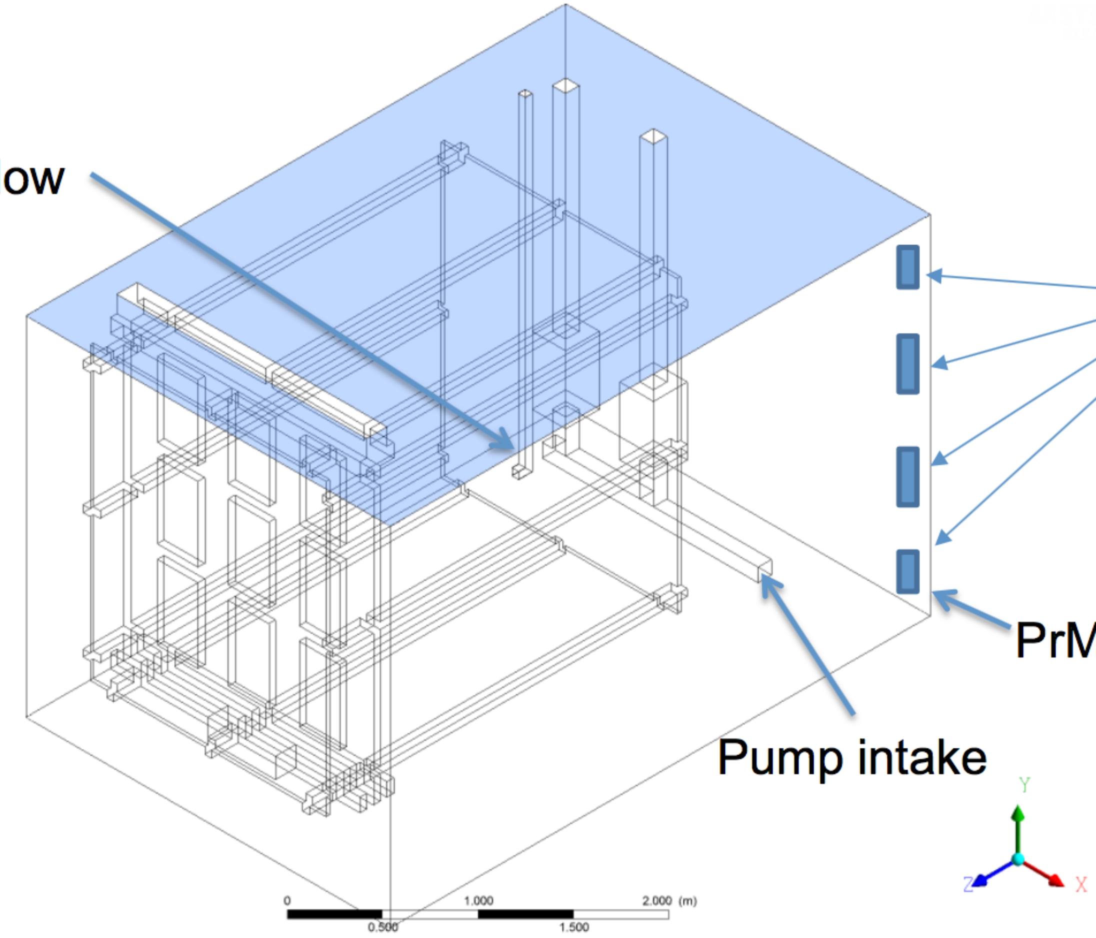
x-offset: -2 mm



Measure Δ*z* = -1 mm

Geometry of 35 Ton Cryostat

(from E.Voirin 35 Ton FEA calculations Dune DocDb 1156)



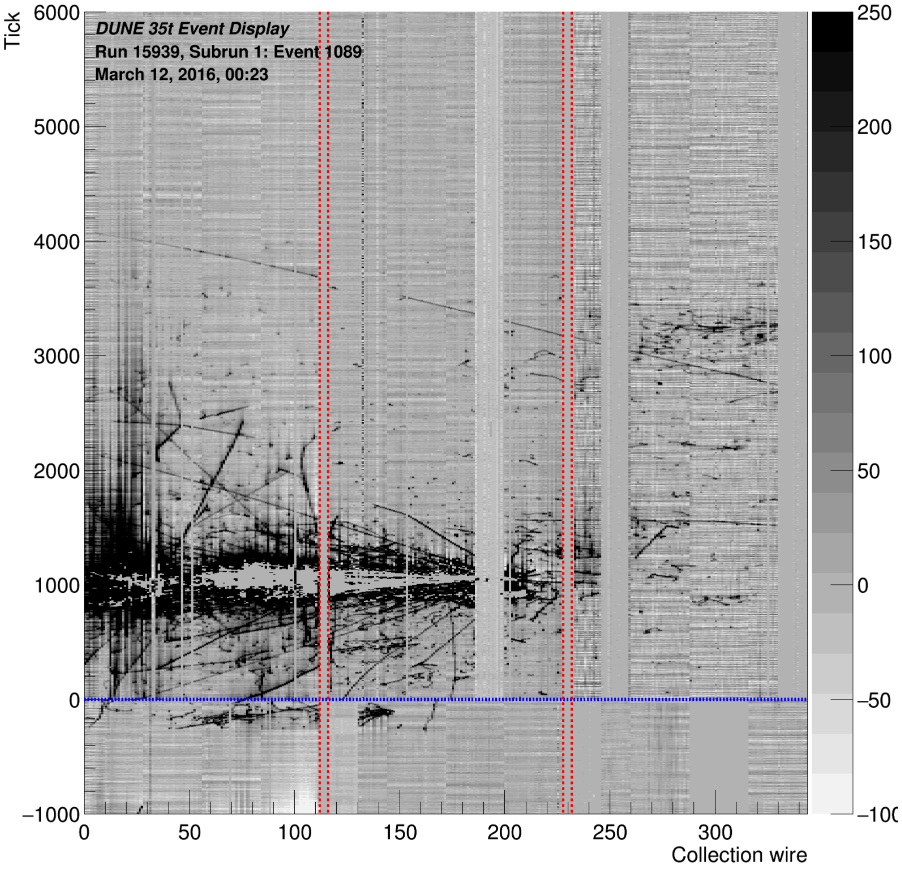
Pump outflow

4 purity monitors in this corner (Geometry Not in CFD model)

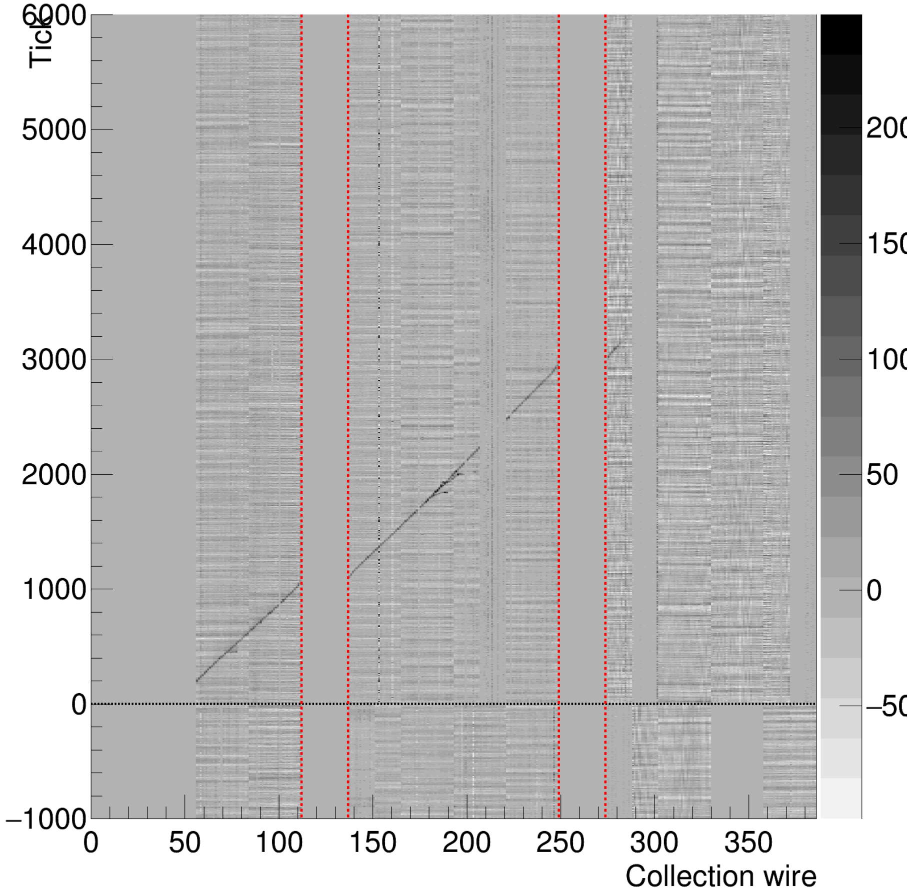
PrM1

Pump intake

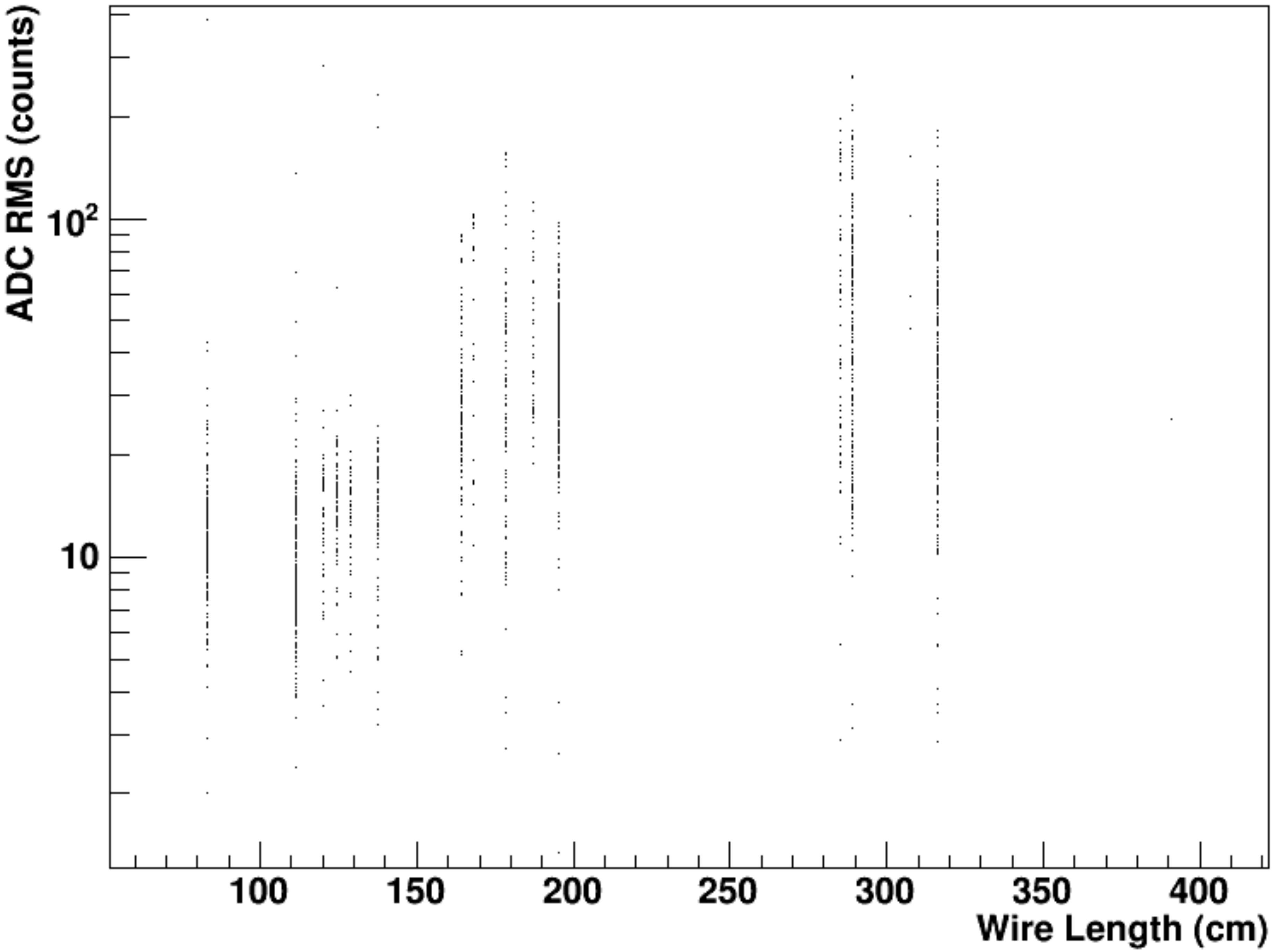
A Big Shower

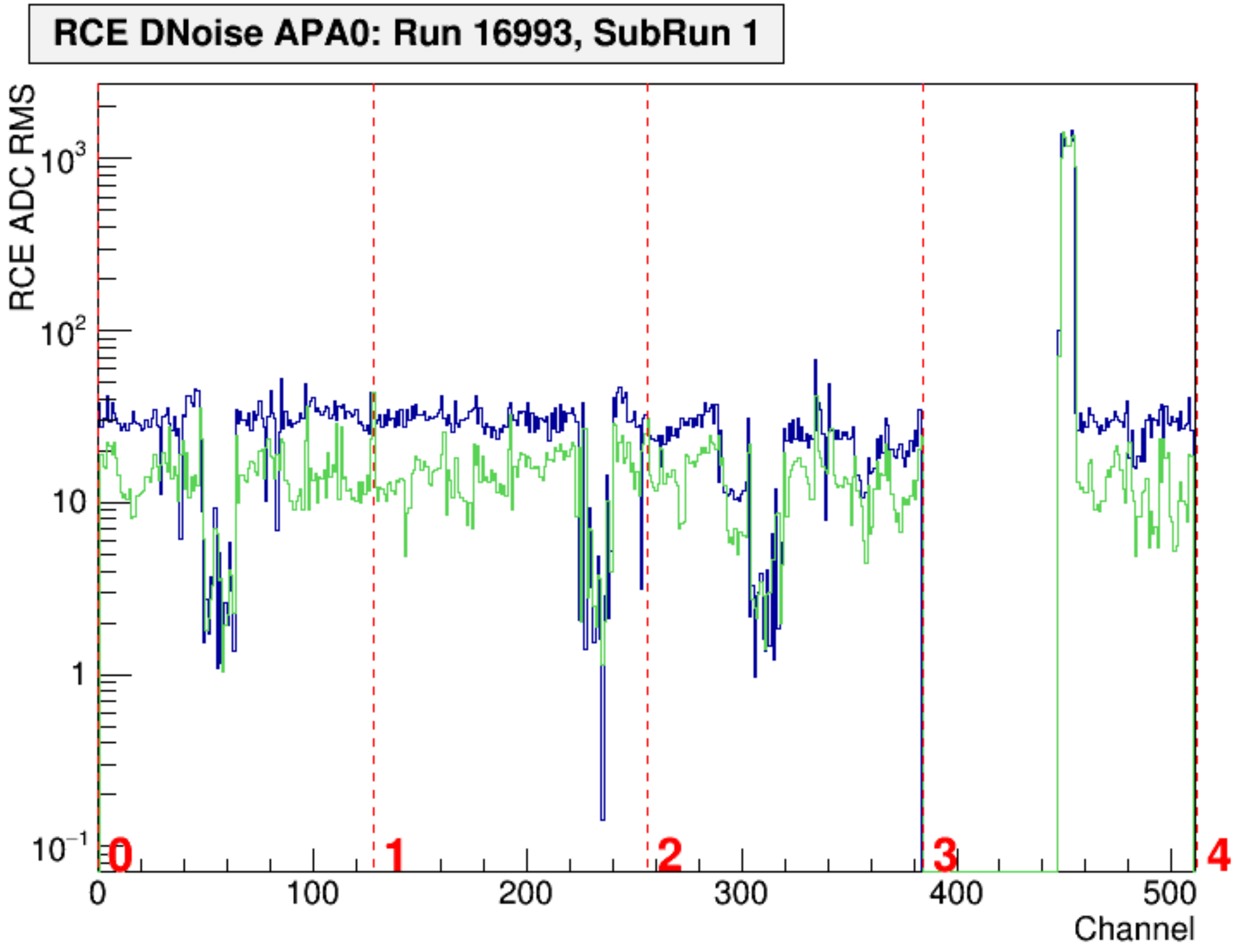


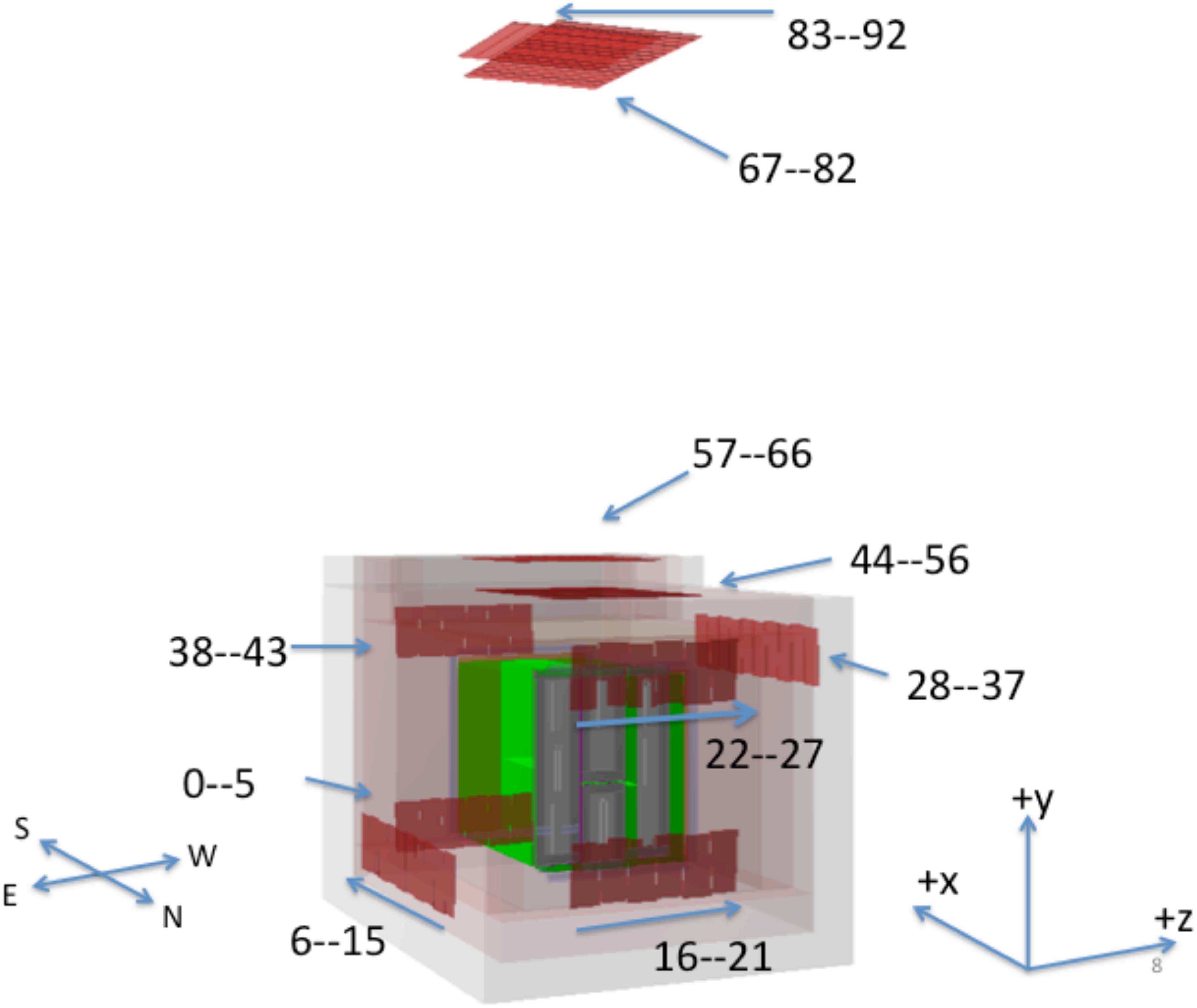
Early Online EVD with wrong gaps shown



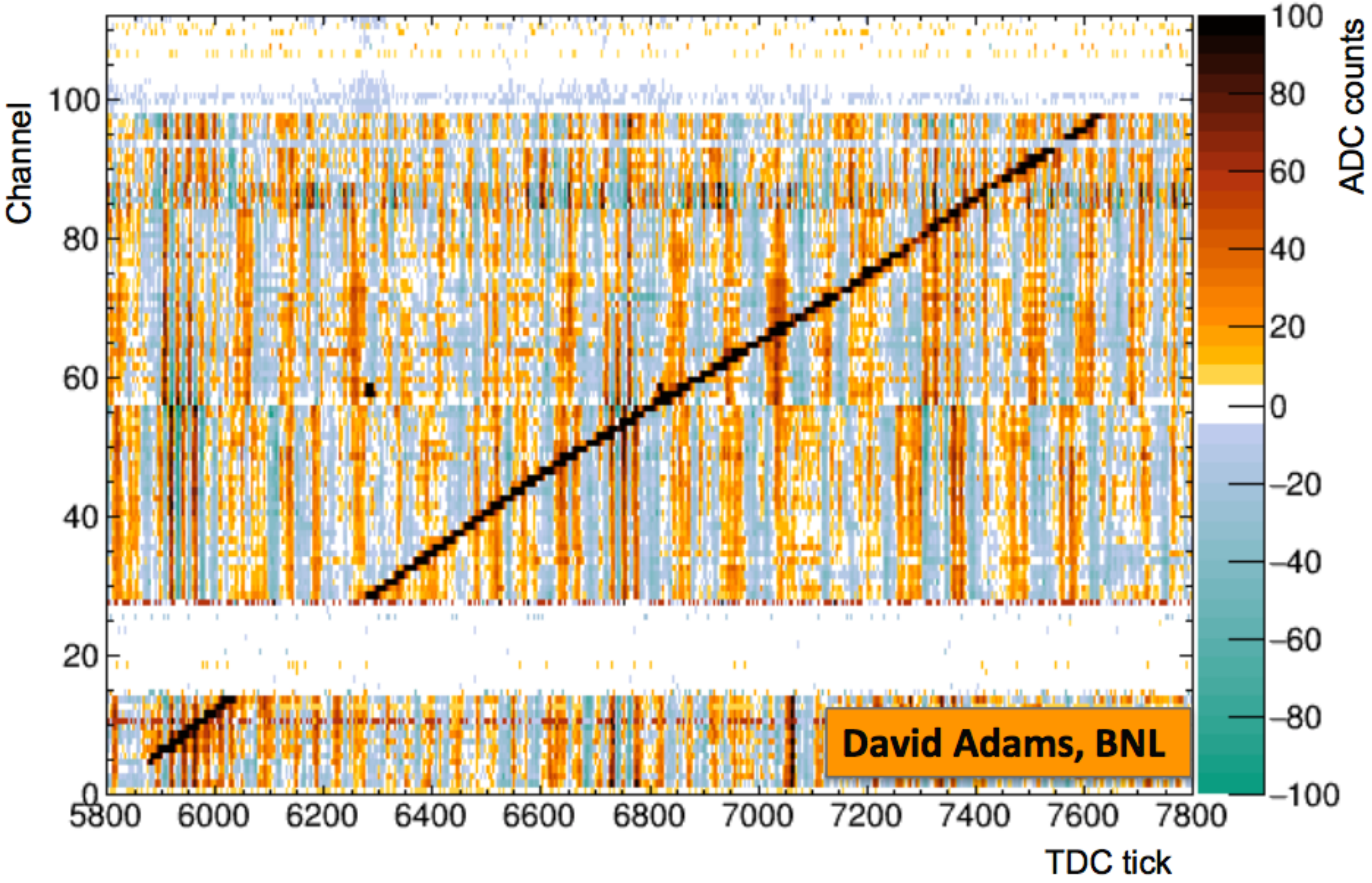
Noise vs. Wire Length – Normal Running




RCE DNoise APA0: Run 16993, SubRun 1
RCE ADC RMS
10^3
10^2
10
1
10^{-1}
0
1
2
3
4
0
100
200
300
400
500
Channel

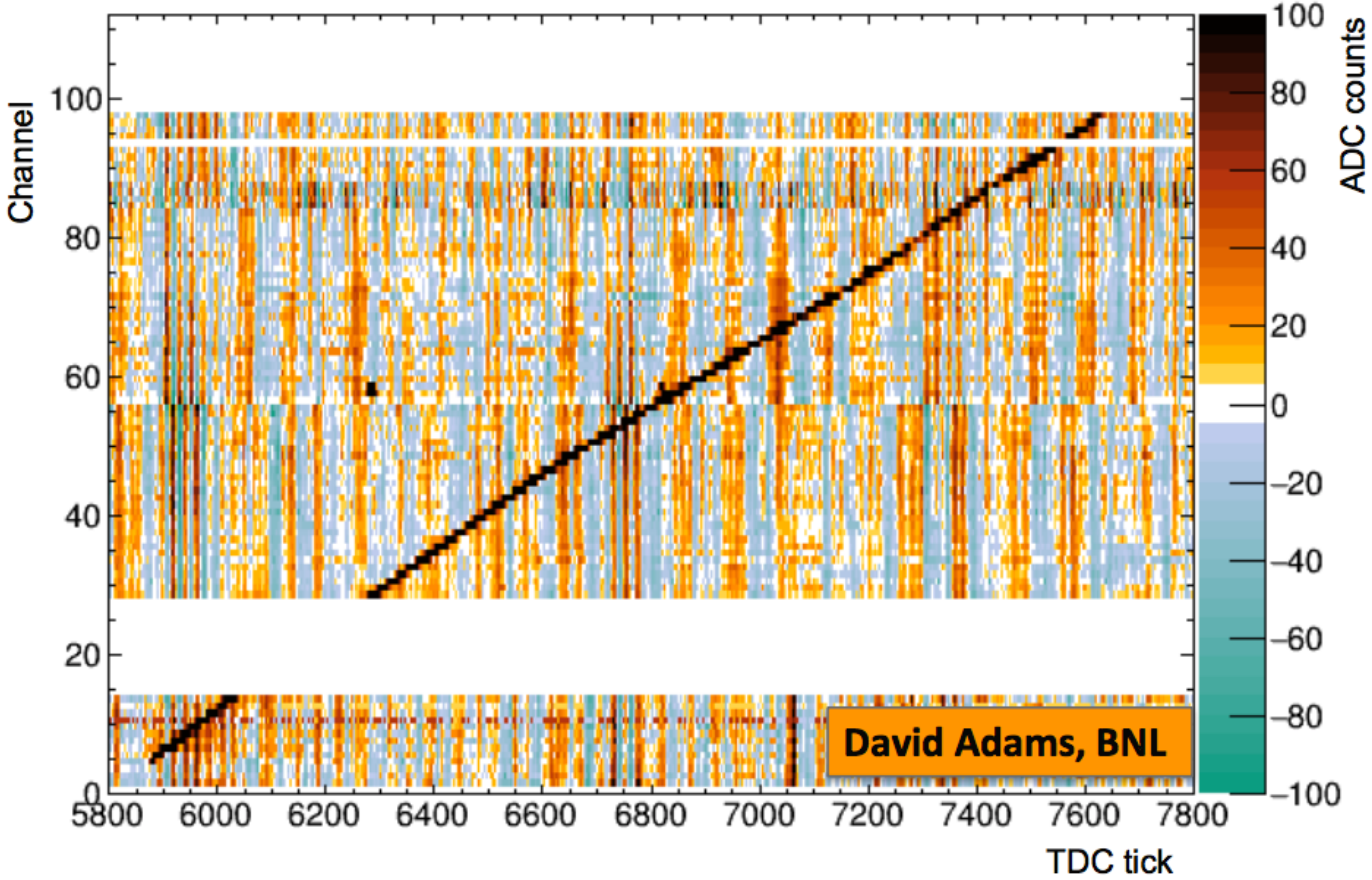

83--92
67--82
57--66
44--56
38--43
28--37
22--27
0--5
6--15
16--21
S
W
E
N
+y
+x
+z

Pedestal subtracted raw signal



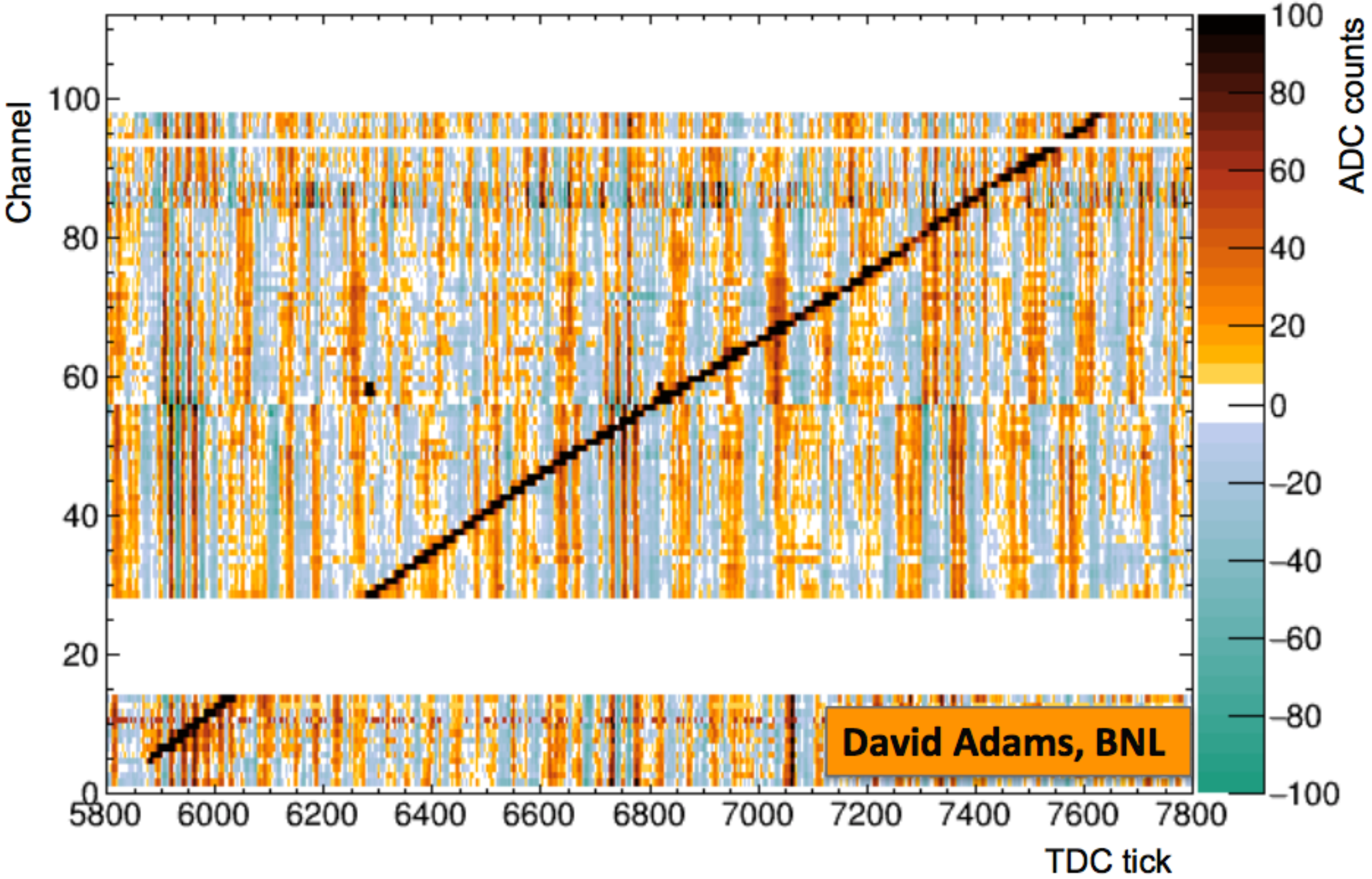
David Adams, BNL

Remove bad channels



David Adams, BNL

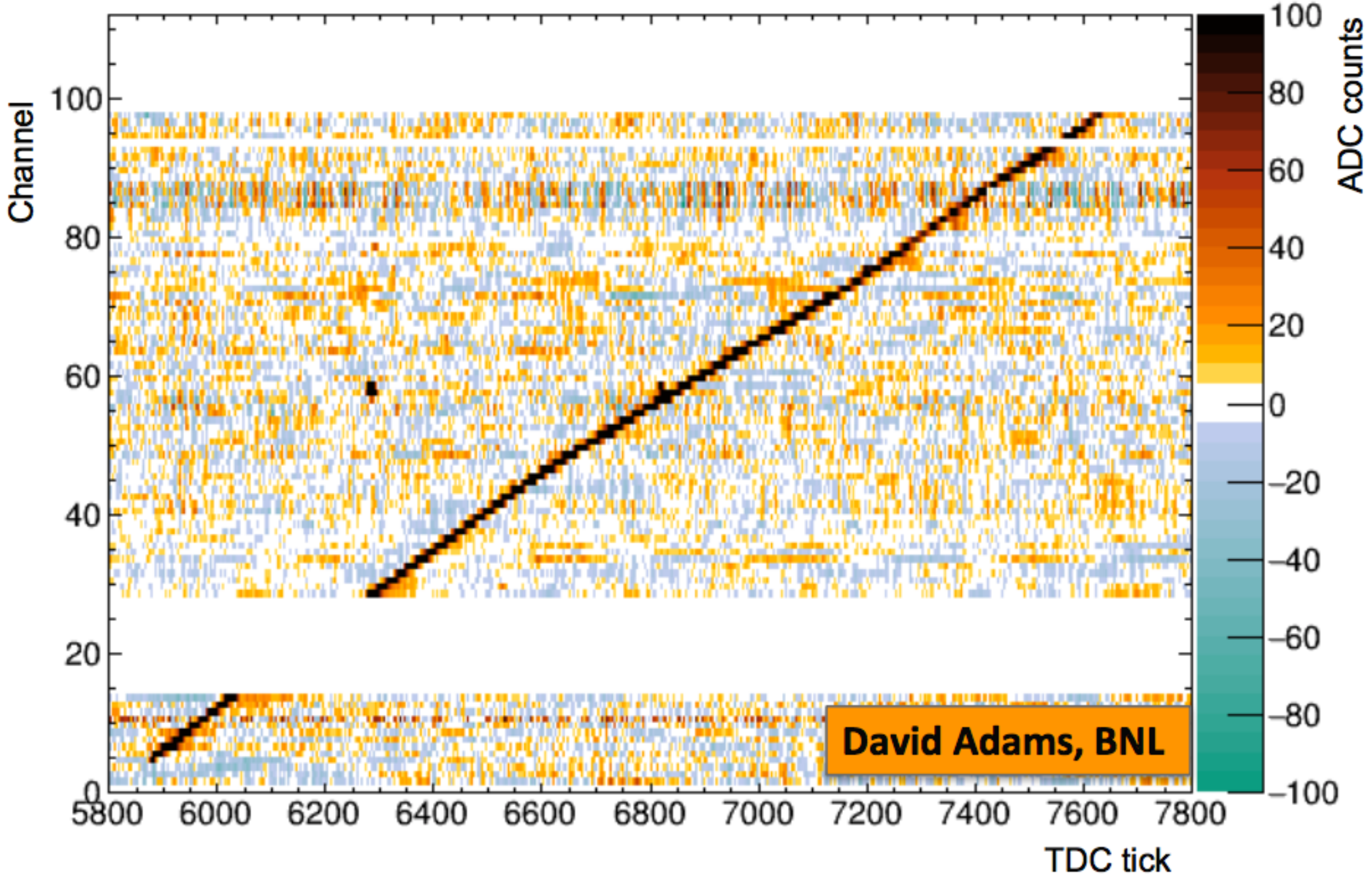
Remove stuck ADCs



David Adams, BNL

Remove coherent noise

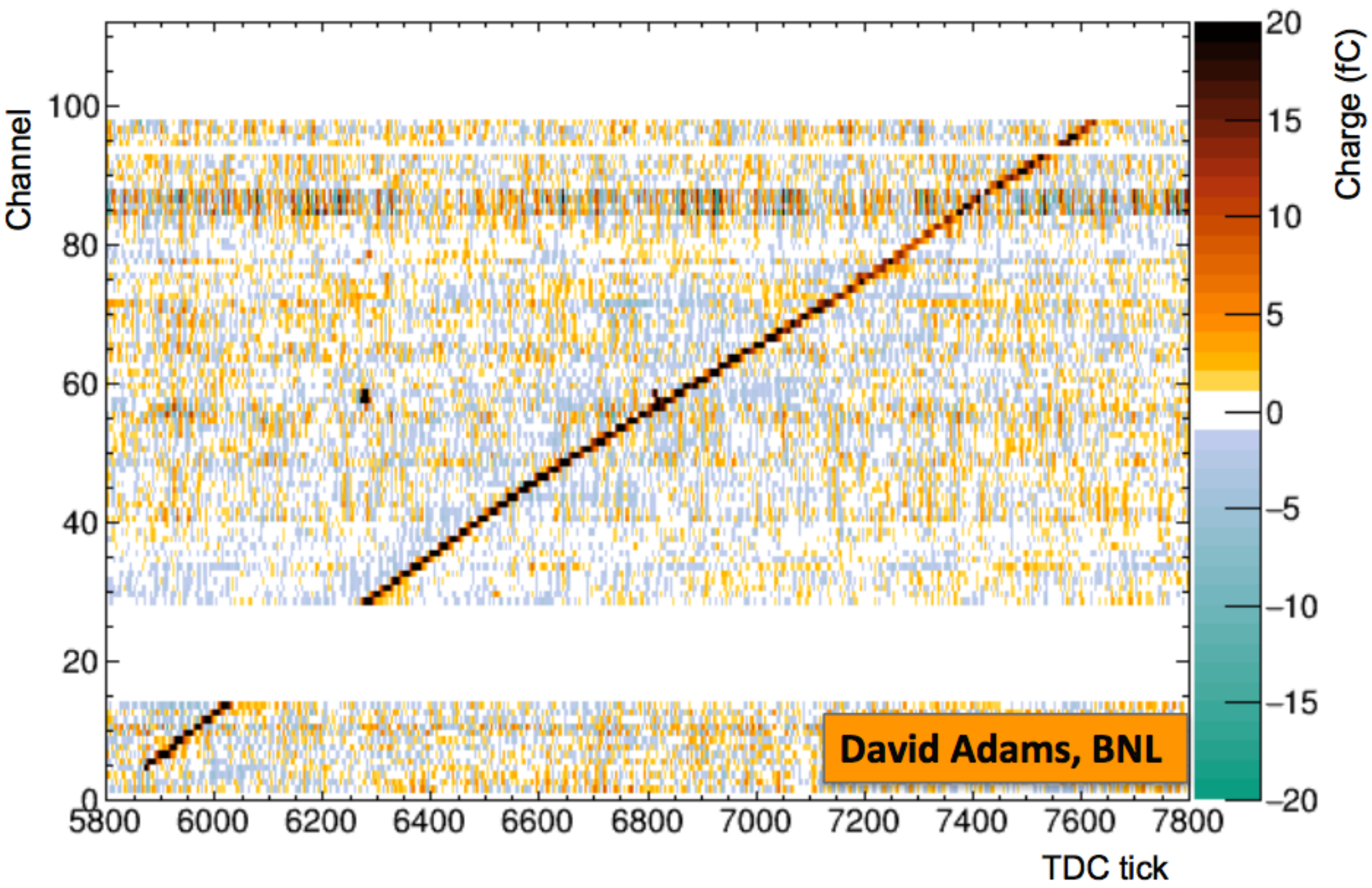
Subtract off median of channels sharing a power regulator



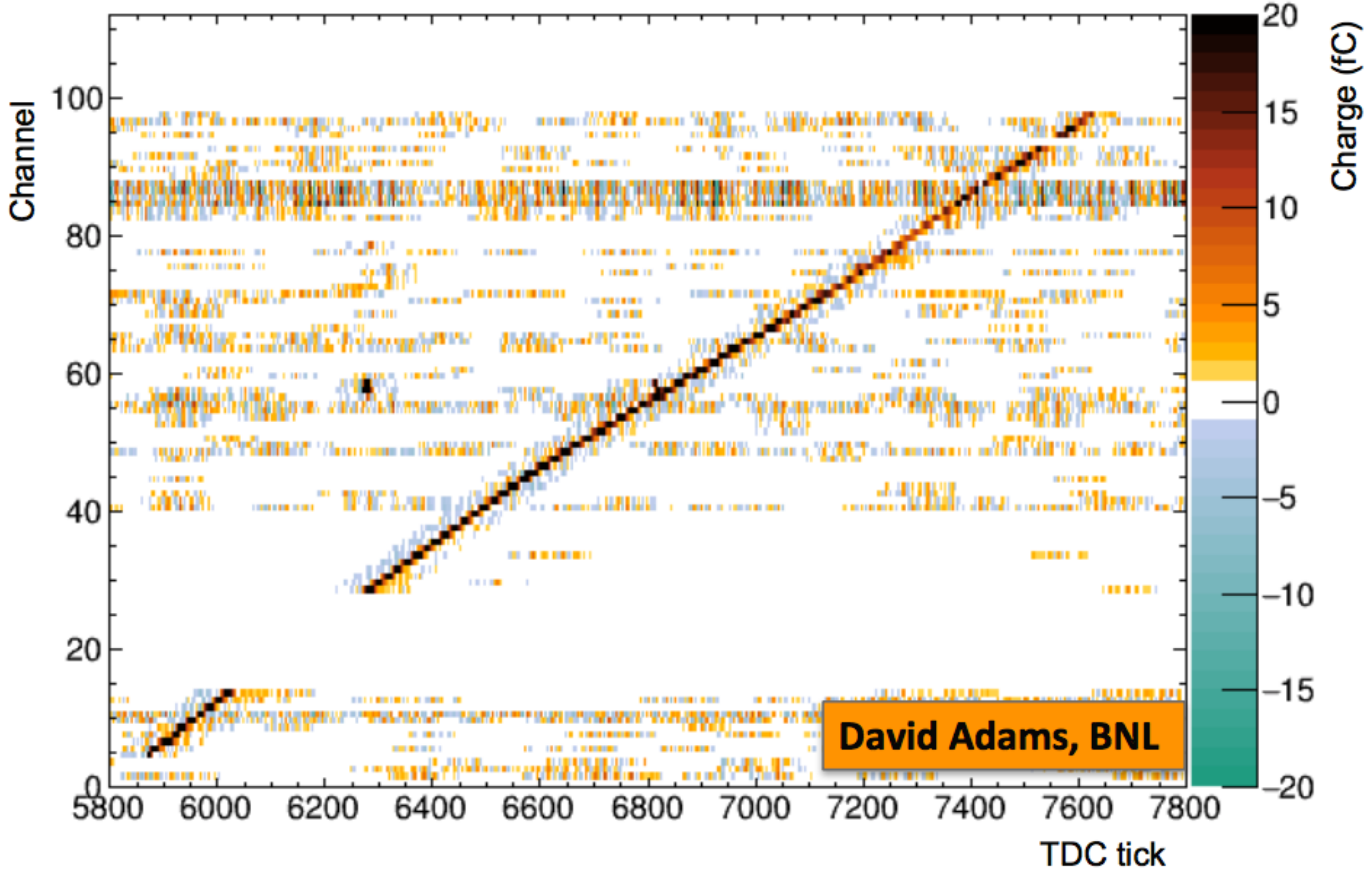
David Adams, BNL

Deconvolution

Includes Noise Filtering
in frequency space



Select region of interest



David Adams, BNL

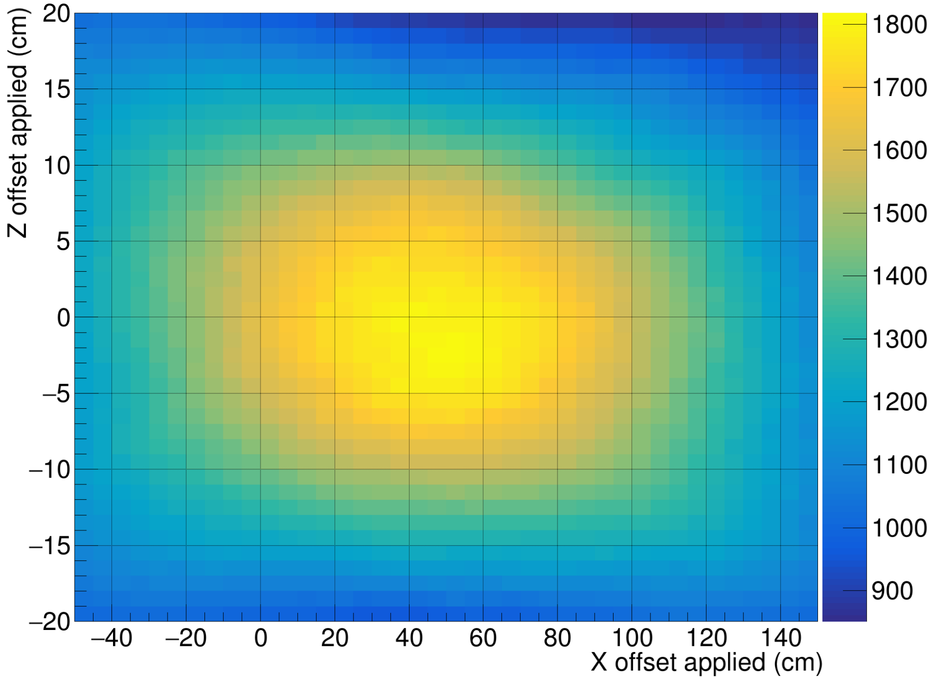
North-South Alignment Offset Measurements

Matt Thiesse

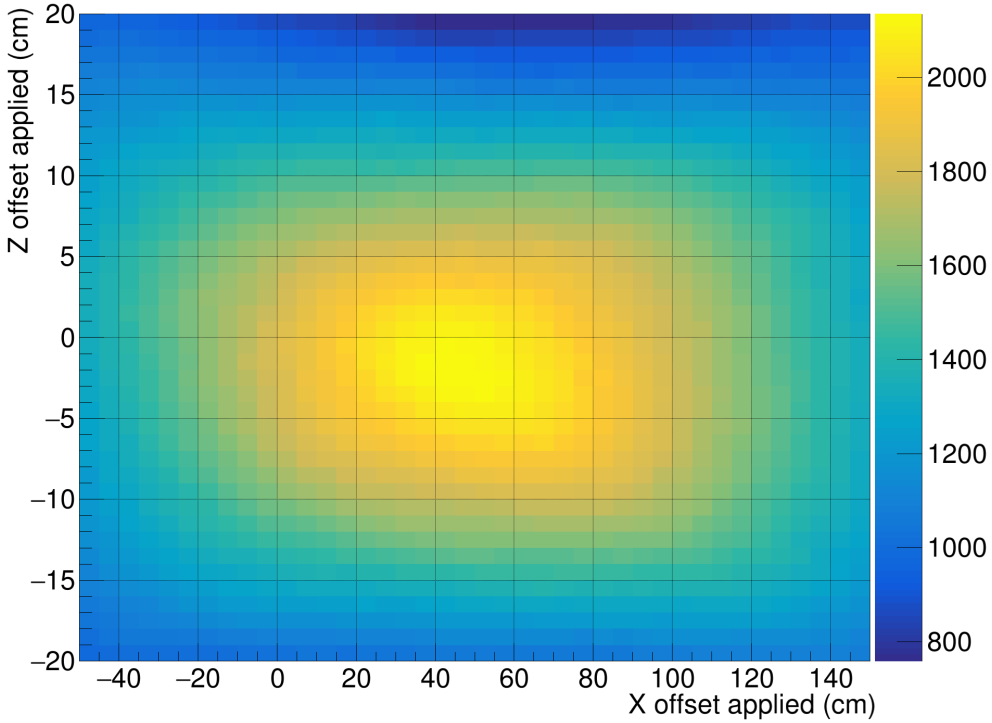
Extrapolate 2D tracks (collection view) to counter positions. Minimize joint χ^2 as a function of X and Z offsets of the counters.

Work in Progress

Biggest offset seen in X positions



South Counters (combined)



North Counters (combined)

ProtoDUNE-SP Electron Diverter

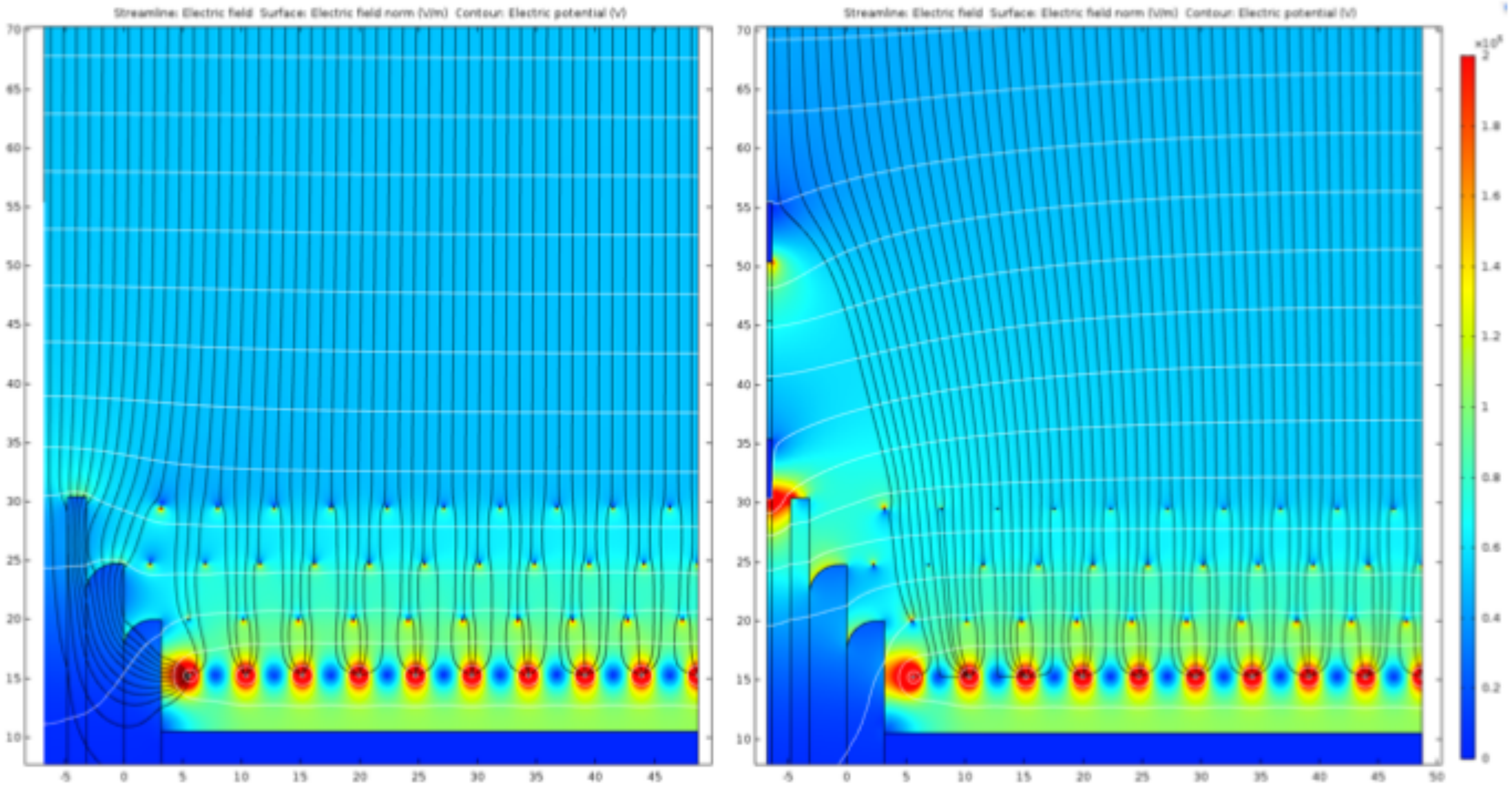


Figure 2.11: Left: field map of the region near the inactive gap of an APA without the electron diverter; Right: field map with the electron diverter in place. Electric field lines are shown in black, equipotential contours are in white, and electric field strength is represented in color gradient.

Adjacent APA's in ProtoDUNE-SP

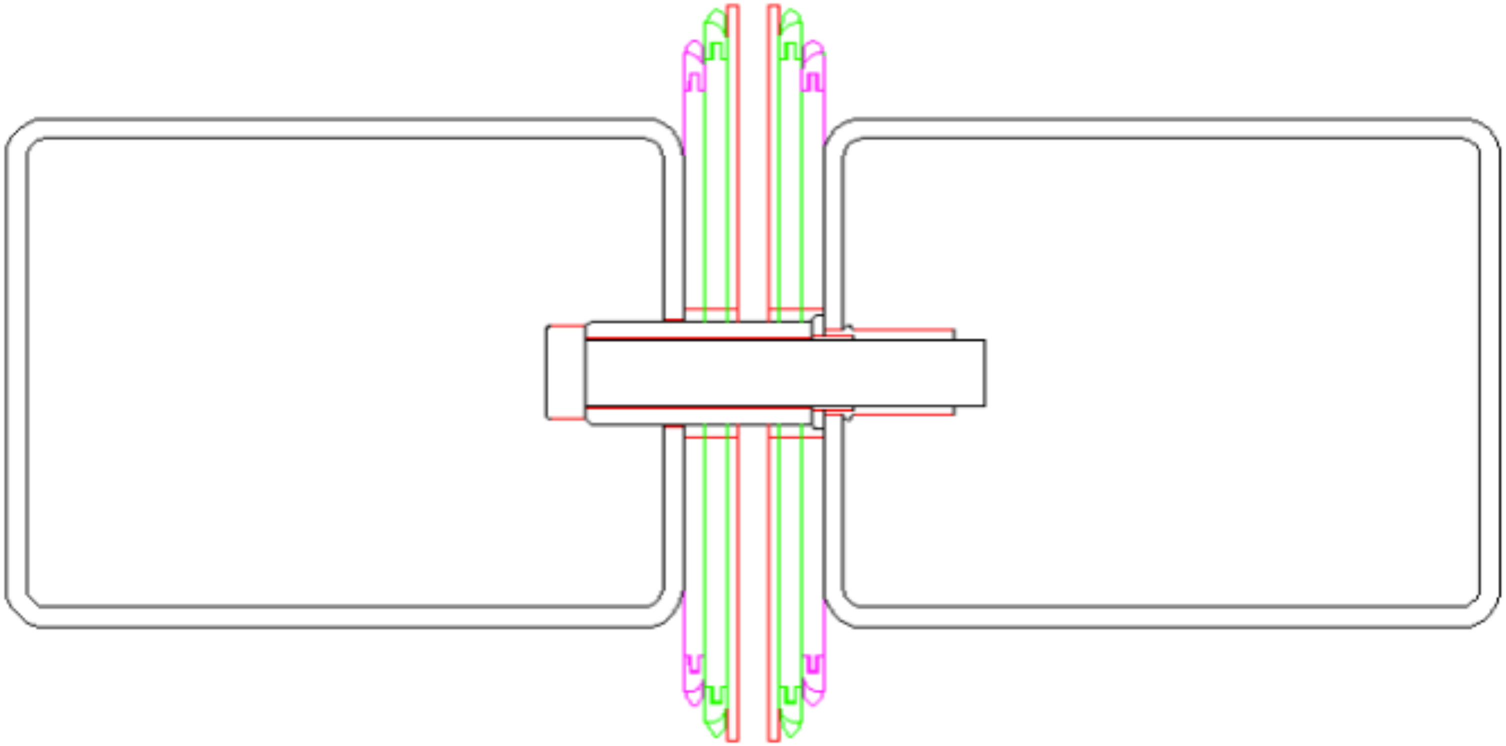


Figure 2.14: The pin/slot constraint. The pin screws into an insert in the outside frame member of one APA and engages a slot in the outside frame member of the adjacent APA. An insulating sleeve surrounds the guiding pin to ensure electrical isolation between the APAs.