DUNE Electron Diverter Task Force Report

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Fermilab, Cambridge, and BNL

DUNE Tech Board Meeting

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DUNE doc-14950

Fermilab DUNE

Christos Touramanis
Alberto Marchionni

Task Force Charge (1)

Context

Electron diverters installed between neighboring APAs and biased at appropriate voltage can be used to shape the electric field in front of the APA-to-APA gaps so that drifting charge does not get lost undetected in the corresponding dead areas.

Electron diverters were deployed between the APAs only on the beam side in ProtoDUNE-SP. Due to some current draw they were not biased during most of the data run, and as they were grounded they affected dq/dx measurements and track matching in the offline analysis.

Test runs with one diverter biased showed that “most shortcomings can be mitigated with biasing at the right voltage range” (Tingjun Yang, 01/2019). Concrete gains over the no-diverters configuration are yet to be demonstrated.

In the DUNE SP FD modules the gaps between APAs will be larger (15mm to 30mm) and therefore the beneficial effects on total charge collection would be more important. At the same time the wider, and different size gaps to be covered, and the double APA vertical assemblies would increase the complexity of the diverter system and therefore the associated cost and risks in its design, demonstration, construction, installation and long-term operation.

Task Force Charge (2)

Action Plan

In order to inform the decision to pursue electron diverters for the DUNE SP FD, the consortium is setting up a Task Force to provide advice. The advice will be discussed as appropriate within the consortium and a proposal will be submitted to the DUNE FD TB.

Time scale

The Task Force is expected to provide the requested advice within a few weeks from appointment as all technical decisions must be finalized in early June in view of TDR submission deadlines.

Task Force Charge (3)

Charge

1. Reco & Physics: how do diverters affect the quality of pattern recognition / tracking / clustering / vertexing /PID / deposited energy reconstruction if they operate optimally, at the wrong voltage, grounded, absent. Which information loss in the absence of diverters, and to what extent, can be recuperated in offline analysis with the use of corrections derived from real and simulated data samples. Due to the short time available the Task Force is expected to mostly collect already available results from real and simulated data studies rather than embark in large scale MC or data production and analysis.

2. Physics: diverters would shape the electric field over the gaps and direct drifting charge away from the dead region and into the active area of the APAs. This will improve total charge collection and thus calorimetry for showers. The effects on dE/dx for tracks crossing / starting / ending in the gap area, neutrino vertex reconstruction, short tracks (protons, pions) counting in a neutrino interaction vertex and reconstruction etc also depend on spatial resolution and therefore require MC studies to be understood. The Task Force is expected to present a summary of the available evidence from real and simulated data.

Task Force Charge (4)

3. Resources required to design, prototype and demonstrate diverters for the FD: the Task Force is expected to present estimates and comments for both the electrical and mechanical aspects of a diverter system.

4. Resources required for integration into the APAs including modifications required to the APAs themselves, and then production, integration, and installation in the DUNE FD, including additional electrical infrastructure (power supplies, cabling etc): the Task Force is expected to present estimates and comments as for the previous point.

5. Risk analysis for the construction and operation phases of the detector.

For points (1) and (2) any additional evidence and experience from other LAr TPCs data analysis would be also welcomed.

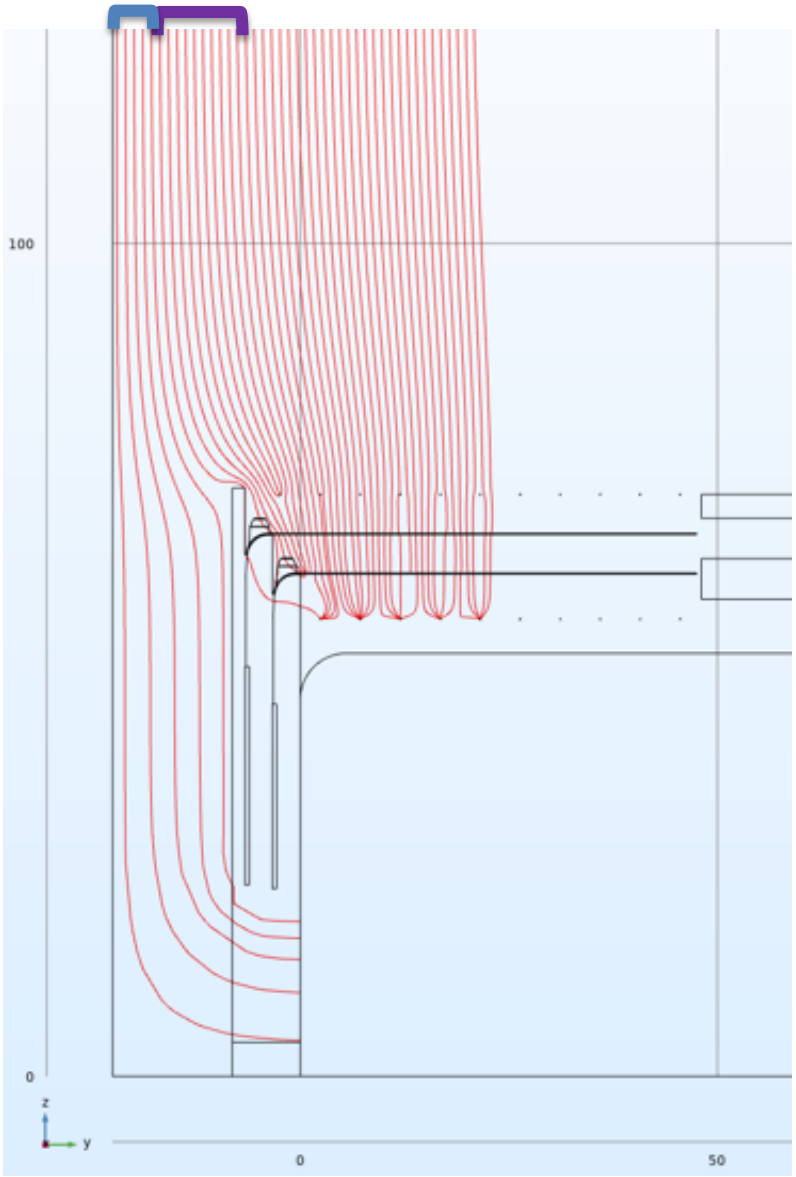
Comments on Charge

- Charge delivered to the task force on May 20. All members agreed to work on the task force. Leigh Whitehead added at a later time by invitation.
- Short timescale – no new simulations were made, and hand-waving descriptions of future calibration strategies are given.
- The same calibration strategies are needed under all circumstances, so the fact that they are not final or optimized is less important.
- Residual systematic uncertainty after calibration is important, and difficult to assess.

Diverter Cases Studied

Diverter Option	Prototypes
No diverters	35-ton, ProtoDUNE-SP
Active strip electrode	35-ton, ProtoDUNE-SP
Passive diverters	not yet
Something else (covers on exposed metal in gaps?)	

Predictions: No Diverters



Fully charged insulating surfaces

Boundary condition: No more charge can accumulate, so E has no normal component for dielectric surfaces

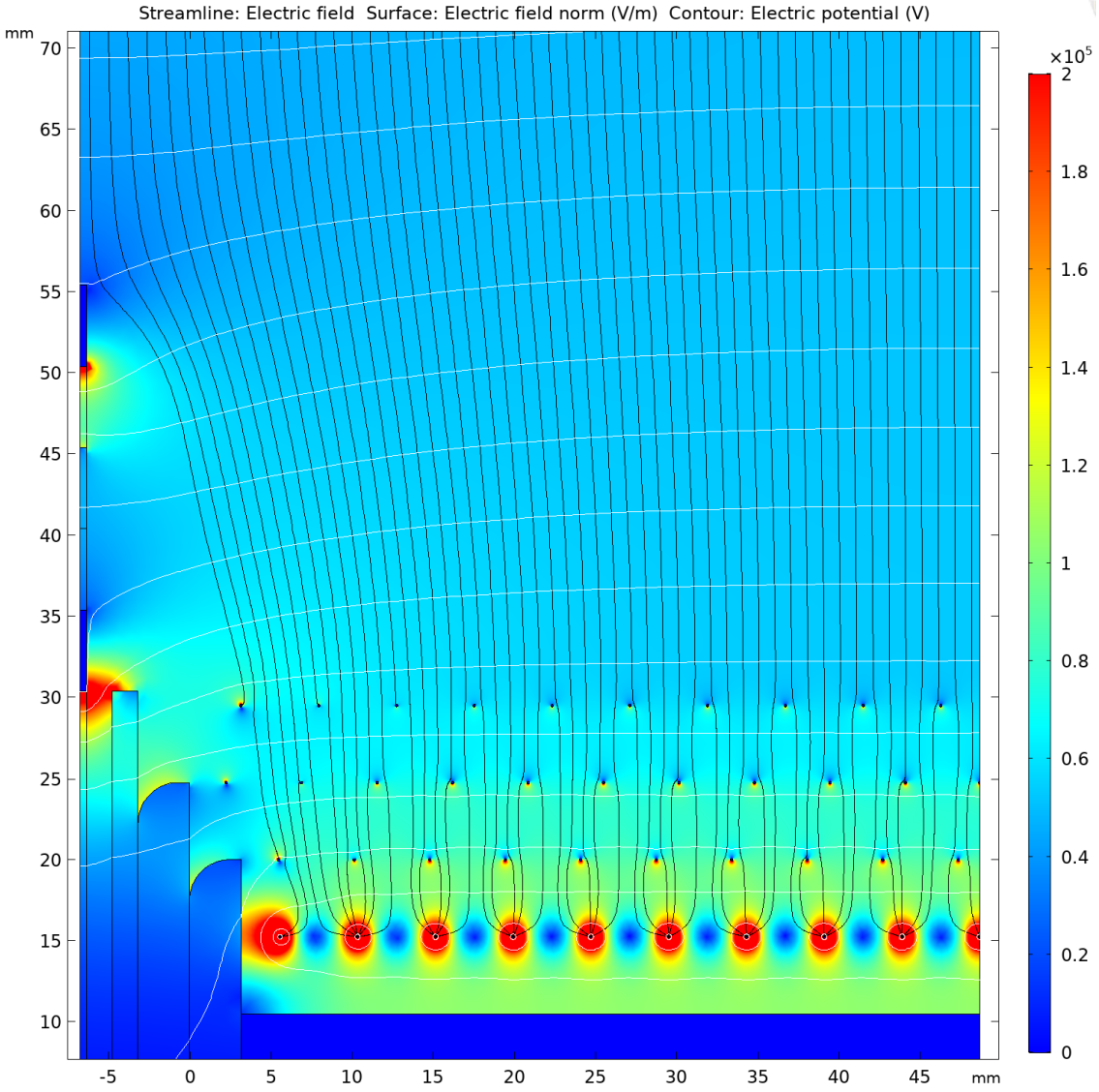
Blue Bracket: charge collects on conductors in the gap

Purple bracket: Charge collects on Grid, U, or V wires.

Line count on collection-plane wires:
4, 7, 5, 5, 5 ...

Bo Yu

Predictions: Active Diverters



Two strips – nominal voltage:
-1300 V (inner strip)
-2300 V (outer strip)
when the drift field is 500 V/cm

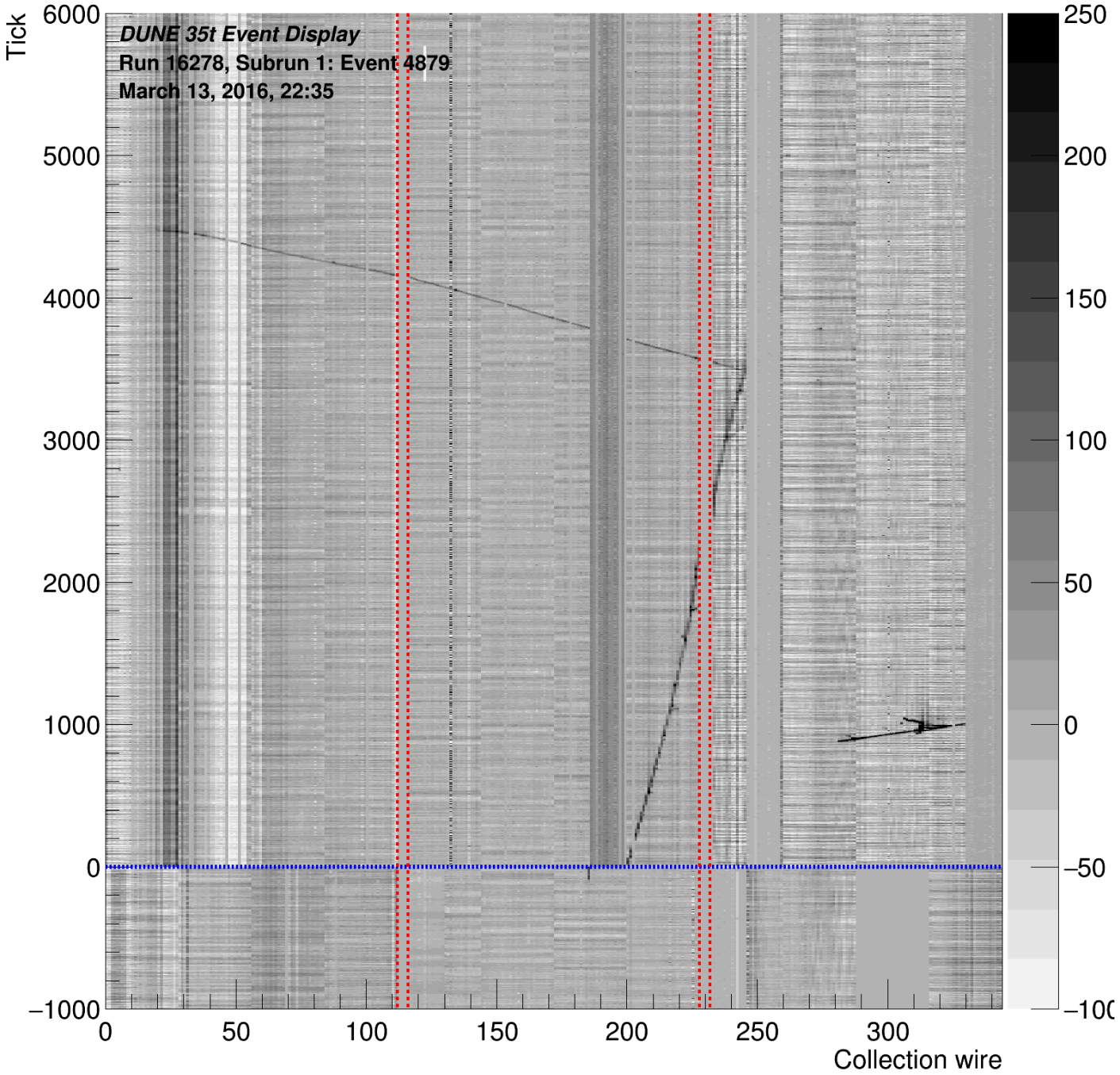
Bo Yu, in the ProtoDUNE-SP TDR

Experience with 35-ton

- One active two-strip diverter between the short APA and its neighbor.
- Held voltage.
- Voltage scanned in special runs
- Short APA electronics turned off to avoid noise for part of run.
- Low signal/noise ratio made detailed dQ/dx studies difficult in 35t.
- No systematic offline studies of charge near APA edges.

A 35-ton Event

A no-diverter gap

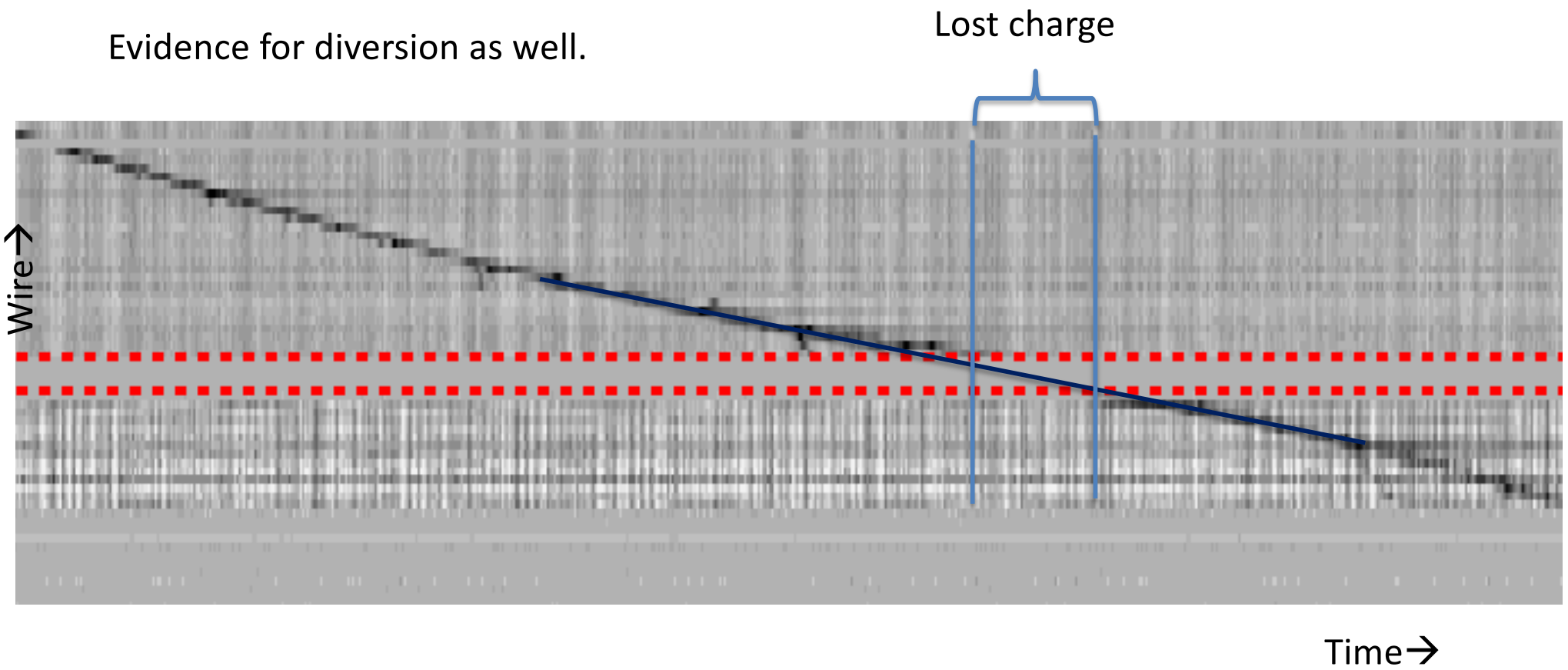


M. Wallbank's online event display

Zoomed in

Times in which no charge arrived on any wire
correspond to lost charge. Perhaps some collected on the induction-pane wires.

Evidence for diversion as well.

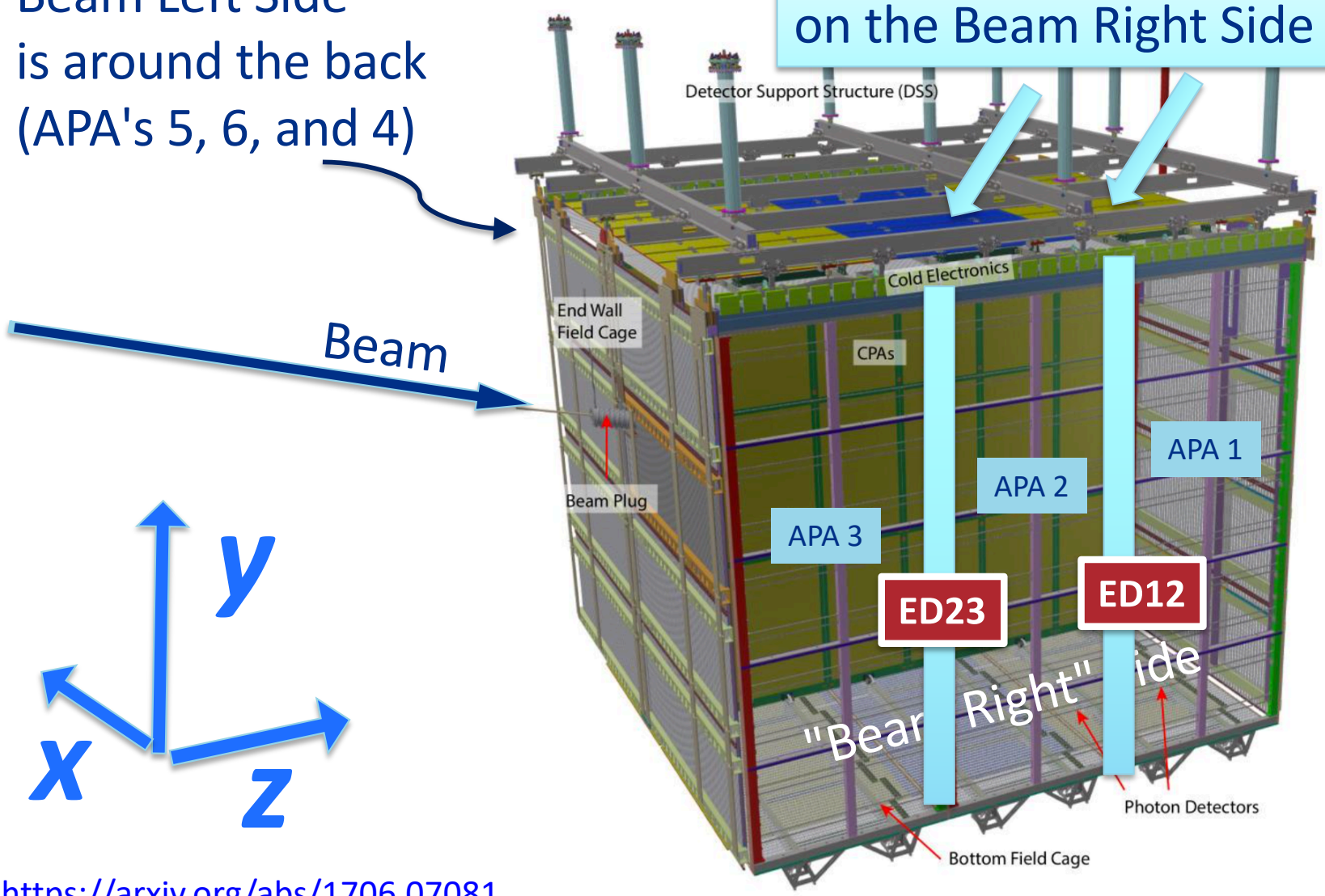


A straight line has been drawn to guide the eye.

ProtoDUNE-SP Layout

Beam Left Side
is around the back
(APA's 5, 6, and 4)

Electron Diverters Installed
on the Beam Right Side Only

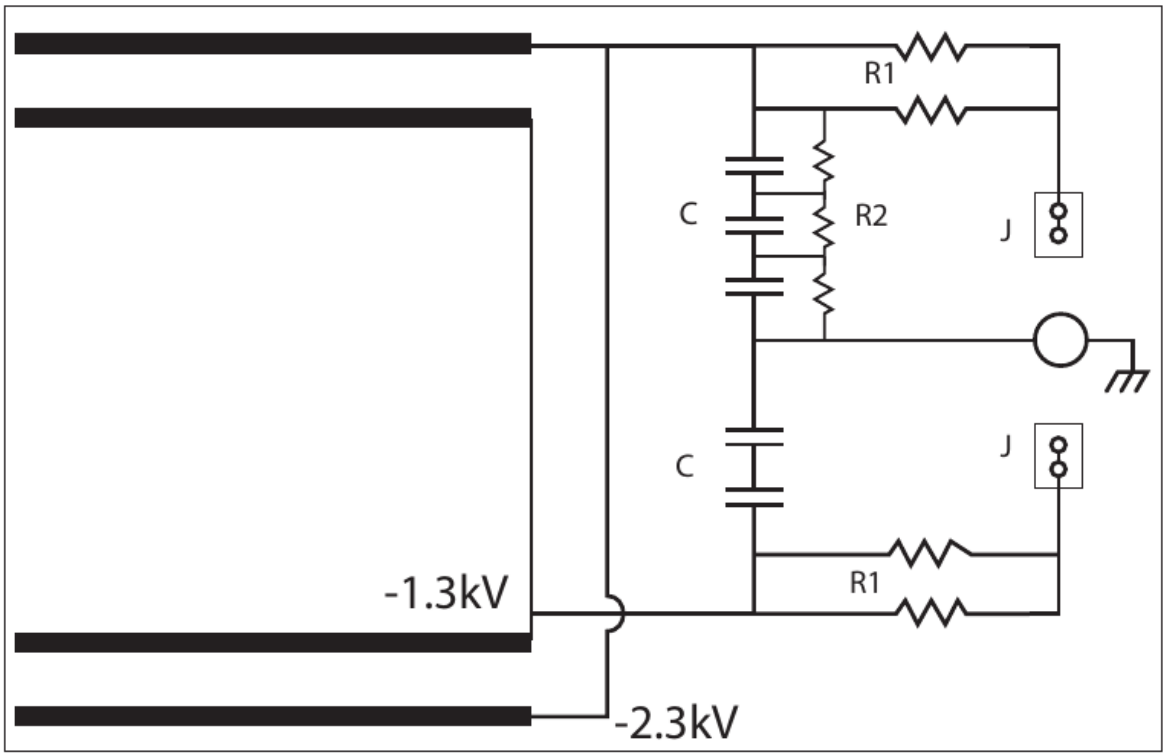


https://arxiv.org/abs/1706.07081
(ProtoDUNE-SP TDR)

Figure 1.1: The major components of the ProtoDUNE-SP TPC.

Fermilab

ProtoDUNE-SP ED HV Board



C: 18nF/2kV (399-13344)

R1: 50M (HVA12FA50M)

R2: 500M (SM102035006FE)

J: IPL1-102-01

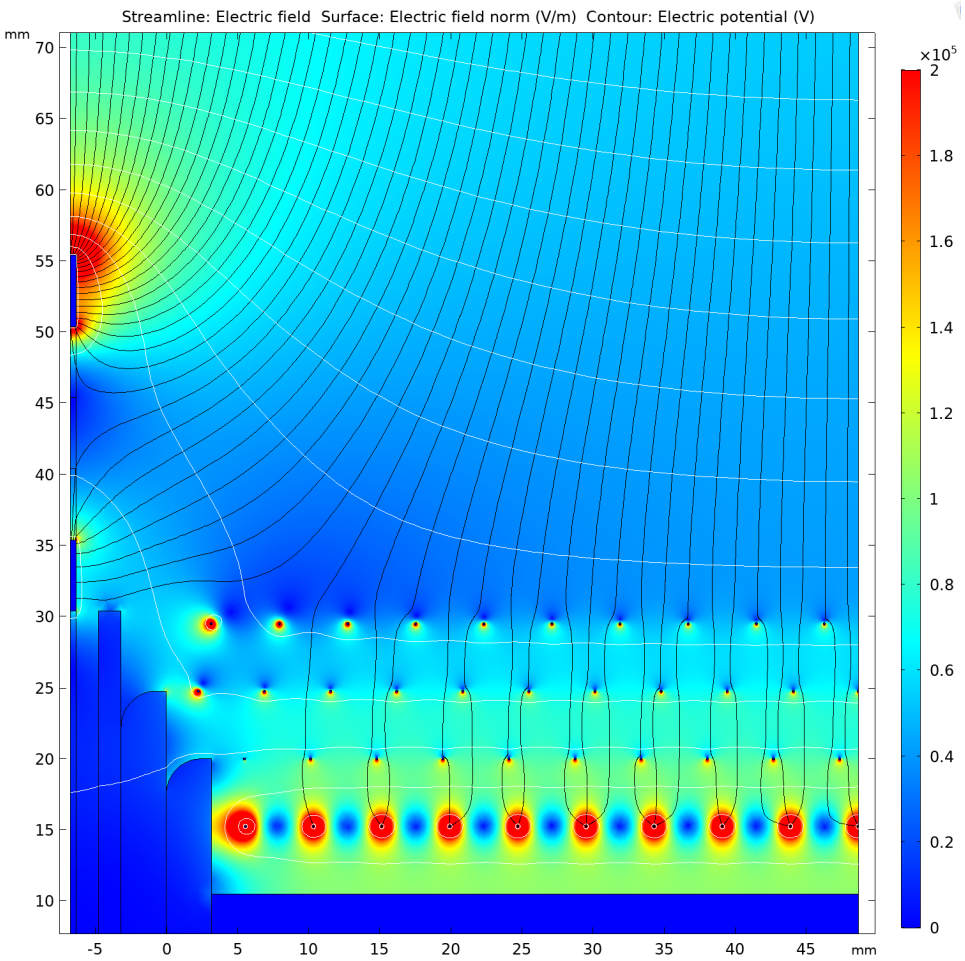
HV side capacitors (on top) cracked in a cold bench test. Replaced with three caps and a voltage divider (1.5 GΩ total). No such path to ground for the inner strips.

Outer strips effectively grounded when HV not applied

ProtoDUNE-SP Experience

- No time in schedule to test EDs on arrival, after installation, or in the cold box or after moving APAs into the cryostat.
- EDs both held voltage when powered on at first test (Sep. 24, 2018) after cathode HV ramped to full volts.
- October 4-10: all HV powered off
- October 10: diverters powered back on: ED12 has 1.4 MΩ resistance to ground on the outer strip HV which trips the power supply at 500V. ED23 has a resistance of 1.6 GΩ which is expected.
- Both diverters' power supplies turned off for duration of beam run.
- Only later discovered that this meant grounding them (!)
- HV scan of ED23 done after beam run. Trips at 125% nominal HV
- It is difficult to make an active ED fail safe.

Predictions: Grounded Active Diverter



Bo Yu

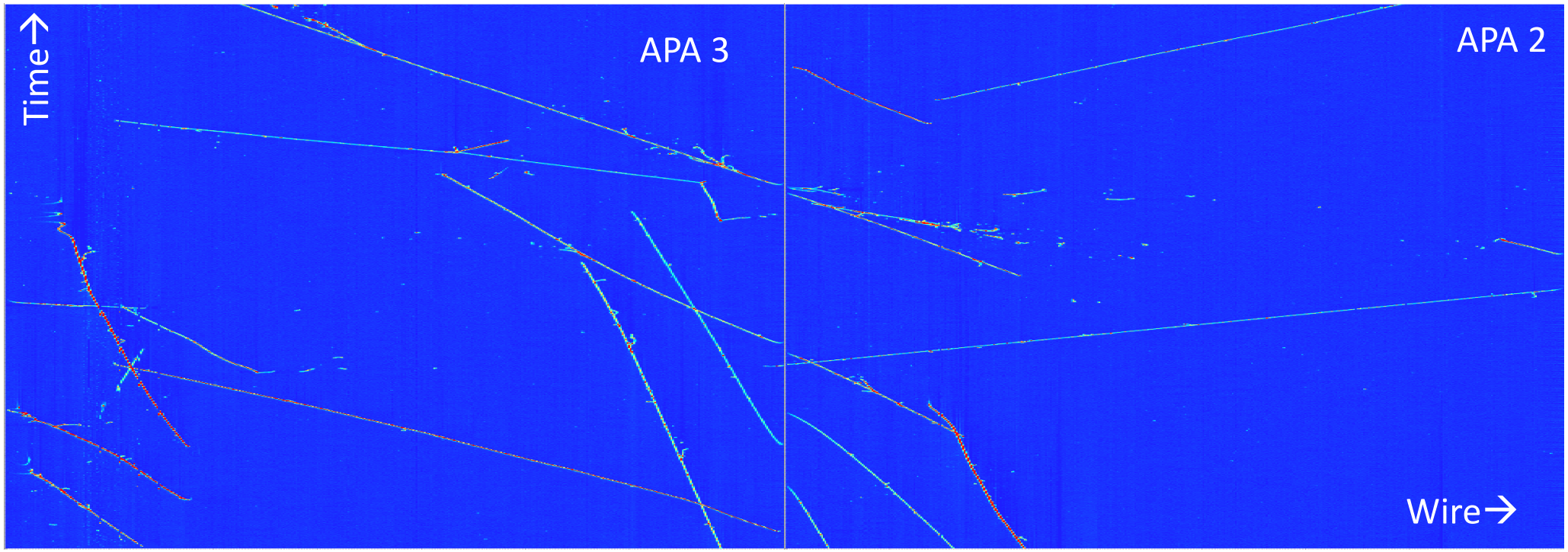
Instead of pushing charge away from the gap, grounded diverter draws drifting charge towards it

Charge collecting on diverter is lost.

Tracks and showers are "stretched" towards the diverter.

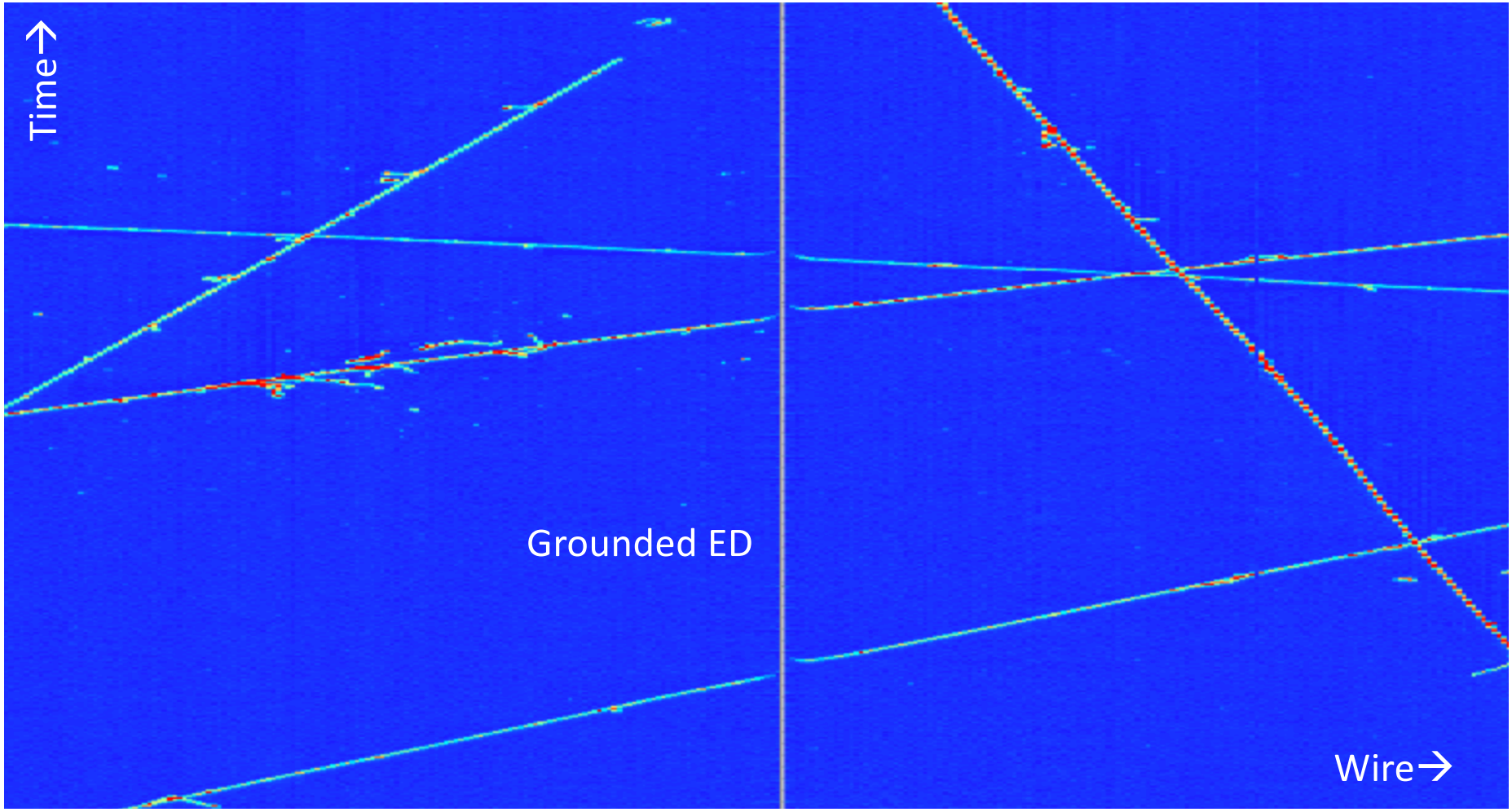
Some delay in arrival times too due to longer path lengths

Observations: Grounded Active Diverter in ProtoDUNE-SP

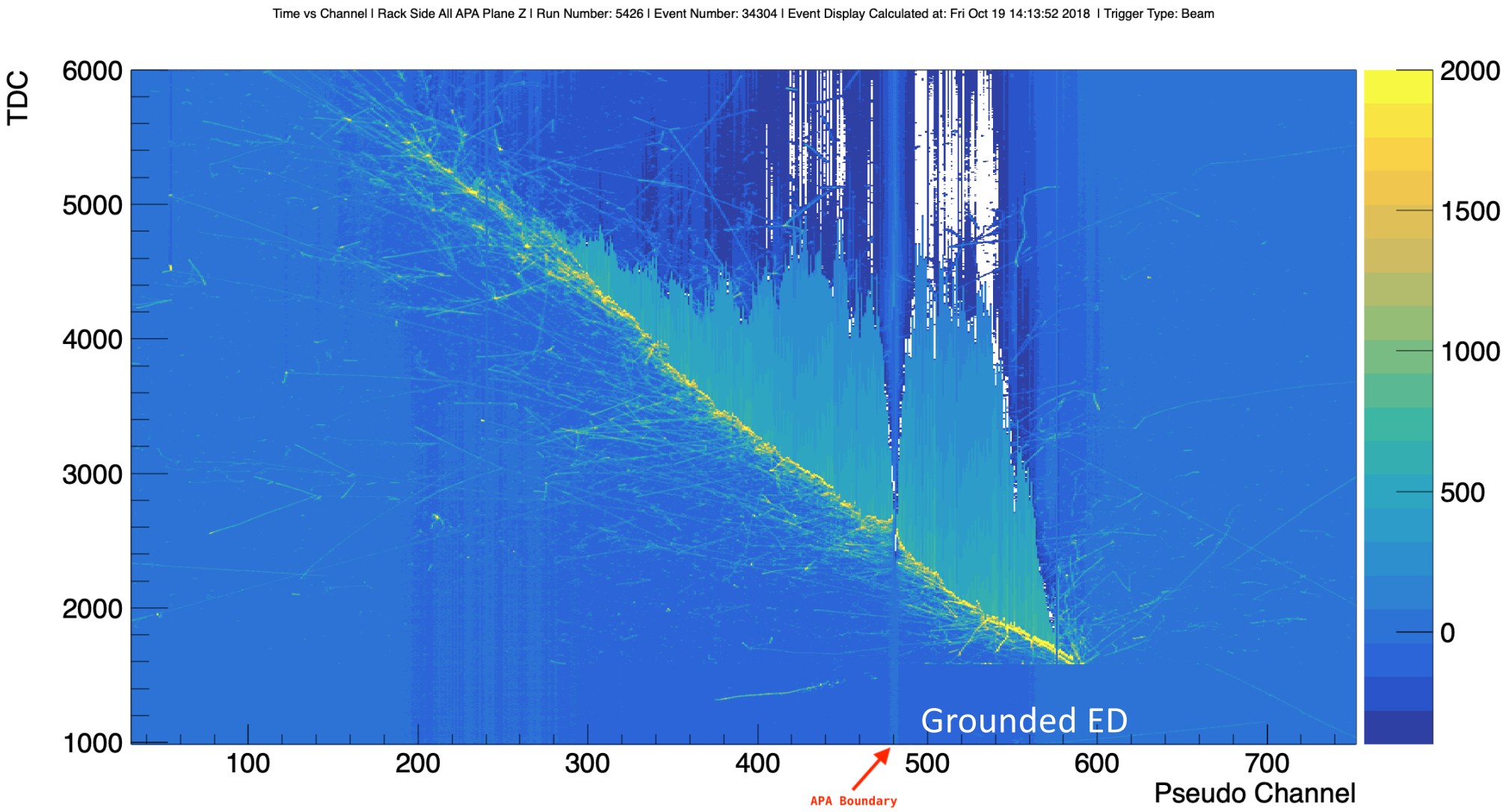


Charge loss and spatial distortions present.
Most obvious in steep tracks, but affects all tracks.
Other artifacts visible too – distortions due to field cage nonuniformity

Isochronous Tracks Measure Charge Arrival Time Delays



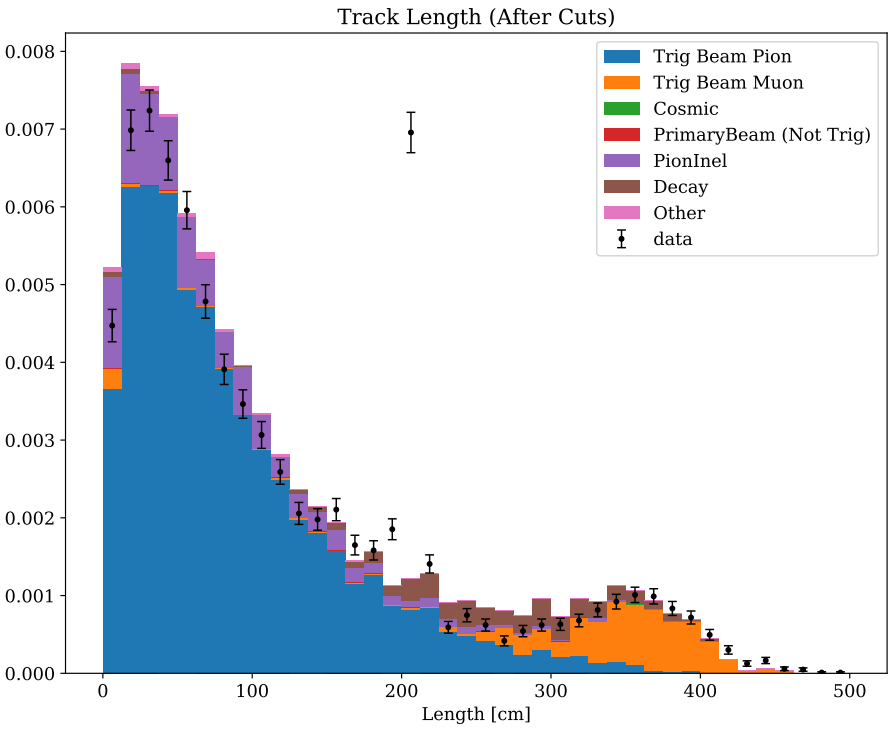
Effect on Showers



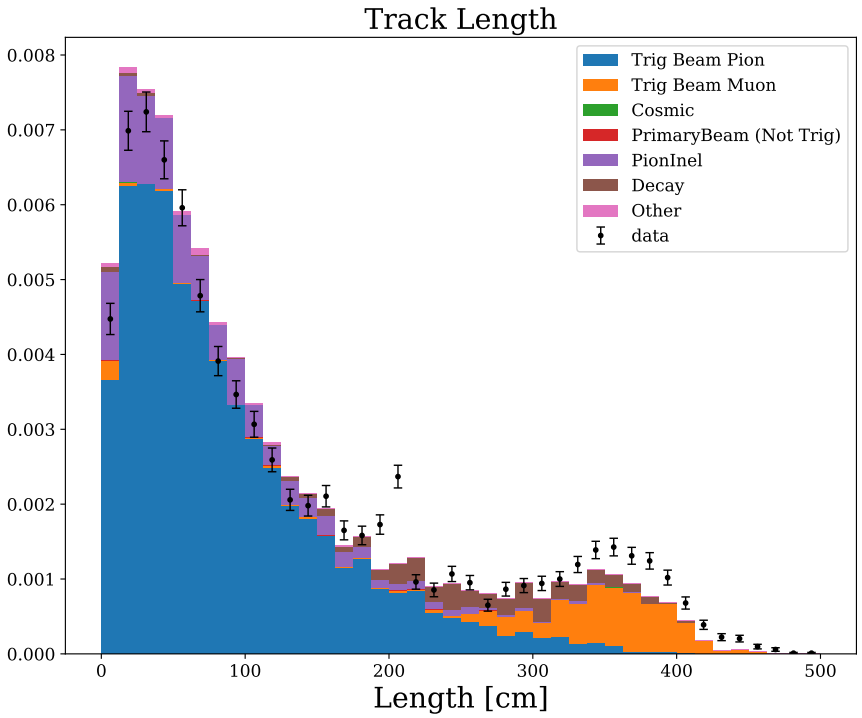
Split Tracks

Owen Goodwin's pion cross section analysis. Beam comes in drift volume seen by APA 3; long tracks proceed to APA2.

Pandora tracks out of the box



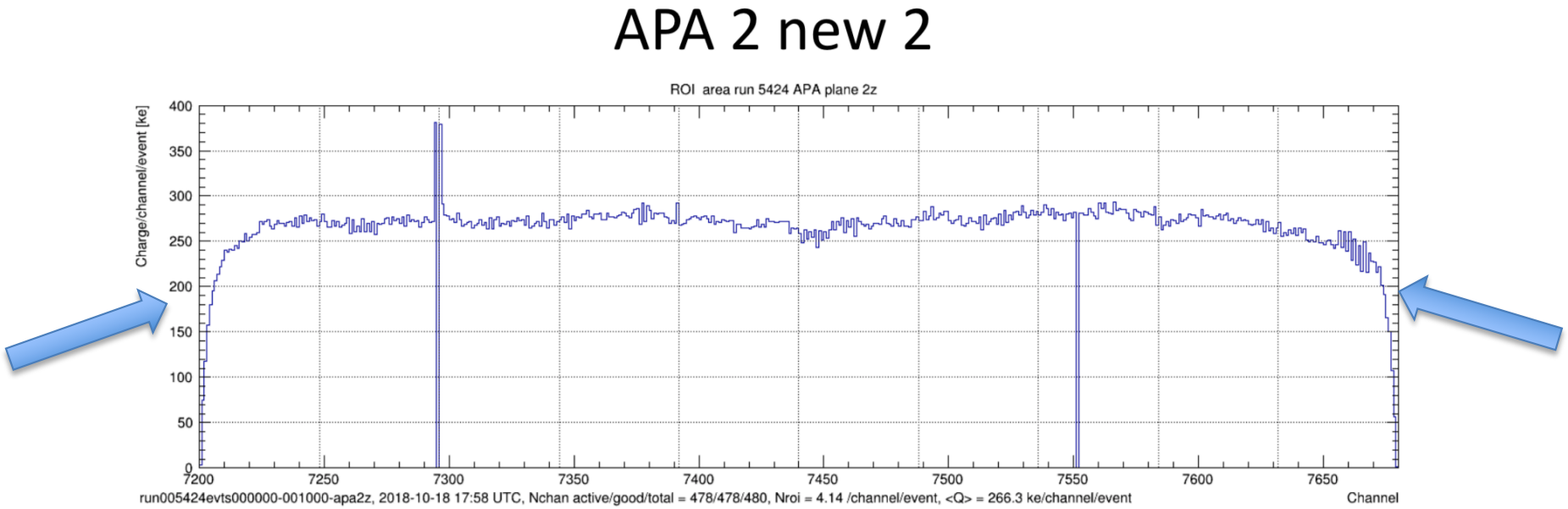
After stitching



Grounded Diverters

Average Collection-Plane Response with Grounded Diverters

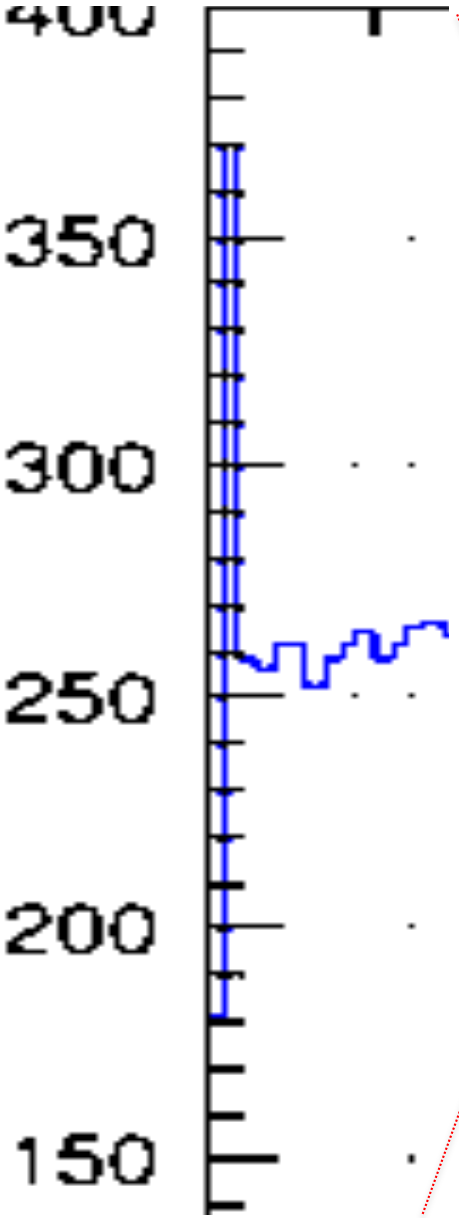
David Adams, Aug 16, 2019



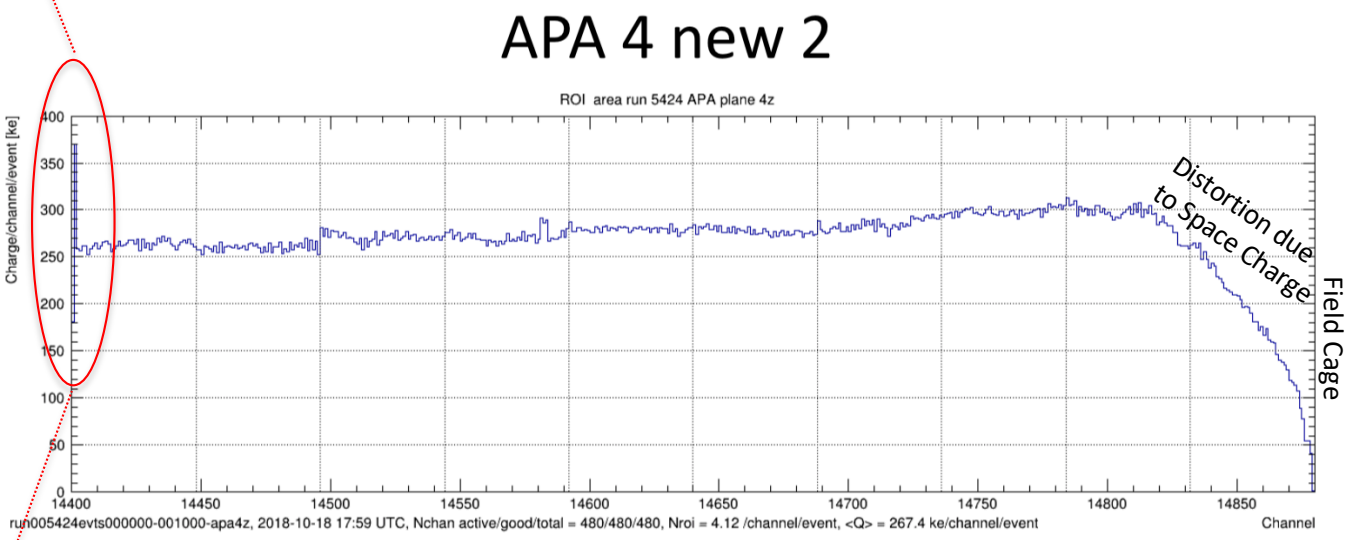
Spatial extent of distortion – About 30 wires

David Adams, Aug 16, 2019

Average Collection-Plane Response with No Diverters

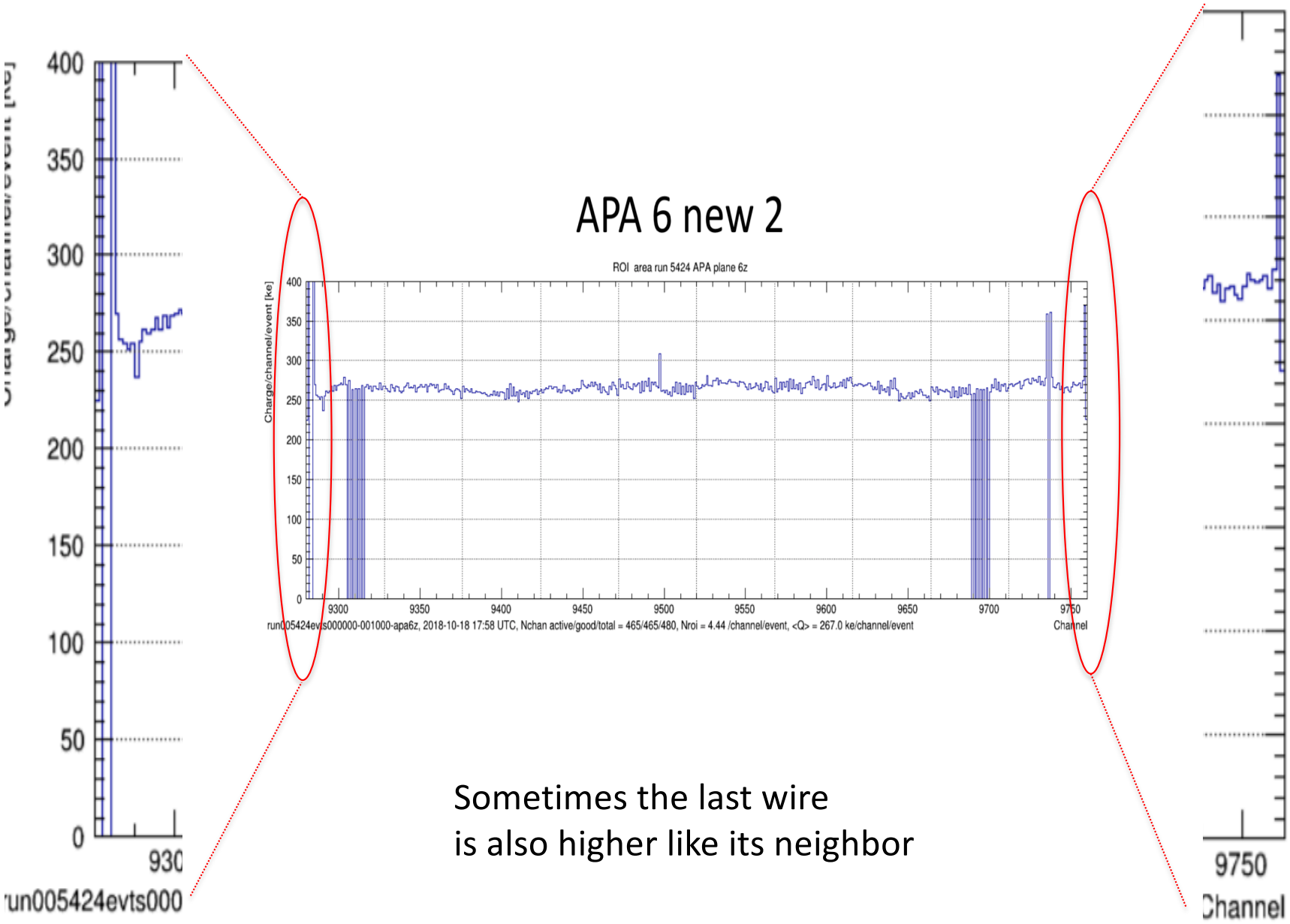


Diverterless Gap



David Adams, Aug 16, 2019

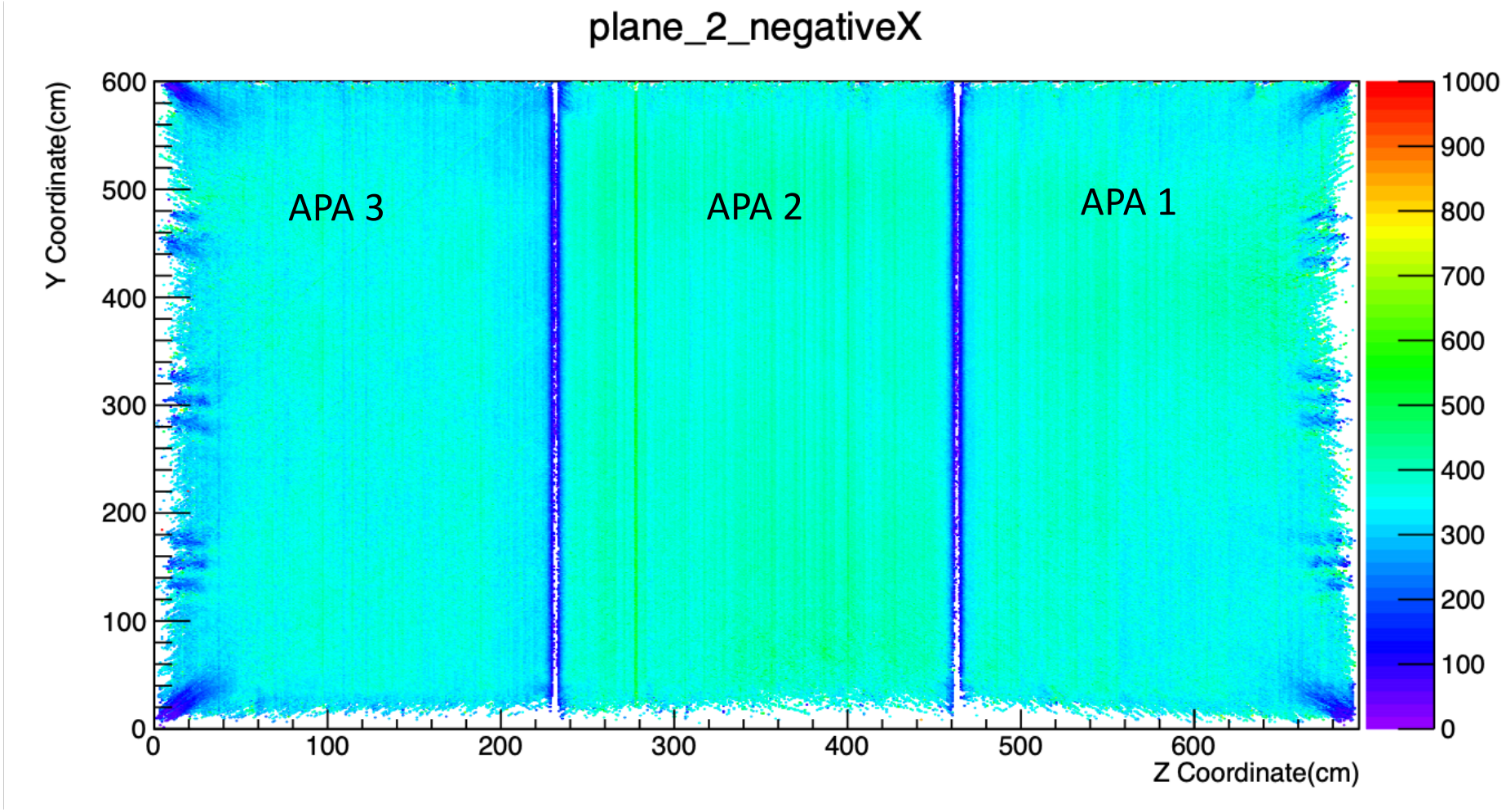
Average Collection-Plane Response with No Diverters



Sometimes the last wire
is also higher like its neighbor

dQ/dx Map with Grounded Diverters

ProtoDUNE-SP Run 5387

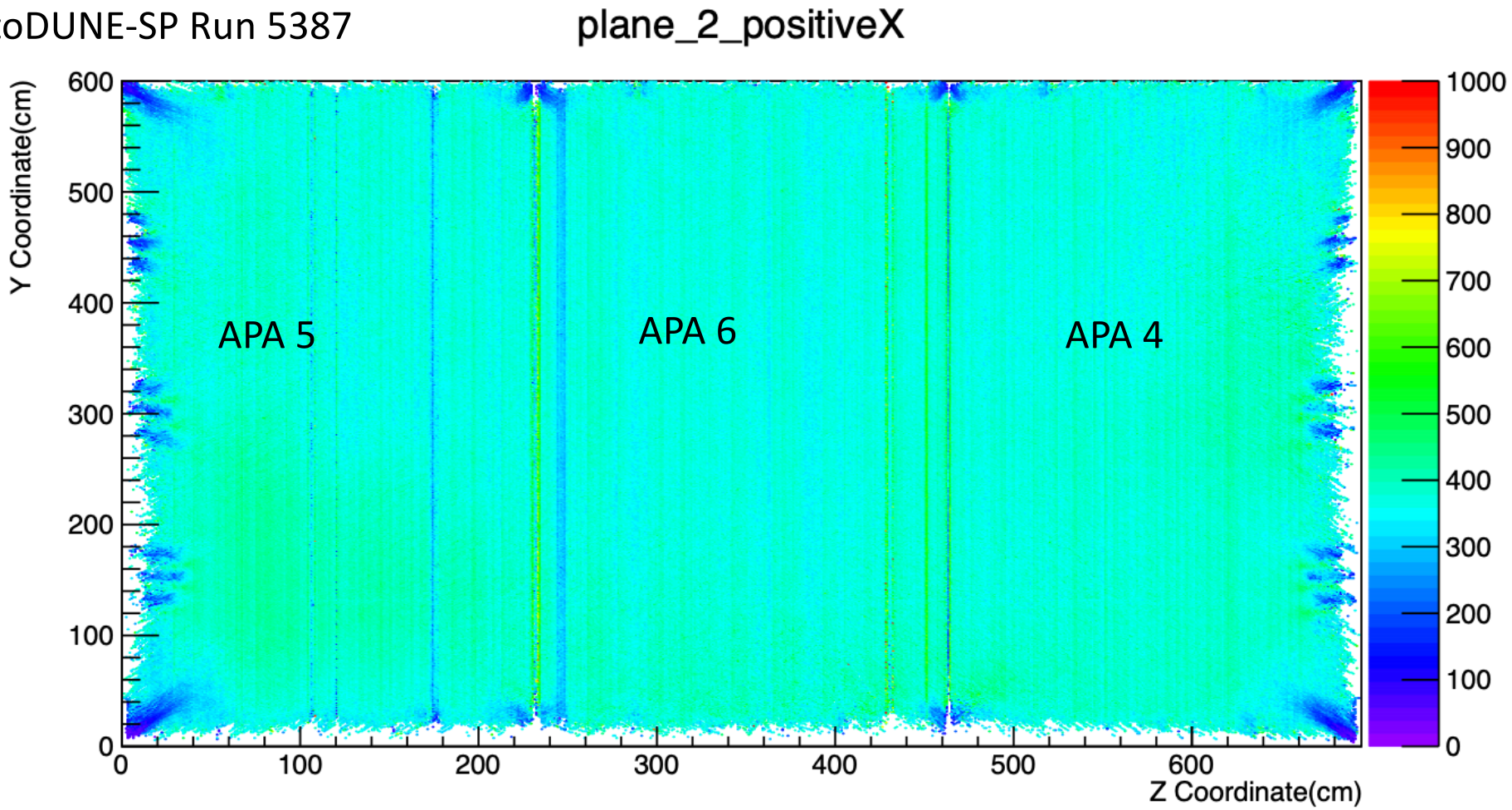


Ajib Paudel

Collection Plane, Beam-Right Side, 1 cm x 1 cm binning

dQ/dx Map with No Diverters

ProtoDUNE-SP Run 5387



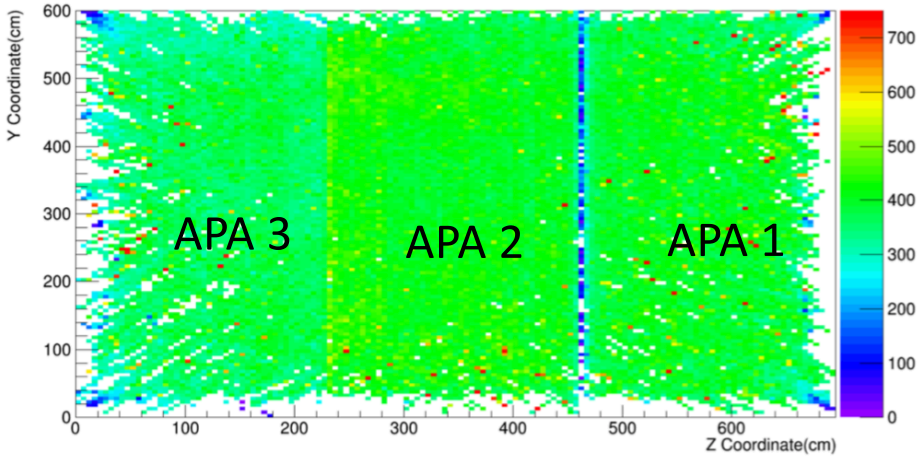
Ajib Paudel

Collection Plane, Beam-Left Side, 1 cm x 1 cm binning

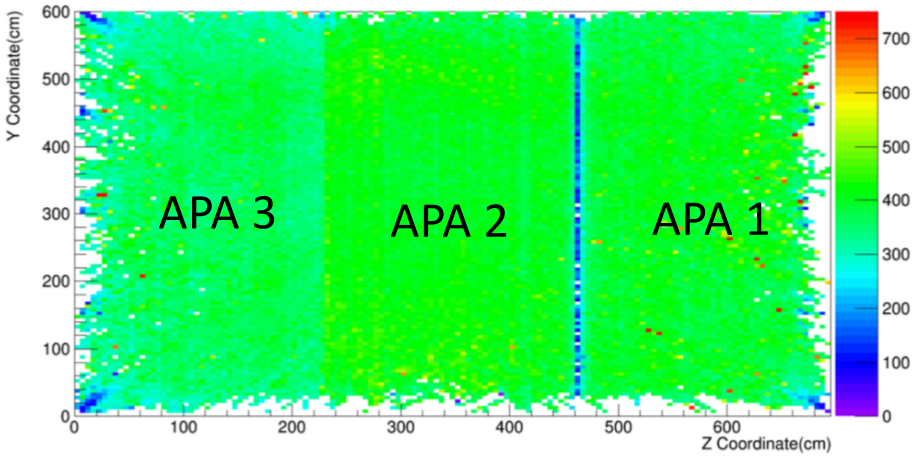
dQ/dx Map for Diverter Voltage Scan Runs

Ajib Paudel

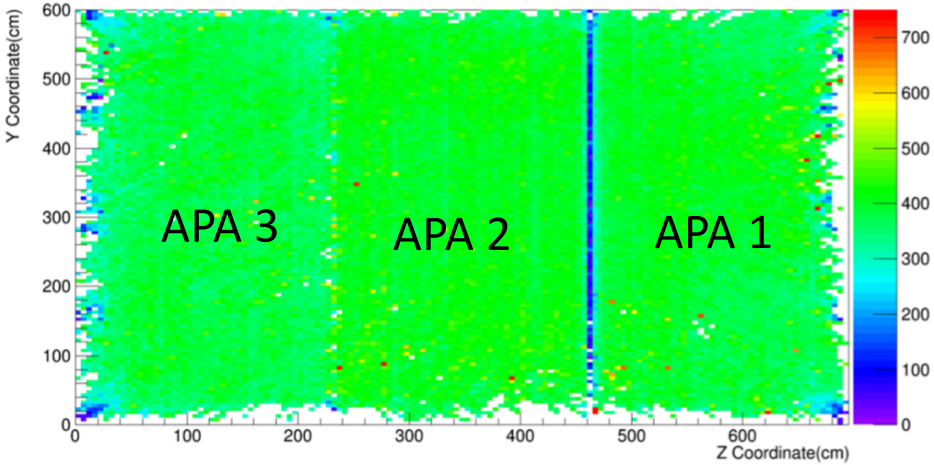
Run 5924 (100%) plane_2_negativeX



Run 5925 (75%) plane_2_negativeX



Run 5930 (125%) plane_2_negativeX

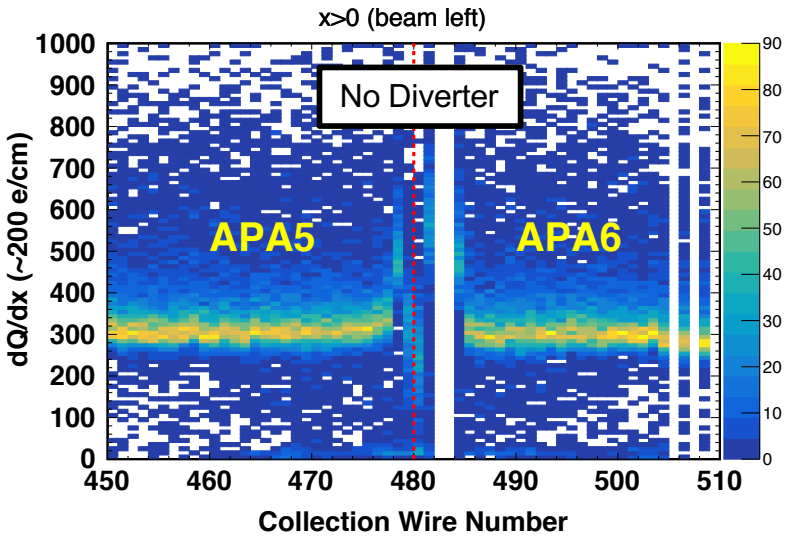


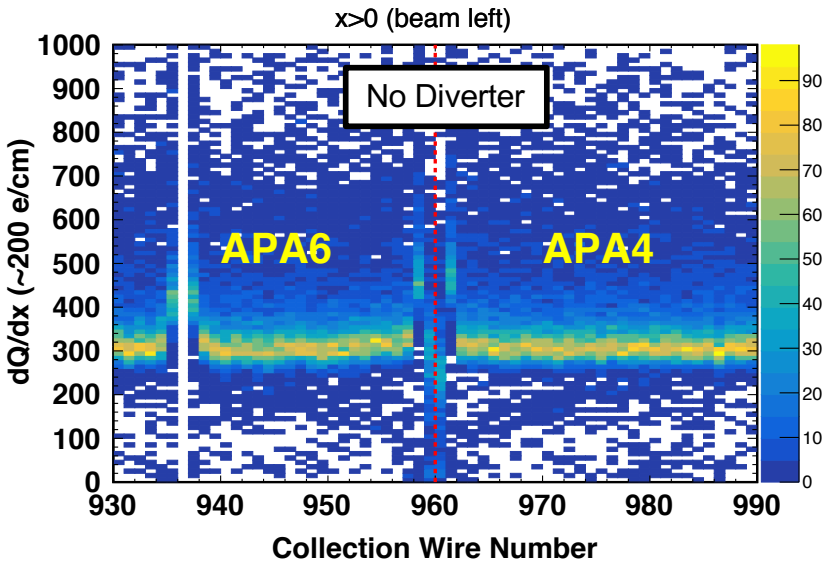
dQ/dx distributions look more uniform near the APA boundaries. But there is still indication of discontinuity.

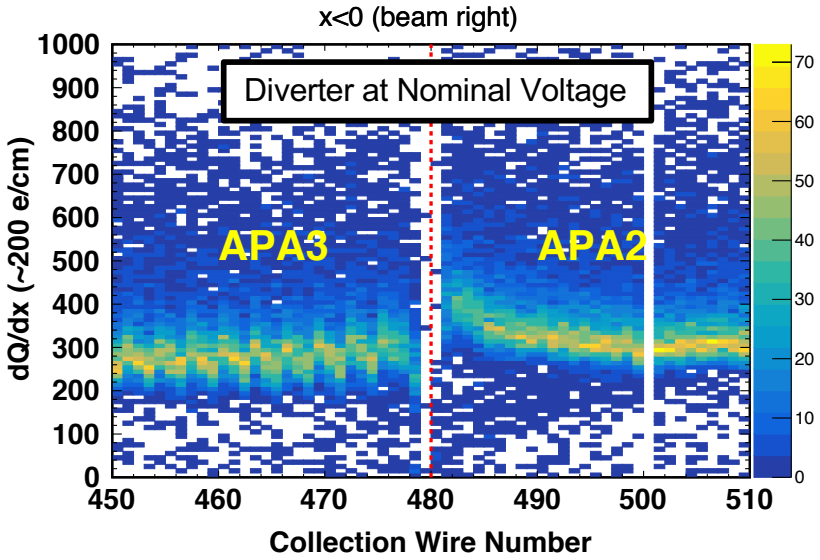
Run 5924

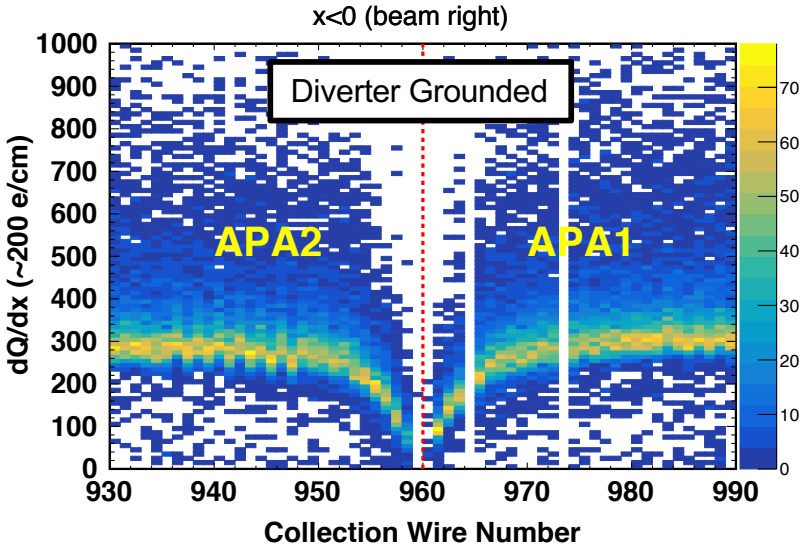
ProtoDUNE-SP Calorimetry Zooms

T. Yang

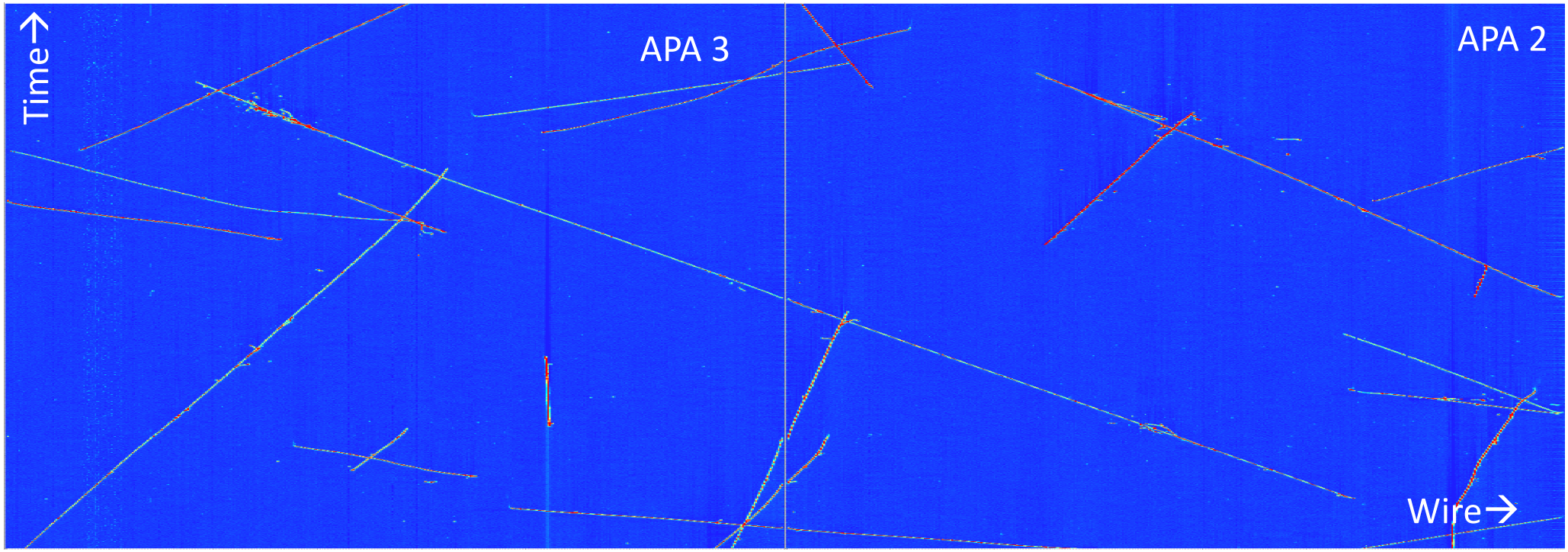






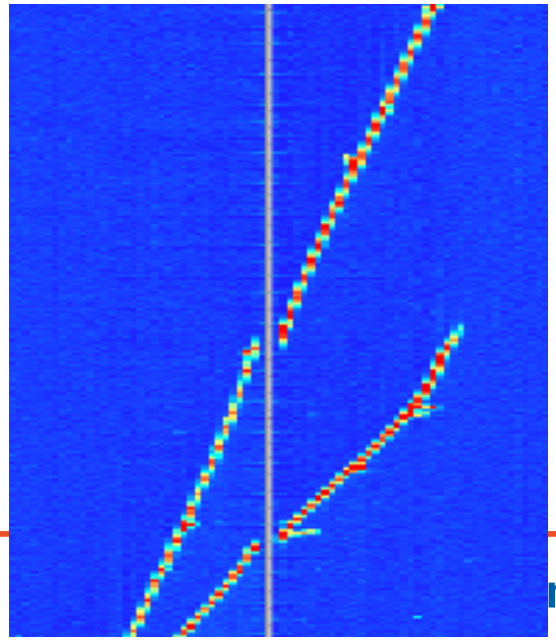


Active Diverter at 100%

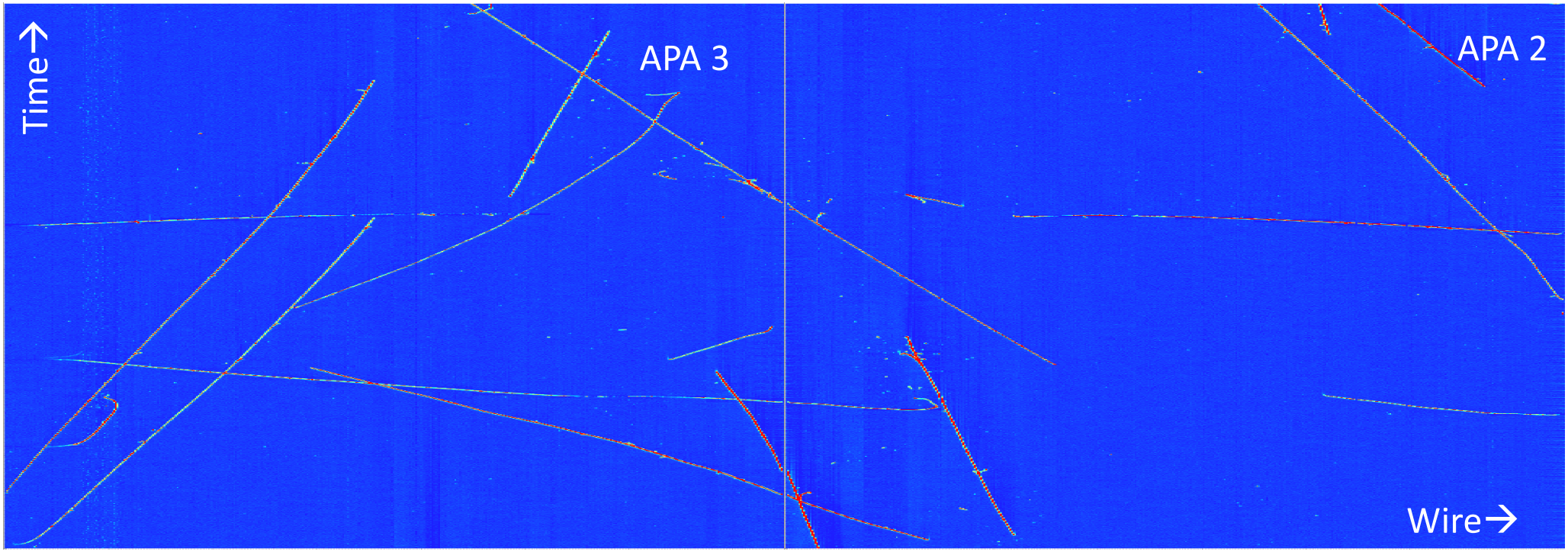


Tingjun Yang. ProtoDUNE-SP
Run 5924, event 132,
collection-plane data

Zoomed in a lot:



Active Diverter at 100%



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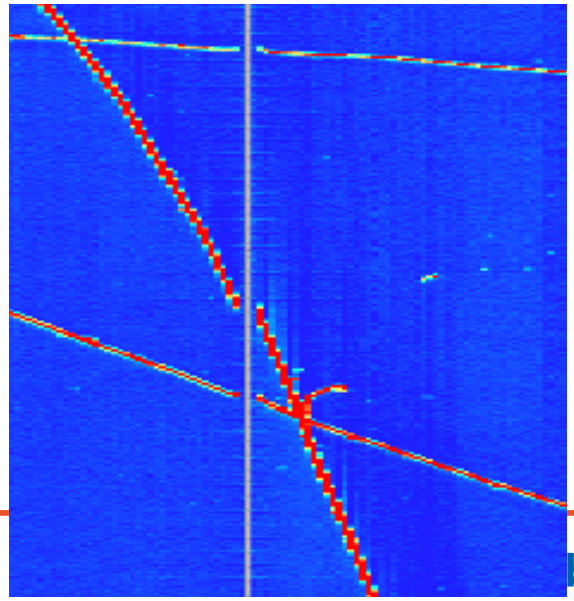
Run 5924, event 132
collection-plane data

Zoomed in a lot:



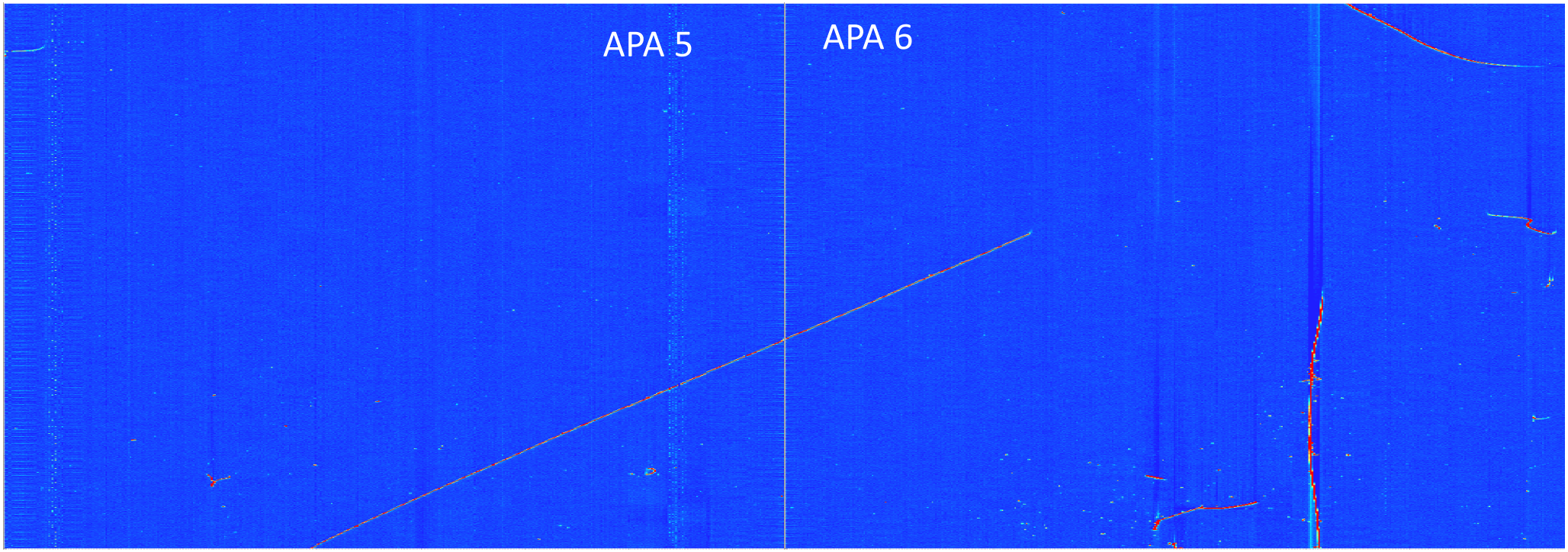
Effect on Alignment Offsets

Runs with different ED23 Voltages used to measure APA 2-3 gap width with cosmic rays.

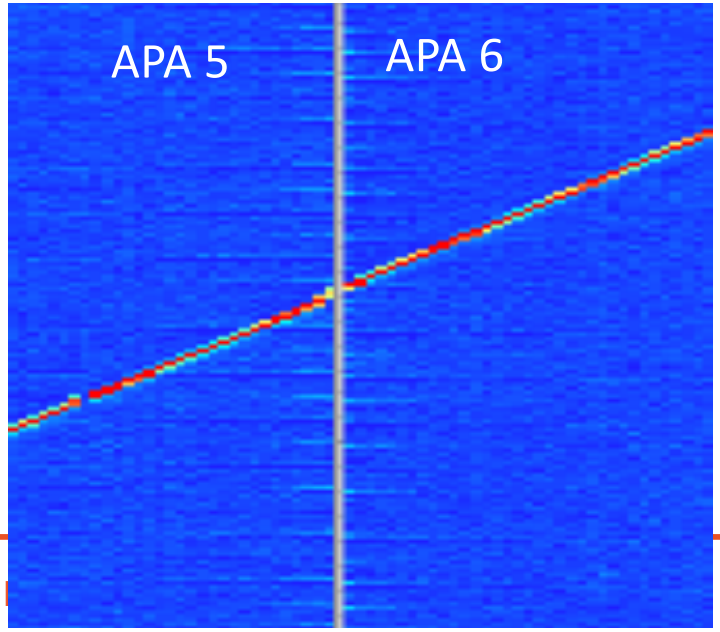
Putting a harder cut on distance from gap will help reduce bias

Run	ED23 Voltage			Gap 0 (ED23)	
	Inner (V)	Outer (V)	Frac. nom.	Δx (cm)	$\boldsymbol{\Delta z}$ **(cm)**
5177	0	0	0%	-0.15 ± 0.09	$\mathbf{-1.46 \pm 0.23}$
5941	-650	-1150	50%	-0.15 ± 0.05	$\mathbf{0.10 \pm 0.20}$
5925	-975	-1725	75%	-0.10 ± 0.06	$\mathbf{0.78 \pm 0.11}$
5924	-1300	-2300	100%	-0.10 ± 0.06	$\mathbf{1.32 \pm 0.12}$
5930	-1625	-2875	125%	0.0 ± 0.5	$\mathbf{1.56 \pm 0.5}$

A No-Diverter Event Display



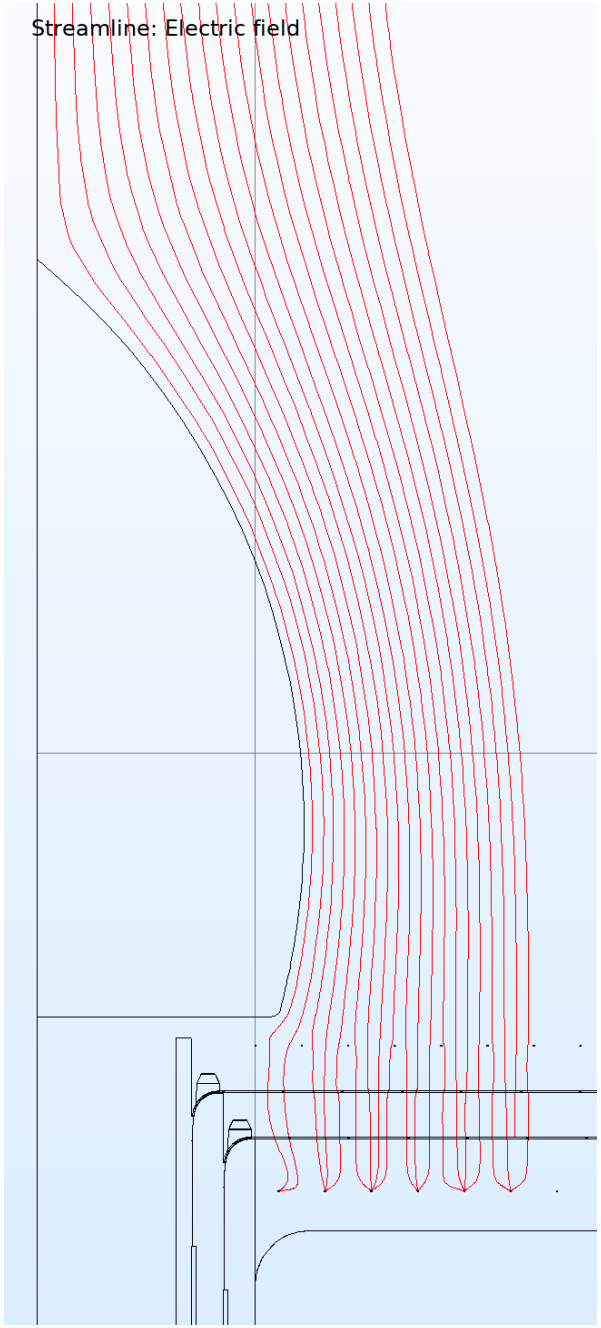
Zoomed in a lot



T. Yang

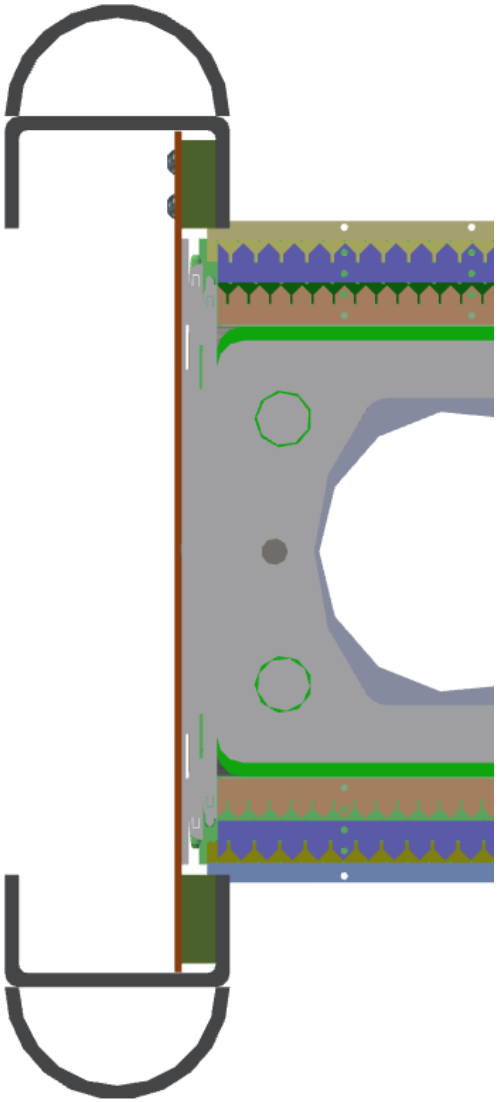
Passive Diverters

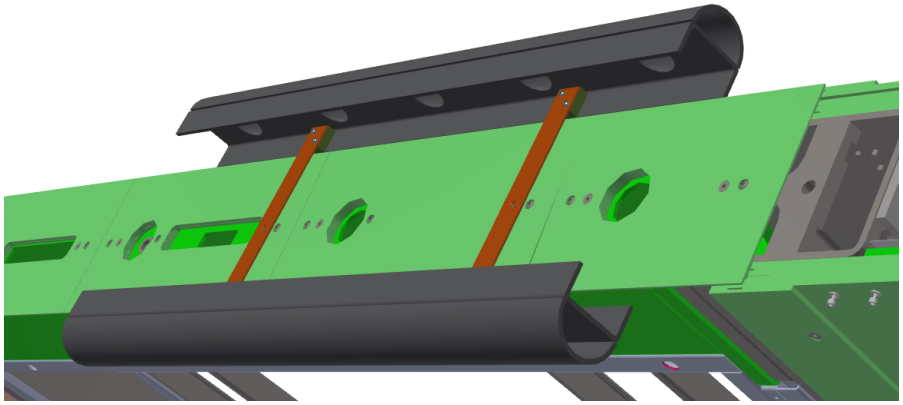
- Dielectric form projects into drift volume
- Charges up until it can no longer accept more electrons
- Boundary condition – no E field component normal to the surface
- No HV supply needed – main failure mode of active diverters is eliminated.
- Field shape is similar to that of active diverters



Bo Yu

Passive Diverter Mechanics





Bo Yu

A Calibration Strategy

- Isochronous tracks tell us about charge arrival delays
- Steep tracks tell us about spatial distribution of charge loss and spatial distortions, as well as gap widths
- Calibrate these for each gap (every third gap is bigger after all)
- Need maps of Δt and Δz vs z (and y), as well as charge-loss metrics
- Unipolar signal component on induction-plane wires may recover some charge that would otherwise be lost.

Impacts of Lost Charge on Shower Energy Reco: Collection Plane simulation

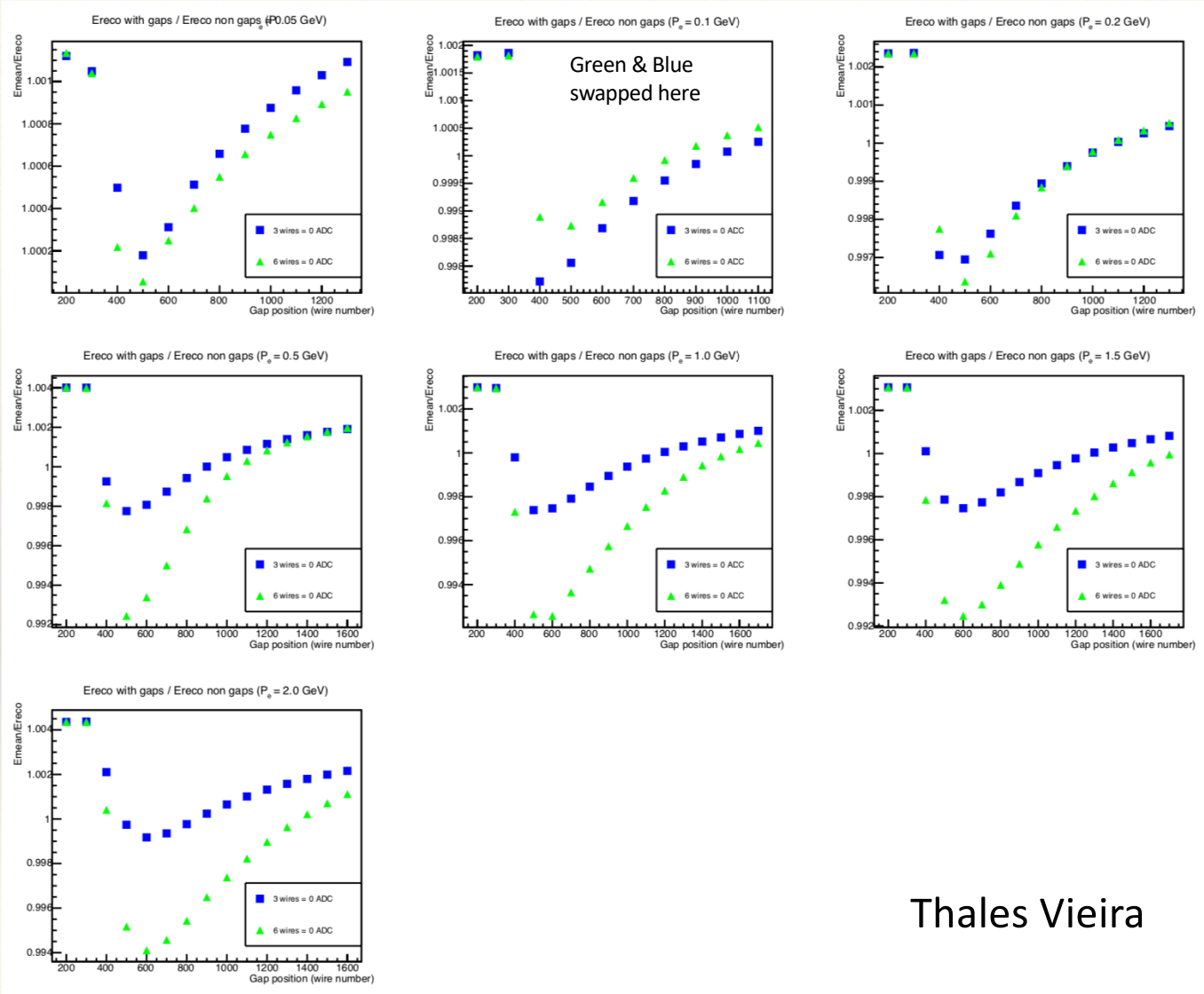
3mm wire spacing simulation.

Impact on shower reco if we lose

3 wires, or
6 wires of charge loss.

No interpolation or correction applied. We can do better.

Max <1%

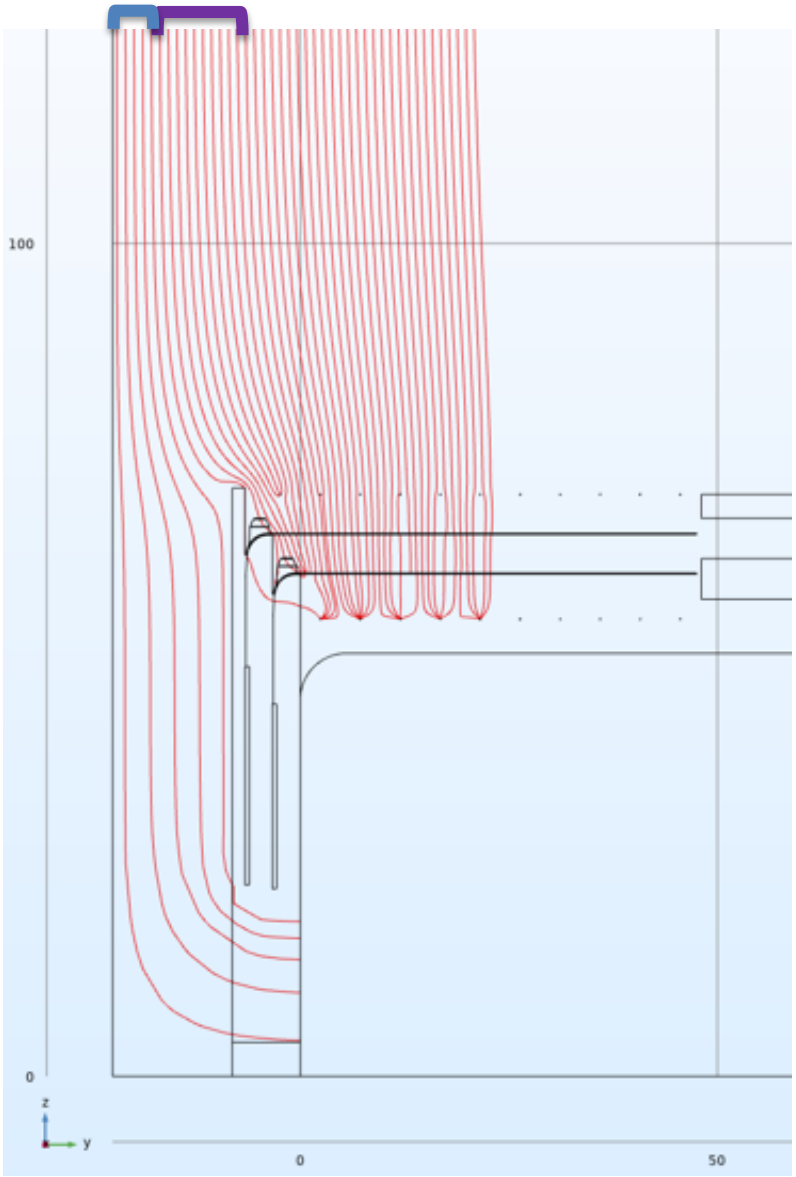


Thales Vieira

Effect on Induction-Plane Signals

- Some of the charge drifting over the gaps is not predicted to be lost, but rather it collects on the grid-plane and induction-plane wires
- Can we see this happening in ProtoDUNE-SP data?
- Can we calibrate this and make use of the charge?

Predictions: No Diverters



Fully charged insulating surfaces

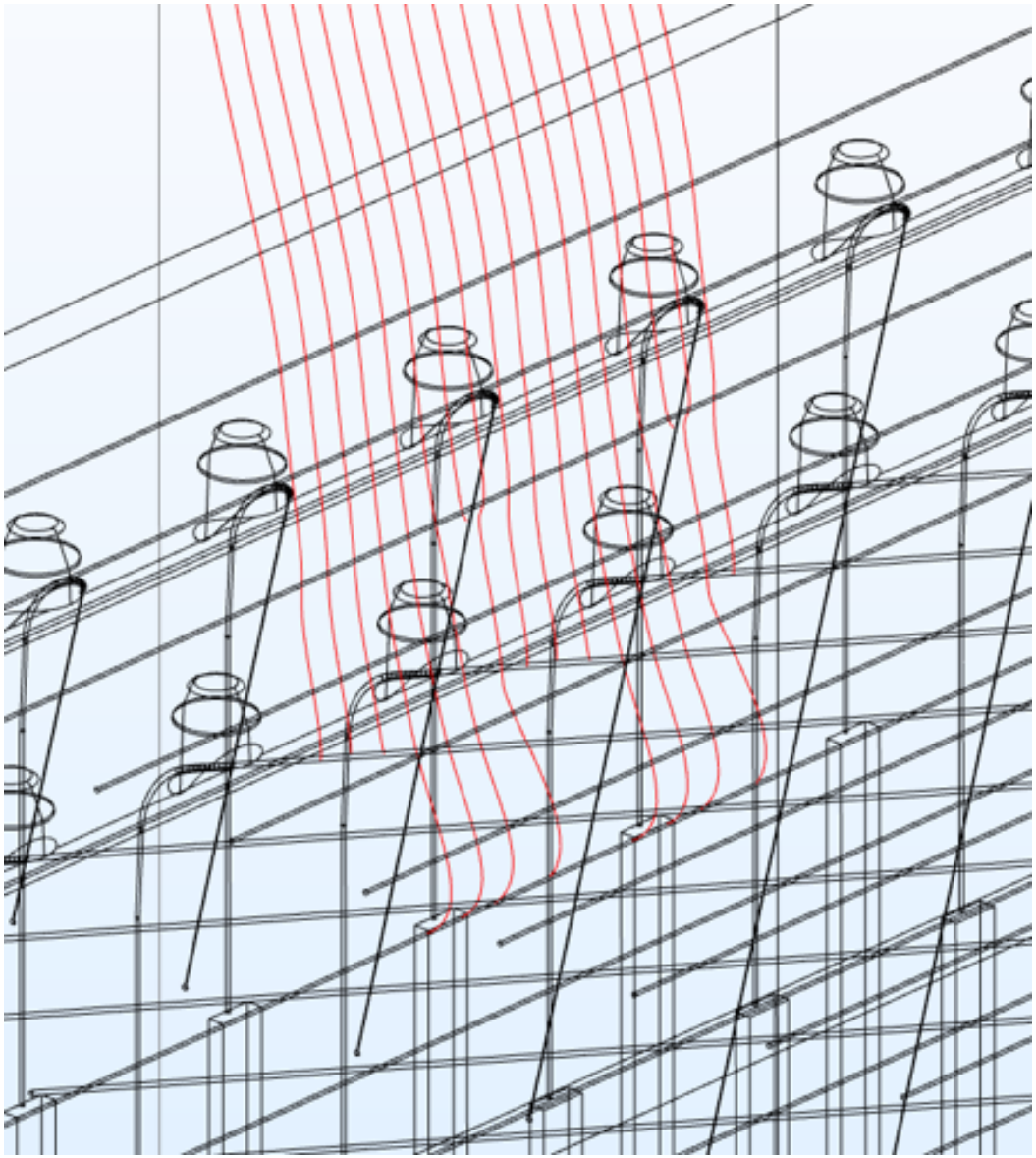
Boundary condition: No more charge can accumulate, so E has no normal component for dielectric surfaces

Blue Bracket: charge collects on conductors in the gap

Purple bracket: Charge collects on Grid, U, or V wires.

Bo Yu

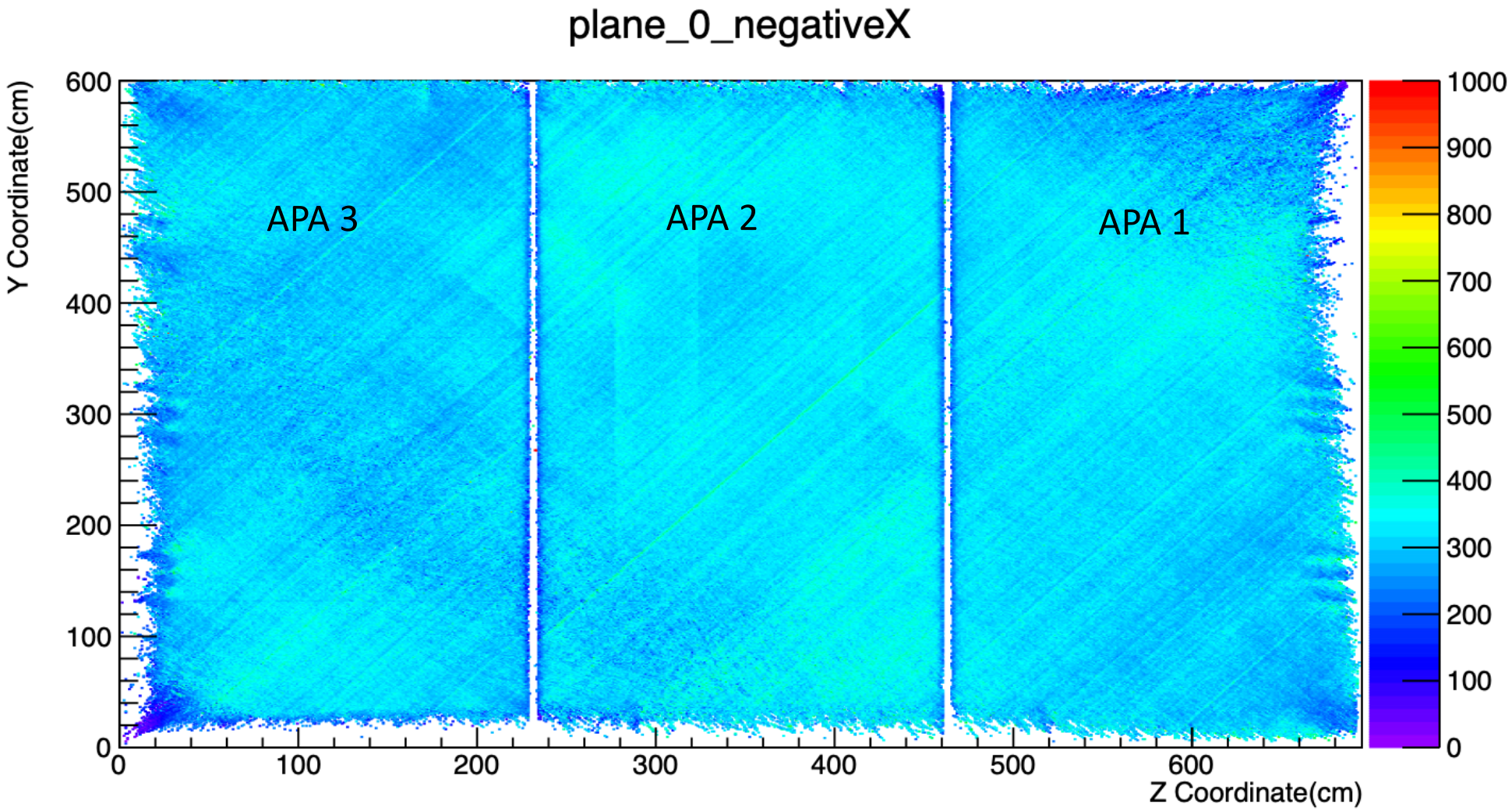
3D Simulation No Diverter



Bo Yu

dQ/dx Map with Grounded Diverters

ProtoDUNE-SP Run 5387

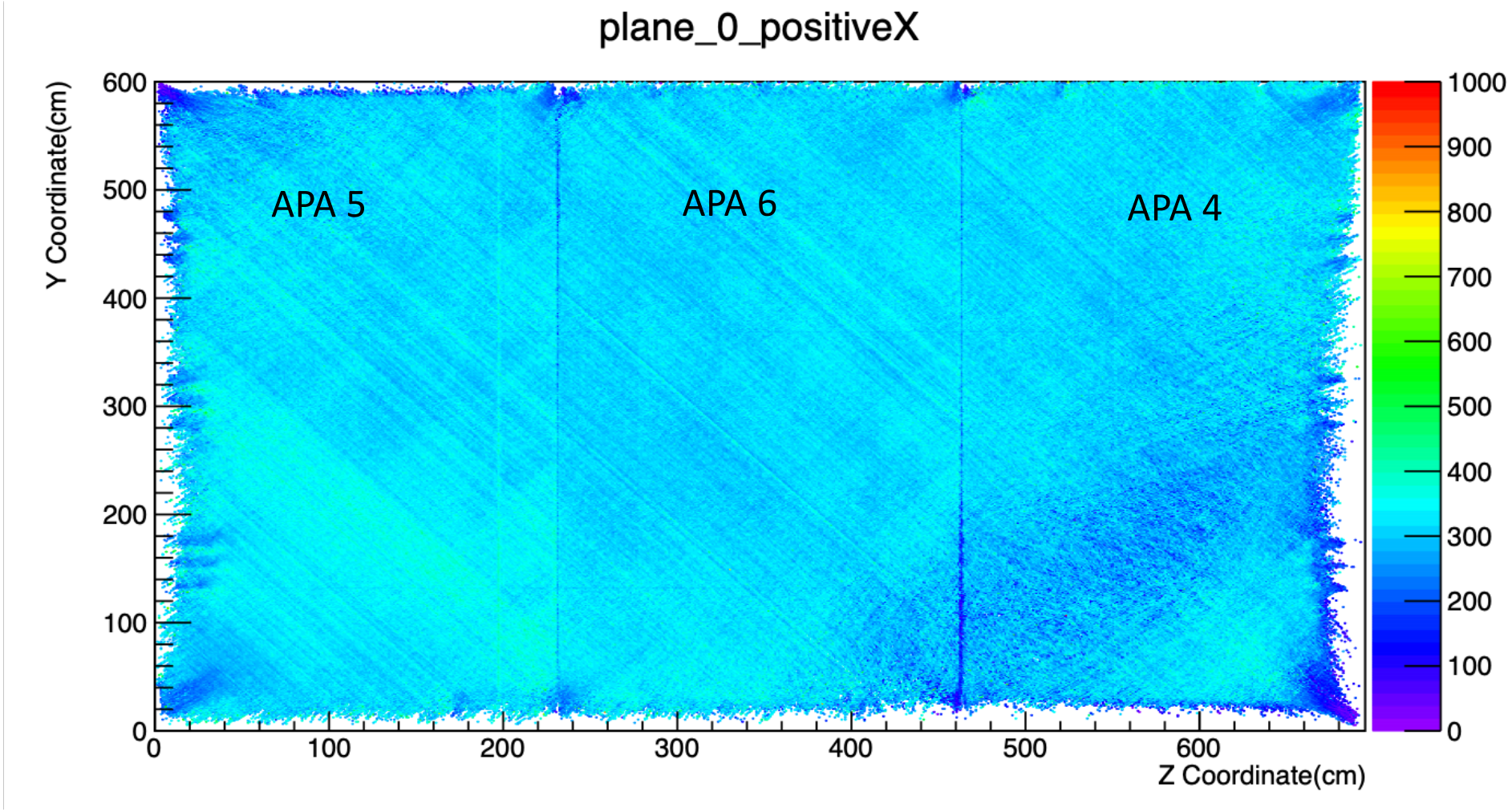


Ajib Paudel

U Plane, Beam-right Side, 1 cm x 1 cm binning

dQ/dx Map with Grounded Diverters

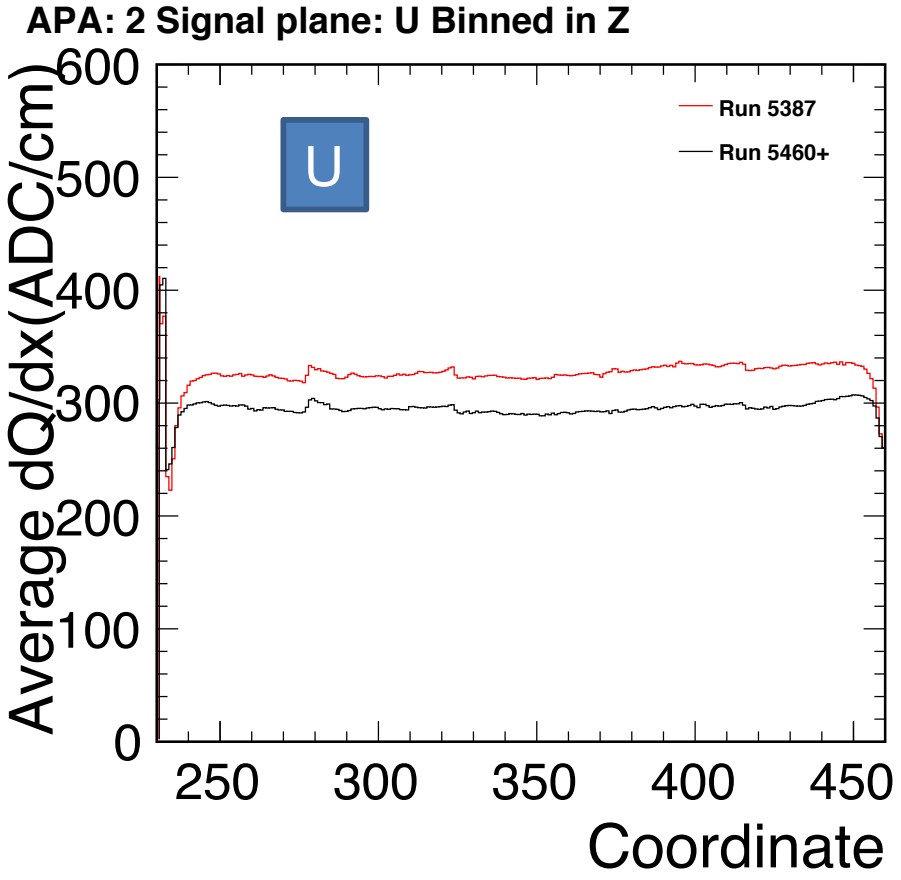
ProtoDUNE-SP Run 5387

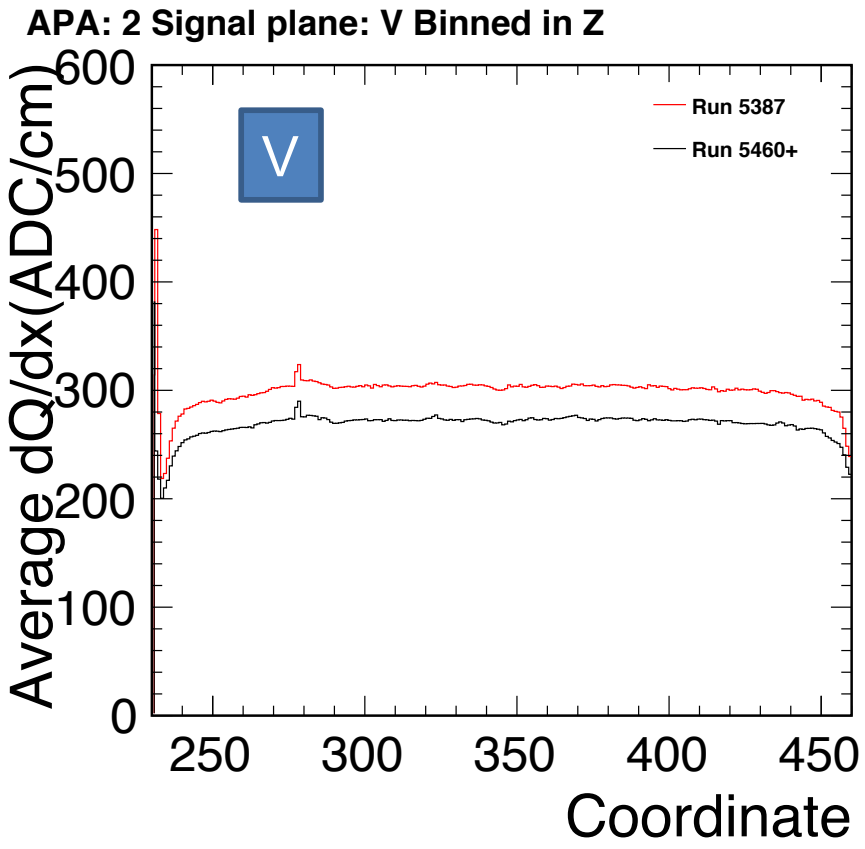


Ajib Paudel

U Plane, Beam-Left Side, 1 cm x 1 cm binning

Grounded Diverters Induction dQ/dx APA2

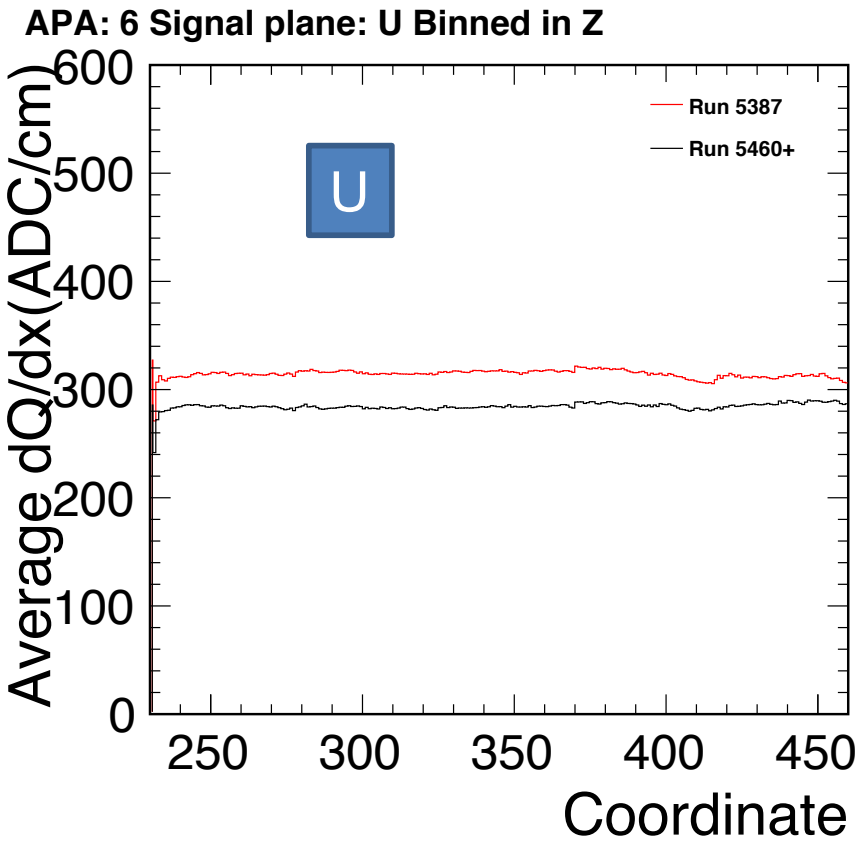


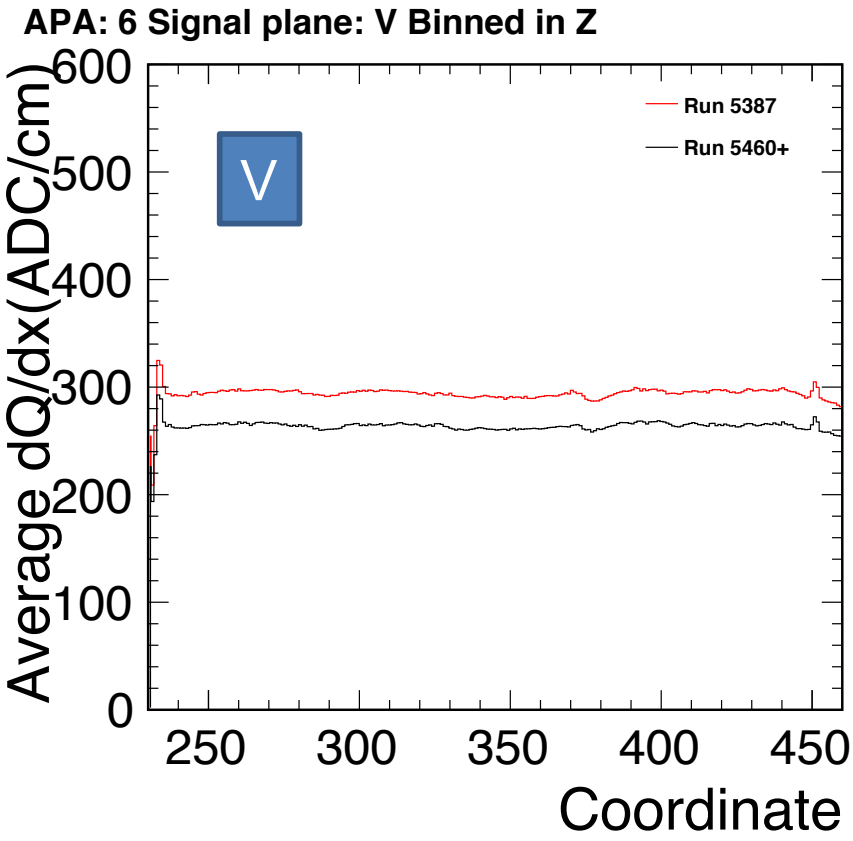


U and V signals binned in Z (cm)

Grounded Diverters on Both Sides

No Diverters Induction dQ/dx: APA 6

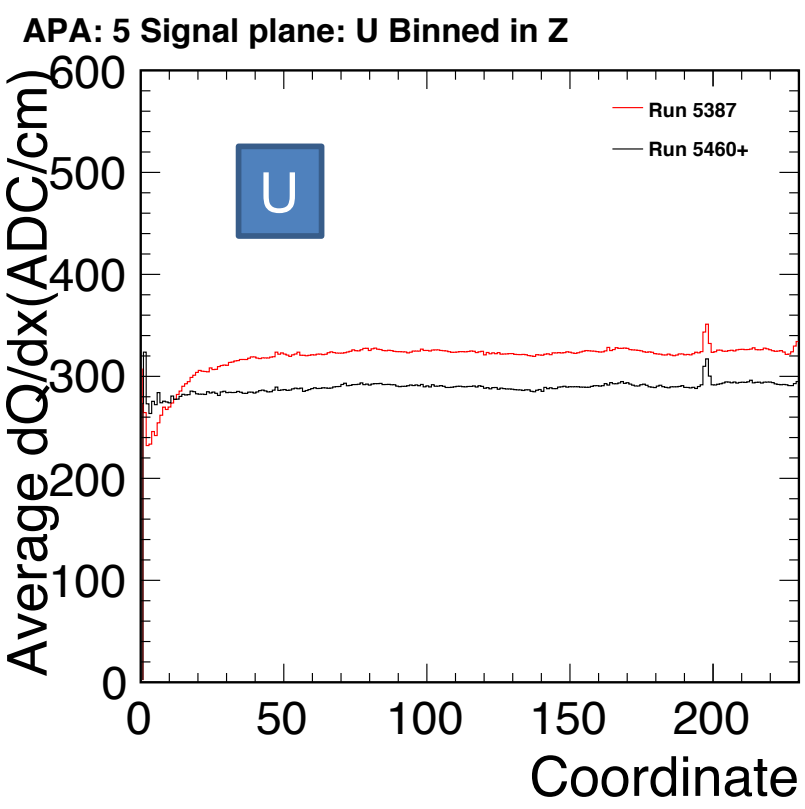


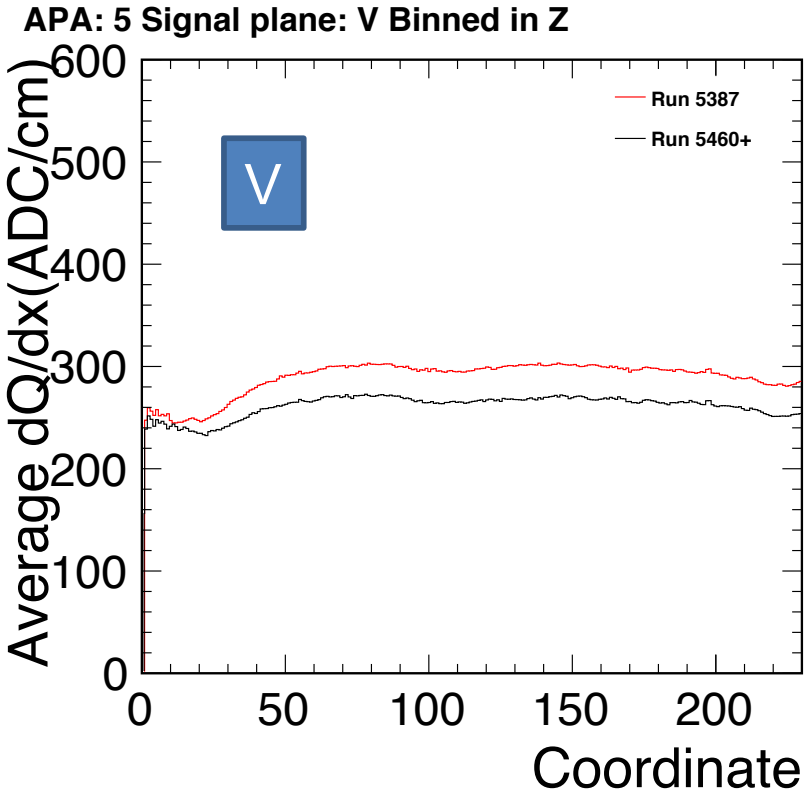


U and V signals binned in Z (cm)

No Diverters on Either Side

No Diverters Induction dQ/dx: APA 5

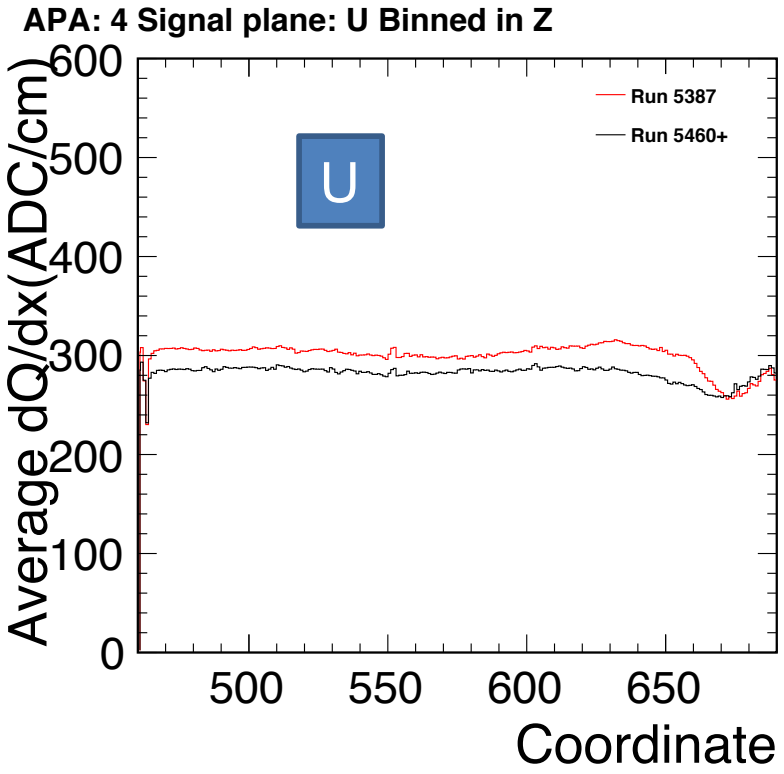


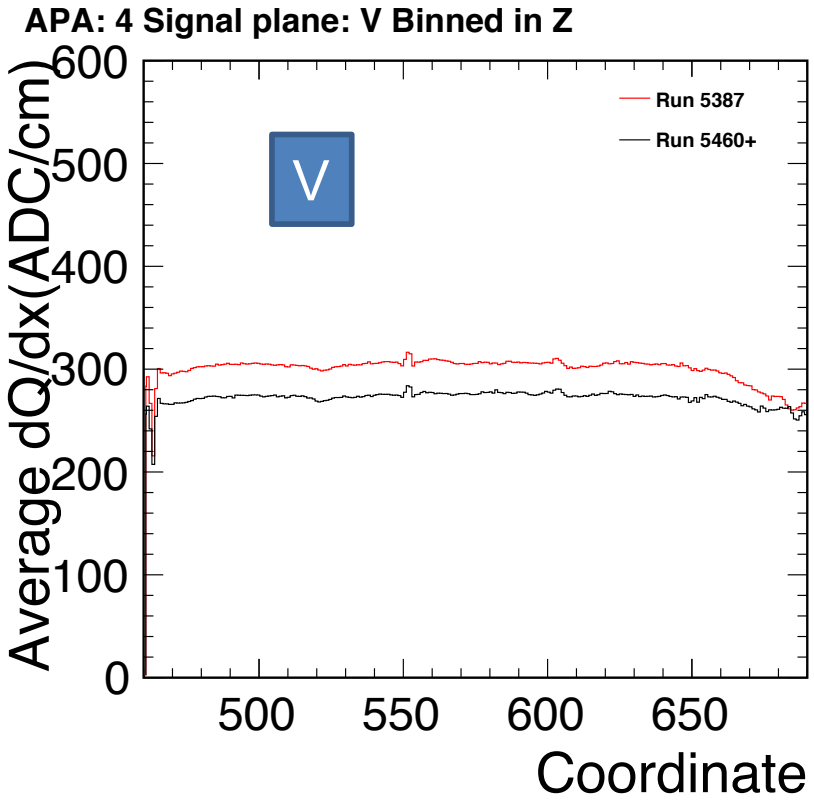


U and V signals binned in Z (cm)

FC on Left, No Diverter on Right

No Diverters Induction dQ/dx: APA 4



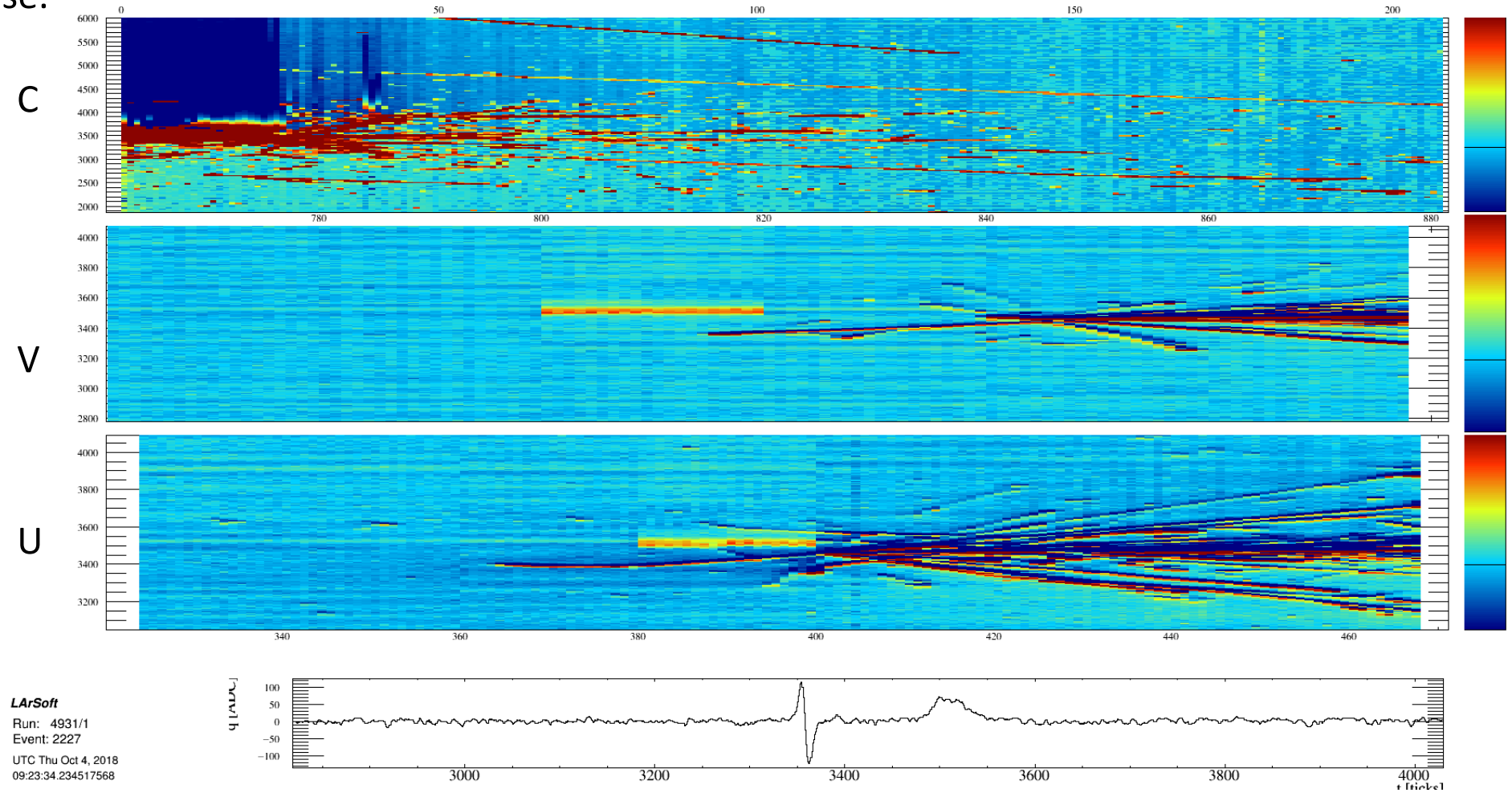


U and V signals binned in Z (cm)

FC on Right, No Diverter on Left

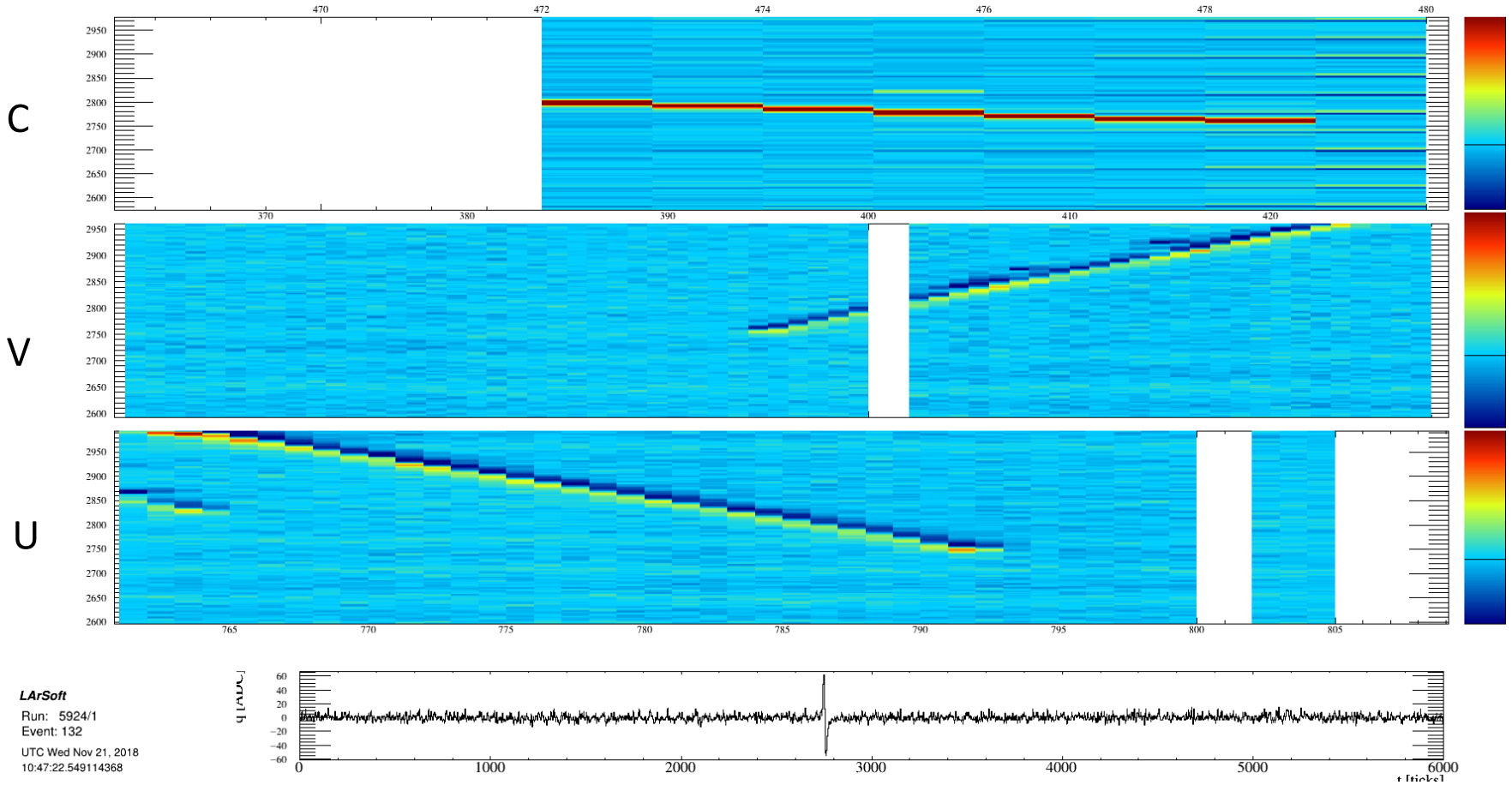
We already see unipolar signals on induction-plane wires

This one's caused by saturation on the same FEMB. We have to watch out for them in any case.

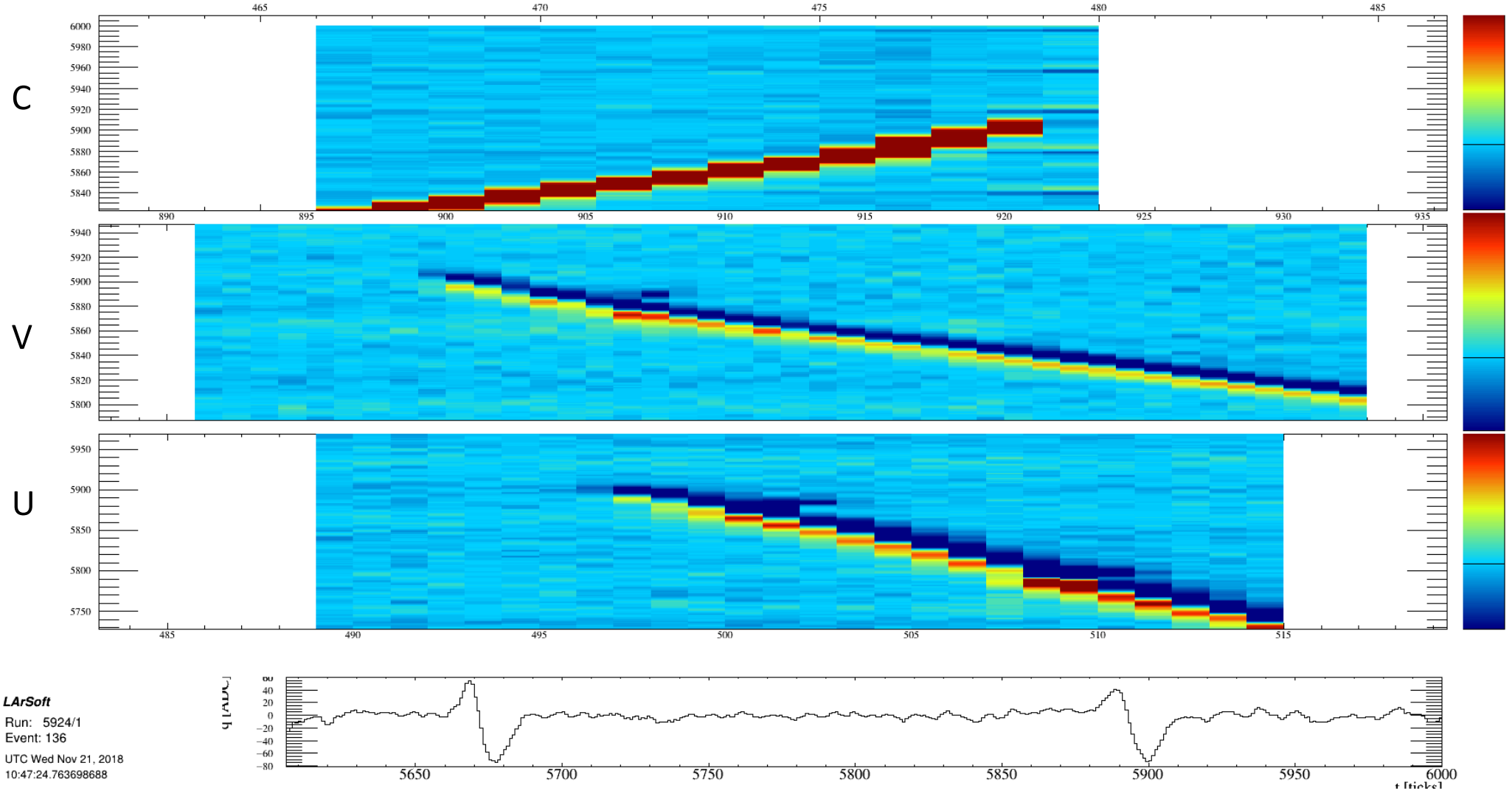


ED23 @100% (Run 5924)

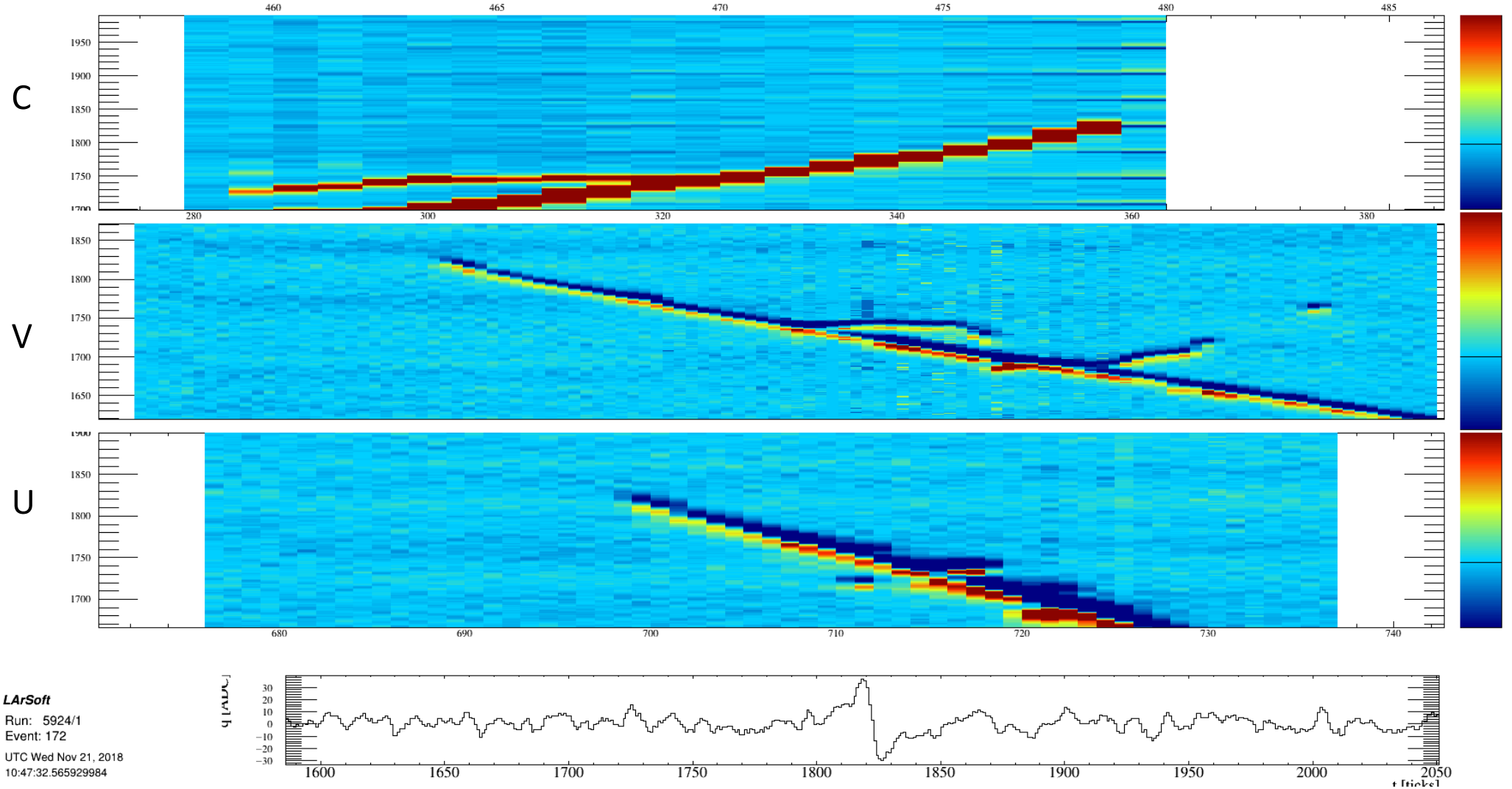
Endpoints of Induction-Plane Tracks are bipolar for the most part



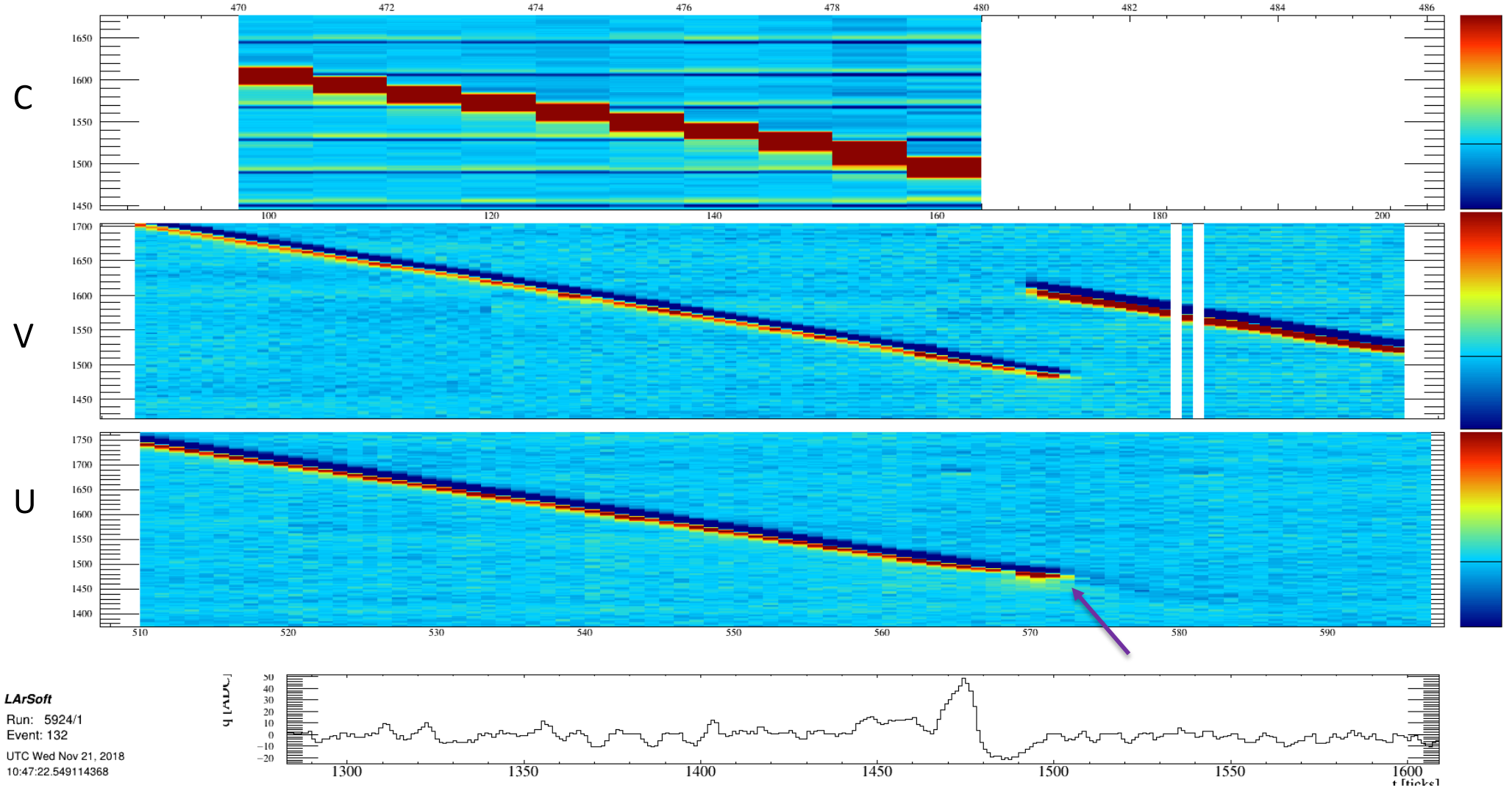
Another track @100% ED23 volts



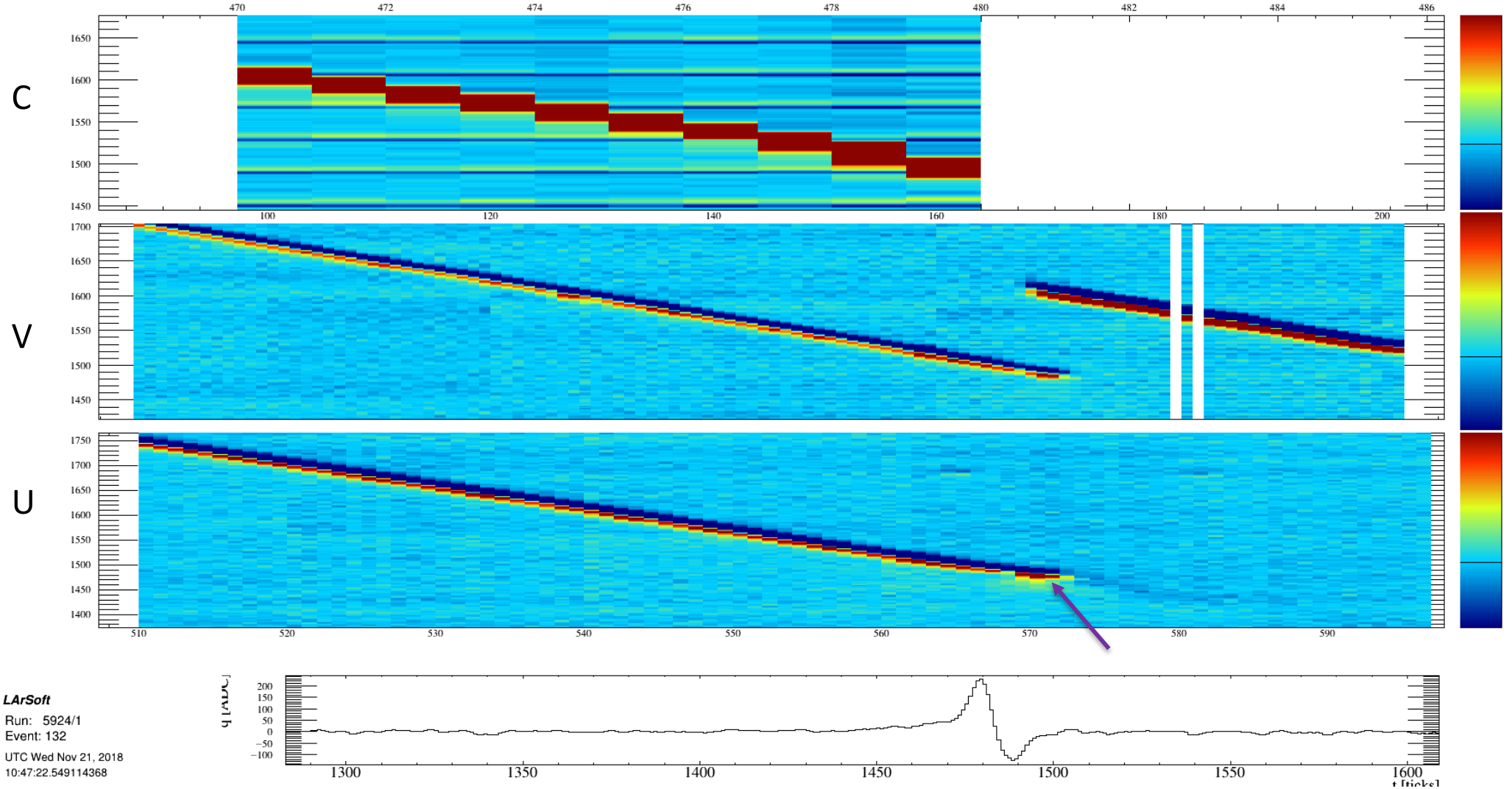
Another track @100% ED23 volts



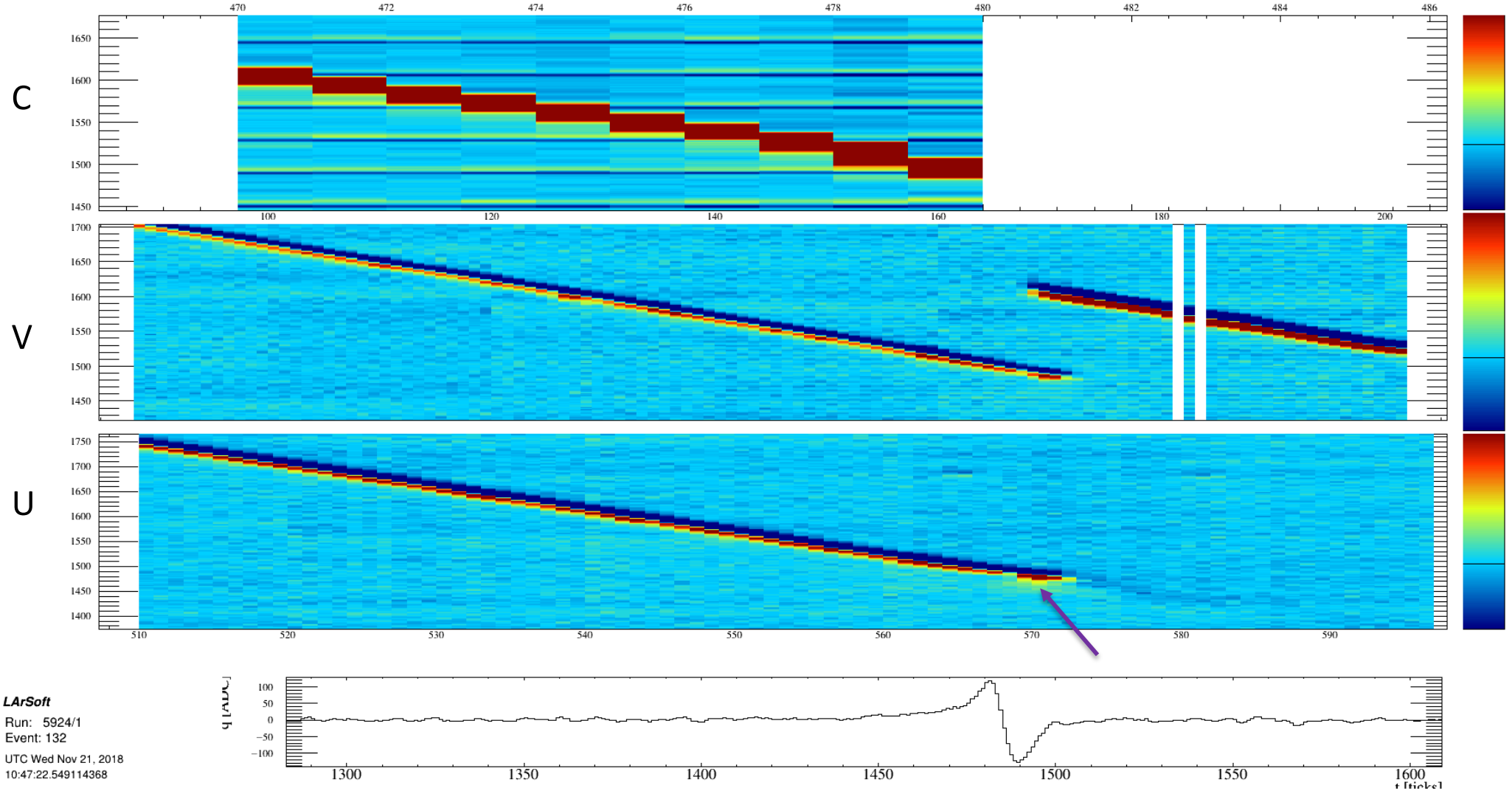
No Diverter 1



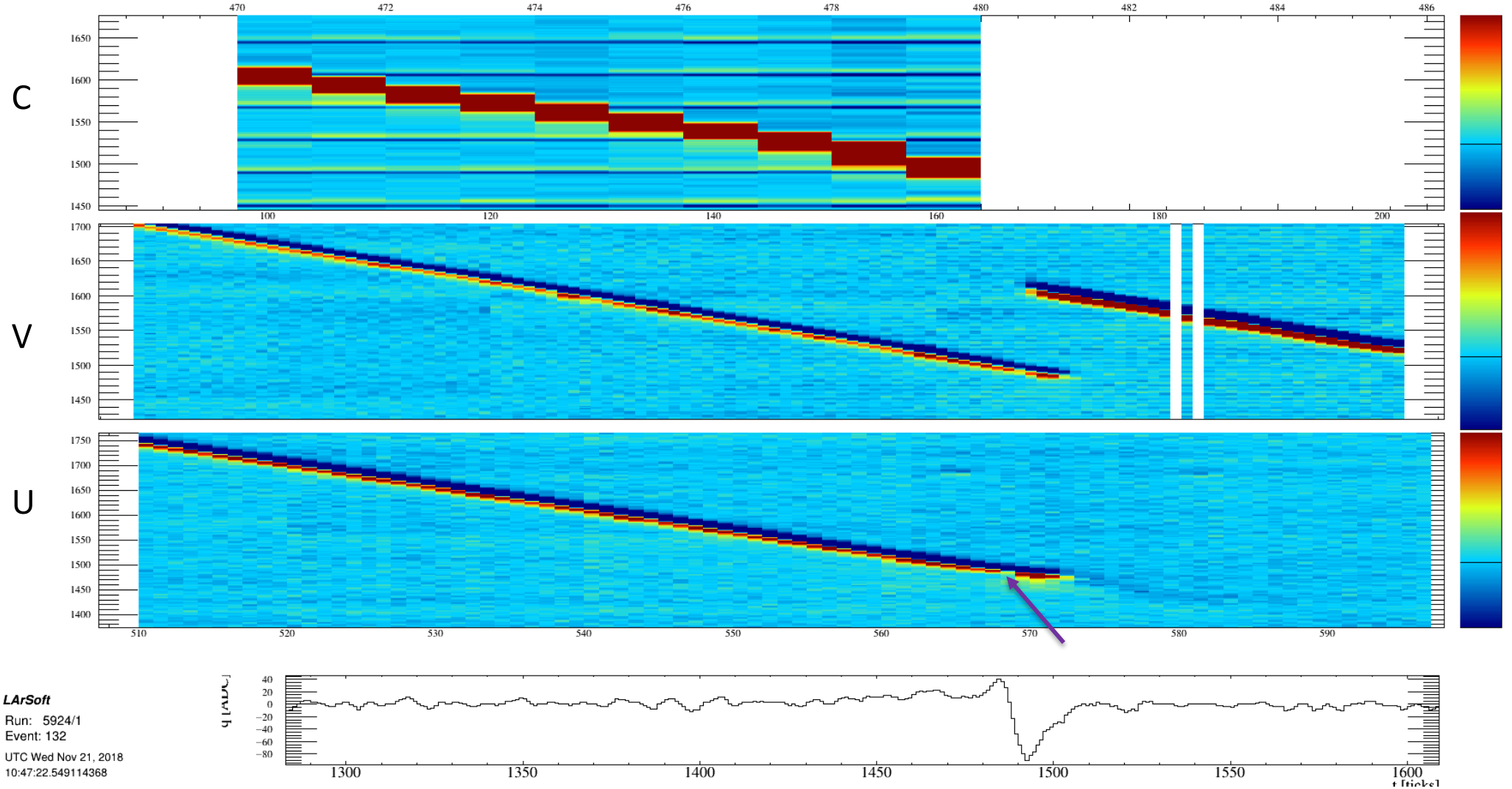
No Diverter 2



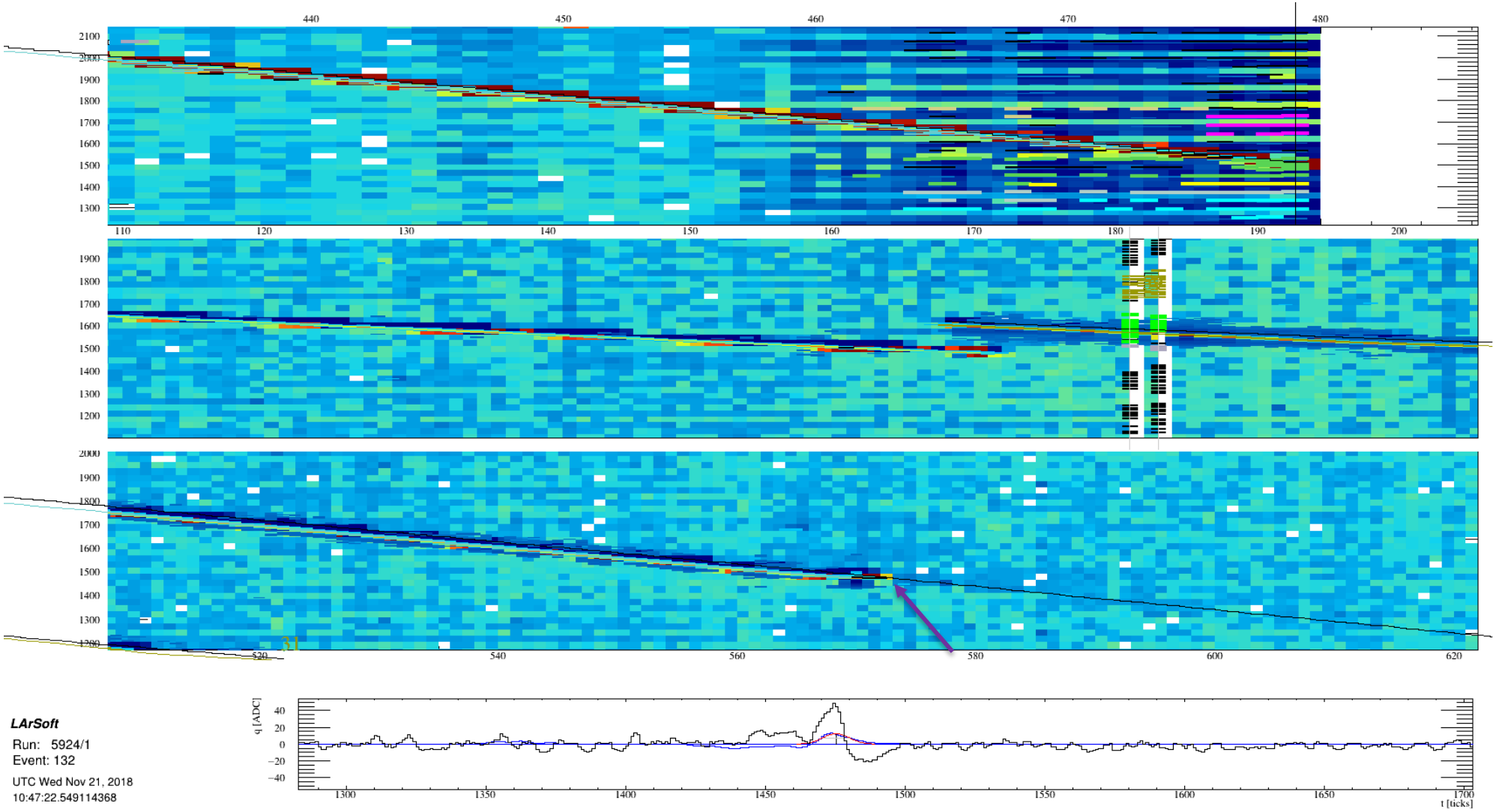
No Diverter 3



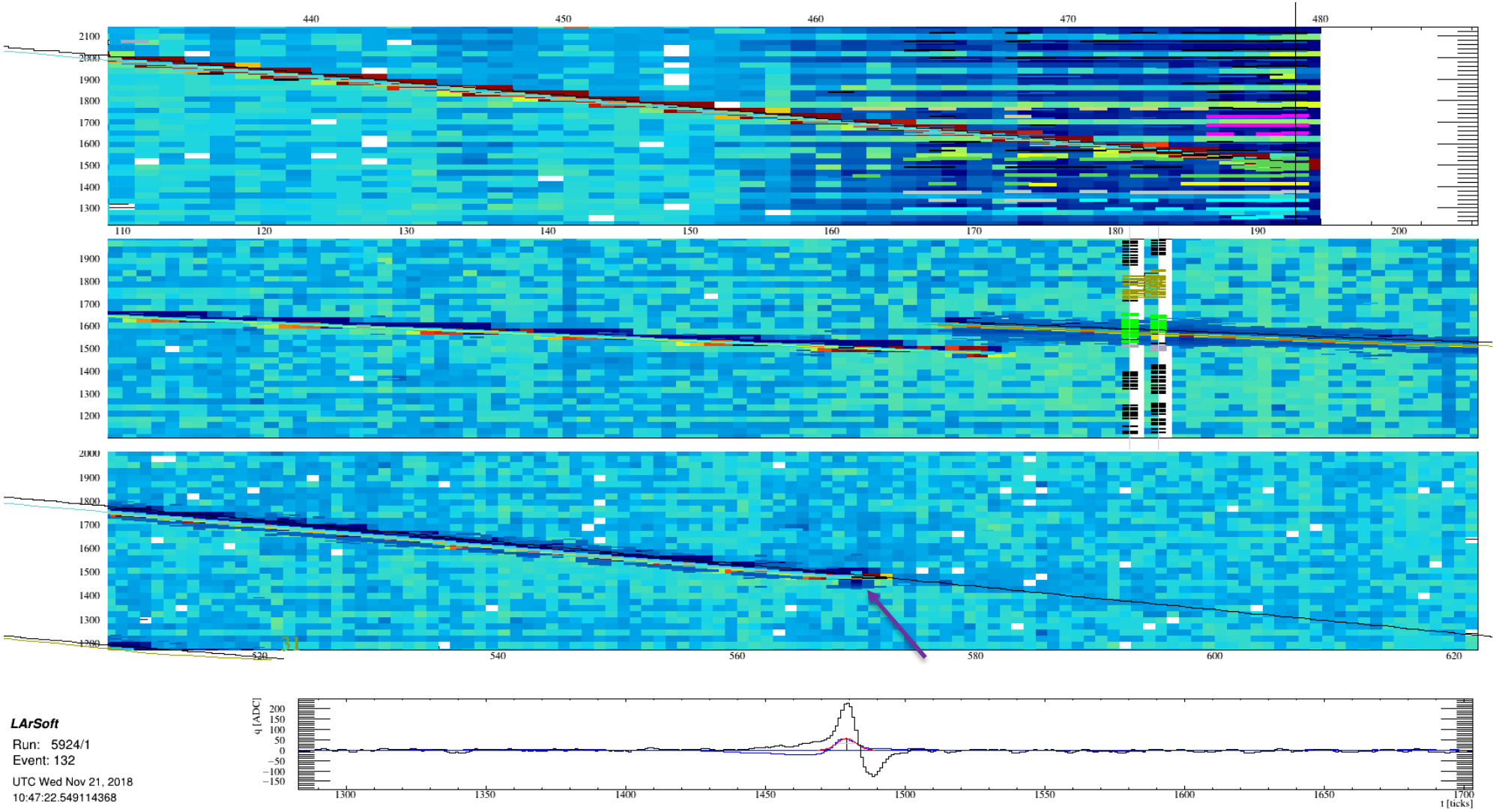
No Diverter 5



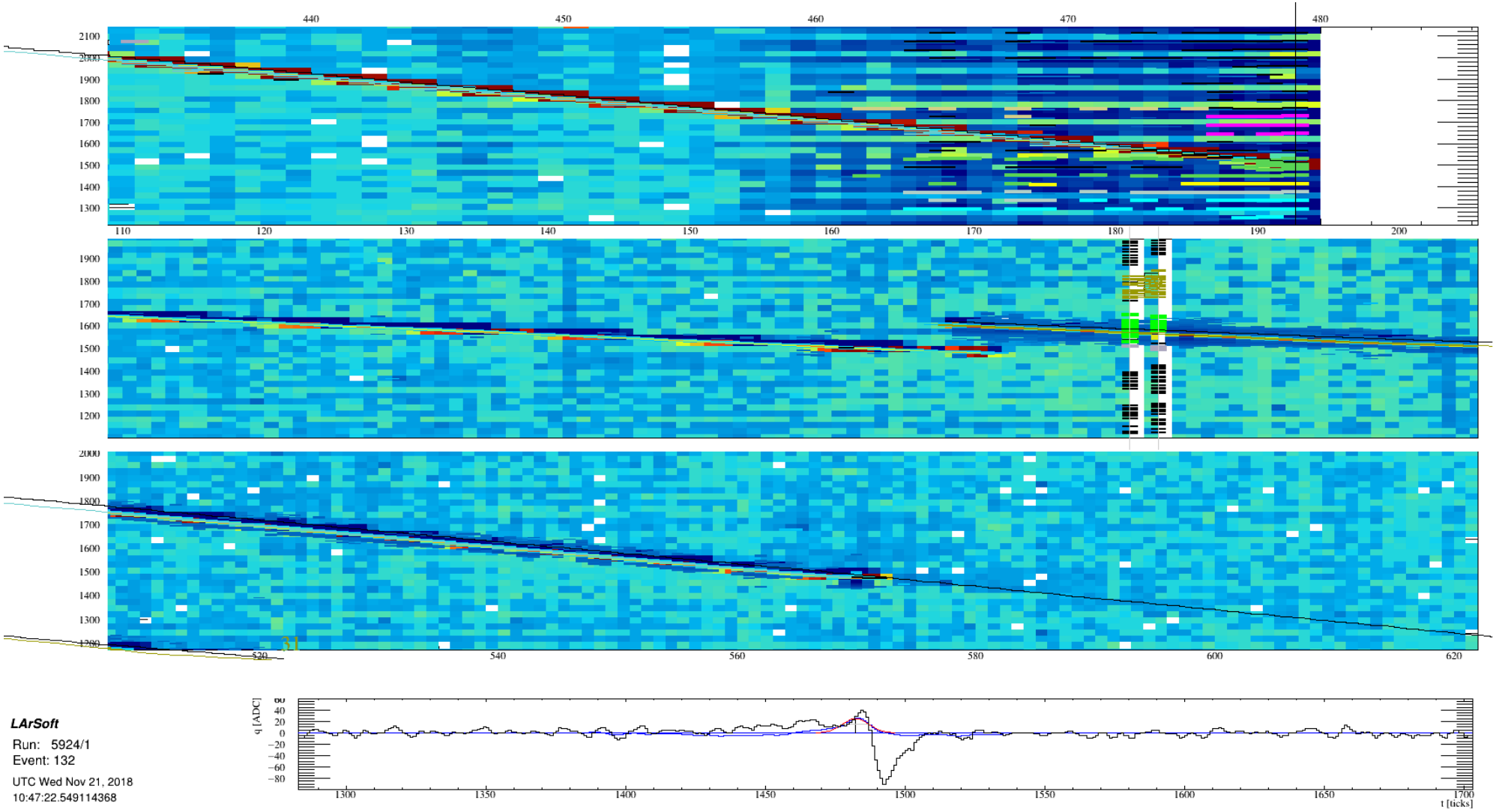
1D Deconvoluted No-Diverter 1 Waveform



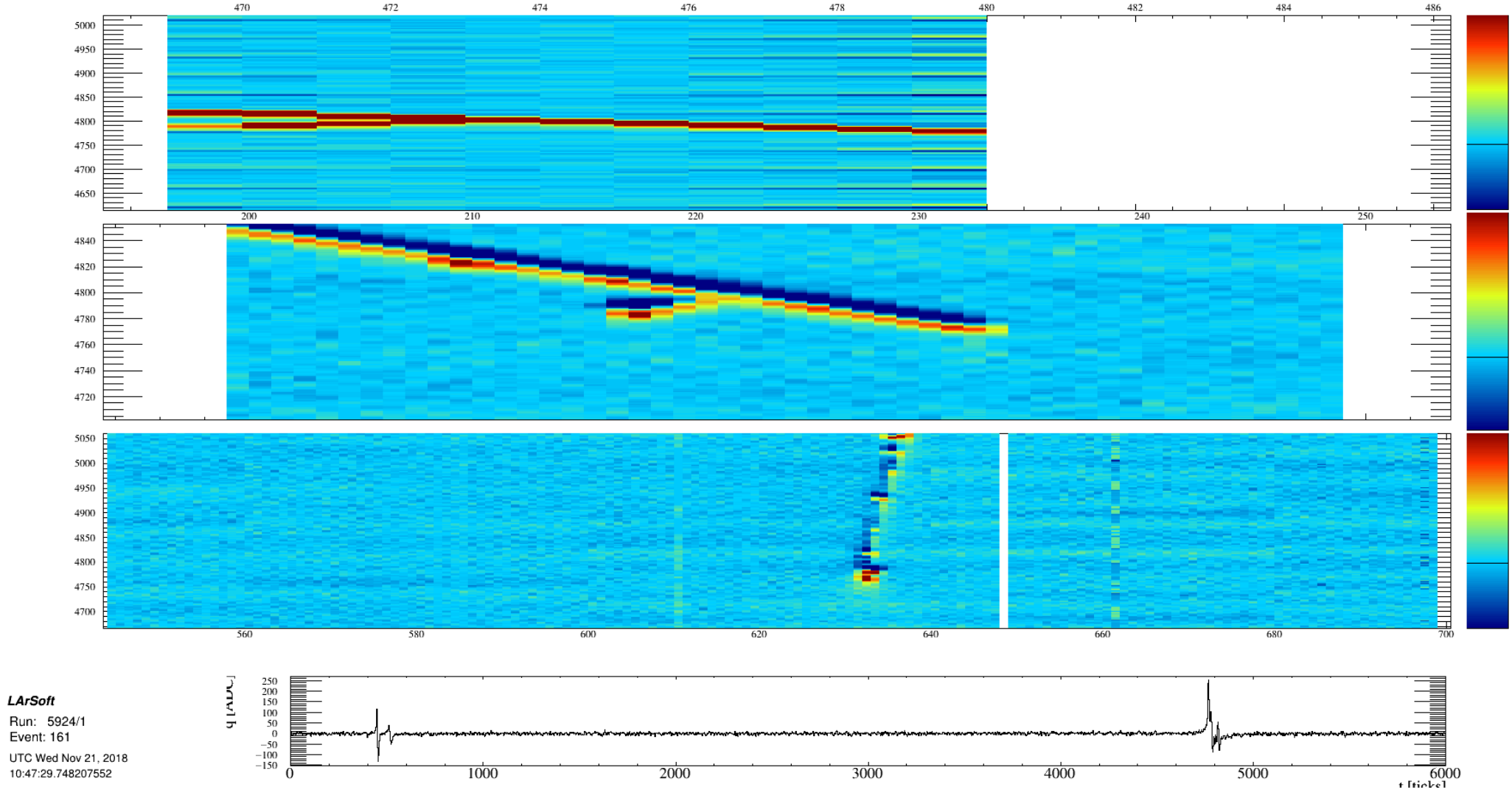
Deconvoluted No-Diverter Waveform



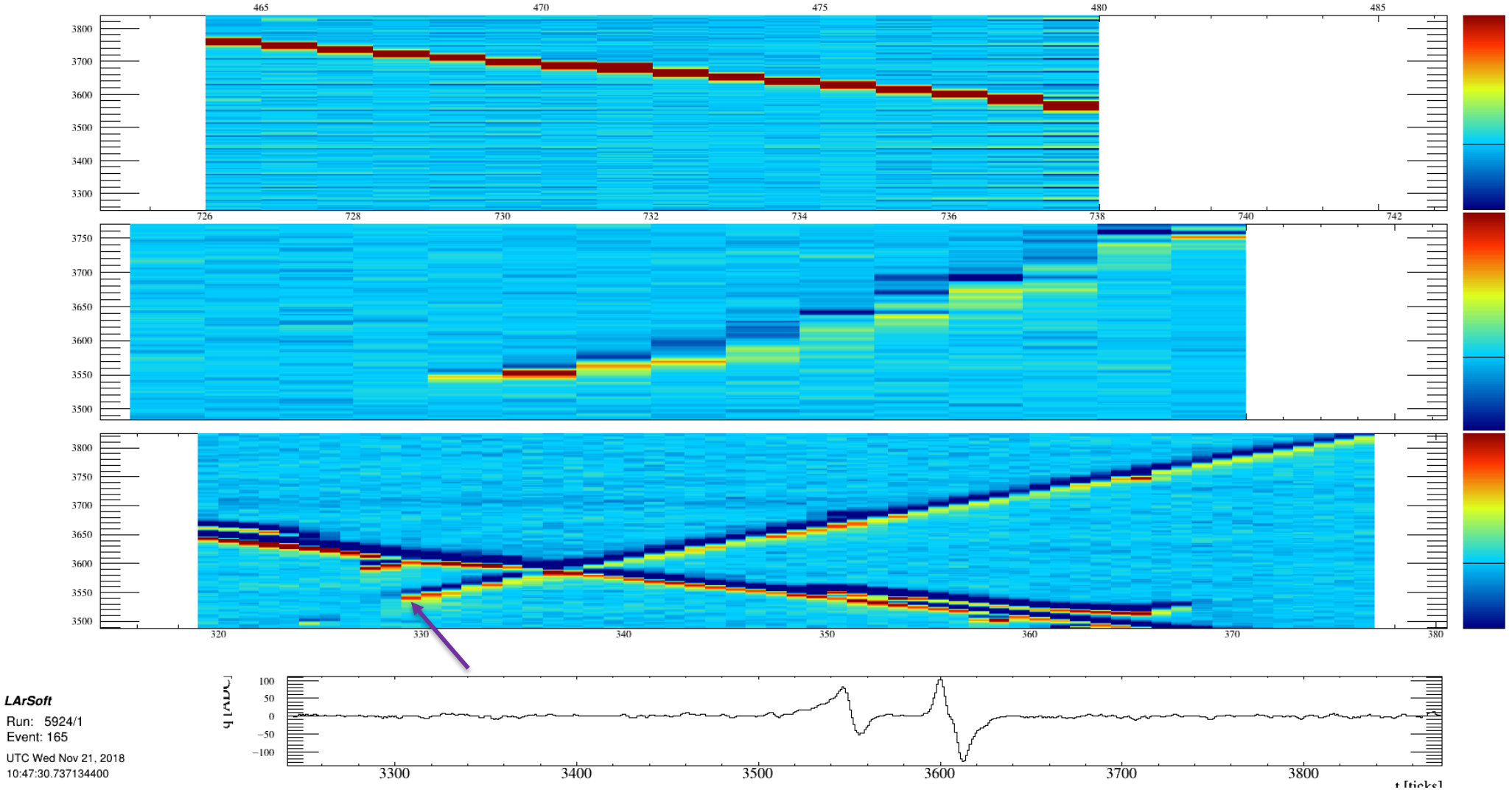
Deconvoluted No-Diverter Waveform



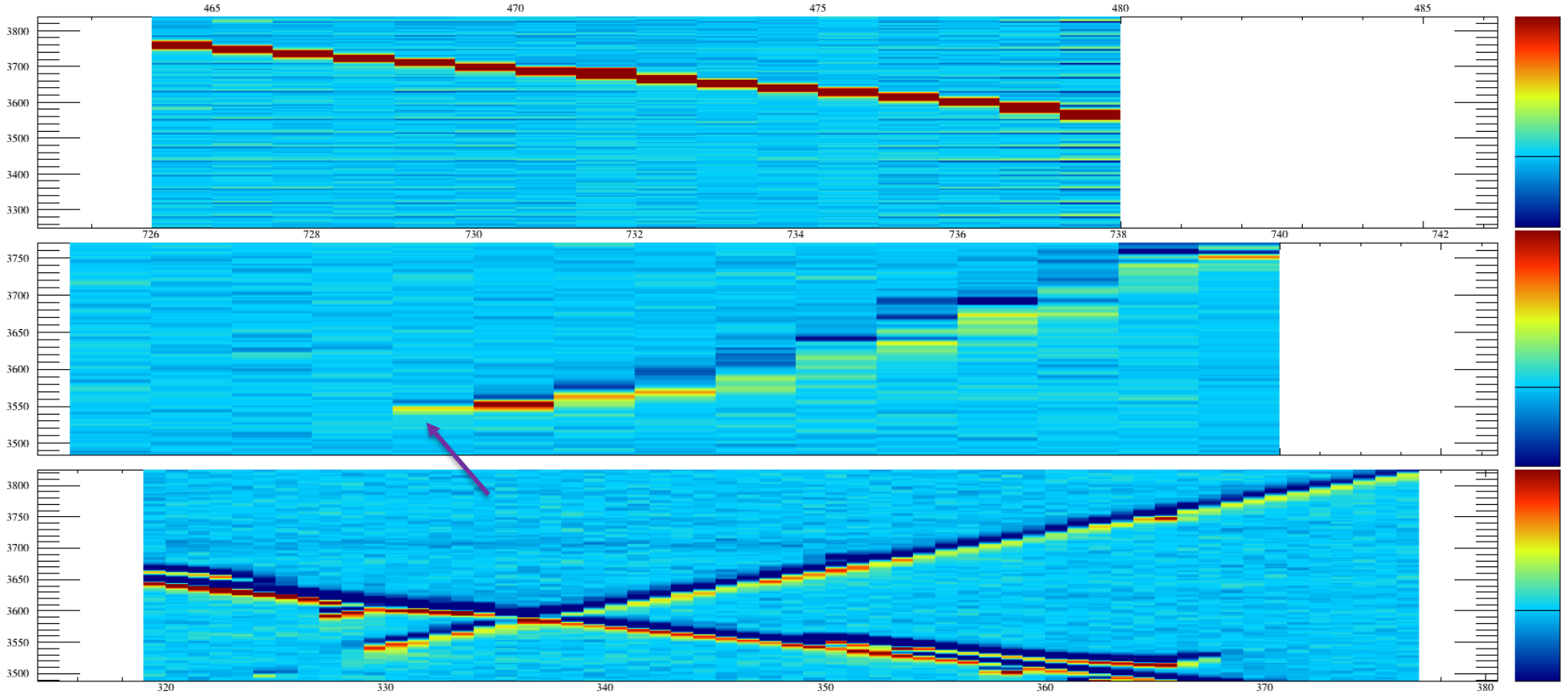
No Diverter Track Along U

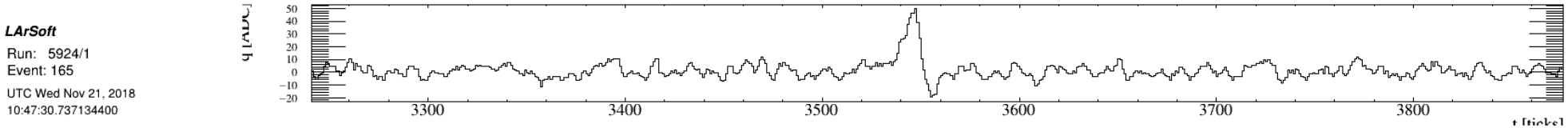


No Diverter U1

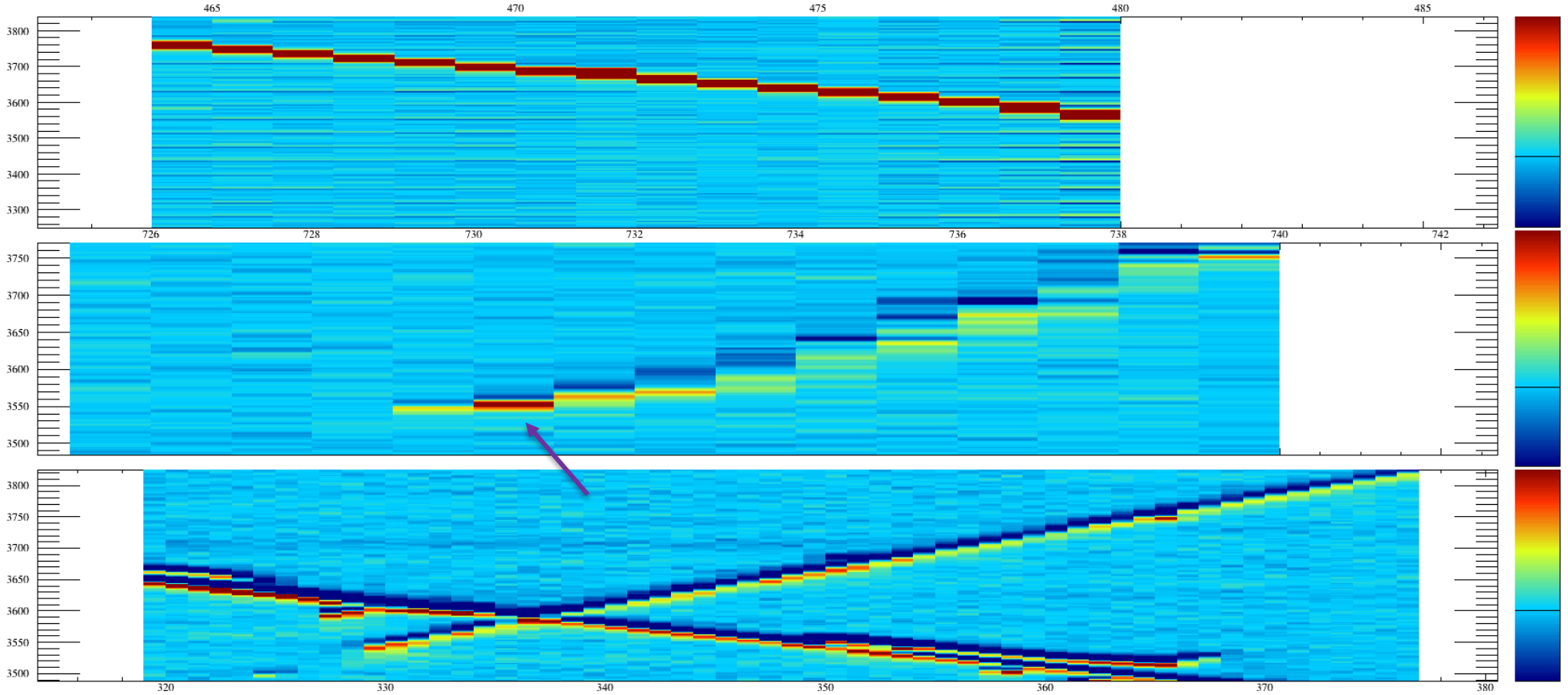


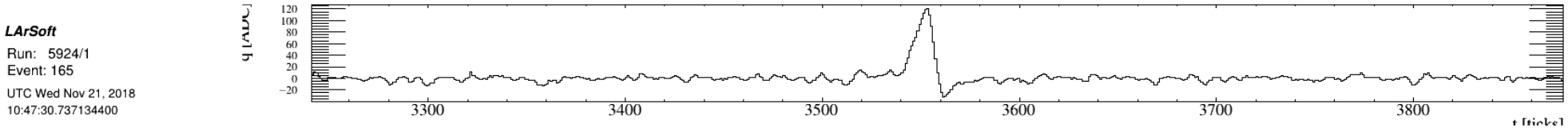
No Diverter V1



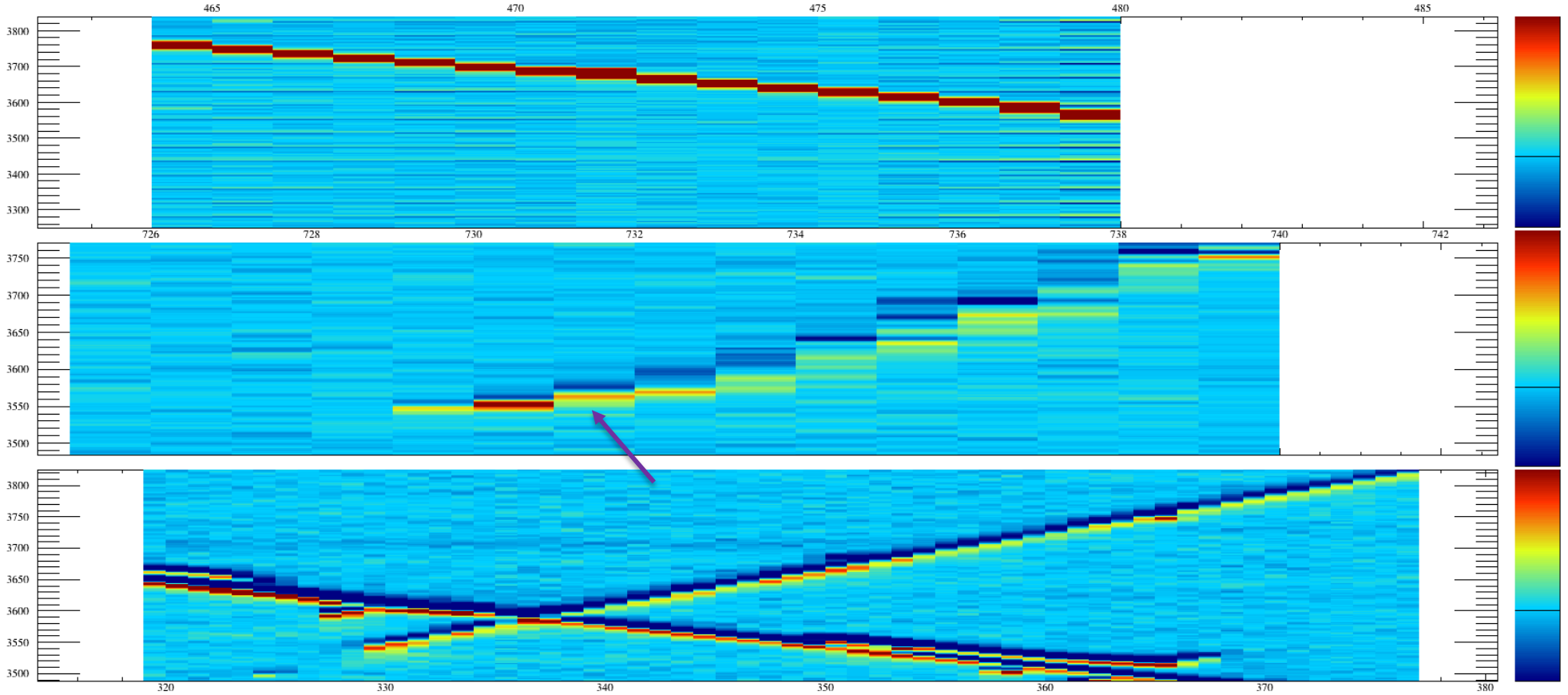


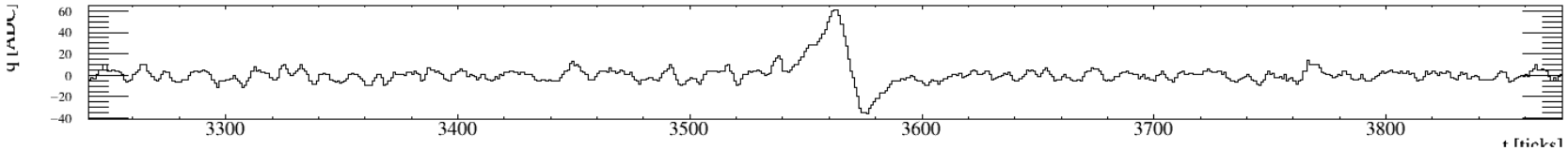
No Diverter V2





No Diverter V3





LArSoft
Run: 5924/1
Event: 165
UTC Wed Nov 21, 2018
10:47:30.737134400

Impact on Fiducial Volume

- Fiducial volume cut is applied to the primary vertex, not on objects in the event.
- Main issue is to not split or stretch too badly tracks near the primary vertex
- dE/dx in the first 2.5 cm of an EM shower is critical for signal/background separation. Should cut vertices out that could have an electron track straddle a gap.
- Corrected charge distributions may not be precise enough to do this PID and we will have to cut around the gaps anyhow for careful work (proton decay has little tolerance for mismeasurement)
- Volume inside diverters and near them have different maps. May be interpolatable.

Resources Needed

- Active diverters – resources not estimated.
- Passive diverters
  - Design: One month of Scientist or Engineer + 2 weeks technician
  - Prototyping: Several cycles of prototyping needed + cold cycling to test electrical and mechanical properties. Need a full-scale APA to test diverter. Time not estimated.
  - Production of five prototype diverters: ~1 FTE week.
  - Integration and installation of prototype: ~1 FTE day @Ash River
  - FD Production: 1200 meters of ED: $120k for material, and 1800 FTE hours, 400 of which is for a machinist
  - FD Installation: 1 FTE hour per APA = 150 FTE hours

Risks

- Active diverters can short out during operation, even if they pass tests.
- Active diverters may have marginal HV characteristics requiring special care during a long DUNE run.
- Passive diverters may take a long time to charge up. ^{39}Ar helps in this regard.
- Passive diverters may over-charge. Positive ions drift slowly and the region with field that sweeps them onto an over-charged diverter is small.
- Dust and debris may accumulate especially on horizontal diverters.
- Diverters protrude, creating mechanical interference challenges.
- Radiologicals may accumulate on diverters
- If no diverters are installed, we lose charge to any grounded, exposed surface, and to grid and induction-plane wires.

Recommendations

- We took a vote. Options: No Diverters, Active Diverters, Passive Diverters, or Something Else
- Results: 4 votes for No Diverters, 1 vote for Passive Diverters
- Passive diverters need to be demonstrated to work. Time is short, and we were asked to provide advice.
- No diverters is our recommendation.
- Care should be taken not to expose grounded conductors in the gaps.

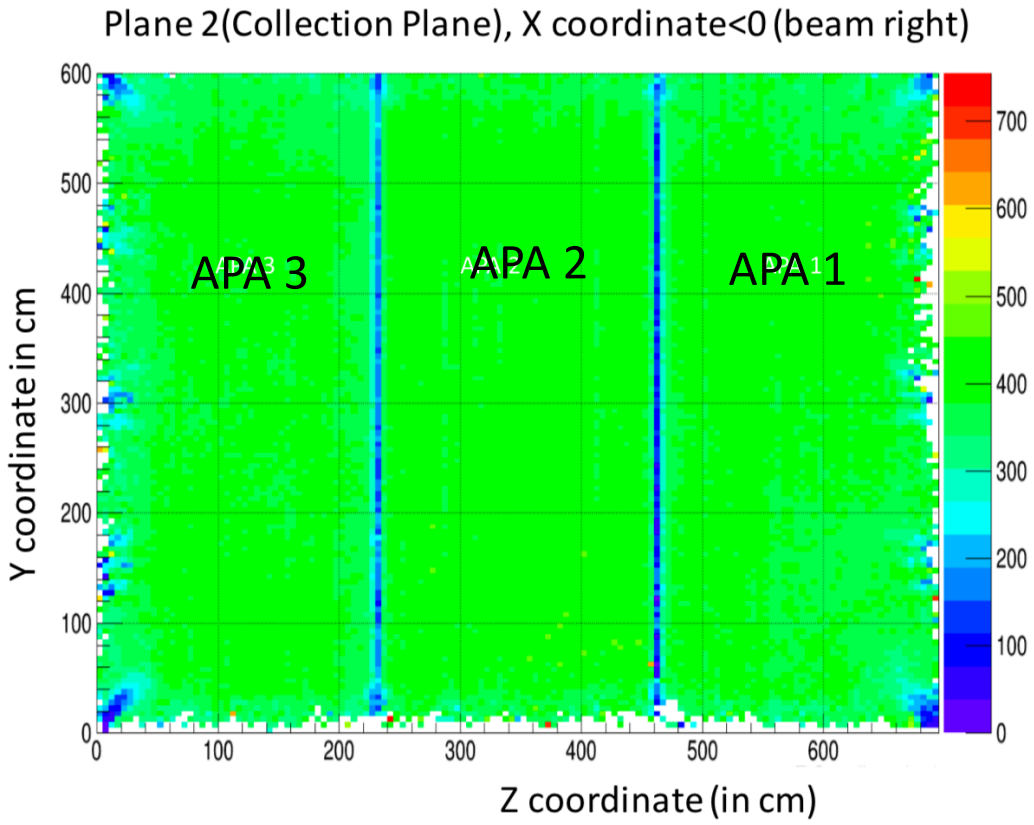
Extras

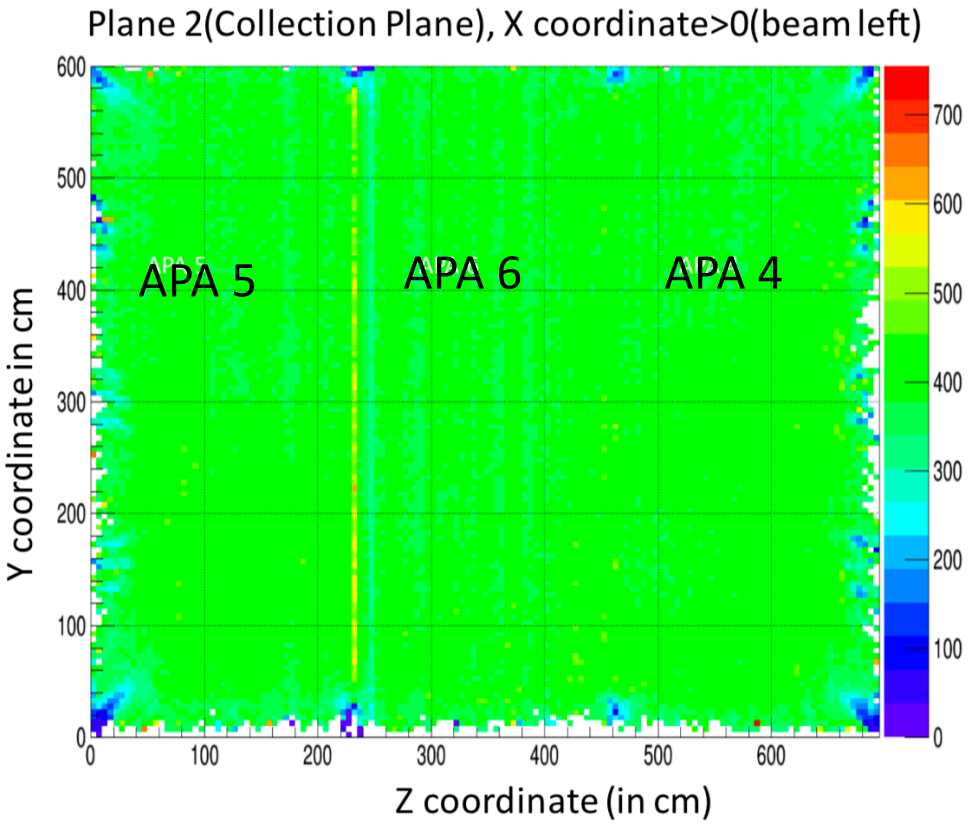
dQ/dx Map with Grounded or No Diverters

Ajib Paudel

Results: dQ/dx distribution for YZ plane

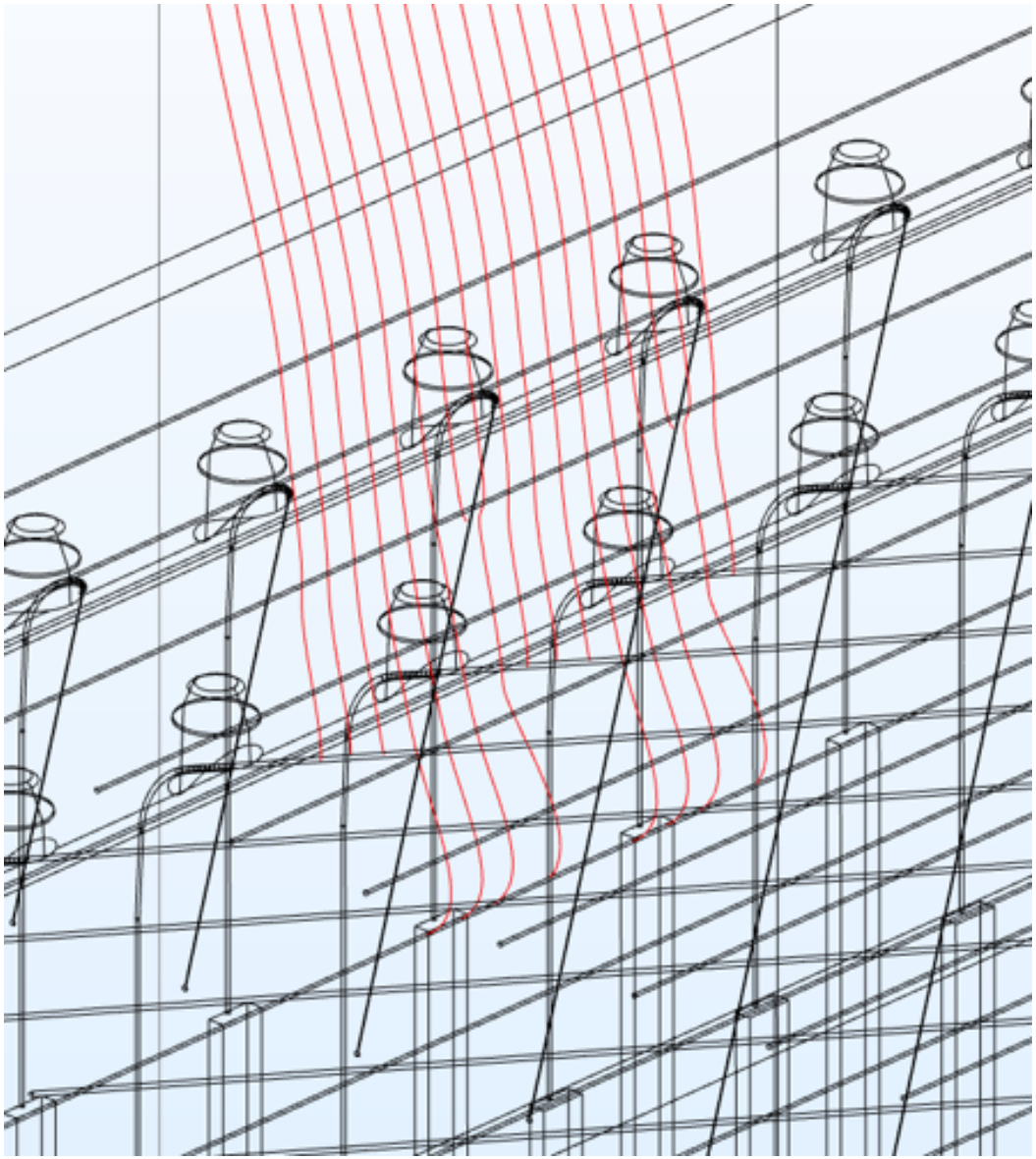
Run 5460





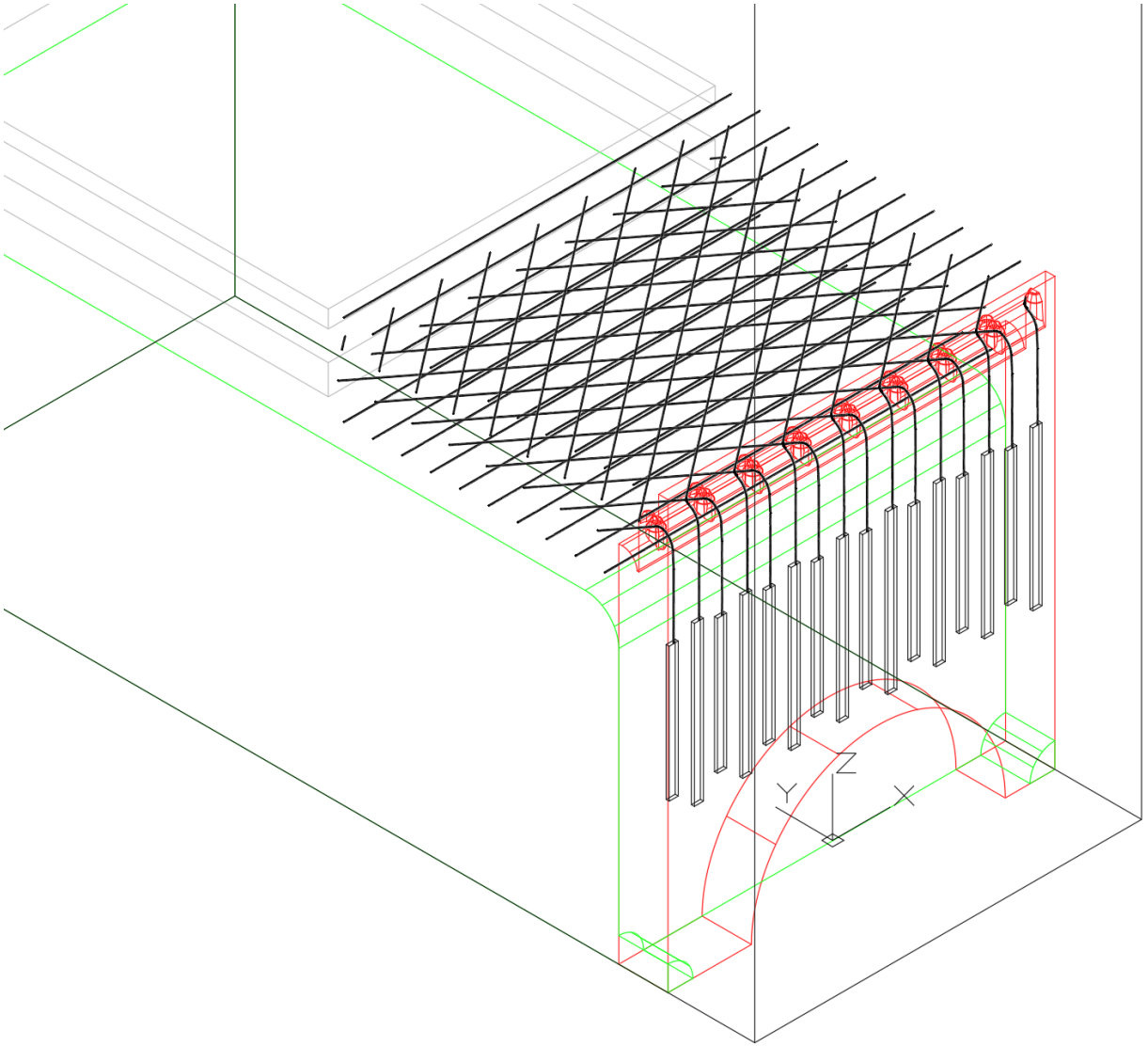
The above plots shows median dQ/dx values for each 5cm x 5cm bins for YZ plane. We can observe that for the left plot dQ/dx values around the APA boundaries are unusually low.

3D Simulation No Diverter



Bo Yu

FD APA Gap Model



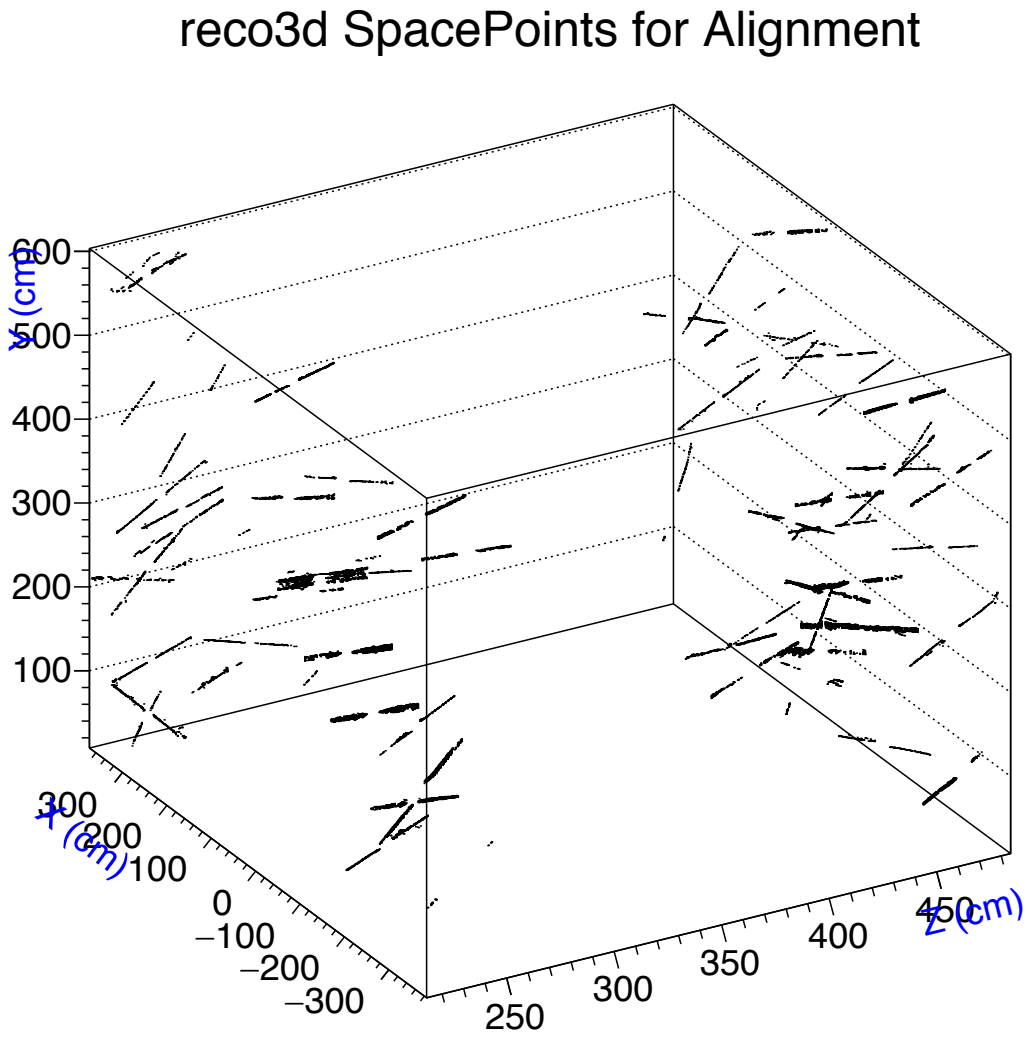
Bo Yu

Selected Stub Pairs

Stub pairs are associated with loose pointing miss-distance requirement.

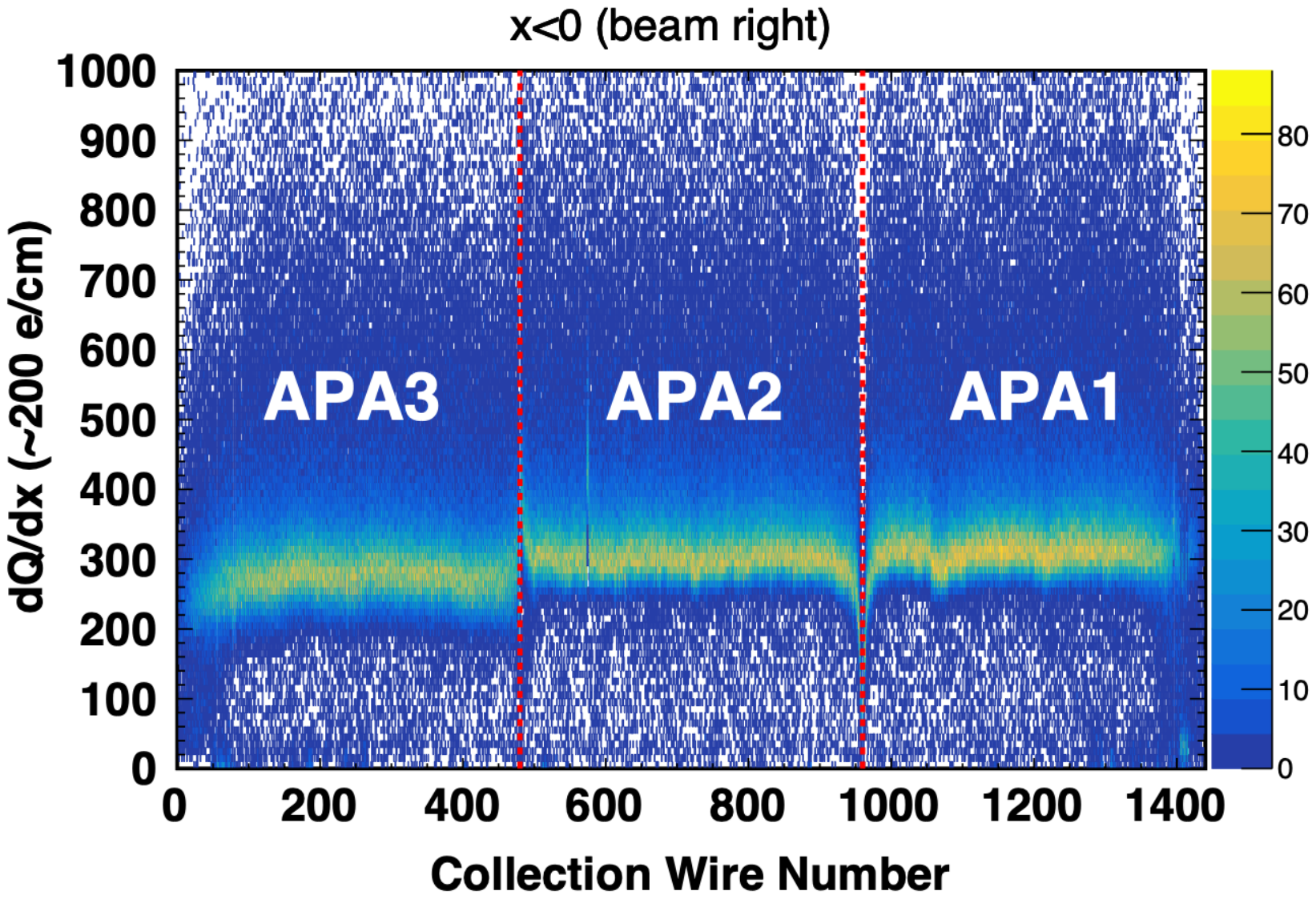
One file's worth of data from Run 5177

Alignment strategy:
For each value of (dx, dz) distortion from nominal, re-fit the space points in a stub pair in 3D to a single line segment. Add up χ^2 for all stub pairs. Plot $\sum\chi^2$ as a function of (dx,dz)



Effect on Calorimetry

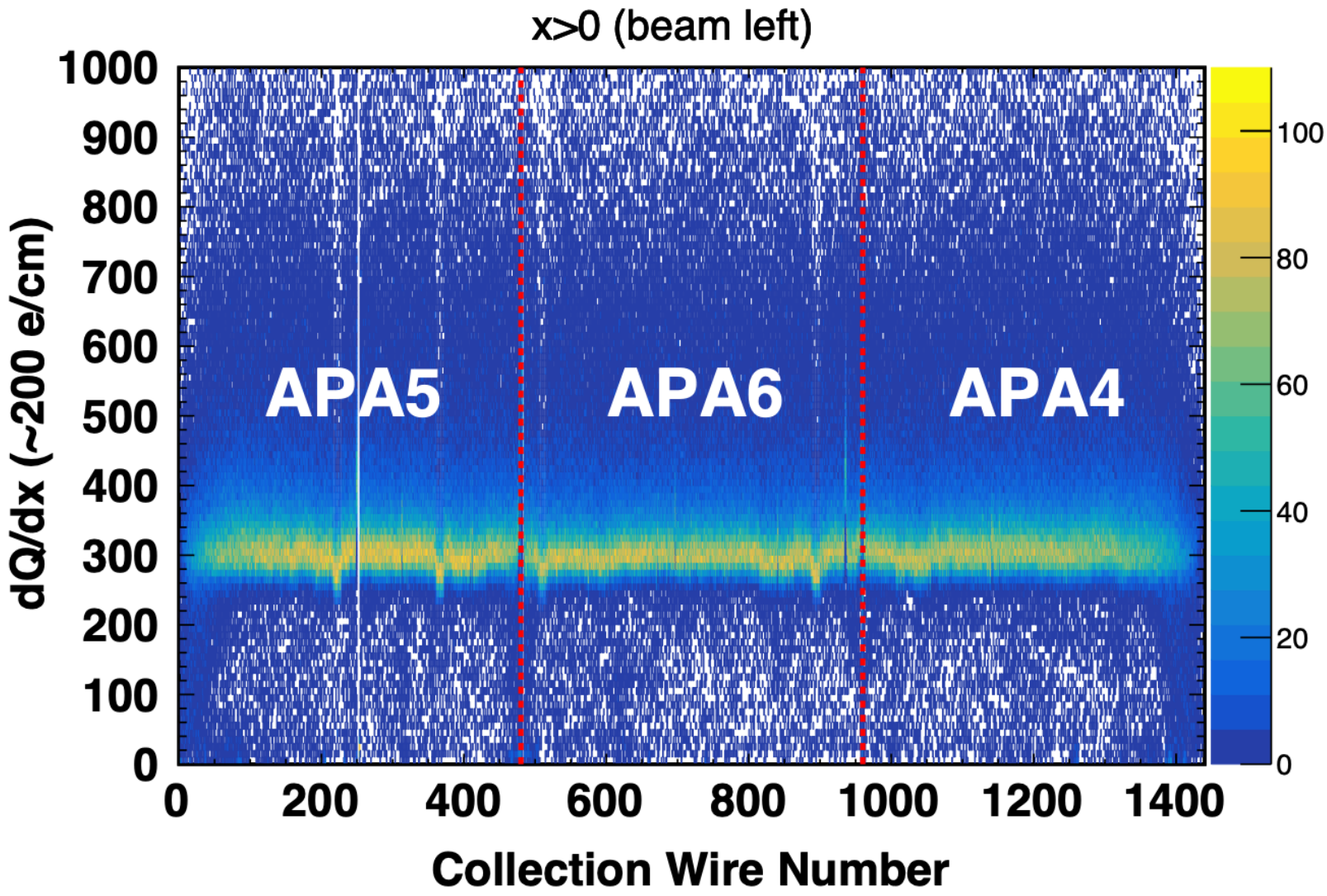
Run 5924
ED23 @100% HV
ED12 @0% HV



T. Yang

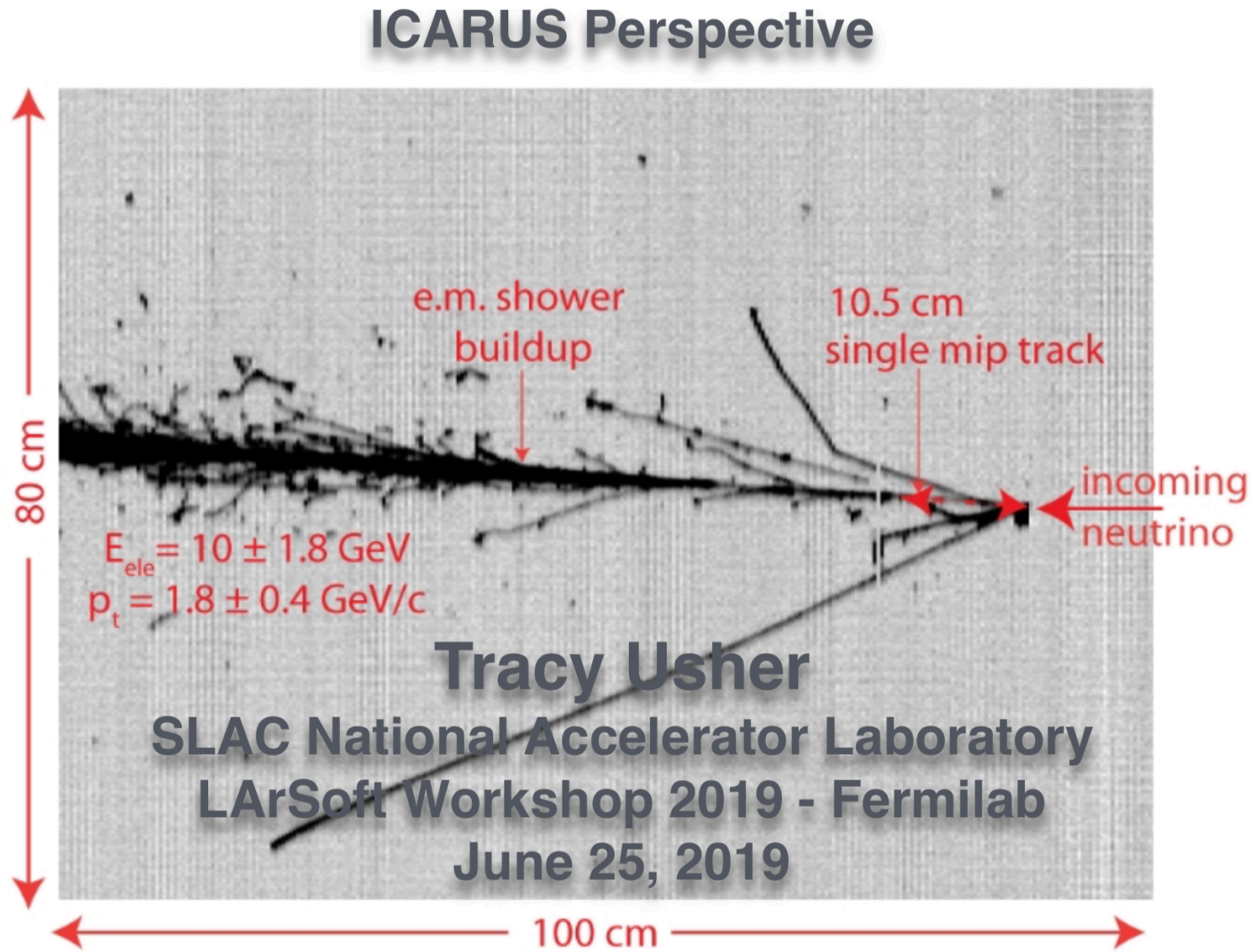
No diverters on this side

Effect on Calorimetry

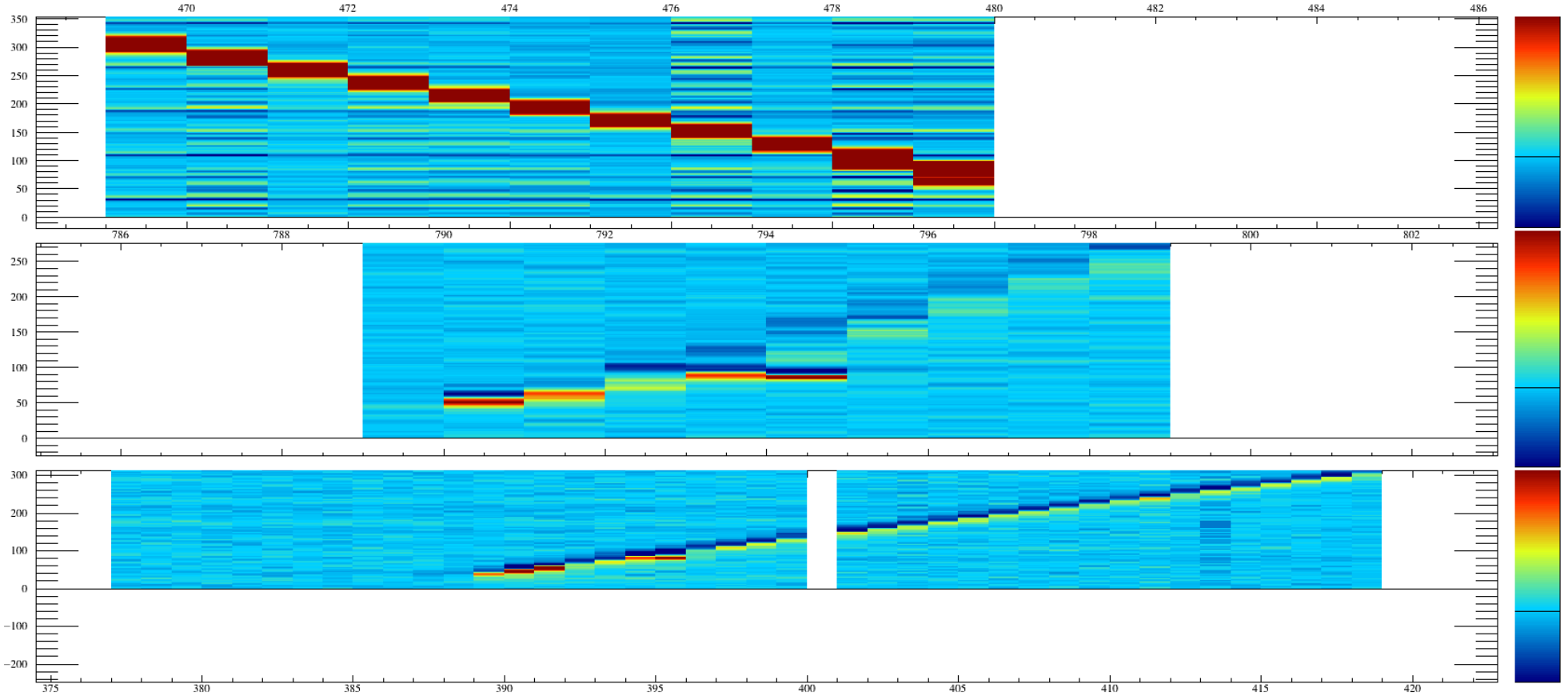


T. Yang

An ICARUS nueCC Candidate



Another No Diverter Track



Alignment Table

DUNE-doc-14950-v5

Run	ED23 Voltage			Gap 0 (ED23)		Gap 1		Gap 2 (ED12)		Gap 3	
	Inner (V)	Outer (V)	Frac. nom.	Δx (cm)	$\boldsymbol{\Delta z}$ **(cm)**	Δx (cm)	Δz (cm)	Δx (cm)	Δz (cm)	Δx (cm)	Δz (cm)
5177	0	0	0%	-0.15 ± 0.09	$\mathbf{-1.46 \pm 0.23}$	-0.34 ± 0.12	0.63 ± 0.22	-0.20 ± 0.10	-1.22 ± 0.44	0.29 ± 0.10	0.05 ± 0.30
5941	-650	-1150	50%	-0.15 ± 0.05	$\mathbf{0.10 \pm 0.20}$	-0.10 ± 0.06	0.63 ± 0.15	-0.24 ± 0.12	-1.27 ± 0.06	-0.05 ± 0.05	0.49 ± 0.13
5925	-975	-1725	75%	-0.10 ± 0.06	$\mathbf{0.78 \pm 0.11}$	0.00 ± 0.00	0.49 ± 0.17	-0.15 ± 0.05	-0.73 ± 0.42	0.00 ± 0.00	0.63 ± 0.12
5924	-1300	-2300	100%	-0.10 ± 0.06	$\mathbf{1.32 \pm 0.12}$	-0.10 ± 0.06	0.73 ± 0.15	-0.15 ± 0.05	-1.03 ± 0.15	0.00 ± 0.00	0.68 ± 0.06
5930	-1625	-2875	125%	0.0 ± 0.5	$\mathbf{1.56 \pm 0.5}$	-0.15 ± 0.05	0.63 ± 0.12	-0.20 ± 0.08	-1.37 ± 0.21	0.00 ± 0.00	0.51 ± 0.26