Cosmic Ray Calibration: Detector Alignment/Distortions, Timing, and E-Field Uniformity

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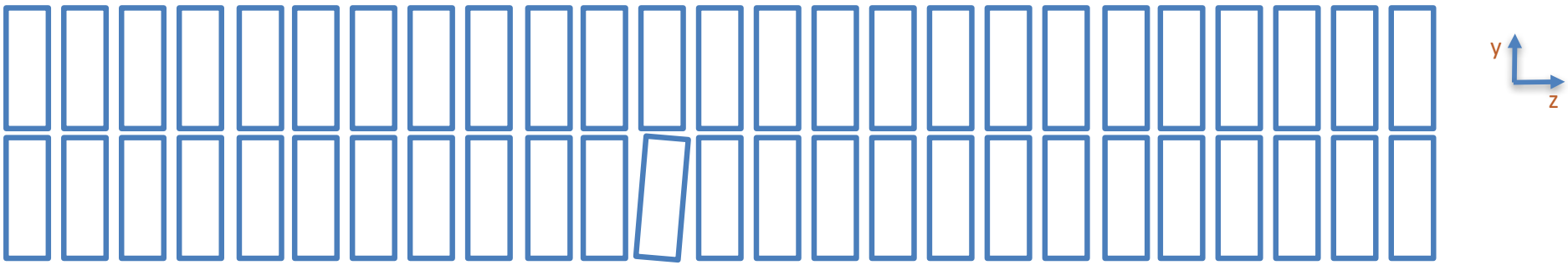
DUNE Calibration Workshop

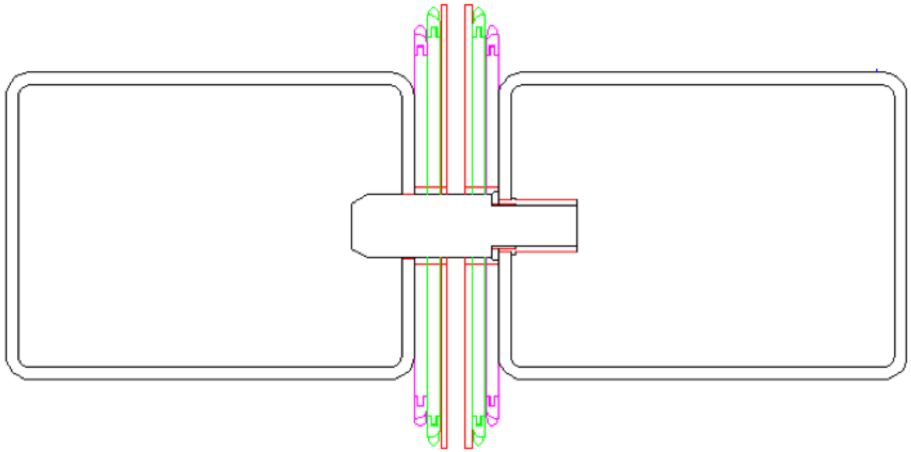
July 27, 2017



Fermilab DUNE

APA Alignment Pin and Slot

- From the ProtoDUNE-SP TDR



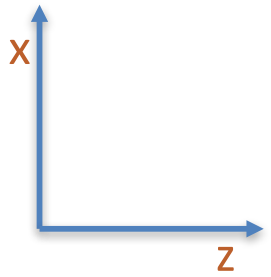


Figure 2.12: The pin/slot constraint. The pin screws into an insert in the outside frame member of one APA and engages a slot in the outside frame member of the adjacent APA.

I'll use LArSoft coordinates in the talk and label everything. Electric Field goes along *x*

- Provides a One-Dimensional Position Constraint (X but not Y or Z, unless they are locking).
- Provides a One-Dimensional Angular constraint if the slot is tight (roll in the above picture)
- A series of pins provides an additional angular constraint (pitch)
- On the figure above, roll and pitch are constrained but not yaw.
- Manufacturing tolerances: With the pins engaged, wires can still be offset in ways we can measure.
- 35-ton Prototype was assembled without Alignment pins and slots

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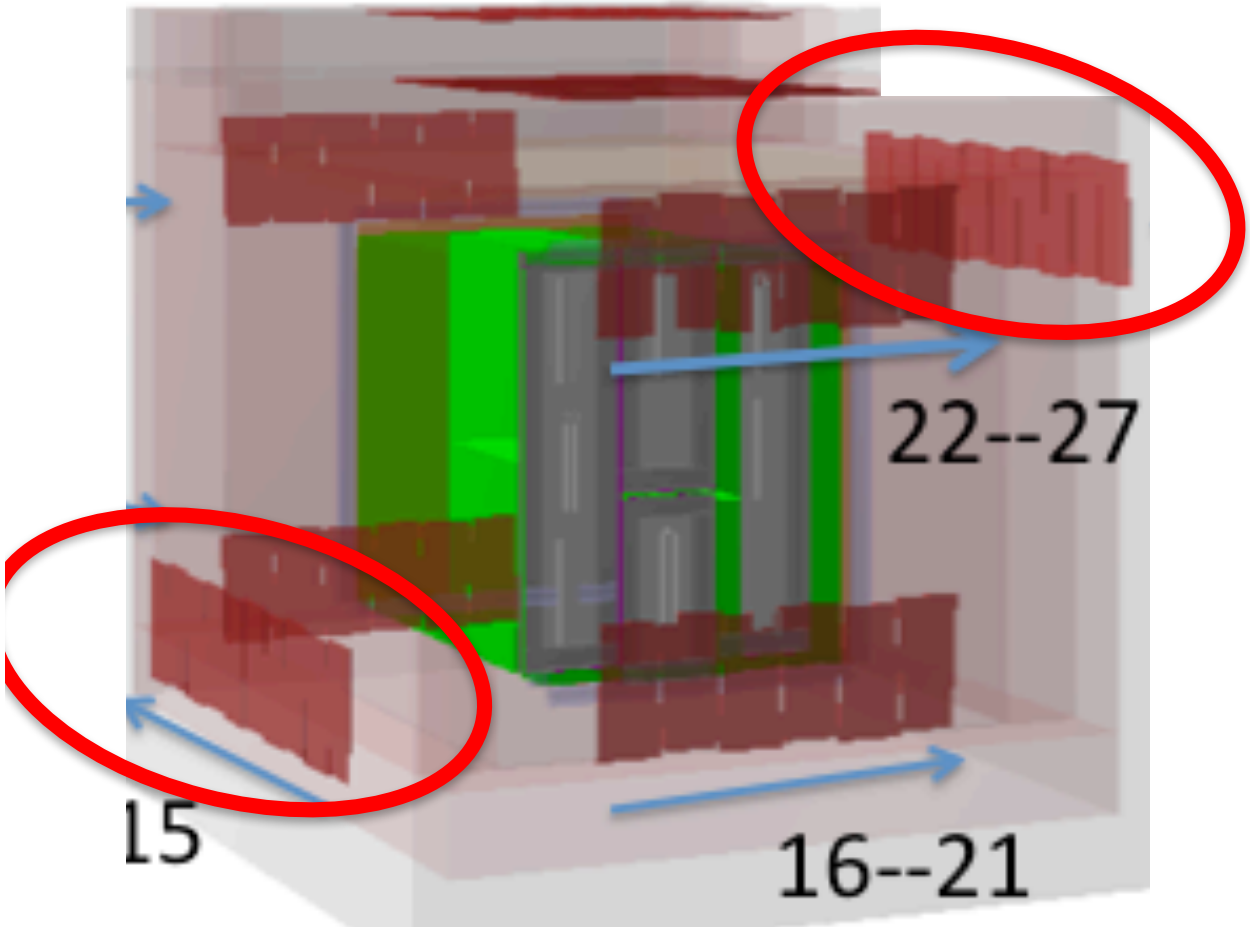
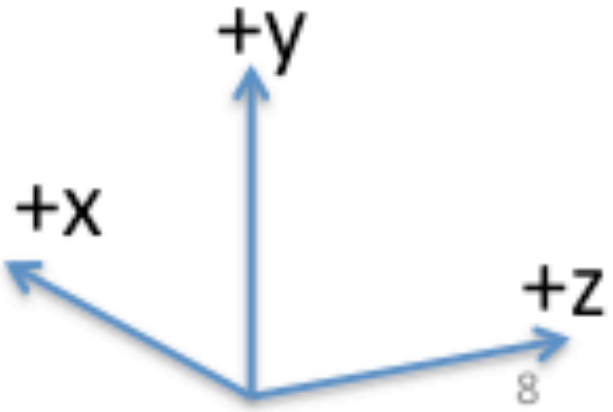
35-ton Measurement Experience



APA Gap Measurements Done with Events ith Muons triggering East-West Counter pairs (+~1 additional cosmic ray per event)

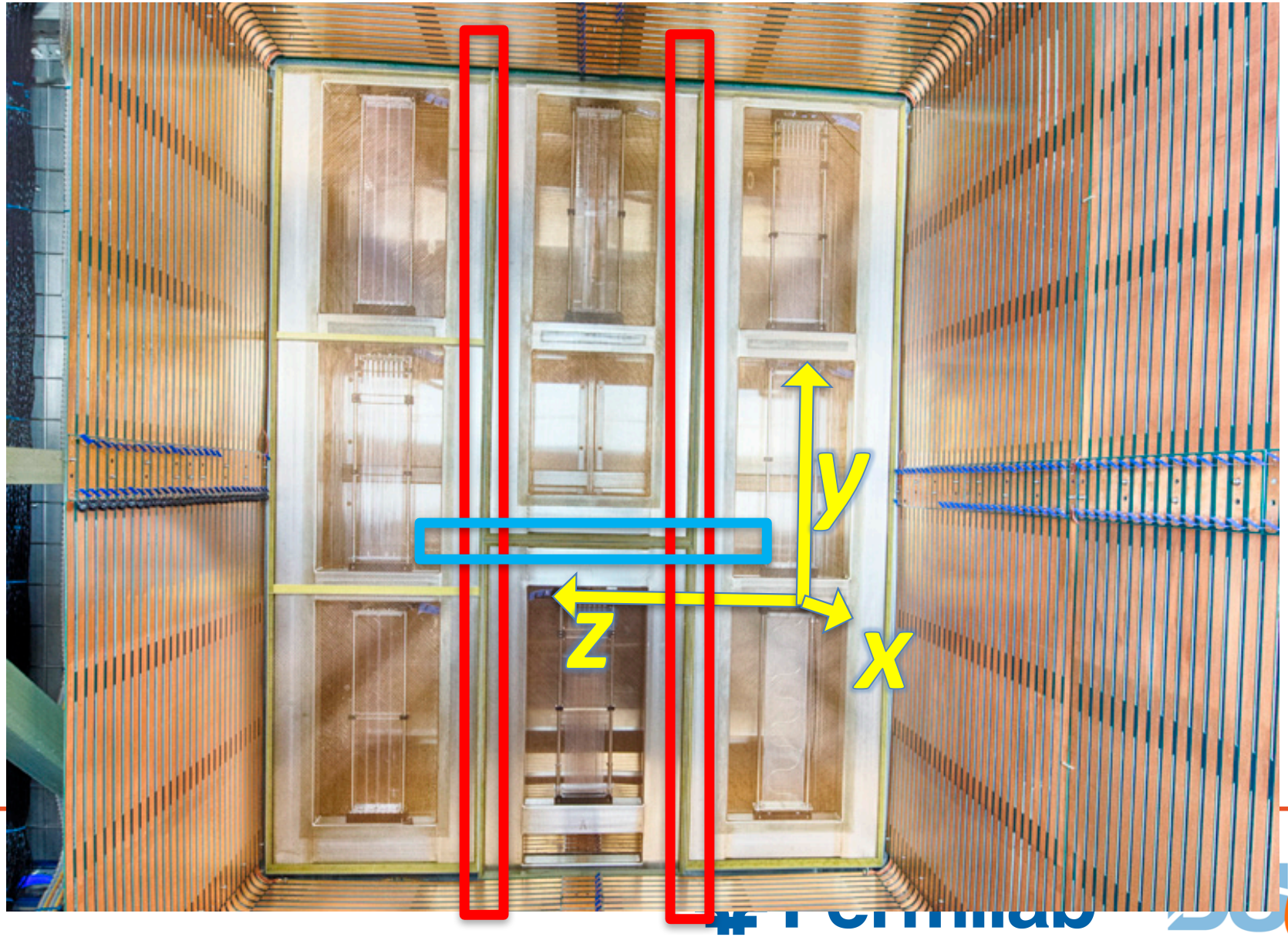


A word of thanks

- 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

35-ton APA Arrangement

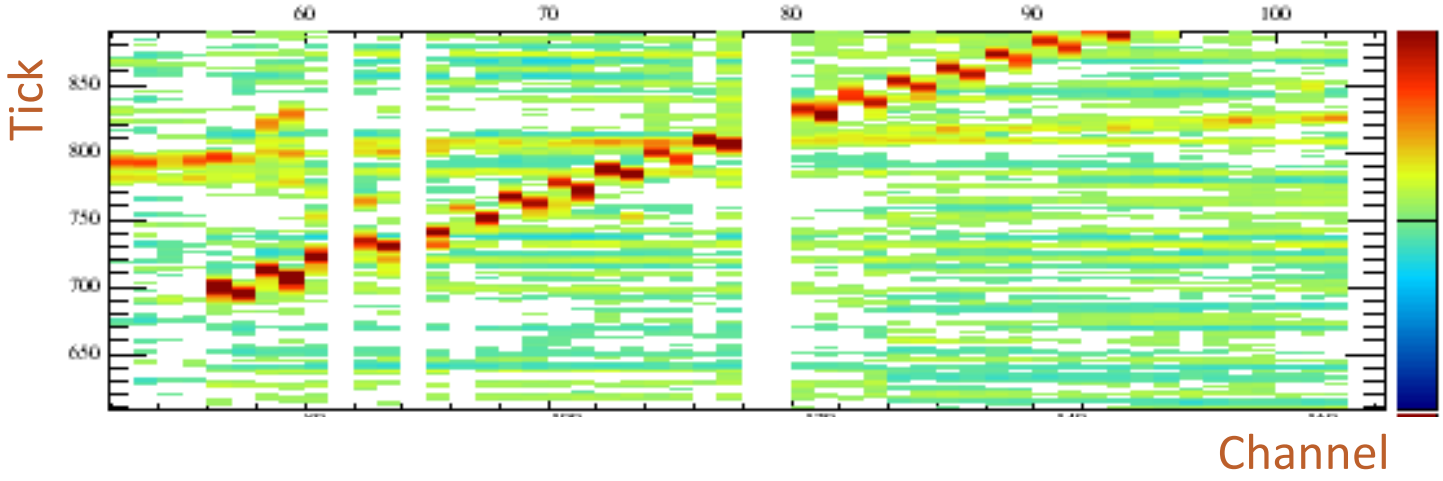


Z-Gap in red

Horizontal gap in blue

Checking the Channel Map

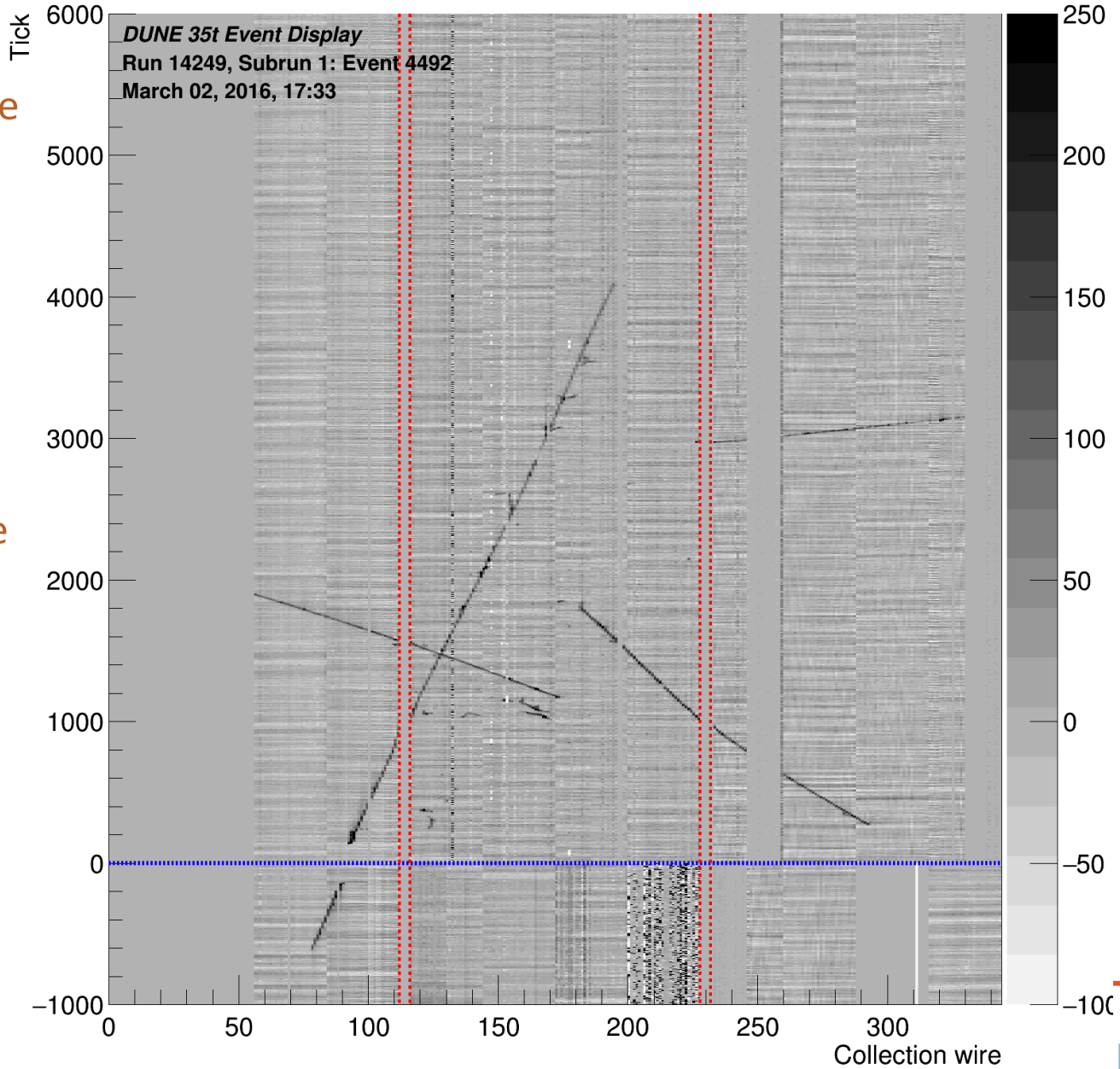
- One I remember: even and odd collection-plane channels were swapped in the channel map. Zig-zag tracks (visible for non-isochronous tracks). Maybe a ribbon cable was plugged in backwards?
- Other swaps possible. APA put in backwards (symmetrical, but bad channels). Channels numbered backwards.



A 35-ton Event Display With an APA Crosser and three Z Crossers

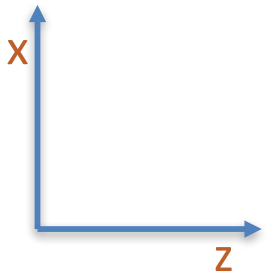
Induction-plane S/N was poor so we didn't get to align across the only horizontal gap in 35-ton

We studied the APA crossers and the Z-gap crossers



We won't get APA crossers in ProtoDUNE-SP (well, maybe...)

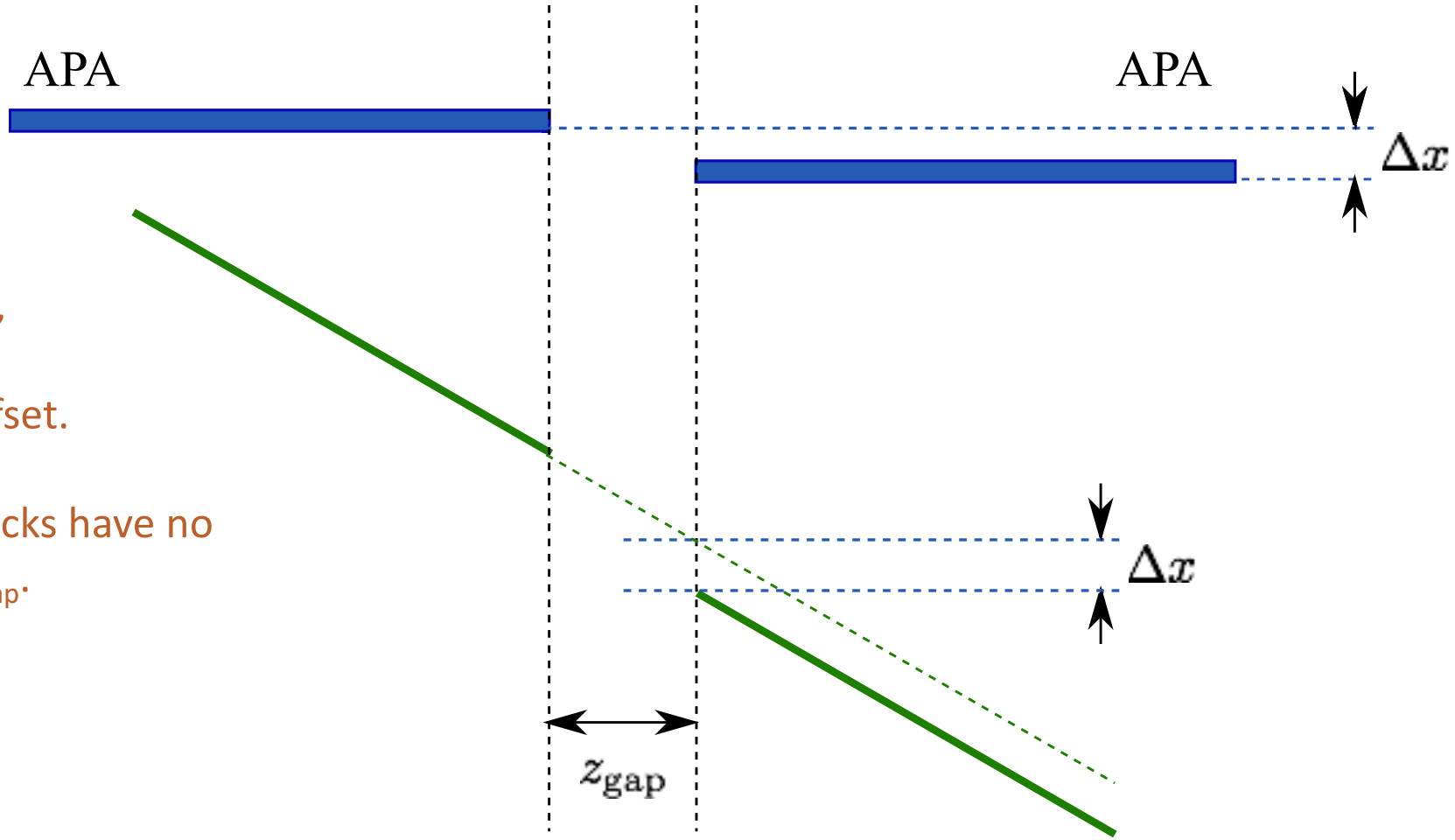
We will get them in the central APA's in the DUNE SP FD



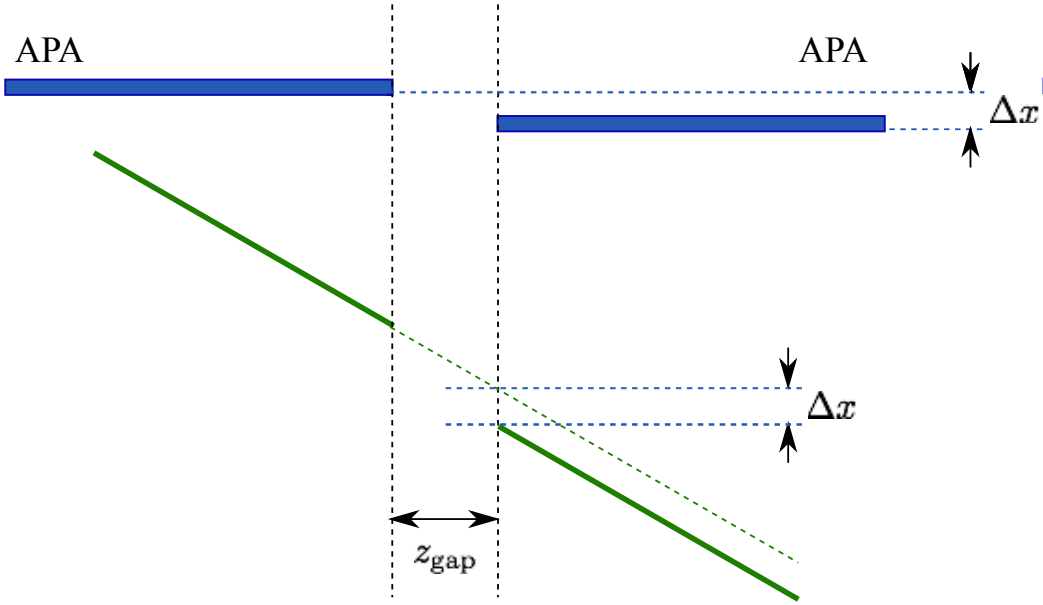
Sensitivity to Δx and Δz

If the tracks don't match up, it could be an *x* offset, or a *z* offset.

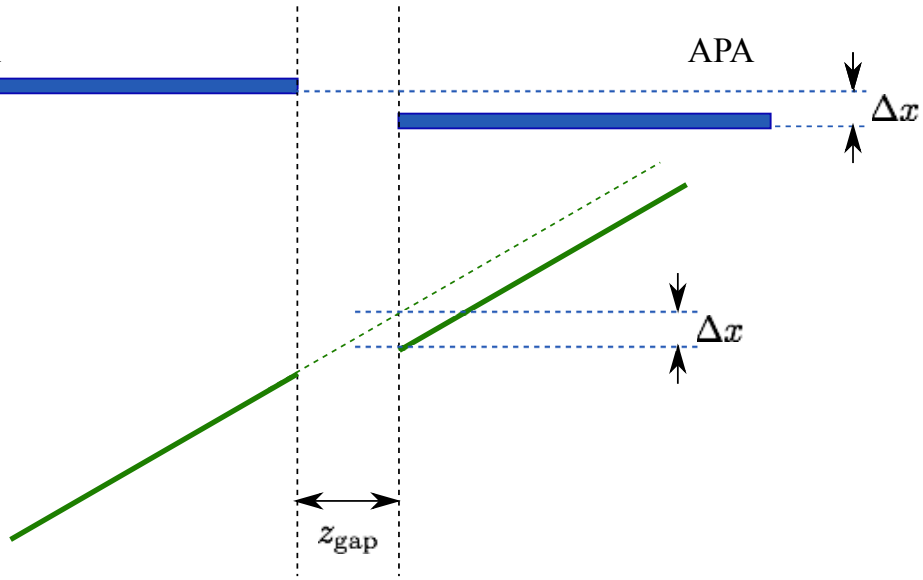
Isochronous tracks have no sensitivity to z_{gap}.



Need Tracks With + and - Angles



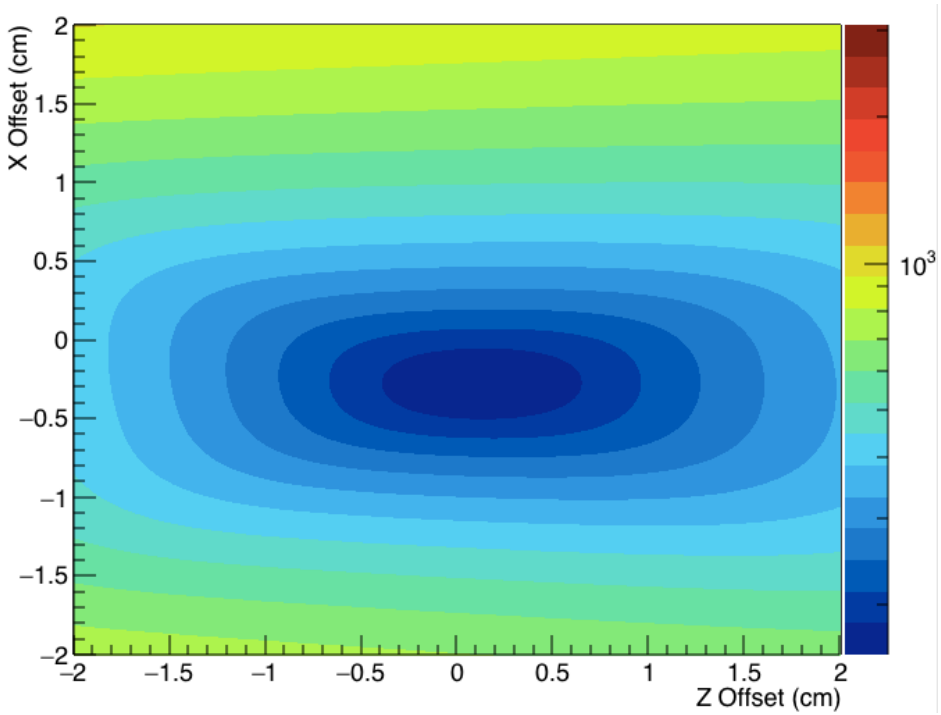
Need positive Δx or positive Δz
to fix this track (really a combination)



Need positive Δx or negative Δz
to fix this track (really a combination)

Correlations Between Δx and Δz

- If you have only one track to fit that crosses the gap between APA's, you measure a linear combination of Δx and Δz
- With many tracks, the correlation goes away
- Joint χ^2 over 871 tracks for TPC5 vs TPC7
- Note: with tracks on just one side of an APA, a Δx shift is indistinguishable from Δt. Tracks on the other side break that ambiguity.

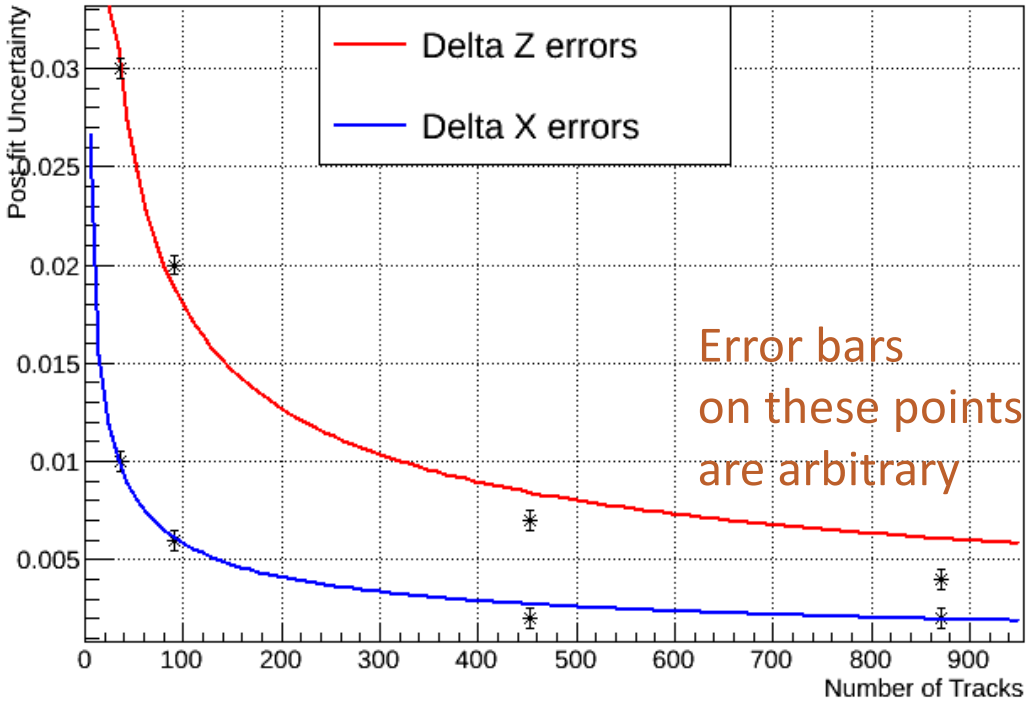


Statistical Uncertainties in Δx and Δz vs. Track Count

- From Mike Wallbank's work on 35-ton measurements.
- Some gaps had more crossing tracks than others and are thus better measured.
- Assumes: Δx and Δz are constant along the length of the gap

$$\sigma_{\Delta z} = \frac{1.79\times10^{-1}\ \text{cm}}{\sqrt{N_{\text{tracks}}}}$$

$$\sigma_{\Delta x} = \frac{5.83\times10^{-2}\ \text{cm}}{\sqrt{N_{\text{tracks}}}}$$

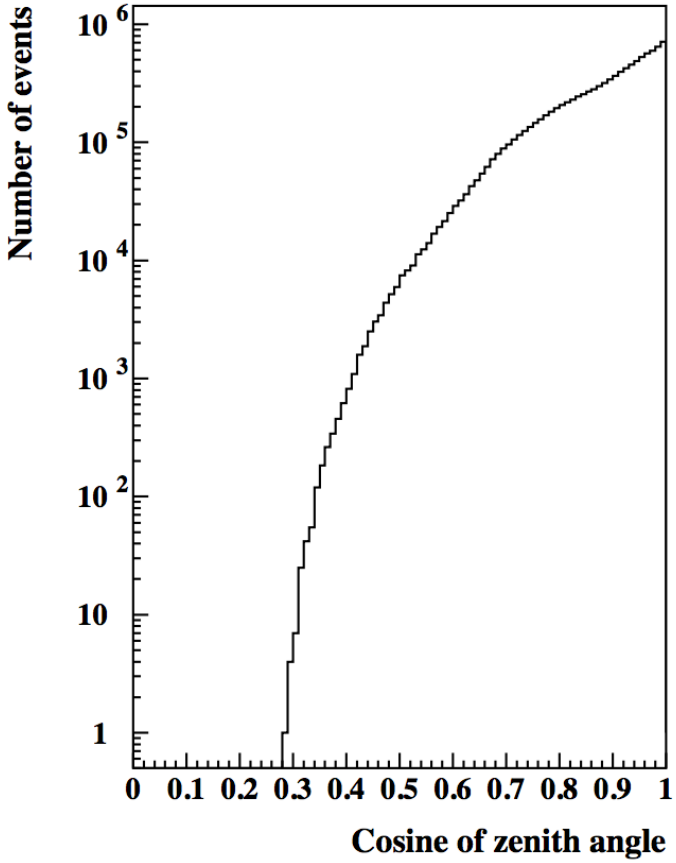


Collection-plane-only measurements: no measurement of *y*

How about Δy?

- Resolution probably similar to Δz but depends on angular distribution of cosmic-ray tracks

LBNE DocDB 9673
V. Kudryavtsev,
M. Richardson
J. Klinger
T. K. Warburton



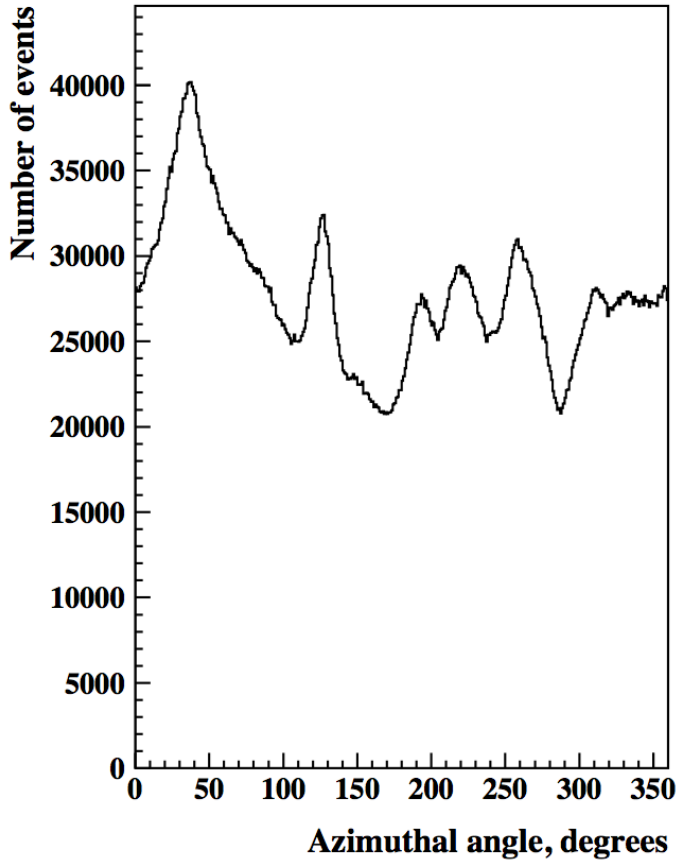


Figure 2: Zenith (left) and azimuth (right) angle distributions of muons at SURF (potential far detector location) as generated by MUSUN; azimuth angle ϕ in this case is counted from East to North.

Measuring Angles

- What if the gaps between the APA's aren't of uniform width?
- What if the offsets along the drift field direction (*x*) vary with height (*y*)?
- Repeat analysis in bins along *y* for each gap. Approximate analysis with two bins with centers 3 m apart and uncertainties for half as many tracks in each:

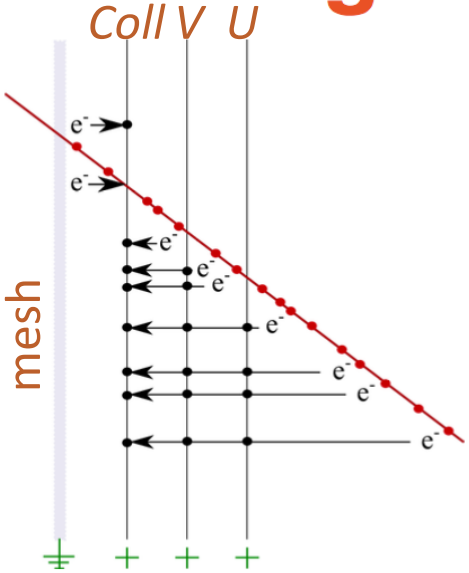
$$\sigma\left(\frac{d\Delta z}{dy}\right) = \frac{\sqrt{2}\sigma_{\Delta z}(N_{\text{tracks}}/2)}{3\text{ m}} \approx \frac{1.19\times10^{-3}}{\sqrt{N_{\text{tracks}}}}$$

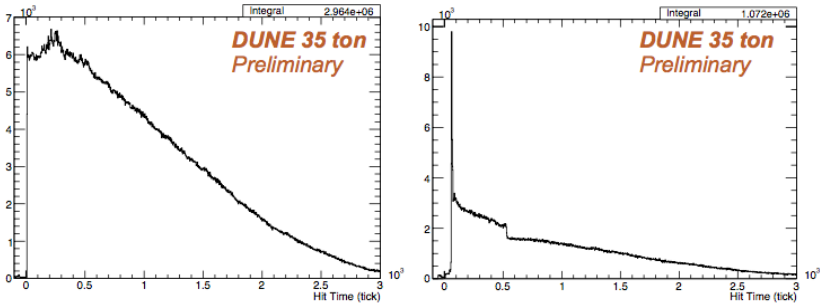
$$\sigma\left(\frac{d\Delta x}{dy}\right) = \frac{\sqrt{2}\sigma_{\Delta x}(N_{\text{tracks}}/2)}{3\text{ m}} \approx \frac{3.89\times10^{-4}}{\sqrt{N_{\text{tracks}}}}$$

M Wallbank

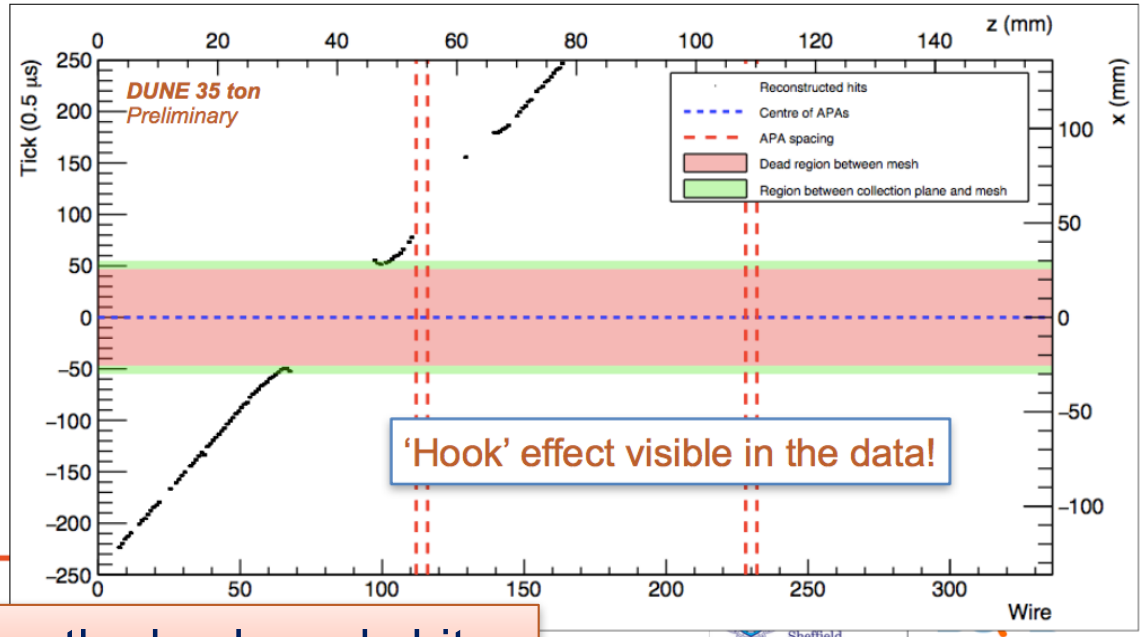
APA-Crossing Muons: Deposited Charge

- All the field lines originate on the collection plane and terminate on either the cathode plane, or the grounded mesh
- An ionising track passing through deposits charge throughout.
- Because of the electric fields on both sides of the collection plane, interesting effects have been observed in the data.
- Not currently simulating this — will eventually need to!





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

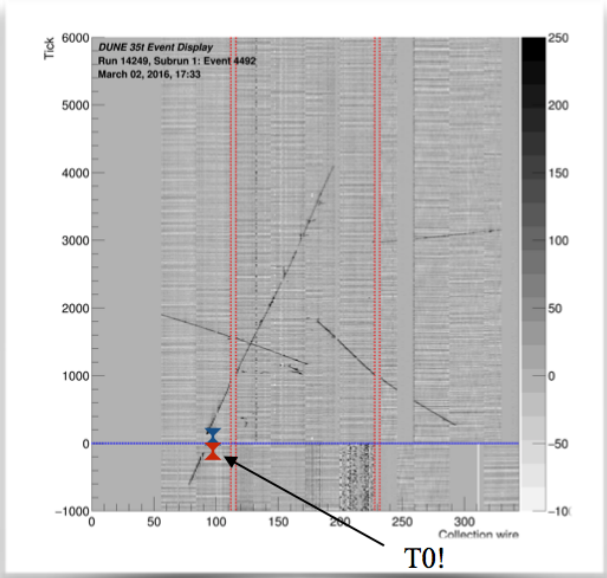


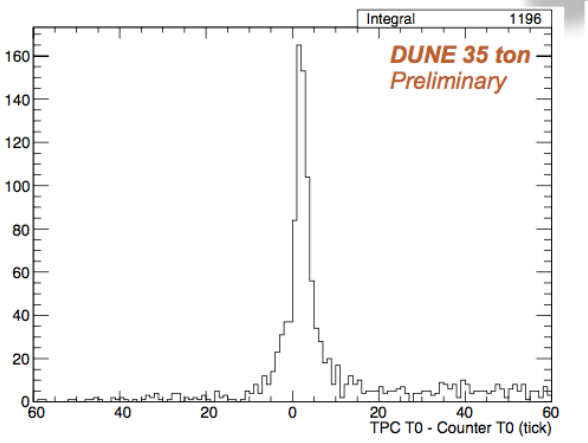
35t APA without the mesh is missing the backwards hits

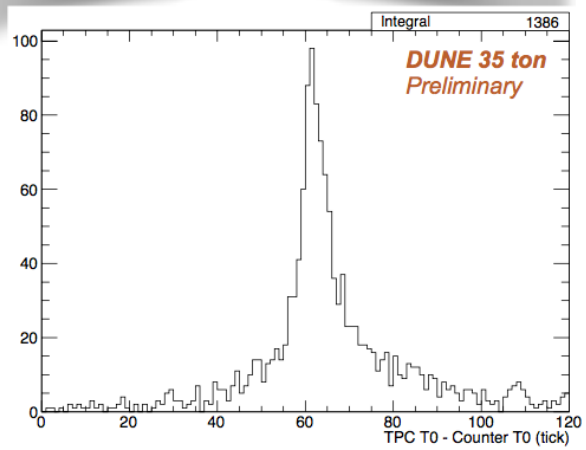
M Wallbank

APA-Crossing Muons: T0 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 T0 directly from TPC data.
- Determined by minimising the residuals of a linear fit across the gap, as a function of various T0 hypotheses.
- Found timing offset between the counters and TPC data of ~62 TPC ticks (31 μs).
- Very useful calibration method; would never have found this offset otherwise.
- Also important for DUNE FD!







Difference between counter T0 and TPC-measured T0 in simulation (left) and data (right).

Estimate of Uncertainty on t_0

- Width of core of data distribution in 35-ton: 2 μs. Half of the tracks are in the core, other half in the tails.

$$\sigma_{t_0} \approx \frac{2.8\ \mu s}{\sqrt{N_{\text{tracks}}}}$$

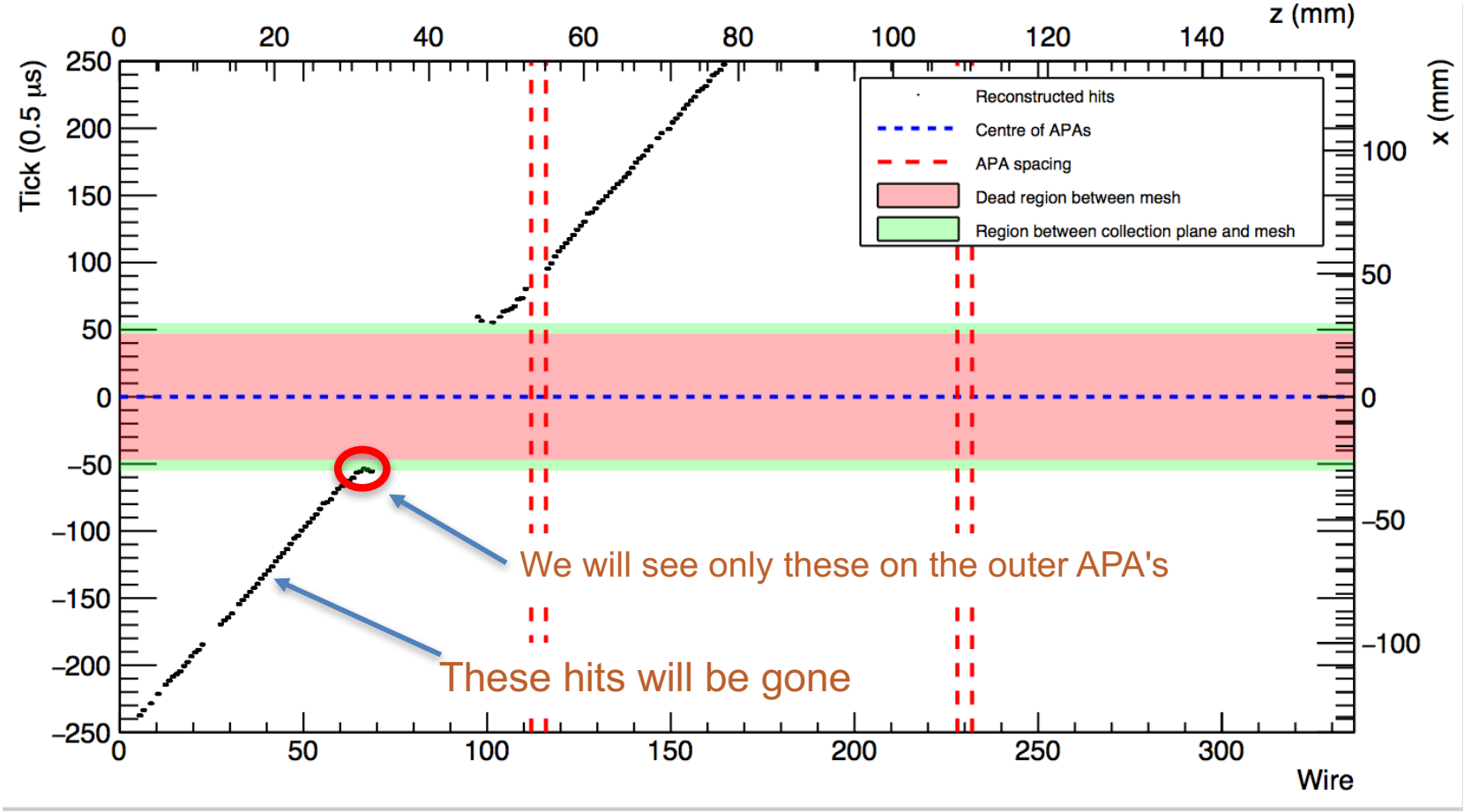
Here, N_{tracks} is the number of APA-crossing tracks.

You can average over the entire module or perform this APA-by-APA.

But only inner APA's

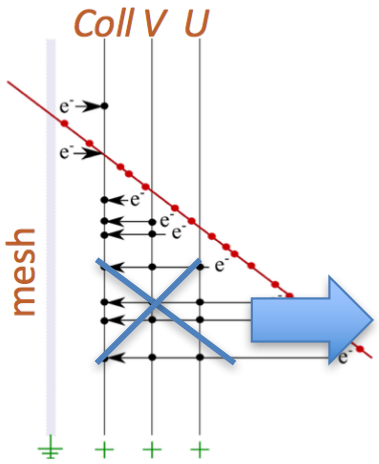
Outer APA's Contribution (ProtoDUNE-SP) and FD

- With a mesh, you get a couple of hits on the far side



Hits on the Outer Side

- Electric field drifts electrons away from the APA, towards the cryostat wall
- Hits made inside the wire planes will still be there, but they will have different pulse shapes (asymmetric induction-plane signals)
- Samples of these hits can be selected for study



Electron Diverter

To be installed between "some" of the APA's in ProtoDUNE-SP to determine if they should be included in DUNE FD-SP

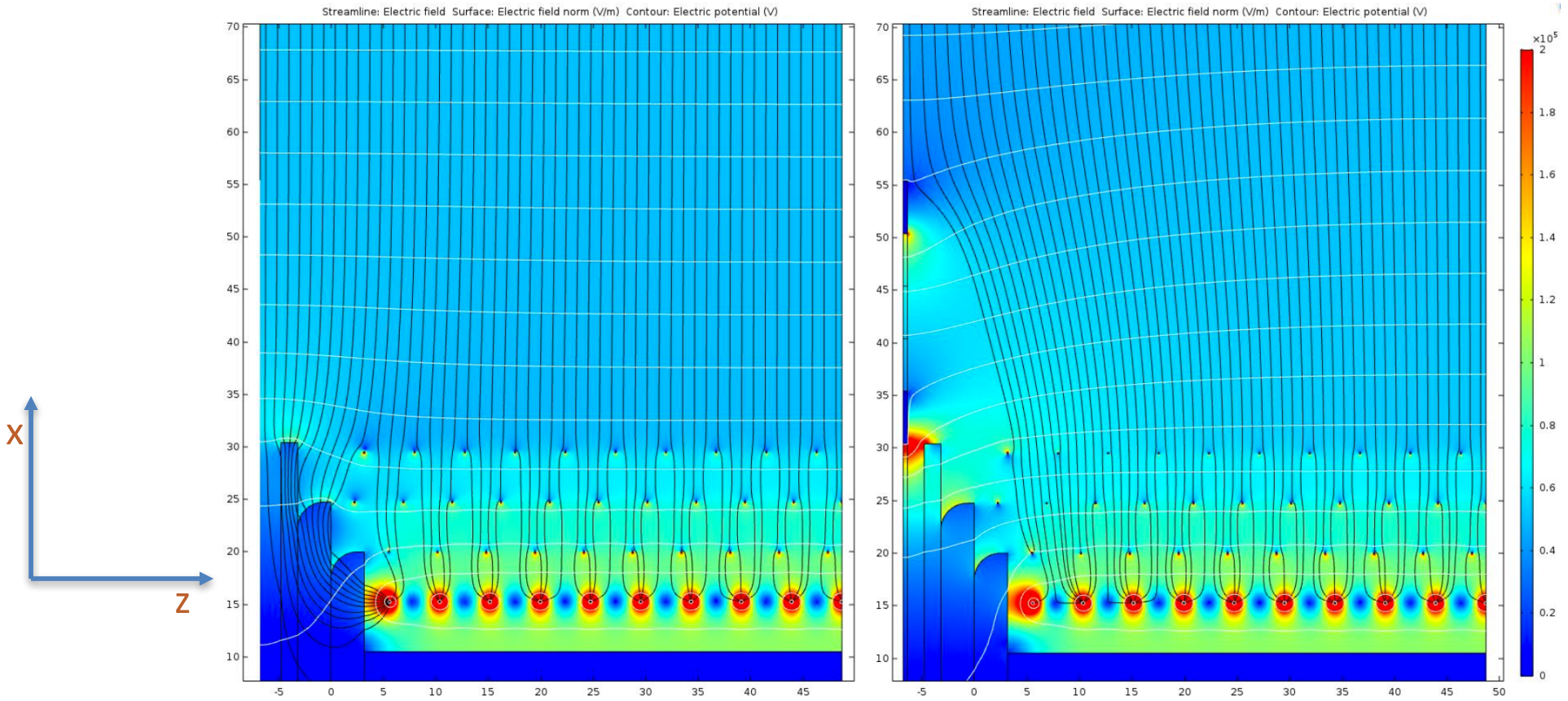
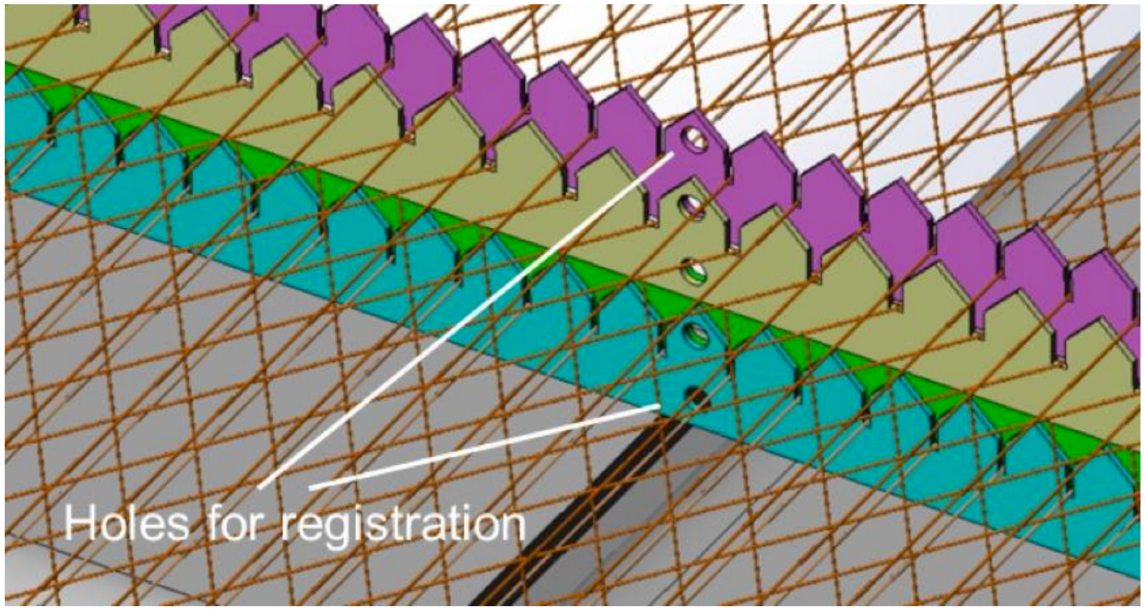


Figure 2.11: Left: field map of the region near the inactive gap of an APA without the electron diverter; Right: field map with the electron diverter in place. Electric field lines are shown in black, equipotential contours are in white, and electric field strength is represented in color gradient.

DUNE Doc 1794 (PD-SP TDR)

Wire Sag

Support combs placed so that the maximum unsupported run is 1.6 m.

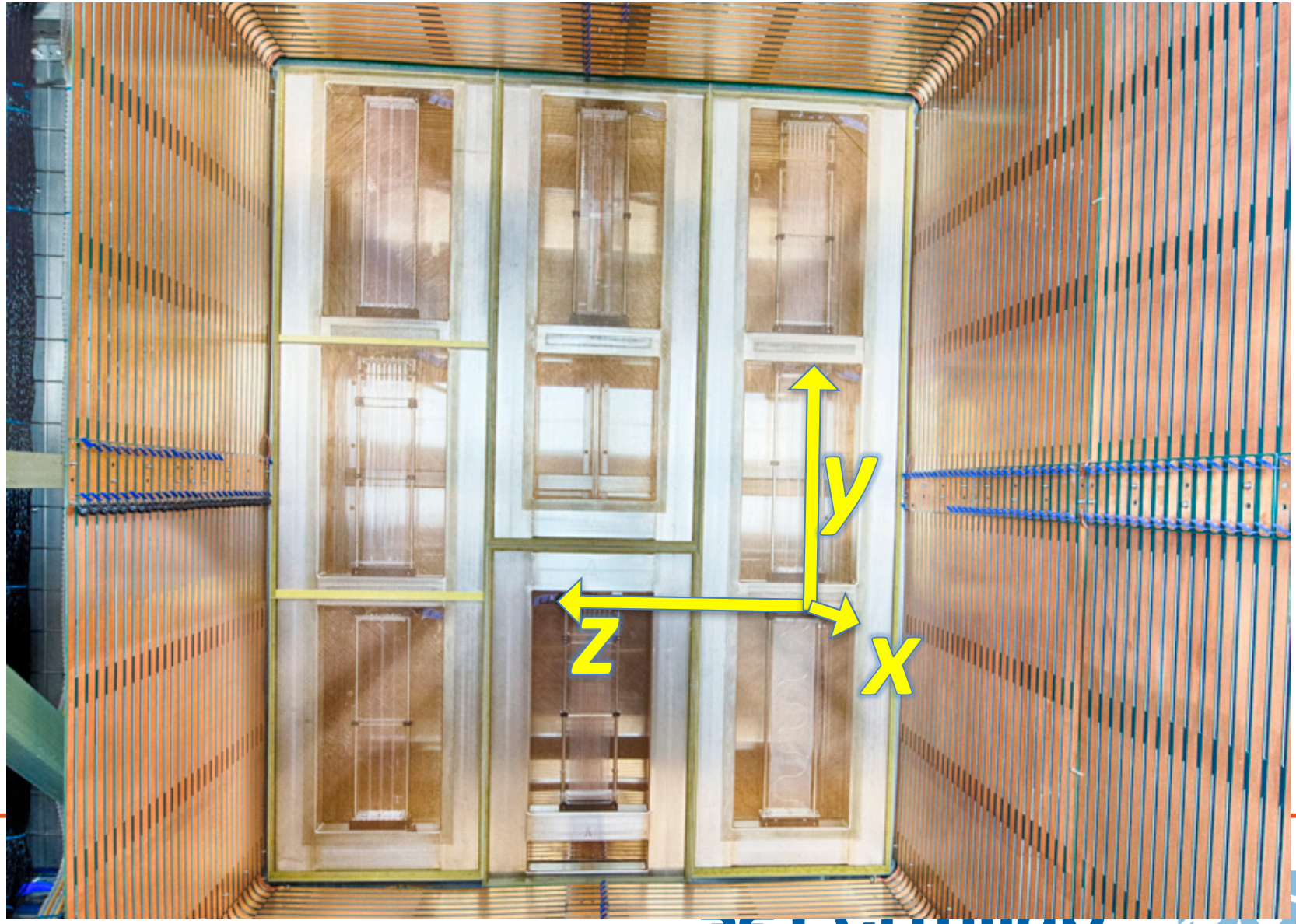


ProtoDUNE-SP TDR

The nominal wire tension is 5 N but even the 1.6-m-long wires could fall to 3 N of tension before the wire, held horizontally, would deviate 150 microns – one wire diameter. During operation the wires are either vertical or 35.7° from vertical, so the actual deviation would be less.

Ed. comment: Thermal expansion of comb vs. APA frame could cause deviations larger than 150 microns

Field Cage Overhang



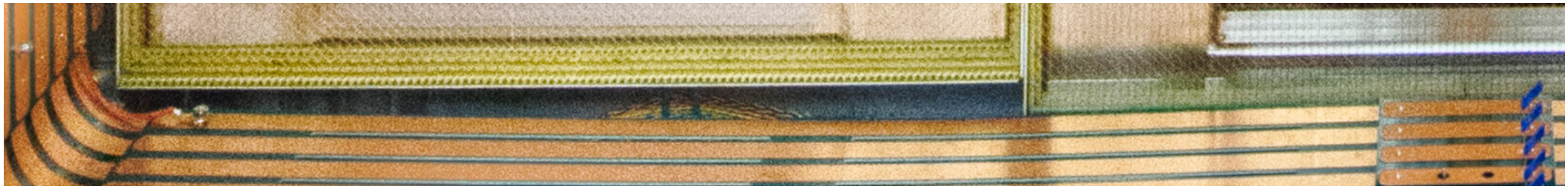
35-ton APA's and Field Cage

Field Cage Overhang

Charge drifts along the edge of the field cage – how does it get to the anode?

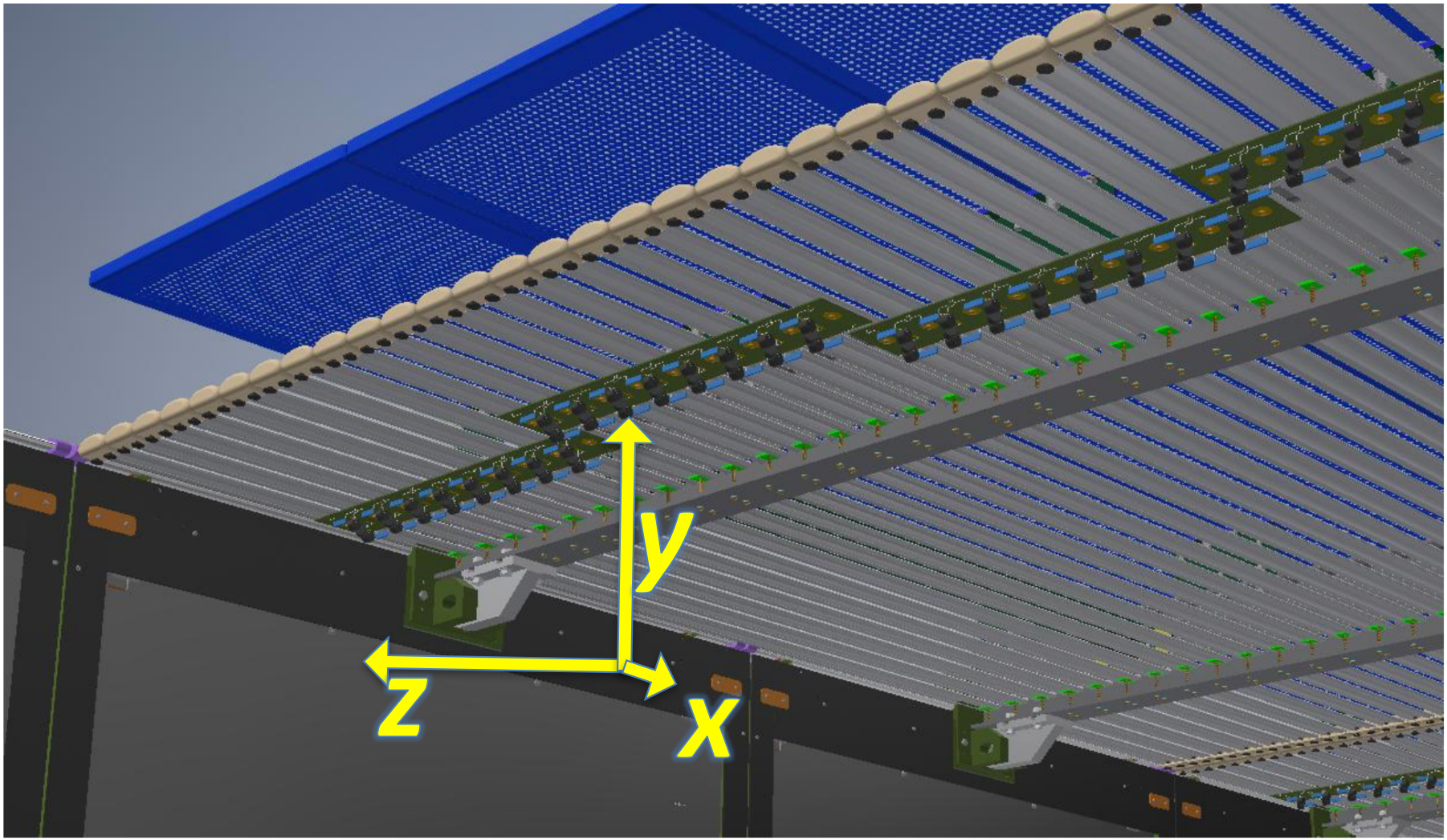
Simulation assumes argon outside the rectangle covered by the wires is not active.

Should see extra hooks on tracks that exit.



Also: Field cage is visibly not very straight on the bottom.
We may not care to calibrate this, preferring to cut the edges out.

Field Cage and CPA Shapes



From the ProtoDUNE-SP TDR

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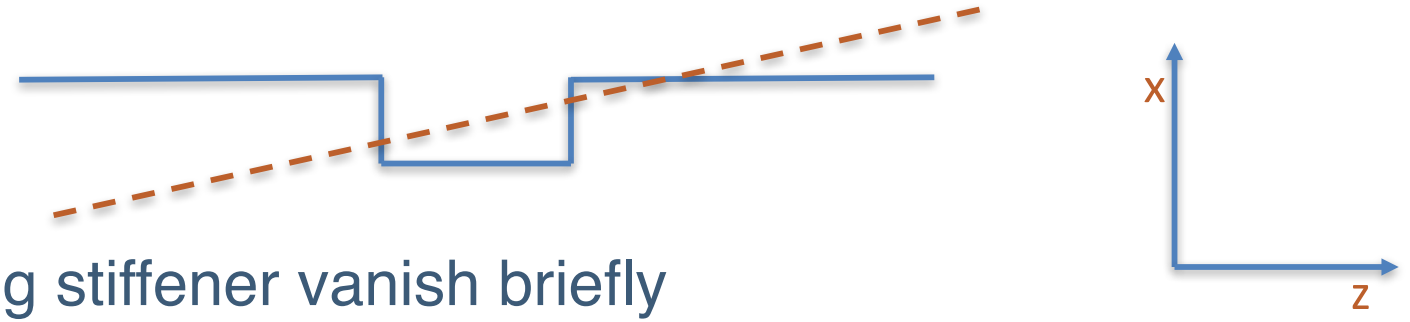
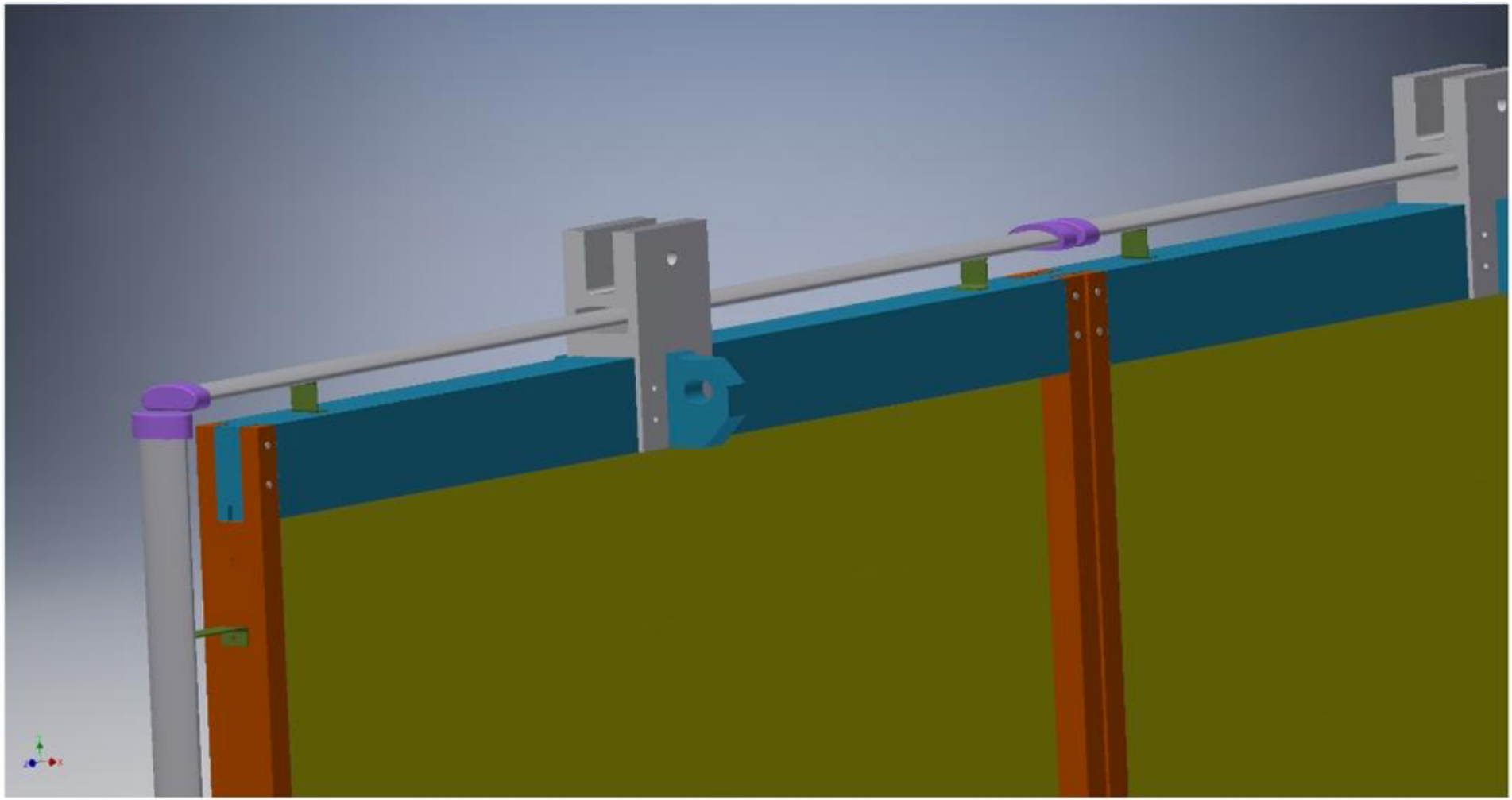
CPA Stiffener Bars/Panel Frames

- Built into the 35-ton CPA
- S/N not adequate to do detailed studies of hits near the CPA in 35-ton – hit efficiency tailed off

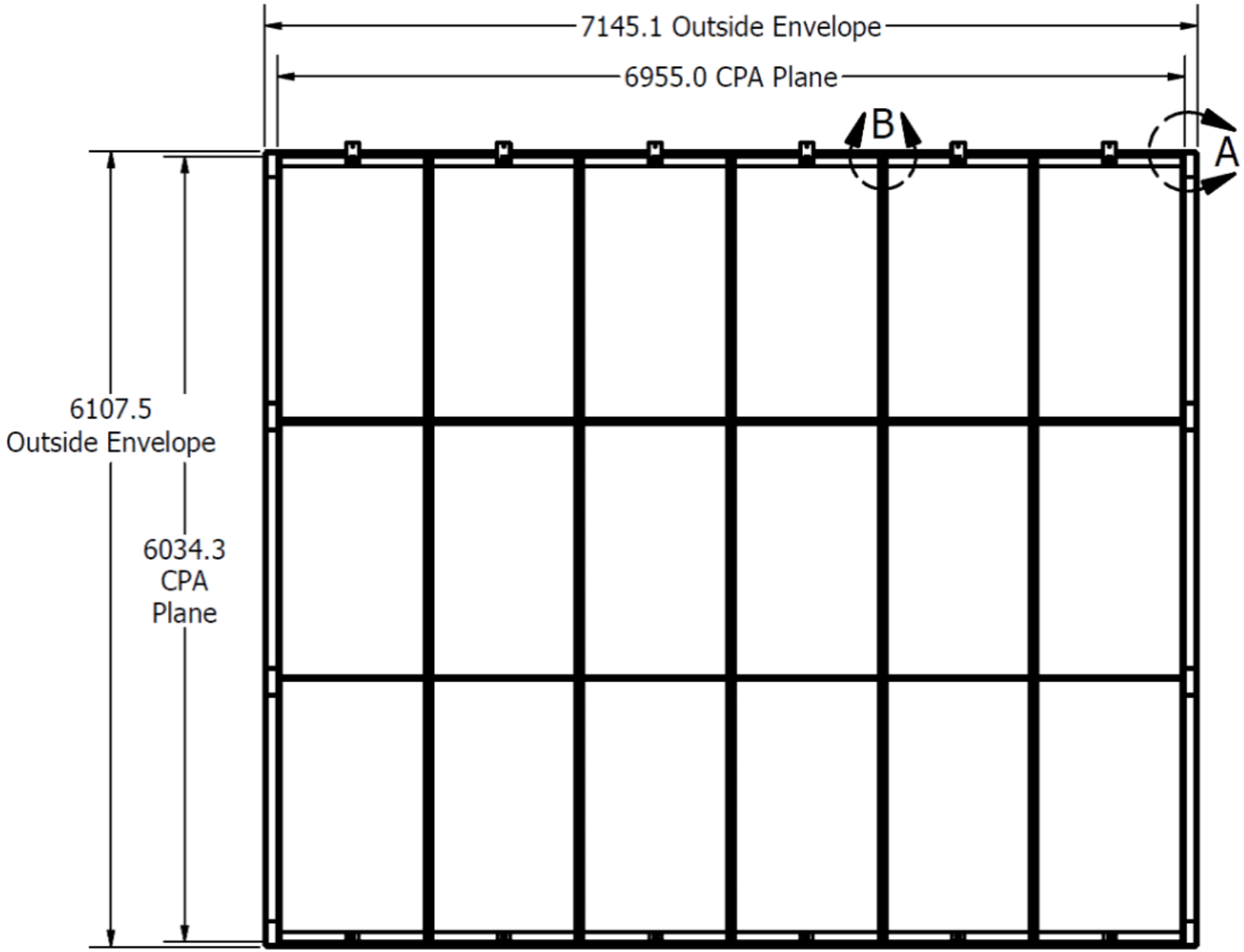


- Tracks crossing stiffener vanish briefly
- Low-field region in concave corners -- less charge produced
- Can be used as a fiducial mark for space-charge distortion measurements. Can make an image of this at the anode?
- But you need lots of tracks passing through the bars. ProtoDUNE but not DUNE perhaps...

CPA Geometry



ProtoDUNE-SP CPA Panels



Can we "X-ray" the frames with tracks?

Look for gaps in CPA-crossers

The reco image will tell us about space charge

Possible concern

- Current in the cathode plane – causes field distortions due to resistive material.
- Hard to separate from space charge.