SBN Calibration in Context of Wire-Cell

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The Second Wire-Cell Reconstruction Summit

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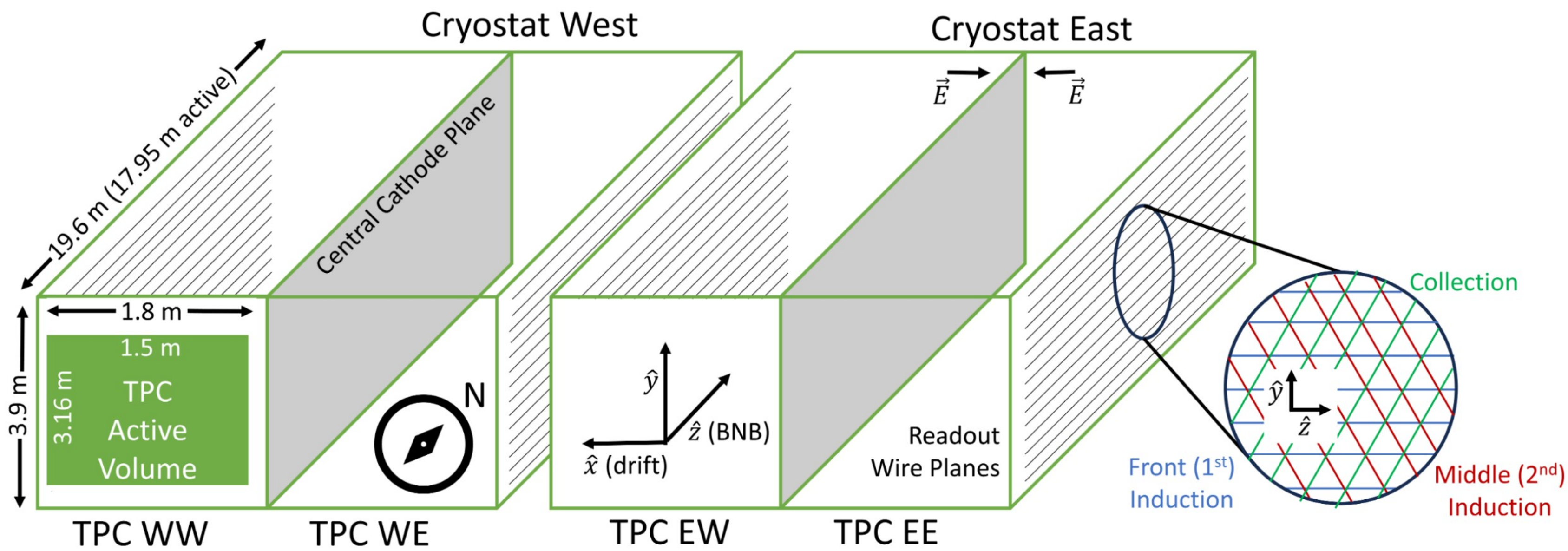
Introduction

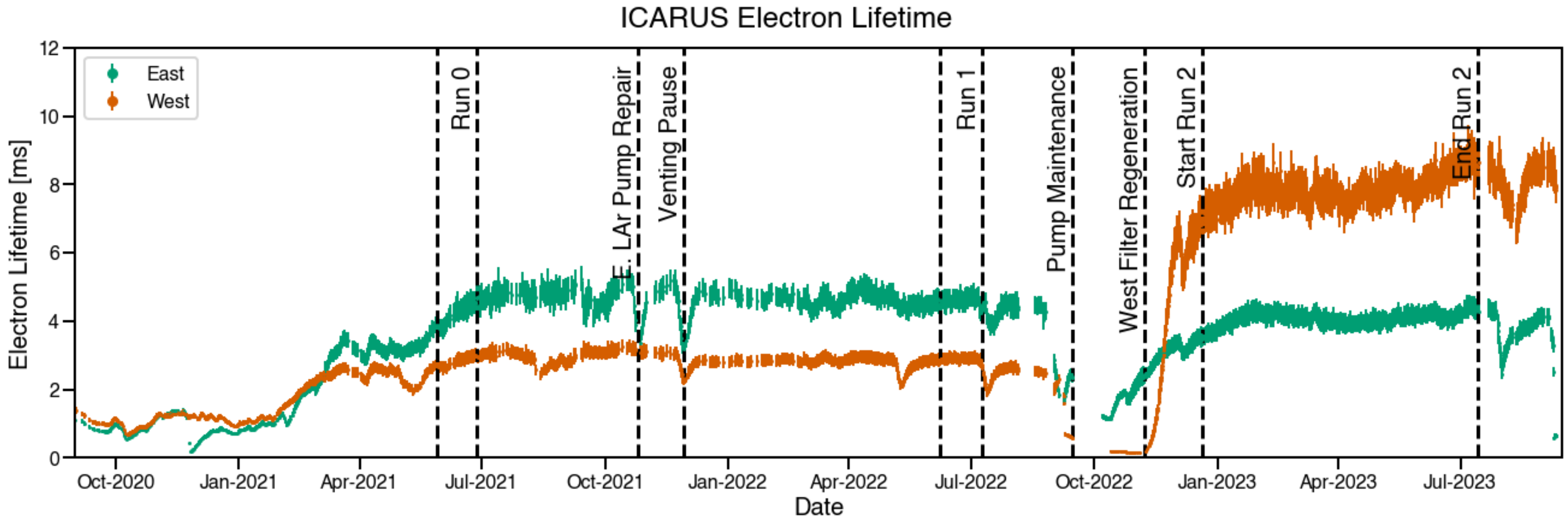
- Wire-Cell is an important part of both the simulation chain and reconstruction chain at SBND/ICARUS
  - TPC noise and signal simulation including 2D field response and simulation of other detector physics (e.g. electron lifetime)
  - TPC signal processing including ROI finding and 2D deconvolution
- Many interfaces between Wire-Cell simulation, signal processing and **detector calibration**
  - Example: ensuring TPC simulation agrees with data regarding wire field response after characterizing wire field response in data
- Purpose of talk is to point out some needs of SBND/ICARUS regarding Wire-Cell features given calibration experiences
  - Focus on **ICARUS** given large amount of data already available and studied in depth, though needs extend to SBND in many cases (and possibly other detectors, like ProtoDUNEs)

ICARUS In a Nutshell

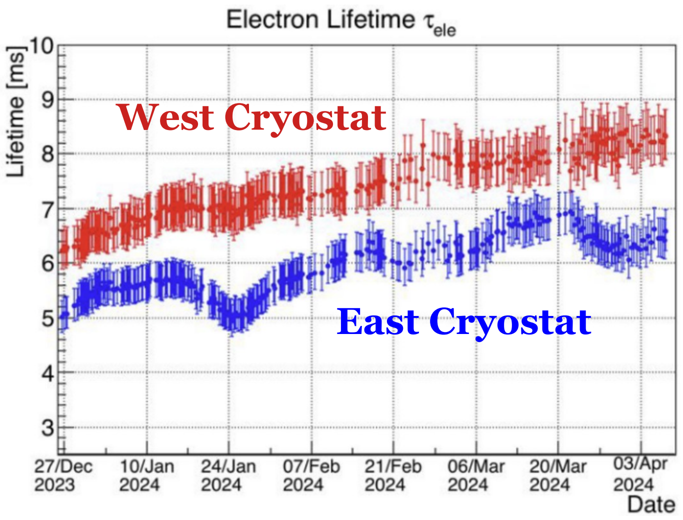


- Roughly 60k TPC channels across two cryostats (four TPCs)
- Three wire planes rotated 300 w.r.t. SBND/MicroBooNE
- TPC noise levels higher than at SBND/MicroBooNE due to warm FE electronics (by a factor of 3-5, depending on plane):
  - ~1200 (~2000) e- ENC for Induction 2 and Collection (Induction 1)
- PDS (360 PMTs) for event triggering, CRT for tagging cosmics

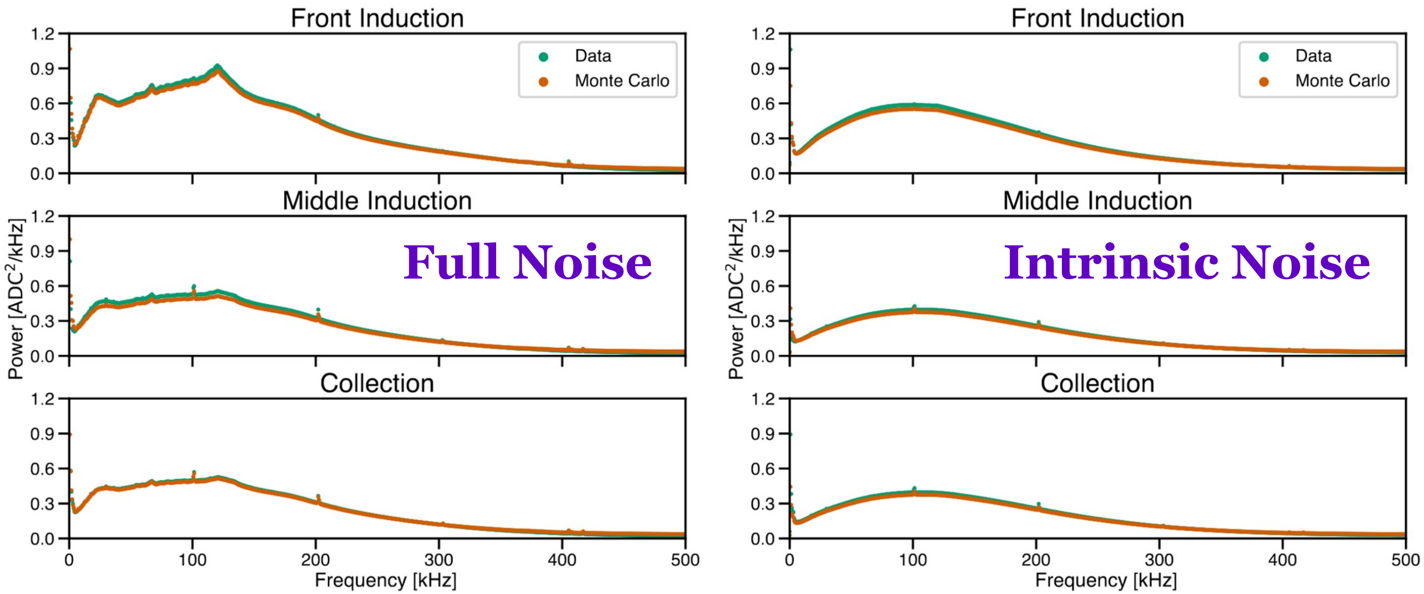
Electron Lifetime @ ICARUS



- Electron lifetime lower than at MicroBooNE and ProtoDUNE-SP, but **higher than ~3 ms requirement**
  - Short drift length (1.5 m at maximum)
  - Operating at ~500 V/cm
- In earlier data, S/N modestly impacted by lower electron lifetimes; more recent data should see little impact (higher lifetime)

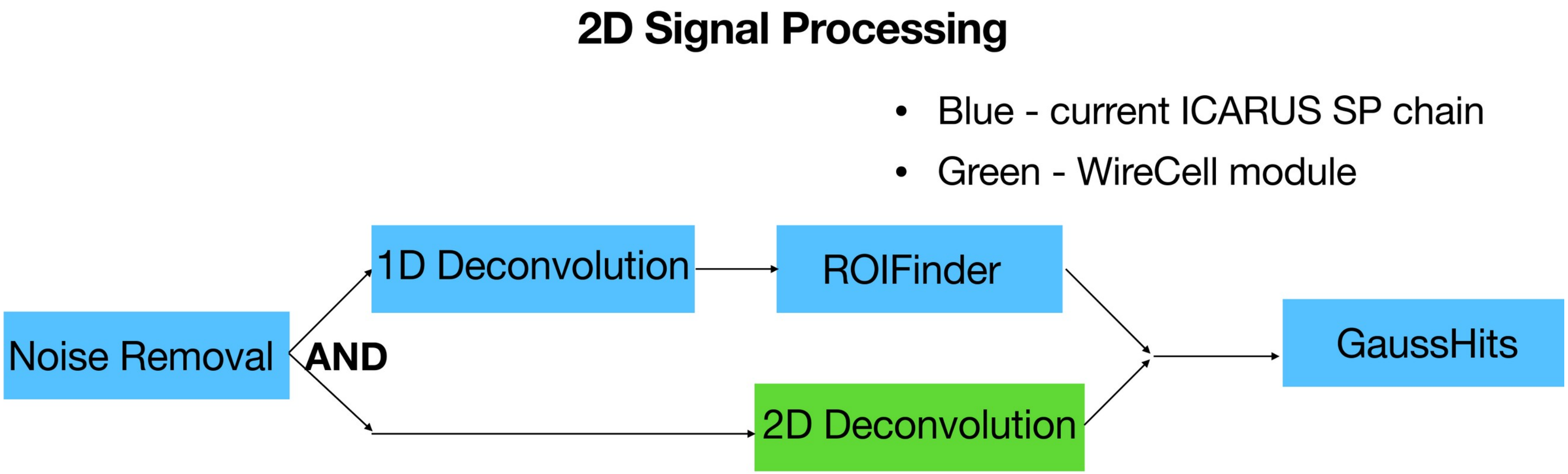


Noise Simulation w/ Wire-Cell



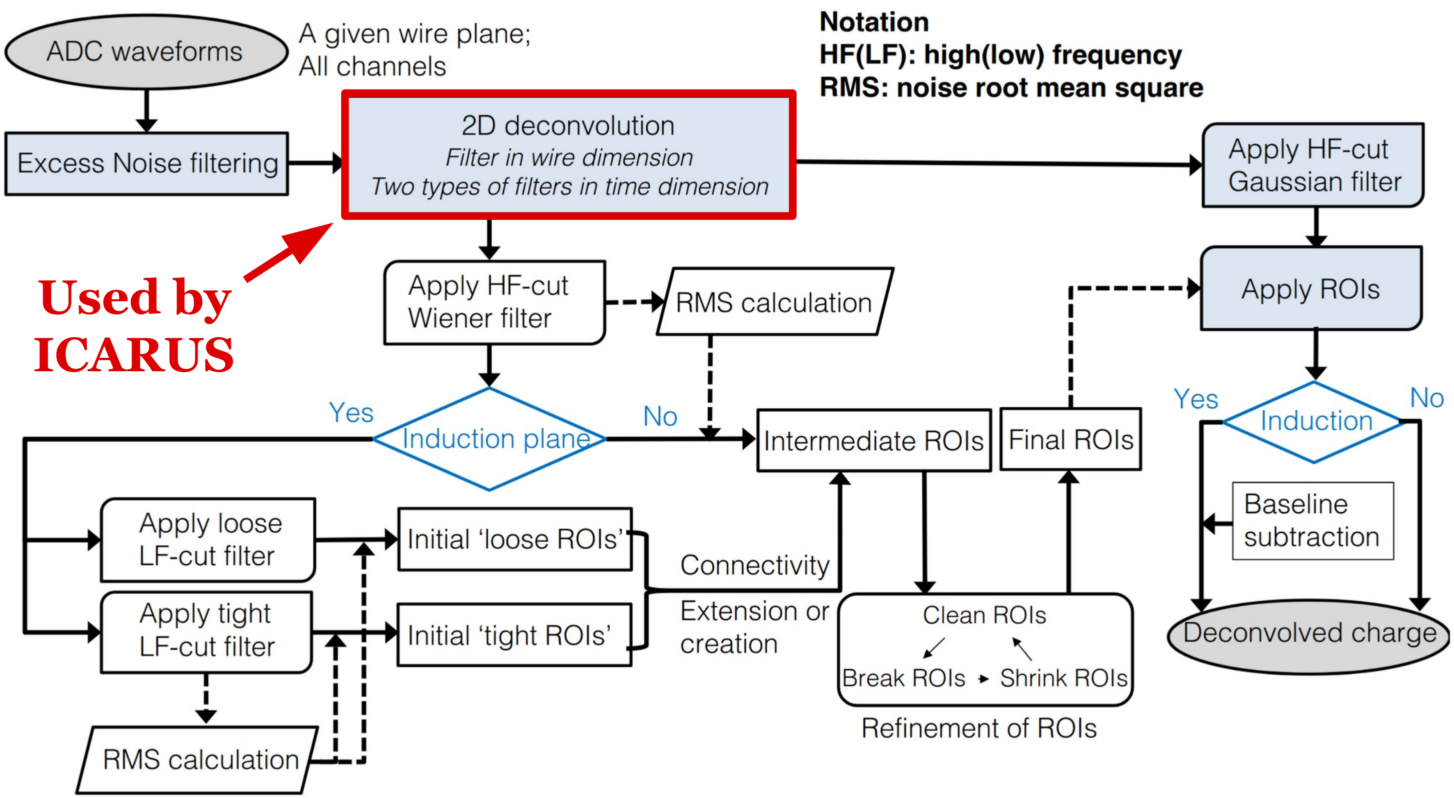
- Characterized TPC noise spectra (before and after coherent noise filtering) in ICARUS data
  - Noise levels very stable over time
- Using Wire-Cell to simulate data-driven noise spectra in MC simulation – excellent agreement w/ data (as expected)
  - Includes simulation of both intrinsic and coherent (extrinsic) noise, extracted from data – simulated at FE board level (64 TPC channels)

Signal Processing @ ICARUS



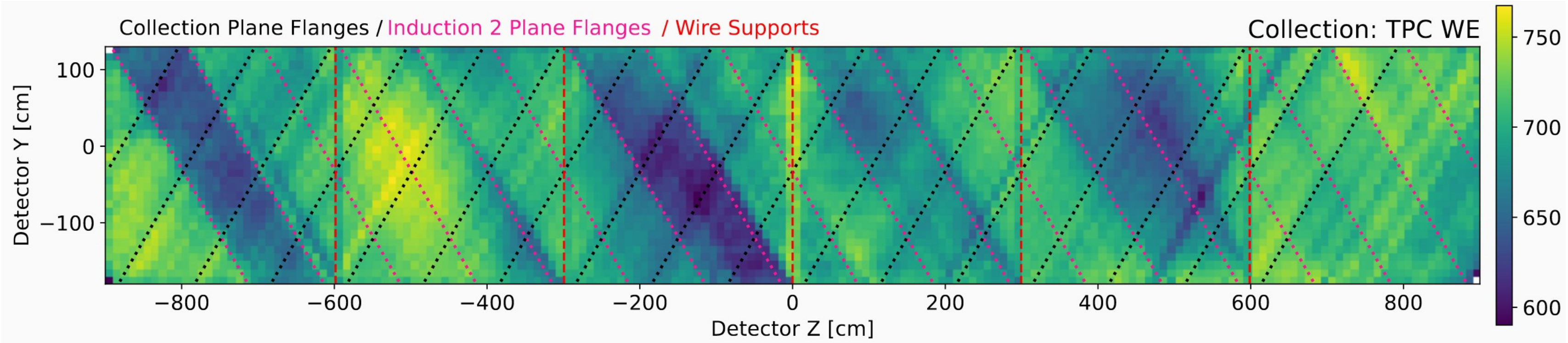
- Currently testing **2D deconvolution** (Wire-Cell) for charge estimation, but still using 1D deconvolution for ROI finding
  - Understanding is that Wire-Cell ROI finding does not work at ICARUS given relatively low S/N ratio compared to other LArTPC neutrino experiments
  - It would be very helpful to know more about the Wire-Cell team's experience in trying to get this to work at ICARUS

"Nominal" Wire-Cell Workflow



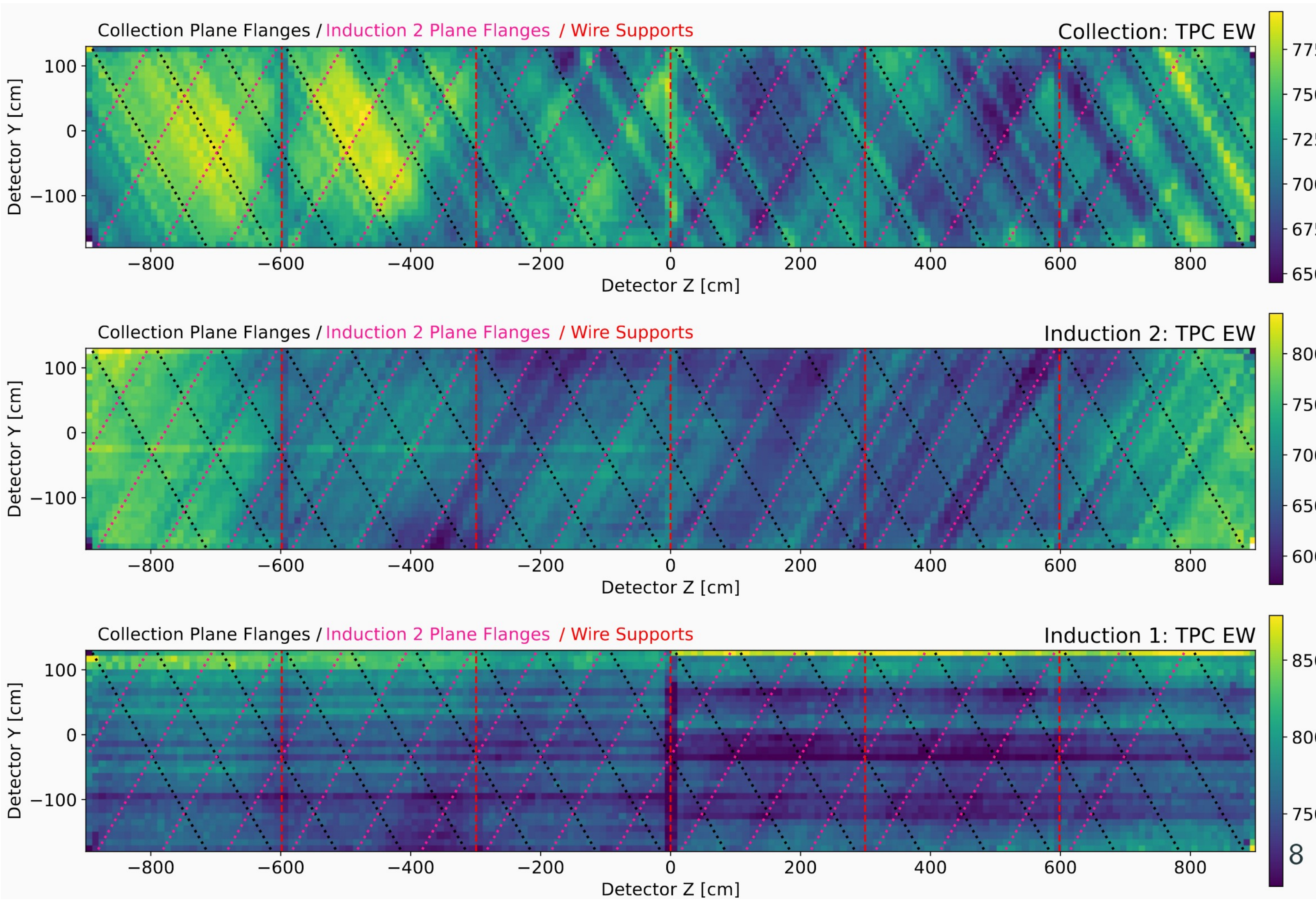
- Compare to MicroBooNE Wire-Cell TPC signal processing workflow being used at other detectors (e.g. SBND)
- Maybe lower S/N of ICARUS can benefit from ML techniques for ROI finding? This would be an interesting investigation!

TPC Non-uniformities

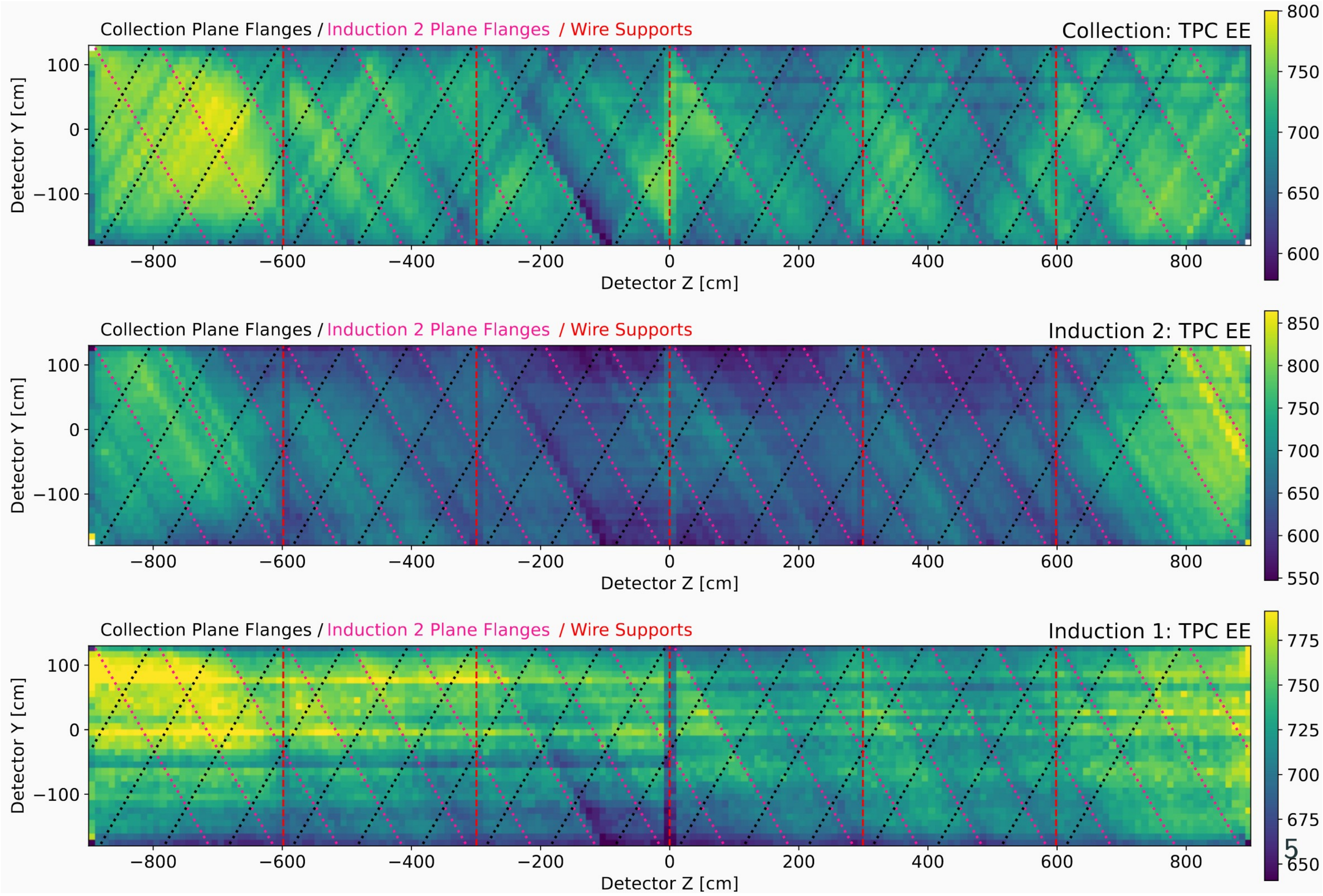


- TPC signal response non-uniformities observed by studying variations in extracted charge scale (dQ/dx MPV)
  - Range of variations across each TPC: **15-20%**
- Also TPC signal response waveforms show data/MC disagreement, likely another manifestation of same issue
- Given nature of variations across the different planes in each TPC, seems very likely this is a **transparency issue**
  - The source of the transparency loss has yet to be identified (wire bias HV distribution issue, wires losing tension, etc.)

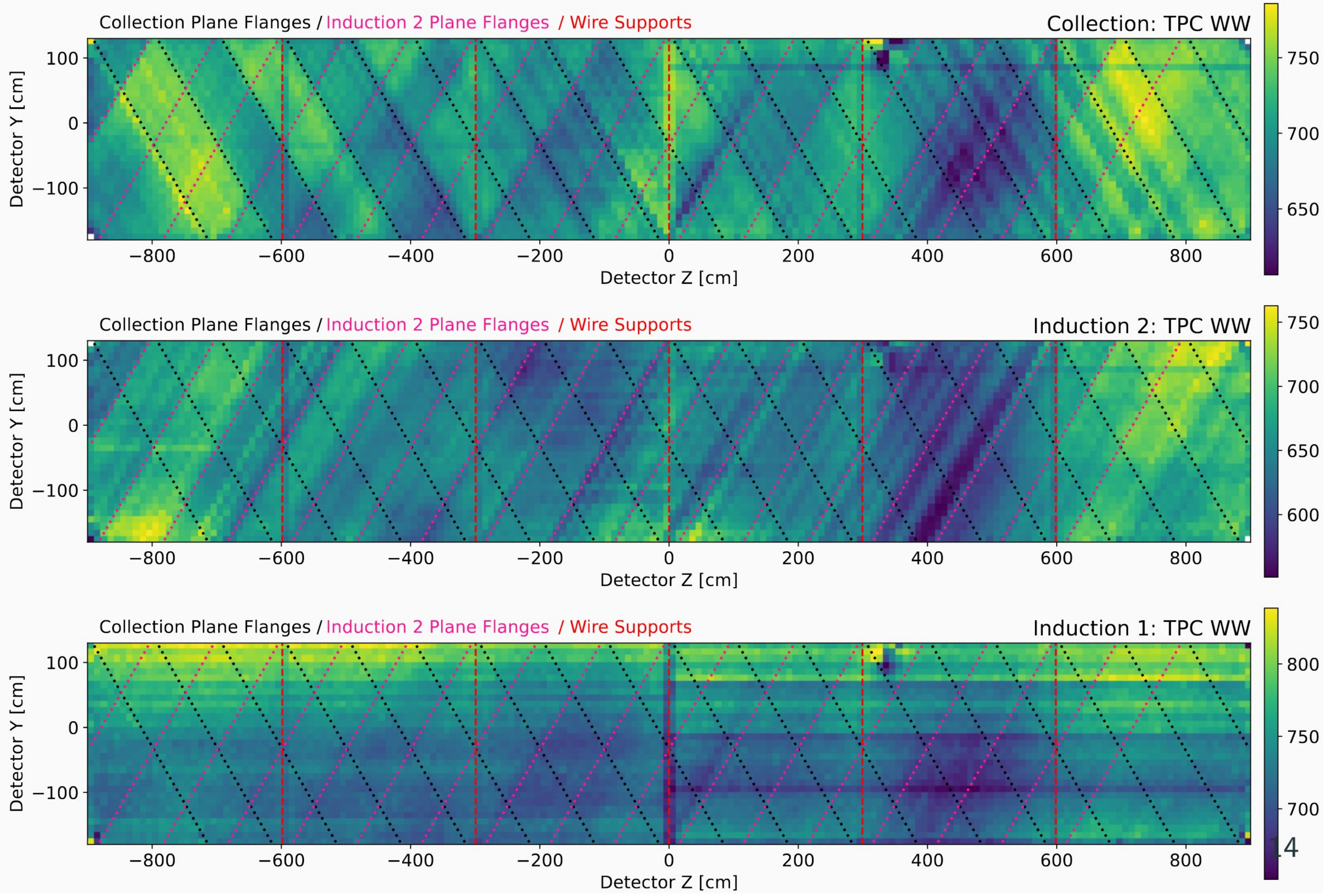
TPC EW Response



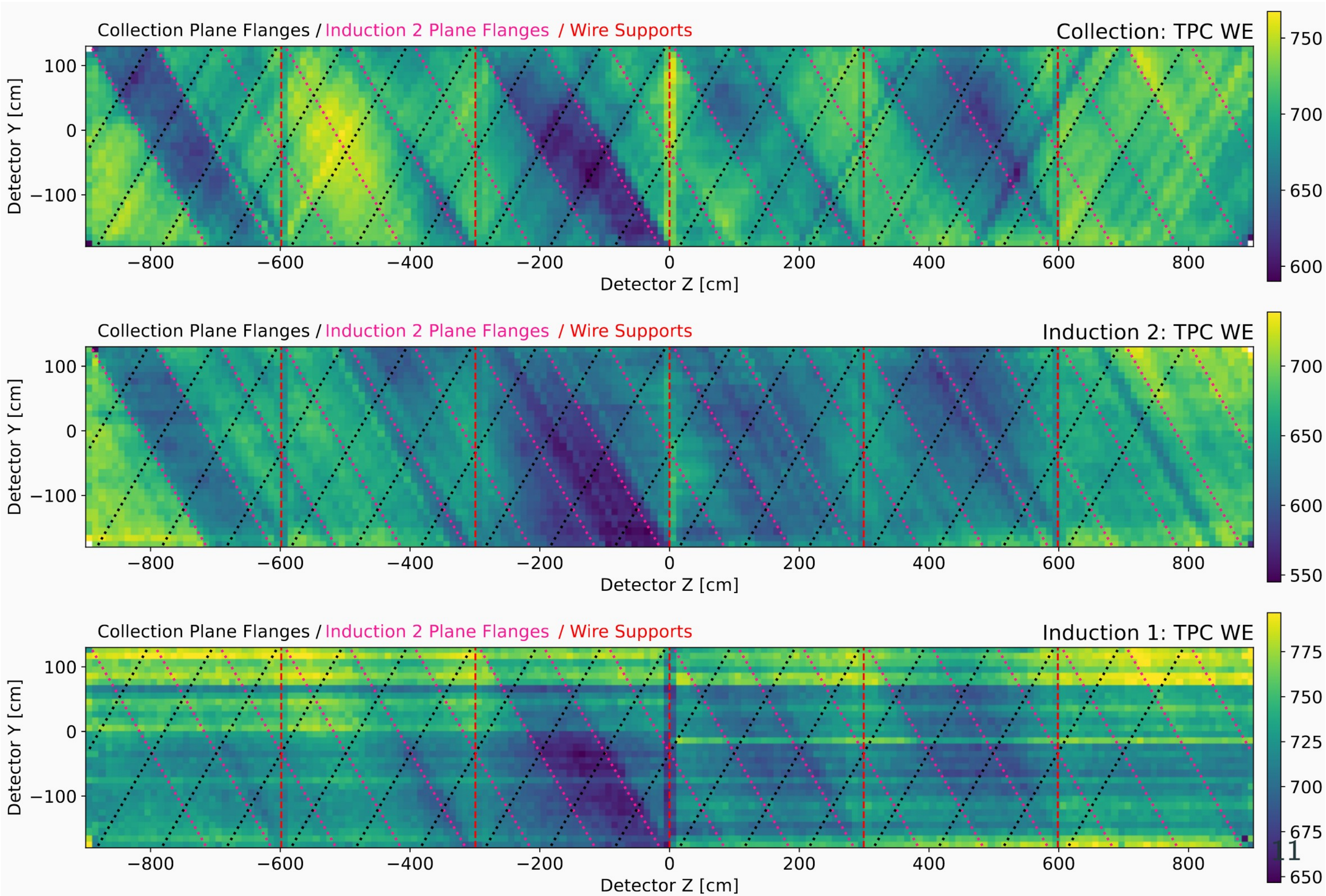
TPC EE Response



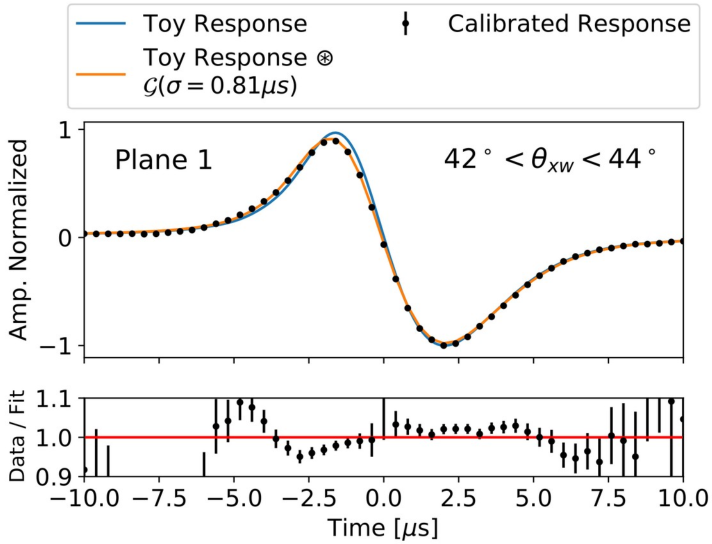
TPC WW Response



TPC WE Response

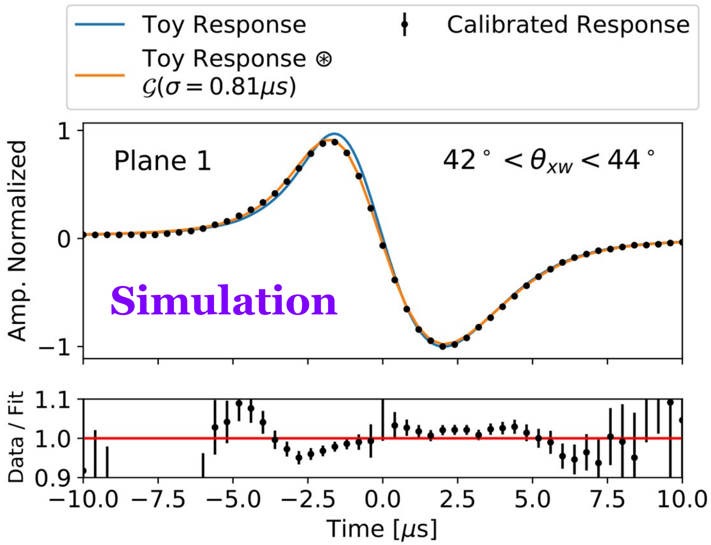


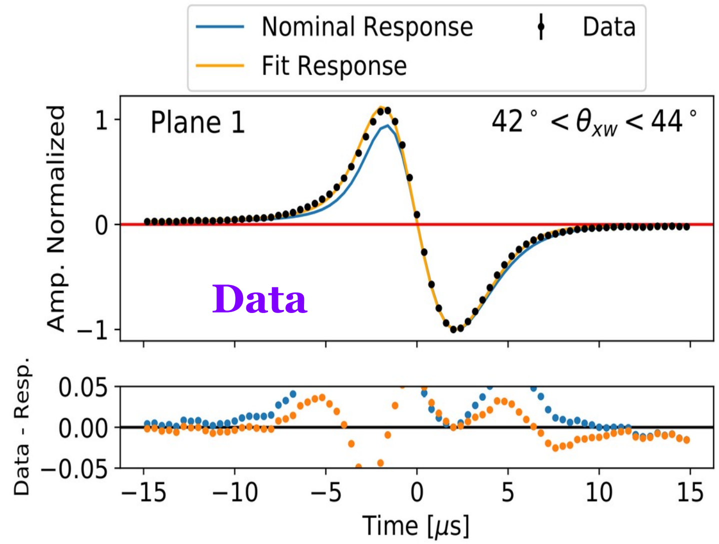
TPC Signal Shape Extraction



- Take average waveform at anode across many anode-cathode-crossing tracks: signal adds, noise cancels out
  - Drift coordinate requirement: [13 cm, 16 cm] away from anode (minimize diffusion without biasing Induction 1 signal)
  - Impact of noise is smearing of signal – can account for using MC
- Line signals up event-to-event using time bin with largest positive (negative) signal for collection (induction) plane(s)
  - Additional linearity requirement rejects tracks with delta rays

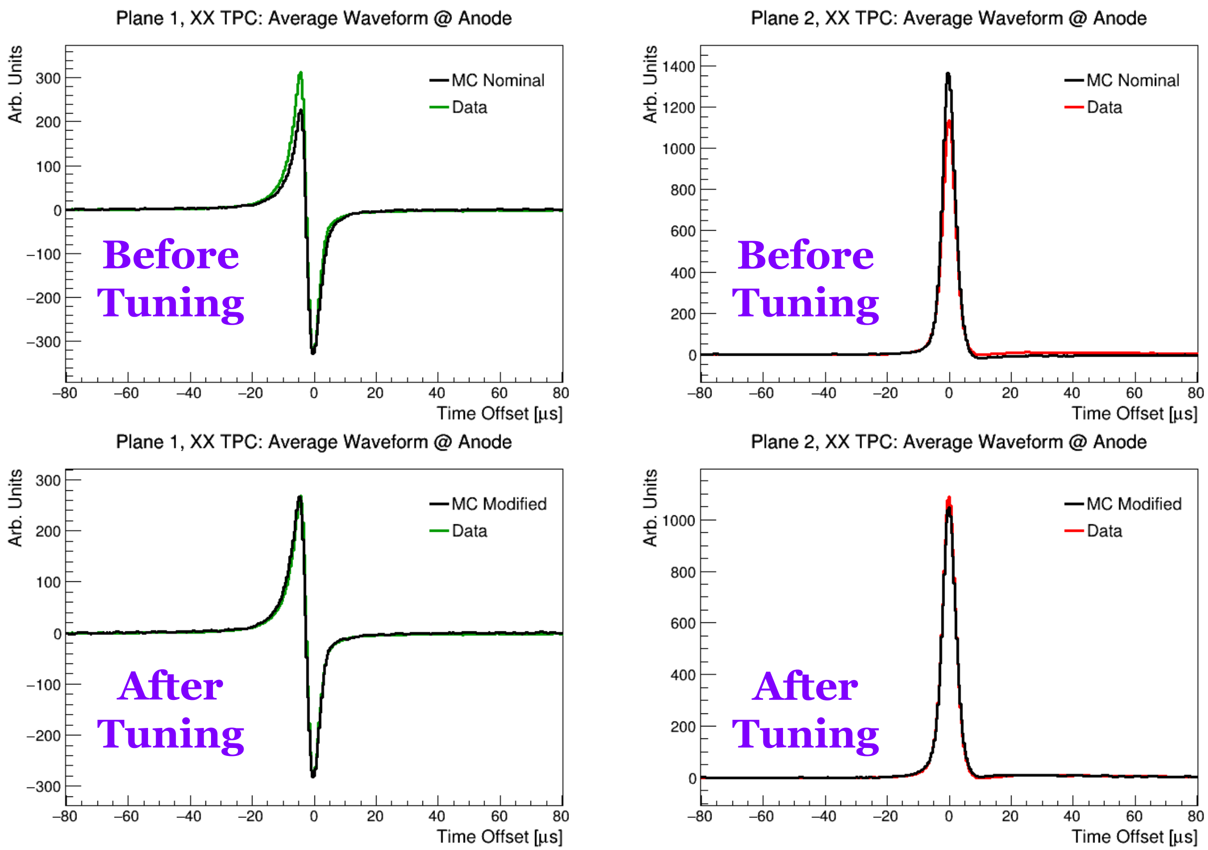
TPC Signal Response Tuning





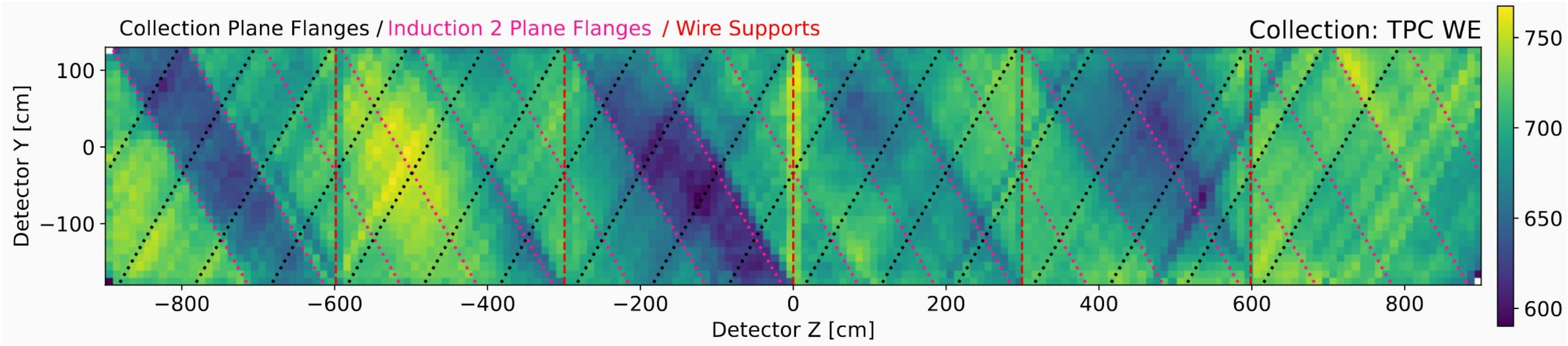
- Brief summary of methodology:
  - Produce average signal waveforms in data, MC (splitting by angle)
  - Take toy MC model of signal response and use to extract amount of "smearing" due to noise as function of track angle
  - Fit same toy MC model to data, modifying electronics/field response to obtain data/MC agreement, including noise smearing
  - Produce MC sample using tuned signal response for validation

Response Tuning Results



- ♦ Much improvement in modeling of signal response after tuning, checked with tuned MC simulation sample (now “nominal” ICARUS MC) – method being summarized in forthcoming publication (currently under internal review)

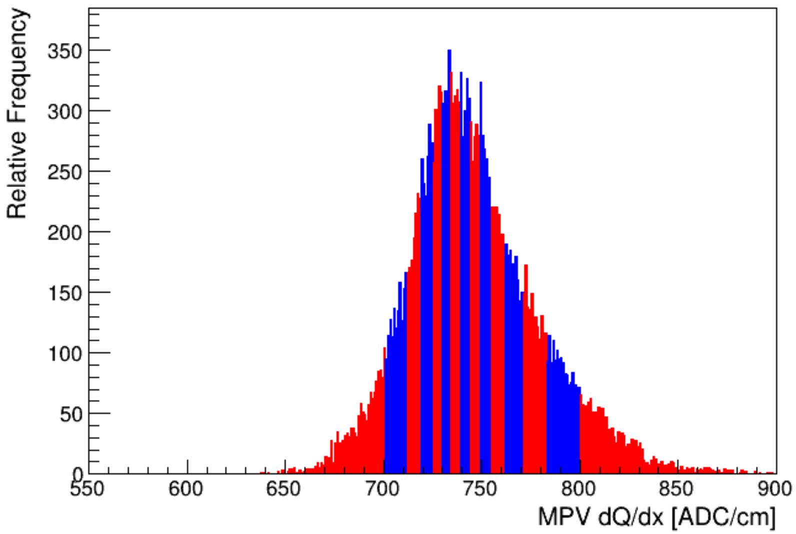
Spatial Variations in Signal Shape



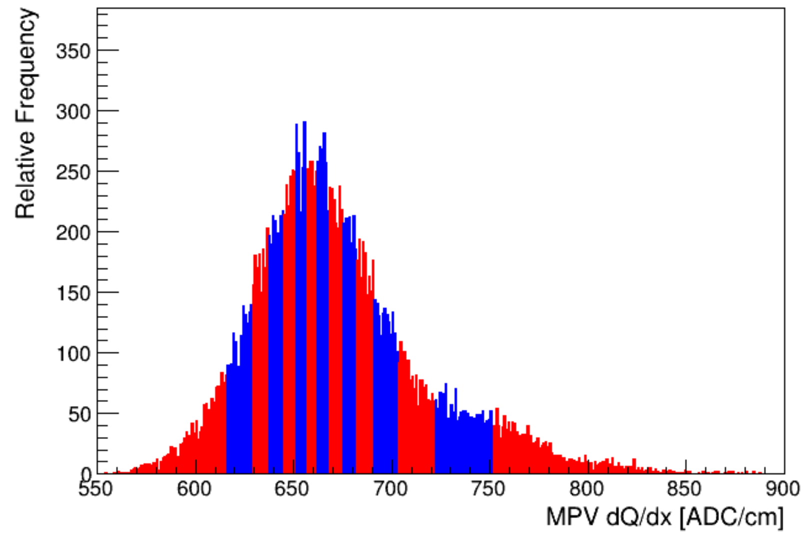
- We can also study spatial variations in signal shape (field response) as transparency condition changes throughout TPC volume
- Repeat average waveform extraction on each plane, but in bins of transparency (based on dQ/dx MPV, shown in 2D maps such as one above)
- Does a pattern emerge? *See next slides*

Binning in MPV dQ/dx

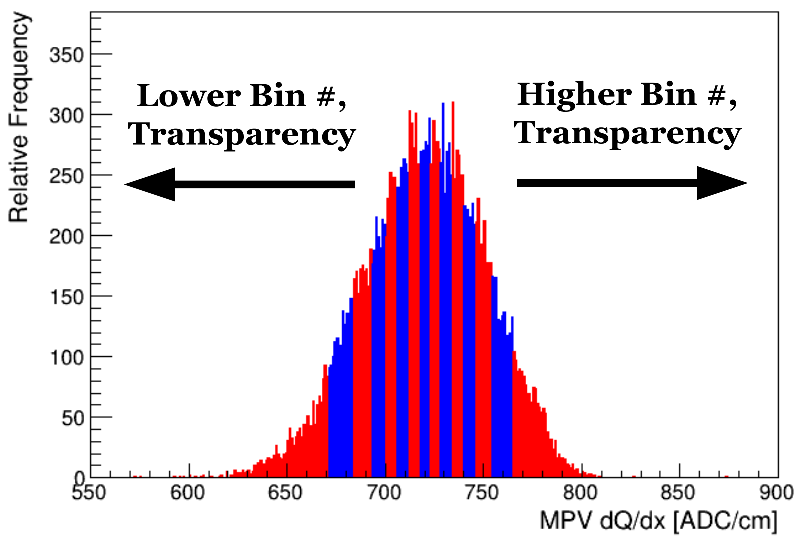
Plane 0: MPV dQ/dx Binning



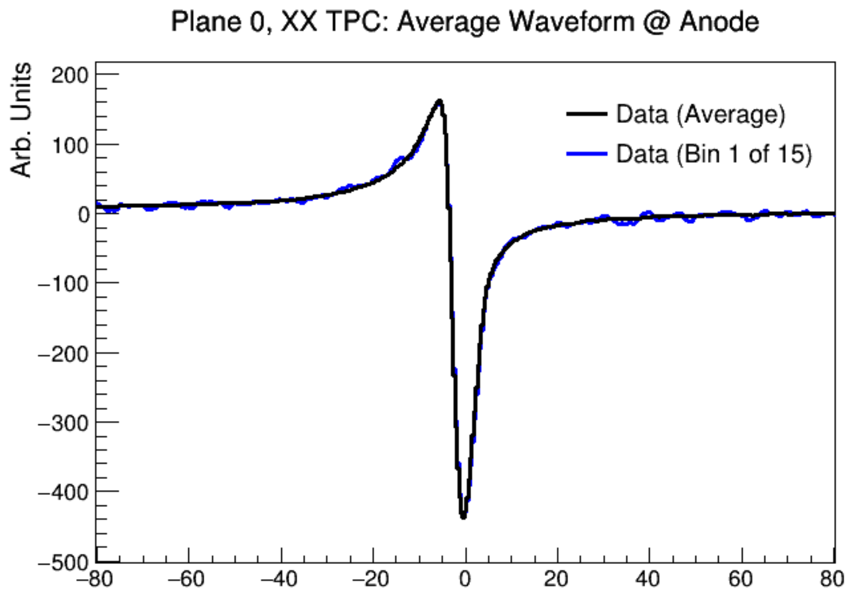
Plane 1: MPV dQ/dx Binning

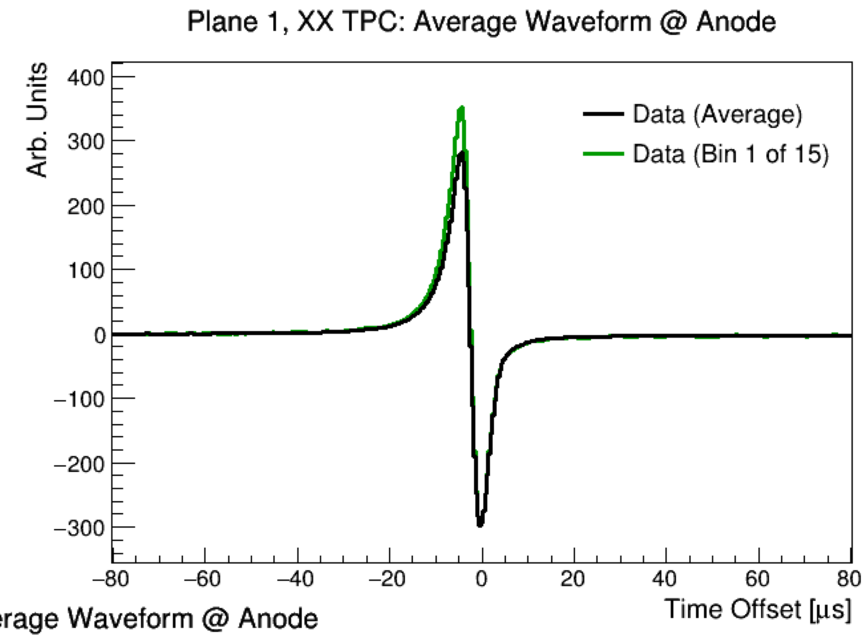


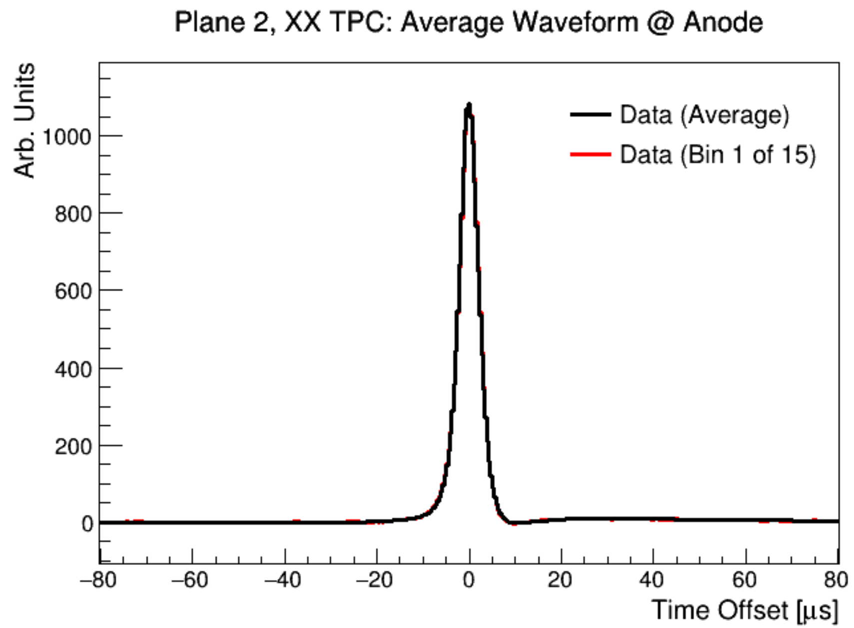
Plane 2: MPV dQ/dx Binning



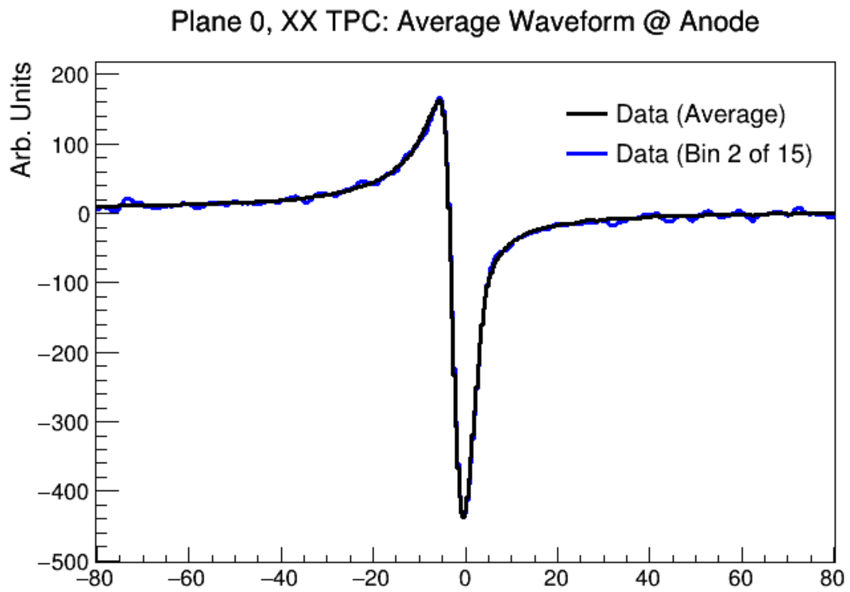
Spatial Study Results – Bin 1

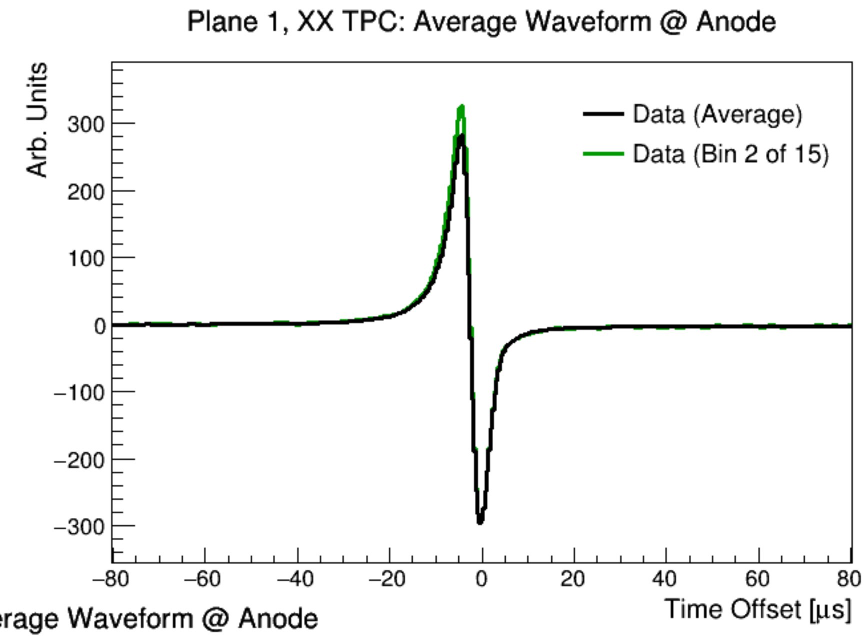


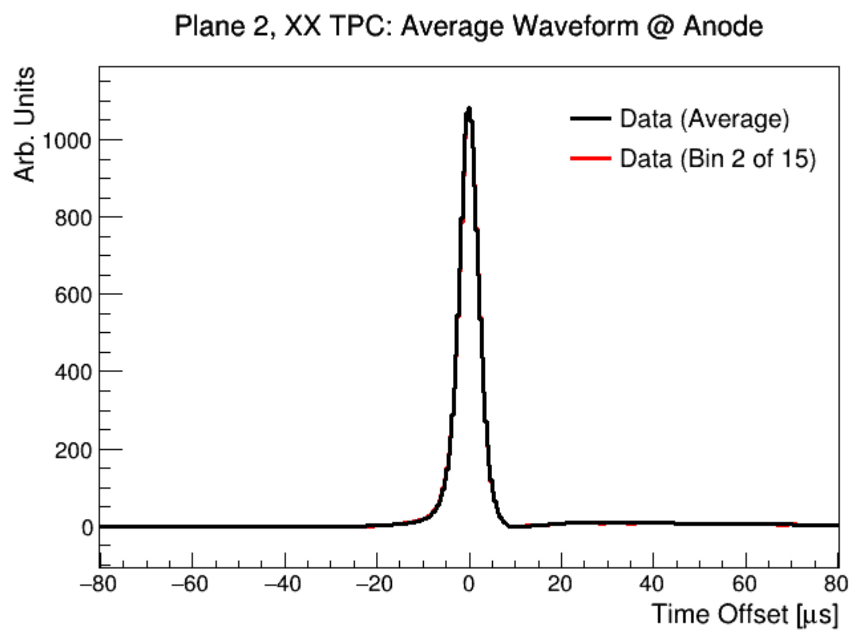




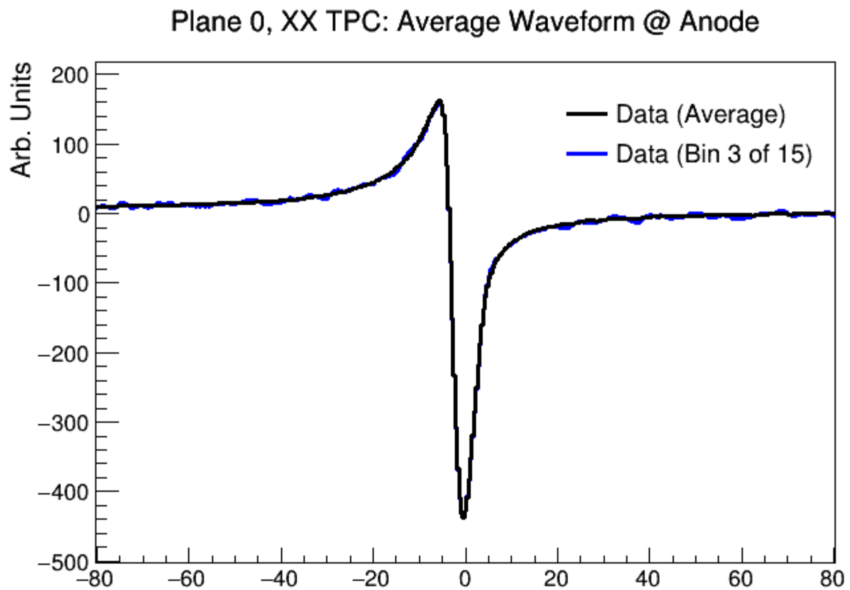
Spatial Study Results – Bin 2

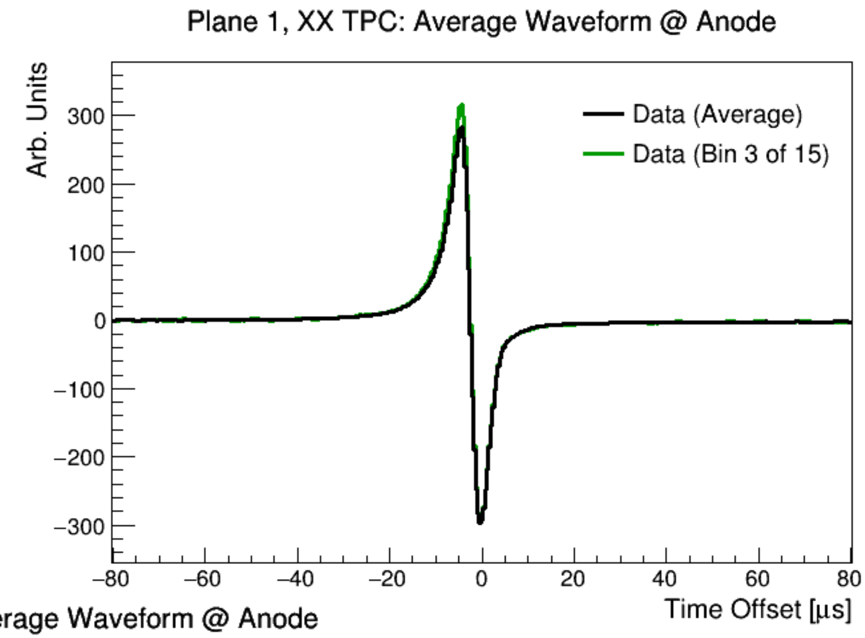


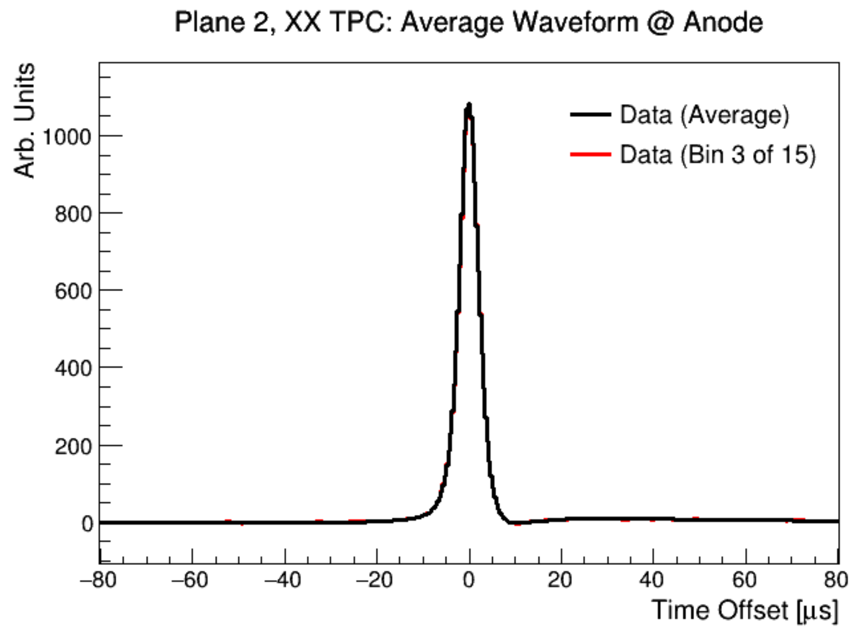




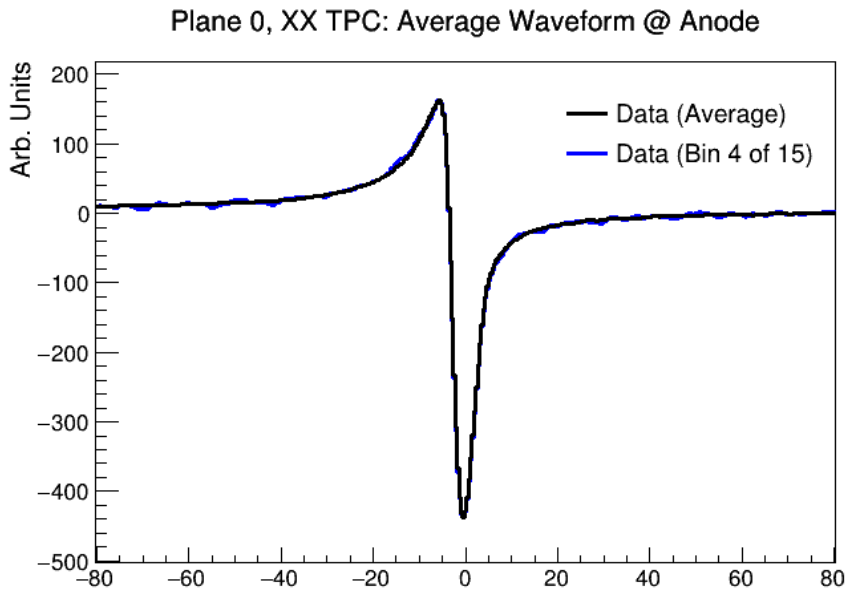
Spatial Study Results – Bin 3

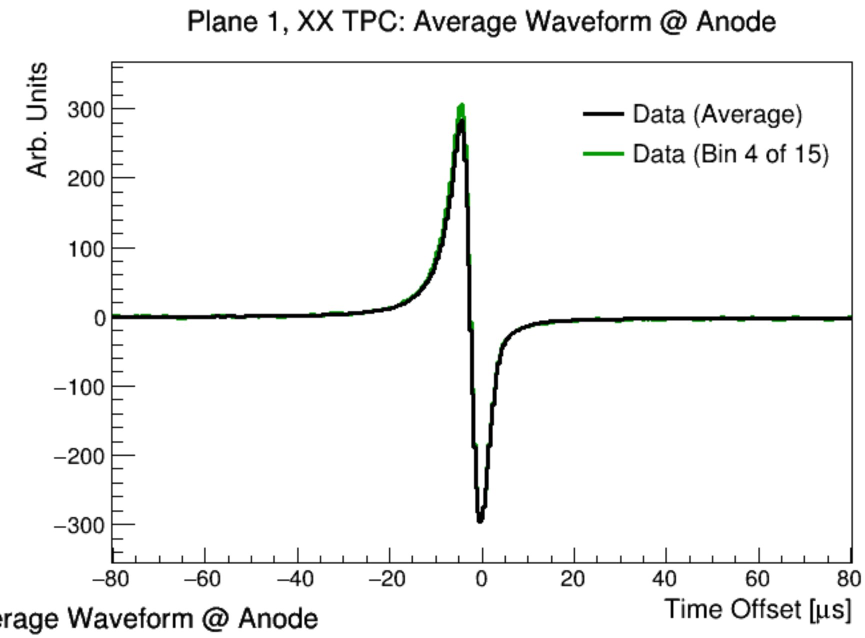


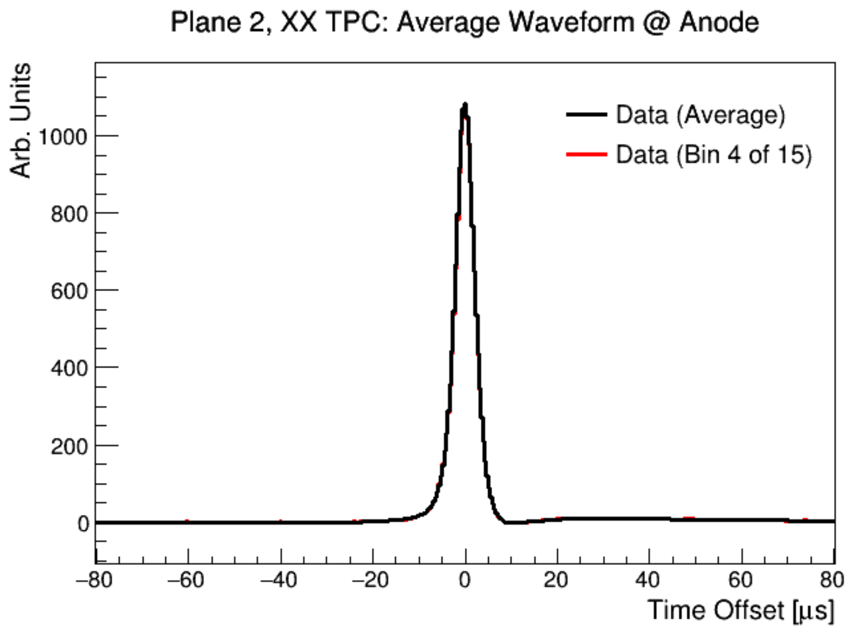




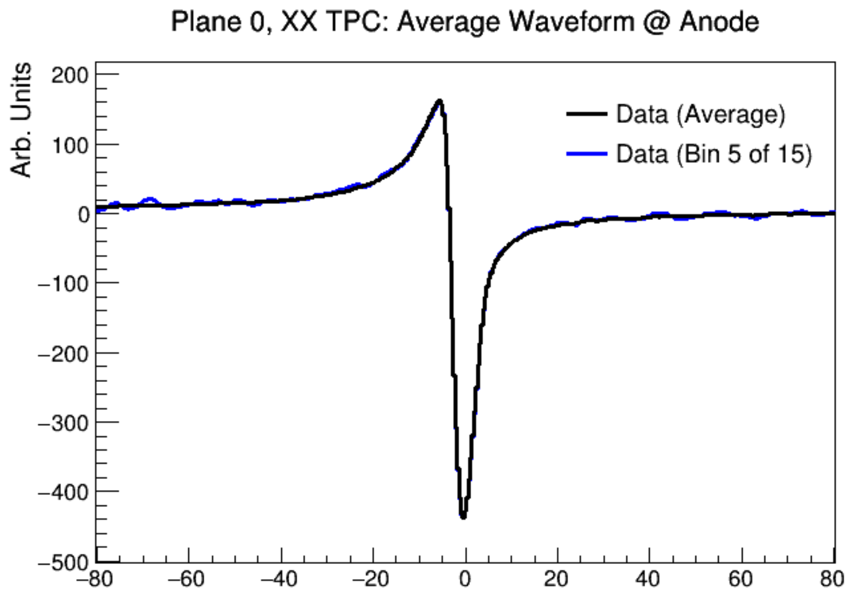
Spatial Study Results – Bin 4

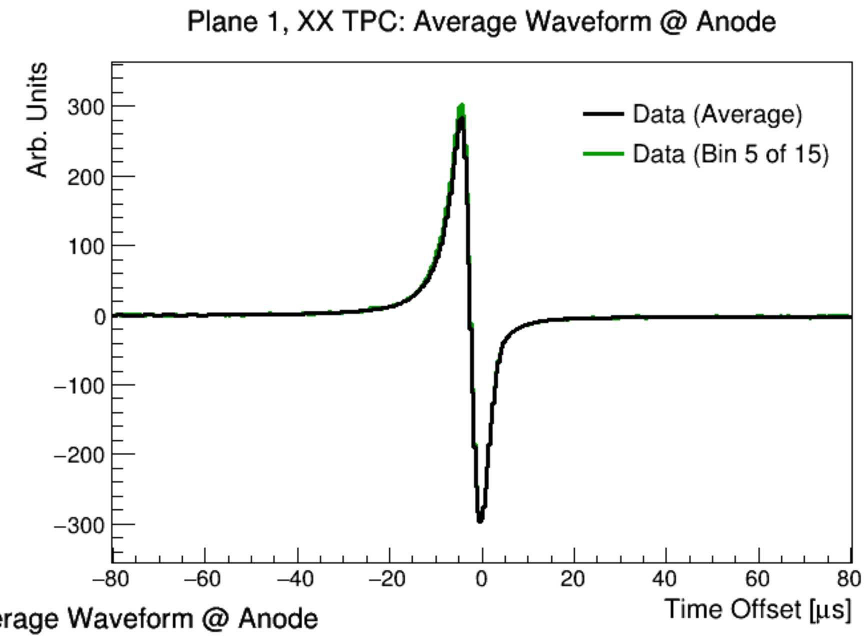


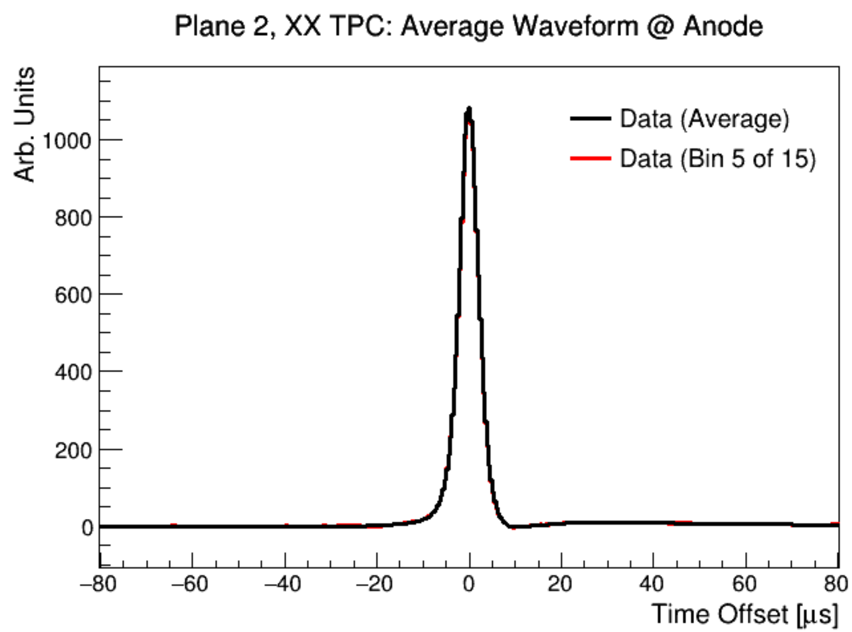




Spatial Study Results – Bin 5

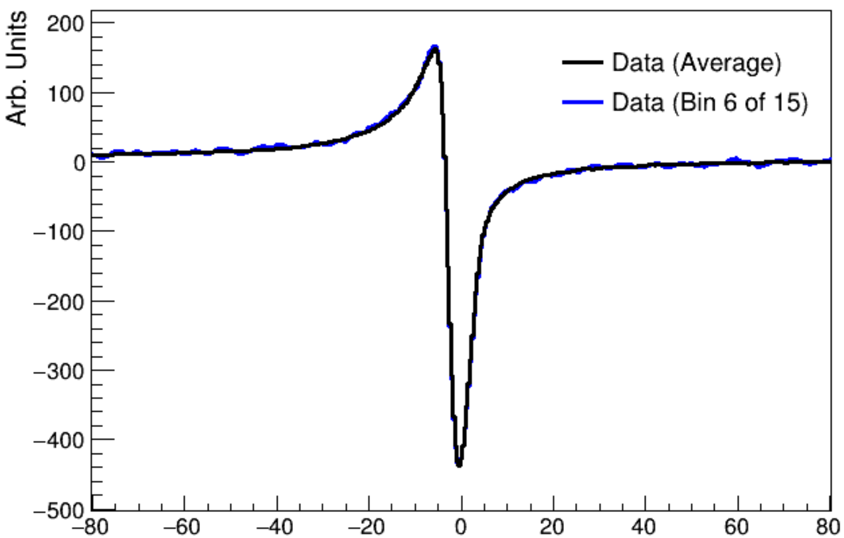




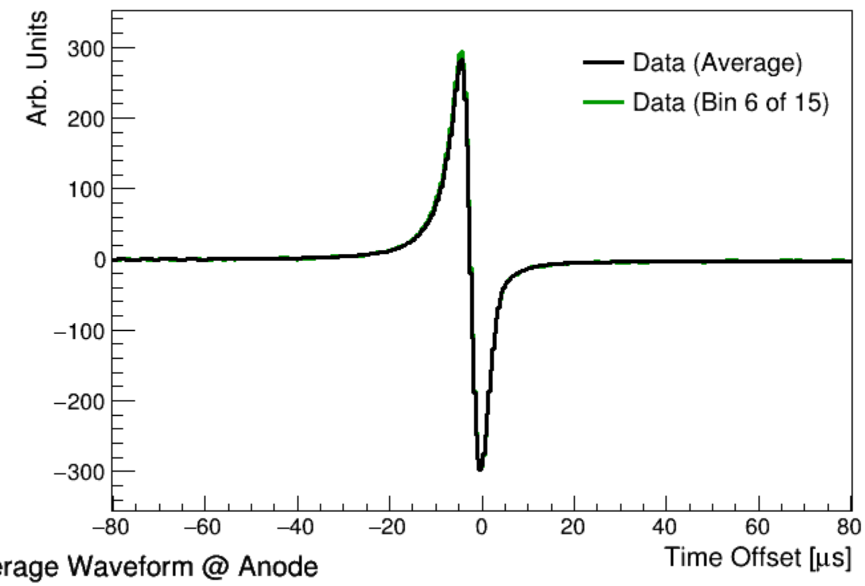


Spatial Study Results – Bin 6

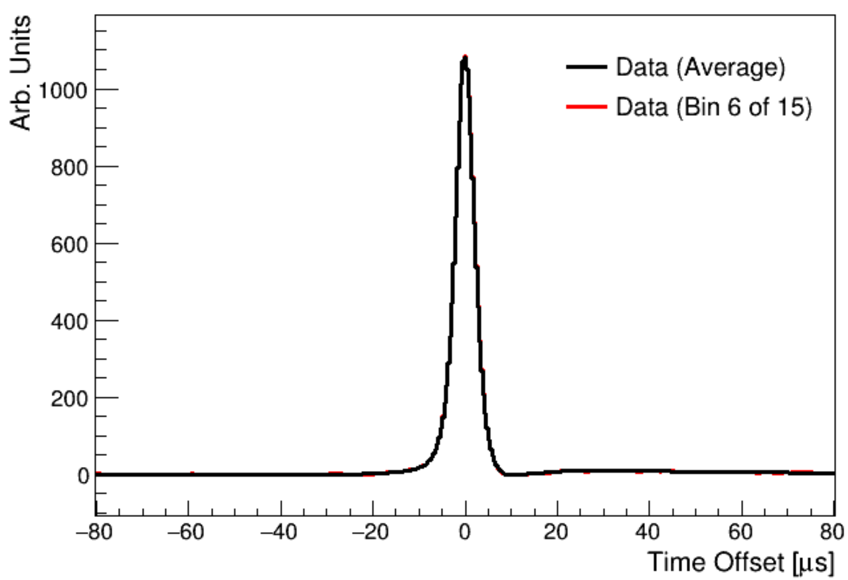
Plane 0, XX TPC: Average Waveform @ Anode



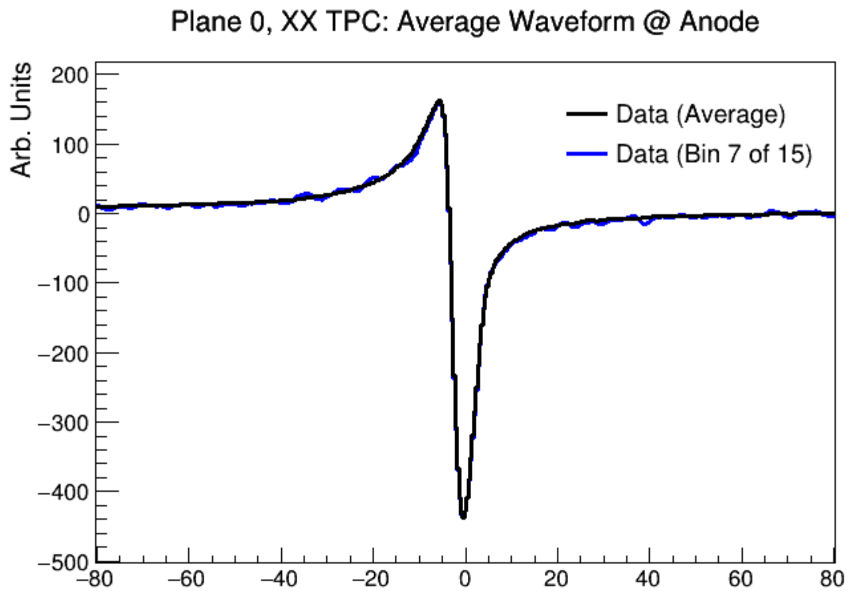
Plane 1, XX TPC: Average Waveform @ Anode

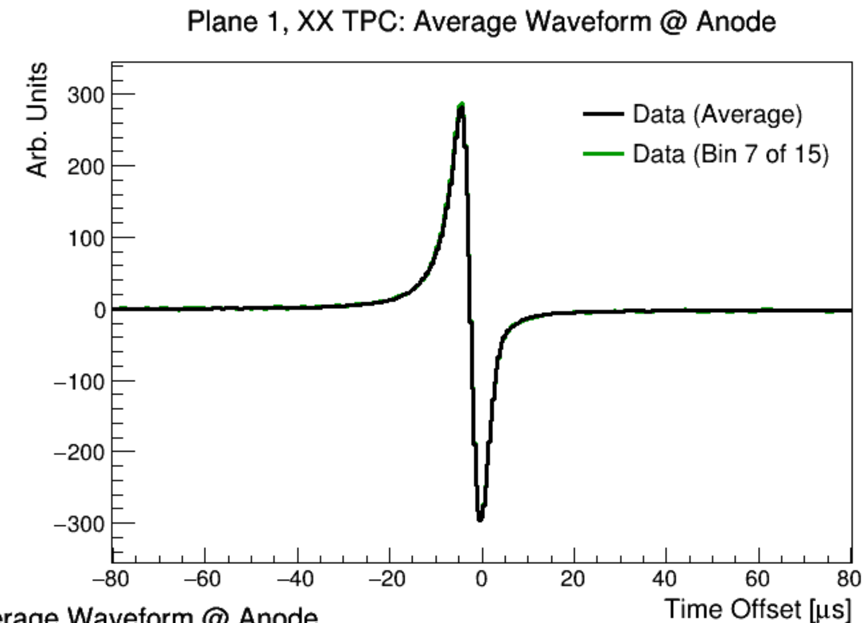


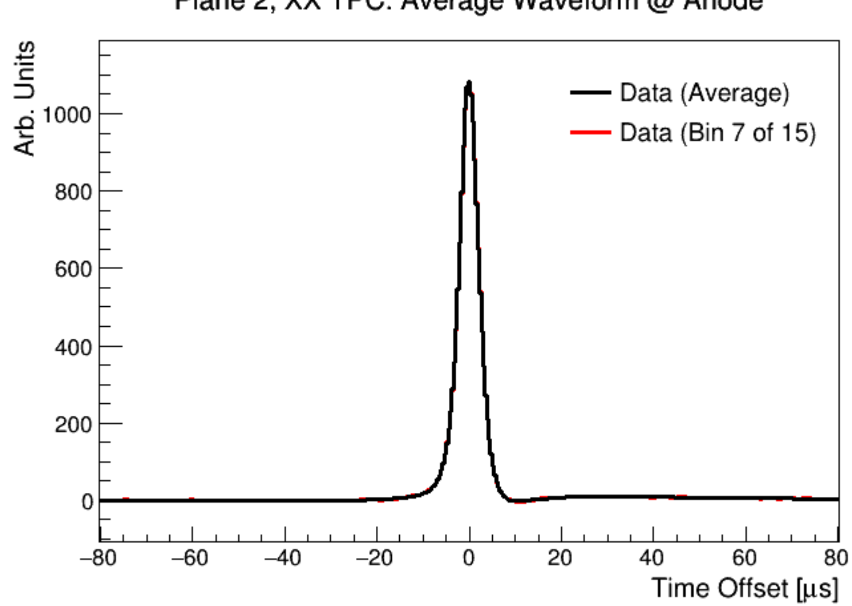
Plane 2, XX TPC: Average Waveform @ Anode



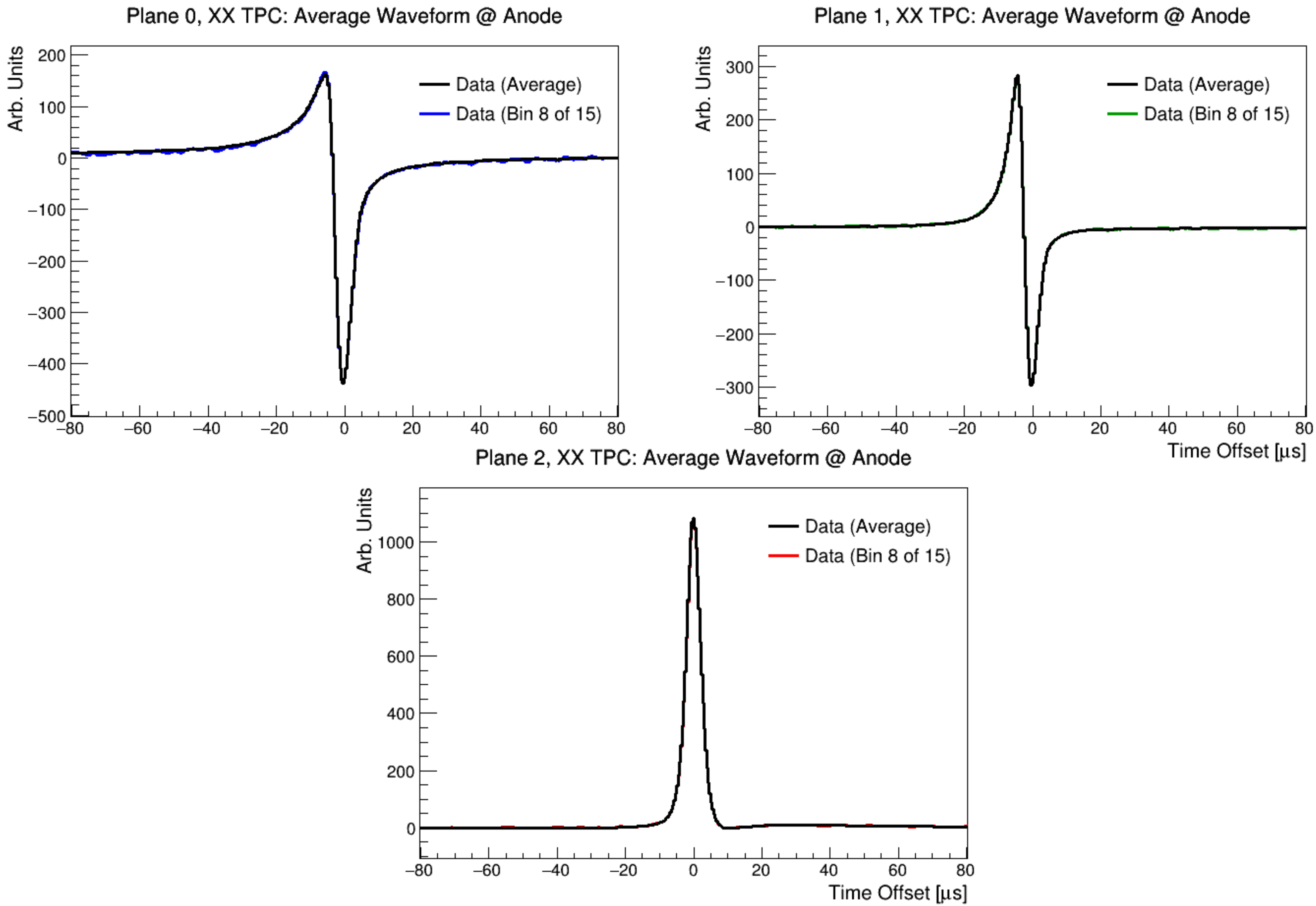
Spatial Study Results – Bin 7



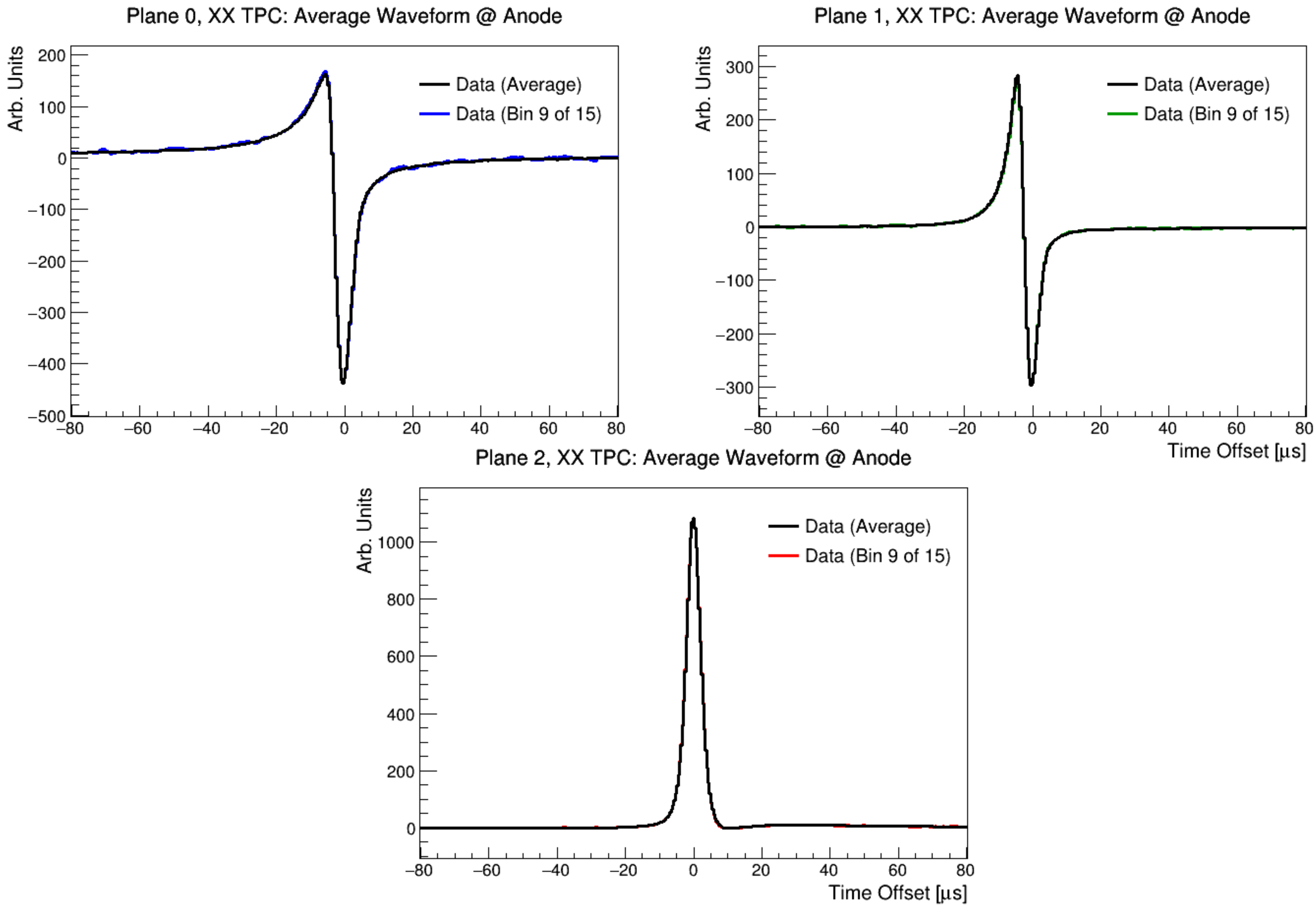




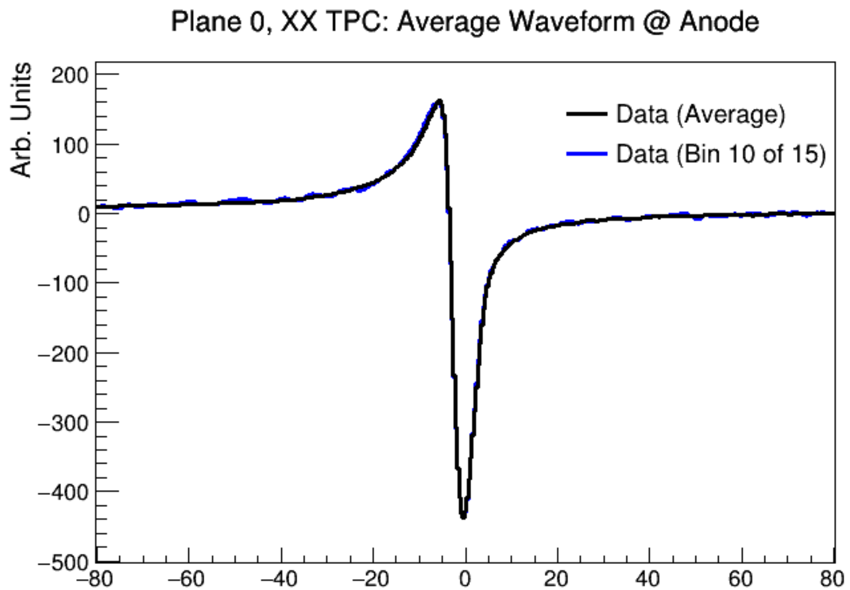
Spatial Study Results – Bin 8

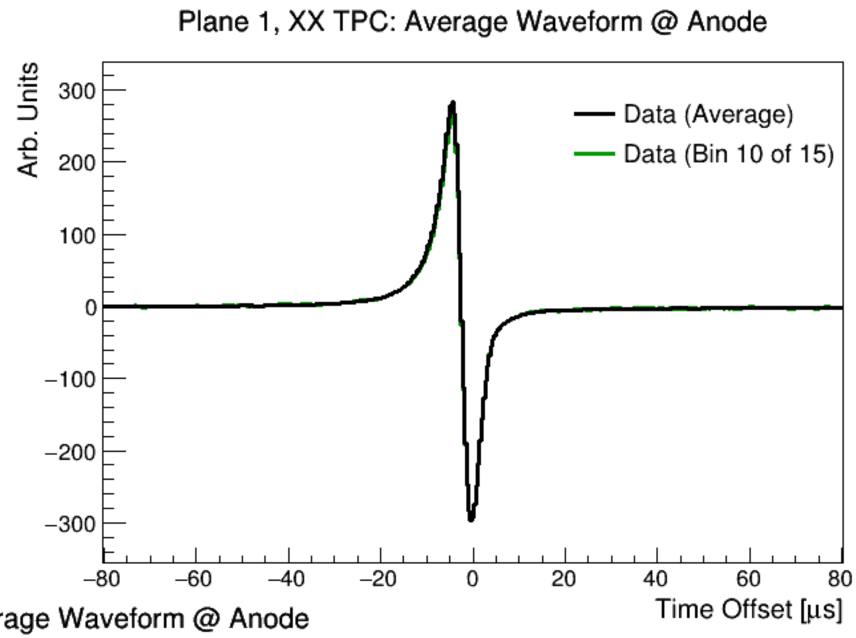


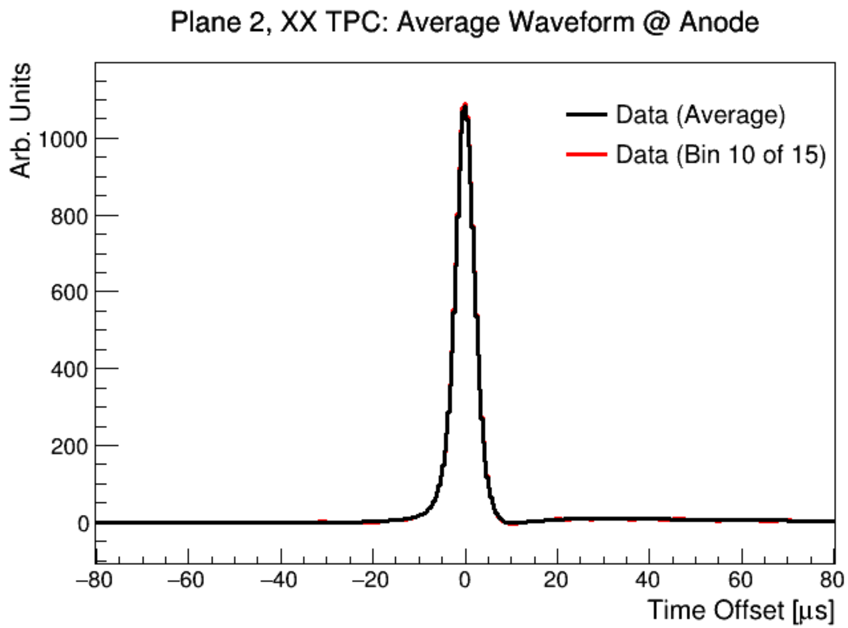
Spatial Study Results – Bin 9



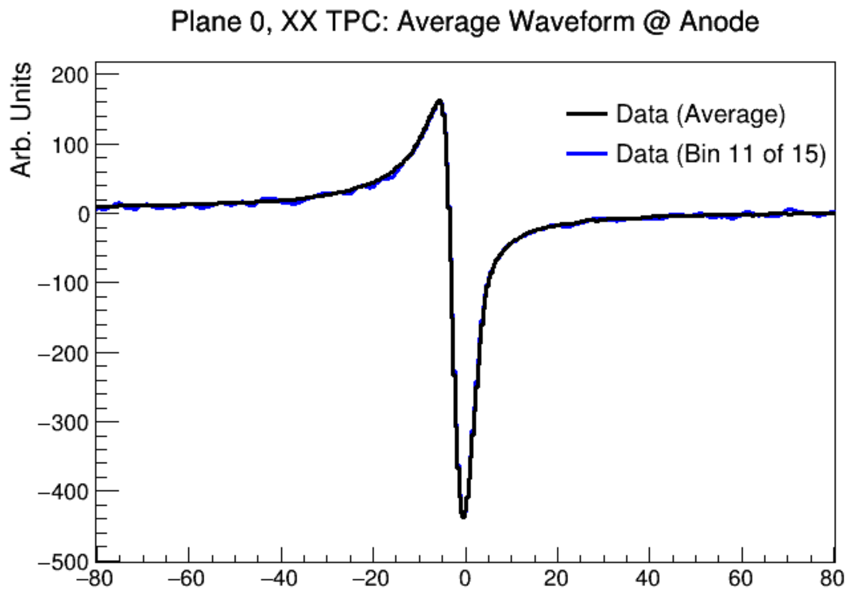
Spatial Study Results – Bin 10

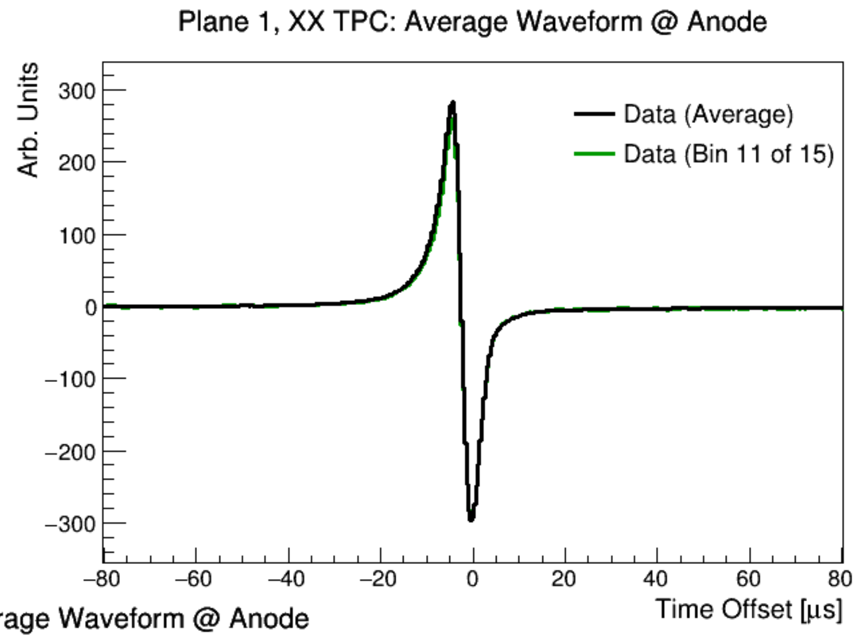


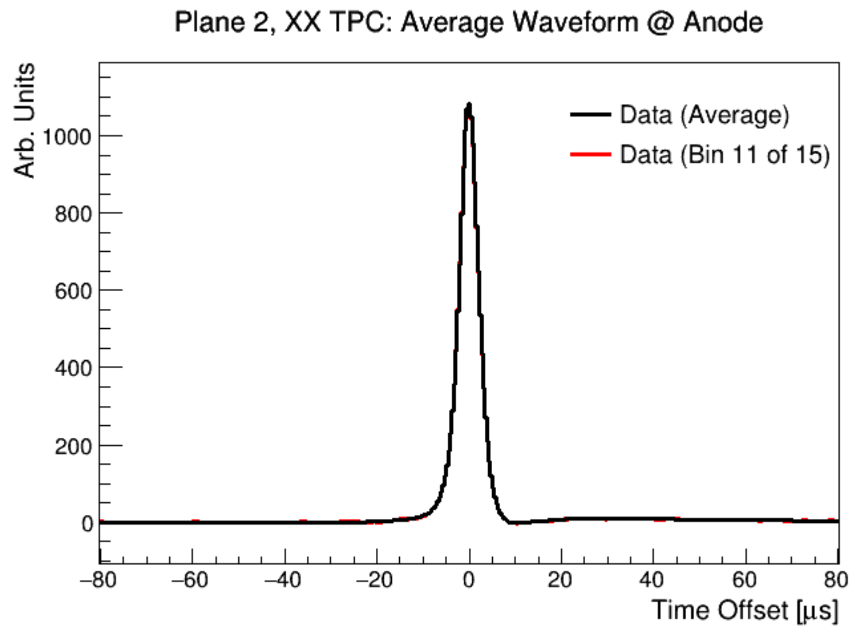




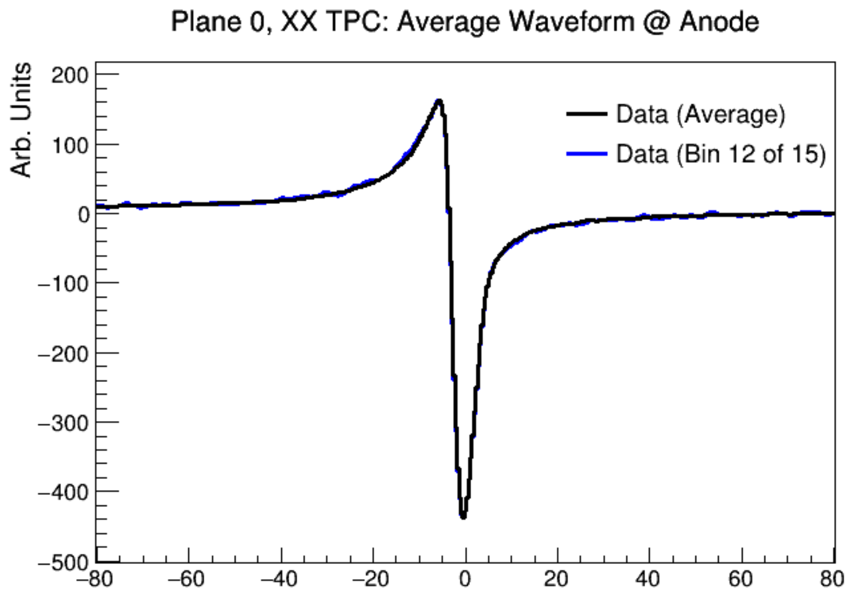
Spatial Study Results – Bin 11

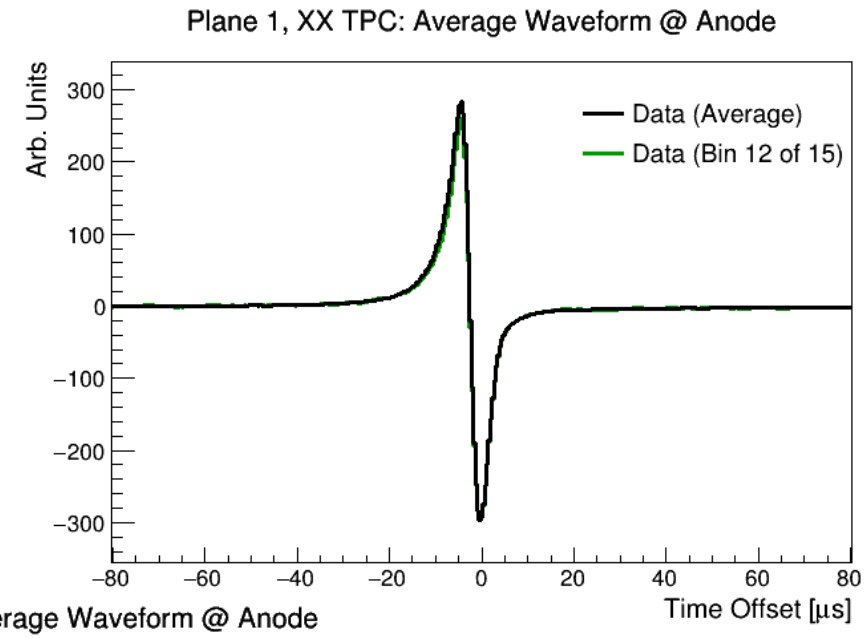


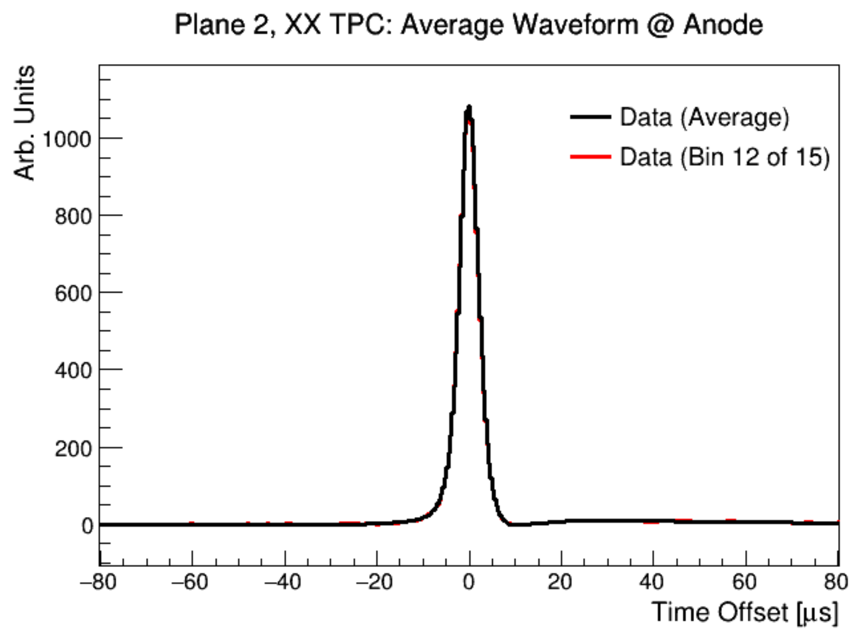




Spatial Study Results – Bin 12

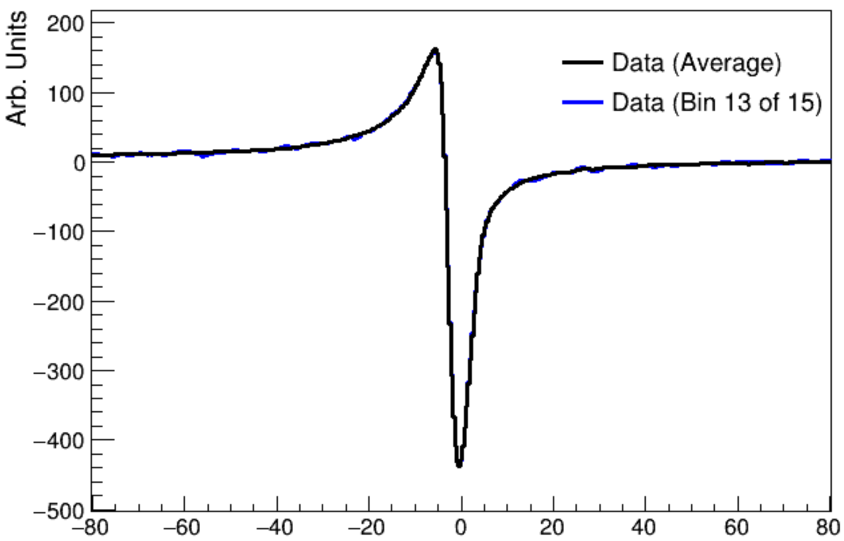




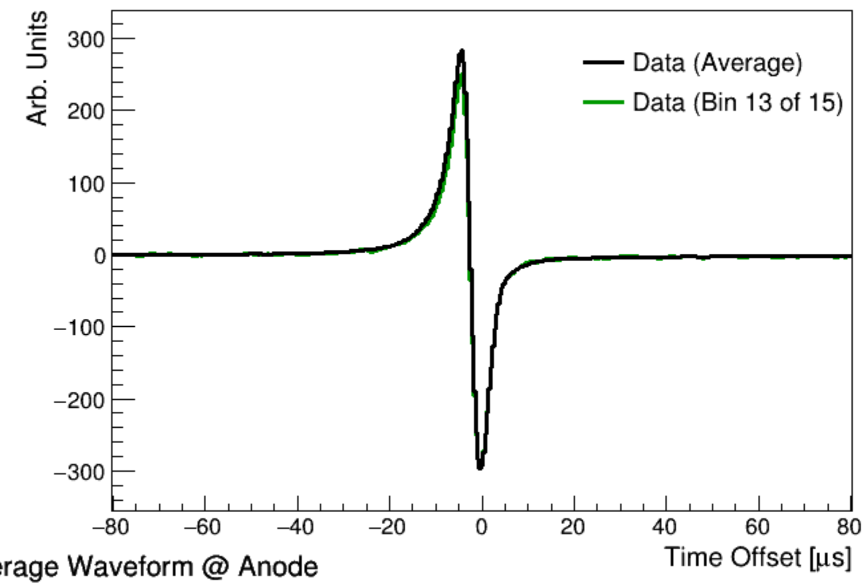


Spatial Study Results – Bin 13

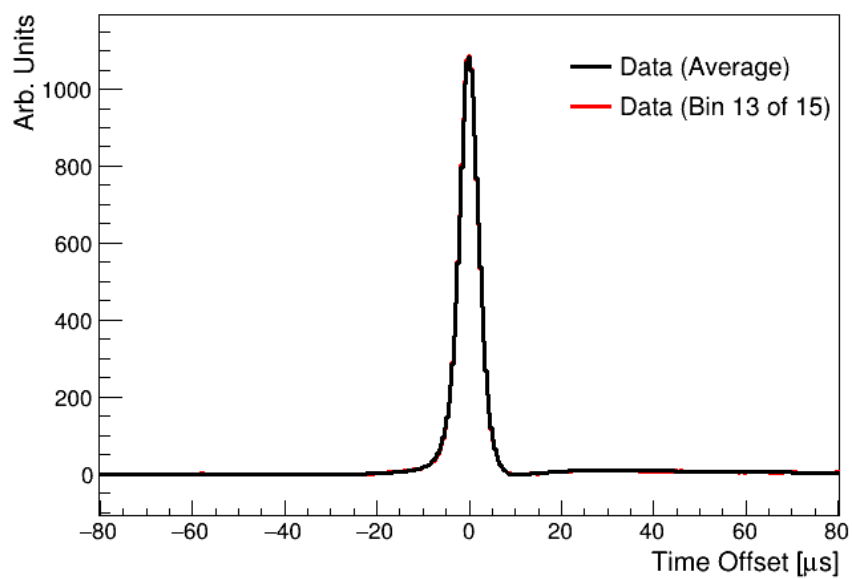
Plane 0, XX TPC: Average Waveform @ Anode



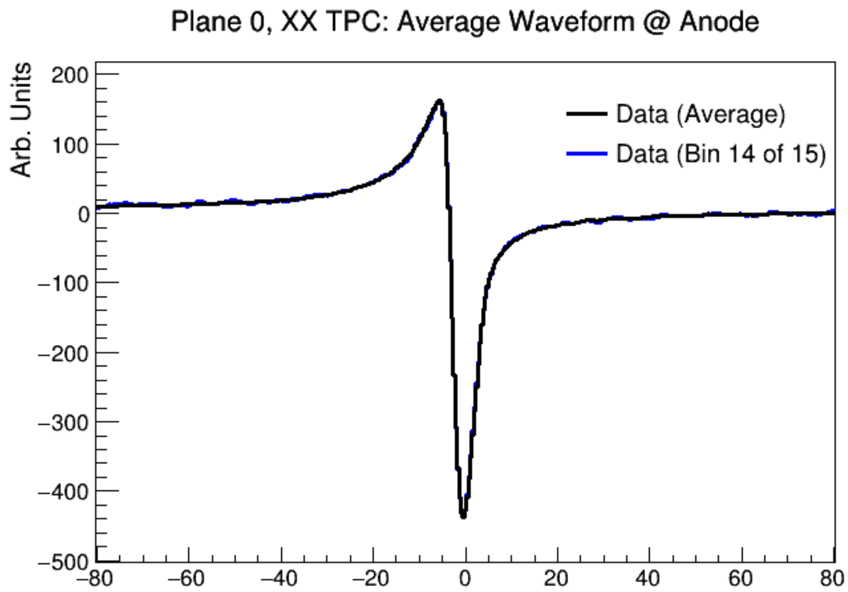
Plane 1, XX TPC: Average Waveform @ Anode

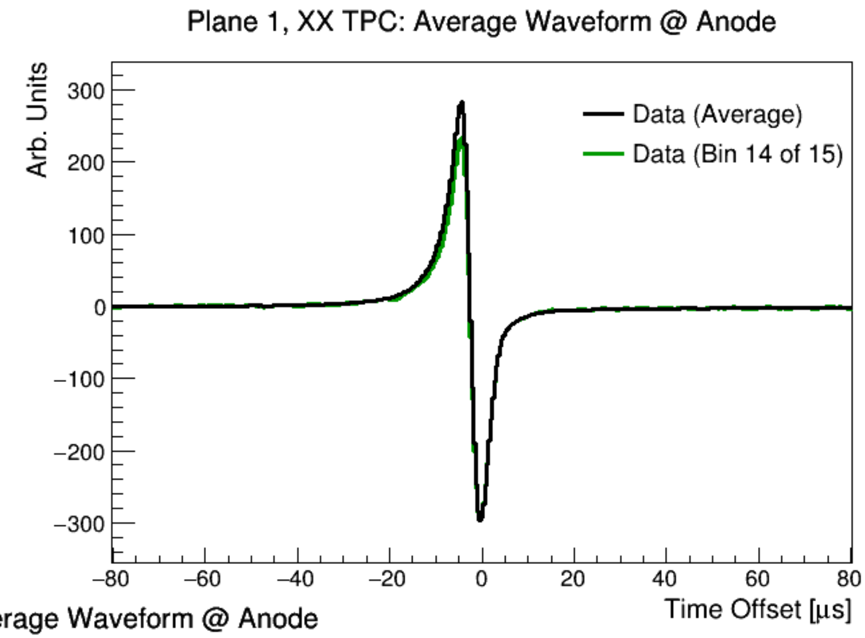


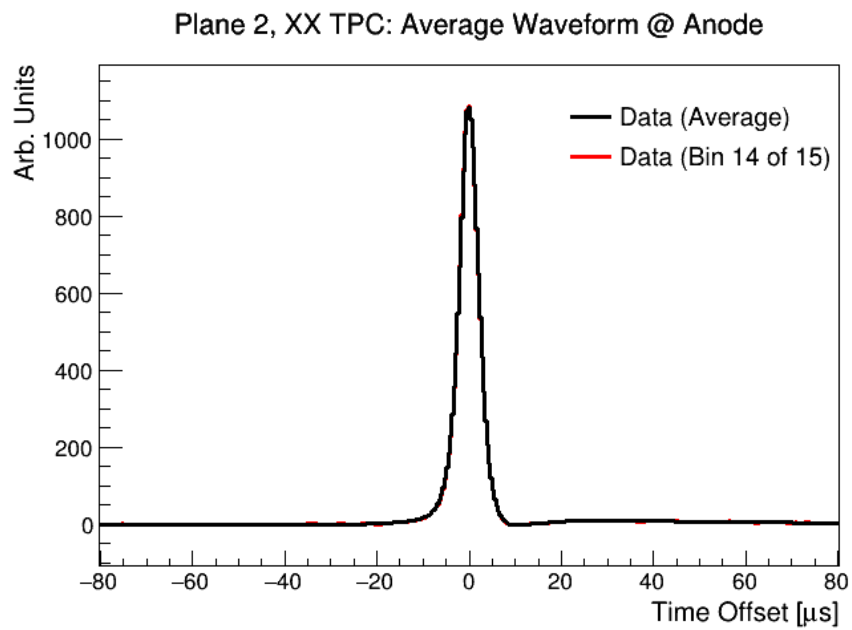
Plane 2, XX TPC: Average Waveform @ Anode



Spatial Study Results – Bin 14

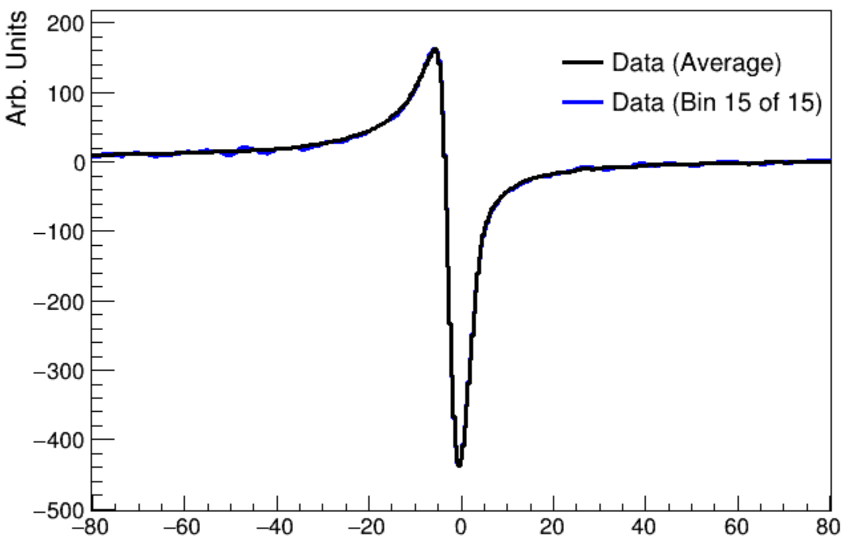




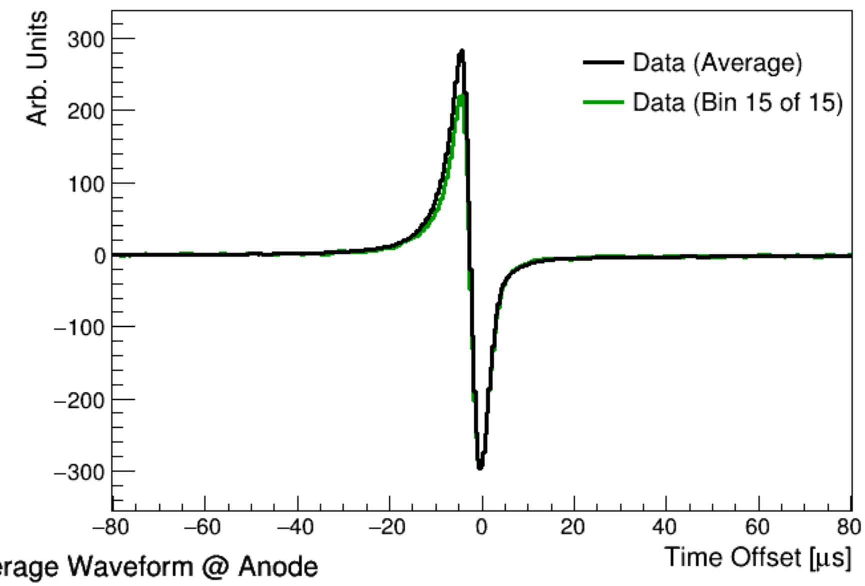


Spatial Study Results – Bin 15

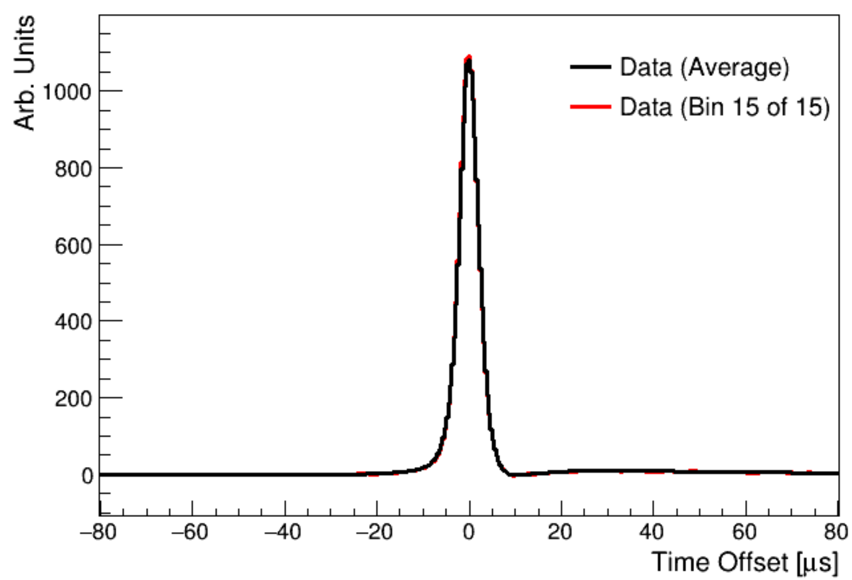
Plane 0, XX TPC: Average Waveform @ Anode



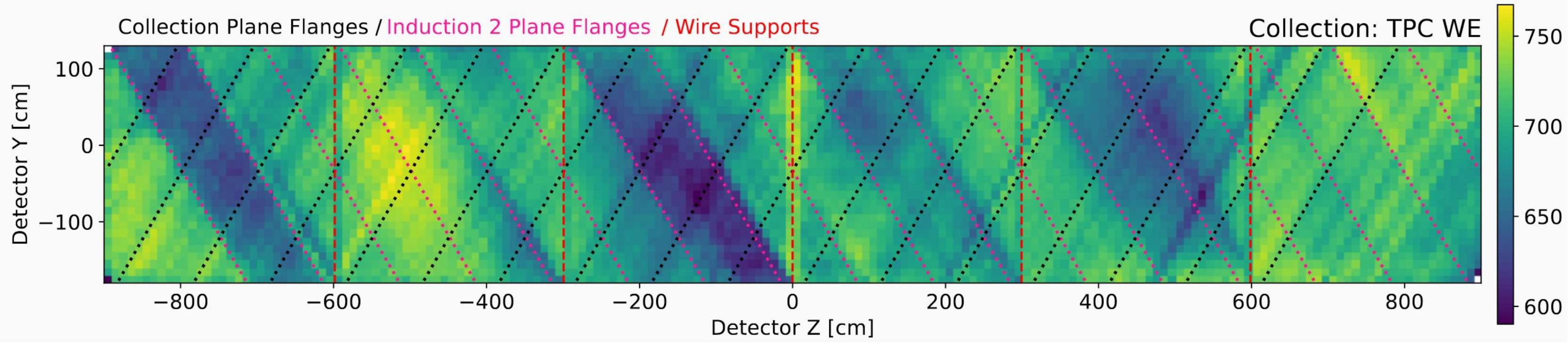
Plane 1, XX TPC: Average Waveform @ Anode



Plane 2, XX TPC: Average Waveform @ Anode



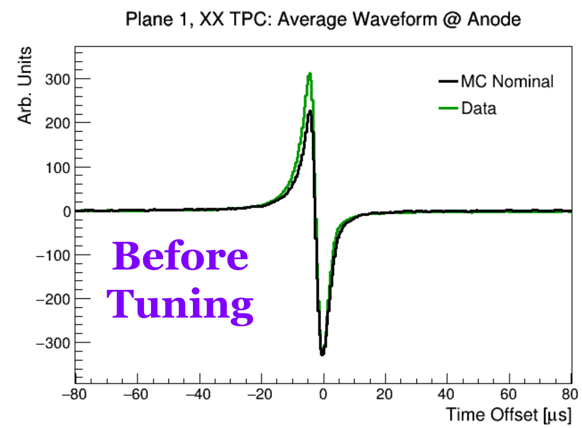
Modeling Non-uniformity at ICARUS

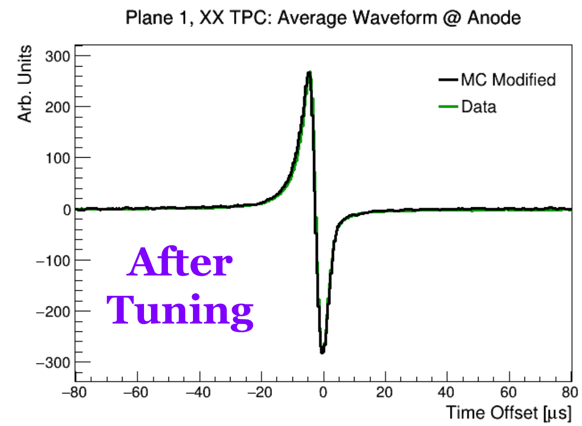


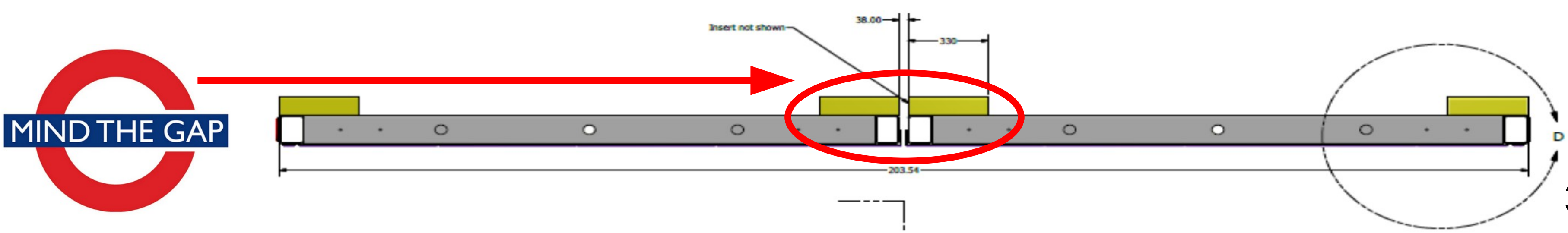
- Ideally want to model non-uniformities (charge scale impact from transparency loss, field response variations) in MC simulation
- One scheme to address this within Wire-Cell:
  - Query MPV dQ/dx in above map to estimate local transparency for deposited charge in an event
  - Based on local transparency condition, pick field response function (extracted from data) from a small set of response variations (< 20)
  - Also simulate charge scale impact from transparency loss with finer granularity using same map
- Joseph Zennamo looking into this for SBN, with **major guidance from Wire-Cell team** – thank you for your support!

Field Response @ SBND

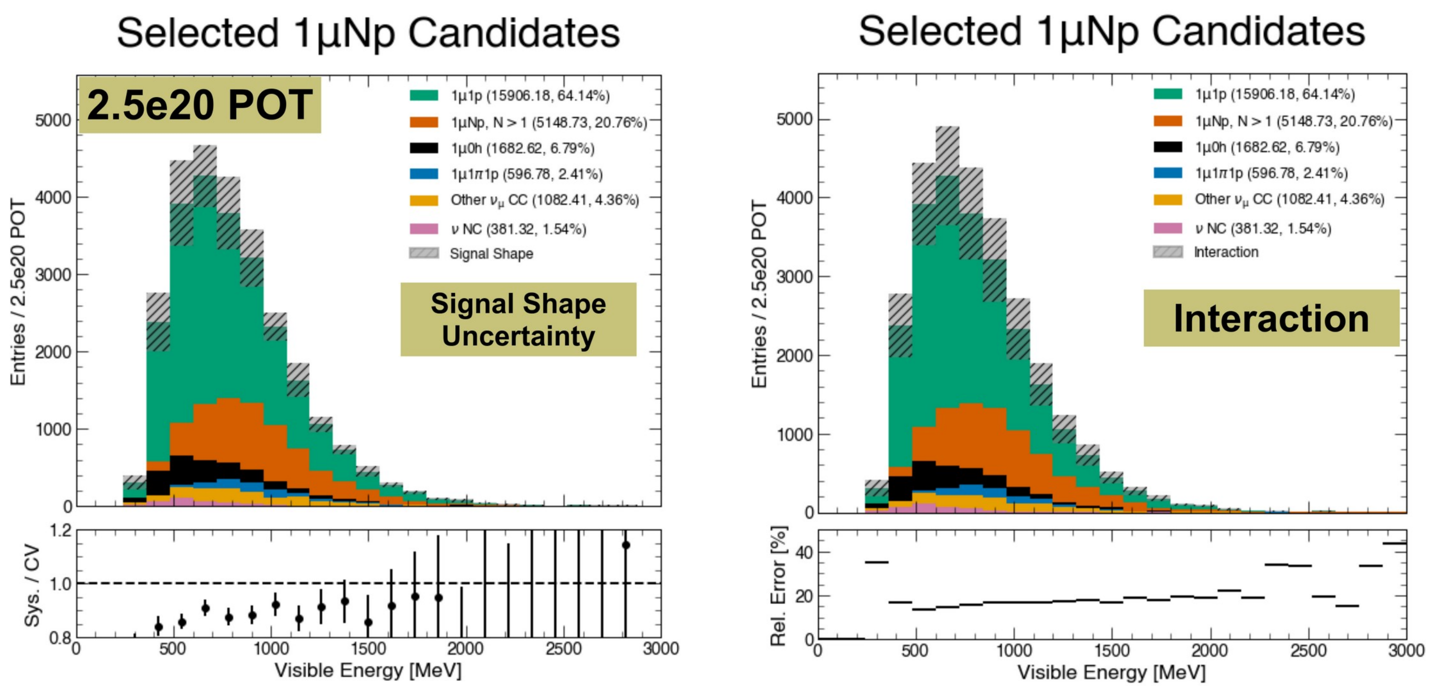
- SBND still in early commissioning days, but hopefully no transparency issues to deal with like ICARUS (fingers crossed!)
- SBND does have a **gap between the APAs** requiring special consideration
  - Induction wires only in gap, so response more like collection plane
  - Can still use same approach as for ICARUS transparency issues for modeling different field response in SBND MC simulation







Impact of Signal Shape Uncertainties



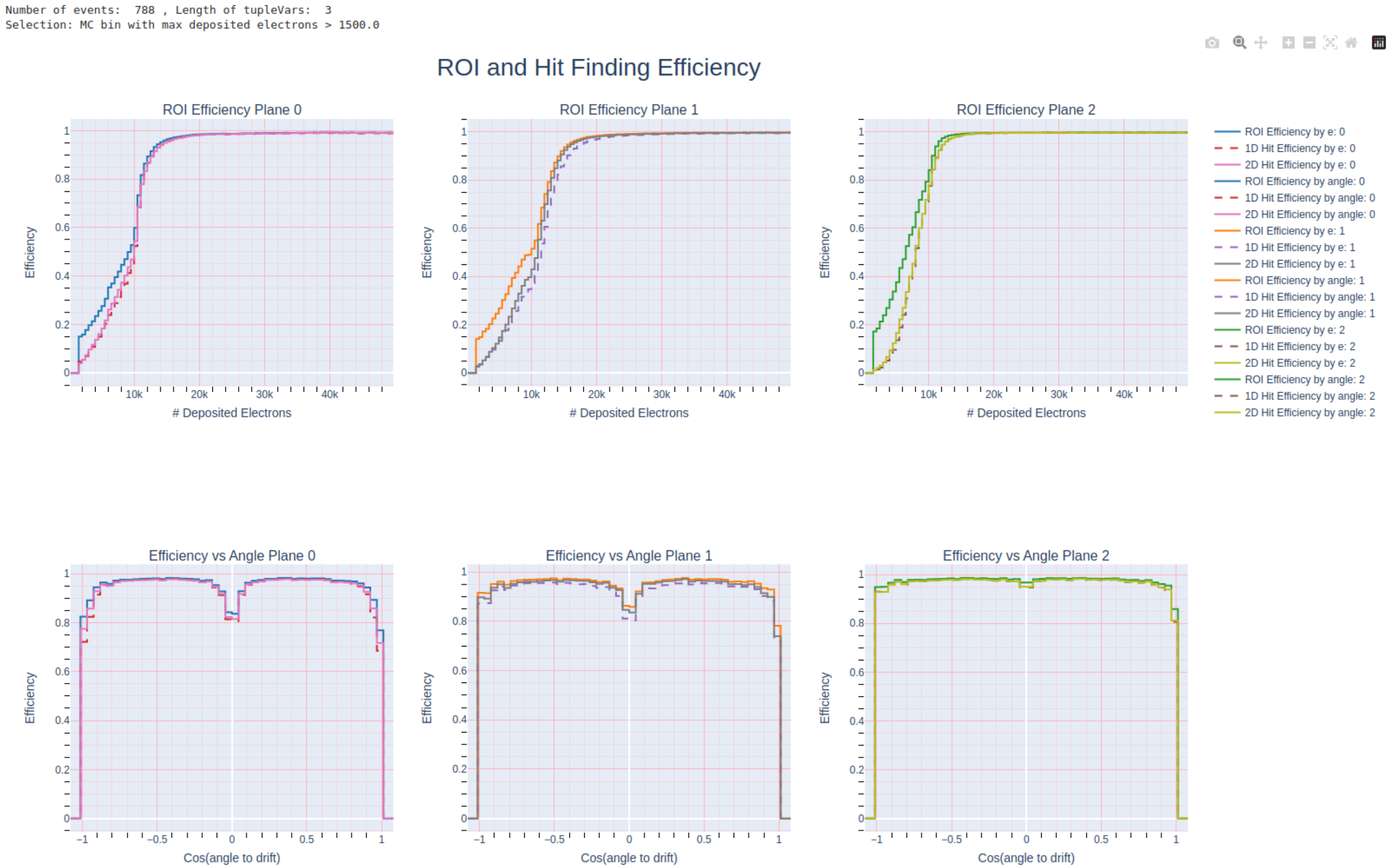
- A lack of understanding to field response can **lead to large detector systematics** that impact physics of interest
    - Above example is ML 1μNp selection at ICARUS, looking at impact from tuned (data-driven) vs. untuned field response used in TPC signal simulation → **O(10%)** impact to reconstructed event yields!
    - This is probably OK for single-detector physics, but for two-detector oscillation physics can be a *huge problem*

Discussion and Final Thoughts

- Wire-Cell TPC signal simulation and signal processing in significant use at both SBND and ICARUS
  - Already heard a lot about SBND effort from Lynn and Ewerton
  - ICARUS not using "nominal" Wire-Cell ROI-finding – is it possible to get this to work, or should we pursue different ideas like ML?
  - Wire-Cell 3D imaging not currently being explored at ICARUS (to my knowledge at least) – will this effort receive attention? Is it compatible with lower S/N of ICARUS?
- Detector calibrations being explored w/ ICARUS data helpful for improving modeling of TPC field response, including use in Wire-Cell TPC deconvolution
- Ongoing effort to model TPC signal shape/magnitude effects due to ICARUS transparency issues within Wire-Cell simulation
  - Can Wire-Cell simulation also be made to accommodate spatial variations in electron lifetime (observed at e.g. ProtoDUNE-SP)?

BACKUP SLIDES

ROI/Hit-Finding Efficiency



- ROI-finding and hit-finding efficiency vs. true deposited charge magnitude and track angle – also comparing 1D deconvolution vs. 2D deconvolution (2D signal simulation used in both cases)

TPC Noise Time Dependence