Wire-Cell for ProtoDUNEs

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Brookhaven National Laboratory

The Second Wire-Cell Reconstruction Summit
April 11, 2024

Brookhaven National Laboratory

Newport, VT

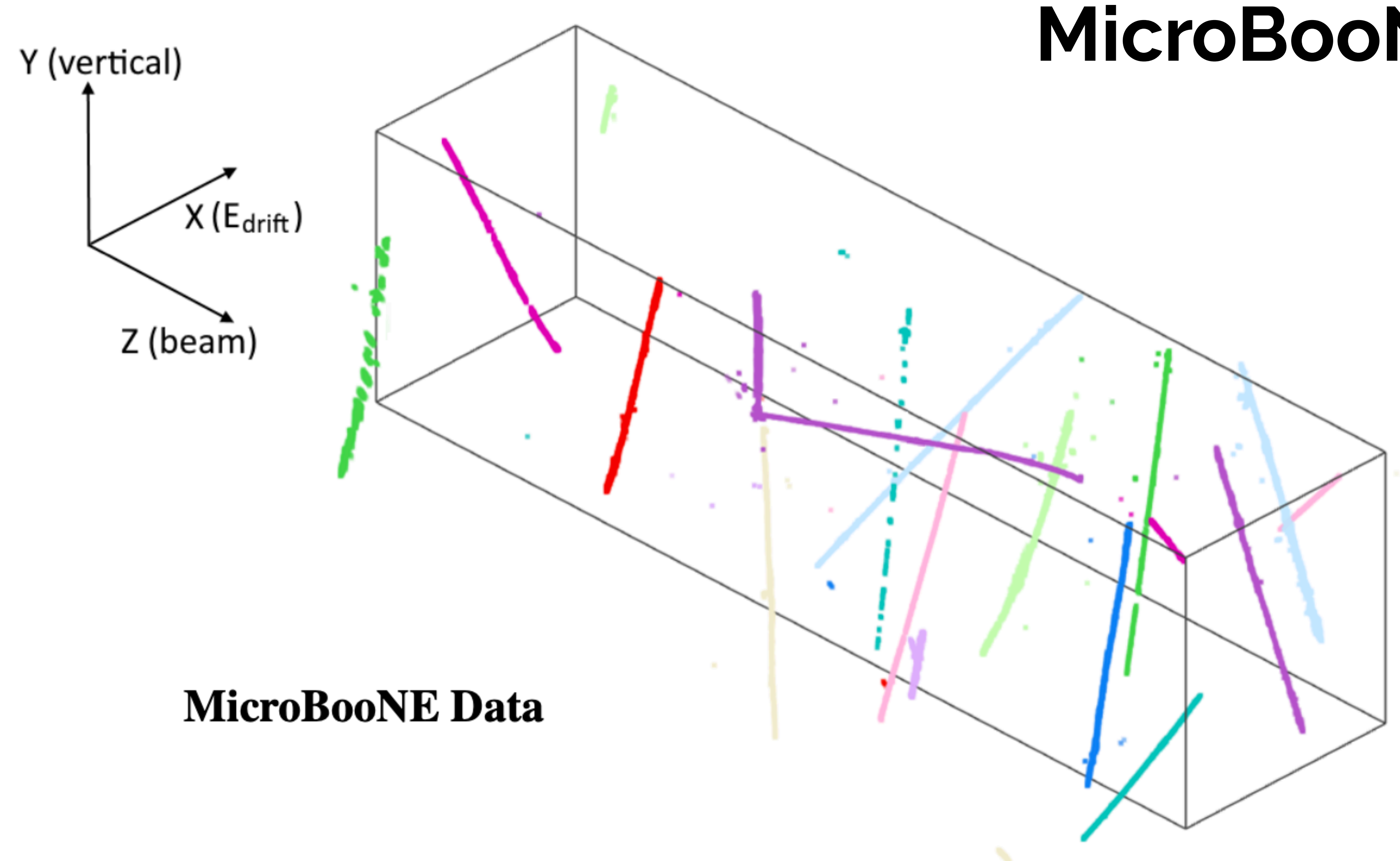
Wire-Cell and ProtoDUNEs

see talks from Chao and Brett for more details on WCP/WCT

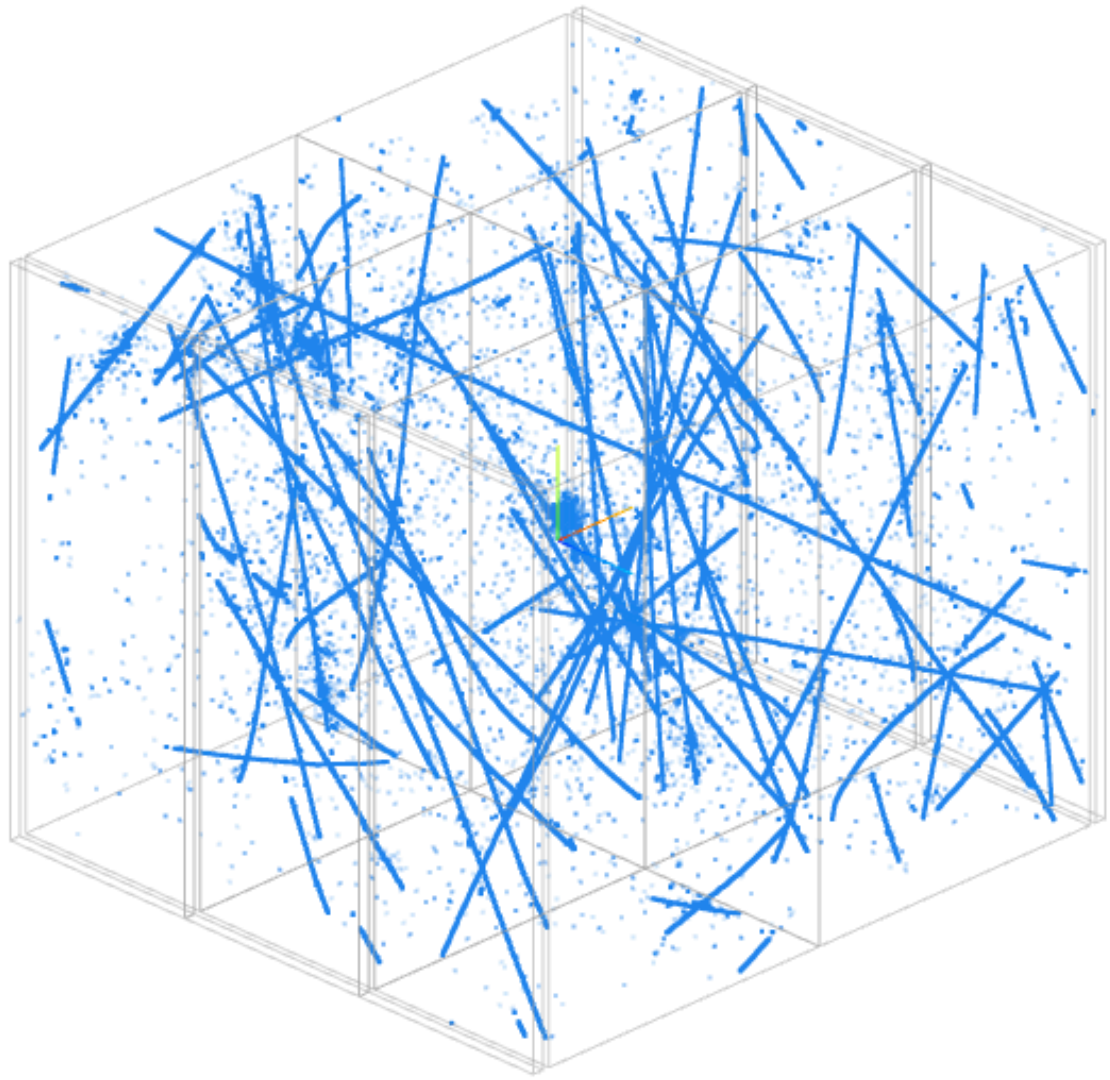
see talks from Hanyu (uB), Lynn (SBND), and Haiwang (DUNE FD) for WC implementation

- for Wire-Cell's perspective, **ProtoDUNEs are second set of LArTPCs for WC implementation**
  - first-gen: MicroBooNE
  - second-gen: SBN(D), ProtoDUNE, …
- for MicroBooNE, Wire-Cell was used mostly as "prototype"; hence Wire-Cell-**Prototype**
  - many pieces that are specific for uB detector
  - hard-coded, heuristic components
- ProtoDUNEs, along with SBND, are the first experiments to have Wire-Cell-**Toolkit** to take place
  - also, the first time Wire-Cell is being used other than one specific detector
  - develop WCT as universal & configurable framework
  - crucial step for the ultimate goal for WC: full WC implementation for DUNE Far Detector

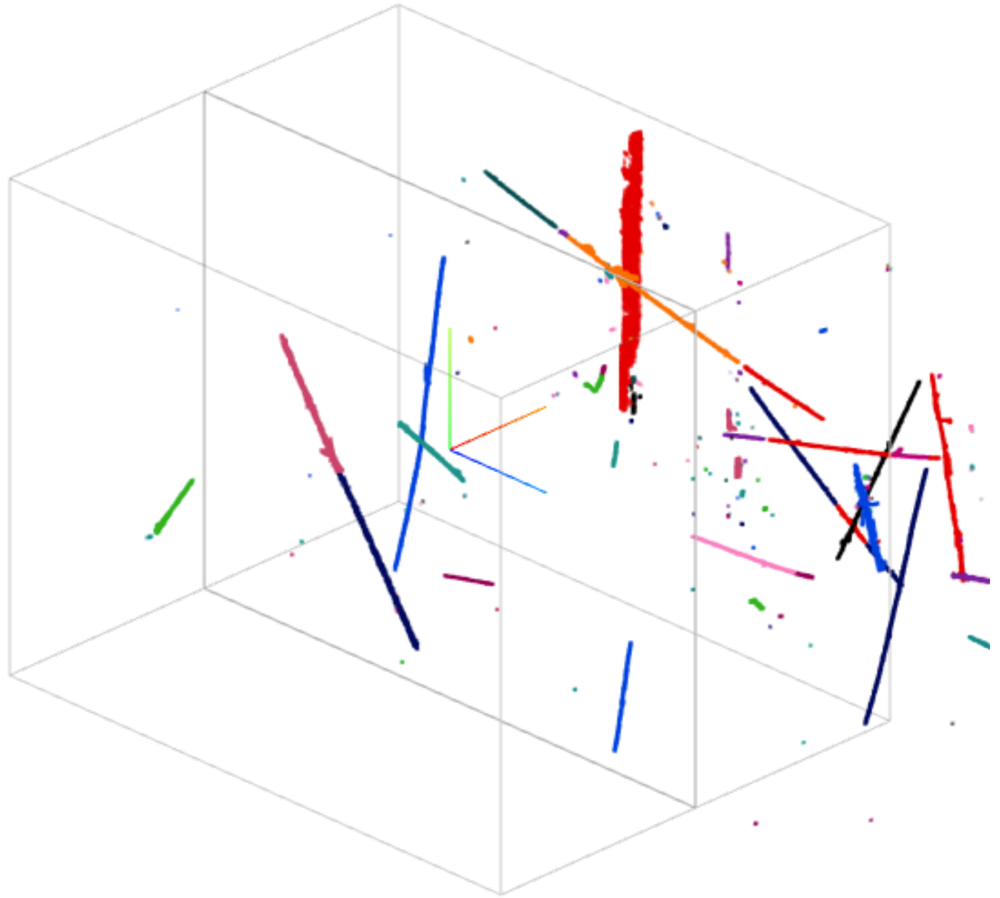
MicroBooNE



PD-SP



SBND preliminary



credit: Haiwang Yu

Wire-Cell and ProtoDUNEs

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Wire-Cell Prototype and Toolkit

prototype

- Allow for fast-pace development, MicroBooNE-specific.
- Contains: 3D imaging, clustering and pattern recognition.
- Basis for MicroBooNE Wire-Cell physics analysis team.

toolkit

- Focus on long-term support and detector-generality.
- Contains: simulation, signal processing, 3D imaging.
- Ongoing effort to "port" prototype algorithms, starting with clustering.

Shared

- Approximately the same waf based build system.
- File based data exchange prototype $\rightarrow$ toolkit.

Brett Viren | Wire-Cell Toolkit Technical Overview | April 10, 2024 | 4 / 23

Brett's talk yesterday

Wire-Cell-Prototype

see talks from Chao and Brett for more details on WCP/WCT

TPC simulation

noise filtering

signal processing

3D imaging

clustering

charge-light matching

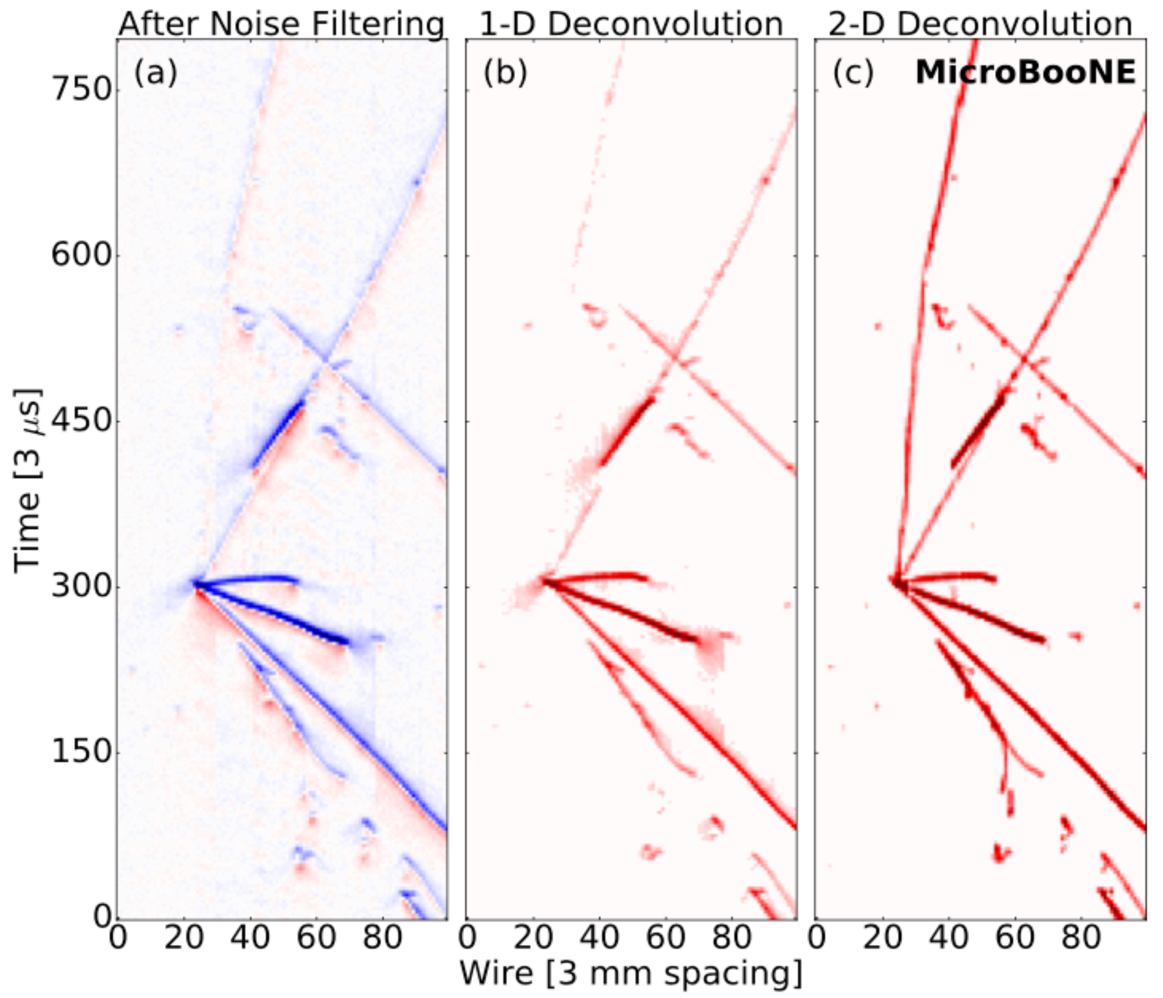
3D trajectory & dQ/dx fitting

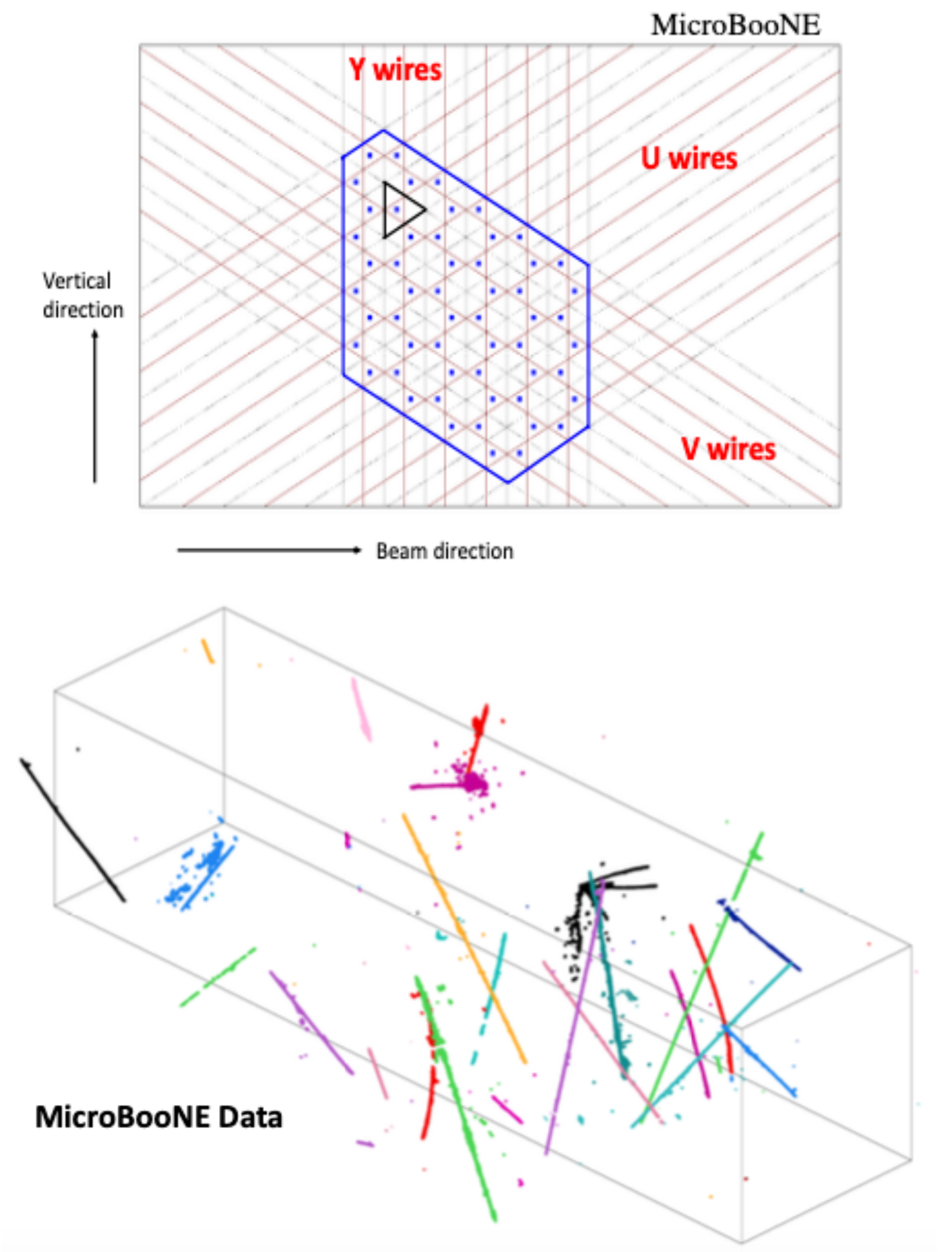
cosmic muon tagger

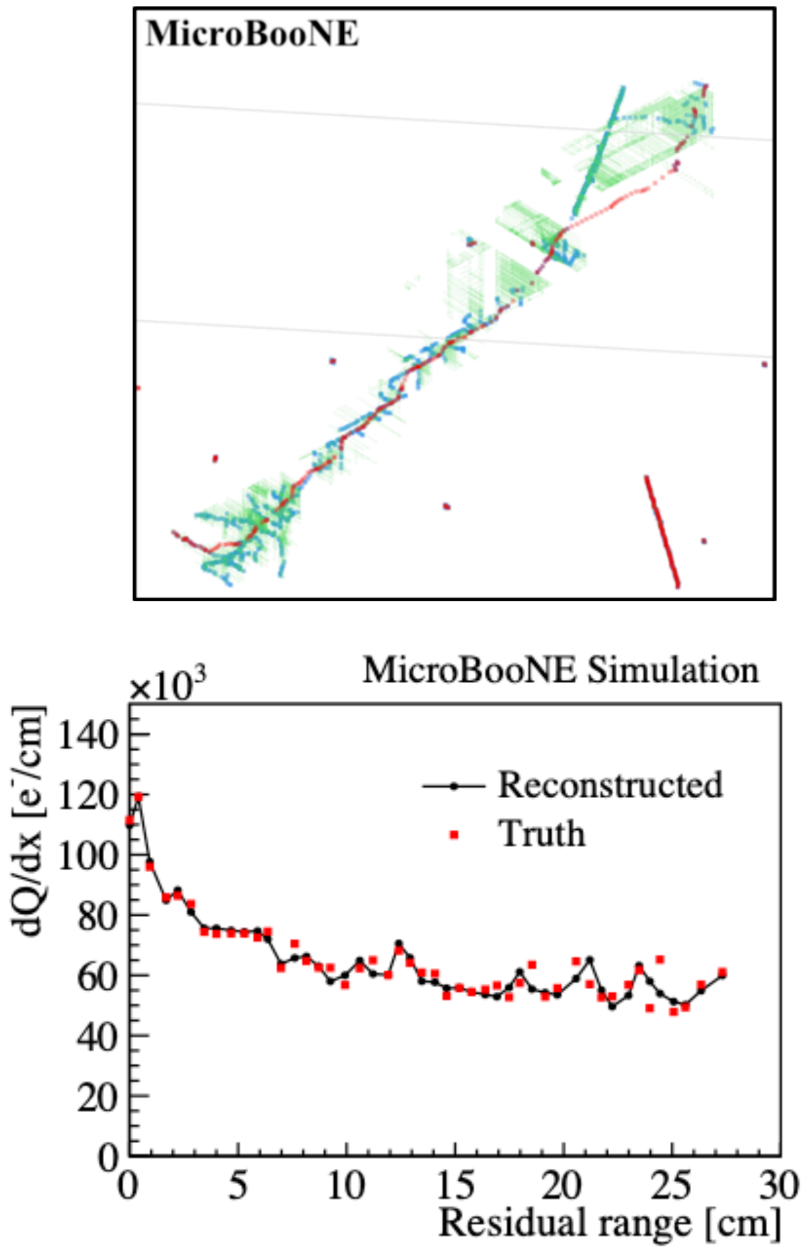
multi-track fitting

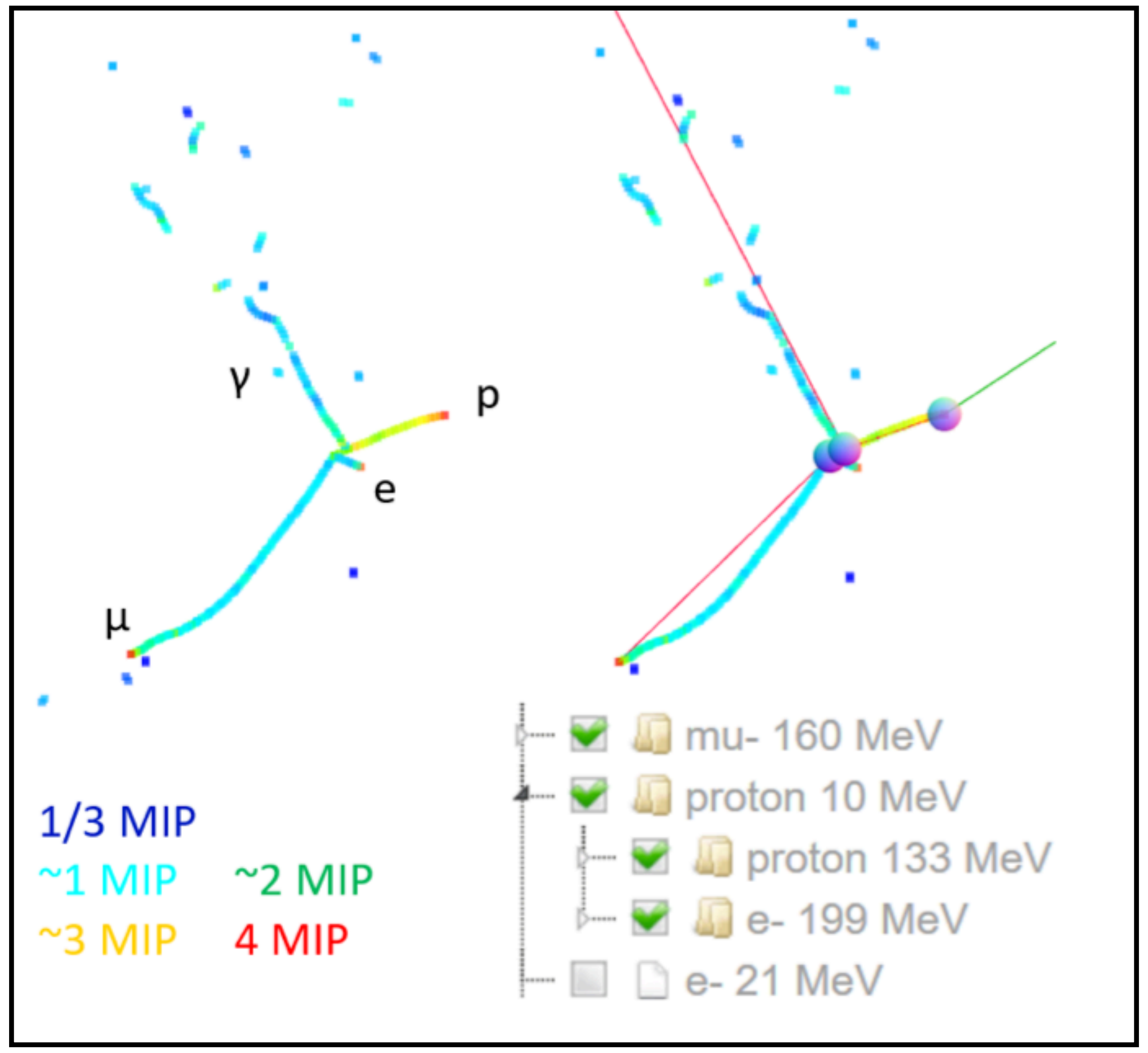
DL-3D vertexing

particle identification









Wire-Cell-Toolkit

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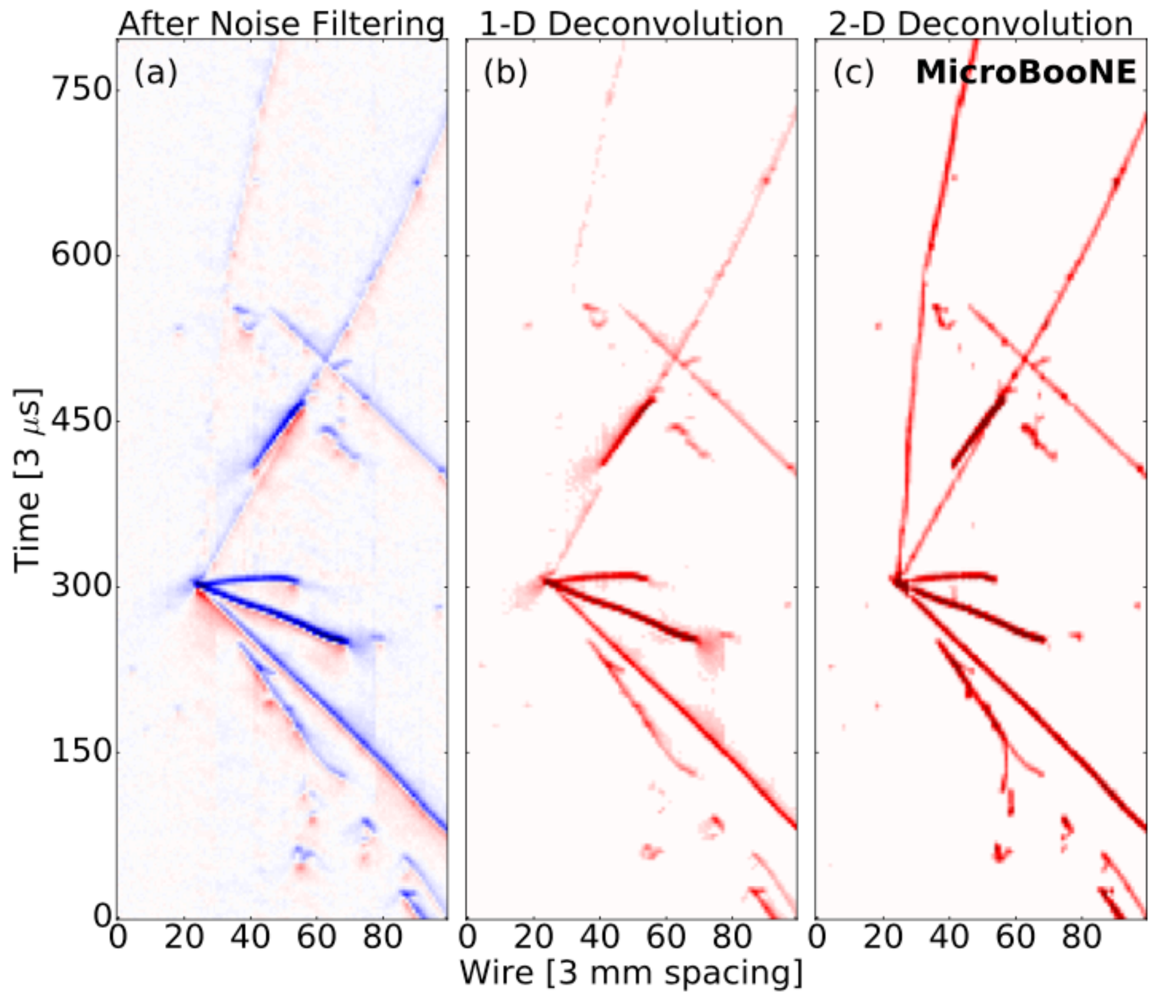
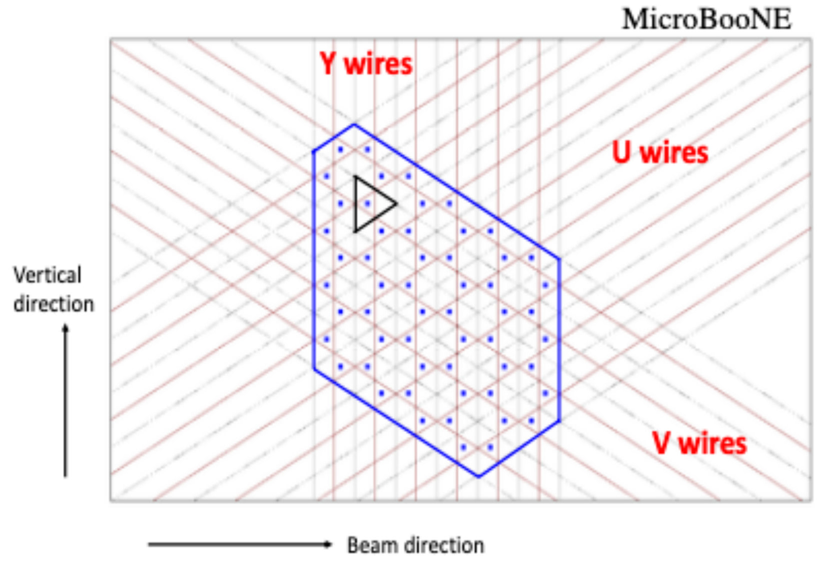
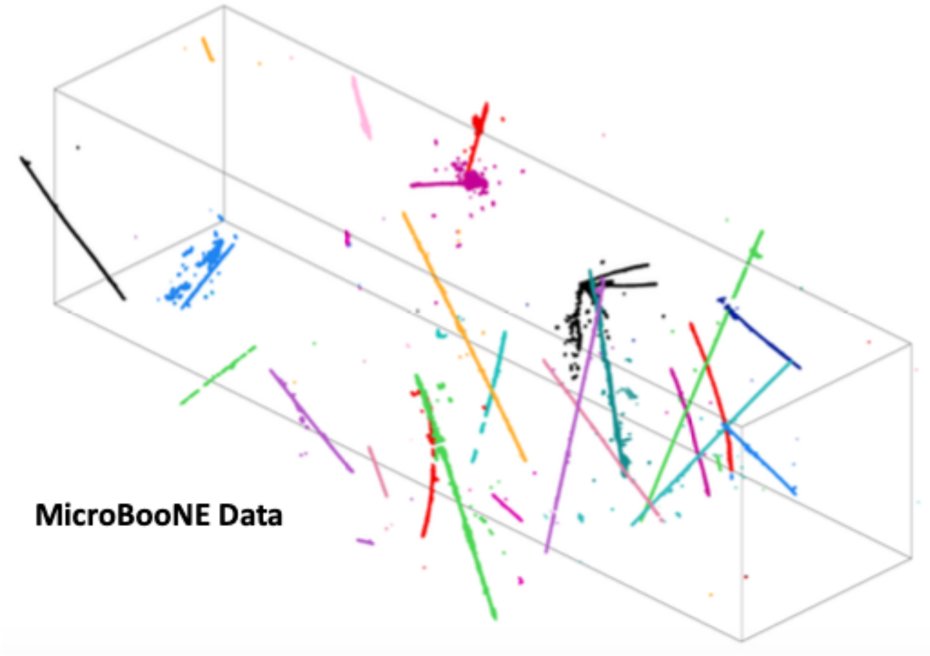
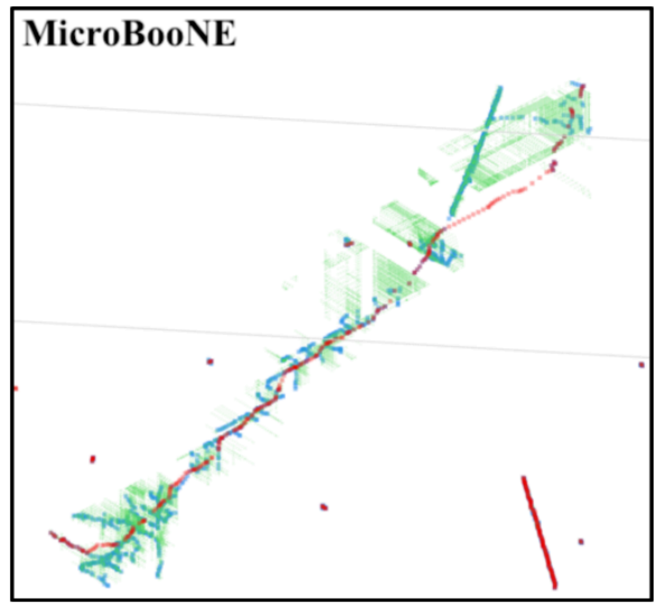
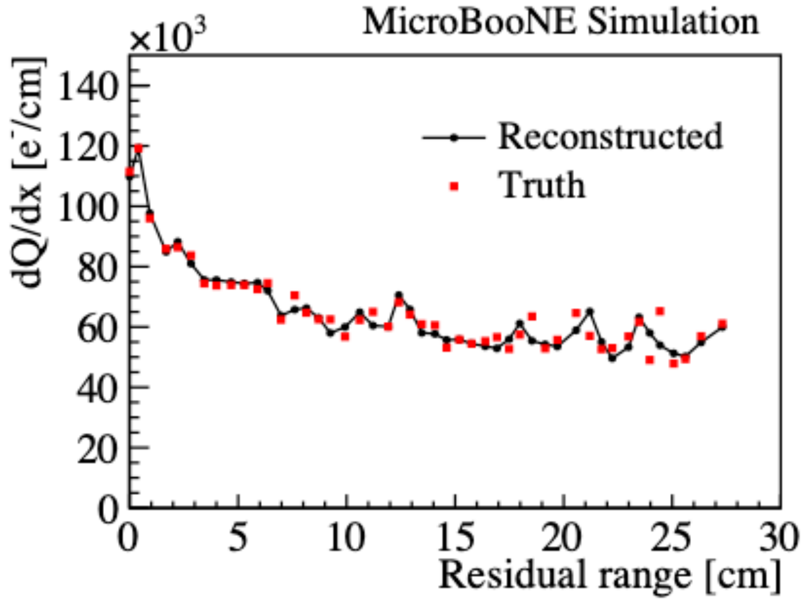
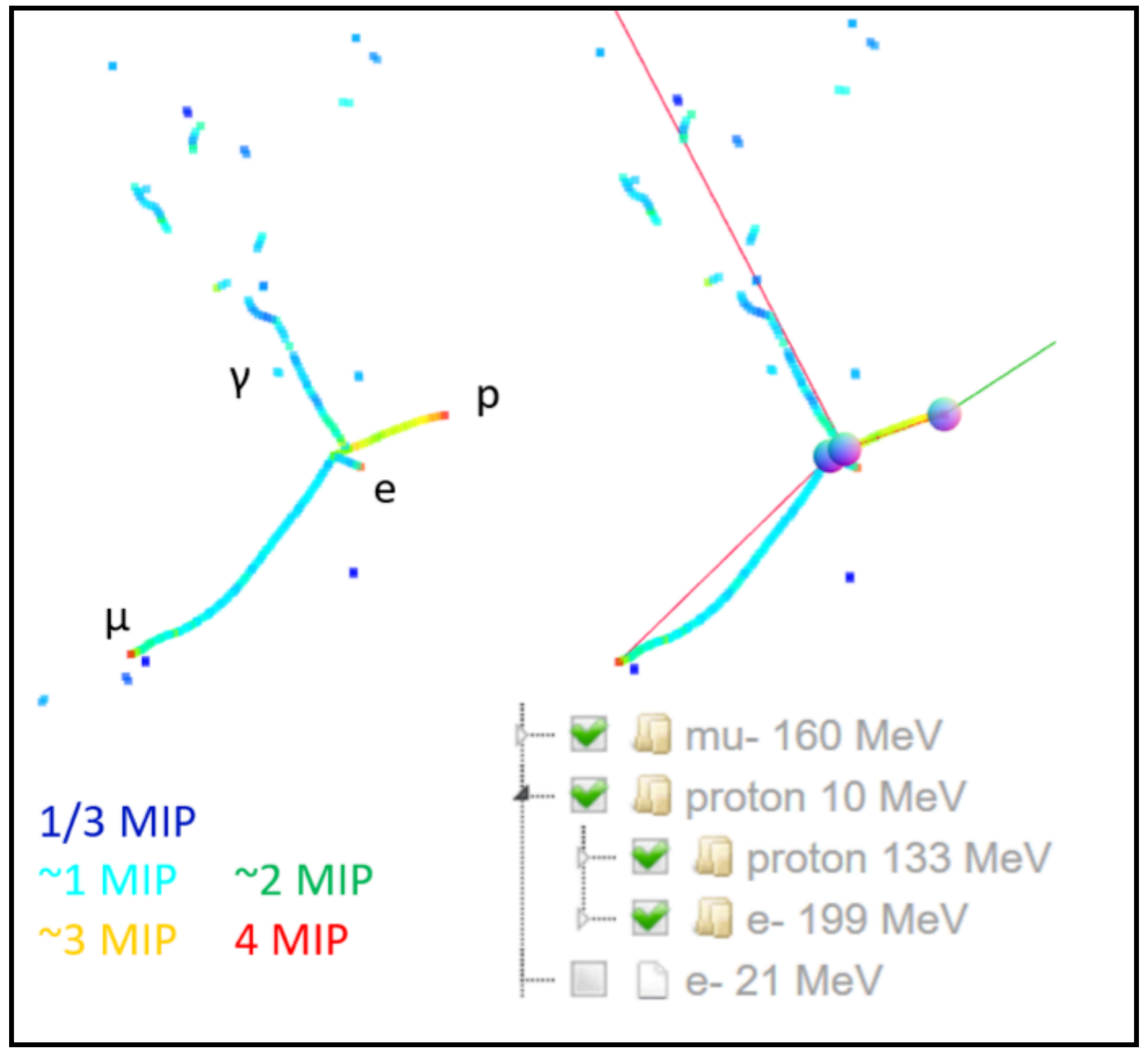






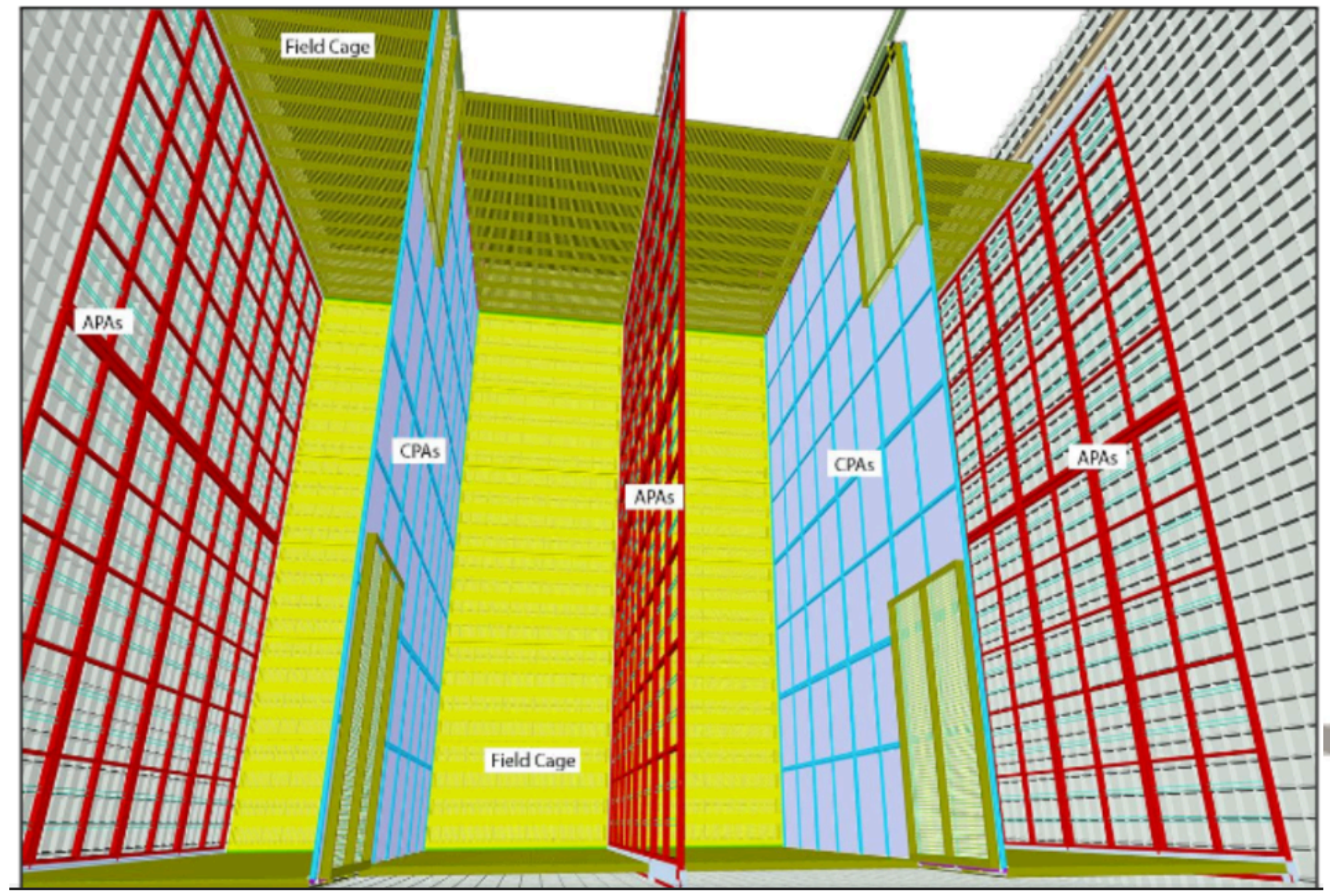






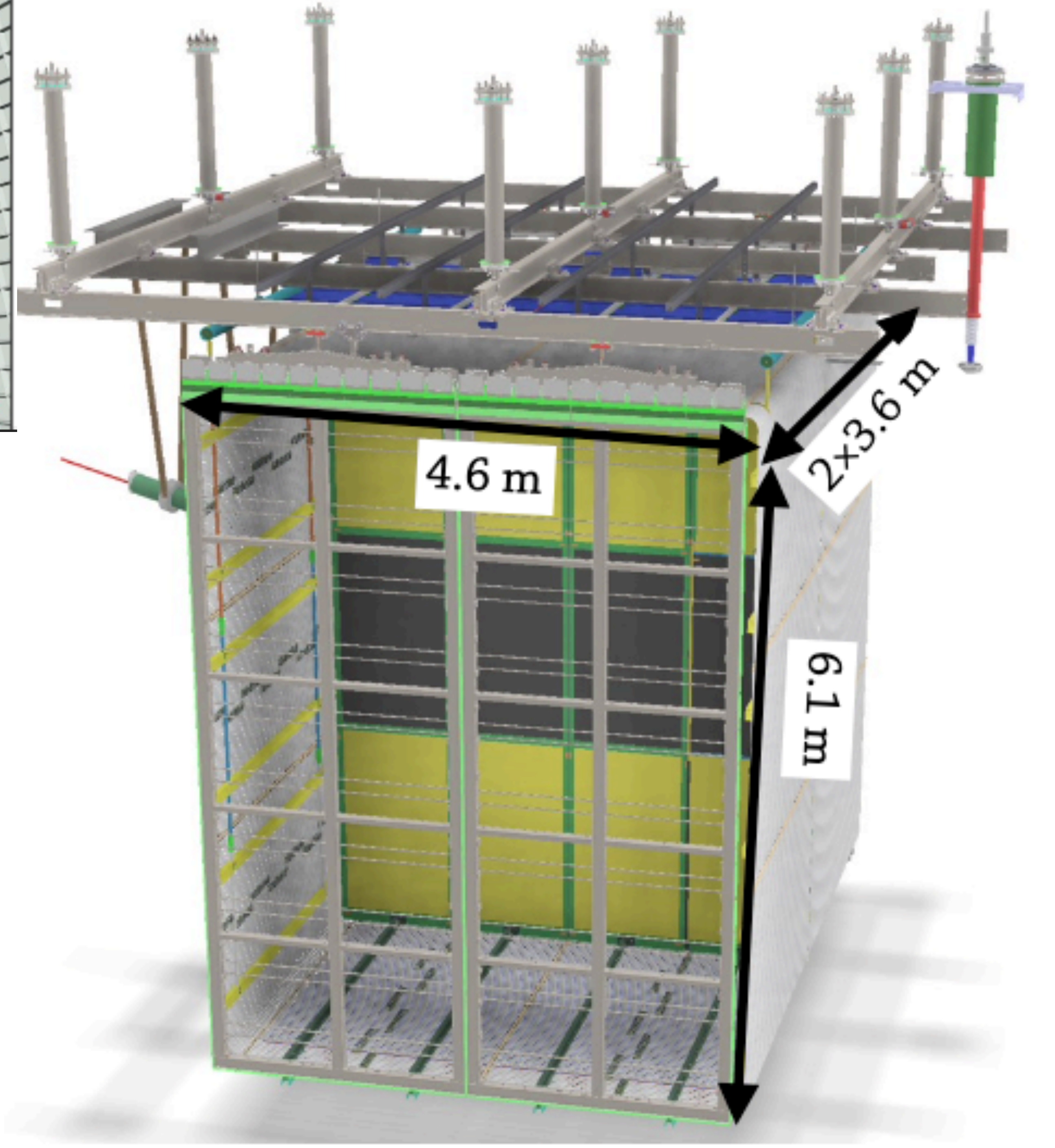
ProtoDUNEs

- **ProtoDUNE Single Phase (PD-SP)**
  - APA (Anode Plane Assembly) with 3 wire planes
  - 2 drift volumes with 3.6m drift each
  - Light collection system embedded in APA, 3 designs tested
- **ProtoDUNE Horizontal Drift (PD-HD)**
  - APA with 3 wire planes
  - updated electronics
  - X-ARAPUCA light collection system
- **ProtoDUNE Vertical Drift (PD-VD)**
  - CRP (Charge Collection Plane) with 3 PCB (Printed Circuit Board)
  - 2 drift volumes, vertically drifting
  - X-ARAPUCAs on the cathode & field cage

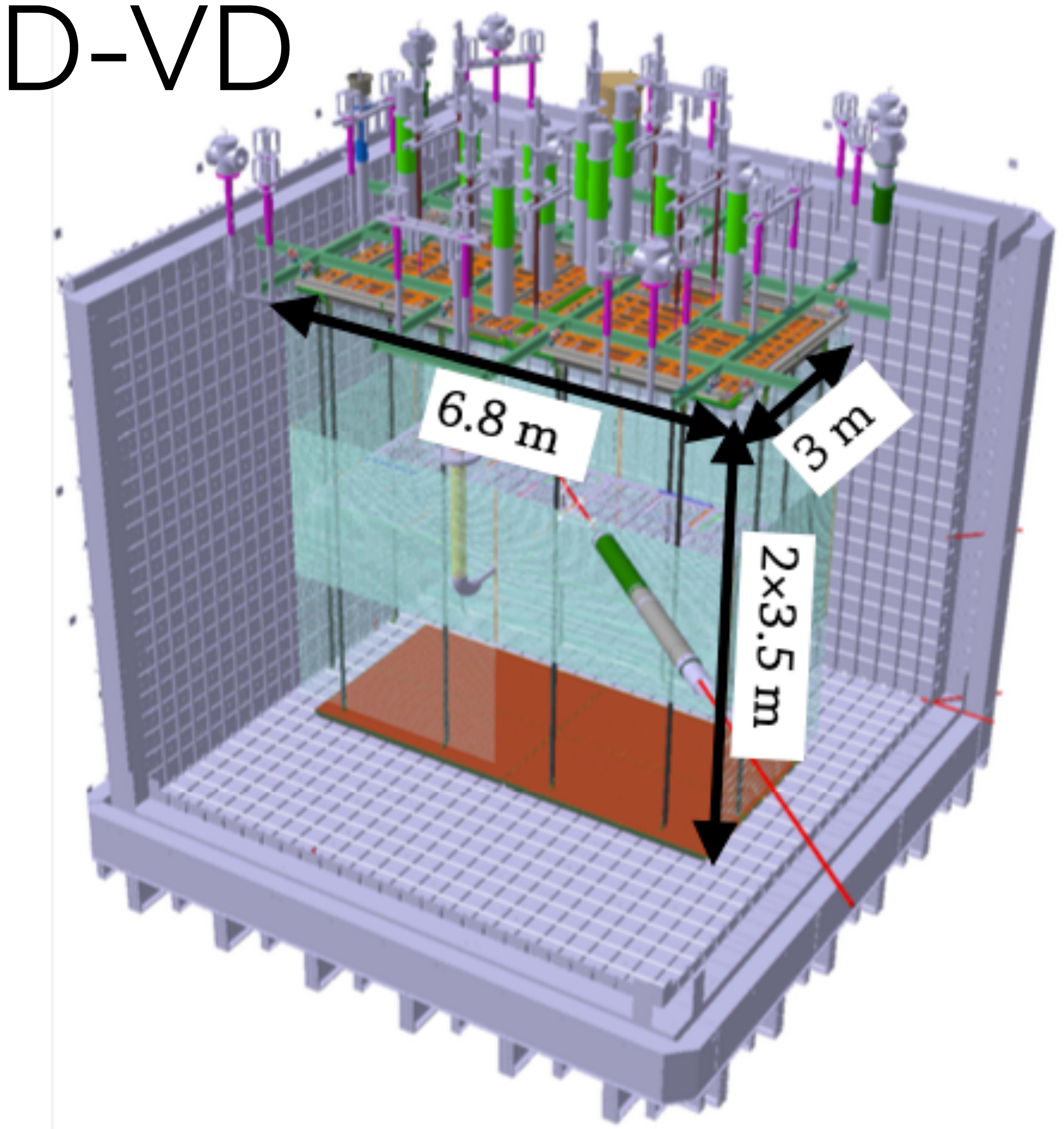


PD-SP

PD-HD



PD-VD

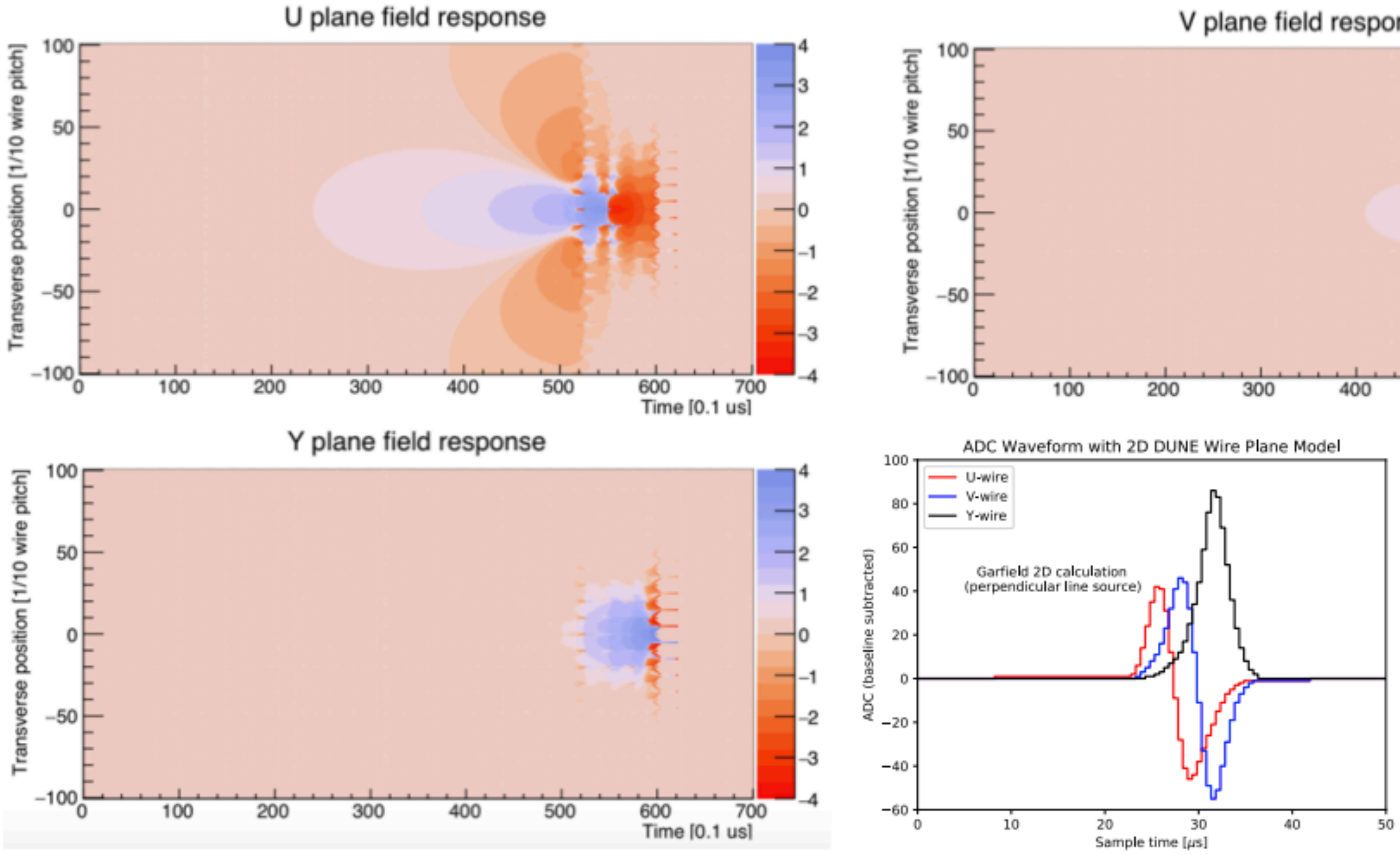


ProtoDUNE-SP

see talk from Wenqiang for more details on WC simulation & signal processing

- **first time implementing Wire-Cell outside uB**
  - interface *larwireccell* was developed to support WCT inside of *art* structure
- **TPC simulation improved/updated**
  - **field response**
  - electronic response (with entire waveform per channel)
  - noise simulation
- signal processing
  - “traditional” ROI implementation
  - DNN ROI development

Jingbo Wang, DUNE CM 2019



Average response over the full range of 2D responses = isochronous track induced current on the central wire

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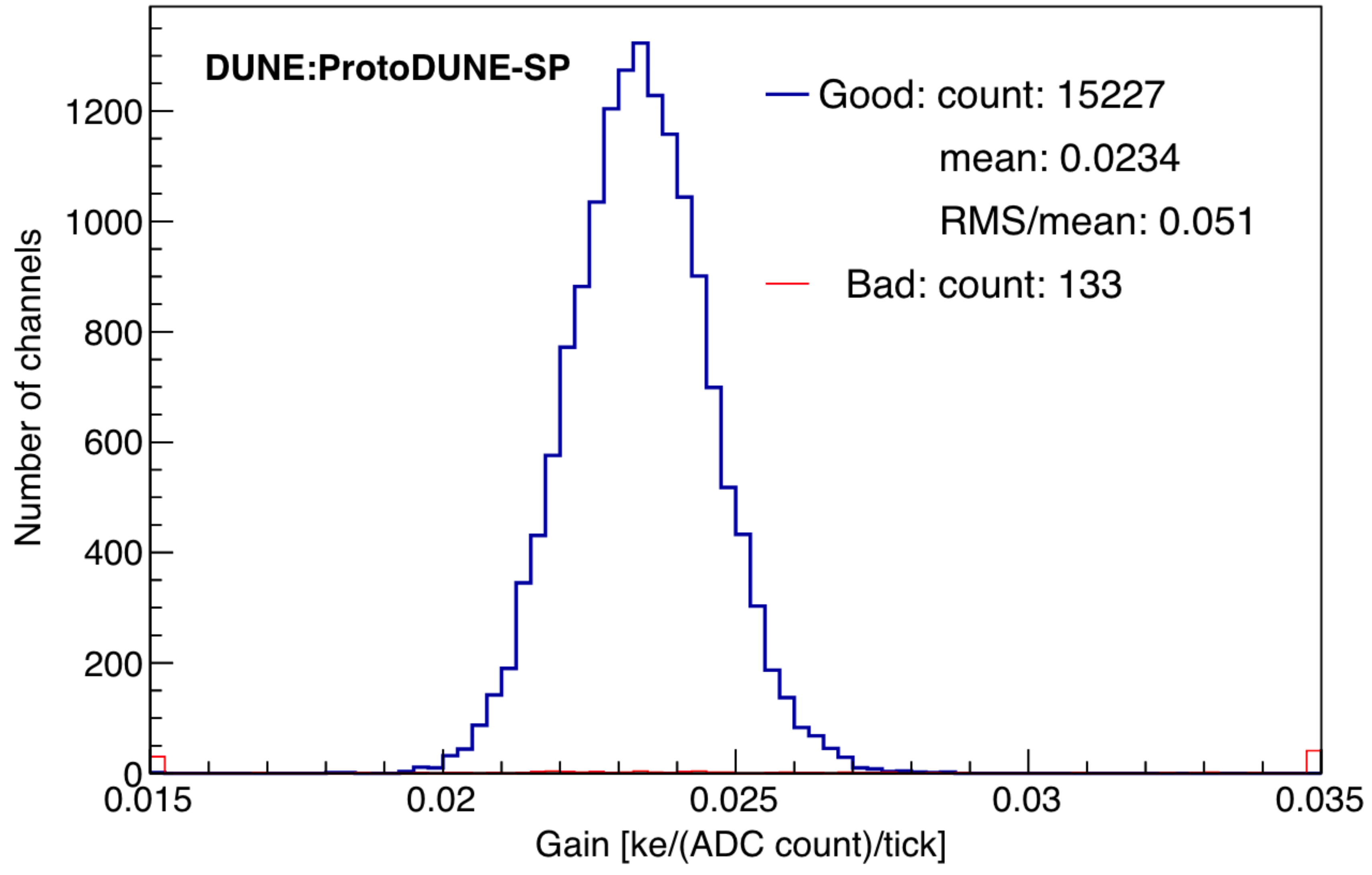
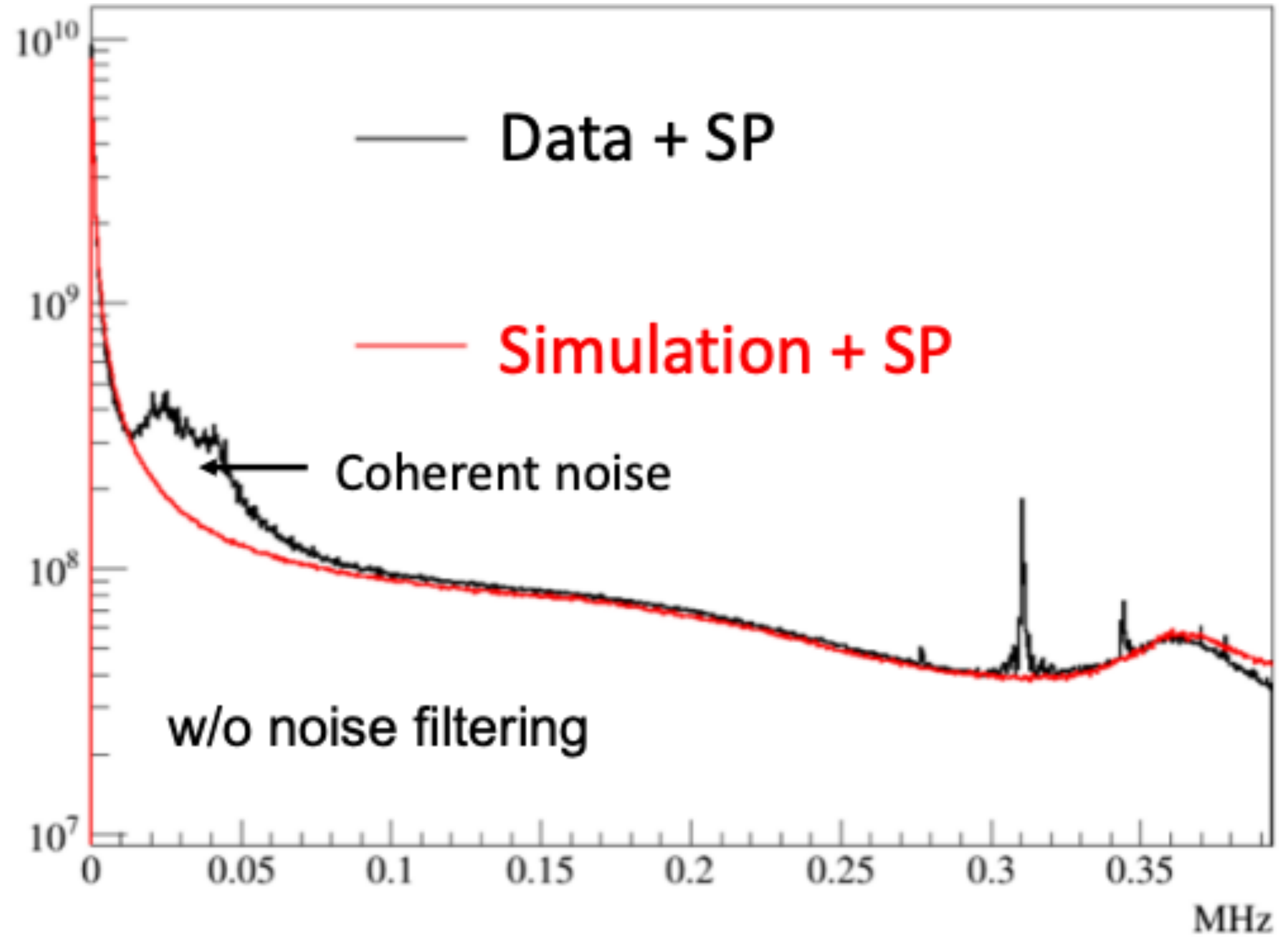


Figure 18: Distribution of fitted gains for good (blue) and bad/noisy (red) channels. The legend indicates the number of channels in each category and gives the mean (23.4 e/(ADC count)/tick)) and RMS/mean (5.1%) for the good channels.



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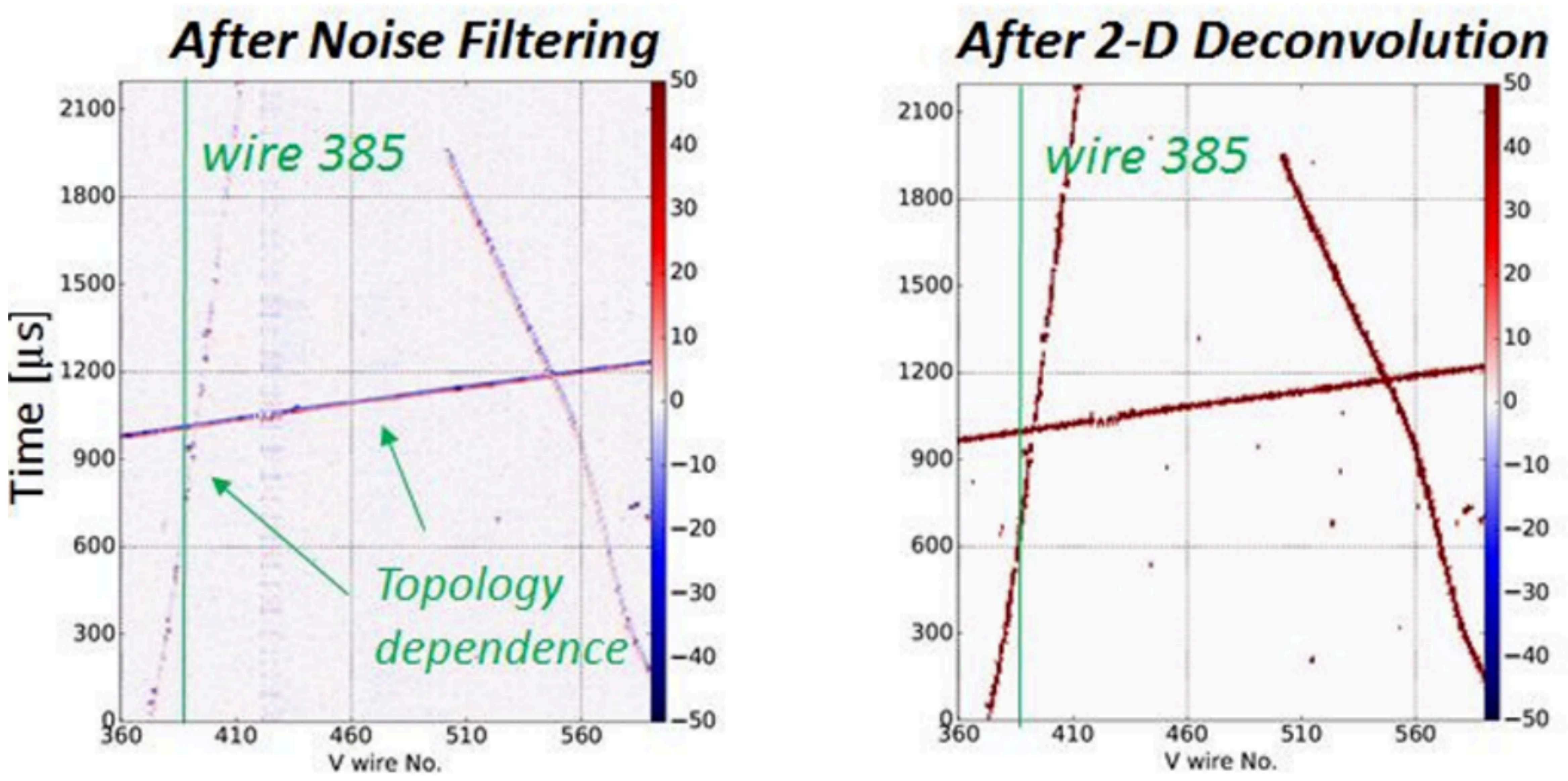
Wenqiang Gu, DUNE CM



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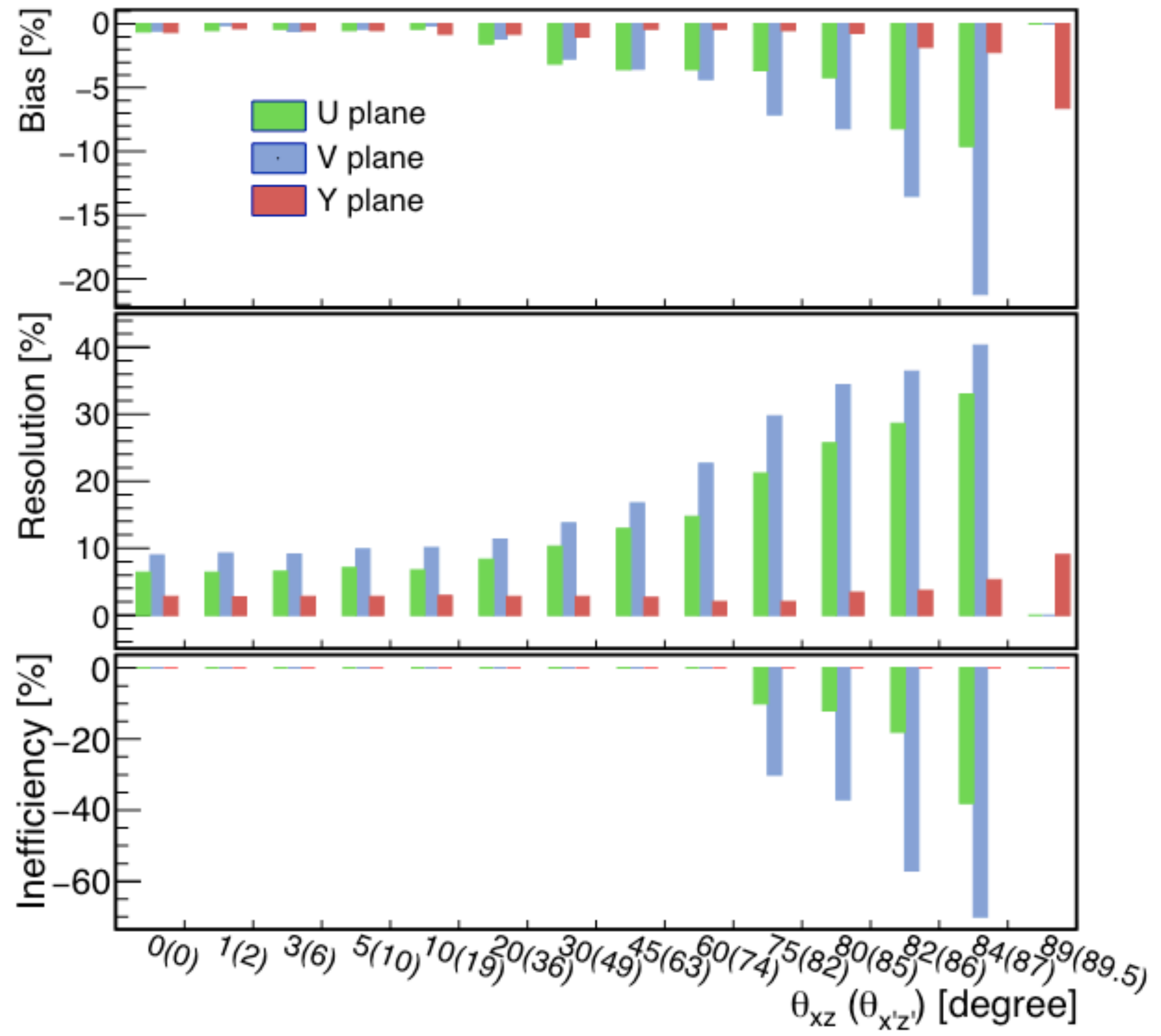
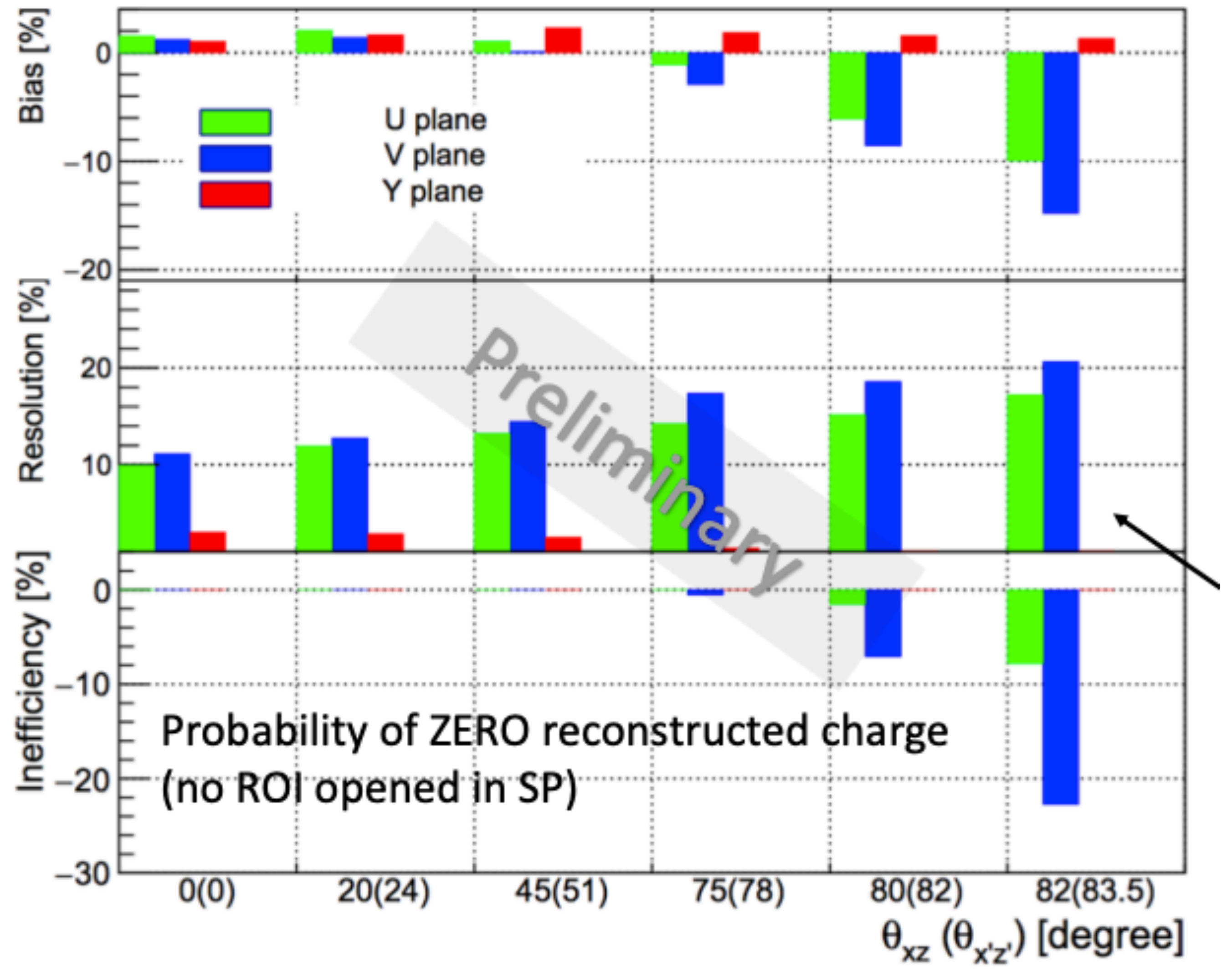
uB Signal Processing Performance



PD-SP Signal Processing Performance



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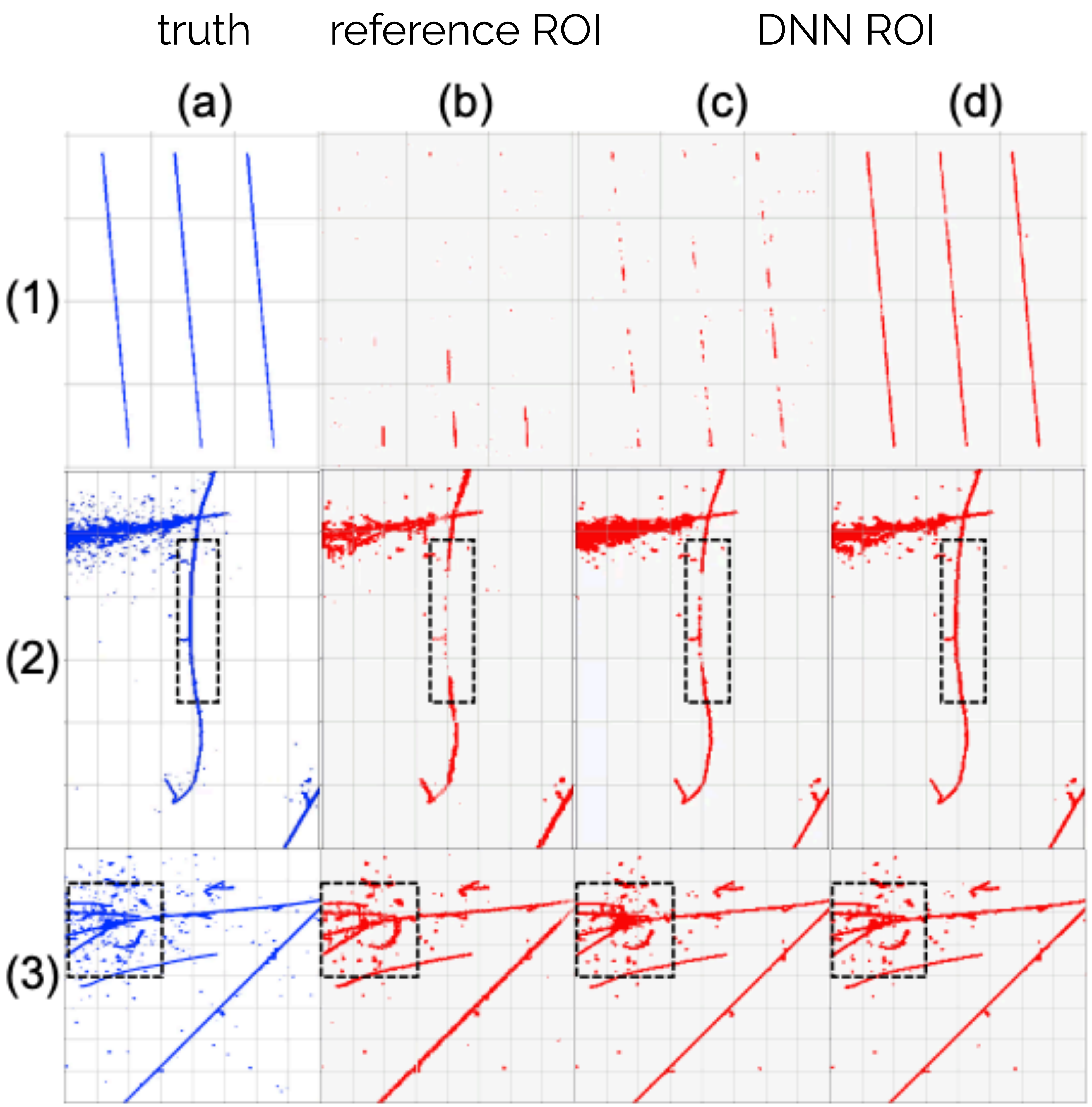
H. Yu et al., JINST 16 P01036 (2021)



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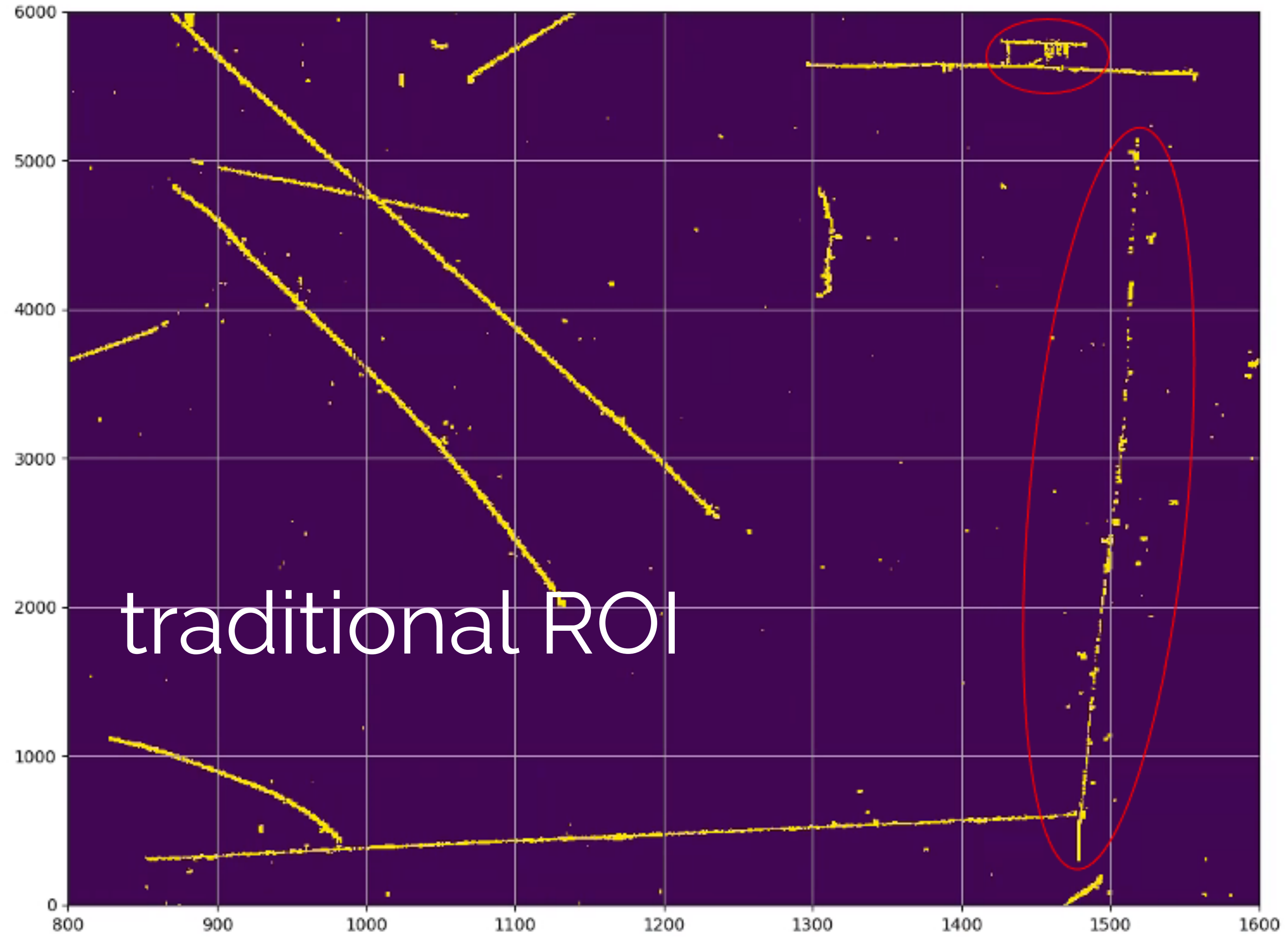
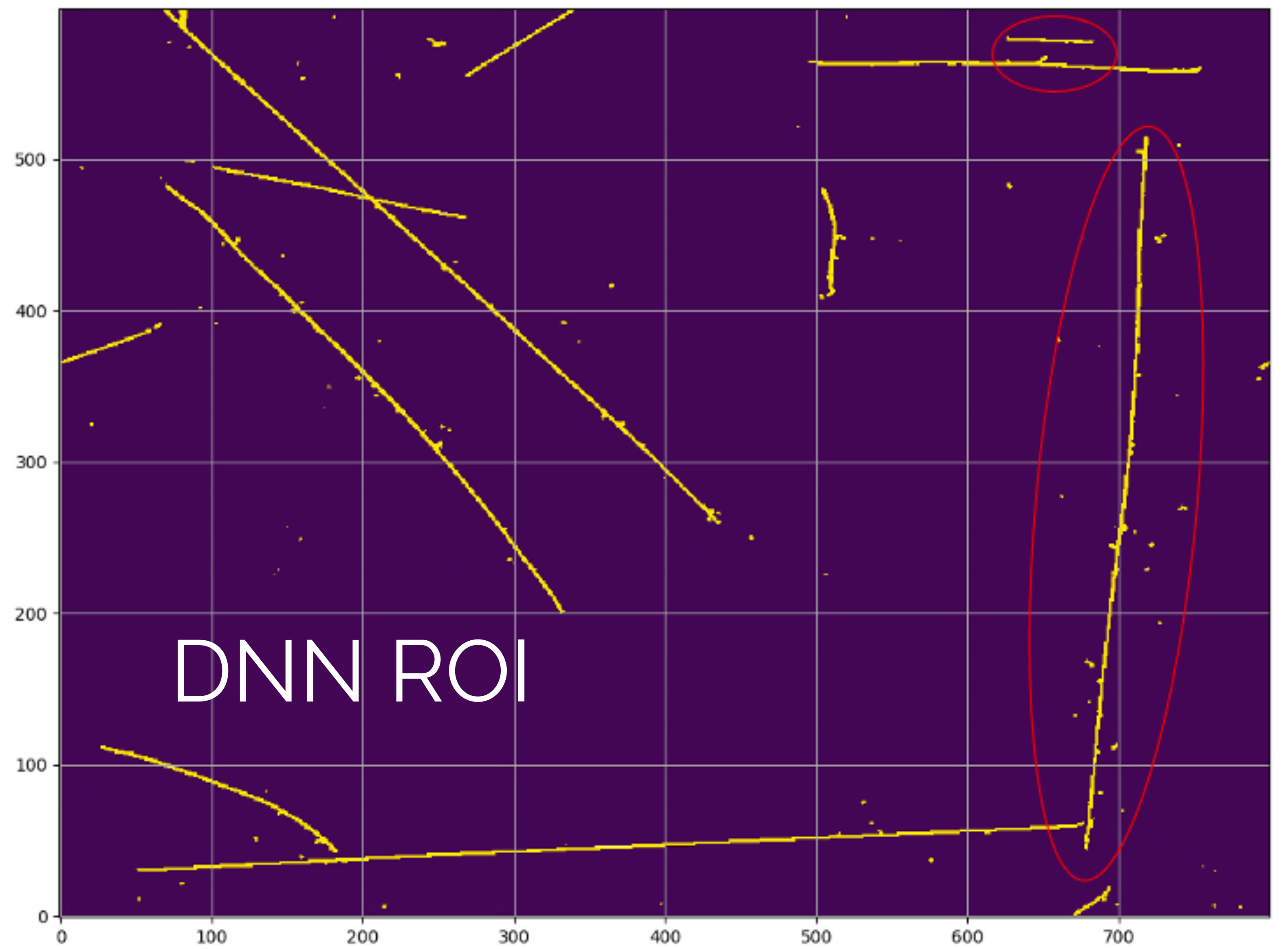
PD-SP data: Run 5145 subrun 1 event 26945, v plane





H. Yu, CPAD 2021

ProtoDUNE-VD

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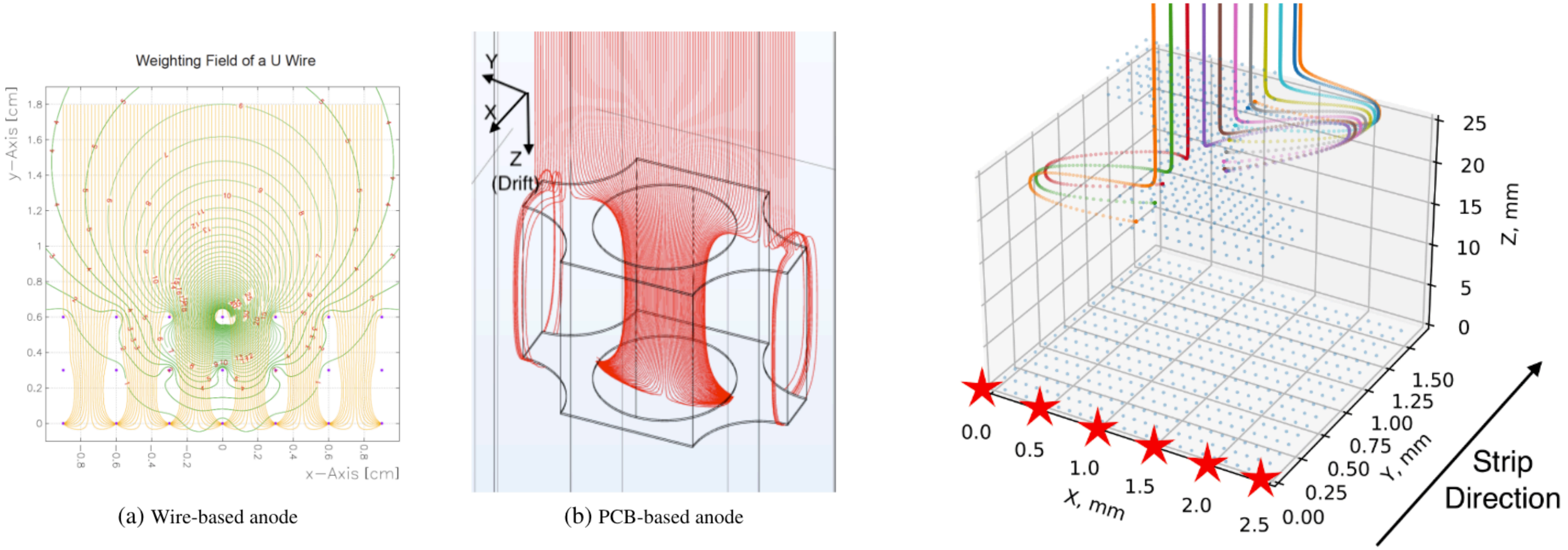
S. Martynenko et al., JINST 18 P04033 (2023)



(a) Wire-based anode (b) PCB-based anode

computationally faster/reliable 2D+3D response model developed for field response, validated with PD-VD data

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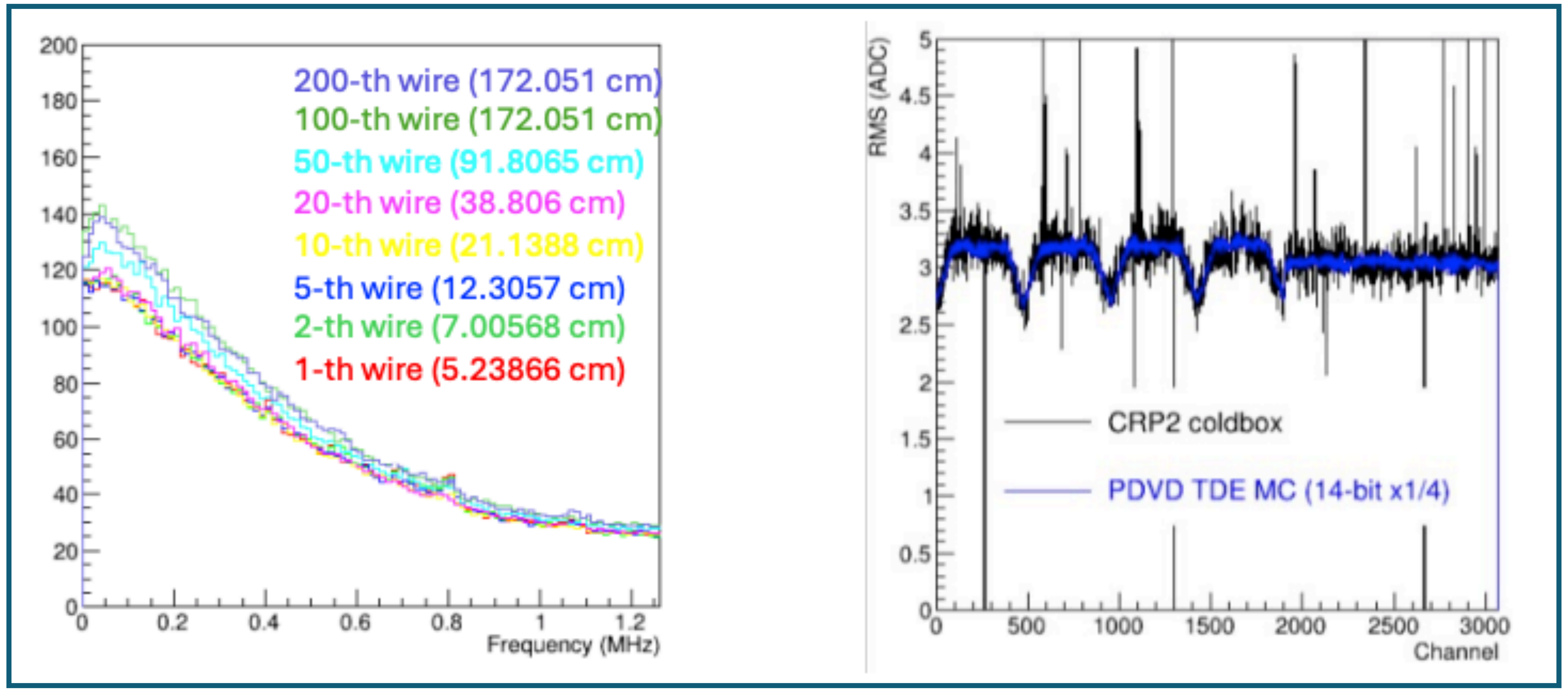
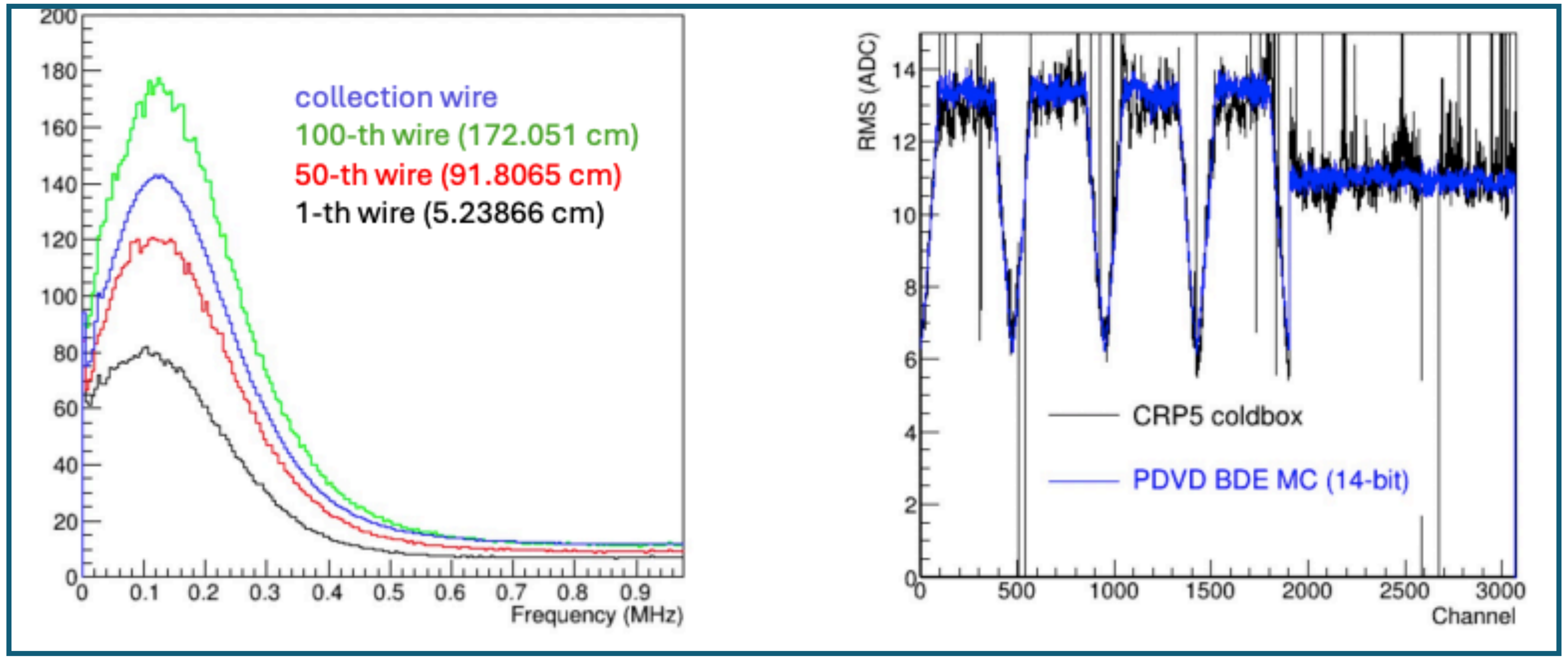
TDE



BDE



noise modeling for BDE/TDE with data-driven approach, validated against coldbox data

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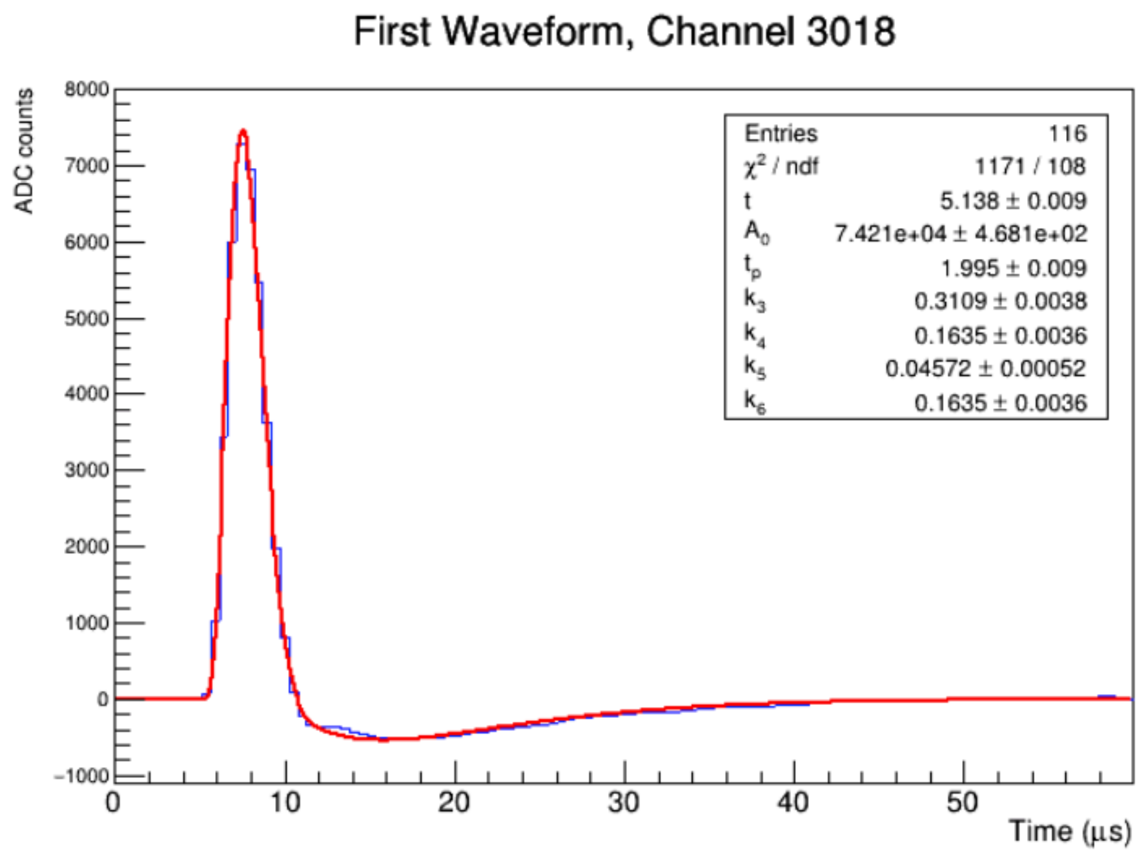
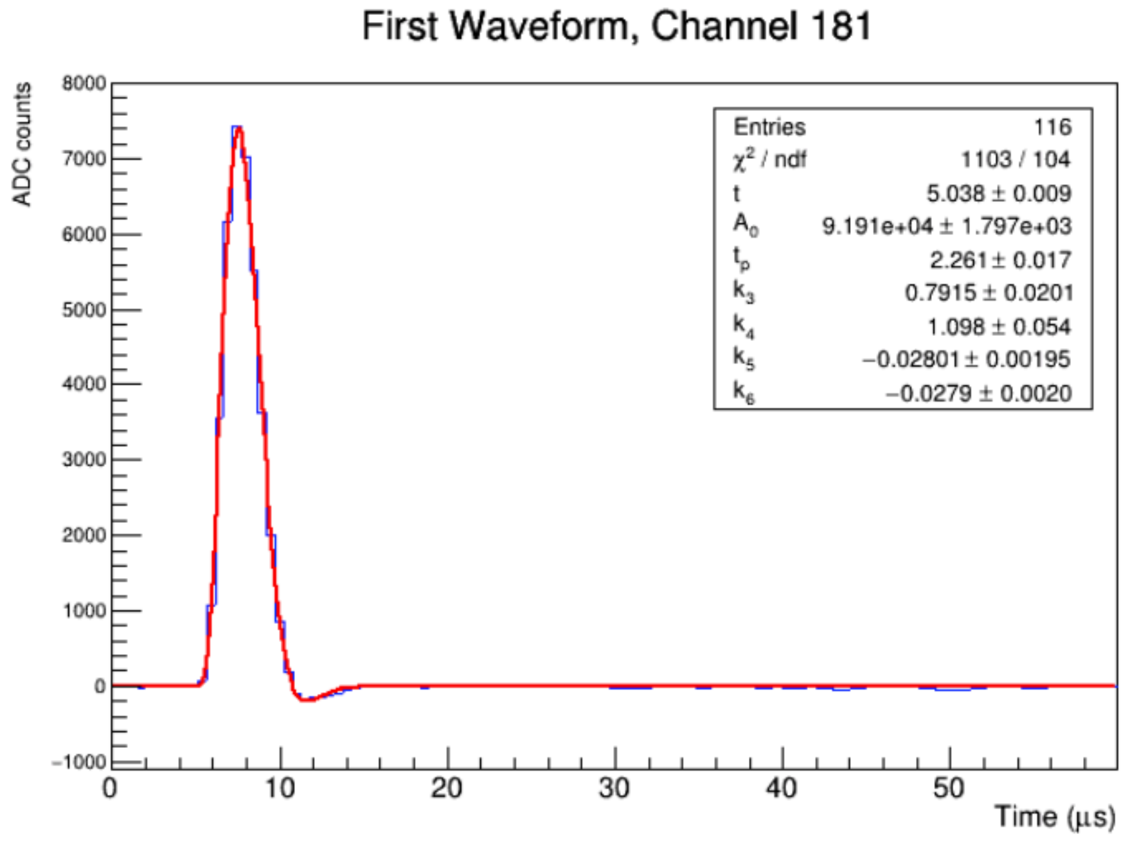
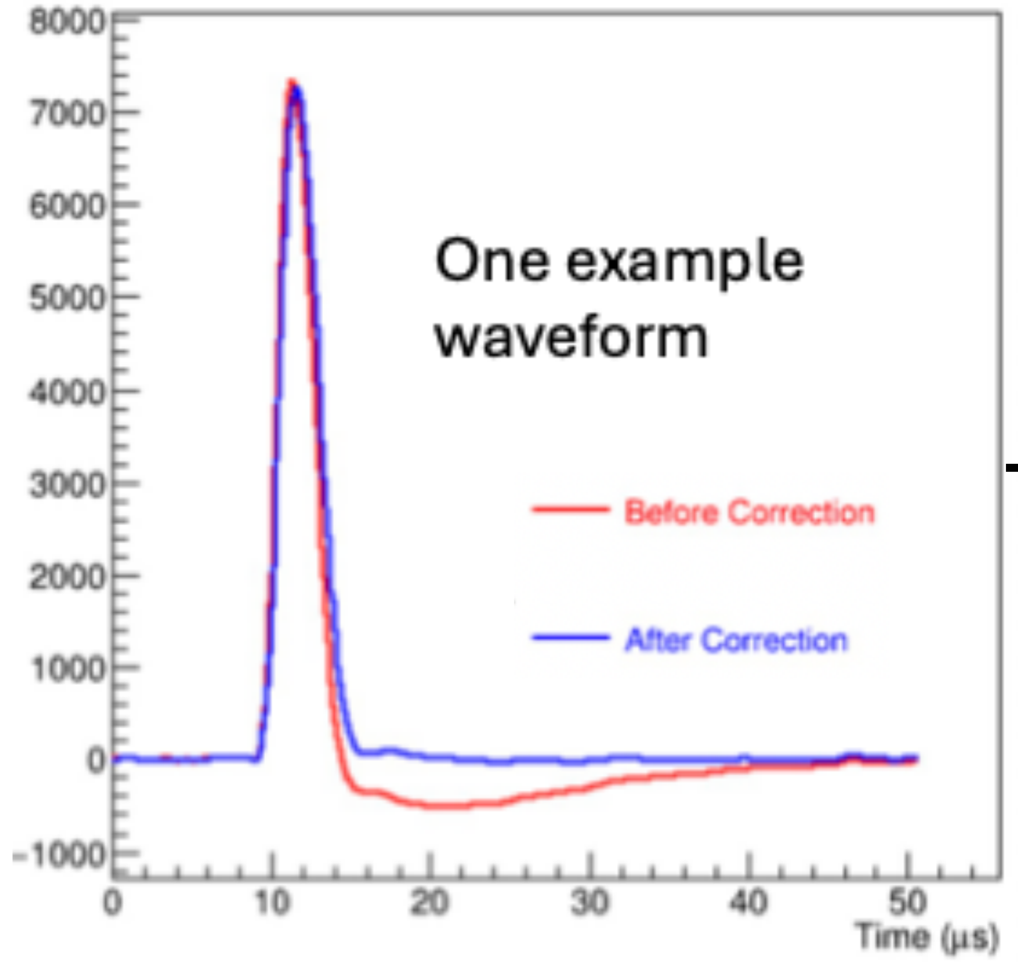
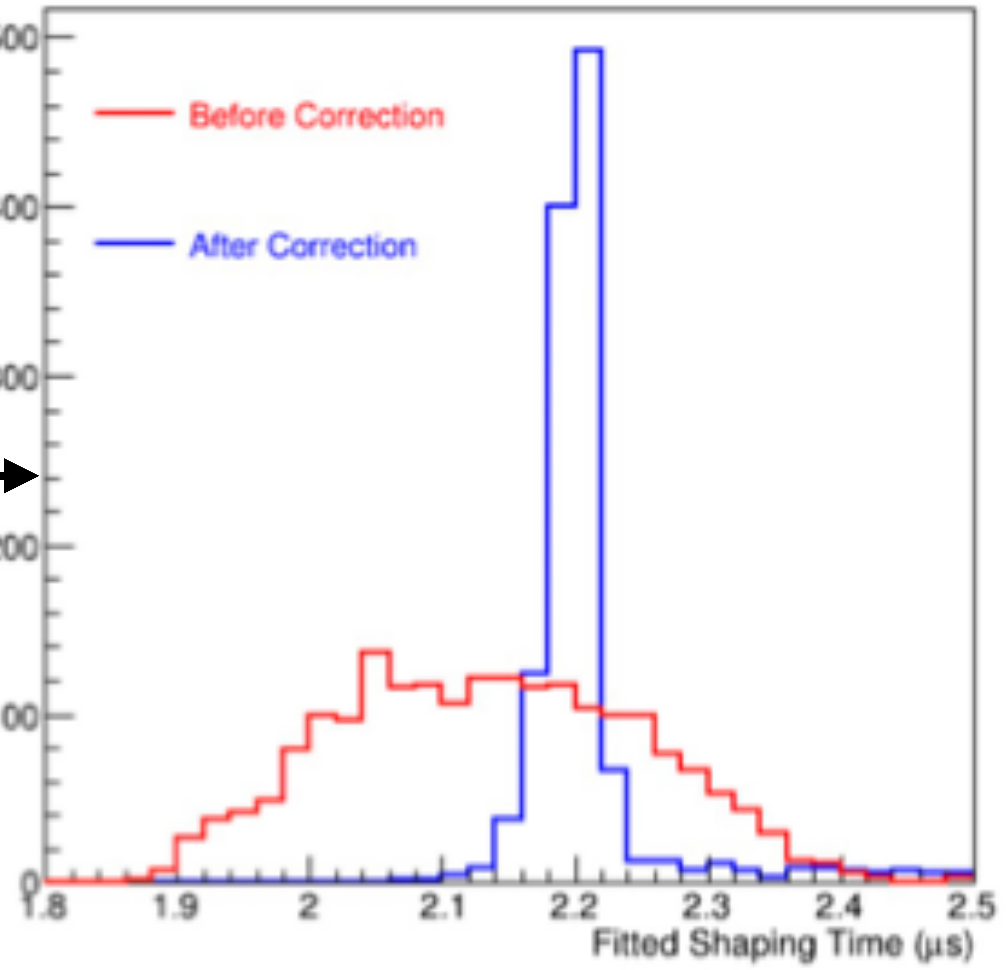




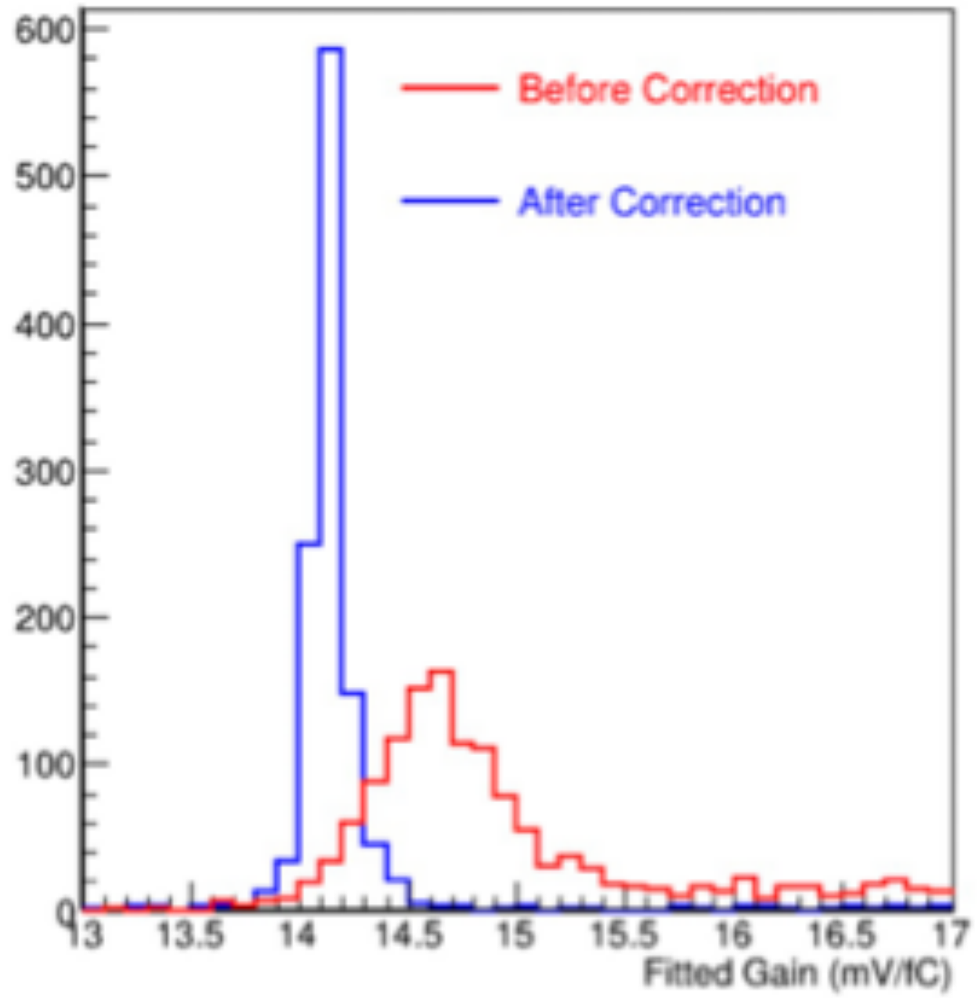
fit to take undershoot/overshoot behavior into account



correction after the fit & parameter extraction



σ= 0.11us -> 0.017us
(85% reduction in std. dev.)



σ= 0.32 -> 0.075 mV/fC
(75% reduction in std. dev.)

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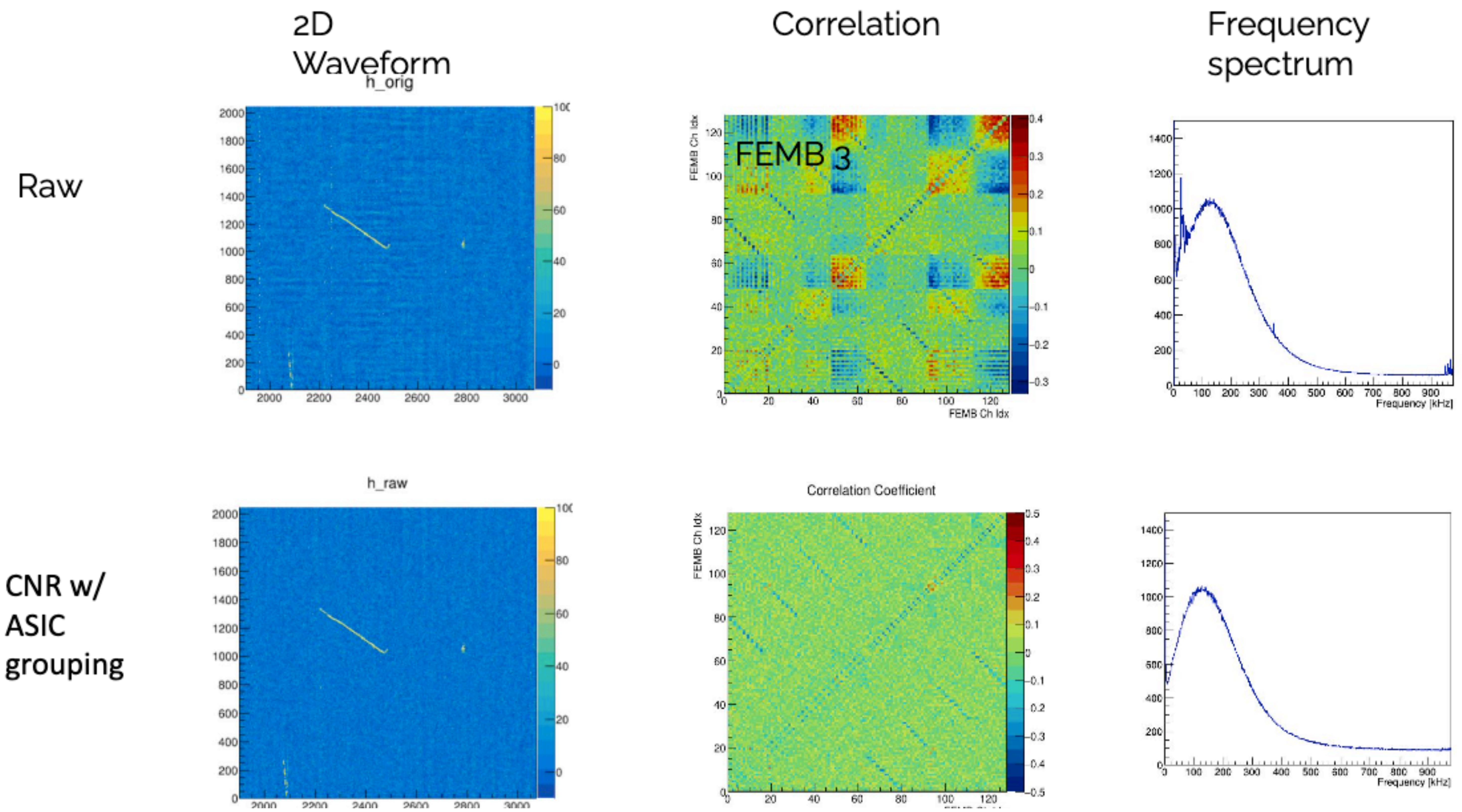

optimization of CNR by changing channel "grouping"

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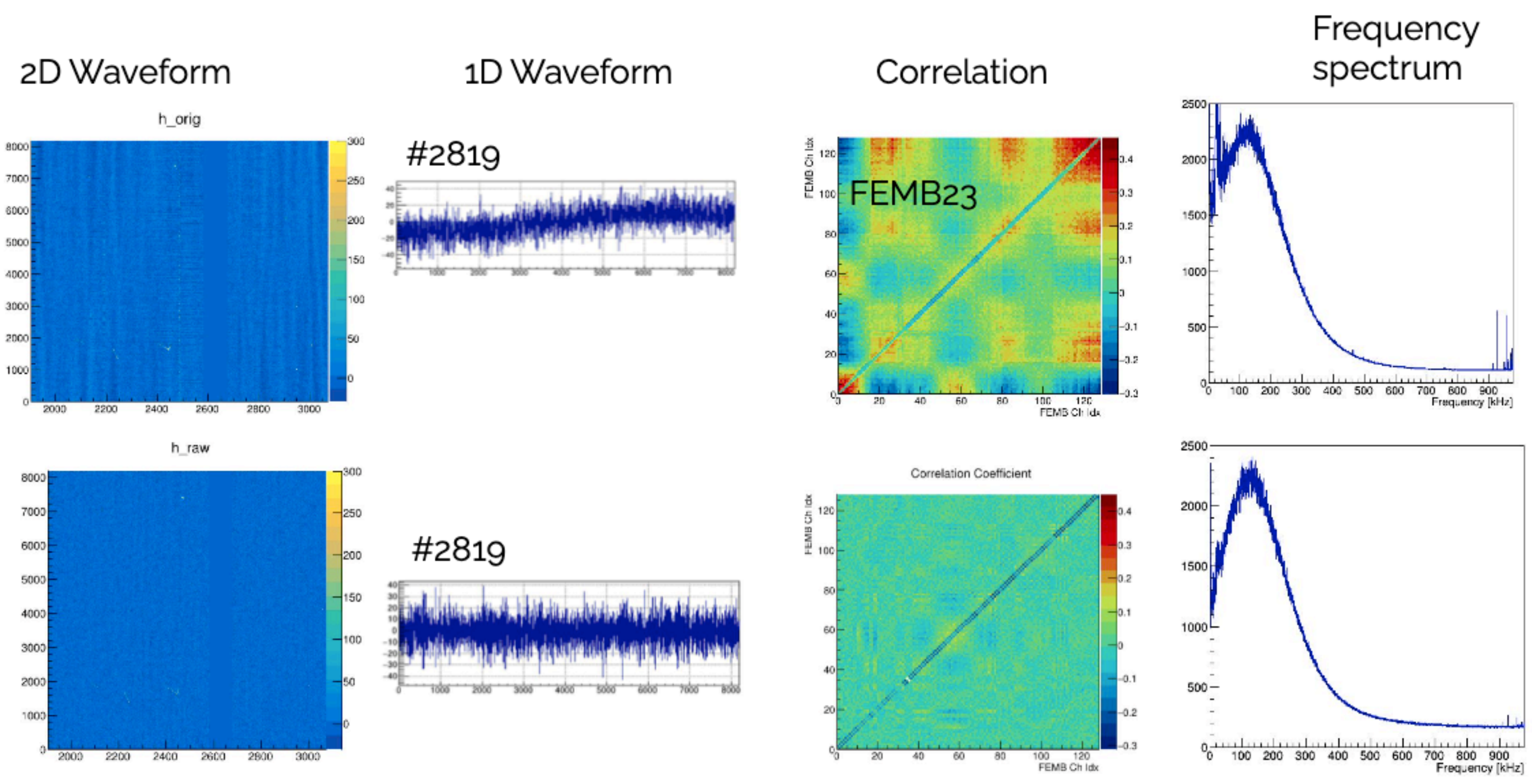

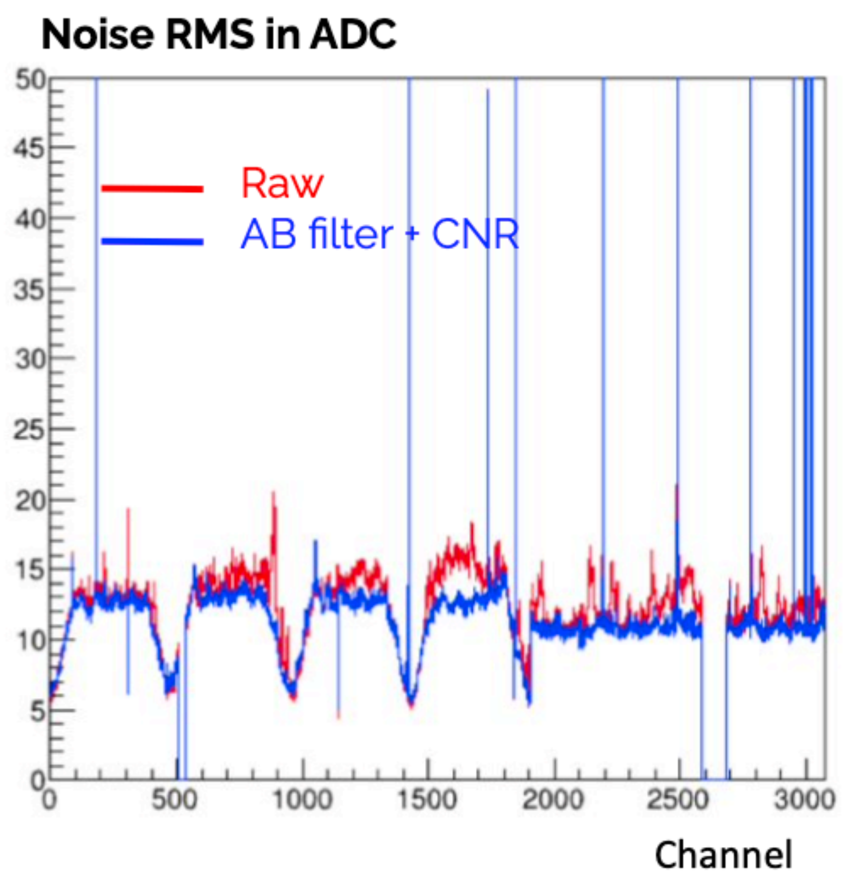

CNR with adaptive baseline correction

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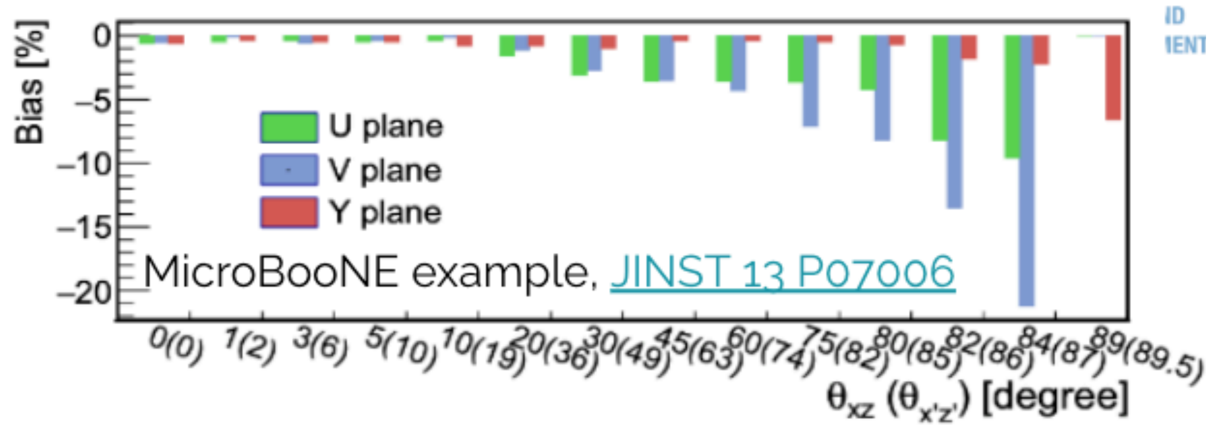

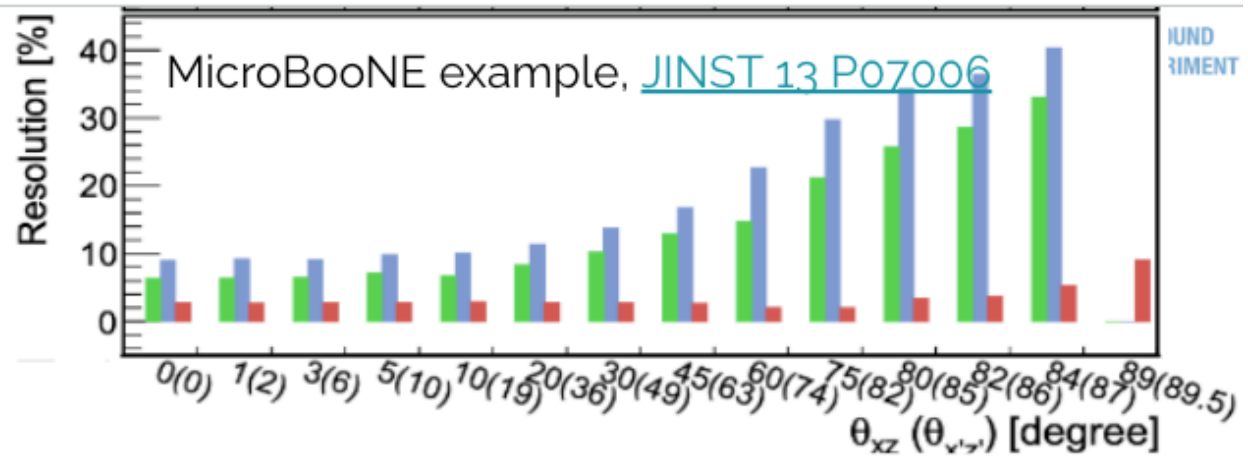

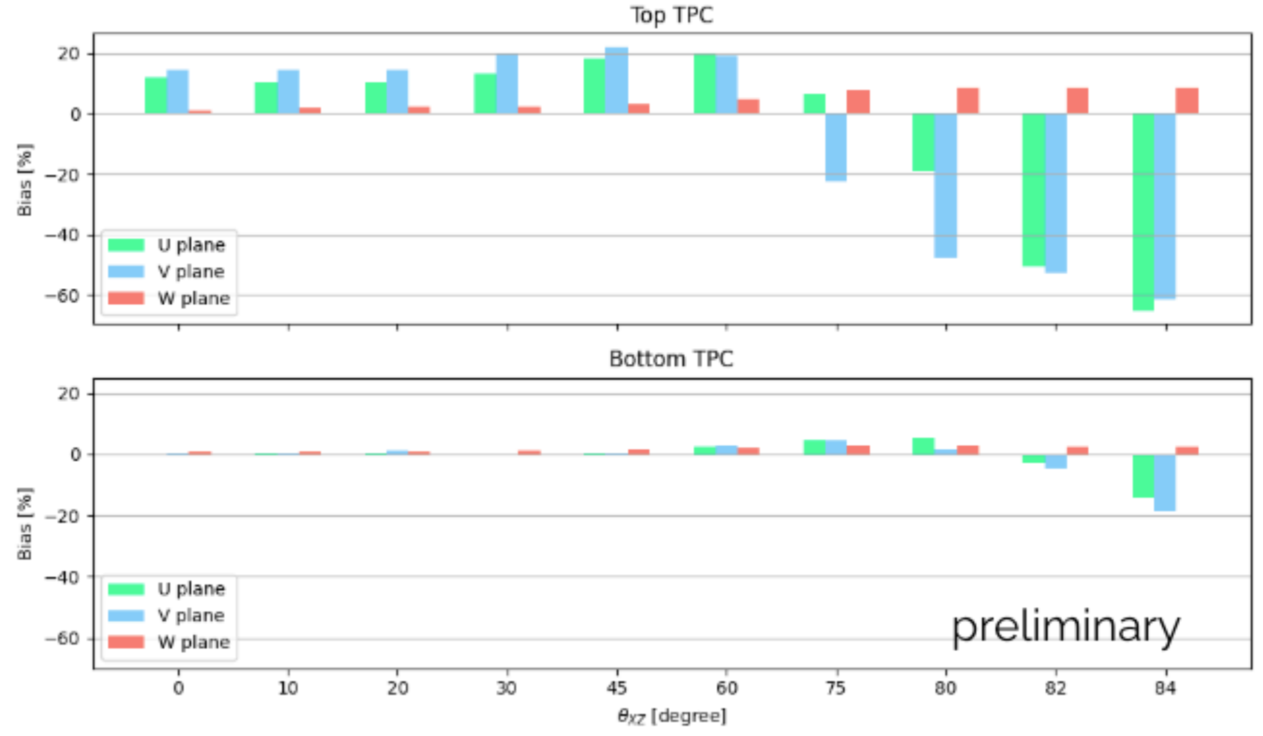

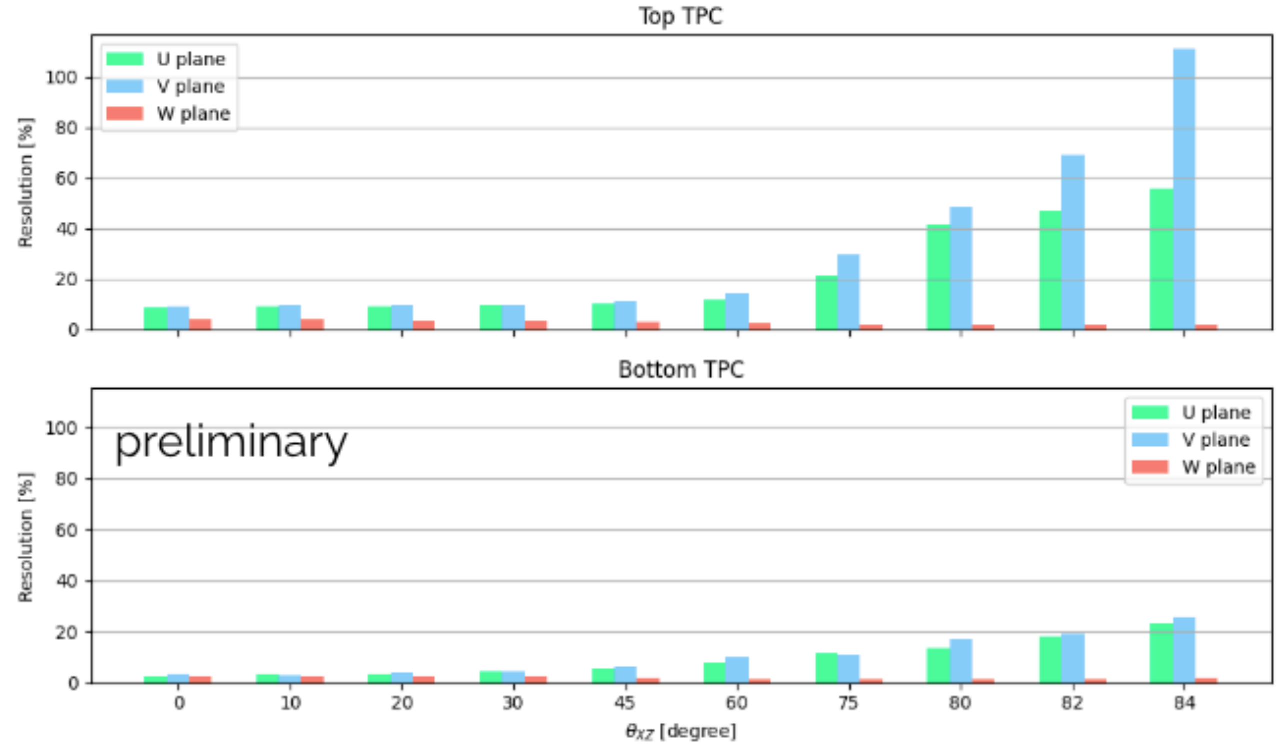

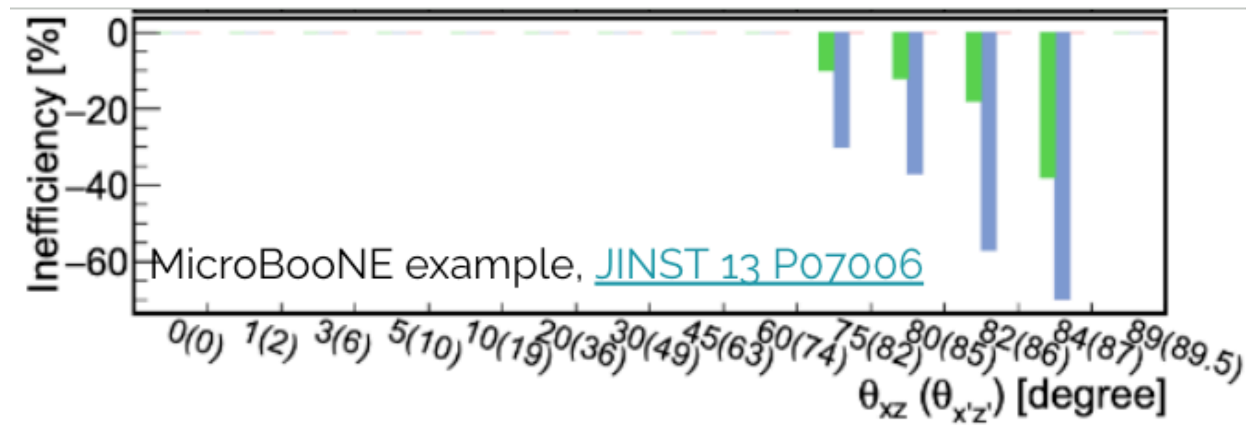

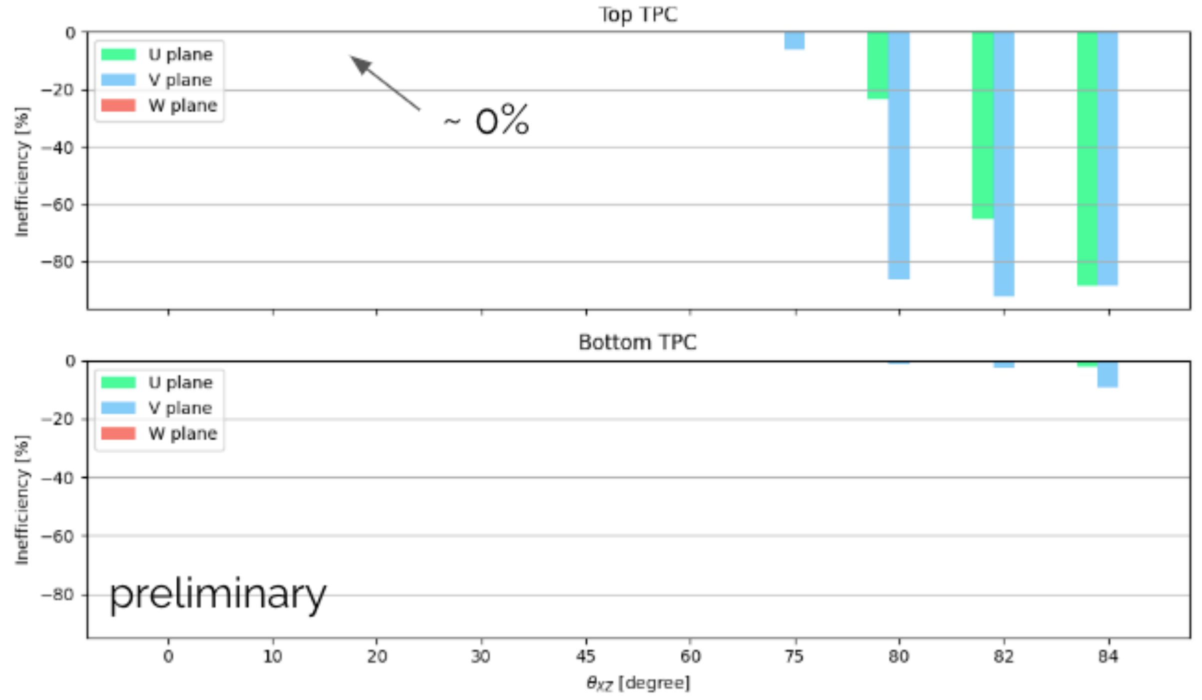

with traditional ROI, signal processing works reasonably, especially with optimized BDE

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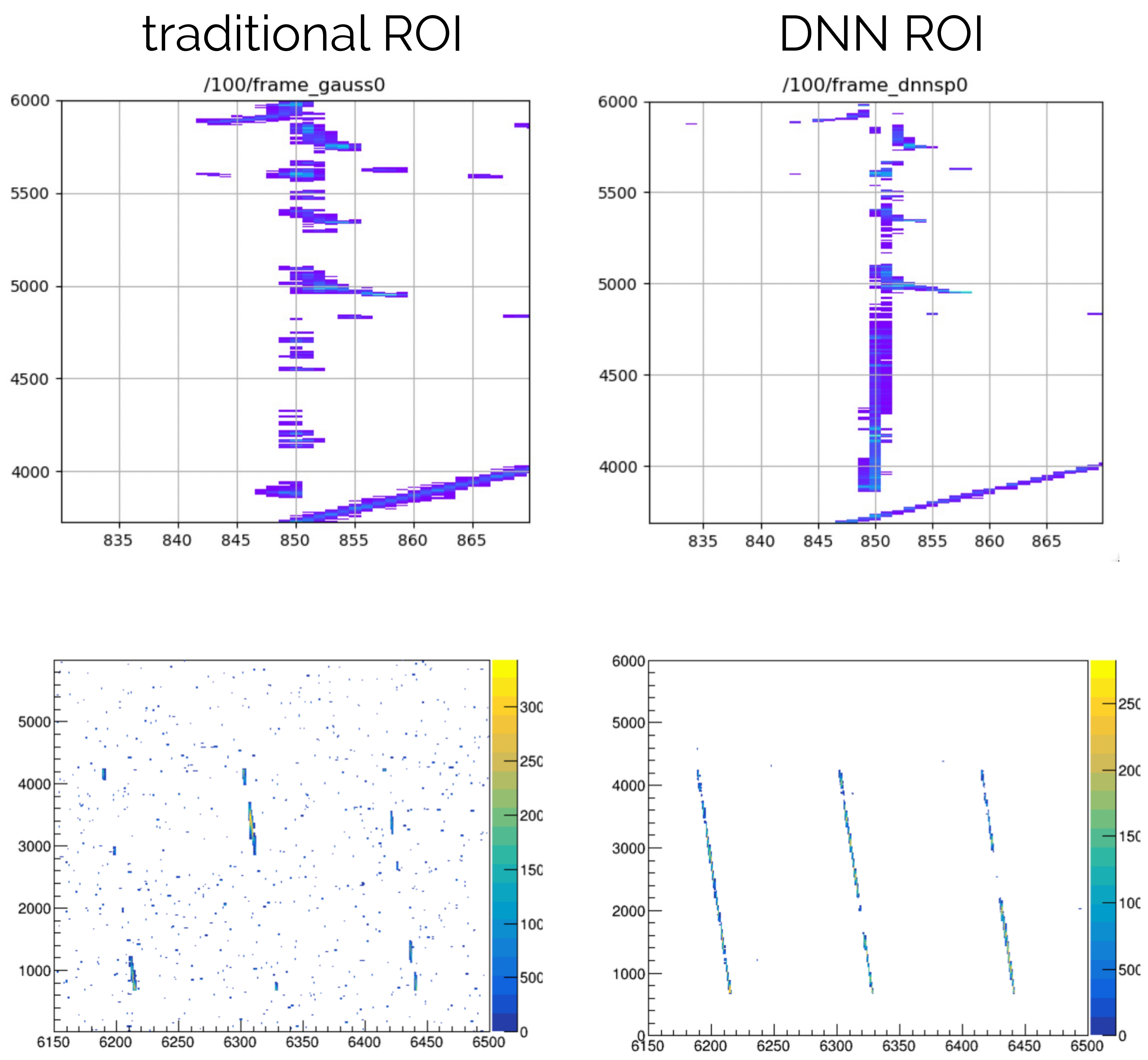

thetaXZ=82 deg
thetaXZ_prime = 86deg

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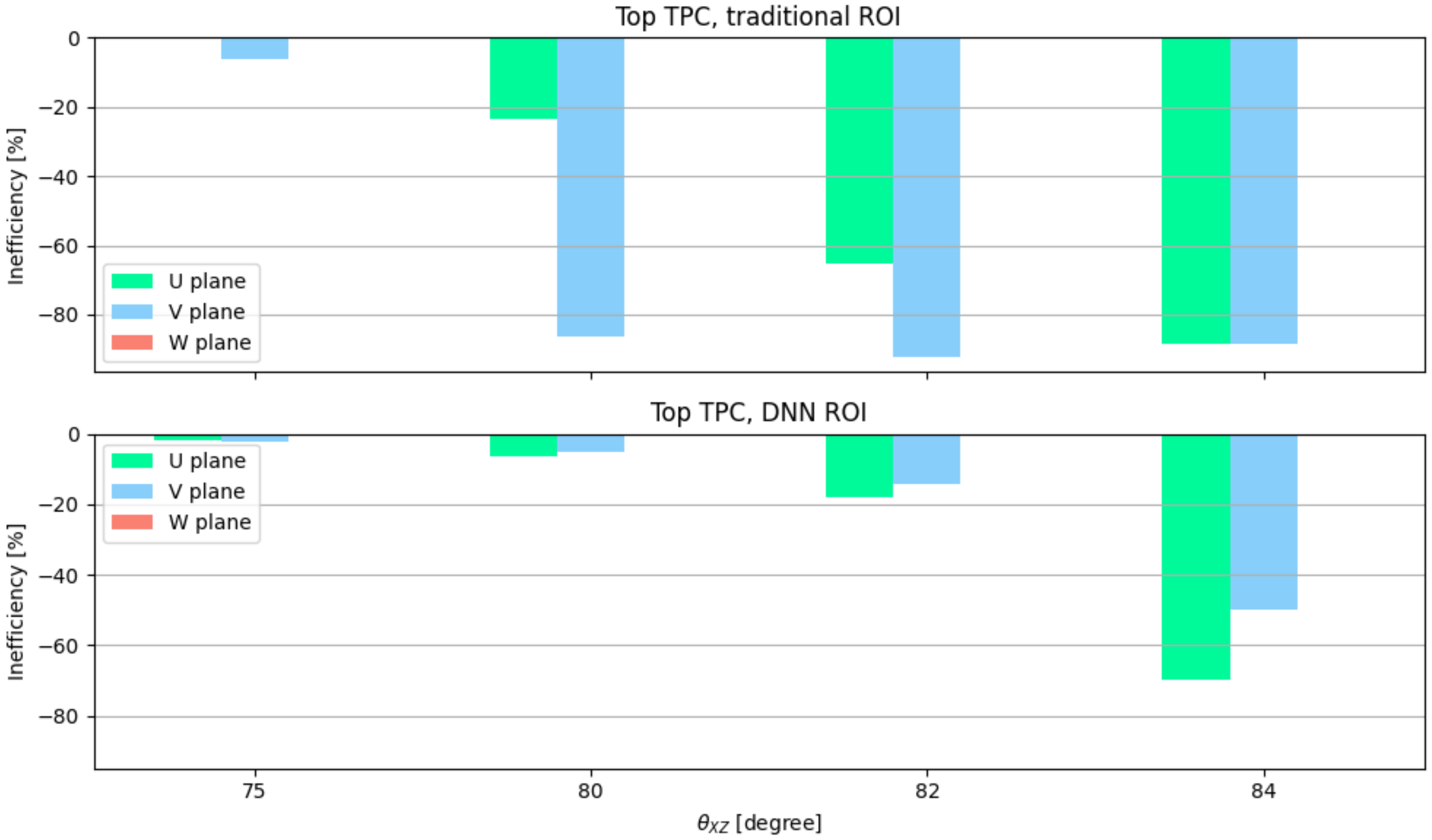
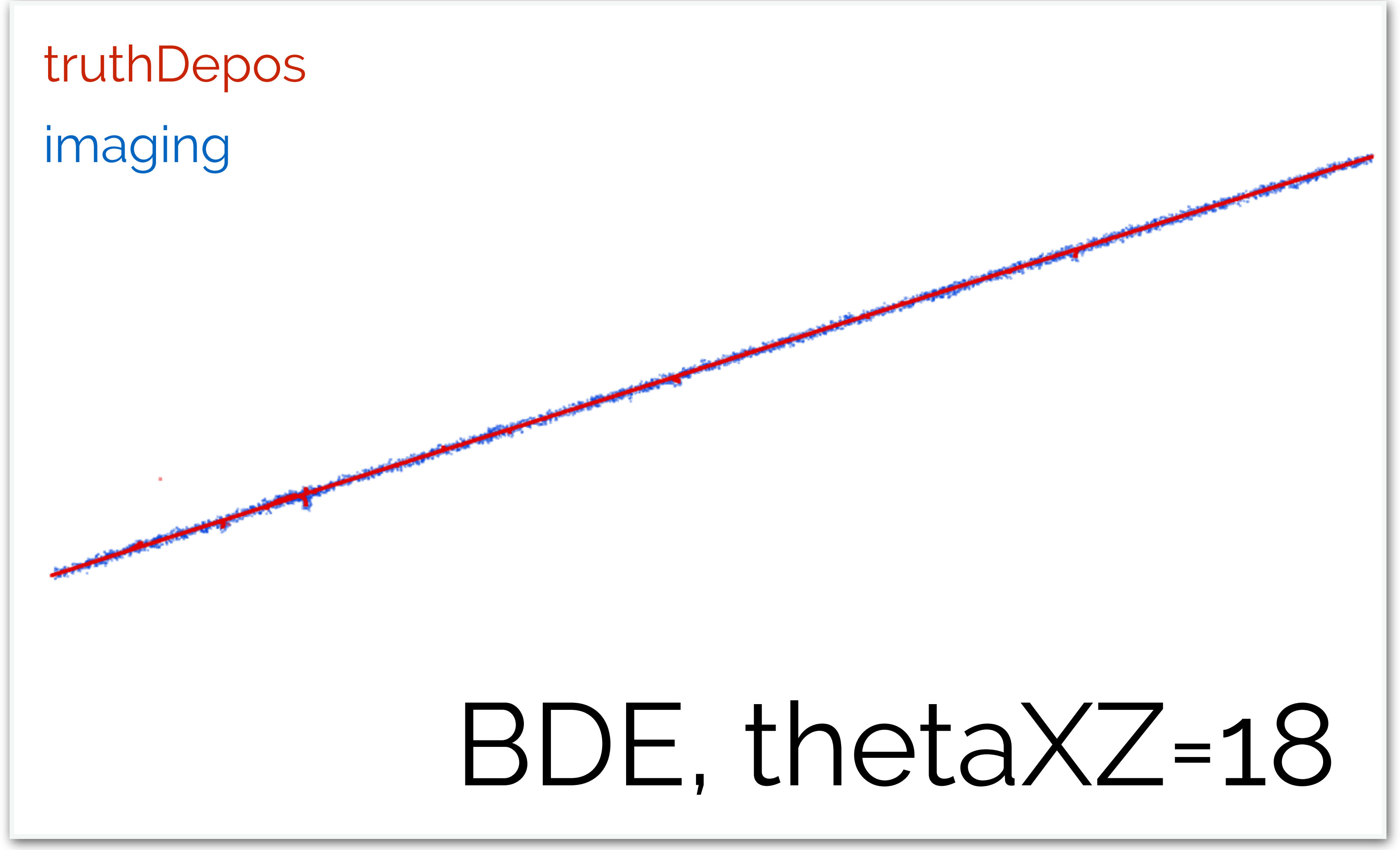


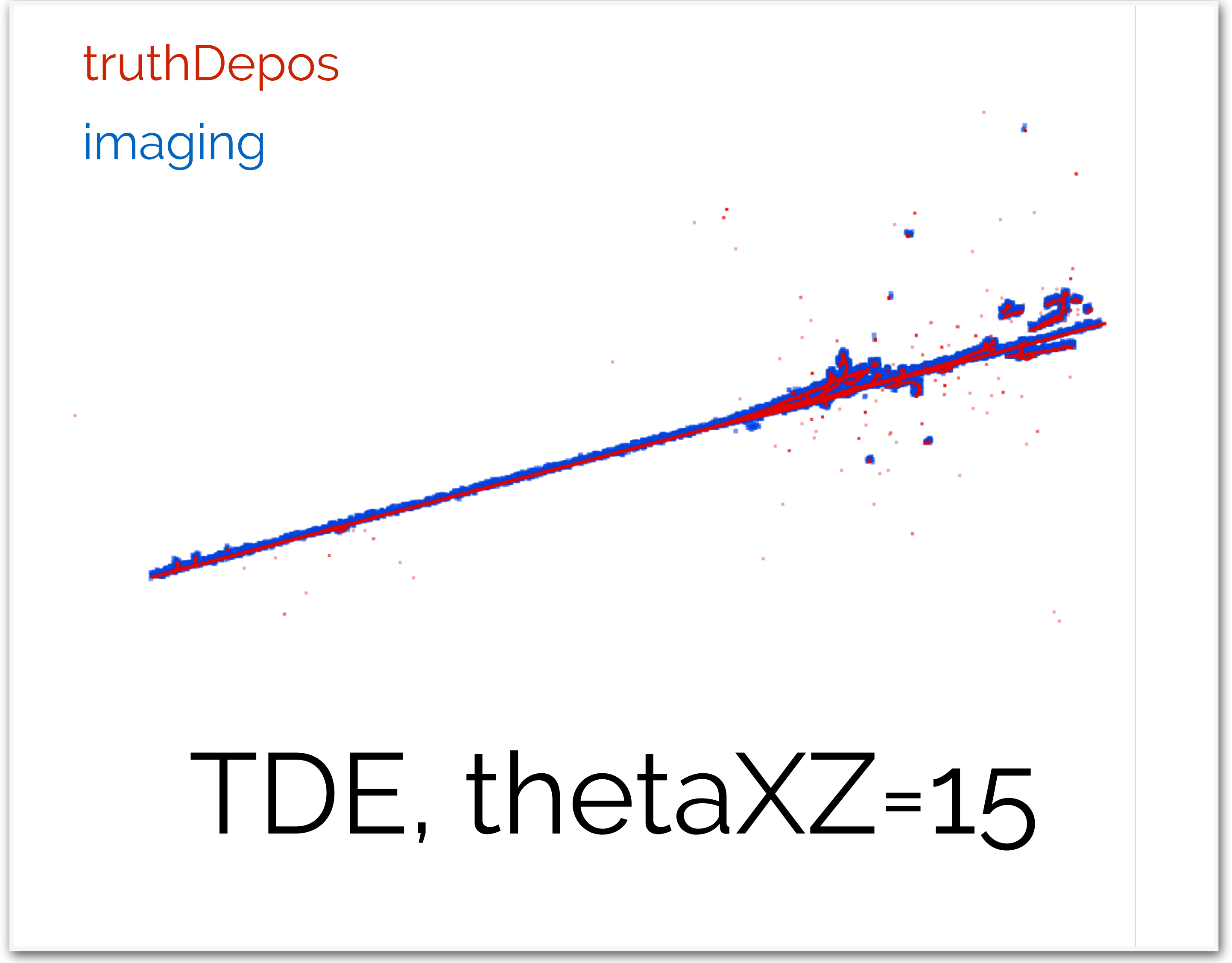
compared with traditional ROI, DNN ROI result shows much lower inefficiency in all the TPCs/planes for high angle tracks

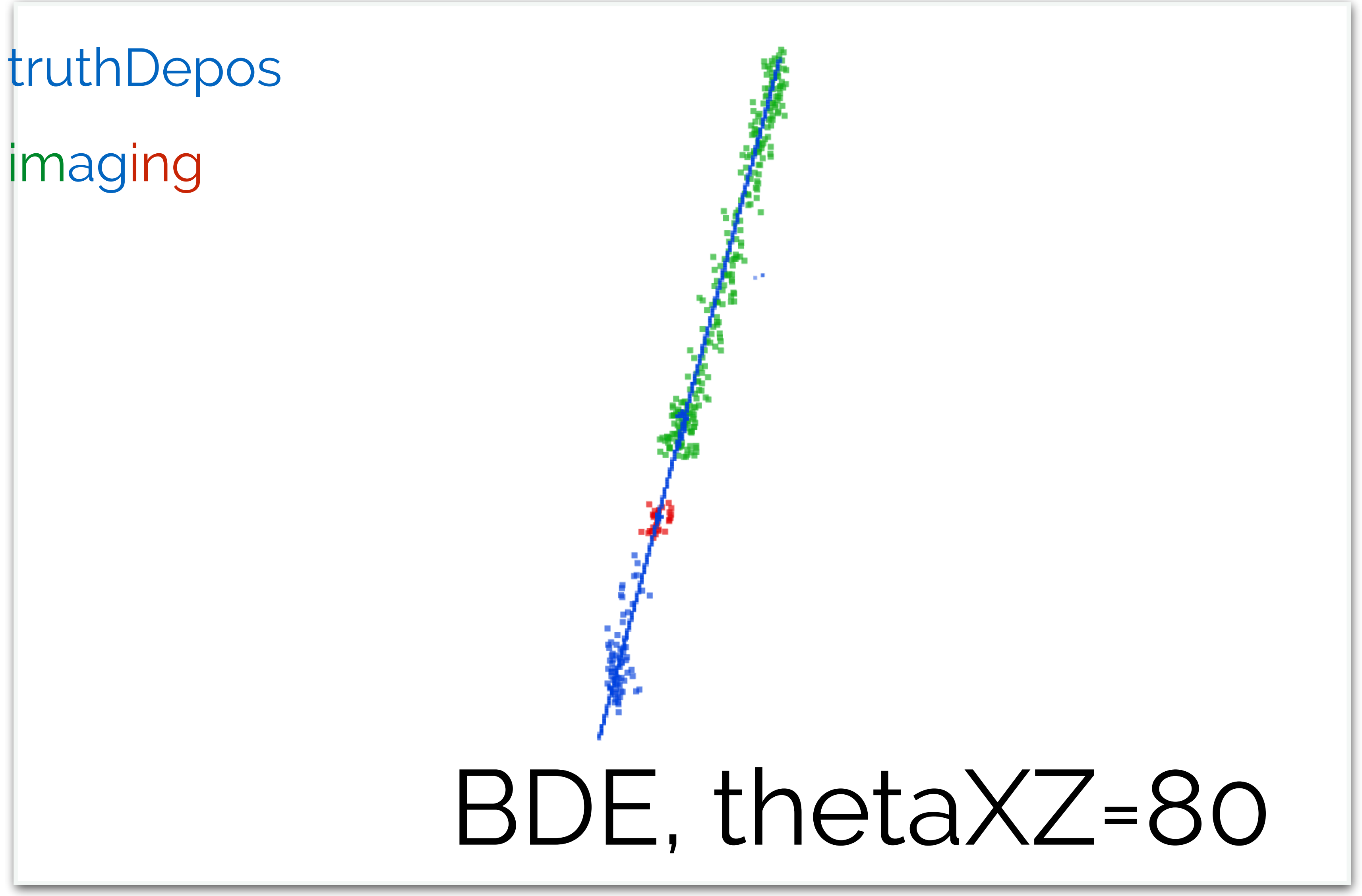
ProtoDUNE-VD

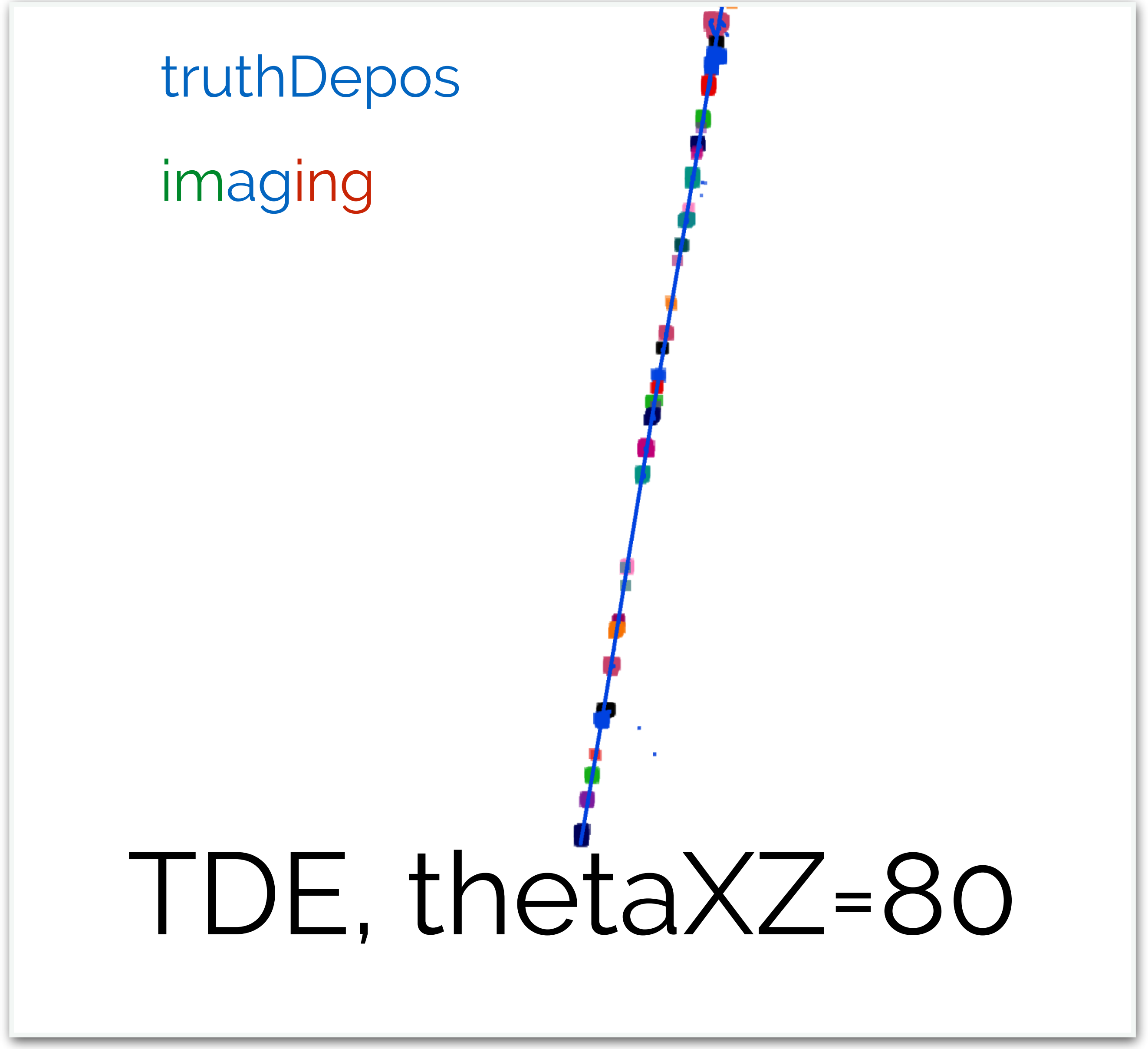
see talk from Wenqiang for more details on WC simulation & signal processing

- inherited most of the workflow from PD-SP
  - initial development focused on bottom drift electronics (BDE)
  - top drift electronics (TDE) optimization in progress
- TPC simulation updated
  - 2D/3D hybrid field response developed & implemented
  - noise modeling updates
- electronics response calibration
- noise filtering
  - initially DataPrep, now WC NF
- signal processing
  - initial evaluation shows promising result
  - DNN ROI will further improve performance
- **imaging**
  - **WCT-ported imaging available, first look**
  - **performance evaluation ongoing**





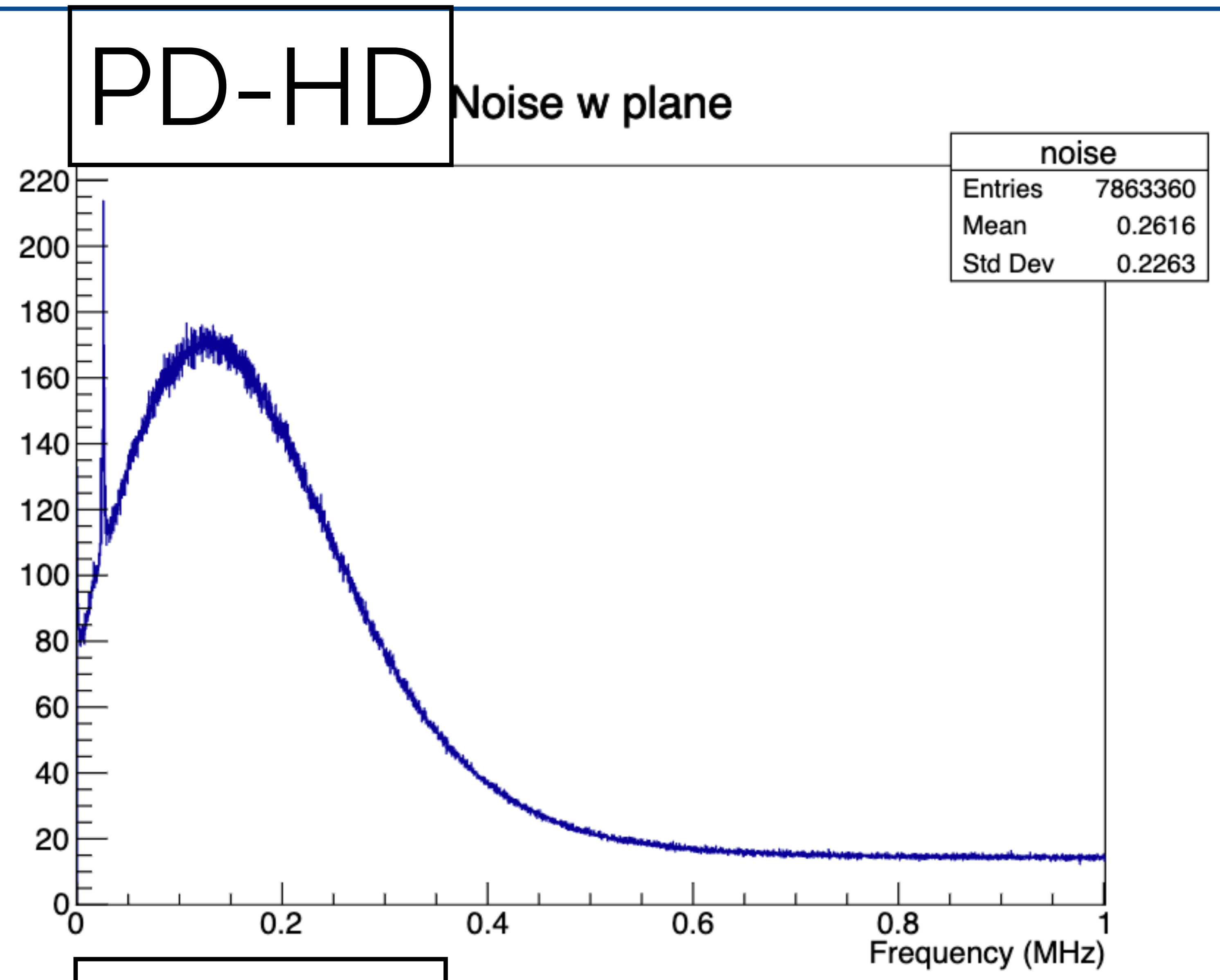


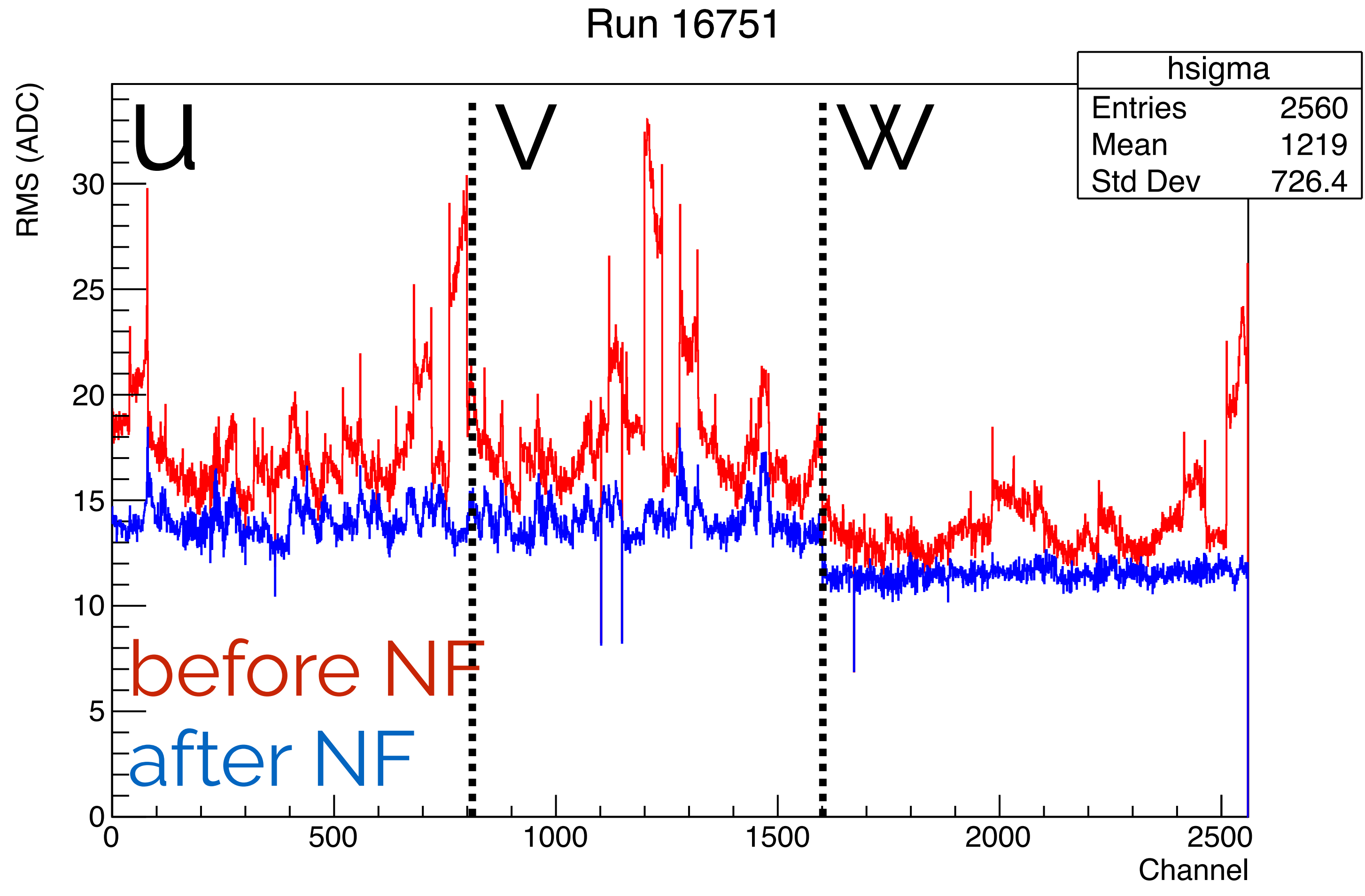


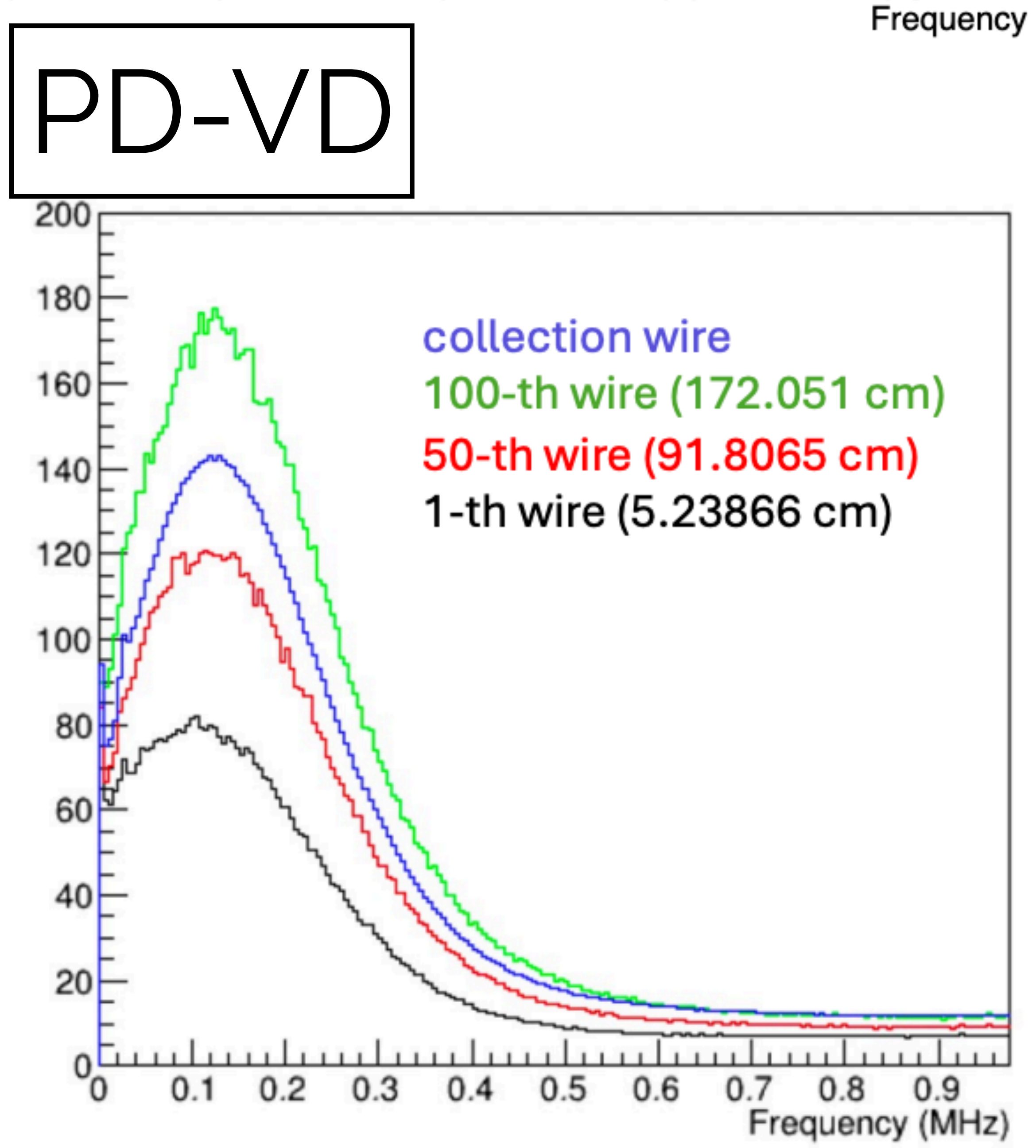
ProtoDUNE-HD

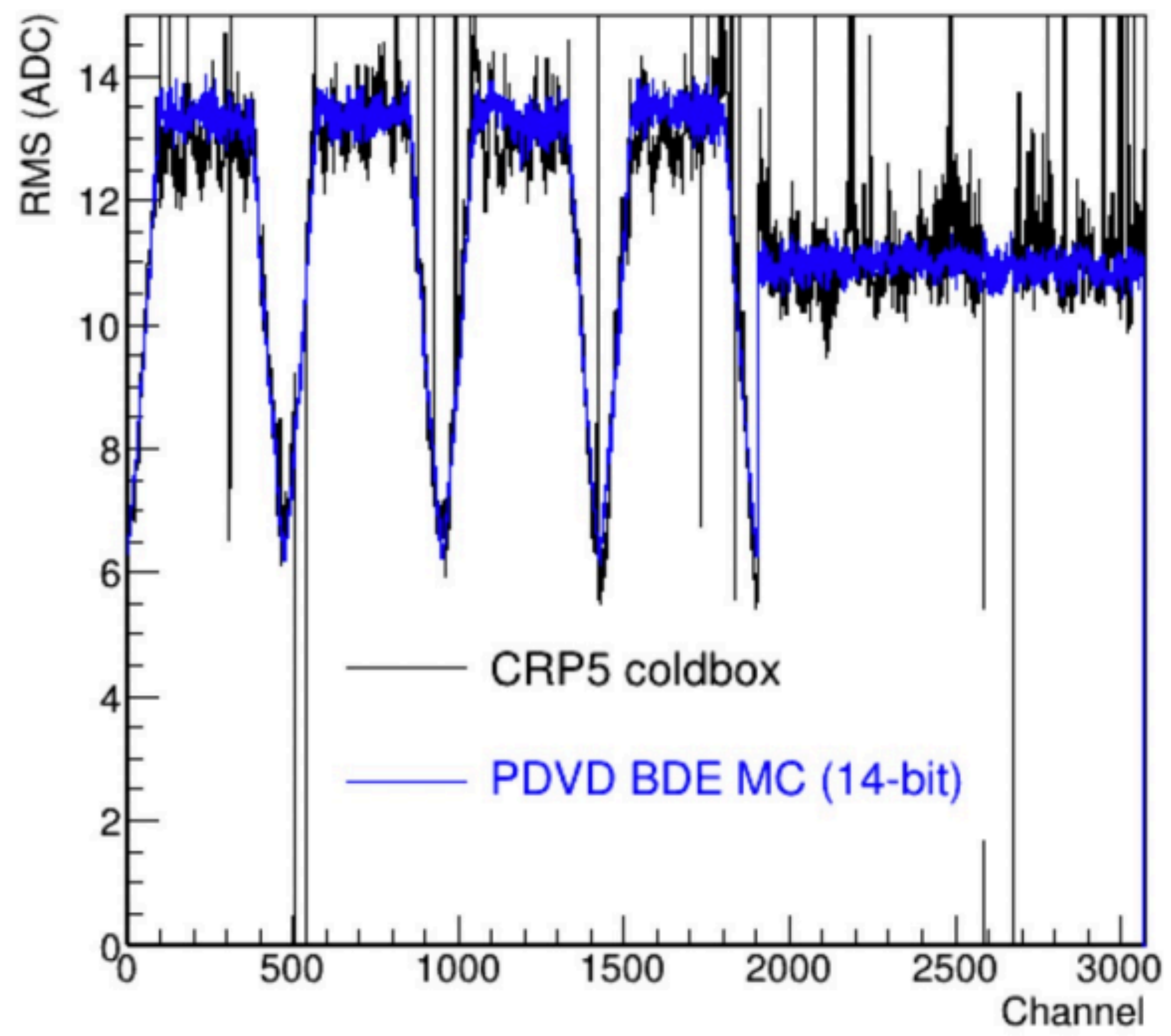
see talk from Bernali for more details on WC noise filtering for PD-HD

- inherited most of the workflow from PD-SP
- WC noise filtering replacing DataPrep, performance evaluation in progress
  - **initial study shows WC NF works quite well with PD-HD coldbox data with minor tweaks**
  - additional study, especially on coherent noise removal optimization, will soon take place
- will be followed by:
  - electronics response calibration
  - signal processing









ProtoDUNE-HD

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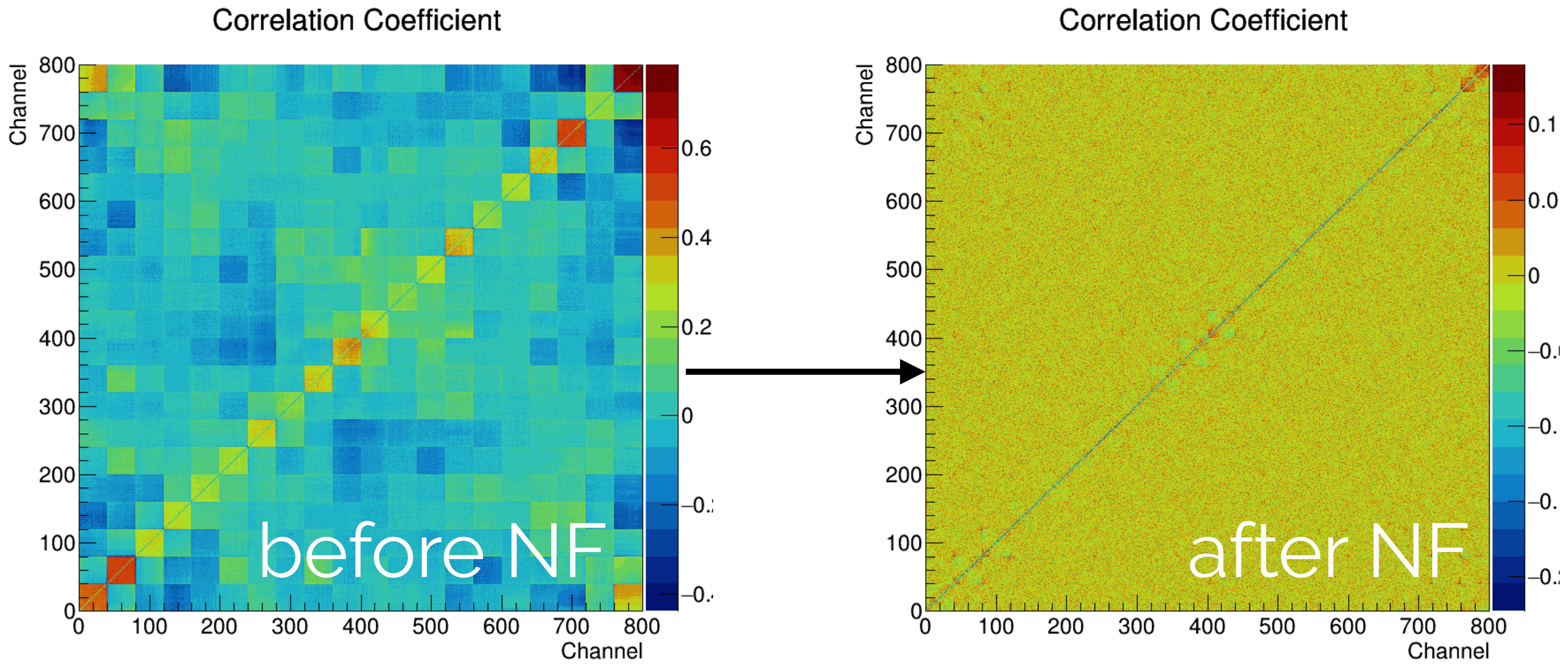

What have we learned?

- **many aspects of WCT implemented with PD-SP are solid & can be used as base frame for other generations of ProtoDUNEs**
- newly developed electronics per-channel calibration show good performance, should be used in future
- **noise filtering is generally good across, but need careful detector-specific checks**
  - all PDs show good noise filtering performance
  - PD-HD; some type of evaluation against DataPrep and CNR validation needed
  - coherent noise removal may need the most careful checks & optimization; channel grouping, signal protection, ,,,
- **DNN ROI is expected to boost signal processing performance**
  - development in near-final stage
  - once finished, validation across different PDs and electronics can be performed
- **for PD-VD, downstream WC is being ported, active efforts needed**

Summary

- Wire-Cell has a huge success story with MicroBooNE, and ProtoDUNE will be one of the first place to have Wire-Cell applied elsewhere

- ProtoDUNE provides testing ground for Wire-Cell-Toolkit, aiming for DUNE FD implementation

- upstream Wire-Cell, including TPC simulation/noise filtering/signal processing has been ported successfully, it's performance shows promising result with different ProtoDUNE detectors

  - optimization/improvements of these components are actively ongoing

- downstream Wire-Cell, which will enable full event reconstruction and physics analysis, is expected to be ported for PD-VD: providing a milestone for full Wire-Cell implementation for DUNE FD