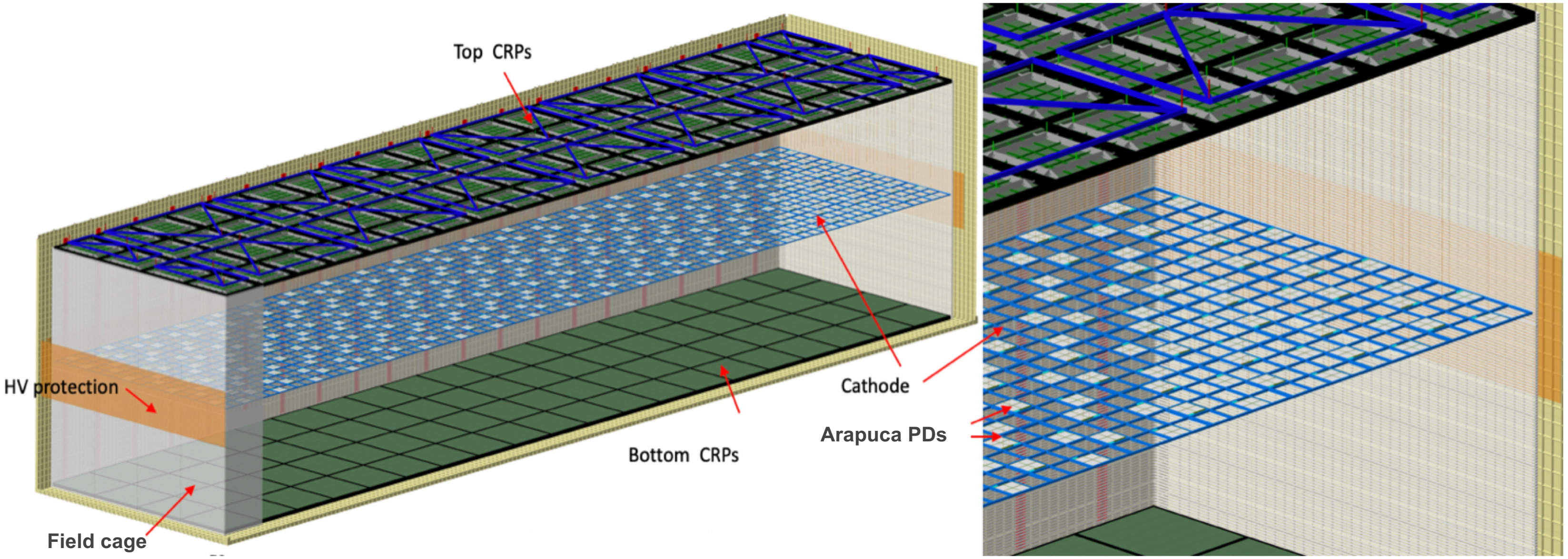
Wire-Cell LArTPC Simulation and Signal Processing



Haiwang Yu
(BNL)

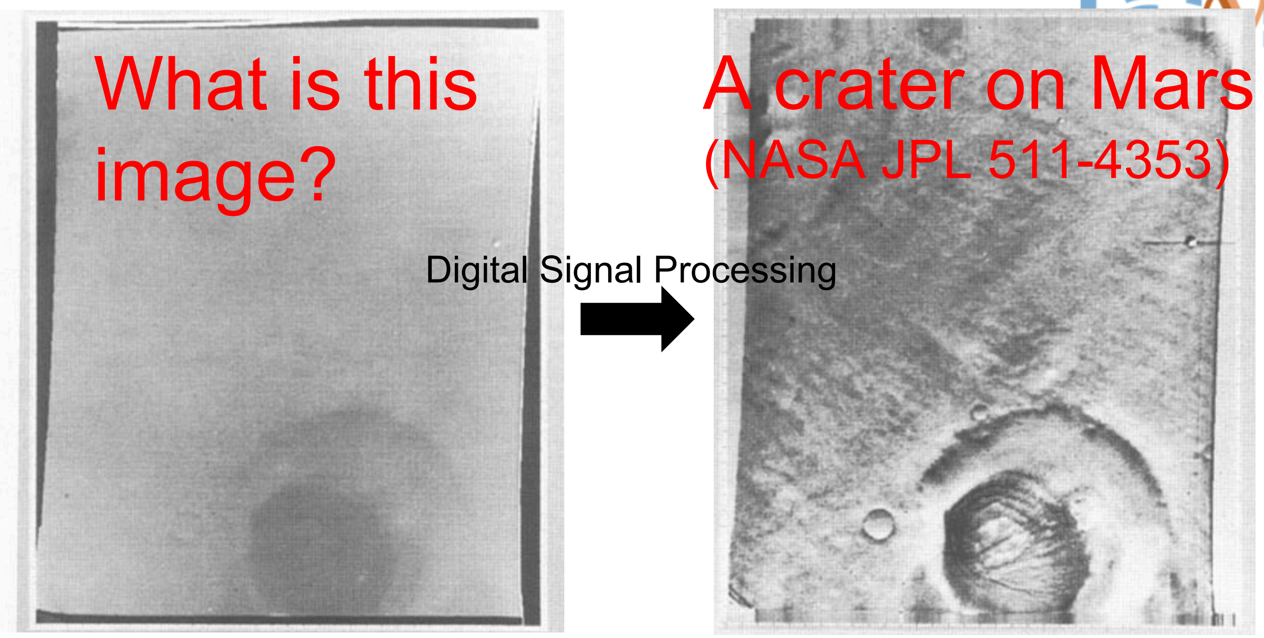
10 May 2021

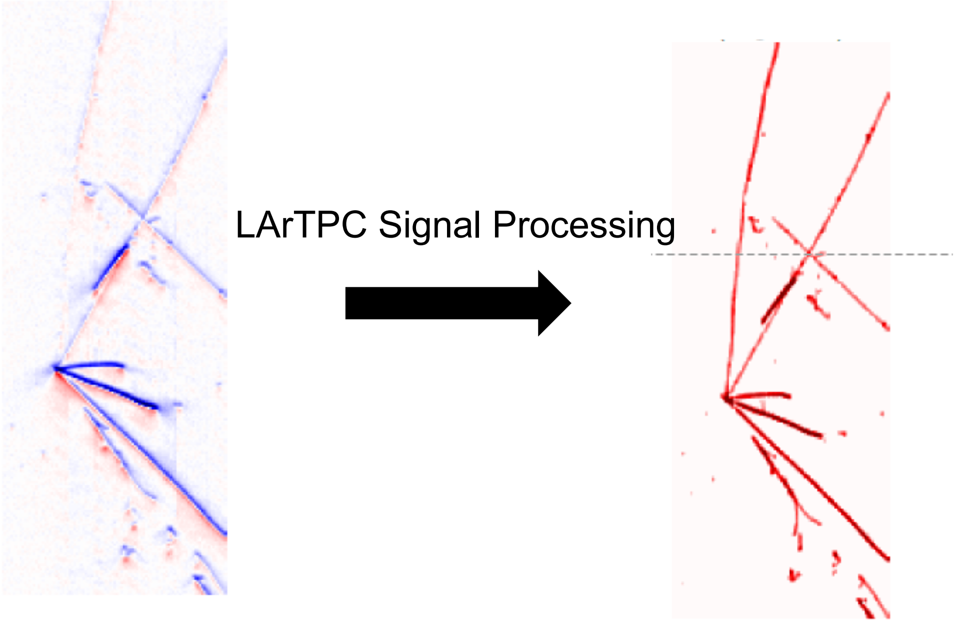
Outline

Wire-Cell LArTPC Simulation and Signal Processing

- Basic principle
- Data-MC validation
- Vertical Drift
- Two selected topics

- *Digital signal processing widely used in image measurements and analyses such as medical imaging, astronomy imaging, …*
- *For high-energy physics application, a realistic Monte Carlo simulation (e.g. detector) is crucial*





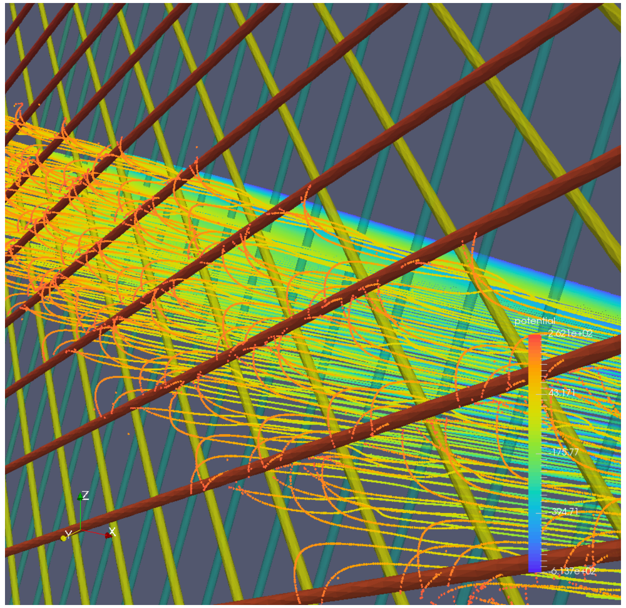
2D-Convolution based Wire-Cell LArTPC Simulation

LArTPC wire-readout measures induced charge ⊗ response

$$M(t',x') = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} R(t,t',x,x')\cdot S(t,x)dtdx + N(t',x')$$

2D: assuming translational symmetry in the third dimension

$$\text{Ramo's theorem: } i = -q\,\vec{E}_w \cdot \vec{v}_q$$

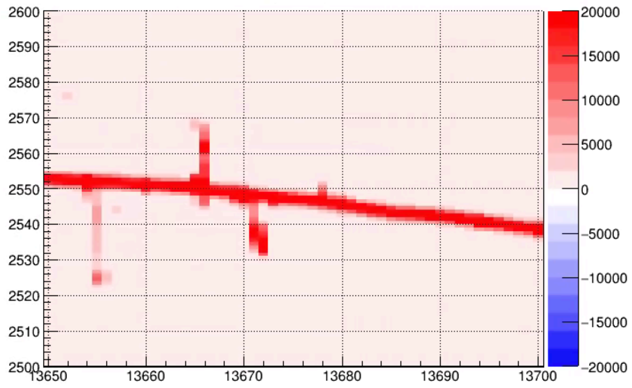


Energy depo + diffusion + rasterization

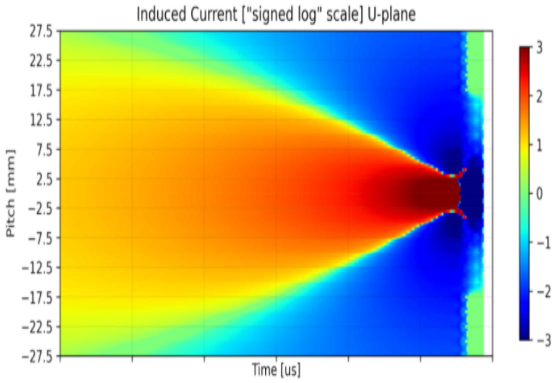
Long-range and position-dependent field response

Noise Spectrum

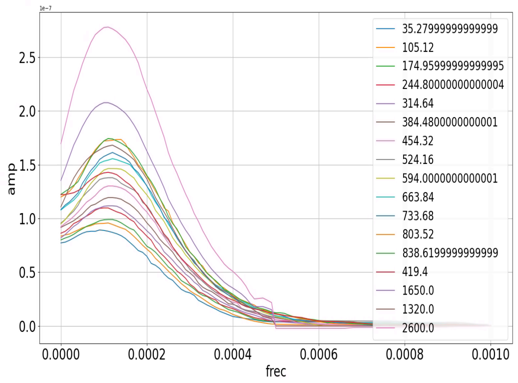
Final Signal



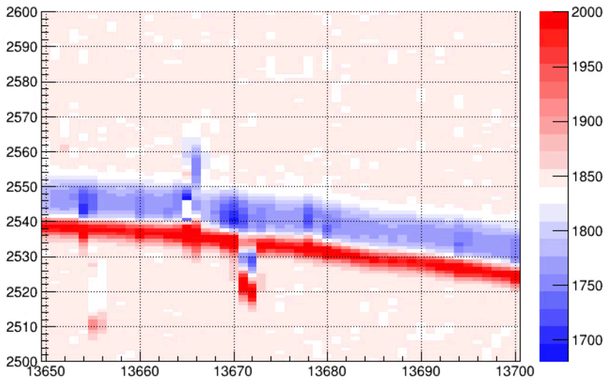
⊗



⊕



→

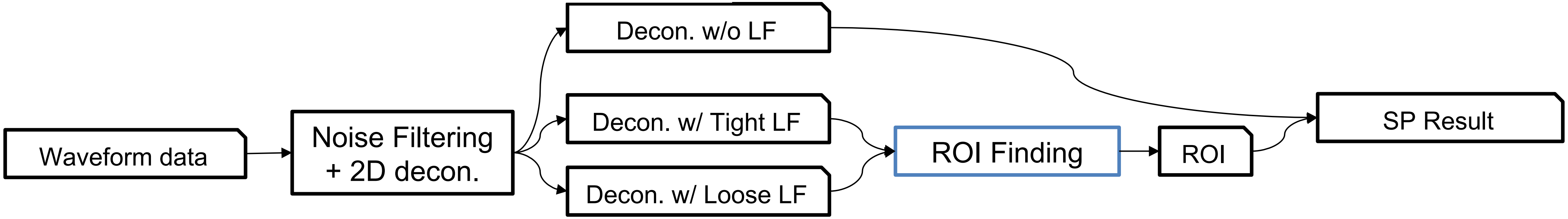


Wire-Cell Signal Processing

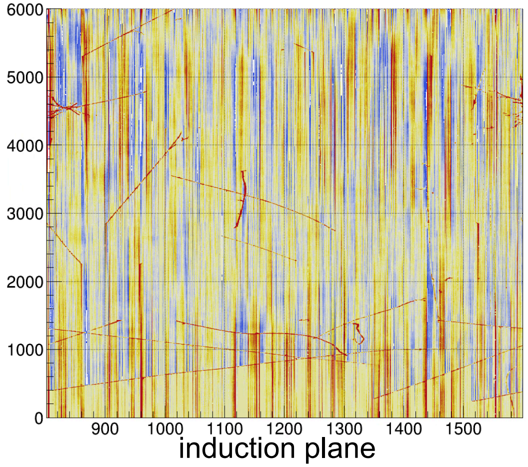
Signal Processing (SP) of LArTPC resolves charge from the original measurement:

$$S(\omega_t, \omega_x) \sim \frac{F(\omega_t, \omega_x) \cdot M(\omega_t, \omega_x)}{R(\omega_t, \omega_x)} \xrightarrow{IFT} S(t, x)$$

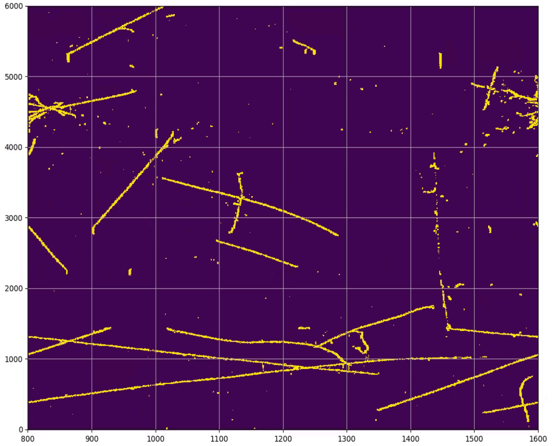
- *"2D deconvolution": assuming translational symmetry in the third dimension*
- *Utilize the signal/noise separation in both frequency and time domain*



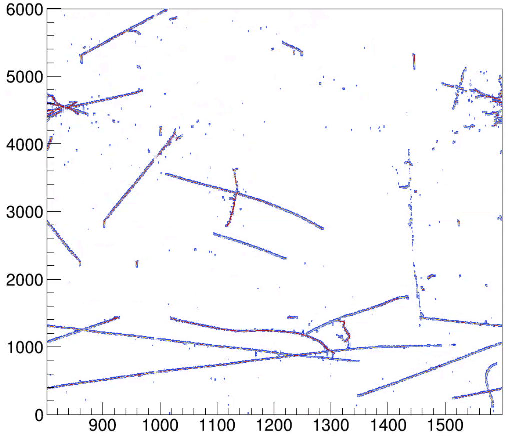
Decon. w/o LF filter
Waveform ⟶ charge, dense



ROI:
Hit finding, sparsify



SP result:
Sparse, charge



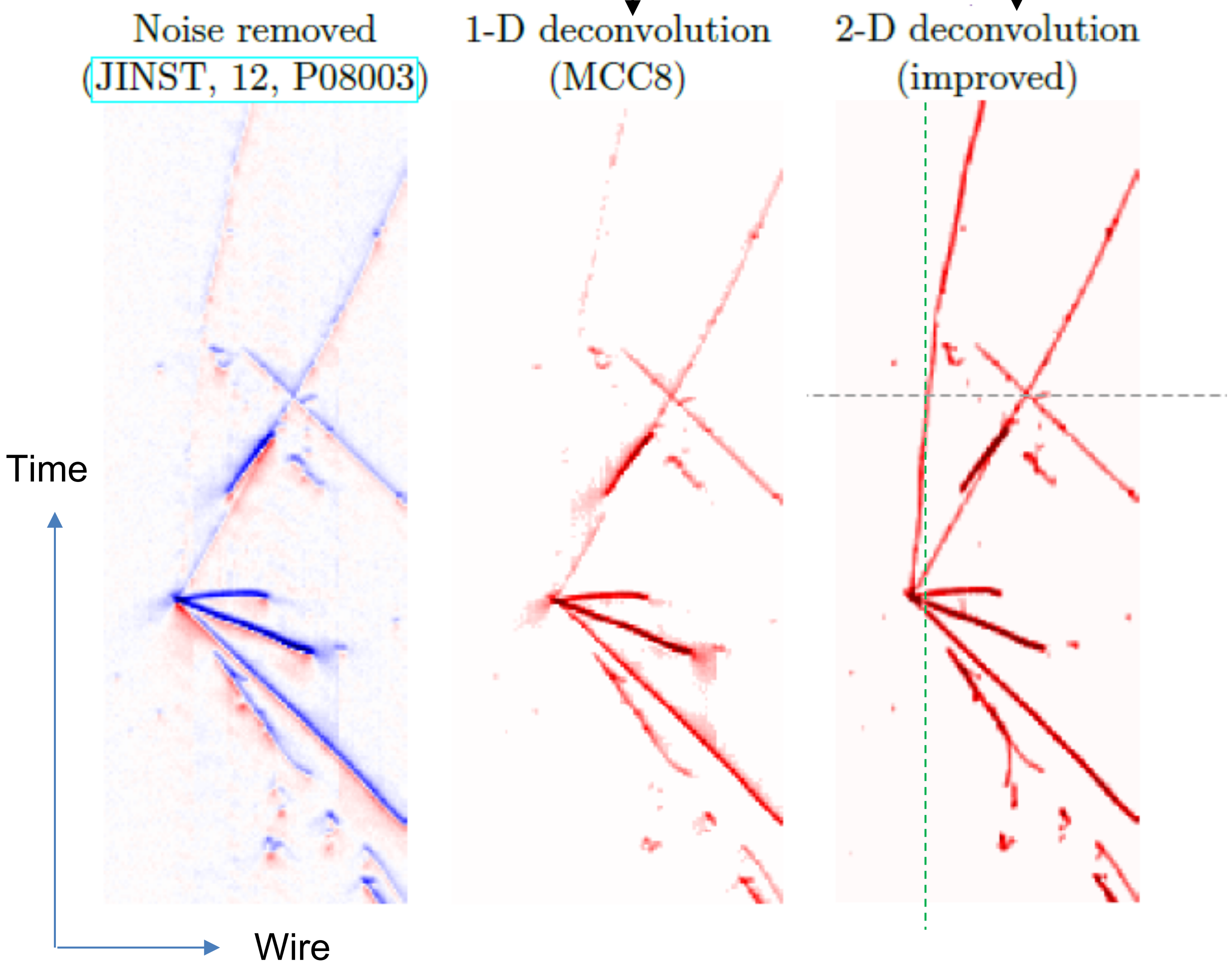
Data-MC Validation

MicroBooNE

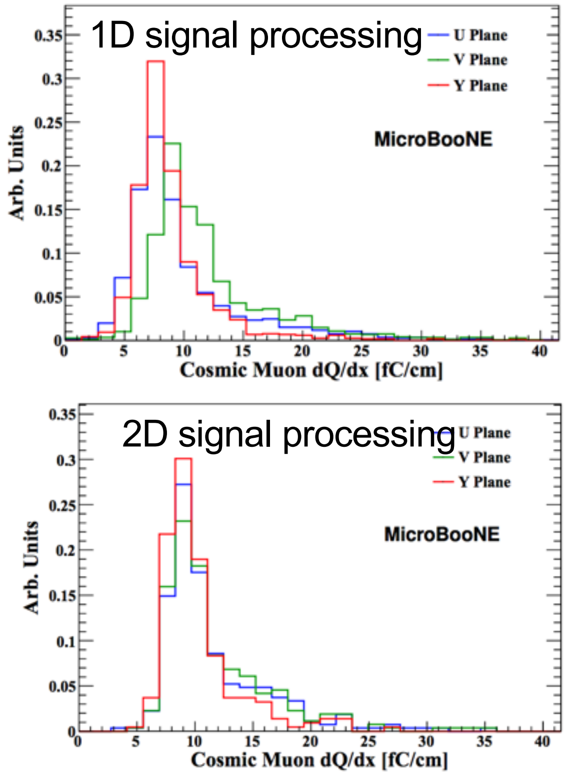
MicroBooNE Data Induction plane

This works for collection plane, but not induction plane.

2D signal processing (time + wire domains)



Data-MC consistency was demonstrated for the first time at the detector signal level

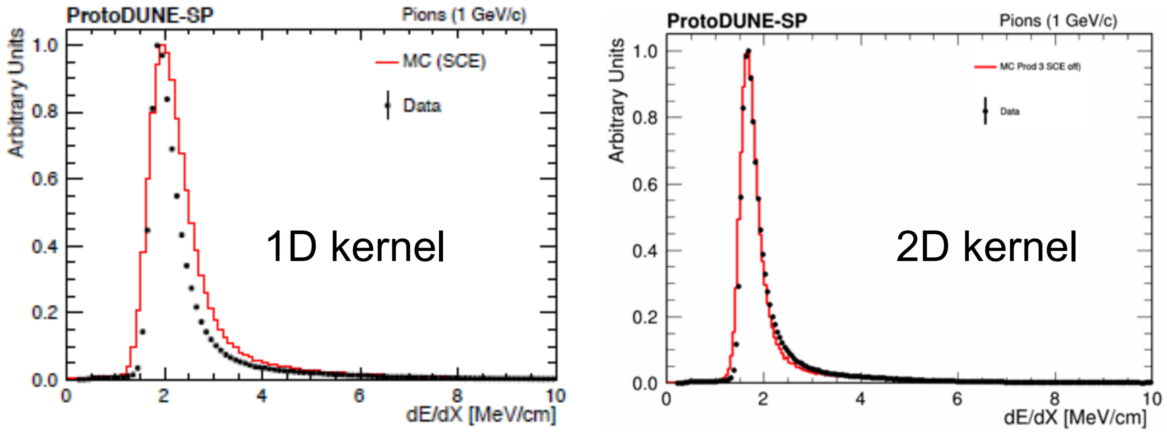


JINST 12 P08003
JINST 13 P07006
JINST 13 P07007

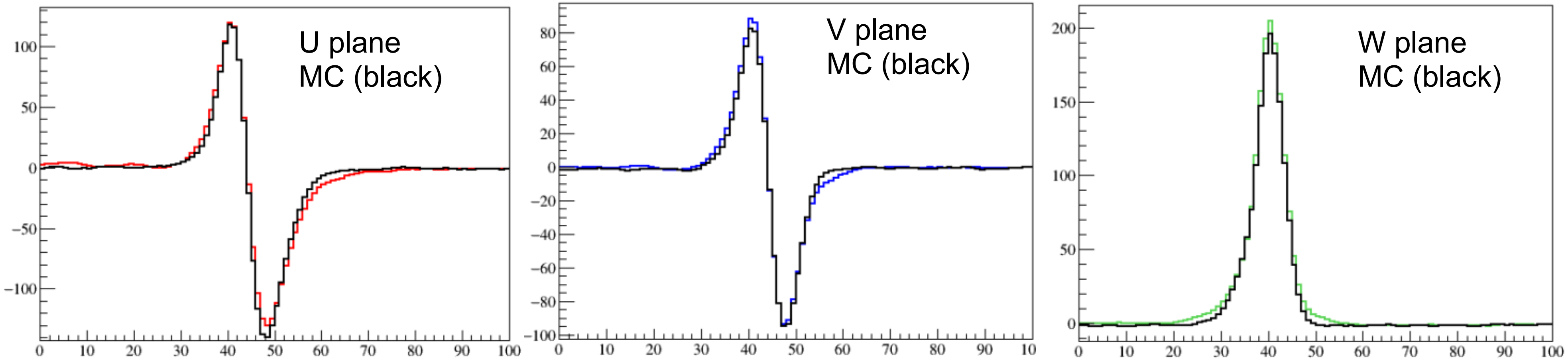
ProtoDUNE (I)

Data-MC consistency has been demonstrated also in ProtoDUNE using 2D simulation and signal processing

ProtoDUNE dE/dx reco. MC vs DATA



Average raw waveform: data vs. MC

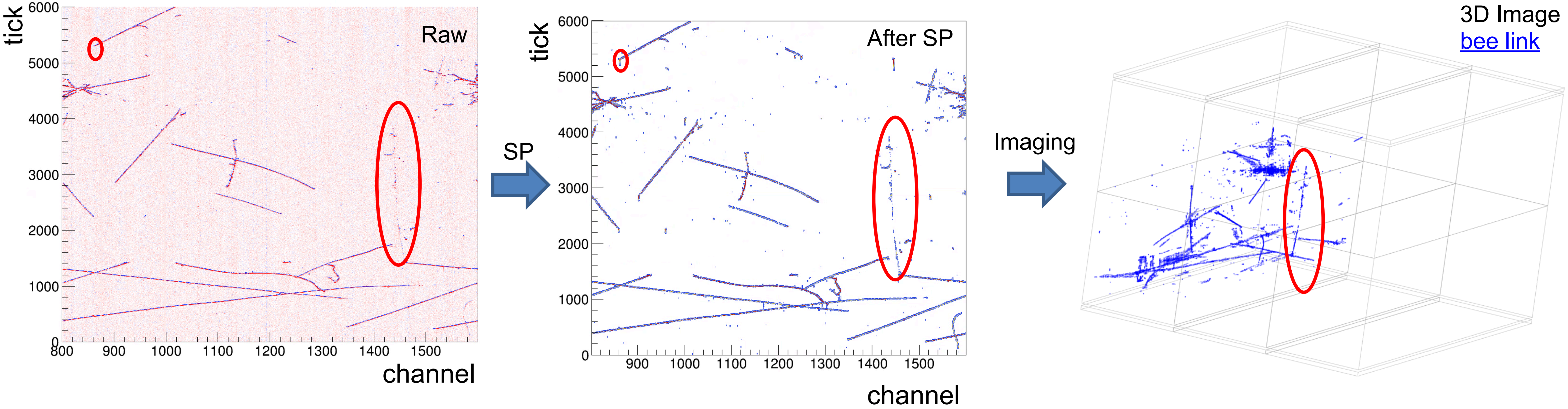


[ref link]

ProtoDUNE (II)

Current 2D Signal Processing works well in most cases.
Some remaining issues:

- “teardrop” (distortion)
- *gaps for prolonged track ⟶ gaps in 3D track reconstruction (imaging in Wire-Cell)*

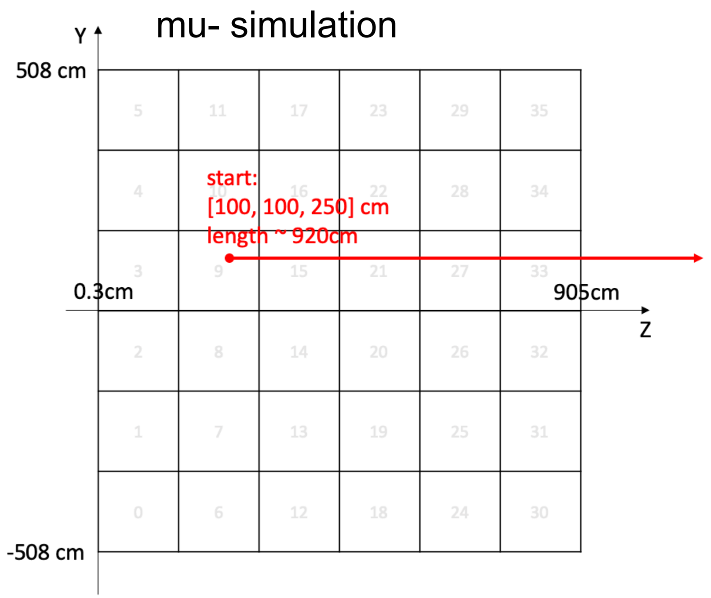


Vertical Drift TPC Simulation and Signal Processing

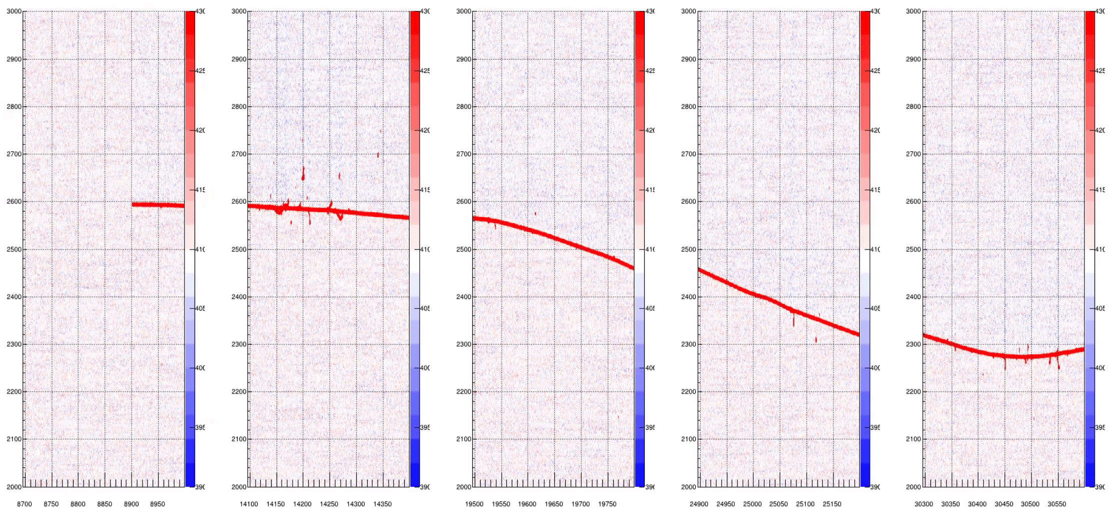
Wire-Cell TPC simulation for DUNE Far Detector Vertical Drift

Wire-Cell TPC simulation for Vertical Drift is ready:

- ✓ Geometry – gdml file + porting utilities for Wire-Cell
- ✓ Field response – 50L 2view prototype and 3view-30deg
- ✓ Noise model – using data from ProtoDUNE-SP and MicroBooNE
- ✓ Wire-Cell Configuration
- ✓ Integration with LArSoft - V. Galymov's talk
- ✓ Initial validations

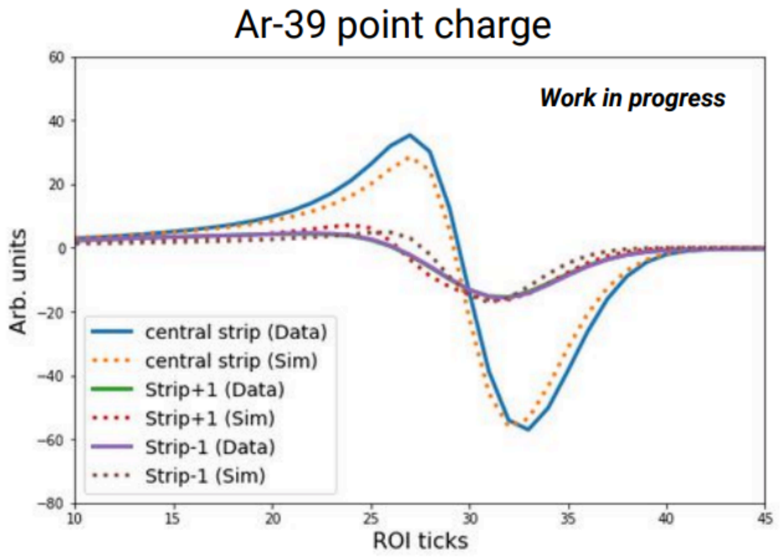


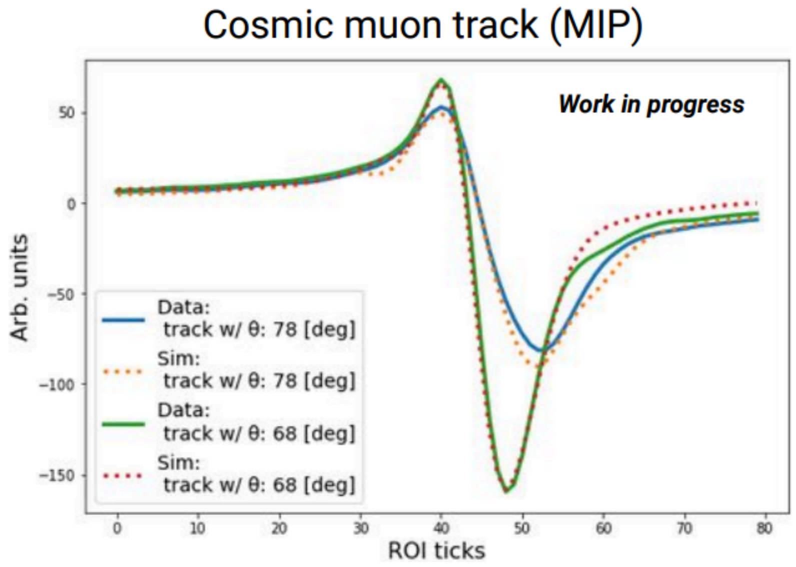
TPC simulation results for the collection plane, showing CRM 9, 15, 21, 27 and 33



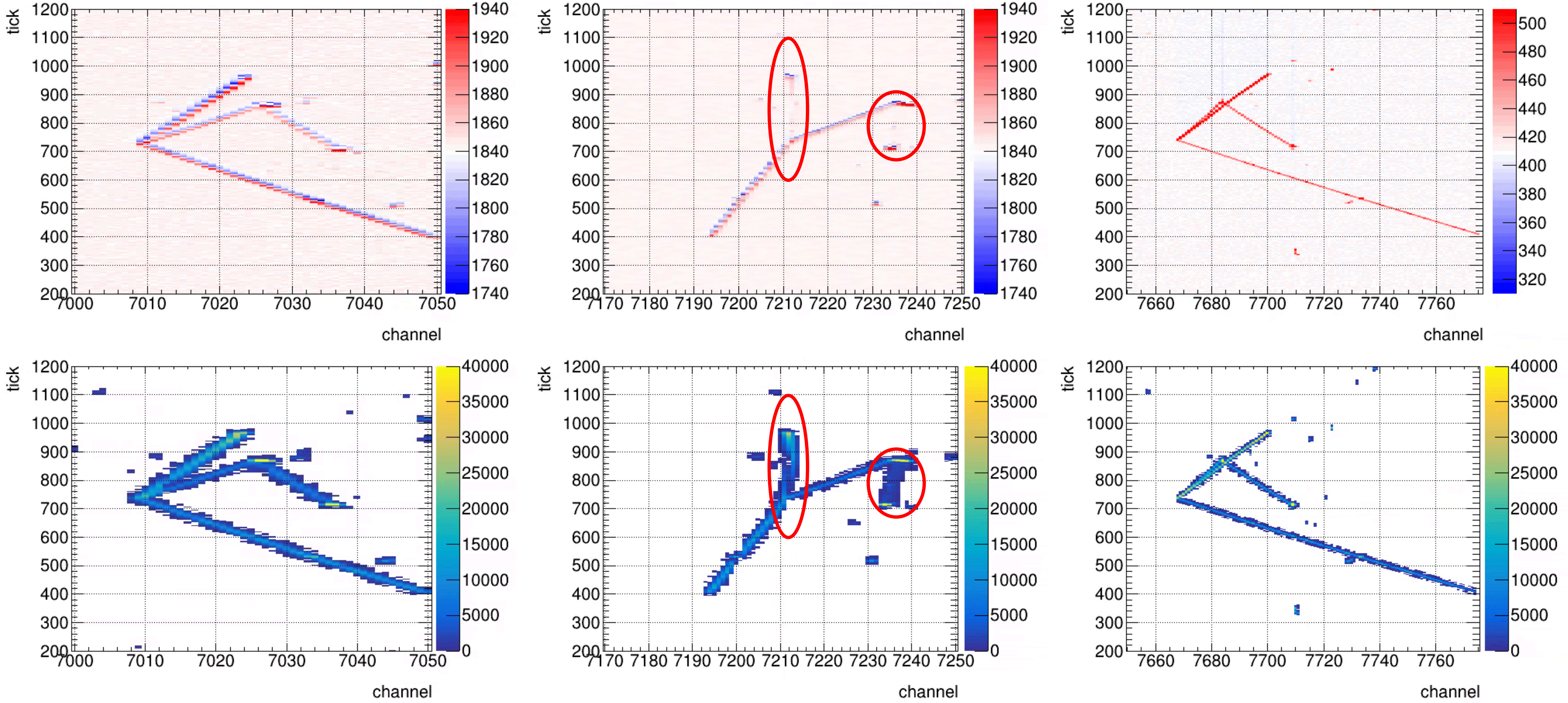
Initial Shape Validation of the field simulation 50L 2view prototype

- Validation done with Ar39 and Cosmic muon tracks from 50L 2view prototype
- Initial shape comparison shows nice agreement





Wire-Cell TPC Simulation and Signal Processing on Vertical Drift



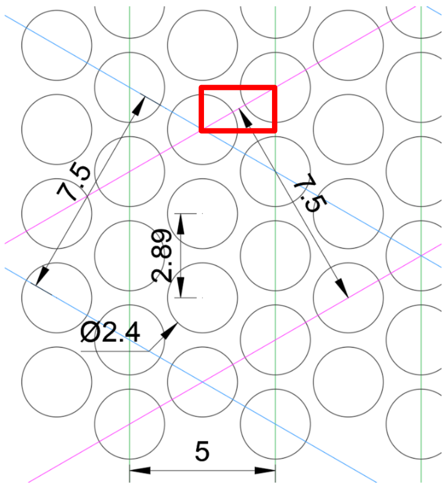
Two Selected Topics

Field response (FR) calculation

Current TPC detector 2D simulation and 2D signal processing assumes *translational symmetry in the third dimension*. However, field response calculation is essentially 3D

- Rectangular repetition patches – F. Pietropaolo
- Laplace Equation with FDM
  - E field and weighting field E_w
  - Ramo's theorem: $i = -q\vec{E}_w \cdot \vec{v}_q$
- Current available FR: 50L 2view prototype, 3view-30deg

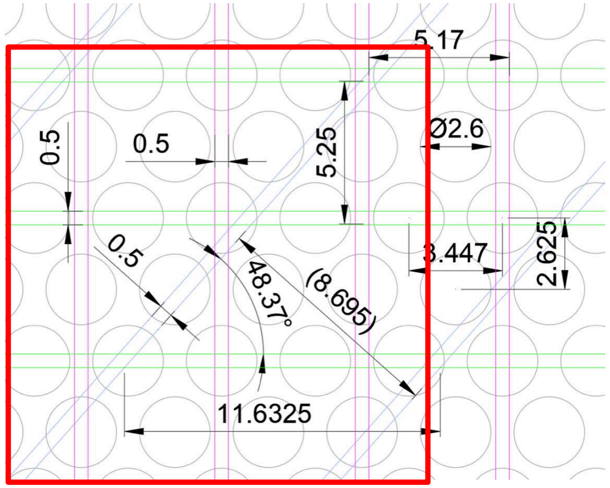
-30, 30, 90 design



Because of the hardware constrains, current 48° 3view design needs a much larger repetition patch, which gives additional challenges to the simulation and SigProc

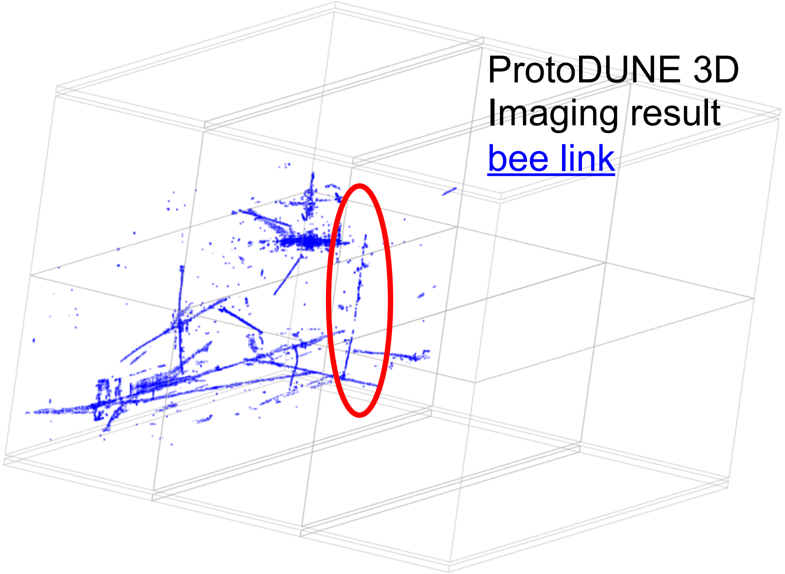
- ~ ×68 of 30° ⟶ computationally expensive
- 3D ⟶ 2D averages too large distance ⟶ larger charge/energy uncertainties
- We may need to build a 3D simulation/SigProc (e.g. iterative approach to extract the impact position along the strip)

-48, 0, 90 design



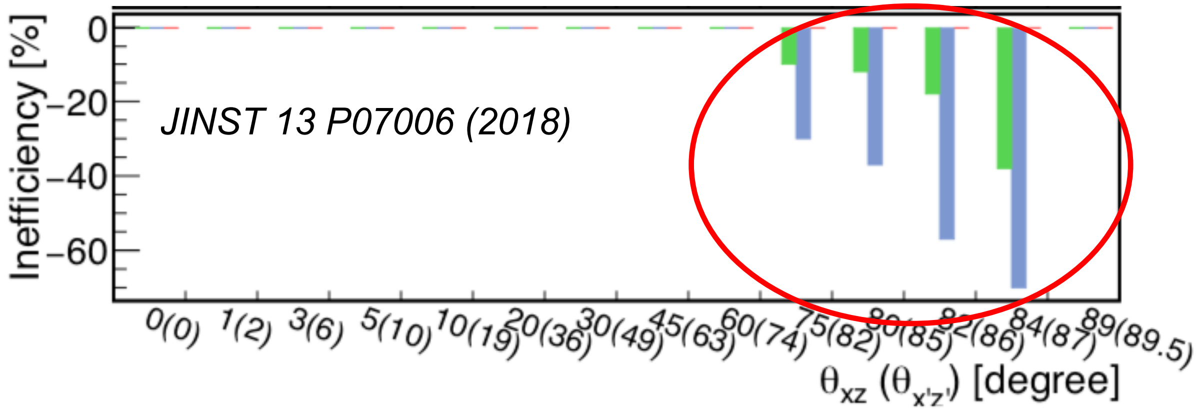
Translational symmetry approximation is good if considering region much larger than the red box.

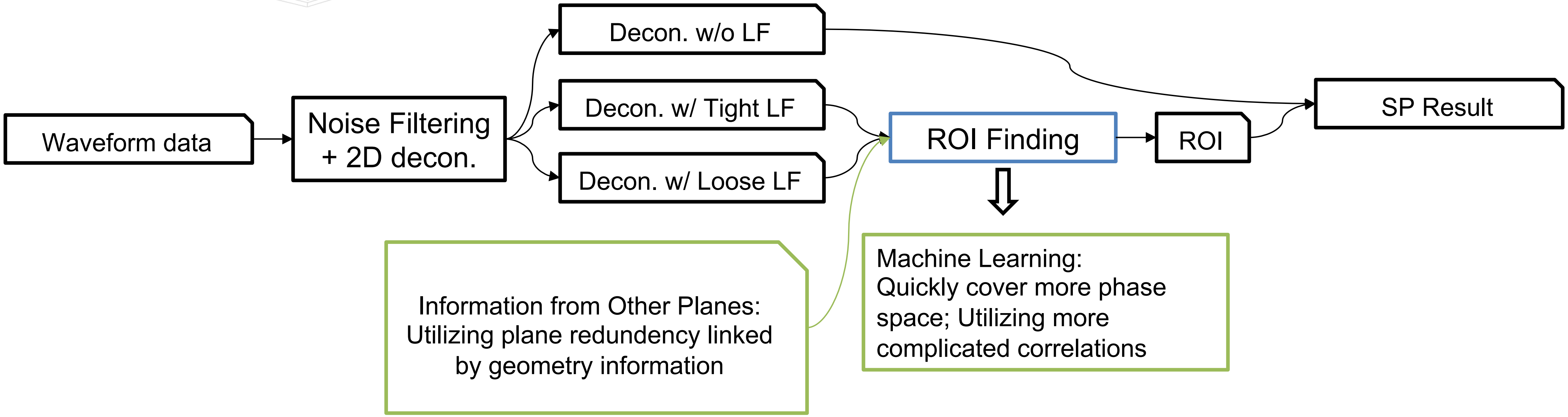
Prolonged tracks



ProtoDUNE 3D
Imaging result
[bee link]

MicroBooNE simulation evaluation

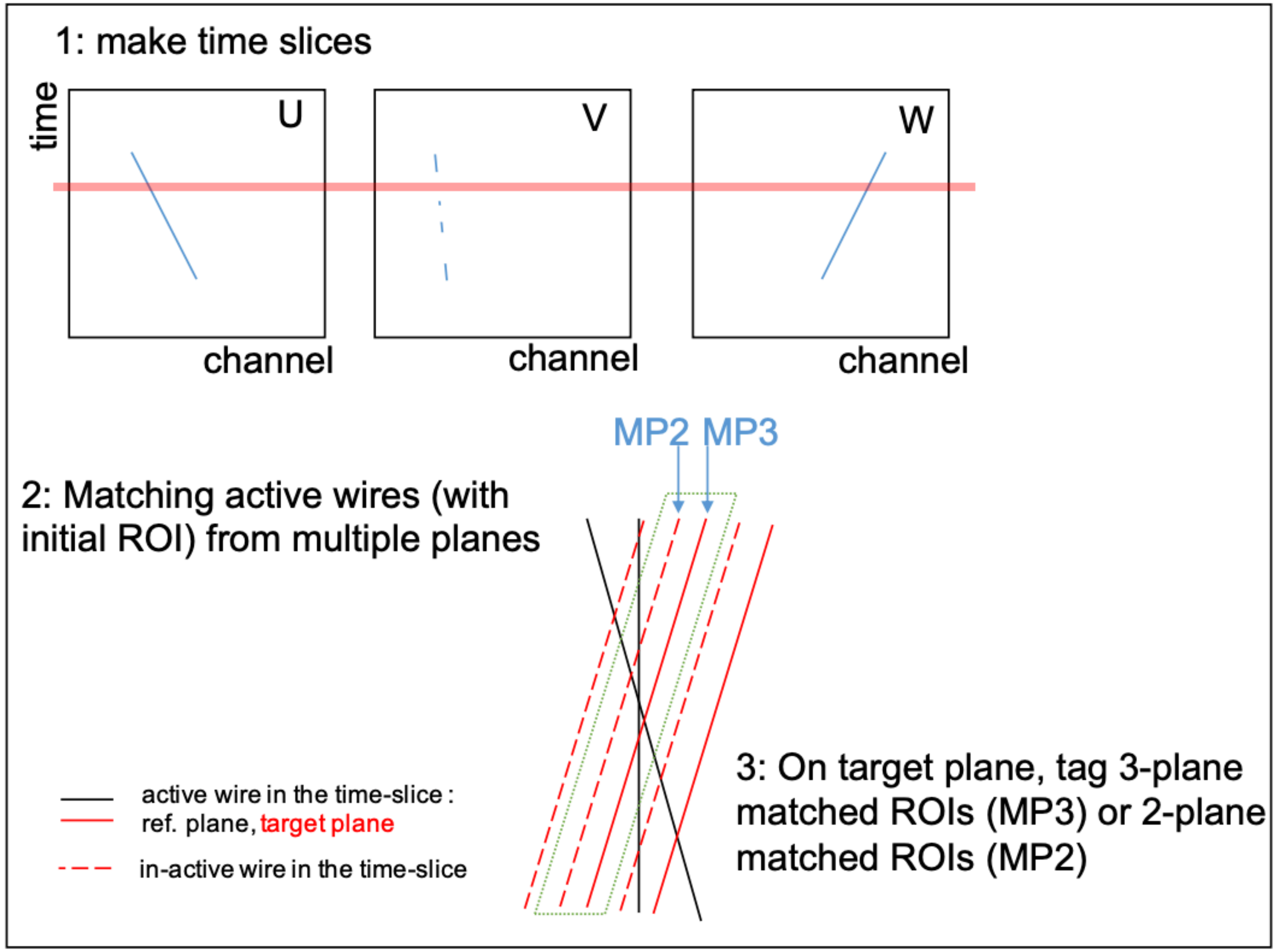




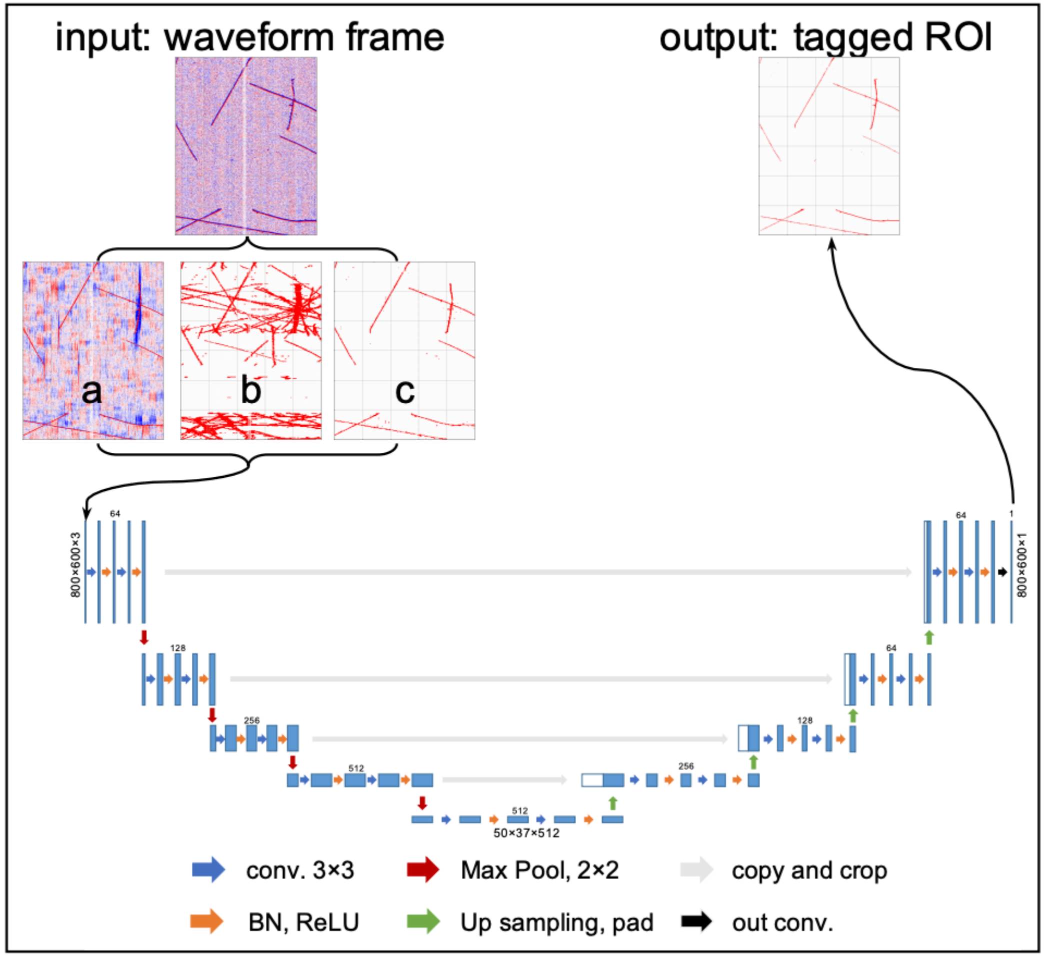
DNN ROI finding with 3-plane information

JINST 16 (2021) 01, P01036

Multi-plane information in Signal Processing

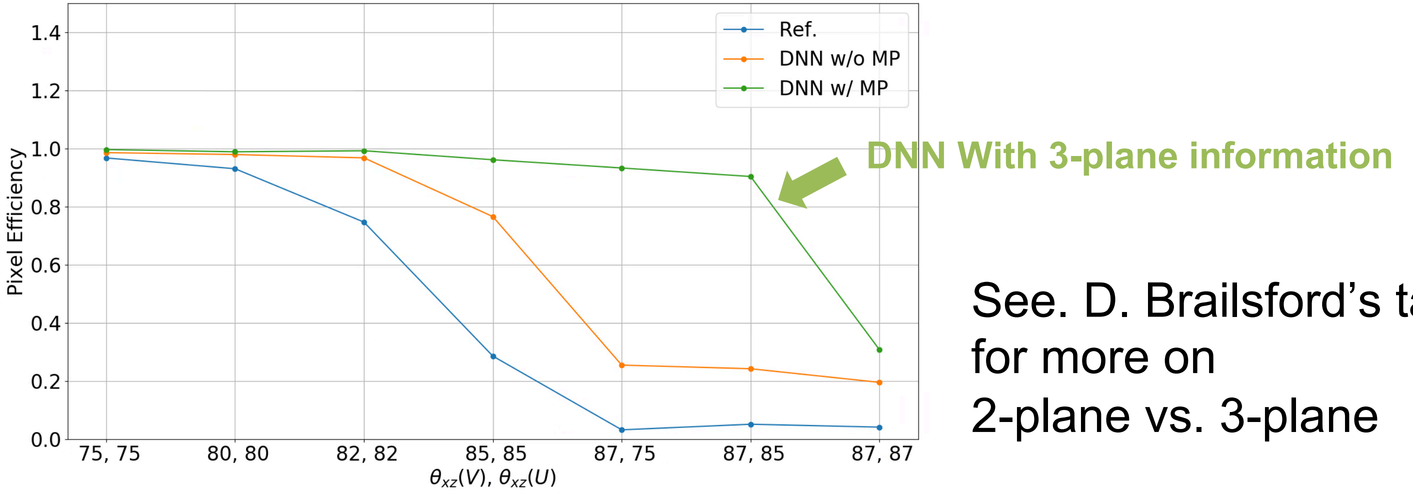


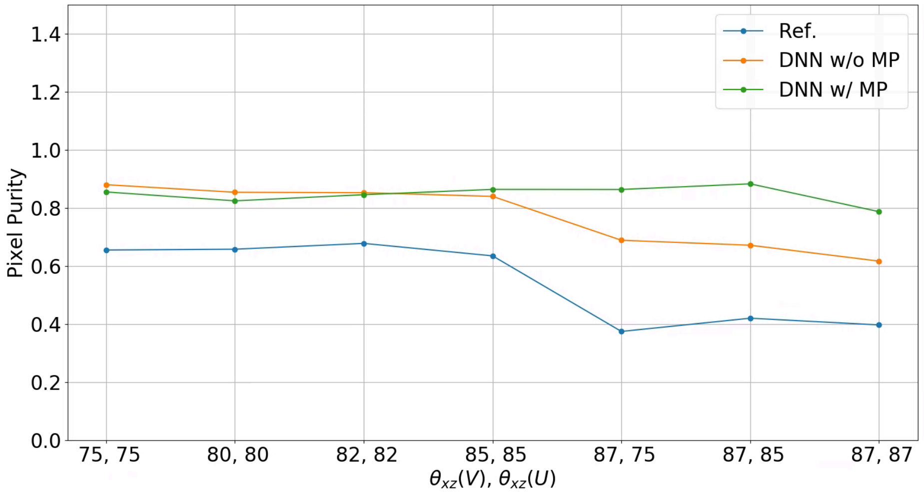
DNN ROI finding with multiple input channel



DNN ROI finding with 3-plane information (II)

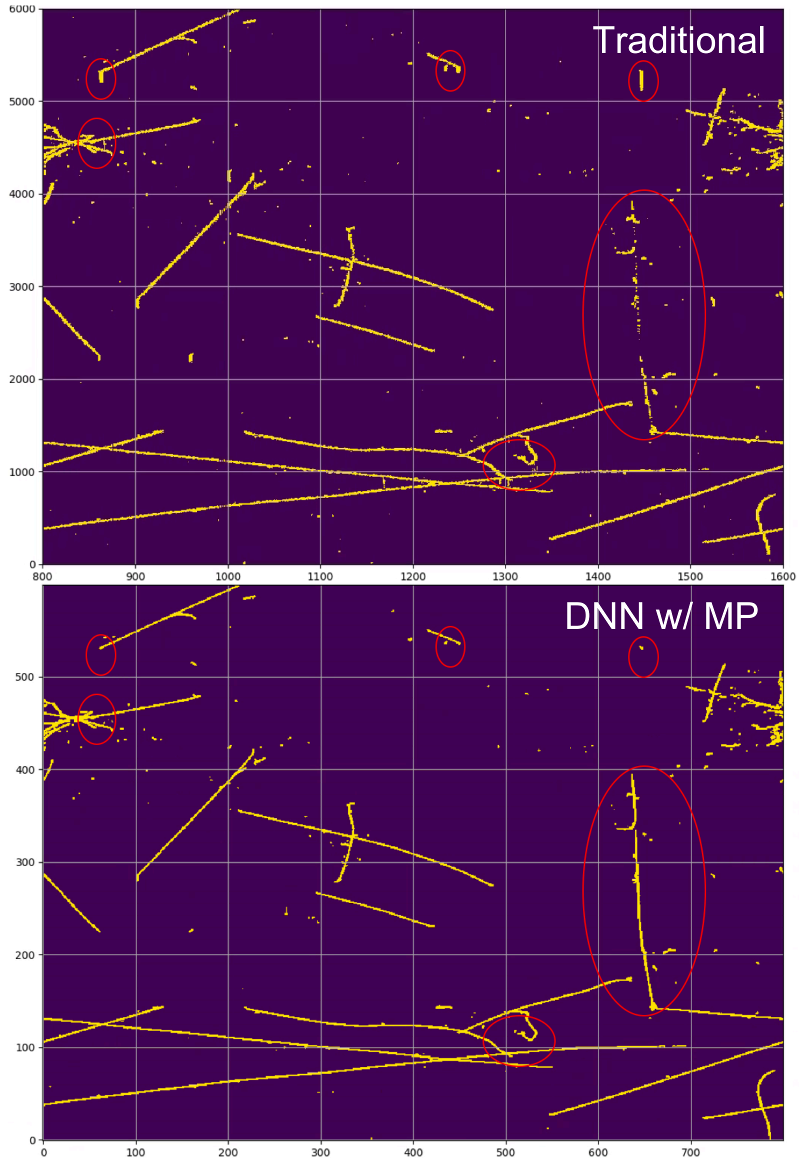
ProtoDUNE simulation
ROI finding on V plane





See. D. Brailsford's talk for more on 2-plane vs. 3-plane

tested on ProtoDUNE data

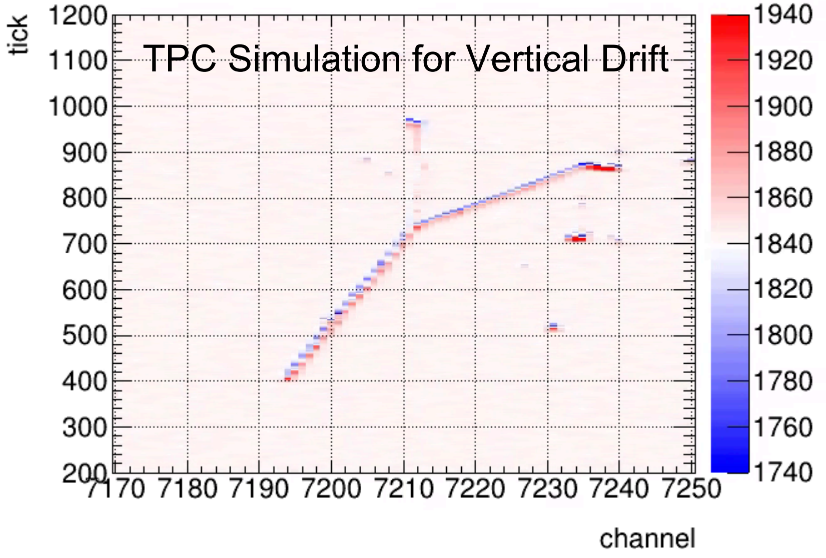


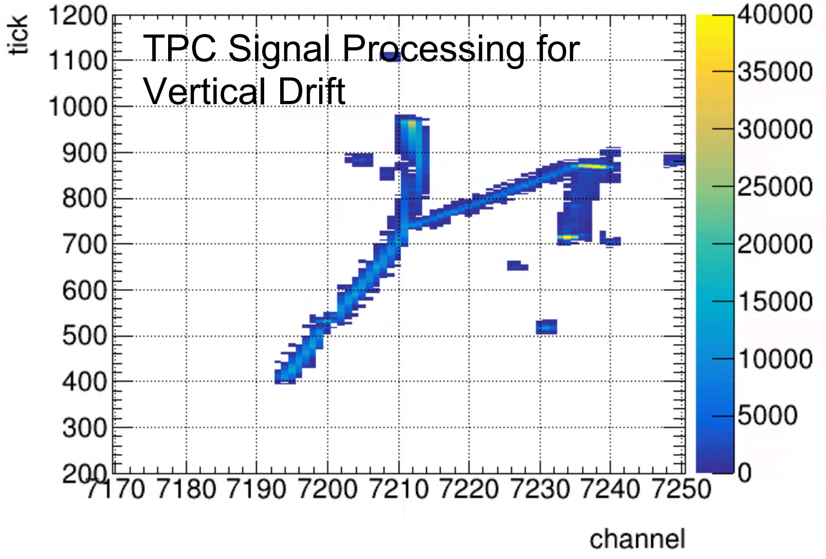
Summary

- Detector simulation and TPC signal processing have been successfully implemented for Vertical Drift Configuration
  - Wire-Cell 2D simulation and signal processing package have been extensively validated by data in MicroBooNE and ProtoDUNE

- We will continue validation with more experimental data in the DUNE Vertical Drift Detector Project

- Good signal simulation/reconstruction is important to the ultimate physics reach of this detector. Two related issues were discussed:
  - Smaller repetition patch is crucial for the validity of the translational symmetry assumption used in 2D signal simulation and processing
  - Deep-learning based signal processing with 3-plane geometry information





References

Wire-Cell simulation and signal processing:

- *JINST 12 P08003*
- *JINST 13 P07006*
- *JINST 13 P07007*

Wire-Cell DNN ROI finding:

- *JINST* 16 P01036

Wire-Cell Vertical Drift development:

- Noise Simulation
- Vertical Drift SimChannel and Horizontal Drift validation
- Wire-Cell TPC simulation for Vertical Drift
- Field Response Simulation
- Initial Shape Validation of the field simulation 50L 2view prototype

BACKUP