Signal Processing in the ProtoDUNE-SP LArTPC

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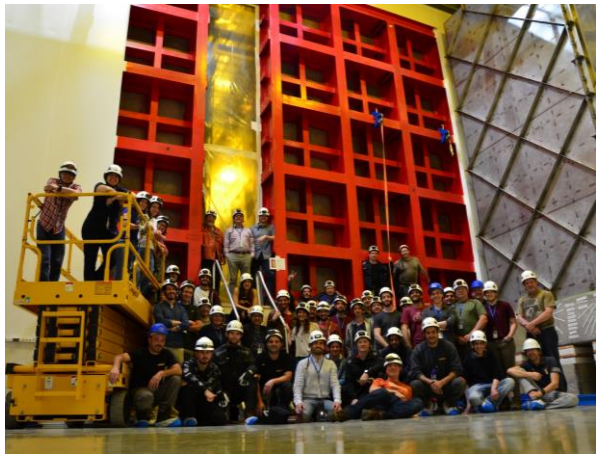
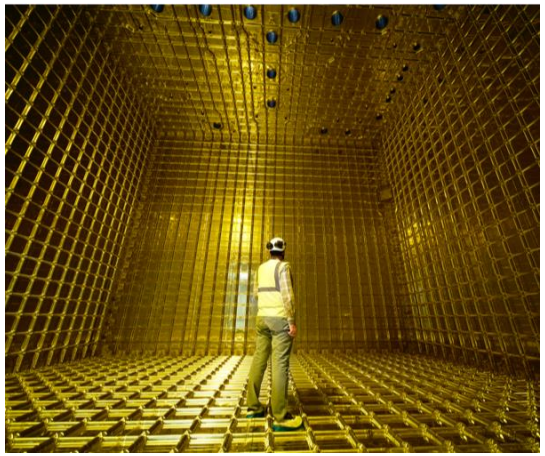
For the DUNE collaboration

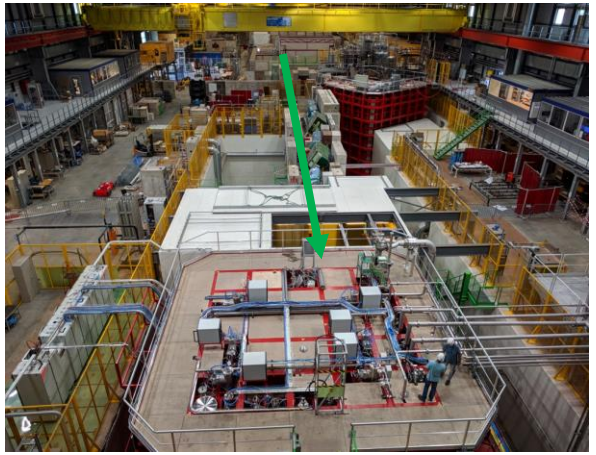
T12.00005, Hannah Elizabeth Rogers
Overview of ProtoDUNE and Initial Study of Space Charge

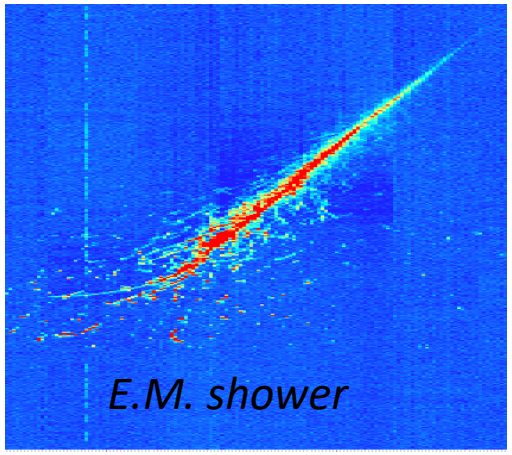
ProtoDUNE Single Phase (SP)

- A **0.77-kt** LArTPC at the CERN Neutrino Platform (NP)
  - World largest monolithic single-phase LArTPC
- Prototypes DUNE far detector (FD) components design at **1: 1 scale**
- Started operation in late 2018
  - Exposed to cosmic & a dedicated charged particle beam (0.3 - 7 GeV) → *similar energy to ν's interaction in DUNE*









ProtoDUNE-SP Overview

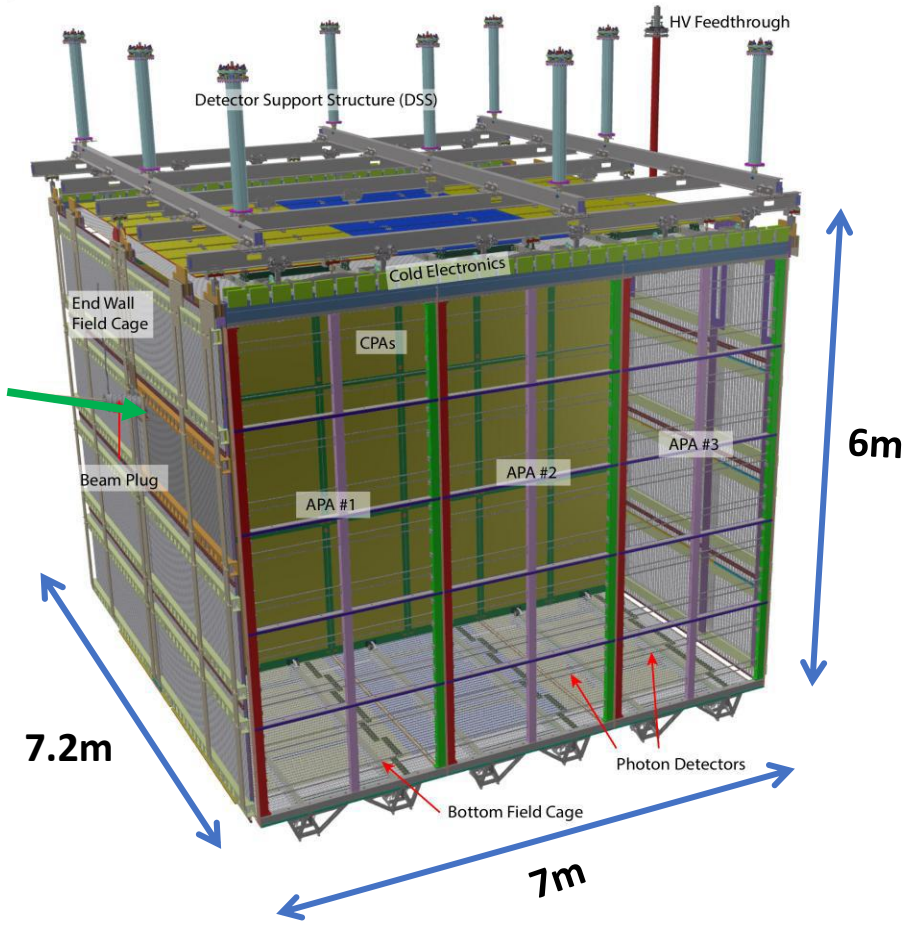
- **6 Anode Plane Assemblies (APAs)**
  - Total **15,360** TPC sense wires/channels with ~ 5mm pitch

  99.74%: active channels

- **3 Cathode Plane Assemblies (CPA)**
  - Resistive Kapton laminated on dielectric panels
  - 180 kV nominal (2 x 3.6 m drift @ 500 V/cm)

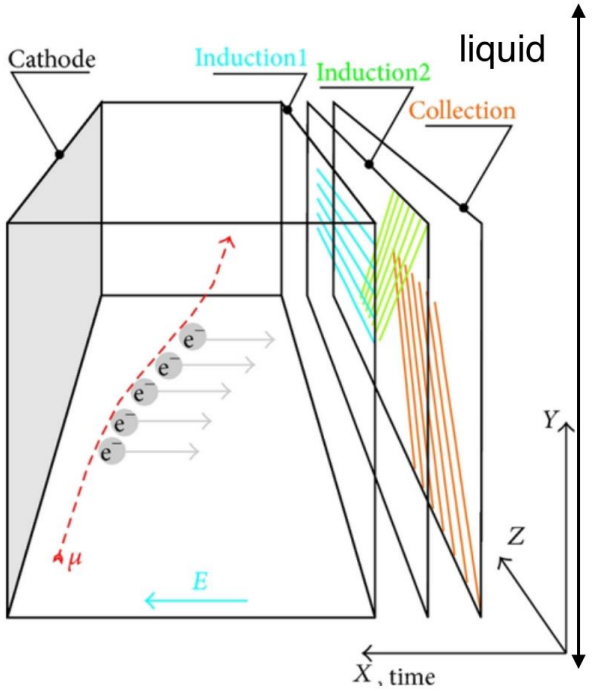
  Highest voltage in all LArTPCs to date

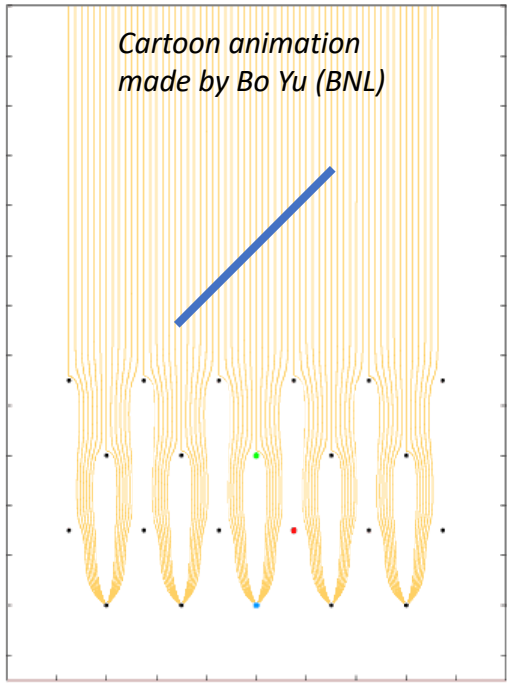
- **60 Photon Detectors**
  - Light collecting bars read out by SiPMs installed in the APA frame (10 detectors/APA)
  - 3 distinct versions installed → testing solutions for DUNE

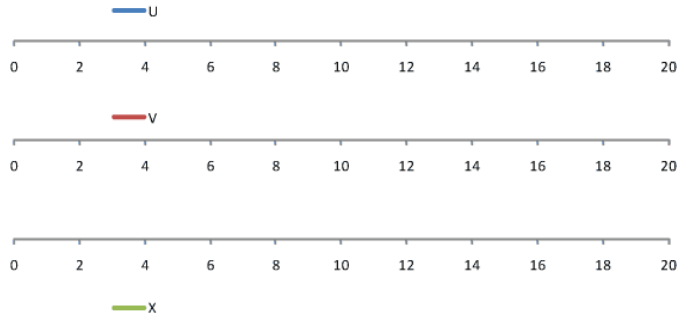


L17.00004, Bryan J Ramson
The Photon Detection System (PDS) at ProtoDUNE

ProtoDUNE: How does it work?



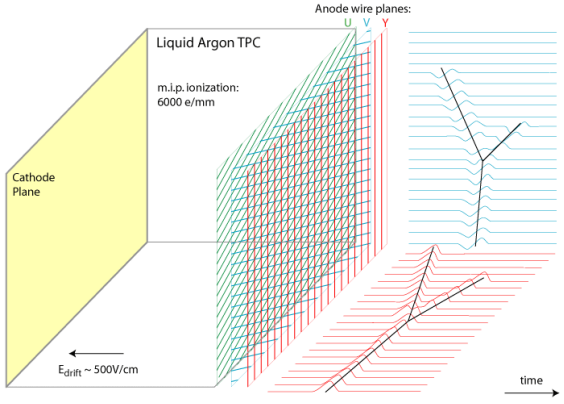




- Ionization electrons drifted and induced current read out by three wire planes
- Scintillation light collected by photon detection system
  - Providing event t_0

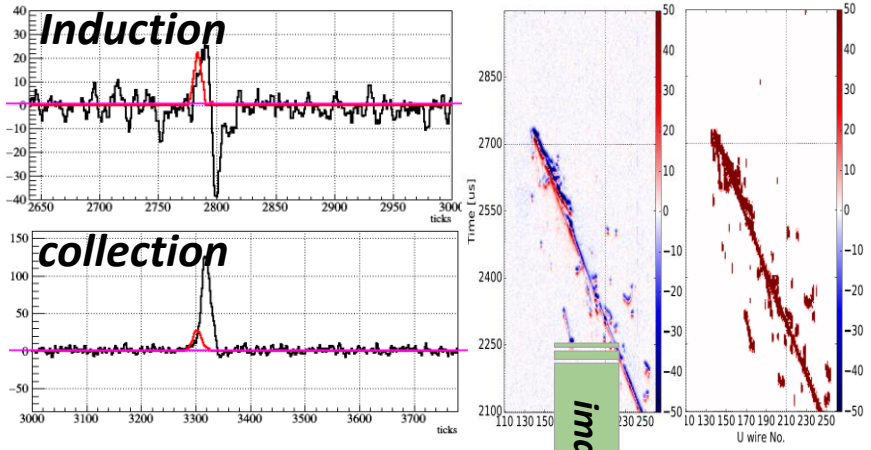
General Overview of LArTPC Reconstruction

LArTPC Signal Formation



deconvolving

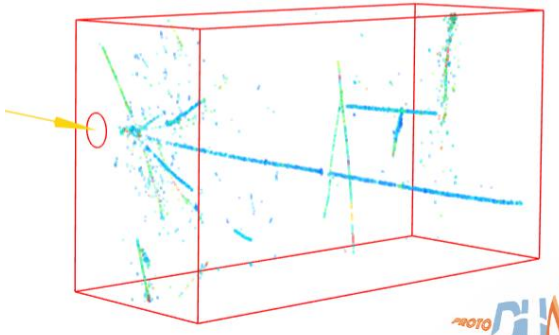
Noise Filtering & Signal Processing



Main focus of today's talk

imaging

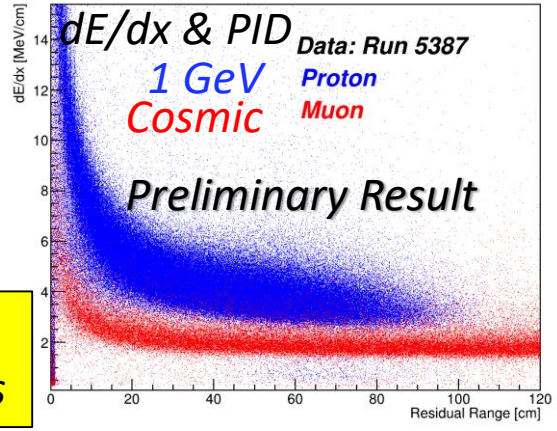
2D Matching / 3D Recon.



Imaging, pattern recognition, clustering, etc.

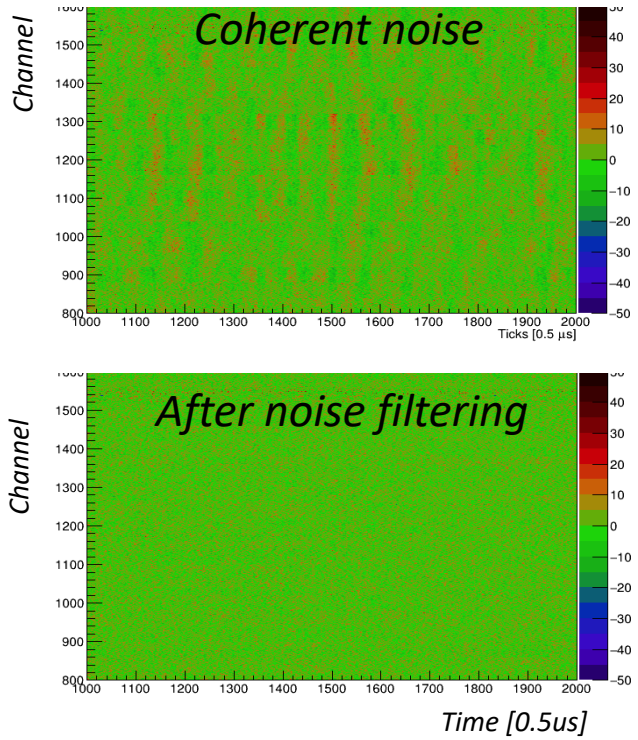
fitting

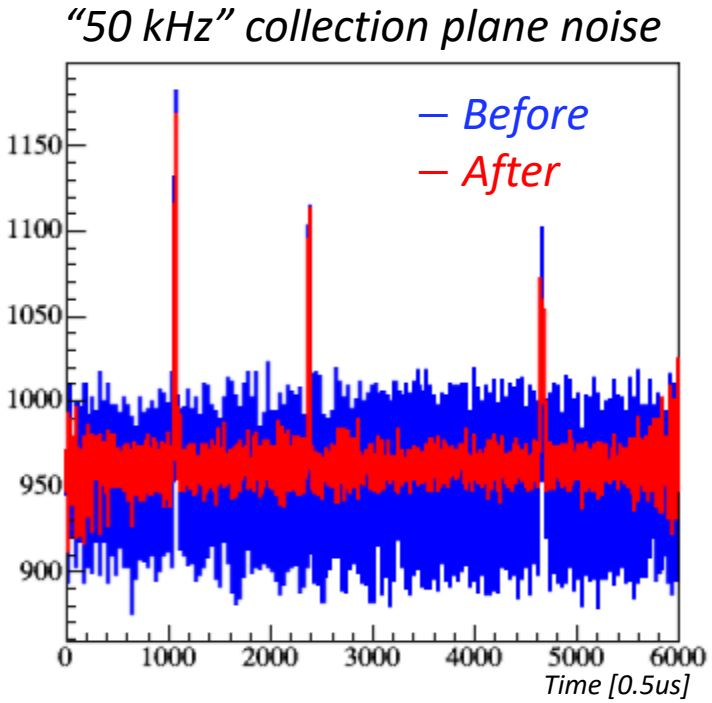
Kinematic Recon.

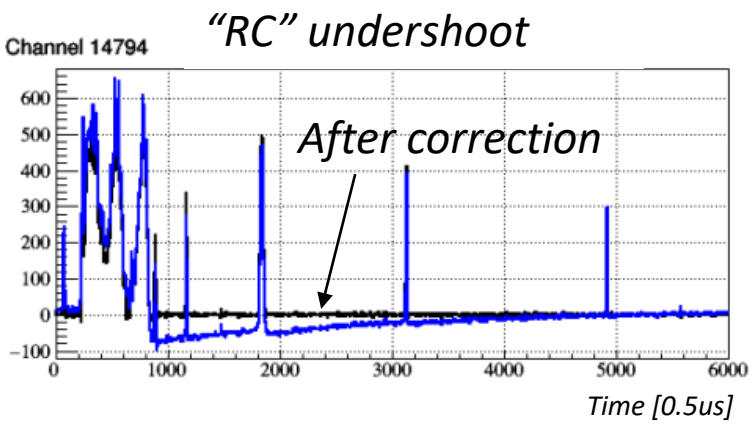


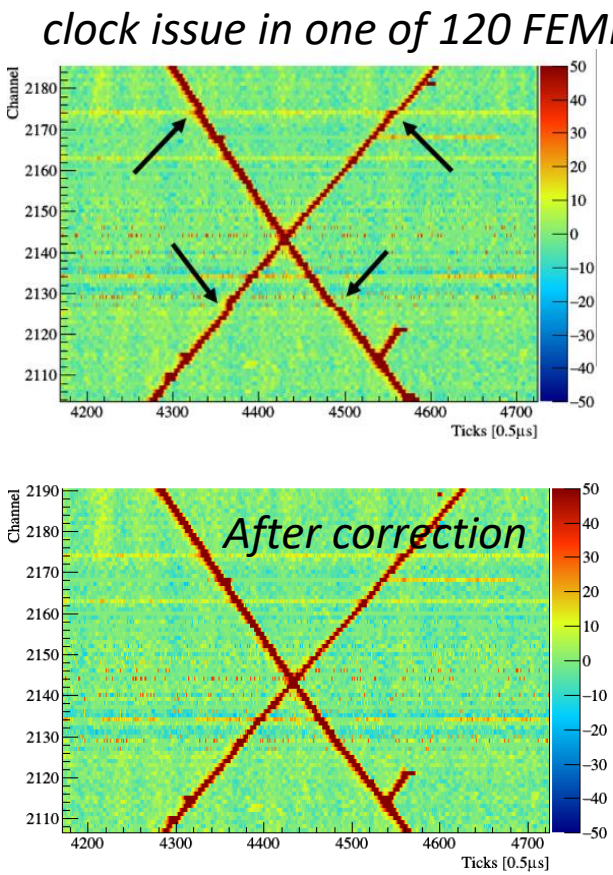
T17.00007, Heng-Ye Liao
ProtoDUNE Proton Analysis

Noise Filtering





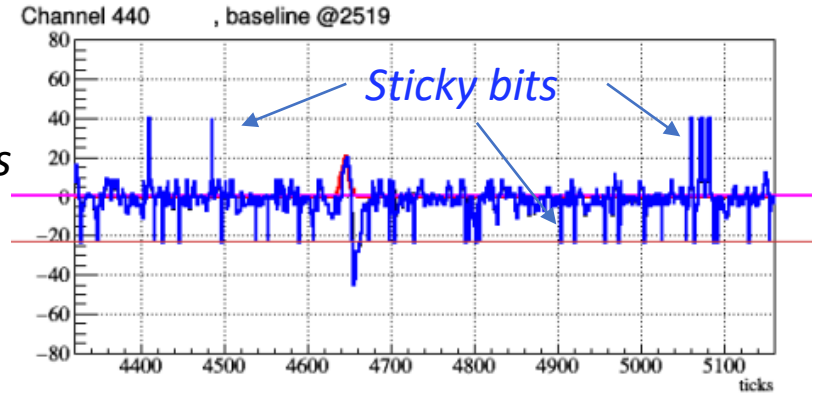


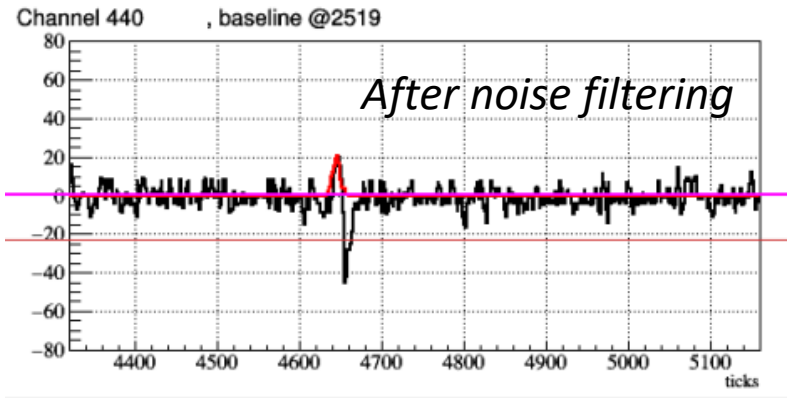


- Filter out external noise properly
- Correct additional hardware effect/distortion

Noise Filtering (cont')

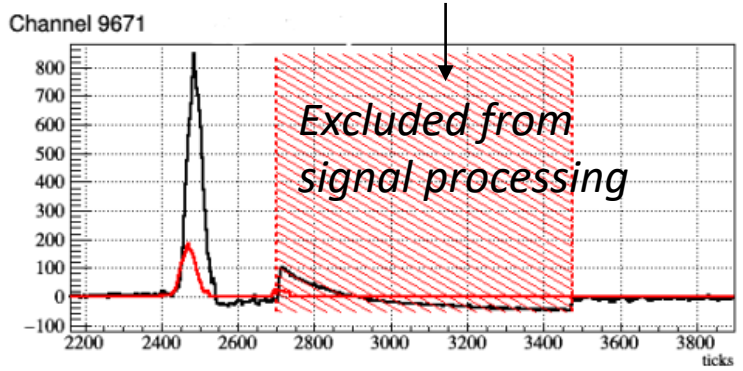
evidence in ~3% of total channels

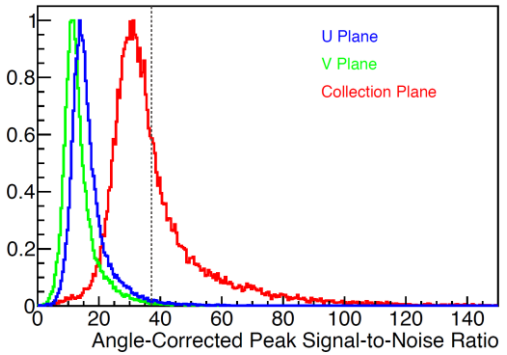




< 1% of total channels

"ledge" waveform





- Fix some residual electronics issues
- Overall performance of noise filtering is good

ENC of collection (X) plane 565 ± 60 e^-

ENC of induction (V) plane 662 ± 56 e^-

ENC of induction (U) plane 651 ± 54 e^-

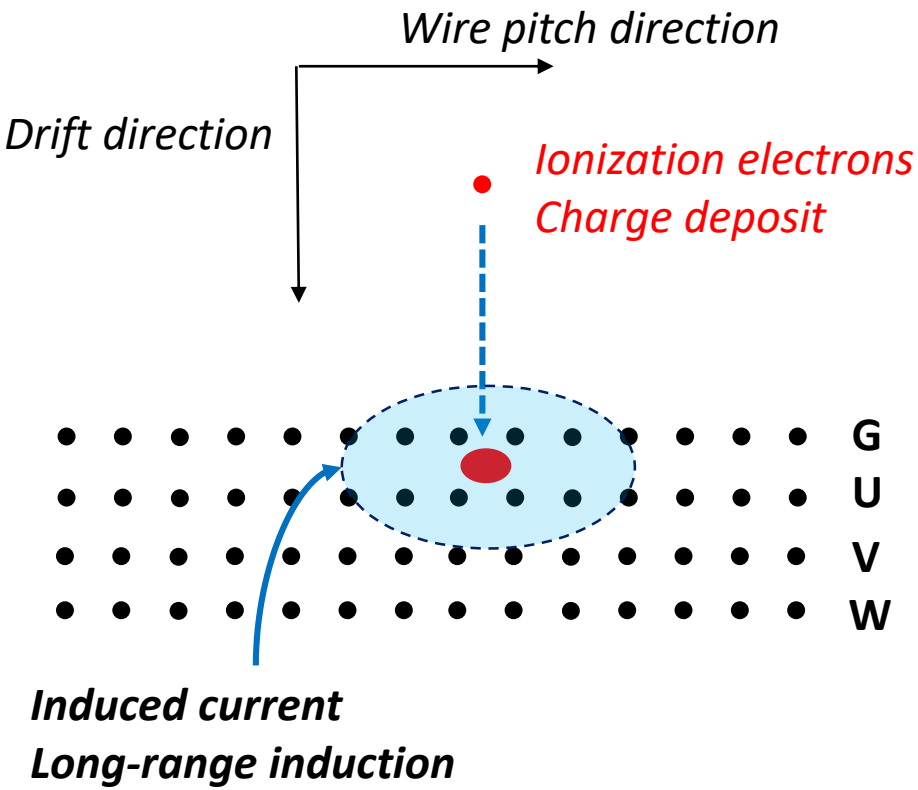
Garfield, a drift-chamber simulation program User's Guide, Veenhof, R. (1993)

Field response: ***Garfield*** drift simulation

Ramo's theorem

$i = e\vec{v} \cdot \vec{E}_v = e\vec{v} \cdot (-\nabla\phi)$

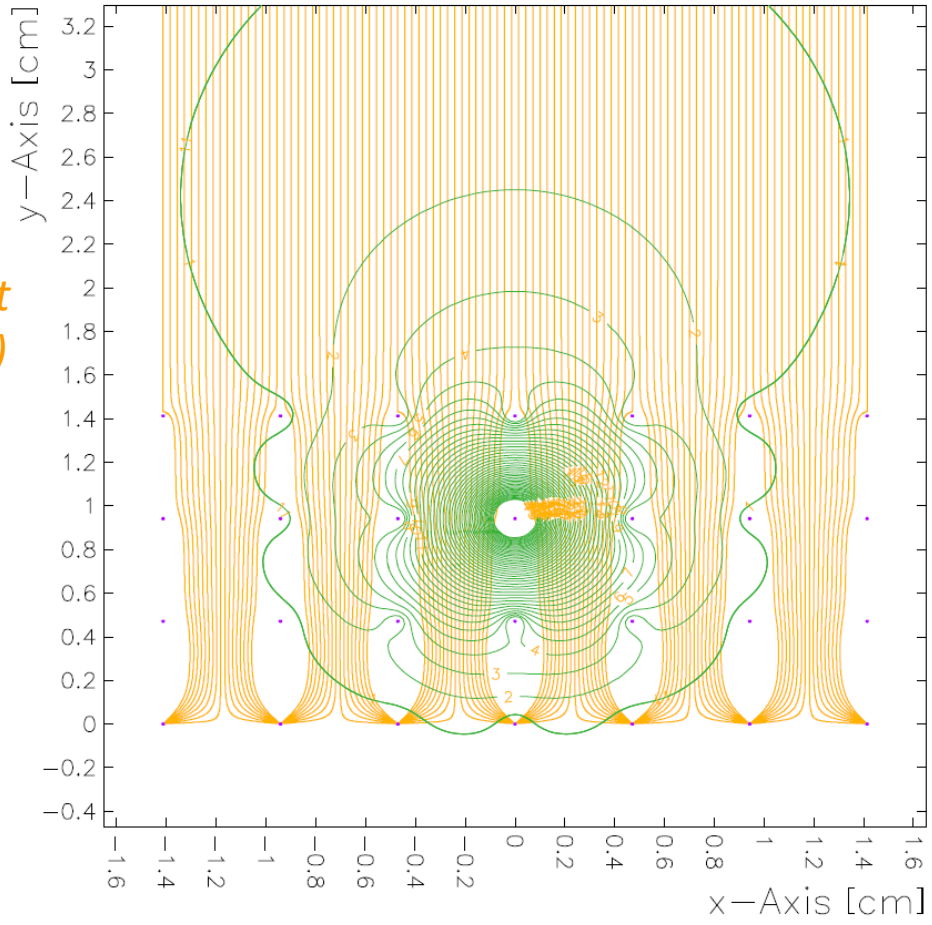
Weighting potential ϕ



Electron drift path (E field)

+

Weighting potential ϕ



Field response: ***Garfield*** drift simulation

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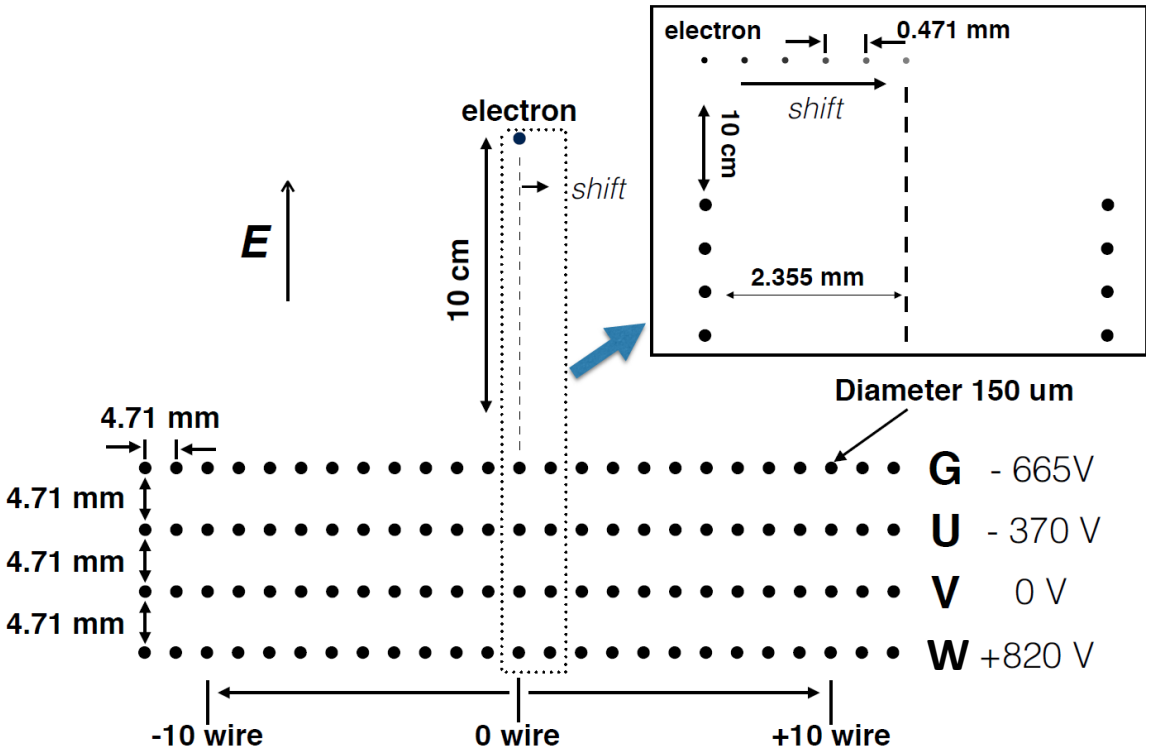
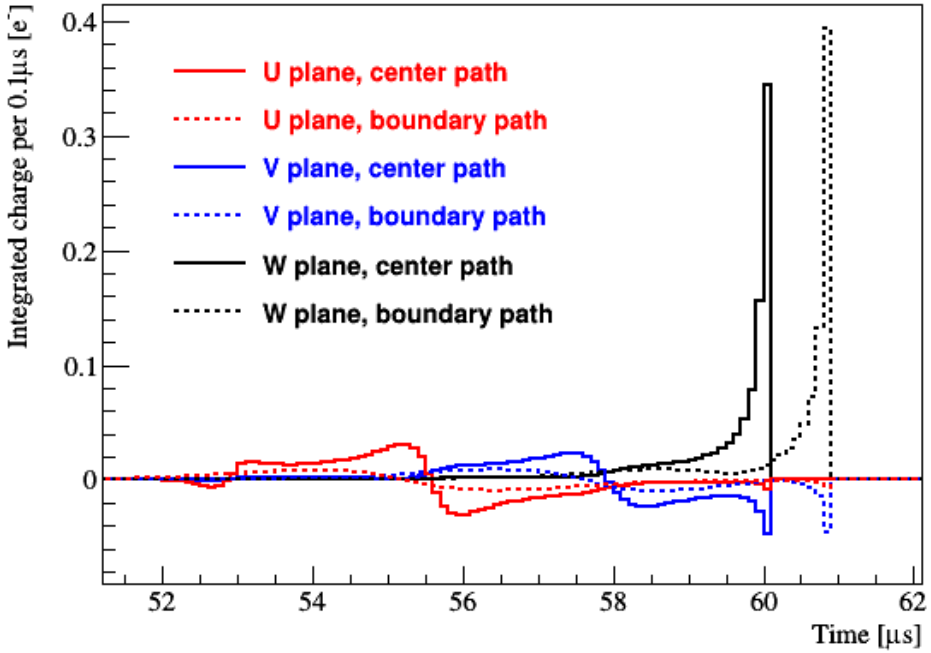


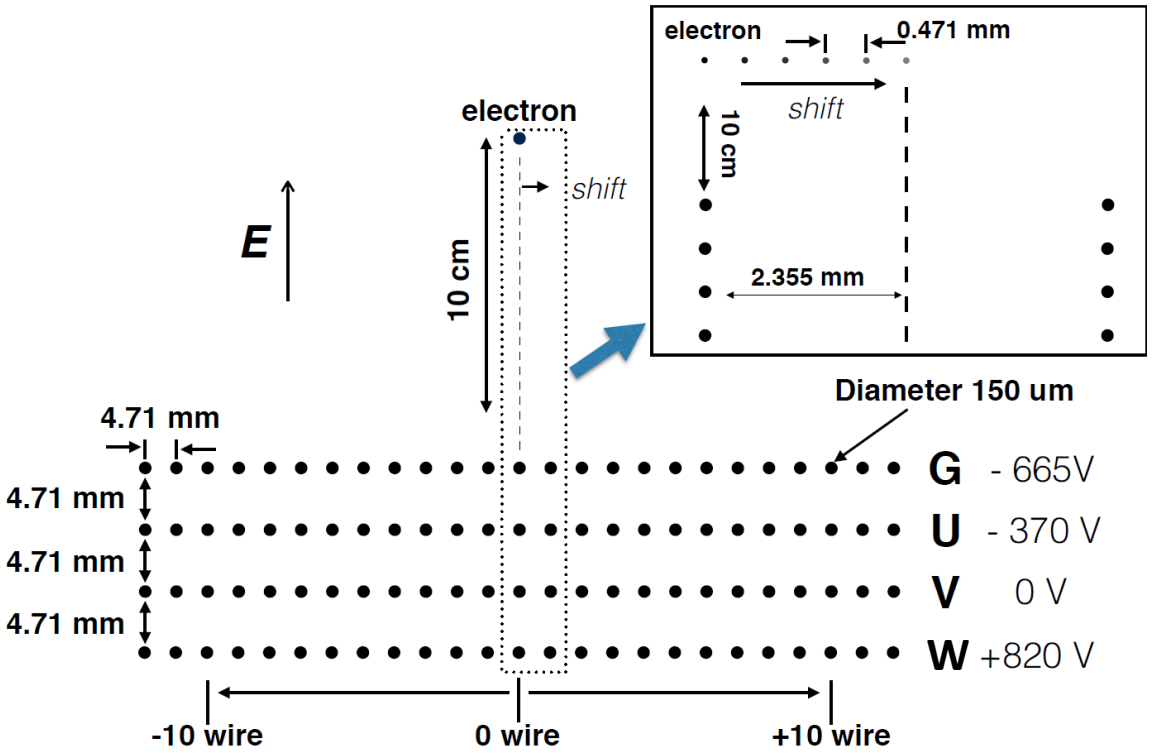


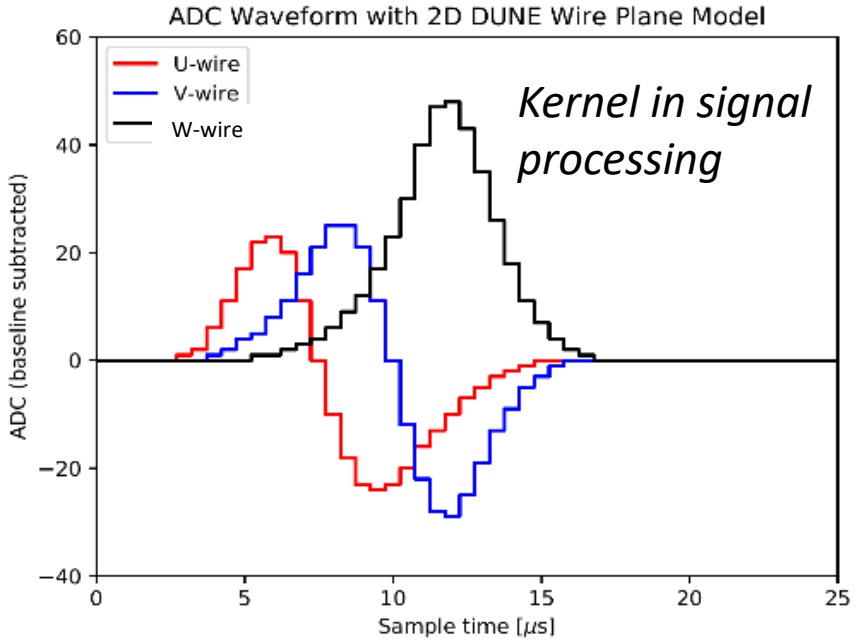
- Field response in the central wire

Field response: ***Garfield*** drift simulation

Ramo's theorem

$i = e\vec{v} \cdot \vec{E}_v = e\vec{v} \cdot (-\nabla\phi)$





- Central wire field response ⊗ electronics response (preamp etc.)
- $\mathrm{M}(t_0) = \int_t R(t - t_0) \cdot S(t) \cdot dt$

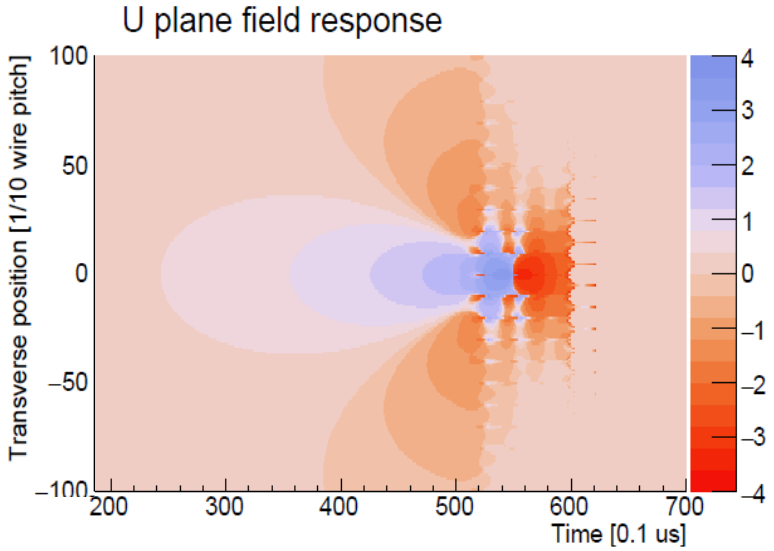
Long-range Induction: 2-D deconvolution

- It is natural to include the **long-range induction** effect in the deconvolution kernel

$$\mathrm{M}_i(t_0) = \int_t (R_0(t_0 - t) \cdot S_i(t) + \mathrm{R}_1(\mathrm{t}_0 - \mathrm{t}) \cdot S_{i+1}(t) + \ldots) \cdot dt$$

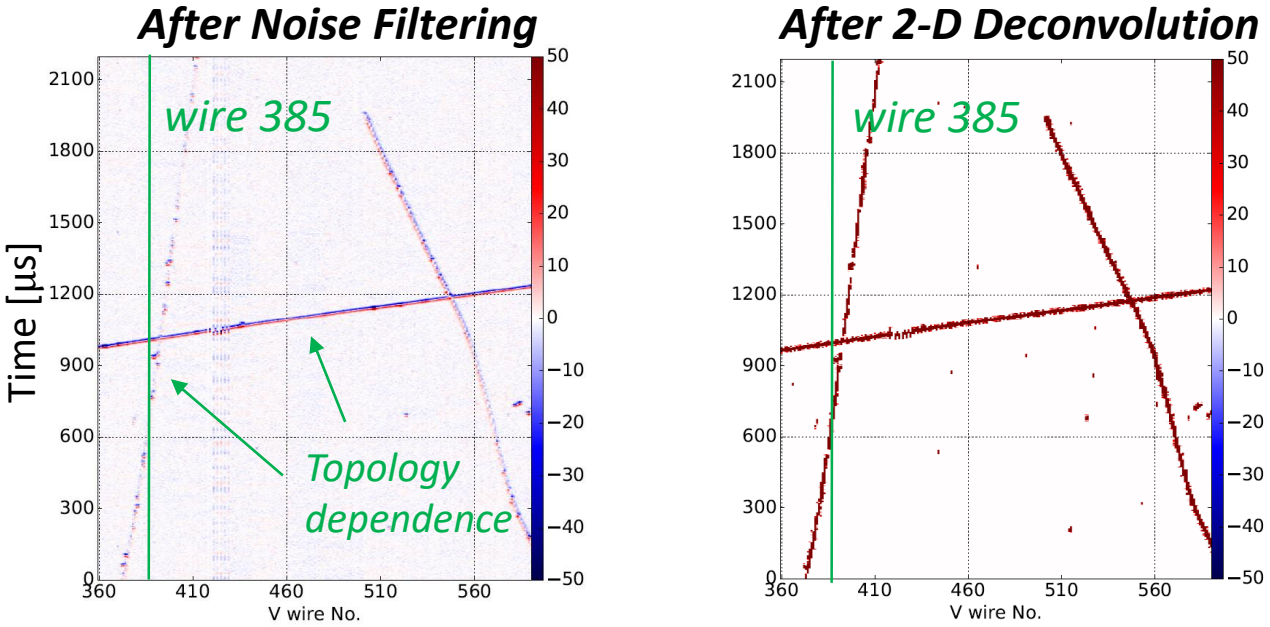
t: time, α: wire

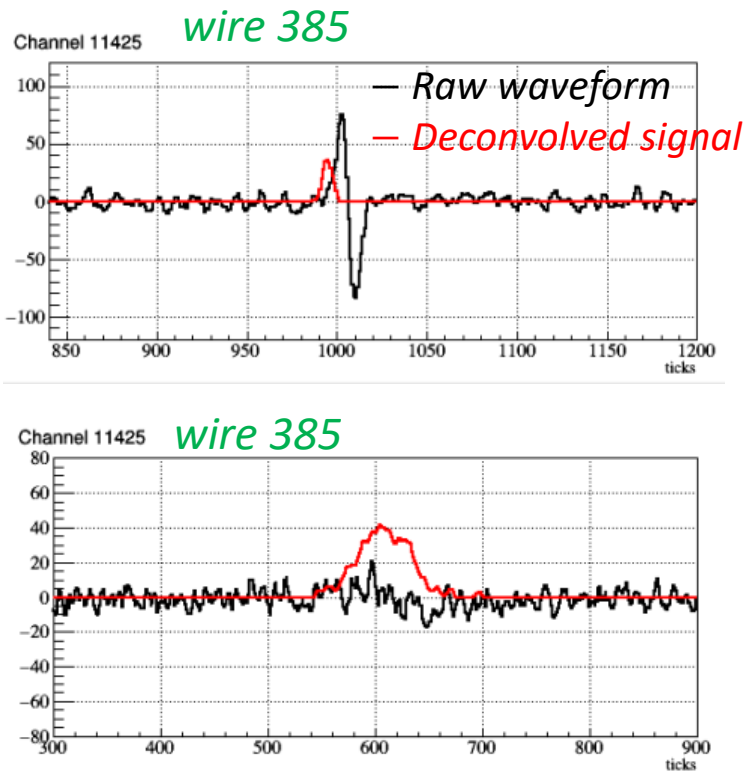
$$\mathrm{M}_i(t_0) = \iint_{t,\alpha} \boldsymbol{R}(t_0 - t, i - \alpha) \cdot \boldsymbol{S}(t, \alpha) \cdot dt\, d\alpha$$



- "2D" deconvolution (time + wire direction): M(t) -> S(t) through FFT
- Equivalently, recover ionization charges from induced current from all wires

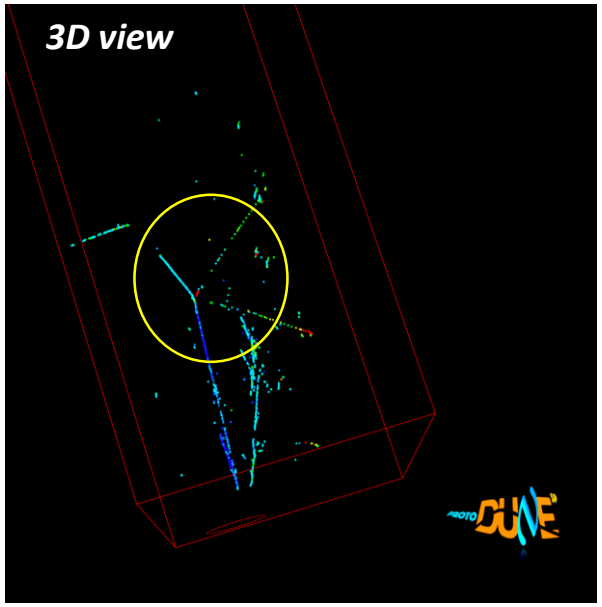
Signal Processing Example



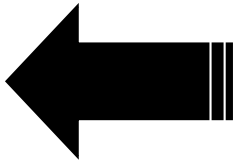


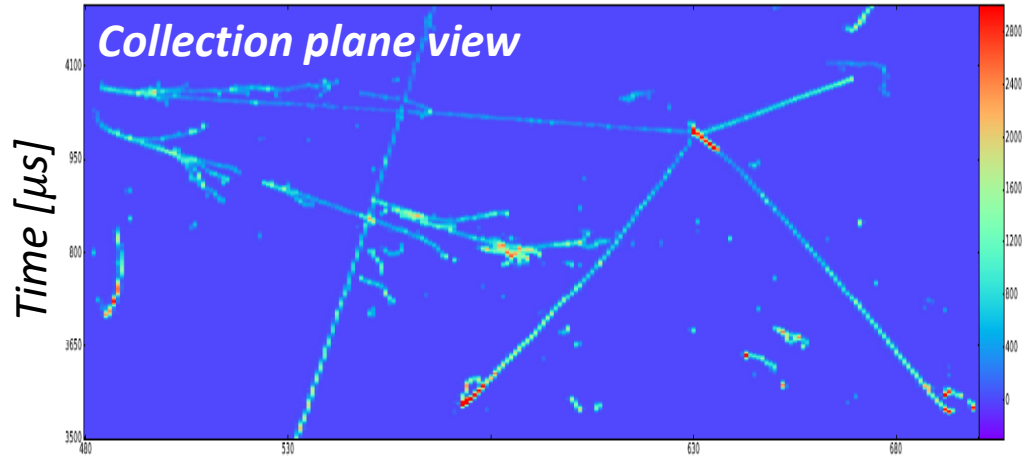
- Bipolar signal deconvolved into an unipolar charge distribution
- Long tracks in drift direction are obscure in the induction waveform
  - cancellation of successive bipolar signals ⇒ **recovered via the 2D deconvolution**

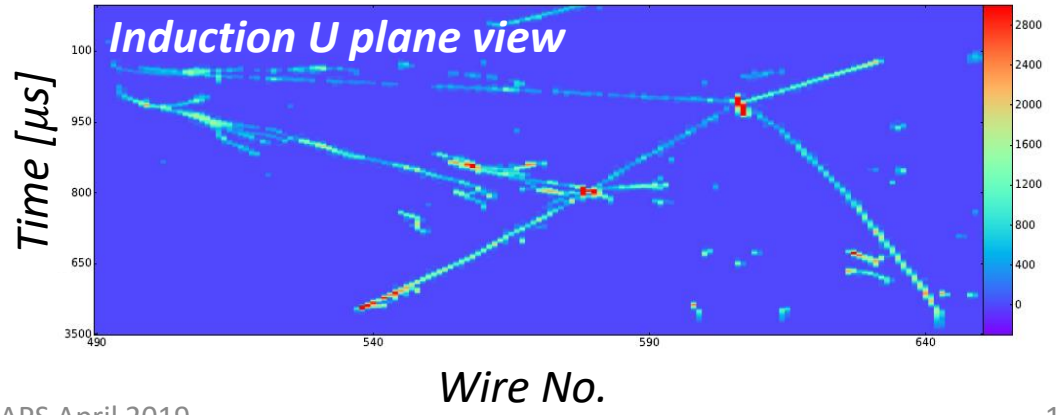
Track Reconstruction Example



Three-plane "matching" solves the degeneracies inherent from wire readout ambiguity







2 EM showers and a pion interaction with 4 outgoing particles

Summary

- ProtoDUNE-SP has been successfully operated since late 2018
  - Full-scale component design of the DUNE FD
- The “2D” signal processing technique has been developed and successfully applied to the wire readouts
  - High-quality noise filtering
  - Field response kernel: ***Garfield*** electron drift simulation
  - Long-range induction handled in the deconvolution
- High-performance signal processing is essential to the downstream event reconstruction and physics analysis

Backup Slides

Goals and challenges

ProtoDUNE-SP goals:

- Validate the prototype production and installation procedures
- Confirmation of the design and suggest improvements

- Test-beam data to calibrate the detector response to different particle species and to measure argon-hadrons cross sections
- Demonstration of the long term stability of the detector

Challenges (not exhaustive list):

- Size and modularity: all components full size for DUNE-SP

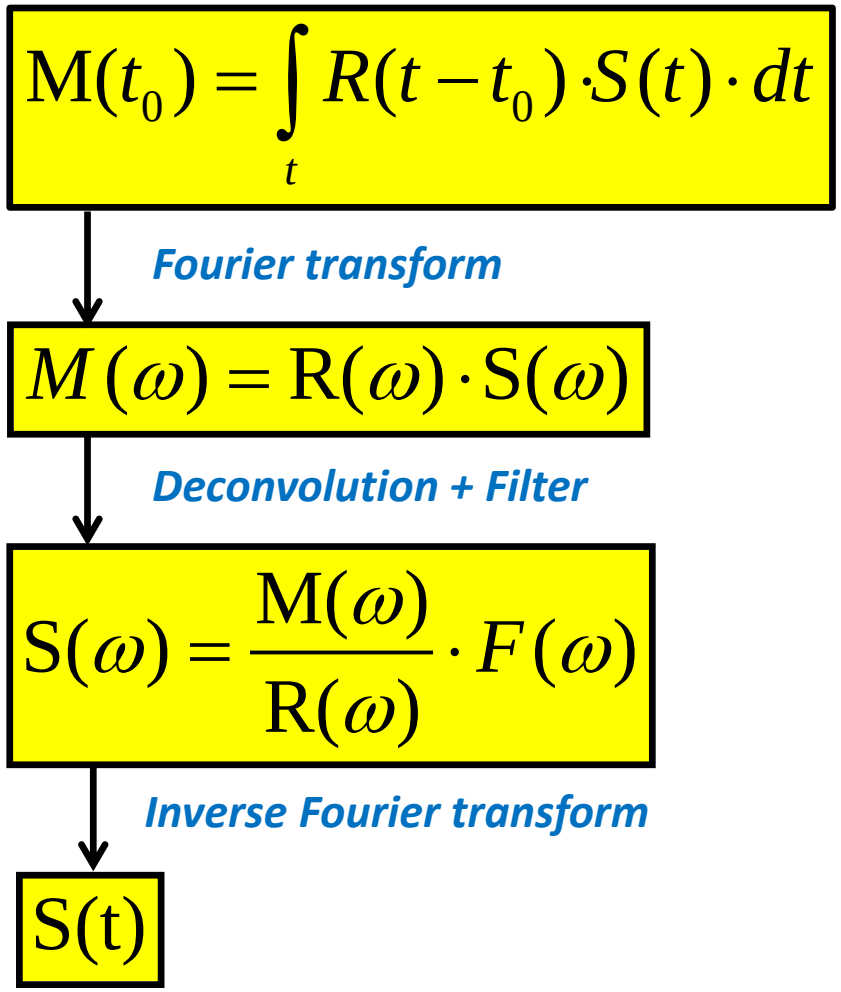
- Cryostat: warm structure, passive insulation, LNG technology

- Purity: non-evacuable volume, piston purge, purification, …

- HV: highest voltage TPC ever operated, resistive cathode

- Stability: light scintillation, HV, purity, cold electronics, …

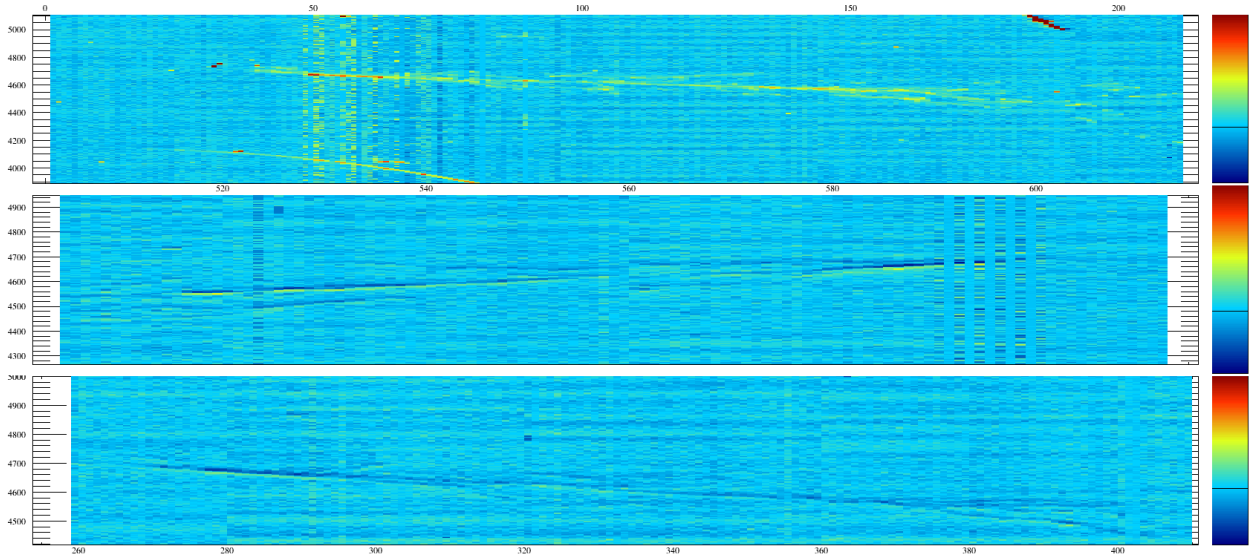
Basics of (1D) Signal Processing

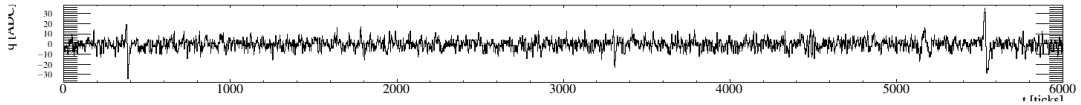


- Principal method to extract wire charge S(t) is deconvolution
- By given a response function R(t), signal S(t) can be easily derived via *Fourier transform*
- A filter function F(ω) introduced to suppress the big fluctuation after deconvolution

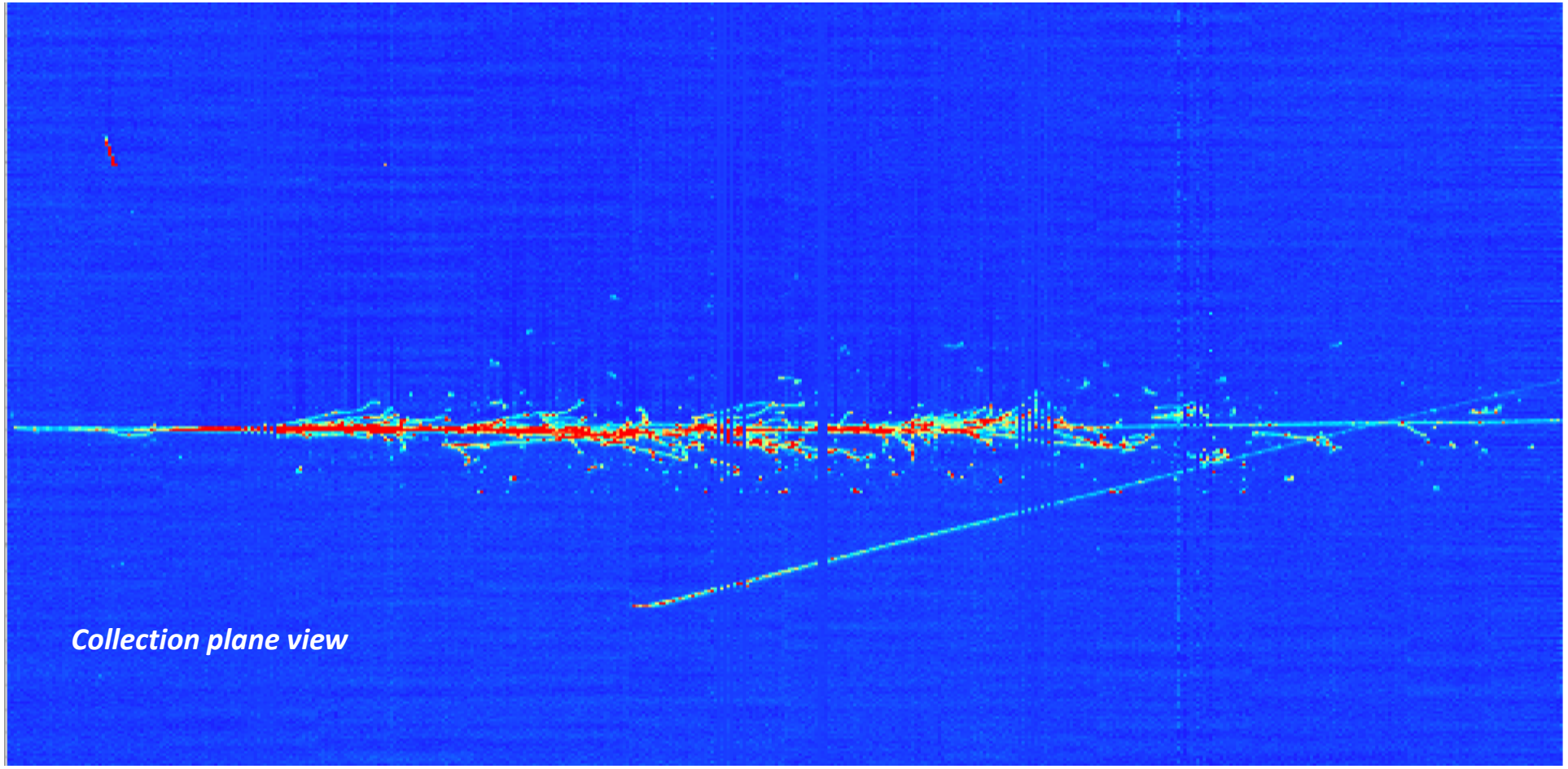
Liquid Argon TPC Signal Formation, Signal Processing and Hit Reconstruction
Bruce Baller, *JINST 12 (2017) no.07, P07010*

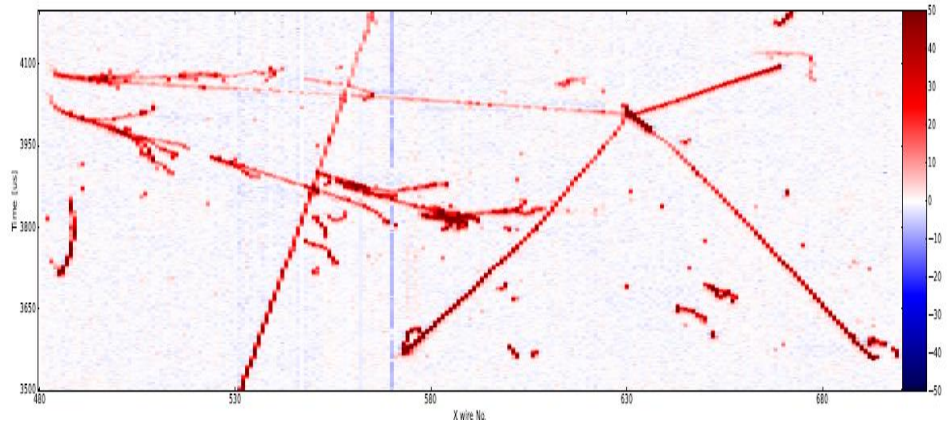
02/10/2018:
First event seen from beam!
(1 GeV electron)

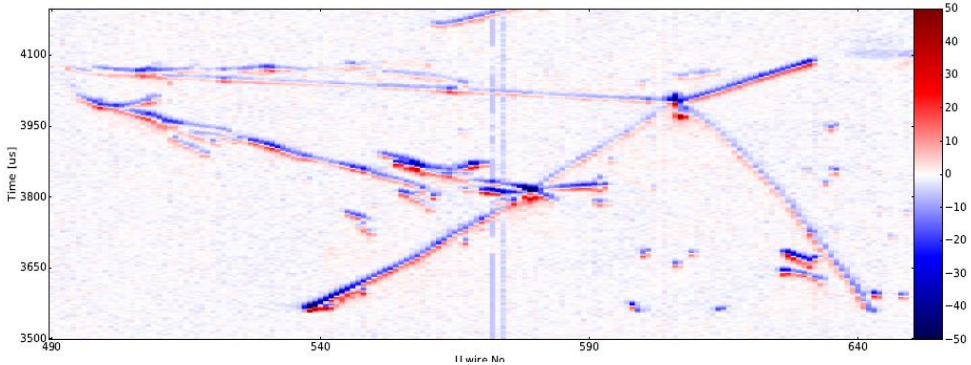


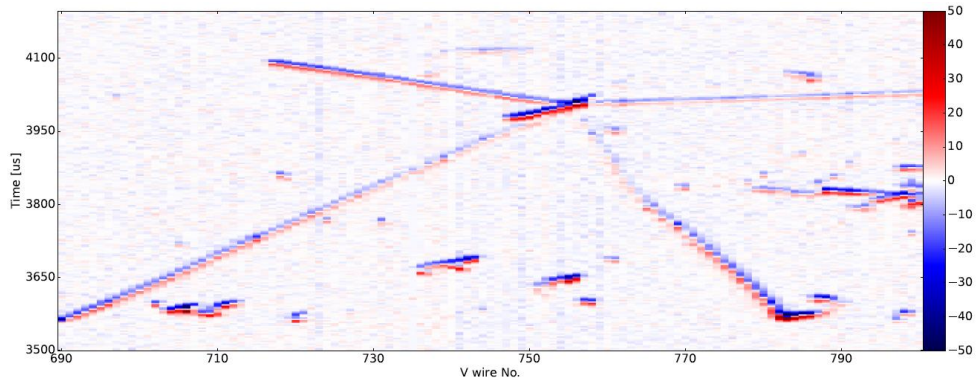


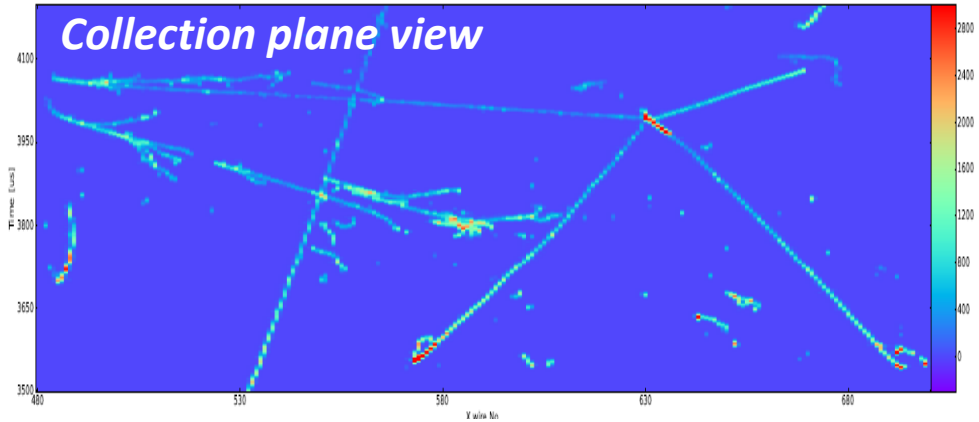
Beam halo (high energy) muon with bremsstrahlung initiated E.M. shower

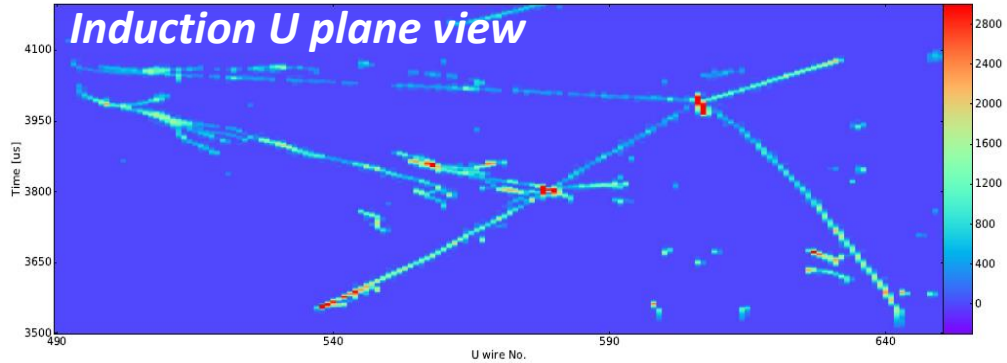


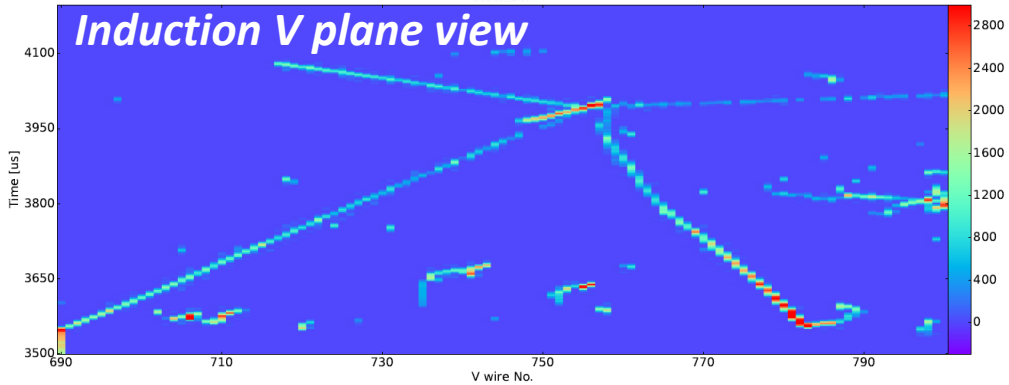

X wire No.


Time [us]
U wire No.


Time [us]
V wire No.

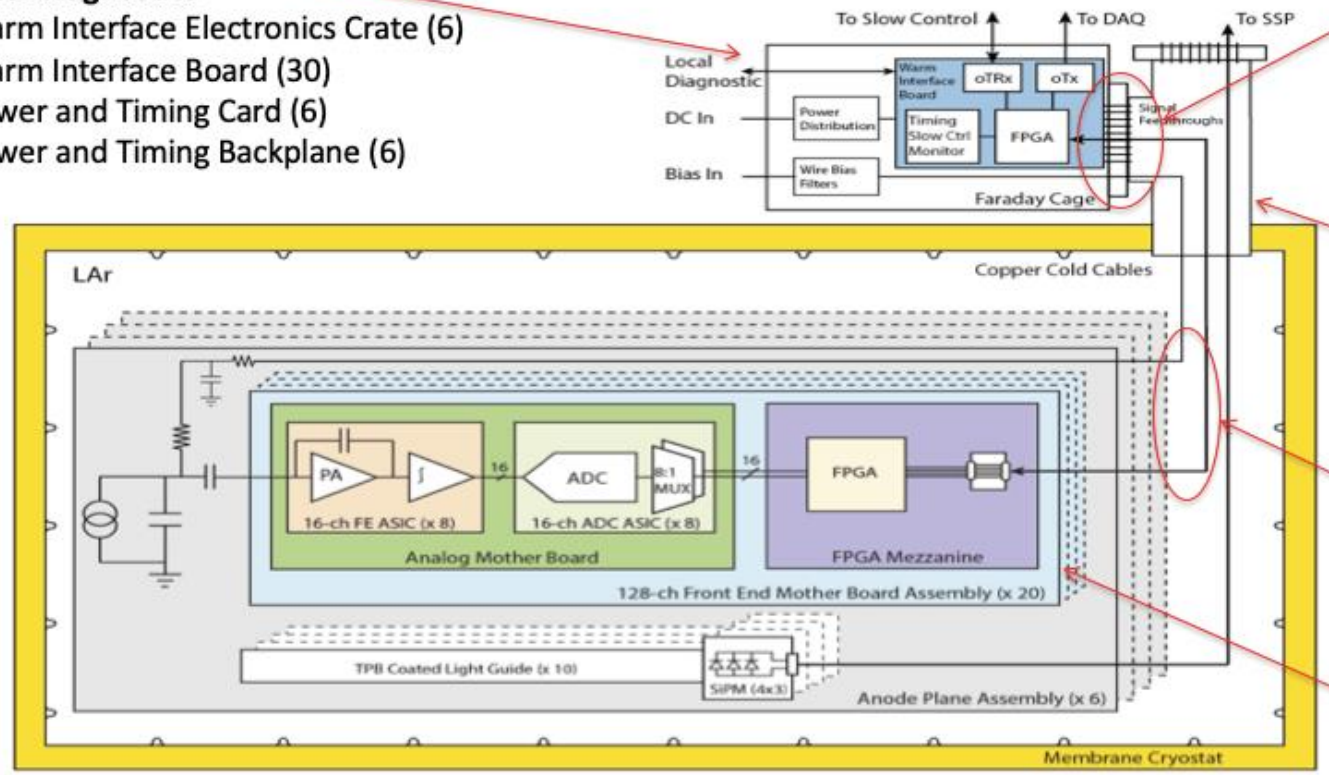

Collection plane view
Time [us]
X wire No.


Induction U plane view
Time [us]
U wire No.


Induction V plane view
Time [us]
V wire No.

A BNL contribution to ProtoDUNE SP: Cold Readout Electronics

Warm electronics
Local diagnostics
Warm Interface Electronics Crate (6)
Warm Interface Board (30)
Power and Timing Card (6)
Power and Timing Backplane (6)



CE flange
Flange assembly with cable strain relief and flange PCB for cable/WIB connection (6)

Signal feed-through
Tee pipe with 14" Conflat flanges and crossing tube cable (CTC) support (6)

Cold cable
LV and data cable (120+120) to FEMB and APA wire-bias SHV cable (48)

Front End Motherboard
(FEMB) 128 channels of digitized wire readout enclosed in CE Box (120)

Integrated LAr-TPC Readout