BROOKHAVEN NATIONAL LABORATORY

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Performance of the protoDUNE-Single Phase LArTPC

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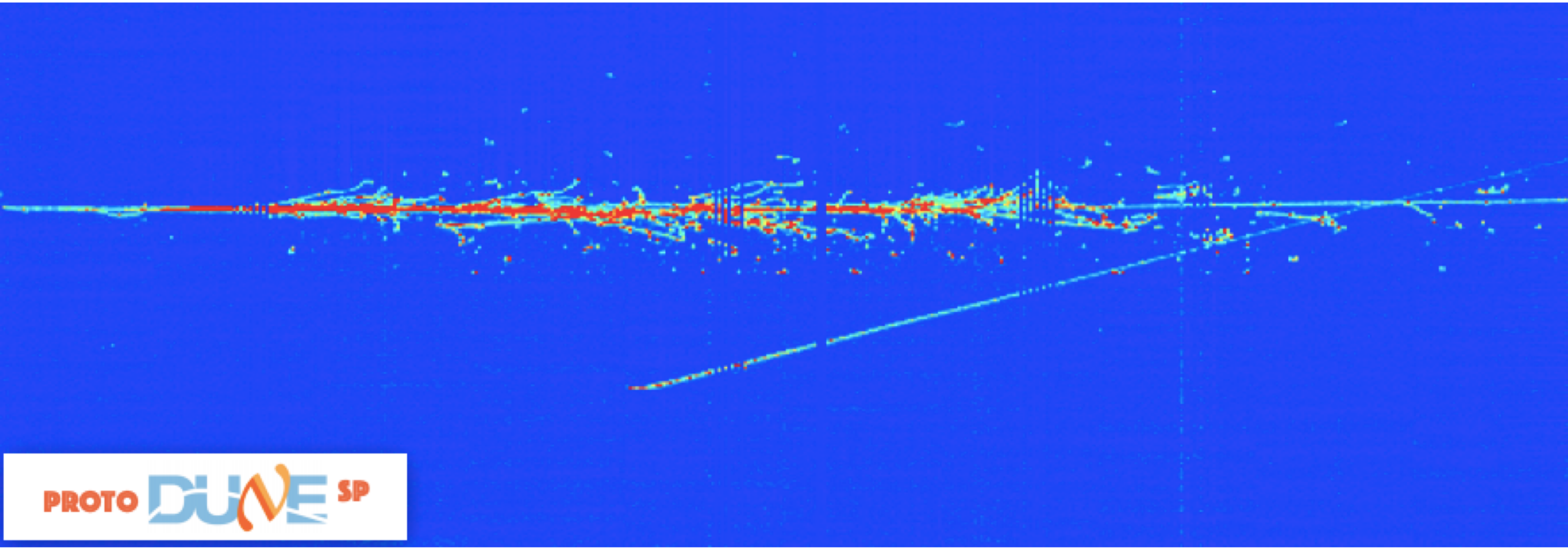
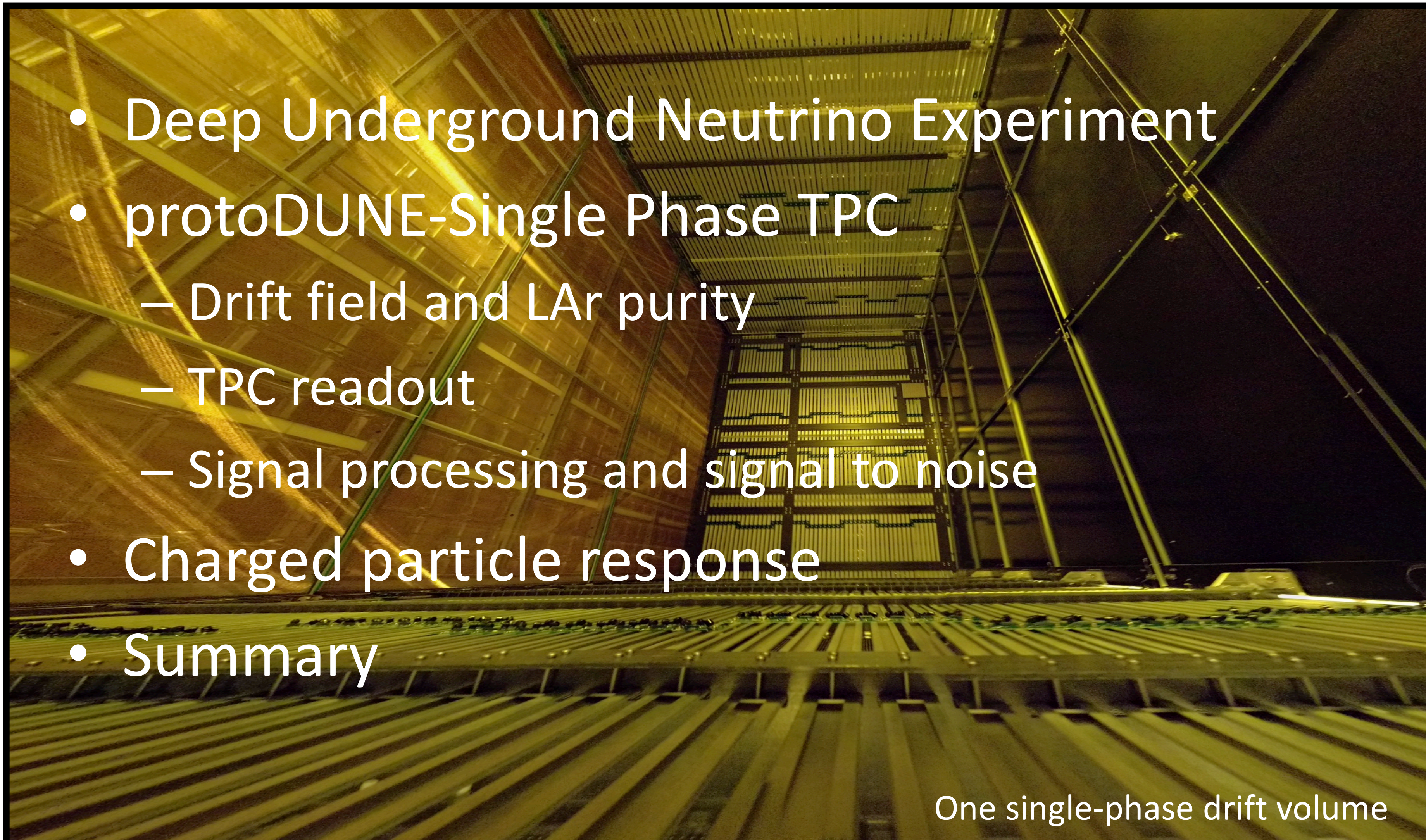
CPAD Instrumentation Frontier Workshop, Madison, Wisconsin
December 9, 2019



Outline

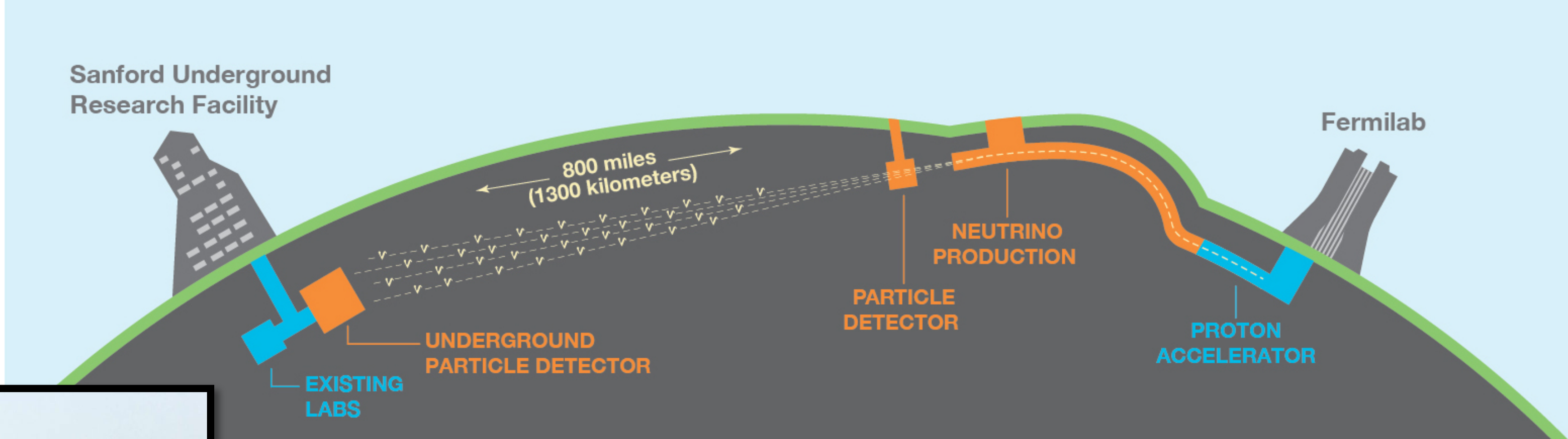


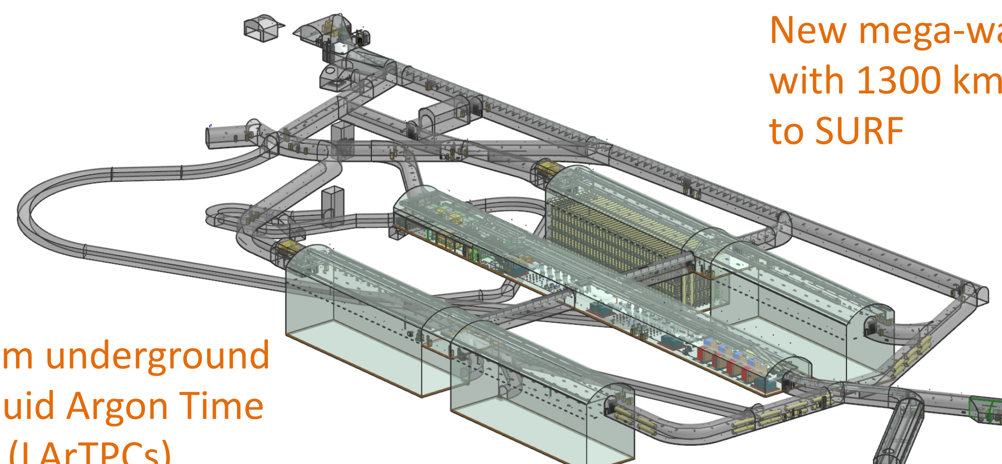
- Deep Underground Neutrino Experiment
- protoDUNE-Single Phase TPC
  - Drift field and LAr purity
  - TPC readout
  - Signal processing and signal to noise
- Charged particle response
- Summary

One single-phase drift volume

DUNE

DUNE Interim Design Report: [arXiv: physics.ins-det/1807.10334](https://arxiv.org/abs/1807.10334)

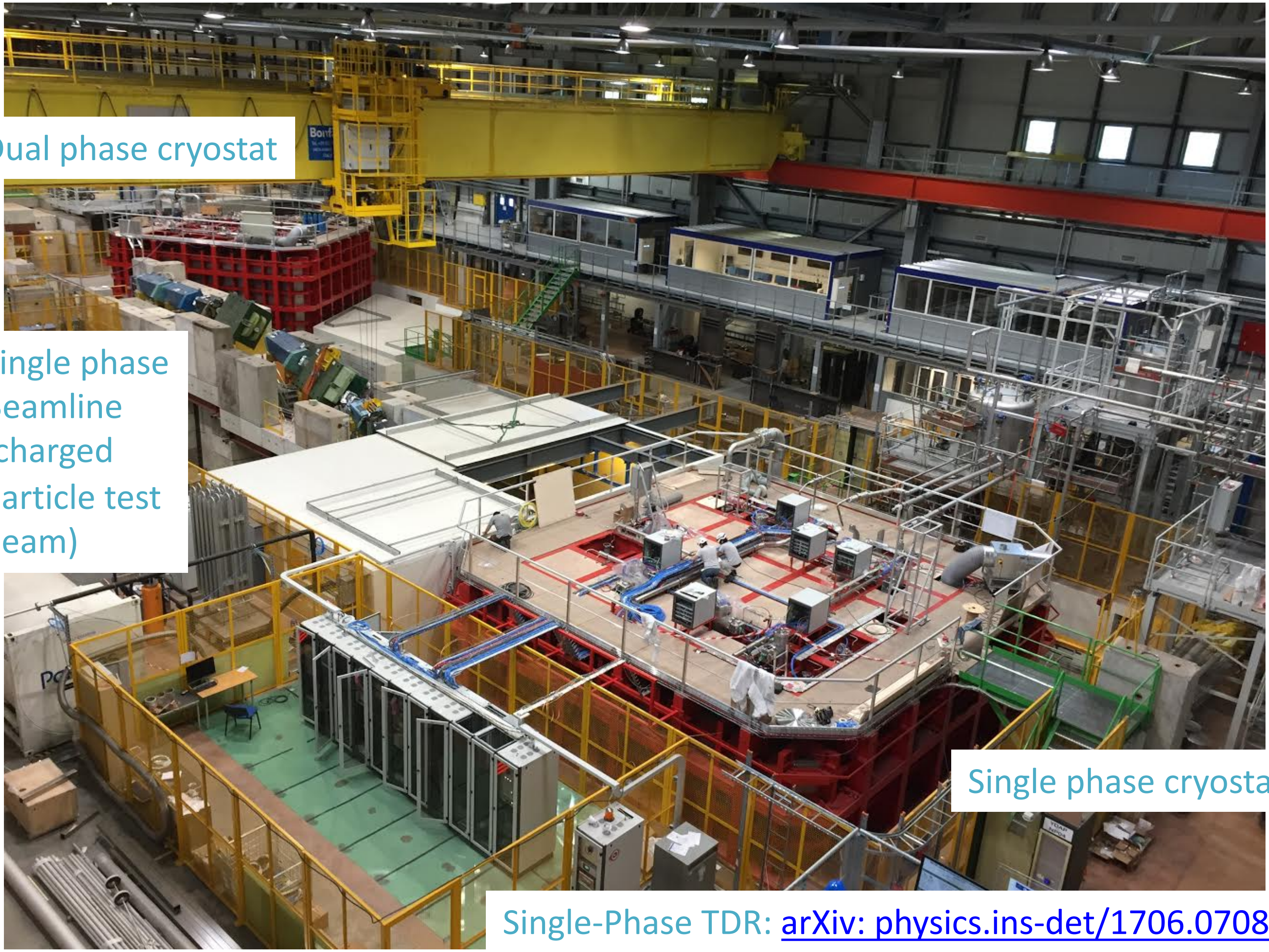




New mega-watt power neutrino beam with 1300 km baseline from Fermilab to SURF

Far detectors at 1.5 km underground
4x10 kton fiducial Liquid Argon Time Projection Chambers (LArTPCs)

protoDUNEs at CERN



Dual phase cryostat

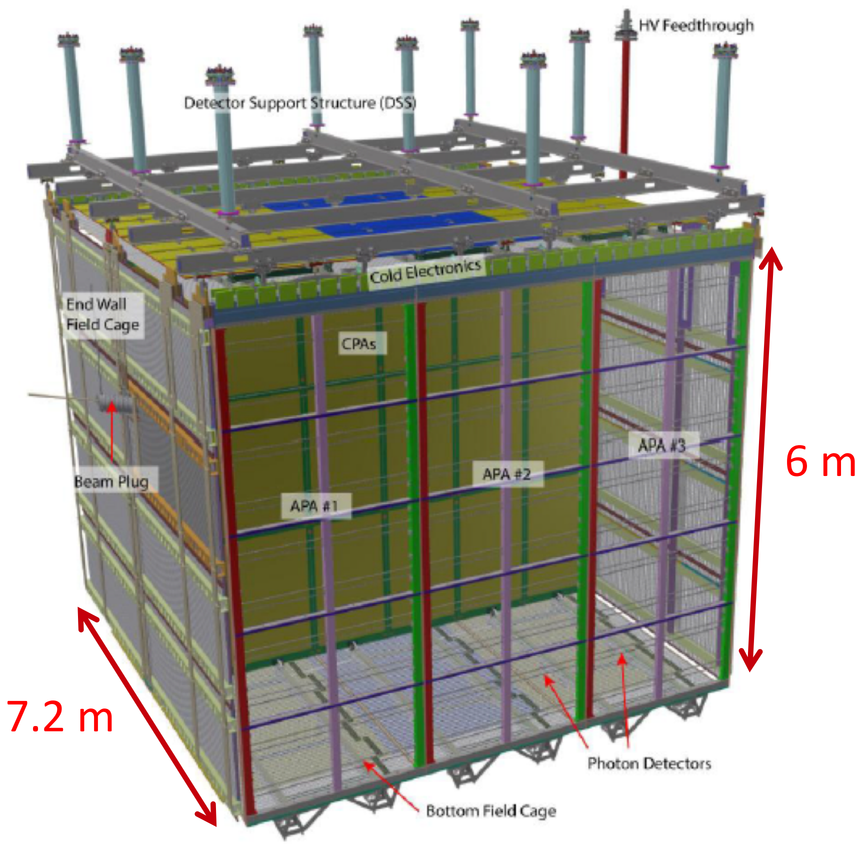
Single phase Beamline (charged particle test beam)

Single phase cryostat

Single-Phase TDR: [arXiv: physics.ins-det/1706.07081](https://arxiv.org/abs/1706.07081)

protoDUNE-Single Phase TPC

Enabled by the CERN Neutrino Platform



15,360 total channels

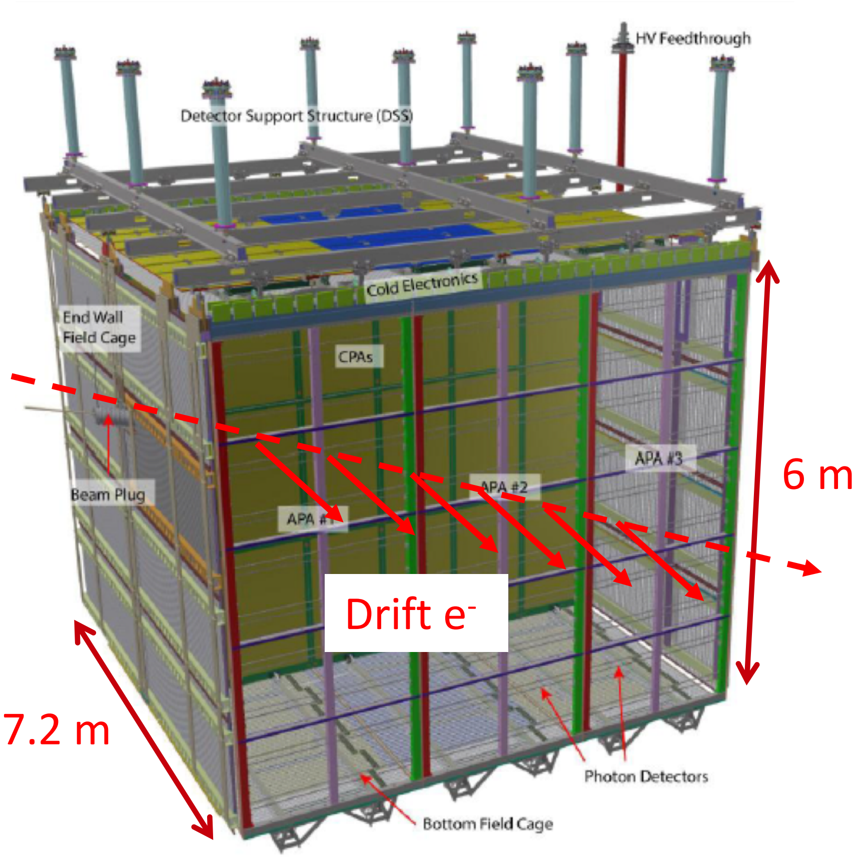
2 LAr volumes: 3.6 m drift length each

TPC readout ”cold” electronics submerged in LAr

- 6 Anode Plane Assemblies (APAs)
  - 2,560 sense wires each
  - Integrated readout electronics: amplification, shaping, digitization
  - *Full scale DUNE modules*
  - See Zelimir Djurcic’s talk on Photon Detectors
- To validate DUNE TPC design:
  - Noise (ENC) < 1000 e^-
  - Drift HV field: 500 V/cm
    - 180 kV at cathode
  - LAr purity of > 3 msec e^- lifetime

protoDUNE-Single Phase TPC

Enabled by the CERN Neutrino Platform



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A MIP generates ~6000 e-/mm in LAr
~2.25 msec to drift full 3.6 m volume
@3 msec purity a MIP at the cathode
will generate a ~10ke$^-$ signal at each wire:

~10:1 signal/noise

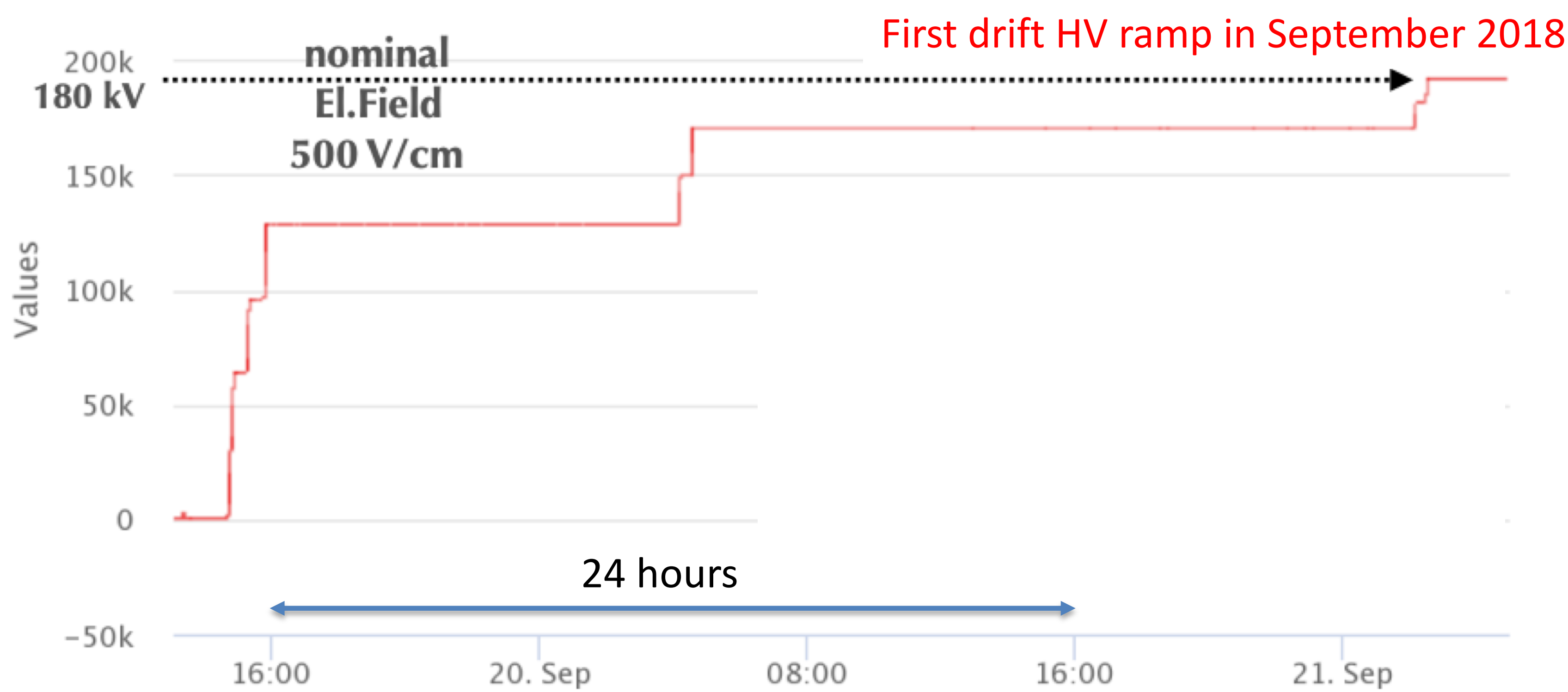
Timeline

- Oct 2017: begin detector installation
- Jun 2018: detector closed and begin LAr filling
- Sept 2018: beam data starts
- Nov 2018: beam ends, cosmic-only data

Beam Events

Momentum	Total Triggers	Expected Pi trig.	Expected Proton trig.	Expected Electr. trig.	Expected Kaon trig.
0.3 GeV/c	269K	0	0	242K	0
0.5 GeV/c	340K	1.5K	1.5K	296K	0
1 GeV/c	1089K	382K	420K	262K	0
2 GeV/c	728K	333K	128K	173K	5K
3 GeV/c	568K	284K	107K	113K	15K
6 GeV/c	702K	394K	70K	197K	28K
7 GeV/c	477K	299K	51K	98K	24K
All momenta	**4175K**	**1694K**	**779K**	**1384K**	**73K**

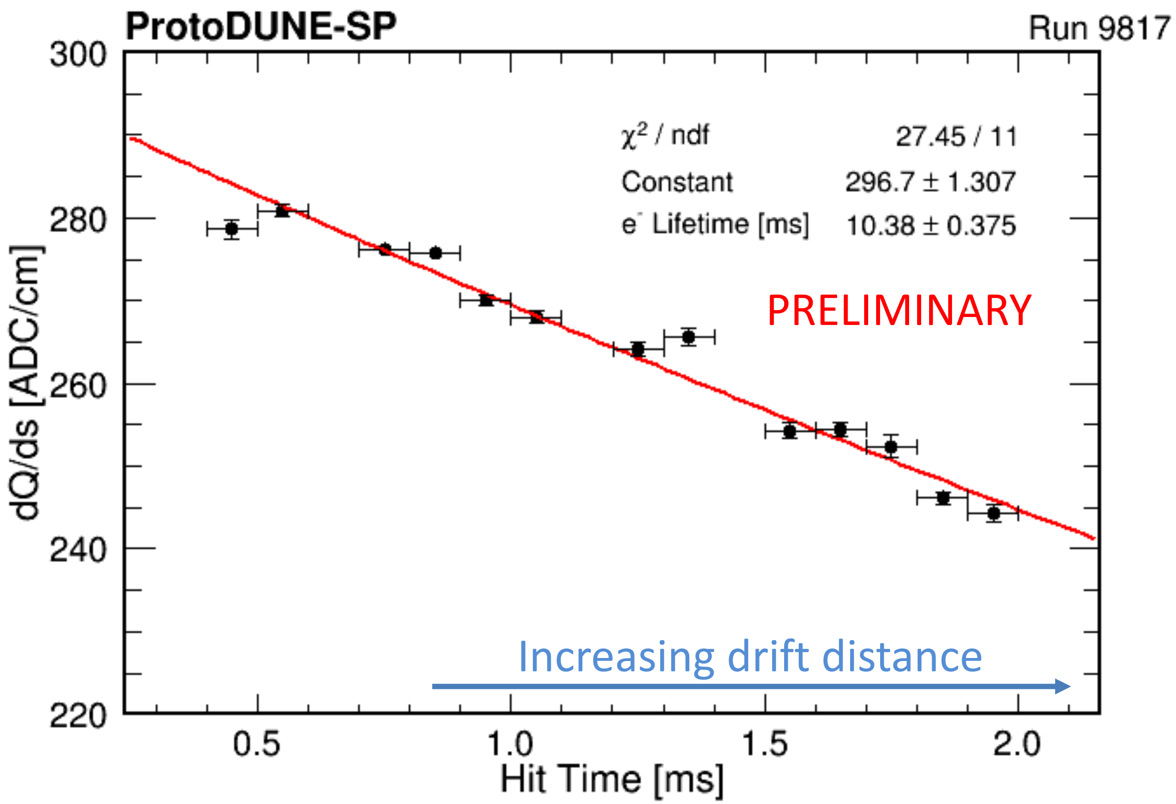
Drift Field



- All the drift field HV components are operating reliably and stably at the nominal electric field (500 V/cm)
- In the last several months drift field uptime is > 99.5%

LAr Purity

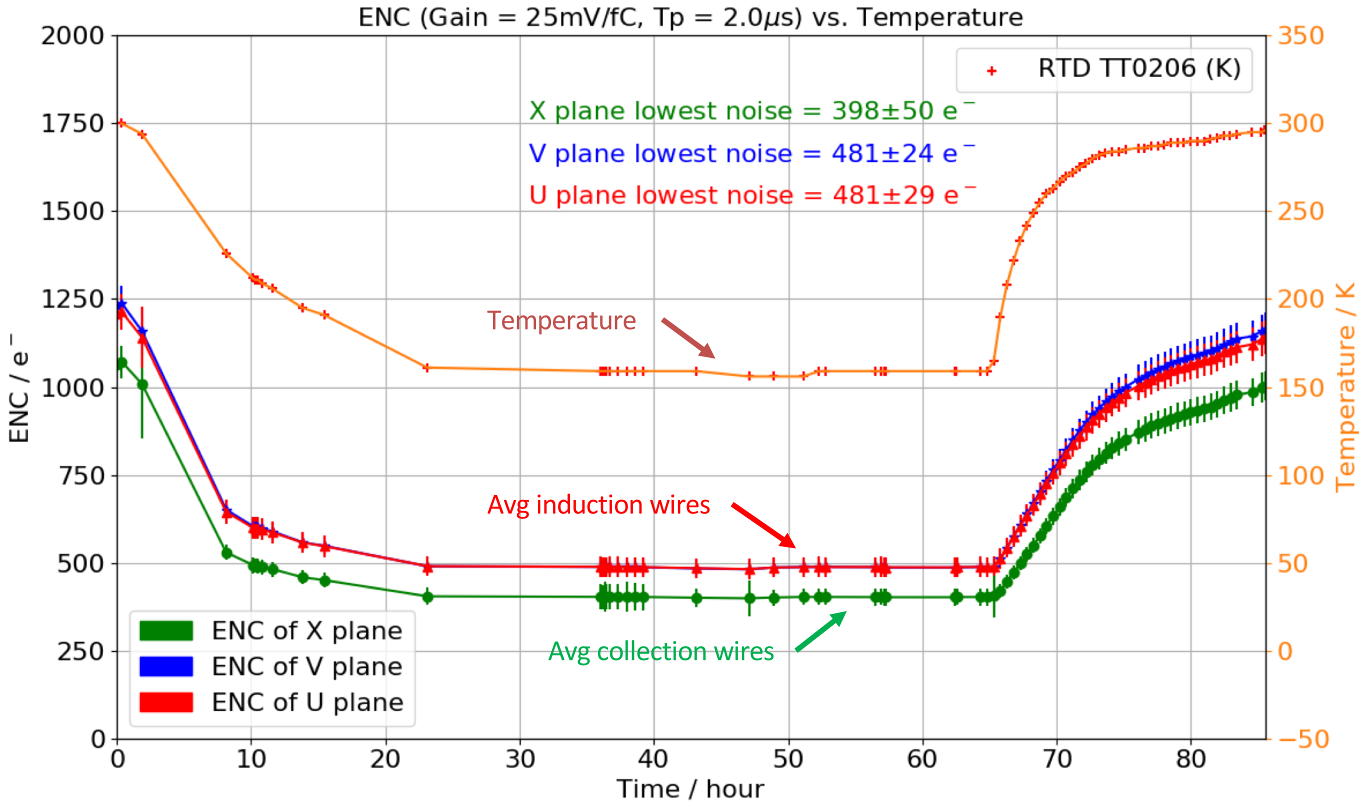
- During beam data-taking, purity was measured with 3 purity monitors
  - After initial filtering e^- lifetime > 3 msec was measured during beam throughout the TPC
- Measured with muons crossing the central region of the TPC tagged by Cosmic Ray Tagger (CRT) detectors outside the cryostat (see Richie Diurba's talk)
  - Purity of e^- lifetime > 6 msec was measured throughout the TPC



Cold Electronics

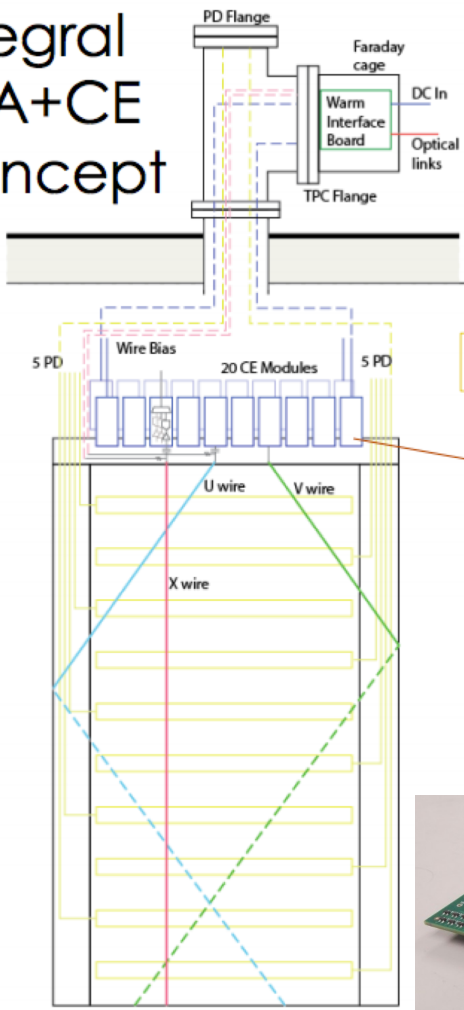
- Cold Electronics (CE) are an enabling technology for "giant" single-phase LArTPCs
  - Provides signal amplification, shaping, filtering, and digitization of wire signals in the LAr (87°K)
  - Exceptionally low noise operation, long lifetime, and scalable cryostat design

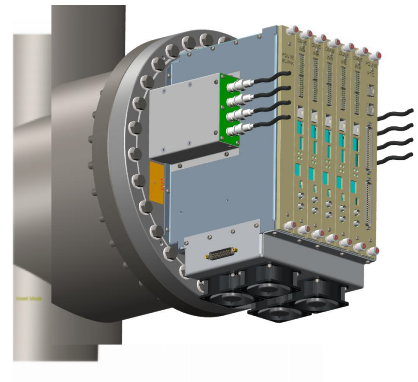
Noise vs time for 1 APA (2560 channels) cycled under GN2



Integrated LArTPC Readout

Integral APA+CE Concept



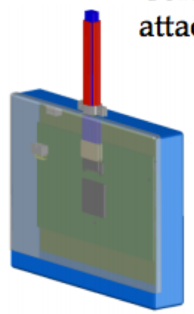


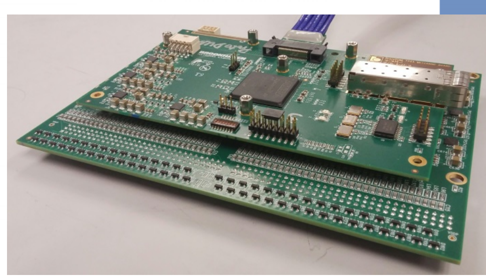
ProtoDUNE-SP

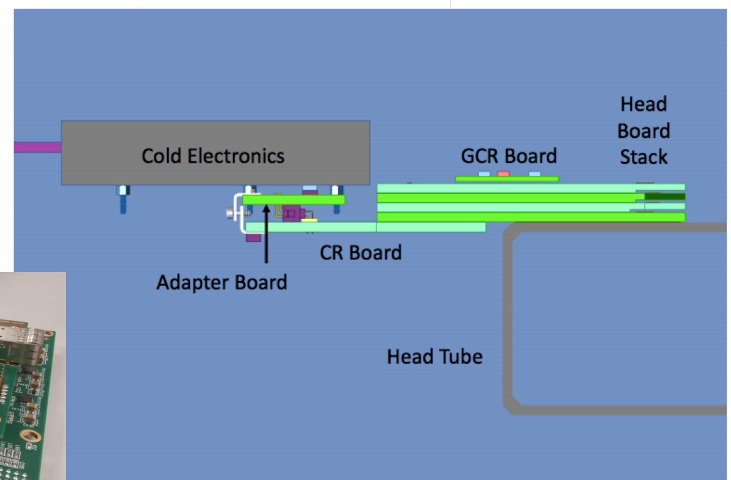
Each APA is isolated inside the cryostat and only connected to the detector ground through the CE at its own CE flange.

Warm Interface Electronics: interface from CE to DAQ with shielding and local real-time diagnostics.

Cold electronics module and its attachment to the APA frame



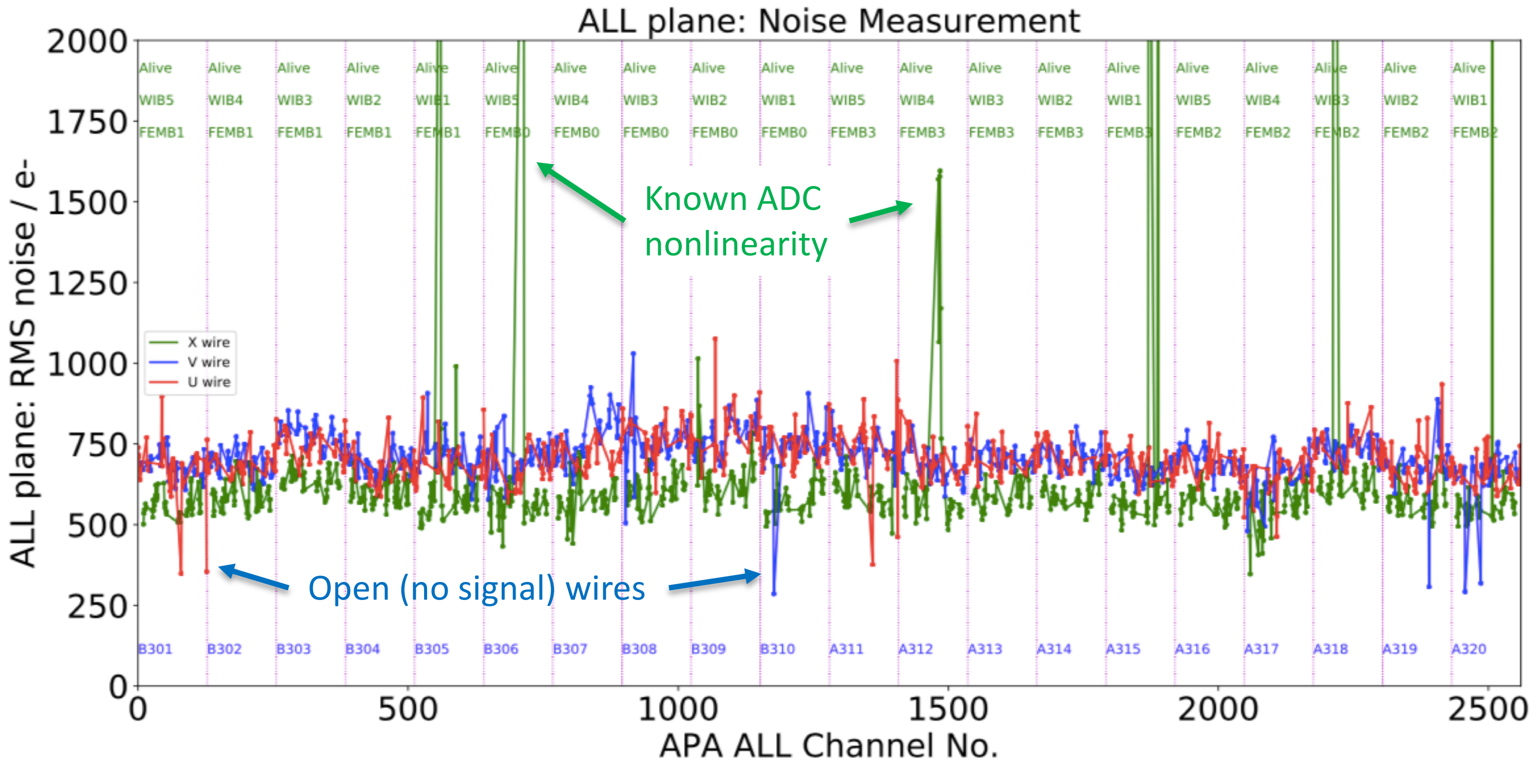




Front End Motherboard (FEMB)

TPC Readout Performance

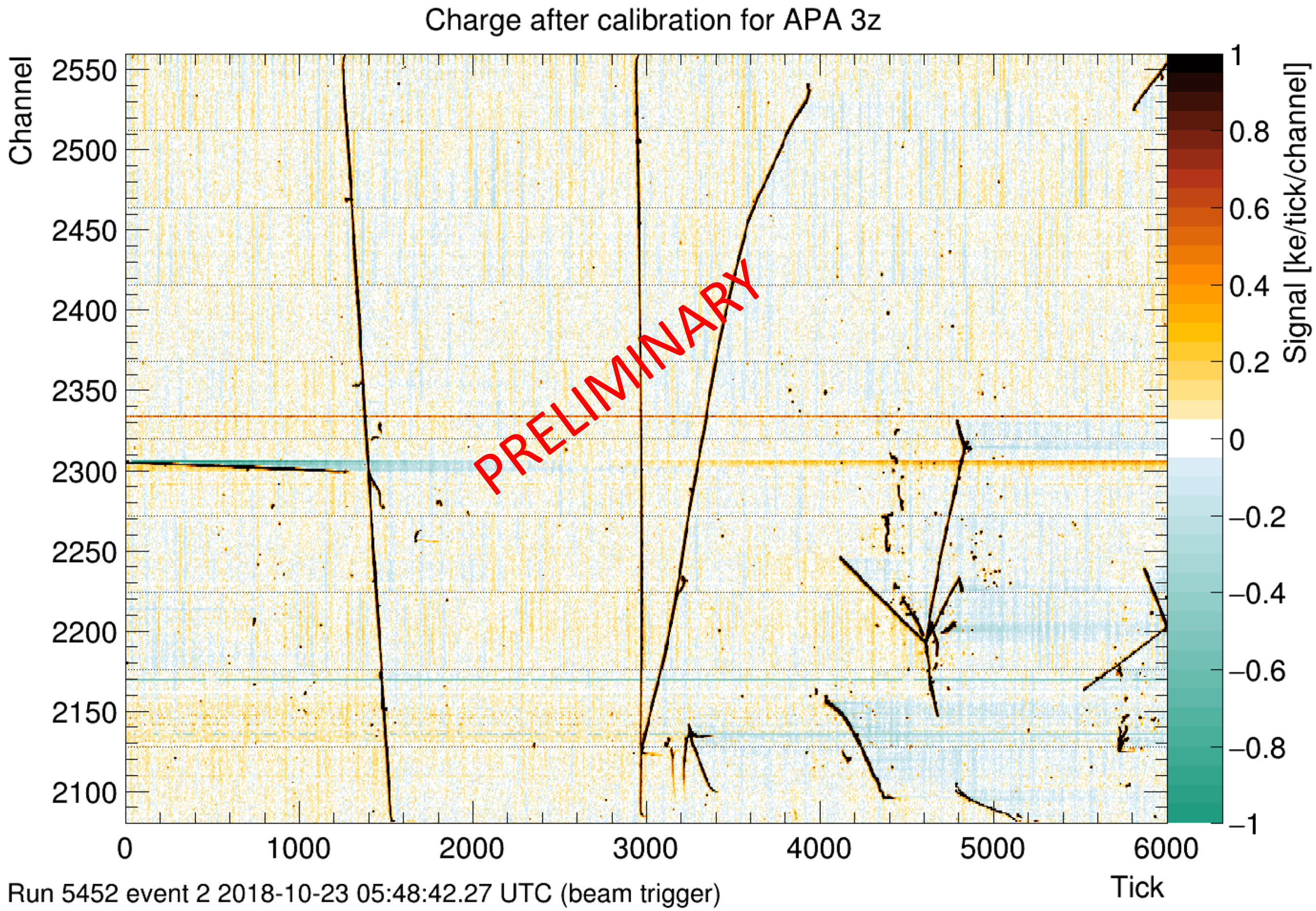
Raw ENC vs channel for 1 APA (2560 channels) in LAr during beam data-taking



- During beam data taking 99.7% of 15,360 TPC readout channels are alive
  - 4 total channels known to be dead in the electronics based on internal calibration circuit
  - ~40 channels are consistent with an open wire in front of the electronics
- Average raw ENC of ~550 e- (collection) and ~650 e- (induction)

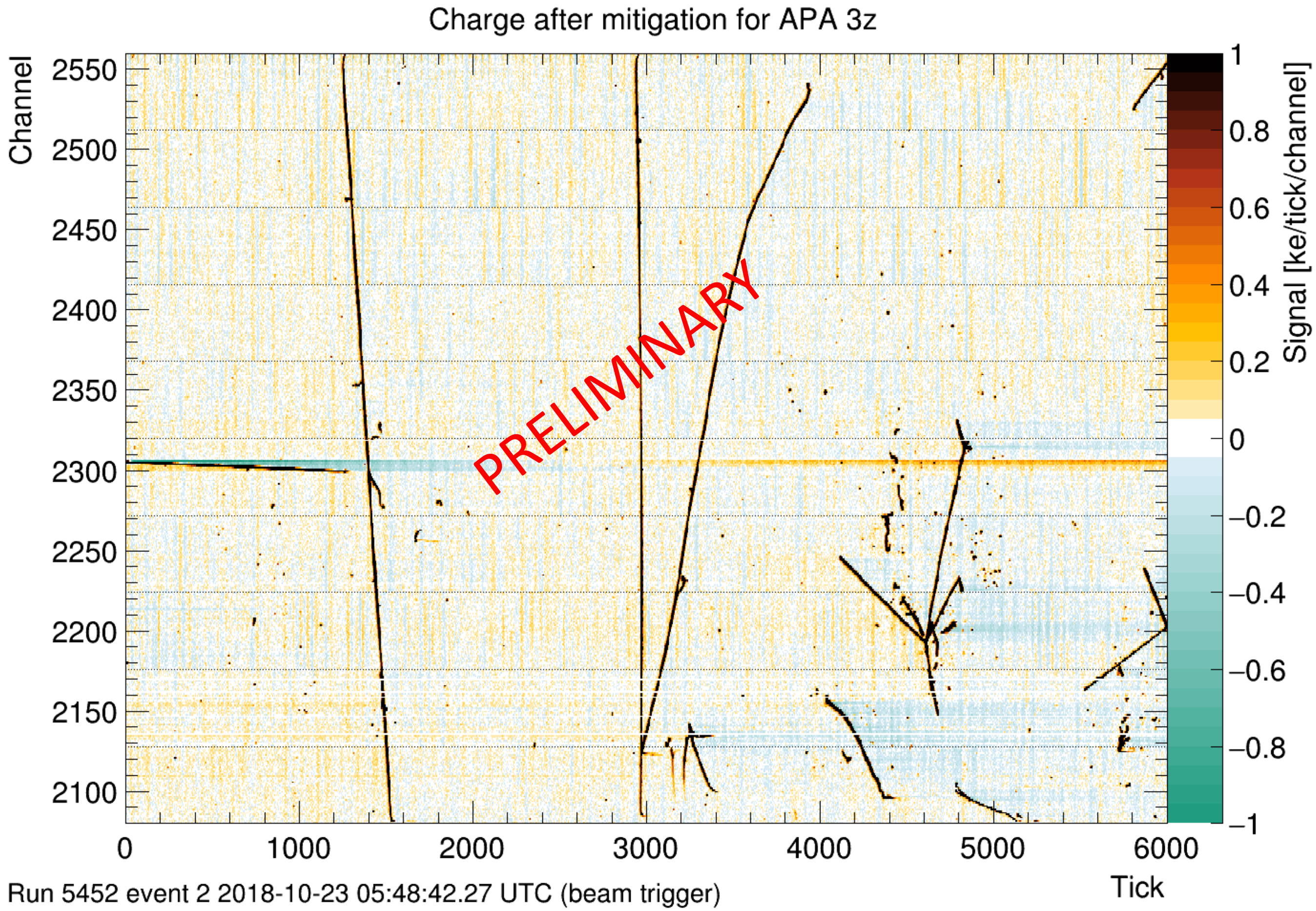
Signal Processing

Collection waveforms after gain calibration with pedestal subtraction



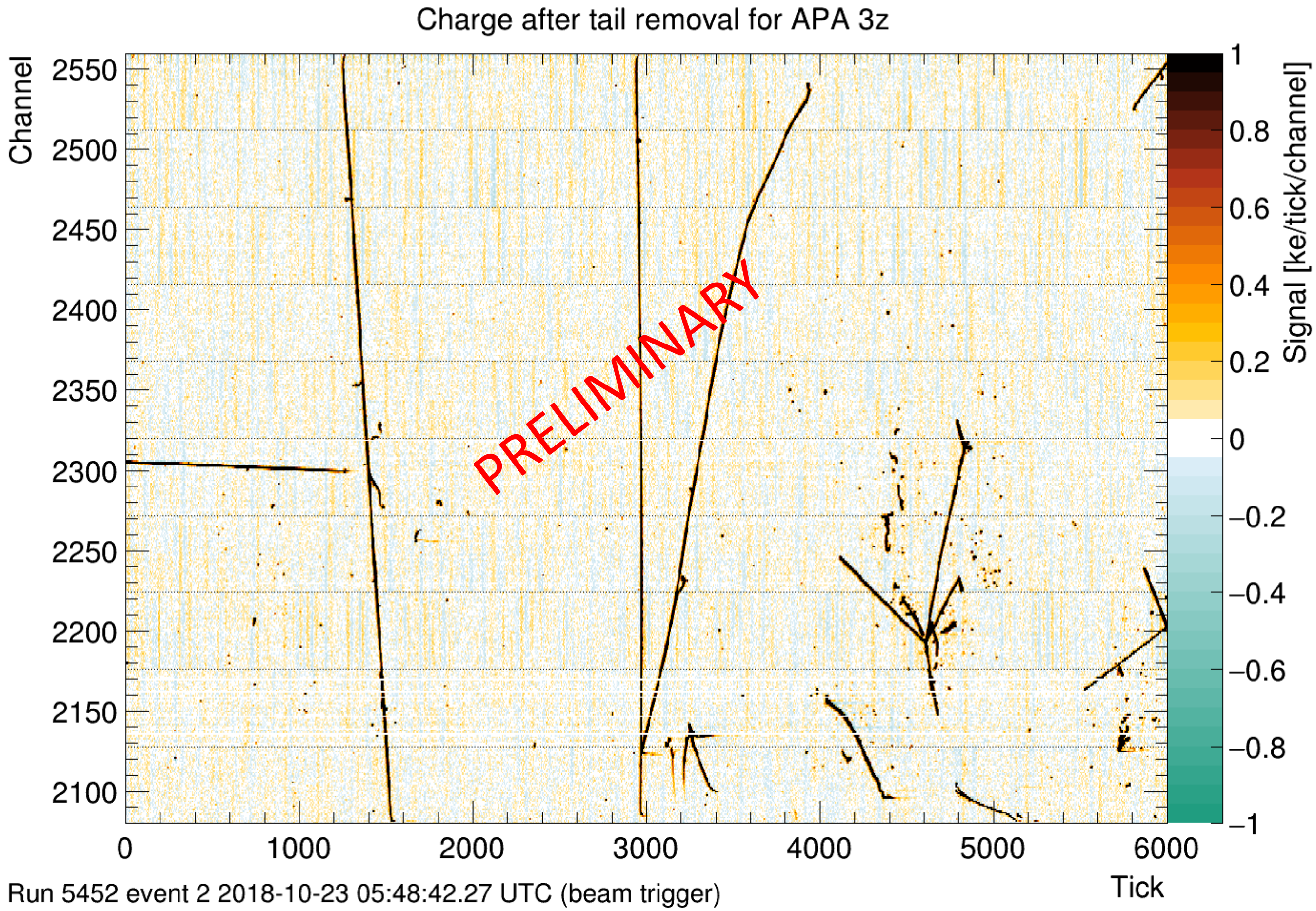
Signal Processing

Collection waveforms including ADC nonlinearity correction



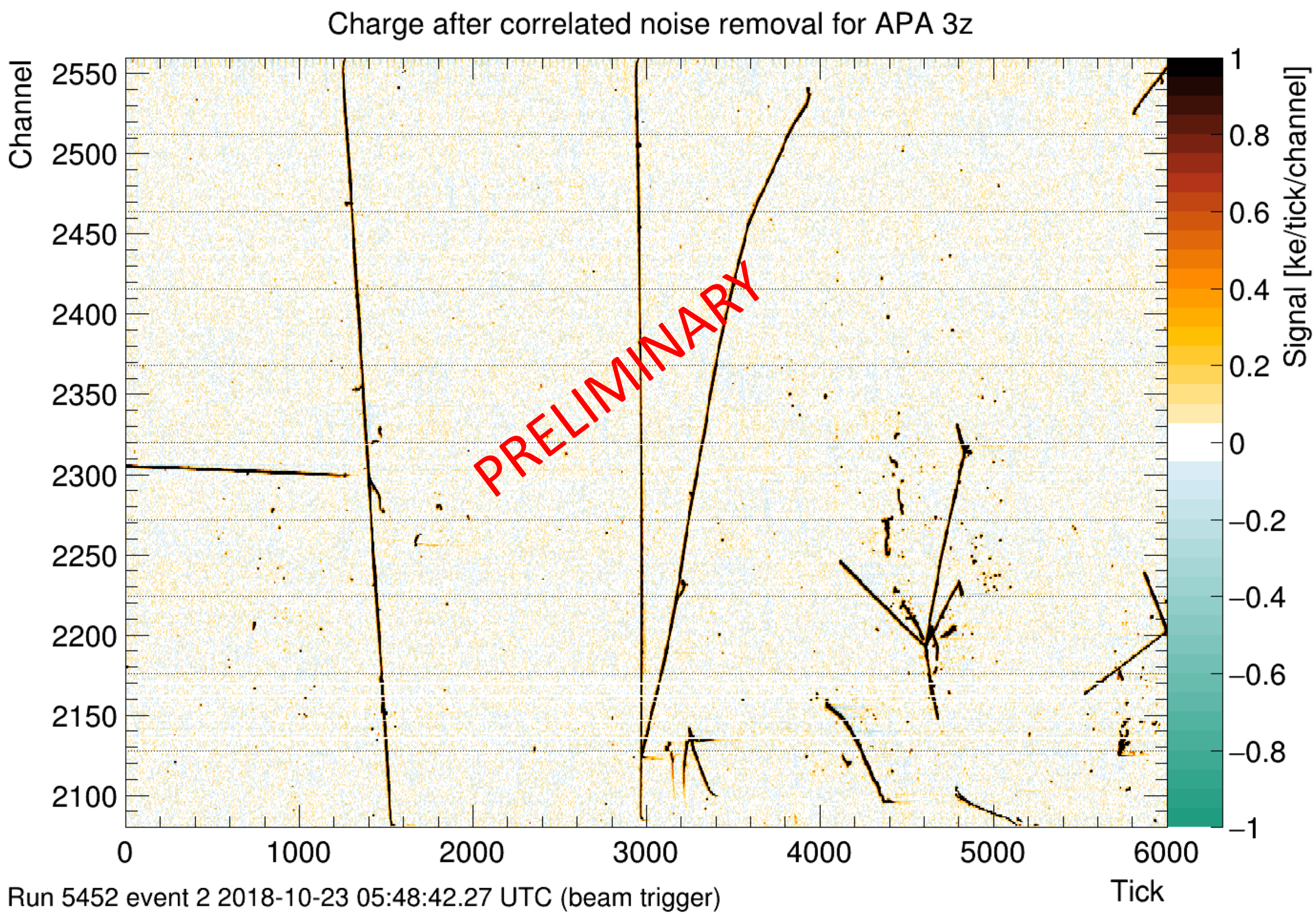
Signal Processing

Collection waveforms including baseline restoration correction

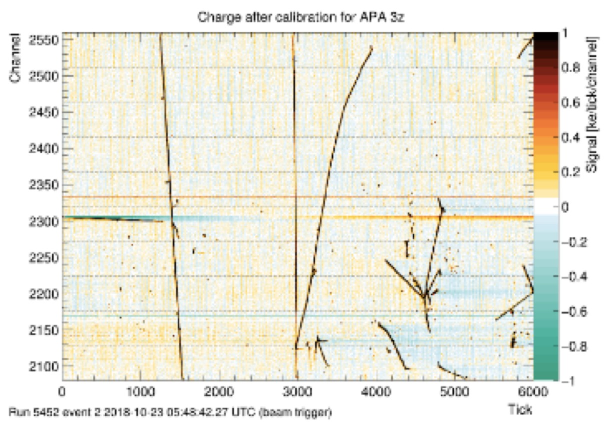


Signal Processing

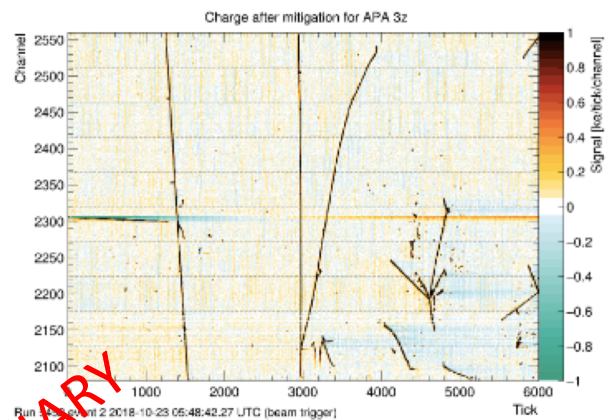
Collection waveforms including correlated noise removal



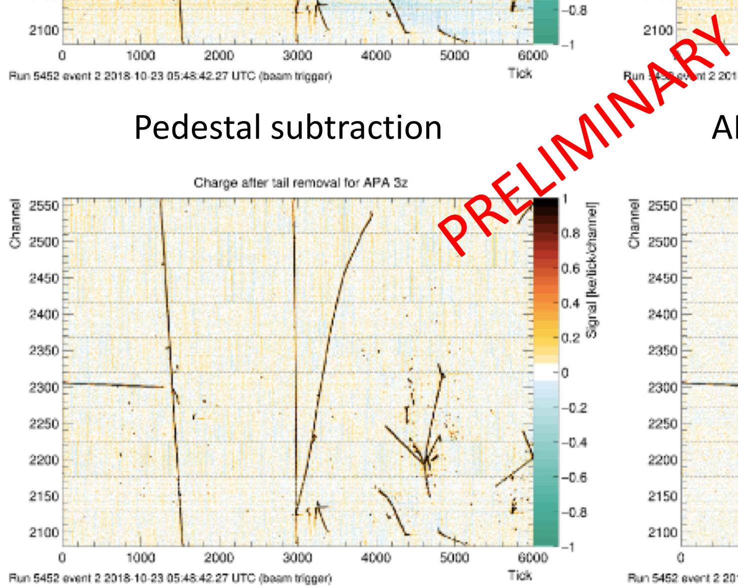
Signal Processing



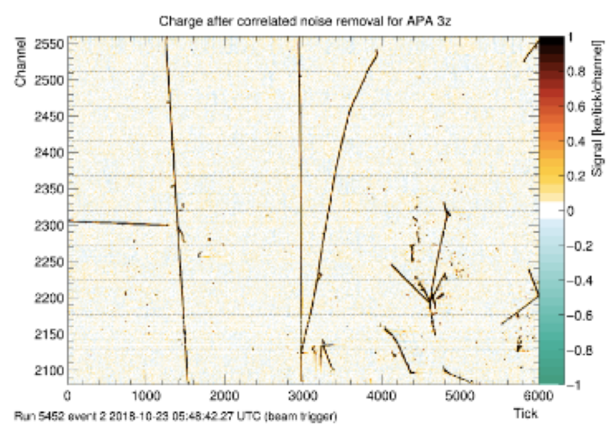
Pedestal subtraction



ADC nonlinearity correction



Baseline restoration correction

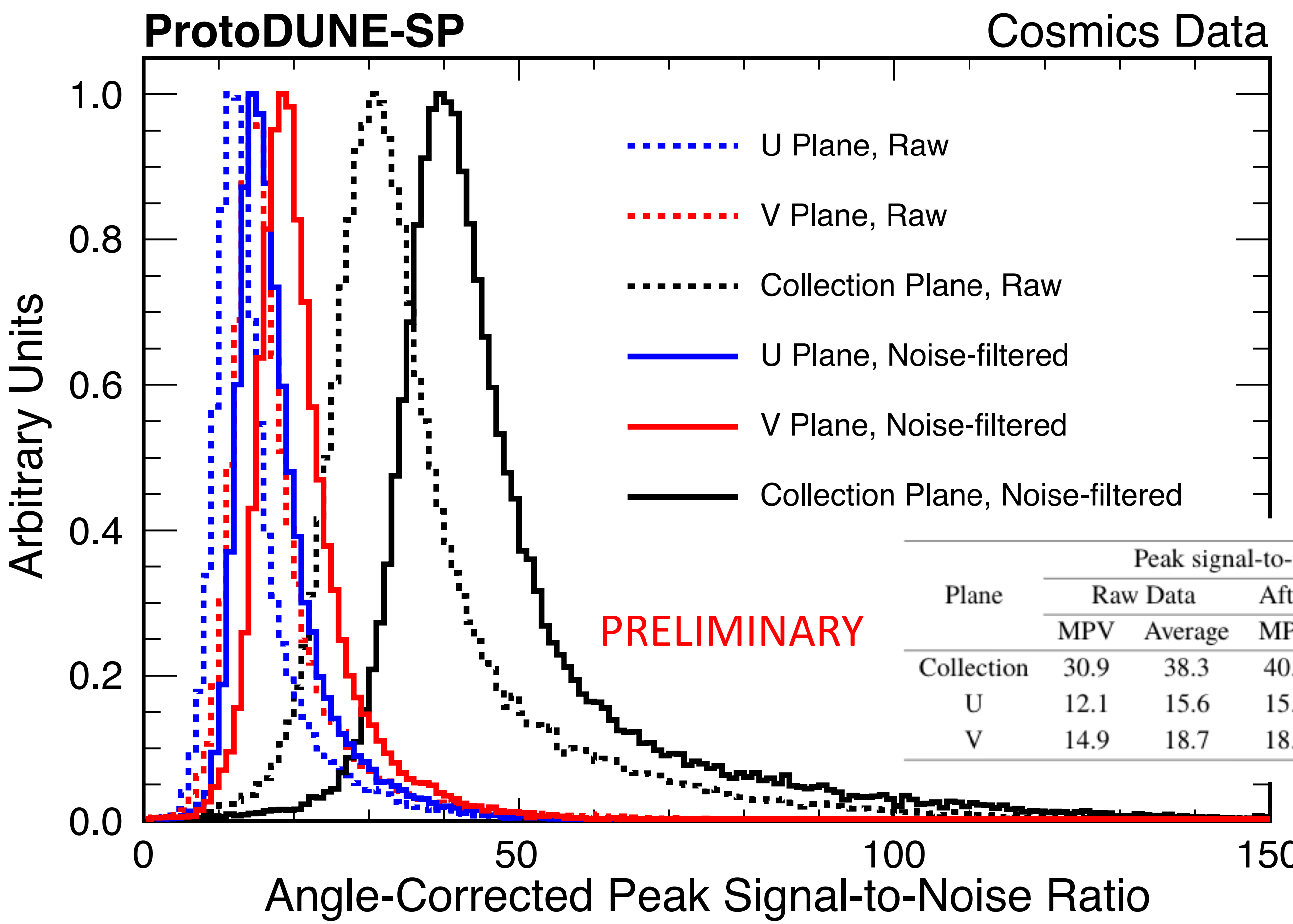


Coherent noise removal

- After signal processing, average ENC of ~430 e- (collection) and ~500 e- (induction)

Signal to Noise

Signal to Noise from Data at 4.9 msec e$^-$ Lifetime and Nominal 500 V/cm Drift Field

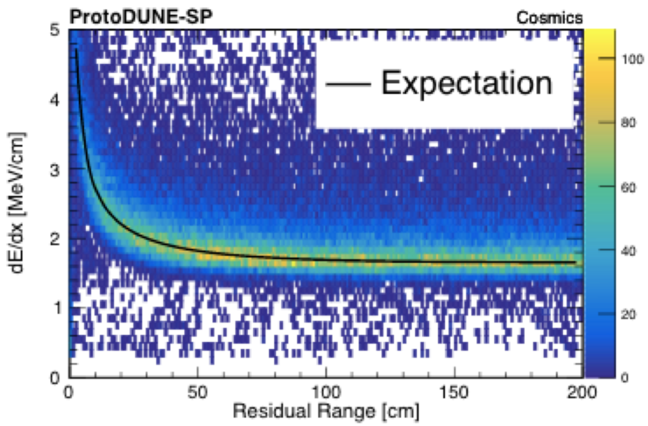


Plane	Peak signal-to-noise ratio			
	Raw Data		After Noise Filtering	
	MPV	Average	MPV	Average
Collection	30.9	38.3	40.3	48.7
U	12.1	15.6	15.1	18.2
V	14.9	18.7	18.6	21.2

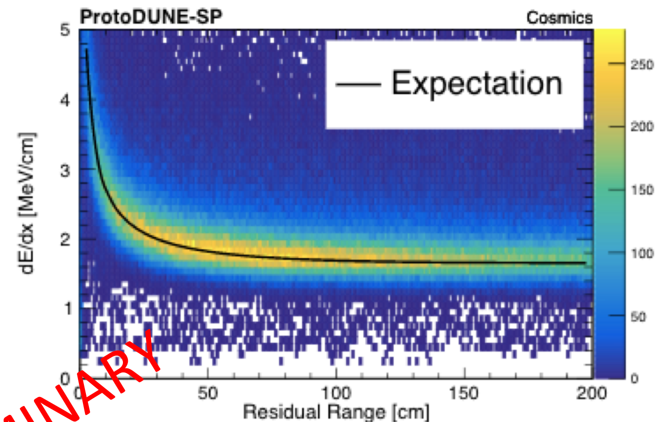
All readout planes measure better than 10:1 S/N

Energy Scale Calibration

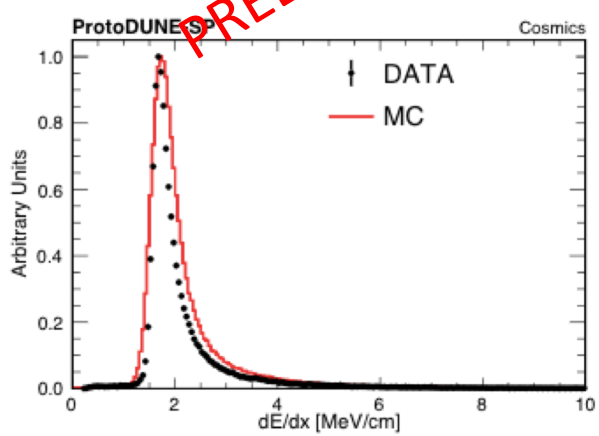
Cosmic ray stopping muon data



Cosmic ray muon MC



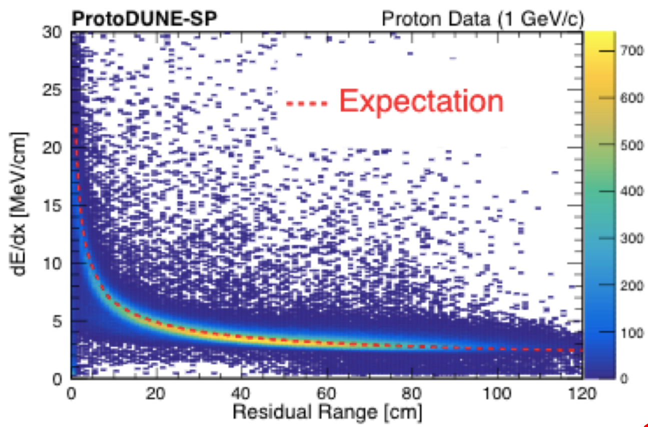
PRELIMINARY



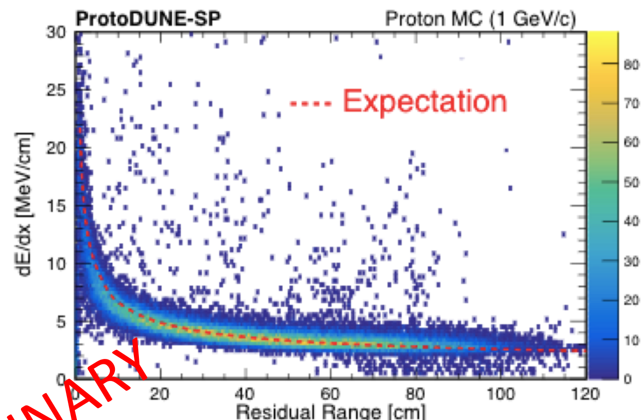
Energy scale measured with pure sample of stopping muon tracks

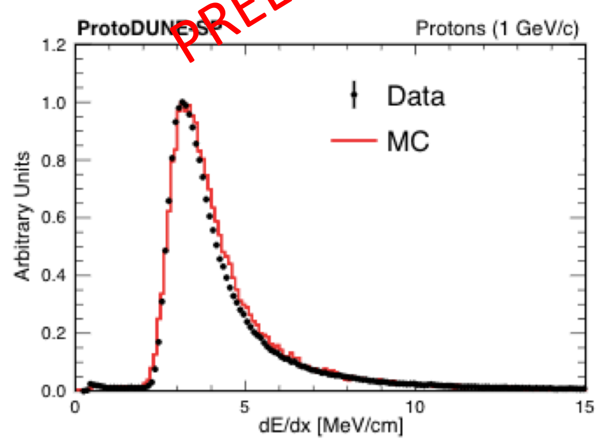
Beam Particle Response

1 GeV/c proton beam (12 hours exposure)



Proton beam MC

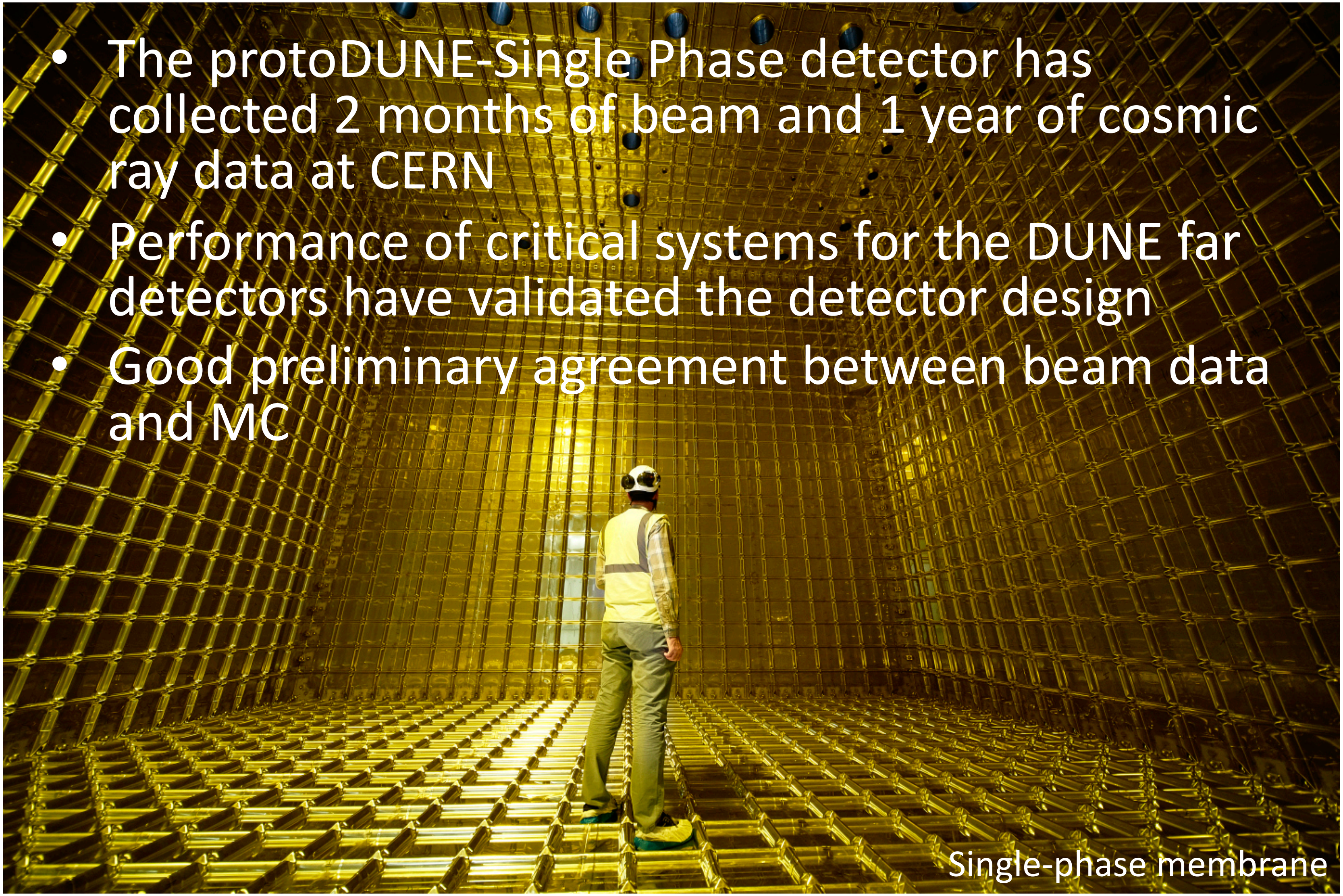




Studies of detector response to beam muons, pions, and positrons also ongoing

Conclusions

- The protoDUNE-Single Phase detector has collected 2 months of beam and 1 year of cosmic ray data at CERN
- Performance of critical systems for the DUNE far detectors have validated the detector design
- Good preliminary agreement between beam data and MC



Single-phase membrane