First results on ProtoDUNE-SP LArTPC performance from a test beam run at the CERN Neutrino Platform

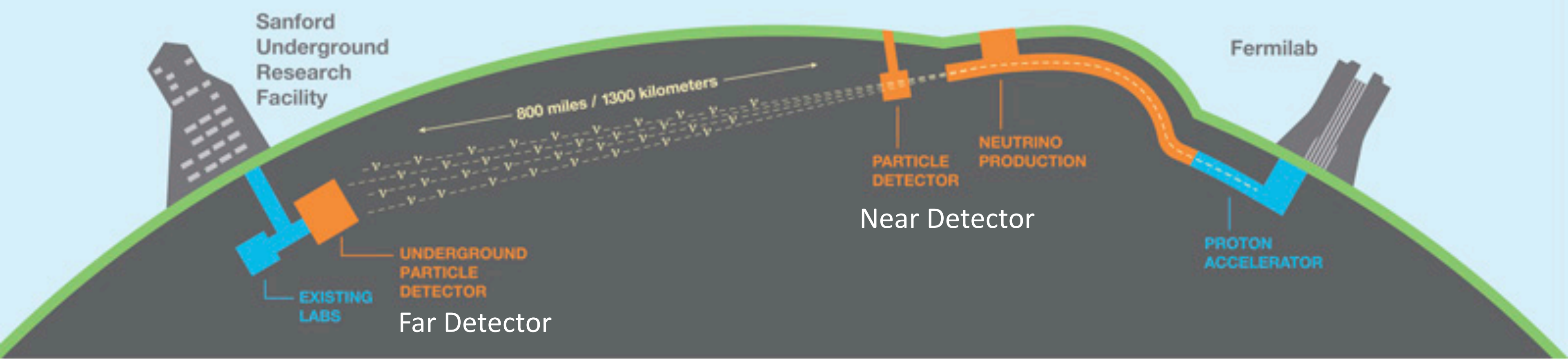
Tingjun Yang for the DUNE Collaboration

DPF2019

July 29, 2019

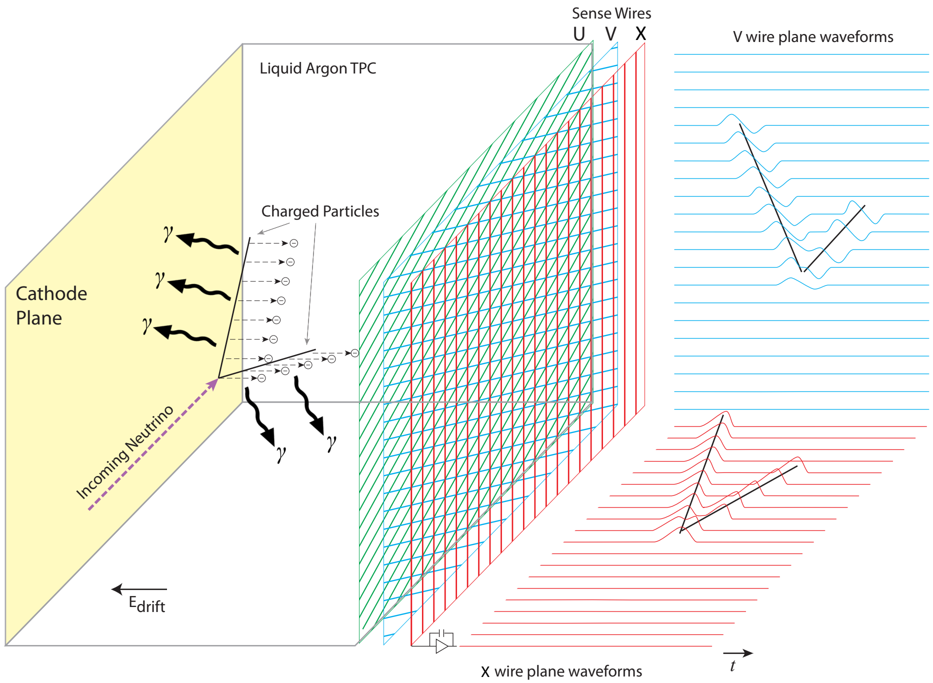
Deep Underground Neutrino Experiment (DUNE)

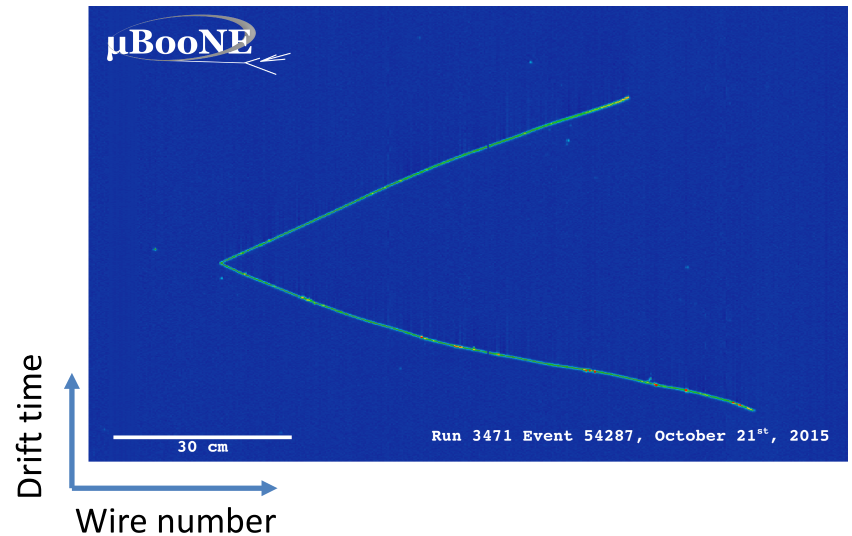
More than 1000 scientists and engineers from 31 countries



- **DUNE will be a world-class neutrino observatory and nucleon decay detector**
  - A broad and rich physics program: neutrino mass hierarchy, CP violation, supernova neutrinos, nucleon decays
  - A baseline of 1300 km
  - The world's most intense neutrino beam from Fermilab
  - A deep underground site, massive liquid argon detectors, and a precision near detector

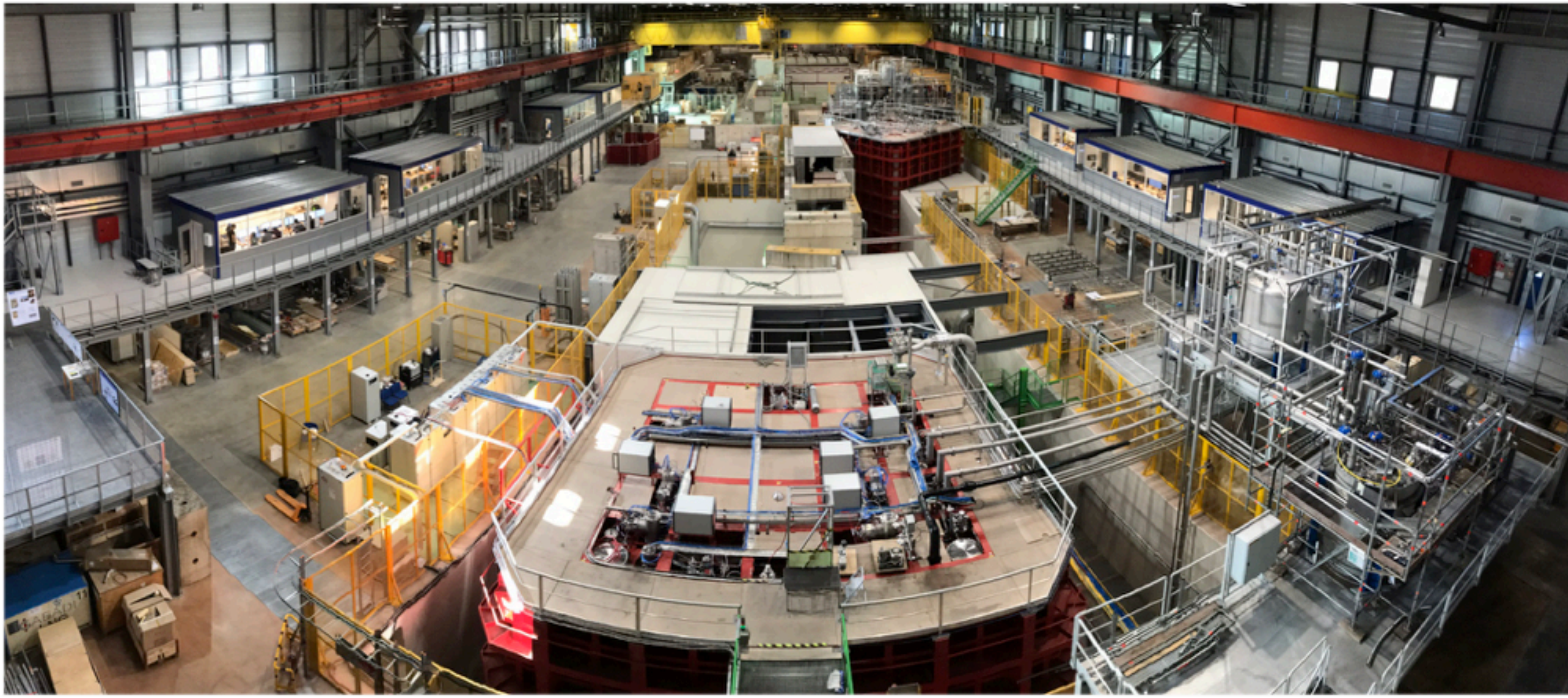
Liquid Argon Time Projection Chamber (LArTPC)





- **The DUNE far detector consists of four LArTPC detector modules**
  - High spatial and calorimetric resolutions
  - Each module has a total mass of 17 kton, located 1.5 km underground
  - Prototyping is critical for such a big detector

Detector Activation - start: Sept. 21, 2018



ProtoDUNE SP ~1kt LAr-TPC at CERN

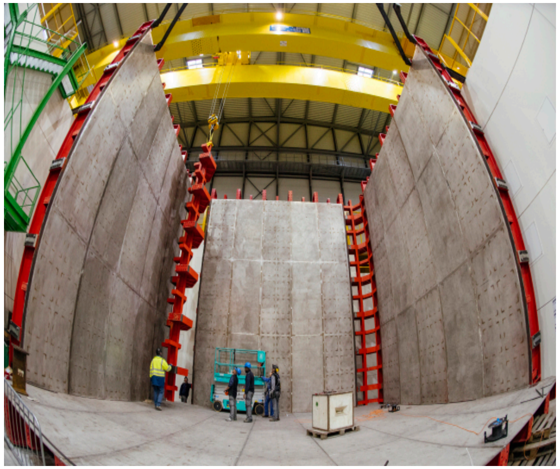
One of the two prototypes for DUNE far detector

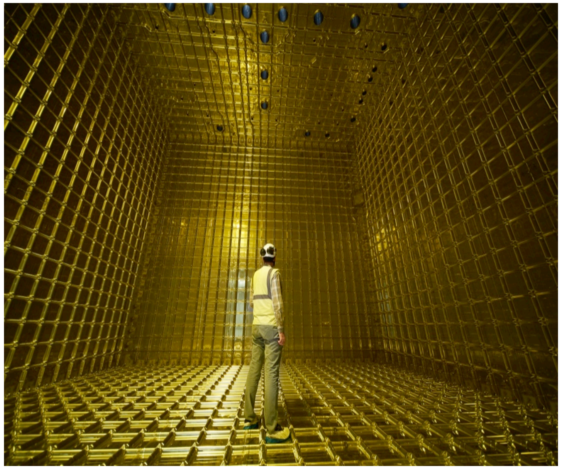
PROTO DUNE SP MISSION

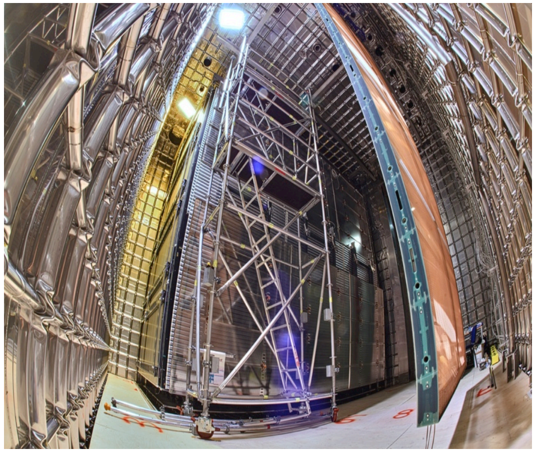
- Prototyping production and installation procedures for DUNE Far Detector Design
- Validating design from perspective of basic detector performance
- **Accumulating test-beam data to understand/calibrate response of detector to different particle species**
- **Demonstrating long term operational stability of the detector**

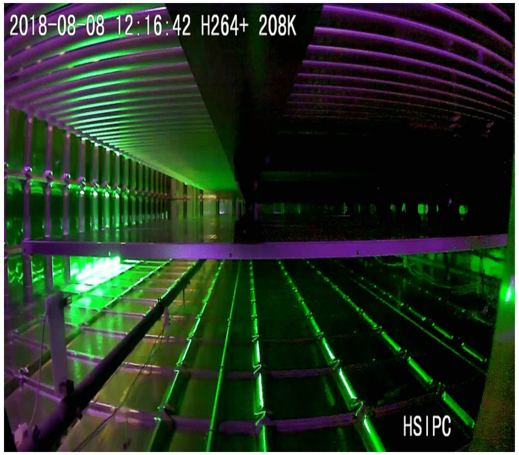
Path to ProtoDUNE-SP completion in EHN1

March 2016, construction of EHN1 extension


November 2016, cryostat structure assembly


September 2017, cryostat completion

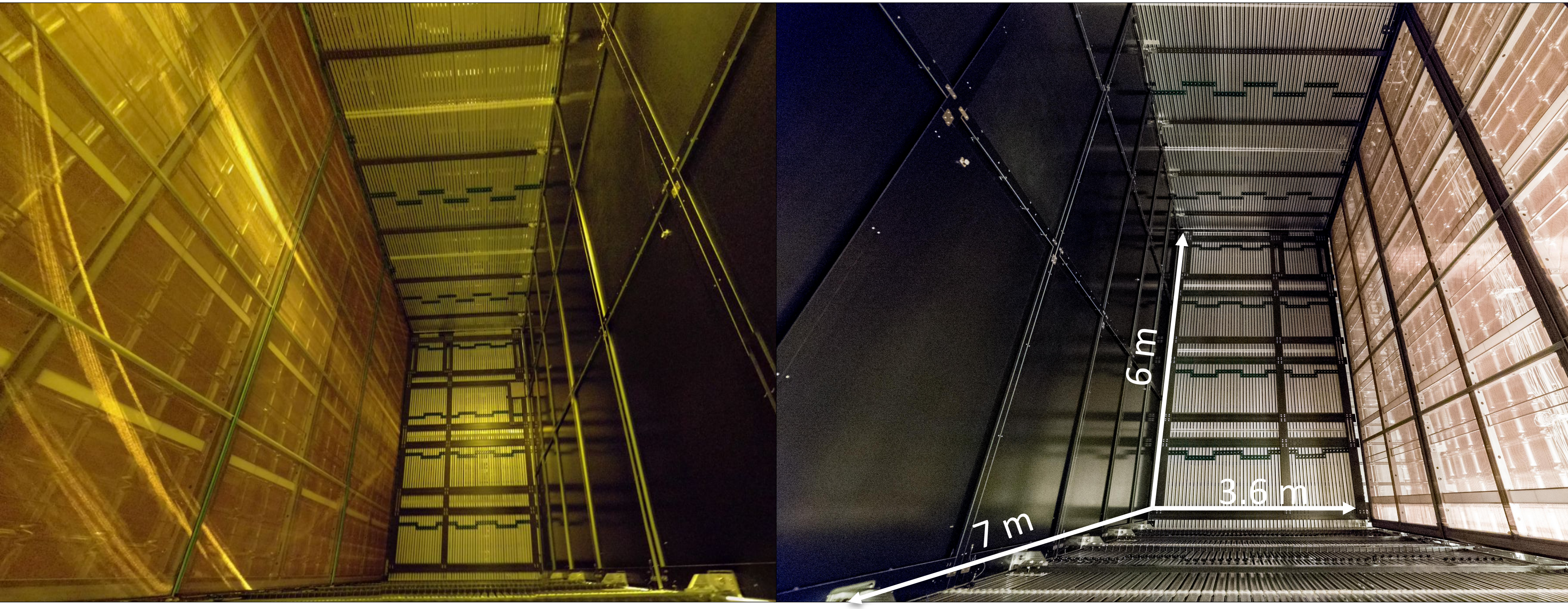

February 2018, detector assembly



August 2018, LAr filling


September 19, 2018 – HV @ 180 kV ready for beam!

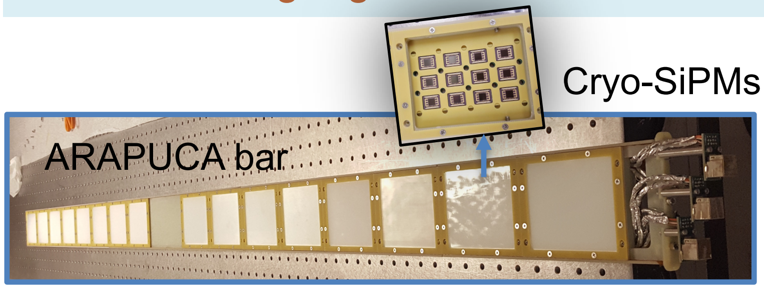
TPC Installed



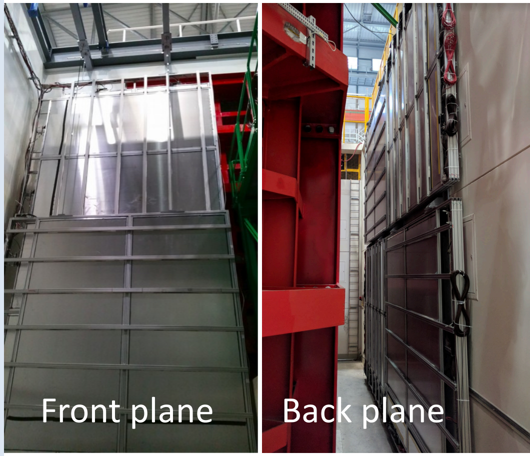
- 2 drift volumes, each with a 3.6 m drift distance
- 6 anode plane assembly (APAs) (one far detector module has 150 APAs)
- Cold electronics (preamplifier + digitizer) with 15360 channels.
- 0.42 kton active volume
- HV at 180 kV, which provides the nominal E-field 500 V/cm

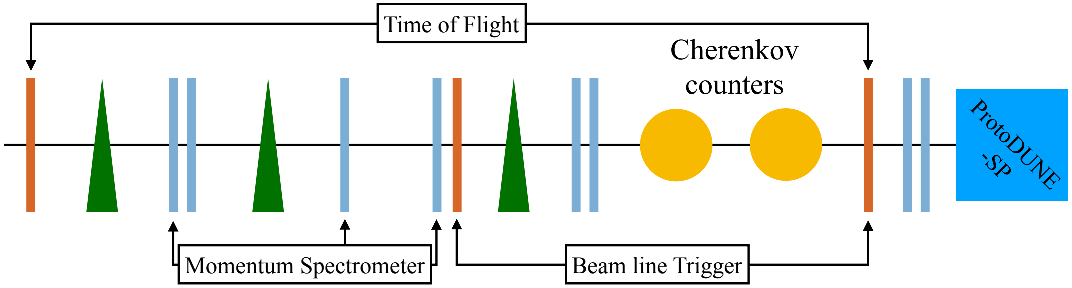
Other systems

- Photon detector system
  - **60 light collecting bars** (*10 per APA*) installed in the APA frame
  - 3 detector technologies: ARAPUCA light trap, double-shift light guide, dip-coated light guide.



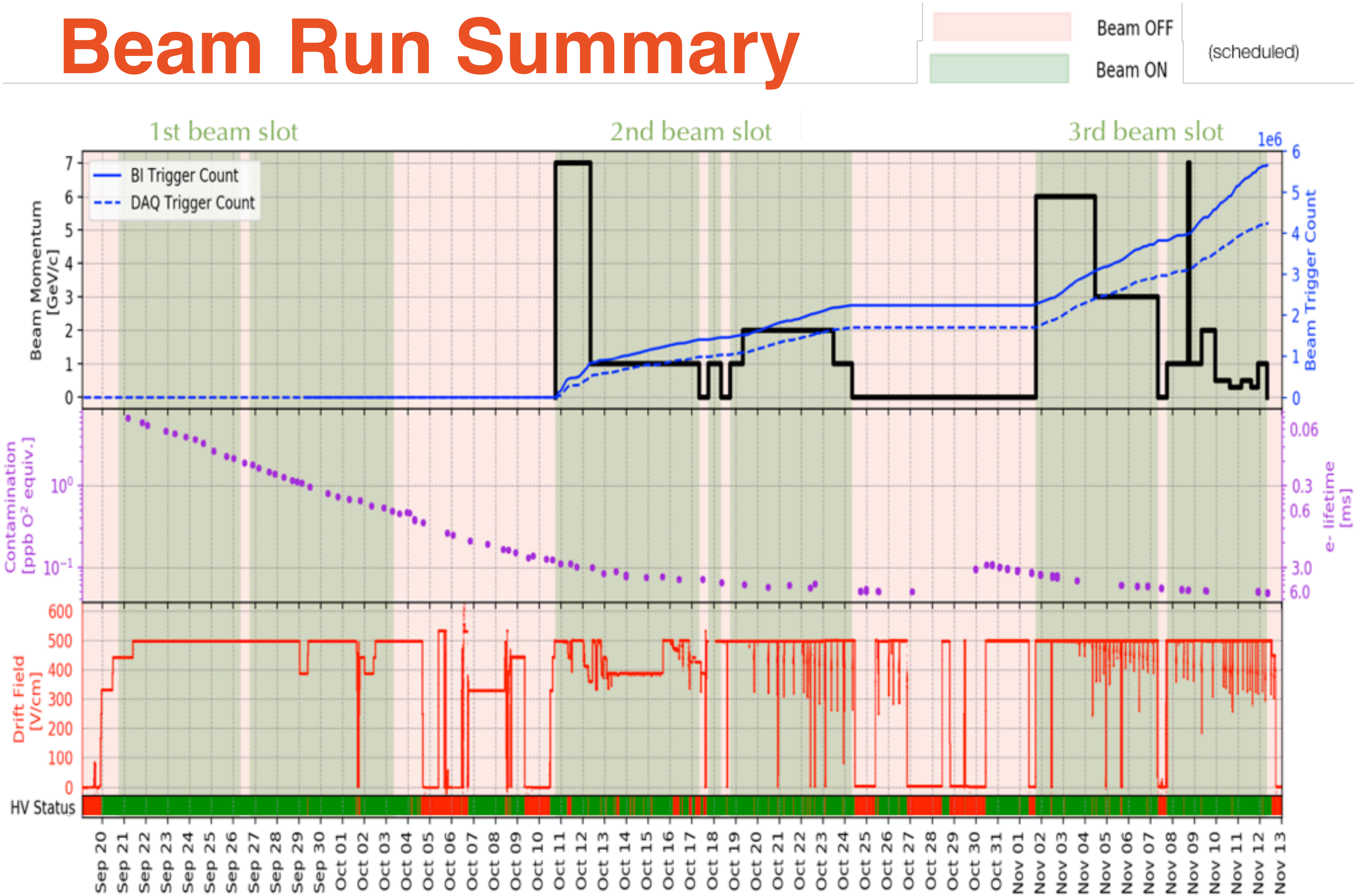
- Cosmic ray tagger
  - 6.8 m x 6.8 m scintillator panels upstream and downstream
  - Provide t0-tagged through going muons for detector calibration.





- H4-VLE beam line
  - New tertiary, low-mom beam line
  - 2 secondary targets
    - W for lower momenta (0-3 GeV/c)
    - Cu for higher momenta (4-7 GeV/c)
  - TOF and Cherenkov counters for PID
  - Phys. Rev. Accel. Beams 22, 061003 (2019)

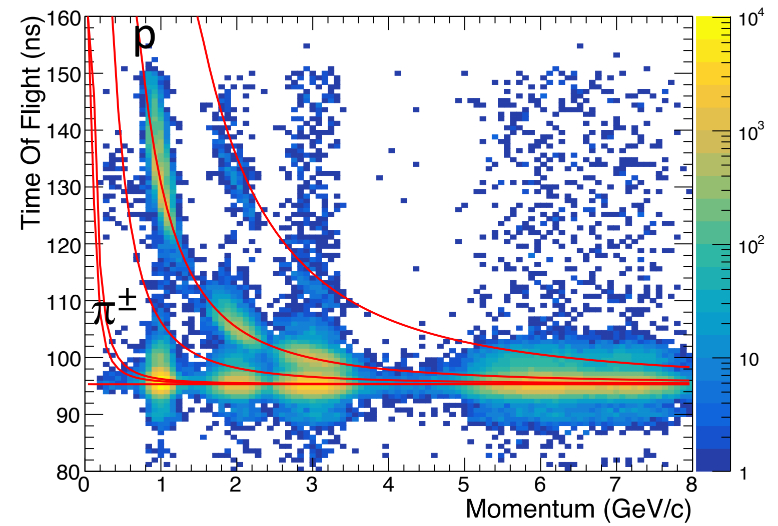
Beam Run Summary



Collected beam events: Oct-Nov 2018

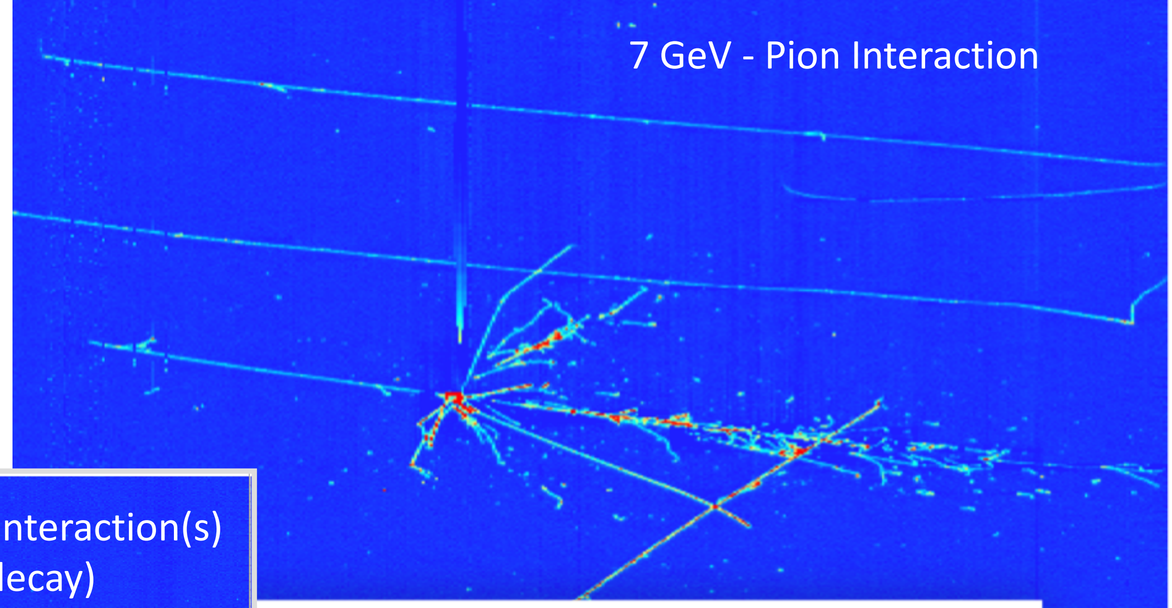
Momentum (GeV/c)	Total Triggers Recorded (K)	Total Triggers Expected (K)	Expected Pi trig. (K)	Expected Proton Trig. (K)	Expected Electron Trig. (K)	Expected Kaon Trig. (K)
0.3	269	242	0	0	242	0
0.5	340	299	1.5	1.5	296	0
1	1089	1064	382	420	262	0
2	728	639	333	128	173	5
3	568	519	284	107	113	15
6	702	689	394	70	197	28
7	477	472	299	51	98	24
All momenta	4173	3924	1693.5	777.5	1381	72

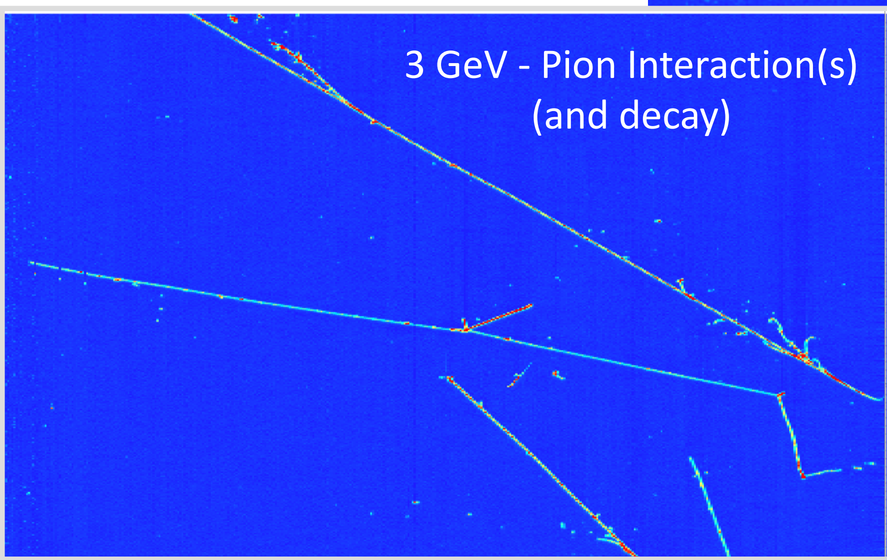
- 300 k pion events at 1, 2, 3, 6, 7 GeV/c.
  - Reasonable uncertainty on the smallest cross section (charge exchange)
- Large statistics proton and electron data. Some high energy kaon data.
- Beamline measurements for PID.

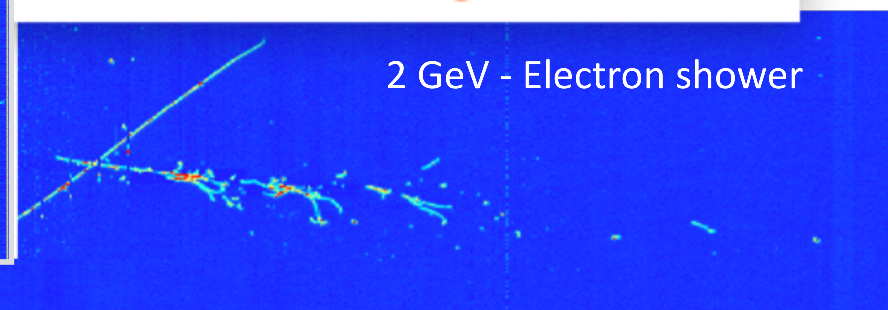


At first glace:

LArTPC data of unprecedented quality



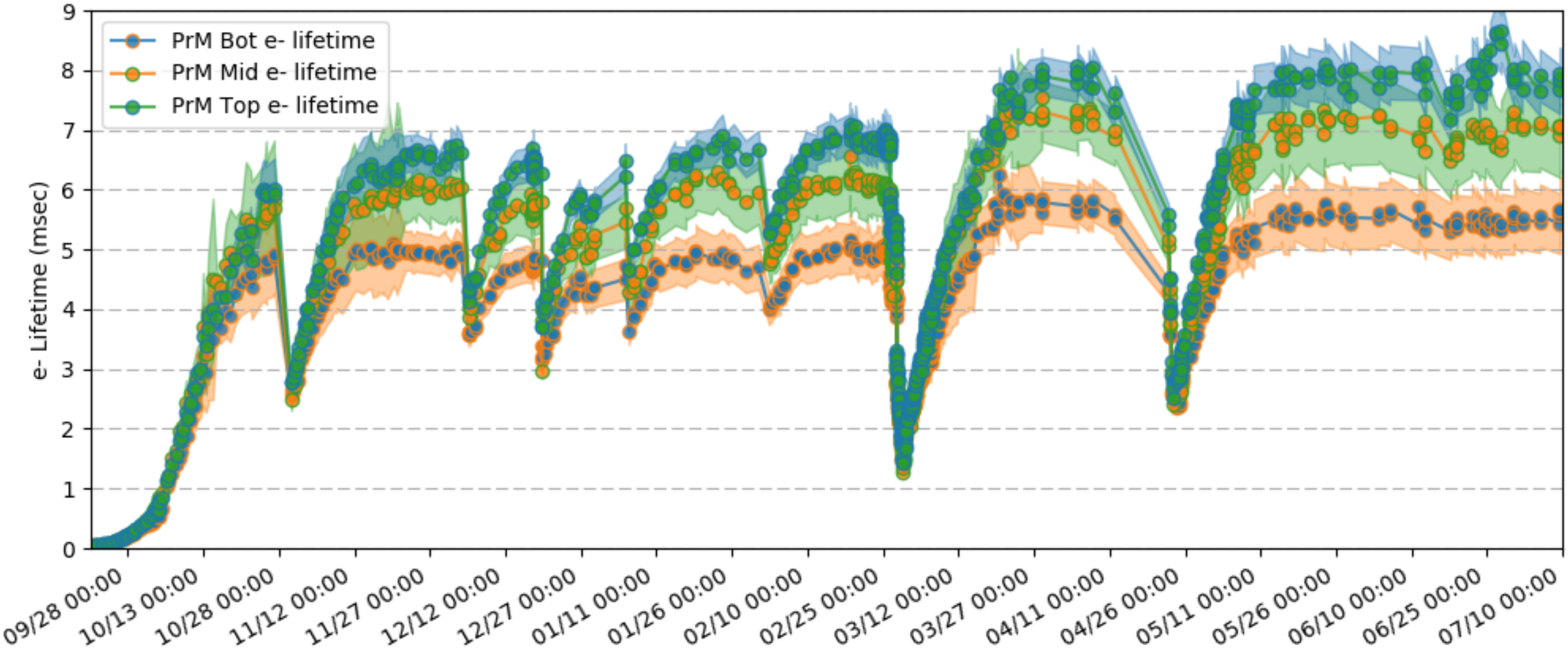




ProtoDUNE-SP Analysis Plan & Goals

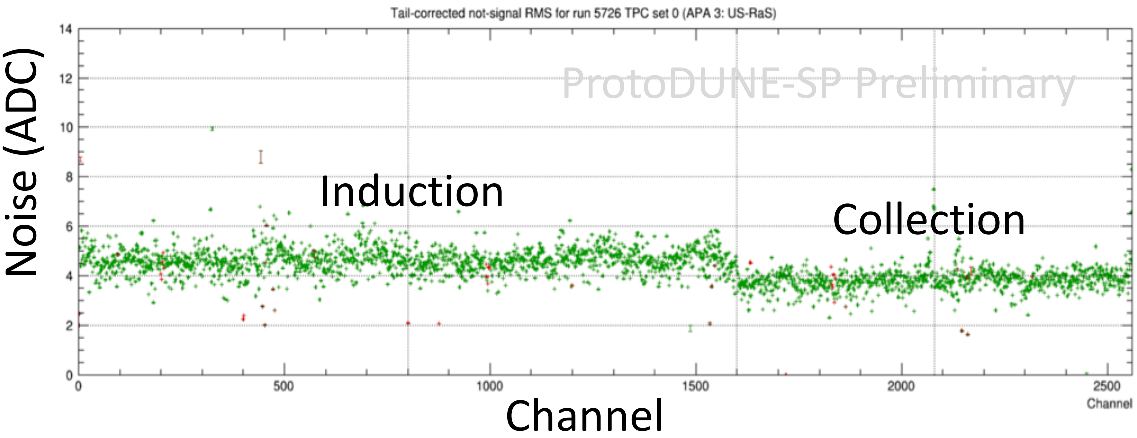
- Detector Performance – Information for DUNE TDR & first papers
  - ✓ LAr purity
  - ✓ Noise level, signal to noise ratio
  - ✓ Detector calibration, removing space charge effects etc.
  - ✓ dEdx of muons, protons, pions, kaons, electrons
  - ❑ Energy and momentum resolutions (w/ Charge-TPC and *(in progress)* Light-PDS)
- Physics measurements - physics publications
  - ❑ (*started*) Total pion cross section in [1-7] GeV range
  - ❑ (*started*) Exclusive channels Cross Section:
    - ➢ π absorption: $\pi^{\pm} \rightarrow 2p, 3p, 2p1n,..$
    - ➢ $\pi^{\pm} \rightarrow \pi^{0}$ charge exchange, etc.

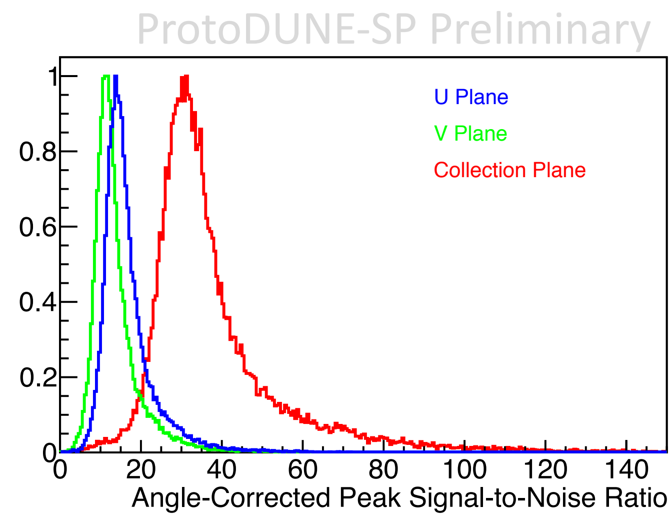
Detector performance: LAr Purity



- Liquid Argon purity is routinely measured by the three Purity Monitors at 1.8 m, 3.7 m, and 5.6 m from the bottom of the cryostat.
- High purity reached thanks the gas/liquid recirculation & filtering (1 volume / ~ 4.5 day): Purity drops when Ar circulation pumps stop.

Electronic noise and S/N ratios





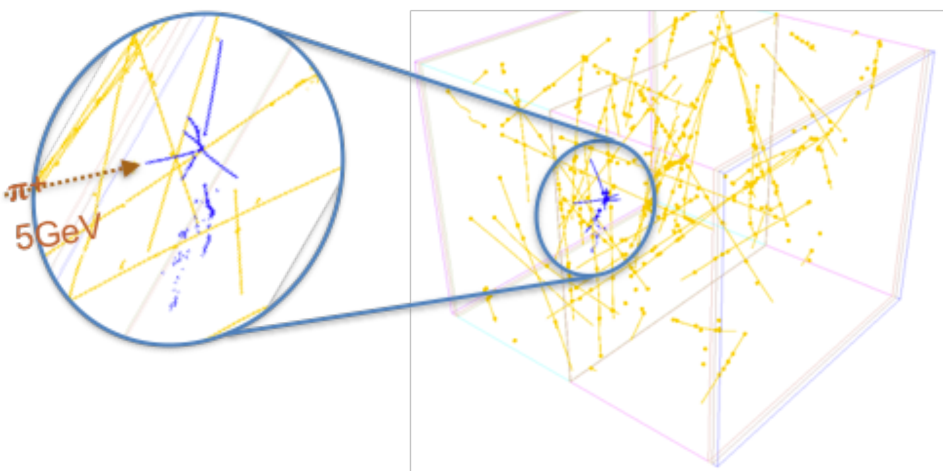
- Noise level measured by pedestal RMS before noise filtering
  - Collection: 550 e^-
  - Induction: 650 e^-
  - Noise filter reduces both by 100 e^-

- Signal-to-noise ratio measured by cosmic muons
  - Collection: 38:1
  - Induction U: 14:1
  - Induction V: 17:1

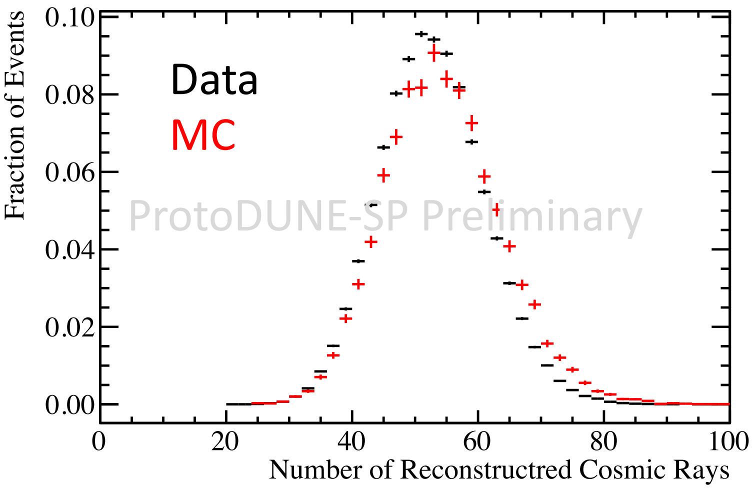
See two related ProtoDUNE talks:

- **Brian Kirby**: The protoDUNE-SP LArTPC Electronics Production, Commissioning and Performance
- **Carlos Sarasty Segura**: Noise Filtering and Signal Processing in the ProtoDUNE-SP LArTPC

Reconstruction Performance



Number of reconstructed cosmic ray tracks in the 3 ms readout window

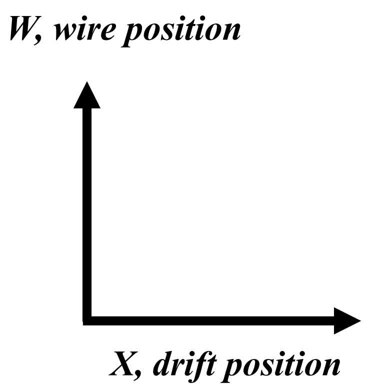


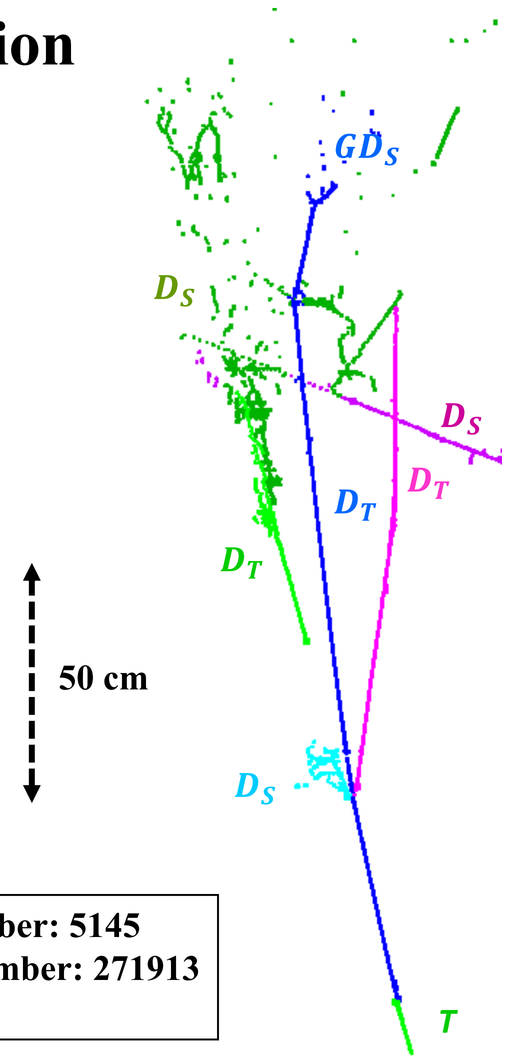
- PANDORA pattern recognition separates and classifies the beam event from the cosmic muons tracks in the 3 ms TPC readout window.
- Subsequent off-line analysis can proceed separately for the beam event and for the cosmic ray muon tracks.

arXiv:1708.03135: The Pandora multi-algorithm approach to automated pattern recognition of cosmic-ray muon and neutrino events in the MicroBooNE detector

Reconstructed Beam Event

W VIEW – Pandora Reconstruction





D_T = Daughter Track
D_S = Daughter Shower
GD_T = Granddaughter Track
GD_S = Granddaughter Shower
T = Trigger Parent Particle (π^+)

Run Number: 5145
Event Number: 271913
7 GeV

ProtoDUNE-SP – Data

Detector calibration strategy

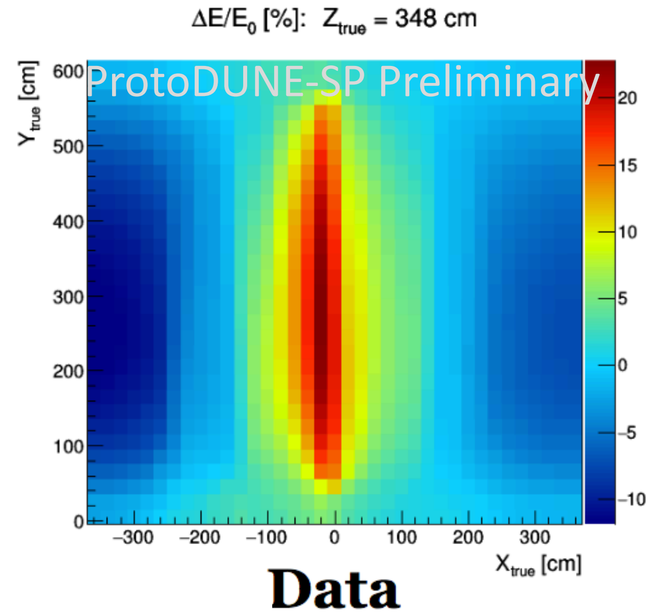
- Remove any nonuniformity in the detector response
  - ✓ **Space charge effects (SCE)** – removed using E-field map
  - ✓ Attenuation caused by impurities – removed using muon MIP map
  - ✓ Variations in electronics gain – removed using pulser data
  - ✓ Other effects (grounded electron diverters, floating grid plane, etc.) – removed using muon MIP map
- Determine the absolute energy scale
  - ✓ Using stopping muons
    - dE/dx in the MIP region is very well understood theoretically to better than 1%

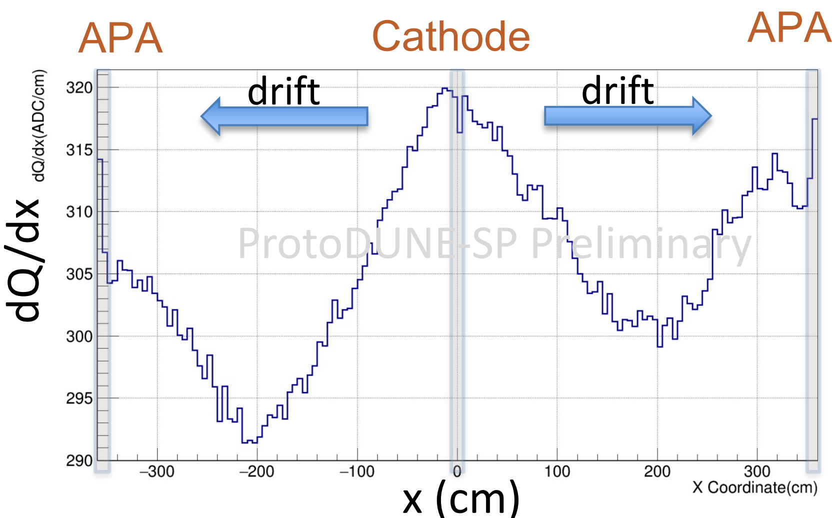
Using the same method developed by MicroBooNE: **arXiv:1907.11736**

Space Charge Effects

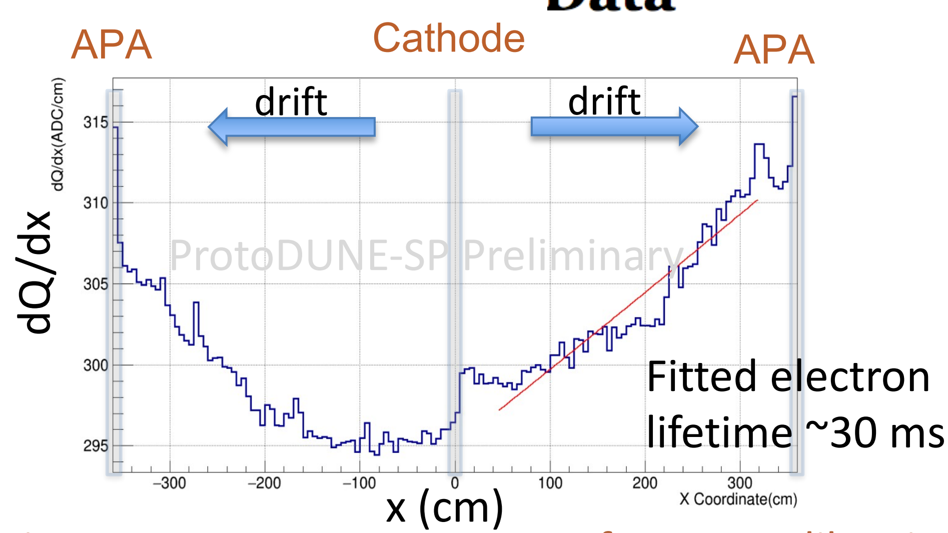
- Space charge due to accumulation of slow drifting ions
- E-field distortion changes reconstructed particle trajectory and recombination.
- E-field map measured using cosmic ray muons for calibration

E-field map: +20% at cathode, -10% at anode



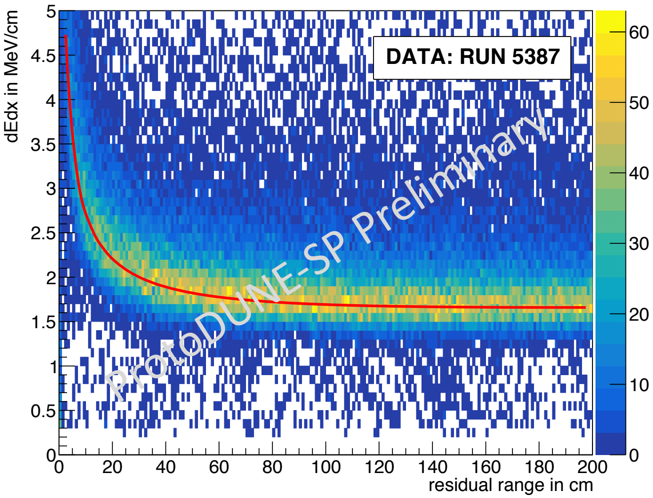


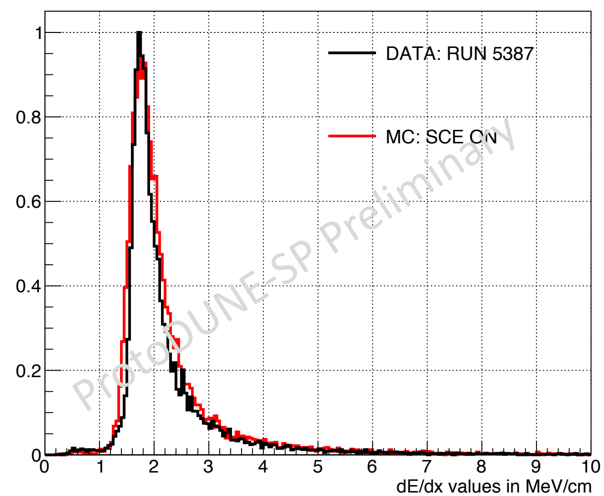
Before SCE calibration



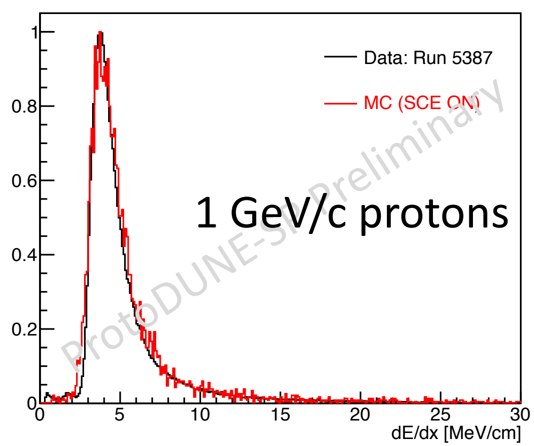
After SCE calibration

dE/dx reconstruction





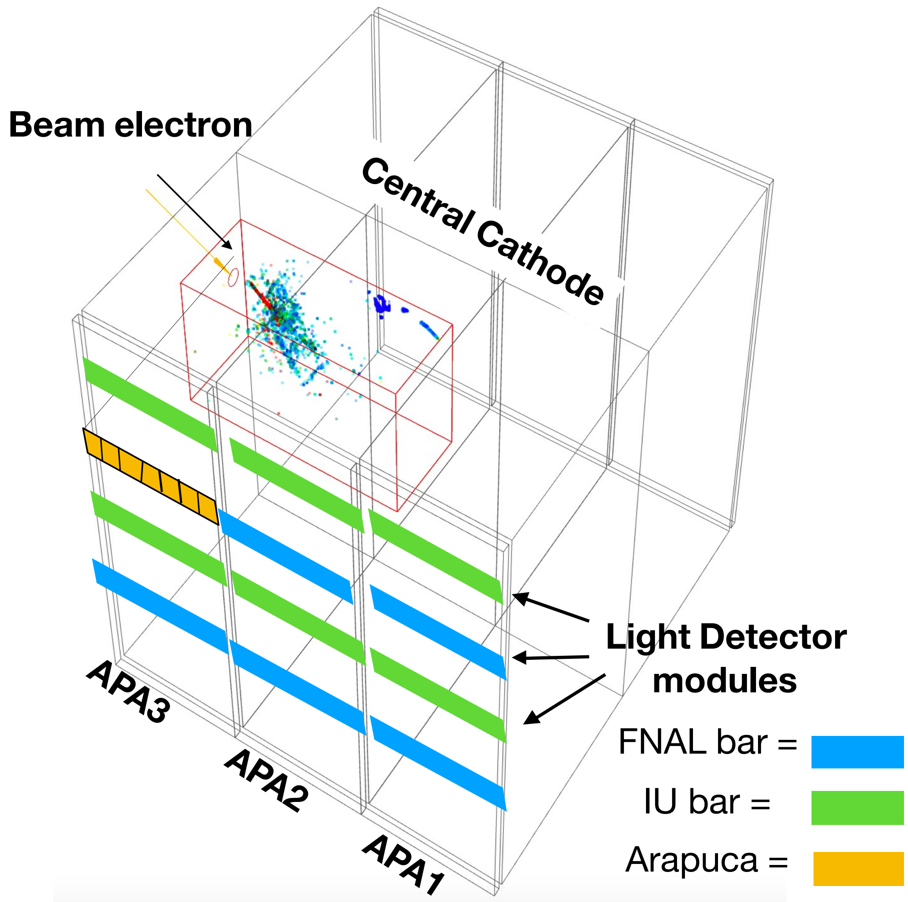
Use stopping muons to determine the absolute dE/dx scale.

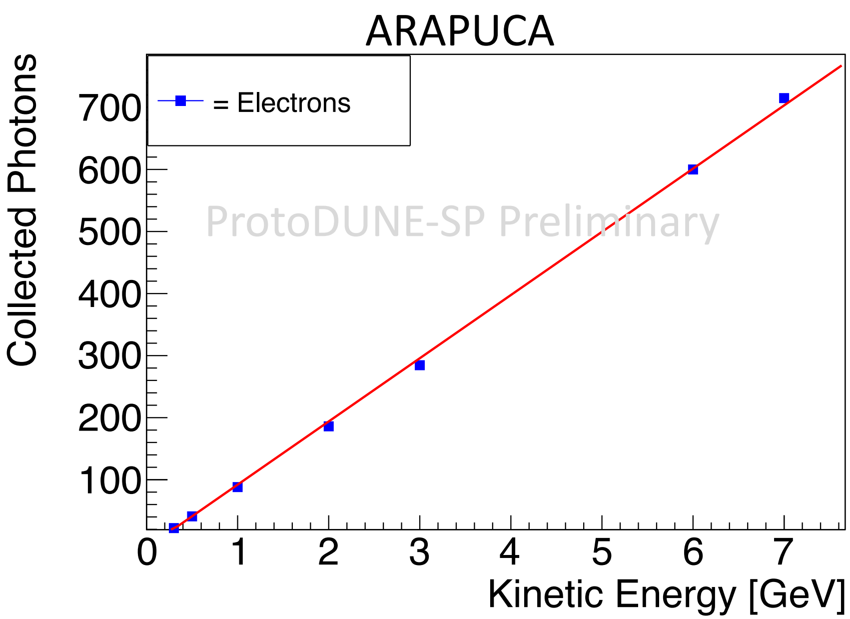


Same calibration applied to beam proton data.
Very good agreement!

Heng-Ye Liao: ProtoDUNE-SP Proton Analysis

Photon detector response

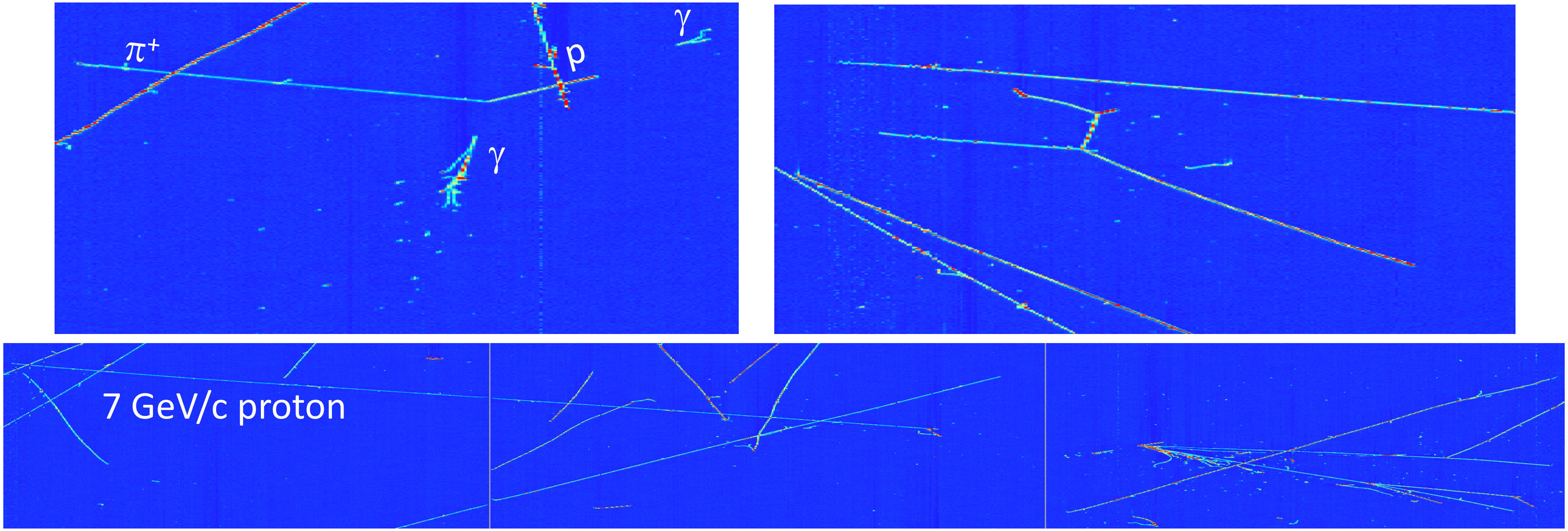




- Achieve energy linearity for beam electrons contained in the detector
- Not corrected for geometry and detection efficiency

Perspective for cross section measurements

- The precision hadron cross section measurements will help the DUNE physics in many ways
  - Provide input to the neutrino generators to improve the final state interaction models.
    - For example: the charge exchange process π^++Ar->Ar*+p+π^0 is an important background to the ν_e signals
  - Validate the GEANT simulation of hadron interactions in the LAr.

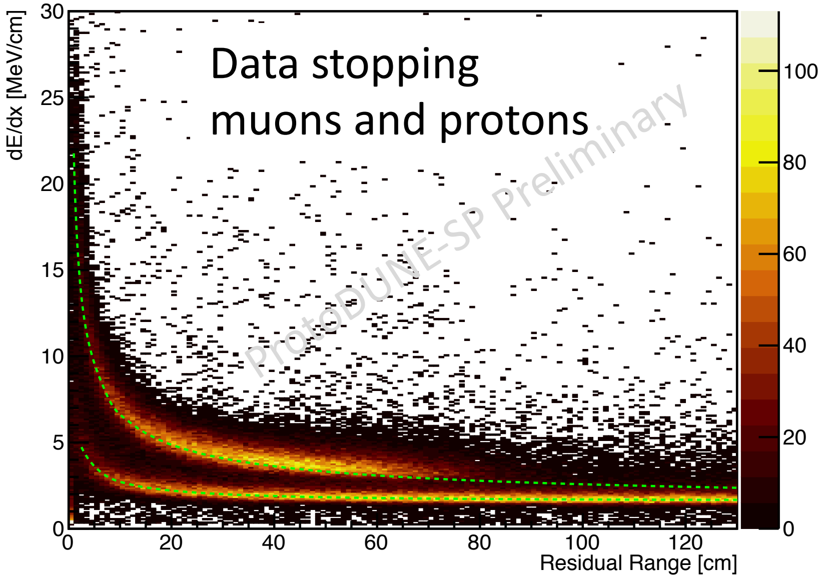


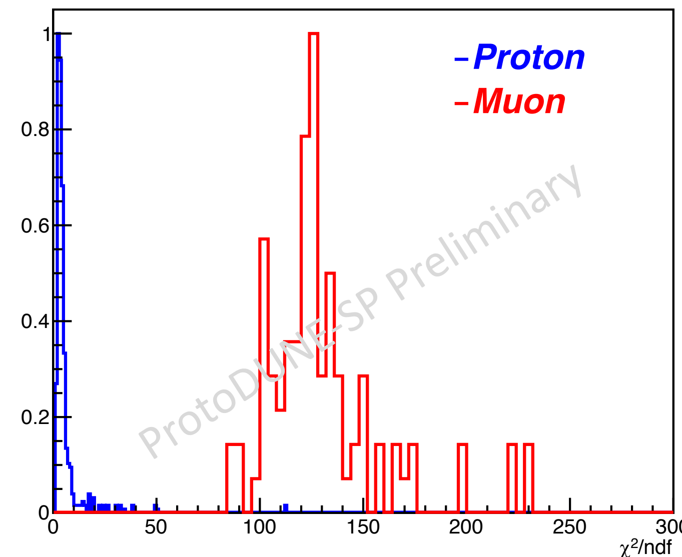
Conclusions

- The data taken with the ProtoDUNE-SP detector demonstrates the excellent performance of the detector.
- We achieve a good understanding of the detector response
  - Detector nonuniformity removed
  - Energy scale determined
  - Excellent particle ID demonstrated
  - Two papers are being prepared on technical details and detector performance
- We are working on physics measurements, which will provide valuable information to DUNE

Stay tuned!

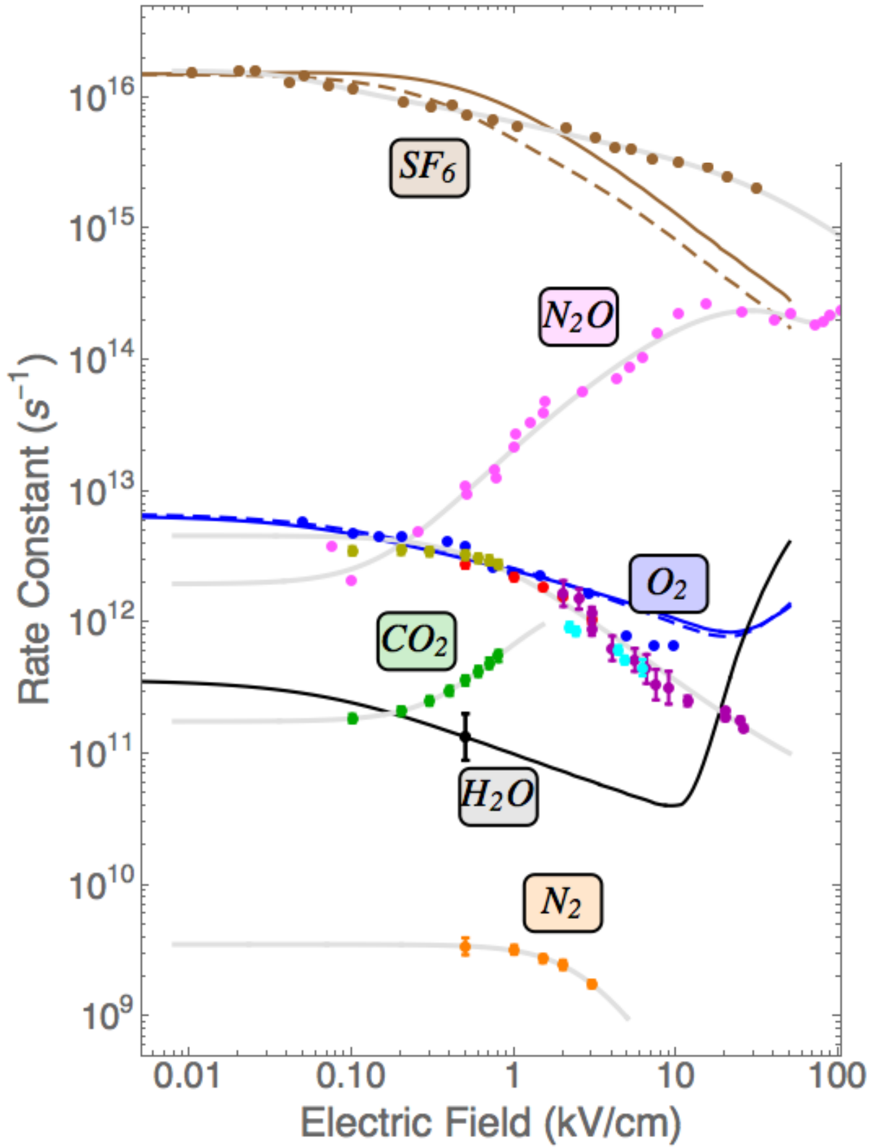
Particle Identification





PID

- Very well understood detector response to particles of different species.
- Excellent separation of muons and protons using calorimetric information.
- This allows detailed studies of hadron interactions in LAr!



Craig Thorn: attachment rates
Purity monitor: ~50 V/cm
TPC: 500 V/cm