# ProtoDUNE SP: Proposals at the CERN Neutrino Platform after LS2

*Flavio Cavanna*

**SPSC132 Meeting**

CERN - Jan 23, 2019

# OUTLINE

- **brief answers to SPCS Questions (Jan. 20, 2019)**

**SP: 2018-Test beam**

1. comparison of the expected number of particles requested of each type/energy and the actual number collected.
2. update on the detector performances, particularly the achieved purity, drift field stability and light detection system.
3. current status and response of the purity monitors
4. space charge effects
5. Which is the preferred option for the photon detection design?
6. issues with the ADCs
7. issues with the HV filters and the planned improvement

**SP: Operations after LS2**

1. tentative timeline for the upgrade, particularly specifying the plans for the installation of a calibration systems, the electronics and the modification of the light detection.
2. You request 120 days. Does this cover SP and DP? Will both detectors run in parallel?
3. more details on the requested beams and on the physics reach of the test beam program.

- **Program for 2019 Cosmic Run**
- **Current plans for 2020 (detector upgrade) and for Beam Run after LS2 (2021-22)**

# ProtoDUNE 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**

## New/Innovative elements of the *DUNE Single Phase Far Detector Design* implemented in protoDUNE-SP:

- CRYOSTAT: Membrane Cryostat (non evacuable, based on LNG container technology)

- APA (TPC wire planes assembly with wrapped wire geometry)
- Cold Electronics (FE and ADC stages both in cold)
- PhotoDetector (3 options implemented, including ARAPUCA)

- 3.6 m drift distance (longest drift ever implemented in LArTPC experiments)

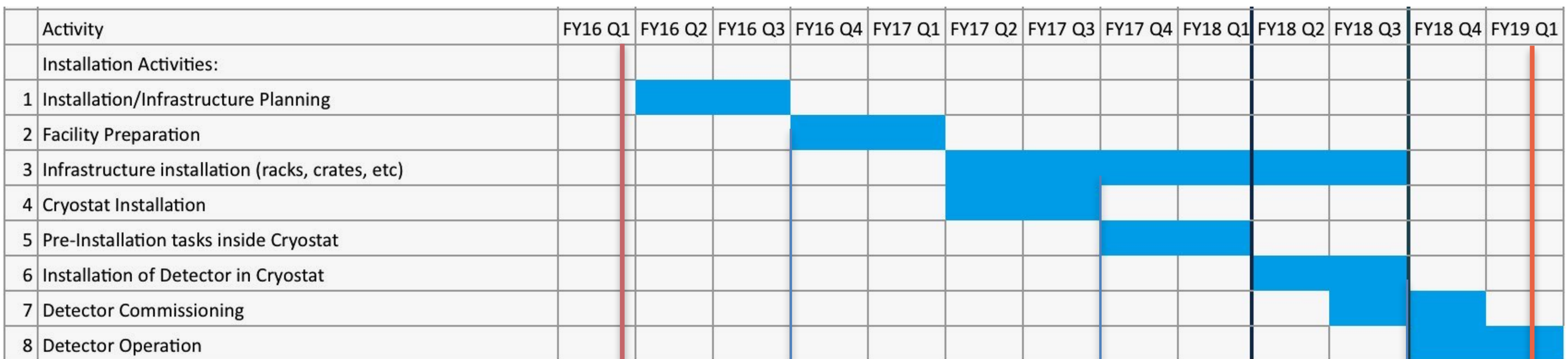
- Resistive Cathode + HV bus
- Field Cage (based on Al profile assemblies) + Ground planes

- Cryo Instrumentation and Slow Control for monitoring LAr properties (high resolution Vertical T-Profiler, VideoCameras, Purity Monitors,..)

PROTO DUNE SP → DUNE TDR

# High-Level Time Schedule at protoDUNE SP approval

The *original schedule* called for the detector to be ready for filling in Summer of 2018 and operation with test beam in Fall of 2018, test beam running to end with the start of the CERN Long Shutdown (LS2).




Dec.’15, ProtoDUNE Approved

Sept.’16, Neutrino Platform ready

May ’17, Cryostat ready

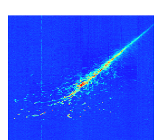
Jun.’18, Detector in Cryostat

**Jul-Nov ’18** **Commissioning** **Beam Run**

**CERN LS2**

Neutrino PLATFORM DUNE

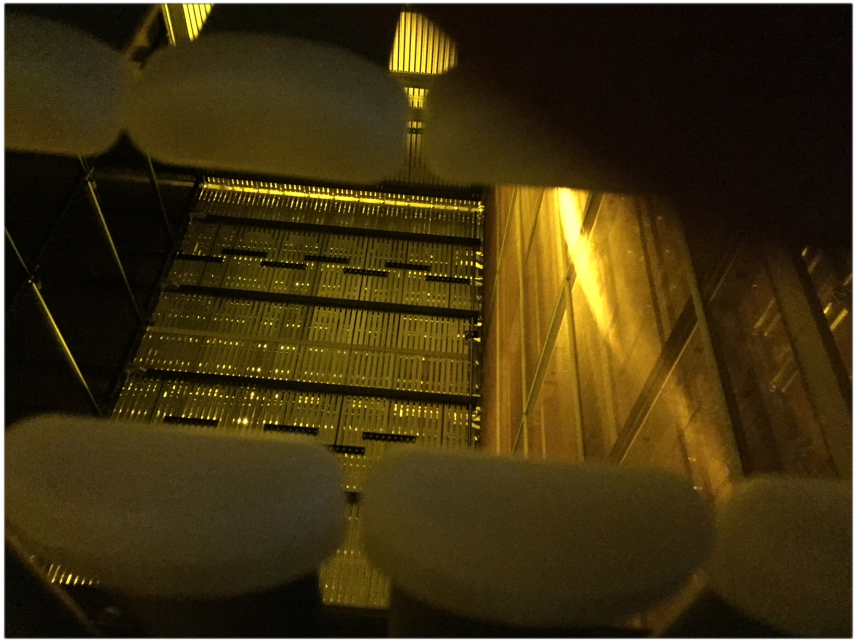
From digging the pit to data taking in 2.5 yr



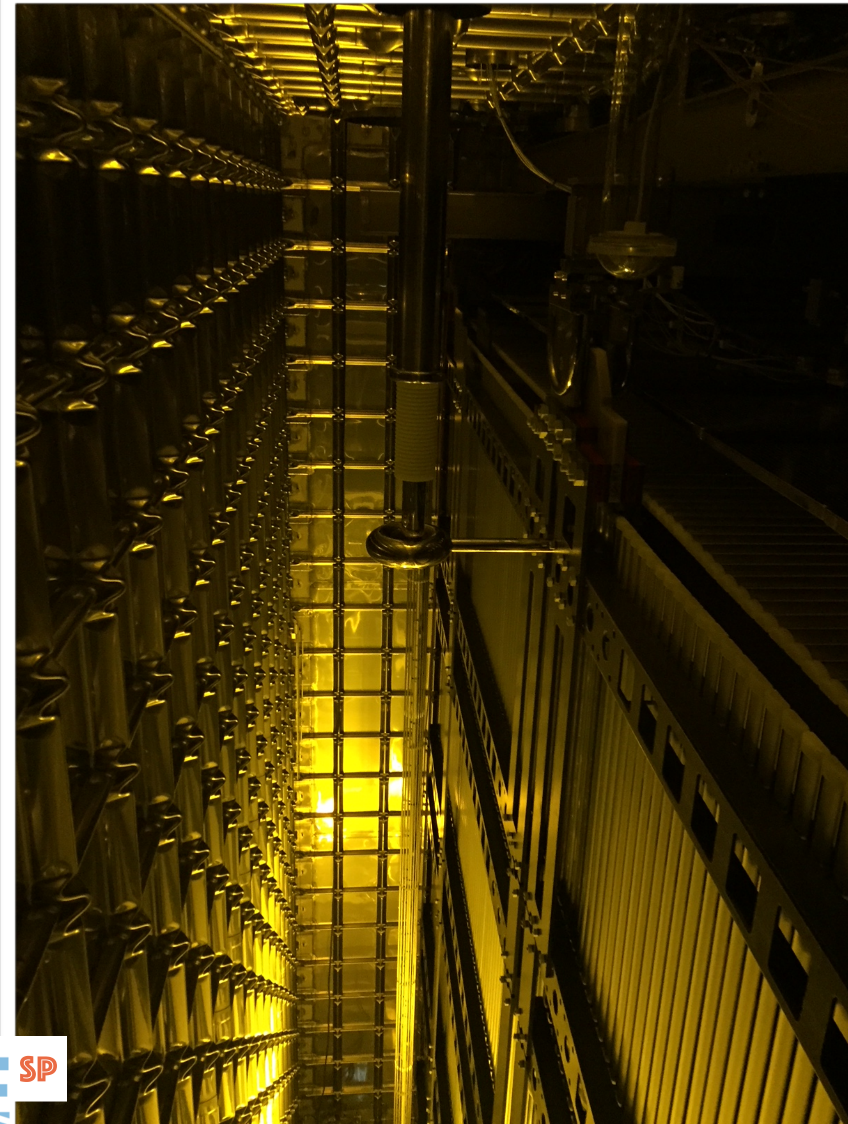
respecting the schedule)

Since the last SPSC: Jun. 29

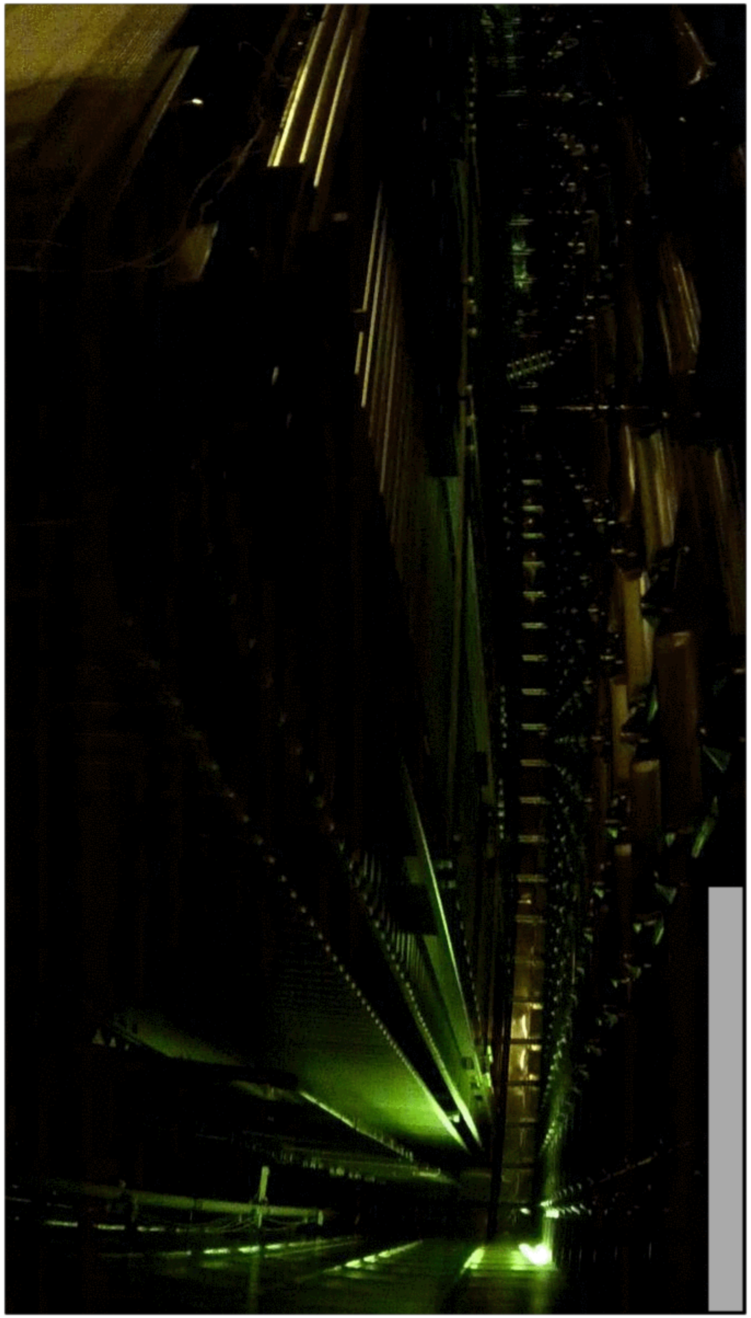
# Detector Completed



the last exiting the cryostat



PROTO DUNE SP

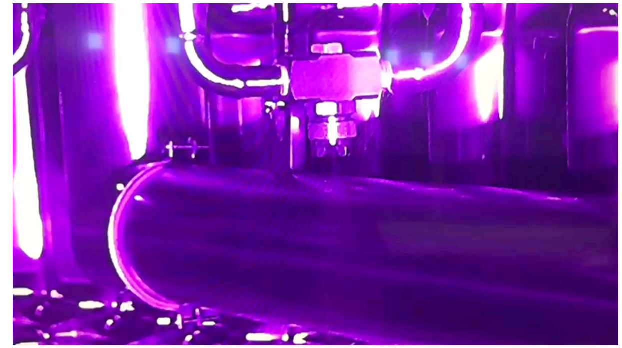


# Cryogenic Commissioning Purging, Cooling and LAr Filling

July 15 to Sept. 13 - 2018

LAr Filling:

LAr level going up as seen by a camera from Bottom of the Cryostat



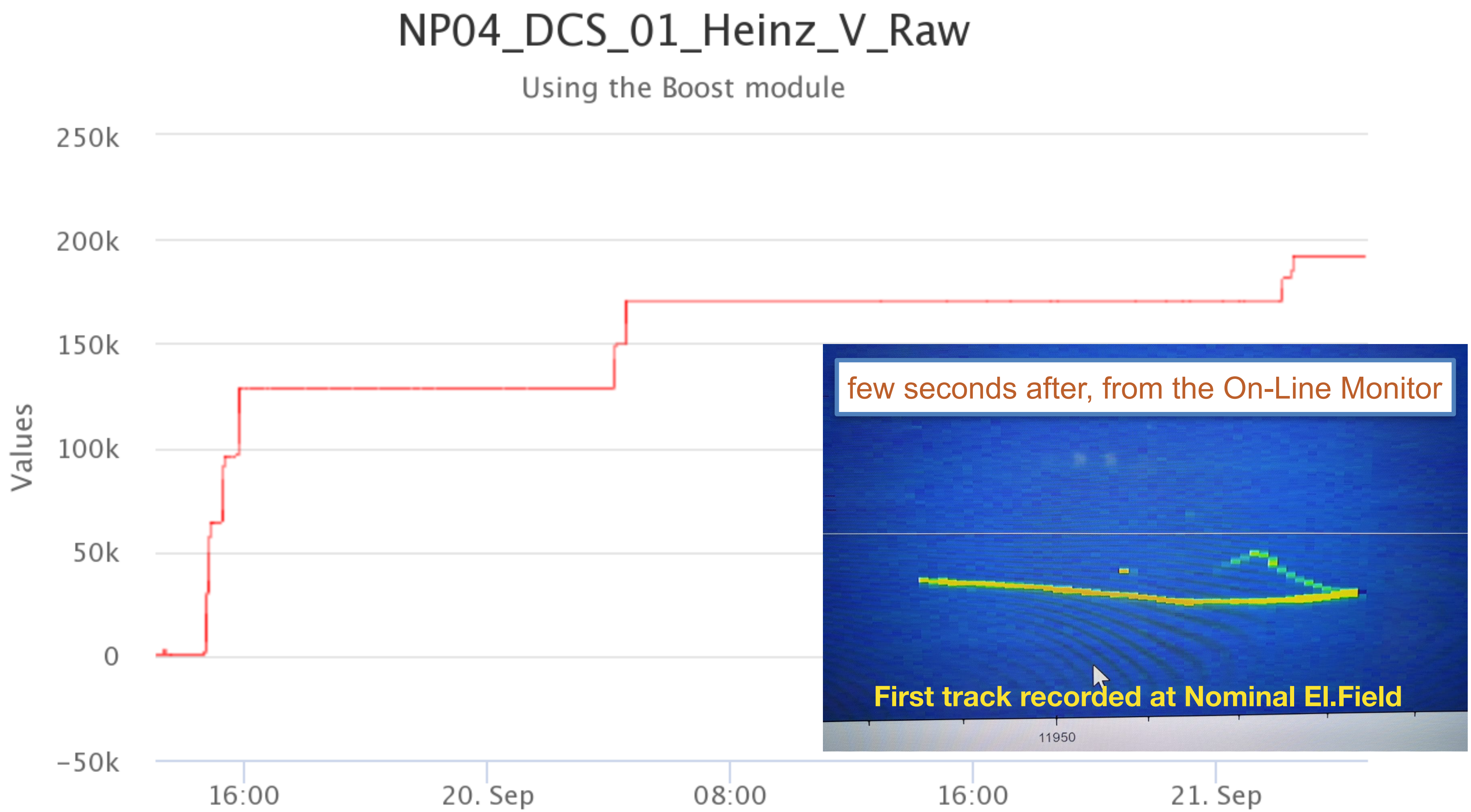
and Cooling:

spraying cold Ar from top of the Cryostat for cooling

- Kept the LAr level below the APA until the temperature gradient across its height was no more than 50K
- August 13th, increased fill rate
- September 13th, reached nominal level

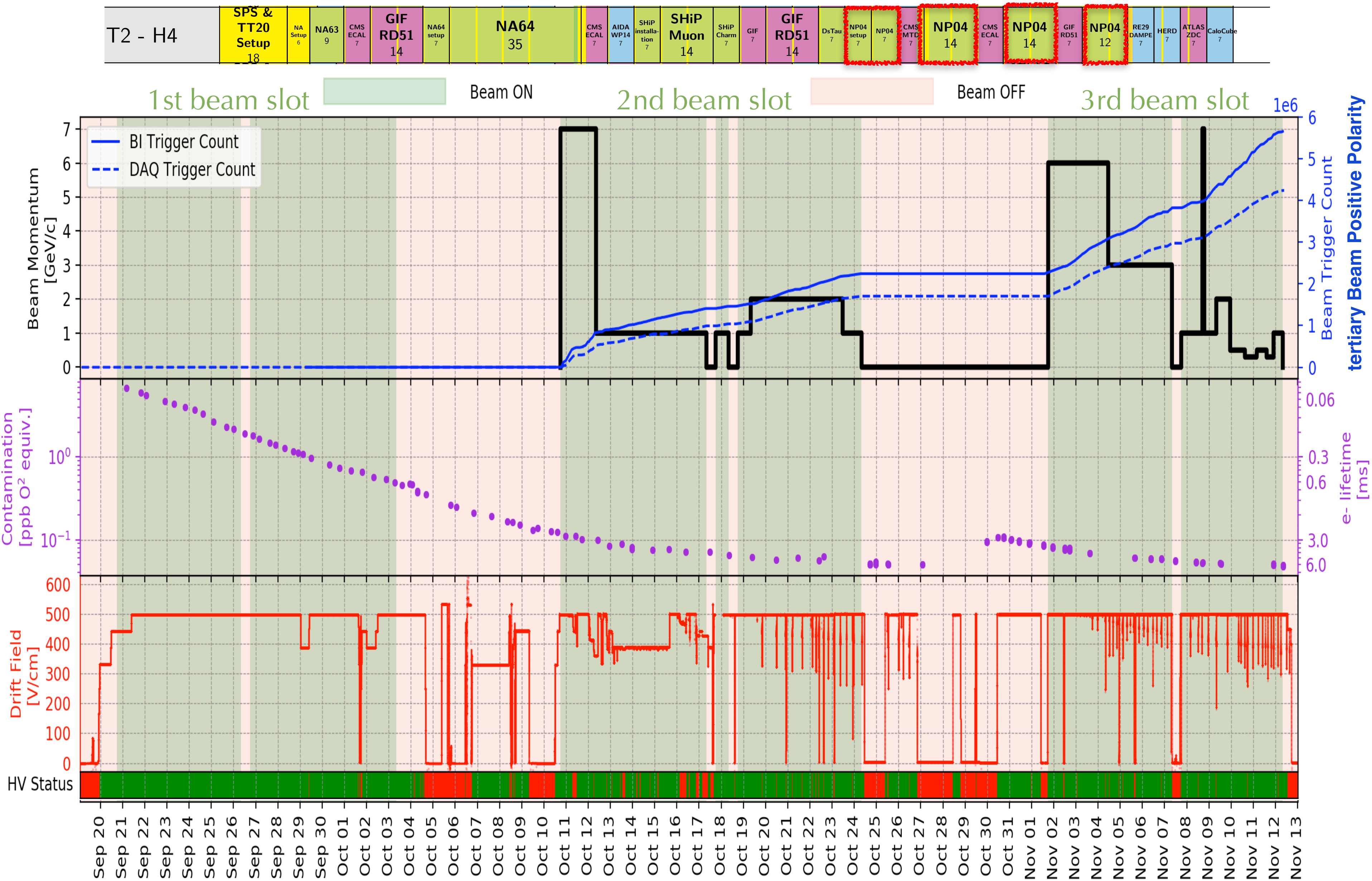
# Detector Activation Procedure

**Sept. 19, h. 15:32 - started**




**HV Ramp from 0 to 180 kV (Nominal) successfully completed**

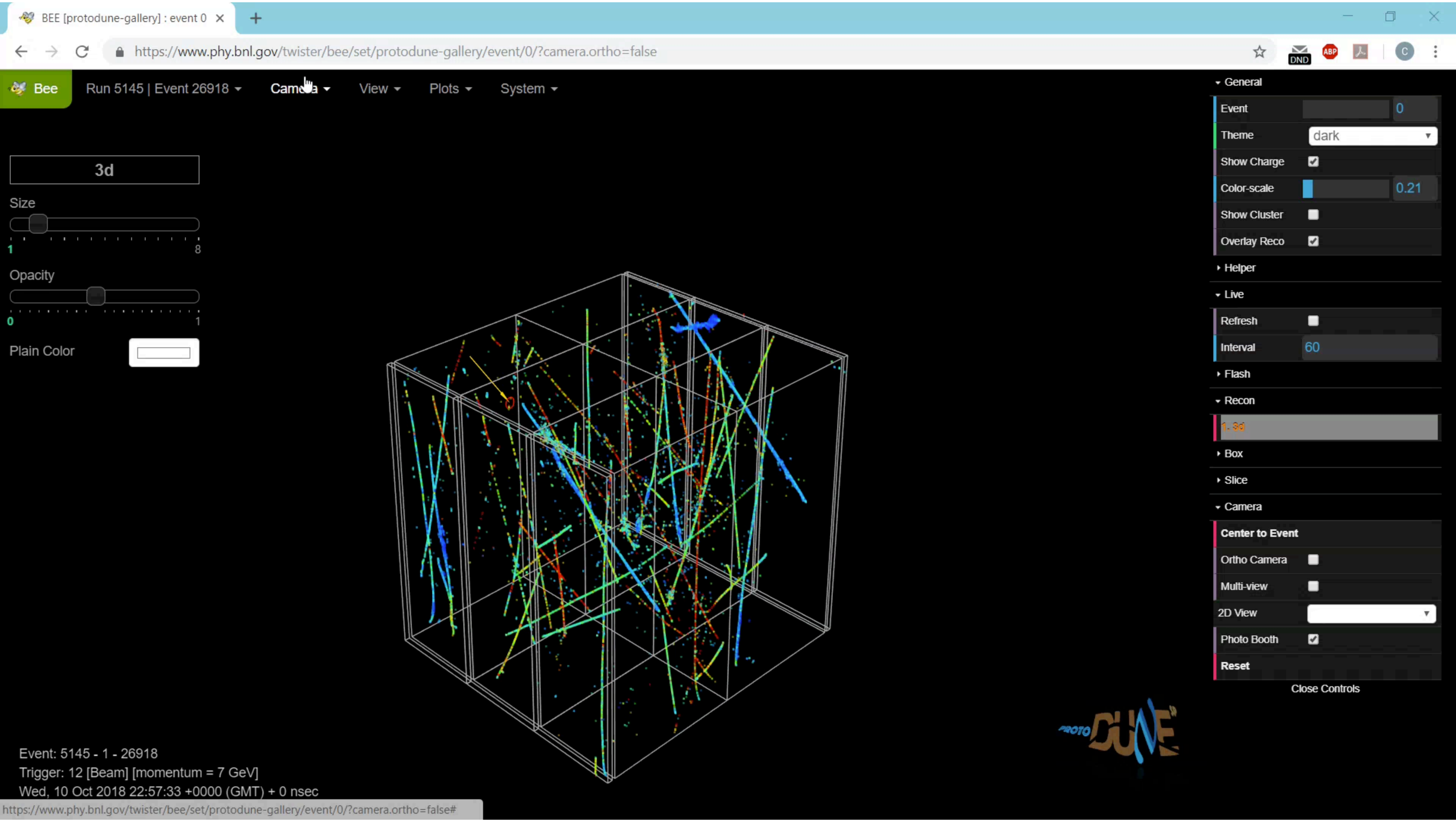
**Sept. 21 - h. 2:32 am -**




# Beam Run Summary

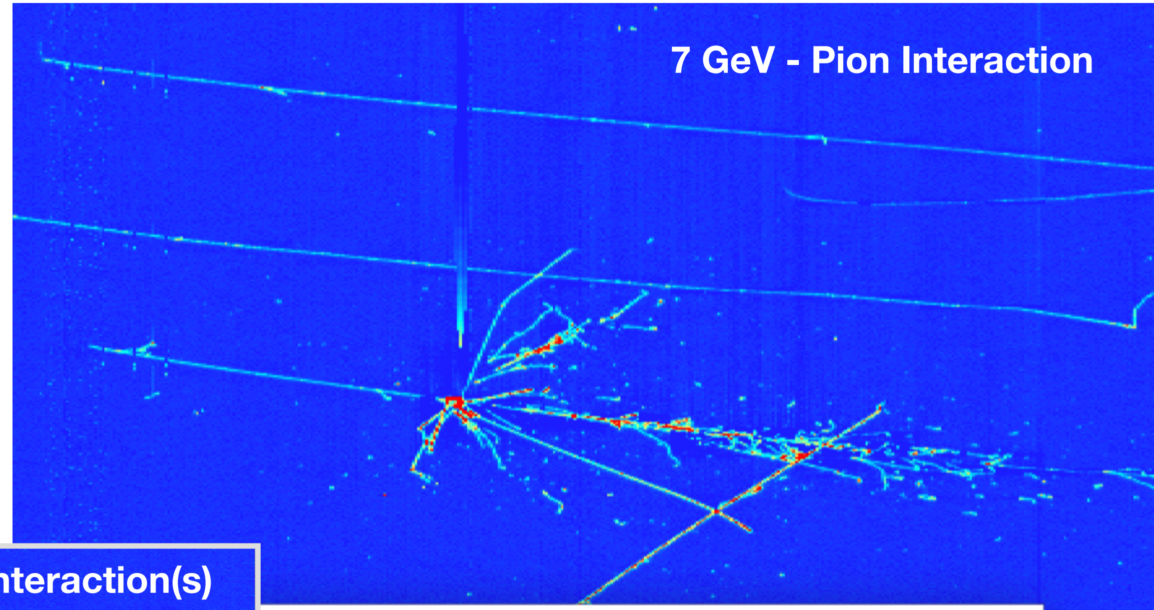
# a first look to real data

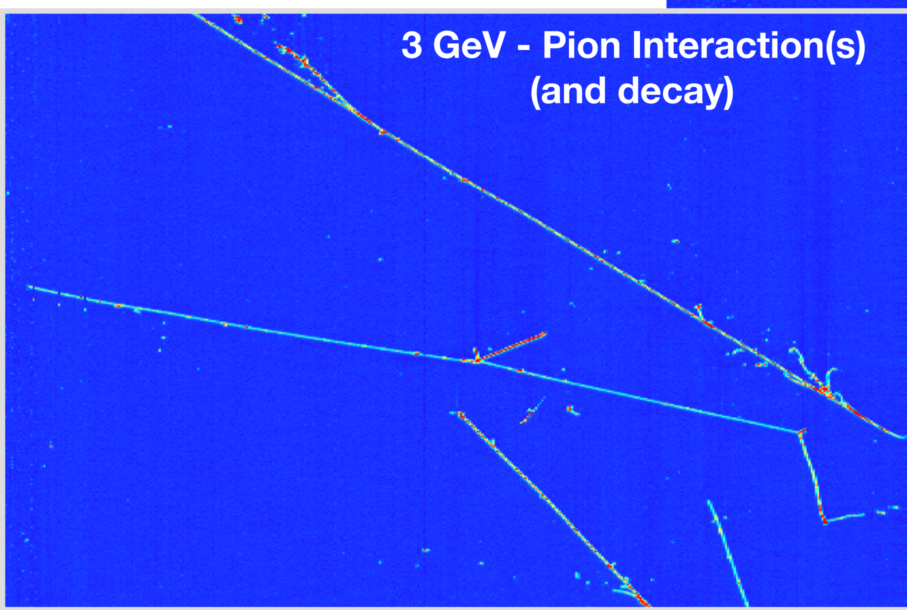
click here for a
[gallery of ProtoDUNE events]



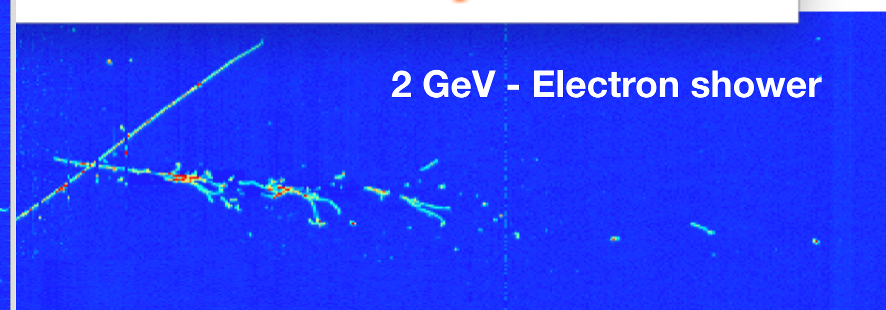
# LArTPC data of unprecedented quality

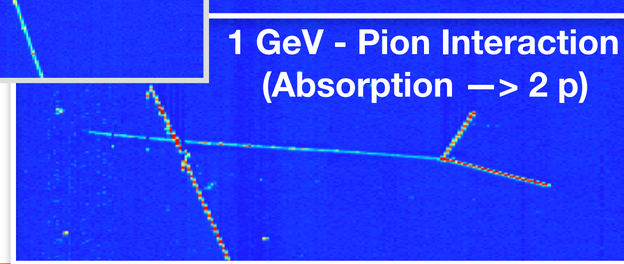
Data Analysis in progress




PROTO DUNE SP



# Beam Data Accumulation

*Particle content is based on the expected rates from the Geant simulation of the beamline*

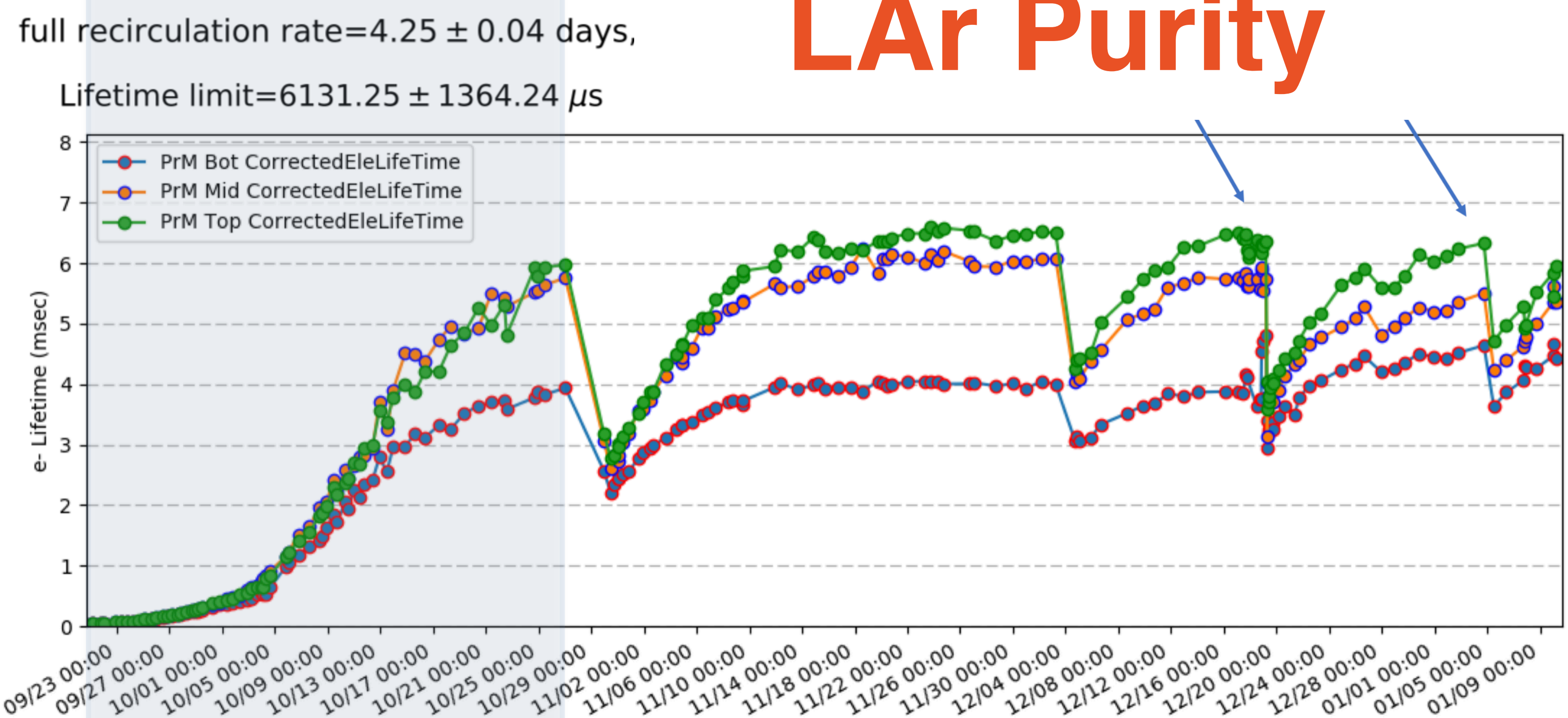
| Momentum (GeV/c) | Total Triggers Recorded (K) | Total Triggers Expected (K) | Expected Pi trig. (K) | Expected Proton Trig. (K) | Expected Electron Trig. (K) | Expected Kaon Trig. (K) |
|---|---|---|---|---|---|---|
| 0.3 | 269 | 242 | 0 | 0 | 242 | 0 |
| 0.5 | 340 | 299 | 1.5 | 1.5 | 296 | 0 |
| 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 |

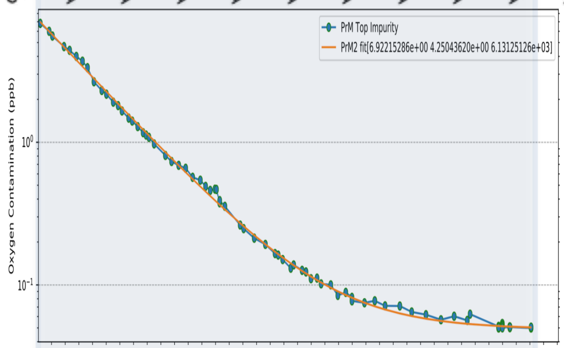
From the DUNE
Beam Time request for 2018
submitted to SPSC
on Oct. 11, 2017

- **Physics Run** [**expected 3000 spill/day**]:
  - ➡Hadron Beam - Goals:
    ≥ 500 k Pion evt per momentum setting (~3 M Total $\pi$-sample)
    ≥ 100 k Proton evt per momentum setting (700 k Total p-sample)
  - ➡Electron Beam - Goal:
    ≥ 75 k Electron evt per energy setting (900 k Total e-sample)

# Analysis of Cryo-Instrumentation Data

# LAr Purity




$$\tau_e = \frac{1}{k_A\,[O_2]}$$ from e-Lifetime to

Impurity Concentration [Oxygen equivalent]

- Fit $[O_2]$ data to $A\, e^{\frac{-t}{B}} + C$

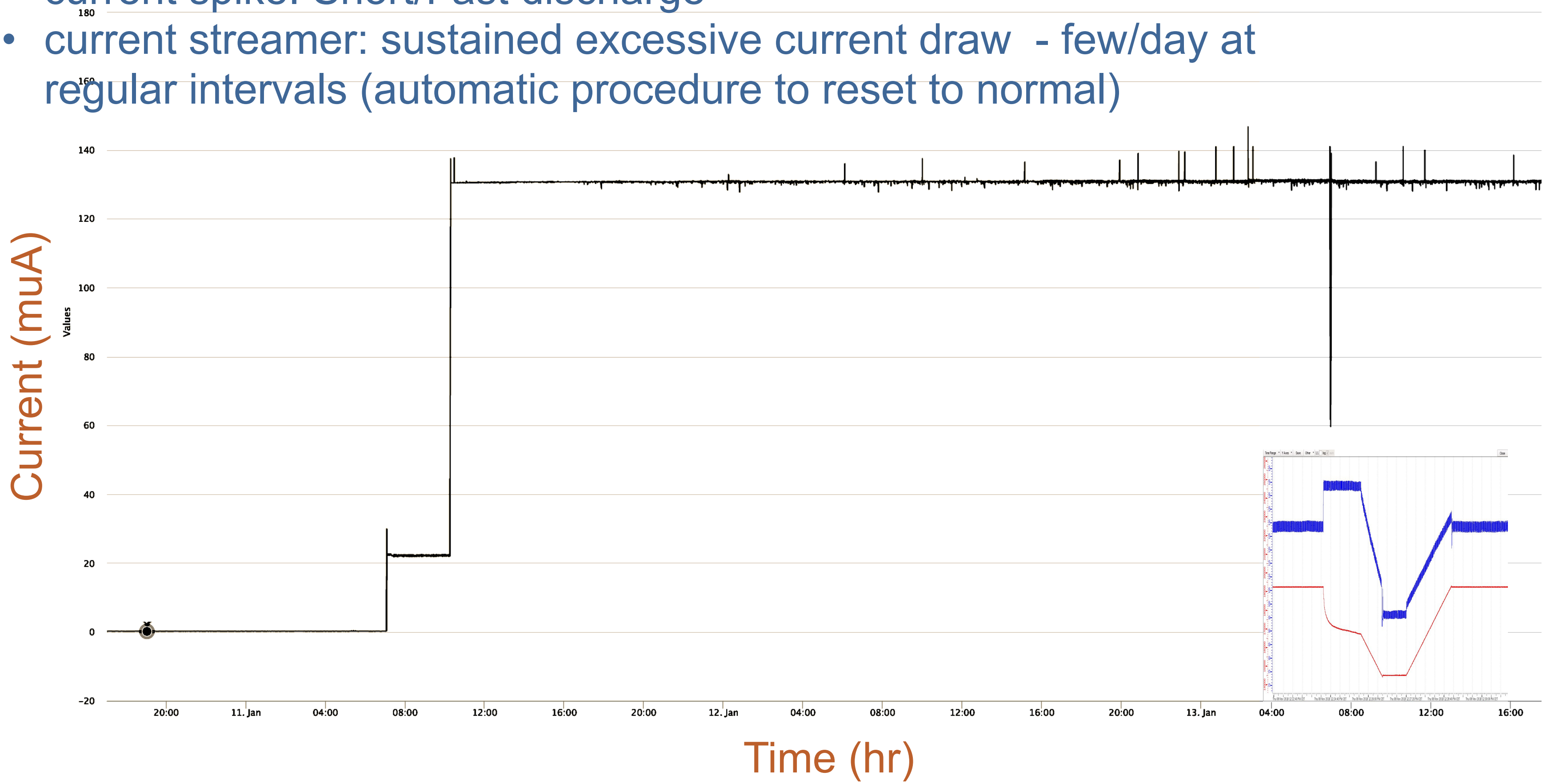
  B = 4.25 d (recirculation rate from fit)

# Analysis of DCS/SlwCtrl Data
## HV (drift Field) Stability

ProtoDUNE operated stably at EF=500V/cm ⟺ HV=180 kV at the Cathode

Two classes of instabilities observed:

- current spike: Short/Fast discharge
- current streamer: sustained excessive current draw - few/day at regular intervals (automatic procedure to reset to normal)

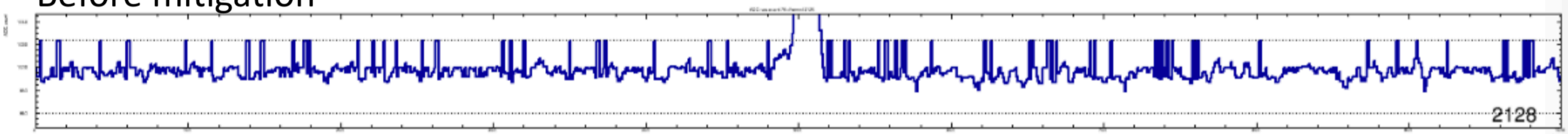


# Sticky Code Mitigated

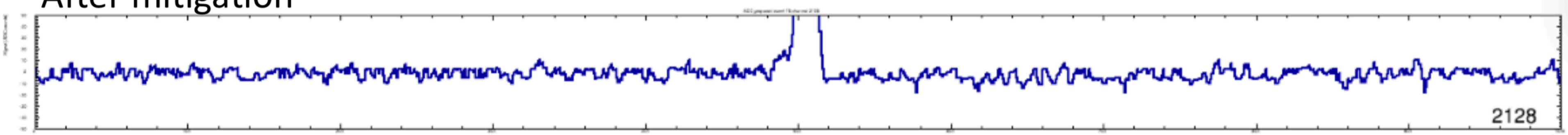
About 2% of channels show sticky code issues

- Sticky code - the 6 LSBs in ADC ASIC was found to be "sticky" around 000000 (0x00) or 111111 (0x3F).
- Can be mitigated through linear interpolation or constant-curvature interpolation.
- A new method is developed to interpolate through FT.

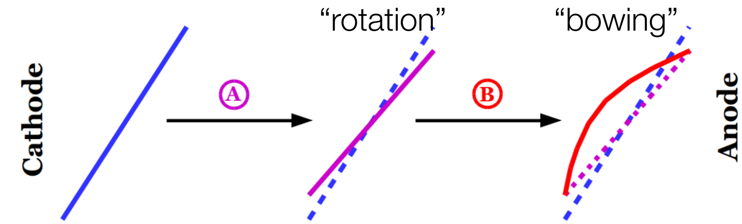
Before mitigation




After mitigation

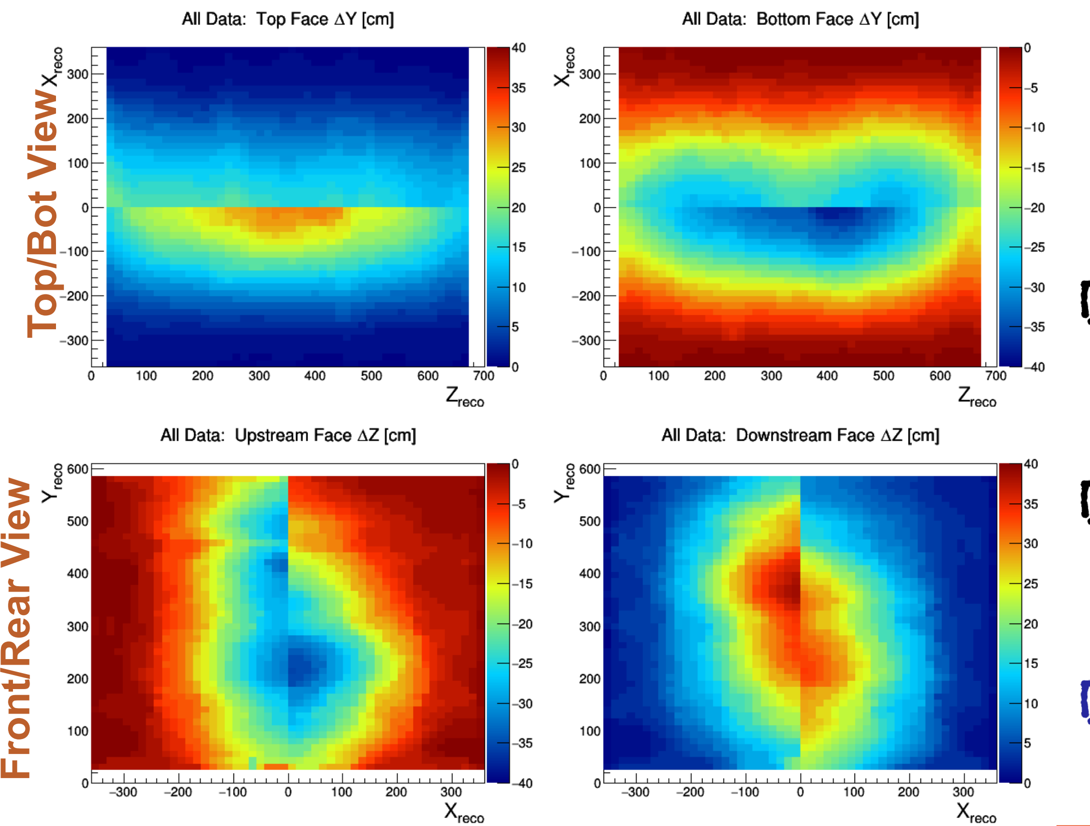


# Analysis of TPC Data




***Space Charge:*** **due to accumulation of slow-drifting Ions from high rate of c.r. on surface, producing Drift Field distortion from nominal uniform El**

## Data Results

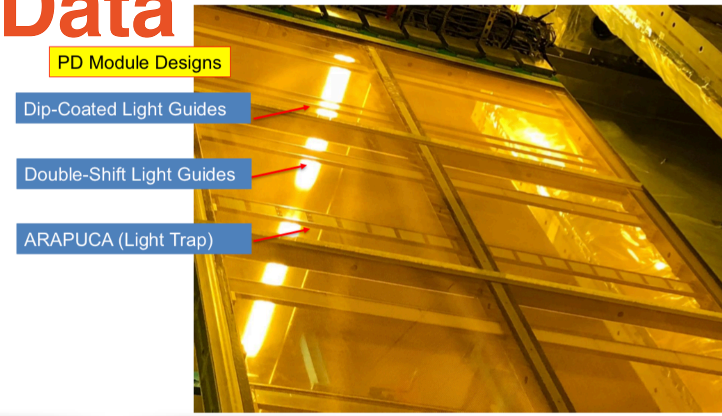


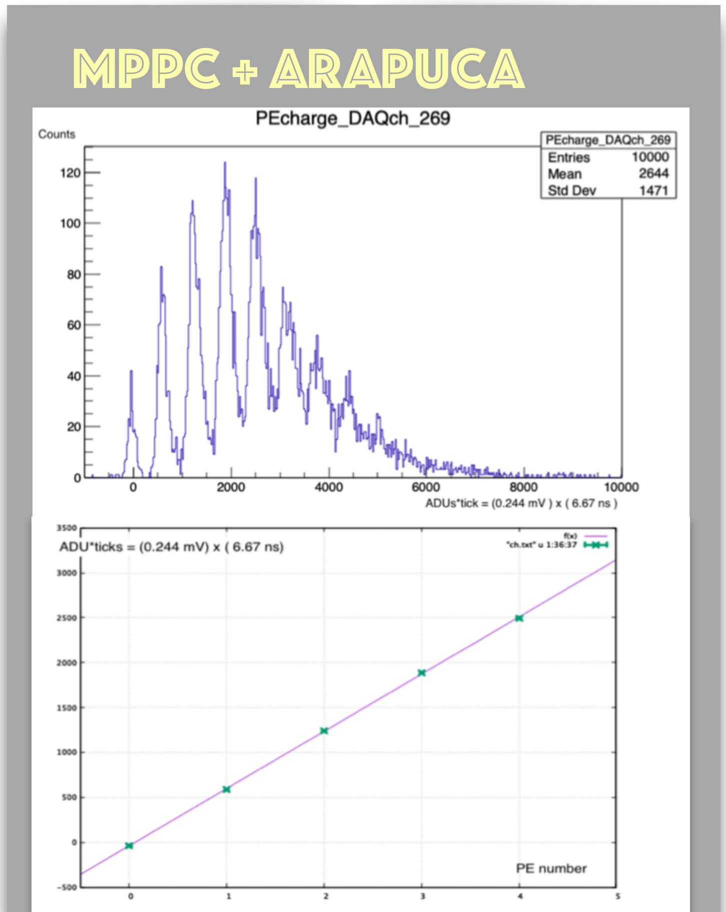

**First SCE "Calibration":**
*[based on SCE study and correction strategy developed for MicroBooNE]:*

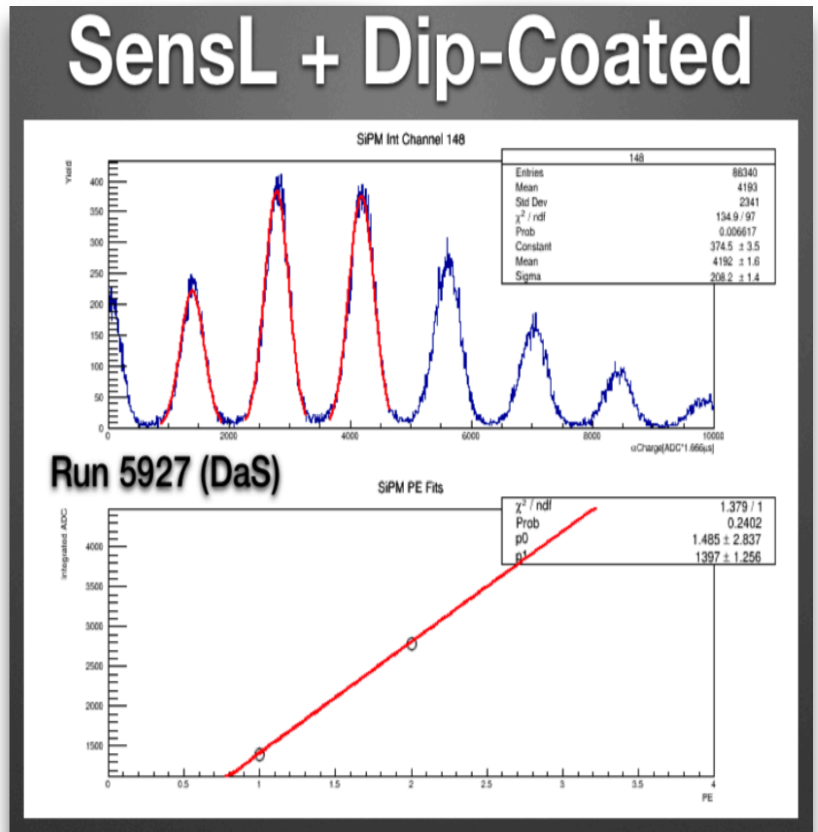
- ☑ use Cathode-crossing (t0-tagged) cosmic muons for track start/end spatial offset mapping at TPC faces
- ☑ compare w/ MC, including effect on Ion distribution of LAr Fluid-Dynamic from LAr recirculation
- ☐ obtain 3D SCE correction map *(in progress)*

# Analysis of Photon Detector Data

***PE Calibration:*** **3 different ph-detectors with 3 different photo-sensors, using LED pulser w/ light diffuser**



# SUMMARY

# ProtoDUNE-SP Performance

| Detector Parameter | Specification | Goal | ProtoDUNE Performance |
|---|---|---|---|
| Electric Drift Field | > 250 V/cm | 500 V/cm | 500 V/cm * |
| Electron Lifetime | > 3 ms | 10 ms | > 6 ms * |
| Electronics Noise | < 1000 enc | ALARA | 550-750 enc |

* Further studies planned for 2019 to understand performance stability with long-term detector operation

# 2019

## The Long Term Stability & Technology Development Run

**Detailed Plan/Schedule for the 2019 Cosmic Run in place/in preparation**

**Organization: Core Team at CERN (under formation)**

- run Coordinators
- protoDUNE sub-detectors experts (APA, CE, PD, HV, DAQ, Cryo-Instrum, CRT)
- Neutrino Platform/CERN  Cryo- and DCS experts

**+**

**rotating teams (DUNE Consortia) for specific tests**

# 2019

## The Long Term Stability & Technology Development Run

**In addition to *long term stability test of detector performance***

**3 main objectives of LArTPC Technology Development (remaining challenges):**

- *investigate limiting factors toward **higher LAr purity** level*
- *investigate origin (and define mitigation/solution) of observed **HV/current instabilities***
- *collect data for **Fluid** and **Space Charge Dynamics determination***

+

***Consortia dedicated tests:***

- ***Cryo-parameters, APA wire plane transparency, CE noise, new DAQ systems, PhDet sensitivity/efficiency, ….***

# 2020-21 Q1

# protoDUNE-SP “long shutdown”

- cryostat emptying and warm-up (4-6 months)
- TCO opening (access in 4 months (?) - *to be evaluated)*
- inner detector (partial) dismounting (.. months - to *be evaluated*)
- upgraded detector installation (*3 APAs + CE* - final design, drift distance to be defined, *PhDet* (30 units) - base option X-ARAPUCA double/single sided, light enhancement by reflector foils option, DAQ development) (.. months - to *be evaluated*)
- organizational structure and team on the ground at CERN

# 2021-2022

## 2nd Beam Run

**A document prepared and submitted to SPSC in Nov.19**

Running of ProtoDUNE-SP (NP04) and ProtoDUNE-DP (NP02) After Long Shutdown 2

The DUNE Collaboration[1]

[1] Contacts: Ed Blucher (blucher@hep.uchicago.edu), Stefan Soldner-Rembold (soldner@fnal.gov)

# 2021-2022

# Goals of the 2nd Beam Run

- **Complete Test Beam Data collection with *Negative Polarity beams* ($e^-$, $\mu^-$, $\pi^-$, $K^-$ and possibly some anti-protons), at all available Momenta [0.3 - 7 GeV]**

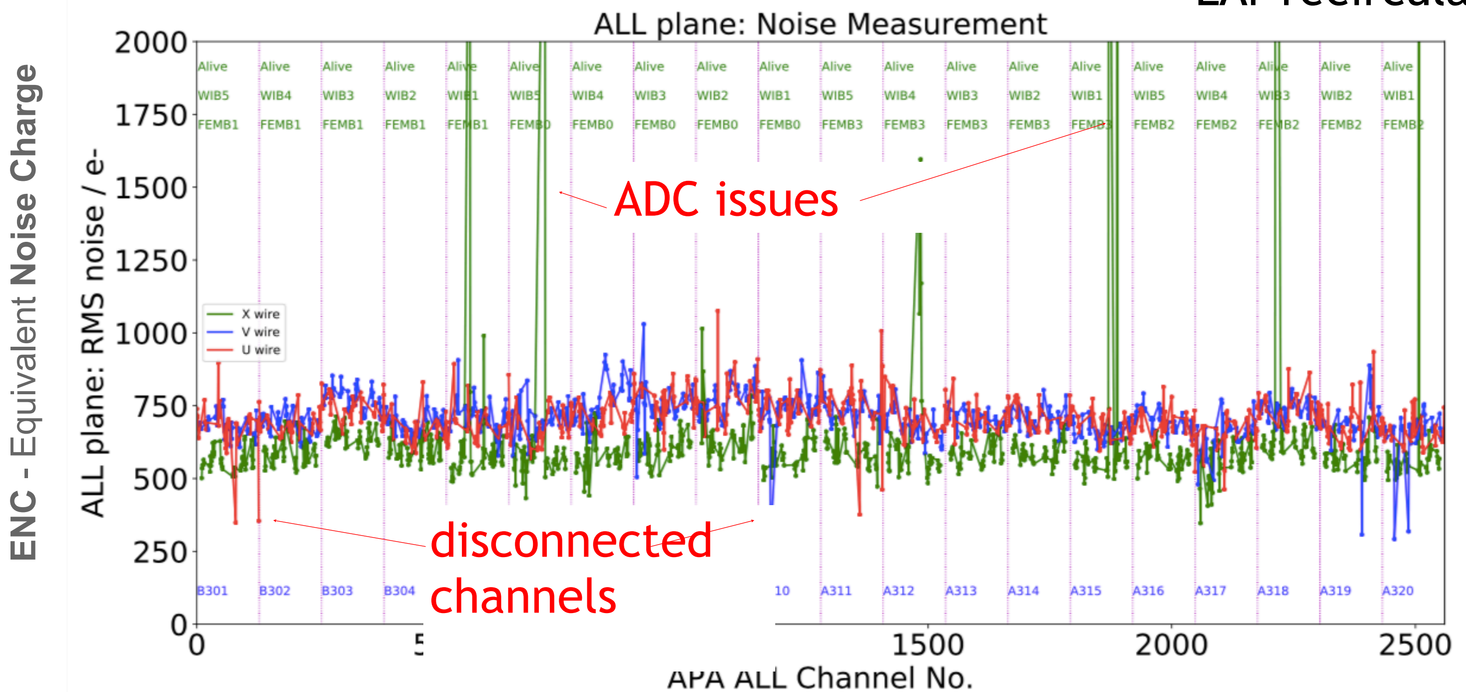
- **Full Characterization of "Module 0" for DUNE FD:**
  - **Final *APA design* & *final R/O electronics* system, either the 3-ASIC solution (FE amplifier+custom ADC+data handling ASIC) or the CRYO ASIC**
  - **Incorporate DUNE *final PhotoDetector* design (X-ARAPUCA baseline option for PhDet w/ higher light collection efficiency collecting light from both sides**
  - **Incorporate a *Light enhancement system* (wls+reflective foils on the cathode plane or Xe doping) to improve light detection uniformity and efficiency**

- **Development/implementation and test of (new) *calibration methods*, e.g. with neutrons produced by Neutron Generator and with a Laser System**

BACKUP Slides

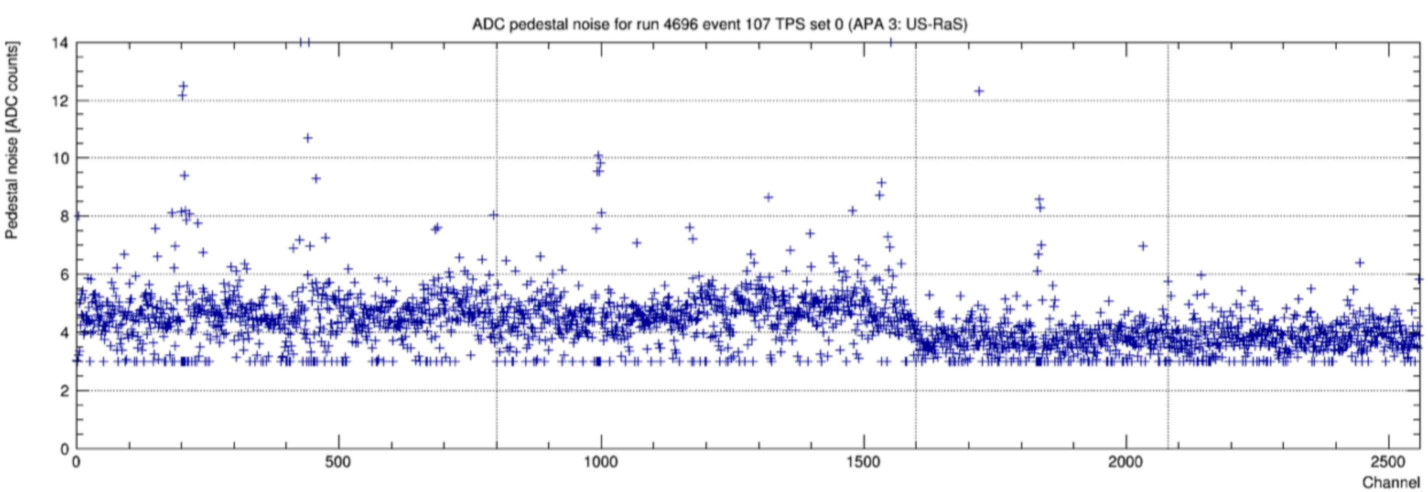
# (e.g)APA3 Noise at -180kV

Nominal wire bias voltages
LAr recirculation on




from CE Expert data&analysis

Gain = 14 mV/fC
(140 e/ADC)
Shaping time = 2 us

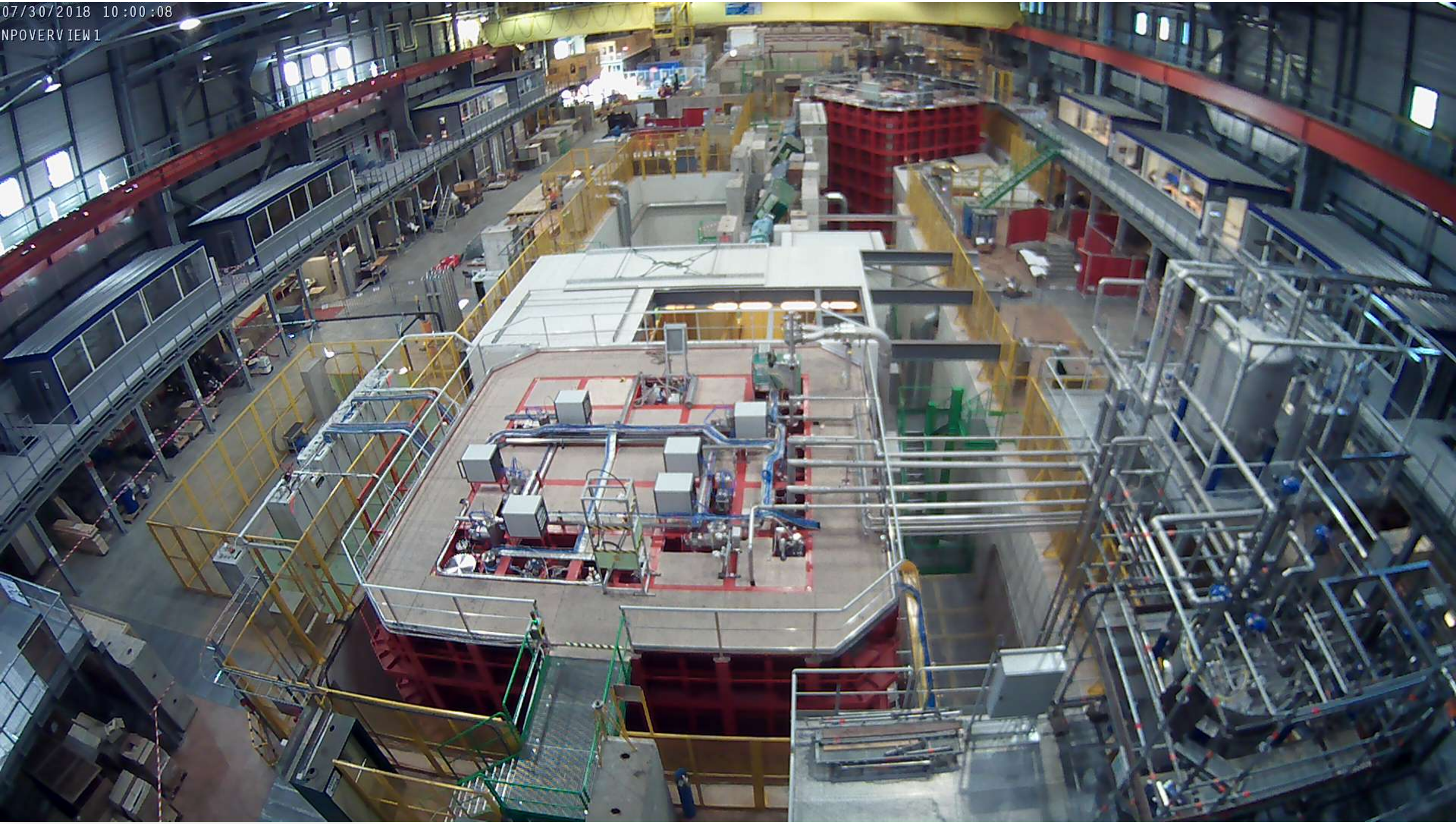



from Data Quality Monitor

Over much of detector, noise level is

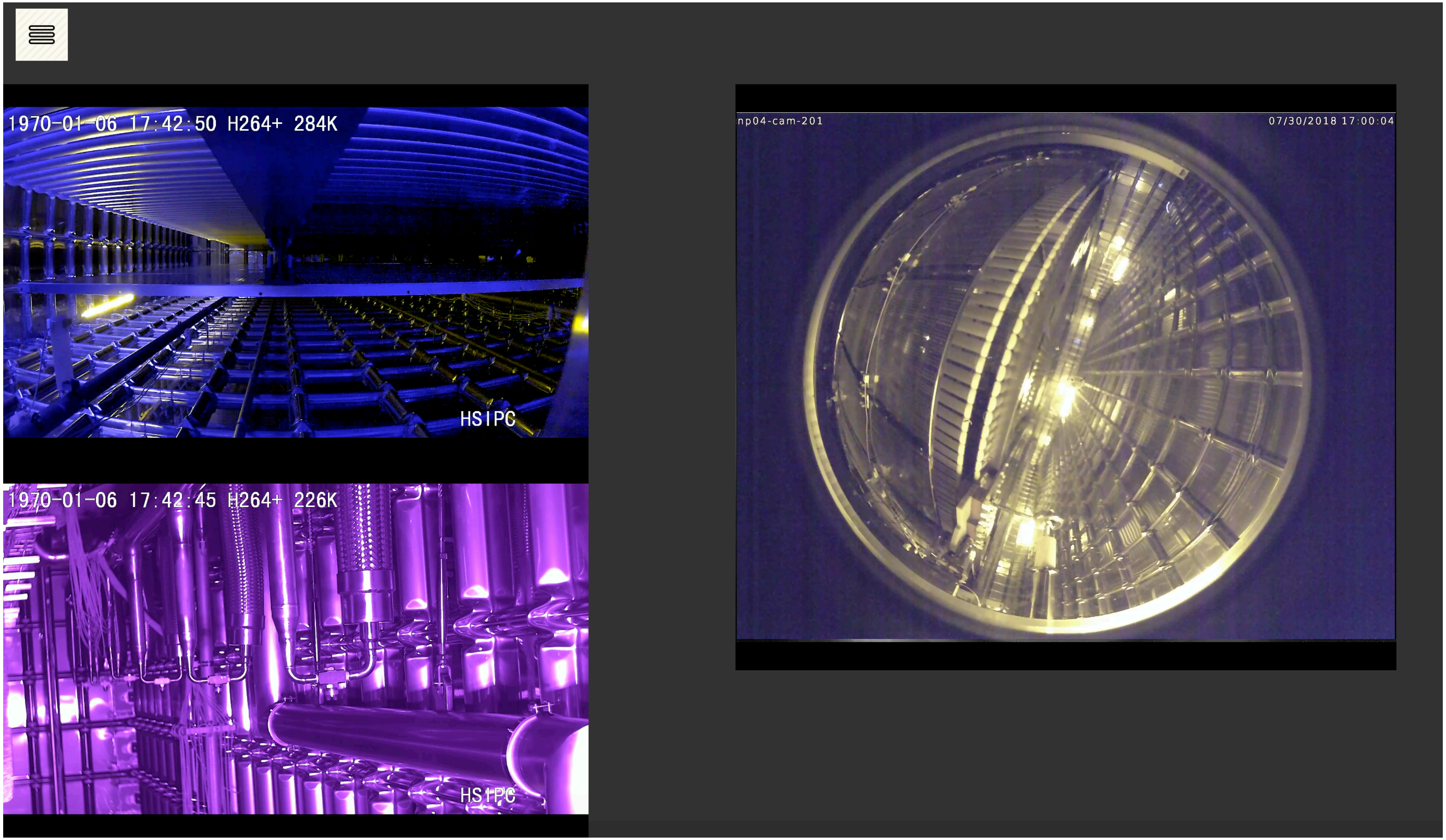
- Collection: 3.5 ADC (500 e)
- Induction: 4.5 ADC (600 e)
- Nice!

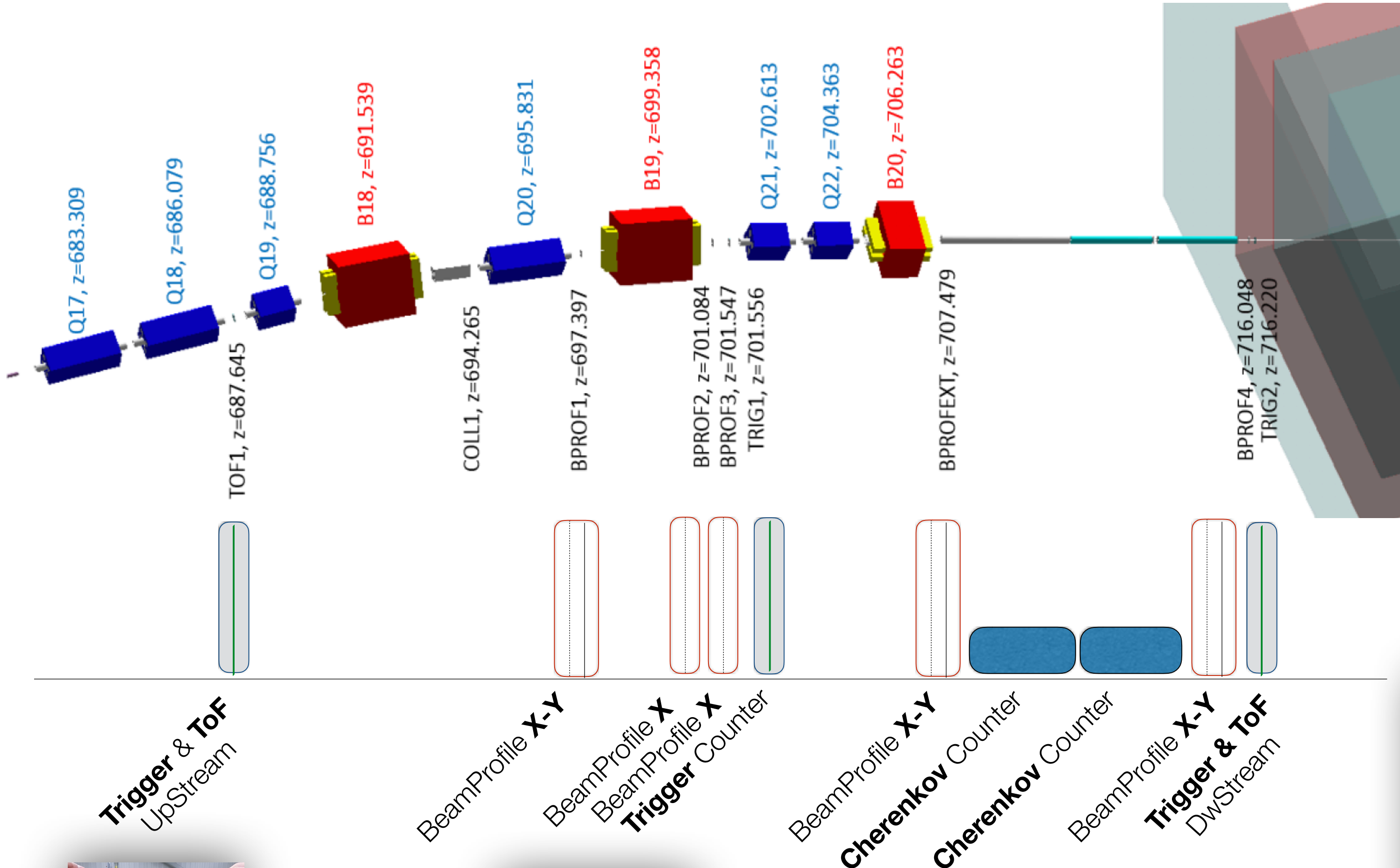
# PROTODUNE SP commissioning under way

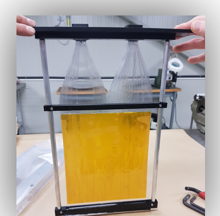



✓ piston purging completed, ➡ cooling phase started

# real-time camera views from inside the cryostat





**Blue: quadrupoles.**
**Red: bending magnets**

**Boxes: Beam detector supports**

Beam Profile X,Y = Scint. Fibre Tracker
Trigger & Time-of-Flight detector =
= Scint. Fibre paddle

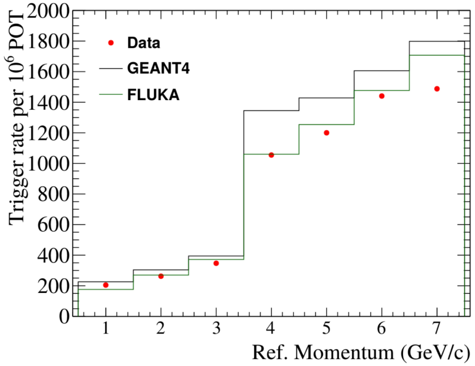
Cherenkov counters

# NP04/H4 Beam Line & Beamline Detectors

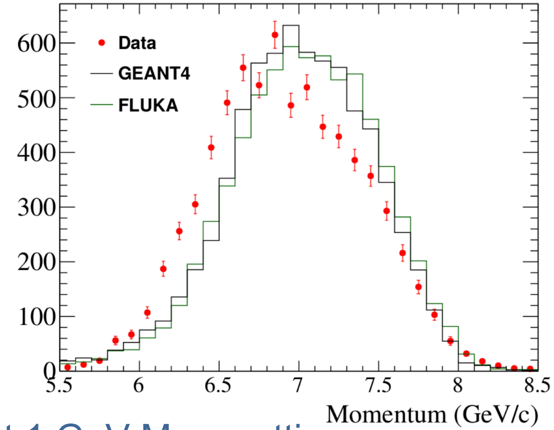
Neutrino PLATFORM

# Analysis of H4 Beam Line Instrumentation Data

- **Particle Rates** (data vs MC) - good agreement

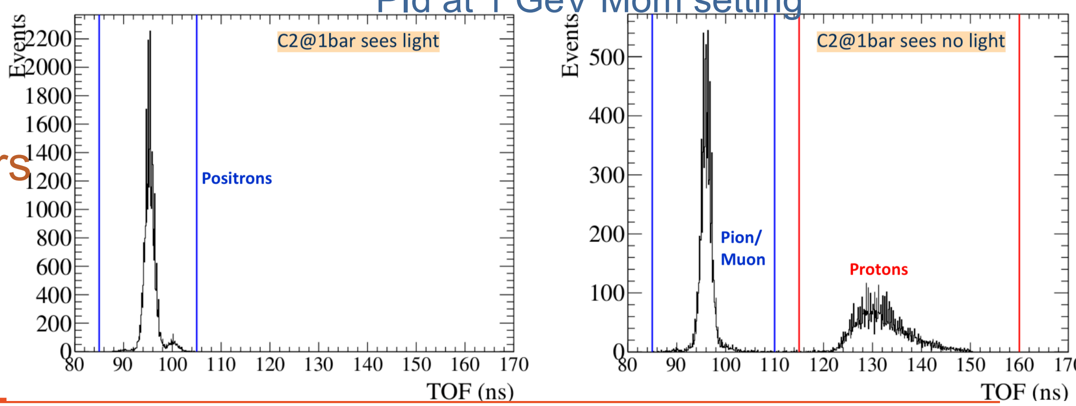


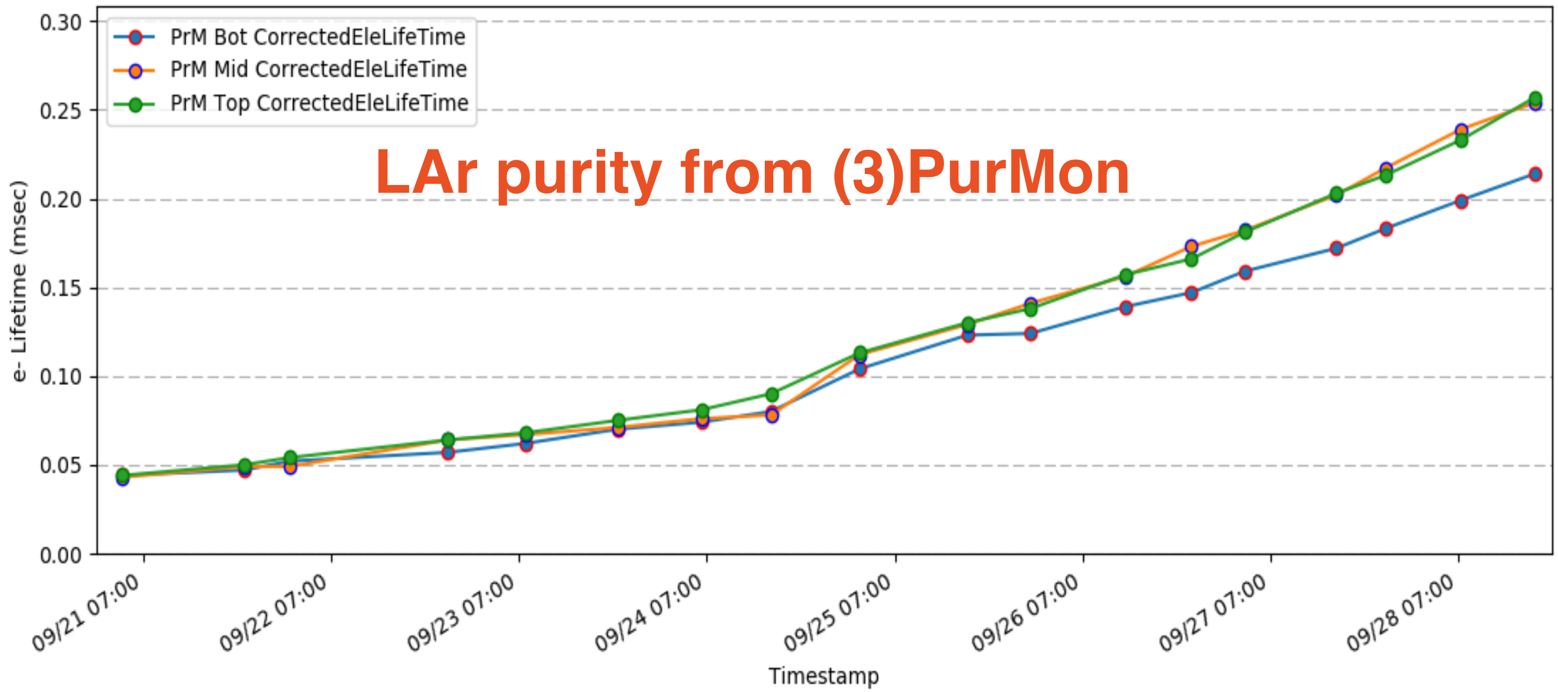

- **Momentum reconstruction:**
  - Measured Beam Profilers efficiency > 95.5 % for all momenta
  - Systematically low reconstructed momenta accounted/corrected for with a 1.45 mm shift of one of the Beam Profilers (**transverse misalignment of fibre planes, one with respect to another).**

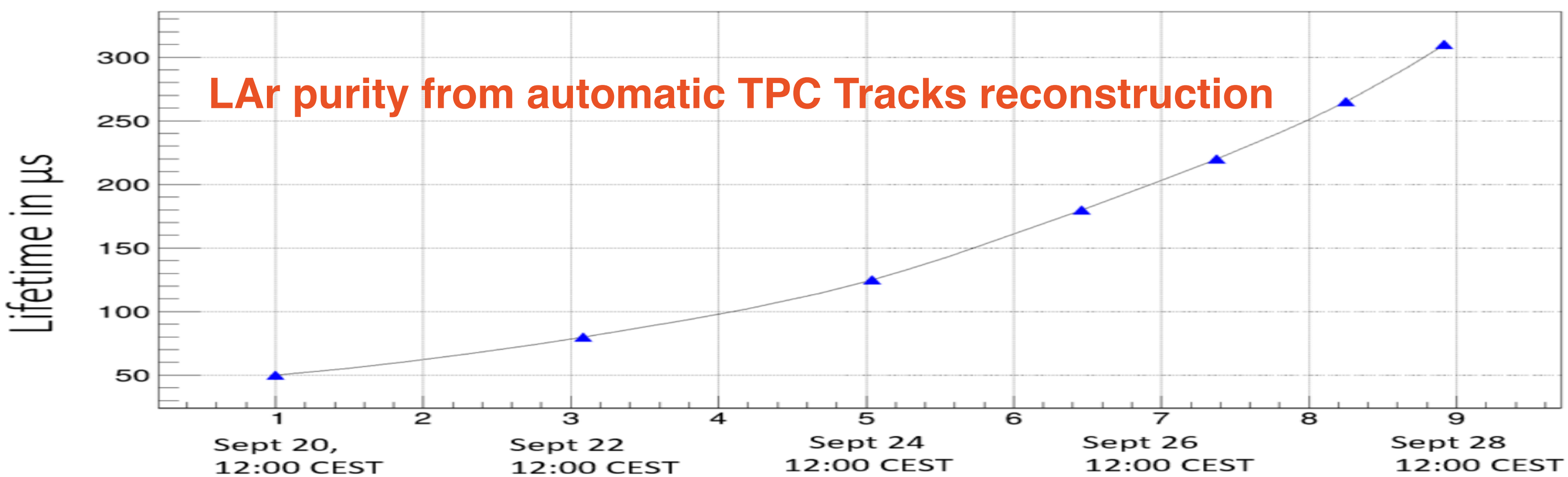



- **Particle Identification:**
  - Time-of-flight between ToF Counters
  - Cherenkov Signal (C1 and/or C2) - adjustable gas pressure/threshold

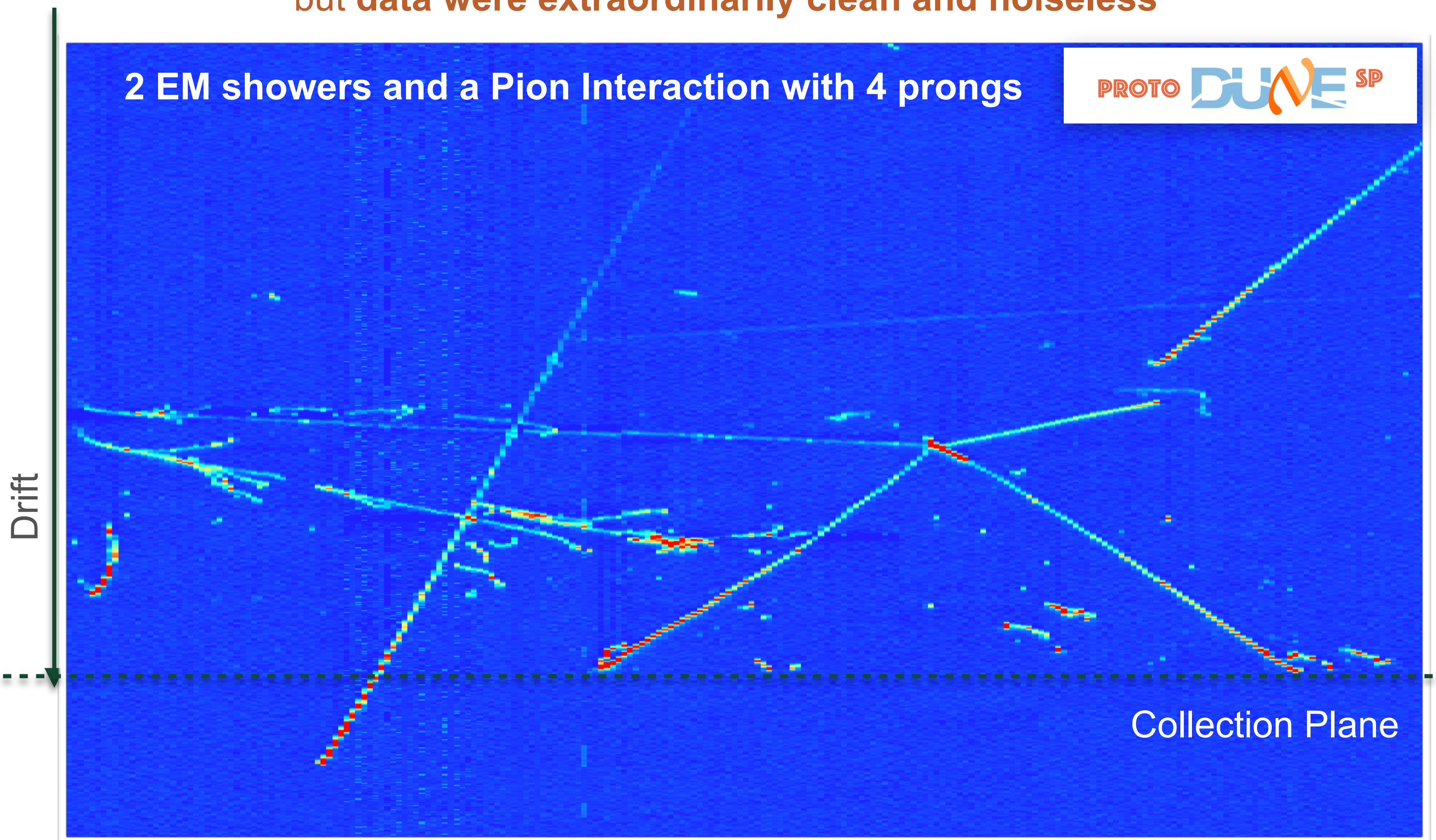
PId at 1 GeV Mom setting





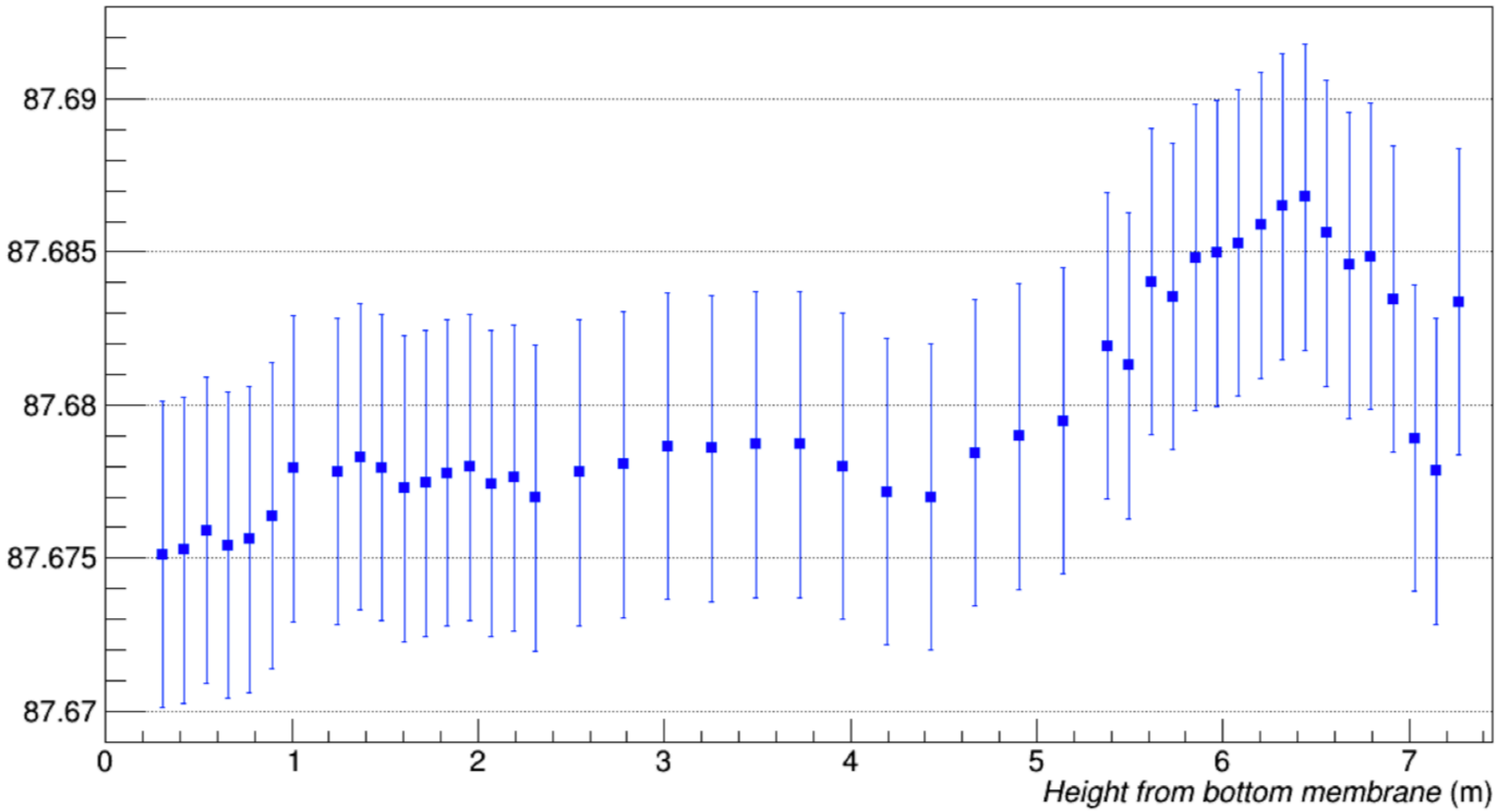

Initial low Purity, Recirculation ON, start noting Space Charge effects (ion accumulation) due to low purity, only a fraction of the drift volume (near the anode plane) was “visible”, but **data were extraordinarily clean and noiseless**




collection view. Run 4696, event 103.

# Analysis of Cryo-Instrumentation Data

## Vertical T Profile

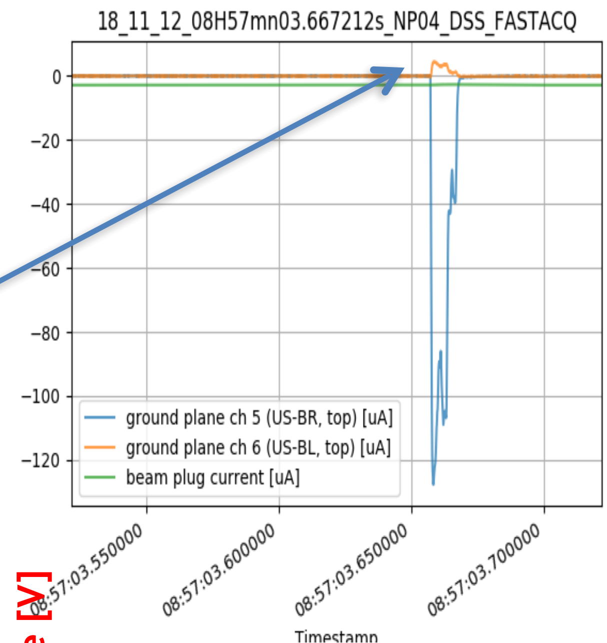


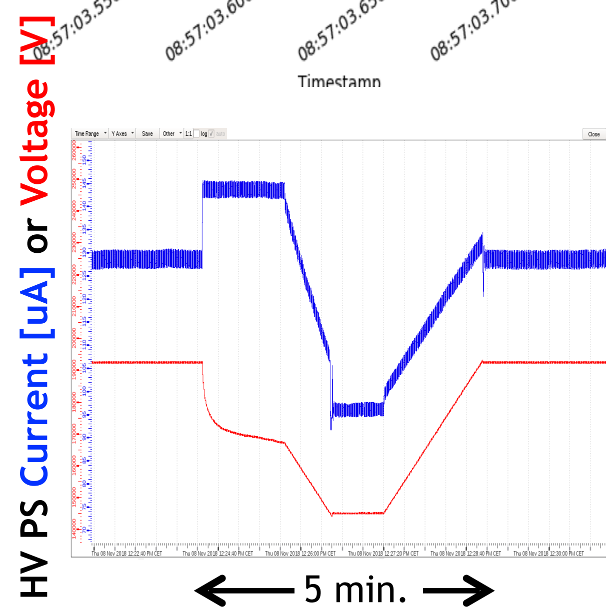
## 1) Fast discharges:

- O(10/day) recorded by the DCS fast acquisition
- All of them report a current signal on at least one ground plane
- Total charge from PS correspond to total charge on planes

## 2) Sustained excessive current streams:

- Few per day (rate builds up over time)
- Typically current limiting (voltage drops)
- Only a fraction of the PS current visible on US-BL-Top ground plane & beam plug
- We manually lower the voltage further for a small time and then return it to the normal voltage and the current draw has returned to normal



# 1 - protoDUNE informing DUNE TDR

***From the completed phase of detector components Construction and Integration, Cold Test procedures and Assembly in confined space (inside Cryostat):***

- ✓ validated basic principles of the DUNE APA modular design
- ✓ developed APA factory model for production, based on Wisconsin-PSL and Daresbury-UK experience and production tooling and methods
- ✓ validated Photo-detector design concept (slots and connections)
- ‣ to be revised Cable routing for PDS and TPC electronics
- ✓ developed design for Integration and Test Facility at SURF, based on CERN-EHN1 experience [APA, CE and PD Integration Procedures and **Test full-size Detector Unit** in cold nitrogen gas - Cold Box]
- ✓ provided input to Quality Assurance for all systems and for planning Quality Control procedures

# 2 - protoDUNE informing DUNE TDR

***From the currently under-way protoDUNE Commissioning phase:***

- information about **Membrane Cryostat performance**:
    - Mechanical design
        - ✓ *overpressure test (successfully passed - July 9)*
    - ultimate level of impurity concentration in LAr:
        - ✓ air evacuation by GAr piston purging *(successfully accomplished - July 23-27)*
        - ➡ Ar recirculation/filtration circuit *(expected by end of Aug)*
    - Heat Load and cryogens consumption for cooling
- validation of internal cryo-instrumentation and detector components monitoring system [thousand variables/parameters are simultaneously and continuously logged by the DCS/SlwCtrl fully automated system]
- **validation of HV system design vs Goal (Drift EF = 500 V/cm)**

**(most critical step, relevant for DUNE detector design)**

# Outline:

DEEP UNDERGROUND NEUTRINO EXPERIMENT

- preliminary results from the recent data taking period

**from first tracks and light flashes recorded**

**to (preliminary) results from charge and light data analysis**

# ProtoDUNE Measurement Plan & Goals

- **Short-term goals** – ***Detector Performance***
  - ☑ (noisy or dead channels map)
  - ☑ Noise level, signal to noise ratio
  - ☑ Electron lifetime *(LAr purity)*
- **Medium-term goals** – ***Detector Response***
  - ☐ dE/dx of ✔ muons, pions, *(in progress)* protons
  - Energy and momentum resolutions
- **Long-term goals** – ***Physics Measurements***
  e.g. ***π-Ar cross sections***
  - ☐ *(started)* Total pion cross section in [1-7] GeV range
  - Exclusive channels Cross Section:
    - $\pi$ *absorption:* $\pi^{\pm} \rightarrow 2p, 3p, 2p1n,..$
    - $\pi^{\pm} \rightarrow \pi^{0}$ *charge exchange*, etc.

(NEVER MEASURED)

Information for DUNE physics TDR

Physics publications

1. comment on plans and person-power for your protodune test beam data analysis

# ProtoDUNE Measurement Plan & Goals

- **Short-term goals** – ***Detector Performance***
  - ☑ (noisy or dead channels map)
  - ☐ Noise level, signal to noise ratio *[to be completed after SCE deconvolution]*
  - ☐ Electron lifetime *(LAr purity)* *[cfr PurMon vs Tracks to be made after SCE deconvolution]*
  - ☐ *Gain/channel-to-Channel Variation from CE Pulser data (to be completed and implemented)*
- **Medium-term goals** – ***Detector Response***
  - ☐ SCE deconvolution
  - ☐ Core Calibration: dQ/dx → dE/dx of ✔ muons, *(in progress)* protons, pions, electrons
  - – **Energy and momentum resolutions for both Charge** (TPC signal) and Light (PhDet)

Information for DUNE physics TDR

- **Long-term goals** – ***Physics Measurements***
  - ☐ *(started)* Total pion cross section on Ar in [1-7] GeV range
  - – Exclusive channels Cross Section:
    - – $\pi$ *absorption:* $\pi^{\pm} \rightarrow$ *2p, 3p, 2p1n,..*
    - – $\pi^{\pm} \rightarrow \pi^{0}$ *charge exchange*, etc.
  - ☐ *(started)* Total PROTON cross section on Ar in [1-7] GeV range
  - ☐ Kaon topological Identification and Interaction Xsect on Ar
  - ☐ E.M. component in hadronic shower (calorimetry/compensation in LAr homogeneous calorimeter)

(NEVER MEASURED)

Physics publications

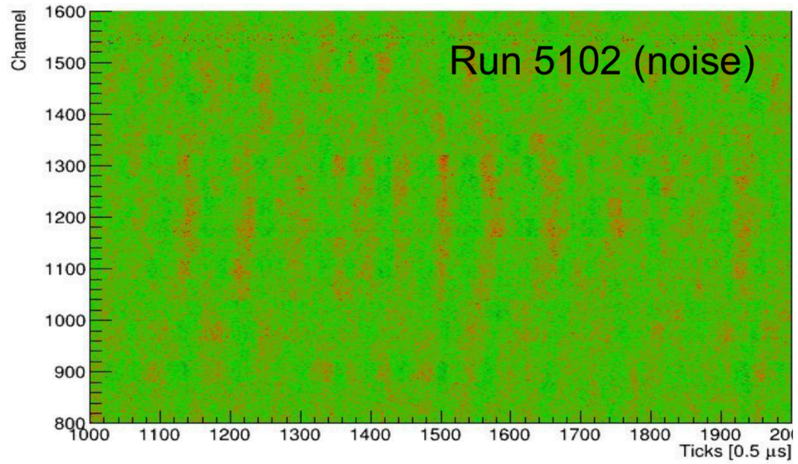
# Analysis of TPC Data

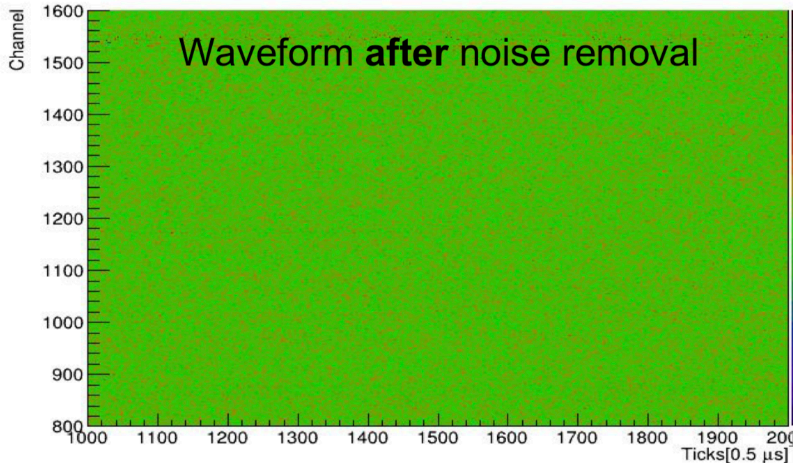
## Coherent Noise Filtering

Correlation among adjacent channels ⇒ coherent noise

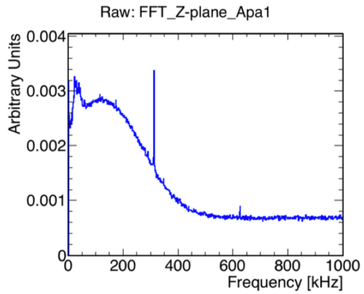
One source of coherent noise is identified at low frequencies ≈ 40 kHz (the low voltage regulator that provides power to the cold electronics)

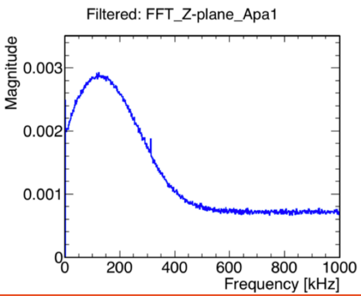
EVENT DISPLAY




FOURIER SPECTRA



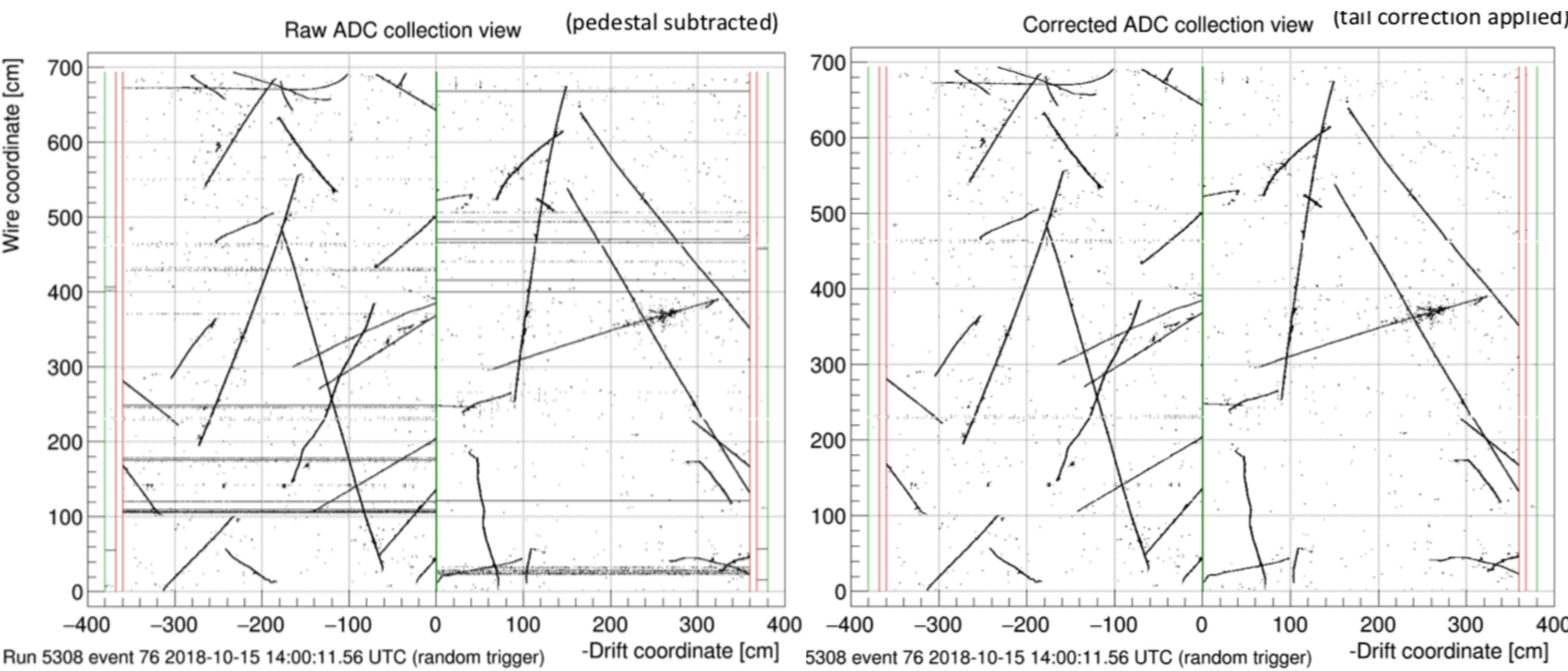



# Analysis of TPC Data

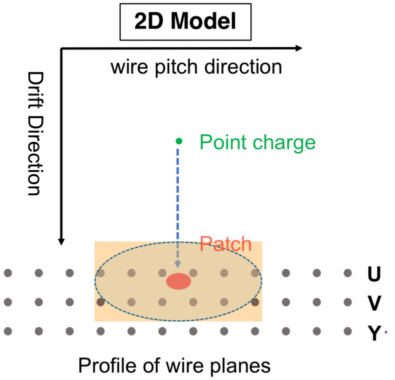
In the TPC, 99.7% of the 15,360 channels are alive and responsive

- bad channels removal
- sticky code and timing mitigation
- undershoot correction

## Signal processing

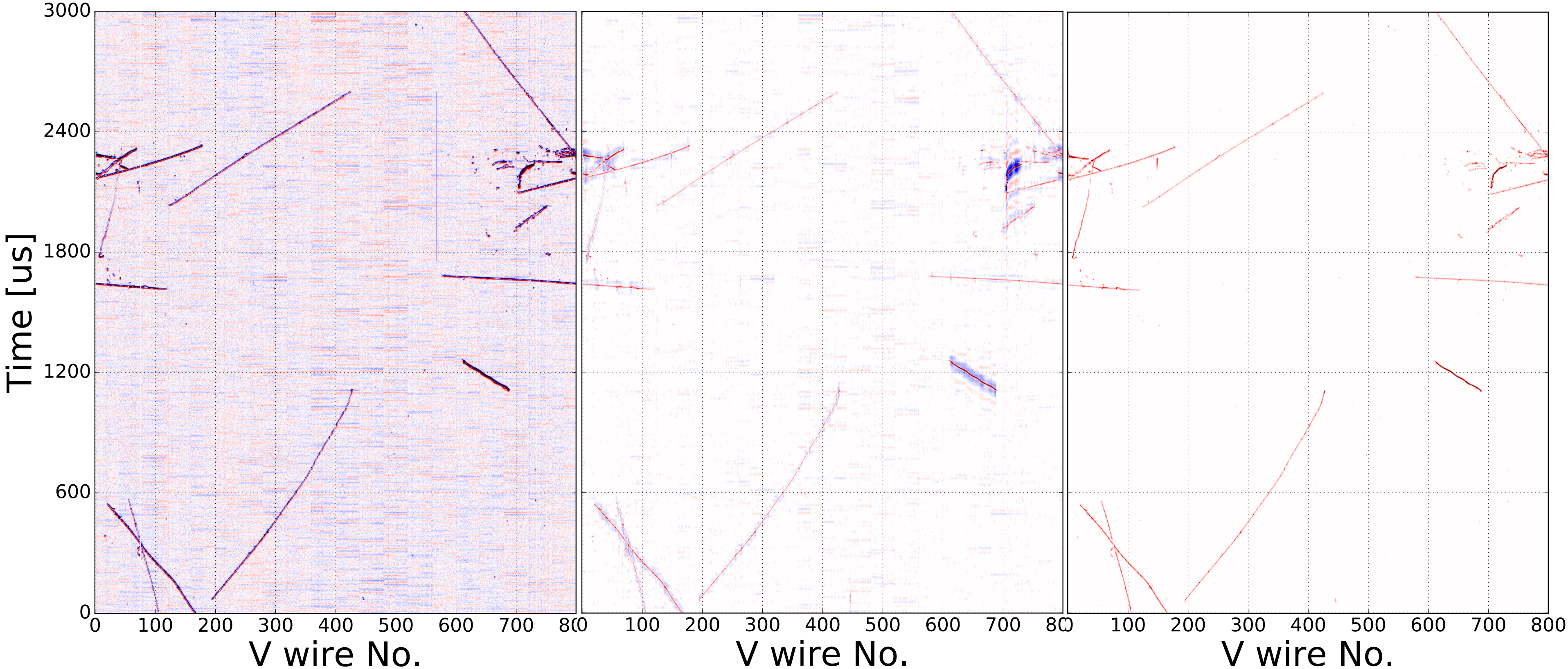


# Analysis of TPC Data




## one more step in Signal processing

## 2D deconvolution




Raw Data

Signal processing (SP): deconvolution & filter

NEW: 2D deconvolution (Long-range induction)

The physics performance of a LArTPC is a function of many intertwined detector parameters: *Argon purity, drift distance, Electric Field strength, wire pitch, wire length and noise levels in the readout electronics.*

**For a LArTPC on surface**, ***space charge effects*** (SCE) is another leading detector effect on Physics Performance

- **Core calibration:** *from detected Charge to deposited Energy*

  converting dQ/dx (ADC/cm) to dE/dx (MeV/cm)

  includes
  - ➡ Electronics calibration
  - ➡ **Space charge effects**
  - ➡ Electron lifetime
  - ➡ Recombination effects
  - ➡ Muon/Pion/Proton based abs. energy conversion

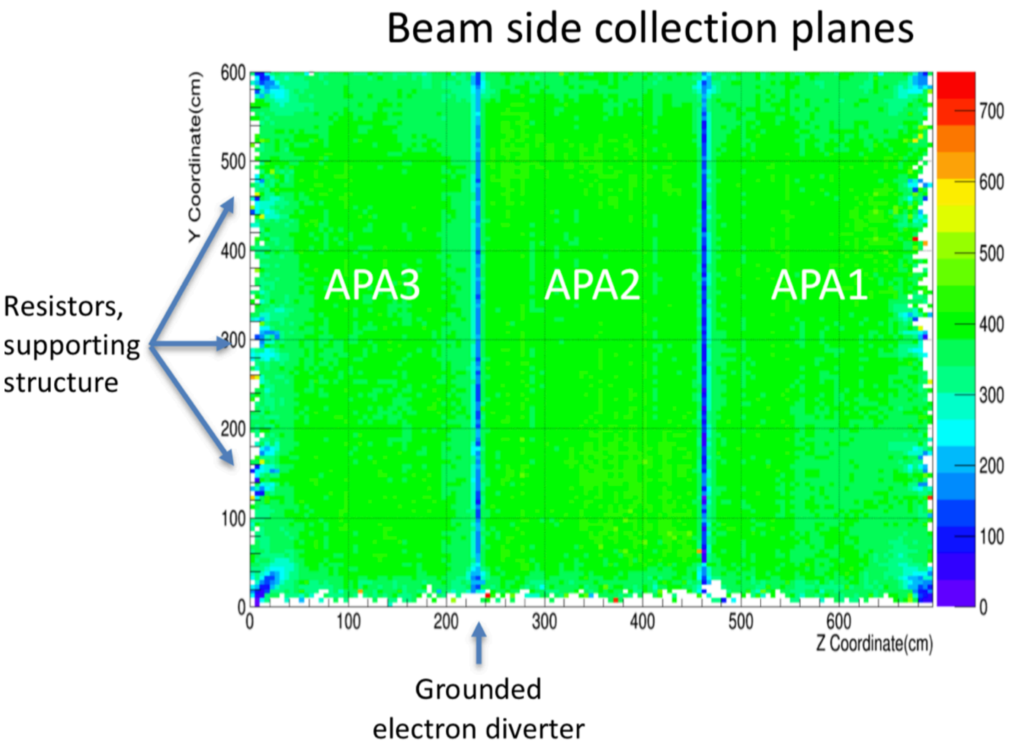
**Core Calibration is the basic Detector performance measurement fundamental to inform DUNE design**

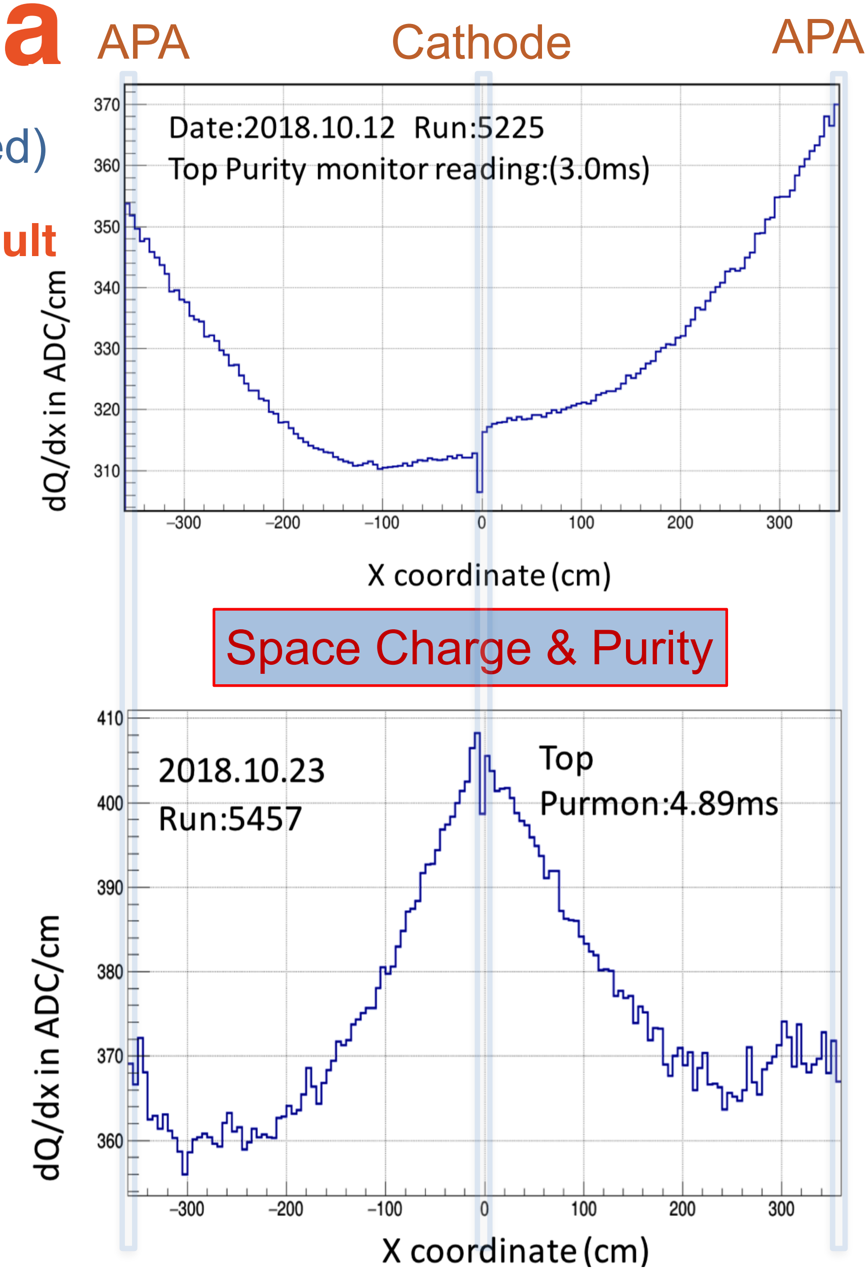
# Analysis of TPC Data

Using Cathode-crossing cosmic muons (t0 tagged)

**Detector Performance first (yet preliminary) result**

- <u>Core calibration 1</u>: charge response uniformity




Detector Response uniform but evidence of SCE

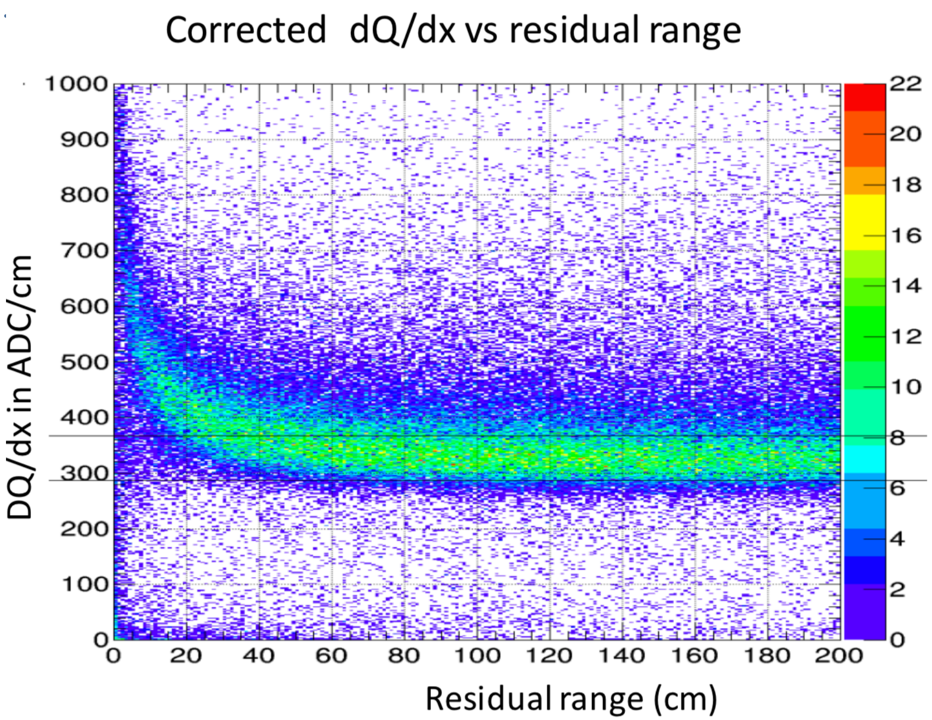
# Analysis of TPC Data

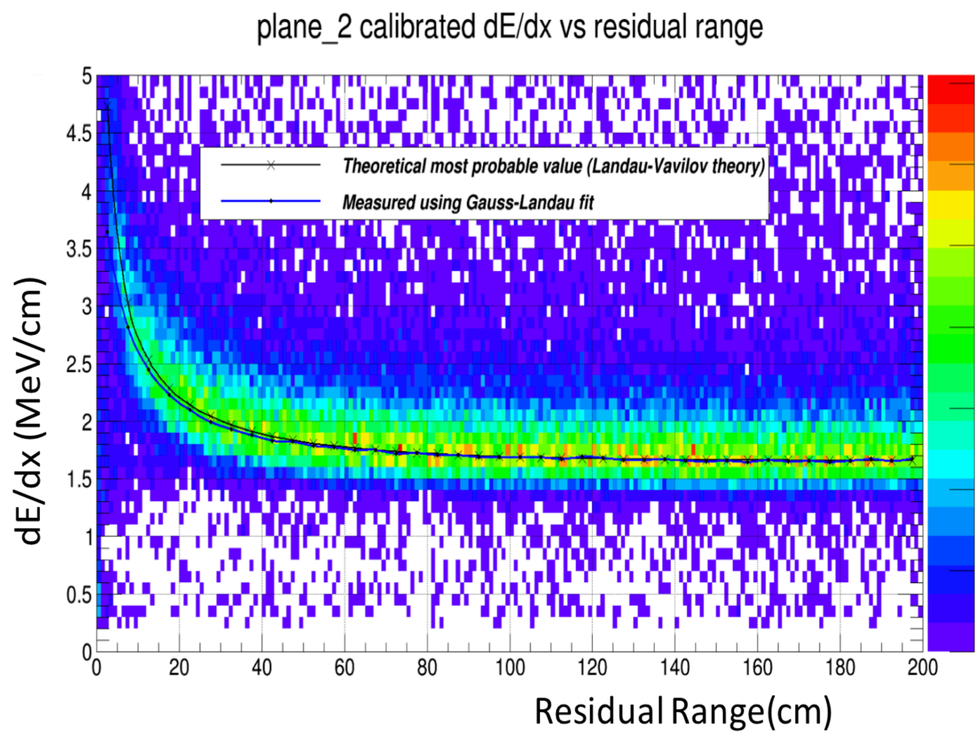
Using Cathode-crossing and stopping cosmic muons

## Detector Performance first (yet preliminary) result

- <u>Core calibration 2:</u> Absolute Energy Calibration

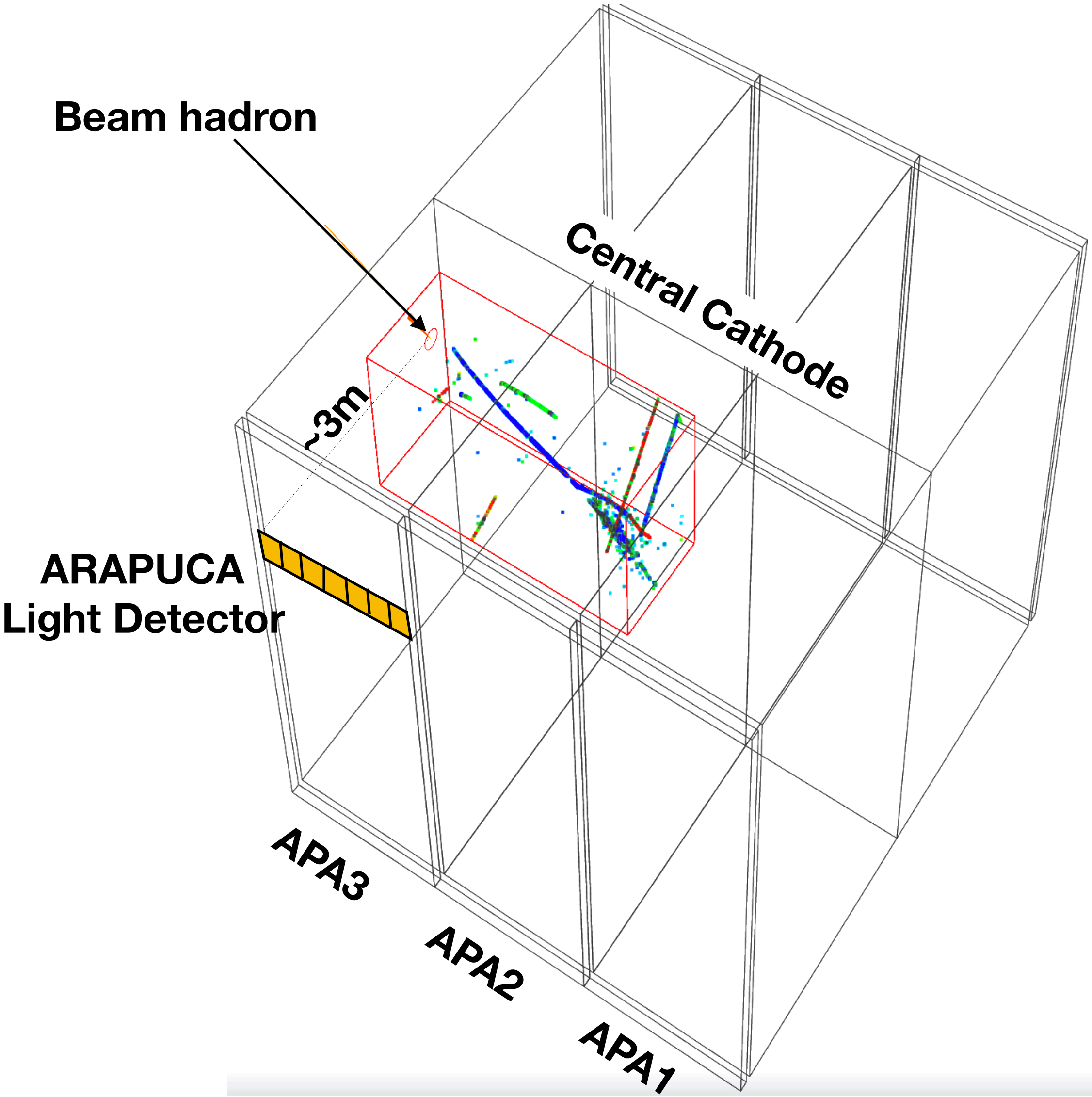
  (calibration constant from fit of most probable dE/dx for stopping muon data with most probable dE/dx predicted by Landau-Vavilov theory (in the 250-450 MeV kin energy range)




At high dE/dx there some discrepancy between observed and theoretical values, primarily due Space Charge (correction applied but full deconvolution not yet implemented)

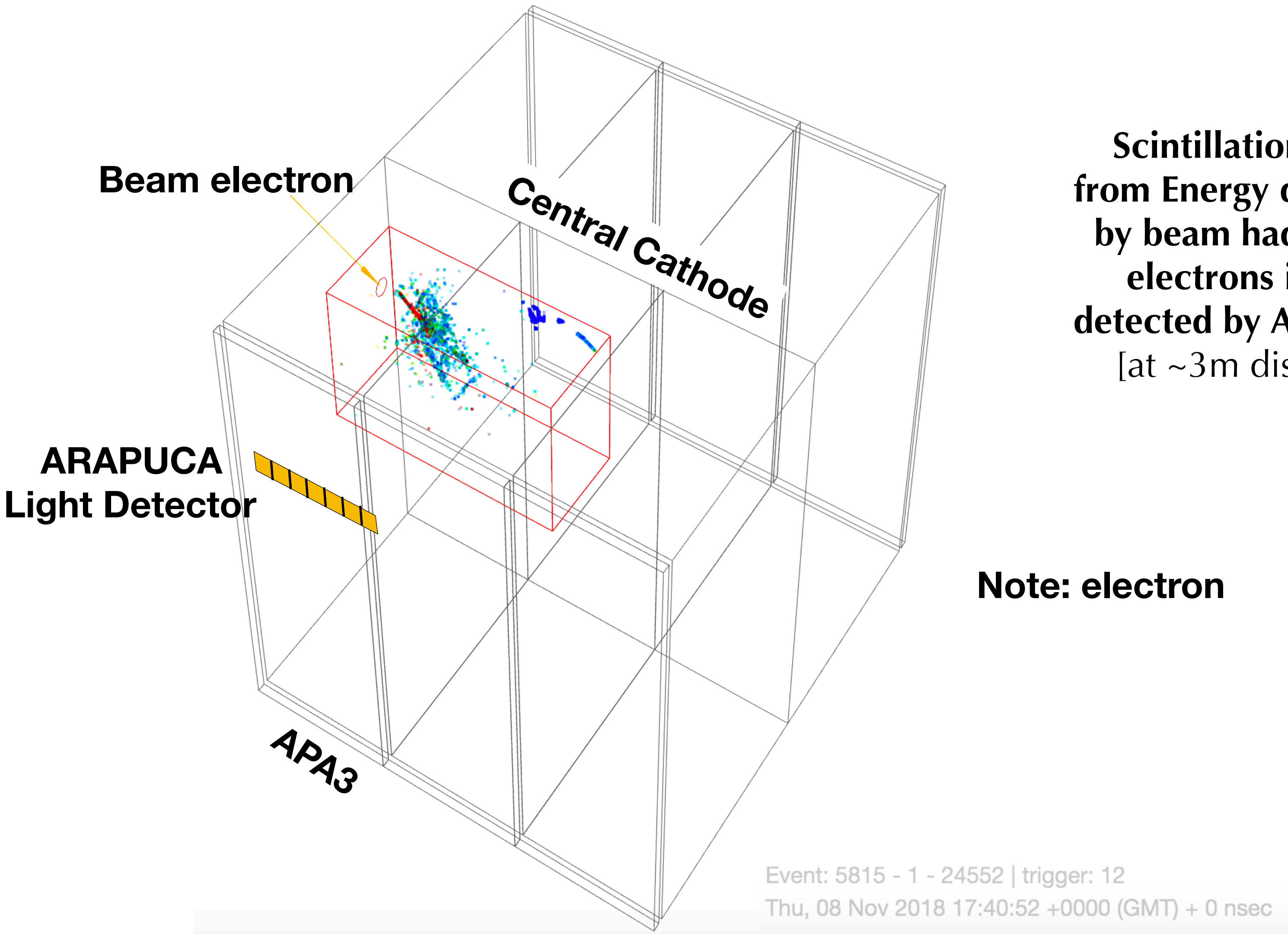
# Test Beam Data:
# 1 - 7 GeV Momentum Charged Particle (e, had) Beams




**Scintillation Light from Energy deposited by beam hadrons or electrons in LAr detected by ARAPUCA**
[at ~3m distance]

**Beam Particle Energy tunable in 1-7 GeV range**

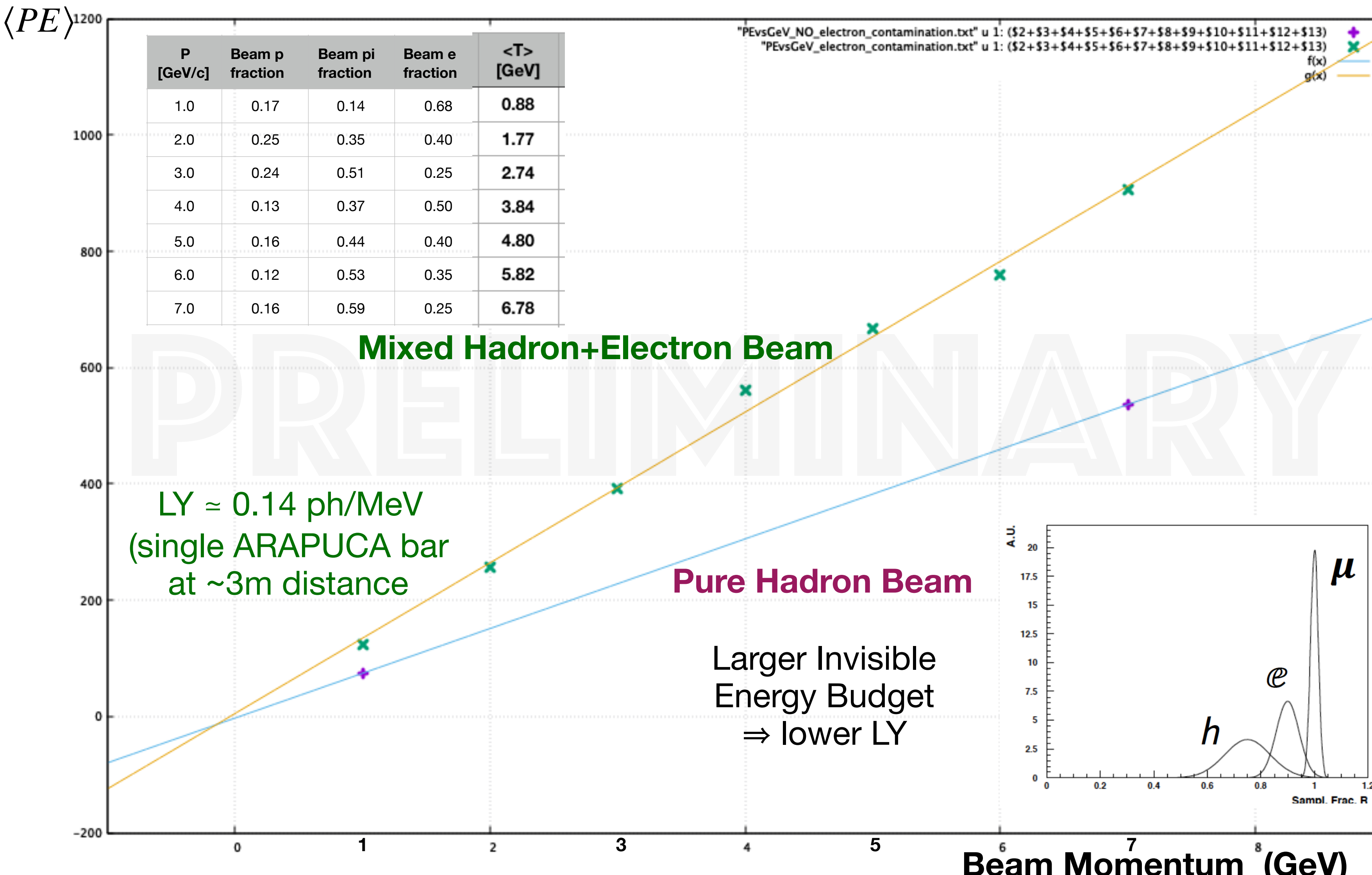
# Test Beam Run:
# 1 - 7 GeV Momentum Charged Particle (e, had) Beams




**Scintillation Light from Energy deposited by beam hadrons or electrons in LAr detected by ARAPUCA**
[at ~3m distance]

**Note: electron**

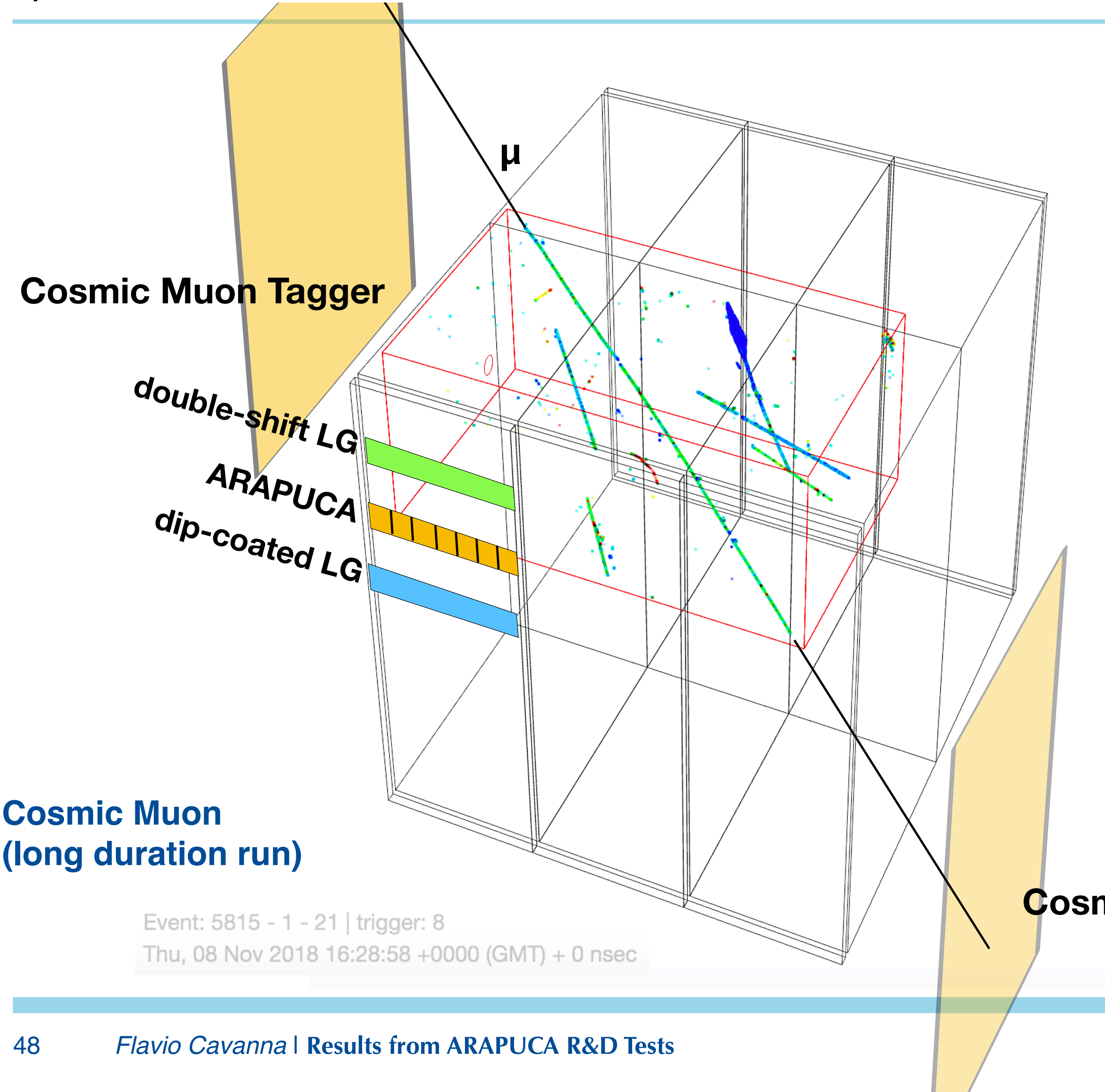
# First result (preliminary analysis) of ENERGY reconstruction from LAr Light Signal Detection by ARAPUCA Bar (scintillation homogeneous Calorimeter)




| P [GeV/c] | Beam p fraction | Beam pi fraction | Beam e fraction | <T> [GeV] |
|---|---|---|---|---|
| 1.0 | 0.17 | 0.14 | 0.68 | **0.88** |
| 2.0 | 0.25 | 0.35 | 0.40 | **1.77** |
| 3.0 | 0.24 | 0.51 | 0.25 | **2.74** |
| 4.0 | 0.13 | 0.37 | 0.50 | **3.84** |
| 5.0 | 0.16 | 0.44 | 0.40 | **4.80** |
| 6.0 | 0.12 | 0.53 | 0.35 | **5.82** |
| 7.0 | 0.16 | 0.59 | 0.25 | **6.78** |

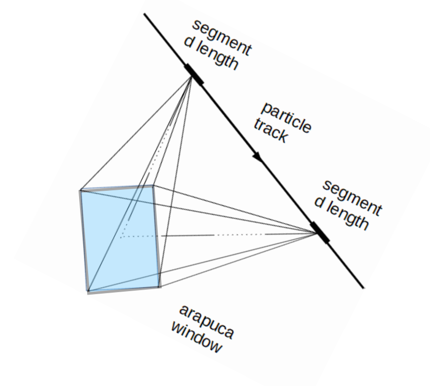
1. comment on the 3 photon prototype systems and the performance metrics that will be used for the selection

# Comparative Efficiency (PE/PH) Measurement to be performed with Muon Tracks from CRT trigger




**Cosmic Muon (long duration run)**

$$PH = A_{\Omega} \frac{1}{4\pi} \frac{dN^{\gamma}}{dx}$$



# Feasibility of 600 kV dual phase demonstrator

- operating LArTPC over long drift distance at nominal 500 V/cm drift Field represents the most critical technical challenge in the development of both Single Phase and particularly Dual Phase technology:
    - *Icarus: 1.5 m, MicroBooNE: 2.5 m*
    - *current record: 3.6 m by protoDUNE SP, 180 kV at the Cathode*
    - *Single Phase aiming for 6-7 m drift, 300 kV at the Cathode*
    - *Dual Phase aiming for 12 m drift, 600 kV at the Cathode.*

Dedicated Tests and test Facilities are planned at **CERN/Neutrino Platform** (2019-20):

- **HV-system Test**: custom HV power supply (600 kV) + cable + HV FeedThrough
- **Long Drift test**: protoDUNE-DP - 6m Drift w/ TPC read-out, 300 kV at the Cathode

Feasibility for a
***full drift (12 m)*** with ***final 600 kV HV-system*** **DEMONSTRATOR**
to be realized and operated at **FNAL** (2020-21)
is currently being considered.

# 12 m drift / 600 kV Demonstrator

## Basic Concepts:

- large volume LAr vessel: min. dimensions **3 $\ell$ x 3 $w$ x 14 $h$ m$^3$ (~180 t of LAr)**
- full and efficient LAr cryo-recirculation system: min. lifetime $\tau_e \gtrsim$ **10 ms**
- simplified cryostat (eg DP cold box at CERN, with extended depth)
- simplified TPC r/o: 1 x 1 m$^2$, 3 planes SP TPC (eg LArIAT - printed circuit G10 frames)

Different possible lab spaces at FNAL are being identified - suitable to host the 12 m drift / 600 kV Demonstrator

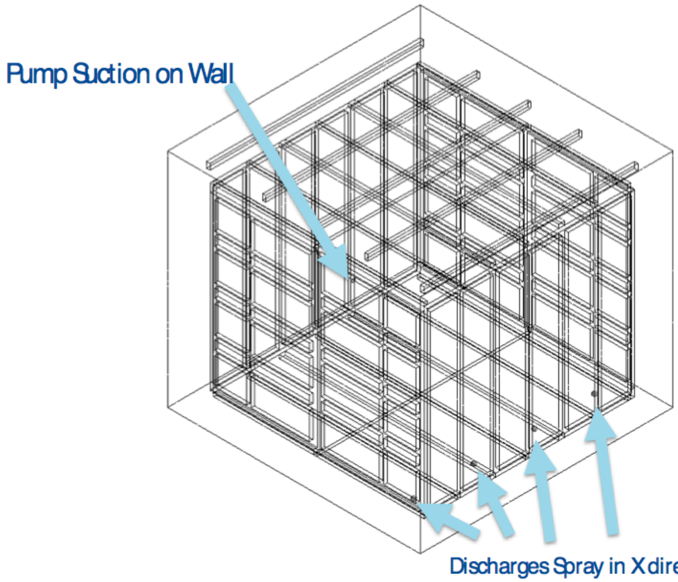
**Cost and resources needed to be determined**
*(mainly based on availability of existing cryogenic/purification plant)*

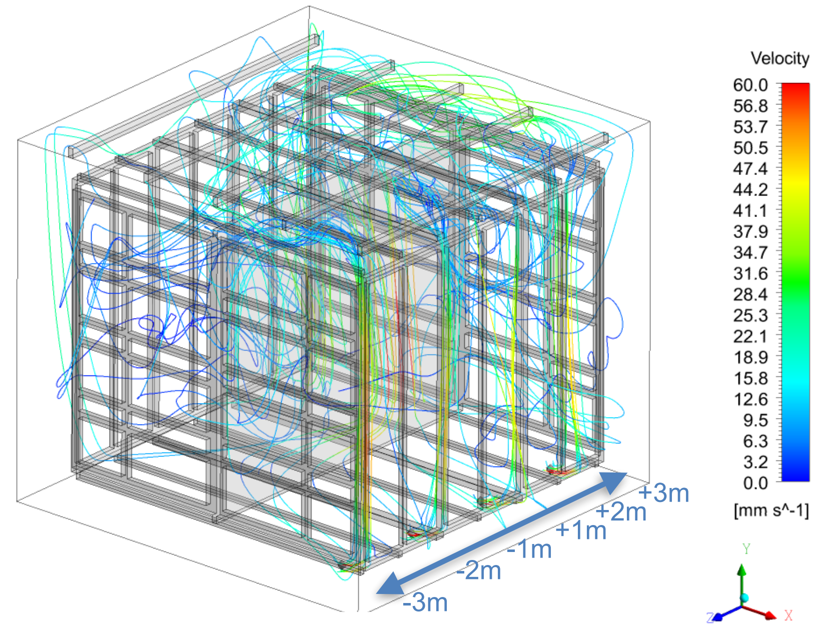
# LAr Flow Simulation w/ Space Charge

based on Computational Fluid Dynamics Analysis

Erik Voirin

| Discharge Points (m) | | |
|---|---|---|
| X | Y | Z |
| 2.464 | -3.49 | 2.753 |
| 2.464 | -3.49 | 0.713 |
| 2.464 | -3.49 | -1.327 |
| 2.464 | -3.49 | -3.367 |
| **Suction Point (m)** | | |
| X | Y | Z |
| -4.64 | -3.187 | -2.243 |



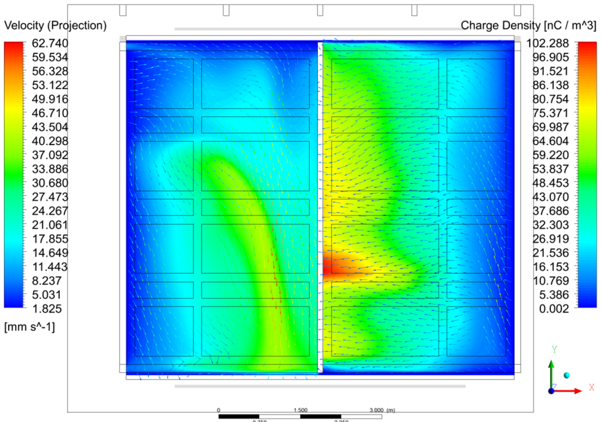

- **Pump discharge locations** and liquid return temperature are main variables for changing the flow pattern.

- Developed for ProtoDUNE-SP – see DUNE-doc-928
- 3D simulation of LAr flow, 8 mm/s ion drift @ 500 V/cm, uniform space charge deposition from cosmics (1100 Ions/cm^3/sec Ion generation)
- **Calculated velocity, temperature, impurity fields and Ion charge density map inside ProtoDUNE cryostat using CFD methods.**

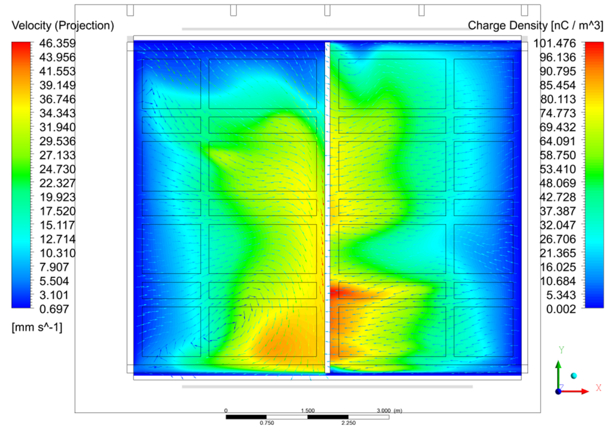
https://indico.fnal.gov/event/17340/contribution/1/material/slides/0.pdf

# Space Charge

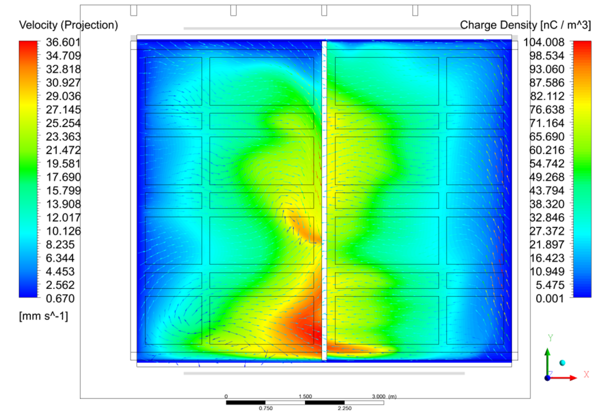
## Z=0m

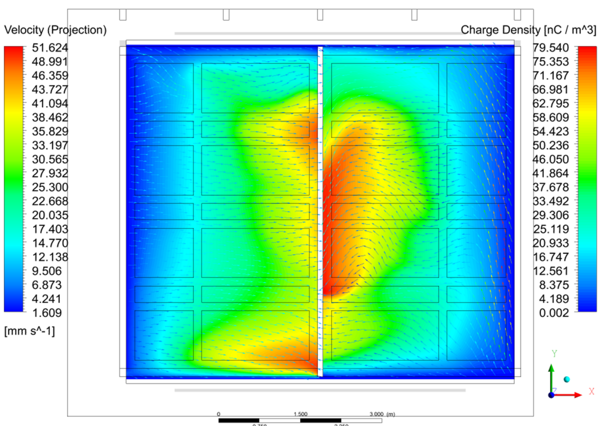



## Z=1m

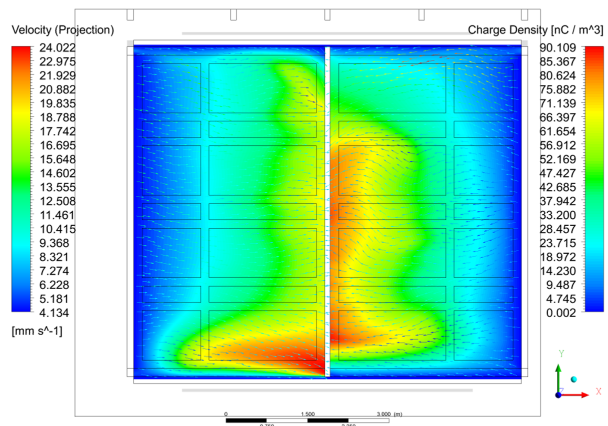



## Z=2m

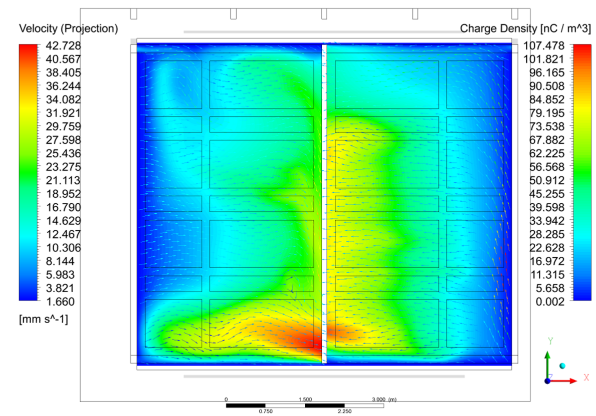



## Z=4m

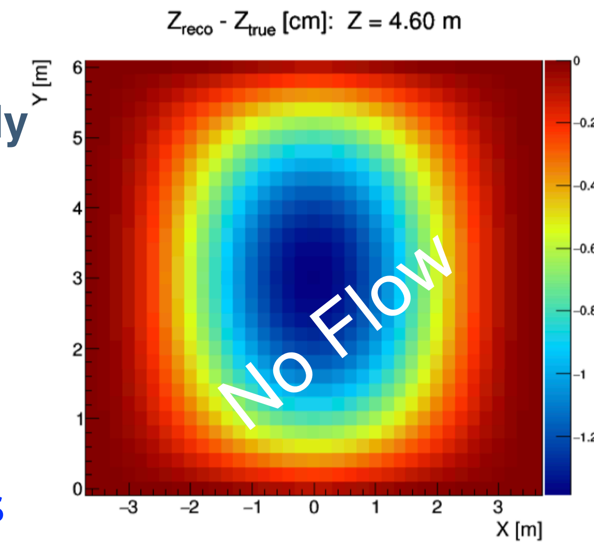



## Z=5m




## Z=6m

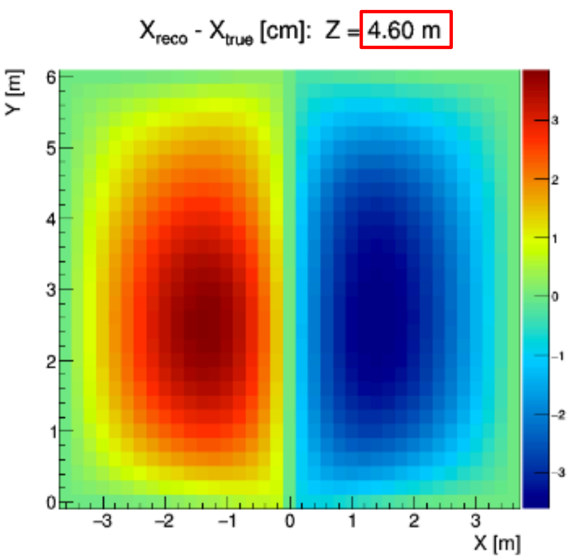
# Space Charge Simulation with LAr Flow

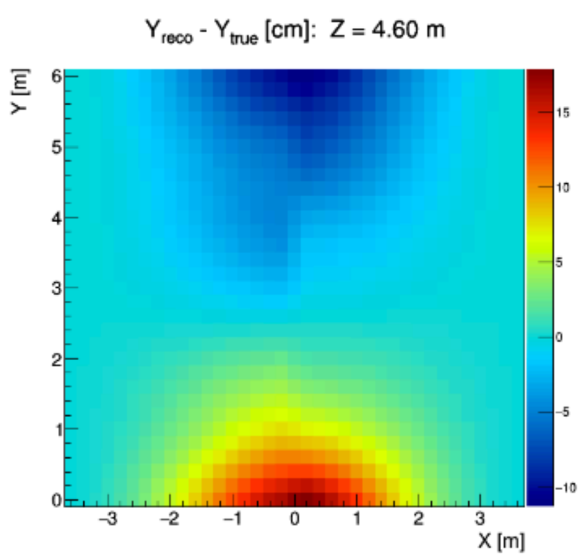


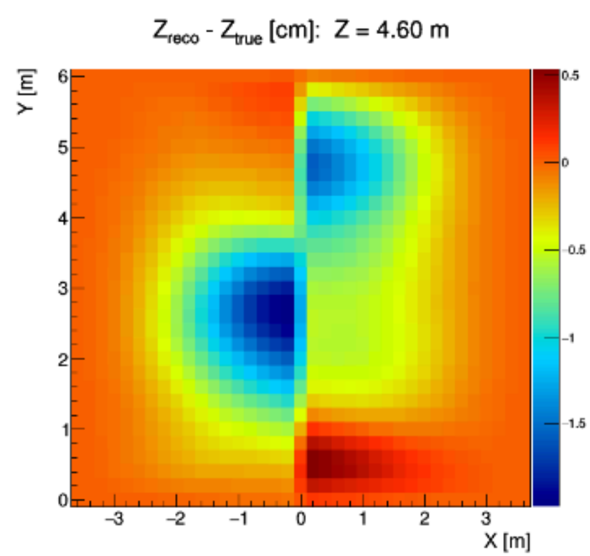

- space charge density map used as inputs to derive track reconstruction distortion: [$(x,y,z)_{\mathbf{reco}}$ vs $(x,y,z)_{\mathbf{true}}$] (**first study of LAr flow impact on SCE)**
- Very different distributions in the two drift volumes
- New maps are being added to simulation
- Essential to have **data-driven calibration**

Mike Mooney

Spatial distortion maps



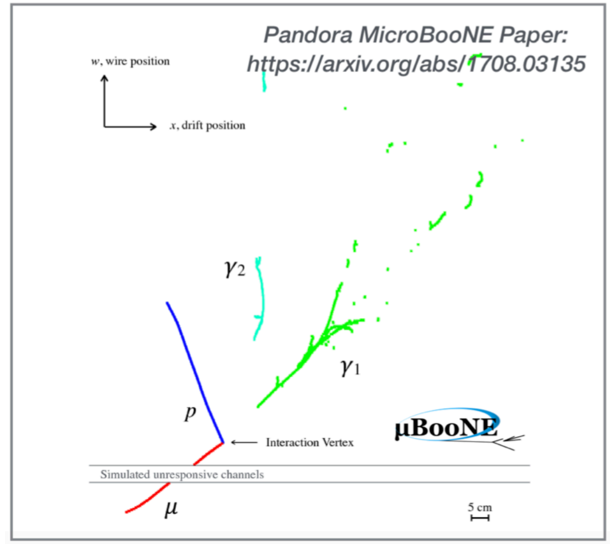



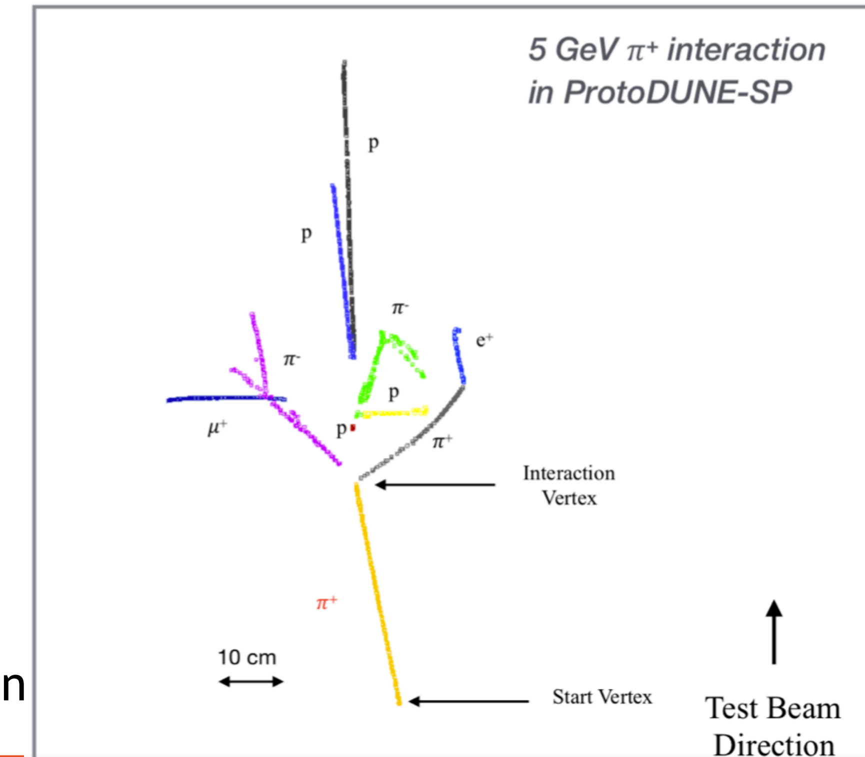




https://indico.fnal.gov/event/17340/contribution/1/material/slides/0.pdf

# Reconstruction

- Pandora progress to improve reconstruction specifically for ProtoDUNE.
- Adaptive Boost Decision Tree based Beam Particle ID:
  - Efficiencies: 72.3% for beam and 94.5% for cosmic muons
  - PFParticle hierarchy and tagging to facility analysis

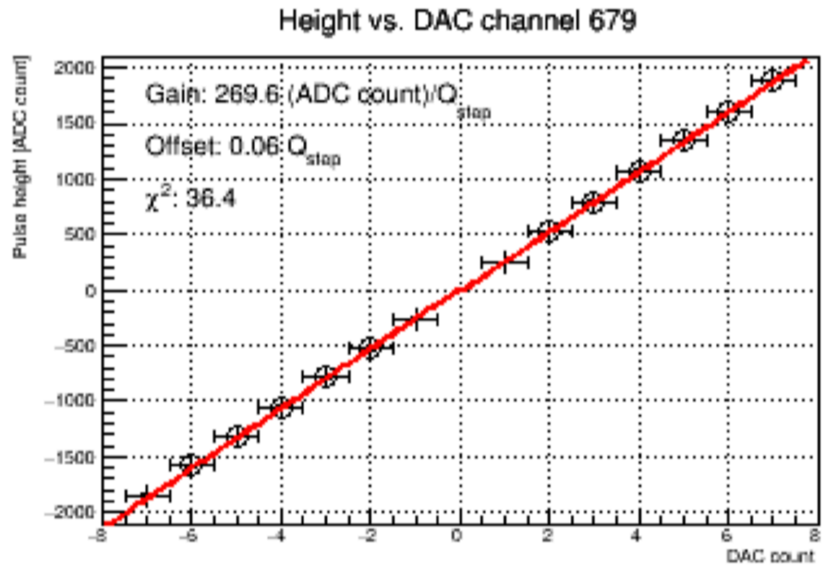


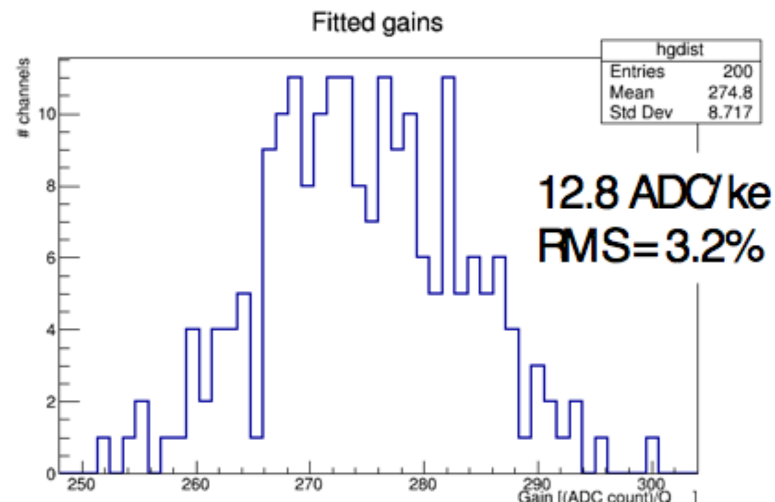




Steve Green

# ADC Calibration

- data from the coldbox data at CERN.
- An average gain of 78 e/(ADC count) with σ = 3.2%.
- More work needed to correct for non-linearity or get response in the single MIP region.

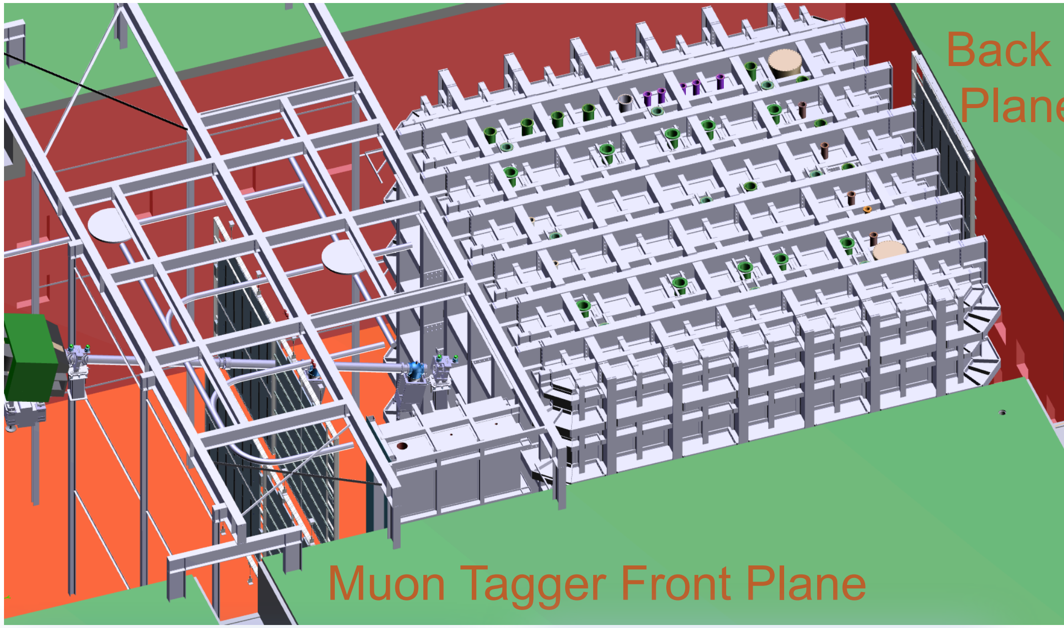


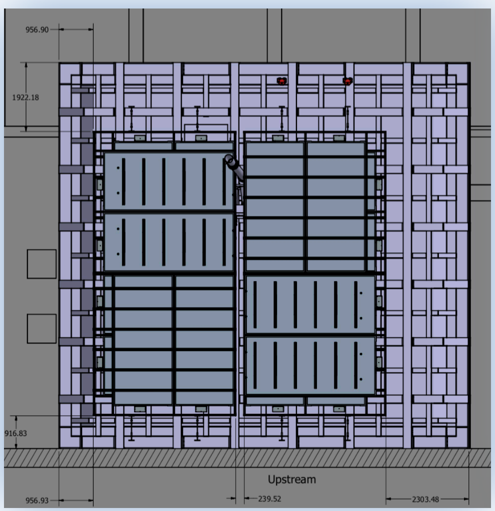



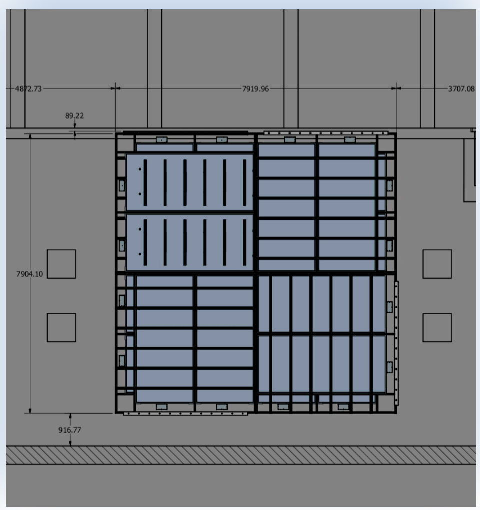

https://indico.fnal.gov/event/17410/contribution/1/material/slides/0.pdf

# Muon Tagger

U of Chicago, Virginia Tech,
U Minnesota, U Rochester, FNAL



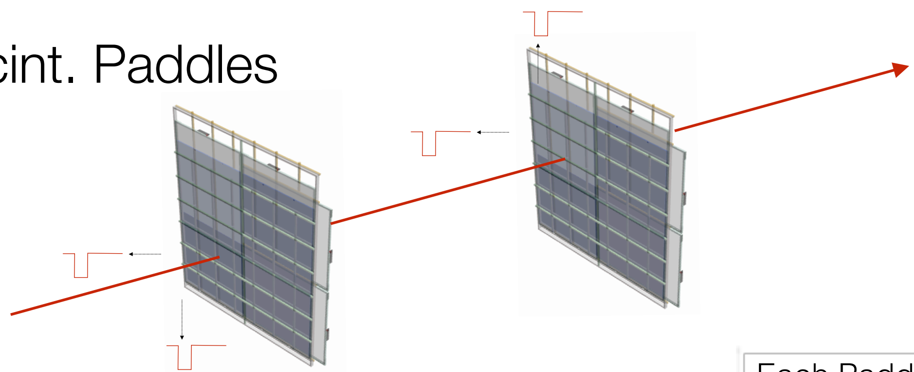

Muon Tagger Modules

# External Muon Tagger

Trigger logic using coincidence signals from upstream and downstream modules

**A FAST NIM signal is generated when a coincidence is found btw the two layers of the hit paddle**

2 Hor Scint. Paddles

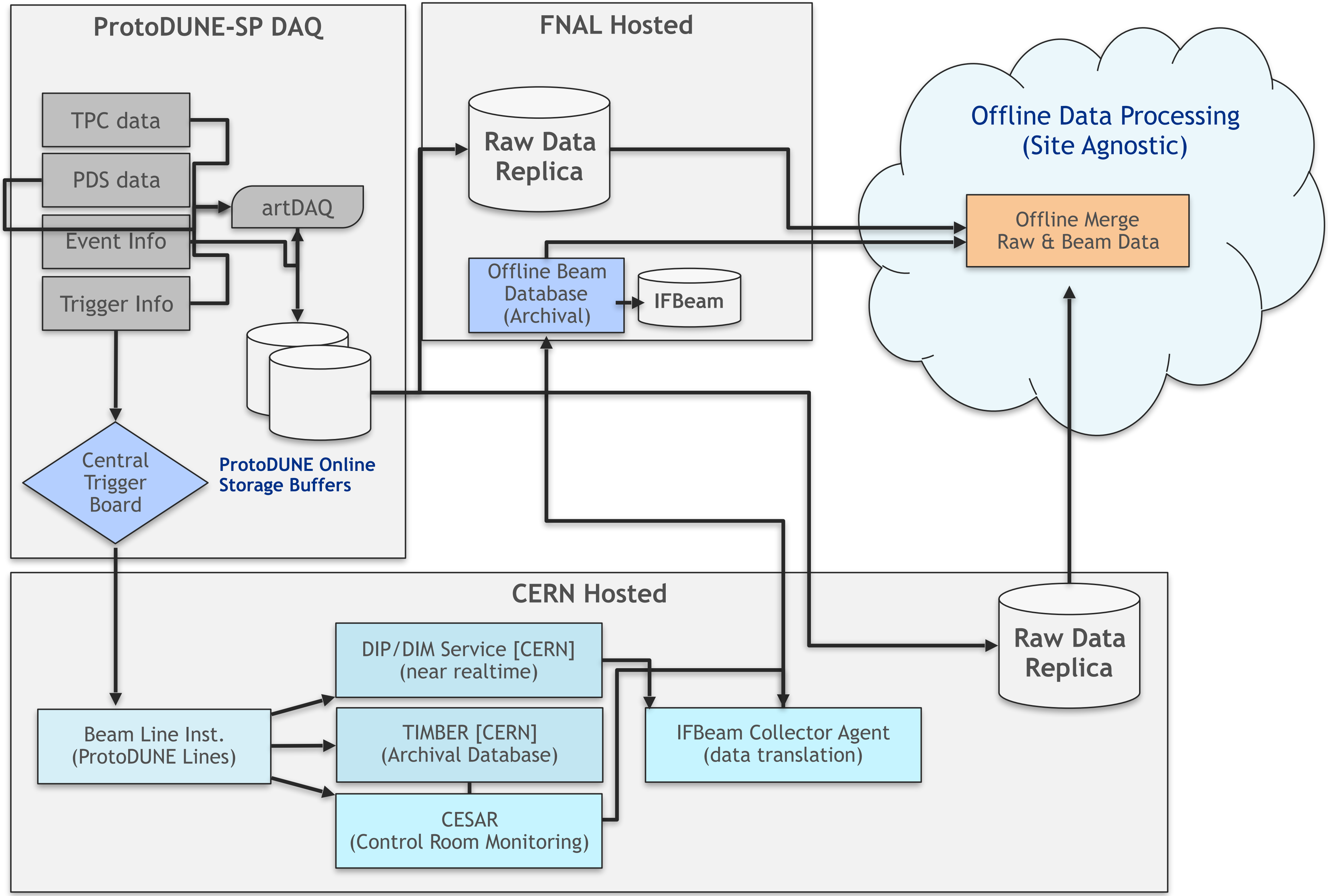


2 Vert

CRT Module

Each Paddle is made by TWO scintillator planes segmented in 5 cm wide strips (staggered).

- **during beam spill (BeamOn):**
  - ➡ Muon Tagger stand-alone trigger ⇨ ***hor-muon halo*** *trigger* for LAr TPC Calibration (e-lifetime, SCE)
  - ➡ in “anti-combination” w/ beam counter trigger ⇨ ***veto*** TPC readout in case of pile-up or halo/punch-through
- **out of beam spill (CosmicOn):**
  - ➡ Muon Tagger stand-alone trigger ⇨ ***hor-muon cosmic trigger*** for LAr TPC Calibration (e-lifetime, SCE)
  - ➡ in combination w/ internal PhDet trigger ⇨ *special* ***cosmic event trigger*** (cosmic ray induced muon bundles or electromagnetic cascades in atmosphere)


ProtoDUNE-SP DAQ
TPC data
PDS data
Event Info
Trigger Info
artDAQ
Central Trigger Board
ProtoDUNE Online Storage Buffers
FNAL Hosted
Raw Data Replica
Offline Beam Database (Archival)
IFBeam
Offline Data Processing (Site Agnostic)
Offline Merge Raw & Beam Data
CERN Hosted
DIP/DIM Service [CERN] (near realtime)
TIMBER [CERN] (Archival Database)
CESAR (Control Room Monitoring)
Beam Line Inst. (ProtoDUNE Lines)
IFBeam Collector Agent (data translation)
Raw Data Replica