Report on ProtoDUNE SP

Flavio Cavanna

PAC Meeting

FNAL - Jan 16, 2019

OUTLINE

PAC Charge January 2019

ProtoDUNE:
We ask the committee to review
- the status of the experiment,
- preliminary results from the recent data taking period,
- plans for the (post-) shutdown program

and to comment on
- remaining technical challenges to be addressed including the feasibility of the 600kV dual phase demonstrator.

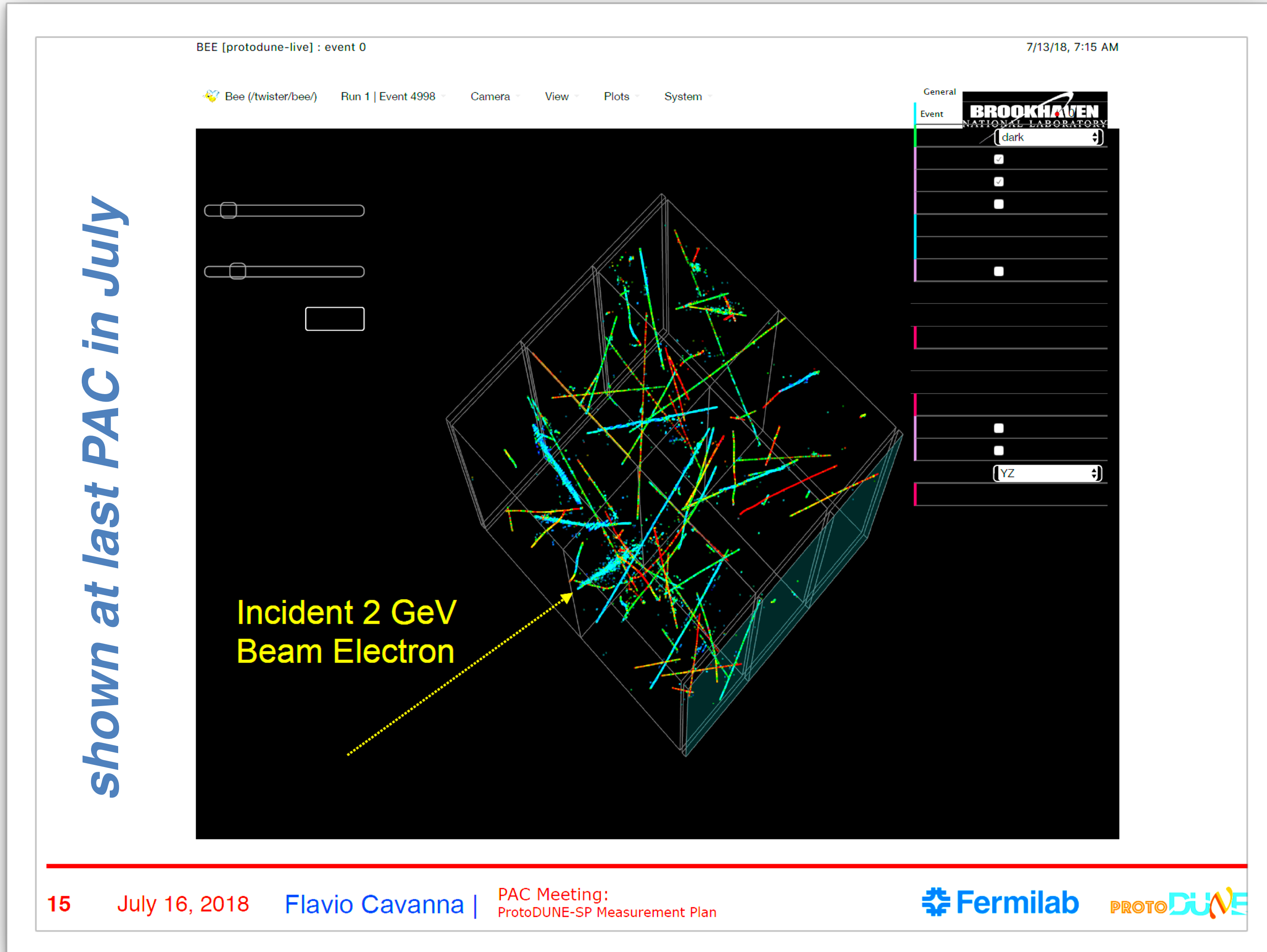
PROTO DUNE SP

Status of the experiment

and summary since last PAC:

- commissioning completed
- detector activation
- beam run
- long duration cosmic run

from Simulations…

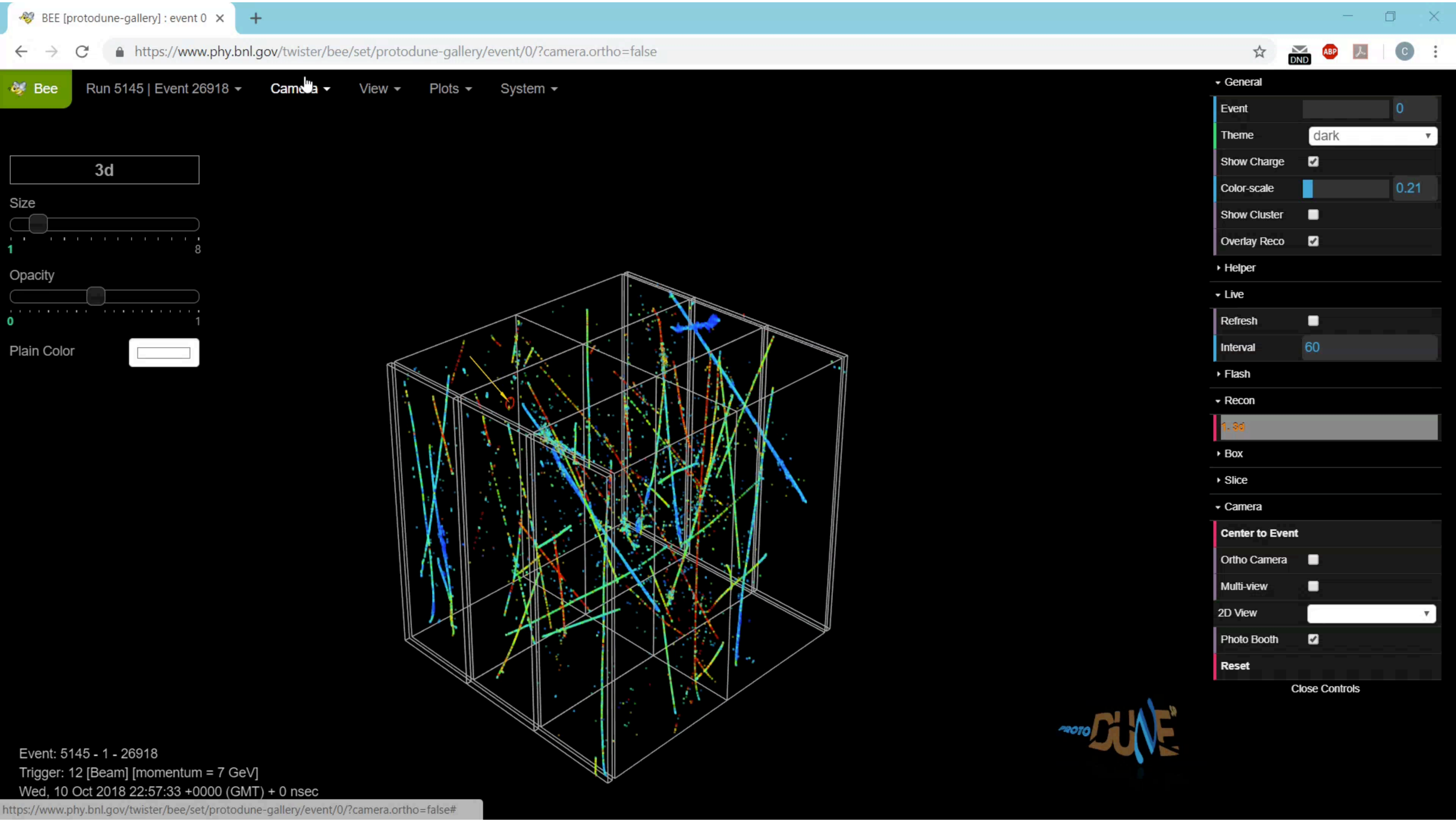


The new protoDUNE 3D event Display

MonteCarlo Data: beam particle and overlaid cosmic rays

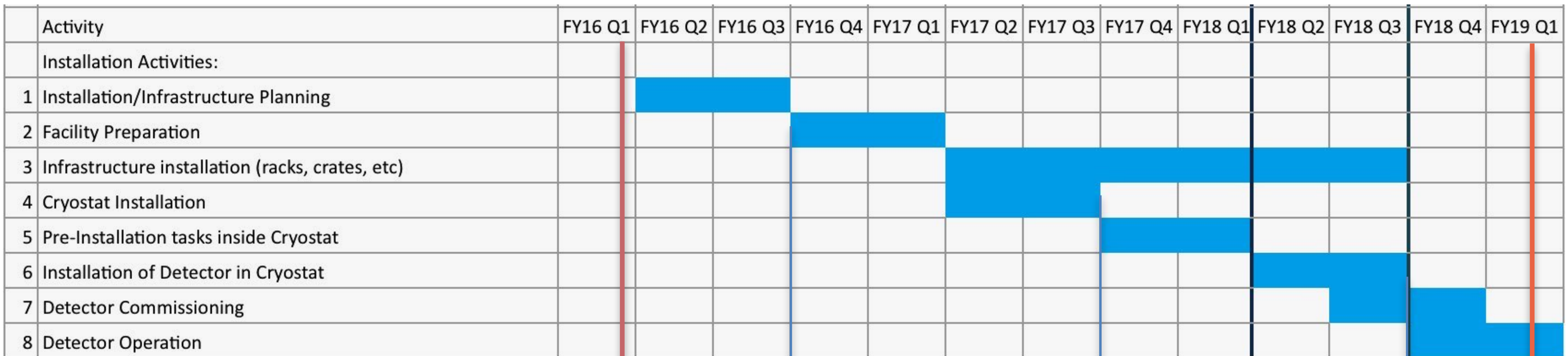
...to real data

clock here for a [*gallery of ProtoDUNE events*]



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

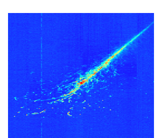
May '17, Cryostat ready

Jun.'18, Detector in Cryostat

Jul-Nov '18, Commissioning and Beam Run

CERN LS2

From digging the pit
to data taking in 2.5 yr

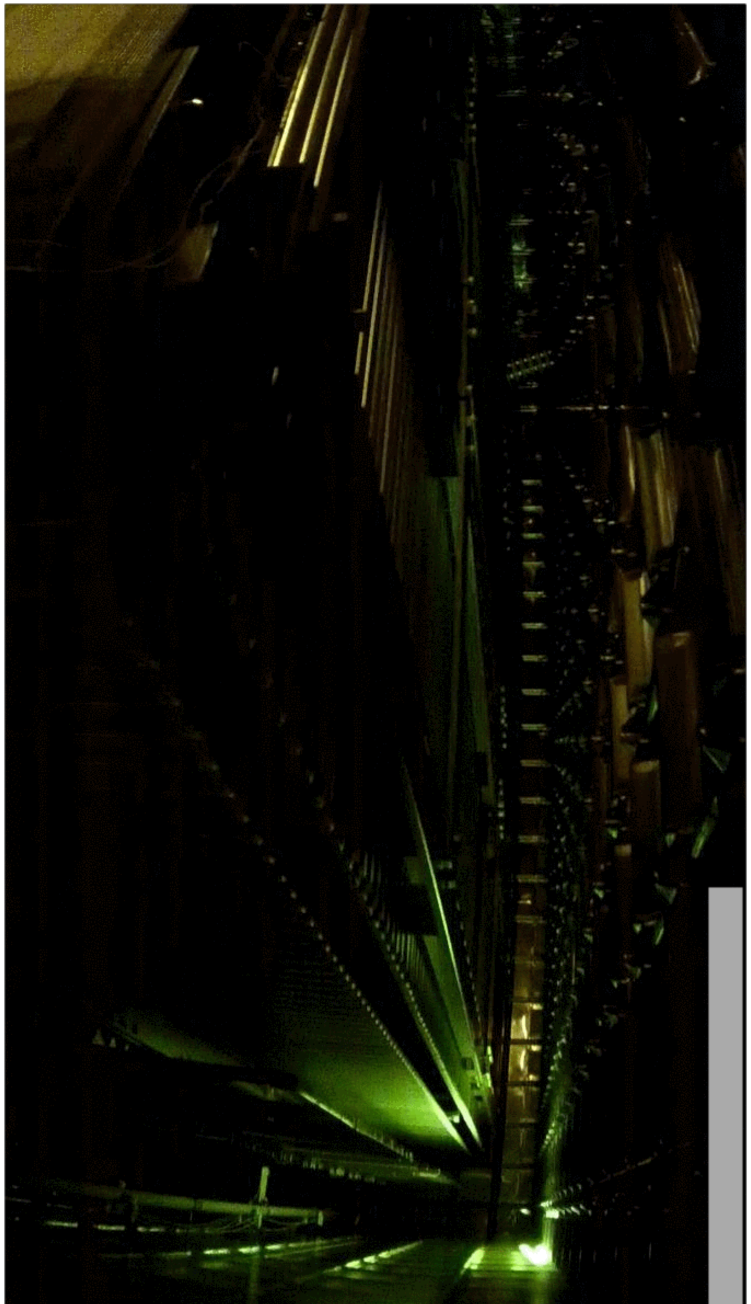


PROTODUNE SP **MISSION**

- 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**

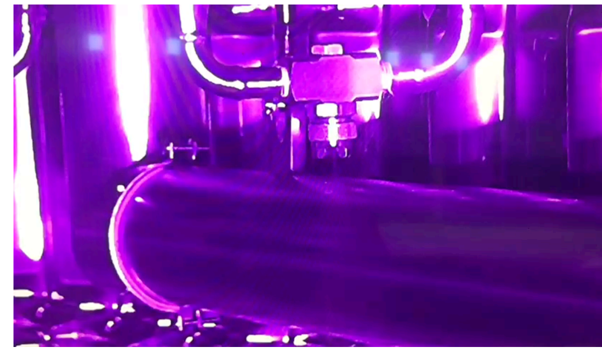
Cryogenic Commissioning Purging, Cooling and LAr Filling

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

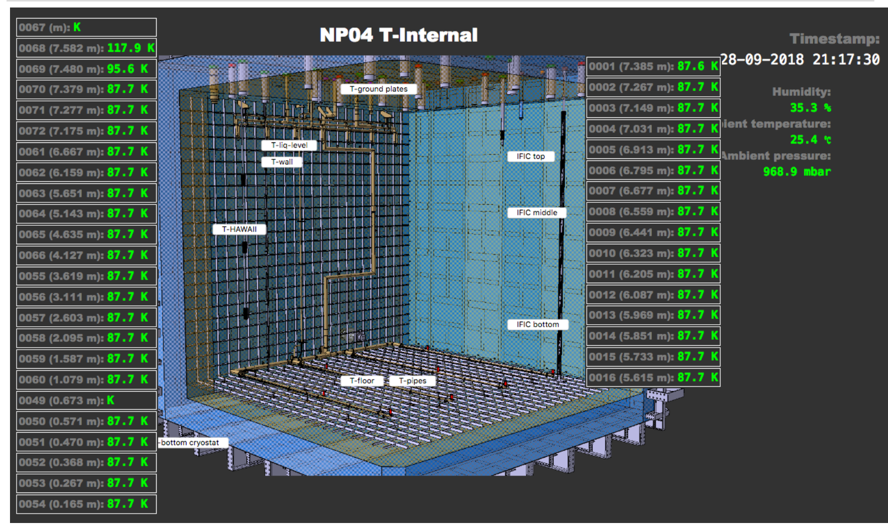
Detector Activation Procedure

Sept. 19, h. 15:32 - ready to start

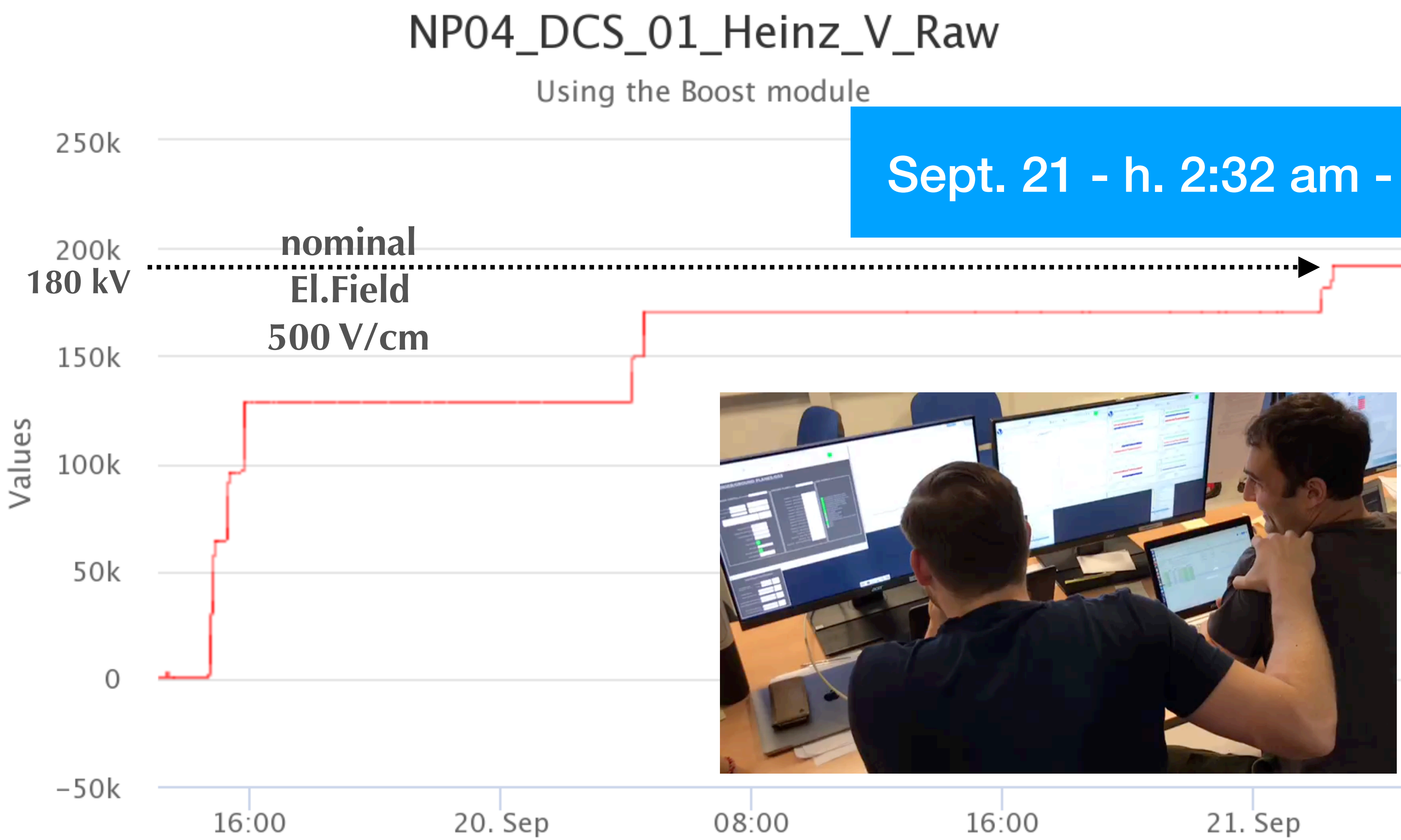
Detector Status - Checklist:

- ☑ - LAr filling Completed (LAr at Nominal level)
- ☑ - LAr recirculation ON
- ☑ - HV chain (from Pwr Supply to HV FeedThrough, from Cathode to the end of field Cage resistor divider) “tested”
- ☑ - grounding checked
- ☑ - CE electronic powered ON
- ☑ - Detector Control System active
- ☑ - DAQ ready for data taking
- ☑ - On-line monitor active
- ☑ - Computing for data transfer and first evt./data reconstruction operational
- ☑ - near-line Data Quality Monitor ready
- ☑ - full off-line analysis and reconstruction ready for real events
- ☑ - Beam ON (and beam instrumentation responding)

Sept. 21, h. 2:32 am - completed



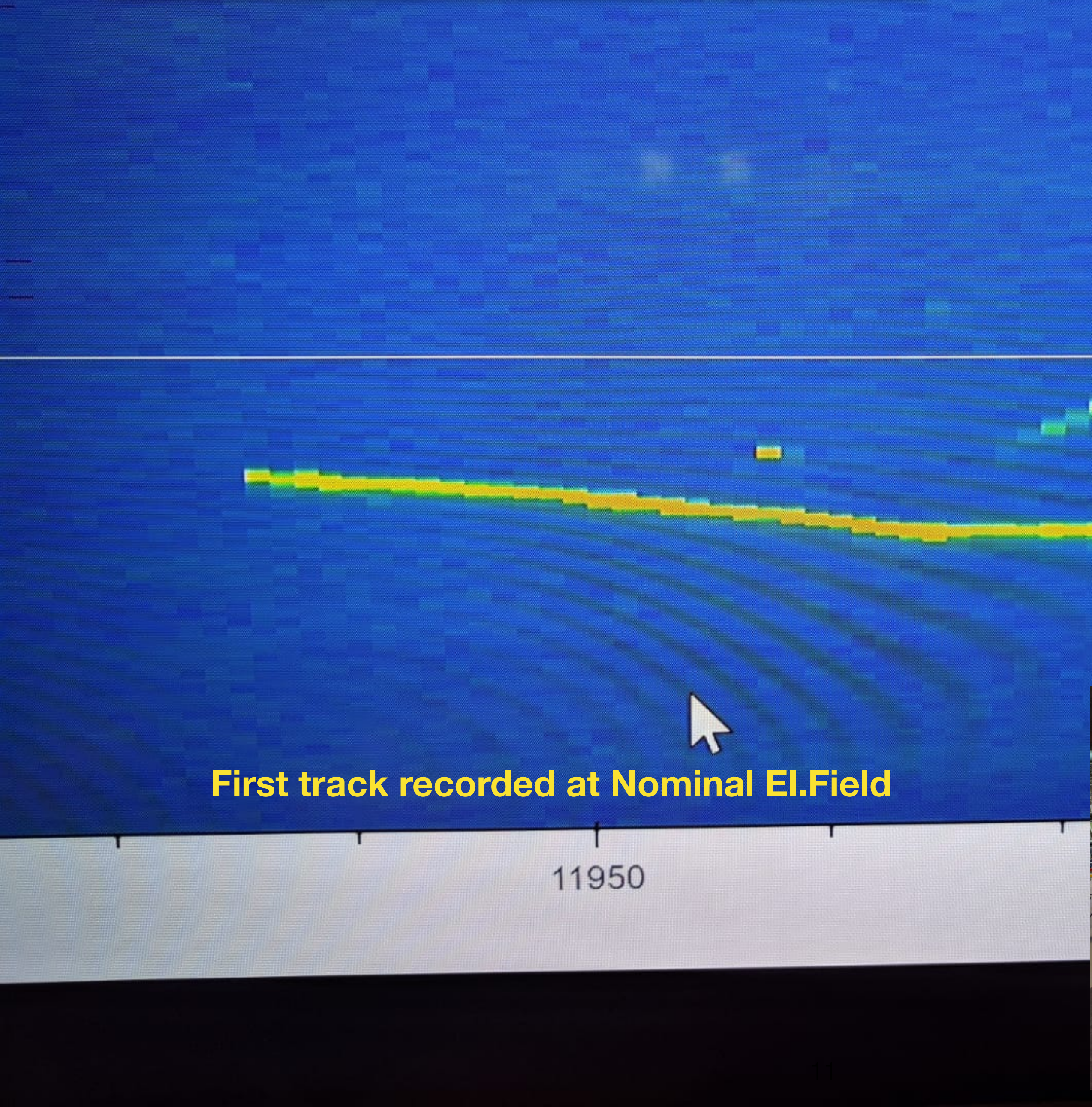
PROTO DUNE SP



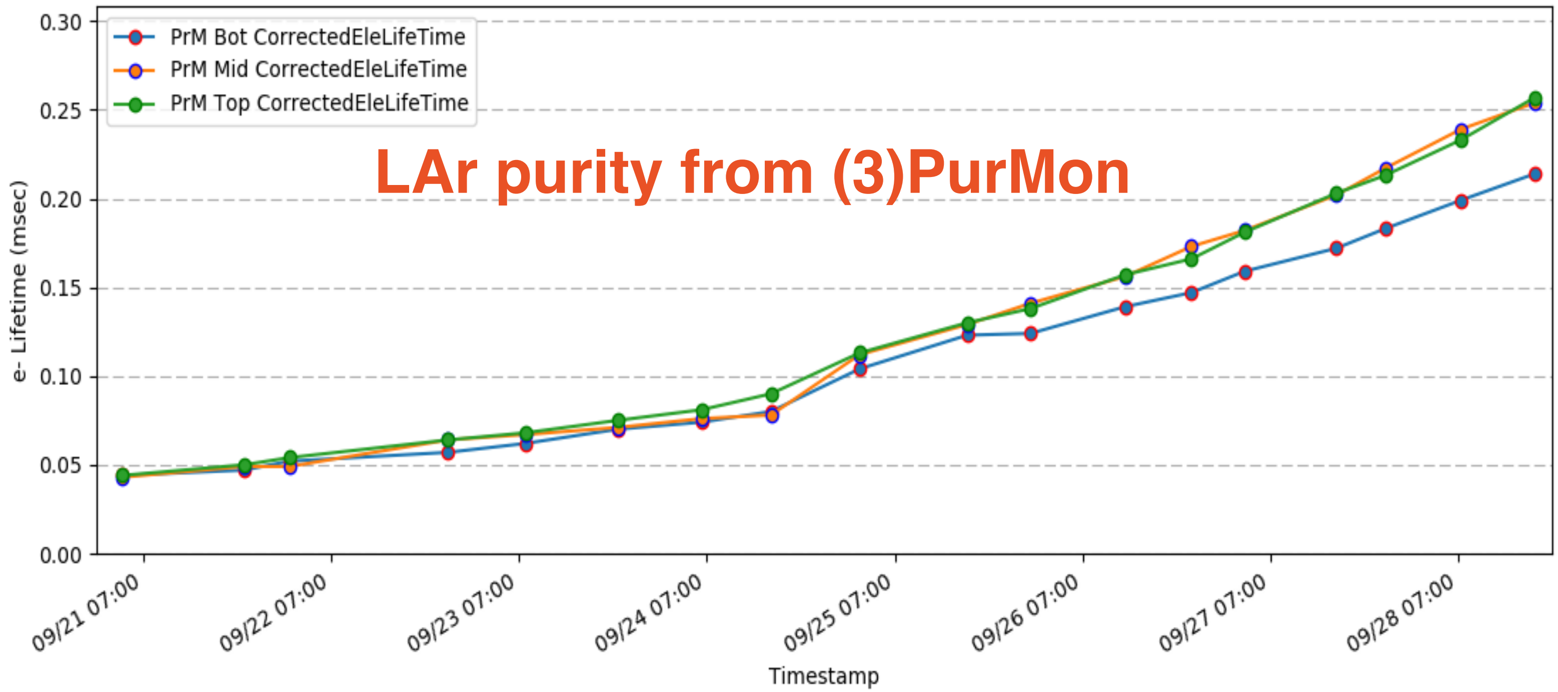
Sept. 21 - h. 2:32 am - CDT

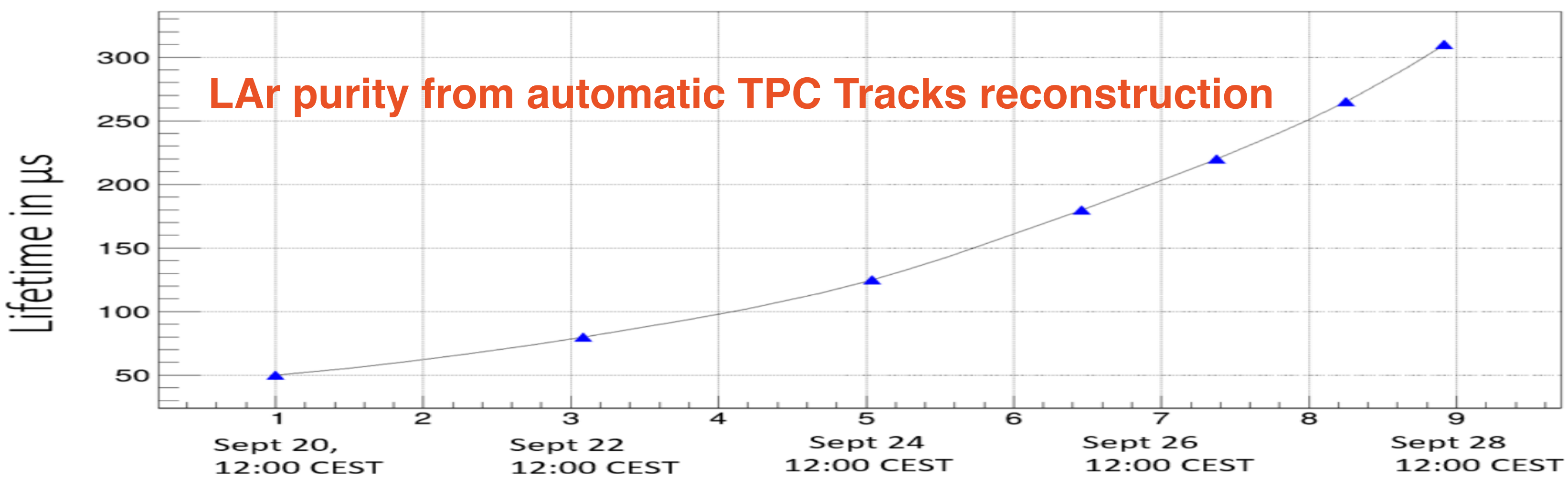
HV Ramp from 0 to 180 kV (Nominal) successfully completed

few seconds after, from the On-Line Monitor

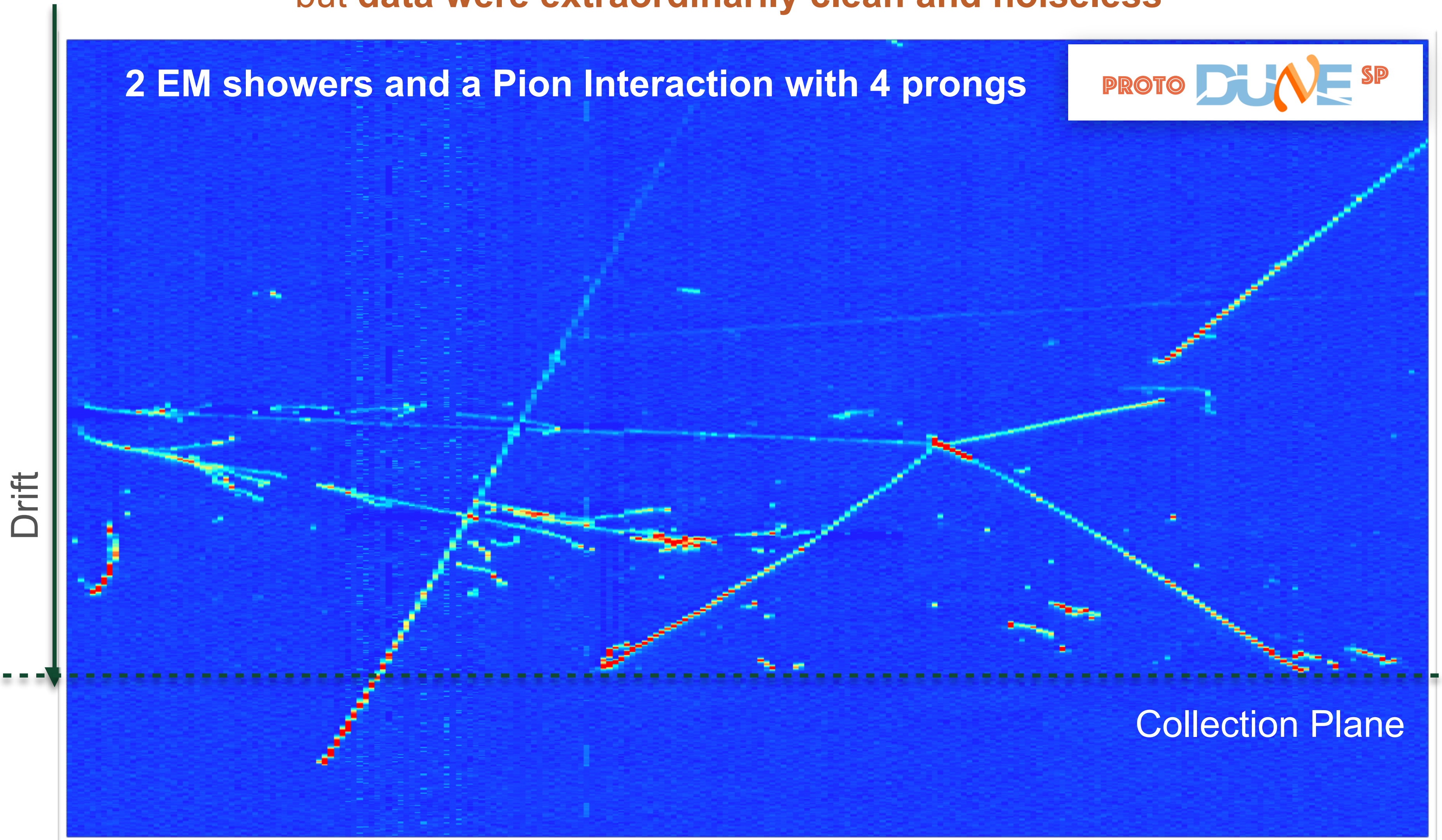


First track recorded at Nominal El.Field





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.

Beam Run Plan

August 29, 2018 (Start)

November 11, 2018 (End)

H4 Beamline & extension

400 GeV/c p primary beam from SPS

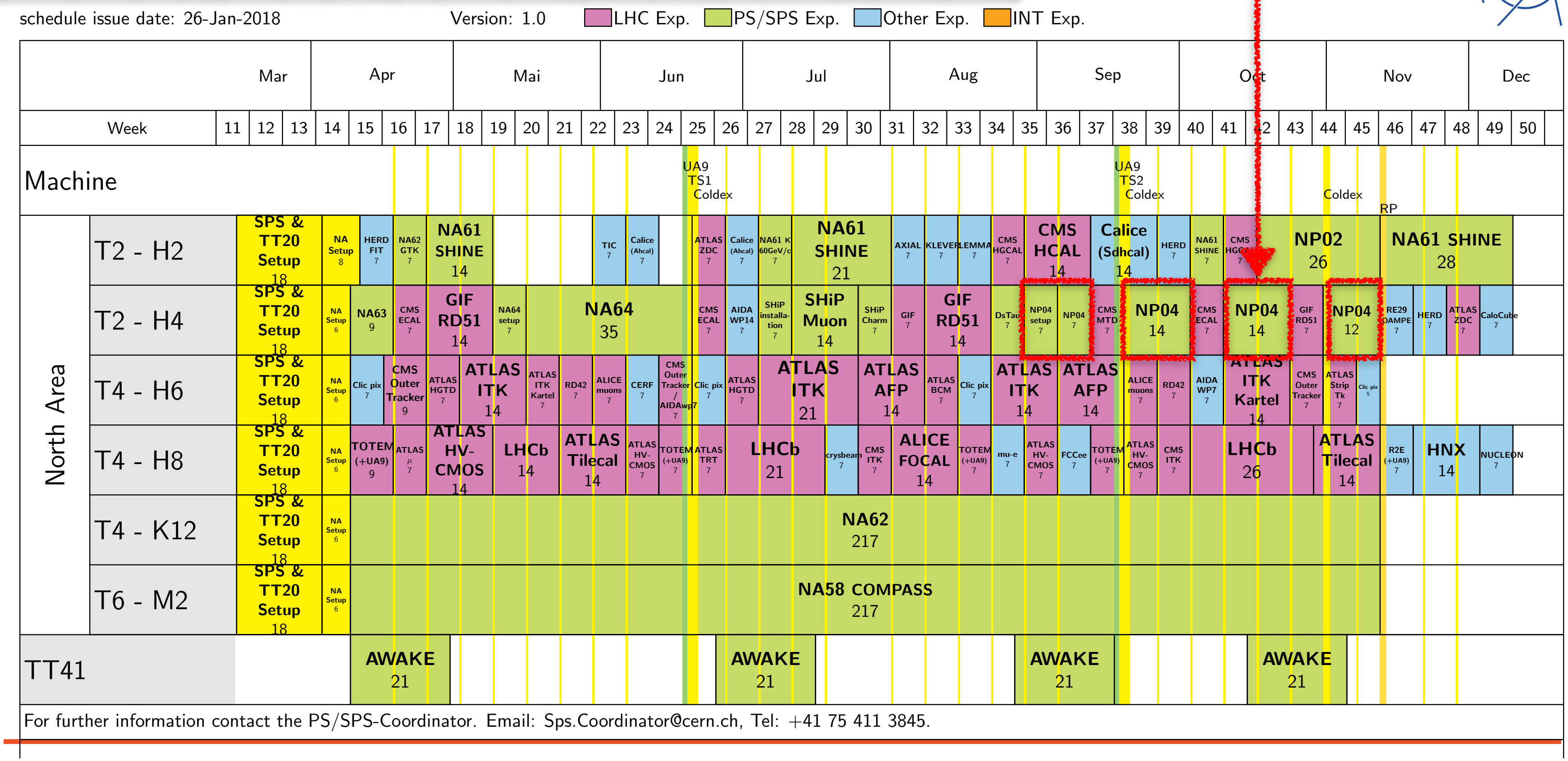
➜ 80 GeV/c secondary π^+

➜ 0.5 – 7 GeV/c tertiary Positive Polarity

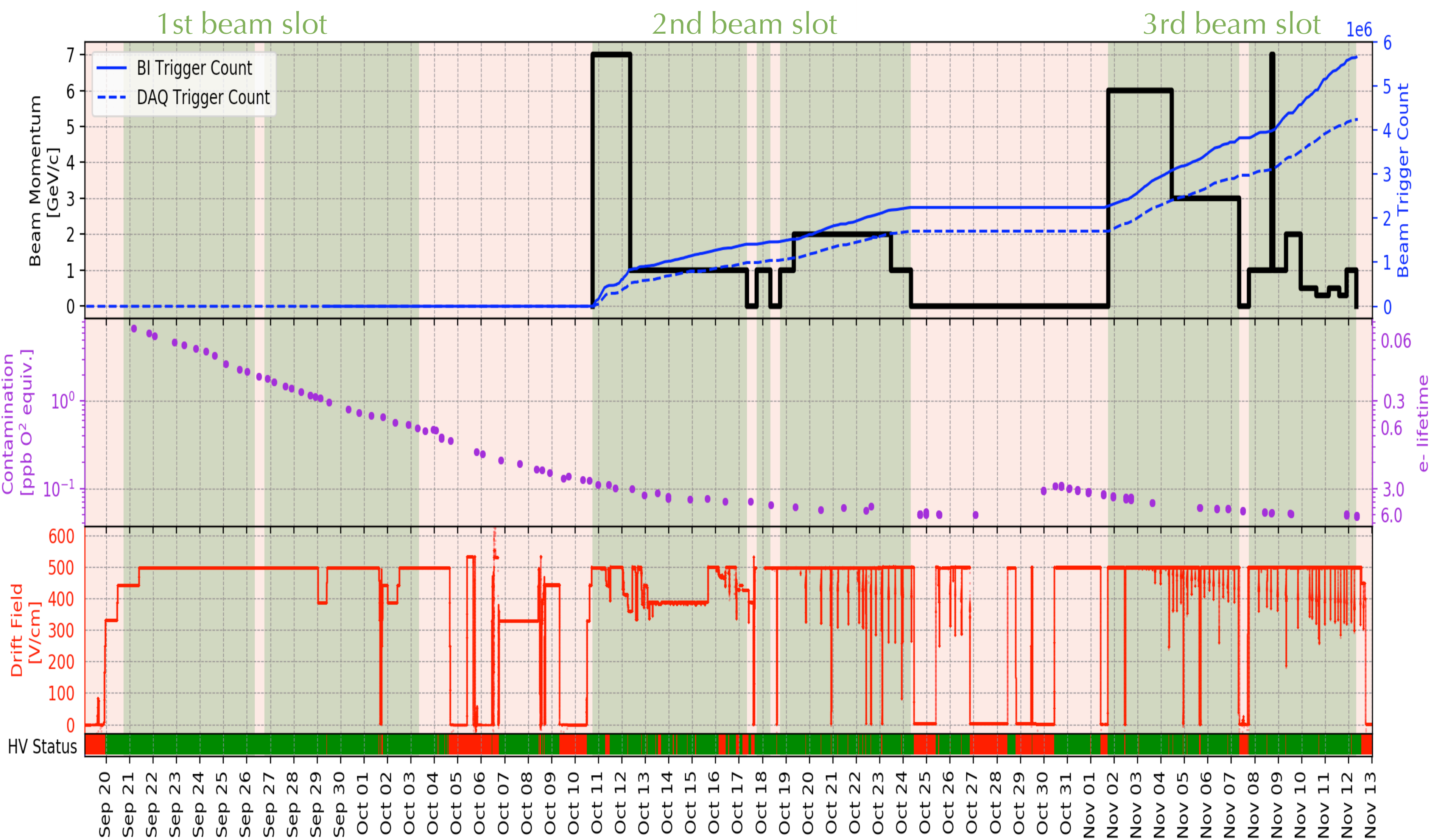
e^+, p, μ^+, π^+, (K^+)

H4 Beam Time Allocation to NP04 by SPS-C:

7.5 weeks (including Beam Commissioning Time) ***in 4 blocks (2w + 2w + 2w + 1.5w)***

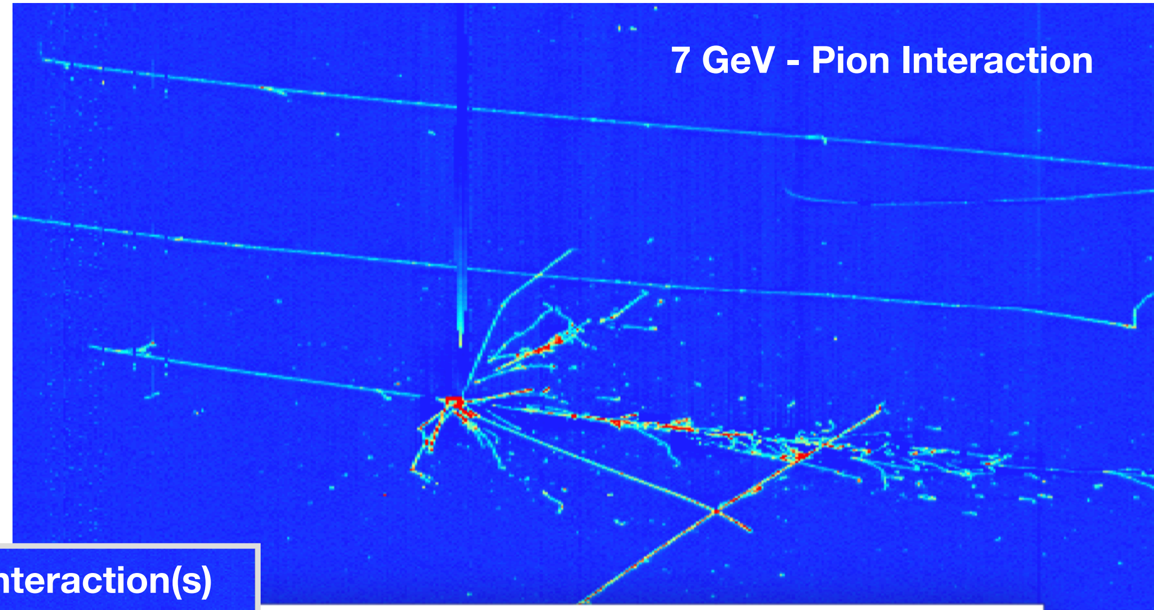


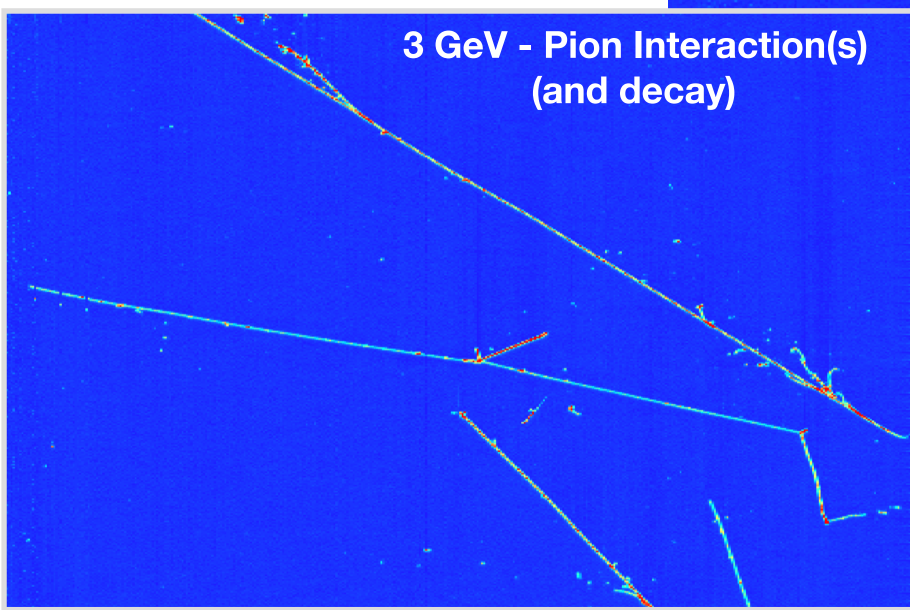
Beam Run Summary

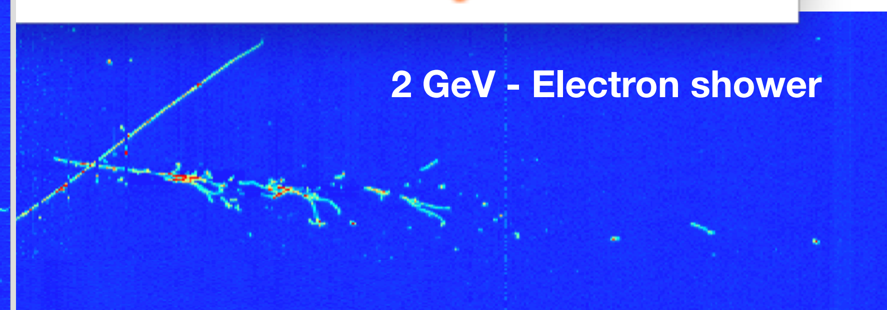


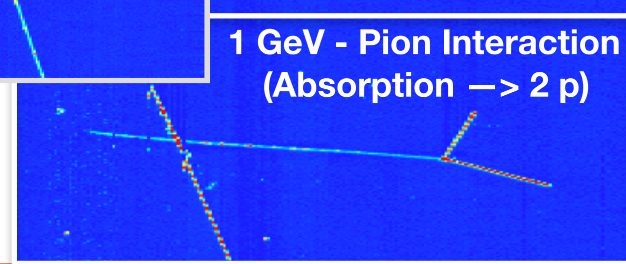
at first glance:

LArTPC data of unprecedented quality









Outline:

PROTO DUNE SP

- 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

Information for DUNE physics TDR

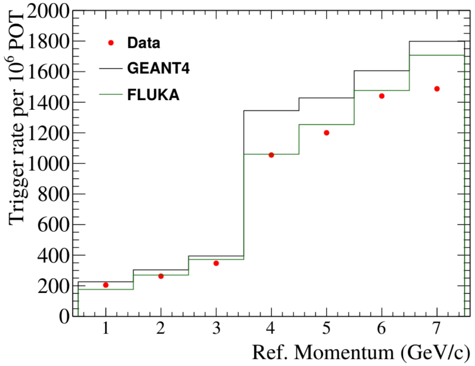
- **Long-term goals** – ***Physics Measurements***
  e.g. ***π-Ar cross sections***
  - ☐ *(started)* Total pion cross section in [1-7] GeV range
  - – Exclusive channels Cross Section:
    - – π *absorption:* $\pi^{\pm} \rightarrow$ *2p, 3p, 2p1n,..*
    - – $\pi^{\pm} \rightarrow \pi^{0}$ *charge exchange*, etc.

(NEVER MEASURED)

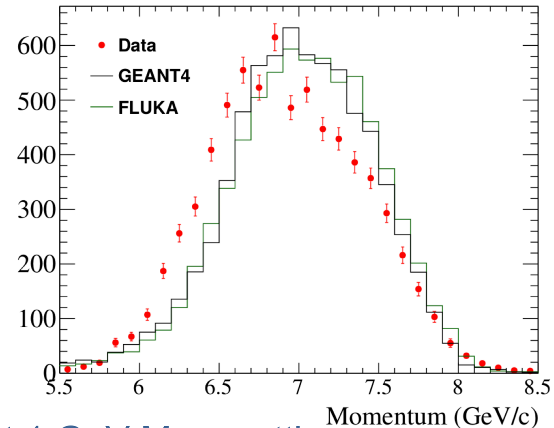
Physics publications

Analysis of H4 Beam Line Instrumentation Data

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

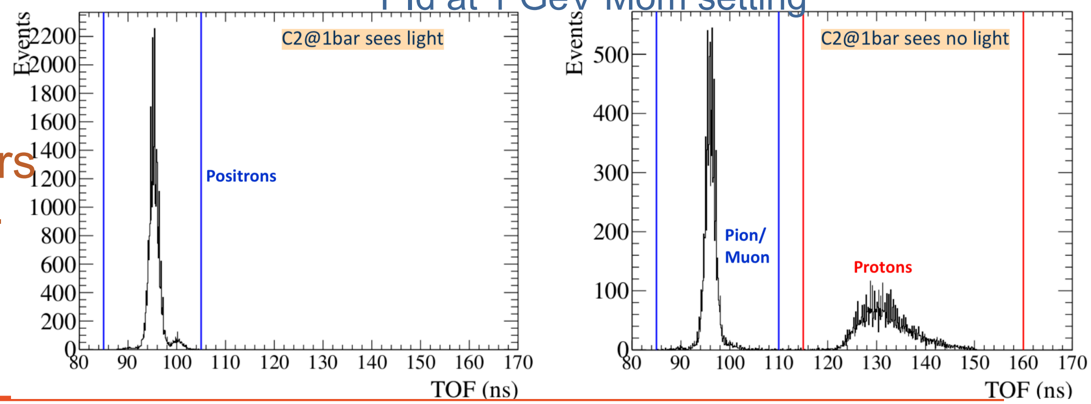


- **Momentum reconstruction:**
  - Measured Beam Profilers efficiency > 95.5 % for all momenta
  - Systematically low reconstructed momenta accounted/corrected for with a 1.45 mm shift of one of the Beam Profilers (**transverse misalignment of fibre planes, one with respect to another).**



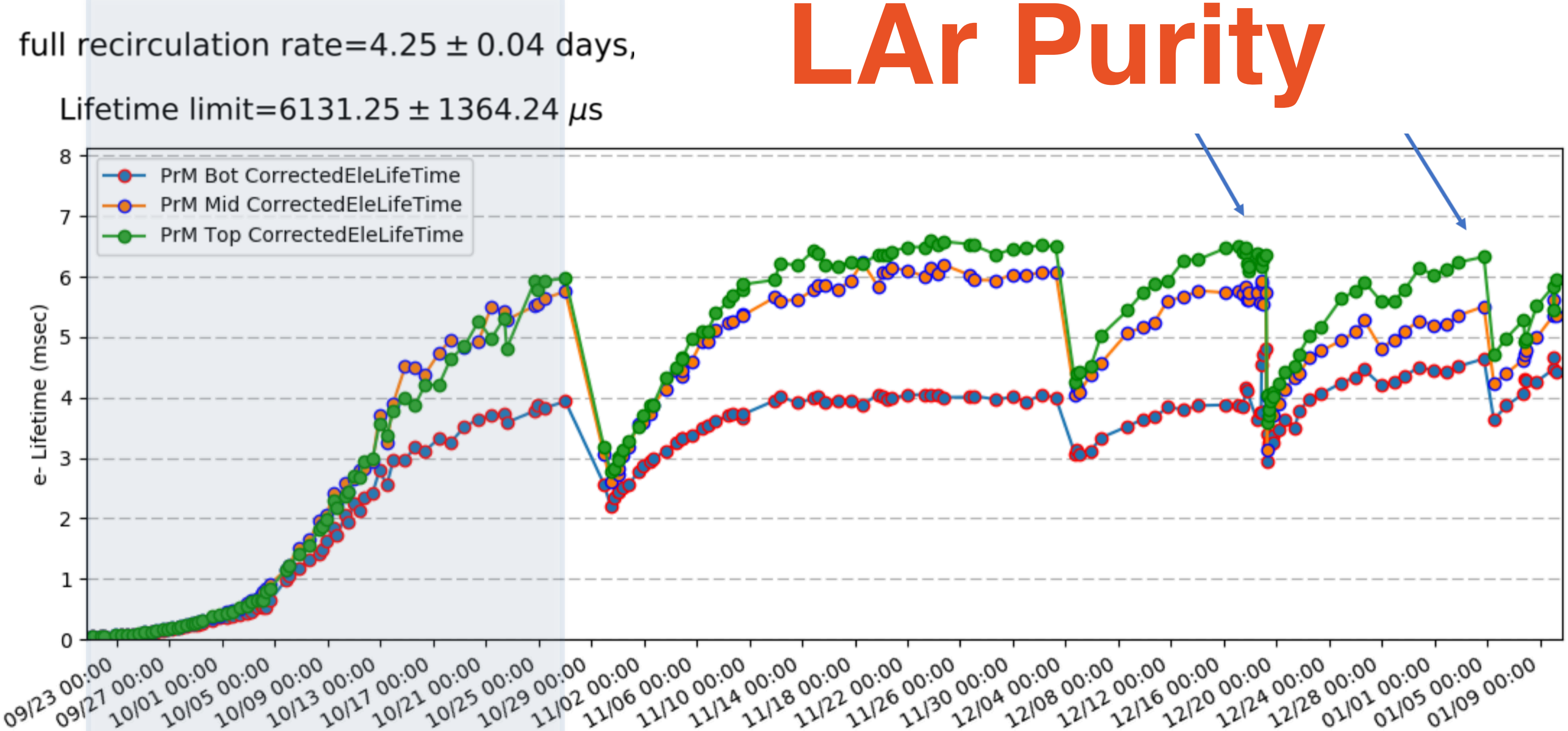
- **Particle Identification:**
  - Time-of-flight between ToF Counters
  - Cherenkov Signal (C1 and/or C2) - adjustable gas pressure/threshold

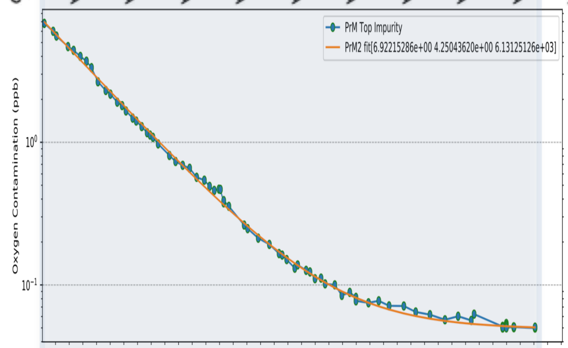
PId at 1 GeV Mom setting



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)

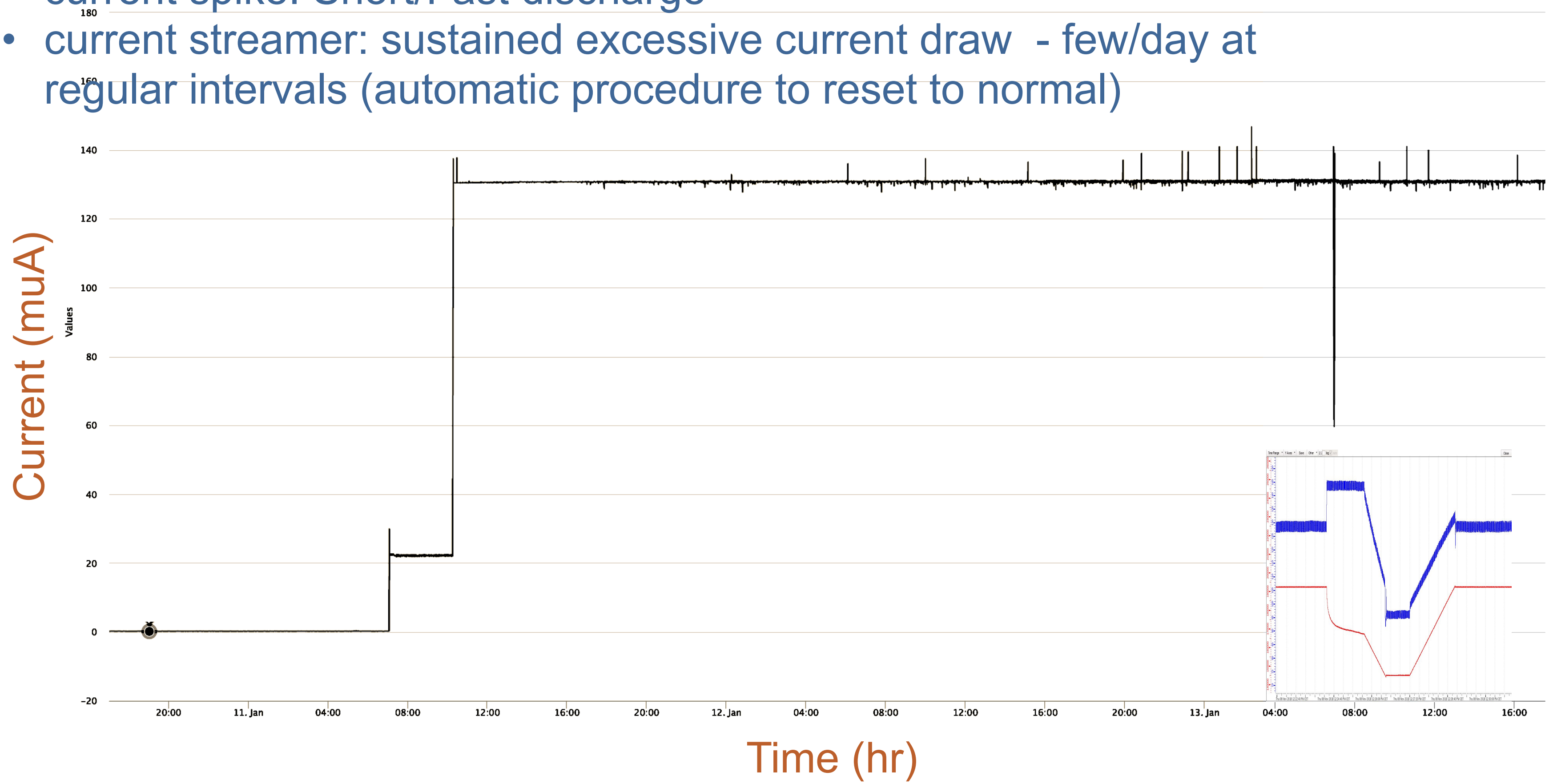
Analysis of DCS/SlwCtrl Data

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)



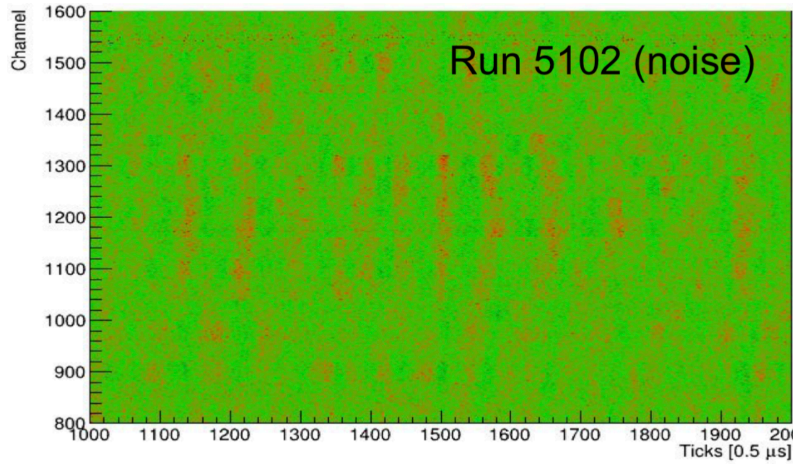
Analysis of TPC Data

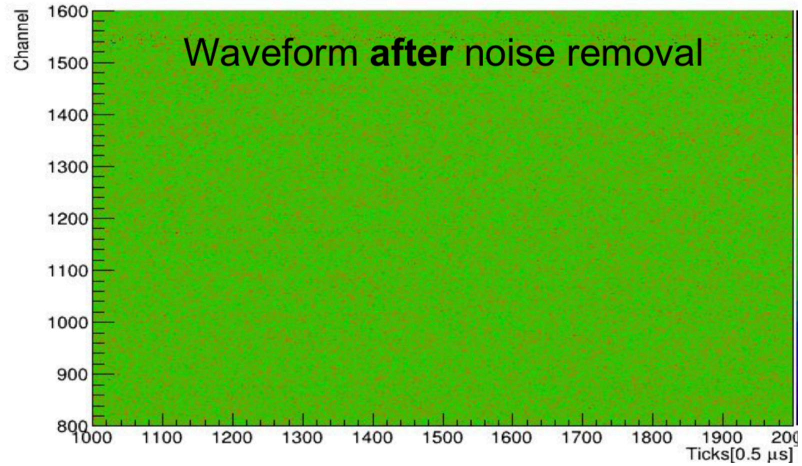
Coherent Noise Filtering

Correlation among adjacent channels ⇒ coherent noise

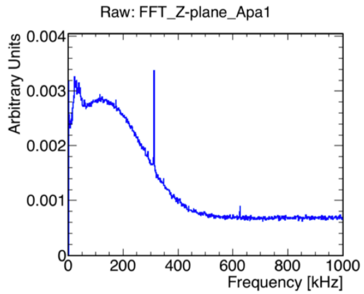
One source of coherent noise is identified at low frequencies ≈ 40 kHz (the low voltage regulator that provides power to the cold electronics)

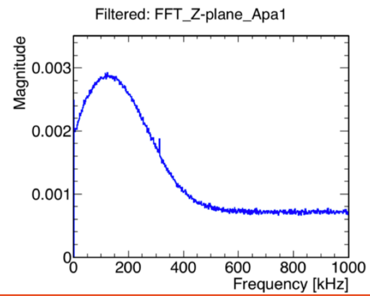
EVENT DISPLAY





FOURIER SPECTRA



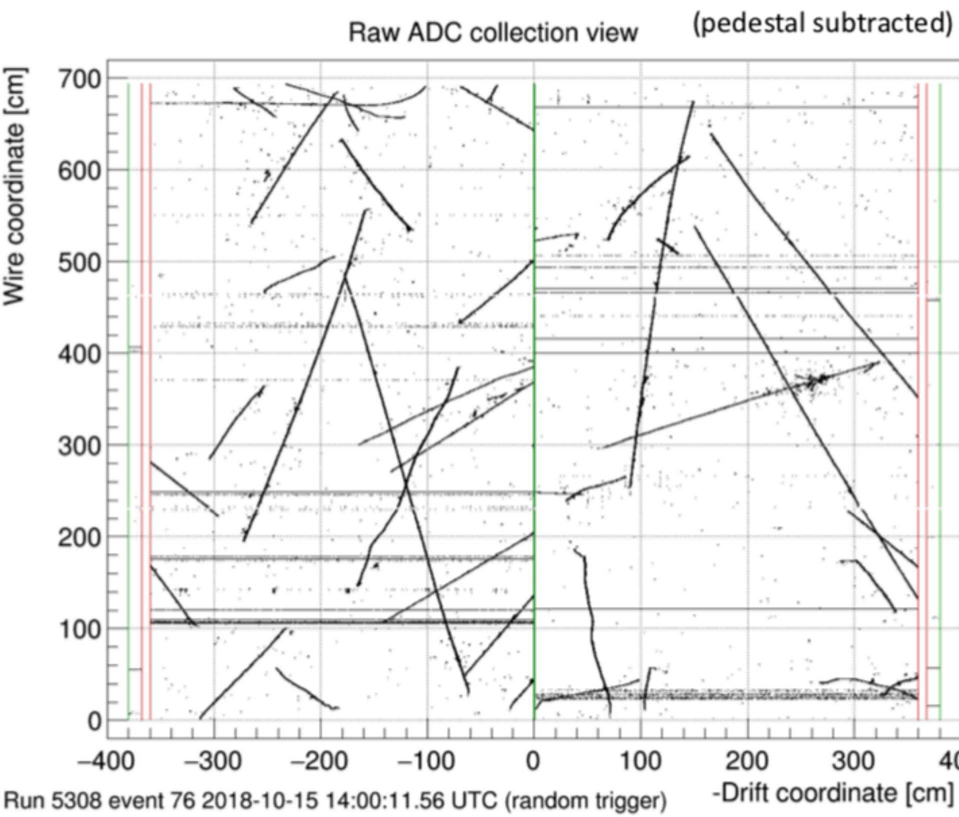


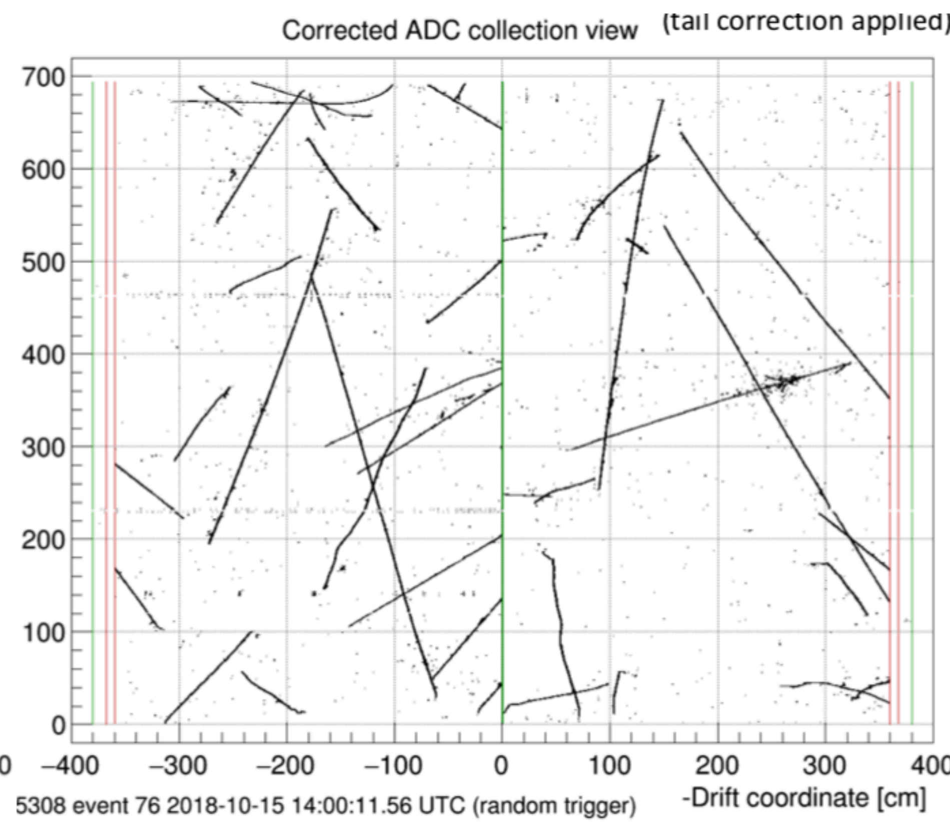
Analysis of TPC Data

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

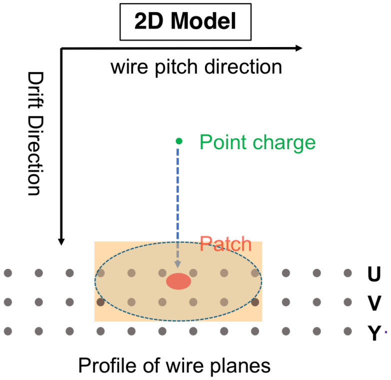
- bad channels removal
- sticky code and timing mitigation
- undershoot correction

Signal processing



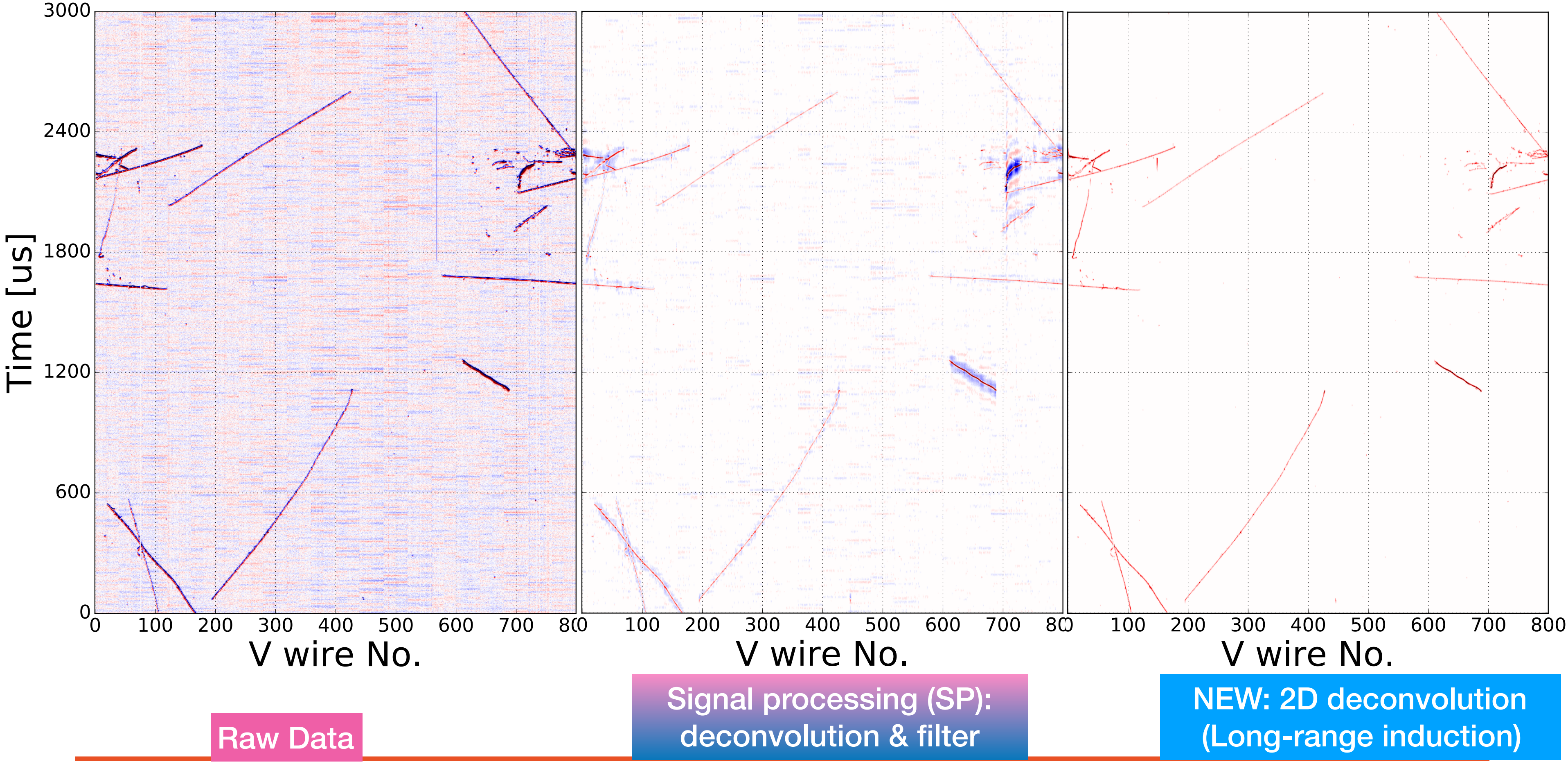


Analysis of TPC Data



one more step in Signal processing

2D deconvolution



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

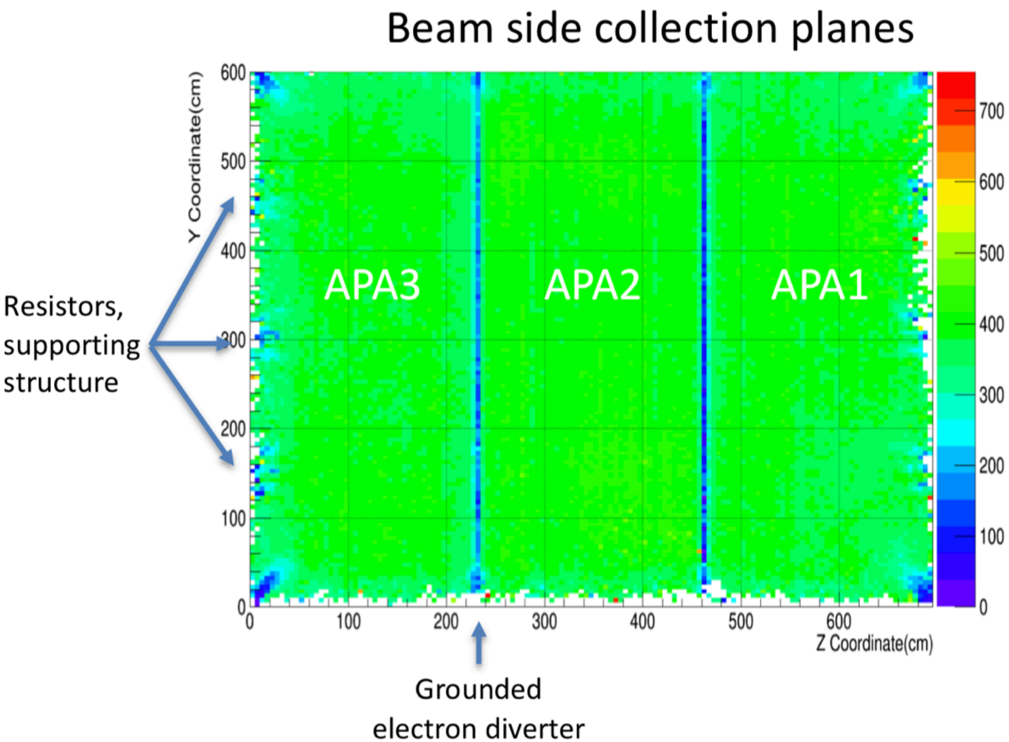
Core Calibration is the basic Detector performance measurement fundamental to inform DUNE design

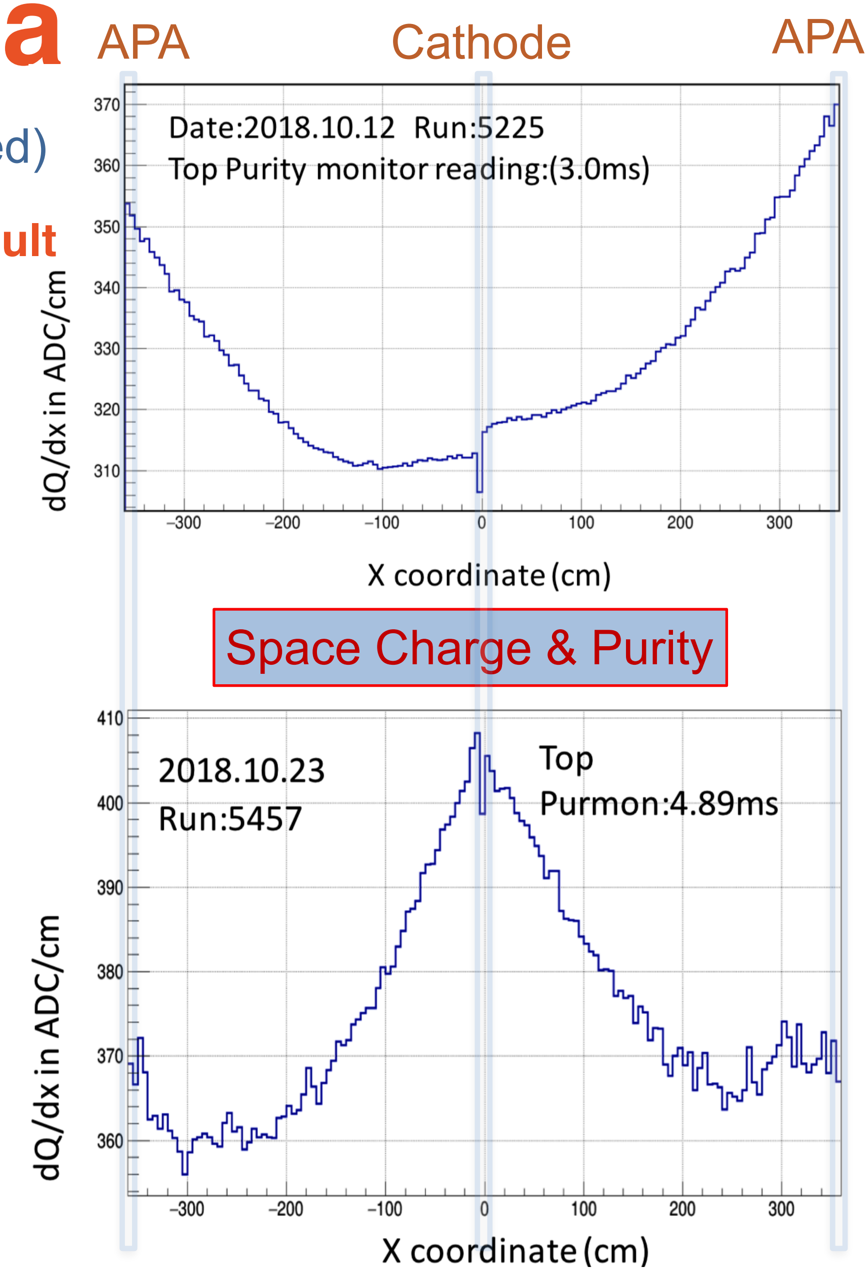
Analysis of TPC Data

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

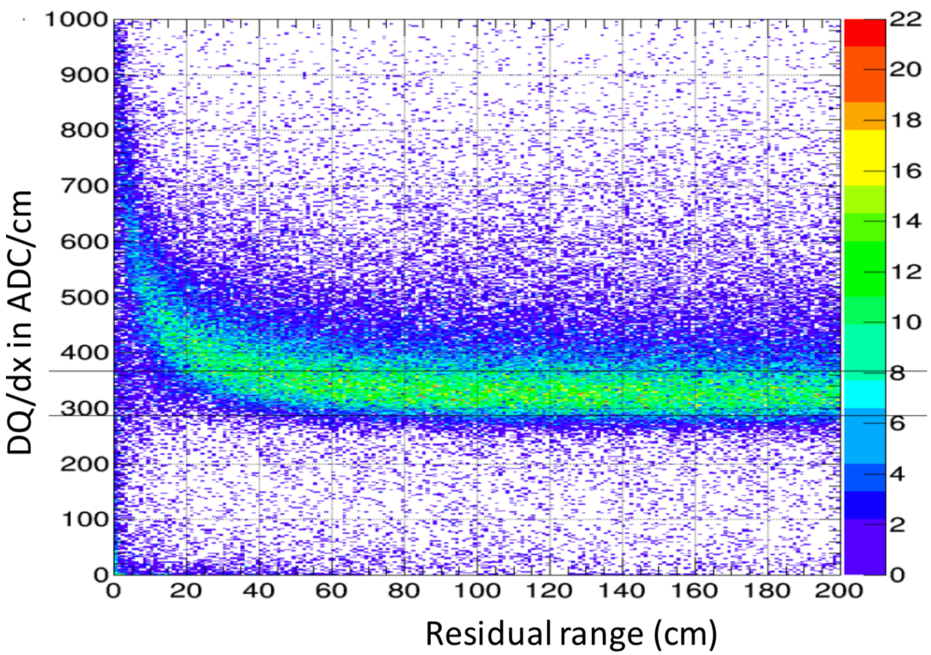
Using Cathode-crossing and stopping cosmic muons

Detector Performance first (yet preliminary) result

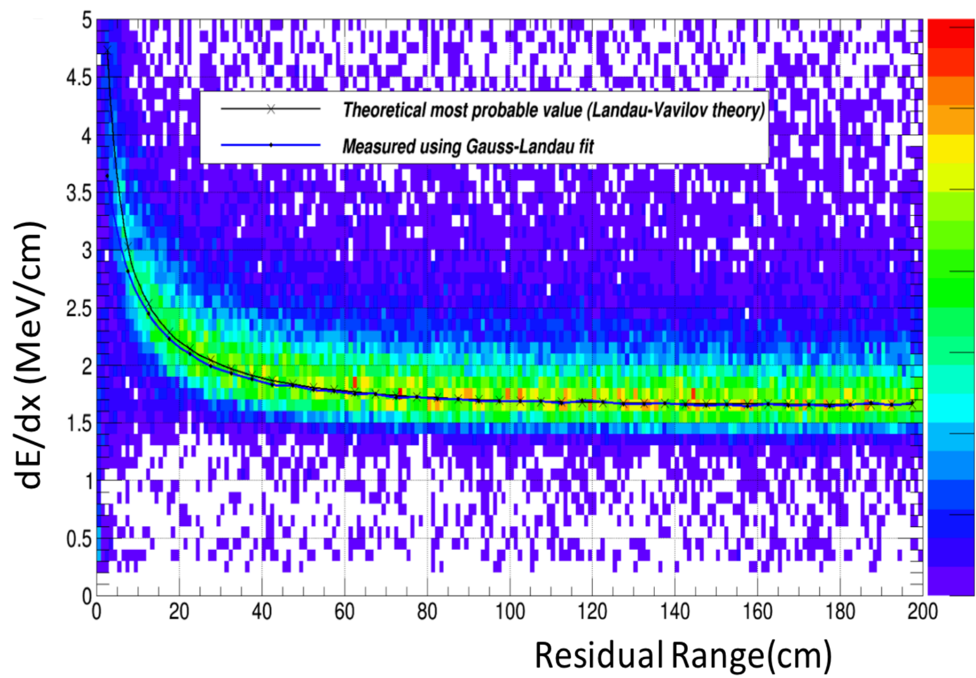
- Core calibration 2: Absolute Energy Calibration

  (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)

Corrected dQ/dx vs residual range

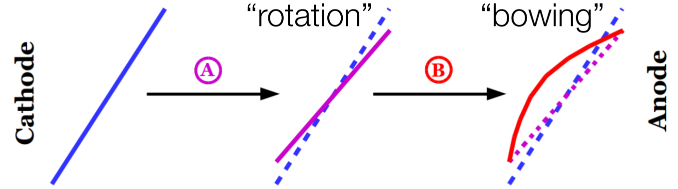


plane_2 calibrated dE/dx vs residual range



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

Analysis of TPC Data



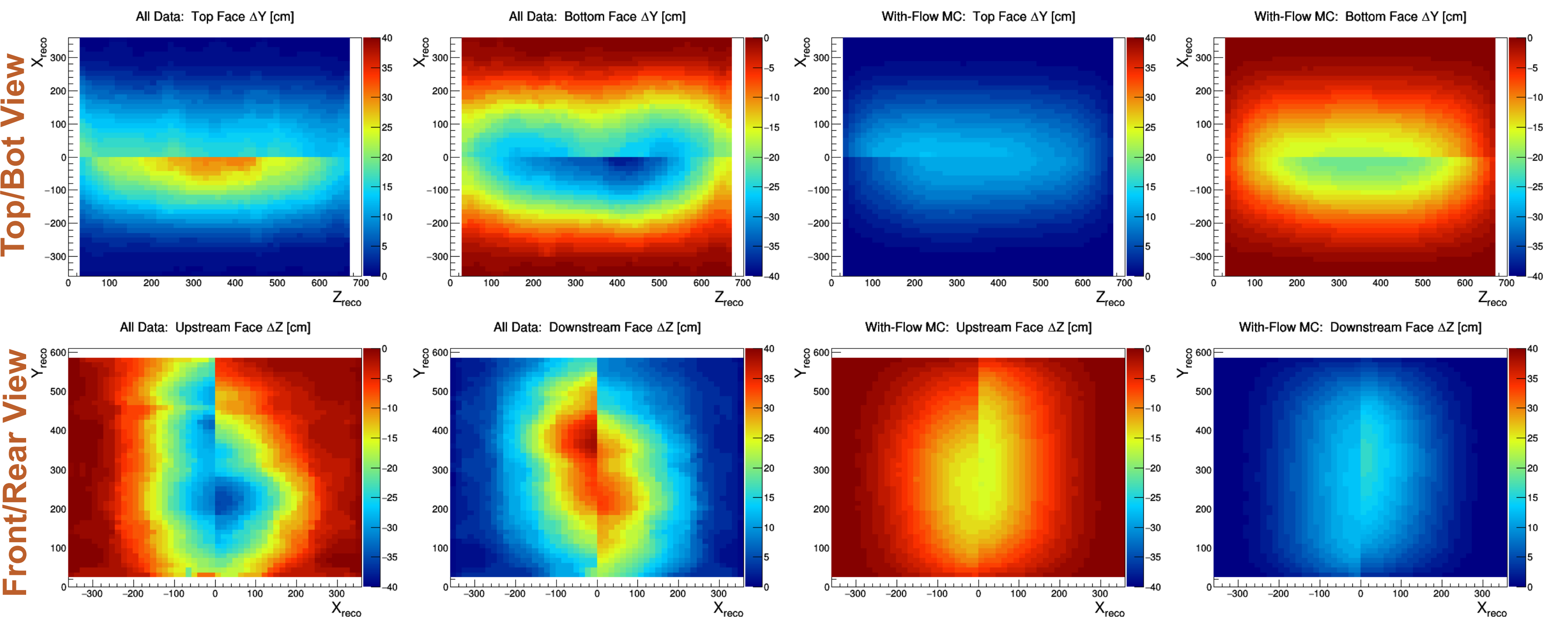
Space Charge: **due to accumulation of slow-drifting Ions from high rate of c.r. on surface, producing Drift Field distortion from nominal uniform EF**

First SCE “Calibration”:

[based on SCE study and correction strategy developed for MicroBooNE]:

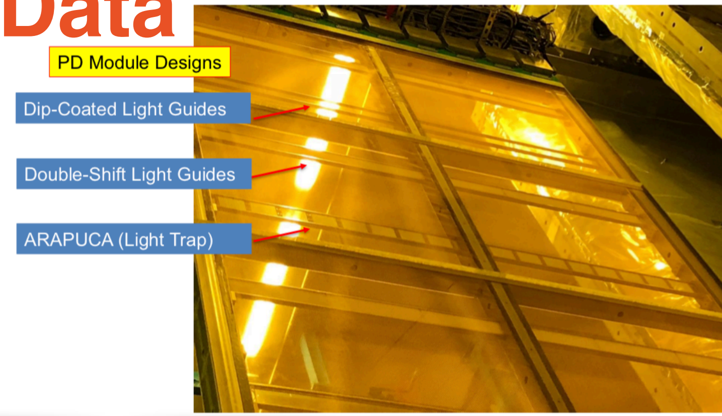
- [x] use Cathode-crossing (t0-tagged) cosmic muons for track start/end spatial offset mapping at TPC faces
- [x] compare w/ MC, including effect on Ion distribution of LAr Fluid-Dynamic from LAr recirculation
- [ ] obtain 3D SCE correction map *(in progress)*

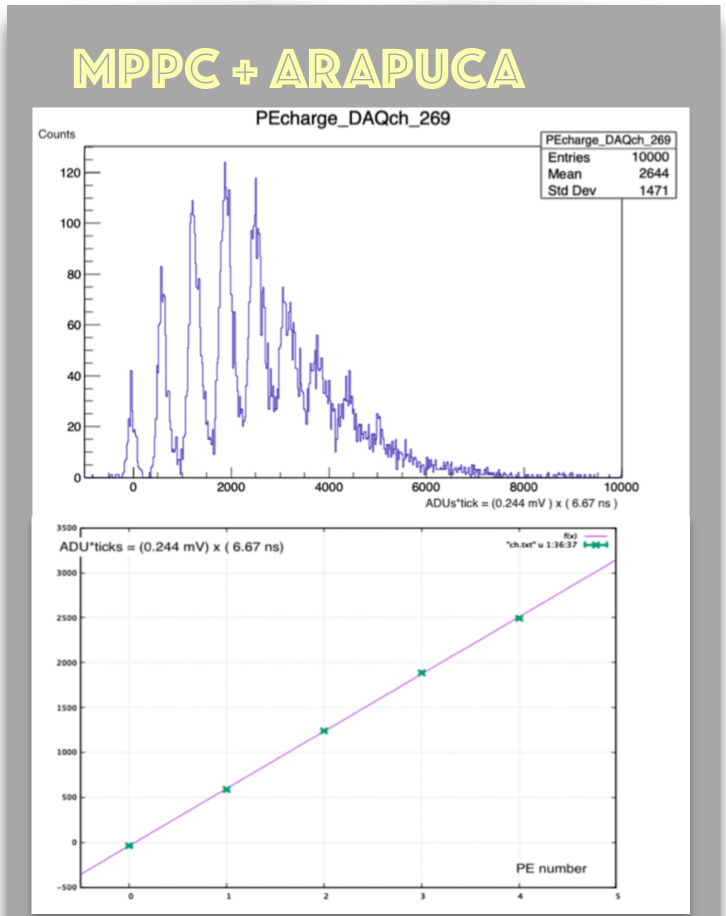
Data Results | With-Flow MC Results

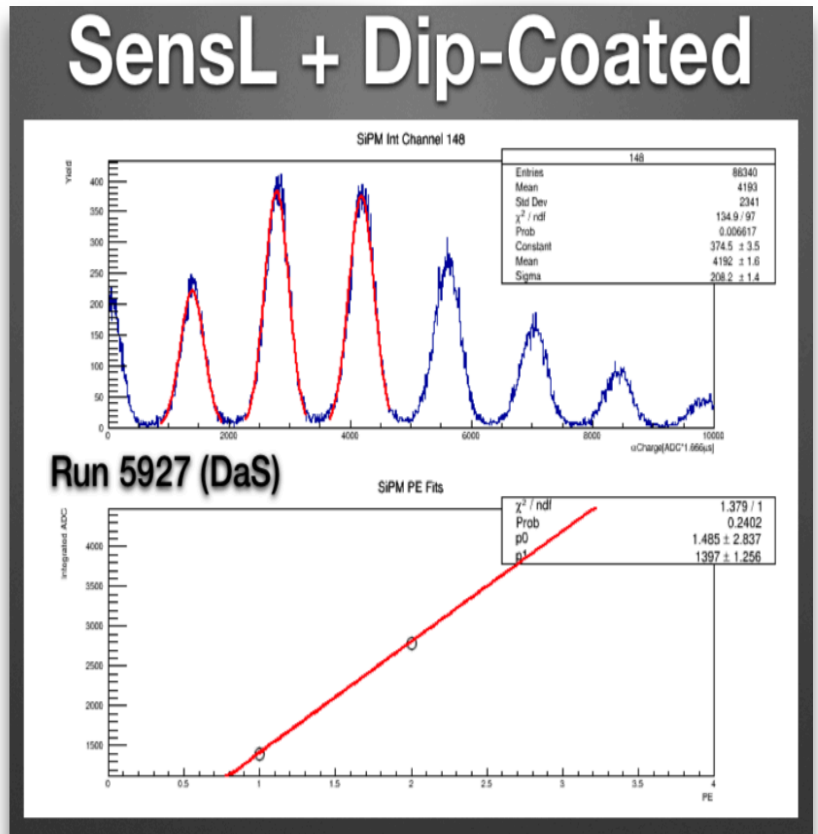


Analysis of Photon Detector Data

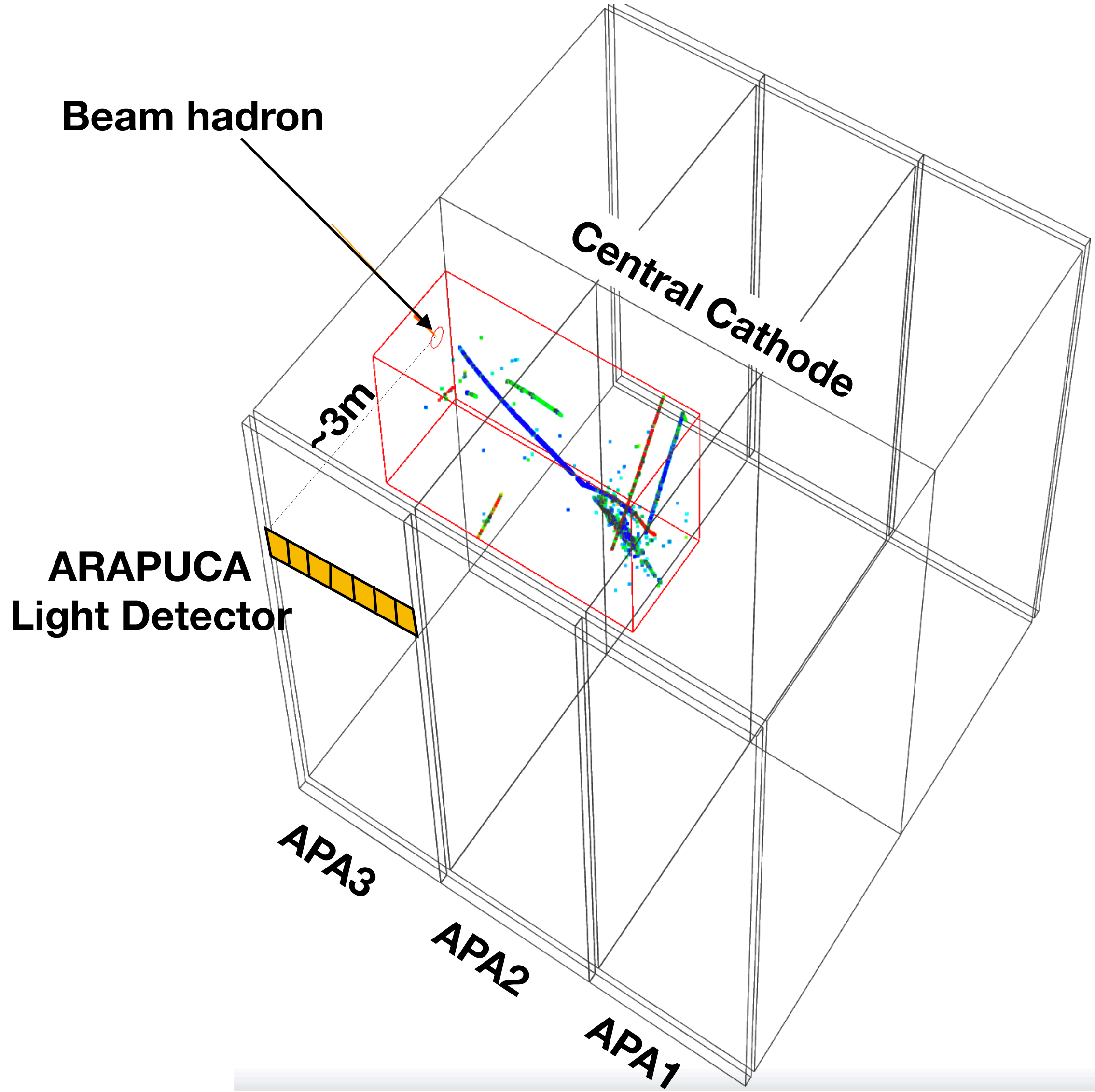
PE Calibration: **3 different ph-detectors with 3 different photo-sensors, using LED pulser w/ light diffuser**







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

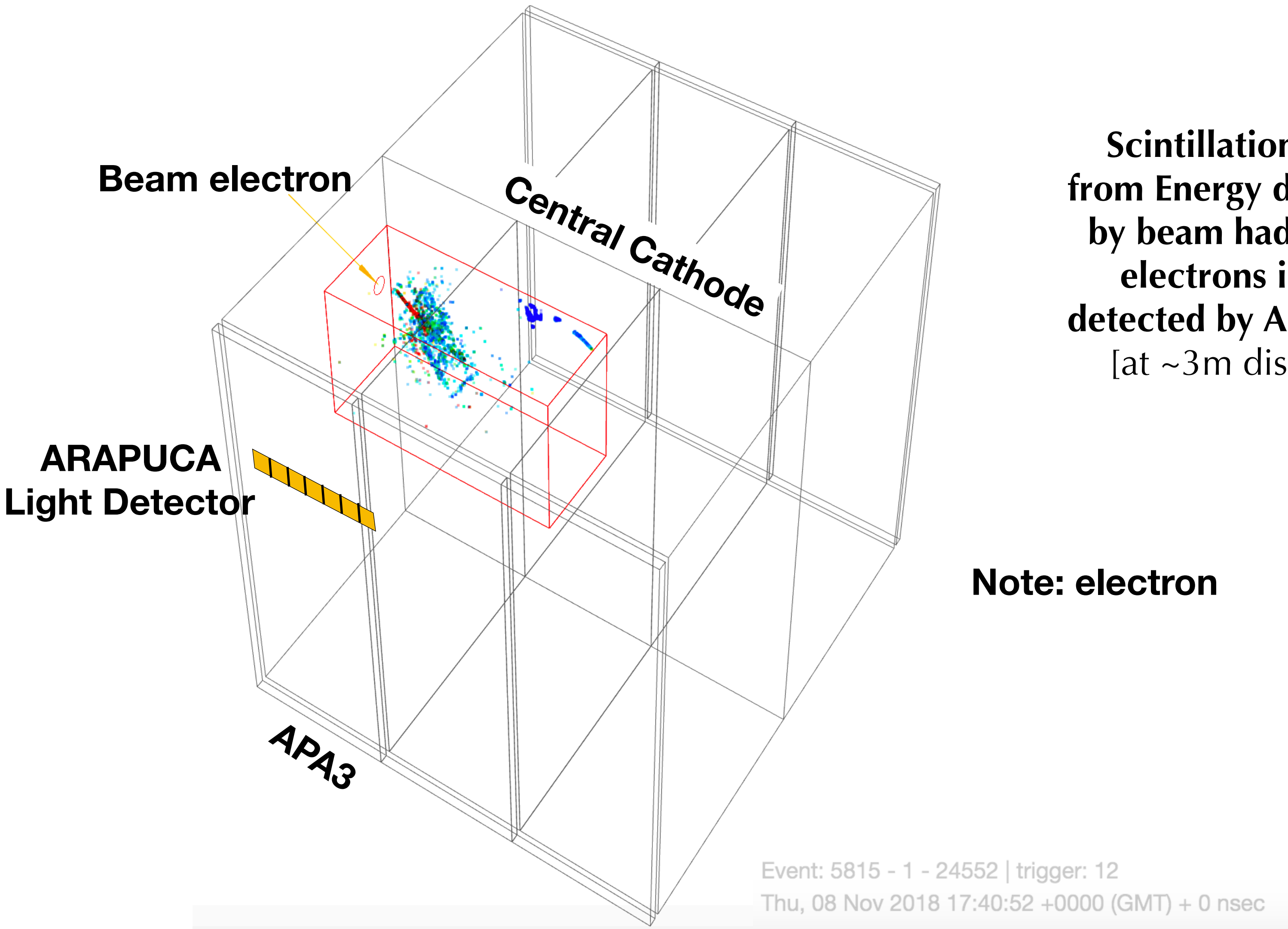


Scintillation Light from Energy deposited by beam hadrons or electrons in LAr detected by ARAPUCA
[at ~3m distance]

Beam Particle Energy tunable in 1-7 GeV range

Fermilab

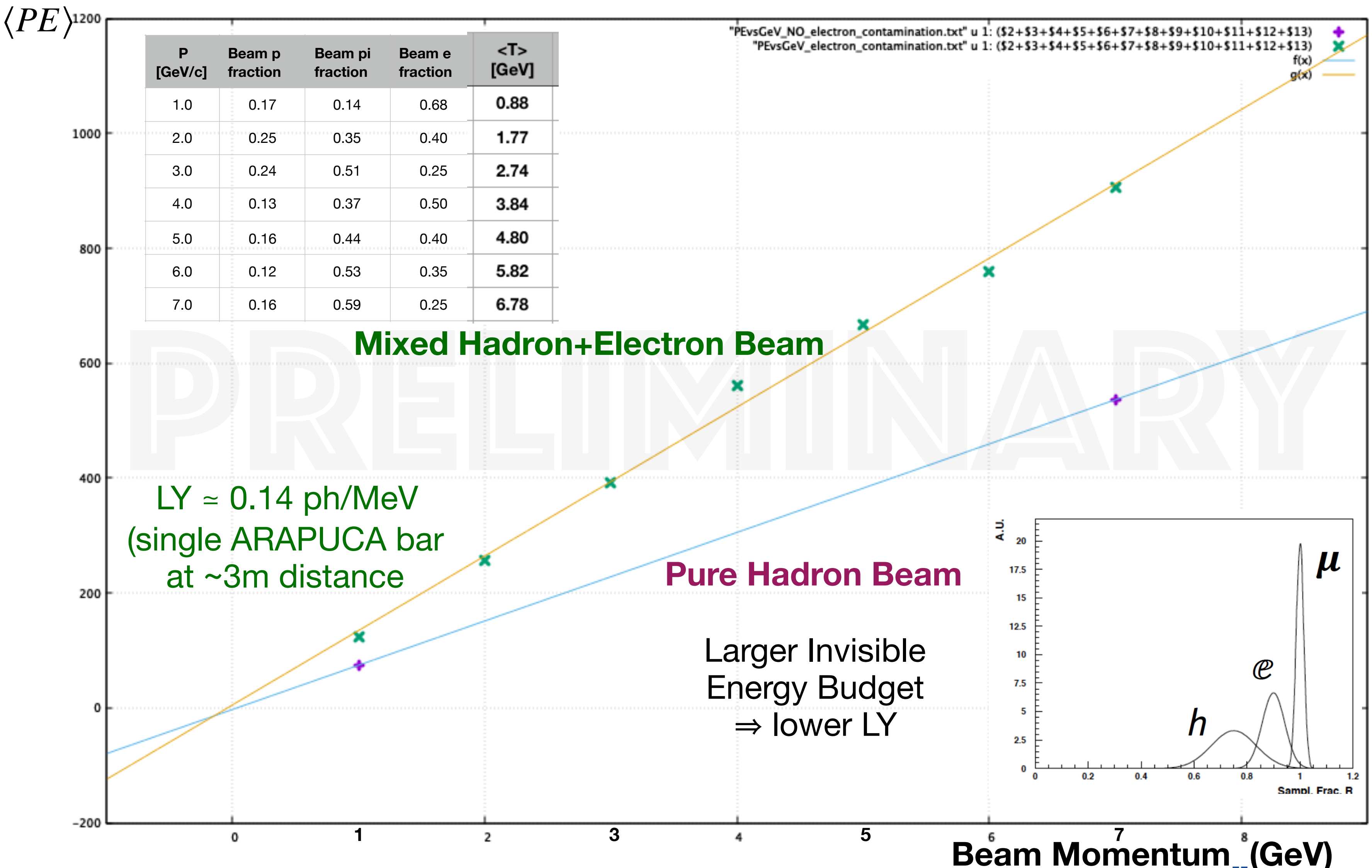
Test Beam Run:
1 - 7 GeV Momentum Charged Particle (e, had) Beams



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**

The long term stability Run with Cosmic

- 6 to 12 months extending in 2019 -

[agreed and supported by Neutrino Platform]

Plans for the post-shutdown program (2021)

[proposed/to be agreed with CERN SPSC]

The Long Term Stability & Technology Development Run (2019)

Detailed Plan/Schedule for the 2019 Cosmic Run started/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

The Long Term Stability & Technology Development Run (2019)

Goals of the 2019 Run

In addition to *long term stability of detector sub-component 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:

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

12 m drift / 600 kV Demonstrator

Basic Concepts:

- large volume LAr vessel: min. dimensions **3** ℓ **x 3** w **x 14** h **m³ (~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)

CONCLUSIONS

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

Answers to PAC Questions

1. comment on plans and person-power for your protodune test beam data analysis
2. comment on the 3 photon prototype systems and the performance metrics that will be used for the selection
3. brief comment on the status of the Dual Phase
4. Is there more test beam contingency plan and time planned with CERN?

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)
- **Long-term goals** – ***Physics Measurements***
  - ☐ *(started)* Total pion cross section on Ar in [1-7] GeV range
  - Exclusive channels Cross Section:
    - π *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)

Information for DUNE physics TDR

Physics publications

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

Organization:

- protoDUNE-DRA WG (TPC Data Reconstruction, Calibration and Analysis)
  Coordinators: T. Yang (FNAL), G. Christodoulou (CERN/Liverpool)

- protoDUNE-PD WG (Ph Det data Reco, Calibration and Analysis)
  Coordinators: P. Sala (CERN), L. Mualem (Caltech), Z. Dijurcic (ANL)

core people at FNAL, BNL and at CERN (and also CSU, LSU, UK Manchester, …).
2 Weekly (2hr) Mtg attended by 50+ people

Detector Response studies (urgent for TDR) under responsibility of senior, LArTPC/LarSoft experienced team-leaders

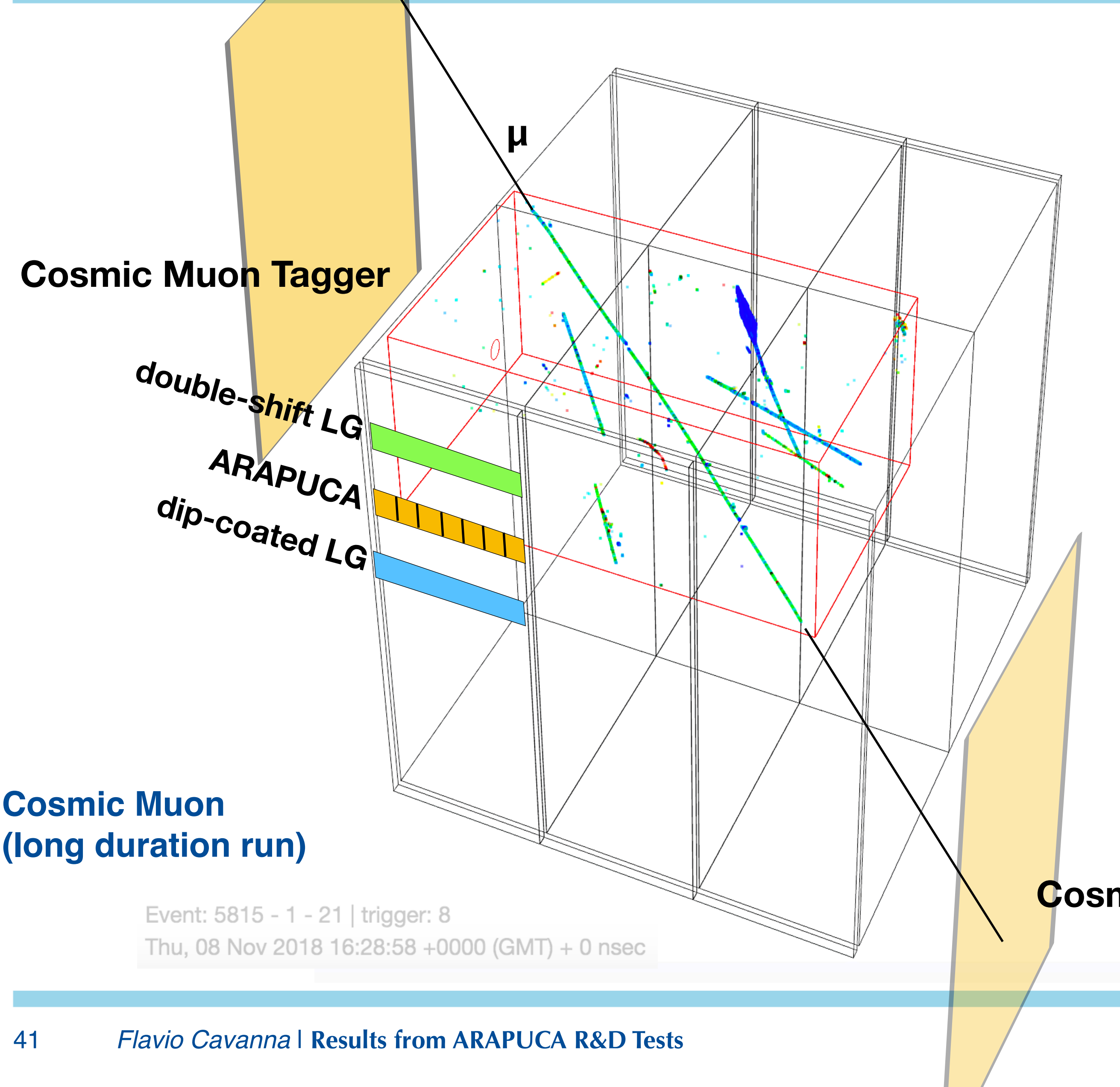
Physics studies are now attracting new students and PD (currently under training or beginning more independent activities)

Less covered the sector of PhDet Analysis (need more resources)

Person-power is increasing - new students are welcome

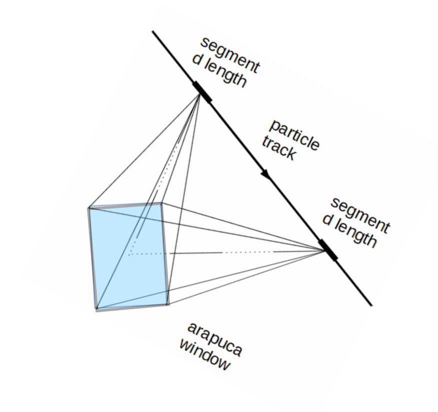
1. comment on the 3 photon prototype systems and the performance metrics that will be used for the selection

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



Cosmic Muon (long duration run)

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



1. brief comment on the status of the Dual Phase

- Several modifications and upgrades have been implemented on the CRP after the various cold box tests
- On 21/12/19 inserted and installed in the NP02 cryostat a second CRP (CRP2) - one of the two fully instrumented with LEMs and anodes.
- successfully concluded the cold box test of the other fully instrumented CRP (CRP1) - with corrected LEMs and new half grid. CRP1 in EHN1ready for installation inside cryostat (tomorrow).

The foreseen goal for ProtoDUNE-DP assembly in cryostat is :

- Install the 4 CRPs in the cryostat by the end of January (last CRP ready for cold box test)
- Install the cathode, ground grid modules, the photomultipliers in the following month
- Start the TCO closure mid March
- Goal to start Operation by late spring/beginning of summer

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.

1. Is there more test beam contingency plan and time planned with CERN?

➜ not yet. But discussion/proposal will take place next week at SPSC-132 Mtg at CERN:

SPSC132, Discussion of Requests Submitted on the Call for Proposals for Projects at the CERN Neutrino Platform after LS2

23 Jan 2019, 14:25 → 24 Jan 2019, 14:00 Europe/Zurich

6-2-024 - BE Auditorium Meyrin (CERN)

Wednesday, 23 January

14:30 → 16:55 **Open Session**

14:30 **Overview on ProtoDUNE, NP02 and NP04: joint perspective for both technologies** 10m
Speaker: Stefan Söldner-Rembold (University of Manchester)

14:40 **Proposal for ProtoDUNE-Single Phase (NP04)** 15m
Speaker: Flavio Cavanna (Fermi National Accelerator Lab. (US))

14:55 **Proposal for ProtoDUNE-Double Phase (NP02)** 15m
Speaker: Dominique Duchesneau (Centre National de la Recherche Scientifique (FR))

focus on achievements of the ProtoDUNE-SP, and give a tentative plan what we want to do with future running.

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)

Plans for the post-shutdown program (2021)

Goals of the 2021(2022) Run

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

- **Development/implementation and test of *calibration method*s with neutrons produced by Neutron Generator**
- **Characterize DUNE *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), 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**

BACKUP Slides

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)

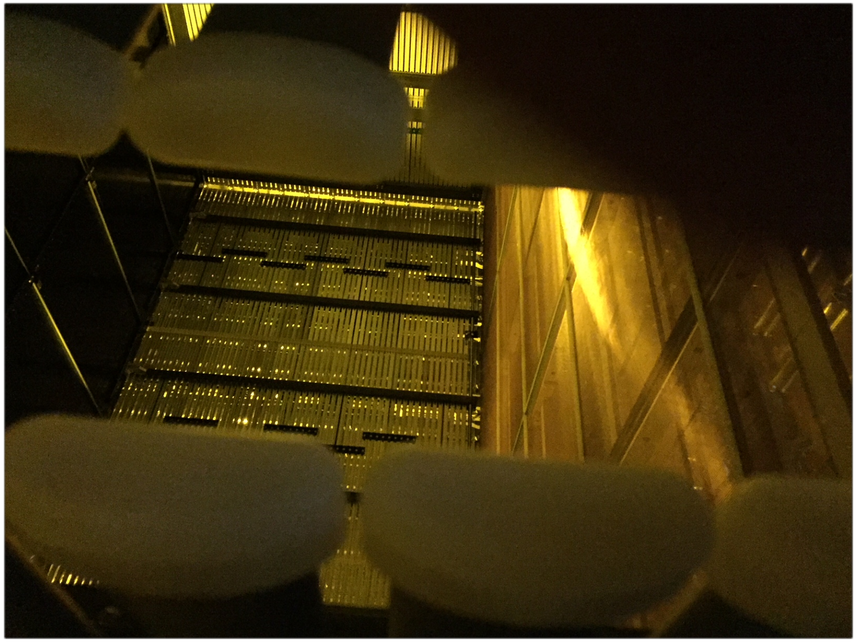
- 3.6 m drift distance

- 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

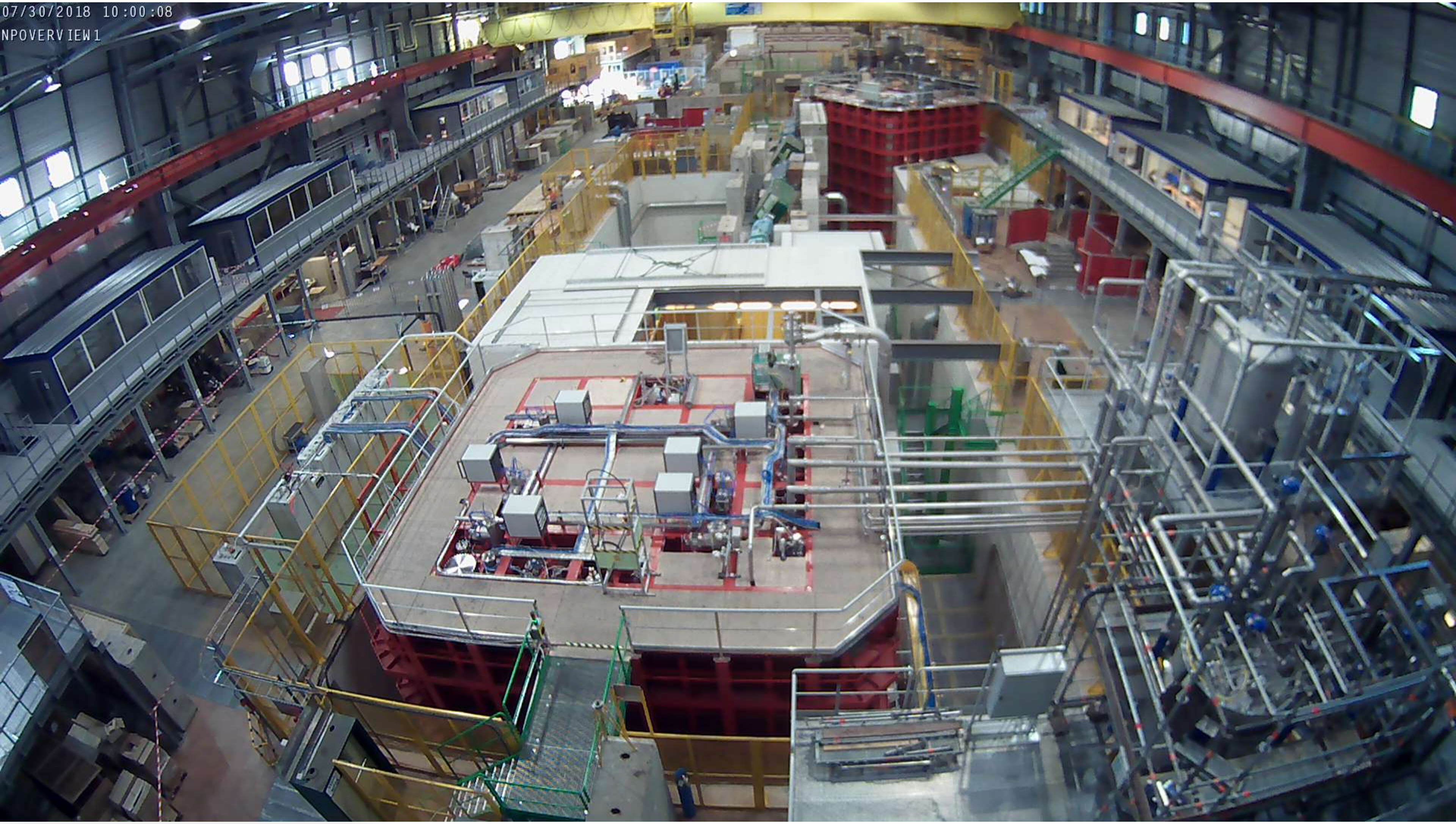
PROTO DUNE SP Detector Completed



the last exiting the cryostat (June 29, 2018)

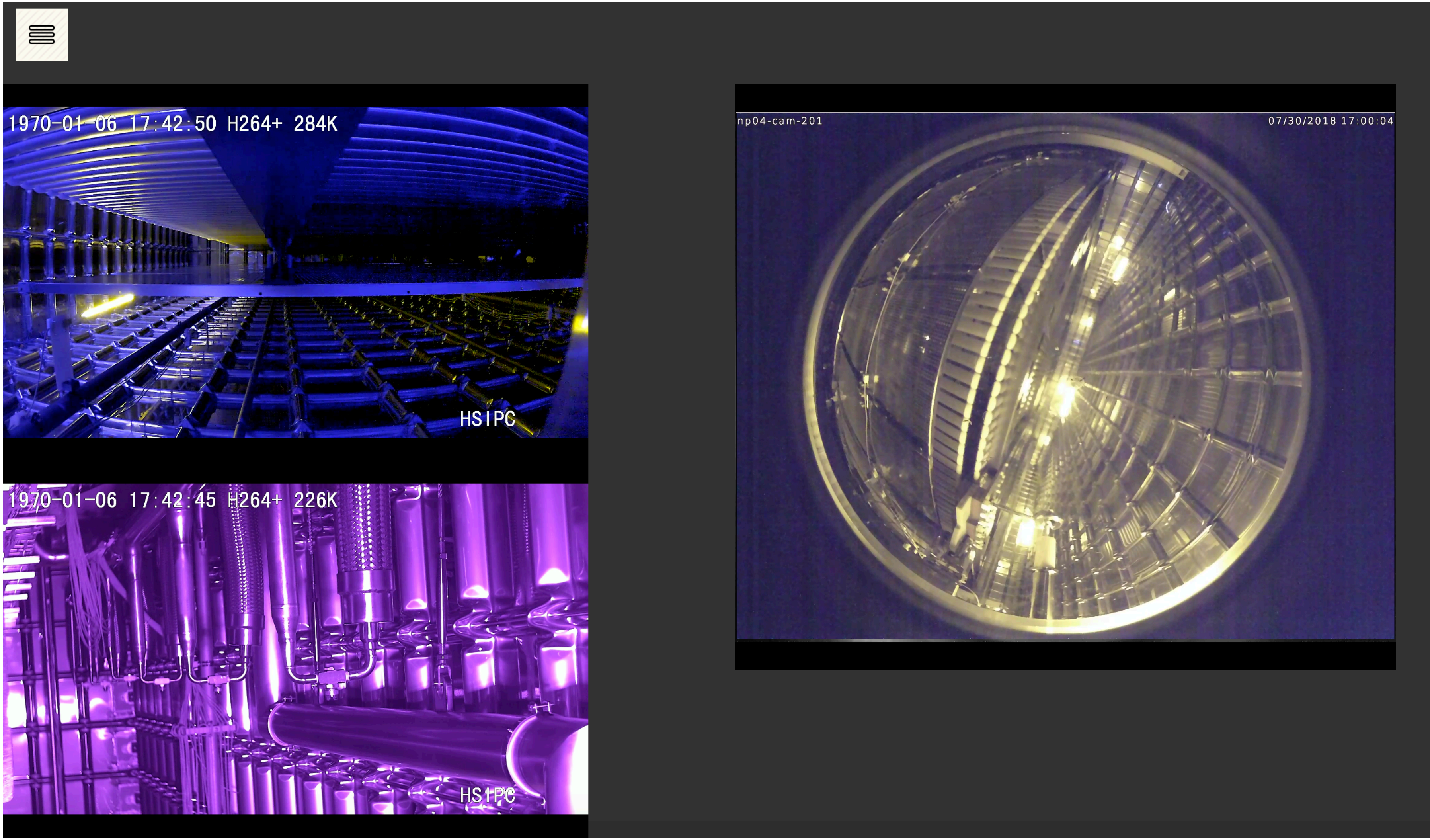
PROTO DUNE SP commissioning under way

Neutrino PLATFORM



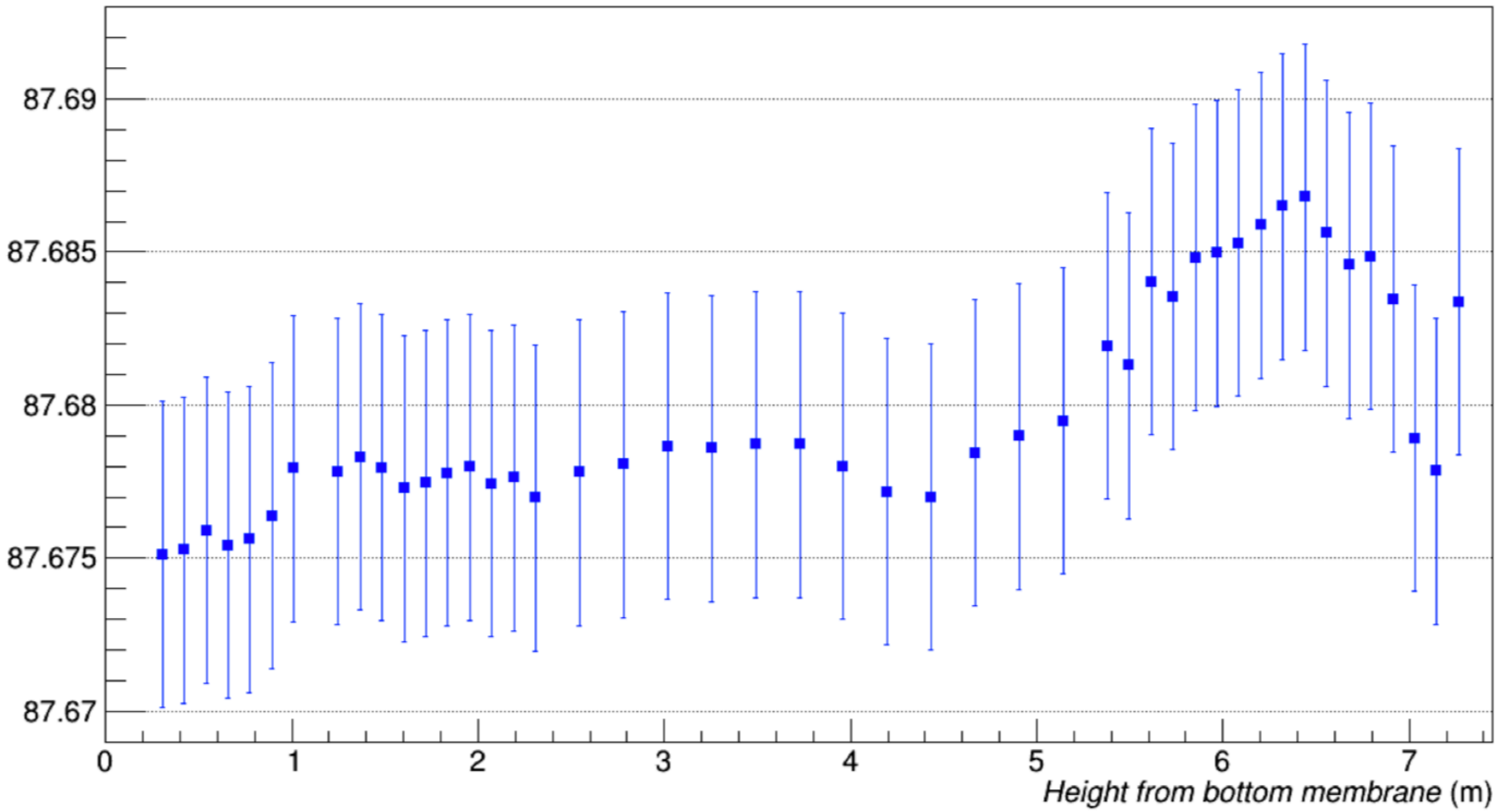
✓ piston purging completed, ➡ cooling phase started

real-time camera views from inside the cryostat



Analysis of Cryo-Instrumentation Data

Vertical T Profile

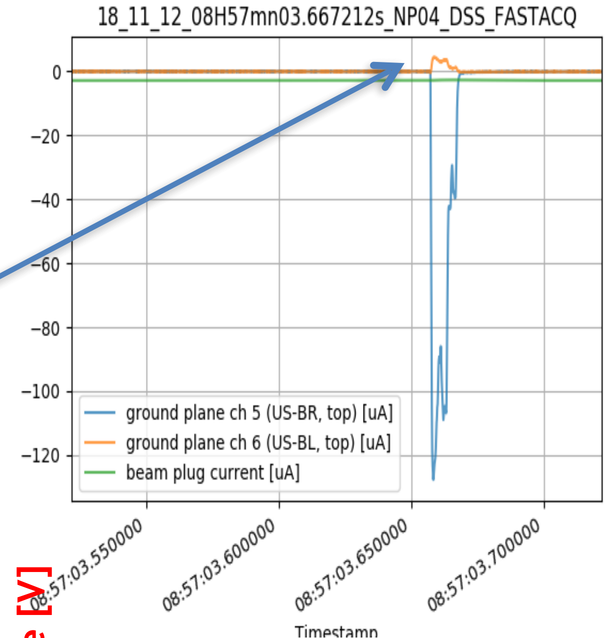


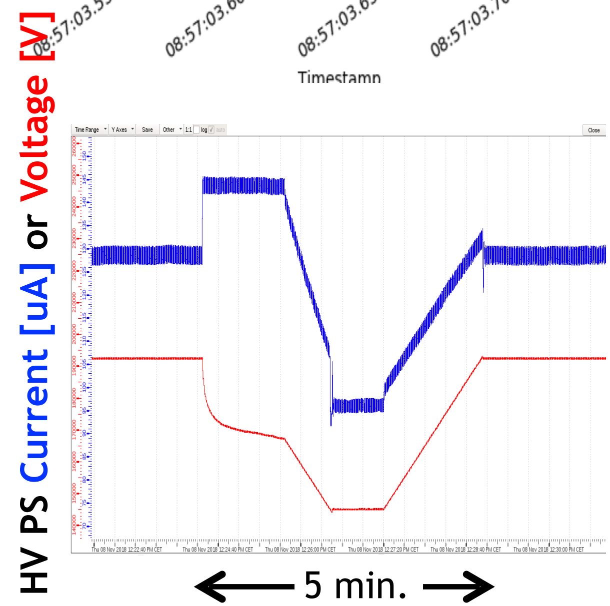
1) Fast discharges:

- 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



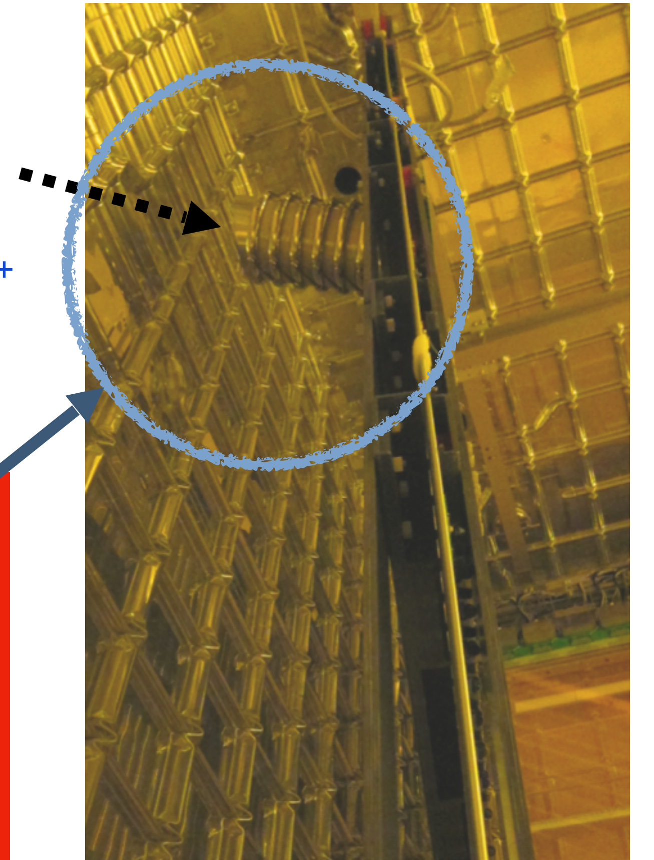


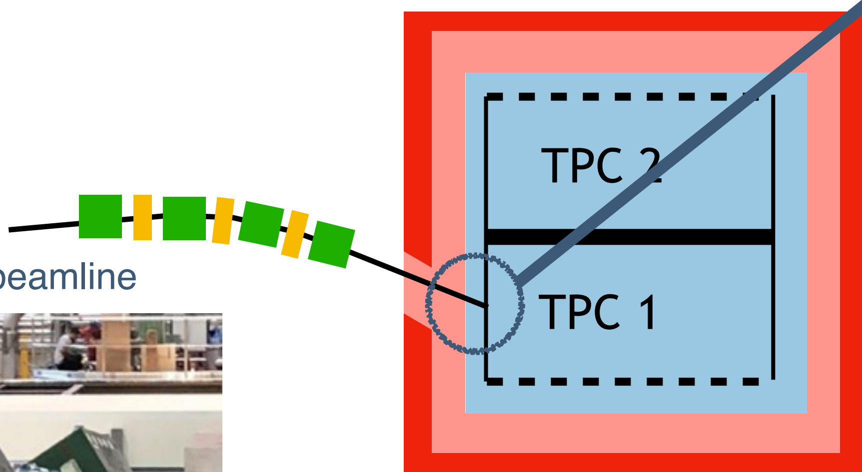
ProtoDUNE Test Beam

Beamline

400 GeV/c p beam from SPS ➜ 80 GeV/c secondary π^+

➜ 0.5 – 7 GeV/c tertiary e^+, p, μ^+, π^+, (K^+)





EHN1 extension, H4 beamline

Beam plug = END of beamline into cryostat to get charged particles inside TPC, filled with N2

PHYS. REV. ACCEL. BEAMS ***20****, 111001 (2017)*

Beam Data Accumulation

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

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

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)**

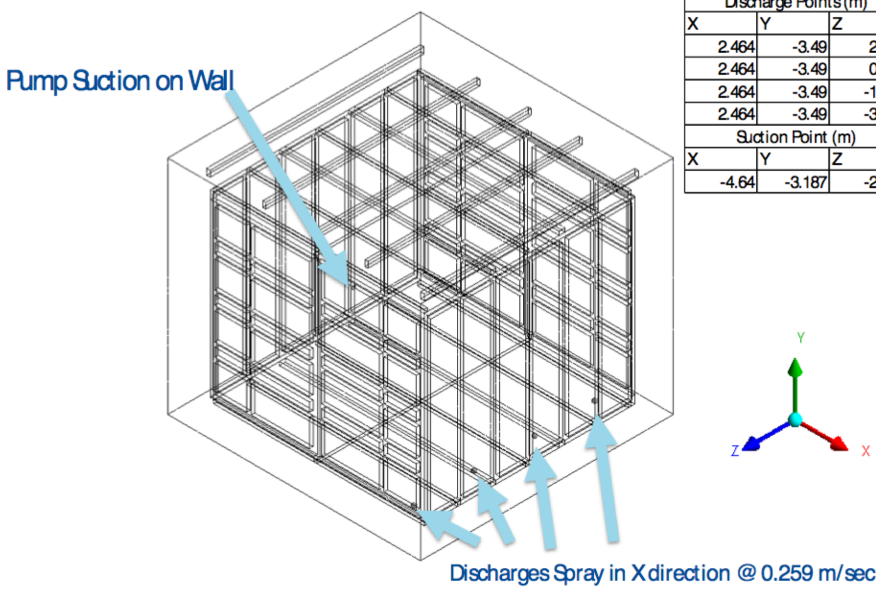
(most critical step, relevant for DUNE detector design)

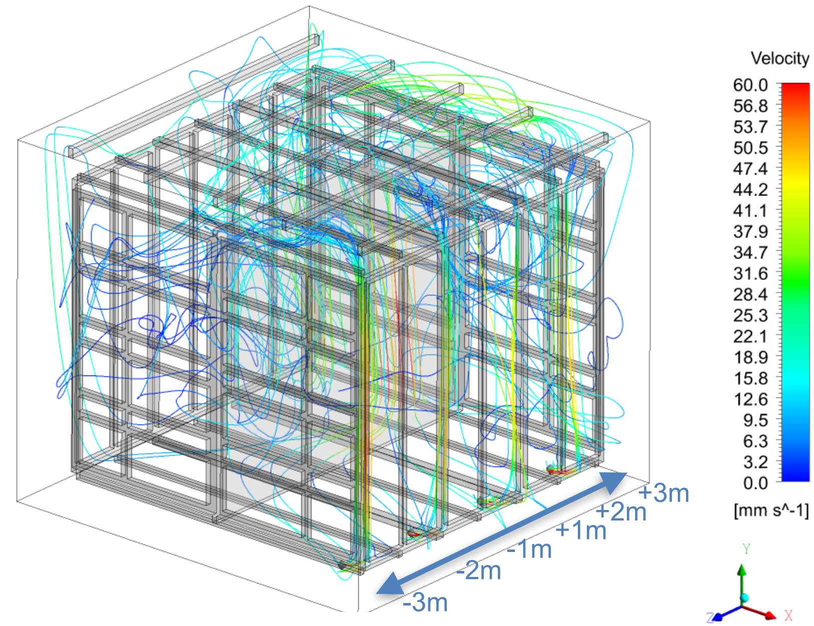
LAr Flow Simulation w/ Space Charge

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





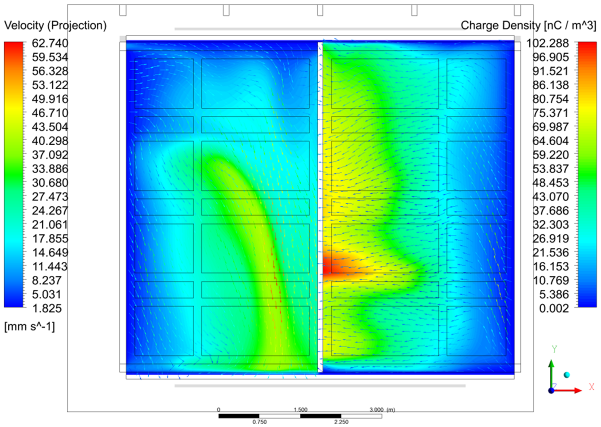
- **Pump discharge locations** and liquid return temperature are main variables for changing the flow pattern.

- 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.**

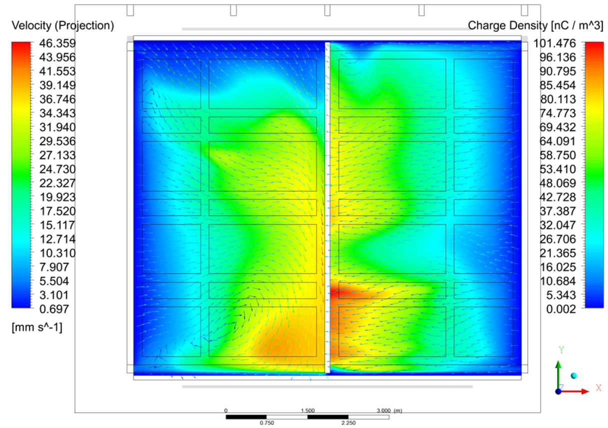
https://indico.fnal.gov/event/17340/contribution/1/material/slides/0.pdf

Space Charge

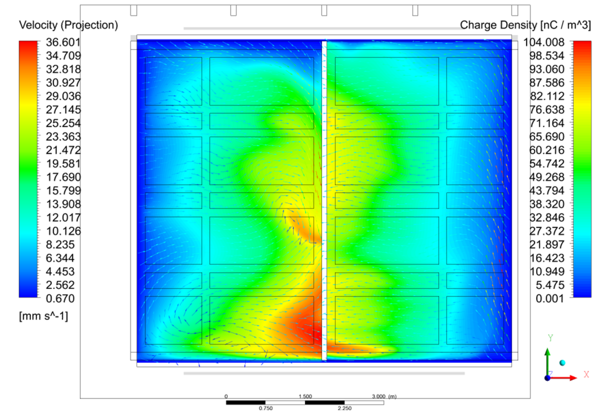
Z=0m

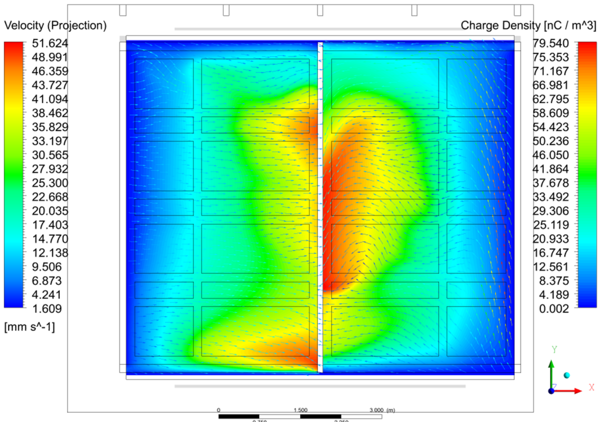


Z=1m

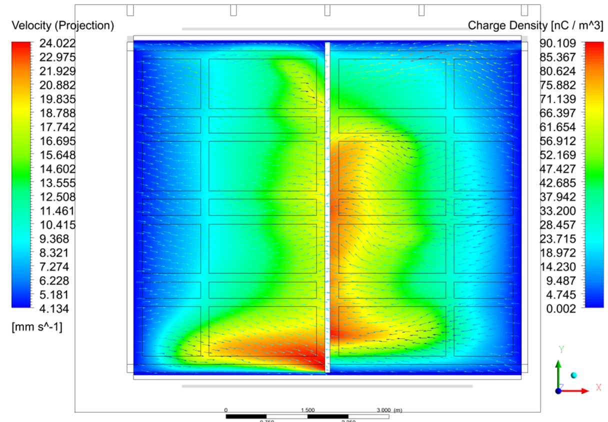


Z=2m

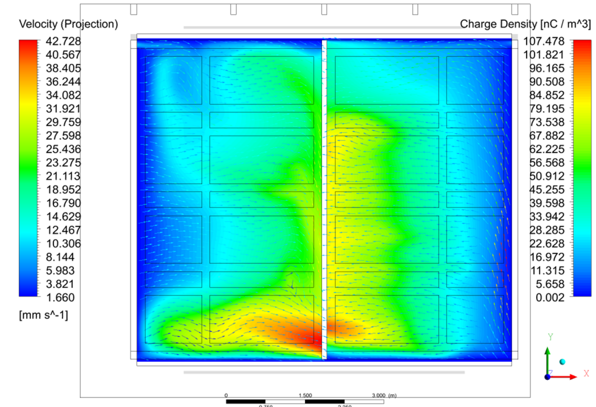




Z=4m



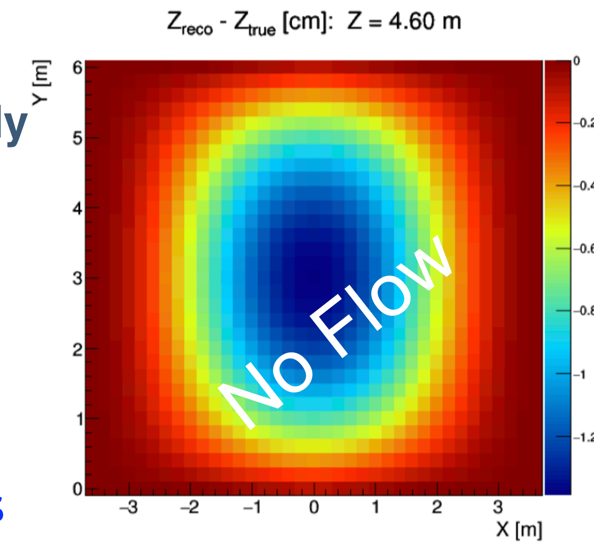
Z=5m



Z=6m

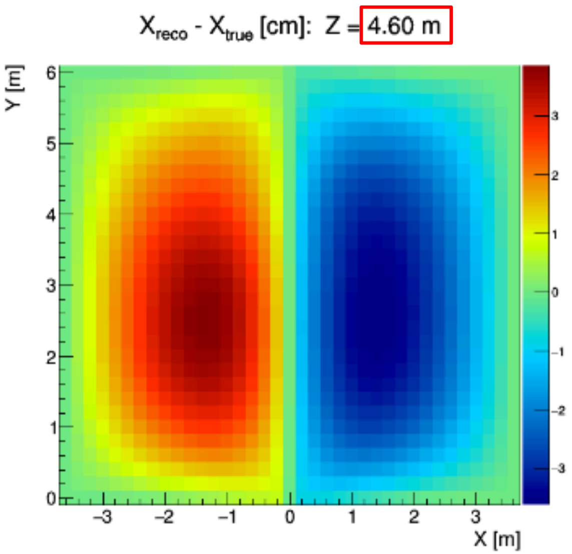
Space Charge Simulation with LAr Flow

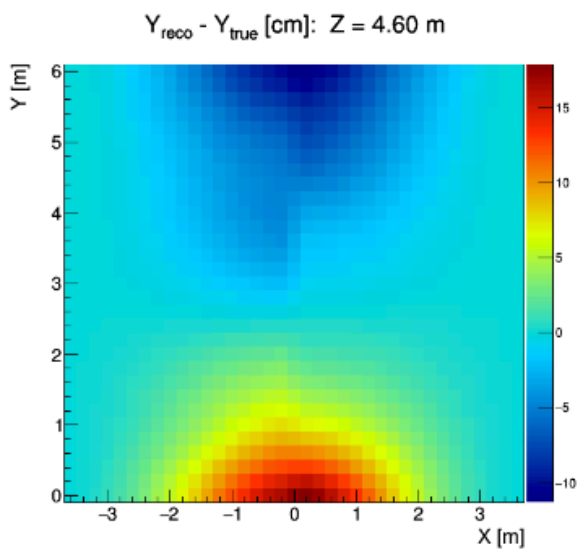
- space charge density map used as inputs to derive track reconstruction distortion: [$(x,y,z)_{reco}$ vs $(x,y,z)_{true}$] (**first study of LAr flow impact on SCE)**
- Very different distributions in the two drift volumes
- New maps are being added to simulation
- Essential to have **data-driven calibration**

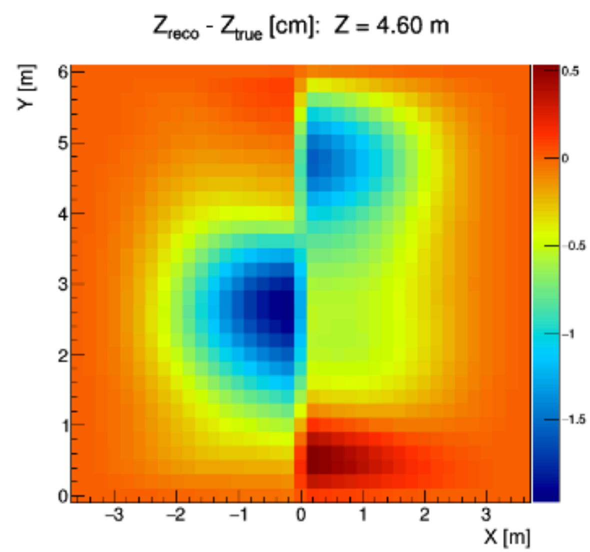


Mike Mooney

Spatial distortion maps



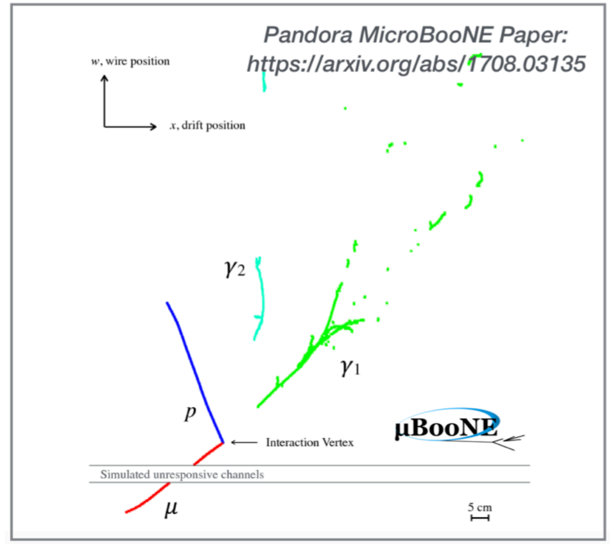


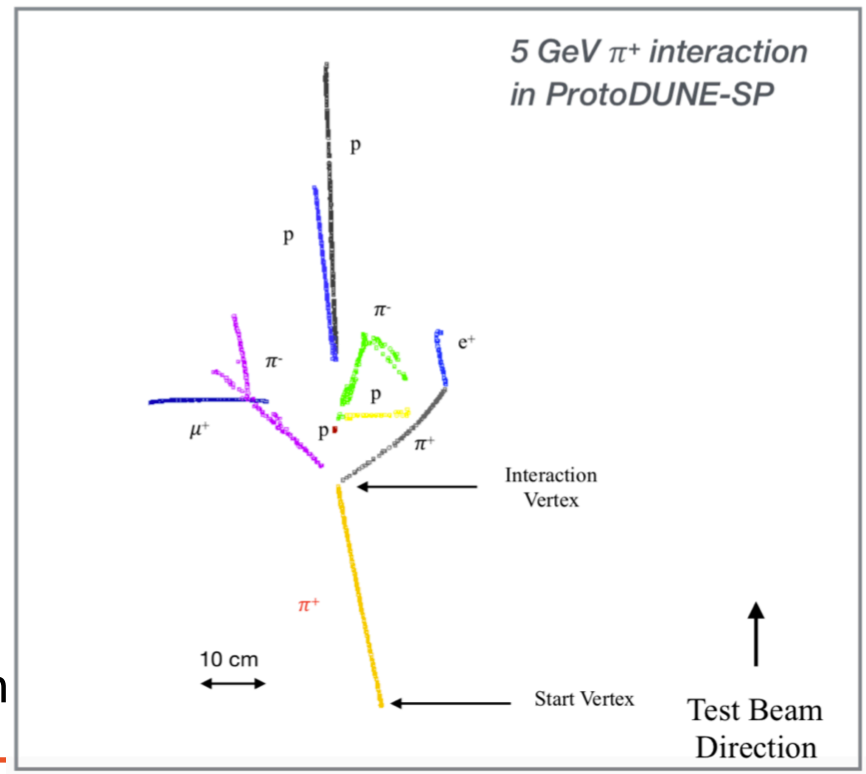


https://indico.fnal.gov/event/17340/contribution/1/material/slides/0.pdf

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

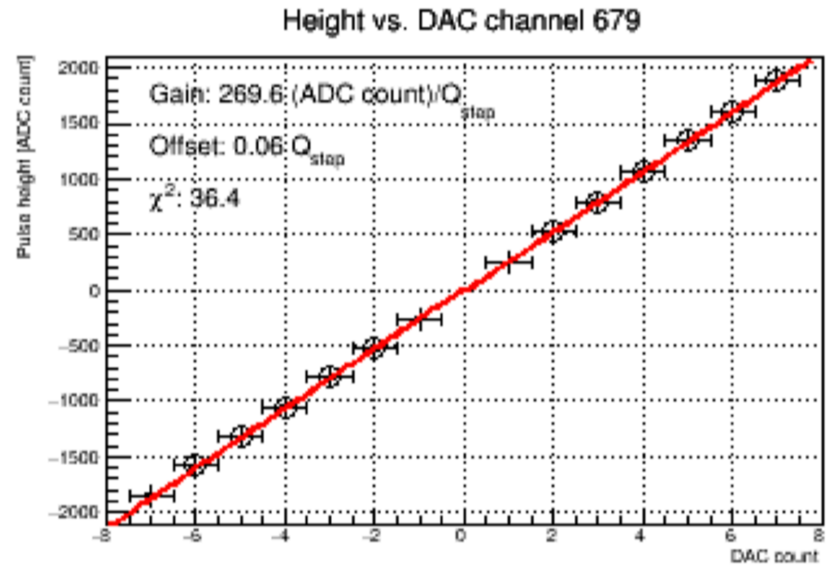


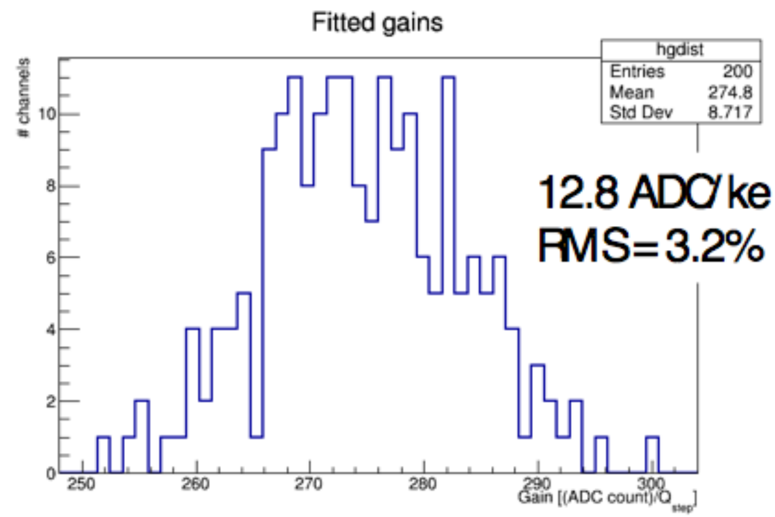


Steve Green

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.





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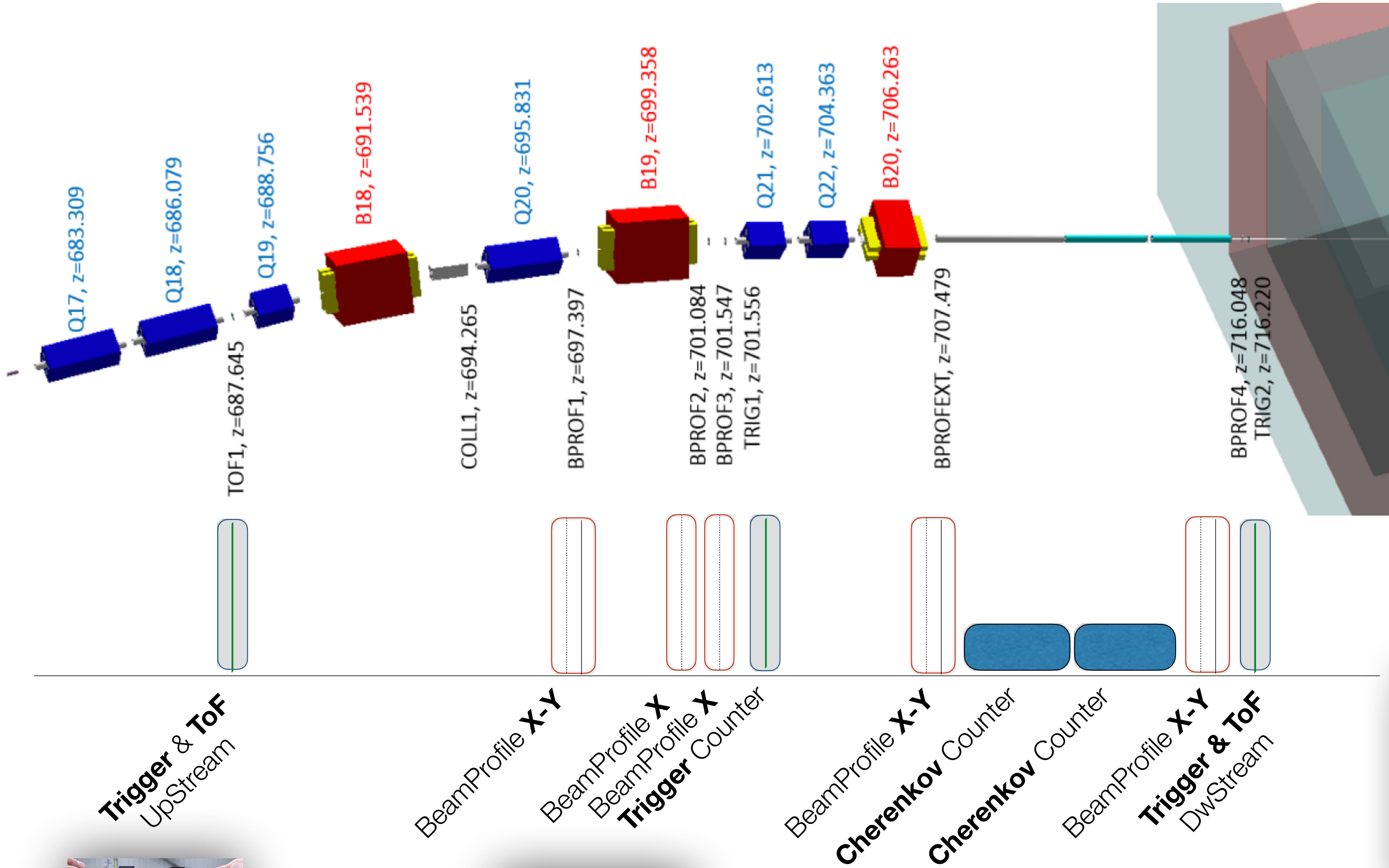
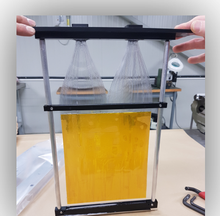




Blue: quadrupoles.
Red: bending magnets

Boxes: Beam detector supports

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

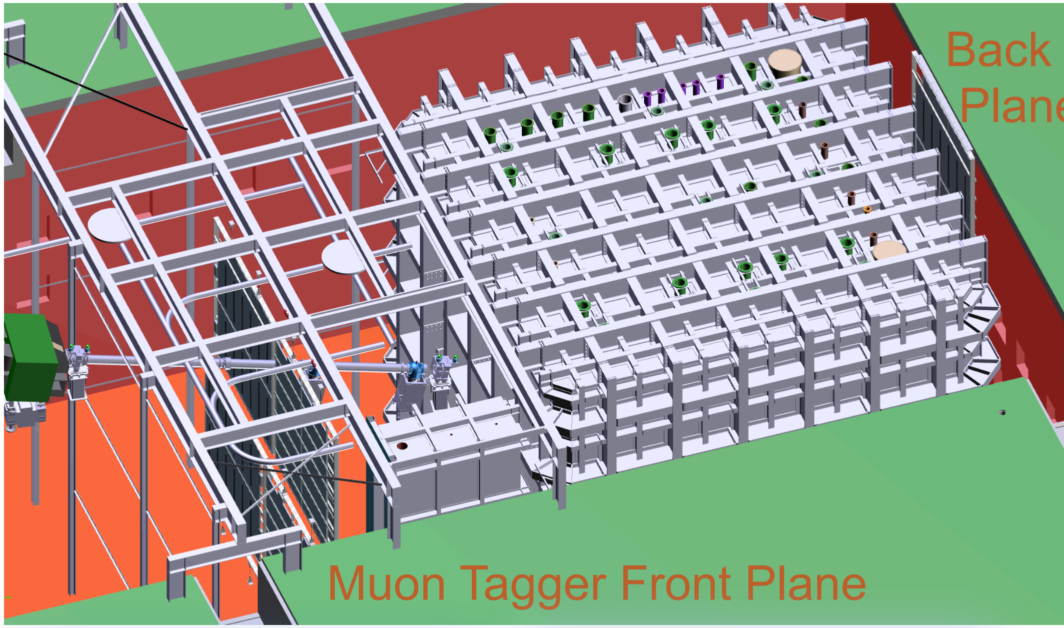
Cherenkov counters

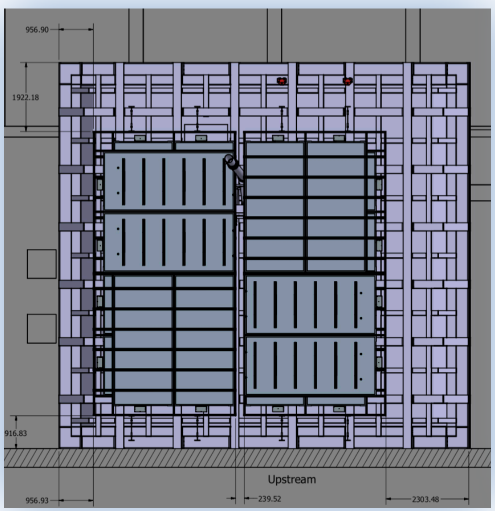
NP04/H4 Beam Line & Beamline Detectors

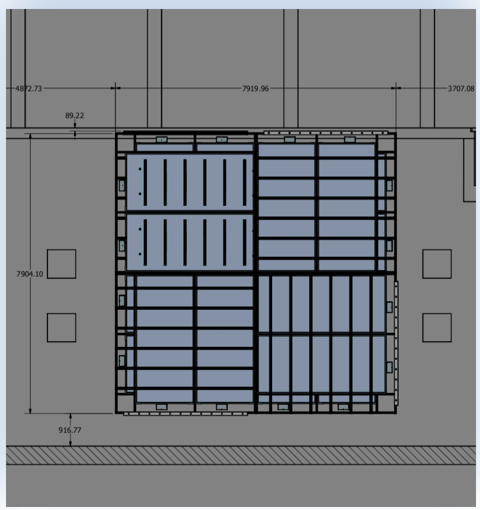
Neutrino PLATFORM

Muon Tagger

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







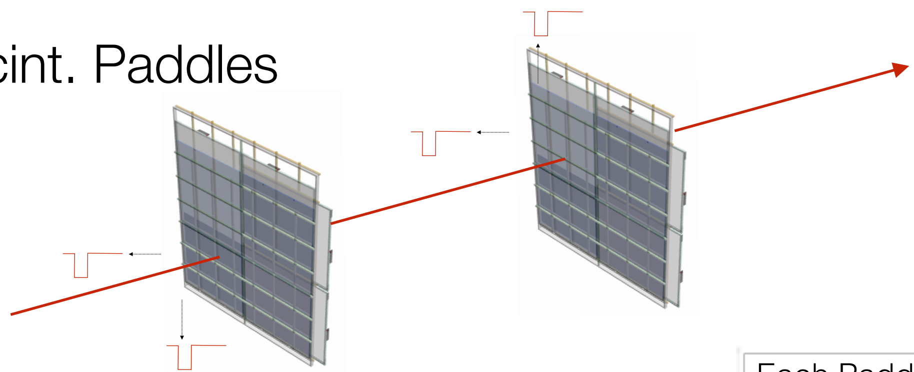
Muon Tagger Modules

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

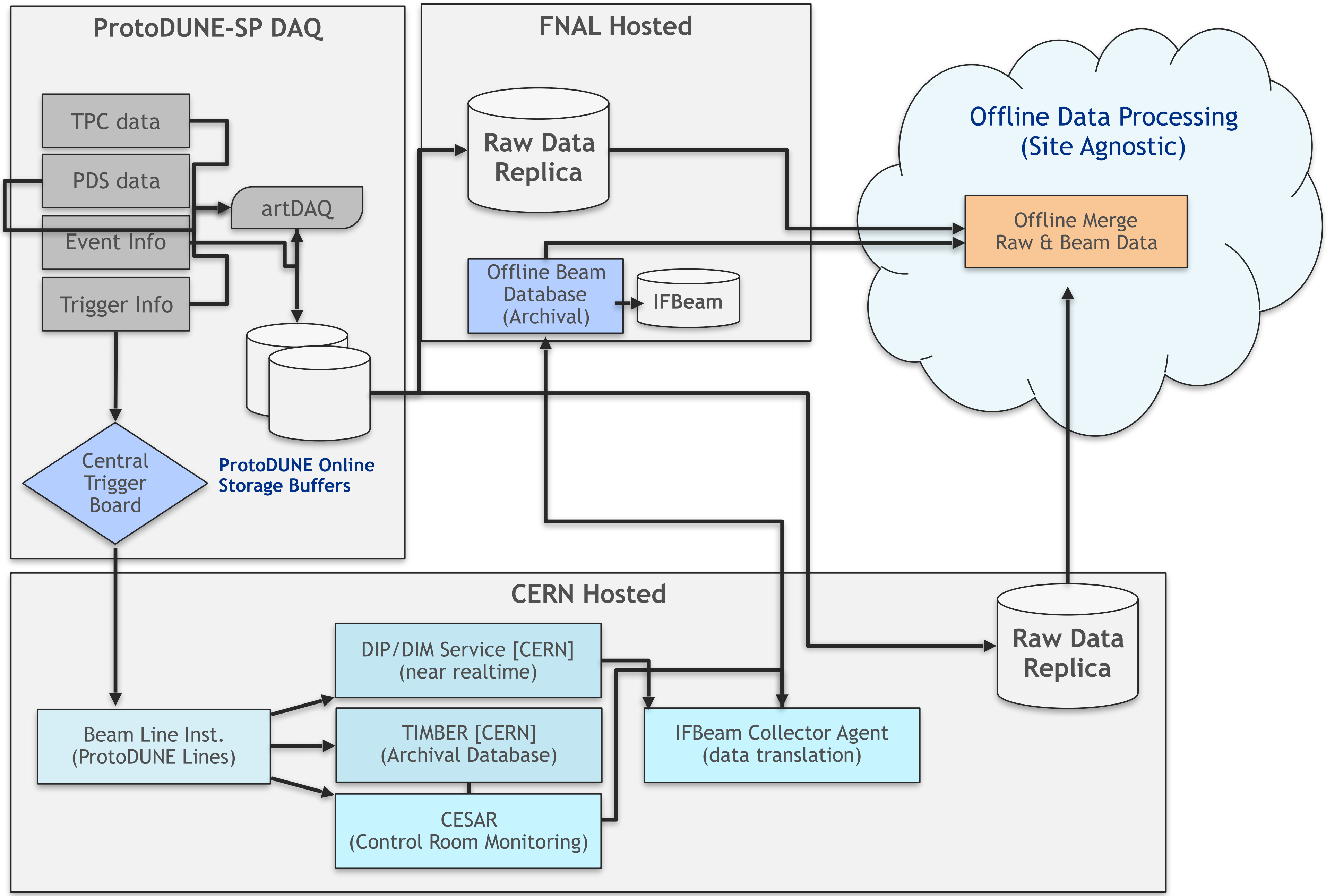


2 Vert

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