Neutrino Oscillation Workshop
Ostuni, 9-16 September 2018

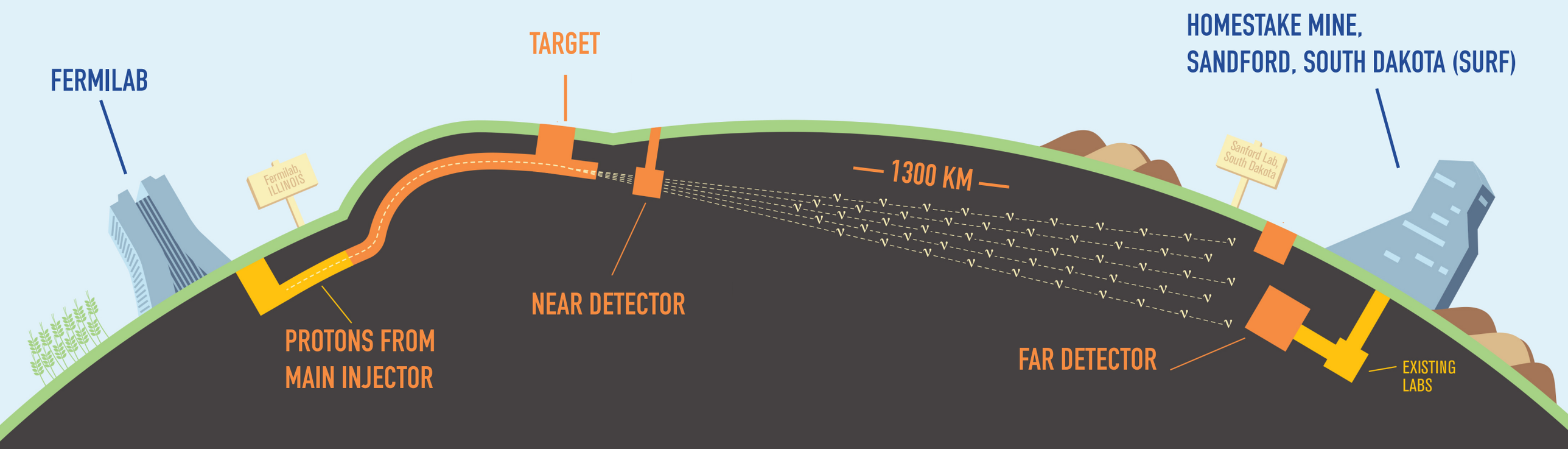
ProtoDUNE and a Dual-Phase LArTPC

Andrea Scarpelli
on behalf of the DUNE collaboration

(APC/CNRS - Université Paris Diderot)

Large international collaboration:
1000+ scientists from 176+ institutes

⇒ See N. Barros talk on Tuesday



Accelerator Neutrino:

- Precision measure of oscillation parameters
- Discovery of CP violation for leptons

Neutrinos from natural sources:

- Supernovae core collapse
- Atmospheric neutrino flux

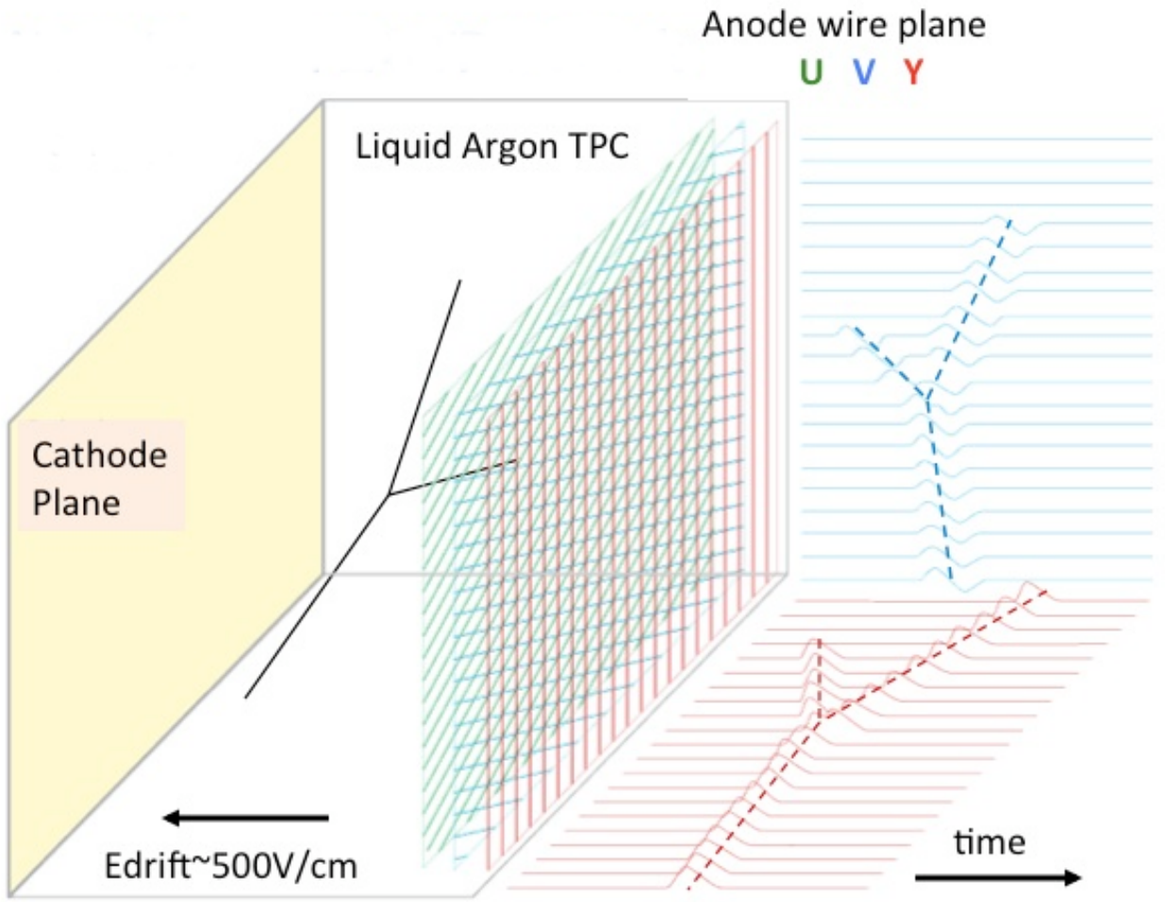
DUNE FD:

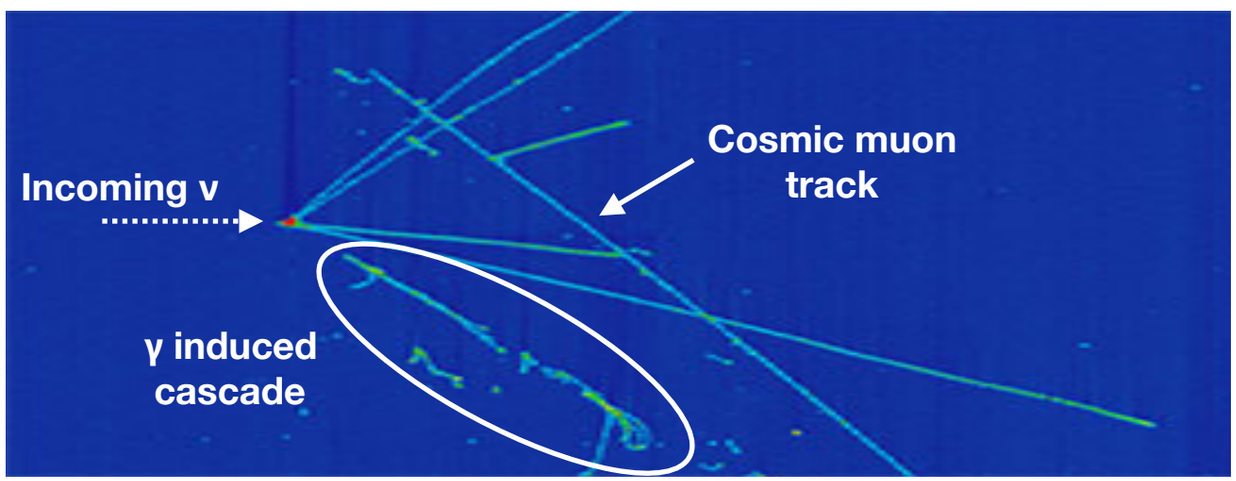
- 1300 km baseline, 1.5 km underground
- **4** LArTPCs, **10kt fiducial mass** each

ProtoDUNE:

- Validate technology over large scale
- Precise detector calibration and characterization

Why a Liquid Argon TPC for DUNE?





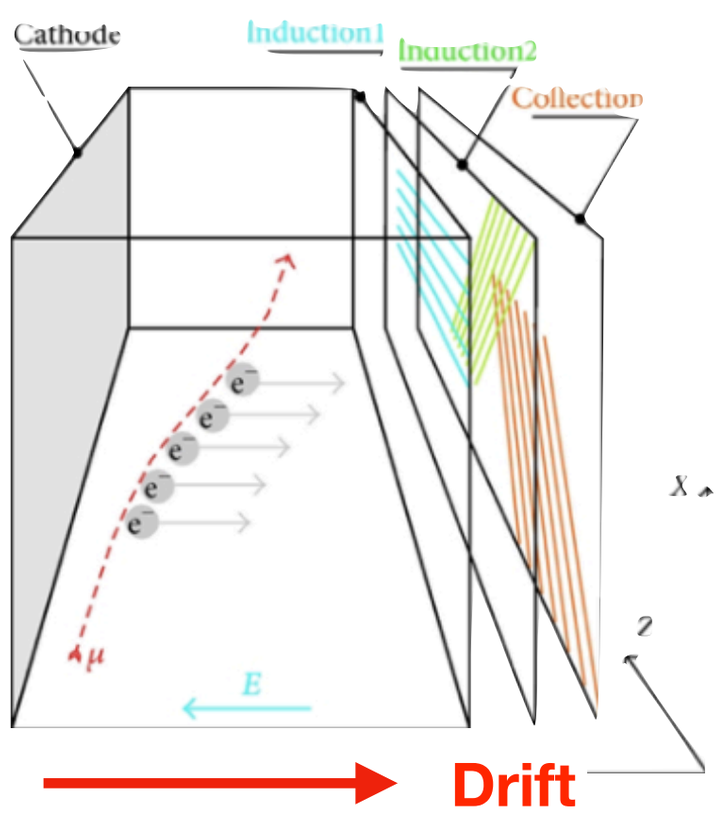
Courtesy: μBoone collaboration

- Argon is cheap and abundant
- High resolution (**~mm**) imaging detector
- Fully homogeneous calorimeter
- Signal from:
  - Ionization electrons drifted onto wire planes
  - Scintillation prompt light (trigger +complementary calorimetry information)
- Solid technology for neutrino detection (ICARUS, μBoone, …)

LArTPC: concepts

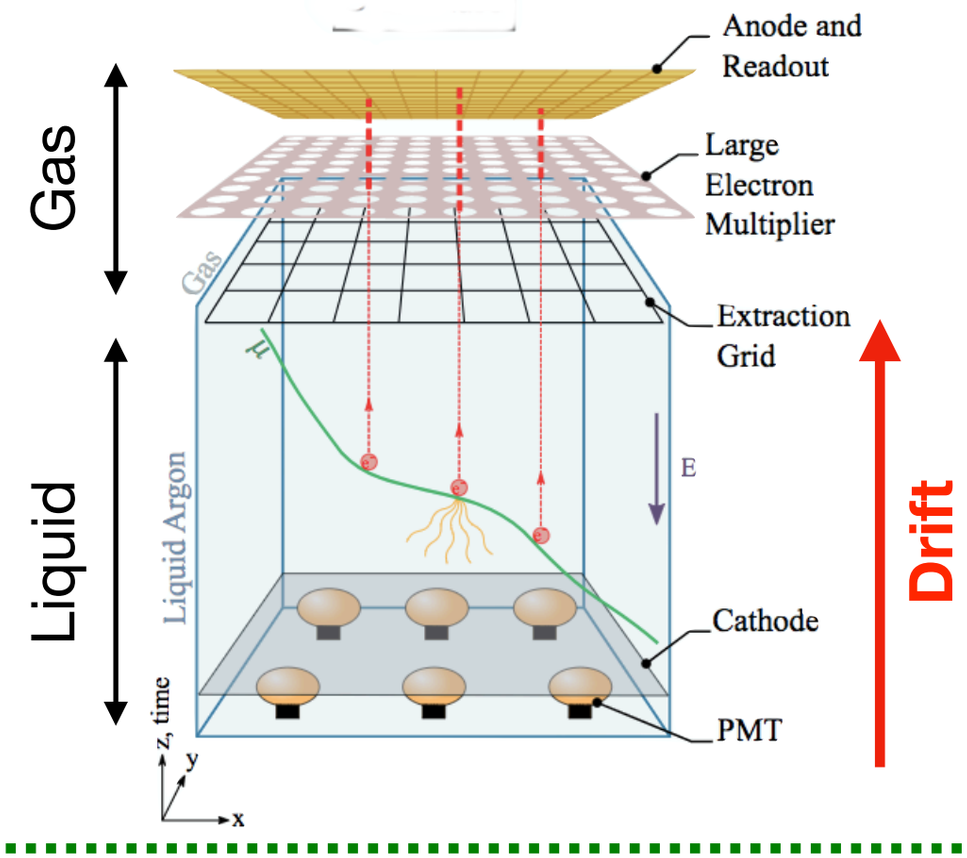
Single phase (SP)

- Only liquid Ar
- Horizontal drift
- No amplification
- 2 Induction and 1 collection plane



Dual phase (DP)

- Liquid and Gas Argon
- Vertical drift
- Amplification in gas
- 2 collection views



Courtesy of L. Zambelli: http://vietnam.in2p3.fr/2017/neutrinos/transparencies/5_friday/2_afternoon/4_zambelli.pdf

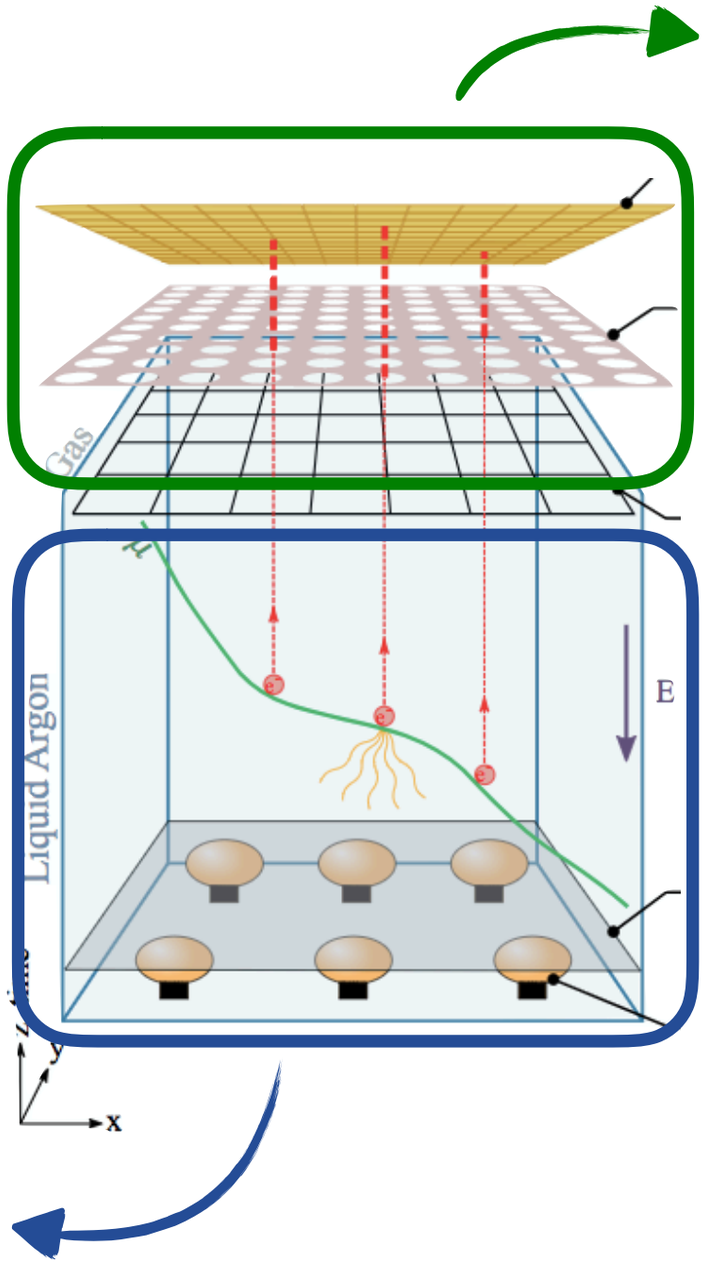
LArTPC: working principle

In Liquid (SP & DP)

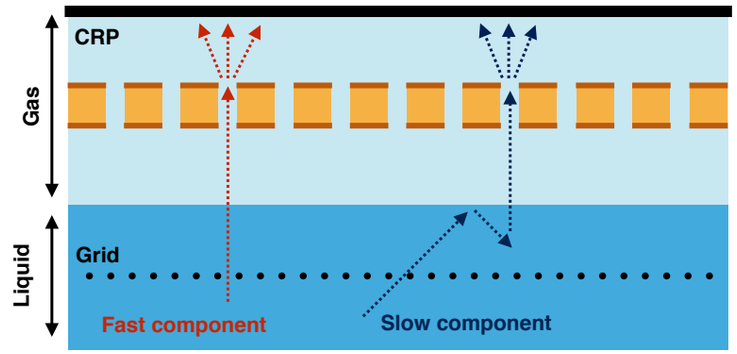
- **Ionization:** ~8k electrons/ mm from a *mip* (80% of total energy)
- **Recombination**: electron captured by their original ion
- **Lifetime:** electrons captured during drift by impurities. @ τ_e **= 3 ms**:

  ~50% electron loss in **3m drift (SP)**

  ~92% electron loss in **12m drift (DP)**



In Gas (DP only)

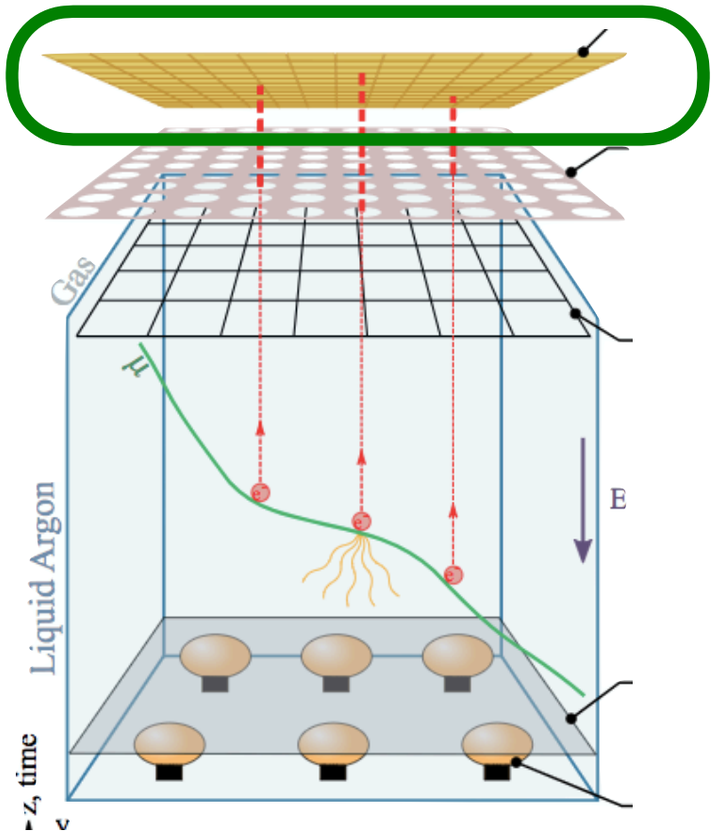


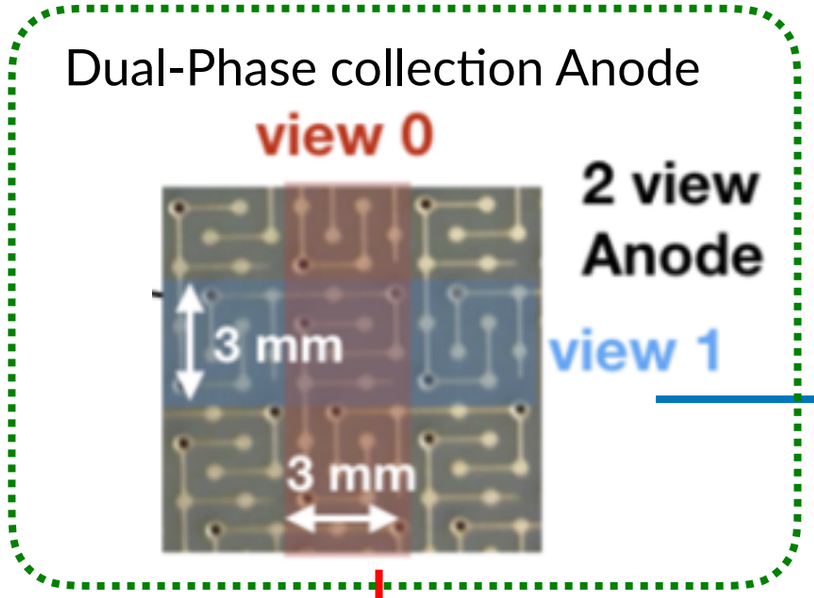
- **Extraction:** > 90% electrons extracted @ E_{ext} = 2 kV/cm
- **Amplification:** Townsend avalanches of electrons in gas Ar. Nominal E_{amp} = 33 kV/cm and ENC 1500 e-

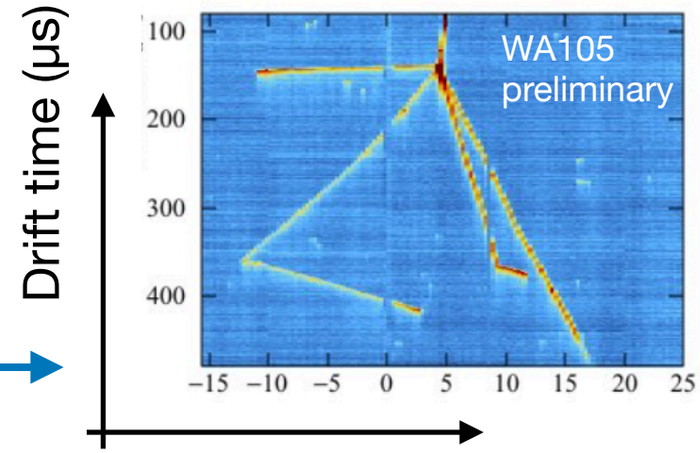
  S/N > 10 for a mip for both views

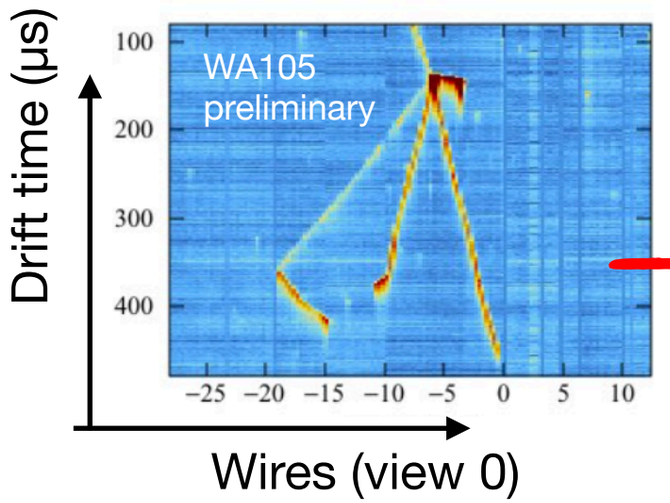
A precise knowledge (~1-2 %) of **drift field** and **Argon purity** is demanded at the scale of DUNE

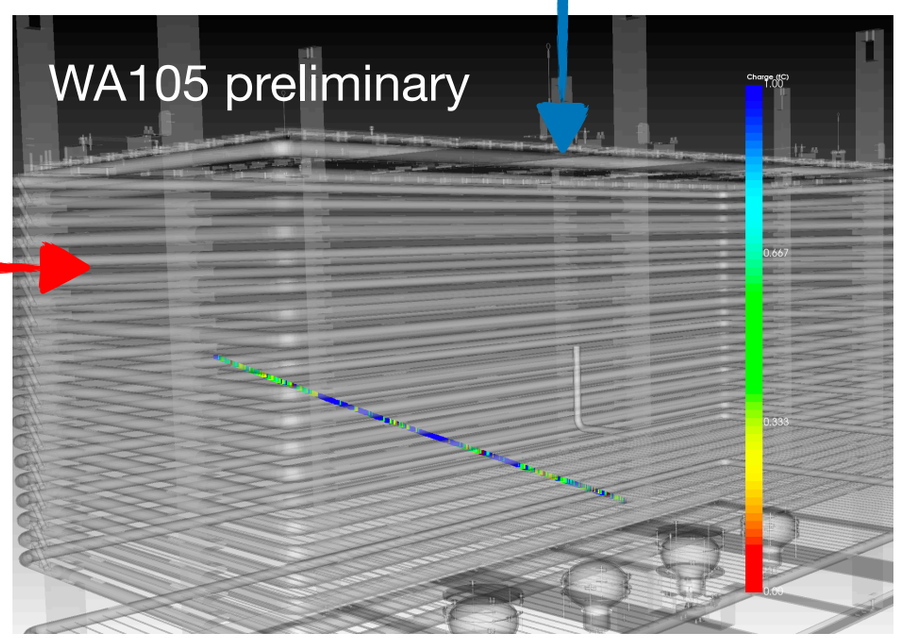
LArTPC : charge signal and reconstruction











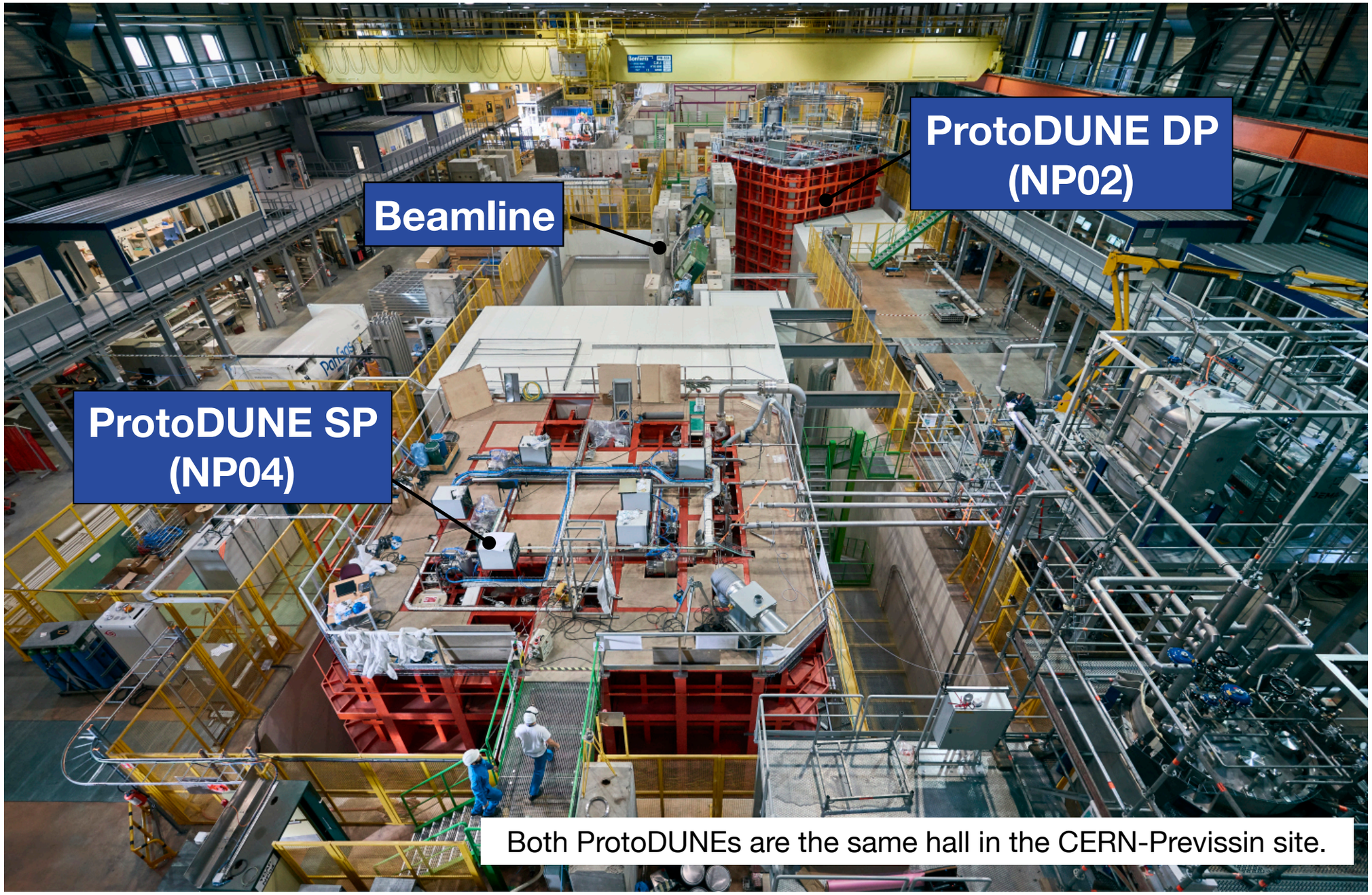
2D pattern recognition and 3D reconstruction from view matching

Observables:

- Track/shower ID
- Particle ID
- Energy reconstruction
- Event selection
- …

ProtoDUNE(s) @ CERN

ProtoDUNE is a set of Liquid ArgonTPC (one single, one dual phase) being constructed and operated @CERN



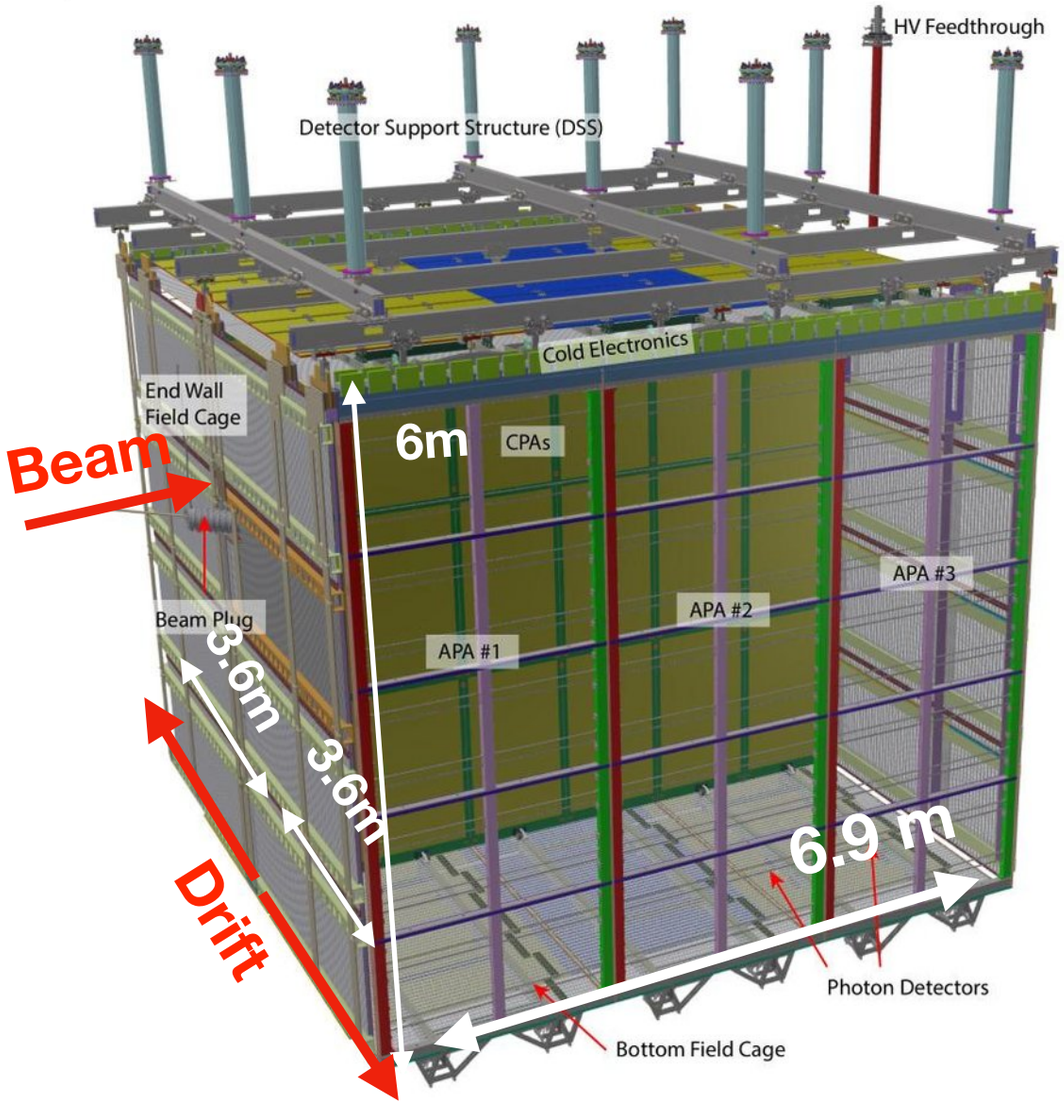
Both ProtoDUNEs are the same hall in the CERN-Previssin site.

ProtoDUNE: goals

- **TECHNICAL goals**
  - Validate production and installation procedures
  - Validate **design and basic detector performances**
  - Demonstrate **long term stability**

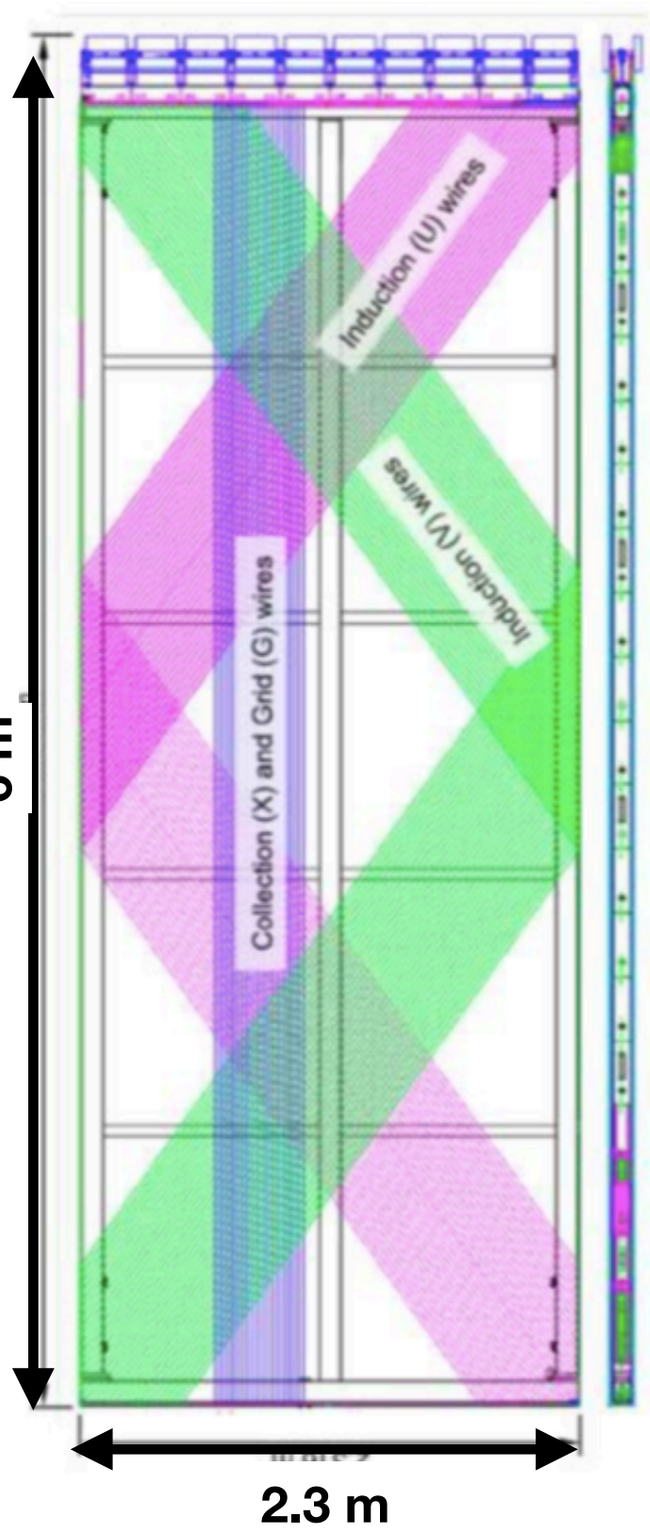
- **PHYSICS goals**
  - Data with **cosmics** and **calibrated particles beam** (0.5-6 GeV)
  - **PiD** and **Energy reconstruction**
  - **Electron energy resolution**
  - Validate **reconstruction algorithm performances**
  - Measure **Hadrons-Ar** cross section: control over DUNE systematics
  - Space charge and **electric field distortions**
  - **Calibration** and Michel electrons

ProtoDUNE SP @CERN

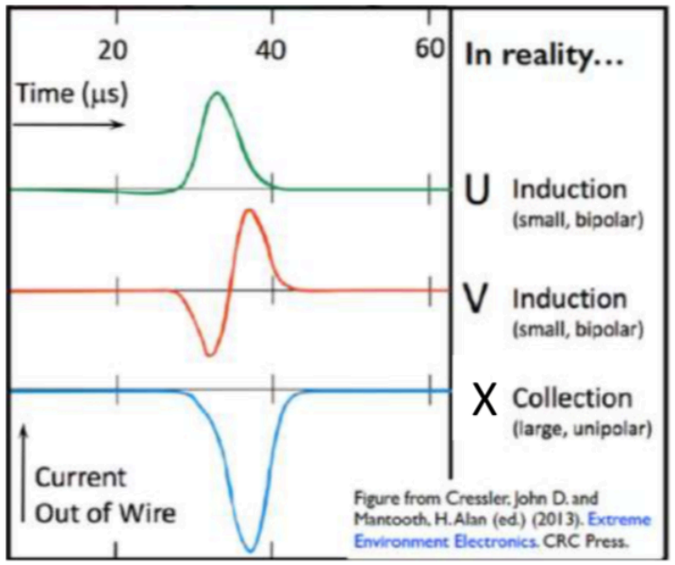


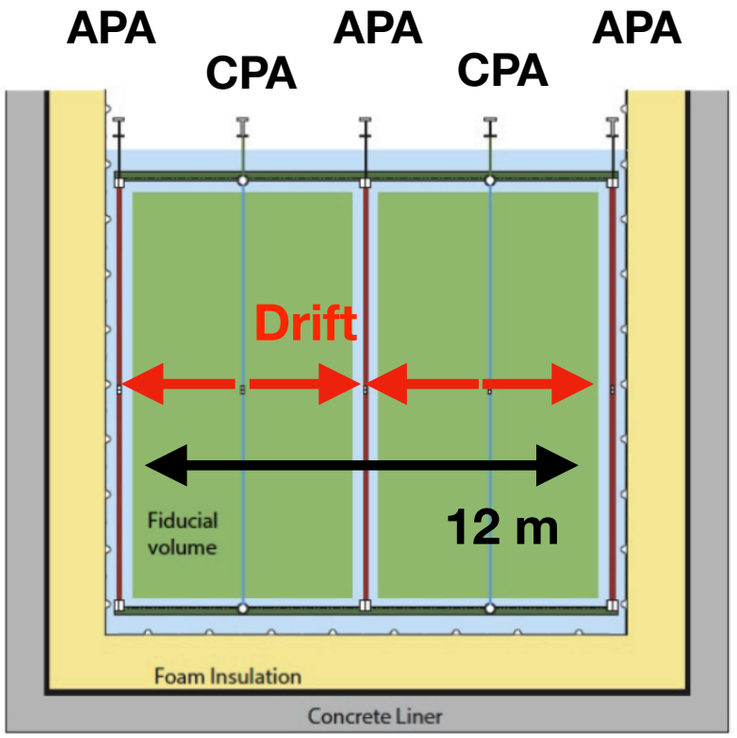
- **Total mass 0.77 kt**
- **Double 3.6 drift length** (DUNE-SP drift)
- **Central Cathode plane Assembly (CPA)**
  - 180 kV for 500 kV/cm
- **Anode plane assembly (APA)**
  - 2 planes with 3 APAs each
  - 1 APA 6 m height 2.3 m large
  - **Photodetector integrated in APA**

Anode Plane Assembly (APA)



- **Induction wires** (U, V): inclined +/- 37.5°, induced bipolar signal
- **Collection wires** (X): collect charge, monopolar signal
- **5 mm wire pitch**
- **fixed S/N: 9 for a mip**





DUNE FAR DETECTOR (side view)

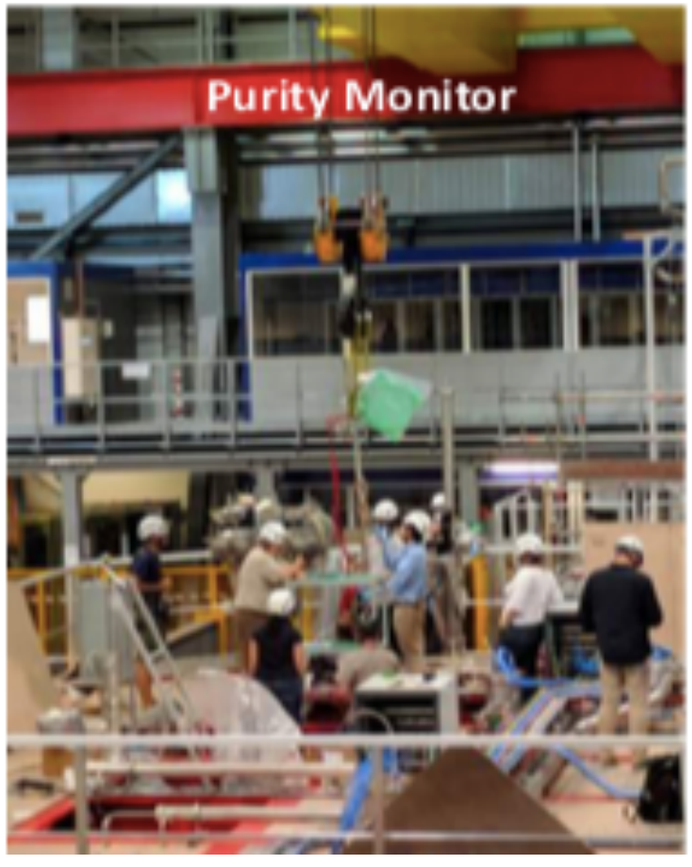
- Modular APA-CPA sequence for the far detector
- Full drift length segmented into 4 drift of ~3 m to limit electron losses
- APA-CPA are inside the fiducial volume

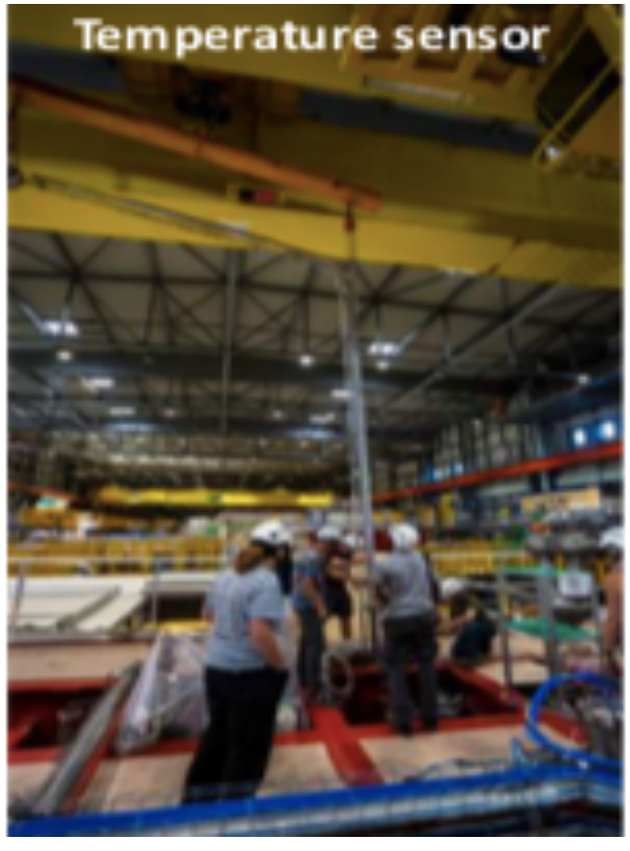
ProtoDUNE SP: current status

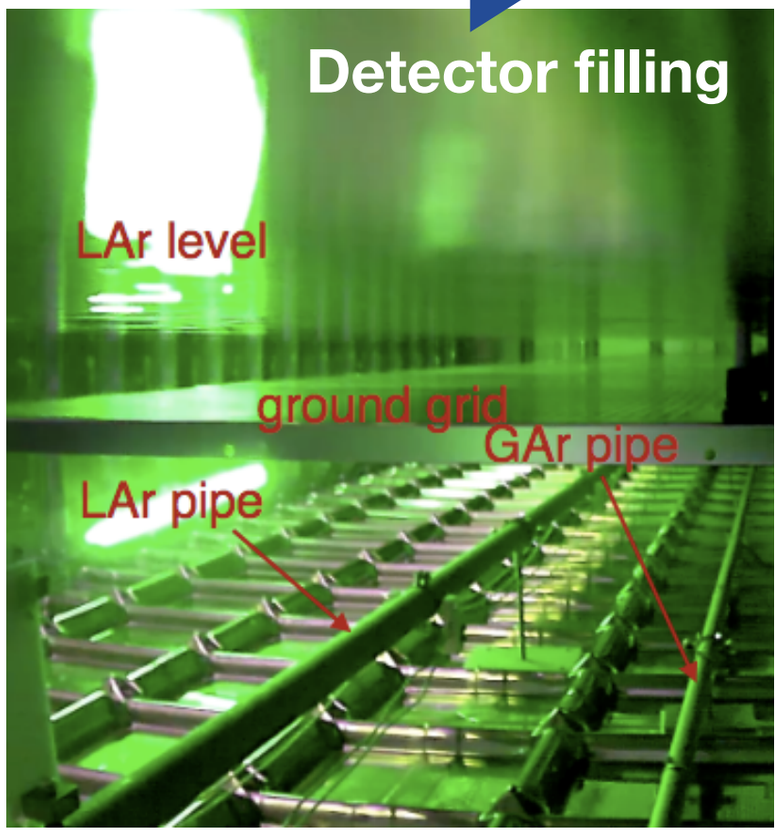
end of April
All the components of the detector tested and installed

August
Detector instrumentation and filling

September
Detector commissioning
First noise data



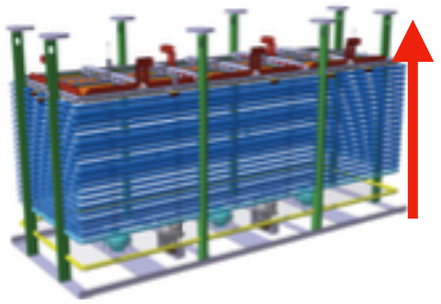


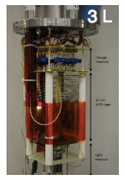


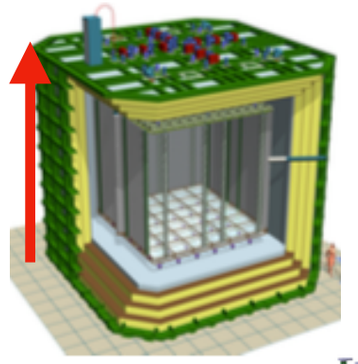
Detector commissioning this week!

Dual-Phase staged prototyping

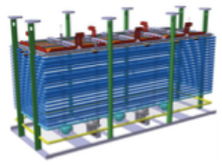
3x1x1 m³ @CERN (2016-2017)



4 t =  **x 1000**



ProtoDUNE-DP, 6x6x6 m³ @CERN (2016-2019)

300 t =  **x 100**

- **Full 12 meter drift**
- No dead material in the fiducial volume
- **Tunable S/N ratio**
- **2 collection planes**

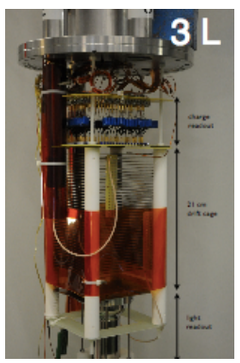
  higher granularity (**~3mm**)
- Fewer number of readout channels
- Accessible cold FE

➡**Detector stability and homogeneity**

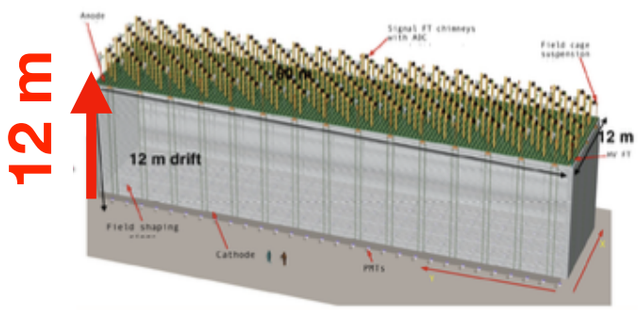
➡**Minimal S/N achievable (> 10 for mip)**

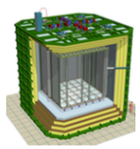
4 kg

Small TPCs for R&D and DM detectors

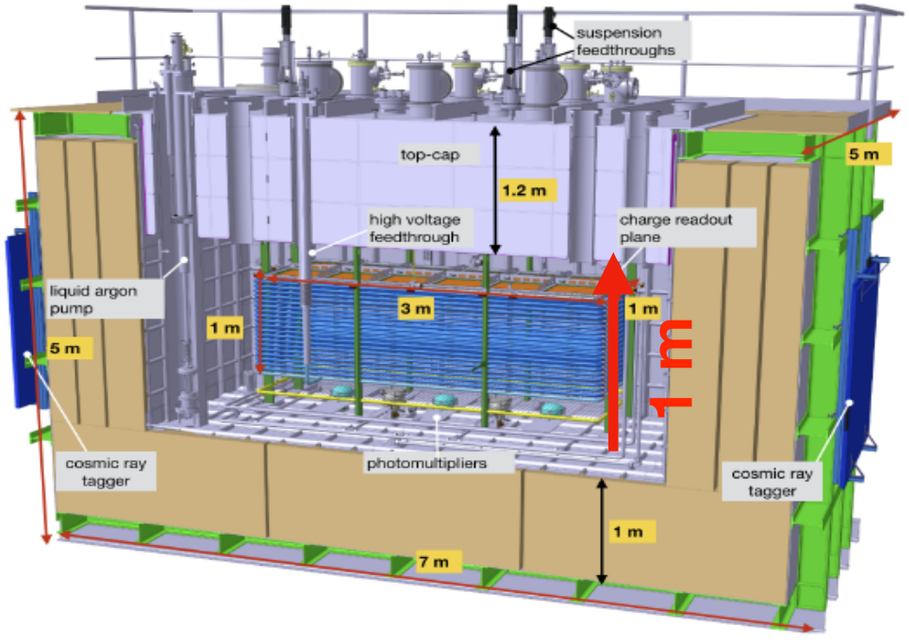


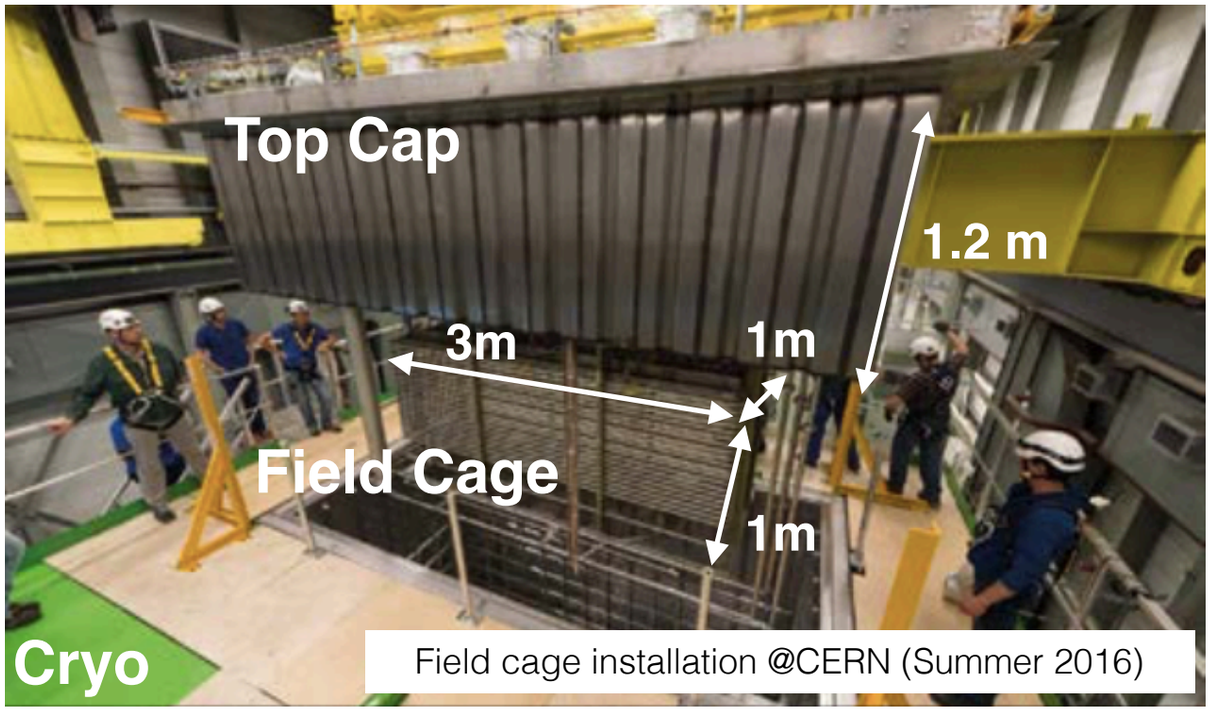
DUNE FD-DP, 60x12x12 m³ @SURF (> 2020)



10 kt =  **x 100**

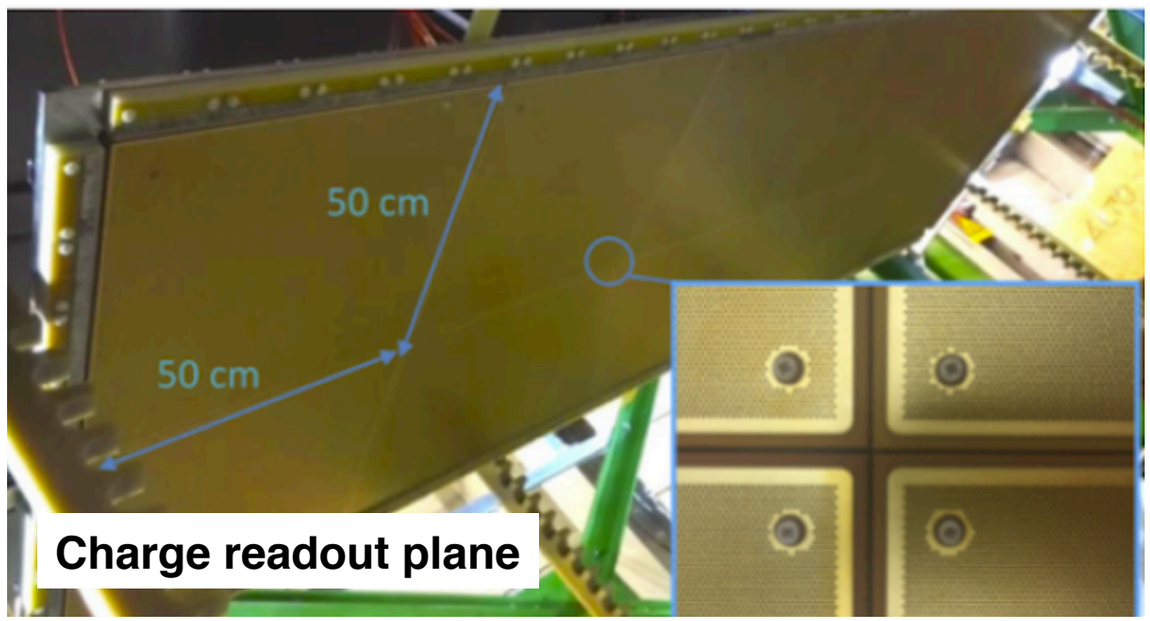
4 t LArTPC-DP @CERN





Field cage installation @CERN (Summer 2016)

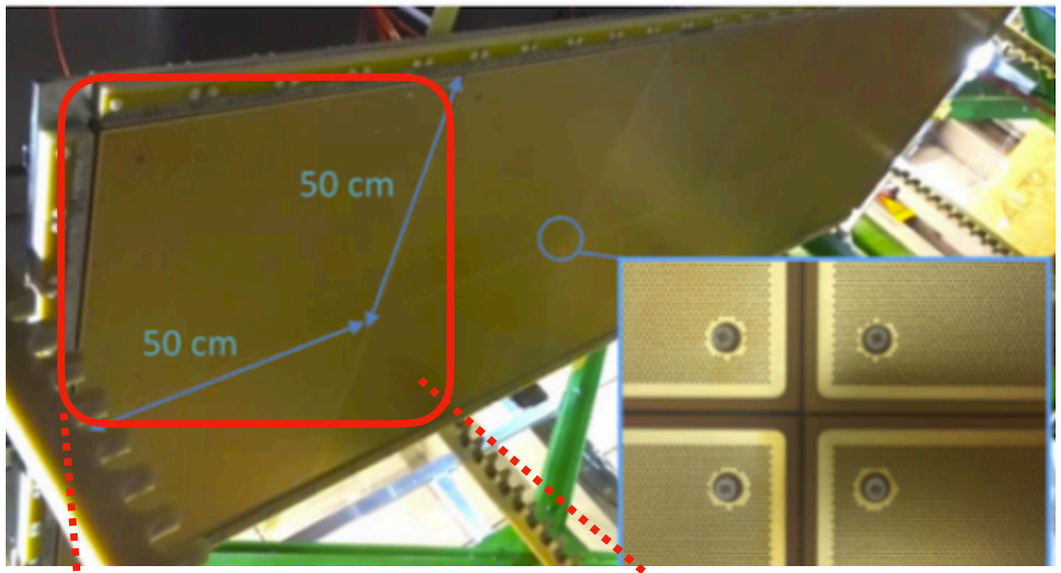
- **1 m drift, 4 t LAr DP prototype**
  - Proof of principle of DP concept
  - LAr purity and CRP uniformity
- 50k cosmic trigger in Summer-Fall 2017
- Tested detector stability
- First test of the design for DUNE



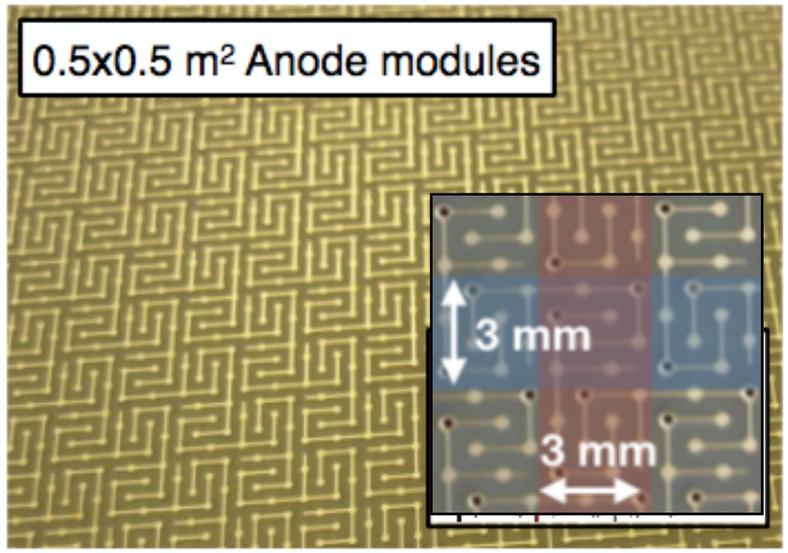
Charge readout plane

Charge readout plane (CRP)

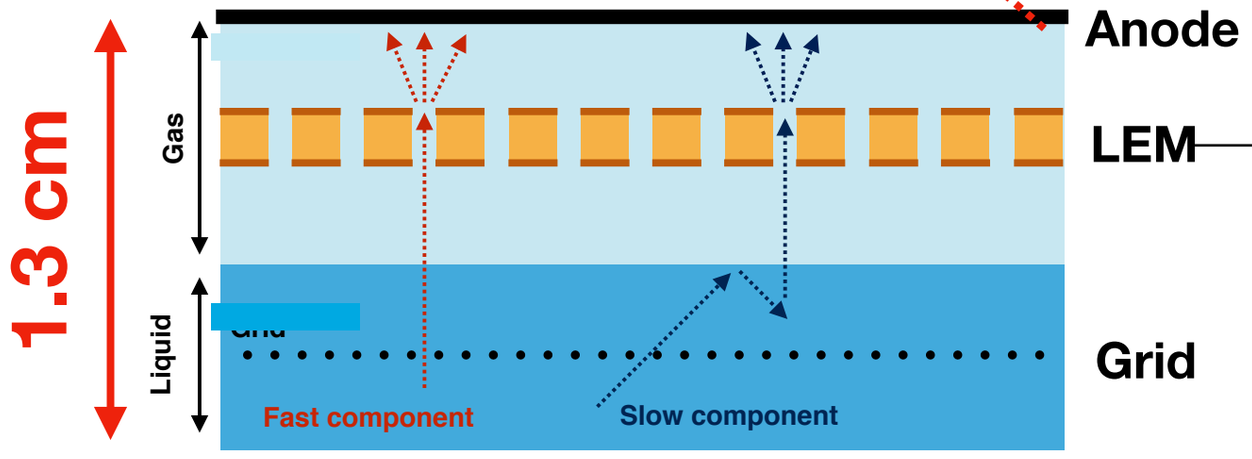
1 CRP assembly: 12 50 x 50 cm² elements in the 4 t prototype

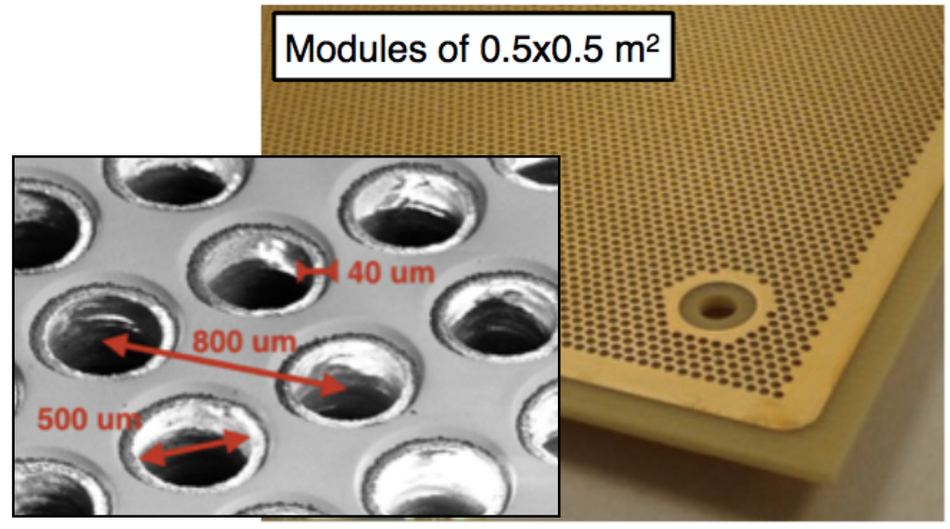


Micro pattern PCB **collection anode** designed for **equal charge sharing between two views** and low inter-strip capacitance 150 pF/m (**1500 ENC noise**)



1 mm thick LEM layer, standard PCB with 150 holes/cm²

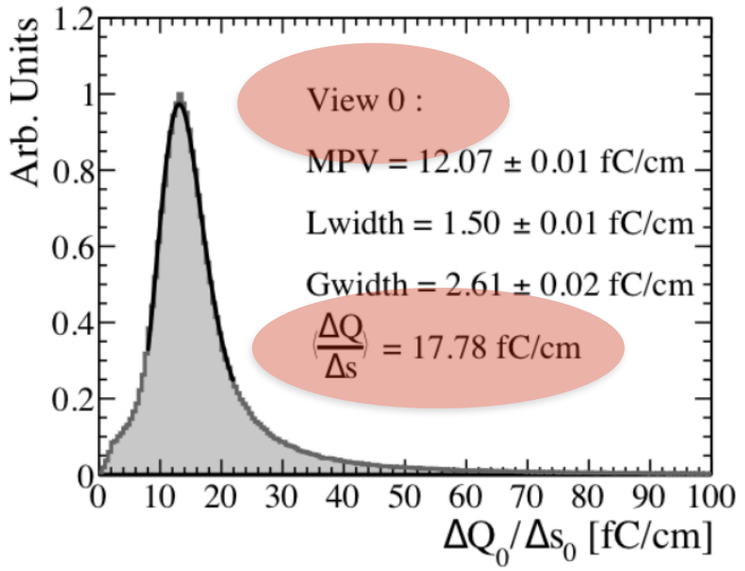


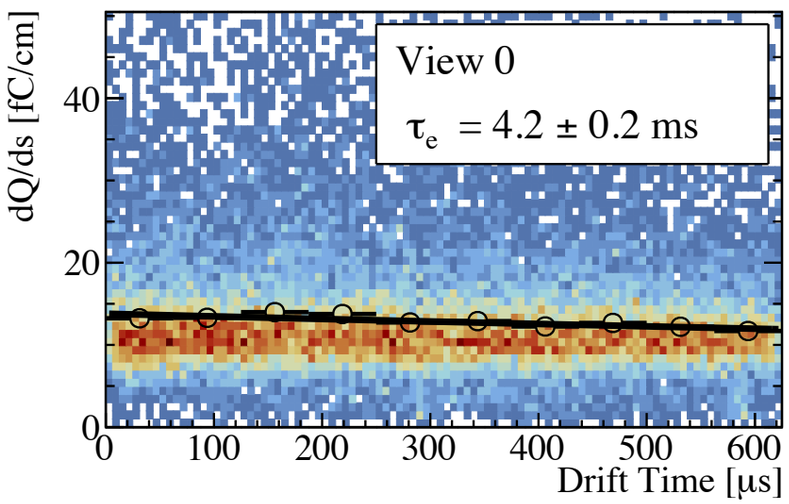


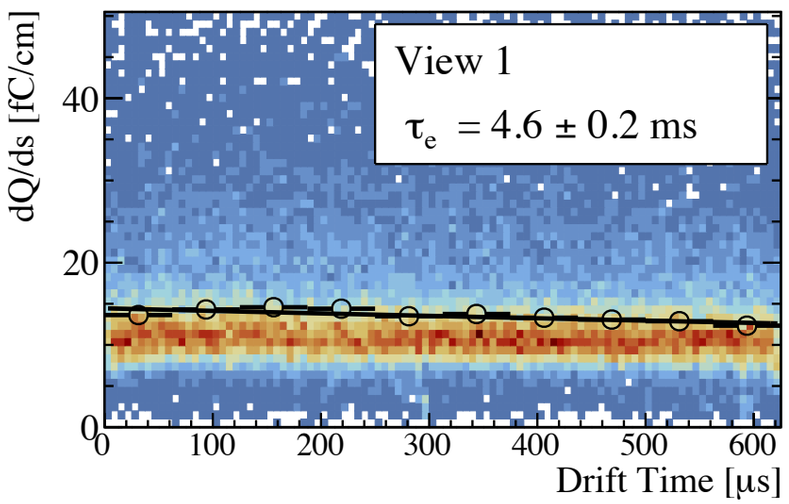
4 t LArTPC-DP: technical achievement

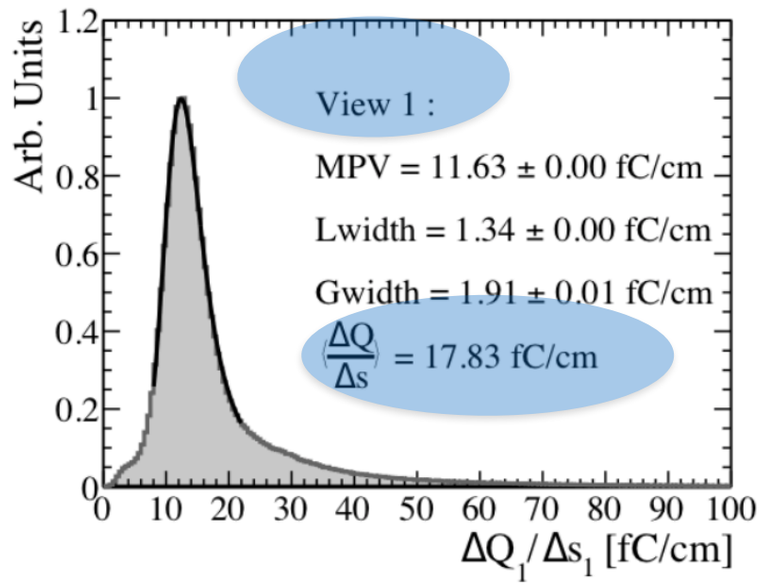
Several milestones achieved with the 4t Dual-Phase demonstrator

- LAr level stability over time (σ +/- 0.05 mm)
- Stable drift filed for the entire operation period
- Equal charge splitting at the anode
- Purity compatible with ms electron lifetime in Argon







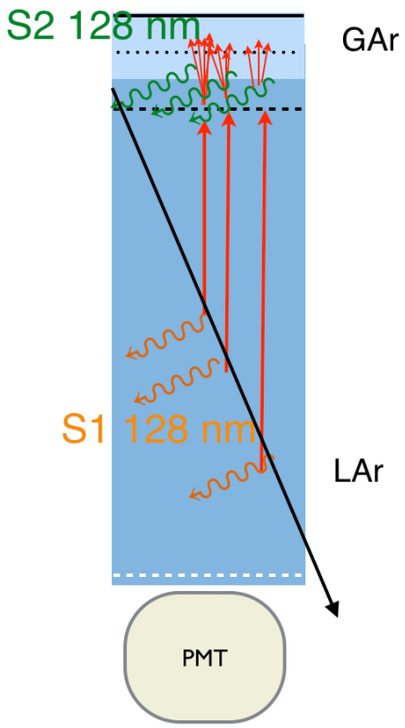


Summary of the performance in:

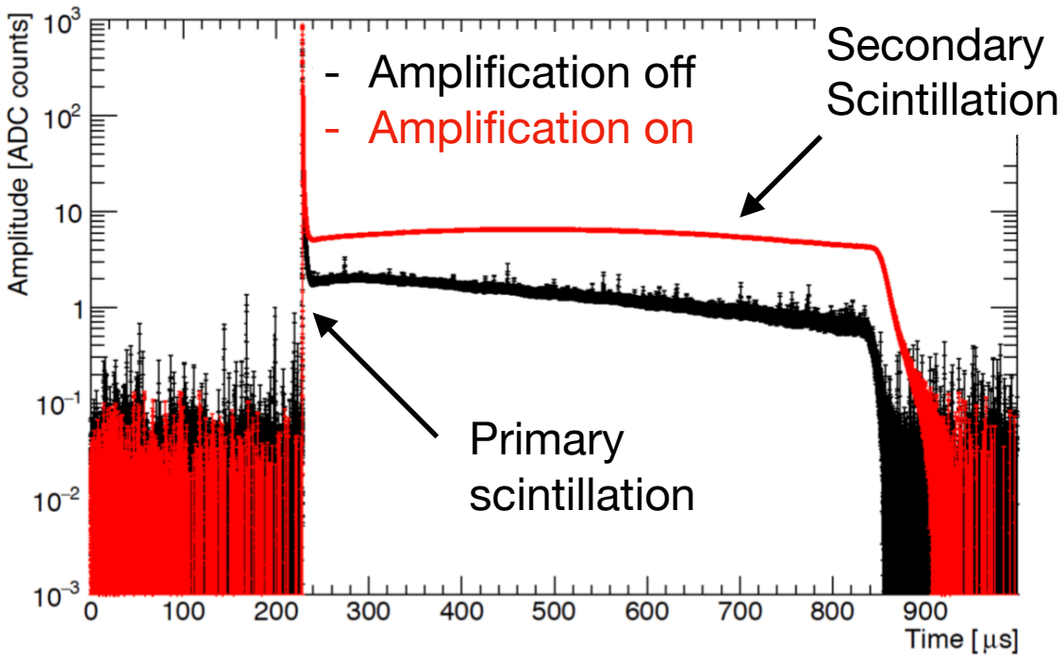
"A 4-tonne demonstrator for large-scale dual-phase liquid argon time projection chamber"

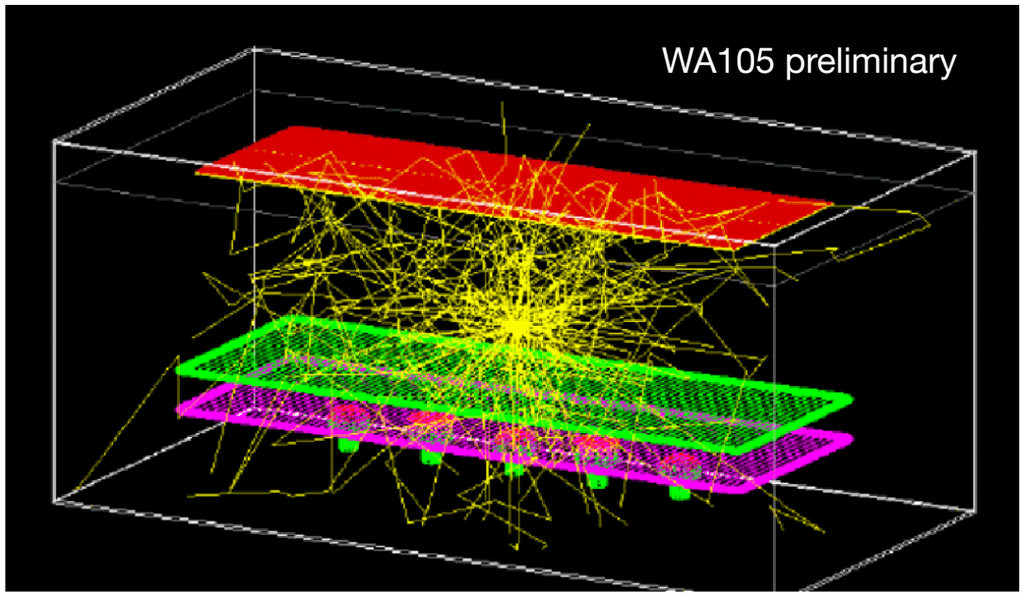
arXiv: ins-det/1806.03317, submitted to JINST

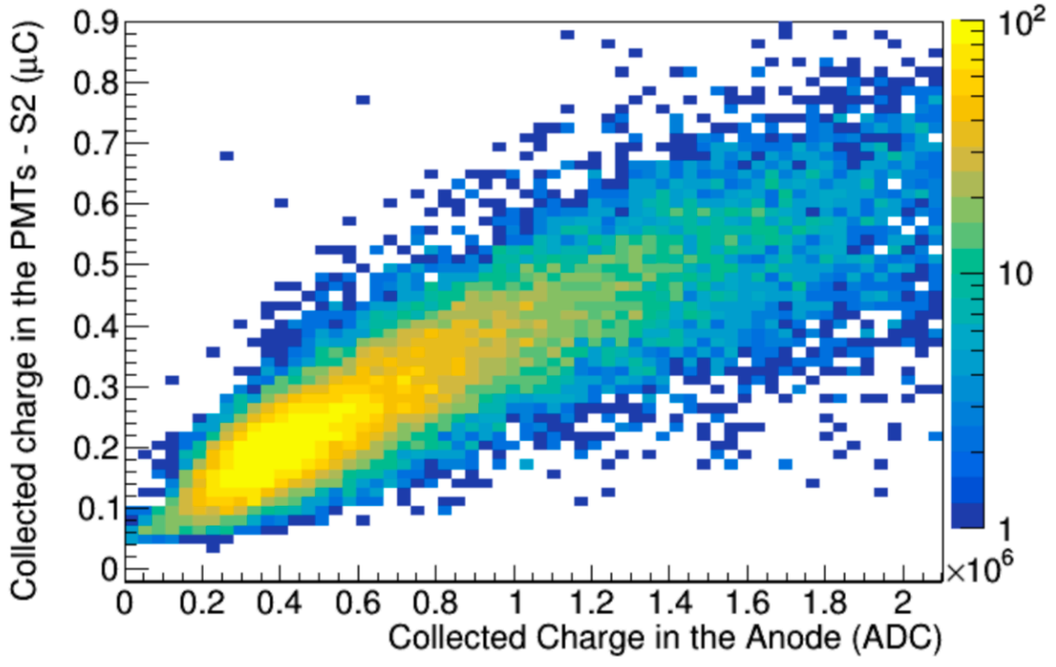
4 t LArTPC-DP: light measurement



- Clearly visible light from primary and secondary scintillation.
- Correlation between the quantity of light and charge detected between matched events.
- Comparison between the light simulation and data.







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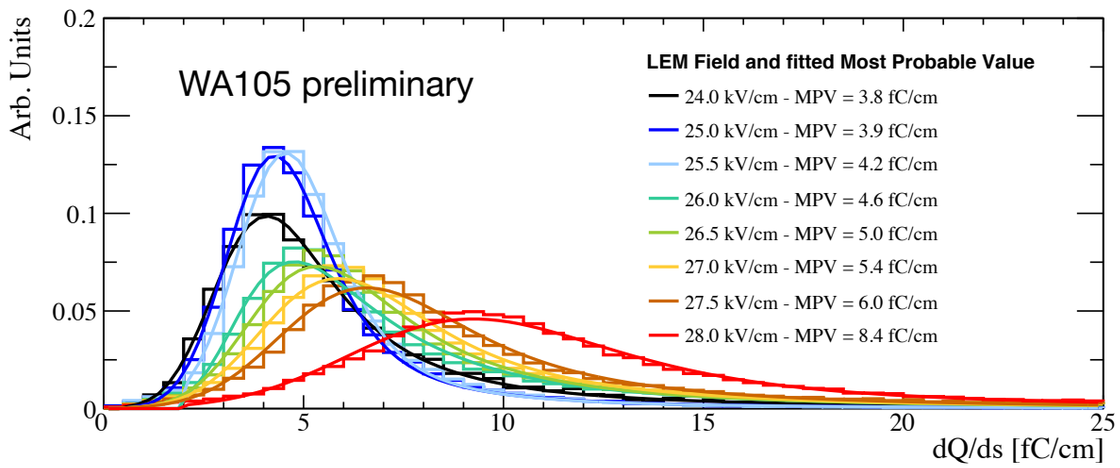
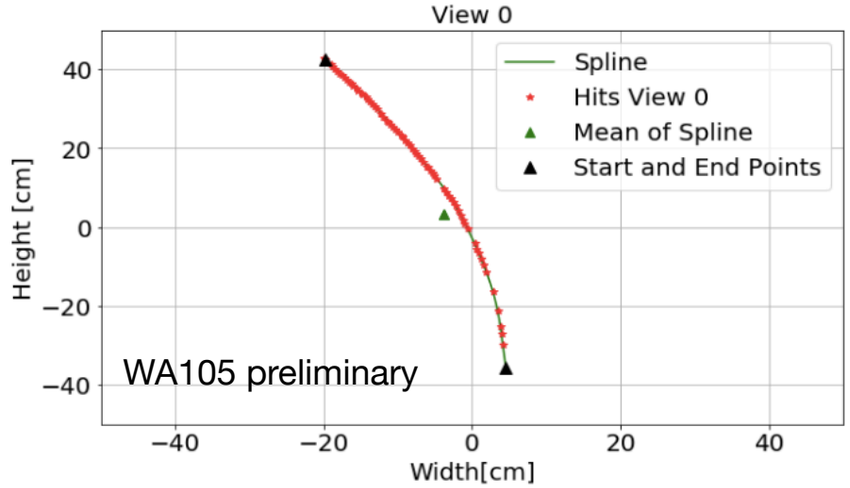
4 t LArTPC-DP: analysis ongoing

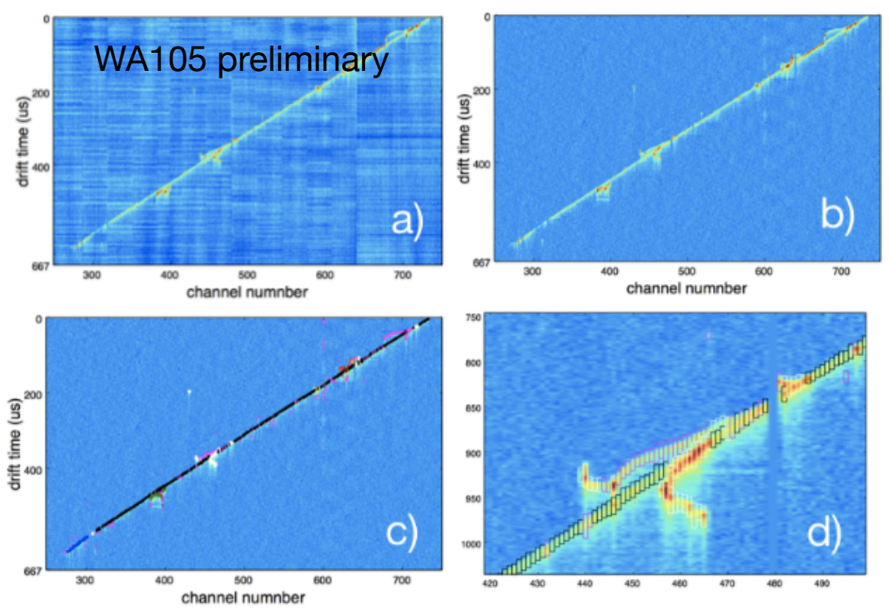
Already many valuable information learned for ProtoDUNE DP, data analysis is still ongoing…

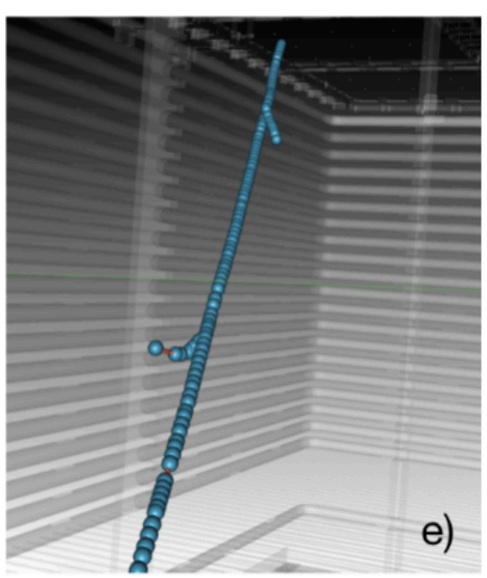
Study of Townsend amplification and measure of the effective S/N ratio



Electric field uniformity and space charge effect using tracks curvature



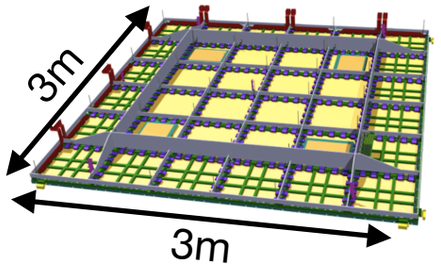




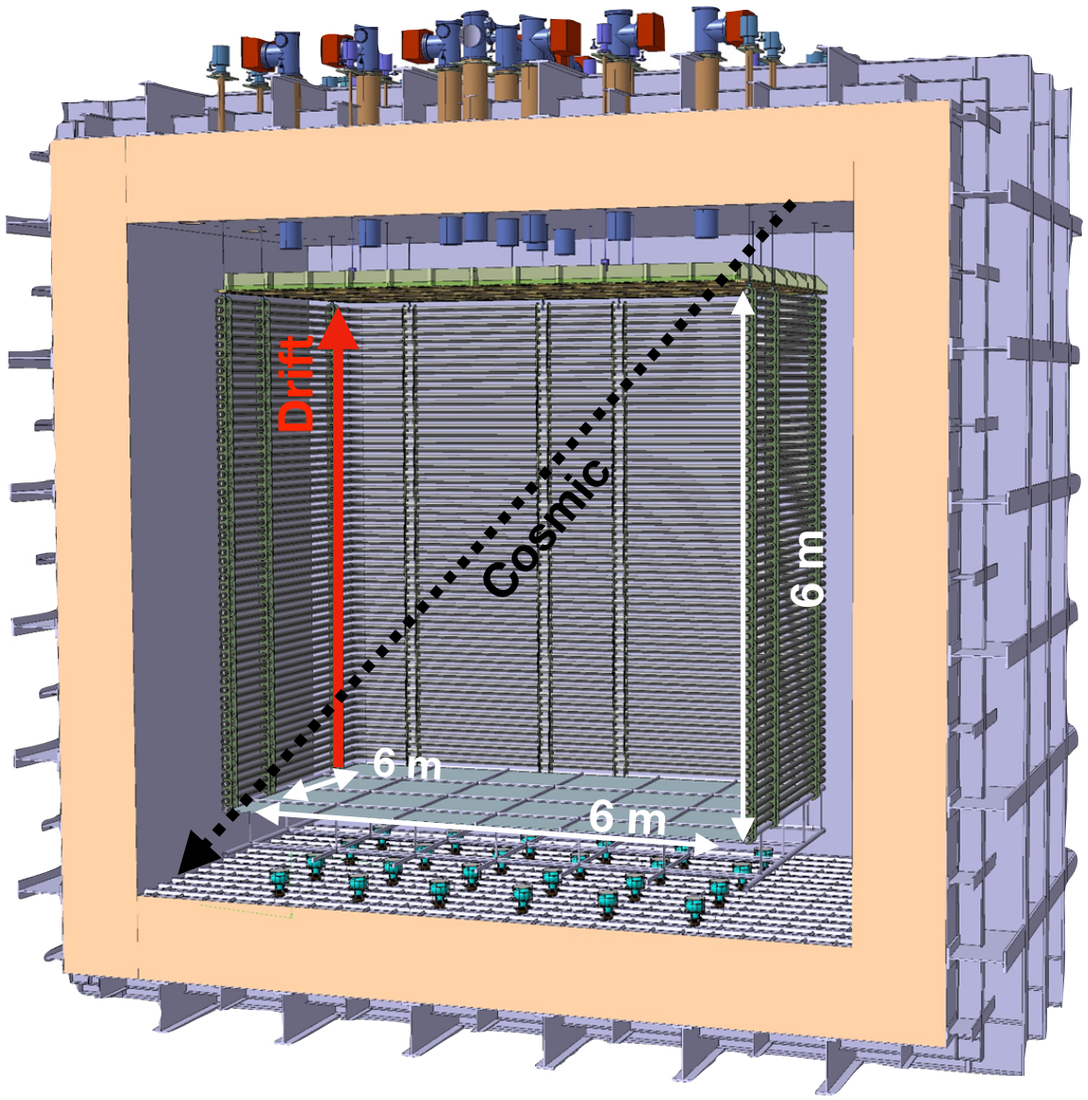
Noise filtering, 3D reconstruction and track selection

ProtoDUNE Dual Phase @CERN

- Fiducial mass **300 t**
- **Drift length: 6 m** (1/2 DUNE-DP drift)
- Drift filed: 500 V/cm ~ **300 kV at the cathode**
- **Expected S/N: 80-100**
- Four 3x3 m^2 Charge Readout Planes (CRP), similar design as the 4 t
- 36 Photomultipliers tubes for light collection



x 4



ProtoDUNE DP: current status

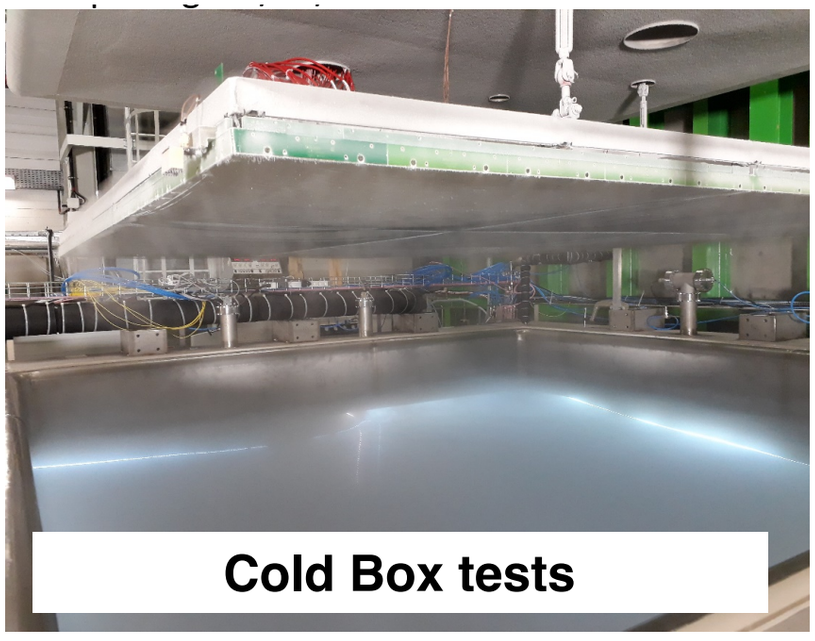
April
Field cage completed
Stable operation @ 150 kV

June
First CRP assembly completed

July-September
Dedicated CRP cold tests

Filed cage installed

CRP assembly in clean room

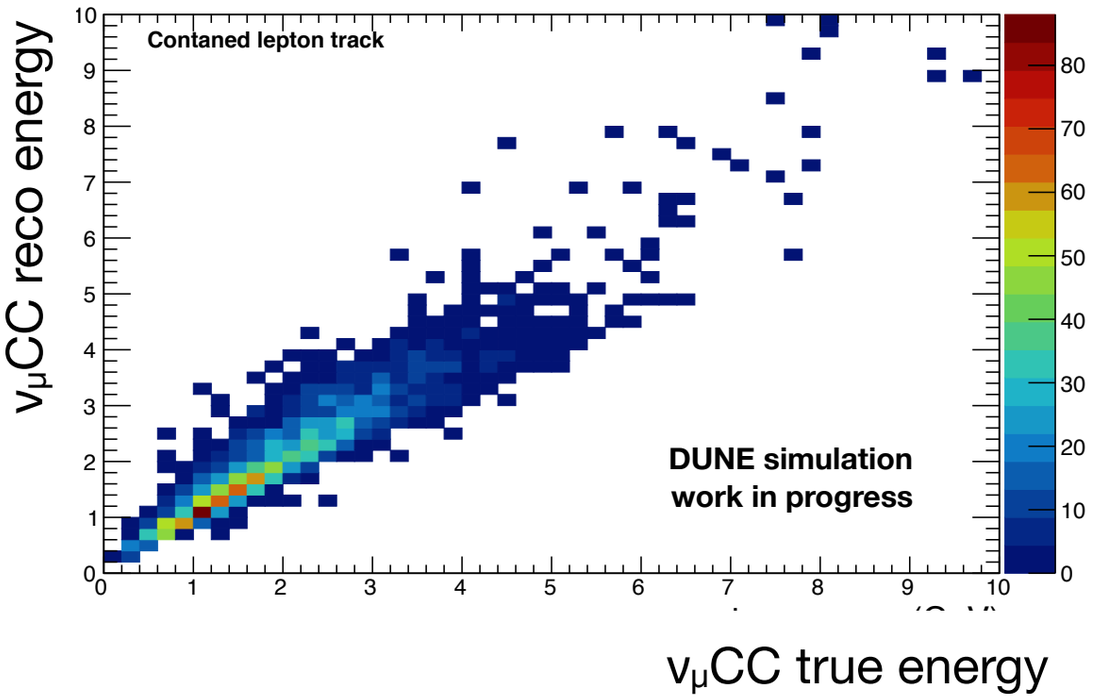


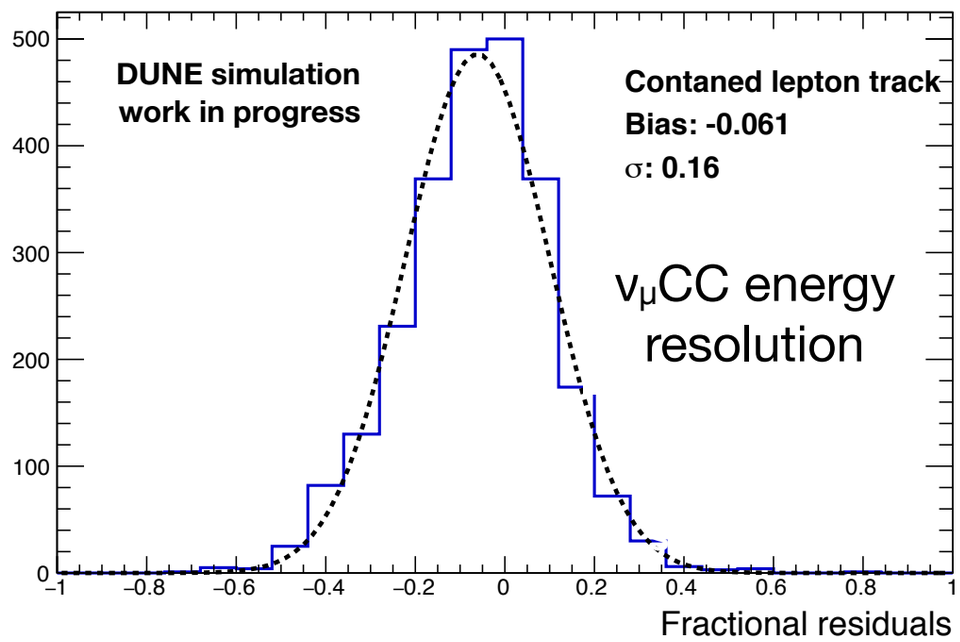
Cold Box tests

- First CRP installation by the beginning of October
- Second CRP is under construction
- Detector commissioning in early 2019 with 2 full CRP instrumented

Toward DP in DUNE

- Dedicated full simulation studies are ongoing to study the physics performances of DUNE using Dual-Phase technology (both **light** and **charge** signal)
  - Impact of 12m drift and electron amplification on energy reconstruction and event selection for Long baseline studies
  - Low energy physics





SUMMARY

- LAr technology , in both single and dual phase, has been object of intense R&D in the past years

- A Dual phase 4 t demonstrator has successfully operated at CERN in 2017
  - Data analysis ongoing, already lots of insights for ProtoDUNE and DUNE

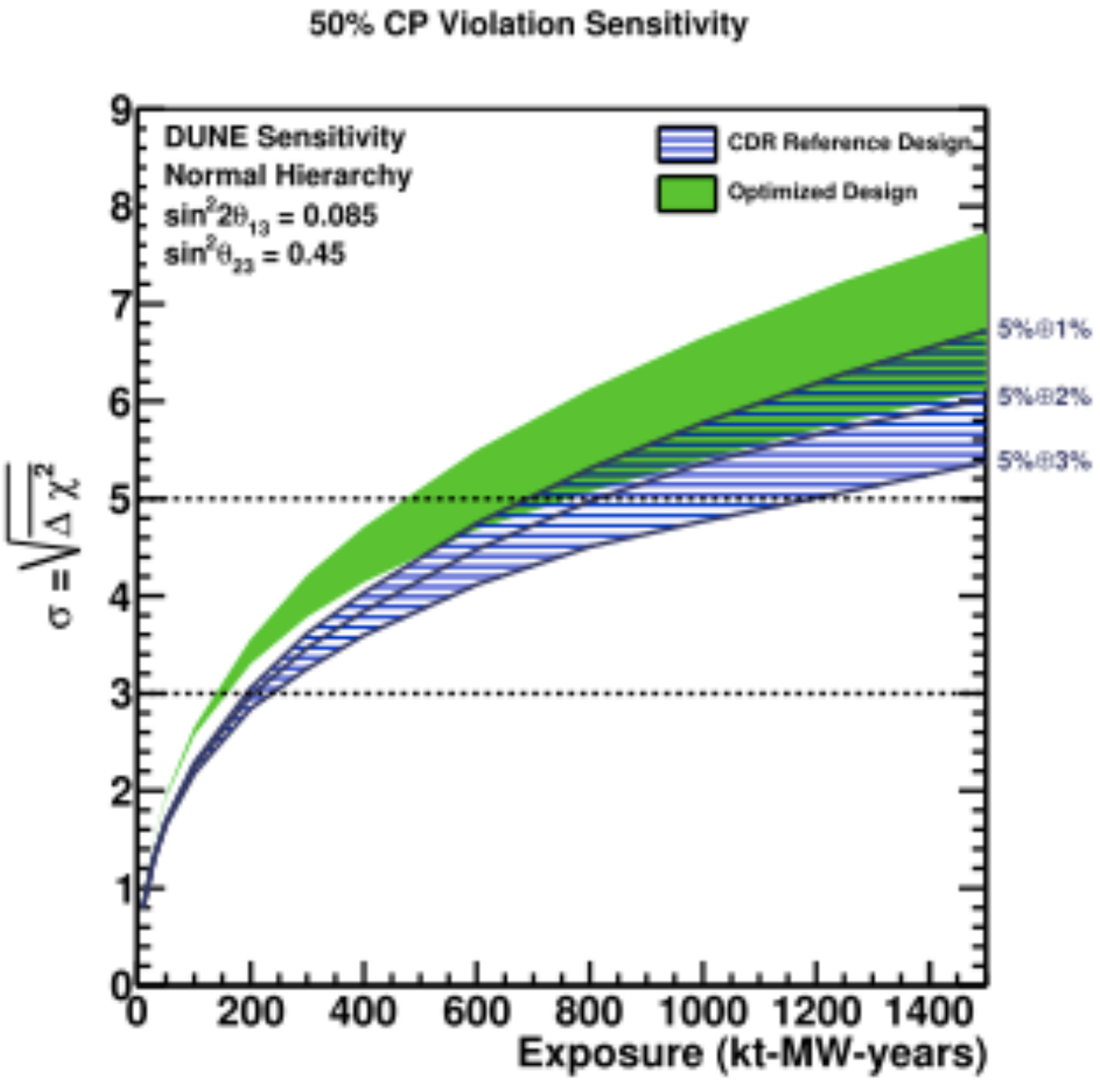
- The DUNE collaboration is going to test the far detector design @CERN
  - ProtoDUNE -DP is under construction and will commissioned by end 2018
  - ProtoDUNE-SP is being commissioned...

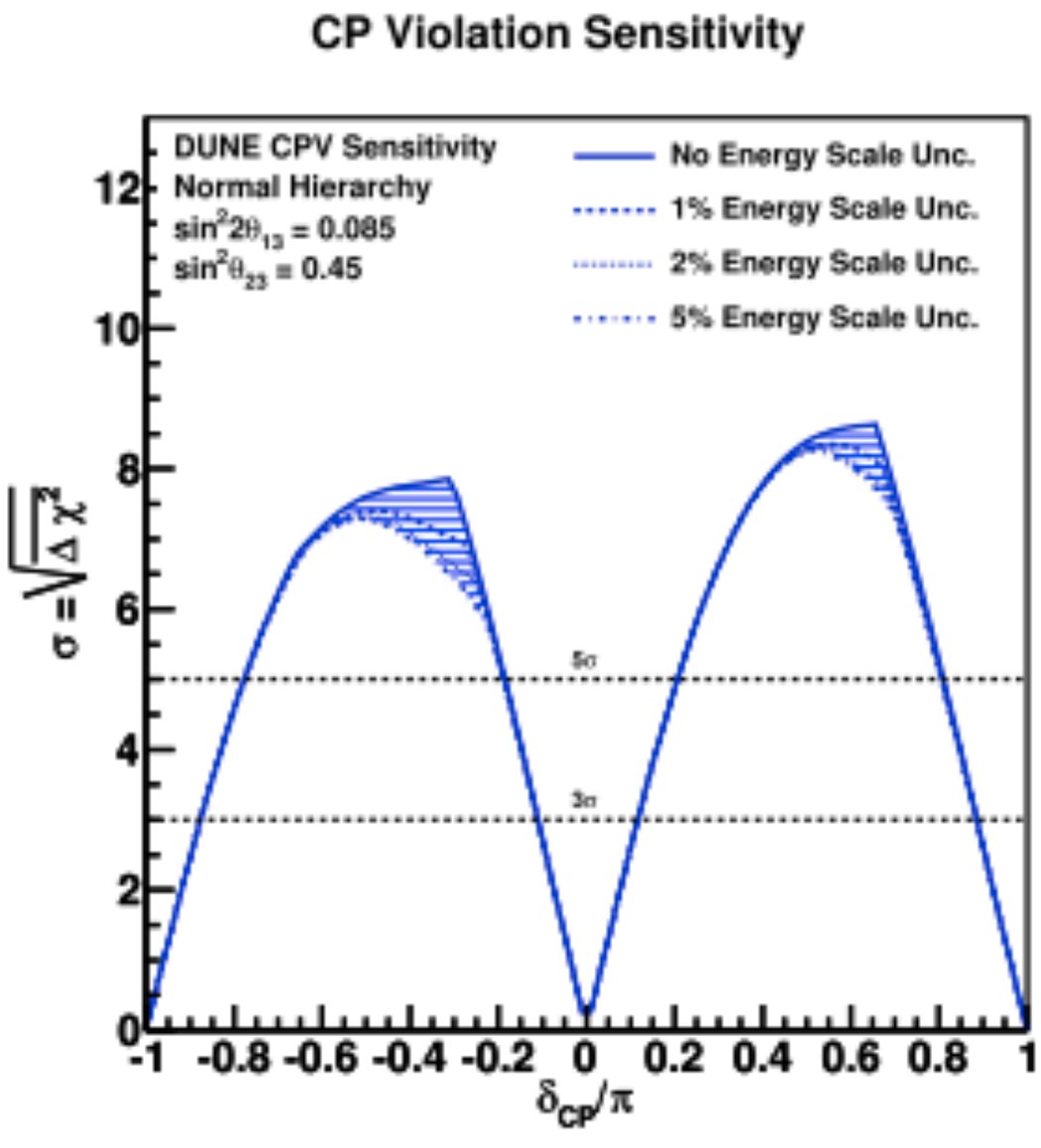
...stay tuned!

Thank you!

LB physics @DUNE

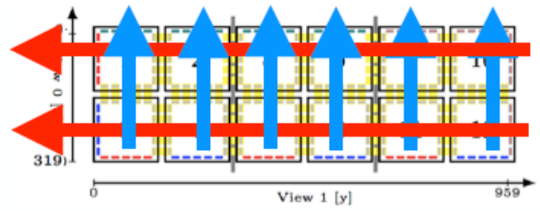
- DUNE signal normalization uncertainties 5% ⊕ 2%
- Effect of the energy scale uncertainties





LEM effective gain

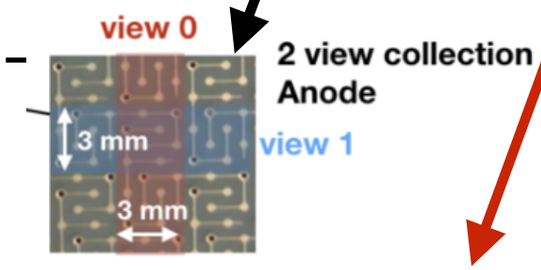
Deposited charge measured on view 0 (3m strips)
and view 1 (1 m strips)



Effective Gain = (<dQ/ds>$_{view0}$+<dQ/ds>$_{view1}$)/<dQ/ds$_{expected}$>

$dQ/ds_{view} = f_{share} \times (\varepsilon_{extr} \times G_{LEM} \times E_{coll}) \times dQ/ds_{expected}$

50%



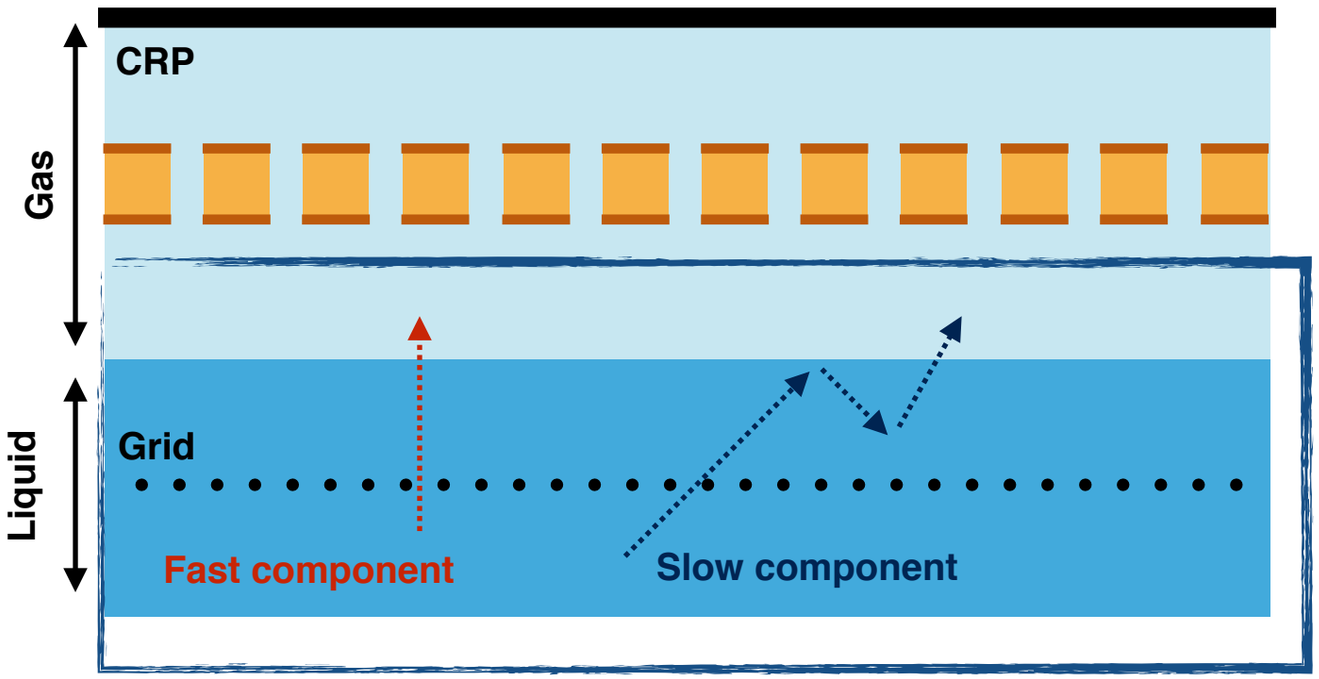
Extraction efficiency
fraction of electrons which are extracted from the liquid

LEM Amplification
multiplication factor of the electrons x transparency of its bottom electrode

Collection Efficiency
fraction of electrons transferred from LEM to anode

G_{eff}, effective gain → **goal 20**

Extraction

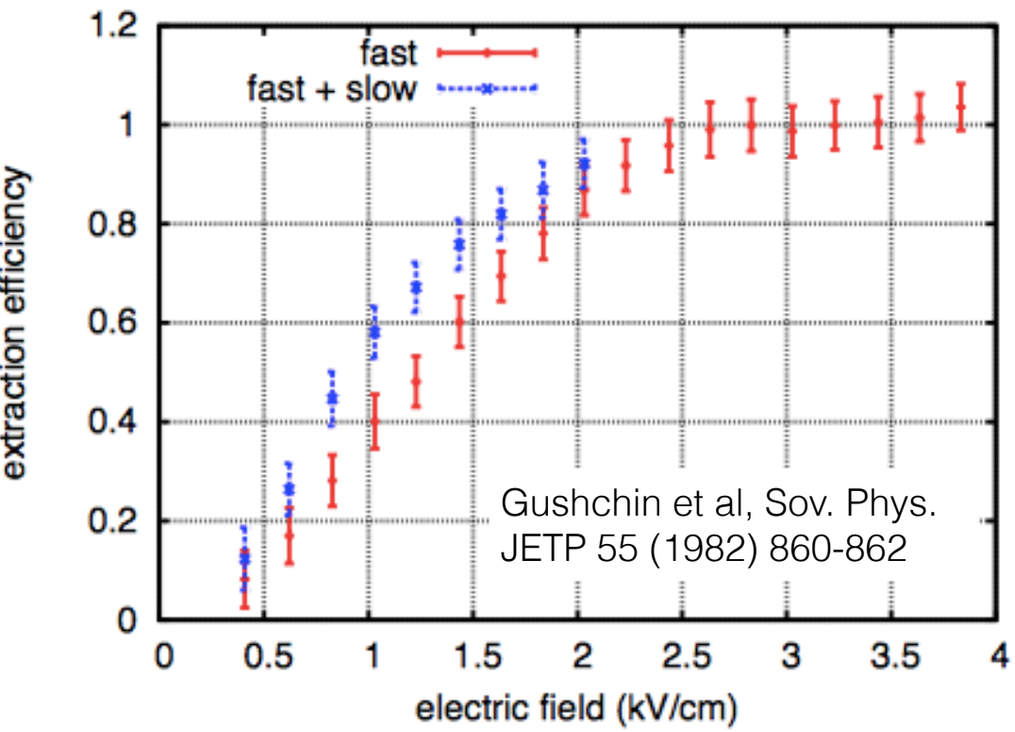


Extraction: Electric field from grid to LEMs extracts electrons from liquid to phase.

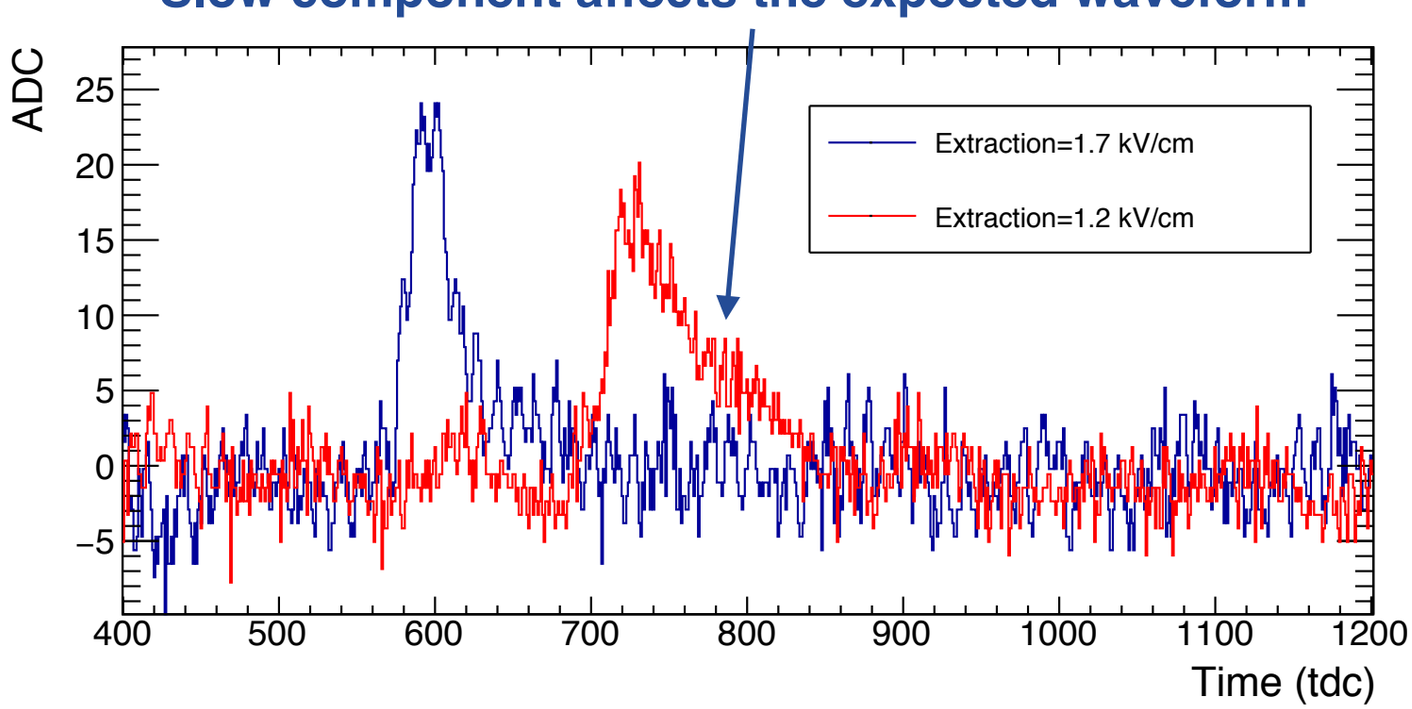
Not all the electrons are extracted at the same time:

1. **Fast component:** immediately extracted
2. **Slow component:** remains at the gas interface for longer (~10 μs)

Grid transparency further reduce efficiency

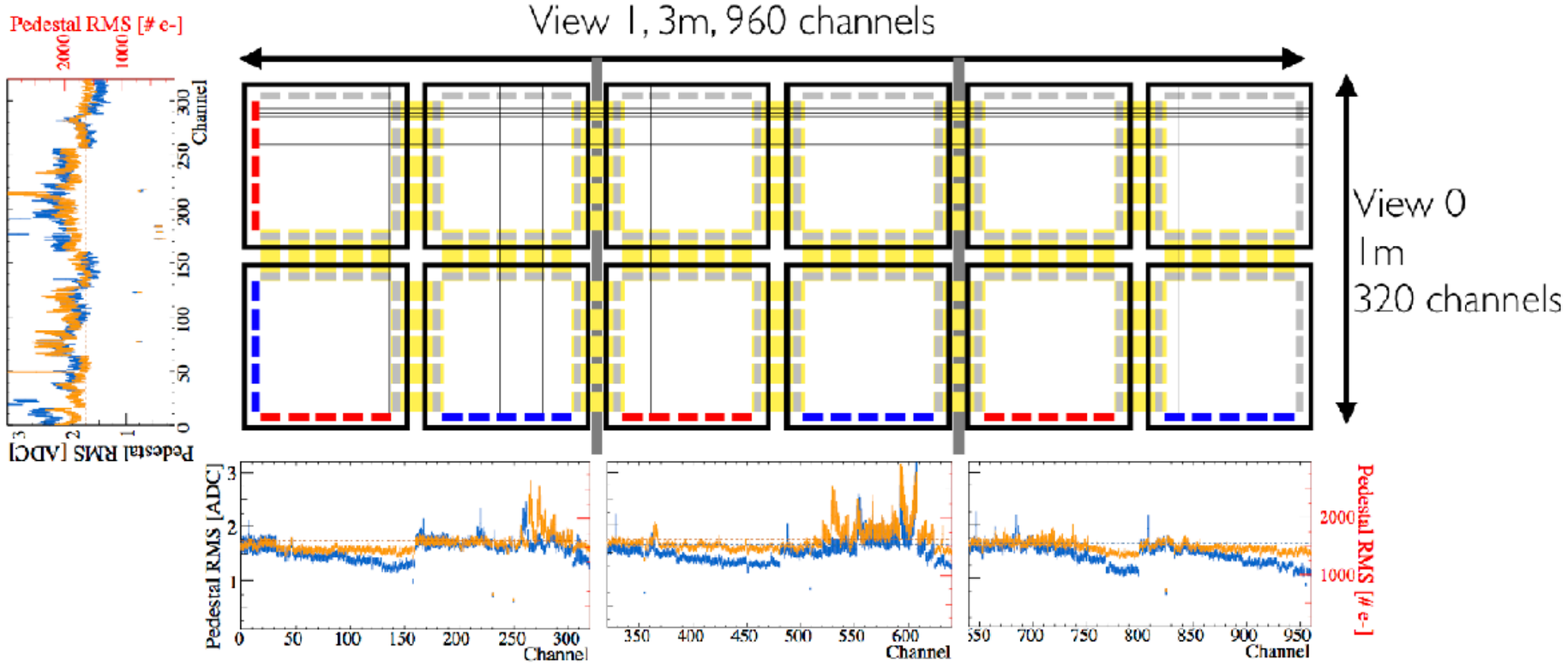


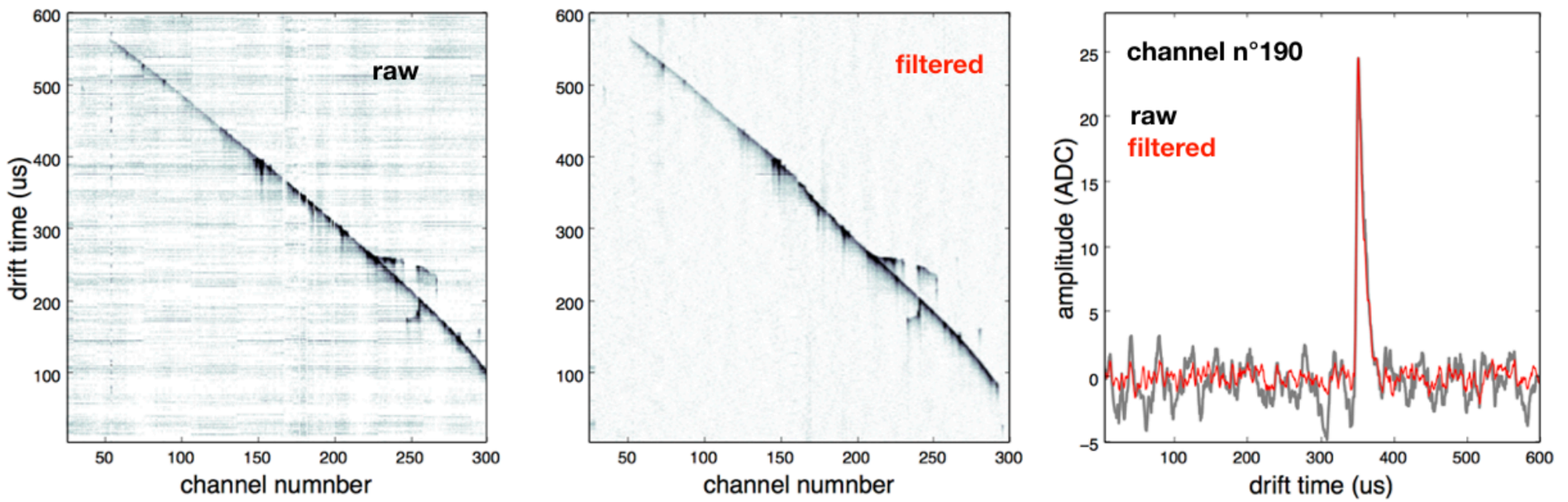
Slow component affects the expected waveform



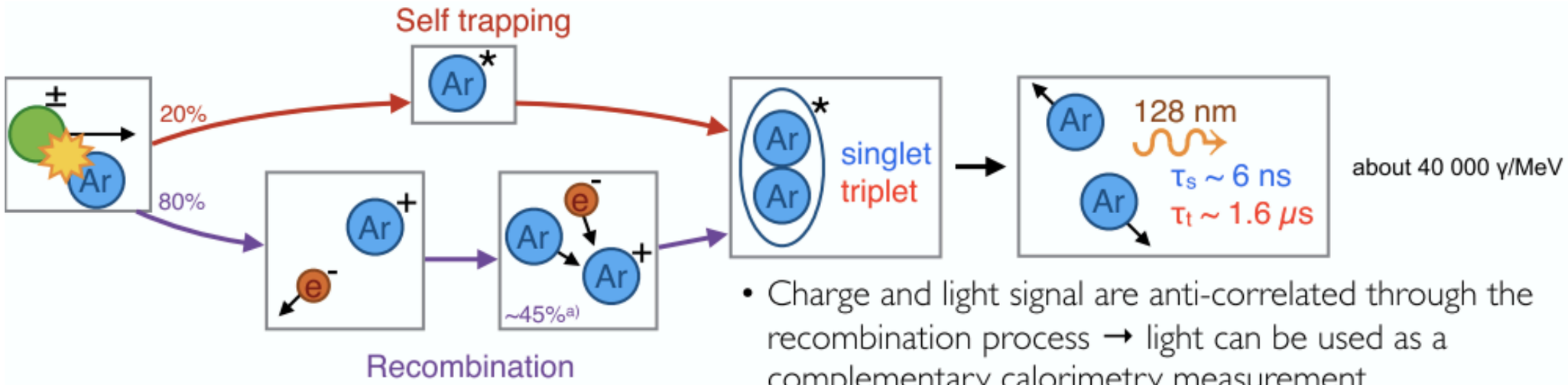
Noise level

Noise stable at cryogenic temperature at around 1550 e⁻



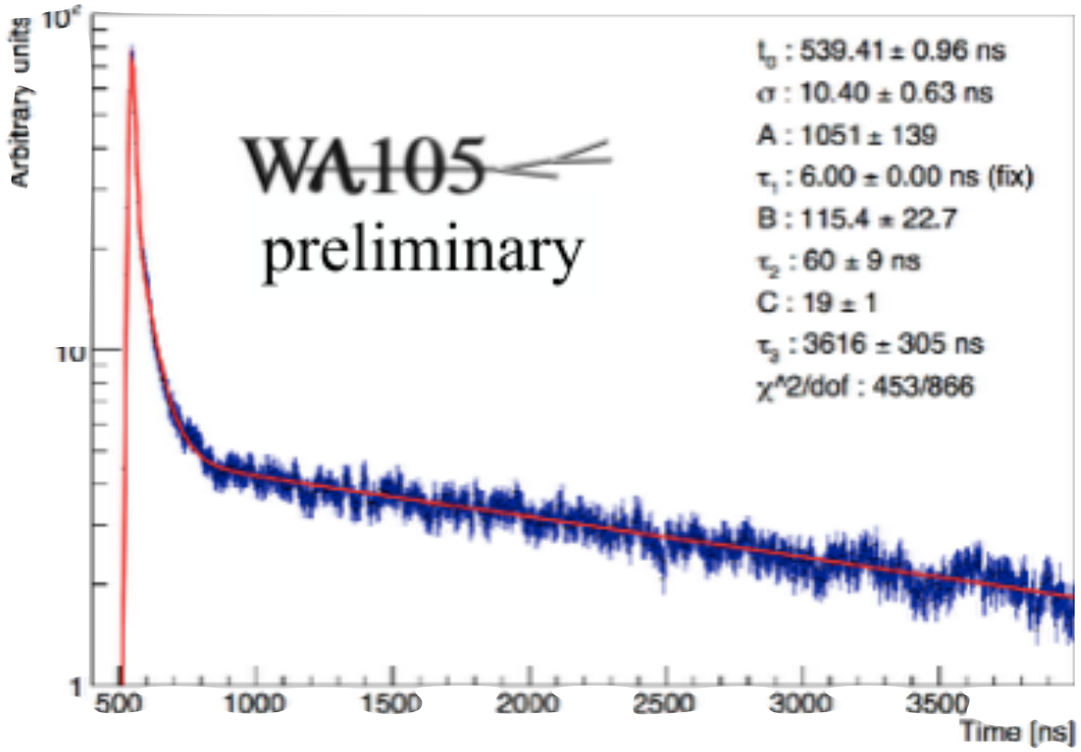


Light signal in Argon

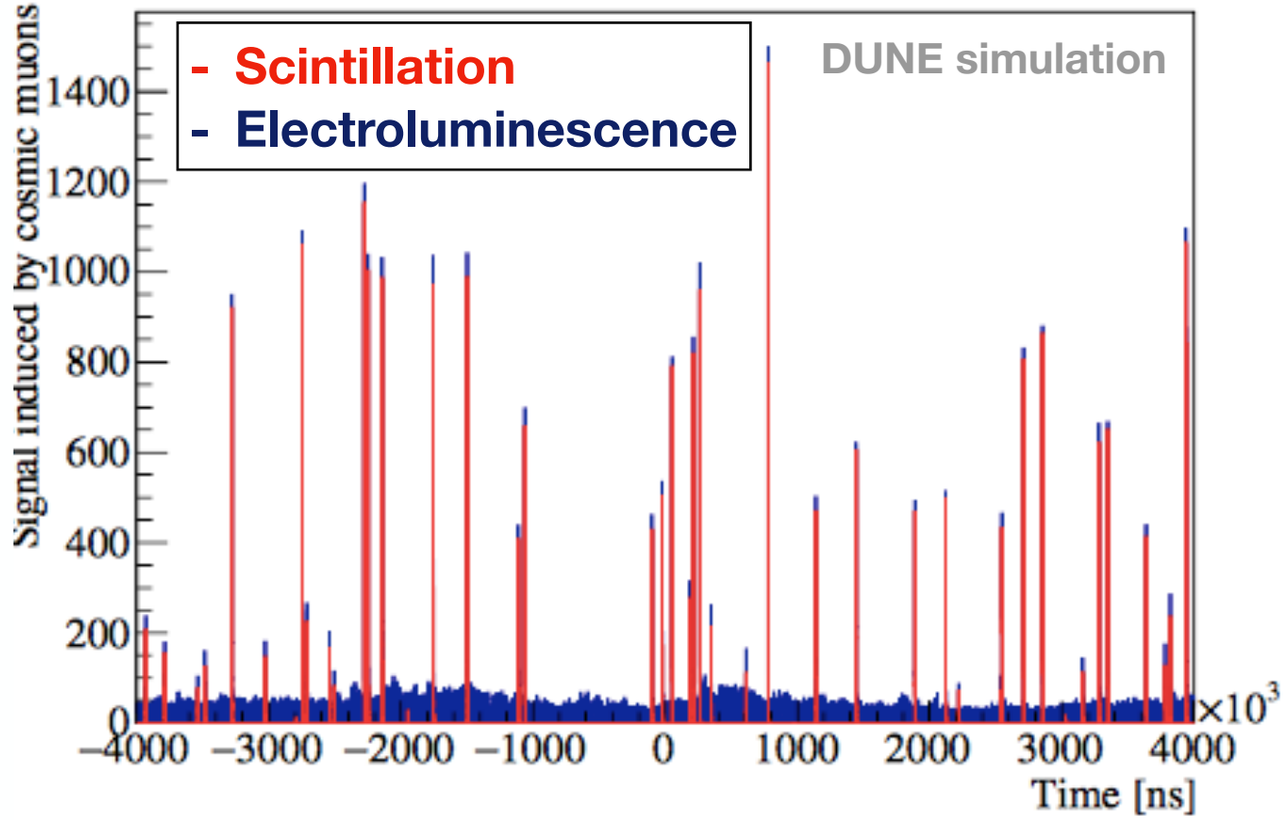


a) : at mip energy and Edrift = 0.5 kV/cm

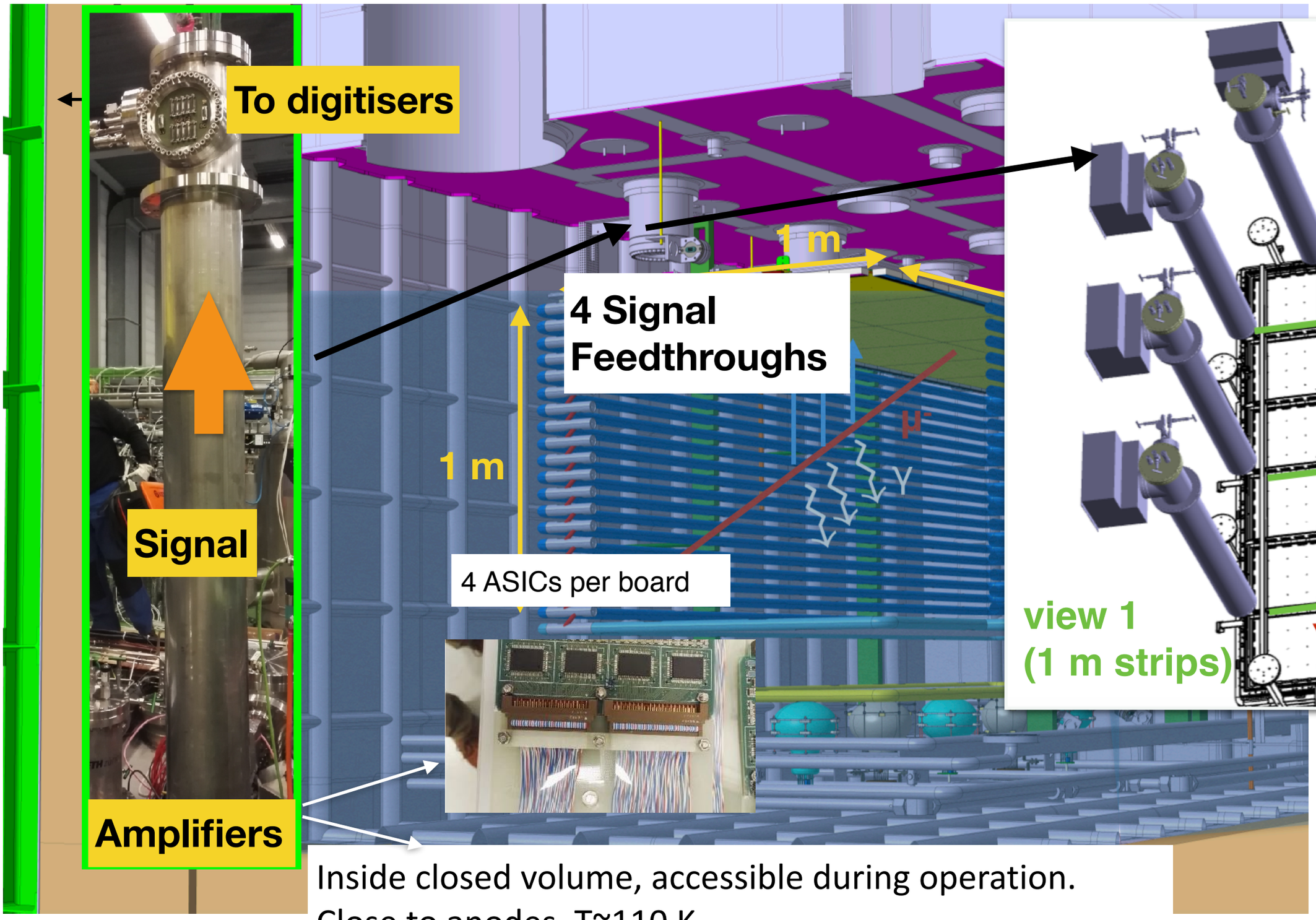
- Charge and light signal are anti-correlated through the recombination process → light can be used as a complementary calorimetry measurement
- The recombination factor depends on the drift electric field and dE/dx



Measurement in the 3x1x1 during detector cool down



Dual Phase FE electronics



Inside closed volume, accessible during operation.
Close to anodes, T~110 K

ProtoDUNE-SP: Beam

Table 6.1: Particle beam requirements. (Kaon rate is low for beam momentum below 2 GeV/c.)

Parameter	Requirements
Particle Types	$e^{\pm}, \mu^{\pm}, \pi^{\pm}, (K), p$
Momentum Range	0.5 - 7 GeV/c
Momentum Resolution	$\Delta p/p \leq 3$ %
Transverse Beam Size	RMS(x,y) $\approx$ 1 cm (At the entrance face of the LAr cryostat)
Beam Entrance Position	Beam # 3 (Figure 6.1) - Saleve side TPC
Rates	$\sim 25 - \sim 100$ Hz

B. Abi et al., The Single-Phase ProtoDUNE Technical Design Report. http://arxiv.org/abs/1706.07081

- Beam instrumentation:
  - Cherenkov threshold counters
  - pLAPPDs ToF detectors