ProtoDUNE Dual Phase: Design, Construction and First Results

ICHEP 2020

Guillaume Eurin

for the DUNE collaboration

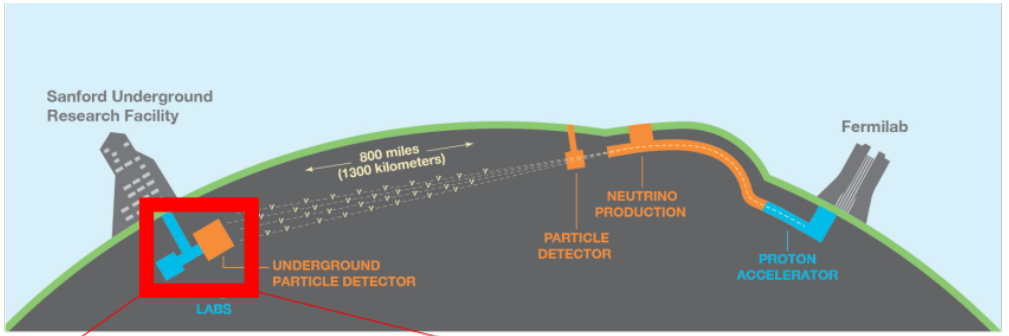
CEA-Saclay/IRFU

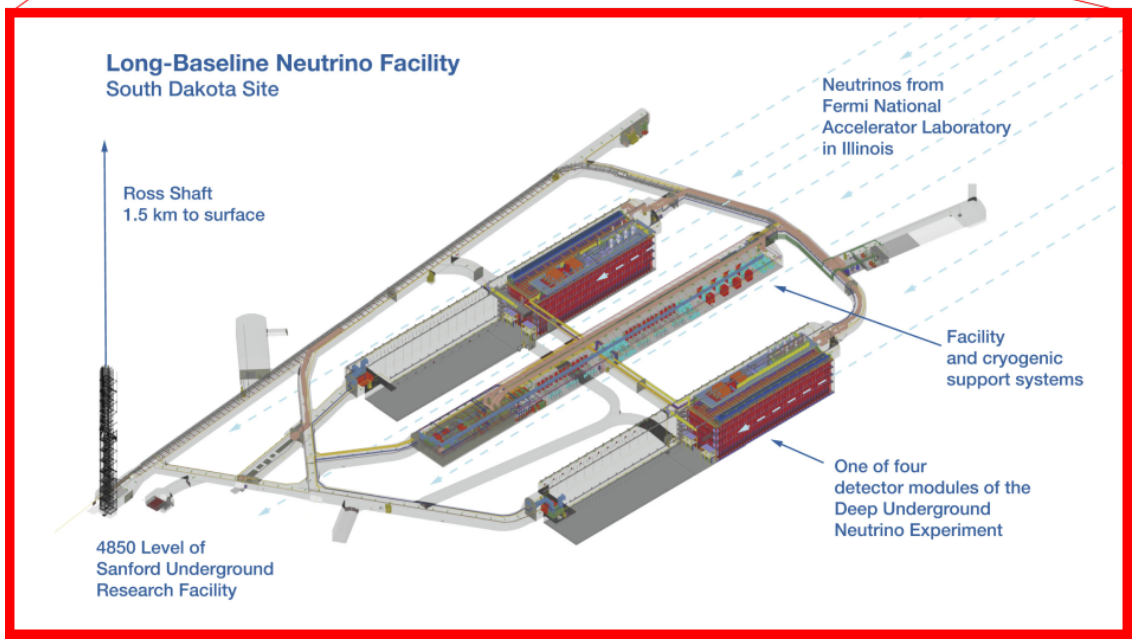
2020/07/29

Irfu
Institut de recherche sur les lois fondamentales de l'Univers

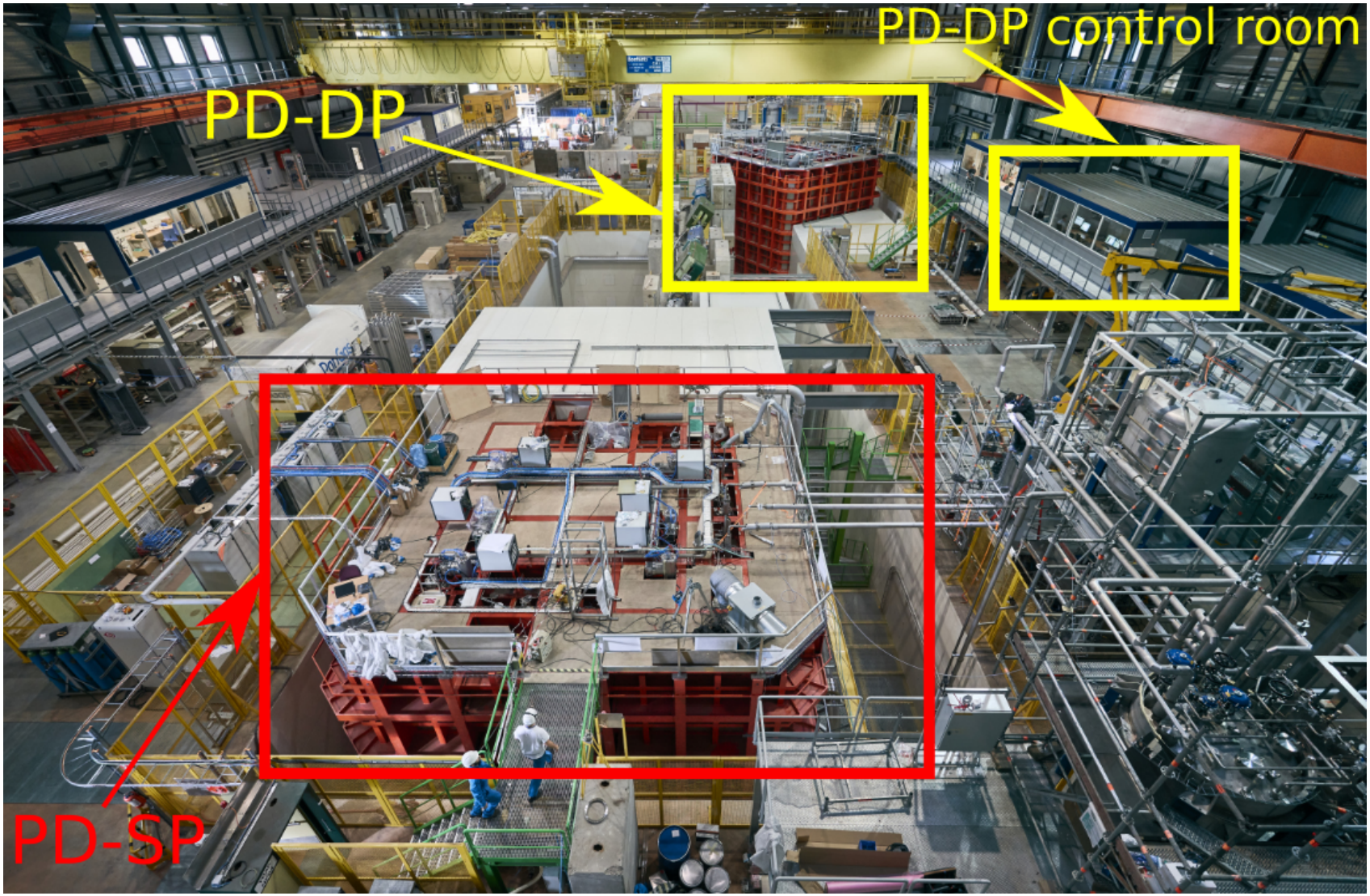
Deep Underground Neutrino Experiment

- Primary physics goals:
  - ν oscillations
  - δ_{CP}, θ_{23}, θ_{13}
  - **ν mass ordering**
  - Supernova burst neutrinos
  - BSM processes
- 4 $\times$ 17 kt LArTPCs **far detector** 1.5 km underground
- **ProtoDUNE-DP** and ProtoDUNE-SP: far detector LAr R&D program
- ProtoDUNEs installed at CERN neutrino platform

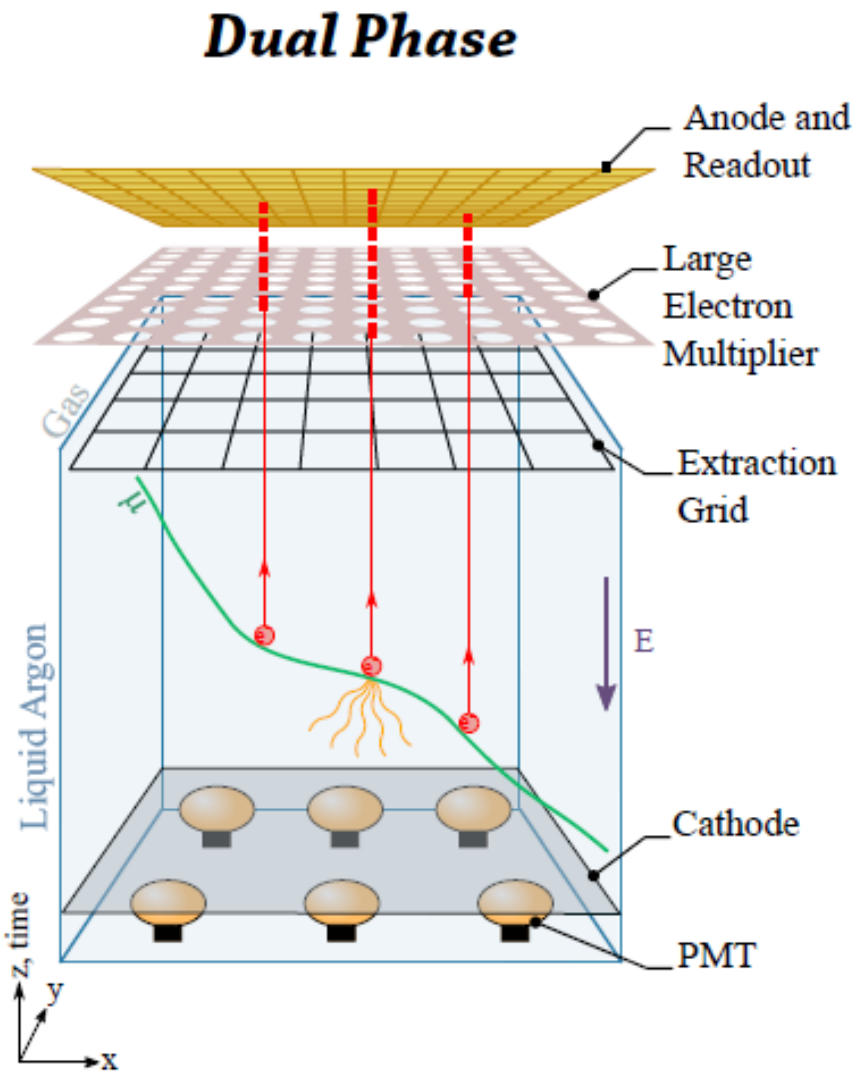




ProtoDUNE-DP @ CERN neutrino platform

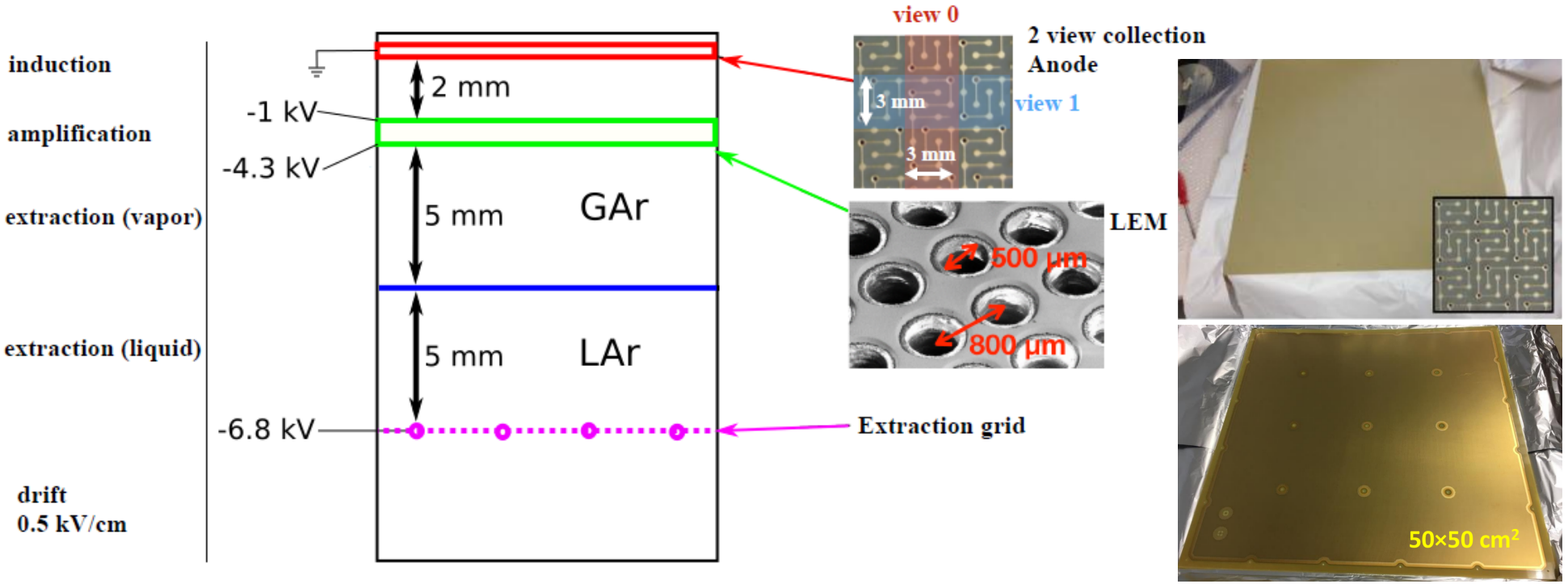


Operating principle of ProtoDUNE-DP



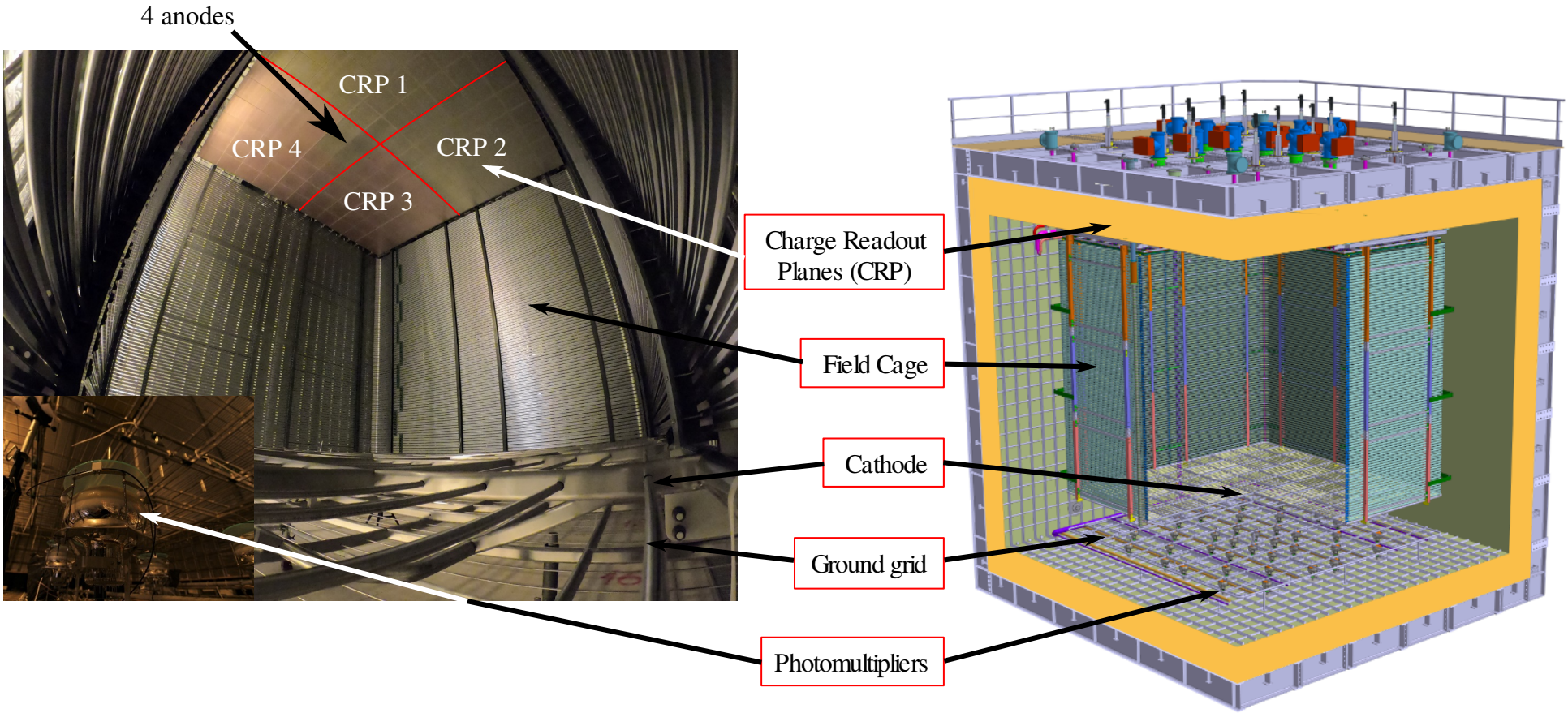
- Cryostat filled with 720 t LAr
- PMTs detect scintillation light at the bottom
- Electrons drifted vertically
- Electrons extracted from liquid into gas phase
- Charge signal amplified and read out at the top
- 3D track reconstruction

Operating principle of ProtoDUNE-DP



- Homogeneous 0.5 kV/cm drift field (cathode + field cage)
- Extraction field $\sim$ 2.5 kV/cm between grid and LEM bottom
- Amplification $\sim$ 20 in LEMs holes
- Readout in two directions (3.125 mm pitch) by collection on anode via field between LEM top electrode and anode
- Challenge: instrument large surface with small GAr/LAr gap

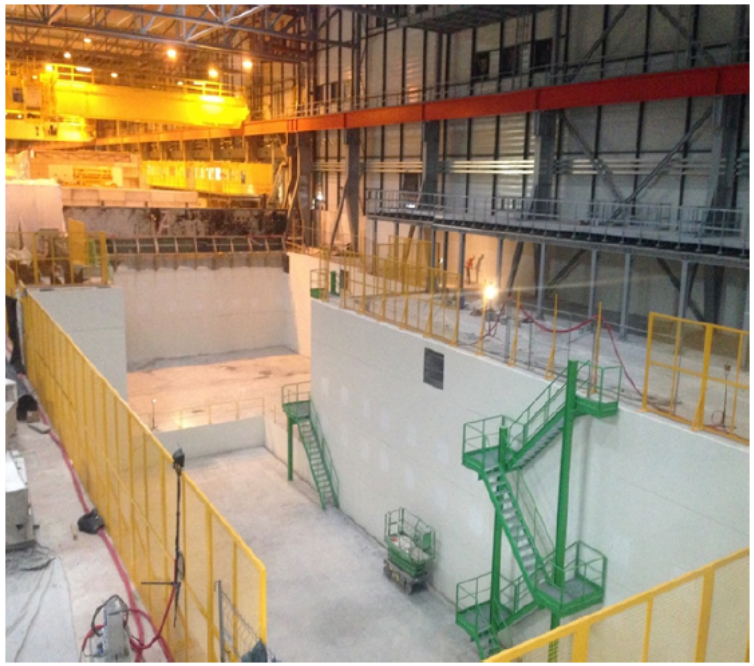
ProtoDUNE-DP @ CERN



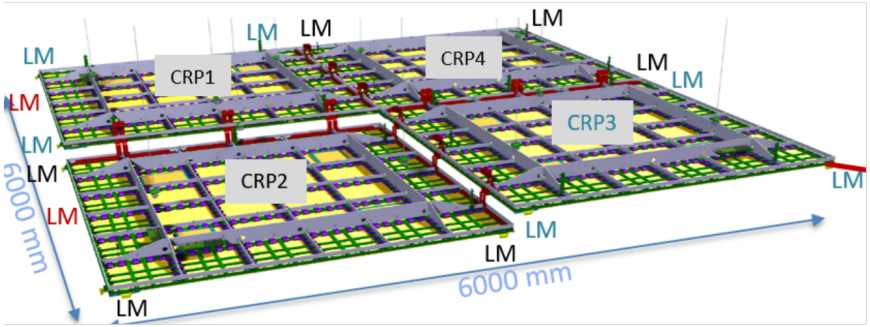
- Main detector components installed in March 2019
- Temporary Cryostat Opening closed in May 2019
- Manhole sealed in June 2019

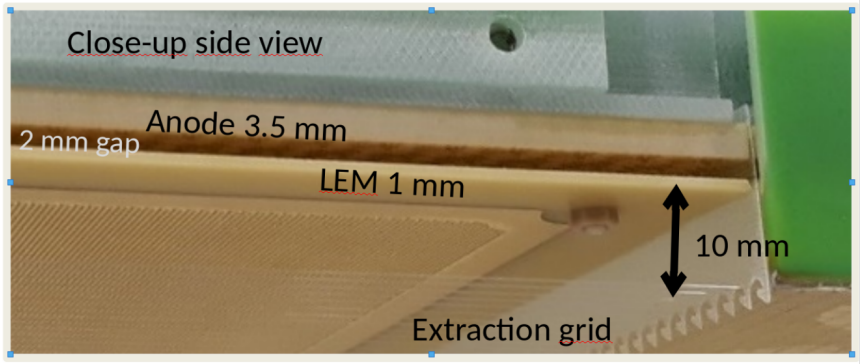
Commissioning of ProtoDUNE

- March 2017: start of construction of the cryostat
- 2018: Start of detector installation
- 13/06 - 04/07 2019: Cryostat closure then purge and cooling down
- 05/07 - 09/08 2019: LAr filling
- 12/08/2019: Start TPC commissioning
- 29/08/2019: First tracks from cosmics

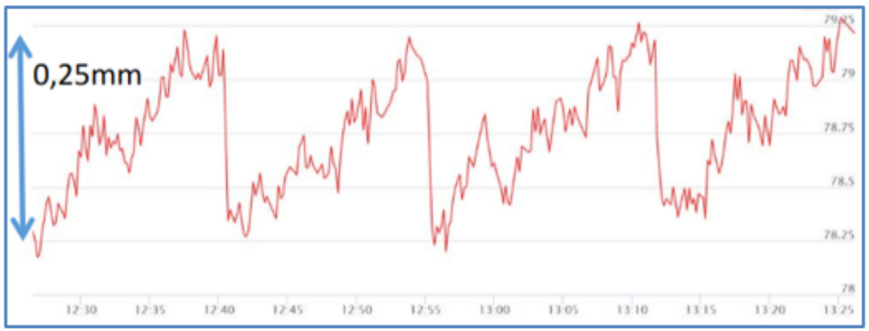


Charge Readout Planes and readout electronics



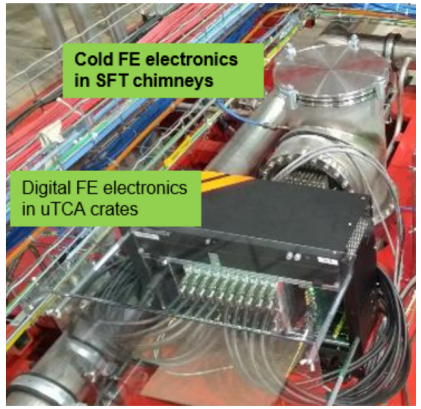


- CRP planarity of $\pm$ 2 mm

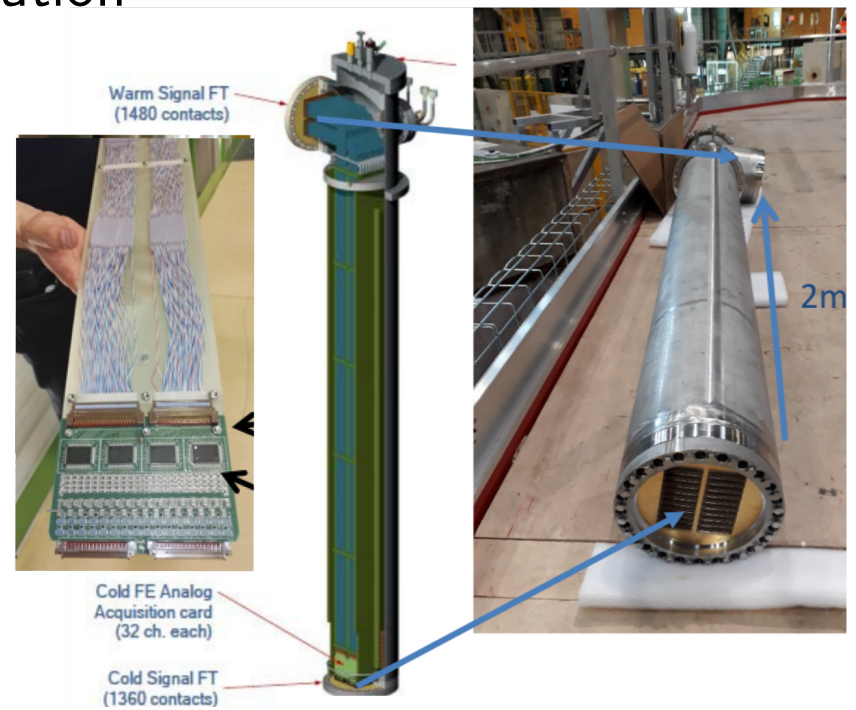


- Automatic tracking of the liquid level

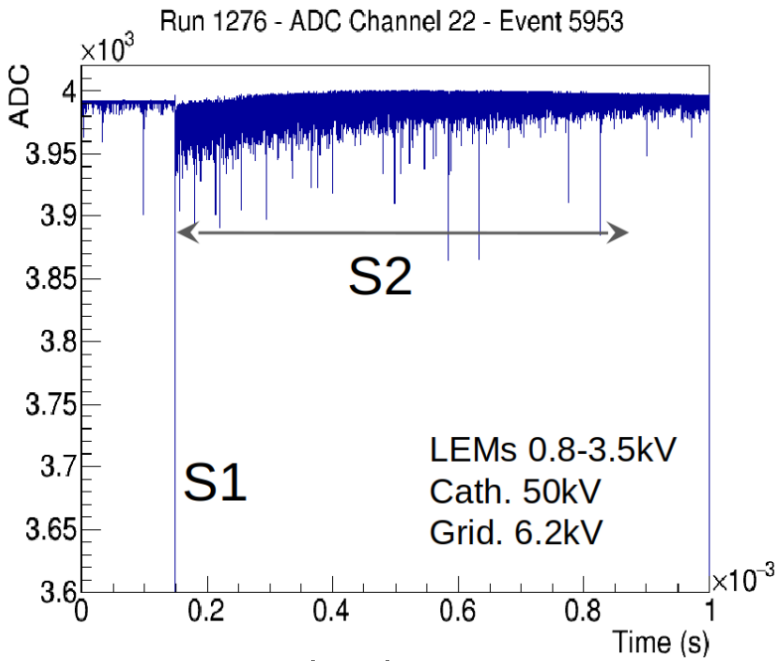
- 12 µTCA crates
- 10 digitizer cards per crate @ 10 GBit/s
- 64 channels per card



- FE cryo-amplifiers accessible during operation



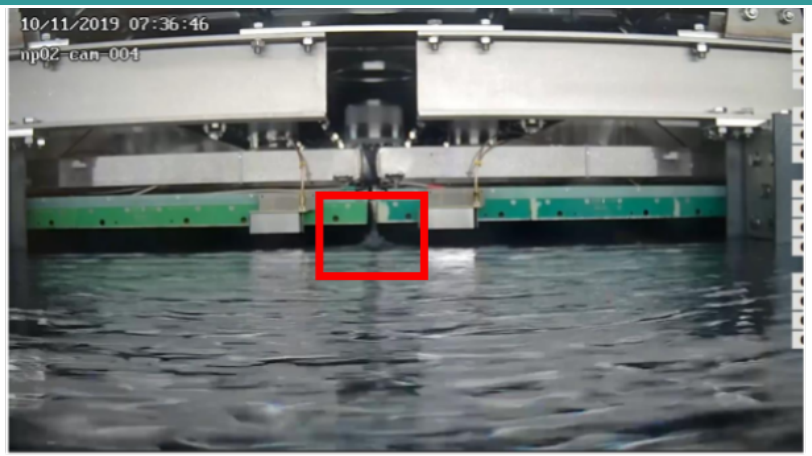
Photodetection system in ProtoDUNE-DP

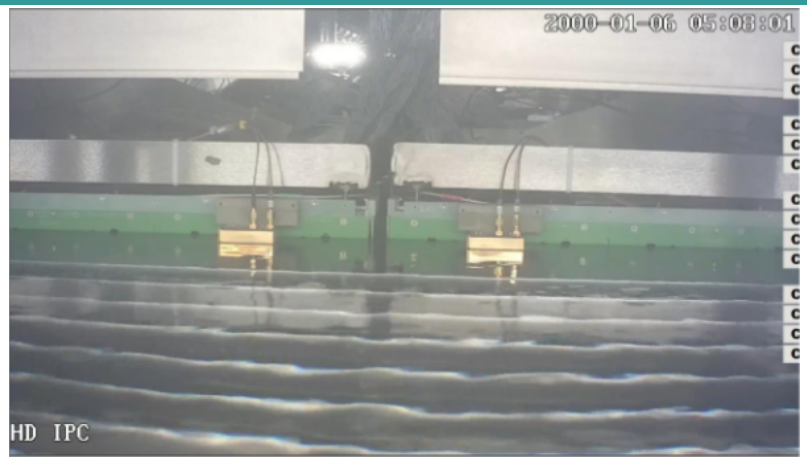


- Prompt (S1) and delayed (S2) electroluminescence

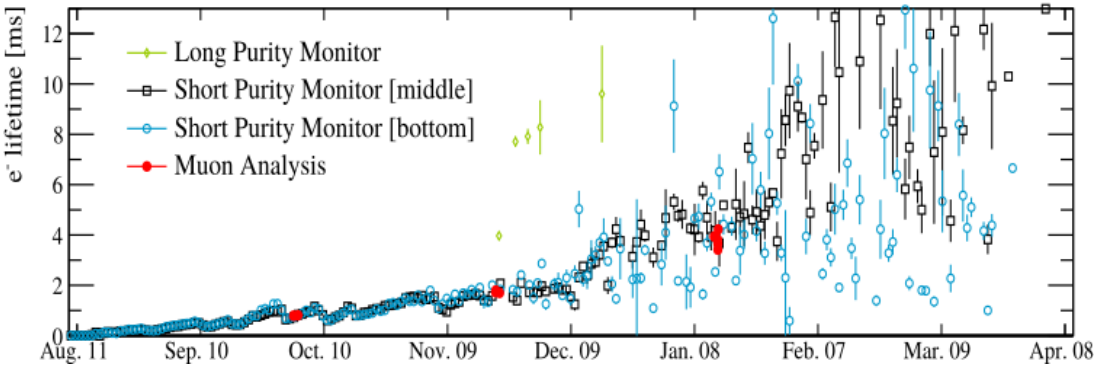
- 36 $\times$ 8" cryogenic PMTs Hamamatsu R5912-02-mod using wavelength shifter (PEN / TPB coating)
- Scintillation light measured since 06/19
- Position optimized for light collection in cosmic rays events
- Light Calibration System for PMT stability estimation using blue LEDs and optical fibers
- S/N $>$ 11 for SPE at G $= 10^7$ (requirement of S/N $>$ 5)
- Analyses: performance (PEN/TPB efficiency, timing resolution), light propagation, muon detection, SPE background

Cryogenics conditions and argon purity





- Bubbles and waves: location known but origin unclear
- Liquid surface instabilities mitigated by high pressure cycles

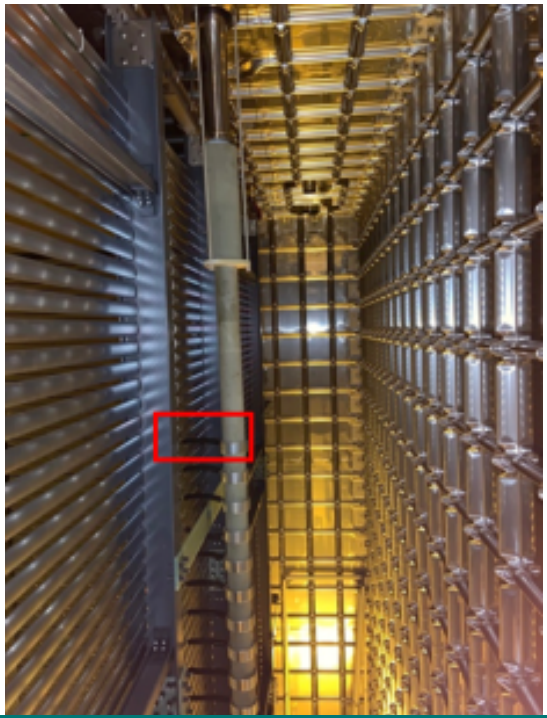


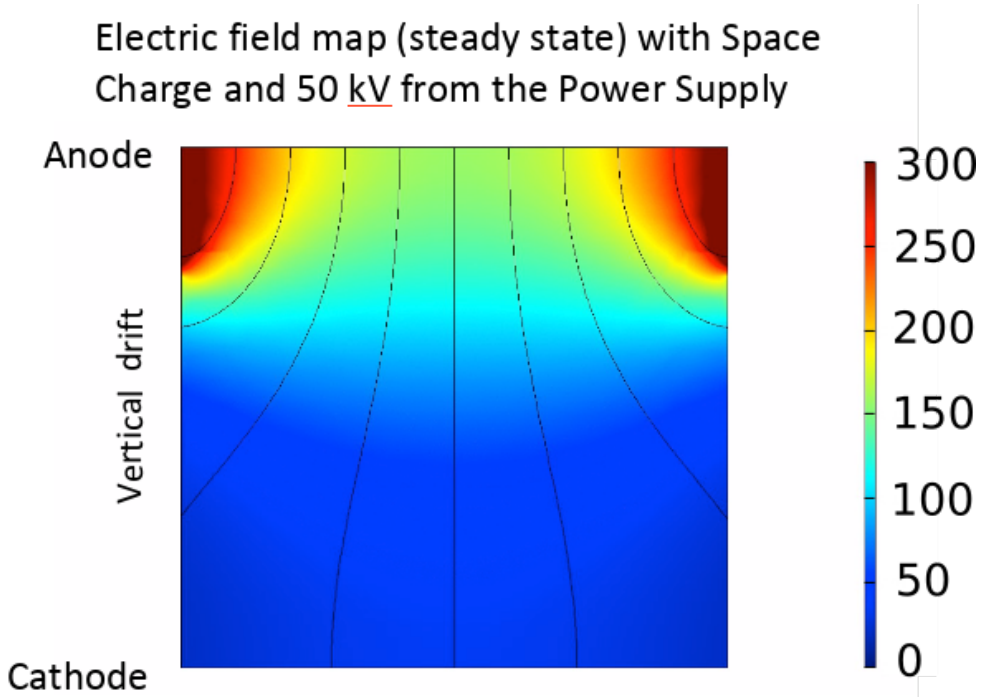
- 3 purity monitors:
  two *short* 17 cm-long and one *long* 48 cm-long
- Required electron lifetime of 3 ms exceeded

- Filter clogging issues in LAr recirculation, improved in November 2019

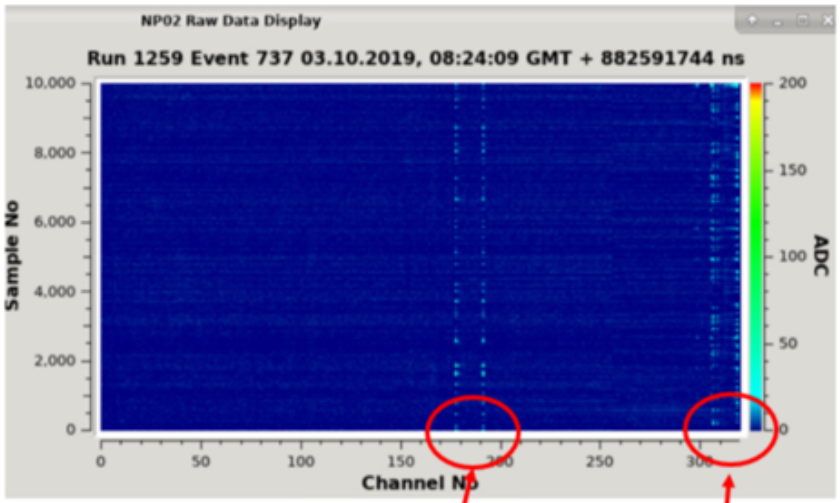
Electric field inhomogeneity in ProtoDUNE-DP

- Short between field cage and HV extender (08/19)
  $\Rightarrow$ electric field very inhomogeneous
- Different electric field could impact TPC performances (recombination, electron velocity, etc.)
- Reparation of HV extender performed in June 2020
  $\Rightarrow \sim$ 1.5 m of LAr removed and faulty connection cut
- New data taking next August



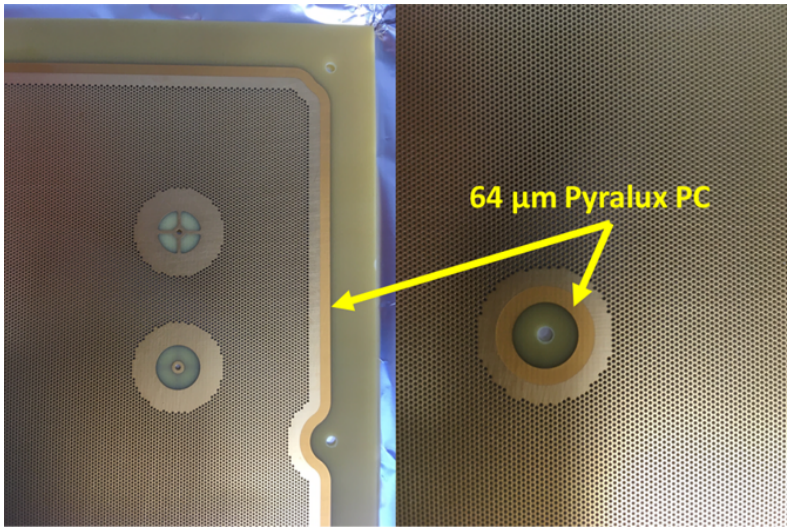


Sparking and PD-DP Phase II improvements



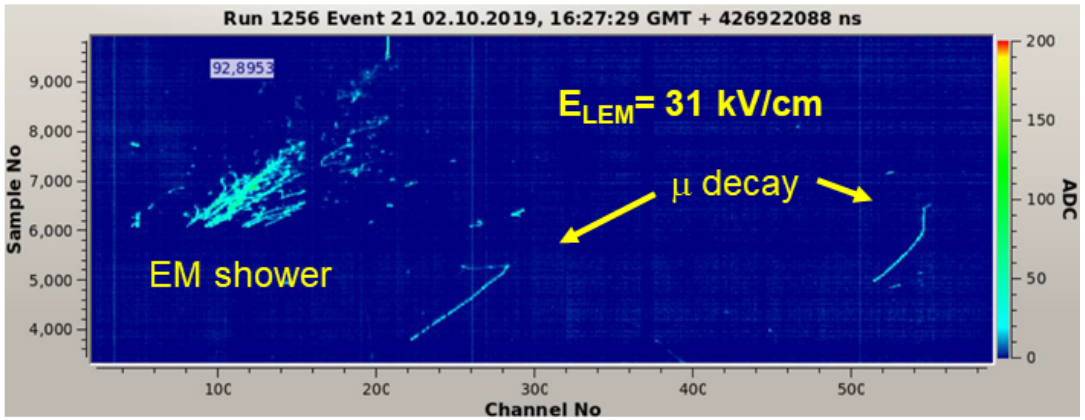
- 6kV extraction grid sparking
  $\rightarrow$ damages to FE electronics
- Origin unclear: grid wires immersed by 4-5 mm in LAr
- Extensive HV stability tests
- Anode re-designed to protect FE (guard ring)

- LEM sparking rate target:
  $\leq$ 1 spark/CRP/hour not achieved
- LEM re-designed to reduce sparking:
  - Insulator around edges and fixation
  - Segmented and resistive LEMs under study (reduce sparking energy)

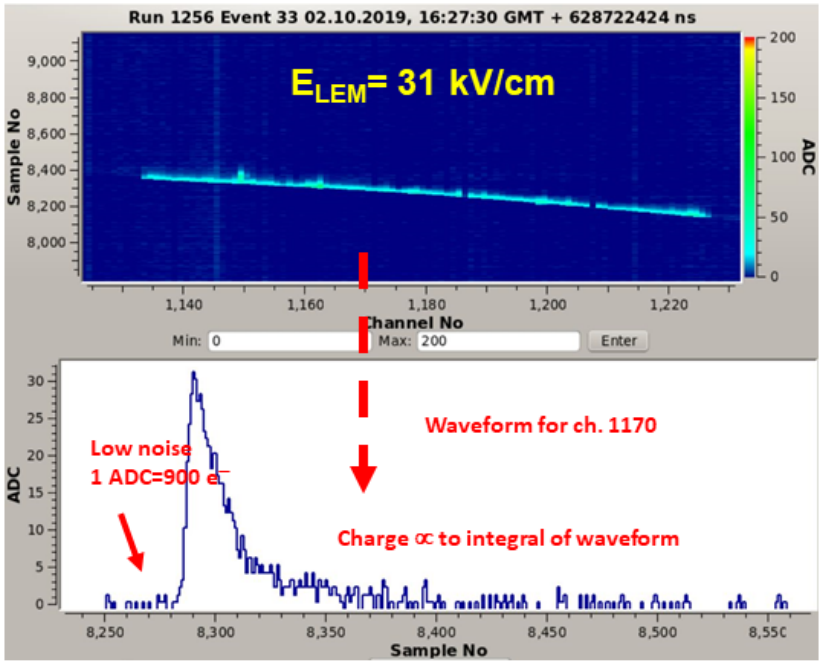


Cosmic ray events recorded in ProtoDUNE-DP

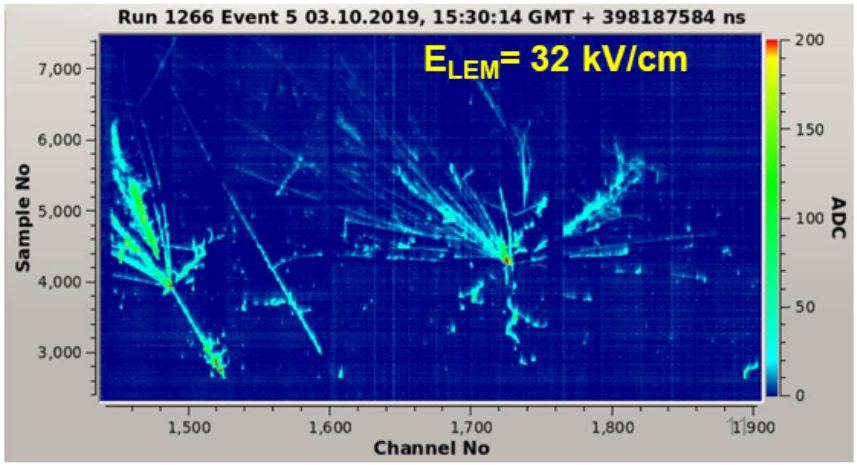
- Events with LEM ΔV of 3.1-3.2 kV (October 2019)
  - Electromagnetic shower + 2 muon decays



  - Horizontal muon track

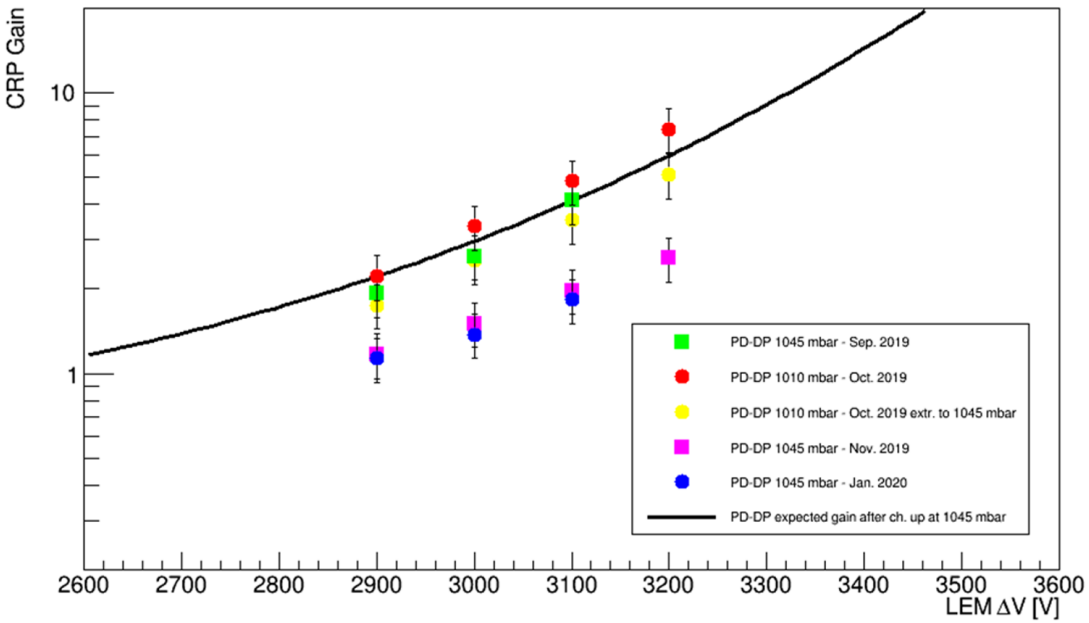


  - Multiple hadronic interactions in a shower



Charge Readout Plane gain measurement

- Measurements between September 2019 and January 2020 with cosmics
- Operating conditions: 1045 mbar and $\sim$ 90 K
- CRP gain: $\epsilon_{\text{extraction}} \times G_{\text{LEMs,amplification}} \times \epsilon_{\text{Q collection}}(E_{\text{induction}})$
- $\epsilon_{\text{extraction}}$ estimated to be well above 90%



- September $\rightarrow$ November: Reduction by at least a factor of 2 due to LEM charging up effects
- November $\rightarrow$ January: very small reduction: charging up completed

- Gain a factor of 2 lower than extrapolated from previous prototypes

(https://arxiv.org/abs/1412.4402)

- Discrepancy not yet understood, dedicated study to come

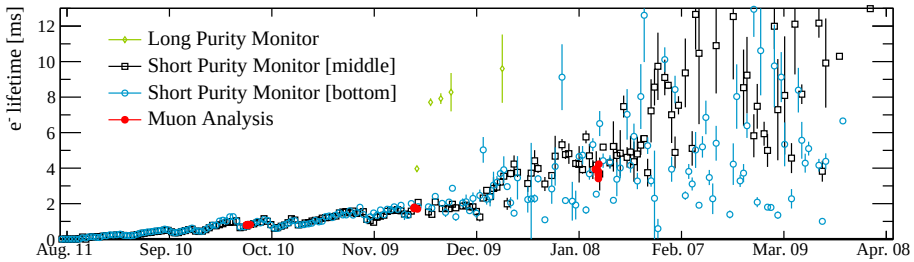
Conclusions and outlook

- PDDP: proof of principle achieved for 300 t DLAr TPC over 3×3 m^2 CRP units
- Short on HV extender fixed in June
- CRP gains lower than expected, needs to be understood
- LEMs R&D campaign in progress (2020-2022) for ProtoDUNE-DP Phase II
- Upgrade of CRPs (anode, LEMs, grids fixation, planarity) to tackle HV instability
- Origin of LAr surface instabilities needs to be understood
- Foreseen LEMs/CRPs improvements should allow 10 kt DP module far detector for DUNE feasibility to be demonstrated

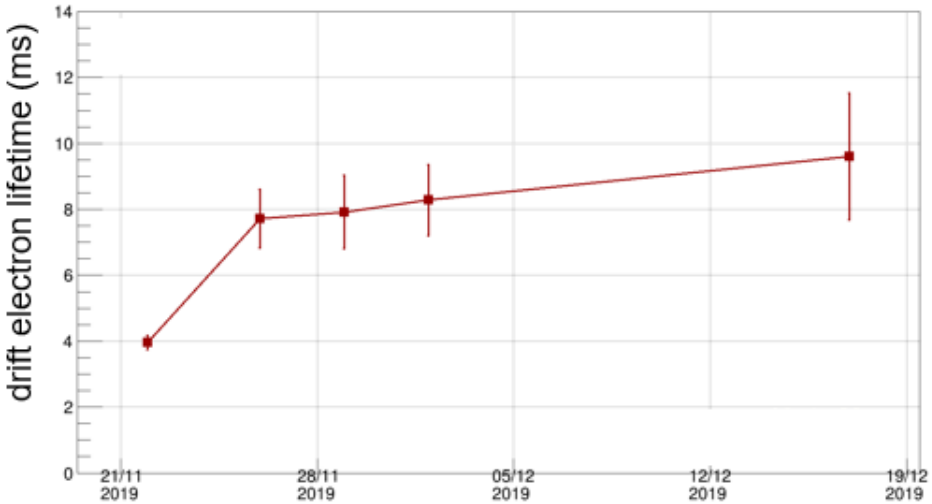
Thank you for your attention!

Argon purity in ProtoDUNE-DP

Purity measurements from short purity monitors



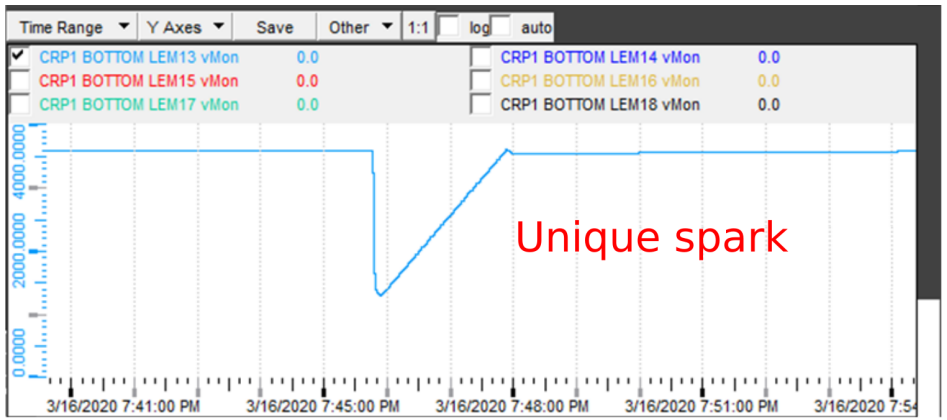
Purity measurements from long purity monitor

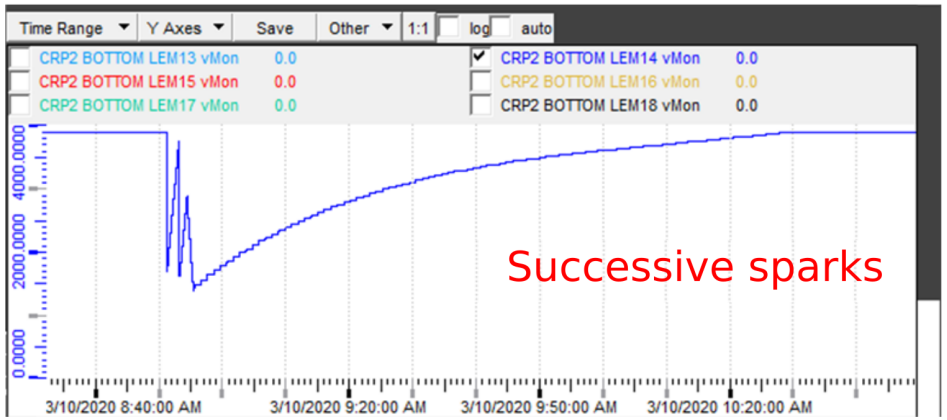


- 3 purity monitors (two *short* 17-cm long and one *long* 48cm-long)
- Since November 2019, short purity monitors sensitivity reached
- Long purity monitor more sensitive
- Discrepancies between long and shorts under investigation
- According to long monitor, electron lifetime larger than 7 ms since November and increasing

Slow control and LEM sparking

- Cold box: no automated protection of LEMs
  $\Rightarrow$ carbonization on several LEMs from continuous discharges
- Two types of LEMs spark events: unique and successive
- In ProtoDUNE-DP, automatic reduction of HV from slow control:
  - $\sim$ 50 V for unique sparks
  - up to 2.5 kV + slow ramping up for successsive sparks (carbonization)
- Recovery time for a unique spark $\simeq$ 2 minutes
- Dead time for successive sparks of up to 2 hours





- $\sim$ 8 % of sparking events are successive sparks in standard operation

LEMs sparking rates analysis

- LEMs sparking rates per hour normalised to a full CRP
- Numbers in grey given as an indication (different ΔV or number of LEMs, earlier period)

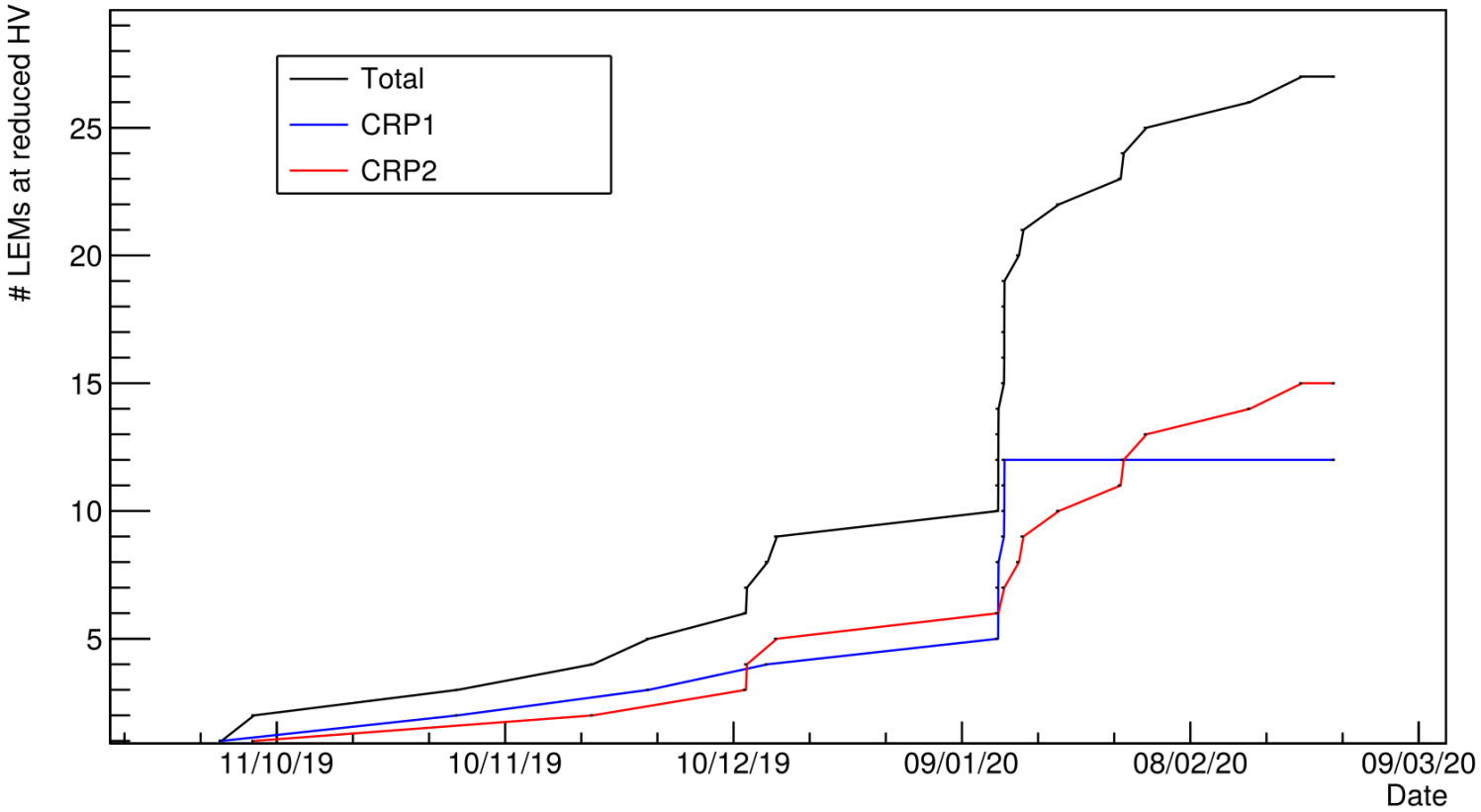
Spark/CRP/h	Extraction	Cathode	R = 0	R = 10 MΩ	R = 500 MΩ
CRP1 $\Delta V = 3.1$ kV	ON	ON	1.4 ± 0.2	2.9 ± 0.3	*4.6 ± 0.5*
		OFF	1.9 ± 0.2	2.6 ± 0.2	1.0 ± 0.2 — *1.6 ± 0.2*
		ON - OFF	-0.5 ± 0.3	0.3 ± 0.3	*3.0 ± 0.5*
	OFF	ON		*1.2 ± 0.3*	*1.3 ± 0.3*
		OFF		*0.4 ± 0.2*	*0.3 ± 0.1*
		ON - OFF		*0.8 ± 0.3*	*1.0 ± 0.3*

CRP2 $\Delta V = 3.4$ kV	Extraction	Cathode	R = 0	R = 10 MΩ	R = 500 MΩ
	ON	ON		5.9 ± 0.5	4.7 ± 0.6
		OFF		6.2 ± 0.6	3.9 ± 0.7
		ON - OFF		-0.3 ± 0.8	0.8 ± 0.9
	OFF	ON			5.4 ± 0.5
		OFF			0.9 ± 0.2
		ON - OFF			4.4 ± 0.6

- Larger ΔV across the LEMs $\Rightarrow$ higher sparking rate
- With extraction: no visible contribution of drift field
- Current limiting resistors value impact sparking rates
- The extraction field seems to increase the sparking rate

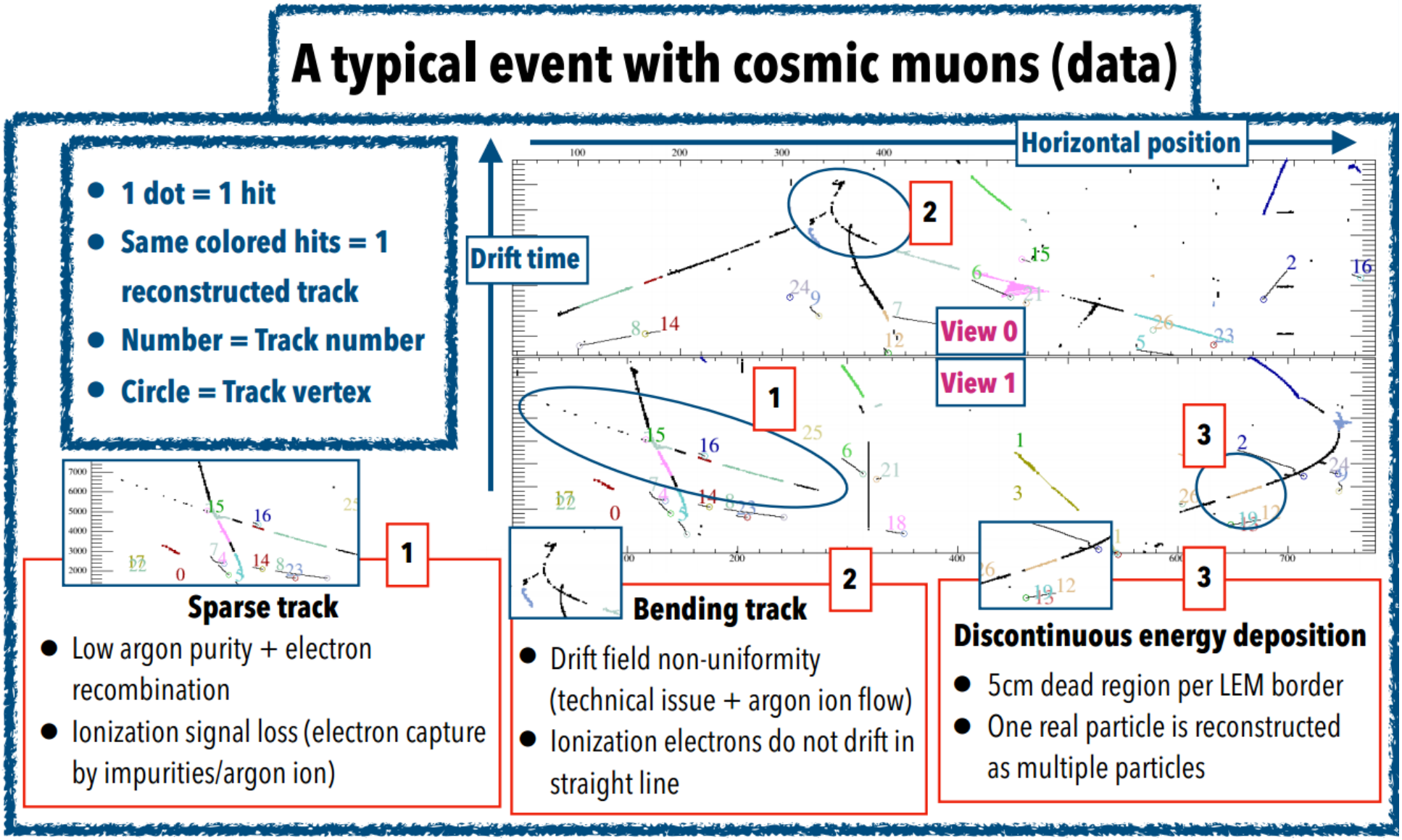
LEMs aging during ProtoDUNE-DP operations

- Increasing number of LEMs with nominal ΔV below 2.9 kV



- To this date, 27 LEMs limited to $\Delta V = 2.9$ kV or less

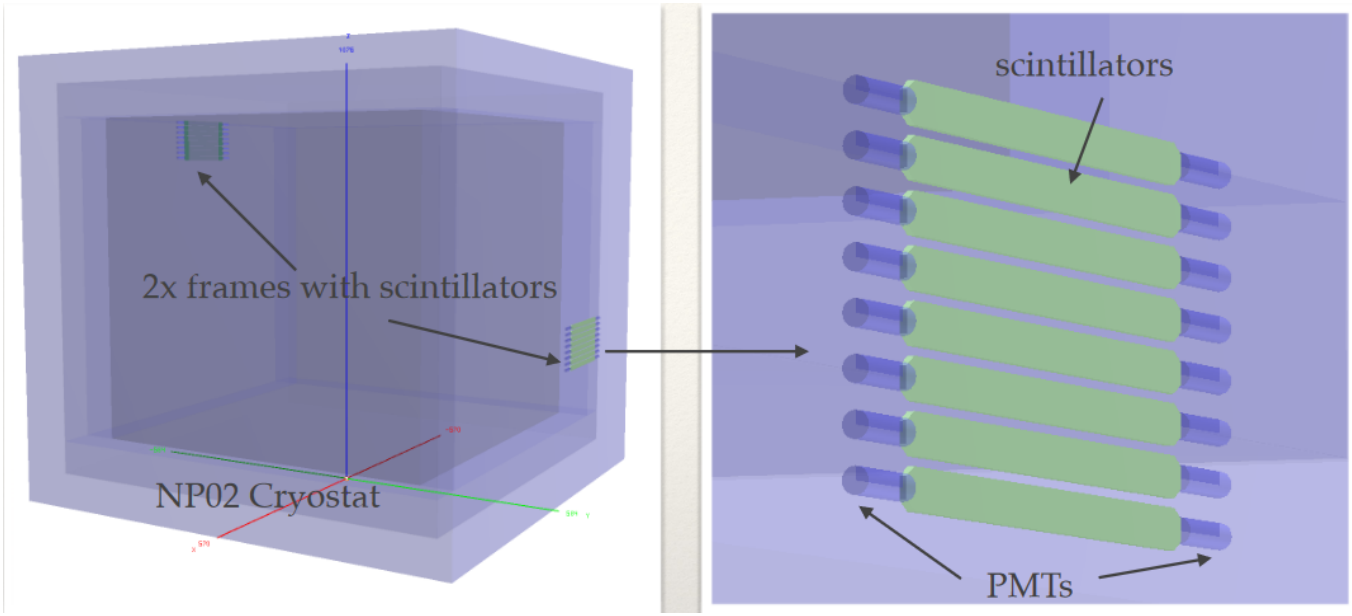
Events reconstruction with Pandora



E. Chardonnet, Neutrino 2020

Cosmic Ray Tagger (CRT)

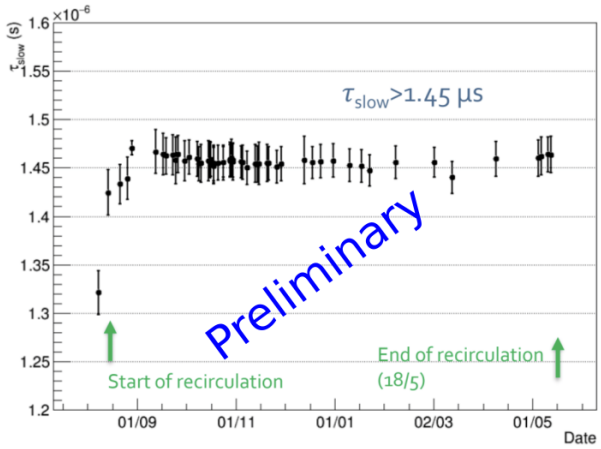
- 2 Cosmic Ray Tagger planes installed in November 2019
- 8 scintillator paddles covering 1 m^2
- 32 PMTs read out by custom μTCA system
- Top: side of CRP2 close to LAr surface
- Bottom: close to the cathode, next to CRP1



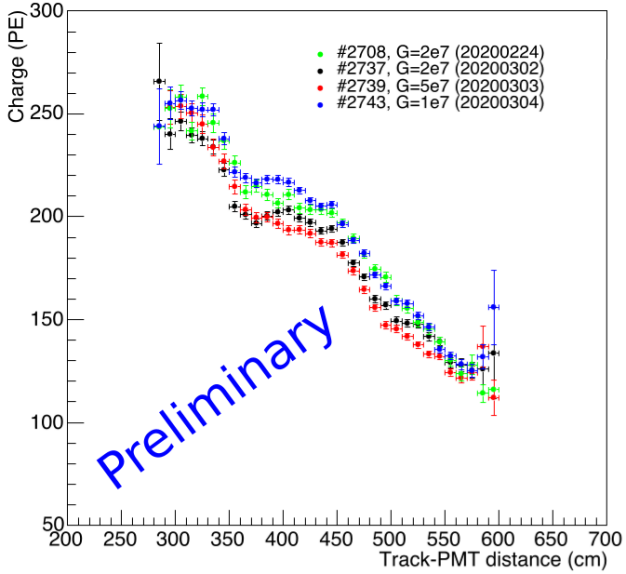
Light data analysis

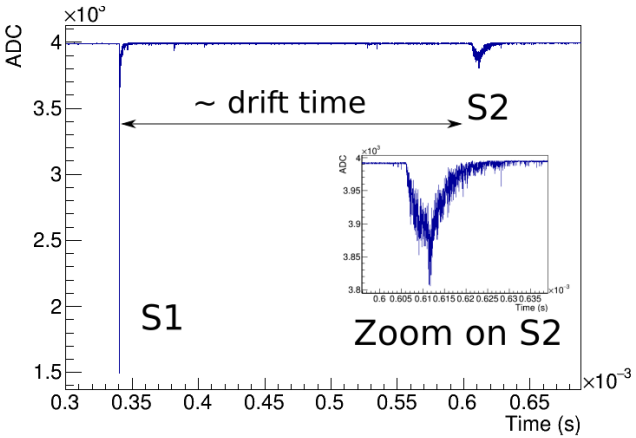
- ProtoDUNE-DP PDS performance:
  - τ_{slow} component as LAr purity indicator
  - Timing accuracy < 16 ns
  - PEN/TPB performance comparison
- Light propagation in LAr in different drift field condition
- Muon detection:
  - Muon (S1) rate
  - CRT muon track study
  - Data-Monte Carlo comparison
- Low energy background
- Electroluminescence light (S2) detection

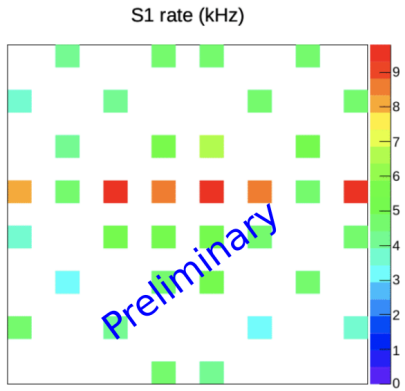
- LAr purity (τ_{slow})



- CRT muon tracks



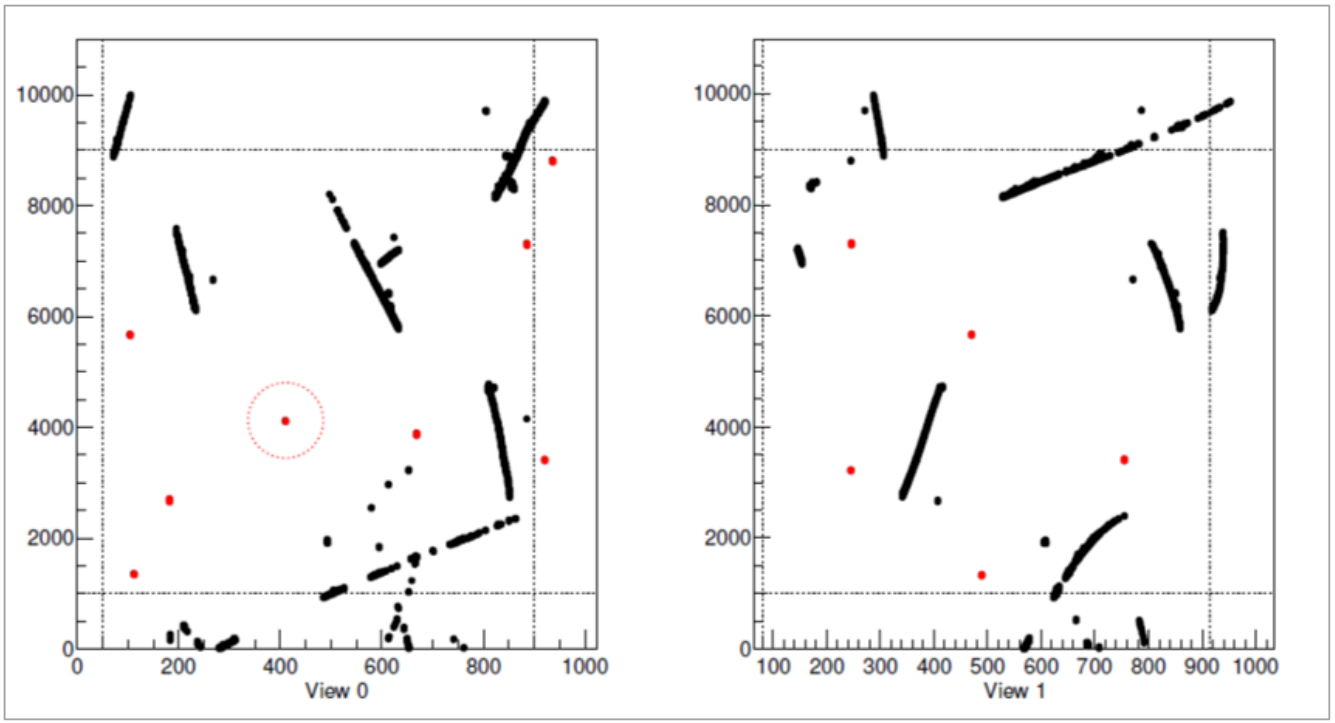




*Top view, each bin represents a PMT at its position in the detector.

^{39}Ar analysis with ProtoDUNE-DP

- ^{39}Ar naturally and homogeneously present in Ar: decay rate per CRP $= 1.5 \times 10^4$ Bq
- Charge deposition constant with time $\Rightarrow$ calibration of LEM gain and monitoring of space charge effects



- Events selected as isolated hits matched in the two independent views
- Charge sharing between views evenly centered around 50 %

Technical issues

- Short-circuit between VHV cable and 21st ring of field cage
  $\Rightarrow$ Inhomogeneous electric field
  $\Rightarrow$ maximum 150 kV
  (50 kV standard, 70 & 90 kV recently tested)
  $\Rightarrow$ Should be fixed soon but challenging
- Surface instabilities:
  - Short pressure increase of 35 mbar performed every few days
  - Eliminates bubbles from top of field cage and HV feedthrough
  - Briefly eliminates waves on liquid surface
- Cryogenics instabilities could correlate with CRPs instabilities
- Cold filters clogging initially requiring cleaning every 10 days
  $\Rightarrow$ No more clogging after last intervention in November 2019
- Purity level systematics to understand
- Several electronics channels damaged by grid sparks