Commissioning of ProtoDUNE-DP (NP02) & LEM Development

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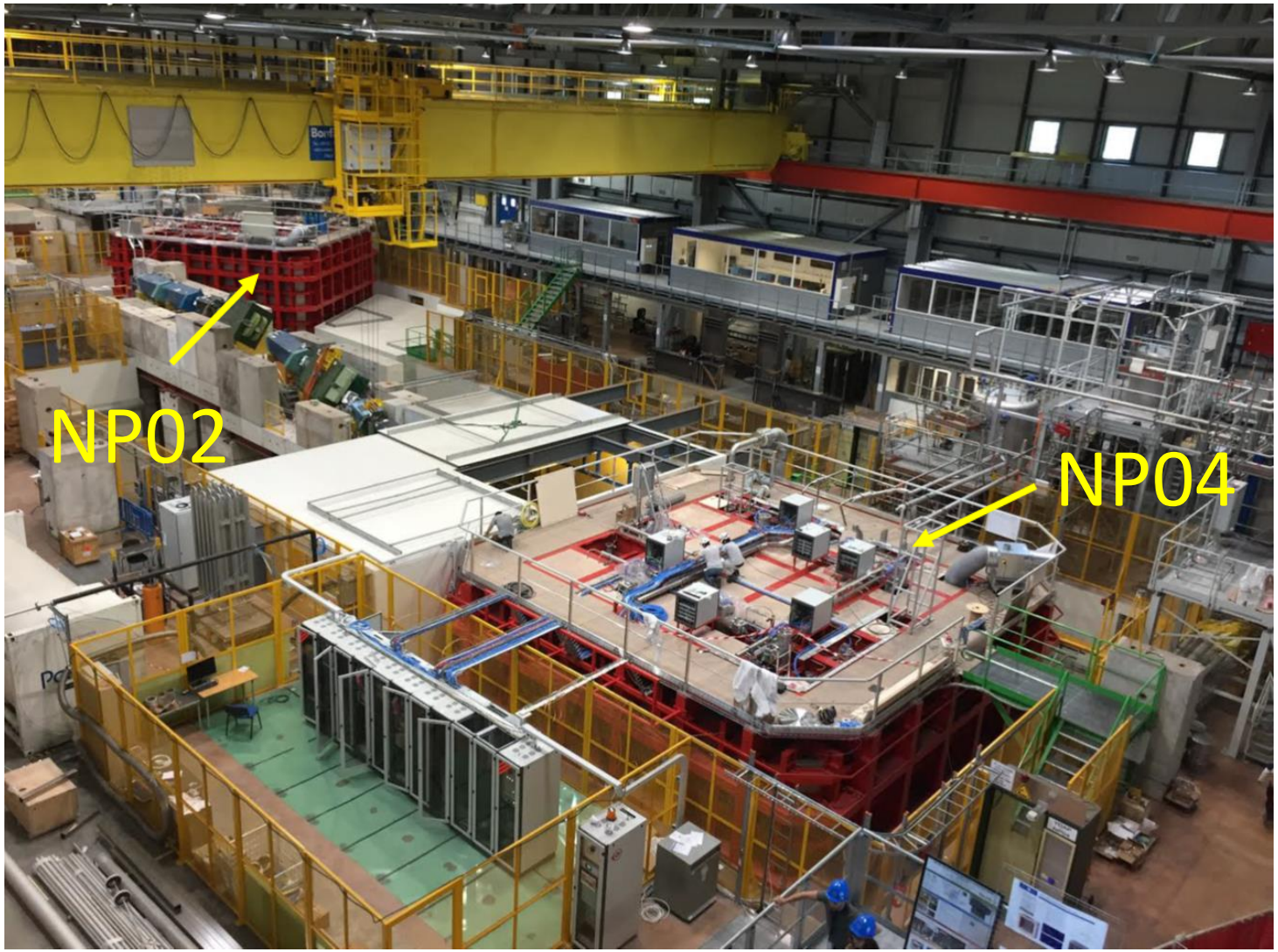
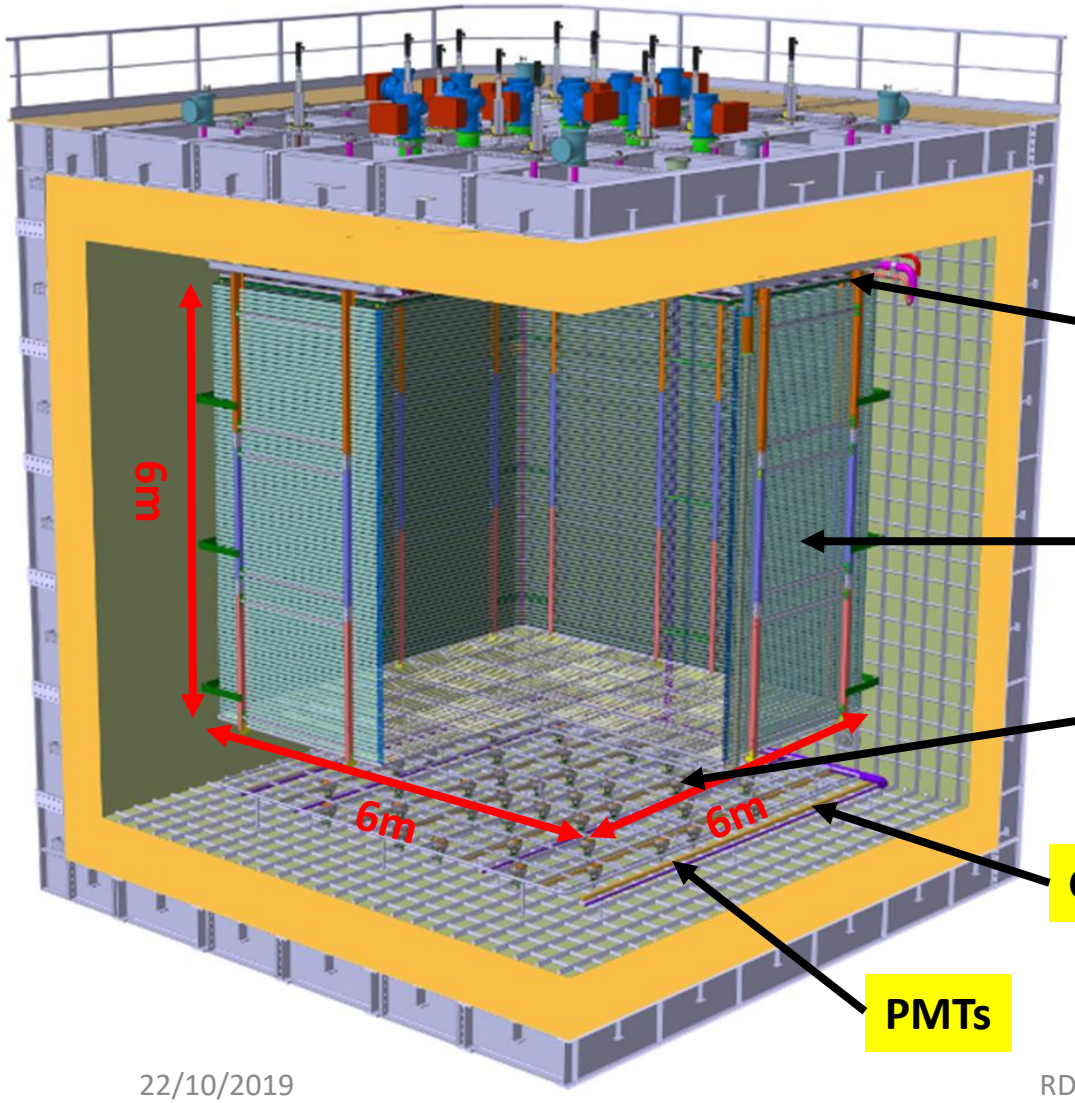
ProtoDUNEs @ CERN EHN1

- Two large (> 700 t) LArTPC prototypes built at the CERN Neutrino Platform.
- LAr technologies for the future DUNE 10kt ν FD modules in U.S.A. :
  - ProtoDUNE-SP or NP04 (single phase) in operation since Sept. 2018.
  - ProtoDUNE-DP or NP02 (dual phase) in commissionning phase since Aug. 2019.



ProtoDUNE-DP : a 300t LArTPC



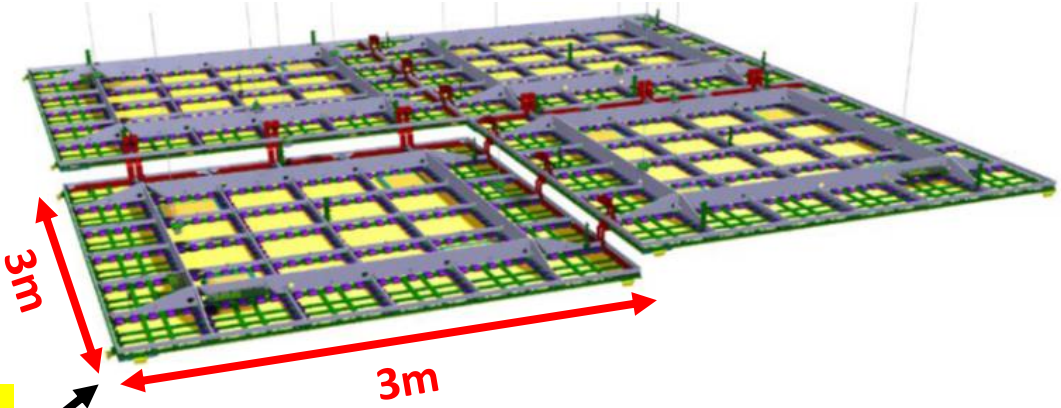
Charge Readout Planes (CRP)

Field Cage

Cathode

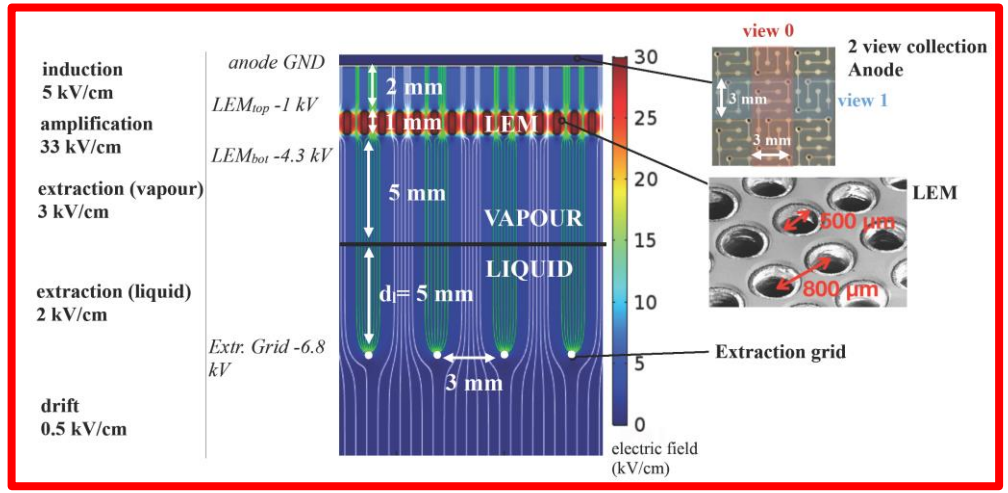
Ground Grid

PMTs



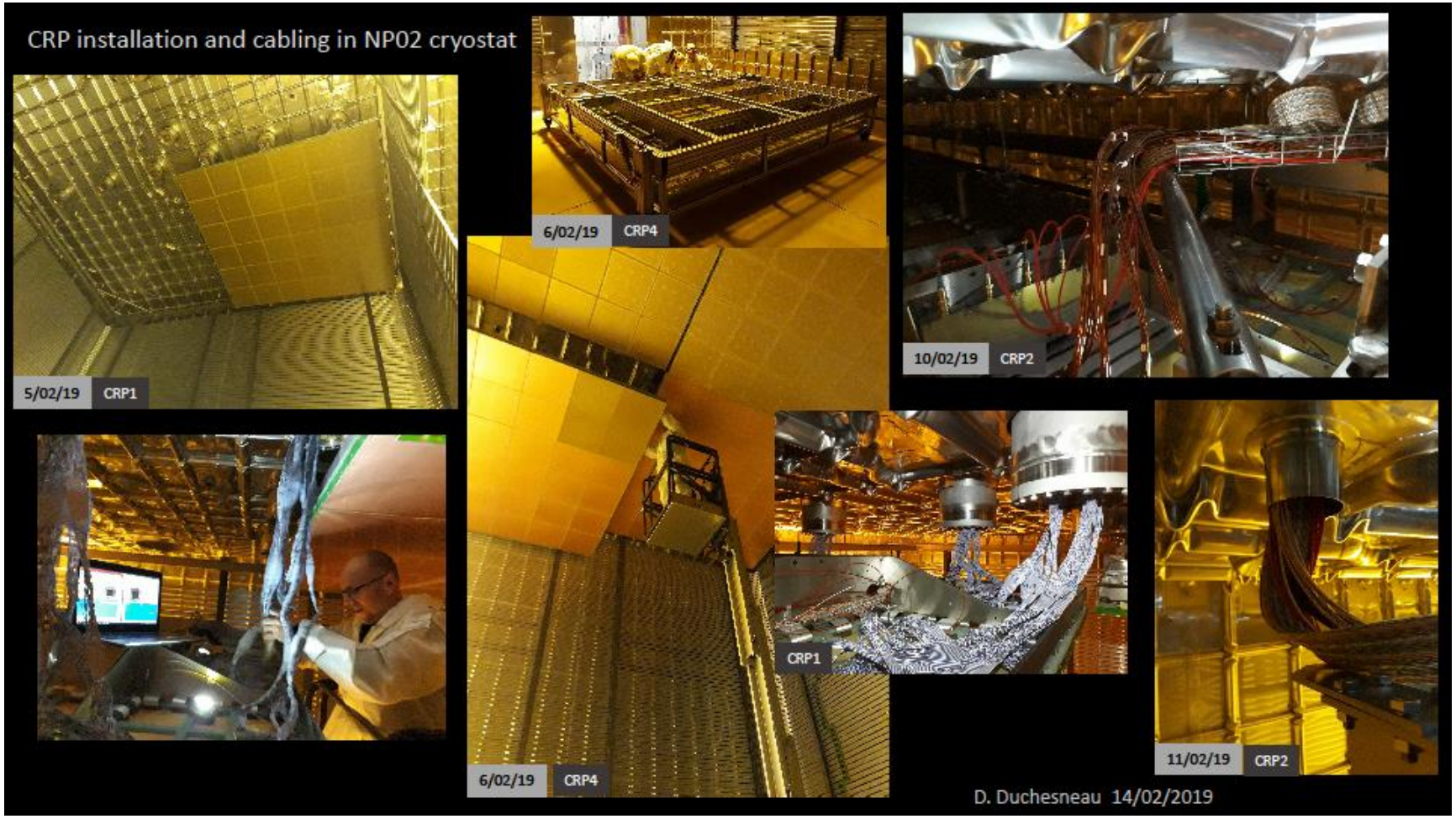
1 CRP = 36 Anodes + 36 LEMs (50×50 cm²) + 3×3 m² Extraction Grid

Dual phase principle



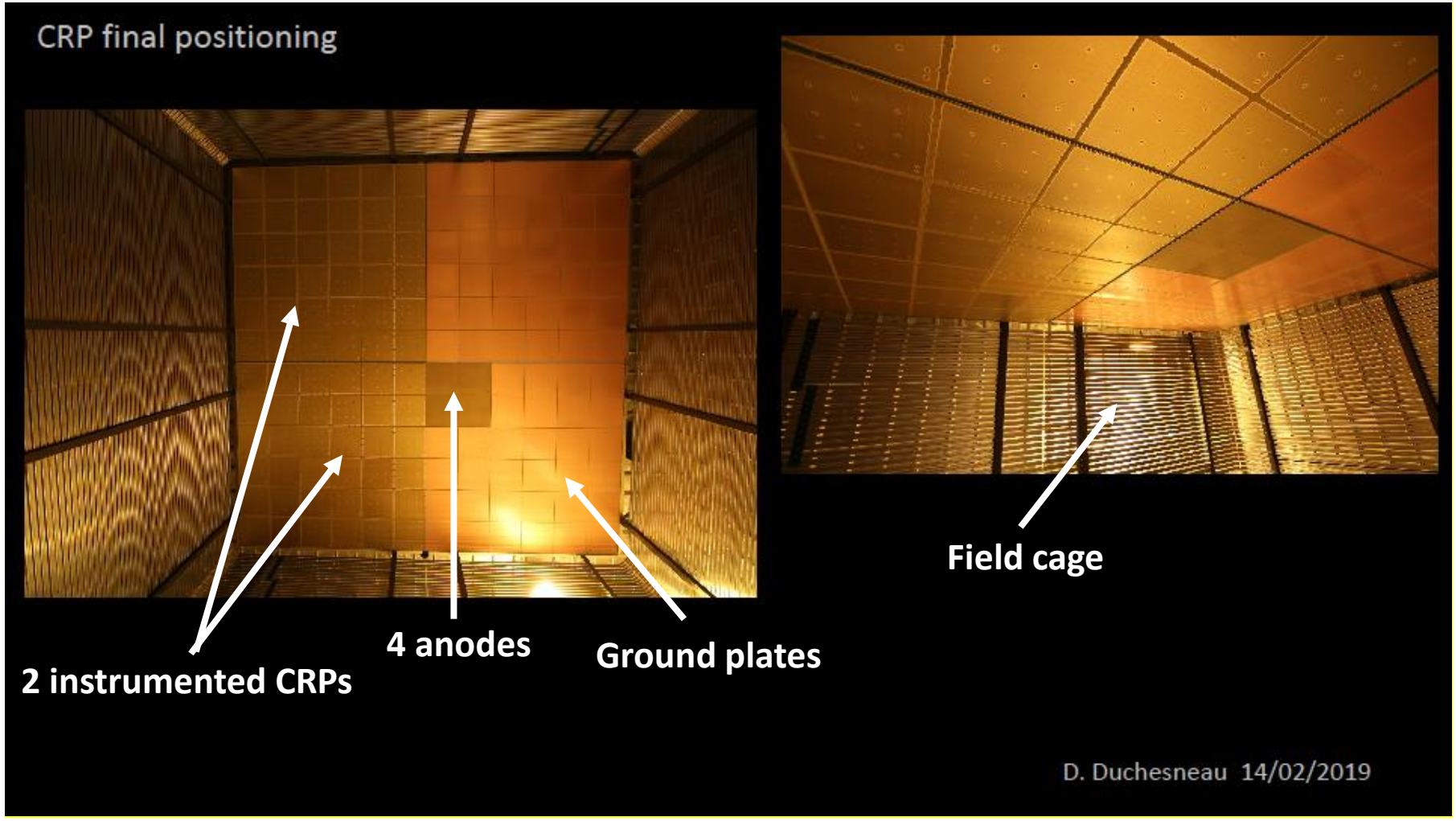
Installation of CRPs inside the NP02 cryostat

(Jan. – Feb. 2019)



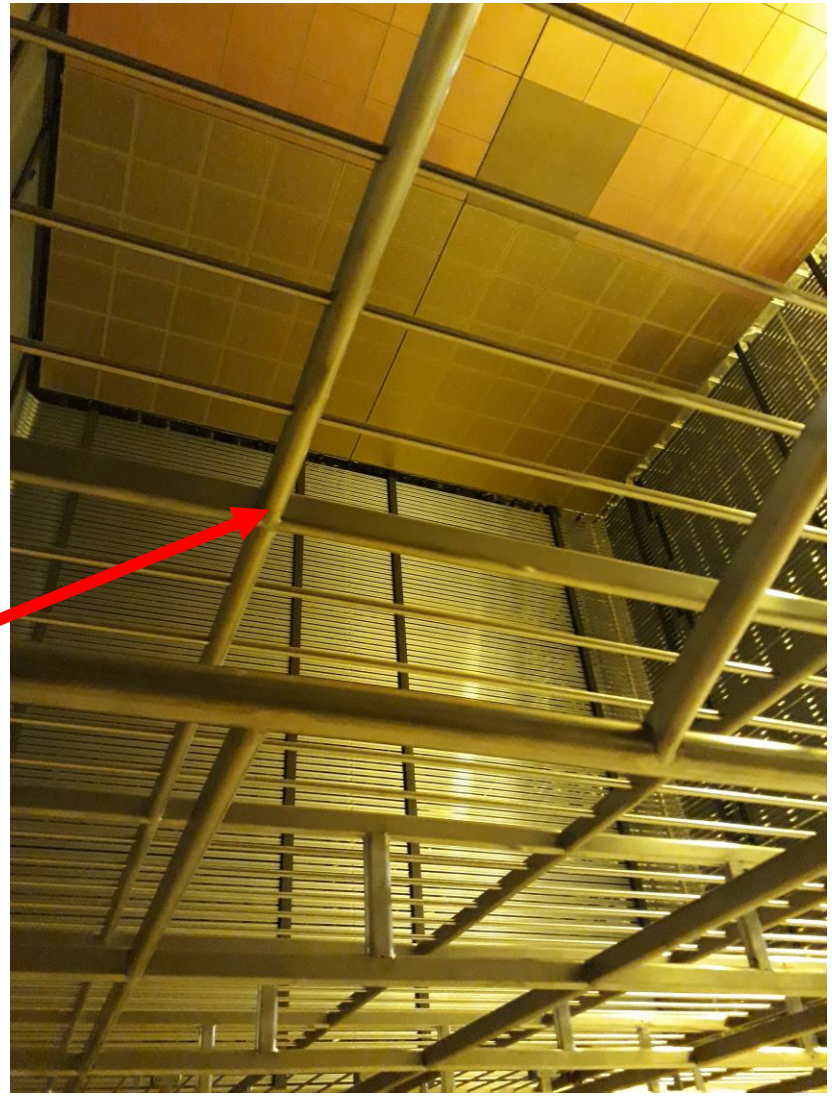
CRPs in their final position

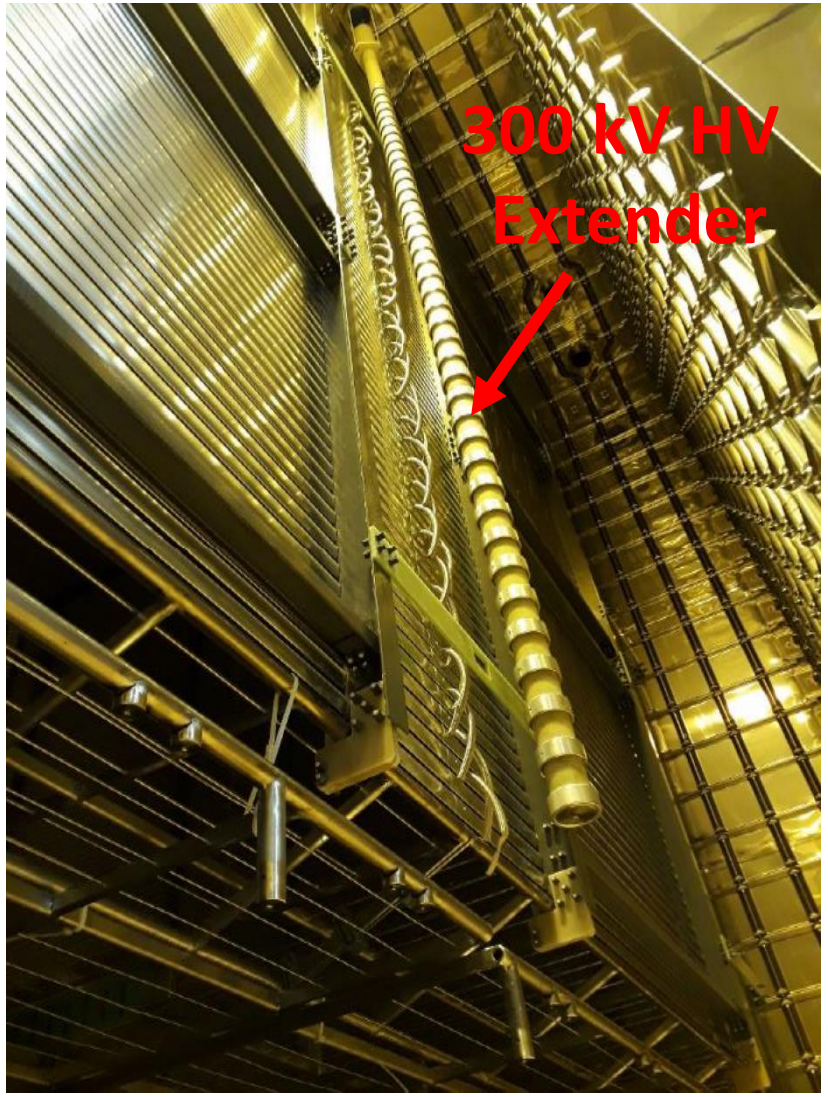
(Feb. 2019)



Installation of cathode and the VHV system

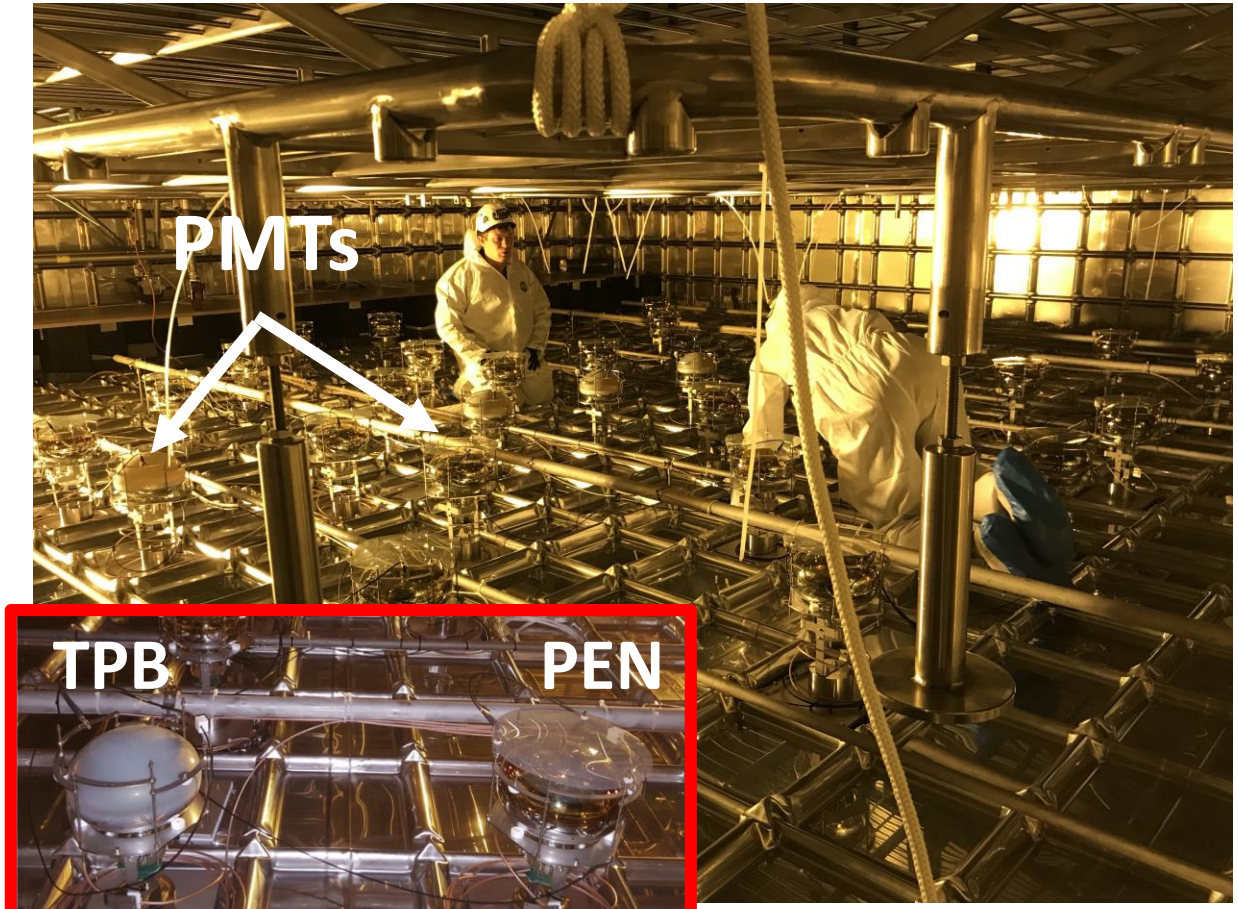
(Mar. - April 2019)





Installation of 36 PMTs and Ground Grid

(Feb. – Jun. 2019)

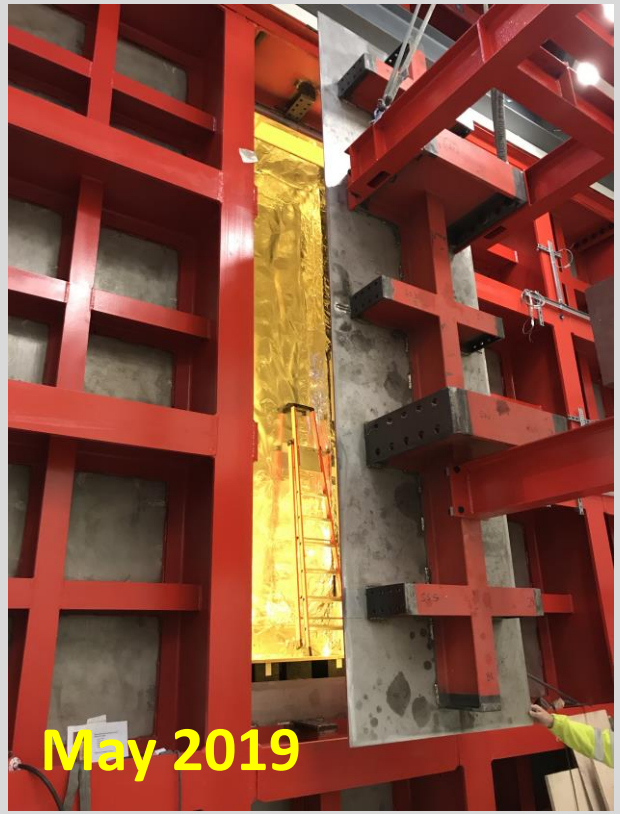


TCO closure and final steps

(Apr. – Jun. 2019)

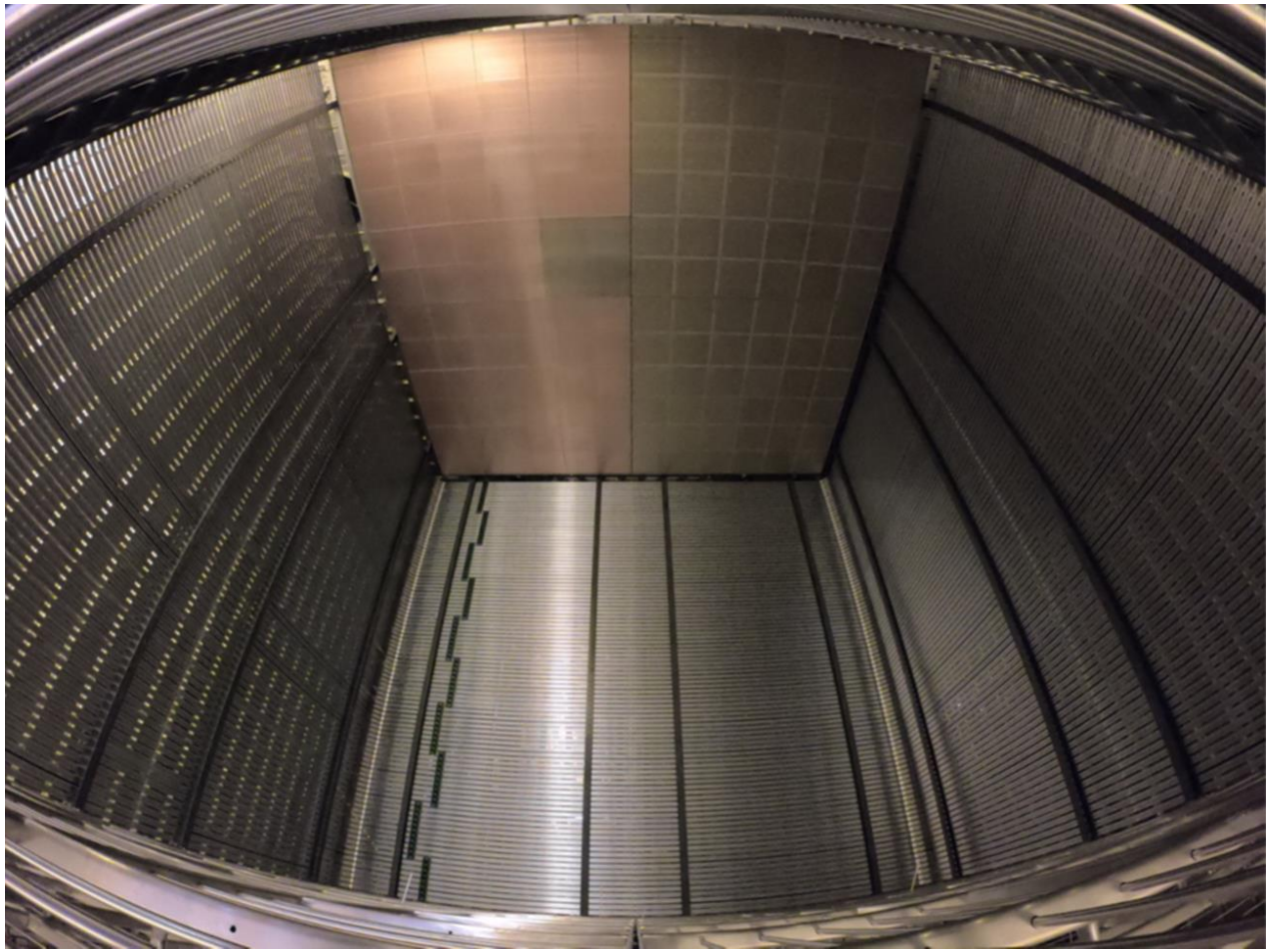
- Final operations (installation & tests) inside and outside cryostat :
  - Purity monitors, LEDs, Cryo Cameras, Level Meters, Temperature Probes.
  - SC, CRP motorization, Cold Electronics + Digitizers, PMT HV and R/O, Light calibration system, LEM HV.

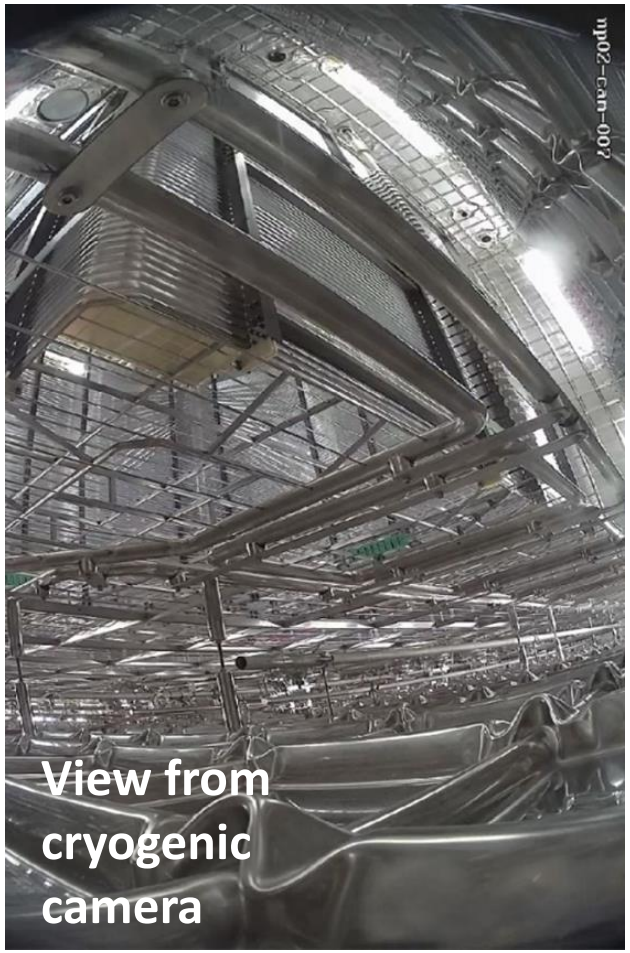
Temporary Cryostat Opening



LArTPC fully assembled and cryostat closed

(Jun. 13th, 2019)





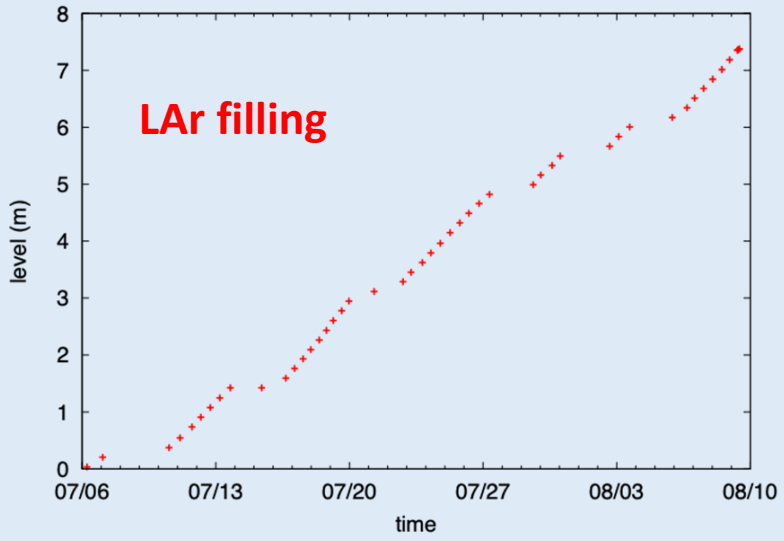
Cryostat Purging, Cooling and Filling

- Purging air inside cryostat with GAr (Jun. 14^{th} - 30^{th}) :

  $O_2 \sim 2$ ppm and $H_20 \sim 350$ ppm further reduced using cryogenic moisture traps

- Cooling with LAr sprayers from (Jul. 1^{st} - 4^{th})
- Filling with LAr (Jul. 5^{th} - Aug. 9^{th}) :

  - Two 20t trucks/weekday
  - 10 ppb O_2^{eq} after filling through filters

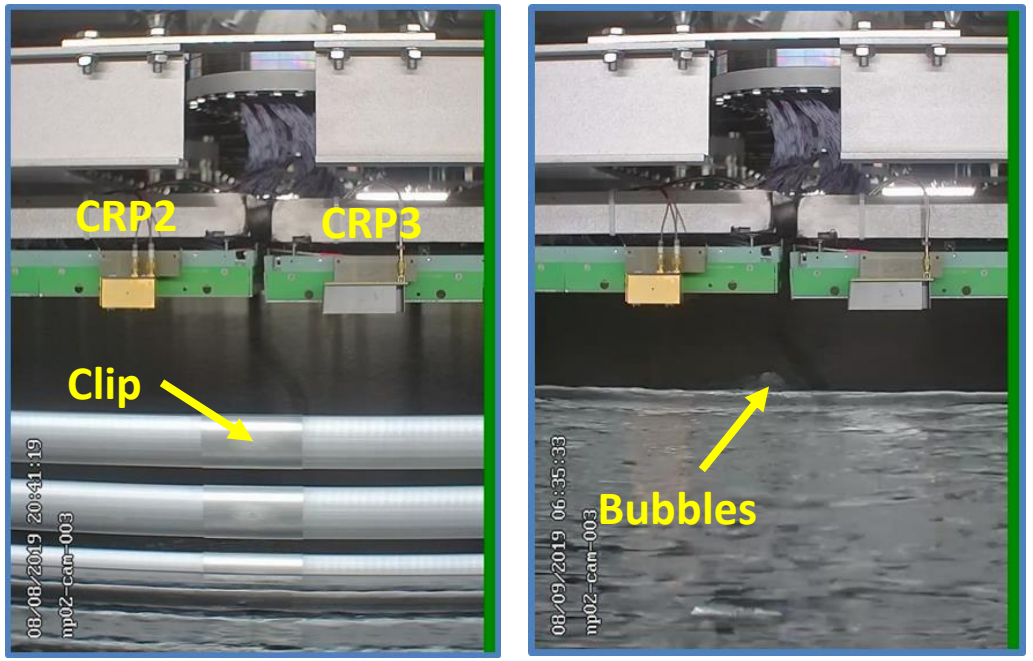


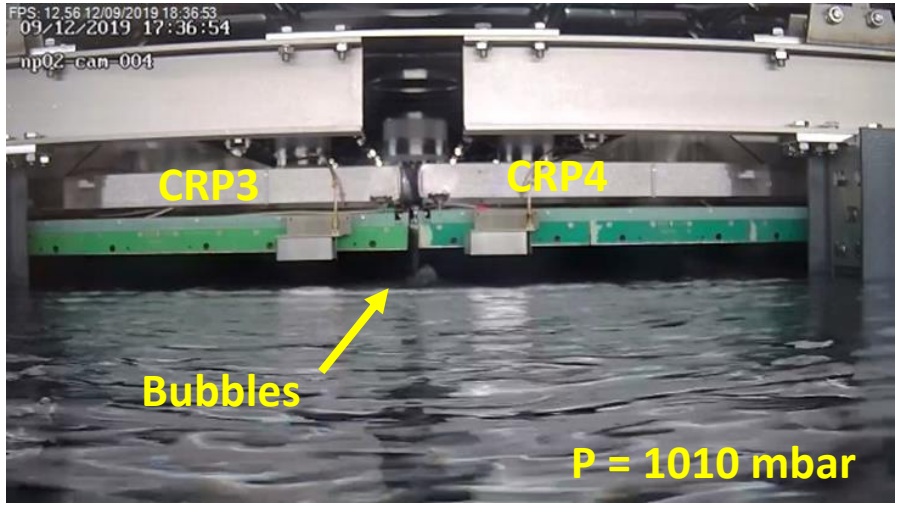
D. Duchesneau, LAPP :

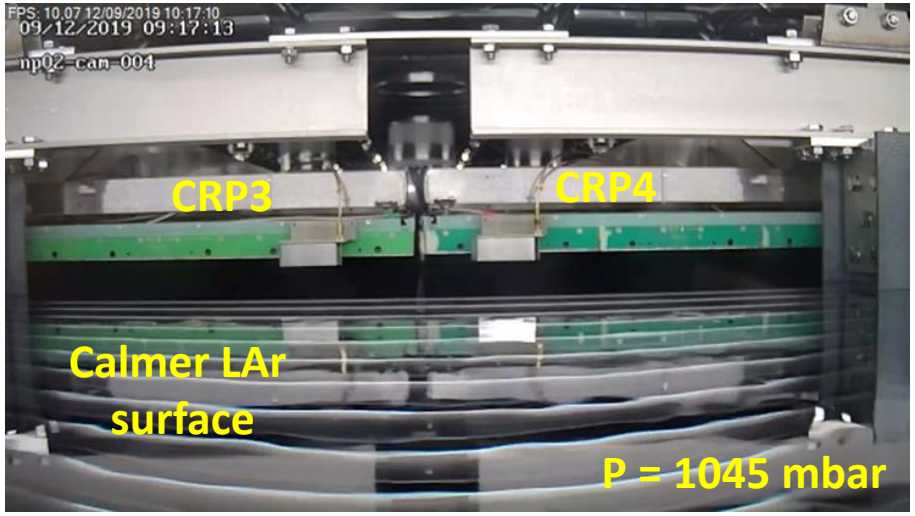
https://cernbox.cern.ch/index.php/s/AjG1OX7kUjX23s0

Commissioning : cryogenics

- While filling almost completed, bubbles started to appear at specific locations through the clips of the FC profiles.
- Origin of bubbles not known yet. Under investigation.
- Linked to hydrostatic pressure. One way to stop bubbles for some time (up to several days) is to perform an over pressure cycle (> 30 mbar for 30 min. to a few hours).
- LAr recirculation + filtration (purity) started after filling.

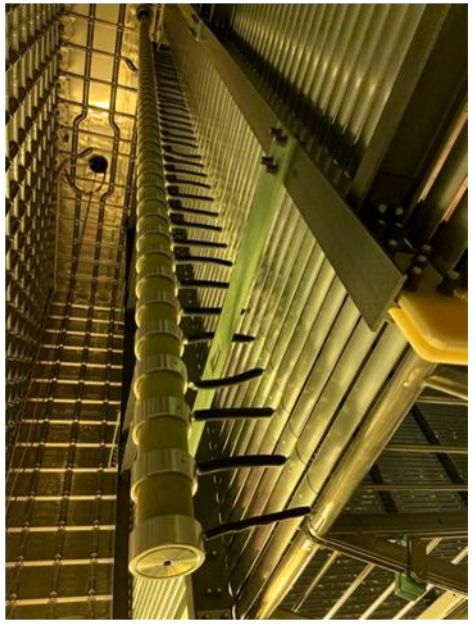


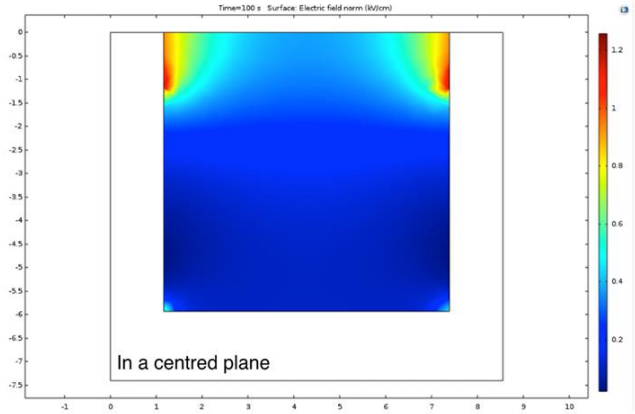




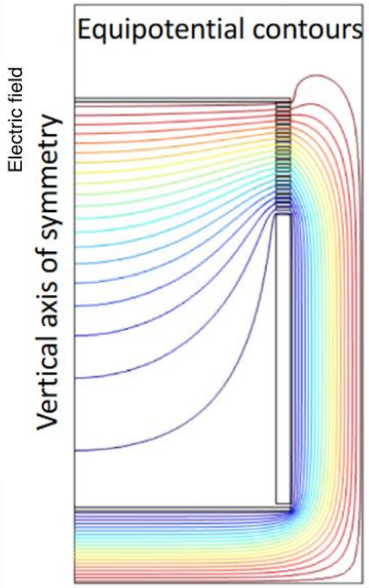
VHV and Drift Field

- Cathode foreseen to operate at 300 kV.
- However on Aug. 11th, during ramping up a PS trip occured at 200 kV due to a short between the first equipotential ring connected to the FC and the extender inner conductor.
- Very likely due to a crack inside the vetronite surrounding the HV inner connector.
- Located at about 1.2 m drift distance.
- Maximum operation voltage is 150 kV.
- At 120 kV, nominal field of 500 V/cm can be obtained in the upper part of the TPC. Longer drifts are possible.
- Can possibly be repaired, but intervention is delicate.



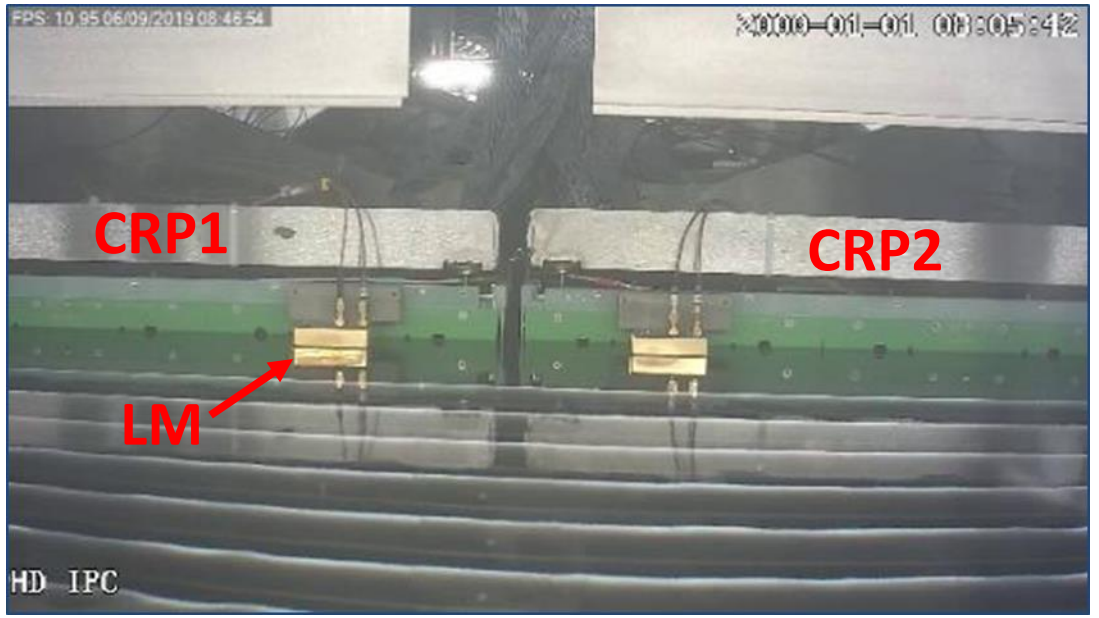


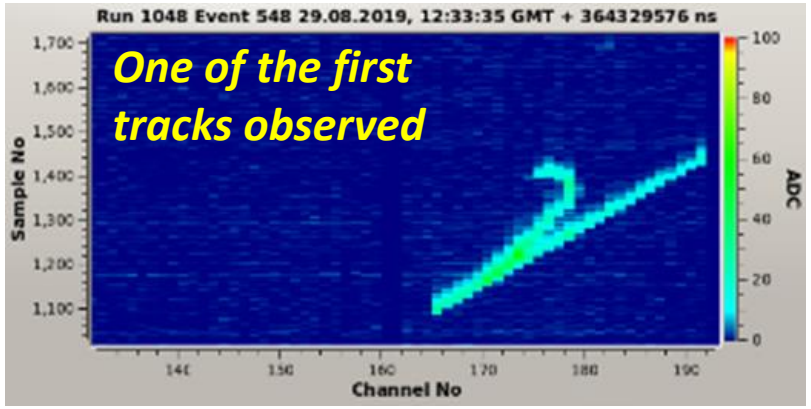
E-field simulation



DLArTPC Operation

- CRP alignment and precise (0.1 mm) positioning w.r.t. liquid surface using 14 Level Meters (LM) on the 4 CRPs.
- Automatic tracking of LAr level performed with the LM.
- Grids immersed in liquid by about 5mm leaving 5mm of Ar gas between LEM and LAr.
- Grid HV tested successfully up to 7.5 kV.
- 72 LEMs operated so far with V_{TOP} = 0.5 kV and ΔV =2.9 to 3.2 kV across the 1mm LEM thickness.
- Grid operation at HV between 5 kV and 6.5 kV provided high electron extraction efficiency.
- First tracks observed on August 29th with E_{LEM} = 29 kV/cm, V_{GRID} = 6 kV and $V_{CATHODE}$ = 50 kV and an electron lifetime of 200 µs.
- Noise : ~1400 e^- dominated by coherent component.

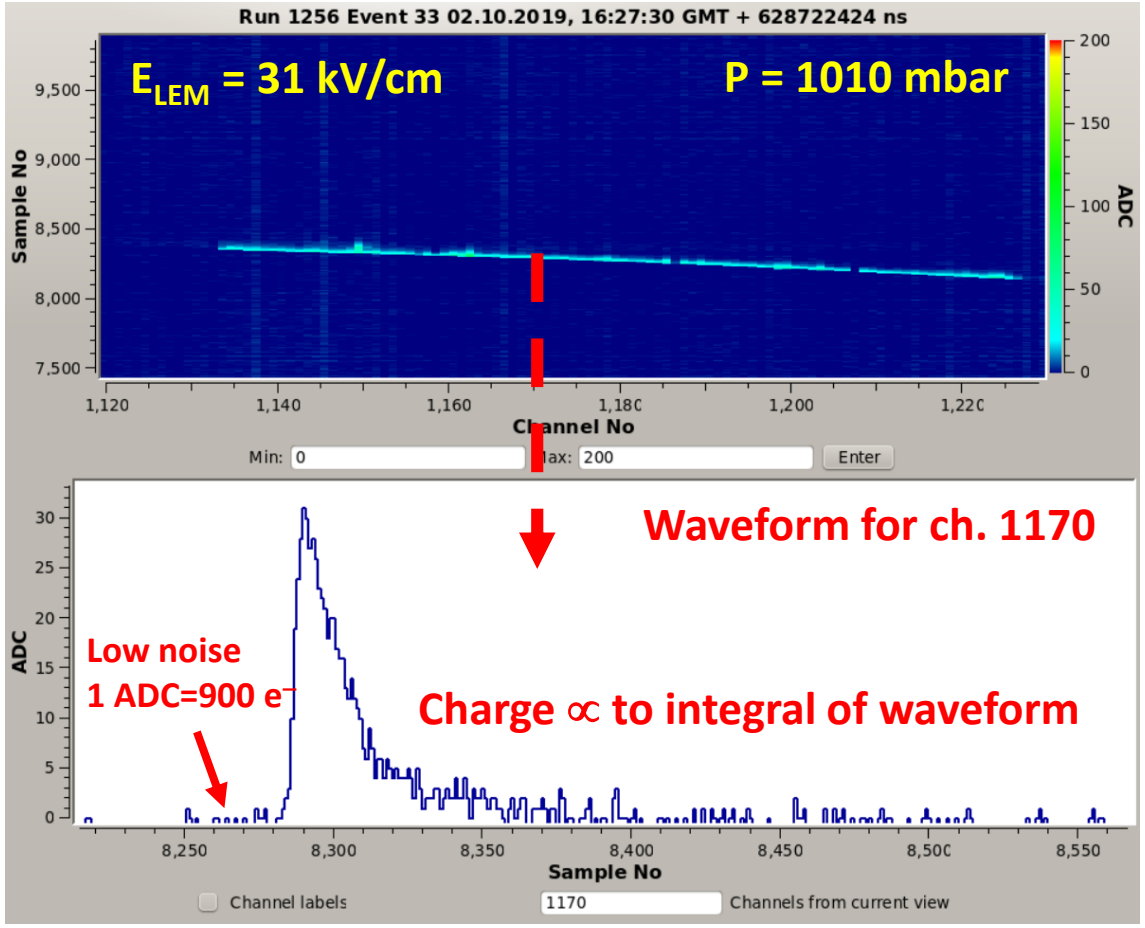




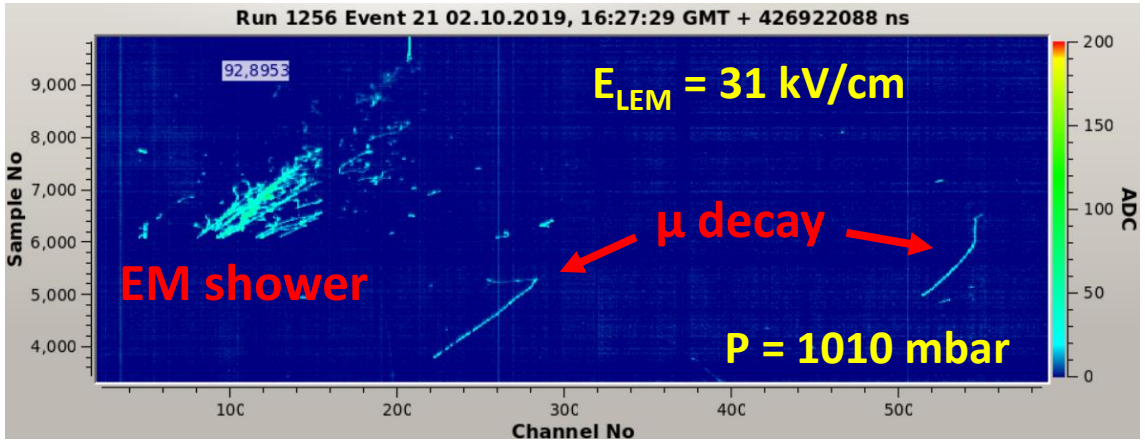
Event Gallery

So far > 130 TB and > 10^6 triggers

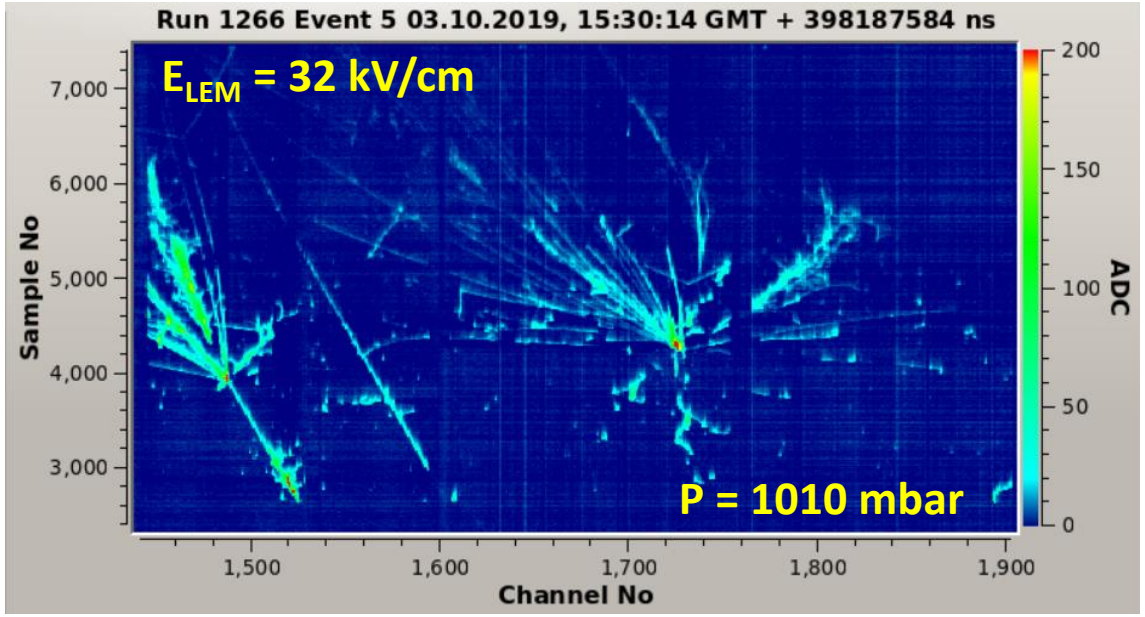
Horizontal muon track



Electromagnetic shower + two muon decays



Multiple hadronic interactions in a shower



LEM Operation *(so far)*

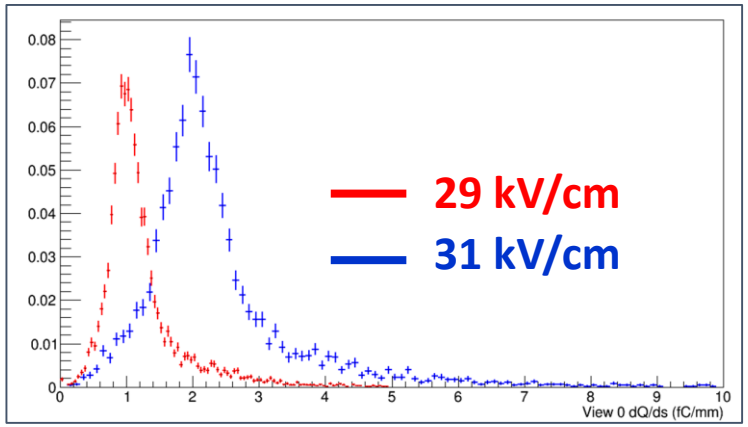
- V_{TOP} @ 0.5 kV and V_{BOT} @ 3.4, 3.5, 3.6 and 3.7kV
  - G_{eff} (ΔV = 2.9 kV) ~ 2 @ 1045 mbar (V_{GRID} = 6 kV)
  - R_G (3.0 kV / 2.9 kV) = 1.4 (expected 1.3)
  - R_G (3.1 kV / 2.9 kV) = 2.0 (expected 1.8)
  - LEM gain @ 3.2 kV ~ 8
  - More detailed analysis ongoing

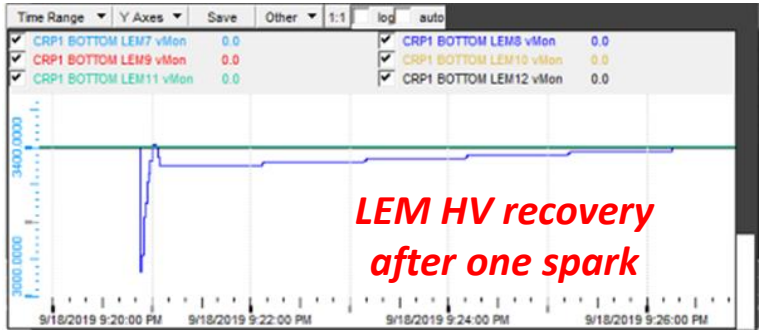
LEM charging up not complete

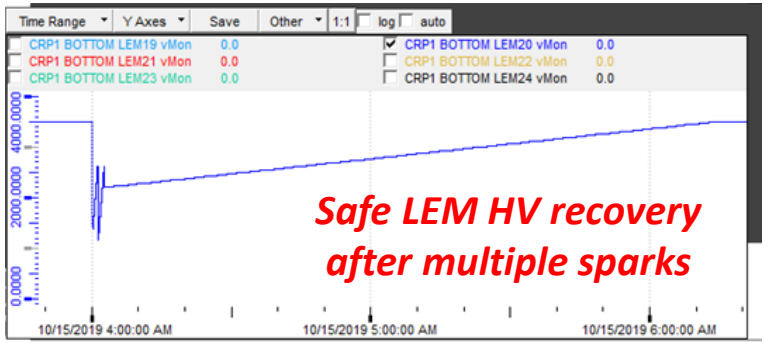
- Spark rates @ ΔV = 2.9 kV :
  - Cathode OFF : < 0.05/h per CRP
  - Cathode ON : 0.4/h per CRP
- Aim at ~ 1 spark/h per CRP at higher gain.
- Automatic recovery of LEM HV after a spark :
  - Avoid power supply trips
  - Safe operation of LEMs
- Ion backflow due to high cosmic ray flux very likely observed after several hours of continuous operation. Positive ions tend to stay on the liquid surface. Mitigated by LAr evaporation. Need to better understand such process.

Not an issue for an underground detector like DUNE FD

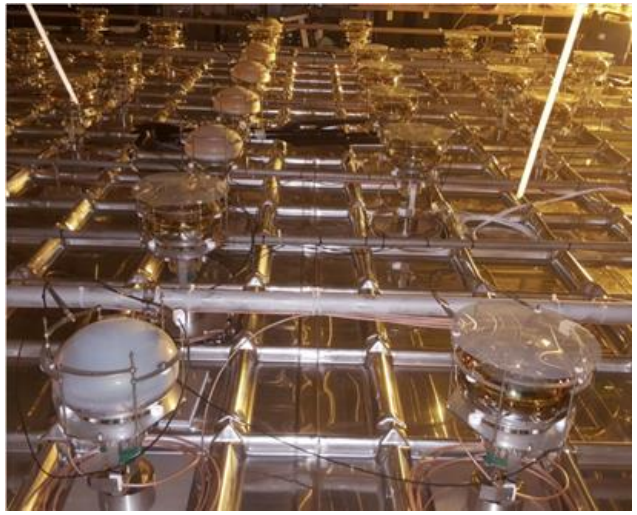
dQ/dx in one of the two collection views





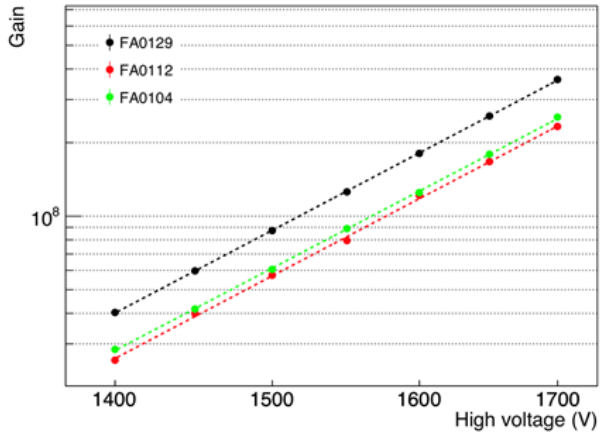


Photon Detection System (PDS)

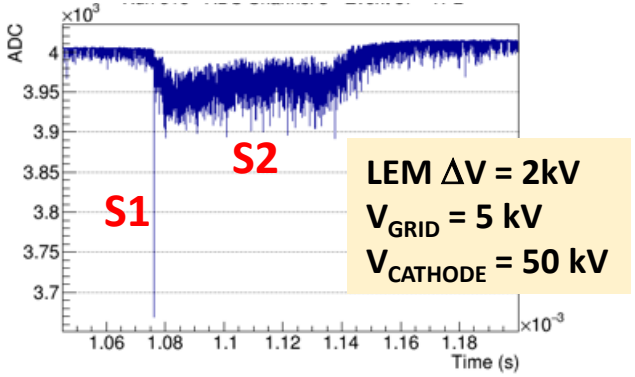


- All 36 PMTs operational.
- Regular PDS data taking and calibration.
- Low noise PMTs
- All PMTs see S2 electroluminescence signal produced in gas phase.
- Fit of slow component (τ_{slow}) is a LAr purity indicator.

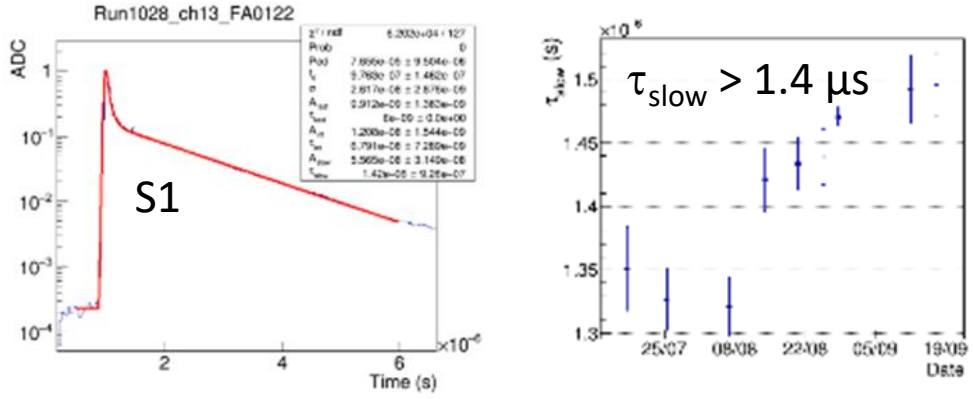
Gain -vs- HV calibration



First electroluminescence signals

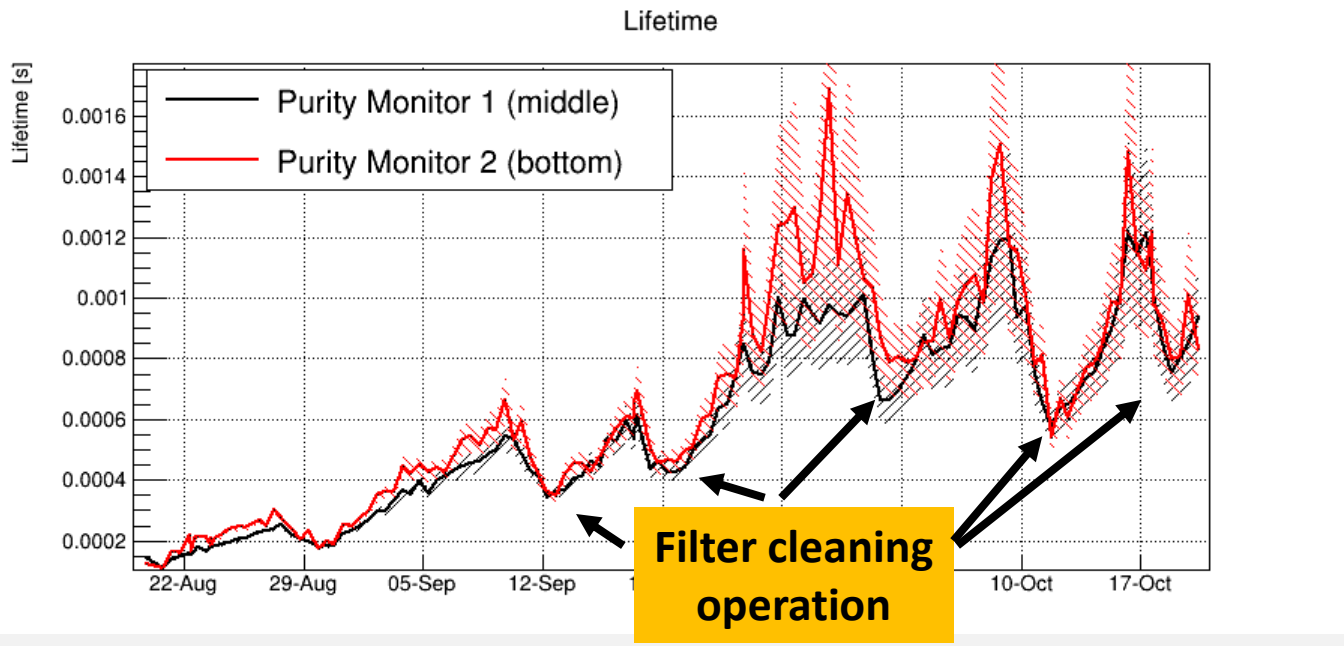


Scintillation light profiles from cosmic muons



Liquid Argon Purity

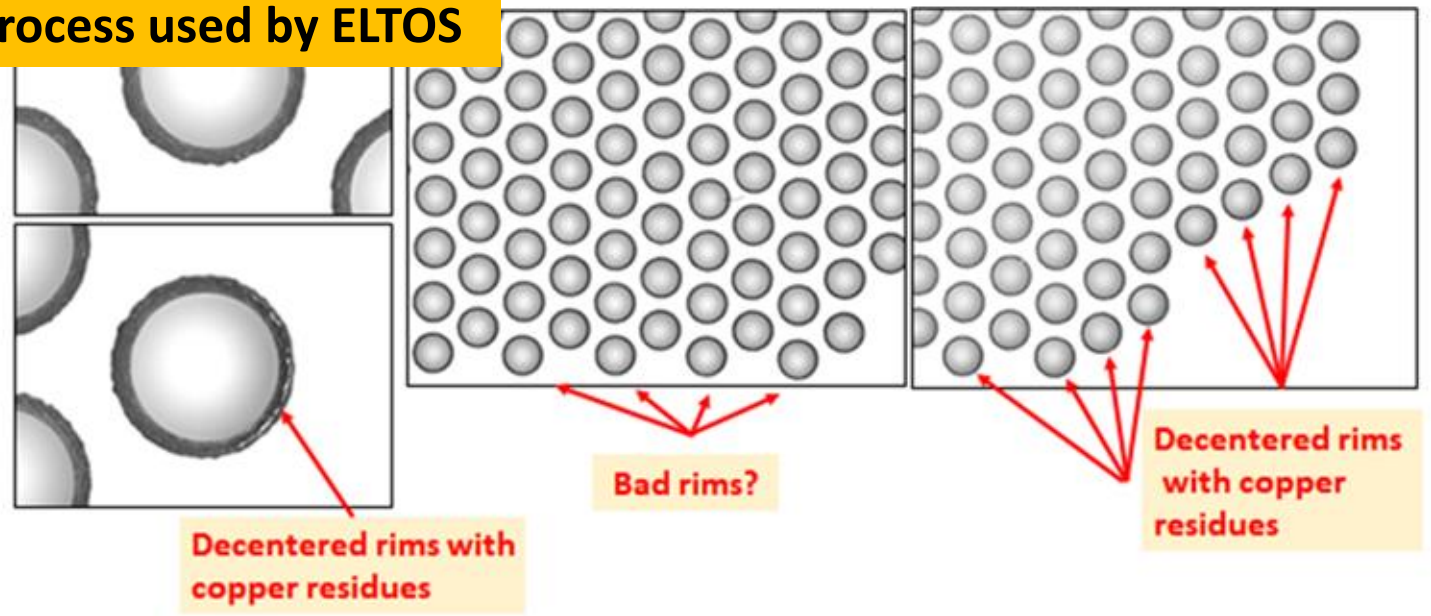
- LAr purity monitored so far by two 17 cm long PMs located at the bottom of the cryostat and about 1 meter above.
- Recirculation improves e^- lifetime by factor 2.7 every ~5 days (1 volume recirculated).
- LAr purity limited to about 1 ms e^- lifetime by several filter clogging and cleaning operations.
- Lifetime measurements consistent with track attenuation.



LEM Developments

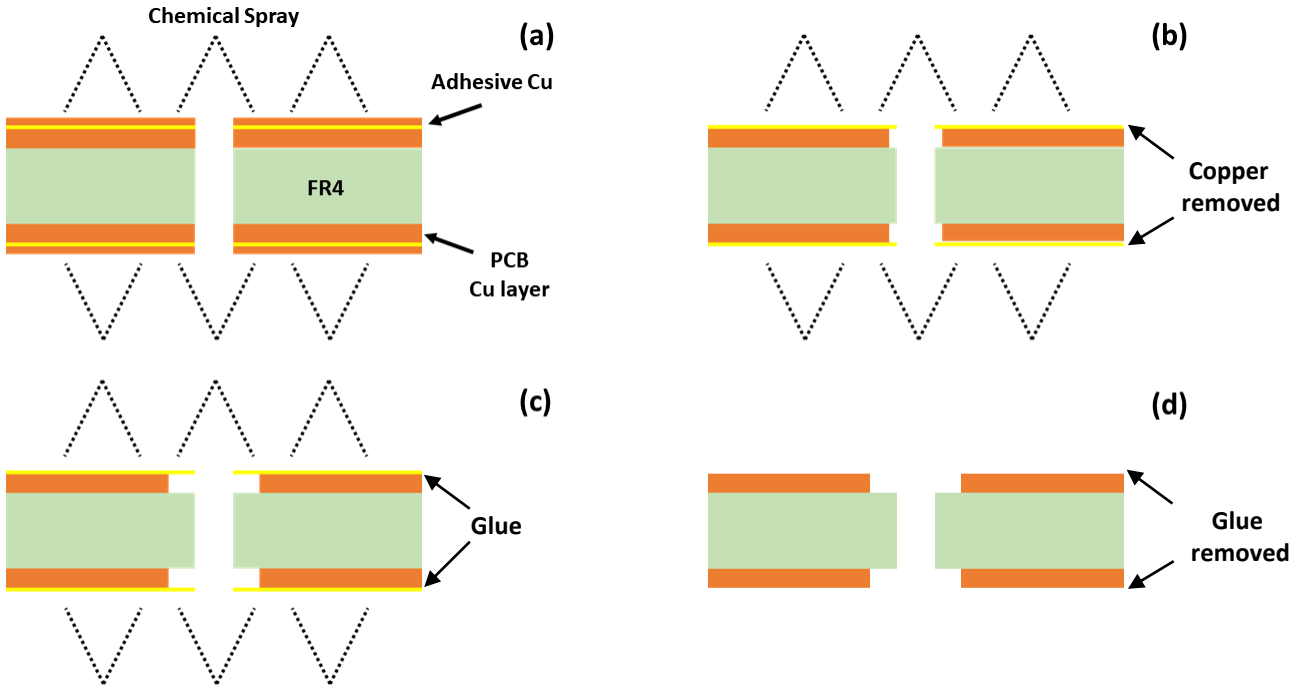
- Improve long term HV stability.
- Solve carbonization issues observed during Cold Box tests last year by improving micro-etching process for rims.
- Increase active area from 86% to > 95%.

Standard micro-etching process used by ELTOS

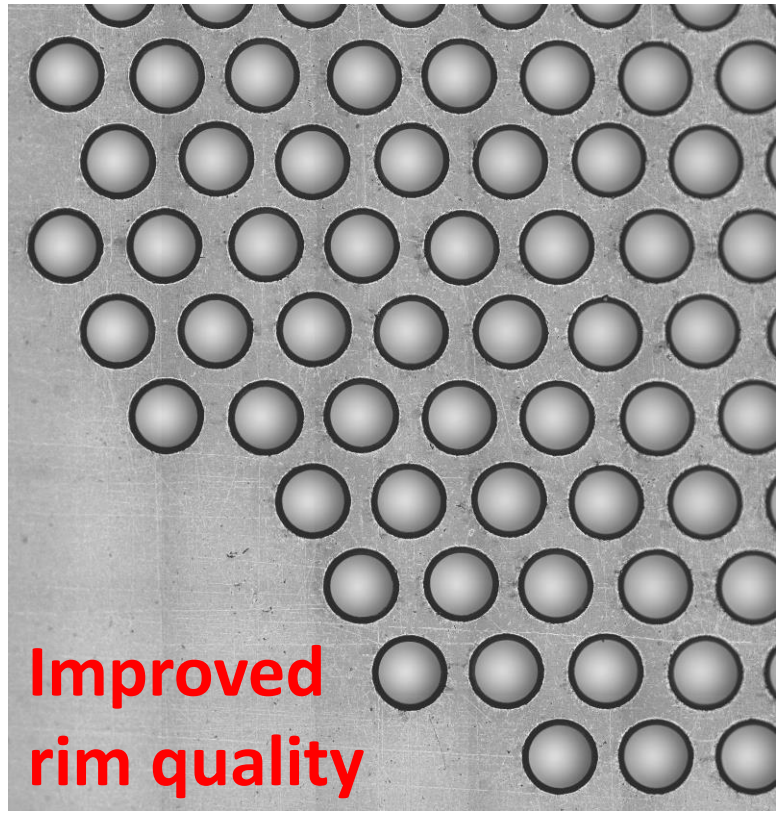


Improved micro-etching process for rims

- Developed at CERN by EP-DT-EF.
- LEM copper surfaces protected with thin adhesive copper foils before drilling.
- Micro-etching only around holes, visible through transparent glue.

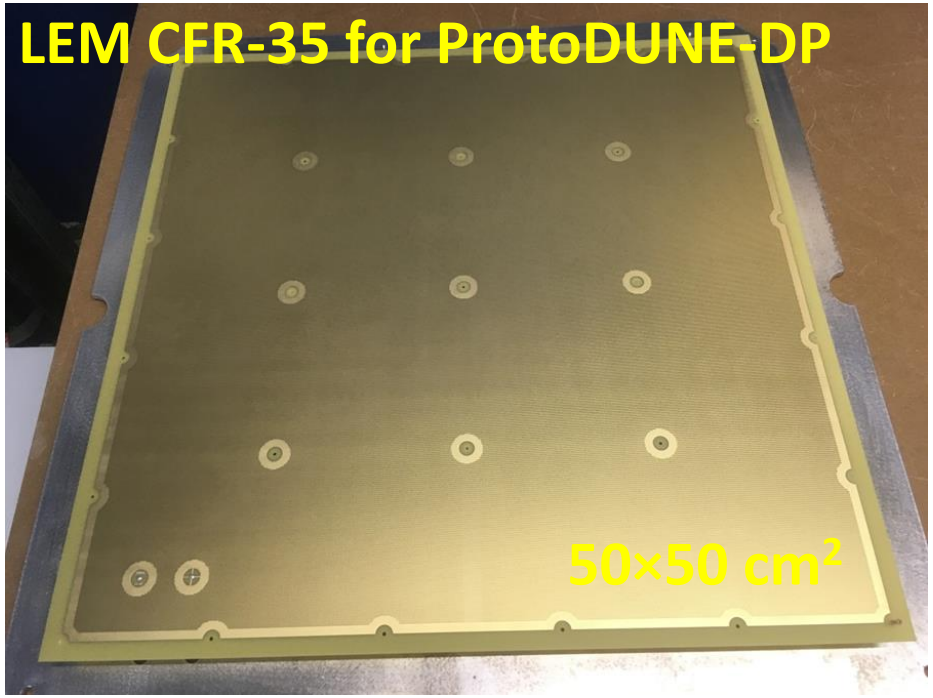


50×50 cm^2 LEM manufactured at CERN

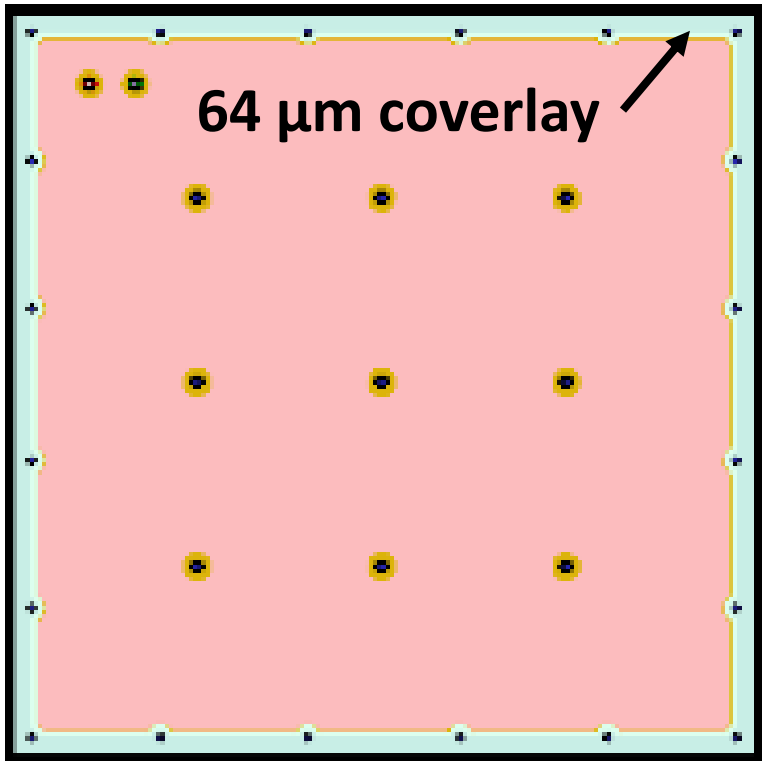


LEM with insulation

- Improve HV stability by insulating areas where E-field is high (edges, corners, boundary regions).
- Add 64µm coverlay on dead areas.
- Use improved rim micro-etching process.
- If successful, increase active area.

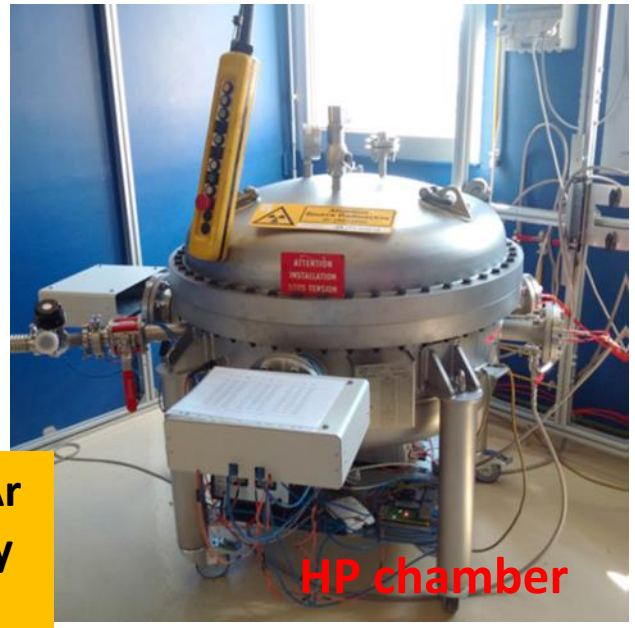


LEM prototypes being constructed at CERN

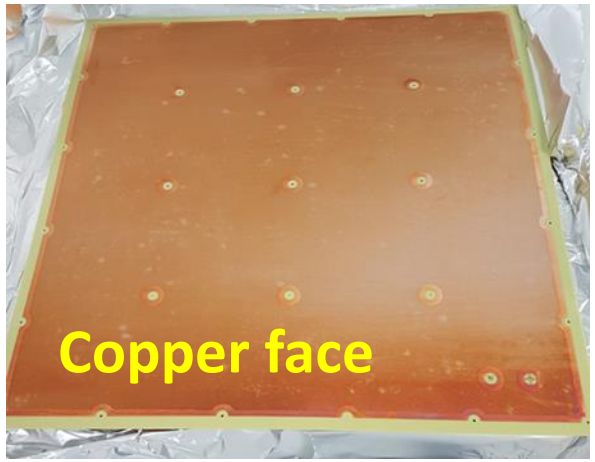


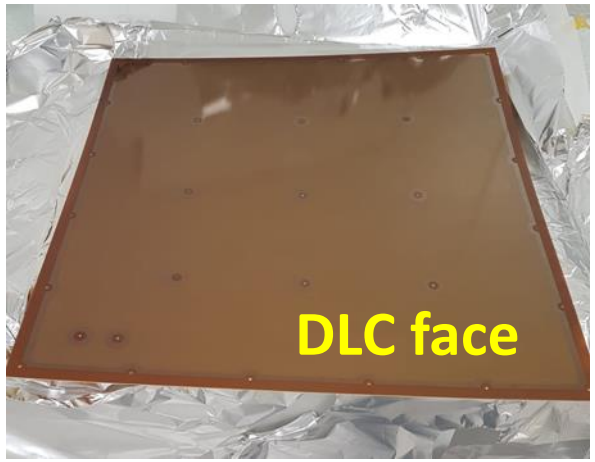
Resistive LEM

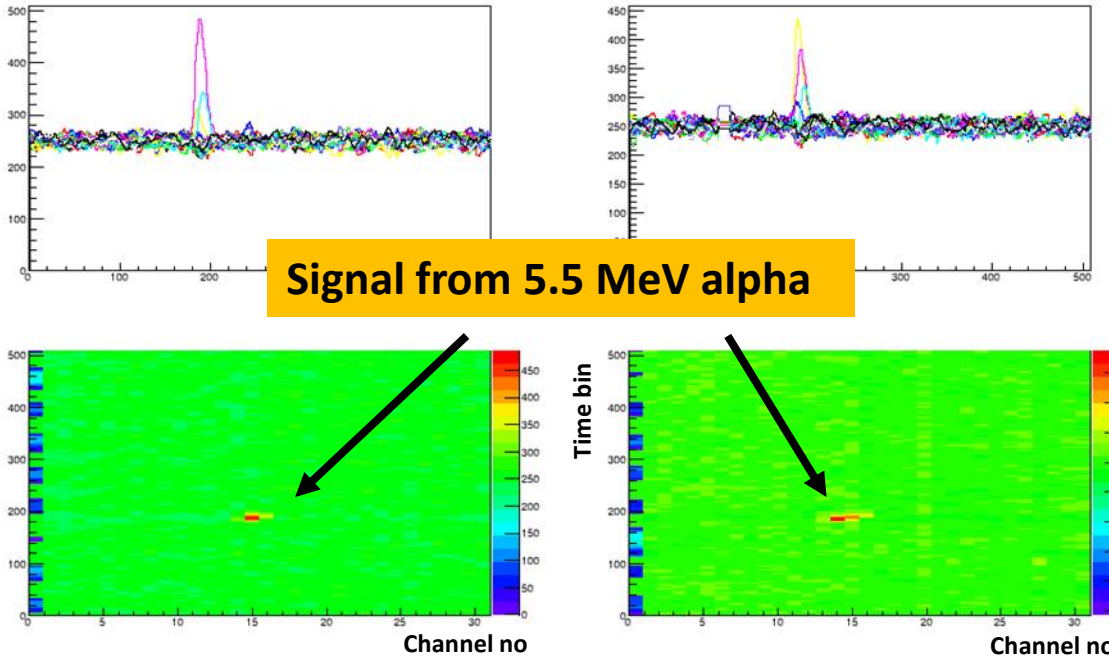
- Resistive 50×50 cm^2 LEM prototype made at CERN :
  - copper side facing readout anode
  - DLC on 50 µm APICAL polyimide film
  - same geometry as CFR-35 (ProtoDUNE-DP)
  - no rims, no gold plating on copper face.
- Tests in progress at CEA/Irfu.



Tests with ^{241}Am source in Ar @ 3.3 bar (same gas density as in ProtoDUNE-DP)







Summary

https://www.symmetrymagazine.org/article/dune-scientists-see-particle-tracks-with-dual-phase-technology

- Commissioning of ProtoDUNE-DP started last August.
- First tracks observed soon after.
- Understanding of the DLArTPC is progressing well.
- CRPs, LEMs and PMTs operate in a stable way.
- Long term detector operation limited now by cryogenic issues (bubbles, LAr surface quality).
- VHV Extender expected to be repaired early 2020.
- Current ProtoDUNE-DP LEM design being improved for DUNE with the help of CERN EP-DT-EF.
- Quite an exciting time ahead of us!