STATUS OF THE WA105 DUAL PHASE LIQUID ARGON TPC DETECTOR

Laura Zambelli (LAPP - CNRS/IN2P3)

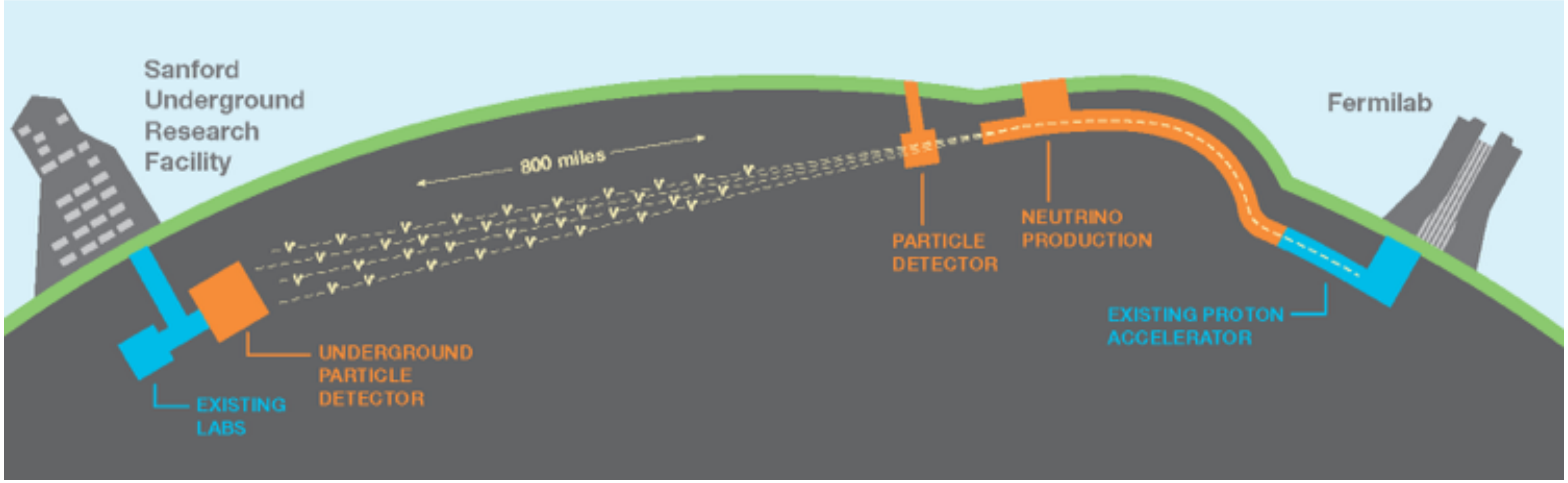
Outline :

- LArTPC technology
- WA105 3x1x1 demonstrator
- Towards the protoDUNE-DP prototype

GDR neutrinos — November 20th 2017 — Paris, LPNHE

LArTPC for a future LBL ν experiment : DUNE

DUNE CDR Vol 2 [1512.06148]



- 1300 km baseline
- 40 kt liquid argon TPC detector
- 3D imaging with high granularity for precise tracking
- Low energy threshold (~10s MeV)

- Important R&D efforts ongoing :
  - Scalability
  - Purity
  - Engineering
  - Physics performance

- First neutrino event in the FD for 2026

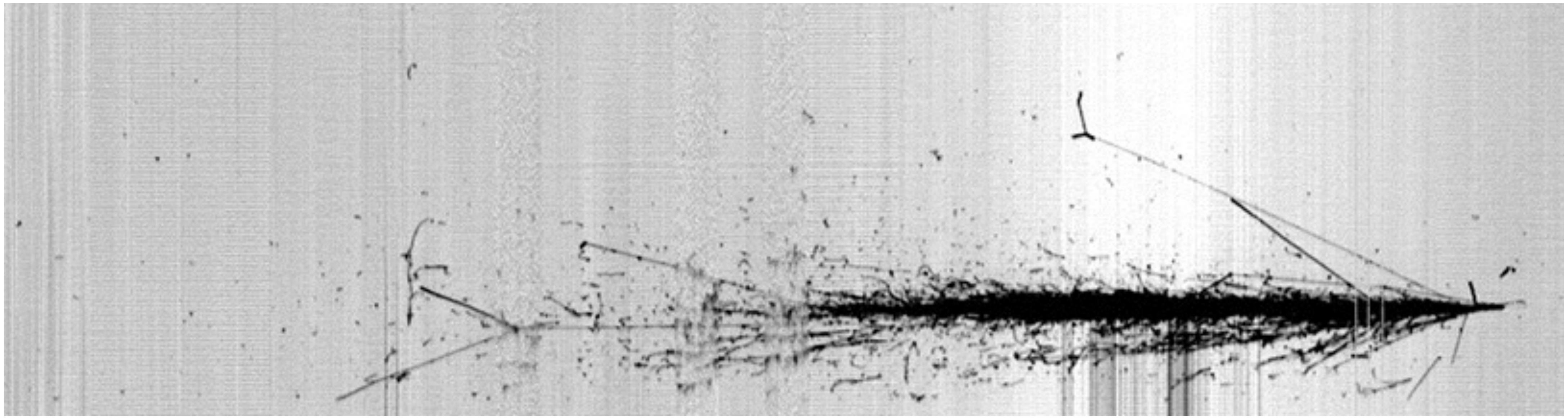
Liquid Argon TPC

- Liquid Argon [T = 87 K] is inert, dense [ρ=1.4 g/mL] and naturally abundant.

- Strong electric field applied across the TPC [E ~ 500 V/cm] to collect electrons [v_{drift} ~ 1.6 mm/μs] produced by energy loss [W_i = 23.6 eV/pair]. Electron attachment is low [$\tau_e \simeq 300/\rho(O_2$ in ppb)] which allow long drifts.

- Scintillation light [λ = 128 nm] produced [W_s = 19.5 eV/γ] with a fast [τ_f = 6 ns] and a slow [τ_s = 1.6 μs] time constants. Can be used as a trigger and a complementary calorimetry measurement.

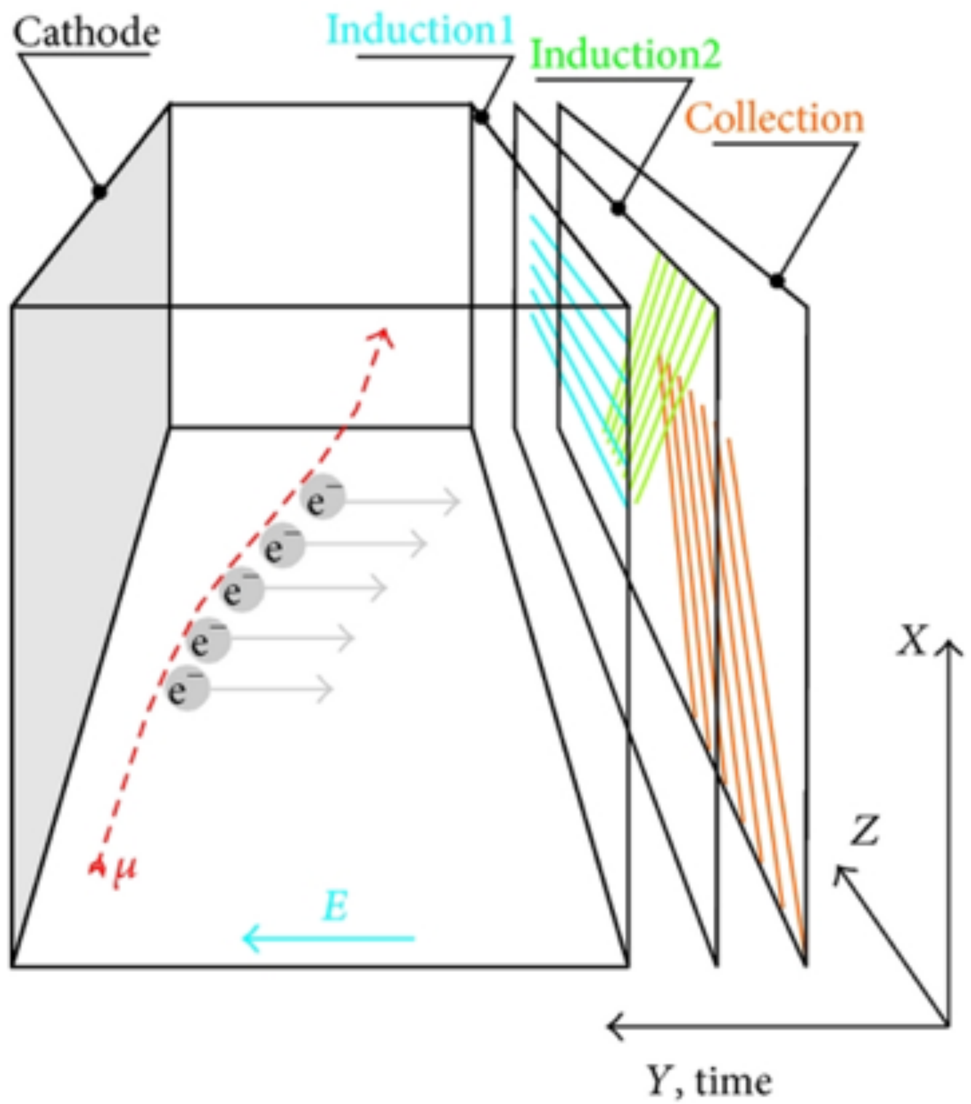
Neutrino interaction in the ICARUS detector



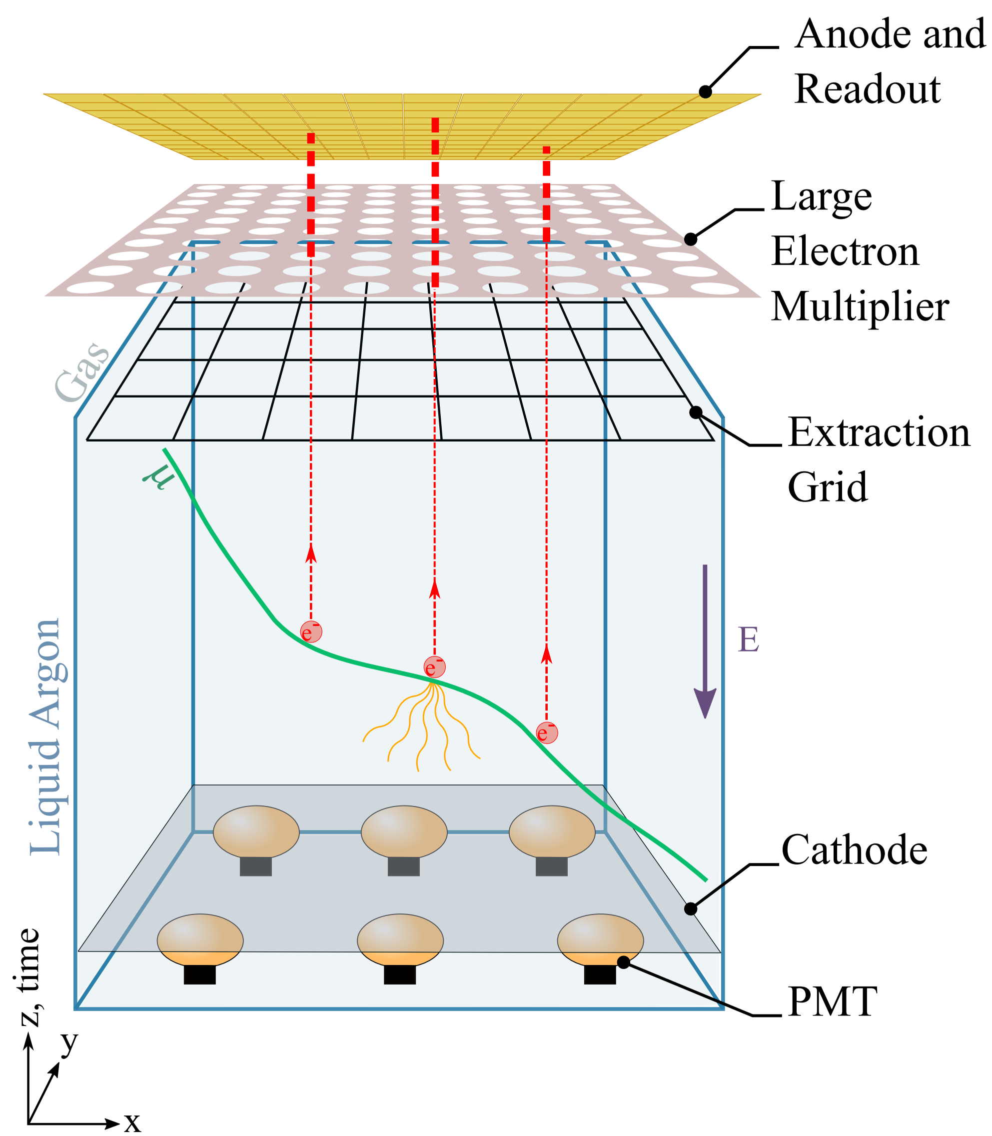
http://icarus.lngs.infn.it/gallery.php

Two technologies for LArTPCs

Single Phase

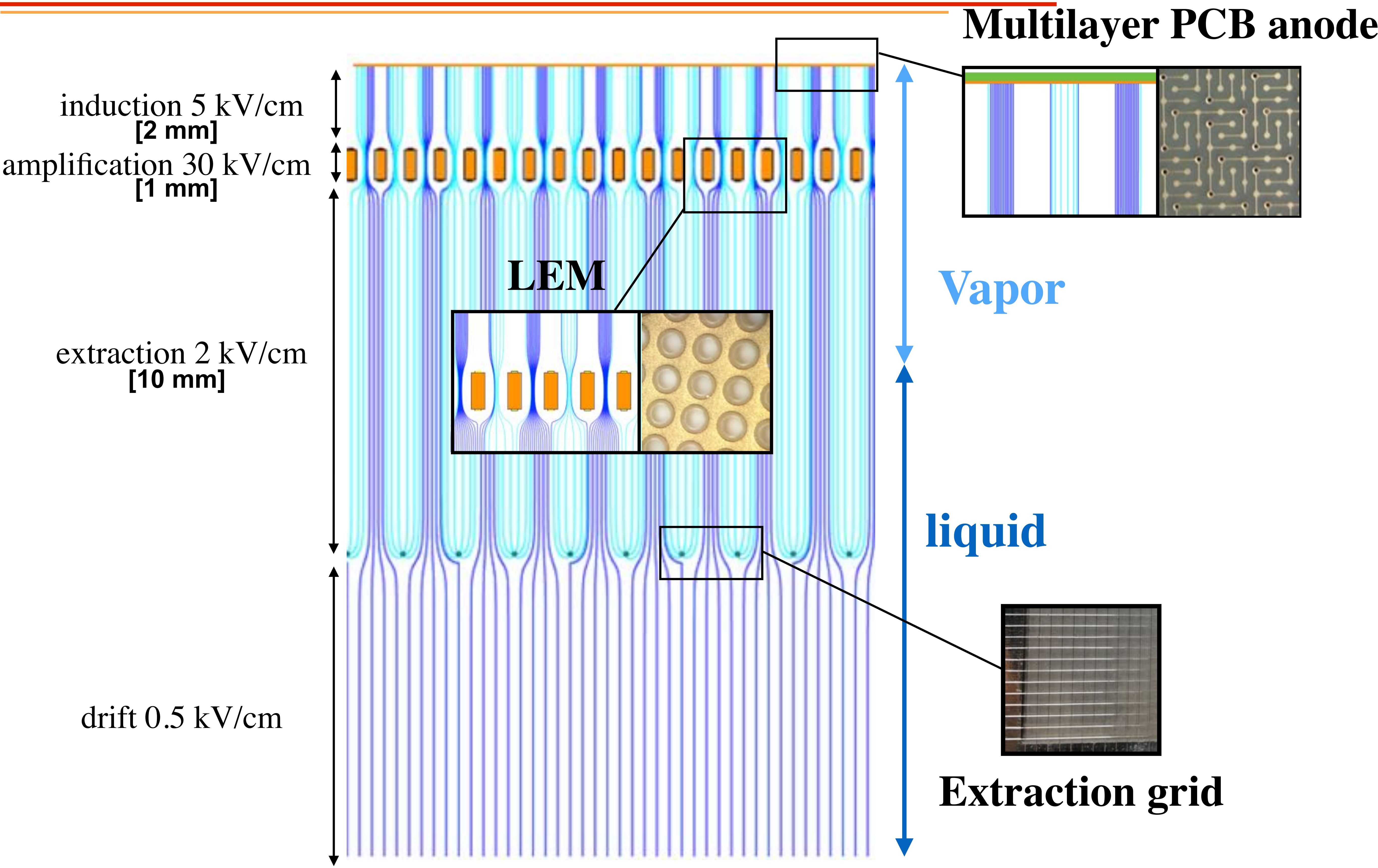


Dual Phase



Advantages of the dual phase design :
- Longer drift allowed thanks to the amplification
- Fewer readout channels with better resolution
- Accessible cold front end electronics, digitization at warm

Dual Phase LArTPC

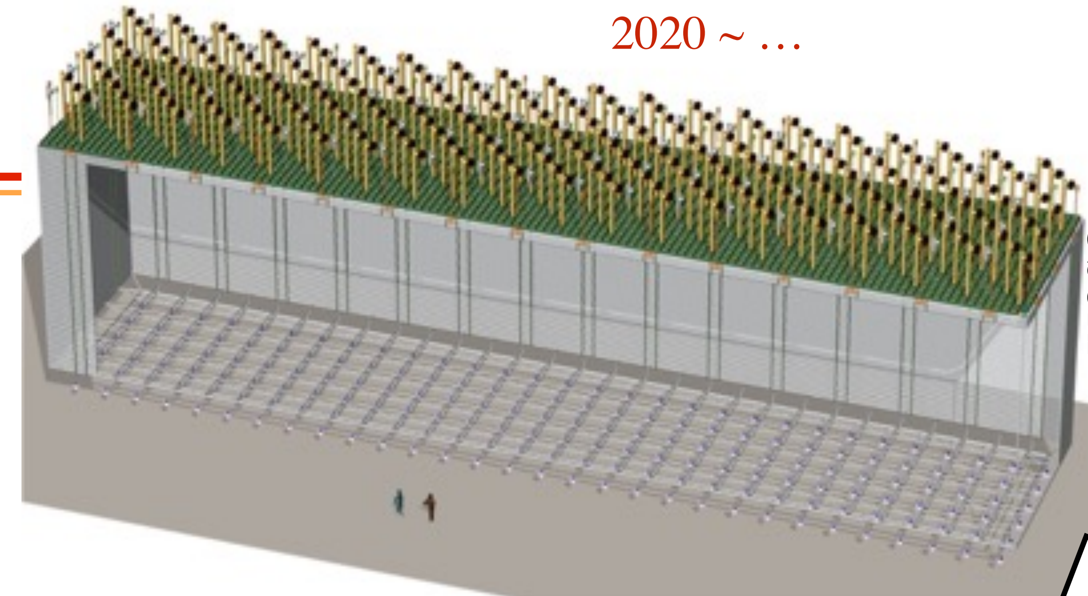


The WA105 collaboration

Demonstrate the capabilities of the dual phase technology at the kton scale

DUNE far detector module to be built underground, 60x12x12 m^3 →

2020 ~ …

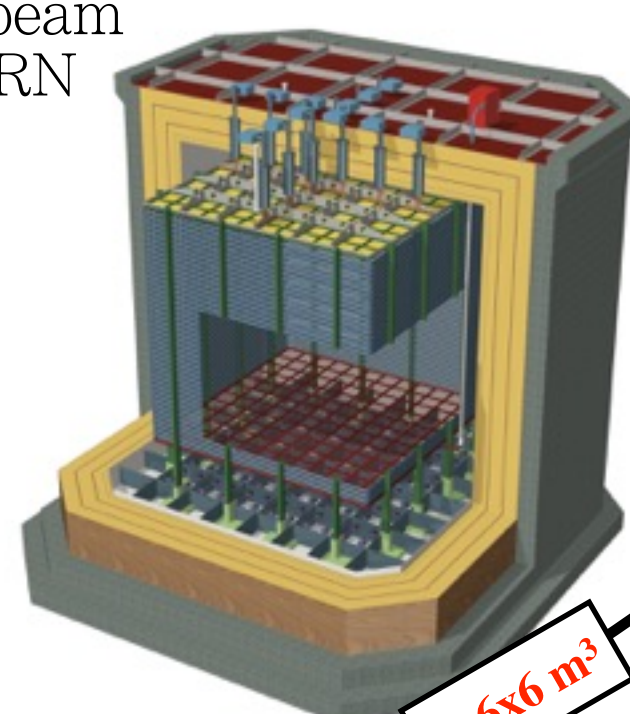


@SURF

10 kt

ProtoDUNE-DP to be exposed to test beam at CERN ↳

2016 ~ 2019

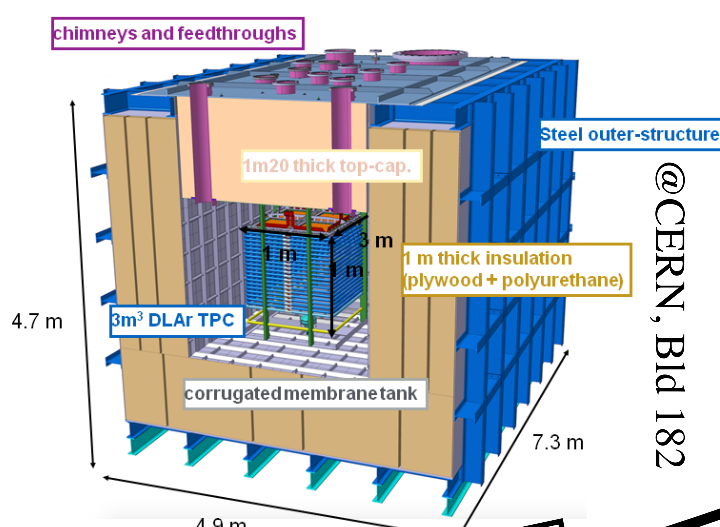


@CERN, EHN1

6x6x6 m^3

First large scale demonstrator exposed to cosmic rays ↓

2014 ~ 2017

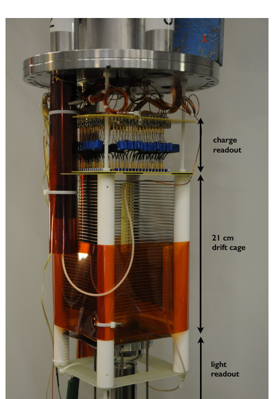


@CERN, Bld 182

3x1x1 m^3

Small chambers for R&D ↓

2010 ~ 2014



@CERN, KEK, …

3 L

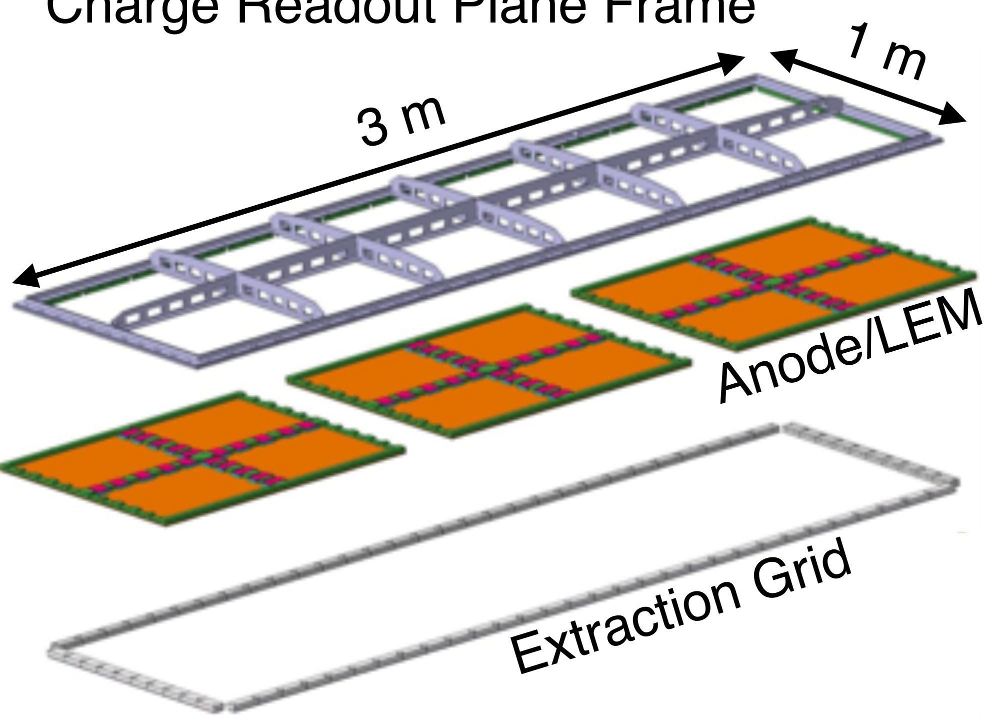
Today

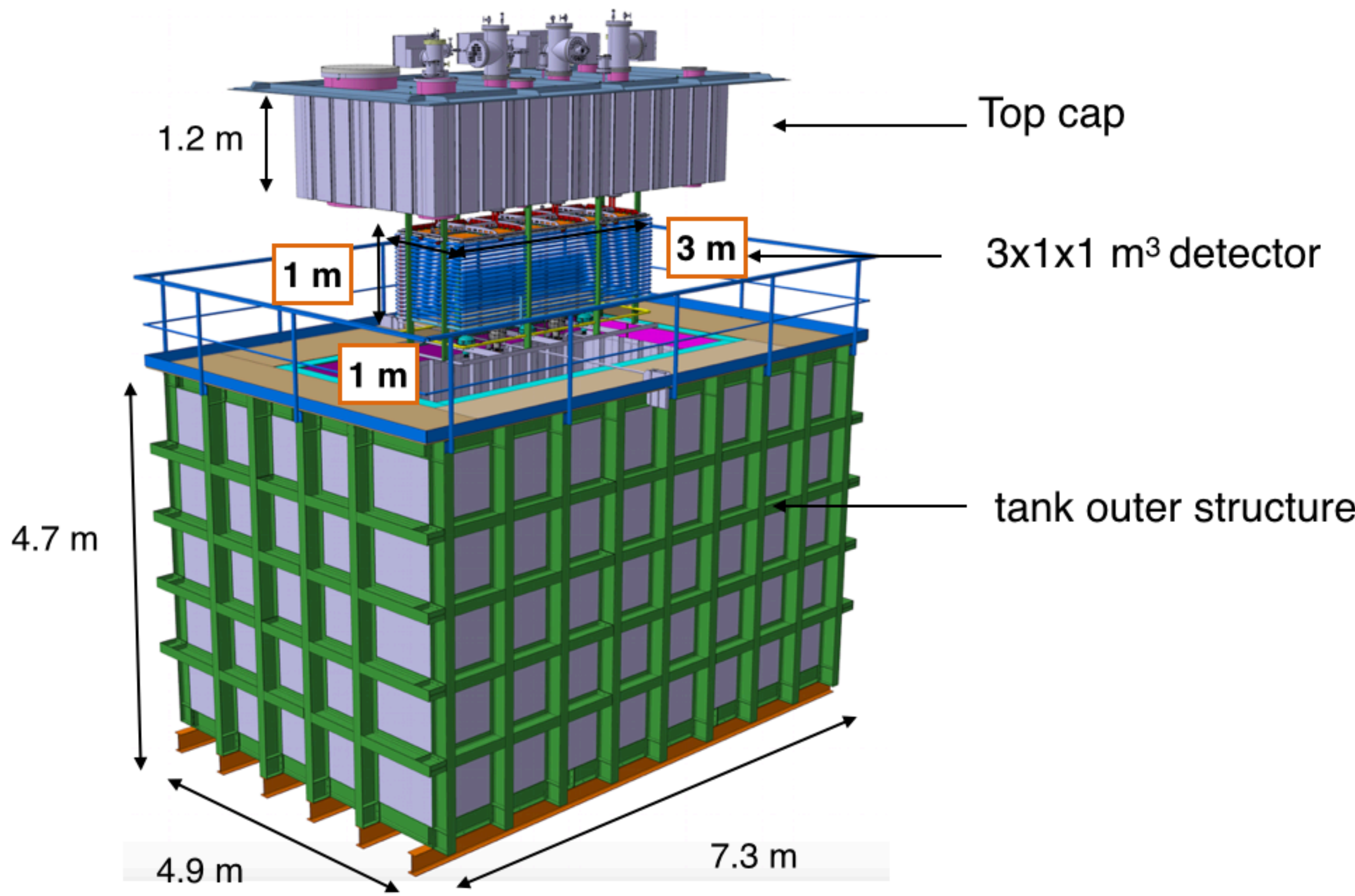
WA105

CERN-SPSC-2017-011, SPSC-SR-206

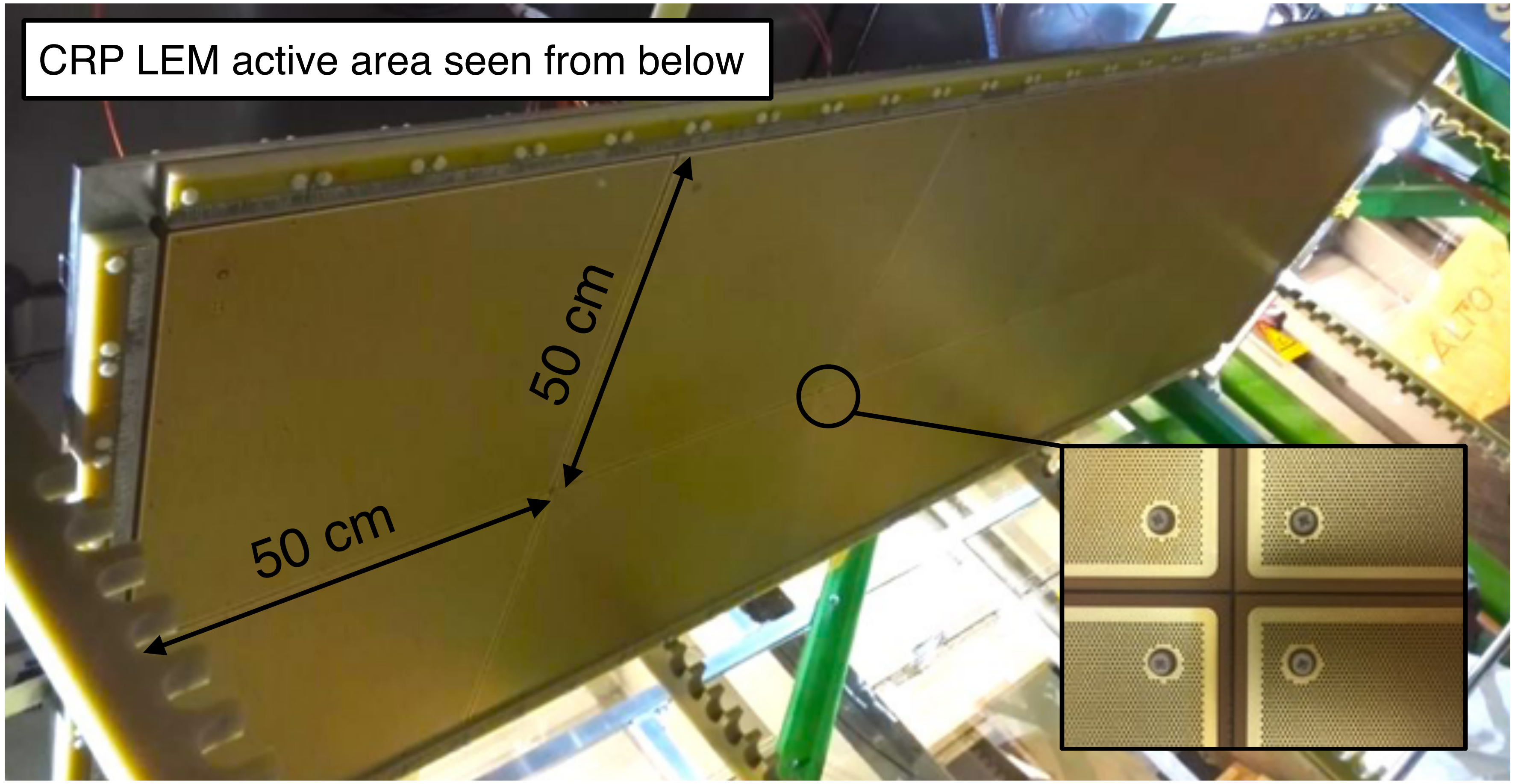
Goals of the 3x1x1 demonstrator

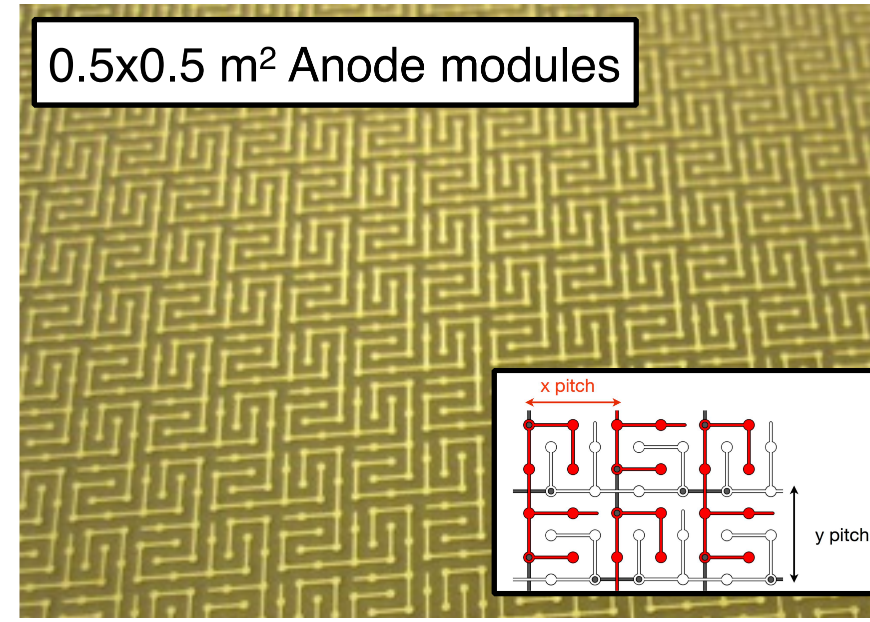
- Establishment of routine procedure for mass production
- Quality assurance and control tests
- Calibration of LEMs
- Cryogenic installation, feedthrough
- Validation of production schedule for the 6x6x6 m^3

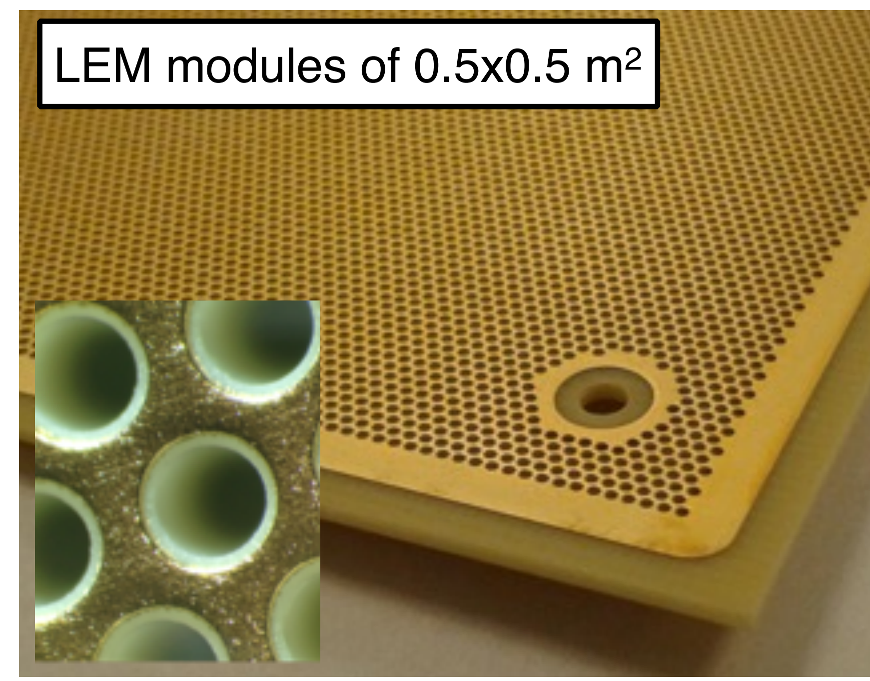


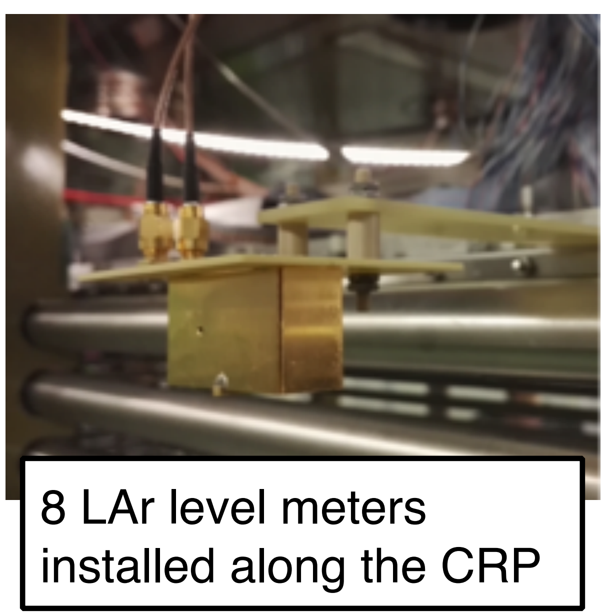


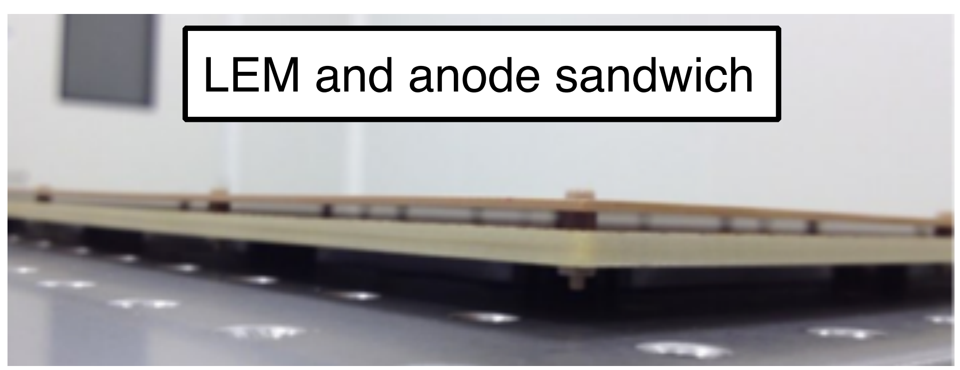
Charge extraction, amplification and collection









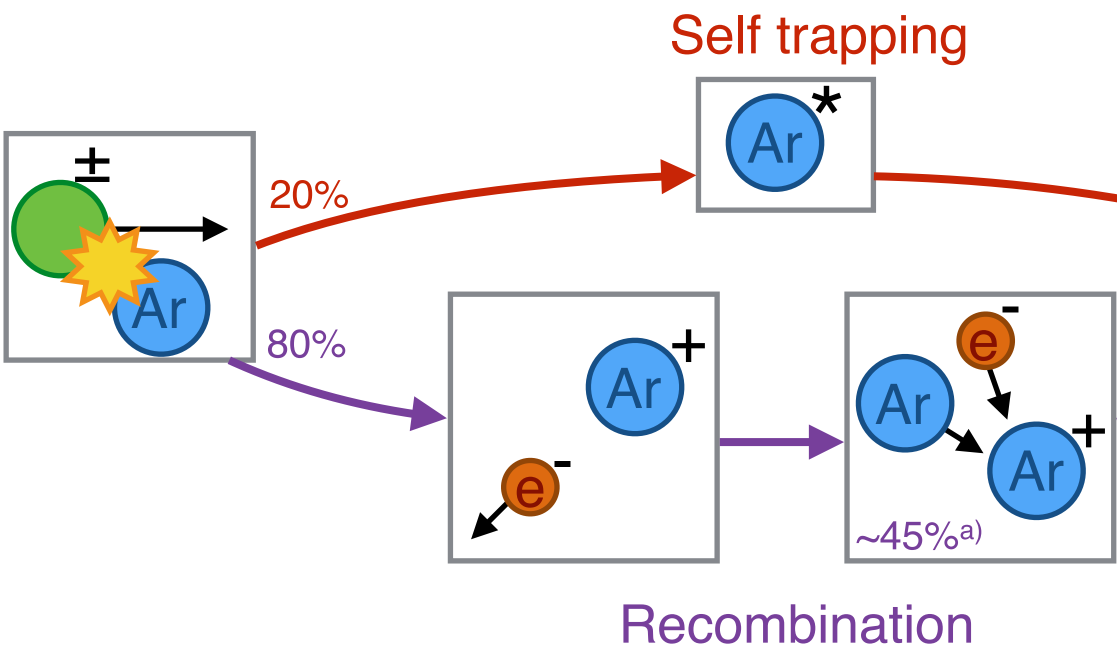


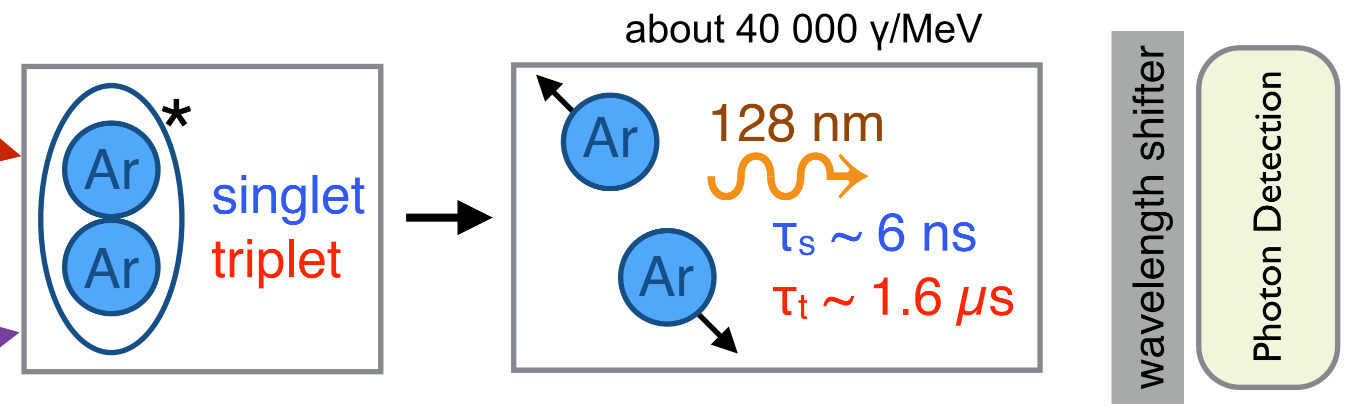
- Fully active 3x1 m^2 amplification and readout adjustable to LAr level.
- Mechanical tolerances tested at warm and in open cold bath test

extraction grid made of 100 μm SS wires

C. Cantini *et al.*, JINST 9 (2014) P03017
C. Cantini *et al.*, JINST 10 (2015) no.03, P03017

Light signal





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

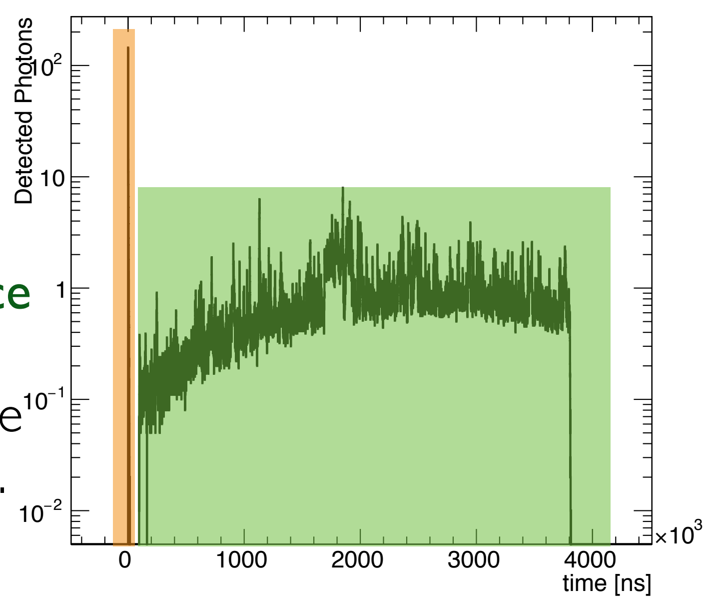
- Charge and light signal are anti-correlated through the recombination process → light can be used as a complementary calorimetry measurement
- The recombination factor depends on the drift field and energy loss
- TPB is used as the wavelength shifter

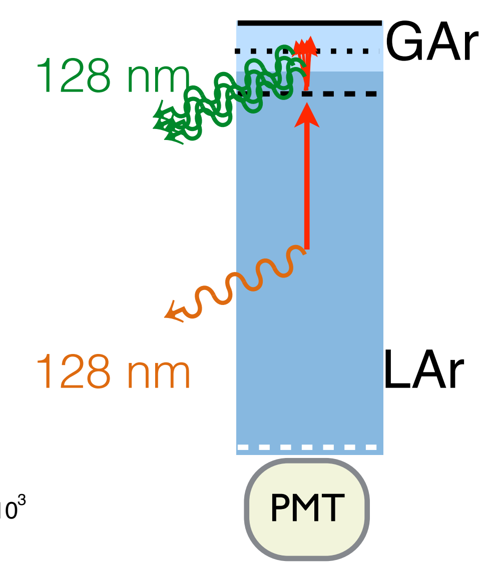
<u>2 light signals in a dual phase LArTPC :</u>

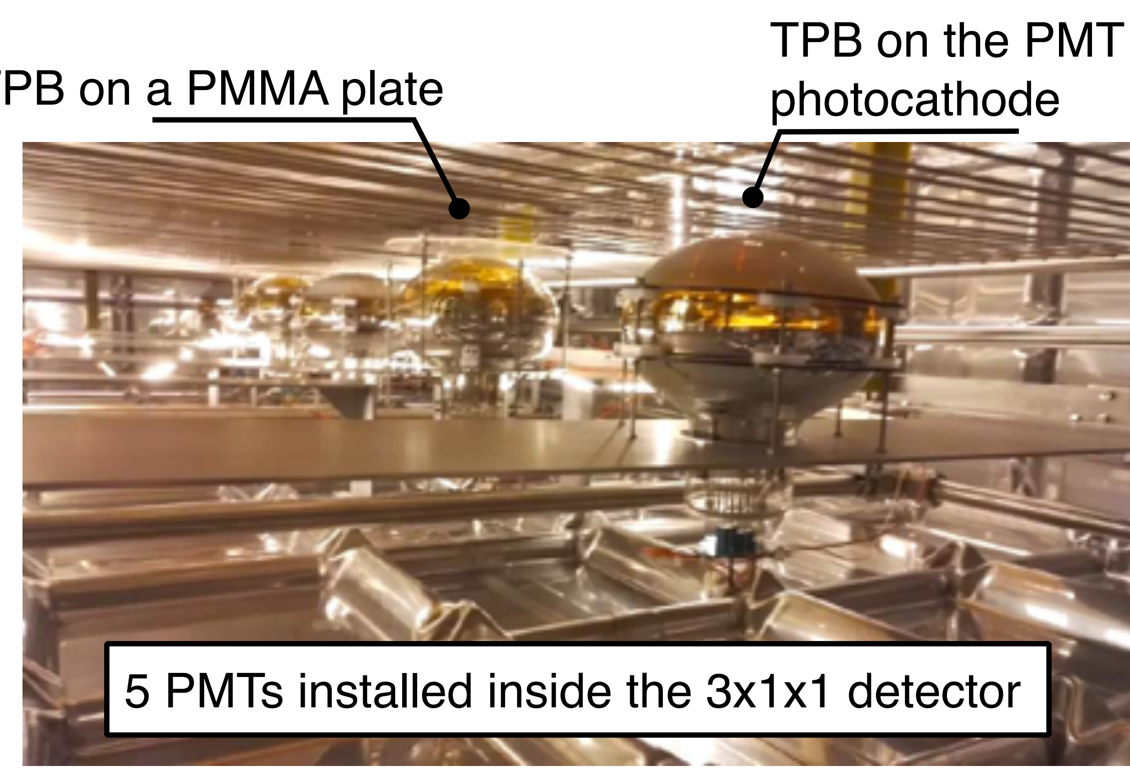
Prompt signal from LAr [S1]

Electroluminescence from GAr [S2]

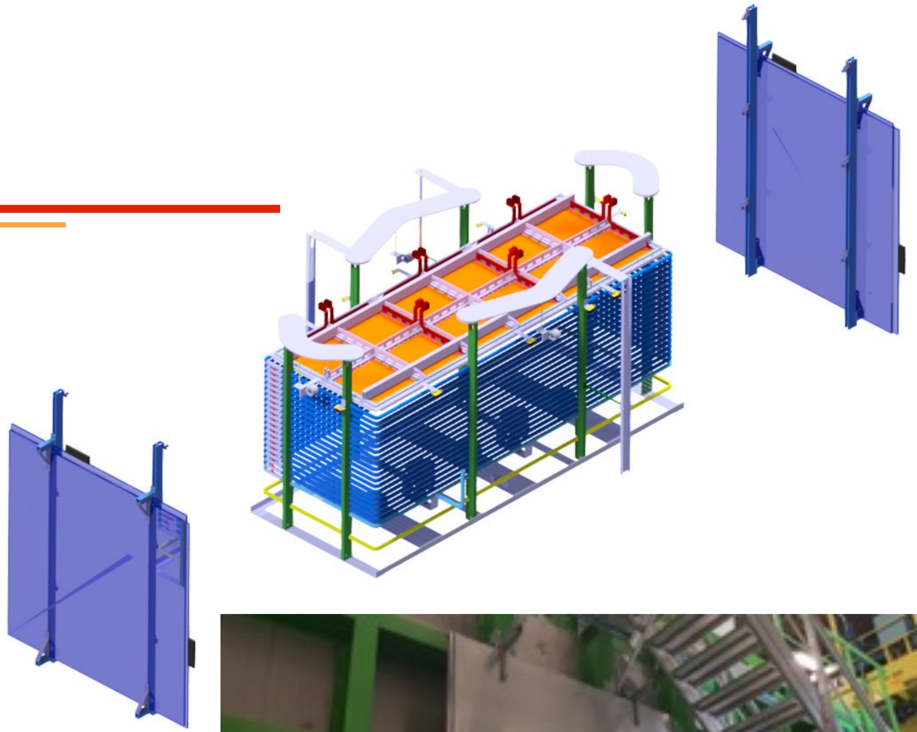
Continuum from the amplification region. Threshold for EL is 3.5 kV/cm



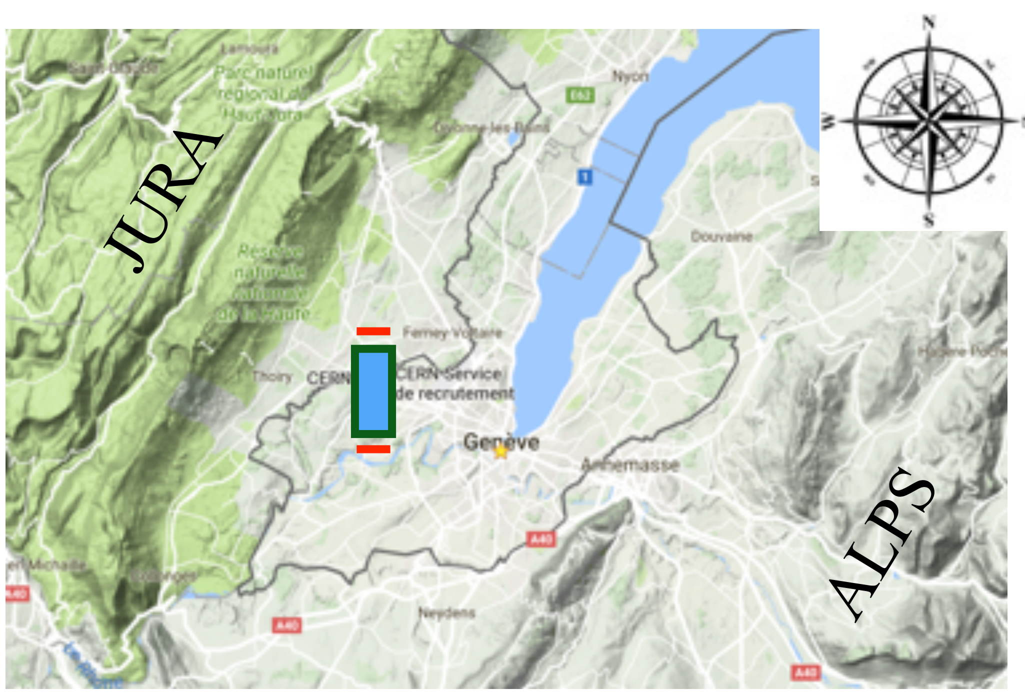


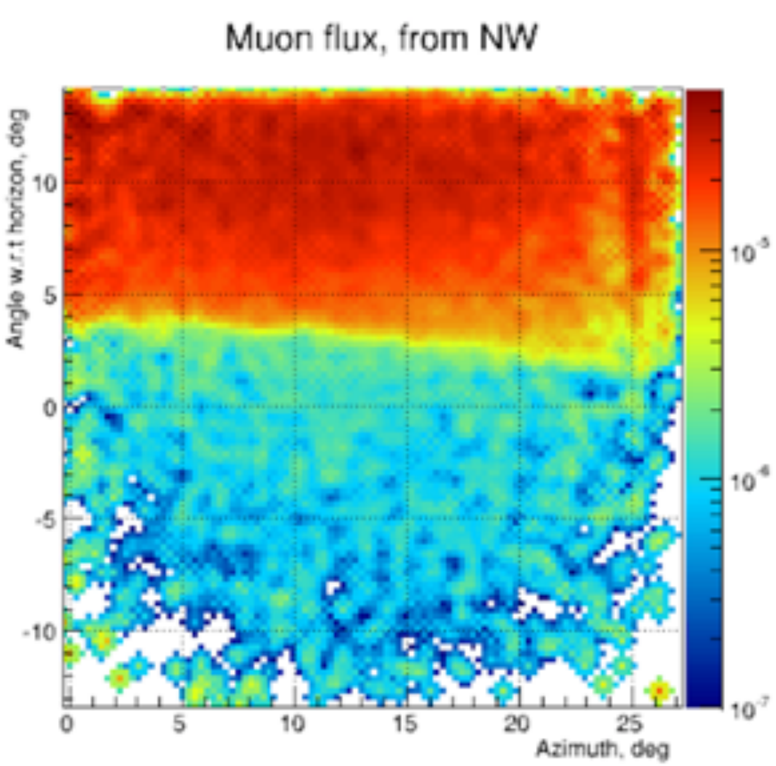


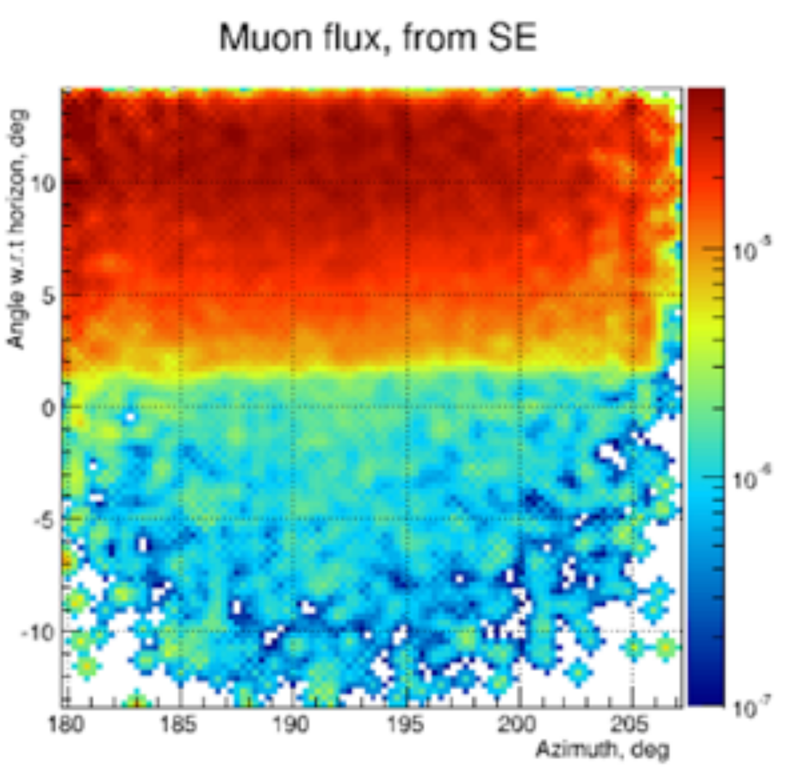
Cosmic Ray Taggers



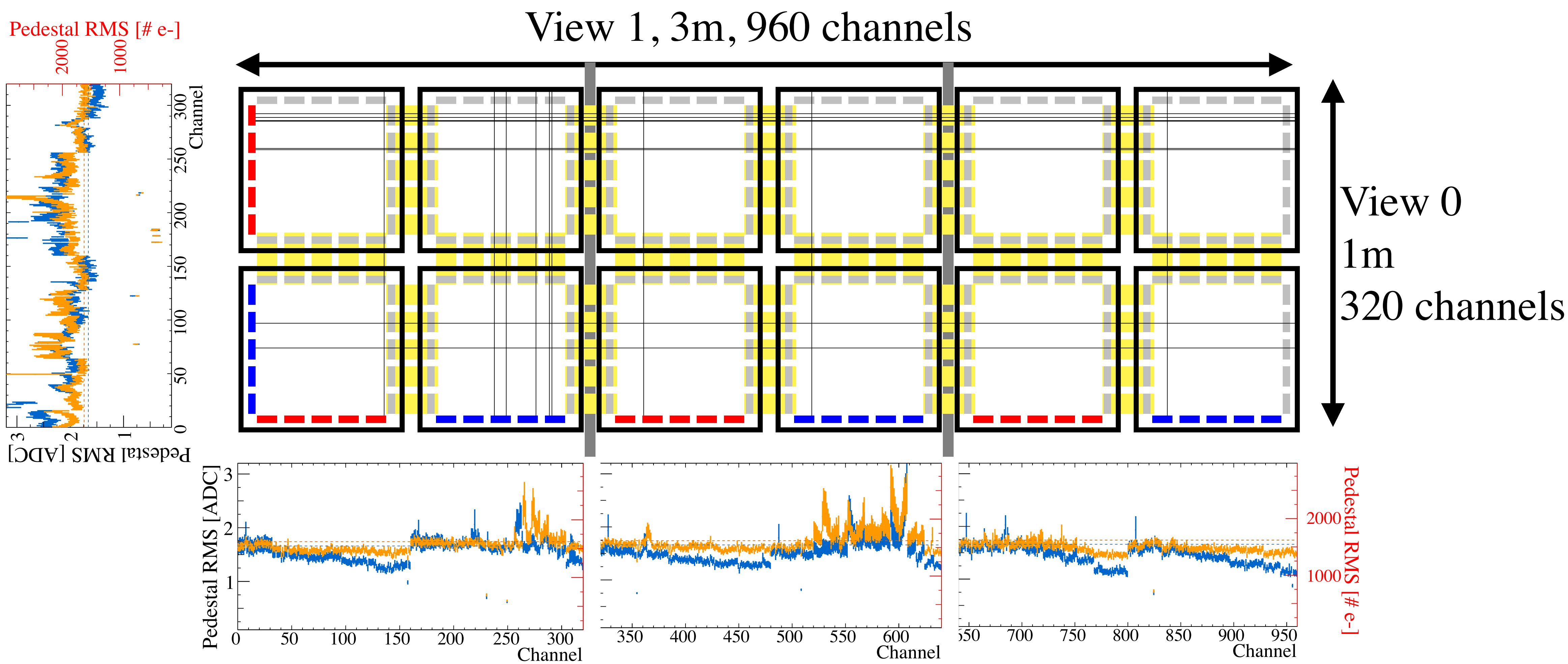
- 2 CRTs installed on short sides of the detector
  $\longrightarrow$ Each made of scintillators bars in x-y to provide 2D coordinates
- Provide trigger for selecting crossing tracks along the detector, and inputs for μ tracking
- Trigger rate at ~ 0.3 Hz
- Can see the effect of Jura mountain shape on the cosmic ray flux !







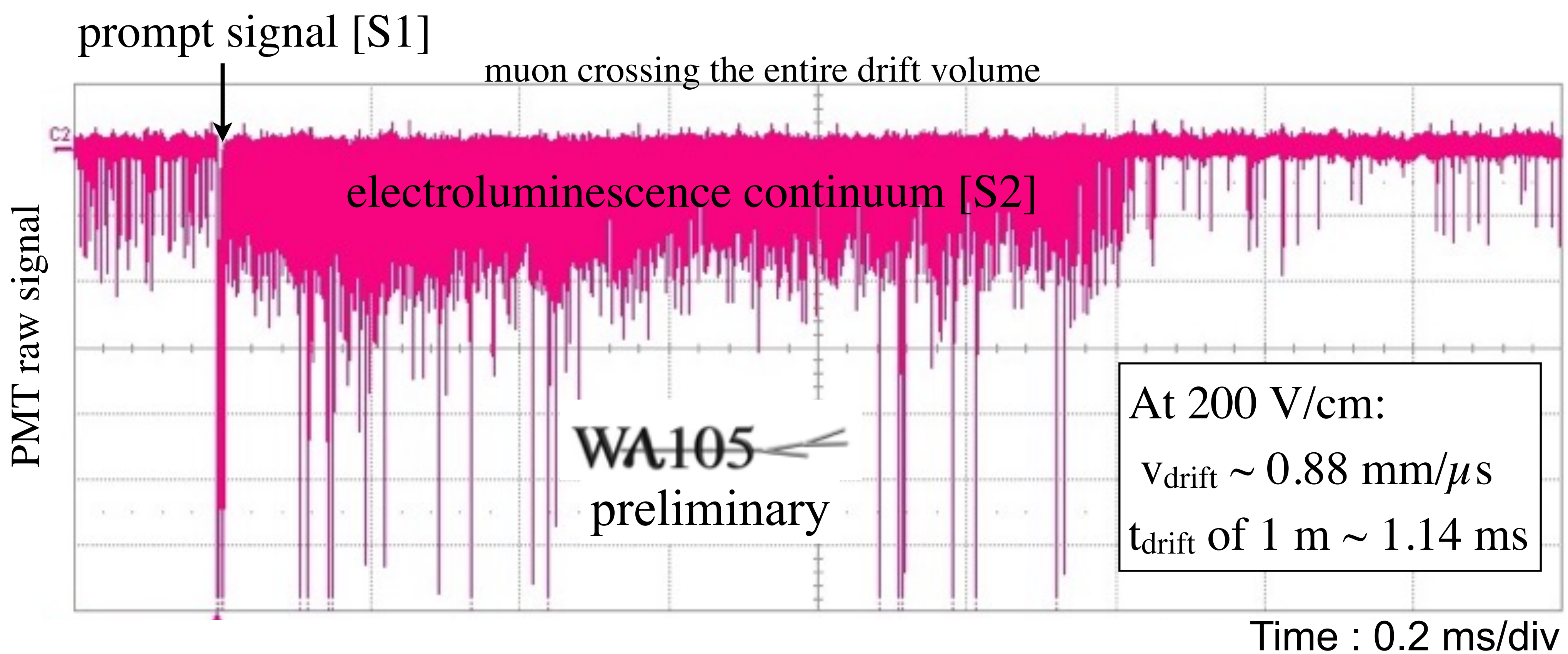
Detector Commissioning



- Out of 1280 channels, 17 found problematic or dead (1.3%)
- Noise at room temperature stable at around 1600 e$^-$
- Noise at cryogenic temperature stable at around 1550 e$^-$
- Calibration runs with pulsed injected charge runs have shown ~ 4% of crosstalk

Since last GDR : June 15th

First light signal !
Evidence of electron extraction



Long PMT runs (~10 ktriggers/run) are being analyzed.

HV configuration :
Drift Field = 200 V/cm
Extraction Field = 1.6 kV/cm
LEM Field = 10 kV/cm

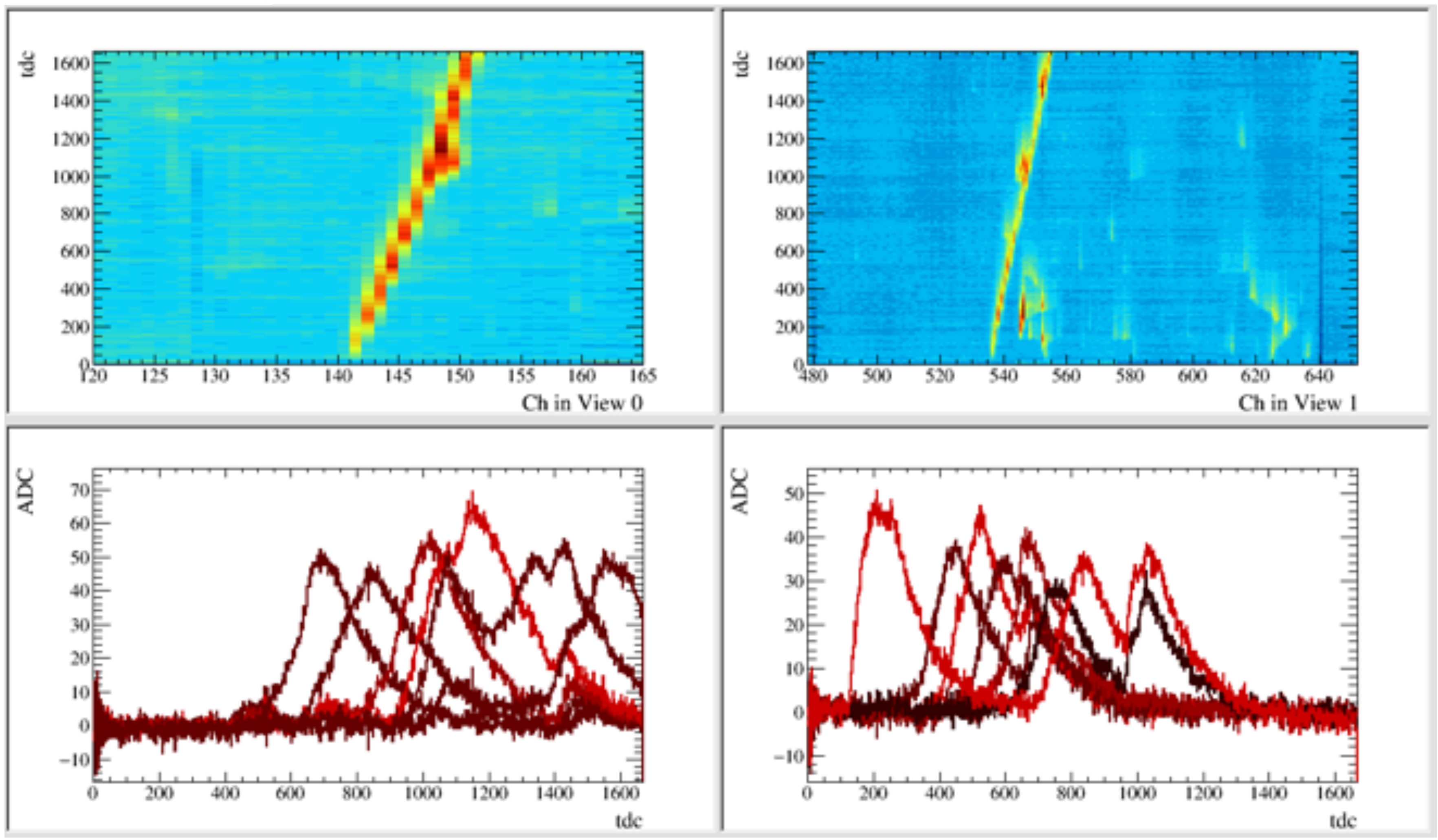
From this event acquired on the scope :

- Evidence electron extraction and amplification in the LEM
- Evidence of good liquid argon purity through ms drift observed

Since last GDR : June 21st

First track !

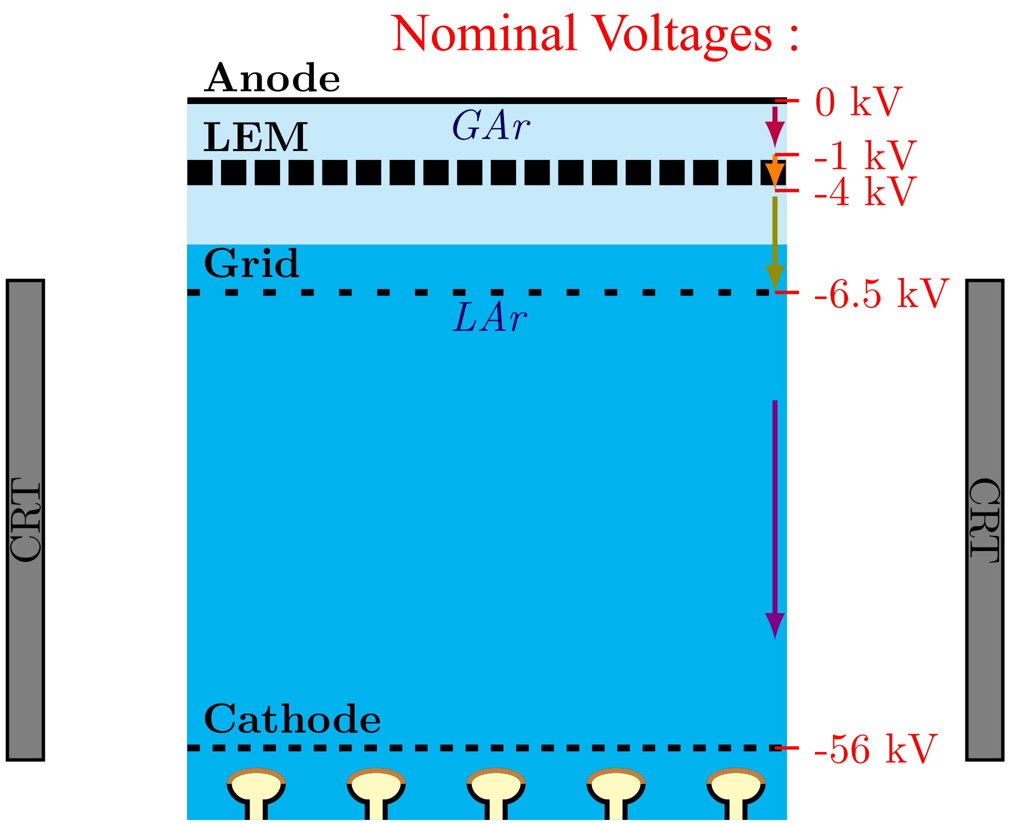
WA105 preliminary



HV configuration :
Drift Field = 320 V/cm
Extraction Field = 0.6 kV/cm
LEM Field = 29 kV/cm
Induction Field = 1. kV/cm

- First through going cosmic track observed
- Detector was in a un-optimized configuration
- Raw event display, only pedestals are removed

Data collected



Drift Field, nominal at 0.5 kV/cm
↳ Achieved [0.3 ~ 0.7] kV/cm

Extraction Field, nominal at 2 kV/cm in LAr
↳ Achieved with a maximum voltage applied of -5 kV

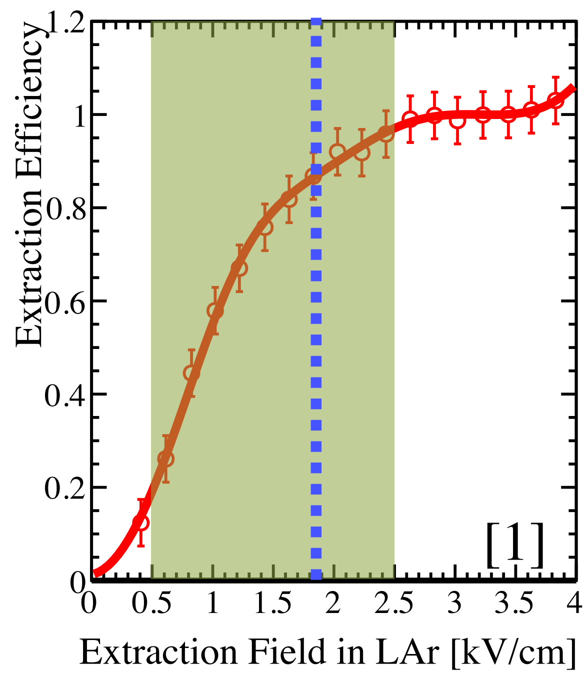
Amplification Field, nominal at 30 kV/cm
↳ Limited by the grid

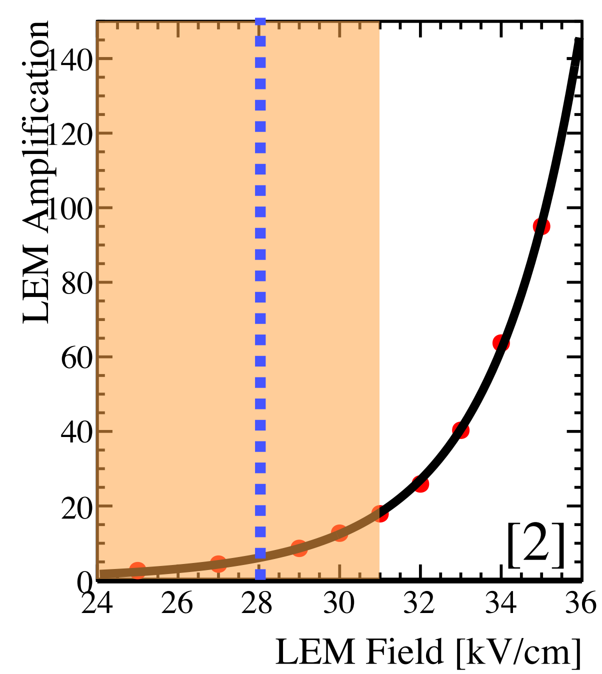
Induction Field, nominal at 5 kV/cm
↳ Limited by the grid

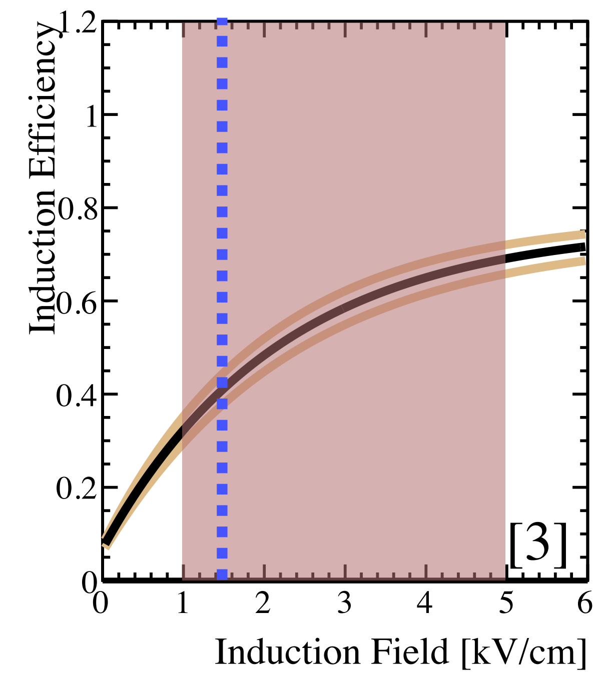
2 triggers : CRT and PMT

▪▪▪▪ : Best HV settings in stable condition

■ : Achieved fields



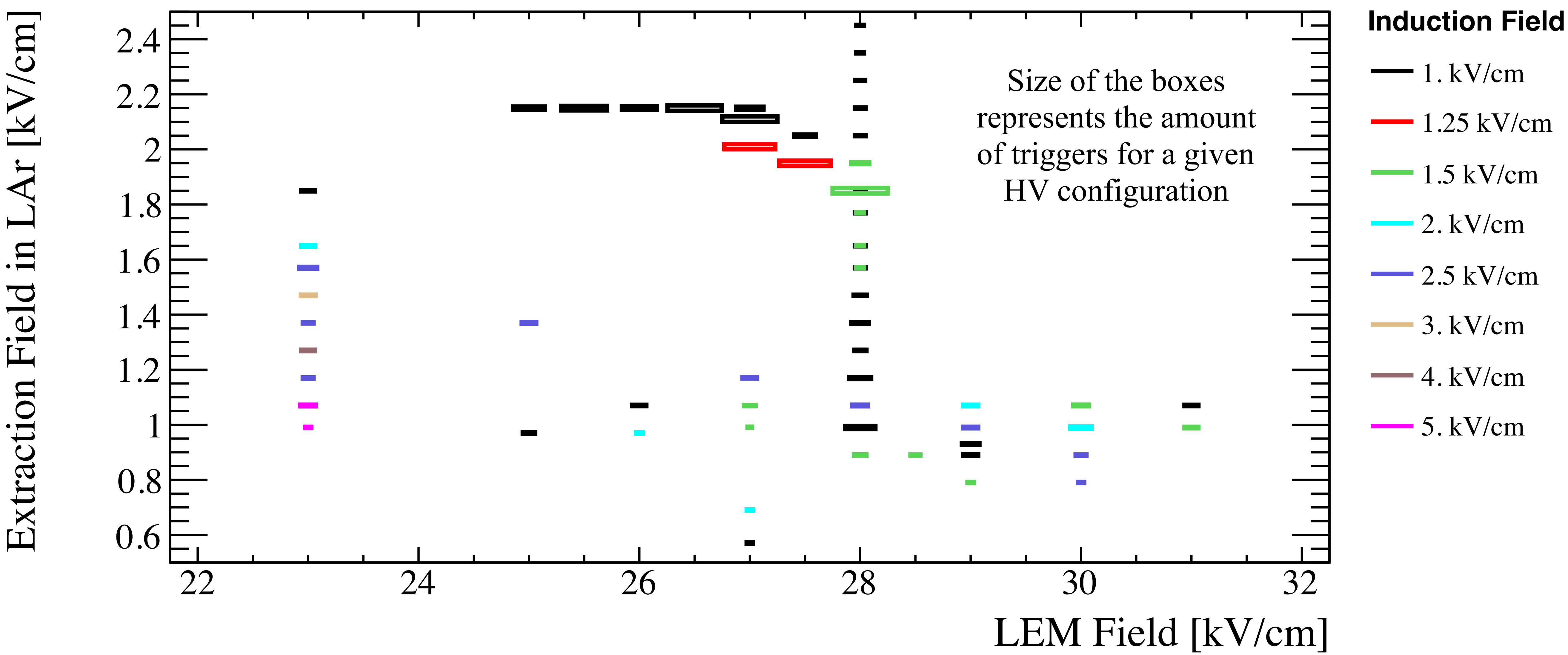




[1] : Gushchin *et al*, Sov. Phys. JETP **55** (1982) 860-862
[2] : LBNO TDR
[3] : Simulations

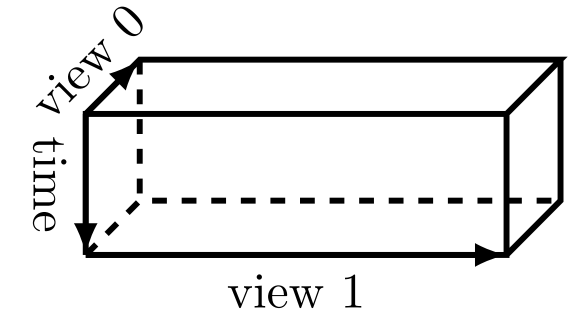
Data collected

About 500 000 triggers taken in more than 50 HV configurations

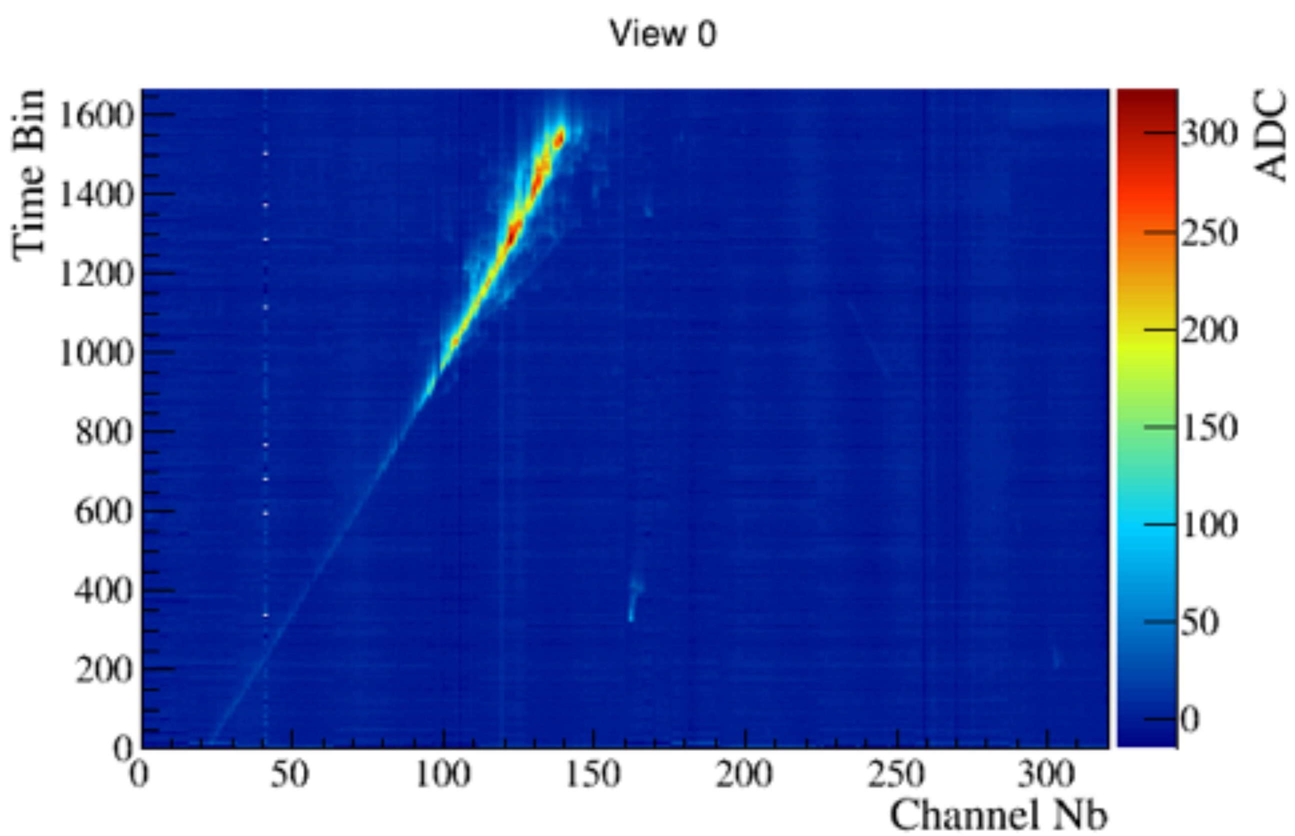


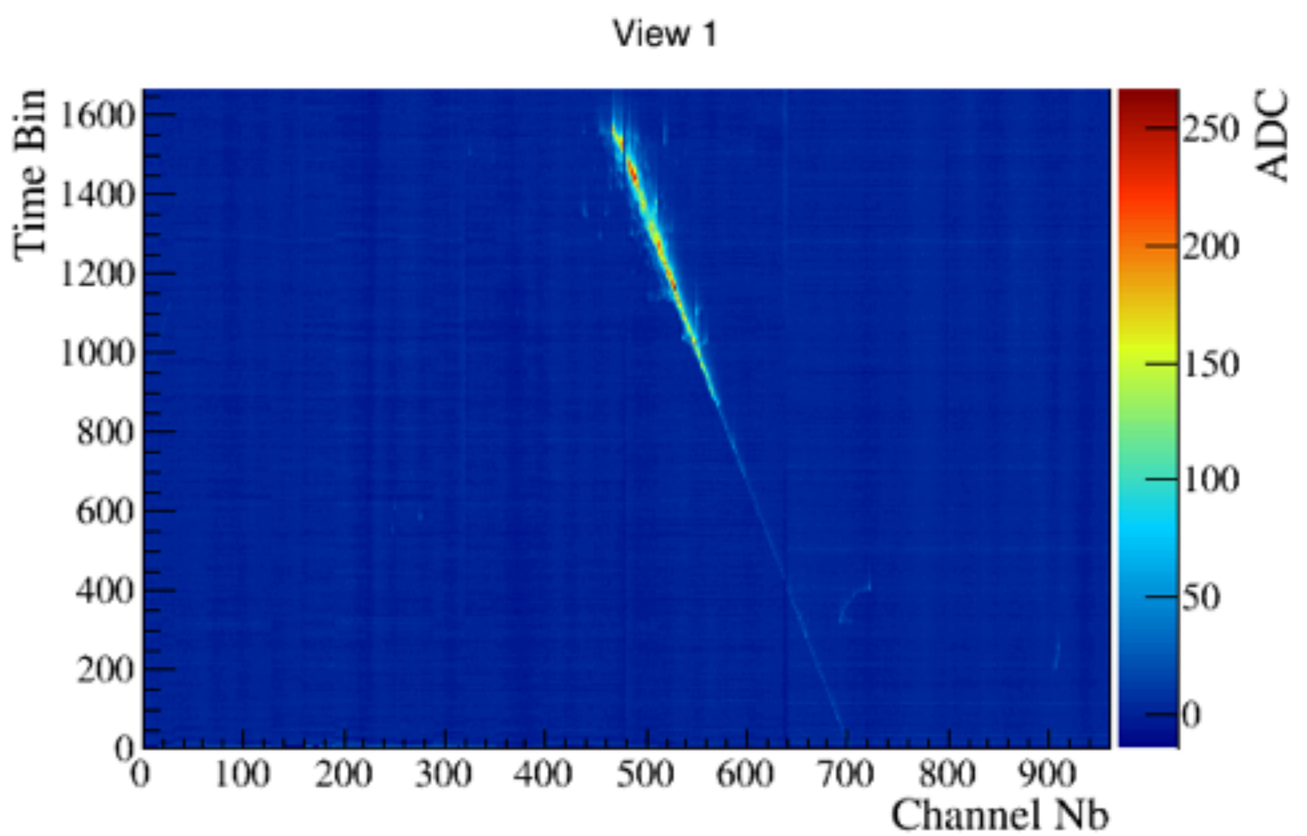
NB : The different drift field conditions and different triggers are not represented

Event Gallery



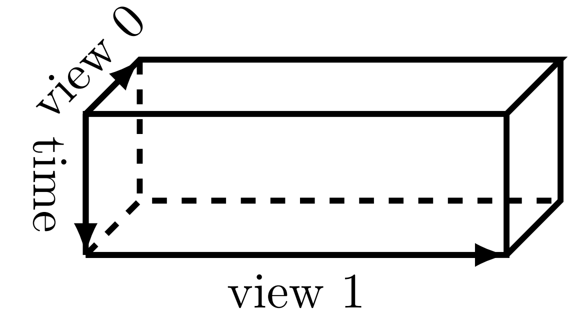
Raw data
1 time bin is 0.4 μs
1 channel is 0.3125 cm





HV configuration :
Drift Field = 500 V/cm
Extraction Field = 1.85 kV/cm
LEM Field = 28 kV/cm
Induction Field = 1.5 kV/cm

Event Gallery



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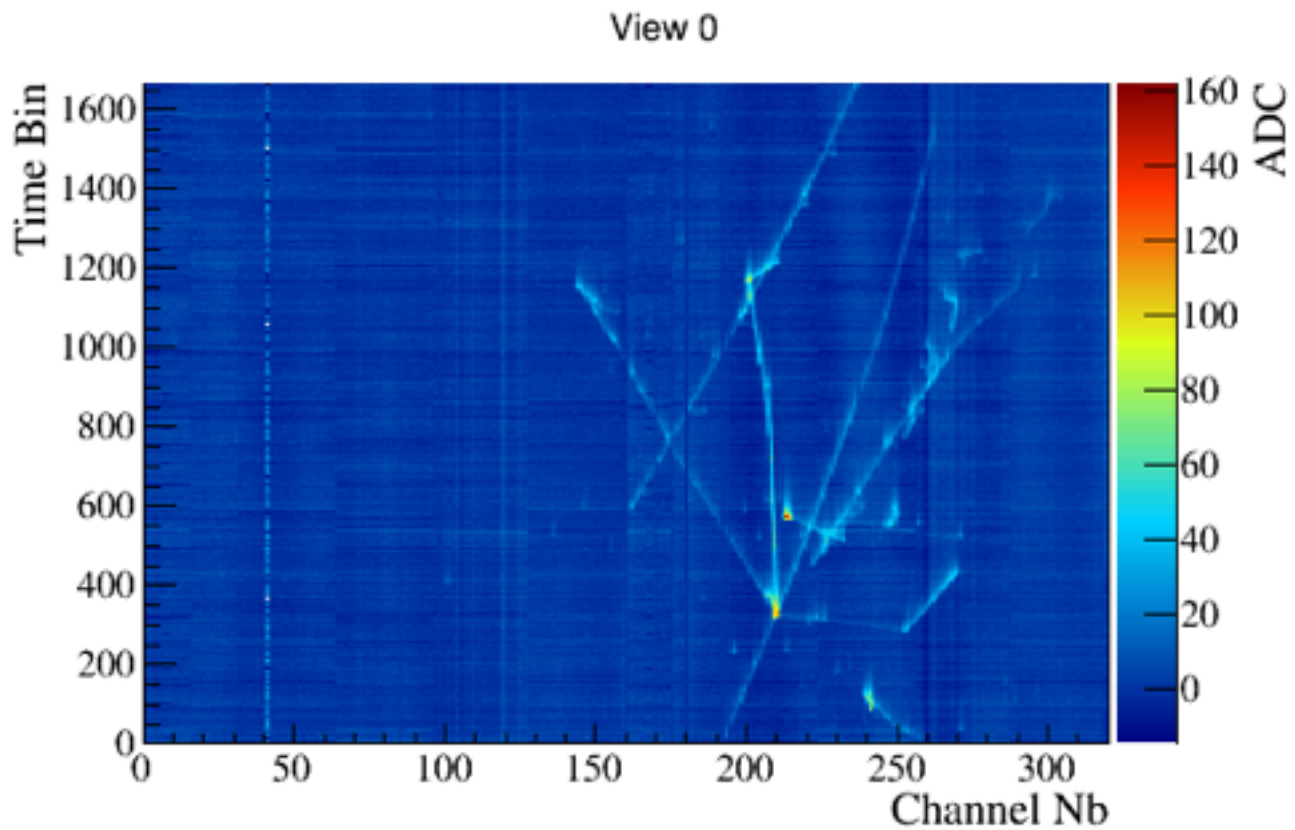
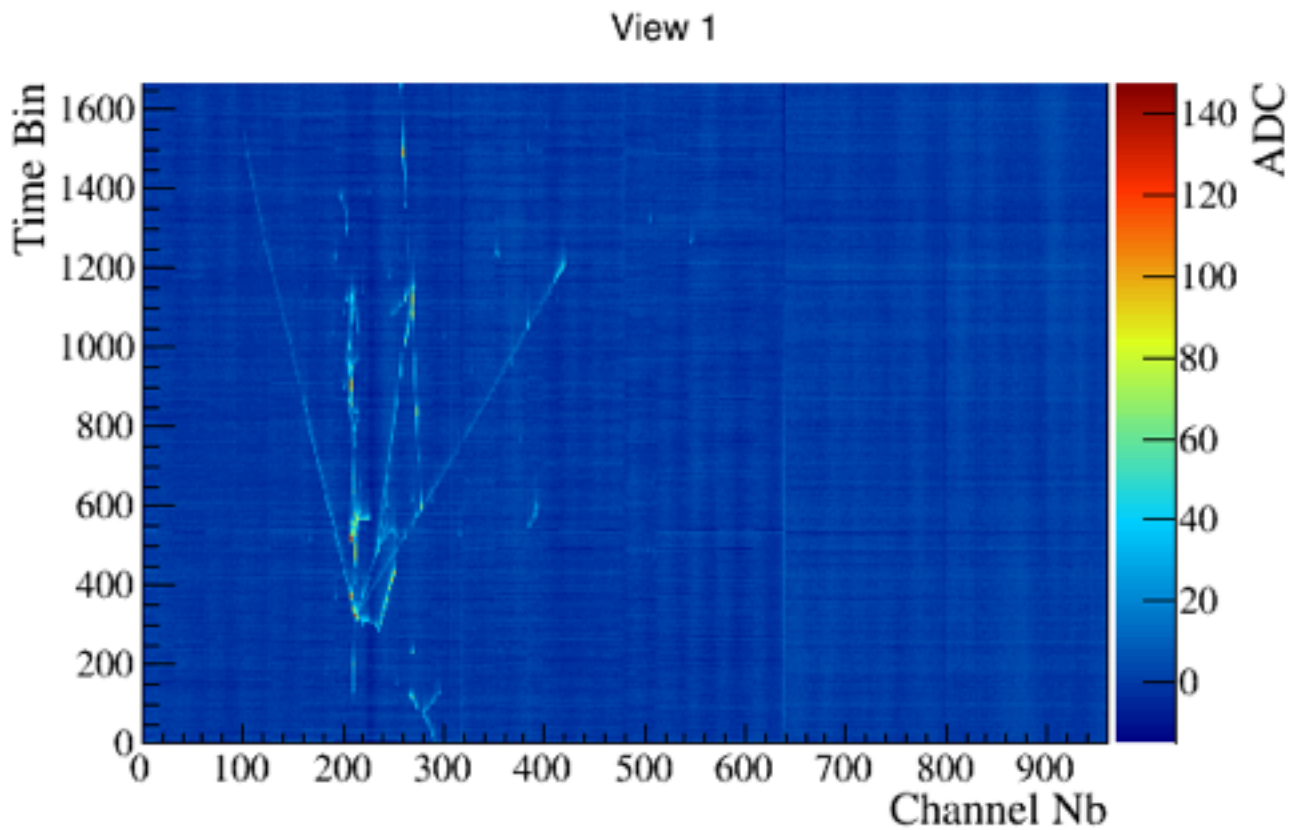
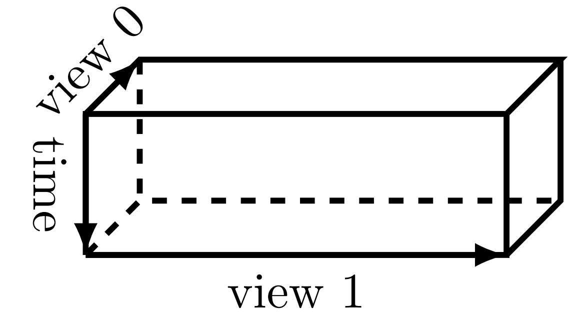


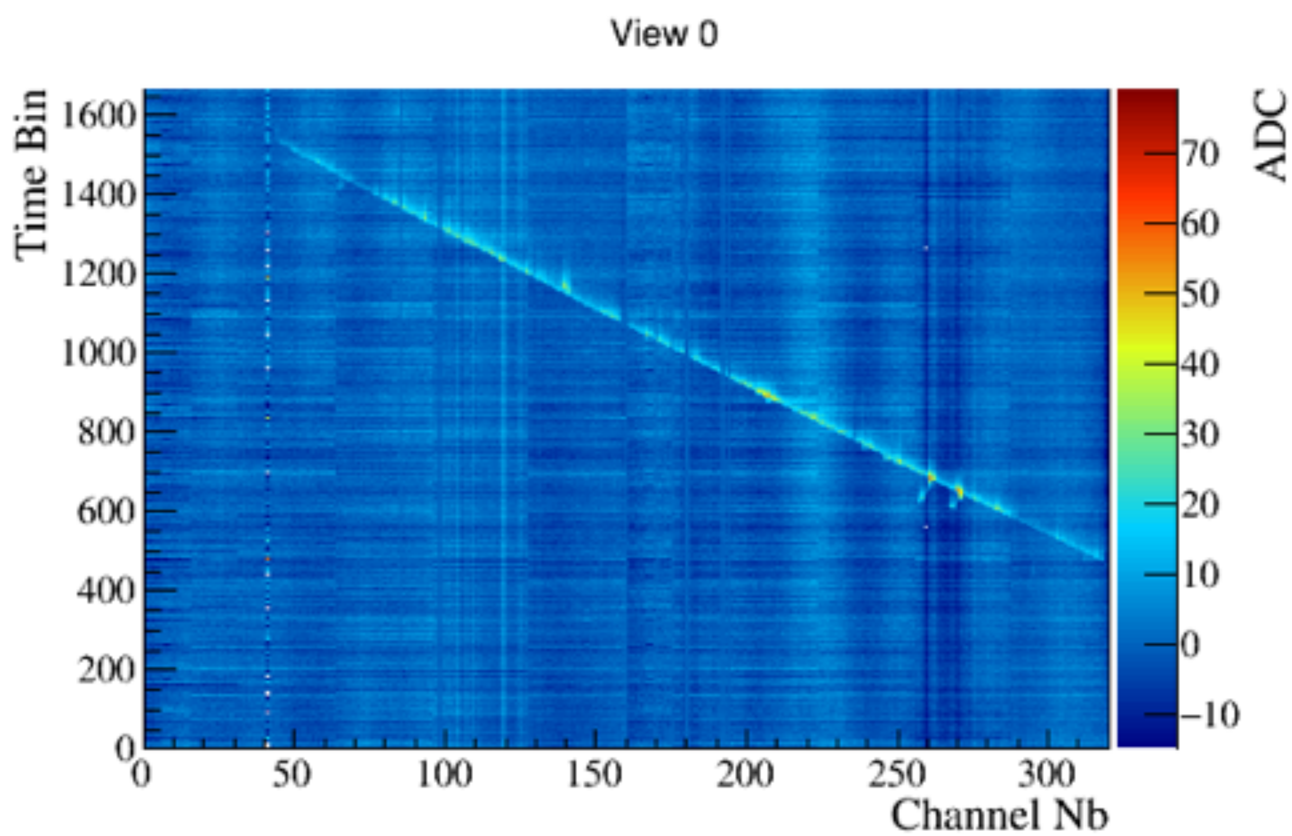


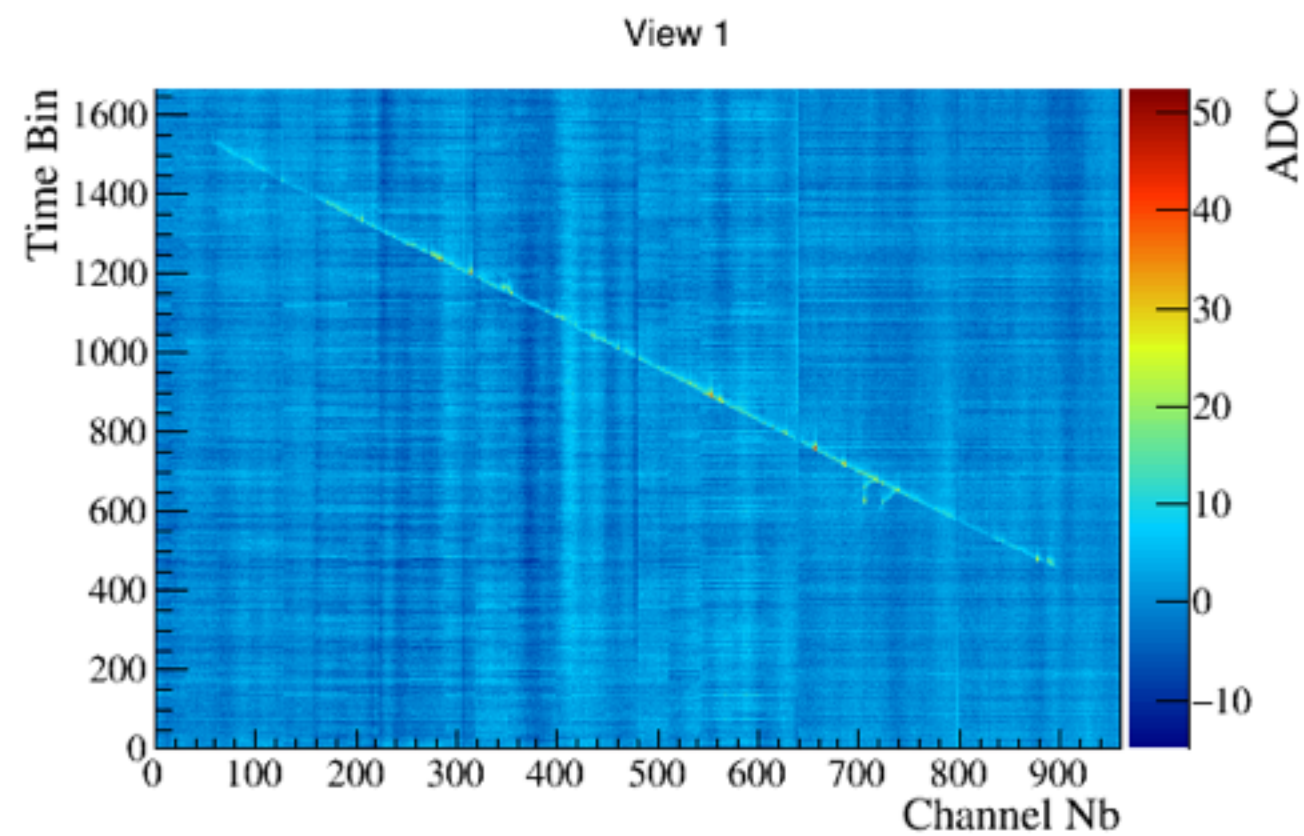
<u>HV configuration :</u>
Drift Field = 500 V/cm
Extraction Field = 1.85 kV/cm
LEM Field = 28 kV/cm
Induction Field = 1.5 kV/cm

Event Gallery



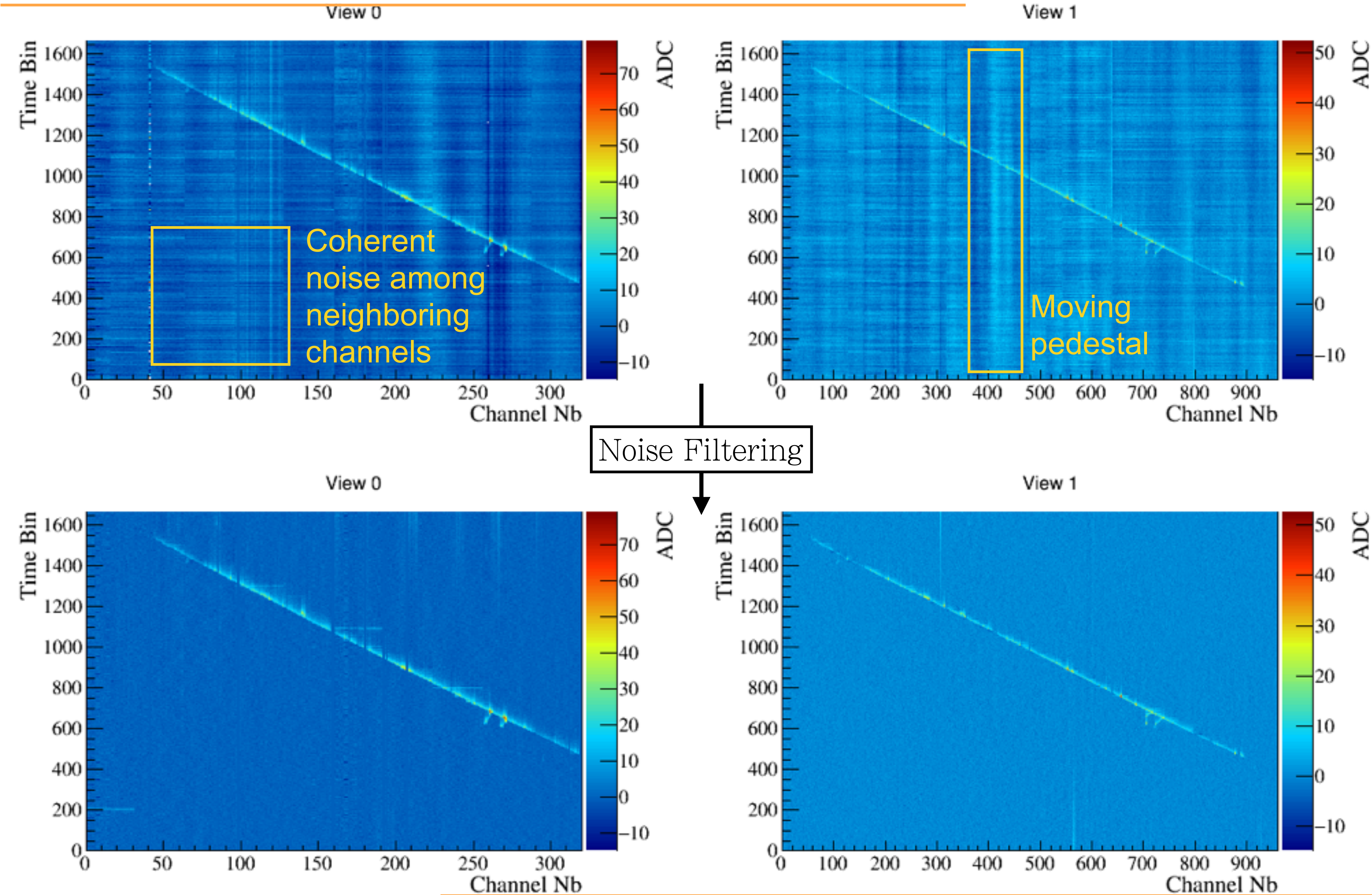
Raw data
1 time bin is 0.4 μs
1 channel is 0.3125 cm



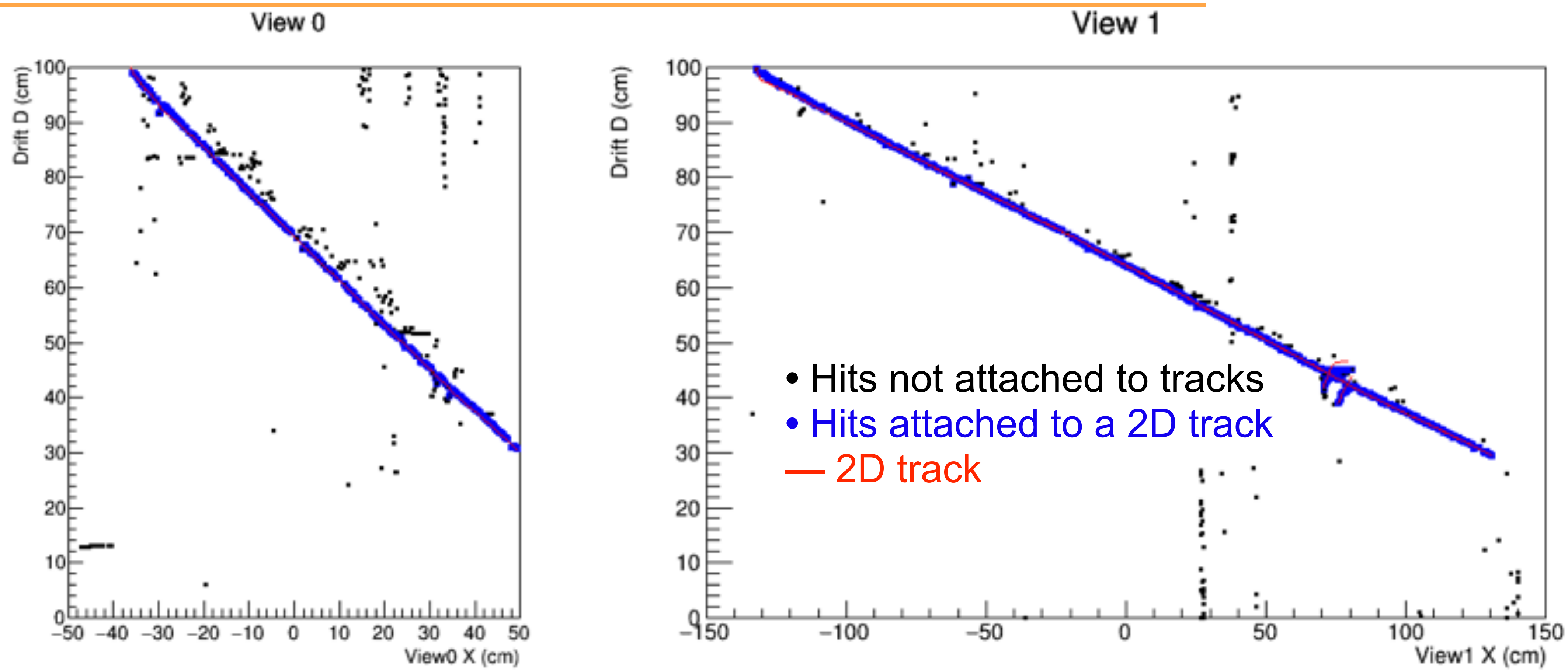


<u>HV configuration :</u>
Drift Field = 500 V/cm
Extraction Field = 1.85 kV/cm
LEM Field = 28 kV/cm
Induction Field = 1.5 kV/cm

Reconstruction of charge data, noise filtering

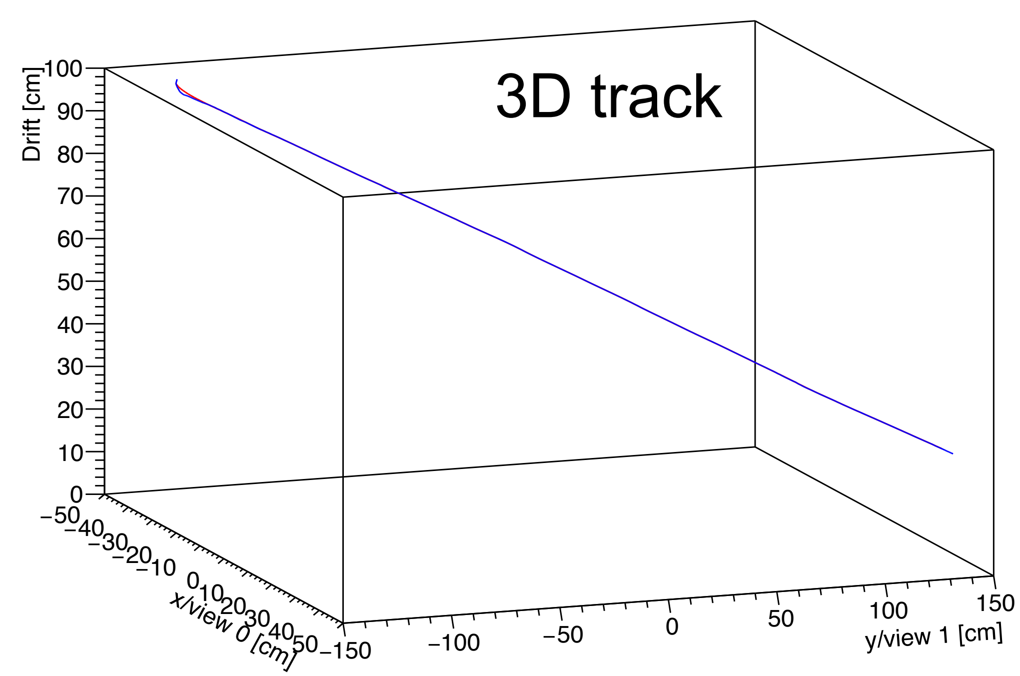


Reconstruction of charge data, noise filtering



Many reconstruction code used for our data, but all follow a similar approach :

- Hits are found by thresholds above the pedestal. The total charge is computed either by summing the ADC counts or fitting the waveforms
- 2D tracks are found following Kalman filtering
- 3D tracks are constructed from time and charge matching of 2D tracks in both views
- Some development on neural network-based reconstruction are on-going



First look at the charge data

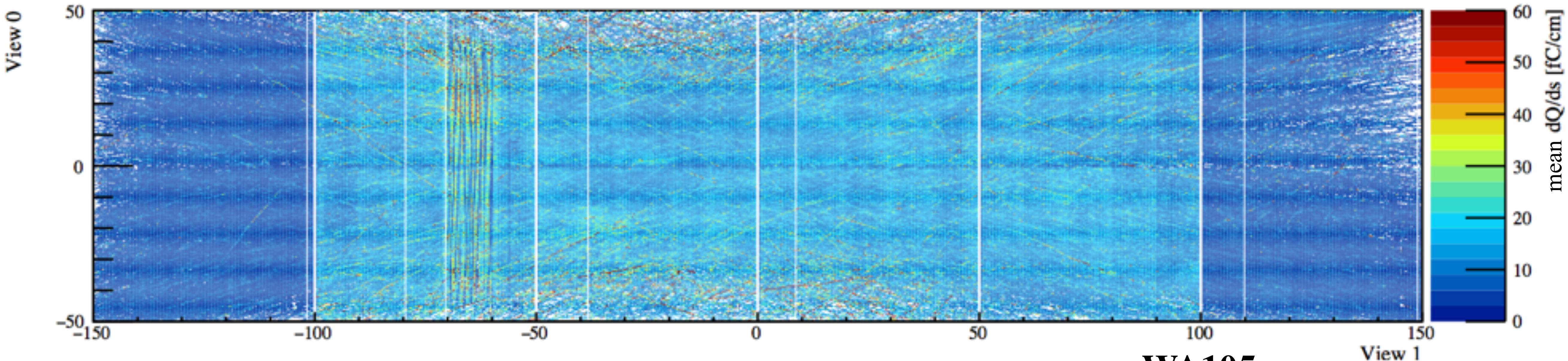
HV configuration :
Drift Field = 500 V/cm
Extraction Field ≥ 1.85 kV/cm
Induction Field = 1.5 kV/cm

— From our longest and best HV condition run —

1	2	5	6	9	10
3	4	7	8	11	12

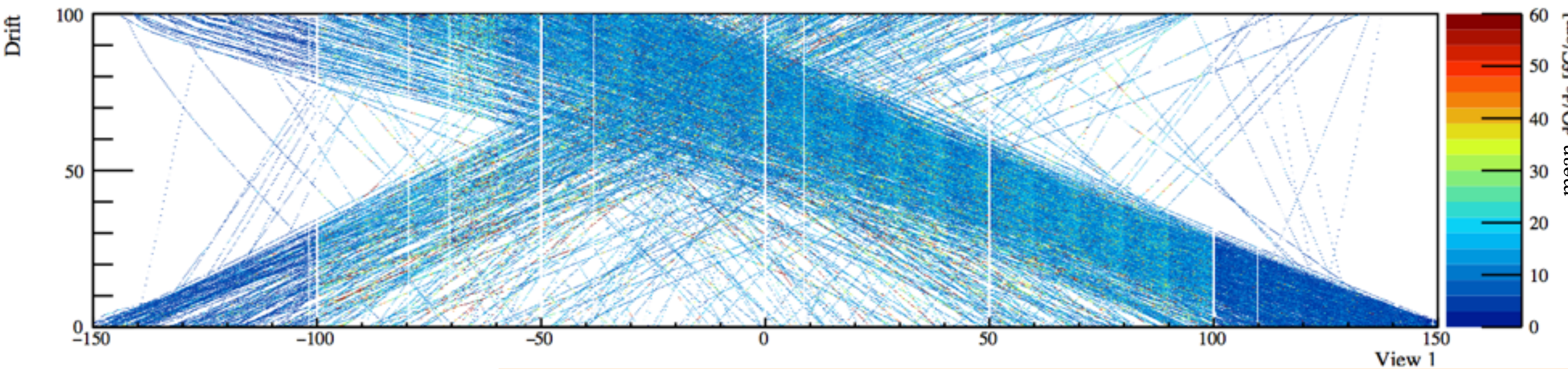
corner LEMs at 24 kV/cm
central LEMs at 28 kV/cm

All good 3D tracks reconstructed view from above :



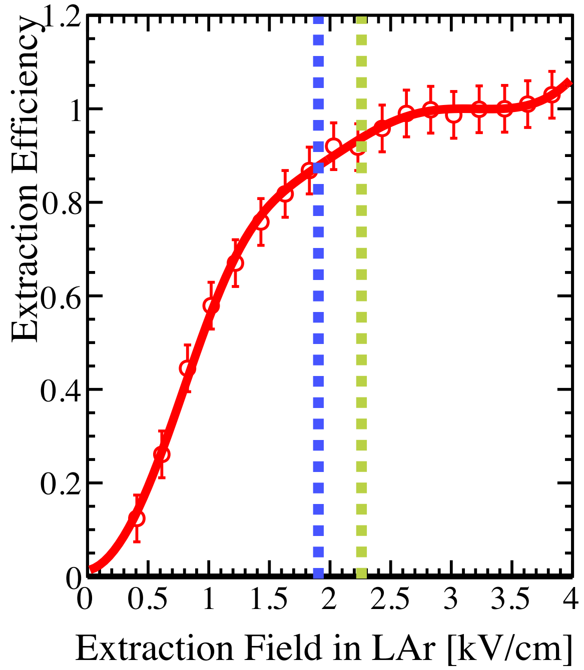
WA105
PRELIMINARY

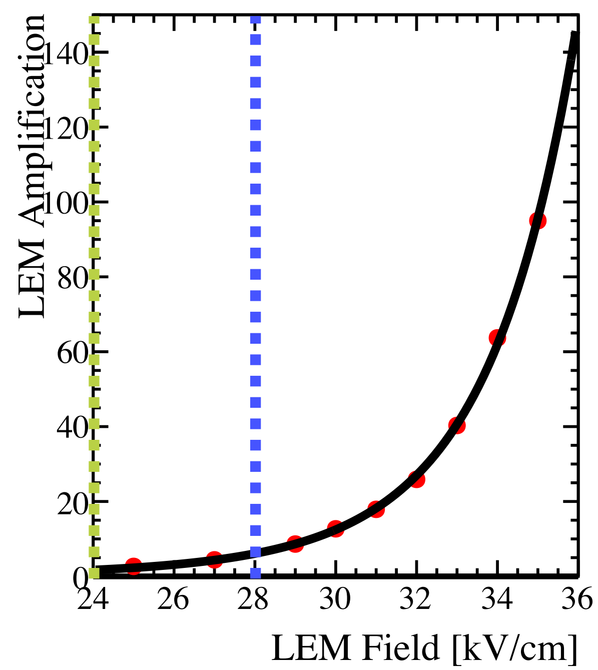
All through going tracks view from the long side :

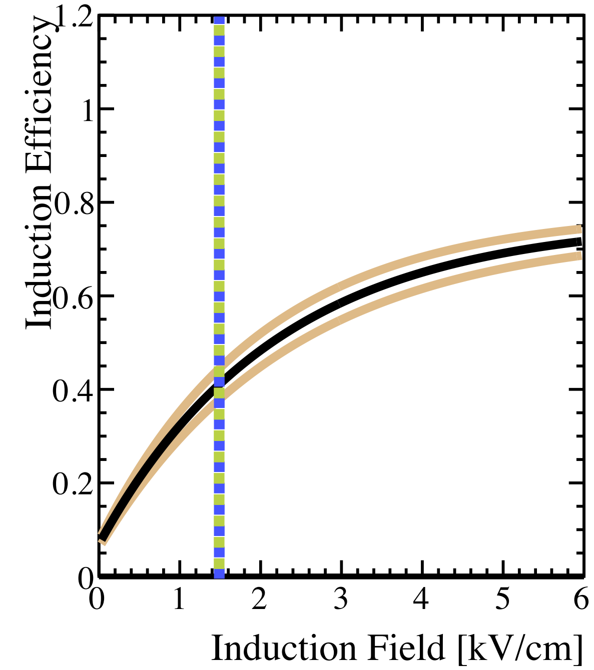


First look at the charge data : effective gain

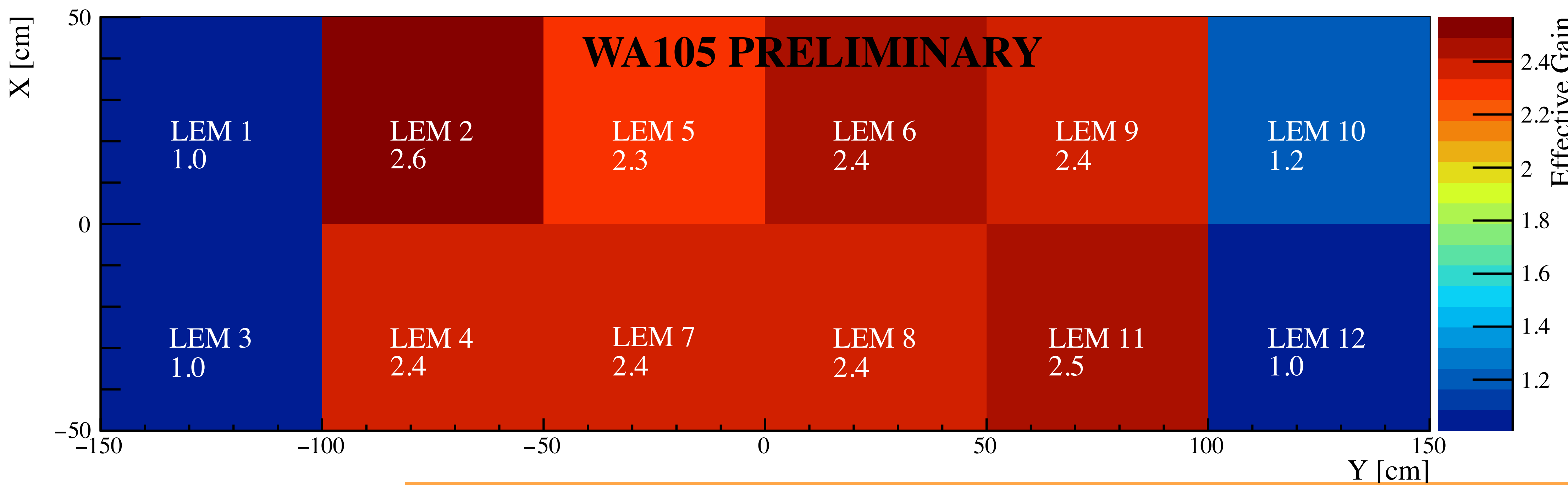
$$G_{eff} = \varepsilon_{extr} \times G_{LEM} \times \varepsilon_{ind}$$



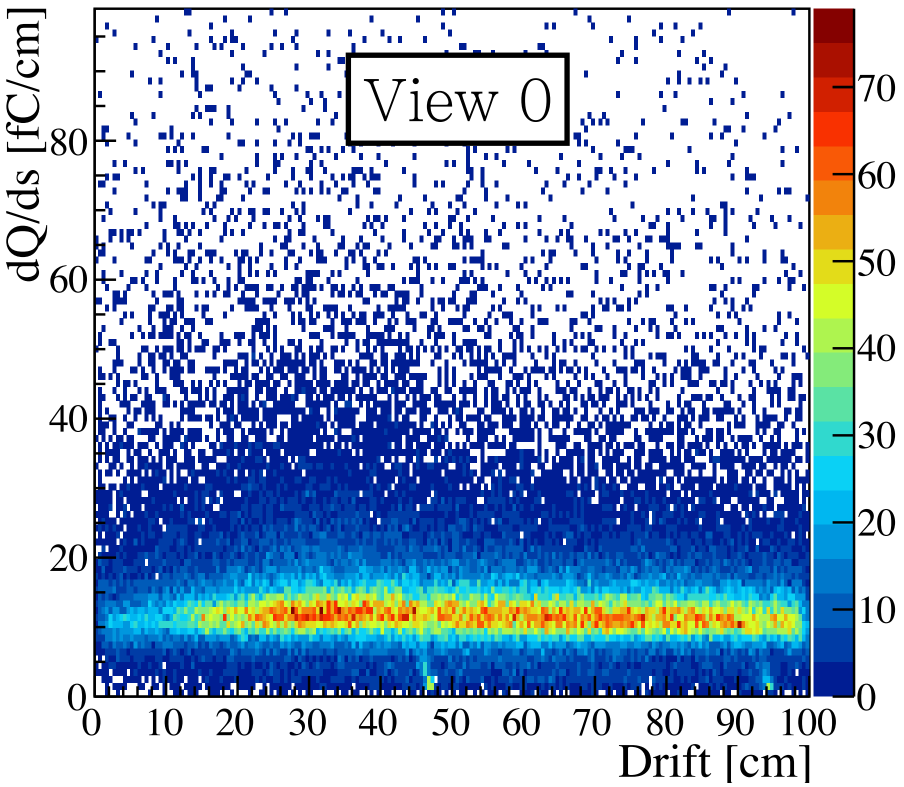


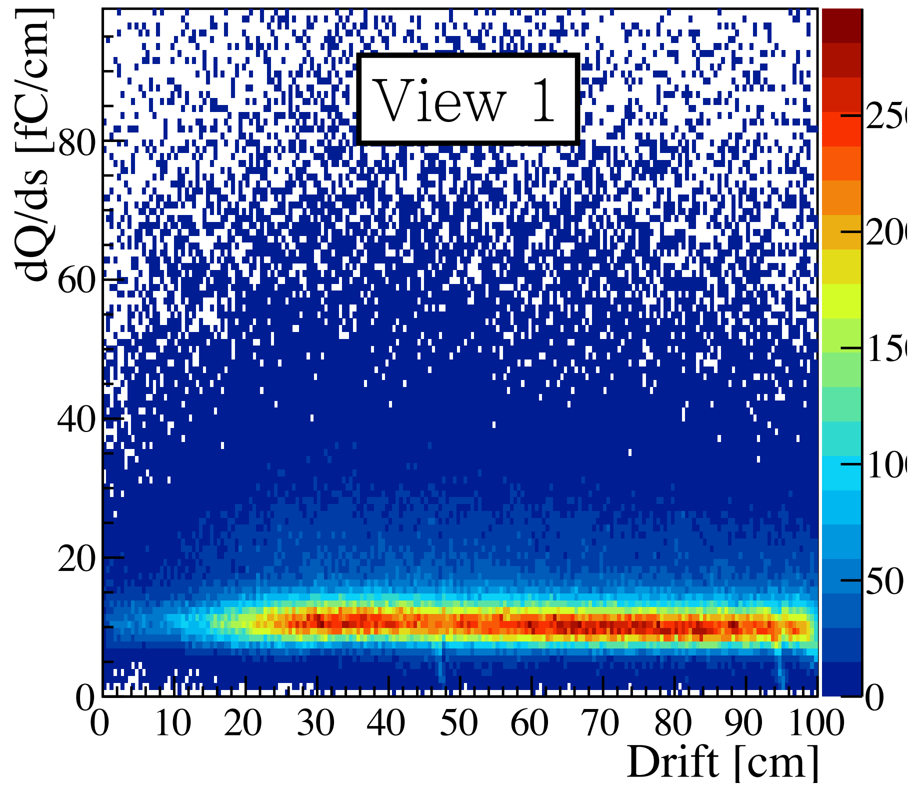


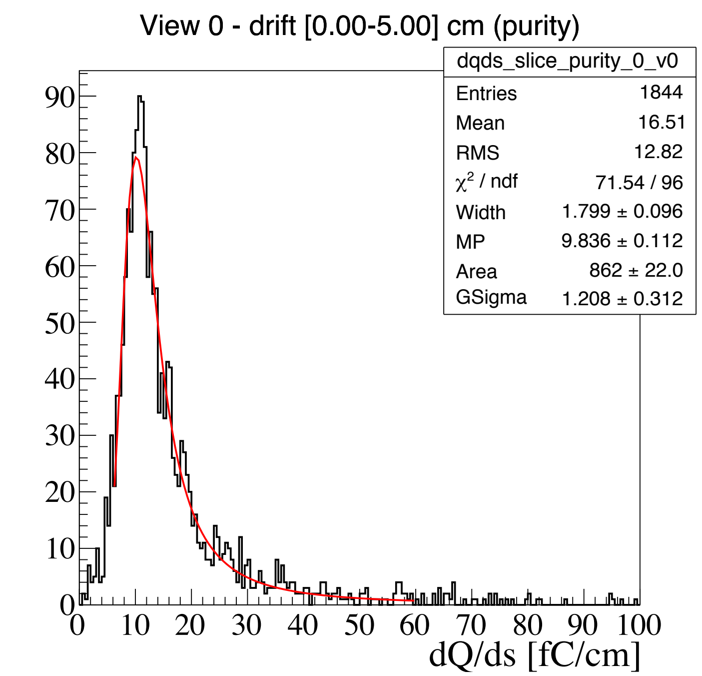
: Central LEMs ~ 0.9 x 6 x 0.4 = 2.2
: Corner LEMs ~ 0.95 x 2.3 x 0.4 = 0.9

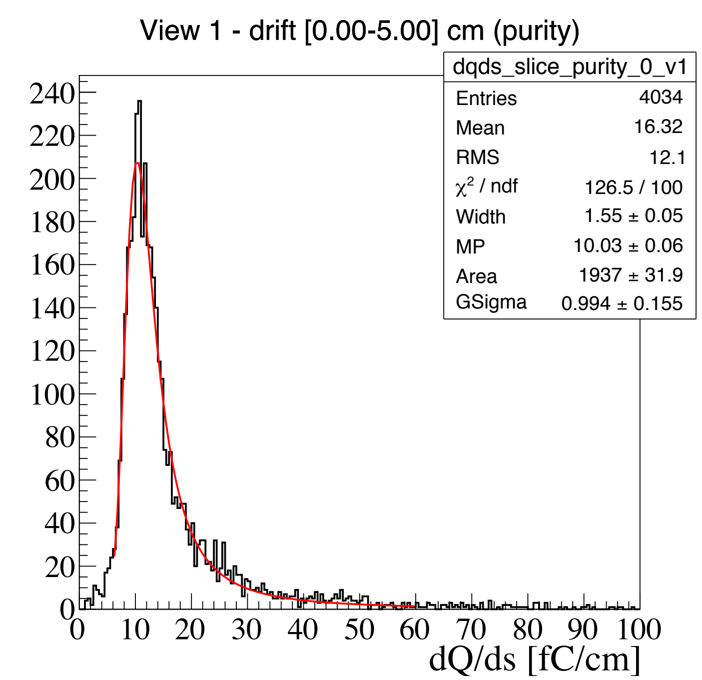


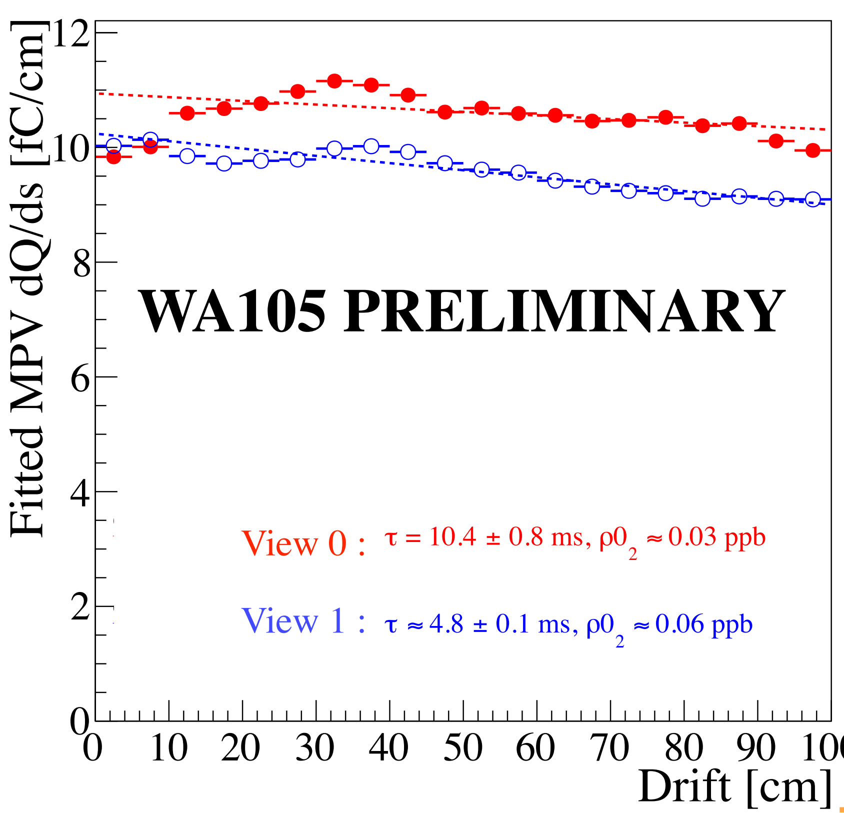
First look at the charge data : purity











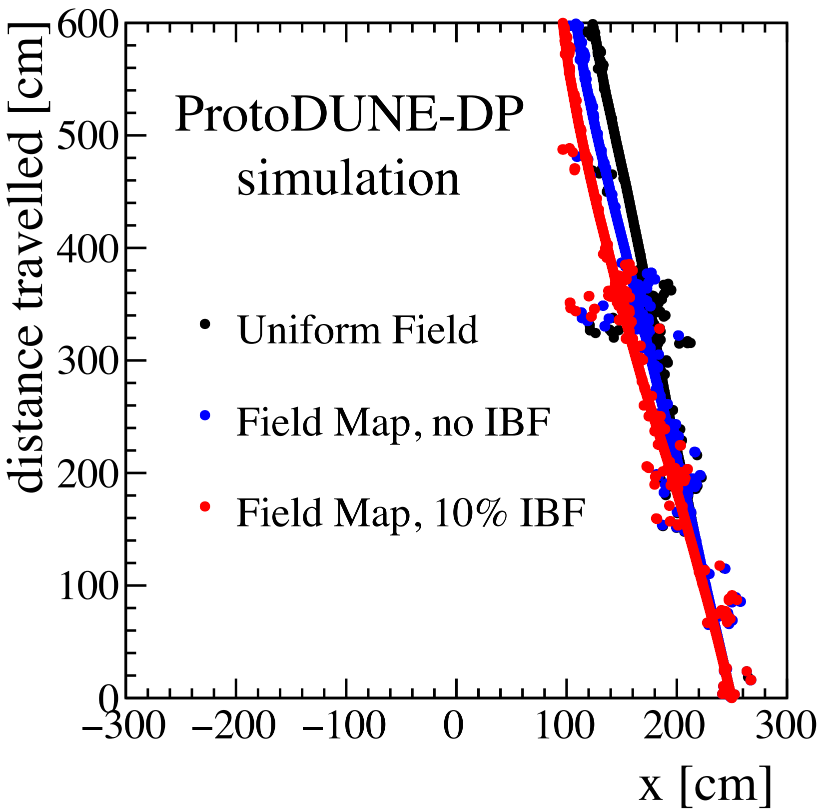
From reconstructed through going tracks, the charge collected as a function of drift distance (in slices of 5 cm) are fitted with a landau convoluted with a gaussian.

The evolution of the collected charge with the drift indicates a good LAr purity with an electron lifetime of ~5ms

Field distortions

Local drift field distorsions can appear in the chamber :
- At the edges of the field cage
- By space charge effect : Field screening due to clouds of Ar^{+} drifting towards the cathode

↳In dual phase configuration, the SCE may be higher due to Ar^{+} coming from the amplification region backflowing across the whole chamber

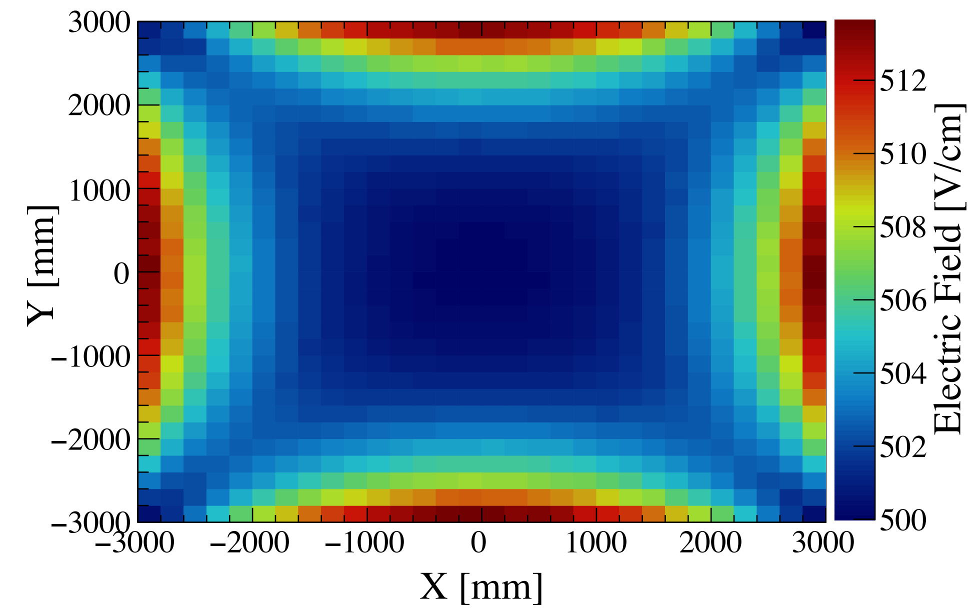


Drift field non-uniformities :

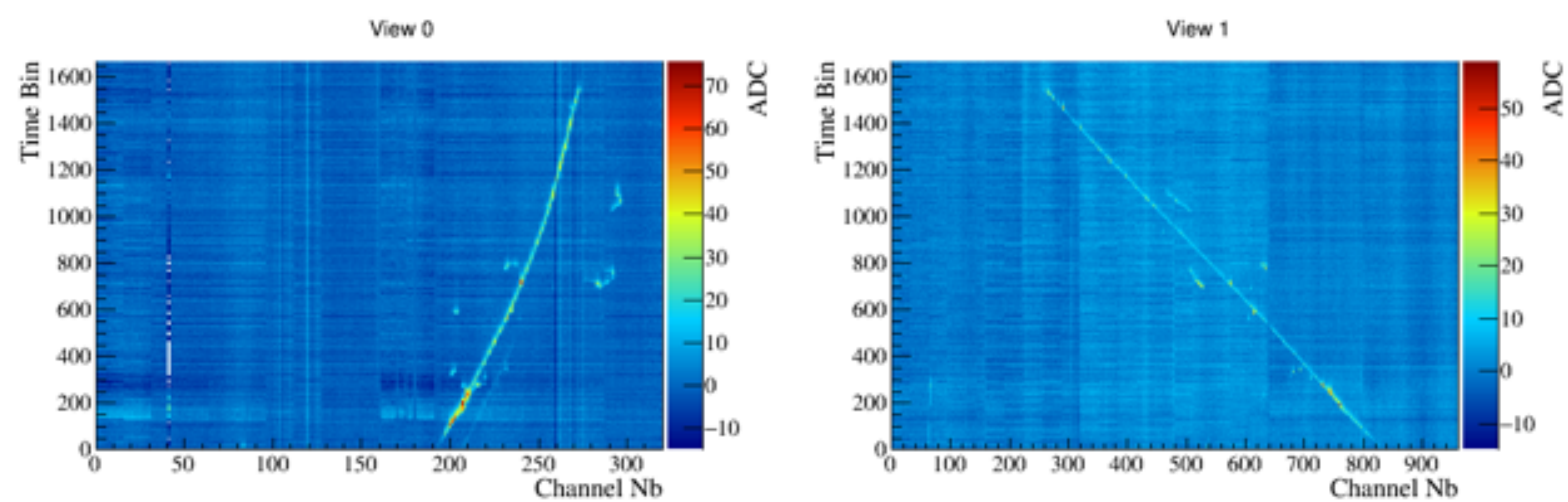
←Affect the arrival time and position on the readout

Affect the charge deposition →

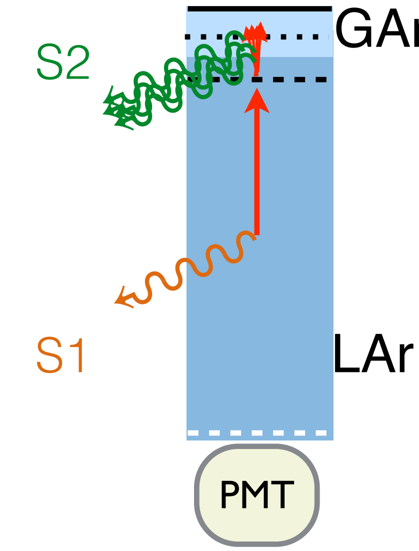
ProtoDUNE-DP simulation
Mean Drift Field along drift direction



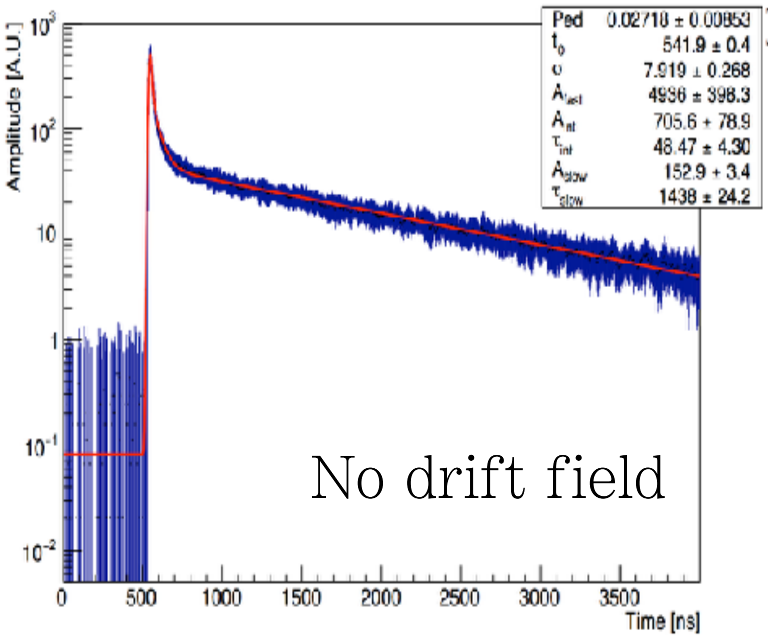
Some hints of field distortions have been observed in the 3x1x1 data, analysis is ongoing →



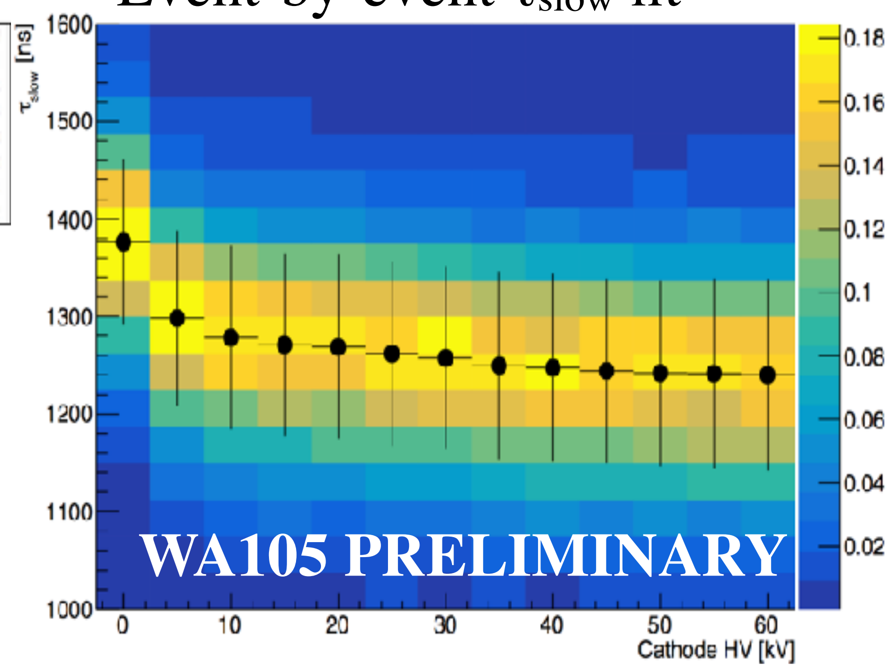
First look at the light data : S1 signal



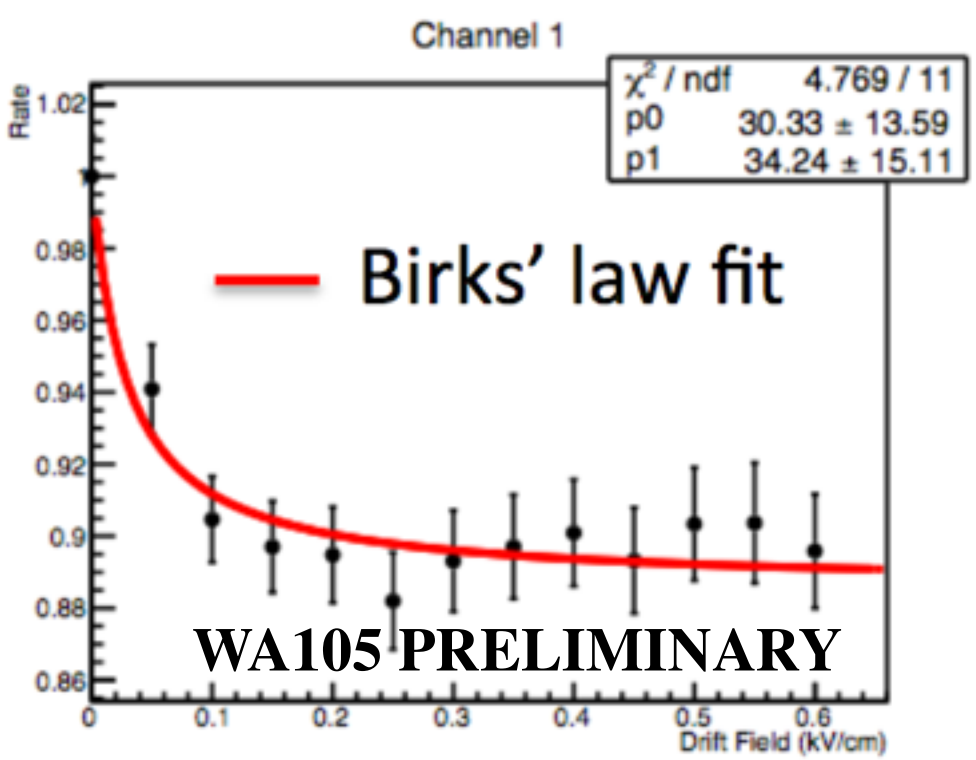
mean waveform



Event-by-event τ_{slow} fit

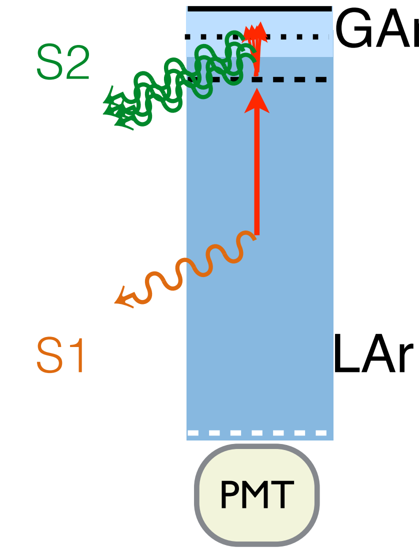


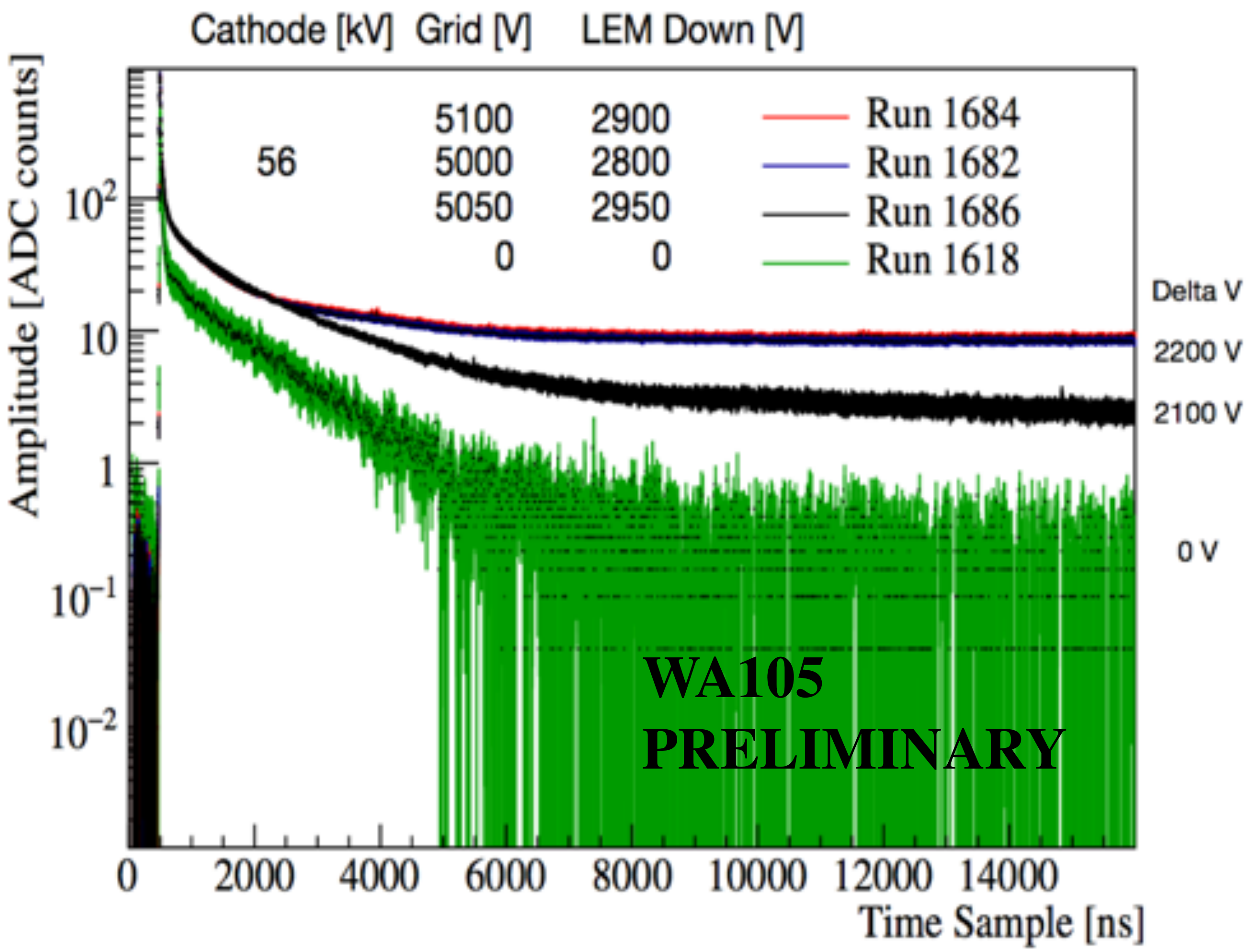
Fitting the raw waveforms to retrieve the slow time constant, we have observed a dependance with respect to the cathode voltage.



Decrease of integrated light charge with drift field follow the expected attenuation of scintillation light due to the recombination.

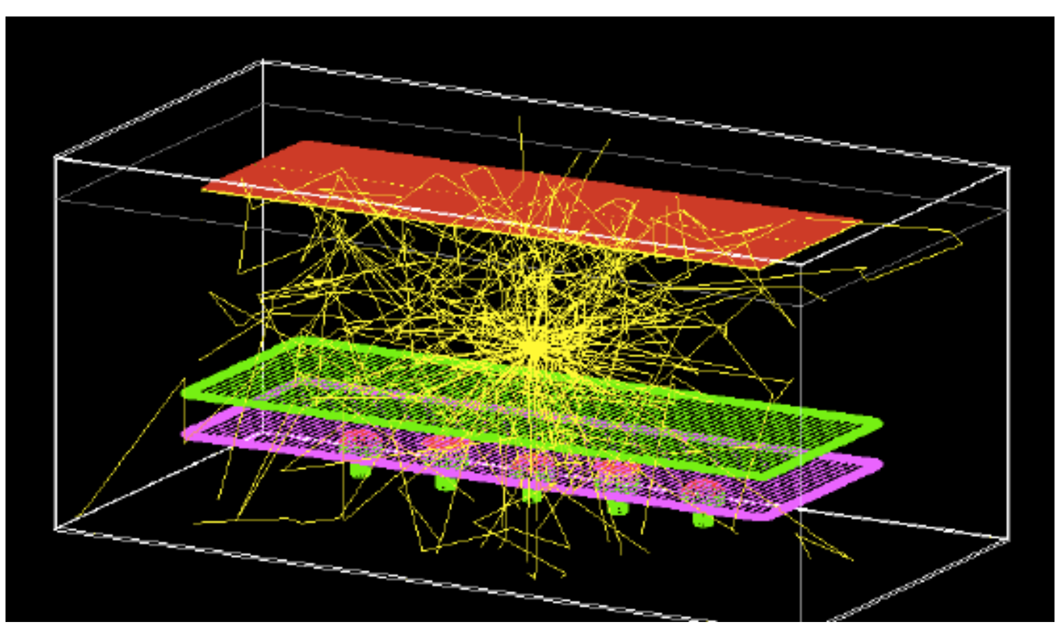
First look at the light data : S2 signal

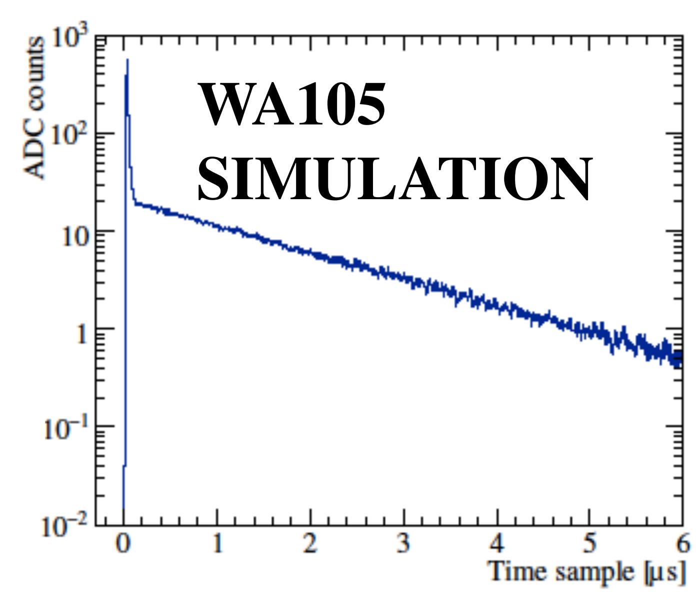




The amount of S2 light is :

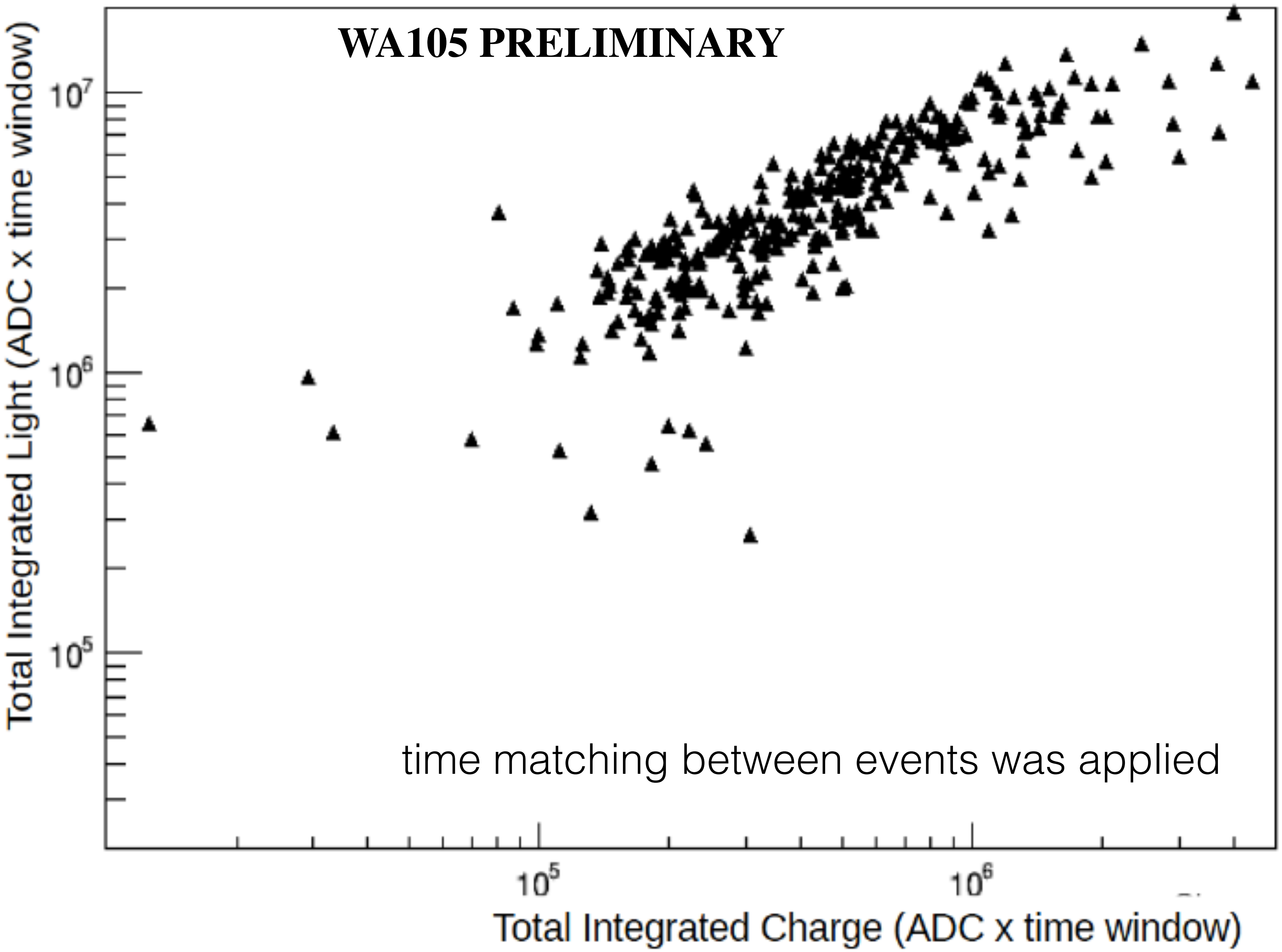
- Constant with the extraction field
- Proportional to the LEM field





Detailed light simulations in both detector have been computed and data/MC comparisons are ongoing

First look at the charge & light data correlation

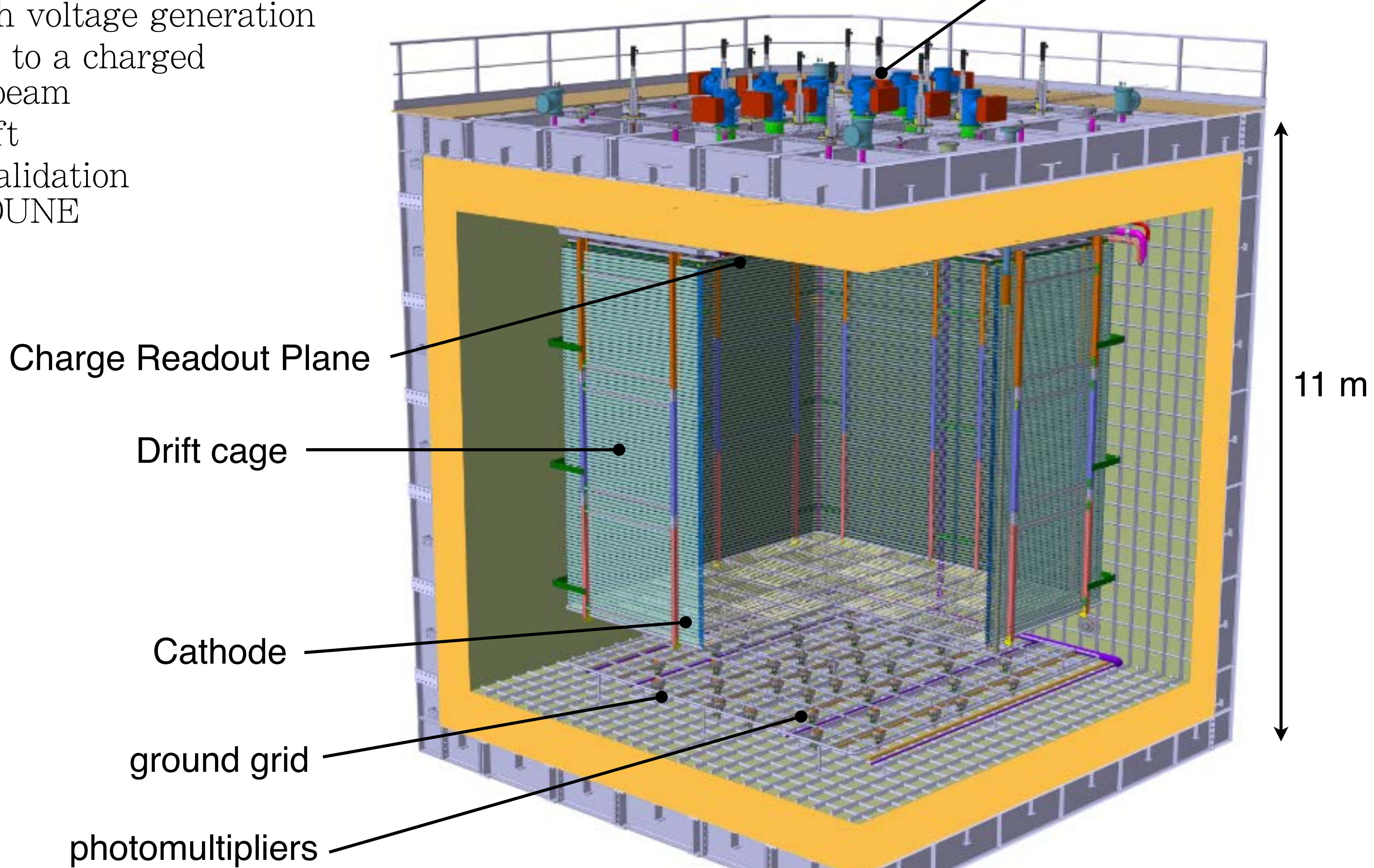


time matching between events was applied

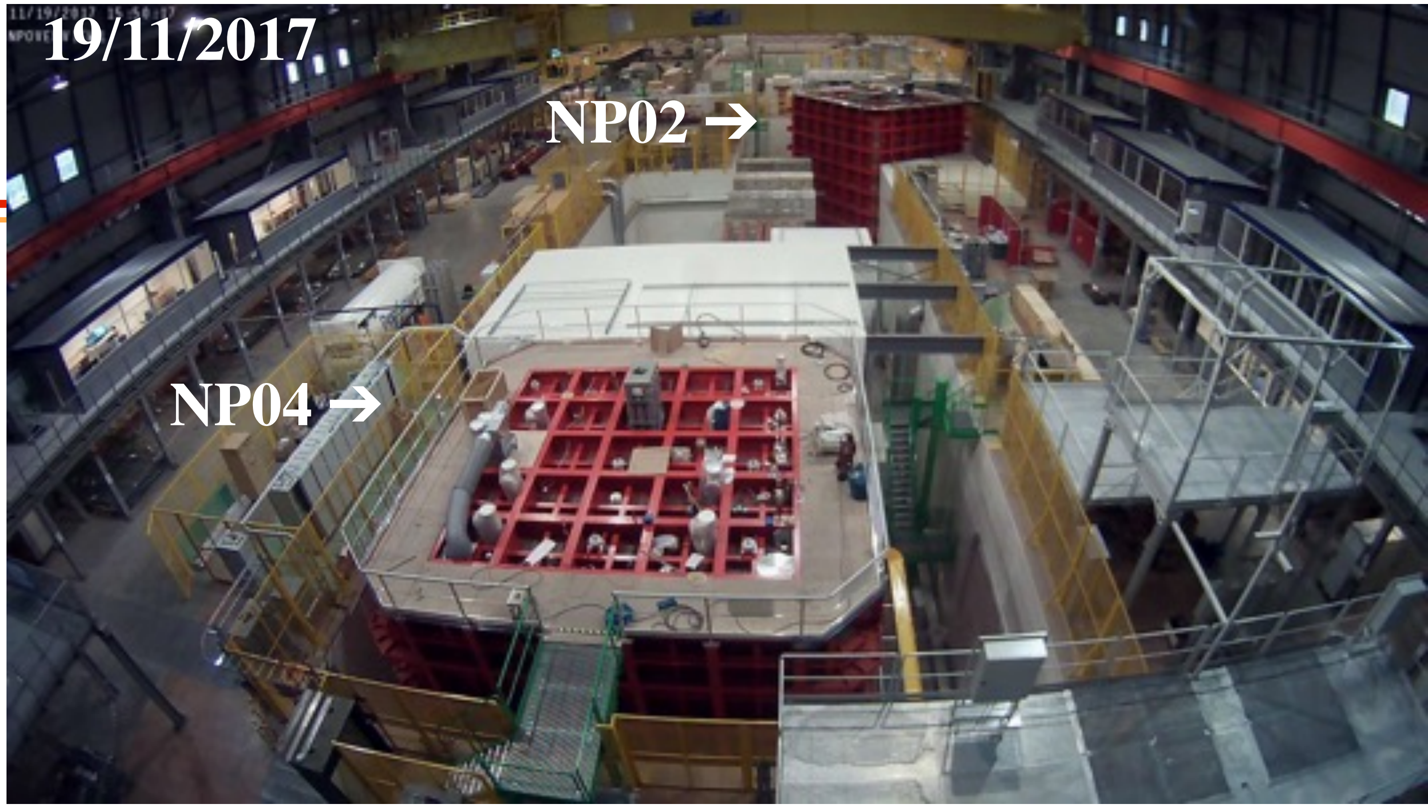
Goals of the ProtoDUNE-DP

A bigger prototype of 6x6x6 m^3 will be constructed to assess :

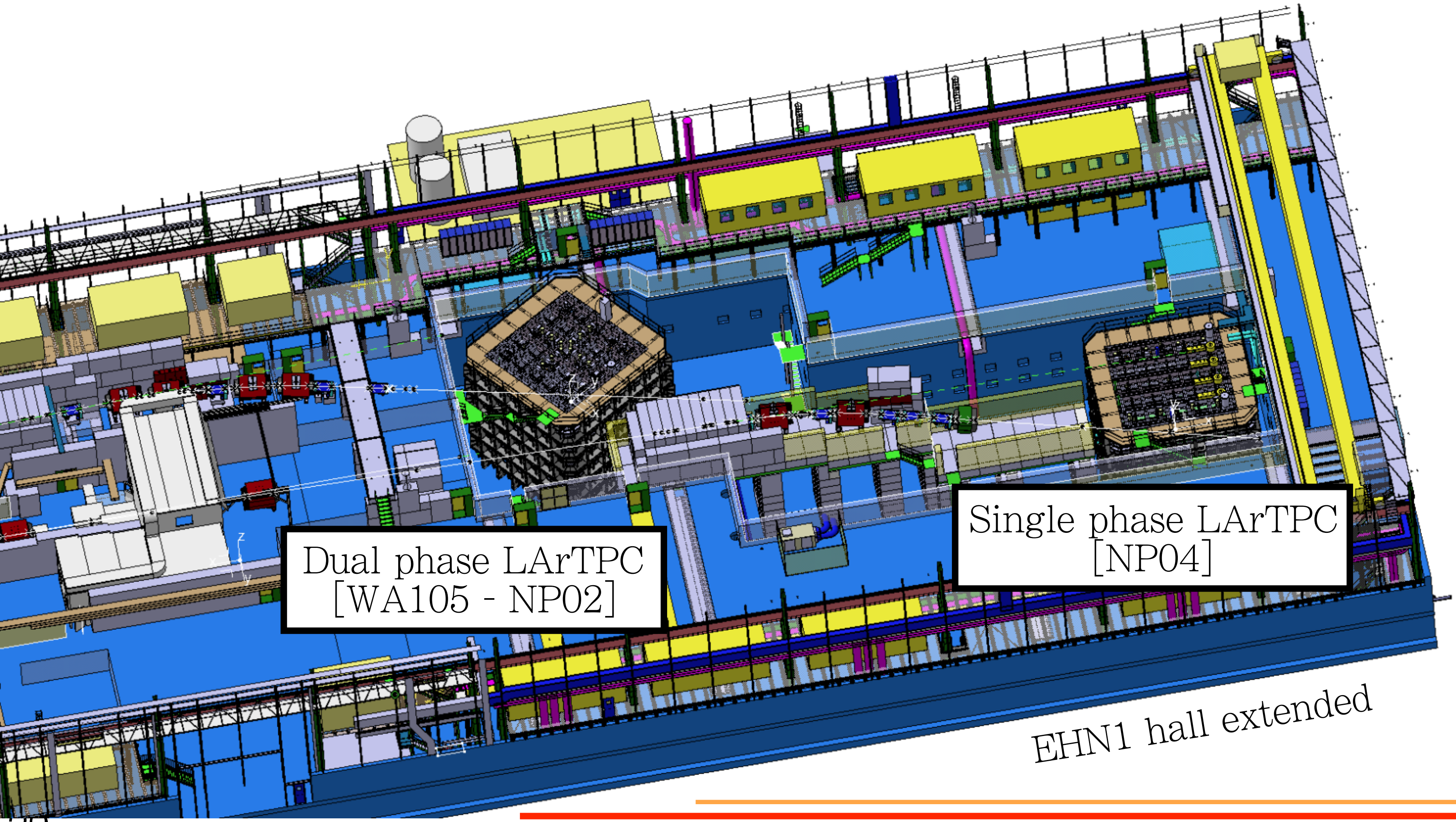
- Large vessel and field cage structure
- Large surface of charge readout
- Very high voltage generation
- Exposure to a charged particle beam
- Long drift
- Design validation towards DUNE



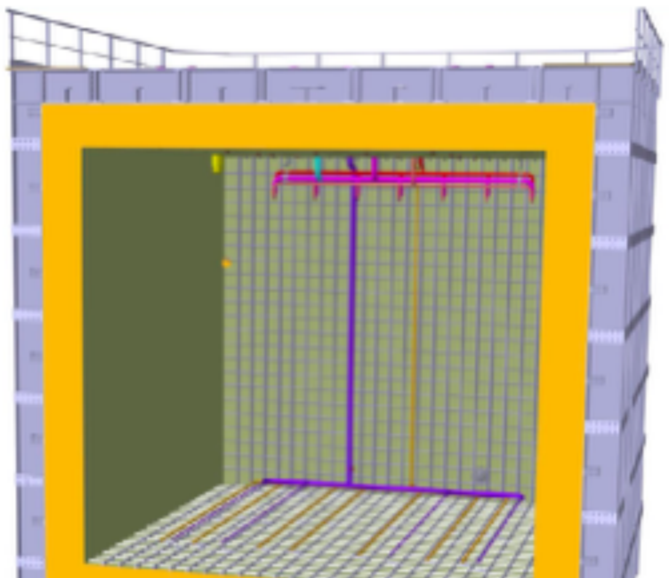
ProtoDUNEs



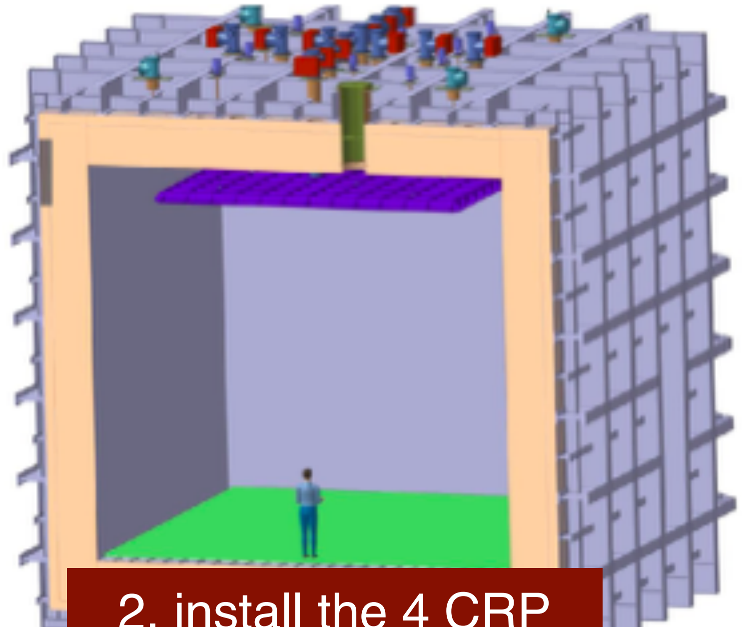
Both prototype will be exposed to hadronic beam in 2018



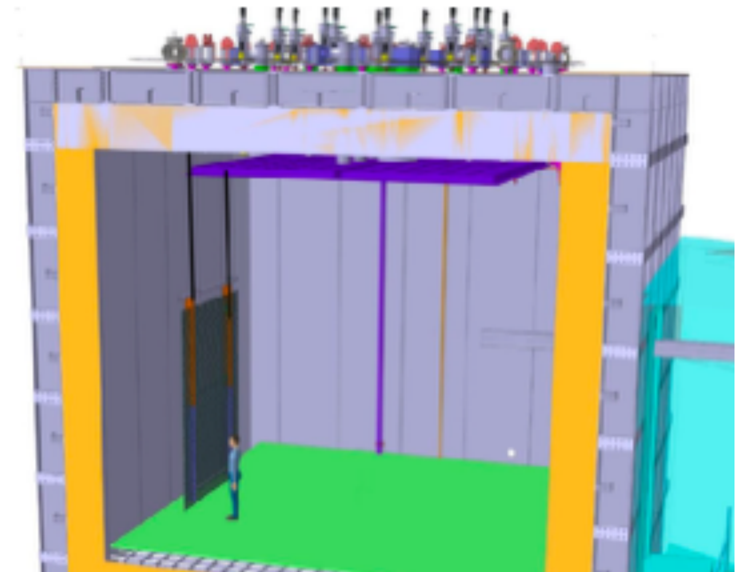
protoDUNE-DP construction & integration



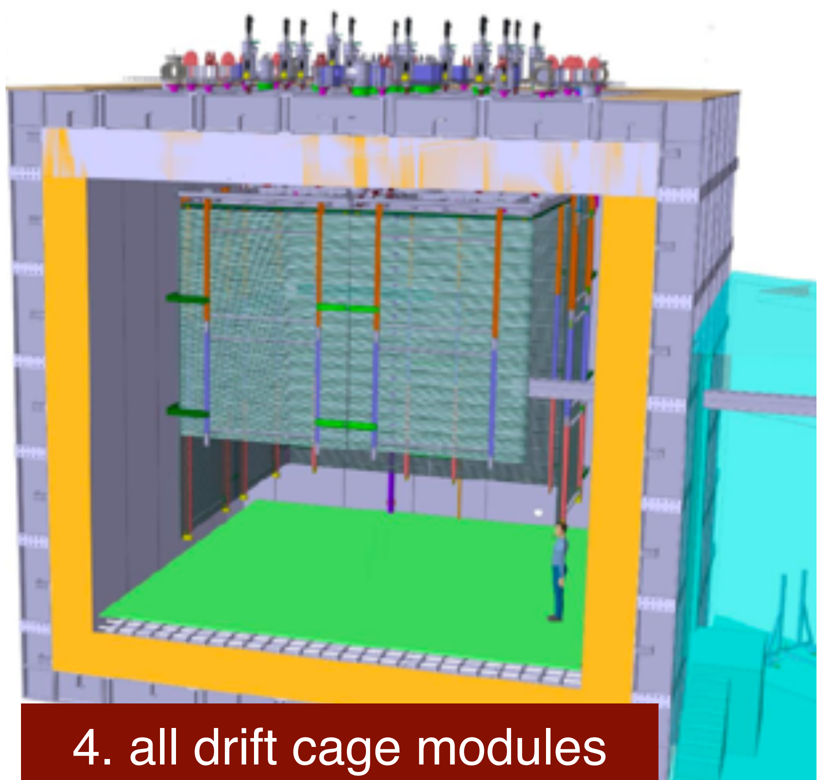
1. install internal piping & temporary floor



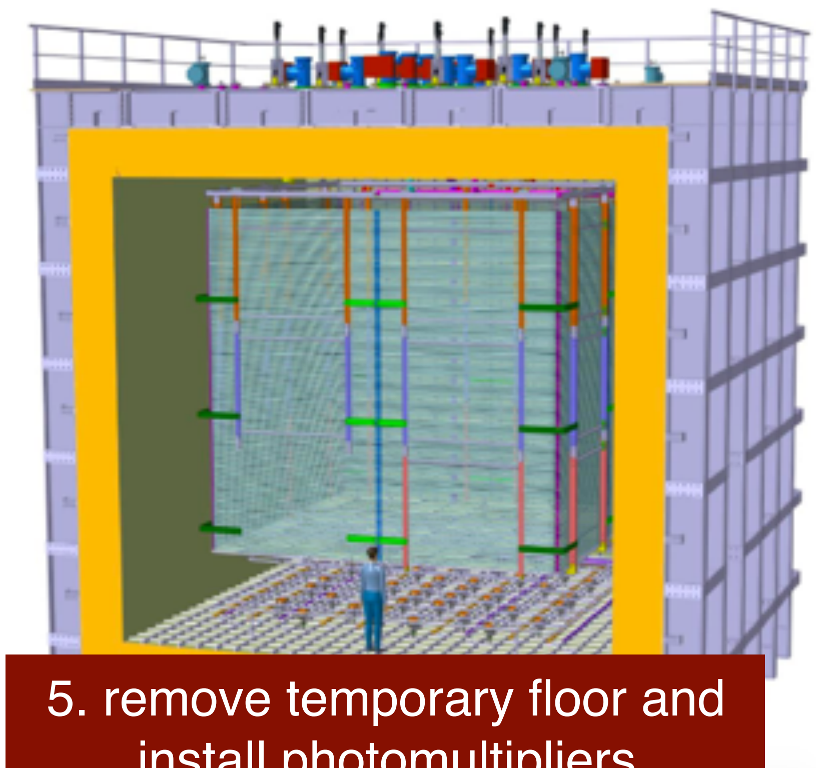
2. install the 4 CRP frames



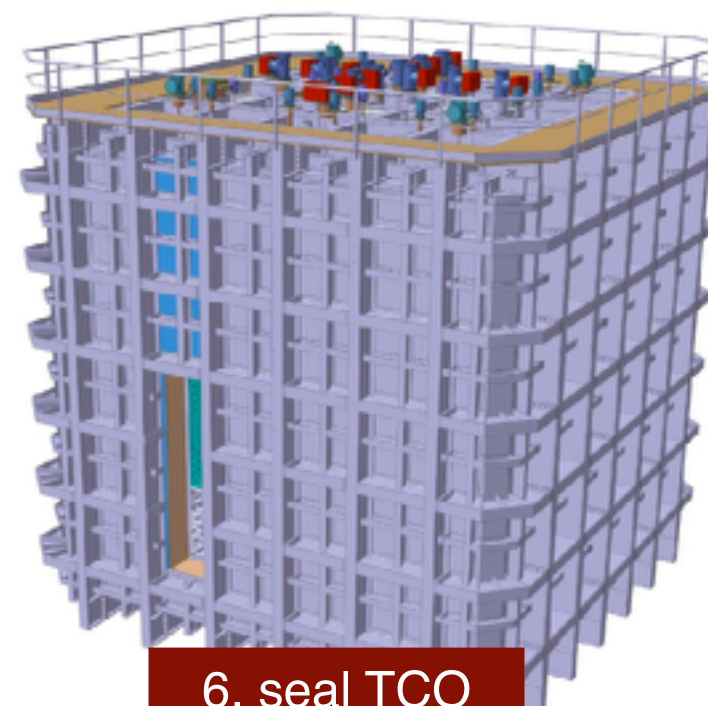
3. install the first drift cage modules



4. all drift cage modules installed

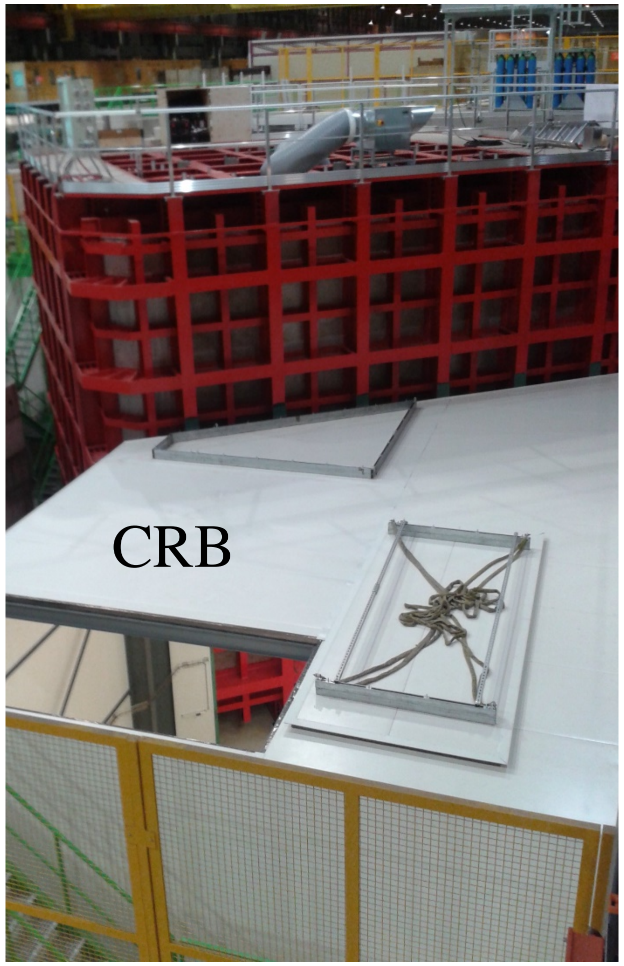


5. remove temporary floor and install photomultipliers

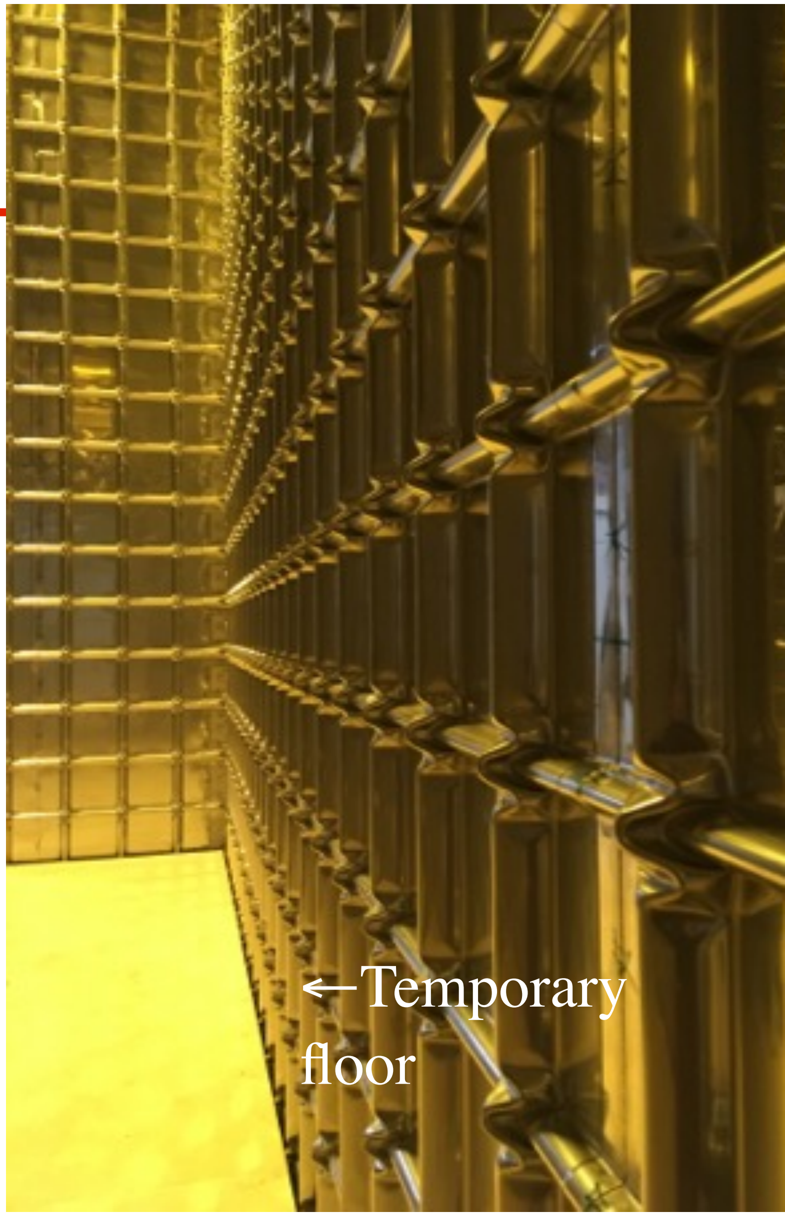


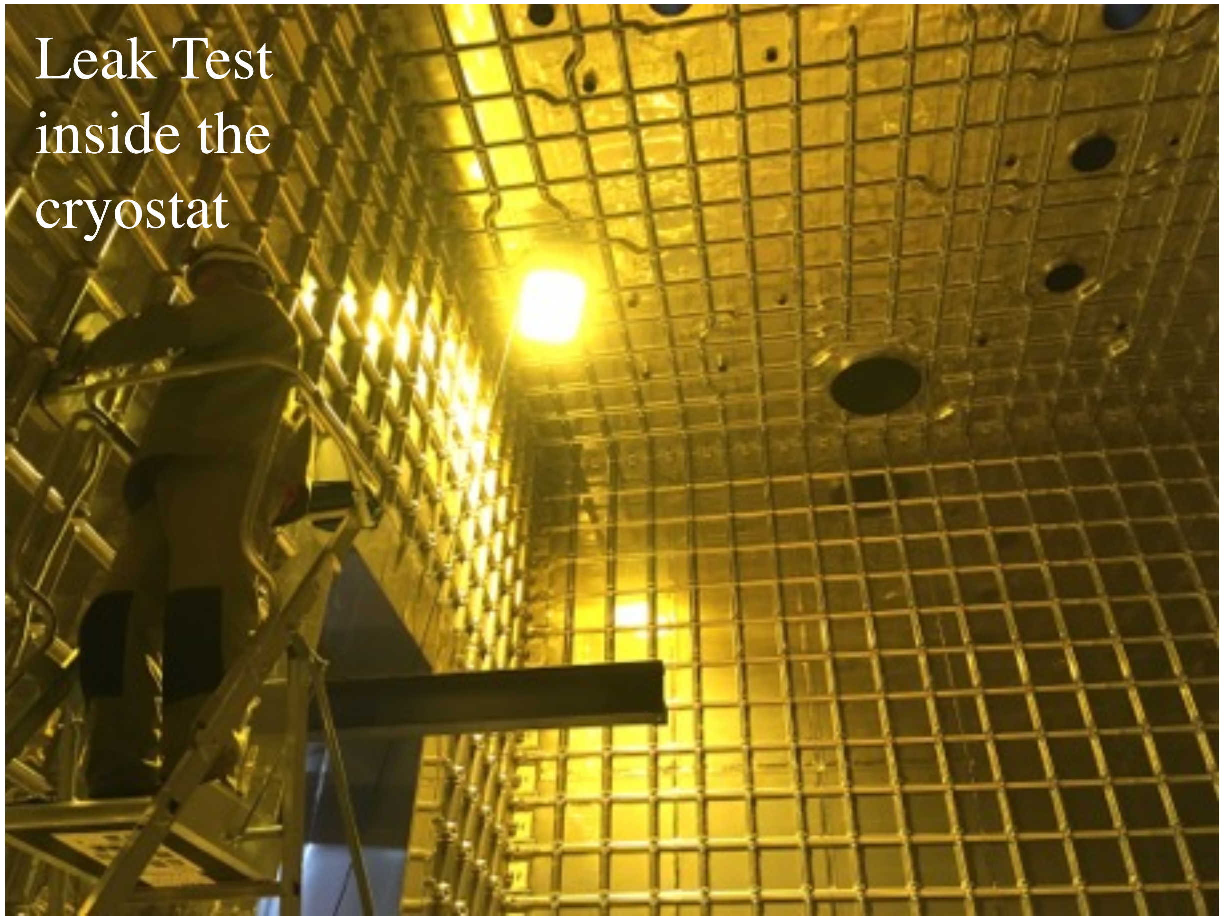
6. seal TCO

protoDUNE membrane & cryostat



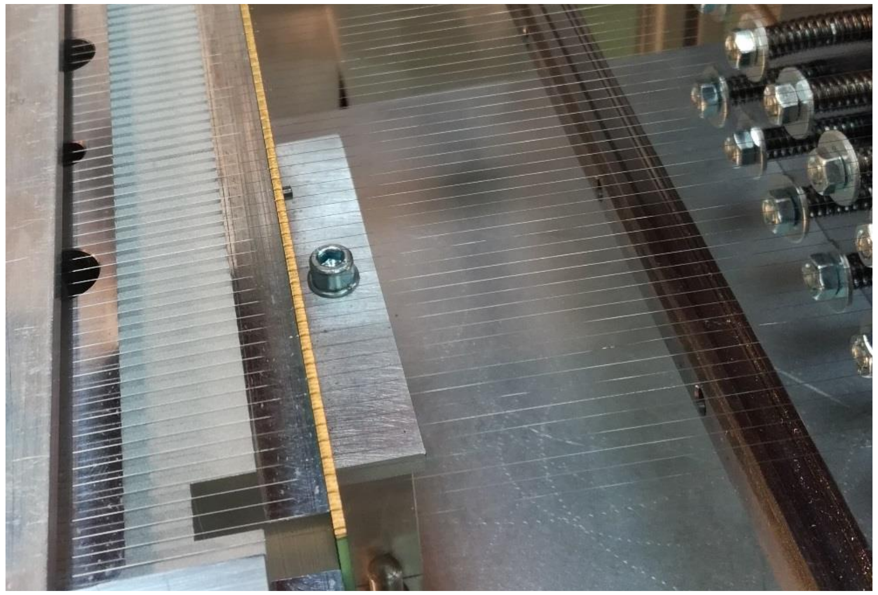
- Membrane completed on sept. 21st
- Temporary floor installed
- Clean room buffer finished
- Leak test performed in november



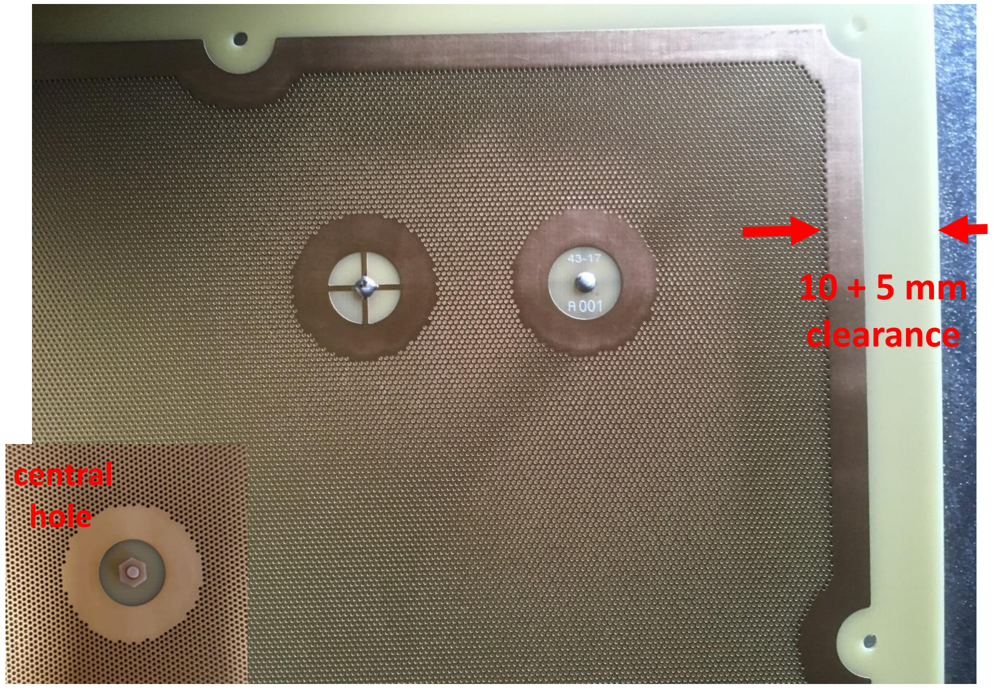


Status of CRP Assembly

Invar frame of first CRP



Extraction Grid tooling procedures established



Improved design of LEM based on the 3x1x1 experience

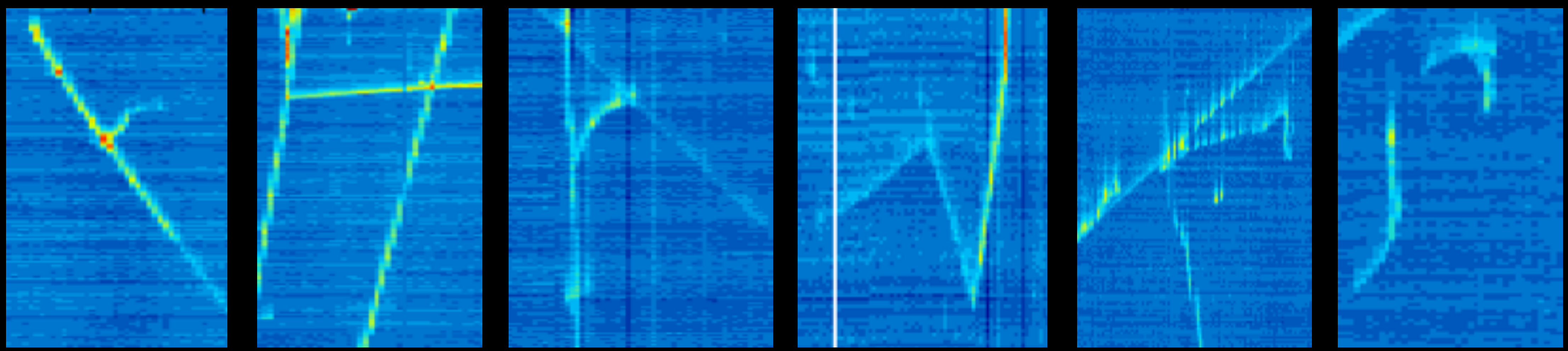
Conclusions & Prospects

Important milestones achieved since the last GDR meeting !

- **Evidence of electron extraction with light & charge signal**
- Tracks recorded with many HV configurations
- Many improvements regarding noise filtering and the reconstruction
- Analysis are ongoing (purity, gain, space charge effect, …)
- Large experience gained for protoDUNE-DP

- The protoDUNE design has been finalized in November
- Membrane and cryostat construction finished
- Test installation of the Field Cage and assembly of the CRP about to start
- Detector ready to take data foreseen in a year from now !

→Stay tuned !

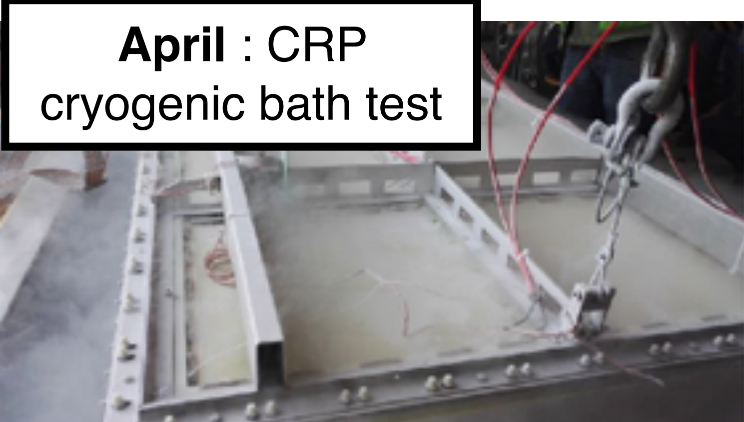


3x1x1 construction in 2016

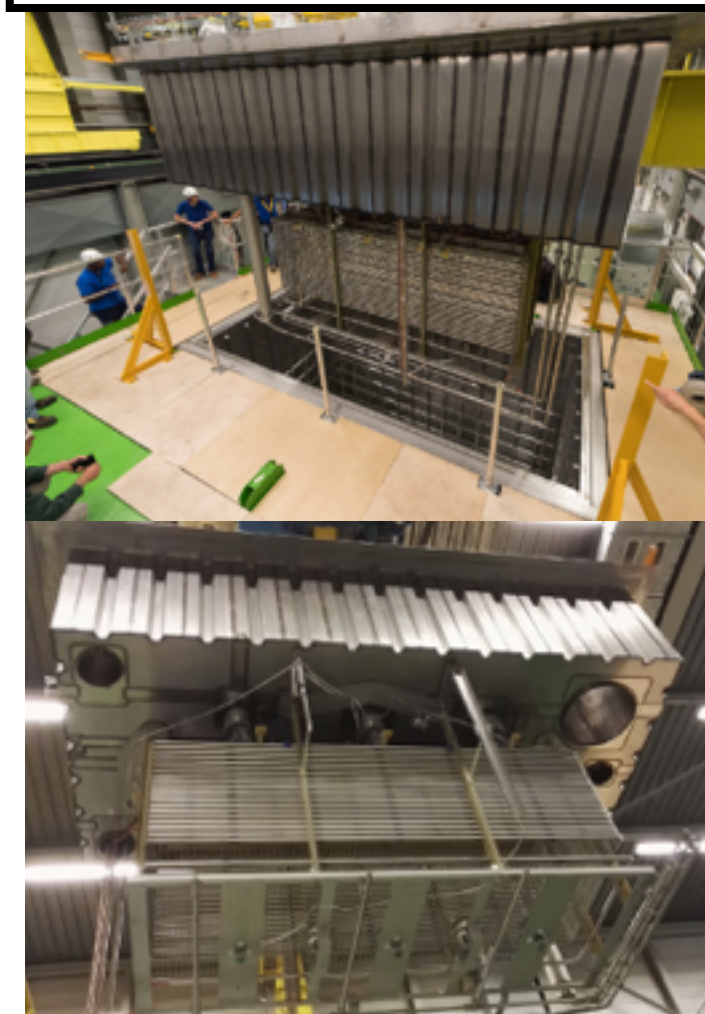
Feb : Top Cap delivered

March : CRP installed under top cap

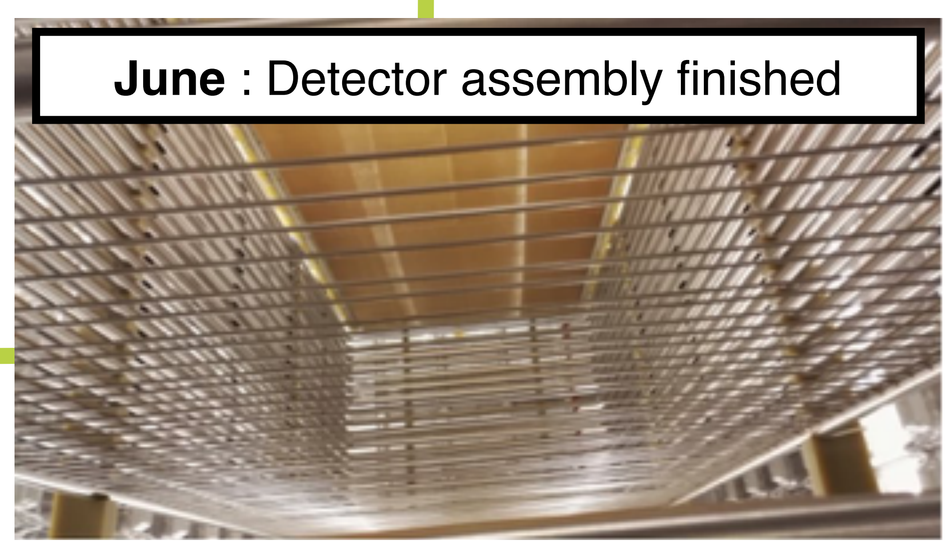
April : CRP cryogenic bath test

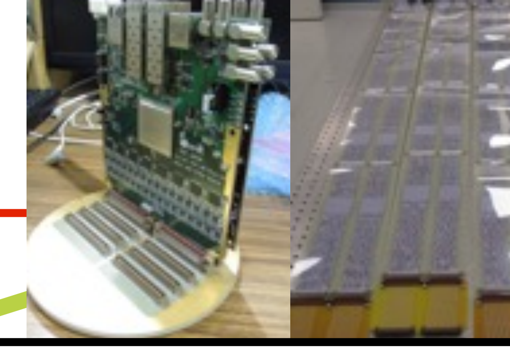


July : Top Cap lifted inside the cryostat



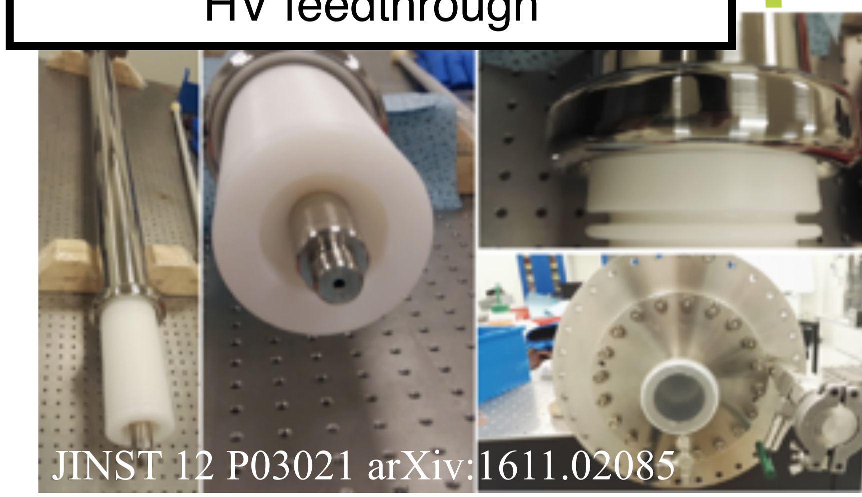
June : Detector assembly finished





Aug : FE electronics + cables installed inside feedthroughs

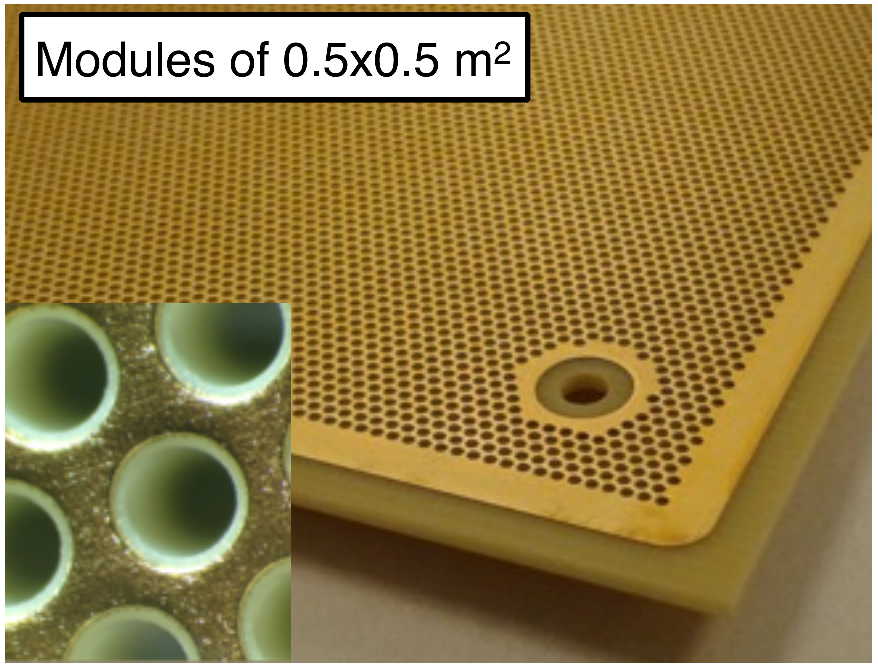
Sept : Test & insertion of 300 kV HV feedthrough



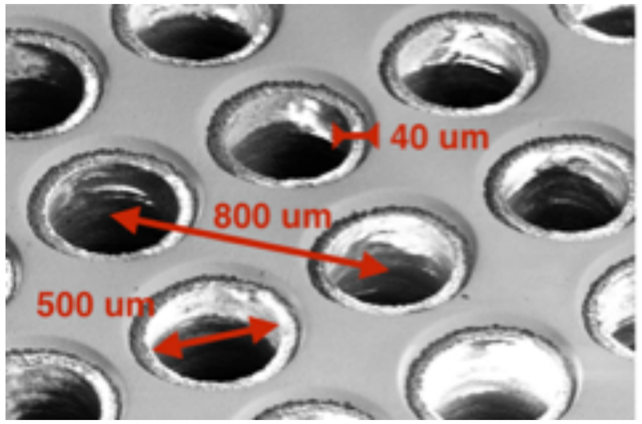
Nov : control racks, DAQ and cryogenics installed, cabled and tested

LEM design

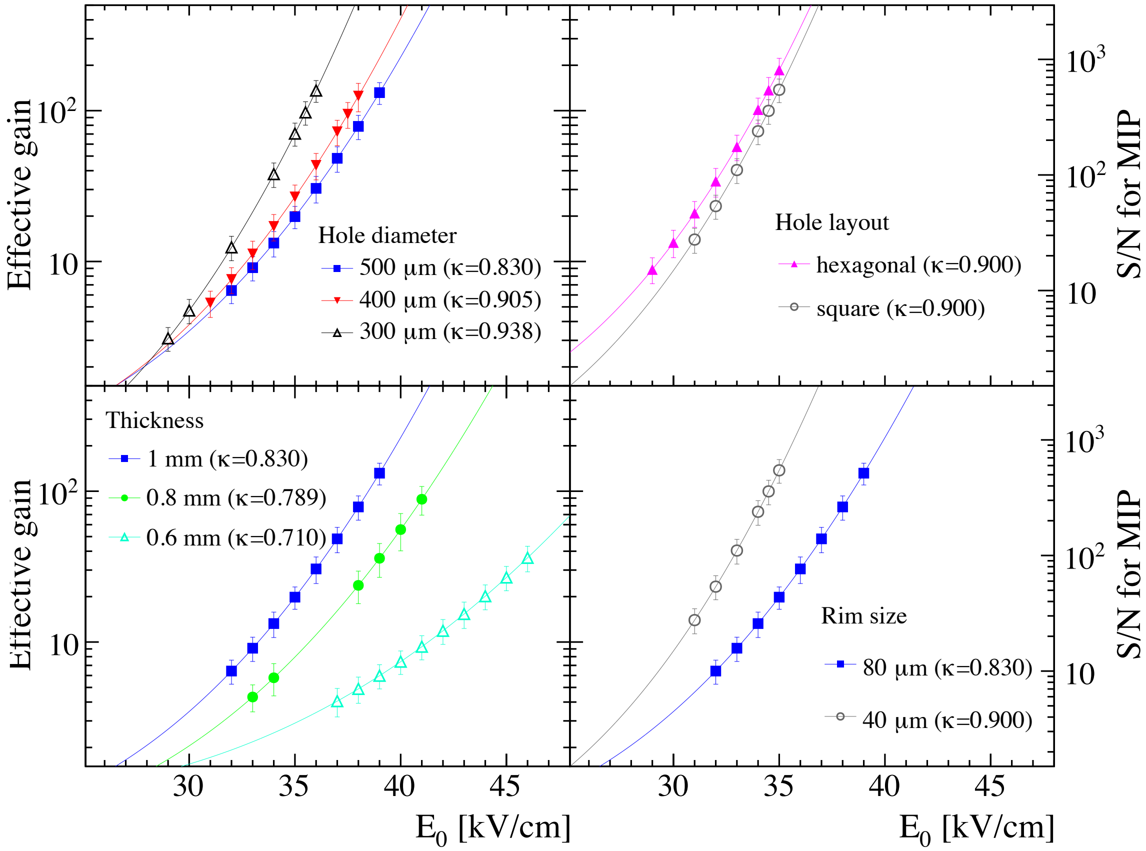
C. Cantini *et al.*, JINST 10 (2015) no.03, P03017



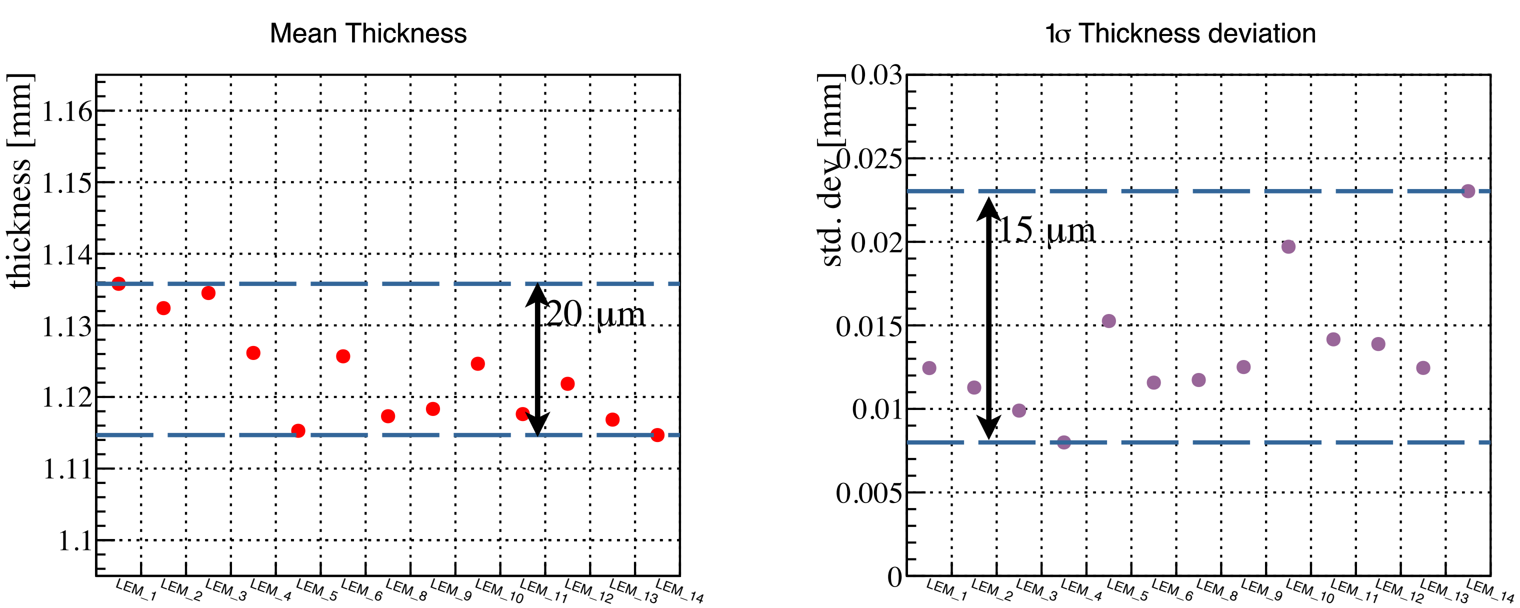
- Design from extensive R&D on small DP-LArTPC
- Easy to manufacture on large scale
- Standard PCB with $\mathcal{O}(150)$ holes/cm^2
- 1 mm thick, 500 μm diameter holes, 40 μm dielectric rim
- Thickness uniformity measured on LEM samples with a few micron precision



LEM design optimization from the 3L setup

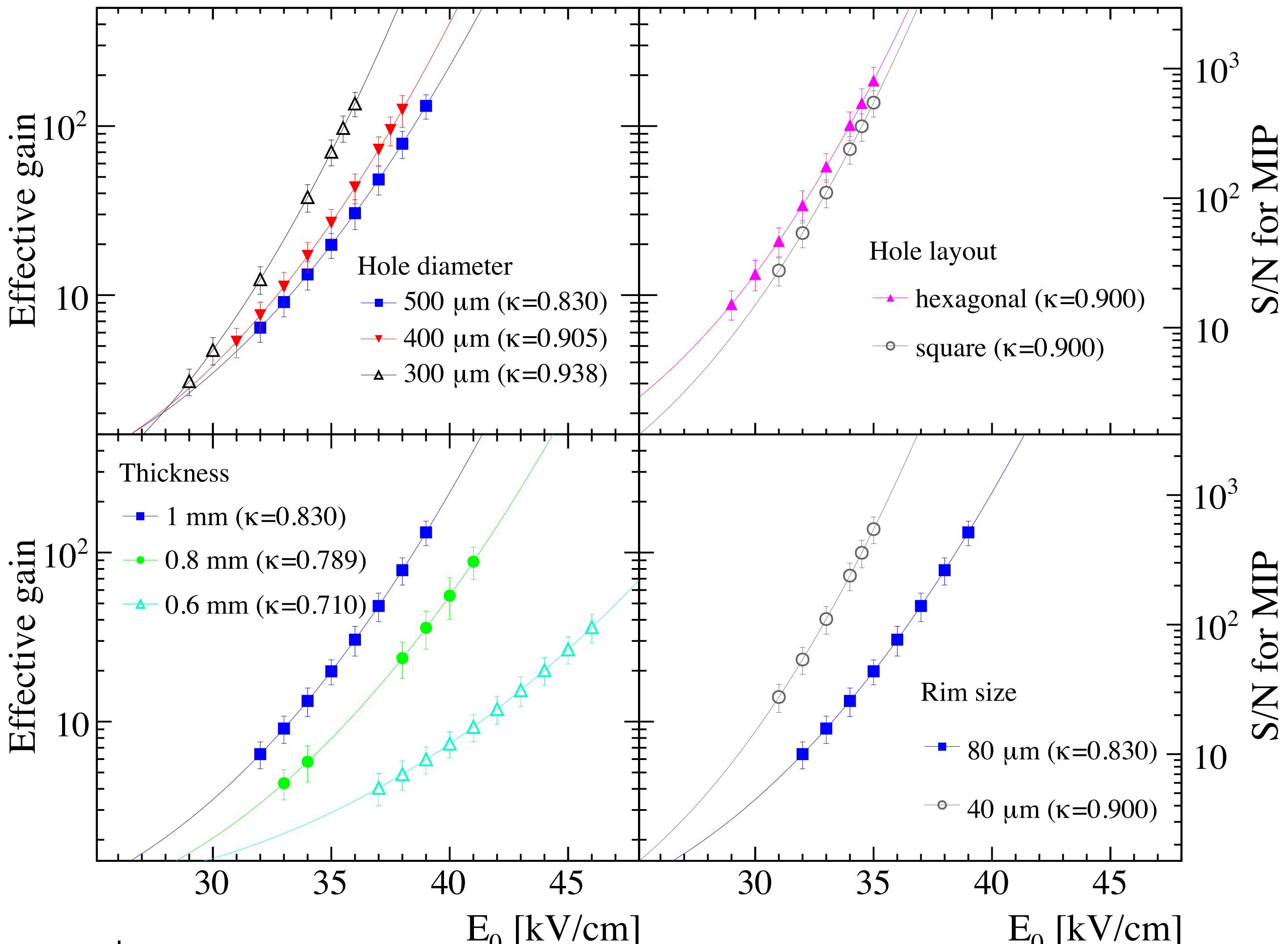


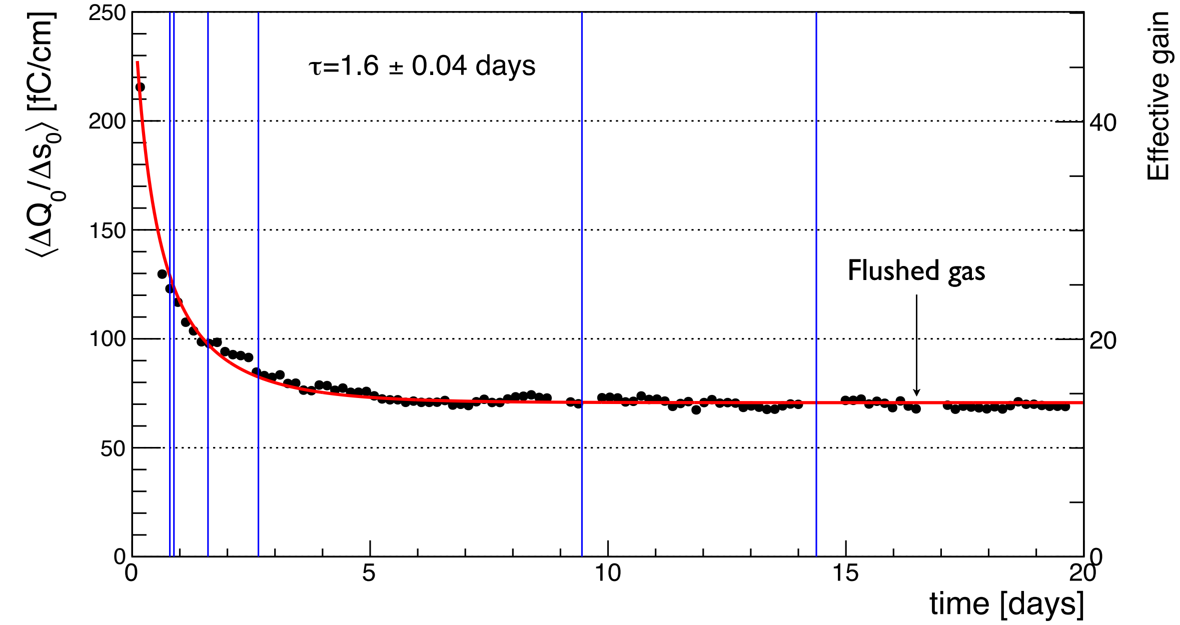
LEM thickness measurement for the 3x1x1



↳ Max gain of 180 ↔ S/N of ~ 800 for m.i.p.

LEM Amplification factor





where :

$$G_{eff}(E,\rho,t) \equiv \mathcal{T} e^{\alpha(\rho,E)x} \times \mathcal{C}(t)$$

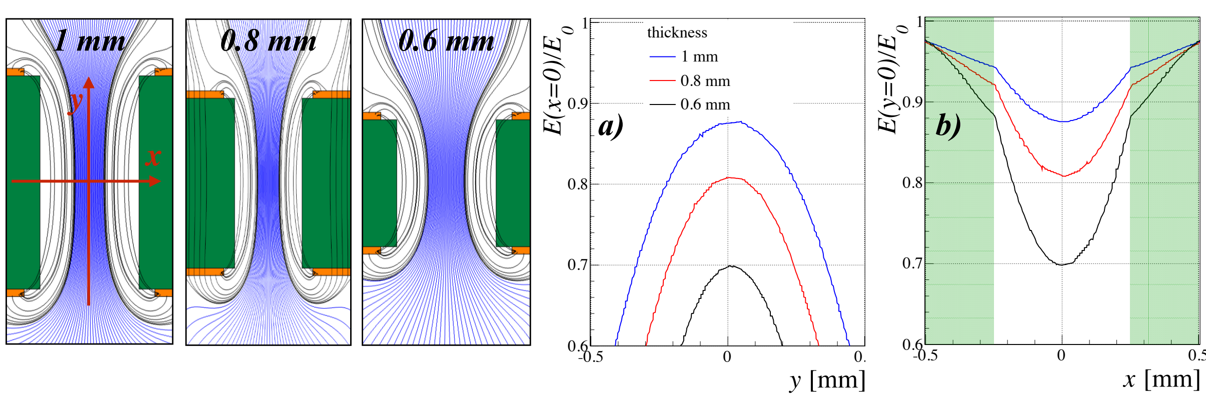
$\mathcal{T}$: Electrical transparency of the chamber

$E \equiv \kappa E_0 = \kappa \times \Delta V/d$

$\alpha(\rho,E)$: First Townsend ionisation coefficient

$\mathcal{C}(t)$: Time variation of the gain

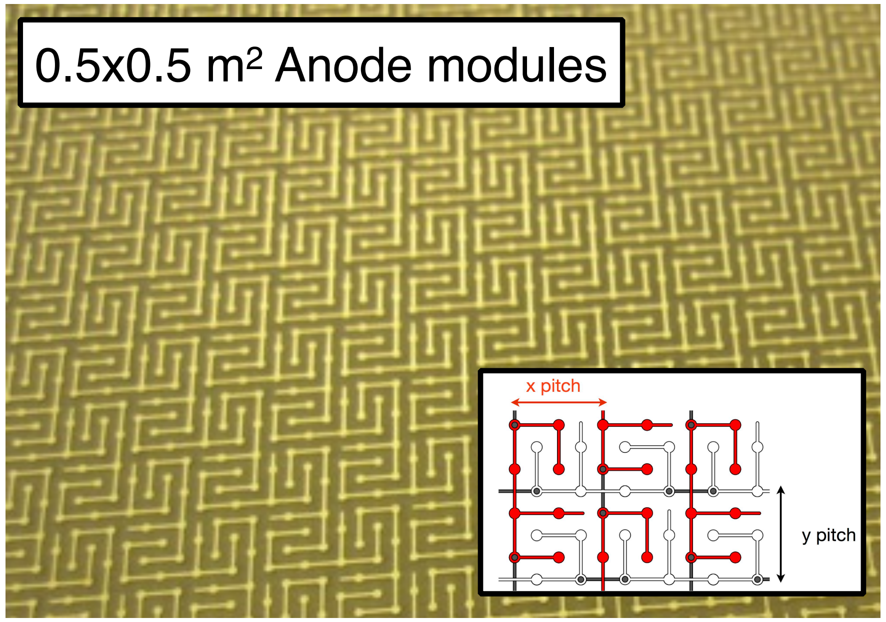
Amplification field inside the LEM holes



Maximum amplification field is always less than the naïve **Δ**V/d computation. The reduction factor, **κ**, is computed by COMSOL simulation.

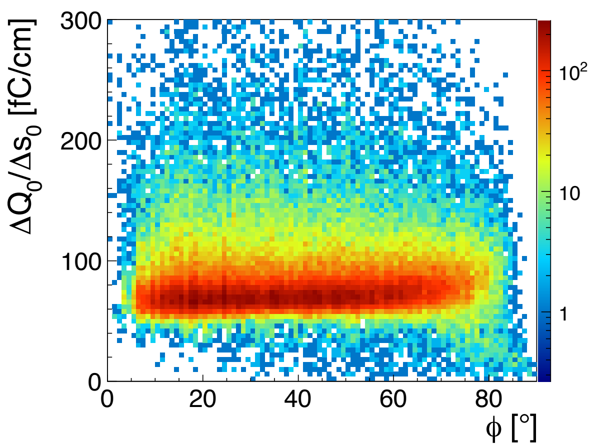
Anode & charge readout design

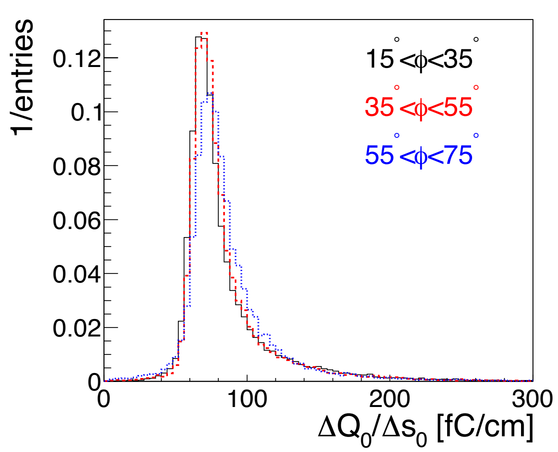
C. Cantini *et al.*, JINST 9 (2014) P03017

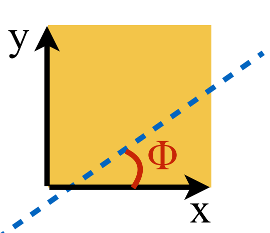


- Anode design from extensive R&D on small DP-LArTPC
- Easy to manufacture on large scale
- 3.125 mm pitch, 160 channels on each views per module.
- Equal sharing of the charges among the 2 views
- Low capacitance to allow long strips while keeping the noise to minimum [dC/dl ~ 120 pF/m]

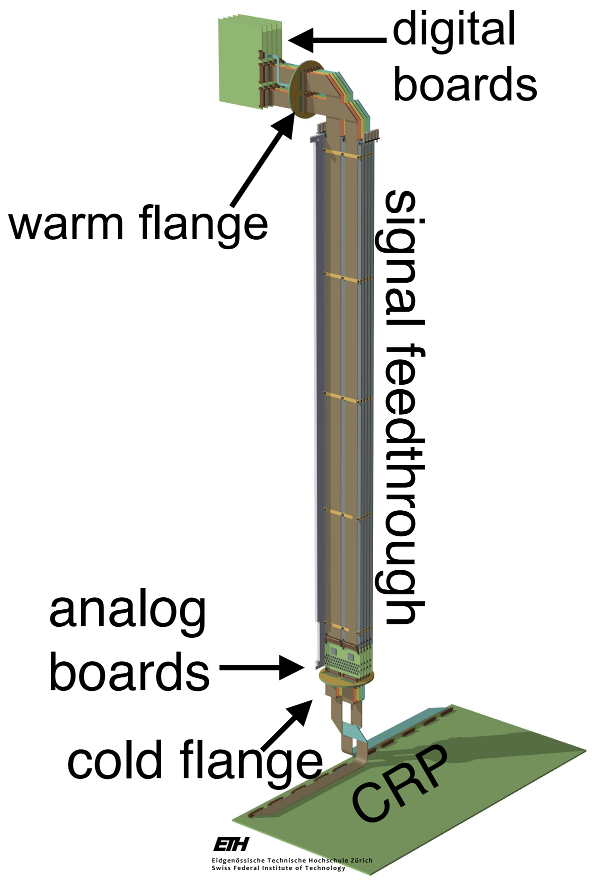
View 0 charge deposition as a function of track Φ angle



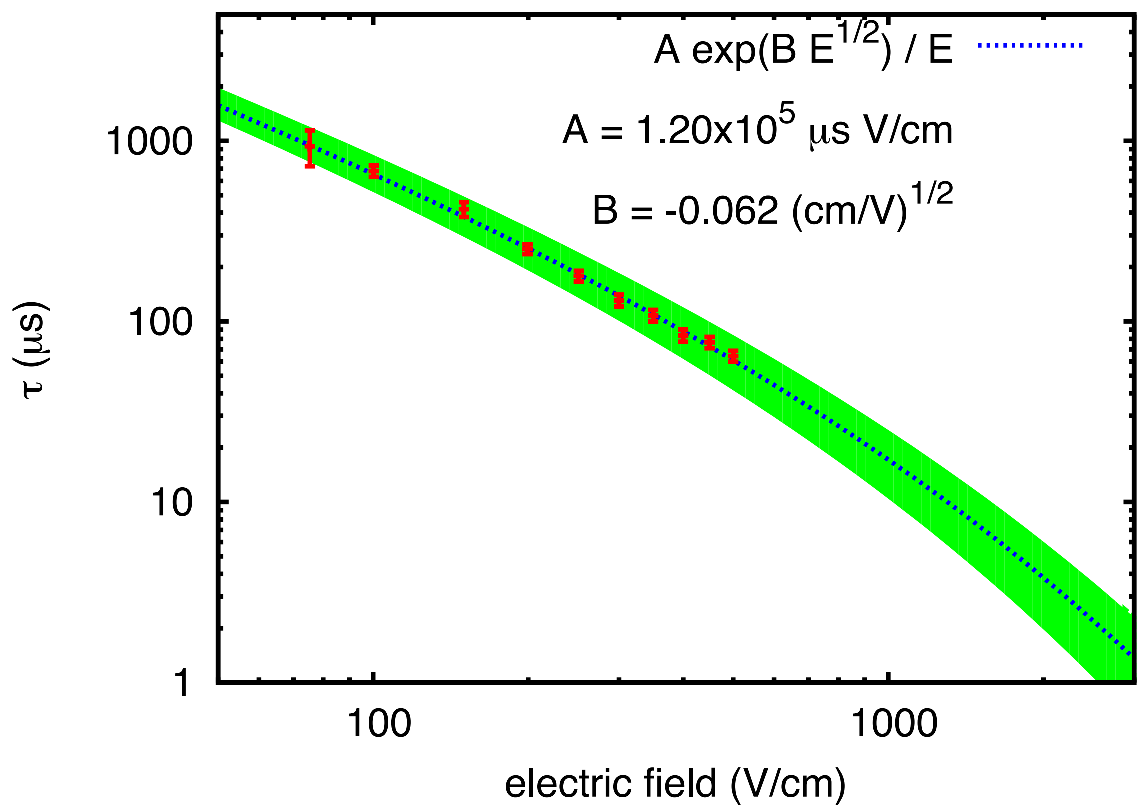


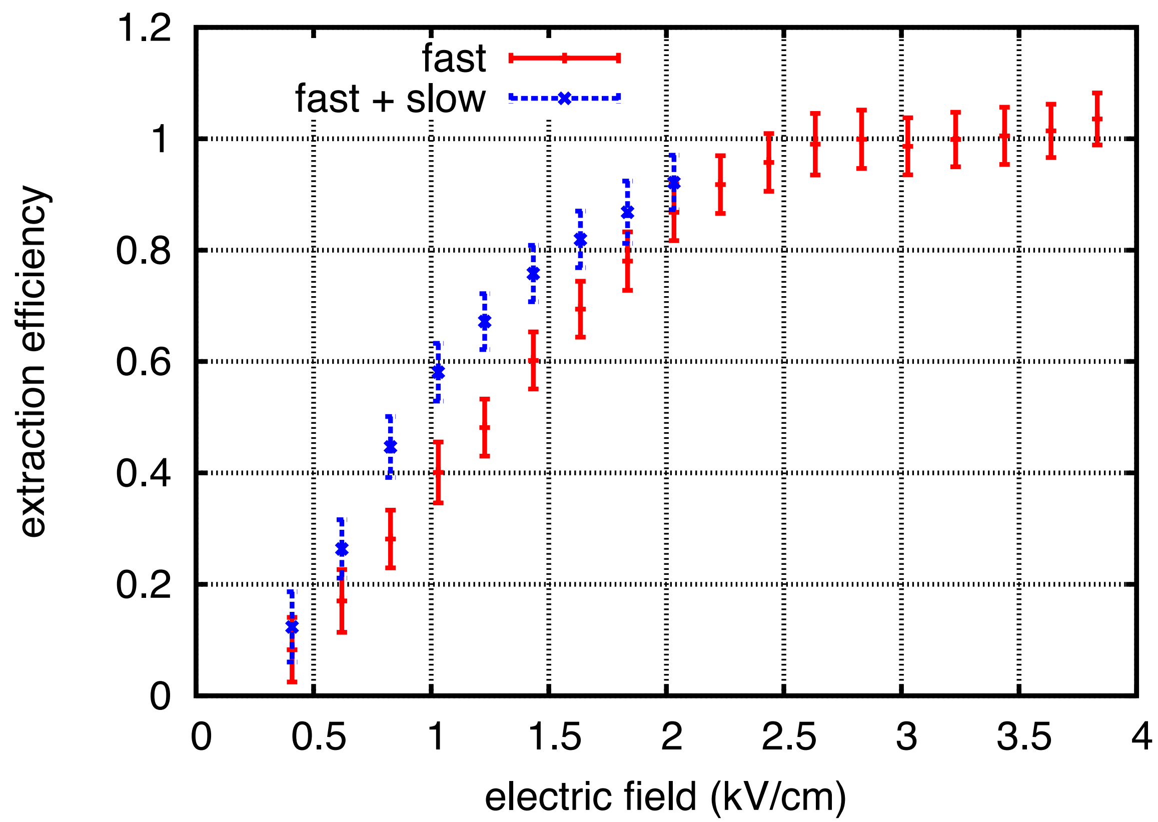


- Accessible cold FE electronics in isolated chimneys
- Dynamic range of 40 mips (double slope gain)
- power consumption of 18 mW/channel



Electron extraction at the liquid-gas interface

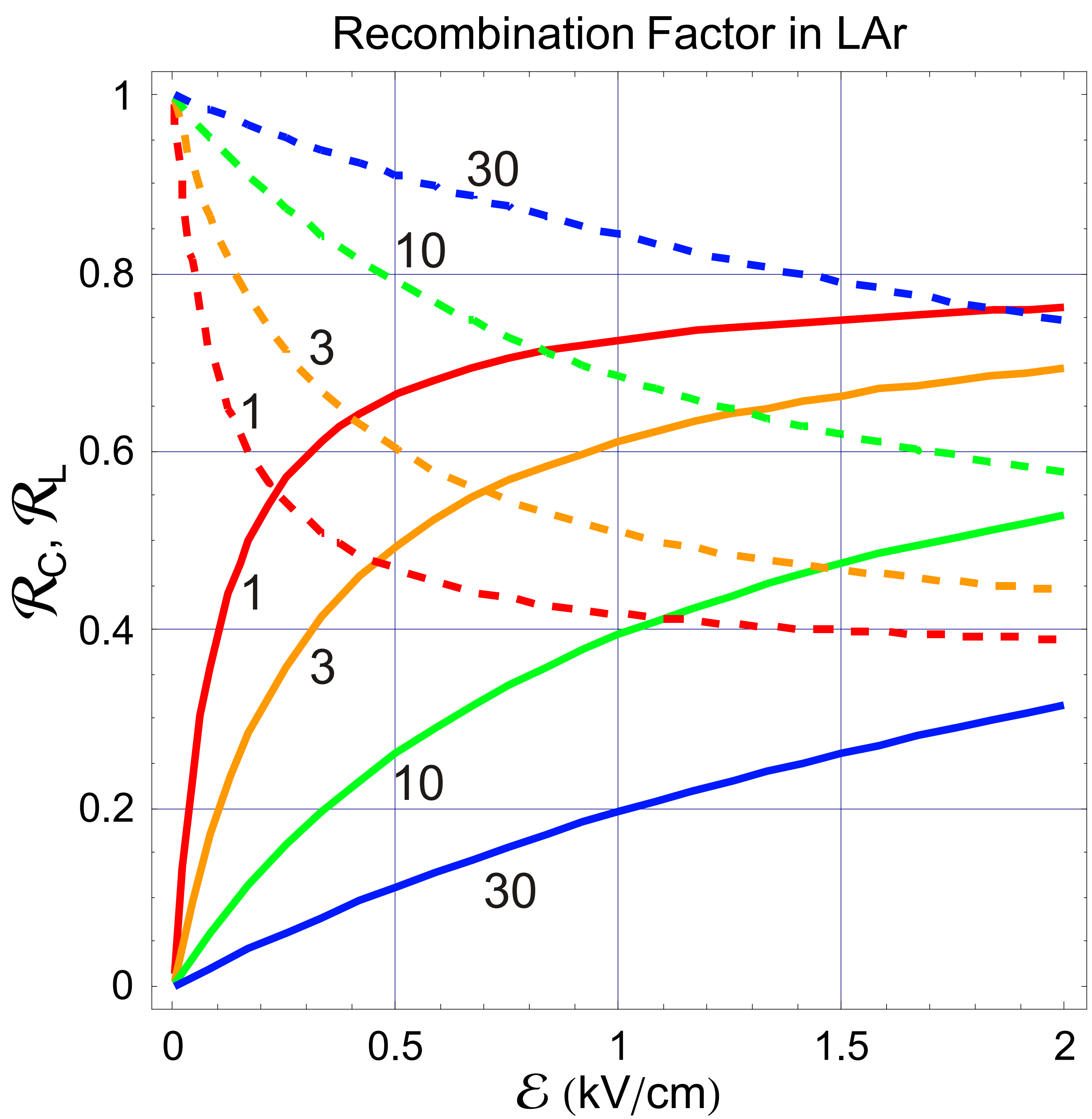




LBNO TDR, CERN-SPSC-2014-013, 1409.4405

Gushchin et al, Sov. Phys. JETP 55 (1982) 860-862

Recombination factor



Solid lines are the recombination factor for charge (charge collected at finite field divided by charge collected at infinite field) [31, 32]. Dashed lines are the light recombination factor (light collected at field divided by light collected at zero field) [43]. The numbers labeling the curves are the specific energy loss (dE/dx) in units of mip.

$$R_C = \frac{Q}{Q_\infty} = \frac{A}{1 + \frac{k}{\mathcal{E}} \times \frac{dE}{dx}}$$

$$R_L = \frac{L}{L_0} = 1 - \alpha R_C$$

$\mathcal{E}$ *is electric field in kV / cm*

dE/dx is specific energy loss in MeV cm^2/g

with A=0.800, α=0.803, and k=0.0486 (kV/cm)/(MeV cm^2/g)

for $0.1 < \mathcal{E} < 1.0\ kV/cm$ *and* $1.5 < \mathrm{dE}/\mathrm{dx} < 30\ MeV\ cm^2/g$

http://lbne2-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=4482