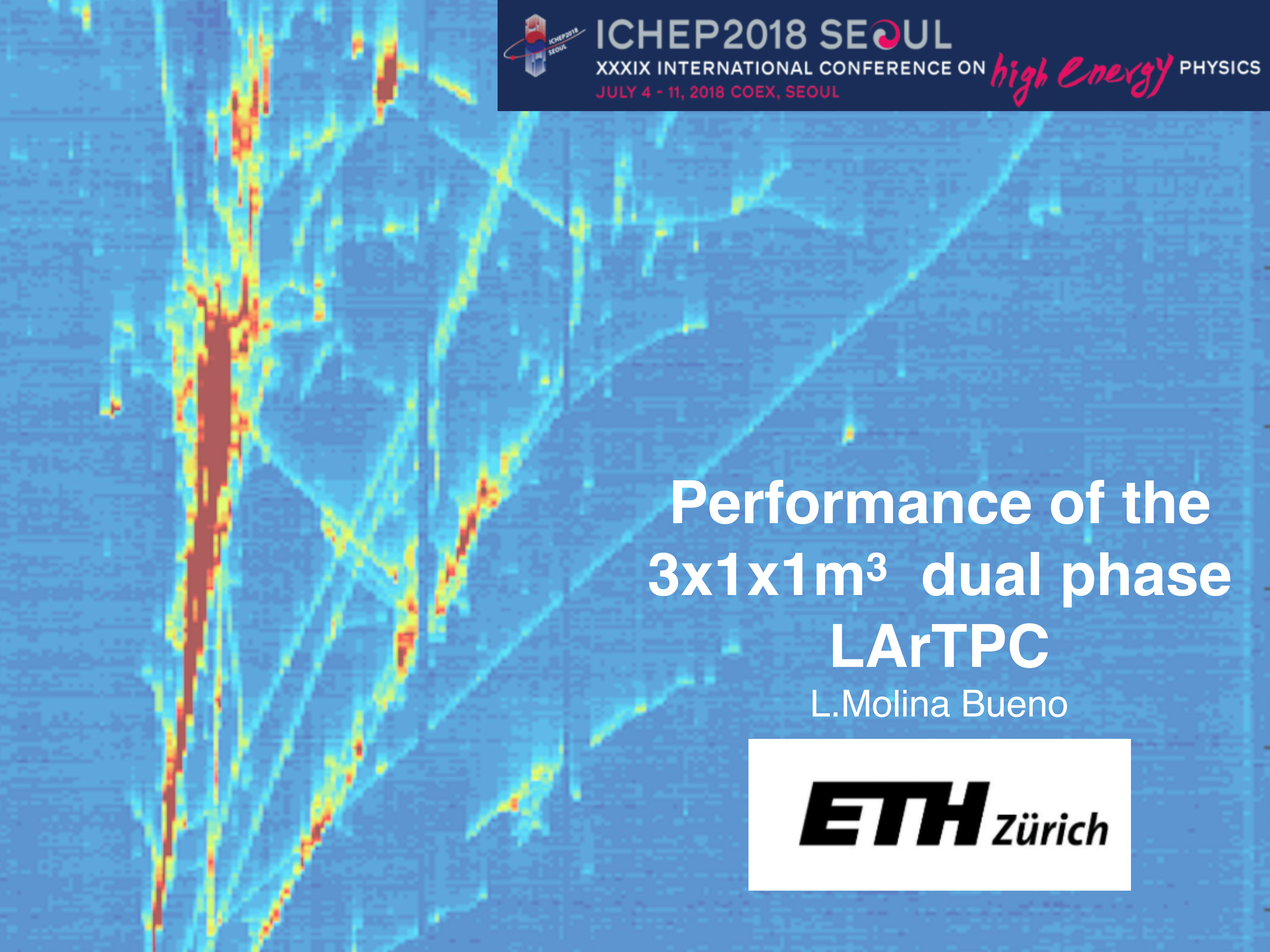


ICHEP2018 SEOUL
XXXIX INTERNATIONAL CONFERENCE ON high Energy PHYSICS
JULY 4 - 11, 2018 COEX, SEOUL

Performance of the $3x1x1m^3$ dual phase LArTPC

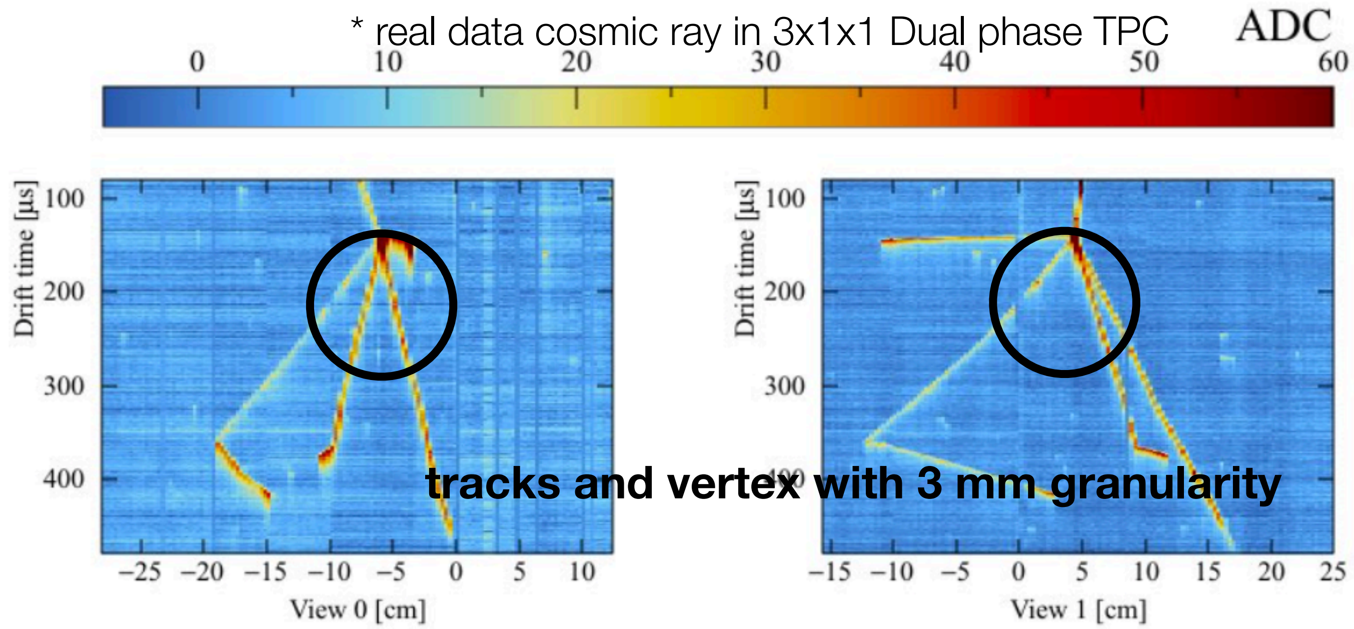
L.Molina Bueno

ETH Zürich

Motivation

Next generation of long baseline experiments aiming for CP discovery.

High resolution imaging is the key to efficient background rejection and good particle identification.



Dual phase principle = LArTPC potentialities + amplification inside Ar vapour

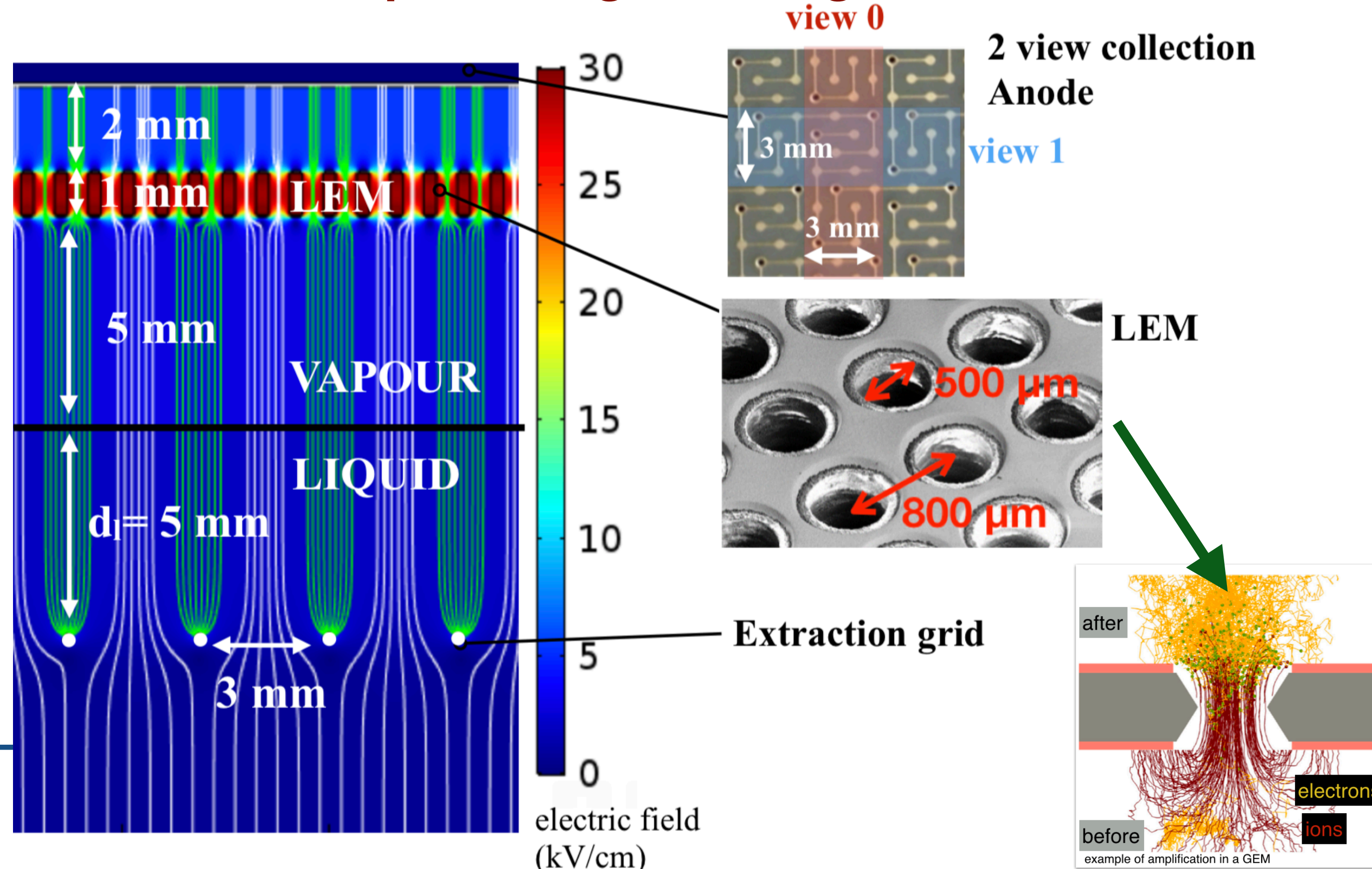
Why LAr?

- High density medium.
- Excellent dielectric which allow high voltages inside the detector.
- It is cheap and easy to obtain, so it is scalable to large detectors.
- High energy resolution.
- Excellent calorimeters which allow for precise 3D reconstruction of the track of ionising particles traversing the liquid.

+

Key concepts:

Amplification of the signal inside the LEM
+ Equal charge sharing in the anode



Towards large scale DP detector

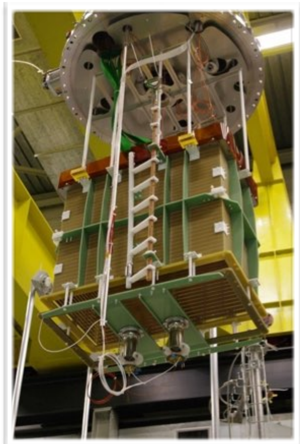
2007-2014	2014-2017	2016-2019	>2020

10x10 cm³ TPC

@CERN BLDG.182

3 l

40x80 cm³ TPC

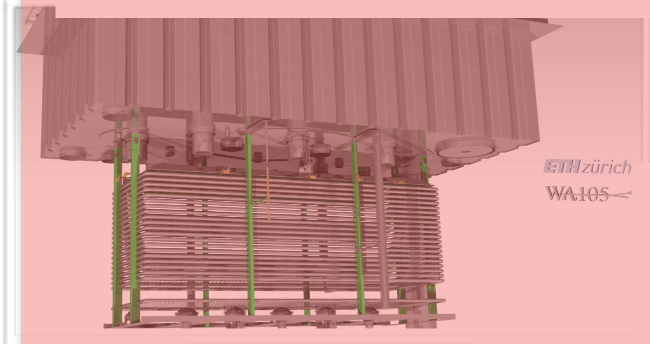


@CERN BLDG.182

250 l

4 t

WA105 3x1x1 m³
DP LAr TPC demonstrator

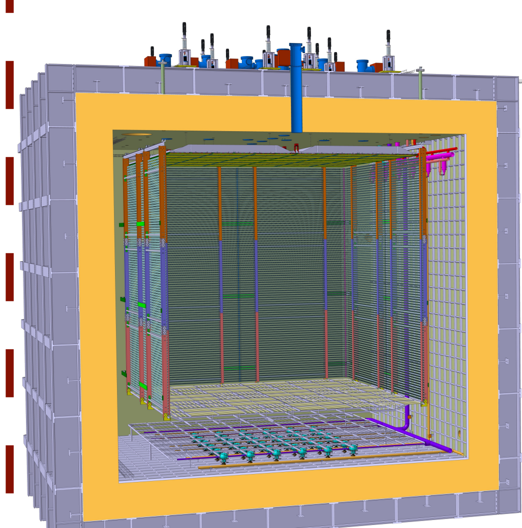


@CERN BLDG.182

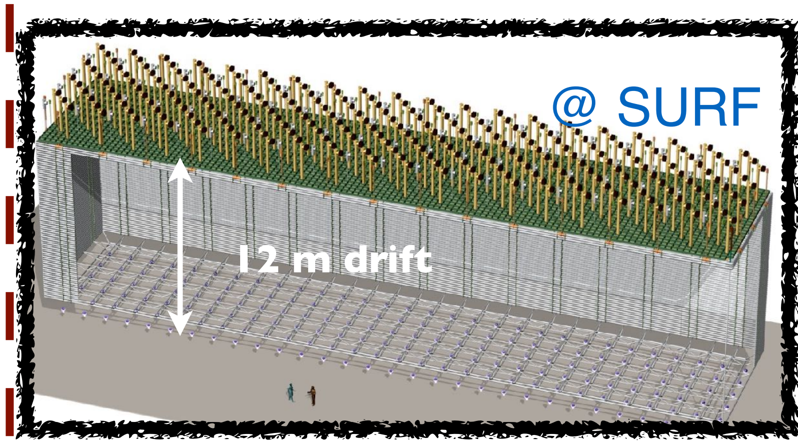
More details in:
"The protoDUNE detectors"
Leigh Whitehead

700 t

ProtoDUNE DP
6x6x6 m³



@CERN NORTH AREA



DUNE DP Far detector
6x6x6 m³

10 kt

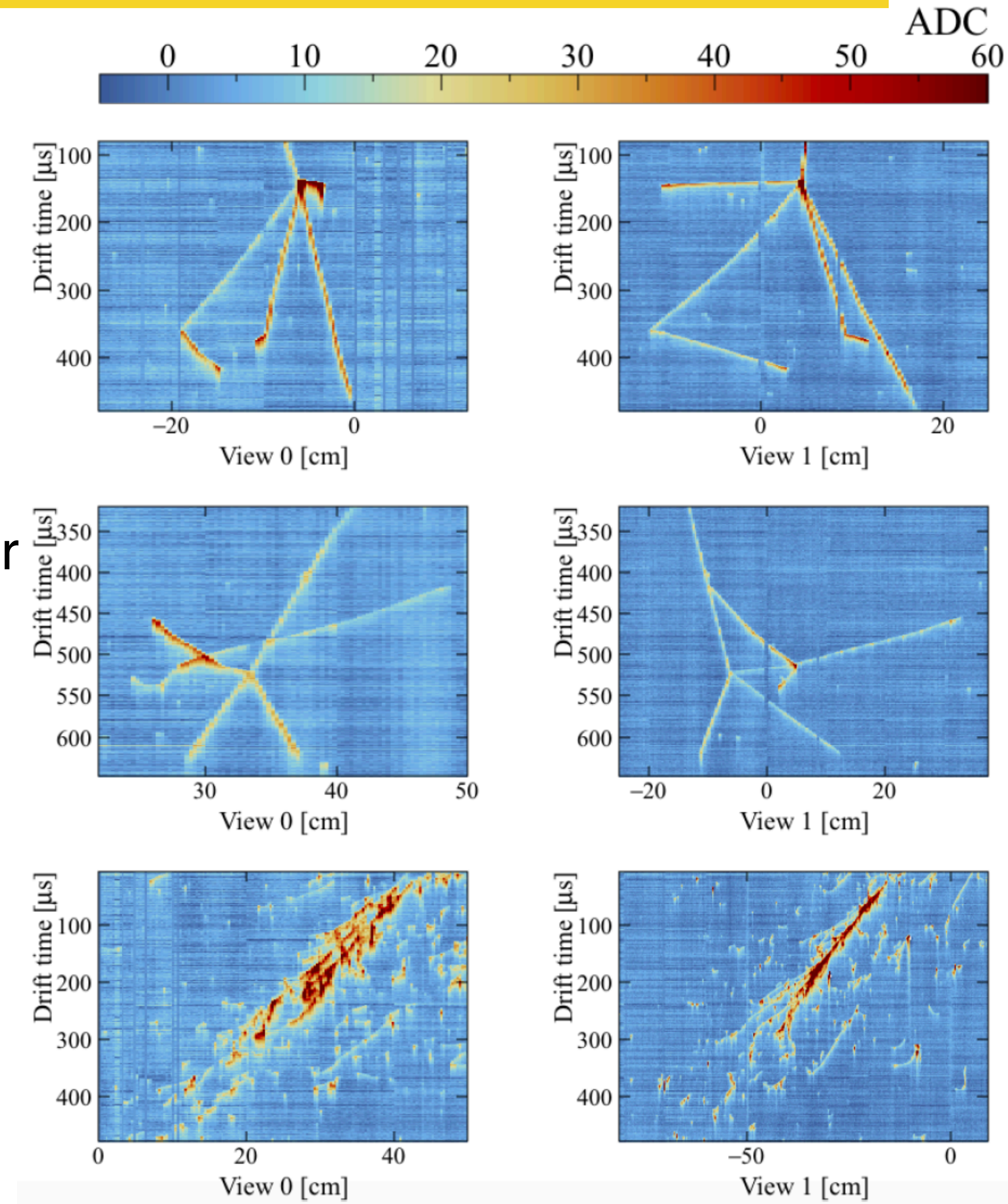
More details in:
"The DUNE Experiment"
Jae Yu

The 3x1x1m³ dual phase prototype

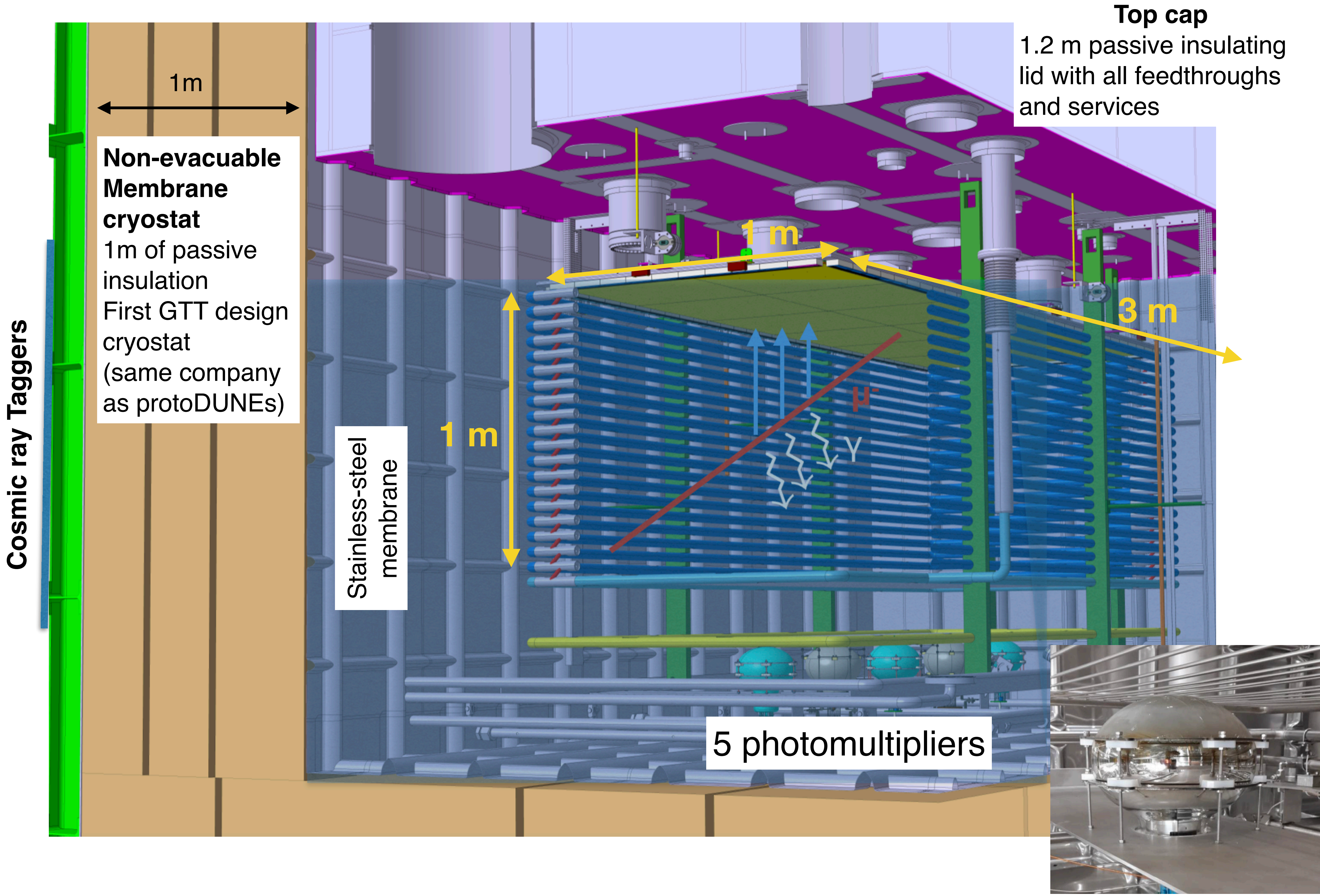
Feedback from performance

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

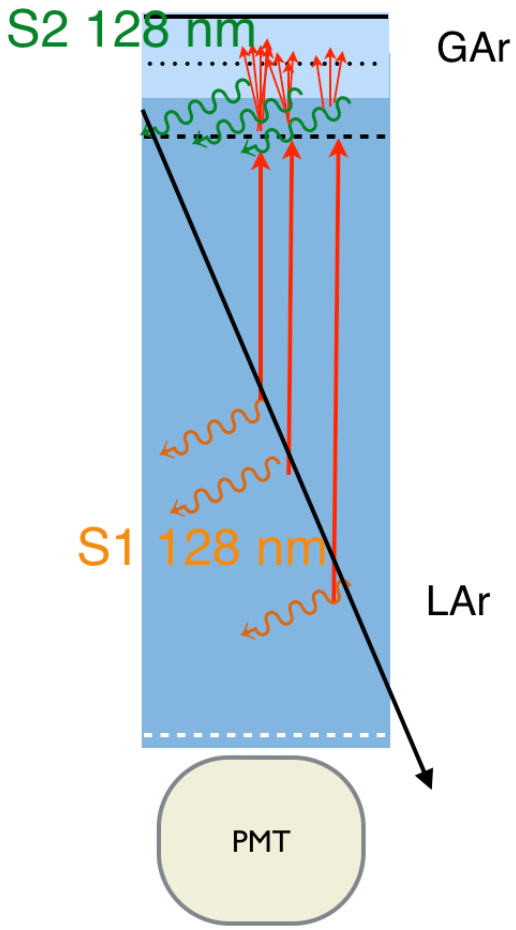
- **First time charge extraction over a 3 m² squared area and amplification inside 50x50 cm² LEMs.** However, the target effective gain of 20 was not reached. Performance limited due to discharges of the extraction grid at -5kV (nominal -6.5 kV).
- **Stable liquid surface** as required for detector operation, **good performance of the cryogenic system and excellent liquid argon purity (compatible with ms electron lifetime)**.
- Stable drift field of 500V/cm.
- Observation of first (in liquid) and second (in gas) scintillation light.



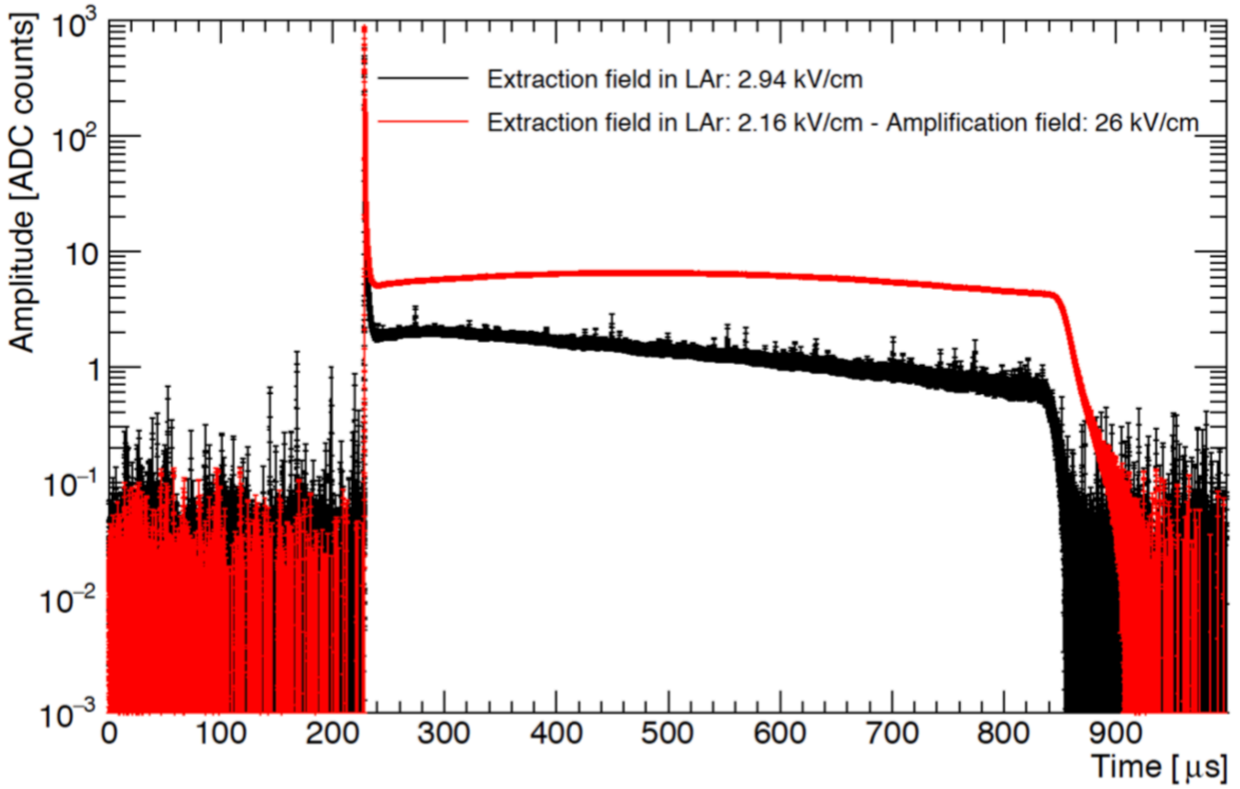
The 3x1x1m³ dual phase prototype

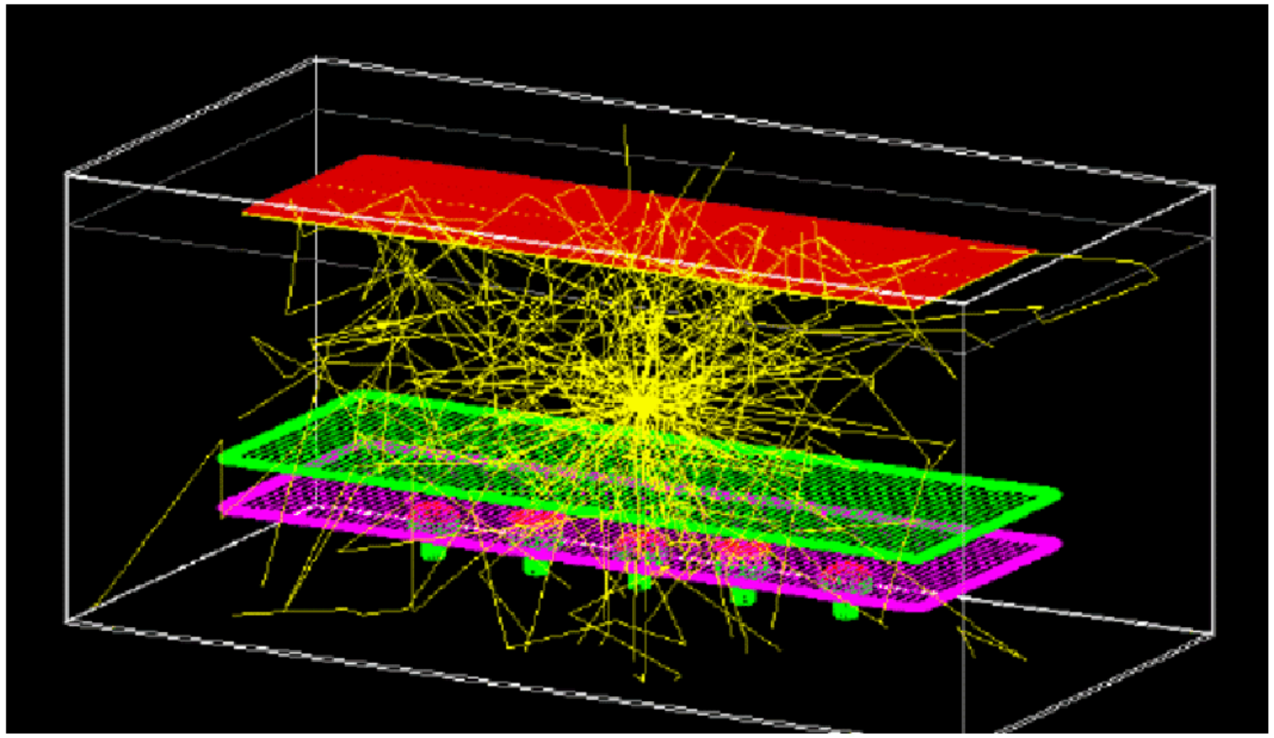


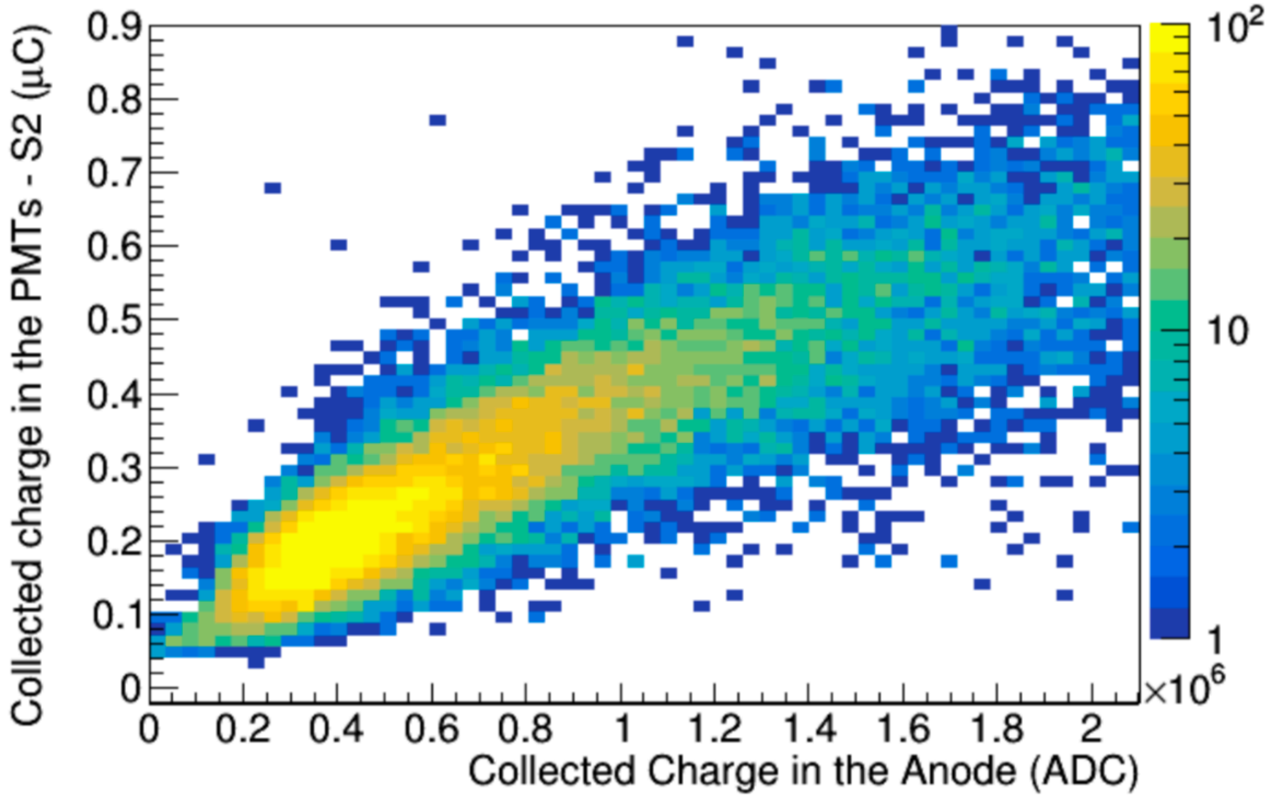
Primary and secondary scintillation in argon



- 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.

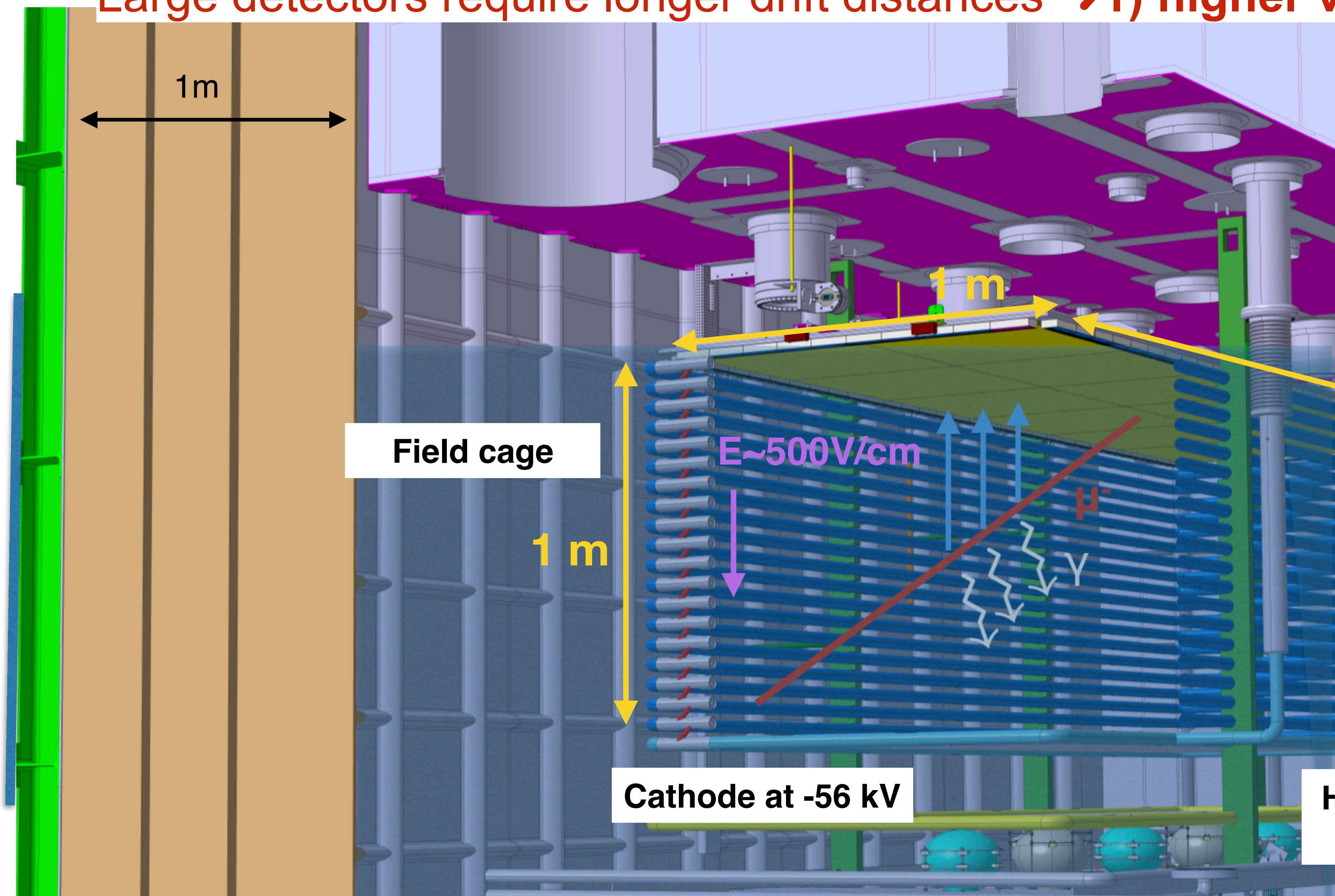






The 3x1x1m³ dual phase prototype: Generate and sustain the voltage

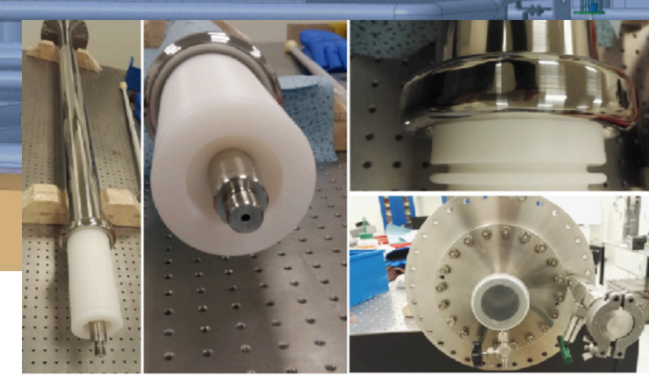
Large detectors require longer drift distances ➜**1) higher voltages**



High voltage feedthrough
Tested up to ~300 kV

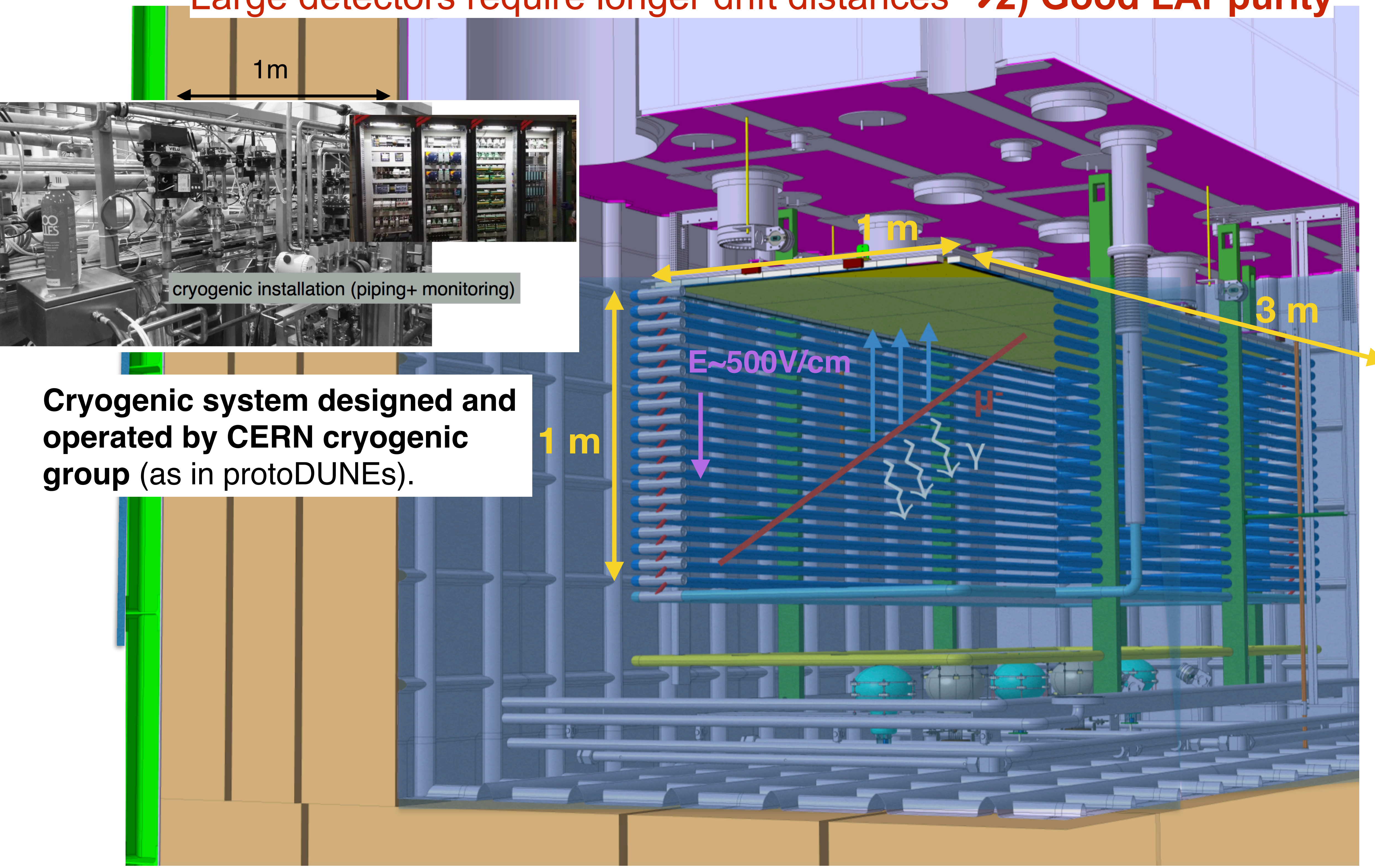
C. Cantini et al., "**First test of a high voltage feedthrough for liquid Argon TPCs connected to a 300 kV power Supply**",

JINST 12 P03021 arXiv:1611.02085



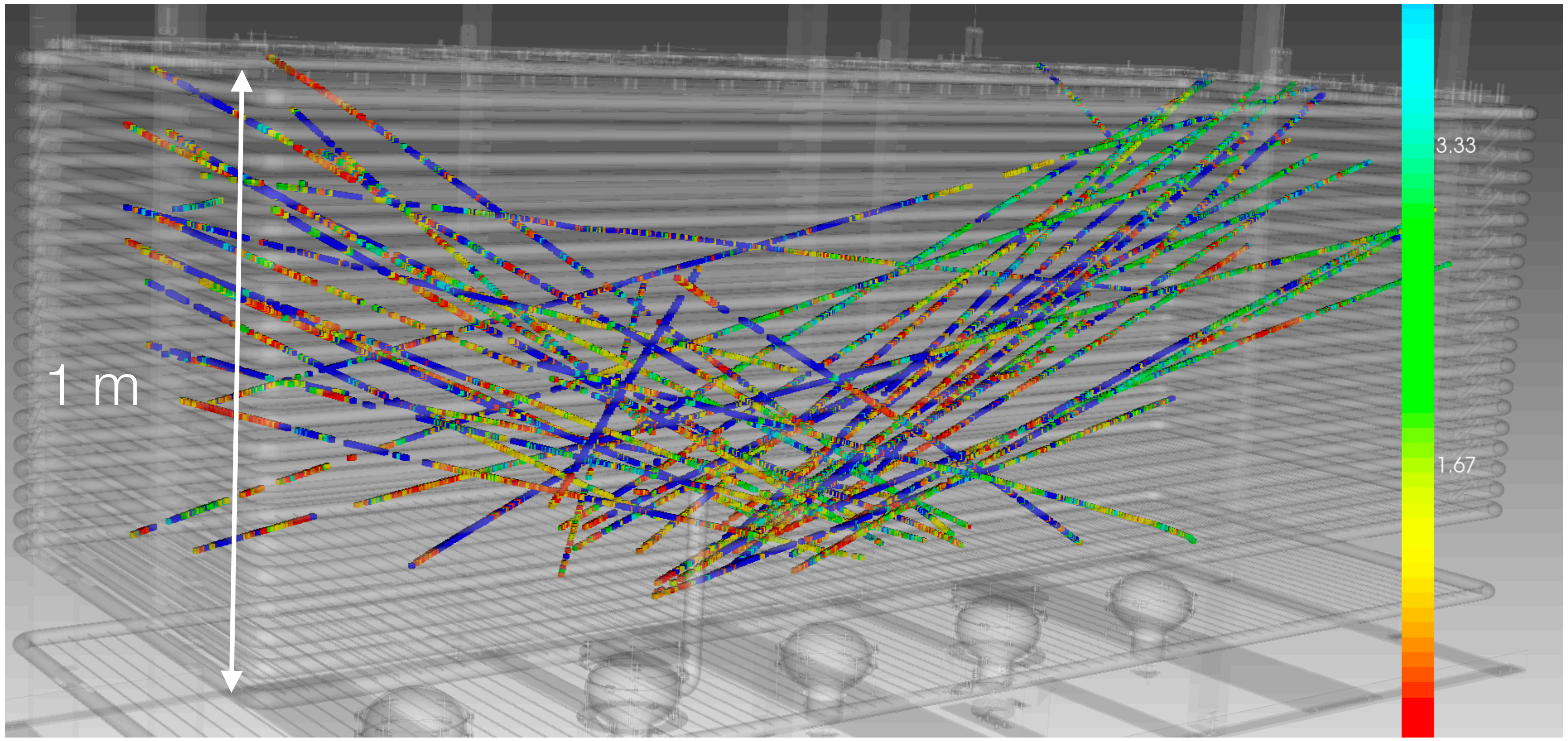
The 3x1x1m³ dual phase prototype: LAr purity

Large detectors require longer drift distances ➜2) Good LAr purity



Cryogenic system designed and operated by CERN cryogenic group (as in protoDUNEs).

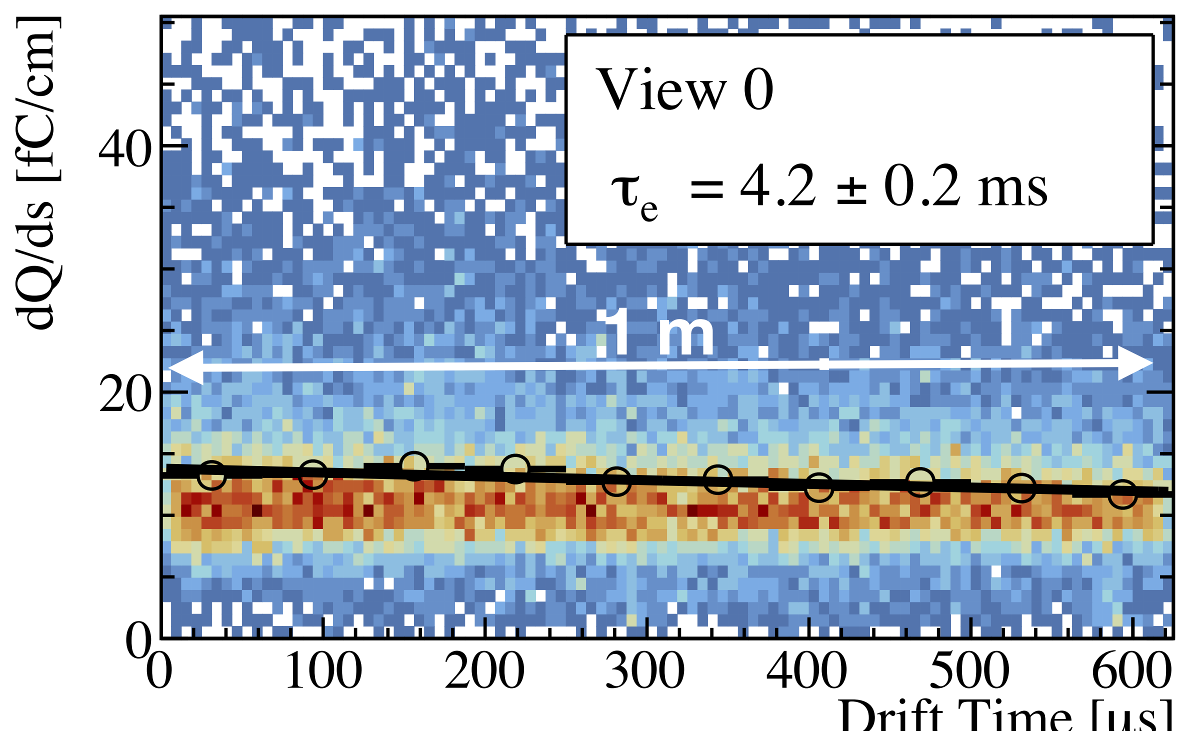
The 3x1x1m³ dual phase prototype: LAr purity

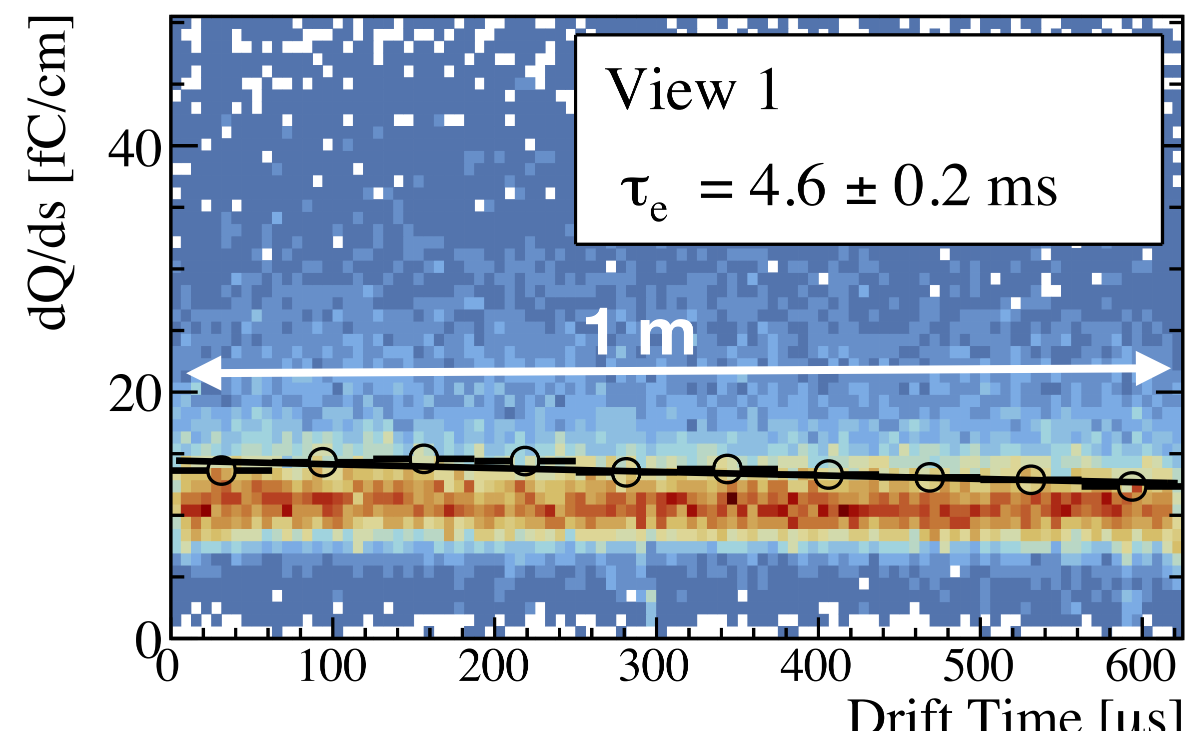


Select tracks that cross the entire 1 m drift. Compute the **deposited charge (dQ/dx) as a function of drift.**

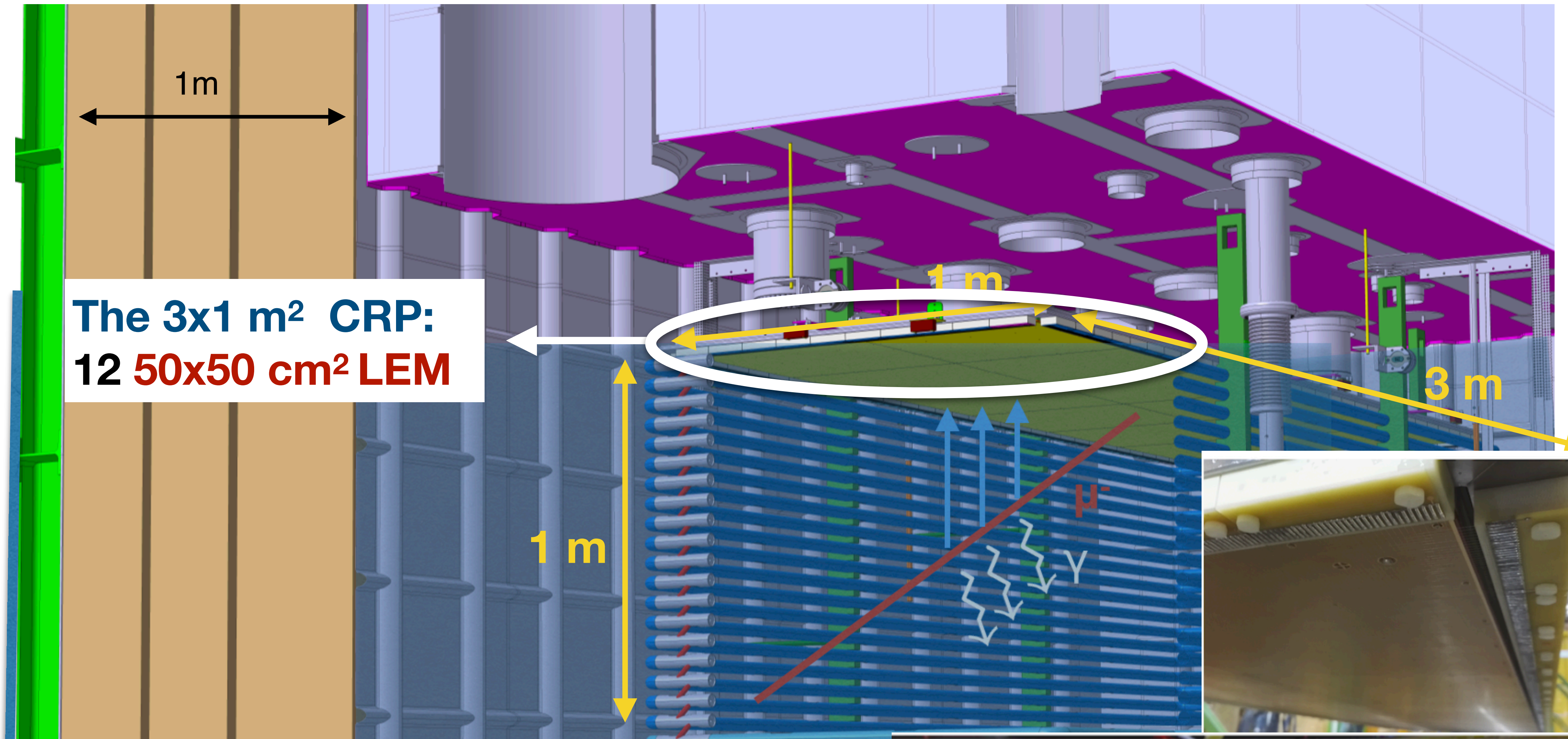
$$\mathrm{d}Q/\mathrm{d}s \propto e^{-t_{drift}/\tau_e}$$

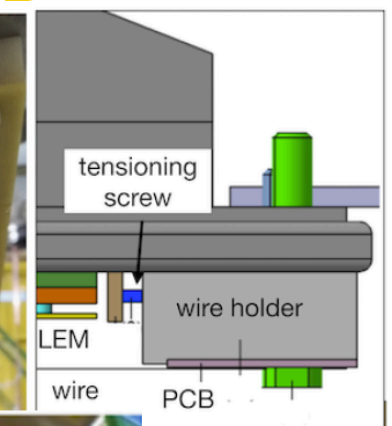
✓electron lifetime of few milliseconds achieved (as required for ktonne scale TPCs)

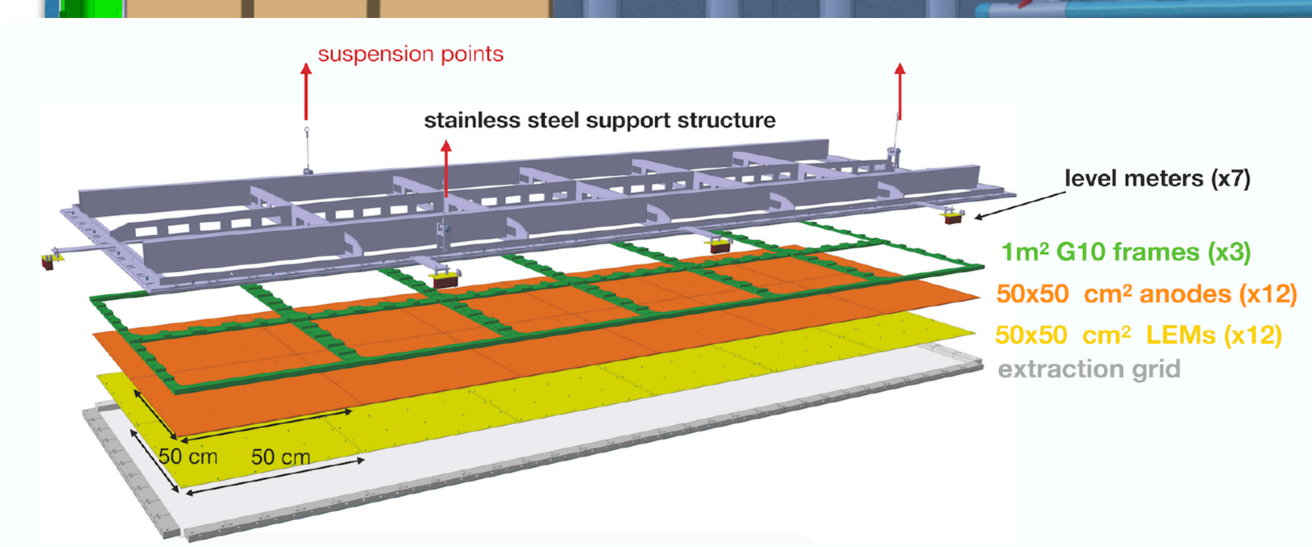


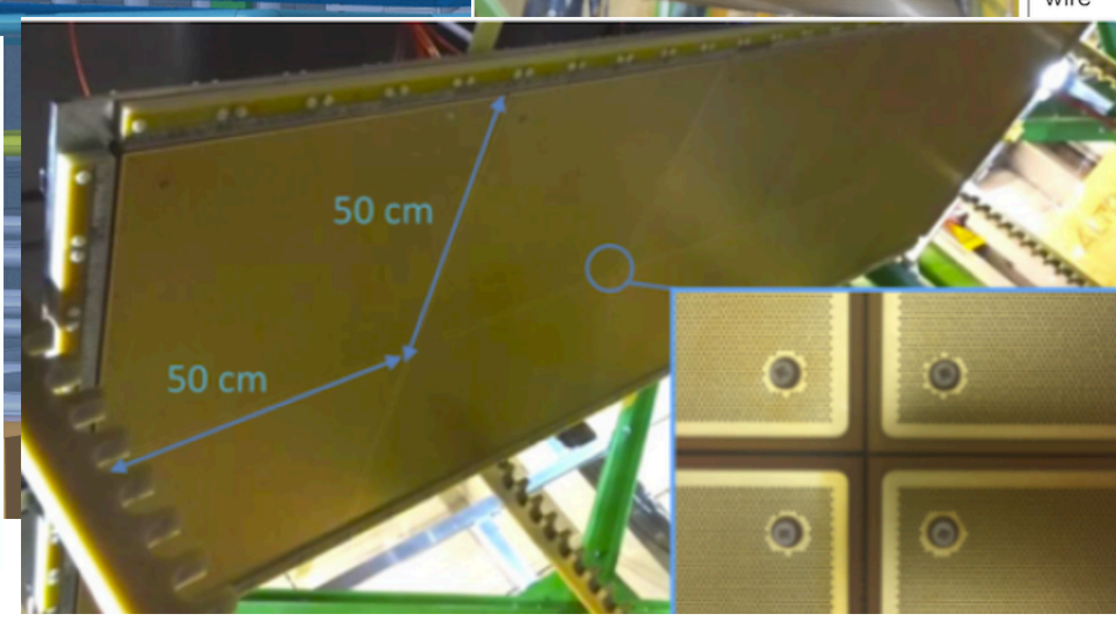


The 3x1x1m³ dual phase prototype: Charge readout system

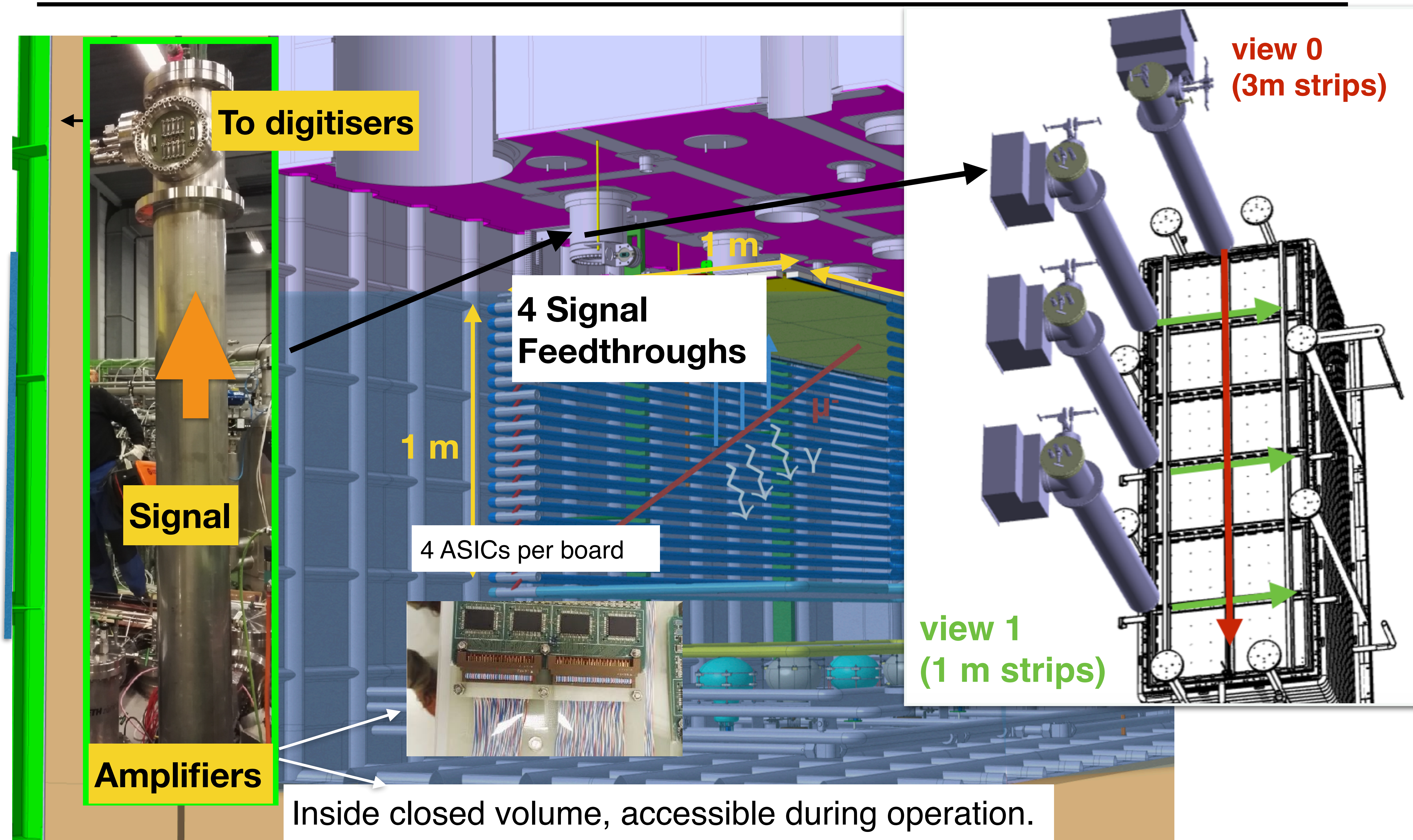








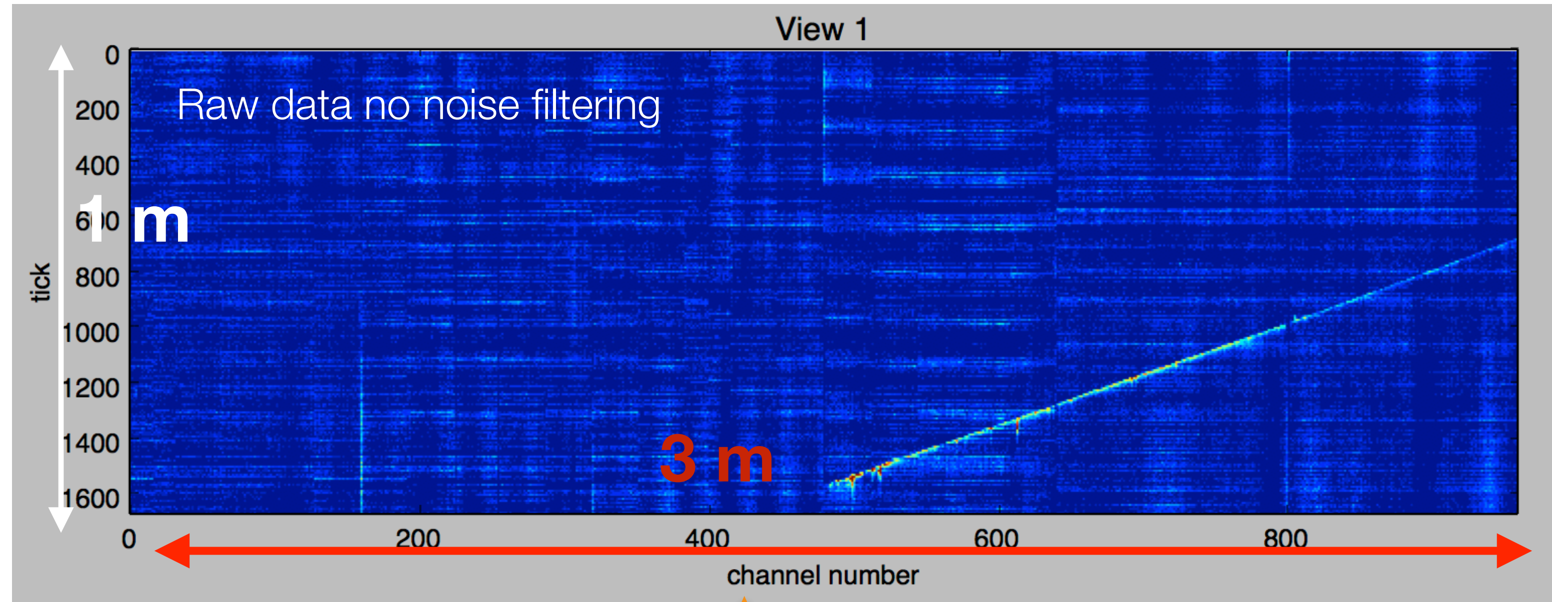
The 3x1x1m³ dual phase prototype: Charge readout system



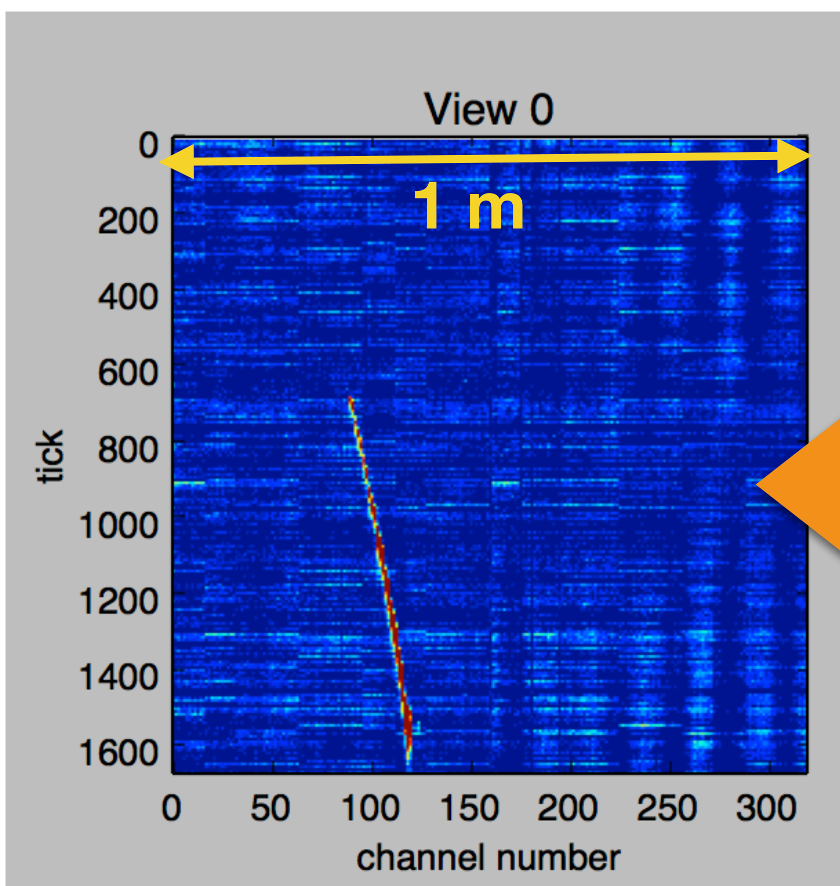
Inside closed volume, accessible during operation.
Close to anodes, T~110 K

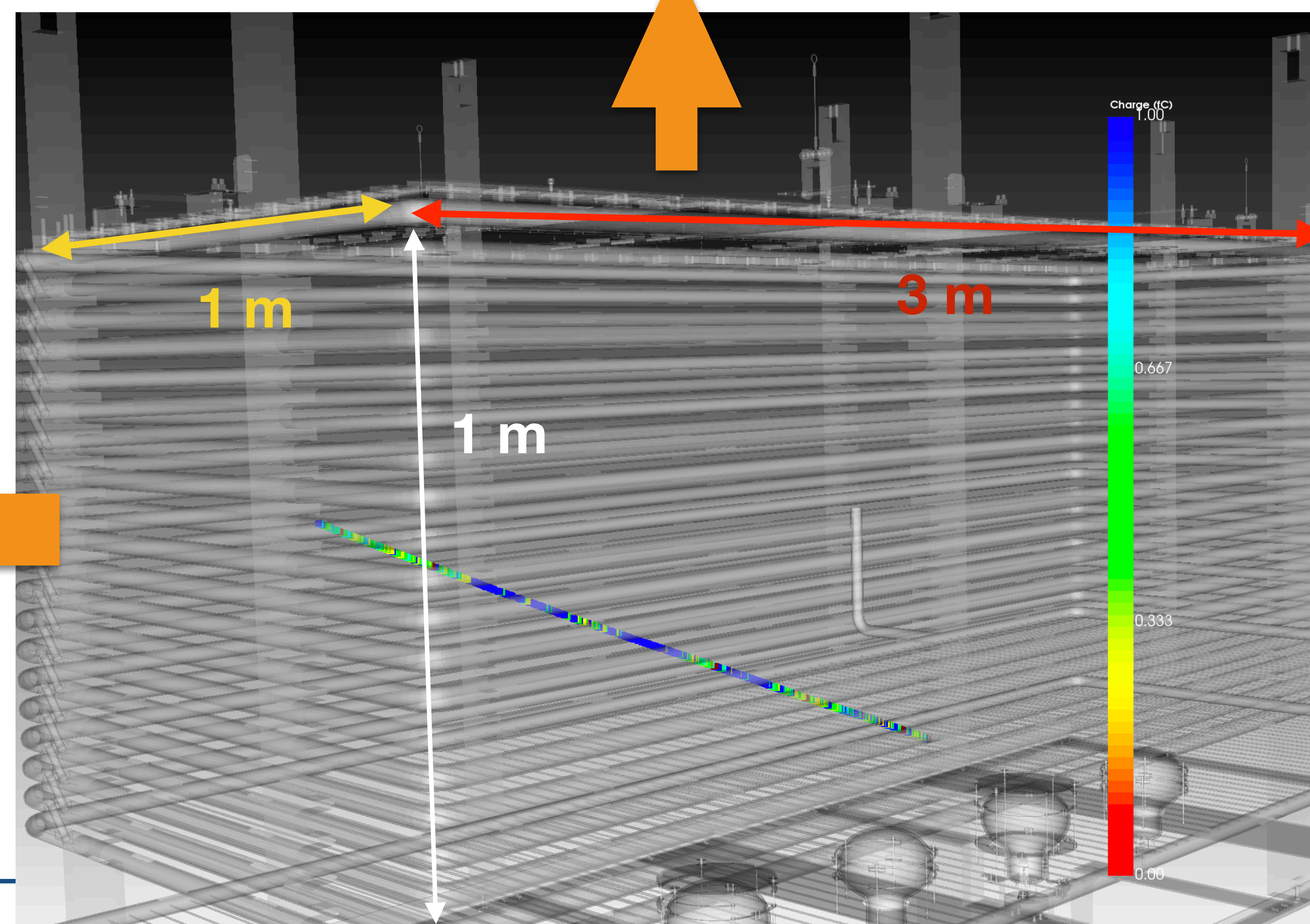
Cosmic track reconstruction

High performance imaging in both views requires:
1)Low noise
2)Amplification: effective gain inside the TPC
3)Equally charge sharing



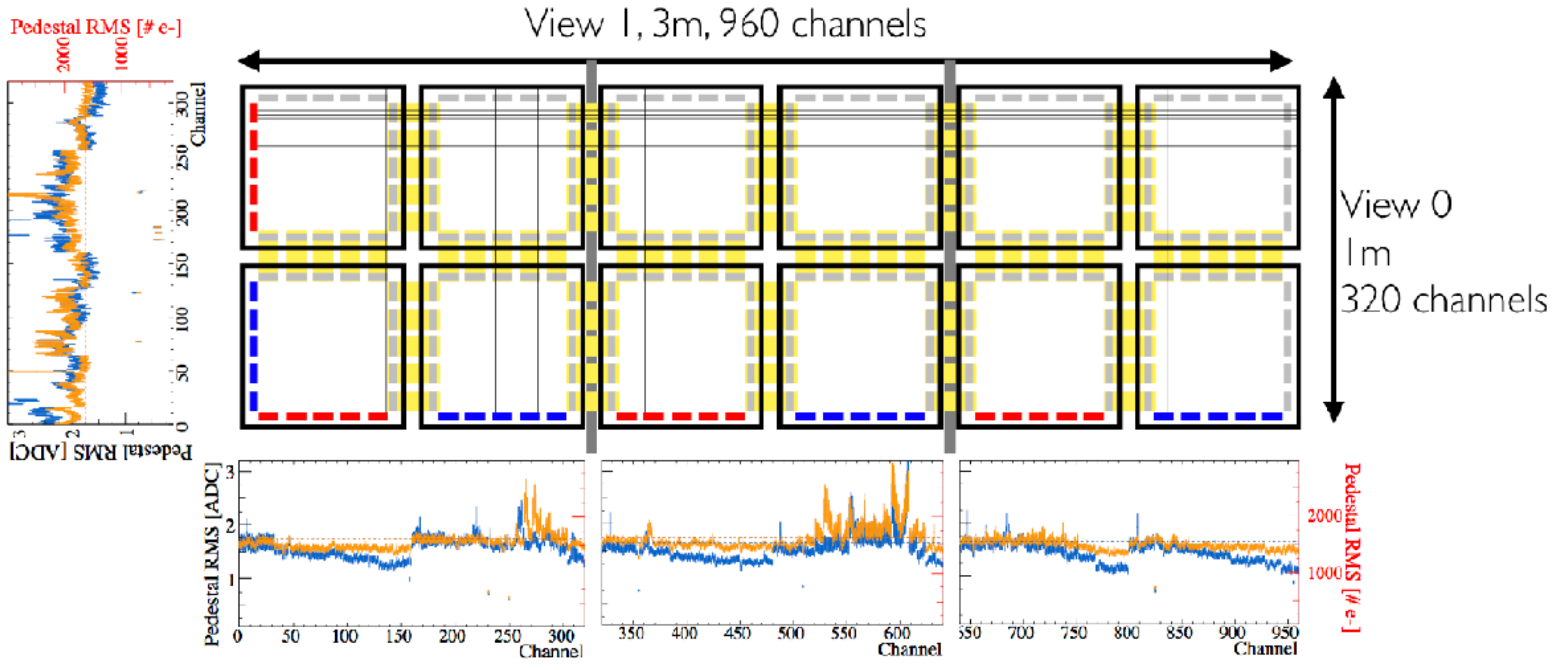
Many analysis ongoing->See **L.Zambelli poster** for more details

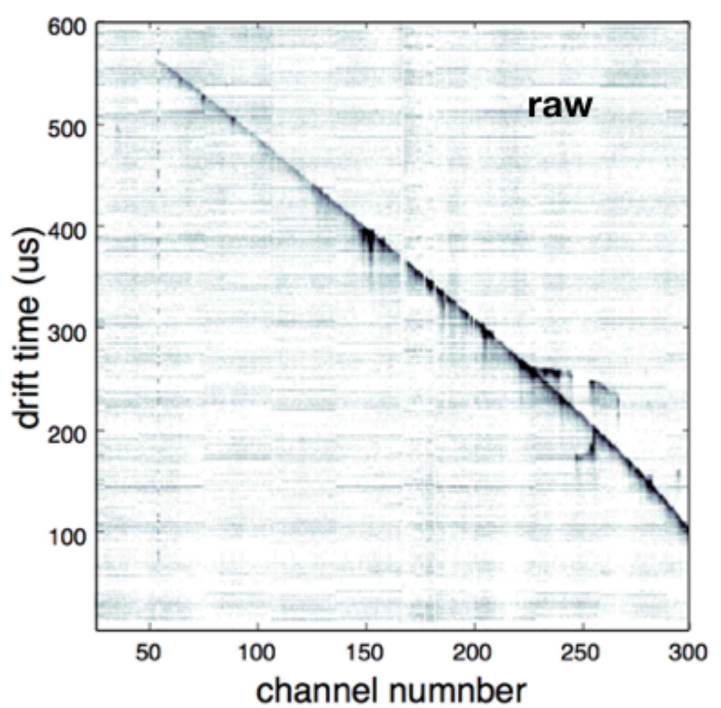


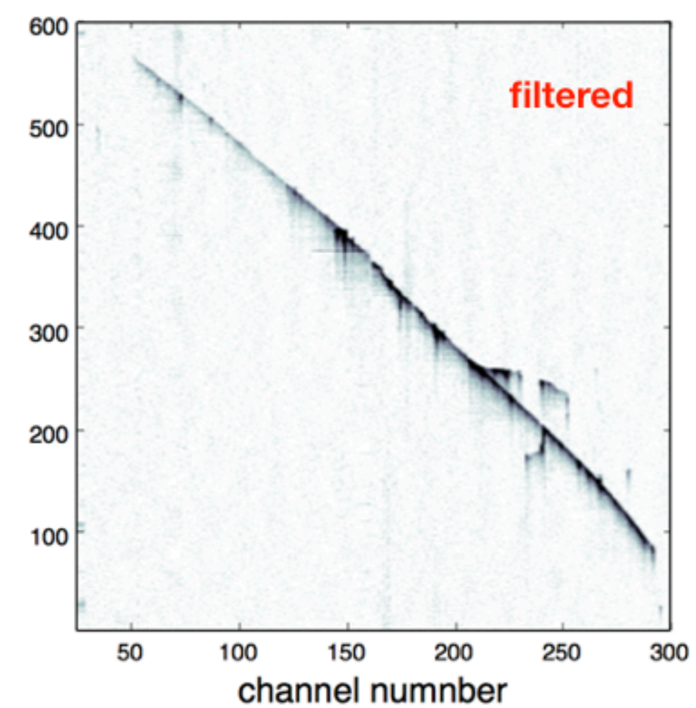


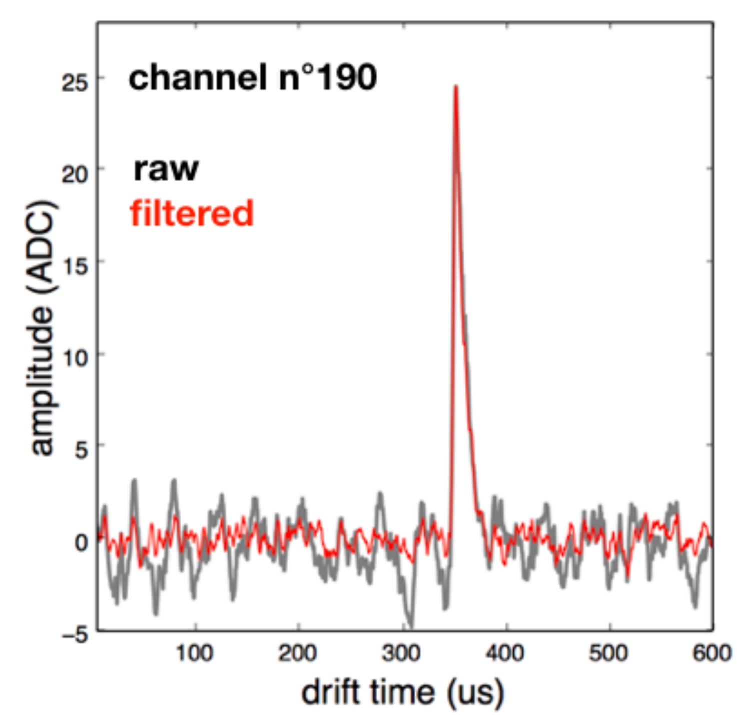
Cosmic track reconstruction: 1)Low electronic noise

Noise stable at cryogenic temperature at around 1550 e^-



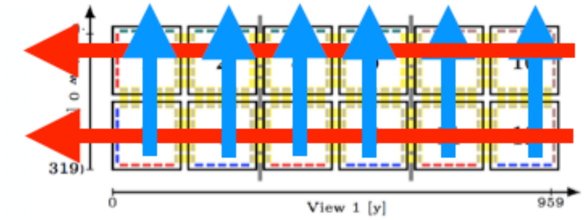






Cosmic track reconstruction: 2)Effective gain

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



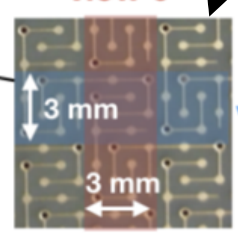
Effective Gain = (<dQ/ds>$_{view0}$+<dQ/ds>$_{view1}$)/<dQ/ds$_{expected}$>

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

view 0

2 view collection Anode

50%



view 1

Extraction efficiency
fraction of electrons which are extracted from the liquid

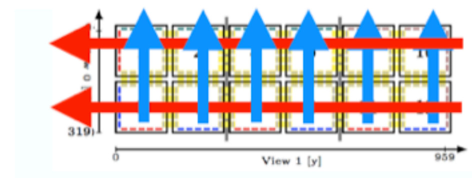
LEM Amplification
multiplication factor of the electrons x transparency of its bottom electrode

Collection Efficiency
fraction of electrons transferred from LEM to anode

G_{eff}, effective gain→ **goal 20**

Cosmic track reconstruction: 2)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$_{expected}$>

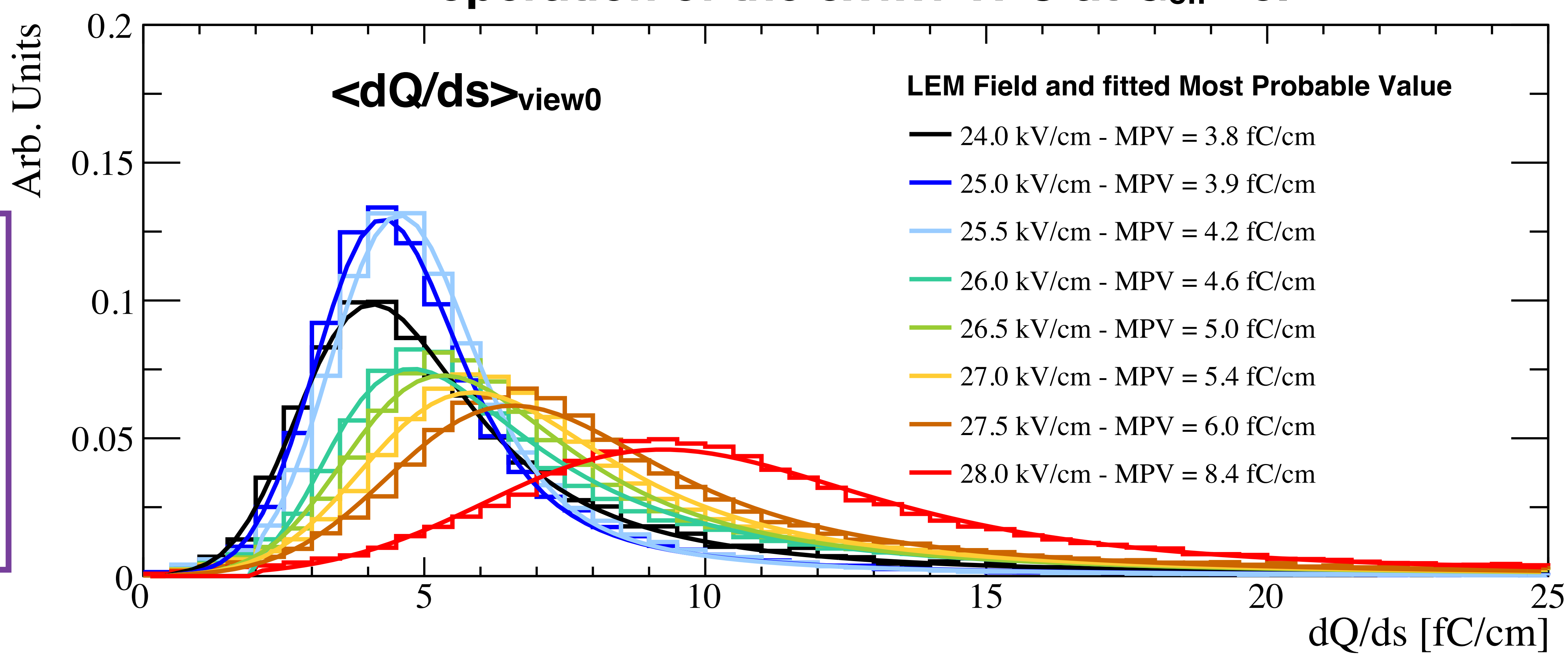
G_{eff}

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

28 kV/cm of LEM field corresponds to an operation of the 3x1x1 TPC at $G_{eff} \approx 3$.

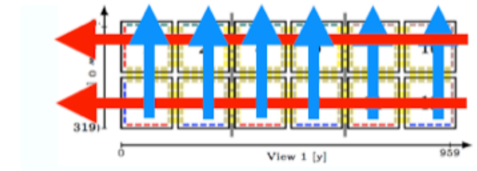
LEM Amplification

increase of the mean and MPV of the dQ/dx distributions as a function of the LEM fields.



Cosmic track reconstruction: 3)Charge sharing

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

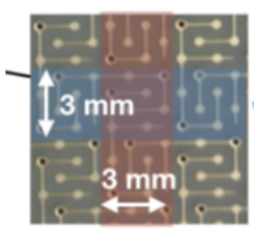


Effective Gain = (<dQ/ds>$_{view0}$+<dQ/ds>$_{view1}$)/<dQ/ds$_{expected}$>

G_{eff}

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

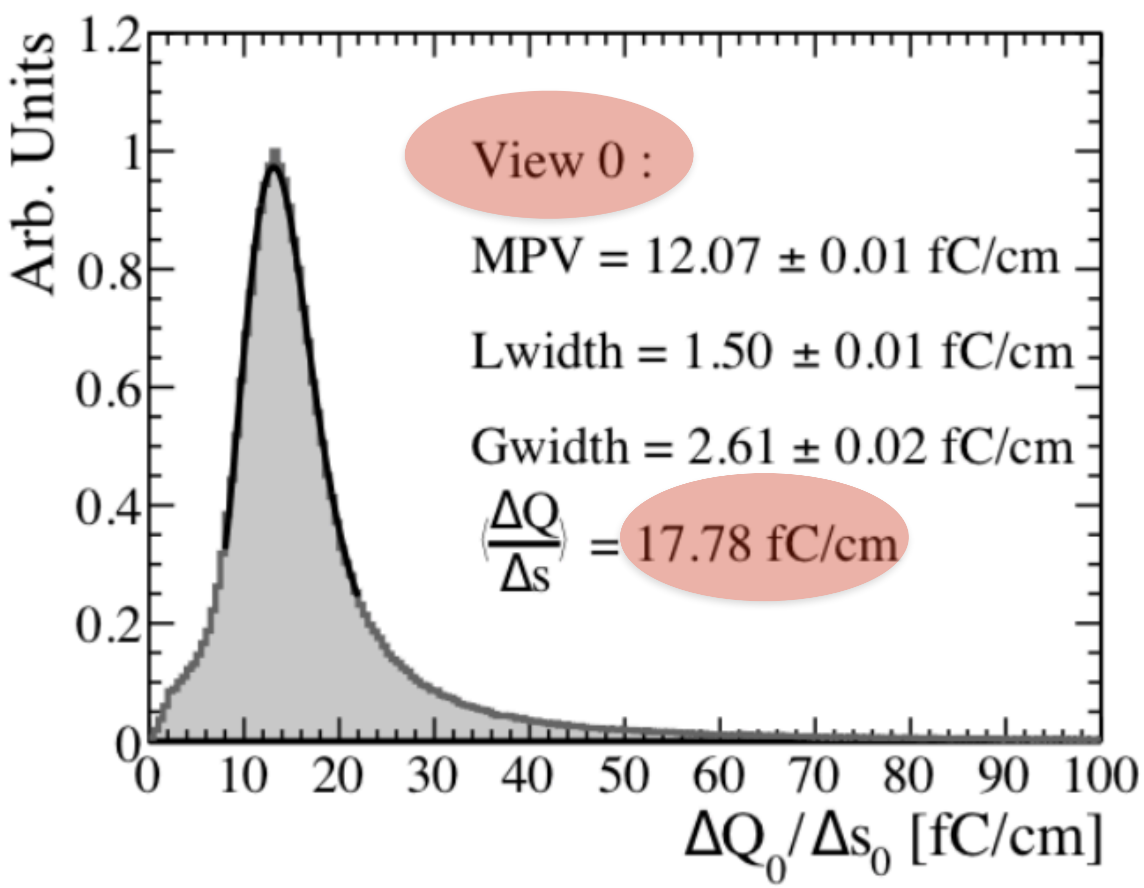
view 0

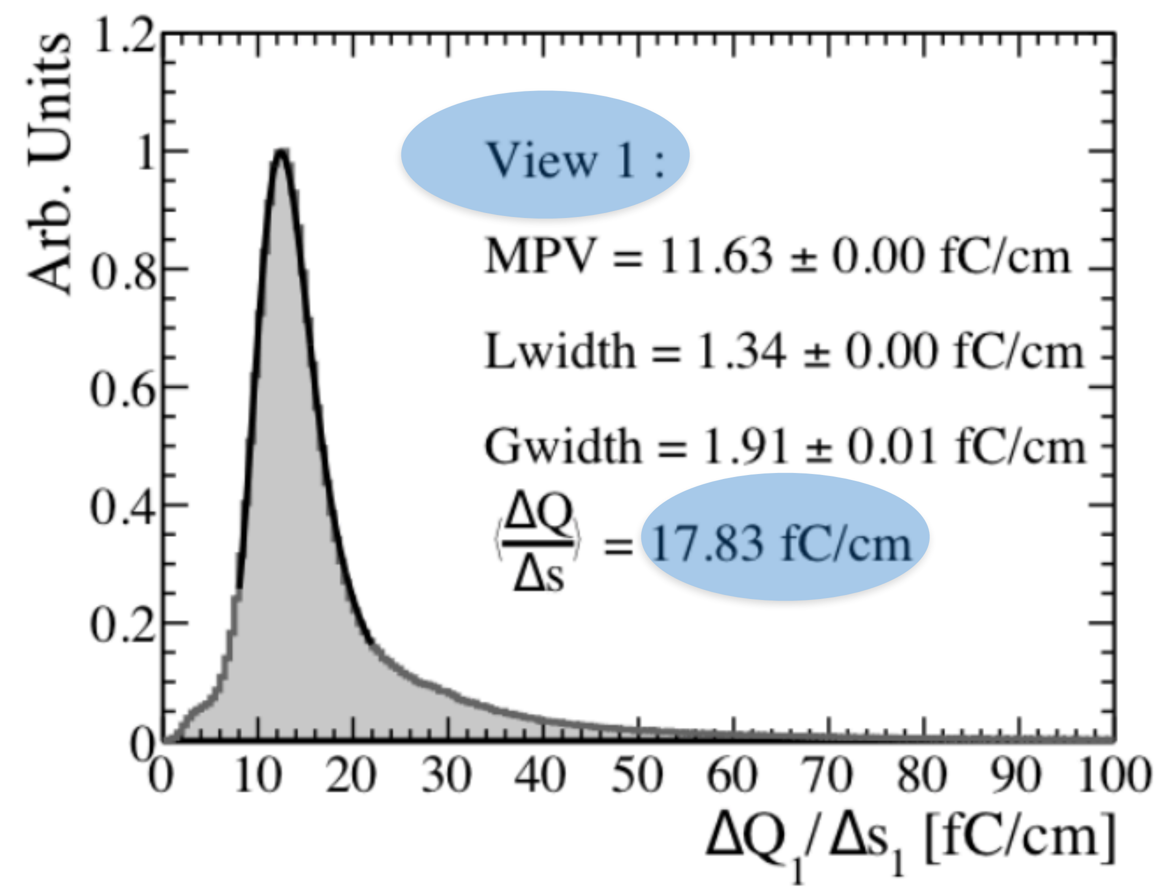


view 1

2 view collection Anode

We need to reconstruct the same charge in each view





Conclusions

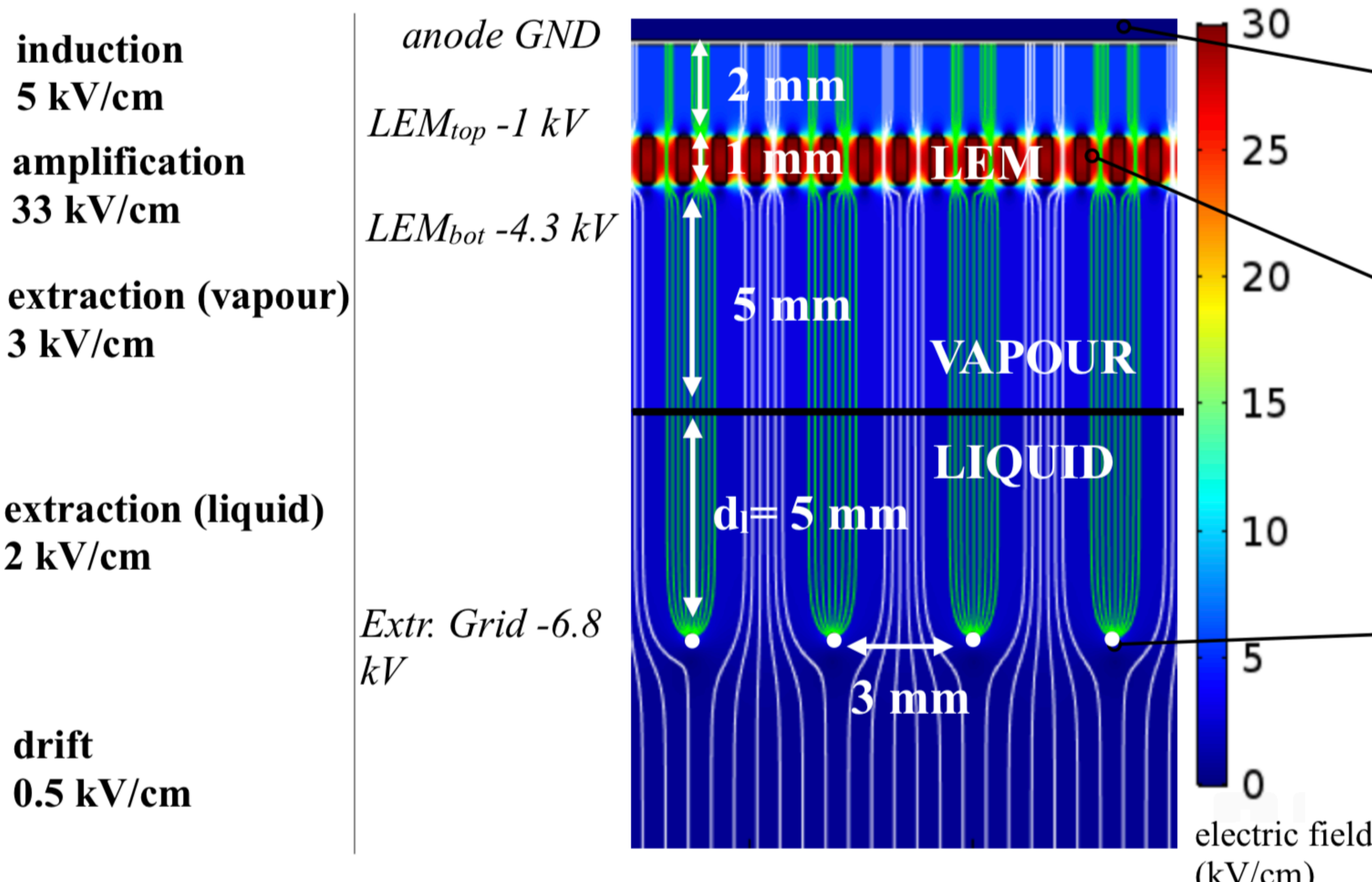
- The 3x1x1 m^3 has successfully opened the path towards large DP LAr TPCs:
  - **Extraction efficiency over $3m^2$ area and LEM amplification with gain has been demonstrated on the 50x50 cm^2 for the first time.** Performance limited by the extraction grid maximum voltage.
  - **First LAr TPC operation in a membrane tank** and excellent performance of the cryogenic system.
  - Stable drift field of 500V/cm over 1m.
  - Purity compatible with ms electron lifetime.
  - **First time use in a LAr TPC of accessible cold front end electronics:** they have shown to be robust to discharges and offer excellent noise performance.
  - More than 500k events recorded. **Full infrastructure for data transfer** has been set up and tested in the 3x1x1.
  - **Fully engineered versions of many detector components** with pre-production and direct implementation.
  - **First overview of the complete system integration**: set up full chains for QA, construction, installation and commissioning
  - **Large experience has been gained for protoDUNE-DP design, installation and commissioning.**

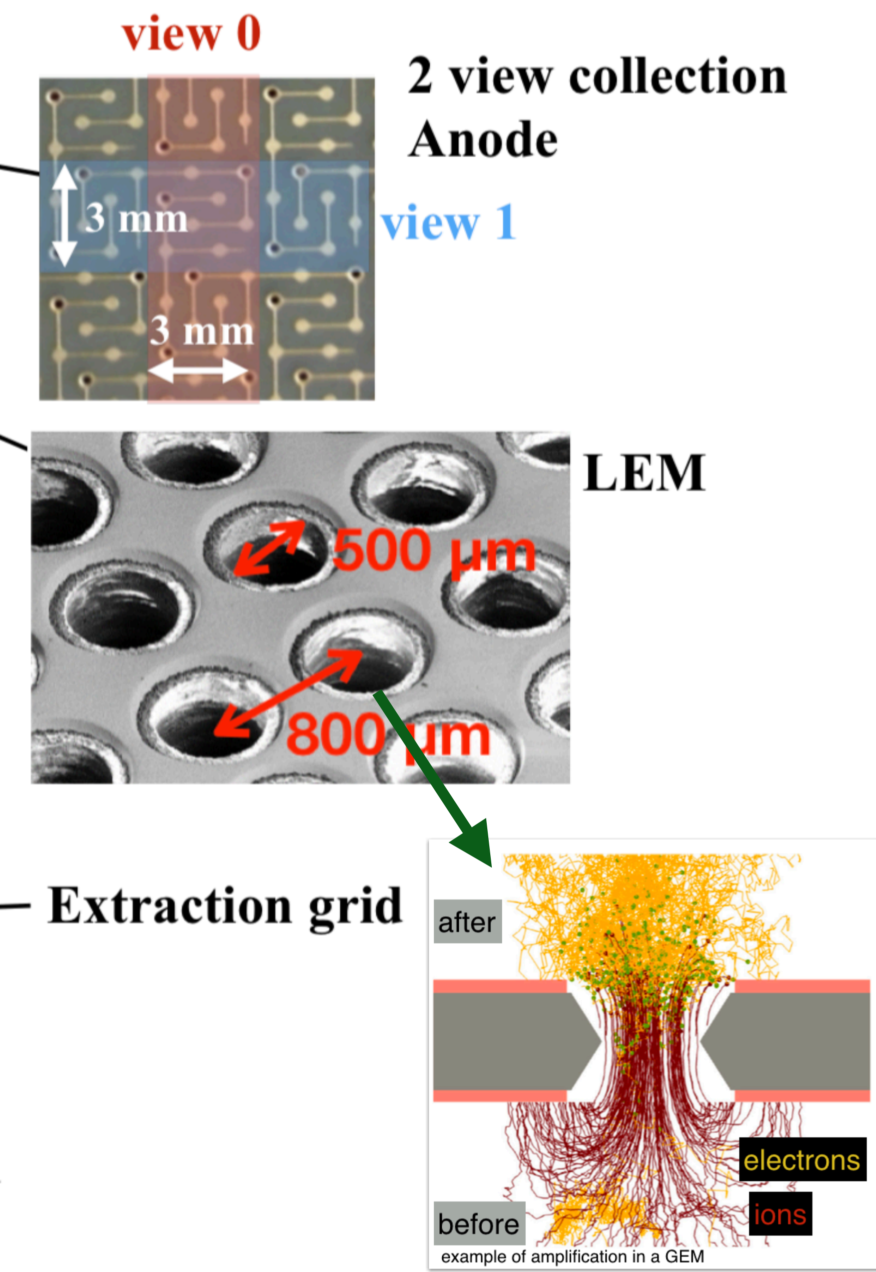

THANK YOU
WA105

Back-up

Dual phase principle

A. Rubbia 2004
“In order to allow for long drift (≈ 20 m), we consider charge attenuation along drift and compensate this effect with charge amplification near anodes located in gas phase.”
Experiments for CP violation: A Giant liquid argon scintillation, Cerenkov and charge imaging experiment? pp 321–350 (Preprint hep-ph/0402110)



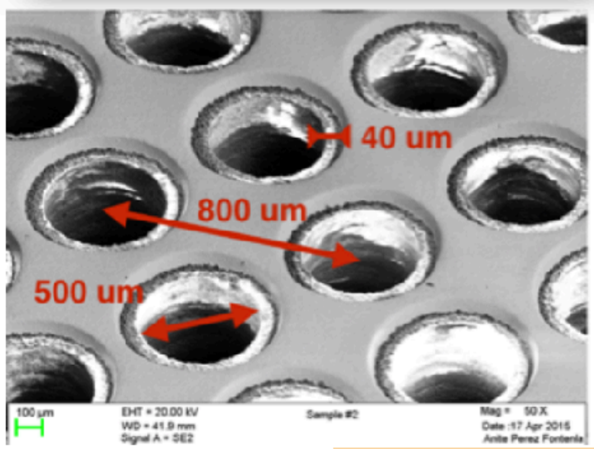


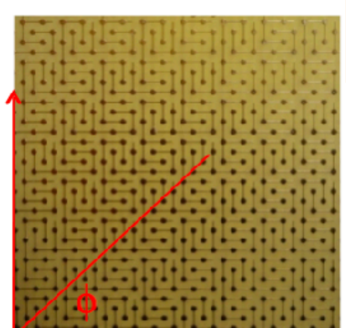
Key concepts:

Amplification of the signal inside the LEM + Equally charge sharing in the anode

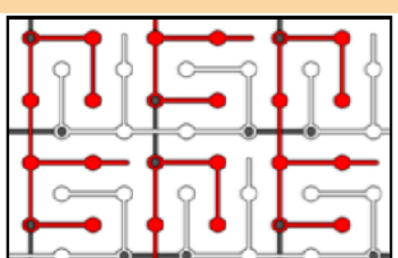
Towards large scale DP detector

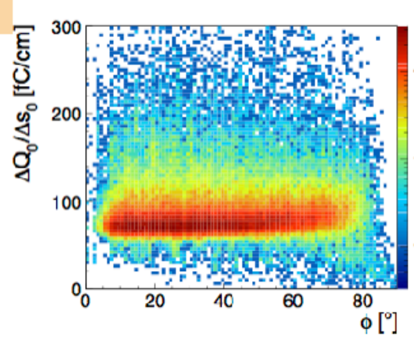
10x10cm^2: LEM/anode R&D



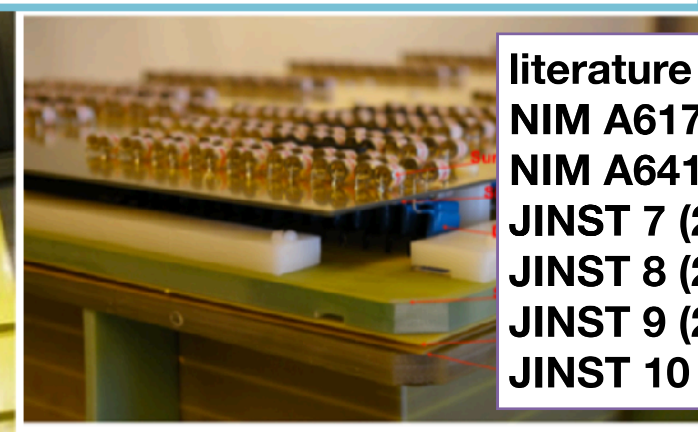


dC/dl ~ 120 pF/m



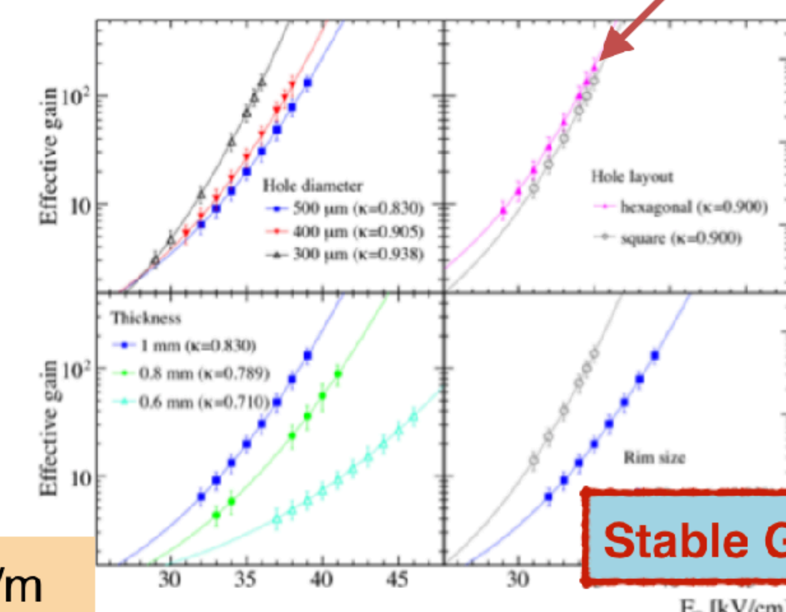


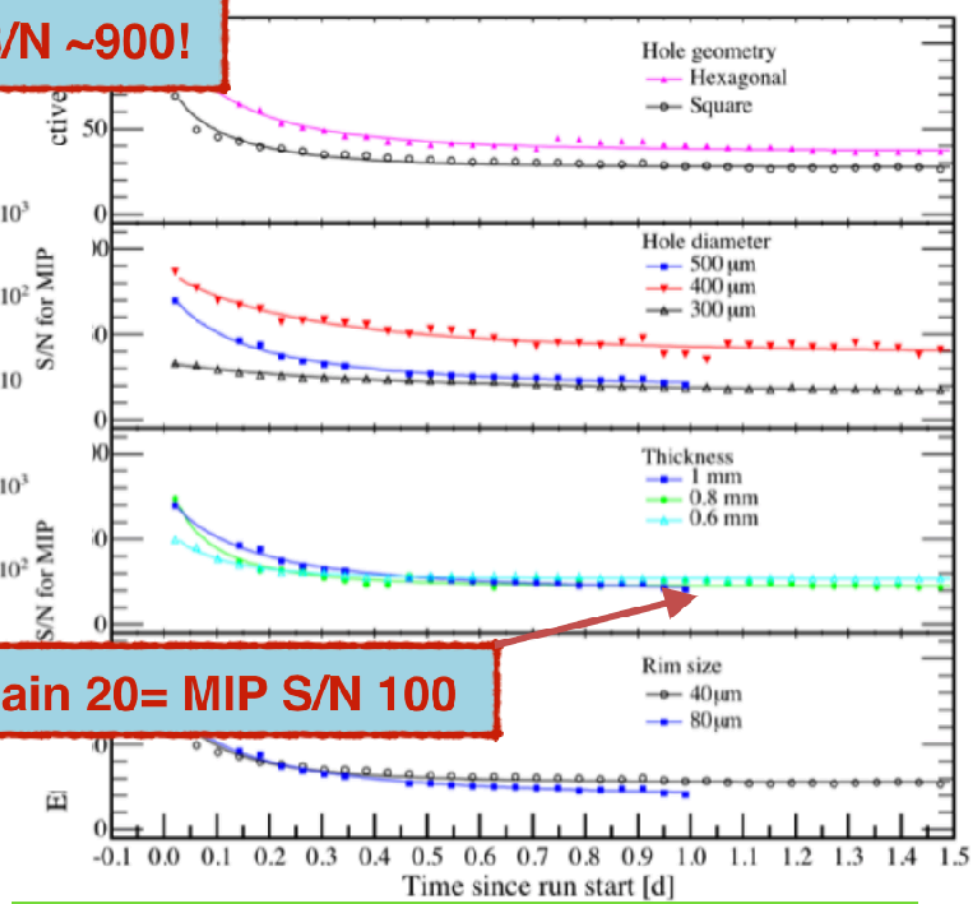
40x80cm^2: stable operation of large area readouts



literature
NIM A617 (2010) p188-192
NIM A641 (2011) p 48-57
JINST 7 (2012) P08026
JINST 8 (2013) P04012
JINST 9 (2014) P03017
JINST 10 (2015) P03017

Max Gain 180 = MIP S/N ~900!





Stable Gain 20= MIP S/N 100

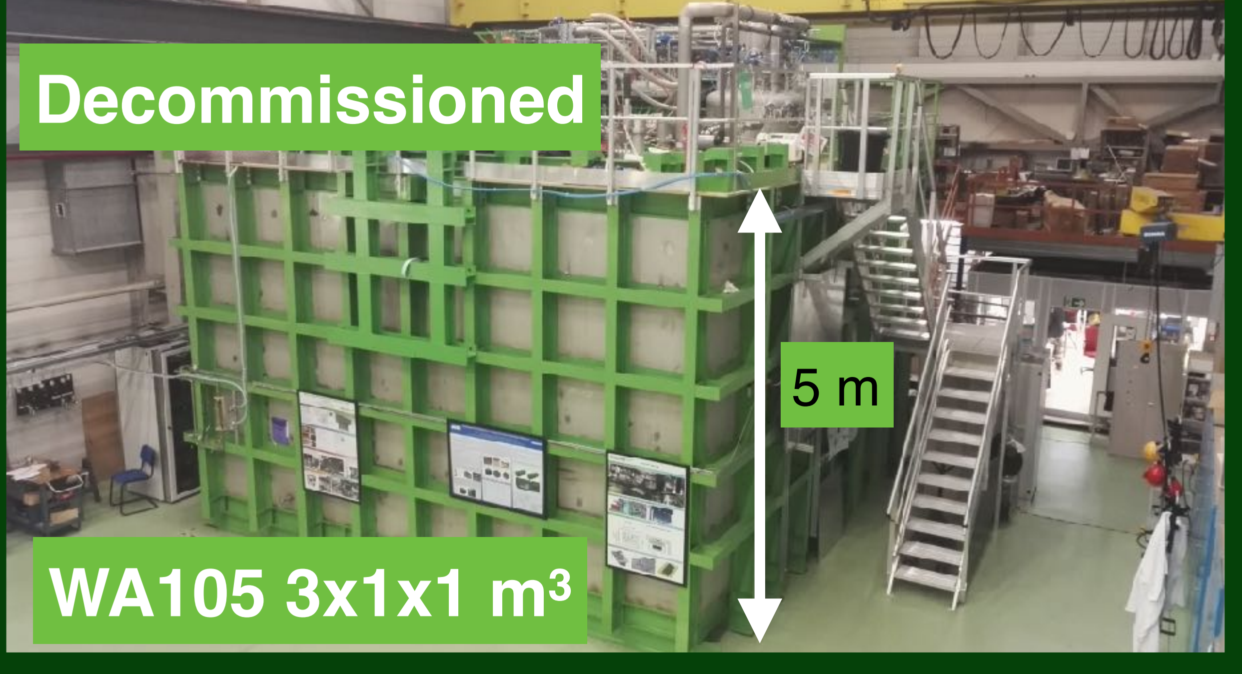
Operating with amplification of about a factor 20

Two dual phase liquid argon detectors

Same technology→different sizes→different goals

Common aspects

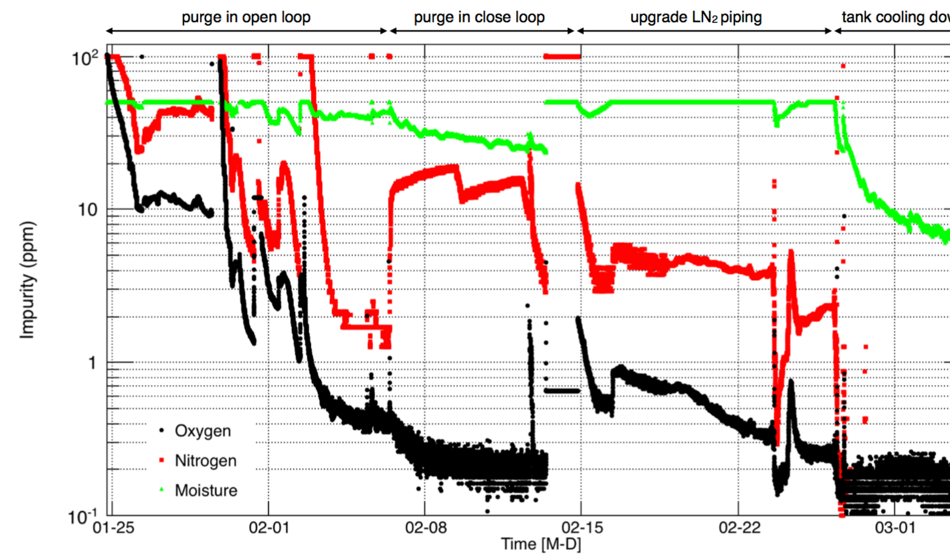
- ✓ LEMs and anode: design, purchase, cleaning and QA
- ✓ chimneys, FT and slow control sensors
- ✓ membrane tank technology
- ✓ Accessible cold front-end electronics and DAQ system
- ✓ amplification in pure Ar vapour on large areas



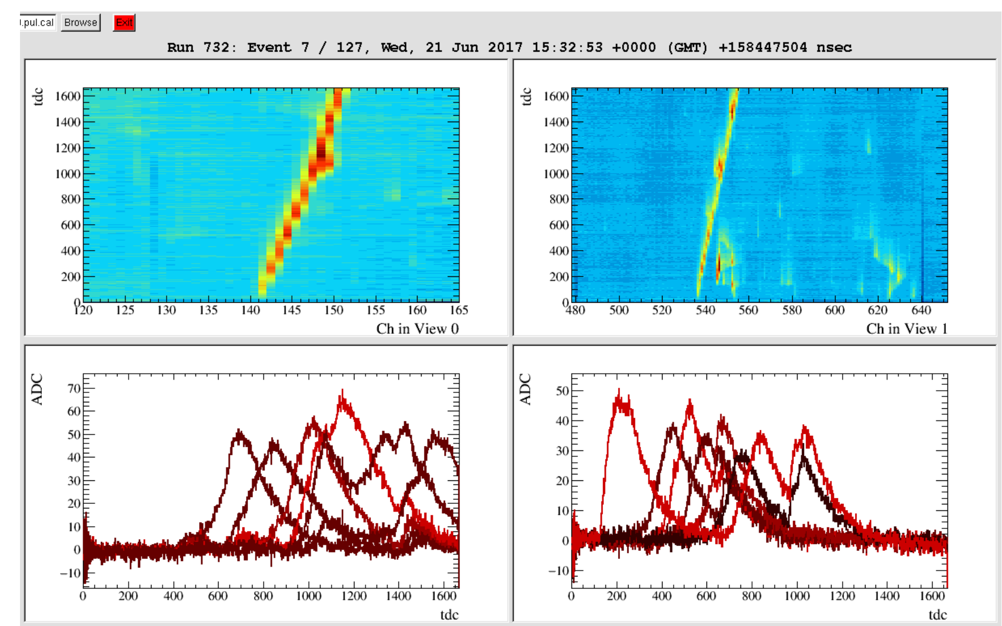
3x1x1 Timeline

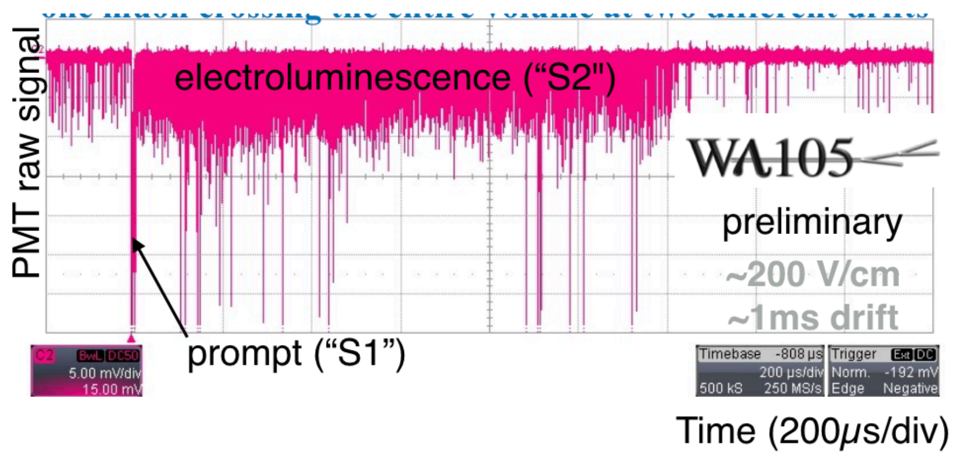
2015 - Cryostat constructed

2016 - Detector installation completed



Jan 2017 - Commission started

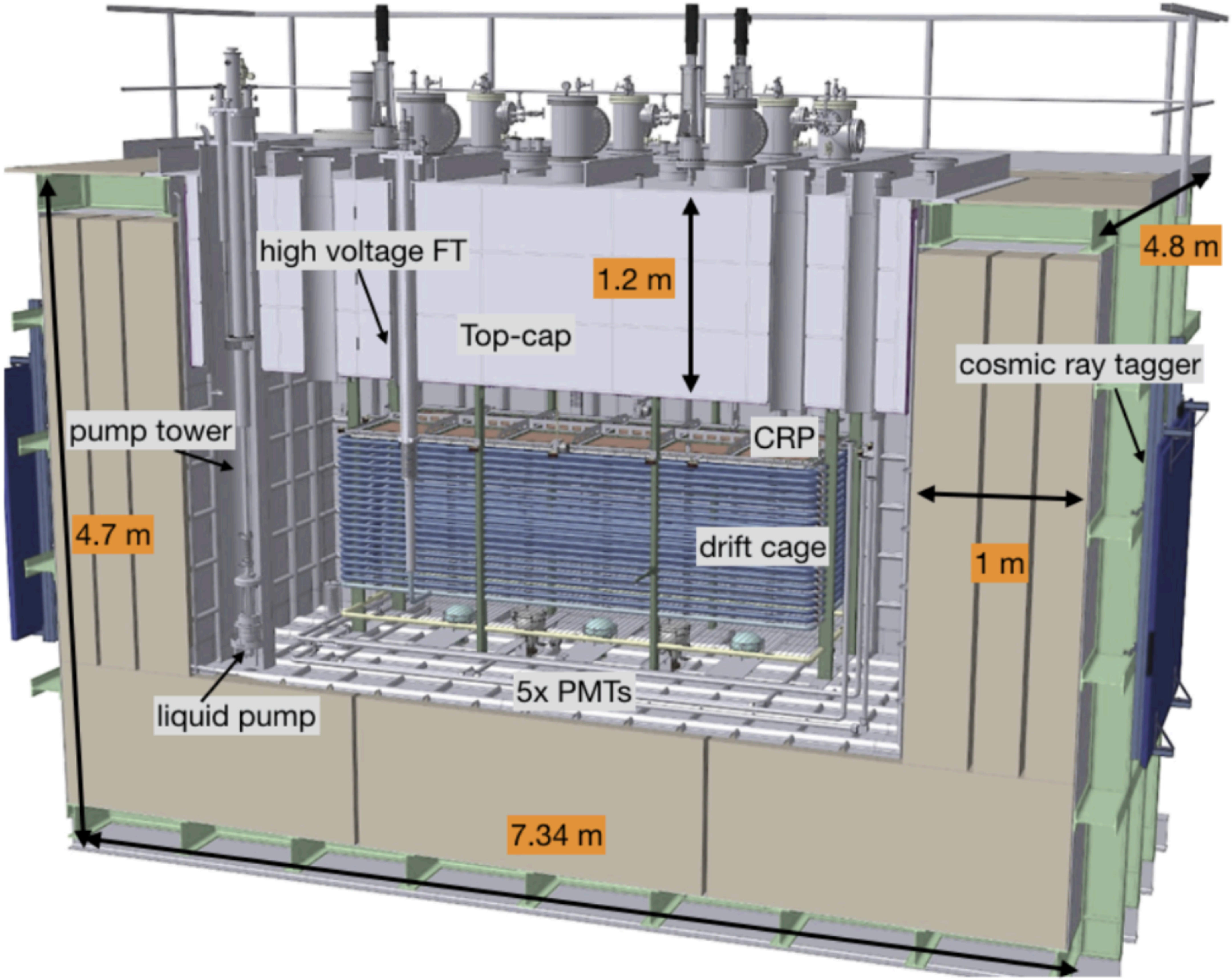




Mar 2017 - Operation 'frozen' due to cryostat issues

June 12th - Recirculation started → **June 15th - evidence of extraction from LAr to GAr** → **June 21st 2017 - First track seen!**

The 3x1x1 Dual phase LAr TPC



The cryogenic system

Cryogenic system tasks

Aims to safely condense the boiling-off gas and provide purification to both the gas and liquid argon

LAr purity better than 0.1 ppb oxygen equivalent

Purge and gas purification system

Boiling-Off gas compensation and purification system

LAr recirculation and purification system

Stages

1.Purge in open loop

Oxygen, nitrogen and moisture below 50 ppm

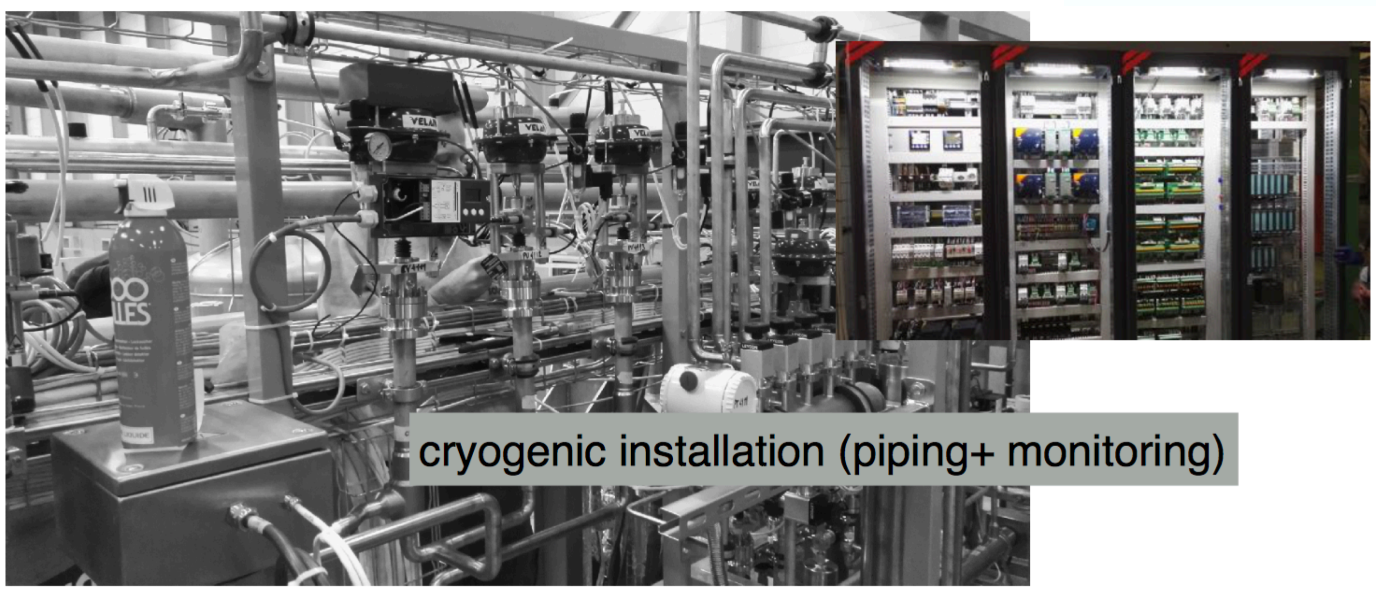
2.Purge in closed loop

Oxygen 0.2 ppm, nitrogen 3.5 ppm and moisture 25 ppm

3.Cool down

Average temperature in the tank~87 K

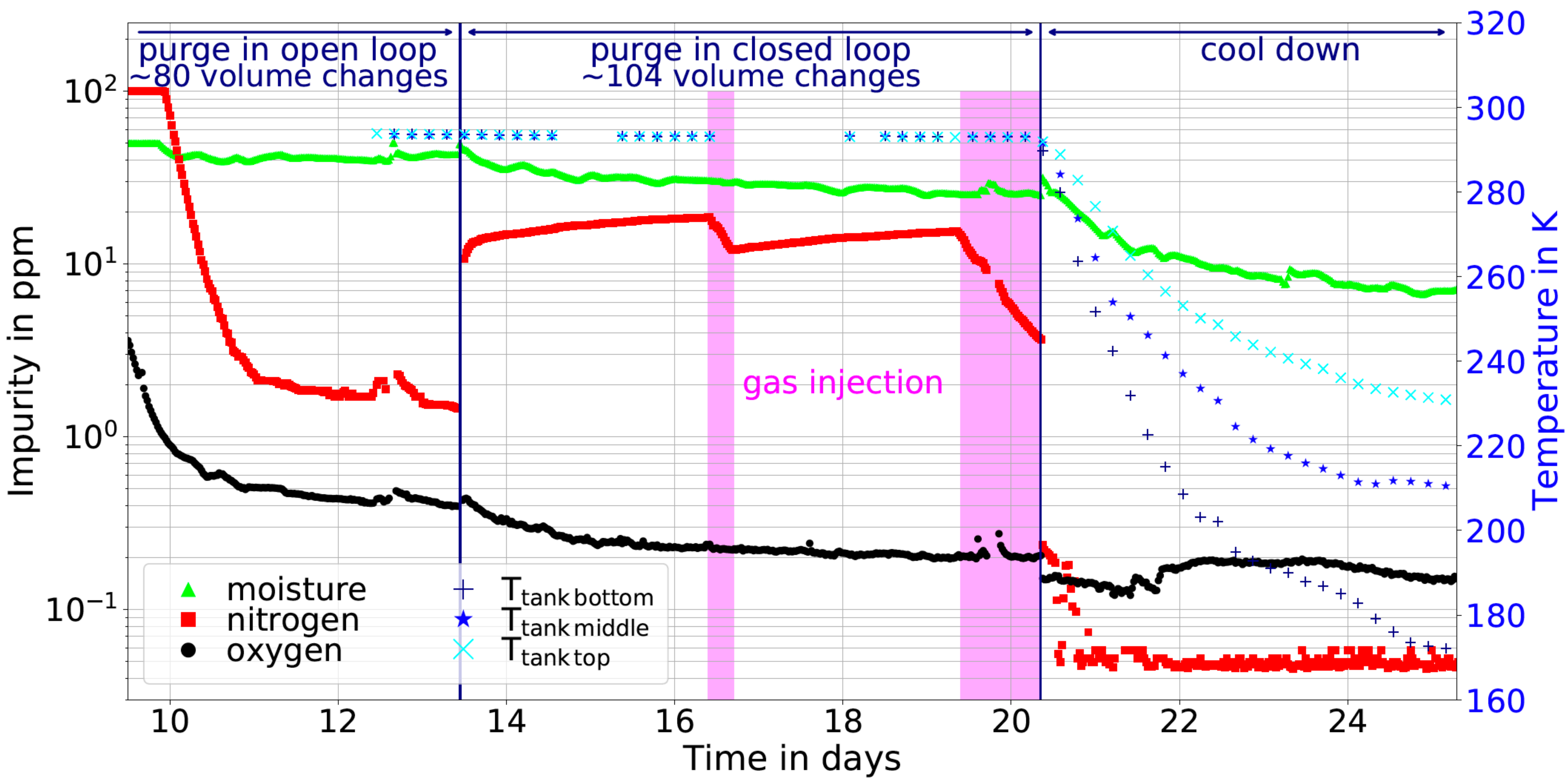
4.Filling



cryogenic installation (piping+ monitoring)

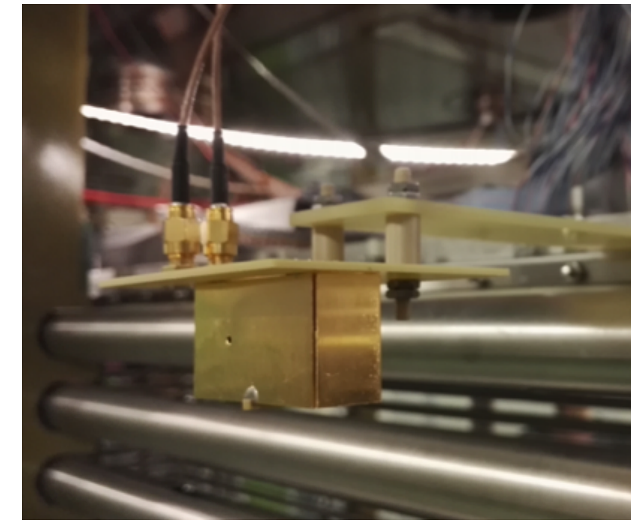
- ProtoDUNE cryogenic system will be designed and operated by CERN cryogenic group.
- **Successful test of the performance on the 3x1x1 prototype.**

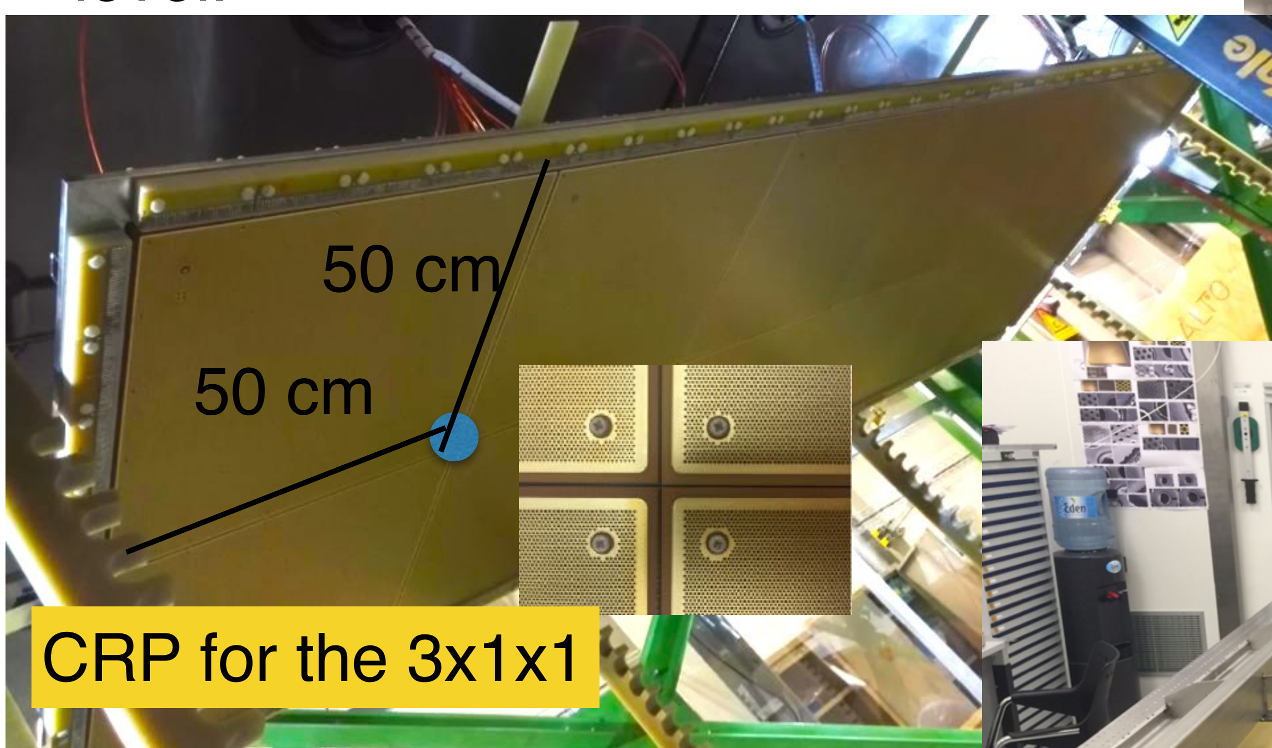
The cryogenic system

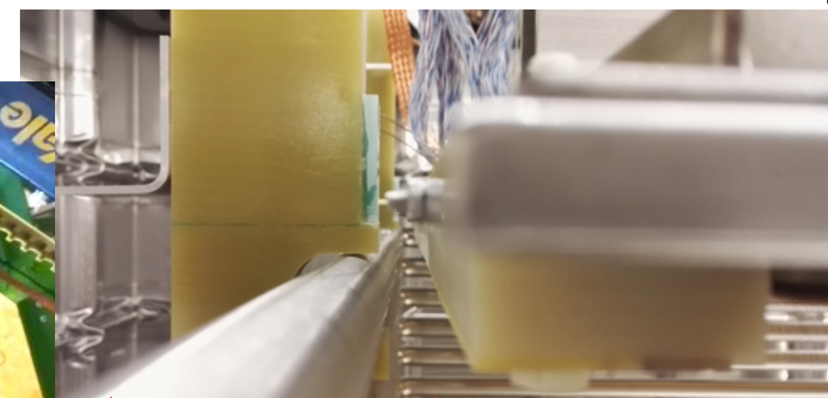


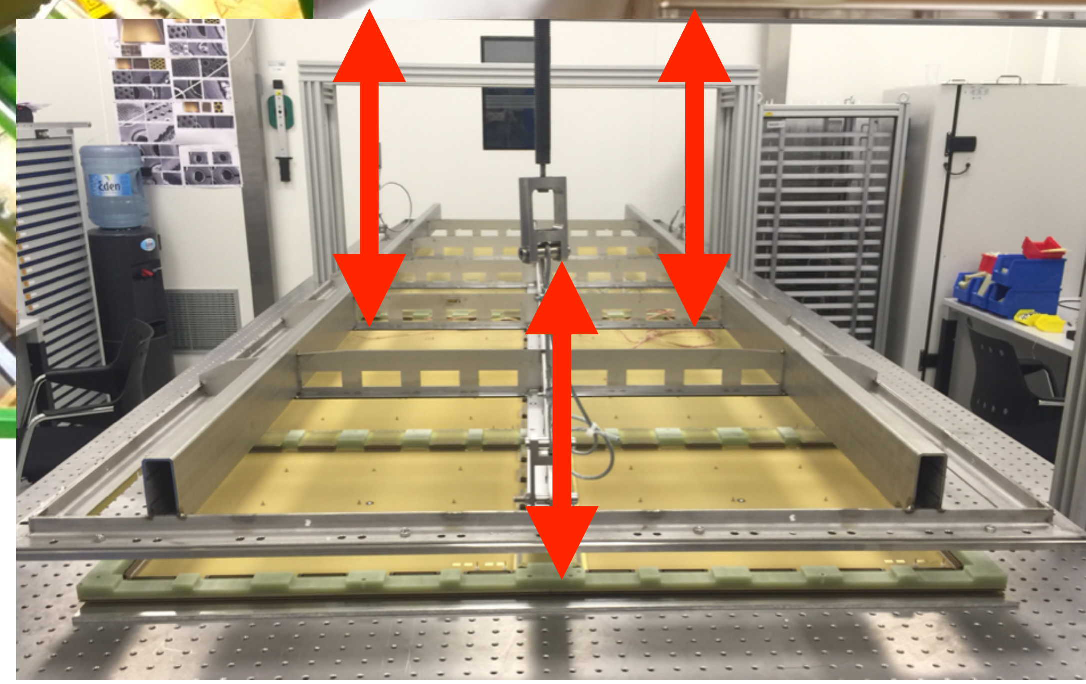
The 3x1m² Charge readout plane (CRP)

- The CRP is designed to precisely maintaining the interstage distances between the grid, LEM and anodes **at warm and cold.**
- The CRP is **modular and independent** from the drift cage.
- It is suspended by 3 ropes coupled to motors on top-cap with a precision of 100 um over 4 cm.
- It allows to **remotely adjust** the liquid argon level in between the LEMs and the extraction grid.
- It is surrounded by 8 capacitive level meters to readout the LAr level.



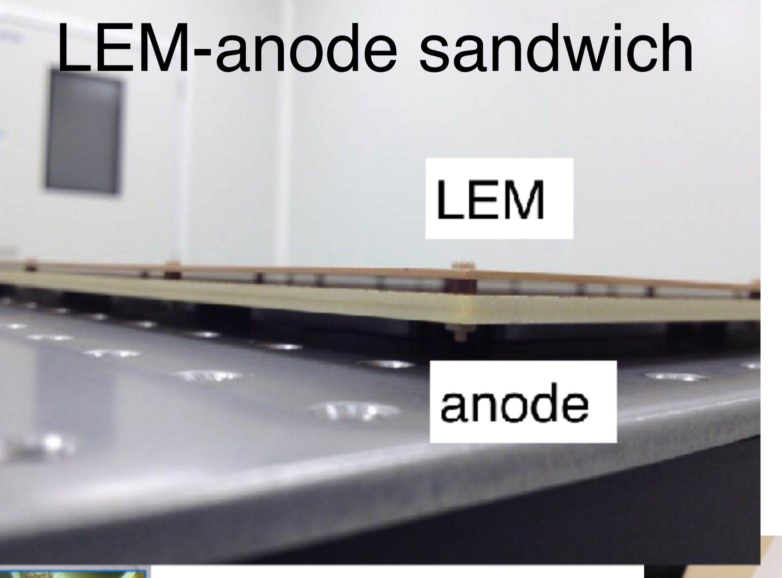






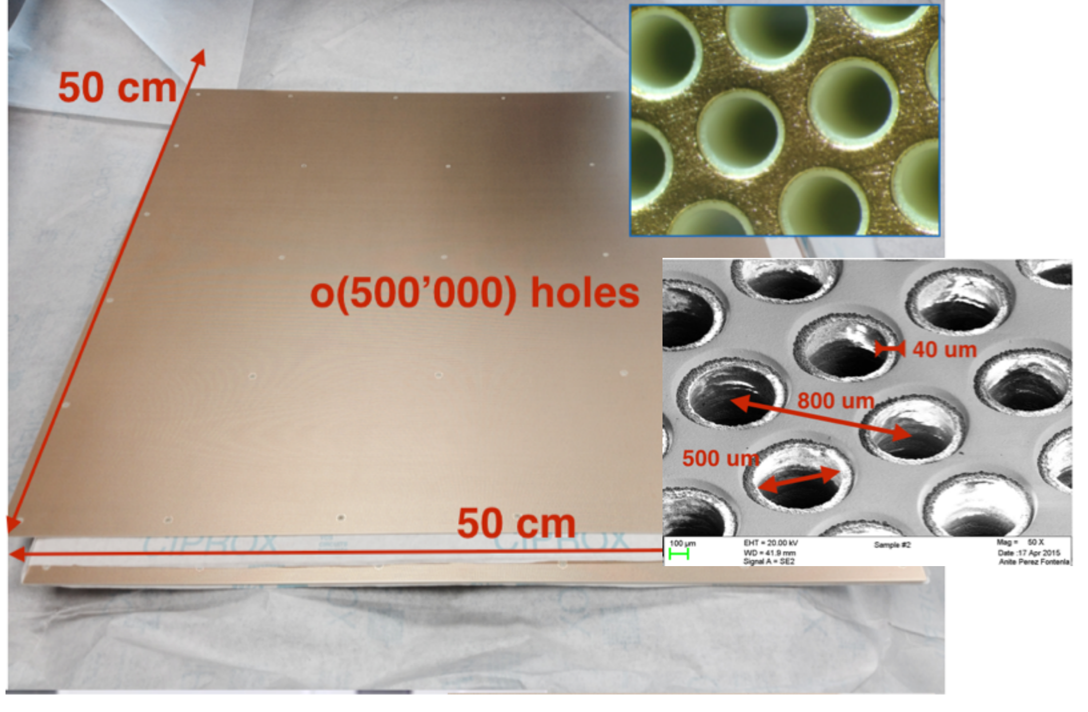
LEM-anode sandwich

design has matured from many year of R&D on small prototypes and from dedicated tests in cryogenic environment of a 50x50.

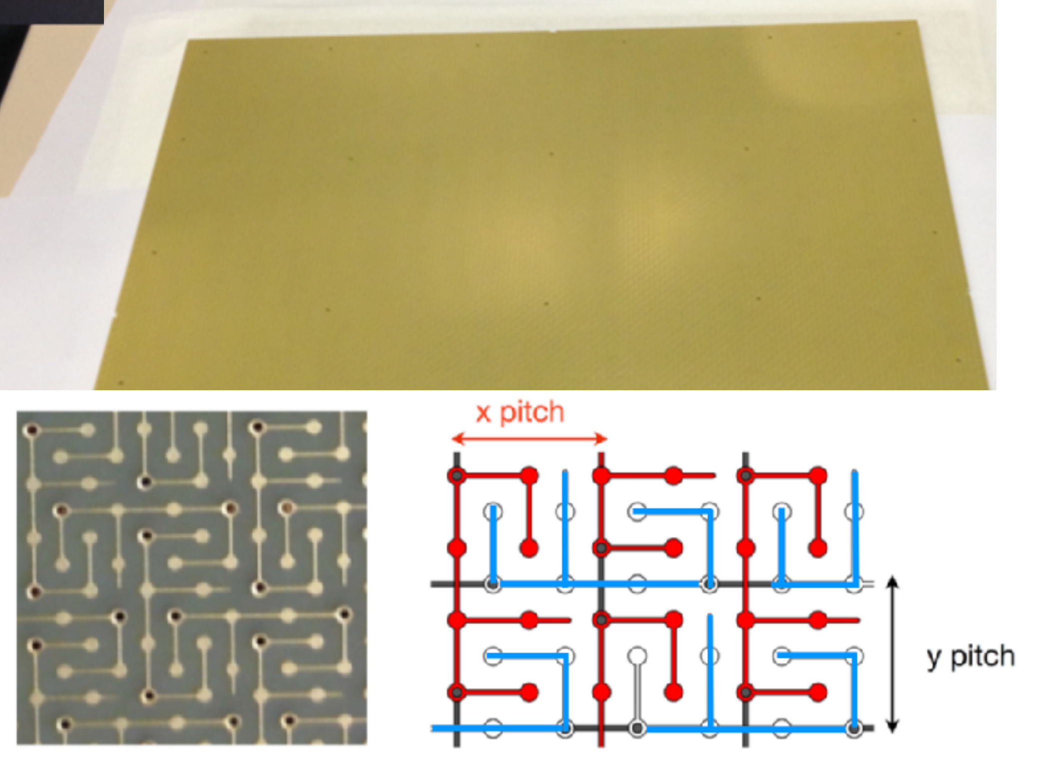


dC/dl 140 pF/m. about 450-500 pF before preamp on 3m readout. ENC of ~ 1500 electrons at 110 K

LEMs



Anodes

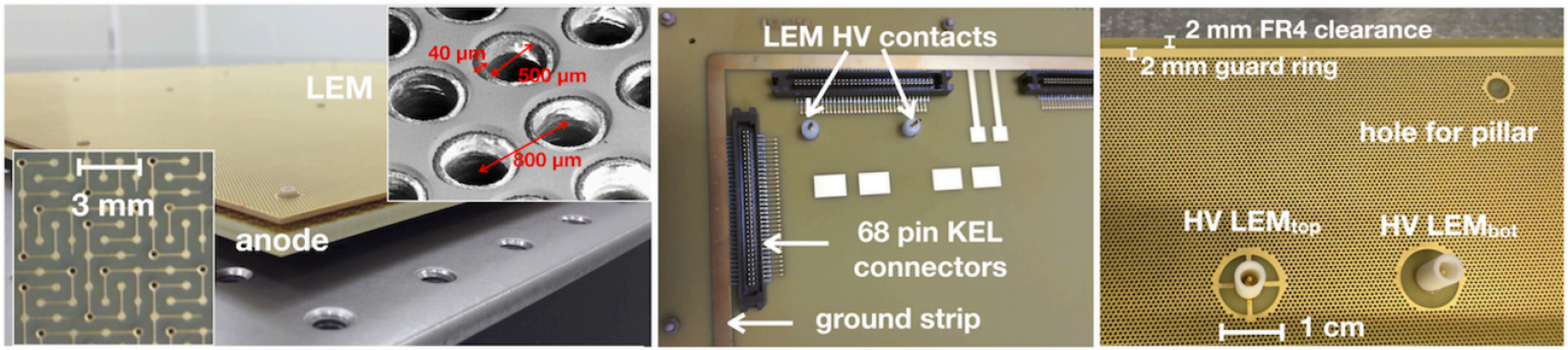


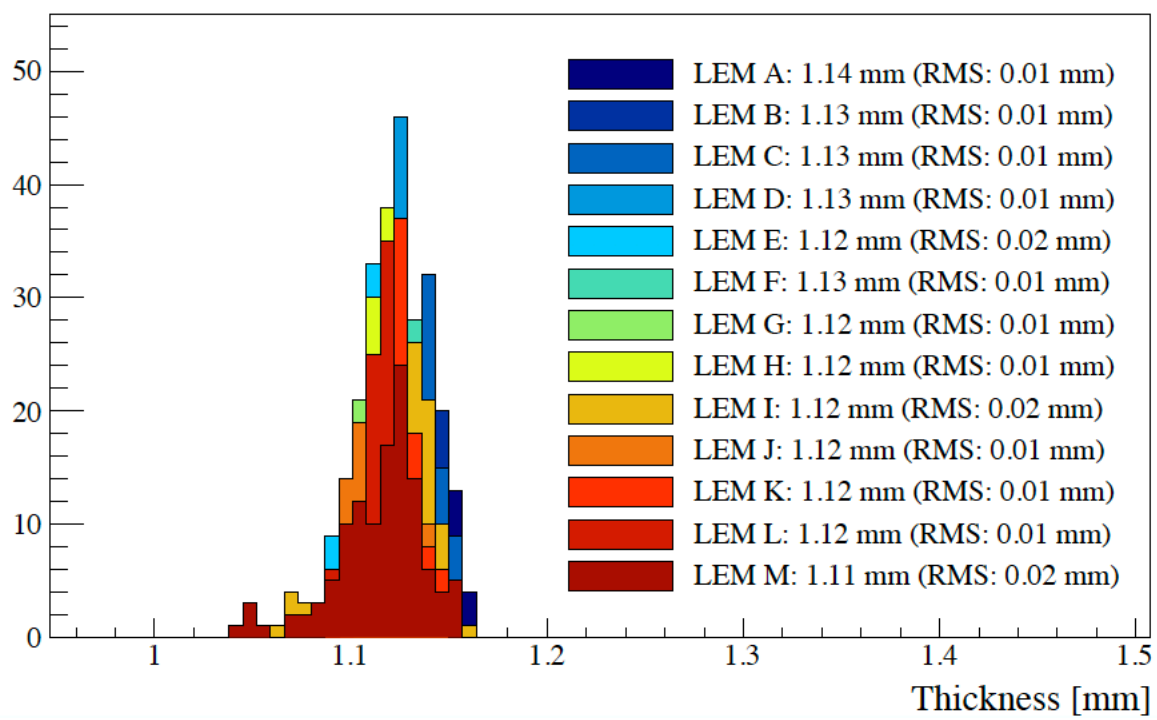
- ✓ PCB CNC drilled with o(150) holes per cm^2. 1 mm thick.
- ✓ 500 um hole diameter 800 um pitch.

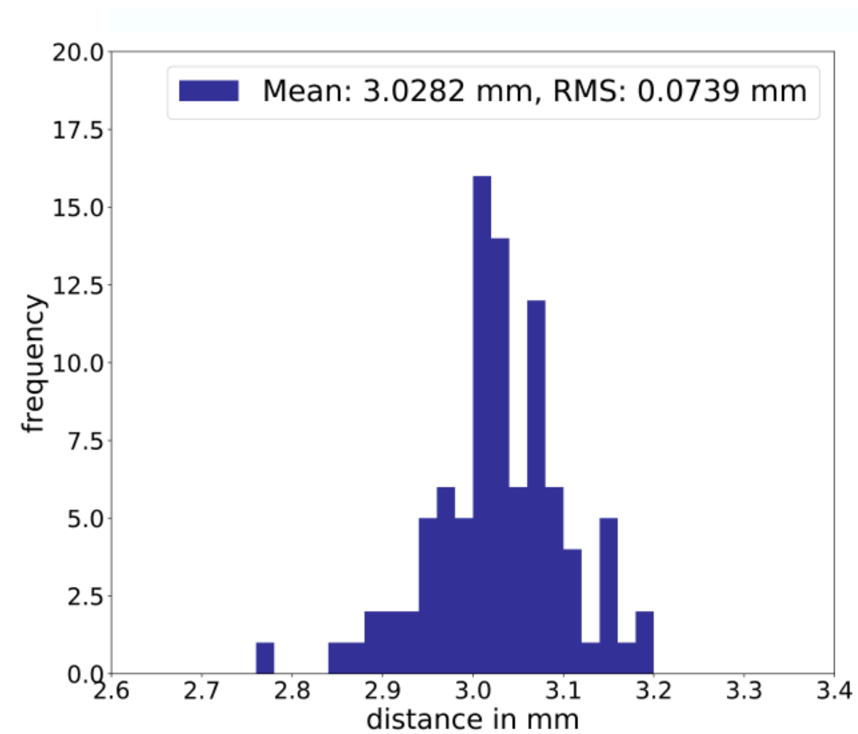
- 4-layer 3.4 mm thick PCB
- Rather standard to manufacture
- electrical continuity tested by company
- Minimal QC needed on our side.

JINST 8 (2013) P04012 JINST 9 (2014) P03017 JINST 10 (2015) P03017

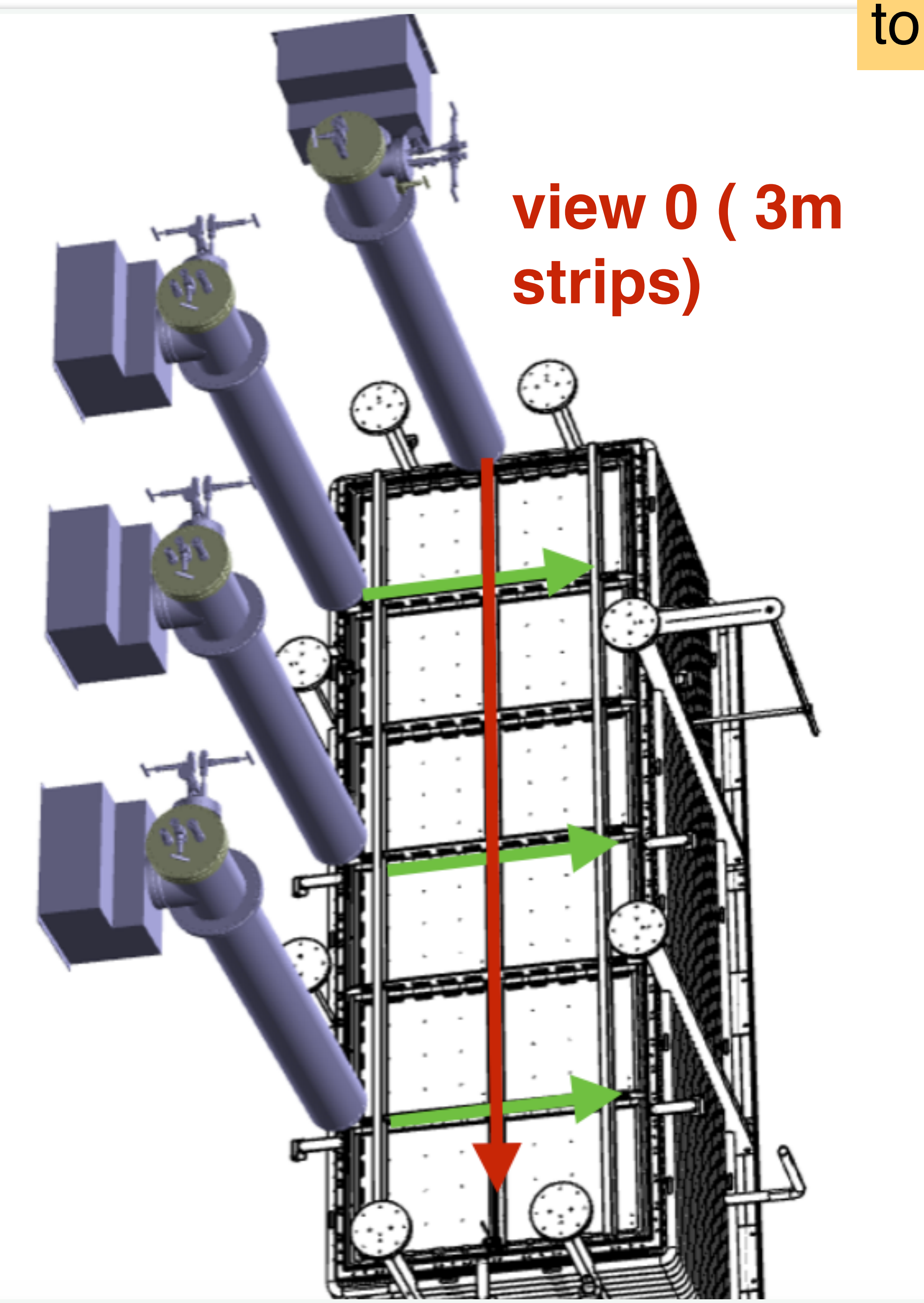
LEM-anode sandwich



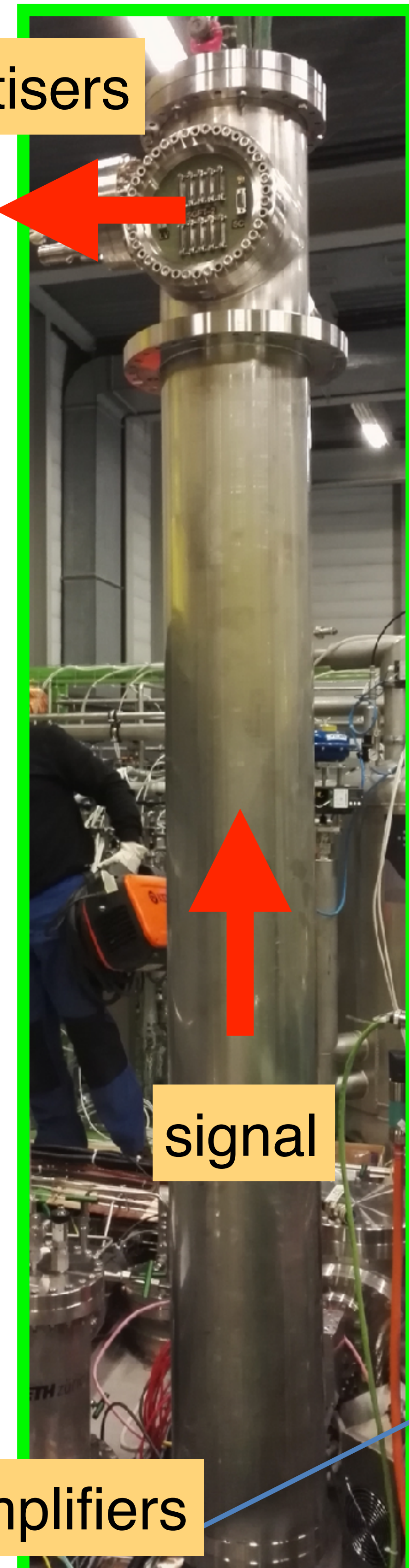




Charge readout



view 1 (1 m strips)

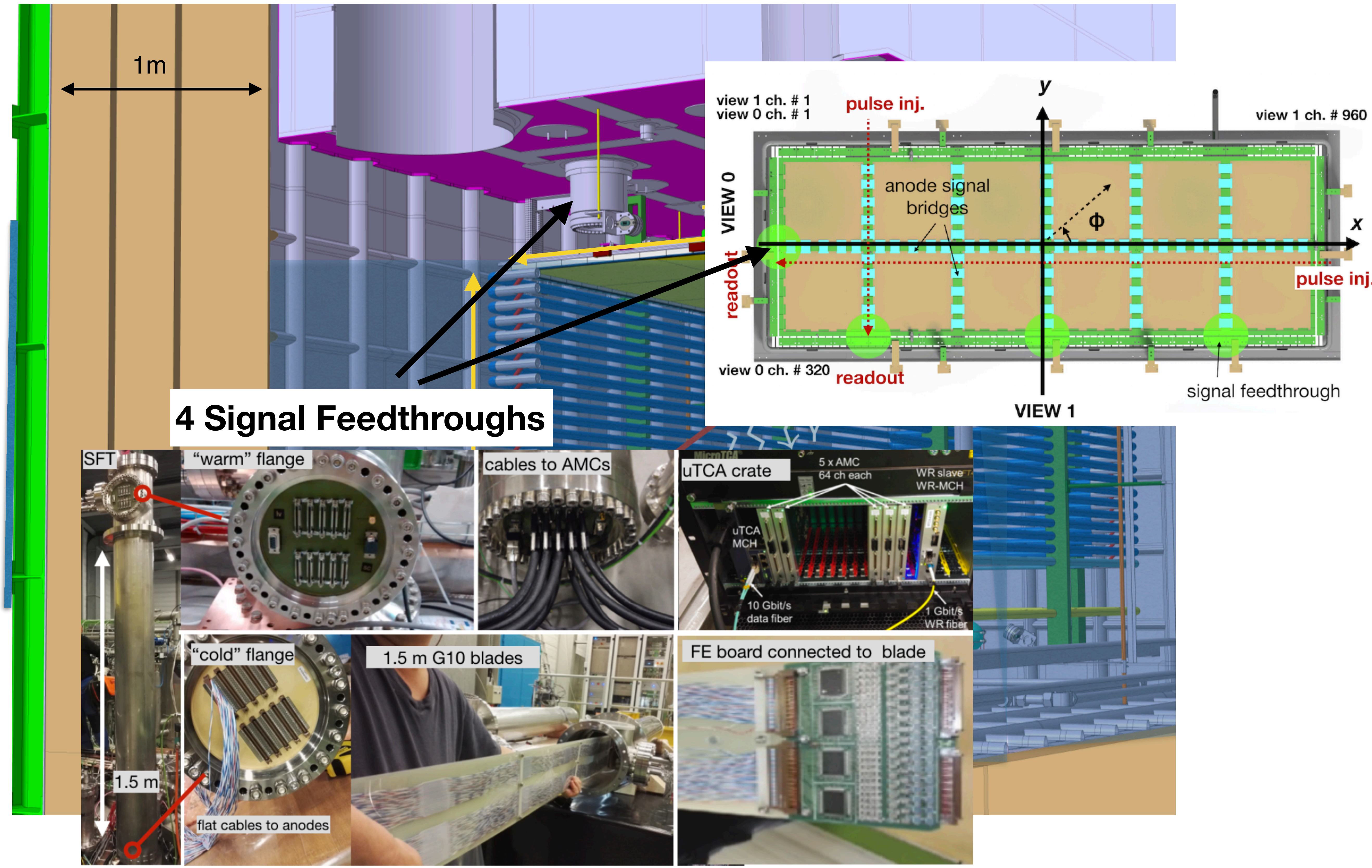


amplifiers accessible during operations

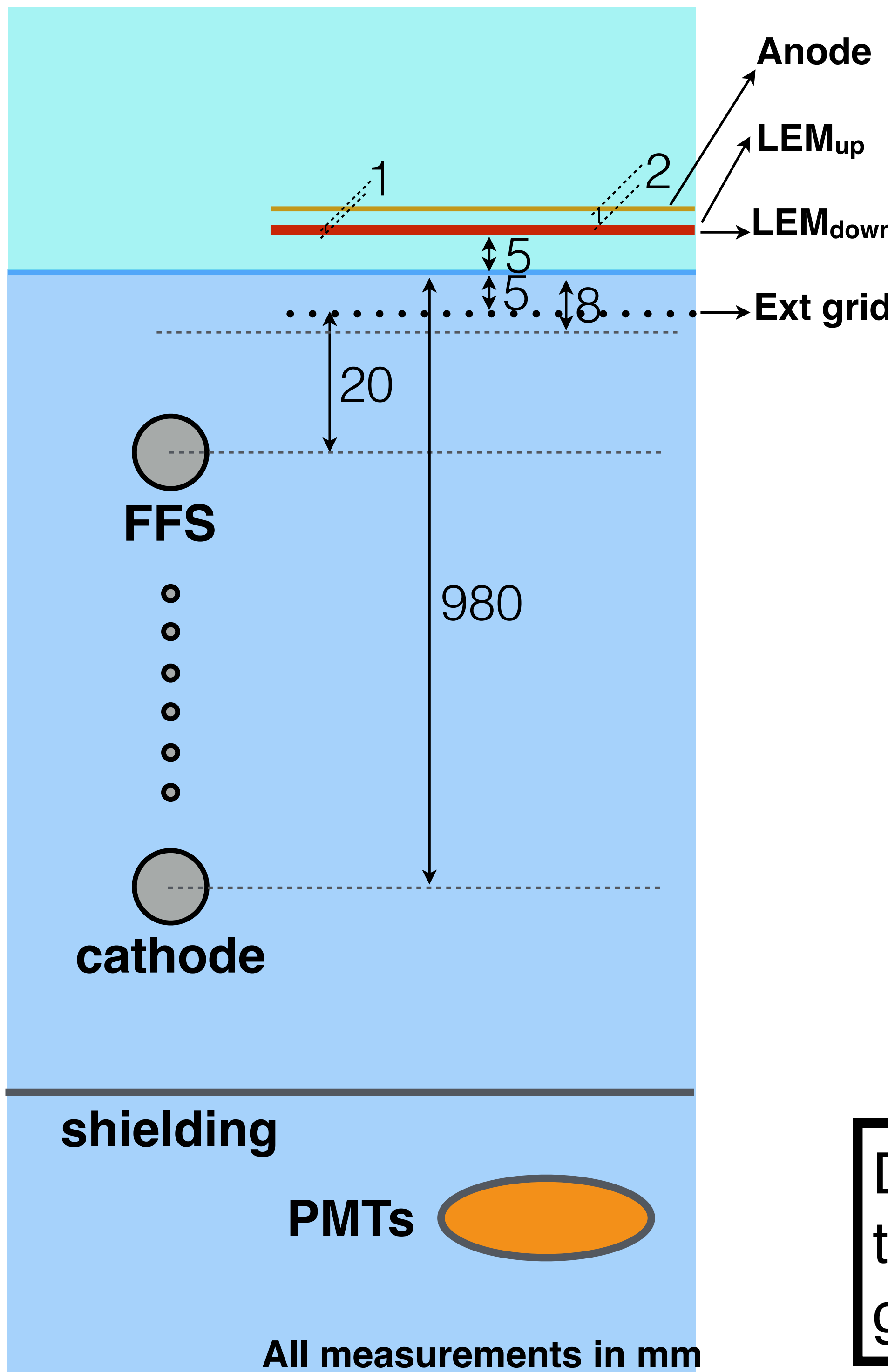
amplifiers inside closed volume. Close to anodes, ~110 K

4 ASICs per board

The 3x1x1m³ dual phase prototype: Charge readout system



Summary of HV configurations during data taking

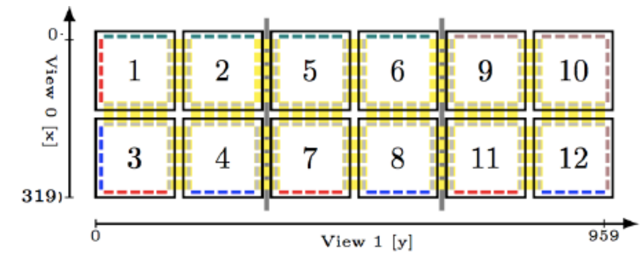


Voltage		Electric fields (Nominal values)	Electric fields (Values reached)
0 kV	Collection field	5 kV/cm	1-5 kV/cm
-1.0 kV	Amplification field	33 kV/cm	24-31 kV/cm
-4.3 kV	Extraction field	> 2 kV/cm	0.6-2.5 kV/cm
-6.5 kV			
-7.6 kV			
	Drift field	500 V/cm	180-700 V/cm
-56 kV			

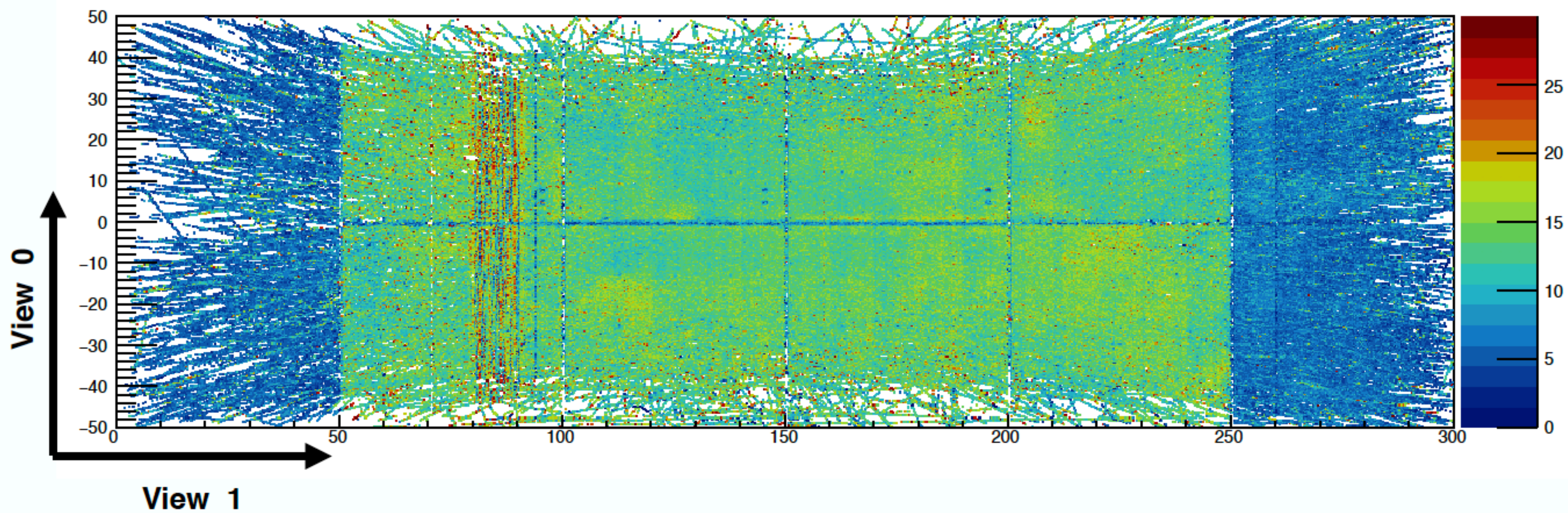
During operations we have always stayed below the nominal operating voltages as the extraction grid trips before reaching its nominal value.

First look at data: Uniformity

Run 840: 2945 crossing tracks

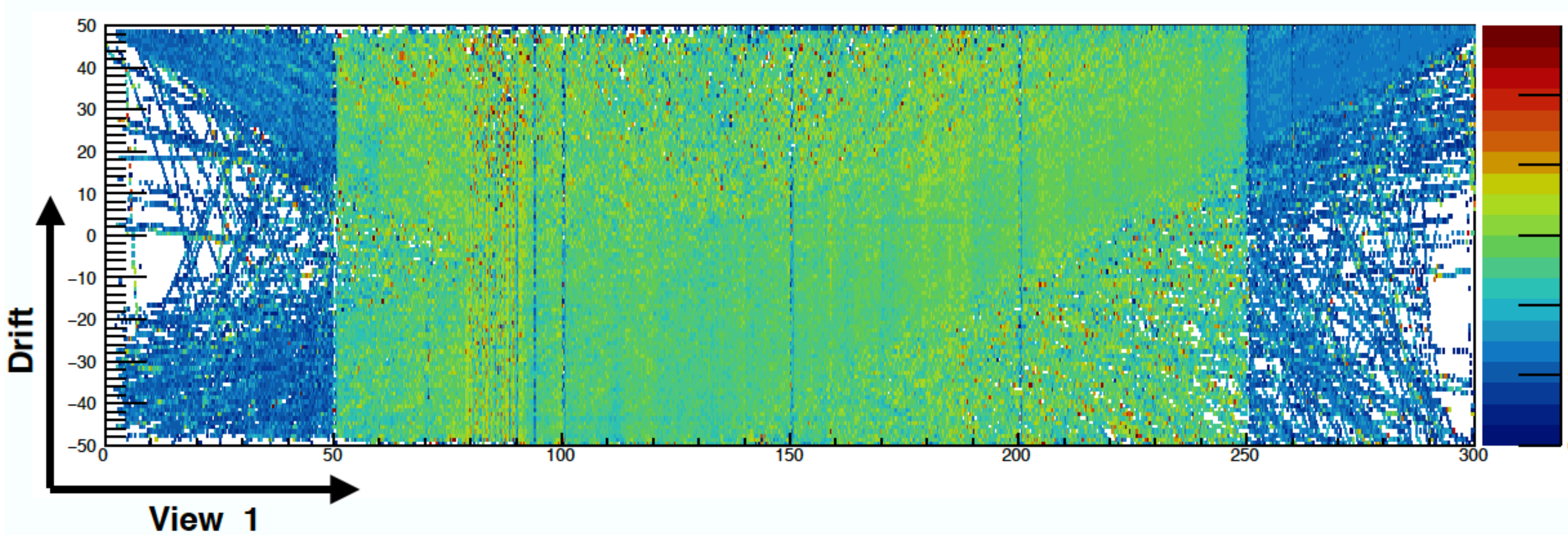


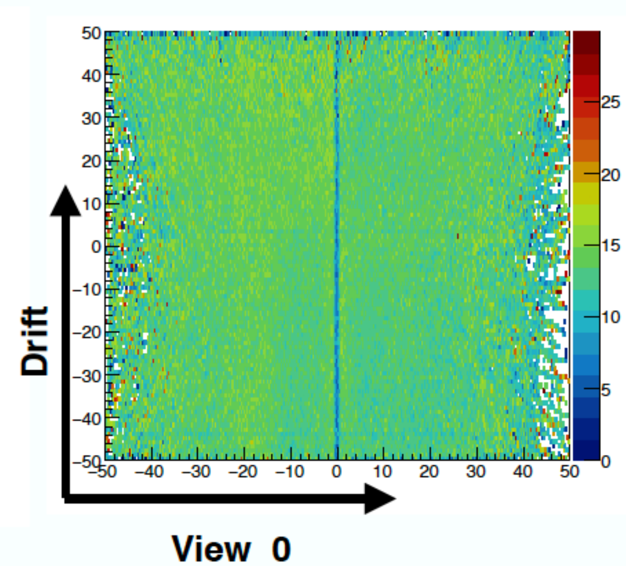
<dQ/ds> uniformity across the CRP



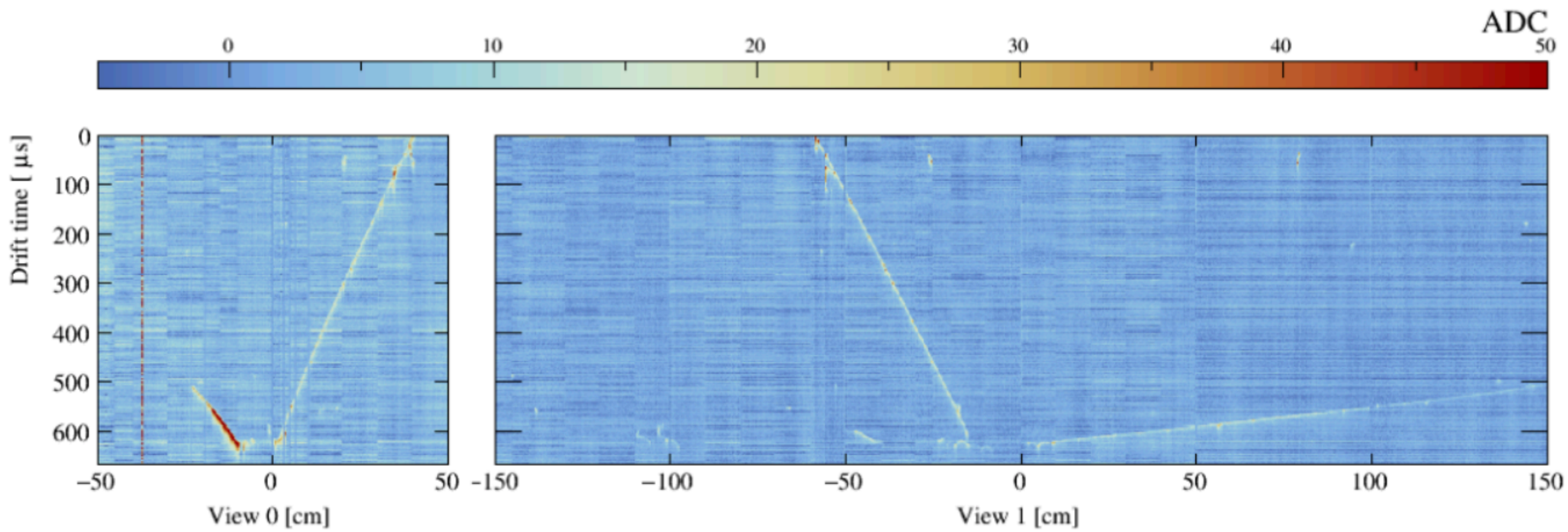
- Drift field: 500V/cm
- Extraction field in liquid: 1.9 kV/cm
- Amplification field: 28 kV/cm (except the corners at 24 kV/cm)
- Induction field: 1.5 kV/cm

<dQ/ds> uniformity along drift

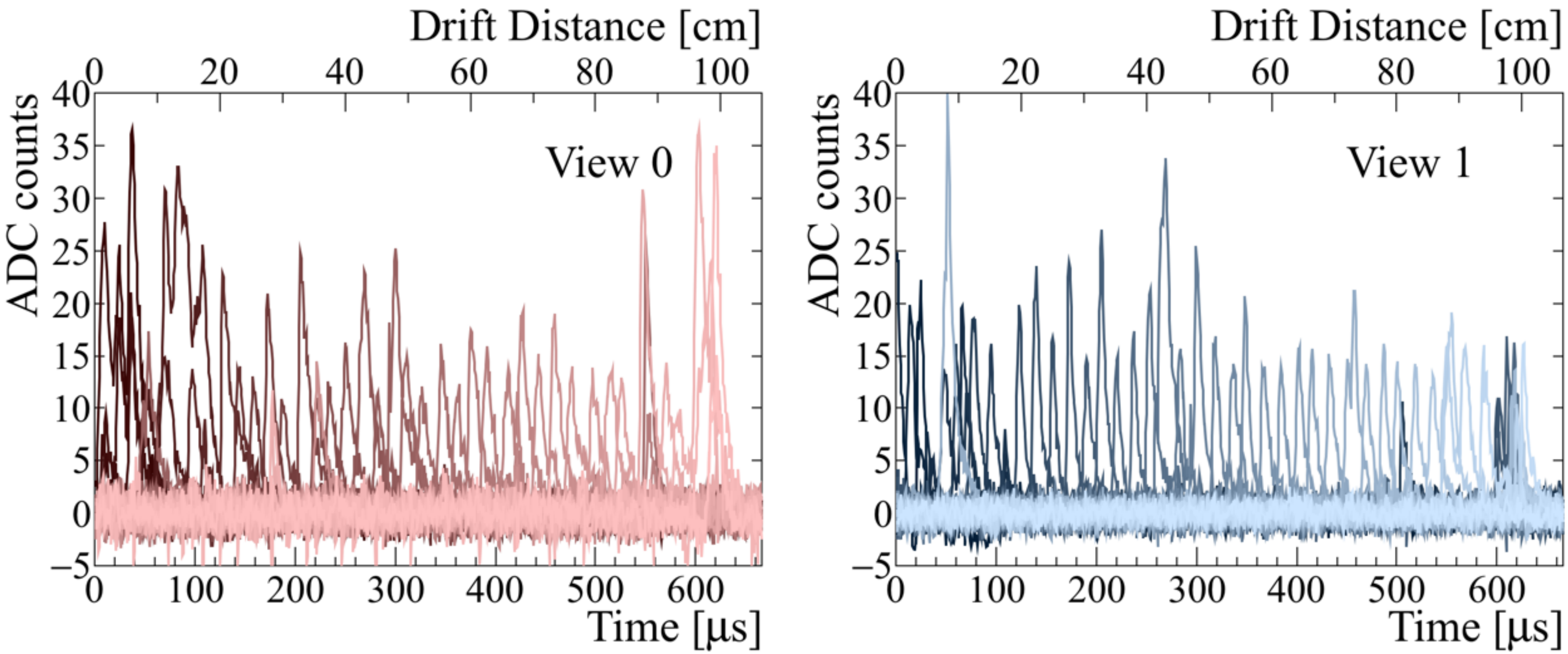




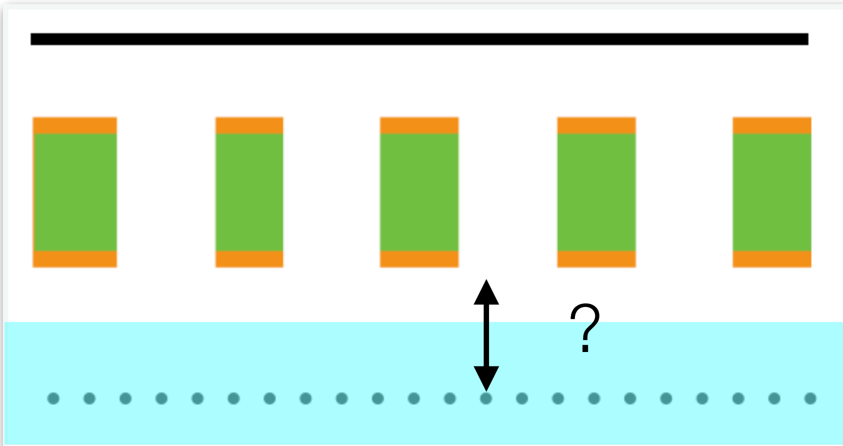
Through going muon



- No signal of attenuation in 1 m drift.
- S/N ratio > 10.

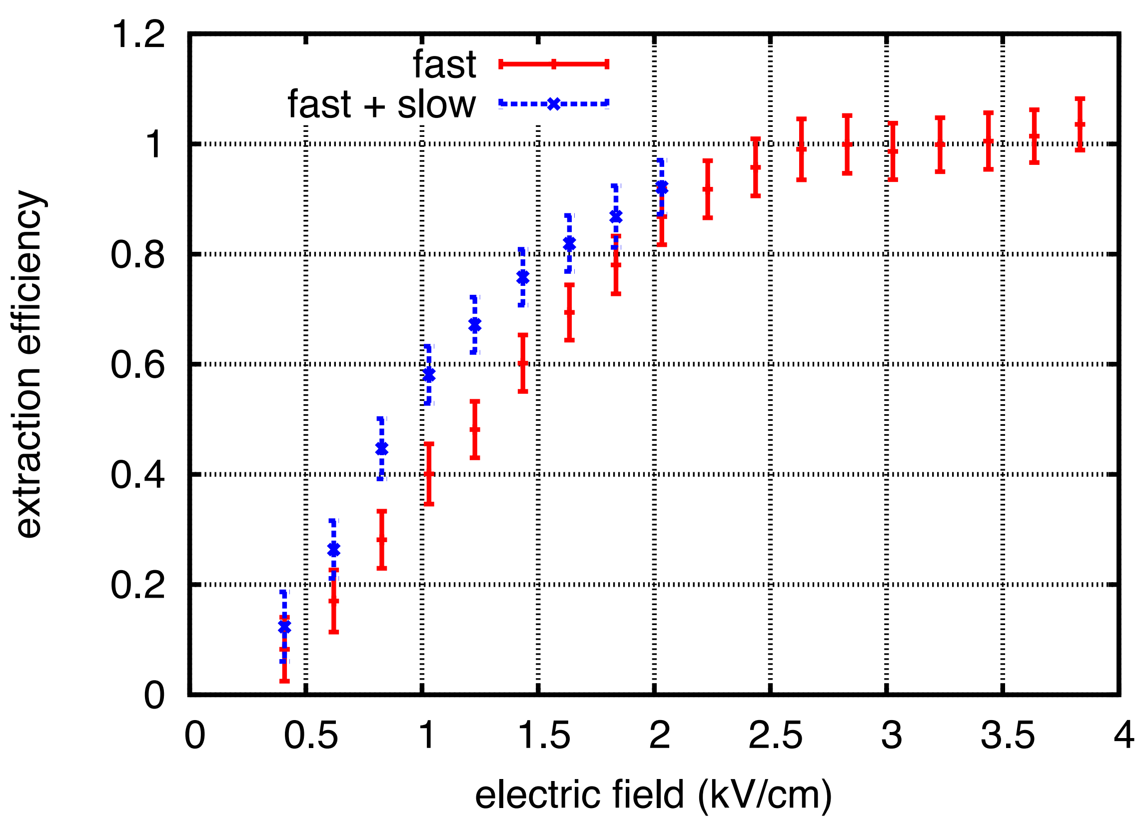


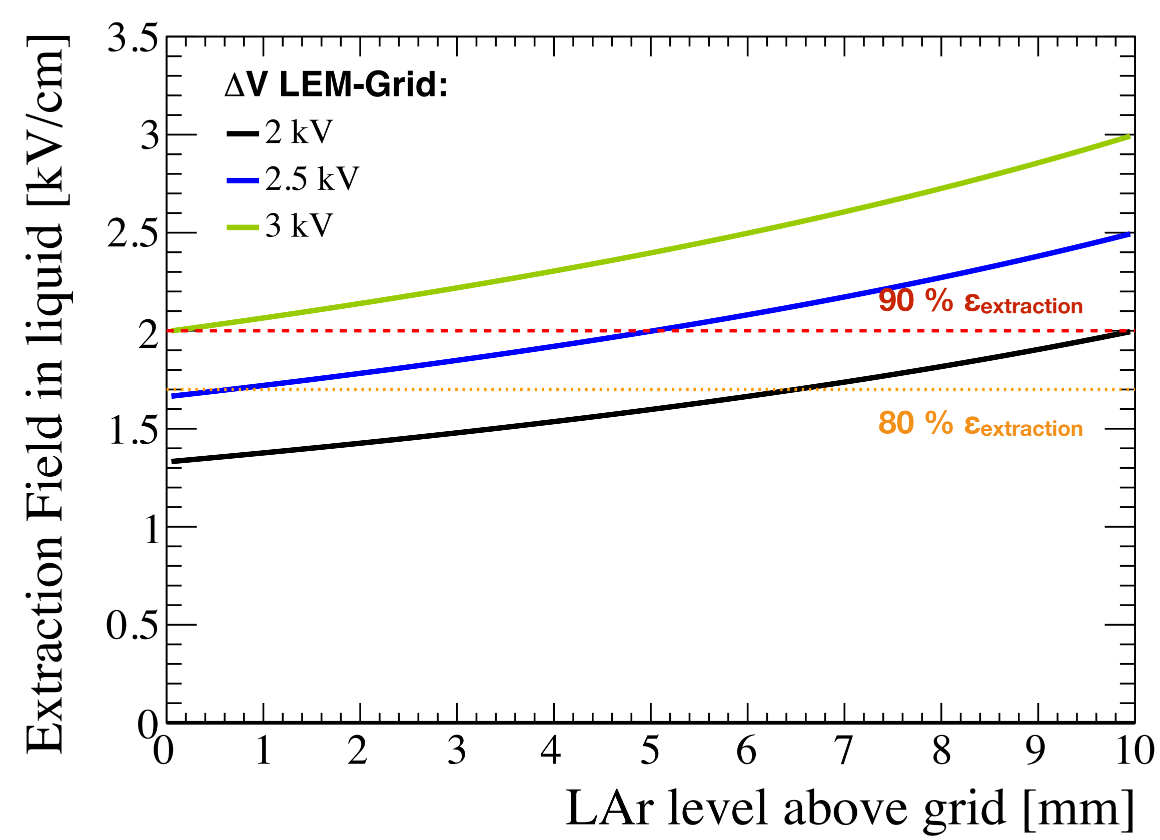
LAr stability



<u>an important point on requirement of level position:</u>

- for a given $\Delta V_{LEM\text{-}grid}$ the extraction *field* depends on the position of the LAr level.
- At sufficiently large $\Delta V_{LEM\text{-}grid}$ (>~2.5 kV) the extraction *efficiency* is near maximal and therefore almost independent of the liquid level.
- The boundary conditions are that the liquid should not touch the LEMs and the grid stays immersed.





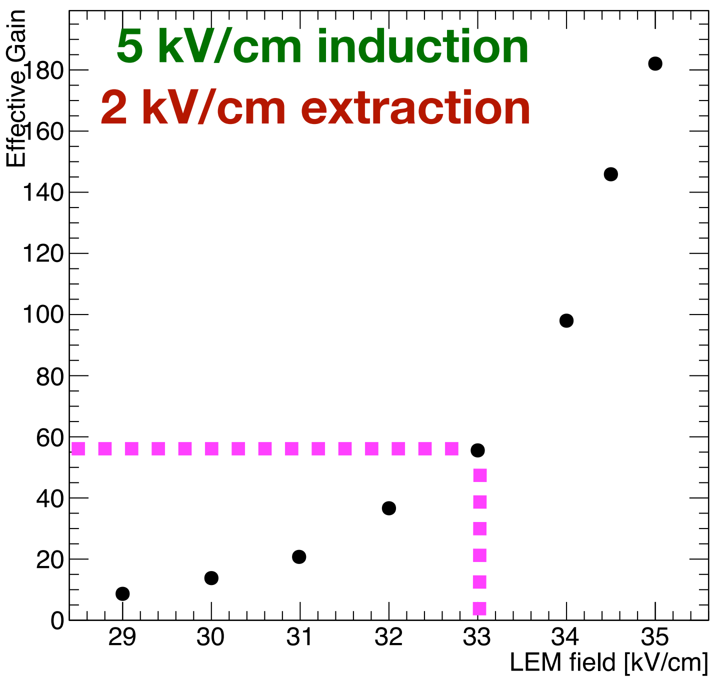
Effective gain factorisation

Effective Gain = Extraction Efficiency X LEM Amplification X Induction Efficiency

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

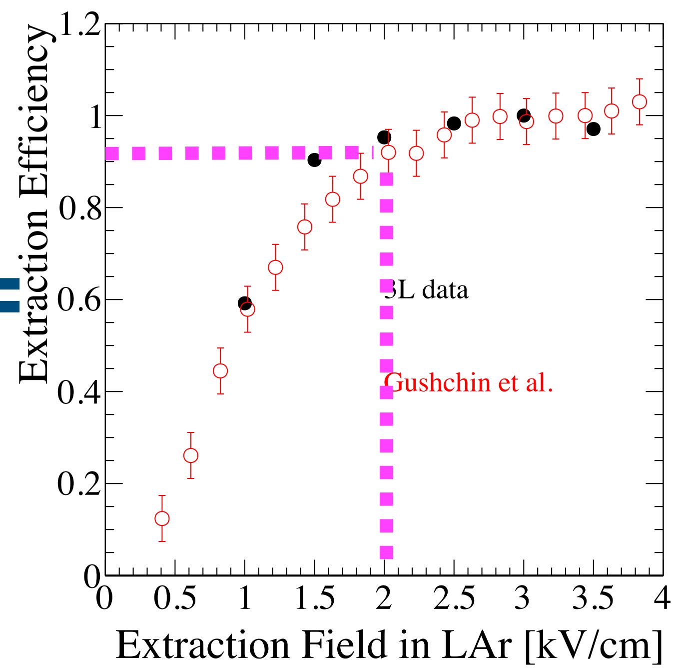
example: for Geff = 56 before charging up = **2 kV/cm**^{liquid} **X** **33 kV/cm** **X** **5 kV/cm**

ε_{eff} **= 0.9** | **LEM-amplification =90** | **0.7**

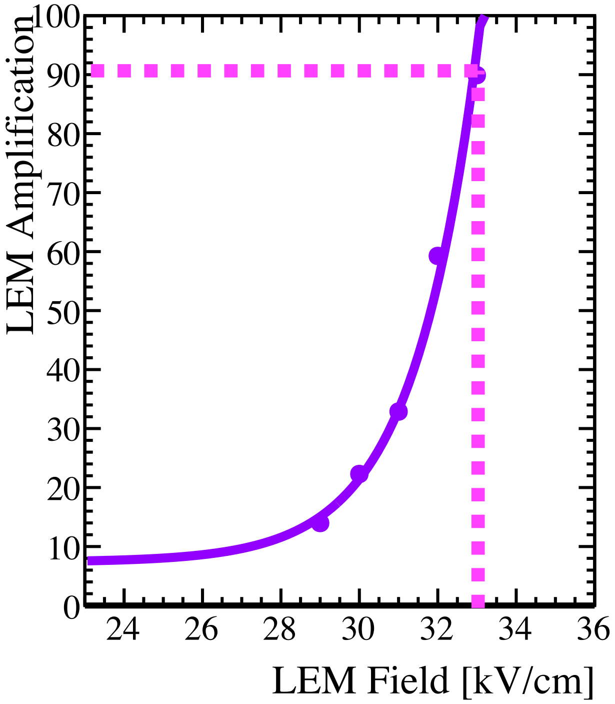


data from 3 l before LEM charging up

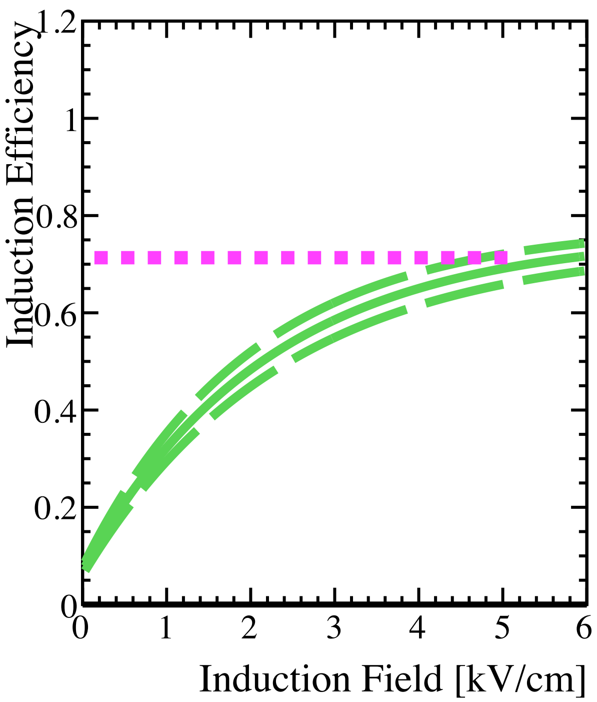
=



from simulation and 3l measurements



from 3l measurements



from simulation and 3l measurements