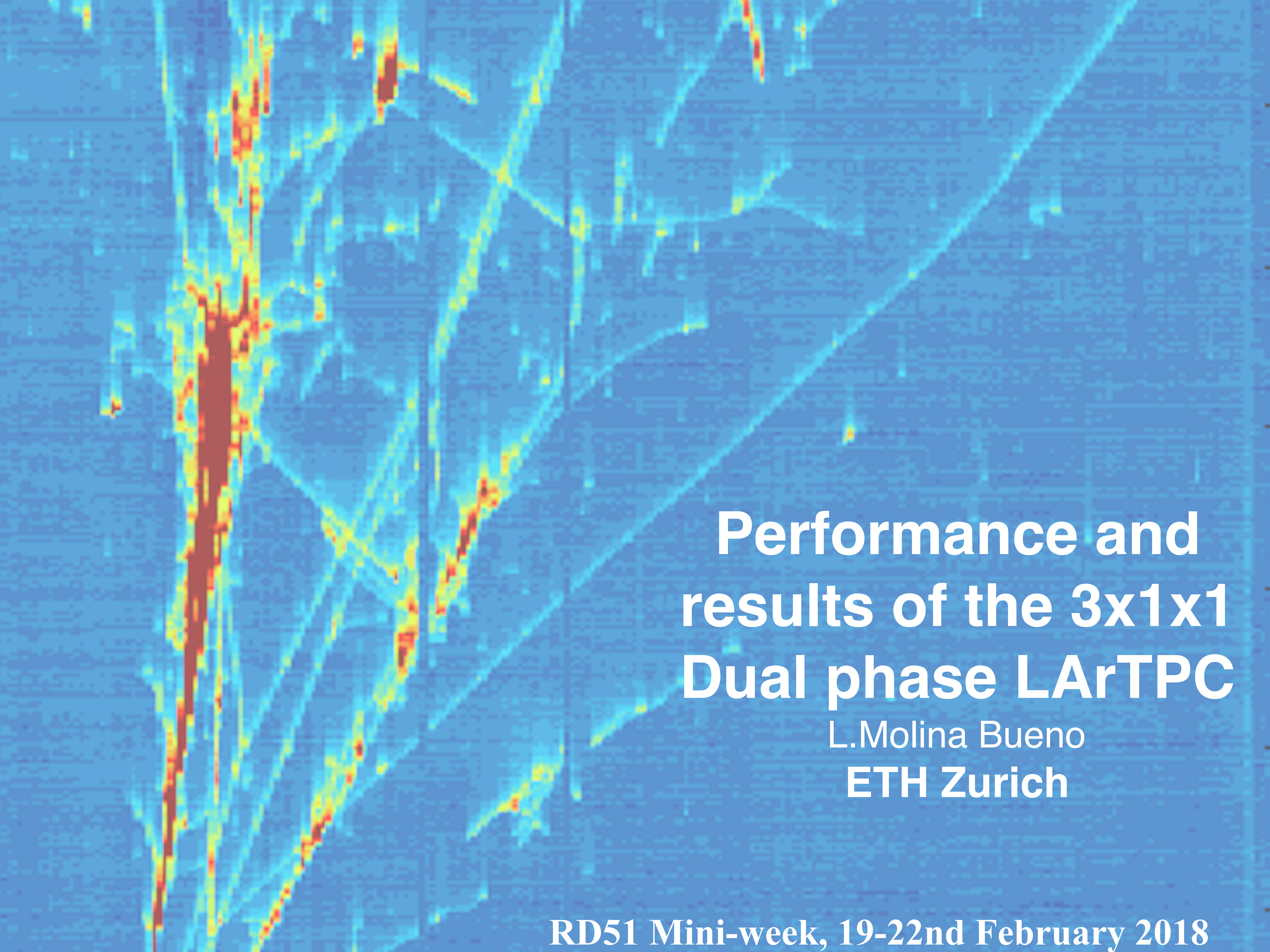


Performance and results of the 3x1x1 Dual phase LArTPC

L.Molina Bueno
ETH Zurich

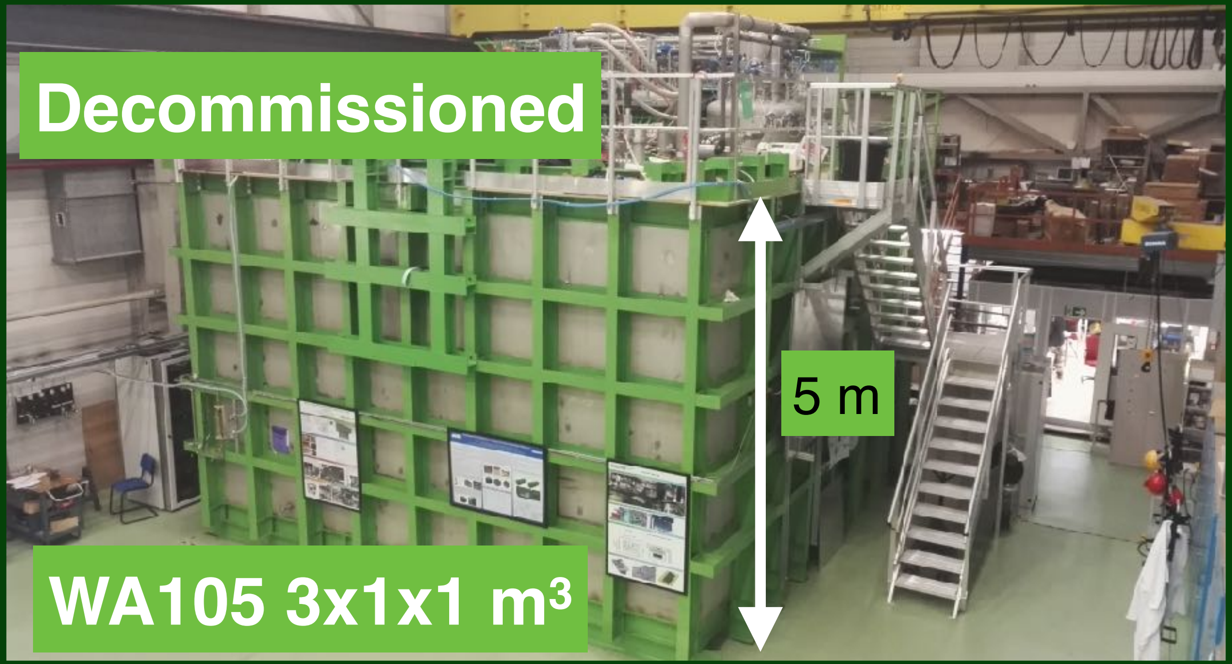
RD51 Mini-week, 19-22nd February 2018

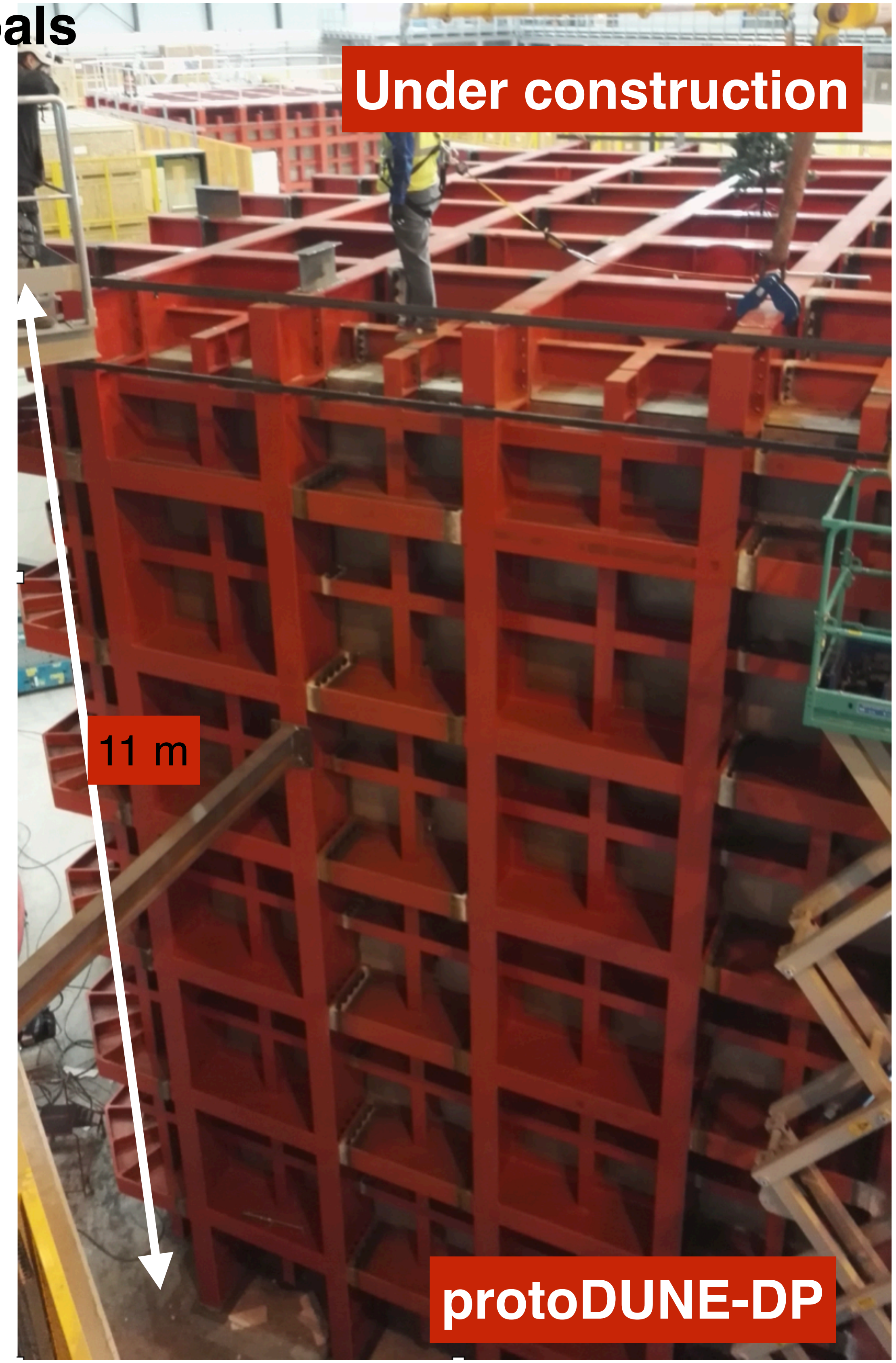
Two dual phase liquid argon detectors

Same technology→different sizes→different goals

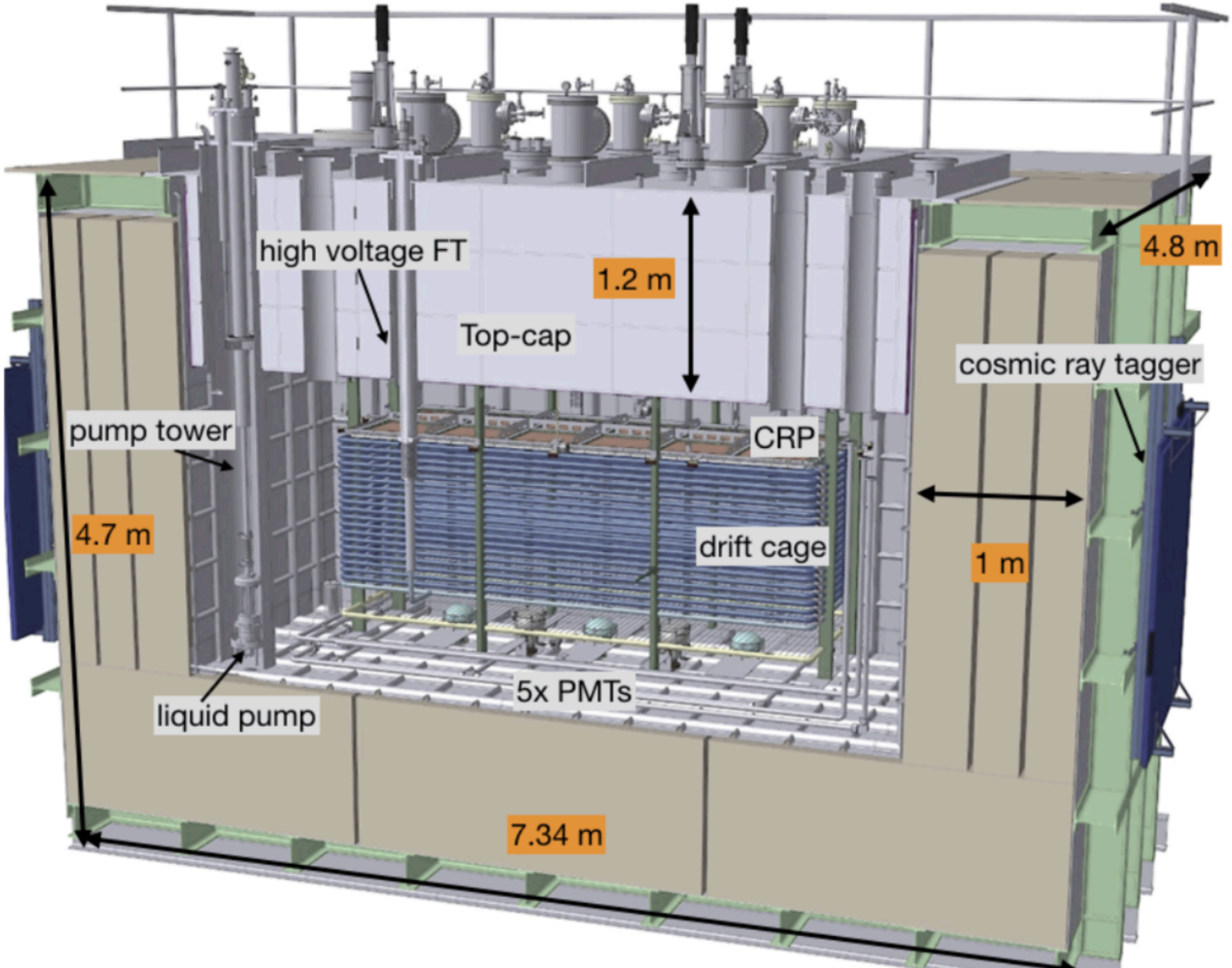
Common aspects

- ✓ 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

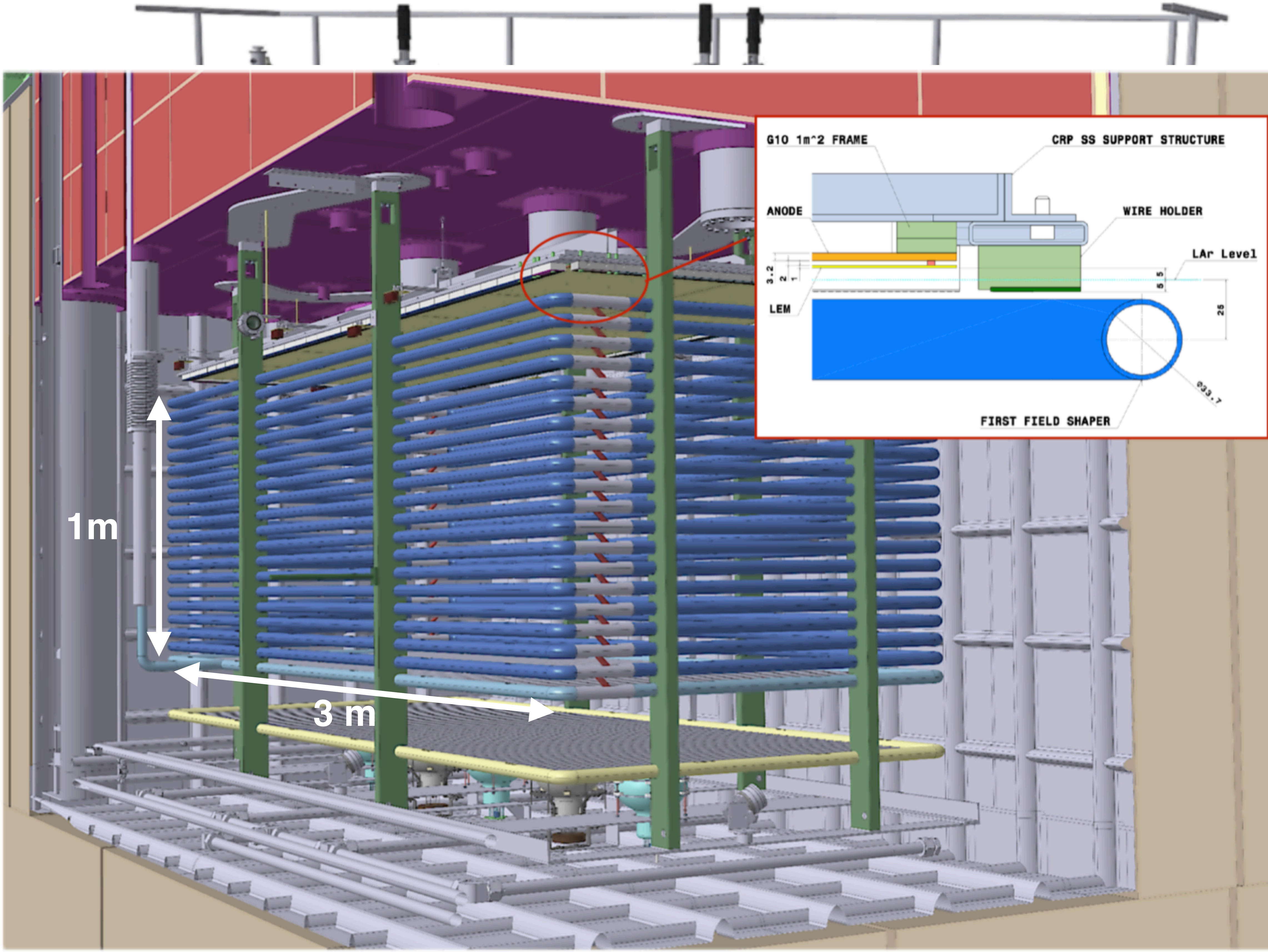




The 3x1x1 Dual phase LAr TPC



The 3x1x1 Dual phase LAr TPC



The 3x1x1 Dual phase LAr TPC

$\varepsilon_{collection}$= fraction of electrons transferred from LEM to anode (inefficiencies essentially due to electrons collected on top electrode of LEM)

G_{LEM}= multiplication factor of the electrons x transparency of its bottom electrode

$\varepsilon_{extraction}$= fraction of electrons which are extracted from the liquid (inefficiencies essentially due to transparency of grid)

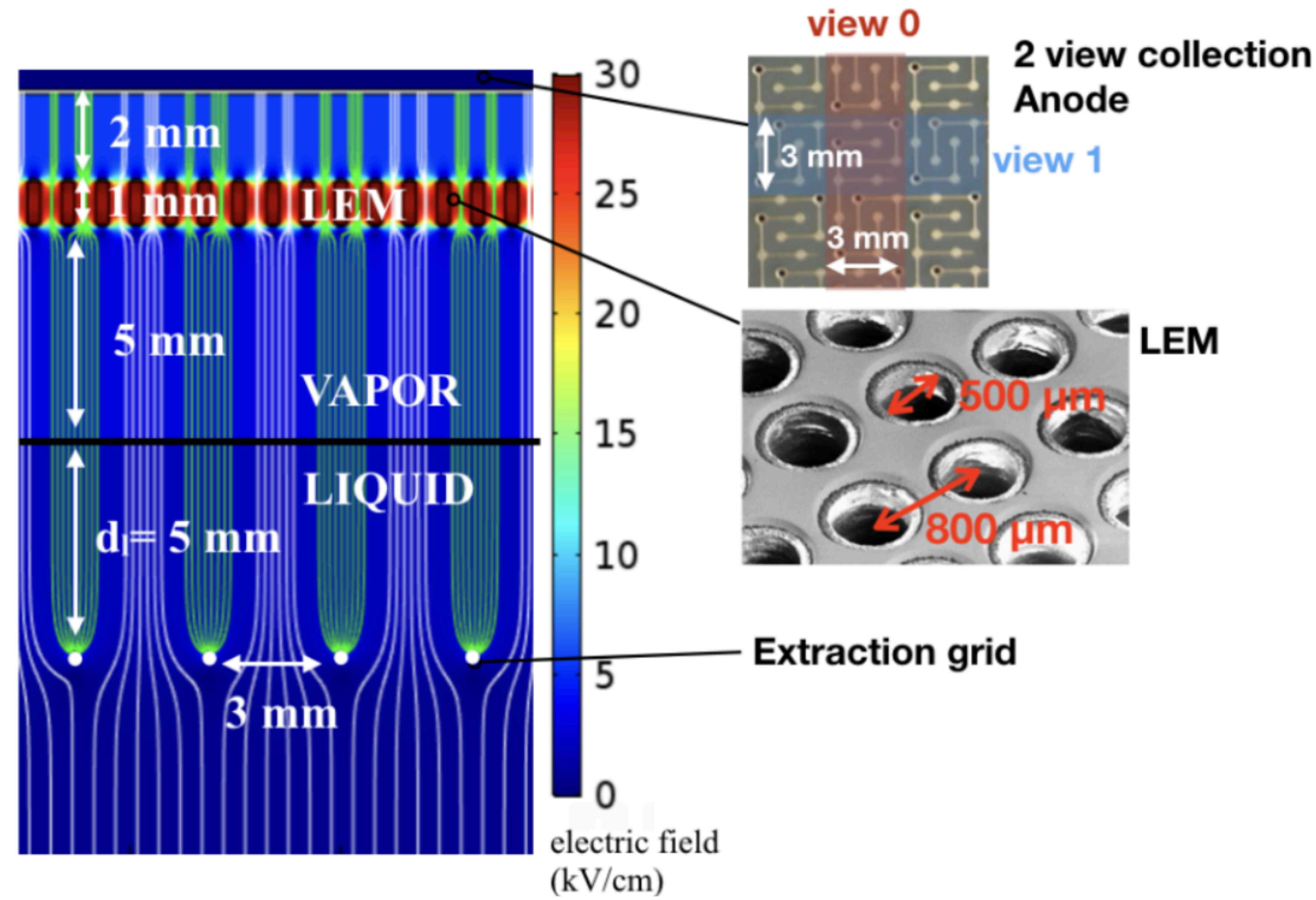
collection
5 kV/cm

amplification
33 kV/cm

extraction (vapor)
3 kV/cm

extraction (liquid)
2 kV/cm

drift
0.5 kV/cm



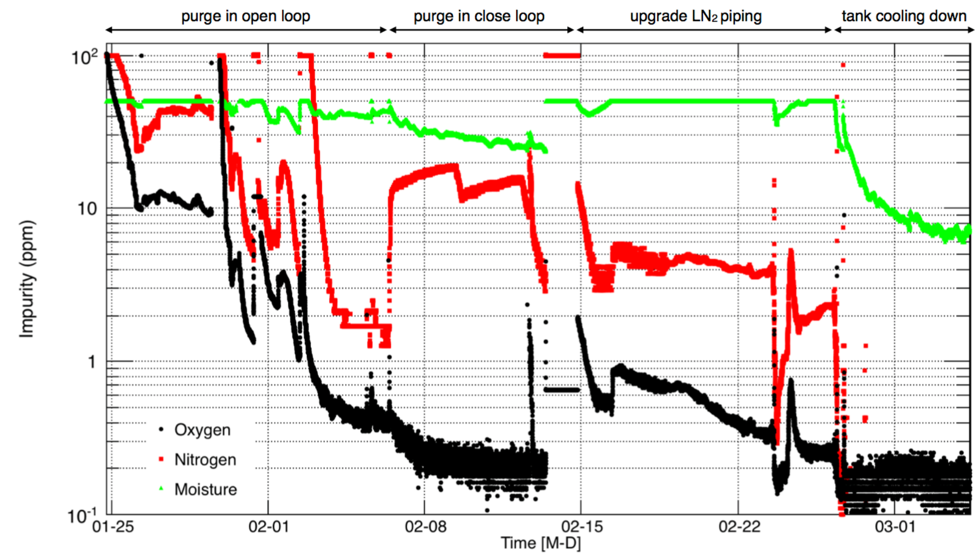
Effective Gain = Extraction Efficiency X LEM Amplification X Collection Efficiency

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

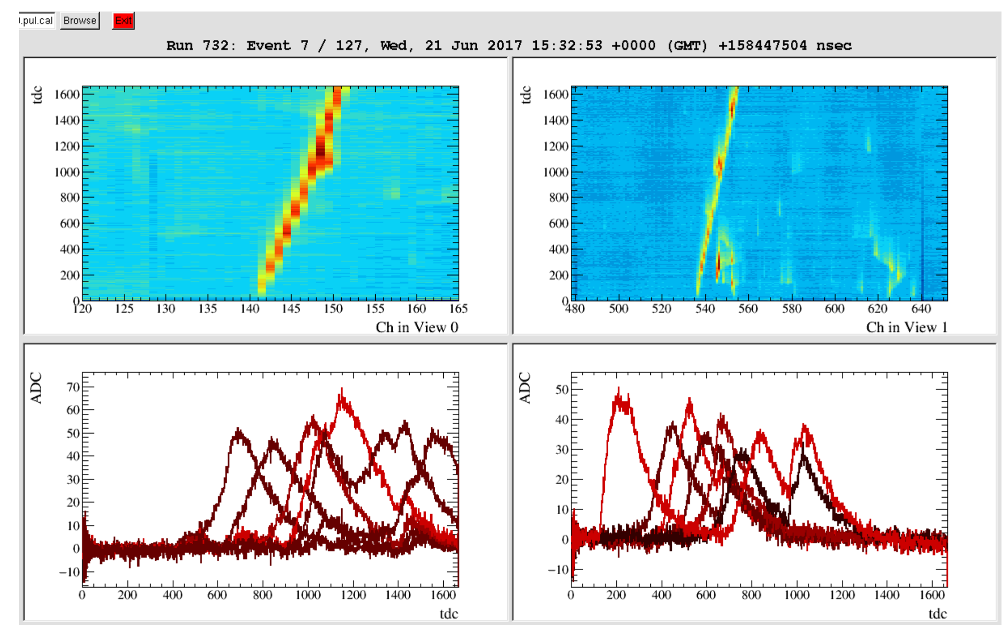
3x1x1 Timeline

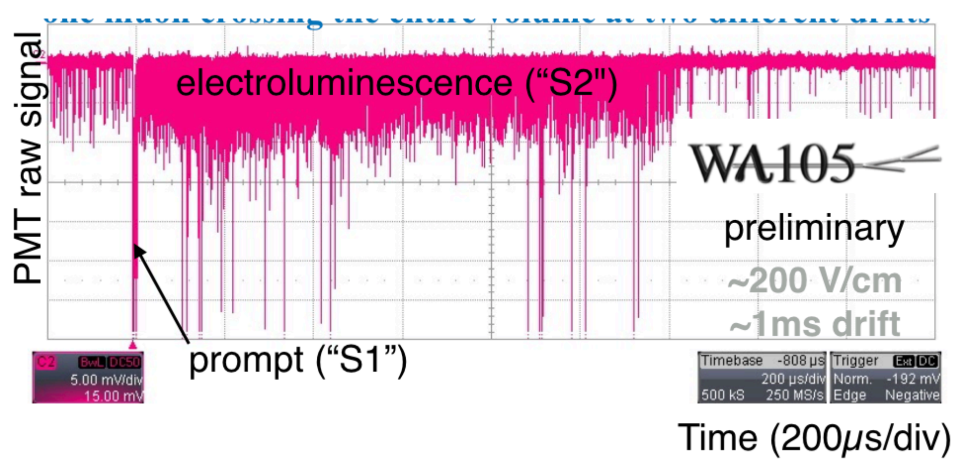
2015 - Cryostat constructed

2016 - Detector installation completed



Jan 2017 - Commission started



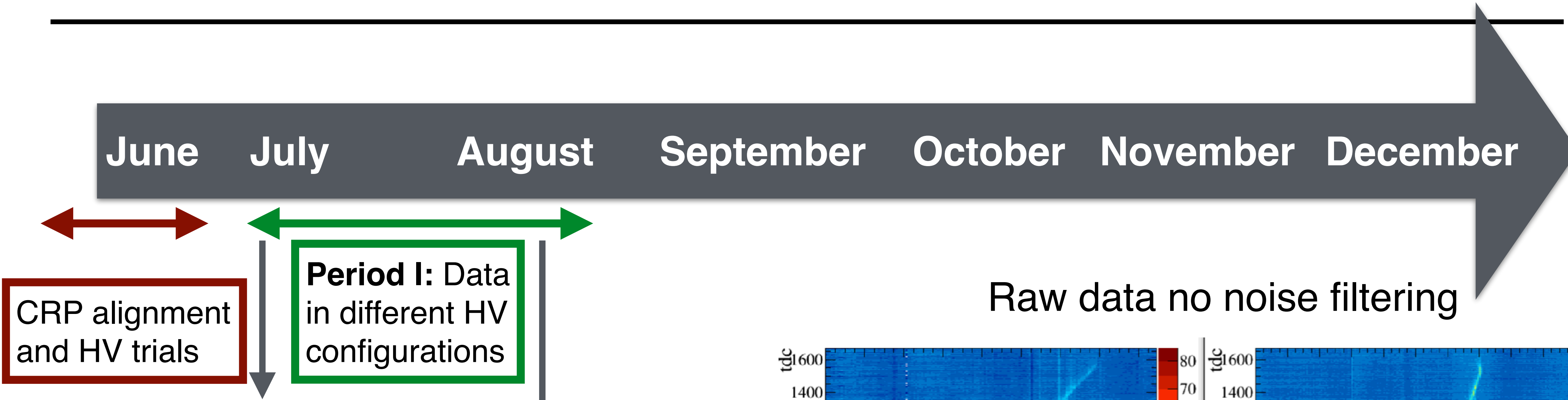


Mar 2017 - Operation ‘frozen’ due to cryostat issues

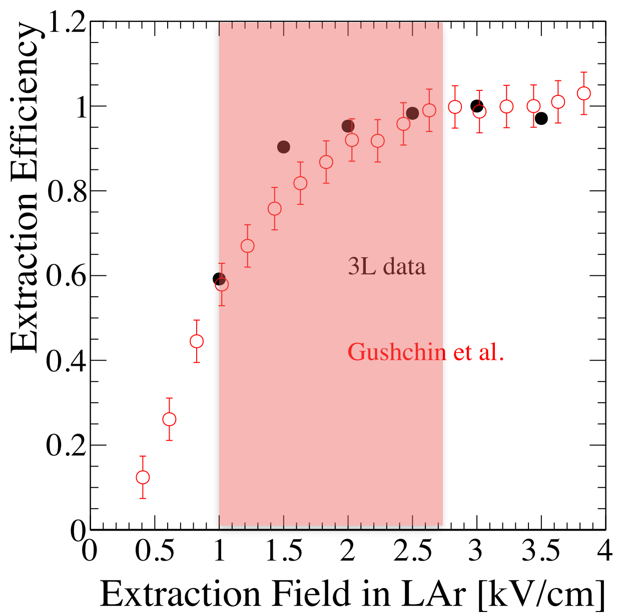
June 12th - Recirculation started → **June 15th - evidence of extraction from LAr to GAr** → **June 21st 2017 - First track seen!**

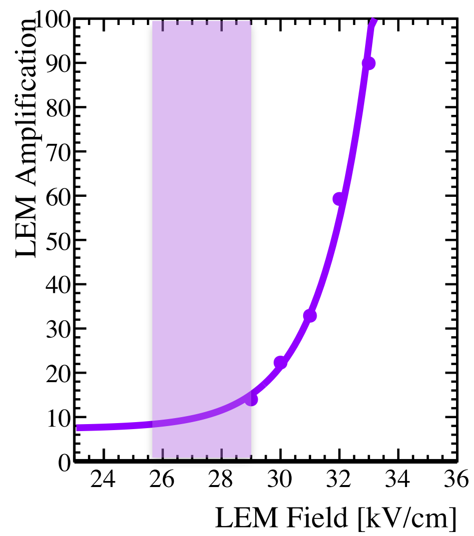
6

3x1x1 Timeline

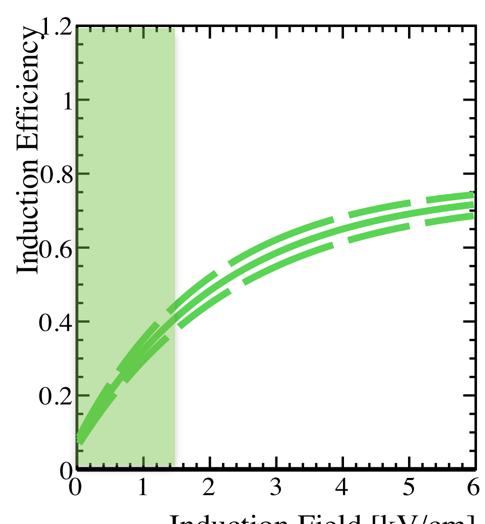


Extraction field scan

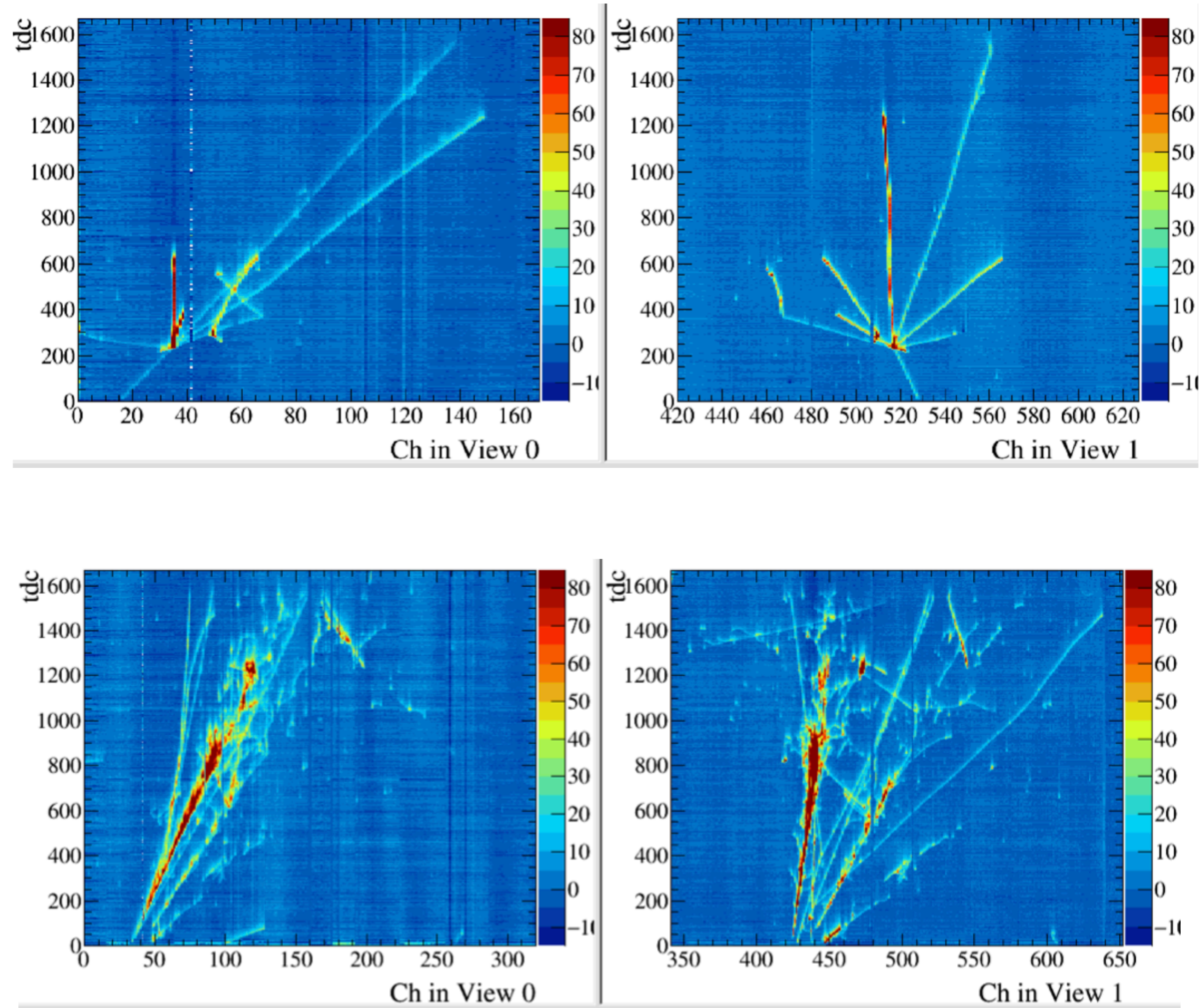




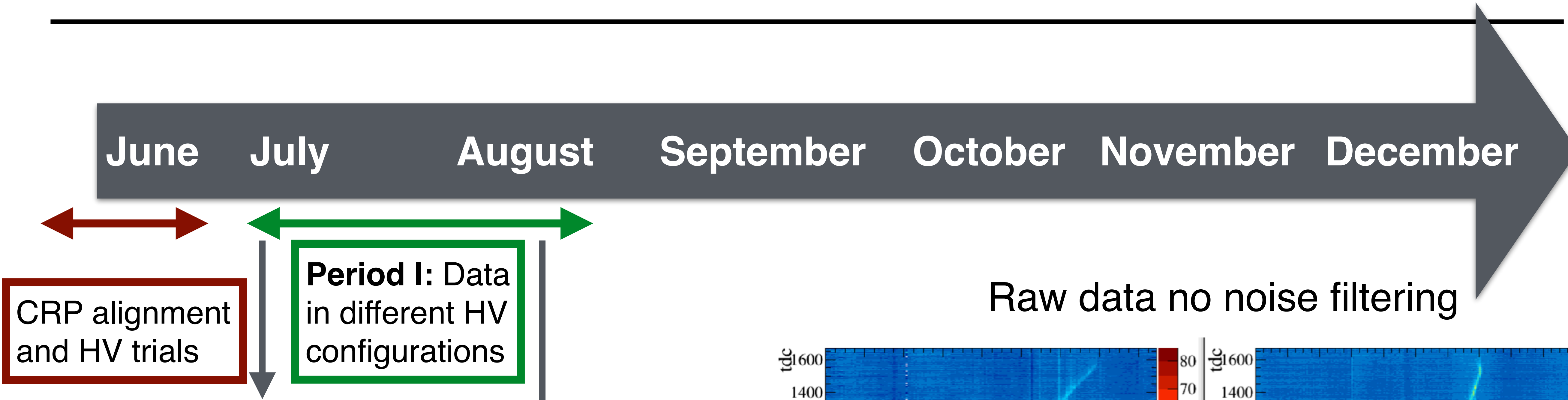
Amplification and **collection** field scan at a **fixed extraction field**



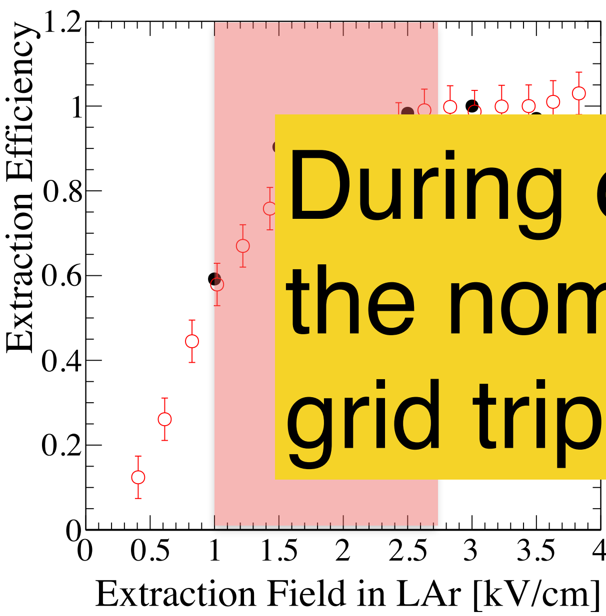
Raw data no noise filtering

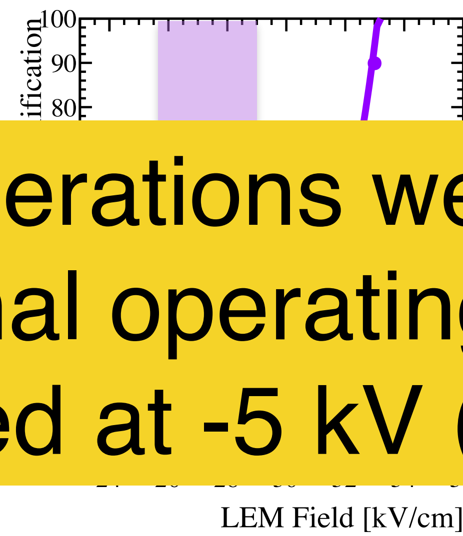


3x1x1 Timeline

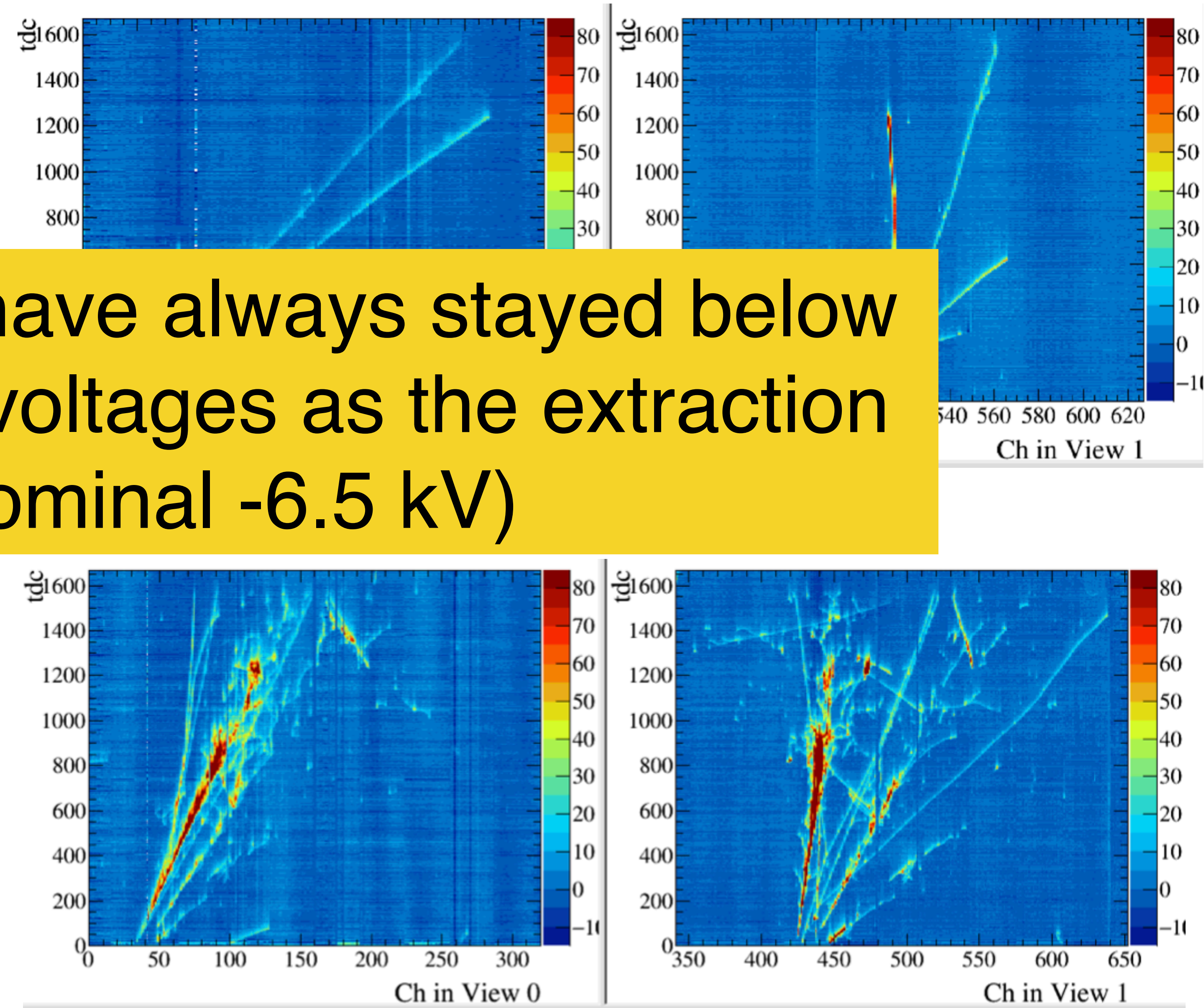


Extraction field scan



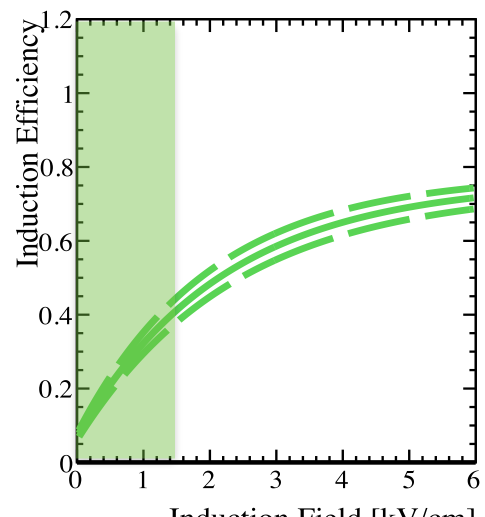


Raw data no noise filtering



During operations we have always stayed below the nominal operating voltages as the extraction grid tripped at -5 kV (nominal -6.5 kV)

Amplification and collection field scan at a fixed extraction field



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

3x1x1 Timeline

An overall of 1352 runs (data, pedestal and pulsing)

June July August September October November December

Dedicated tests on the HV system: **grid** and **LEMs**

Grid

- Maximum voltage -5 kV (nominal -6.5 kV)
- Transient short-circuit between the grid and two LEMs.

Investigations point to a faulty electrical contact on the grid located in the gas and/or a broken or un-tensed wire. Nevertheless, final conclusions will be drawn after visual inspections inside the cryostat.

3x1x1 Timeline

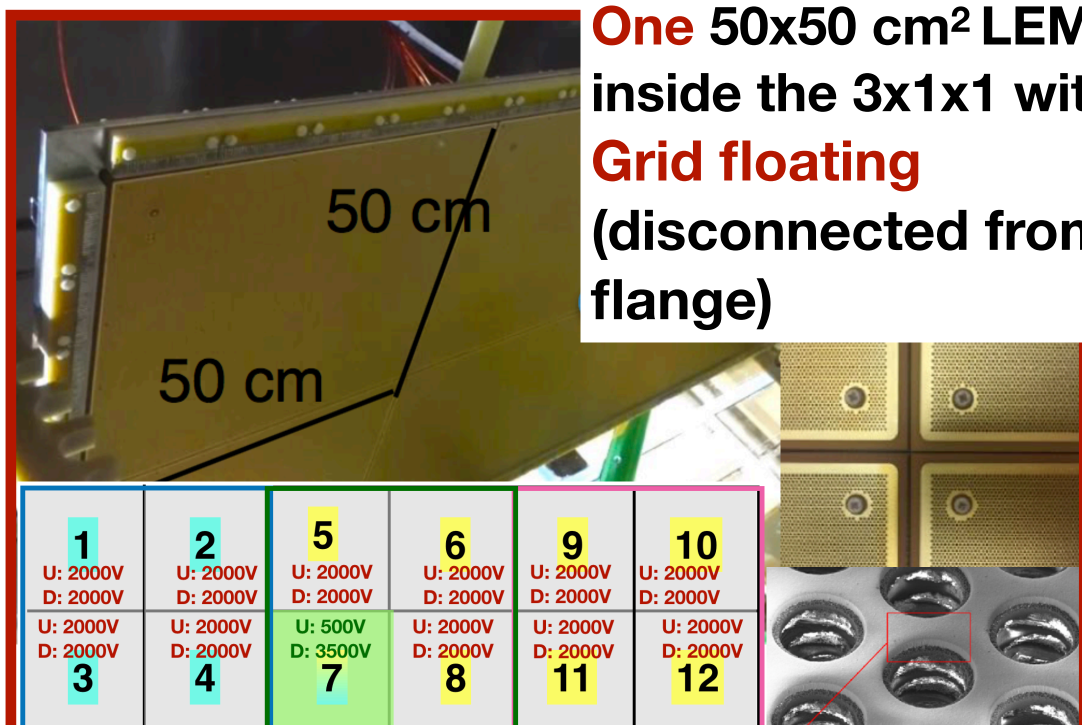
An overall of 1352 runs (data, pedestal and pulsing)

June July August September October November December

Dedicated tests on the HV system: **grid** and **LEMs**

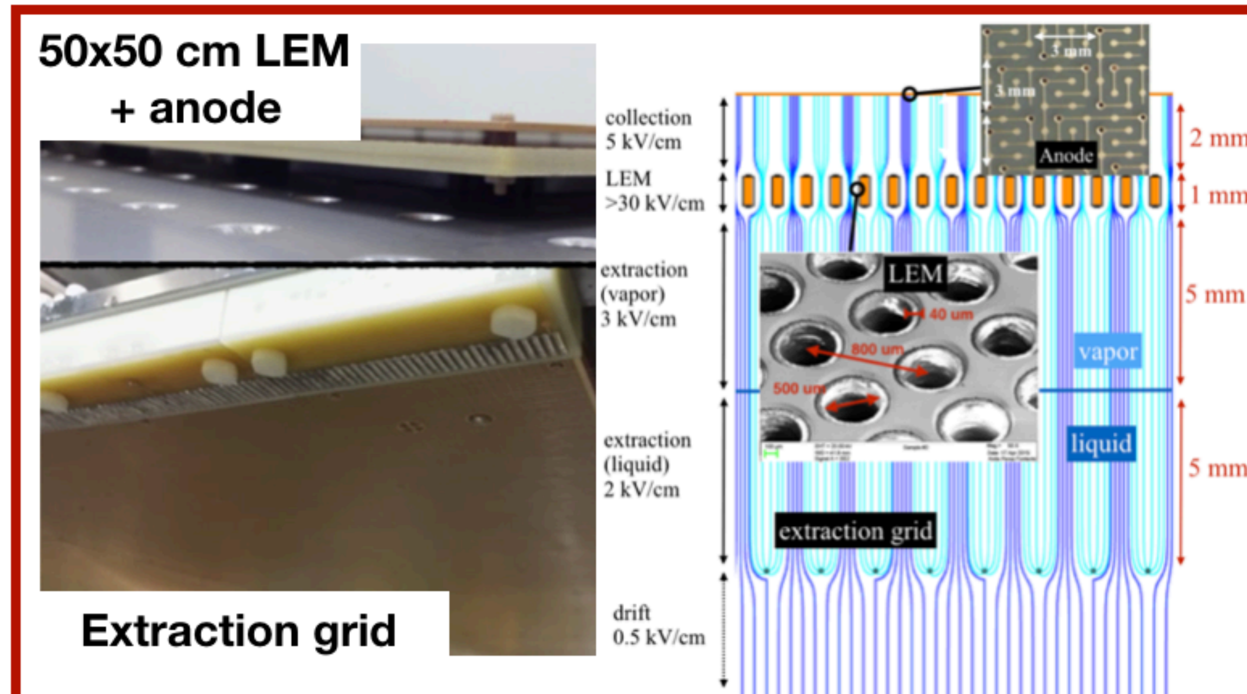
Single LEM without extraction

One 50x50 cm^2 LEM inside the 3x1x1 with the Grid floating (disconnected from the flange)



- **Single LEM-anode inside the 3x1x1 reach 32 kV/cm (gain of ~45 before charging up)**

Multiple LEMs with extraction



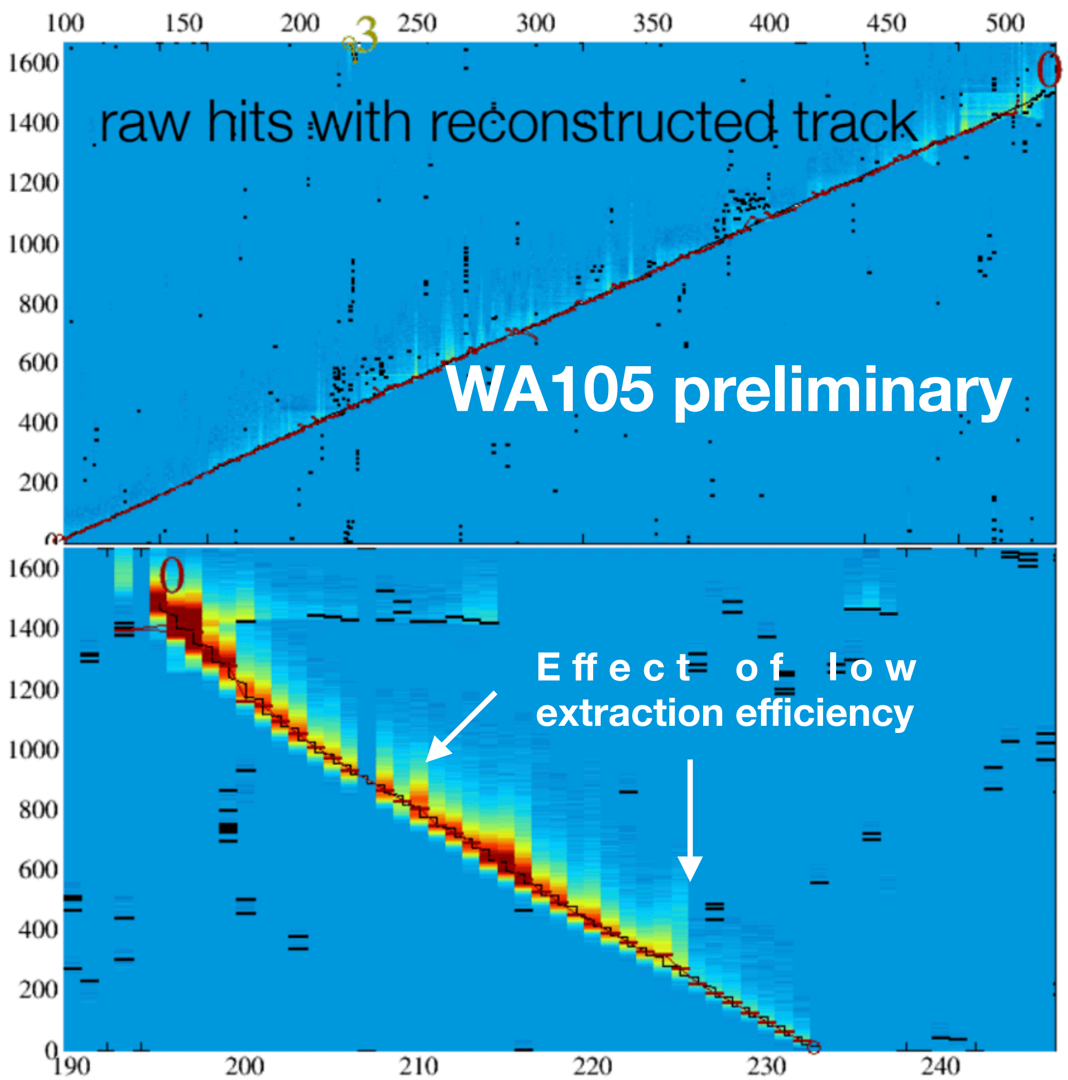
- **The LEMs in the corners were not able to reach the same voltage as the others.**
- **Maximum LEM field 31 kV/cm.**

3x1x1 Timeline

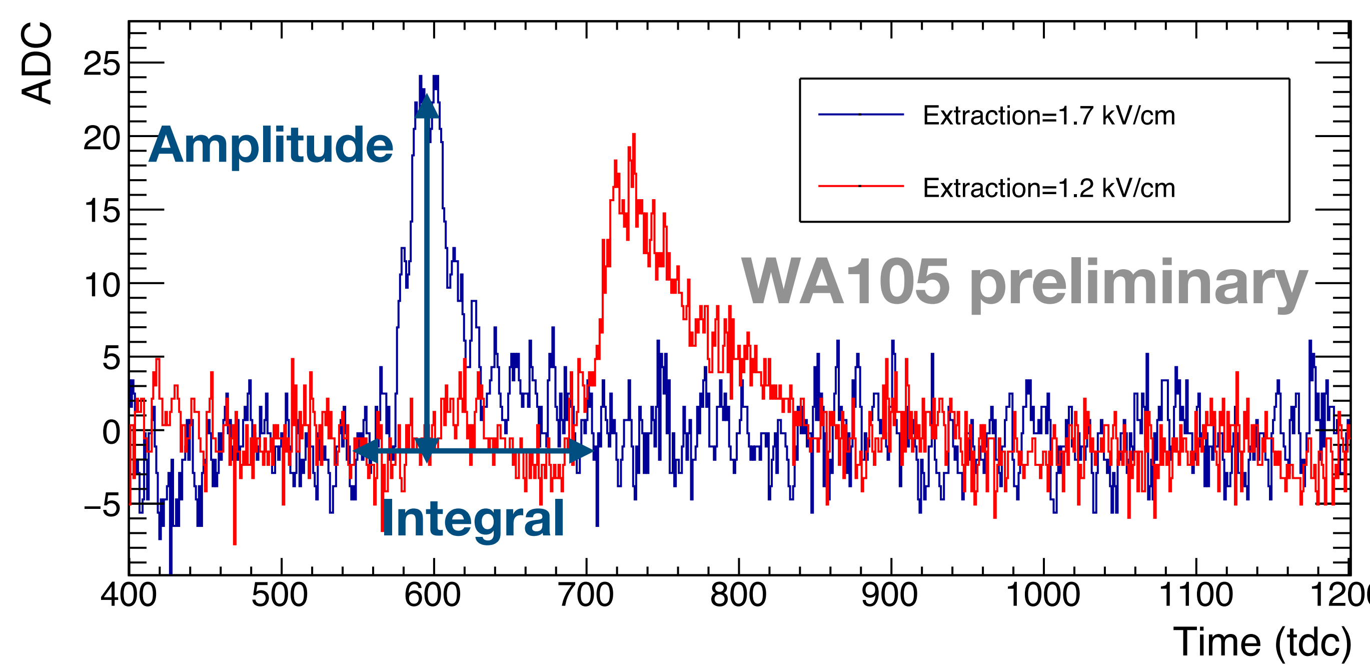
An overall of 1352 runs (data, pedestal and pulsing)

June July August September October November December

Period II: Separate Field scans: extraction, amplification and collection

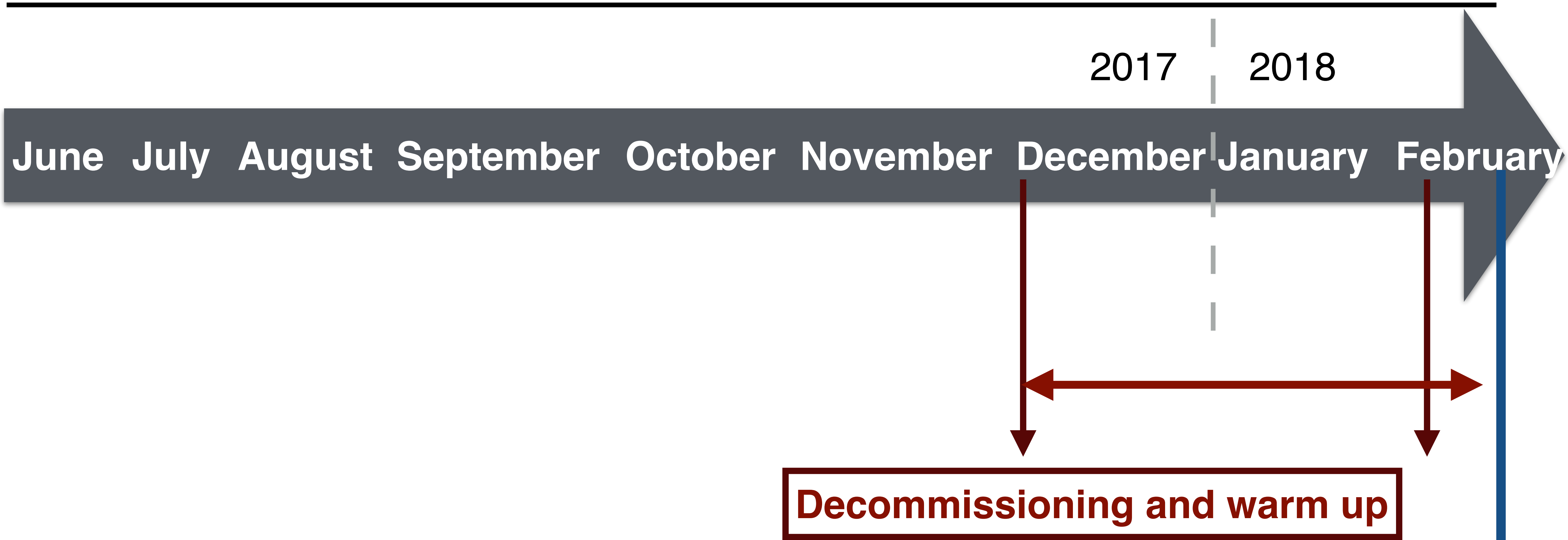


Hit Waveform example at two different extraction fields



	field (kV)
Induction	1.5
LEM	**31**
extraction in liq.	1.0

3x1x1 Timeline

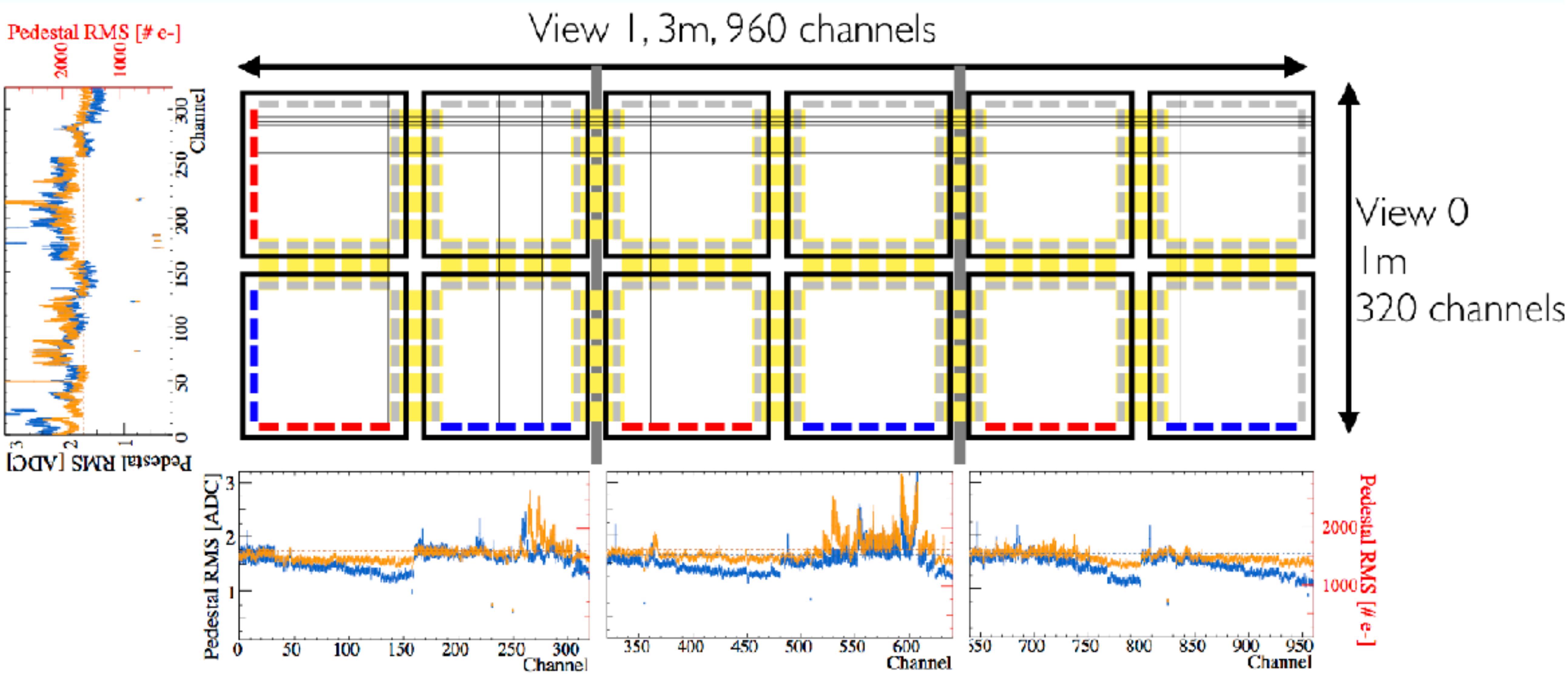


First visual inspection at beginning of December with an endoscope

The manhole was opened last week and today the first access and exploration inside will be performed.

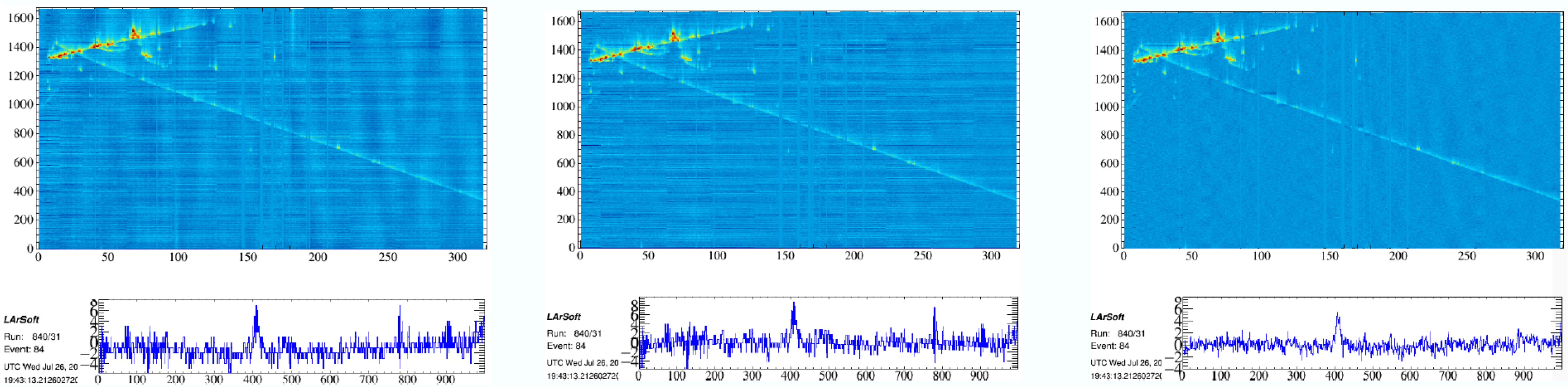
Noise performance

- Noise stable at around 1550 electrons.
- Accessible cold front end electronics successfully tested while the detector was active.



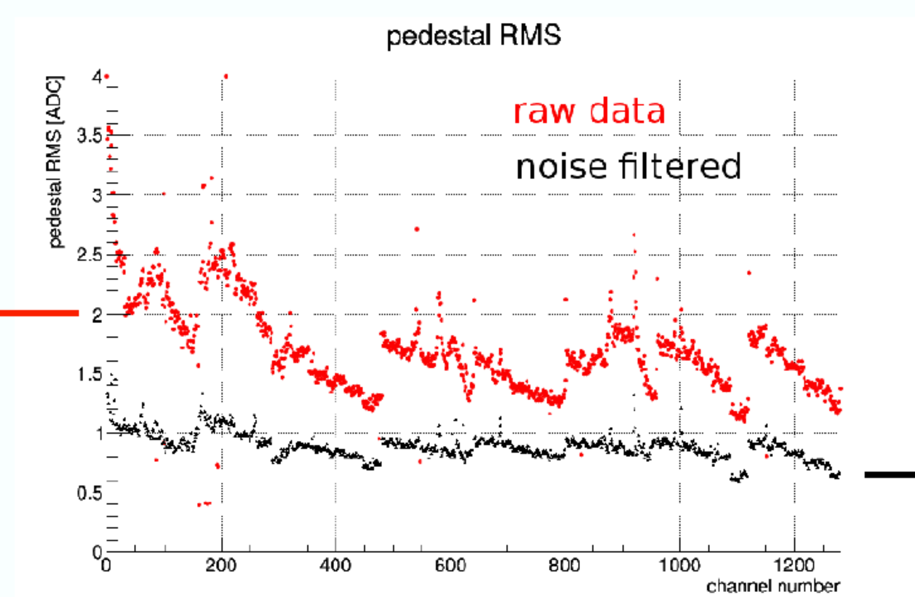
Noise performance

test of noise removal algorithms



"flattening" remove slow fluctuation

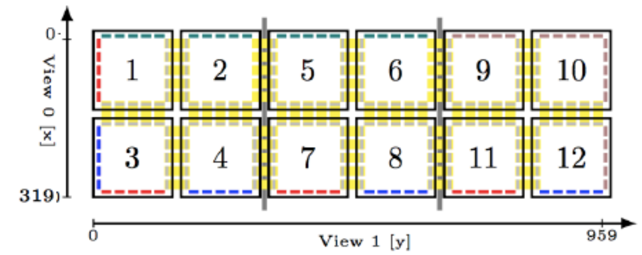
remove coherent noise



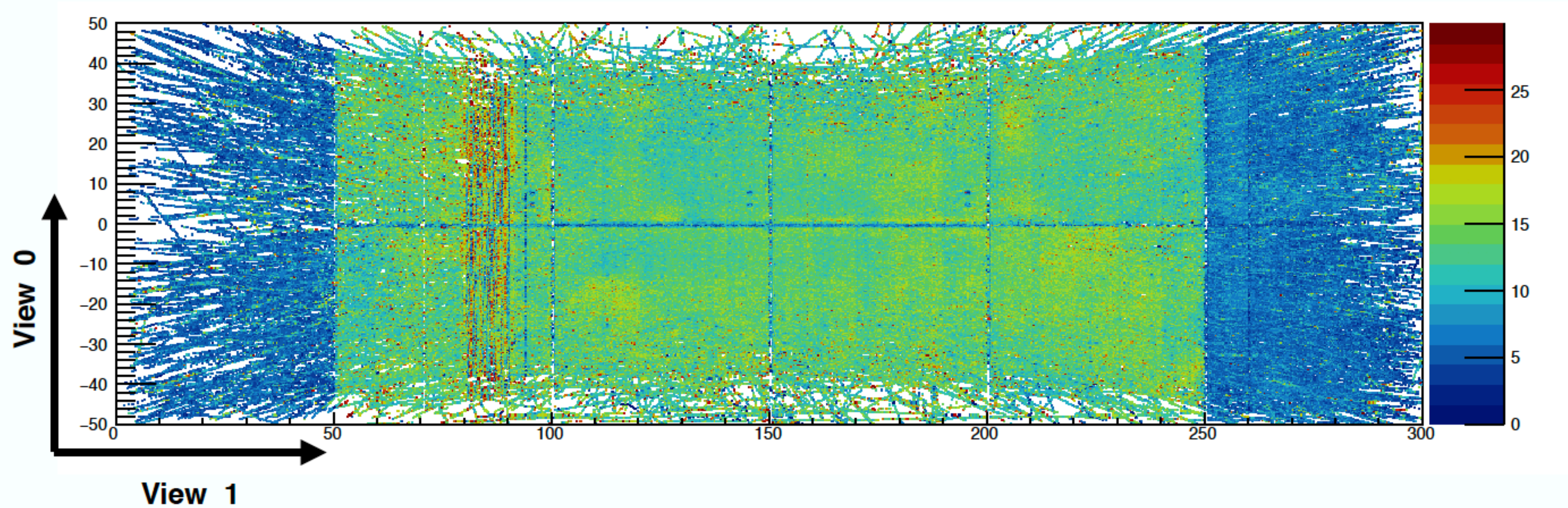
run with high noise in raw data

First look at data: Uniformity

Run 840: 2945 crossing tracks

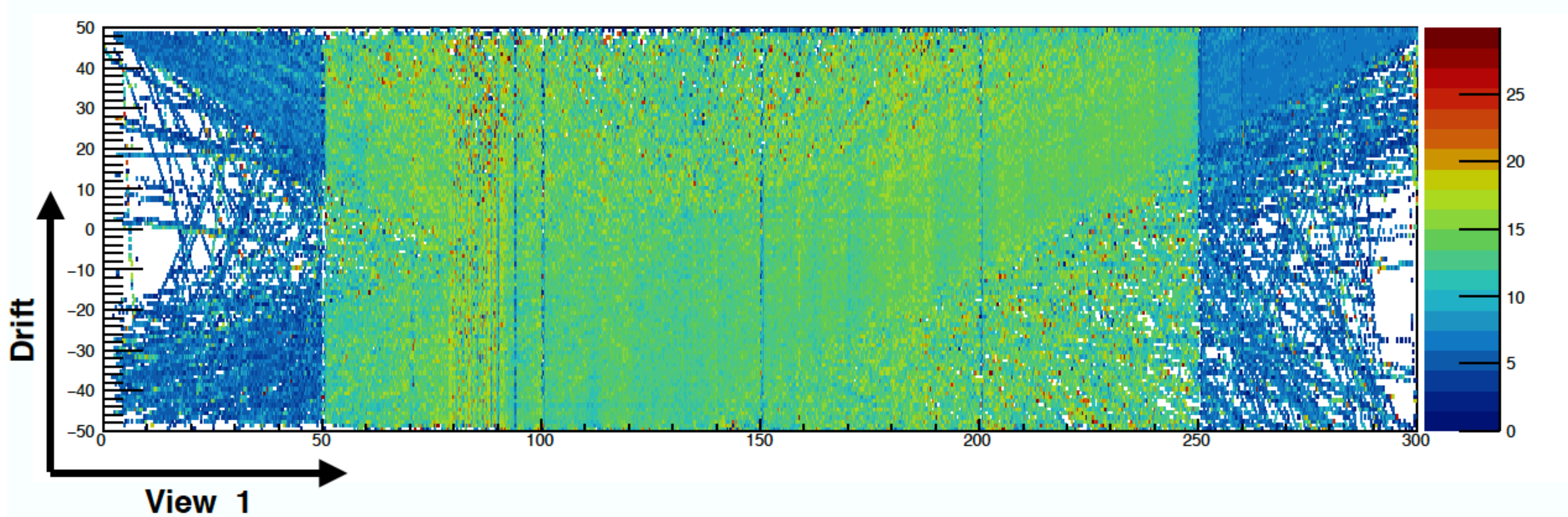


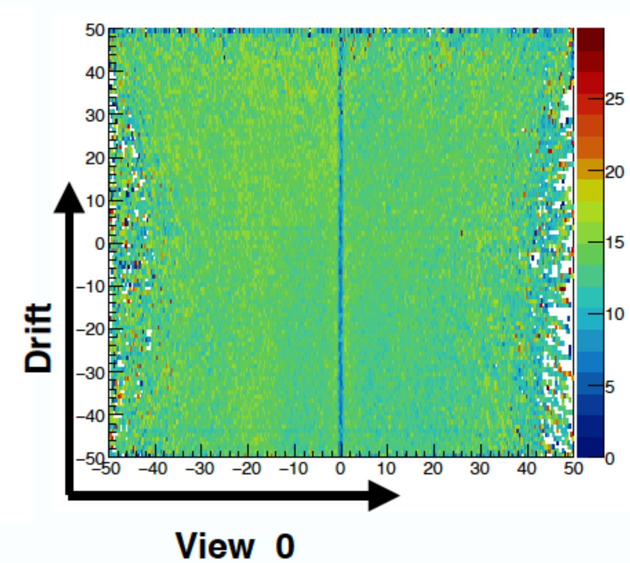
<dQ/ds> uniformity across the CRP



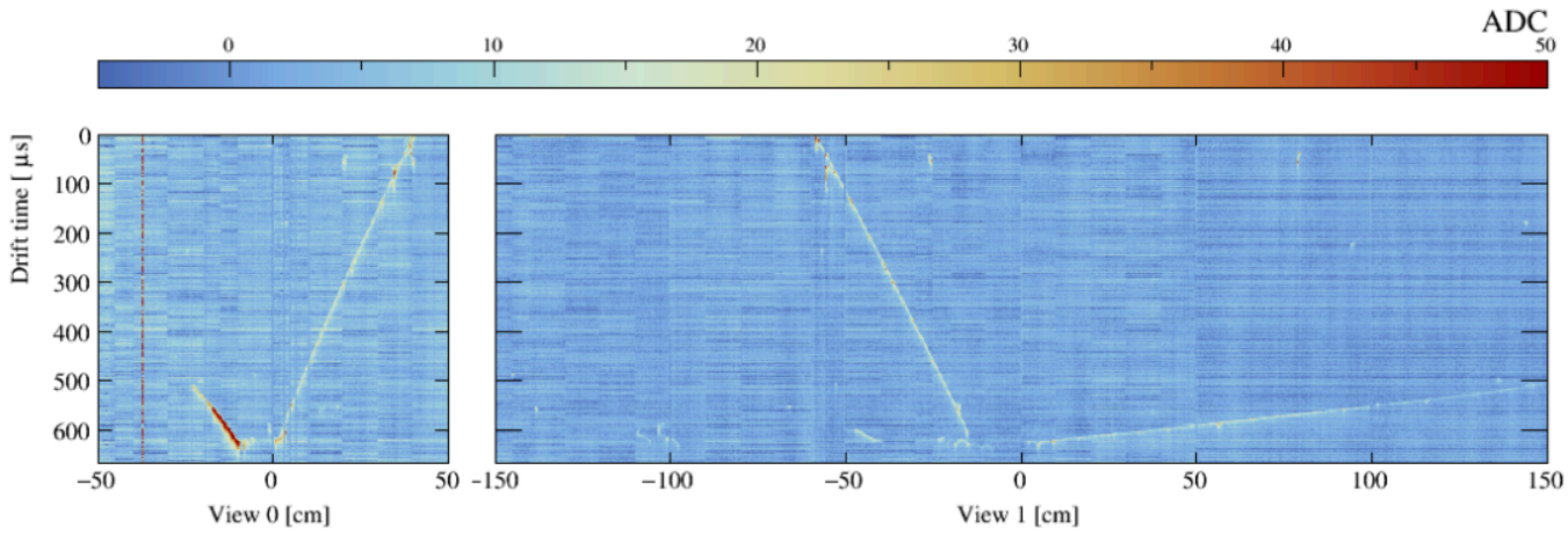
- Drift field: 500V/cm
- Extraction field in liquid: 1.9 kV/cm
- Amplification field: 28 kV/cm (except the corners at 24 kV/cm)
- Induction field: 1.5 kV/cm

<dQ/ds> uniformity along drift

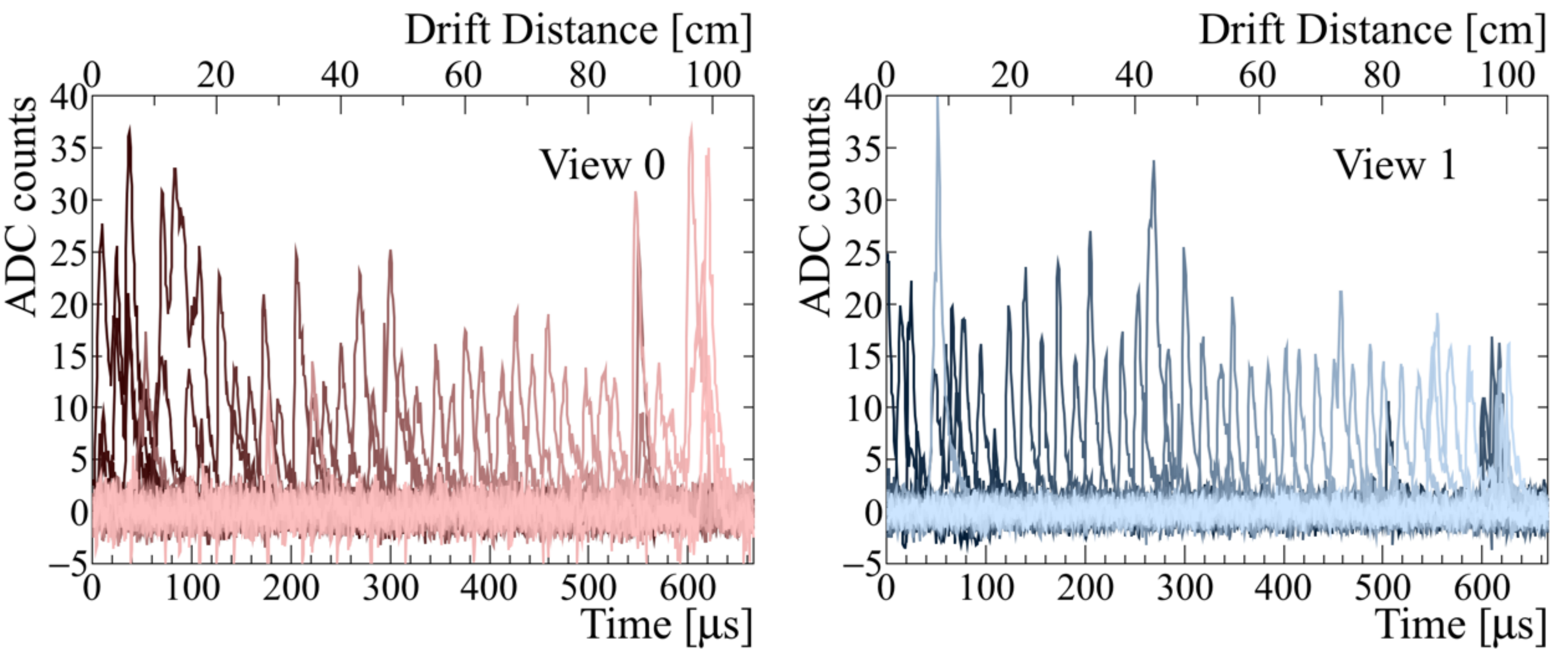




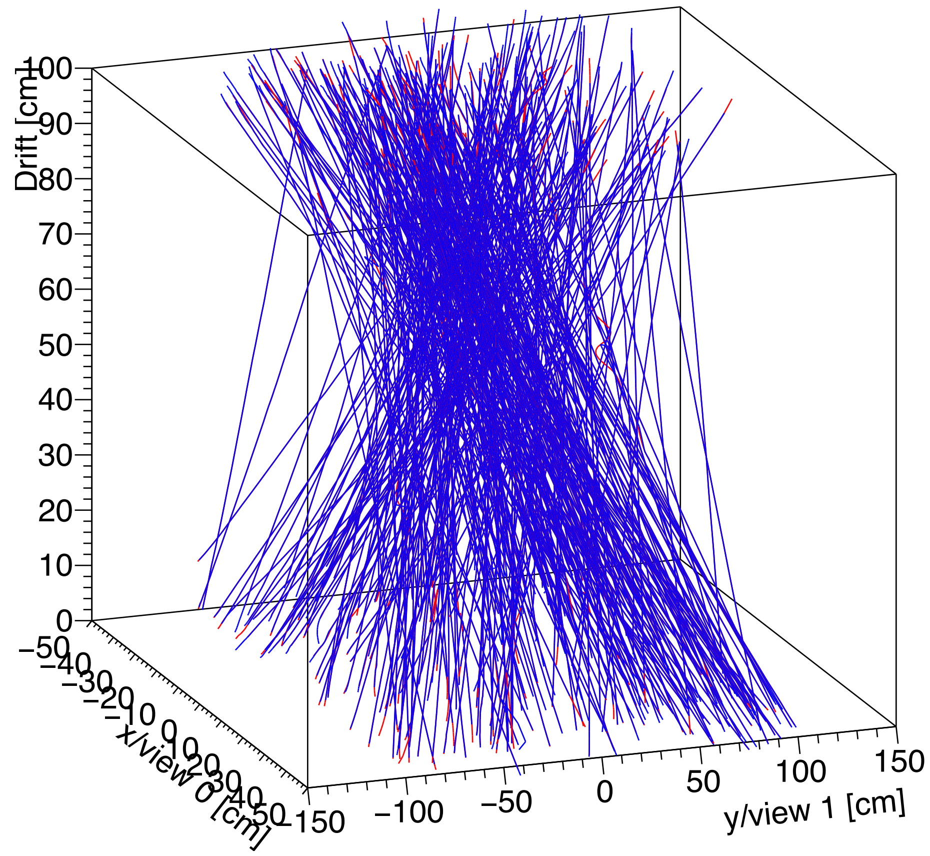
Through going muon



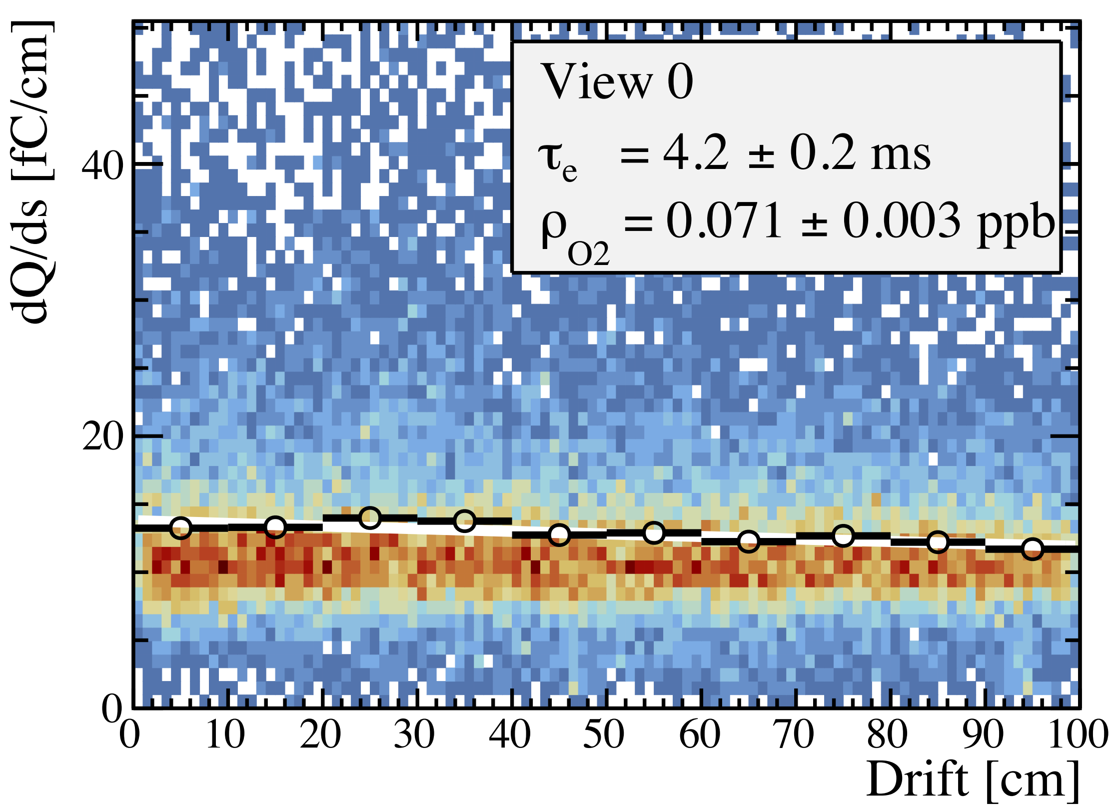
- No signal of attenuation in 1 m drift.
- S/N ratio > 10.

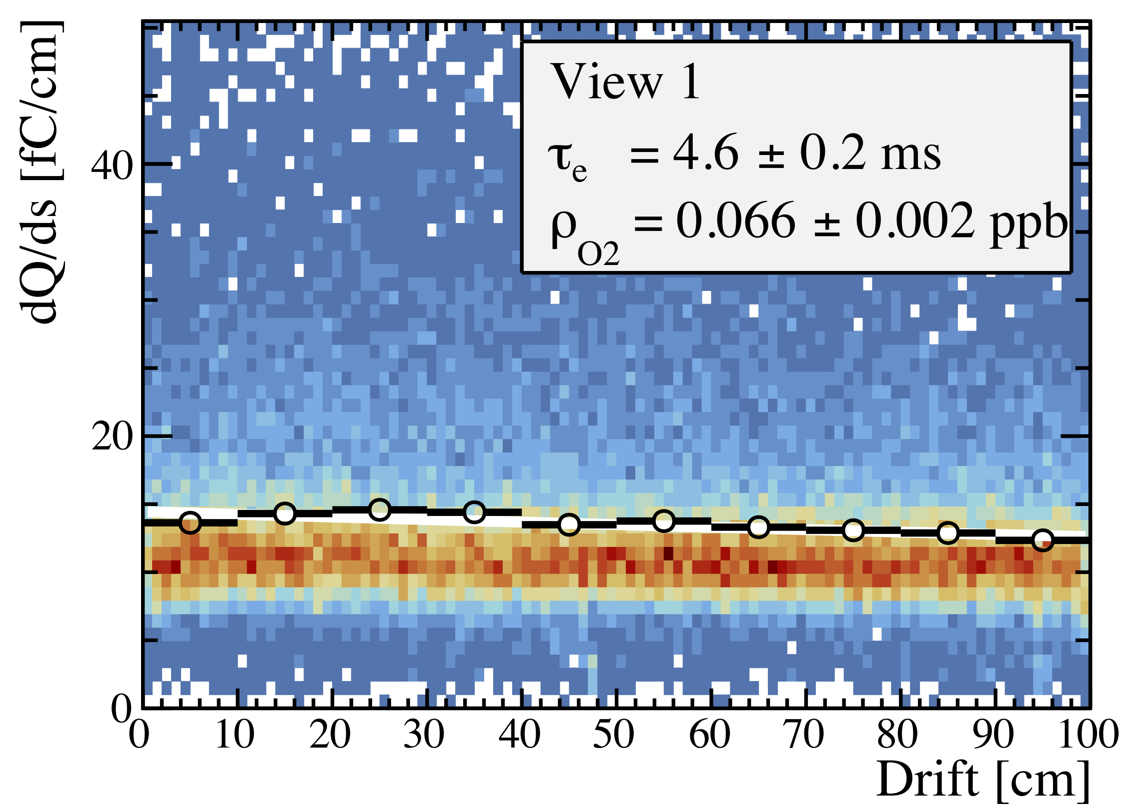


First look at data: Purity



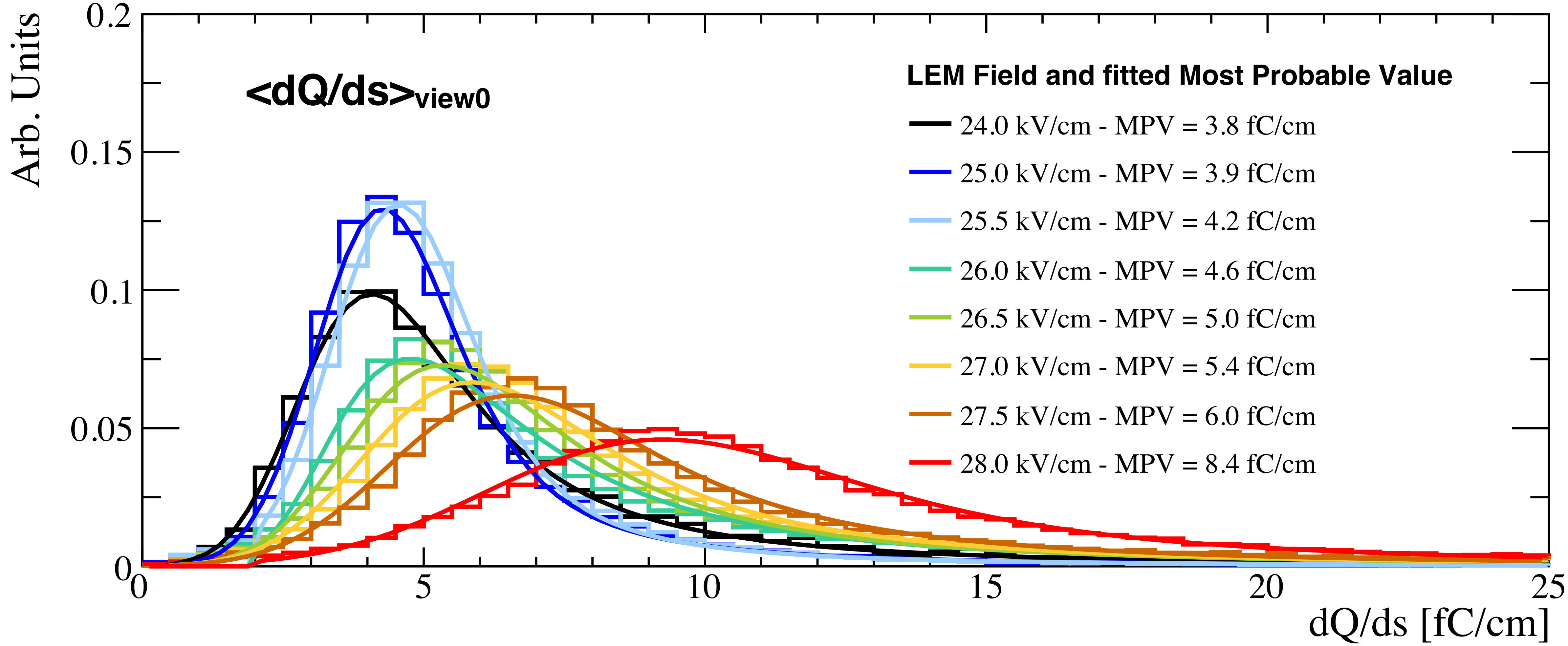
- Select **only through going tracks**.
- Charge deposition in each view as a function of the drift distance.
- Preliminary results indicate a **purity compatible with ms electron lifetime**.





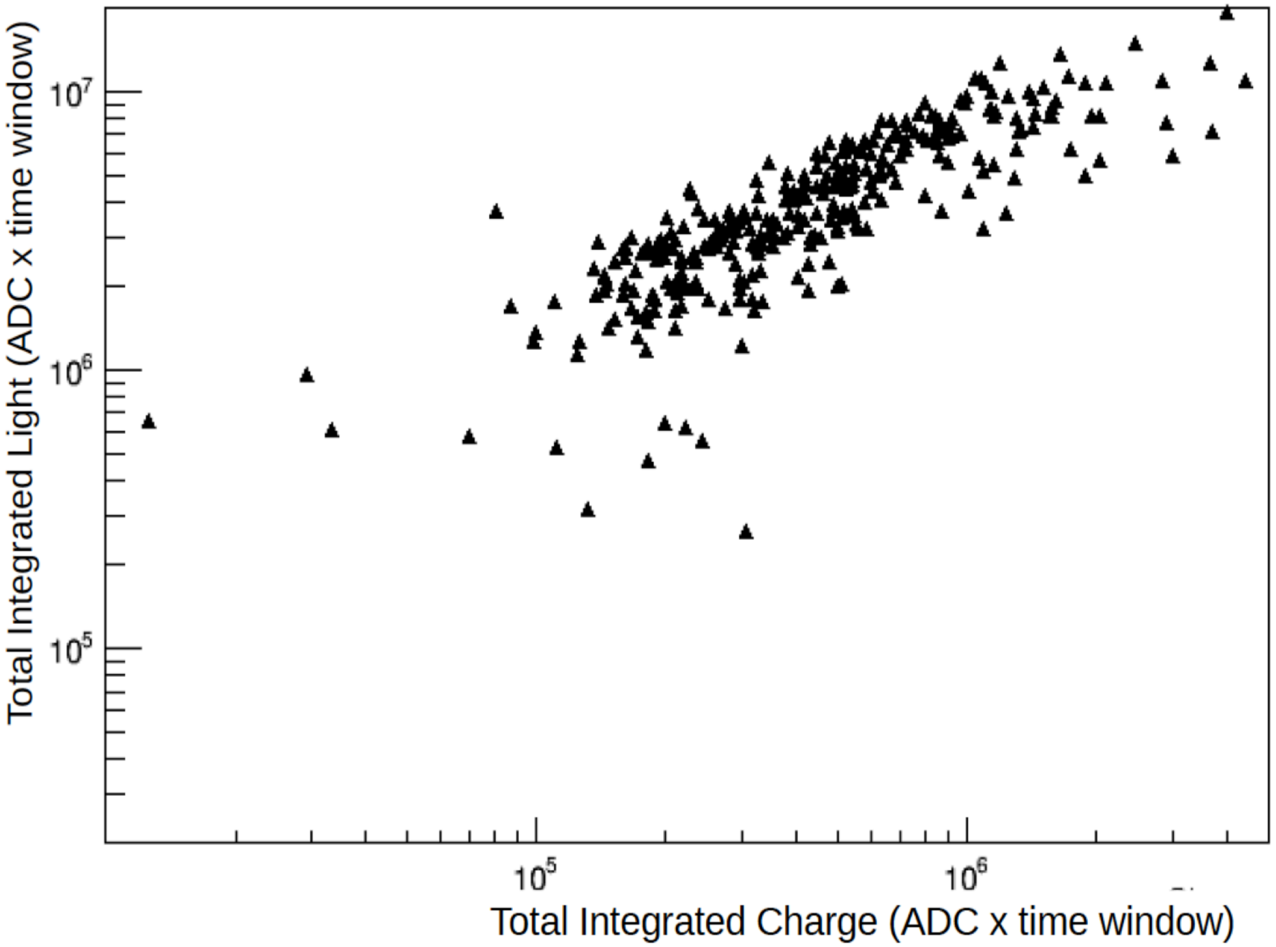
First look at data: Cosmic tracks with gain

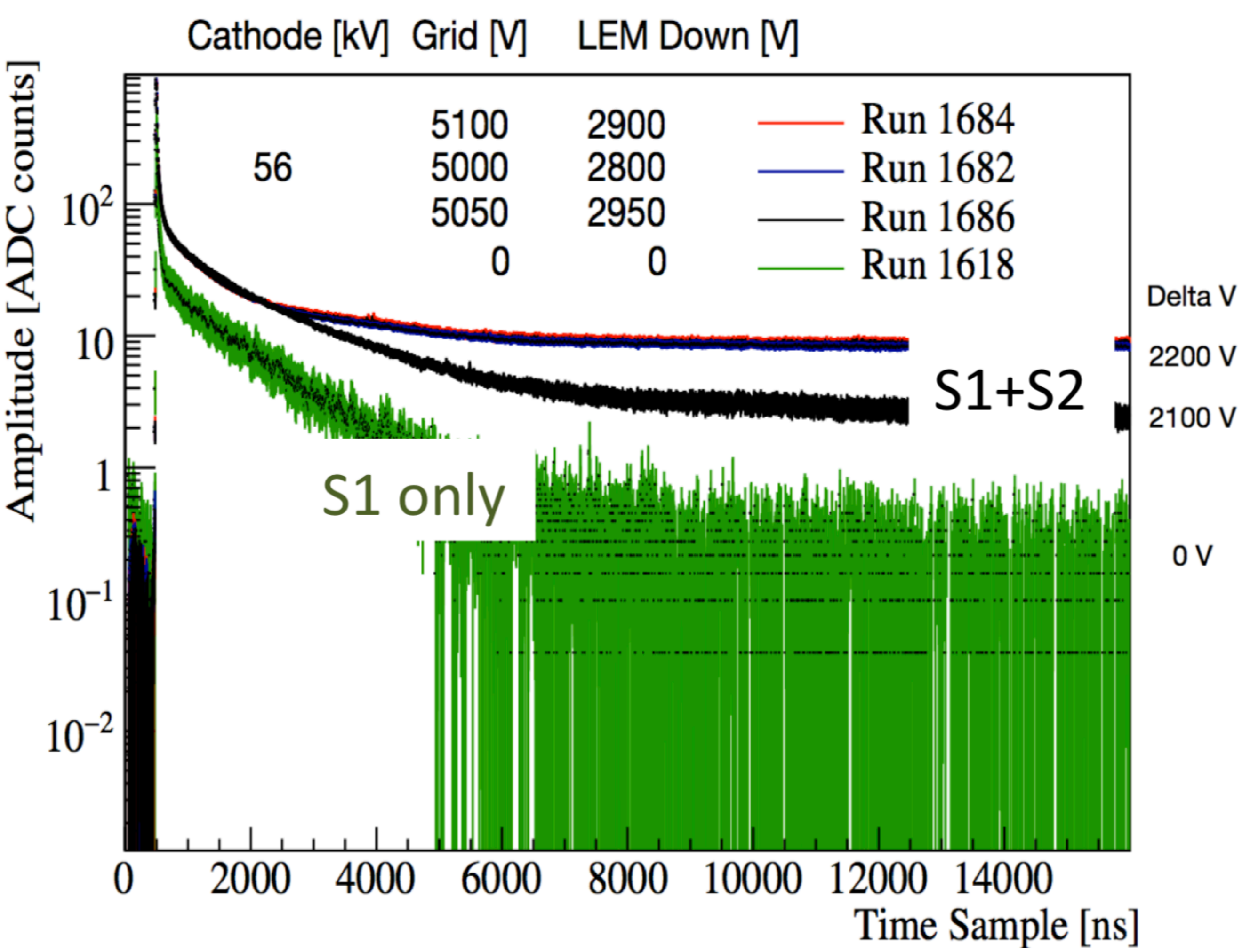
Effective Gain = (<dQ/ds>$_{view0}$+<dQ/ds>$_{view1}$)/<dQ/ds$_{expected}$>

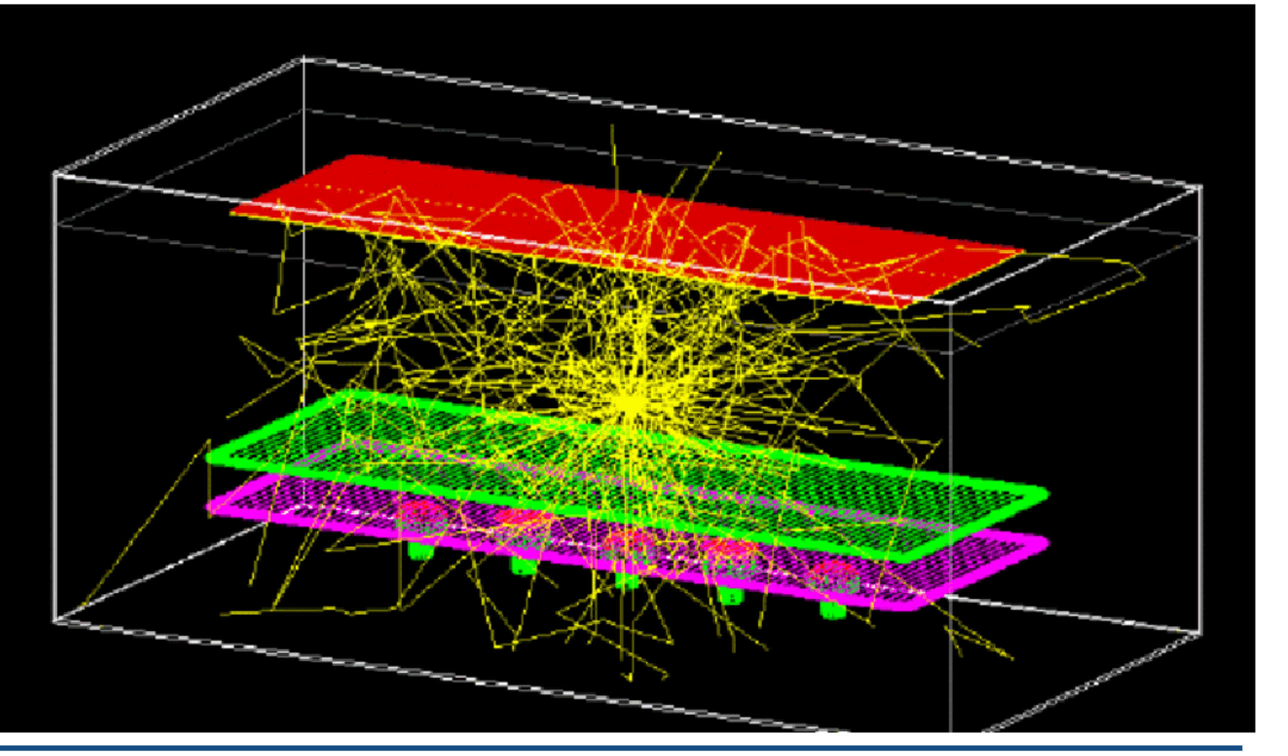


First look at data: Light studies

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







Paper in preparation

Editorial Board: F.Sánchez, S. Murphy, V. Galymov, E. Mazzucato, M. Campanelli

A 5 ton demonstrator for large-scale dual phase liquid argon time projection chambers

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Abstract

Keywords: Neutrino, liquid argon TPC

Contents

1. Introduction

2. The $3\times1\times1$ m^3 as ton scale demonstrator of the dual phase liquid argon TPC

2.1. Experimental setup

The experimental setup is illustrated in Fig. 1 and some pictures are provided in Figure 2. It consists of a $3\times1\times1$ m^3 (4.2 tons) active volume dual phase LAr-TPC inside a passively insulated cryostat with internal volume of $\sim$23 m^3. The entire detector is hung under a 1.2 m thick insulating lid called *top-cap*. The top cap is part of the cryostat structure providing the functionality of reducing heat input and minimizing the liquid and gas argon convection inside the tank. Altogether, twenty pipes of various diameters, called *chimneys*, cross the top cap in order to host the necessary feedthroughs as well as the interfaces to the cryogenic system. The TPC is composed of a 1 m high field cage made by nineteen field shaping rings placed at a constant spacing of 50 mm and a metallic grid cathode at the bottom. A uniform drift field is provided by a resistor divider chain situated between the cathode and the top field shaping ring. Five photo-multiplier tubes (PMTs) are mounted underneath the detector and shielded from the high voltage by a metallic grid grounded to the cryostat. They detect the scintillation light produced by charged particles crossing the LAr target (primary scintillation, S1), as well as the secondary scintillation light (S2) produced via electro-luminescence by the electrons extracted to the GAr phase [1]. They are coated with the wavelength shifter 1,1,4,4-Tetraphenyl-1,3-butadiene (TPB) [2] to detect the deep ultra

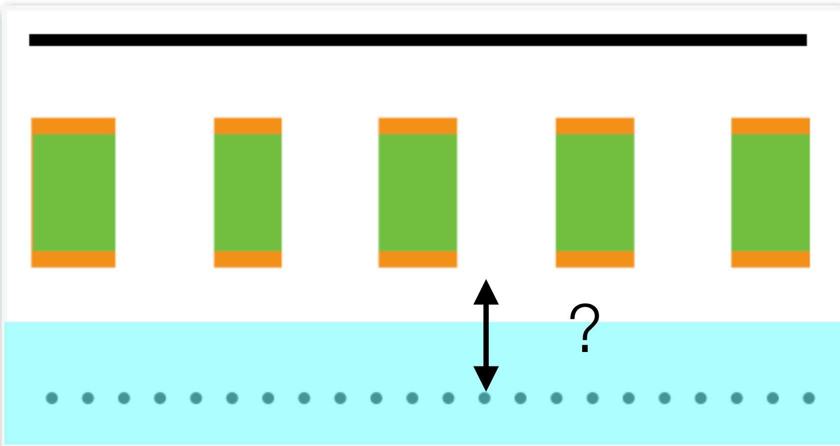
Conclusions

- **First LAr TPC operation in a membrane tank** and excellent performance of the cryogenic system.
- **Preliminary results indicate a purity compatible with ms electron lifetime.**
- First time, **extraction efficiency over 3m² area and LEM amplification with gain demonstrated on the 50x50 cm².**
- **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 even with readouts of ~500 pF (3 m strips).
- **Stable operation of the drift cage** at the nominal voltage, -56 kV.
- **Full infrastructure for data transfer** has been set up and tested in the 3x1x1.
- 500k events recorded: Analysis ongoing.
- **Large experience has been gained for protoDUNE-DP design, installation and commissioning**.

Performance limited by the extraction grid maximum voltage.

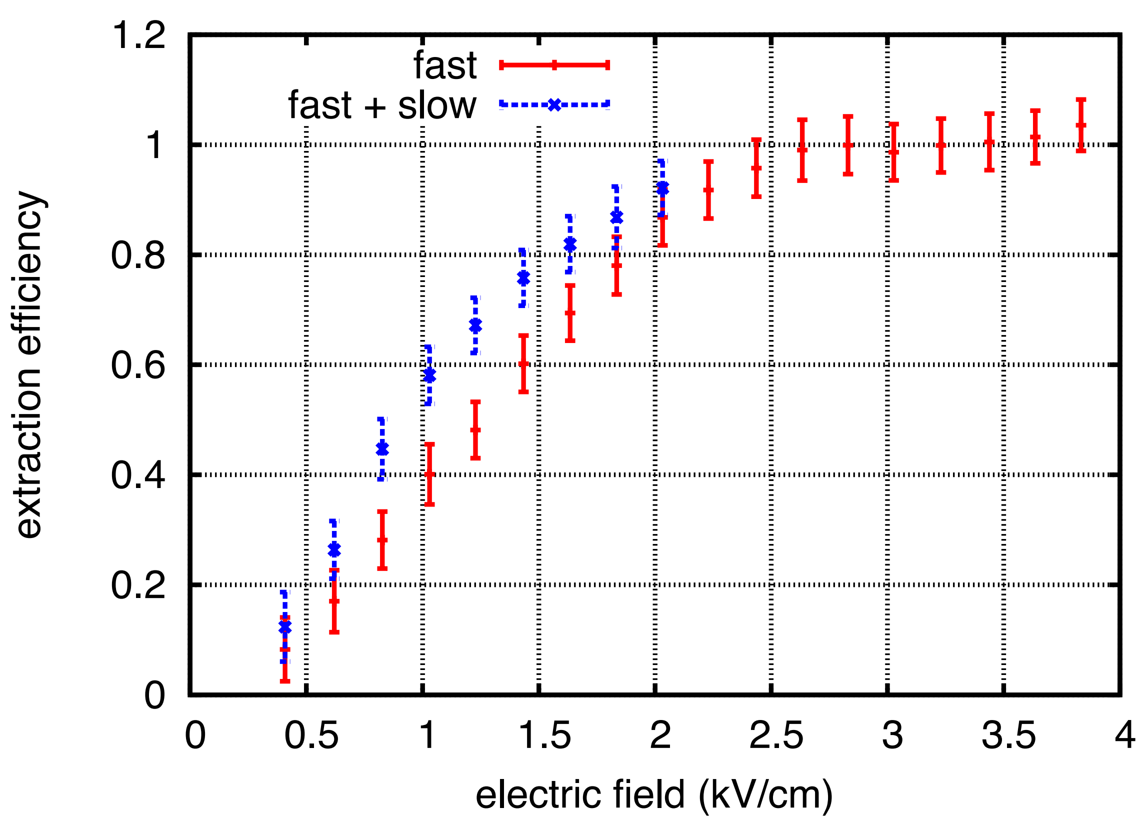
Back-up

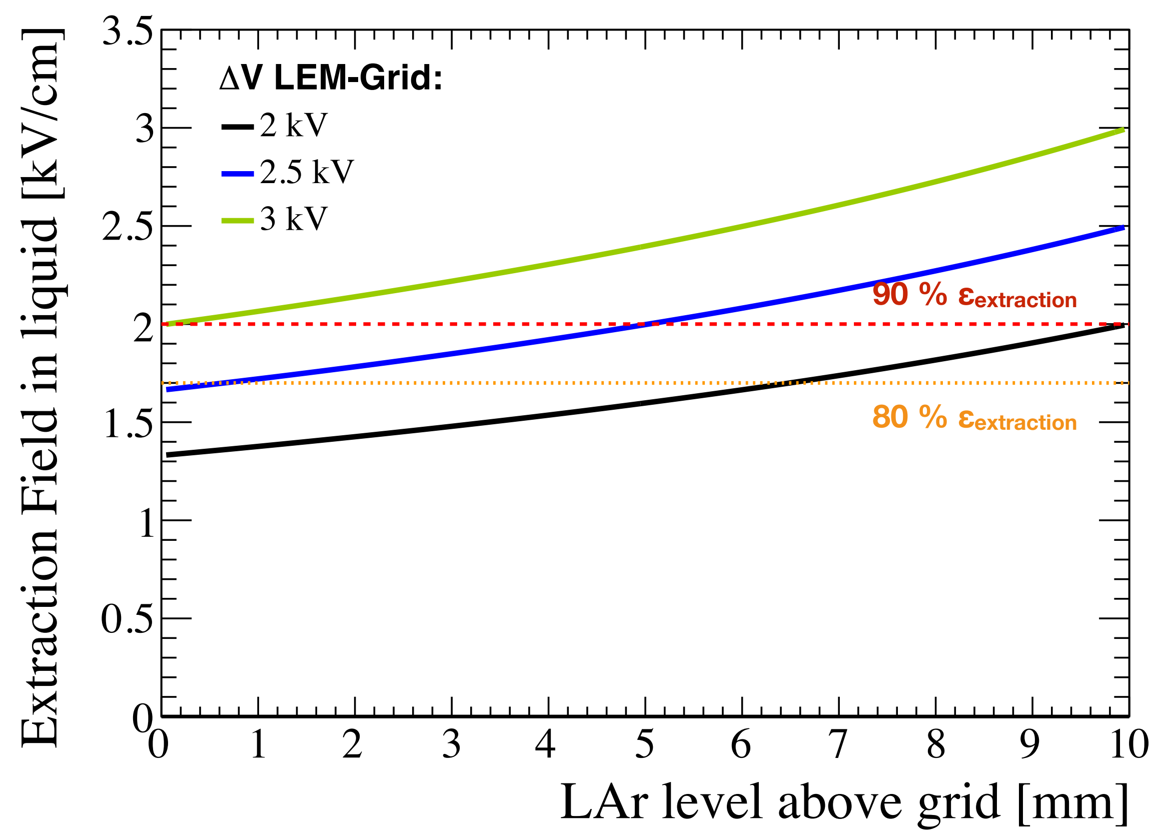
LAr stability



<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.



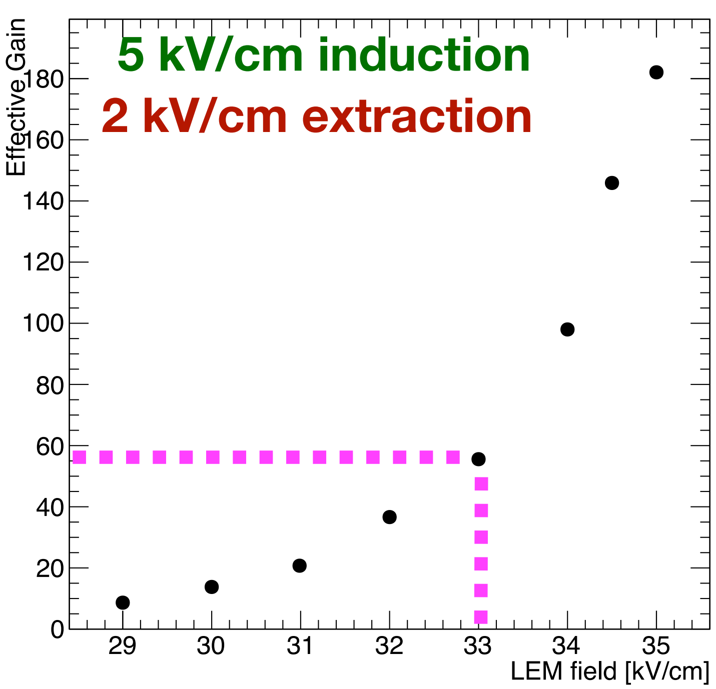


Effective gain factorisation

Effective Gain = **Extraction Efficiency** x **LEM Amplification** x **Induction Efficiency**

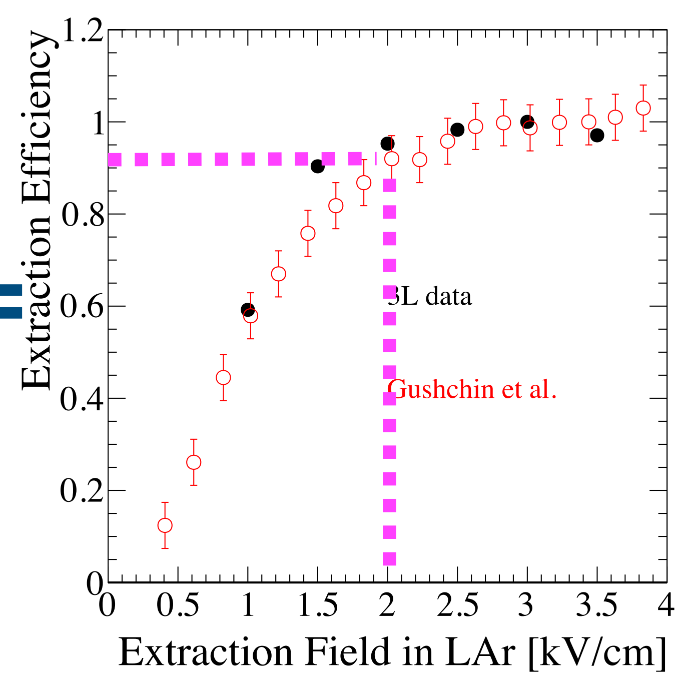
$$G_{eff} = \varepsilon_{extr} \times G_{LEM} \times \varepsilon_{ind}$$

example: for Geff = 56 before charging up = **2 kV/cm^{liquid}** ε_{eff} **= 0.9** **x** **33 kV/cm** **LEM-amplification =90** **x** **5 kV/cm** **0.7**

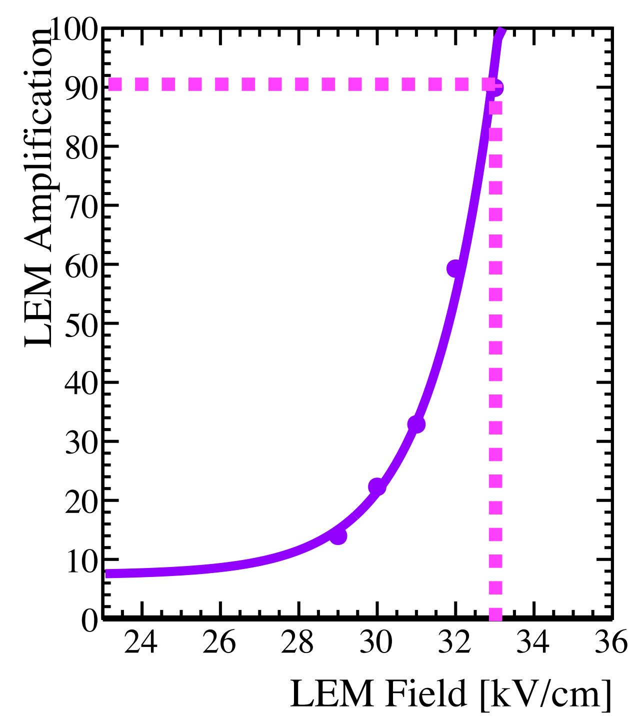


data from 3 l before LEM charging up

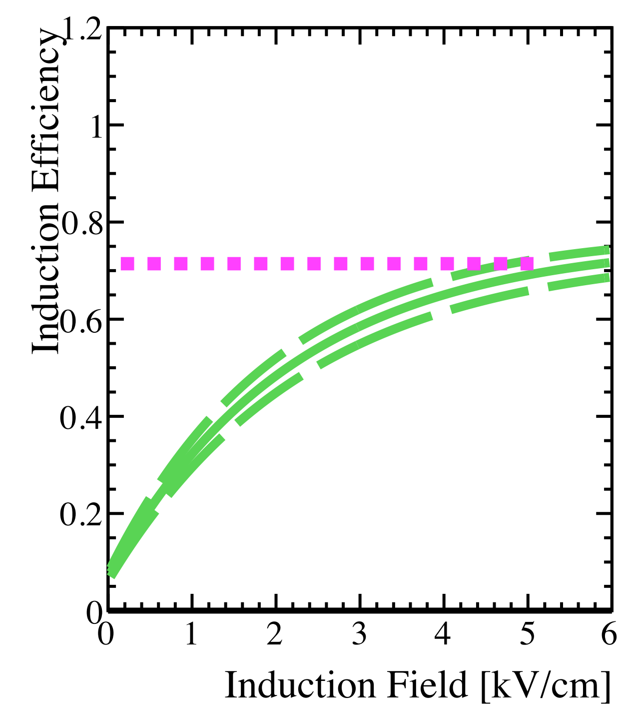
=



from simulation and 3l measurements



from 3l measurements

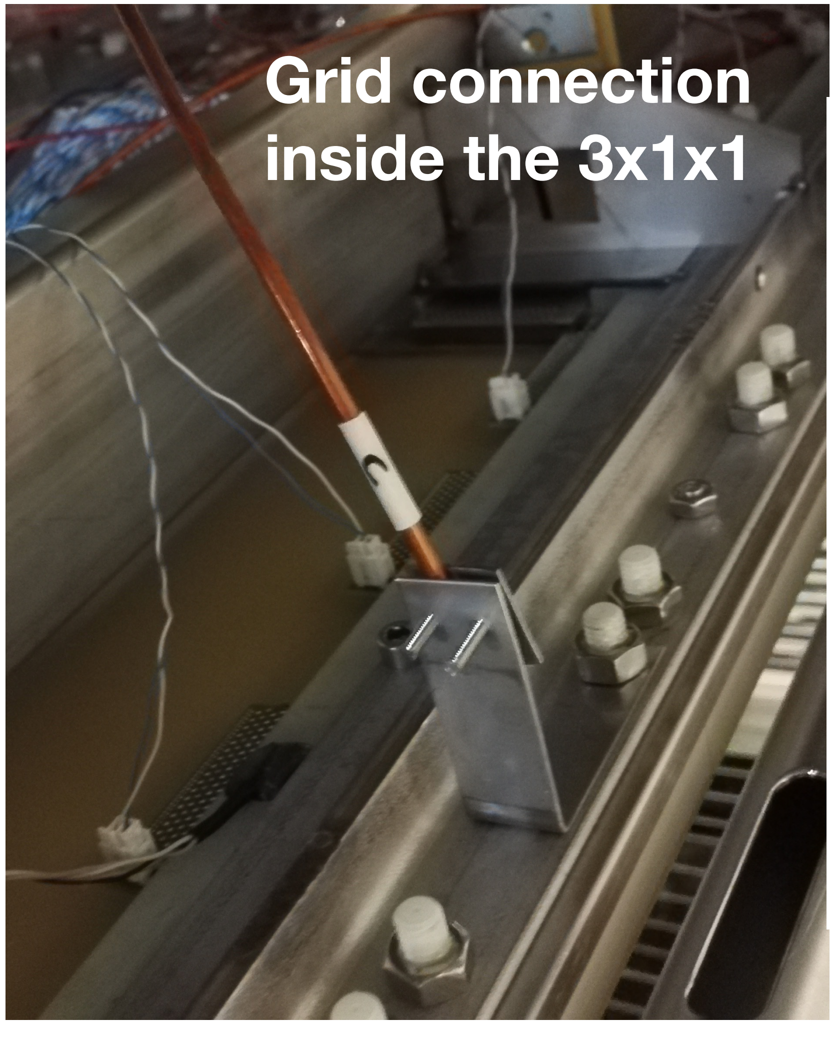


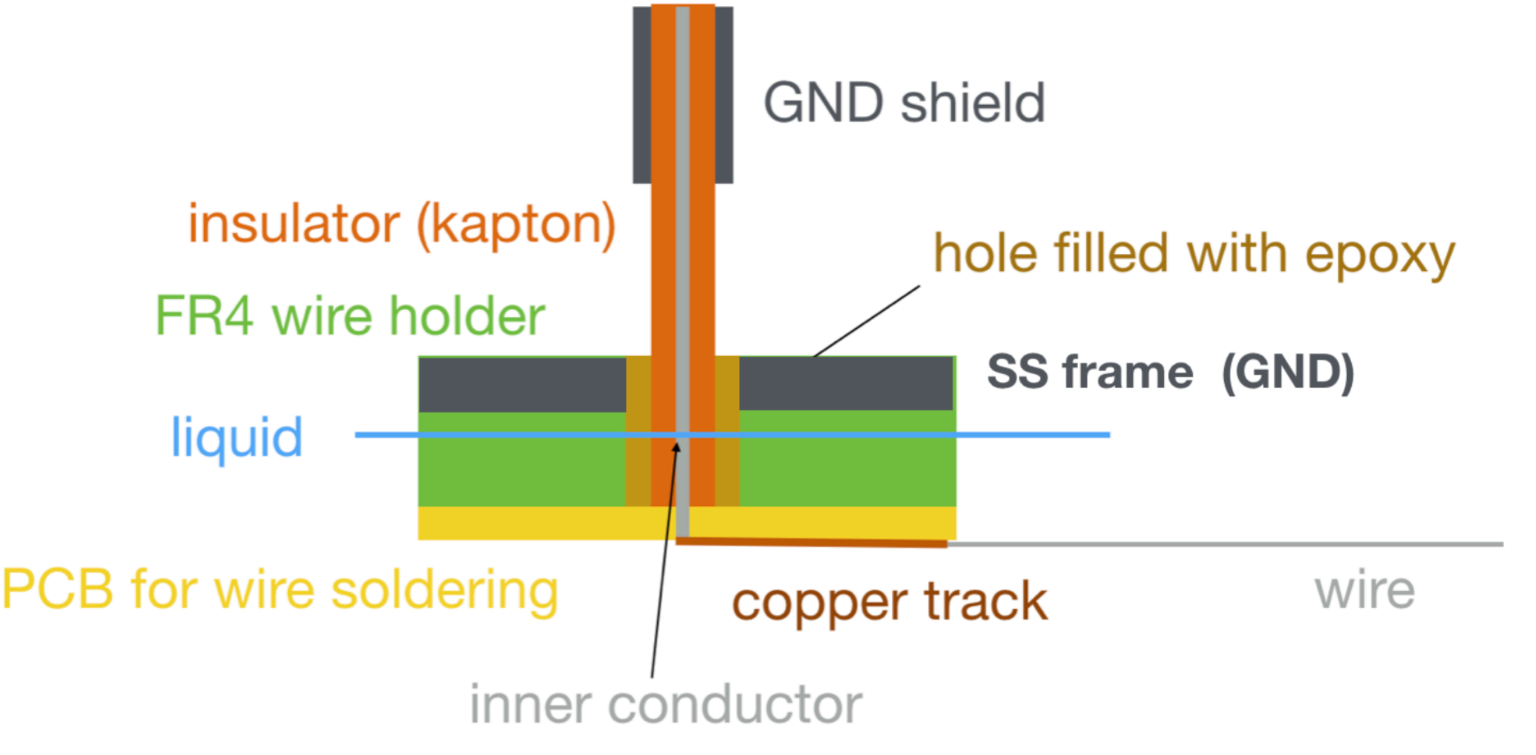
from simulation and 3l measurements

Dedicated HV tests: Grid

Issues found:

The 3x1x1 grid connection was found to have small discharges for voltages above 4.5 kV with the frequency of the discharges increasing with the voltage. At 5 kV, it starts to discharge continuously until it trips. A video of the camera feed of the discharges can be found here: https://www.dropbox.com/s/ieassgopf41oxdw/Grid311HVconnectionTrip.mp4?dl=0





Dedicated HV tests: Grid

WA105

Issues found:

We have a transient LEM-grid short circuit associated with the LAr level but which origin is unknown.

The fact that short was with LEM4 then LEM2 consistent with something moving around inside the detector

Date	Reading from LM-CRP8 [mm]	CRP movement	Short-circuit LEM-Grid
8.09.2017	17.6	No	No
8.09.2017	19.5	No	No
13.09.2017	**21.5**	No	**Yes with LEM4**
14.09.2017	23.6	No	**Yes with LEM4**
15.09.2017	24.6	No	**Yes with LEM4**
5.10.2017	19.3	Yes	No
6.10.2017	18.7	No	No
11.11.2017	**21.5**	No	**Yes with LEM2**
12.11.2017	17	No	**Yes with LEM2**
13.11.2017	13	Yes	**Yes with LEM2**
14.11.2017	9	Yes	**Yes with LEM2**
15.11.2017	5.6	Yes	**Yes with LEM2**

Dedicated HV tests: LEMs

September

15th

October

6th

9th 13th

16th 20th

23rd 2nd

LEMs immersed in LAr

Multiple LEM-anode tests in LAr.
All powered at 800-4000V (except the corners)

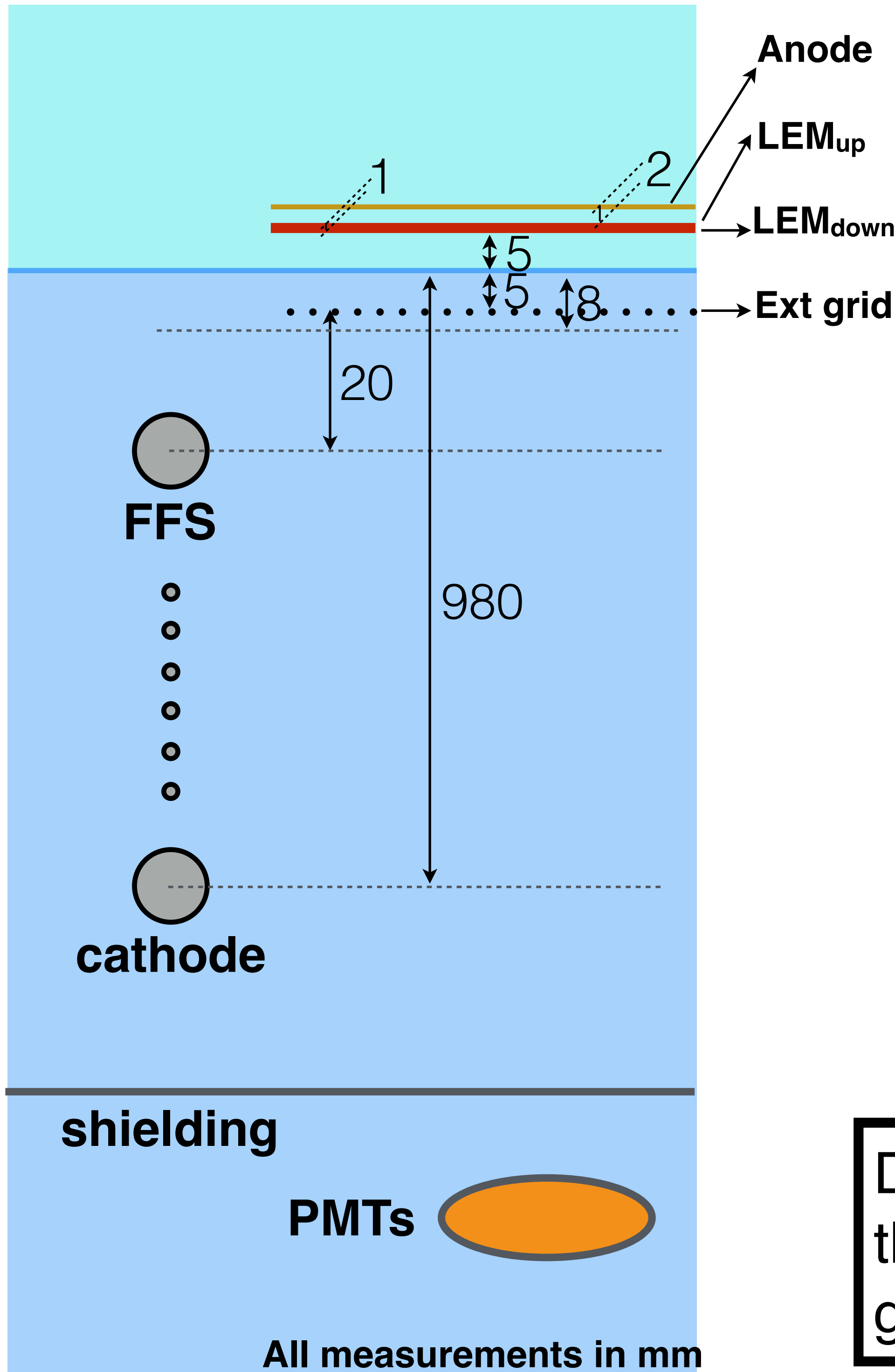
Multiple LEM-anode tests in GAr (nominal configuration).
All LEMs were not able to sustain more than 24 kV/cm

Standalone LEM-anode test: 2 LEMs (out of 9 tested) able to sustain more than 32 kV/cm

Multiple LEM tests and training:5 LEMs able to reach 500-3500V, 30kV/cm

All these tests performed with the grid floating

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			

Nominal values **Values reached**

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