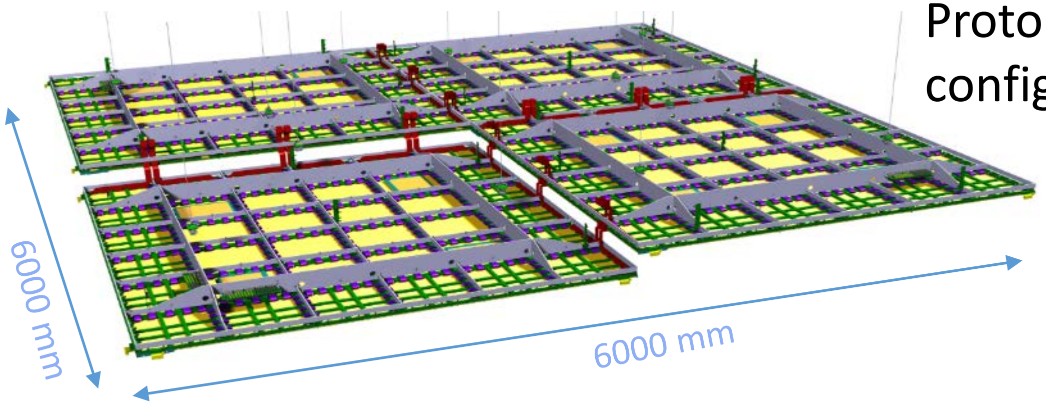
# Experience with Charge Readout Planes in protoDUNE-DP operation

- CRP commissioning after installation
- Geometrical characteristics: horizontality adjustment => planarity
- Extraction grid: HV commissioning and operation => HV stability
- CRP in running mode => microphonic noise and operation conditions
- Known issues, working parameter definition => improvement plan

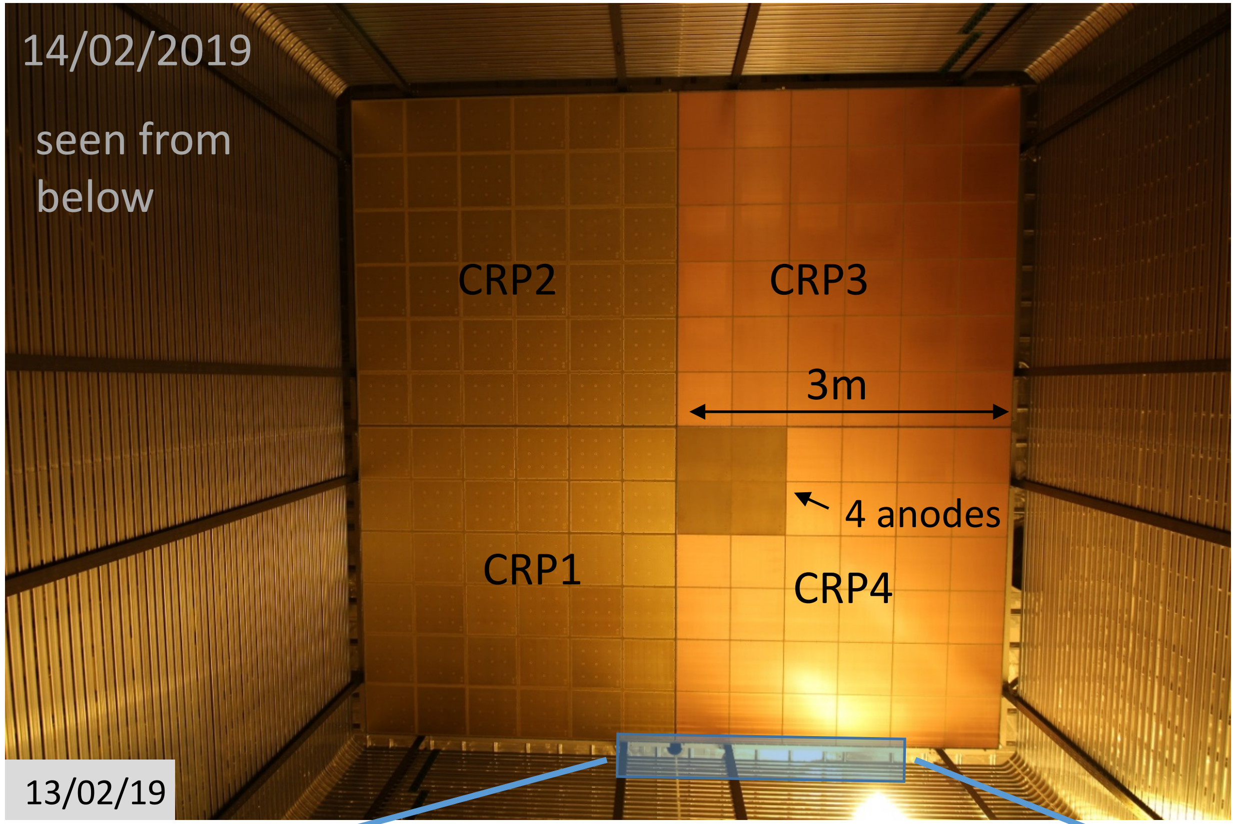
LEM/CRP Workshop
April 7th , 2020

# Charge Readout Plane (CRP)




ProtoDUNE-DP configuration

4 CRPs



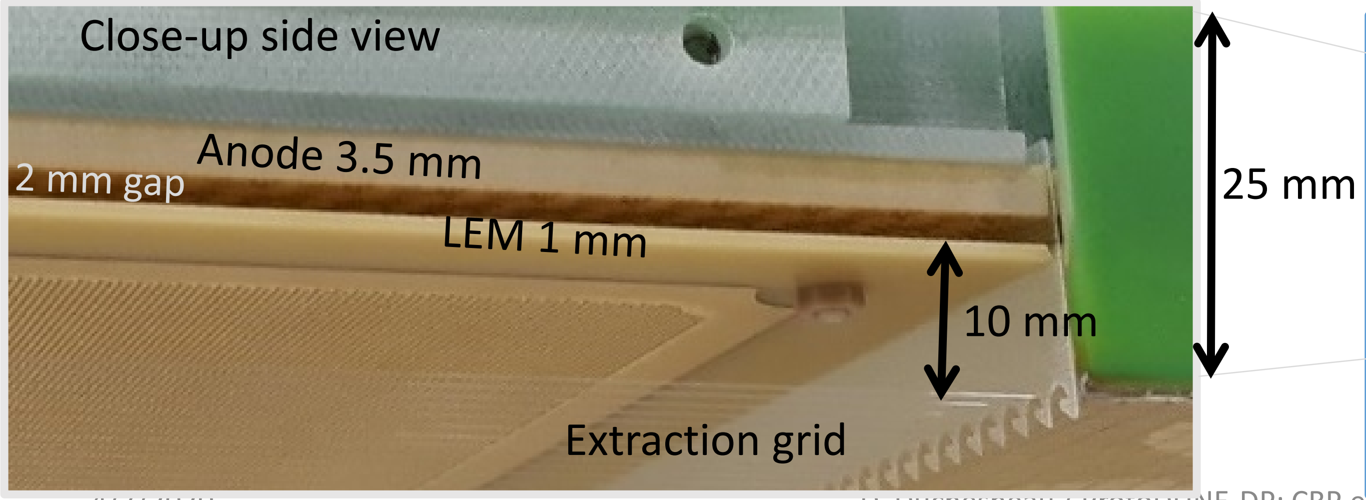

2 instrumented CRPs with 36 LEMs and 36 anodes (50x50 cm$^2$) :

- ✓ CRP#1 and CRP#2

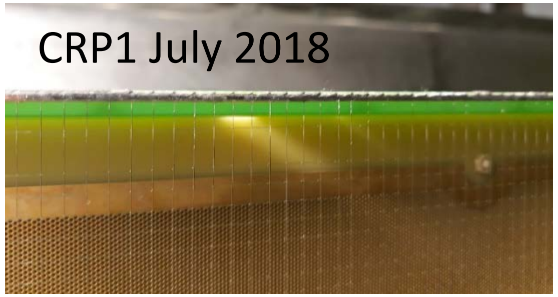
2 CRPs without LEMs:

- ✓ CRP#3 no anode, CRP#4 has 4 anodes (SP like readout)

ALL 4 CRPs have a 3x3 m$^2$ extraction grid

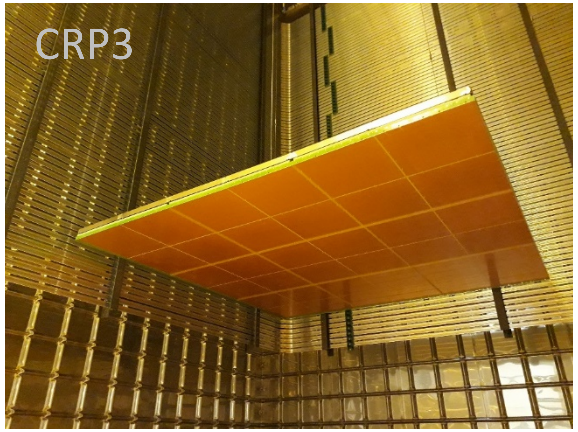


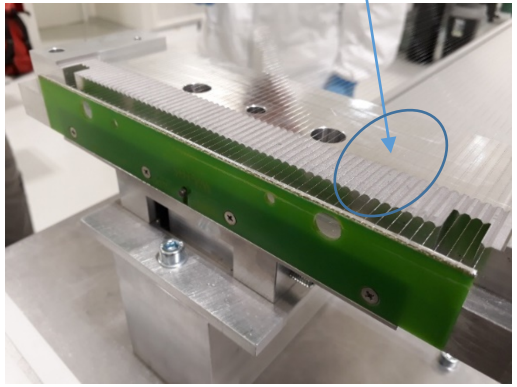

## Some feedbacks from ProtoDUNE-DP construction, tests and installation (cf: previous talk)

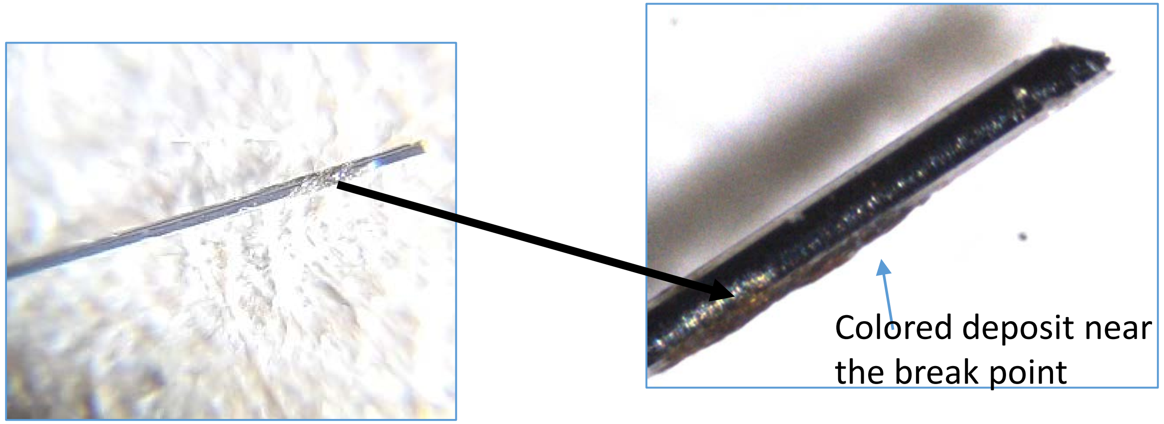



- The **construction and installation** didn't present major difficulties nor drawbacks apart from:
  - ❑ CRP1 first version with **insufficient grid tension** at cold
    ⇒ fixed in July 2018; G10 and stainless steel wire mechanical properties have to be characterized again in specific setups
  - ❑ CRP3 broken grid wires (17/1920) after installation in October 2019 (most probably due to projection of soldering flux on wires not properly cleaned); CRP1 and CRP2 built before were not affected and for CRP4 built after the cleaning procedure was stricter

After investigation and careful check of the 1920 wires it appeared that on a few wires of this CRP there was a sort of small coloration with small deposit along the wires. This was usually located between 1 and 10cm from the PCB supporting plate






=> For next generation CRP: use solder without acid flux

Construction process is understood as well as the schedule and human resources needed

- However some simplified procedures and systems can be foreseen (ex: transport box, G10 frame….)
- Decoupling system: finer adjustment and reliability of sliding



See next talk from Benjamin

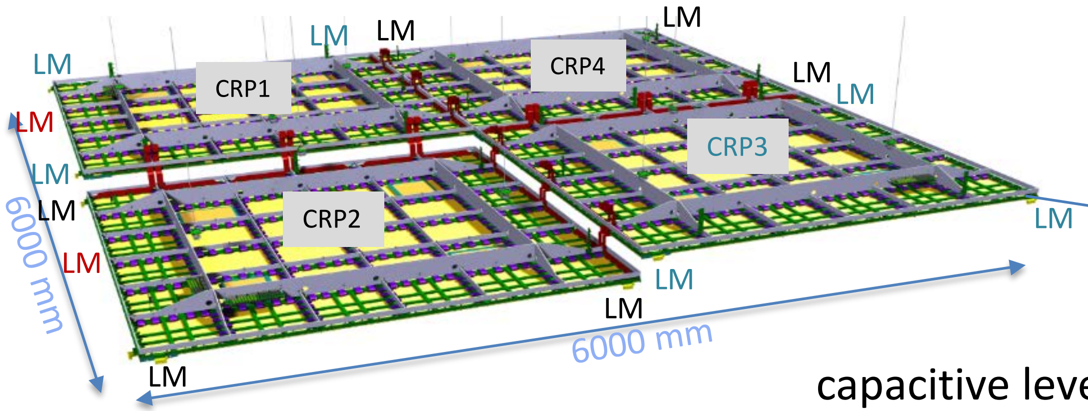
# some feedback from ProtoDUNE-DP construction, tests, installation and operation

- The **cold box tests** were essential in testing LEM and grid HV behaviour and pointing to weak aspects of the CRP grids and HV distribution which were then modified
  - Turn around was very effective but instrumentation was too limited (also HV and Level meter slow control)
  - All the aspects have been improved and retested
  - Liquid argon surface was probably too perfect compared to the real NP02 cryogenic conditions

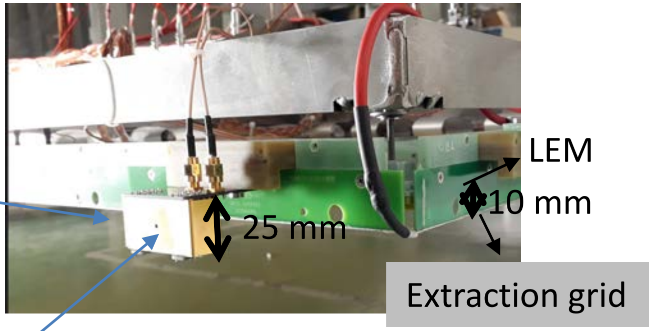

=> in the future need to implement wavy surface and gas purity similar to real conditions


# CRP horizontality adjustments and extraction grid commissioning in ProtoDUNE-DP

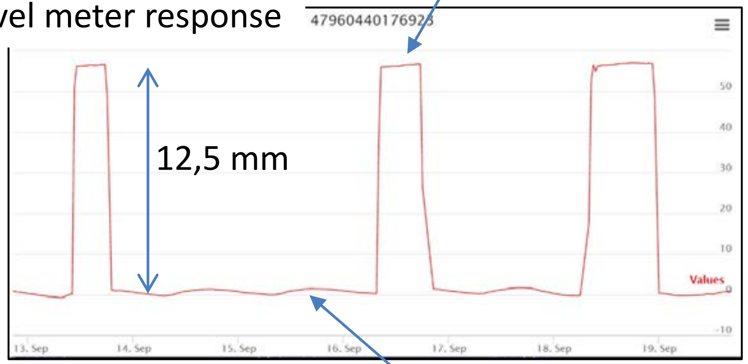
# Level meter calibration



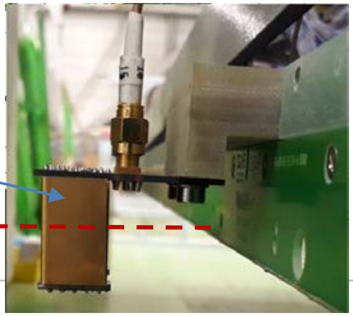

First detector commissioning operation




Level meter response




capacitive level meter: design 250 μm precision

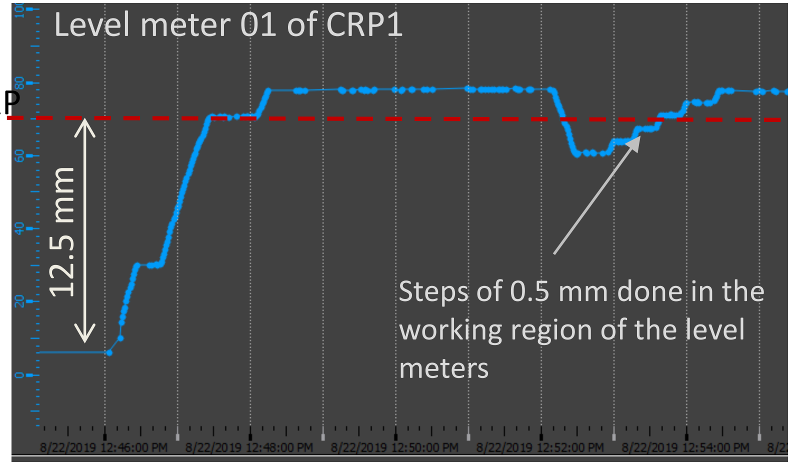


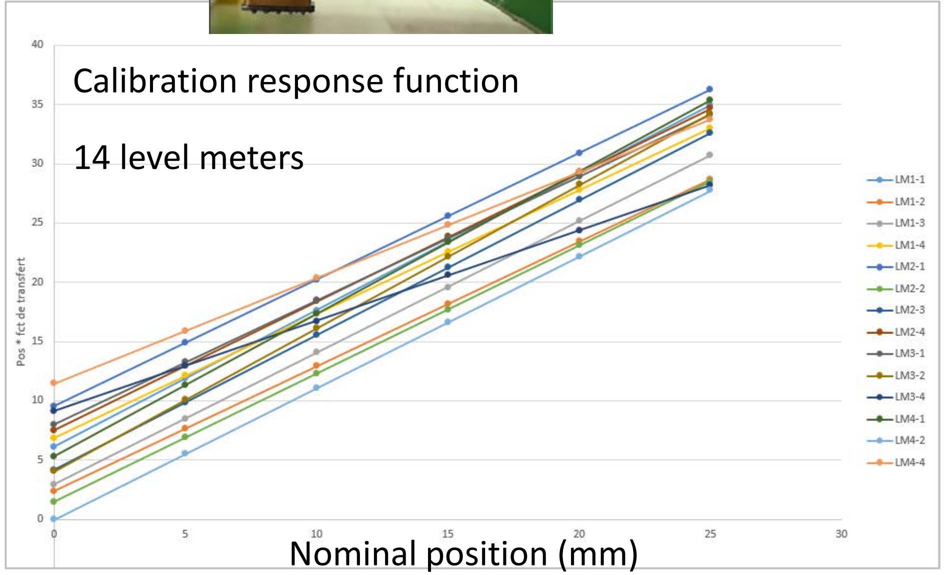

- CRP1 and CRP2 have 4 level meters: 3 corners + 1 along 1 side
- CRP3 and CRP3 have 3 level meters: 3 corners
- **No Level meter in the middle of detection plane**

Calibration of the LM electronics done in Feb 2019 but 10-30% off when operated

Calibration of the 14 level meters located around the 4 CRPs redone in-situ

-moving the CRPs by step of 500 μm around the nominal position
-obtained from the motor system after liquid in contact with level meters

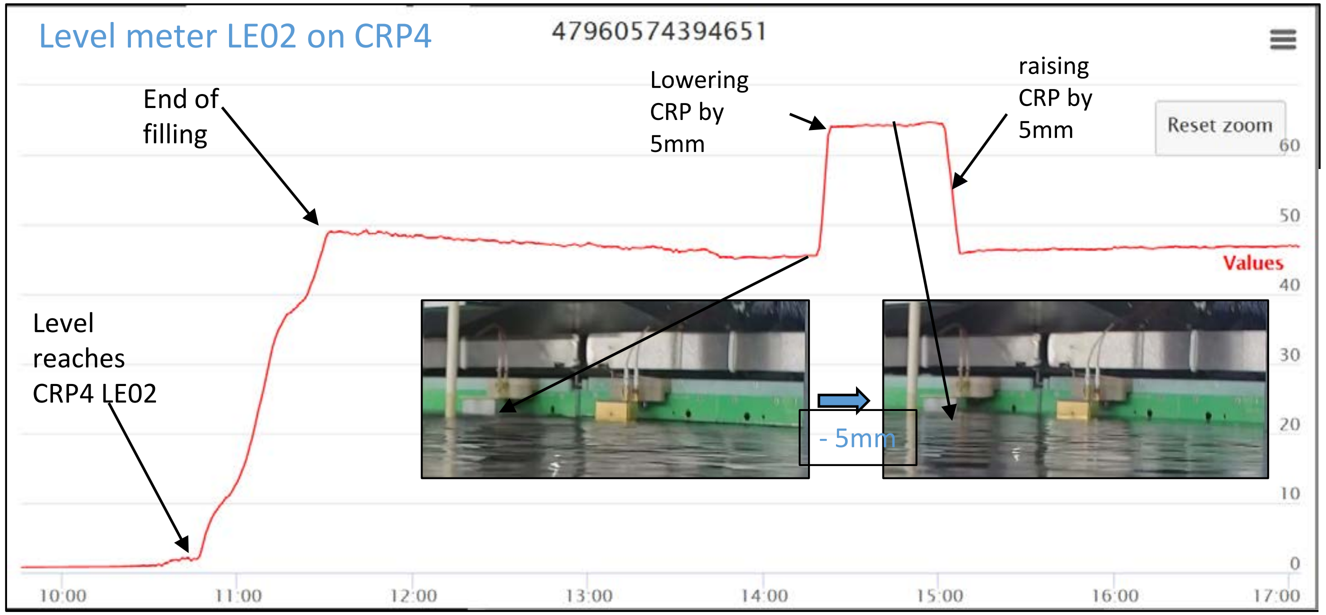


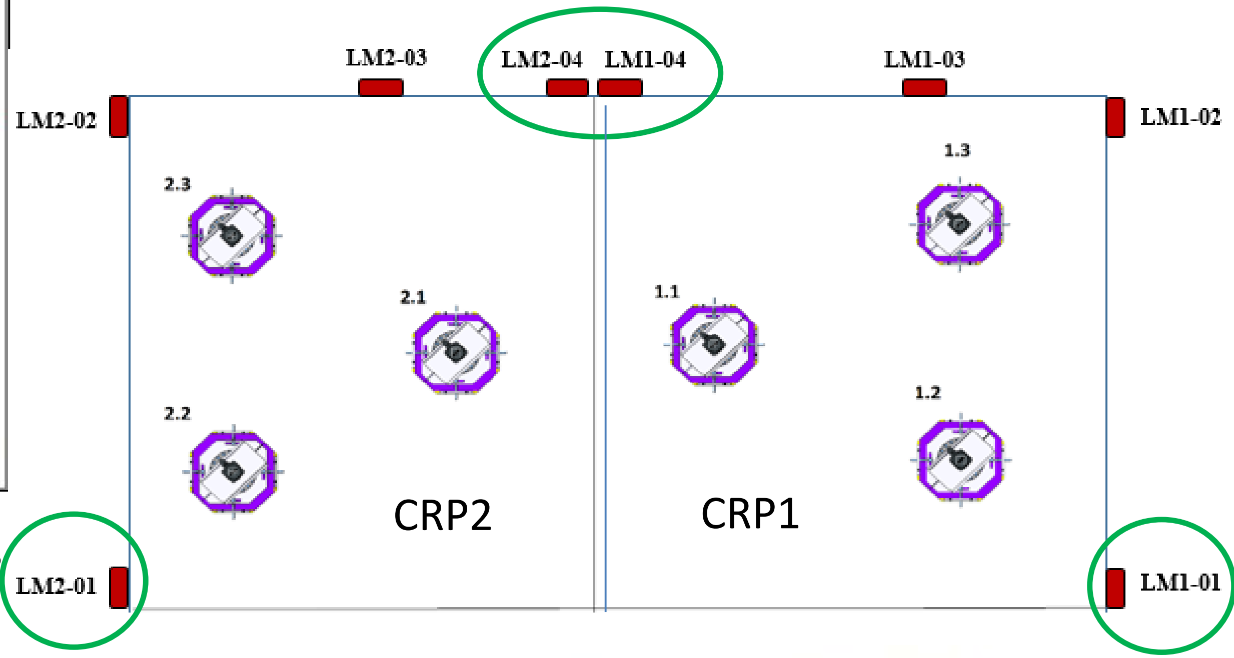



# Level meters and CRP horizontality

August 9, 2019

CRP corner seen by cameras




<u>Observation</u>: during the end of filling on Aug 9th some level meters saw the liquid before the others (up to 12 minutes => a few mm)


LE101 10h42 6% - 50% => delta= 44%
LE102 10h43 9% - 50%=> delta= 41%
LE103 10h47 4%- 47%=> delta= 43%
LE104 10h55 10%-40% => delta= 30%

LE201 10h59 15%-43% => delta= 28%
LE202 10h48 1% - 44% => delta= 43%
LE203 11h01 14%- 48% => delta= 34%
LE204 10h59 15-44% => delta= 31%

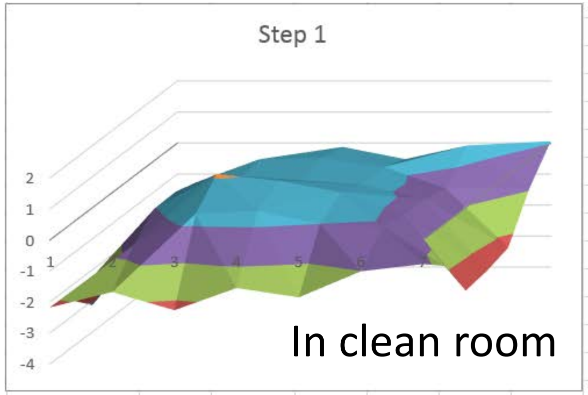
# Planarity measurement in cryostat

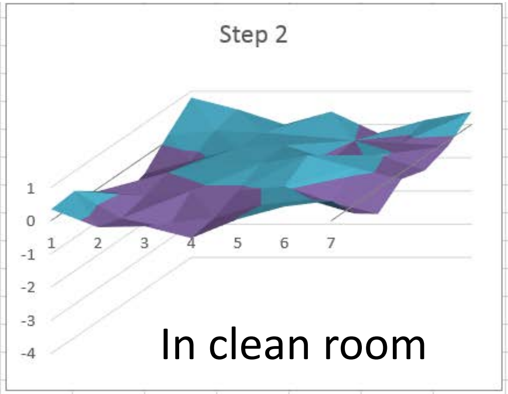
Jan. 2019

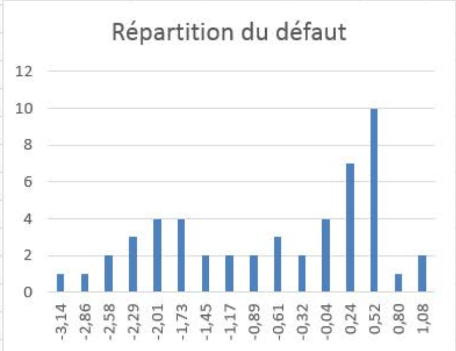

The planarity of the CRP is measured and adjusted on 50 points and 2-3 iterations.

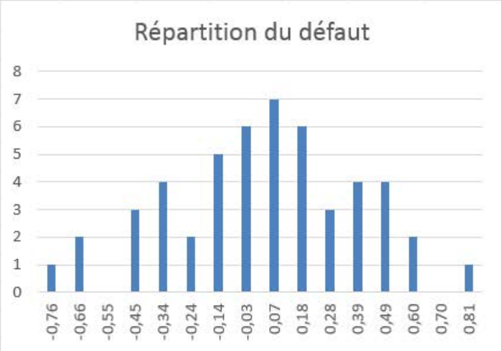
This is performed in one day for a CRP.
There are 2 campaigns of tuning: 1 before the cold box and 1 when inserted in EHN1 cryostat

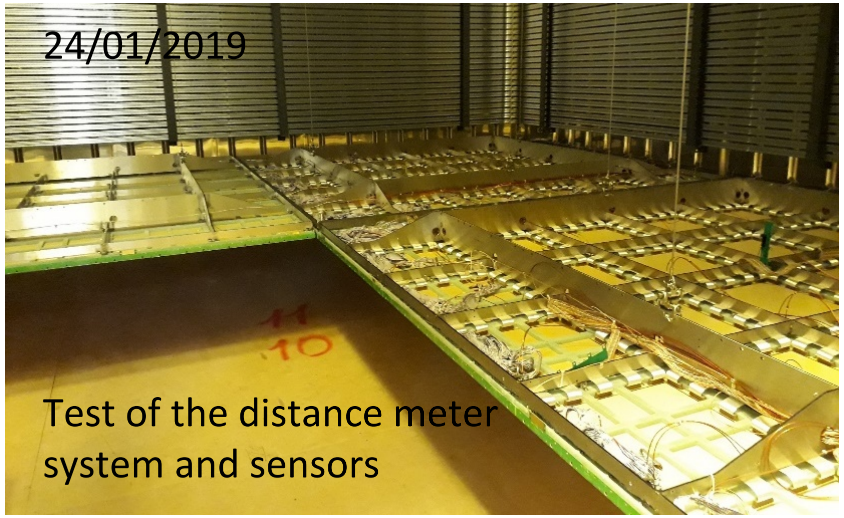
Example: Planarity distribution for CRP3 :




| Values in mm | Initial max diff. | Initial std dev | Bdg 185 Max diff | Bldg 185 std dev | Final max diff (mm) | Final Std dev (mm) |
|---|---|---|---|---|---|---|
| CRP1 | 3,71 | 1,03 | 1,53 | 0,309 | **0,97** | **0,240** |
| CRP2 | 5,95 | 1,55 | 1,54 | 0,363 | **0,94** | **0,200** |
| CRP3 | 4,22 | 1,192 | 1,57 | 0,357 | **0,73** | **0,170** |
| CRP4 | 5,02 | 1,21 | 1,16 | 0,280 | **0,90** | **0,240** |

Planarity over a whole CRP is better than 1 mm.

# CRP horizontality adjustments

**During commissioning** August 2019

**Planarity over a whole CRP measured before final installation better than 1 mm**

Observation: during the end of filling on Aug 9th some level meters saw the liquid before the others

=> CRPs not any more completely horizontal

2 possible main contributions:

- The cryostat top roof deformation where the 12 suspensions sit or any change on the roof since the installation 6 months before:
  
  => can generate an angle of the CRP plane: easy to correct with the 3 suspension adjustment

- Mechanical deformation of the CRP structure between warm installation and the final configuration at cold
  
  => No possibility to correct

Procedure to adjust the horizontality: (not easy with no measurement in the middle)

- Adjust the 3 suspension to find the average CRP plane made by the 3 anchoring point horizontal

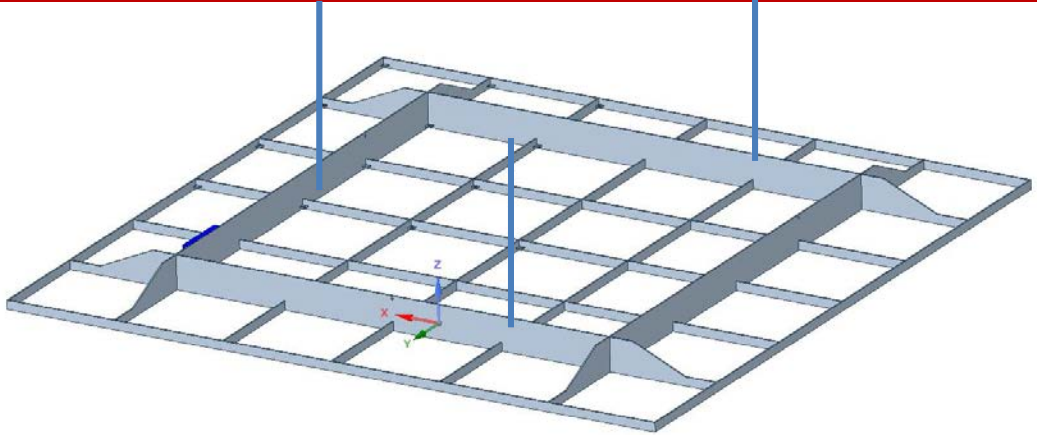
=> iterative process minimising the time spread among level meters when raising the CRP out of liquid

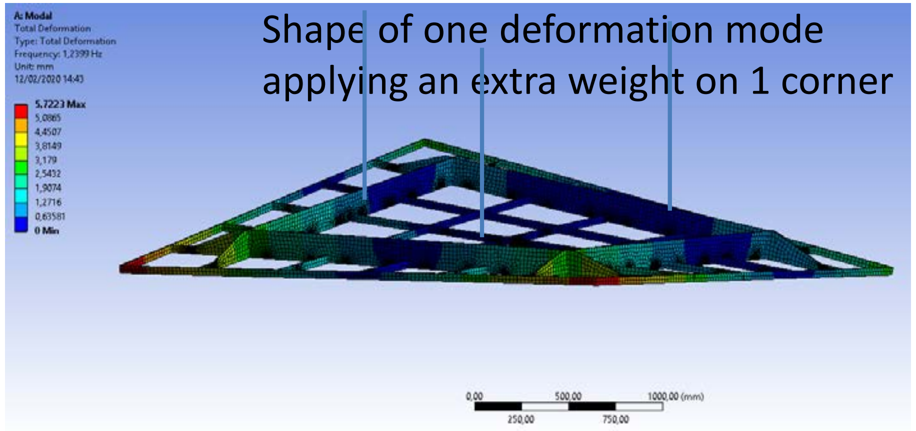
The procedure failed in improving the horizontality because of the absence of information from 1 corner

=> Sign of the presence of a shape distortion

# CRP planarity

- Making the assumption of a ‘saddle’ shape deformation
  - => perform an iterative process assuming 2 opposite corners lower than the 2 others
  - => fine adjustment of the suspensions to align level meter information from 2 opposite corners and find the correction on 1 suspension get the 2 other corners at similar height
- After this horizontality optimisation the planarity on CRP1 and CRP2 was estimated with **spread of +-2mm** which is more than expected from simulation.




Shape of one deformation mode applying an extra weight on 1 corner

<u>From mechanical aspects</u>: one potential reason is from the addition and modified mass distribution along the Invar structure due to installation of the cabling of HV and various sensors after the final positioning in the cryostat.

Effect taken into account in the readjustment of the horizontality and the nominal vertical position of CRP1 and CRP2 such that the **=> grids stay immersed by at least 4 mm in the liquid**

- caveat: at this nominal position of the CRP the 2 low corners may have the gas layer of 2mm instead of 5mm

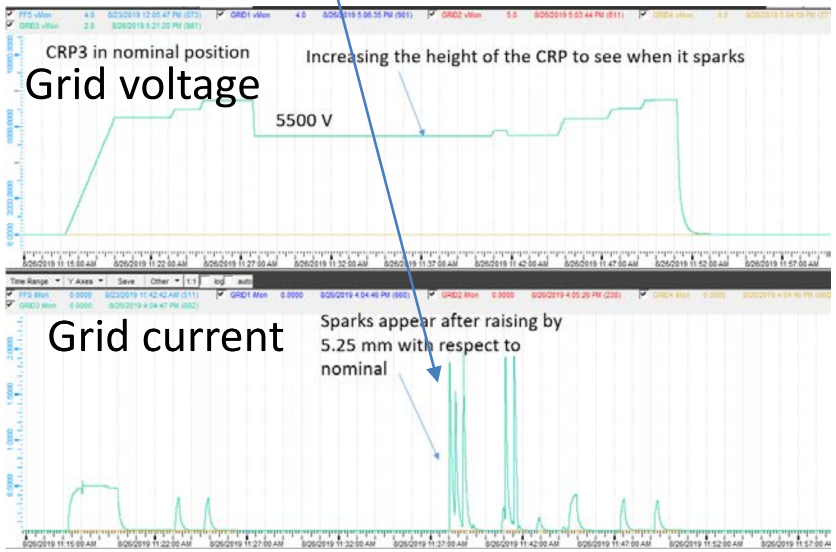
# CRP horizontality control and extraction grid commissioning

The control of the horizontality and the nominal position was performed by raising slowly the CRP with HV set on the grids until sparking occurs

Requirement: 5mm

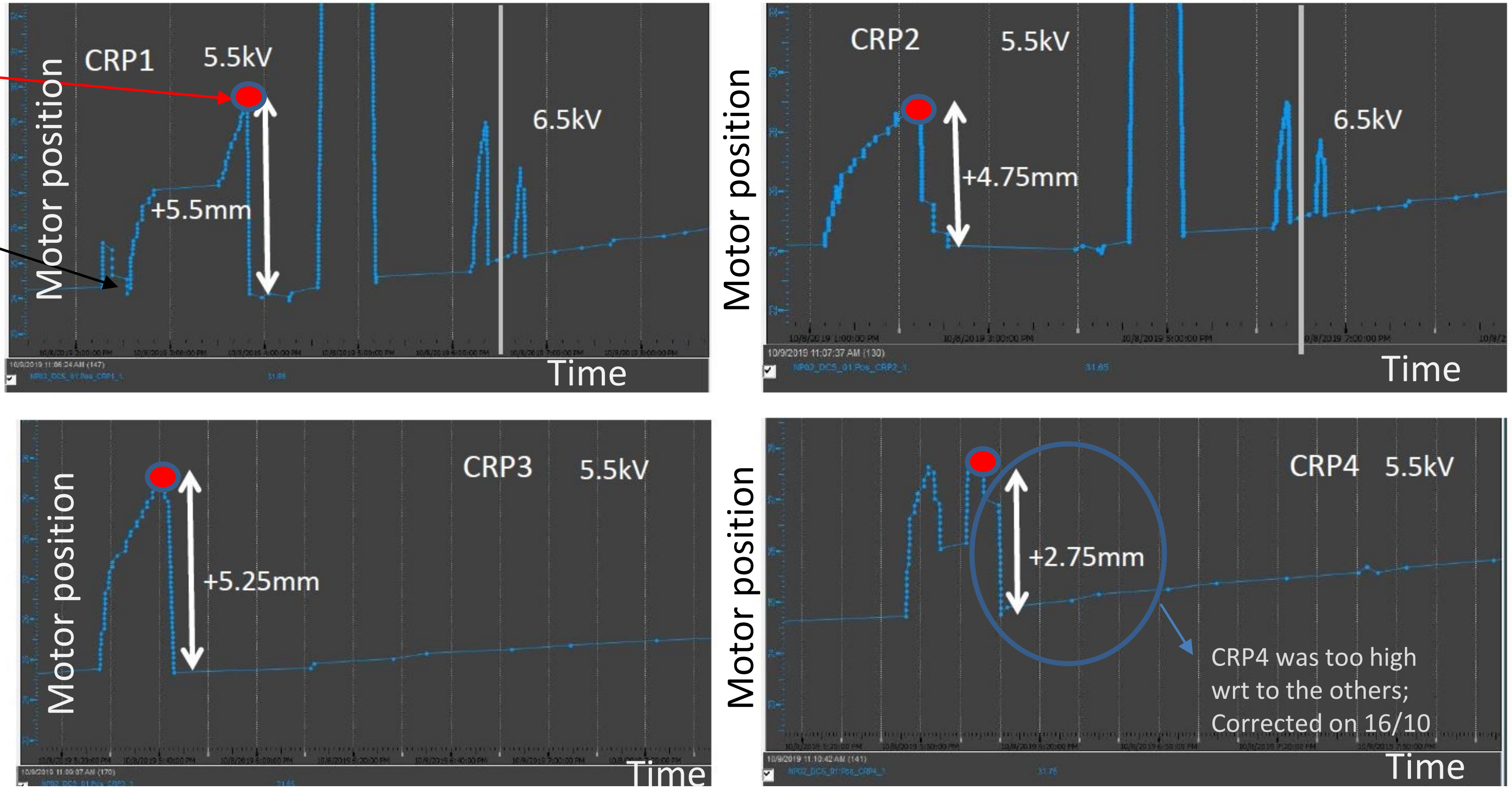
**Measure the position when grid sparking starts**

Nominal CRP position
Grid immersed




CRP Motor position during raising up test : (in mm)

- Start from nominal position grid immersed and raised up
- Monitor the position current or sparking starts




- It confirms that the geometrical deformation is properly taken into account to **keep the grid below the LAr surface at the nominal distance of 5mm for CRP1, 2 and 3**.
- For the CRP4 having no LEMS, the CRP was too high: it has been corrected by lowering it by 1.8 mm on 16/10.

# Commissioning of the automated level tracking system:

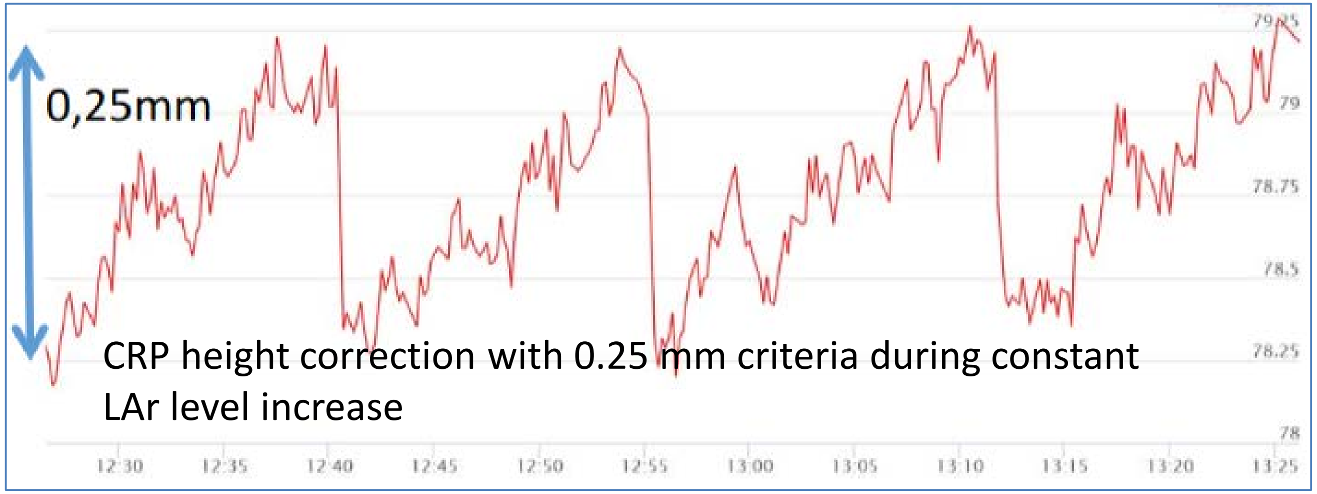
3 motors/CRP

<u>Two main goals:</u>

- ❑ To lower the CRP from its home position until the grid is immersed. Done in 2 steps: a first approach and final positioning
- ❑ To track the liquid argon level variation when the grids are immersed and correct the motor positions when the level has changed by a defined value

=> CRPs stay always within a certain range at its nominal position. The typical range chosen in operation is 150 um in very stable cryogenic condition or 250 um most of the time.
The control of the CRP position with respect to the liquid argon level is done using the average of the CRP level meters computed over 5 seconds


- <u>Setup of automatic CRP tracking</u> of LAr level change :
  - precision better than 0.1 mm reached




CRP height correction with 0.25 mm criteria during constant LAr level increase


The system can act for 1 to 4 CRPs together as a master system. All the motors will get the same position change
Feedback loop is provided by the level meter information.

Siemens automate

# CRP grid commissioning activities in the period from 12/08 to 24/08

- <u>HV tests of the CRP grids</u>
  - At the beginning of the commissioning period the grids of the 4 CRPs had HV trips in similar conditions at ~3kV:
  - Identified due to the presence or Ar accumulating in the SHV connectors of the grid cables on the cryostat roof.
  - The gas was channelled from the cryostat by the cables themselves, flowing in between the red jacket and the ground shield (detected with Ar sniffer)
  - Problem mitigated by building connections boxes filled with araldite for the grid SHV cables in order to stop the flow of the gas in the cable and protect the SHV connectors

- <u>CRP alignment and horizontality adjustment</u>

  ⇒ taking into account geometrical deformation mostly in corners in the readjustment of the horizontality and the definition of the nominal vertical position of CRP1 and CRP2 such that the grids stay always immersed by at least 4 mm in the liquid

  ⇒ The caveat is that at this nominal position of the CRP in the vicinity of the two low corners the gas layer is about 2mm instead of 5mm

  ⇒ These deformations are addressed and will be corrected in an updated design of the CRP structure ongoing

# CRP extraction grid HV commissioning

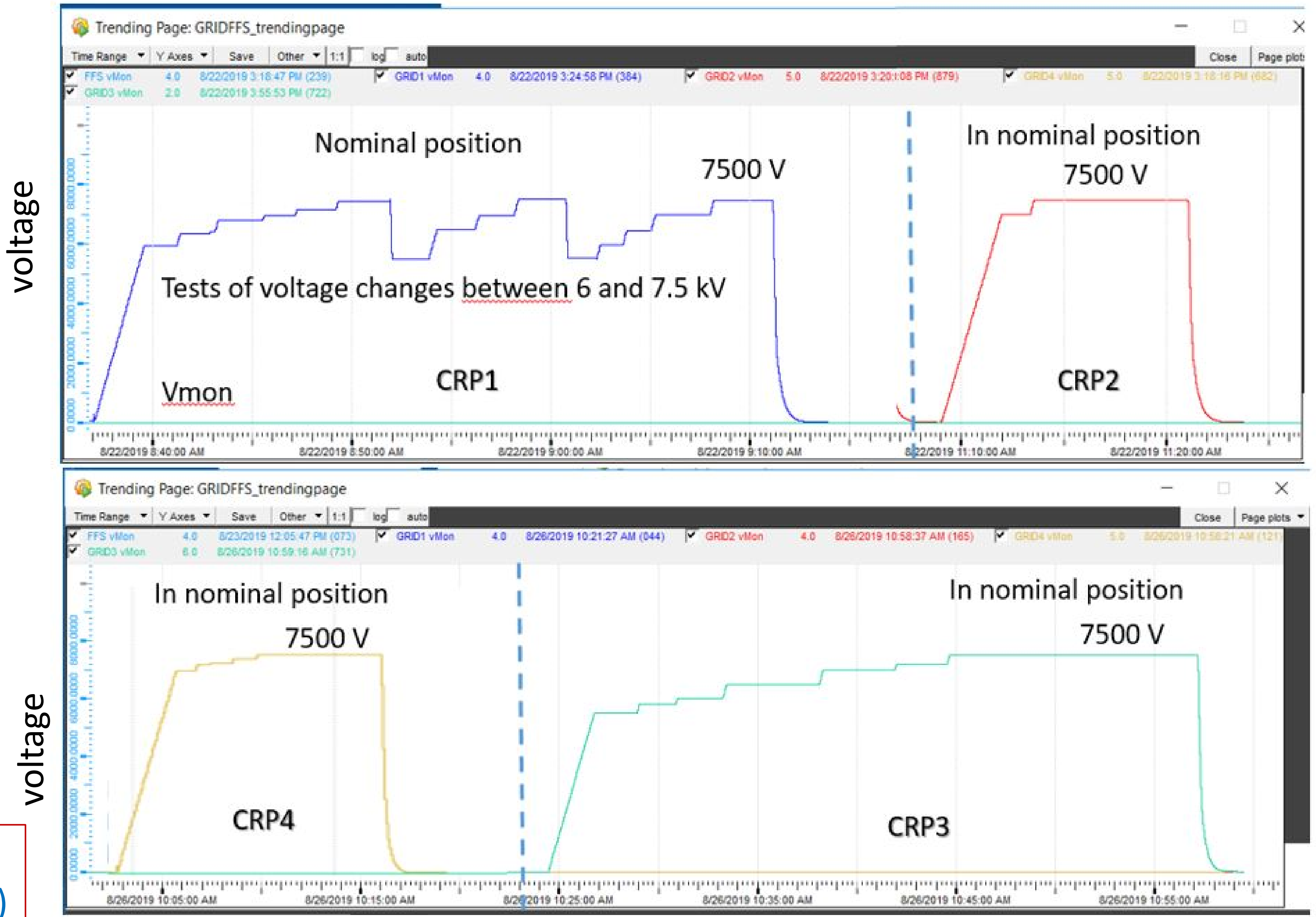
22/08/2019

Goal: 7 kV

- After 14 level meters of the four CRPs were calibrated
- Precise horizontality adjustments performed with 0.1mm precision

- After the alignment process, the CRPs were positioned in their nominal position to test the high voltage performance of the grids
- After implementation of the connection boxes to remove argon leak in cables

Results: Extraction grids of all 4 CRPs reached 7.5kV (goal being 7kV)



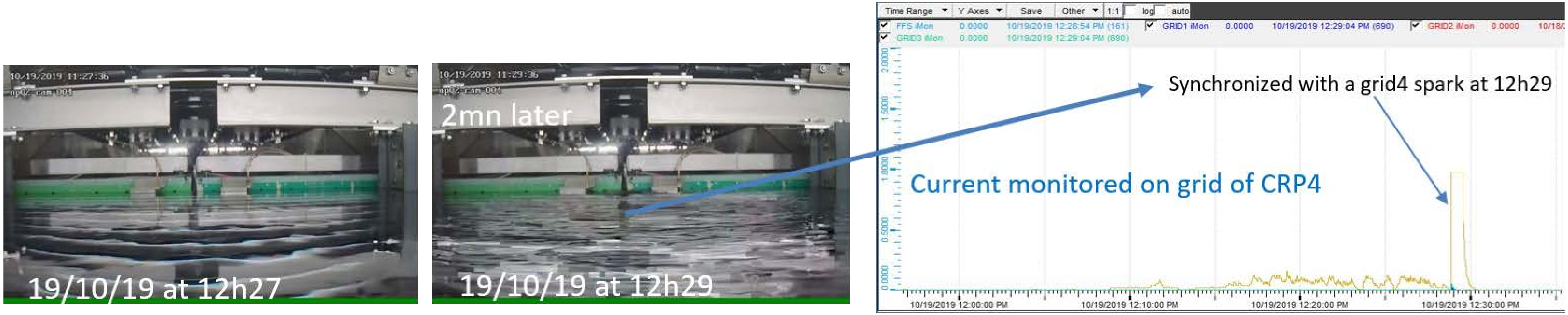
# CRP extraction grid stability

Extraction grid stability in terms of HV is defined by the occurrence of sparks (usually for grid HV above 5 kV)

2 categories observed:

<u>1) Grid sparking when grid exposed to gas:</u>

- ❑ The CRP grid and LEM operation is closely related to the stability of the cryogenics and liquid-gas interface.
- ❑ The presence of bubbles impacts the HV stability of the whole CRP system and makes it difficult to operate.
- ❑ In such conditions, there is a possibility to get local liquid movement exposing the 6\,kV grid to the gas which can produce sparks that can be damageable for the FE electronic cards connected to the grounded anodes




<u>2) Grid sparking from  coupling system with LEMs:</u>

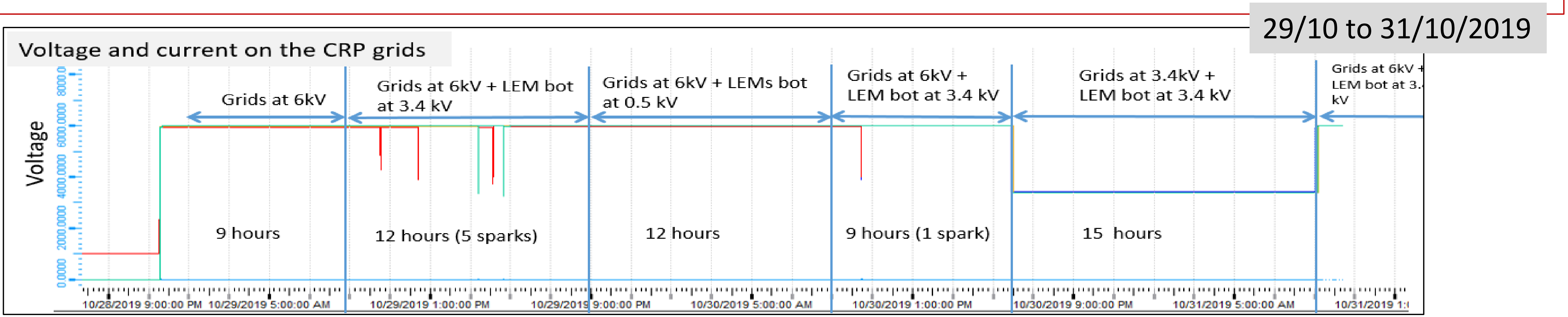
Already covered in yesterday's talk by  G. Eurin

# CRP grid stability tests

- Grid alone at nominal position does not spark, unless of bubbles on the field cage or strong movements of the surface seen also with LAr projections on temperature probes in the gas phase

Detector operated 23 hours with LEMs 2.9 kV across, extraction (grids 6kV) and No cathode:


- Grid sparks occur mainly when LEM HV is ON
- Coupling of grid+LEMs both at HV generates collective instabilities which produce grid sparking + typically several LEMs at the same time




## Results on the rate from longer duration test: (cf: G. Eurin's talk)

- **0.2-0.4 sparks/h/CRP** independent of cathode ON or OFF for **Δ V = 3.1 kV**
- sparking rate increases by increasing the HV across the LEMs: **0.4 -0.9 sparks/h/CRP for Δ V = 3.4 kV**

## CRP in running mode

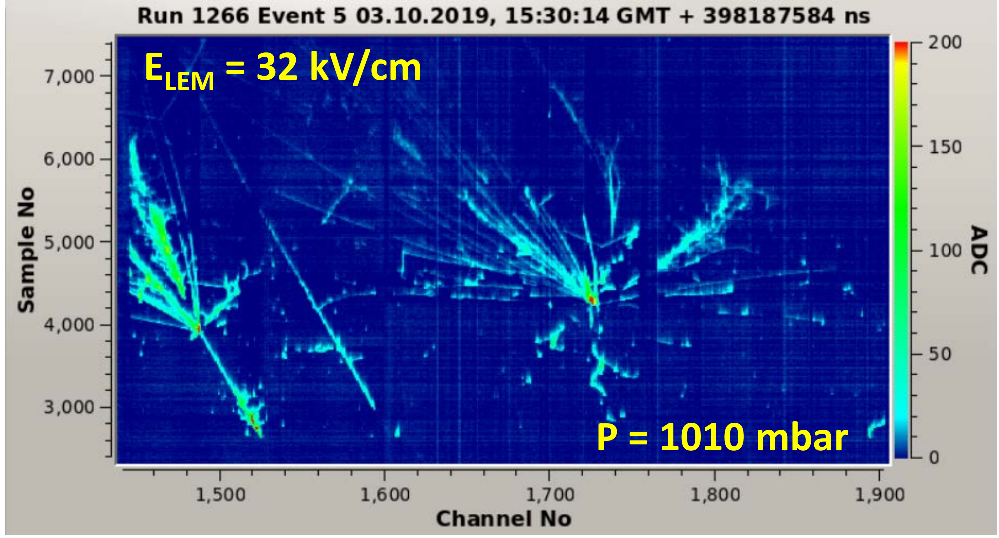
## microphonic noise and operation conditions

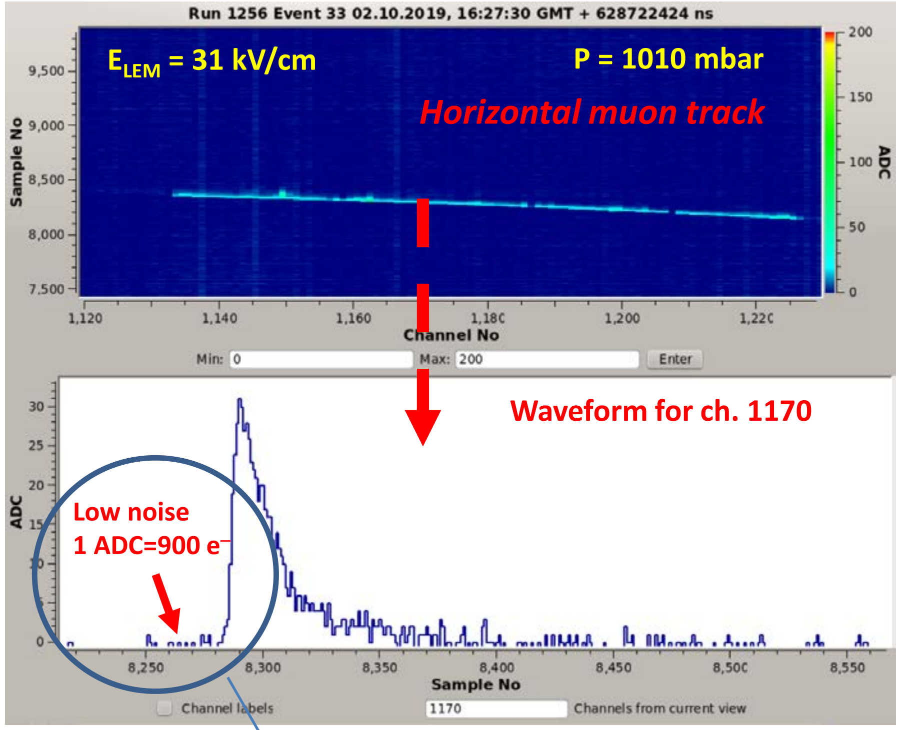
# CRP during data taking

Four different periods of data taking with:

- Voltage across the LEMs: $\Delta V_{LEM}$ **= 2.9, 3.0, 3.1 kV and 3.2 kV** for 2 of the 4 periods
- Induction field of 2.5 kV/cm ($V_{top}$ = 0.5 kV)
- Extraction grid voltage 6 kV ; set to 5.5 kV for Oct data (5.3 kV for the 3.2 kV run)
- Cathode Voltage set to 50 kV => drift field in the first meter about 0.2 kV/cm
- Both CRP1 and CRP2 running together

***Multiple hadronic interactions in a shower***




Noise is usually at the level of 1 ADC count

cosmic ray events from October run

- Sept 2019: during pressure cycles at 1045 mbar
- Oct. 2019: at 1010 mbar (run taken before the increase of the nominal pressure on Oct. 18)
- Nov. 2019: at 1045 mbar
- Jan. 2020: at 1045 mbar

Clean events and tracks recorded

**Main run limitation when LAr surface is without bubbles:**

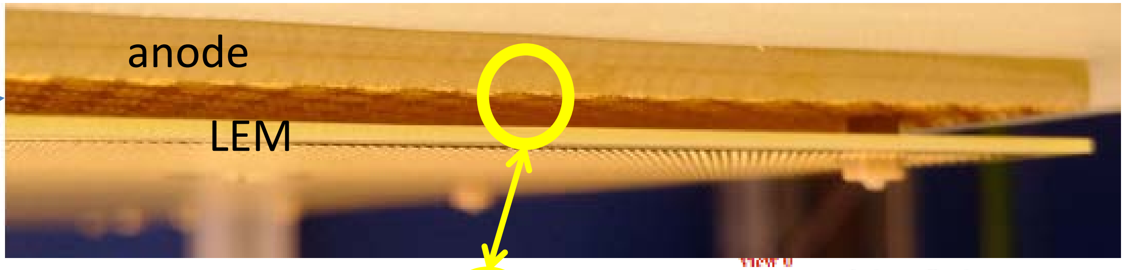
- ➢ Grid sparking inducing damages on front end electronic cards

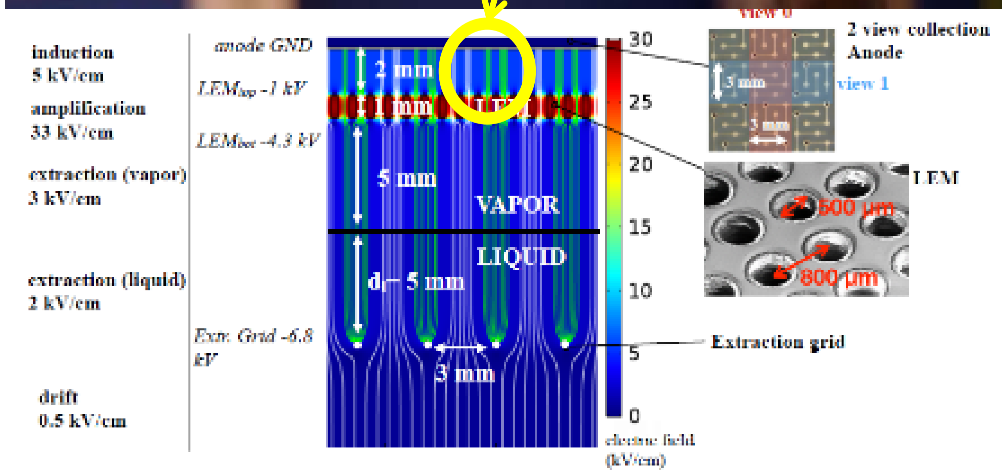
**+ non coherent noise at the level of few ADC count**

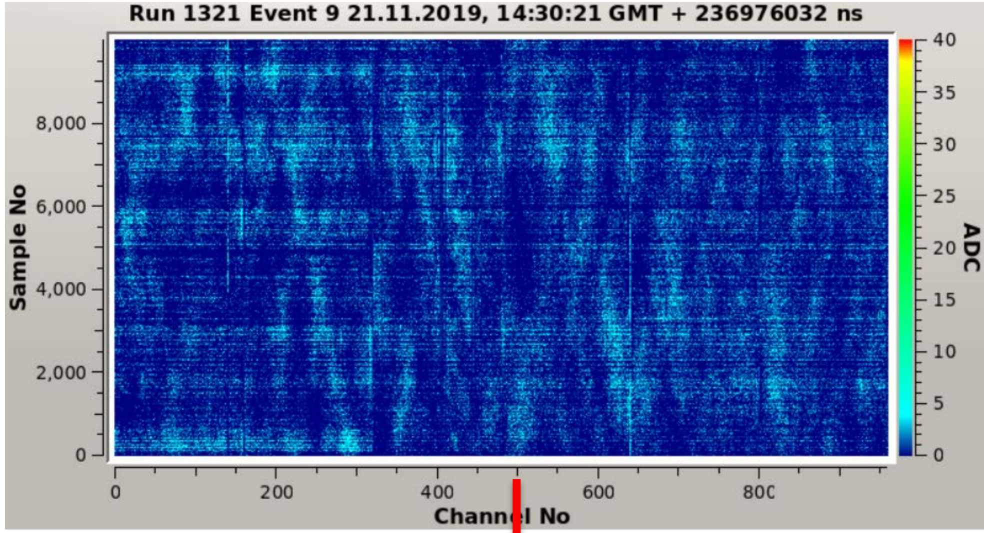
- ➢ Presence of a small noise attributed to a microphonic effect

# Induced signals from CRP microphonic effects

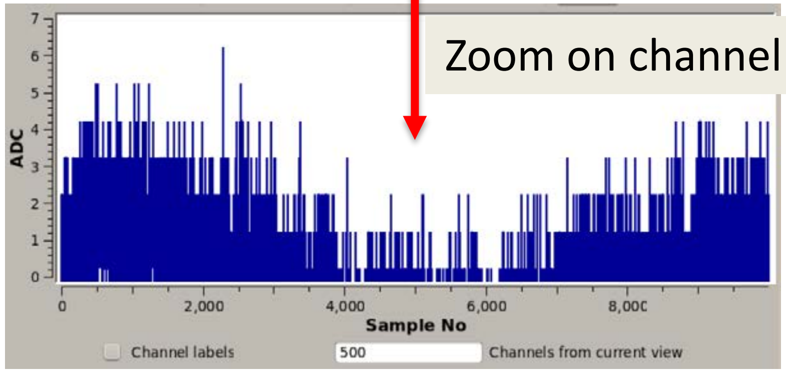
- The CRP stack grid+ 2 LEM faces is a set of capacitors.
- Capacitance variations related to changes in geometry (vibration, change in dielectrics related to waves on LAr surface) may induce tiny signals on the anodes → microphonic effects




Zoom on channel 500




→ Tiny signals ~2-3 ADC counts are induced on anodes

→ The pattern of waves changes continuously from one event to the other

→ After an extensive campaign of investigation this microphonic effect **has been localized in between the anodes and the top surface of the LEMs**

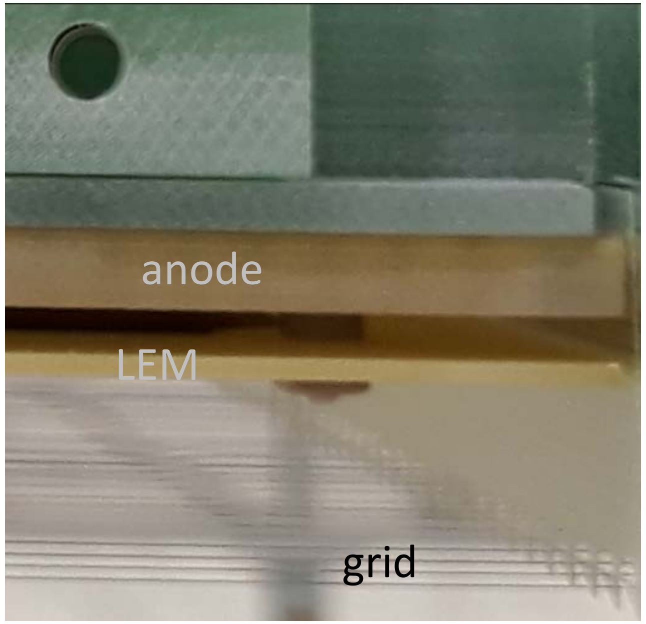
→ The pattern of waves is switched on **when the LEMs top are put at HV (default value 500V) and it is proportional to the HV applied**

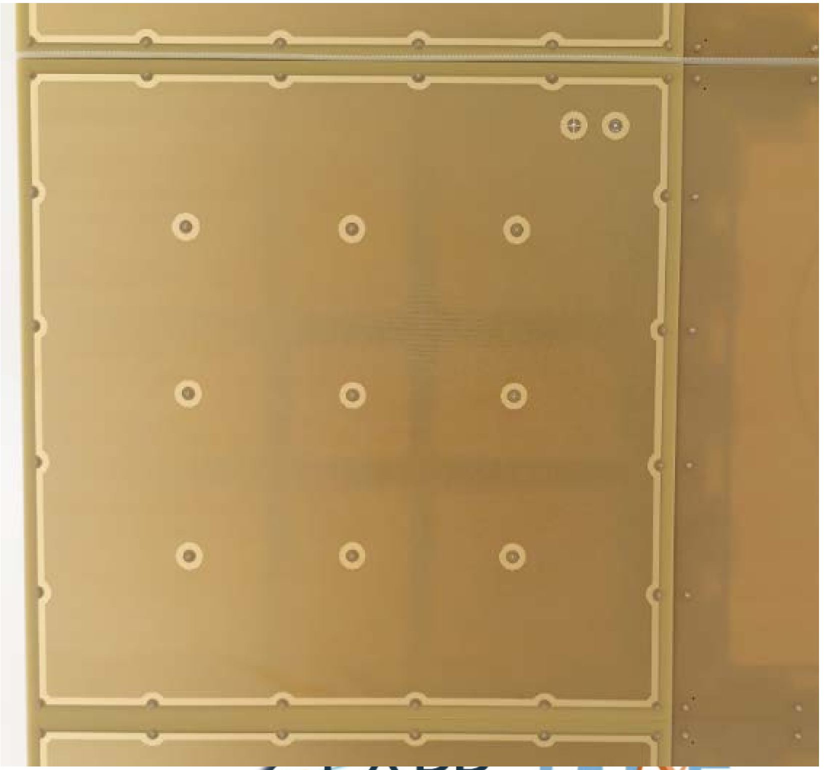
→ Effect is not changed if the CRP is raised above the liquid

→ Vibrations could be transmitted to the LEM-anode sandwiches via the CRP hanging system or by acoustic excitation

# Induced signals from CRP microphonic effects

Reminder: each anode is fixed to G10 with 20 screws and LEM is fixed to the anode with 2mm spacers at the center (9 points) and at the borders on the same 20 screws.



Dedicated studies to be performed on the LEM-anode assembly to find an optimised method of damping these vibrations

# Summary

From a critical point of view

Lessons from CRP commissioning/ operation in ProtoDUNE-DP

- CRP Planarity is worse than expected at cold (4mm instead of 1.5 mm)
  => structure has to be revised to be more stiff

- Liquid argon surface instability complicated the operation: new design should integrate several modifications to be less sensitive
  => larger gap grid-LEM; additional device to get the LAr level knowledge at each corner

- Extraction grid and LEM capacitive couplings and stability over time
  => revise the electrical configuration of both LEM and grid HV distribution

- Grid sparking (independently of the mechanism) is harmful to the readout electronics
  => need to be minimized and controlled to eliminate all risks for the electronics
  ⇒ Guard rings to catch the potential sparks

- Existence of microphonic effects due to potential vibration mode
  => optimise the LEM-anode sandwich system and possible damping

- Charging up of materials or ions may generate electrostatic effects (grid currents…)
  => Adapt a system to drain the charge?

**Solutions foreseen: in next talk about the CRP improvements for phase II of protoDUNE-DP**

# Backup