ProtoDUNE-DP status and progress

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- Cryogenic operation
- CRP performance
- CRP stability tests
- Photon detection system
- Run plan and next steps

LBNC
Fermilab, March 4th , 2020

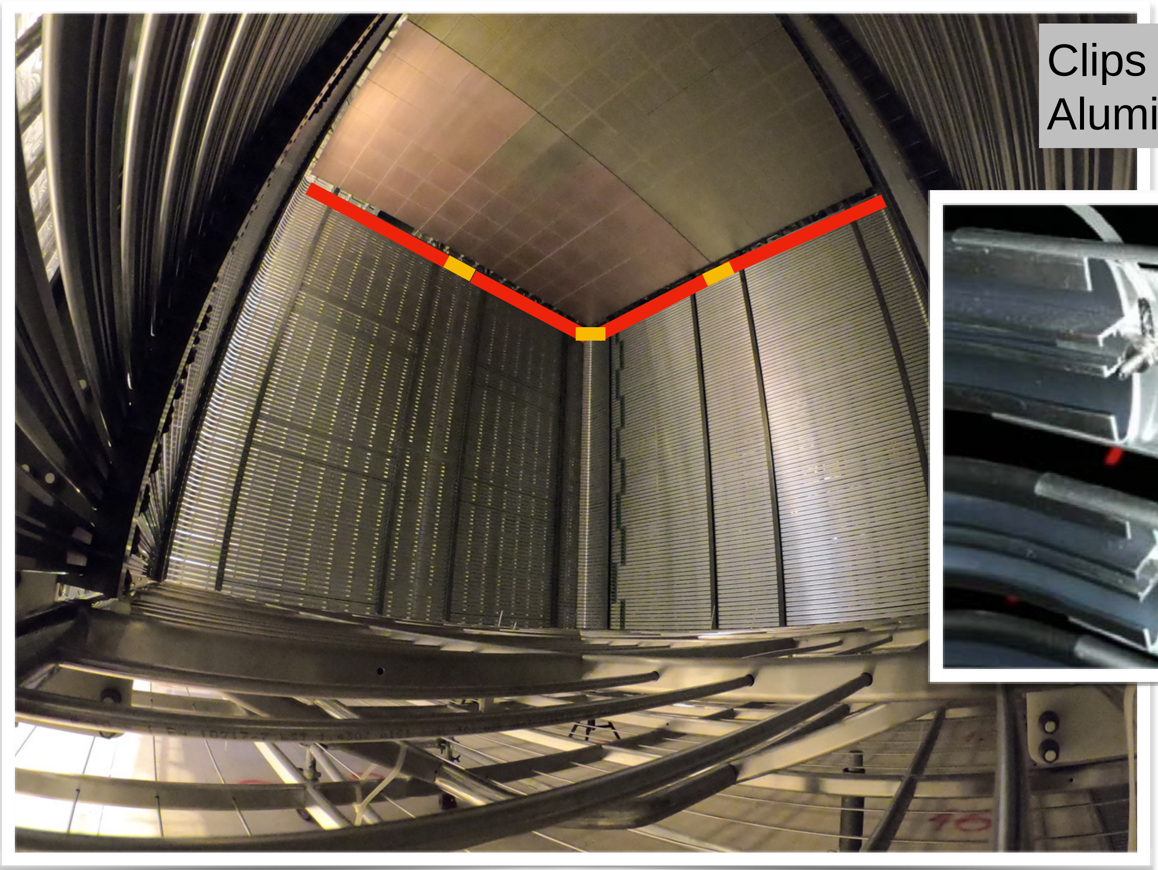
Cryogenic operation

Actual cryogenics performance

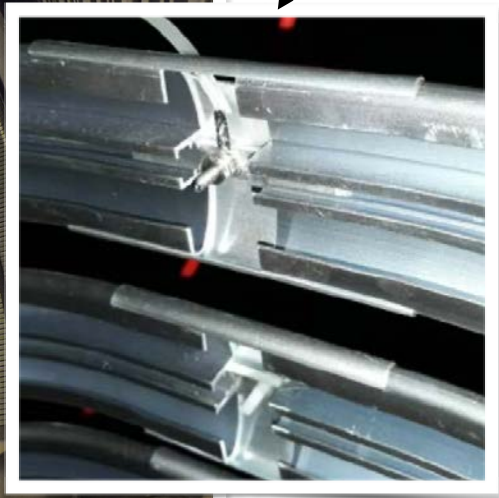
- Pressure stability: < 1 mbar absolute
- Temperature stability: < 100 mK
- Temperature uniformity: < 500 mK (measurement limited by sensors inter-calibration)
- Long term stability of liquid level: 4 mm in 100 days
- Periods of quiet surface (between appearance of bubbles): from few days up to ~2 weeks
- Surface irregularities: ~100 um RMS
- Electron lifetime: > 7 ms

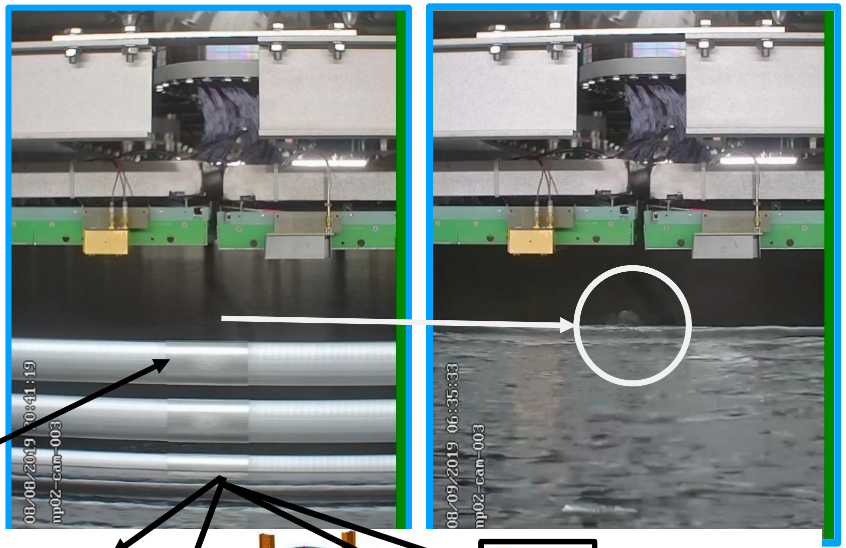
Argon bubbles in NP02

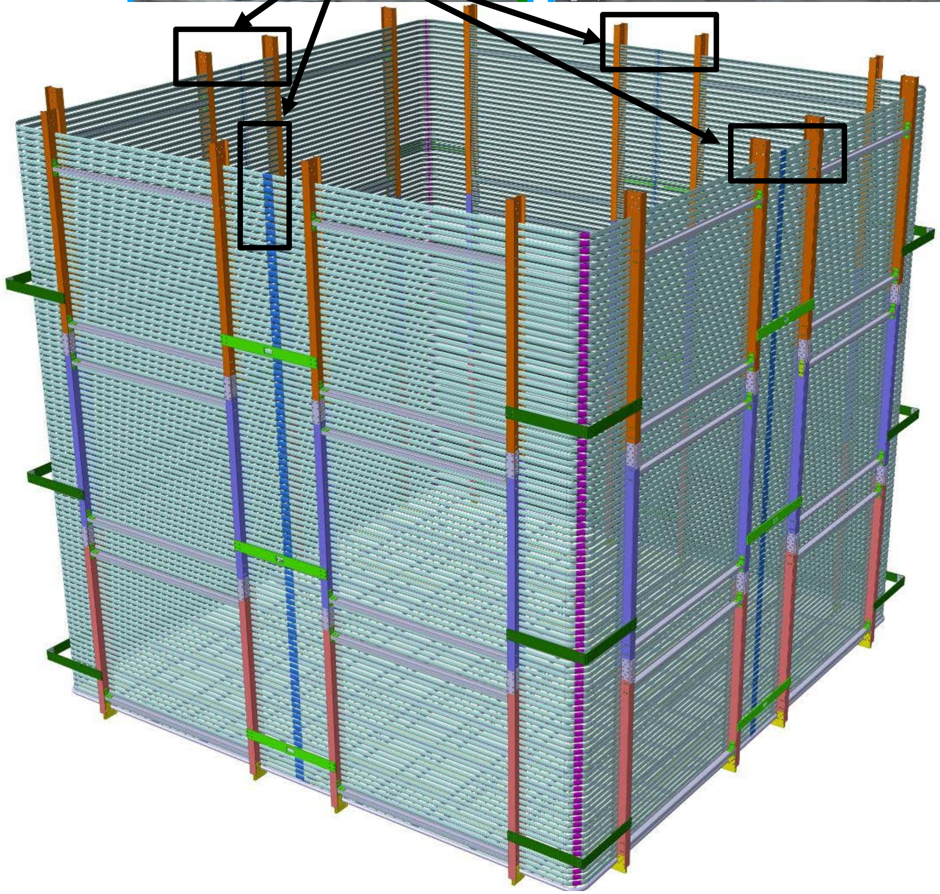
The position of the source of these bubble is known. Their cause is not yet clear.
On the uppermost field cage profile (~10 cm below the liquid argon surface) argon bubbles are trapped in a pocket made by the field cage profiles.
Argon bubbles come out at the clips that join two consecutive profiles.



Clips of the field cage
Aluminium profile





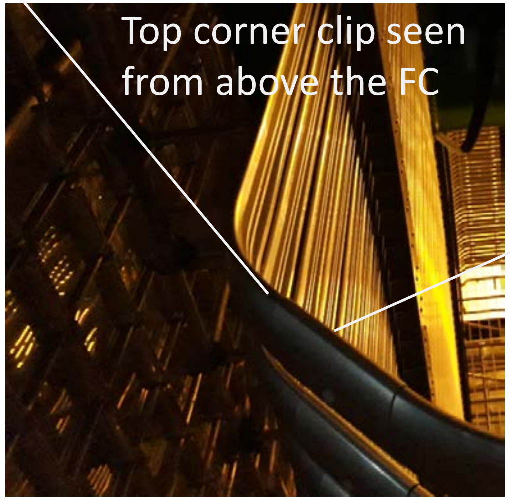


F. Resnati

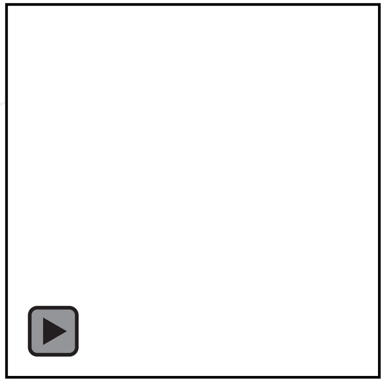
Argon bubbles in NP02

Last week investigate the corner of field cage using a different camera looking from below the ground grid:

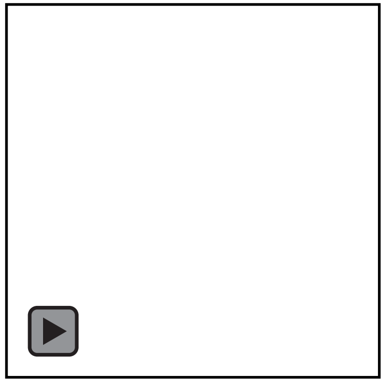
- Evidence of bubbles from the corner of the field cage when the bubbles appear in the centre of the field cage wall (usual location).
- No bubbles are observed at the corner in absence of bubbles at the usual location.



Bubbles present also in the usual location



Bubbles absent also in the usual location



NP02 and NP04 surface comparison

It has been observed in NP04 by operating the cameras installed through the roof.

F. Resnati

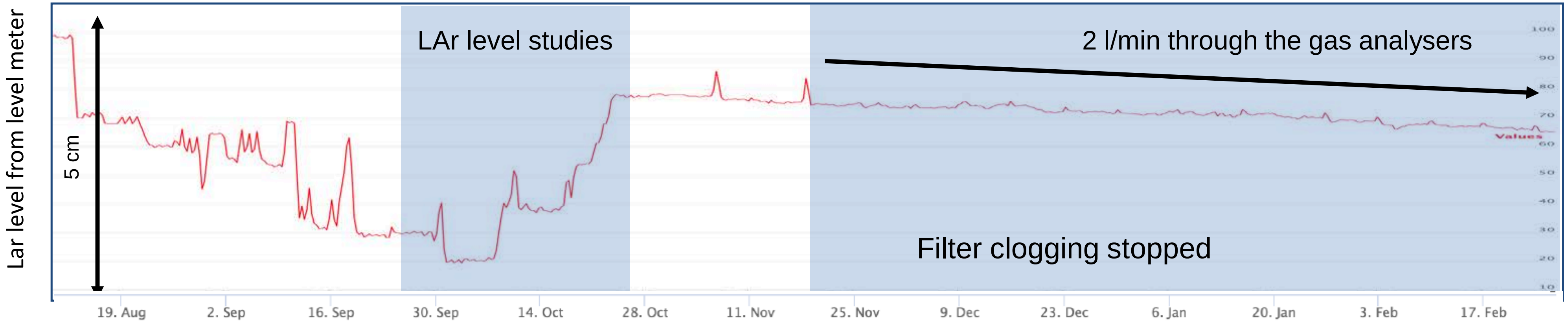
Ripples on the liquid argon surface of NP04 are qualitatively comparable with what is observed in more details in NP02.

Cryogenics operation summary

- No relevant changes on the operation of the cryostat and cryogenics since December 2019:
  - The status of the liquid argon surface has not changed.
- Pressure increase are scheduled every Monday morning to try to *prevent* bubbles appearance
  - Since the beginning of December, the bubbles reappeared 5 times between 2 scheduled pressure increase.

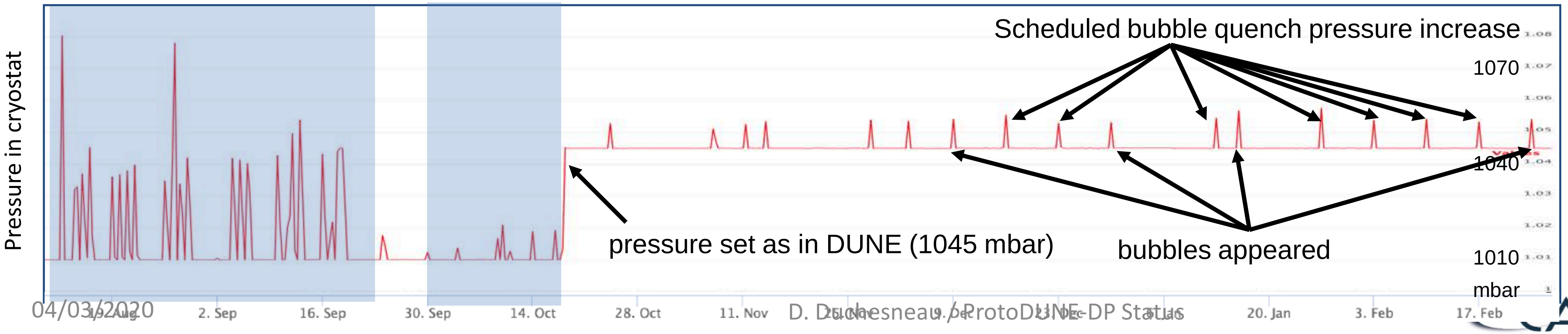
From Aug.10th 2019 to Feb 27th 2020:

F. Resnati



Pressure cycles to remove bubbles

Studies of bubble formation

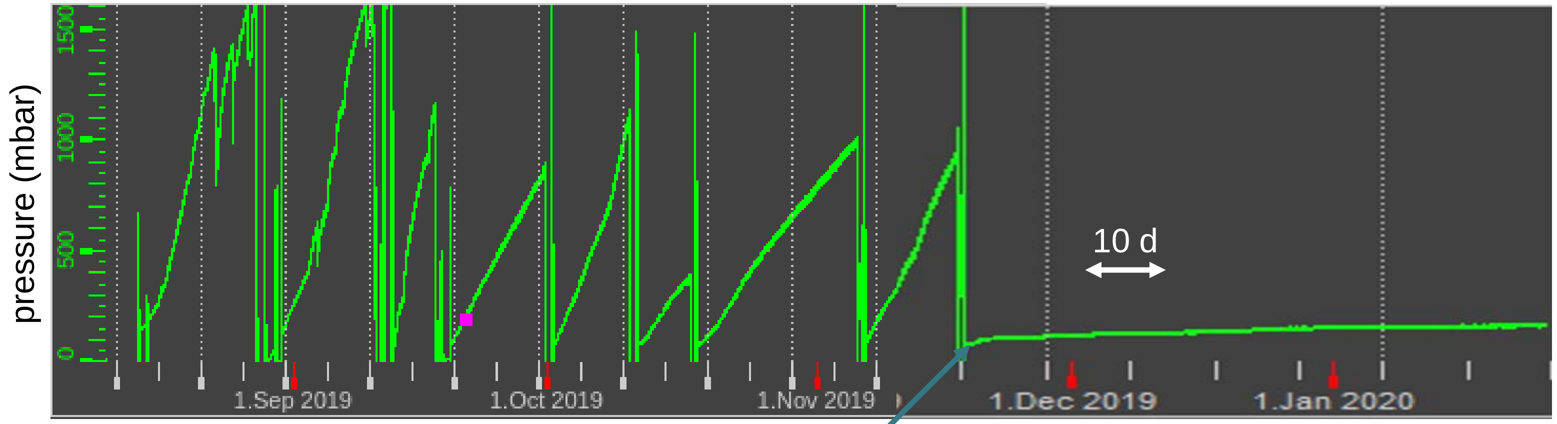


- Purification is ON since middle of November
- Recent purity measurements from the long purity monitor estimate the drift electron lifetime larger than 9 ms.

Filter unclogging

The liquid circulation was interrupted twice to warm up the filters, inspect and extract the dust.
Since middle of September, the filter unclogging is treated as maintenance activity:
- The liquid pump is *not* stopped, the filter is bypassed and only partially warmed up.
- The filter is purged with gas argon from outlet to inlet.
- The bypass is closed, the filter cooled, and the purification restarts.
This operation (that takes ~18 h) has little impact on the pressure and level in the cryostat.
It was done when necessary to avoid the pressure across the filter exceeding 1 bar.

F. Resnati



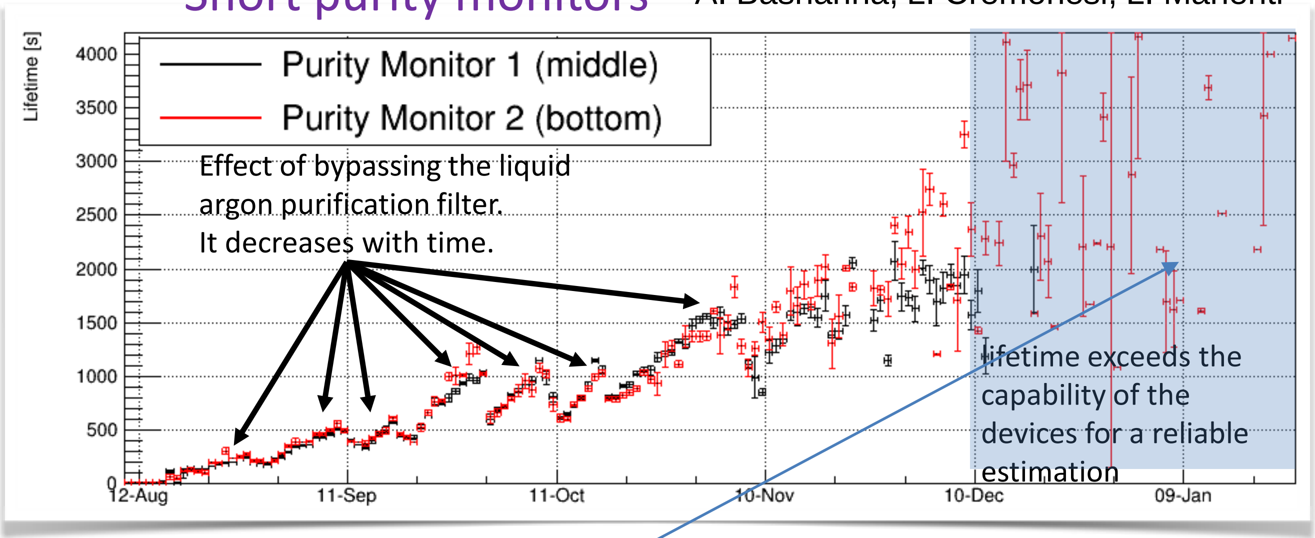
Since the last unclogging operation (equivalent to the others) in middle of November, the pressure across the filter is stabilising below 200 mbar.

- No further filter unclogging interventions were needed since the end of November.
- The pressure drop across the filter continues to increase at much smaller rate than in the past

Purity monitors

Short purity monitors

A. Basharina, L. Cremonesi, L. Manenti

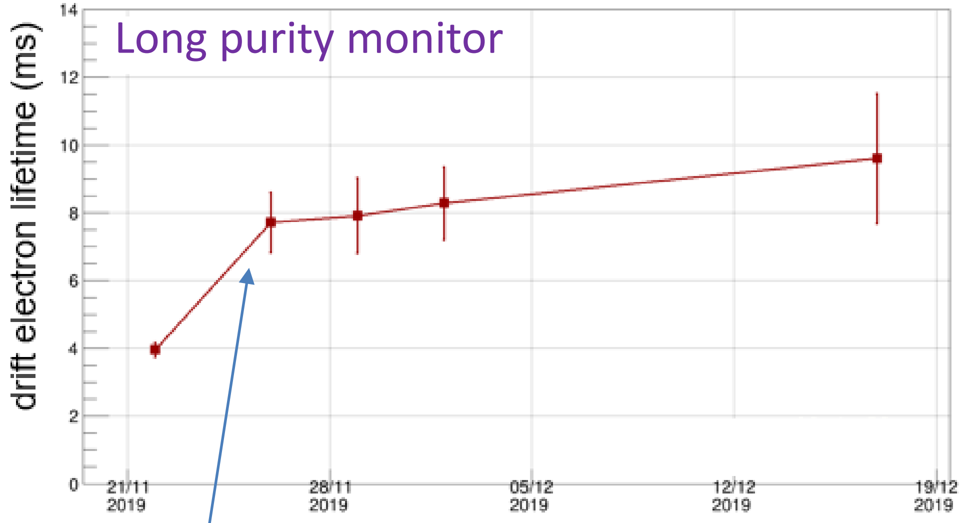


Since February the measurements are compatible with infinite purity

Except for the very beginning, the reported lifetime improvement slower than expected given the recirculation speed.

- Filter unclogging procedures are only part of the cause.
- Additional considerations:
  - Systematic uncertainties in the purity measurements.
  - Inefficiency of the filter (with the filling performance).
  - Poor mixing of the clean and dirty argon (inhomogeneities in contamination concentration

F. Barao, S. Pordes



Since end of November, **lifetime was measured to be always above 7 ms** (considering the most conservative uncertainties) and gently increasing

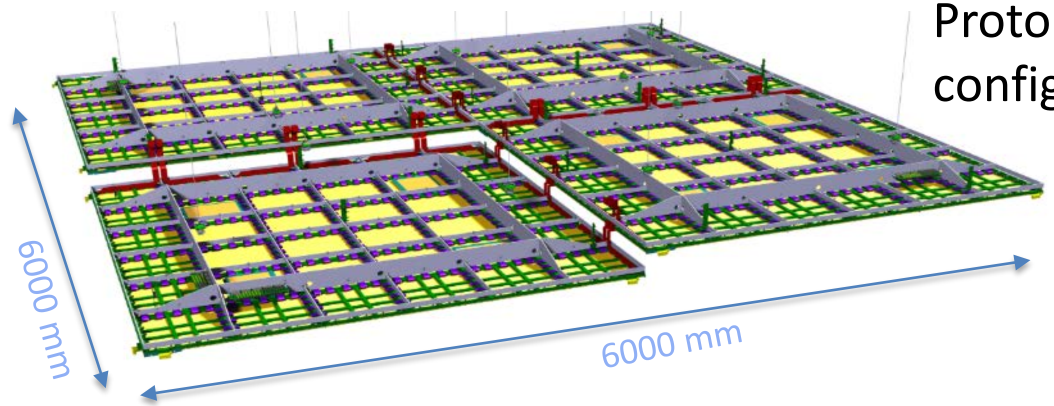
- The short purity monitors are saturated and cannot provide precise indication in this range of electron lifetime.
- The long purity monitor is more sensitive to long lifetime: more reliable evaluation.

- Studies of the long and short purity monitors are ongoing to understand better the systematic uncertainties and the source of the discrepancy in the measurements.

CRP/LEM performances

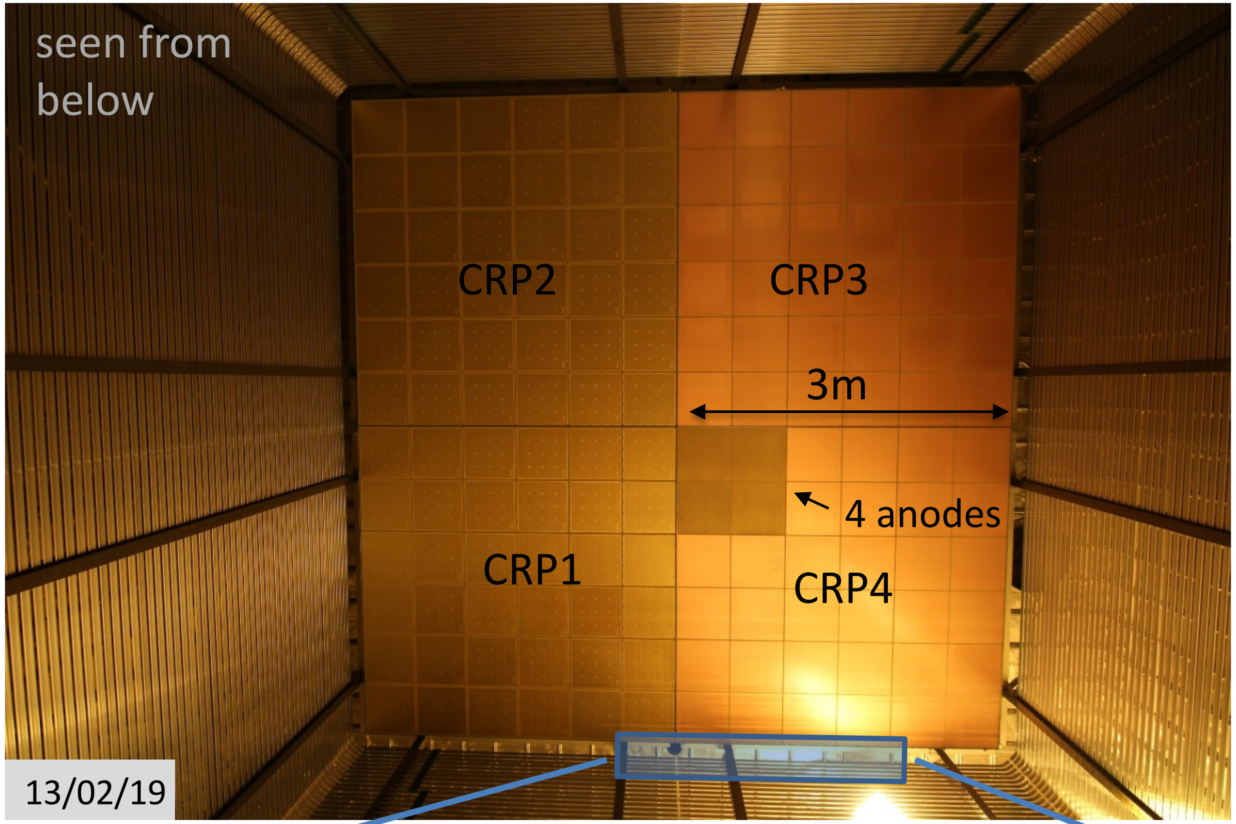
- Gain estimate, charging up effect
- Operation at higher drift field
- Microphonic effects

Charge Readout Plane (CRP)



ProtoDUNE-DP configuration

4 CRPs



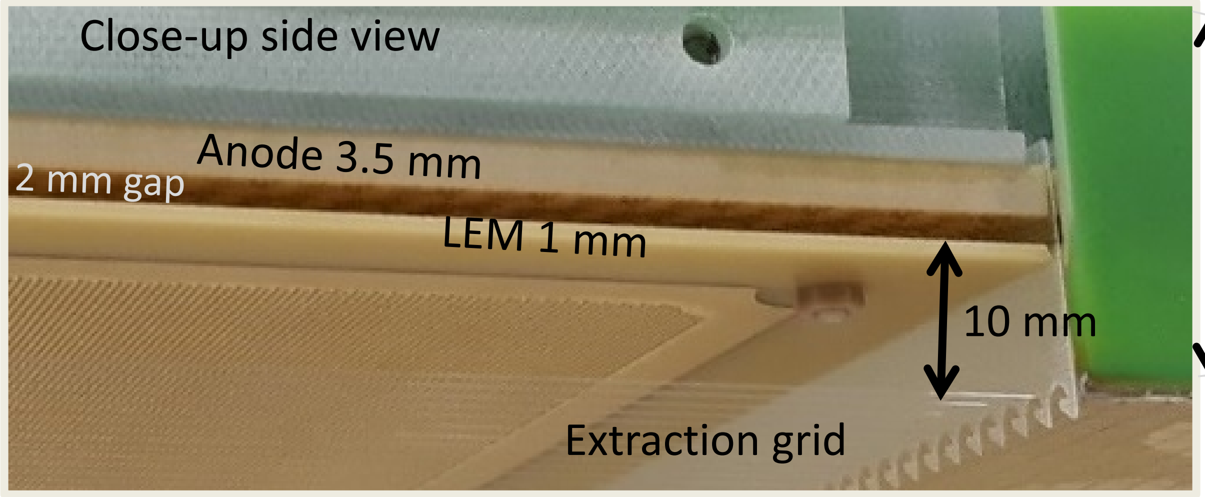
2 instrumented CRPs with 36 LEMs and 36 anodes (50x50 cm^2) :

- ✓ 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



CRP gain

Data samples and LEM + grid Operation parameters

Four different periods of data taking since September 2019 with:

- Voltage across the LEMs: ΔV_{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

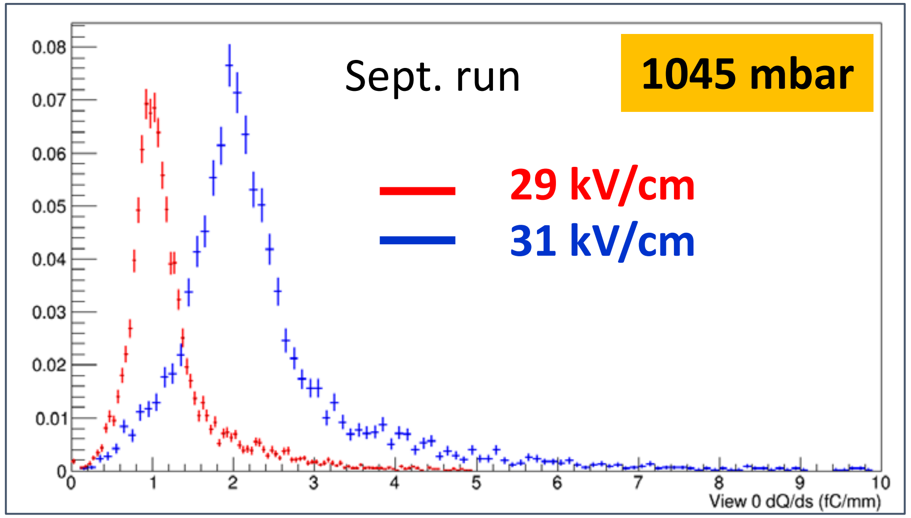
The four periods analysed:

- 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

CRP gain

V. Galymov

dQ/dx in one of the two collection views



R= Ratio of the average charge dQ/dx to the January run one at 2.9 kV

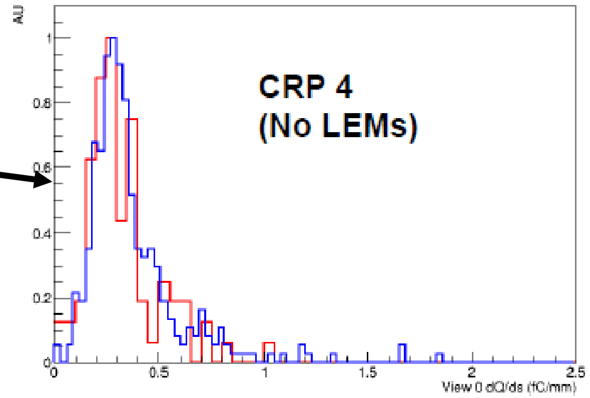
ΔV_{LEM} (V_{grid} =6 kV)	Sept. 1045 mbar	Oct 1010 mbar	Nov. 1045 mbar	Jan. 1045 mbar
2.9 kV	1.7	1.8 (V_{grid} =5.5 kV)	1.0	1.0
3.0 kV	2.3	2.6 (V_{grid} =5.5 kV)	1.3	1.2
3.1 kV	3.7	3.7 (V_{grid} =5.5 kV)	1.8	1.6
3.2 kV	-	5.2 (V_{grid} =5.3 kV)	2.3	-

Uncertainties on R about 18% coming from run uncertainty normalization

<dQ/dx> = 0.45 ± 0.08 fC/mm for the 2.9 kV reference run

From measured dQ/dx per view and assuming 0.8 fC/mm ionization yield:

- 0.4 fC/mm per view after even charge sharing among the two anode views
- Compatible with measurements on CRP4 having no LEMs and no amplification



=> measured CRP gain G (includes extraction efficiency, LEM gain, collection efficiency)

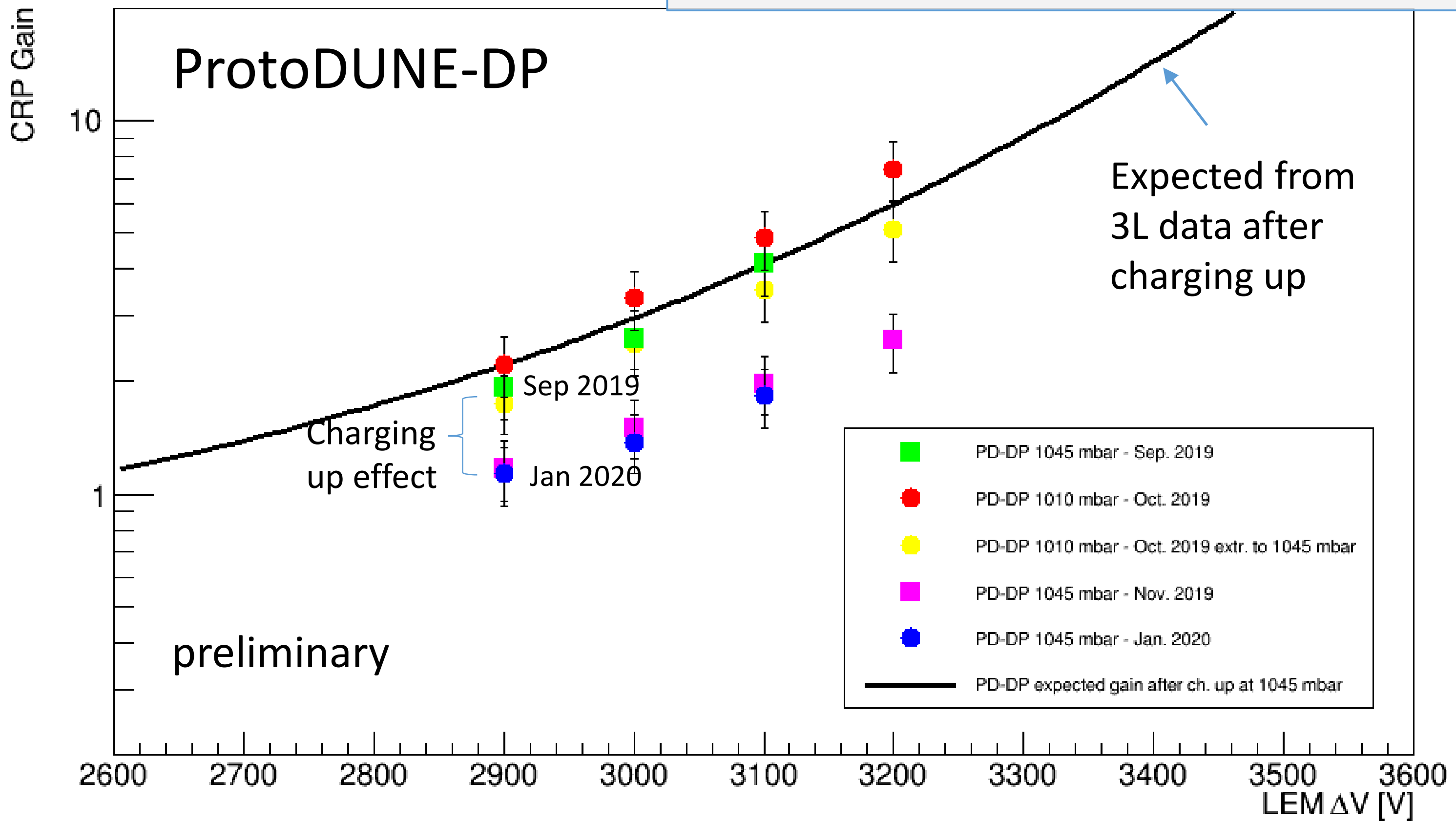
$$\text{CRP gain:} \quad G = R \times \frac{\langle dQ/dx \rangle (1\text{ view})}{0.4\ \text{fC/mm(mip)}}$$

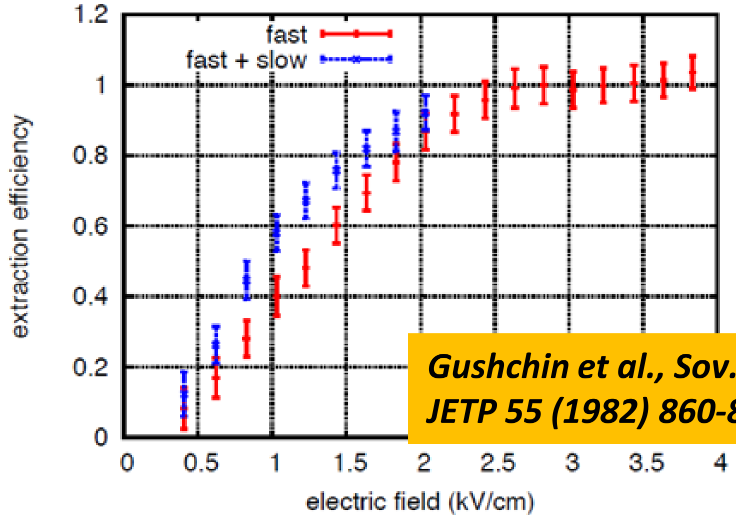
The data at 1010 mbar have to be extrapolated to 1045 mbar: the correction factor depends on the voltage and is in the range 0.7 to 0.8.

CRP gain

E. Mazzucato

Grid HV: 6 kV for all periods except Oct run
5.5 kV for Oct data (5.3 kV for the 3.2 kV run)





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

- $V_{TOP} = 0.5$ kV $\Rightarrow \varepsilon_{coll} \sim 70\%$
- $V_{Grid} = 6$ kV $\Rightarrow \varepsilon_{extr} > 90\%$ for $\Delta V_{LEM} \sim 3$kV

$$G = \varepsilon_{extr} \times G_{LEM} \times \varepsilon_{coll}$$

- The gain reduction by a factor close to 2 observed from September to now is attributed to **the charging up of the LEMs**
  - The process seems to be completed, the values being rather stable since November .
  - The net effect observed after 170 hours of cathode ON is compatible with previous measurements
- The **absolute CRP gain** measured for each ΔV is lower than expected by a factor 2 => need to be understood. The contributions entering in the gain determination like the charge collection efficiency etc.. have to be studied in more details: work on going.

Operation at higher drift field

E. Pennacchio

A cathode HV scan has been performed as well. The "cathode" is usually operated at 50 kV (Vcath) over about 1.2 m drift, runs with Vcath=70 and Vcath=90 have been taken as well in January in high purity conditions. The short in between the FC and the extender is a kind of intermittent contact generating noise but noise conditions were still good for data taking at 70 and 90 kV.

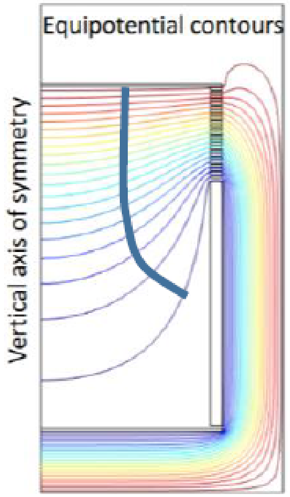
The analysis of these events is going on. Preliminary results show that the increase of deposited related to a better **recombination factor** are consistent with expectations

Vcath (kV)	Assumed Efield (kV/cm)	Vdrift (mm/us)	Recombination factor	Ratio
50	0.17	0.79	0.55	1
70	0.23	1.03	0.60	1.09
90	0.30	1.22	0.64	1.16

Relative change in measured collected charge

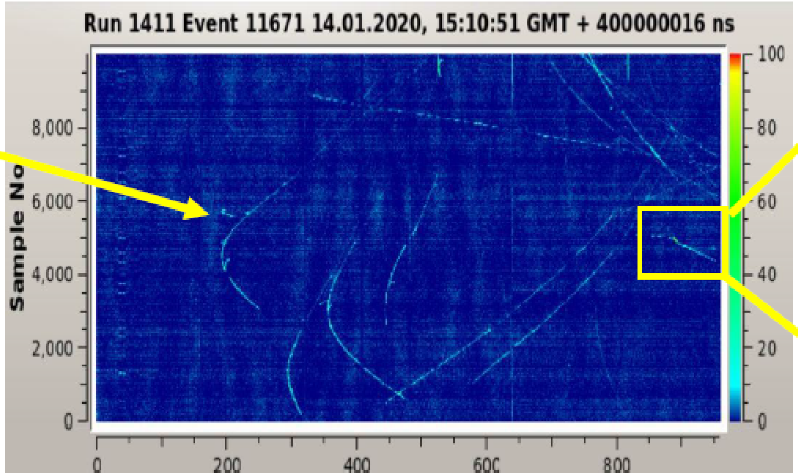
70 kV/50 kV 1.11 +-0.02 (expected: 1.09)
90 kV/50 kV 1.19 +-0.02 (expected: 1.16)
(S. Galymov)

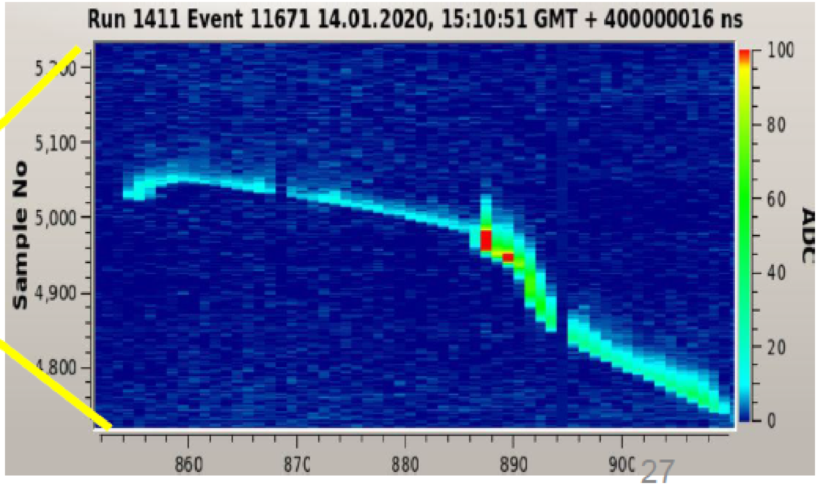
Example of an event taken at 90 kV
Bragg peak visible in muon decay



Cosmic tracks bending at the CRP borders due to field lines distortion

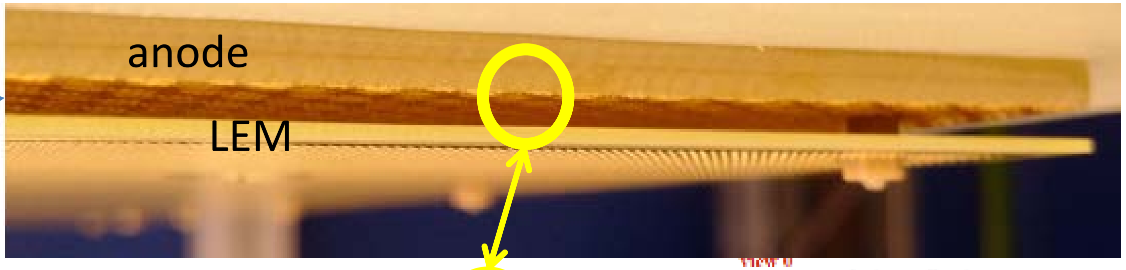
Charge depositions released by tracks at the borders are brought to the center

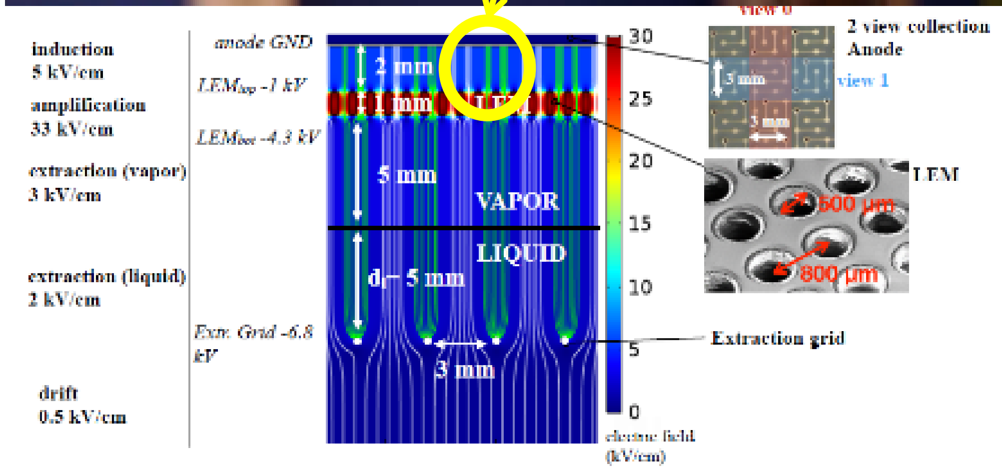


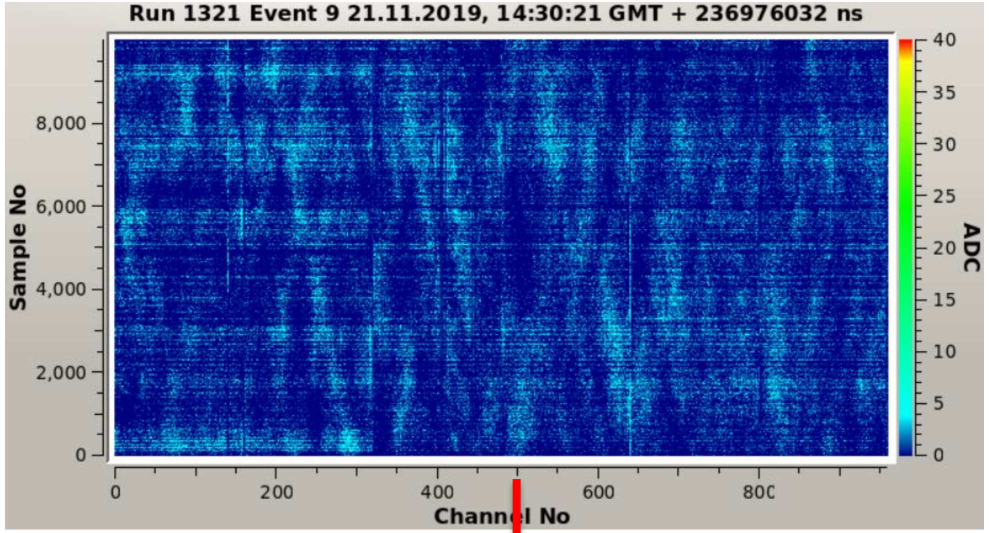


Induced signals from CRP microphonic effects

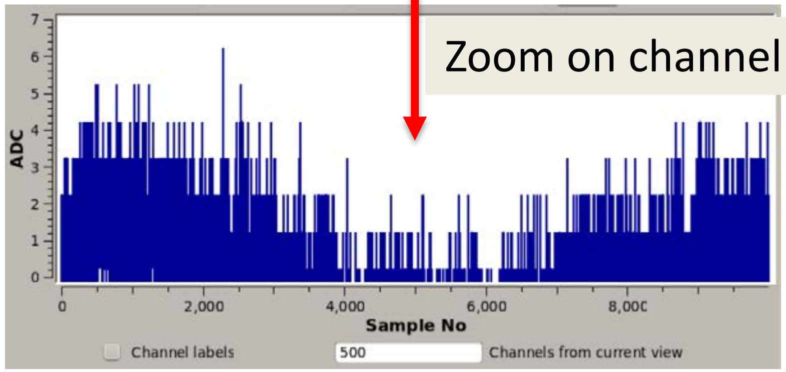
- The CRP stack grid+ 2 LEM faces is a set of capacitors.
- Capacitance variations related to changes in geometry (vibration, change in dielectrics related to waves on LAr surface) may induce tiny signals on the anodes → microphonic effects







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

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

CRP / LEM stability tests

- Long duration stability tests at various configurations
- Main results: cathode ON/OFF, Resistors, extraction ON/OFF
- LEM stability behaviour , time evolution and maximum operating voltage

CRP Stability tests

- Since January a complete CRP stability assessment program has been pursued.
- Possibility to keep stable operation conditions for periods of the order of a week without bubbles and with liquid surface in similar state during the different periods

Goals: run the CRP in various conditions of LEMs and grid HV, with cathode On or Off

- ❑ Determine the stability of the overall system in terms of **spark rate** (LEM and grid sparks)
- ❑ Disentangle LEMs stability from instabilities related to the **capacitive coupling in between the LEMs bottom and the grid** (electrical configuration of the CRP => changes in the quenching resistors, introduction of capacitive coupling)
- ❑ Investigate possible correlations with liquid argon surface condition, HV settings or other factors
- ❑ Find operating conditions and procedures allowing long duration CRP running minimising the perturbation

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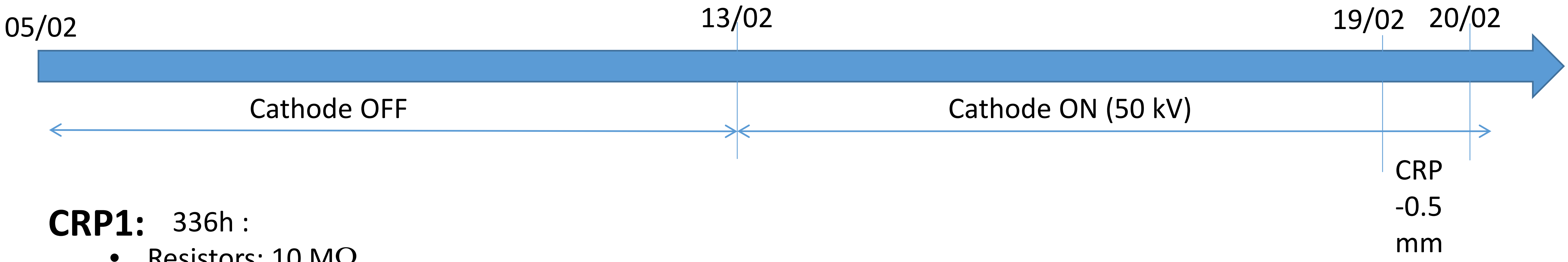
Grid sparks (HV~6 kV) are dangerous for the readout electronics and typically generate damages to the ASICs despite protection components suited for LEM sparks.

- Electronics is protected and not damaged during LEM sparks.
- A grid spark typically involves LEMs at the borders and ends up on the borders on the anodes

During the long stability tests of CRP HV and sparking studies the blades connecting the front end electronics are unplugged from the cold flange
=> a safe configuration to avoid damages on electronic

CRP Stability tests

Long duration tests from 5/02 to 20/02/2020:



CRP1: 336h :

- Resistors: 10 MΩ
- 16 LEMs at 3.6 kV bottom
- 182h (7.5 days) with cathode OFF and
- 137h (5.6 days) with cathode ON,
- Grid at 6kV and LEM at 3.1 kV across for 14 days except for about 19 hours

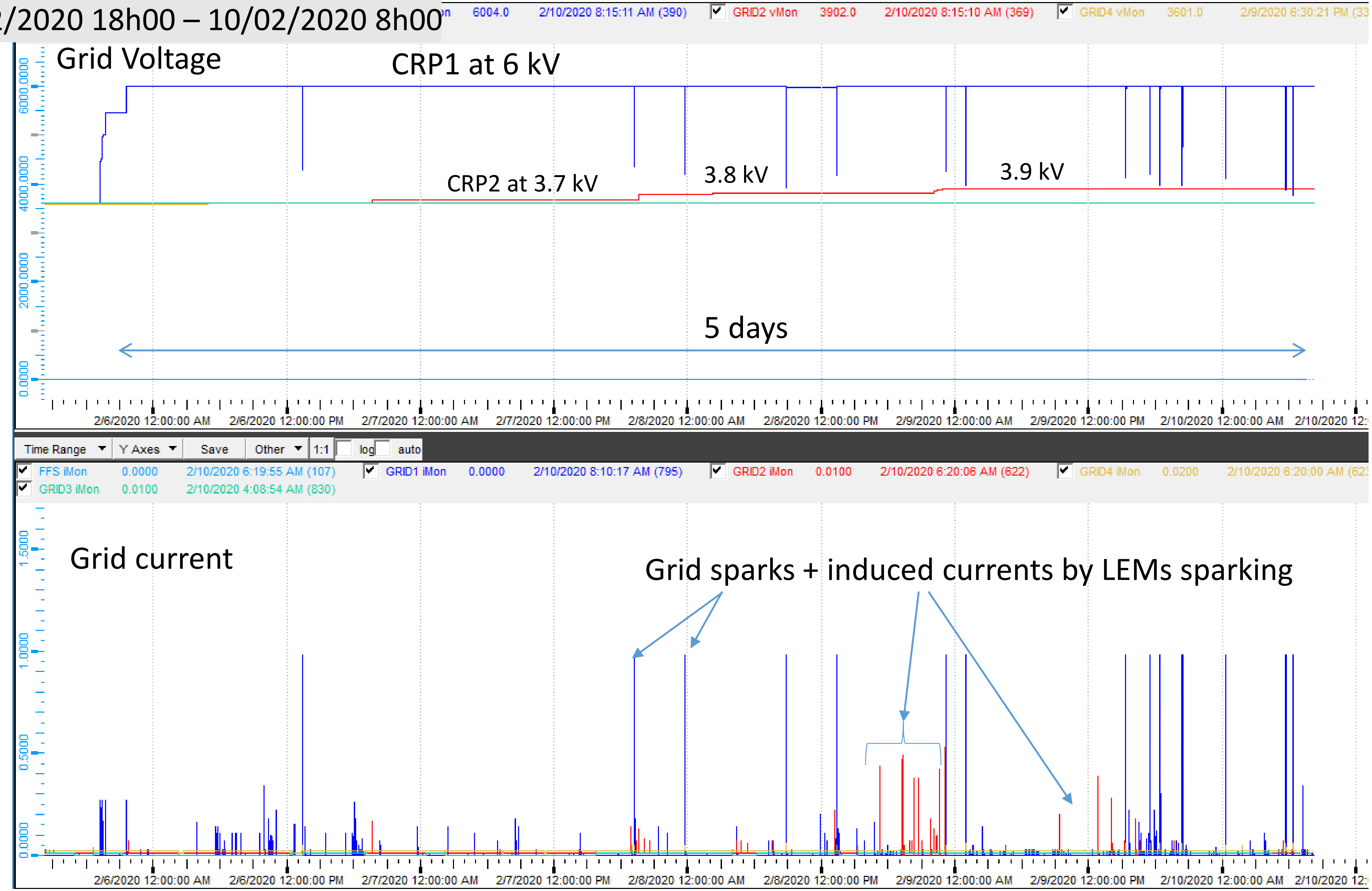
Statistics over 5 to 7 days for each setting seems to be enough for most of the settings

CRP2: 328h   Goal: behaviour at the highest LEM HV

- Resistors 500 MΩ
- 11 LEMs tested at highest voltage (3.6 to 4.0 kV bottom) the others at 2.5 kV bottom at most
- 173h (7.2 days) with cathode OFF with grid at 6.2 kV for 27h (otherwise 3.9 kV)
- 135h (5.6 days) with cathode ON, LEM at 3.4 kV across
- Grid at 6.2 kV for 67 h

CRP Stability tests

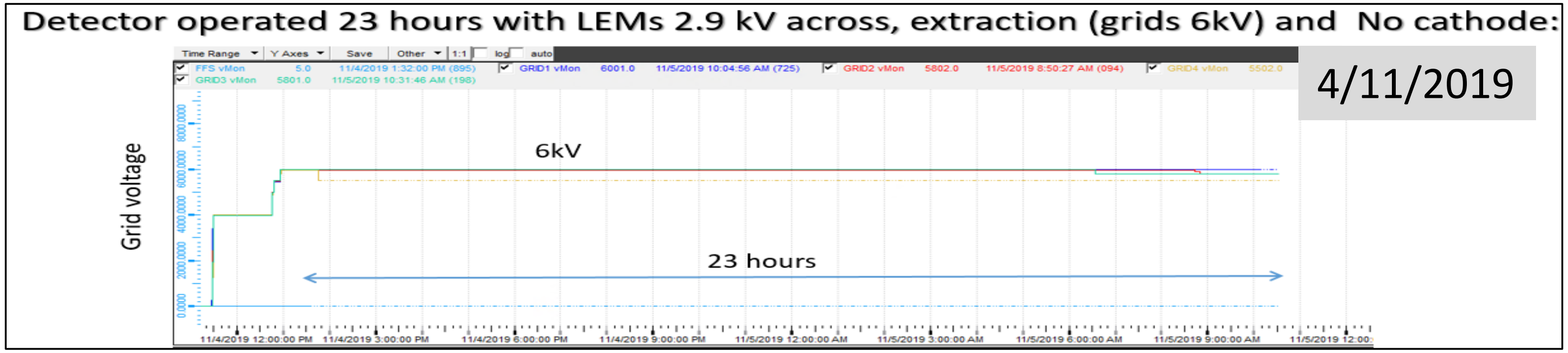
Grid: 5/02/2020 18h00 – 10/02/2020 8h00



CRP Stability tests

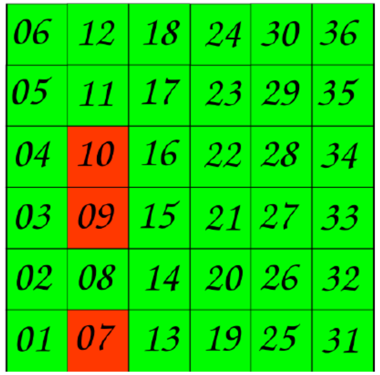
Grid sparks

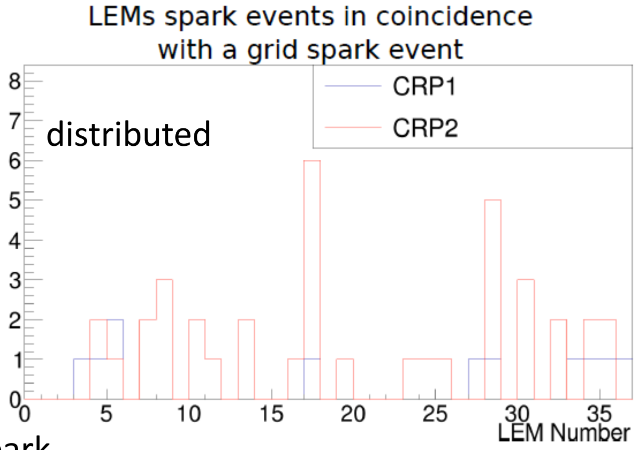
- Grid alone (if well covered by LAr) does not spark, unless of bubbles on the field cage or strong movements of the surface seen also with LAr projections on temperature probes in the gas phase



- Grid sparks occur mainly when LEMs are powered : collective LEM sparks observed during the grid sparks
- The coupling of Grid+LEMs both at HV generates collective instabilities which produce grid sparking + typically several LEMs at the same time

CRP1





Example: 3 LEMs in coincidence with 1 grid spark

G. Eurin
P. Granger

Results on the rate:

CRP1 3.1 kV

Spark type	Cathode ON (101.1 h) Sparks	Rate/CRP/h	Cathode OFF (182 h) Sparks	Rate/CRP/h	Difference
Grid	28.00 ± 5.29	0.28 ± 0.05	39.00 ± 6.24	0.21 ± 0.03	0.07 ± 0.06

CRP2 3.4 kV

Spark type	Cathode ON (42.8h) Sparks	Rate/CRP/h	Cathode OFF (27 h) Sparks	Rate/CRP/h	Difference
Grid 2	29.00 ± 5.39	0.68 ± 0.13	18.00 ± 4.24	0.67 ± 0.16	0.01 ± 0.21

- **0.2-0.3 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:

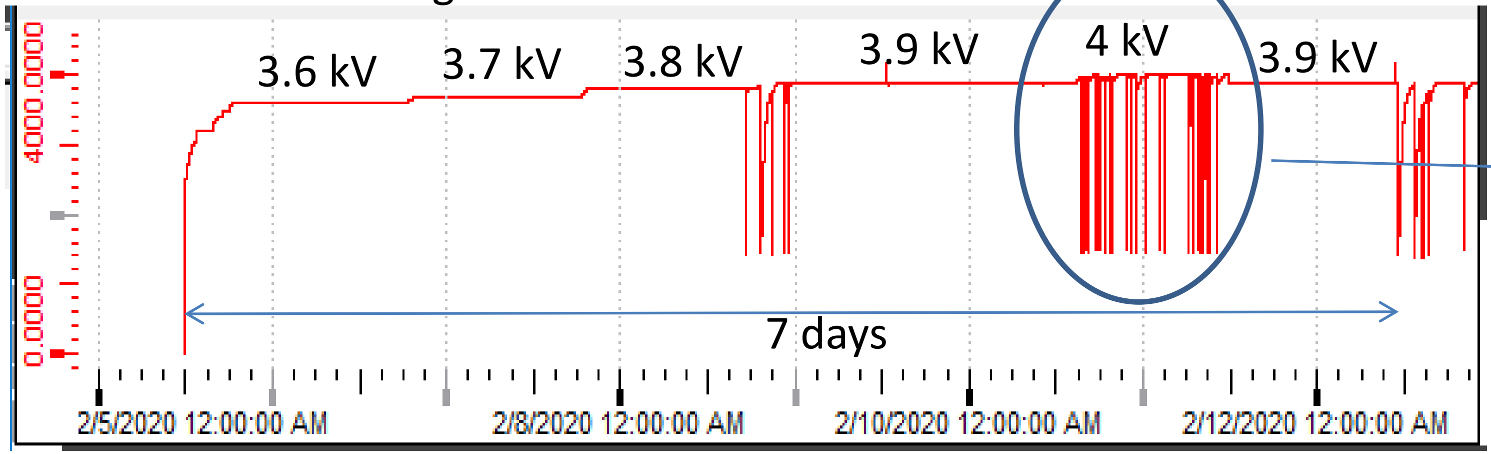
0.6 -07 sparks/h/CRP for Δ V = 3.4 kV

CRP Stability tests

maximal LEM operation voltage

CRP2 LEM slow ramping to highest HV:

LEM15 bottom voltage



Spark rate at ΔV = 3.5 kV corresponds to about 5 /h/CRP

G. Eurin, P. Granger

From tests done on February:

With more than 20 hours between 100 V step

CRP2 grid HV was set equal to LEM bottom HV
=> No extraction field for the high voltage LEMs

ΔV	duration	Single	Multiple	Total
3100 V	20.83 h	0.16 ± 0.16	0.00 ± 0.00	0.16 ± 0.16
3200 V	23.00 h	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3300 V	23.42 h	0.98 ± 0.37	0.28 ± 0.20	1.26 ± 0.42
3400 V	60.50 h	0.39 ± 0.15	0.54 ± 0.17	0.93 ± 0.23
3500 V	18.33 h	1.07 ± 0.44	4.11 ± 0.86	5.18 ± 0.96

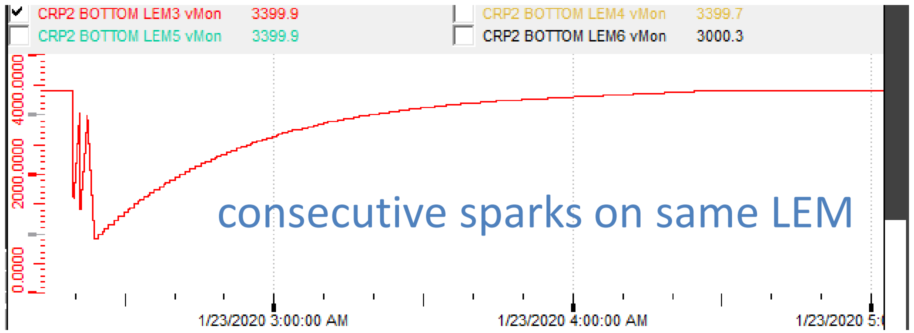
Result:

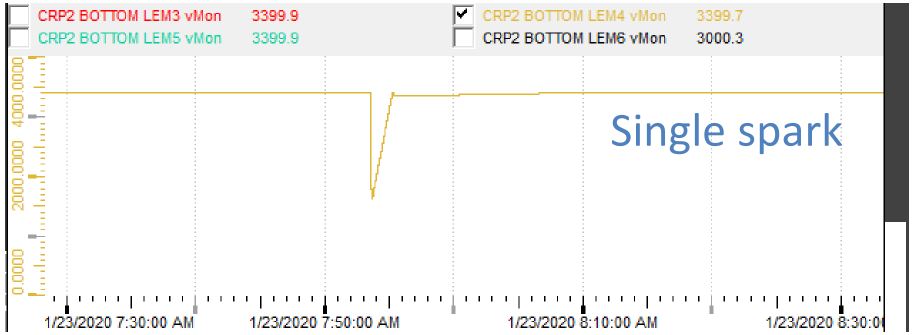
The maximal LEM operation voltage that can be achieved in stable conditions with the LEMs acting as an isolated system in absence of extraction is **3.4 kV across**

CRP Stability tests

characteristics

LEM spark rate:





Classification:

- LEMs sparks in coincidence with grid sparks (multiplicity from 1 to more than 20)
- LEMs sparks without simultaneous grid spark: => single or multiple events (1 LEM or several at the same time)

LEM spark rates with cathode On and Off and extraction (CRP1 grid at 6kV abd CRP2 grid at 6.2 kV)

G. Eurin, P. Granger

CRP1 ΔV= 3.1kV 10 MΩ	Cathode ON (101 h) Rate/CRP/h	Cathode OFF (182 h) Rate/CRP/h	Difference ON-OFF
Single	1.7 ± 0.2	1.5 ± 0.1	0.2 ± 0.2
Multiple	1.2 ± 0.2	1.1 ± 0.1	0.1 ± 0.2
Total	2.9 ± 0.3	2.6 ± 0.2	0.3 ± 0.3

CRP2 ΔV= 3.4kV 500 MΩ	Cathode ON (42.8 h) Rate/CRP/h	Cathode OFF (27 h) Rate/CRP/h	Difference ON-OFF
Single	0.7 ± 0.2	0.5 ± 0.2	0.2 ± 0.3
Multiple	4.0 ± 0.6	3.4 ± 0.6	0.6 ± 0.9
Total	4.7 ± 0.6	3.9 ± 0.7	0.8 ± 0.9

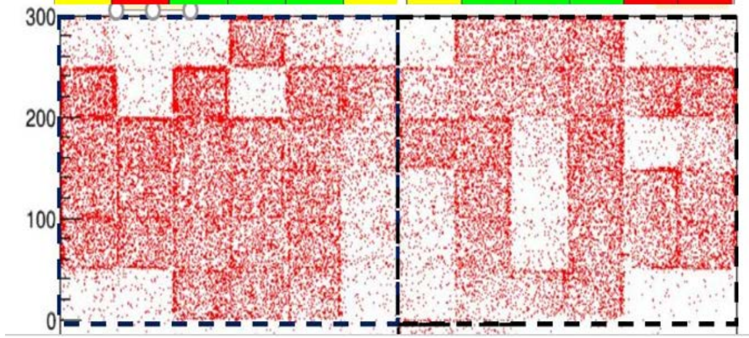
Result:

No large effects when the extraction and the drift field are turned on
=> no hints of instabilities related to accumulation of positive ions over long time periods at maximal gain

LEM stability behaviour and time evolution

January run at 2.9 kV across

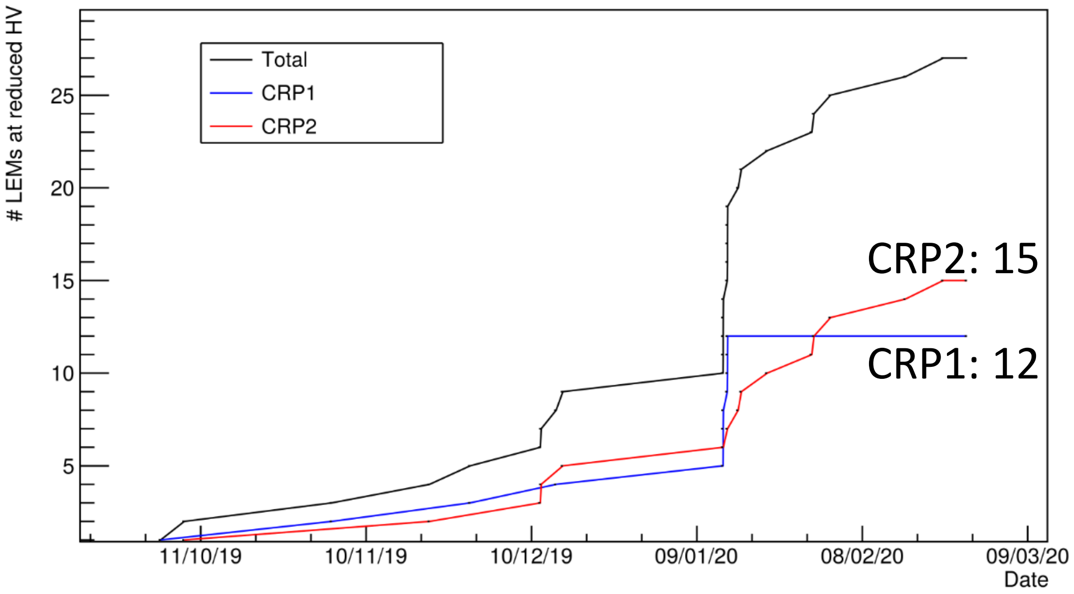
LEMs in green are at nominal voltages
LEMs in red and yellow were lowered in order not to perturb the CRP stability with frequent sparking



CRP2 CRP1

Distribution of the starting points of the reconstructed cosmic tracks

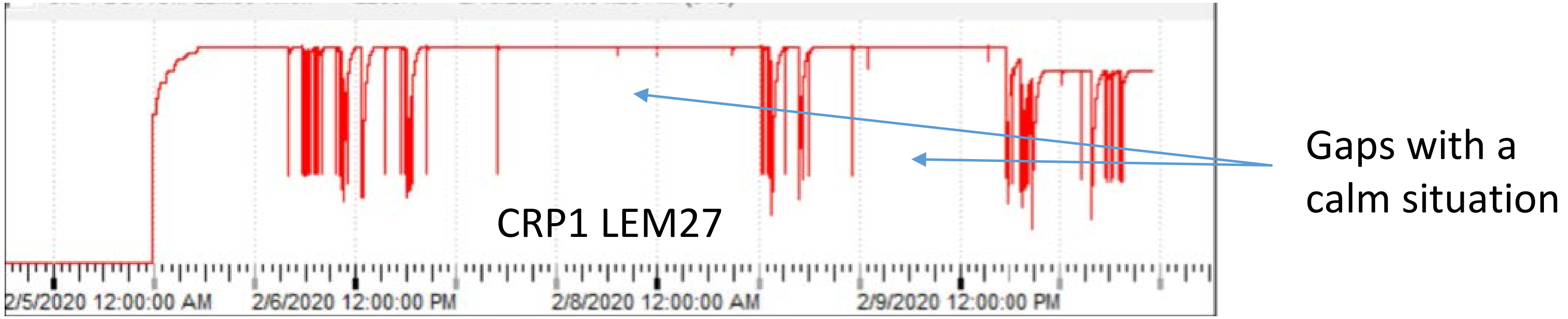
Number of LEMs kept at reduced voltage (< 2.9 kV across)

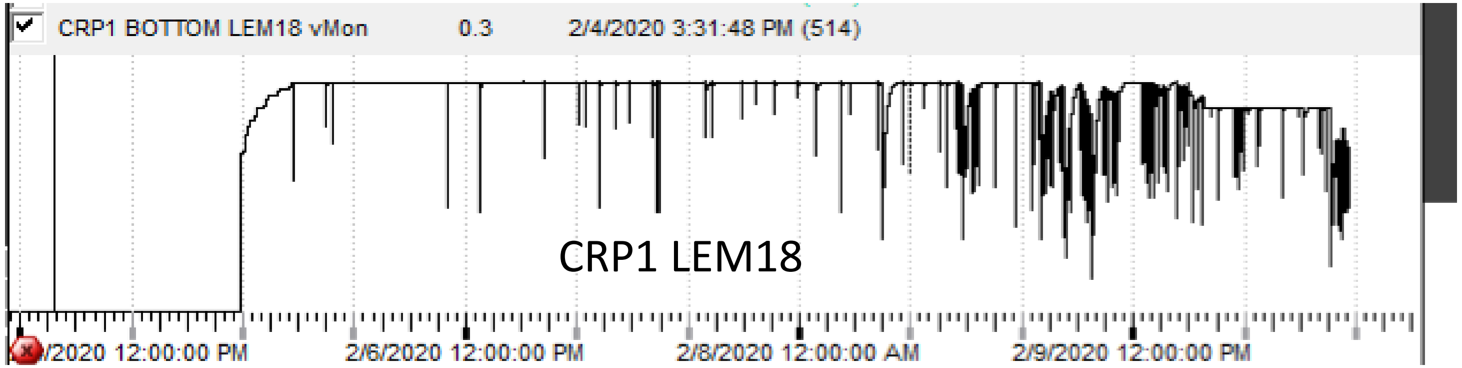


An increasing number of LEM have to be kept at reduced voltages during operation in order to avoid repeated sparking

LEM stability behaviour and time evolution

- over a long time period that some LEMs could develop clusters of sparking activity separated by quiet periods of a few days like the 2 following examples



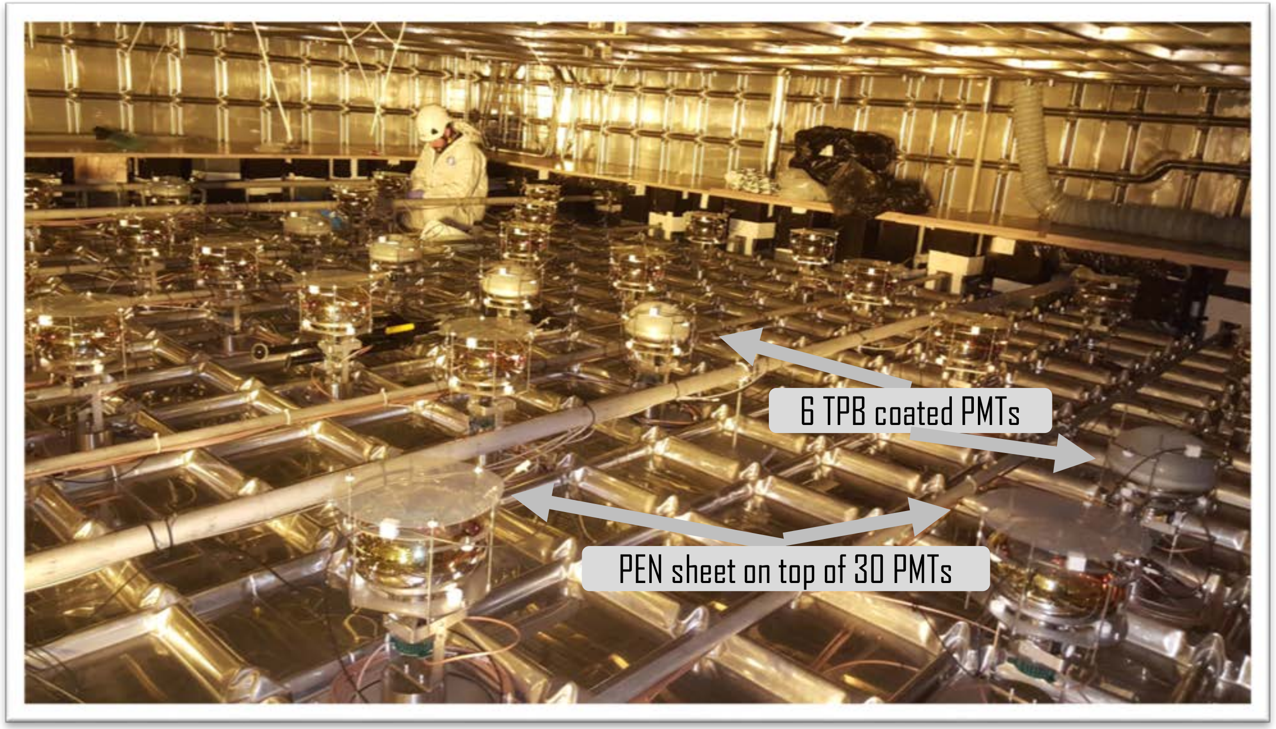


- It was also seen how this activity could interfere with the CRP stability causing grid sparking.

Photon detection system

- New data and analysis

- Data taken with Cosmic Ray Tagger (CRT) with and w/o drift and extraction
- Cathode HV scan from 0 to 50 kV => variation of S1 as a function of field
- Calibration runs with LED-fiber system and with alternative system for systematic comparison
- Light runs with PMT trigger taken weekly to monitor slow scintillation constant for stability studies



Photon detection system:

Summary of data collected (updated from December)

- Data taken almost **every day since June 2019**
  - PMTs are switch ON-OFF several times per day to allow cameras to survey the liquid surface and purity monitor measurements
- All data is long-term saved in eos:
  - Raw data as taken from MIDAS
  - ROOT data converted
- Midas data is also copied to CASTOR
- > 1300 runs taken
- This represents:
  - >200 hours of data (84 M events)
  - 33 TB of MIDAS data, 8.4 TB of ROOT files
- ~ Weekly calibrations
- Several long overnight PMT runs:
  - 11 runs of 8-24 h with and without fields

Trigger	# of runs	# of events	time (h)	
CRT Panels	30	152k	120	stat x40
Random trigger	101	12M	11	
Calibration runs	666	14M	7	
PMT trigger runs	556	57M	81	
Random trigger in coincidence with charge DAQ	10	144k	4	NEW
Total	1363	84M	223	

LEMs voltage	# of runs	# of events	time (h)	
0kV	368	34M	77	
1.5kV	40	1M	0.3	
1.6kV – 3.0kV	98	5M	24	
3.1kV – 3.5kV	193	5.6M	70	
3.6kV	8	360k	0.4	
Tests	659	37M	51	
Total	1363	84M	223	stat x2

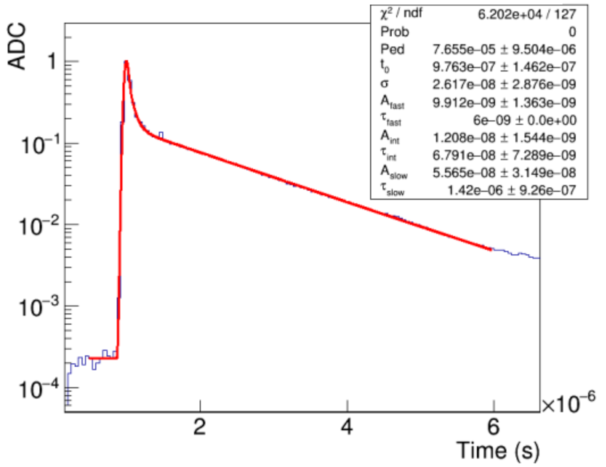
Photon detection system:

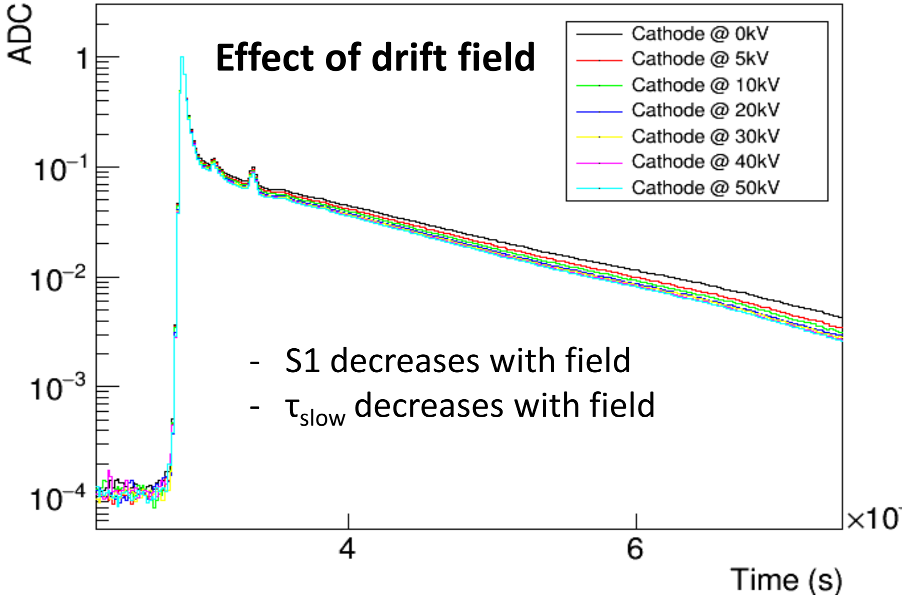
Data analysis: purity monitoring

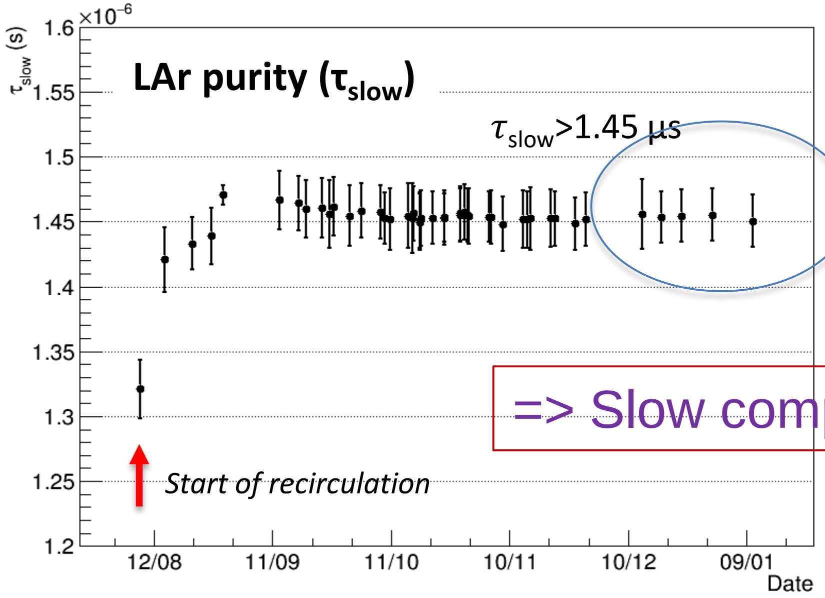
ongoing

- Cosmic muons produce scintillation light on LAr
- Scintillation profile can be obtained averaging waveforms
- No drift field is applied (full recombination of electrons)
- Fit: convolution of 1 gaussian with 3 exponentials
- **τ_{slow} component is an indicator of LAr purity**

Scintillation light profile





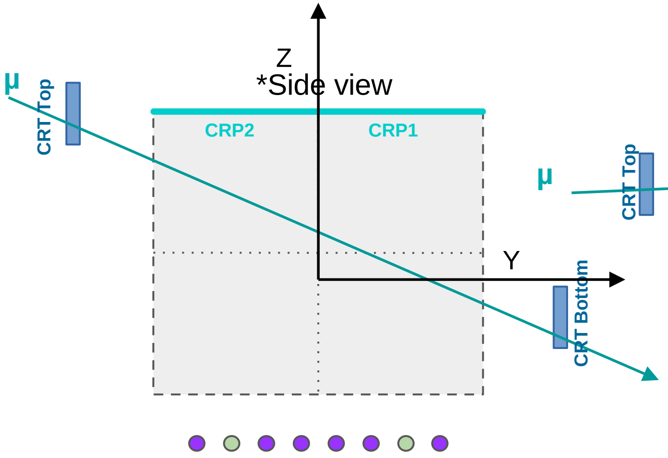


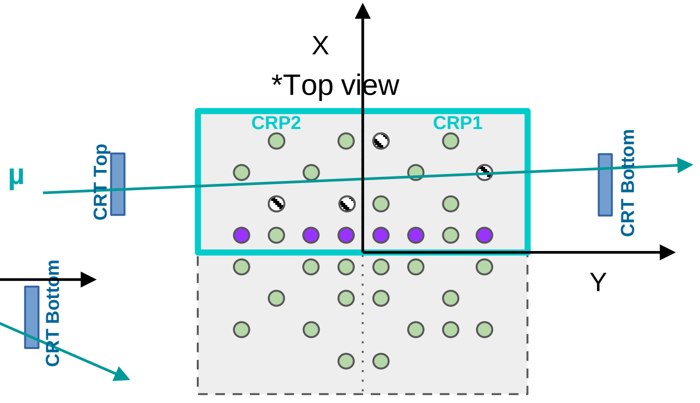
New measurements since last LBNC

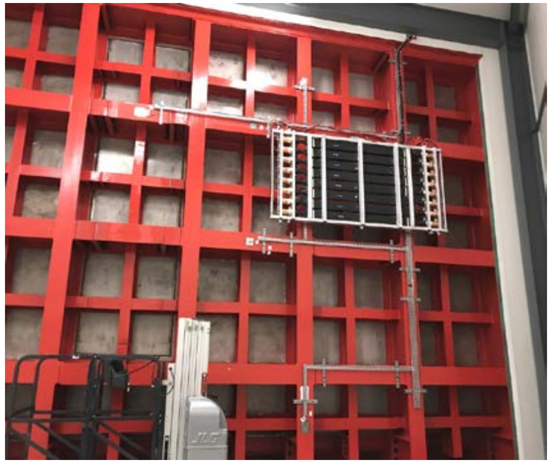
=> Slow component stable

Photon detection system:

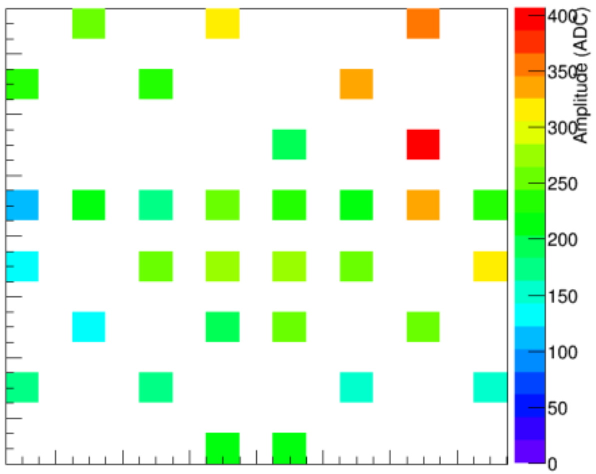
Data with Cosmic Ray Tagger trigger







Average S1 amplitude (ADC)



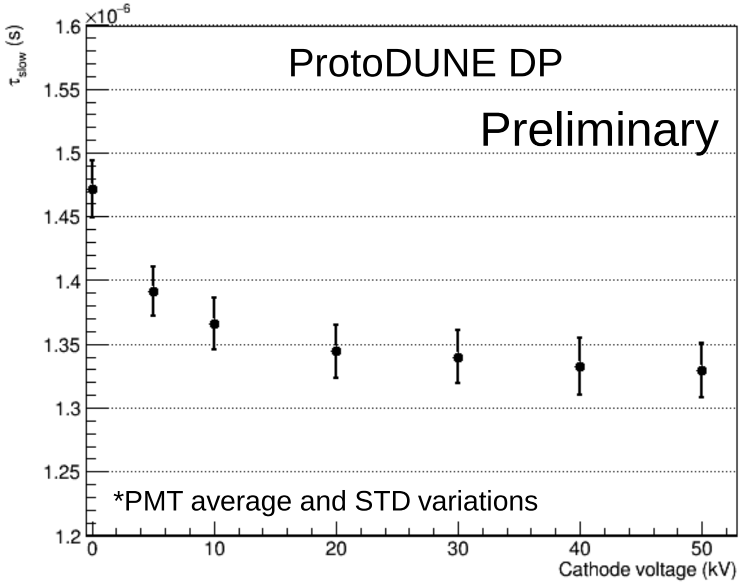
Top view

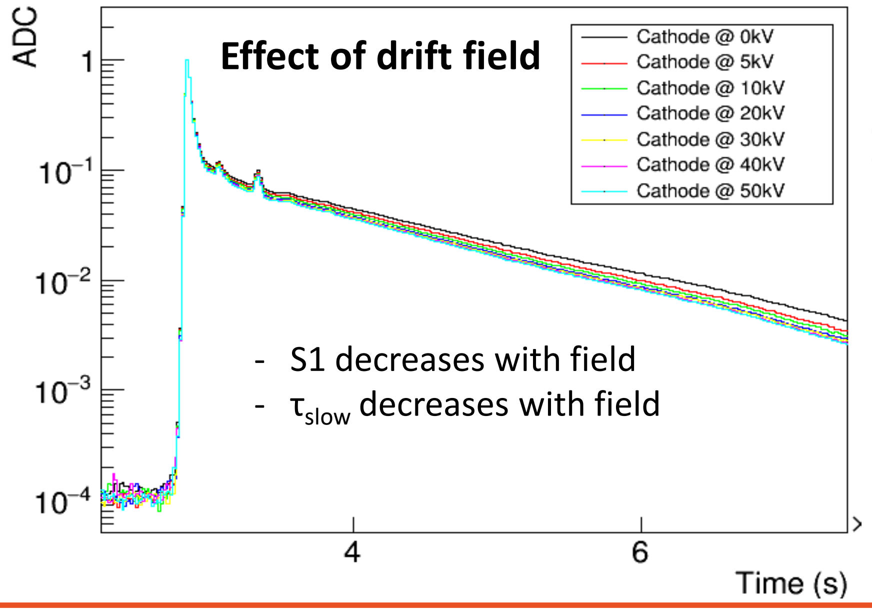
- TPB/PEN PMT gains are tuned to equalize their response
- The pattern CRT_{TOP} - CRT_{BOTTOM} is clearly visible, increasing the amount of light as the muons get closer to the PMTs

Photon detection system:

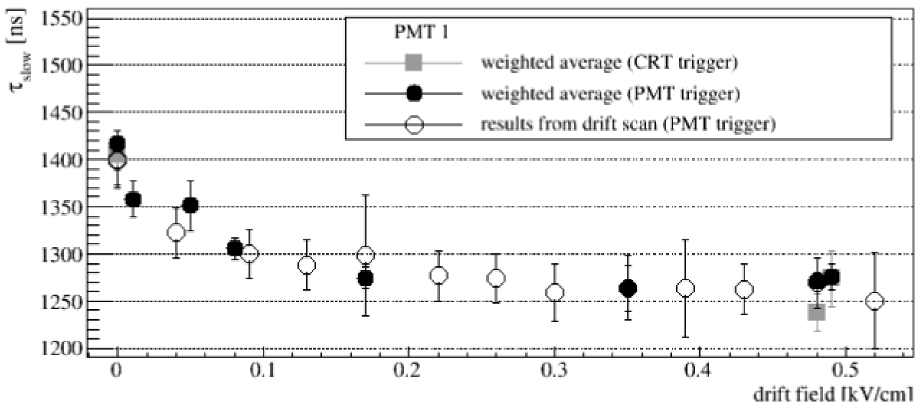
Cathode voltage scan (New)

- A dedicated scan on the cathode voltage was done to study the dependence of the scintillation light with the drift field.
- Scintillation profile is obtained by averaging waveforms, and the tau slow parameter is obtained by fitting the convolution of 1 gaussian with 3 exponential (see previous slide).
- τ_{slow} component shows a dependence with the drift field (top right), as it was observed In the 3x1x1 data (bottom right).





3x1x1

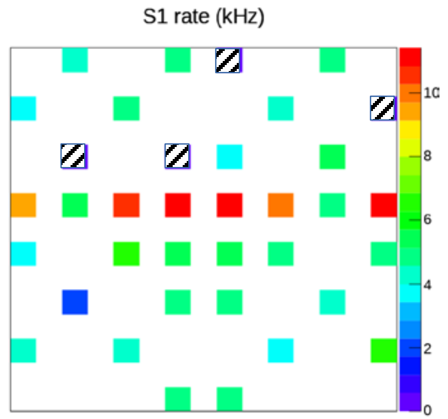


Photon detection system:

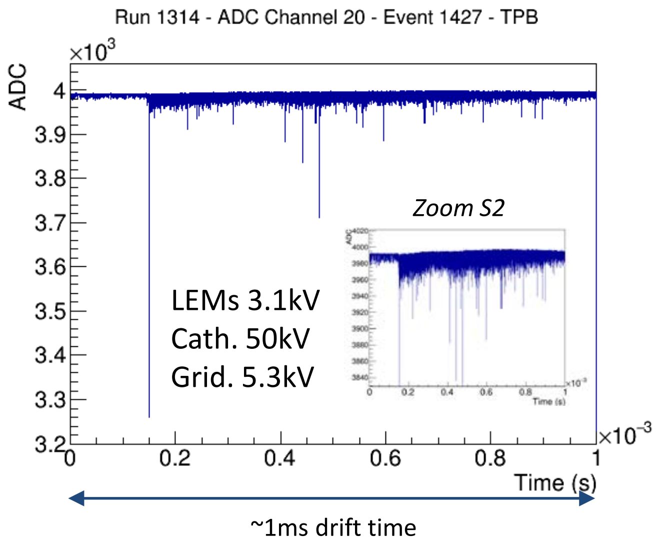
Analysis ongoing

- Data taking continues and analyses are ongoing: S1 and S2 studies
- Several key requirements are being validated (S/N, timing, linearity,…)

- **S1 rate** (muon rate) preliminary:
  - Random trigger, PMTs at G 1e7, no fields
  - TPB PMTs: ~ 9 kHz
  - PEN PMTs: ~ 4 kHz



S2 signal electroluminescence signals



Next goals:

- Operate the system in stable conditions with long runs
- More data with new external muon panels
- Acquire more data in coincidence with charge readout (development of a combined analysis)
- Data with 6 m drift (S1 and S2 signal correlation, electron lifetime measurement, cosmic muon identification...)

ProtoDUNE-DP Run plan

- The long term CRP tests performed in particular conditions should continue until May, when it is foreseen to attempt the surgery of the short circuit on the extender.

  Remaining tests include:

  - Operating with no quenching resistors at all, cathode on/off 2W
  - Test of stability including capacitors in parallel to the LEMs, cathode on/off 2W
  - Measurements of the grid sparking rate by further immersing the CRPs by 1 mm, cathode on 1W
  - Induction field scan and additional gain measurements 1W
  - Investigation of bubbles with additional cameras, study of microphonic effects with acoustic excitation 1W

- This program brings to May when the extender surgery should be attempted.

- The evolution of the program may depend on additional findings during the tests.

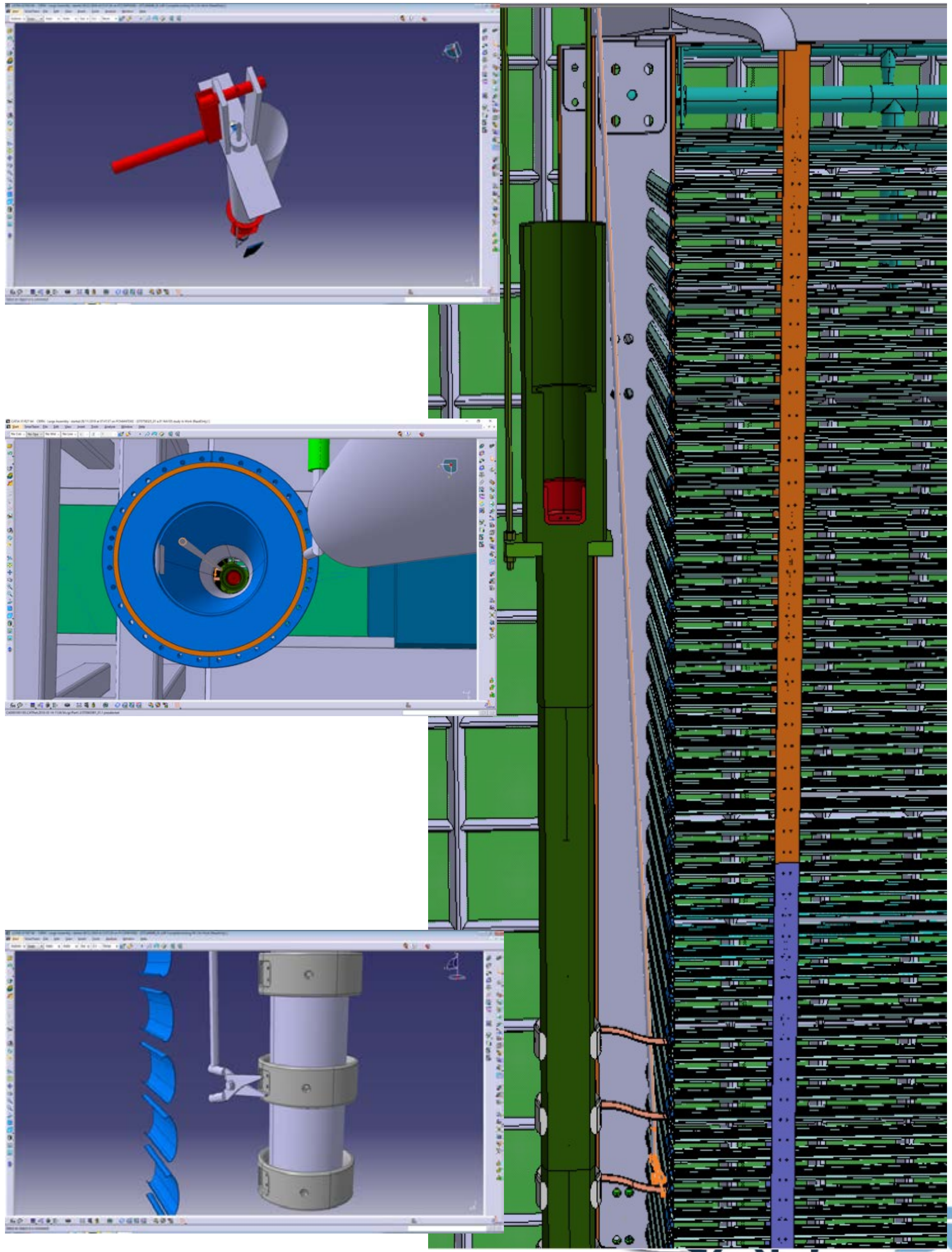
Estimates for the extender repair (next slides)

- The extender repair operation will need of the order of 4 weeks, including partial emptying of 1.5m of LAr.
- A more detailed planning has to be worked out with the CERN cryogenics operation group.
- Once the fix has been performed then it will take of the order of additional 4 weeks to fill back the detector and purify

Plan to reach nominal HV on Cathode

F. Pietropaolo

- Attempt to mitigate the short circuit in the extender rings, cutting the connection between the faulty rings on the extender and the field cage profiles.
- Sequence:
  - Remove the HV feed through to gain access to the HV links (~ 2.5 m below the cryostat top surface)
  - Lower the Liquid level to expose the HV links to be cut (the first 2 or 3)
  - Insert special tools (scissors and hooks, camera assisted) mounted on 3m long rod to remotely cut the faulty HV links (both at the side of the extender and on that of the field cage)
  - Recover tool and HV links

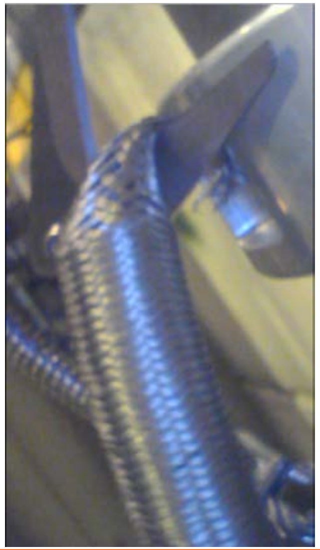
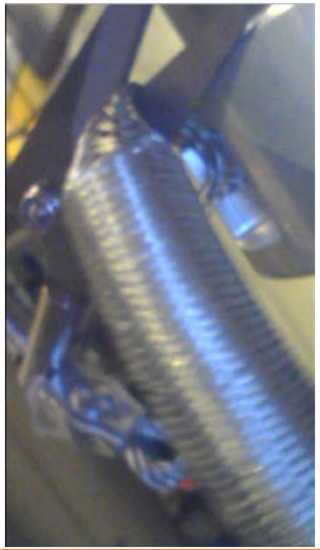


Plan to reach nominal HV on Cathode

F. Pietropaolo

Feasibility tests

- A mockup in 1:1 scale has been assembled at CERN to test the whole cutting sequence
  - The scissor was equipped with an endoscope camera to guide the remote positioning
  - Operation has proven to be feasible
  - The connections can be cut sharp
  - No residual free metallic wires were found
  - Recovering of cut pieces should also be possible

Cutting operation in NP02

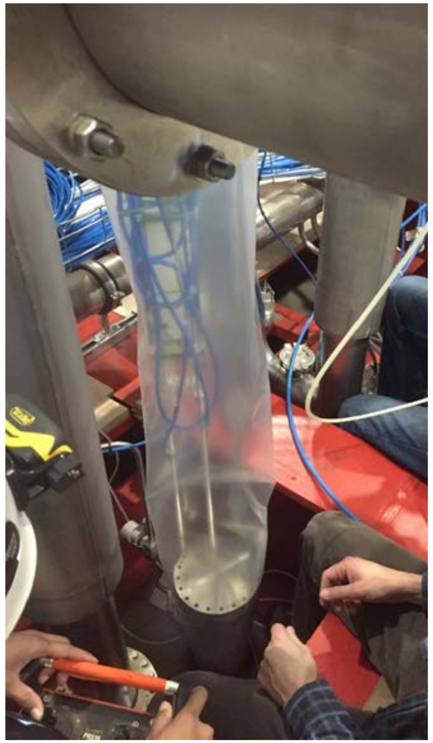
F. Pietropaolo

- Opening of flanges already successfully executed in NP04 to insert new X-Arapucas photon detector for the Xenon doping test
  - Flange left open for 15 minutes at ~5 mbar overpressure
  - "Warm" objects lowered into Liquid Argon
  - LAr Purity (continuously monitored) was NOT affected by this operation
- Possible procedure and schedule:
  - Need to empty ~150 ton of LAr: a pump should be used to speed up the operation: 50-60 ton could be stored in existing storage cryostat, the rest should be vented (or maybe sold)
  - Refilling could take similar time as the first filling (up to 20 ton/day)
  - LAr purity recovery time need to be foreseen
- A more detailed scheme will be worked out with the CERN cryogenic group, well in advance before starting the cutting operations.

Example of open flange insertion in NP04

F. Pietropaolo

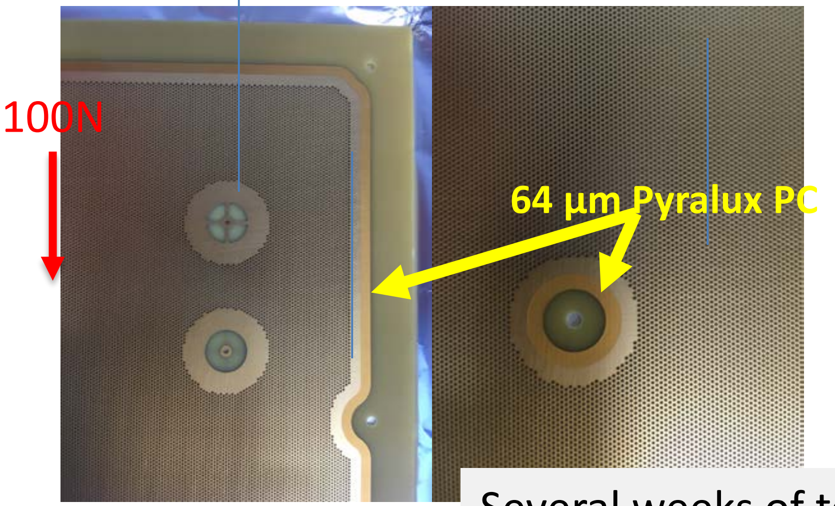
- ~4.5 m long SS tube, supporting X-Arapucas/SiPM Photon detectors and cabling, was mounted on ta DN150 UHV flange
- Insertion lasted 15 minutes including removal of blank flange
- Plastic bag used to limit back diffusion of air into the cryostat

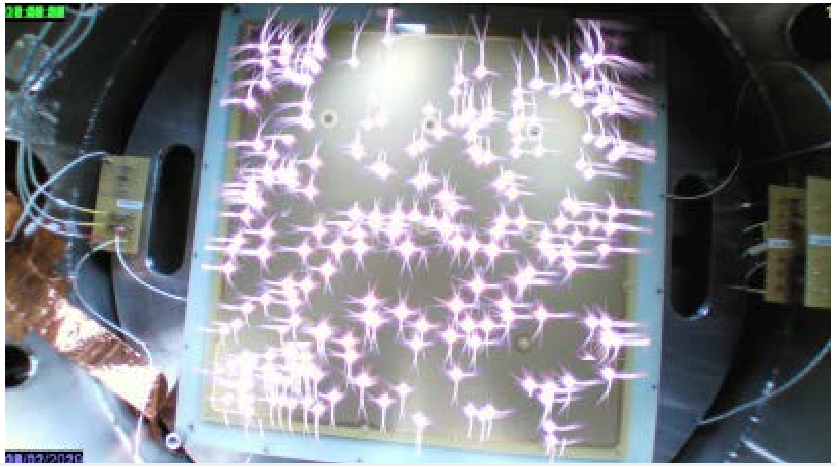


LEM and CRP R&D plan for new generation CRP

LEM and anode improvement plan presented on Dec 5th is continuing at CEA/Saclay:

- improving LEM design with high quality rims using a micro etching tecnnique developed by CERN
- Adding an insulating material in the dead regions of LEM using 64 um thick Pyralux coverlay (successful test at Saclay) very effective to eliminate sparks in those regions
- For the anodes: new design to incorporate a guard ring on both faces of PCB



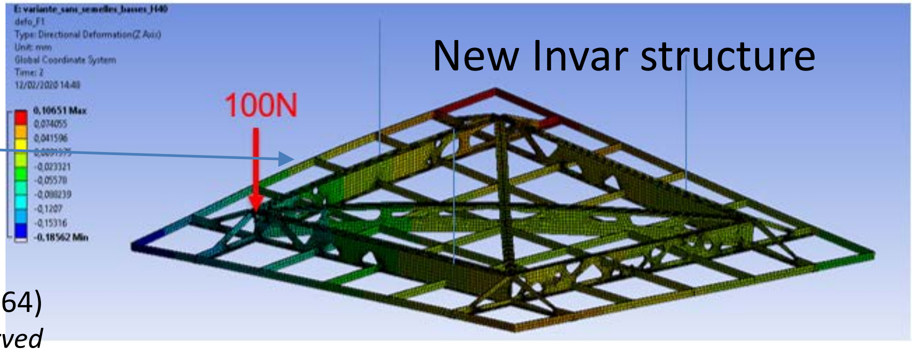


Several weeks of test at 3.4 kV, no spark on the insulated area

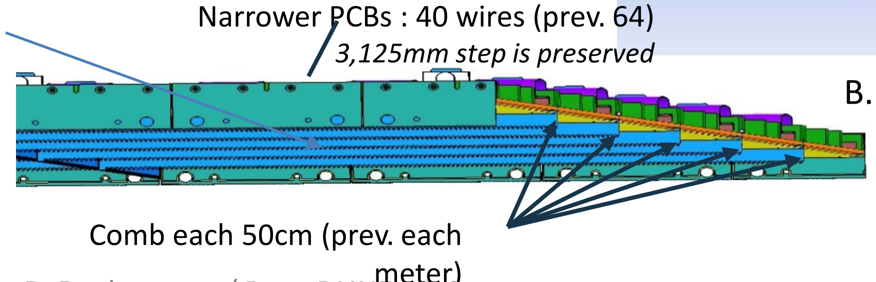
For the CRP structure and extraction grid:

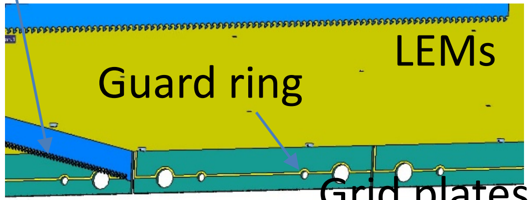
Modifications of the design are being validated to incorporate:

- a more stiff structure (20 times less deformations)
- A guard ring in the extraction grid support structures to guide the possible discharges
- Modifying the combs with resistive material.
- Add 2mm to the grid-LEM distance.



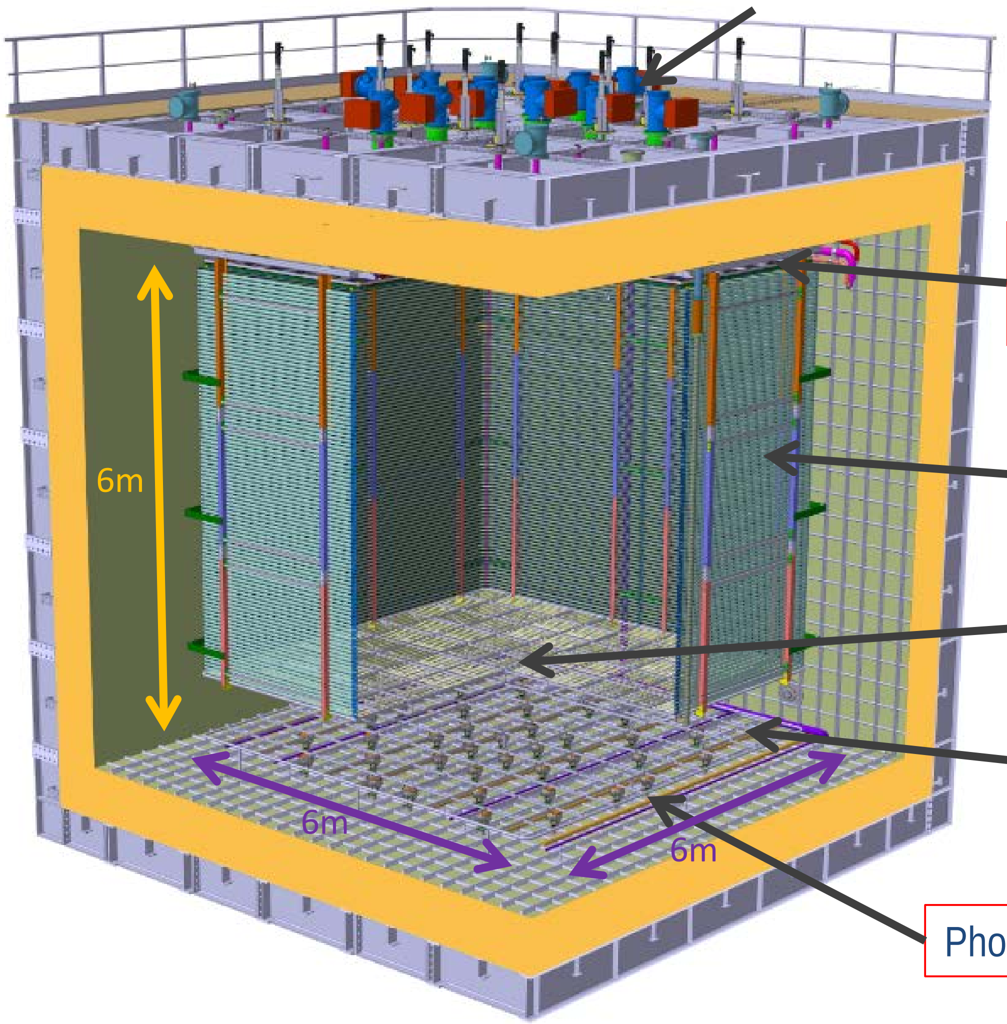
B. Aimard, G. Deleglise, N. Geffroy)





Backup

ProtoDUNE-DP (NP02) detector elements



Charge Readout Electronics

Charge Readout Planes (CRP)

Field Cage

Cathode

Ground grid

Photomultipliers

In the cryostat

CRP4: 4 anodes,
No LEM

Fully equipped:
36 LEMS + anodes