LEM Production and Tests in Cold Box for ProtoDUNE-DP

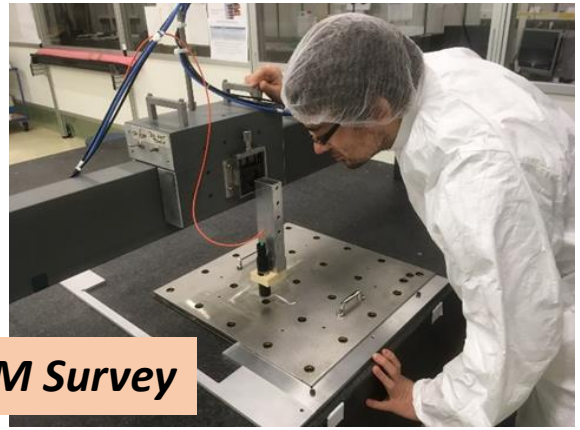
E. Mazzucato (CEA Saclay/Irfu)

- LEM Production
- LEM HV Tests in Cold Box

LEM Production

LEM production

- LEM manufacturing by ELTOS (Italy)
- Characterization and tests @ CEA/Irfu
- 74 LEMs produced and tested for CRP1 & CRP2 (Jan. – Oct./2018)

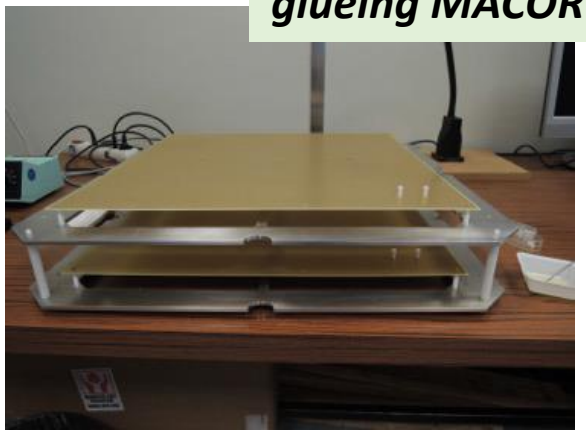


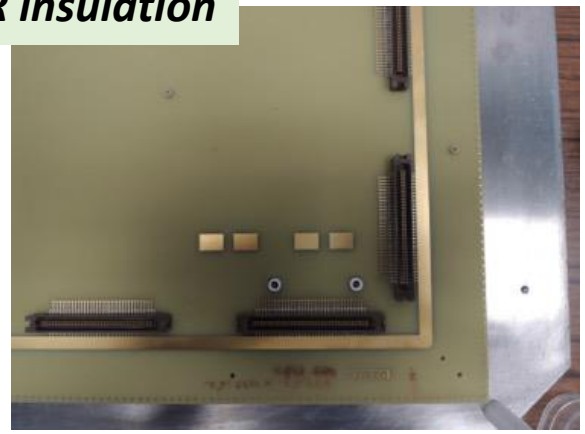
LEM Survey

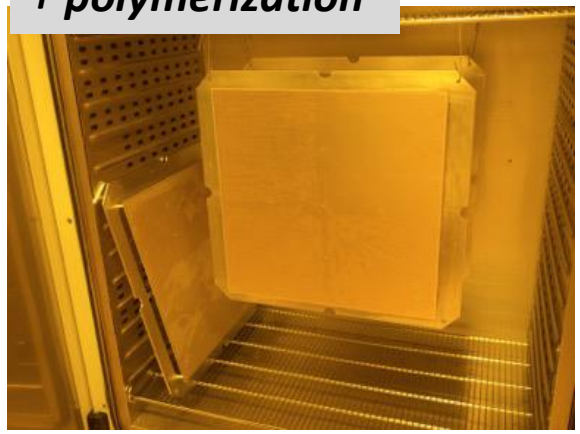
Soldering HV pins + glueing MACOR insulation

Ultrasonic bath

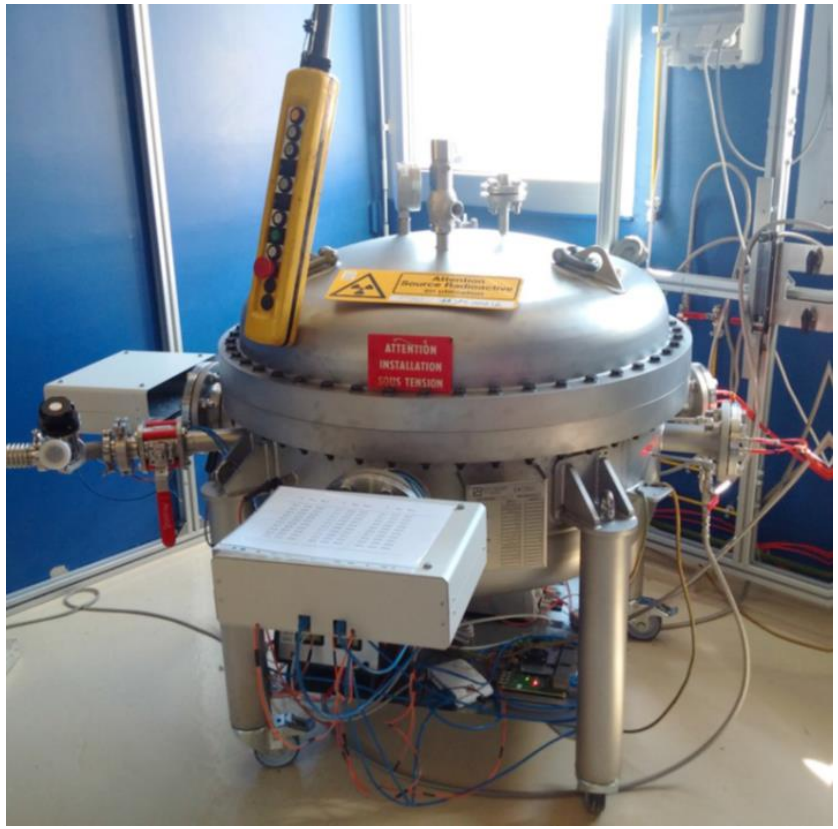
Cleaning + drying + polymerization

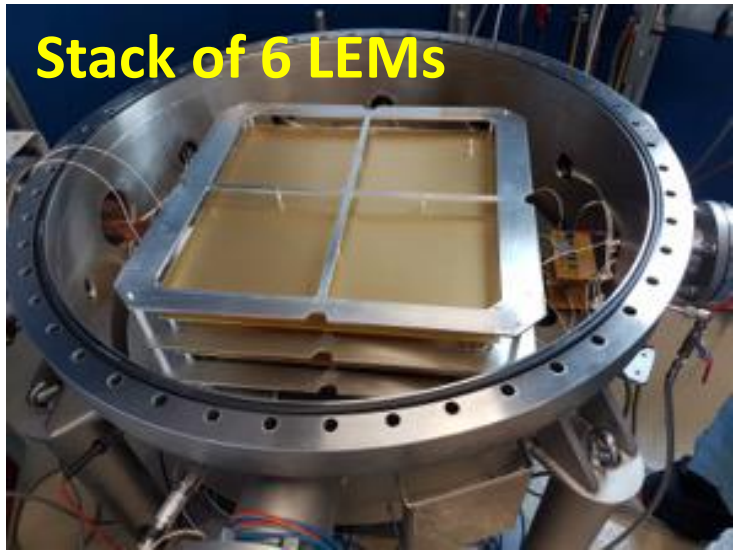


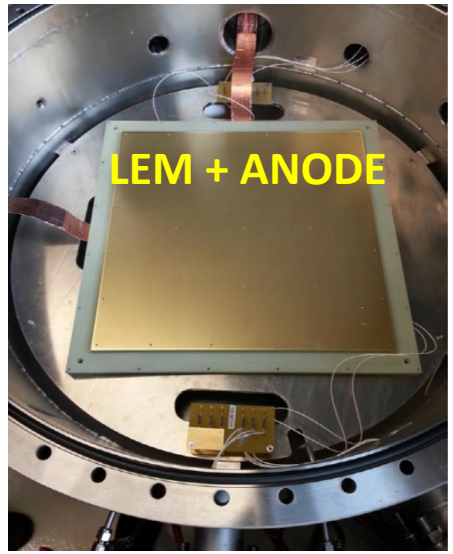




LEM HV Tests in a High Pressure Chamber



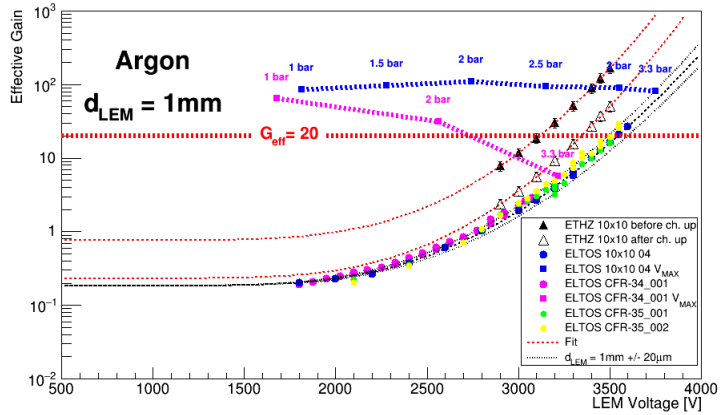




- Amplification gain inside the LEM depends on gas density ρ or P/T :

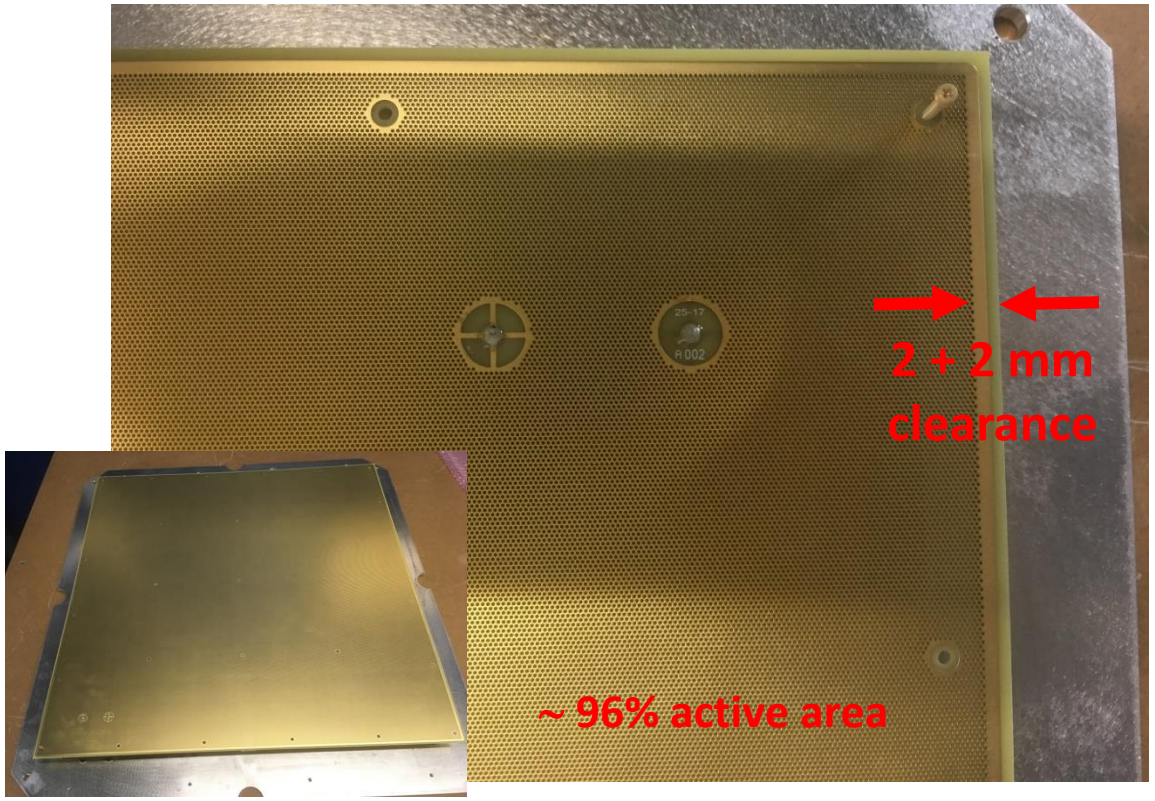
$$G_{eff} = Ce^{\alpha d} \quad \text{with} \quad \alpha = A\rho e^{-B\rho/E}$$

- GAr @ 88°K and ~1 bar ⇔ T = 20°C and P ~3.3bar.

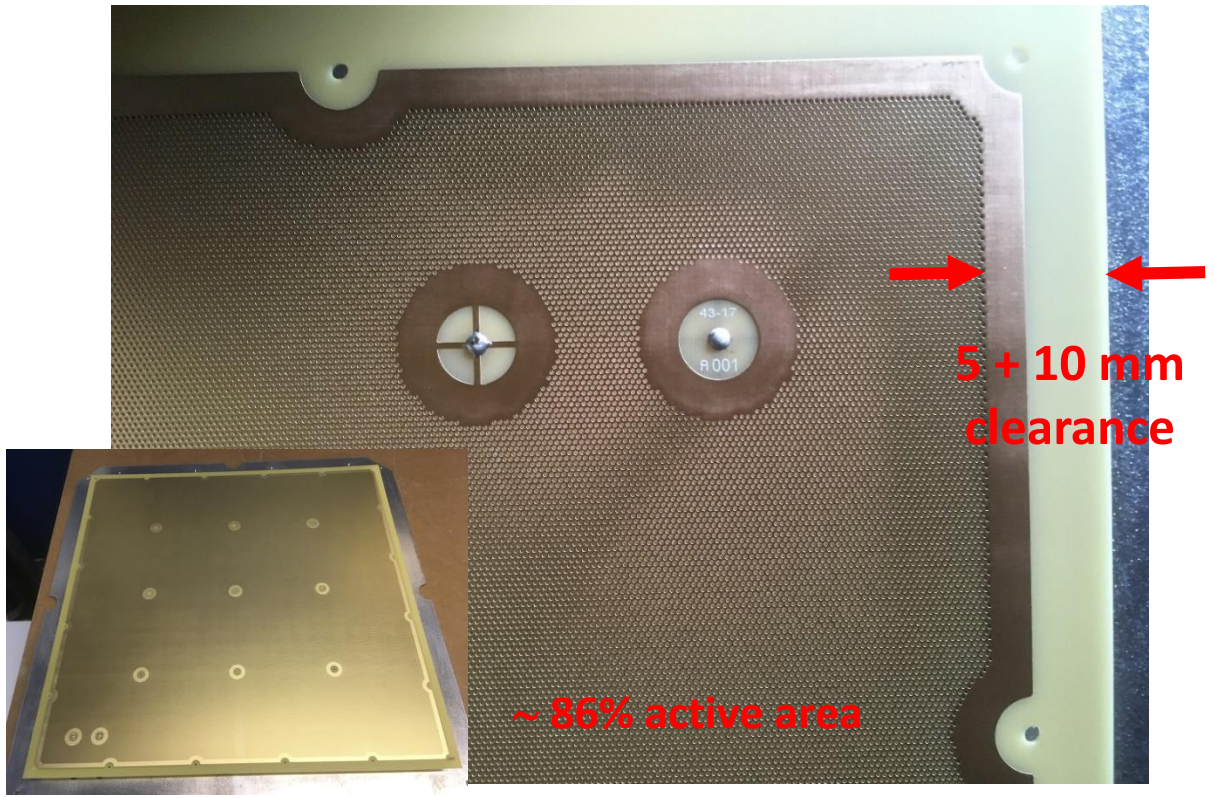


LEM Design for ProtoDUNE-DP

CFR-34 – 311 prototype



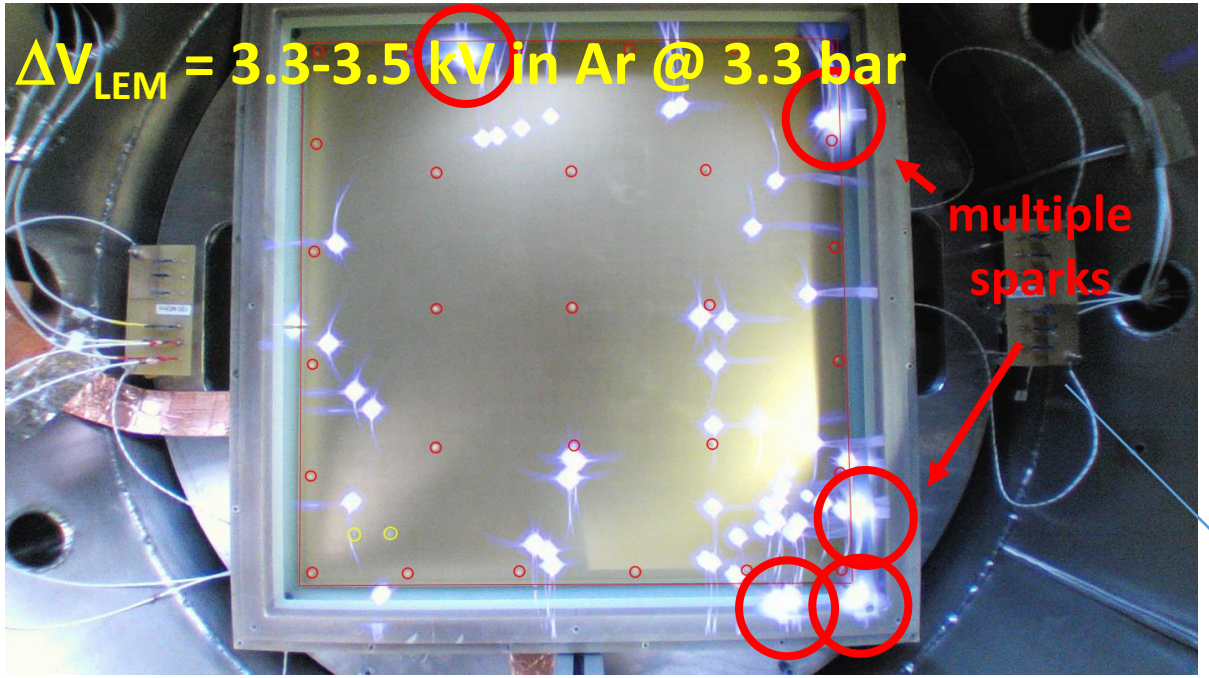
CFR-35 – NP02



Not necessarily the final design for a 10kt detector!

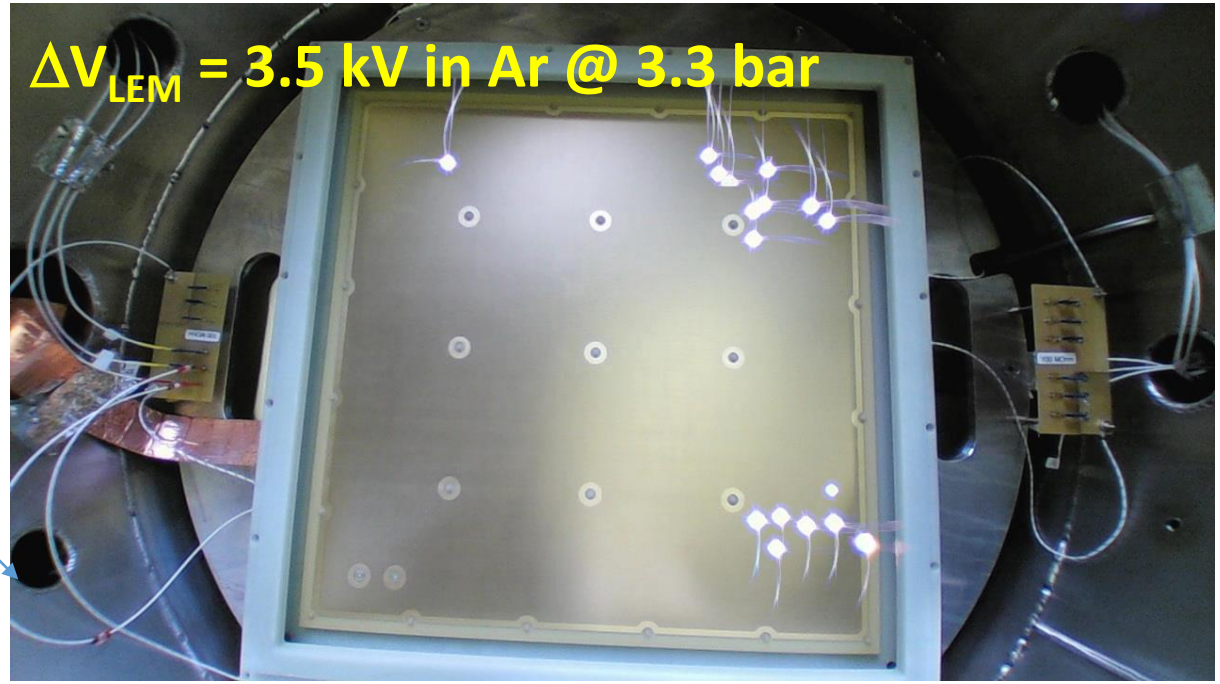
LEM HV Tests in Ar @ 3.3 bar

CFR-34 – 311



- spark rate : ~20/h
 (> 45% of sparks near edges or corners)

CFR-35 – NP02

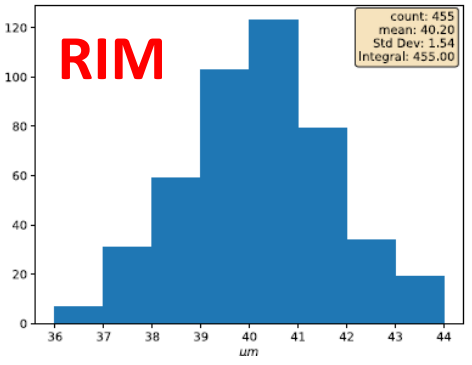


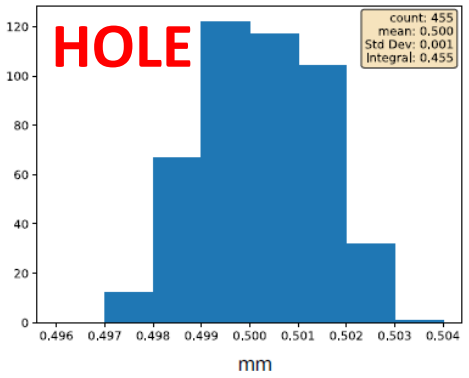
- gain > 100 in DLAr (before charging up)
- no PS trip for > 40h
- spark rate : ~3/h

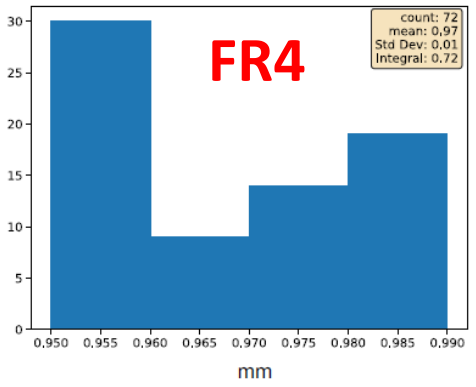
LEM QA/QC by ELTOS

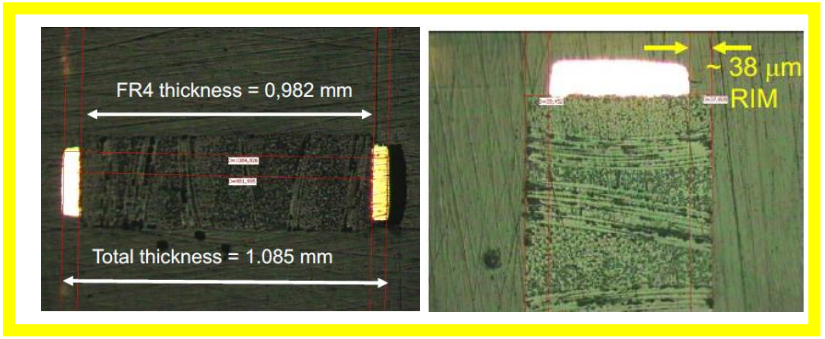
LEM Specifications

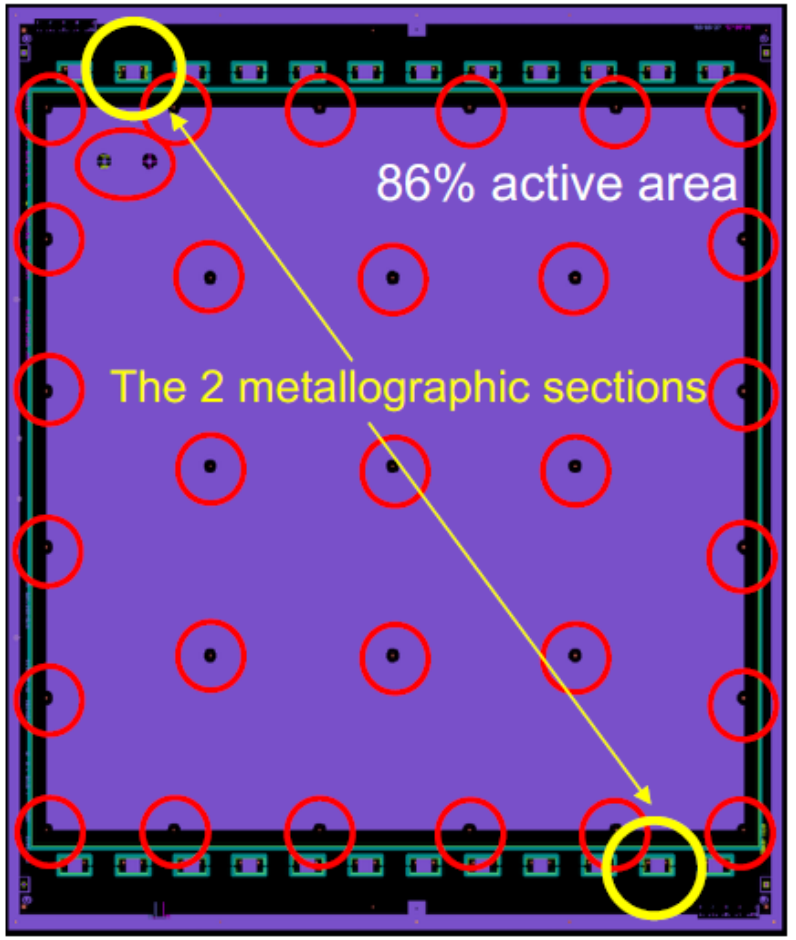
Laminate specifications	
Laminate	FR4 epoxy PANASONIC R-1566W
Dimensions	530 mm x 540 mm
Bare FR4 epoxy thickness	1 mm (-0.05 /+0 mm)
Copper thickness	105 µm
Mean thickness	1,20 (-0.06/+0) mm
Thickness uniformity	+/- 0.04 mm
final LEM specifications	
Dimensions	499.5 mm x 499.5 mm +0/-0.3 mm
Ni/Au	5 µm Ni + 0.1 µm Au
Final thickness	1.10 (-0.05/+0.02) mm
LEM holes	≈ 400 000 non-plated Φ=0.5 mm -0/+0.01 mm
RIM (with Ni/Au)	40 µm +/- 4 µm

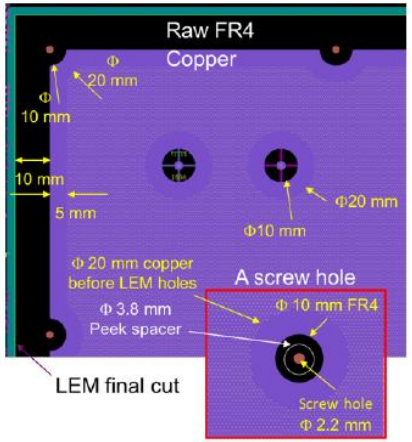


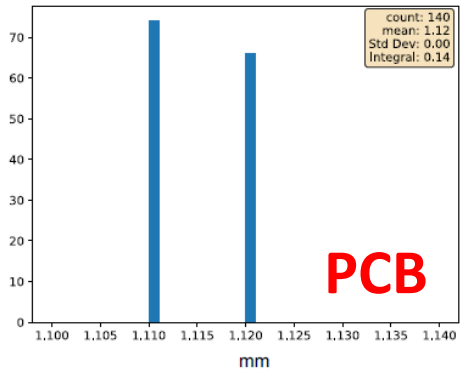




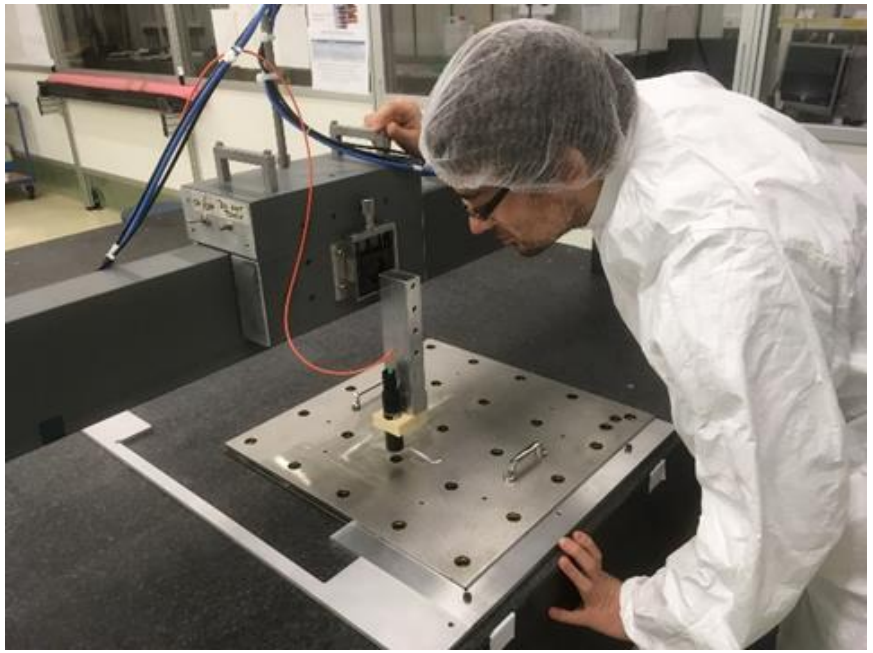


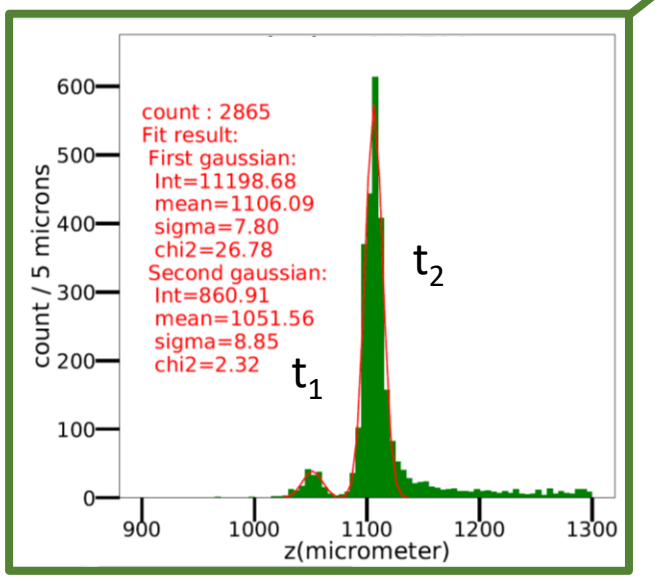


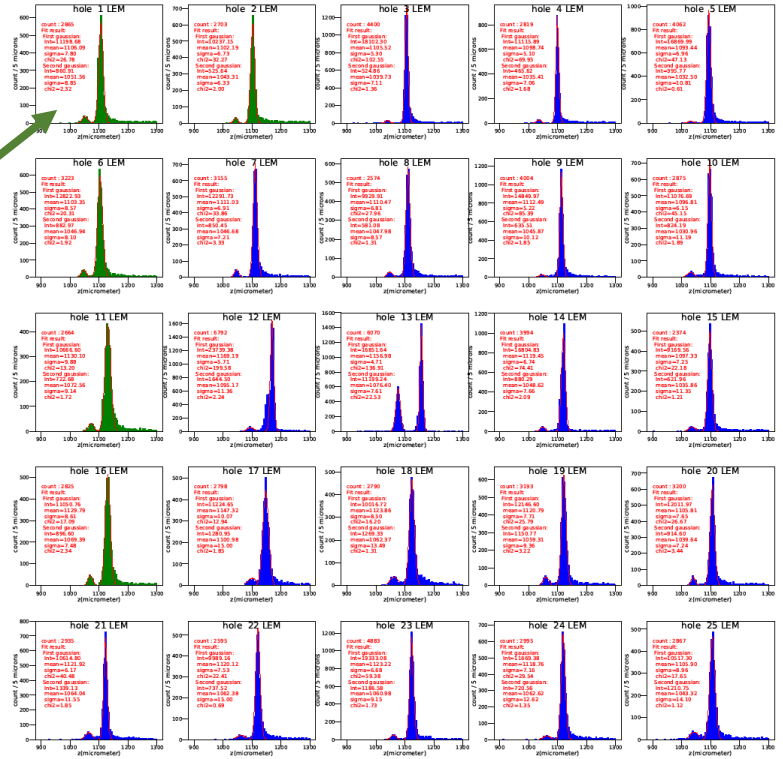




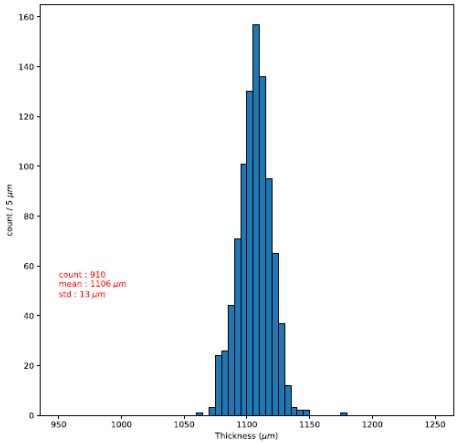
LEM Survey @CEA/Irfu



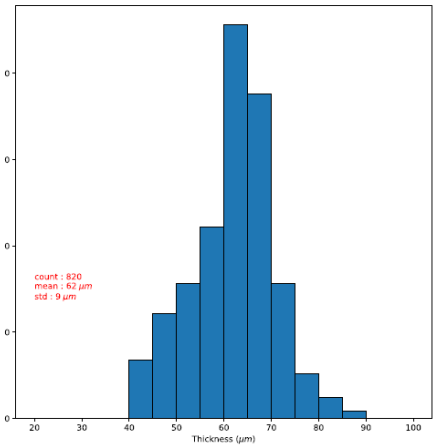




Mean LEM thickness : 1.106 mm

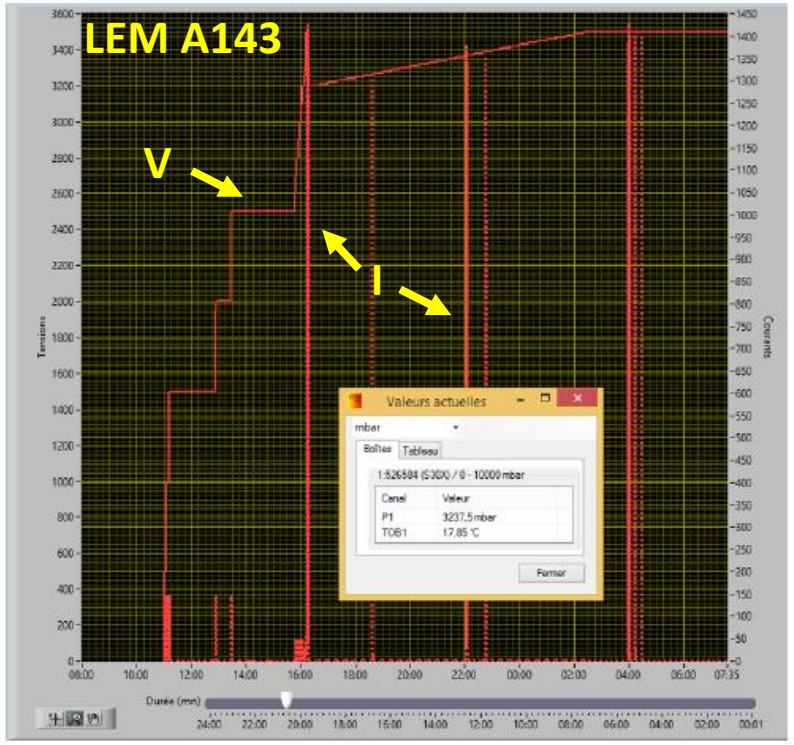


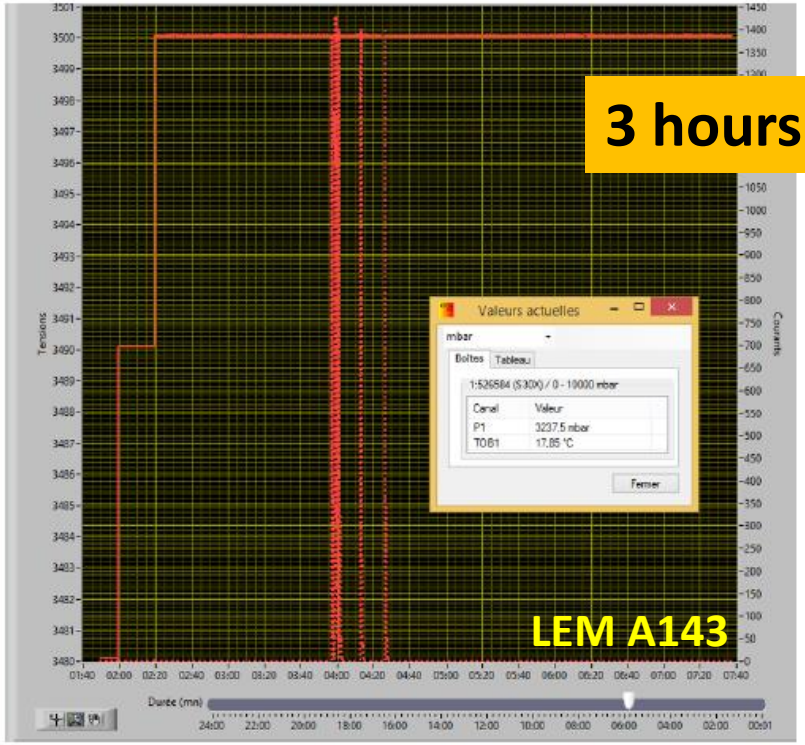
Mean copper thickness : 62 μm



LEM HV training in Ar @ ~3.3 bar

Fully automated HV training up to 3.5kV





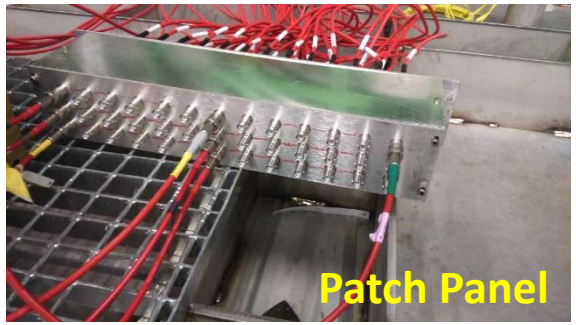
3 hours @ 3.5 kV

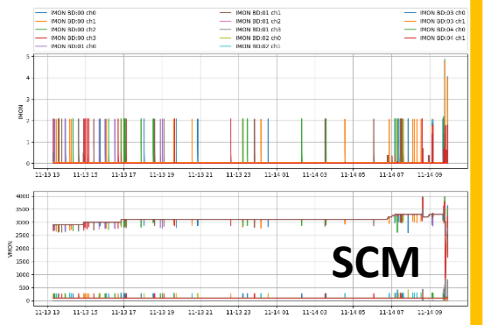
All LEMs in CRP1 and CRP2 tested up to 3.4 – 3.5 kV with < 1 spark / 20 minutes

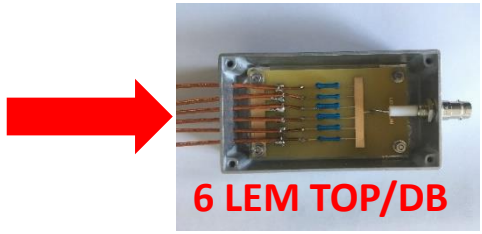
LEM HV Tests in Cold Box

CRP1 and CRP2 HV LEM Tests

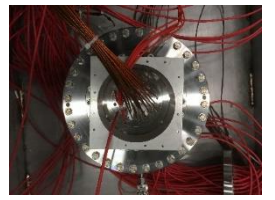
- Since last July, CRP test conditions with Cold Box have been improving (LV, TP, LAr level regulation, GRID, etc…)
- LEM HV system modified (DB, HV connections) for more reliable operation in cold GAr
- HV PS system and SC monitoring still temporary with limited number of channels (LEMs grouped by 6; 14 available LEM HV channels instead of 42)

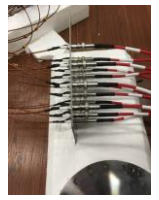






LEM DB and HV





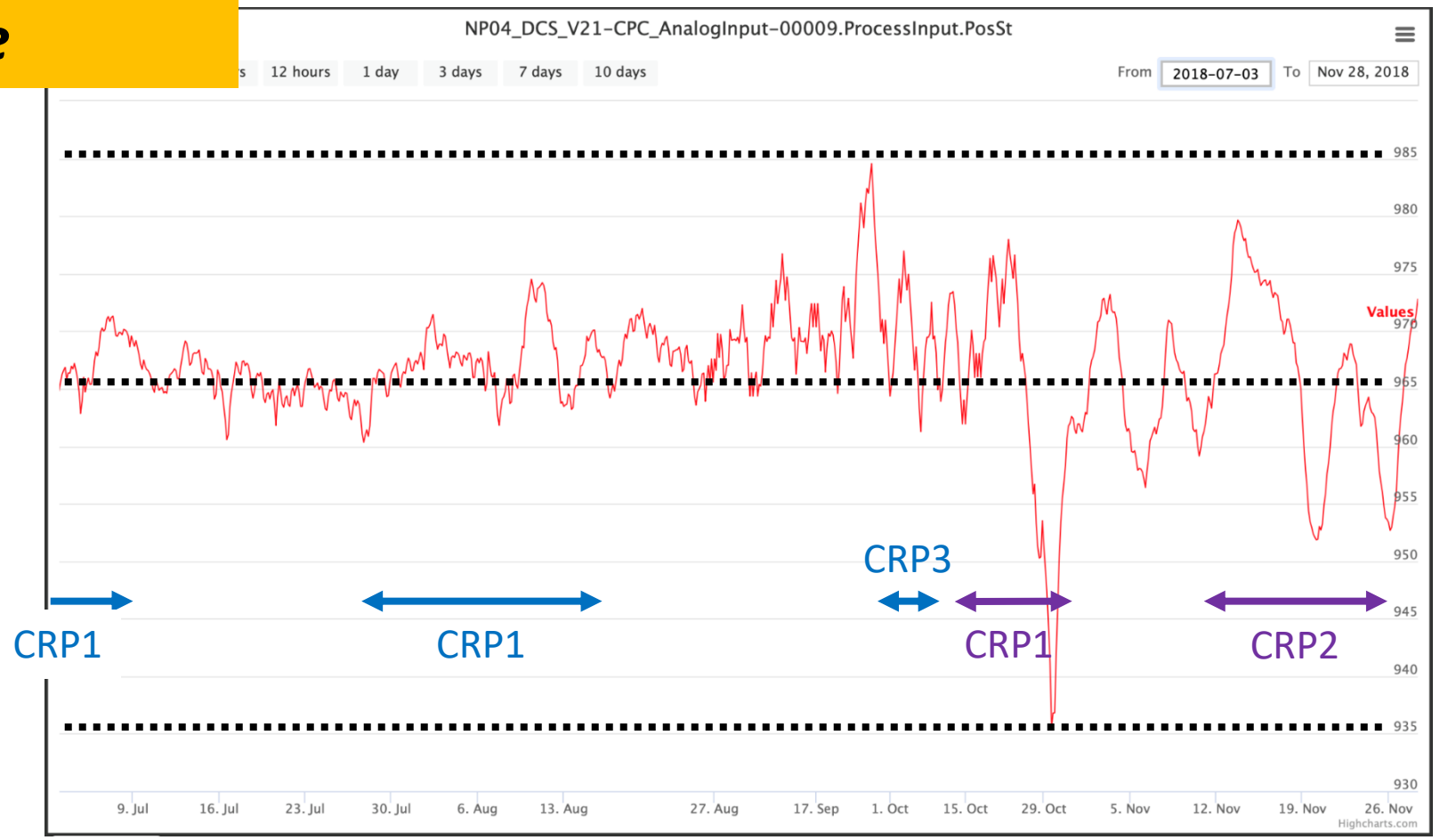
36 LEM BOT

CRP1 and CRP2 LEM HV Tests

- Will mainly address the CRP1 & CRP2 CB tests of Oct. and Nov. as CRPs were in their final configuration
- No control on Ar purity (< 100 ppm) and GAr density (P_{atm})
- Reminder : performance goals for ProtoDune-DP (G ~ 20, stability) are based on the operation of a 3L TPC with an active LEM area 900 times smaller than one single CRP …
- CRP1 and CRP2 operated for « long » periods of time at different HV settings with all 36 LEMs powered, exceeding by far LEM operation time with the 311
- Still, some issues remain to be understood …

Atmospheric Pressure

From ProtoDUNE-SP SC web page



985 mbar

965 mbar

935 mbar

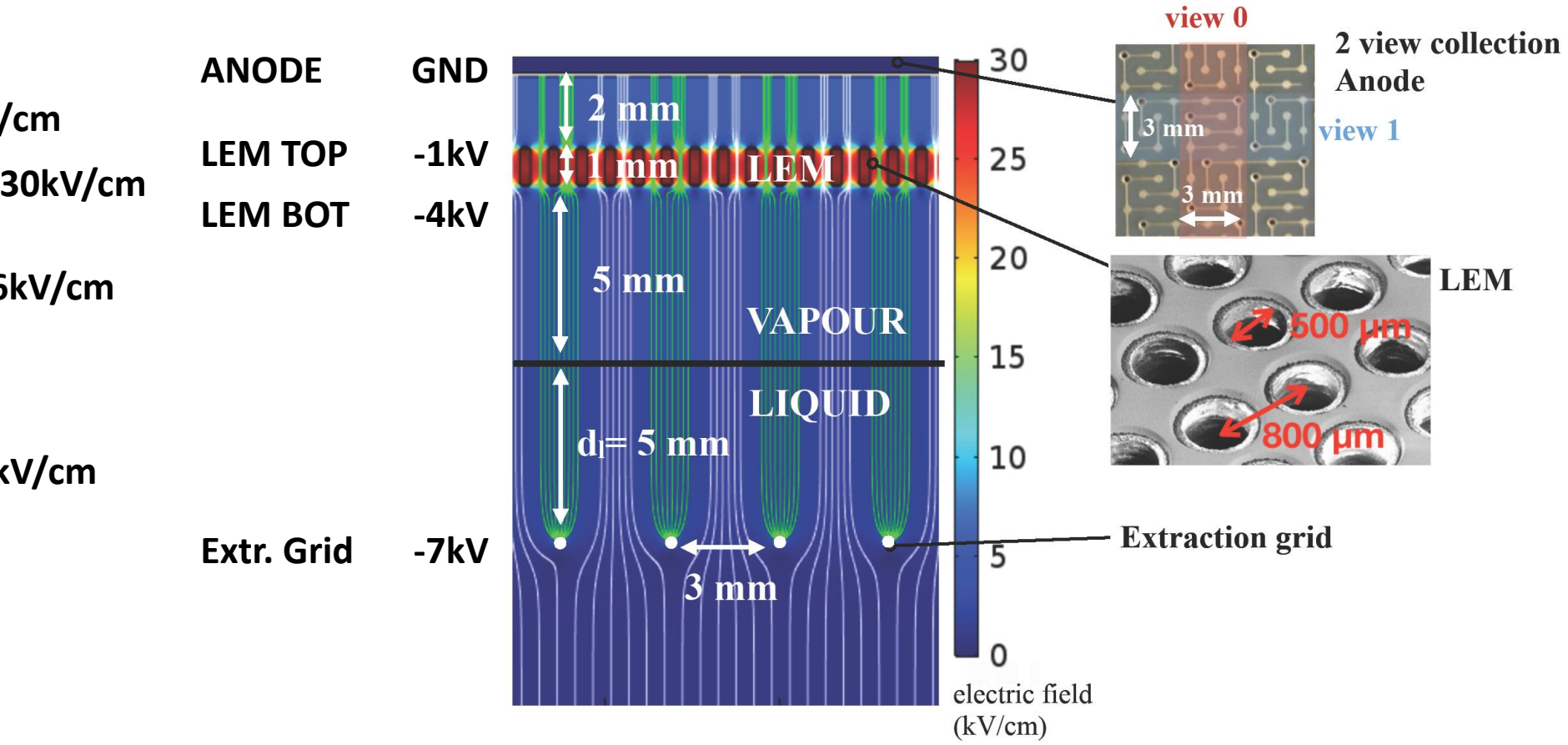
Dual Phase Principle

Induction : 5kV/cm

Amplification : 30kV/cm

Extr. (GAr) : 3.6kV/cm

Extr. (LAr) : 2.4kV/cm



CRP1 LEM HV Test Results (Oct. 15th - 30th)

- Liquid level stable to within ~250µm (2mm rapid increase of level occured during LAr delivery on Oct. 30th)
- $T_{LEM} \sim 91°K$
- $\Delta V_{LEM\text{-}GRID} = 3kV$

V_{TOP} (kV)	V_{BOT} (kV)	E_{LEM} (kV/cm)	Time (h)	Spark Rate (h^{-1})	P_{atm} (mbar)	G_{eff} (no ch. up)
0.25	3.35	31.0	12	1.3	968 - 972	20
0.50	3.55-3.60	30.5-31.0	13	1.3	962 - 966	24 - 31
0.75	3.70	29.5	42	0.6	943 - 953	20
1.00	3.80	28.0	18	2 trips*	970 - 976	9
1.00	3.85	28.5	12	3 trips	936 - 947	15

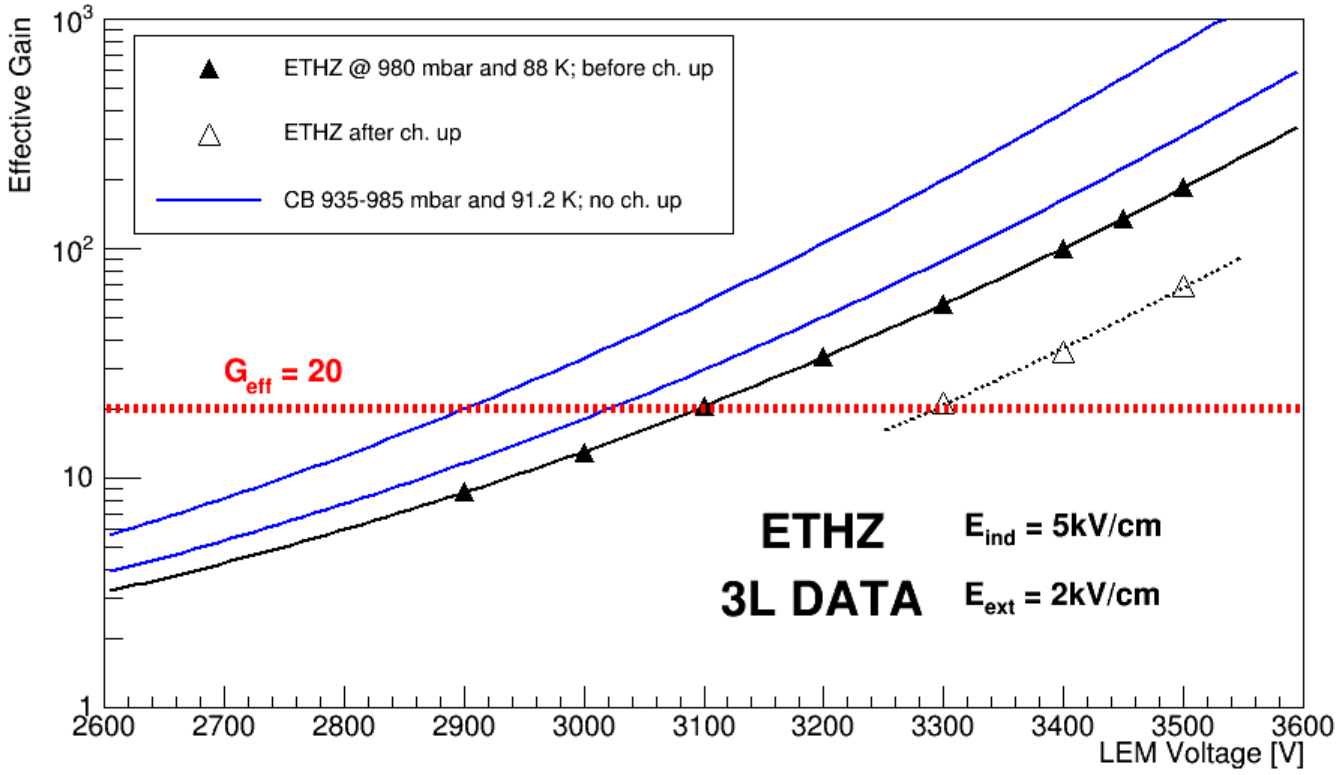
* TRIP time set too short

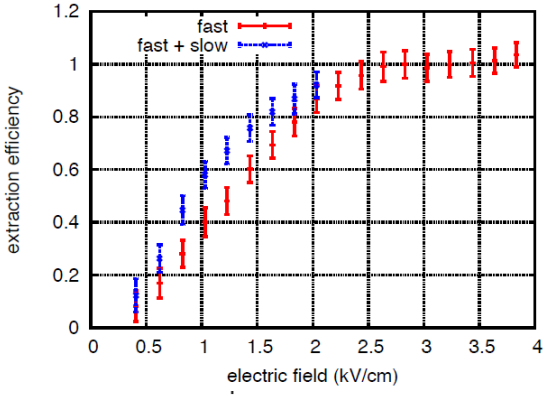
- As V_{TOP} increases up to the 1kV nominal value, the field inside the LEM needs to be decreased in order to keep stable operation conditions.

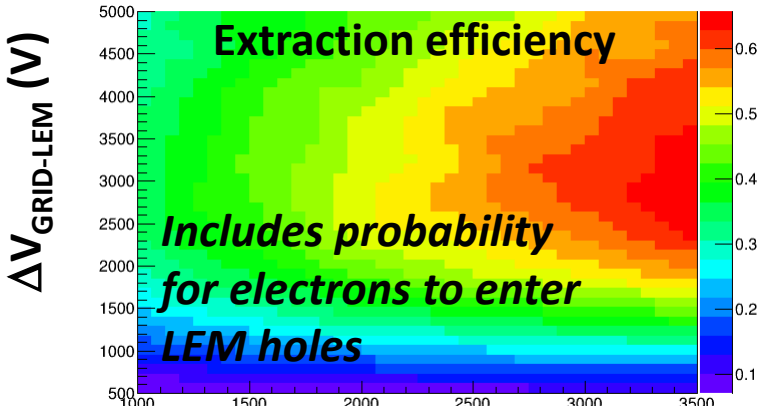
Effective gain

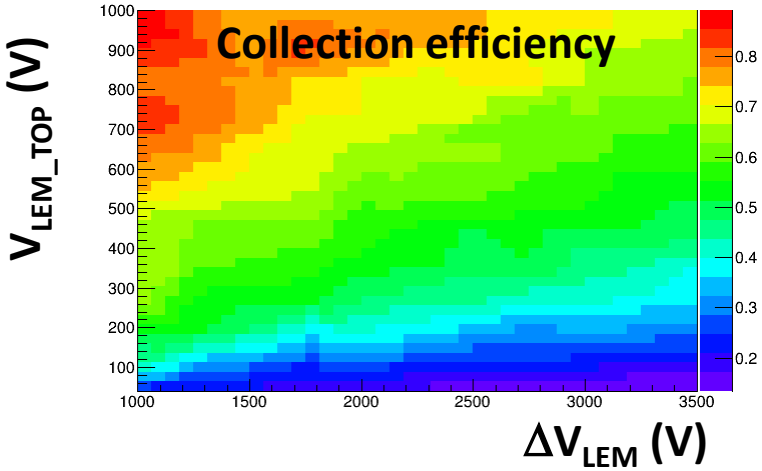
Gushchin et al., Sov. Phys. JETP 55 (1982) 860-862.

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









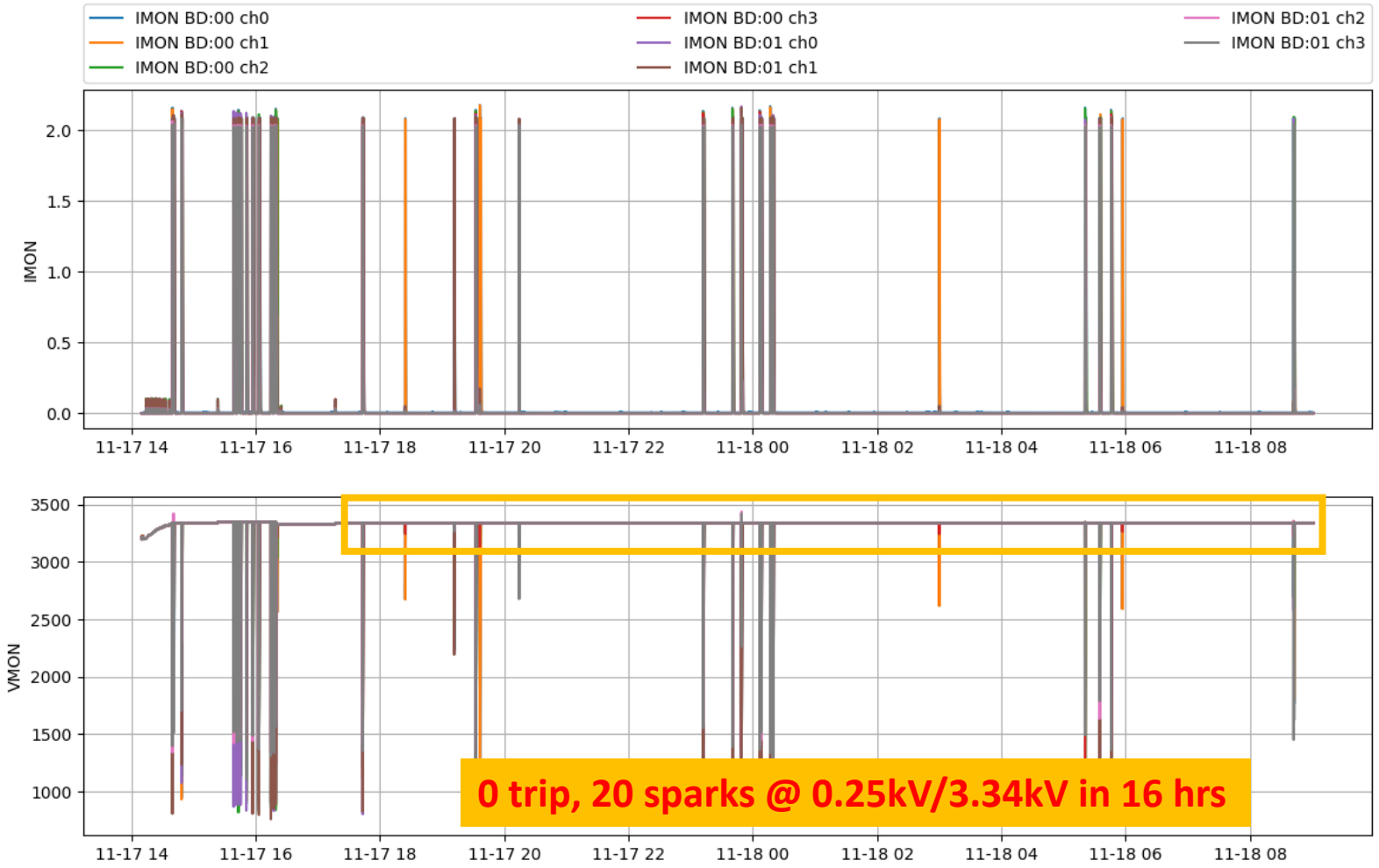
First CRP2 Results (Nov. 15th – 26th)

- LEM HV tests in DLAr mode started on Nov. 15th after CRP positioned w.r.t. liquid level
- Liquid level stability : ~200µm
- $\Delta V_{LEM\text{-}GRID}$ = 3kV

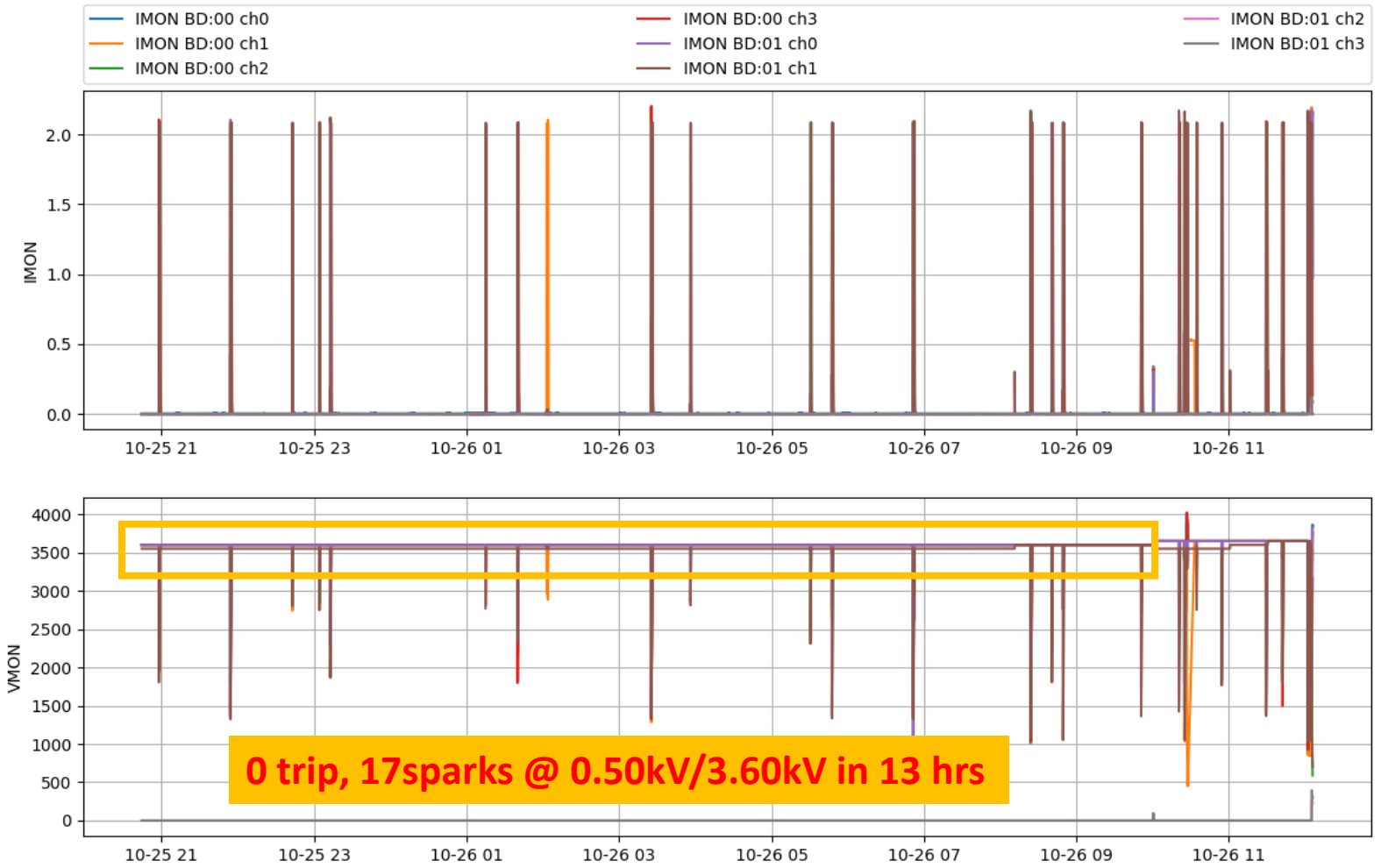
V_{TOP} (kV)	V_{BOT} (kV)	E_{LEM} (kV/cm)	Time (h)	Spark Rate (h^{-1})	P_{atm} (mbar)	G_{eff} (no ch. up)
0.10	3.15 - 3.20	30.5 - 31.0	17	0.8	969 - 973	9 - 11
0.25	3.34	30.9	16	1.3	968 - 970	19
0.50	3.55	30.5	11	0.9	957 - 965	24
0.50	3.555	30.55	42	0.5	962 - 964	25

- Similar trend and HV limitation for CRP2 as CRP1. Being investigated. Not observed during source tests up to 35kV/cm in HP chamber with single LEM + anode.

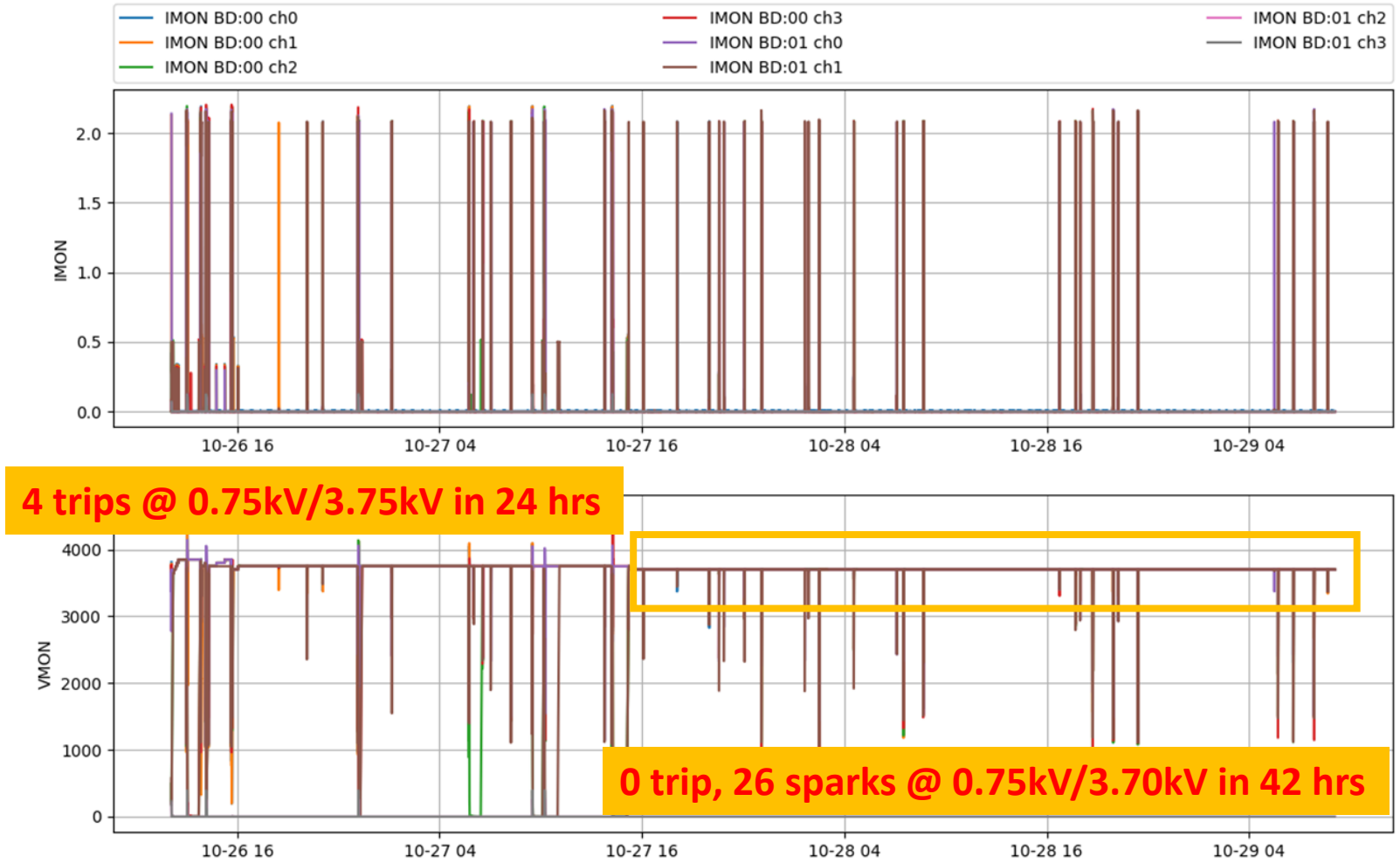
CRP2 : V_{TOP} = 0.25kV and V_{BOT} = 3.34kV



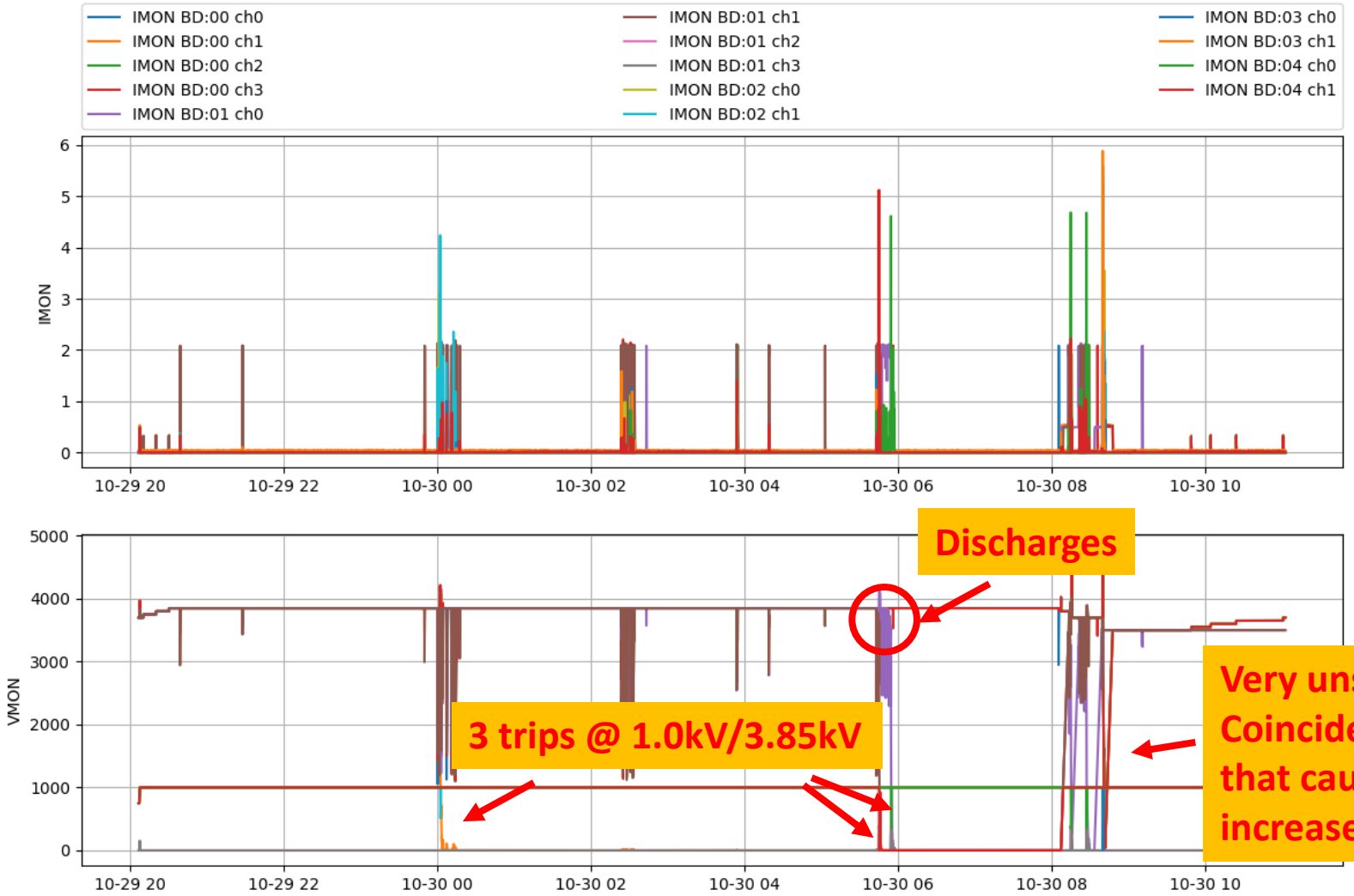
CRP1 : V_{TOP} = 0.50kV and V_{BOT} = 3.60kV



CRP1 : V_{TOP} = 0.75kV and V_{BOT} = 3.70kV

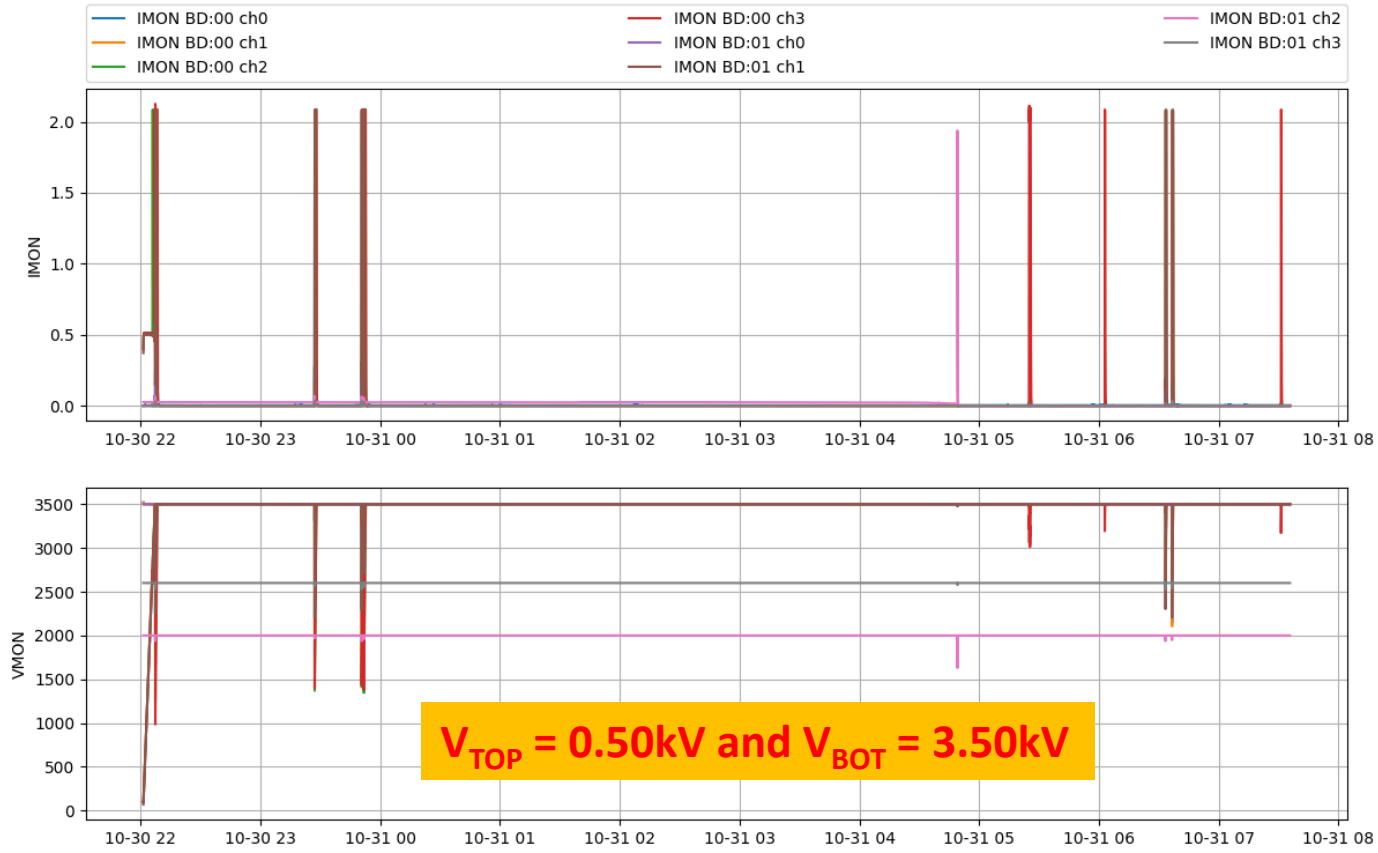


CRP1 : V_{TOP} = 1.00kV and V_{BOT} = 3.85kV



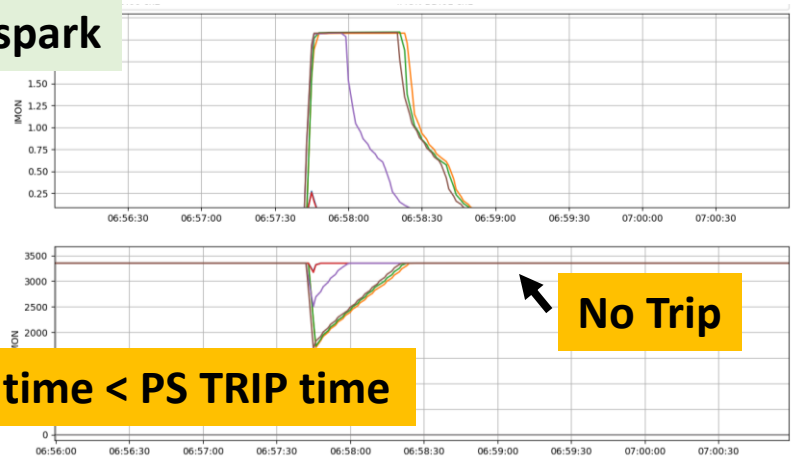
Issues with CRP1

- On Oct. 30th, found 3 problematic LEMs (16,28,30) from 2 different HV channels with similar discharging behaviour
- Needed to lower their V_{BOT} value to run in stable conditions



Sparks, trips and continuous discharges

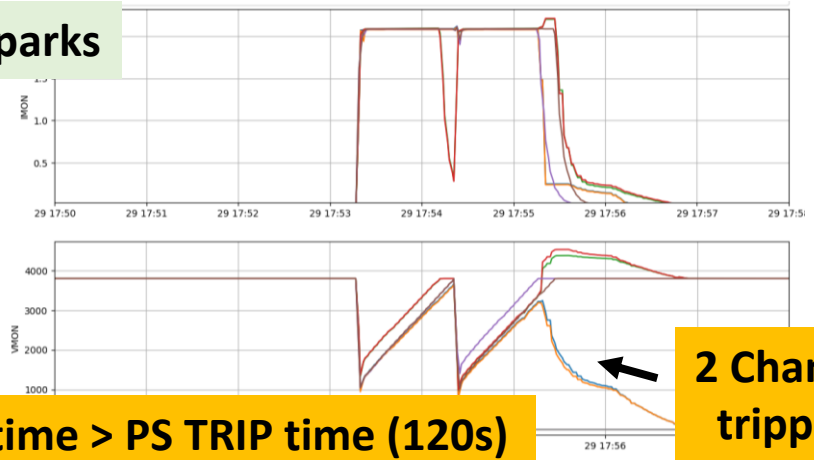
1 spark



No Trip

Recovery time < PS TRIP time

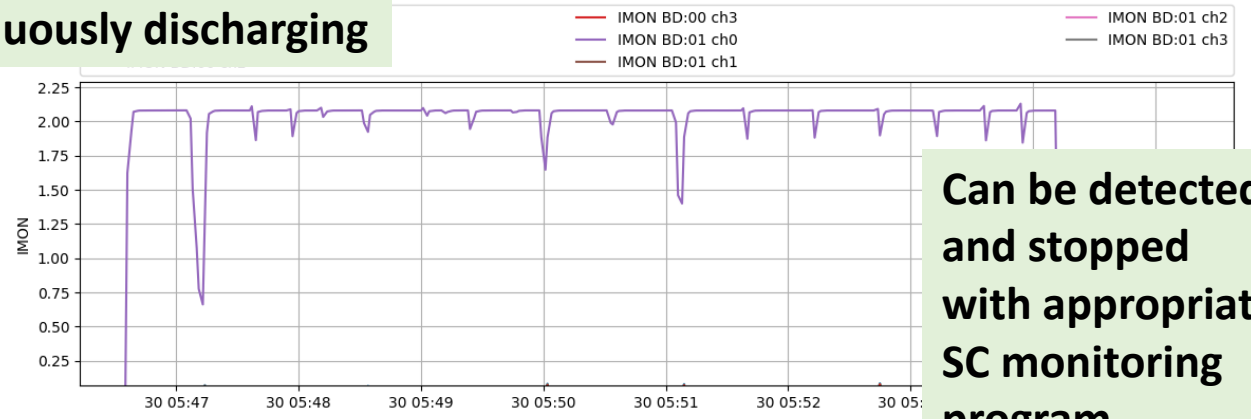
2 sparks



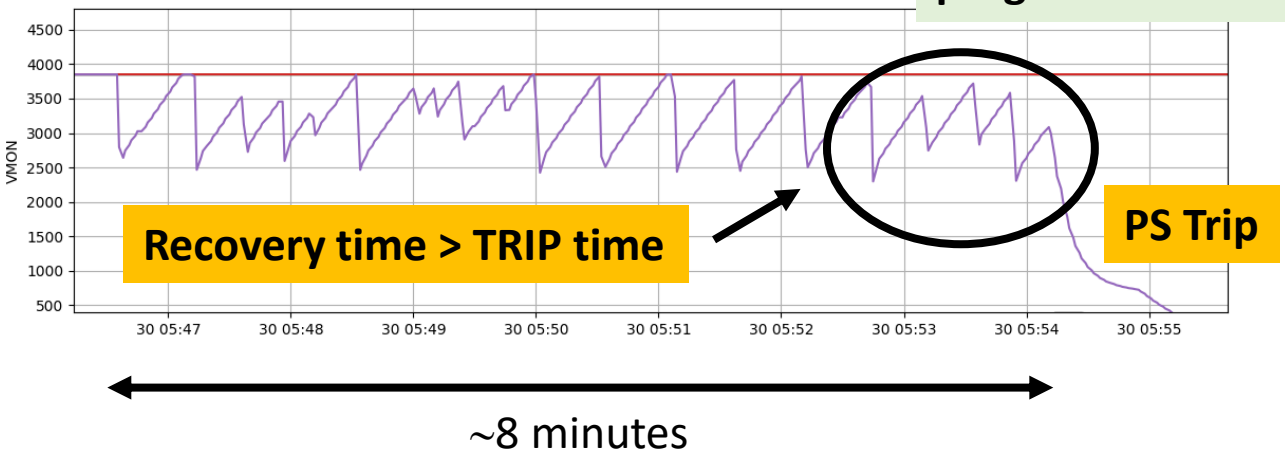
2 Channels tripped

Recovery time > PS TRIP time (120s)

Continuously discharging



Can be detected and stopped with appropriate SC monitoring program



Recovery time > TRIP time

PS Trip

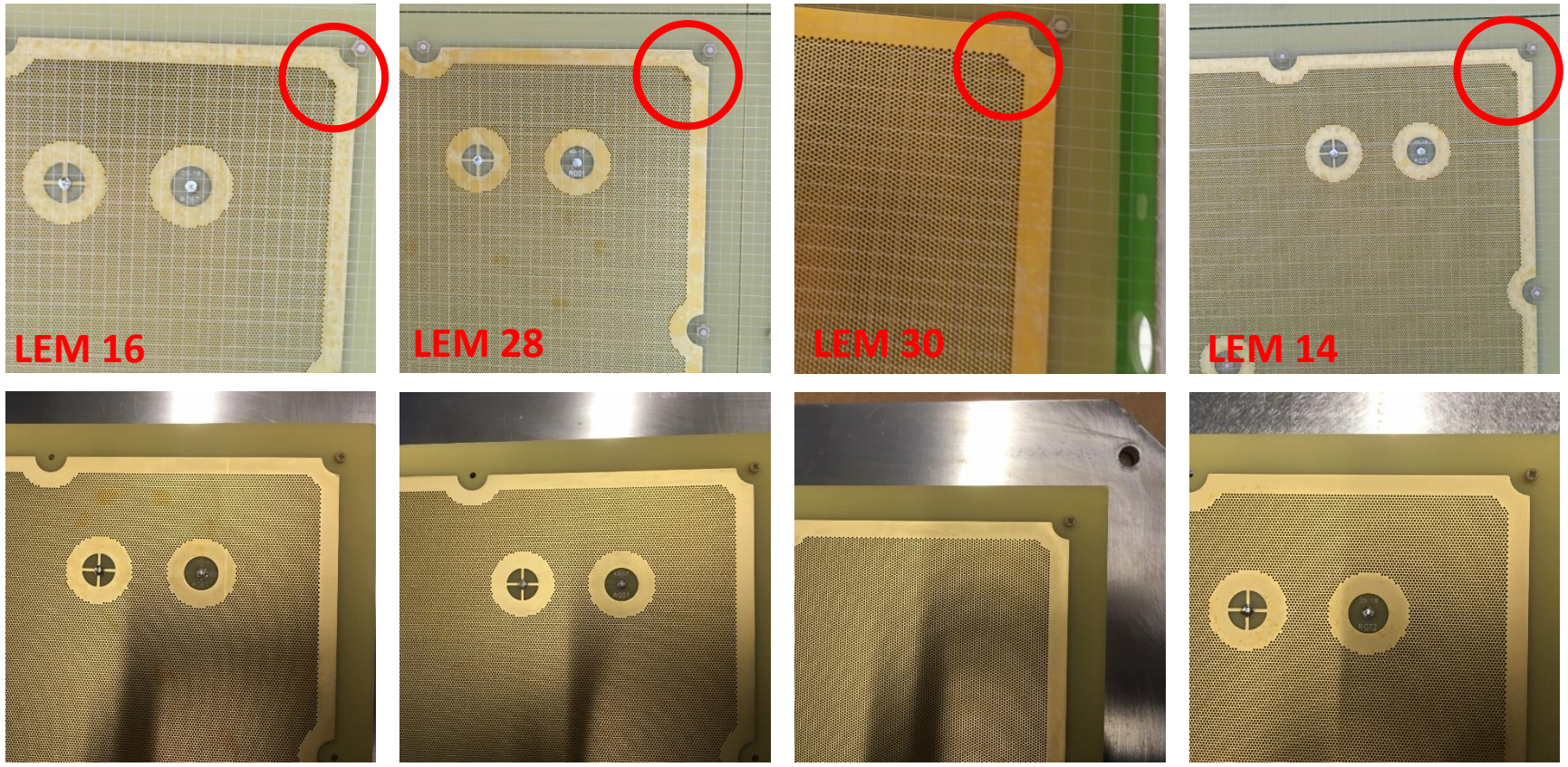
~8 minutes

Issues with CRP1

Inspection of CRP1 after removal from the CB revealed dark spots on 4 LEMs

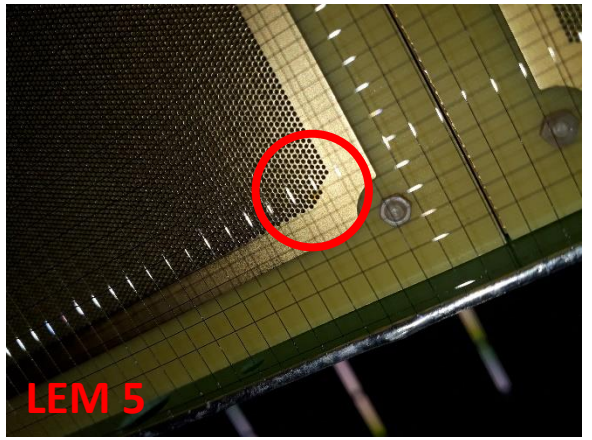
- Points to a weaker regions of the LEM
- Detailed E-field calculations needed

- Treated with potassium permanganate @ CERN to remove carbonized FR4 inside holes. Copper surface unaffected.
- Cleaned at CEA/Irfu and tested up to 3.2kV @ 3.3 bar
- Back on CRP1



CRP2 : V_{TOP} = 0.50kV and V_{BOT} = 3.55kV

LEM 5 continuously discharging for several minutes before HV lowered



LEM 5 of CRP2 to be replaced with a spare one

Summary

- LEMs manufactured by ELTOS for ProtoDUNE-DP meet the required specifications. However, the production for 2 CRPs took longer than expected (×2) due to manufacturing delays.
- The two CRPs are now operational although some problems developped on a few LEMs (cured now) and some HV limitation observed. Nominal effective gain of 20 before charging up is within range.
- Need « intelligent » SC program to better protect LEM against multiple discharges. Question being addressed with CERN-EP-DT-DI for ProtoDUNE-DP.
- Ready now to use CRPs in ProtoDUNE-DP and operate LEMs in real conditions (LAr purity and stable thermodynamic conditions, drift region) to assess performance of a large scale DLAr TPC.
- Understanding/improvement of LEM performance & design can be addressed concurrently.