LEM/Anodes and CRP Improvement Plan

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LEM Improvement Plan

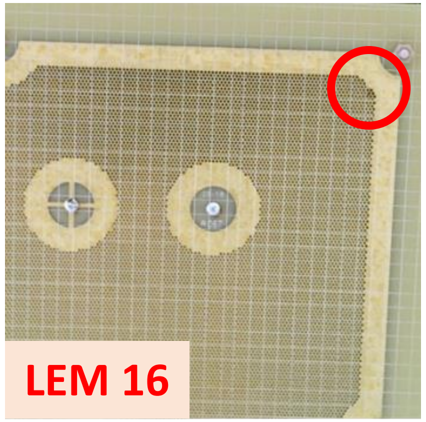
Three issues being addressed:

- LEM active area. In ProtoDUNE-DP, LEM active area reduced to 86% in order to mitigate spark rates in the boundary regions of the PCB. Would like to achieve > 95% for DUNE.

- LEM HV stability. Aim is to keep spark rates as low as possible for very long term operation in DUNE and avoid ageing effects. Spark rates < 1/h per CRP at gains ~ 20 in Cold Box tests at CERN in 2018.

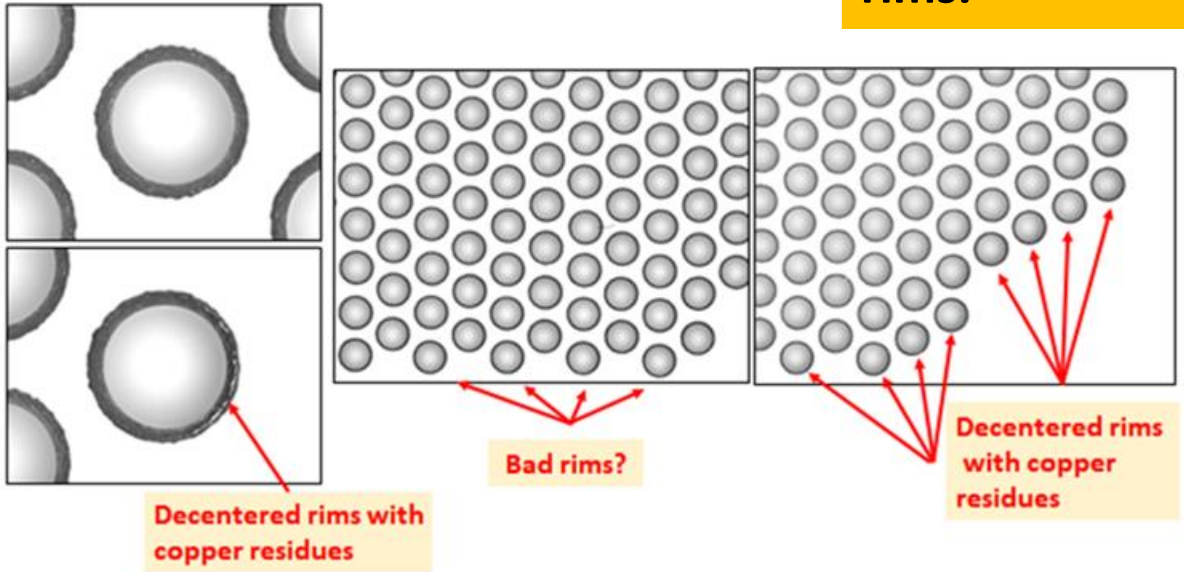
- Rim defects. LEM carbonization issues found during Cold Box tests point to method used by ELTOS (Italy) for the micro-etching process of rims around amplification holes.

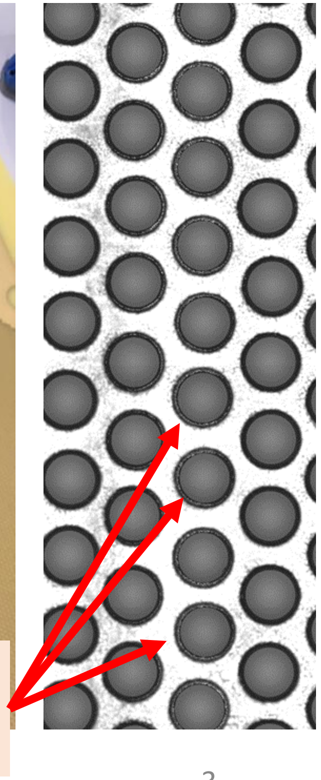
Reminder : carbonization issues during CB tests in 2018



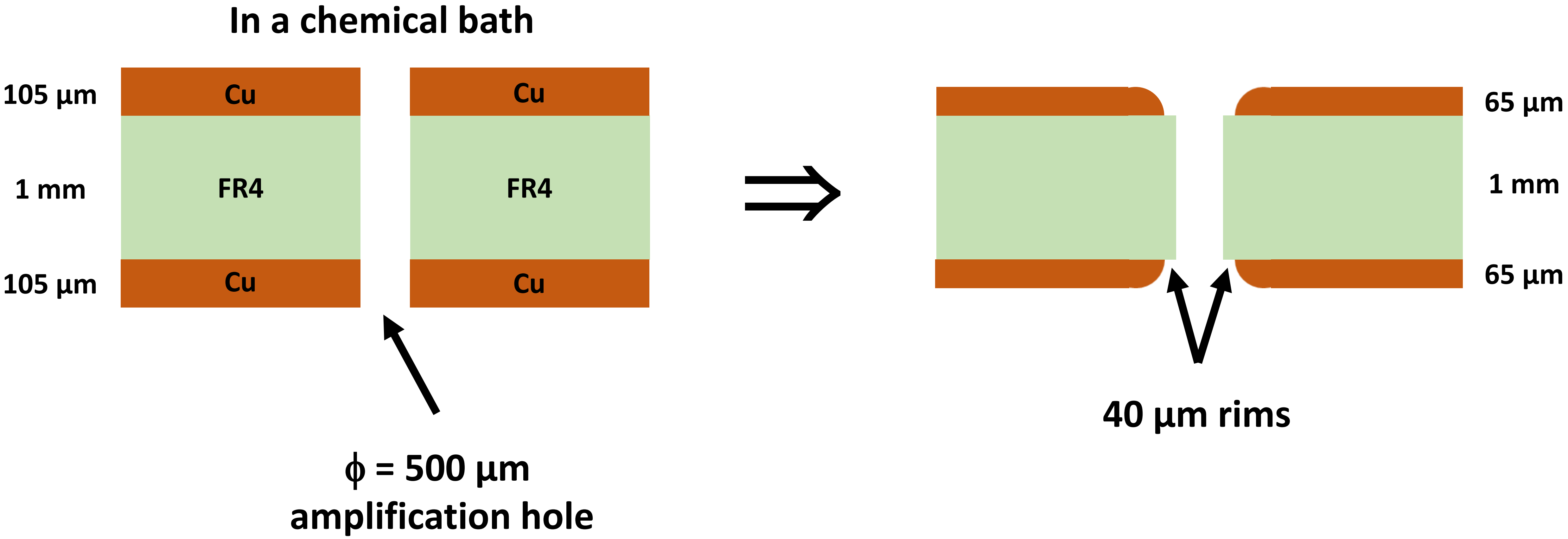
In total, 5/72 LEMs affected by such problems

Issues point to standard micro-etching process used by ELTOS to make rims.



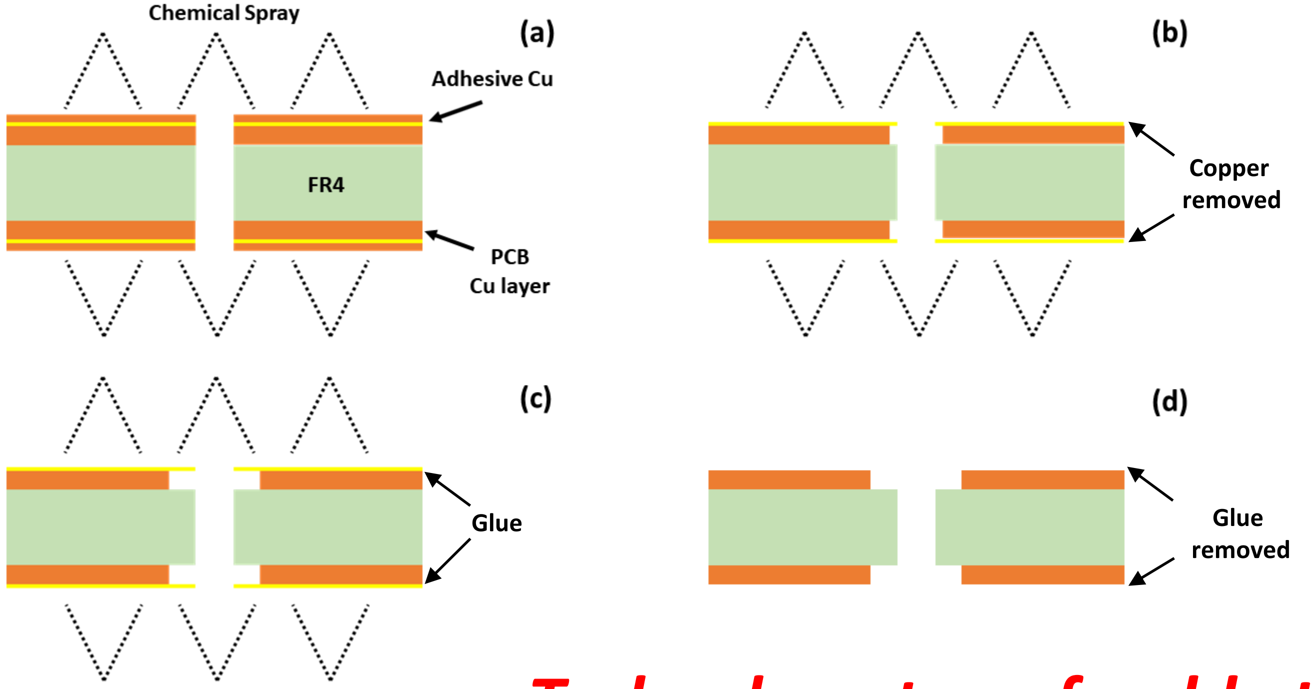


Standard micro-etching process by ELTOS

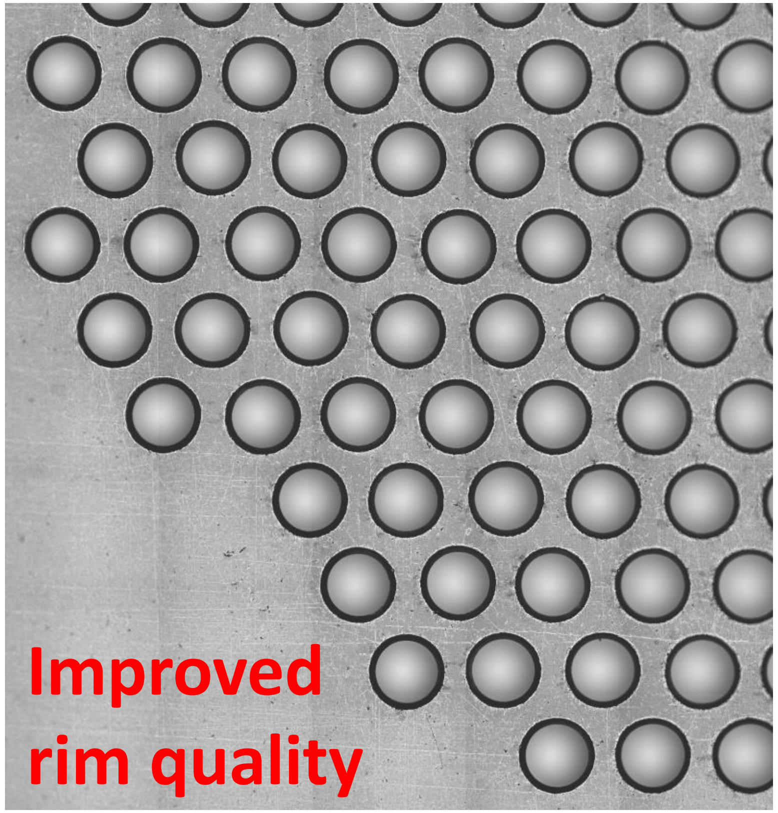


Improved micro-etching process for rims

- Developed at CERN by EP-DT-EF.
- LEM copper surfaces protected with thin (15 µm) adhesive copper foils before drilling.
- Micro-etching only around holes, visible through transparent glue.



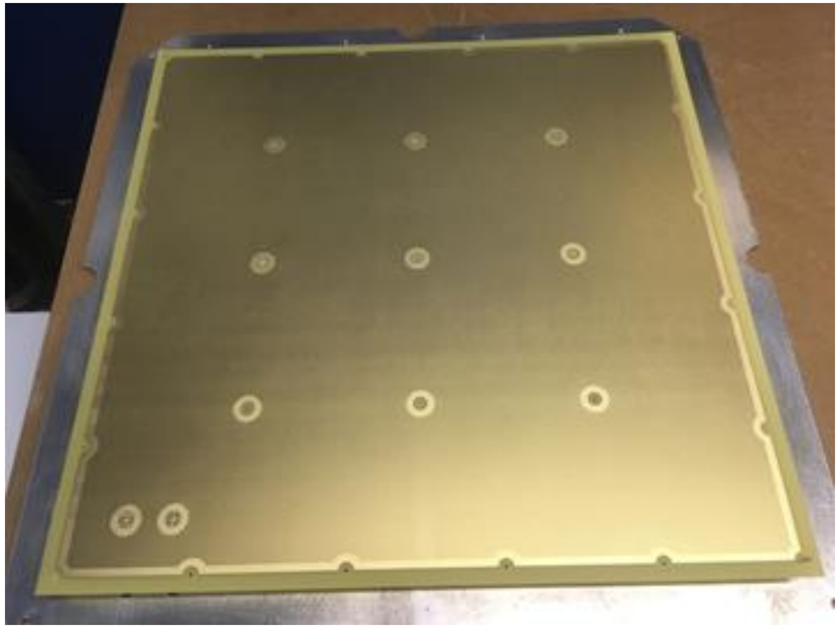
50×50 cm² LEM manufactured at CERN

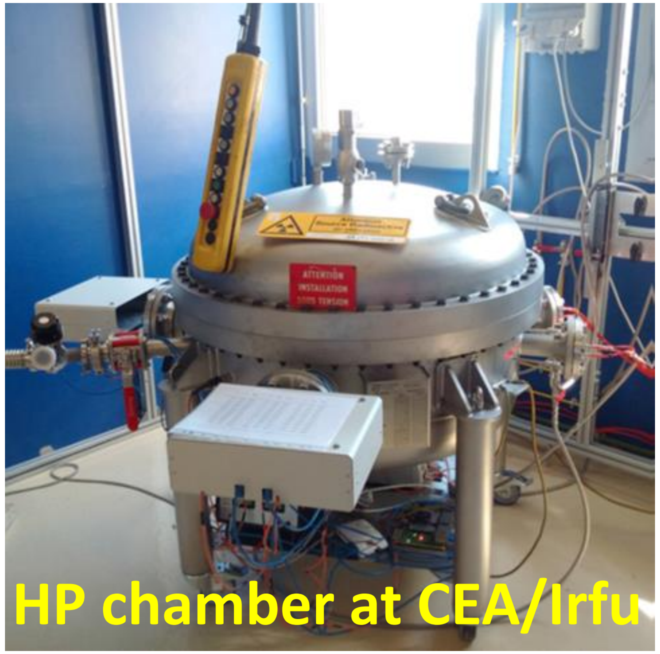


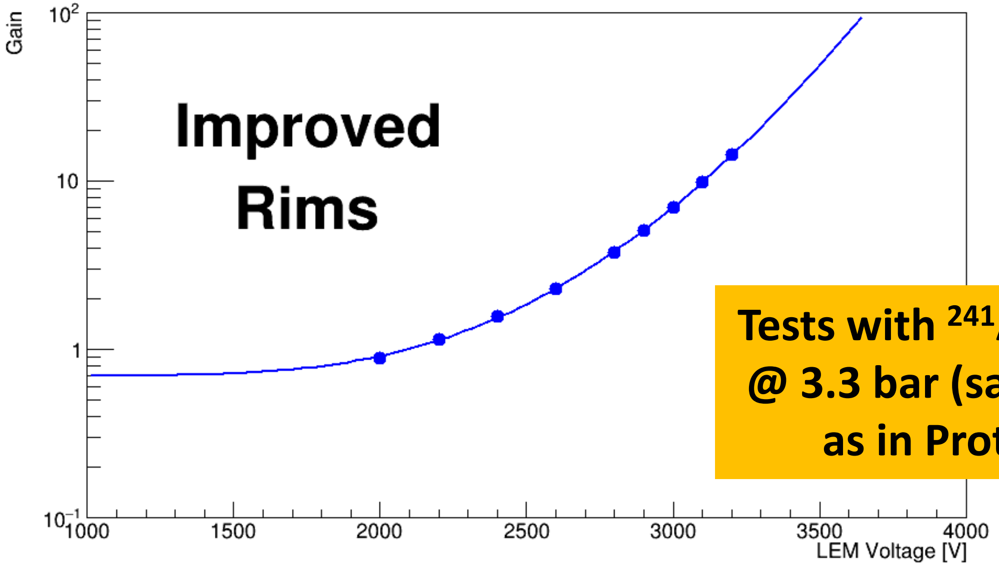
Technology transferable to PCB industry

LEM with improved rims

- Prototype built by CERN with same design as the one for ProtoDUNE-DP







Tests with ^{241}Am source in Ar @ 3.3 bar (same gas density as in ProtoDUNE-DP)

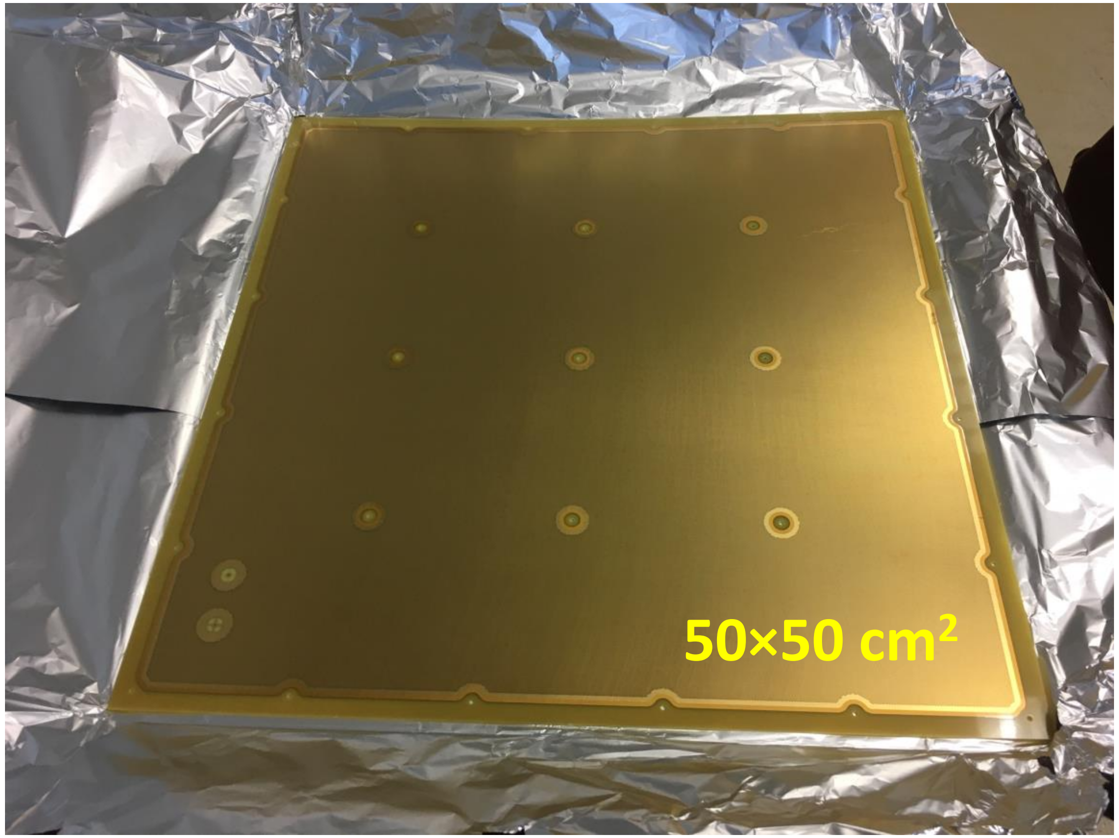
LEM with insulation

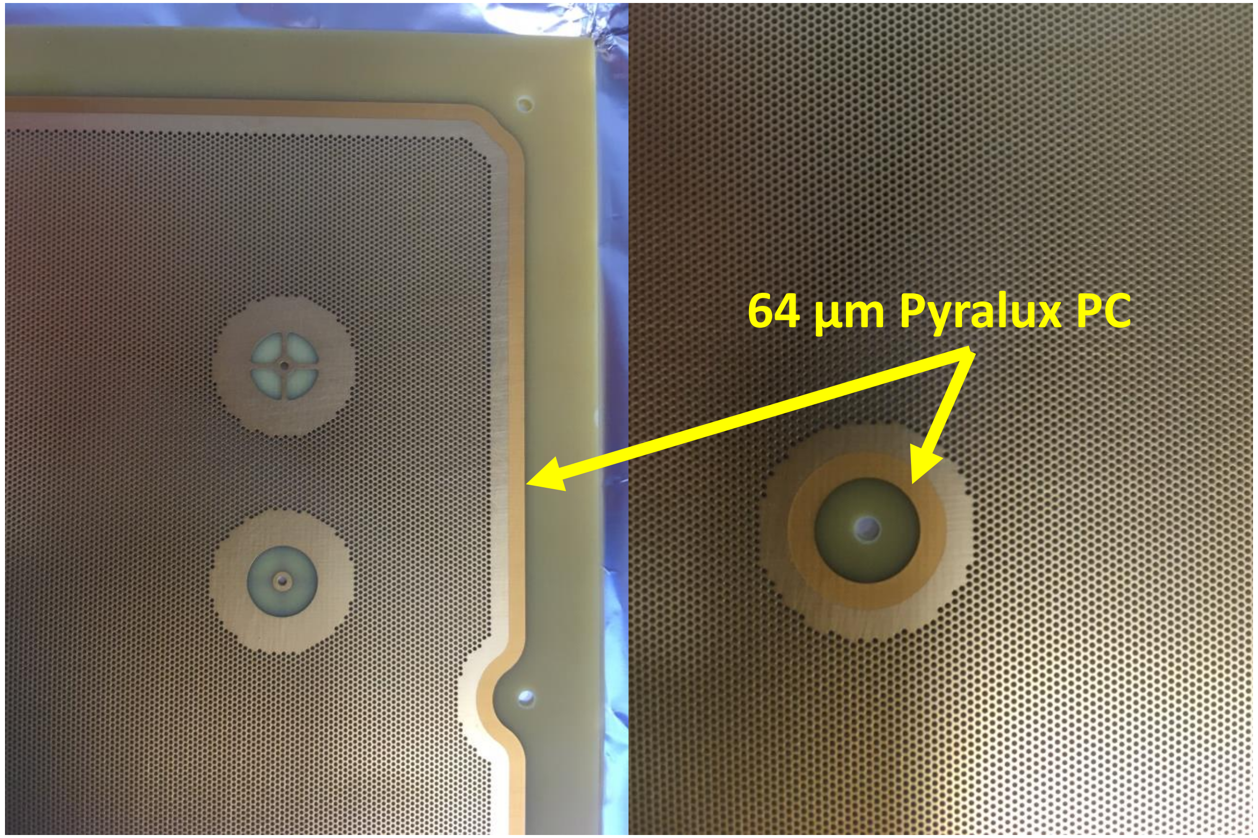
- Improve HV stability by insulating areas where E-field is high (edges, corners, boundary regions).
- Add 64 µm coverlay (Pyralux PC) on dead areas.
- Use improved rim micro-etching process.
- Prototypes built at CERN by EP-DT-EF.
- Technology transferable to industry.
- If successful, increase active area.

LEM prototypes being constructed at CERN

LEM with insulation

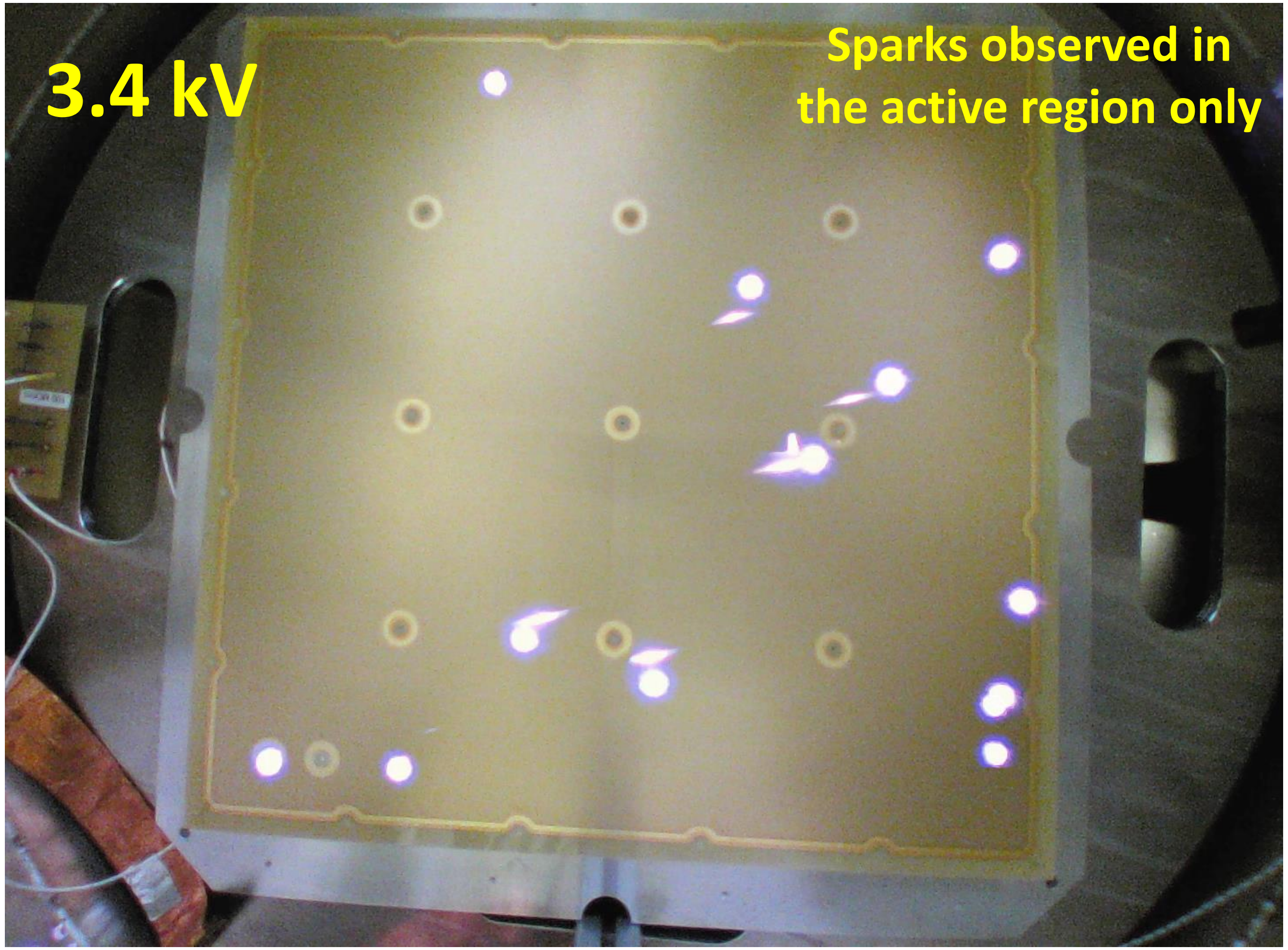
First prototype with insulation and improved rims arrived at CEA/Irfu on Nov. 25th 2019





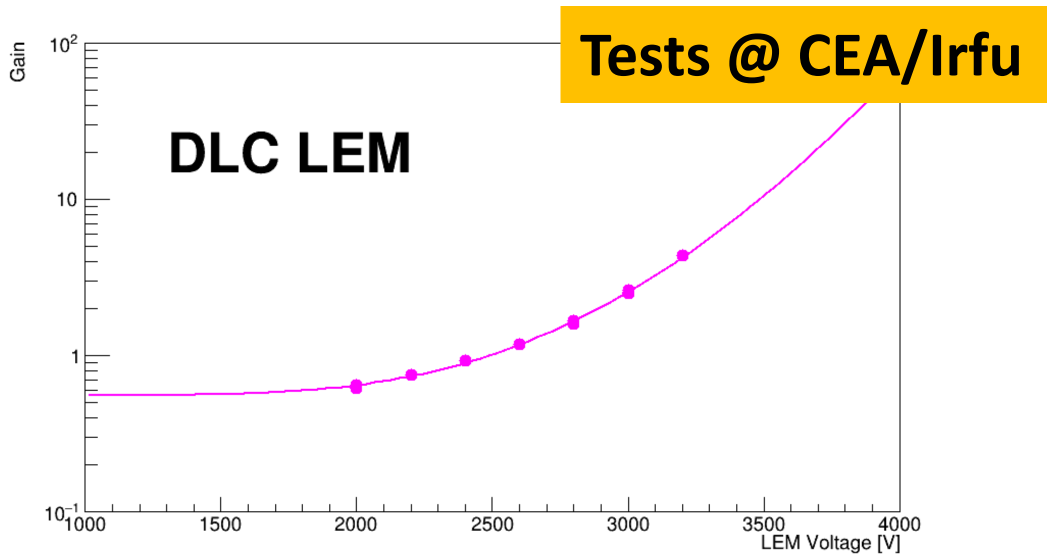
First tests in pure Ar @ 3.3 bar

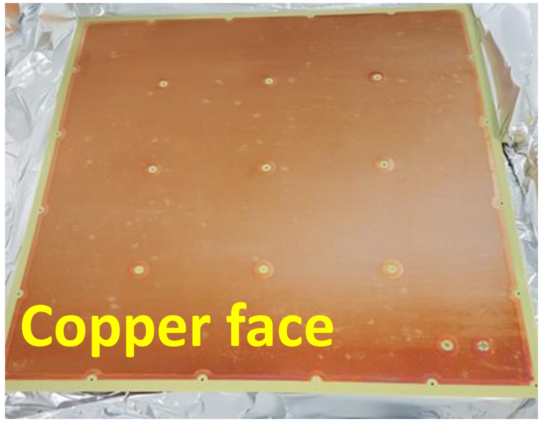
- Tests in progress at CEA/Irfu.
- Spark rates and amplification gain measurements up to max. HV to be performed soon.

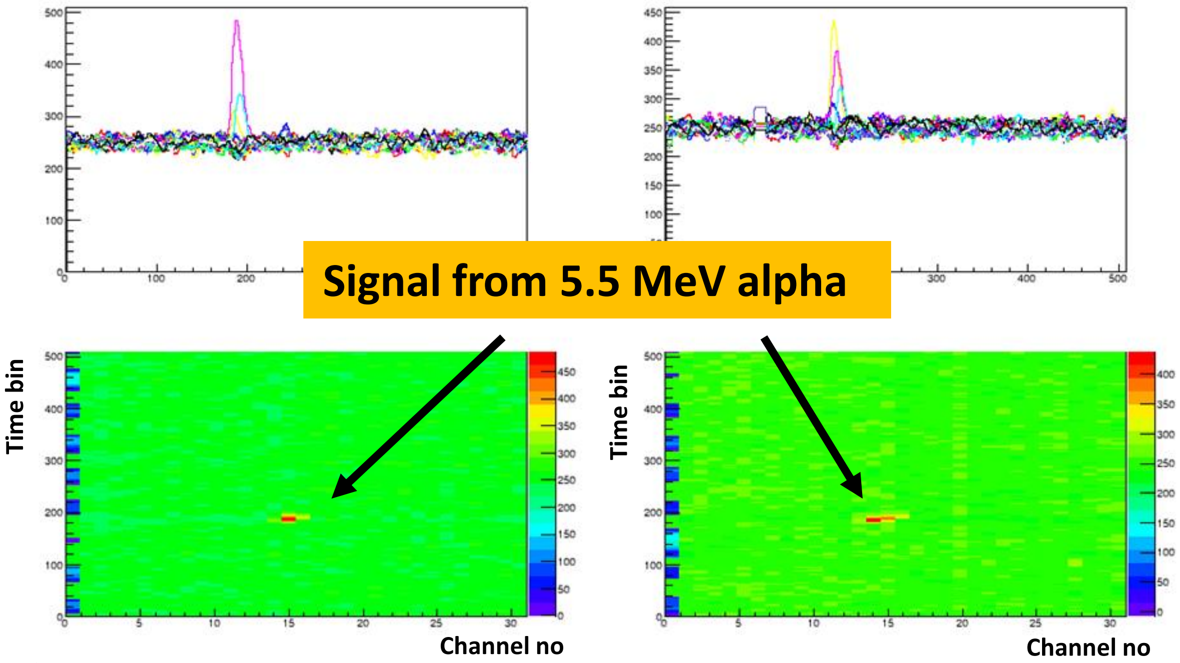


Resistive LEM

- Quenching of discharges with resistive 50×50 cm^2 LEM :
- Made at CERN EP-DT-EF :
  - copper side facing readout anode
  - DLC on 50 µm APICAL polyimide film (250 MΩ/□)
  - same geometry as CFR-35 (ProtoDUNE-DP)
  - no rims, no gold plating on copper face.
- Tests in progress at CEA/Irfu.
- R&D will continue in collaboration with CERN.

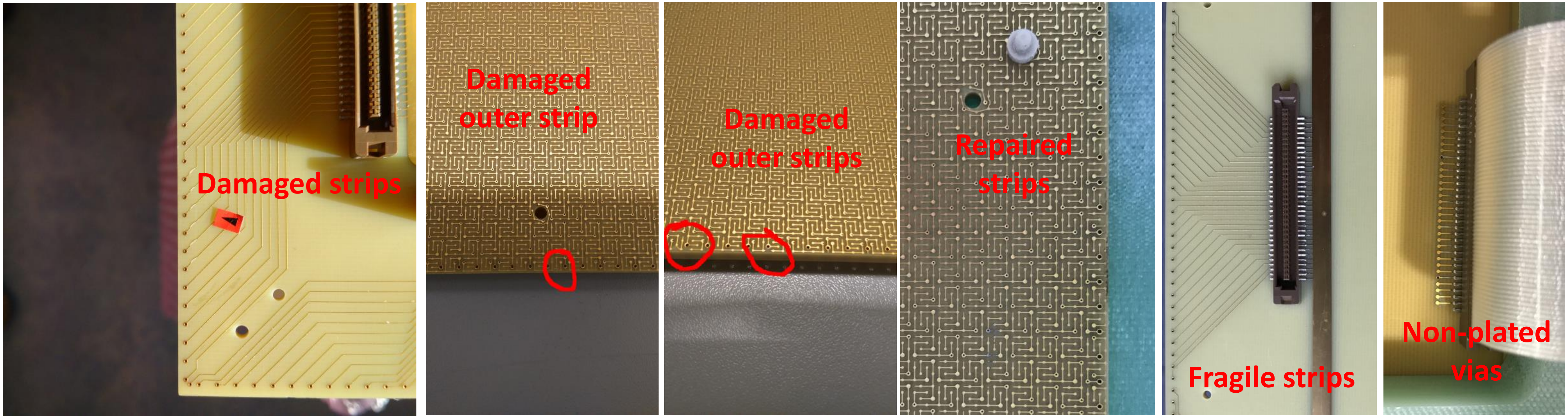






Anode

- No change needed in the anode concept.
- Facilitate manufacturing process with minor changes to fix observed defects (about 10% of anodes for ProtoDUNE-DP had their outer strips damaged $\Rightarrow$ increase clearance).



- In discussion with ELTOS (Italy) and ELVIA (France) to improve QC/QA.

CRP

LAPP in Annecy is working on the following improvements:

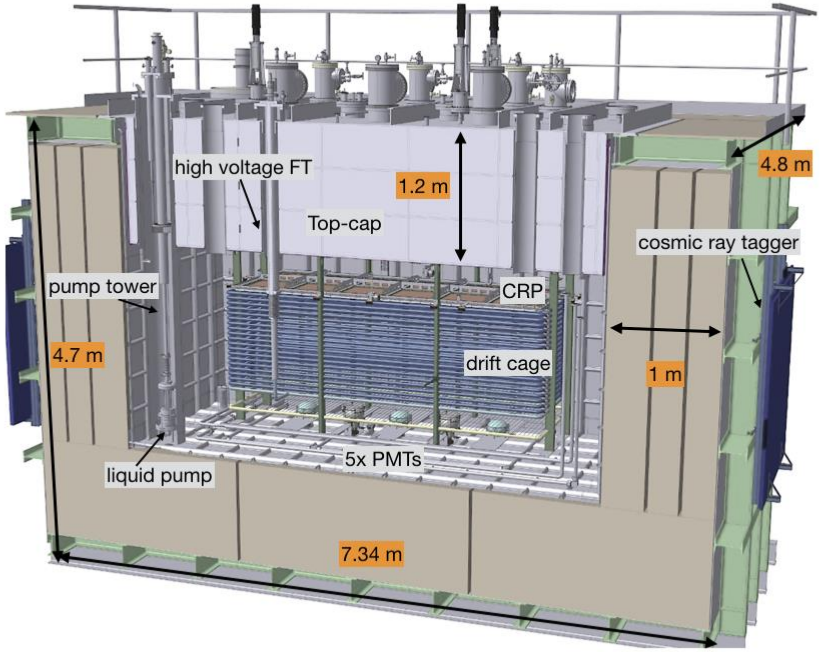
- Stiffening of the Invar structure :
  - to guarantee a $\pm$1 mm planarity in cold
  - to make structure less sensitive to inhomogeneous distribution of mass like cables, instrumentation.
- Implementation of a guard ring around the CRP to avoid grid sparks to reach the anodes and thus potentially damage the FE electronics.
- Development of resistive combs for the Grid to collect ions remaining on the LAr surface (ion feedback). Needs more input from ProtoDUNE-DP

- Consider the possibility to increase LEM-Grid distance from 10 to 12 mm.

Possible schedule for a 2-CRP production
(to replace the current 2 dummy CRPs)

- 2020:
  - LEM prototyping and tests at CEA/Irfu, tests in CB at CERN.
  - LEM & anode final design.
  - CRP prototyping and tests: guard ring, resistive combs.
  - CRP final design.
- 2021:
  - Early 2021: start production of 1^{st} CRP.
  - Mid-2021: tests in CB at CERN and start production of 2^{nd} CRP.
- 2022:
  - Test of 2^{nd} CRP in CB at CERN.
  - Integration in cryostat.

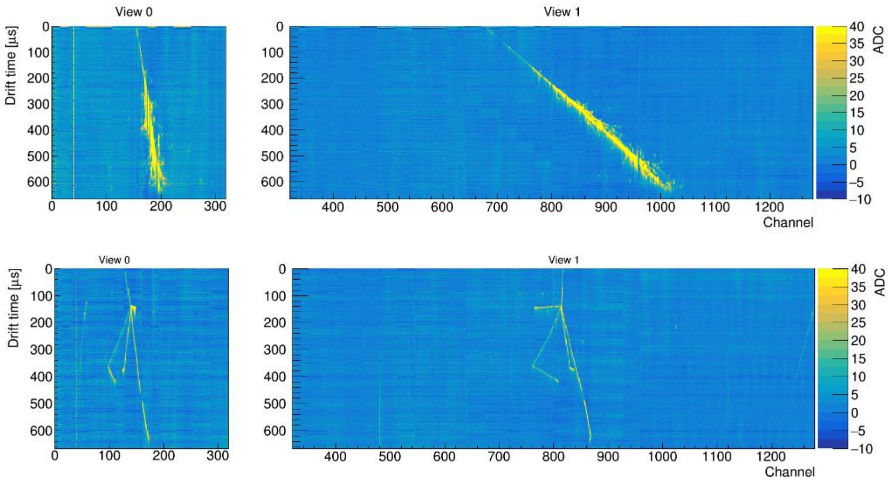
Back up slides



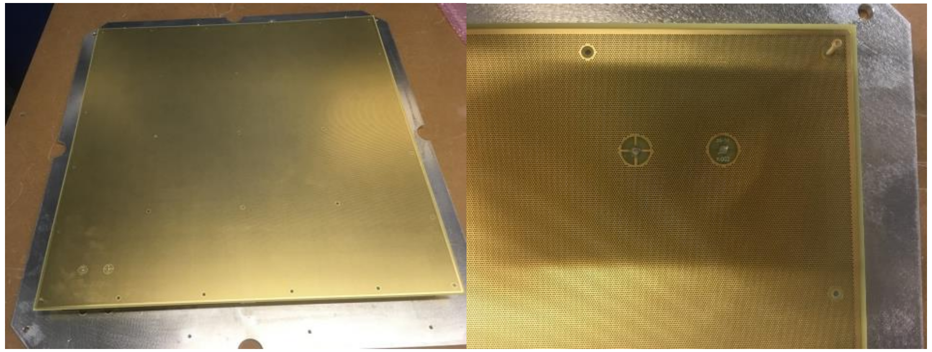
The 311 prototype

The dual phase concept has been validated at the 4-ton scale despite the 5kV limitation problem on the extraction grid, but :

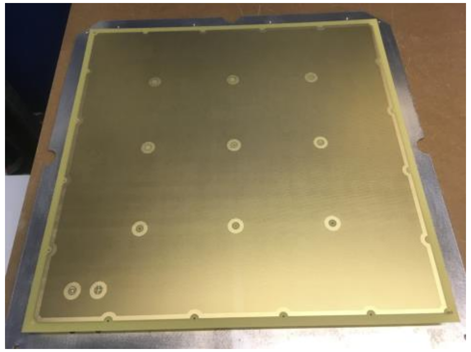
- Max. G_{eff} : 2 – 3 instead of goal value of 20
- Long-term operation not demonstrated (< 8h run), limited by power supply trips
- Max. E_{LEM} = 31kV/cm for short time (~1h) and < 3m^2
- Complete charging-up of LEMs not achieved



CFR-34



CFR-35



ProtoDUNE-DP

What has been achieved during the CB tests?

- Long-term operation stability for both 9m^2 CRPs
- Max. G_{eff} : 20 – 30 , stable for long periods of time (> 12h, days)
- Optimal operation point for V_{TOP} = 500V
- Spark rate : ~1/h per CRP or 1/36h on average for a single LEM
- Maximum electron extraction efficiency

$\Rightarrow$ *Meet operation requirements for ProtoDUNE-DP*

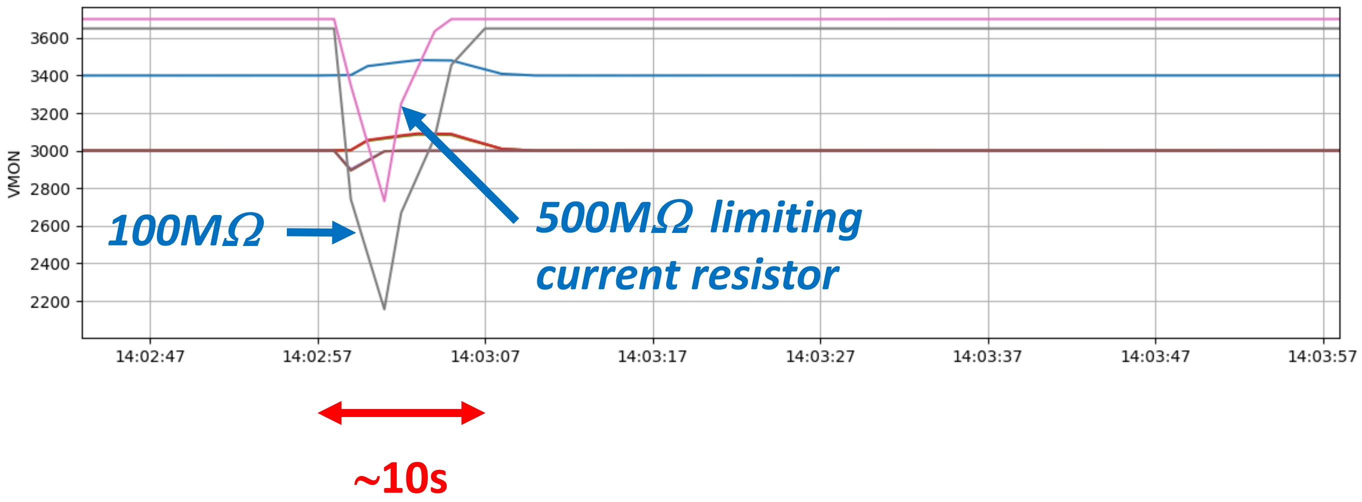
Spark Rates (I)

What is the effect of a 1/h per CRP spark rate on detector dead-time?

With a typical HV recovery time of about 10s and with the pessimistic assumption that 1 full CRP is inactive during a spark, then the dead-time is ~ 0.3% / CRP

$\Rightarrow$ *Negligible effect on physics*

VMON for two adjacent LEMs during a spark



Spark Rates (II)

How does the rate of 1/h per CRP measured in the CB compare with previous studies?

- Compare with published long-term performance studies with a 10×10cm^2 LEM in the 3L setup at CERN
- Spark rate after complete charging-up of the dielectric material (G_{eff} ~15) : 2 sparks in 15 days
- Normalizing to a 9m^2 CRP with 86% active area gives :

2×(3m×3m×0.86)/(.1m×.1m)/(15d×24h/d) = 4.3/h

C. Cantini et al., arXiv:1312.6487

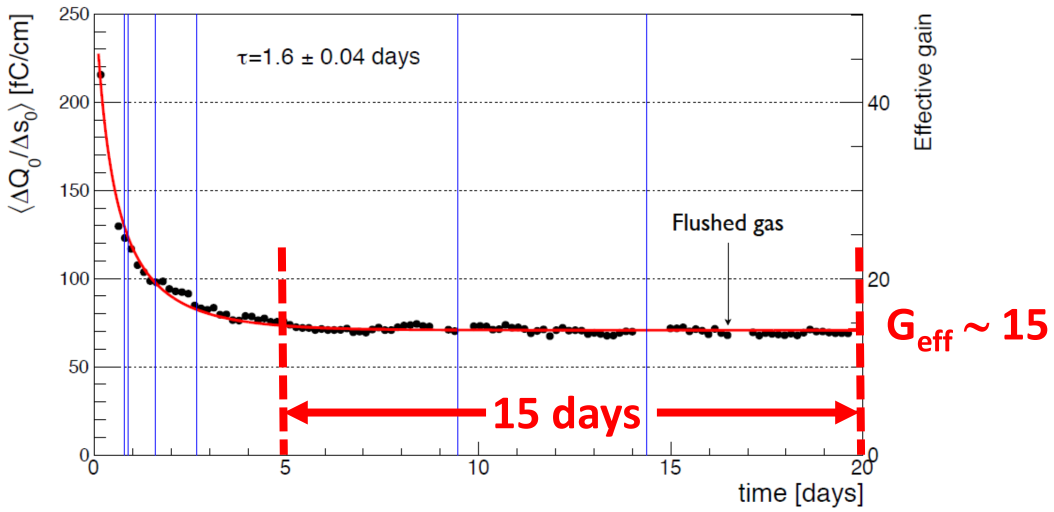


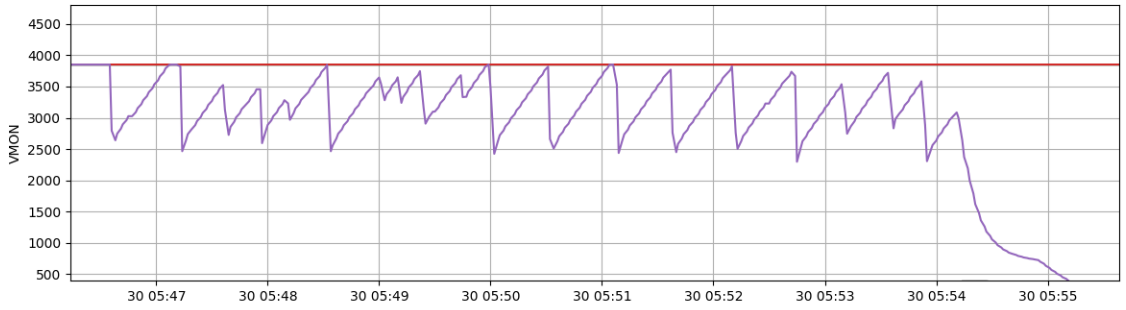
Figure 9. Evolution of the effective gain corrected for pressure variations (all data have been reported with Eq. 3.2 to a pressure of 1 bar). The data points are fitted with the function $G_\infty \times \frac{1}{1-e^{-t/\tau}}$. The blue lines indicate the times at which discharges occurred.

⇒ *Measured spark rates in CB for gains > 20 better than with older prototypes!*

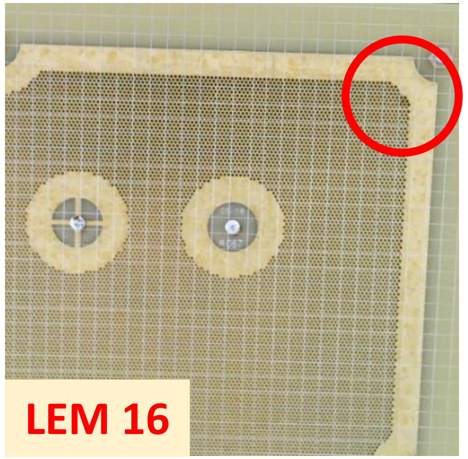
LEM Issues (I)

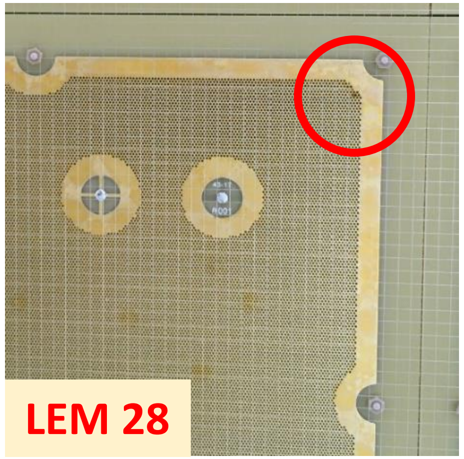
Which are the main issues reported during the CB tests?

- A few LEMs (4/72) underwent continuous discharges for several minutes that prevented afterwards their operation at nominal HV



- Dark spots due to FR4 carbonization observed near LEM corners pointing to weaker regions of the detector (5 LEMs affected)





LEM Issues (II)

How did we cope with this problem?

- LEMs with dark spots were chemically treated at CERN (CERN EP-DT-DI) using potassium permanganate. Reconditioned LEMs were then validated at CEA/Irfu and 4 of them mounted again on CRP1 and successfully tested in Cold Box.
- One of the reconditioned LEMs replaced by a spare LEM on CRP2 and brought to CEA/Irfu for further tests in HP chamber in pure argon at 3.3 bar.
- LEM underwent extensive HV tests at E_{LEM} in the 28 – 35kV/cm range. More than 1k sparks recorded in 2 months. No damage to the LEM was observed. Equivalent of 4 years of DUNE operation with average spark rate of 1/h per CRP.

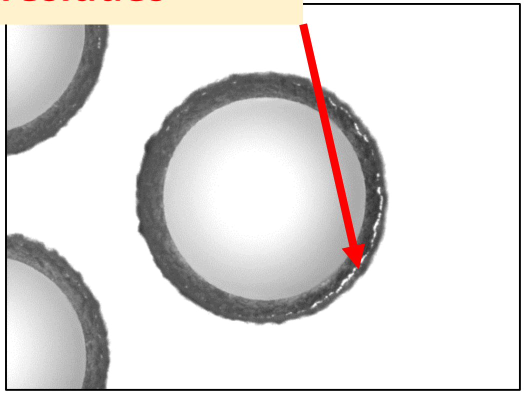
How can we mitigate such risks?

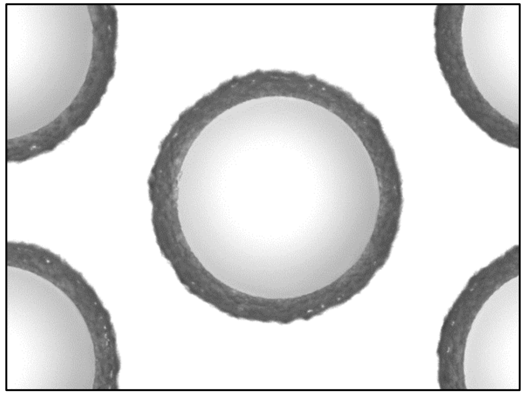
- Developp appropriate slow-control program to detect continuous discharges and take proper action (lower temporarily HV). Work in progress by CERN EP-DT-DF for ProtoDUNE-DP.

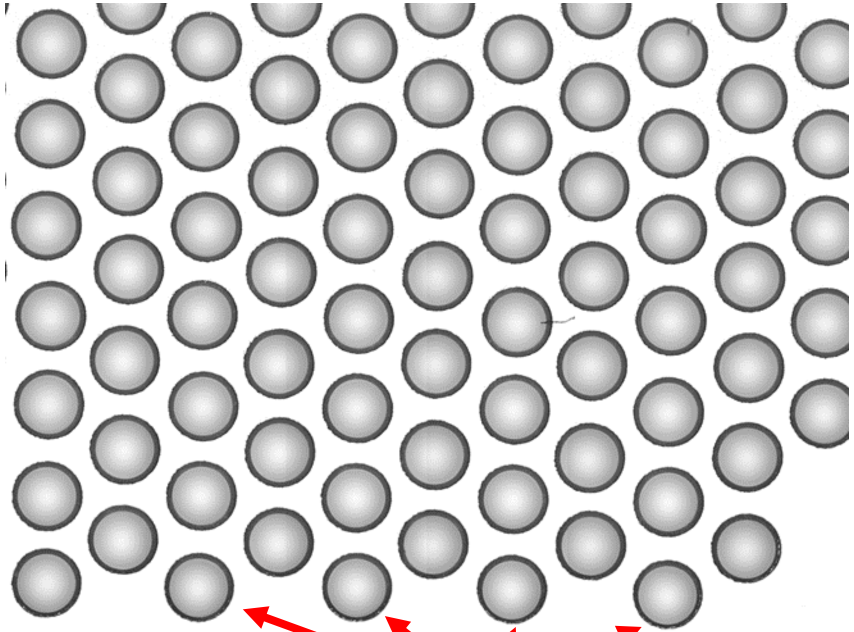
LEM Issues (III)

- Rims around holes near the LEM edges/corners appear to be decentered and containing copper residues
- Problem due to method used by ELTOS for the micro-etching process
- New process developed recently by CERN EP-DT-DI should solve this issue

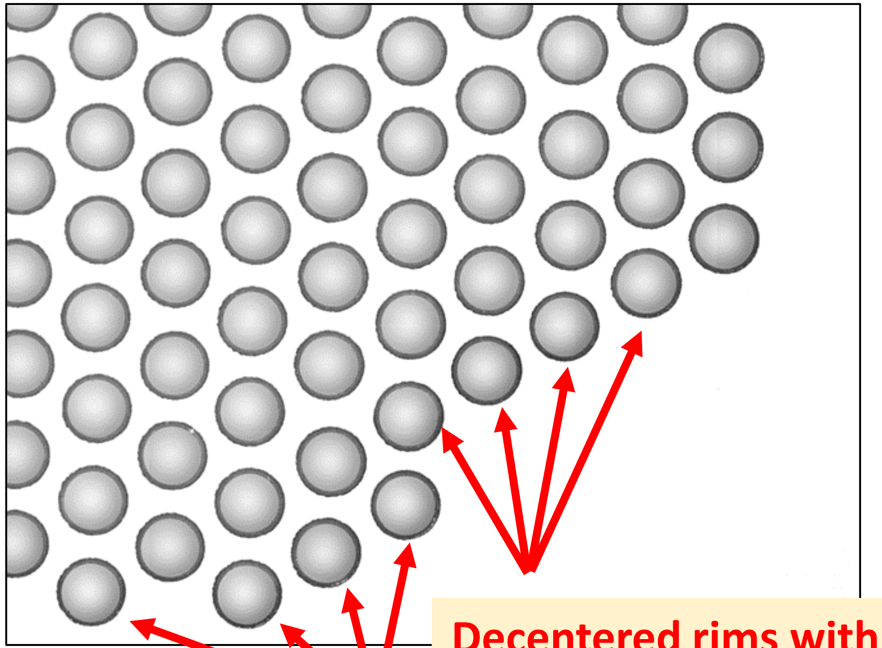
Decentered rims with copper residues







Bad rims



Decentered rims with copper residues

CERN EP-DT-EF is now manufacturing 4 prototypes to be tested soon at CEA/Irfu

New LEM developments

Which developments are foreseen to improve LEM quality in 2019-2020 ?

- Improve RIM quality using CERN new micro-etching process. Prototypes being built at CERN and will be tested at CEA/Irfu in April-May.

- Modify LEM design to increase current active area and to possibly reduce spark rates near the edges of a LEM. A design incorporating larger diameter holes in the boundary regions of the PCB should reduce locally the electric field and hense sparking probability.

- LEM ageing studies at CEA/Irfu to test long-term operation stability in presence of discharges.

- Improvement of the HV electrical scheme to reduce cross-talk effects between LEMs when discharges occur.