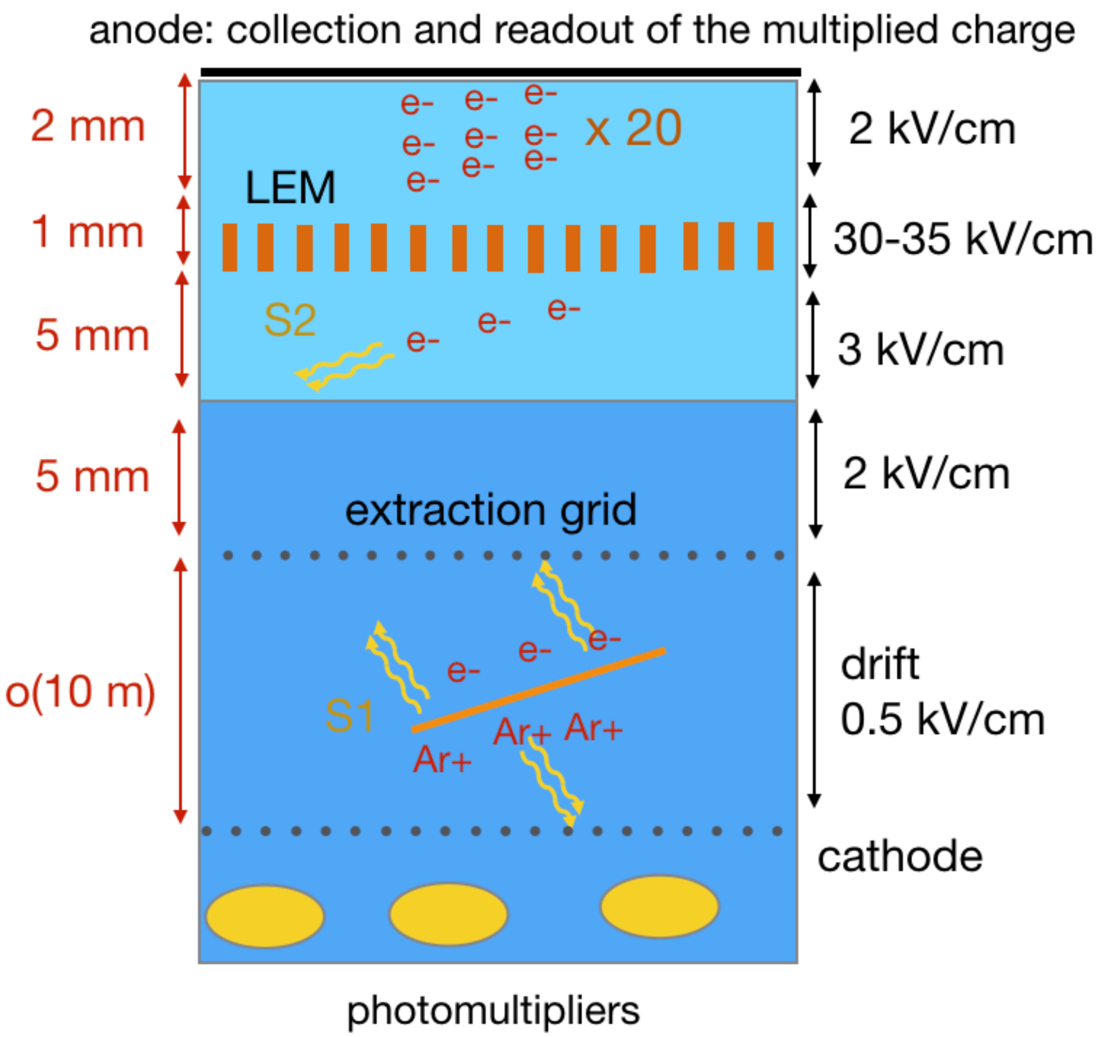
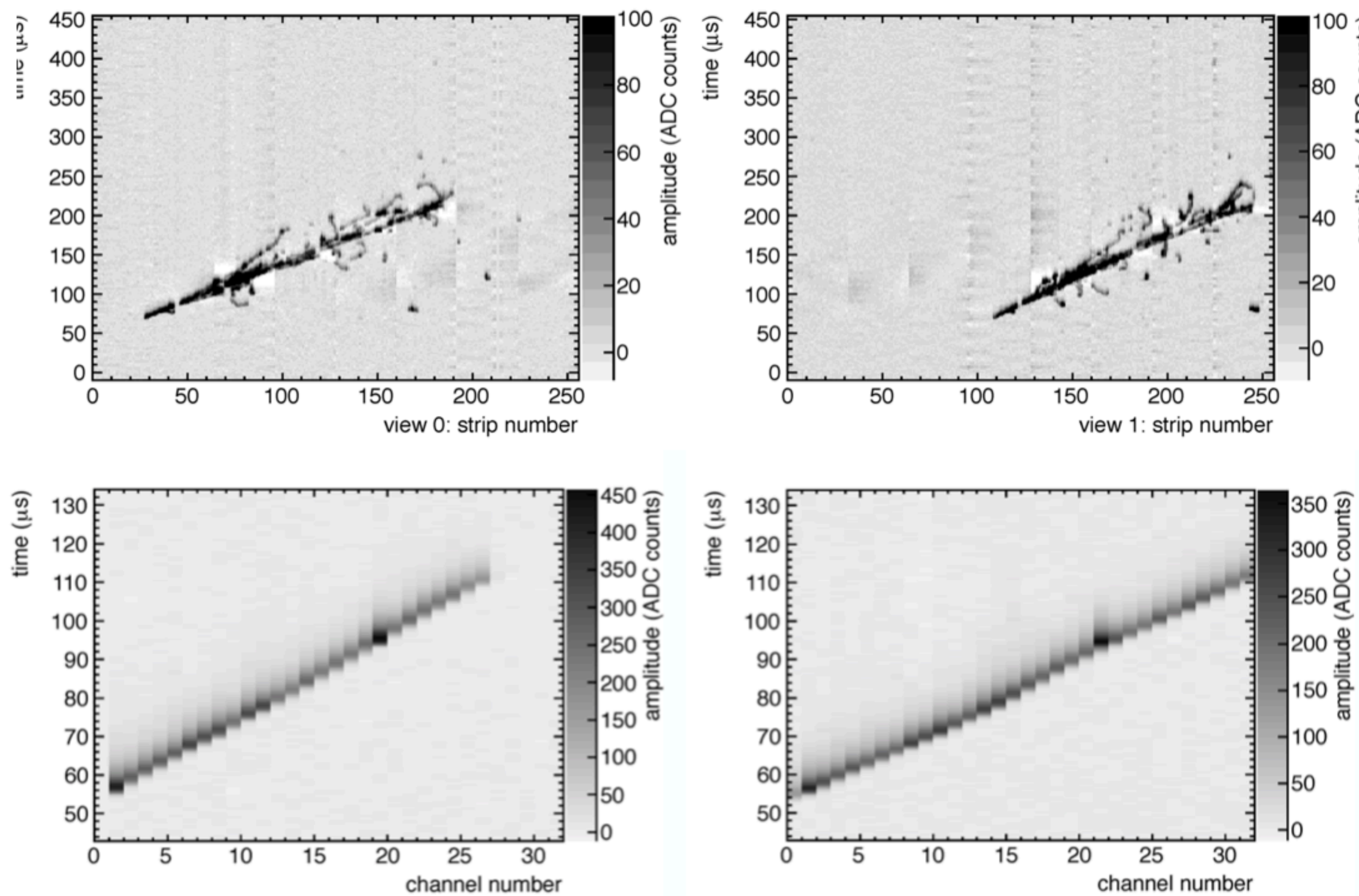
LEM-Anode sandwich design

Sebastien Murphy
protoDUNE-DP PRR 24-25 April 2017

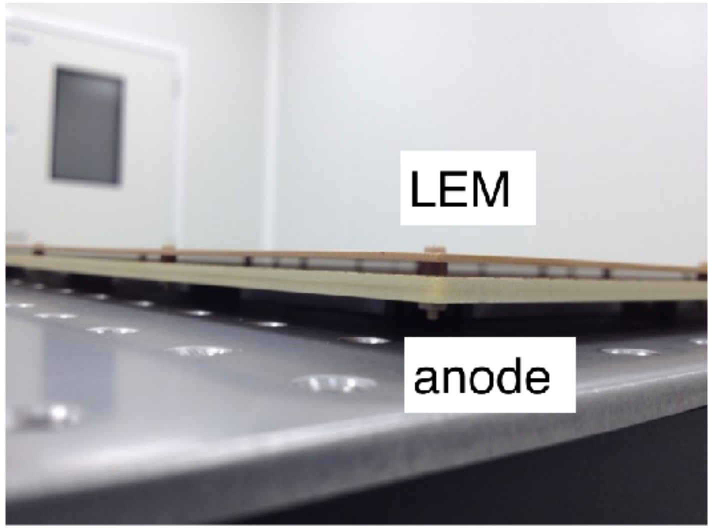
Dual phase readout

WA105

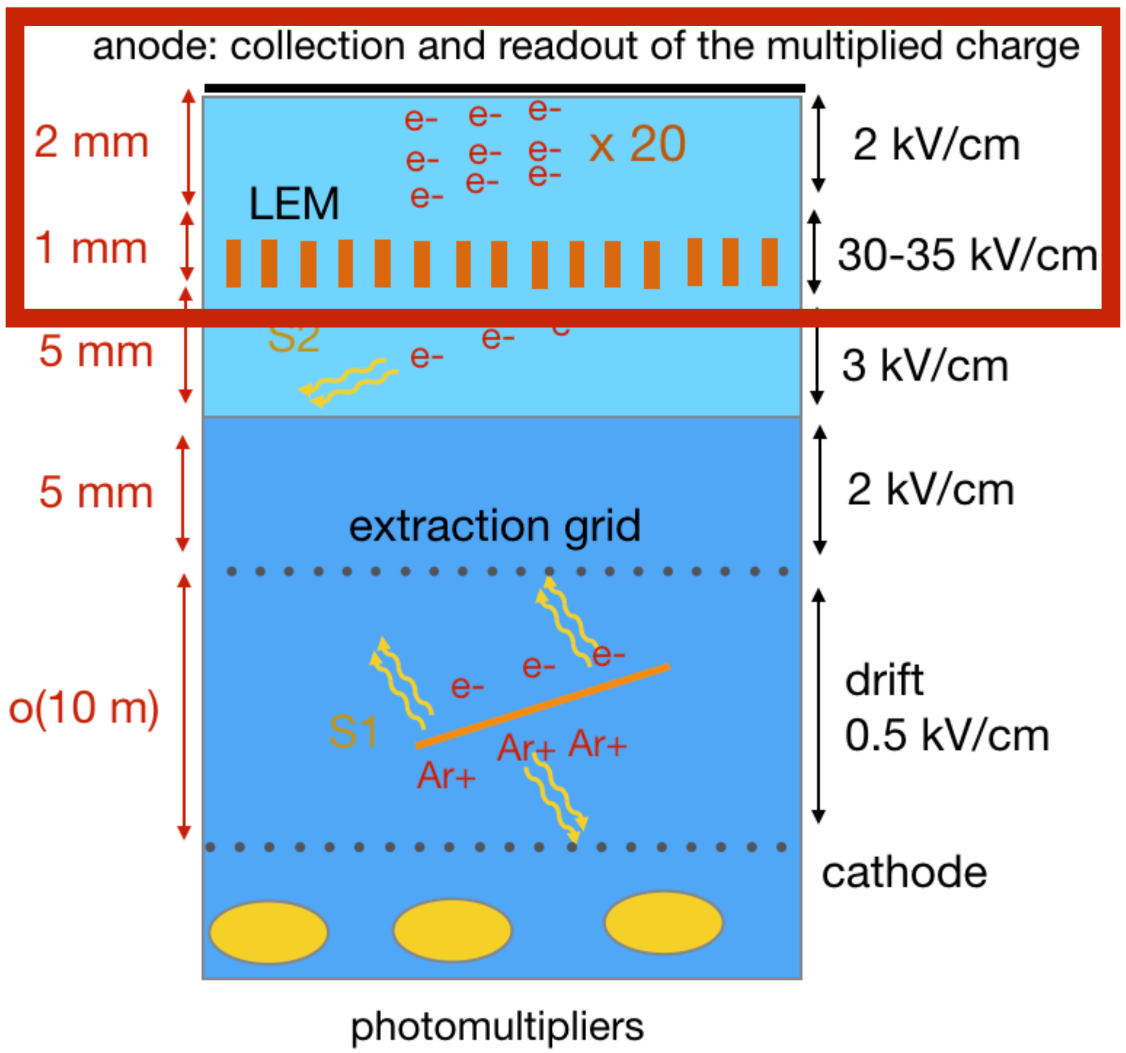


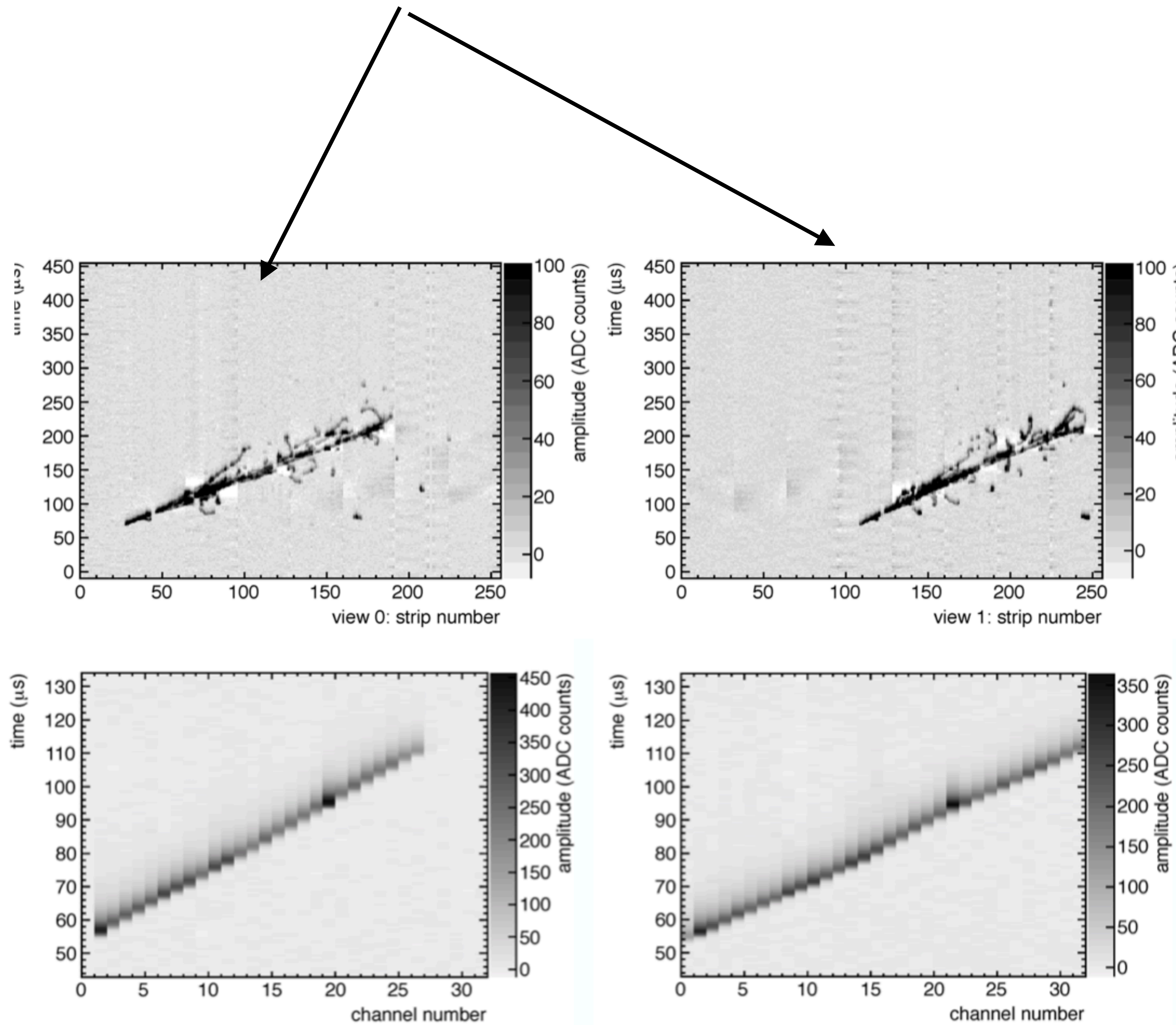


Dual phase readout

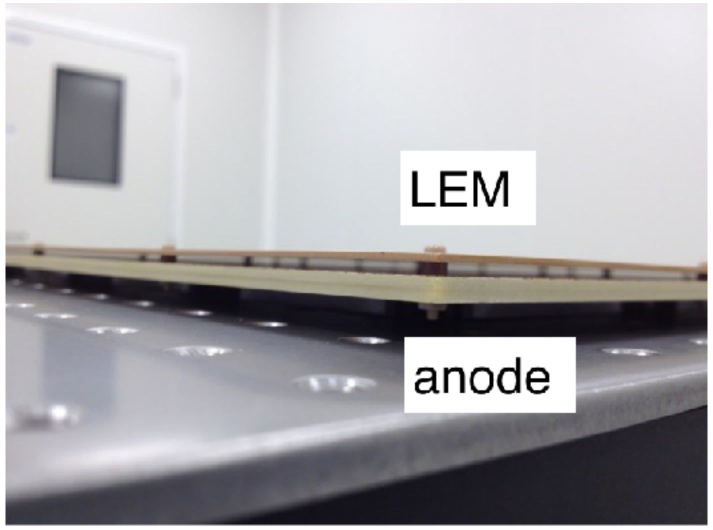


- 2 collection views
- large signal-to-noise ratio
- equal charge sharing between both views





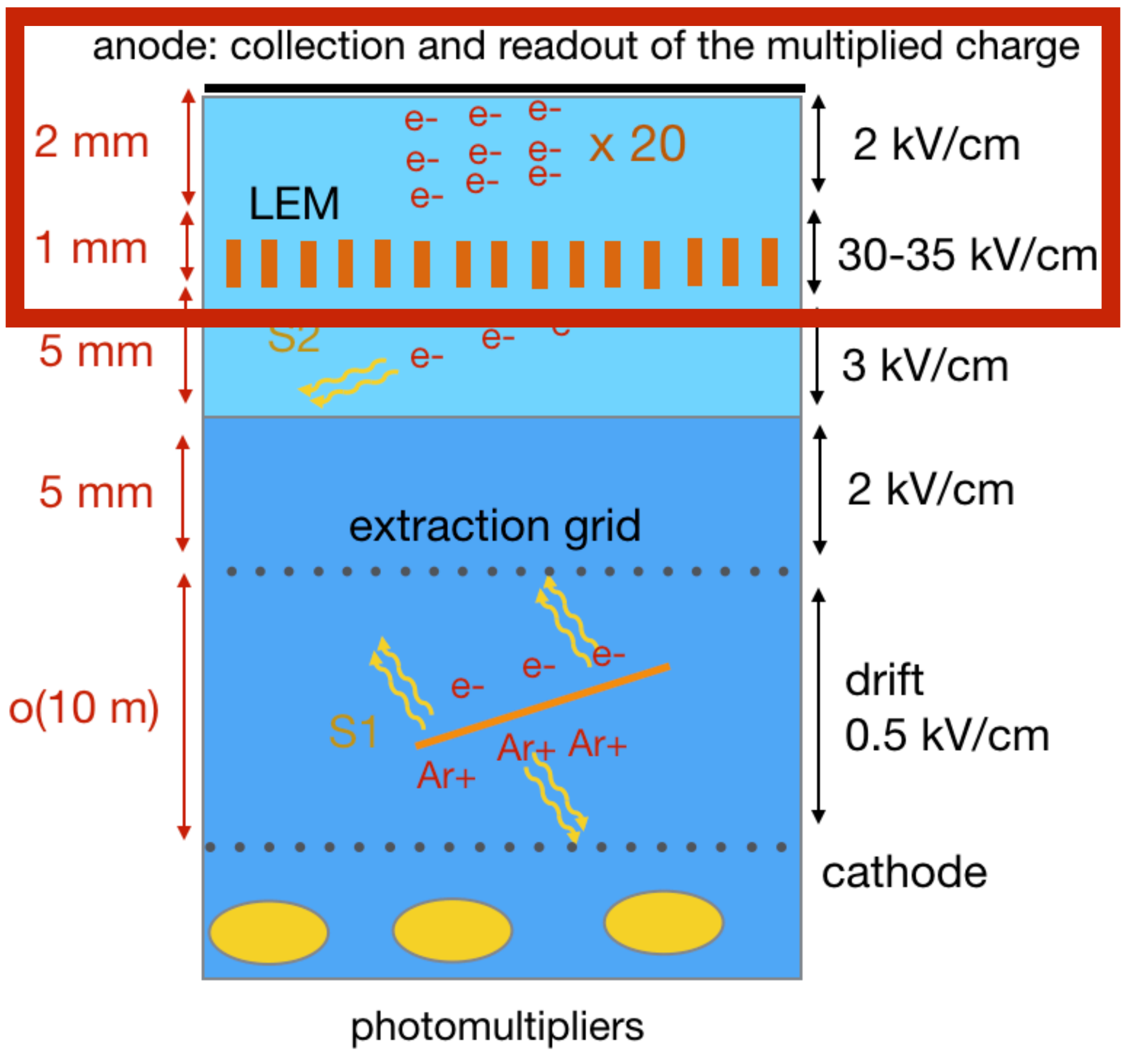
Dual phase readout

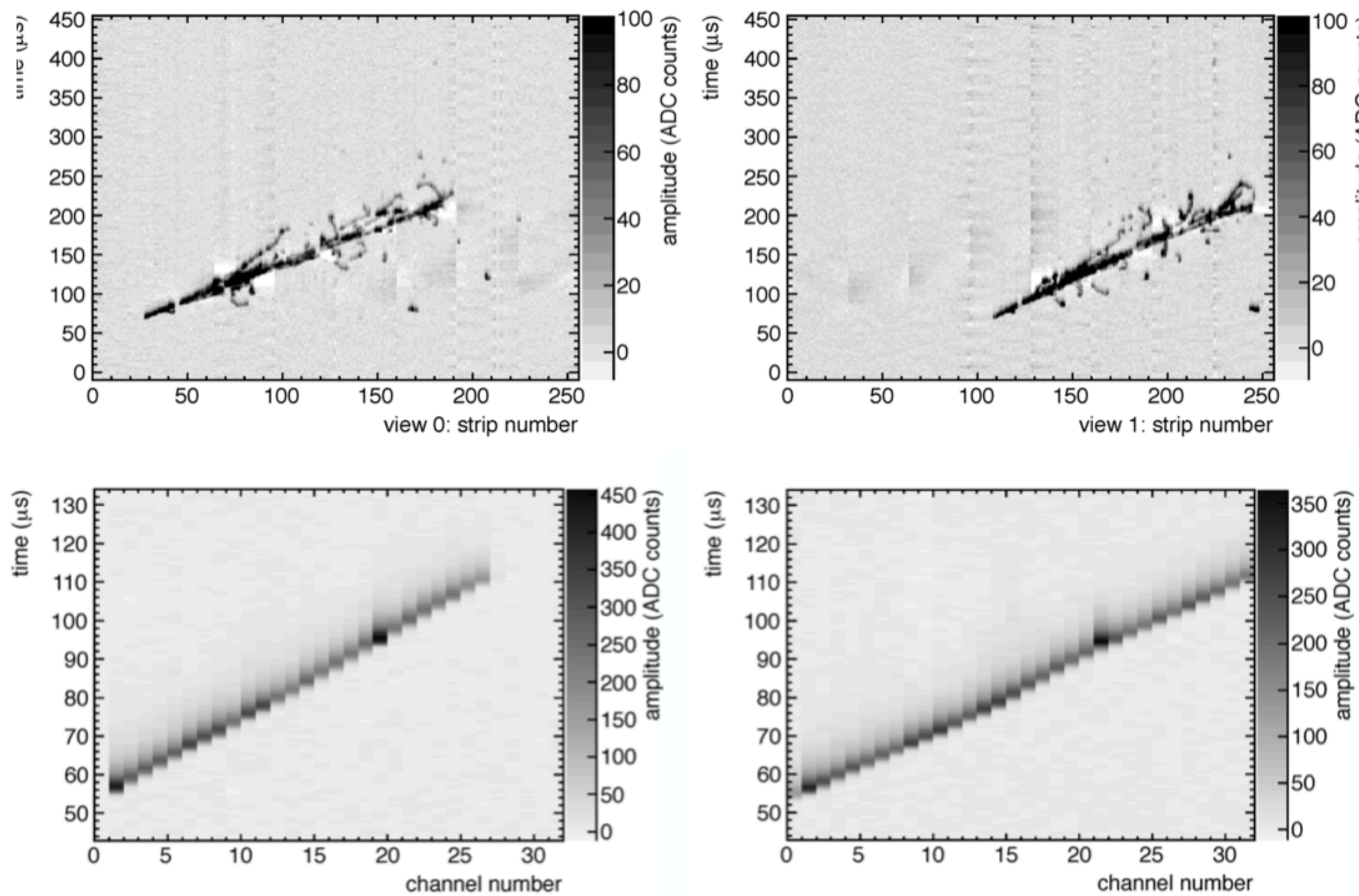


- 2 collection views
- large signal-to-noise ratio
- equal charge sharing between both views

LEM provides: **gain**

- Anode provides:
- **low capacity per unit length anode strips**
- **optimised design of anode strips pattern**





LEM and anode arrangement in CRP

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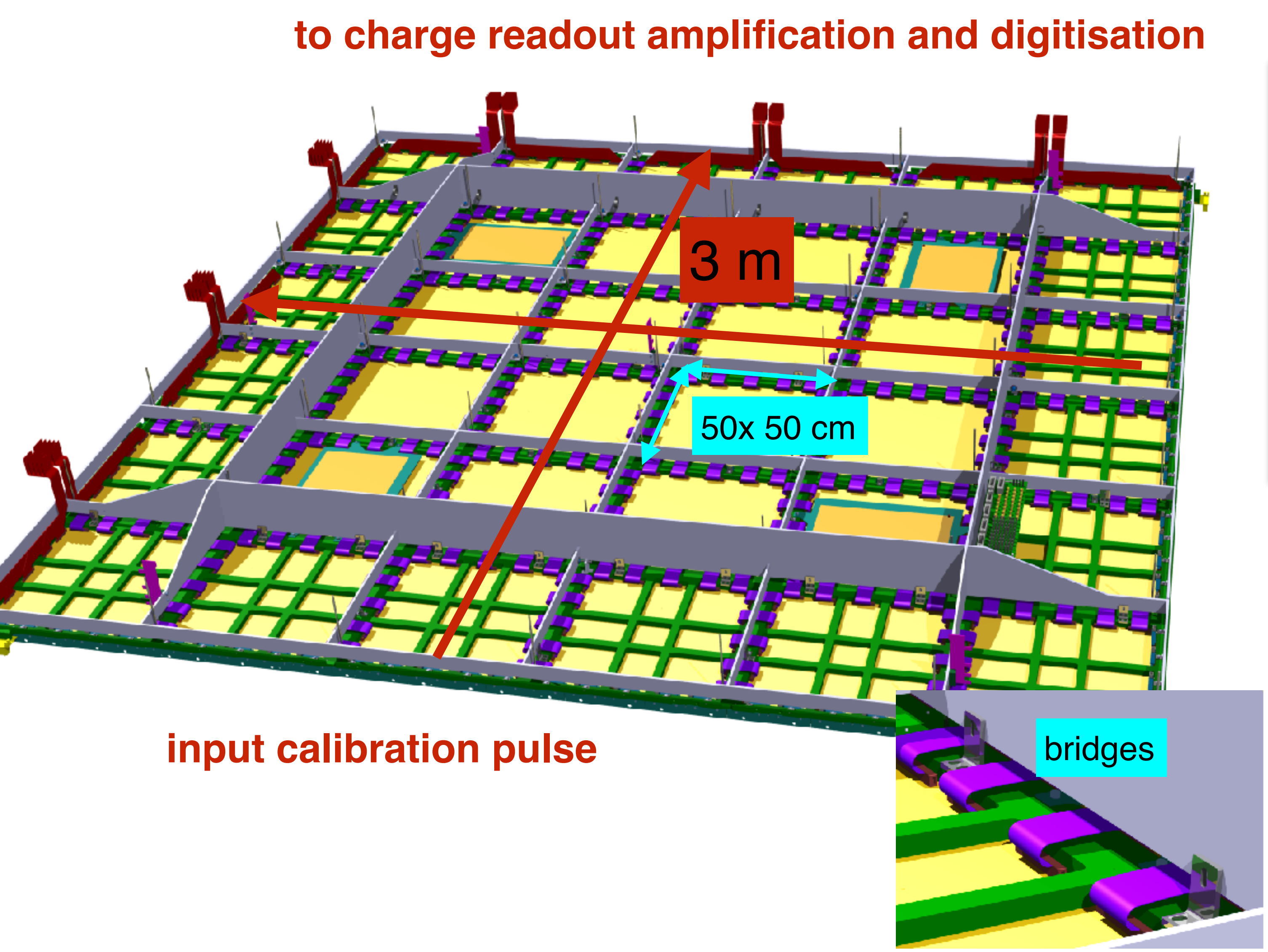
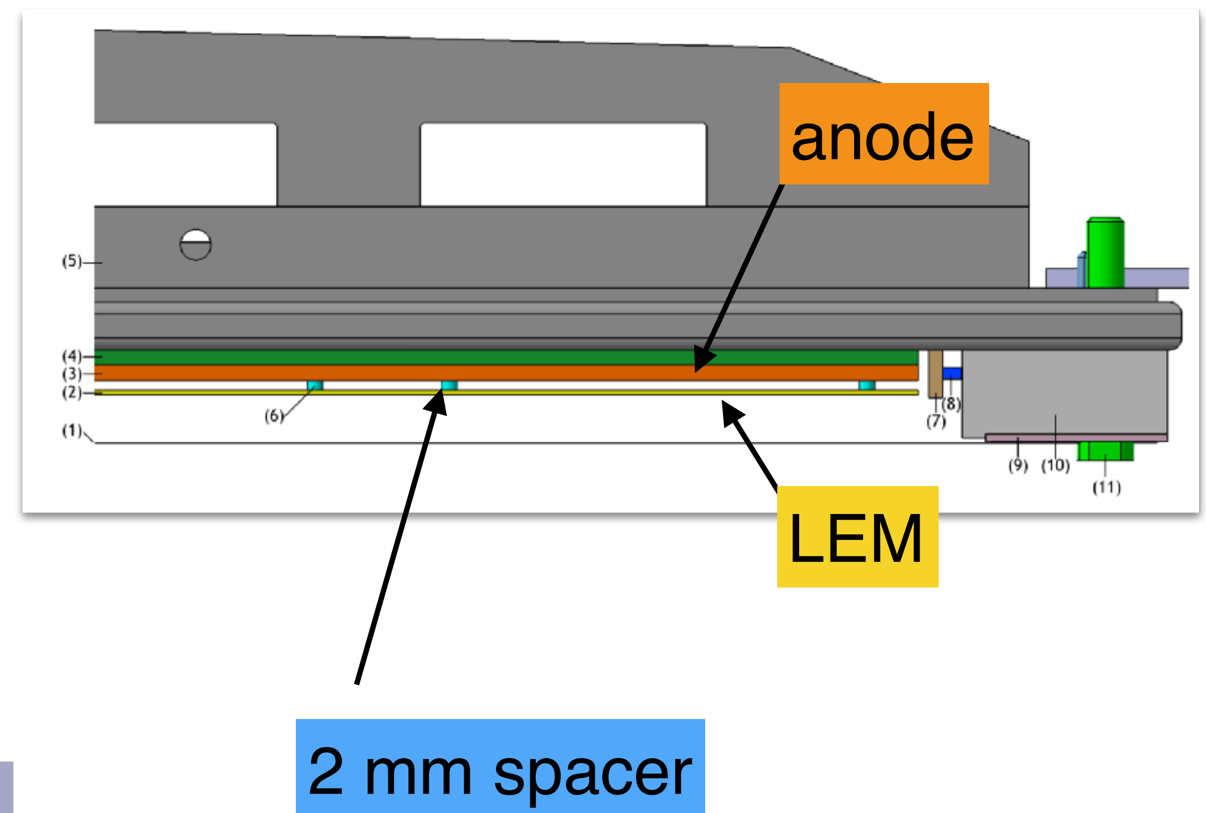
- Tiled arrangement of independent 50x50 cm2 LEM and Anode Sandwiches (LAS).
- Provide fully active amplification area and 3 mm granularity *x-y* strip readout
- The LEMs are independently powered to provide o(30 kV/cm) accros the electrodes
- The anodes are bridged together to provide 3 meter long readout strips
- Both LEM and anodes are made from PCBs. They are produced industrially using standard techniques





50x50 cm^2 LEM & Anode

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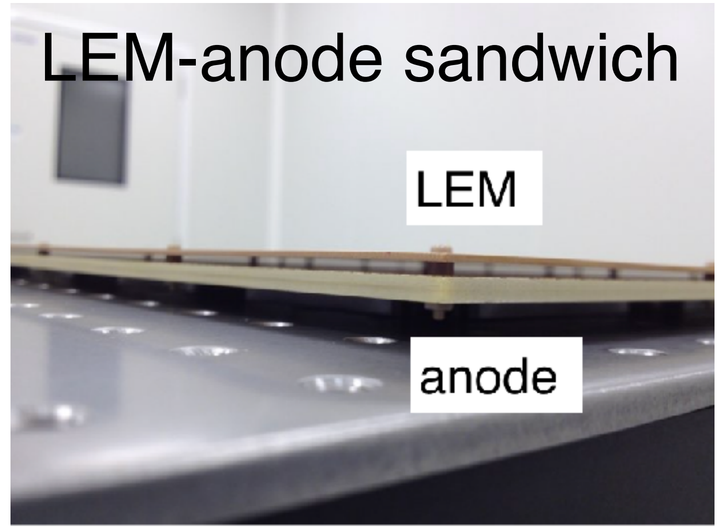
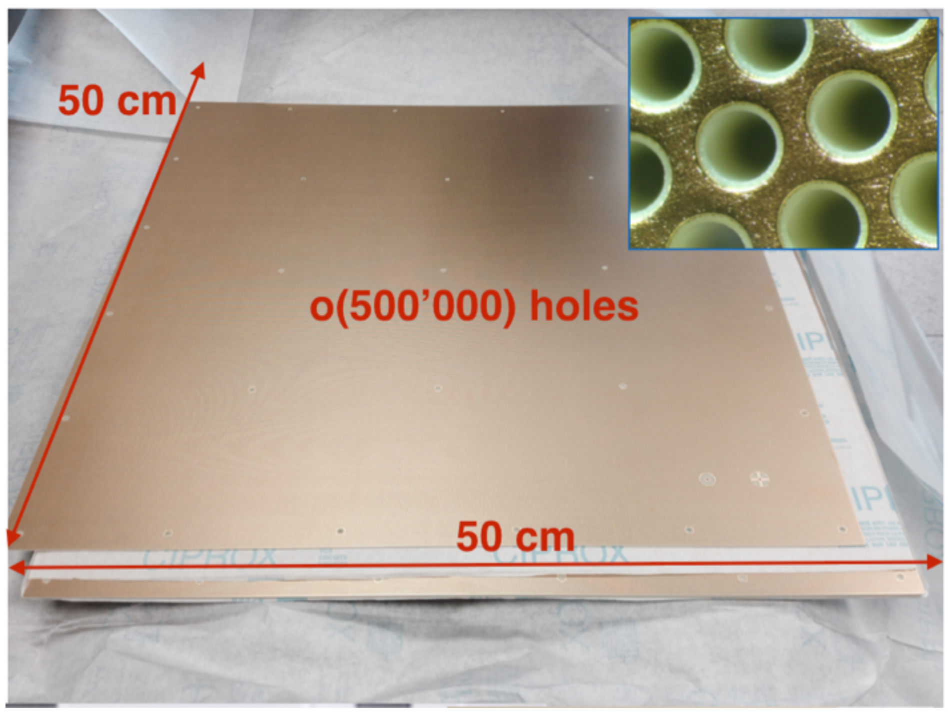
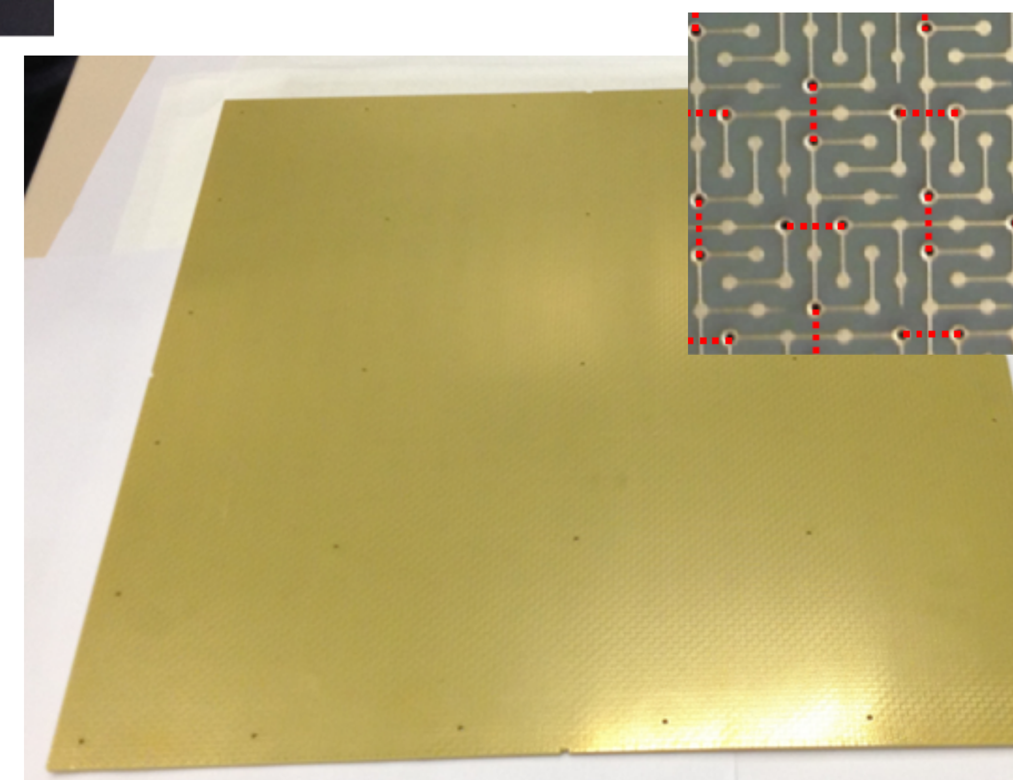


LEMs



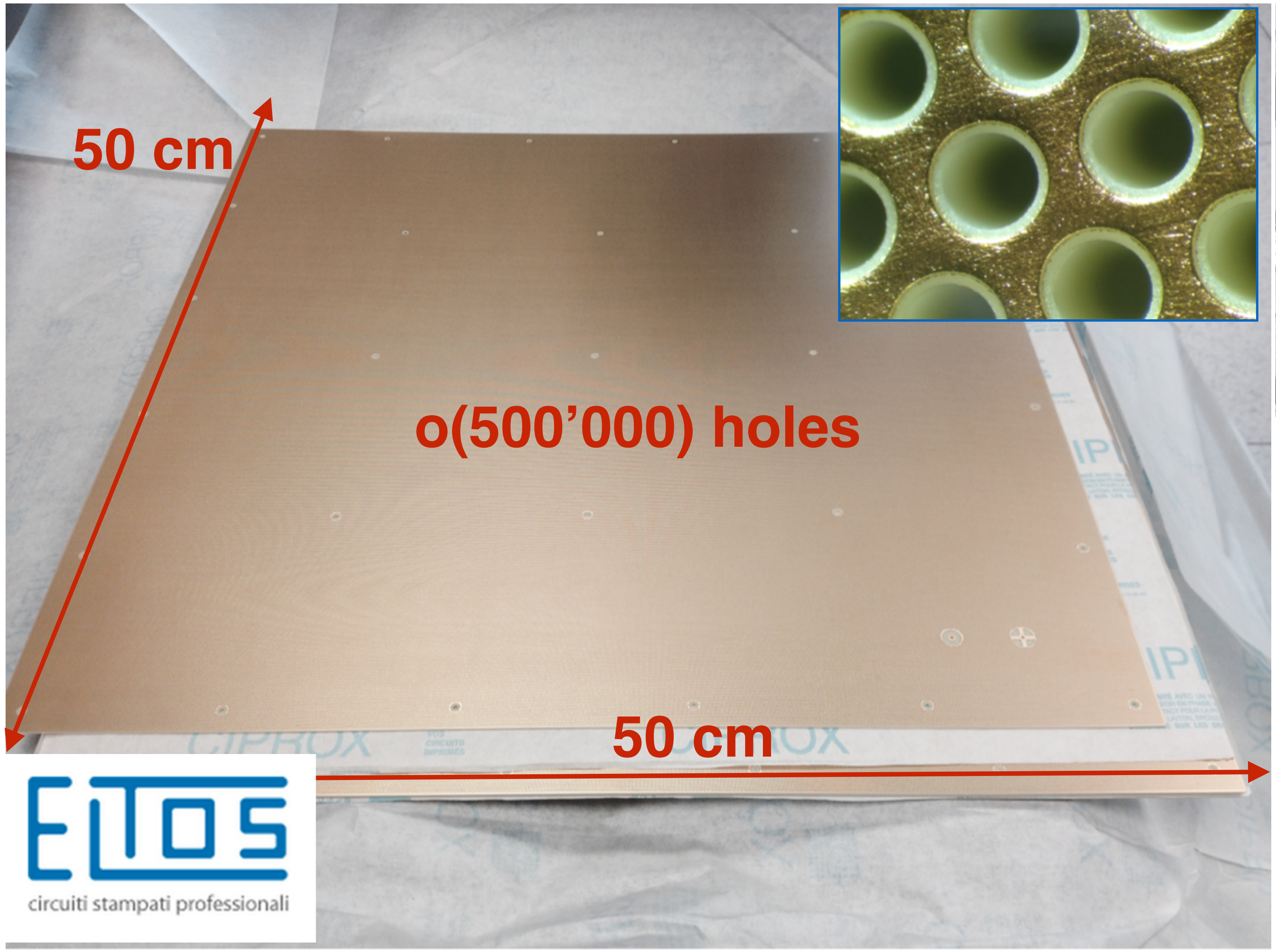
Anodes

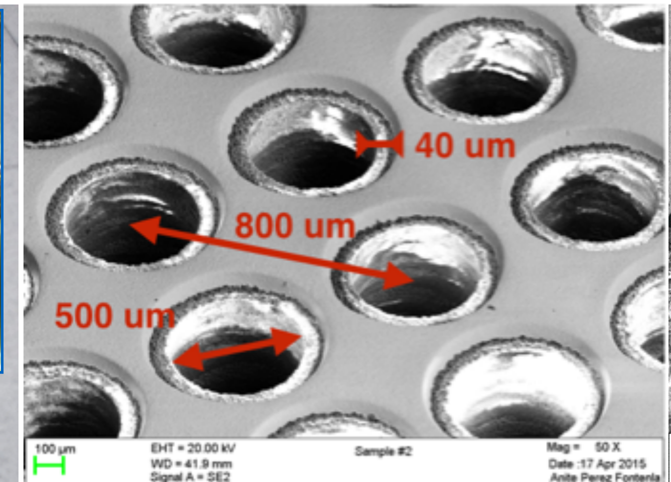


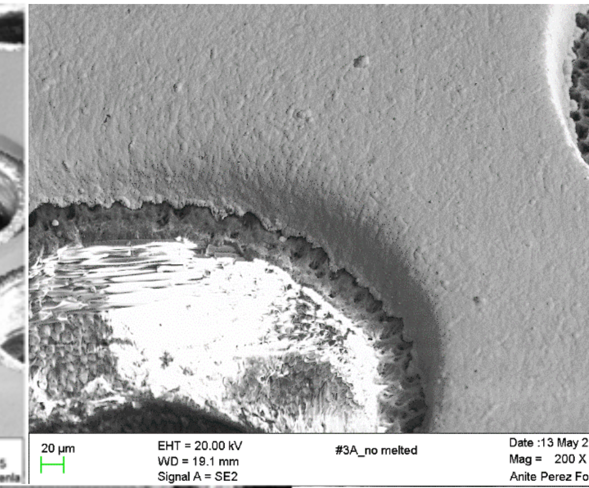
extensive experience on handling, cleaning, testing based on series of 20 (pilot)+ 20 (final design) LEMs for 3x1x1

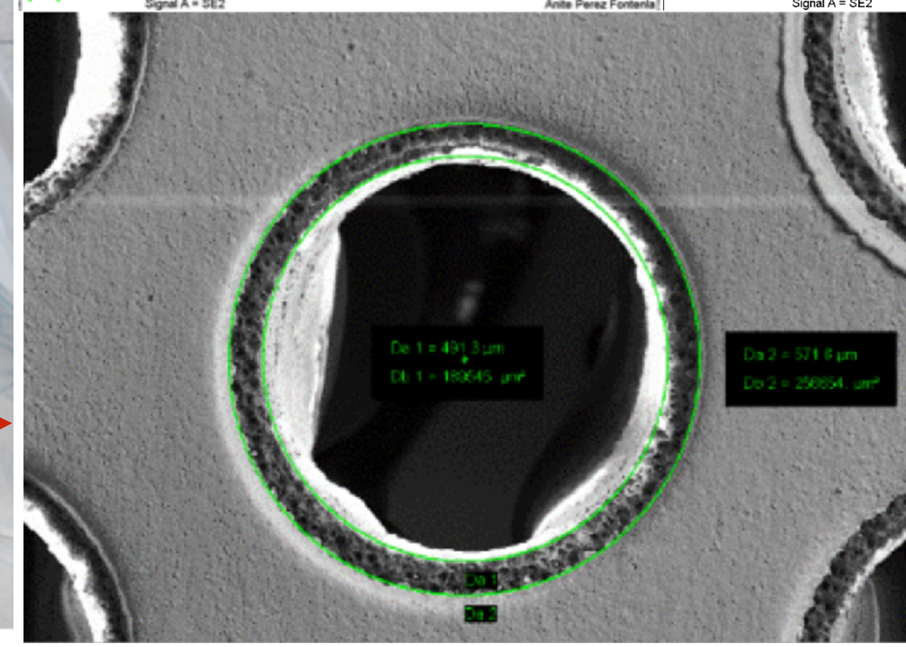
- 4-layer 3.4 mm thick PCB
- Rather standard to manufacture
- electrical continuity tested by company
- Minimal QC needed on our side.

50x50 cm^2 LEM









- ✓ PCB CNC drilled with o(150) holes per cm^2. 1 mm thick.
- ✓ 500 um hole diameter 800 um pitch.
- ✓ 40 um dielectric rim around the holes to avoid edge-induced discharges
- ✓ powered at around 30 kV/cm
- ✓ design is the result of many years of R&D on smaller scale prototypes.

Large Electron Multiplier

WA105

Multiply number electrons by creating large electric field (>30 kV/cm) inside the holes.

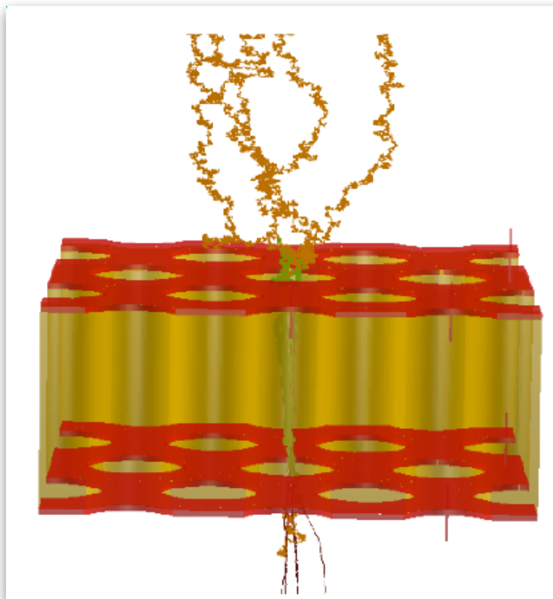
gas density

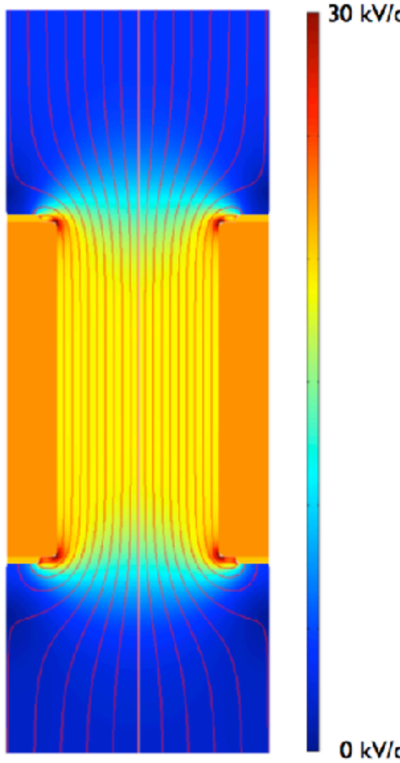
amplification length

$$G_{eff} = Te^{\alpha x} = Te^{A\rho x e^{-B\rho/E}}$$

electrical transparency of the LEM-anode system

electric field inside the LEM hole





- Robust (1 mm thick), economic, high-gain electron multipliers for large area detectors. Well suited for cryogenic detectors and use in pure noble gas without quencher. Avalanche confinement preventing photon-feedback.

NIM A (2005) 10.102 NIM A598 p121-125 JINST 3 P07001 JINST 8 P02008 NIM A423 (1999) p119-125

- Large expertise and almost a decade of developments by ETHZ group concerning operation in pure cryogenic argon gas of multiple 10x10 cm2 and a 40x80 cm2 LEM.

NIM A617 (2010) p188-192 NIM A641 (2011) p 48-57 JINST 7 (2012) P08026 JINST 8 (2013) P04012 JINST 9 (2014) P03017 JINST 10 (2015) P03017

LEM experience from 10x10 cm^2 and 40x80 cm^2

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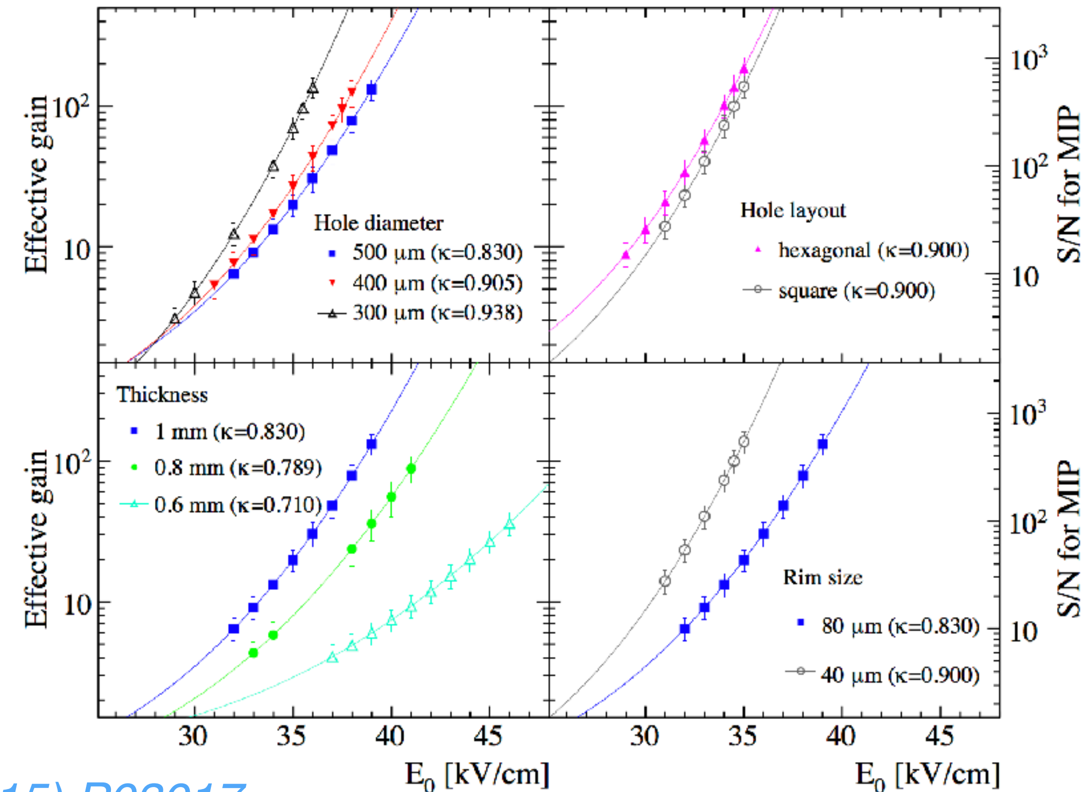
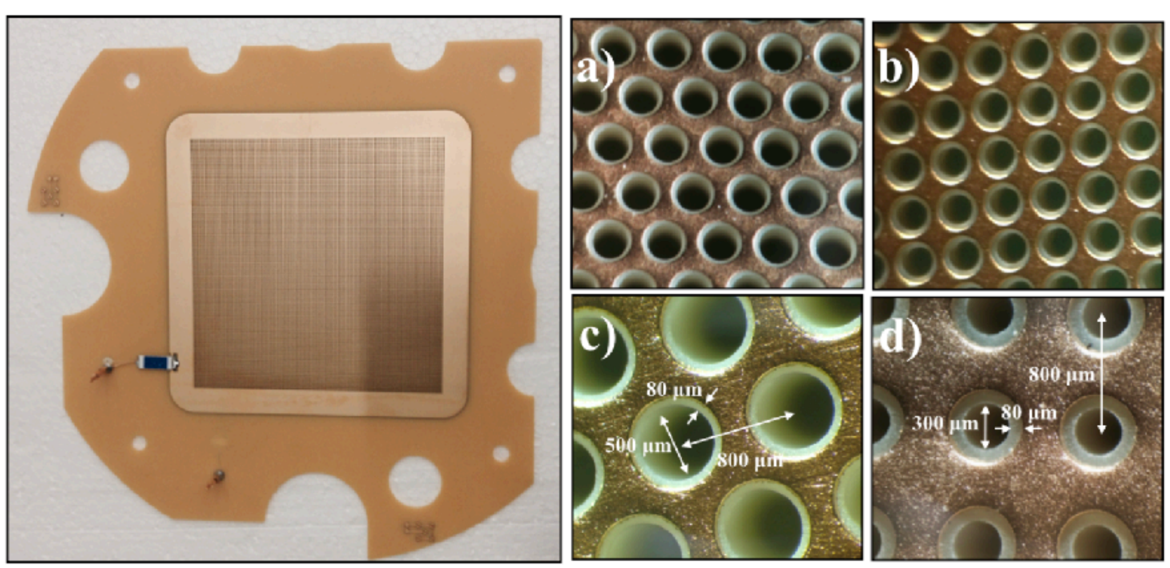
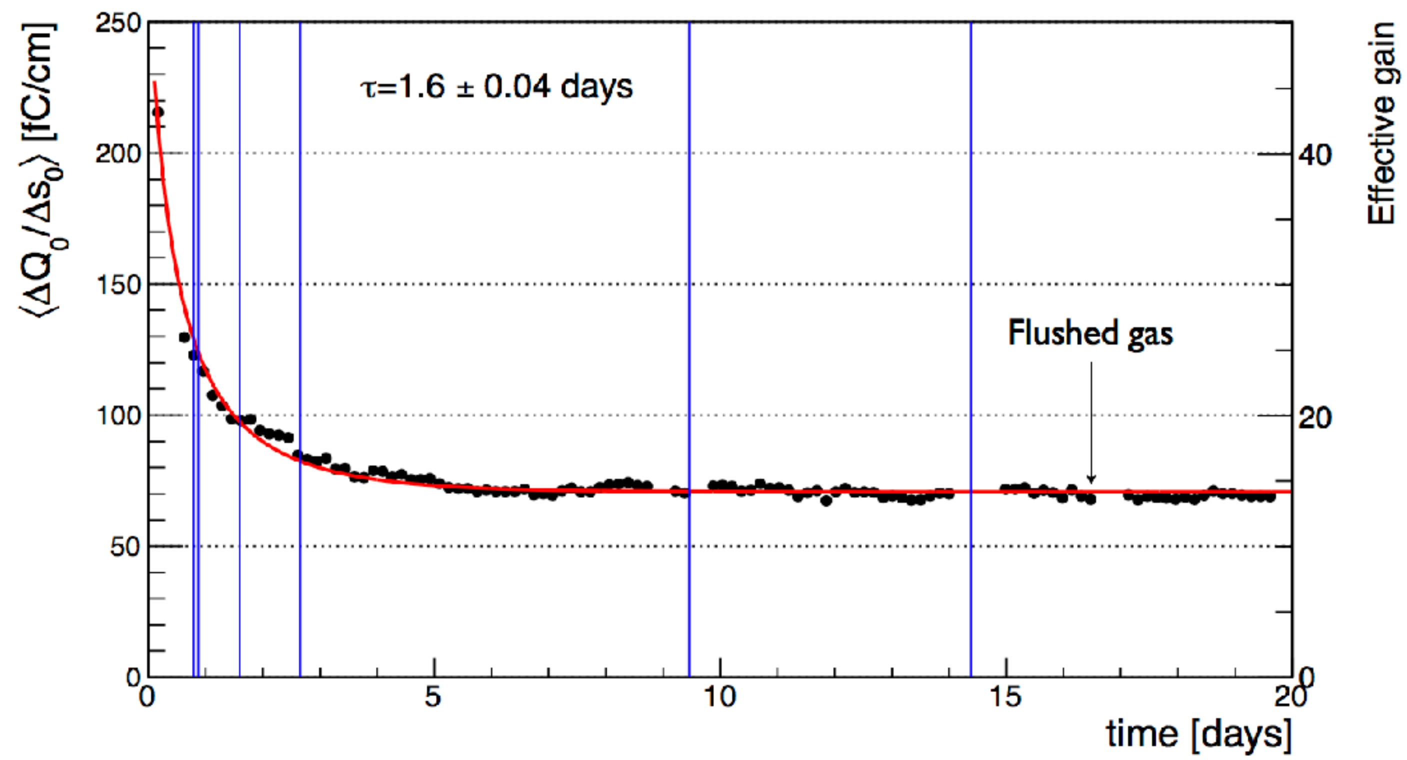
- Operated many LEMs with multiple arrangements and sizes of holes, rims,..
- Reached maximal gains of almost 200
- LEM was operated for periods of many months in stable conditions at gain ~20.
- LEM of large size 40x80 cm^2 successfully tested in 250 l chamber.

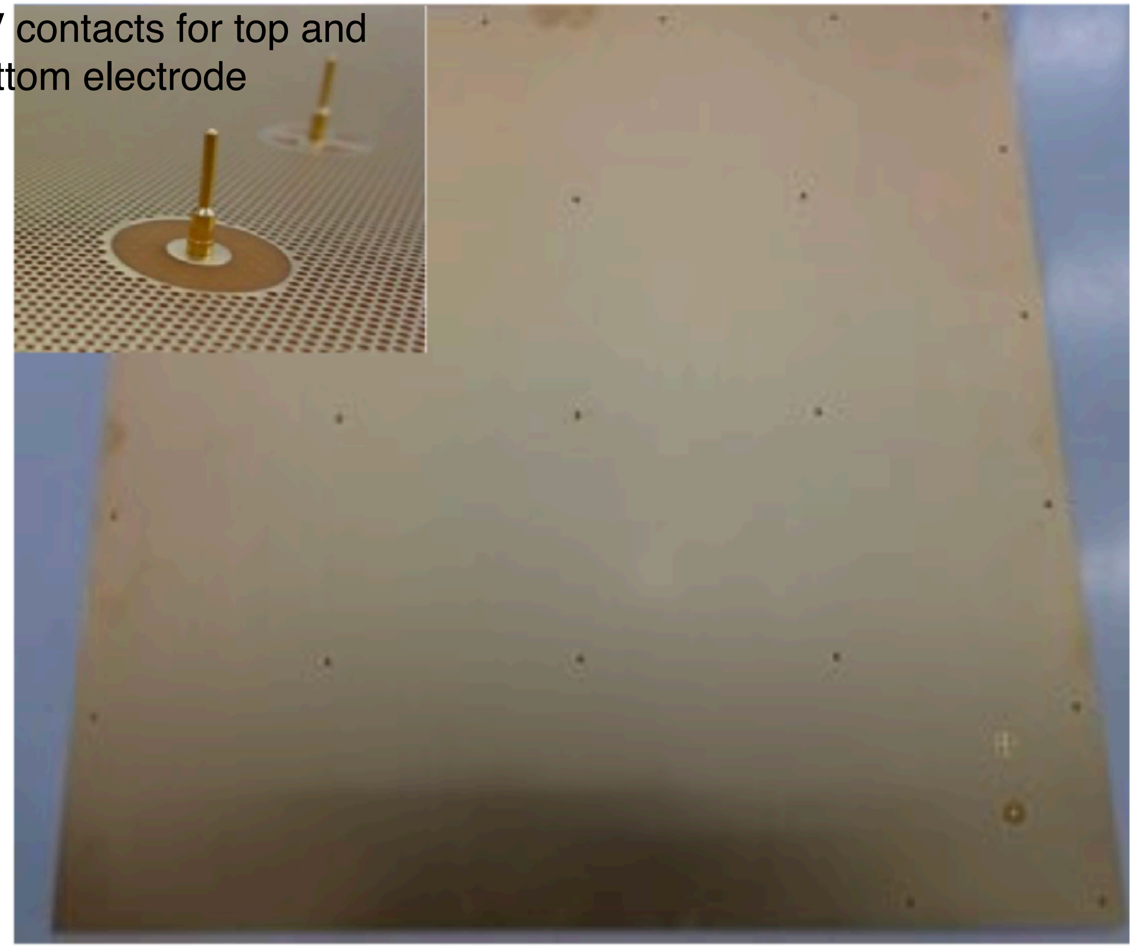


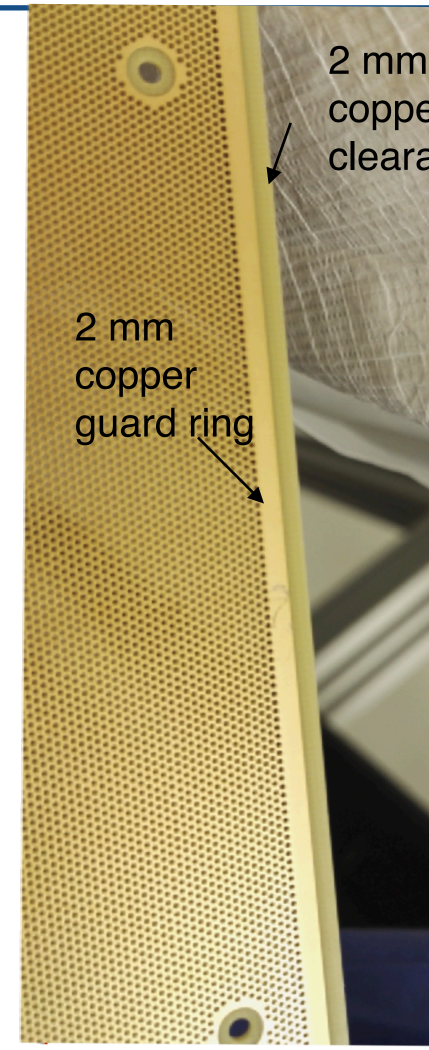
JINST 8 (2013) P04012   *JINST 9 (2014) P03017*   *JINST 10 (2015) P03017*

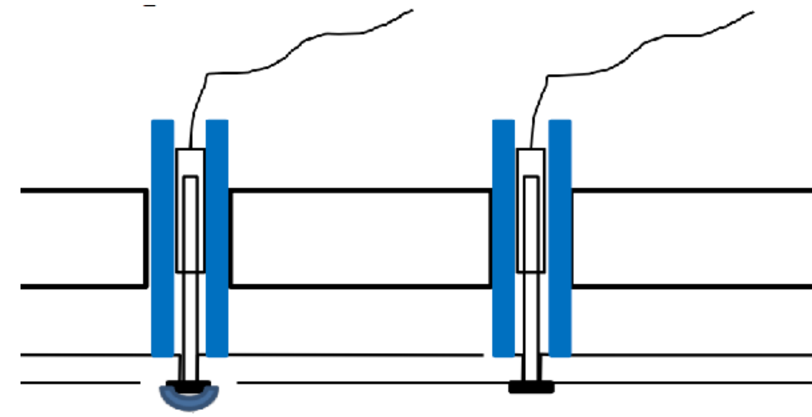




50x50 cm^2 LEM design







HV contacts from the top going through the anode
details of HV contacts,
See talk Marco Z.

- This design has matured from many year of R&D on small prototypes and from dedicated tests in cryogenic environment of a 50x50.
- 12 such LEMs are currently installed on the 3x1x1.
- A detailed QA/QC procedure has been setup thanks to the experience gained during installation of the 3x1x1. See talk M. Zito

Extensive production QA at CERN

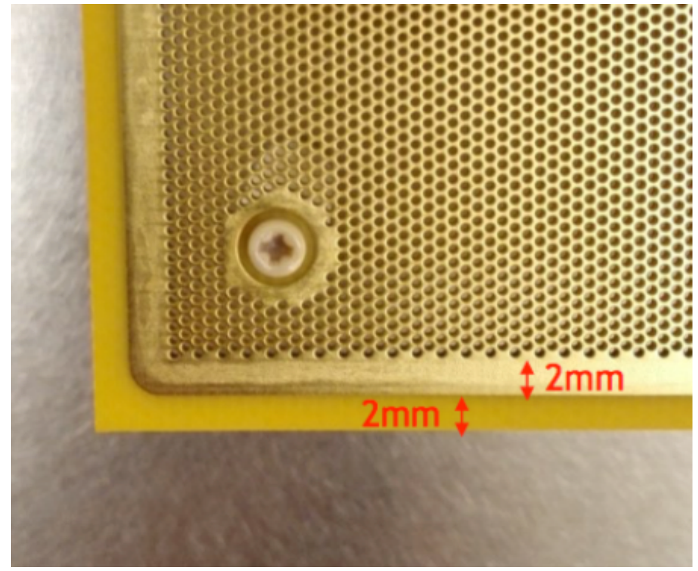
WA105

On a pilot series of 50x50 LEMs we performed many campaigns of observations to guaranty quality of manufacturing

Surface inspection by optical and electron microscopy of Kapton resistive LEM after testing	https://edms.cern.ch/document/1601058/1
Comparison of holes size in liquid electron multiplier (LEM) samples by optical microscopy	https://edms.cern.ch/document/1597160/1
SEM observation of 10 cm x 10 cm LEM with smooth Cu surface	https://edms.cern.ch/document/1557190/1
Microscopy inspection in various LEM samples	https://edms.cern.ch/document/1557200/1
Quality study of LEMs by microscope observation	https://edms.cern.ch/document/1515988/1

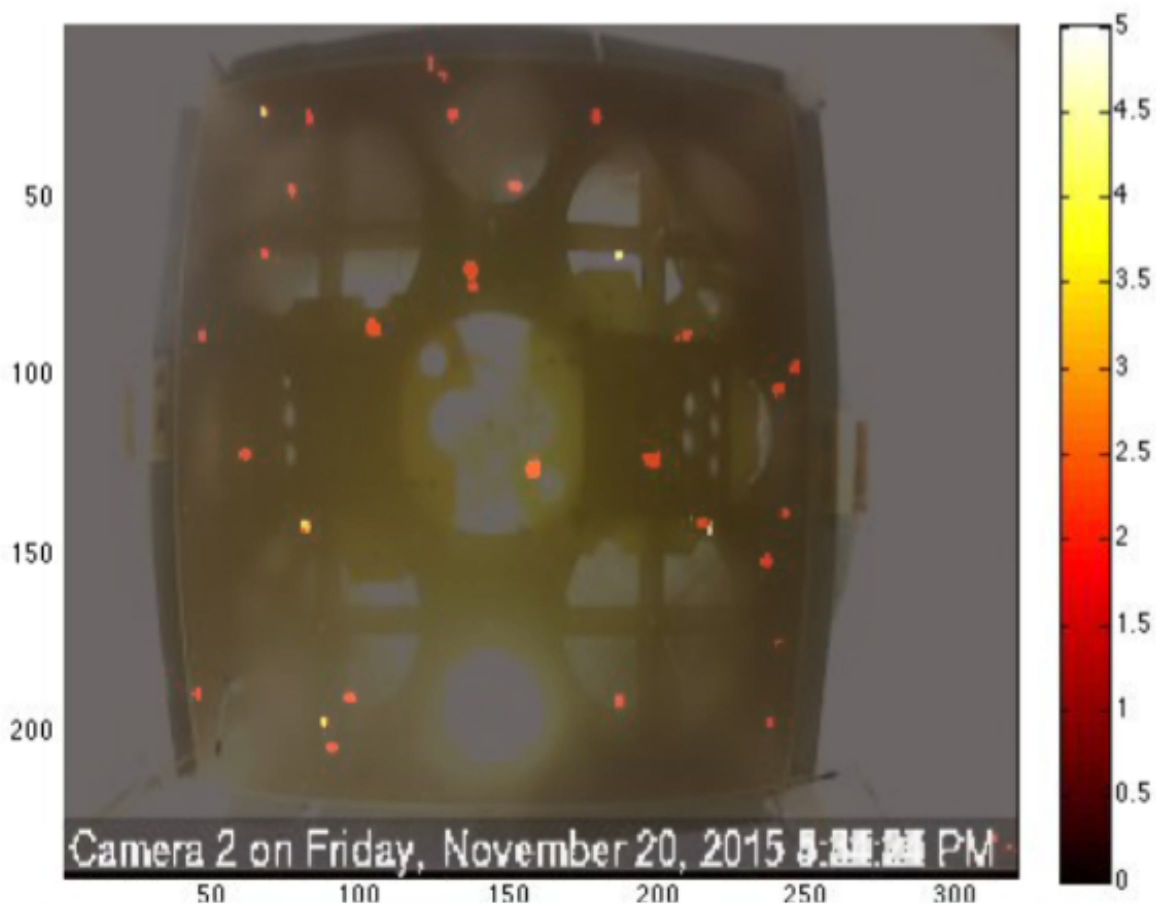
Discharges on 50x50 LEMs with guard ring

50x50 with guard ring

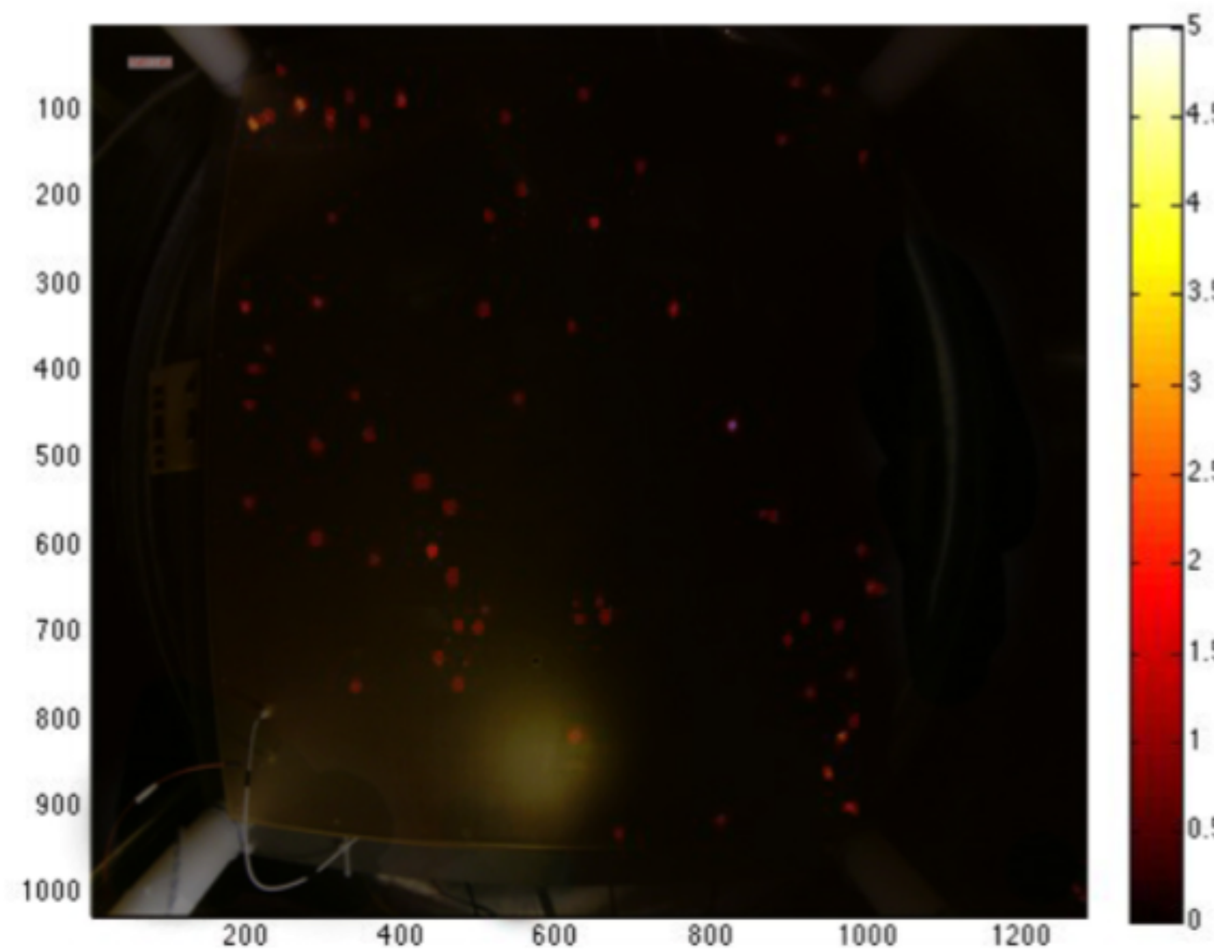


No persistent discharges around the edges or specific locations are observed

spark test pure Ar gas at 300 K



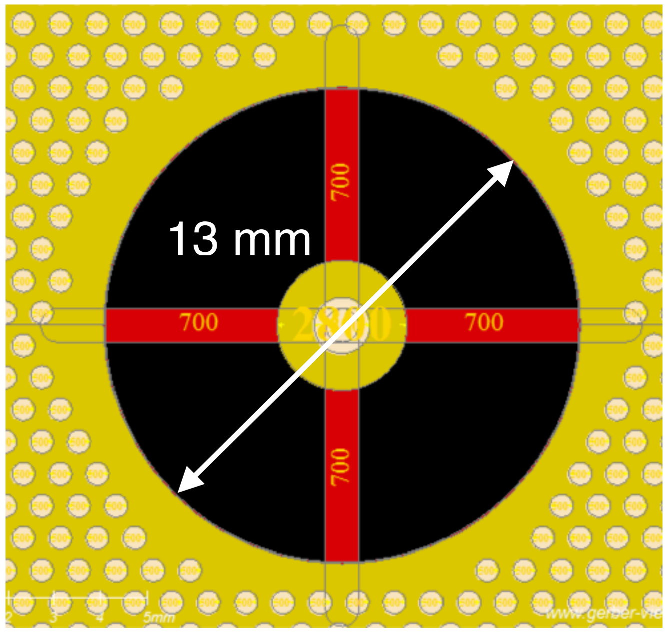
spark test pure Ar gas at 88 K

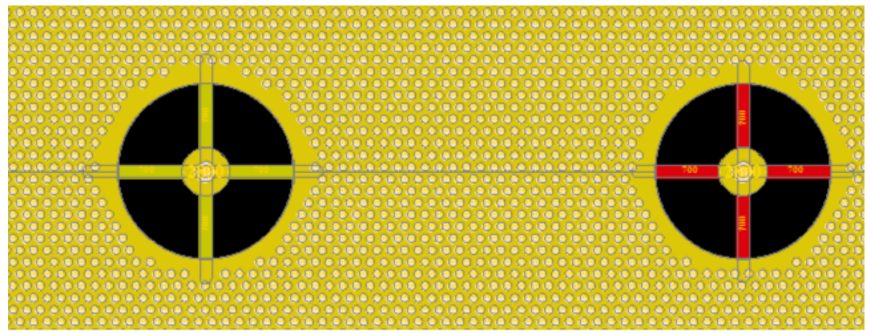


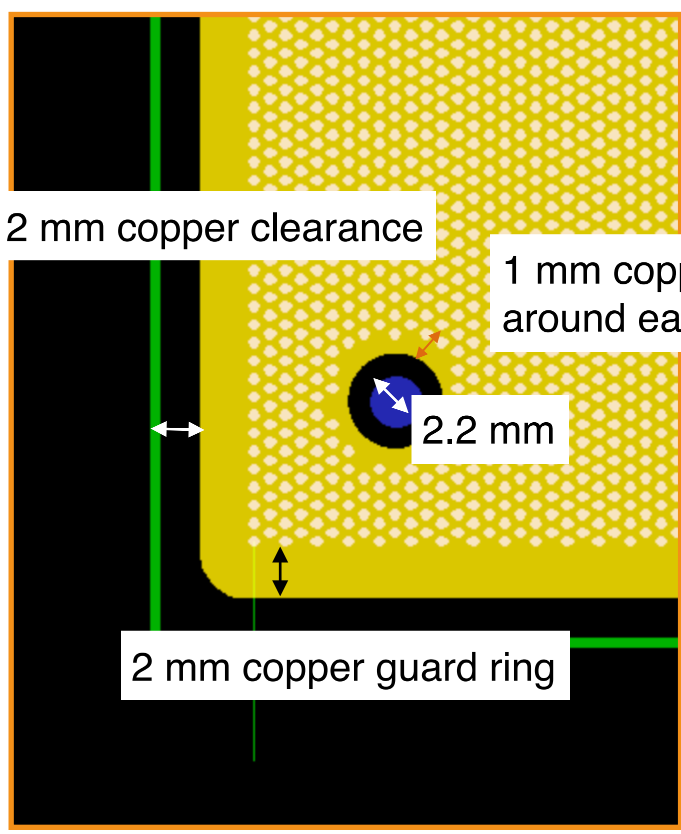
50x50 LEM - Gerber production files

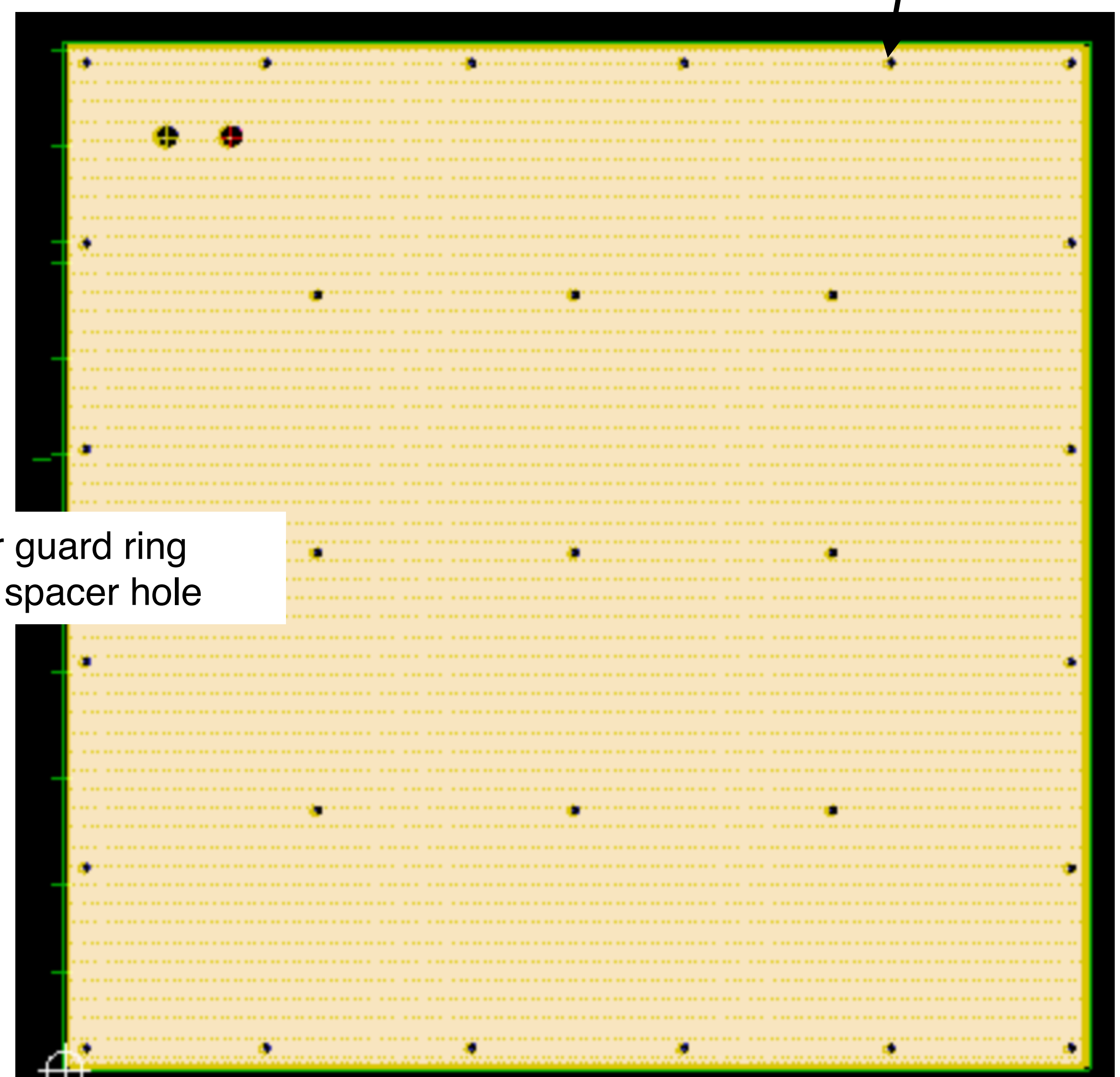
HV contacts for top and bottom electrode

29 holes of 2.2 ø for fixation to the anode with 2 mm thick spacers









All necessary gerber files for production have been prepared. The purchasing aspects are well under control with a detailed specification document.
See presentation by Marco Z.

Anode front and back

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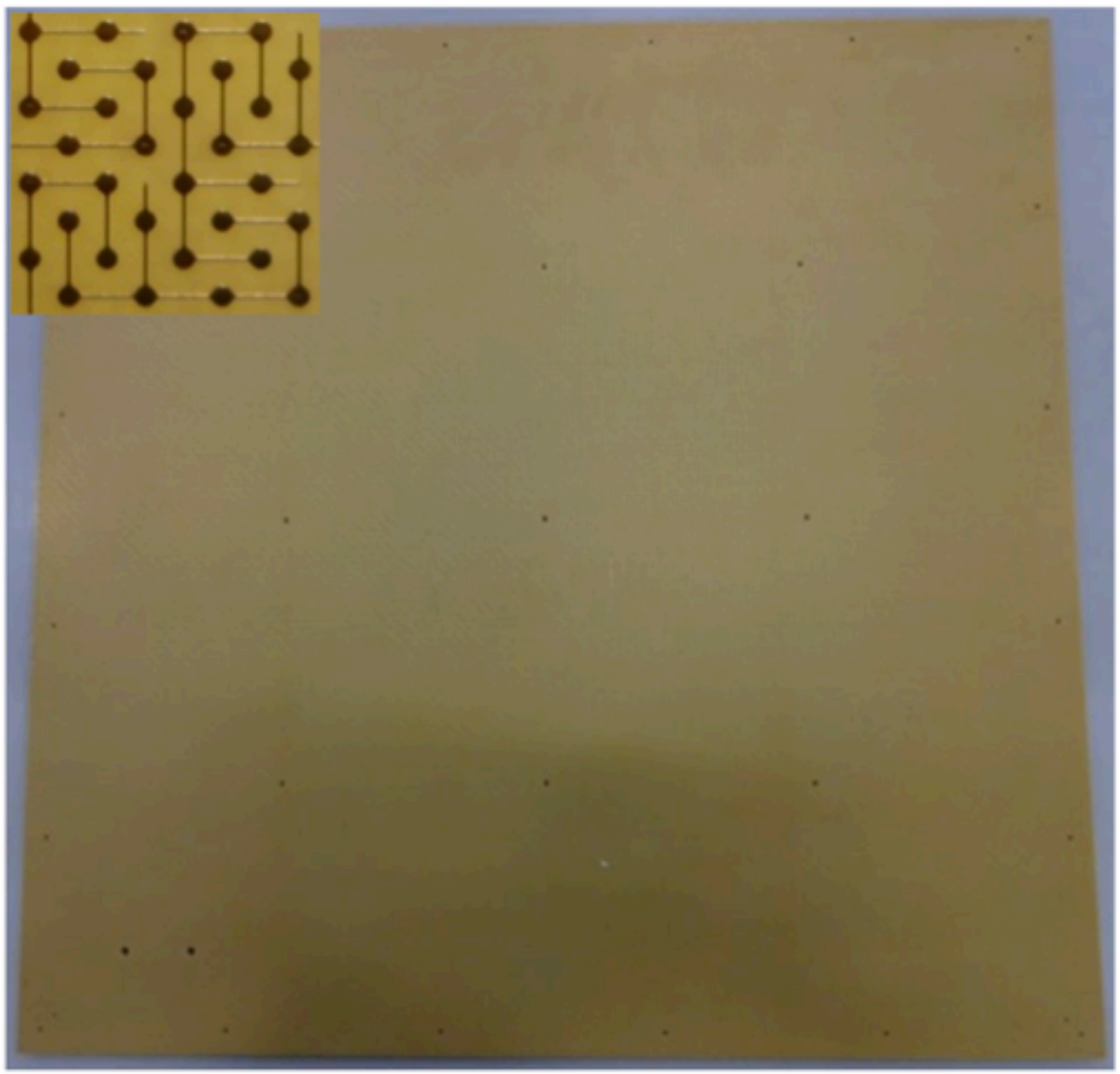
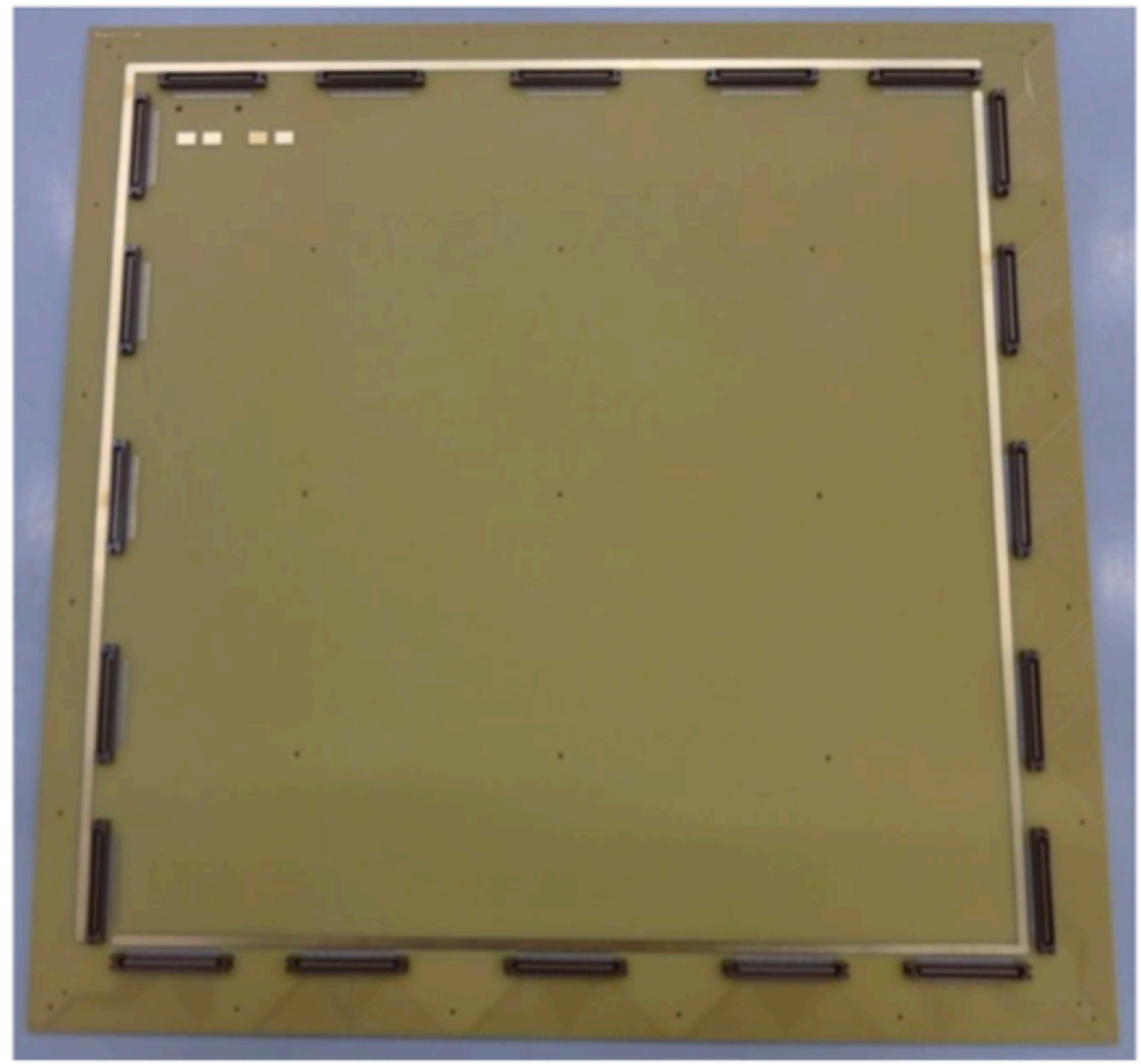
front



back



Anode design optimisation

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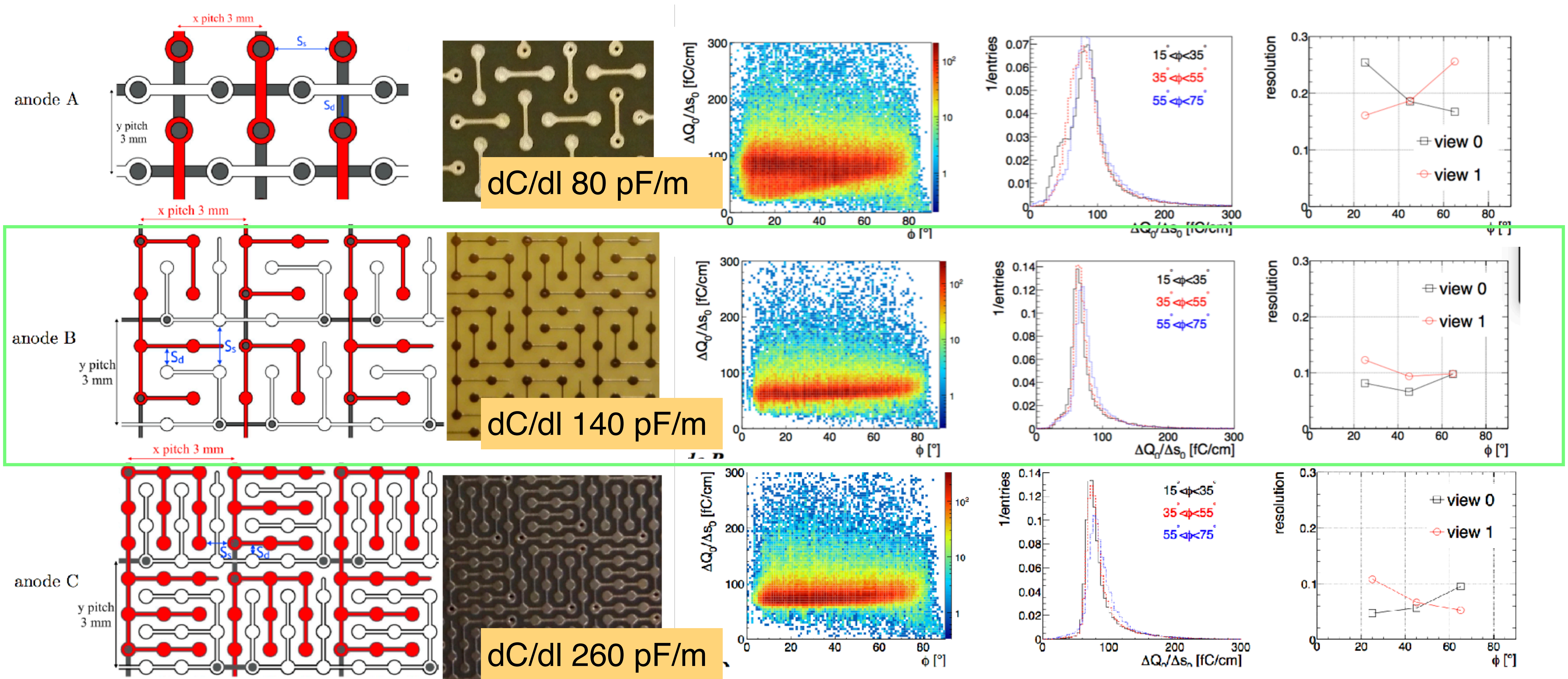
Obtain best charge sharing and minimal capacitance per unit length. Tests on 10x10 cm2 readouts.

dC/dl 140 pF/m. about 450-500 pF before preamp on 3m readout. ENC of ~ 1500 electrons at 110 K



Anode - production drawings

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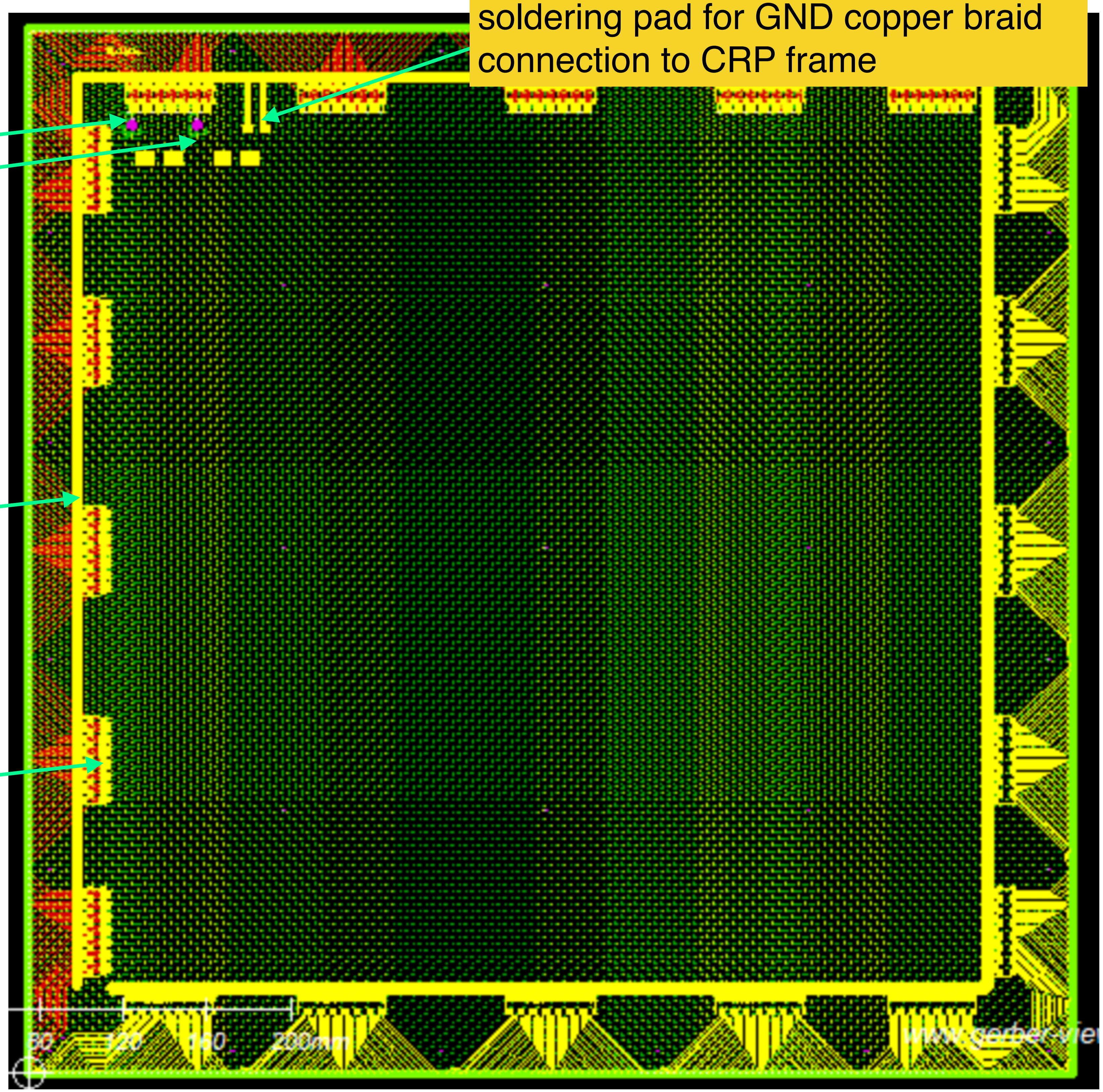
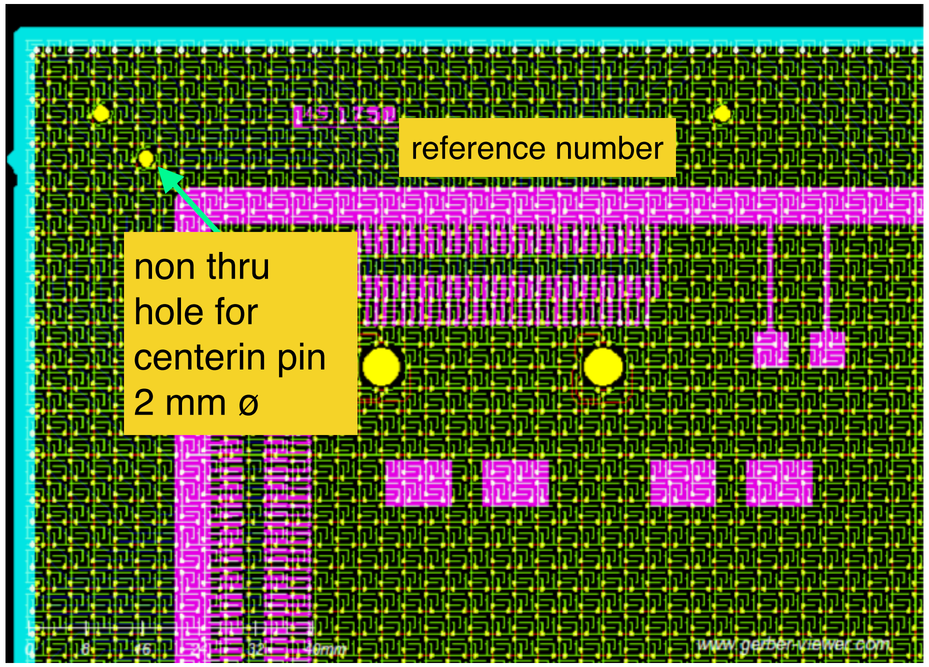
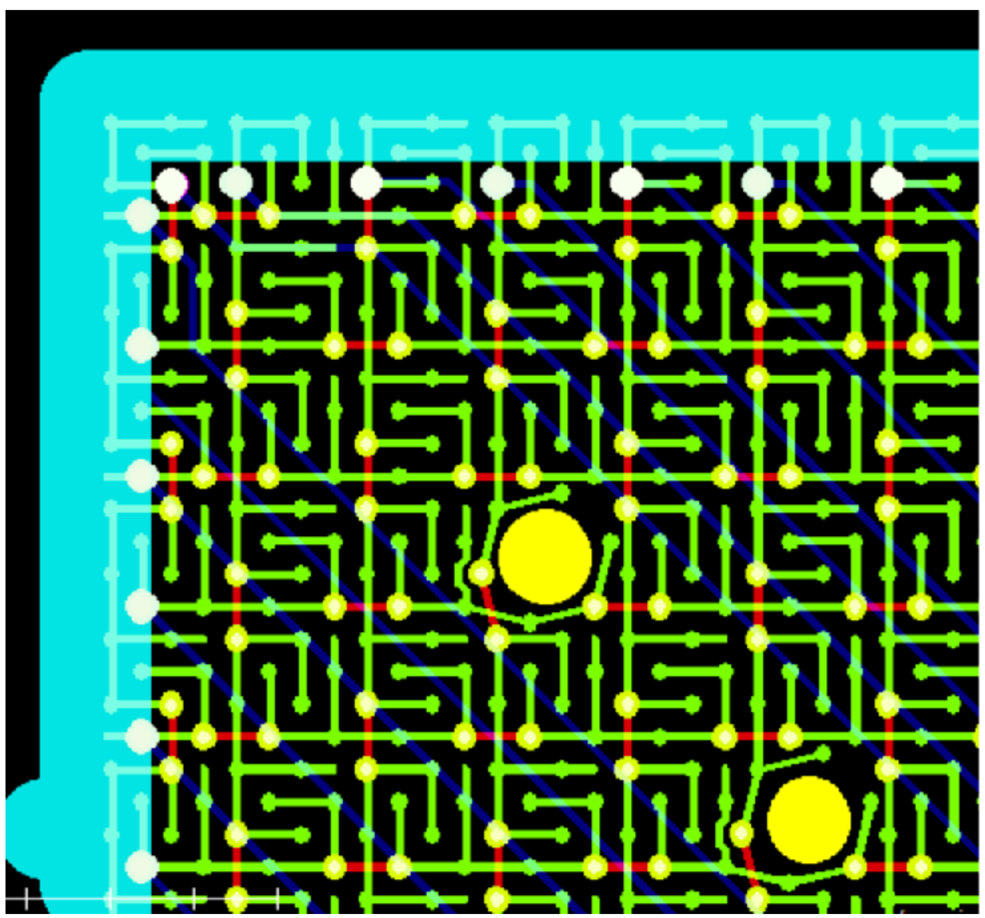
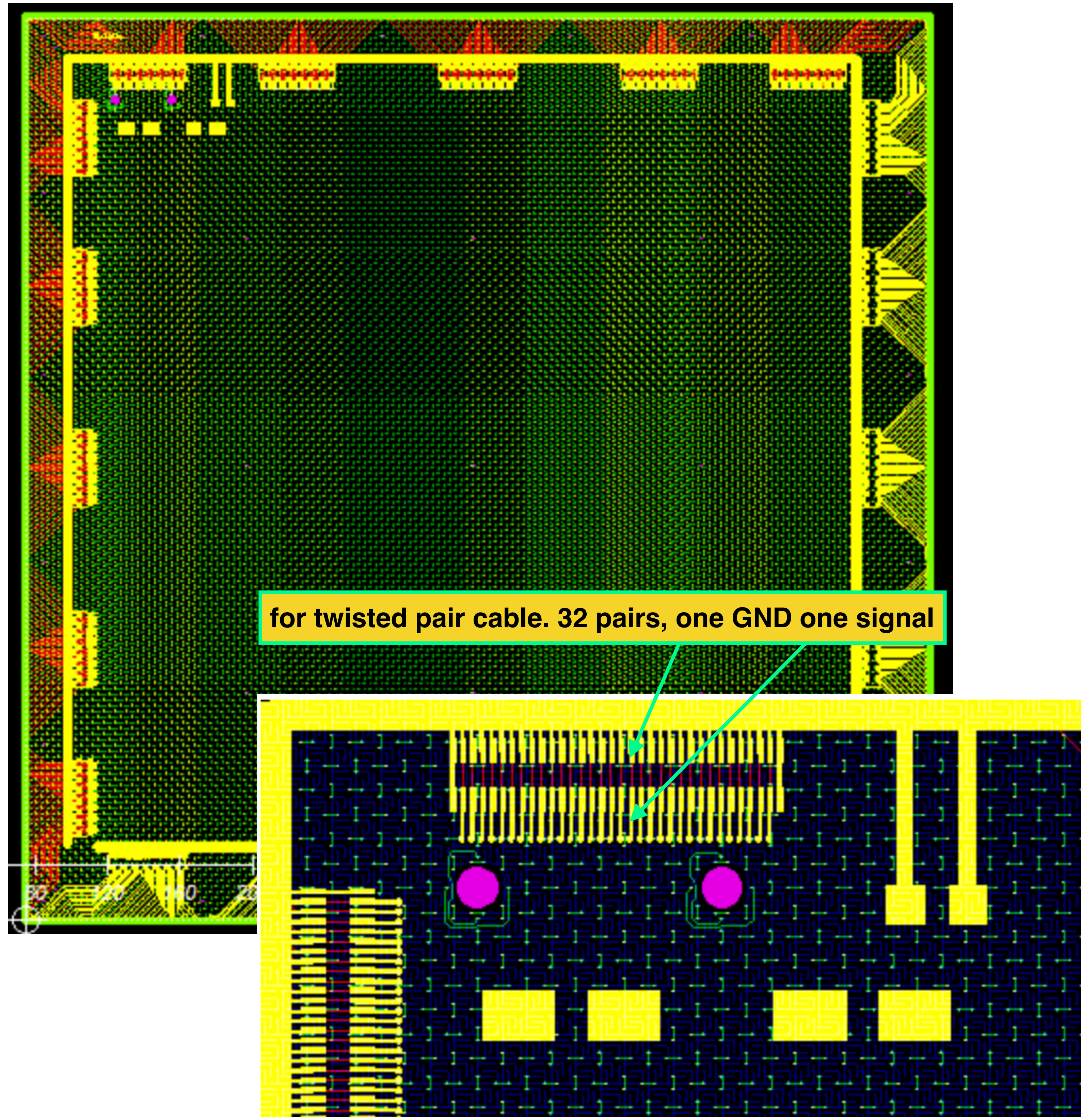


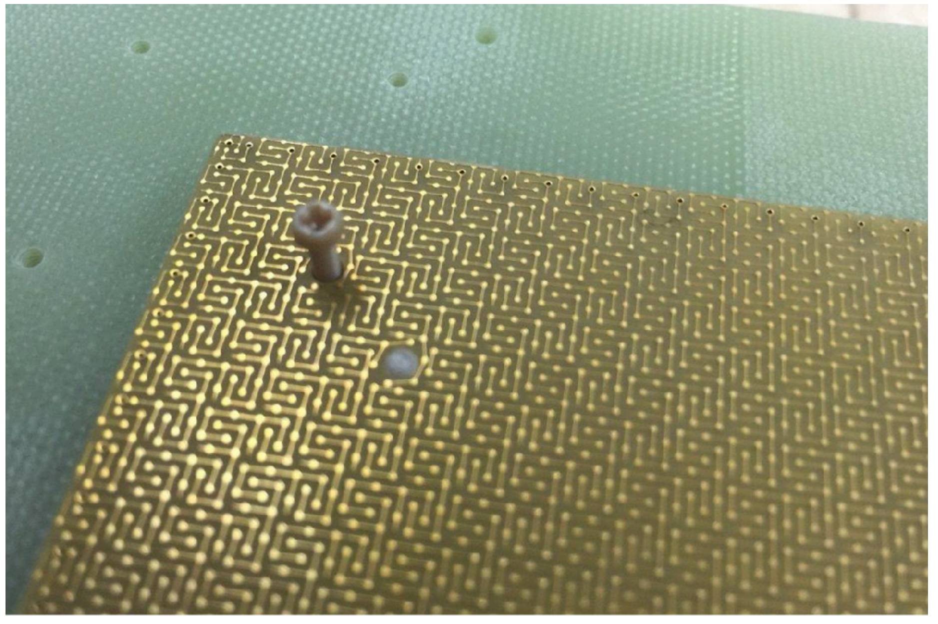
Anode design

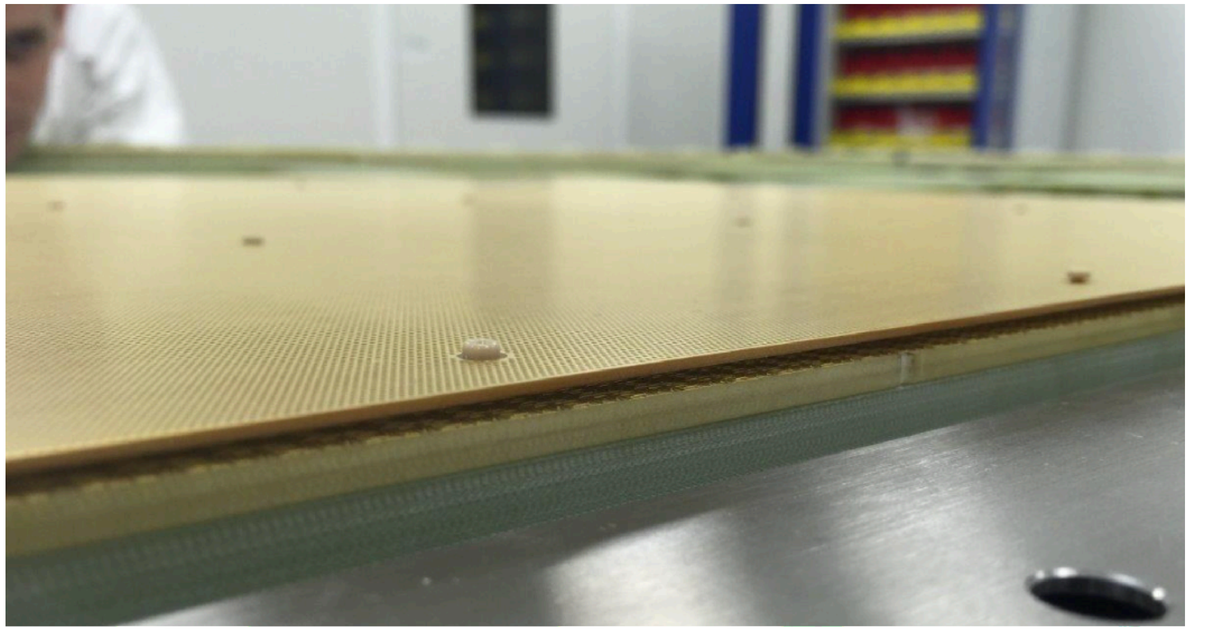




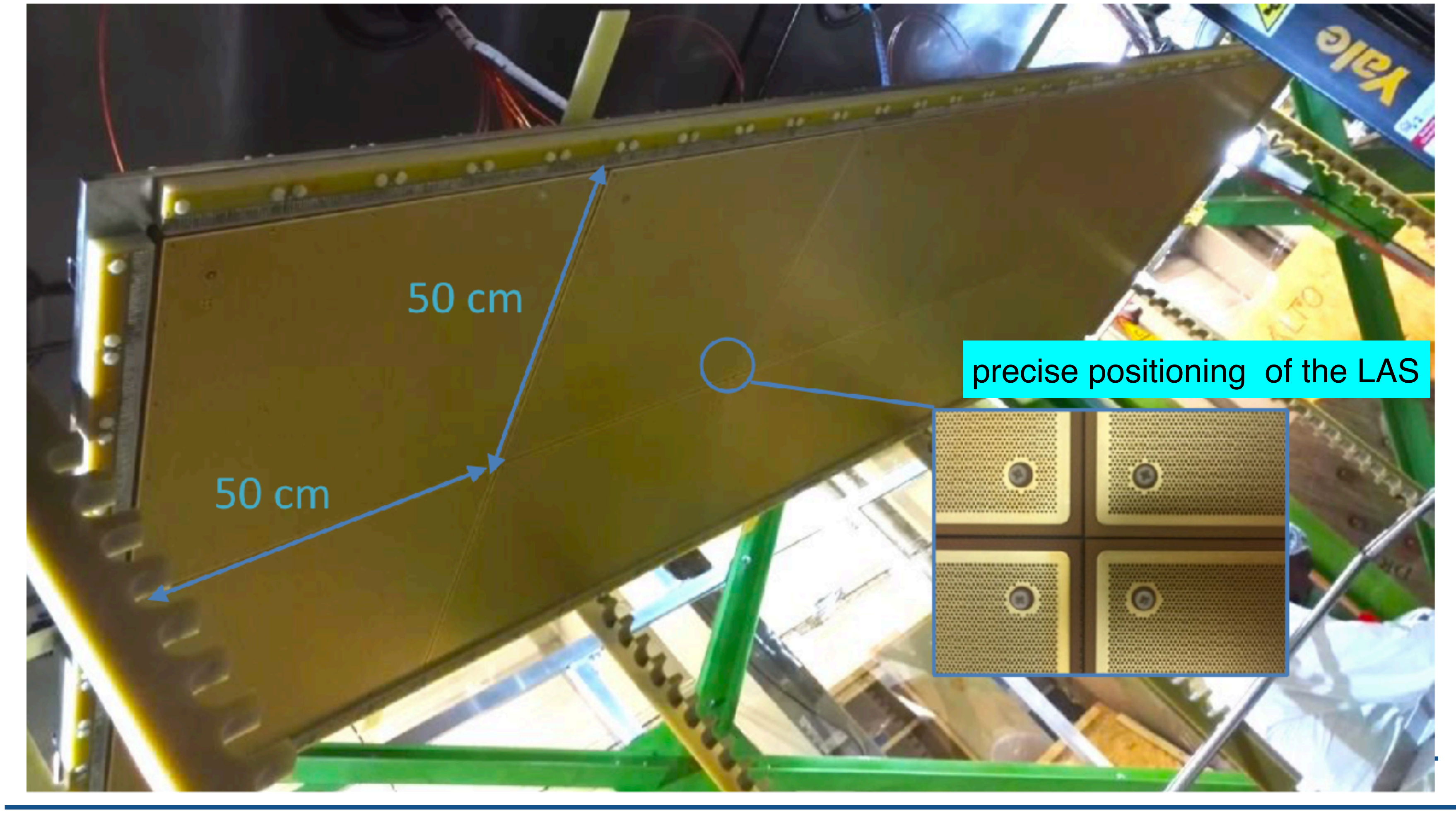


LEMs and anode assembly on 3x1x1

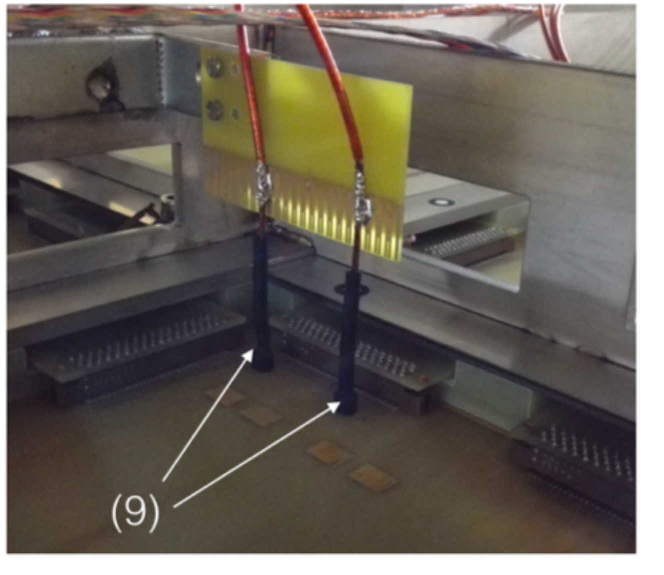




Example of the 3x1x1

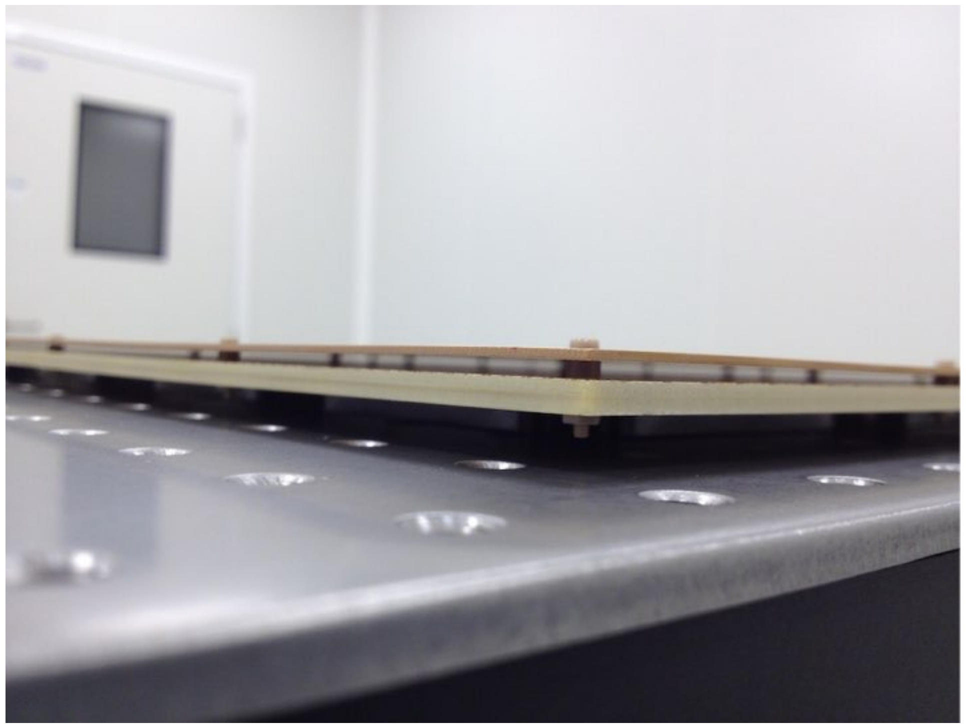


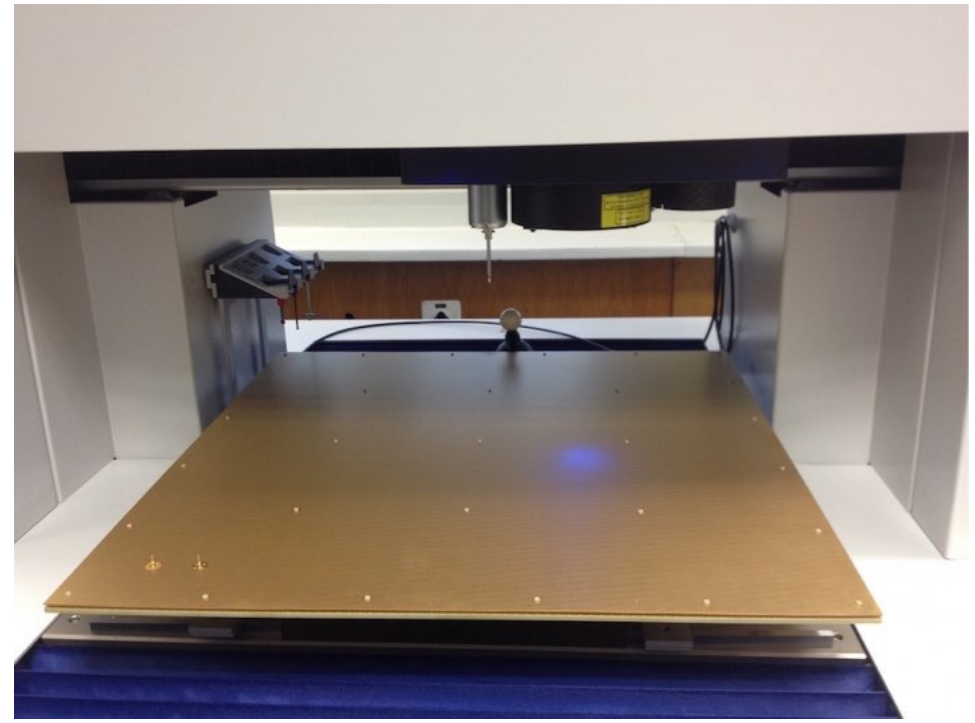
HV connections to the LEM are done from the top through the anode

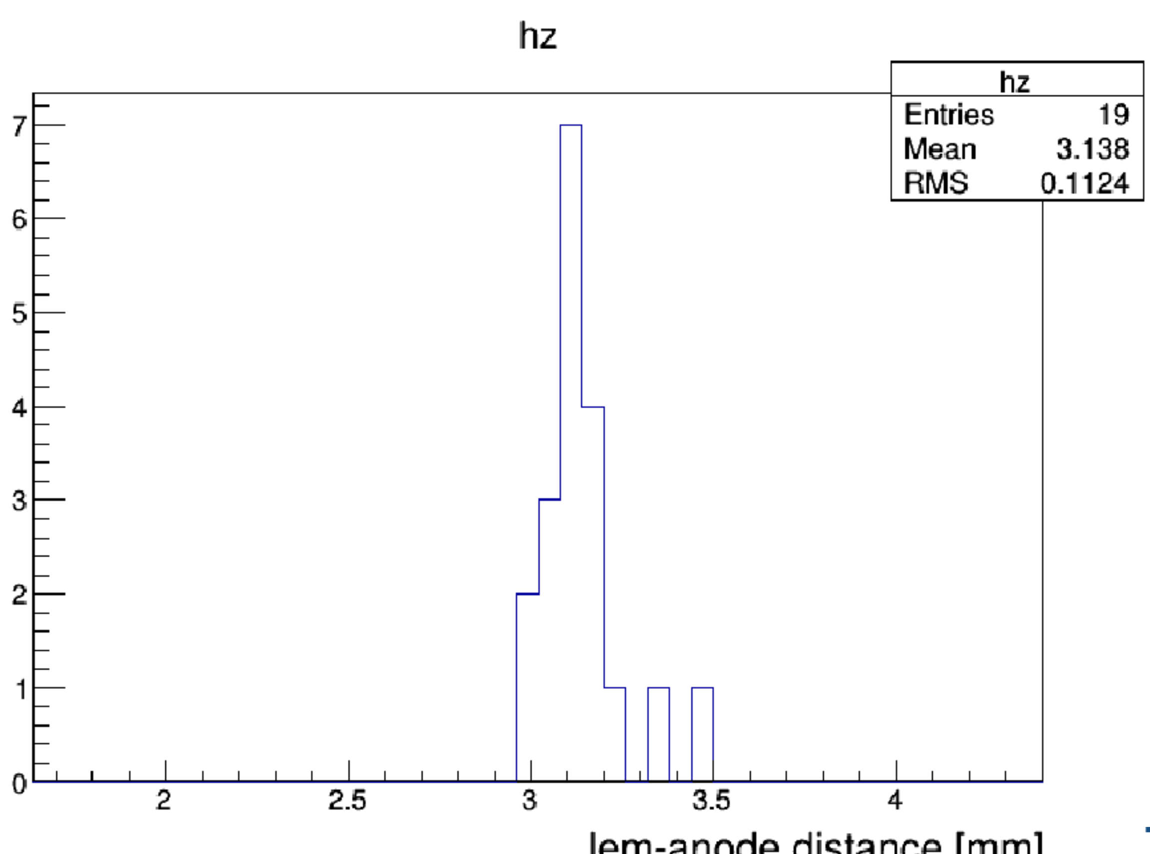


Measurement of inter-stage distance on a LAS

surveyed a 50x50 cm² LEM + anode with a camera through LEM holes

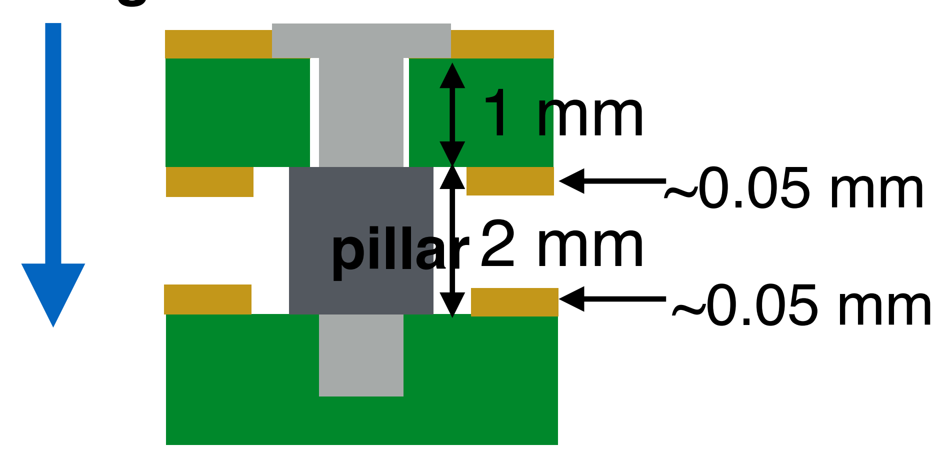




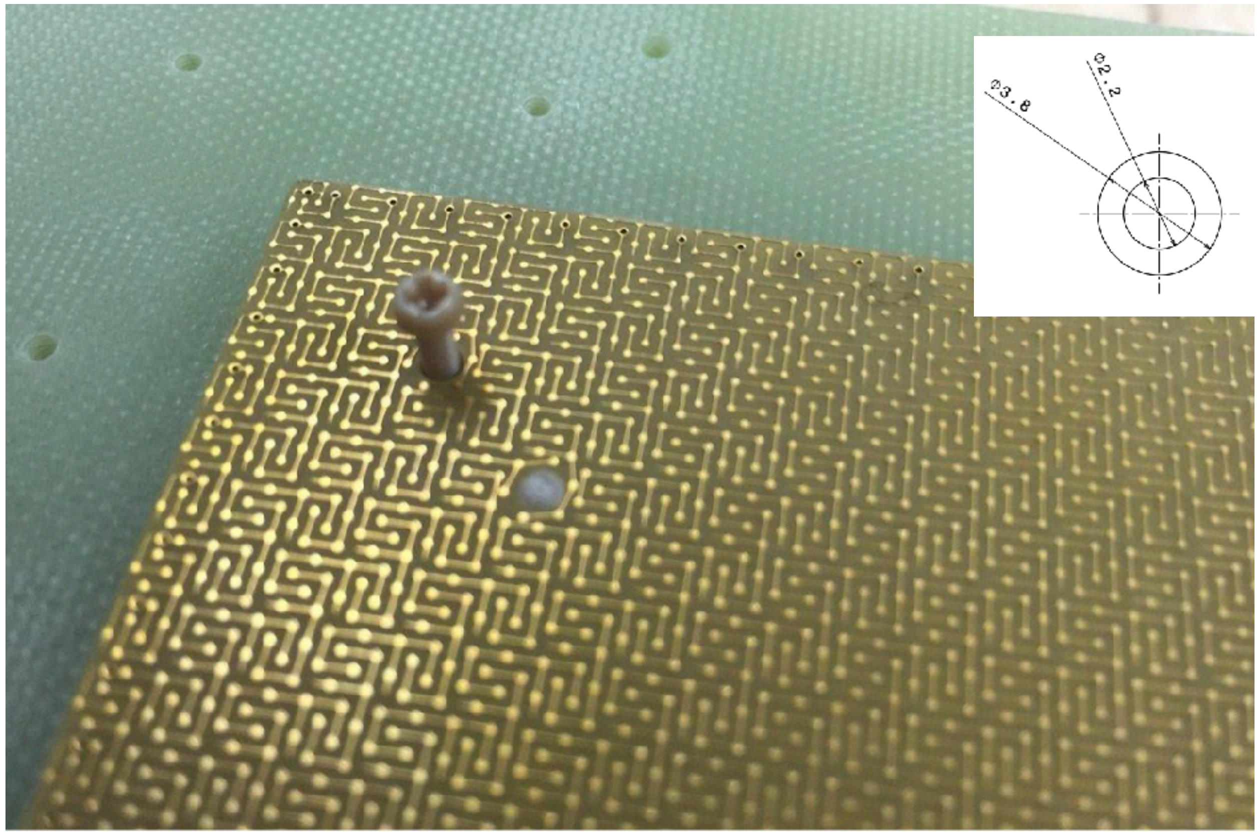


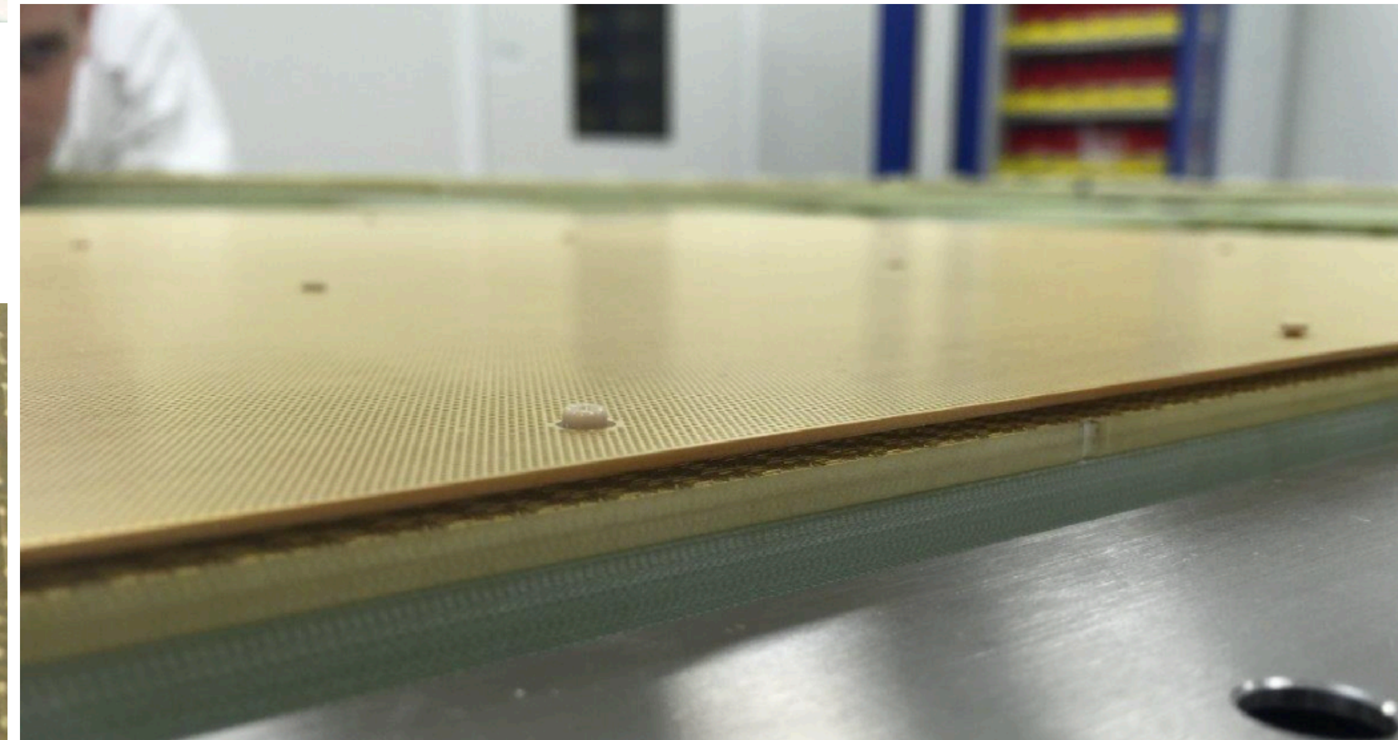
nominal ~ 2 (LEM-anode) + 1 (LEM thickness) + ~.05 mm ≈ **3.05 mm**

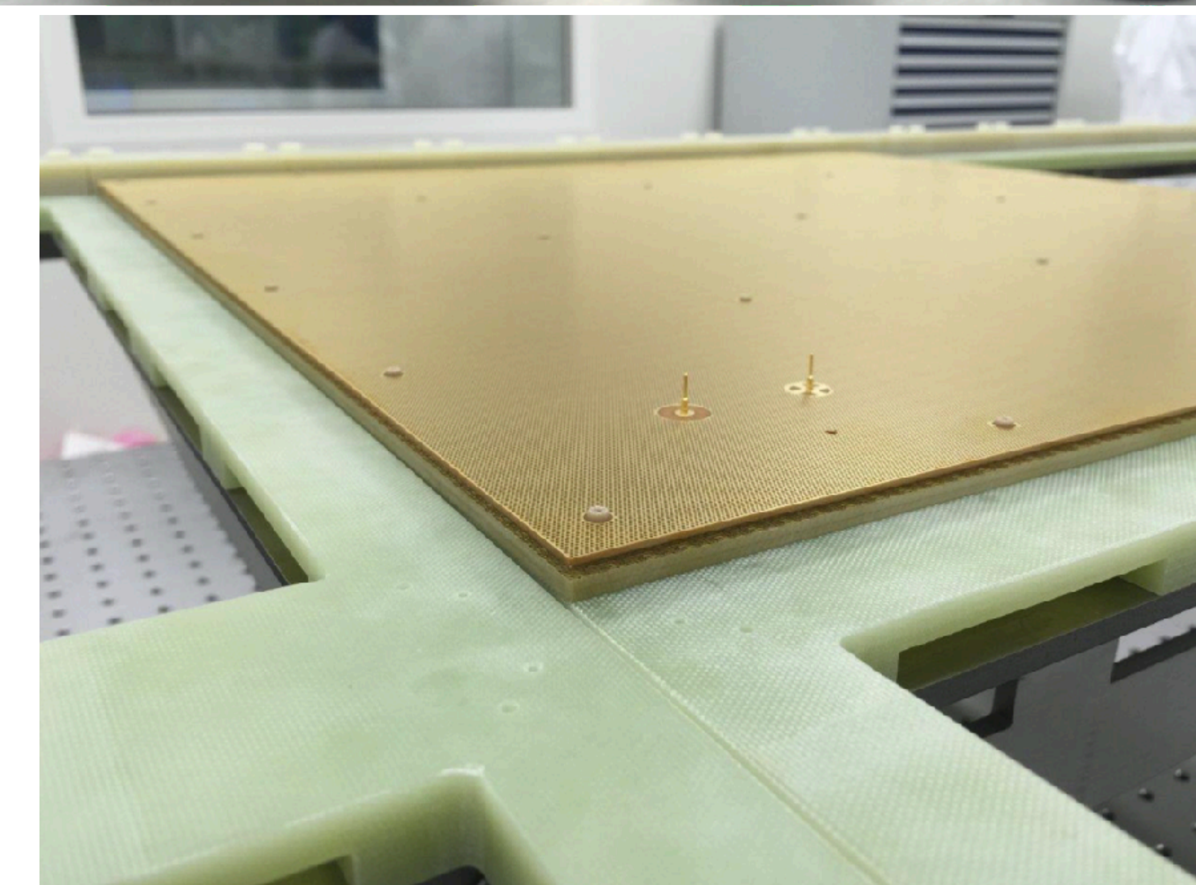
camera through LEM hole



LAS protoDUNE DP







item	material	amount
M2 screw	peek	4176
LAS spacers	PE	4176
centering pins	G10	288

Conclusion

- The design of both LEM and anodes are the result of many years of optimisation on small scale versions.
- The anodes have low capacitance per unit length and their design (tested on prototypes)… allows 50:50 charge sharing between each view. The level of the noise observed on the 3x1x1 is at near to what we expect from the electronics with 3 m readout strips.
- Already the return of experience from 3x1x1 show the intrinsic noise from the strips is consistent with our expectations.
- The 50x50 LEMs have been extensively checked at CERN. From the experience with the 3x1x1 we have a gained a large experience on handling and QA.
- For both we have achieved designs that can be made industrially. We have experience with at least two companies that we know can produce LEMs according to our requirements (more details in next talk). Same is for the anodes.

backup

LEMs and anode example on 3x1x1

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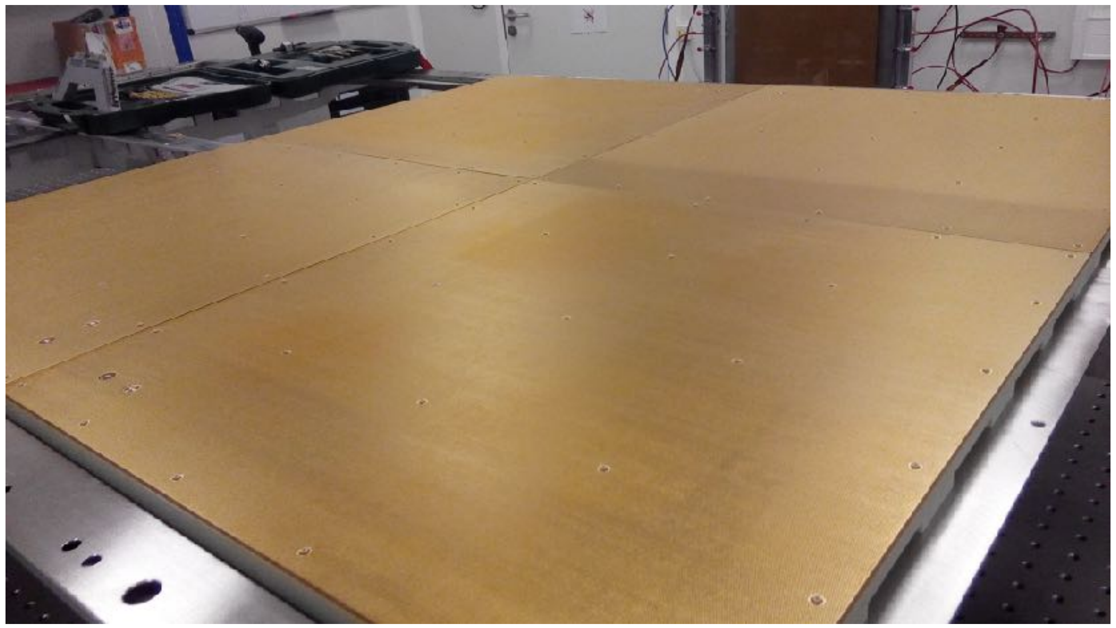
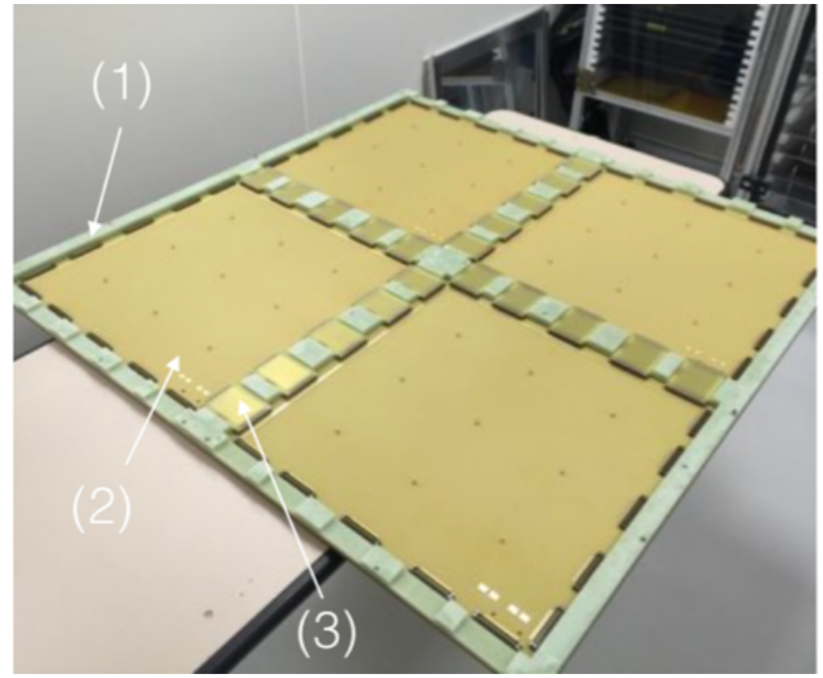
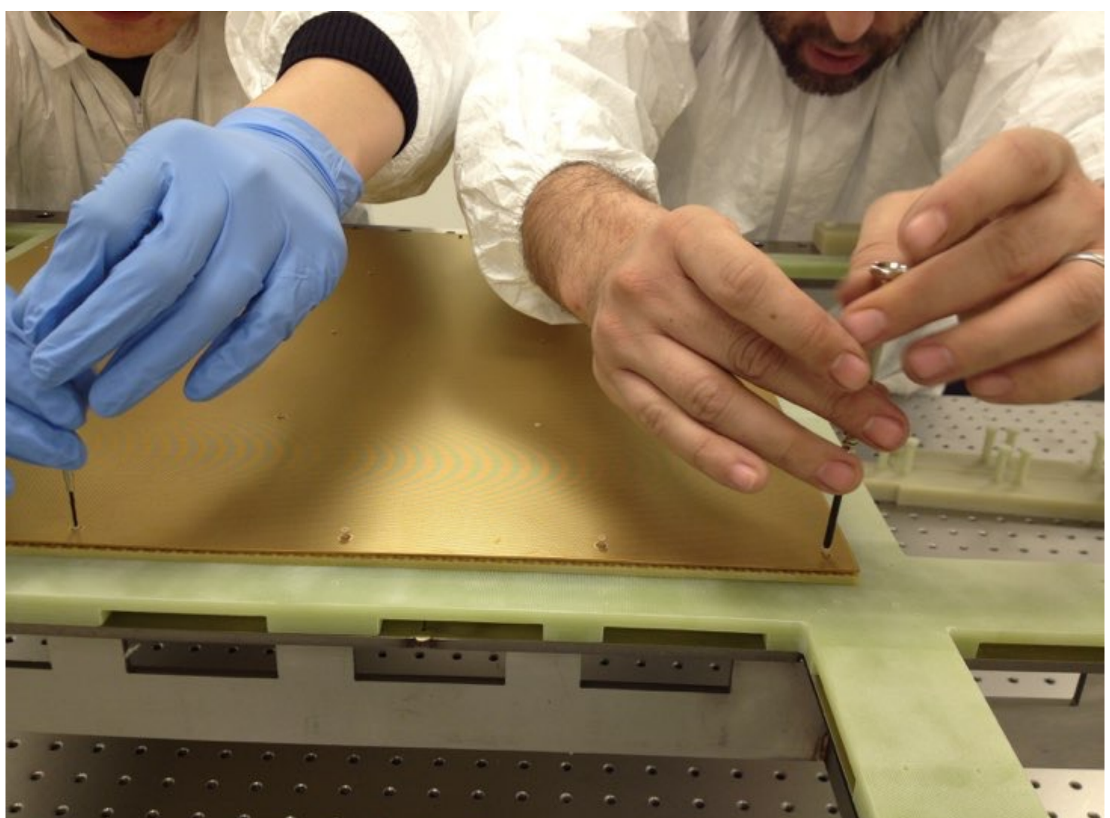
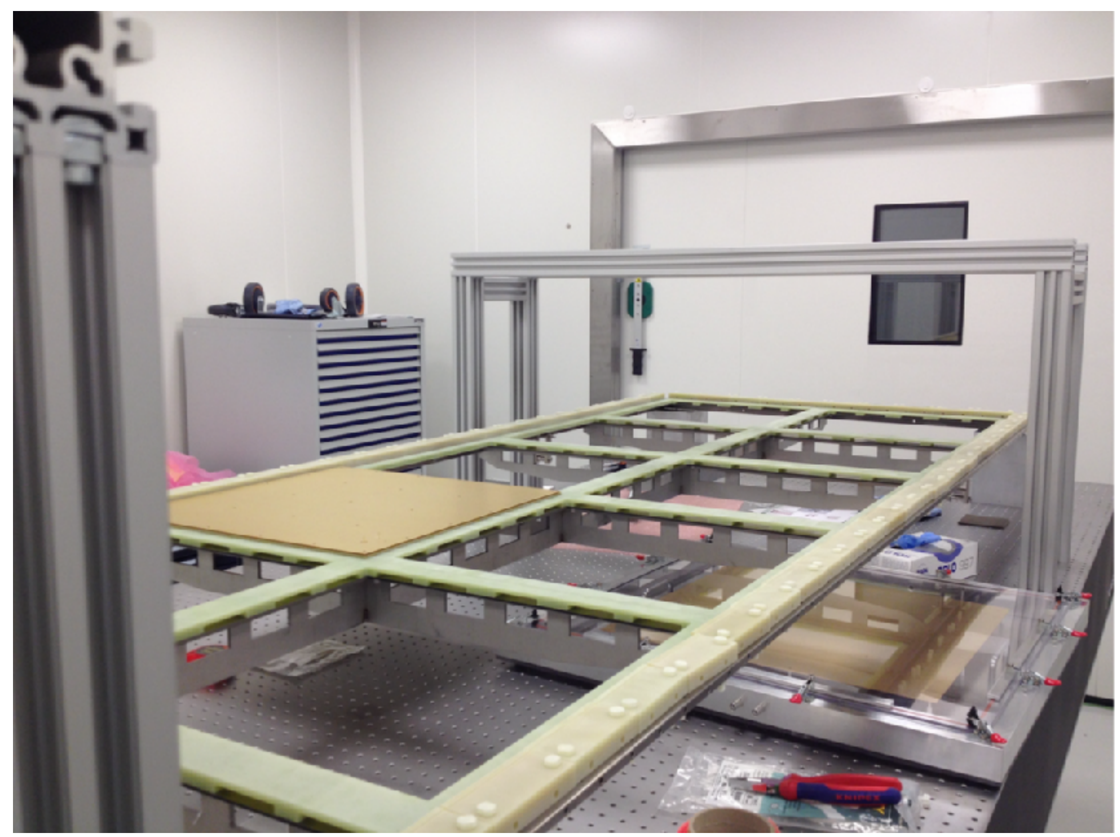
Although of smaller size a lot of experience has been gained from the 3x1 m2 CRP installation

Some photos of 3x1x1 LAS assembly on CRP

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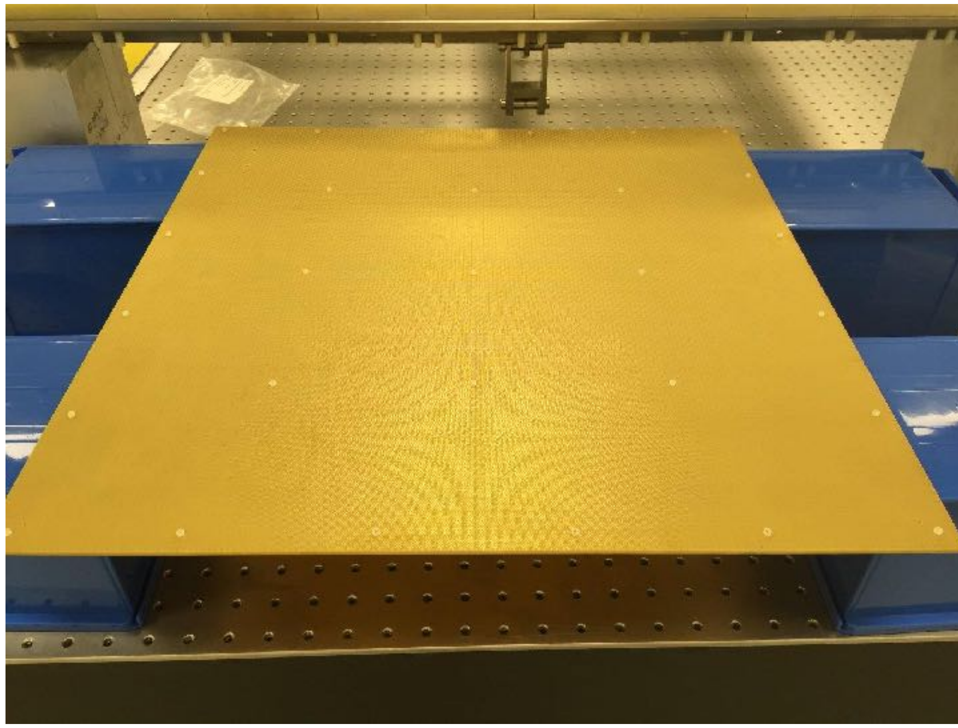

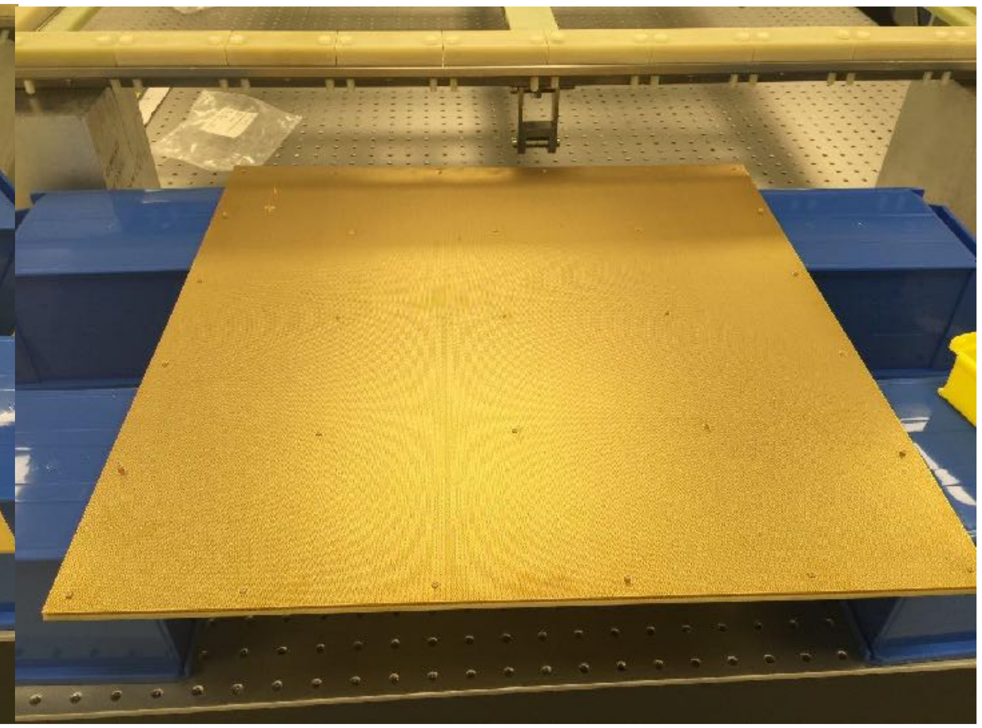

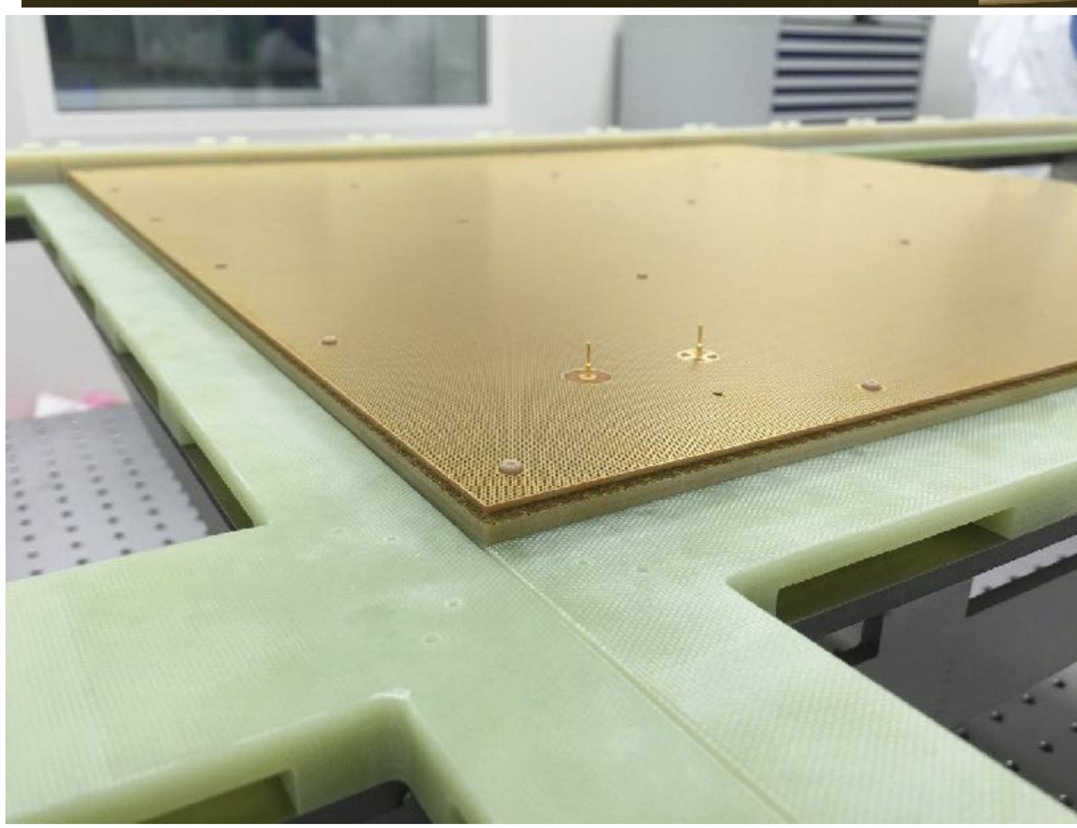

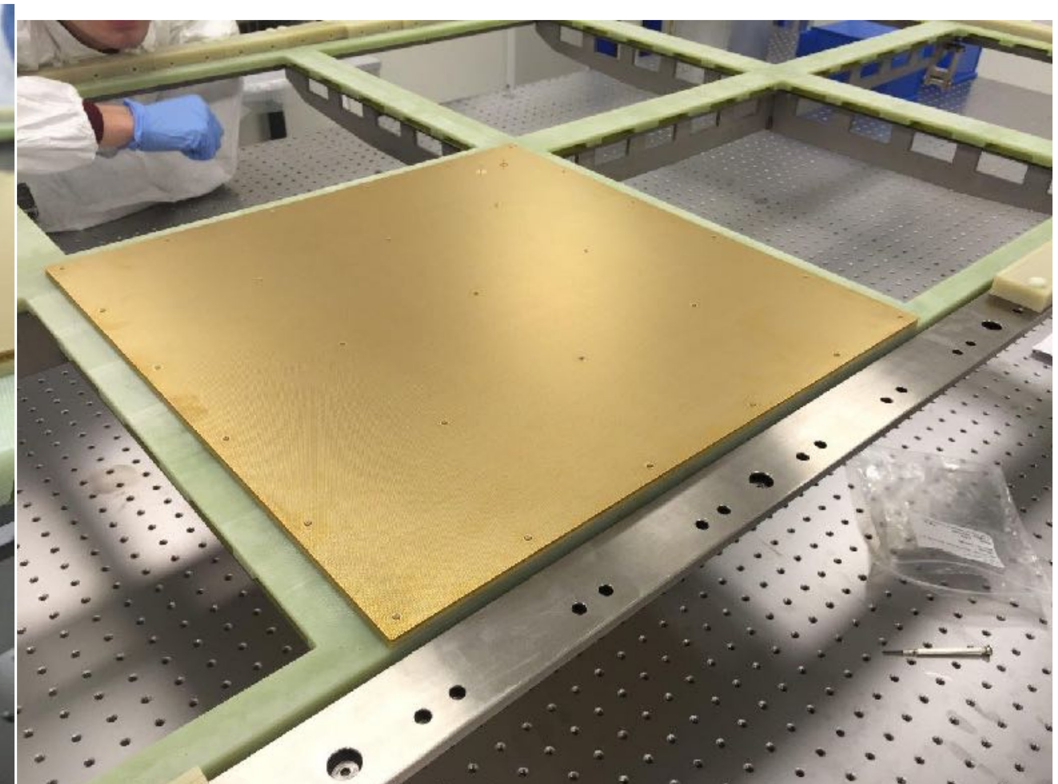

Electric field inside the LEM

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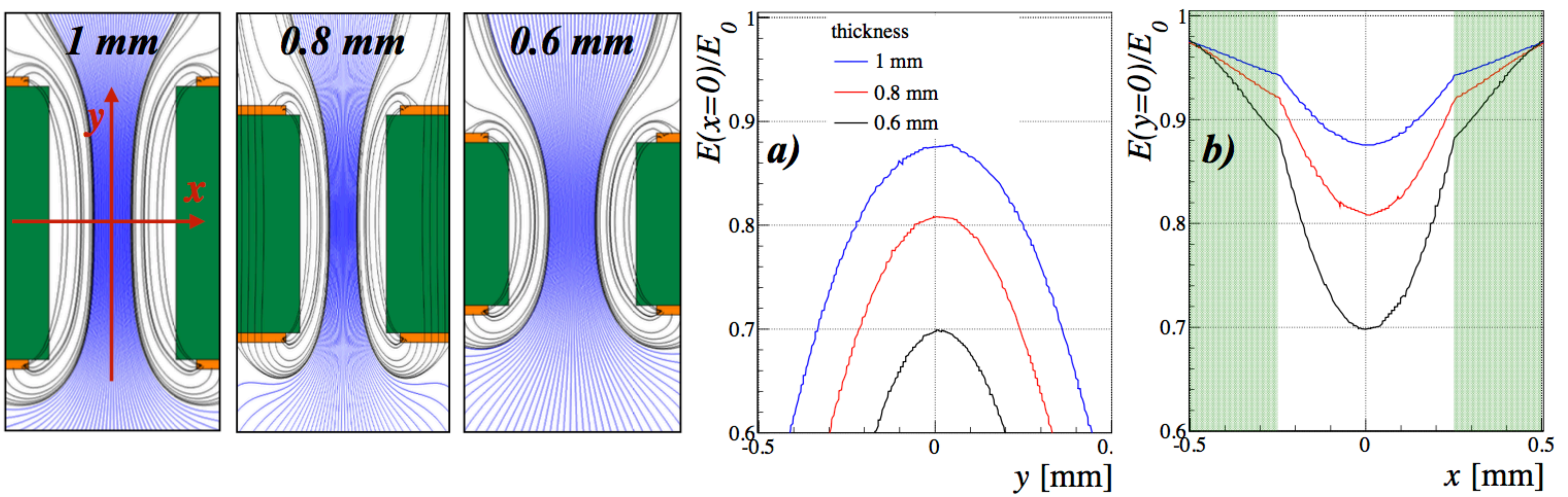
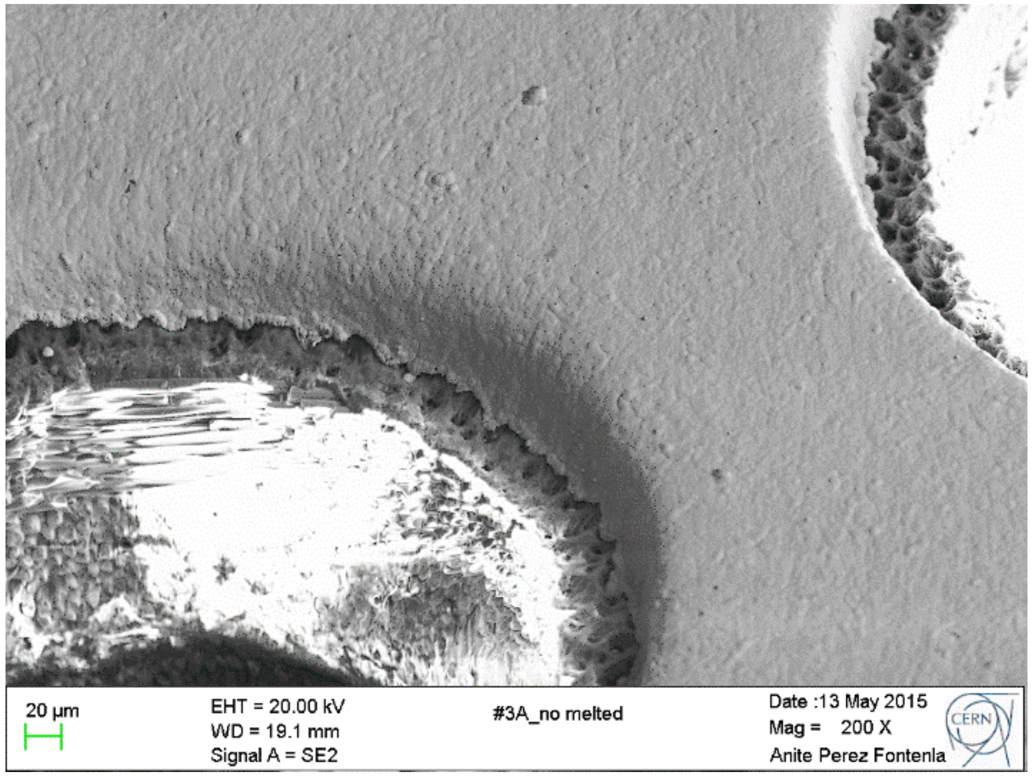
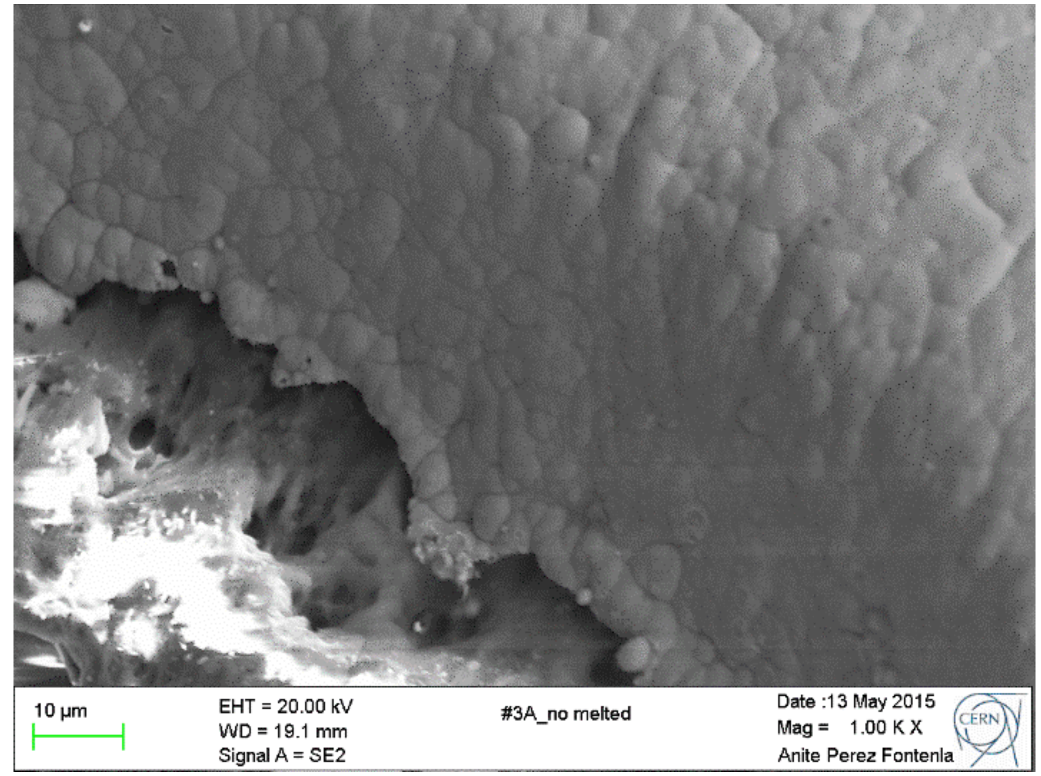
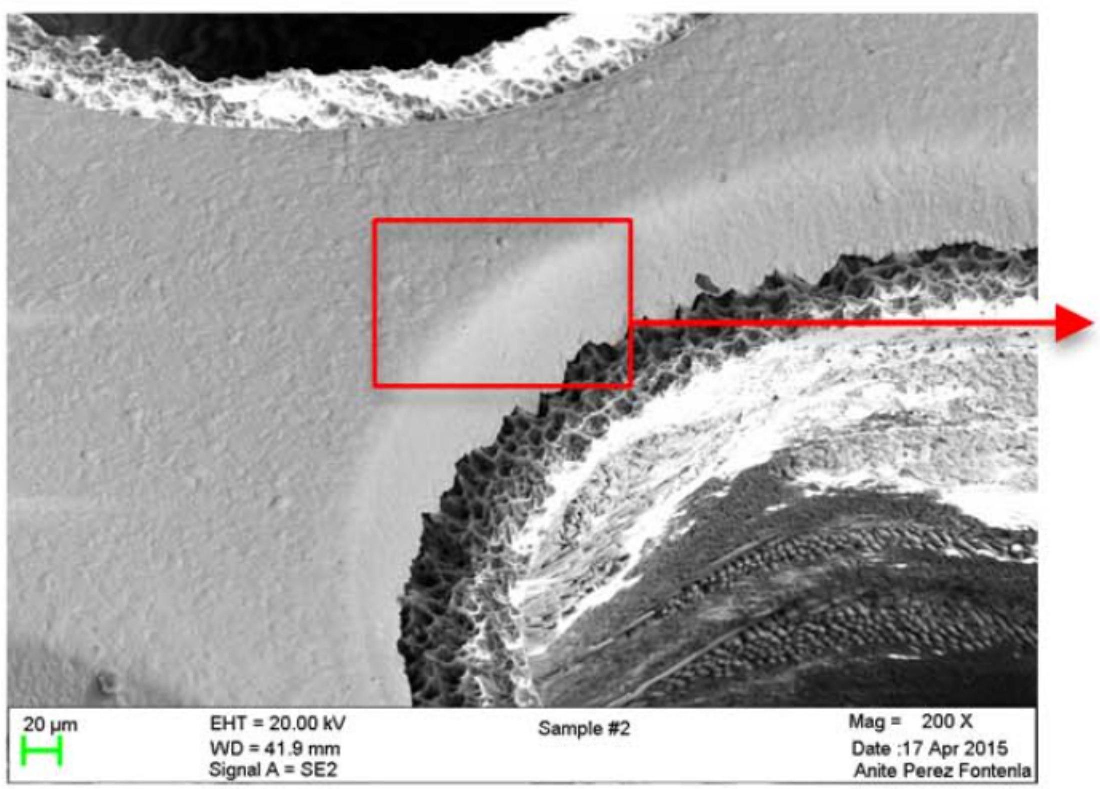


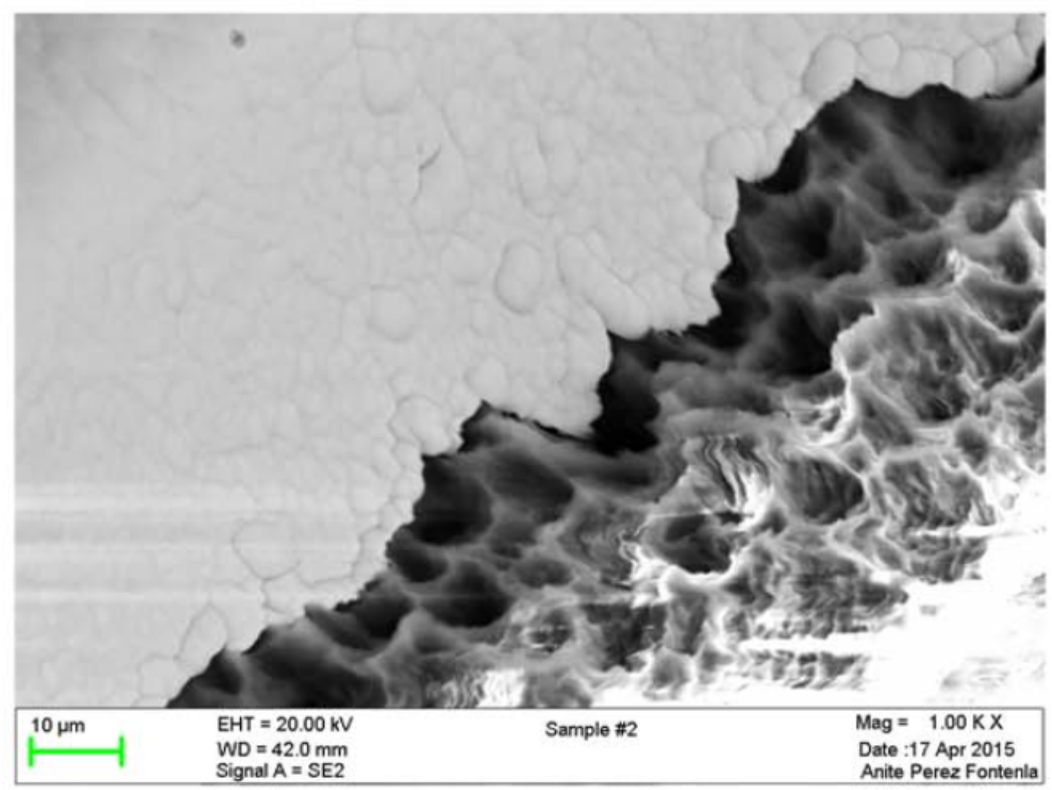
50x50


20 µm
EHT = 20.00 kV
WD = 19.1 mm
Signal A = SE2
#3A_no melted
Date :13 May 2015
Mag = 200 X
Anite Perez Fontenla
CERN

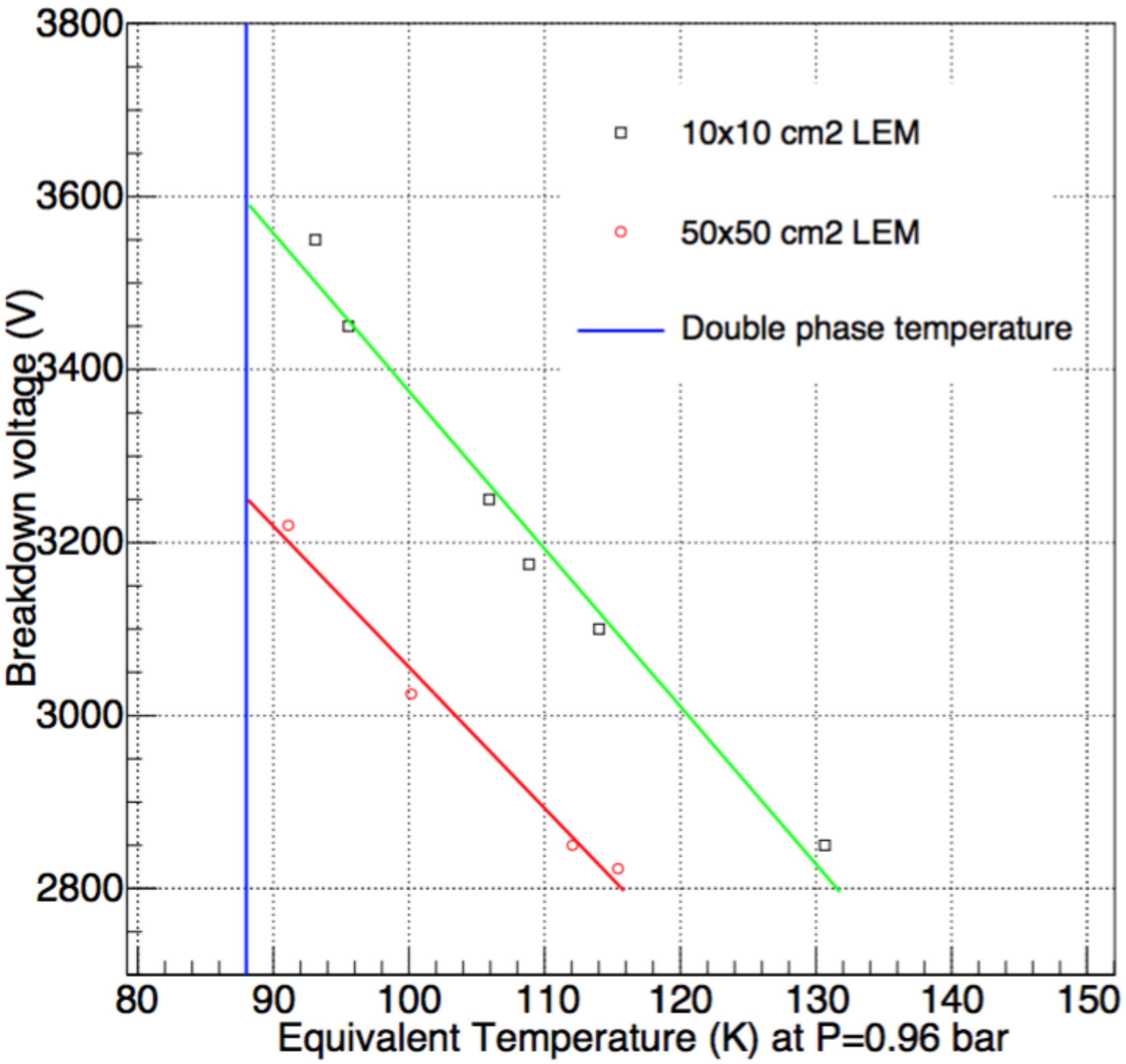

10 µm
EHT = 20.00 kV
WD = 19.1 mm
Signal A = SE2
#3A_no melted
Date :13 May 2015
Mag = 1.00 K X
Anite Perez Fontenla
CERN

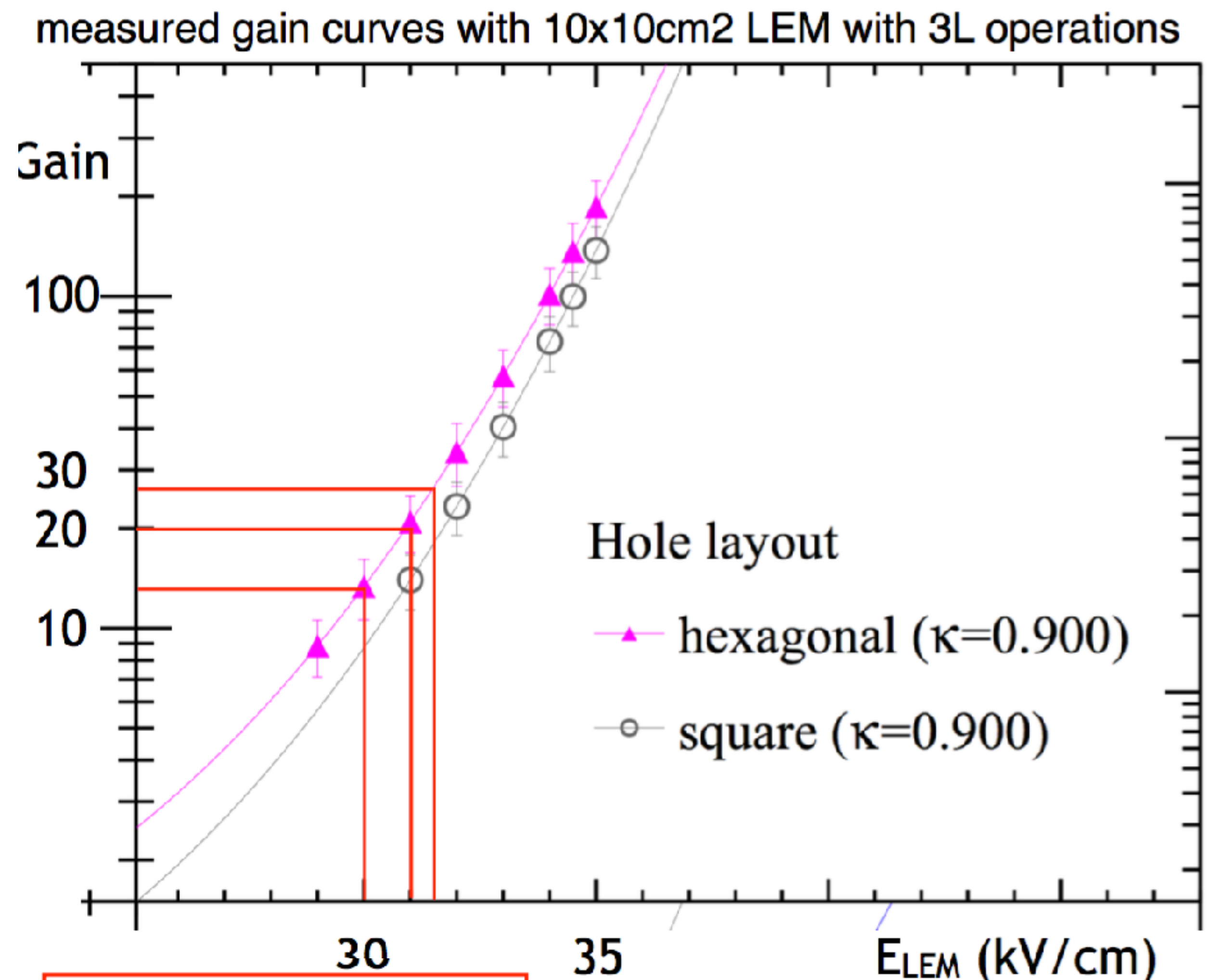
10x10


20 µm
EHT = 20.00 kV
WD = 41.9 mm
Signal A = SE2
Sample #2
Mag = 200 X
Date :17 Apr 2015
Anite Perez Fontenla


10 µm
EHT = 20.00 kV
WD = 42.0 mm
Signal A = SE2
Sample #2
Mag = 1.00 K X
Date :17 Apr 2015
Anite Perez Fontenla

Latest results 50x50 LEMs in cold Argon

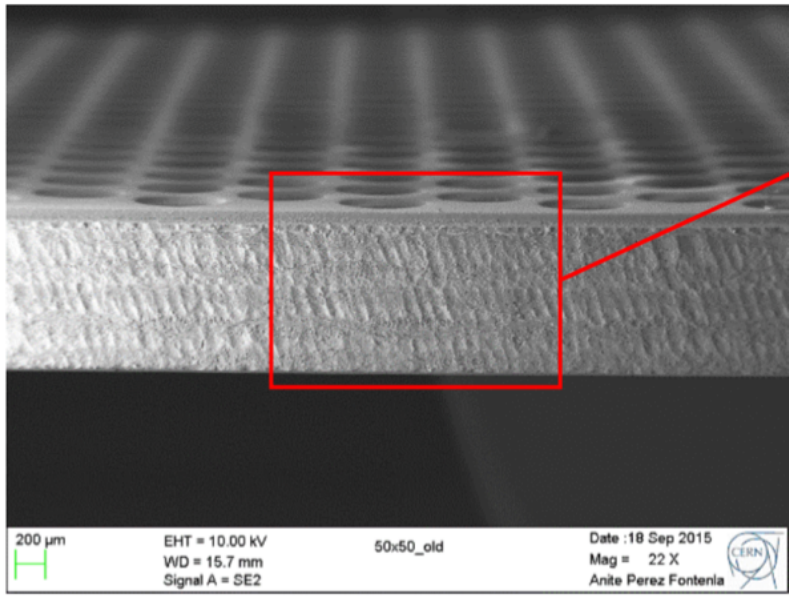


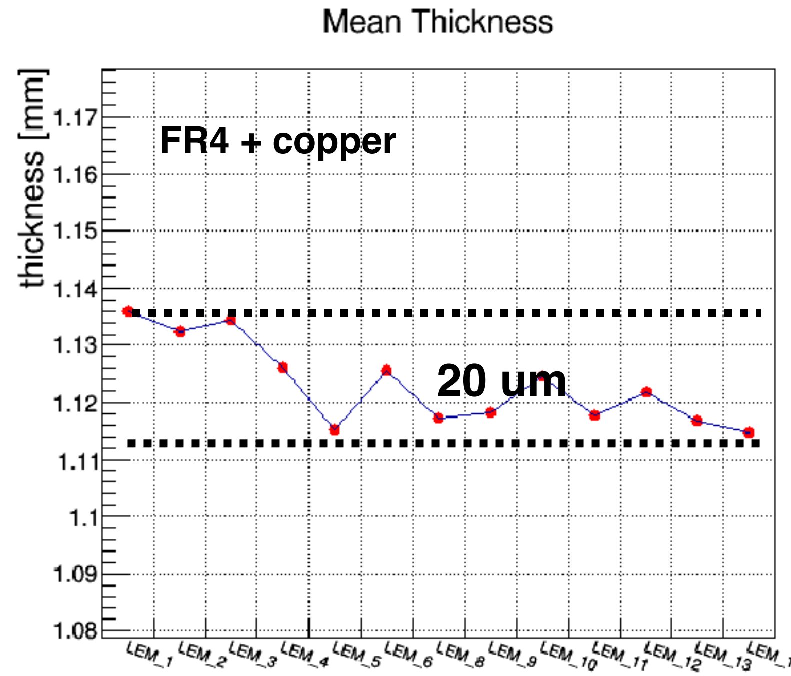


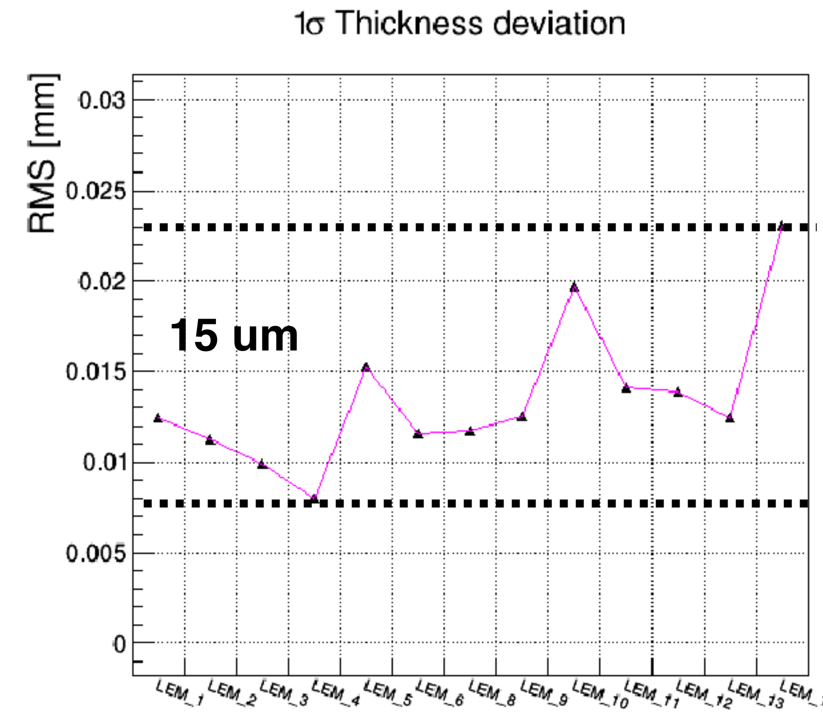
V_{LEM} (V)	Initial Gain
3000	15
3100	20
3150	25

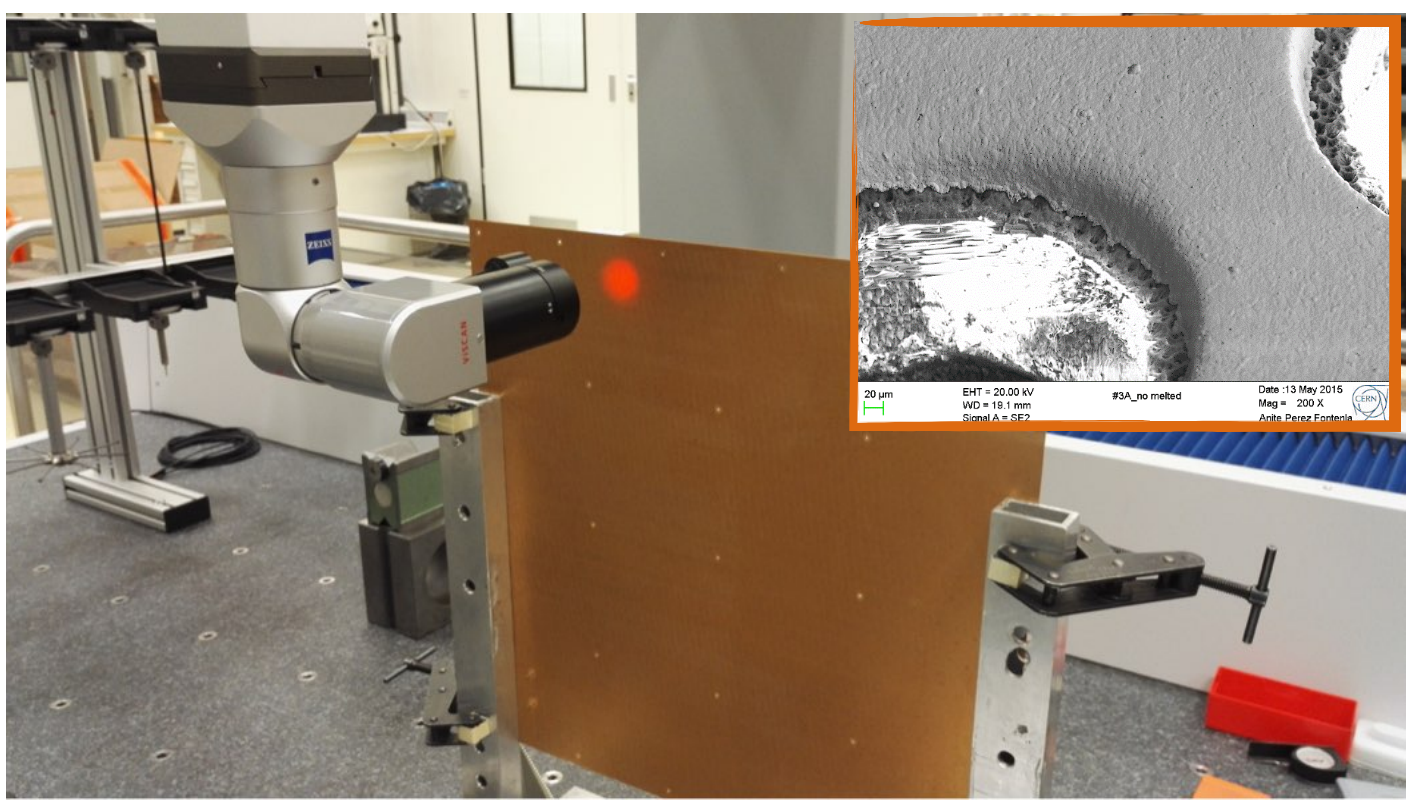
- **Successful LEM operations at 3100V - 3150V corresponding to gain of 20-25**. Need to study effect of charging up.
- **$V_{Breakdown}$ ~ 3250V at T 88K and P 0.96 bar for 50x50 LEM** corresponding to a gain 30 achievable in very stable T,P conditions (as expected in real dual phase operation)

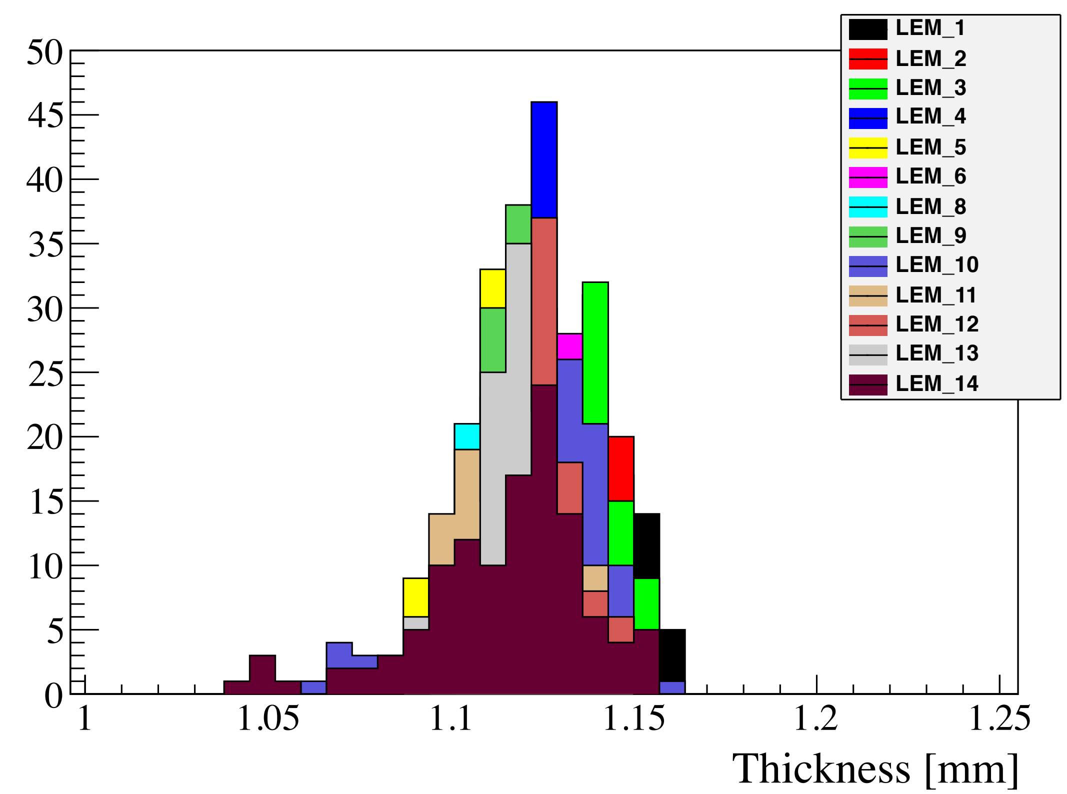
LEM thickness measurement



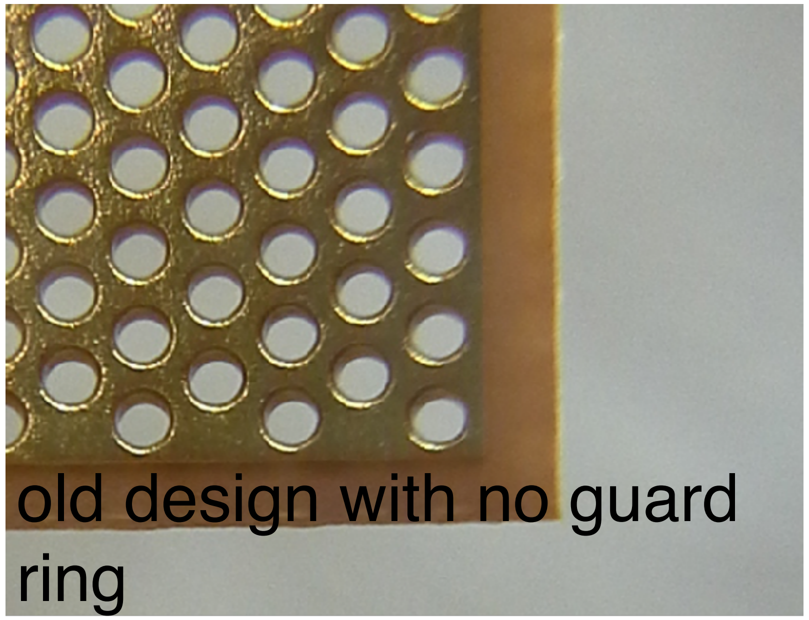


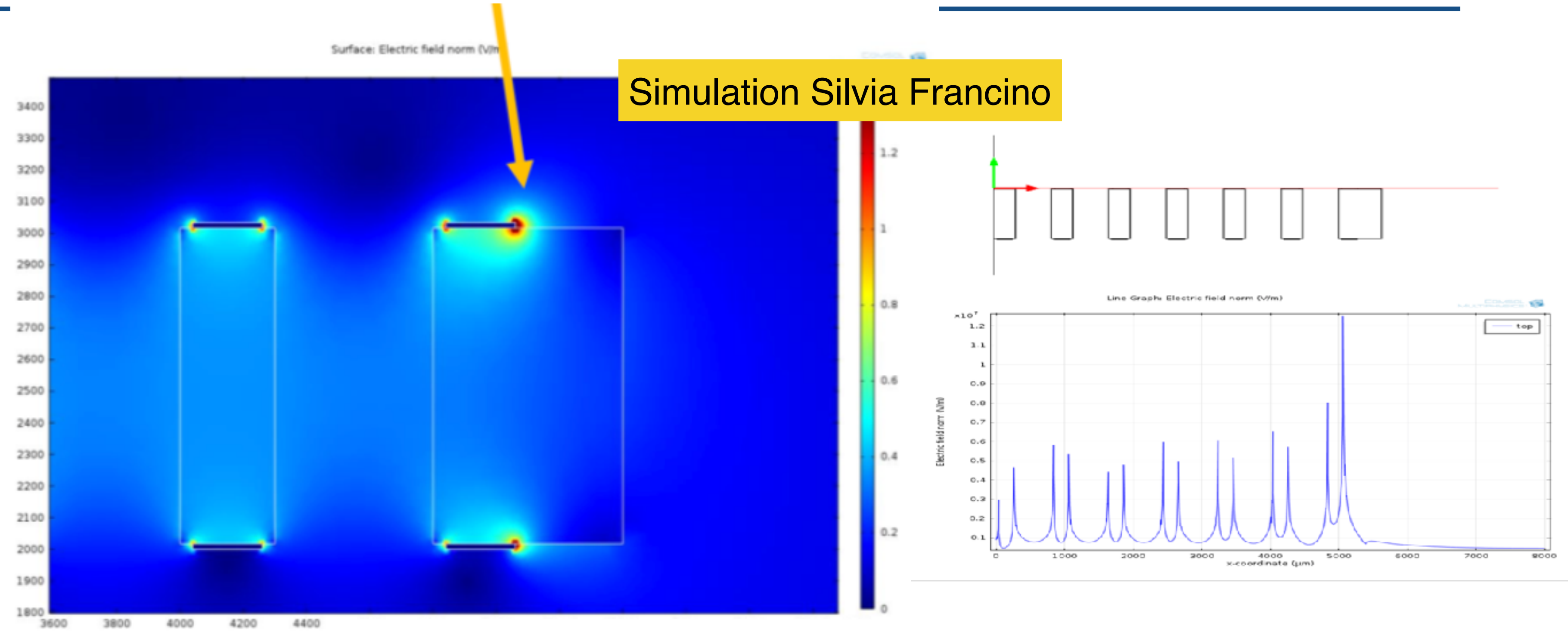


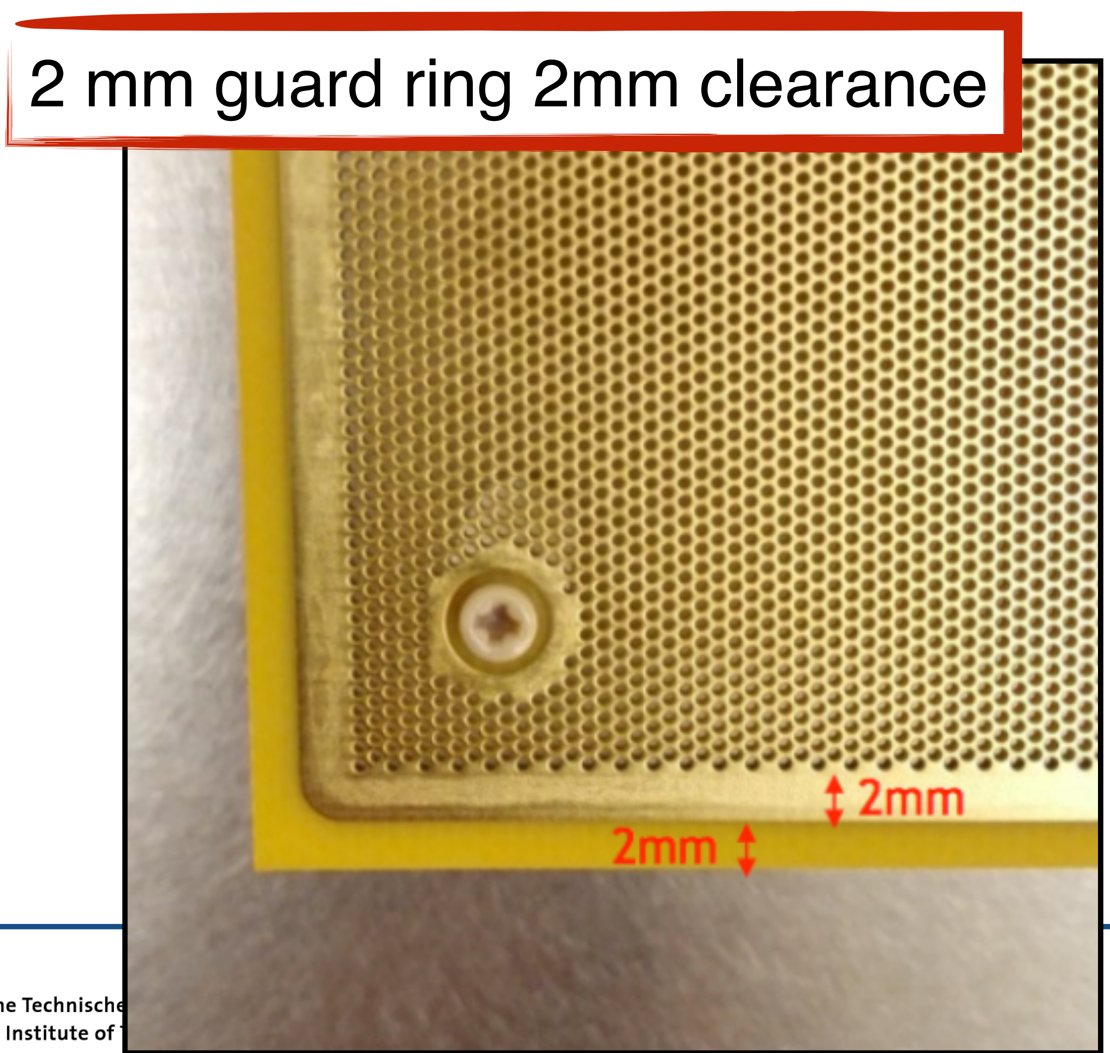


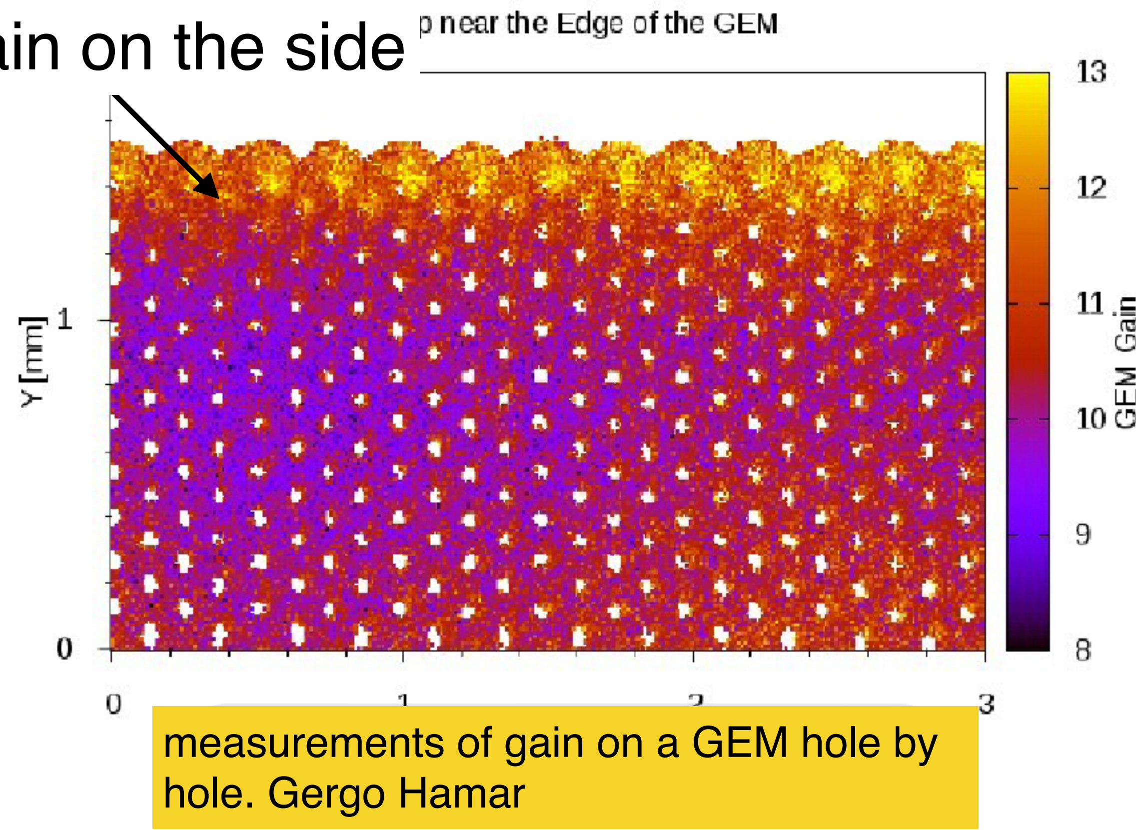


LEMs with guard ring









LEM HV contact

WA105

Requirements:
- As small as possible – minimize the dead space
- Decoupled from the cable to the HV feed-through – robust
- Insulation medium (dielectric strength > 10 kV/mm) – avoid discharge

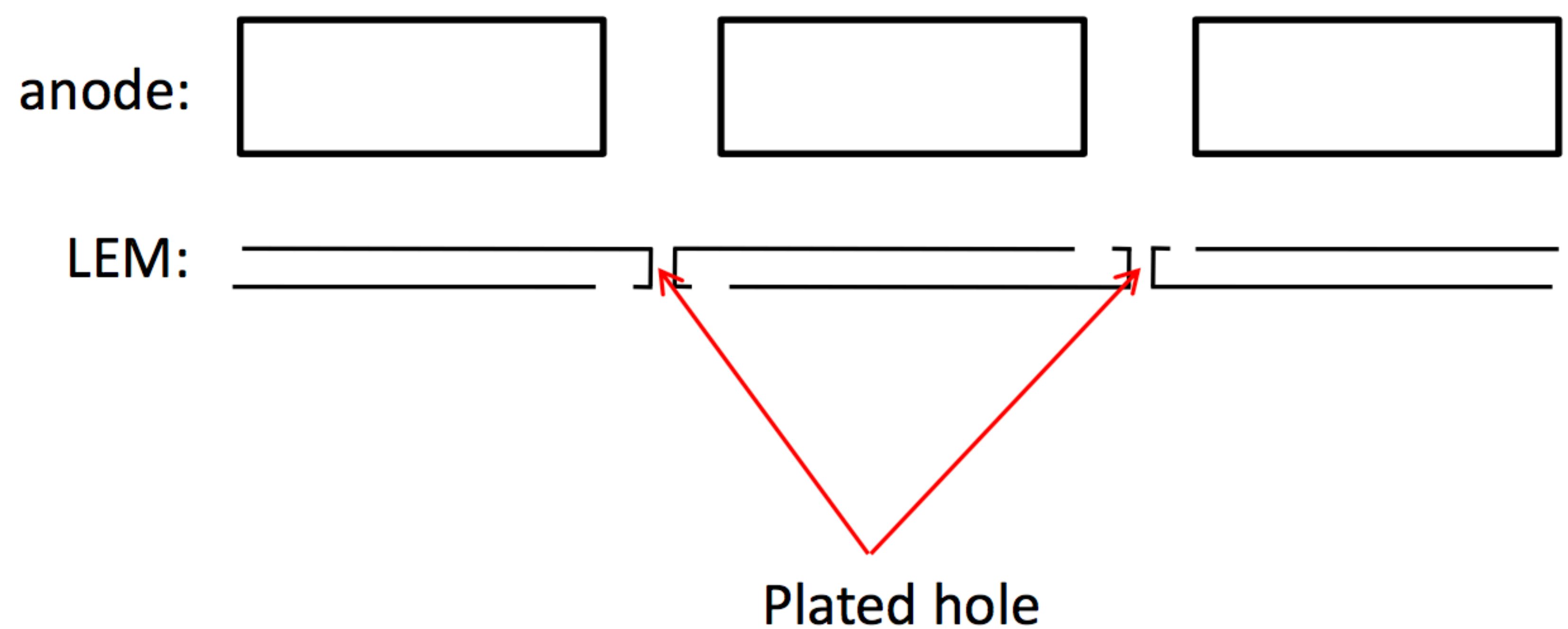
Smallest pin ever found:

Male:

Female:

Together:

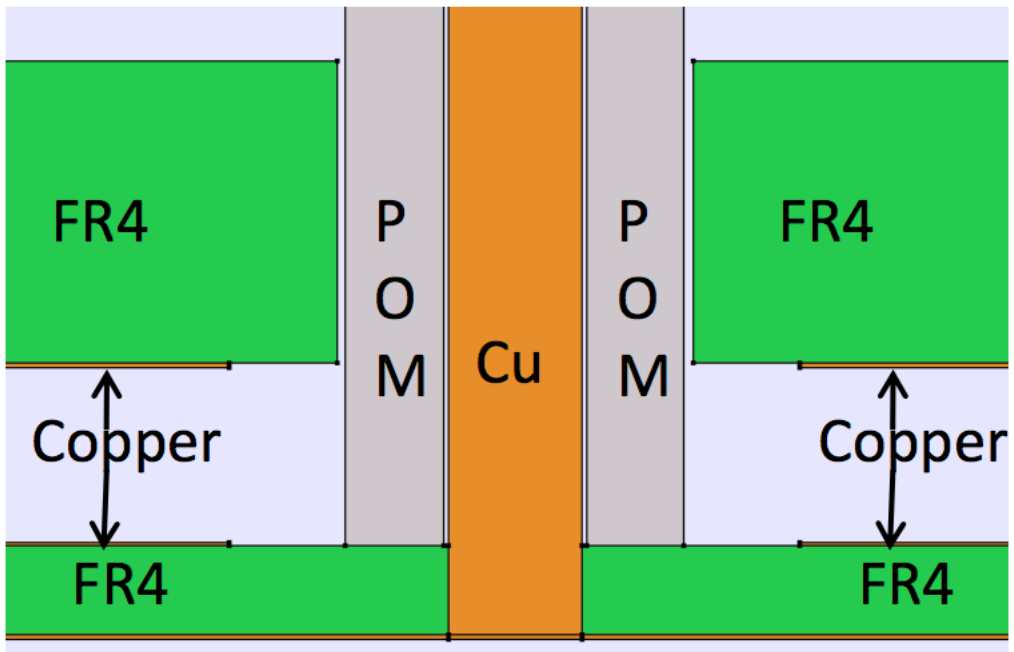
Contact concept:



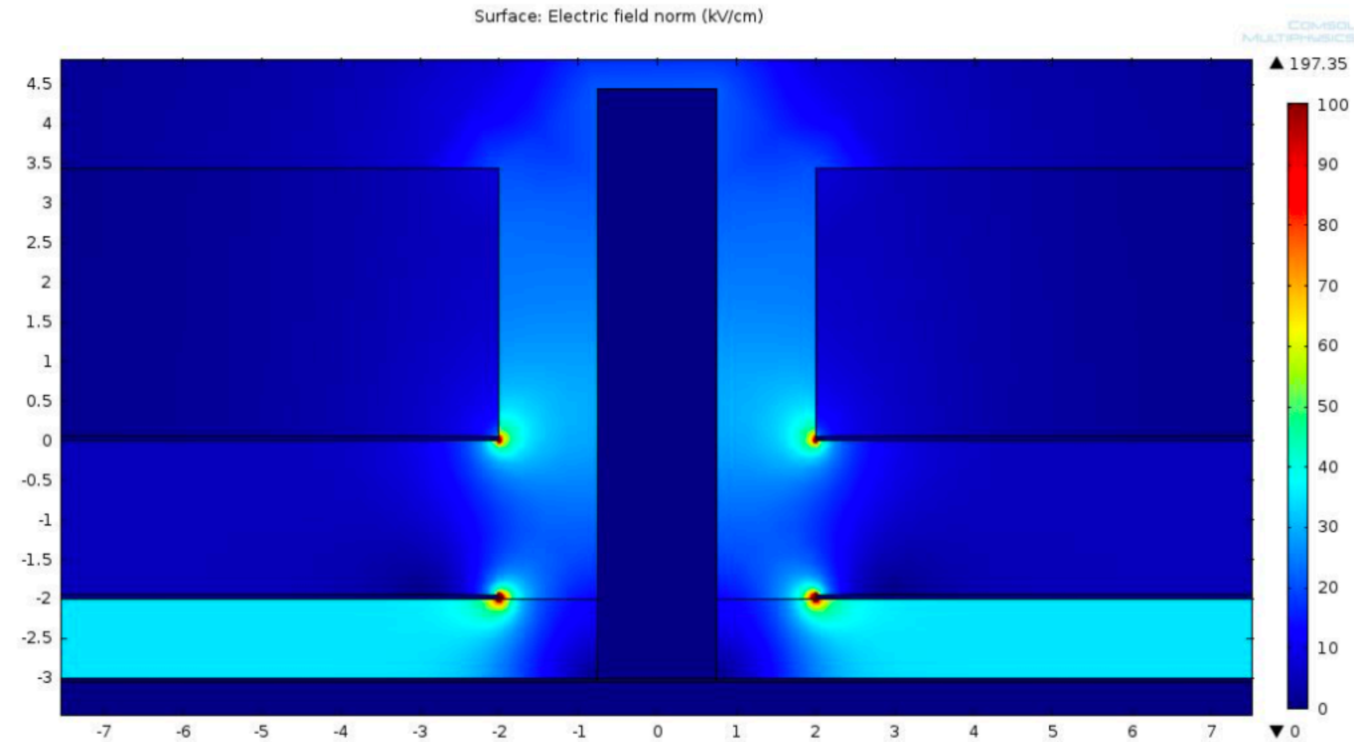
LEM HV contact

WA105

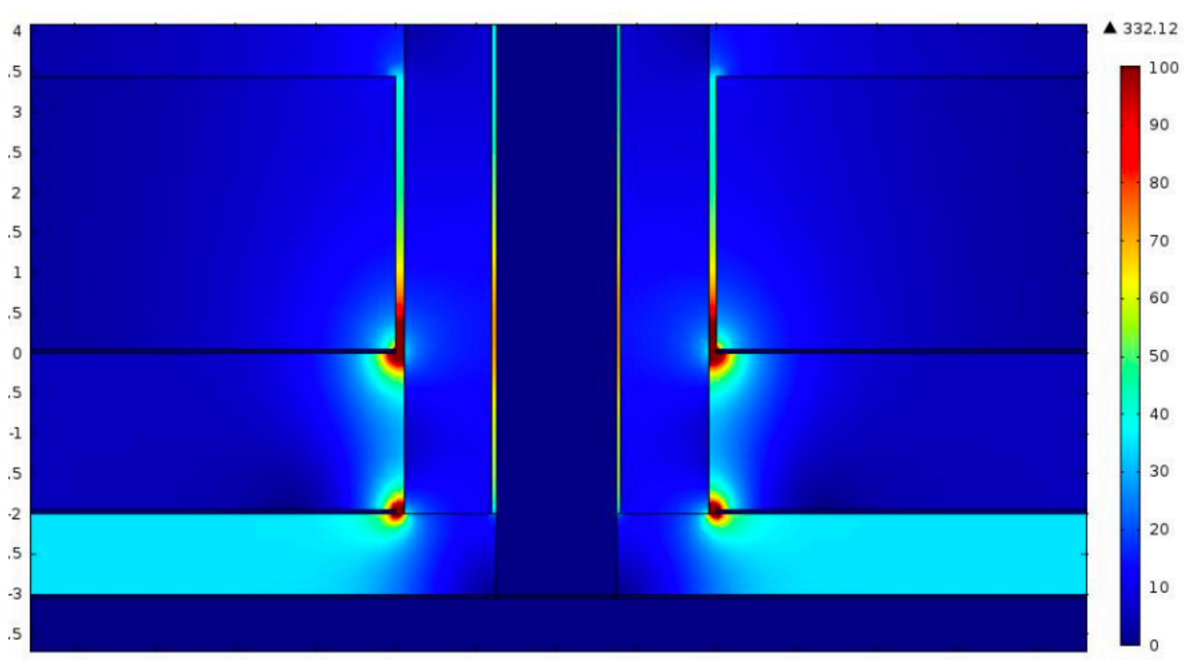
Geometry:



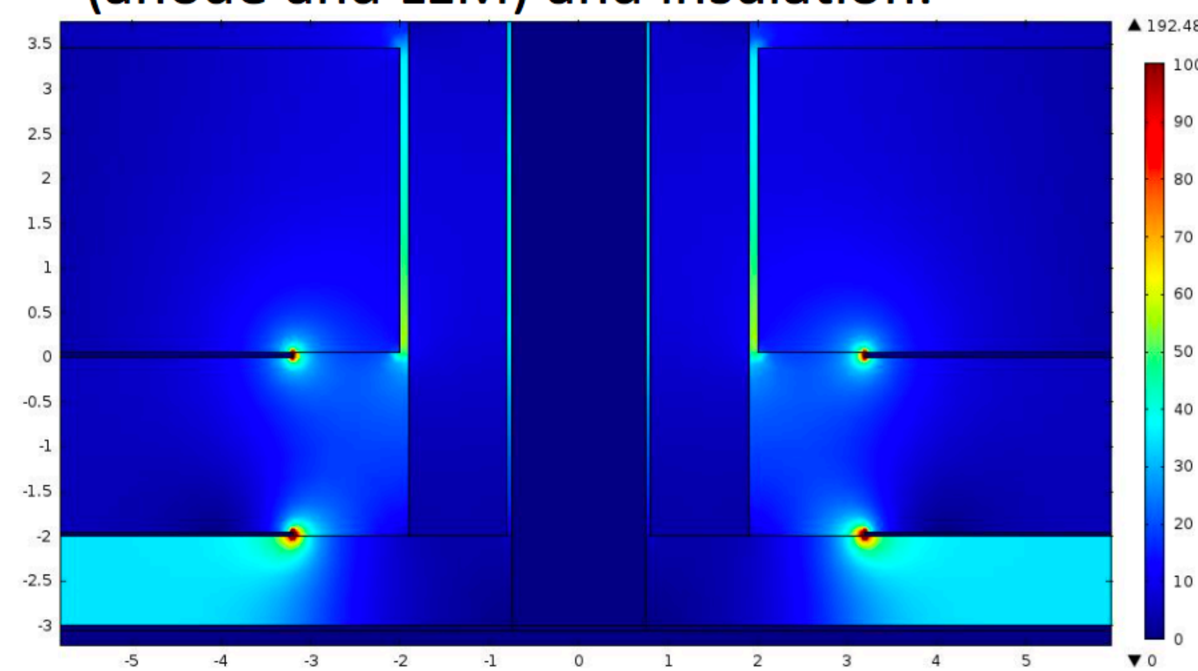
Without insulation:



With insulation:

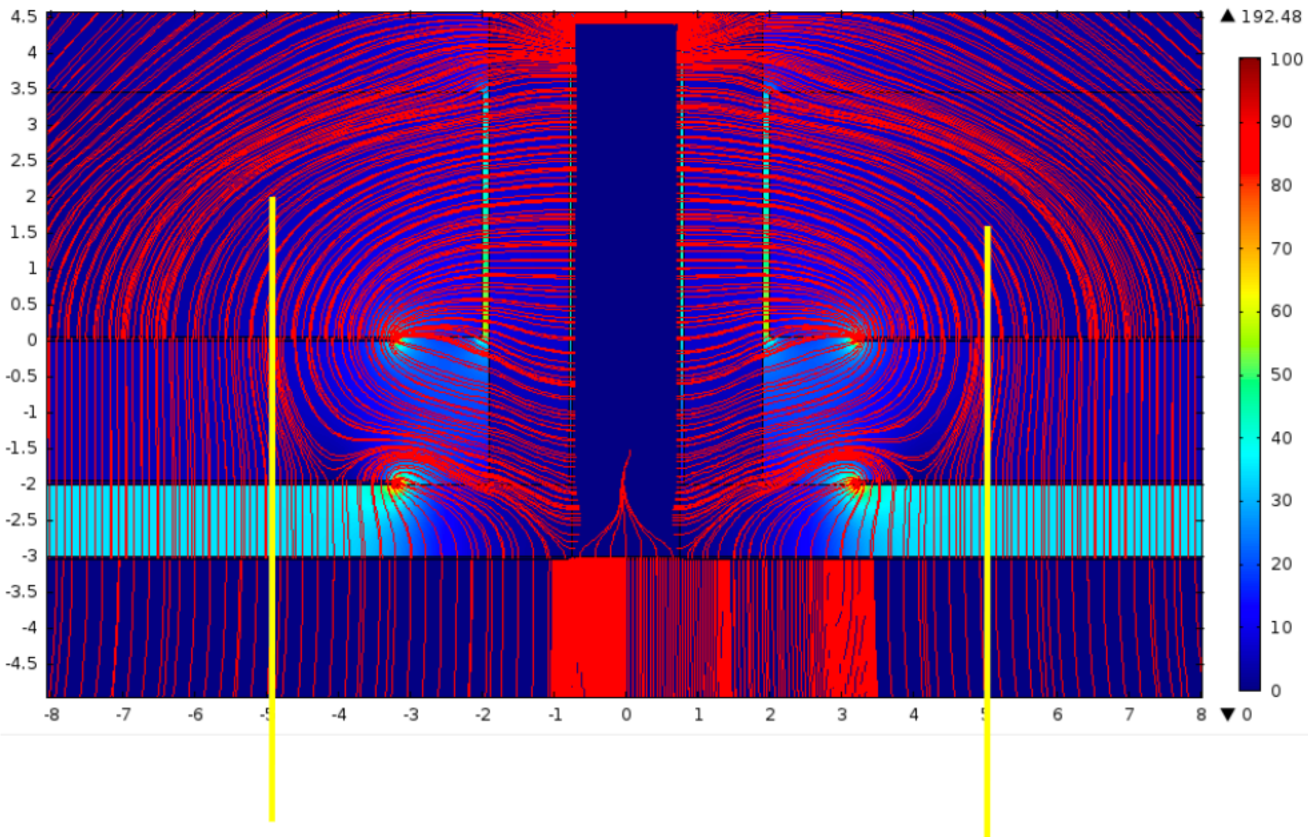


Keep 1mm spacing between copper (anode and LEM) and insulation:

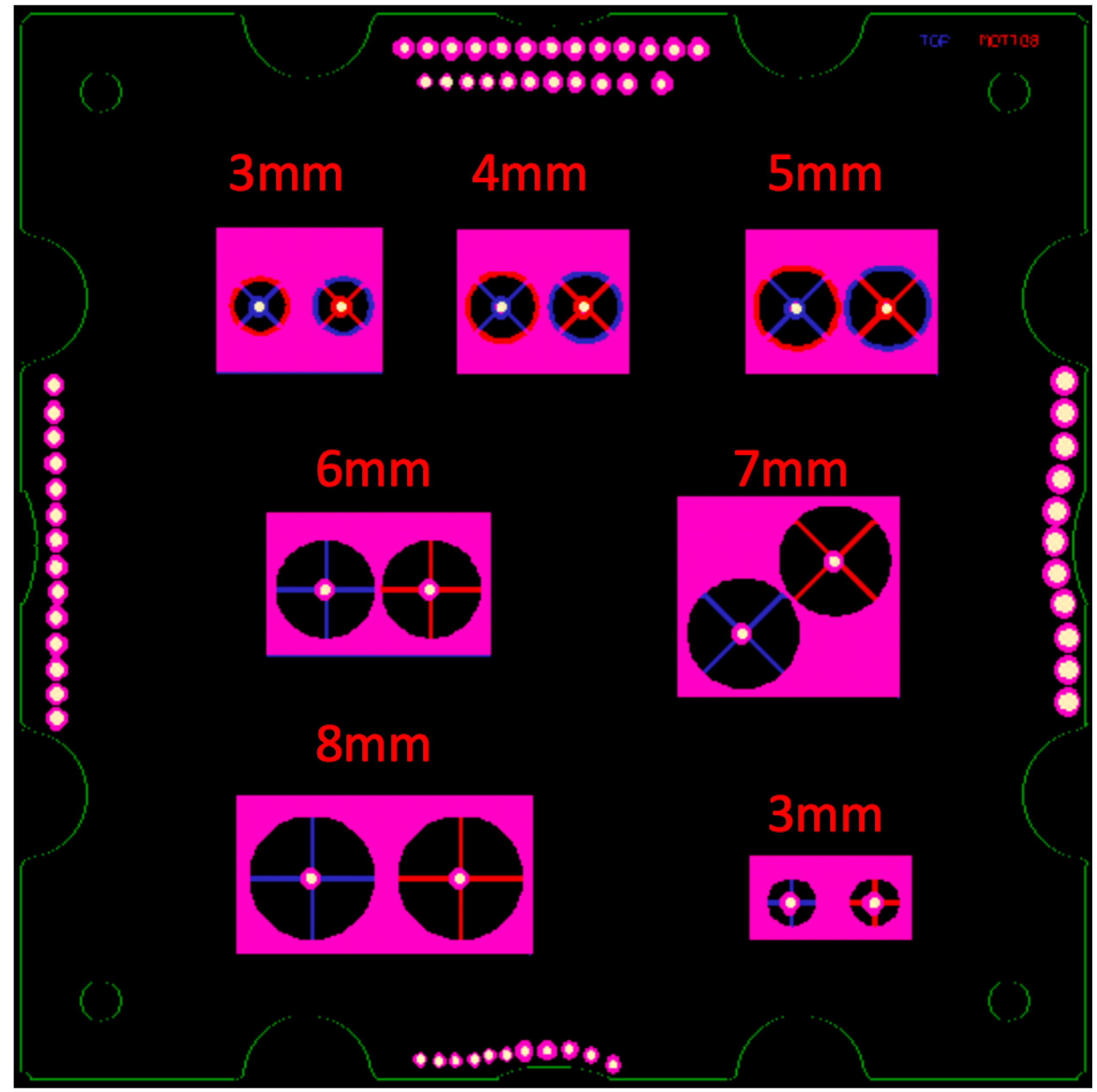


LEM HV contact

Field distortion within 1x1 cm2



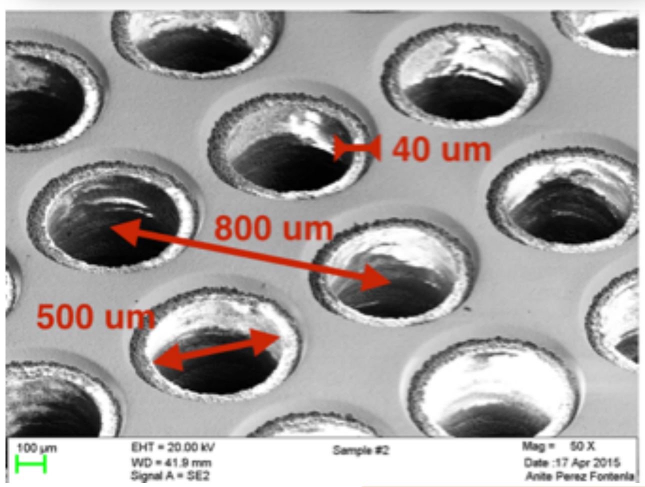
Test PCB:



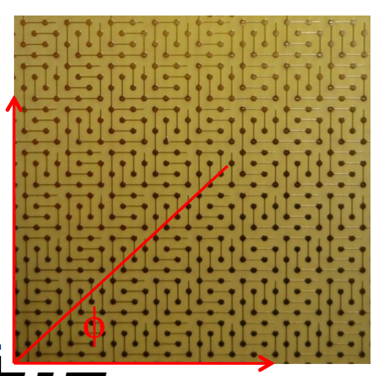
Outcome of 10 years of R&D

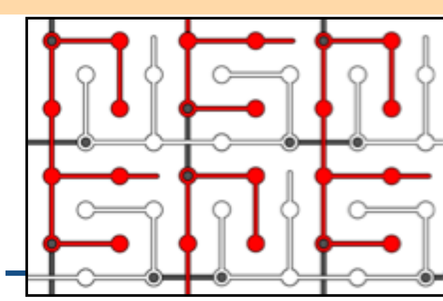
WA105

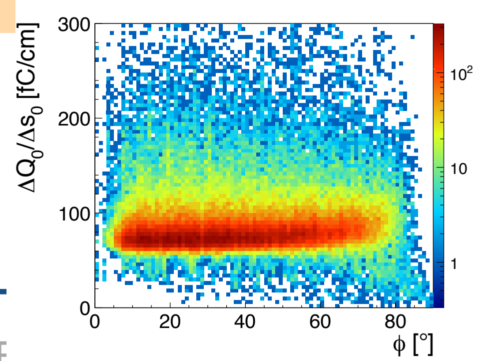
10x10cm^2: LEM/anode R&D



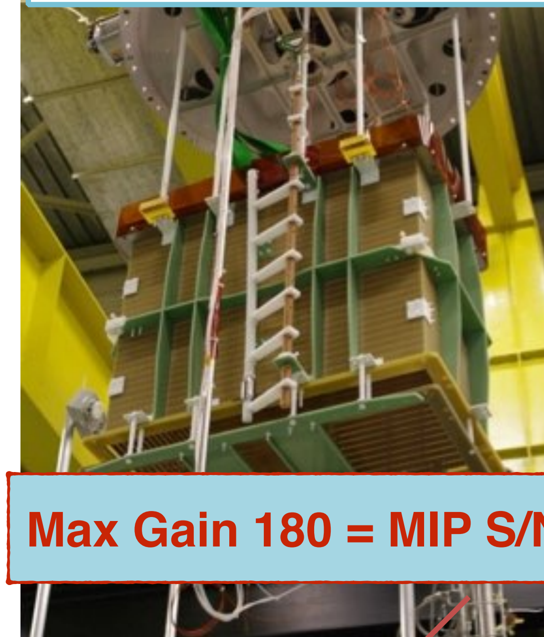
dC/dl ~ 120 pF/m

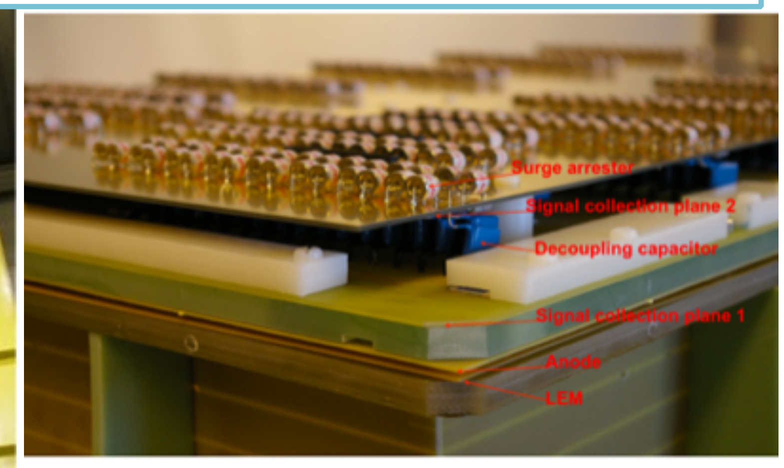




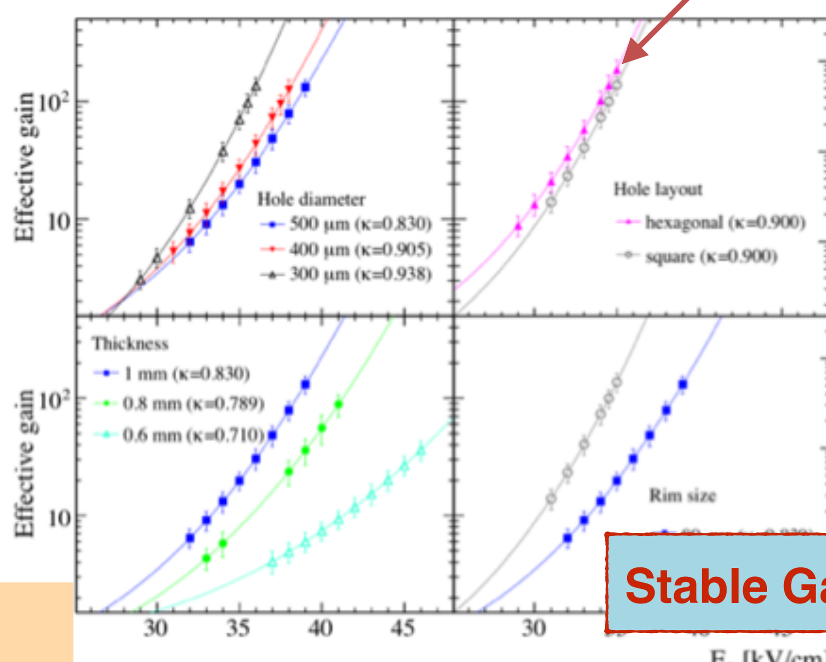


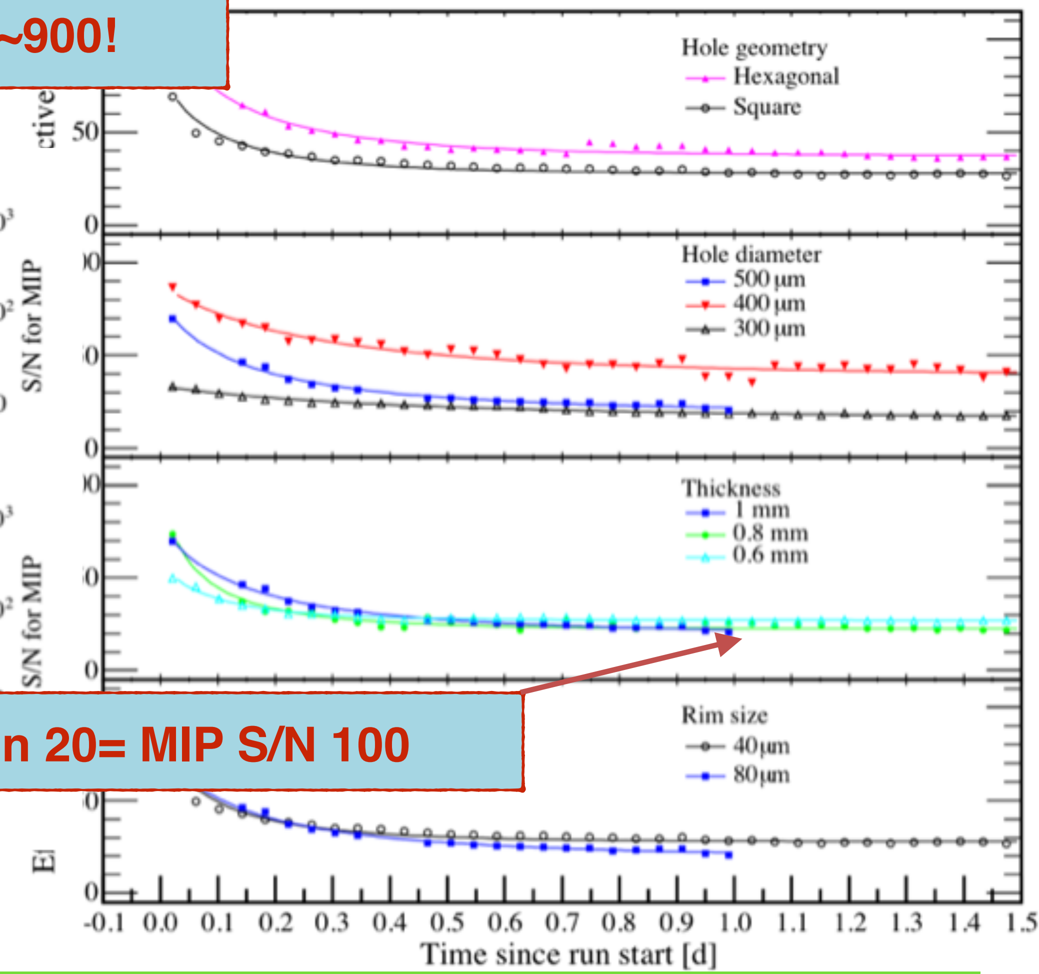
40x80cm^2: stable operation of large area readouts





Max Gain 180 = MIP S/N ~900!



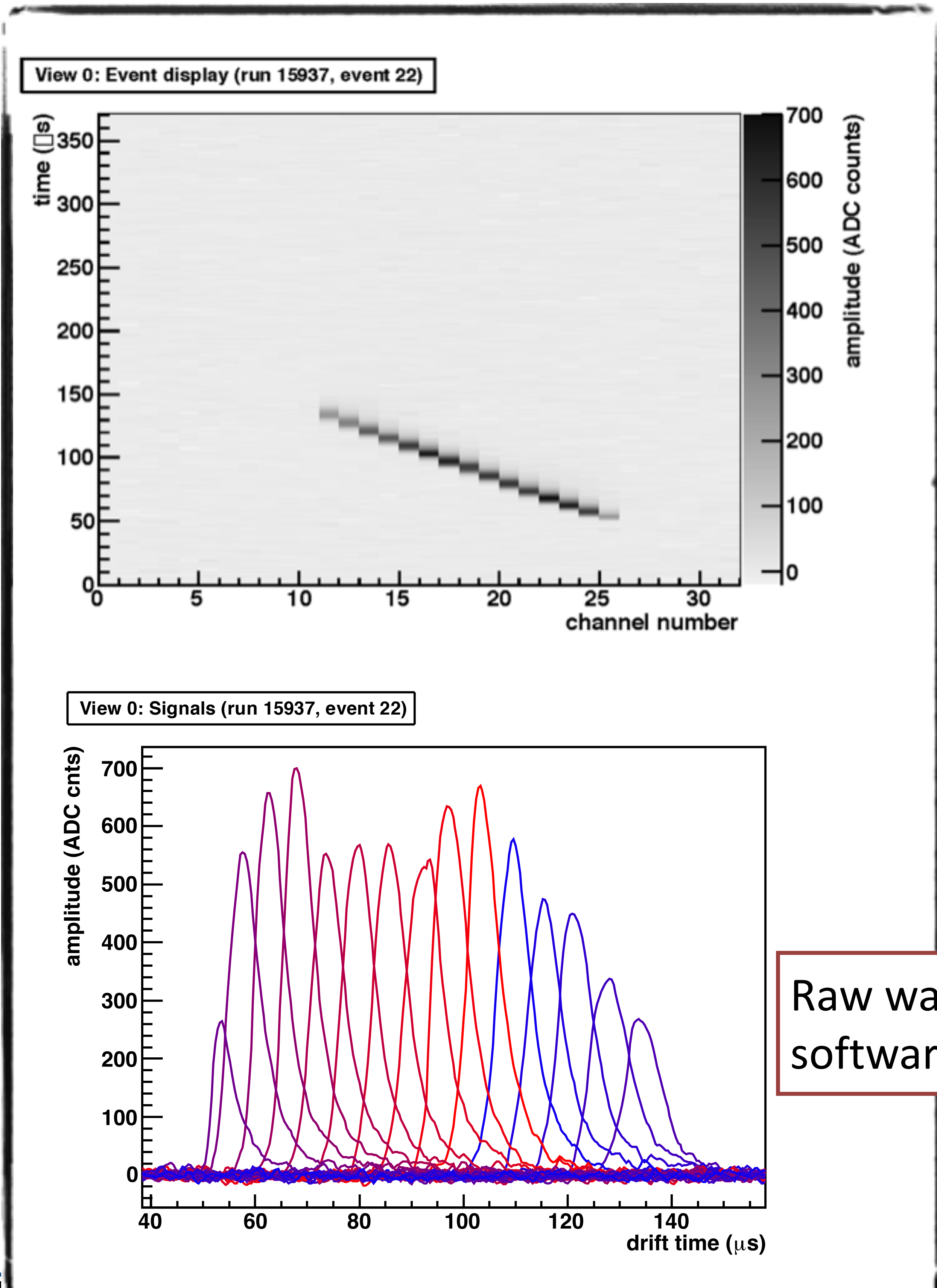


Stable Gain 20= MIP S/N 100

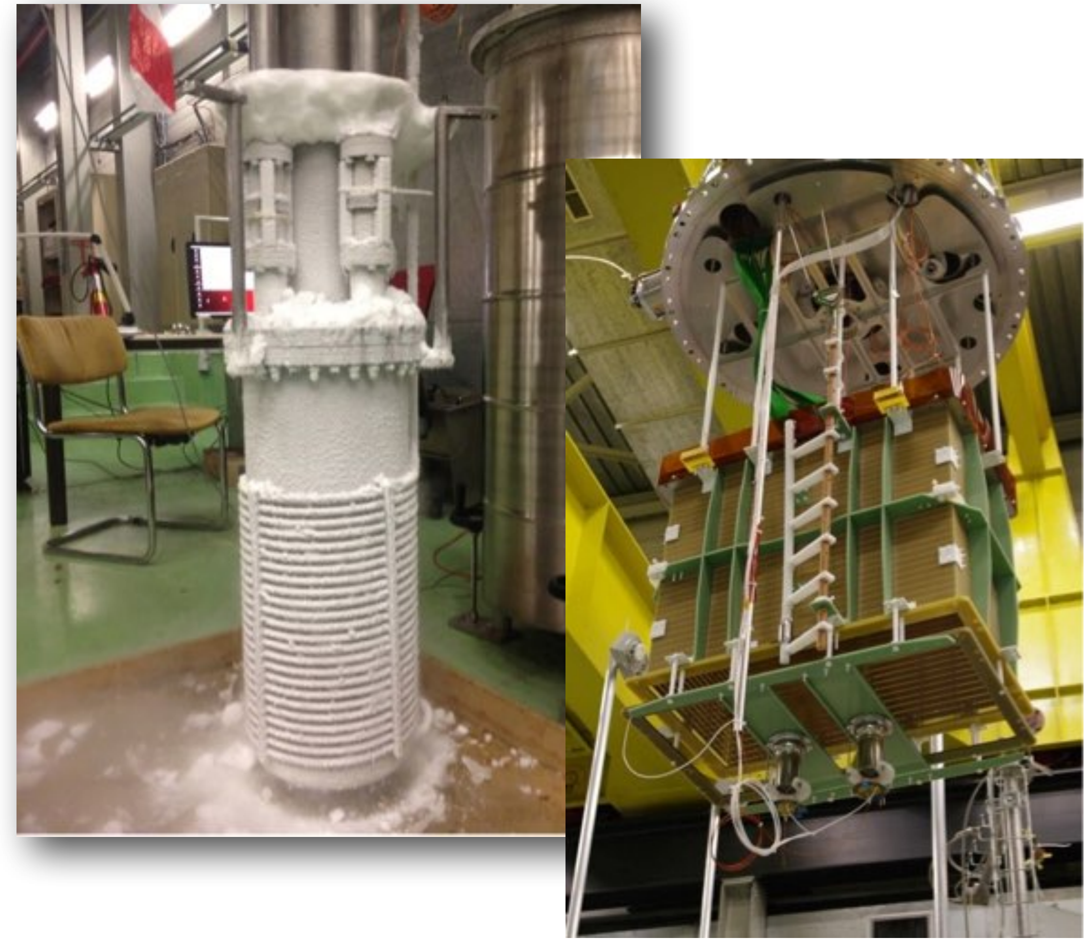
Operating with amplification of about a factor 20

Dual phase readout

WA105



Raw waveform no software filtering

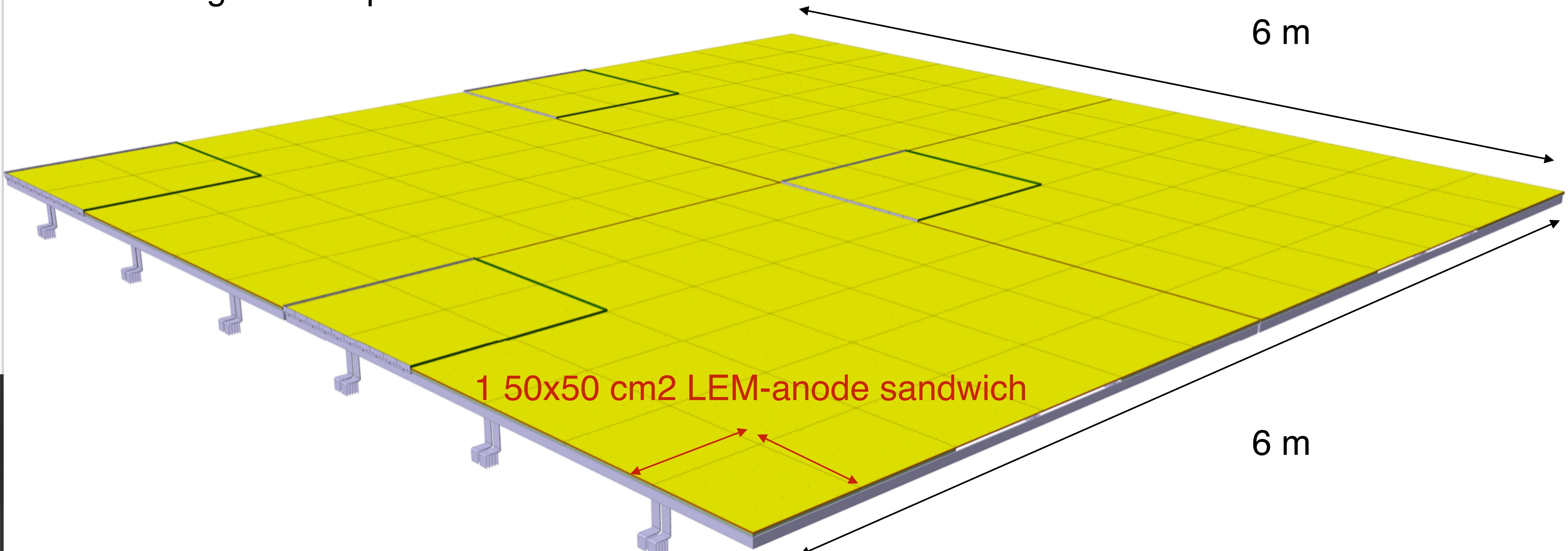


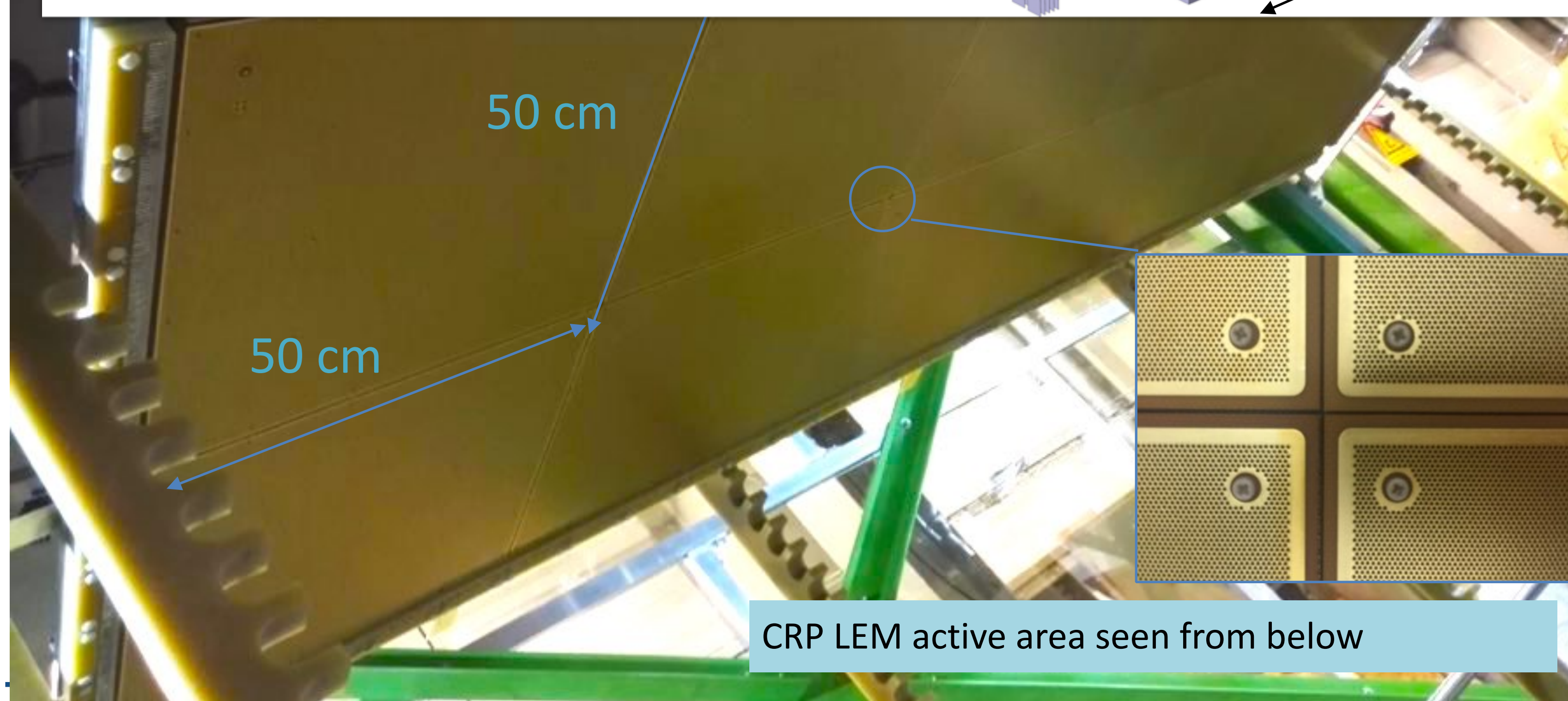
real events on 250 liter LAr dual phase TPC

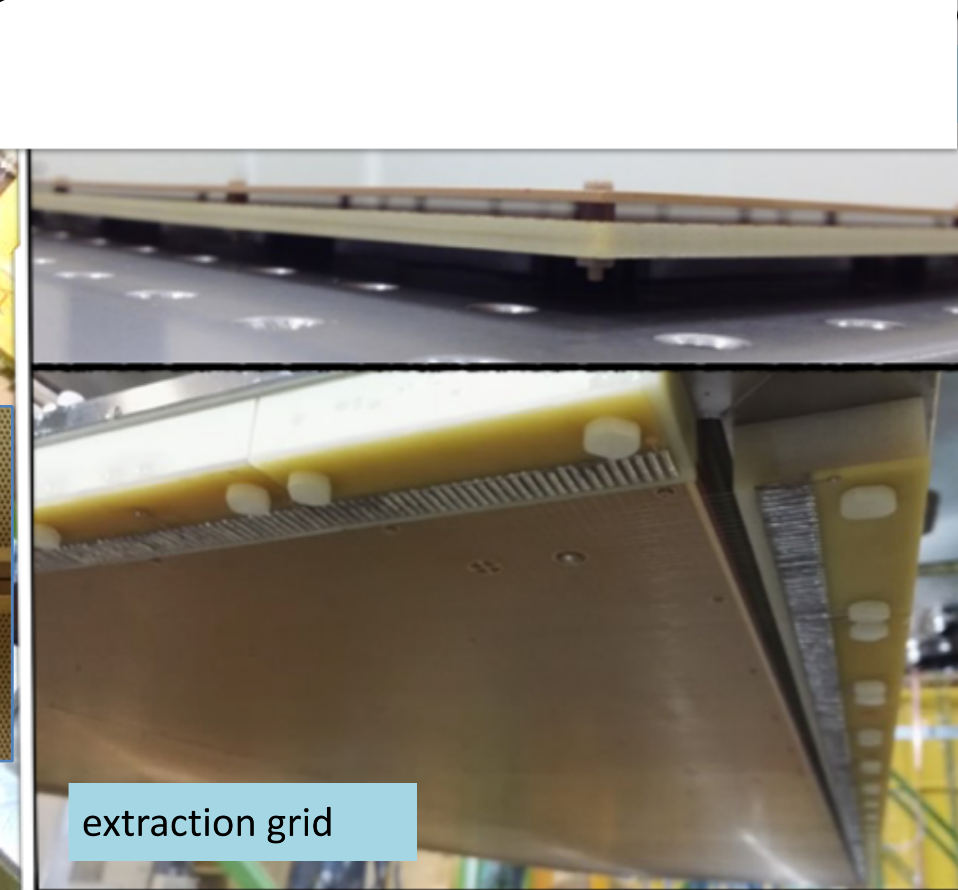
literature
NIM A617 (2010) p188-192
NIM A641 (2011) p 48-57
JINST 7 (2012) P08026
JINST 8 (2013) P04012
JINST 9 (2014) P03017
JINST 10 (2015) P03017

CRP 3x1 m2 -> 3x3 m2

same design for the protoDUNE DP







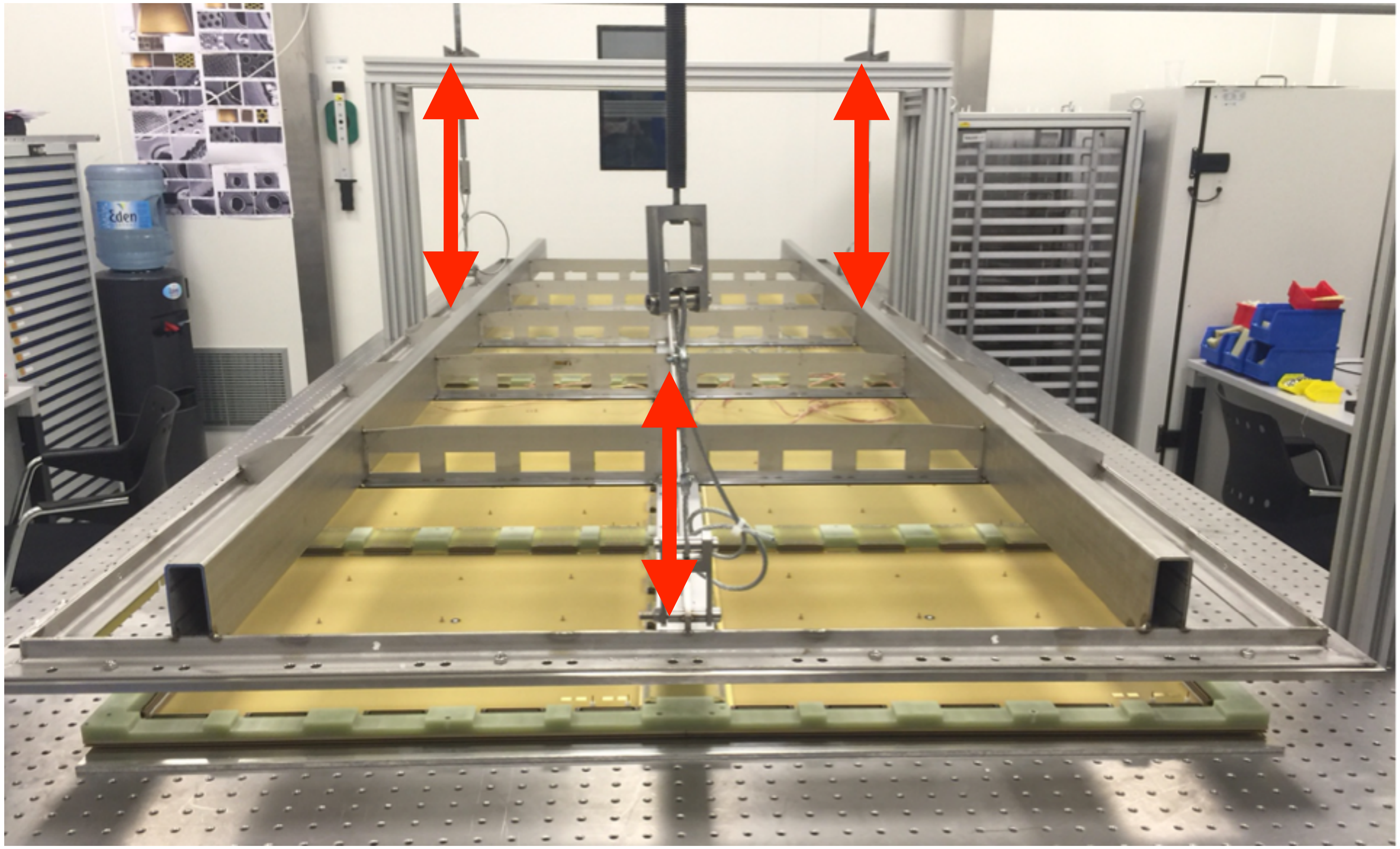
Charge Readout Plane

WA105

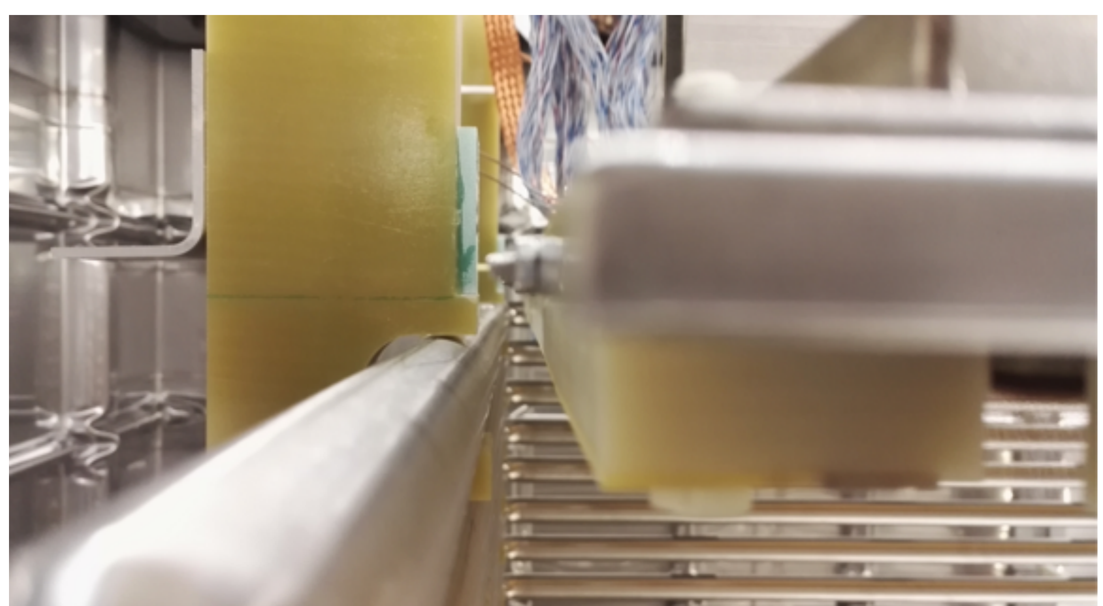
- Fully assembled CRP, partly instrumented and dipped in LAr with photogrammetric targets
- -><u>check resistance to thermal shock and planarity at cold as well as signal continuity.</u>

3x1 m2 CRP suspended in an LN2 bath- for flatness measurements (photogrammetry) and contacts in cold

CRP: adjustable to LAr level

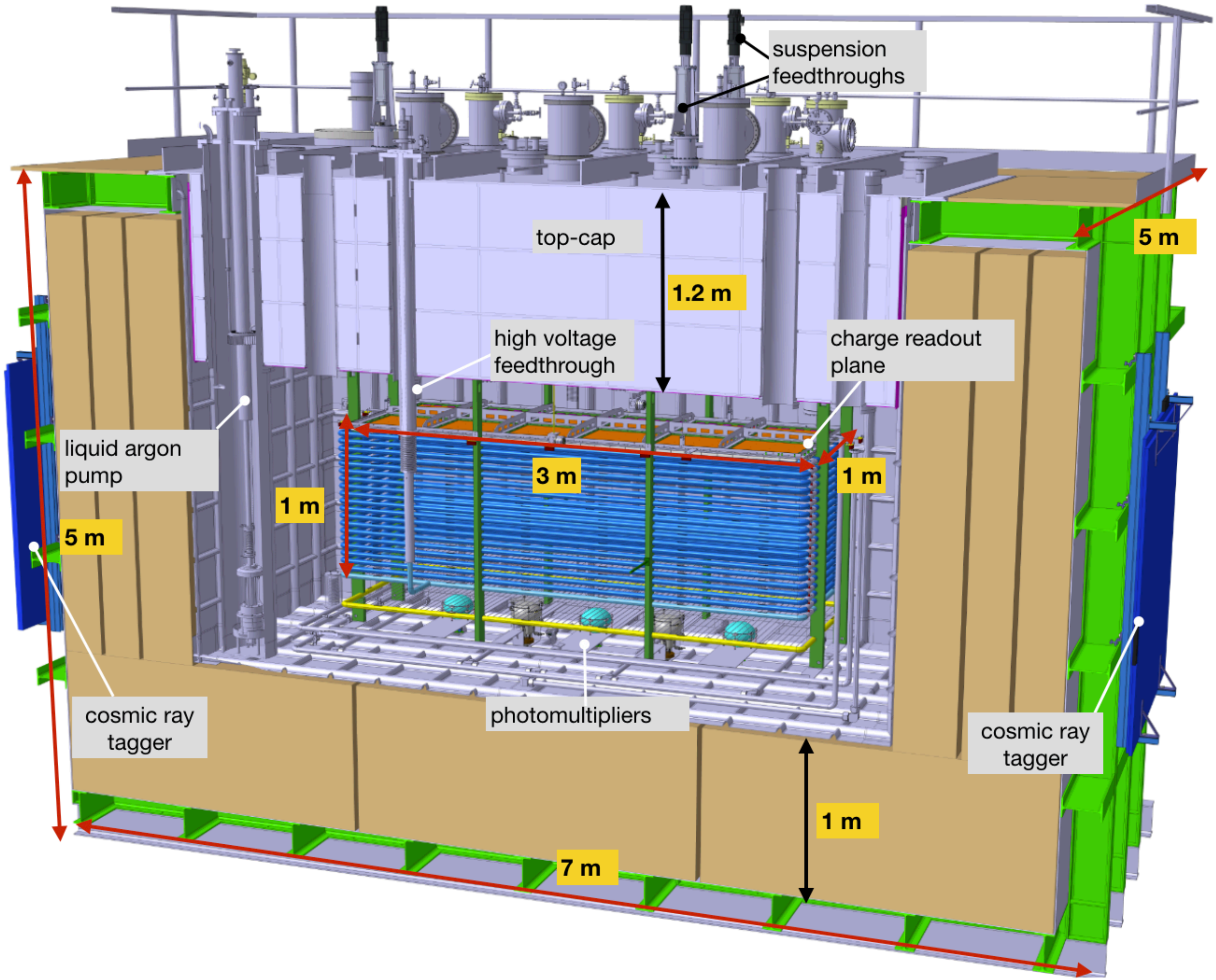


tested and validated for protoDUNE-DP



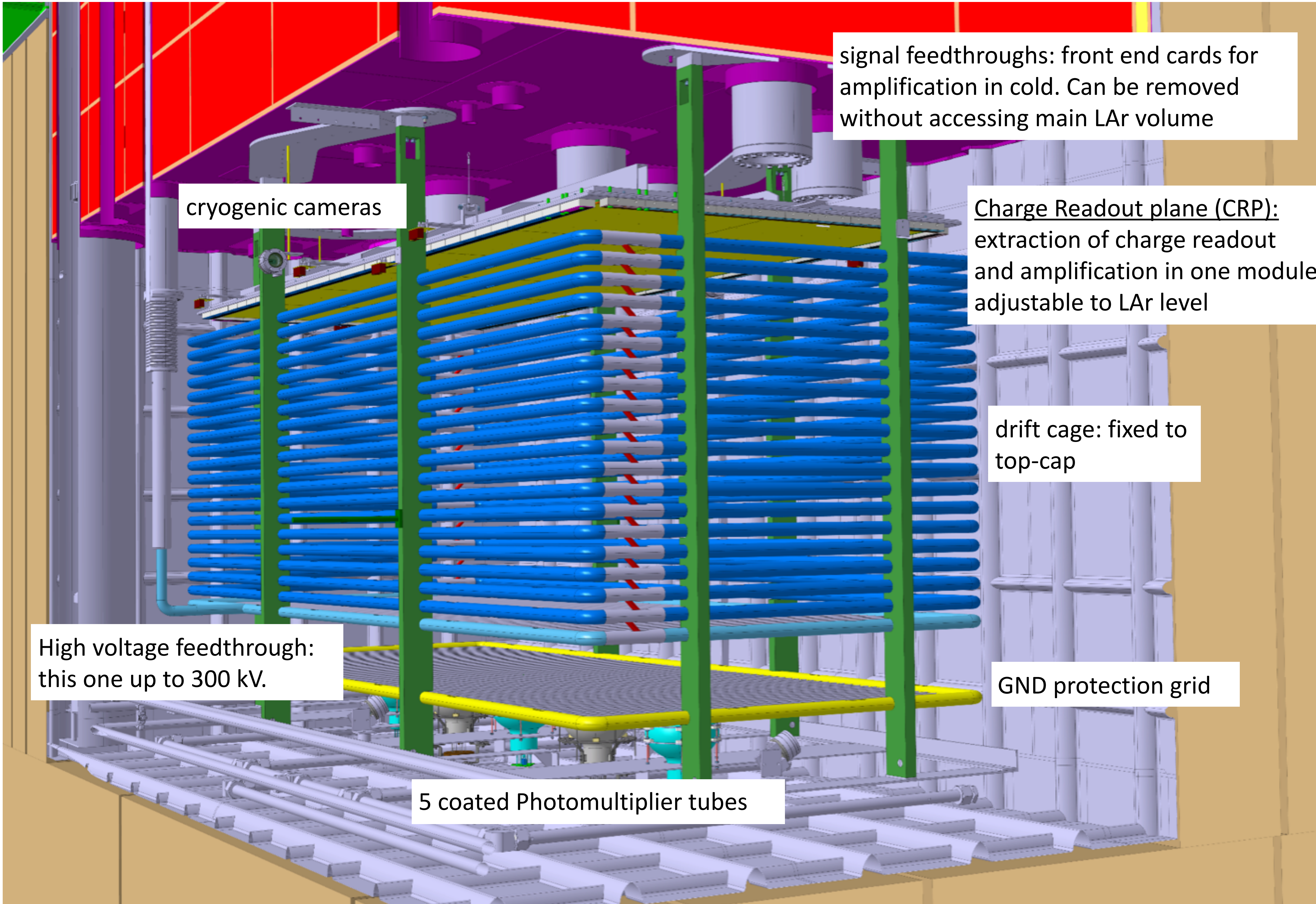
suspended by 3 ropes coupled to motors on top-cap. Precision of motors <u>100 um over 4 cm</u>.
8 capacitive level meters readout the LAr level with similar precision

The 3x1x1


suspension
feedthroughs
top-cap
1.2 m
5 m
high voltage
feedthrough
charge readout
plane
liquid argon
pump
3 m
1 m
1 m
5 m
cosmic ray
tagger
photomultipliers
cosmic ray
tagger
1 m
7 m

3x1x1 detector

WA105



WA105 dual-phase LAr TPC

WA105

Charge Readout Plane (CRP) X and Y charge collection strips
3.125 mm pitch, 3 m long →7680 readout channels

Readout in gas phase:
charge is amplified and
collected on a 2D anode

Drift coordinate 6 m = 4 ms sampling
2.5 MHz (400 ns), 12 bits → 10000 samples per drift window

Total event size 148MB
Data rate 15GB/s (at 100 Hz trigger)
→ DAQ bandwidth on 20 GB/s scale

Detector is built from 4 independent $3x3\ m^2$ units
For multi-kton detector, simply increase the number of CRPs