

# Irfu CEA Saclay: charge readout for WA105 towards DUNE

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January 22 2018

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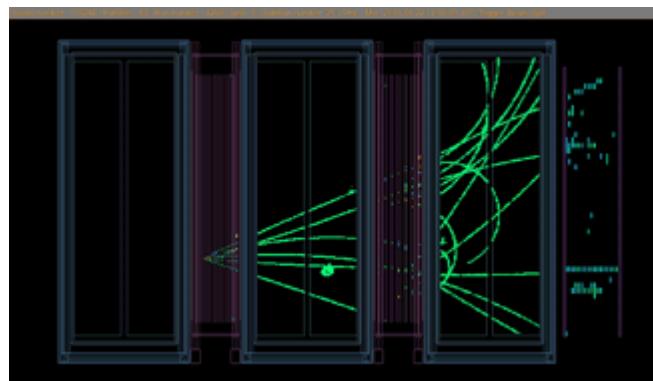
M. Zito: responsable scientifique

# Outline

- Introduction: Irfu expertise in TPC and MPGD, Laguna-Laguna/LBNO
- Charge readout activities for WA105
- Perspectives for DUNE

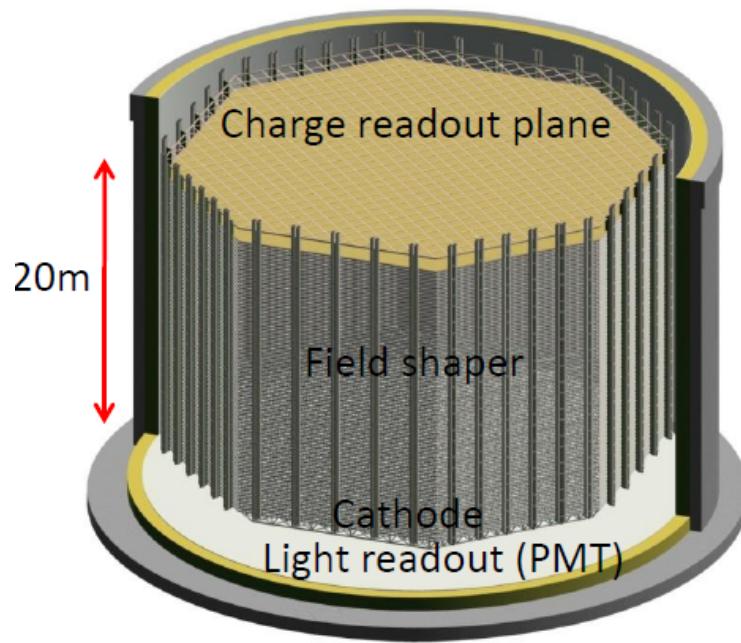
# IRFU CEA Saclay: neutrinos, TPCs and MPGD

- IRFU CEA Saclay has a long experience in building large state-of-the-art detectors, in particular tracking detectors (eg CDHS, NA48, DELPHI TPC, NOMAD ....)
- Since 1996 it has played together with CERN a pioneering role in the development of MicroPattern Gas Detectors with the invention of Micromegas detectors
- Our group has designed and built the Micromegas for the first large TPCs based on MPGD for T2K Near detector ( $9 \text{ m}^2$ ), operating flawlessly since 2010, together with the full front-end electronics



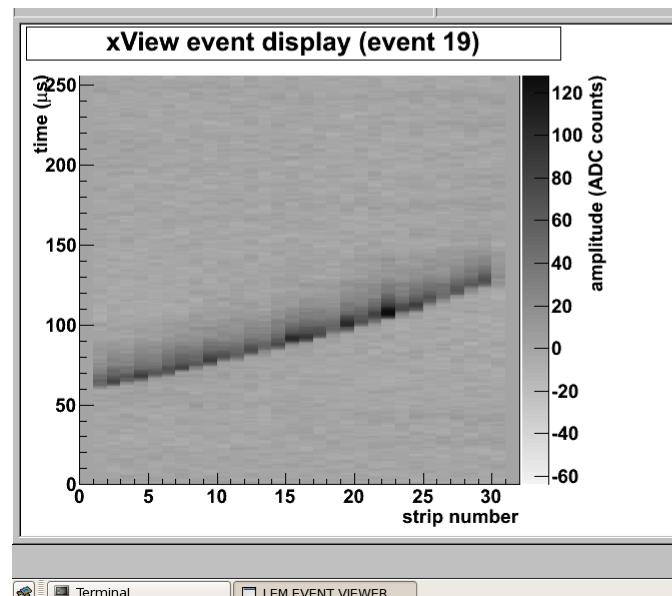
# EU LB design studies: EuroNu-LAGUNA-LAGUNA/LBNO

- Irfu participated in Euronu (coordination of the SuperBeam Work Package), Laguna (physics studies) and Laguna-LBNO (chair of the Technical Board)
- Laguna-LBNO studied the concept of the membrane tank and other engineering and technical solutions, including the beamline optimization, and many aspects of the physics relevant for DUNE



# R&D for Micromegas in Liquid Argon TPC

- Since 2010 Irfu has been involved in R&D with Liquid Argon TPC, in particular proposing to use Micromegas as the gas amplification device
- Micromegas have been tested in Double Phase LAr TPCs together with ETHZ and the Liverpool groups, (with K. Mavrokoridis, C. Touramanis) successfully showing gas amplification

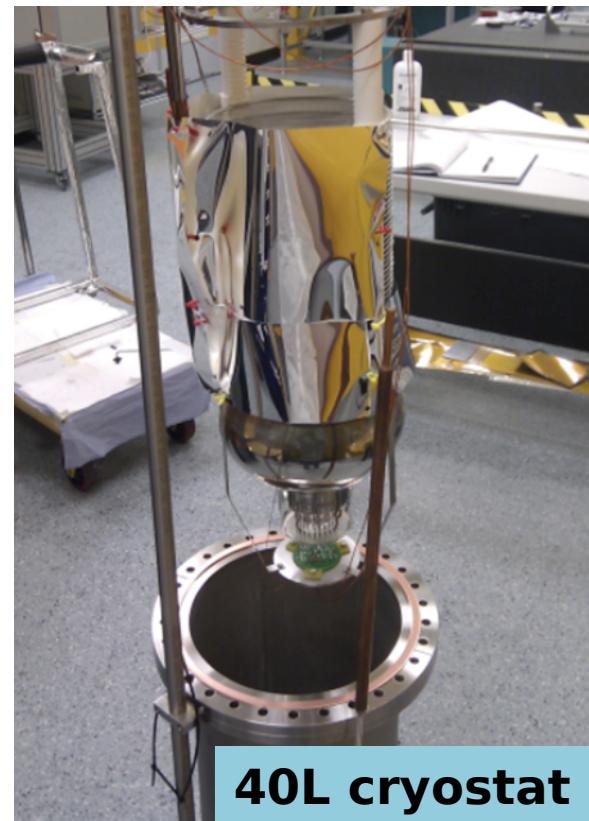
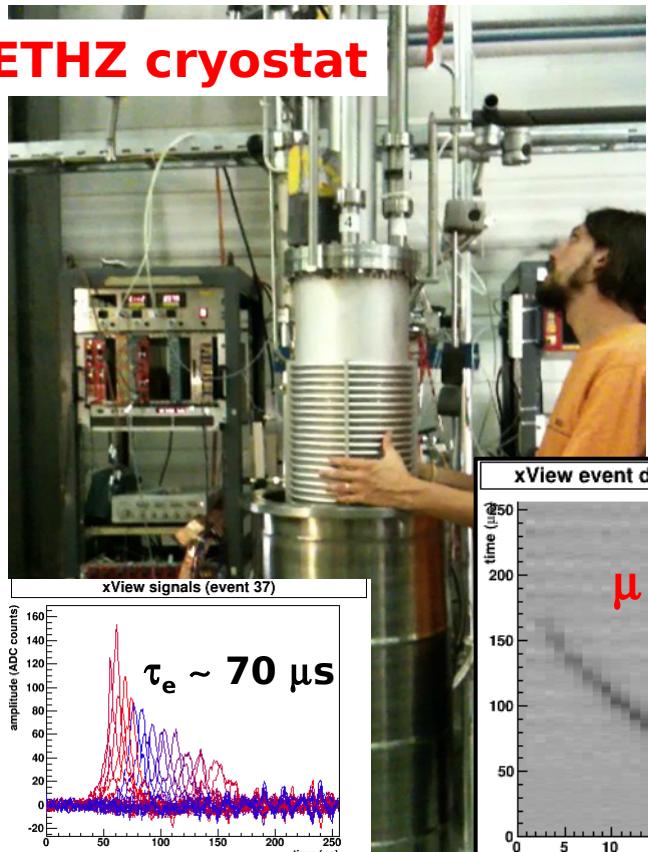


# DéTECTEURS bulk-MicroMegas (MM) dans une TPC DLAr

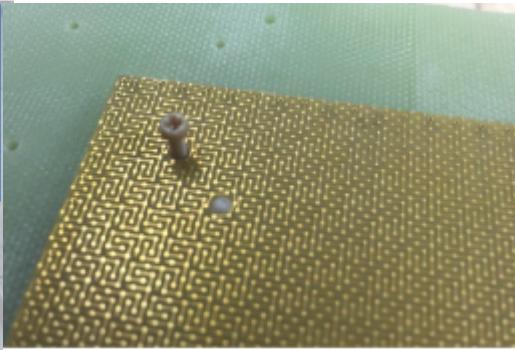
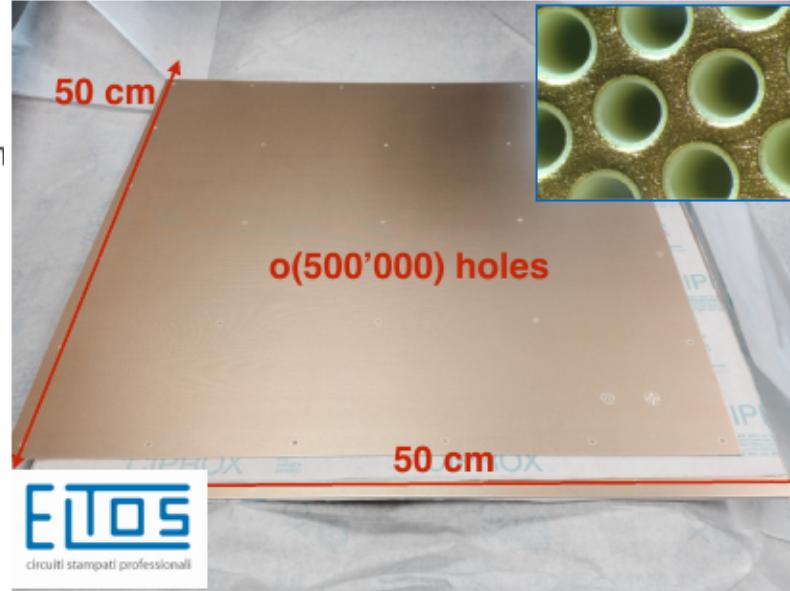
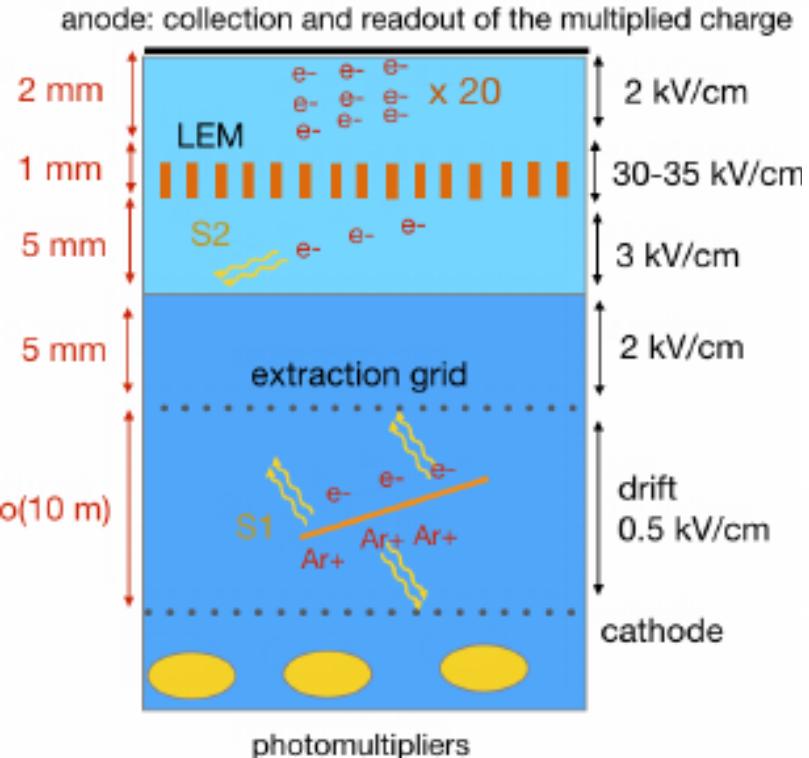
Premiers tests au CERN en 2010  
avec un prototype MM de 102 $\mu$ m

Tests fin 2013 à Liverpool avec des  
prototypes MM de 115 $\mu$ m et 192 $\mu$ m

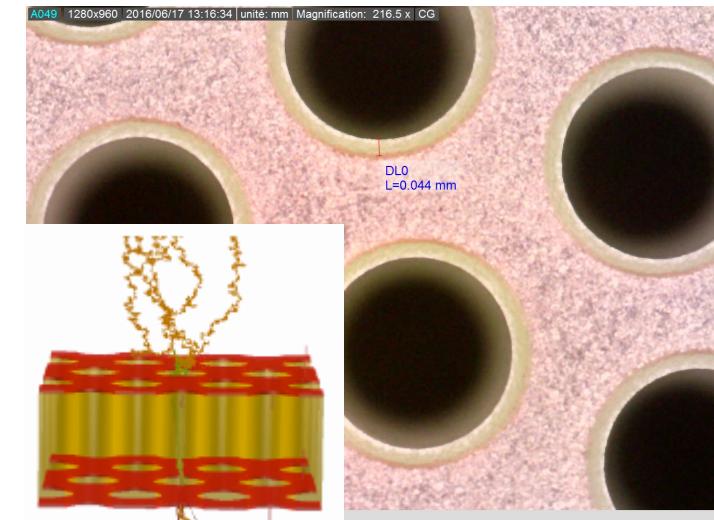
**ETHZ cryostat**



# The double phase charge readout: LEM-Anode



Anode: charge sharing and low capacitance for x,y strips in inner PCB layers



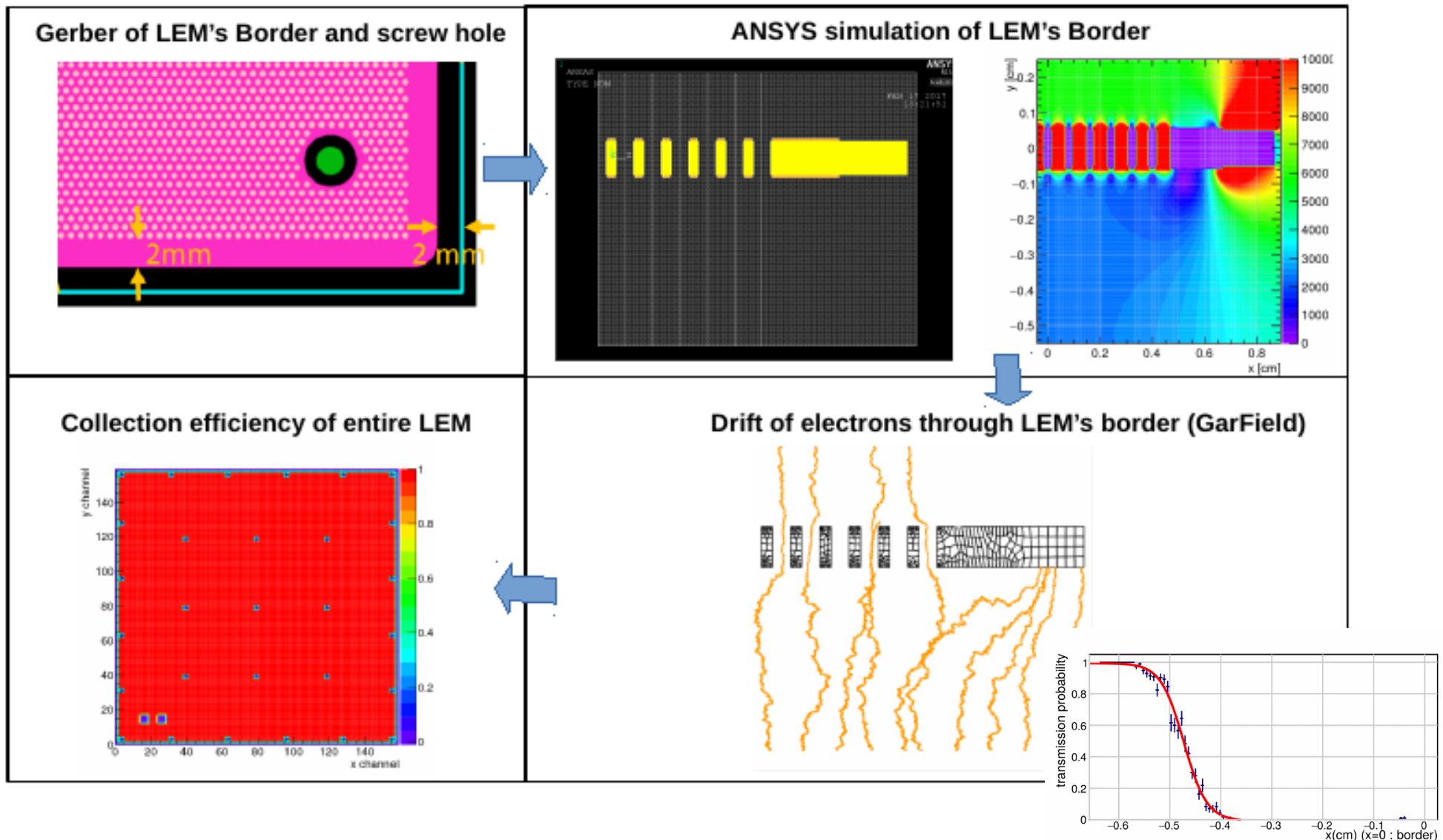
- LEM: PCB, 1mm thick, 50x50cm<sup>2</sup>, ~500 000 CNC drilled holes
- 500 µm hole, 800 pitch
- 40 µm rim (by chemical etching)
- Achieves gain up to ~100 at E~ 35 kV/cm in ultra-pure argon thanks to “mechanical quenching” (amplification in the holes)
- Similar detectors used in Compass RICH
- 144 LEMs for WA105, 2880 for 10kt

# IRFU activities within WA105

- 1) Electrostatics modeling and effect of LEM dead areas for physics (Ph. Cotte)
- 2) Tests of LEM prototypes: from  $10 \times 10 \text{ cm}^2$  to  $50 \times 50 \text{ cm}^2$
- 3) Characterization of LEM gain and HV properties
- 4) Optimization of LEM design
- 5) Definition of LEM technical specification for tendering
- 6) LEM post-production processing
- 7) LEM QA/QC for mass production: procedure and instrumentation
- 8) Validation of a second company (ELVIA) for LEM and anode production
- 9) LEM procurement and validation for WA105: in progress

# Simulation of the impact of the dead zones of the LEMs on the Charge collection Efficiency

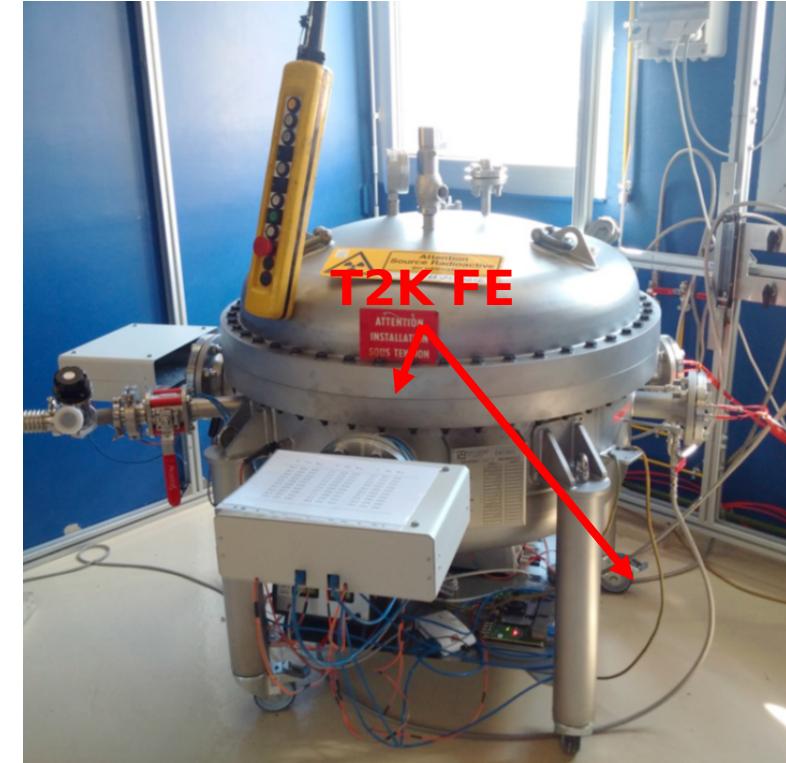
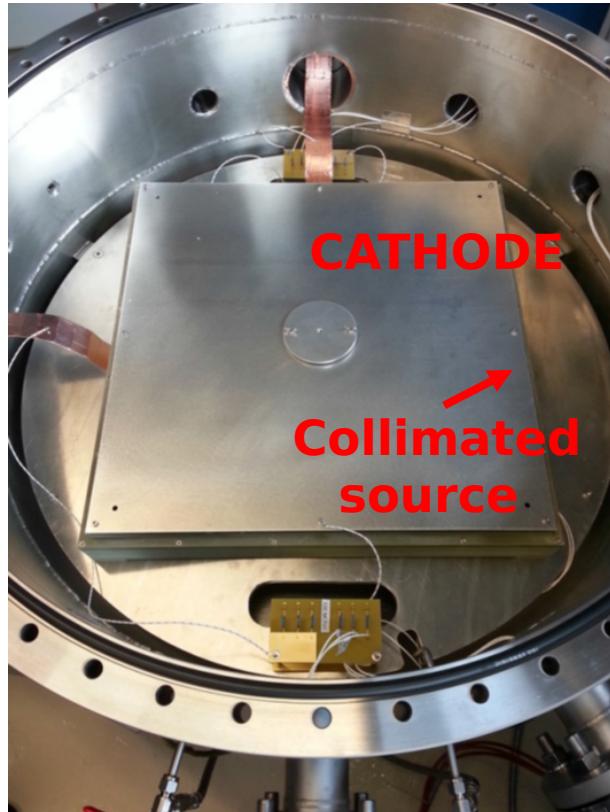
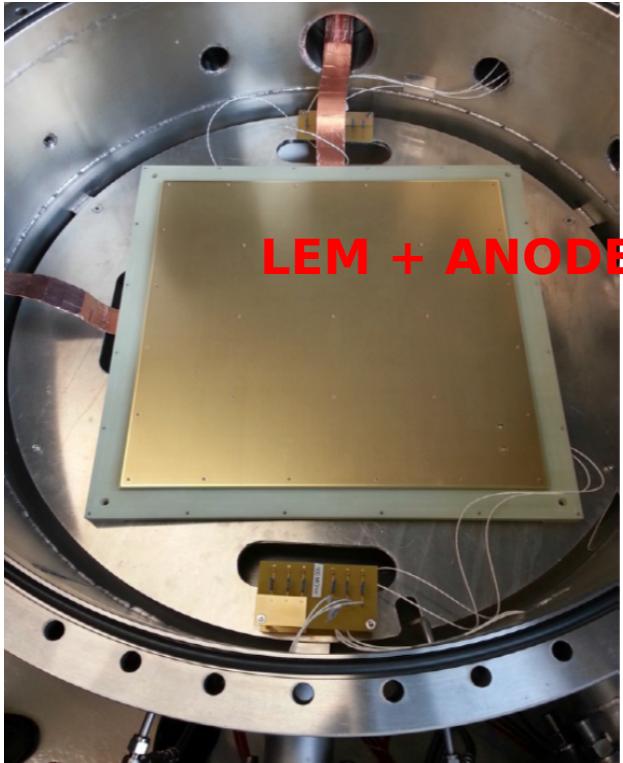
-Done with ANSYS and GarField



# Gas amplification

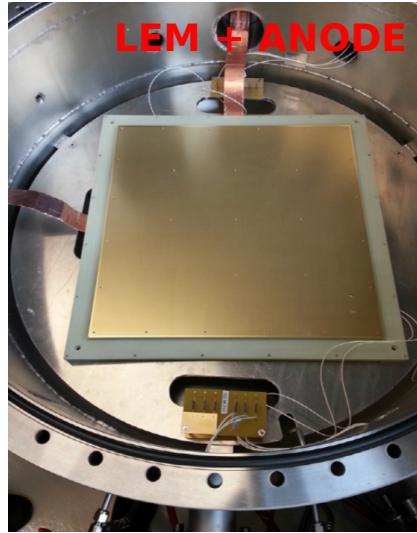
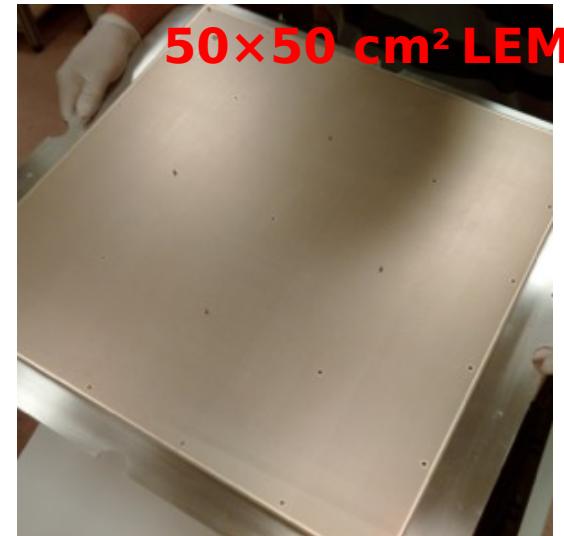
- The gas amplification can be written  $dN = N\alpha ds$  where the first Townsend coefficient  $\alpha$  can be written  $\alpha(E/\rho, \rho) = f(E/\rho)\rho$  ie  $\alpha$  depends only on the density (and not separately on  $T$  or  $p$ ).
- For a mass production of LEM, it is more convenient to test the device at room temperature at the same density of cold Ar gas. This requires a pressure  $p_{eq} = p_{atm} T_{room}/T_{cold} \sim 3.3$  bar

# Gain measurements with $^{241}\text{Am}$ source



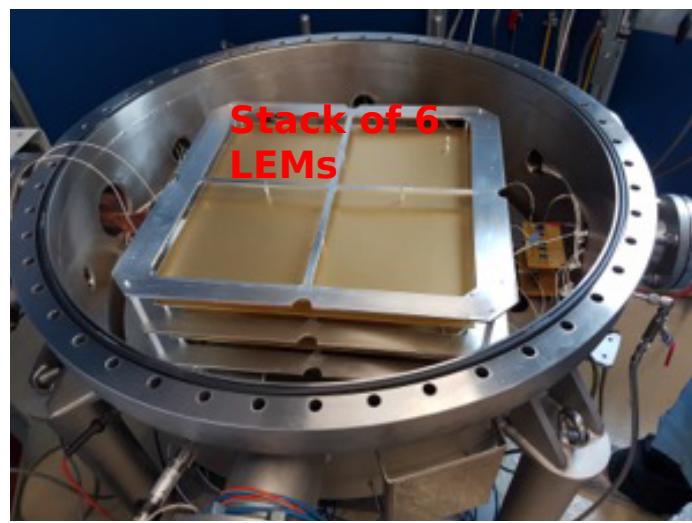
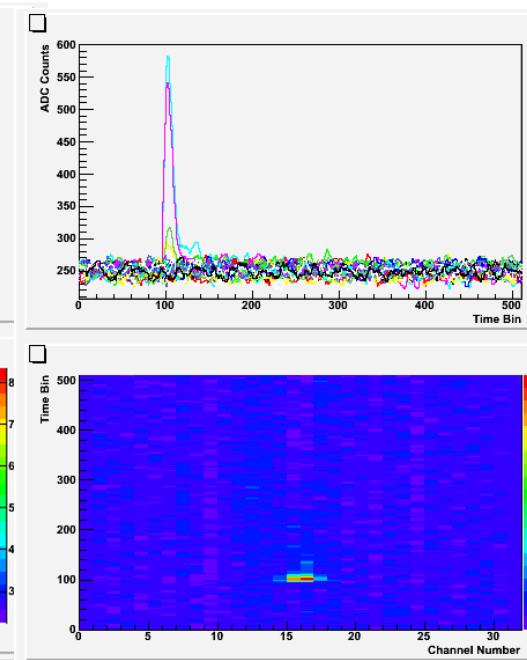
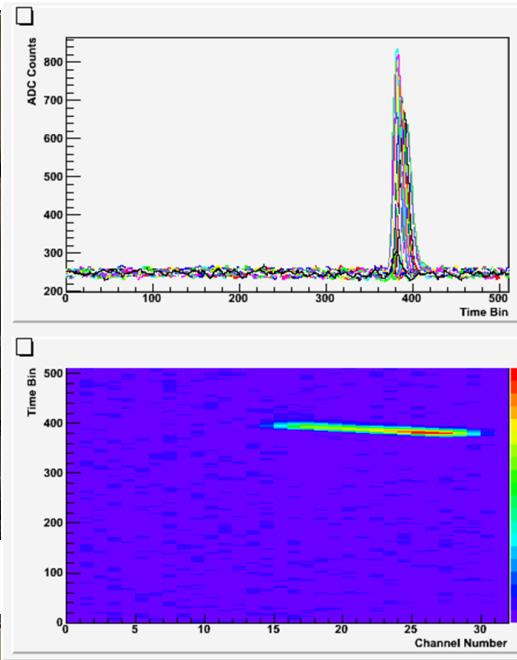
Pressure vessel capable of  
operating at 4 bar

# HV Tests and Gain measurements



Ar @ 1 bar

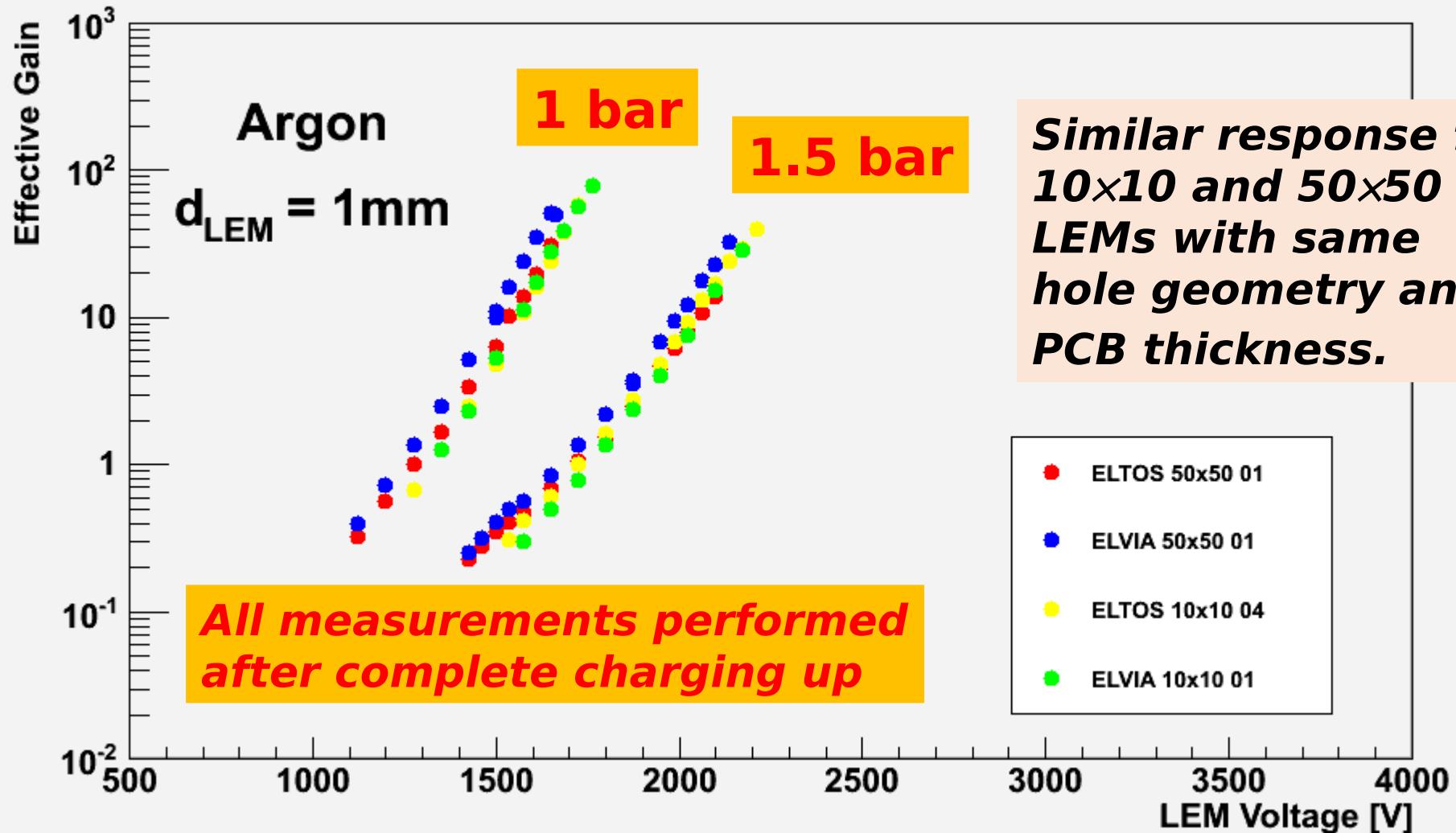
Ar @ 3.3 bar



*First track ever observed  
with a 50×50 LEM!*

241Am  $\alpha$  tracks

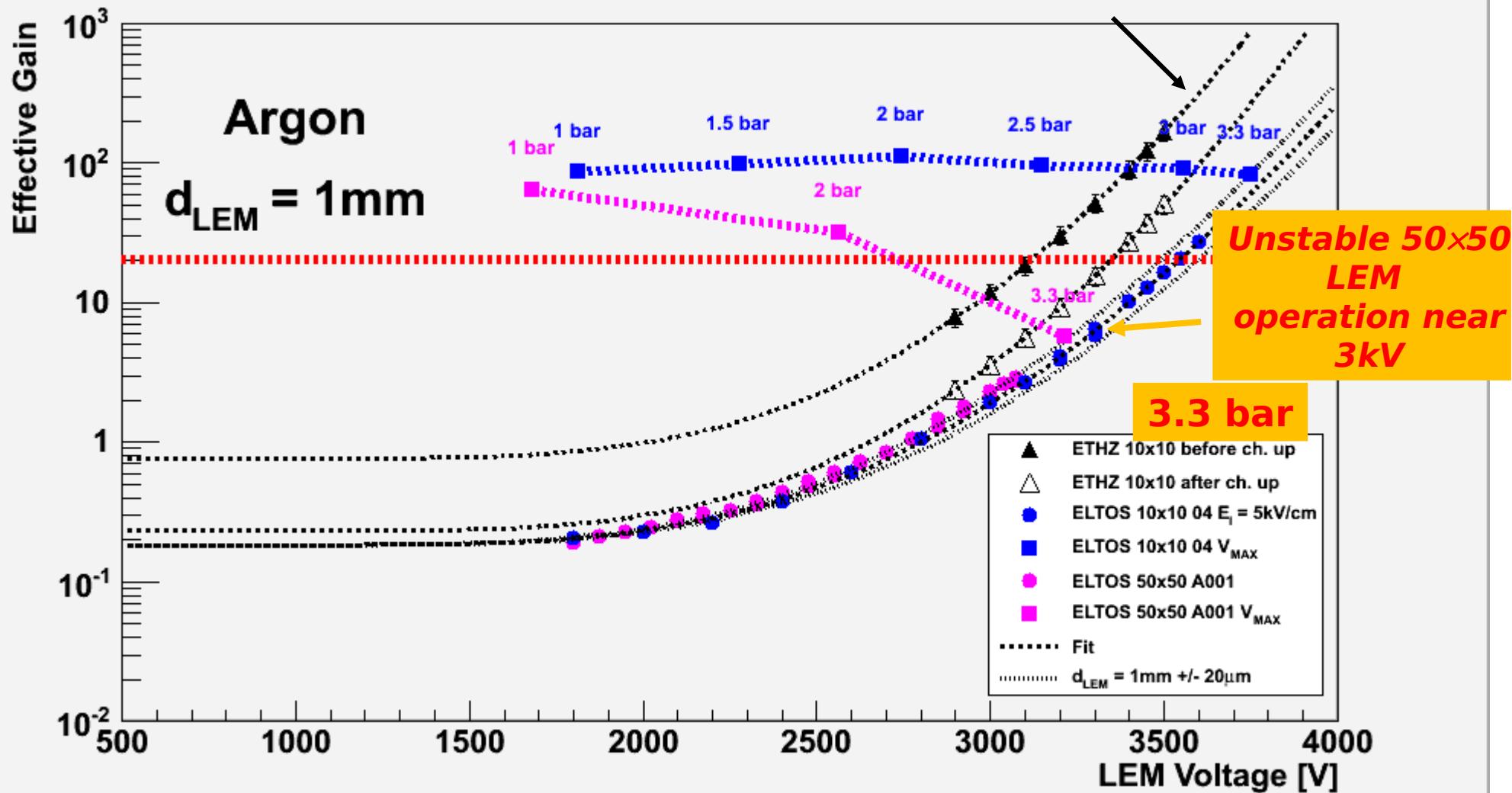
# Gain measurements



# LEM tests : 50×50 -vs- 10×10

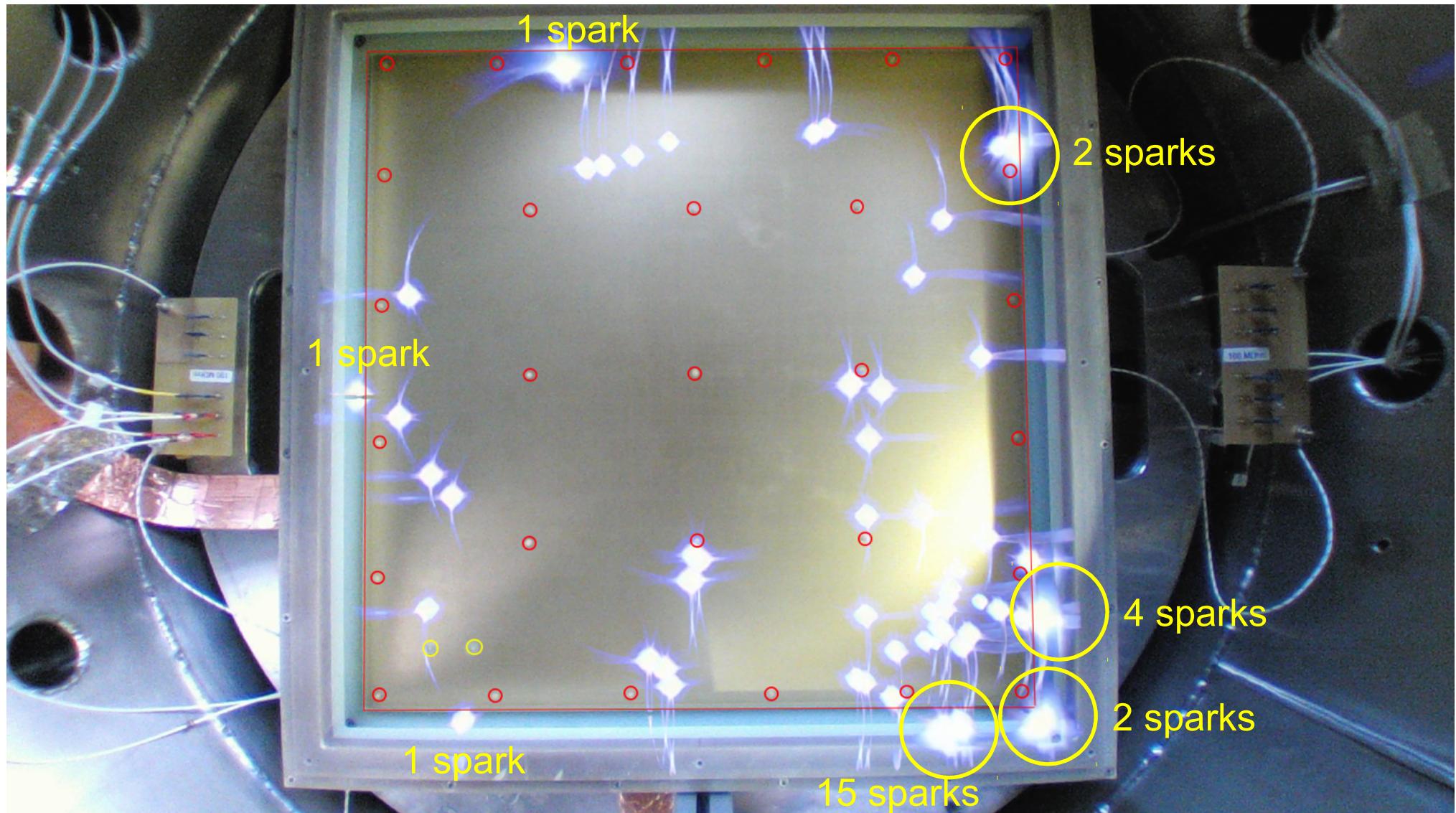
All measurements performed  
after complete charging up

From A. Cantini et al.  
arXiv:1412.4402v1



Unlike the 10×10 module which exhibits ~constant max. gain up to 3.3 bar, there is a clear drop for the 50×50 one.

67 sparks : 24 (36%) close to borders (with 15 in bottom right), 41 (61%) randomly spread on the LEM active area (with 20 in bottom right) and 2 (3%) in bottom right corner

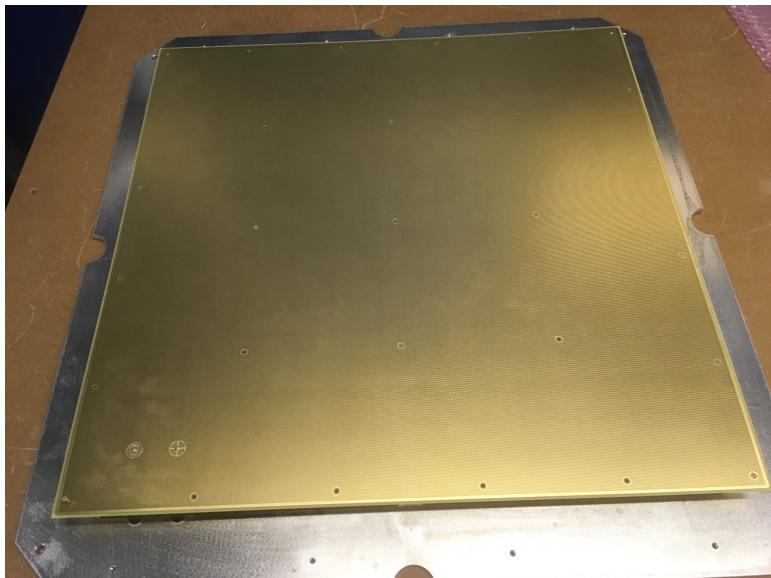


# Motivation for a new LEM design

- Since 2015, the IRFU group has measured a LEM maximum gain which is not compatible with the goal of WA105/DUNE (ie gain = 20)
- This has led to a new design with larger guard ring (copper) and clearance (FR4 with no copper)
- This design is conservative to assess the improvement
- The dead area can be optimized, under study
- The new design attains the design goal for DUNE (see next slides)

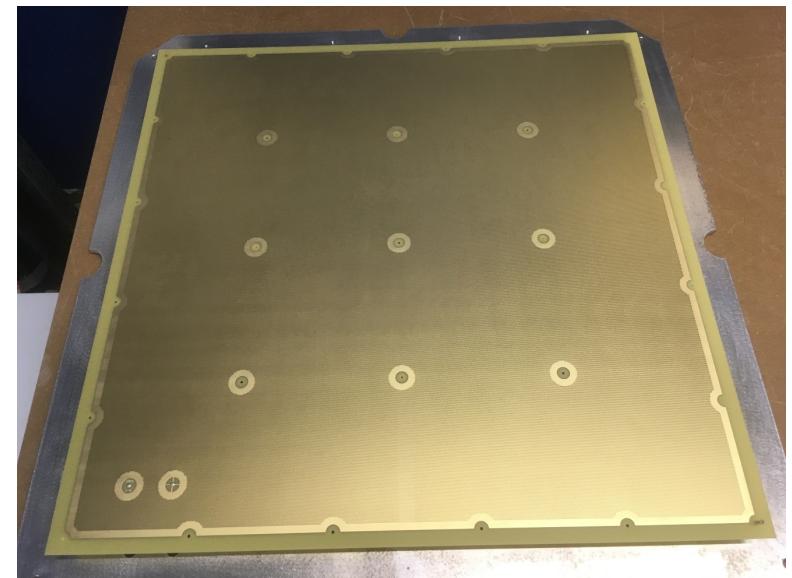
# IRFU new LEM Design

**Current**



**~ 96% active area**

**Modified**



**~ 86% active area**

# The 3 LEM Designs

LEM design	%Active area	LEM borders		Screw holes		HV connections	
		FR4	copper guard ring	FR4 ringΦ	copper guard ringΦ	FR4 ringΦ	copper guard ringΦ
CFR-34	96.2	2 mm	2 mm	4.2 mm	6 mm	10 mm	12 mm
CFR-35	85.8	10 mm	5 mm	10 mm	20 mm	10 mm	20 mm
CFR-36	92.1	2 mm	5 mm	10 mm	20 mm	10 mm	20 mm

CFR-34 design  
(42 LEM produced)  
96% active area

40+2 LEMs produced  
Qualified w/o anode at  
3200 V  
(10 mn w/o spark)  
But unstable operation at  
> 3200 V with anode

CFR-35 conservative design  
85% active area

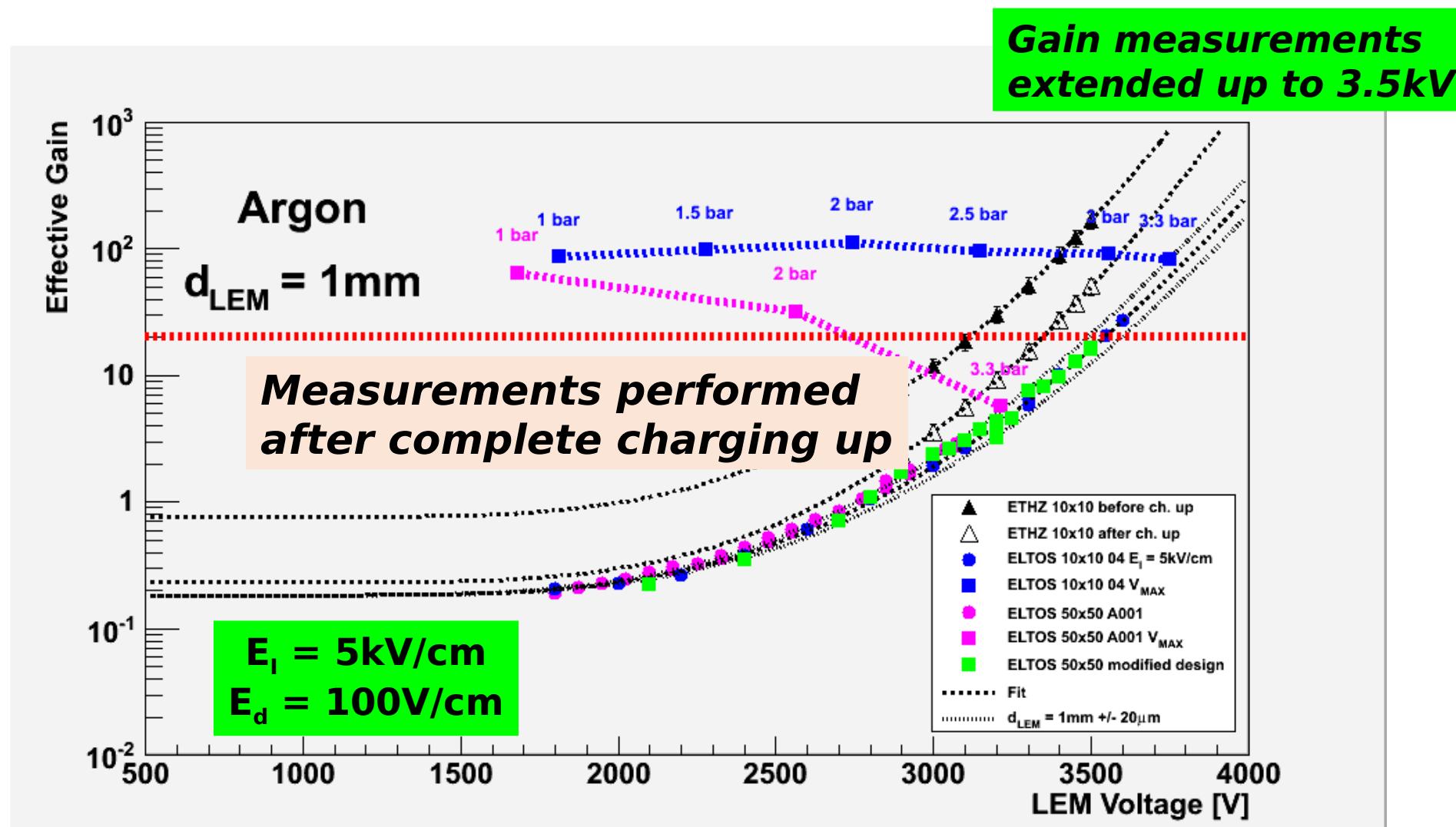
On-going production  
of 36 LEMs  
Increased margin for  
stable operation at  
3200-3400 V

CFR-36 « alternative » design

92% active area

2 prototypes will be delivered  
next week at Saclay  
Same stability as CFR-35 ?

# LEM tests : 50×50 modified design

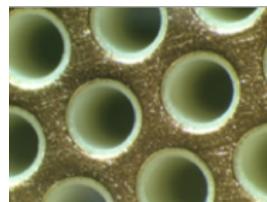
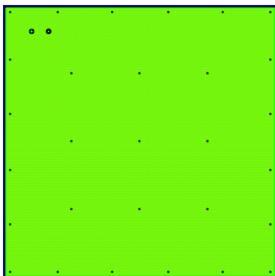


# LEM specification document

<b>Irfu</b> <b>cea</b> saclay	<b>Cahier des charges</b>	Réf: CdCLEMWA105Fr
	<b>LEM DU PROTOTYPE WA105 (DUNE/DP)</b>	Date création : 30/09/2016
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## CAHIER DES CHARGES ET DES SPECIFICATIONS TECHNIQUES

### PRODUCTION DES LEM DU PROTOTYPE WA105 (DUNE/DP)



#### HISTORIQUE DES MODIFICATIONS

Version	Date	Pages modifiées	Motifs
DRAFT	30/09/2016	Création	Pour diffusion restreintes et corrections
DA			Pour diffusion initiale pour l'appel d'offre

Rédacteurs		Vérificateurs	Approbateur	
Nom	A. DELBART	E. MAZZUCATO	Y. PENICHOT	M. ZITO
Fonction	Chef de Projet	Resp. Physicien	Resp. QA	Resp. Scientifique
Date				
Visa				

<b>Irfu</b> <b>cea</b> saclay	<b>LEM DU PROTOTYPE WA105 (DUNE/DP)</b>	Réf: CdCLEMWA105Fr
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- Procurement of raw material in one batch at the beginning of the production
  - Raw FR4 sheets selection for mean thickness and uniformity better than 4%
- 0/ QA/QC by manufacturer

By LEM manufacturer

CNC drilling	Change drills every 1000 holes Drilling of stack of PCBs is forbidden
mechanical polishing	with pumice powder 4 steps (+/- 90°, top/bottom)
permanganate bath +rince	removes glass fiber from holes
Rims by global etching	acide sulphuric bath
passivation (Chromic acid)	
Ni/Au plating	Baking 3 hrs at 50° Rinsing with DM water ( $R > 2$ Mohm)

- 1/ LEM thickness metrology
- 2/ Soldering of HV pins
- 3/ Mounting on aluminum handling plate  
(dismounted when LEM is packed for shipping)

The handling plate is used to prevent the LEMs to be touched during the following production tasks

By WA105

- ultrasonic bath DM water
- lessive (soap) bath at 60°C
- karcher DM water
- baking 3 hrs at 80 degrees
- HV test

Dioinised water  
( $R=18$  Mohm)

- 4/ "Saclay Cleaning"
- 3 mn Ultrasonic bath with "soap NGL 17.40 ALU" at 65°C

+ regular water rinsing BEFORE DM water

- 5/ Gluing of HV insulating MACOR cylinders
- 6/ Final qualification @ 3.3 bar (abs)

Thickness metrology will be done on the first LEM batches to check the conformity with the raw material thickness measurements by the manufacturer

If Breakdown Voltage (BV) and spark rate test in air is passed, final polymerization @ 160°C can be done

# LEM procurement and QC/QA in Saclay

- CEA-IRFU responsible for the procurement of 1/2 of the 144 LEMs + anodes for the 6×6×6 + their validation.
- Irfu has contributed to the current LEM design, LAS assembly and to detector simulation.
- All the infrastructures necessary for the preparation and tests of the LEMs available at Saclay (cleaning, baking, polymerization, metrology, etc...).
- A High Pressure chamber has been built in order to perform LEM tests in argon at same gas density as in DLAr conditions ( $P \sim 3.3$  bar at room temperature).
- LEM production started last July and is progressing well (contract with ELTOS for 78 LEMs).

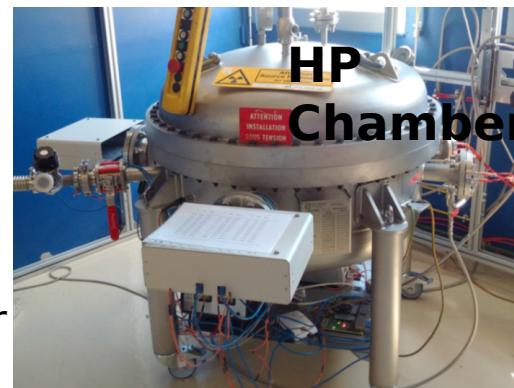
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**Ultrasonic bath**



**DM H<sub>2</sub>O station**



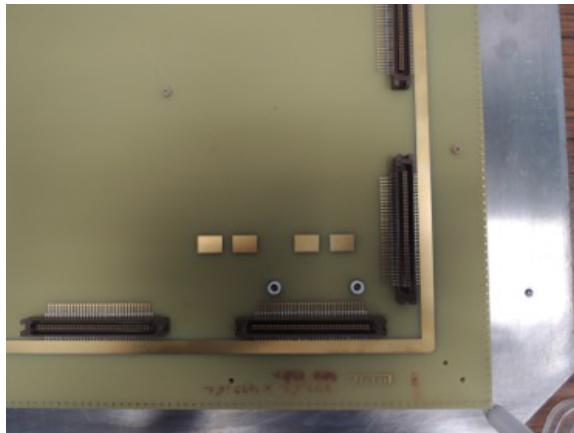
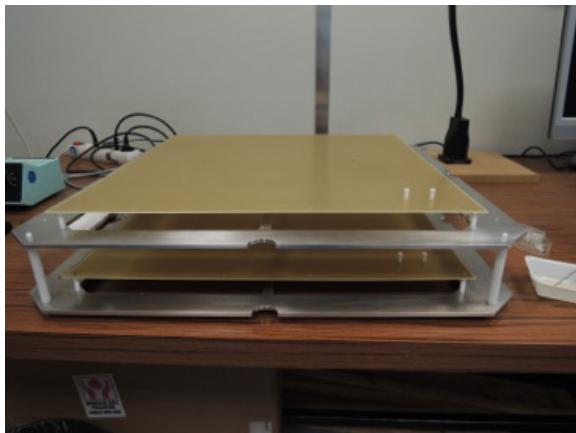
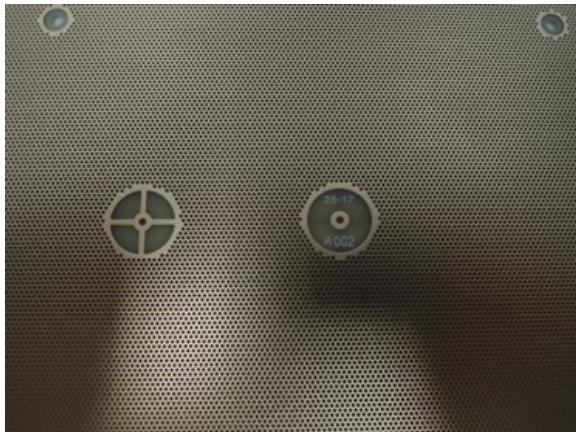
**HP Chamber**



**Polymerization**

# LEM preparation and cleaning

***Soldering HV pins +  
glueing MACOR insulation***



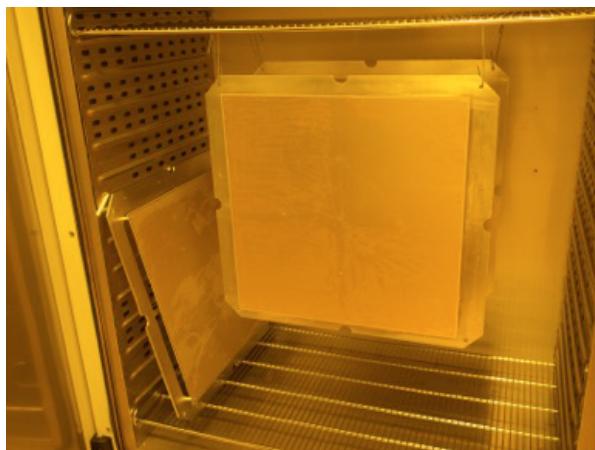
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protoDUNE DReinforcement Meeting

# LEM preparation and cleaning



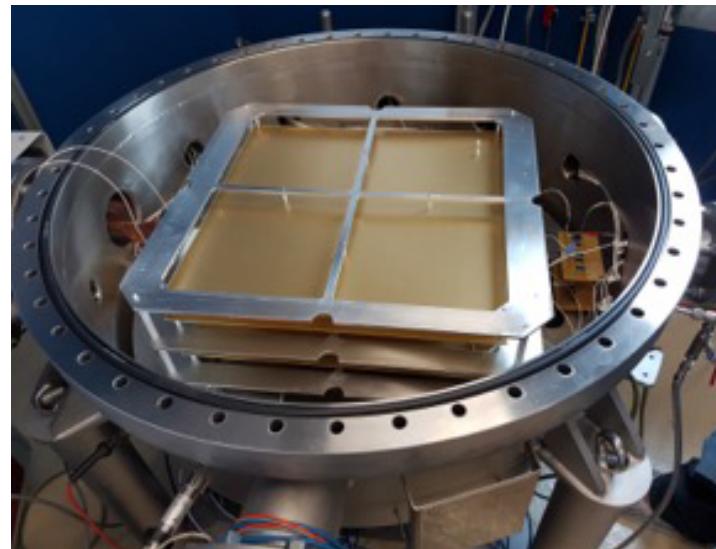
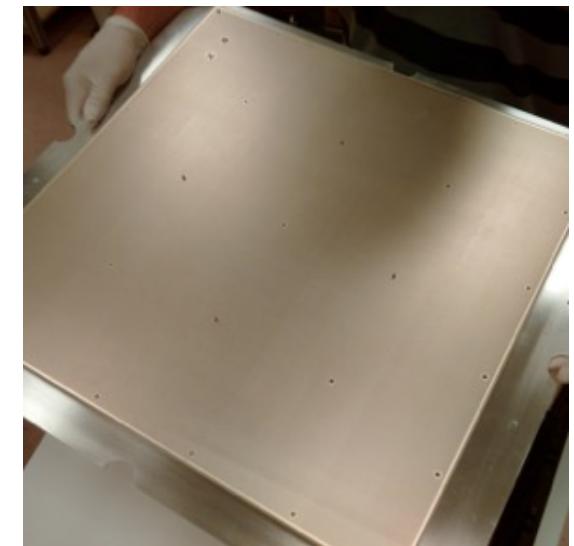
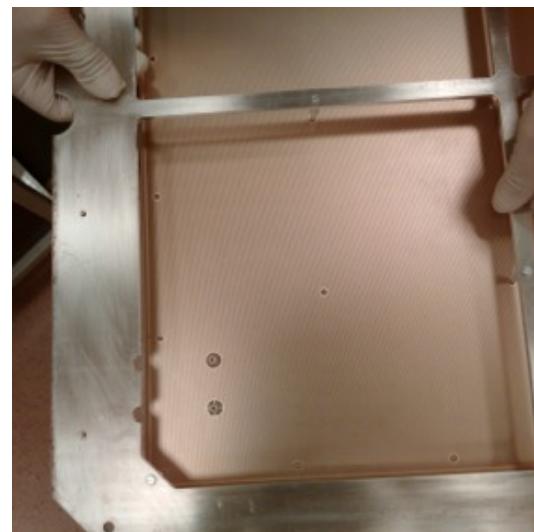
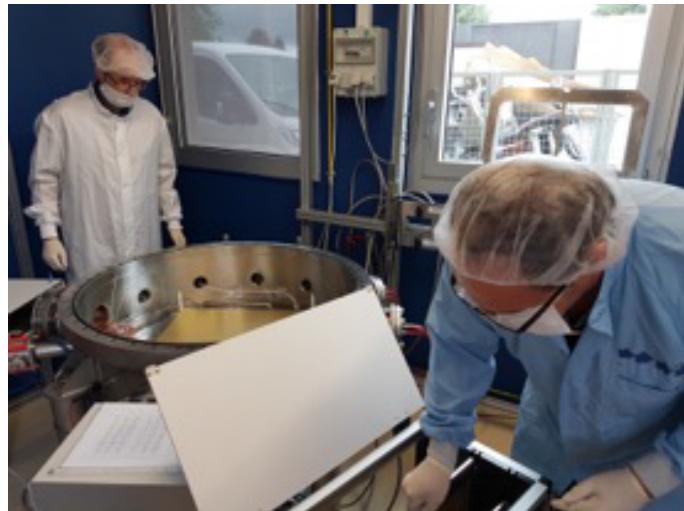
***Cleaning + drying  
+ polymerization***



23/01/2017

protoWAND Recovery Meeting

# HV tests in HP chamber



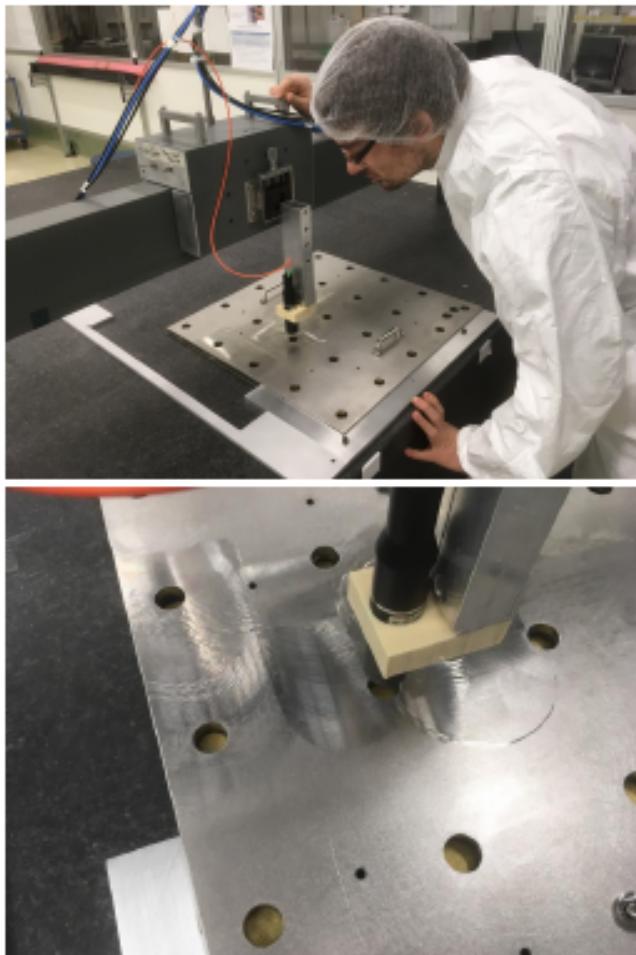
23/01/2017

protoDND-DR meeting

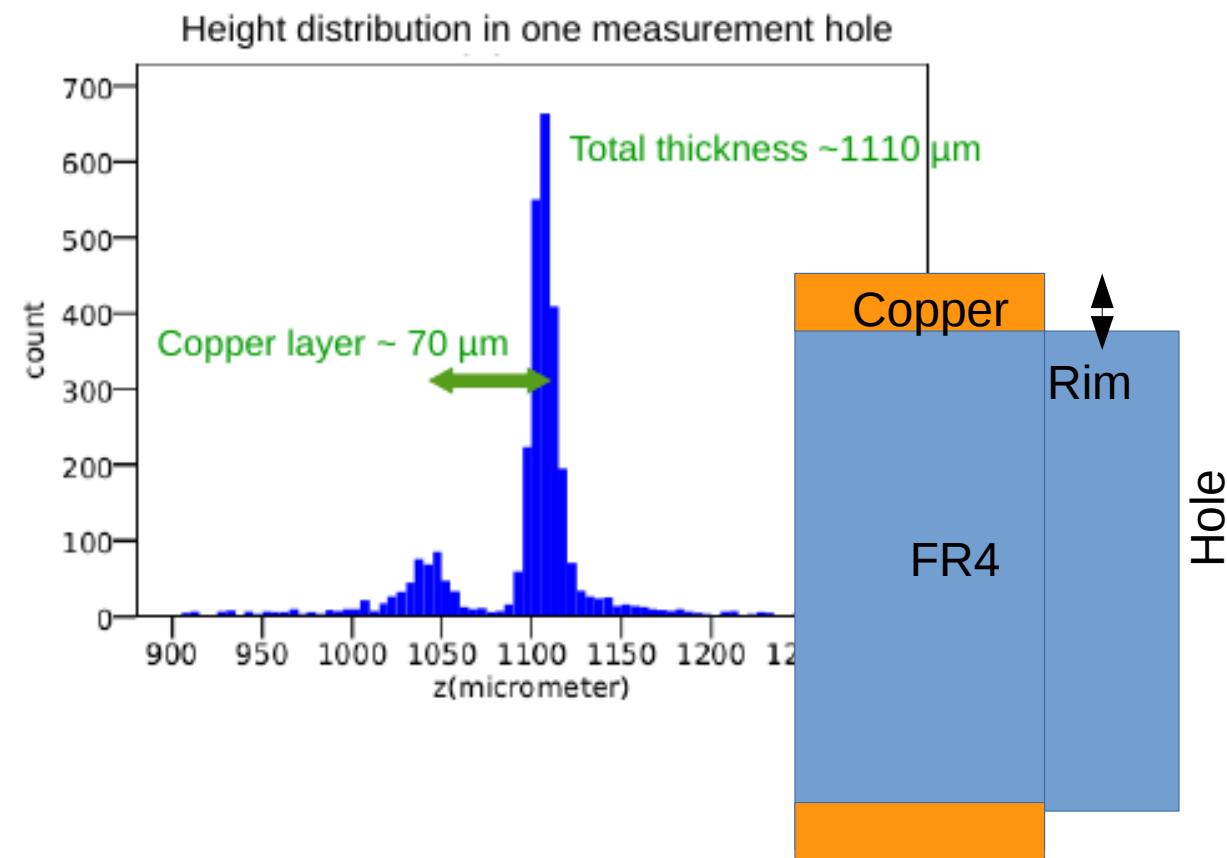
# Status of LEM Production

- Tendering Process (for 72 LEMs) started April 2017
- Production started in June 2017
- Established rate of 6 LEM/week at production and QA/QC
- 42 LEM produced (CFR-34), nn validated
- Production paused in November 2017
- Production resumed with the new LEM design in December 2017
- First batch of LEM CFR-35 expected for week 4, production completed by end of February 2018
- NB: ELTOS is equipped with a new drilling machine and can produce 12 LEMs/week
- Schedule in line with WA105 completion in November 2018

# Measurement of LEM thickness



- LEM is flattened by a 10 kg aluminium plate
- Thickness measured with an optical pen at 25 different places



# From WA105 to DUNE 10kt-DP

- IRFU is seriously considering to participate to the construction of DUNE DP 10kt
- Subject to a scientific strategy decision by IRFU, and subject to availability of funds and personnel
- IRFU could consider providing a significant fraction (~25%) of the LEM-anodes for one 10kt module
- A fact-based cost model derived from WA105 construction has been established (little contingency needed)
- LEM marginal cost could be reduced by ~25% with respect to WA105 for a mass production of ~1000 LEMs

# DUNE 10kt-LEM/anode cost items

Mech. Frames and jigs :

HP chamber +vacuum pumps

High Voltage :

Lab Instrumentation + PC :

Tools, gas etc :

Shipment :

Métrologie

Clean room with laminar flux

Oven + cleaning/rinsing devices :

Additional personnel

# DUNE 10kt-LEM/anode cost items

Mech. Frames and jigs :

HP chamber +vacuum pumps

High Voltage :

Lab Instrumentation + PC :

Tools, gas etc :

Shipment :

Metrology

Clean room with laminar flux

Oven + cleaning devices :

Additional personnel

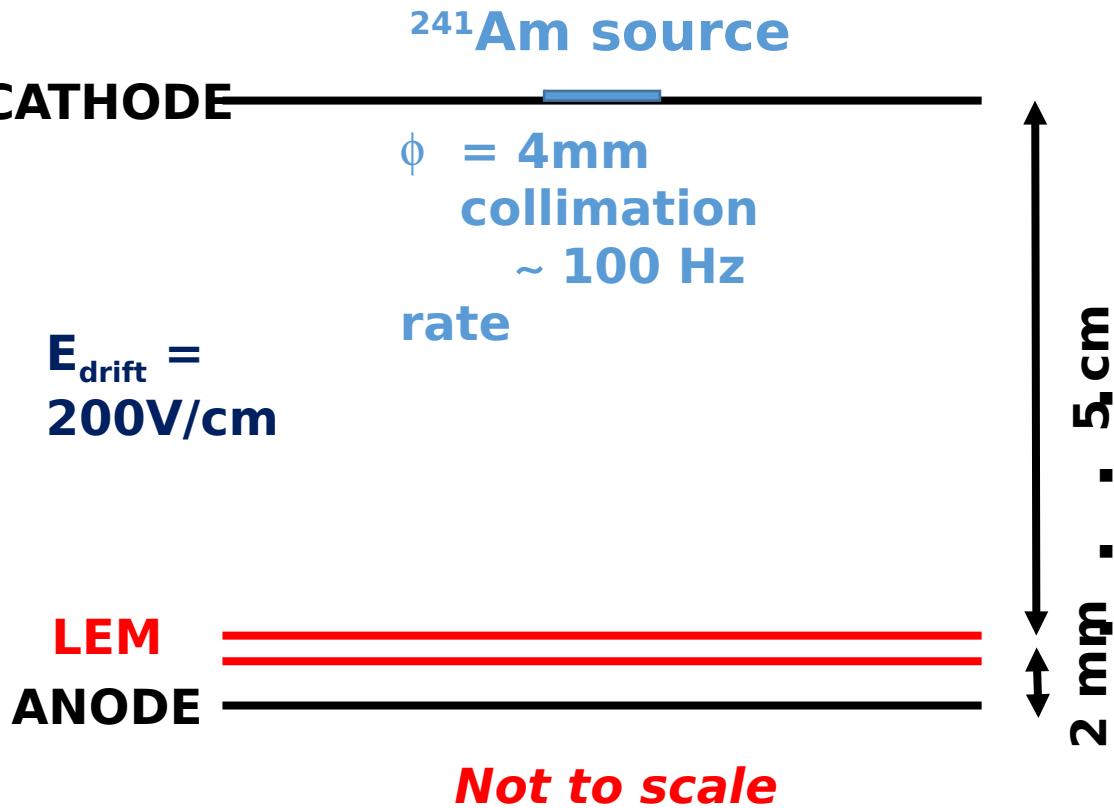
# Conclusions

- IrFU Saclay has a long experience with gaseous detectors, MPGD, and TPC, applied to HEP and neutrino physics in particular
- It has studied and improved the design of the LEM for WA105 and defined the QA/QC procedure for LEMs
- Production of  $\frac{1}{2}$  of LEMs and anodes for WA105 in progress, in line with IRFU MOU commitment
- A proposal for participation to 10kt DUNE DP is being evaluated with a detailed cost estimate based on in house know-how

# Backup

# Setup for gain measurements with an $\alpha$ source

$E_\alpha = 5.5 \text{ MeV}$   $L = \sim 4.5 \text{ cm tracks @1 bar}$



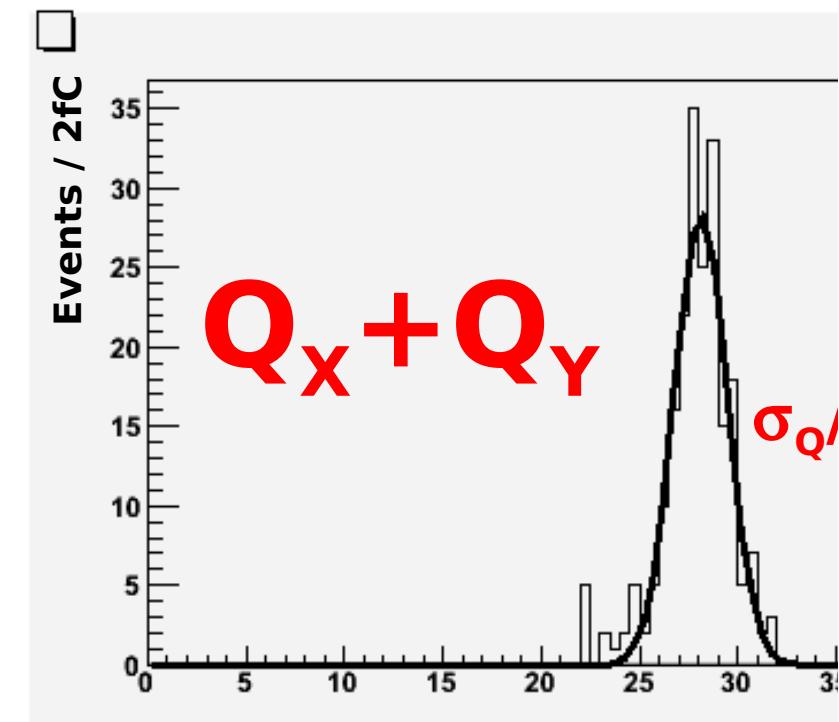
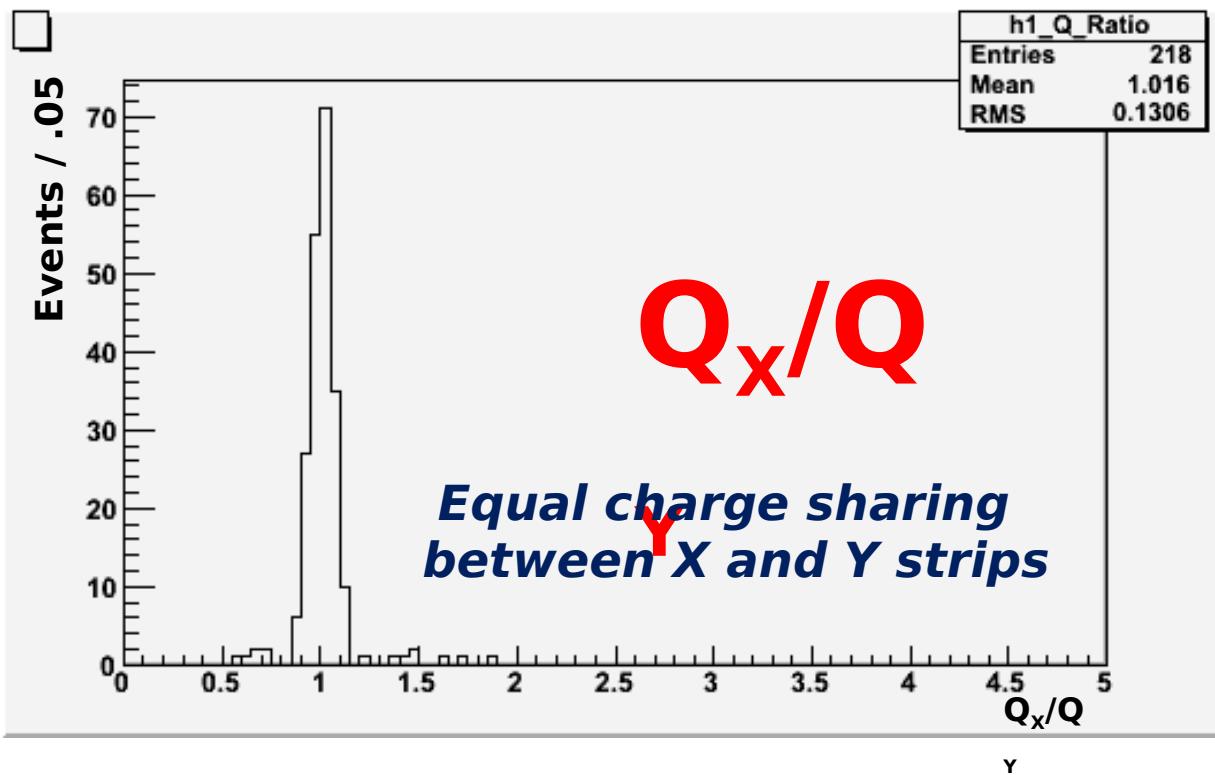
- FE : T2K ASIC AFTER + FEMINOS R/O + TCM :
  - 12 bit ADC
  - 120fC - 600fC full range range
  - 1.9  $\mu\text{sec}$  peaking time
  - 511 time bins R/O @ 6.66 MHz (150ns)
  - 32 channel R/O per view (X,Y)
  - E noise : ~0.2-0.4fC
  - Measurement range : ~ 2 - 1600fC / view
- Ar (5.7) purity : > 99.9999%
- <  $10^{-4}$  mbar pumping before Ar filling
- ~60 ppm of impurities after 30h of operation

Charging up time : 2-3h @ 1bar and  $G^{\text{eff}} \sim 10$

**N.B. Gain measurements performed after charging up and usually with  $E_{\text{LEM}} / E_i = 6$ .**

# Test with $^{241}\text{Am}$ source @ 3.3 l

$E_{\text{LEM}} = 30 \text{ kV/cm}$  and  $E_t = 5 \text{kV/cm}$



# LEM design : $50 \times 50$ -vs- $10 \times 10$

- Although hole geometry and PCB thickness is the same, the  $10 \times 10$  LEM designs (ETHZ or IRFU) differ from the  $50 \times 50$  one : no screw hole, no HV connector in active region but large area insulating material surrounding the LEM edges.
- Difference in LEM maximum voltage may not be due uniquely to size effects.

