Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Recent results of double phase LAr LEM TPC R&D

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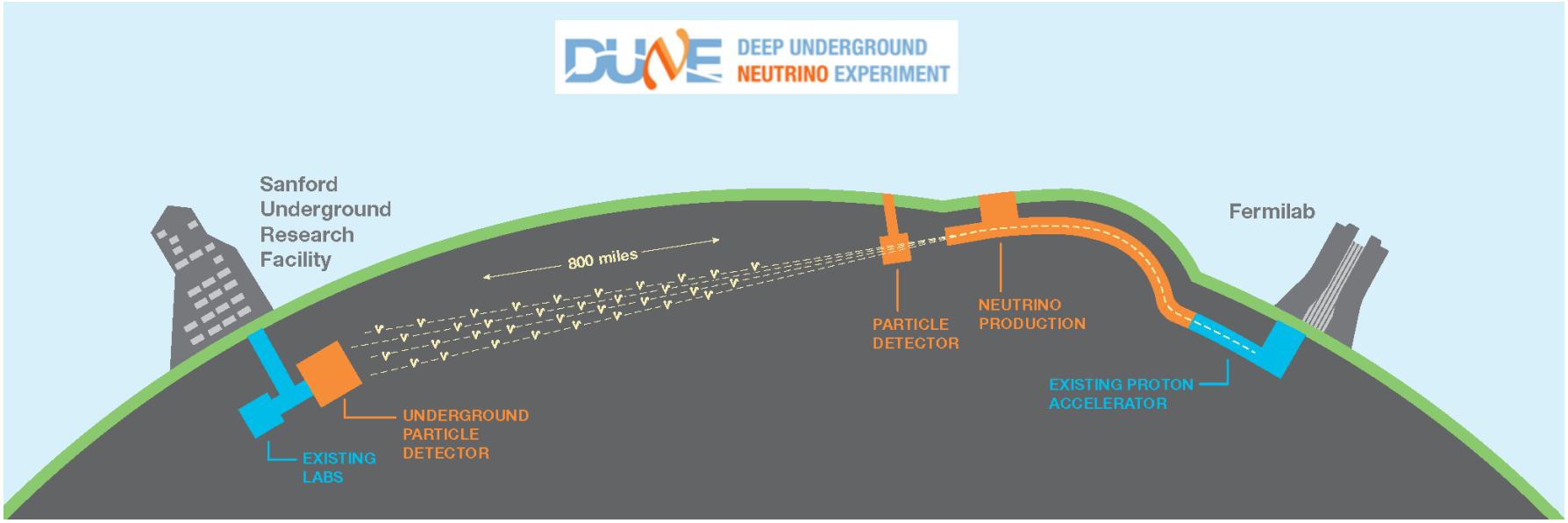
on behalf of
WA105 collaboration

MPGD 2015, Trieste, 12-15 Oct 2015

Deep Underground Neutrino Experiment (DUNE)

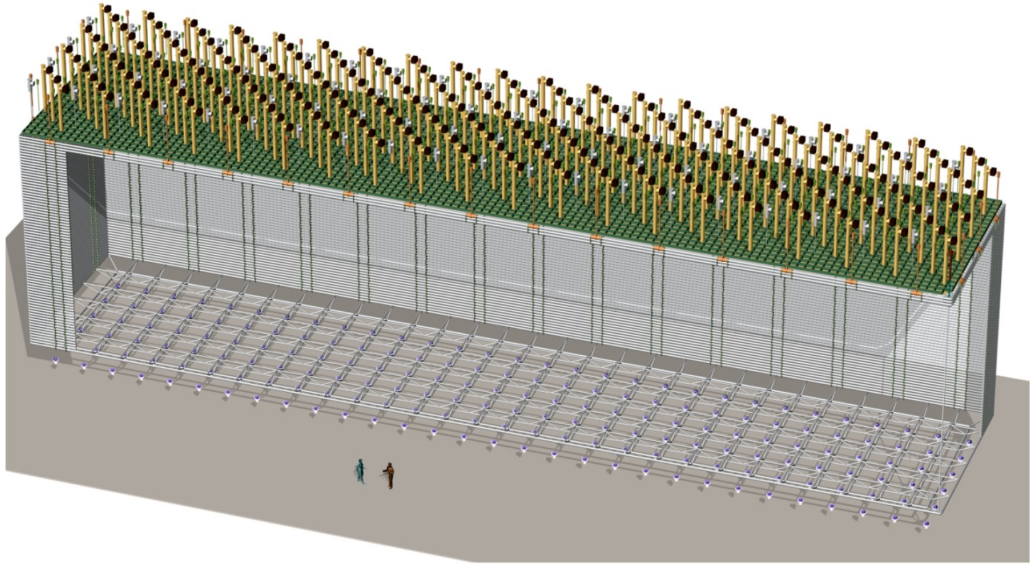


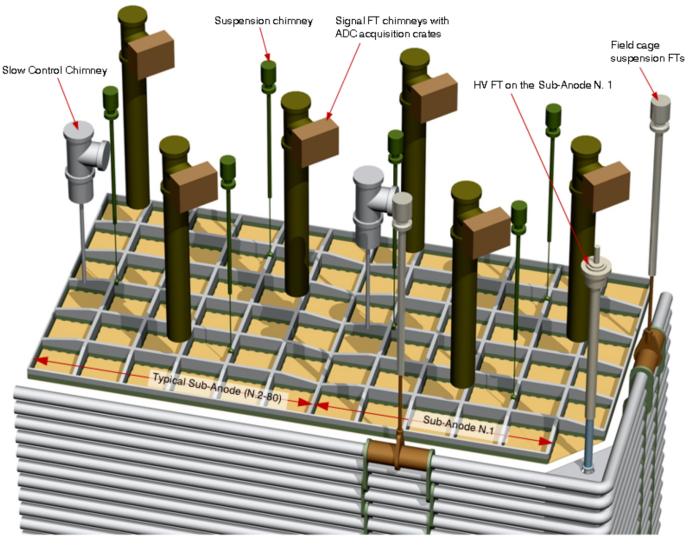
DUNE physics potential:

1. Accelerator based neutrino physics
   - Mass Hierarchy determination — over 5σ level over full δ_{CP} range for an exposure of 300 kt·MW·year, corresponding to 7 years' data with a 40-kt LAr detector and a 1.07-MW 80-GeV beam.
   - δ_{CP} measurement — 3σ sensitivity for 75% of δ_{CP} values at an exposure of 1320 kt·MW·year.
     — 5σ sensitivity for 50% of δ_{CP} values at an exposure of 810 kt·MW·year.
   - Sterile neutrino
2. Neutrino astronomy:
   - Solar neutrino
   - Atmosphere neutrino
   - Super-nova neutrino
3. Proton decay search

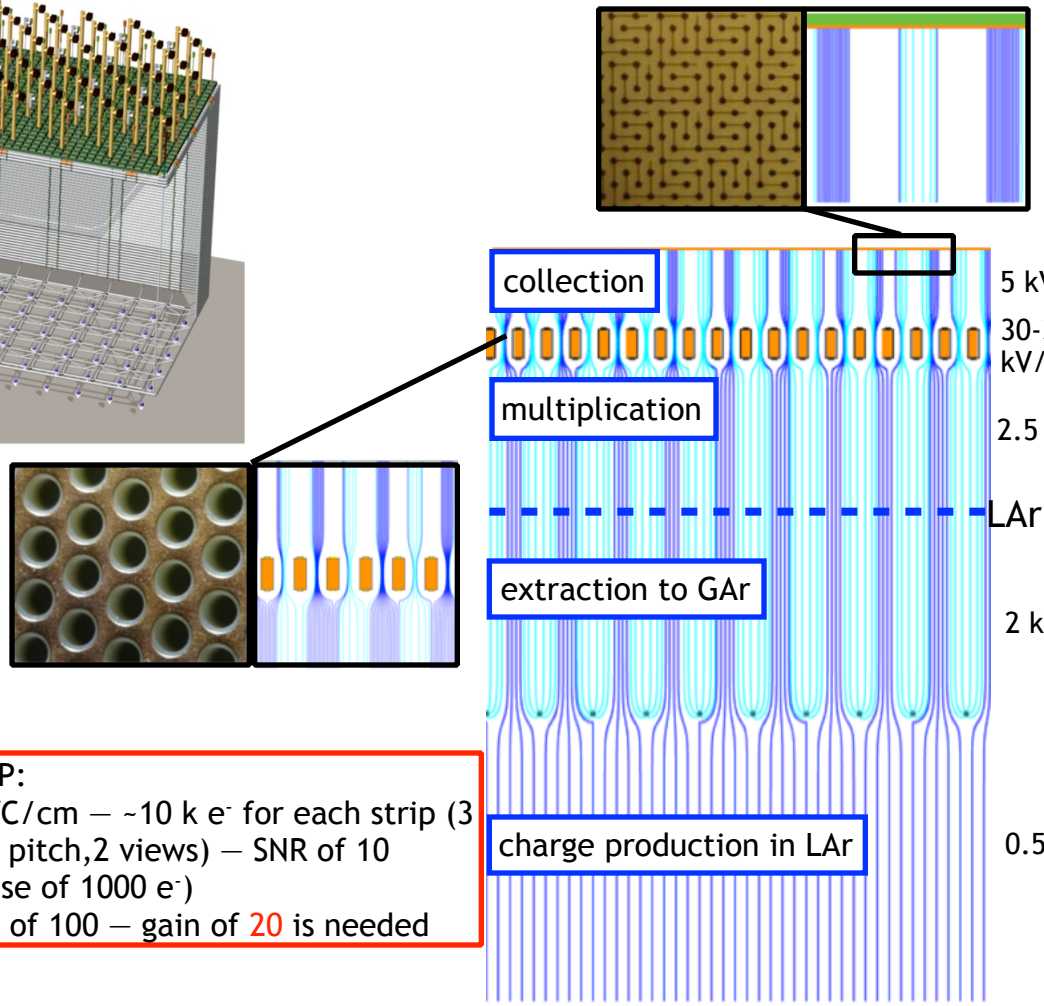
Double phase LAr LEM TPC as DUNE far detector

10 kton double phase module





double phase TPC working principle

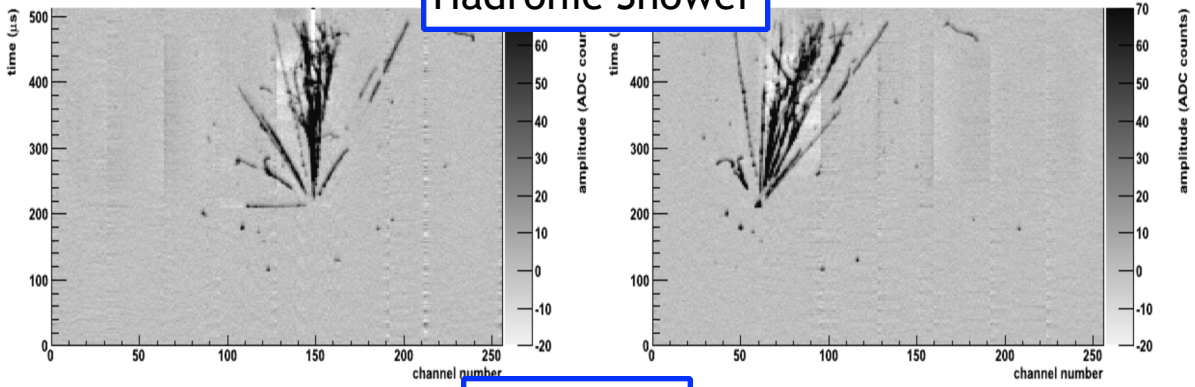


For MIP:

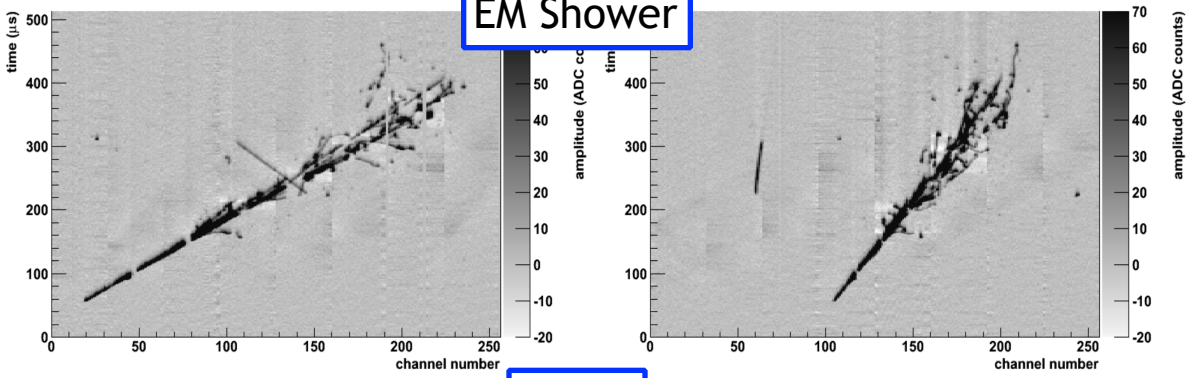
- 10 fC/cm – ~10 k e^- for each strip (3 mm pitch,2 views) – SNR of 10 (noise of 1000 e^-)
- SNR of 100 – gain of 20 is needed

Events from double phase LAr LEM TPC

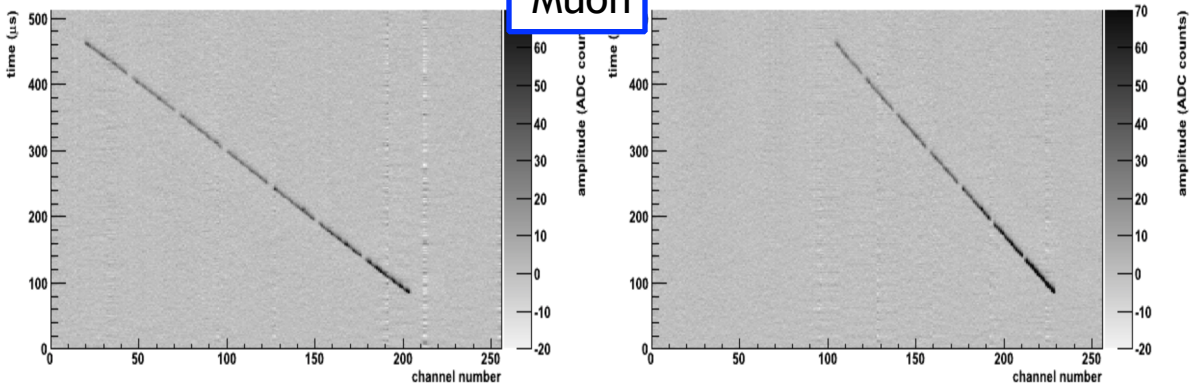
Hadronic Shower



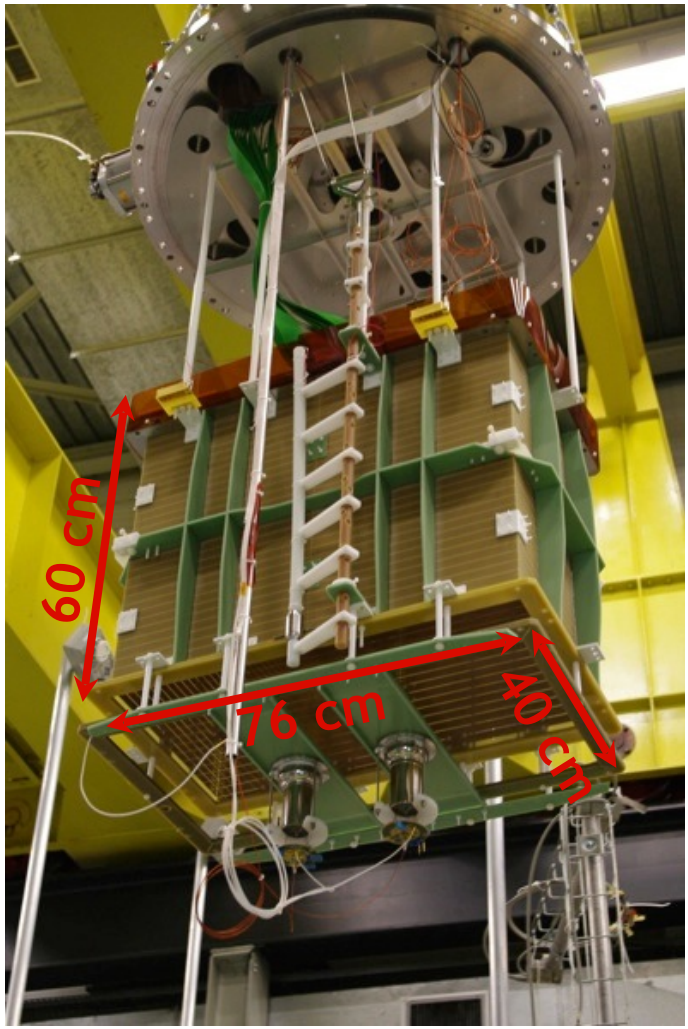
EM Shower



Muon

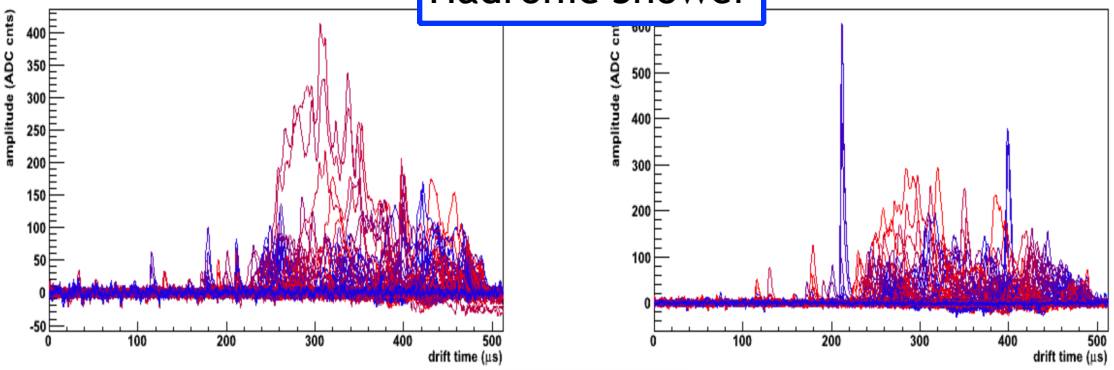


40x76x60 cm^3 LAr LEM TPC

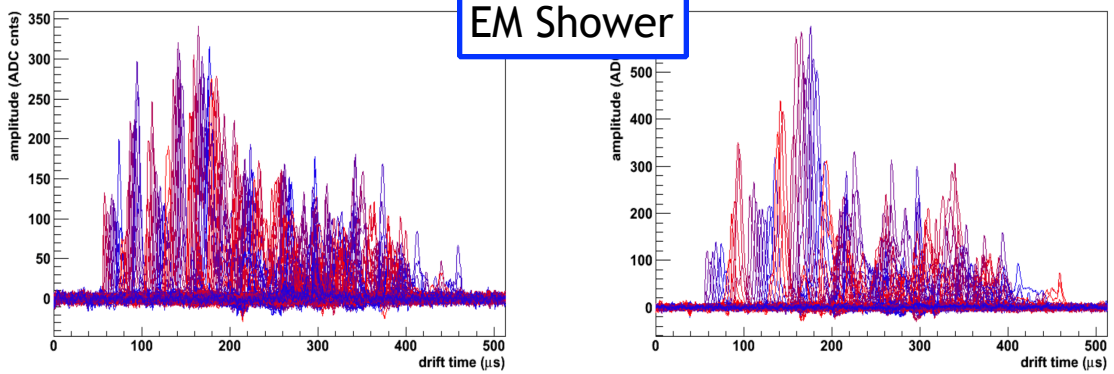


Events from double phase LAr LEM TPC

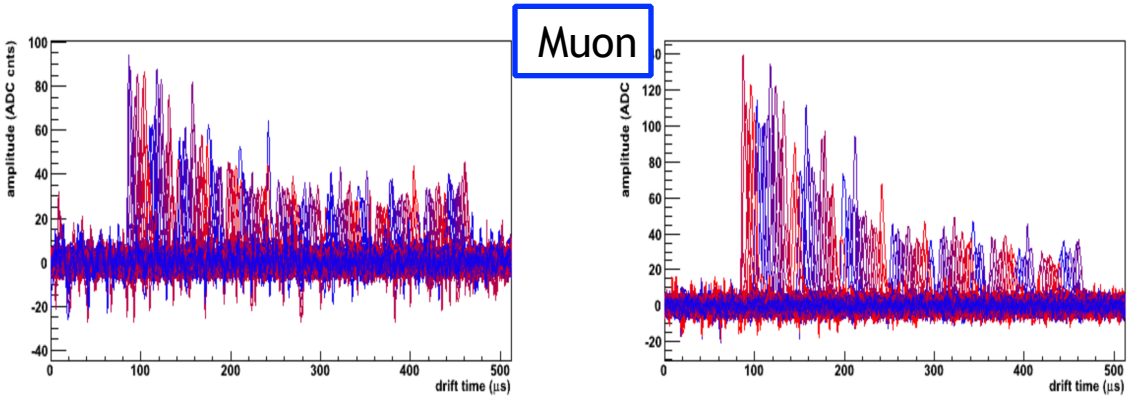
Hadronic Shower



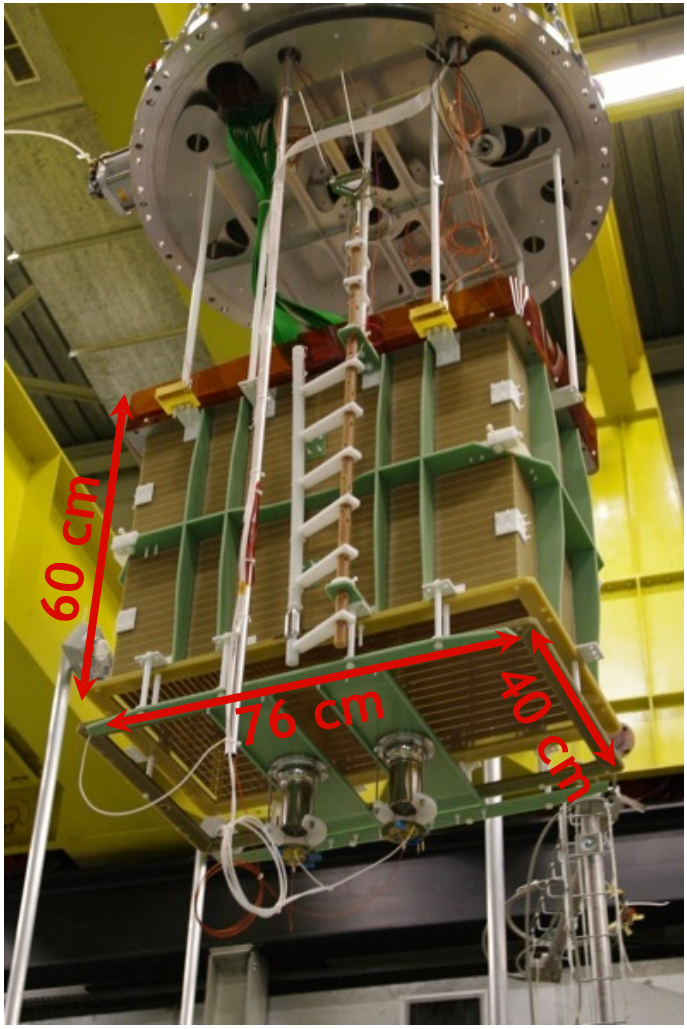
EM Shower



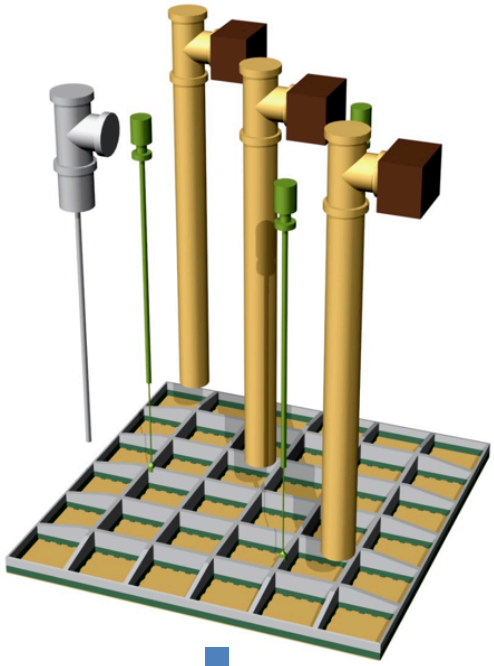
Muon

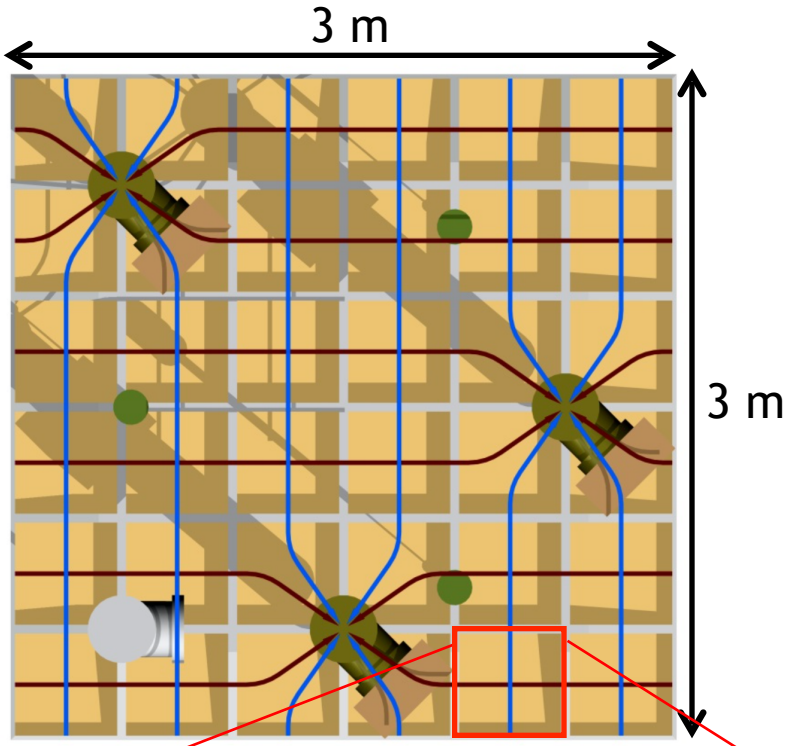


40x76x60 cm^3 LAr LEM TPC

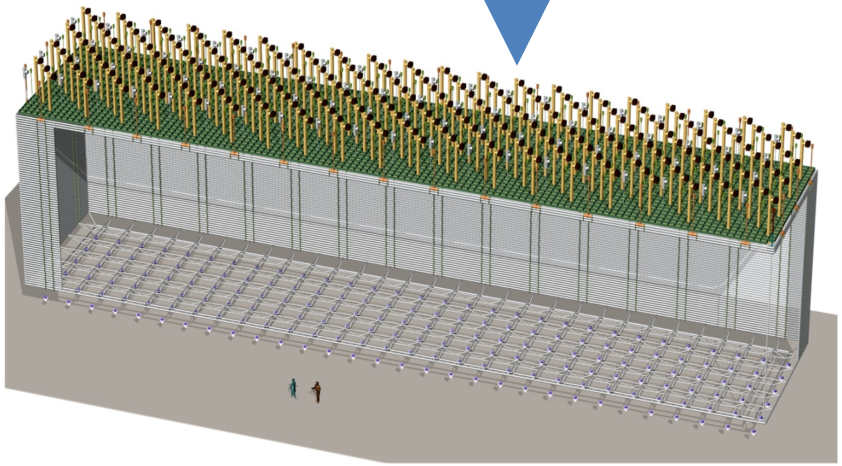


The 3x3 m^2 charge readout plane (CRP) for DUNE

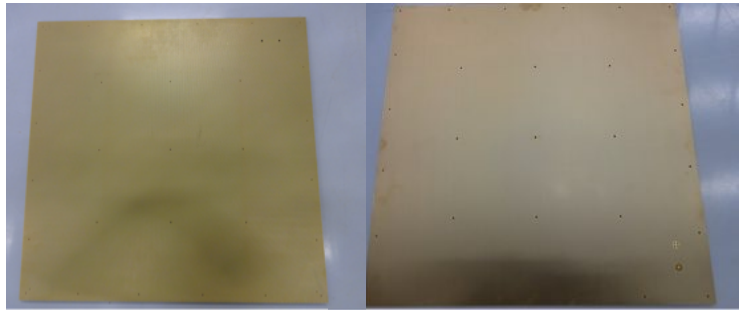




2880 0.5x0.5 m^2 LEMs



0.5x0.5 m^2 anode 0.5x0.5 m^2 LEM 3x3 m^2 grid

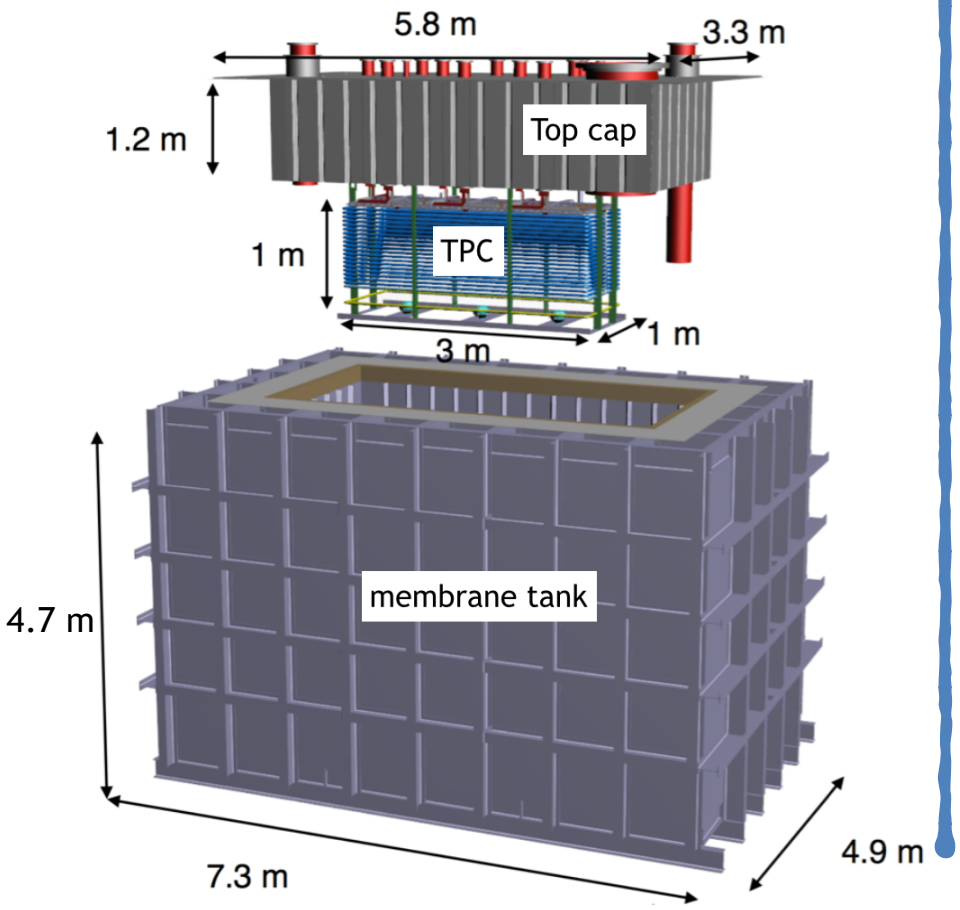


The WA105 experiment at CERN

– double phase LAr LEM TPC demonstrators

3x1x1 m^3 DLAr-proto

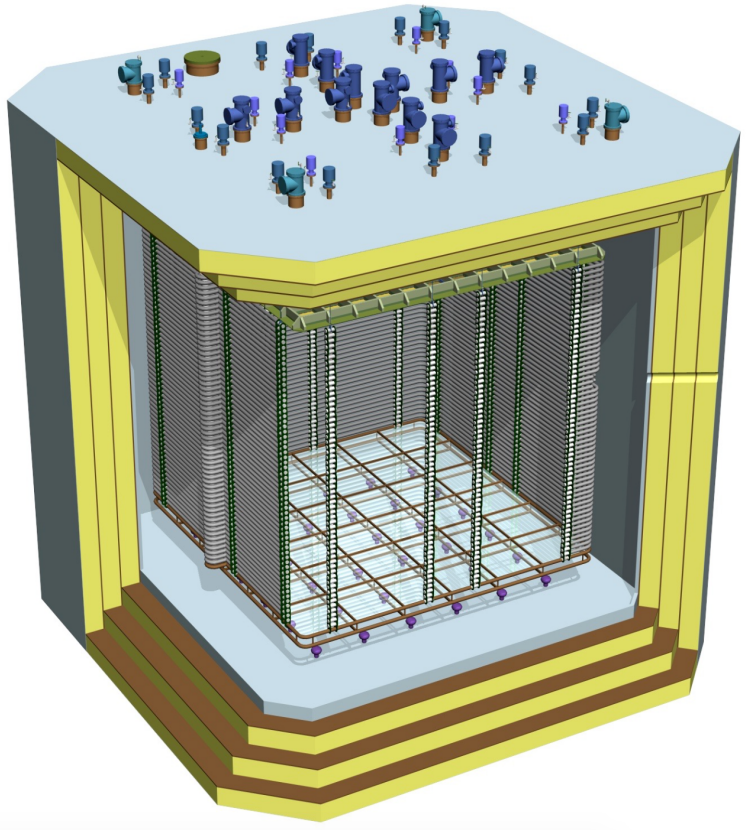
12 50x50 cm^2 LEMs



Timescale: 2015-2016

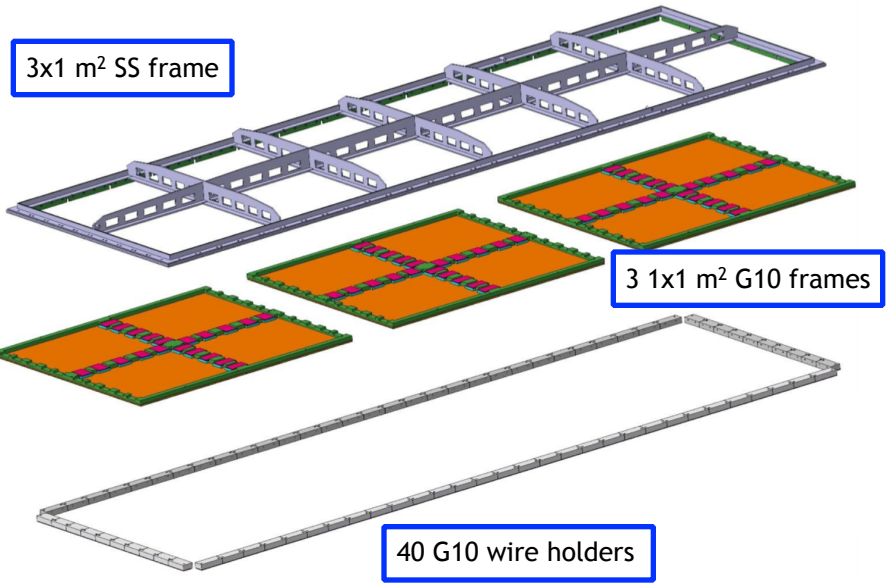
6x6x6 m^3 DLAr in beam test

144 50x50 cm^2 LEMs

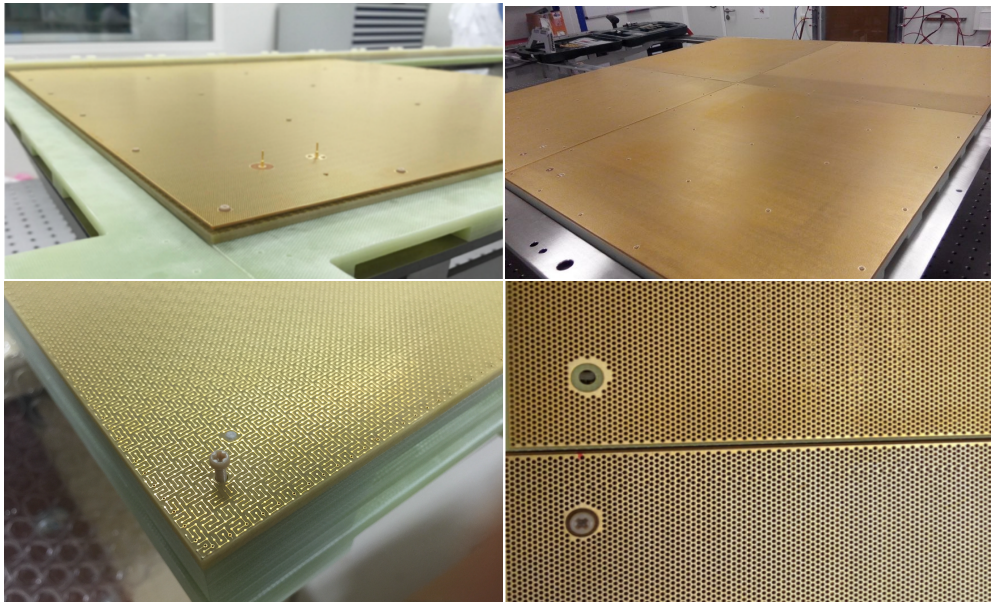


Timescale: 2016-2019

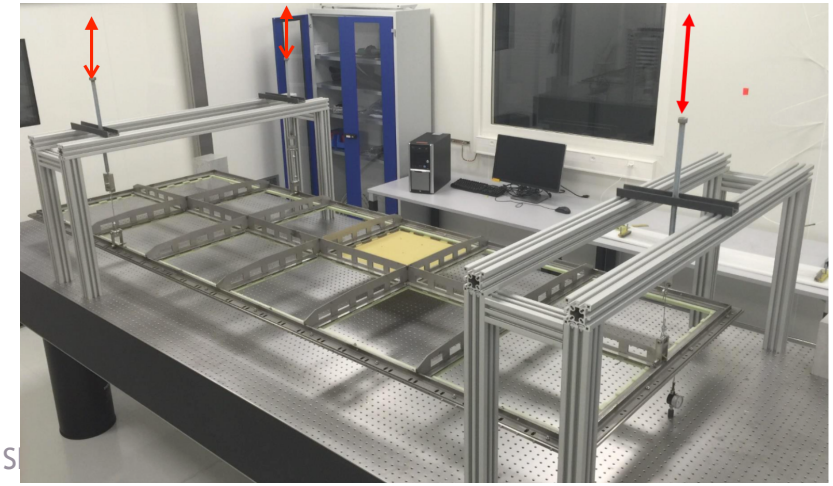
The 3x1 m^2 CRP



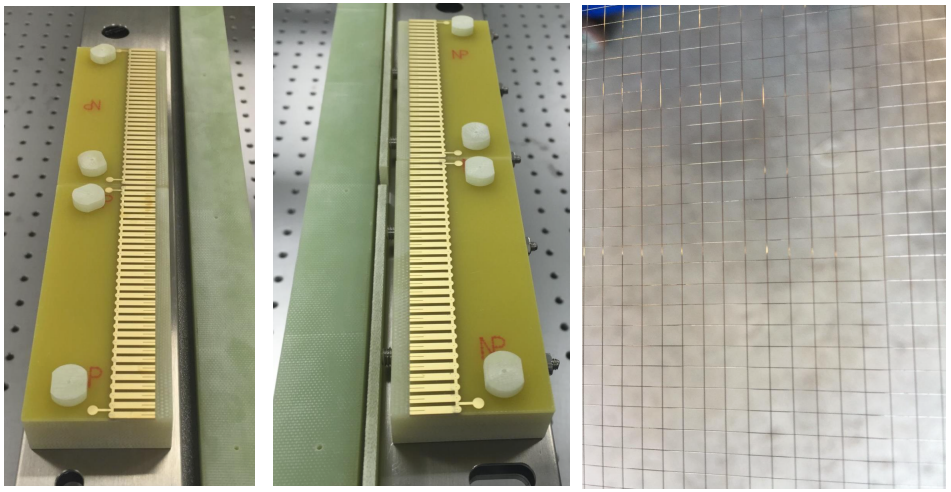
LEM-Anode assemble



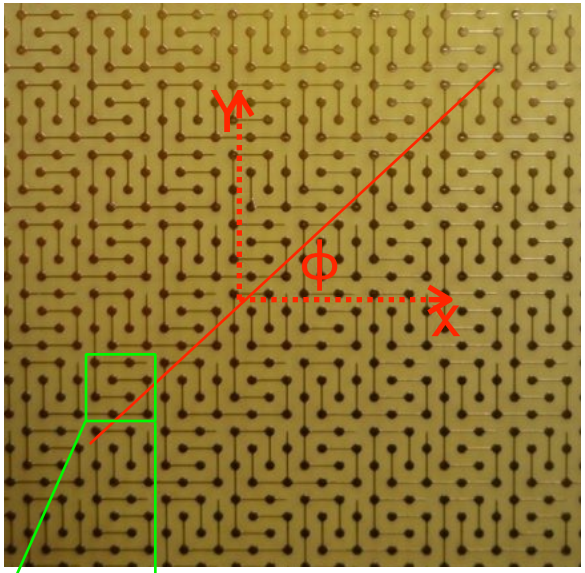
CRP is hang through 3 points

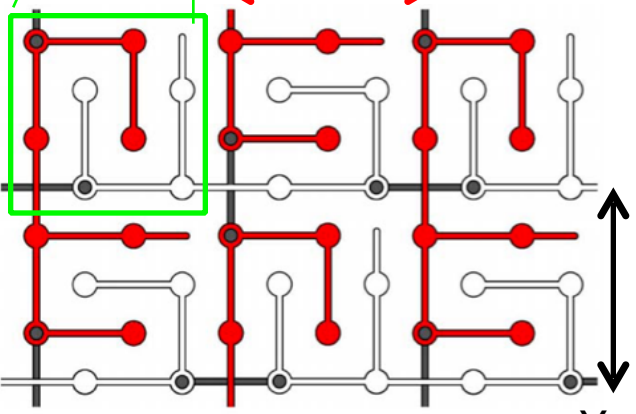


Wire holder and extraction grid



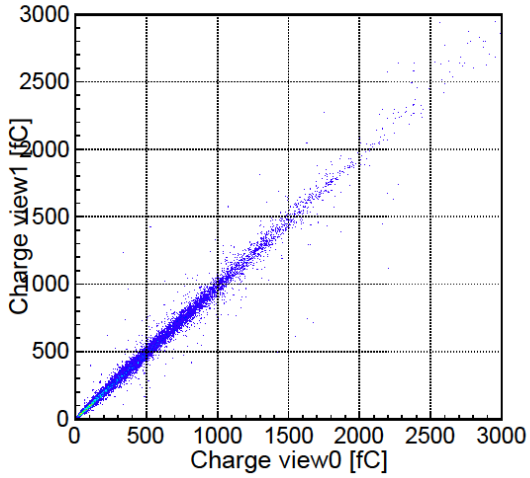
Design of the low capacitance 2D anode

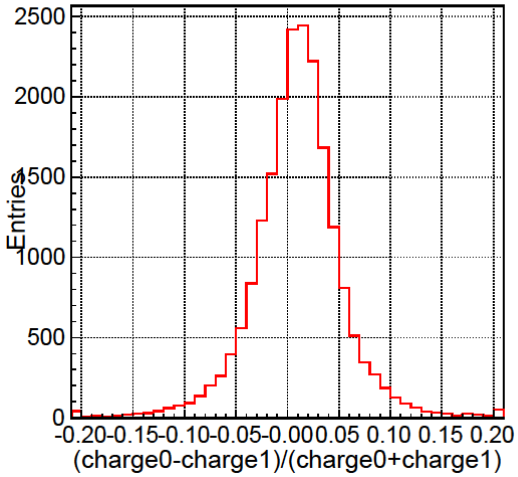




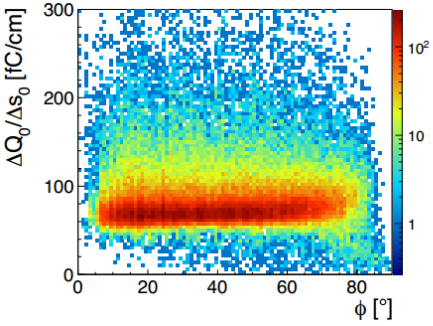
dC/dl~150 pF/m

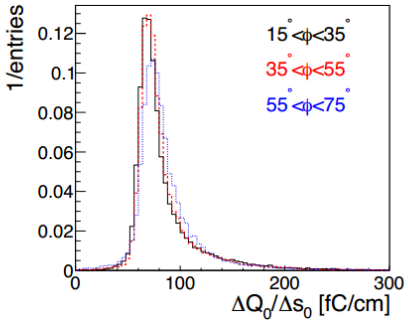
Fully X-Y symmetric:

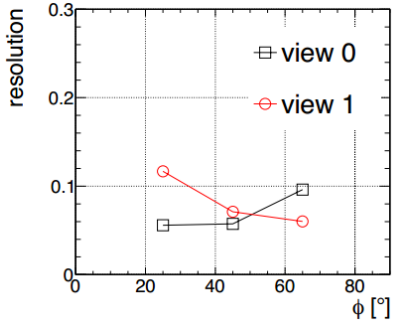




Uniform response to all tracks:

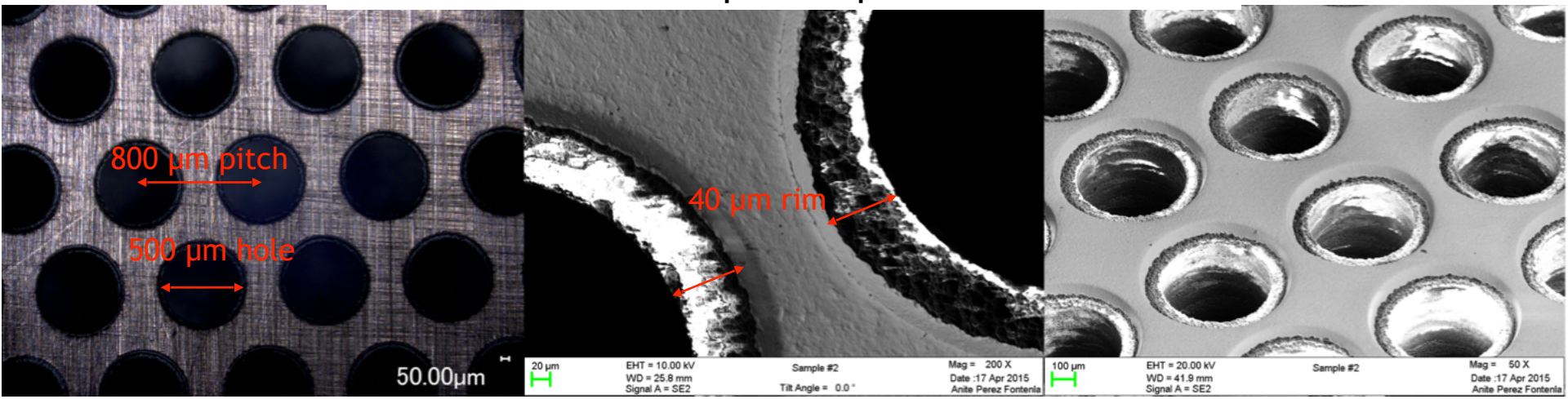






JINST 9 P03017

Optimisation of LEM parameters on 10x10 cm^2 LEM in double phase operations

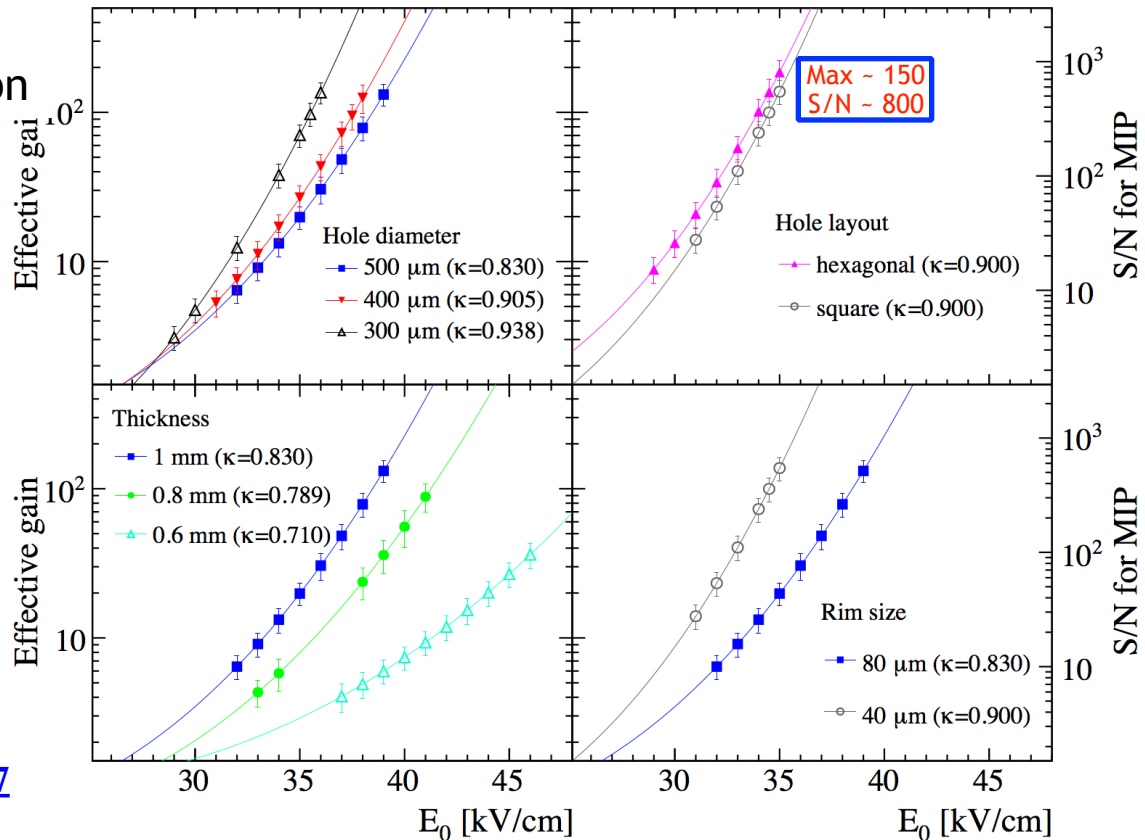


LEM gain and maximal gain depends on

- Rim size
- Thickness of FR4
- Hole diameter
- Geometry of hole layout

Optimised values

- 40 µm rim
- 1 mm FR4 thickness
- 500 µm diameter hole
- 800 µm hole pitch and hexagonal layout



2015 JINST 10 P03017

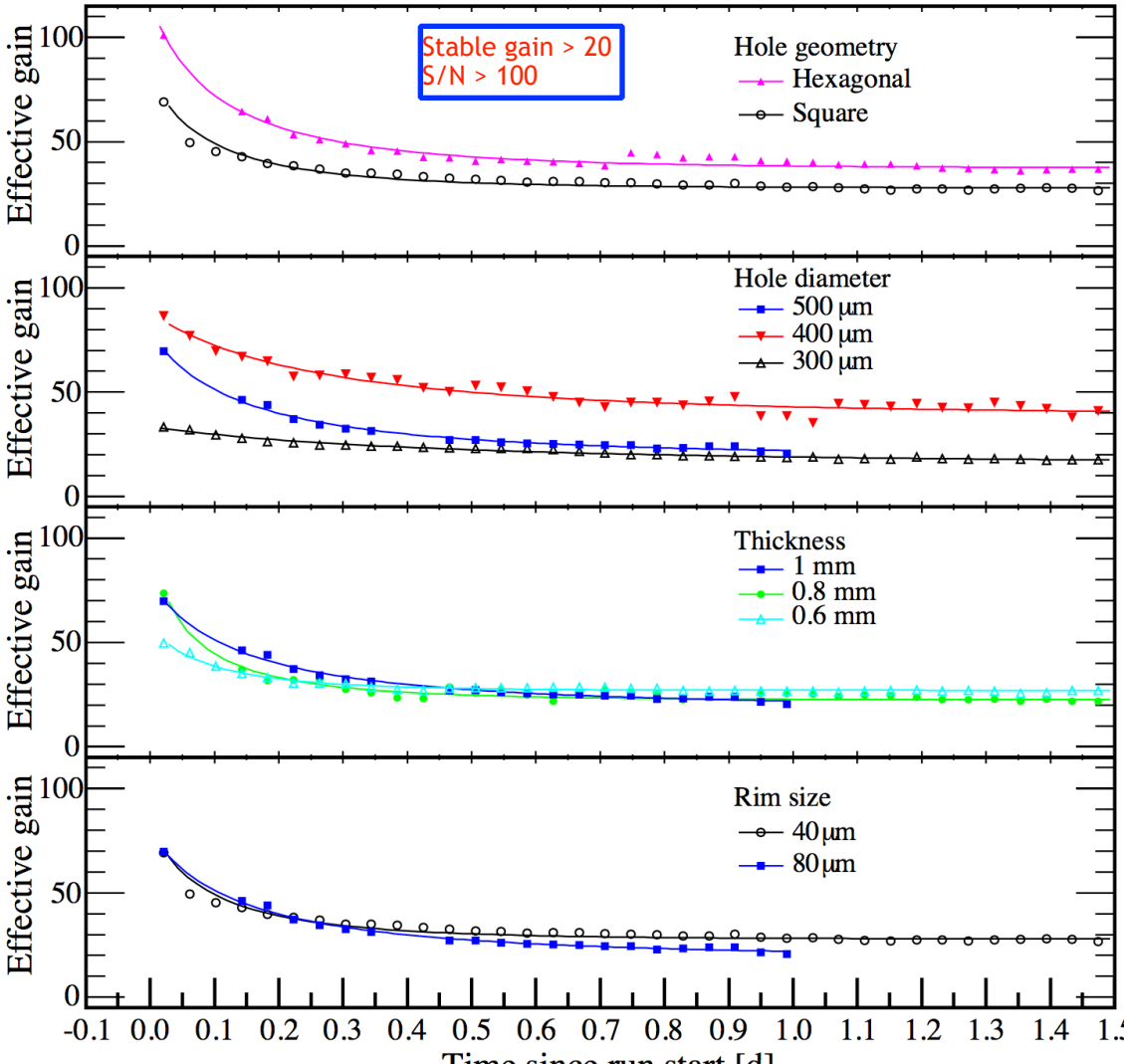
10x10 cm^2 LEM charging-up behaviours in double phase operations

"discharge free" operation mode

Parameter	Value	LEM	E_0 [kV/cm]	Run-time [hrs]	No. of discharges
geometry	hexagonal	3	34	110	0
	square	5	34	52	0
hole	500 μm	2	38	24	0
	400 μm	4	37	50	2
	300 μm	6	33.5	75	3
thickness	1 mm	2	38	24	0
	0.8 mm	1	42	82	0
	0.6 mm	7	46	95	1
rim size	80 μm	2	38	24	0
	40 μm	5	34	52	0

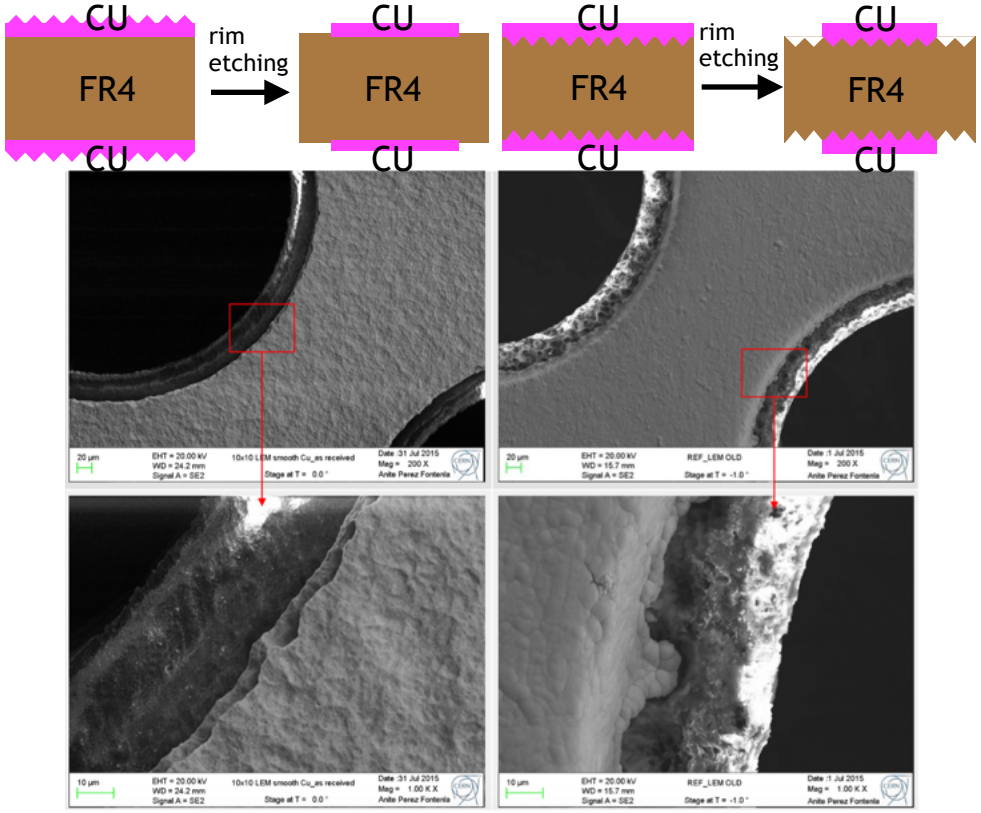
[2015 JINST 10 P03017]

Stable gain over 20

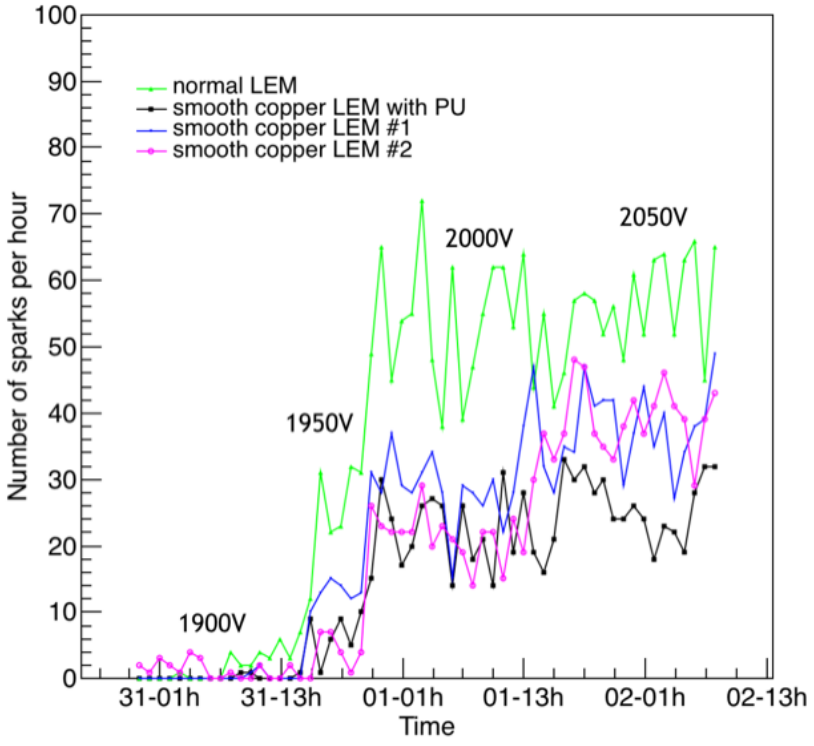


Investigation on other production processes

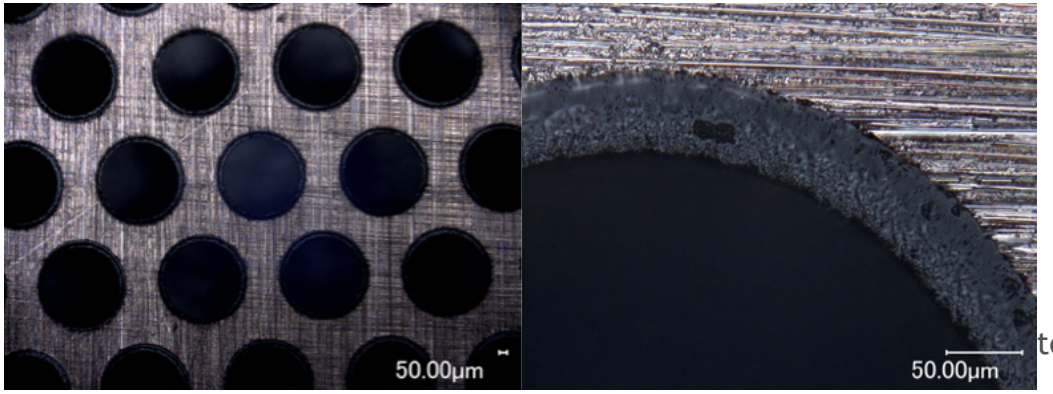
Smoothed FR4 surface



Test in Ar(90%)+CO_2(10%)



PU coating

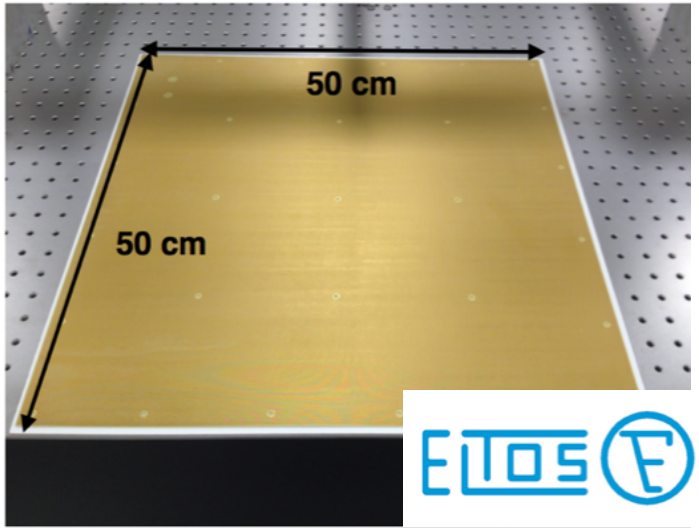


Breakdown voltage in Ar 87K:

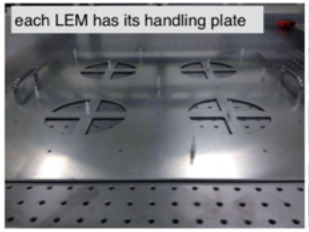
- Normal LEM 3500 V
- Smooth FR4 LEM 3450 V
- PU coated LEM 3500 V

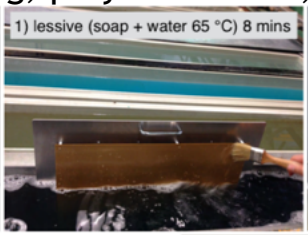
50x50 cm² LEM quality assurance — production and cleaning

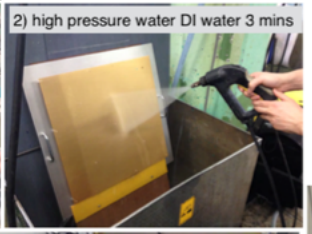
production from ELTOS

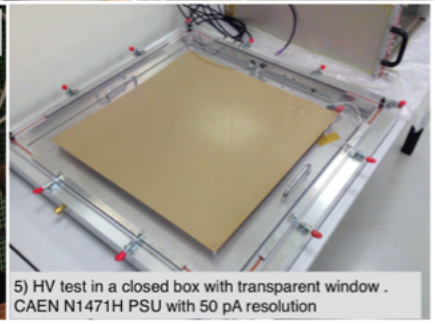


Cleaning, polymerization, HV test and storage at CERN









ELTOS

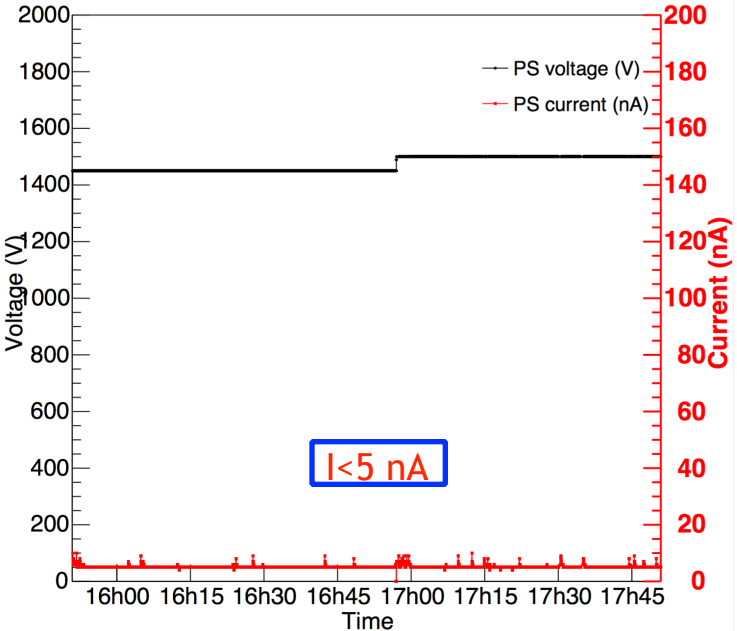
- CNC drilling
- mechanical polishing
- permanganate bath +rince — *removes glass fiber from holes*
- Rims by global etching — *acide sulphuric bath*
- passivation (Chromic acid)
- Ni/Au plating

CERN

- ultrasonic bath DM water
- lessive (soap) bath at 60°C — *removes grease*
- karcher DM water — *removes dust/dirt in holes*
- baking 3 hrs at 180 degrees
- HV test

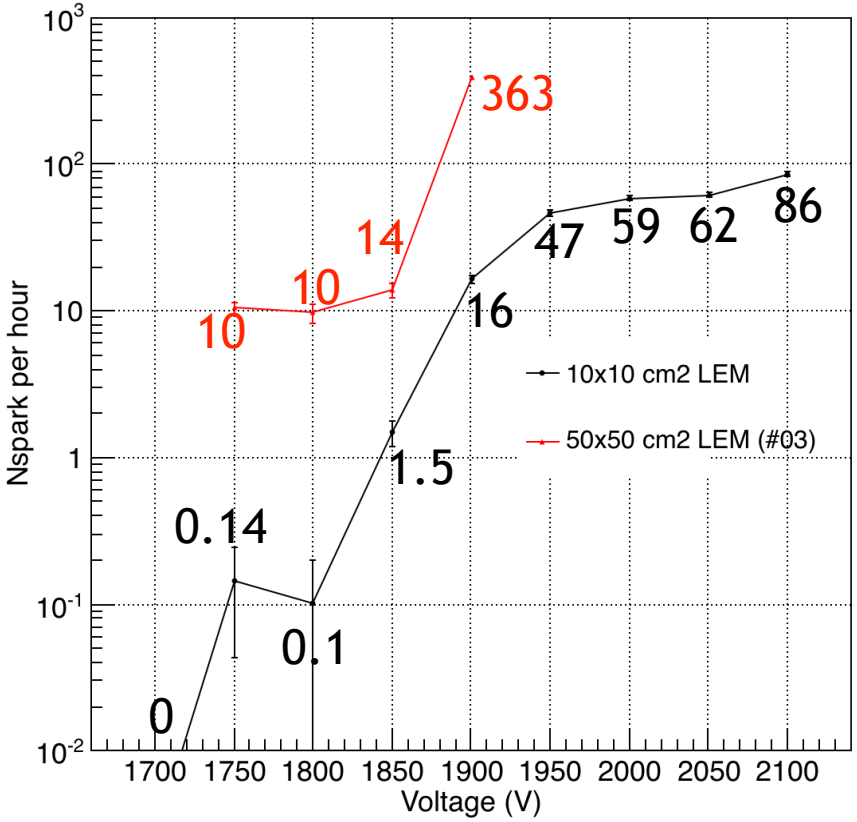
HV test not ok / HV test ok → storage + test

Low leakage current after cleaning

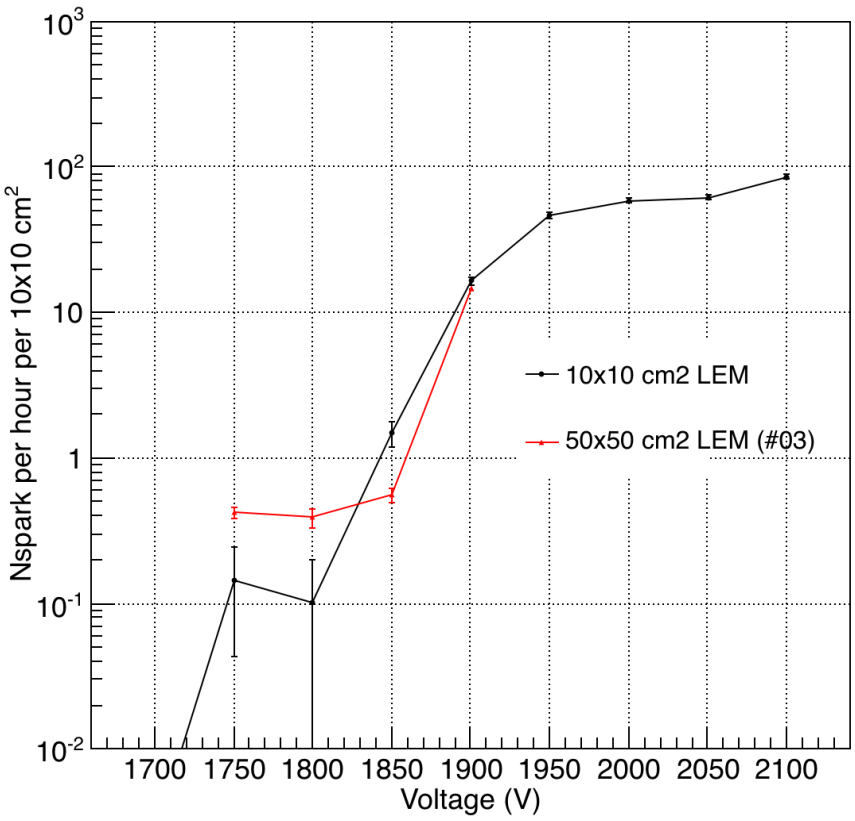


50x50 cm² LEM quality assurance – HV test in room temperature gas

Discharge rate in Ar(90%)+CO2(10%)

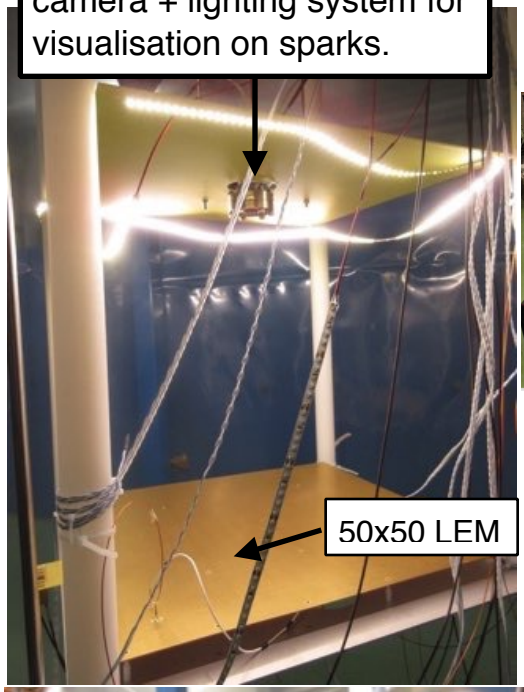


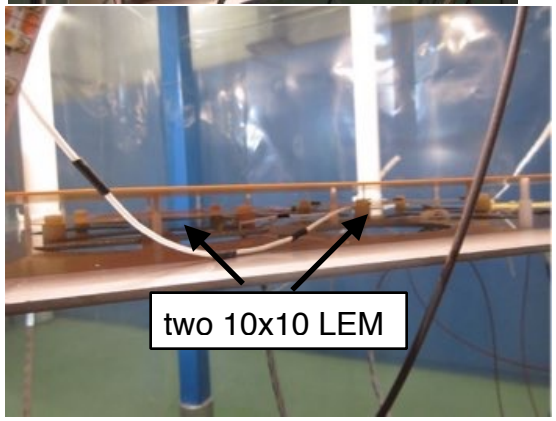
discharge rate normalised to 10x10 cm² area



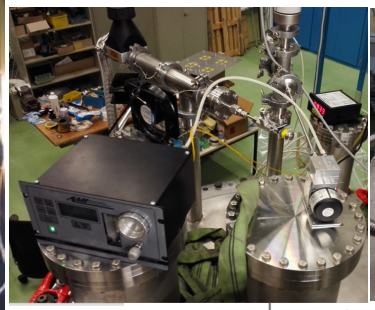
- 50x50 cm² LEM has similar quality as 10x10 cm² LEM and there is no particular bad holes
- Operation of 50x50 cm² LEM in warm gas is difficult due to discharges
- 50x50 cm² LEM is expected to reach similar breakdown voltage as 10x10 cm² LEM due to very rare discharges of 10x10 cm² LEM

Test 50x50 cm^2 LEM in cold Ar gas

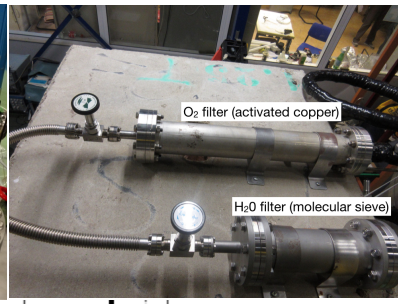


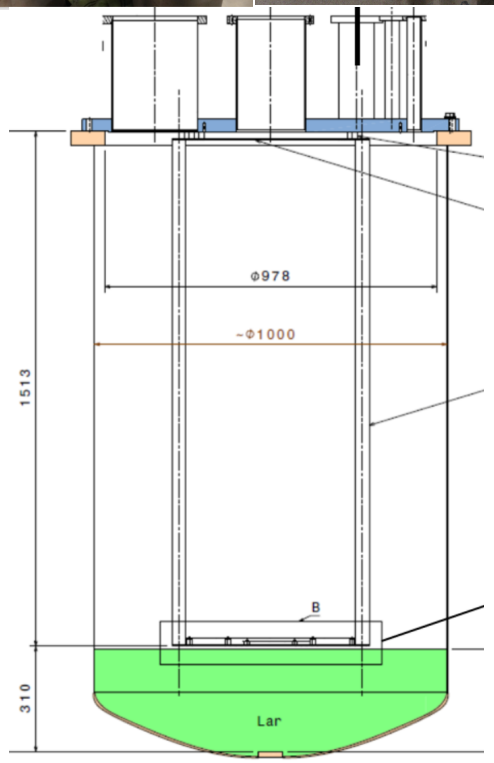


oxygen analyser



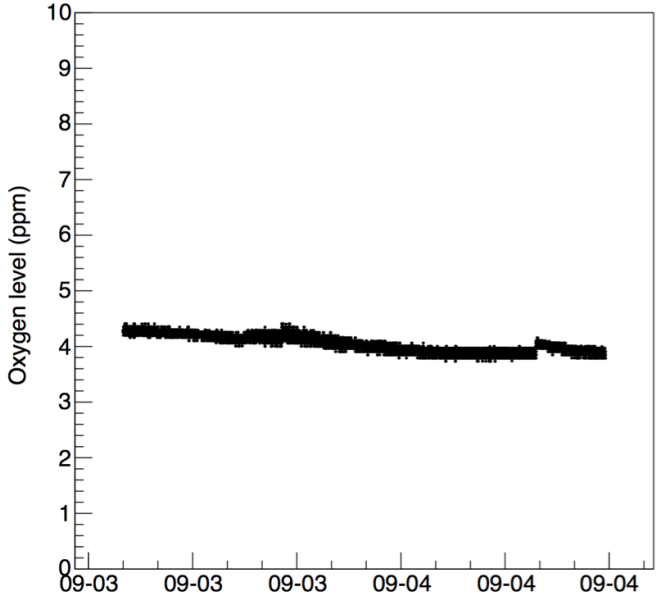
Ar filter



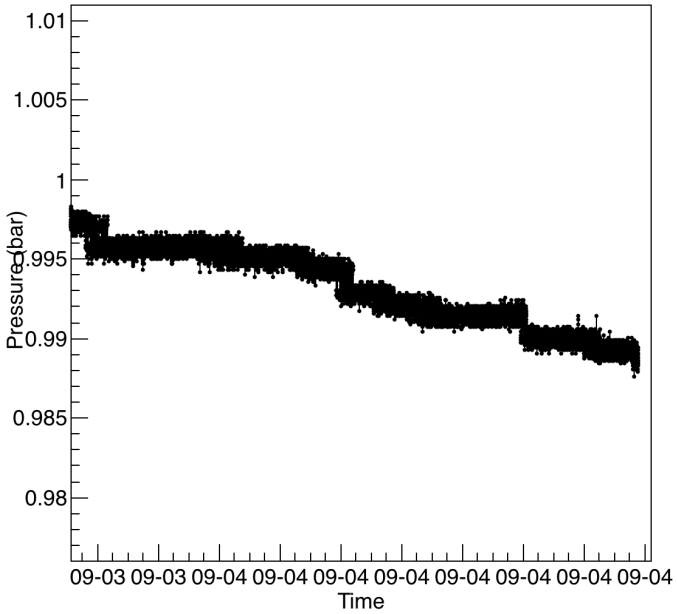


Well controlled gas conditions

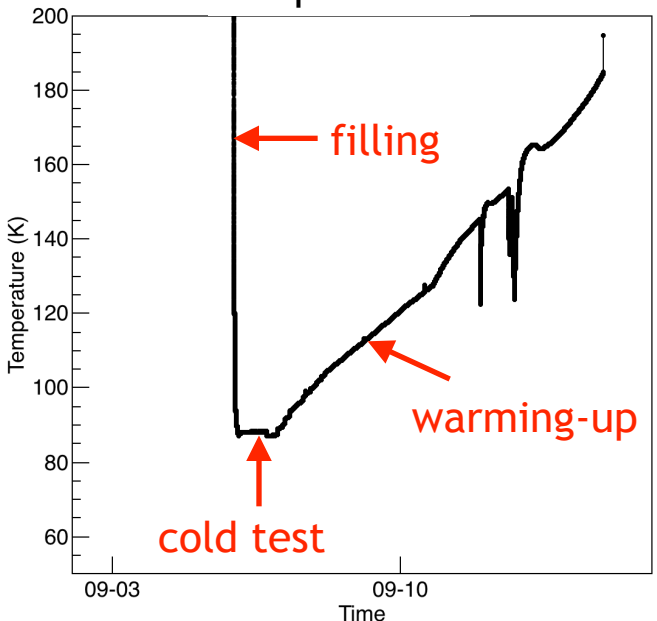
Oxygen level



Pressure



Temperature



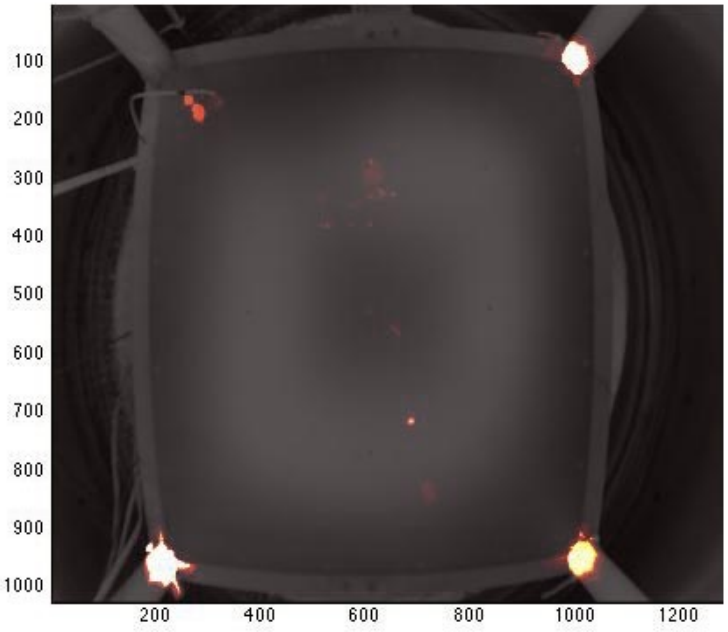
First test results

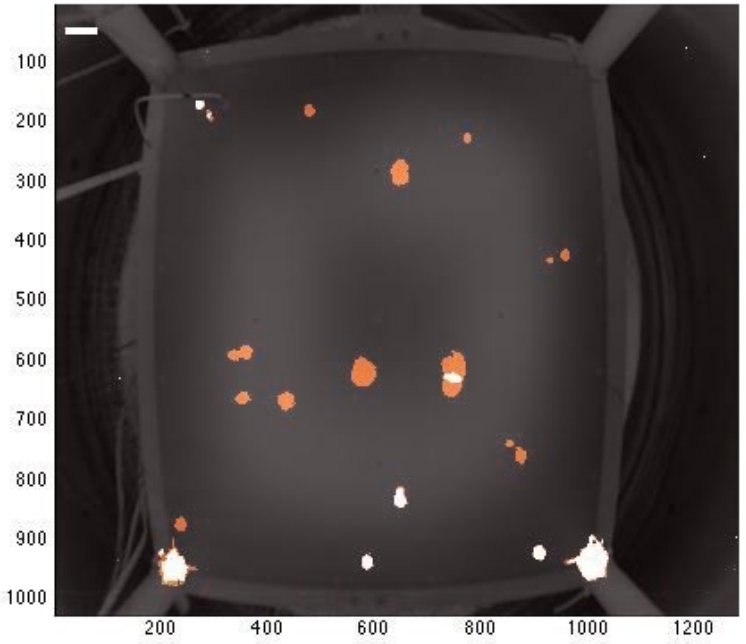
at P=0.989 bar, **T=88 K** and purity ~ 3 ppm

- two small 10x10 cm^2 LEM spark at 3500V and 3450 V. (consistent with previous double phase tests)
- 50x50 cm^2 LEM sparks at 4 corners at 2750 V.

at P=0.965 bar and **T=300 K**, ~ 10 ppm

- two small 10x10 spark at 1725 and 1750 V. (consistent with gas box tests)
- 50x50 sparks mainly at middle and sometimes corners at 1600 V.



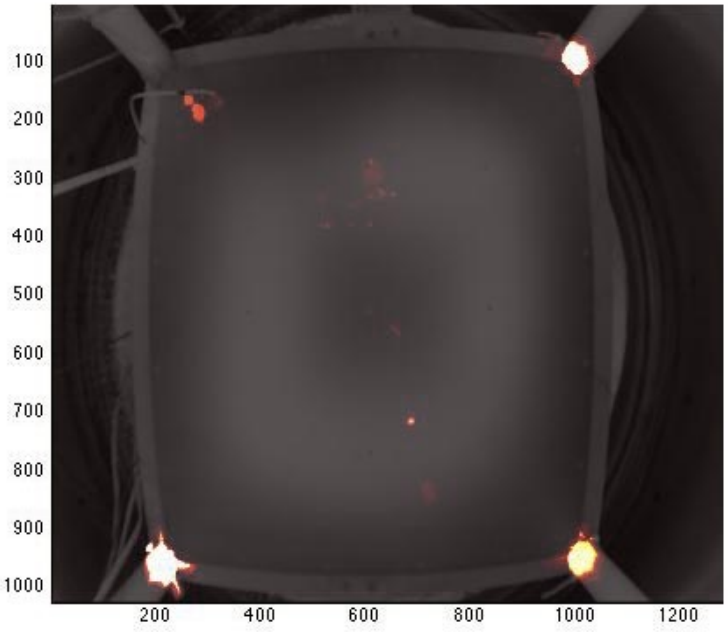


Edge effect becomes more critical in cold Ar

First test results

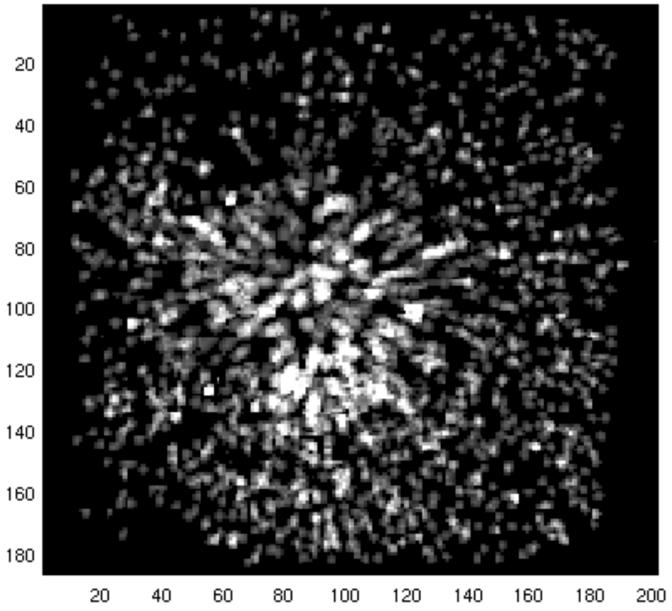
at P=0.989 bar, **T=88 K** and purity ~ 3 ppm

- two small 10x10 cm^2 LEM spark at 3500V and 3450 V. (consistent with previous double phase tests)
- 50x50 cm^2 LEM sparks at 4 corners at 2750 V.



at P=0.965 bar and T=300 K
(Ar 90% CO2 10%)

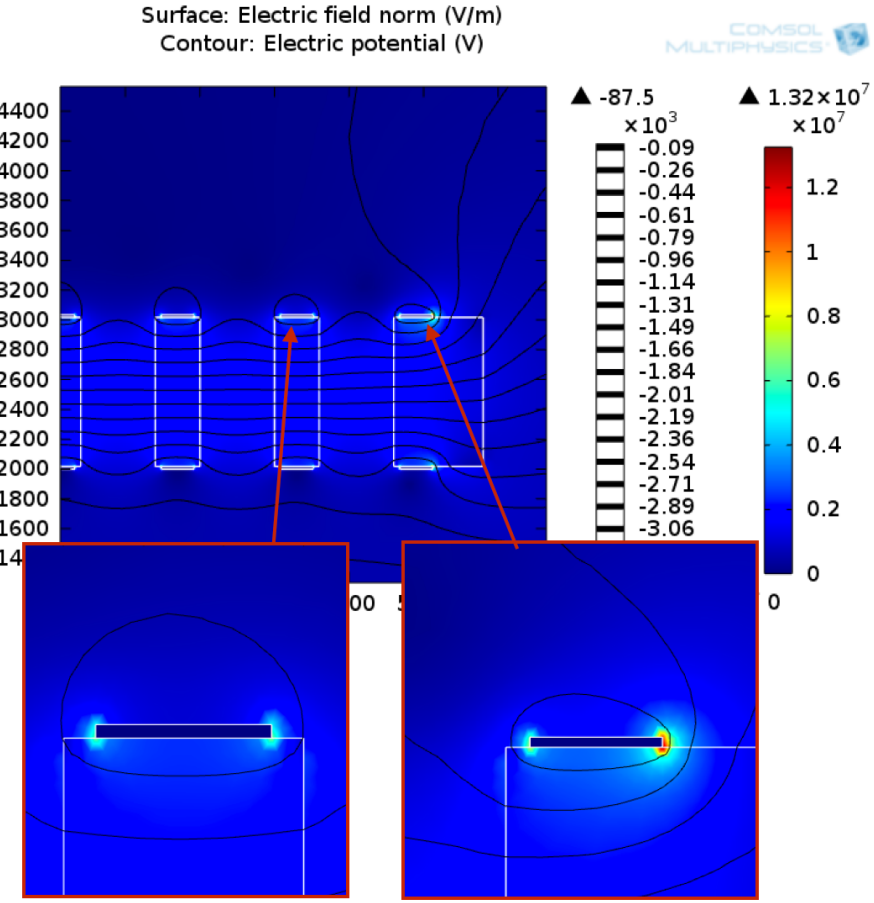
- 50x50 cm^2 LEM sparks only at middle at 1900 V.

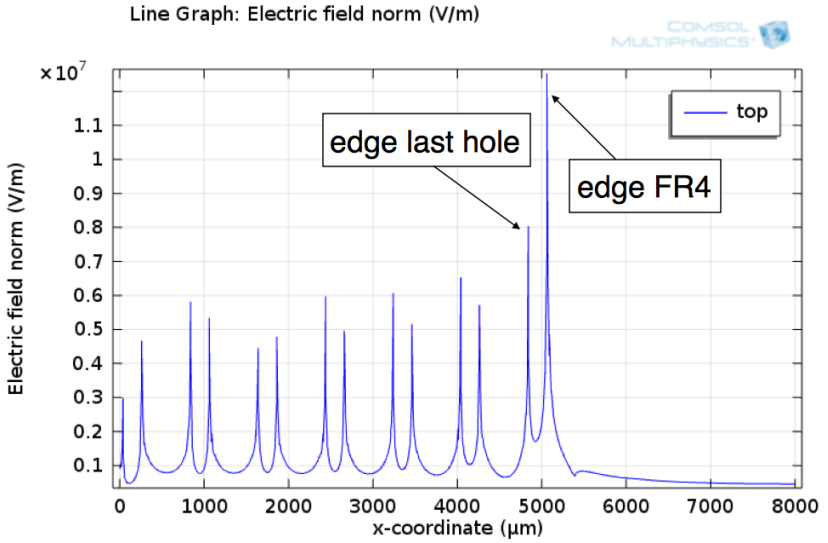


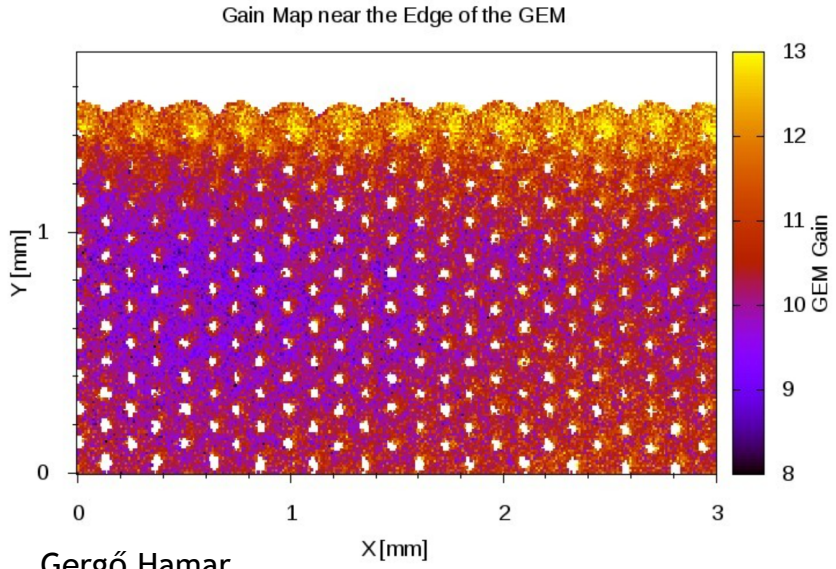
Edge effect becomes more critical in cold Ar

E_{LEM} and gain is larger in the last holes

Electric field configuration with
100 µm guard ring, 500 µm FR4 clearance





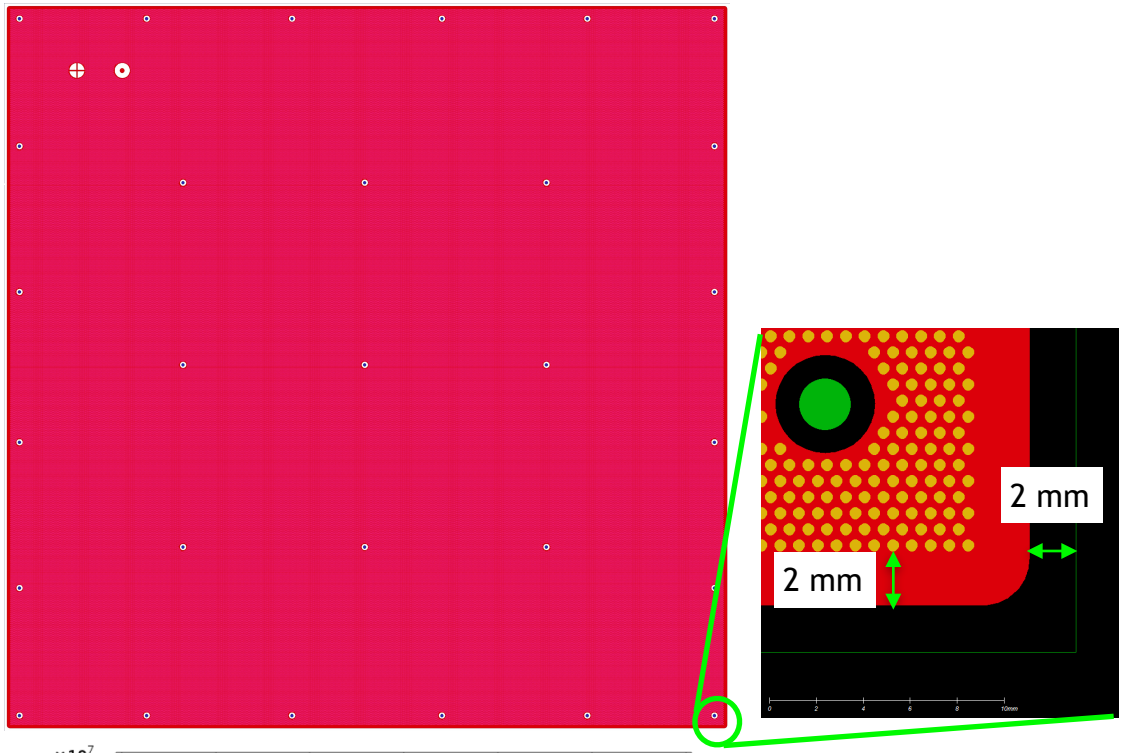


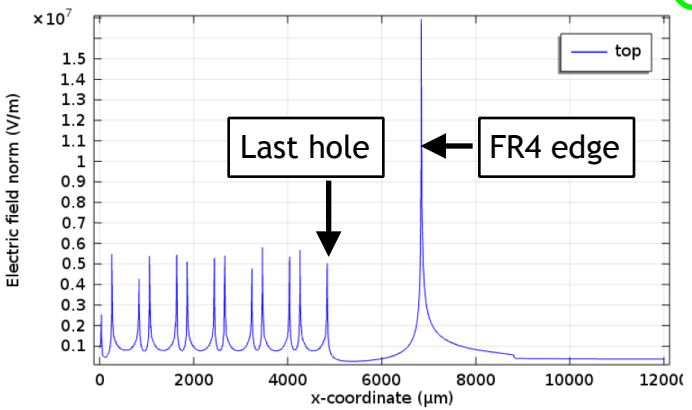
Gergő Hamar

http://www.ccsem.infn.it/issp2015/newtalents/HamarG_Erice_Leopard_201506.pdf

Next steps with 50x50 cm^2 LEM cold test

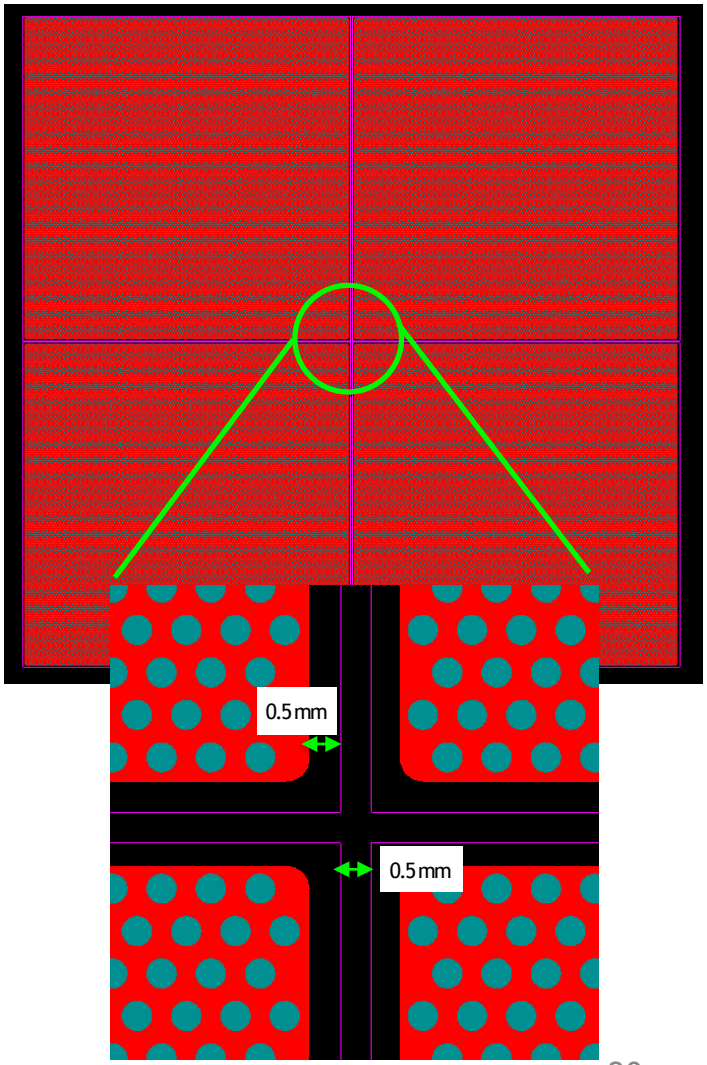
50x50 cm^2 LEM with 2 mm guard ring and 2 mm FR4 clearance





Timescale: beginning Nov

Test with 4 10x10 cm^2 LEMs together



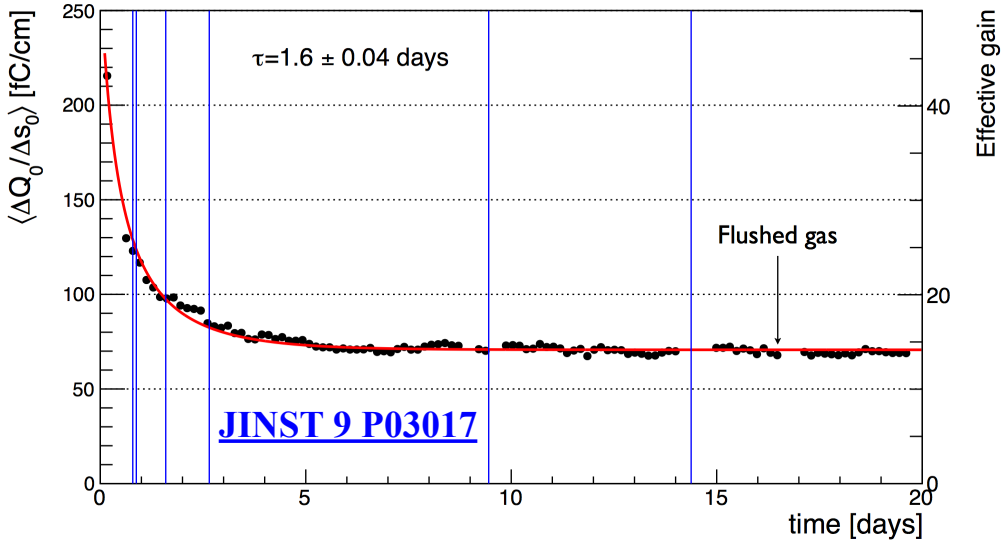
Next steps with 50x50 cm^2 LEM cold test

- Current 50x50 cm^2 LEM cold test does not simulate charging-up effect.
- Charging-up makes LEM stable
  — less and less discharges
- Charging-up improves the breakdown voltage

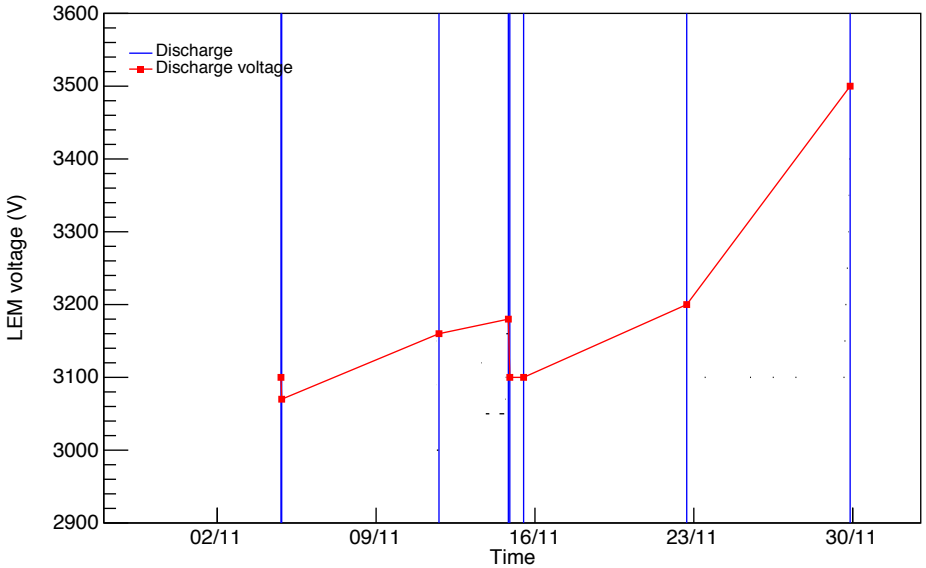
Next step:

To build a micro-TPC including anode, LEM and extraction grid to simulate the charging-up.

Fewer and fewer discharges with charging-up in a 10x10 cm^2 LEM test



Discharge voltage improves with charging-up in the 40x76 cm^2 (250 L) LEM test



Summary

➢ LEM has the potential application for future neutrino physics — the 40-kTon DUNE experiment will require large area (700 m^2 LEM for one 10-kTon module).

➢ We have a defined process of production and quality insurance of 50x50 cm^2 LEMs.

➢ The 10x10 cm^2 LEMs have a known behaviour and works at a gain over 20 at a discharge rate typically < 1 per day.

➢ First tests 50x50 cm^2 LEM in cold argon gas suggests special care should be taken due to the edge effect.

➢ The cold test with improved LEM is foreseen at beginning of November.

Thank you for your attention!

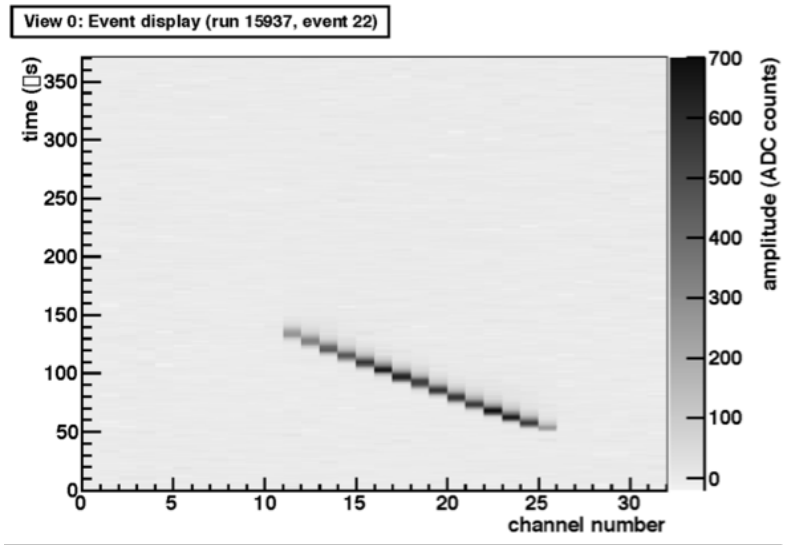
tested parameter	value	$\mathscr{T}$	x (mm)	G_{eff}^{max}	E_0^{max} (kV/cm)
hole layout	hexagonal	0.59± 0.18	0.96±0.07	182	35
	square	0.34± 0.14	0.94±0.08	123	35
hole diameter	500 μm	0.46± 0.14	0.73±0.05	124	39
	400 μm	0.41± 0.11	0.81±0.05	124	38
	300 μm	0.20± 0.03	0.88±0.04	134	36
thickness	1 mm	0.46± 0.14	0.73±0.05	124	39
	0.8 mm	0.46± 0.15	0.69±0.06	88	41
	0.6 mm	0.58± 0.2	0.55±0.06	36	46
rim size	40 μm	0.34± 0.14	0.94±0.08	123	35
	80 μm	0.46± 0.14	0.73±0.05	124	39

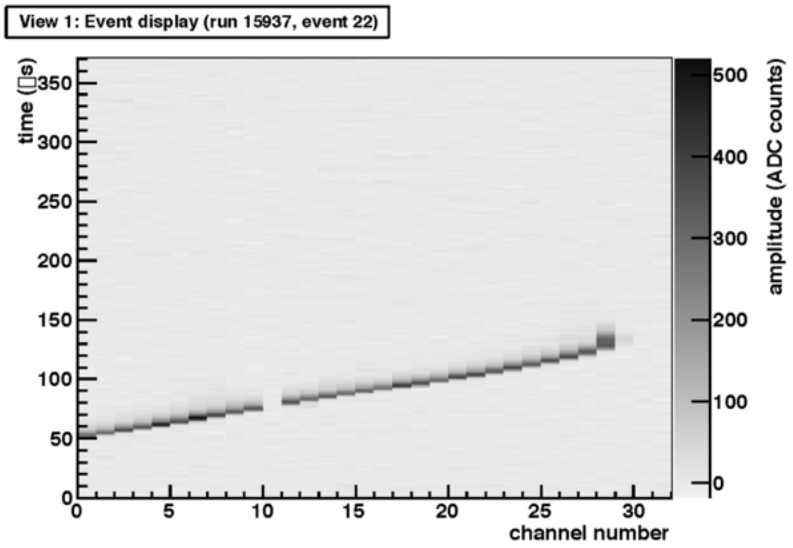
arXiv:1412:4402

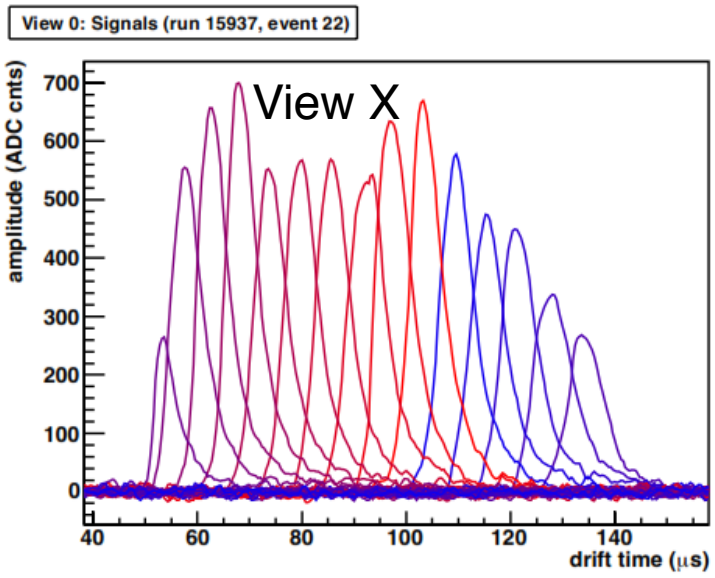
tested parameter	value	E_0 [kV/cm]	run-time [hrs]	Number of discharges	τ [days]	G^0_{eff}	G^∞_{eff}	$\frac{G^0_{eff}}{G^\infty_{eff}}$
geometry	hexagonal	34	110	0	0.32±0.07	99	35	2.7
	square	34	52	0	0.30±0.02	65	27	2.4
hole	500 μm	38	24	0	0.53±0.05	70	20	3.5
	400 μm	37	50	2	0.53±0.07	84	40	2.1
	300 μm	33.5	75	3	0.75±0.04	32	16	2.0
thickness	1 mm	38	24	0	0.53±0.05	70	20	3.5
	0.8 mm	42	82	0	0.24±0.02	73	22	3.3
	0.6 mm	46	95	1	0.18±0.01	51	27	1.9
rim size	80 μm	38	24	0	0.53±0.05	70	20	3.5
	40 μm	34	52	0	0.29±0.02	65	27	2.4

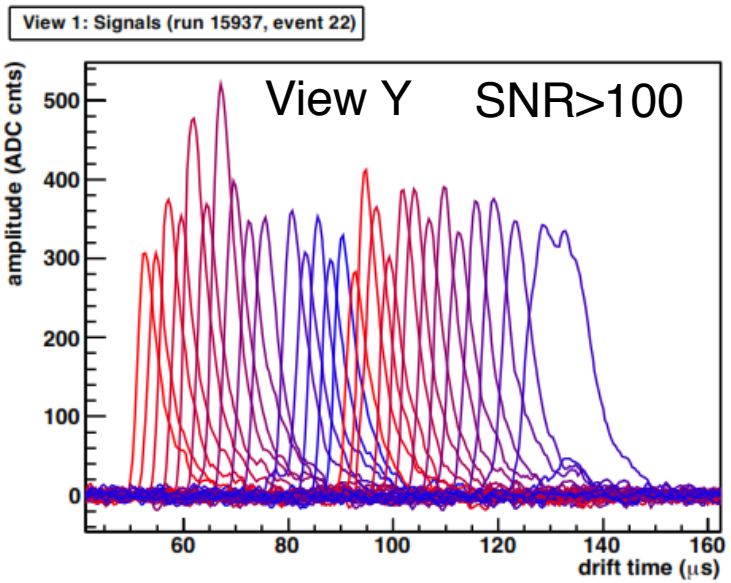
arXiv:1412:4402

Cosmic event in double phase TPC at effective gain~20

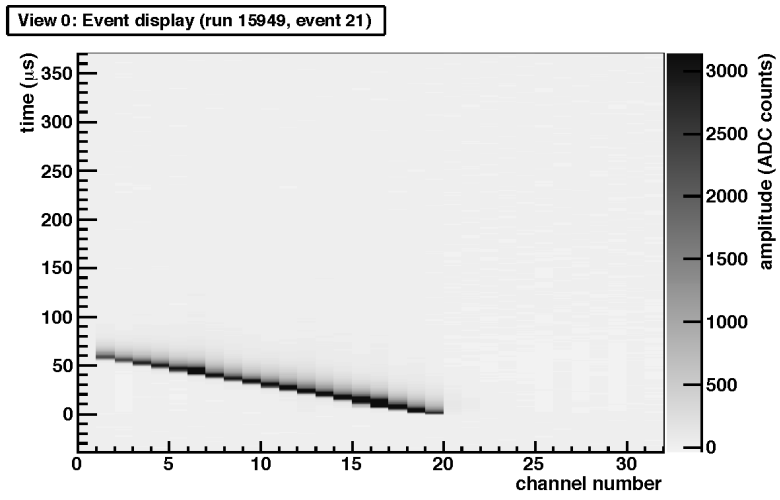


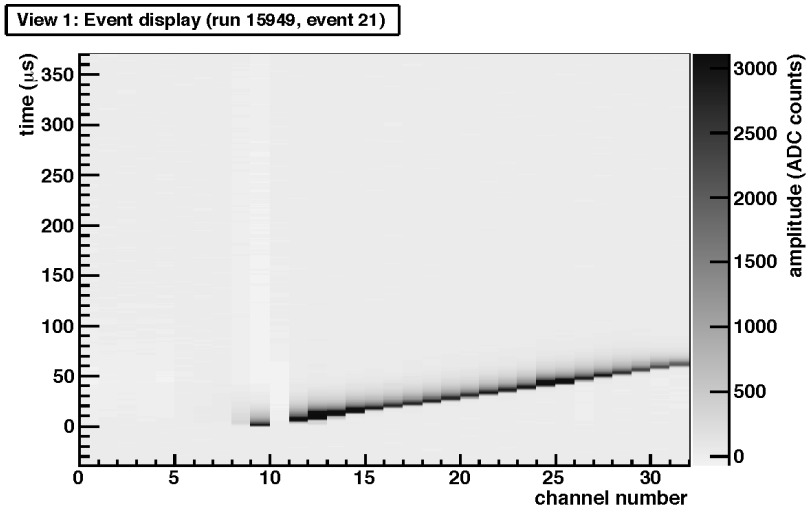


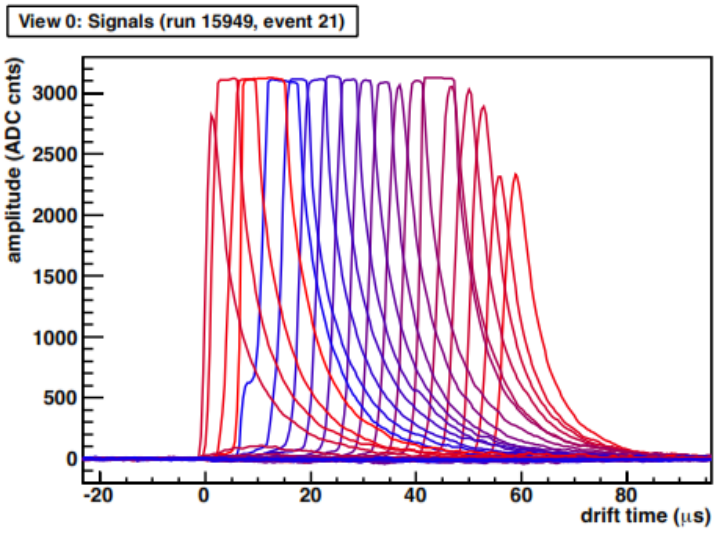


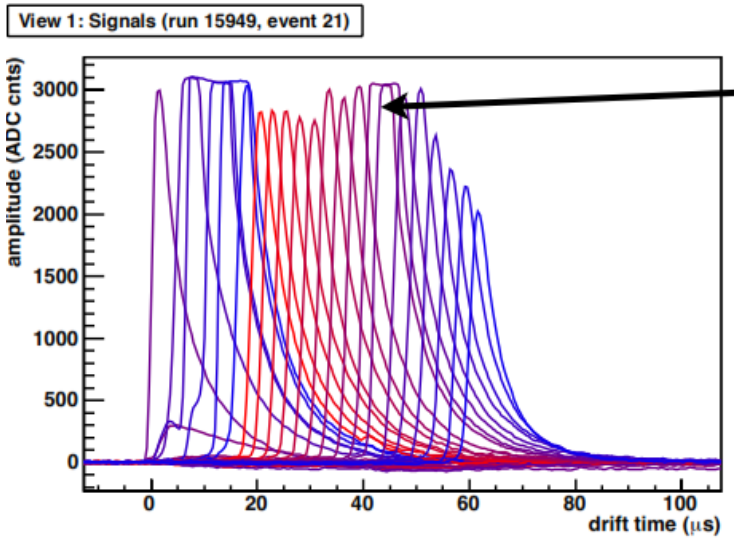


Cosmic event in double phase TPC at effective gain ~ 150



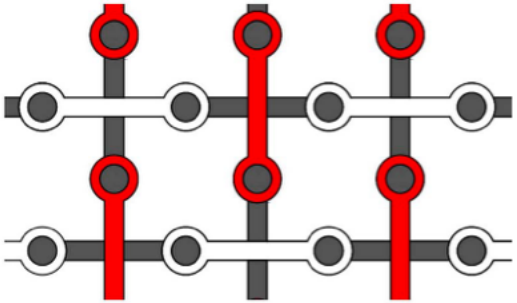




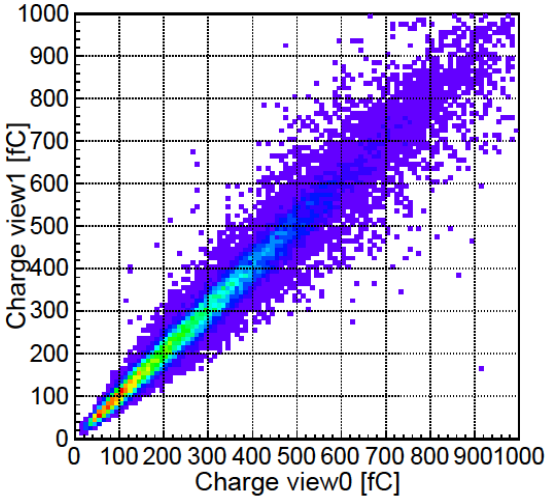


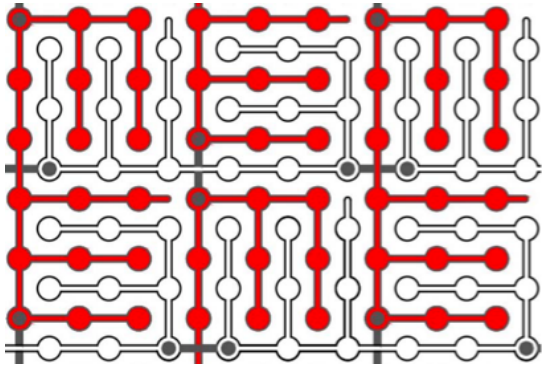
saturation of the pre-amp

Other anodes tested

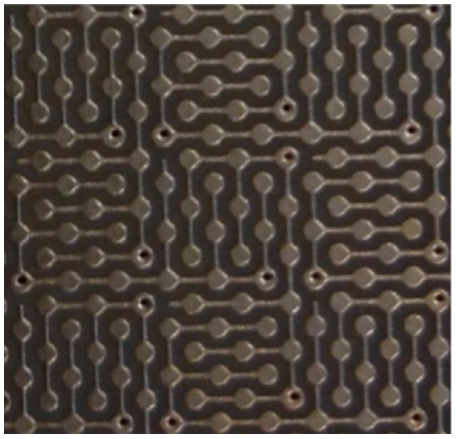


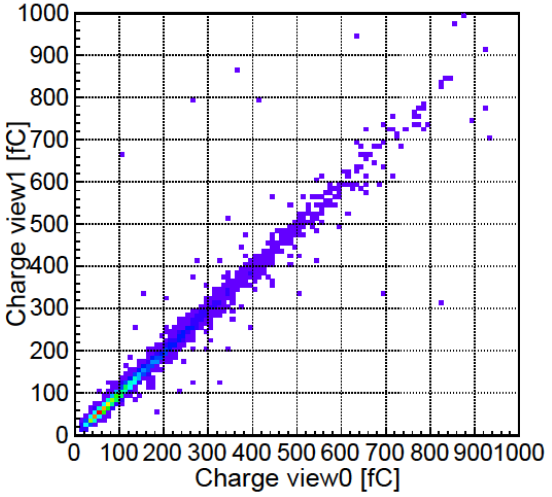
dC/dl~100 pF/m



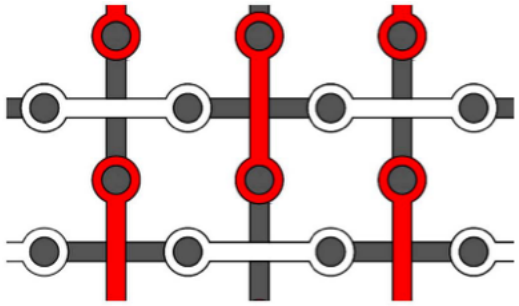


dC/dl~250 pF/m

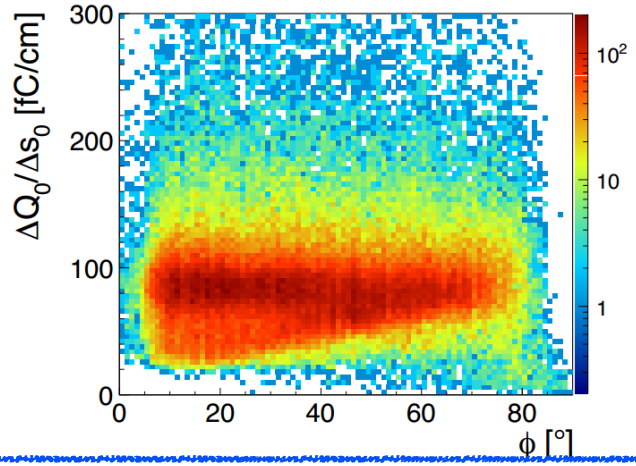


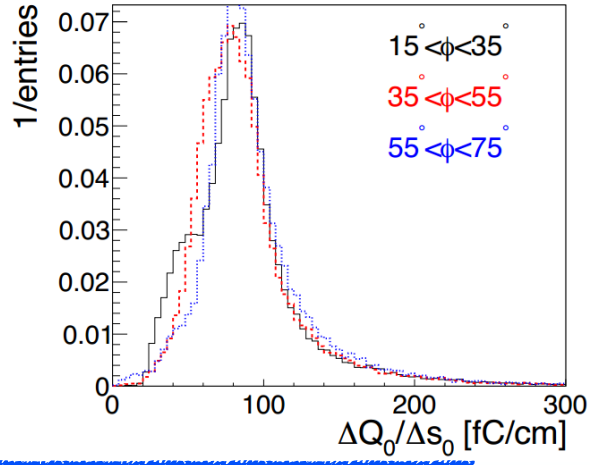


Other anodes tested



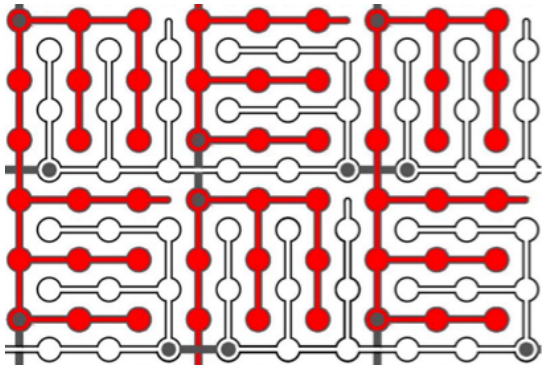
dC/dl~100 pF/m



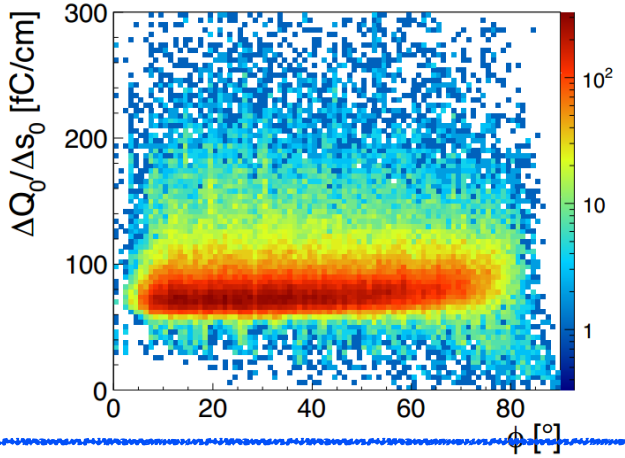


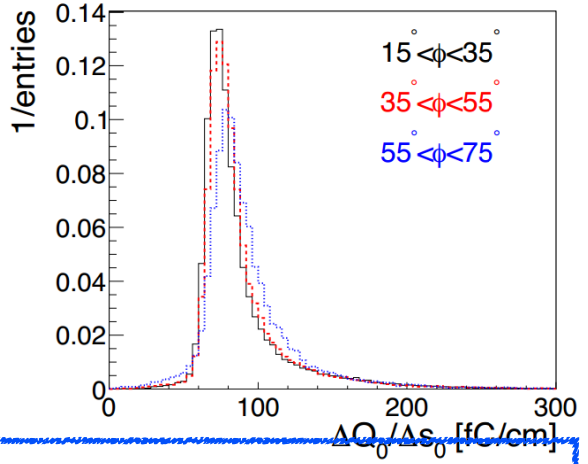
Pattern too loose, non uniform charge collection between strips

JINST 9 P03017



dC/dl~250 pF/m





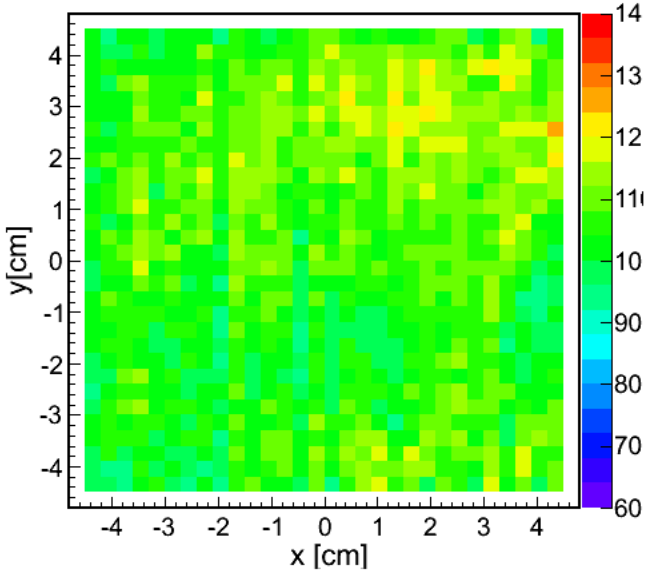
Compatible performance as 150 pF/m anode, but has higher capacitance

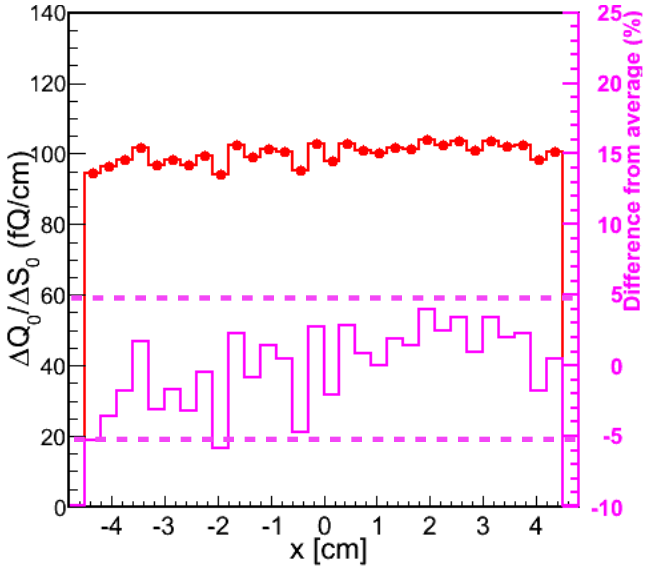
Gain uniformity

<dQ/dx> (fC/cm) (normalized to 100 fC/cm):

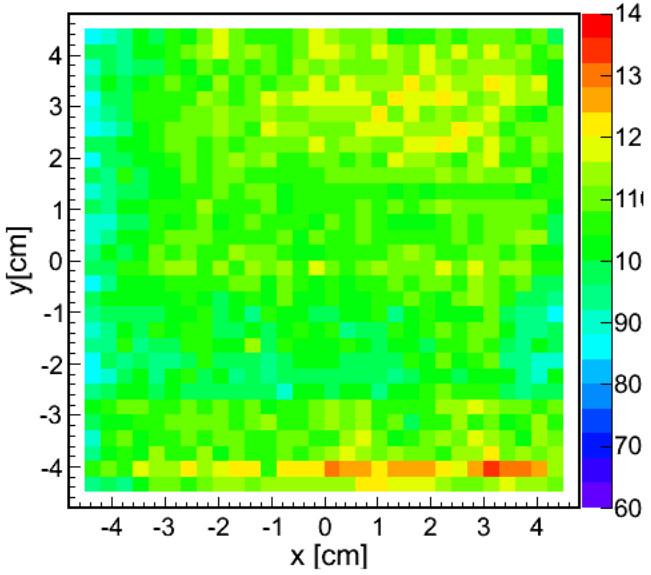
Projections on X and Y axis:

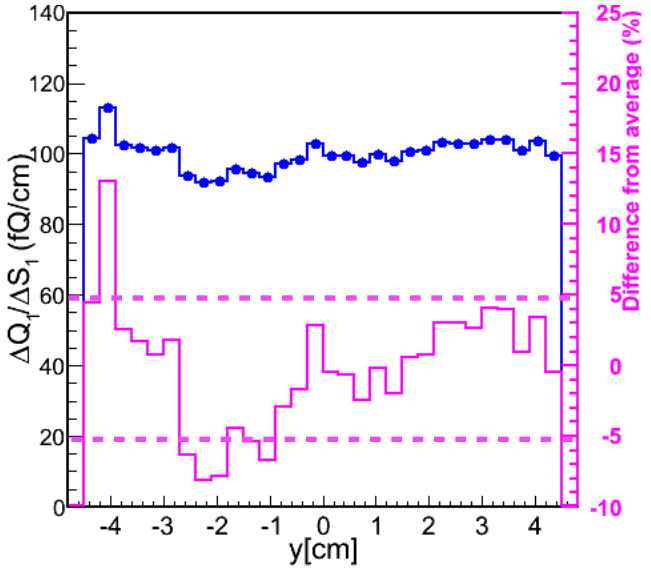
View 0



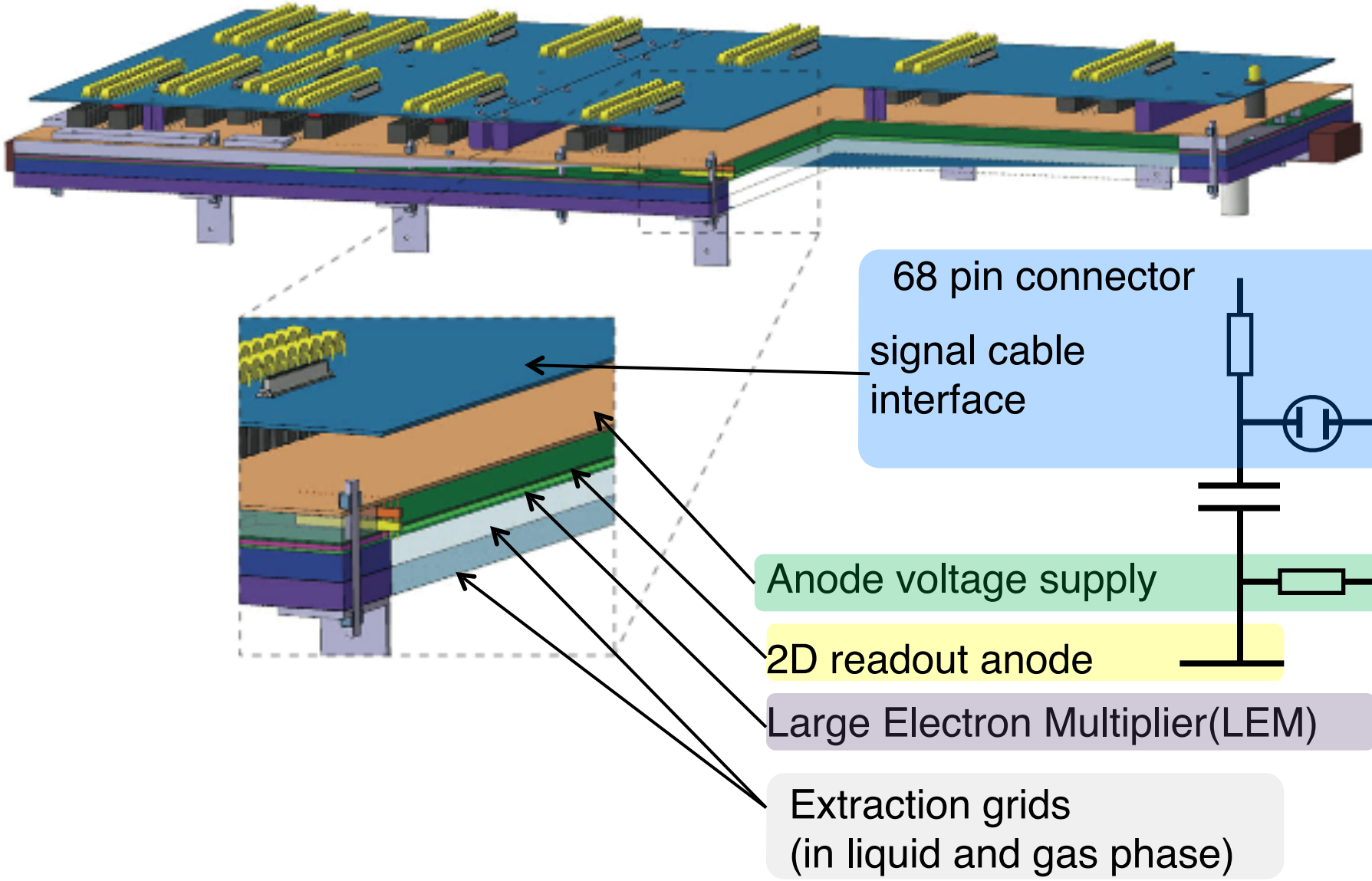


View 1





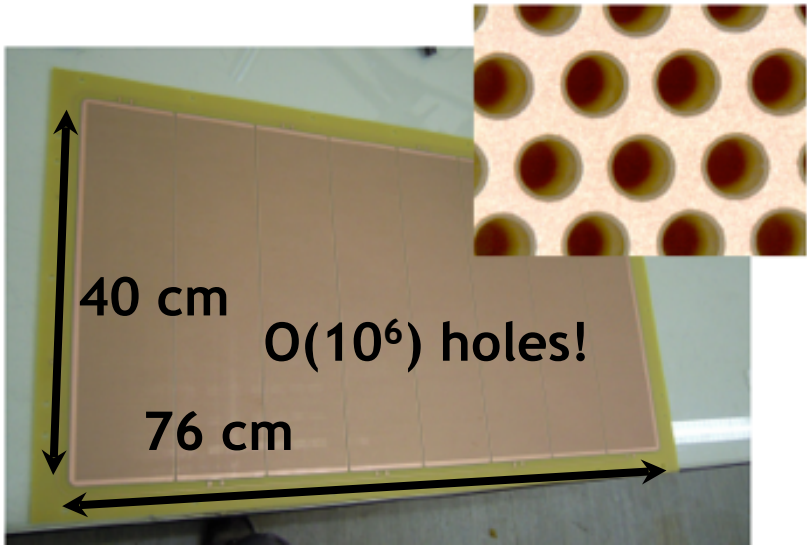
Compact charge readout design



Towards a large area readout: the 40x76 cm^2 prototype

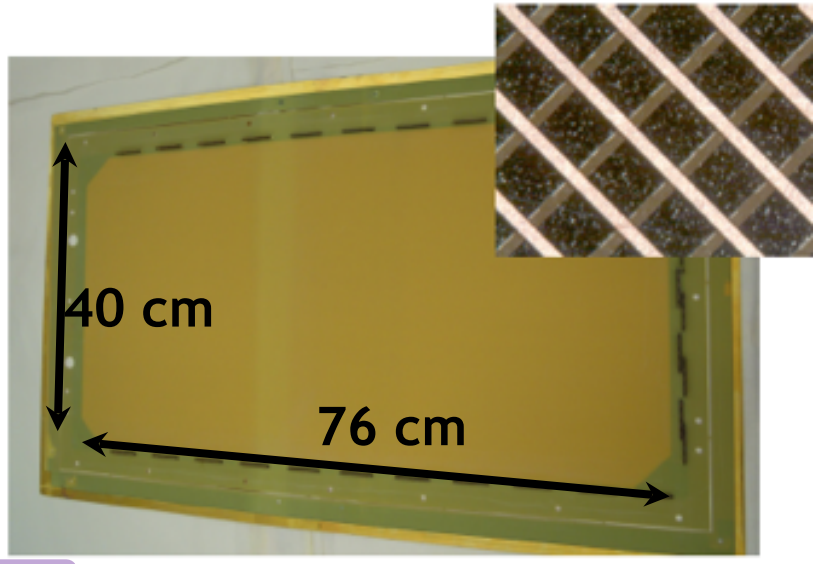
Large Electron Multiplier (LEM)

- Macroscopic gas hole multiplier (Thick GEM)
- more robust than GEMs (cryogenic temperatures, discharge resistant)
- manufactured with standard PCB techniques
- Large area coverable by 50x50 cm^2 modules
- Light quenching within the holes



2D projective anode readout

- Charge equally collected on two sets of strips (views)
- Readout independent of multiplication
- Signals have the same shape for both views:
  -two collection views (unipolar signals)
  -no induction view (bipolar signals) as in the case of a LAr-TPC with induction wires

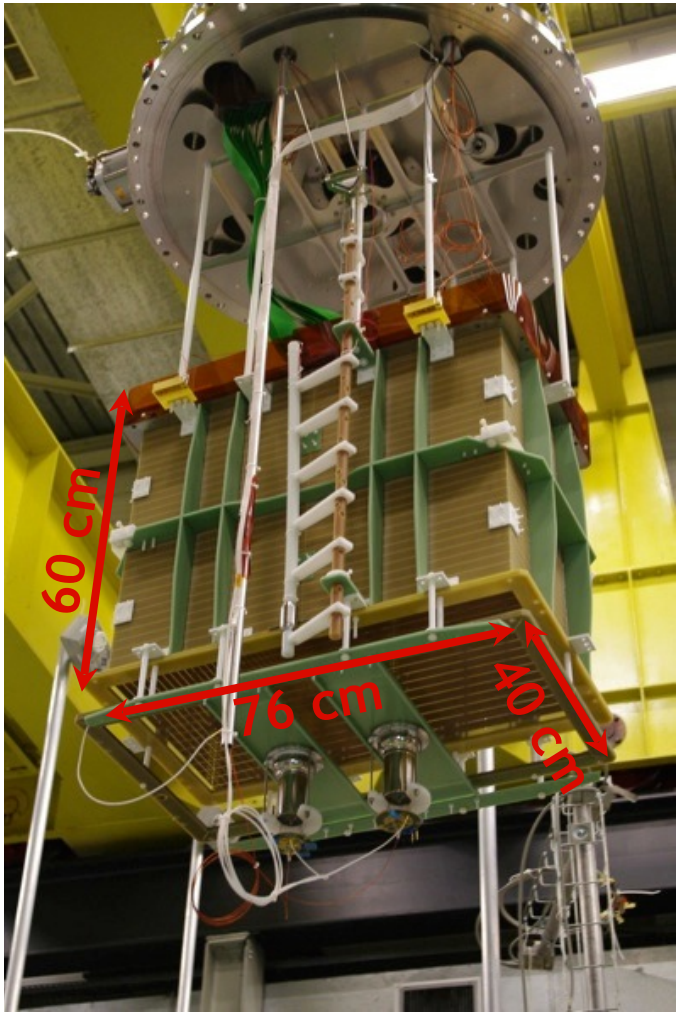


So far largest area LEM/2D anode produced

Large area readout: the 40x76 cm² prototype

A. Badertscher et al. JINST 8 (2013) P04012

detector fully assembled

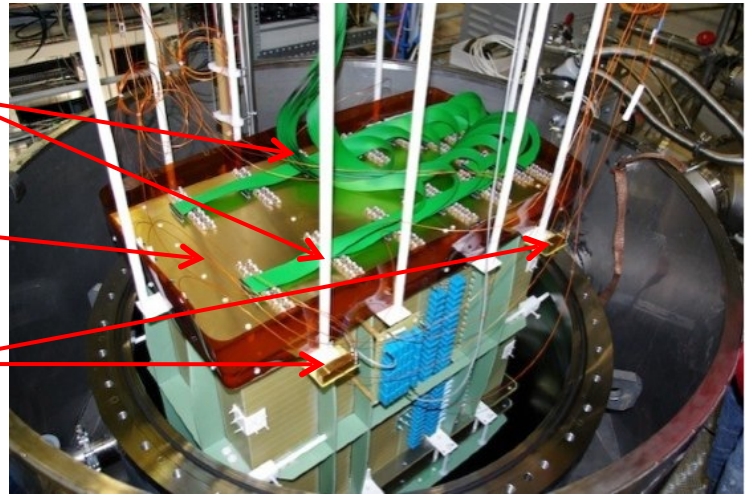


16 signal cables

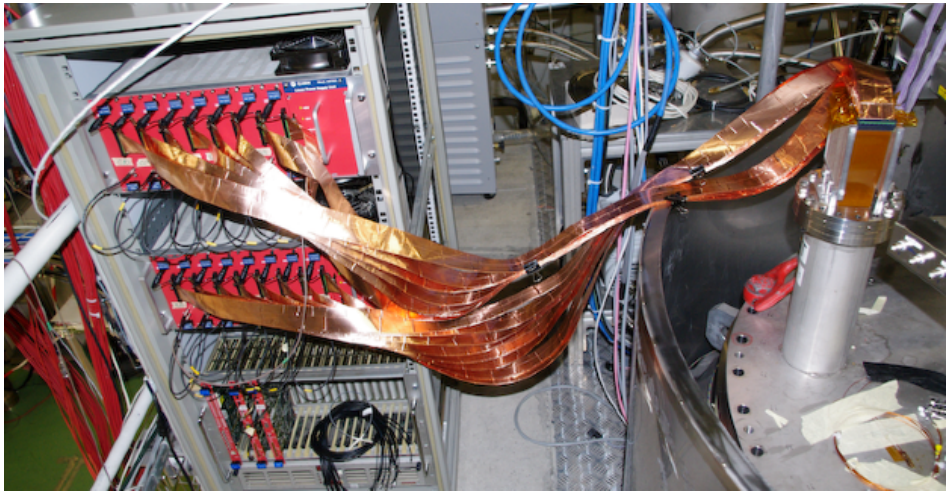
charge readout sandwich

4 capacitive level meters

going into the ArDM cryostat



Final connection to the CAEN DAQ system



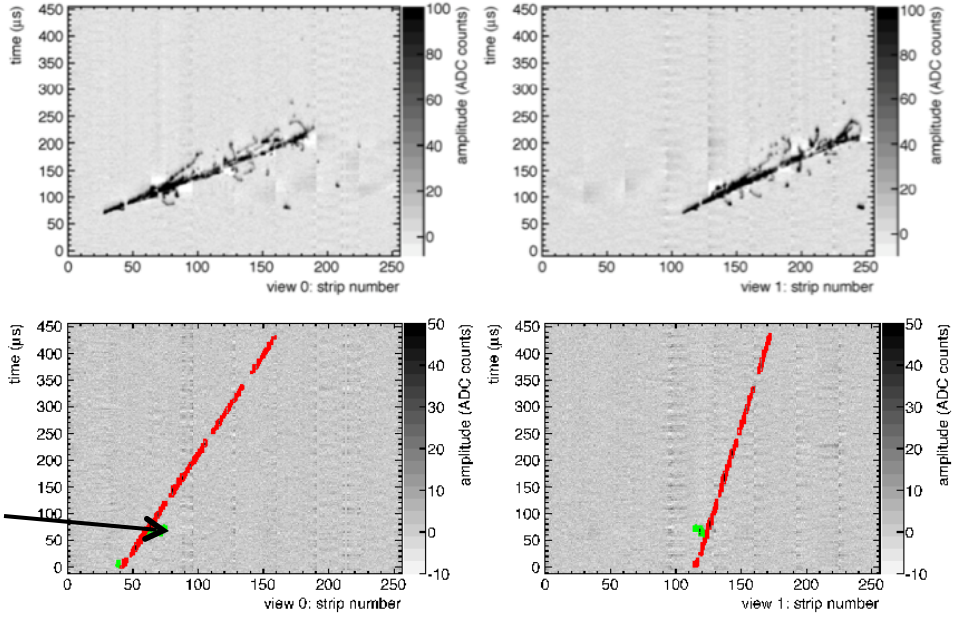
Results from the 40x76 cm² prototype

We have operated the detector for the first time in October 2011 for more than 1 month under controlled pressure: 1023±1 mbar

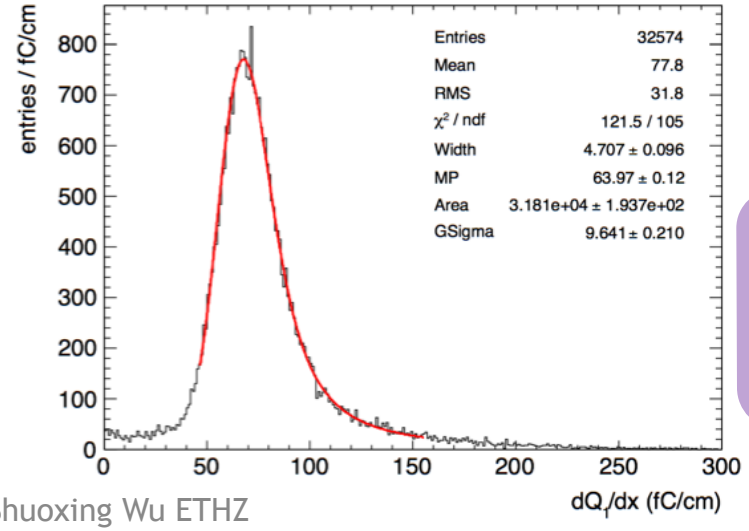
A. Badertscher et al. JINST 8 (2013) P04012

Optimized field configurations:

LEM-Anode	1800 V/cm
LEM	**35 kV/cm**
LEM-grid	600 V/cm
extraction	2300 V/cm
drift	400 V/cm



delta ray identified and reconstructed



Effective gain:
$(dQ/dx_{view0} + dQ/dx_{view1})/dQ/dx_{MIP}$ (≈10fC/cm)

<dQ/dx>=146 fC/cm
->effective gain≈14.6, (S/N≈30)
charge sharing between the two collection views:
$(Q_1-Q_0)/(Q_1+Q_0)$≈8%