Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Recent results of LAr LEM TPC R&D

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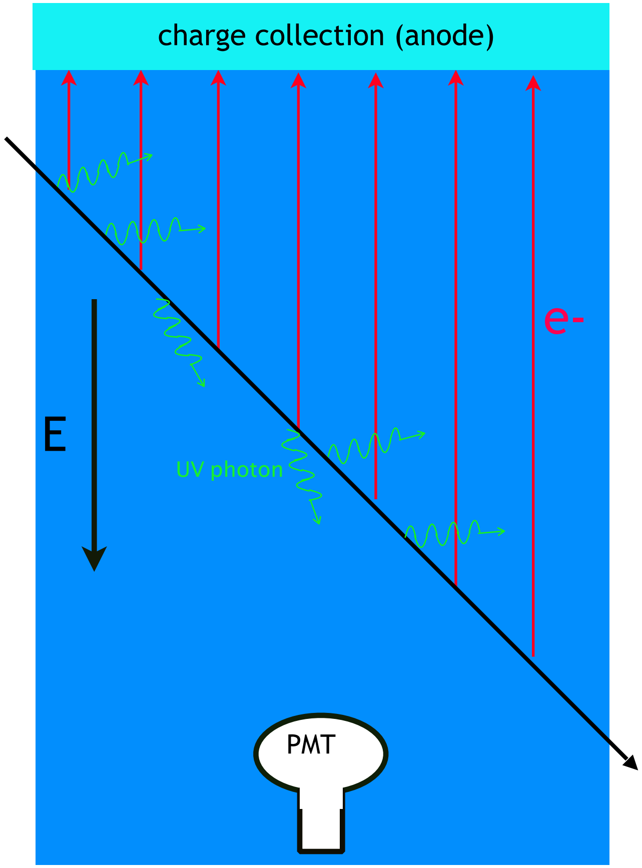
Introduction - the Liquid Argon (LAr) TPC



LAr properties

Deisity	1.4 g/cm
Boiling point @ 1 atm	87.3 K
Triple point	83.8058 K, 68.89 kPa
W_{ion}	23.6 eV
Stopping power (MIP)	2.1 MeV/cm
Rayleigh scattering length	90 cm
radiation length	14 cm
Molière radius	9.25 cm
Percentage	0.93%

- ***Light production in LAr:***
- 128 nm wavelength, ~5×10^4 photon/MeV
- LAr transparent to its own scintillation

- ***Charge production and transportation in LAr:***
- 10 fC/cm (MIP)
- Drift velocity of 2 mm/μs @ 1 kV/cm
- Diffusion ≈ mm after meters' drift

→ Giant LAr TPC suits neutrino detection

LAGUNA-LBNO programme and GLACIER

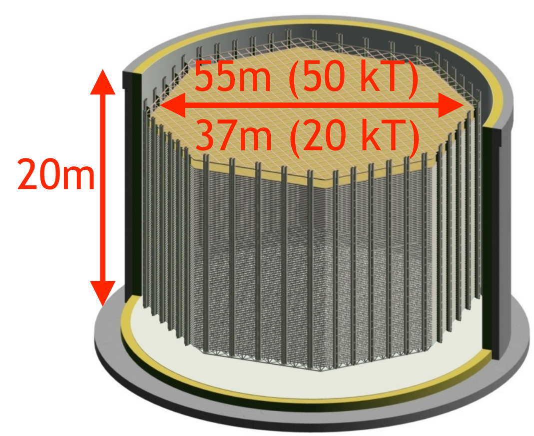
Large Apparatus for Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations

LAGUNA-LBNO physics:

1. Accelerator based neutrino physics
   - Mass Hierarchy determination
   - δ_{CP} measurement
   - Sterile neutrino
2. Neutrino astronomy:
   - Solar neutrino
   - Atmosphere neutrino
   - Super-nova neutrino
3. Proton decay search

Giant Liquid Argon Charge Imaging expERiment

- Double phase LAr LEM TPC
- Two detectors with 20 kton and 50 kton fiducial mass as far detector for LAGUNA-LBNO



Milestones towards GLACIER

➢ **2003: the GLACIER concept**

- A. Rubbia, Experiments for CP-violation: A giant liquid argon scintillation, Cherenkov and Charge imaging experiment? arXiv:hep-ph/0402110

➢ **Proof of principle with 10x10 cm^2 double phase LAr LEM-TPC prototype:**

- A. Badertscher et al., "Operation of a double-phase pure argon Large Electron Multiplier Time Projection Chamber: Comparison of single and double phase operation "NIM A617 (2010) p.188-192
- A. Badertscher et al., "First operation of a double phase LAr Large Electron Multiplier Time Projection Chamber with a two-dimensional projective readout anode" NIM A641 (2011) p.48-57

➢ **First successful operation of a 40x76 cm^2 device in November 2011:**

- A. Badertscher et al., "First operation and drift field performance of a large area double phase LAr Electron Multiplier Time Projection Chamber with an immersed Greinacher high-voltage multiplier " JINST 7 (2012) P08026
- A. Badertscher et al., "First operation and performance of a 200 lt double phase LAr LEM-TPC with a 40x76 cm^2 readout", JINST 8 (2013)P04012

➢ **10x10 cm^2 double phase LAr LEM-TPC prototype: further R&D towards final, simplified charge readout for GLACIER:**

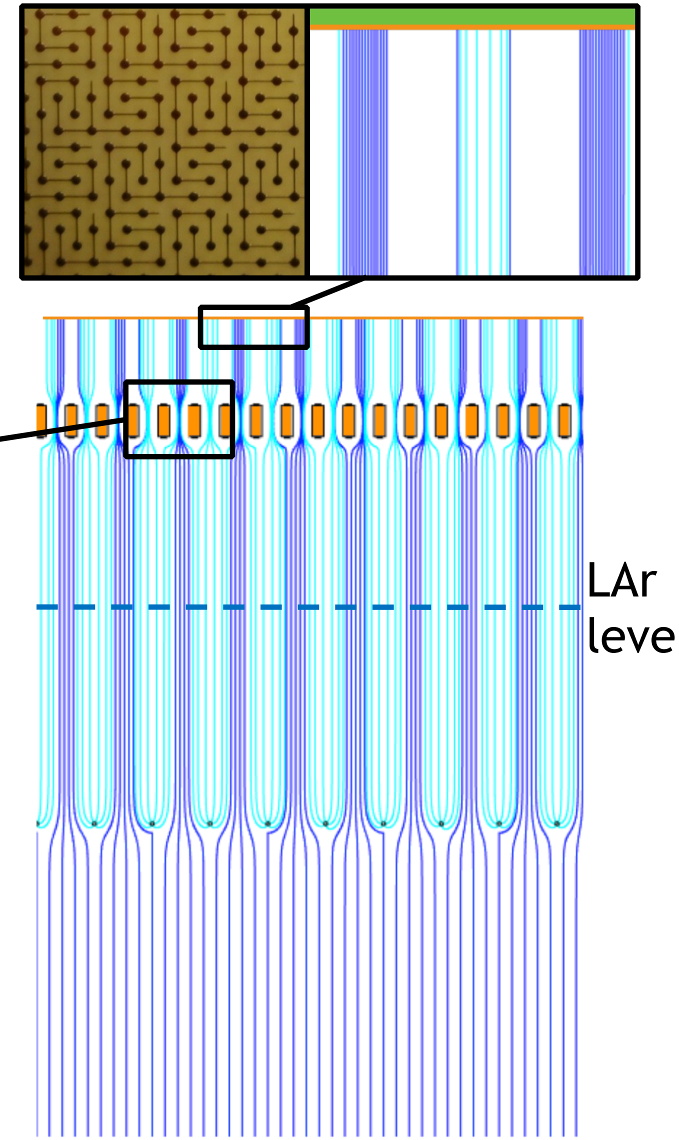
- Long-term operation of a double phase LAr LEM Time Projection Chamber with a simplified anode and extraction-grid design, JINST 9 P03017

➢ **Future**

- **3x1x1m^3** pre-prototype to be put in B182@CERN
- **6x6x6m^3** prototype (WA105) to be operated at CERN NA approved by CERN SPSC.

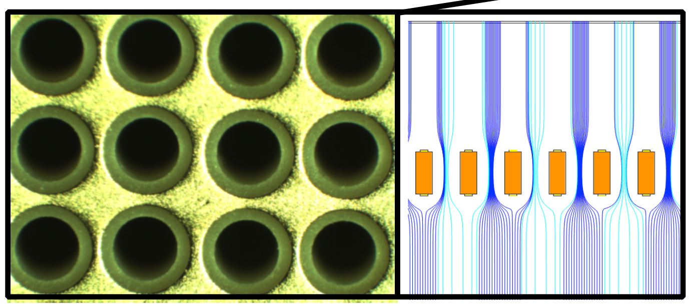
Final goal: Giant LAr LEM TPC as far detector for a Long Baseline Neutrino Oscillation (LBNO) experiment (SPSC-EOI-007)

The novel double phase readout



4.) Charge collection on a multilayer 2D anode readout (symmetric unipolar signals with two orthogonal views)

3.) Charge multiplication in the holes of the Large Electron Multiplier (LEM)



2.) Drift electrons are efficiently extracted into the gas phase

1.) Ionization electrons drift towards the liquid argon surface

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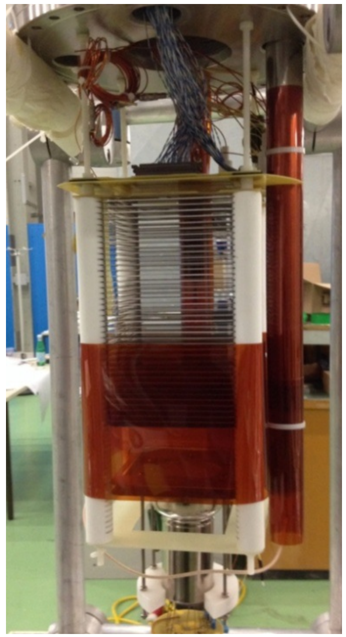
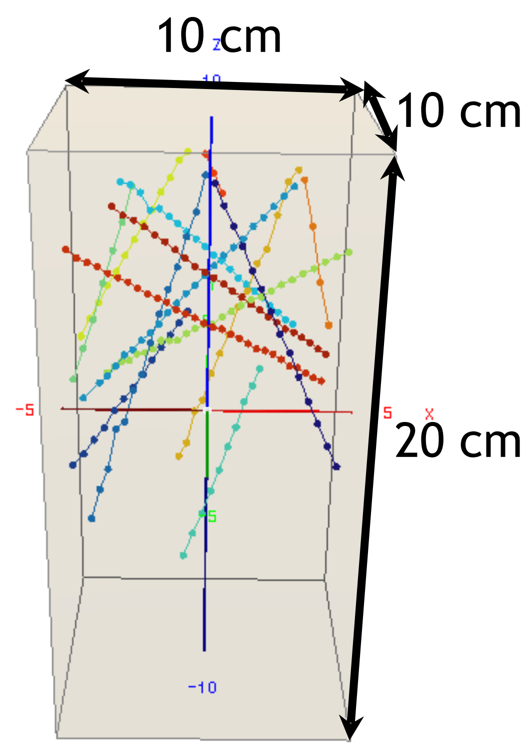
The 10x10x20 cm^3 LAr LEM TPC



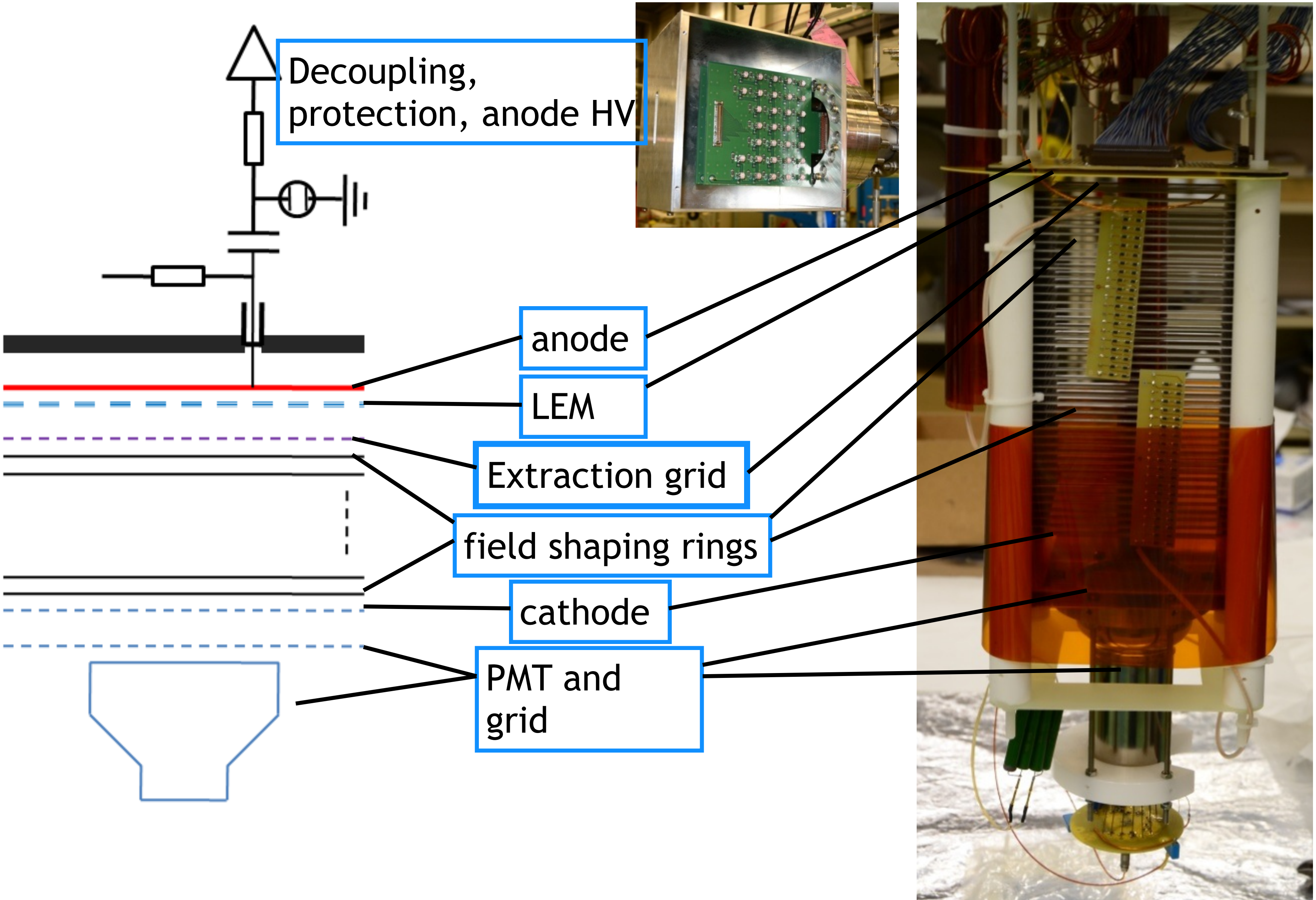
With this small chamber, we can collect in a short amount of time a high quality and **large data-sets of cosmic muon** with constant energy loss per unit length **~10 fC/cm**



We're developing:

- **Low noise (capacitance) 2D anode**.
- LEM with **uniform** and **long term stable** gain and discharge resistance.
- **Simplified** readout electronics system.

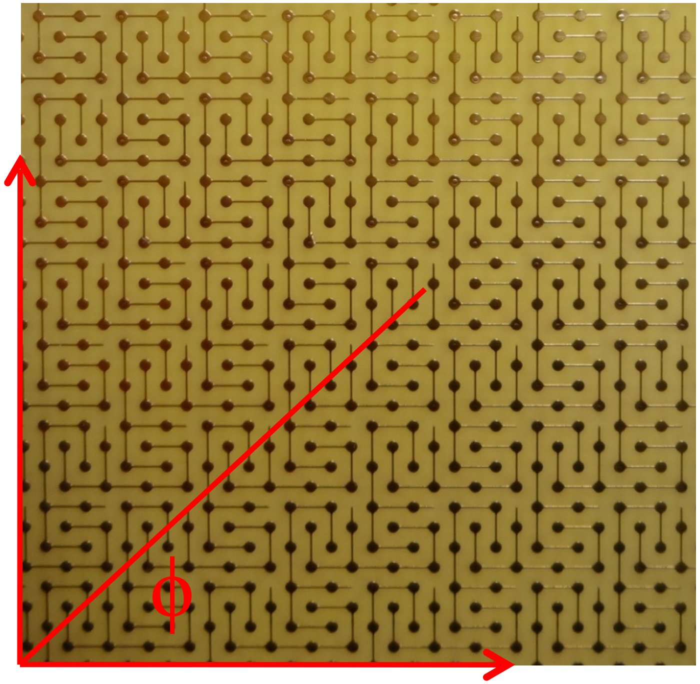
LAr LEM TPC setup

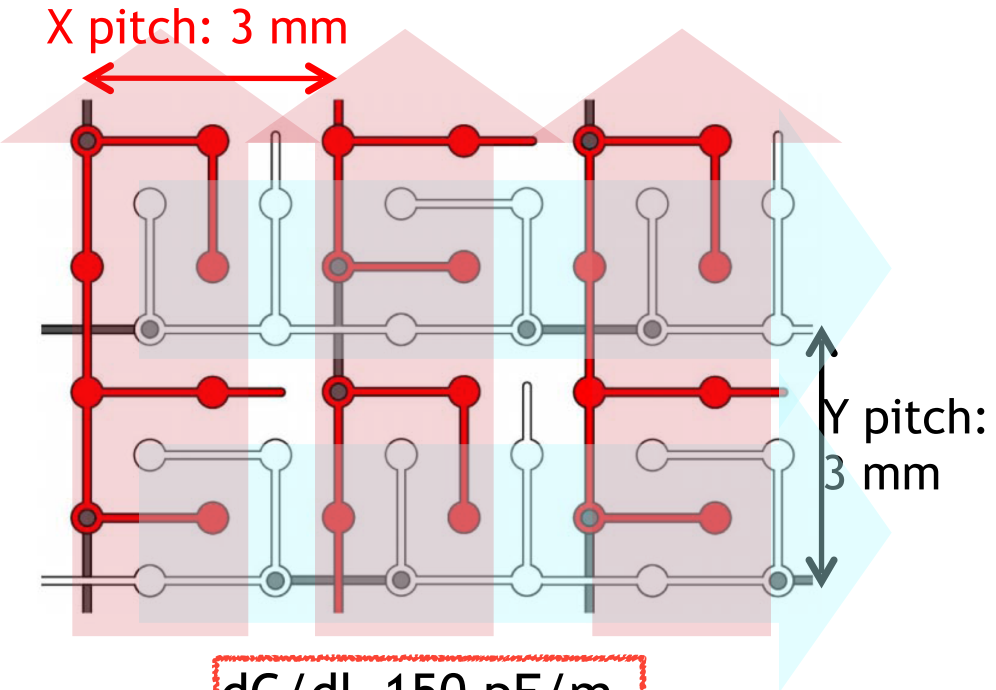


Anode requirements for large area readout

To reach basic GLACIER $4x4m^2$ CRP (2m readout length) design:

- reduce capacitance: have long readout strips while keeping minimum noise (upper limit for ~1000 e^- ENC noise ~ 350 pF)
- simplify production: integrate two views on same PCB layer
- symmetric X-Y charge sharing





dC/dl~150 pF/m

Best solution to optimize capacitance and resolution

Anode performance:

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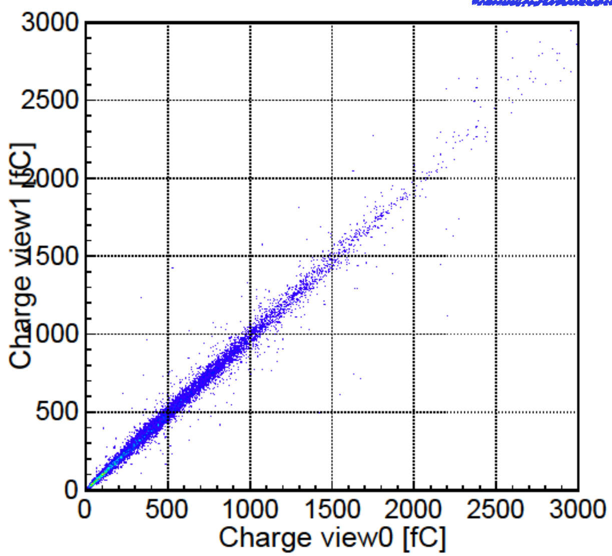
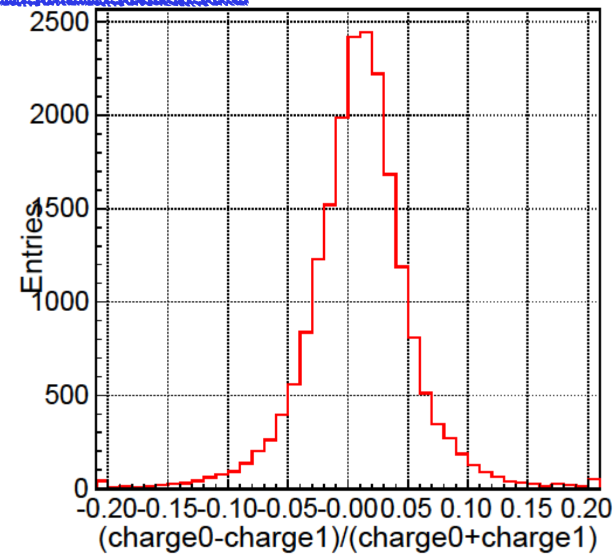
Fully X-Y symmetric:

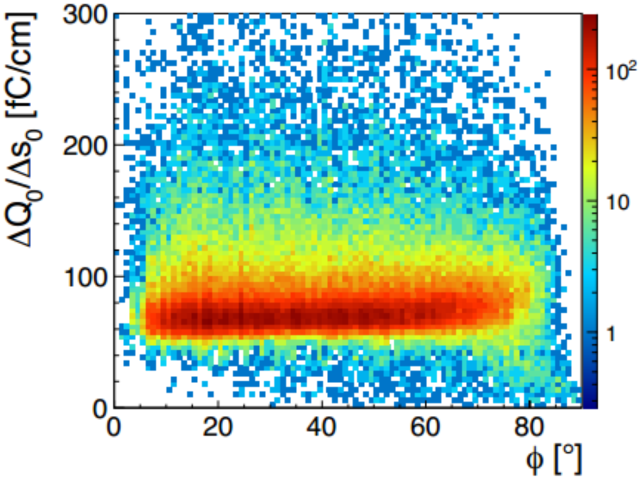


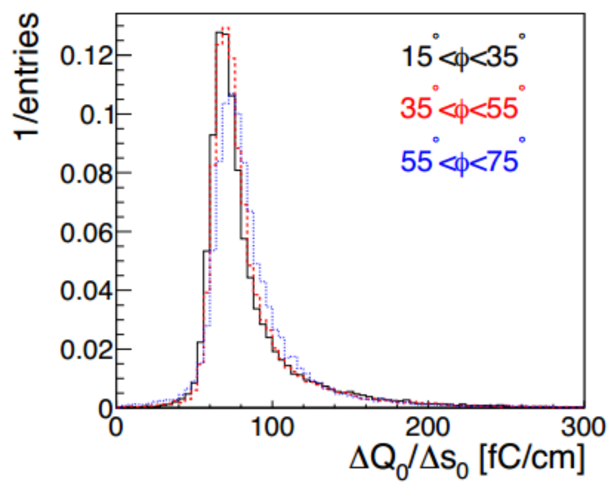


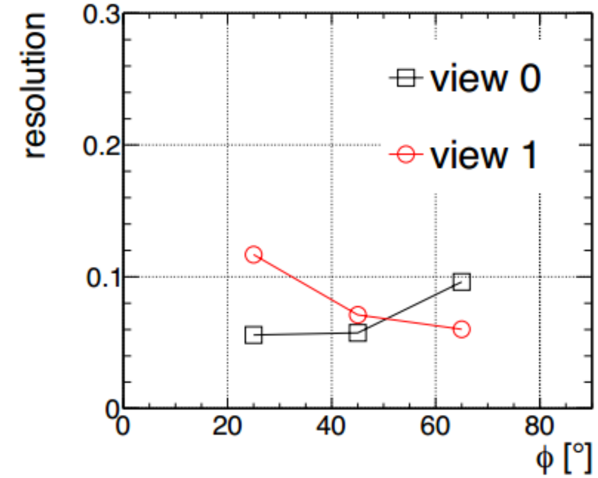
Mean: 0.009
RMS: 0.043

Uniform response to all tracks:

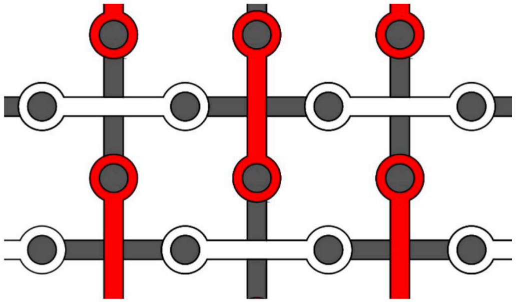
JINST 9 P03017



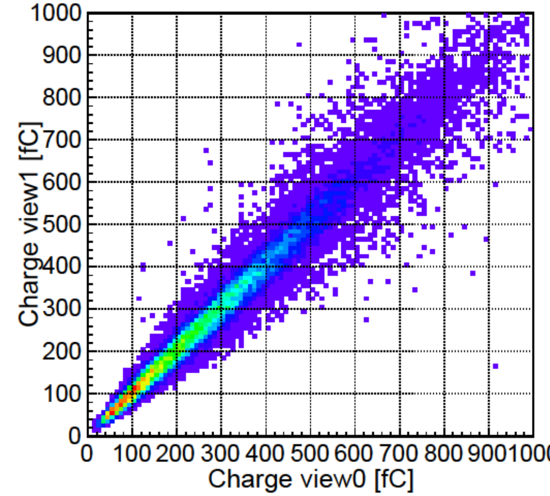


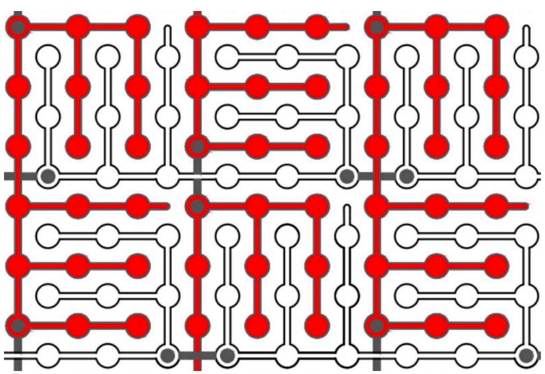


Other anodes tested

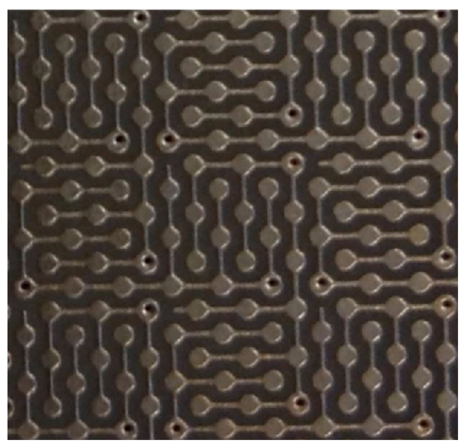


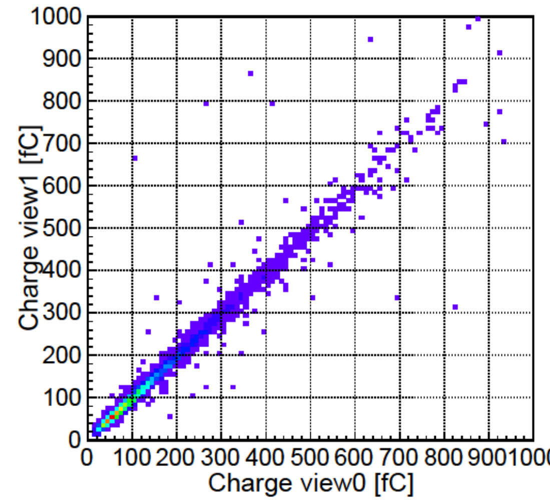
dC/dl~100 pF/m





dC/dl~250 pF/m





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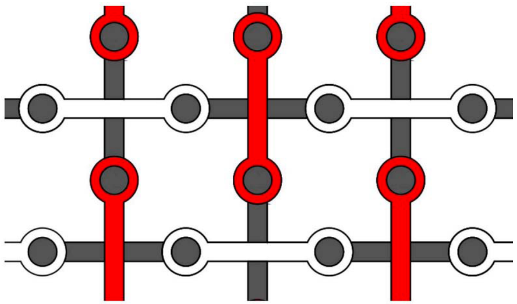
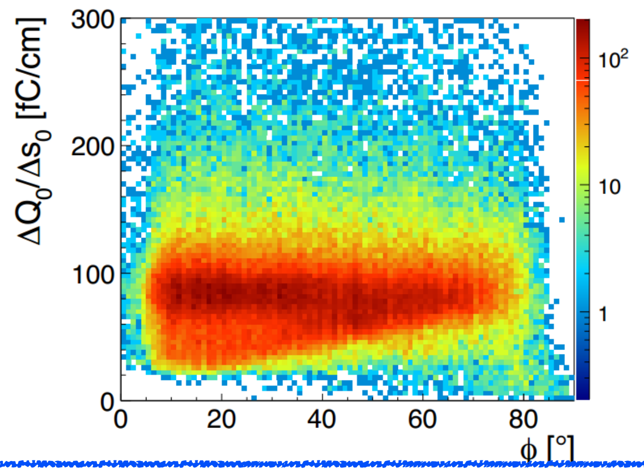
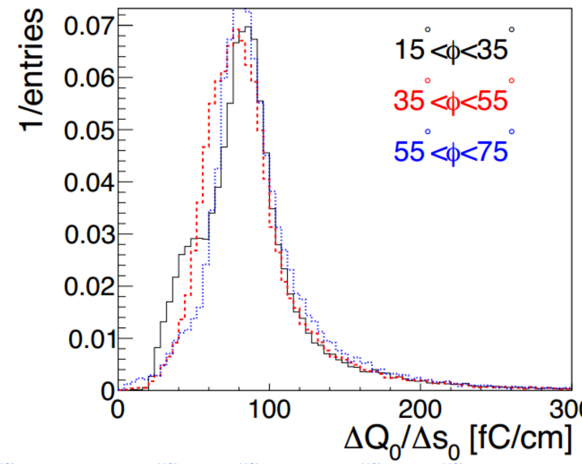
Other anodes tested



dC/dl~100 pF/m





Pattern too loose, non uniform charge collection between strips

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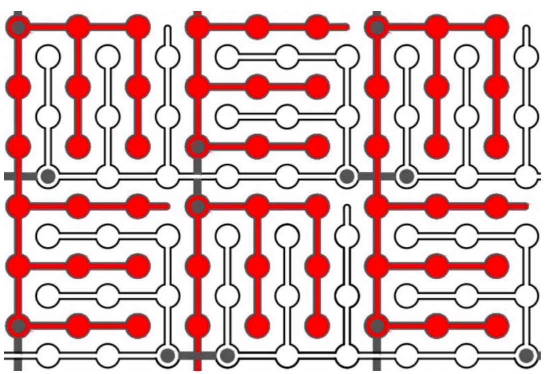
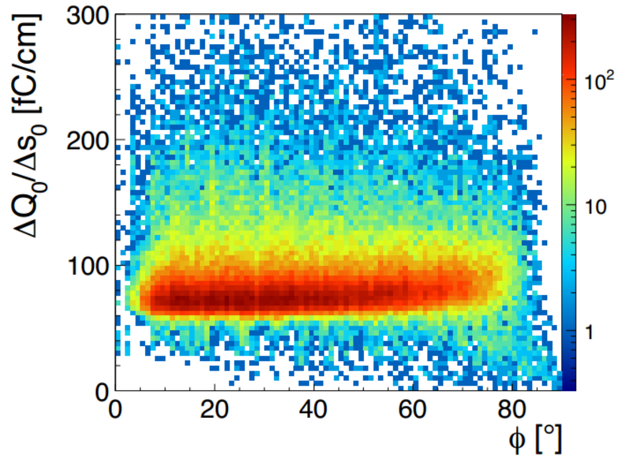
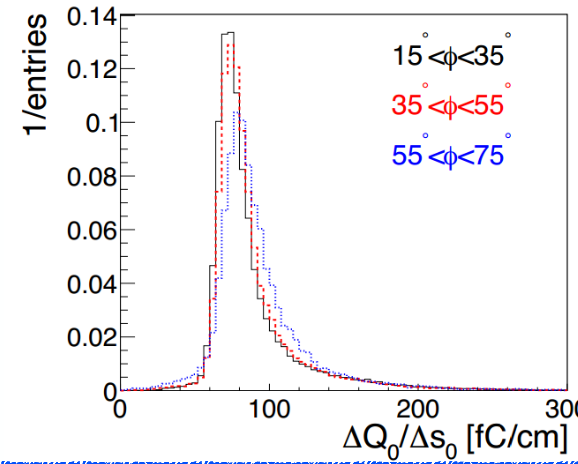


dC/dl~250 pF/m

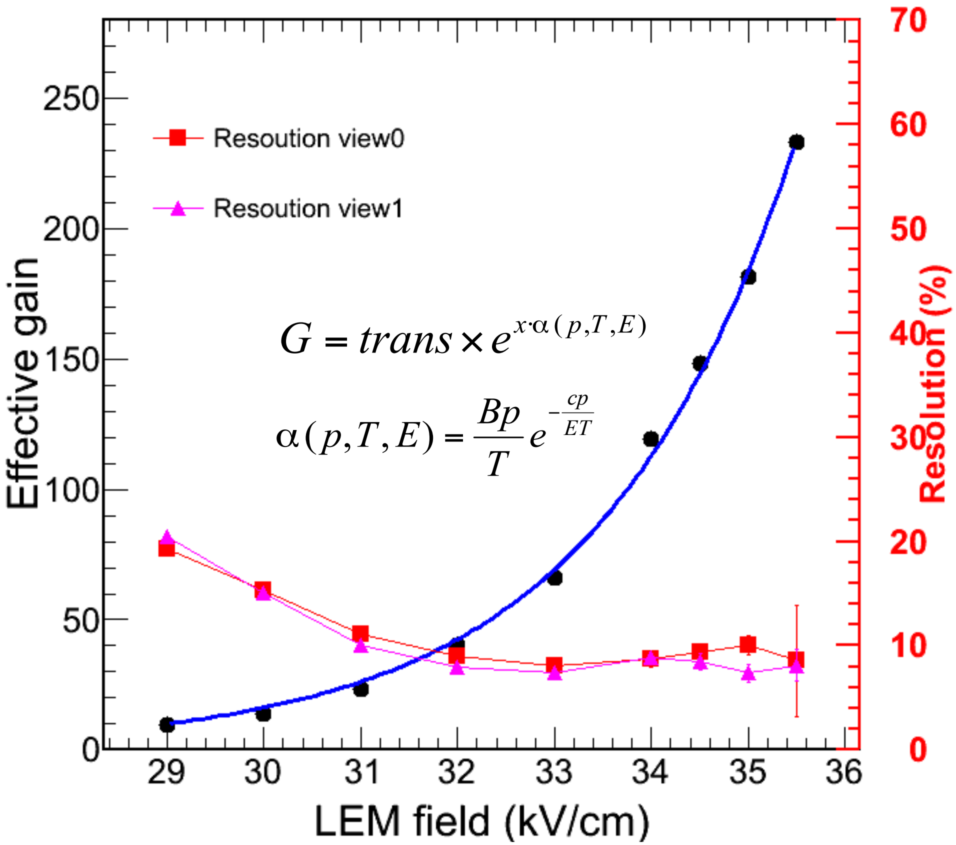




Compatible performance as 150 pF/m anode, but has higher capacitance

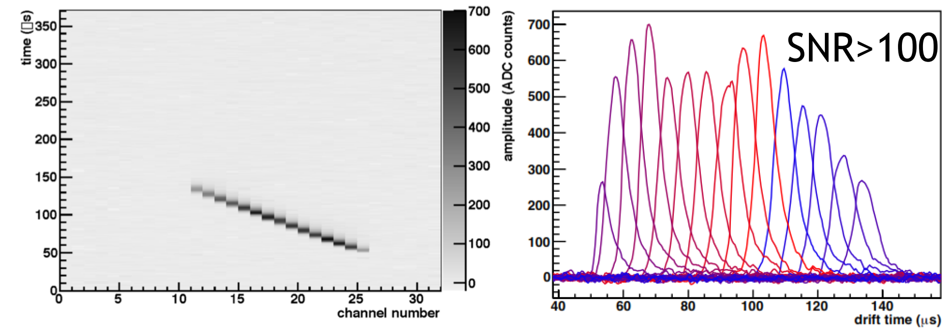
LEM performance

Effective gain vs. LEM field (V/d):

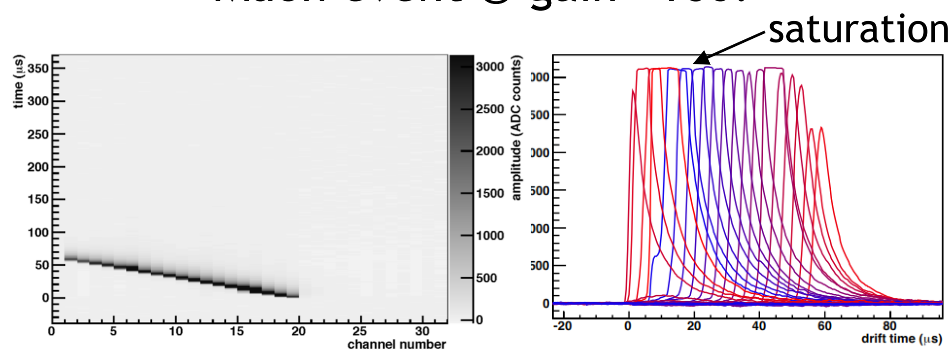


$$\text{Eff. Gain} = \frac{<dQ/dx_0> + <dQ/dx_1>}{dQ/dx_{mip}}$$

Muon event @ gain ~20:



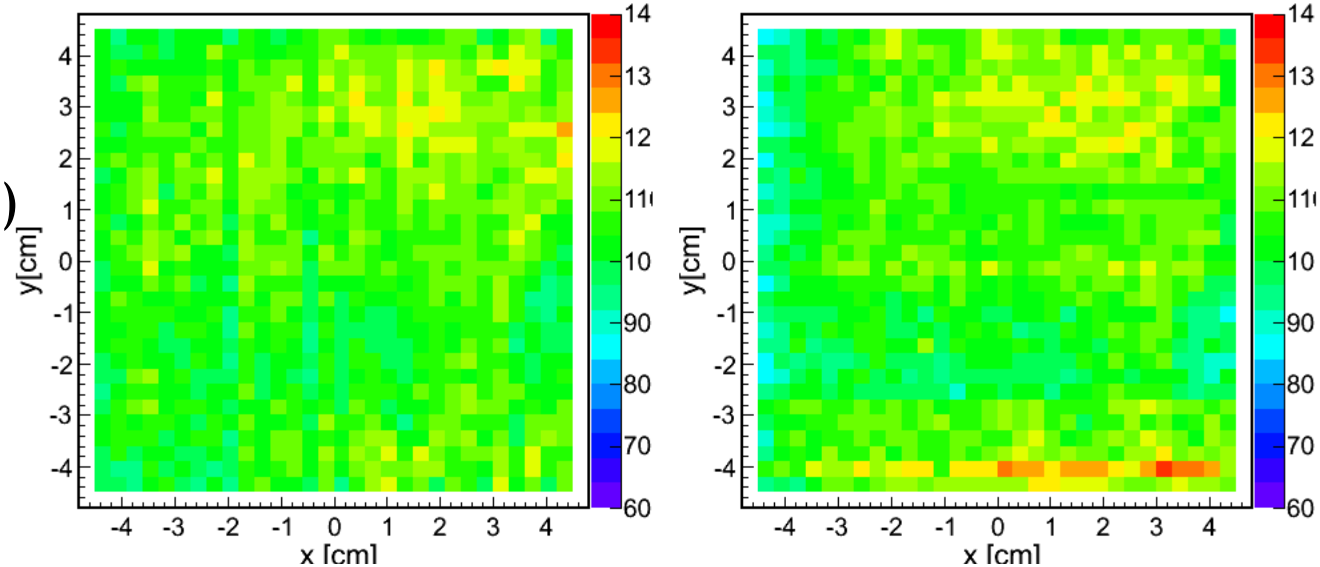
Muon event @ gain ~160:



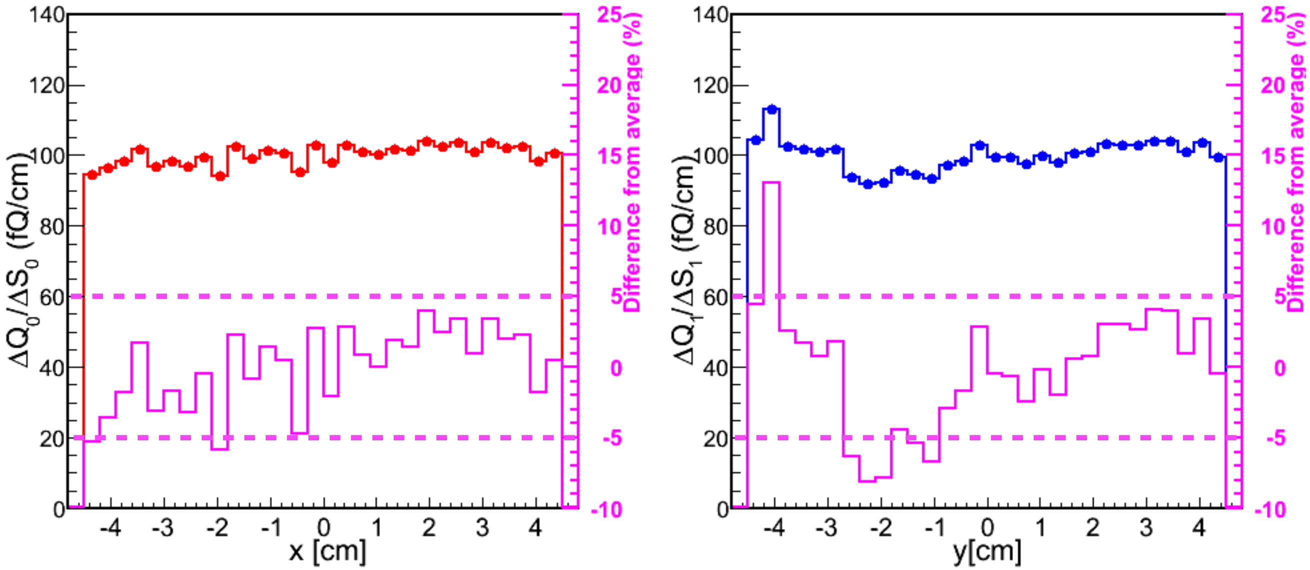
Gain uniformity

View 0 View 1

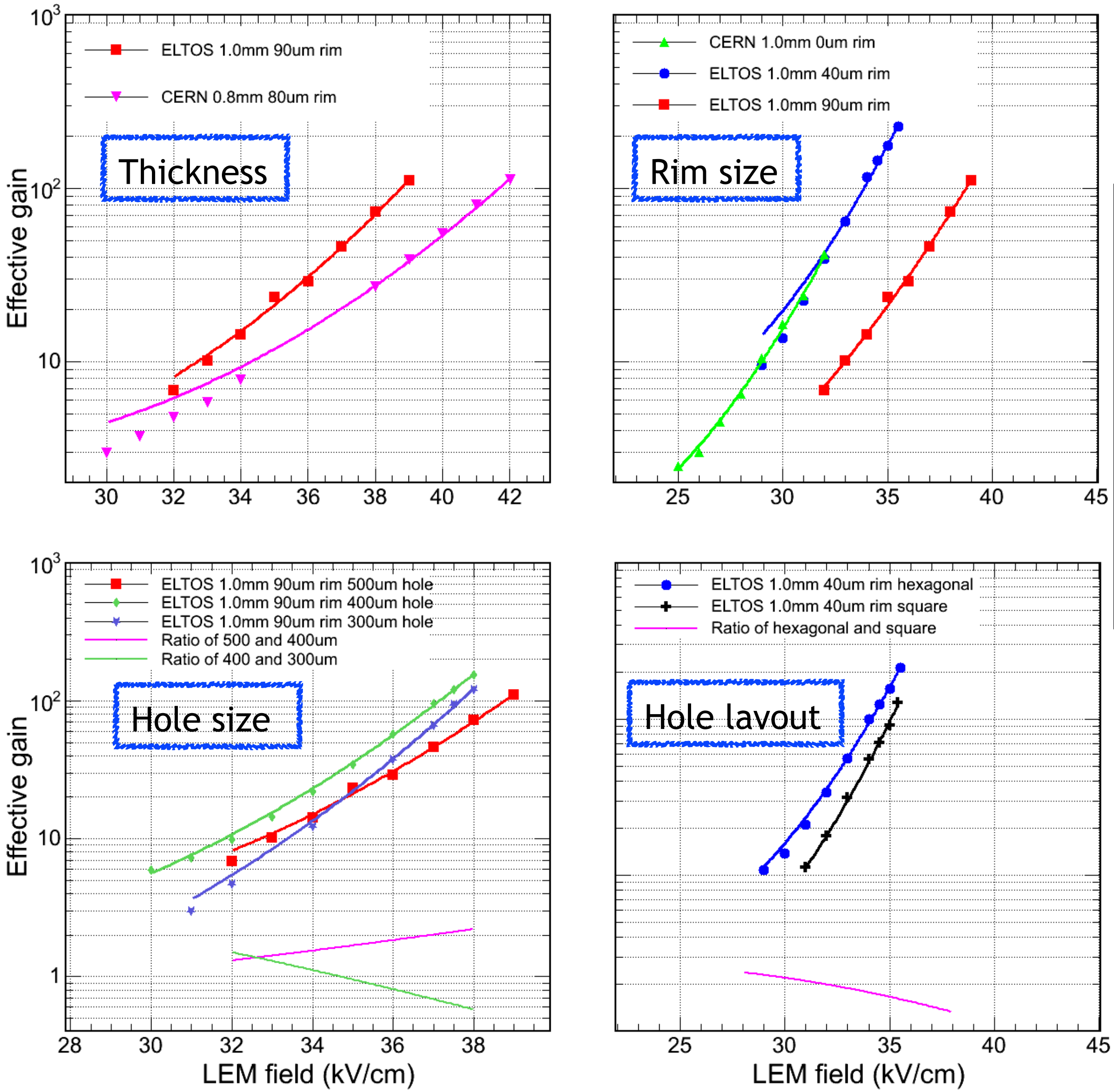
<dQ/dx> (fQ/cm) (normalized to 100 fQ/cm):



Projections on X and Y axis:



Systematic inspection of LEM parameters



- Gain curves difference explainable from amplification length and central E field
- Gain over 100 is feasible for each LEM
- “Discharge-free” operation @ gain 20 for ~ 1 week

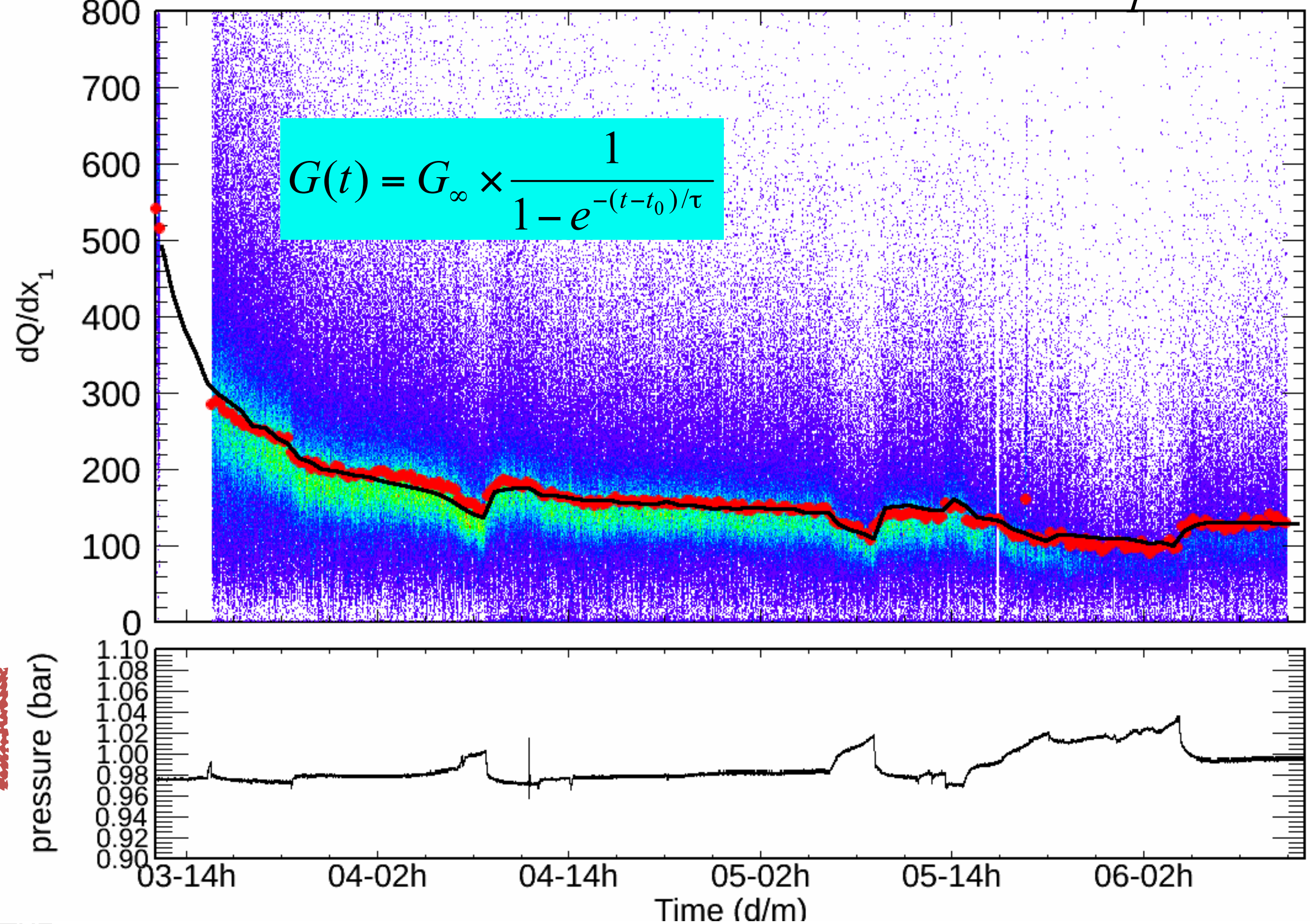
Optimised parameters:

➢ 1mm thickness
➢ 500 μm diameter hole
➢ 40-50 μm rim size
➢ 800 μm pitch
➢ hexagonal arrangement

Stability of the gain

Gain of LEM depends on: 1. gas property (pressure, temperature, mixture…)
2. electric field across the LEM - E
3. effective length across the LEM – x

Described by function: $G_\infty = trans \times e^{x \cdot \alpha(p,T,E)}$ where $\alpha(p,T,E) = \frac{Bp}{T} e^{-\frac{cp}{ET}}$



Pressure inside:

future detectors will operate under controlled pressure

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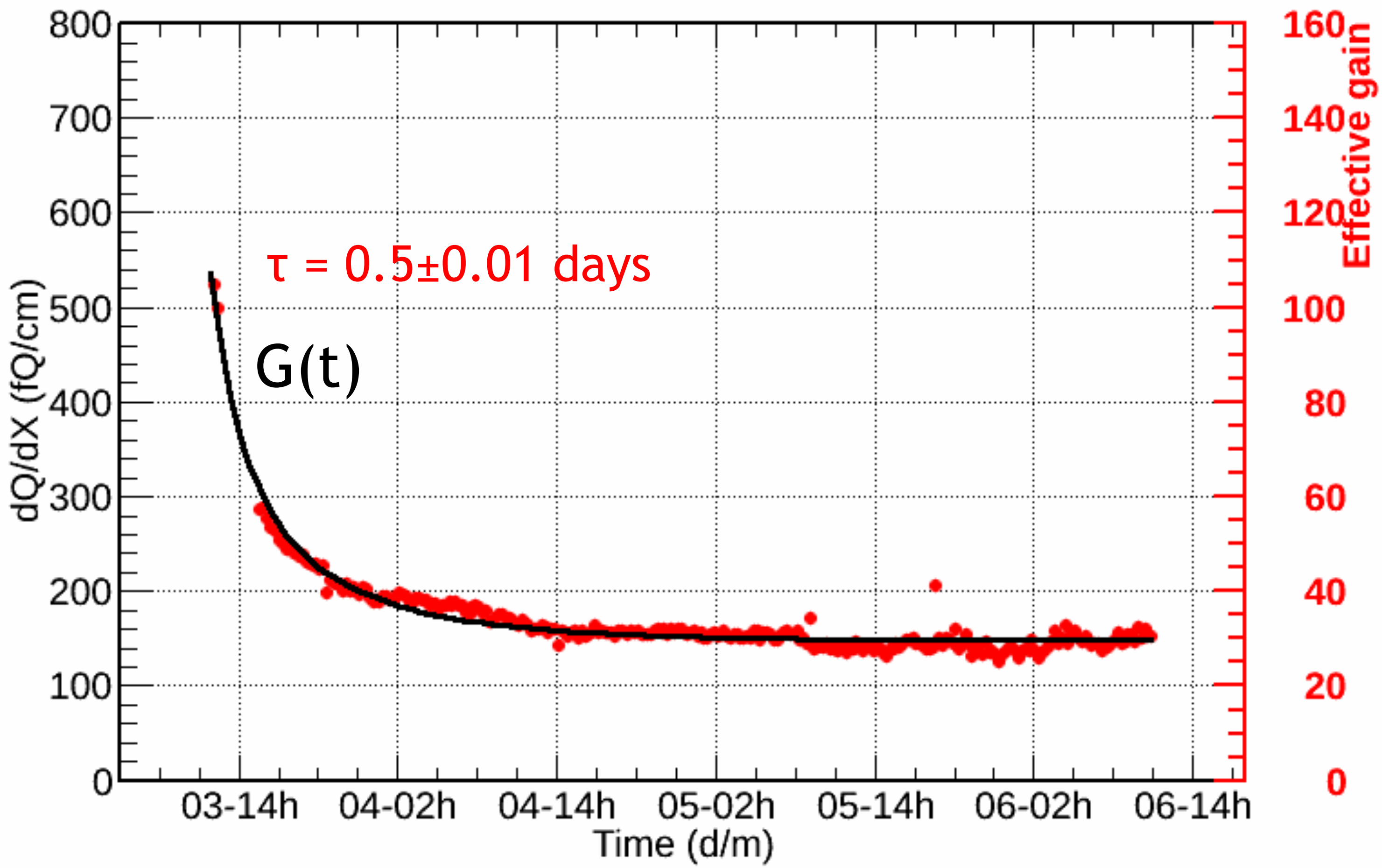
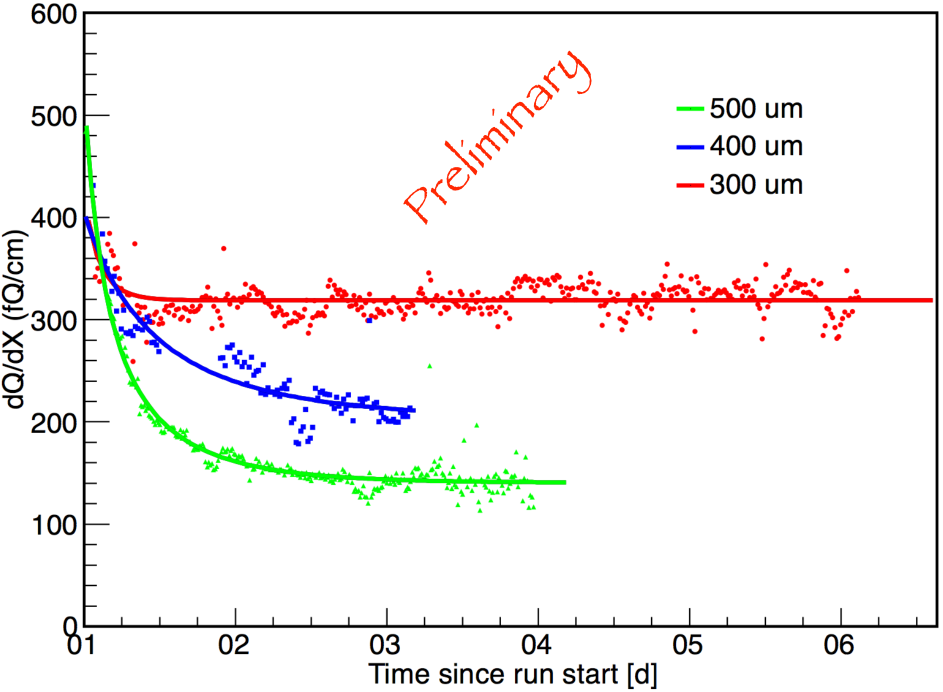
Stability of the gain – after pressure correction

- ✓ Gain stabilizes at ~30 (at LEM field of 34 kV/cm) after an initial decrease with τ ~ 0.5 days
- ✓ Stable gain is ~1/3 of the original one



Gain stability vs. LEM parameter

Distinct difference for hole diameter



stable gain is important for underground operation

Charging-up time and gain ratio

		τ (d)	Gfin/Gini
Rim size	40um	0.45	28.8%
	80um	0.51	32.4%
Thickness	0.8mm	0.23	35.5%
	1mm	0.51	32.4%
Hole diameter	0.5mm	0.45	28.8%
	0.4mm	0.53	48%
	0.3mm	— —	~100%

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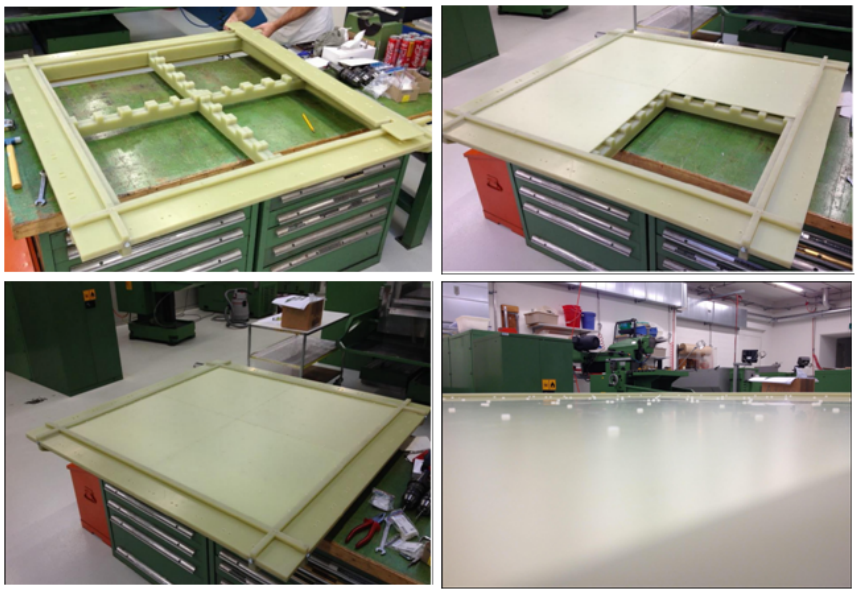
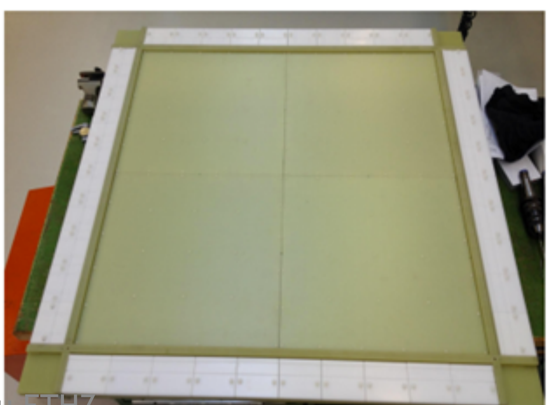
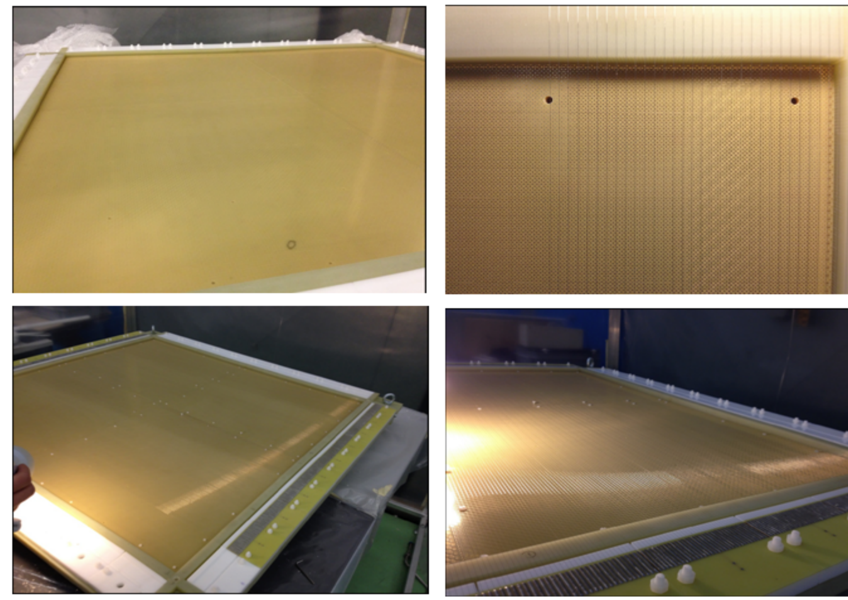
Towards large area readout - the 1x1 m^2 charge readout system

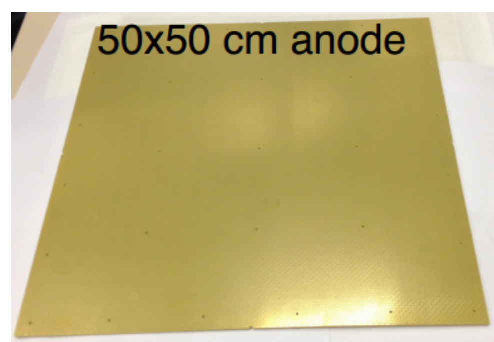
1x1 m^2 G10 structure with fake anode/LEM

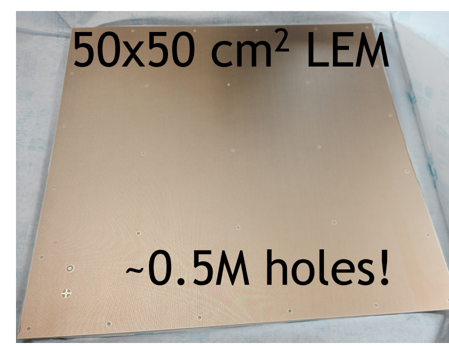




Implemented with real anodes and grid



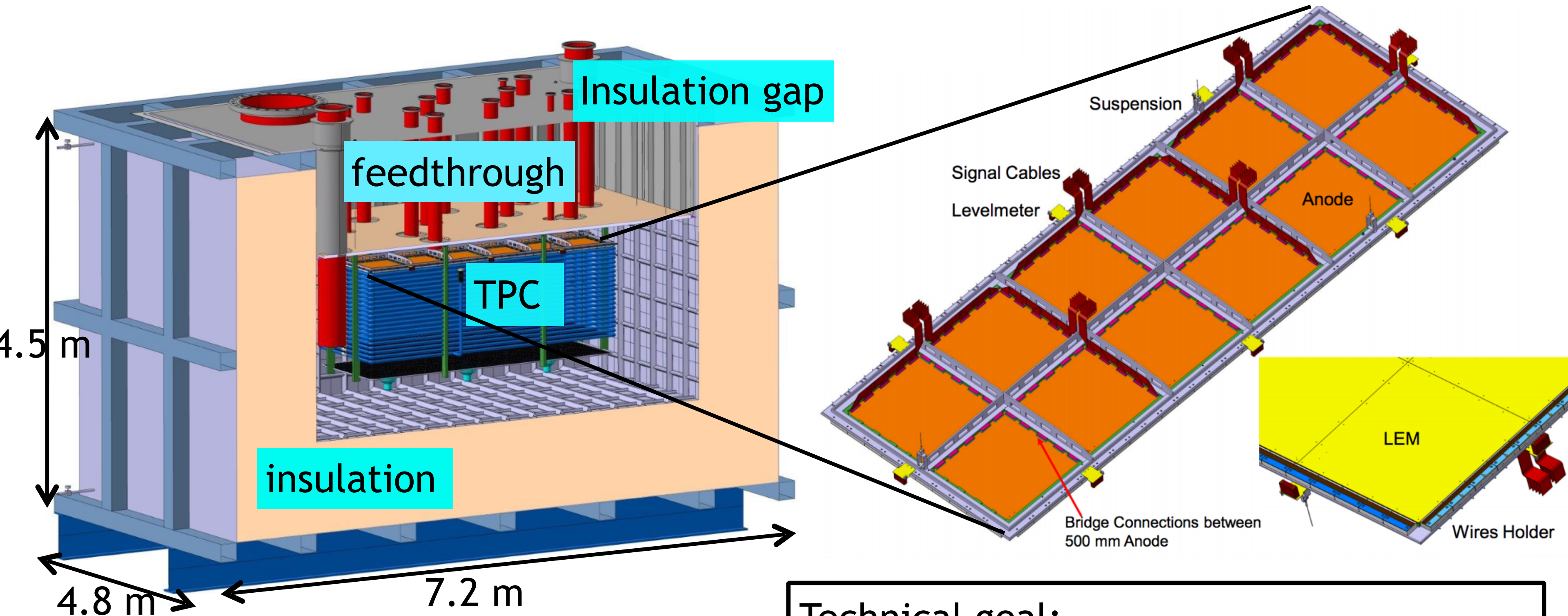




Next step: the 3x1x1 m^3 LAr LEM TPC

5 ton (fiducial) double phase LAr TPC

3x1 m^2 charge readout system:



Time scale:2014-2015
Site: B182@CERN

Technical goal:
LAr purity in non-evacuated membrane tank, performance of large area readout, cold front-end electronics…

Summary

Good progress has been made towards reaching the goal of large area readouts for LAr-LEM TPCs:

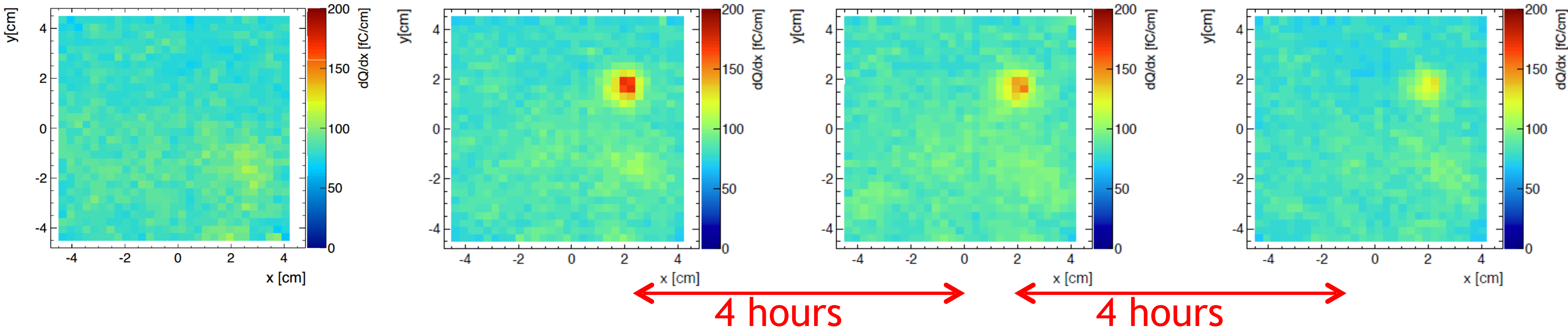
- ➢ Low capacitance (~150 pF/m) 2D anode turns out to fulfill the requirements on resolution
- ➢ Initial gain over 100, stable gain around 30 were reached by LEMs
- ➢ Gain uniformity within ±10% achieved by matching extraction grid with anode strips
- ➢ large area readout mechanically feasible

The next big step is the 3x1x1 m^3 LAr LEM TPC

Thank you and questions?

What happens locally when discharging?

before discharge: when discharging: after discharge:



"hot spot" follows a similar decay:

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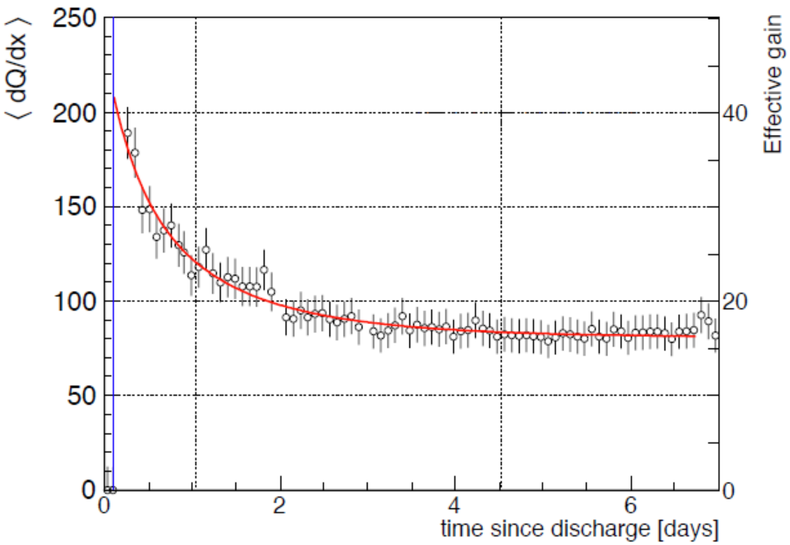
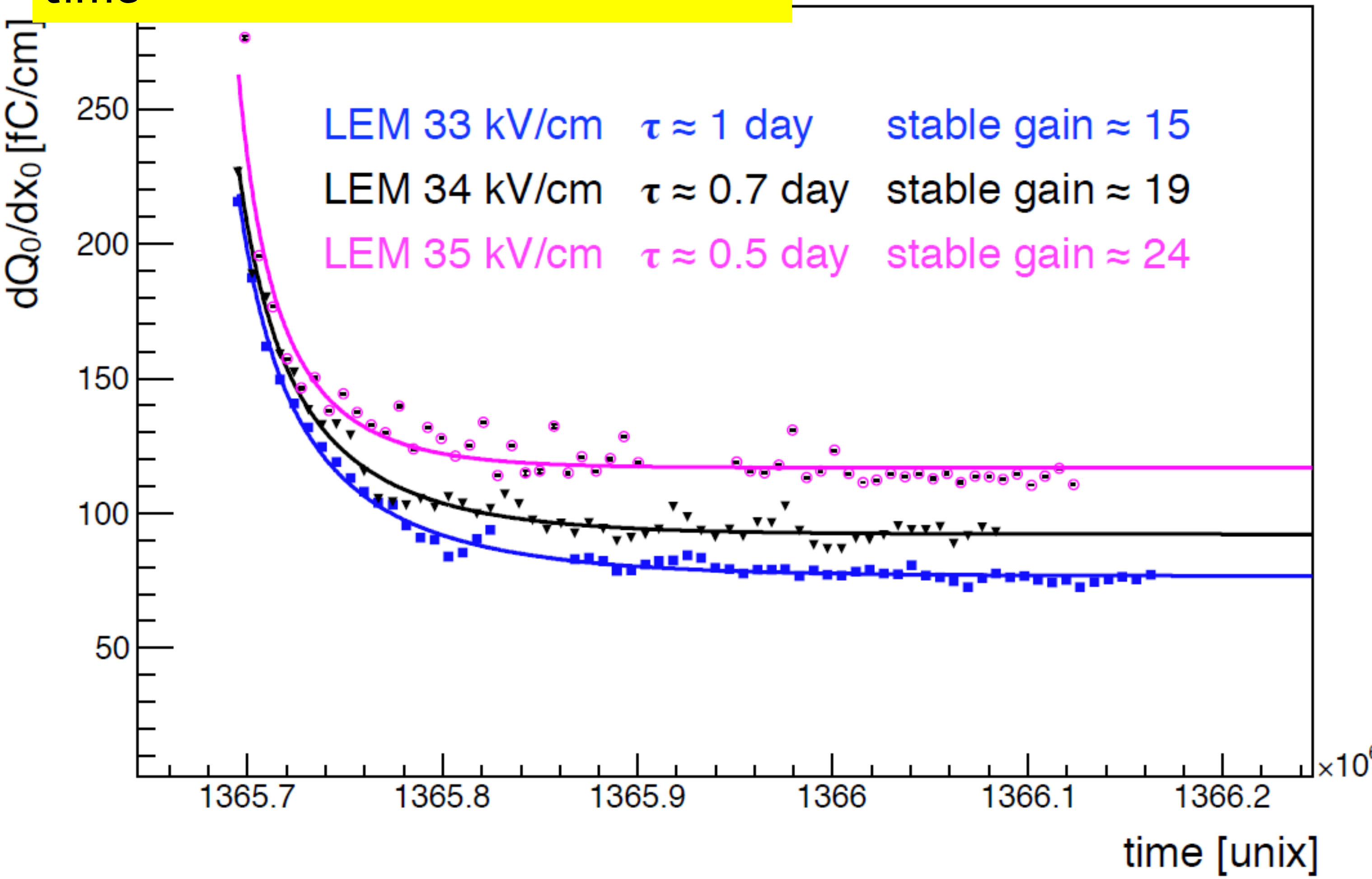
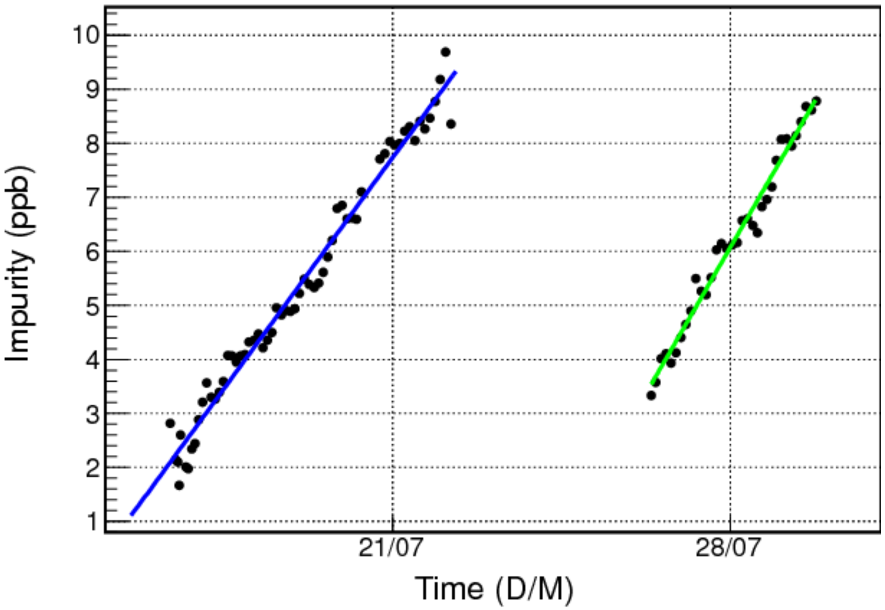
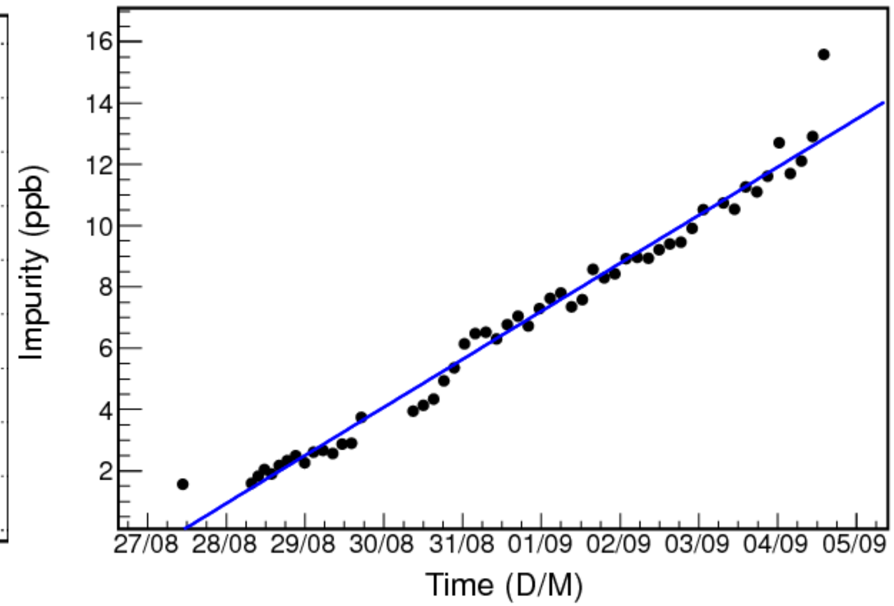
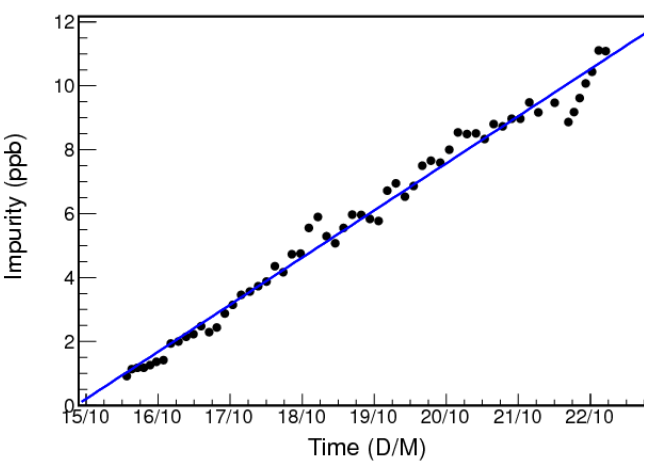
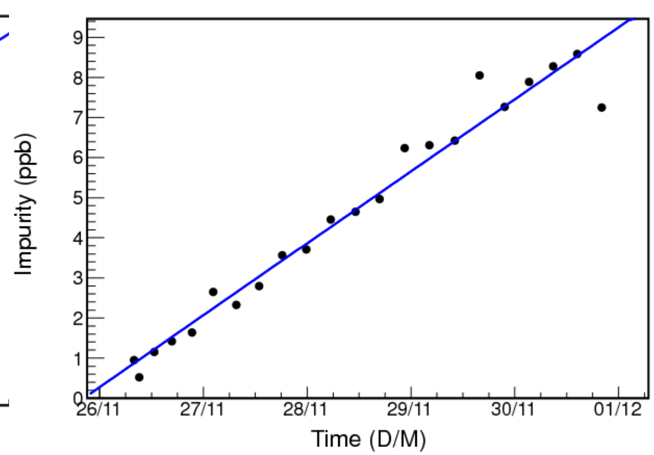
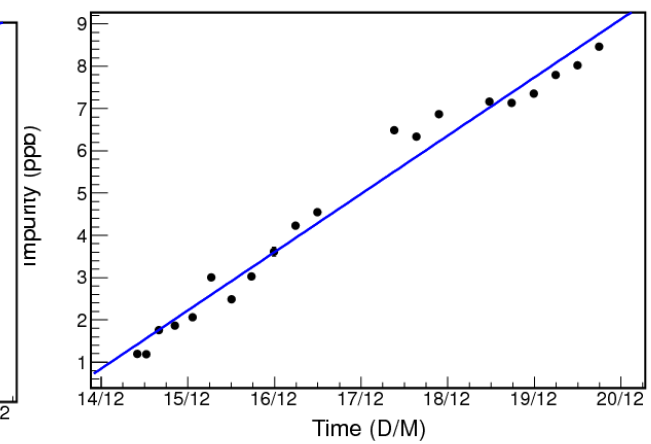


Runs at different LEM fields

Higher field, faster charging up time




Impurity (ppb)
Time (D/M)
21/07
28/07

Impurity (ppb)
Time (D/M)
27/08 28/08 29/08 30/08 31/08 01/09 02/09 03/09 04/09 05/09

Impurity (ppb)
Time (D/M)
15/10 16/10 17/10 18/10 19/10 20/10 21/10 22/10

Impurity (ppb)
Time (D/M)
26/11 27/11 28/11 29/11 30/11 01/12

Impurity (ppb)
Time (D/M)
14/12 15/12 16/12 17/12 18/12 19/12 20/12