Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Recent results of LAr LEM TPC R&D towards GLACIER

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on behalf of
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Giant Liquid Argon Charge Imaging expERiment

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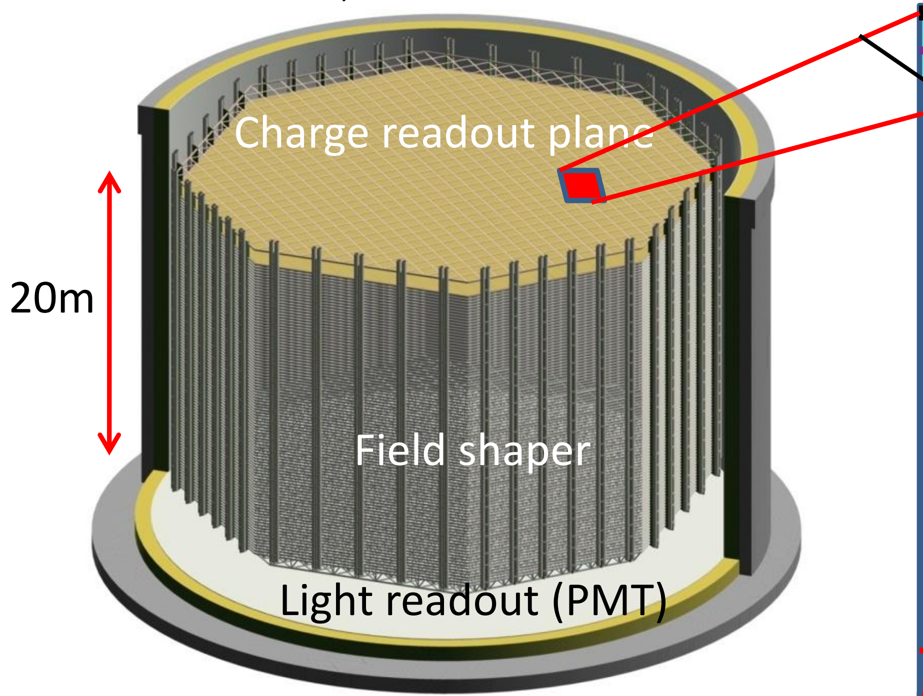
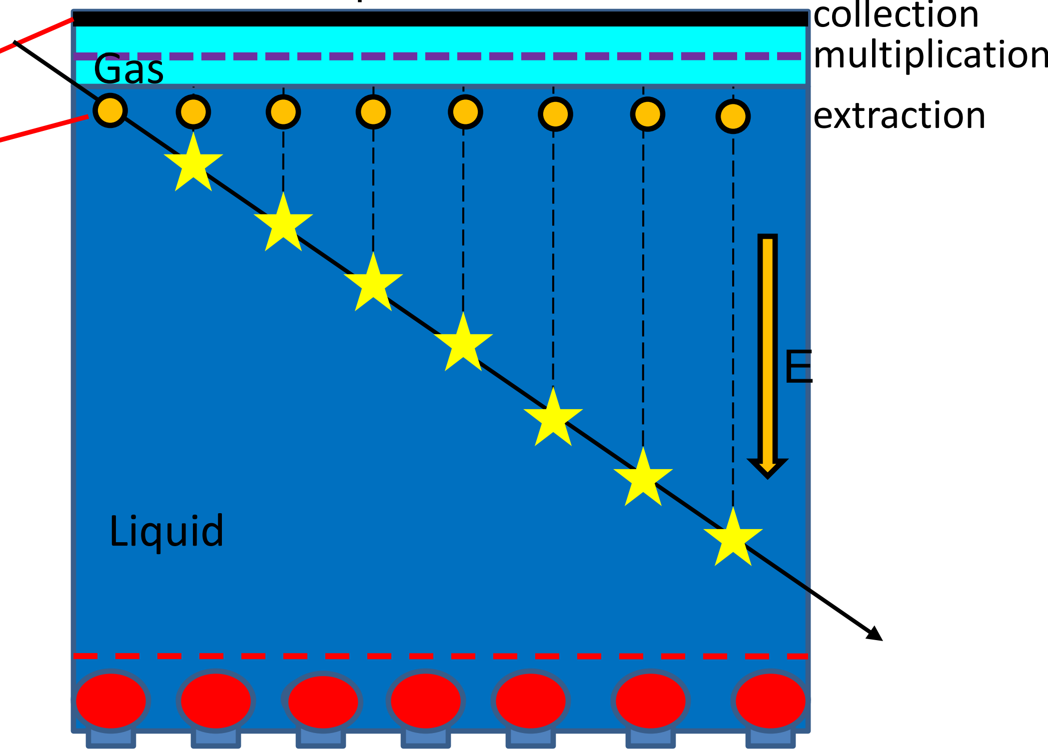
GLACIER 20kT, 50 kT for LAGUNA-LBNO



Double phase LAr TPC:



To get there, need to do R&D on:

1) Design compact large area readouts: LEM and anode of square-meter scale

2) Prove feasibility of long distance drift up to 20m

3) HV up to the MV scale

4) <0.1ppb level purity in non evacuated membrane tank

5) UV scintillation light readout over 20m

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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

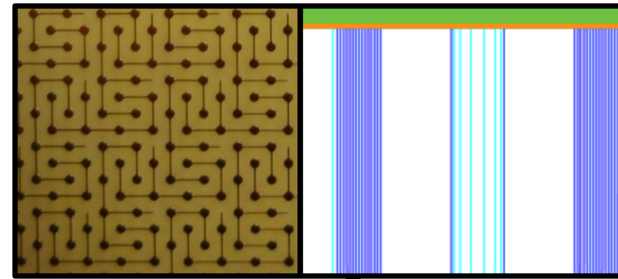
- **First successful operation of a 40x76 cm^2 device in November 2011:**
- A. Badertscher et al., “First operation and drift field performance of a large area double phase LAr Electron Multiplier Time Projection Chamber with an immersed Greinacher high-voltage multiplier ” JINST 7 (2012) P08026
- A. 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.

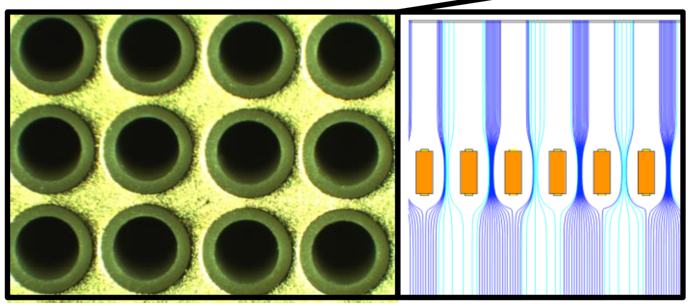
Final goal: Giant LAr LEM TPC as far detector for a Long Baseline Neutrino Oscillation (LBNO) experiment (SPSC-EOI-007)

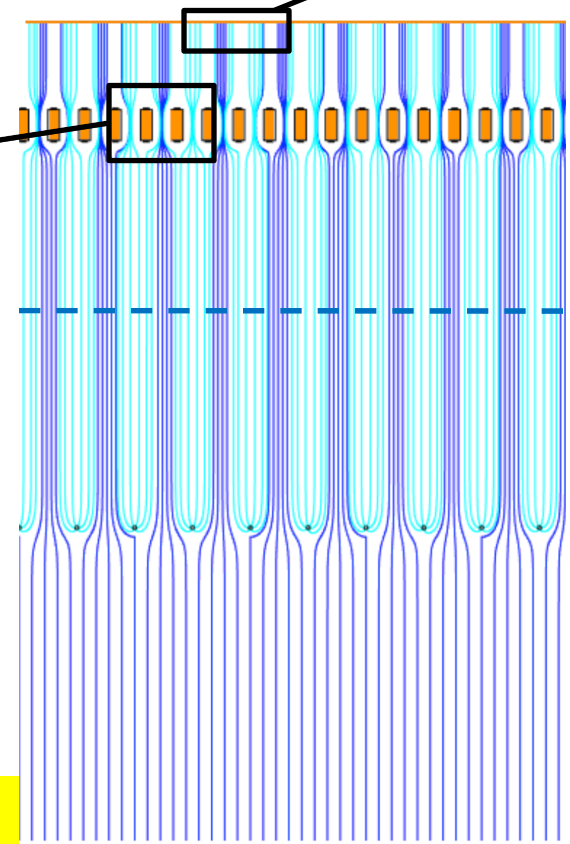
Double phase concept



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)



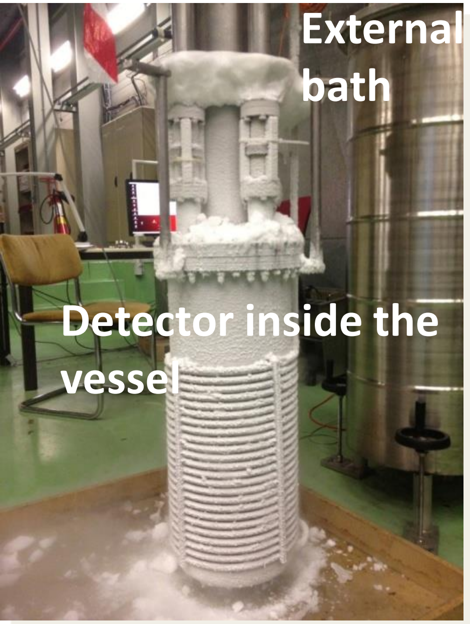


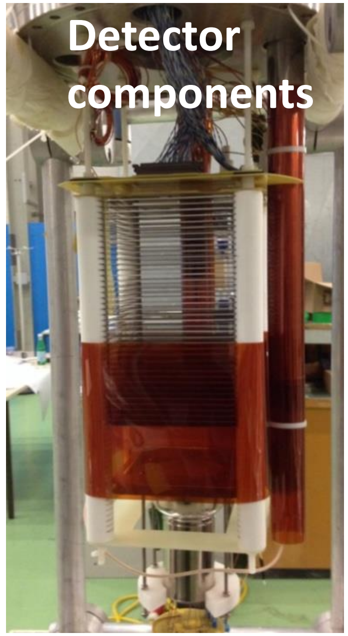
2.) Drift electrons are efficiently extracted into the gas phase

1.) Ionization electrons drift towards the liquid argon surface

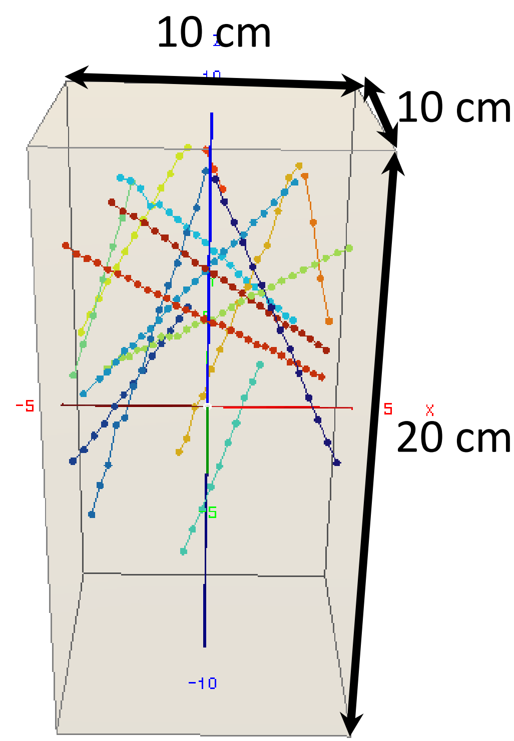
Single compact readout module of square meter doing extraction, amplification and readout – Charge Readout Plane (CRP)

What we are testing: 10x10x20 cm^3 prototype





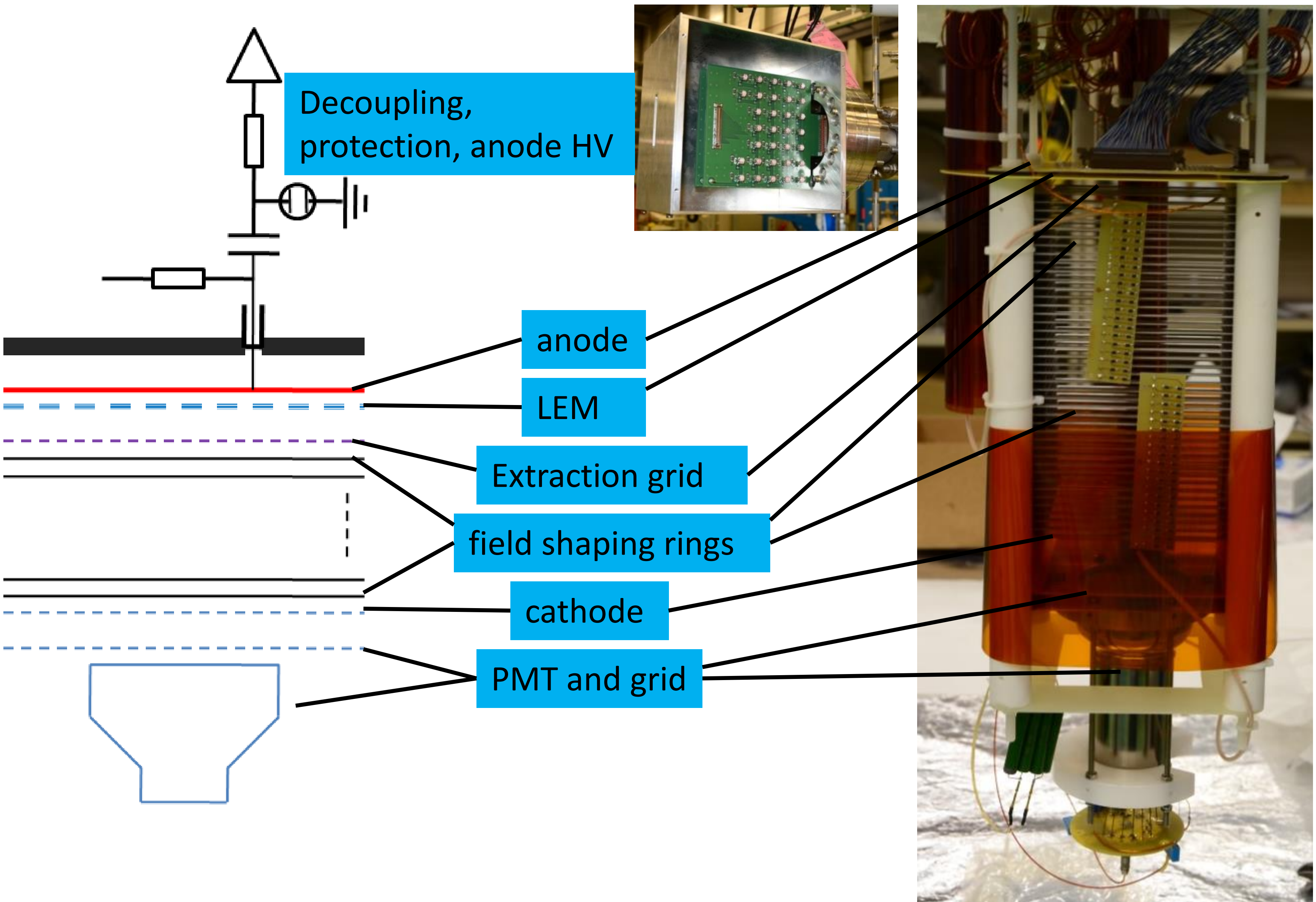
With this small chamber, we can collect in a short amount of time a high quality and **large data-sets of cosmic muon** with constant energy loss per unit length **~10 fC/cm**



We're developing:

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

Detector setup



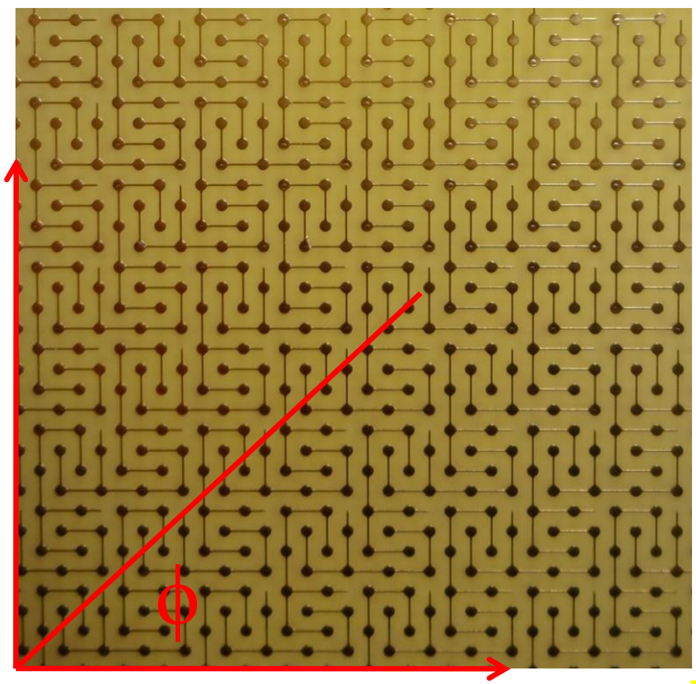
Towards large area readout - anode considerations

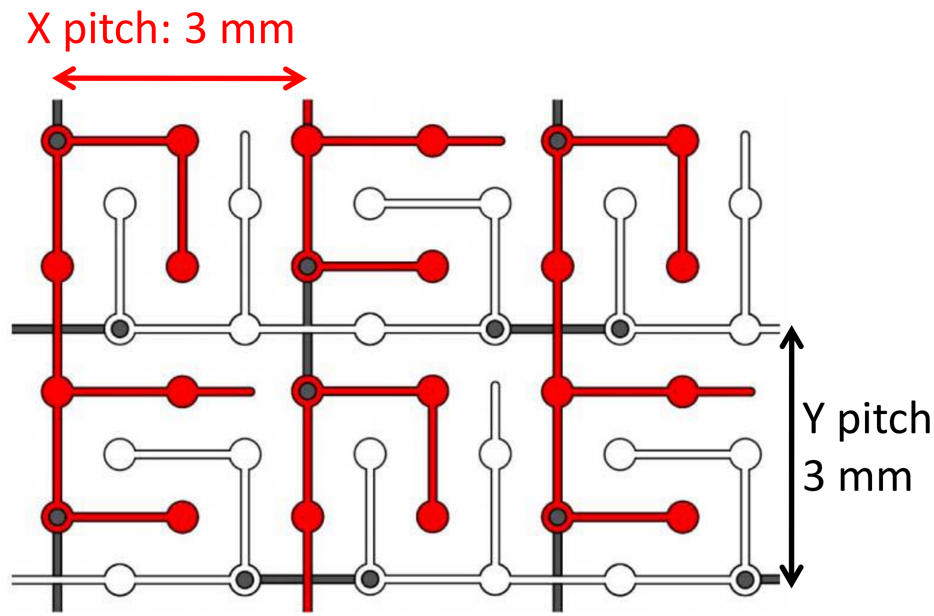
To reach basic GLACIER 4x4m^2 CRP (2m readout length) design:

-> 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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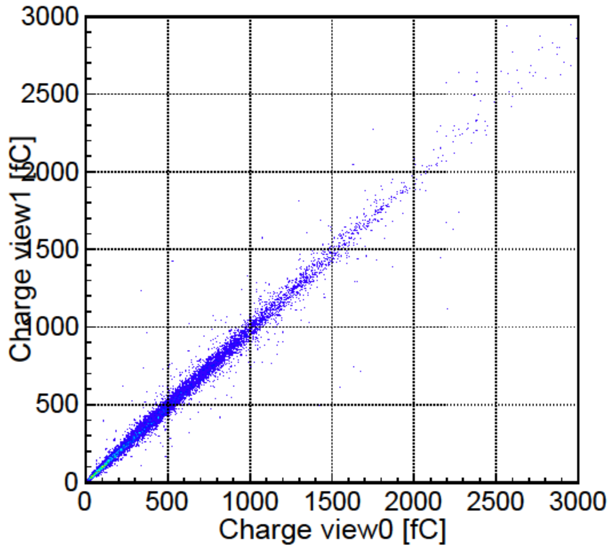
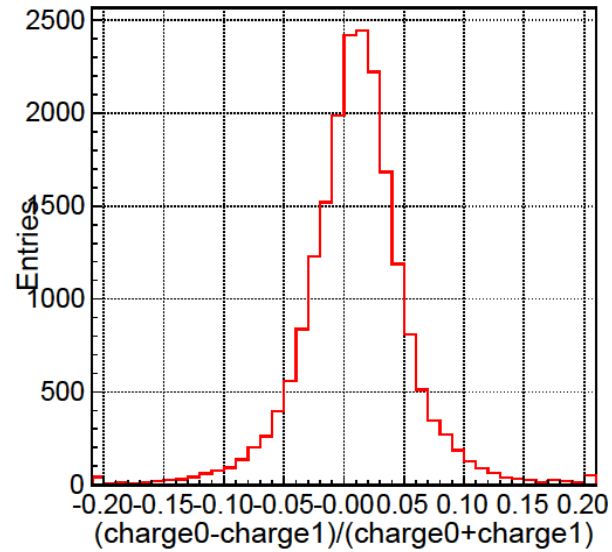
Swiss Federal Institute of Technology Zurich

Fully X-Y symmetric:

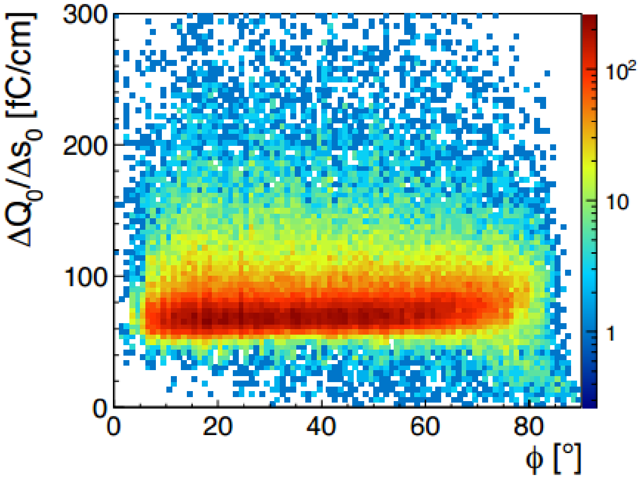


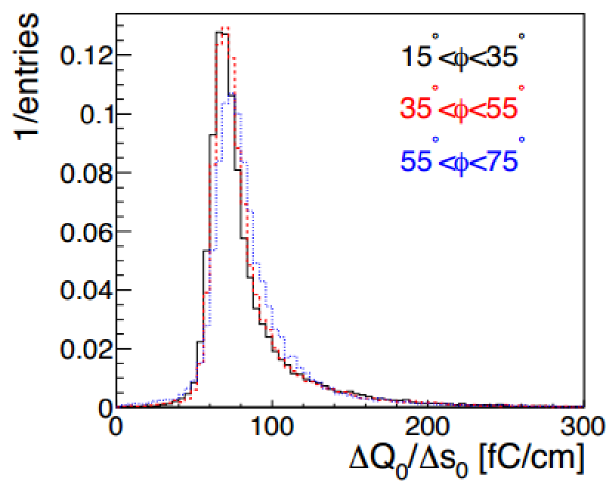


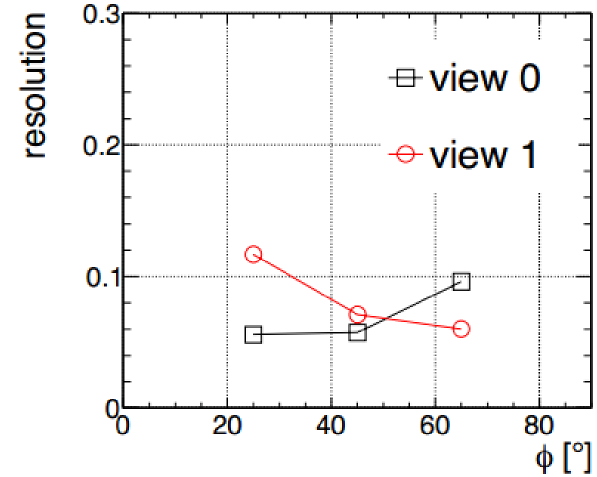
Mean: 0.009
RMS: 0.043

Uniform response to all tracks:

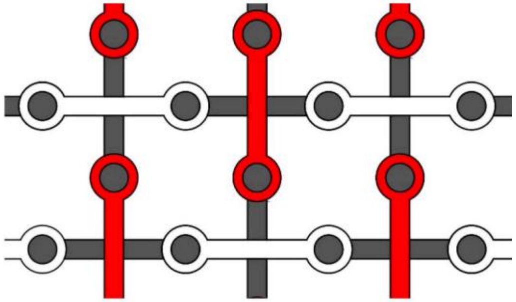
arXiv:1312.6487



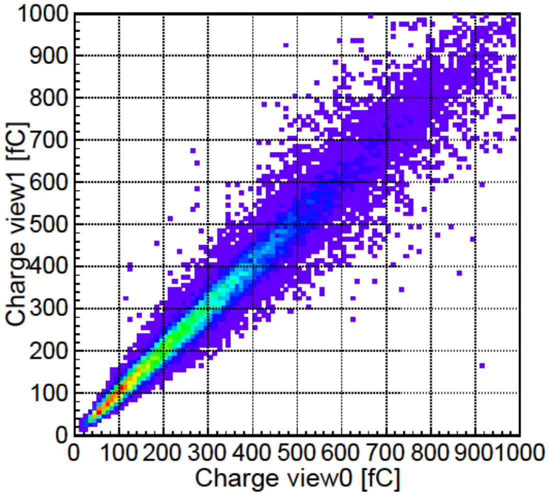


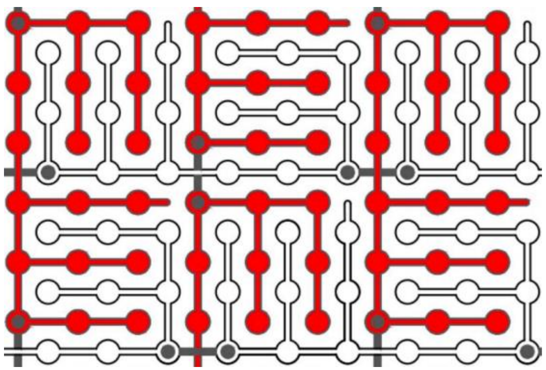


Other anodes tested

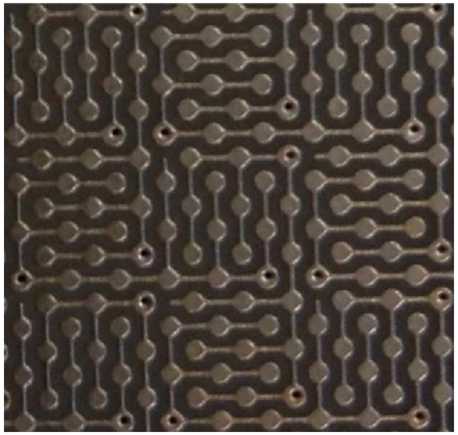


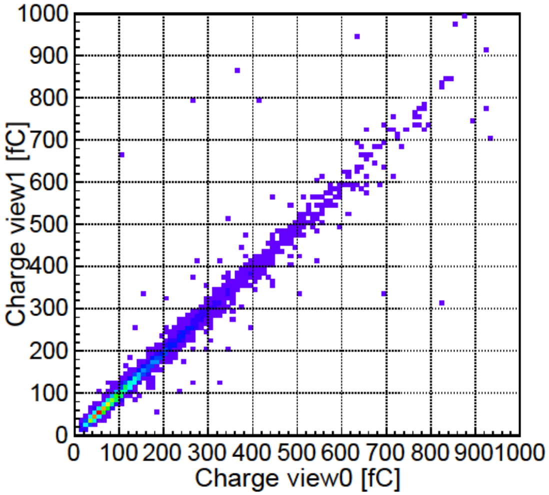
dC/dl~100 pF/m



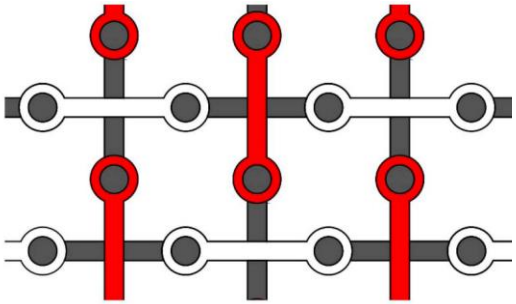


dC/dl~250 pF/m

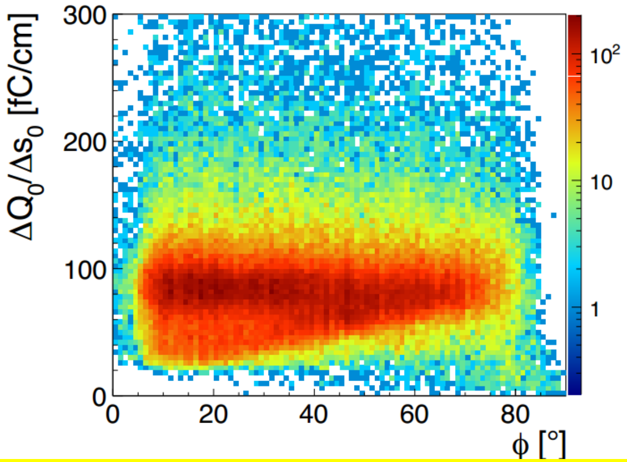


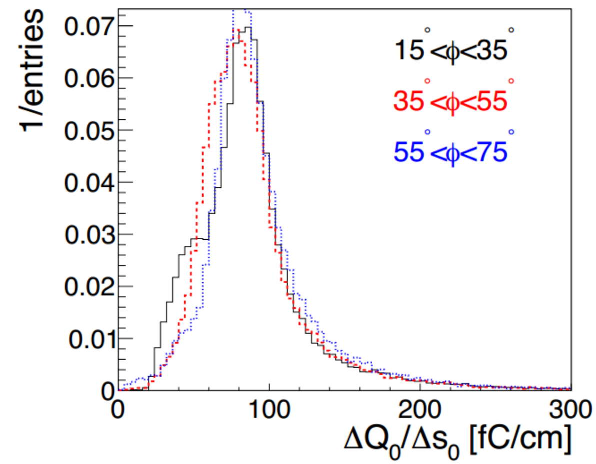


Other anodes tested



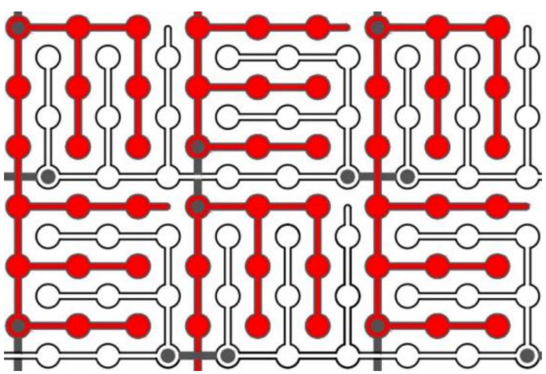
dC/dl~100 pF/m



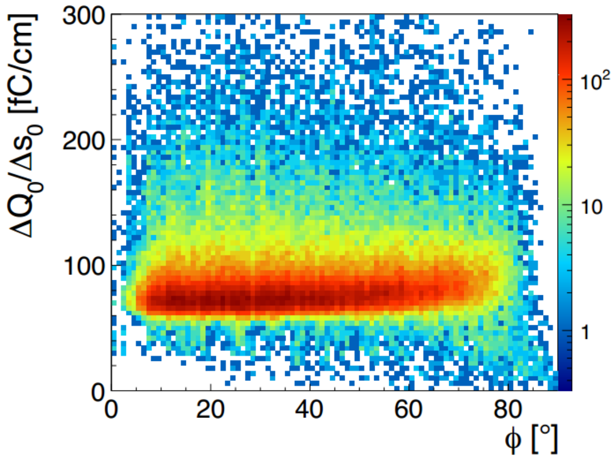


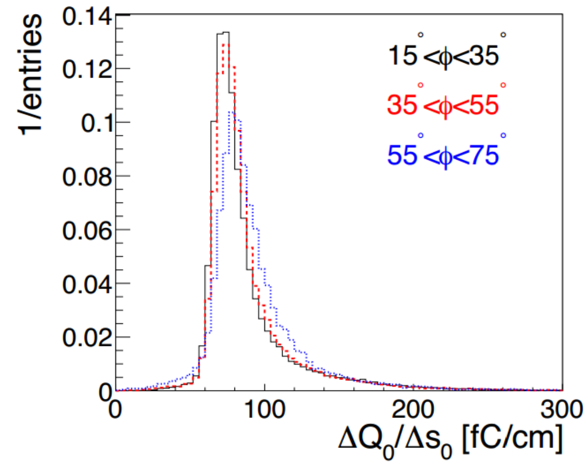
Pattern too loose, non uniform charge collection between strips

arXiv:1312.6487



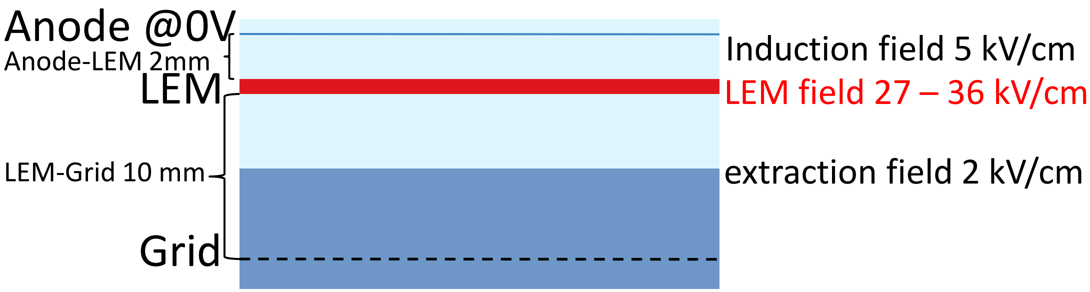
dC/dl~250 pF/m





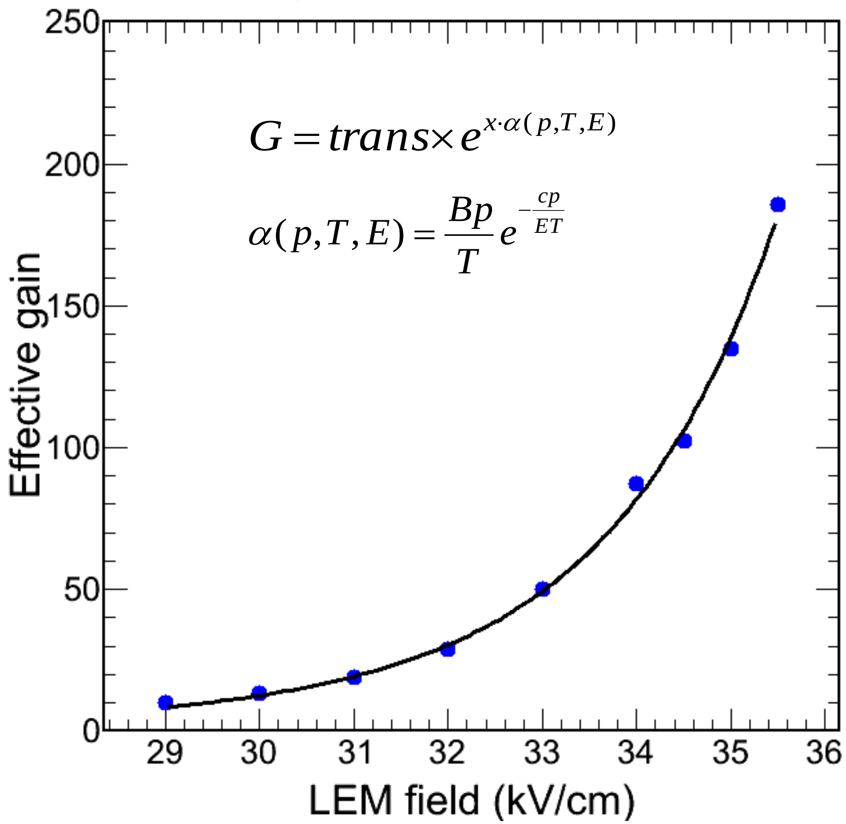
Compatible performance as 150 pF/m anode, but has higher capacitance

Highest effective gain over 150

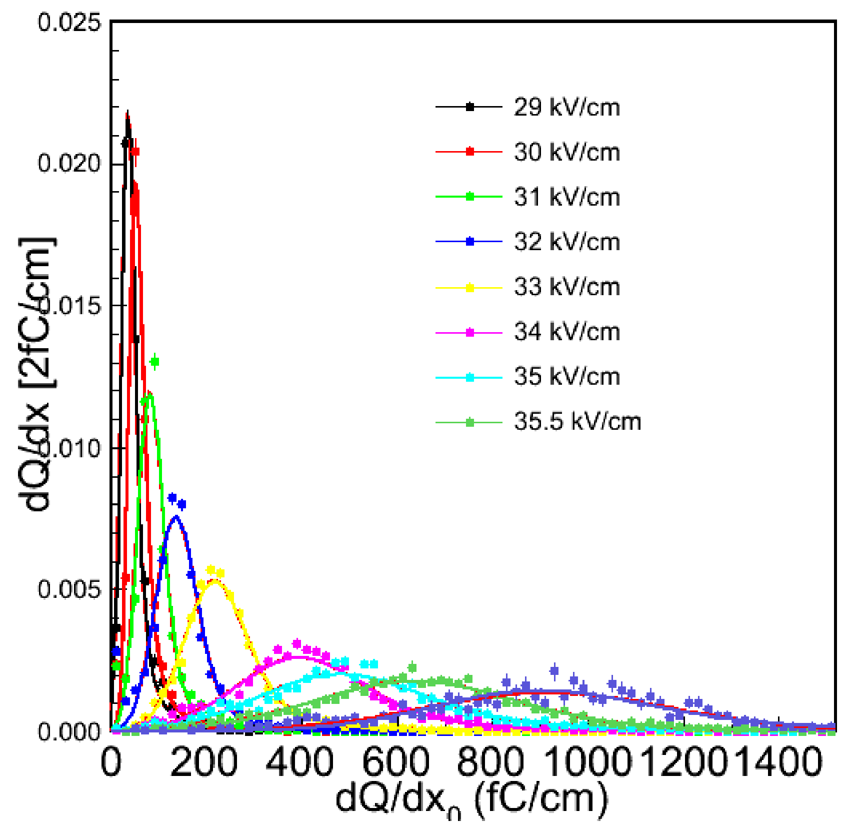


$$\text{Eff. Gain} = \frac{<dQ/dx_0> + <dQ/dx_1>}{dQ/dx_{mip}}$$

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



Landau curves vs. LEM field (V/d):



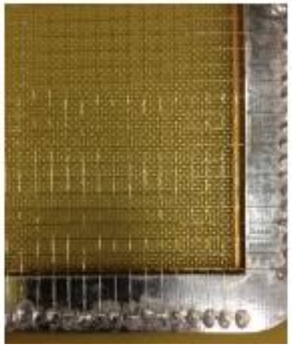
Gain uniformity

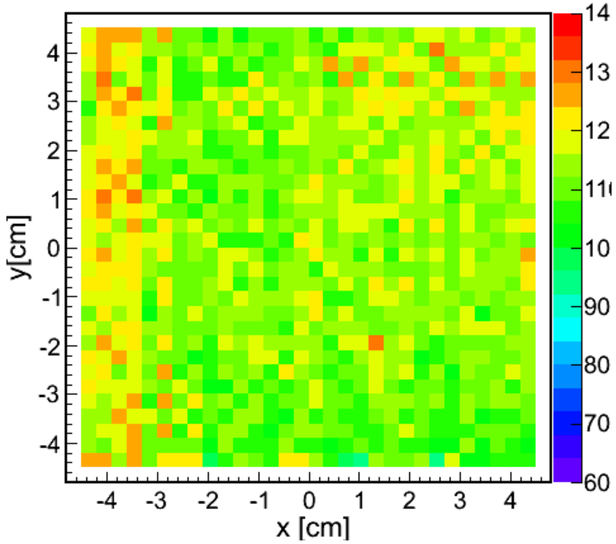
<dQ/dx> (fQ/cm) (normalized to 100 fQ/cm):

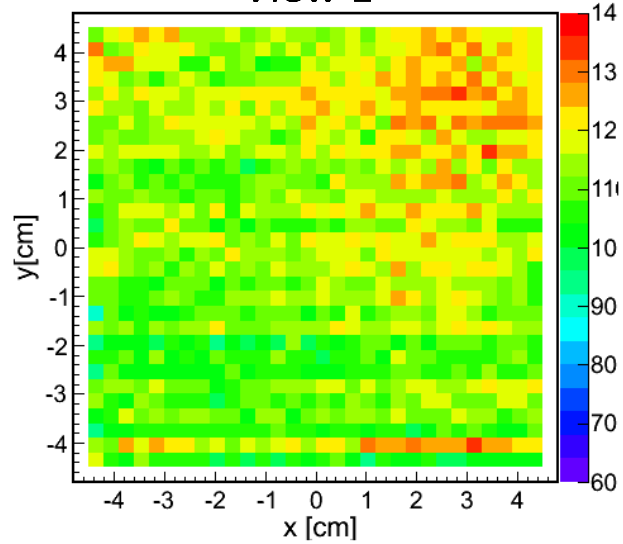
View 0

View 1

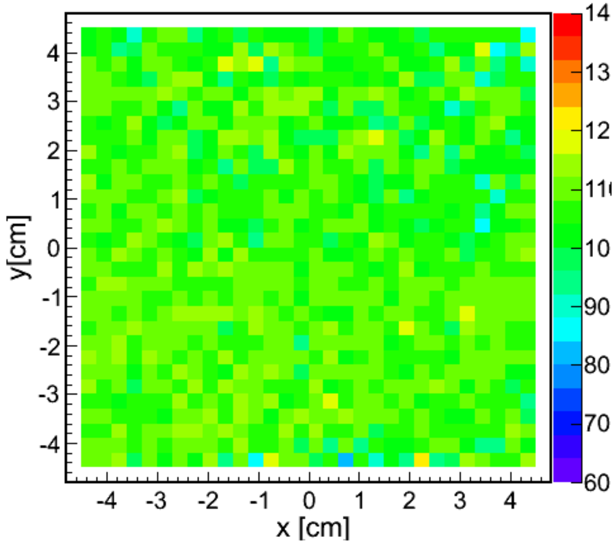
3 mm pitch in x-y
(matching anode strip)

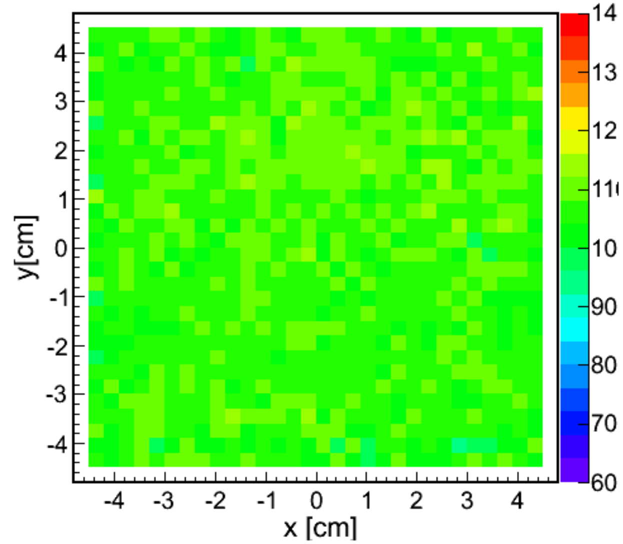






1.5 mm pitch in x



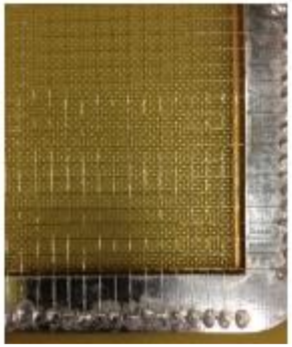


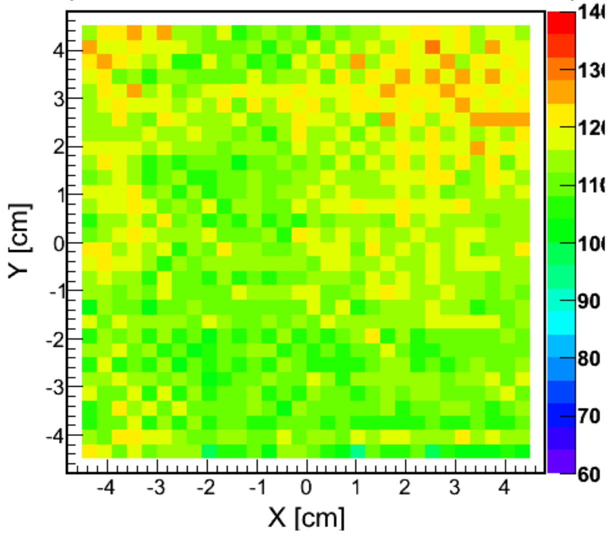
Gain uniformity – sum and difference of two views

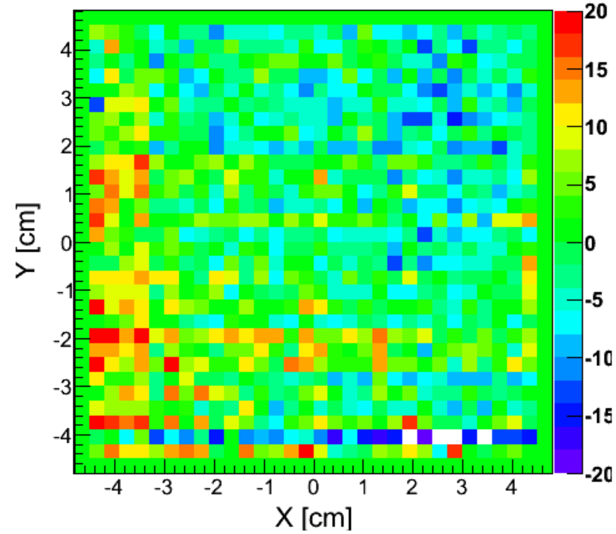
Sum of <dQ/dx> (fQ/cm) (normalized to 100 fQ/cm):

Difference (%):

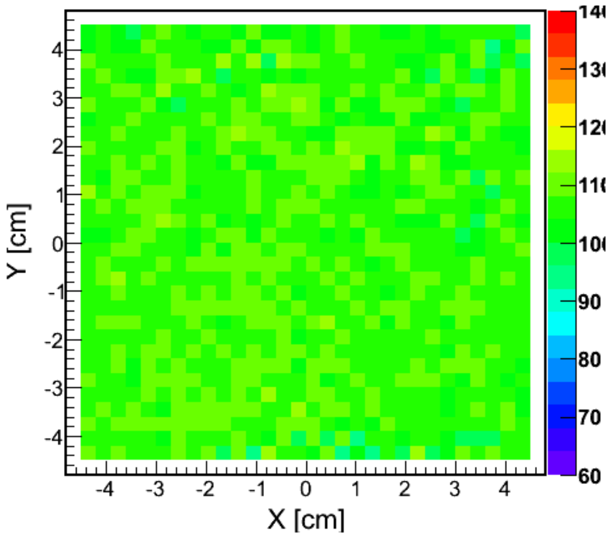
3 mm pitch in x-y (matching anode strip)

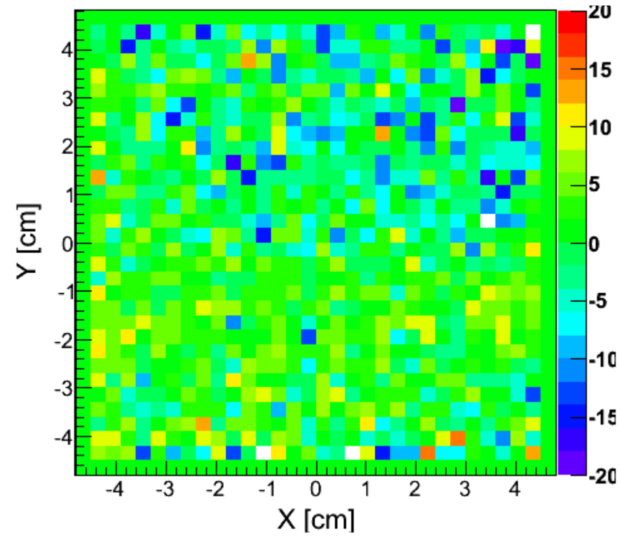






1.5 mm pitch in x





Gain uniformity - projections

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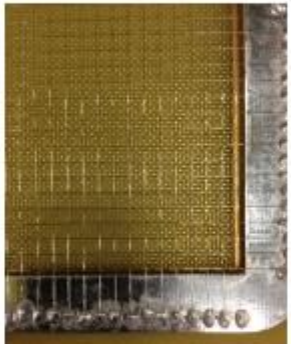
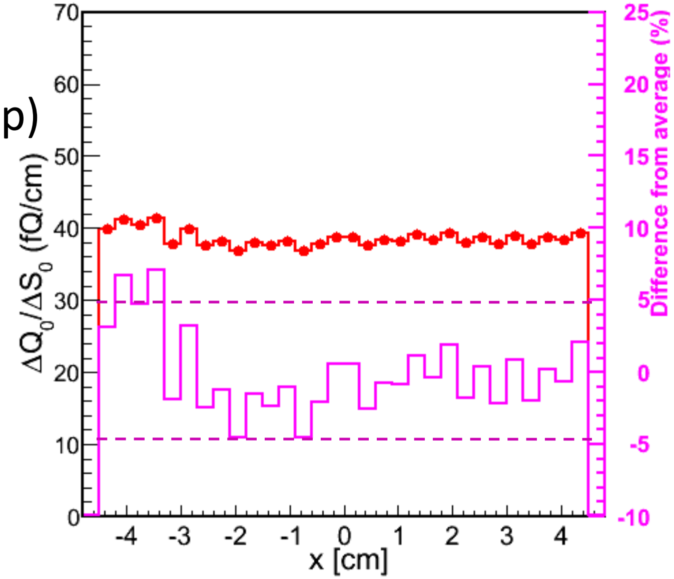
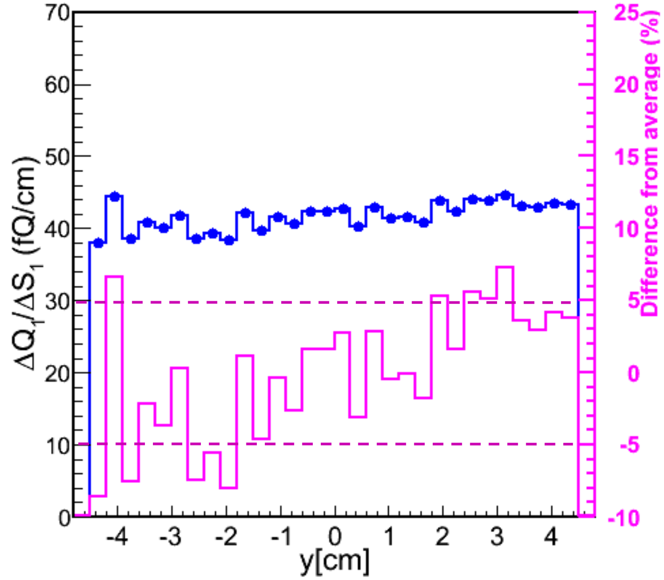
projection along x- coordinate

projection along y- coordinate

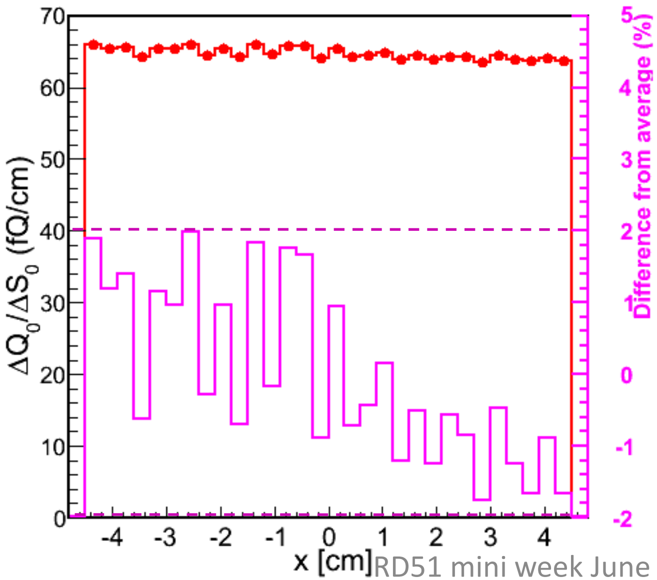
3 mm pitch in x-y
(matching anode strip)

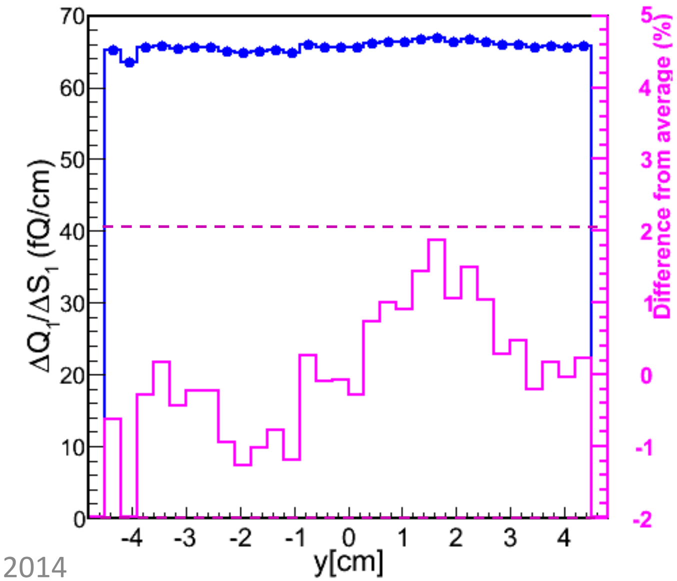




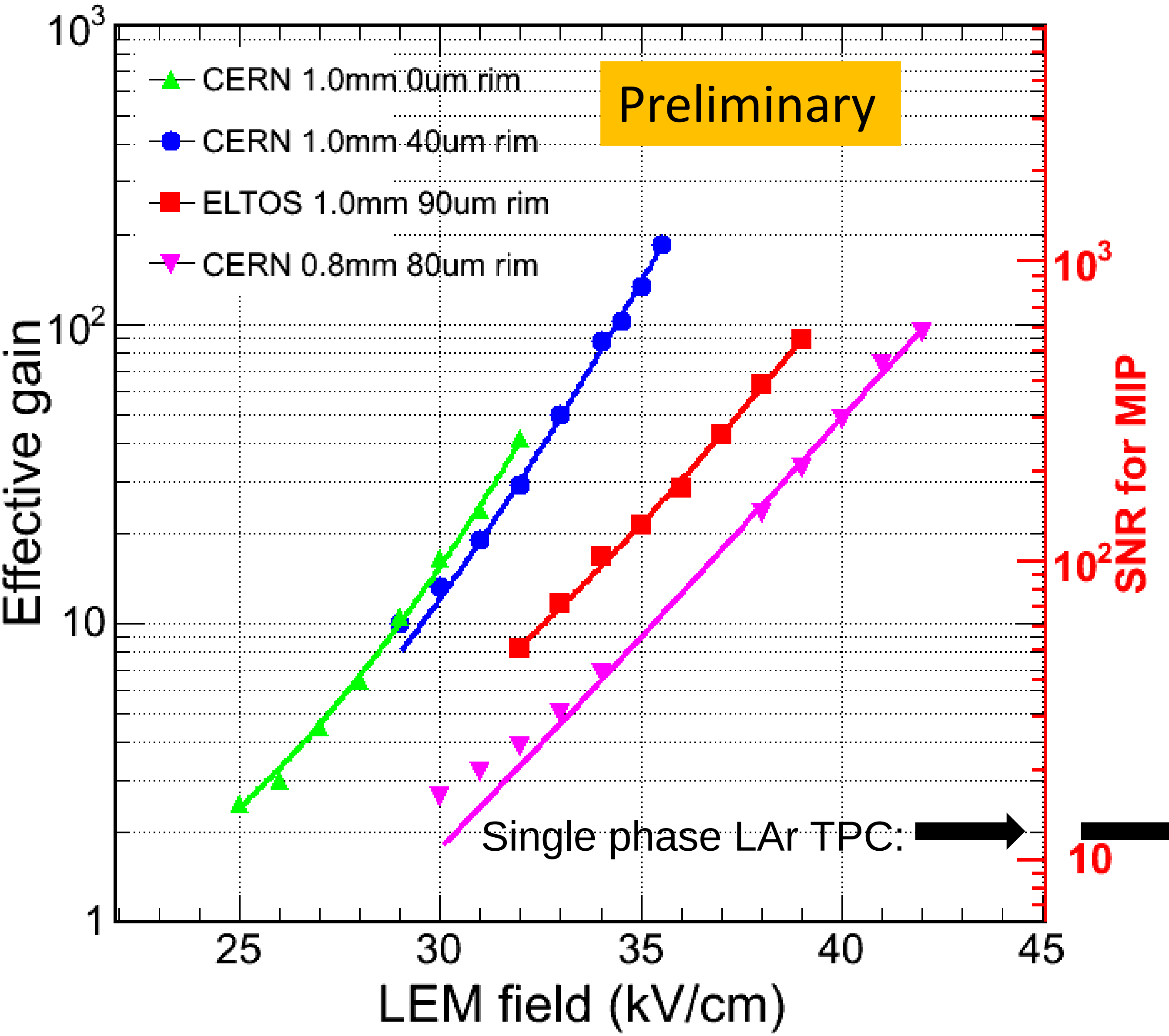


1.5 mm pitch in x





Gain of different LEMs:



15 keV energy deposit threshold per strip

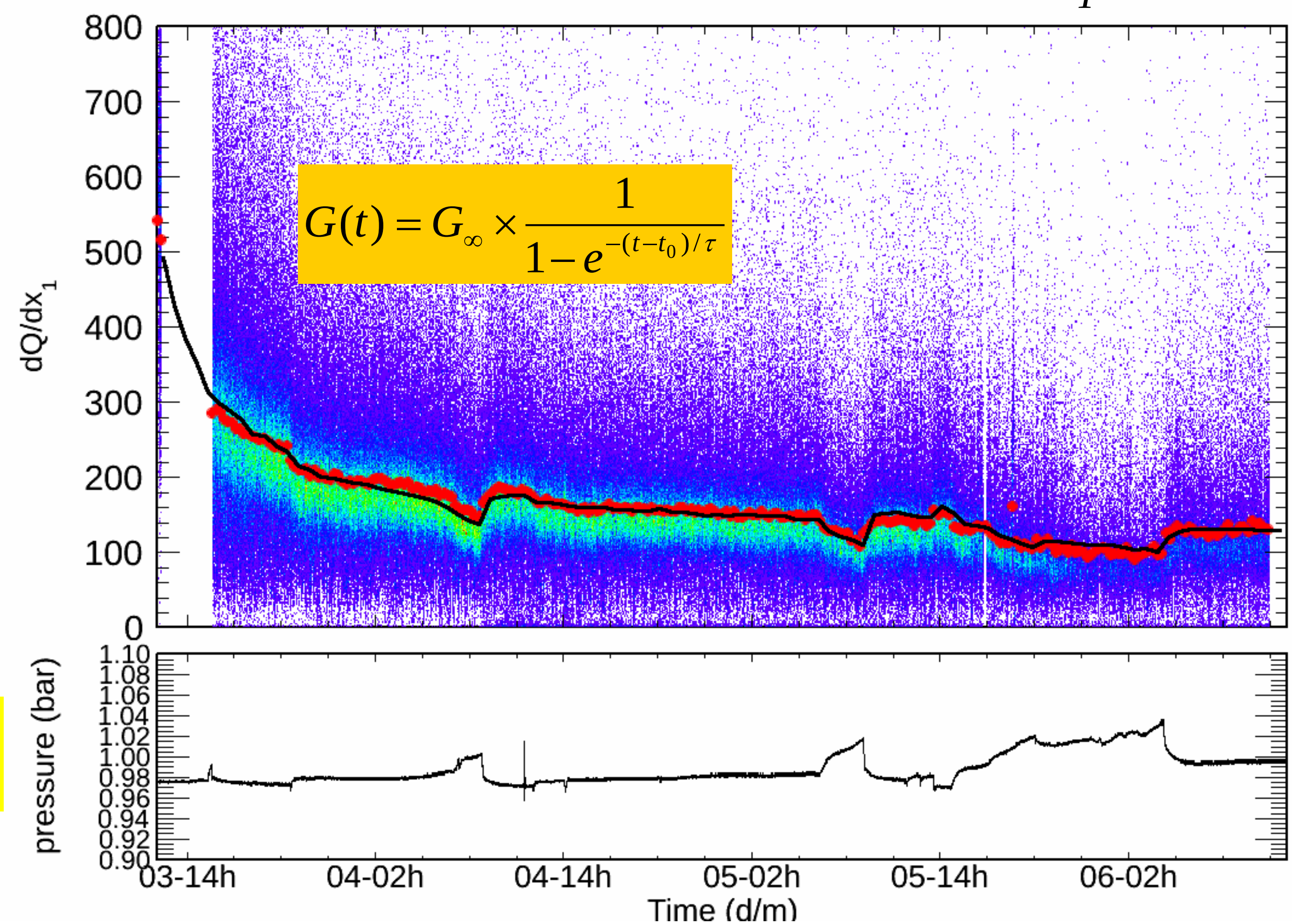
Remarks:

- Optimized rim size ~ 40 um
- Same rim size, same maximal achievable gain
- SNR~200 @ gain 30 - large area readout

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:

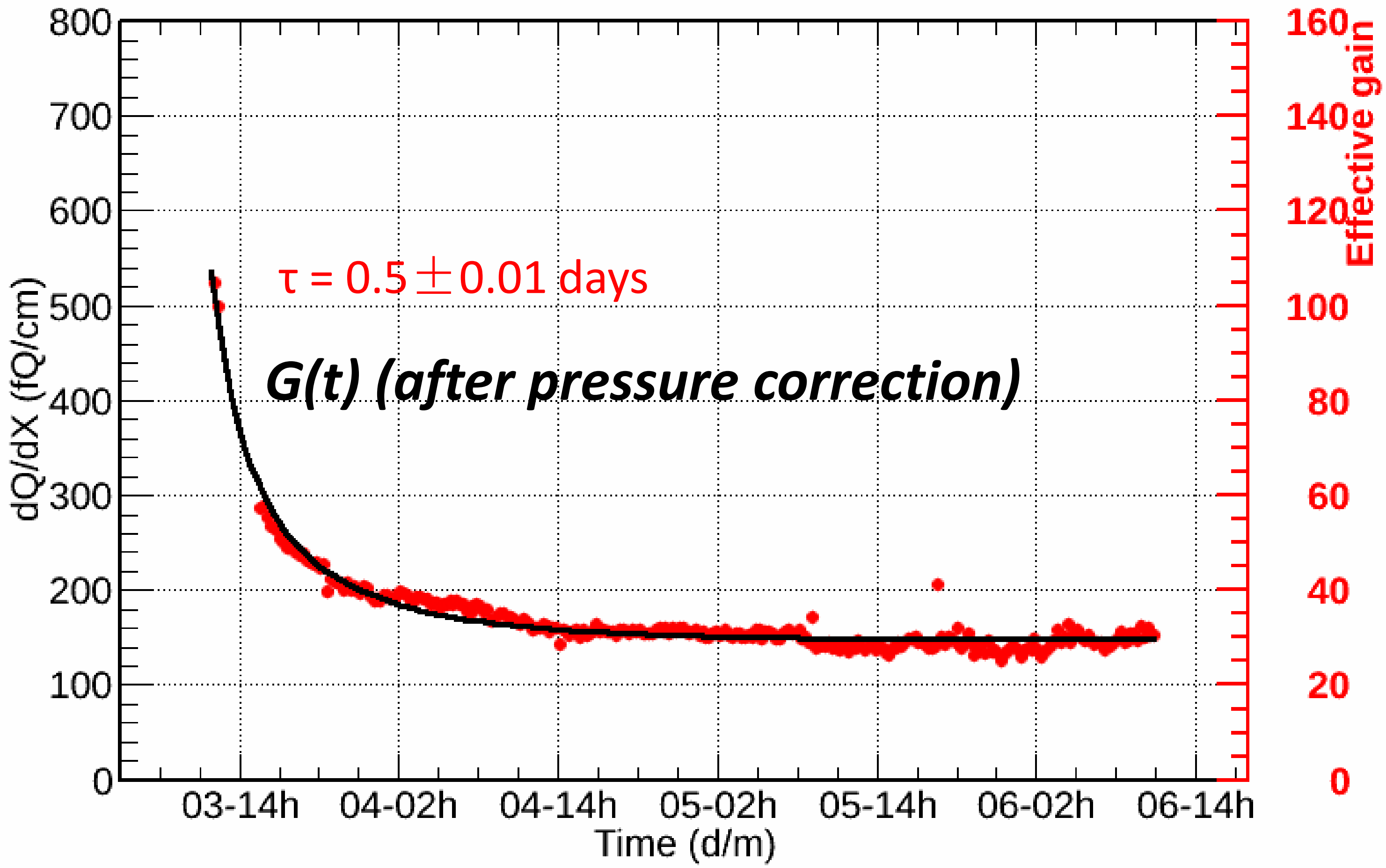
future detectors will operate under controlled pressure!

Stability of the gain

To describe the initial decrease: $G(t) = G_{\infty} \times \frac{1}{1-e^{-(t-t_0)/\tau}}$

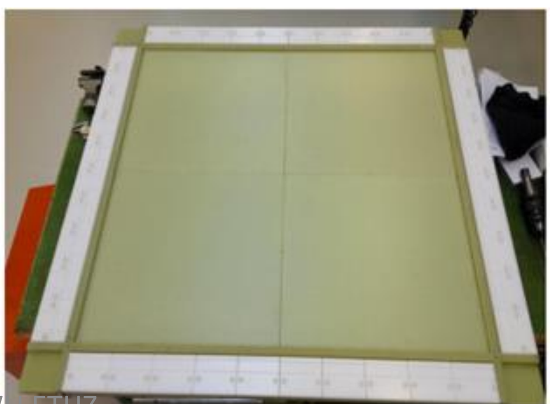
✓ Gain stabilizes at ~30 (at LEM field of 34 kV/cm) after an initial decrease with τ ~ 0.5 days

✓ Stable gain is ~1/3 of the original one

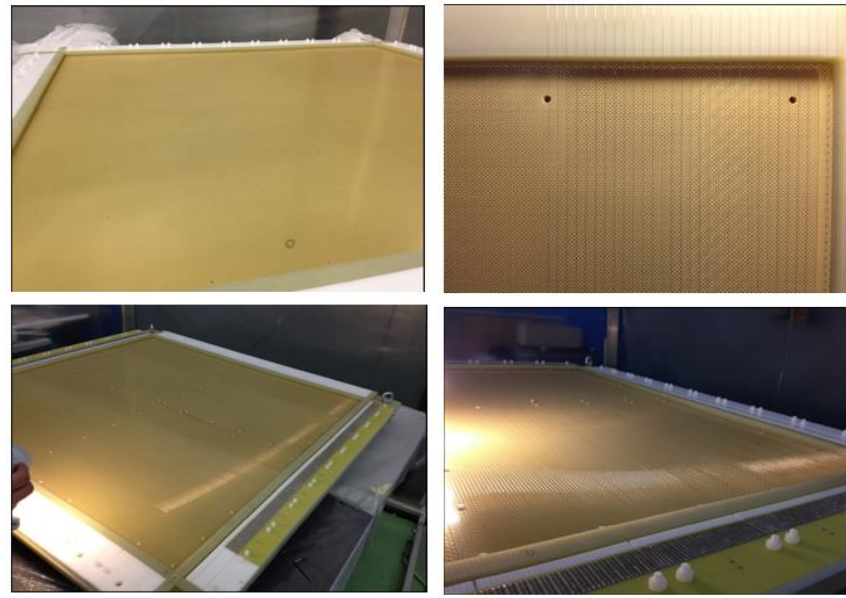


Towards large area readout - the 1x1 m^2 CRP

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



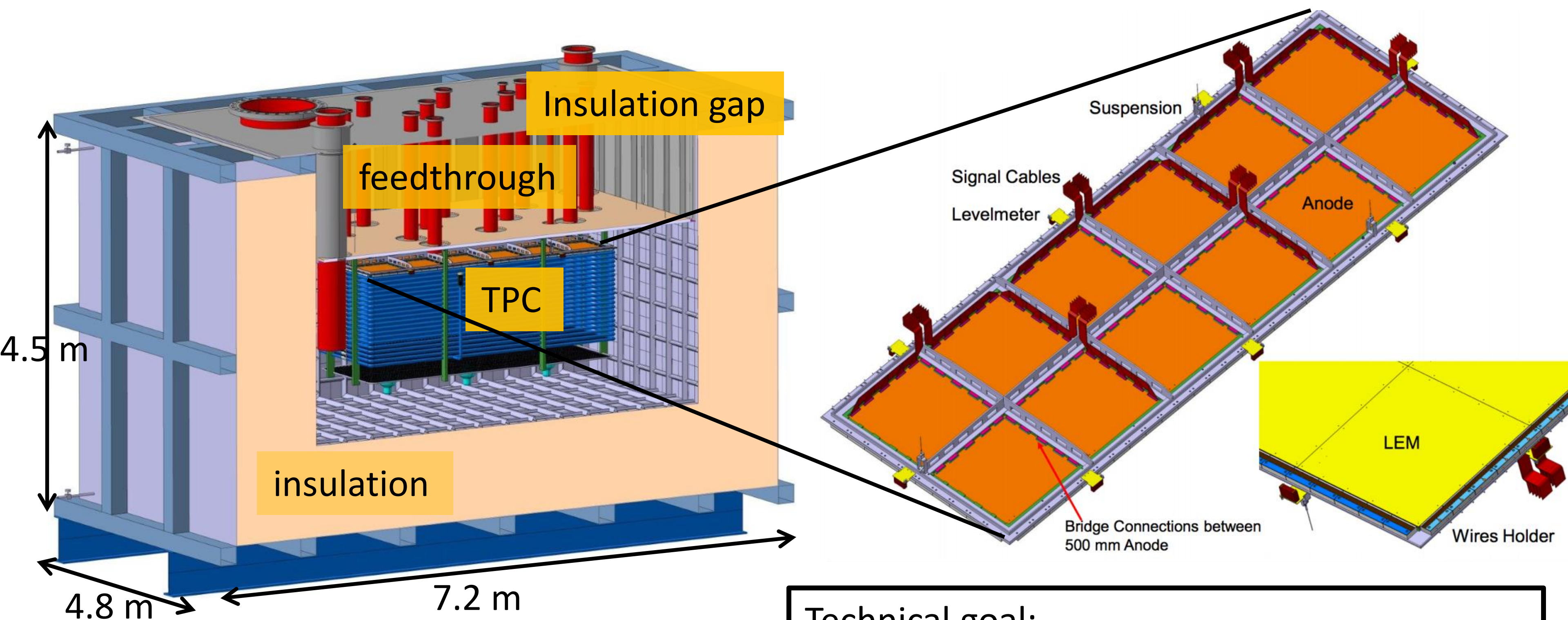
Implemented with real anodes and grid



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

5 ton (fiducial) double phase LAr TPC

3x1 m^2 charge readout system:

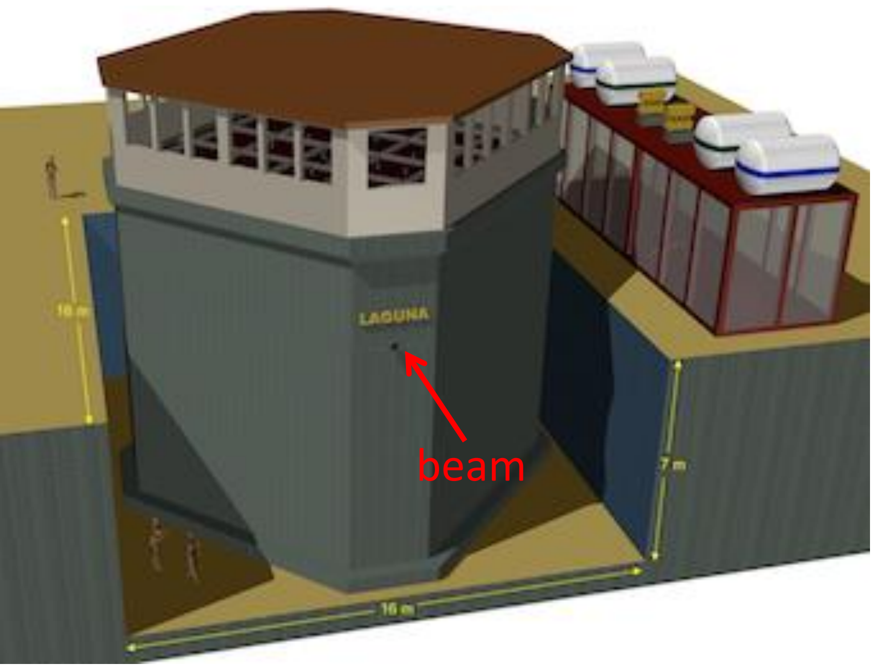


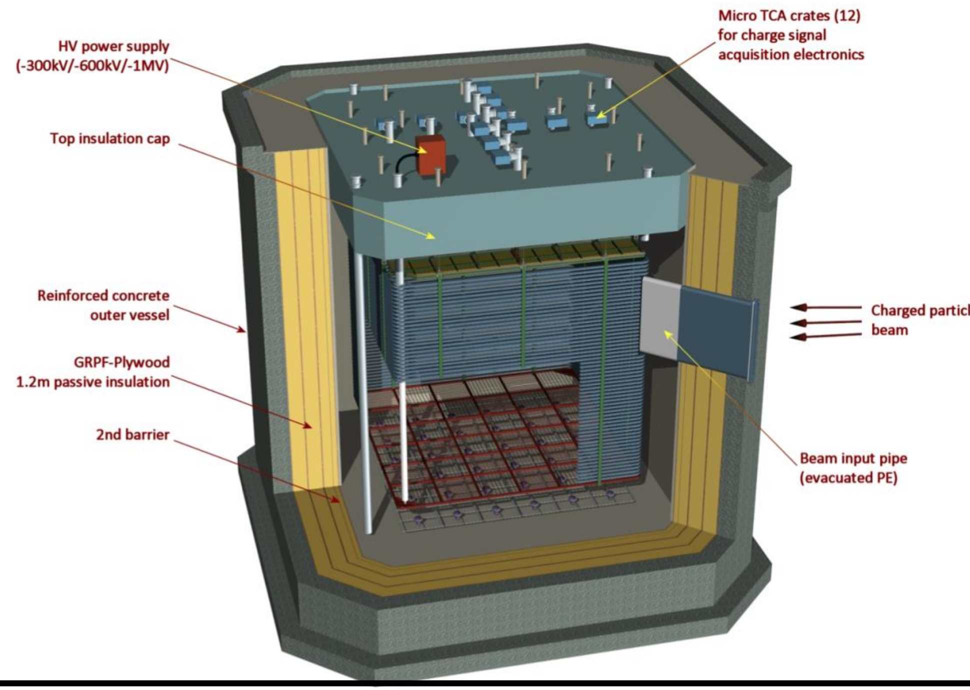
Time scale 2014-2015
Site: B182@CERN

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

In the coming years: the LBNO-DEMO (WA105)

LBNO prototype WA105 to be built at CERN: 6x6x6 m^3 (~300 ton) double phase LAr demonstrator in charged-particle test beam.





Time scale 2015-2018
Site: EHN1@CERN

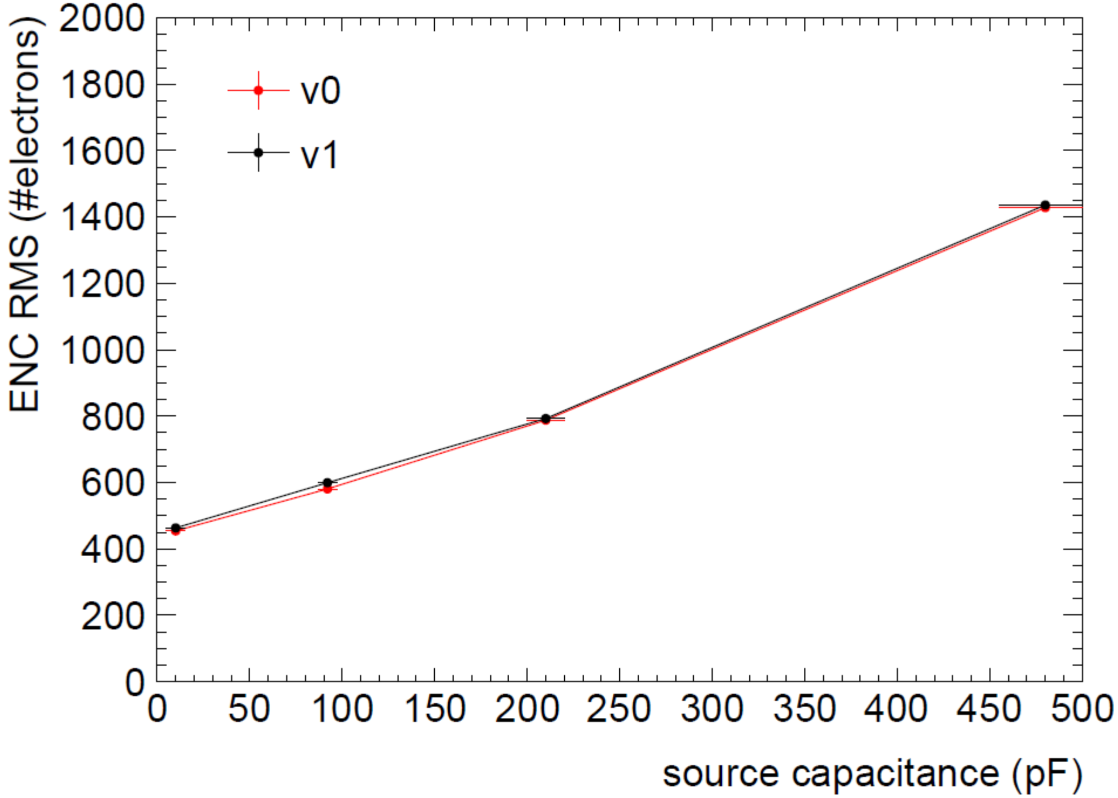
Goal:
Technical: demonstrate all the feasibility of LBNO 20/50 kton scale LAr TPC
Physical: charged pions and proton cross-section on argon nuclei, develop reconstruction algorithm…

Summary

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

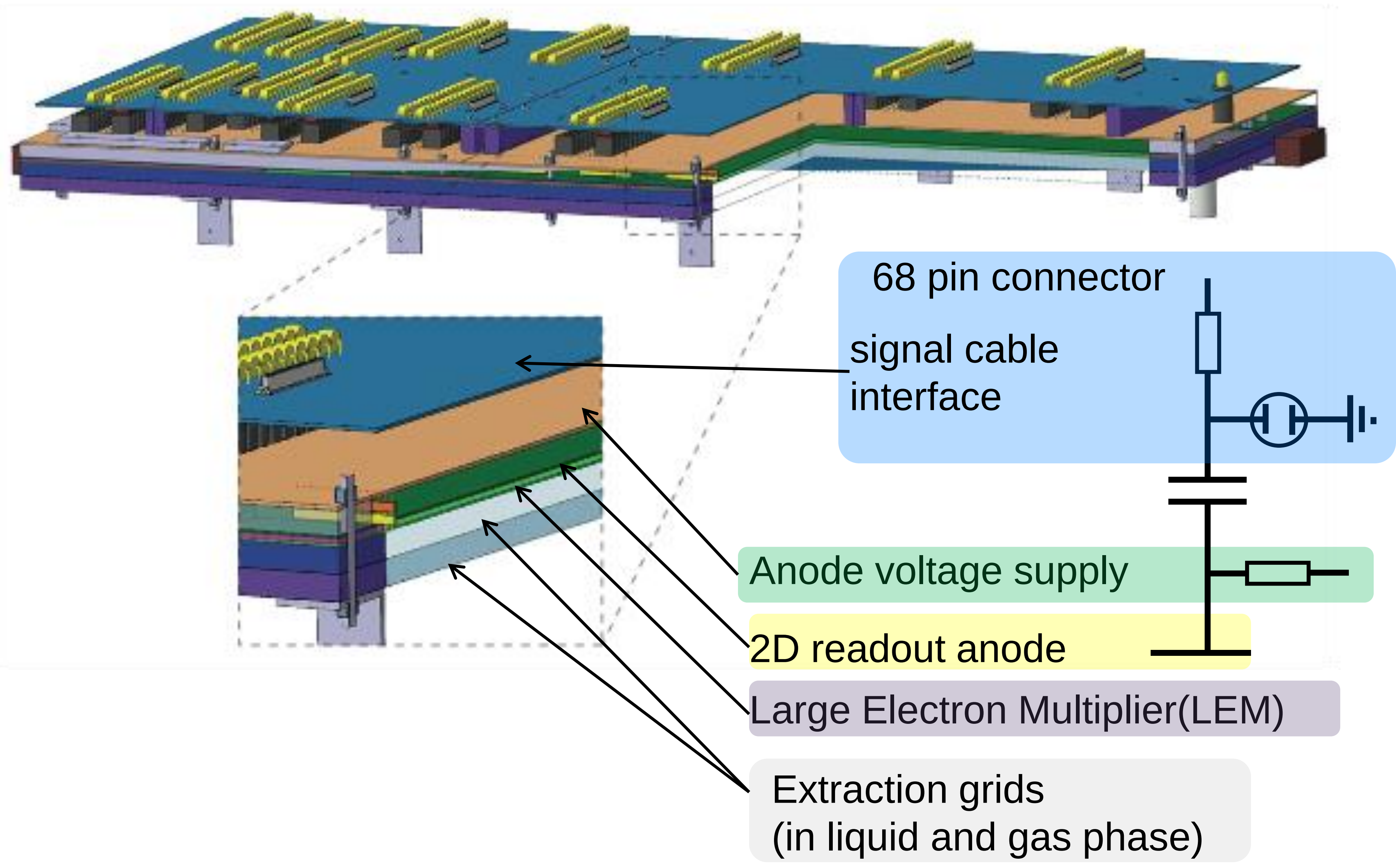
- Low capacitance (~150 pF/m) 2D anode turns out to fulfill the requirements on resolution
- Stable gain over several weeks reached after an initial decrease and resistance to discharge
- Good gain uniformity achieved by matching extraction grid with anode strips
- large area readout mechanically feasible
- Time for the 3x1x1 m^3 LAr LEM TPC

Thank you for your attention!



ENC RMS (#electrons)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
350
400
450
500
source capacitance (pF)
v0
v1

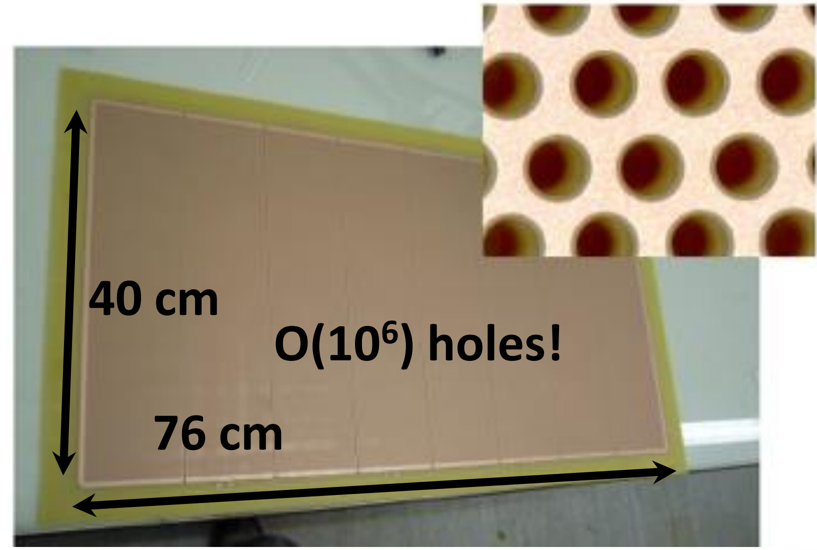
Compact charge readout design



Towards a large area readout: the 40x76 cm² prototype

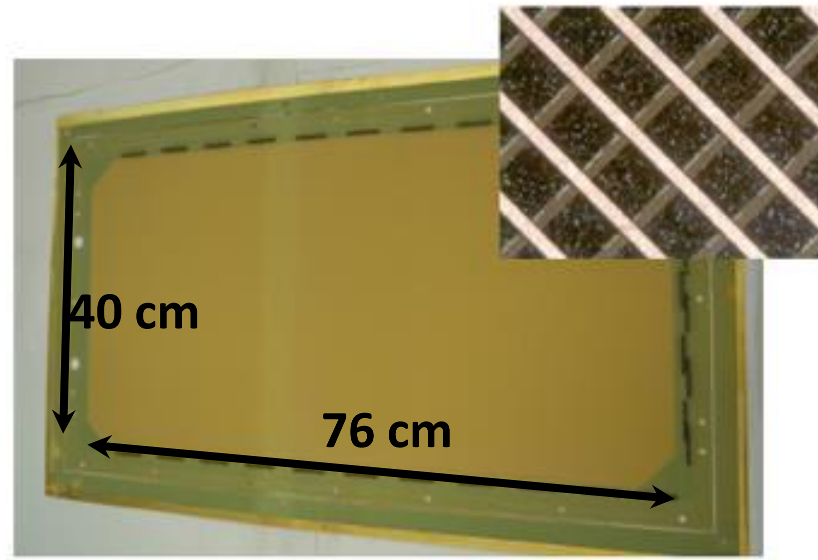
Large Electron Multiplier (LEM)

- Macroscopic gas hole multiplier (Thick GEM)
- more robust than GEMs (cryogenic temperatures, discharge resistant)
- manufactured with standard PCB techniques
- Large area coverable by 50x50 cm² 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

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Large area readout: the 40x76 cm^2 prototype

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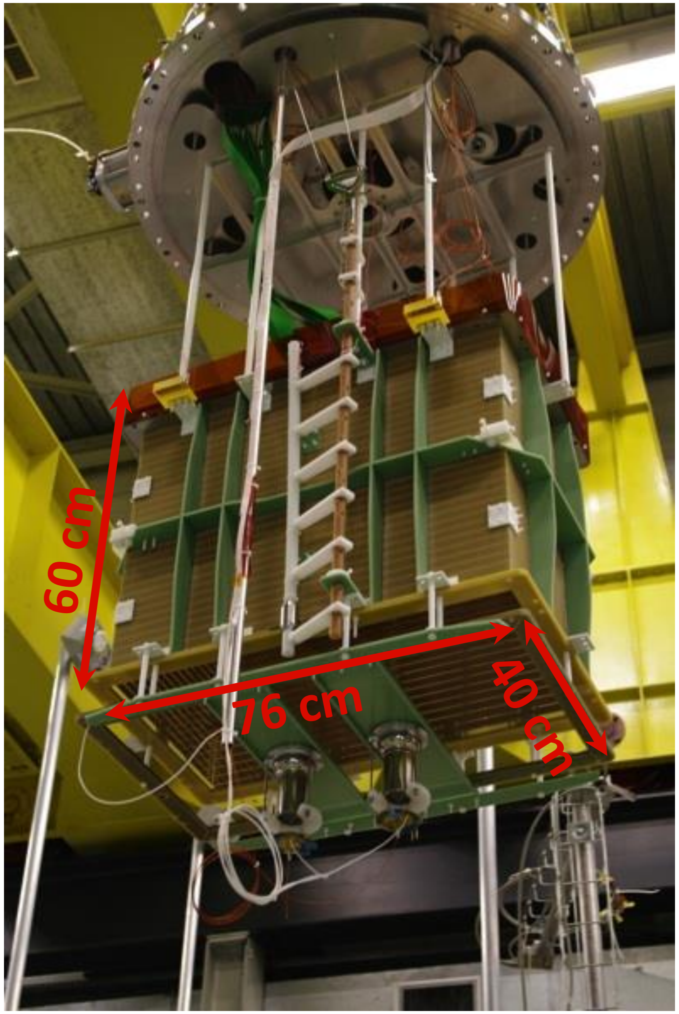
detector fully assembled

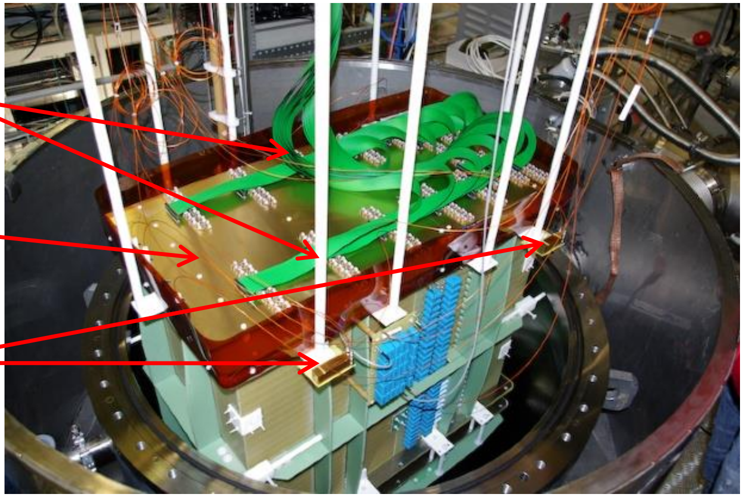


going into the ArDM cryostat

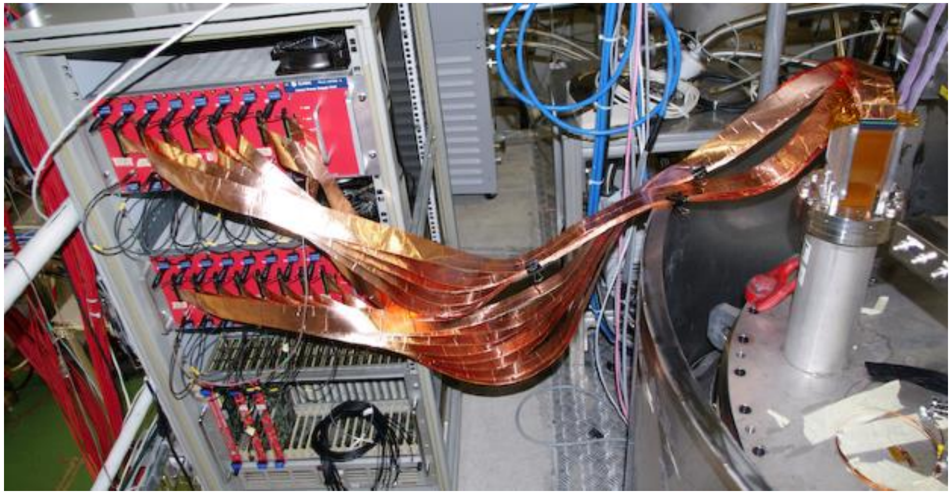
16 signal cables

charge readout sandwich

4 capacitive level meters



Final connection to the CAEN DAQ system



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Results from the 40x76 cm^2 prototype

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

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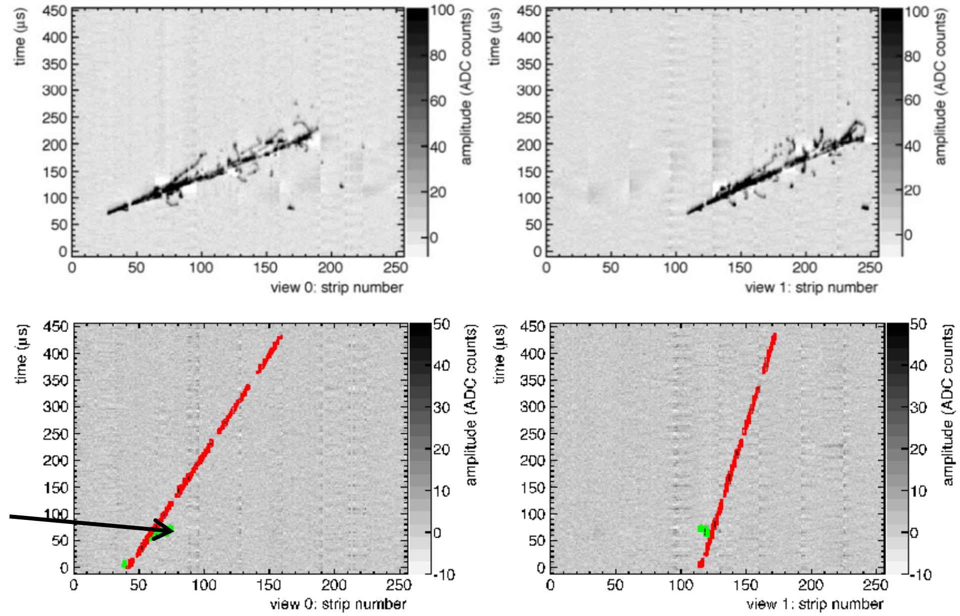
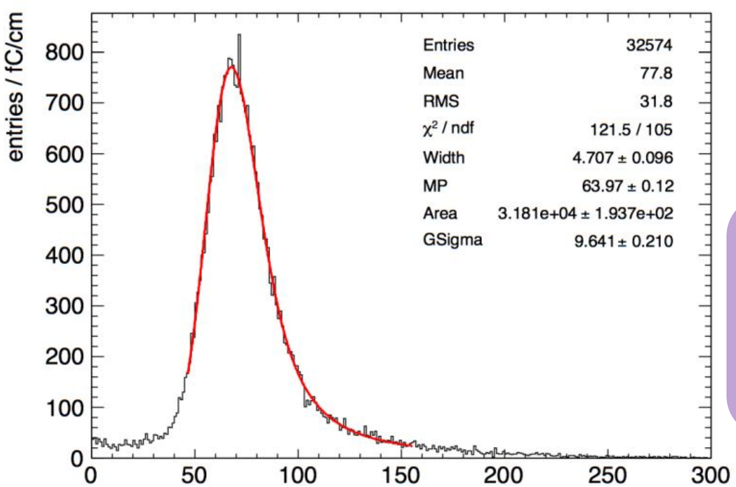
Optimized field configurations:

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%

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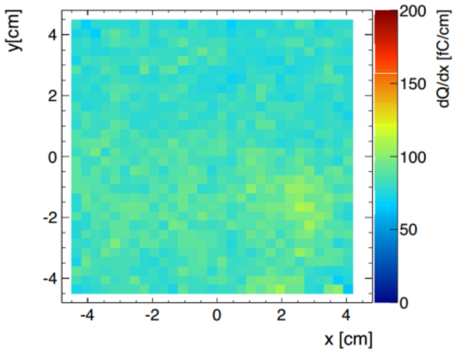
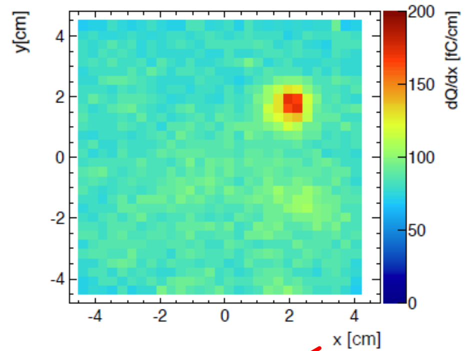
What happens locally when discharging?

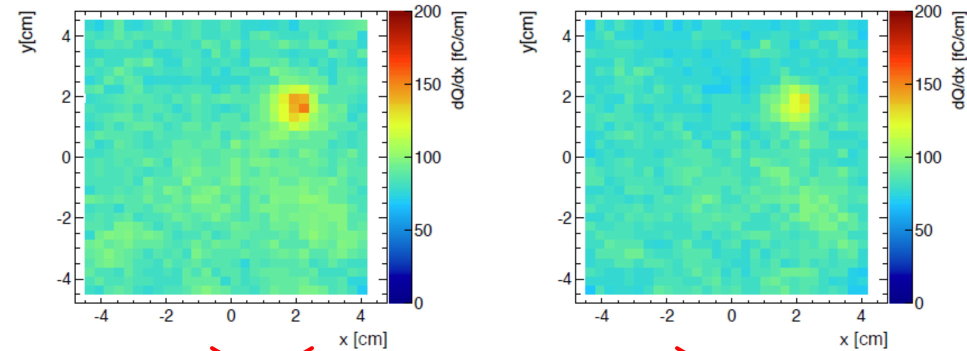
before discharge:



when discharging:



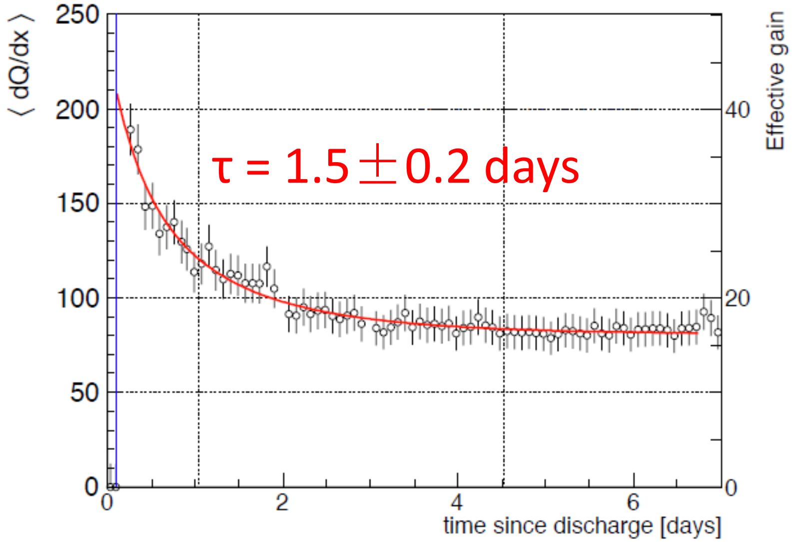
after discharge:



4 hours

4 hours

"hot spot" follows a similar decay:



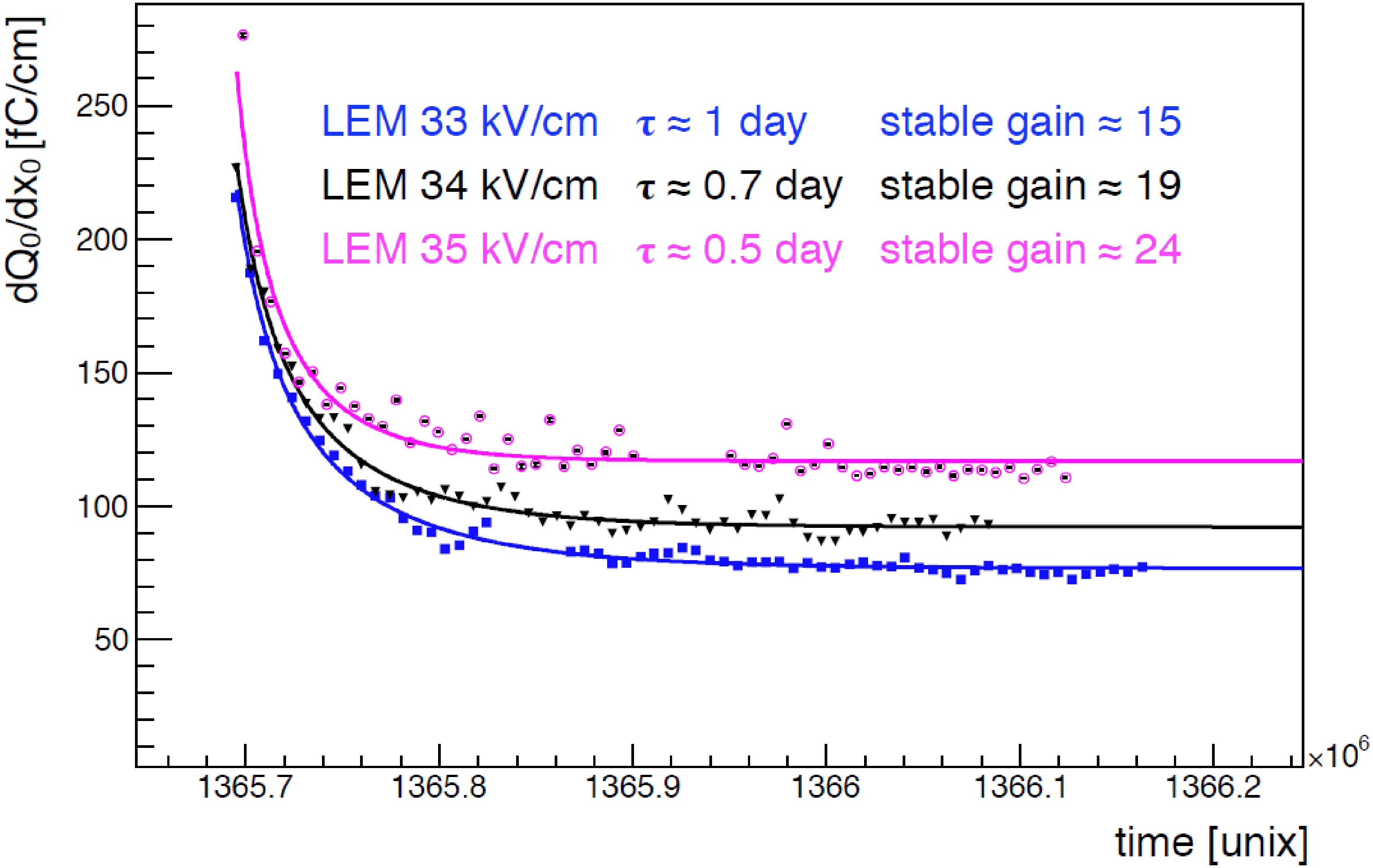
[arXiv:1312.6487](https://arxiv.org/abs/1312.6487)

Summary of number of discharges:

LEM field	Run Time	$N_{discharge}$
33 kV/cm	46 days	8
34 kV/cm	7 days	0
35 kV/cm	7 days	1

Runs at different LEM fields

Higher field, faster charging up time



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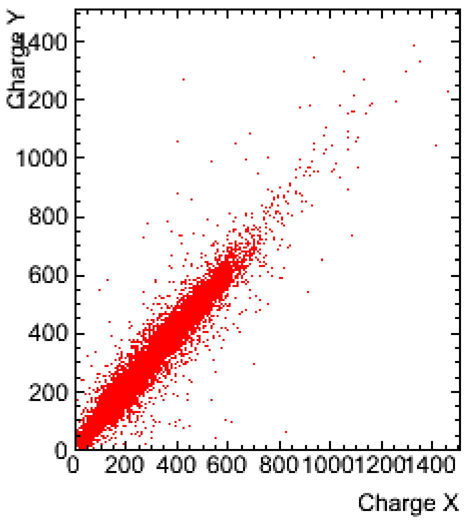
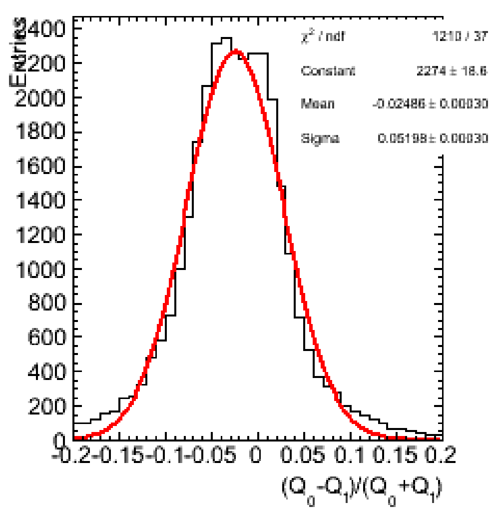
charge sharing asymmetry of 3 anodes

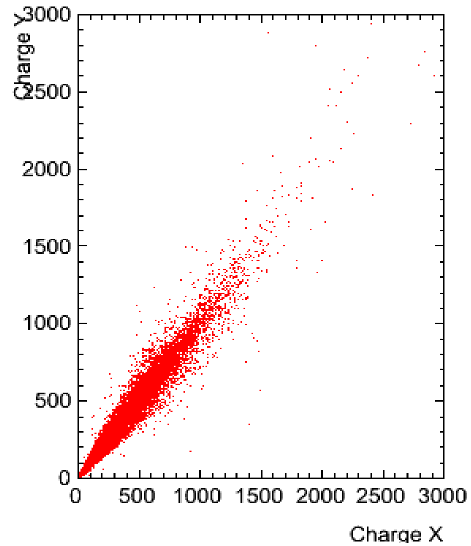
Anode A:

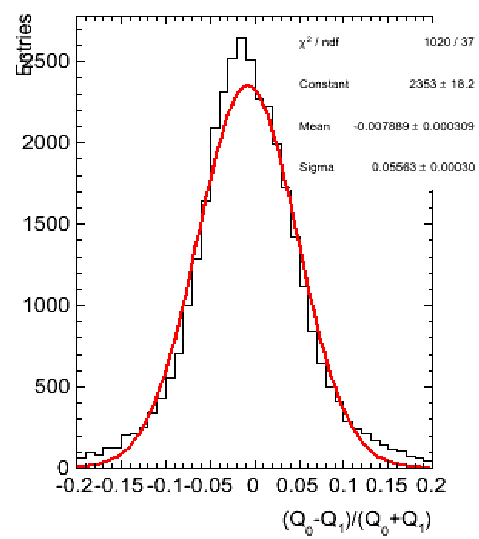




Mean: -2.5%
Sigma: 5.2%

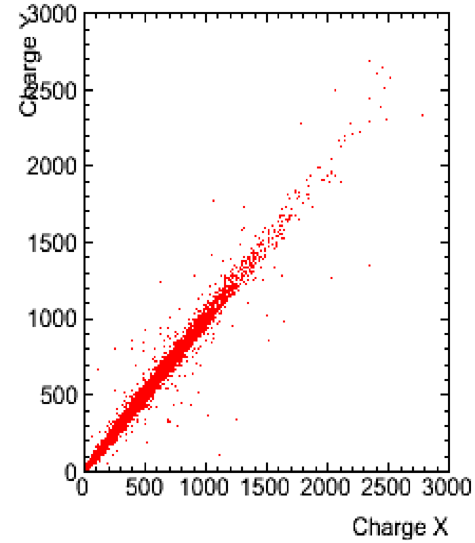
Anode B:

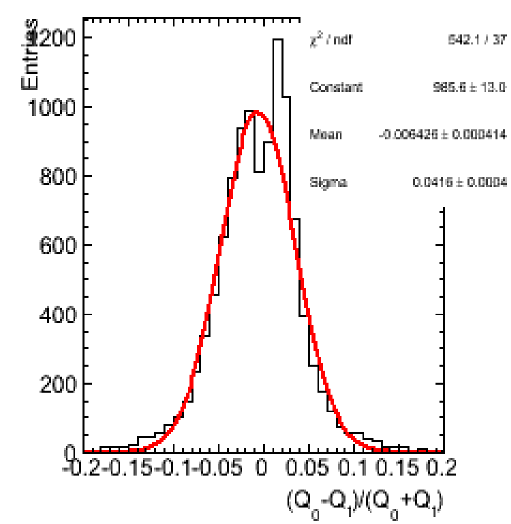




Mean: -0.8%
Sigma: 5.6%

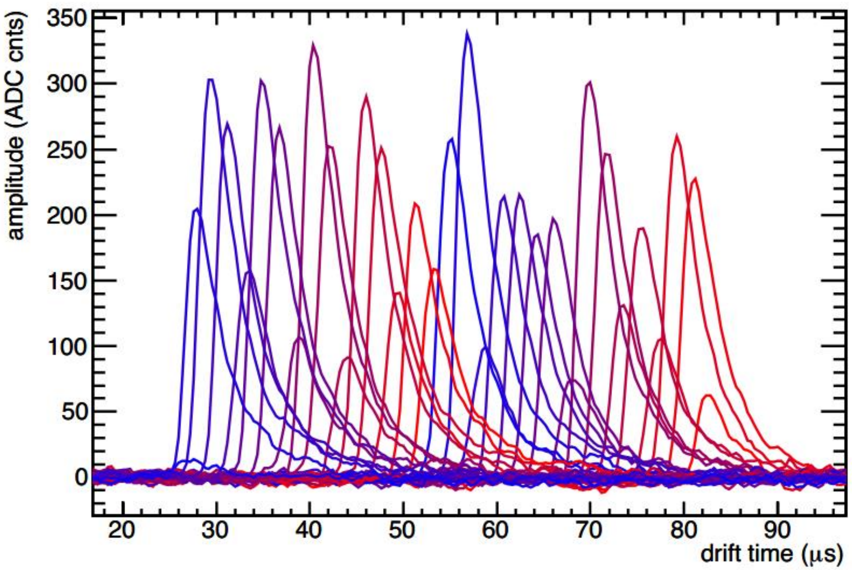
Anode C:

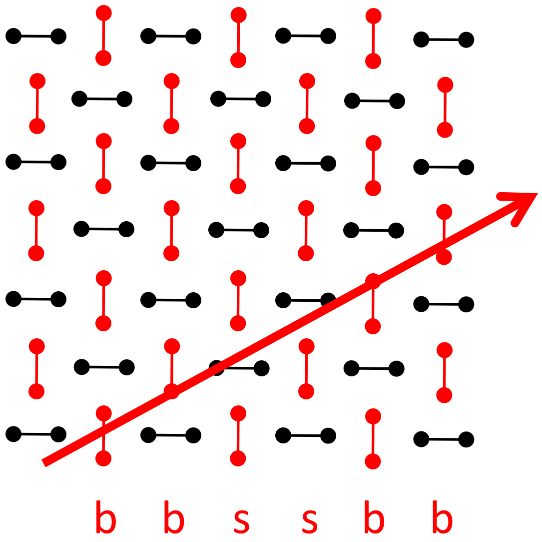




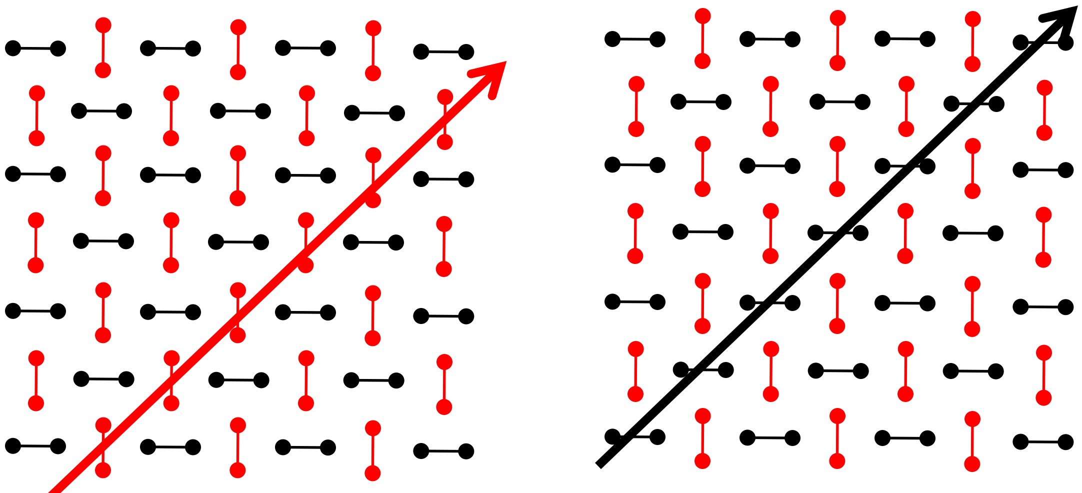
Mean: -0.6%
Sigma: 4.2%

Problem with anode B





45° tracks:



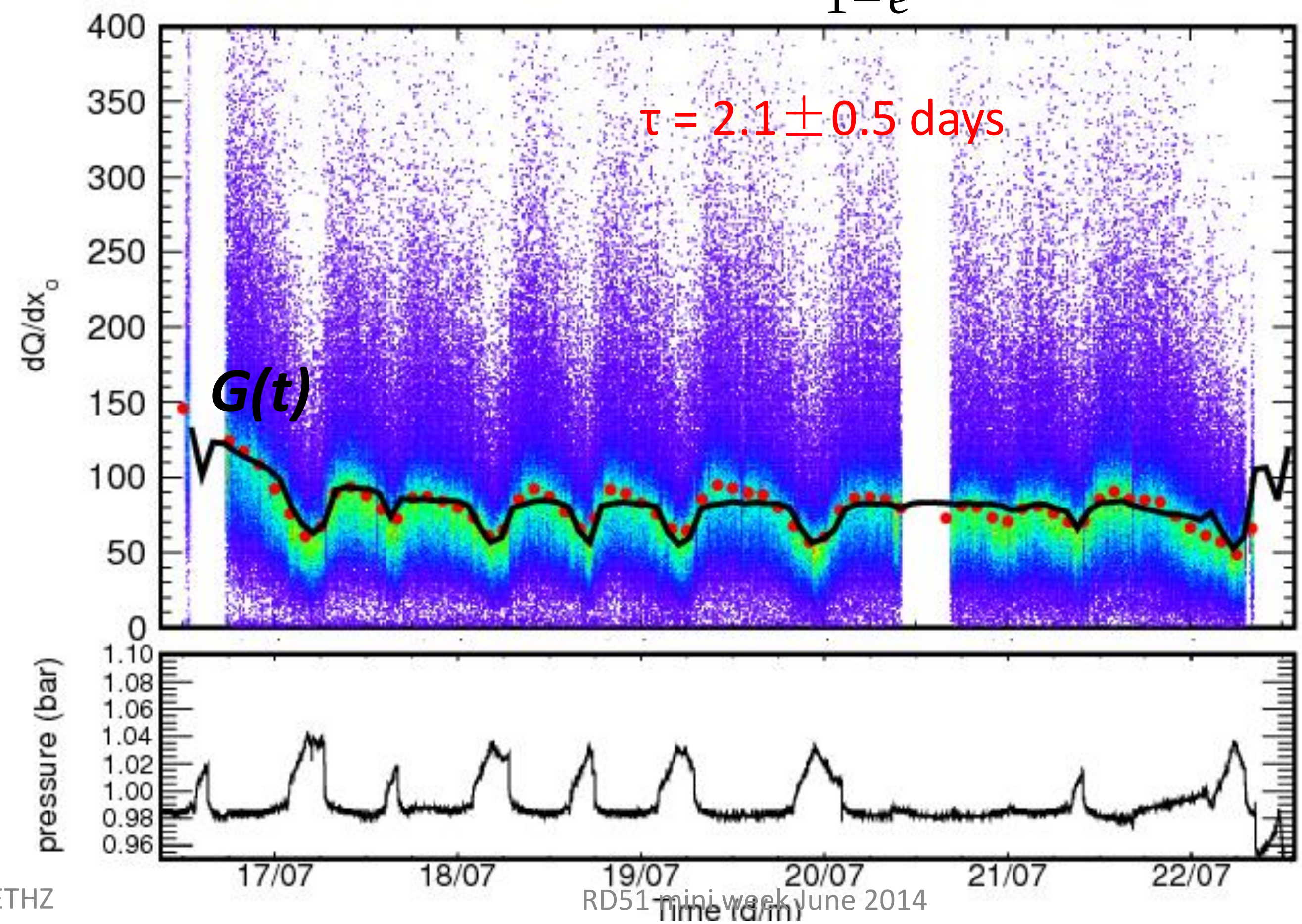
We can only reduce the capacitance provided we have uniform charge collection!

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: $G = A \times e^{x \cdot \alpha(p,T,E)}$ where $\alpha(p,T,E) = \frac{Bp}{T} e^{-\frac{cp}{E}}$

To describe the initial decrease: $G(t) = G_\infty \times \frac{1}{1 - e^{-(t-t_0)/\tau}}$



July run: test Anode B

Pressure inside

future detectors'll operate under controlled pressure!

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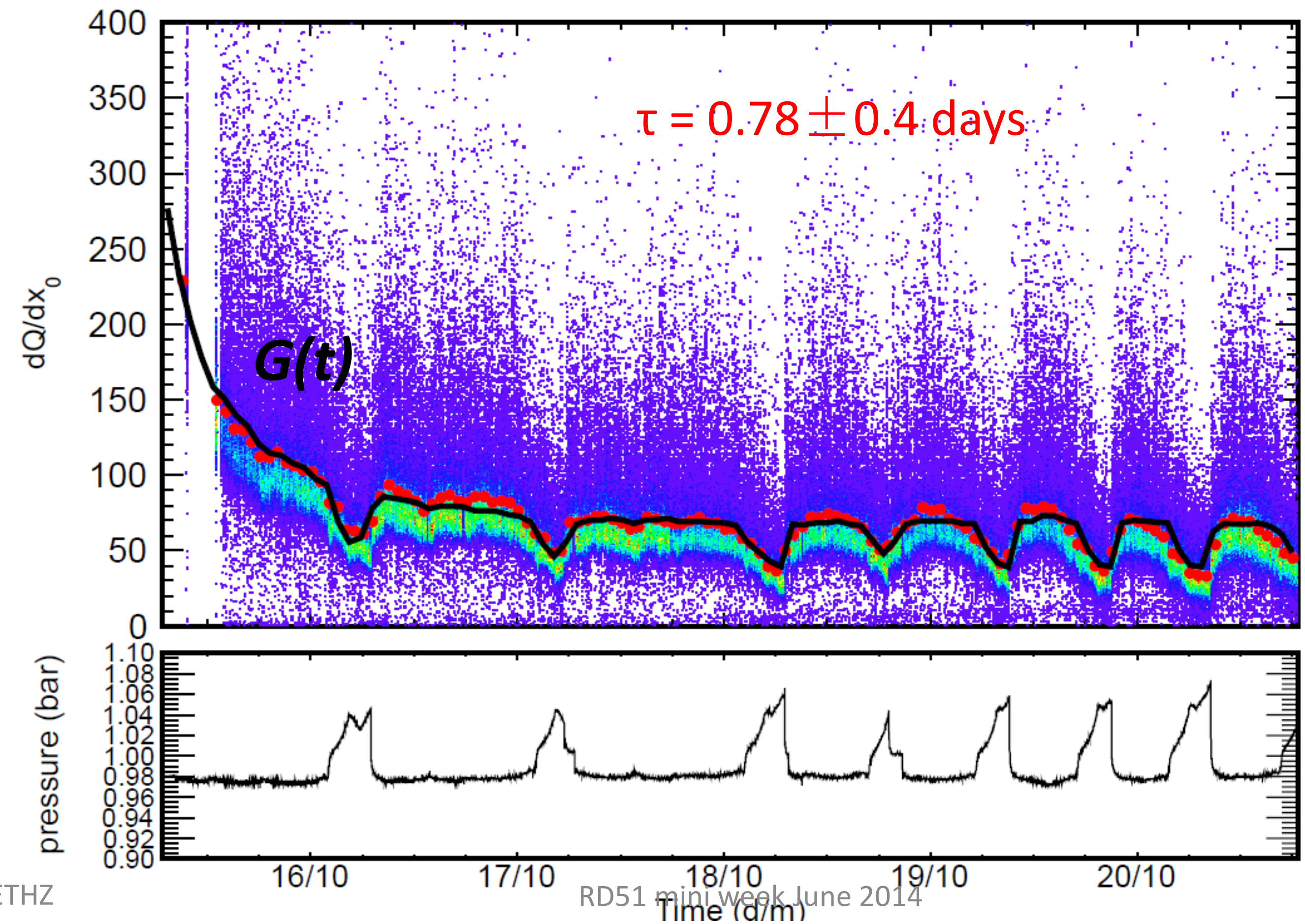
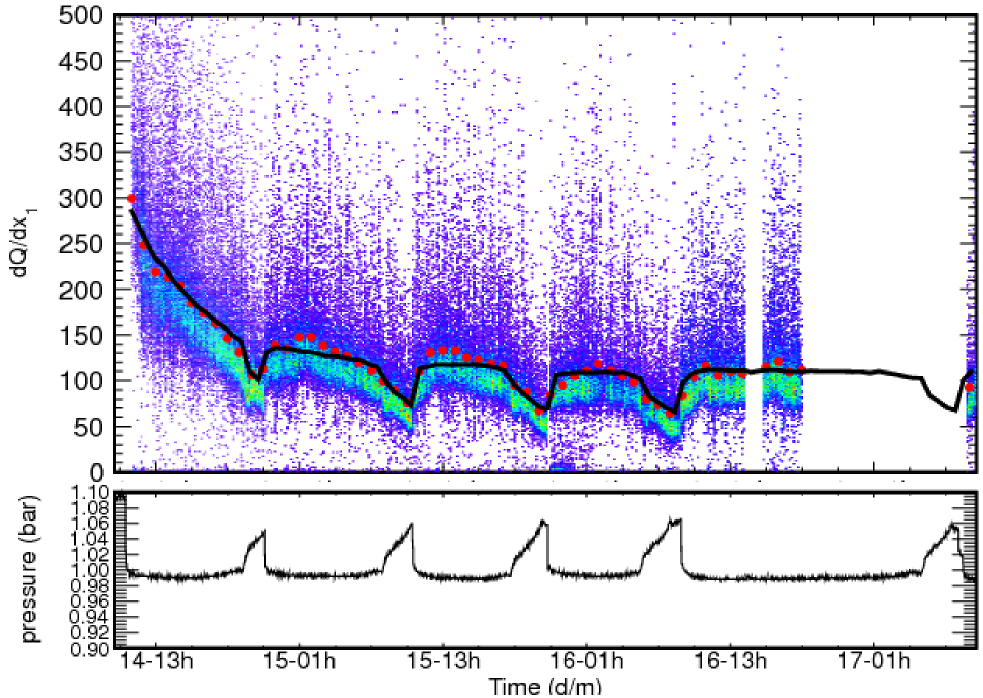
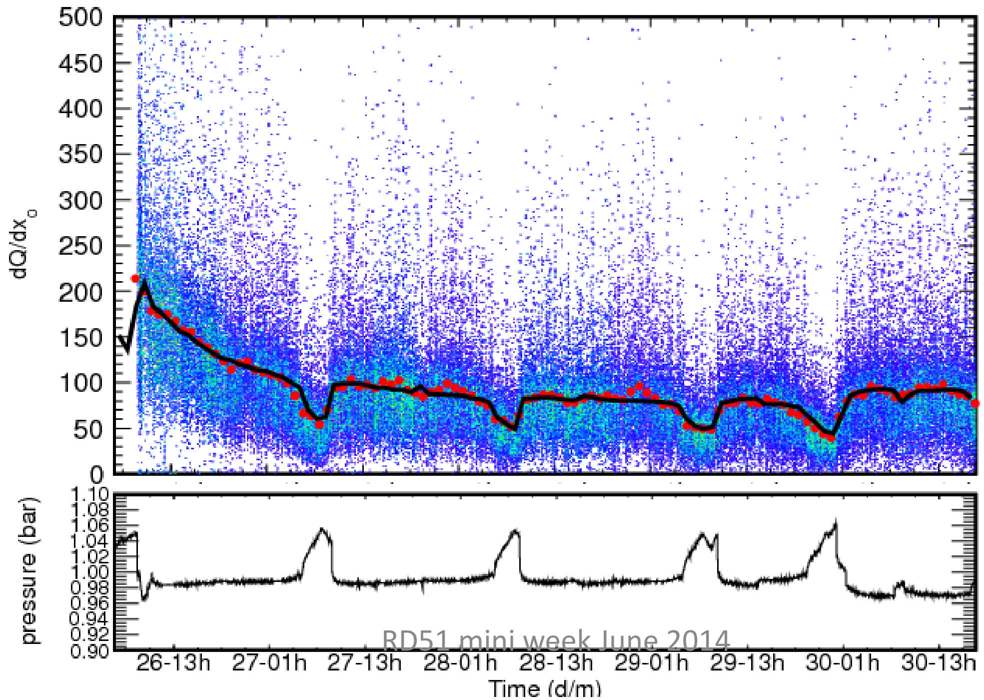
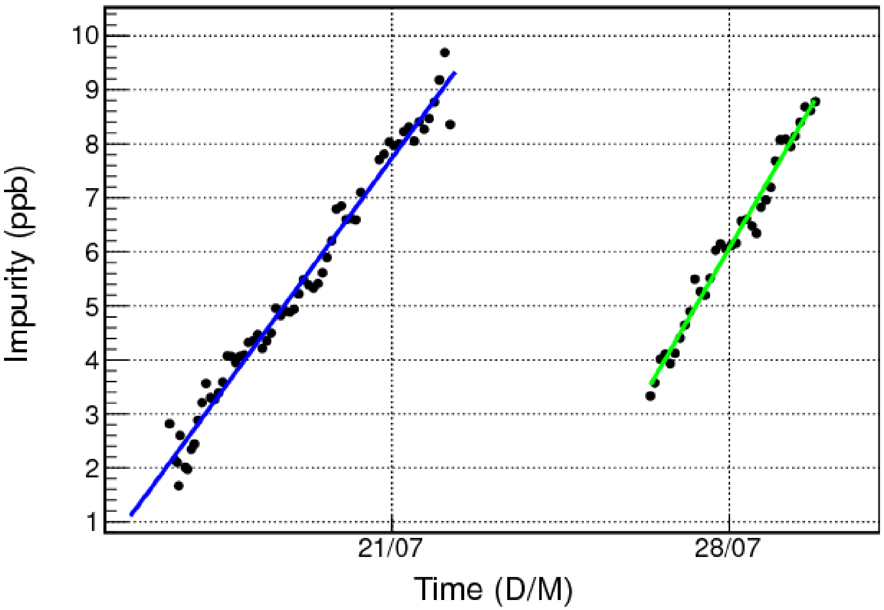


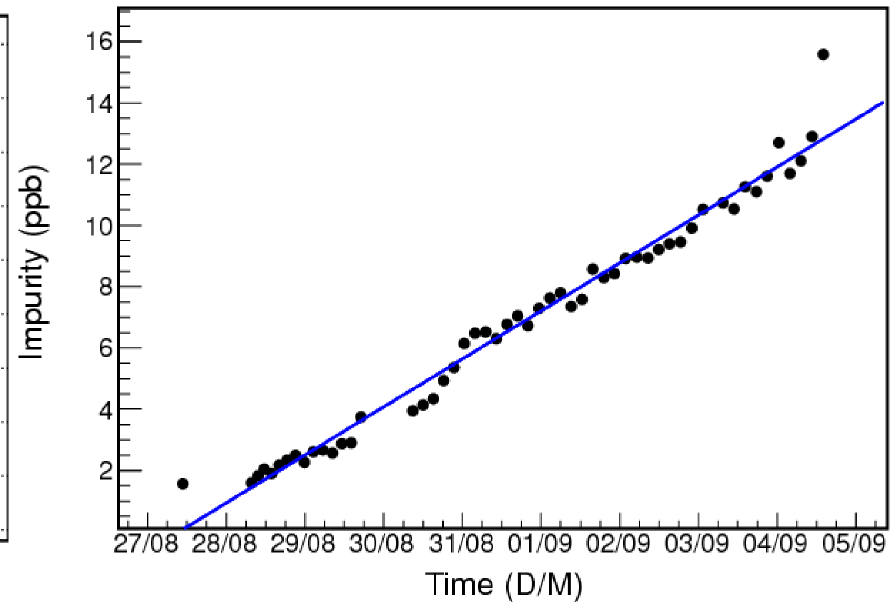
Pressure inside:

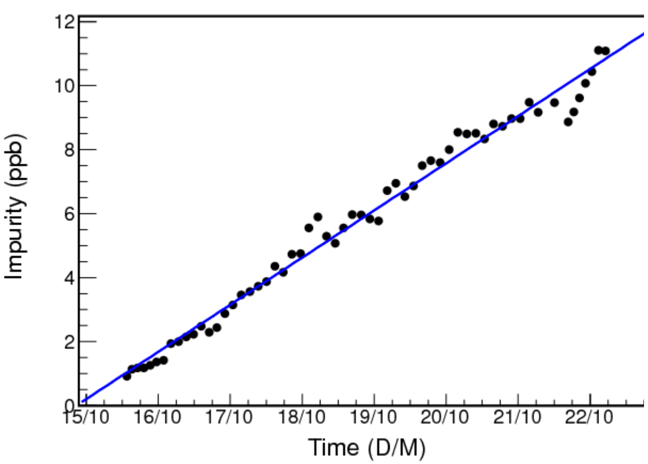
future detectors'll operate under controlled pressure!

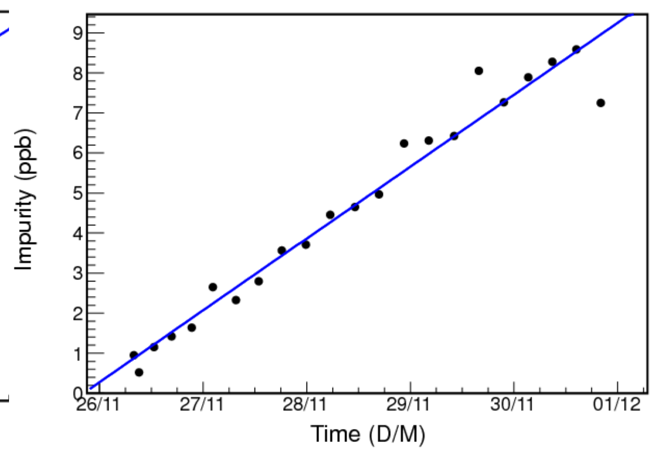

dQ/dx1
pressure (bar)
14-13h
15-01h
15-13h
16-01h
16-13h
17-01h
Time (d/m)

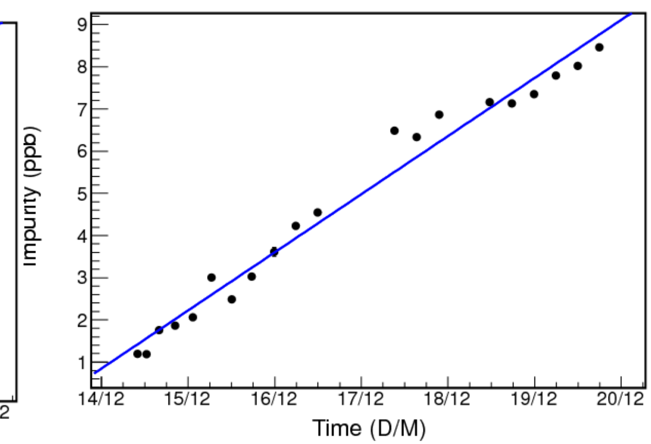

dQ/dx0
pressure (bar)
26-13h
27-01h
27-13h
28-01h
28-13h
29-01h
29-13h
30-01h
30-13h
Time (d/m)

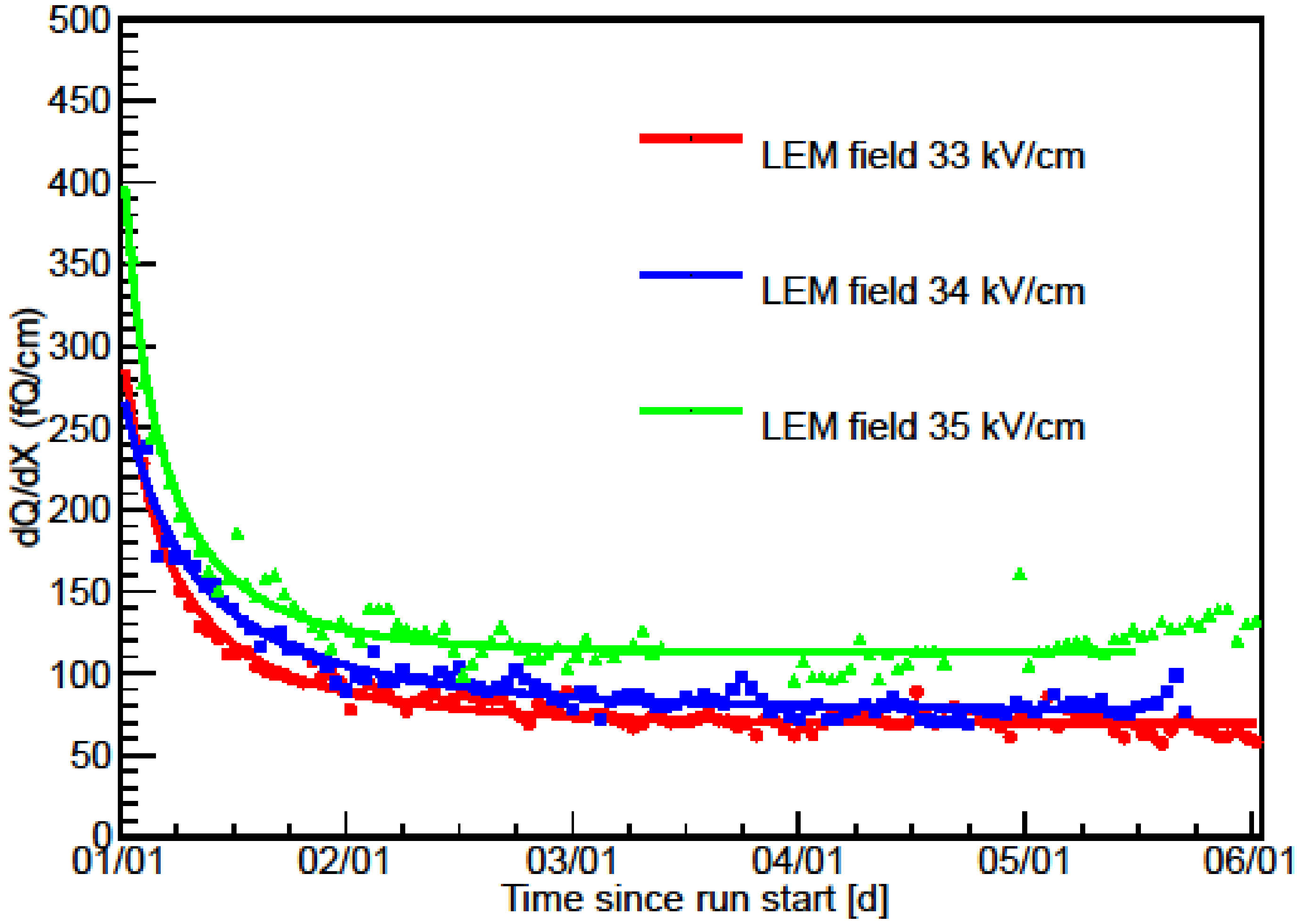

Impurity (ppb)
1 2 3 4 5 6 7 8 9 10
21/07
28/07
Time (D/M)


Impurity (ppb)
2 4 6 8 10 12 14 16
27/08 28/08 29/08 30/08 31/08 01/09 02/09 03/09 04/09 05/09
Time (D/M)


Impurity (ppb)
0 2 4 6 8 10 12
15/10 16/10 17/10 18/10 19/10 20/10 21/10 22/10
Time (D/M)


Impurity (ppb)
0 1 2 3 4 5 6 7 8 9
26/11 27/11 28/11 29/11 30/11 01/12
Time (D/M)


Impurity (ppb)
1 2 3 4 5 6 7 8 9
14/12 15/12 16/12 17/12 18/12 19/12 20/12
Time (D/M)



dQ/dX (fQ/cm)
500
450
400
350
300
250
200
150
100
50
0
01/01
02/01
03/01
04/01
05/01
06/01
Time since run start [d]
LEM field 33 kV/cm
LEM field 34 kV/cm
LEM field 35 kV/cm