Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Recent results and plans of double phase LAr LEM TPC

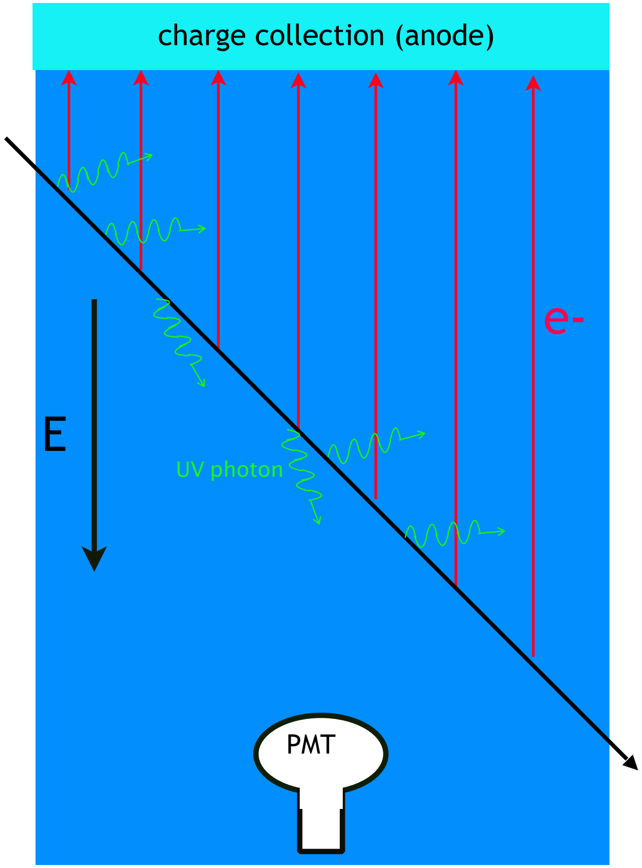
Shuoxing Wu

on behalf of
LAGUNA-LBNO and WA105 collaboration

Institute for Particle Physics, ETH Zurich

TPC symposium, Paris, 15.12.2014

Introduction - the Liquid Argon (LAr) TPC



LAr properties

Density	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 in air	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

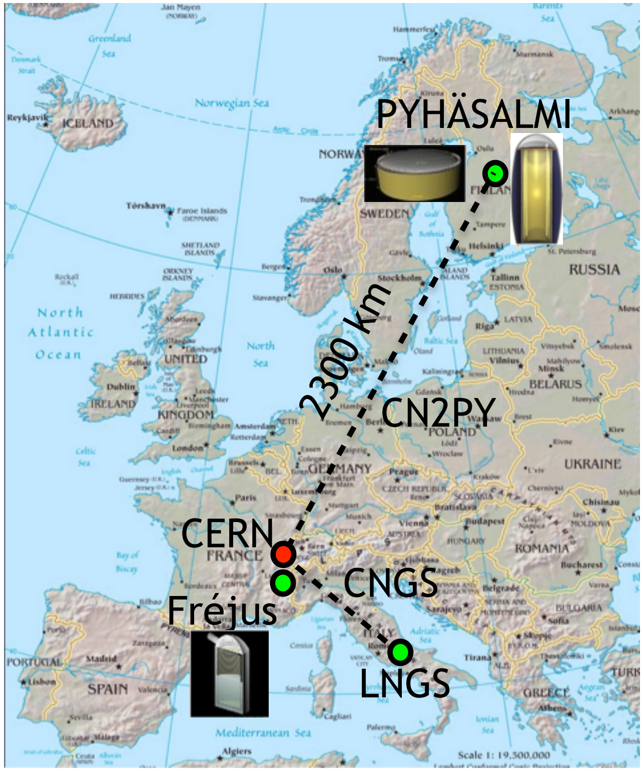
→ Giant LAr TPC is the next generation neutrino experiments

LAGUNA-LBNO programme and GLACIER

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

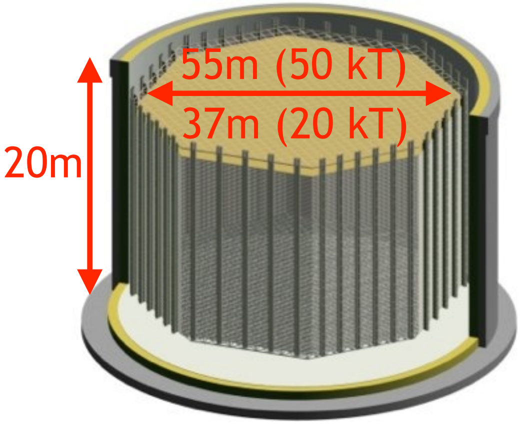
LAGUNA-LBNO physics:

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 cm² 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 cm² 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 cm² readout", JINST 8 (2013)P04012

➢ **10x10 cm² double phase LAr LEM-TPC prototype: further R&D towards final, simplified charge readout for GLACIER:**

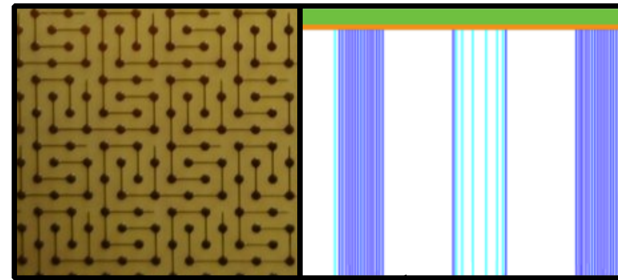
- Long-term operation of a double phase LAr LEM Time Projection Chamber with a simplified anode and extraction-grid design, JINST 9 P03017
- Performance study of the effective gain of Large Electron Multipliers in LAr-LEM TPCs, arXiv:1412:4402

Plans:

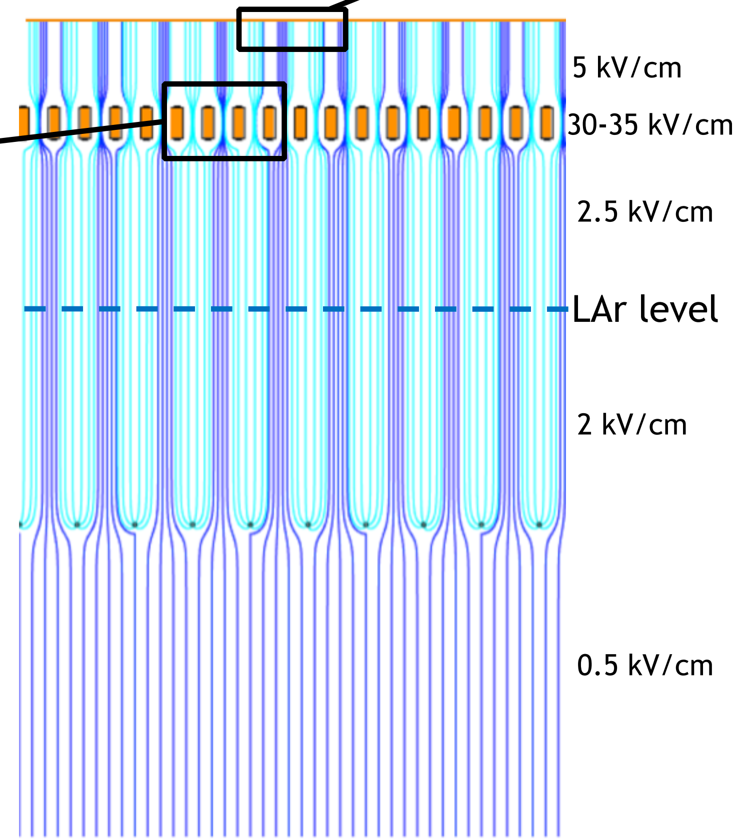
- **3x1x1m³** pre-prototype being built in B182@CERN
- **6x6x6m³** prototype (WA105) to be operated at CERN NA approved by CERN SPSC.

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

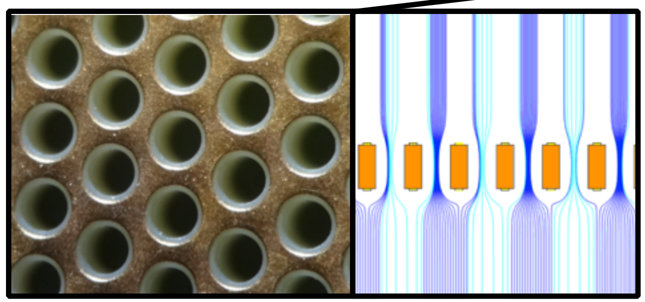
The novel double phase readout



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)



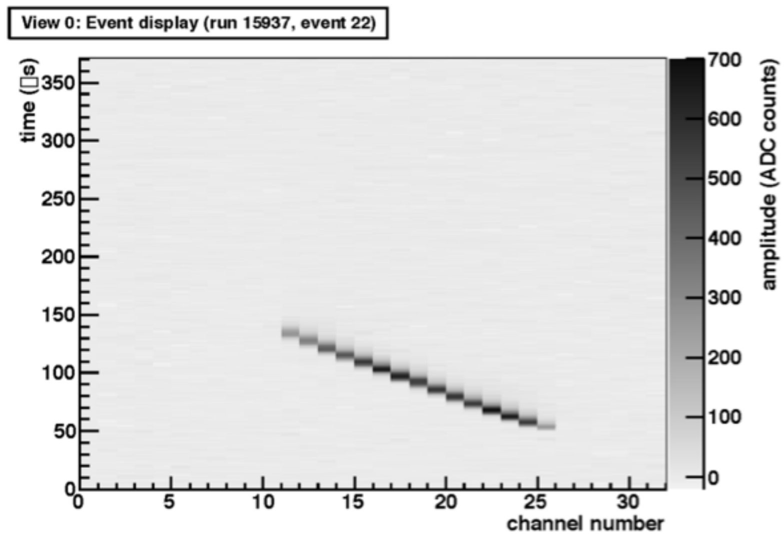
2.) Drift electrons are efficiently extracted into the gas phase

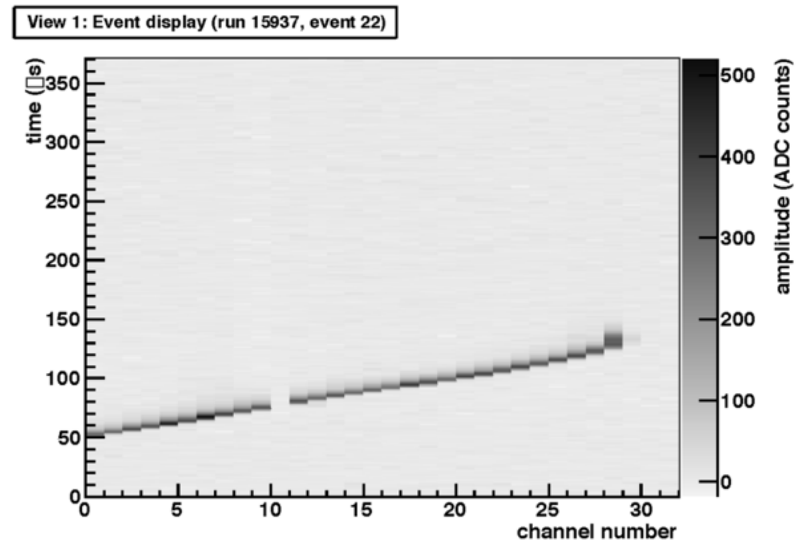
1.) Ionization electrons drift towards the liquid argon surface

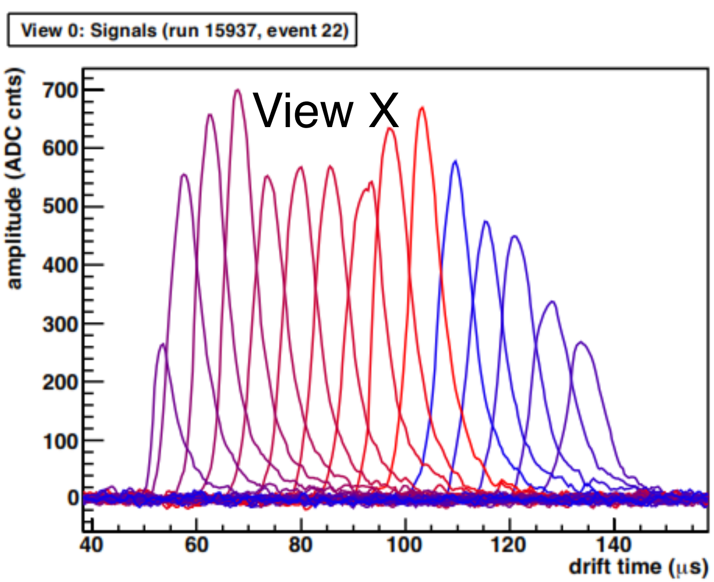
For MIPs:
- 10 fC/cm — ~10 k e^- for each strip (3 mm pitch,2 views) — SNR of 10 (noise of 1000 e^-)
- SNR of 100 — gain of 20 is needed

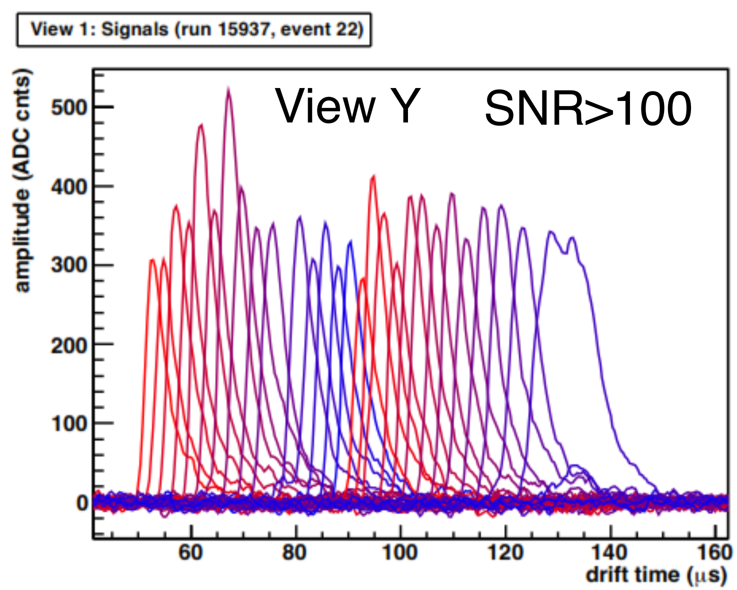
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Cosmic event at effective gain~20



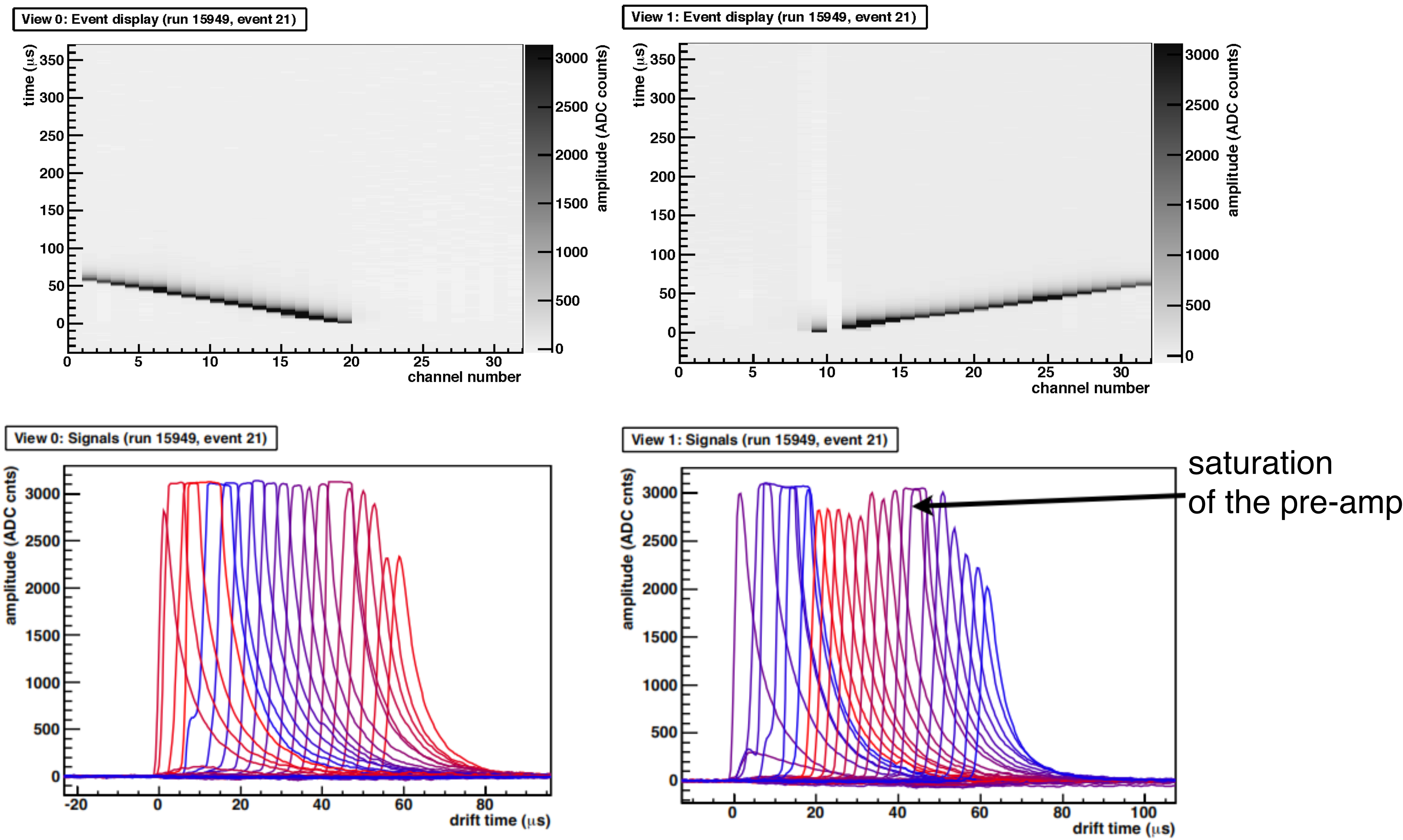






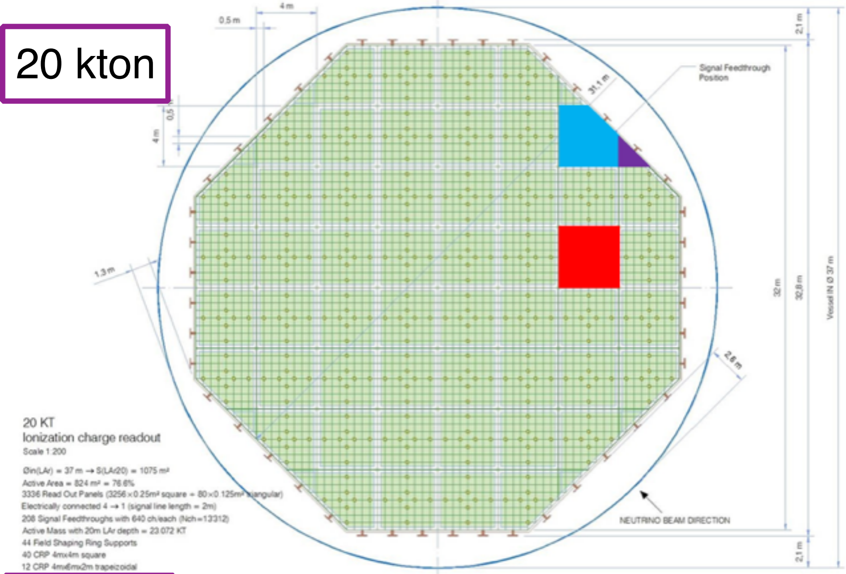
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

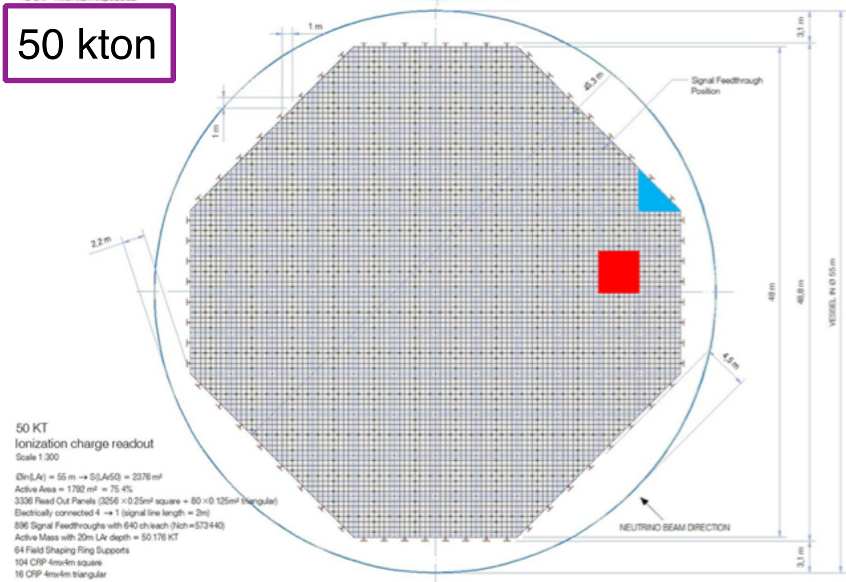
Cosmic event at effective gain~160

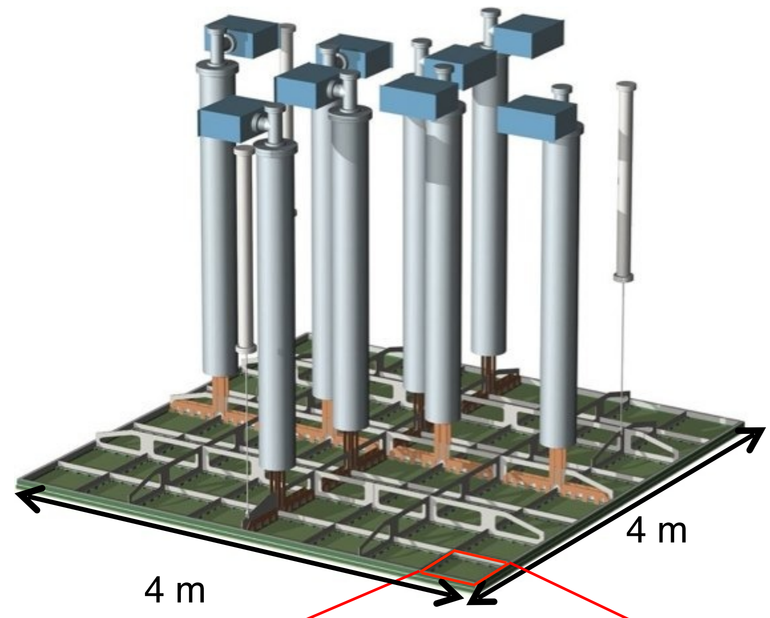


ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

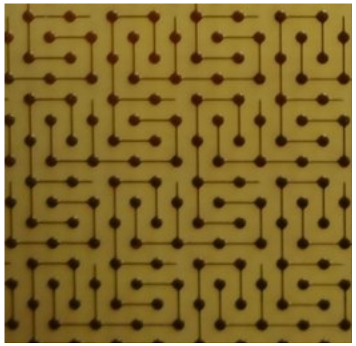
GLACIER 20 and 50 kton charge readout system



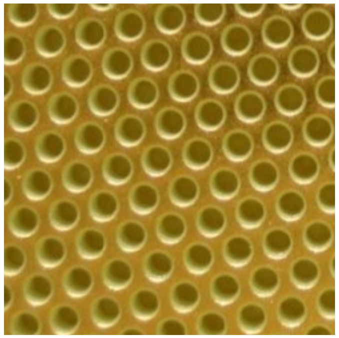




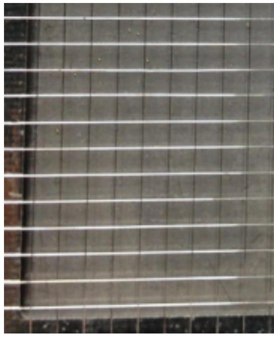
0.5x0.5 m² anode



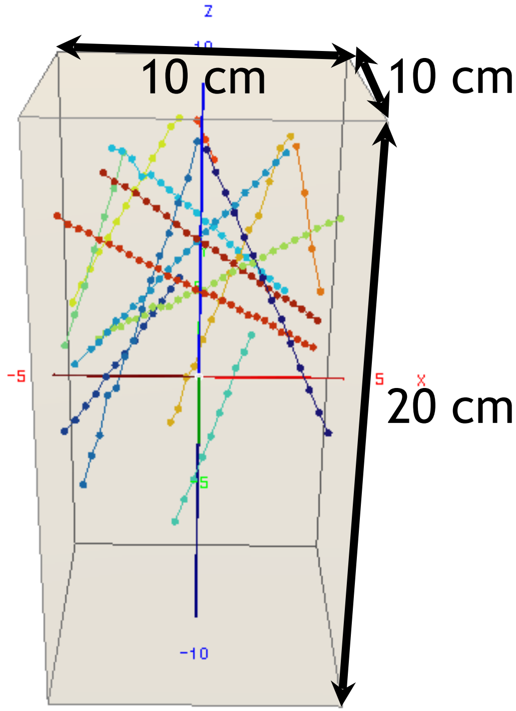
0.5x0.5 m² LEM

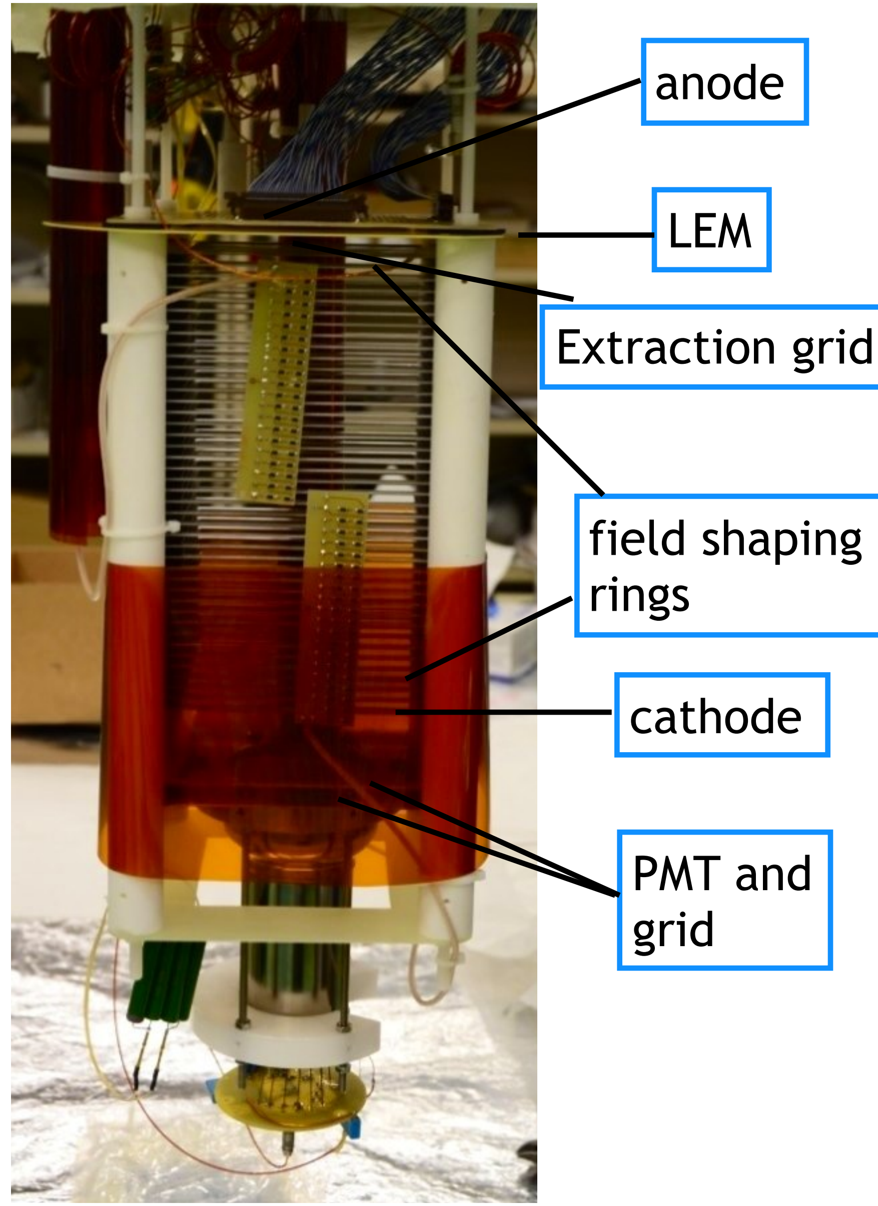


4x4 m² grid



The 10x10x20 cm^3 proof of principle LAr LEM TPC





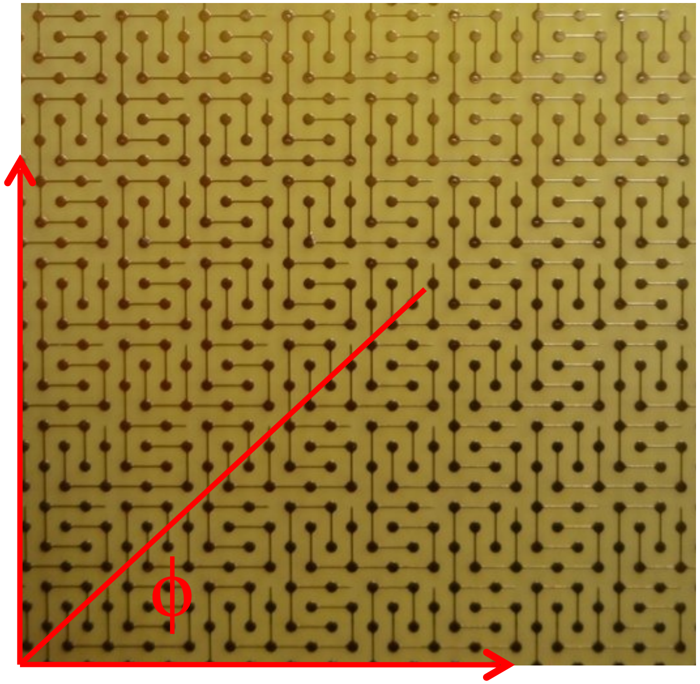
We're developing:

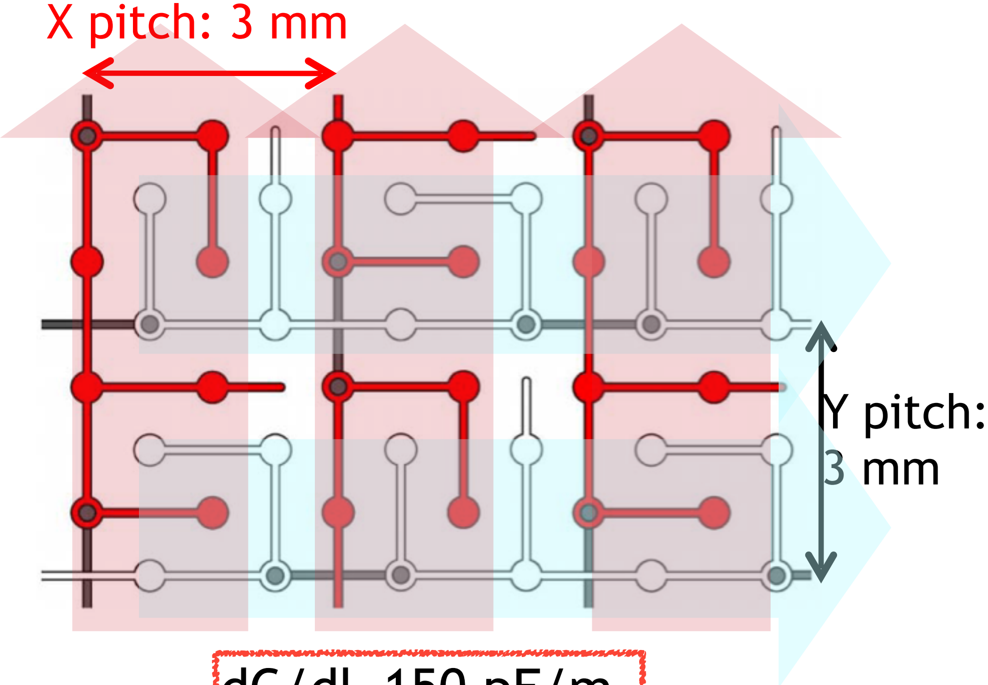
- **Low noise (capacitance) 2D anode**.
- LEM with **uniform** and **long term stable** gain and discharge resistance.
- **Simplified** readout electronics system.

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





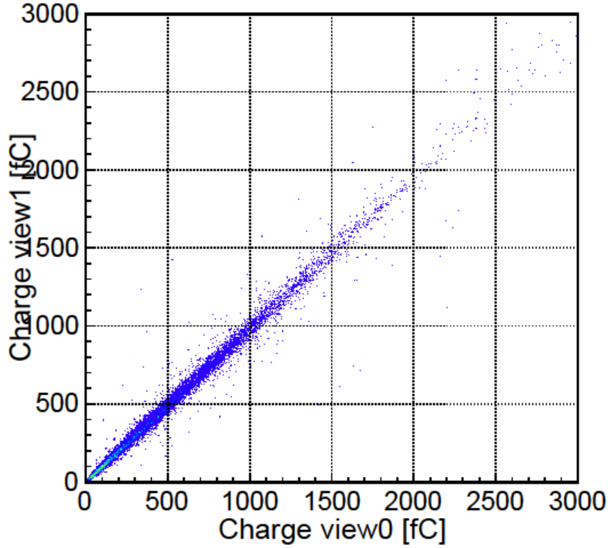
dC/dl~150 pF/m

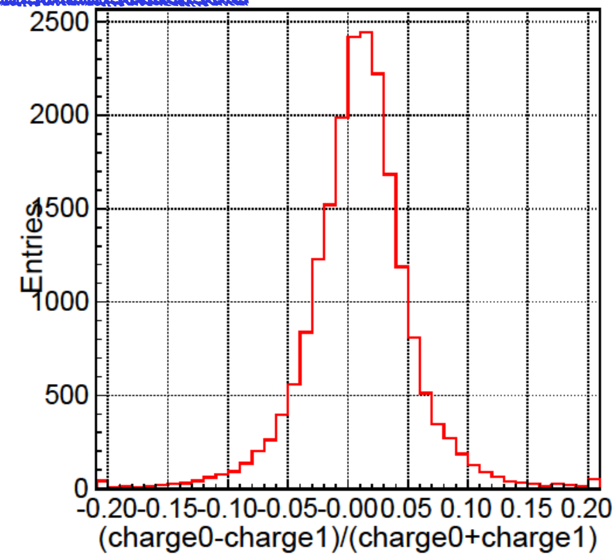
Best solution to optimize capacitance and resolution

Anode performance:

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Fully X-Y symmetric:

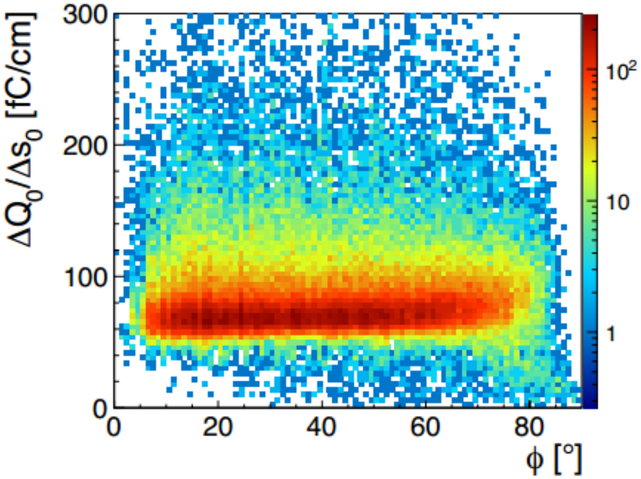


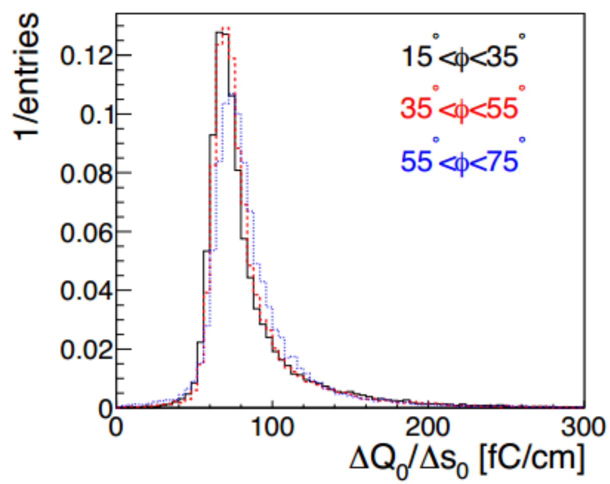


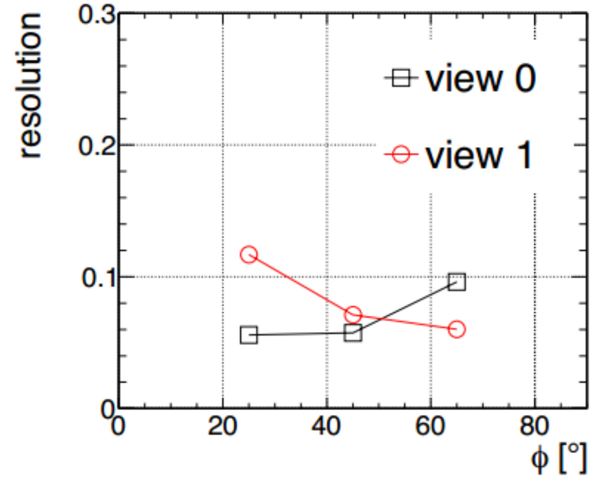
Mean: 0.009
RMS: 0.043

Uniform response to all tracks:

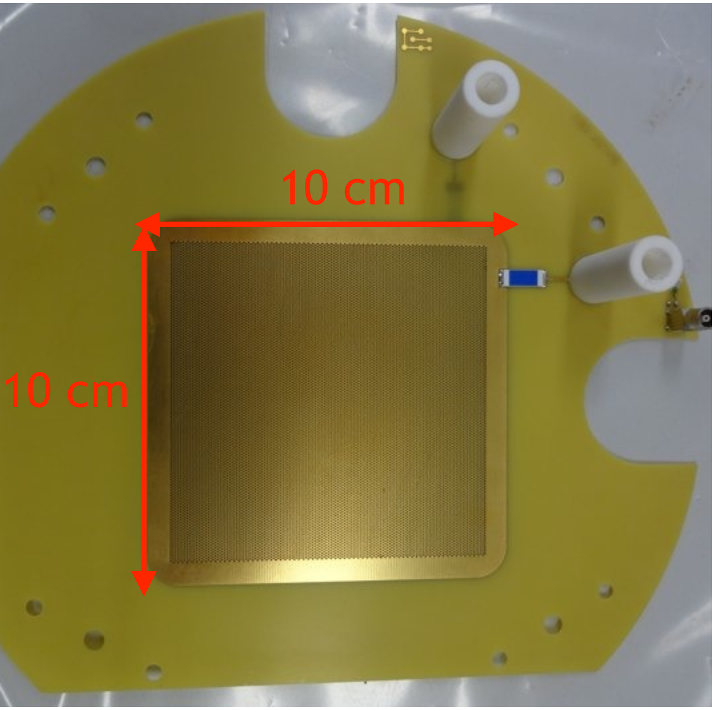
JINST 9 P03017





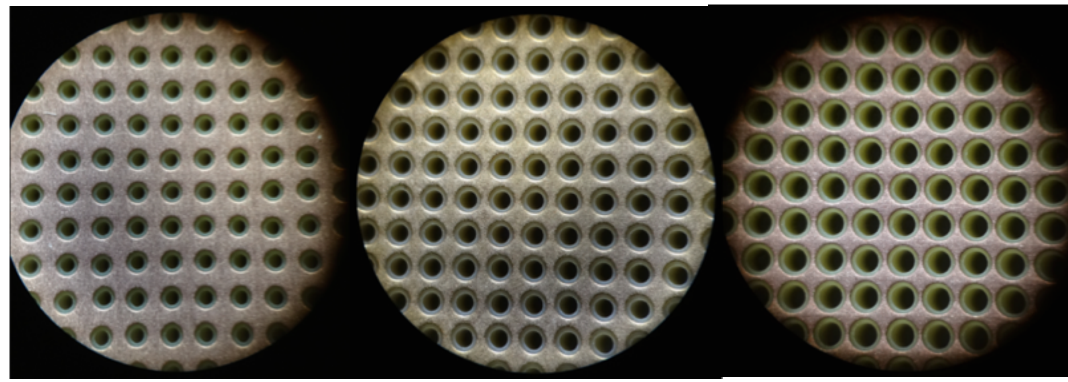


The Large Electron Multiplier (LEM)

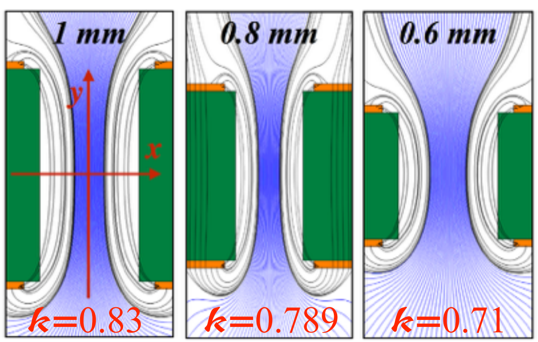


Hole diameter:

300 μm 400 μm 500 μm

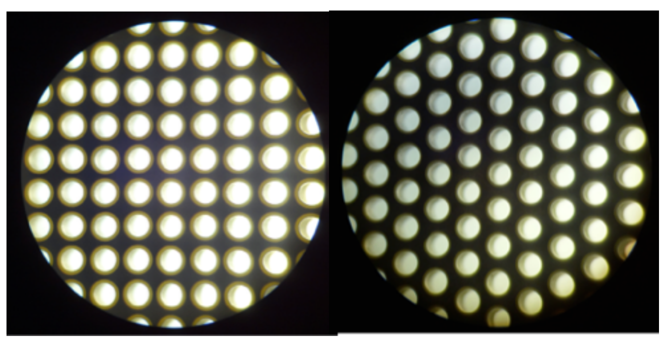


Effects on the E-field



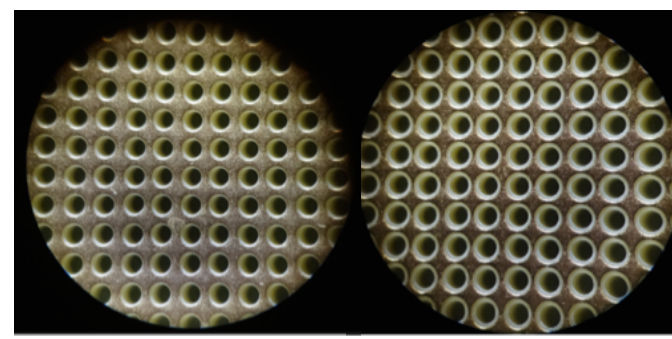
Hole layout:

square hexagonal



Rim size:

40 μm 80 μm

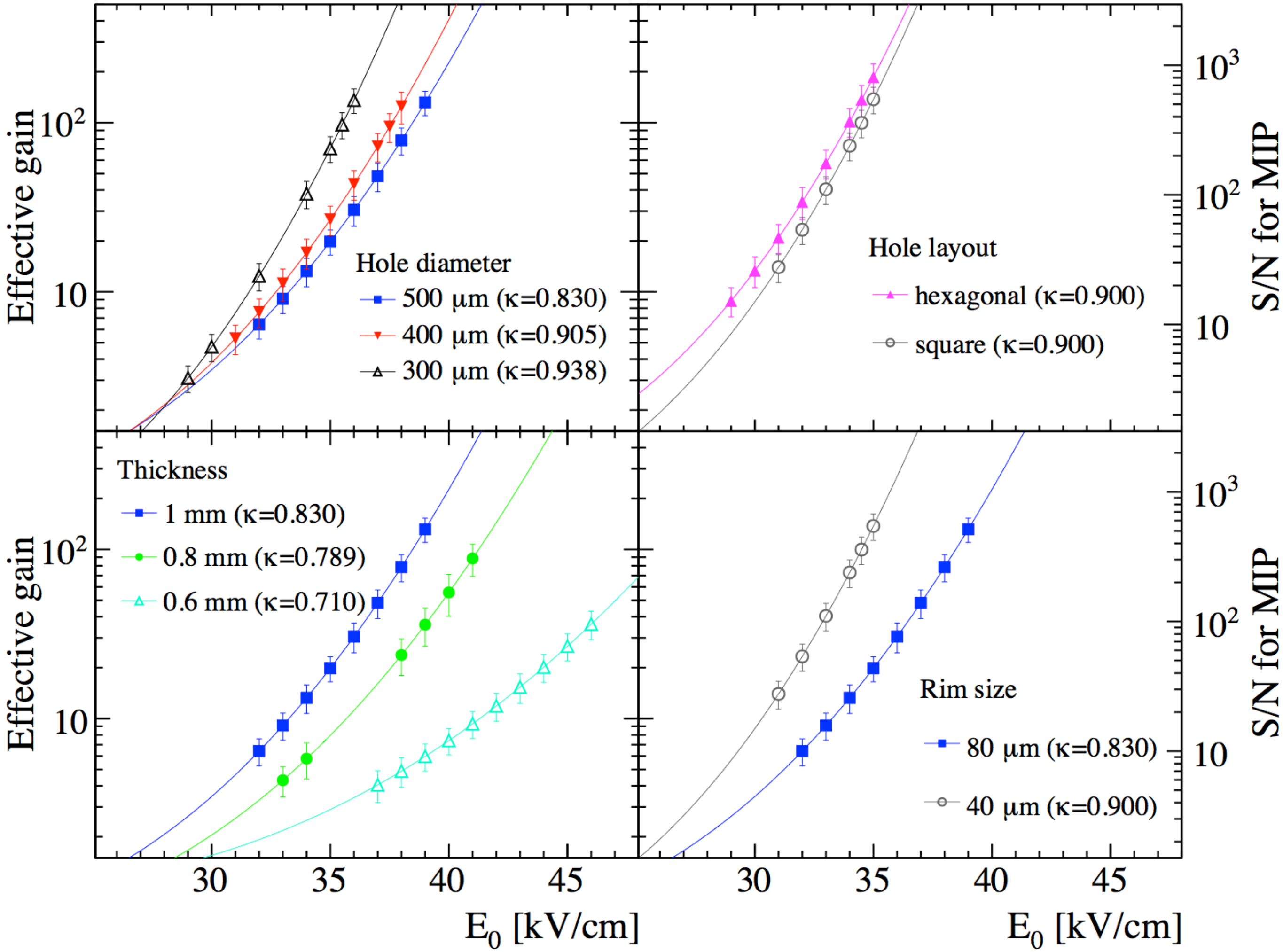


ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Systematic inspection of LEM parameters

Fitting function: $G_{eff}(E,\rho,t) \equiv \mathcal{T} e^{\alpha(\rho,E)x} \times \mathscr{C}(t) \qquad \alpha(\rho,E) = A\rho e^{-B\rho/E}$

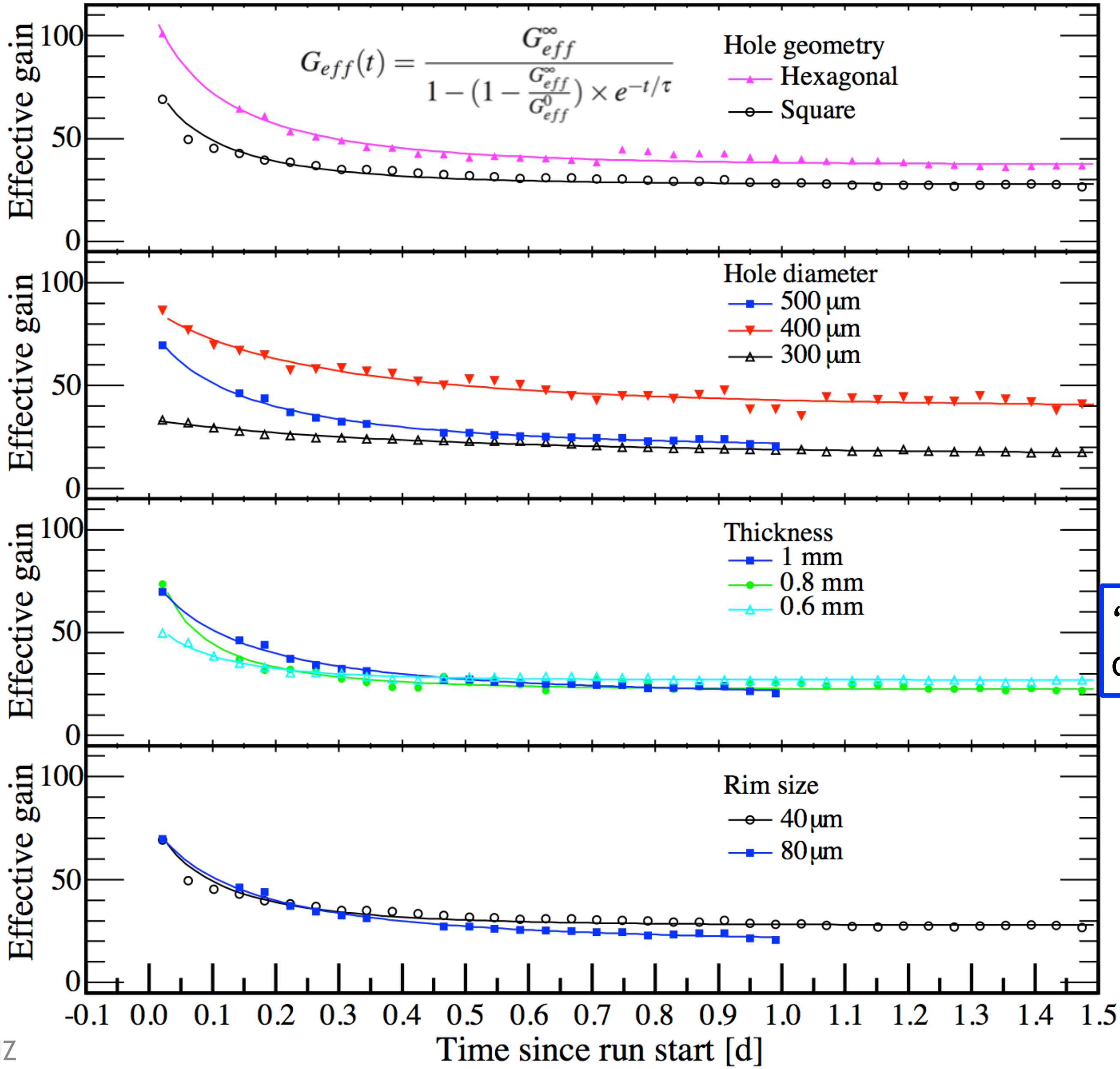
arXiv:1412:4402



- Gain curves difference explainable from amplification length and central E field
- Gain over 100 is feasible for each LEM

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

LEM gain stabilities



arXiv:1412:4402

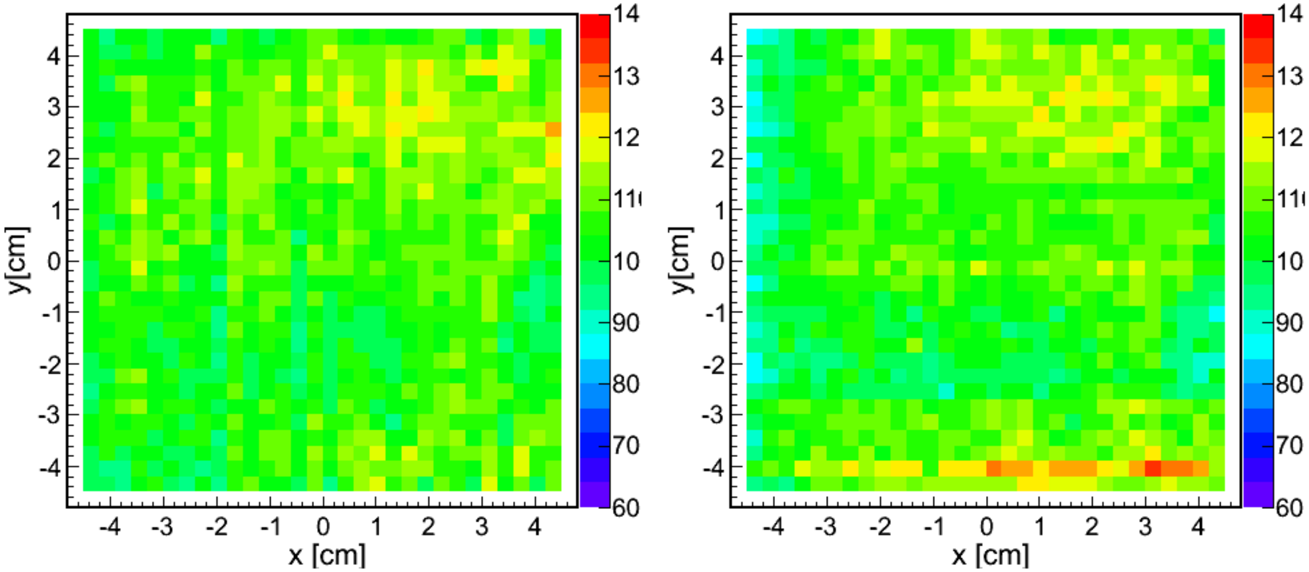
"Discharge-free" operation @gain 20

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

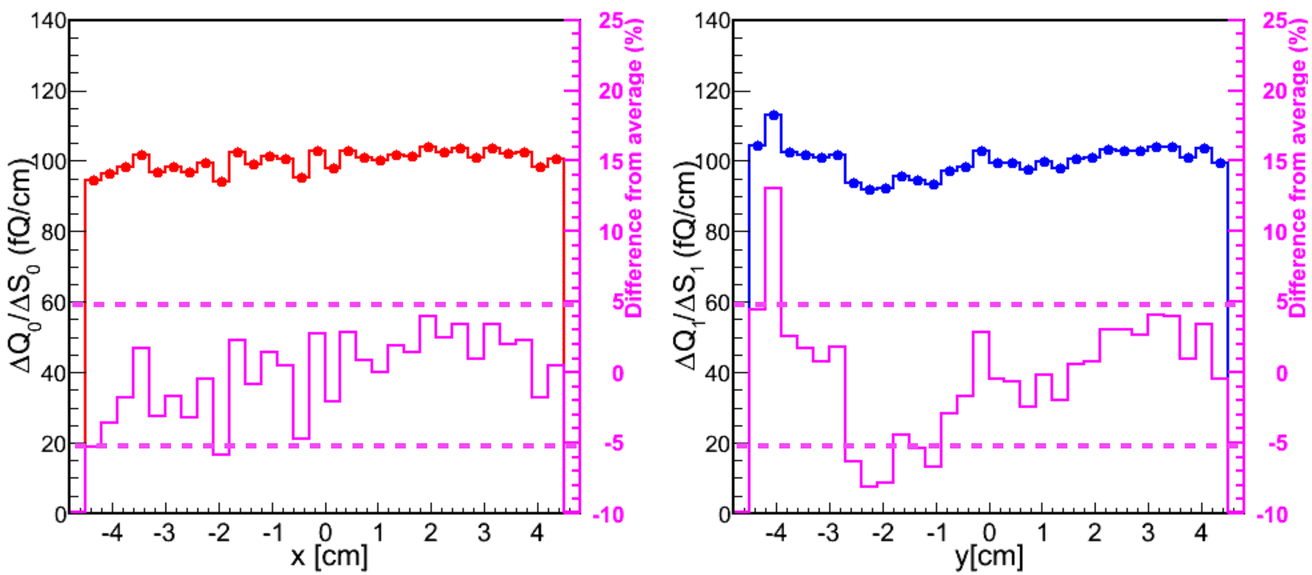
Gain uniformity

View 0 | View 1

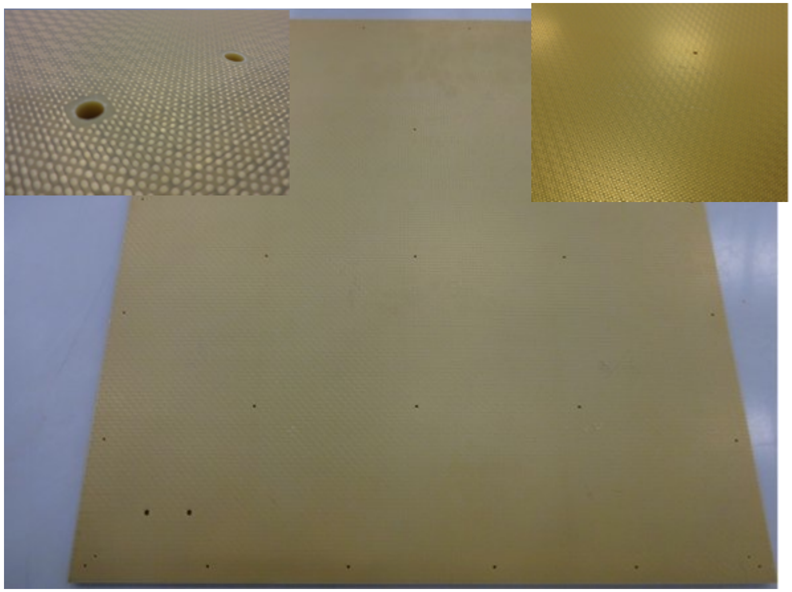
<dQ/dx> (fC/cm) (normalized to 100 fC/cm):

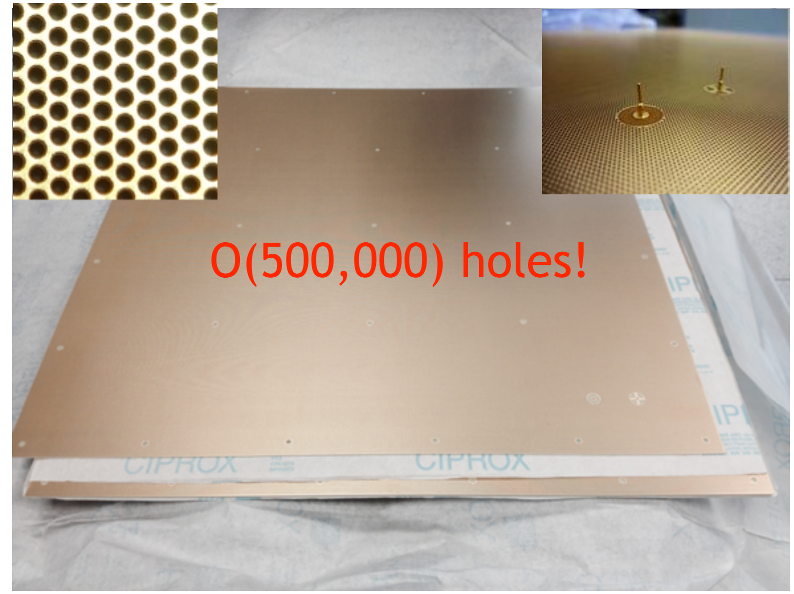


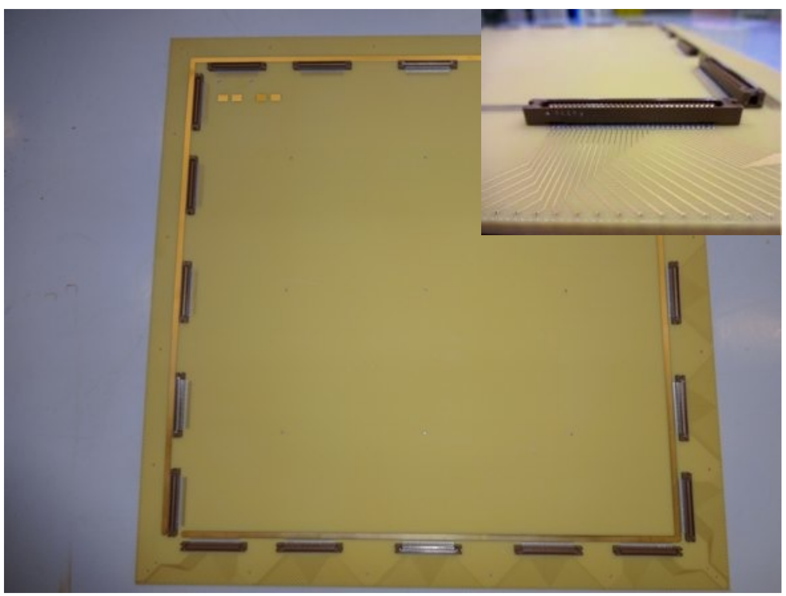
Projections on X and Y axis:

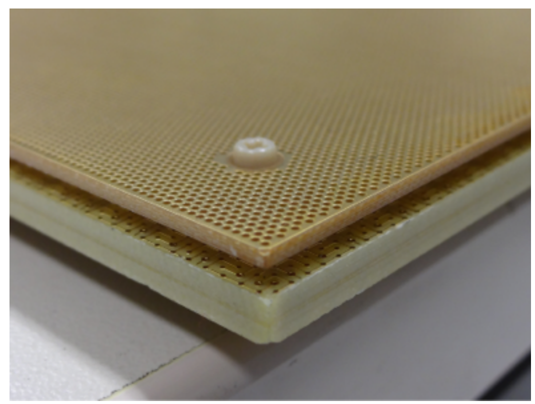


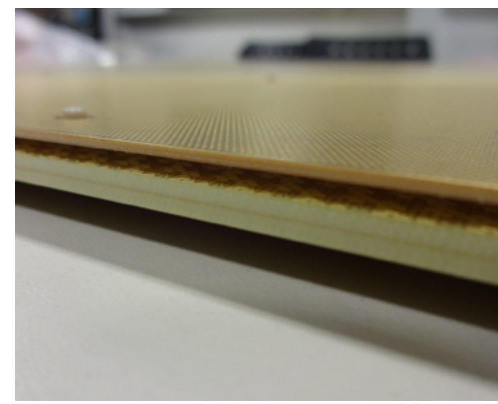
Towards large area: – the 50x50 cm^2 anode and LEM

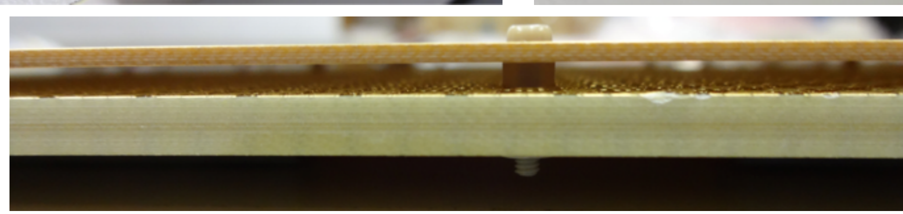




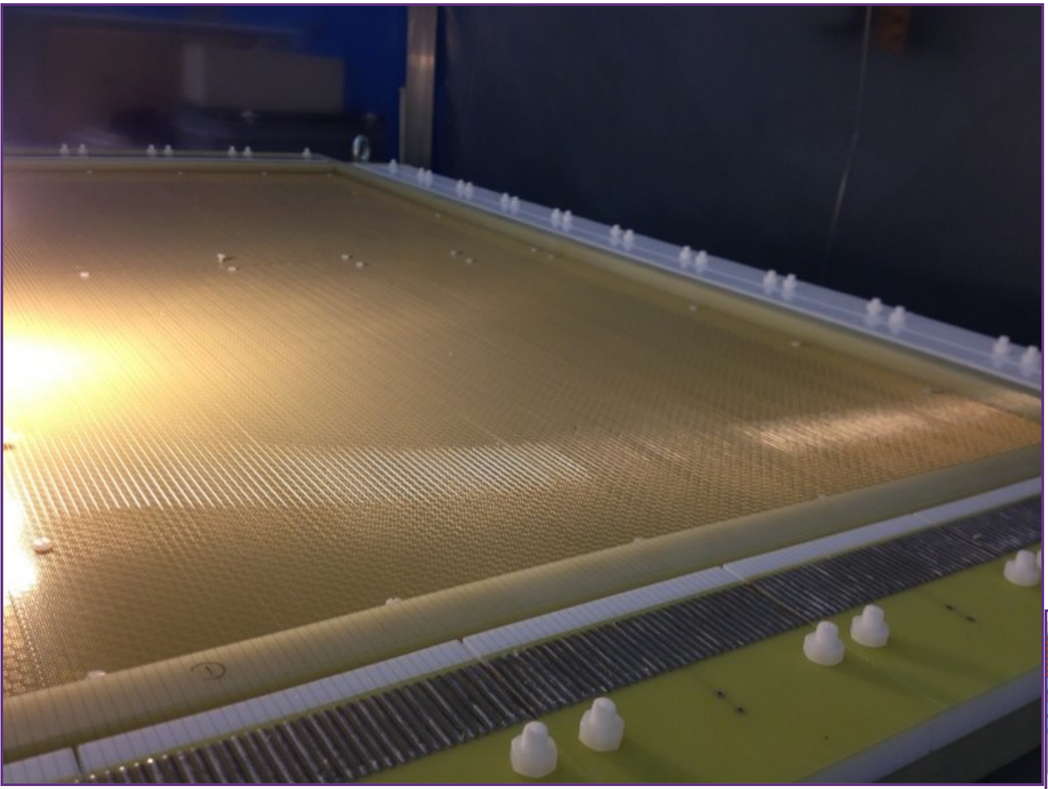






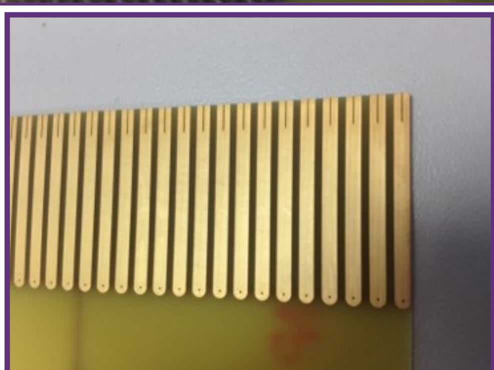


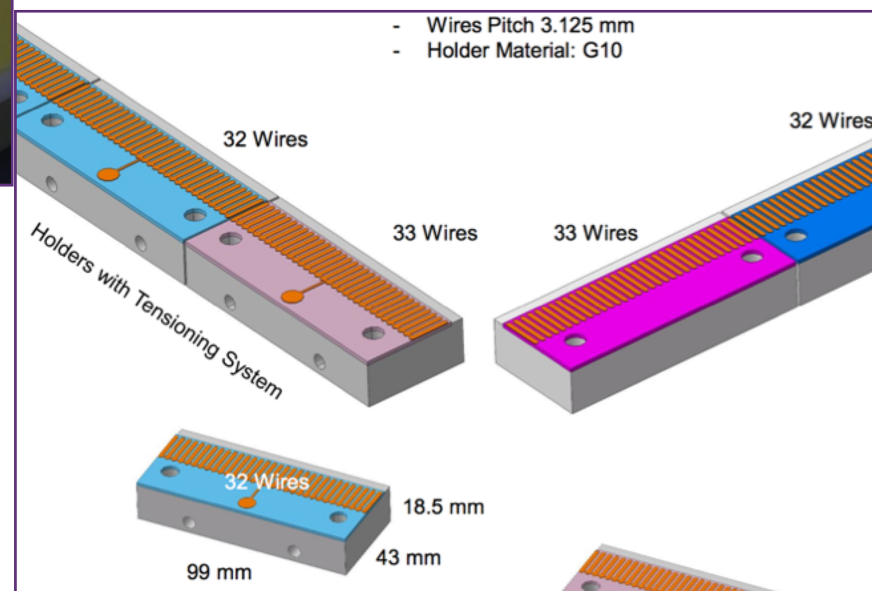
The extraction grid system



Extraction grid

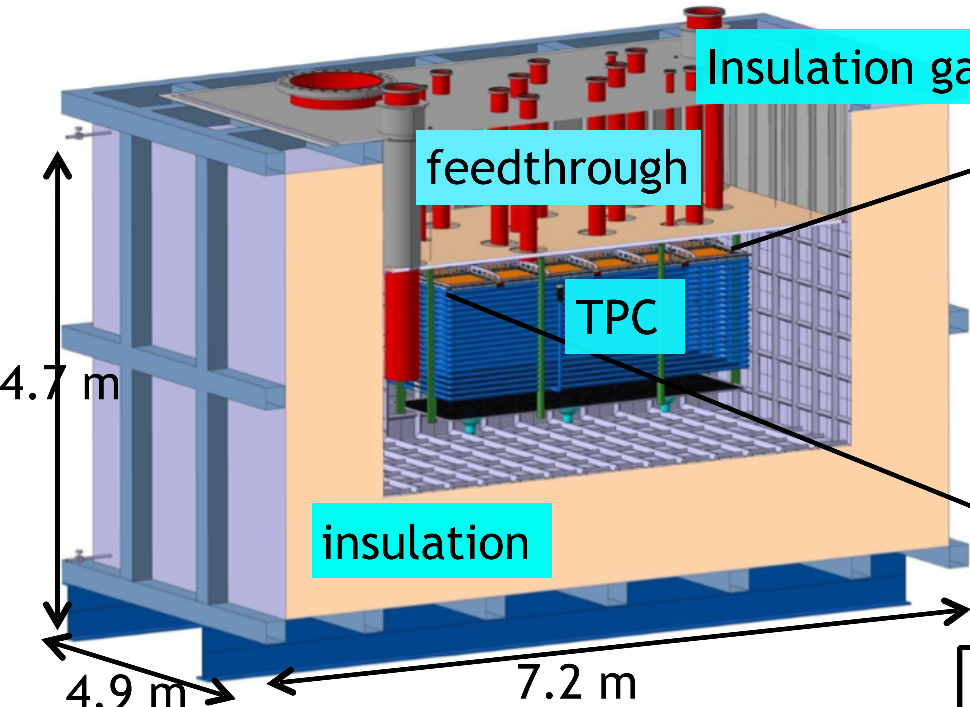
- ✓100 micron stainless wire with 3 mm pitch in x and y directions
- ✓effect on gain uniformity tested in LAr on 10x10 cm^2 readout
- ✓design has been extensively tested on a 1x1 m^2 prototype



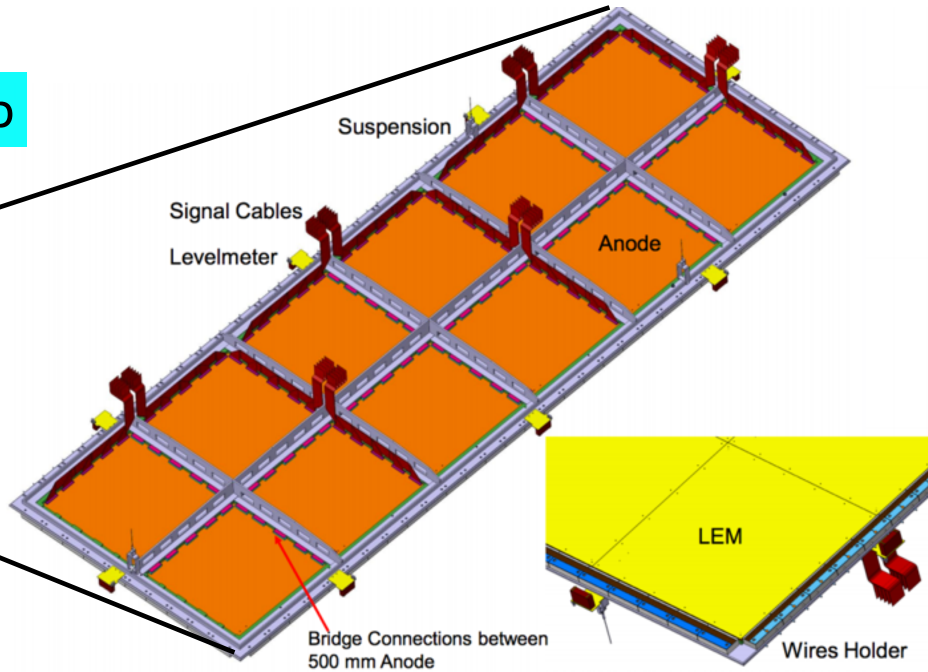


The on-going 3x1x1 m^3 LAr LEM TPC

5 ton (fiducial) double phase LAr TPC



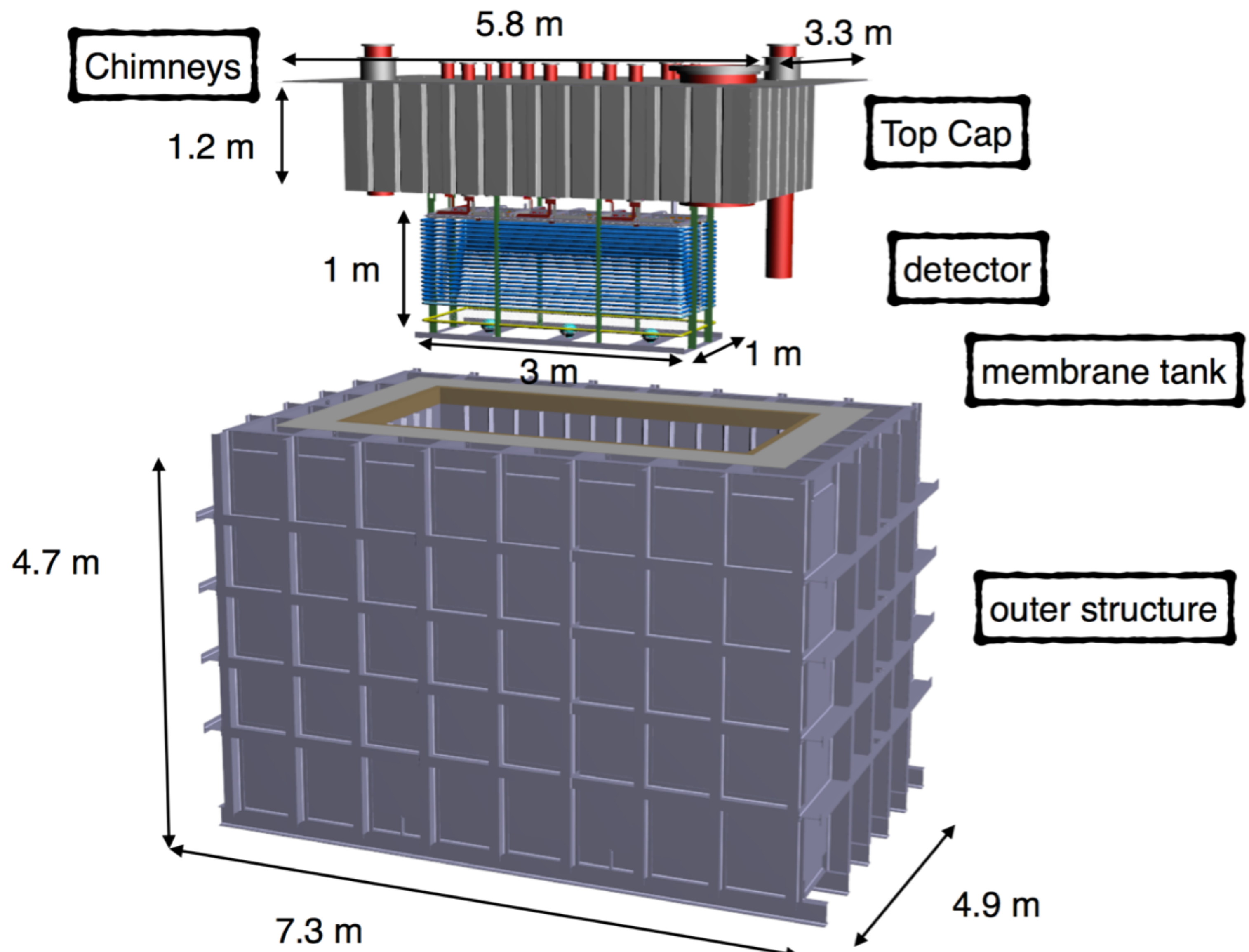
3x1 m^2 charge readout system:



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…

Complete 3D of the 3x1x1 m^3 TPC

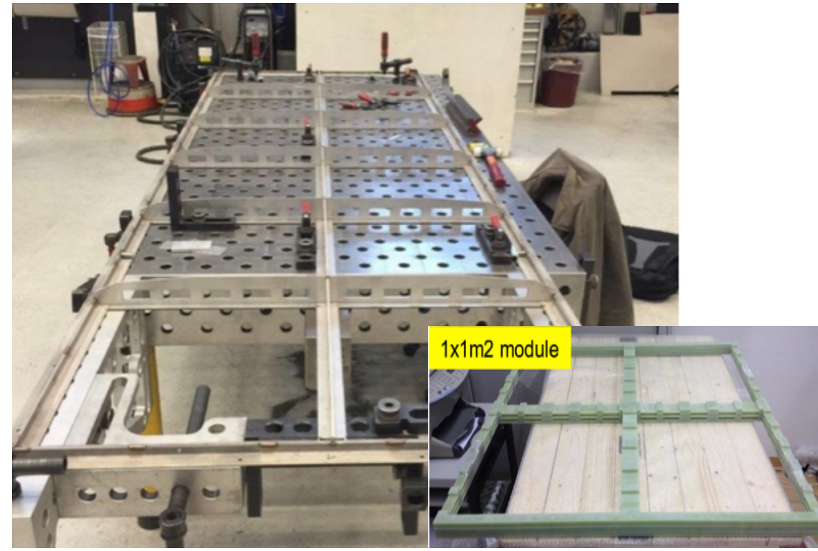


Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

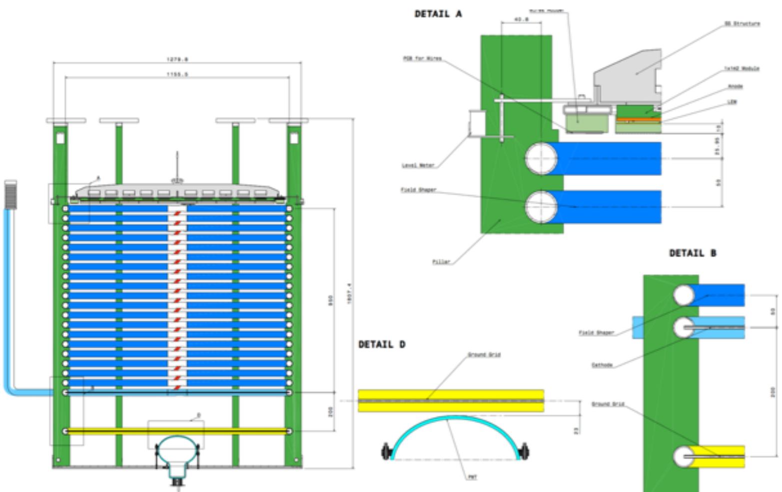
Activities towards the 3x1x1 m^3 TPC

out structure (arrived two weeks ago)

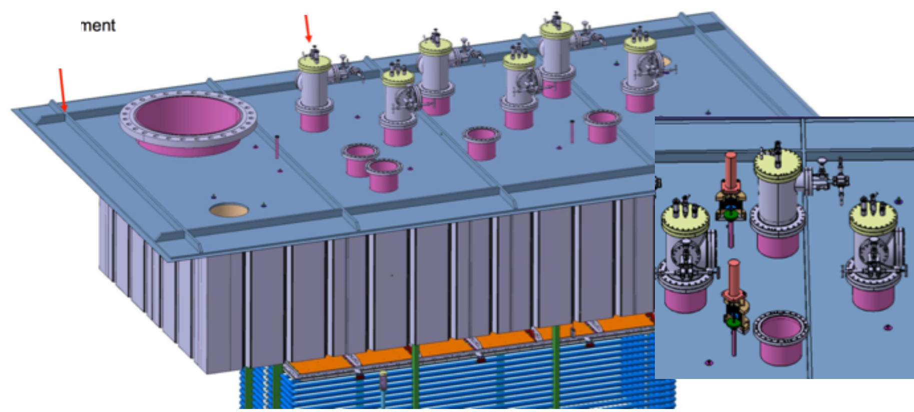
3x1 m2 CRP SS structure being built



drawings of CRP, drift cage

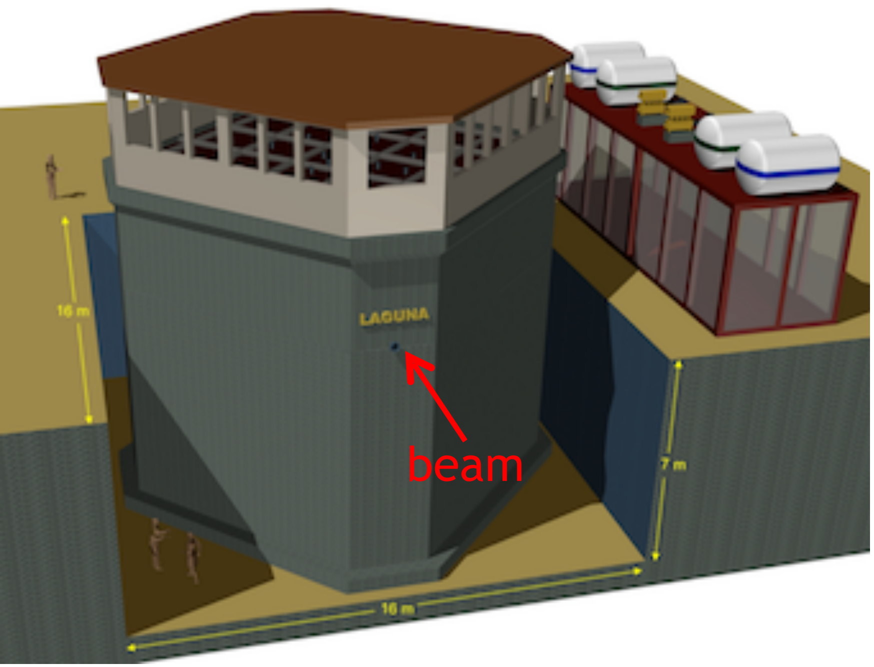


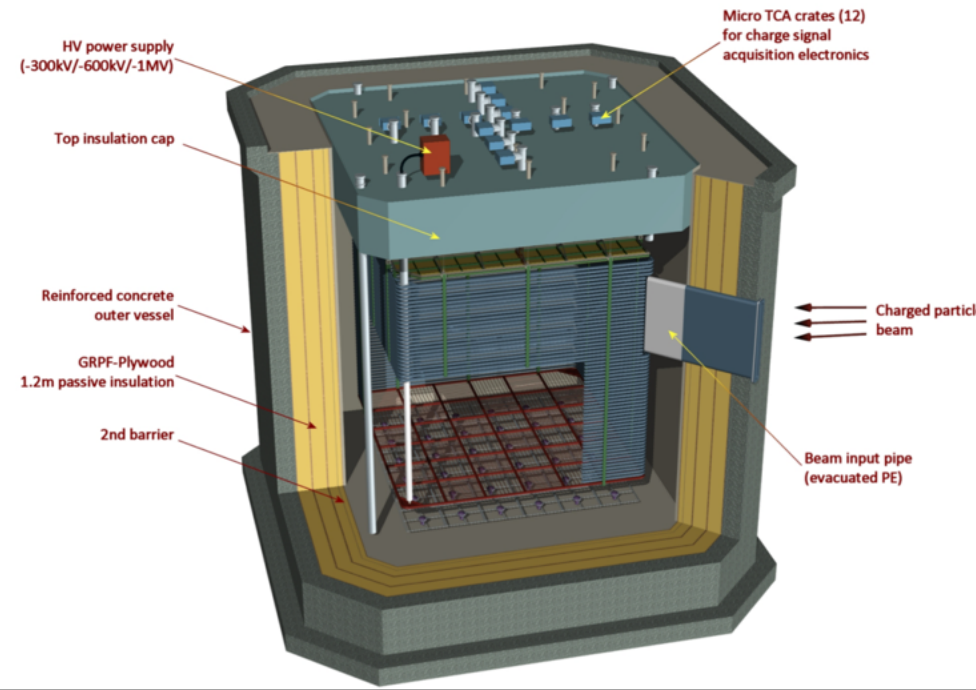
drawings of top cap



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

See Luca Agostino's presentation

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
- ➢ 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 3x1x1 m^3 LAr LEM TPC is the focus for next 1-2 years

Thank you for your attention!

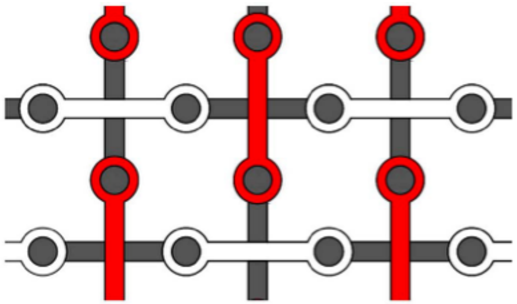
tested parameter	value	$\mathscr{T}$	x (mm)	G_{eff}^{max}	E_0^{max} (kV/cm)
hole layout	hexagonal	0.59± 0.18	0.96±0.07	182	35
	square	0.34± 0.14	0.94±0.08	123	35
hole diameter	500 μm	0.46± 0.14	0.73±0.05	124	39
	400 μm	0.41± 0.11	0.81±0.05	124	38
	300 μm	0.20± 0.03	0.88±0.04	134	36
thickness	1 mm	0.46± 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

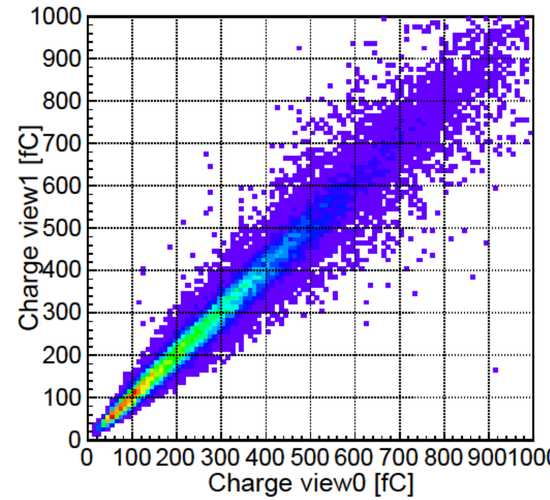
tested parameter	value	E_0 [kV/cm]	run-time [hrs]	Number of discharges	τ [days]	G^0_{eff}	G^∞_{eff}	$\frac{G^0_{eff}}{G^\infty_{eff}}$
geometry	hexagonal	34	110	0	0.32±0.07	99	35	2.7
	square	34	52	0	0.30±0.02	65	27	2.4
hole	500 μm	38	24	0	0.53±0.05	70	20	3.5
	400 μm	37	50	2	0.53±0.07	84	40	2.1
	300 μm	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

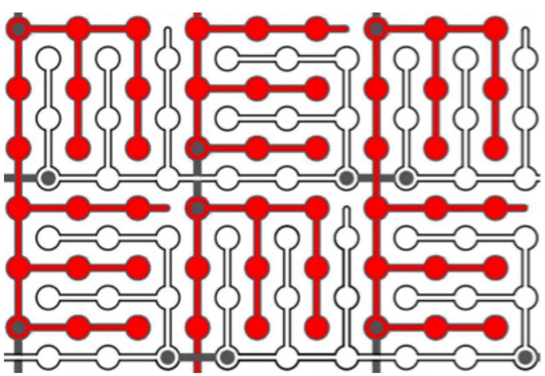
arXiv:1412:4402

Other anodes tested

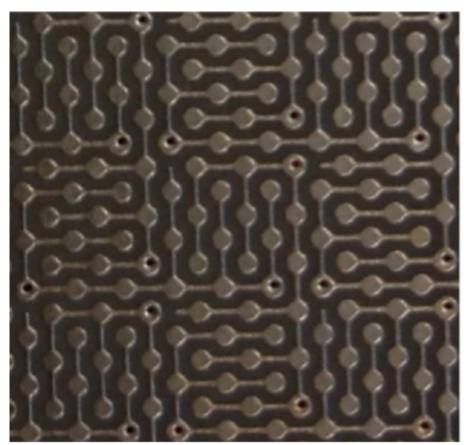


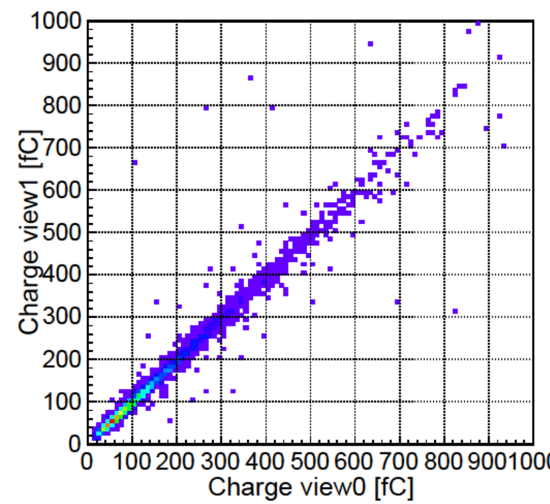
dC/dl~100 pF/m



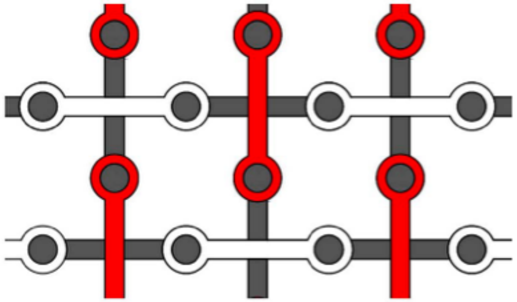


dC/dl~250 pF/m

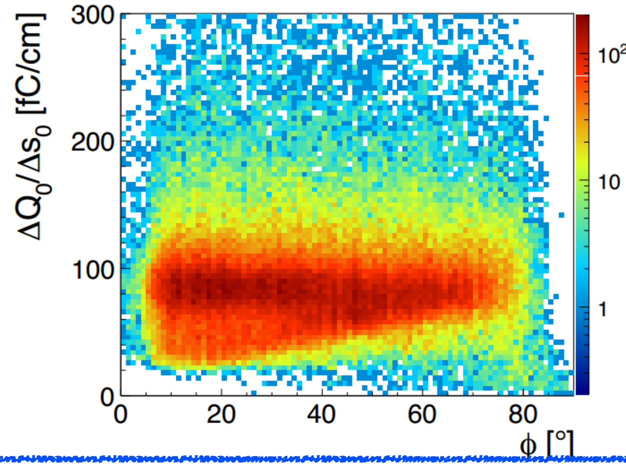


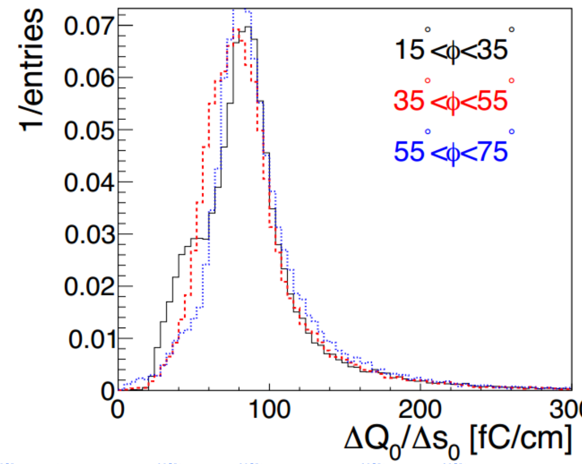


Other anodes tested



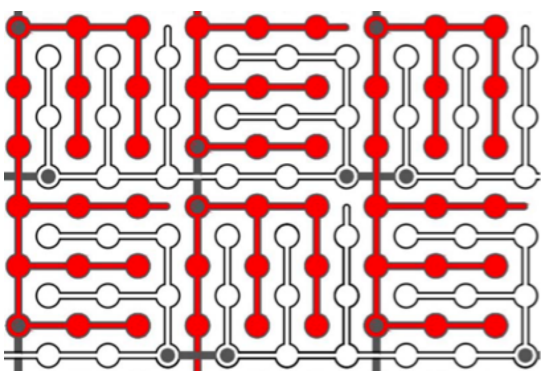
dC/dl~100 pF/m



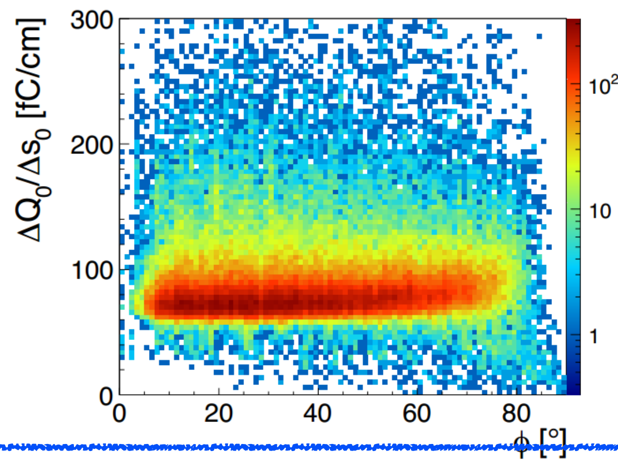


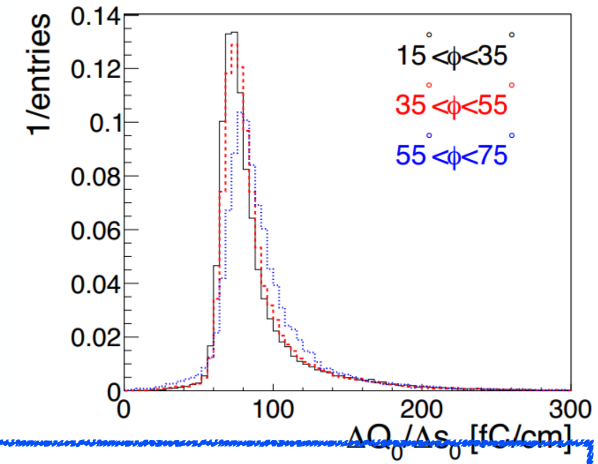
Pattern too loose, non uniform charge collection between strips

JINST 9 P03017



dC/dl~250 pF/m



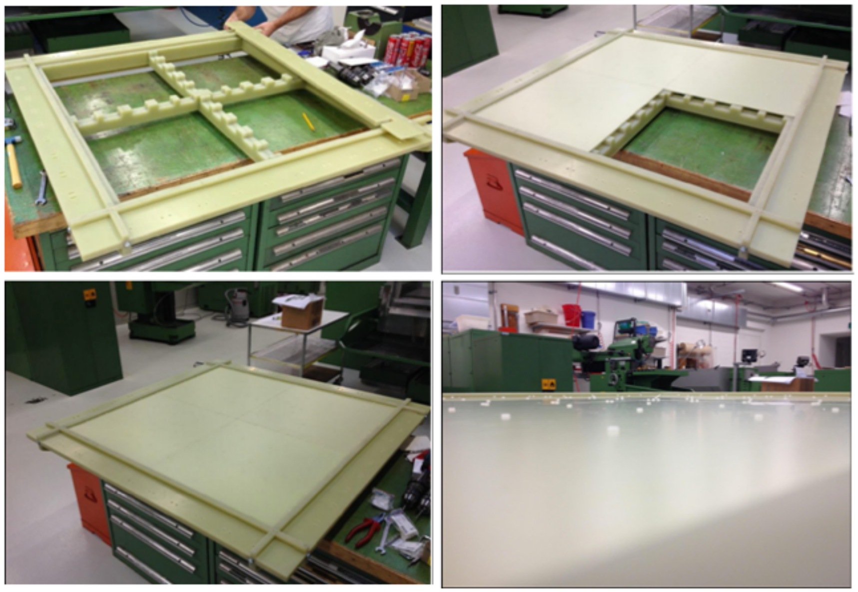


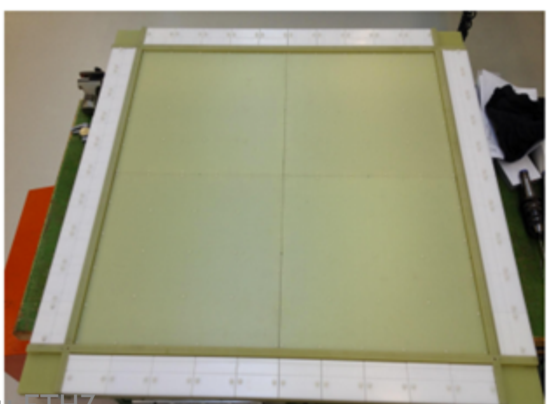
Compatible performance as 150 pF/m anode, but has higher capacitance

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

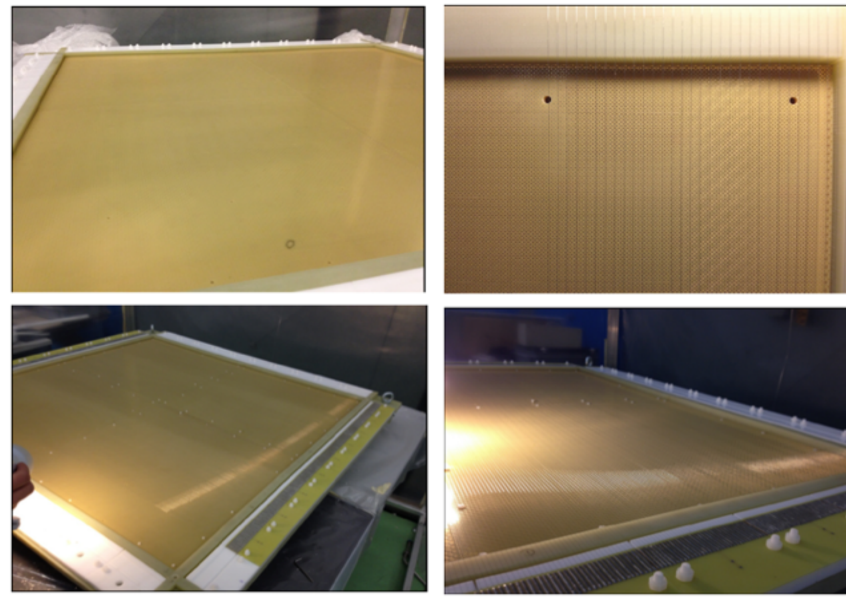
Towards large area readout
- the 1x1 m² charge readout system

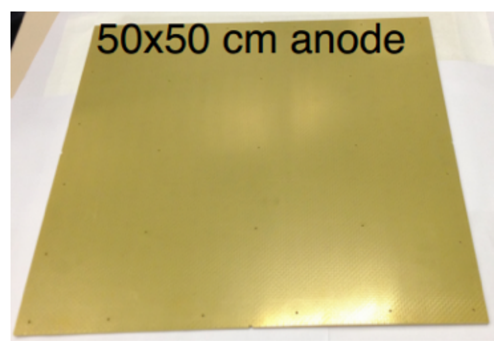
1x1 m² G10 structure with fake anode/LEM

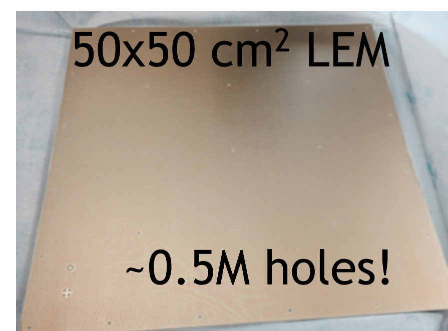




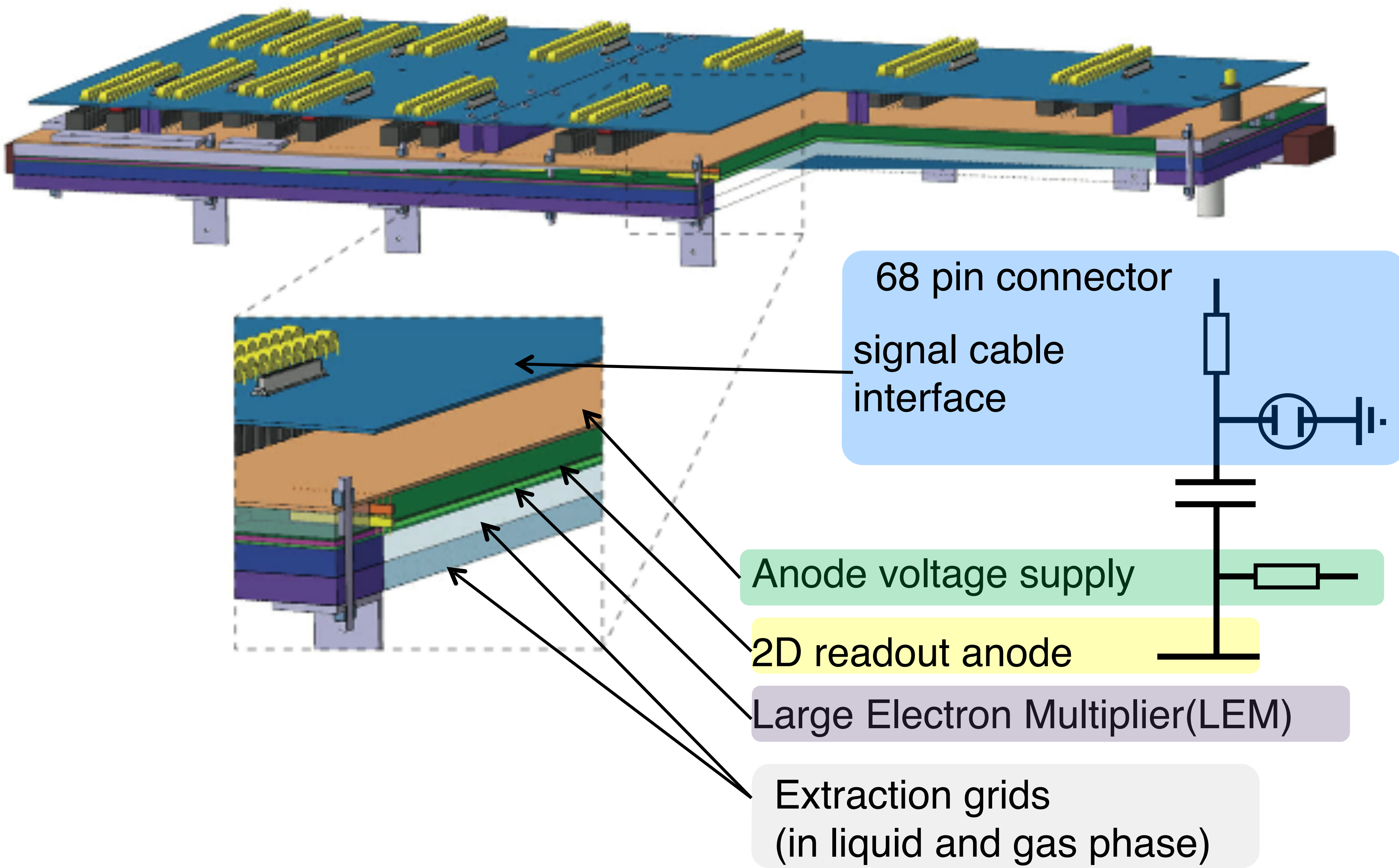
Implemented with real anodes and grid



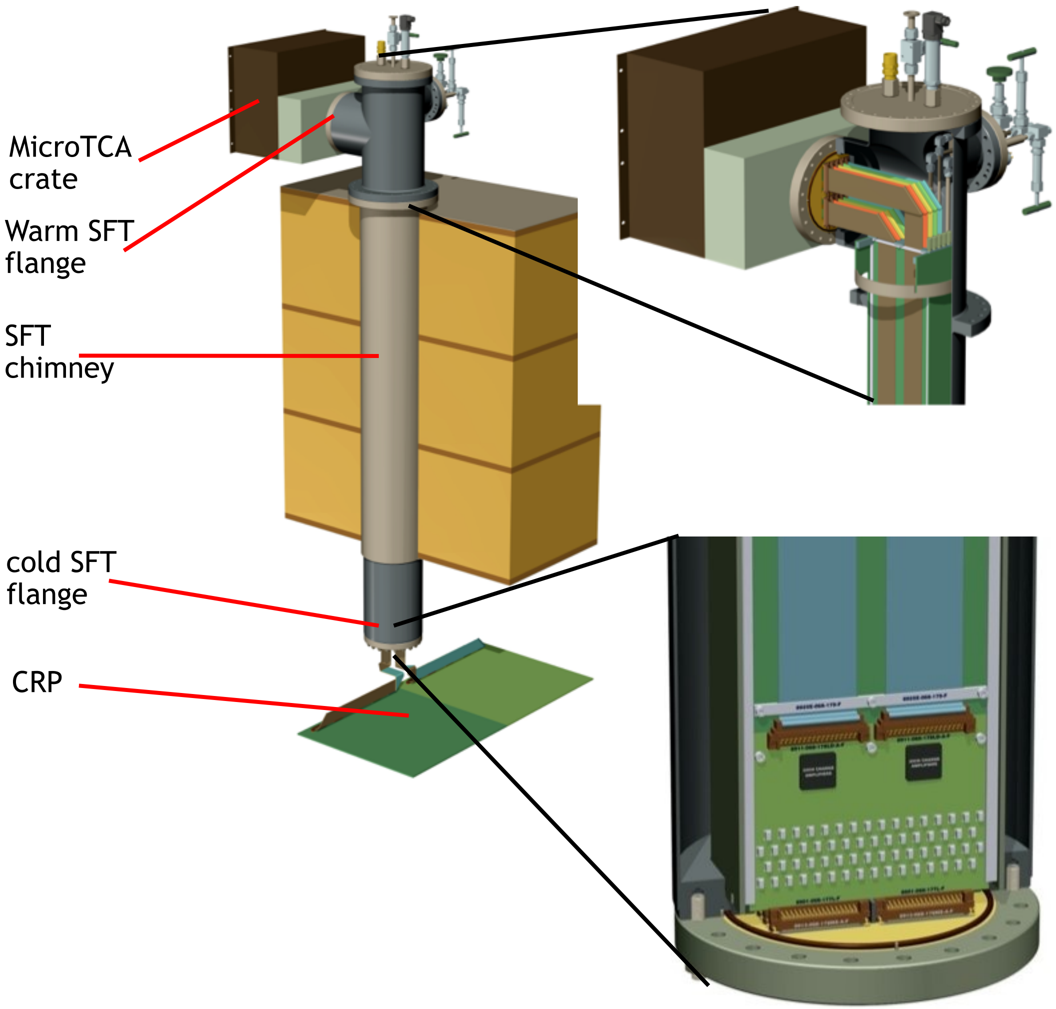




Compact charge readout design



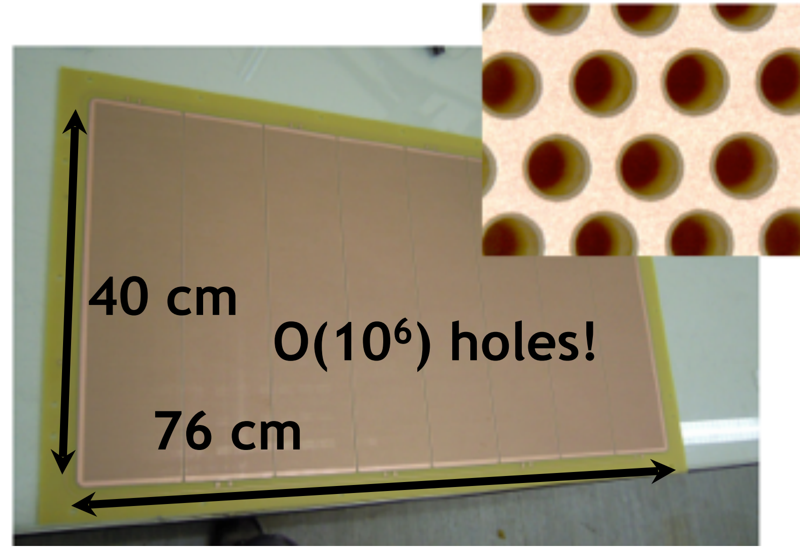
The accessible cold frontend readout electronics and the signal feed-through chimney



Towards a large area readout: the 40x76 cm² prototype

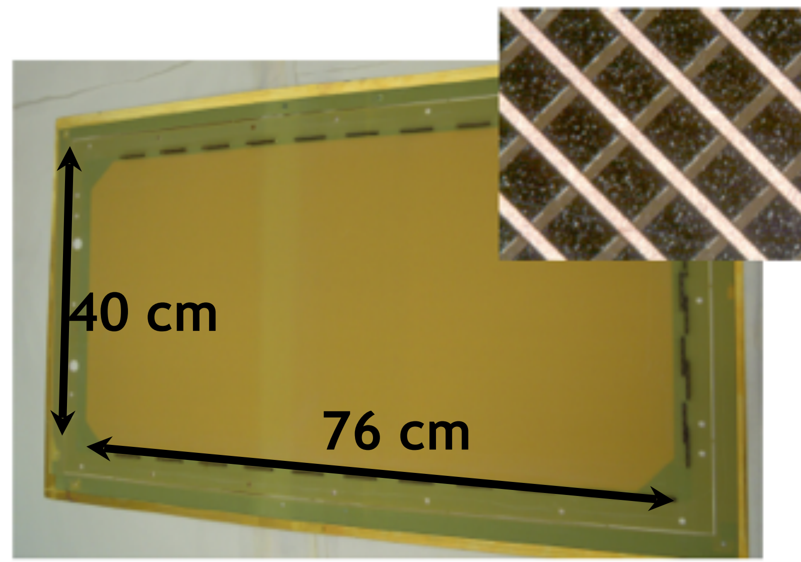
Large Electron Multiplier (LEM)

- 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

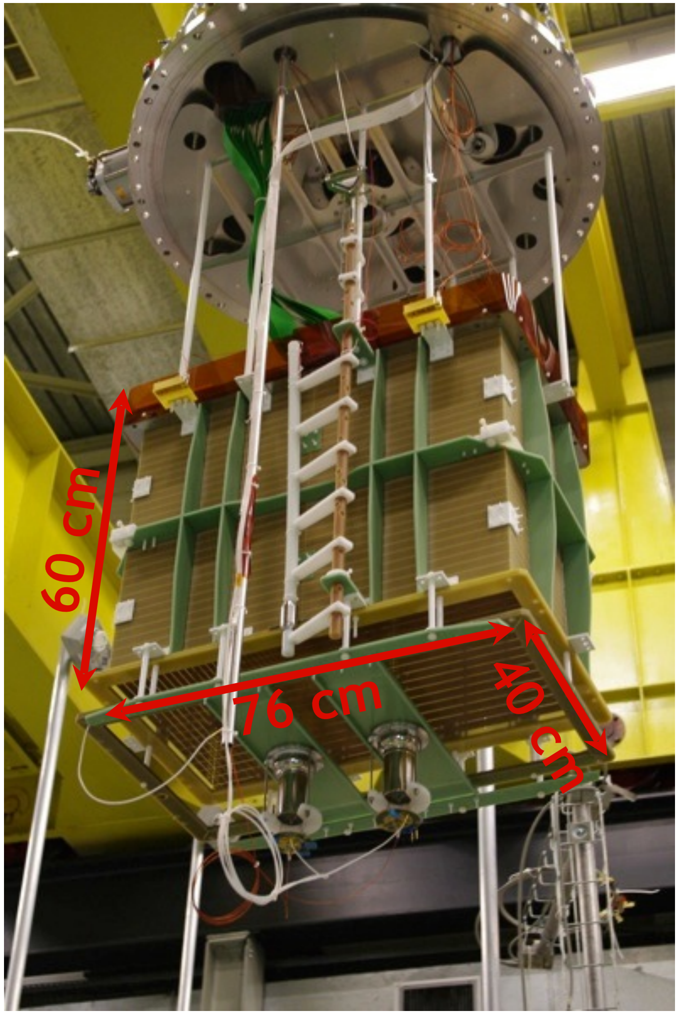


So far largest area LEM/2D anode produced

Large area readout: the 40x76 cm² prototype

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

detector fully assembled

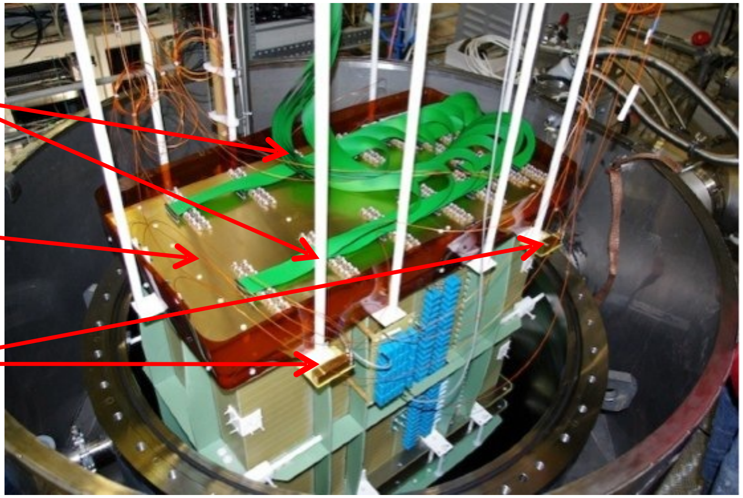


going into the ArDM cryostat

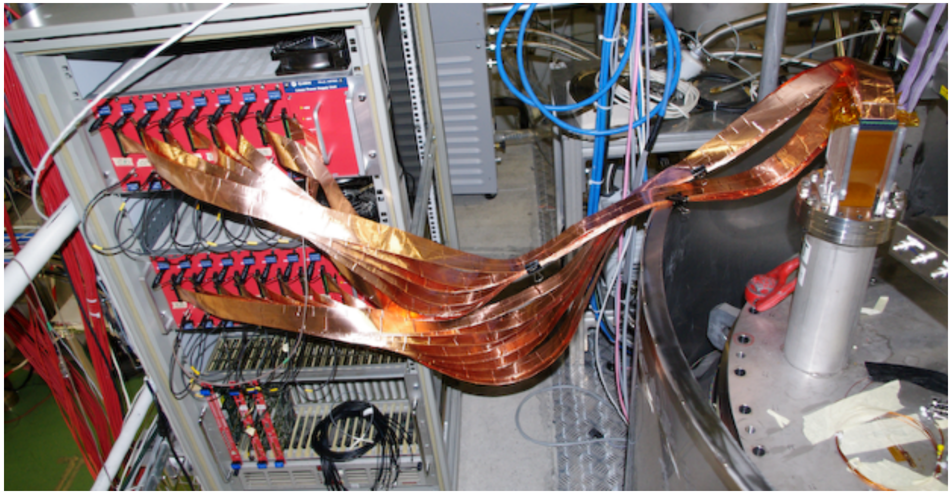
16 signal cables

charge readout sandwich

4 capacitive level meters



Final connection to the CAEN DAQ system



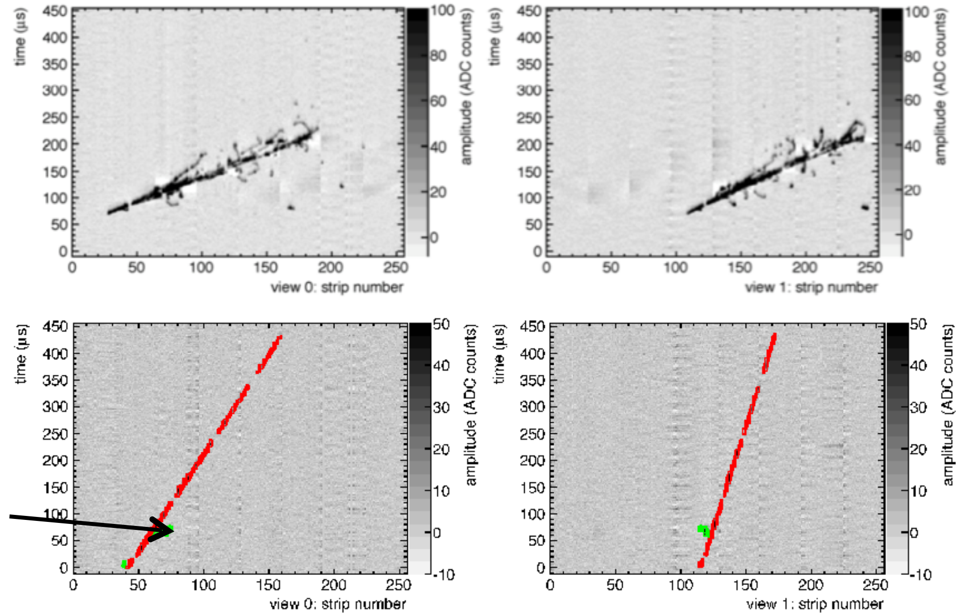
Results from the 40x76 cm^2 prototype

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

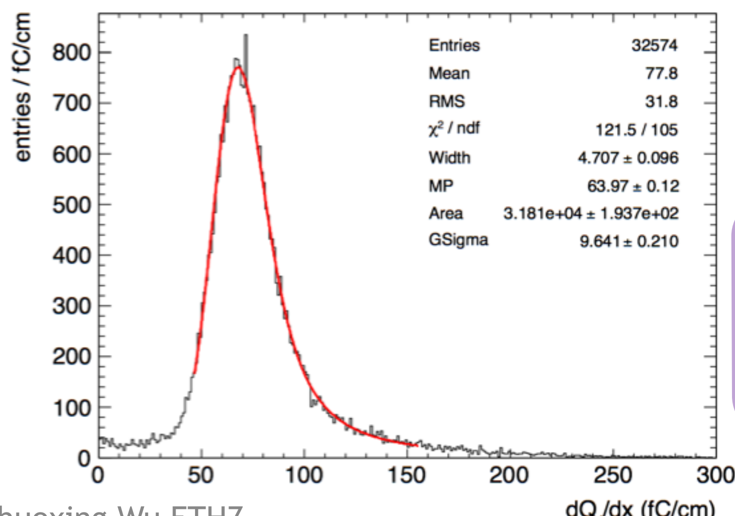
A. Badertscher et al. JINST 8 (2013) P04012

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%