

Recent results on LAr LEM-TPC (R&D)

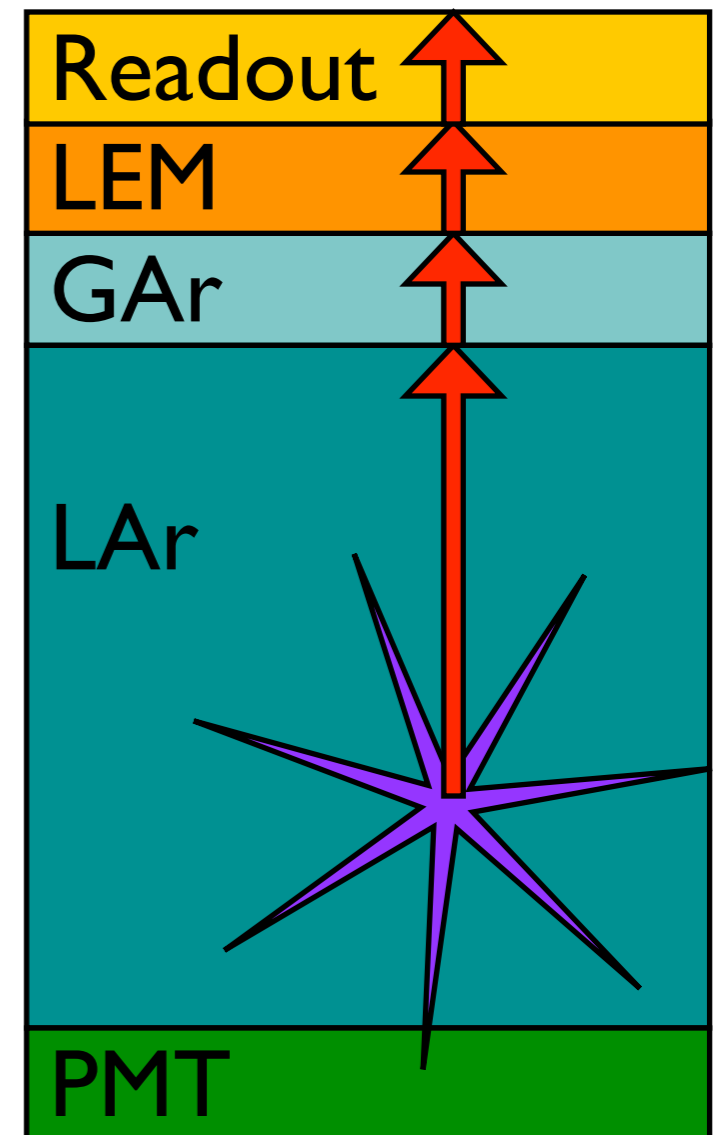
A. Badertscher, A. Curioni, U. Degunda, L. Epprecht,
L. S. Esposito, A. Gendotti, L. Knecht, D. Lussi, A. Marchionni,
G. Natterer, F. Resnati, A. Rubbia, T. Viant

Introduction

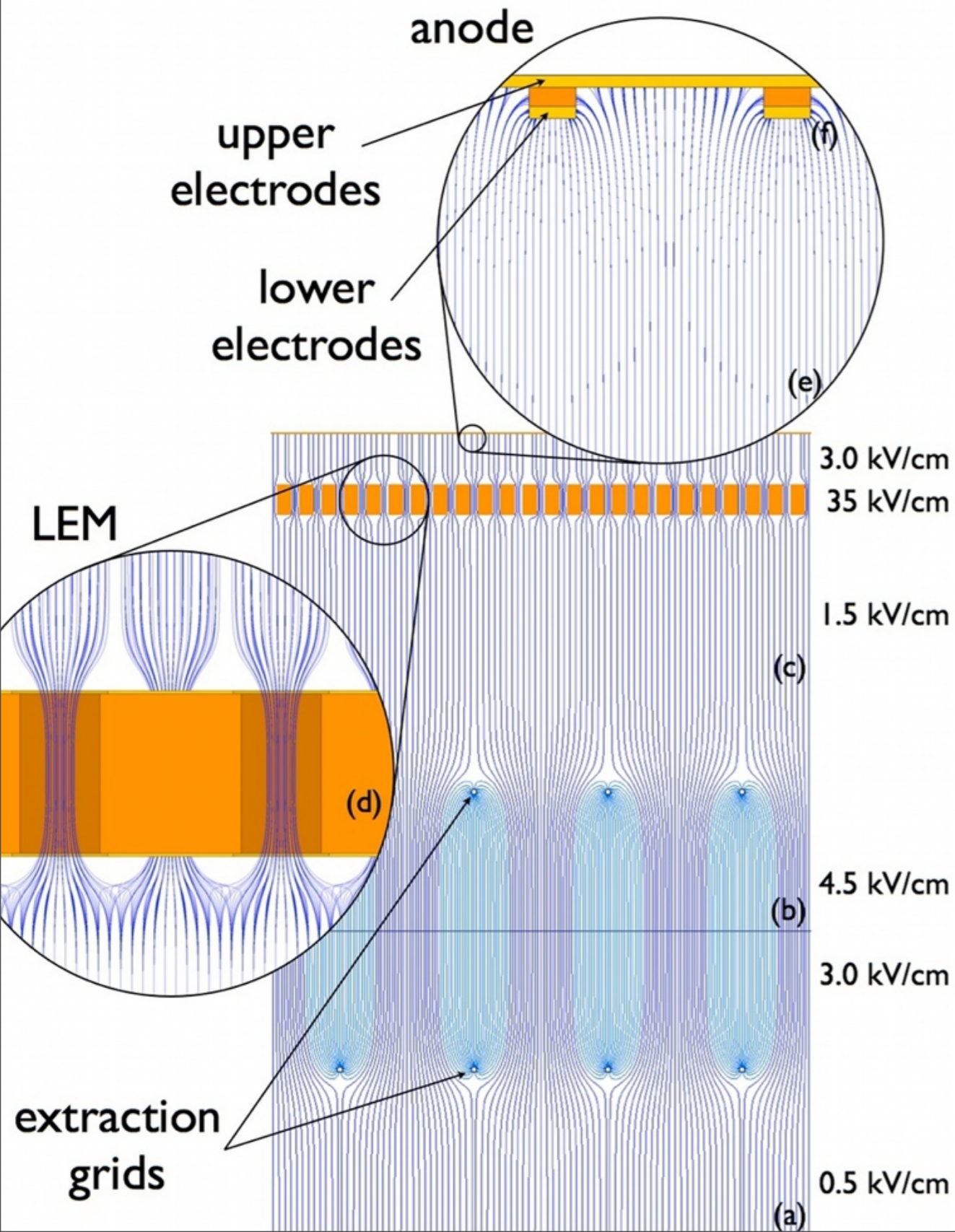
- Double phase argon Large Electron Multiplier (LEM) TPC concept provides a 3D-tracking and calorimetric device capable of adjustable charge amplification.
- It is a promising readout technology for next generation neutrino detectors [1] (fine spatial resolution, large active area and gain of the order of 10) and direct Dark Matter searches [2] (20 keVre threshold requires charge amplification of the order of 1000).
 - [1] A. Rubbia, arXiv:hep-ph/0402110, 2003 - see Prof. A. Rubbia talk (Thursday afternoon).
 - [2] A. Rubbia, J. Phys. Conf. Ser. 39 (2006) 129 - see Dr. A. Curioni talk (Wednesday morning).
- Recent papers:
 - A. Badertscher et al., NIM A 641 (2011) 48.
 - A. Badertscher et al., arXiv:1010.2482.
 - A. Badertscher et al., NIM A 617 (2010) 188.
 - A. Badertscher et al., arXiv:0811.3384.

LEM-TPC working principle I

- Charge and light are produced by an ionizing event in the LAr.
- VUV scintillation light is detected by PMTs, it provides the time reference of the event.
- The charge is drifted to the LAr surface and extracted into the vapour phase.
- The drift field is 0.5-1kV/cm and the extraction field ($>2.5\text{kV/cm}$) is provided by two grids.
- The charge is driven into the LEM where the electron multiplication occurs.
- The moving charges induce signals on the readout electrodes of the anode.



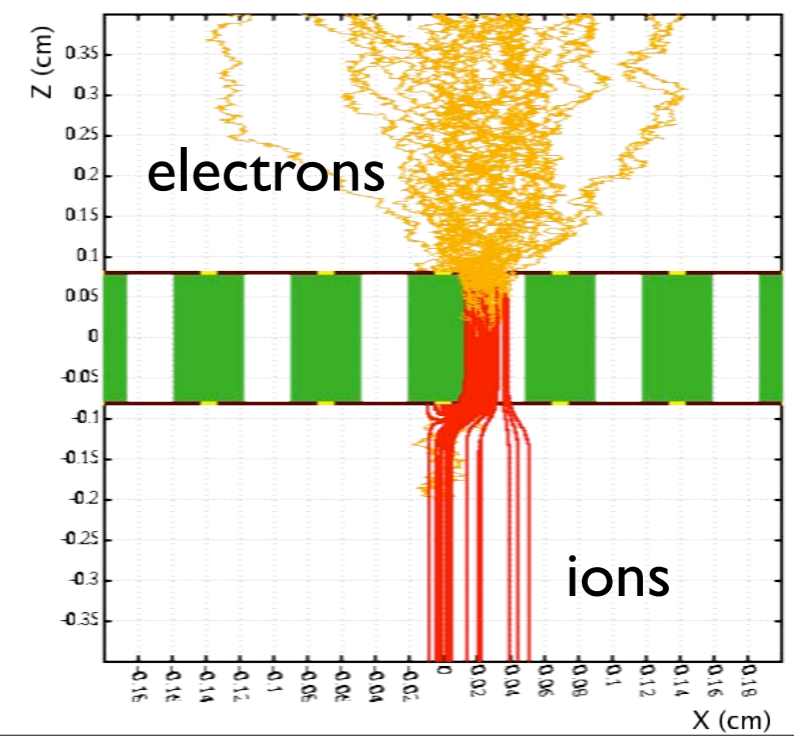
LEM-TPC working principle II



- The LEM is a double sided metallized PCB plate with holes drilled in a regular pattern.
- Applying potential difference to the LEM electrodes, electric field is attained in the holes.
- Charge amplification (Townsend avalanche):
gain: $G = e^{\alpha x}$
 x : effective multiplication length.
 $\alpha \sim Ape^{-Bp/E}$: first Townsend coefficient.

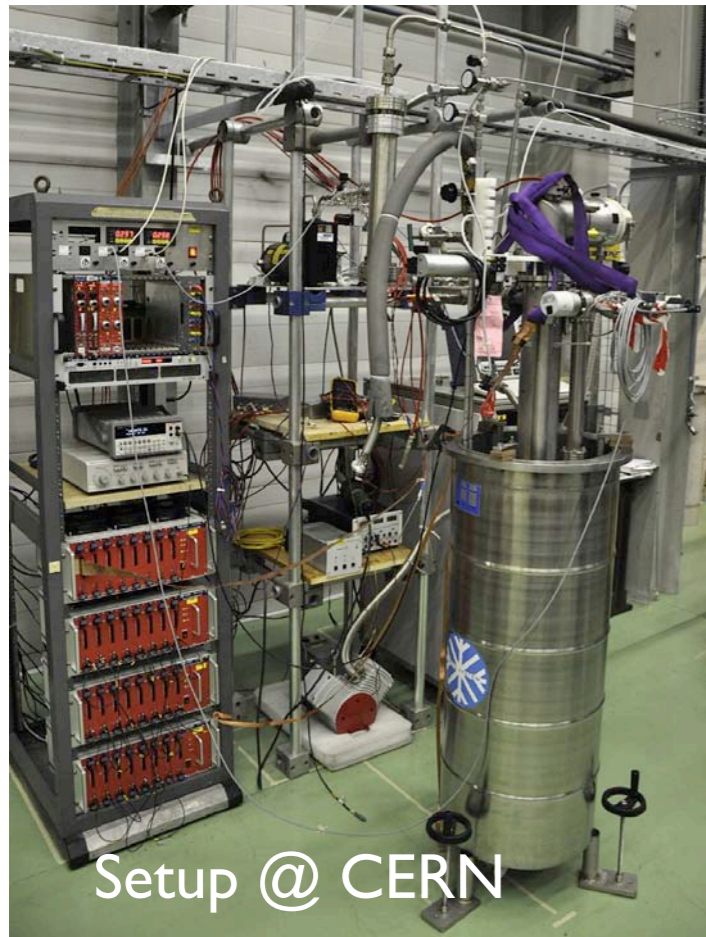
- (a) Drift region.
- (b) Liquid surface.
- (c) Vapor argon.
- (d) LEM holes.
- (e) Induction region.
- (f) 2D projective anode strips.

Simulated electron avalanche

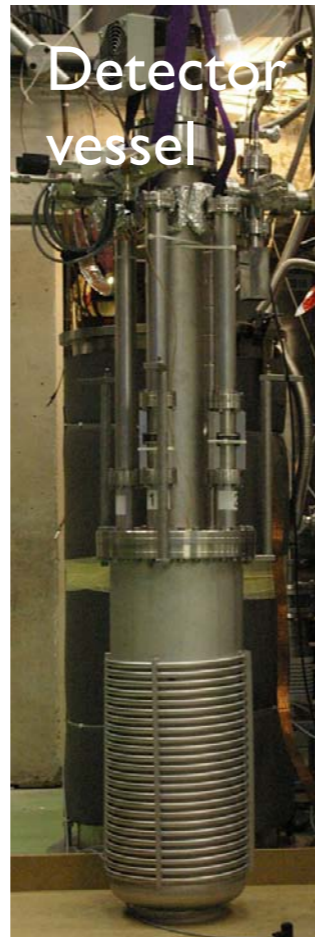


3L setup @ CERN

The setup

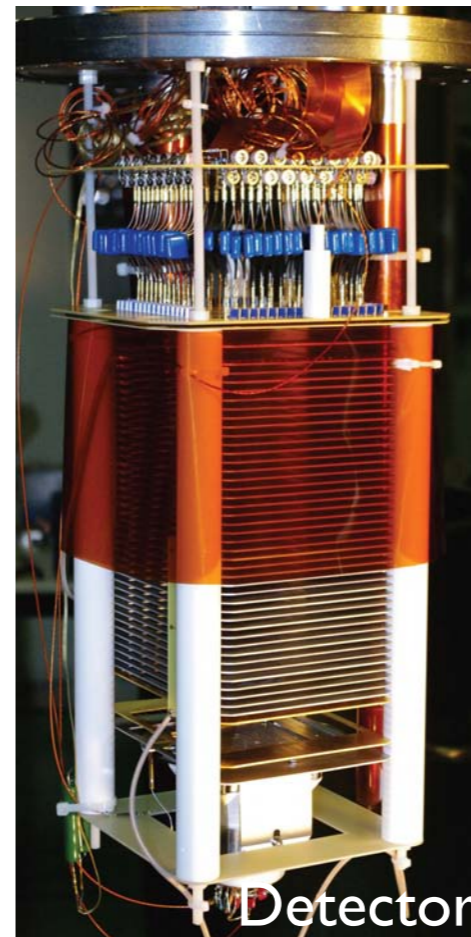


Setup @ CERN



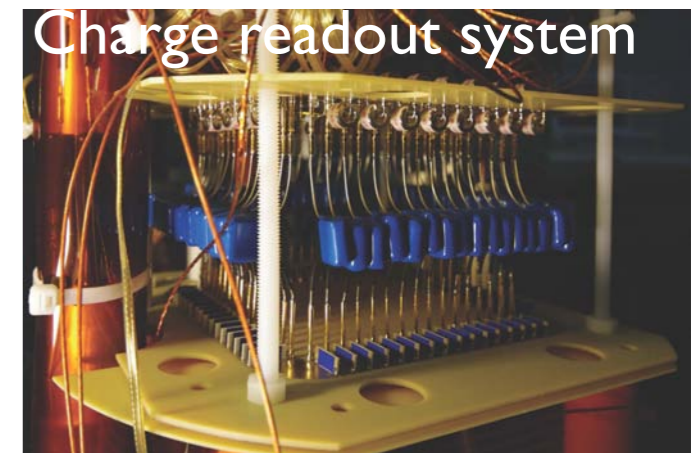
Detector vessel

- R&D setup for testing charge readout prototypes in double phase conditions (LEM, Micromegas, Gridpix already tested).
- Active volume can be $10 \times 10 \times 30 \text{ cm}^3$.
- Monitor the argon purity down to 0.5 ppb.
- Development of software for the 3D reco.
- The detector operates in **realistic conditions**.



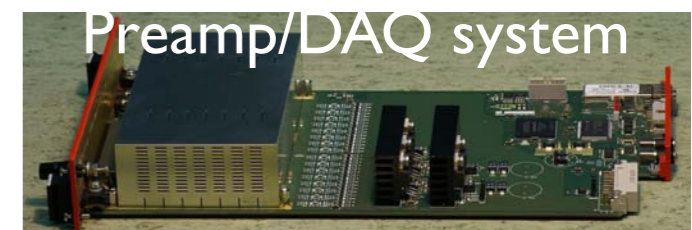
Detector

Double phase TPC equipped with PMT.



Charge readout system

Charge readout apparatus like: Large Electron Multiplier, Micromegas, Gridpix, ...



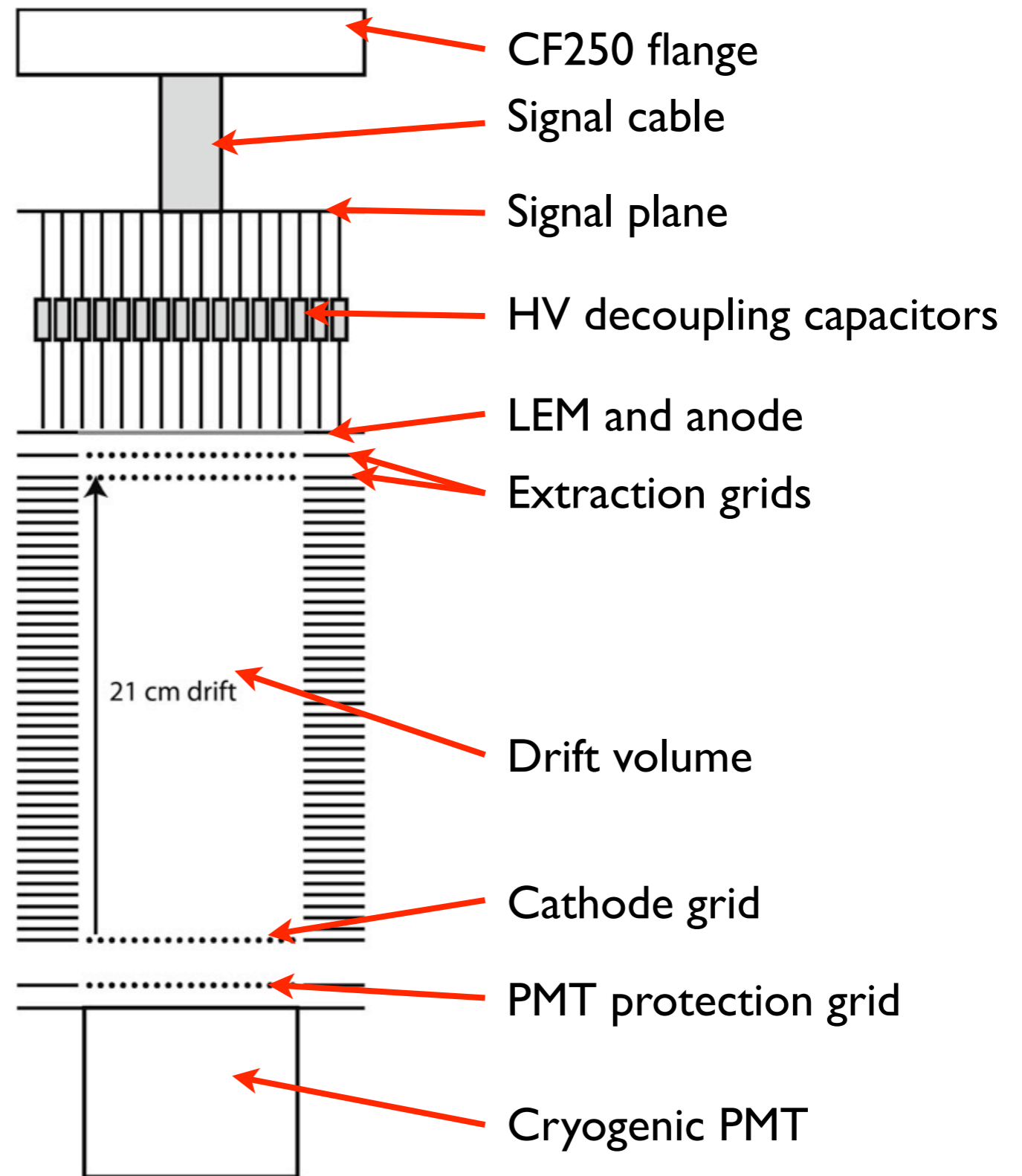
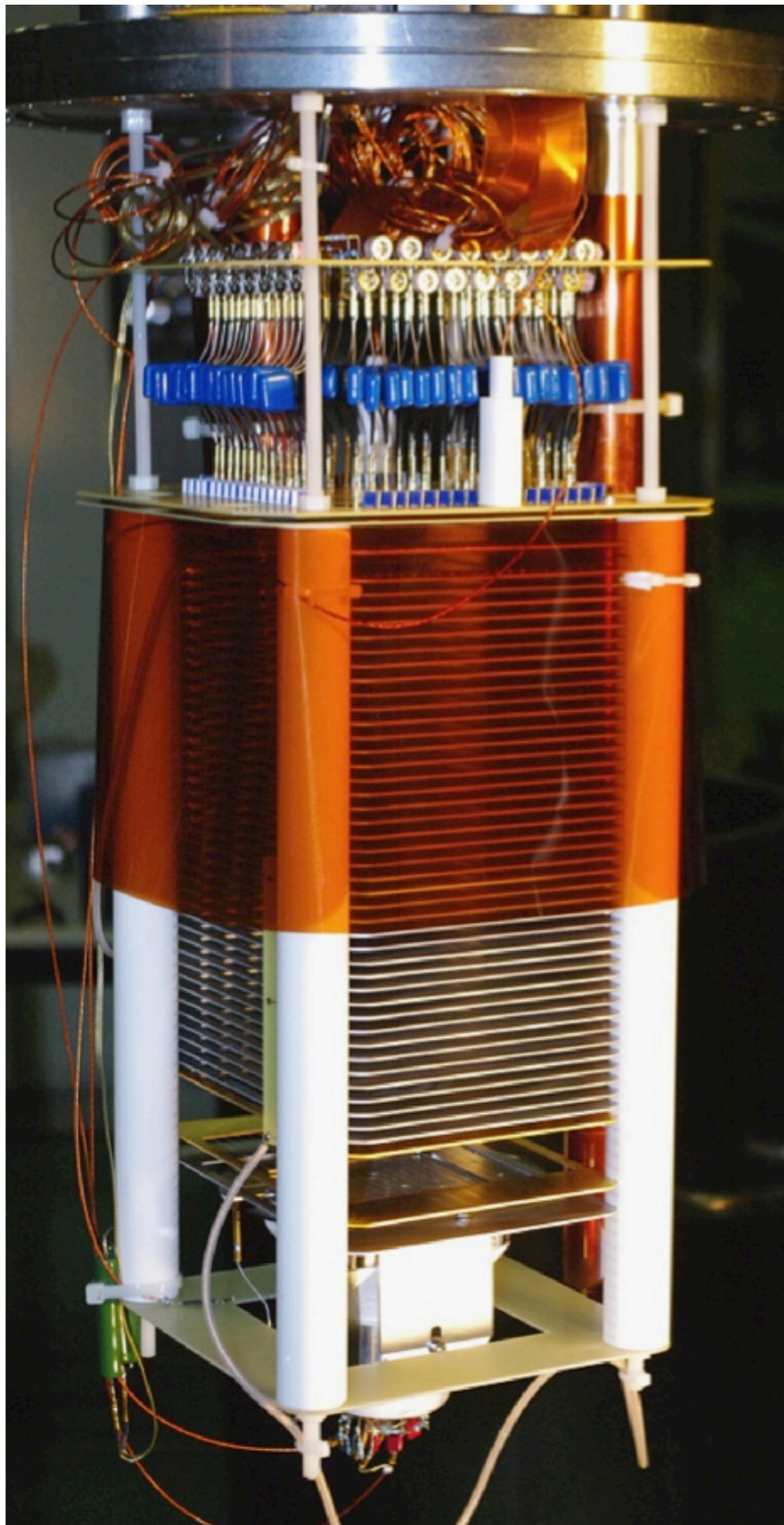
Preamplifier/DAQ system



CAEN SY2791

Complete amplification/digitization system.
Development: CAEN/ETHZ collaboration.
12 bit, 2.5MS/s, 32 ch/board, 8 board/crate.

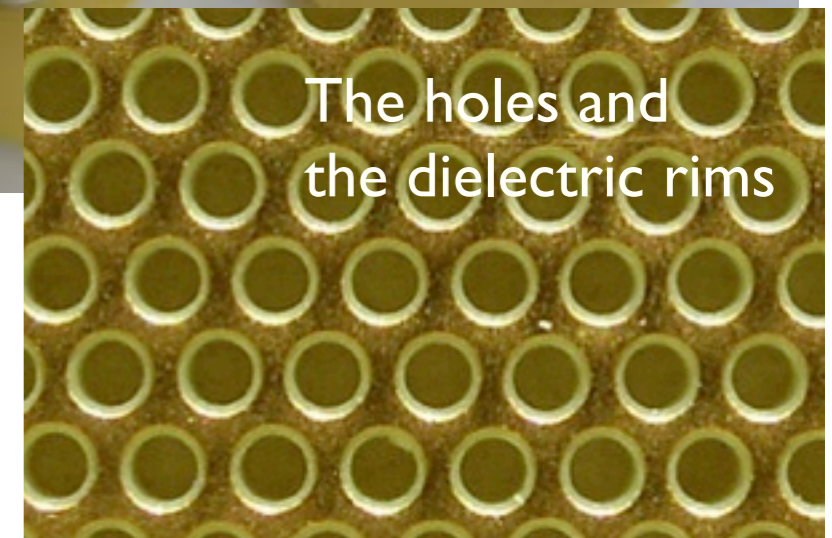
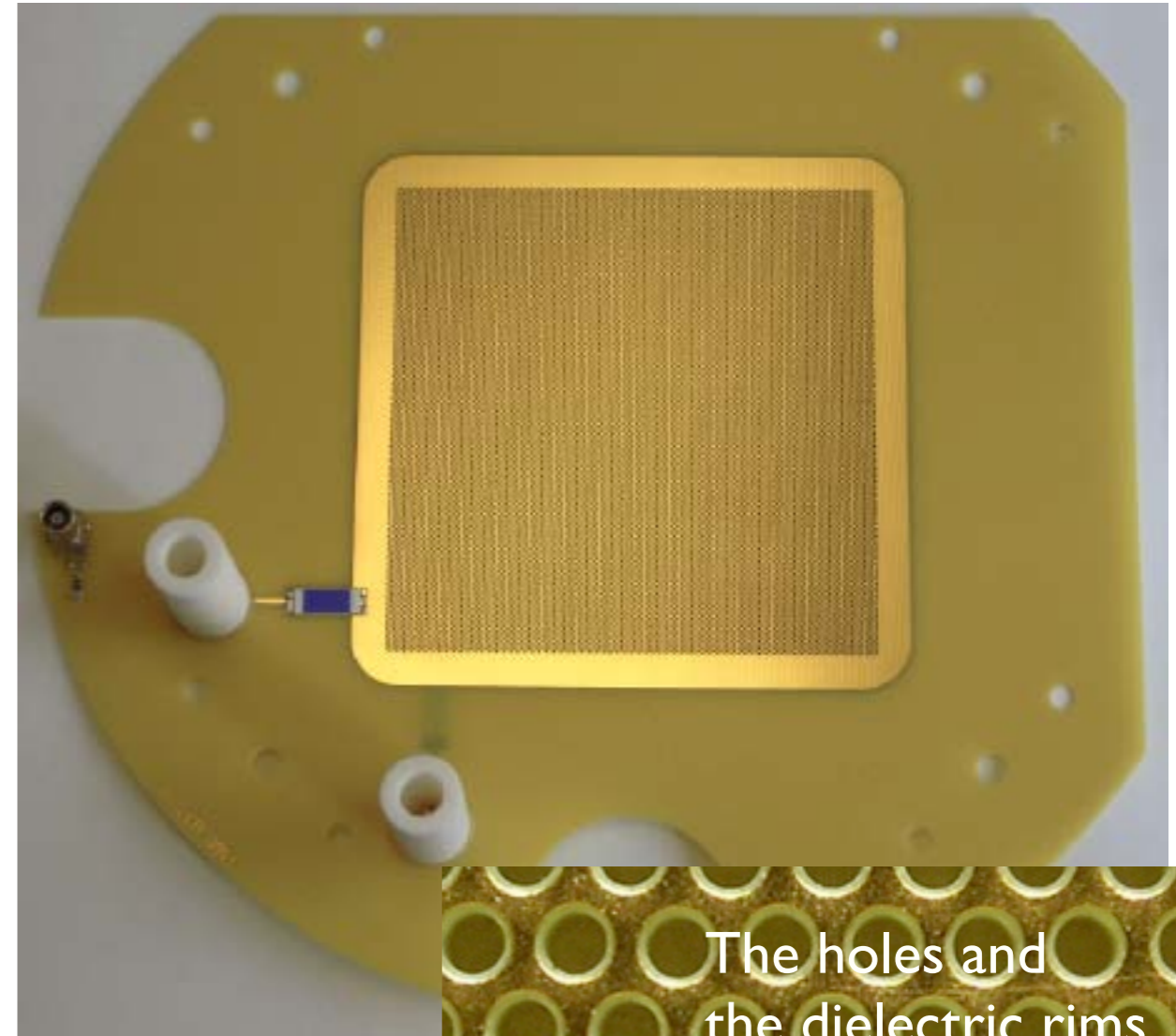
The detector



Large Electron Multiplier

- Macroscopic extrapolation of the Gas Electron Multiplier (Kapton thickness 50 μm , hole \varnothing 100 μm).
- Double side metal cladded PCB plate with holes drilled with honeycomb pattern.
- Manufactured with standard PCB techniques.
- Precision holes done by drilling.
- Dielectric rim etched and perfectly aligned to the hole (increase the sparking limit).
- Hardness to cryogenic temperatures and discharges.
- Large area can be covered.

total area	10x10 cm ²
PCB thickness	1.0 mm
hole diameter	500 μm
hole pitch	800 μm
dielectric rim	70-80 μm



The holes and the dielectric rims

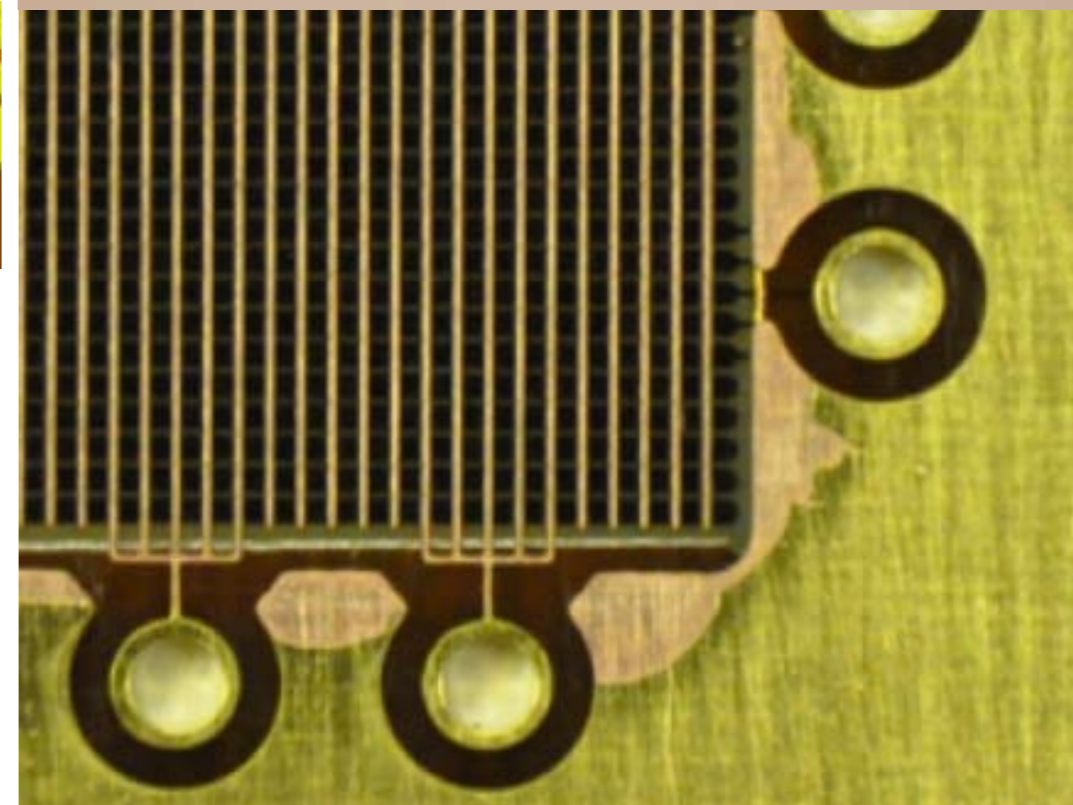
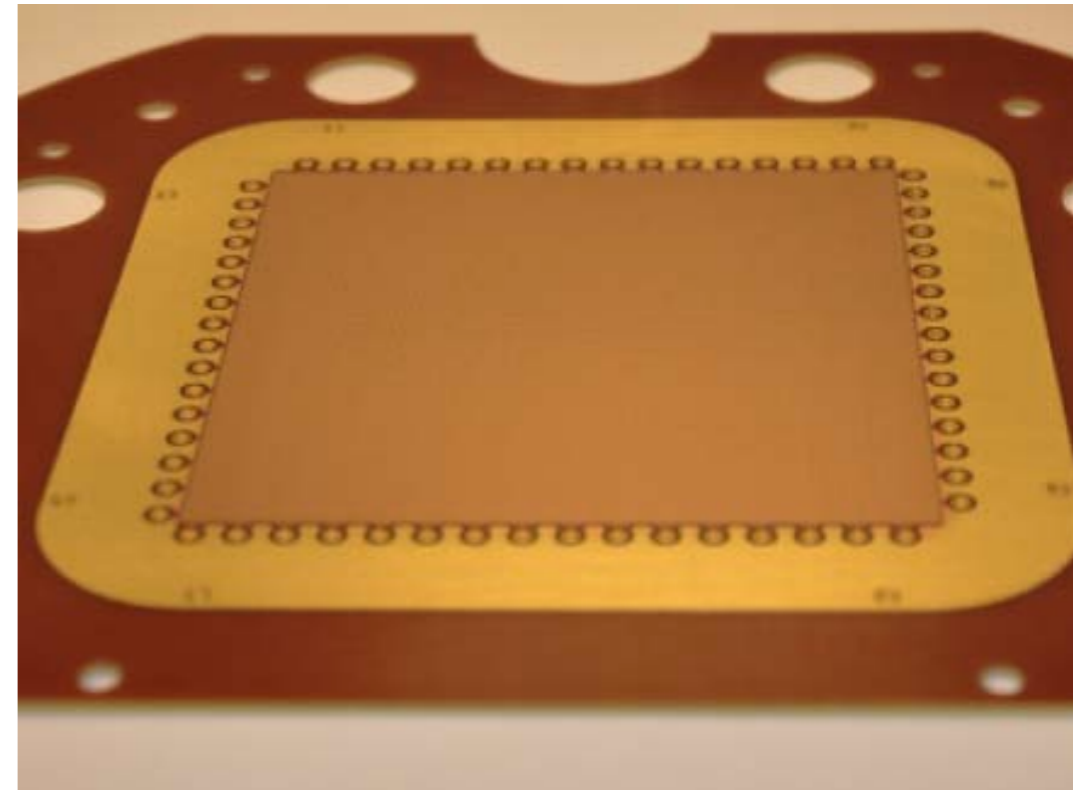
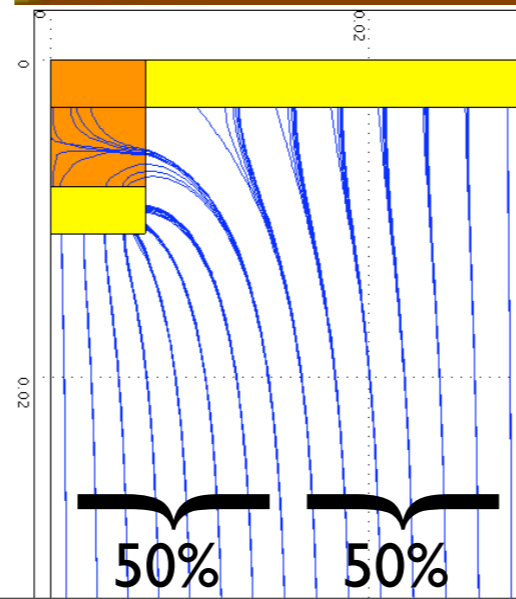
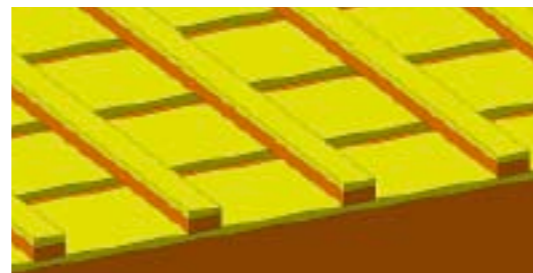
Manufacturer: CERN TS/DEM group

2D projective anode

- Two orthogonal sets of strips (insulated with polyimide strips) are printed on the same PCB.
- Avoid the segmentation of the LEM electrodes (less prone to discharges).
- Charge is equally collected on each view (avoid the use of the so called “induction plane”).
- Induced signals have the same shape (easier data analysis).
- Readout is independent of the multiplication stage.

Manufacturer: CERN TS/DEM group

Readout pitch	3 mm
Strip pitch	600 μm
Strip width (outer)	120 μm
Strip width (inner)	500 μm
Kapton thickness	50 μm
Number of strips	32x32

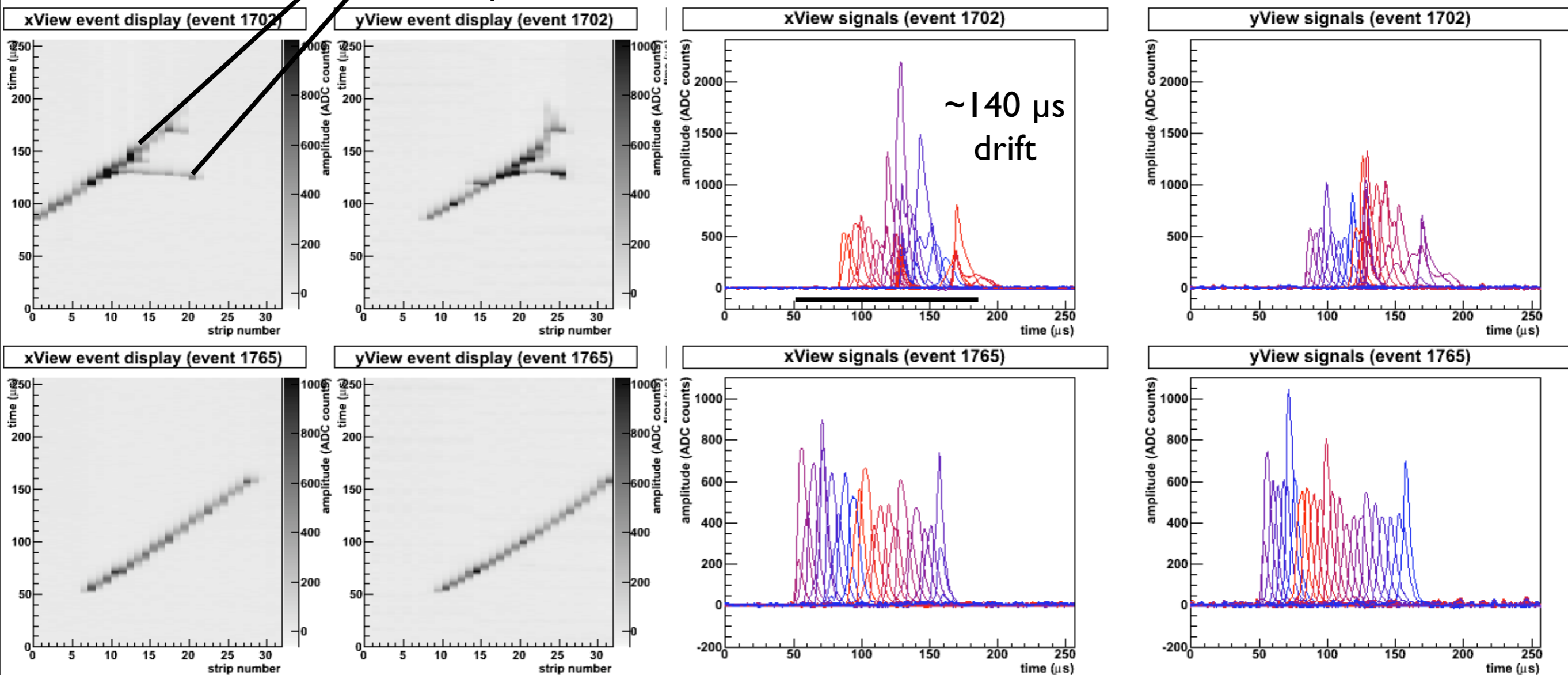


Event display

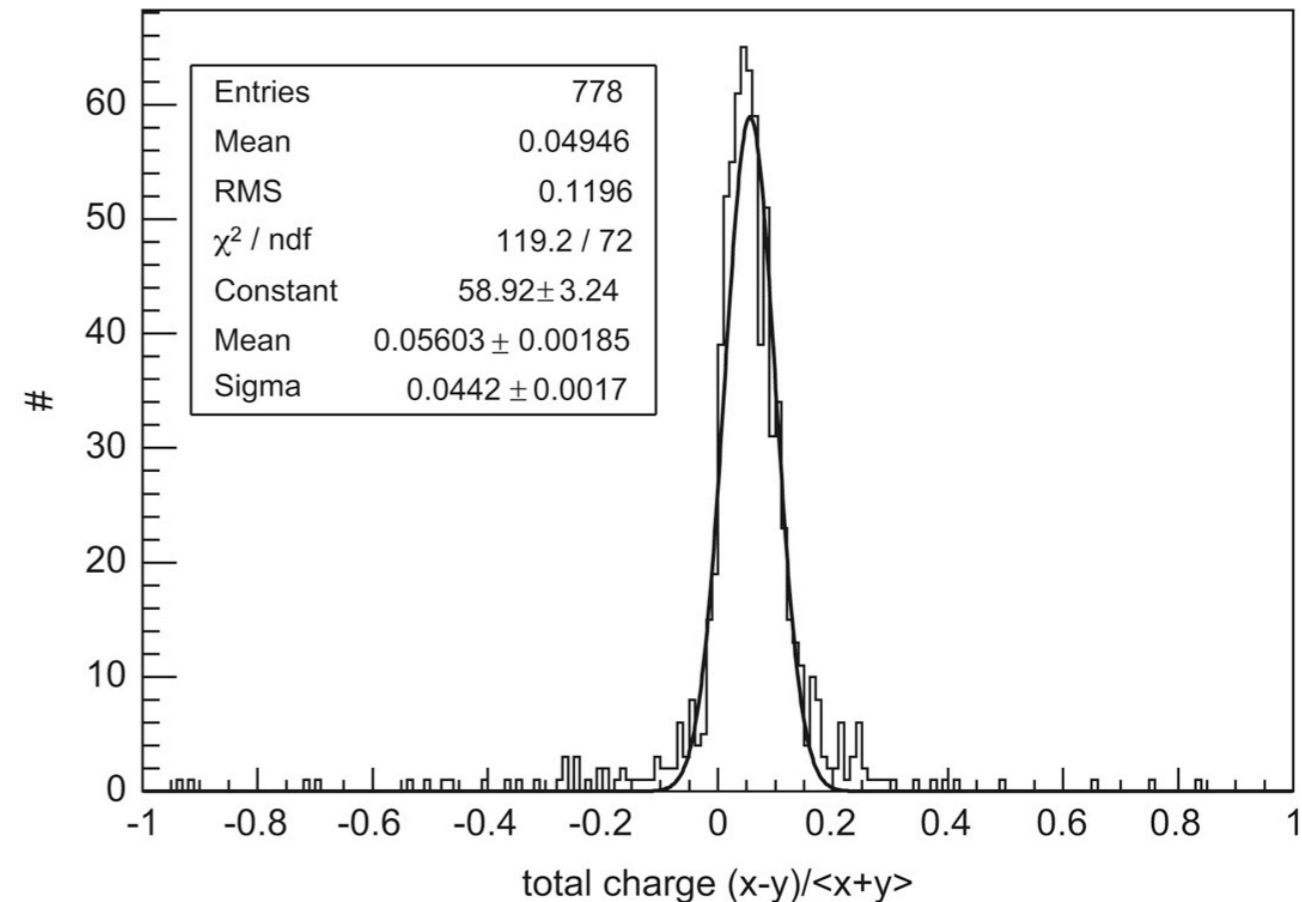
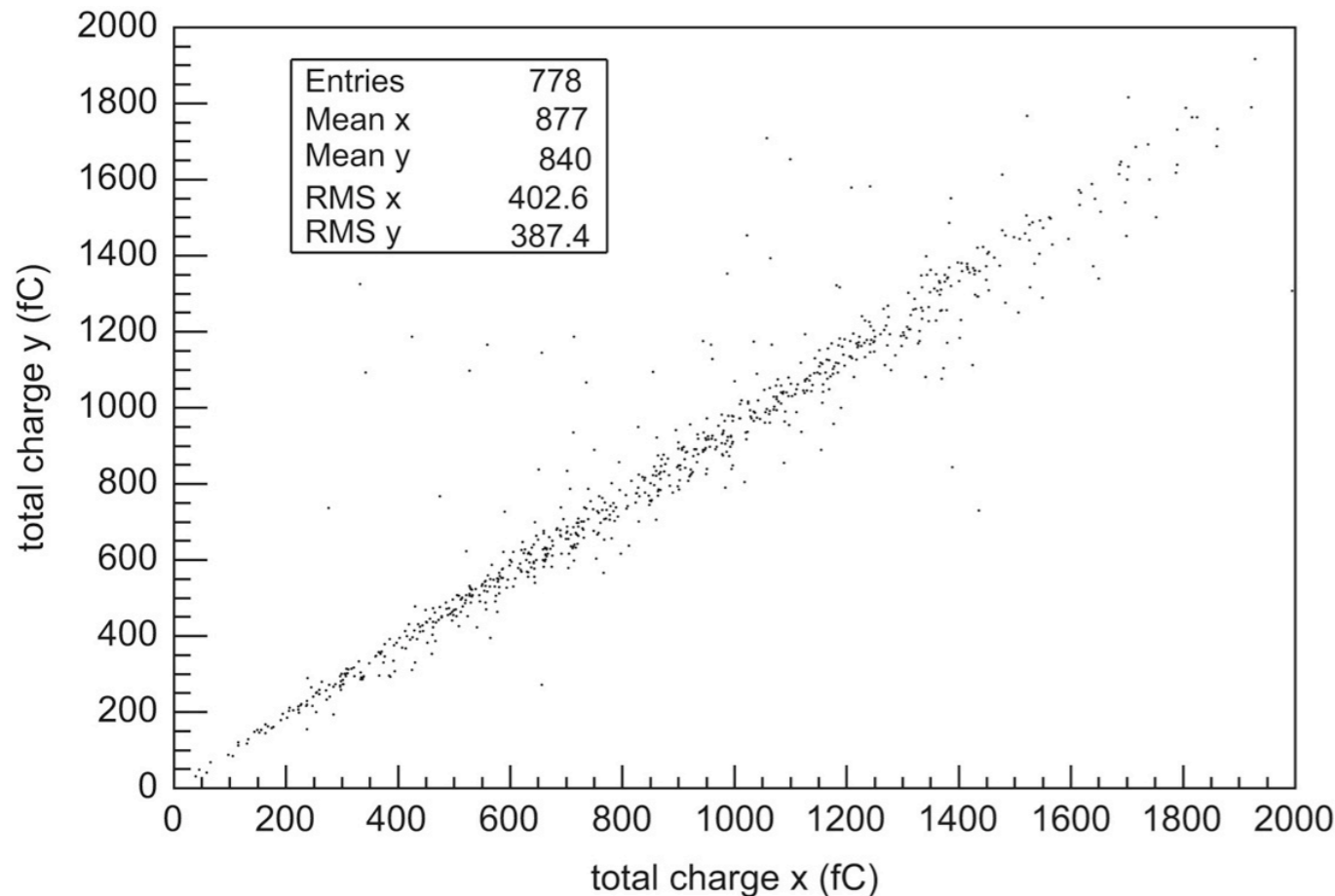
$T = 87 \text{ K}$, $P = 1 \text{ bar}$
LAr purity $\sim 1 \text{ ppb } [\text{O}_2] \text{ eq}$

Double phase operation
Effective gain ~ 27
 $S/N > 200$

Cosmic muon
Delta ray



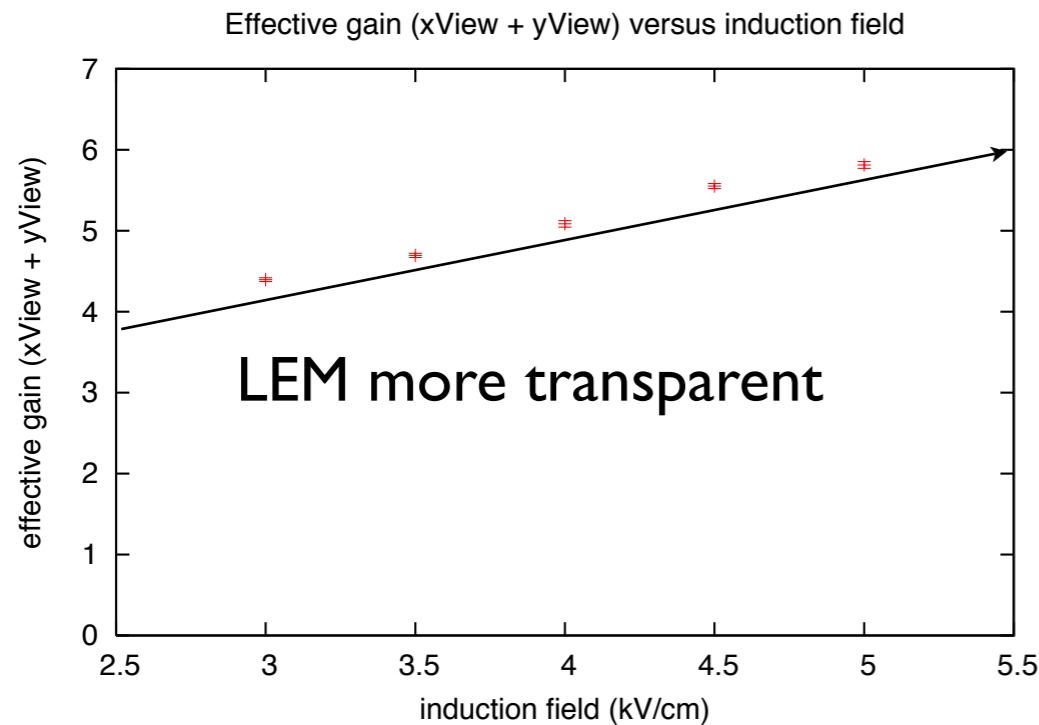
X-Y charge sharing



- The geometry parameter of the two views anode were chosen to share the charge equally between the X and Y views.
- Selecting long muons the total charge collected one each set of strips shows: $(X-Y)/\langle X+Y \rangle \sim 5\%$.

Anode-LEM	3 kV/cm
LEM	35.5 kV/cm
LEM-Grid	1.5 kV/cm
Extraction	3 kV/cm
Drift	0.5 kV/cm

Electric field scans

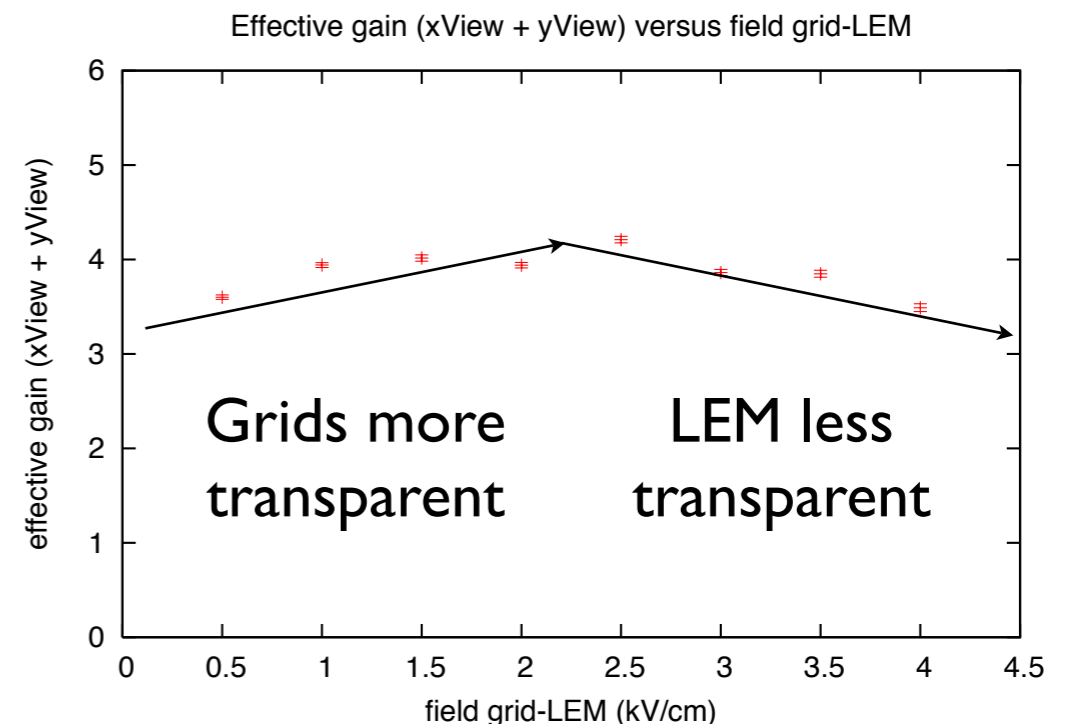


- Scan of the induction field.
- Improve the LEM transparency.

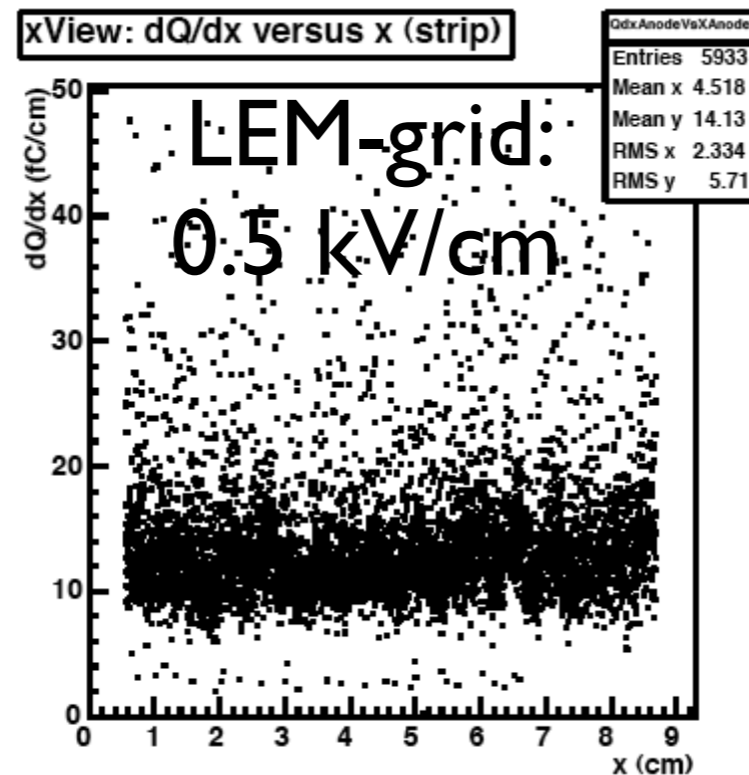
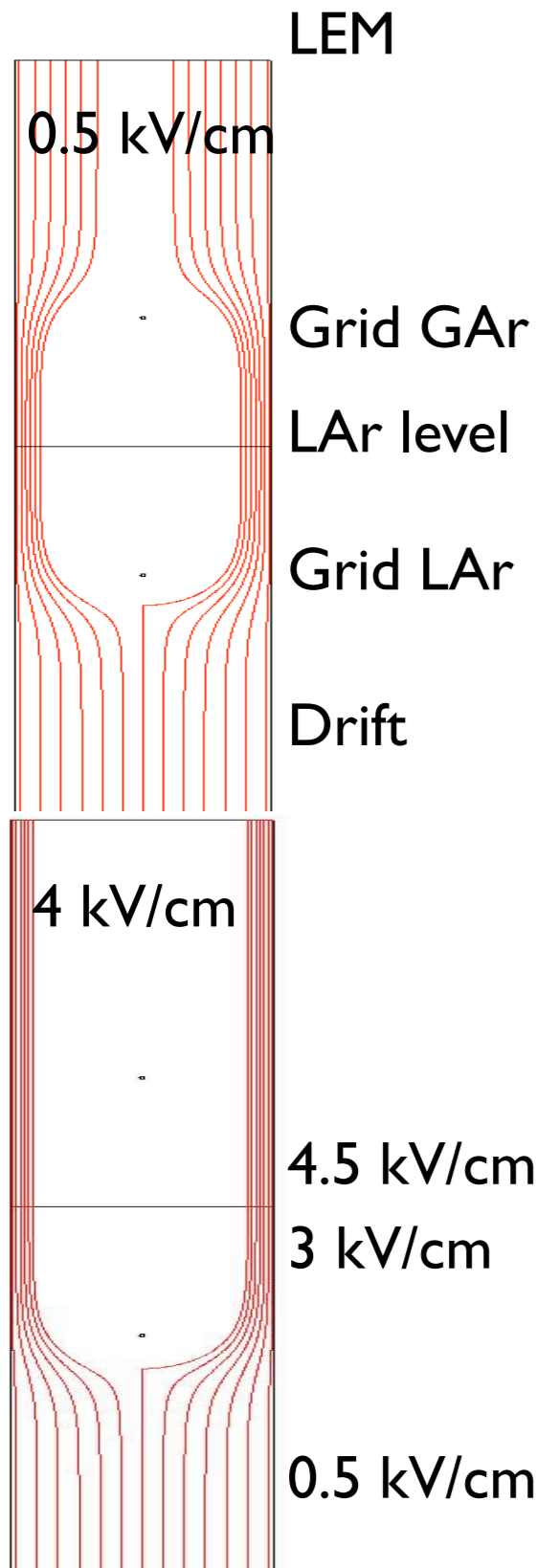
Anode-LEM	x
LEM	30 kV/cm
LEM-Grid	1.5 kV/cm
Extraction	3 kV/cm
Drift	0.5 kV/cm

- Scan of the field above the extraction grids
- There is an optimal field.

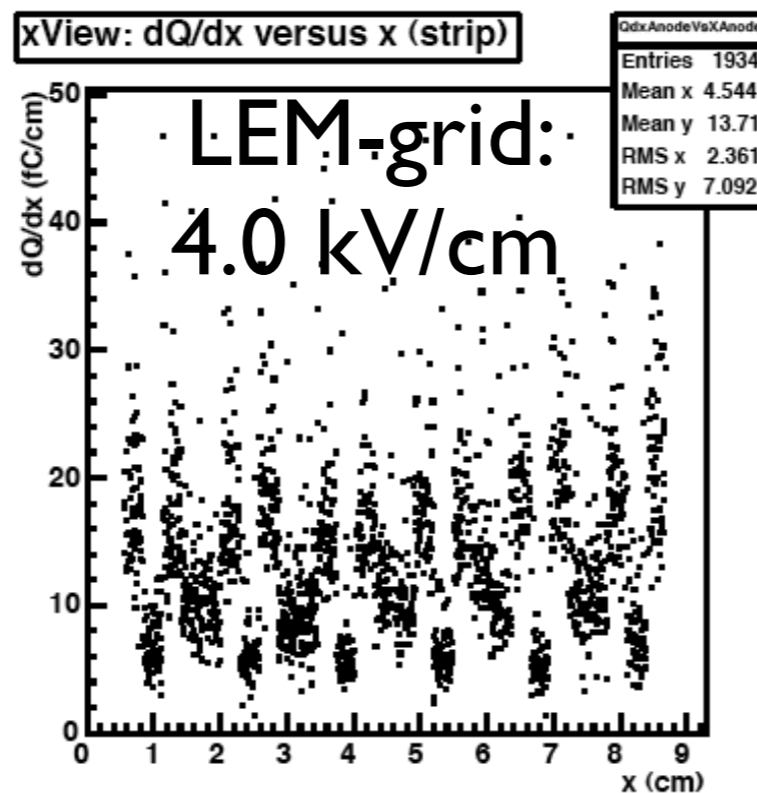
Anode-LEM	3 kV/cm
LEM	30 kV/cm
LEM-Grid	x
Extraction	3 kV/cm
Drift	0.5 kV/cm



Effect of the extraction grids



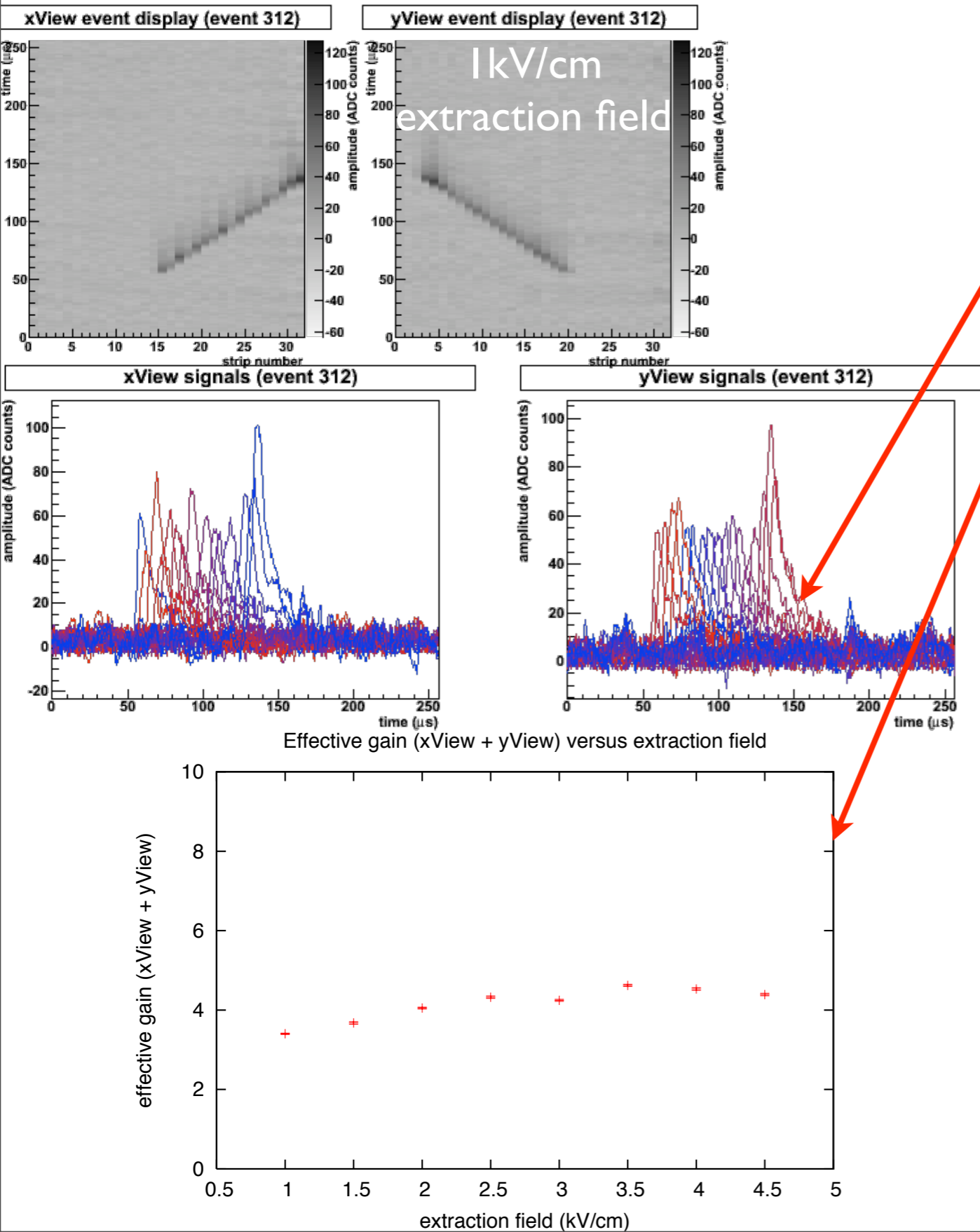
- The grids focus the electrons between the wires in order to increase the electric field for the extraction.
- Amount of charge collected varies with the position (one dimension only).
- The pattern of the grid becomes more evident increasing the field between the grid and the LEM.



Nominal field configuration

Anode-LEM	3 kV/cm
LEM	30 kV/cm
LEM-Grid	x
Extraction	3 kV/cm
Drift	0.5 kV/cm

Extraction field considerations



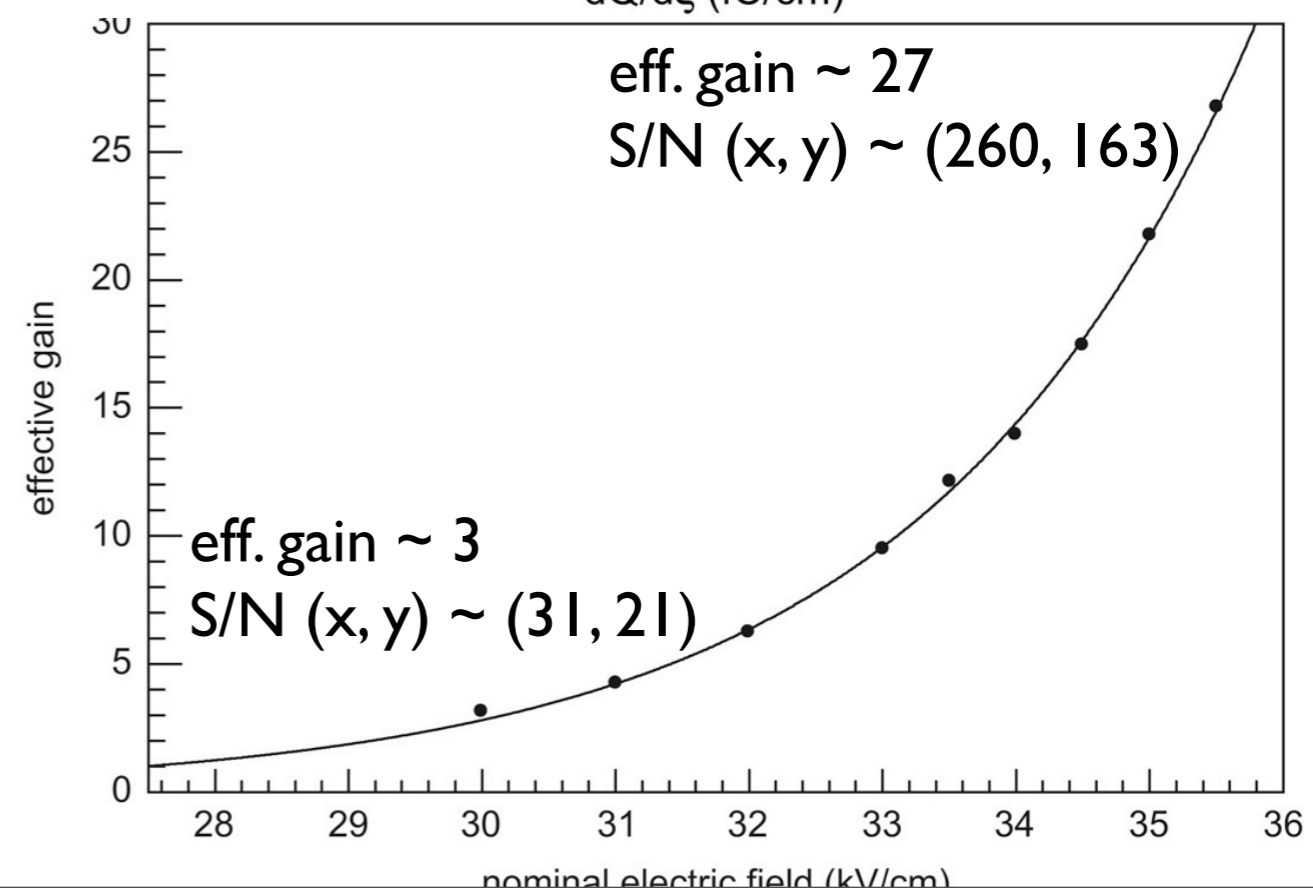
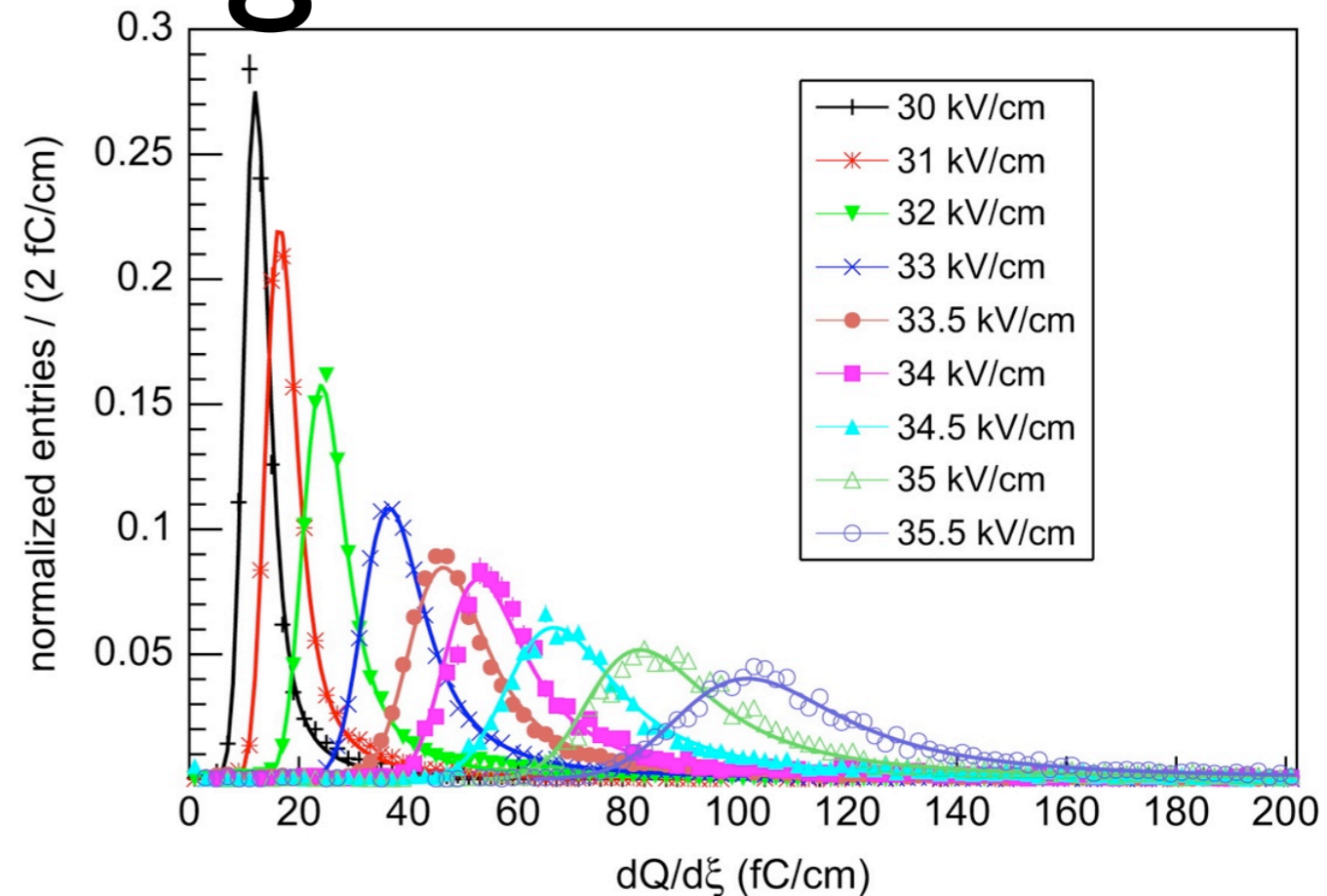
- Signal amplitude decreases at low extraction fields.
- The extraction time increases as the field decreases (order of 20 μ s @ 1 kV/cm).
- But the charge integral does not strongly depend on the field.

Nominal field configuration

Anode-LEM	3 kV/cm
LEM	30 kV/cm
LEM-Grid	1.5 kV/cm
Extraction	x
Drift	0.5 kV/cm

Effective gain

- Cosmic muon tracks are reconstructed 3D.
- dQ : charge collected by each strip.
- dx : 3D length of the muon track below each strip.
- A Gauss-convoluted Landau function is fitted to the dE/dx (dQ/dx) distribution.
- The effective gain is defined as the ratio of the collected charge ($X + Y$ views) and the ionization charge in LAr:
 - The average charge released by a MIP in LAr (electric field: 500 V/cm) ~ 10 fC/cm.



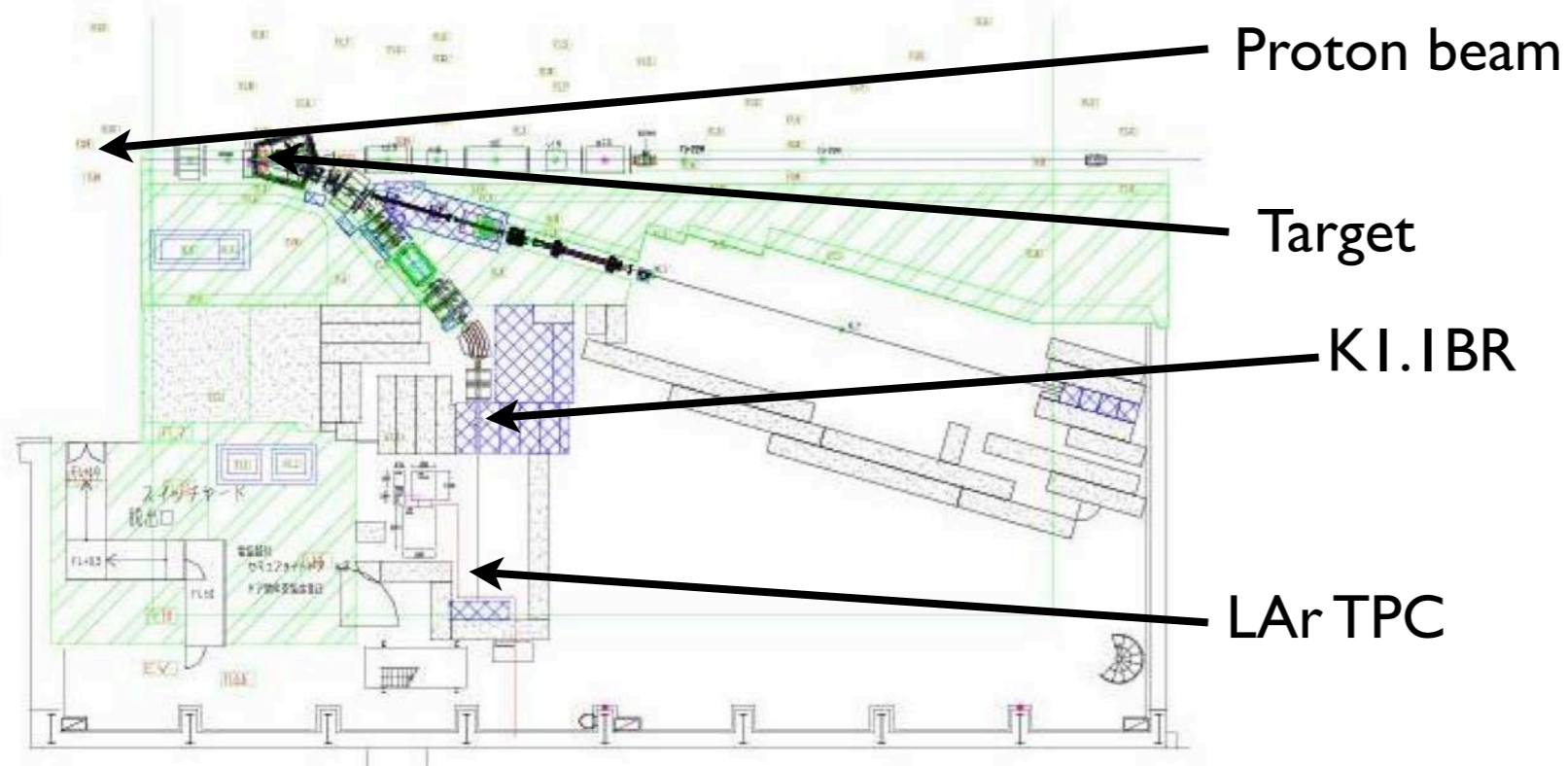
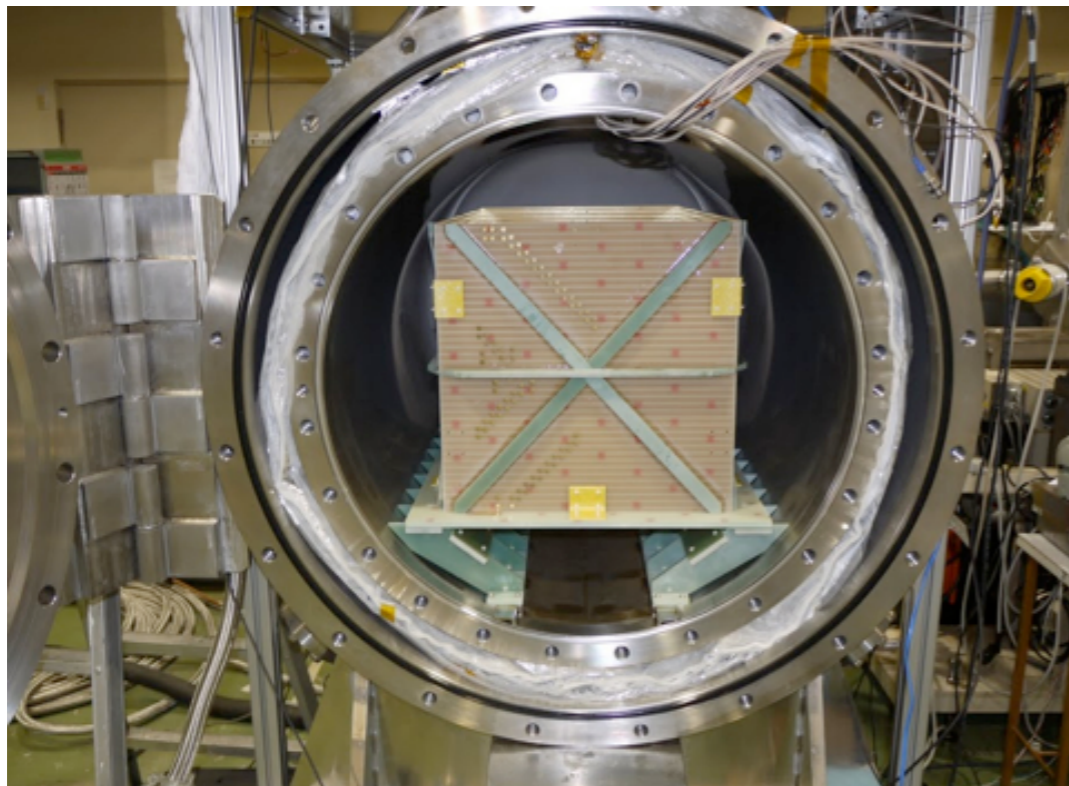
250L detector

T32 experiment @ J-PARC

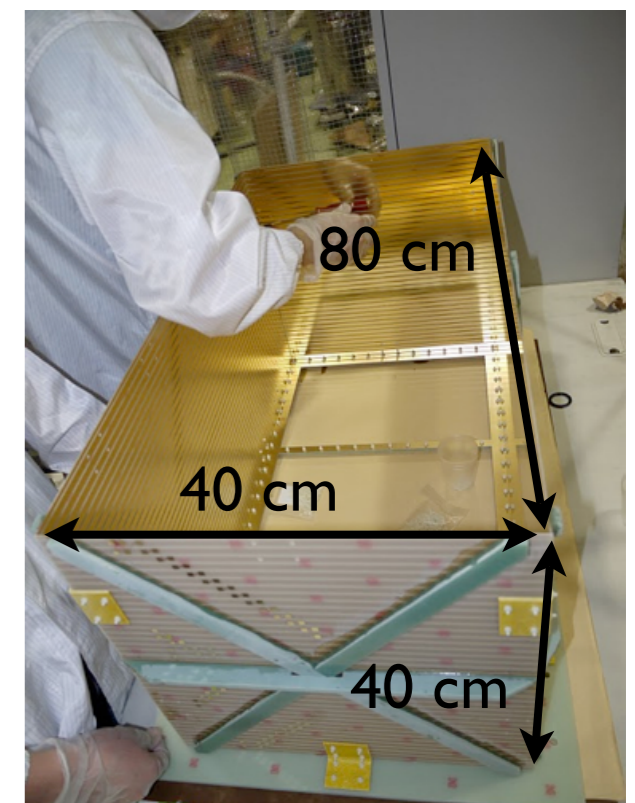
LAr TPC (so called 250L) on a charged particle beam

in collaboration with KEK, Iwate and Waseda

- Exposed to $e/\pi/K/p$ beam at J-PARC hadron facility in October 2010.
- Benchmark the performance of the LAr TPC in particle identification and energy resolution (π/K separation is relevant for proton decay searches).
- Develop simulation software and event reconstruction tools for analysis.

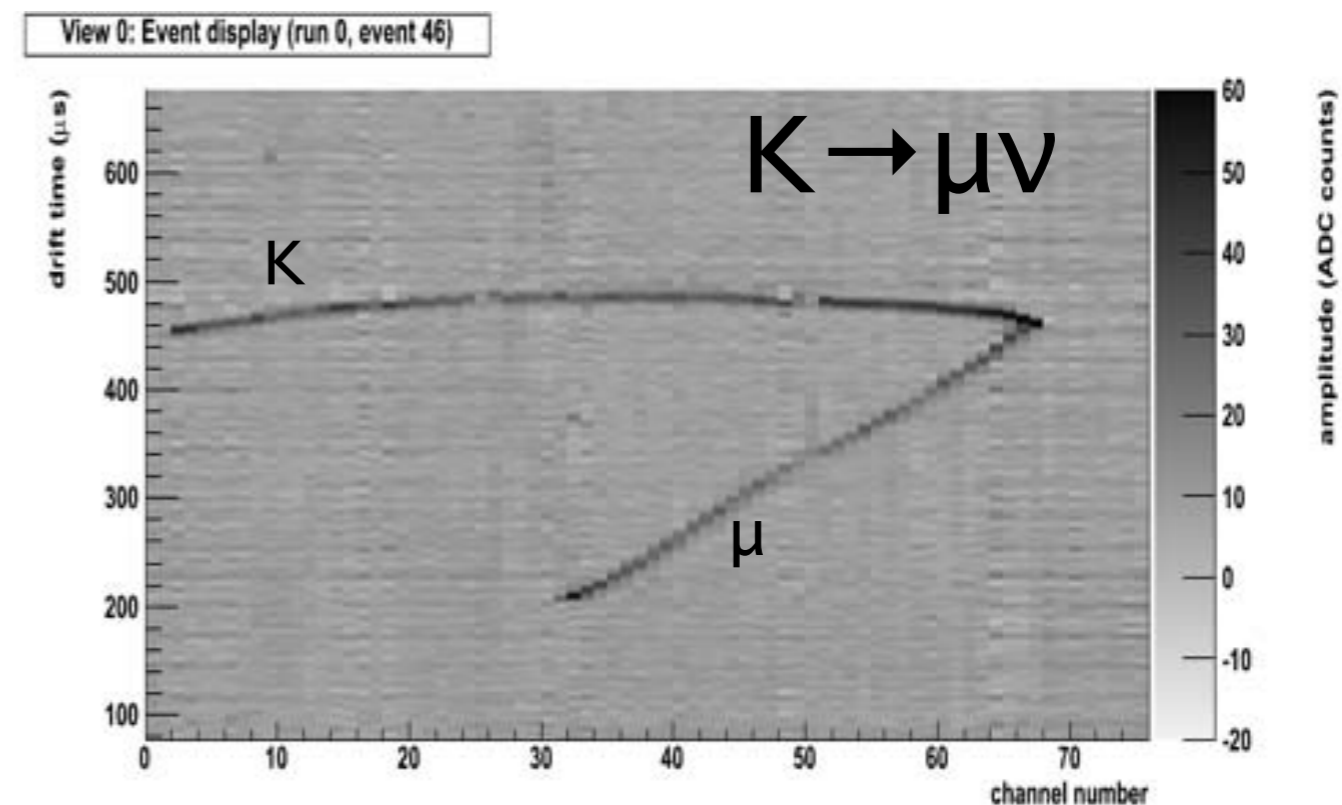
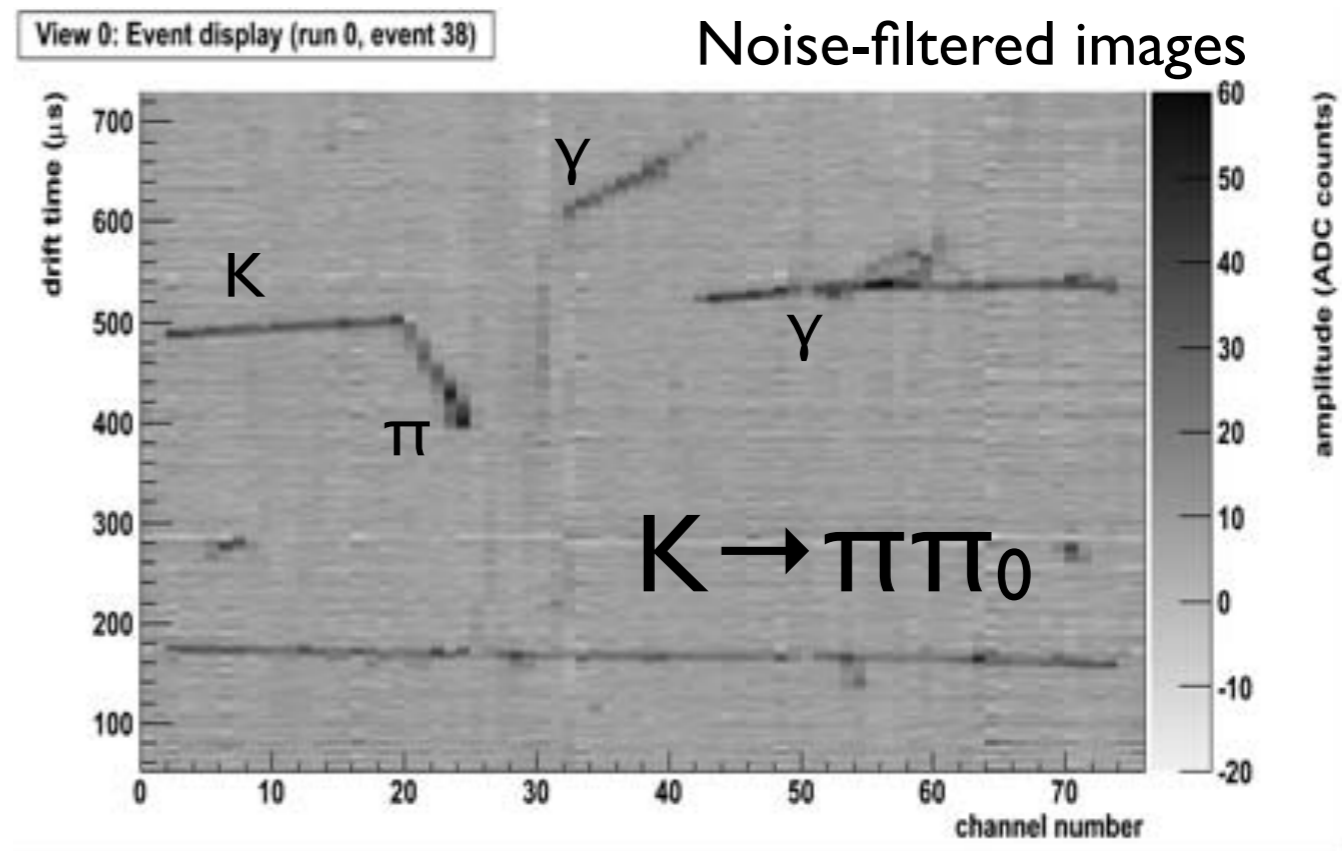


Assembled in KEK



250L LAr TPC operation

- Detector operated in single phase mode (no charge amplification is possible).
- ID anode with 1 cm pitch strips (2D reconstruction of the events).
- Cryogenic vessel originally built for MEG liquid xenon calorimeter.
- Established cryogenic infrastructures on the beam line.
- Stable operation for about one week.
- Good liquid argon purity (drifting electron lifetime $\sim 650 \mu\text{s}$).
- Exposure to low-momentum K/ π beam:
 - ~ 46000 K, 70000 π , 12000 e, 1500 p.
- TREK instrumentation used for triggering.



250L upgrade

- Triggered by the positive results of the charge readout in the 3L detector and as part of the R&D roadmap towards giant liquid argon detector, the upgrade of the 250L detector is in progress.
- Detector in double phase (liquid vapor) mode with charge amplification to improve the signal to noise ratio. A $80 \times 40 \text{ cm}^2$ LEM + 2D-projective anode in vapor phase.
- Corollary devices like the extraction grids (to extract the drifting electrons from the liquid to the vapor phase) and the signal planes (to decouple the signals from the high voltage and route them out of the vessel).
- The whole assembly is the so called readout “sandwich”. It can be thought as a complete charge readout unit.

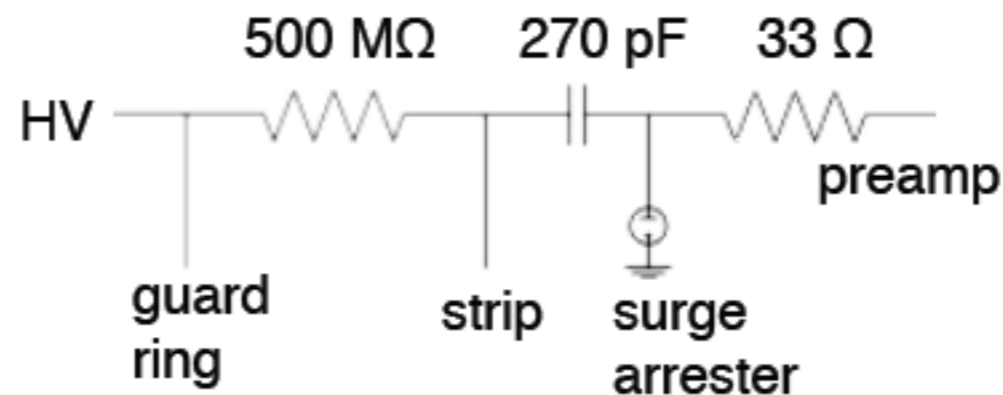
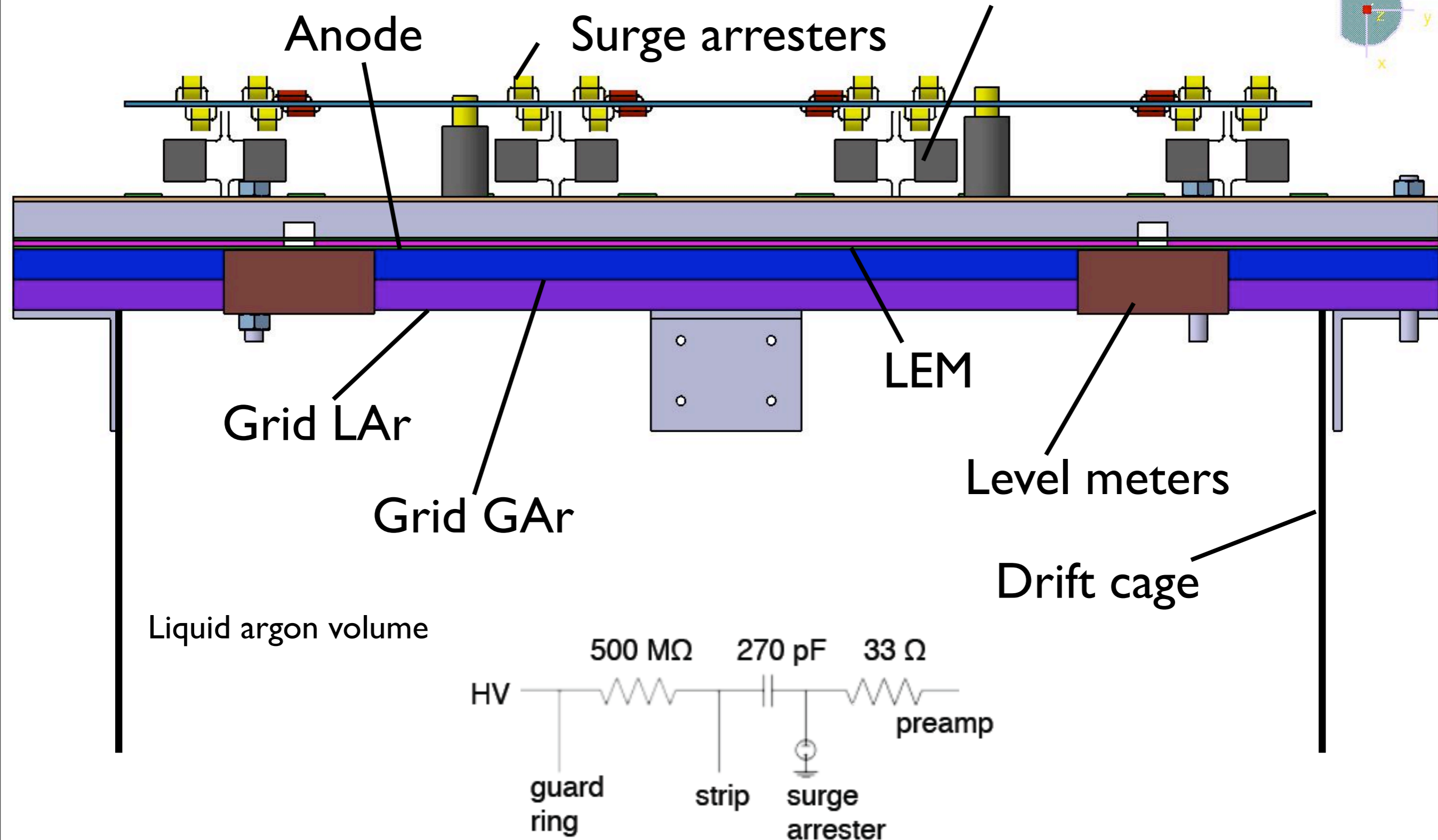
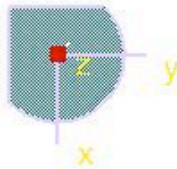
Readout “sandwich” for 250L

Gas argon volume

HV decoupling capacitors

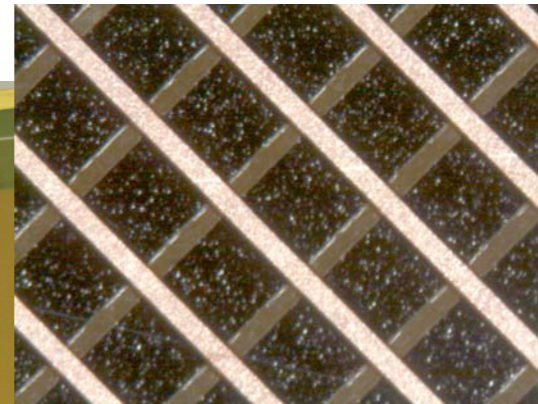
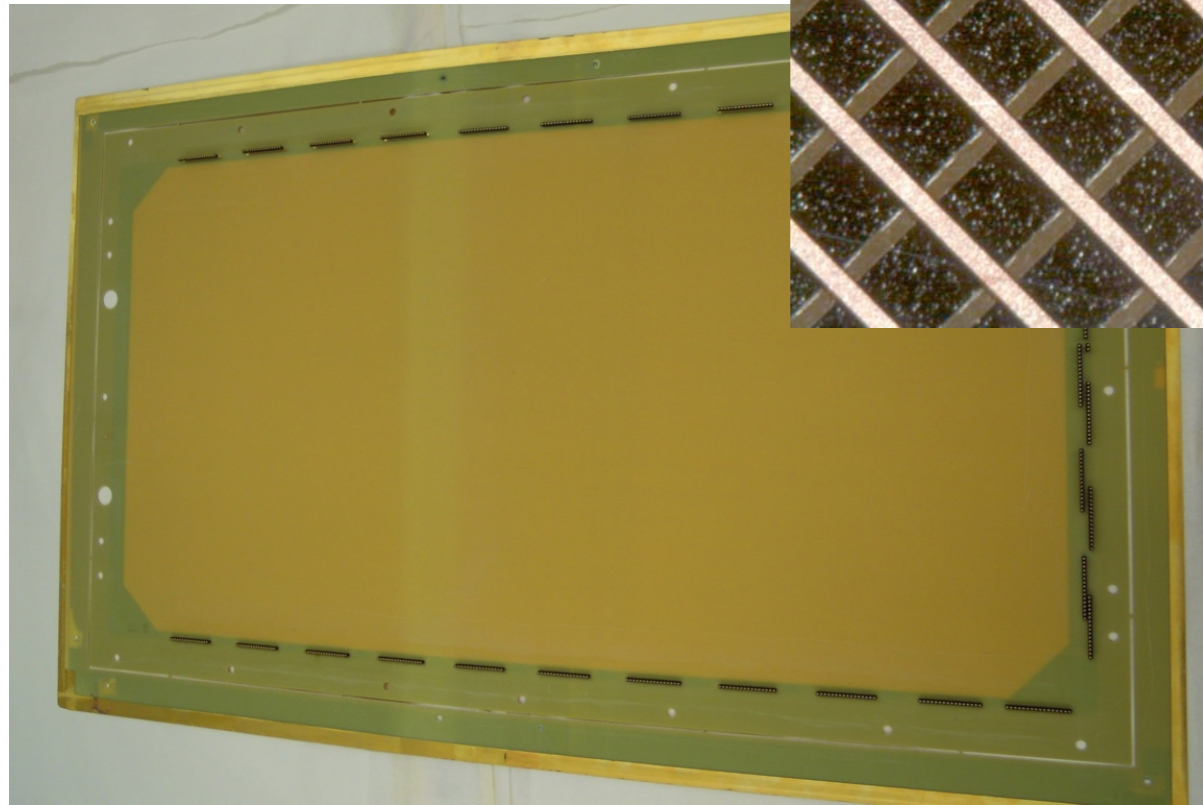
Anode

Surge arresters



2D projective anode and LEM

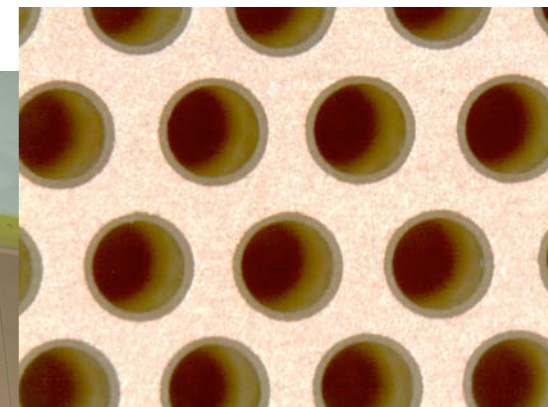
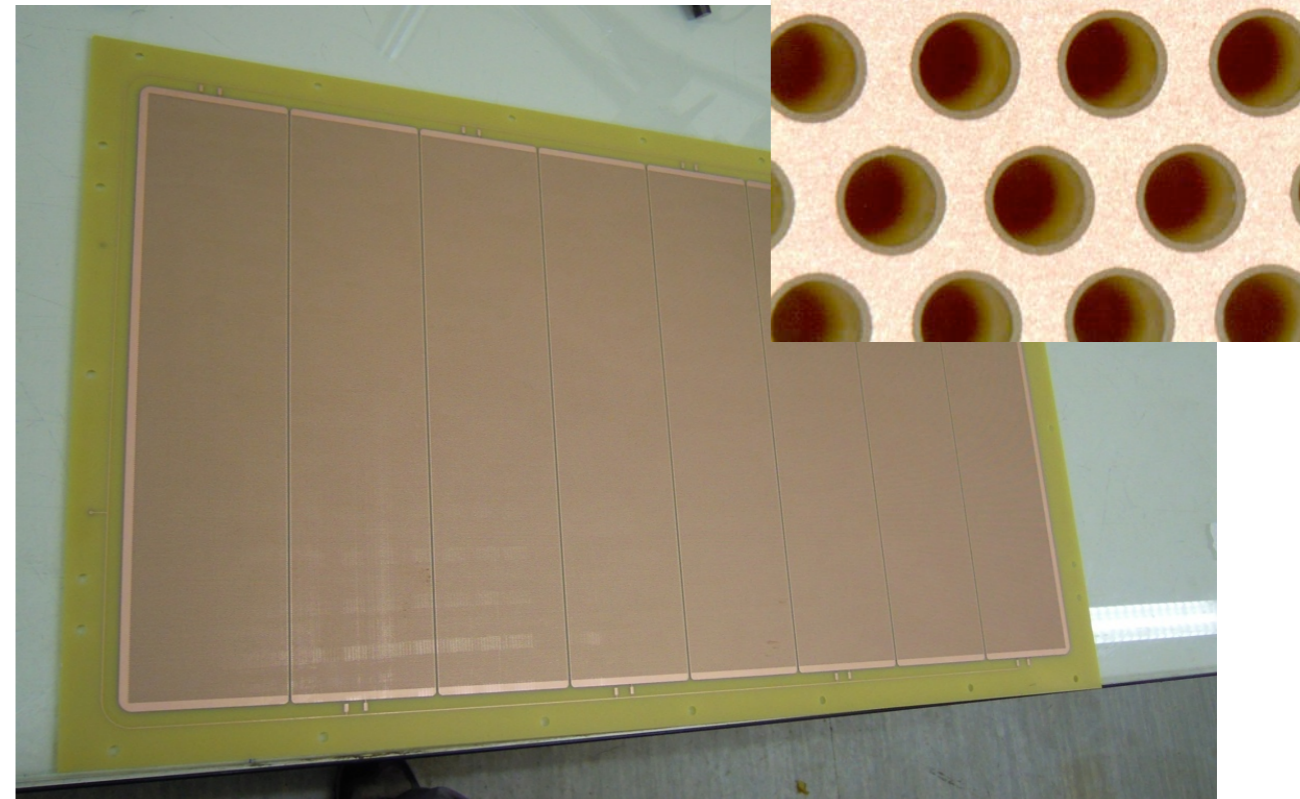
Manufacturer: CERN TS/DEM group



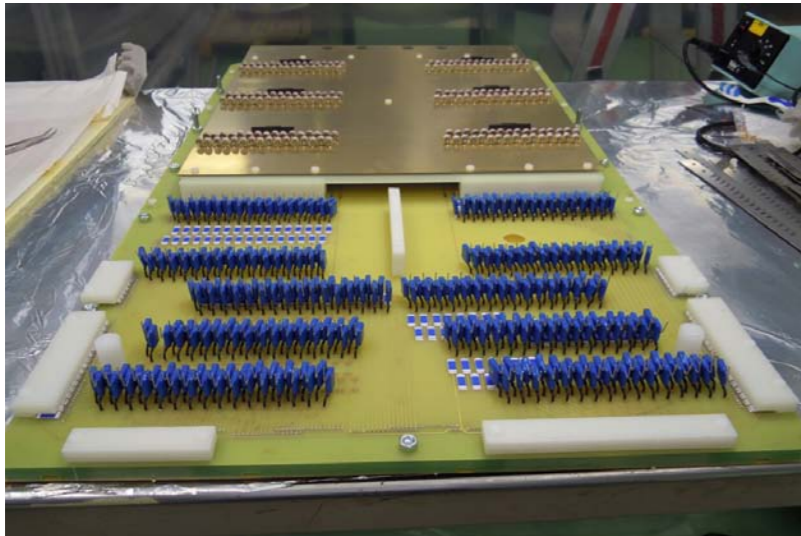
- 40 x 76 cm² active area (biggest ever constructed).
- 256 + 256 channels.
- 3 mm wide strips ($\pm 45^\circ$ with respect to the length).
- 55 cm long strips (longest).

- 40 x 76 cm², $\sim 0.5 \times 10^6$ holes.
- 8 segments to decrease the LEM capacitance.
- PCB: 1 mm thick.
- hole \varnothing 0.5 mm, 0.8 mm pitch.

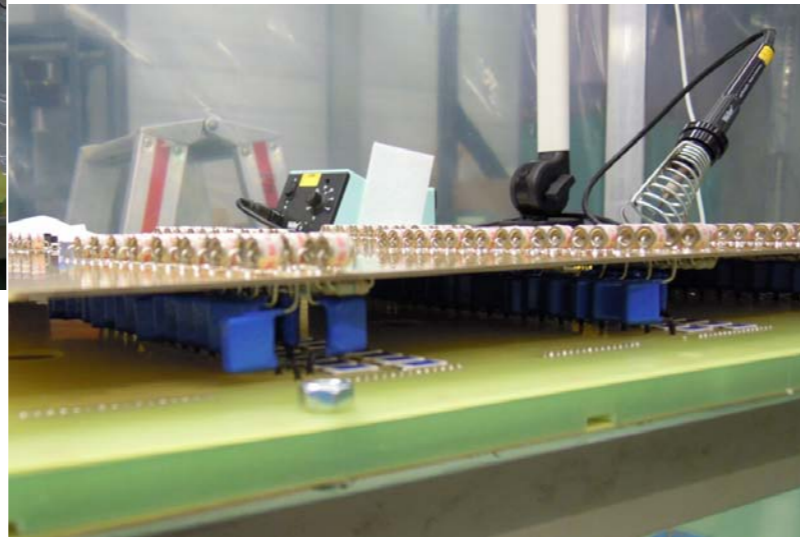
Manufacturer: ELTOS



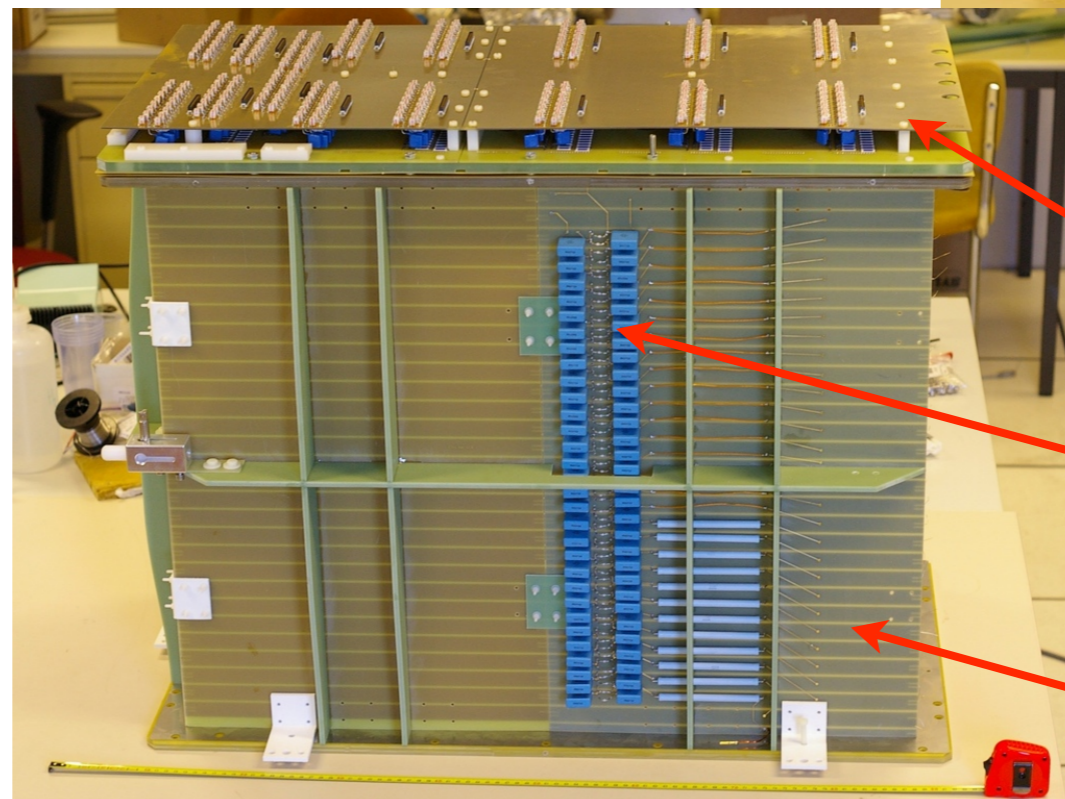
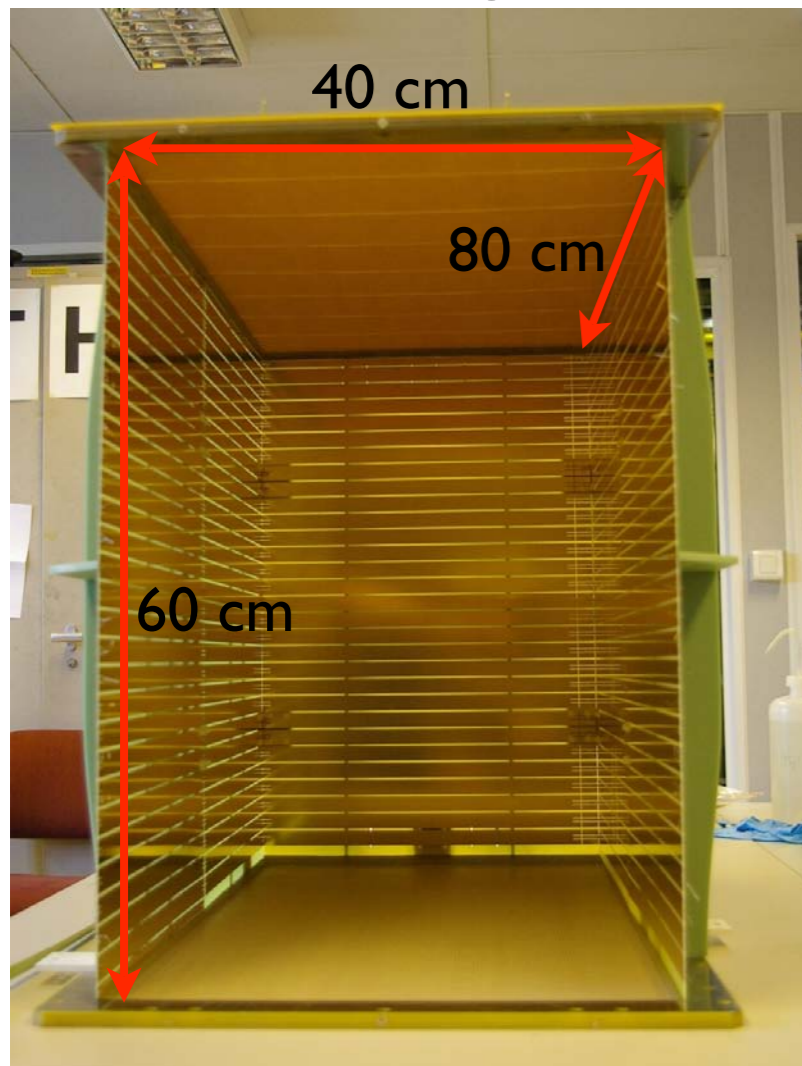
Detector assembly (@ CERN)



Readout sandwich



Drift cage



Readout sandwich

Voltage multiplier
(Greinacher)

Drift cage

The 250L in ArDM vessel

ArDM vessel

- Argon Dark Matter:

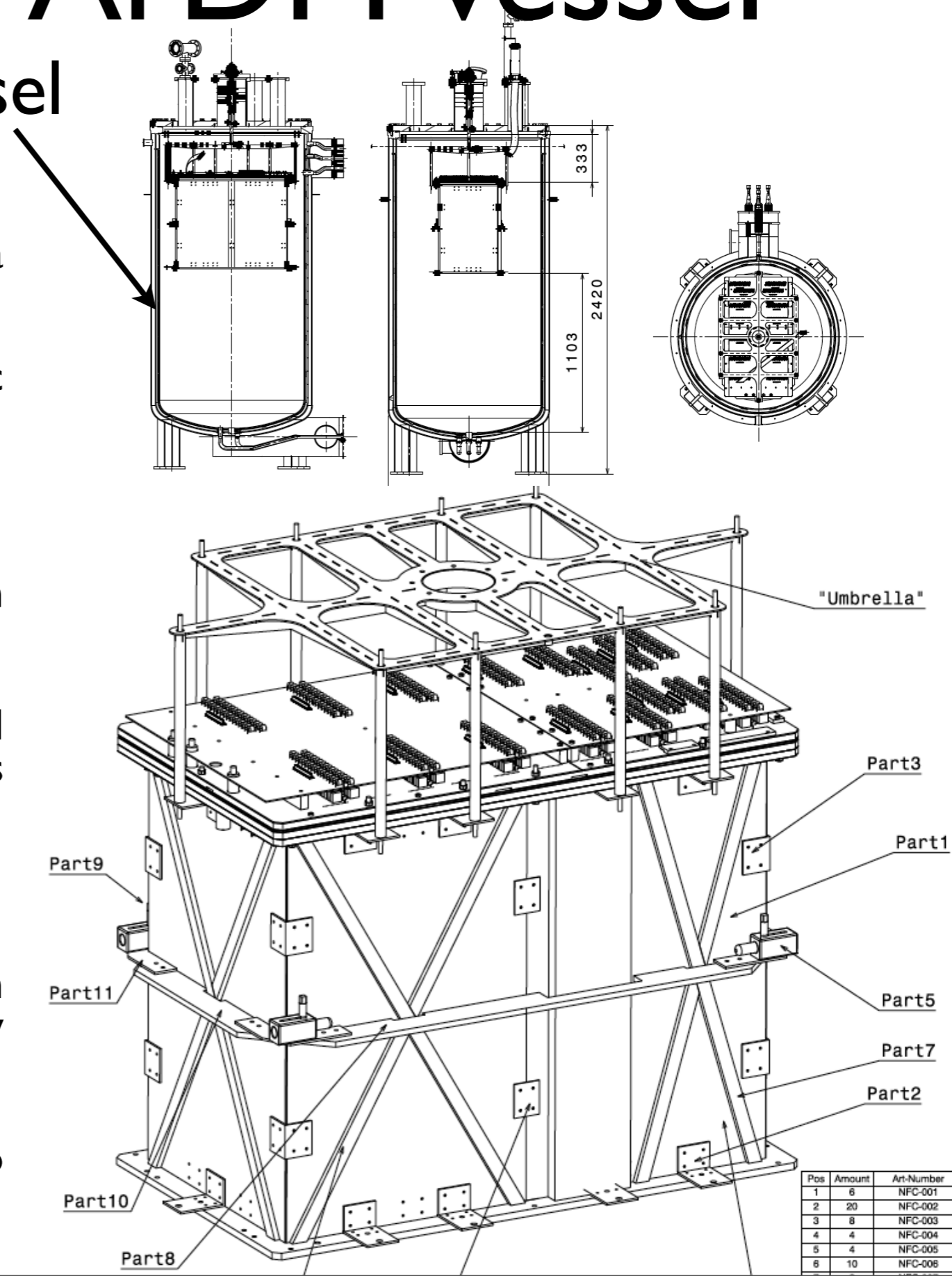
- Direct DM search experiment with a liquid argon imaging detector.
- It will be soon moved in the Canfranc Underground Laboratory.

- The aims of the test are:

- Benchmark the charge readout sandwich (gain, stability, uniformity).
- Measure the argon purity (\sim ppb $[\text{O}_2]$ eq level) in ArDM vessel and the effectiveness of the gas argon purification system.

- Features of the detector:

- Voltage multiplier circuit (Greinacher) in LAr in order to avoid a very HV feedthrough (~ 60 kV).
- 2 cryogenic PMTs below the cathode to trigger the acquisition.



Outlook

- The LAr LEM-TPC is a novel kind of calorimetric and tracking detector capable of charge multiplication.
- For the first time we operated a detector based on the LEM amplification stage decoupled from the 2D projective anode.
- This configuration allows to reach a gain of the order of 30 in realistic double phase operations.
- Gain considerably improve the S/N and the quality of the images. It compensates for the charge loss due to impurities and smearing due to diffusion.
- We are assembling a 80x40 cm² charge readout system to be tested in ArDM vessel during this Summer.
The “sandwich” is a complete charge readout unit.

Backup

ArDM

A. Rubbia, J. Phys. Conf. Ser. 39 (2006) 129

A 1 ton LAr detector for the detection of nuclear recoils induced by WIMPs. To be moved to the Canfranc Underground Laboratory.

The detector is presently assembled on surface at CERN to fully test all functionalities:

- Light readout (PMTs, WLS reflectors).
- HV system (Greinacher circuit).
- Slow control and safety (PLC).
- Cryogenics system with cryocooler.
- LAr purification (liquid and gas recirculation systems).

