The double phase argon LEM-TPC

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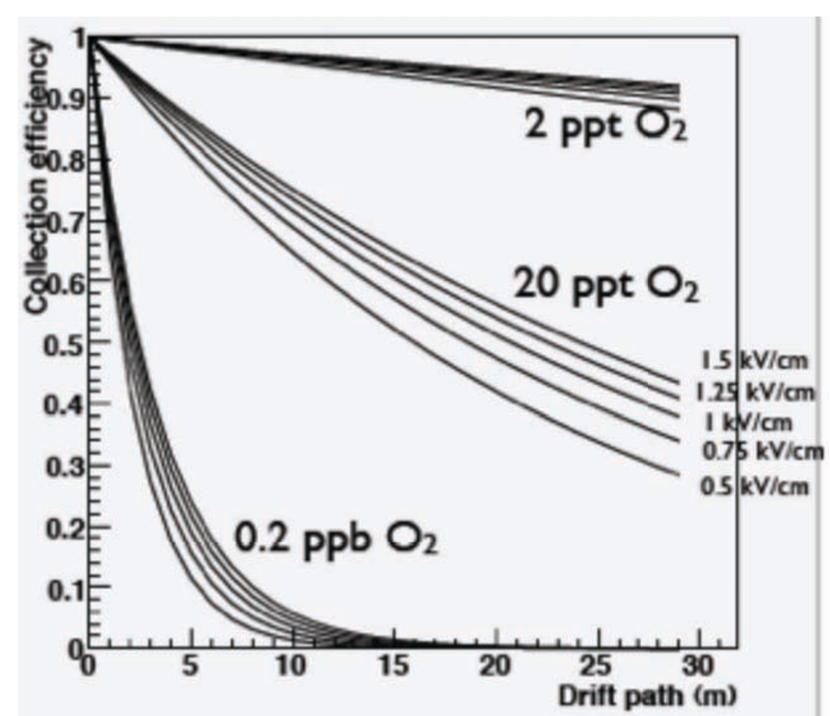
Liquid argon (LAr)

Basic properties of liquid argon

density	1.4 g/cm^3
boiling point @1 atm	87.3 K
triple point	0.689 bar / 83.8 K
<dE/dx> (MIP)	2.1 MeV/cm
radiation length	14.0 cm
Molière radius	9.25 cm
nuclear interaction length	83.6 cm
W_{ion} (1 MeV e-)	23.6 eV
W_{photon} (1 MeV e-)	19.5 eV

- High scintillation yield at 128 nm
  - ➡ light can be used as trigger
- No electron attachment
  - ➡ charge transport in LAr possible
  - ➡ Ultra high purity required!
- Drift velocity = 2 mm/µs with E=1 kV/cm
- small diffusion (σ≈mm after several m of drift)
- moreover: argon is available and cheap

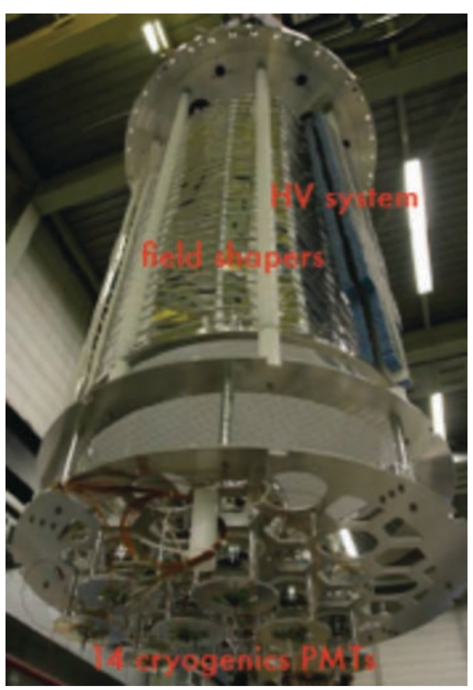
➡ **Feasibility of large liquid argon Time Projection Chambers (LAr-TPC)**



Physics applications

	Argon Dark Matter search (ArDM)	Giant LAr TPC (GLACIER)
physics program	Direct detection of WIMPs (coherent elastic scattering)	neutrino physics (CP violation) and proton decay
fiducial mass	1 ton	100 kilotons
challenge	low threshold for detection of nuclear recoils: 30 keVr	• 20 m drift (losses due to diffusion and impurities) • large area
required gain	≈1000	≈10

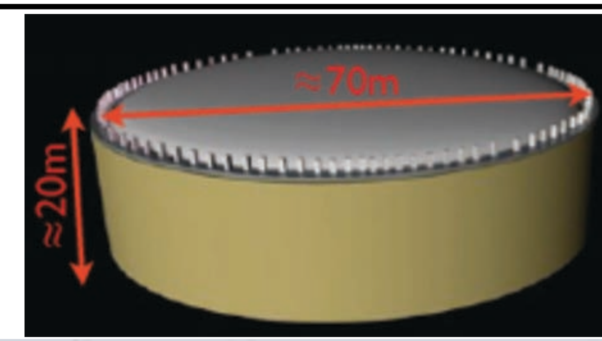
ArDM:

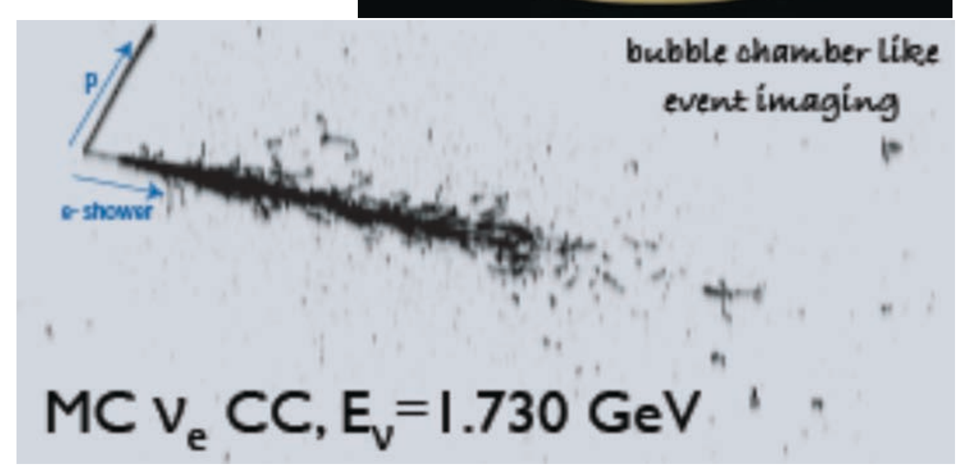


ArDM light readout:
(14 PMTs)

A. Rubbia, J.Phys. Conf. Ser. 39 (2004) 129

GLACIER:





A. Rubbia, arXiv:hep-ph/0402110, 2003

The double phase Ar LEM-TPC

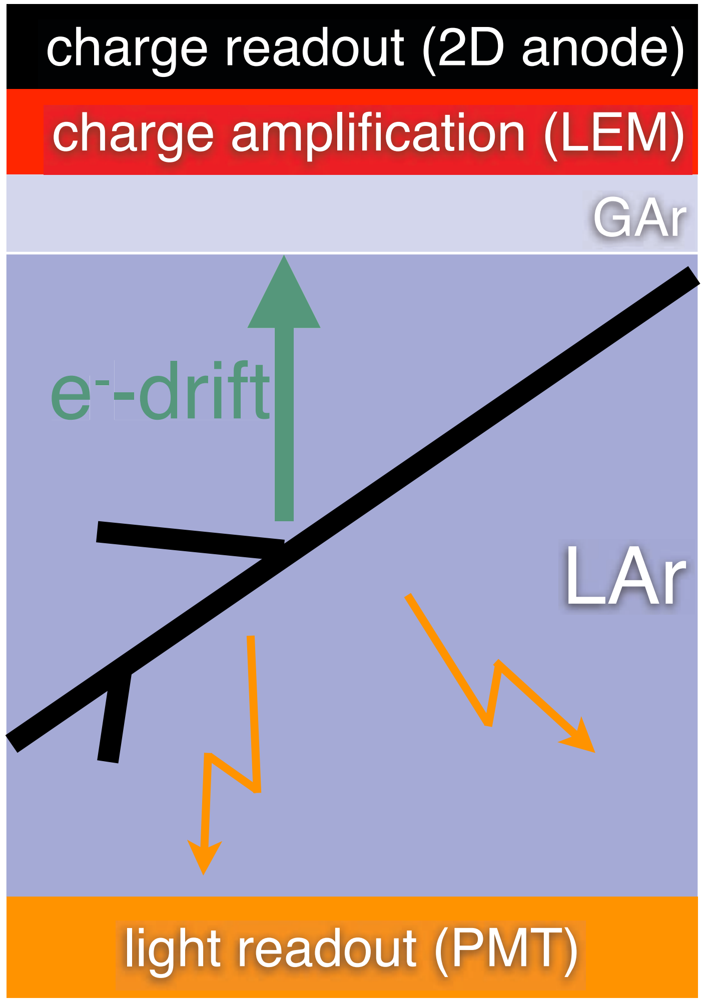
A double phase pure argon LEM-TPC is a complete tracking and calorimetric device, capable of charge multiplication.

recent publications

- A. Badertscher et al., arXiv:0811.3384, 2008
- A. Badertscher et al., Nucl. Instrum. Meth. A617:188-192, 2010

working principle

1. Charge produced by an ionizing event.
2. Primary scintillation light (VUV) detected with TPB coated PMT (t_0 of the event)
3. Electric field of about 500 V/cm drifts ionization electrons up to the liquid-vapor interface.
4. Extraction into the vapor phase (>2500 V/cm needed for fast and efficient extraction)
5. Electron avalanche in GAr due to high electric fields produced in the holes of a LEM (Large Electron Multiplier)
6. Charge induces signals on the projective 2D anode.



The Large Electron Multiplier

LEM/THGEM characteristics:

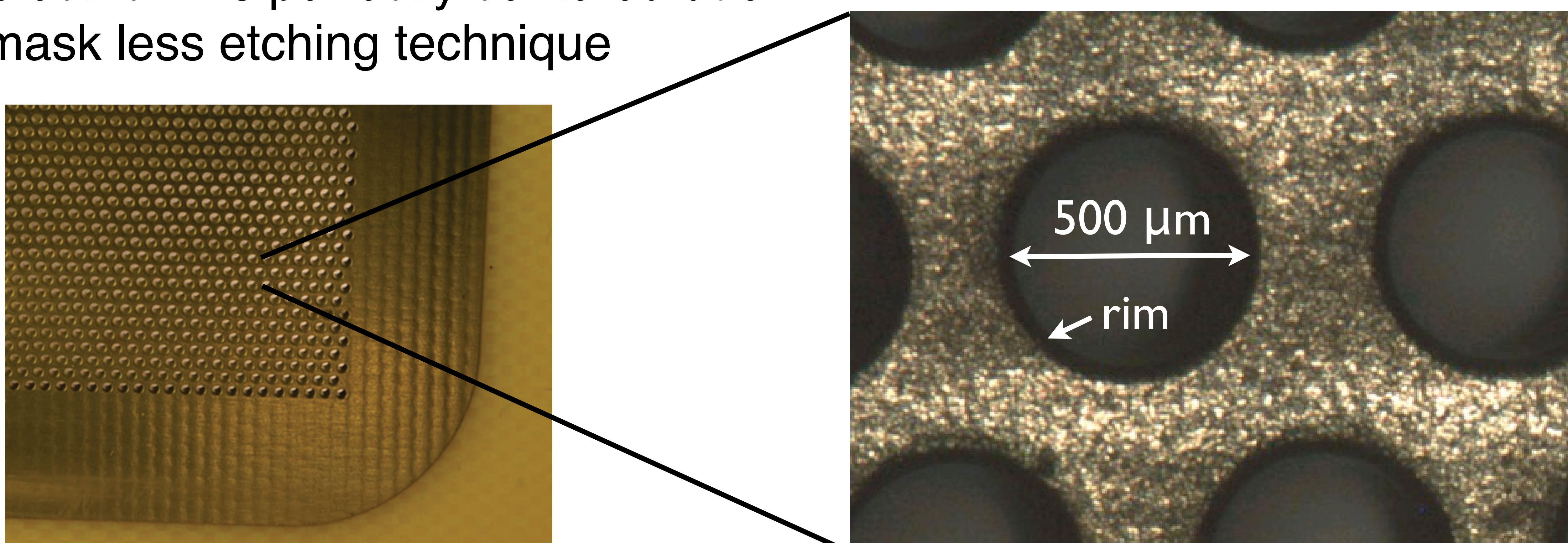
- mechanically robust (possibility to cover large areas)
- can withstand cryogenic temperatures
- high discharge resistivity

Production (CERN PCB workshop):

- copper electrodes gold plated
- dielectric rims perfectly centered due to mask less etching technique

design parameters

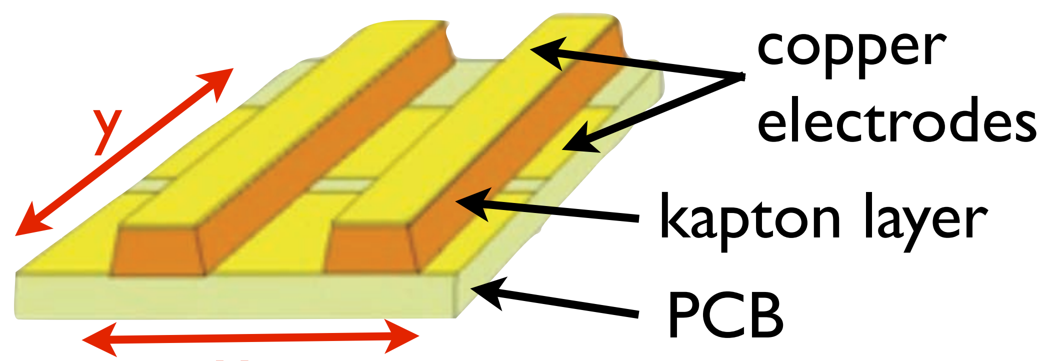
total area	10x10 cm^2
PCB thickness	1.0 mm
hole diameter	500 µm
hole pitch	800 µm
dielectric rim	30-40 µm



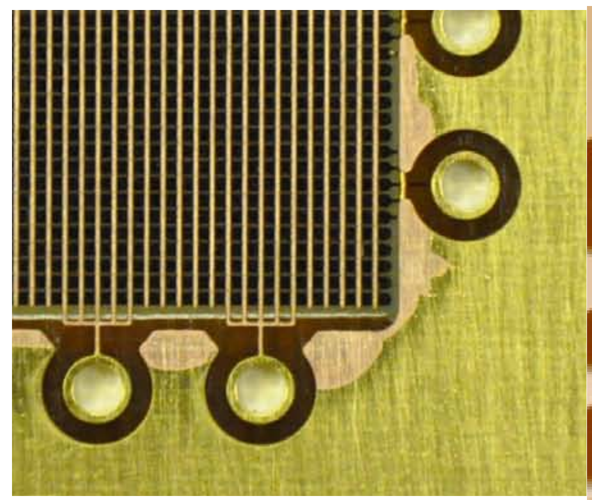
The two-dimensional projective anode

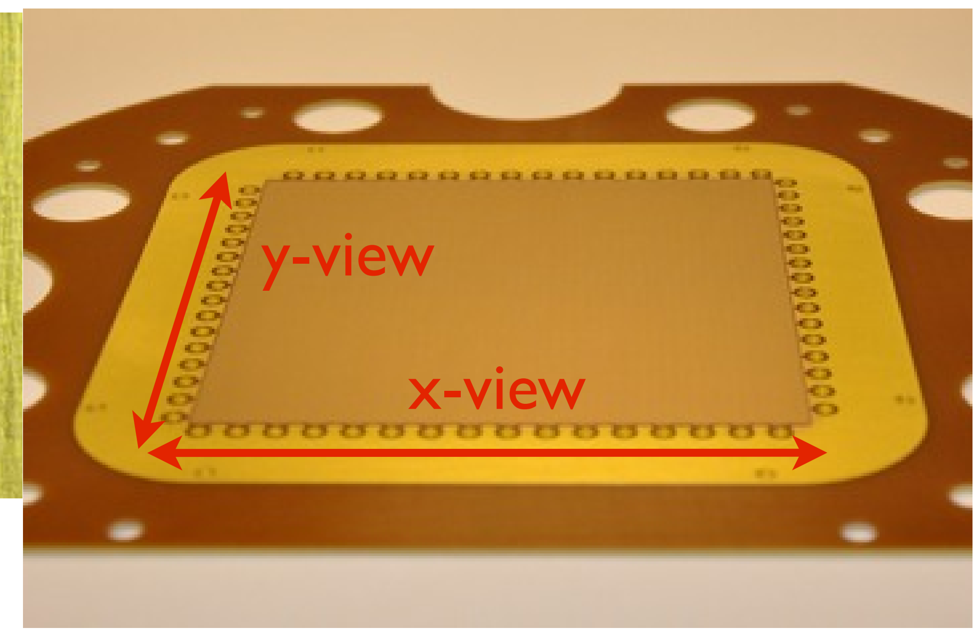
The amplified charge is collected on 2 sets of orthogonal strips:

- Position reconstruction (3 mm pitch)
- x- and y-view signals symmetric

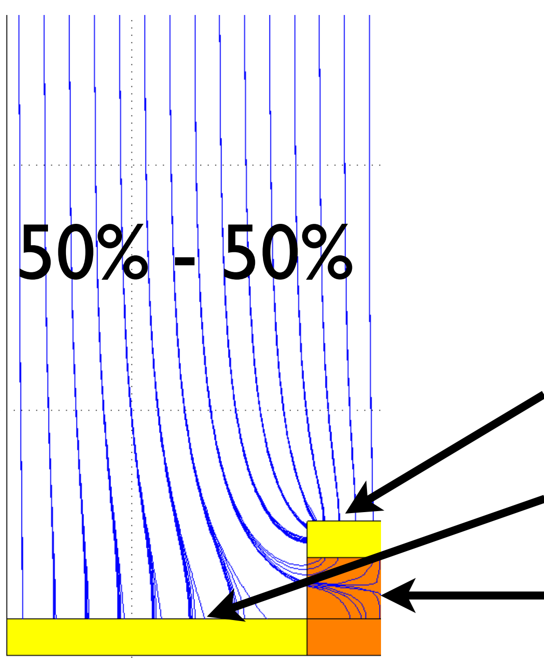


(by COMPASS experiment)



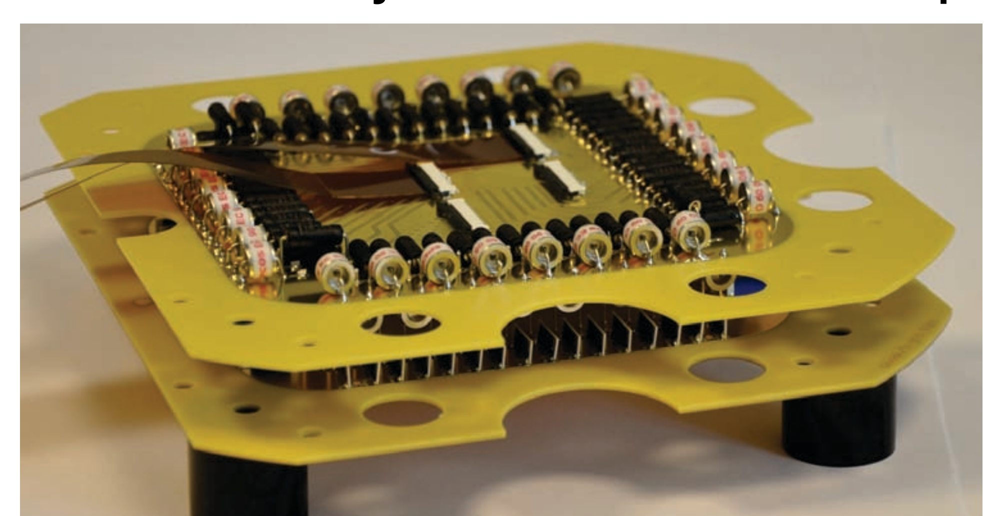


charge sharing & design parameters:



total area	10x10 cm^2
readout pitch	3 mm
strip pitch	600 µm
upper strip width	120 µm
lower strip width	500 µm
kapton thickness	50 µm

Produced by the PCB workshop

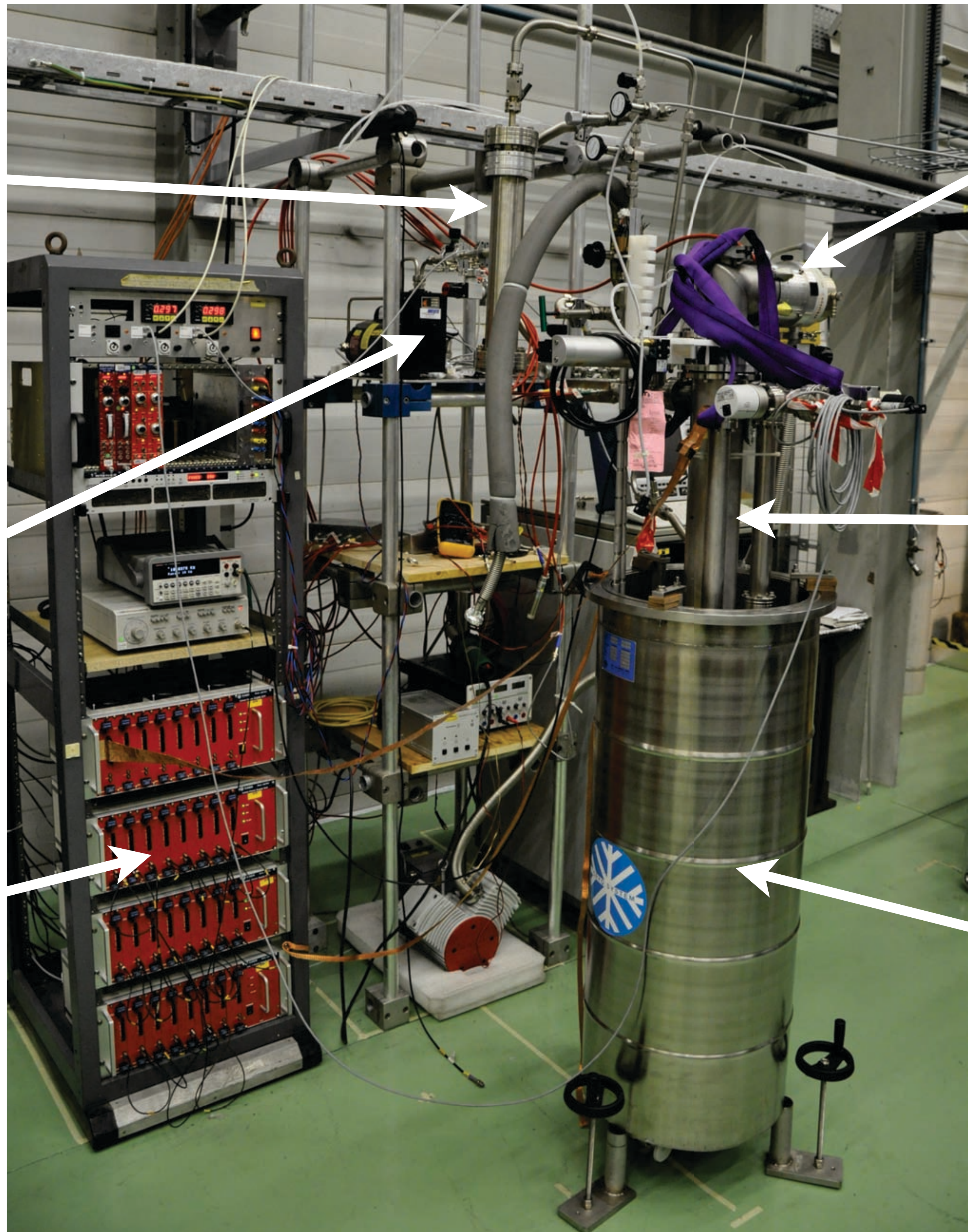


Test setup located at CERN

LAr purification cartridge

GAr purification system

DAQ system



TM pump

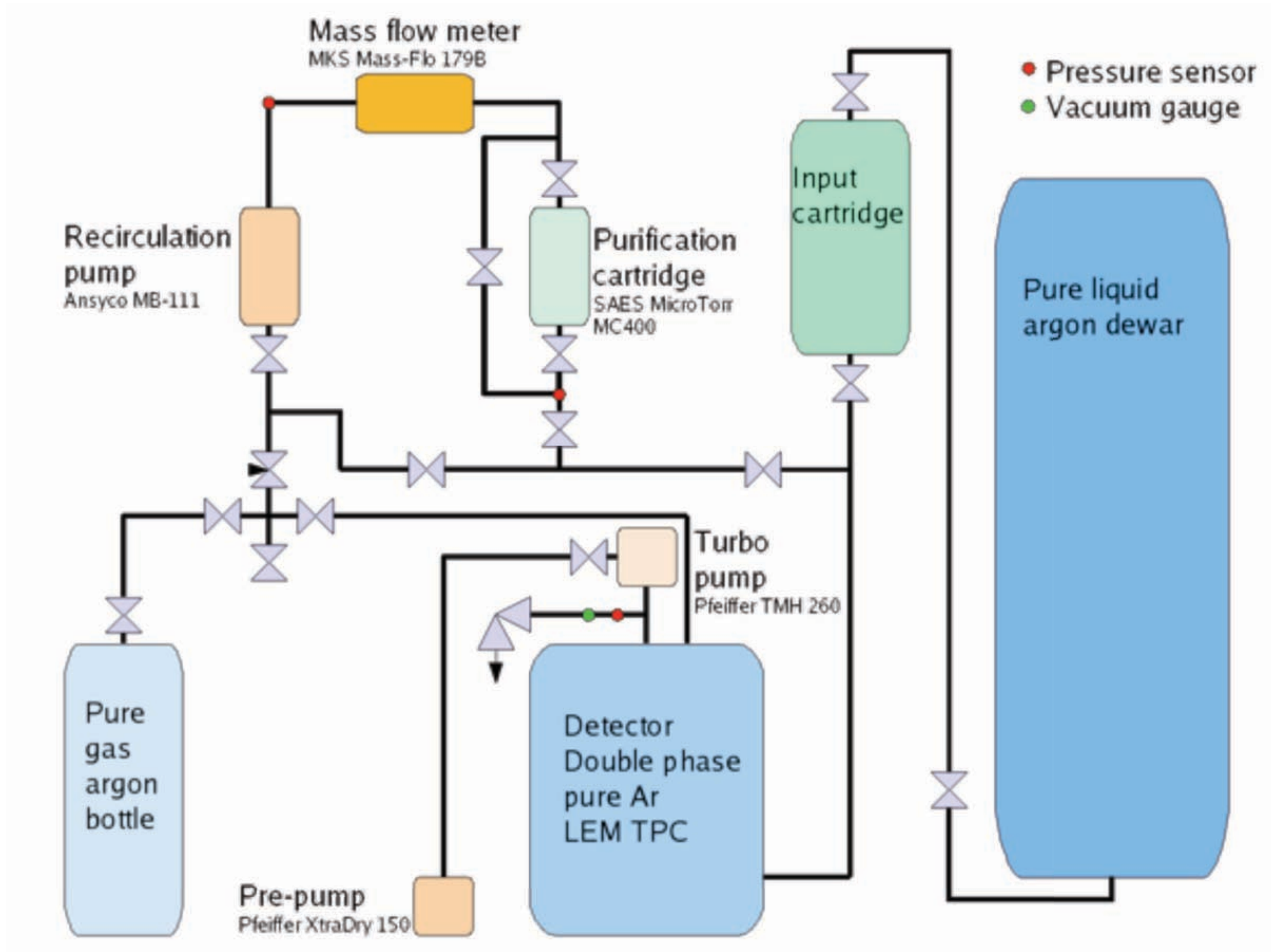
detector vessel

open LAr bath

Argon purification

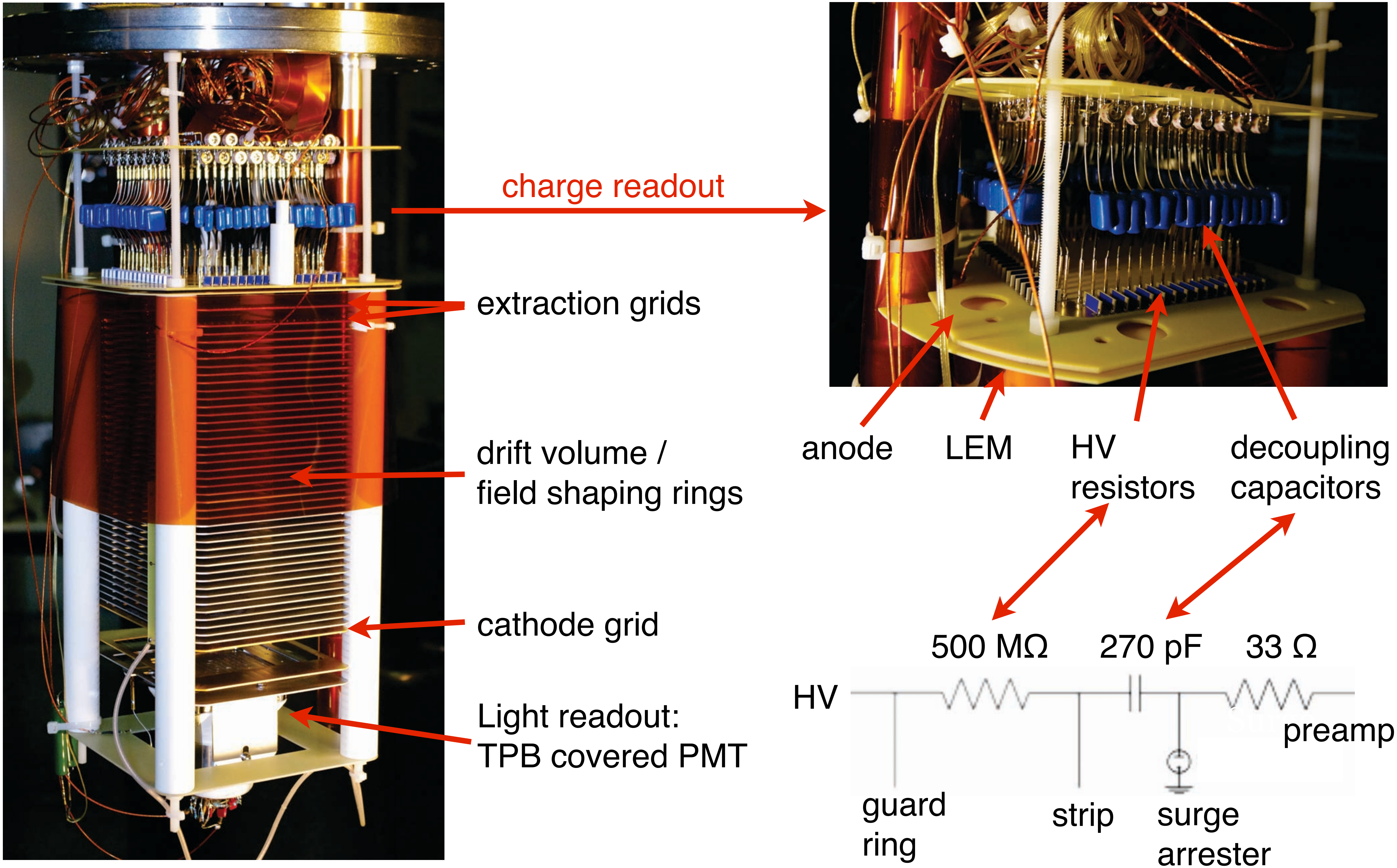
1. **Cool down phase:**
   - detector filled with GAr
   - Metal bellows pump pushes GAr through a SAES getter

   ➡ impurities due to cold leaks and outgassing are removed.
2. **Filling:**
   - Oxygen in LAr is removed by a custom made copper cartridge at the input of the detector.
3. **Gas recirculation:**
   - Heating resistors evaporate LAr.
   - A metal bellows pump pushes GAr through a commercial getter (speed ≈ 1 volume / 48 h).
   - The pure GAr condensates in the detector volume.



best purity achieved: $[O_2]_{eq} < 0.6$ ppb

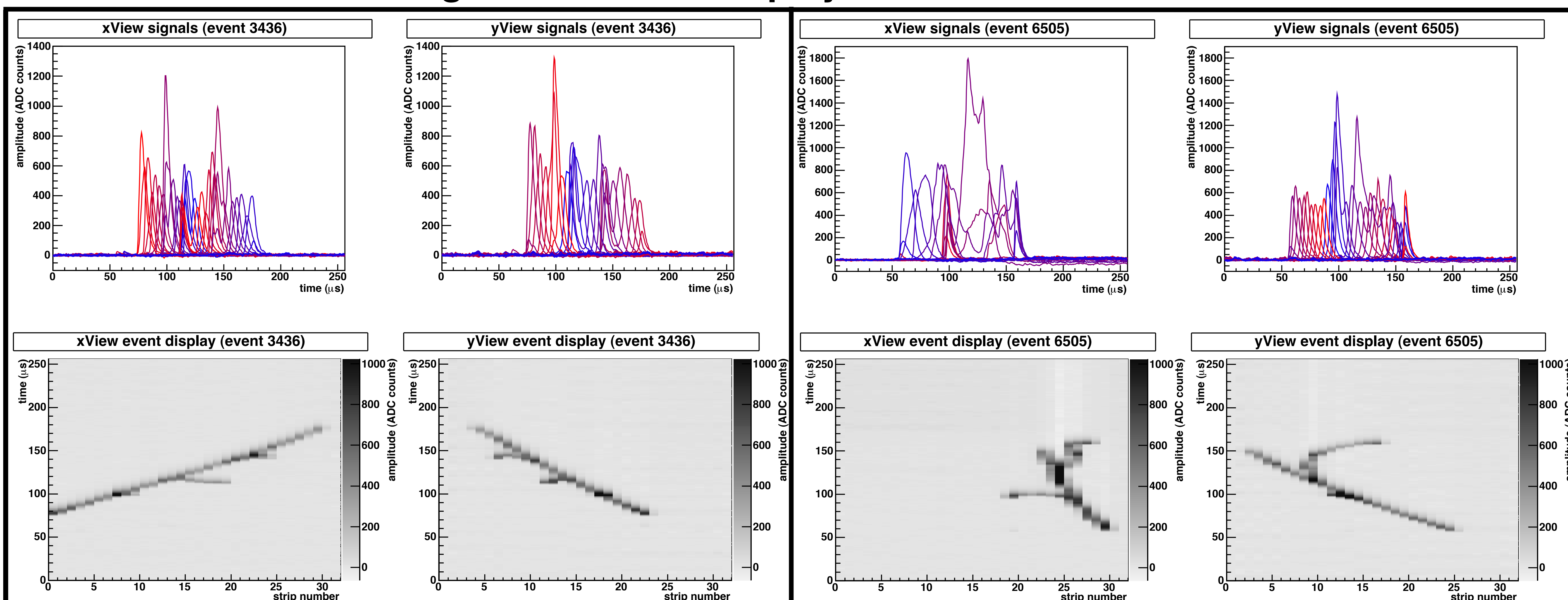
The LEM-TPC


charge readout
extraction grids
drift volume /
field shaping rings
cathode grid
Light readout:
TPB covered PMT
anode
LEM
HV
resistors
decoupling
capacitors
500 MΩ
270 pF
33 Ω
HV
preamp
guard
ring
strip
surge
arrester

2D anode test in double phase operation

- Run Description: First test of a single 1 mm thick LEM with a the 2D projective anode.
- filling: liquefaction of purified GAr (SAES getter, <0.1 ppb)
- operation: pure LAr kept at 87 K with external open LAr bath

Cosmic muon events: signal and event display:



Free electron lifetime

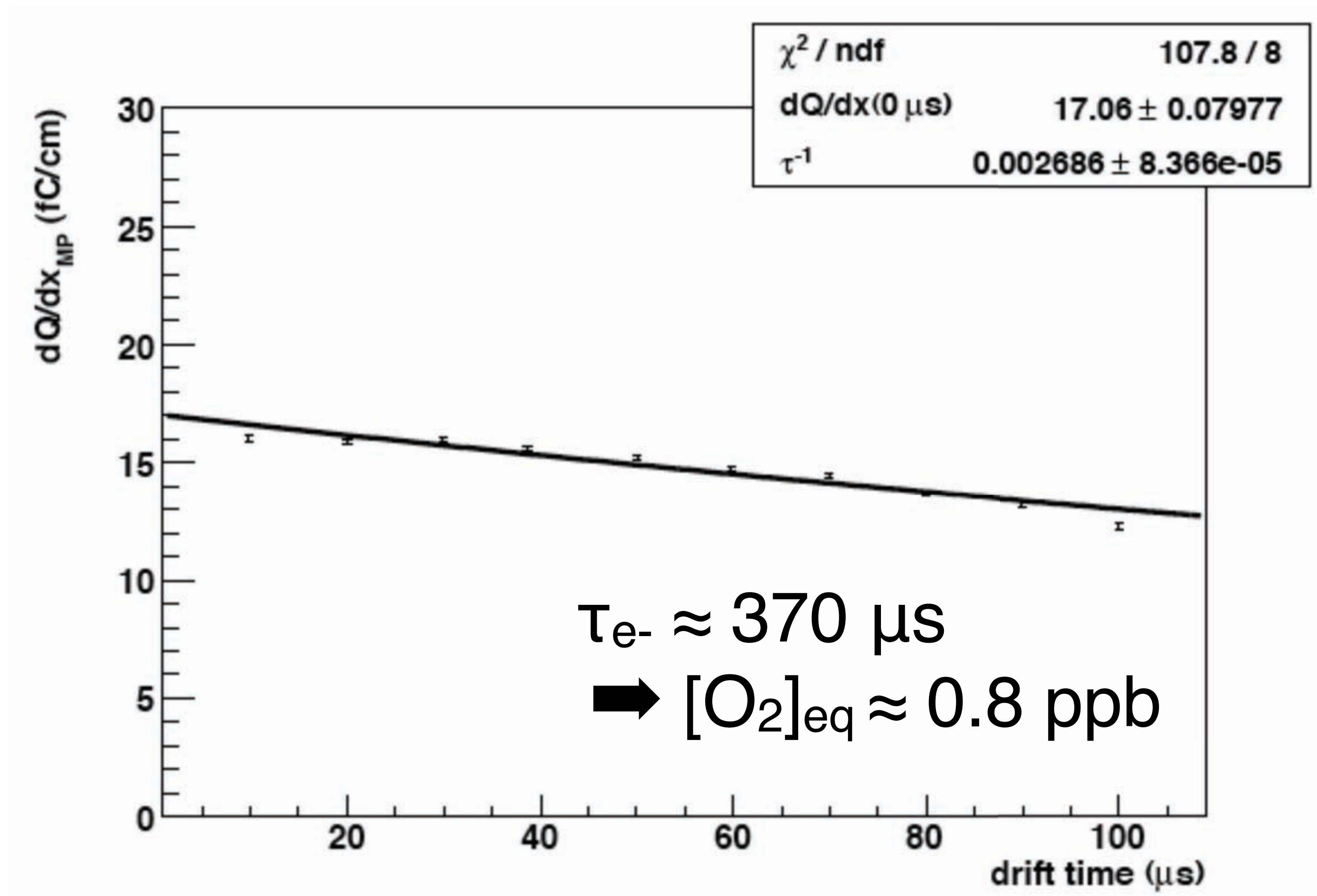
Effect of electronegative impurities (O_2, H_2O and CO_2) on the free electron lifetime

$$\boxed{\tau_{e-} \approx 300\ \mu s\ ppb/[O_2]}$$

Impurities are uniformly distributed in the active volume => the collected charge is given by

$$\boxed{Q(t)=Q_o\, e^{-t/\tau}}$$

dQ/dx: ionization loss per unit length of cosmic muons is used to obtain the free electron lifetime



dQ/dx reconstruction of linear tracks:
- dQ≈ΔQ= charge collected on each strip of the anode
- dx (corresponding ionization length) given by 3D track reconstruction

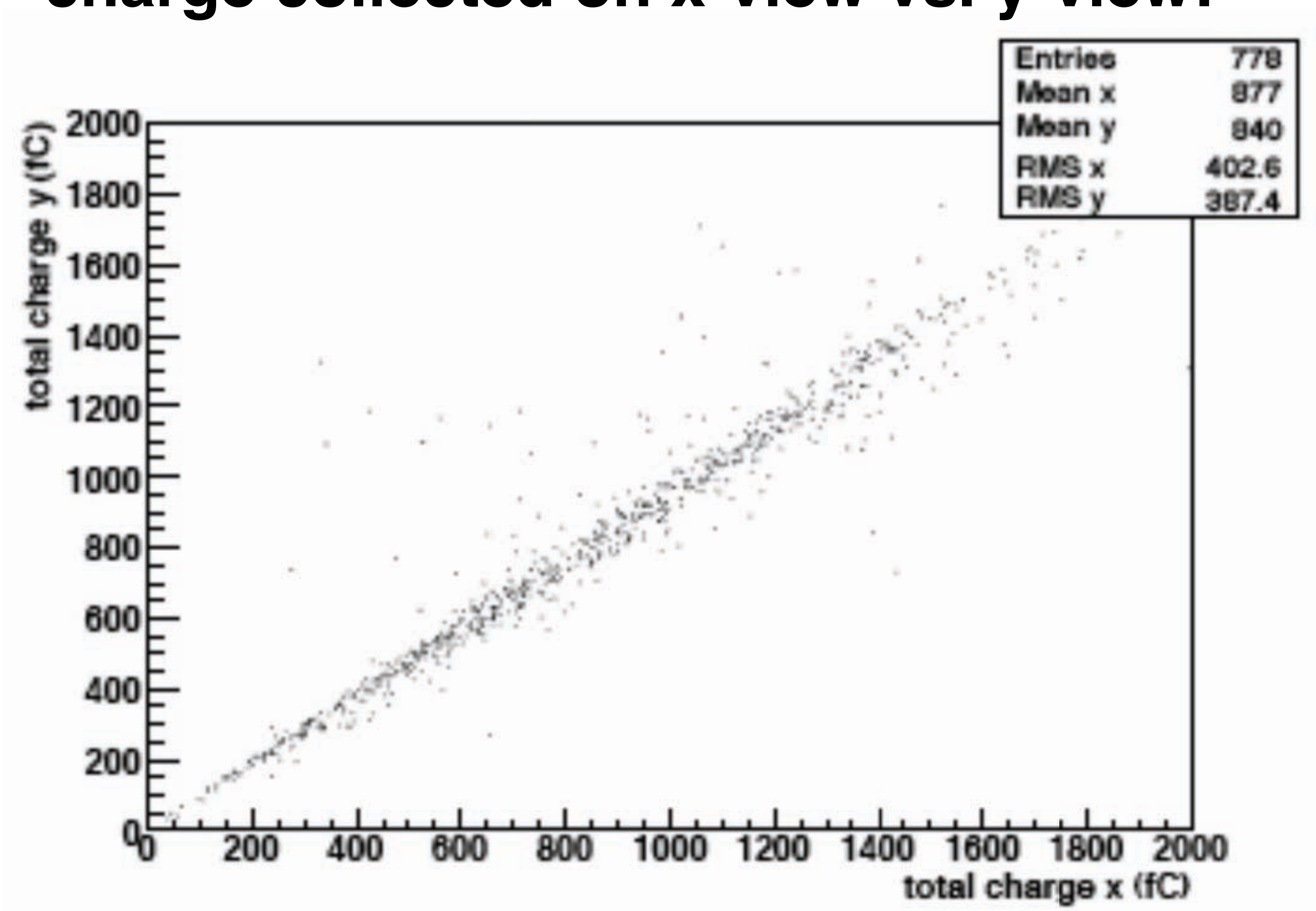
Charge sharing between x- and y-view

The amplified charge is collected either on the x- or the y-view:

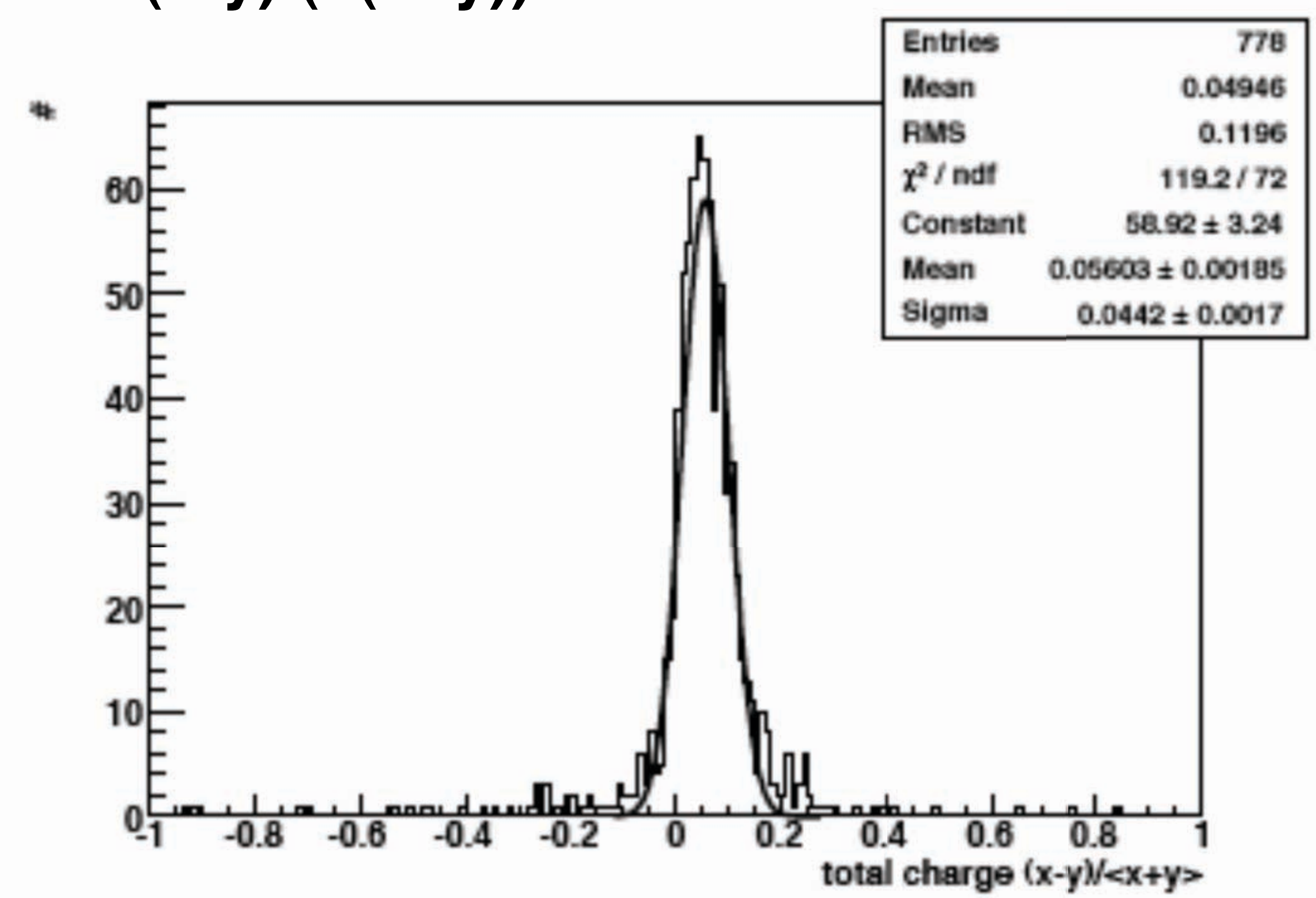
- ideal case: one to one charge sharing => maximum S/N ratio for both views
- ratio depends on the strip geometry => important design parameter of the anode

Selected long muon tracks were used to investigate the charge sharing between the two views.

charge collected on x-view vs. y-view:



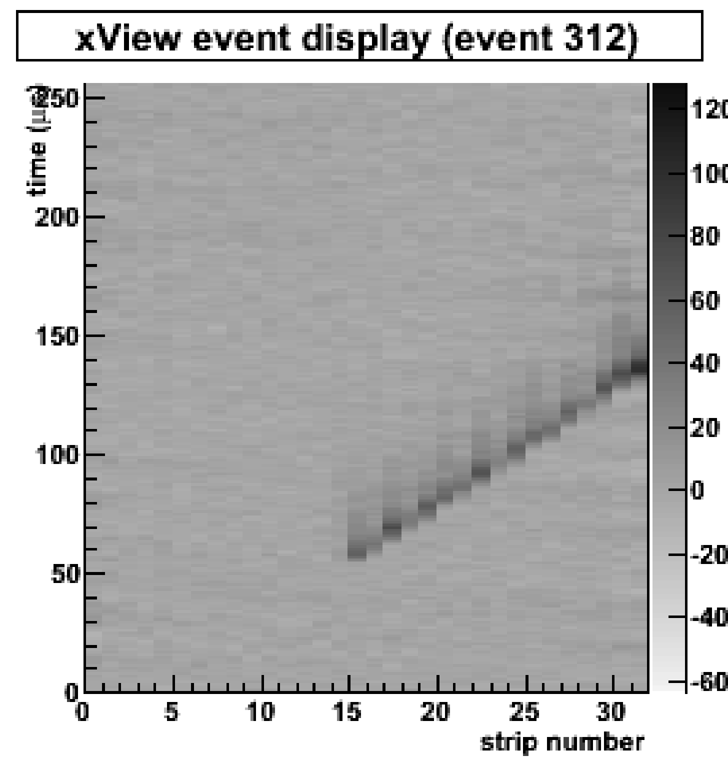
(x-y)/(2(x+y)) less than ≈ 5%:

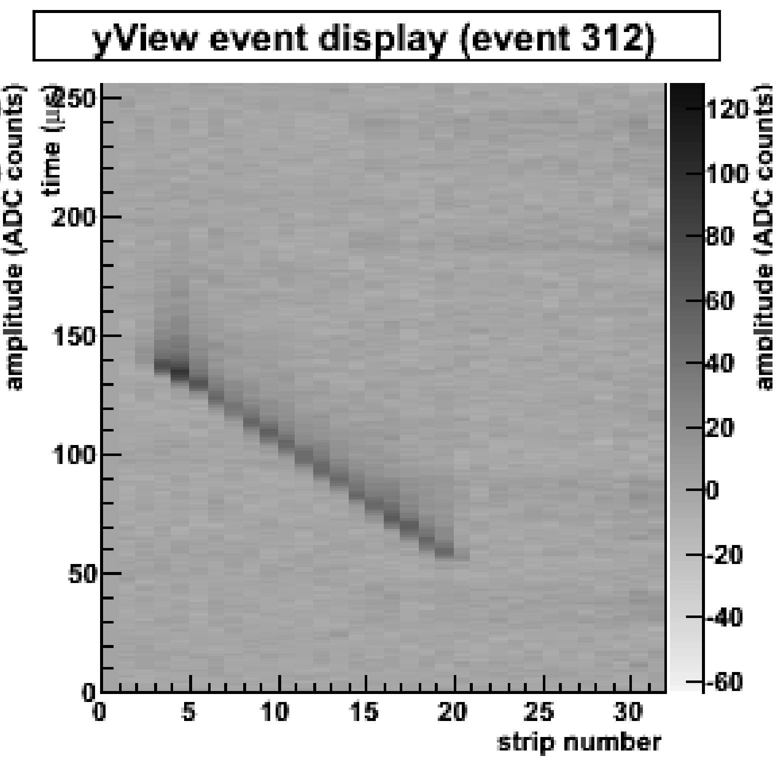


Extraction field scan

The typical extraction field is bigger than 2500 V/cm

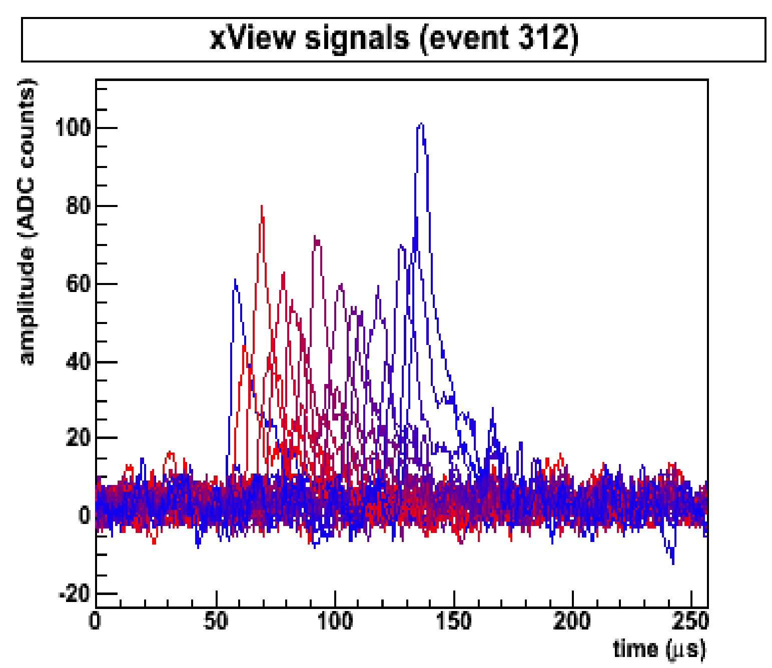
With lower fields (1000 V/cm) the extraction time increases:
➡ The charge is smeared out in time. (loss of track resolution)
➡ The amount of charge decreases due to attachment to electronegative impurities in LAr.

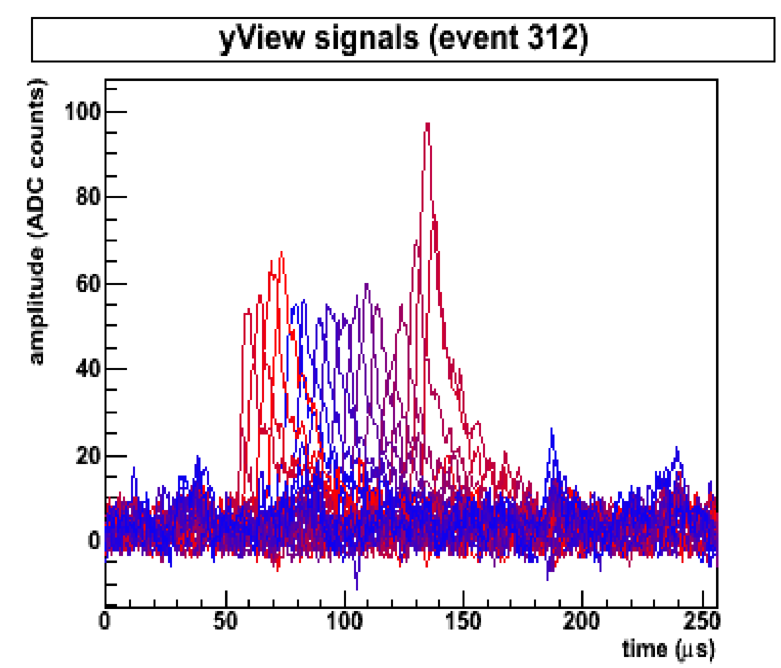




Field configuration

LEM-Anode	3000 V/cm
LEM	30 kV/cm
grid-LEM	1500 V/cm
extraction	1000 V/cm
drift	500 V/cm

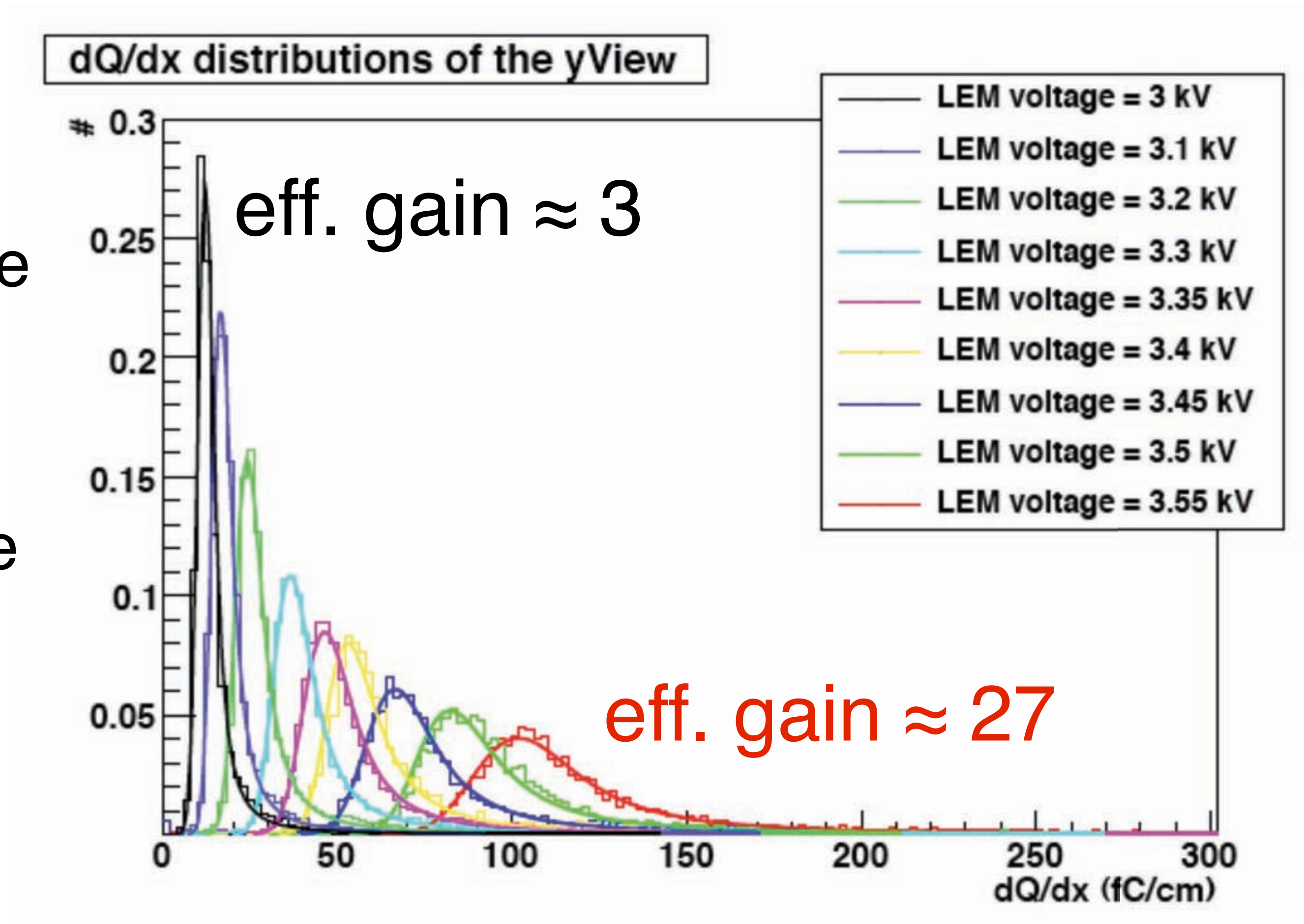


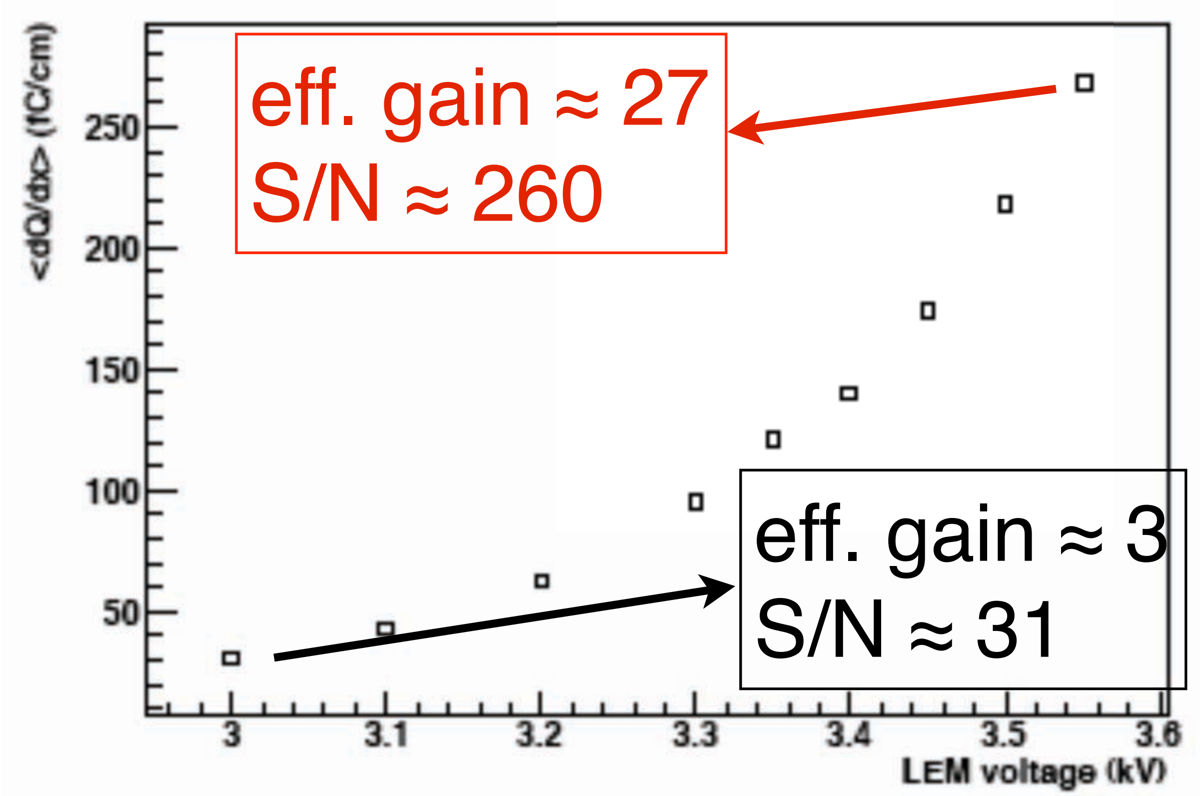


LEM field scan

After applying the free electron lifetime correction factor, the dQ/dx distributions of reconstructed long cosmic muon tracks can be fitted with a Gauss-convoluted Landau distribution.

The effective gain is defined as the ratio of the collected charge (x and y view) and the ionization charge produced in LAr.
The average charge released by a MIP in LAr (electric field: 500 V/cm) ≈10 fC/cm

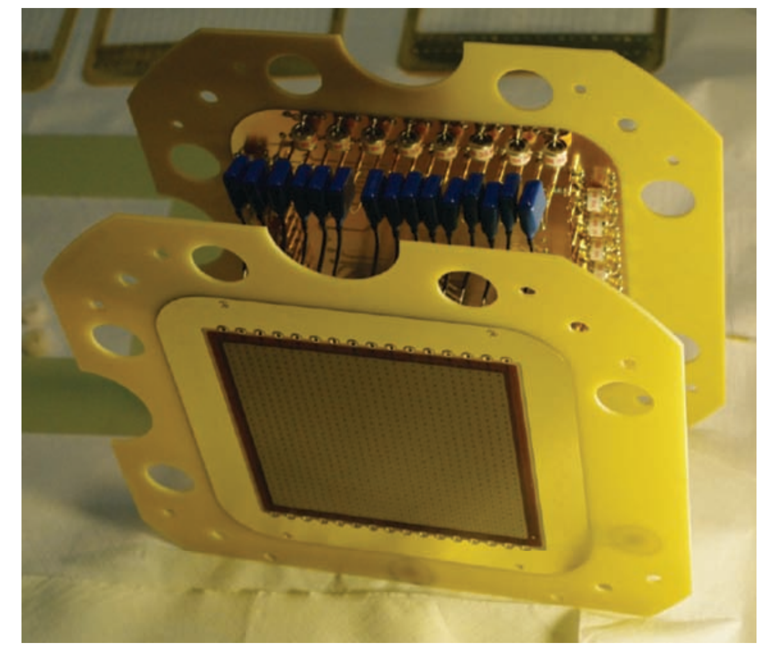




Field configuration

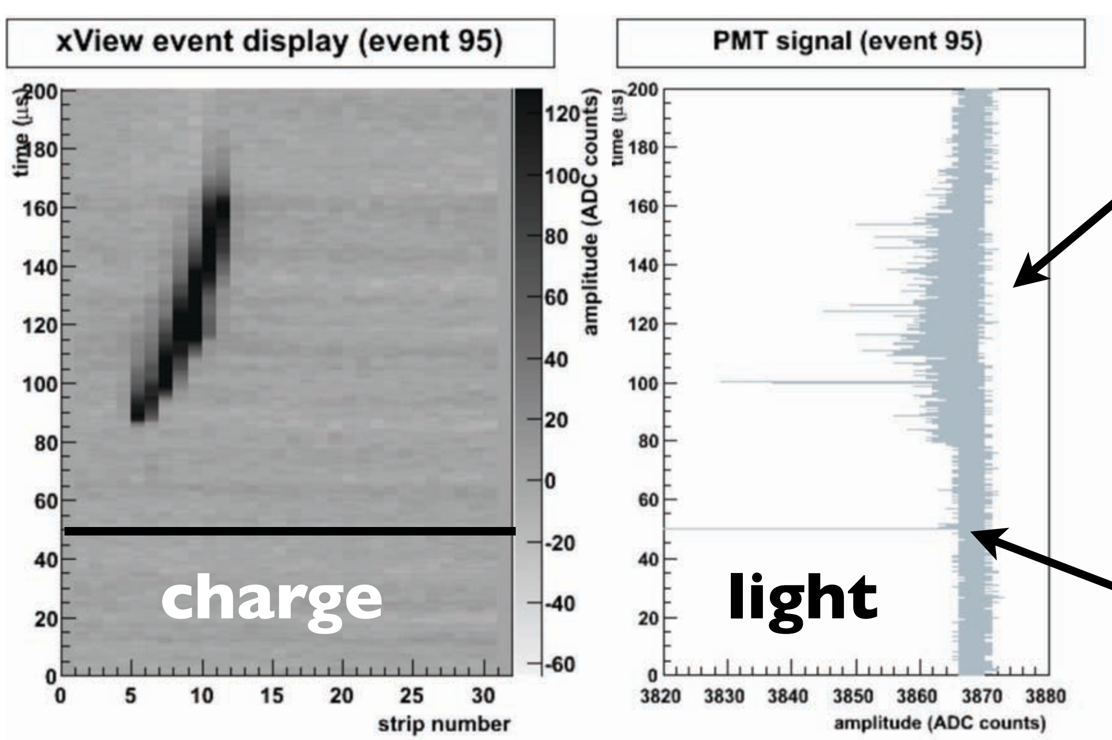
LEM-Anode	3000 V/cm
LEM	30-35.5 kV/cm
grid-LEM	1500 V/cm
extraction	3000 V/cm
drift	500 V/cm

Alternative charge readout: micromegas



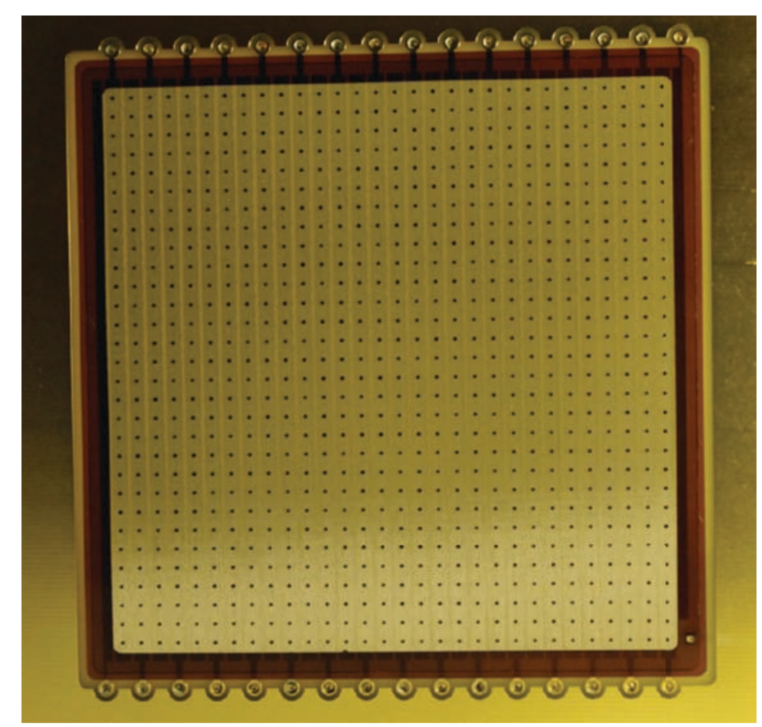
First test of a micromegas as charge readout of a double phase argon TPC (87 K, 1 bar):

- LEM and anode replaced with micromegas (produced by the PCB workshop at CERN)
- readout: 30 strips, 3 mm wide (only one view)
- spacers: diameter=450 μm, pitch=3 mm and gap=100 μm
- mesh: wire pitch=63 μm, wire diameter=18 μm



secondary scintillation light produced in GAr (field between extr. grids and micromegas)
➡ proportional to charge

prompt scintillation light produced in LAr
➡ used as trigger



recorded cosmic muon event

➡More: talk of Alain Delbart

Conclusions

- The projective 2D anode, 1 mm thick LEM and the micromegas were produced by the CERN PCB workshop
- Performance of the projective Anode:
    - Cosmic ray events recorded with a pitch of 3 mm and symmetric x-y readout
    - Excellent charge sharing between both views measured (design parameters verified)
- Performance of the single 1 mm thick LEM:
    - Energy loss spectrum of cosmic rays used to estimate the gain.
    - A gain in the order of 30 was reached in double phase operation mode.
- For the first time a micromegas has been used as charge readout of a LAr TPC!

Outlook:

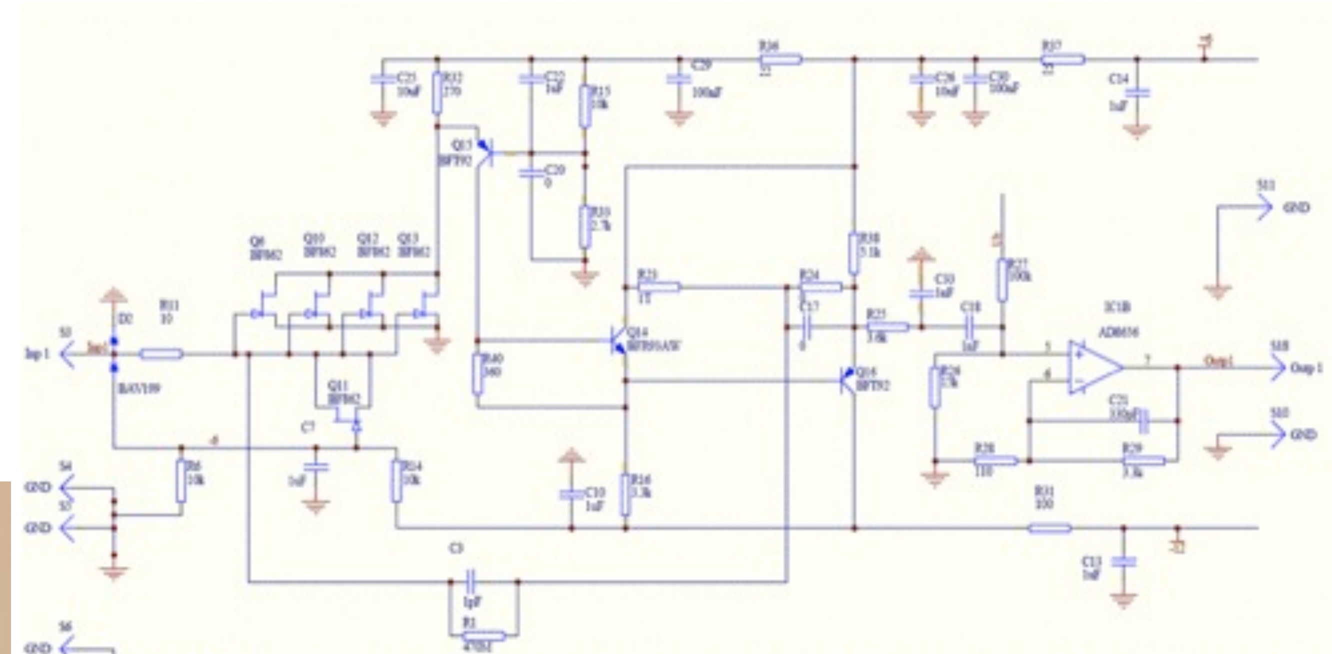
- test of a double stage LEM in order to reach a higher gain
- further tests with the micromegas
- Production of LEM and charge readout for ArDM (1 T LAr LEM-TPC)

Backup slides

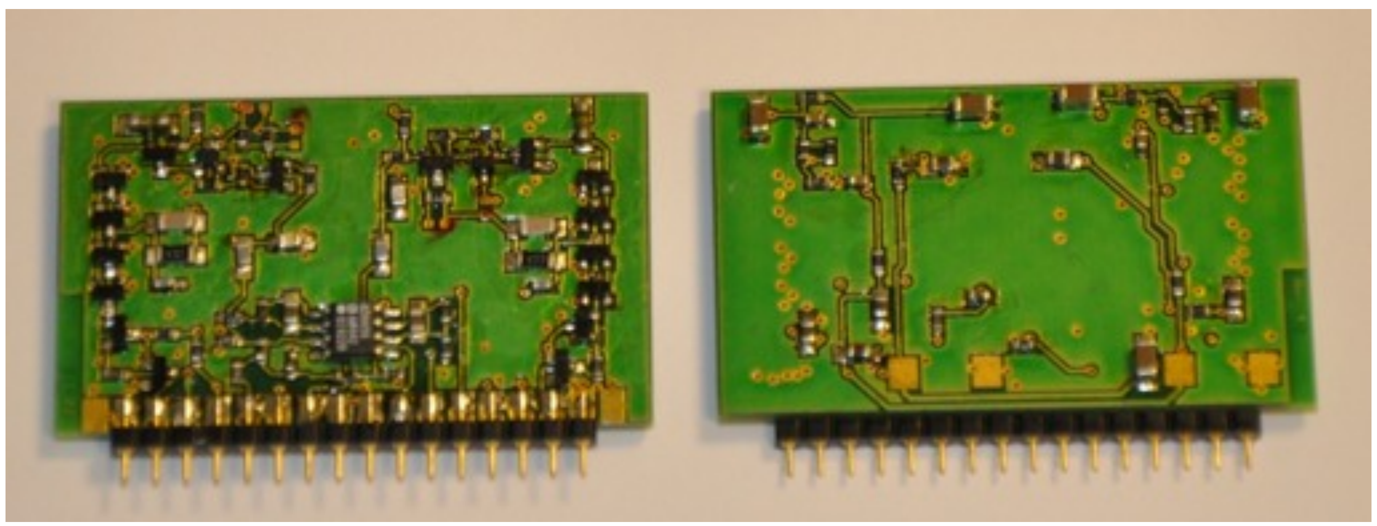
DAQ system

Custom made front-end charge preamp and shaper:

- 2 channel per chip.
- rise time 0.6 μs, fall time 2 μs.
- gain ~11mV/fC.
- S/N ~10 @ 1 fC and 200 pF input cap.



Inspired by C. Boiano et al. IEEE Trans. Nucl. Sci. 52 (2004) 1931

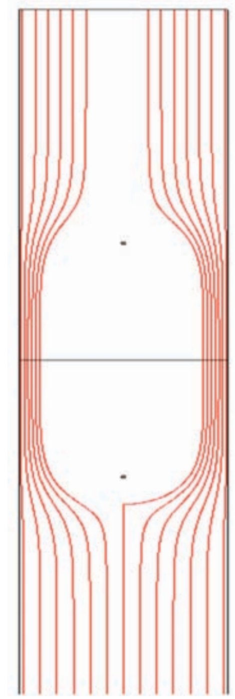


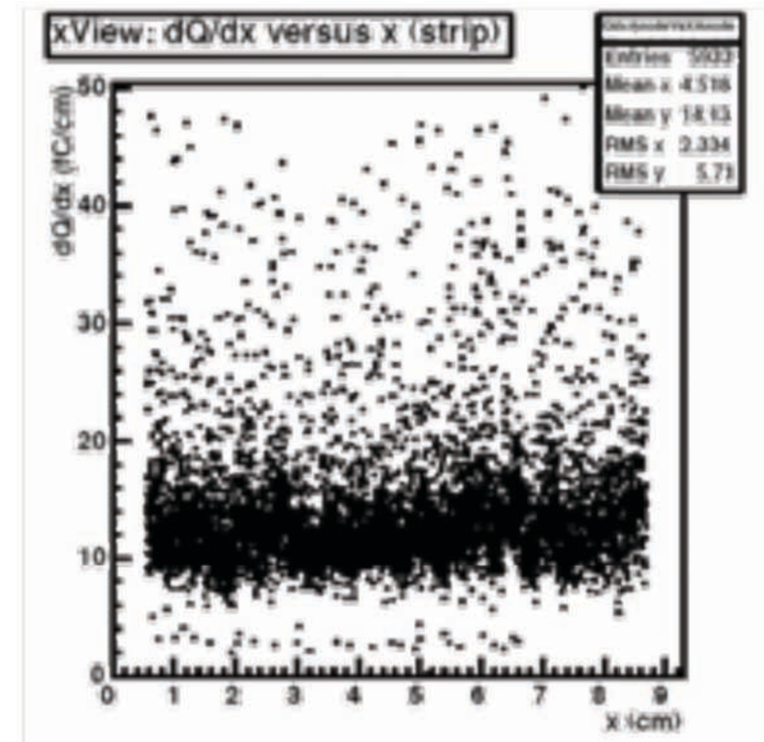
ETHZ in collaboration with CAEN developed a complete DAQ system:

- 12 bit 2.5 MS/s flash ADC.
- programmable FPGA.
- implementation of zero suppression
- channel-by-channel trigger and global "trigger alert"
- 256 channel crate
- chainable optical link.

Effect of extraction grids

The extraction grids focus the electrons between the wires. 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.





Field configuration

LEM-Anode	3000 V/cm
LEM	30 kV/cm
grid-LEM	1.case: **1.5 kV/cm** 2.case: **4.0 kV/cm**
extraction	3000 V/cm
drift	500 V/cm