First operation of a 40x80 cm² LEM in a double phase argon LEM-TPC

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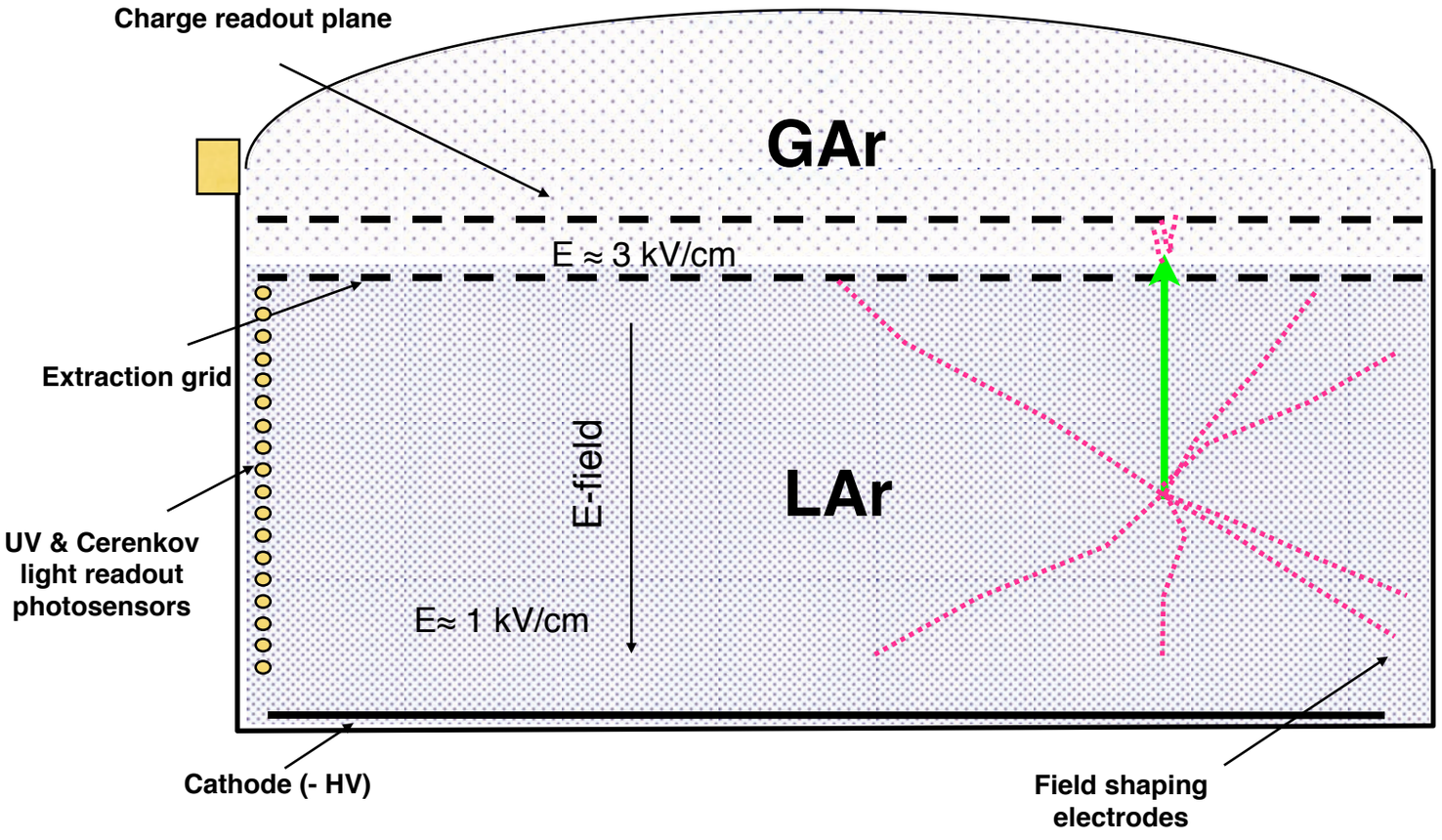
Introduction: GLACIER

Giant Liquid Argon Charge Imaging ExpeRiment

GLACIER (hep-ph/0402110) is a proposed giant liquid argon multi-purpose next-generation underground neutrino observatory at the 100 kton scale.

- **Broad astroparticle and particle physics program, focused at:**
  - ➡ long baseline neutrino studies for the neutrino mass hierarchy determination and mixing angle θ_{13} and CP violating phase δ measurements
  - ➡ nucleon decay searches
  - ➡ known and unknown astrophysical neutrino detection



- **A very large area with single long vertical drift paths with full active mass**

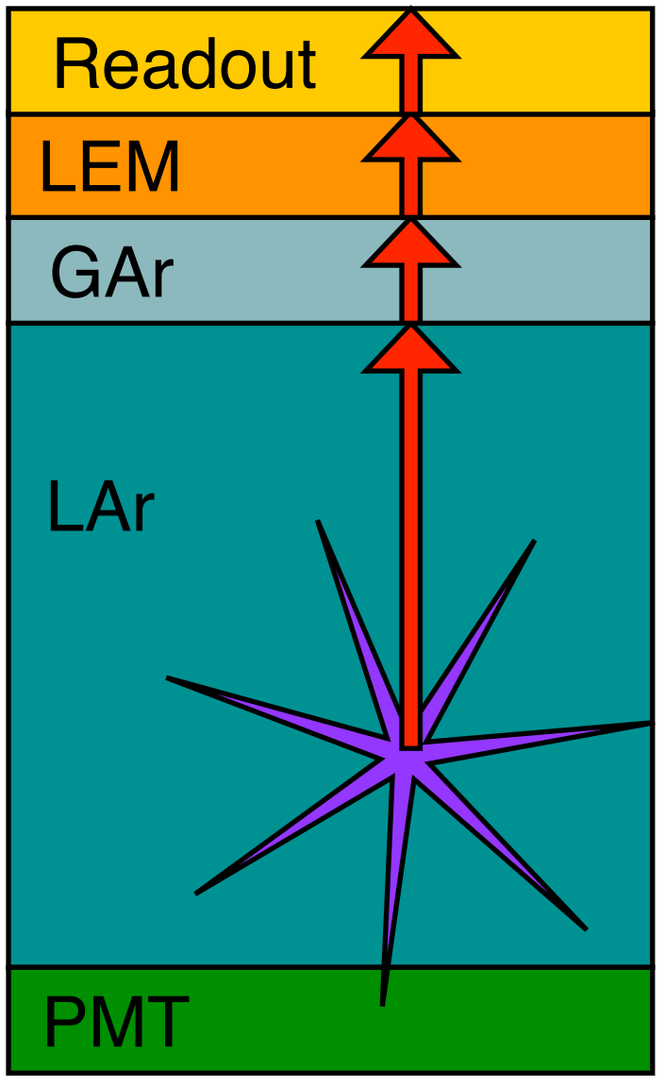
- **Immersed high voltage multiplier for drift field**
  - ➡ 0.5÷1 kV/cm

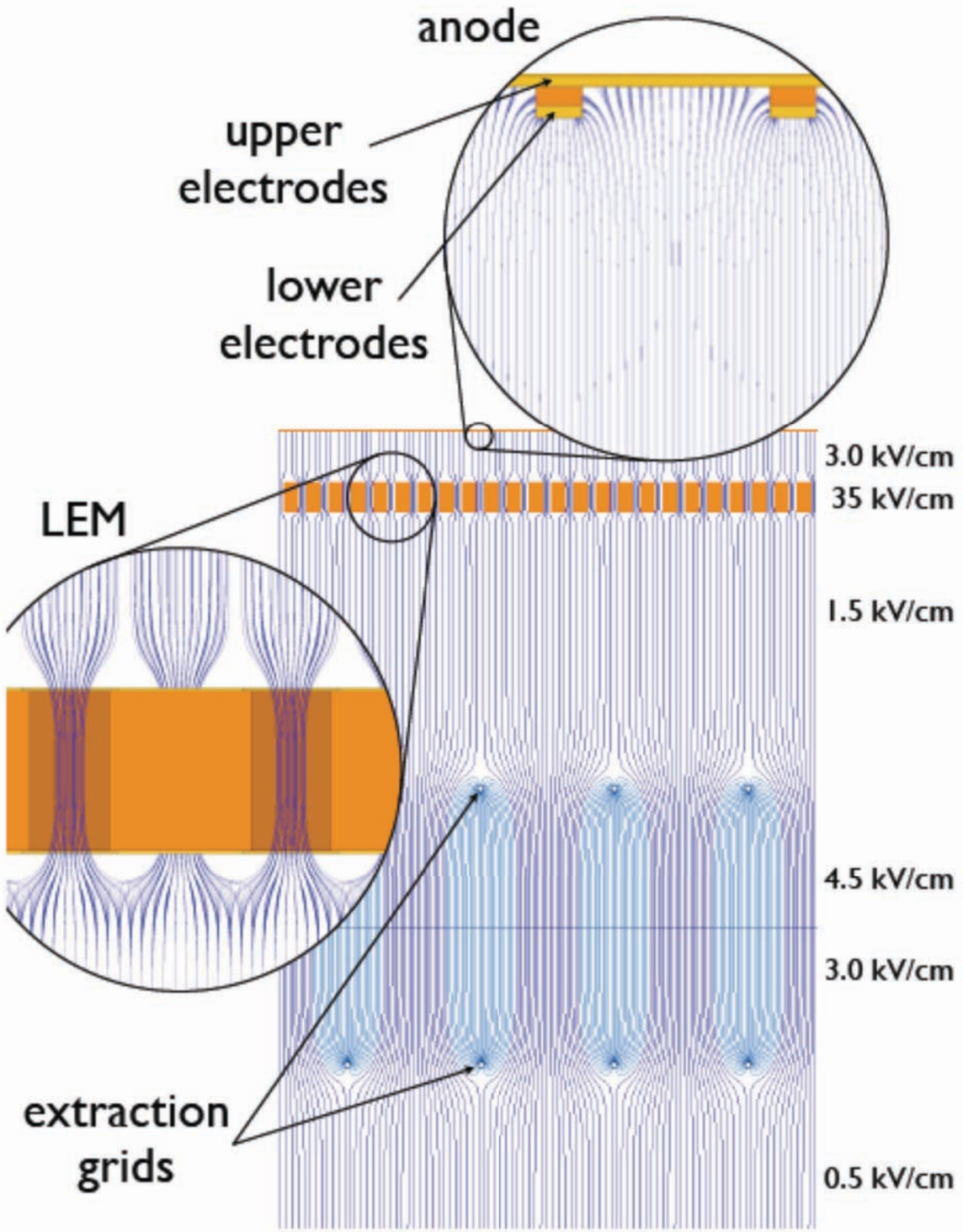
- **Immersed light readout system**
  - ➡ WLS-coated 1000x 8” PMT and reflectors for DUV light detection
  - ➡ Cerenkov imaging with uncoated PMT and increased coverage

- **Double phase readout with adjustable gain at top**
  - ➡ Full extraction from LAr to GAr with ≈3 kV/cm (local)
  - ➡ MPGD, technologies under test LEM, THGEM, Micromegas
  - ➡ Independent readout units
  - ➡ O(10^6) readout channels

Charge readout principle

1. ionization electrons are **drifted** to the liquid-gas interphase (trigger given by prompt scintillation light)
2. if the E-field is high enough (≈ 3 kV/cm) they can efficiently be **extracted** to the gas phase
3. in the holes of the LEM the E-field is high enough to trigger an electron avalanche
4. the **multiplied** charge is collected on a 2D readout





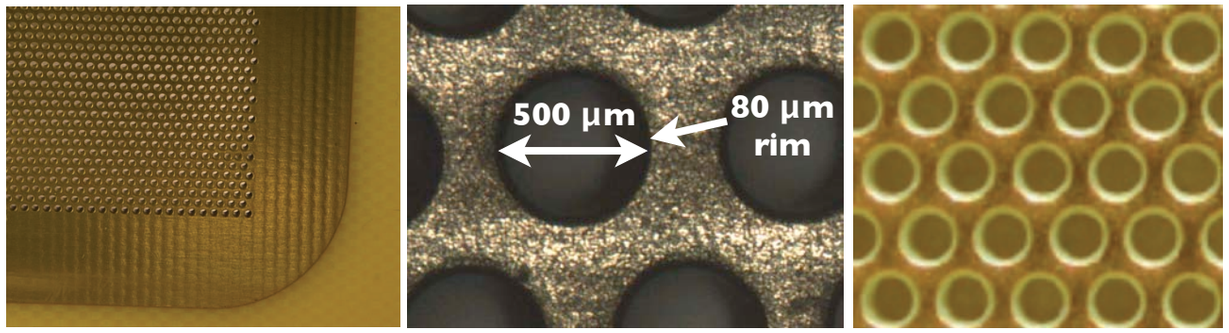
ref: A. Badertscher, et al., NIM A 641 (2011) 48-57

3L double phase Ar LEM-TPC

The proof of principle was done with a 3L size prototype double phase pure argon LEM-TPC
A. Badertscher, et al., NIM A 641 (2011) 48-57

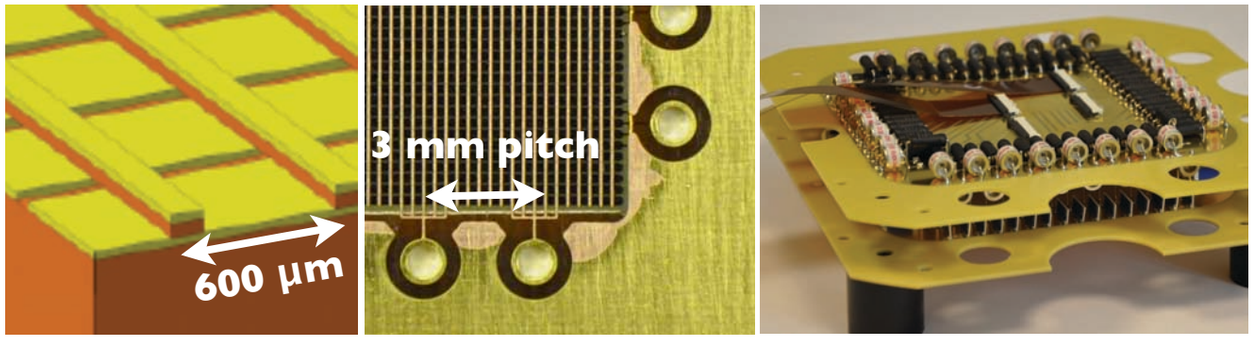
LEM (THGEM): Large Electron Multiplier

- Macroscopic Gas hole multiplier
- more robust than GEMs (cryogenics, discharges)
- manufactured with std. PCB techniques
- large area coverable (1 m^2 size modules)



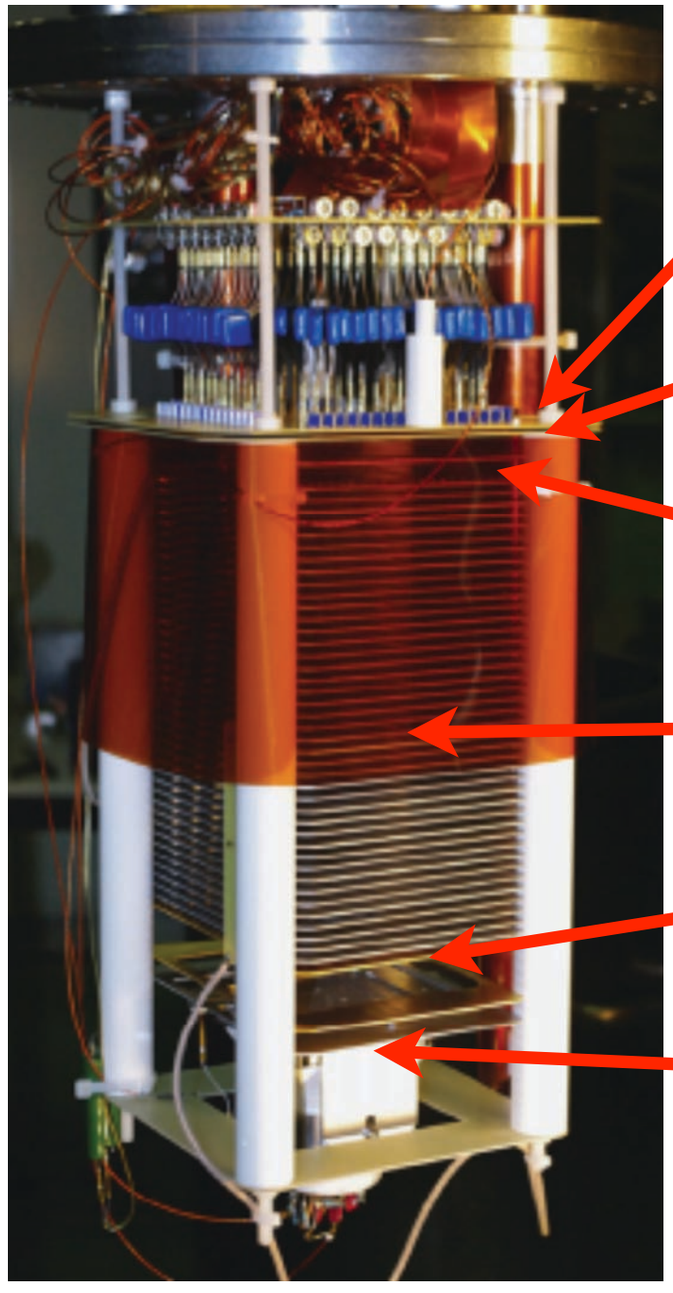
Projective 2D anode readout

- charge is equally collected on two sets of strips (views)
- induced signals have the same shape for both views
- readout independent of multiplication

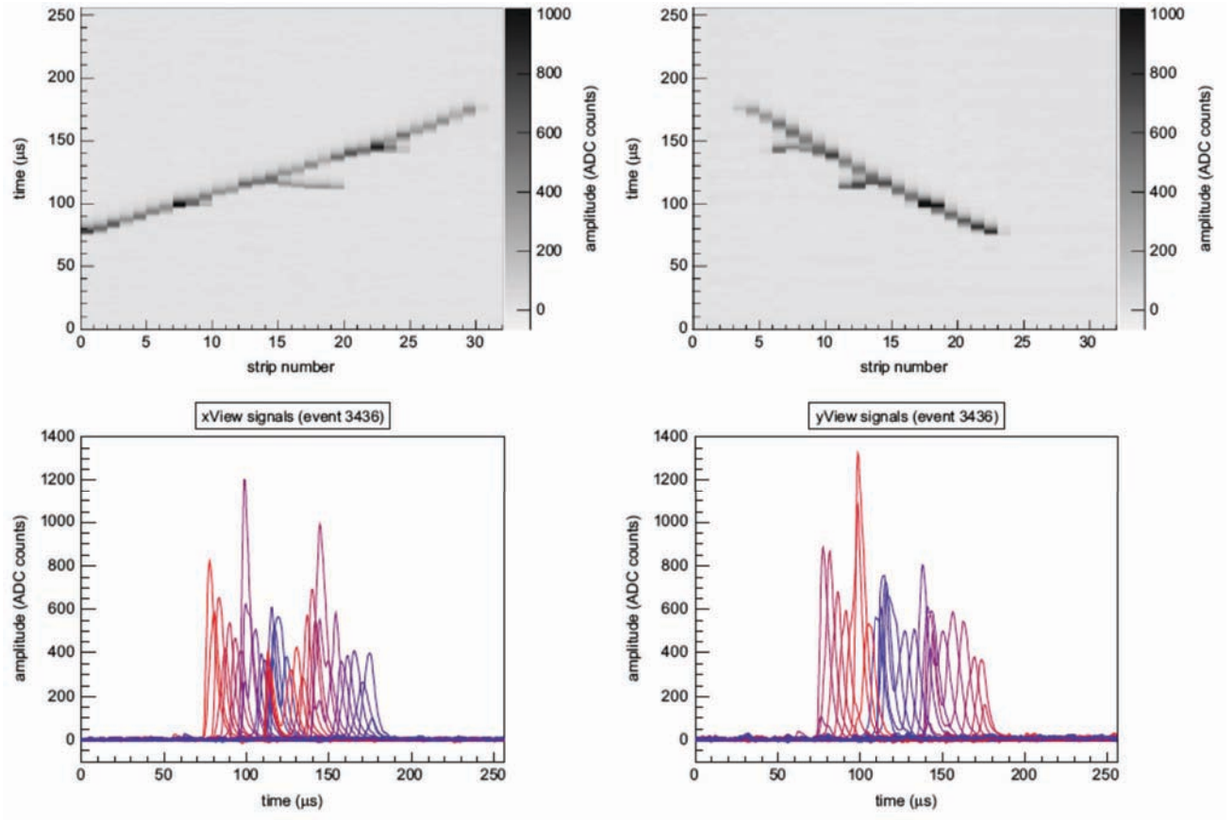


LEM and 2D anode produced by CERN TS/DEM group

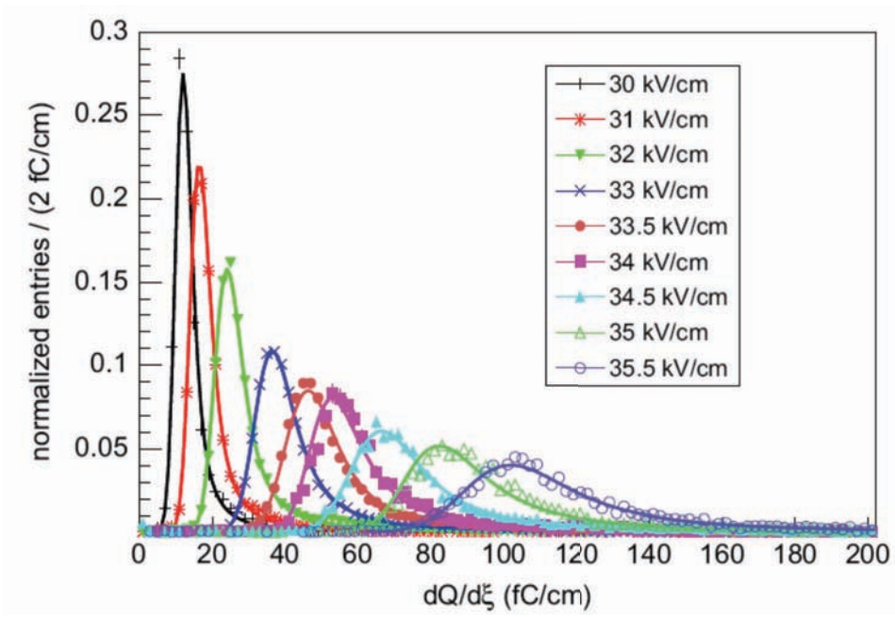
the TPC



Results of a double phase Ar LEM-TPC with a projective 2D anode readout



dQ/dx distribution with different gains

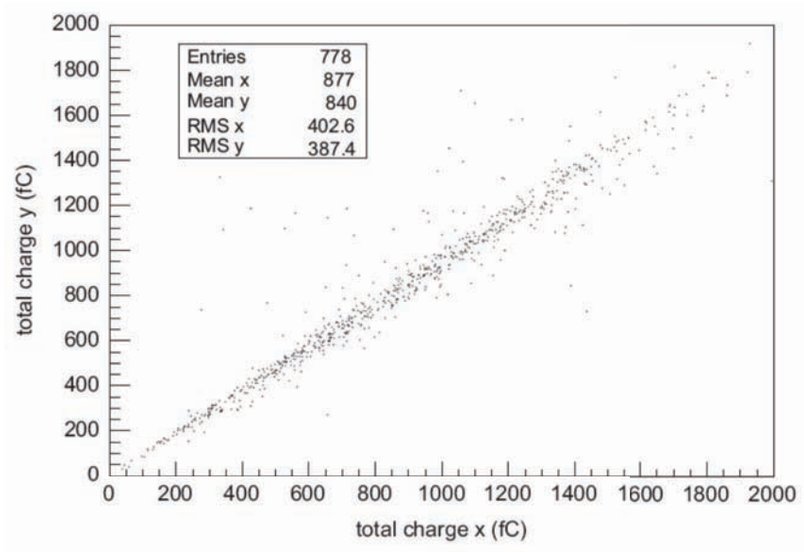


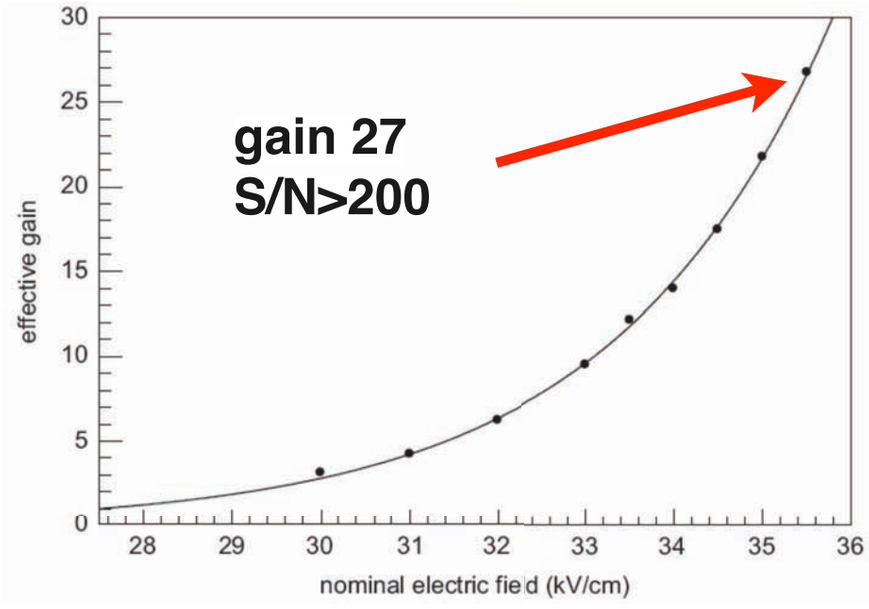
gain curve

➡ dQ/dx data from MIPs have been used to characterize the detector:

charge sharing test of the 2D anode

- signal shape of x and y view identical
- charge sharing verified: (x-y)/<x+y> better than 5%
- design parameters verified

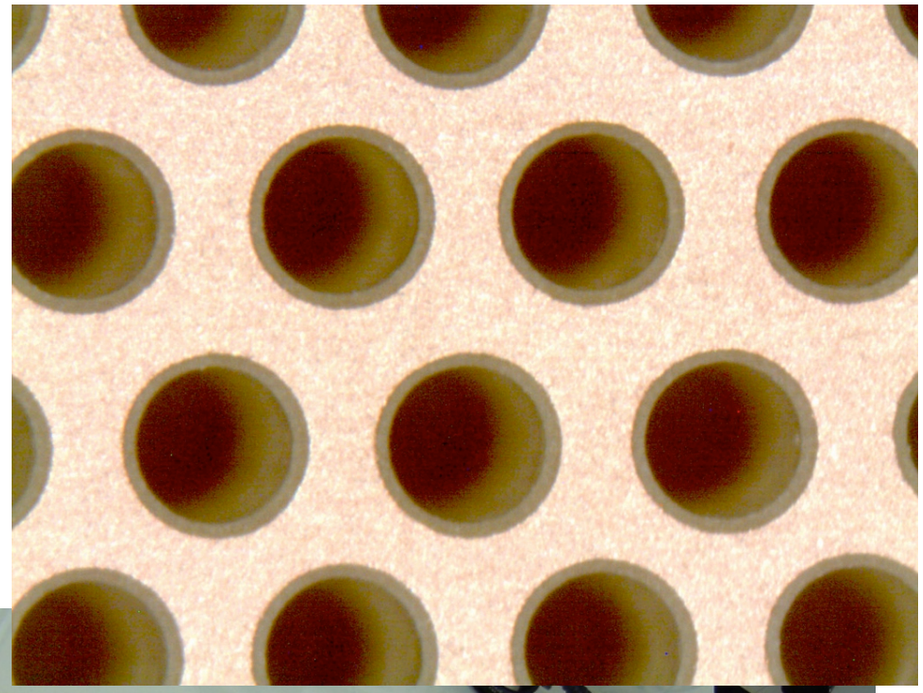




ref: A. Badertscher, et al., NIM A 641 (2011) 48-57

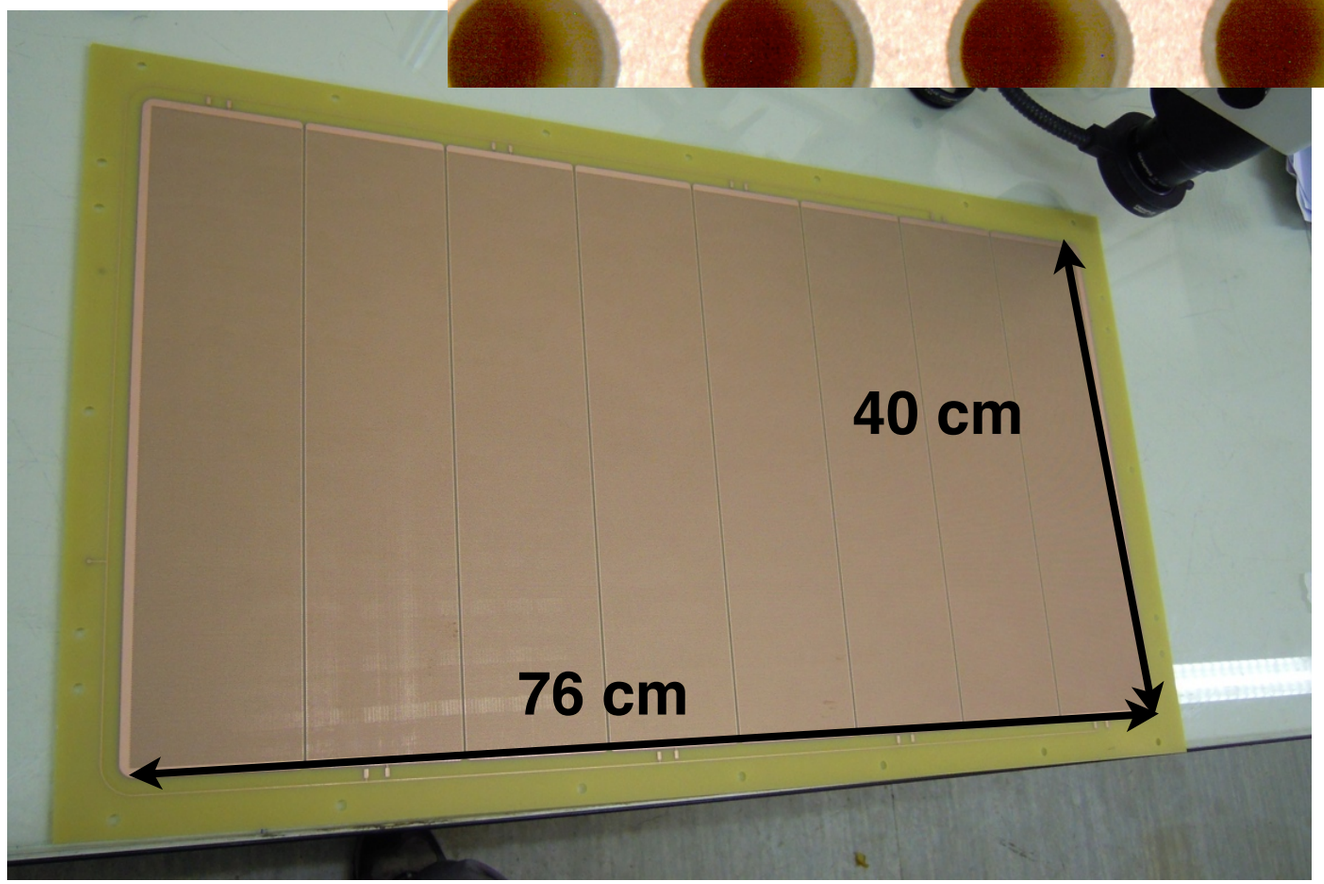
40x76 cm² LEM

•After a successful conclusion of the 3L LEM-TPC we started the production of a new 40x76 cm² charge readout (LEM and 2D anode) for the 250L double phase argon LEM-TPC.
•The design parameters are identical with the ones of the 3L setup (LEM reached sufficient gain, anode provided excellent x/y readout with equal charge sharing)
- Exception: the largest achievable dielectric rim was ≈25 μm due to production issues (to be compared to 70 μm in the case of the 10x10 cm² LEM)



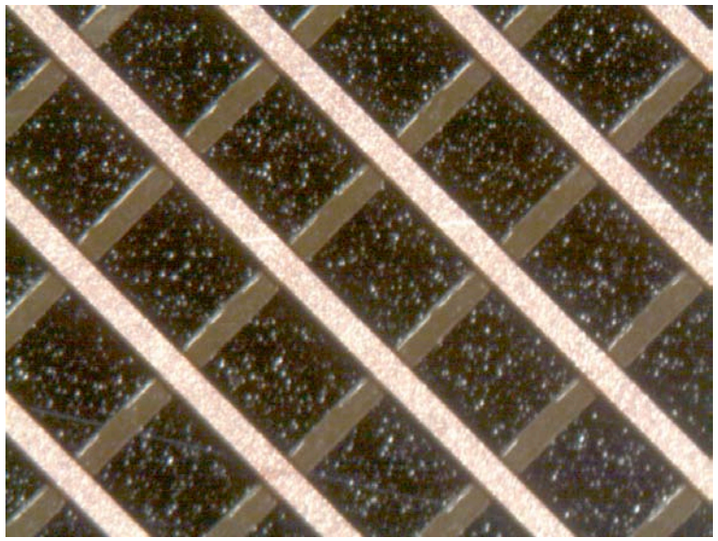
design parameters

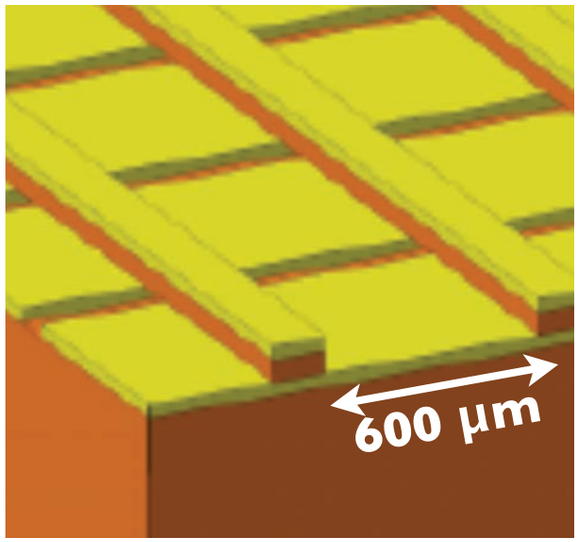
total area	40x76 cm²
number of holes	≈0.5x10⁶
PCB thickness	1.0 mm
hole diameter	500 μm
hole pitch	800 μm
dielectric rim	20-30 μm
segmentation	8 segments

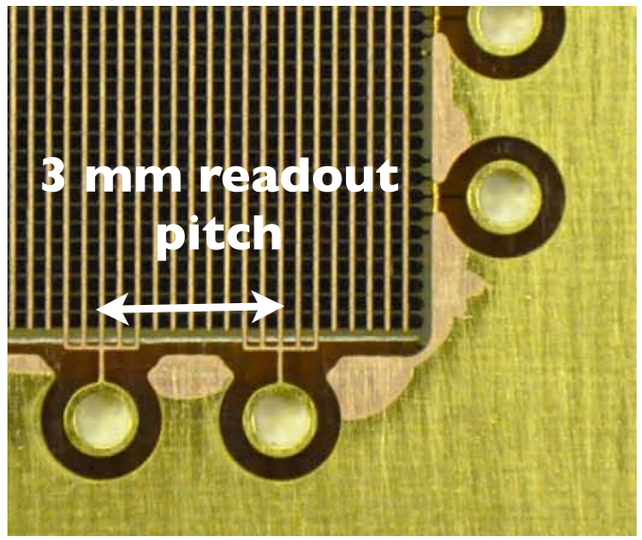


produced by CERN TS/DEM group & ELTOS company (I)

40x76 cm² 2D anode

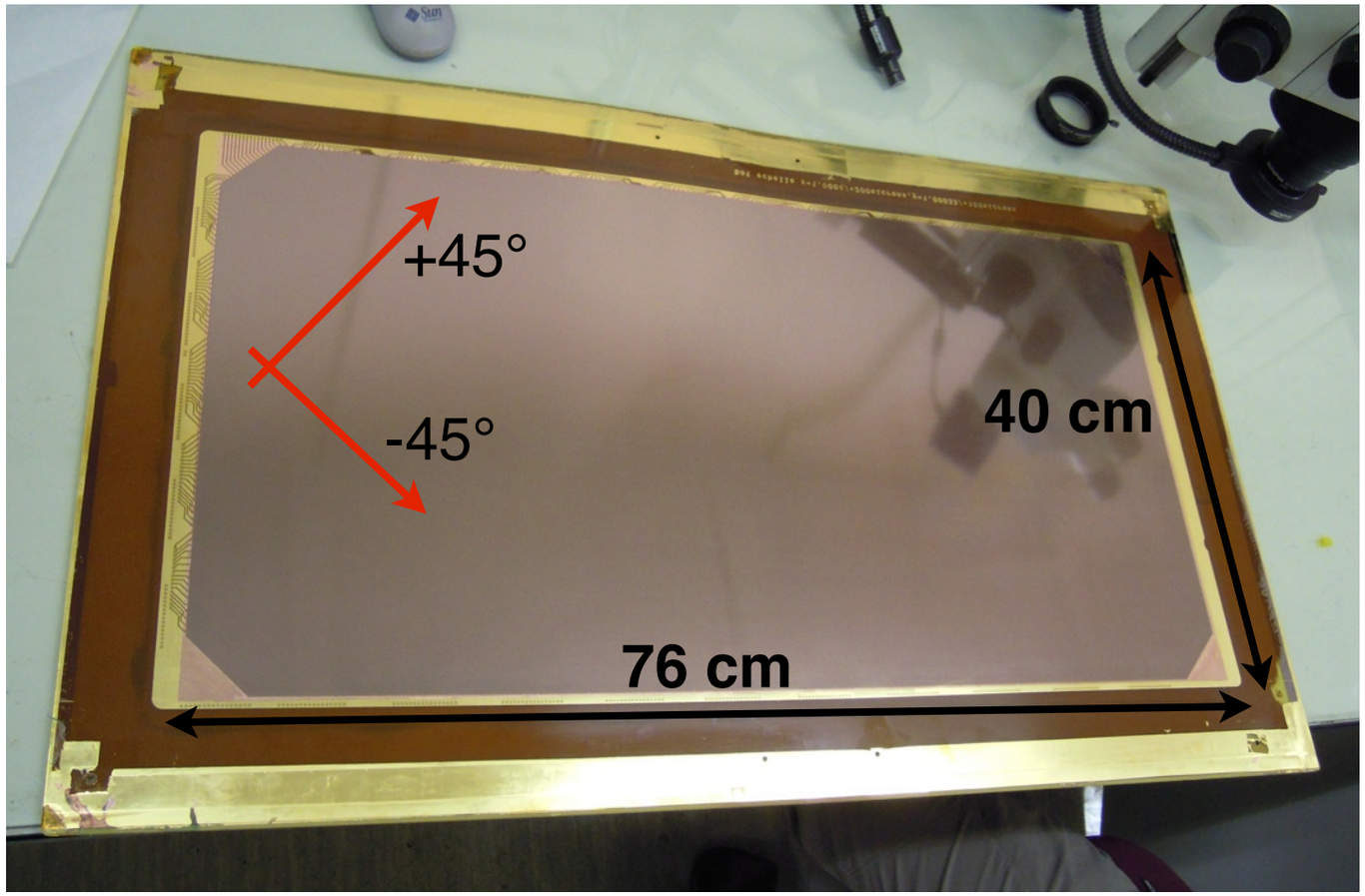






design parameters

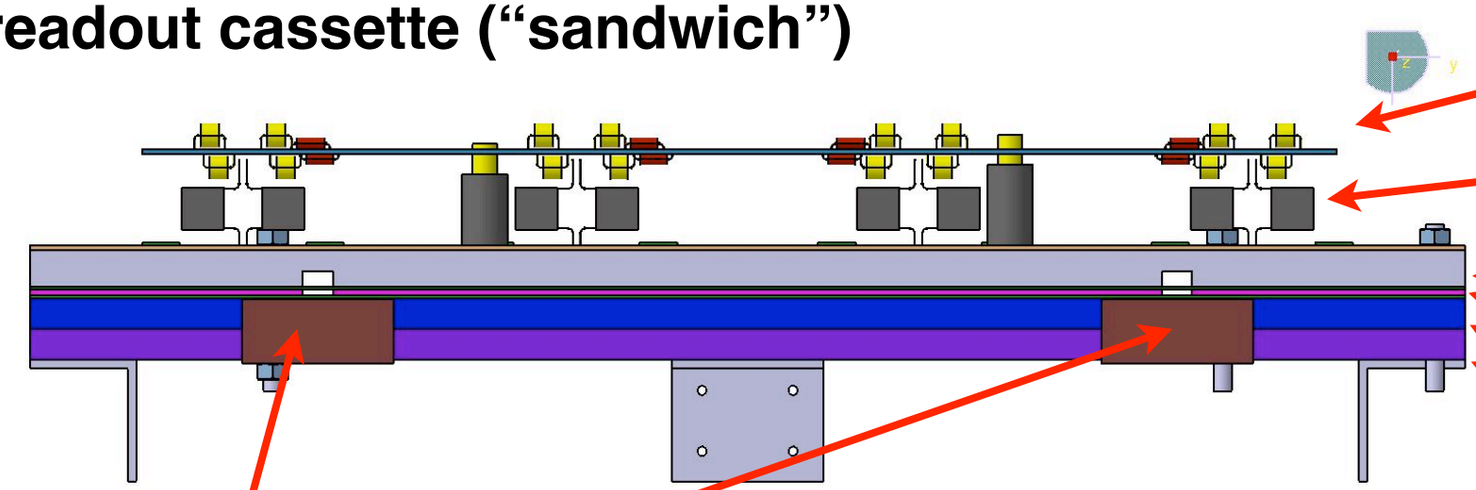
Readout pitch	3 mm
Strip pitch	600 µm
Strip width (outer)	120 µm
Strip width (inner)	500 µm
Kapton thickness	50 µm
Number of strips	256+256



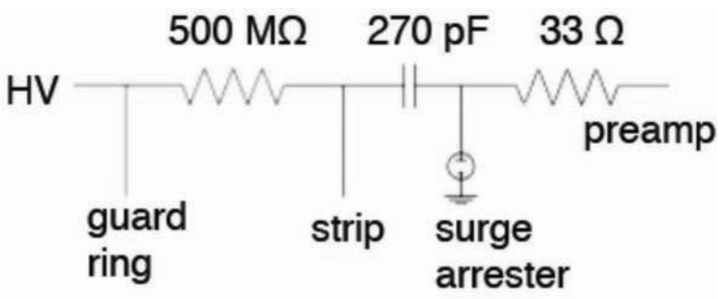
produced by CERN TS/DEM group

Charge readout cassette

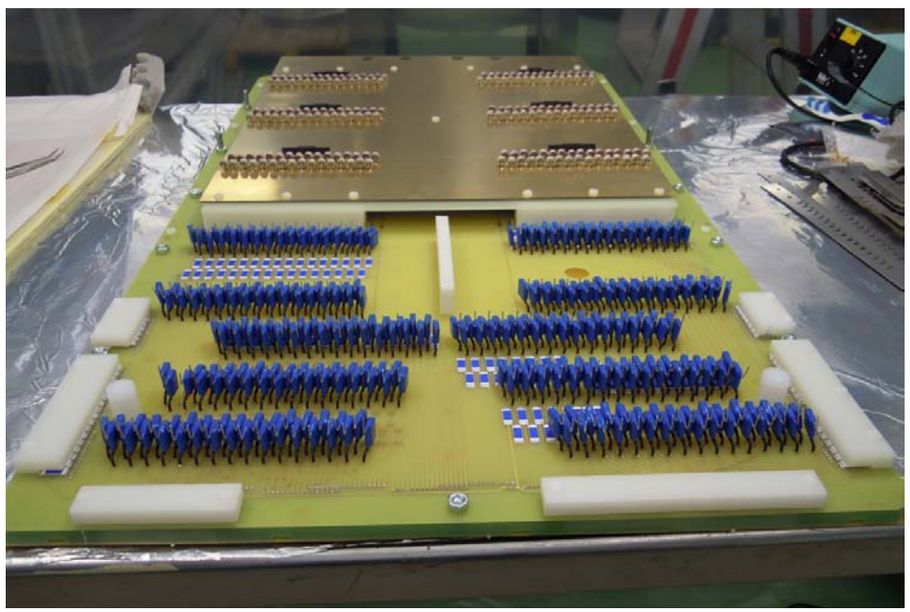
Design of a compact, robust and scalable readout cassette (“sandwich”)



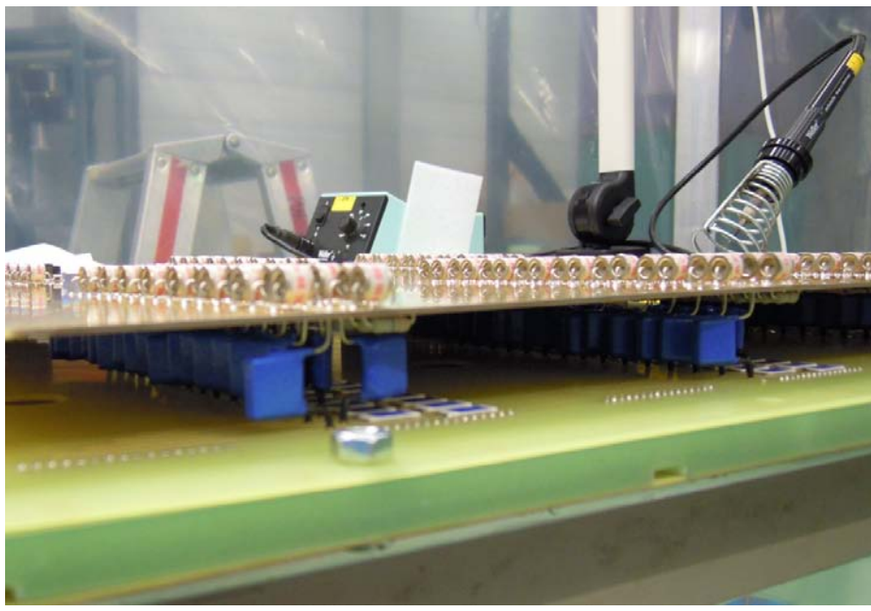
readout scheme



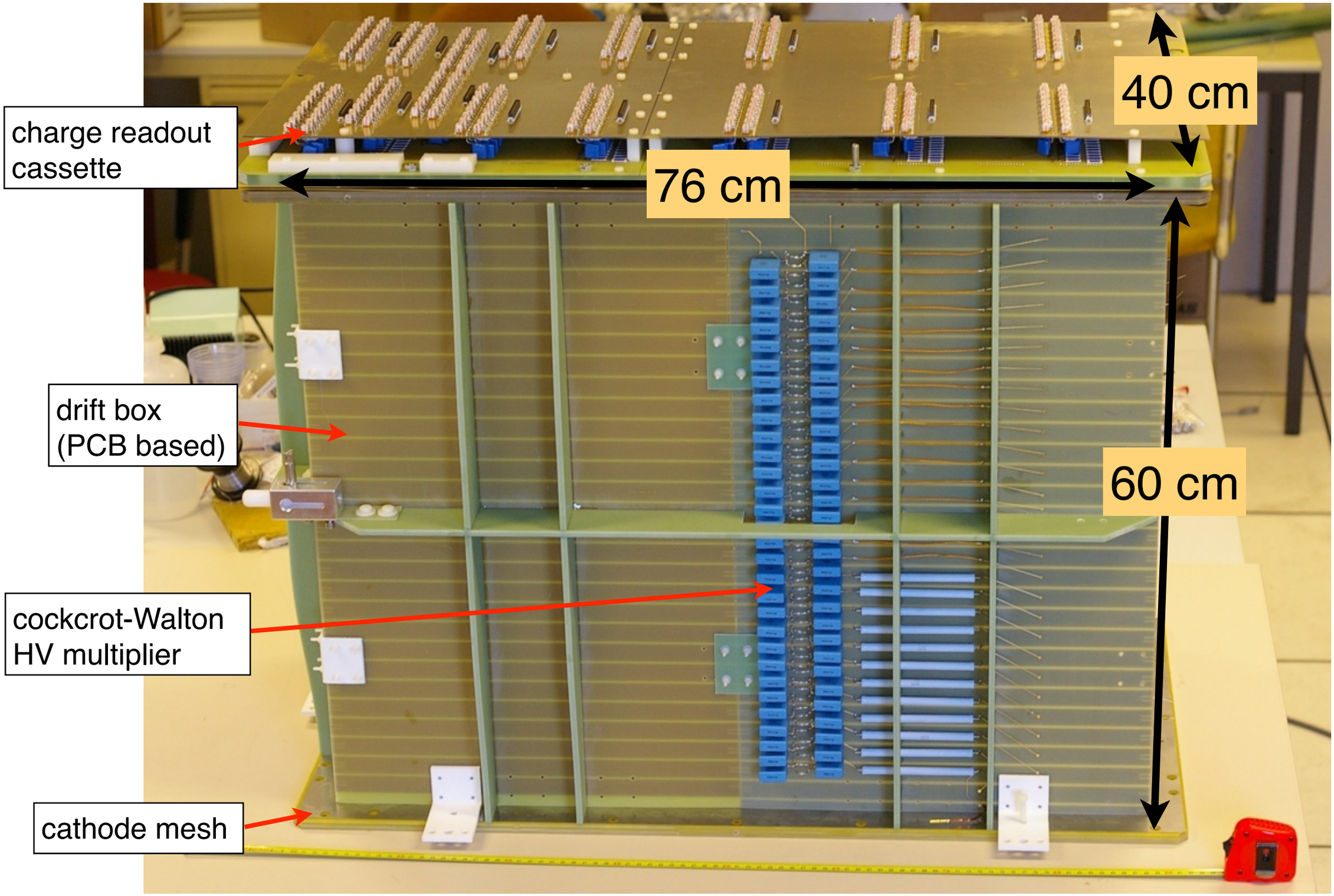
top view



side view

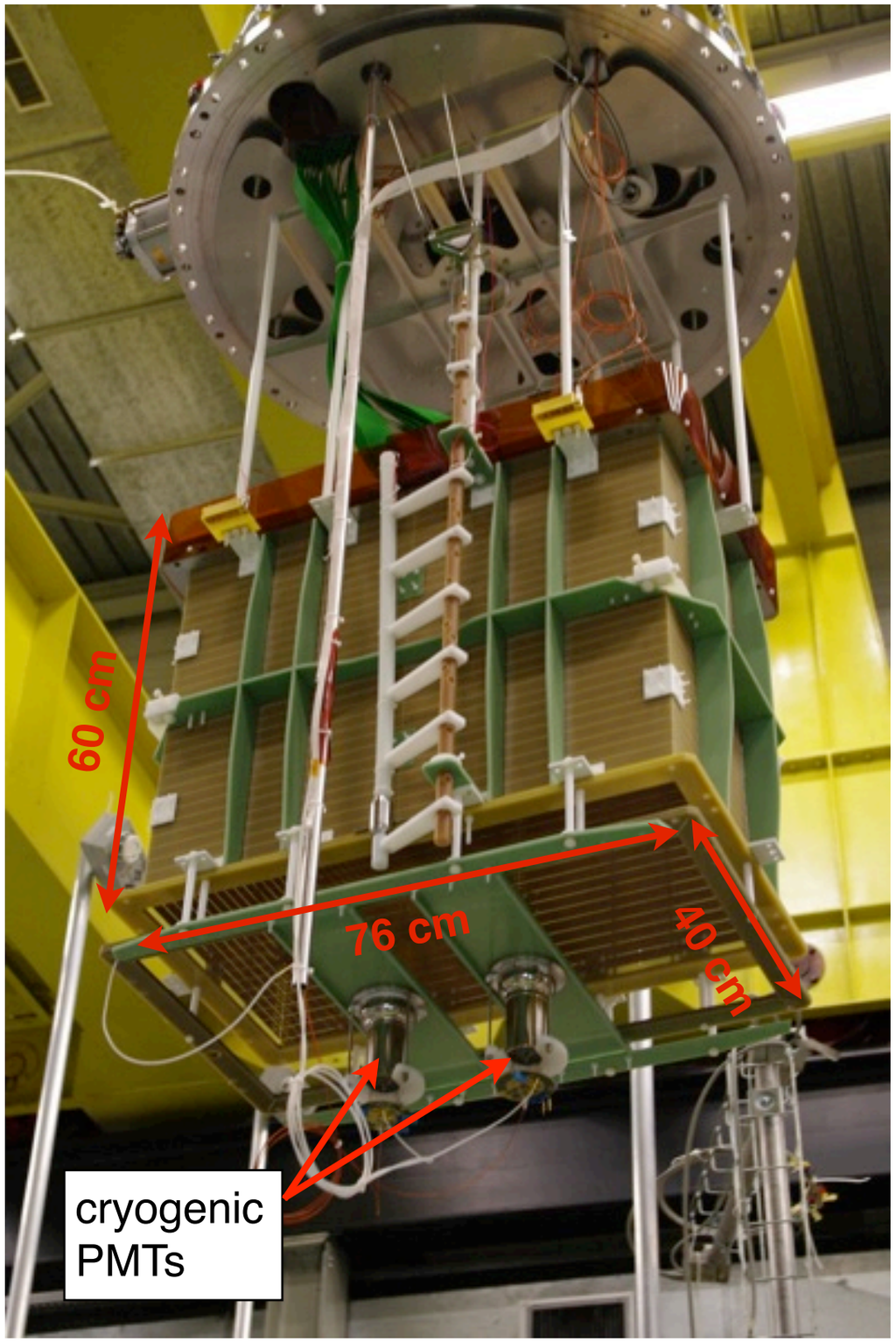


250L double phase Ar LEM-TPC

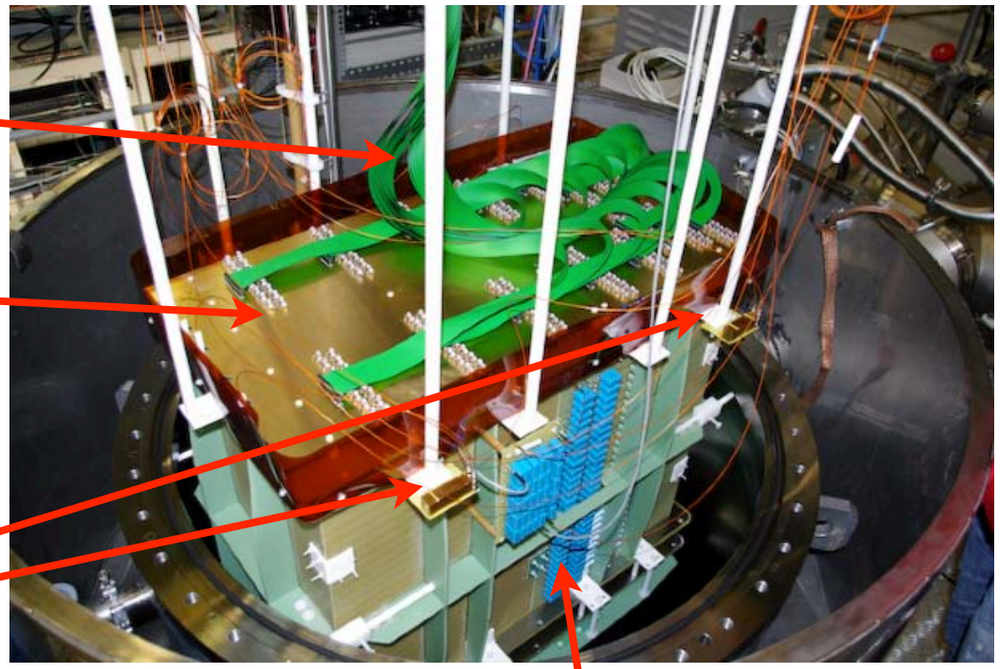


Complete assembly

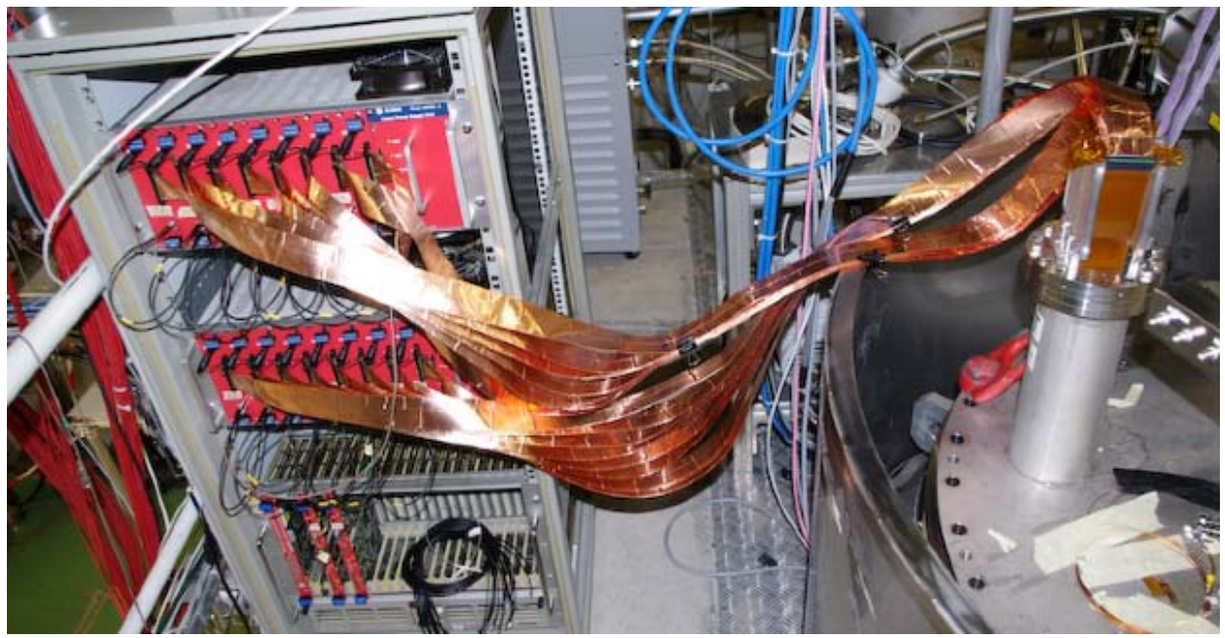
250L detector fully assembled



250L going into the ArDM cryostat



Final connection to the DAQ system



250L test in ArDM-1T @ CERN

Goal

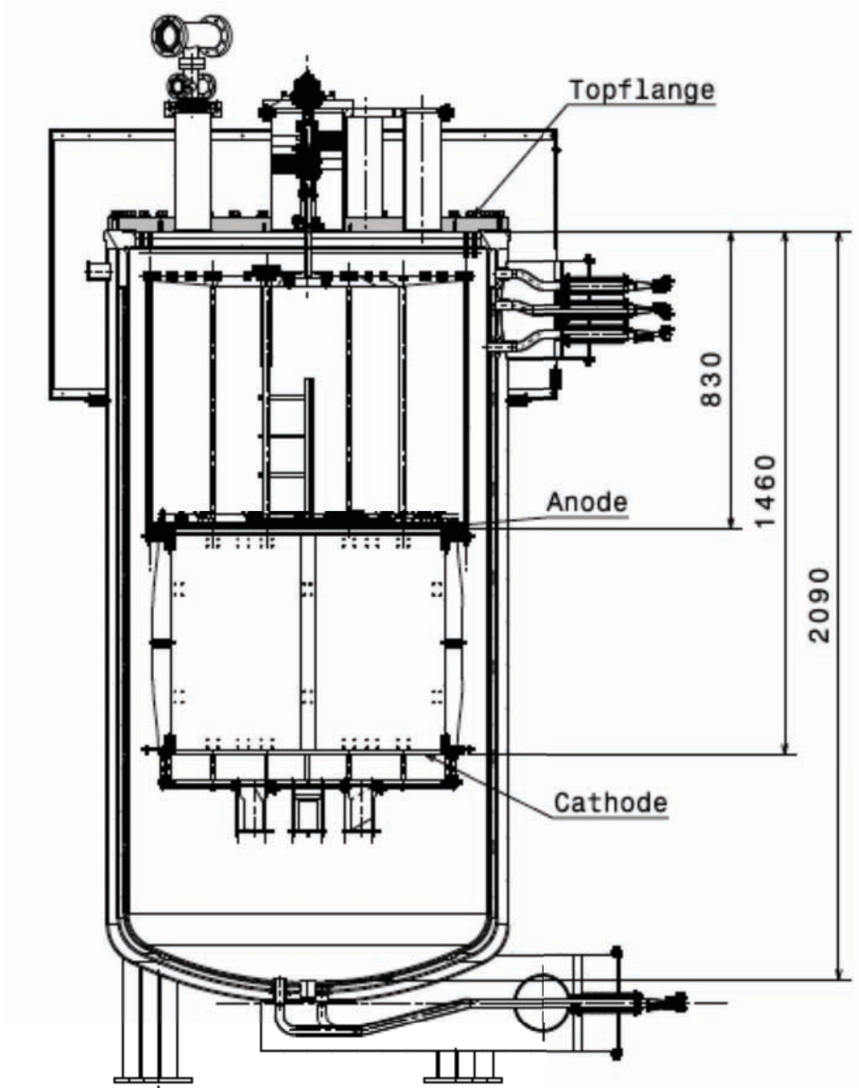
First operation of the largest LEM and 2D anode as readout for a double phase pure argon LEM-TPC

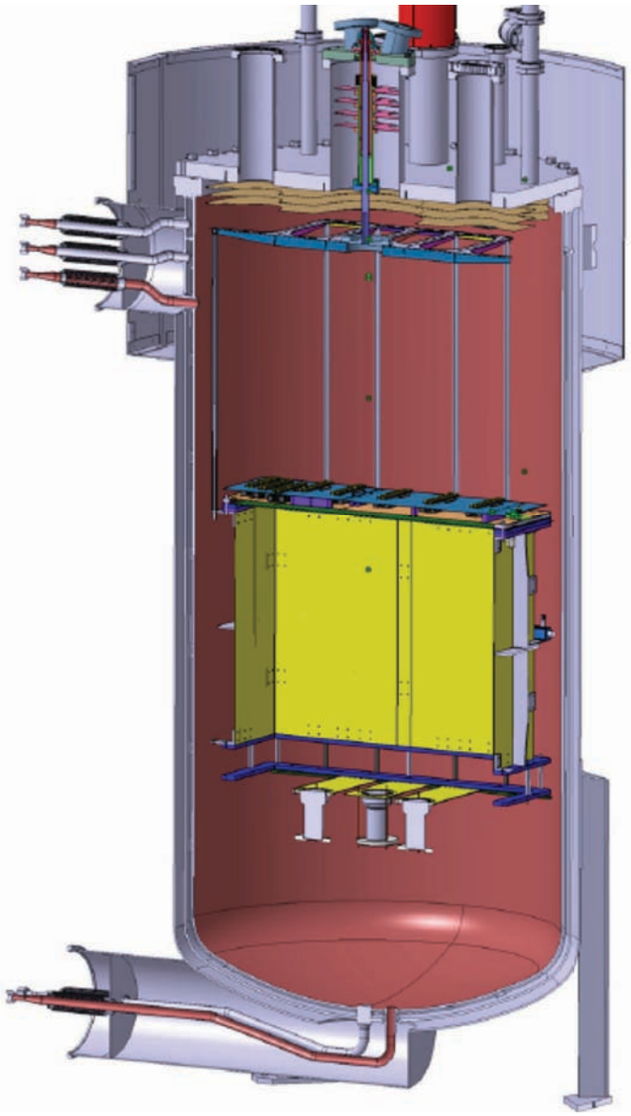
requirements

- **Purity:** less than few ppb of oxygen equivalent impurities are required in order to drift up to 60 cm in liquid argon

  ➡ a large cryogenic UHV vessel with liquid argon purification system in needed

- **Safety:** 1 ton of liquid argon (@87 K) requires safety devices (rupture disk, overpressure valves,...) and permanent monitoring (slow control system)





➡ The ArDM (Argon Dark Matter experiment) cryostat is being used for this test

ArDM cryostat @CERN

•independent gas and liquid purification circuits (needed to fill pure and keep the impurities below 1 ppb)
•The Ar bath is kept cold with two cryocoolers (extremely stable pressure: fluctuations O(mbar))

closed system: condenser (500 W cryocoolers)

GAr purification circuit

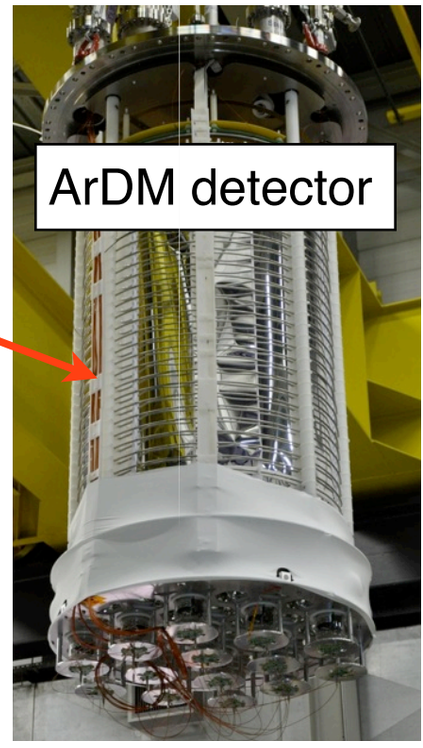
1. heating strips warming up cold GAr

3.SAES getter

2. membrane pump

4. LAr bath cools down warm & purified GAr

ArDM detector

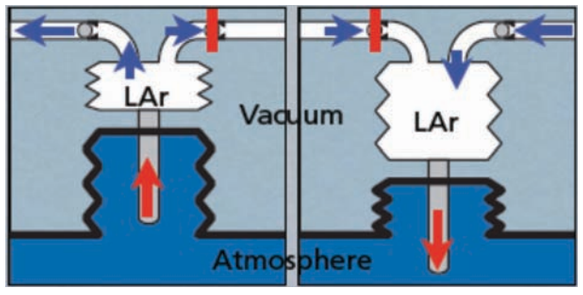


Cu purification cartridge

activated Cu (reddish)

after few seconds in air

LAr recirculation pump



Getting ready...

1. LEM HV test and cleaning in air (between 2-2.5 kV applied):
   - all sparks were randomly distributed, i.e. no defects!
   - after each spark the current went down to few nA!
   - ➡ conclusion: production OK, the LEM is basically functional
2. Evacuation (leak test, removal of impurities, outgassing)
3. Test in Ar-60 and Ar-isobutane (95/5) at room temperature
4. Sealing with Indium (against cold leaks), then evacuating down to $\approx 10^{-6}$ mbar
5. Filling the detector with one ton of ultra pure liquid Ar
   - electronegative impurity concentrations O(ppm) required by long electron drift of 60 cm
   - The leveling was done with 4 capacitive level meters (mm precision obtained)

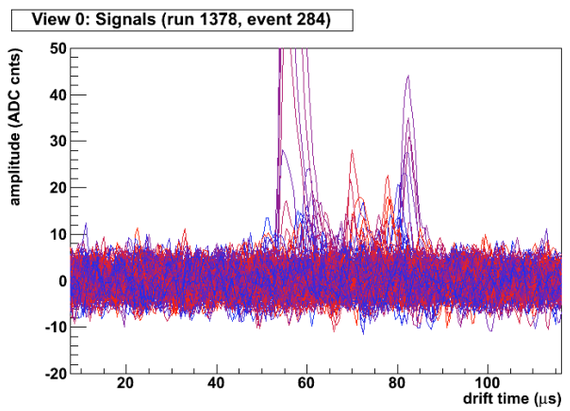
First operation in gas

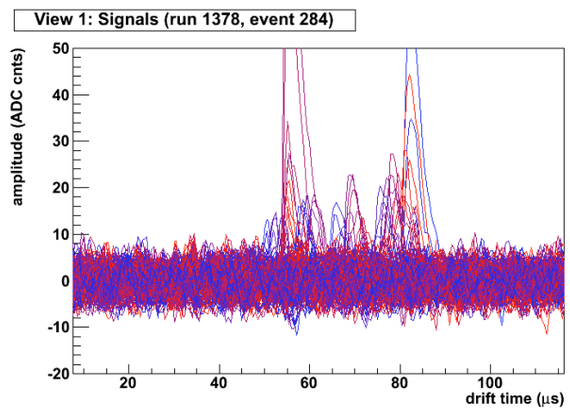
In order to check the functionality of the TPC (drift and charge readout) we did a first test with Ar-60 (*O*(ppm) of electronegative impurities) at room temperature

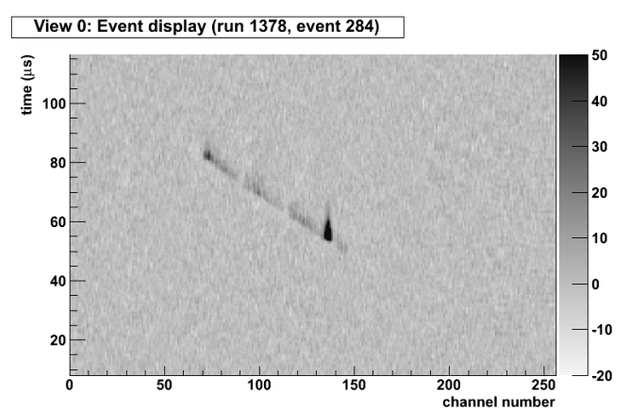
- breakdown point around 1.5 kV (gain <100)
- 3L setup breakdown around 1.7 kV (gains up to 1200 reached)

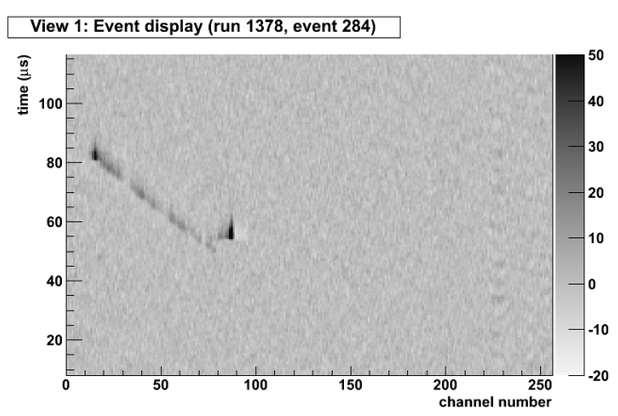
➡ performance of large LEM is worse than the 10x10 cm (smaller rim, larger area, production differences,...)

Minimum ionizing event in pure Ar-isobutane (95/5) @ 1 bar, room temperature

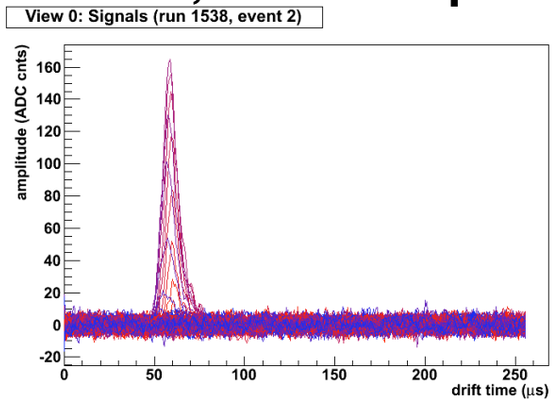


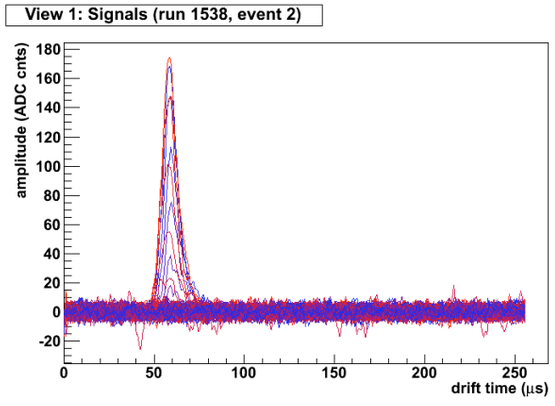


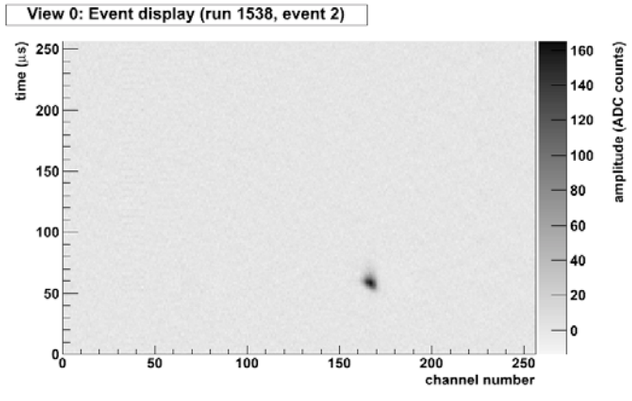


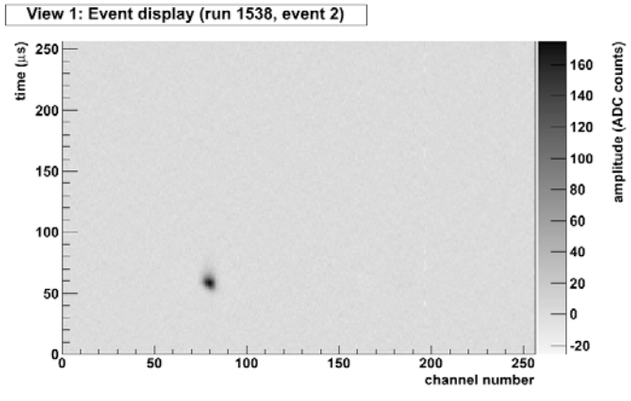


high ionizing event in pure Ar gas @ 1 bar, room temperature









- With Ar-isobutane (95/5) mixture we reached a sensitivity to see MIPs -> gain *O*(200)
- the TPC is working (full drift of 60 cm, all electrodes connected, no shorts,...)
- the charge readout is working!

➡ **Ready for double phase operation**

First operation in double phase Ar

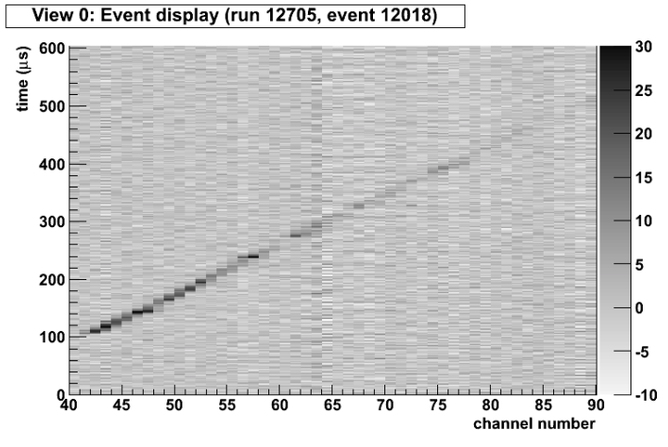
(very preliminary)

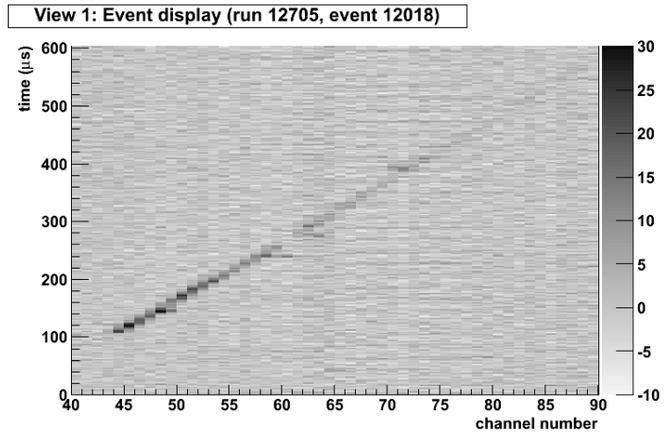
After completion of the filling and successful commissioning of the Cockcroft-Walton HV system we observed first events in double phase operation!

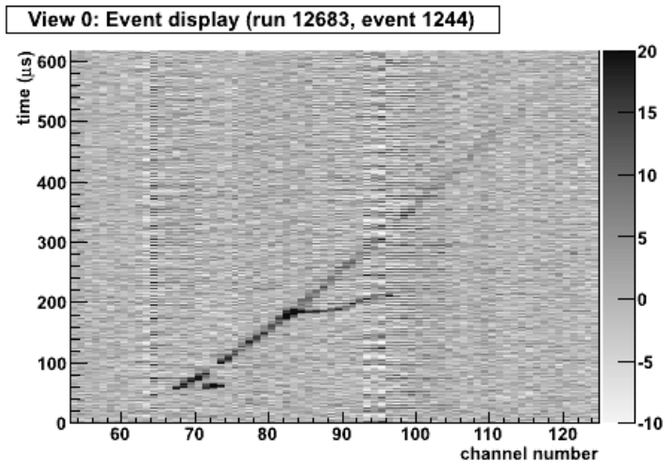
Field configuration

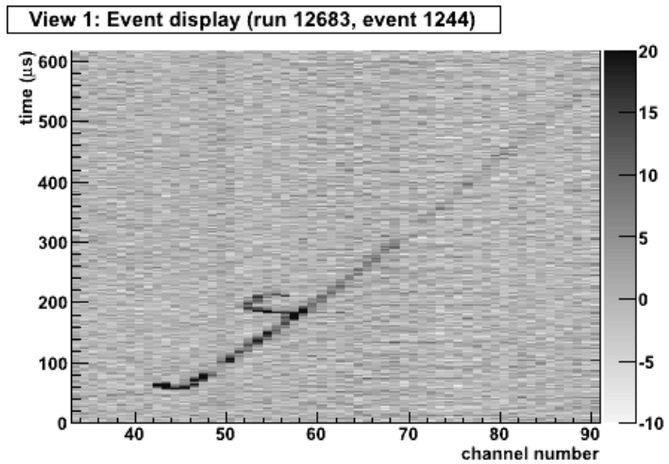
LEM-Anode	1800 V/cm
LEM	**30.5-31.4 kV/cm**
grid-LEM	600 V/cm
extraction	2300 V/cm
drift	200 V/cm

First cosmic ray triggers!

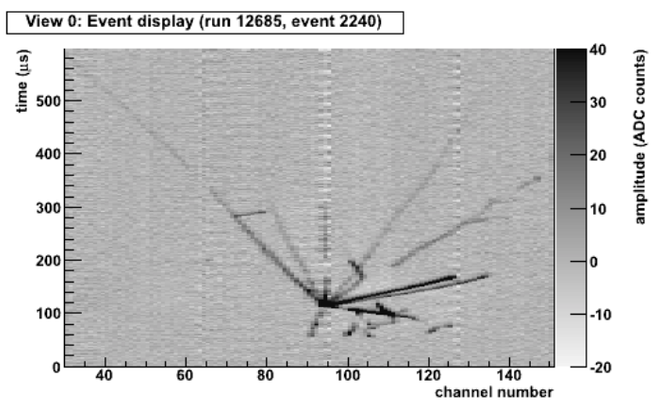


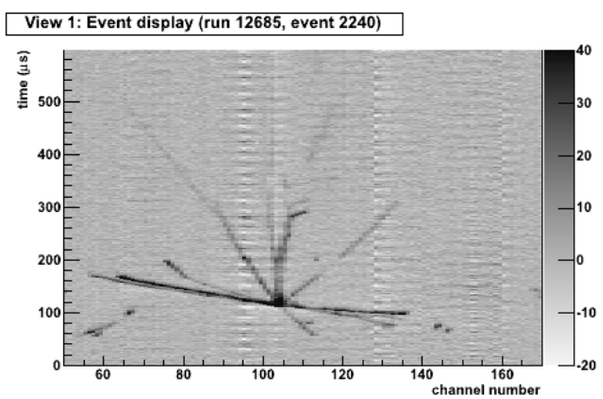


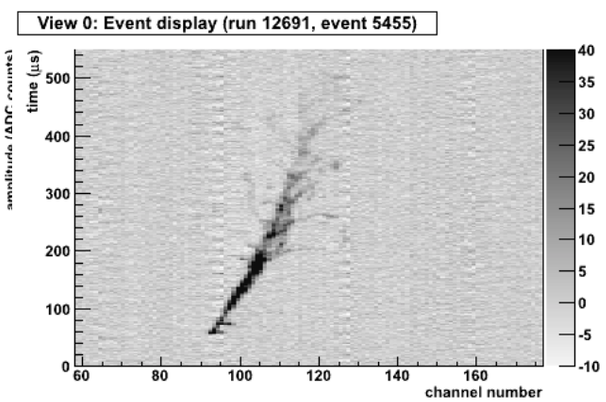


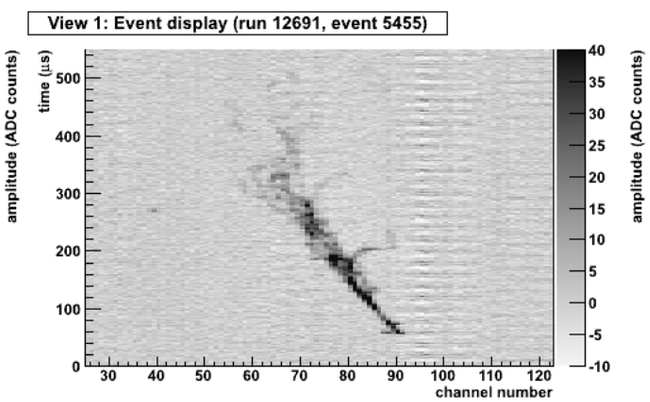


sometimes...









First operation in double phase Ar

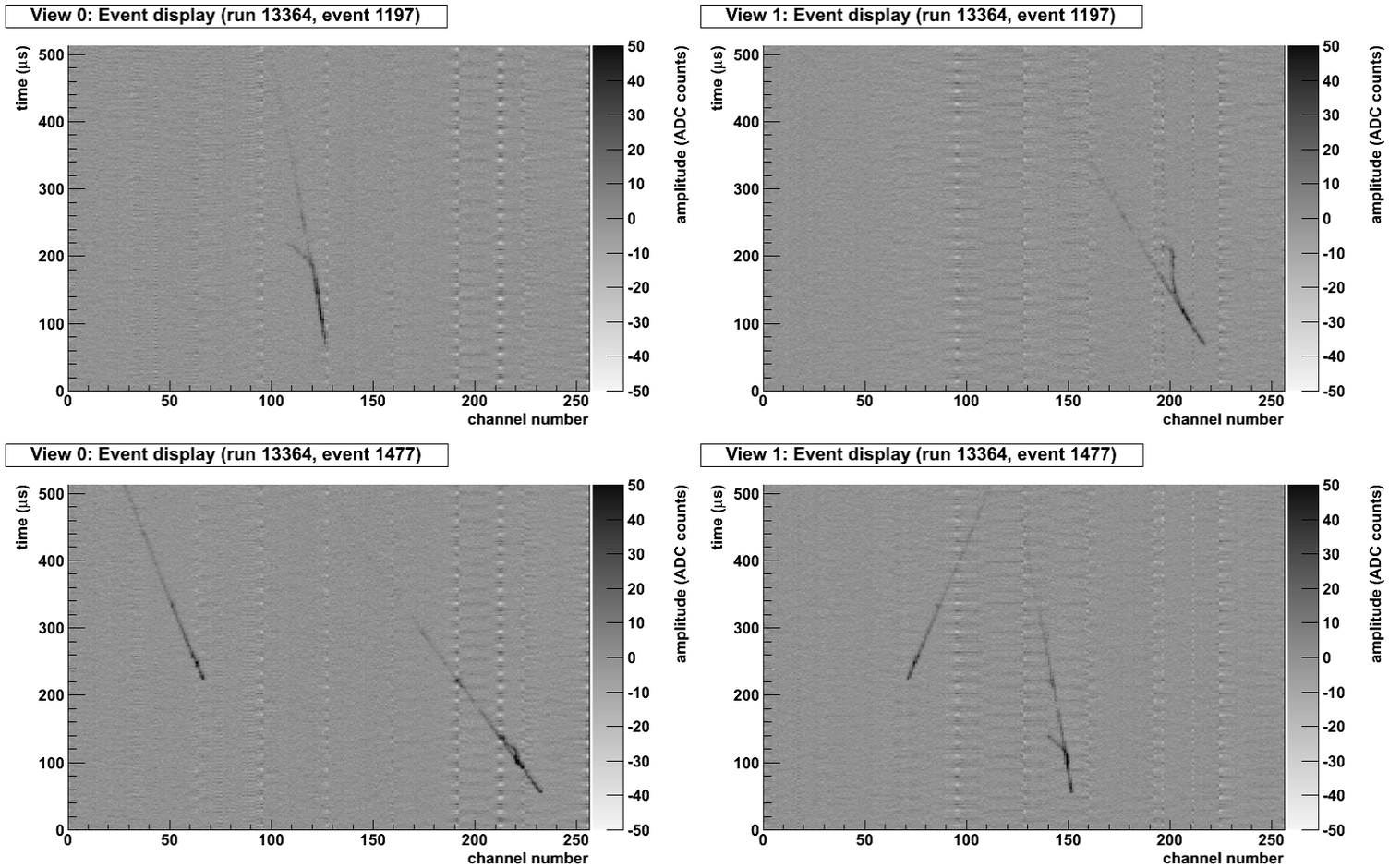
(very preliminary)

- The maximum field that could be applied to this LEM (1.03 bar & 87 K) was 31.8 kV/cm (to be compared with 35.5 kV/cm in case of the 10x10 cm² LEM).
- With the Cockcroft-Walton HV generator we reached a cathode potential of 35 kV without any breakdown (further ramping up planned at the end of the test)

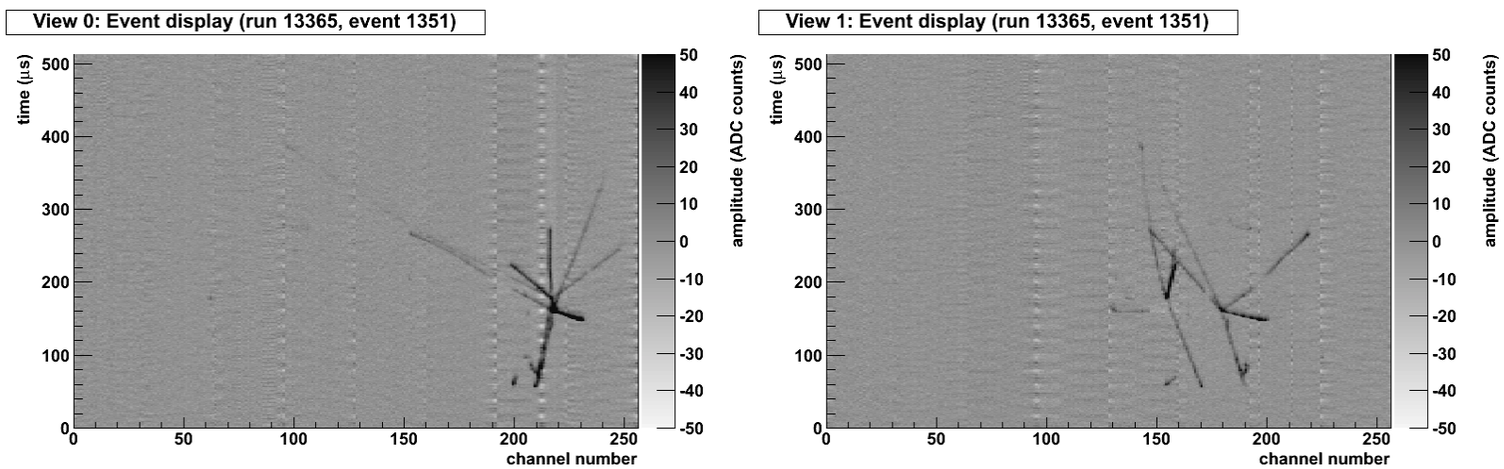
Field configuration

LEM-Anode	1900 V/cm
LEM	**31.8 kV/cm**
grid-LEM	600 V/cm
extraction	2000 V/cm
drift	400 V/cm

cosmic muon events



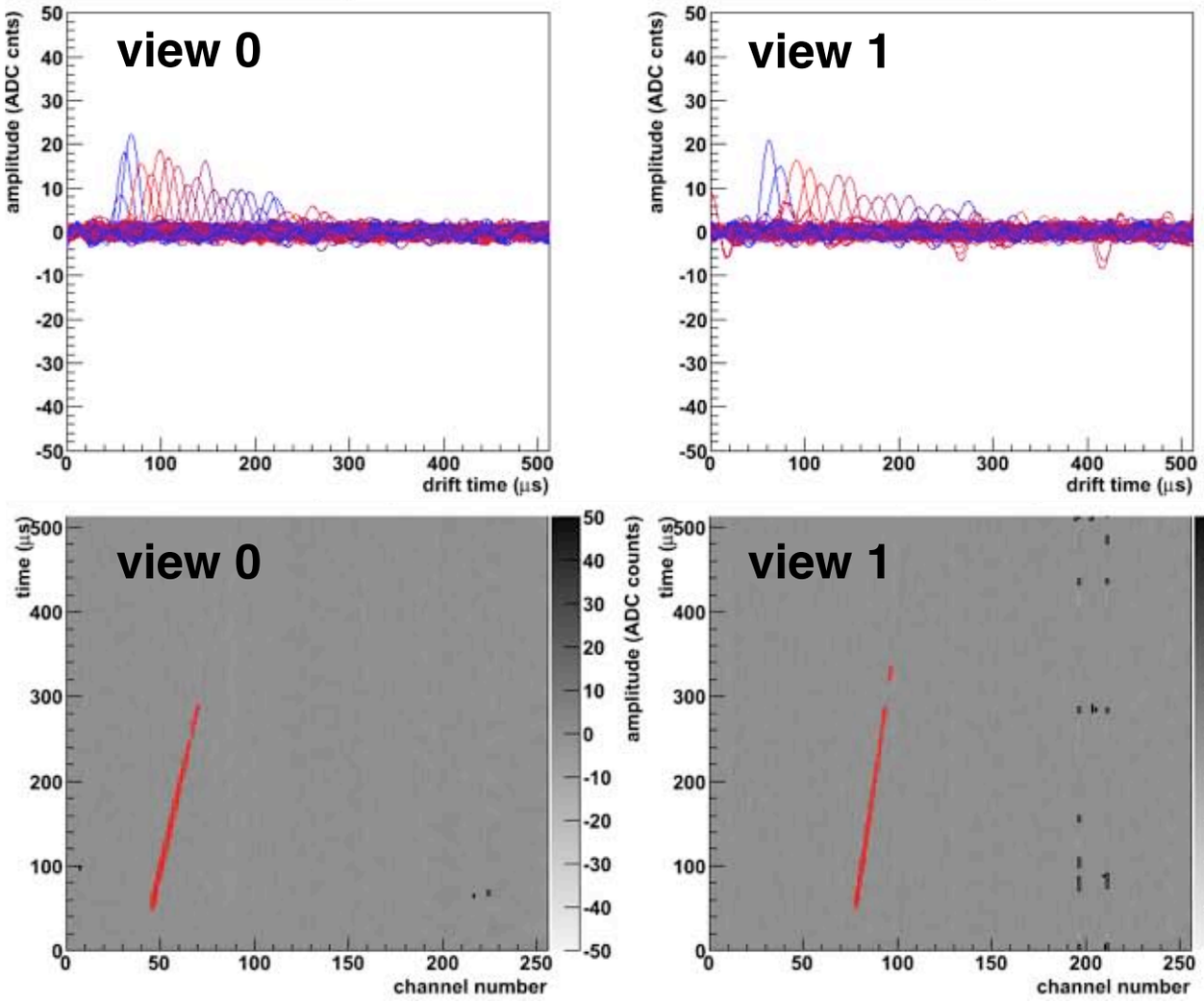
nuclear interaction



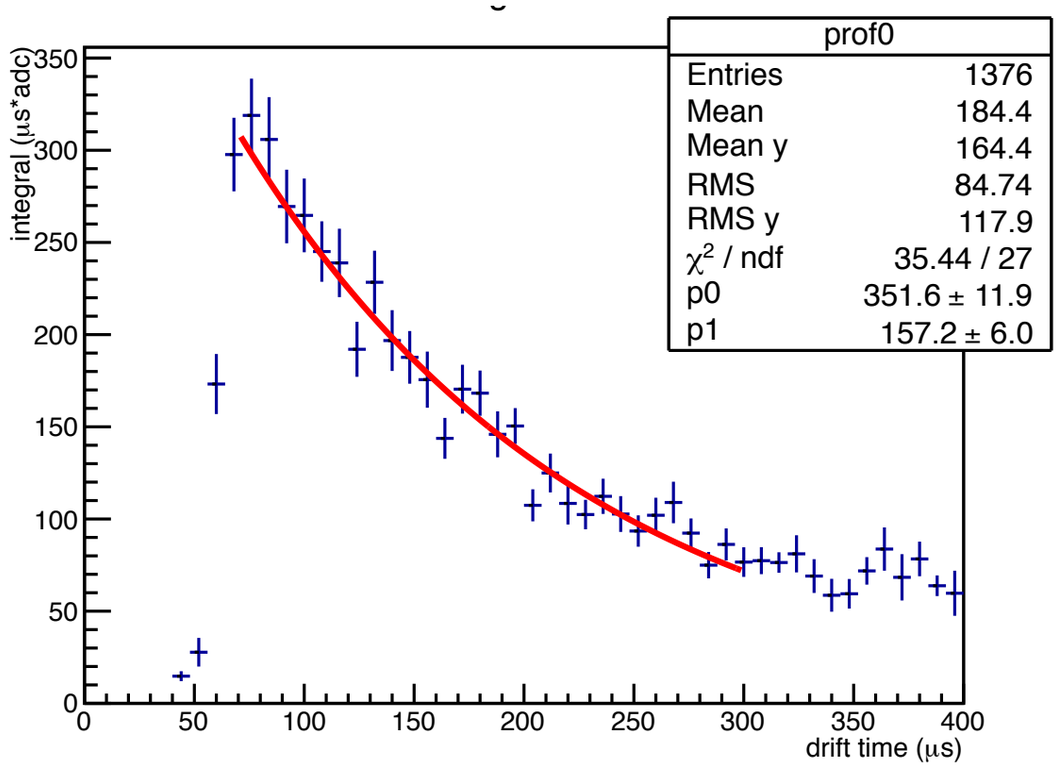
LAr purity estimation (preliminary)

The free electron lifetime / LAr-purity can be measured by reconstructing the charge attenuation observed in long straight tracks coming from cosmic rays

Reconstructed cosmic muon track



average free electron lifetime



- The resulting free electron lifetime is about 160 us
- The initial amount of electronegative impurities like O_2 or H_2O in the detector is ≈2 ppb

➡Currently the purification system is running in order to improve the purity.

Conclusions

- We are doing R&D for GLACIER, a next generation experiment for proton decay an neutrino physics
- A new LEM/2D anode based charge readout for LAr-TPCs has been developed and established with a 10x10 cm^2 prototype
- We produced the so far largest LEM/THGEM and 2D anode for a 250L double phase Ar LEM-TPC
  (special thanks to Rui De Oliveira and the CERN TS/DEM group)
- After first tests in gas at room temperature we filled the detector with liquid argon (87 K, 1.03 bar)
- Tracks seen in double phase operation are a new milestone!
- The test is still ongoing, addressing the improvement of the LAr purity.