Construction and operation of a double phase pure Argon LEM-TPC

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- Principle of a double phase pure Argon LEM-TPC
- The Large Electron Multiplier (LEM)
- 3 Liter setup at CERN
- Analysis of cosmic muon tracks
- Operation of a single stage 1 mm LEM
- Conclusion

Introduction

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

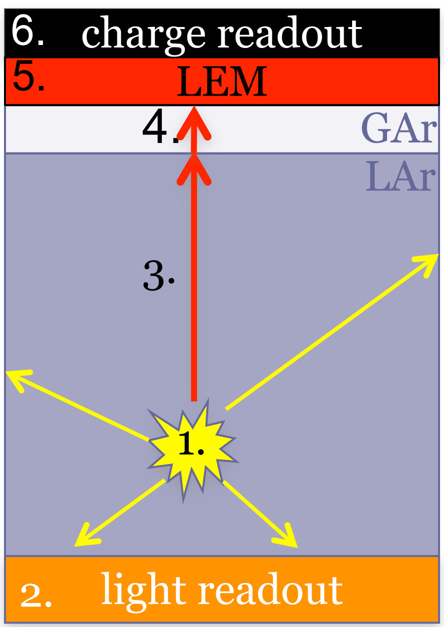
Why do we use liquid Argon?

•no electron attachment → transport of ionization charge permitted
•scintillation light emission at 128 nm
•high density: 1.4 g/cm^3
•energy loss of a MIP: dE/dx=2.1 MeV/cm
•relatively cheap and available (0.9 % of air)

Physics application

- Direct Dark Matter search experiment (ArDM): ton scale, required gain ≈ 100-1000
- detector for future neutrino physics and proton decay search: 100 kton scale, required gain ≈ 10

Principle of a double phase pure Argon LEM-TPC



1. Charge produced by an ionizing event
2. Primary scintillation light (VUV) detected with TPB coated PMT ($\rightarrow$ t_0 of the event)
3. Electric field drifts ionization electrons up to the liquid-vapor interface (500-1000 V/cm).
4. Extraction into the vapor phase (>2500 V/cm needed in order to be 100 % efficient)
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 (segmented) anode.

The Large Electron Multiplier (LEM)

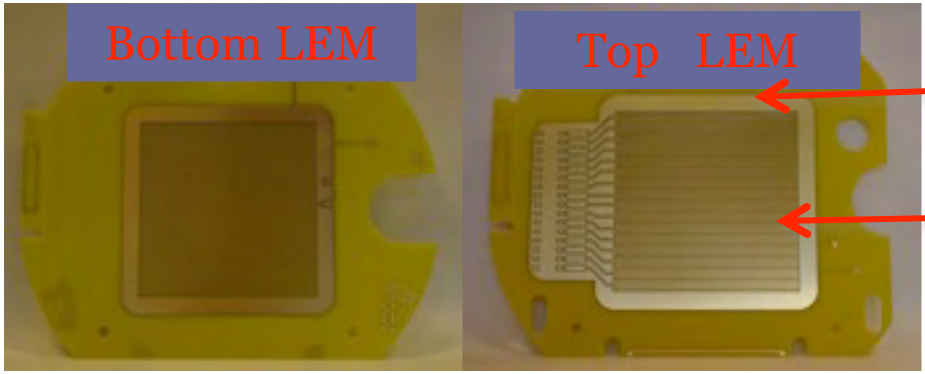
A LEM is a macroscopic hole multiplier (=thick GEM)

production (standard PCB techniques):
•double-sided copper-cladded FR4 plates
•electrodes are gold plated
•precision holes by drilling
•etched dielectric rims (reduced discharge probability)

characteristics:
•High discharge resistivity
•mechanically robust
•electrode can be segmented (spatial reconstruction)
•possibility to cover large areas (m^2 modules)

considered geometries:

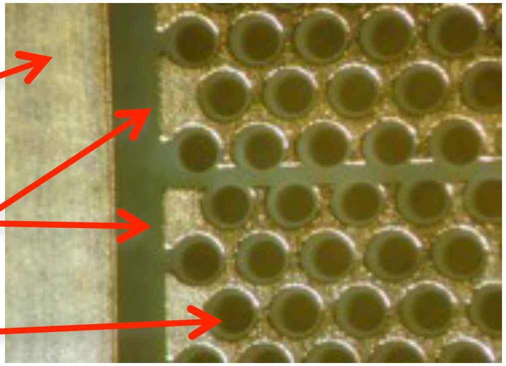
total area	10×10 cm^2
thickness	0.6, 1.0, 1.6 mm
hole diameter	500 μm
hole pitch	600 μm
rim size	10 μm, 50 μm
segmentation	16 strips, 6 mm pitch



guard ring

6 mm strips

dielectric rim



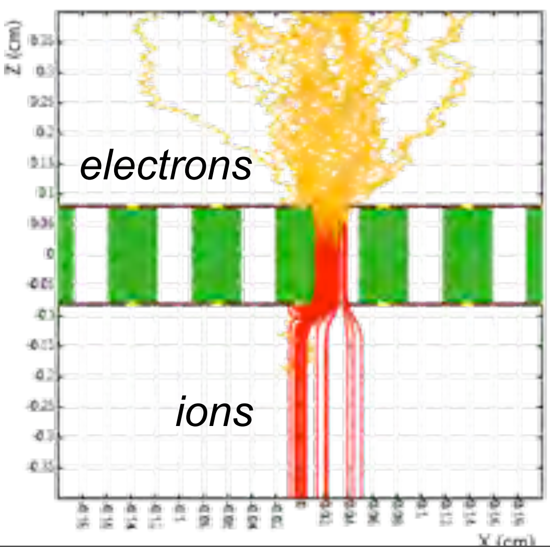
Townsend multiplication

- e^- are driven into the first LEM holes, where multiplication occurs due to a high electric field.
- gain of a Townsend multiplication:

$$G = e^{\alpha x}$$

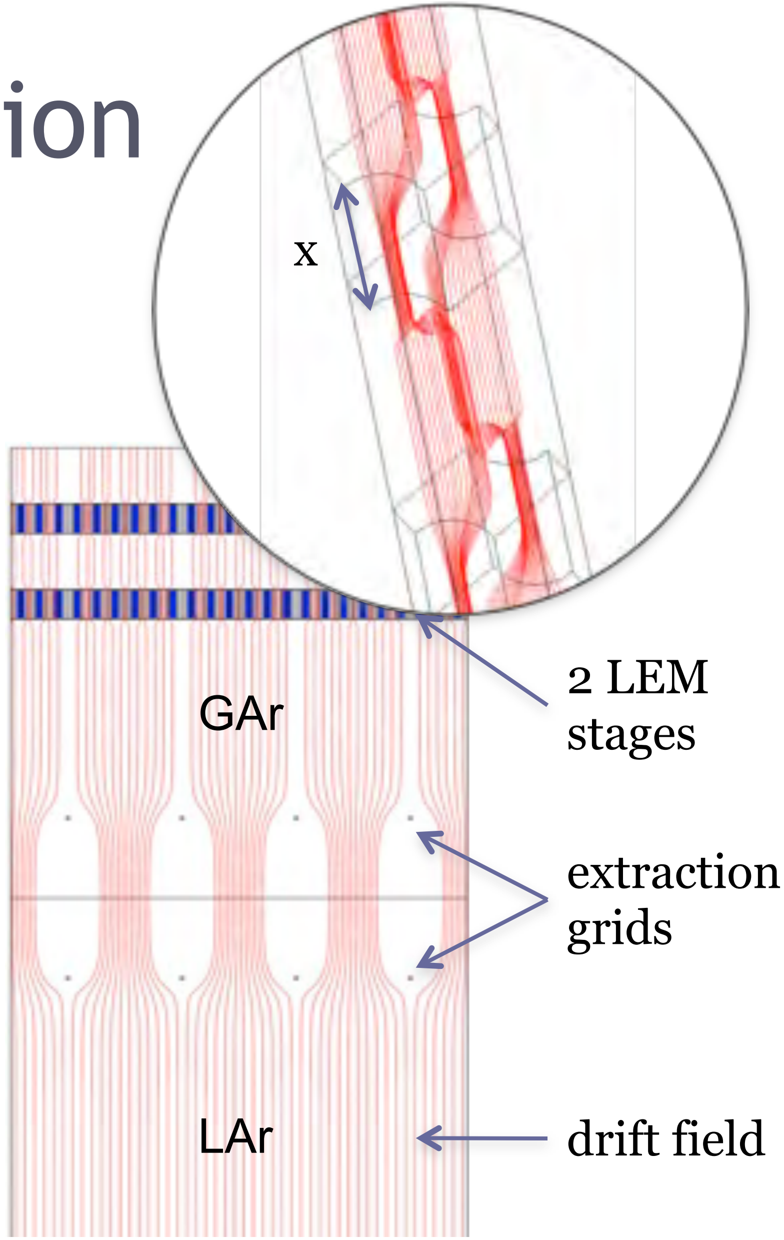
x: effective multiplication length

$\alpha = Ape^{-Bp/E}$: first Townsend coefficient



left:
electron avalanche simulation of a single stage LEM (Garfield)

right:
field computation (COMSOL)

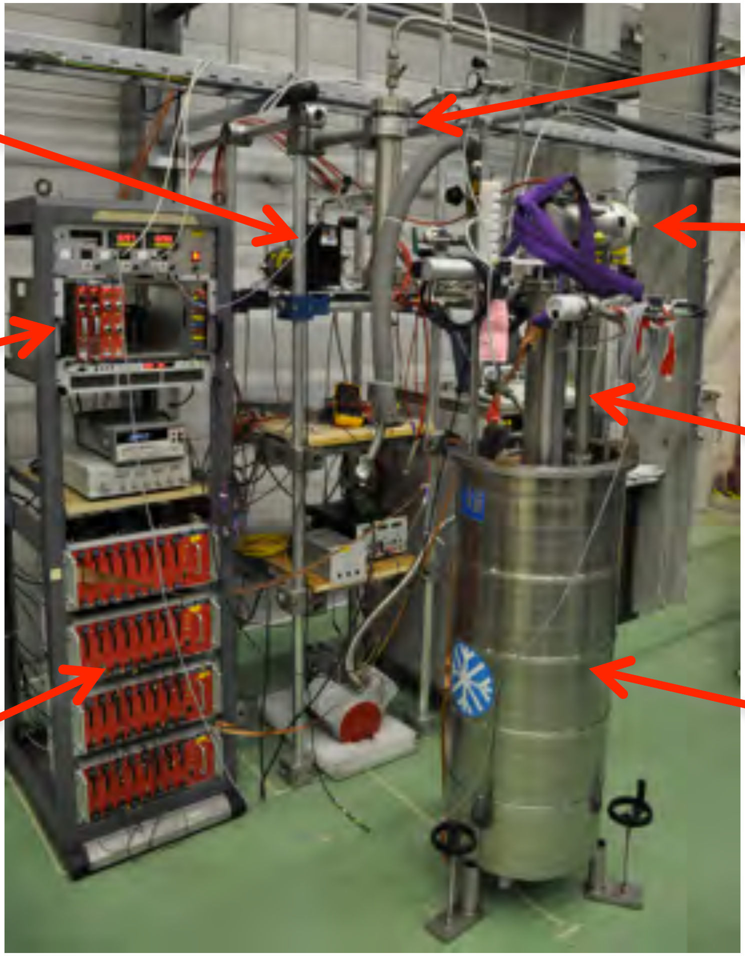


3 Liter test setup at CERN

Argon purification system

power supplies

complete DAQ system for LAr TPC's (ETHZ/CAEN)



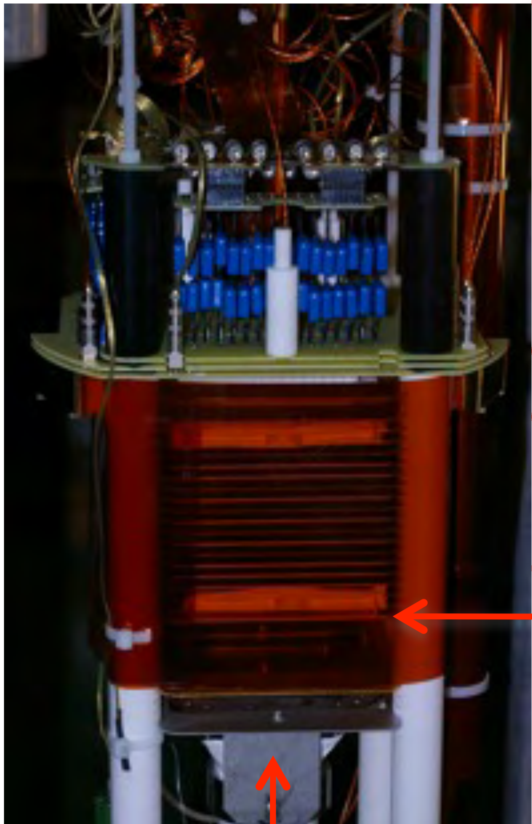
purification cartridge

turbo pump

detector vessel

cryostat (open LAr cooling bath)

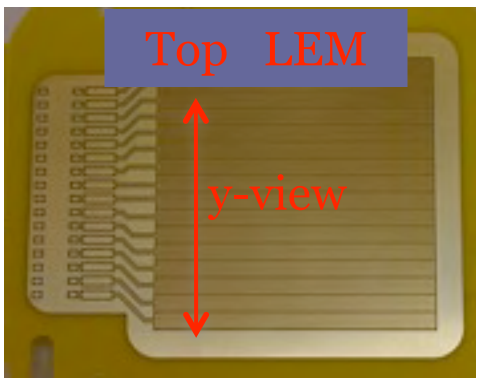
Description of the double stage LEM-TPC

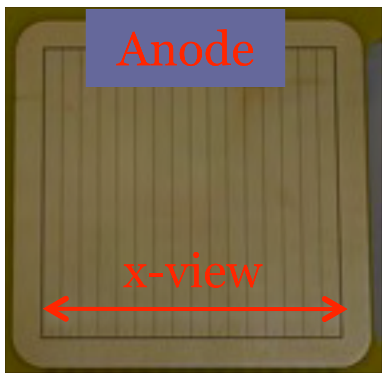


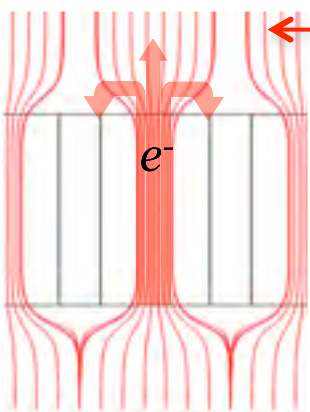
The charge readout

After the amplification the electrons induce signals on electrode strips
2 views allow the spatial reconstruction of ionizing events

1.) Top LEM and anode segmented
x-and y-view: 16 strips, 6 mm pitch



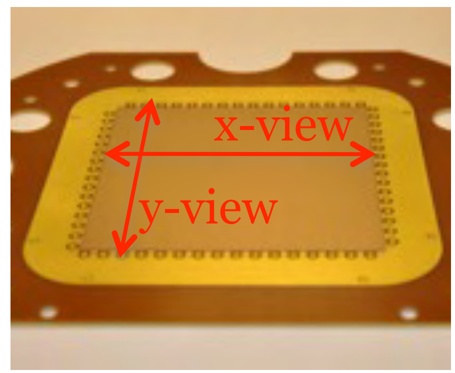


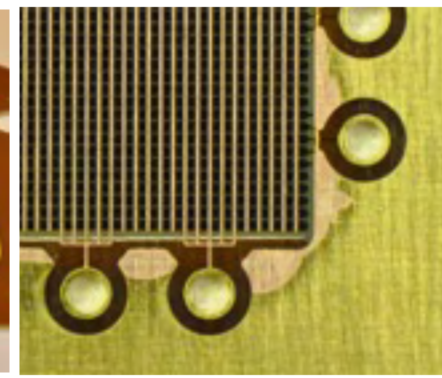


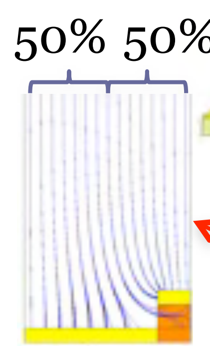
e^- drift lines

ideal configuration:
50% collected on the top LEM plane
50% collected on the anode

2.) Projective anode (LEM not segmented)
x- and y-view: 32 strips, 3 mm pitch







COMPASS experiment at CERN

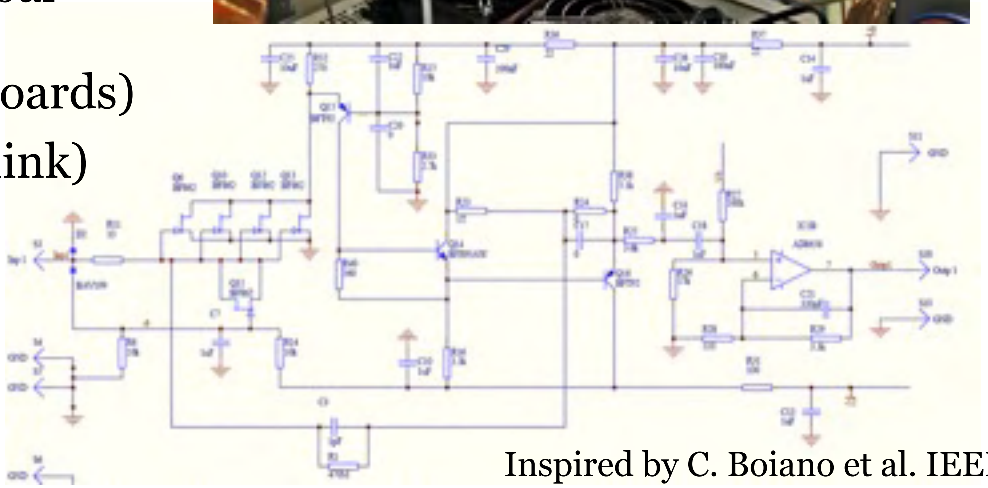
Charge is equally shared between x-view and and y-view-electrodes.

→ to be tested

Readout electronics

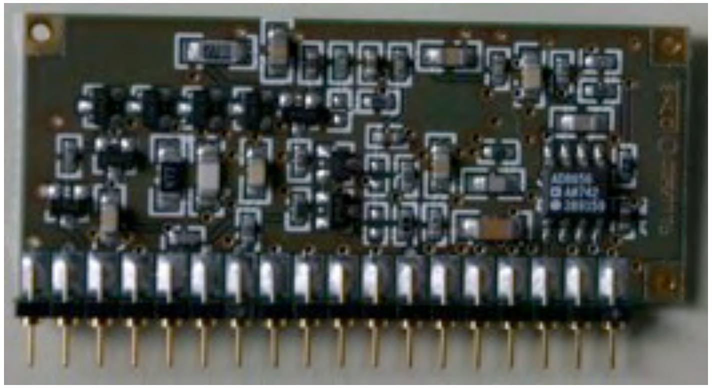
Novel complete readout system developed in collaboration with CAEN:

- 12 bit 2.5 MS/s flash ADC's
- programmable FPGA
- channel-by-channel trigger and global "trigger alert".
- 256 readout channels per crate (8 boards)
- modular system (chainable optical link)



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

custom made front-end low-noise preamplifier (hybrid)

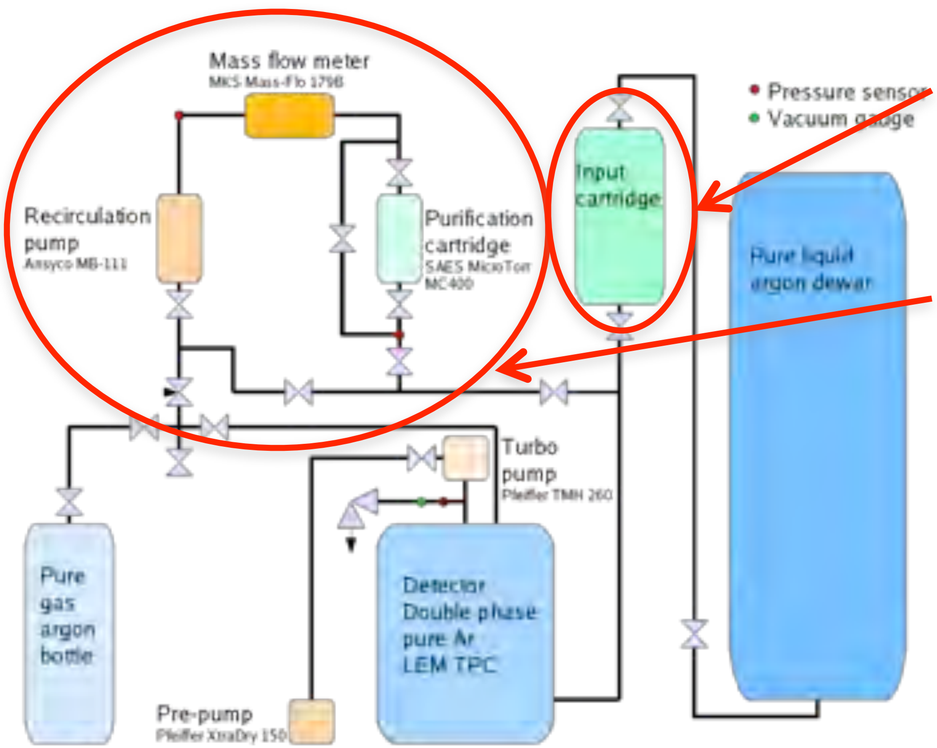


- RC=470 us, sensitivity=12 mV/fC
- shaper: rise time 0.6 μs, fall time 2 μs
- S/N @1 fC=10 (200 pF input capacitance)

The Argon purification system

Electronegative impurities (O_2, H_2O and CO_2) capture ionization electrons.
Probability given by $e^{-t/\tau}$, drift electron lifetime $\tau(\mu s) \approx 300/[O_2]_{eq}(ppb)$

In order to drift 20 cm with 1 kV/cm, a contamination of ≈2 ppb is required
➡ Argon purification system needed (due to out-gassing of materials, leaks)



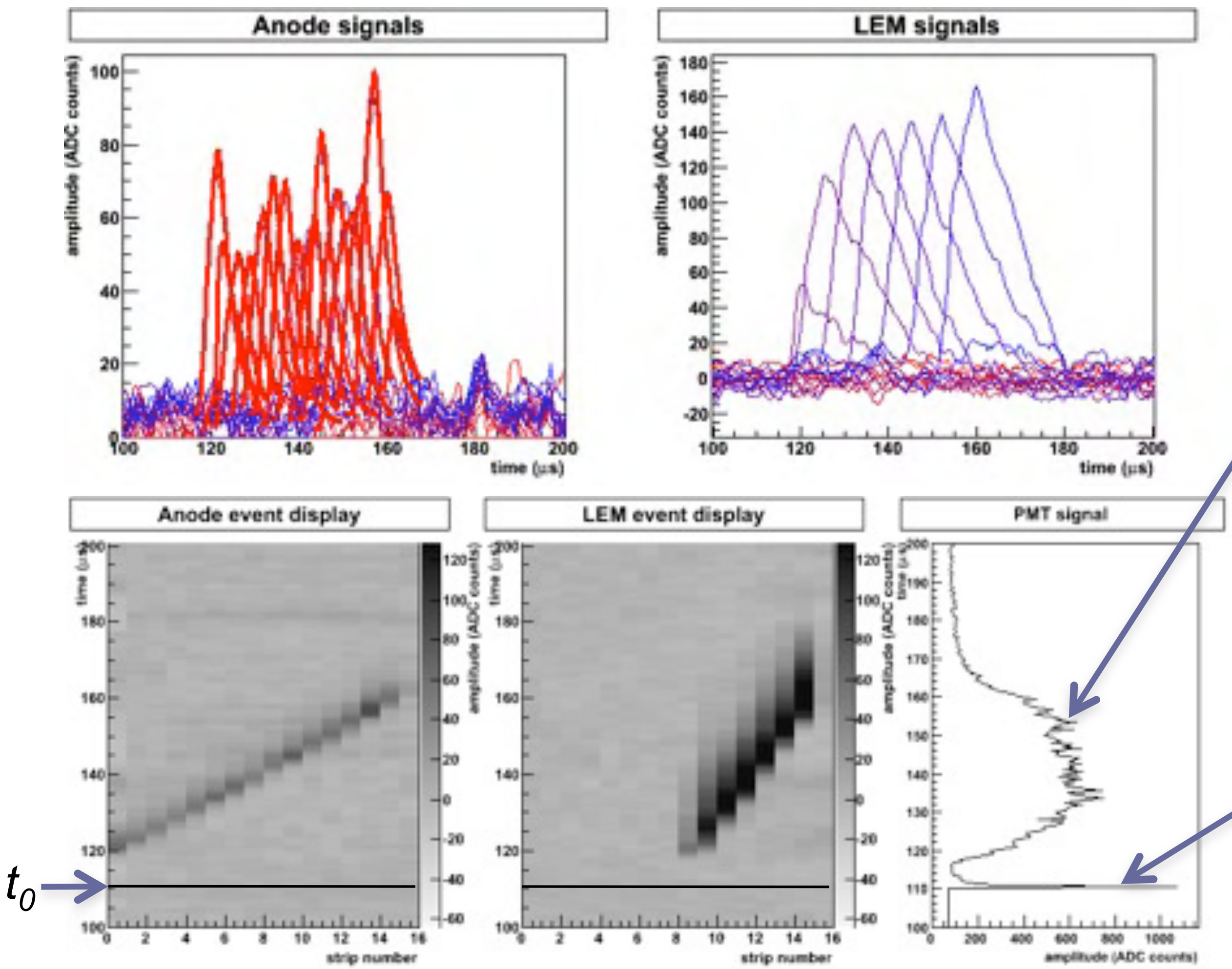
Input LAr purification

- Custom made cartridge for LAr purification at detector input.

GAr purification circuit

- Heating resistors evaporate LAr in the detector.
- A metal bellows pump pushes GAr into a SAES getter (~48h to recirculate 1 volume).
- Purified GAr condensates into the detector volume.

Analysis of cosmic muon data



signal and event display of a typical cosmic muon track

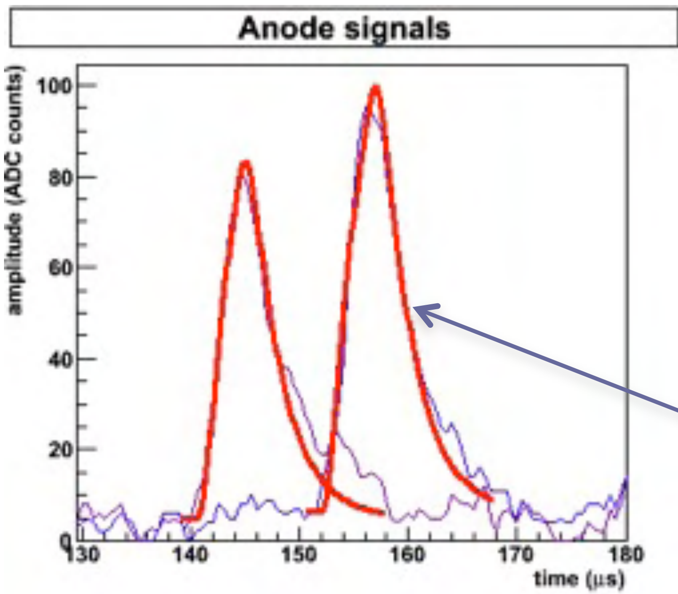
Proportional light

Produced by electrons in high field regions in gas (extraction grid, LEM holes)

Scintillation light

Primary light due to muon crossing LAr

Muon track reconstruction



1. **Hit finding and parameterization (strip by strip)**
   - signal/noise discrimination
   - extract physical information:

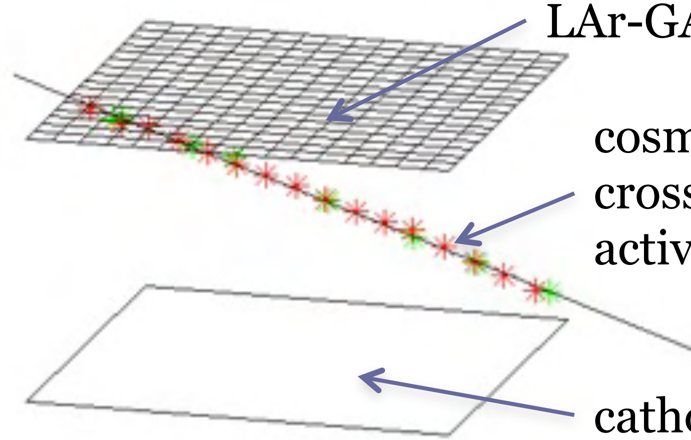
     integral proportional to collected charge

     drift coordinate is given by by $(t-t_o)v_{drift}$

     Preamp. response function fitted to each anode signal (short e^- induced signals)

2. **2D clustering (anode- and LEM-view)**
3. **2D track reconstruction**

   (parameterization of linear tracks)
4. **3D track reconstruction**

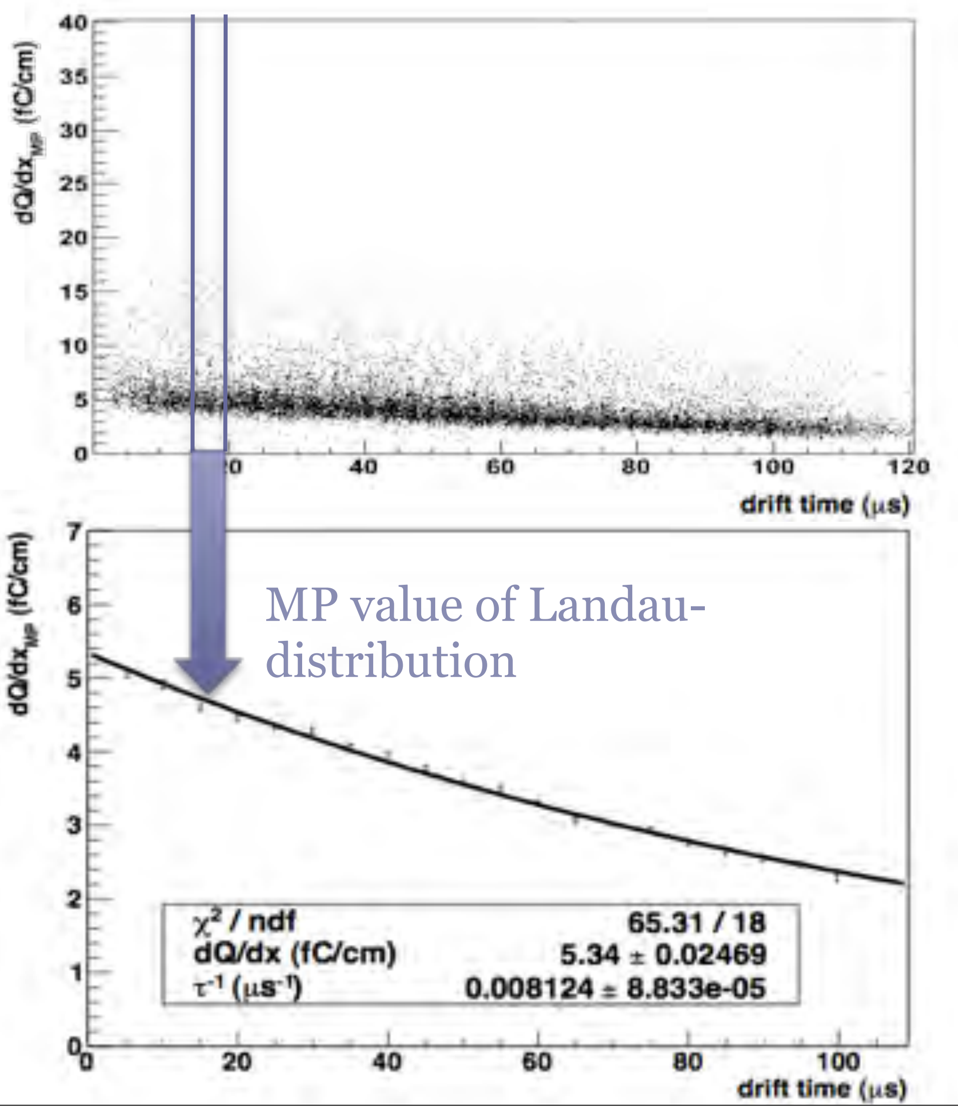


Electron lifetime correction

Charge attenuation due to electro-negative impurities in LAr
→ **correction necessary**

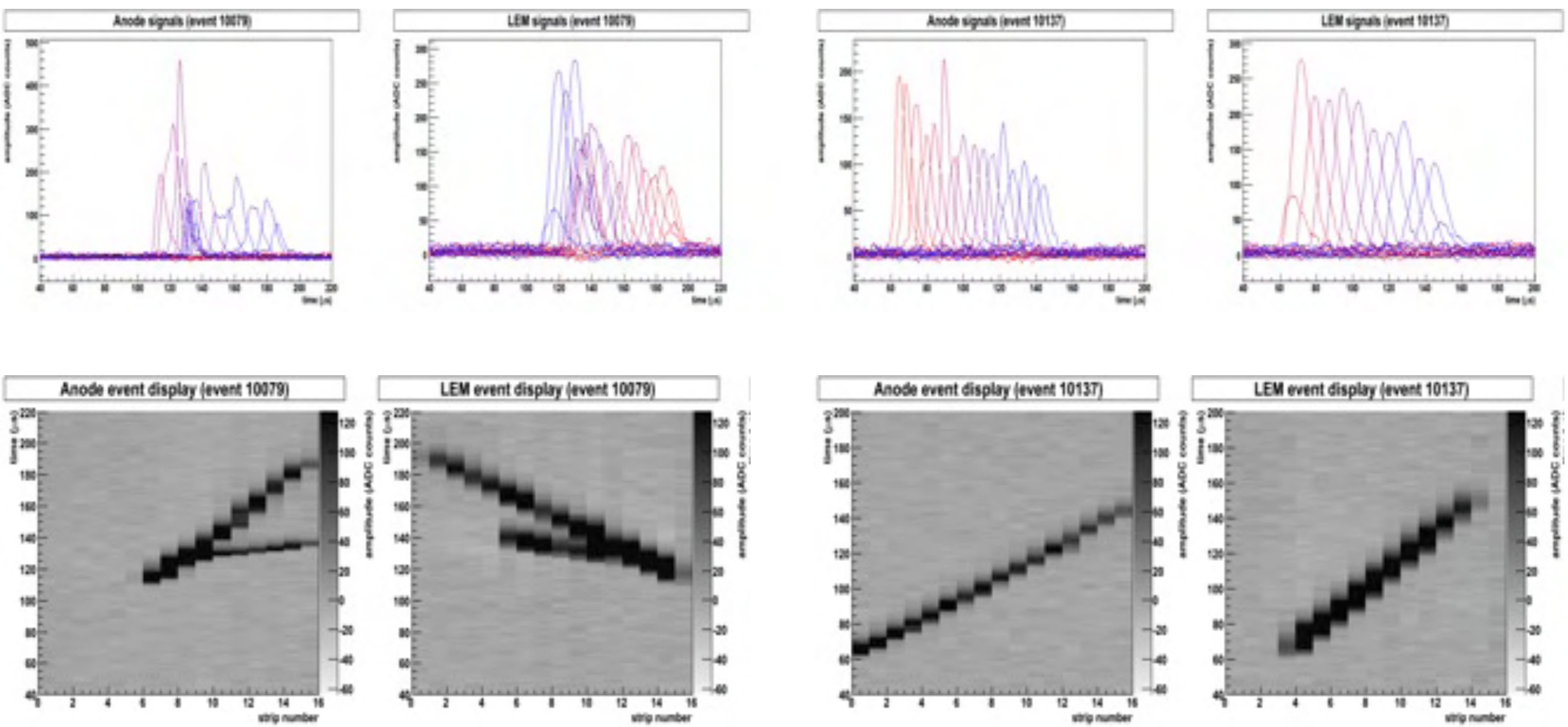
dQ/dx (ionization loss per unit length) of cosmic muons can be used to obtain the free electron lifetime

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



Operation of a single stage 1 mm LEM

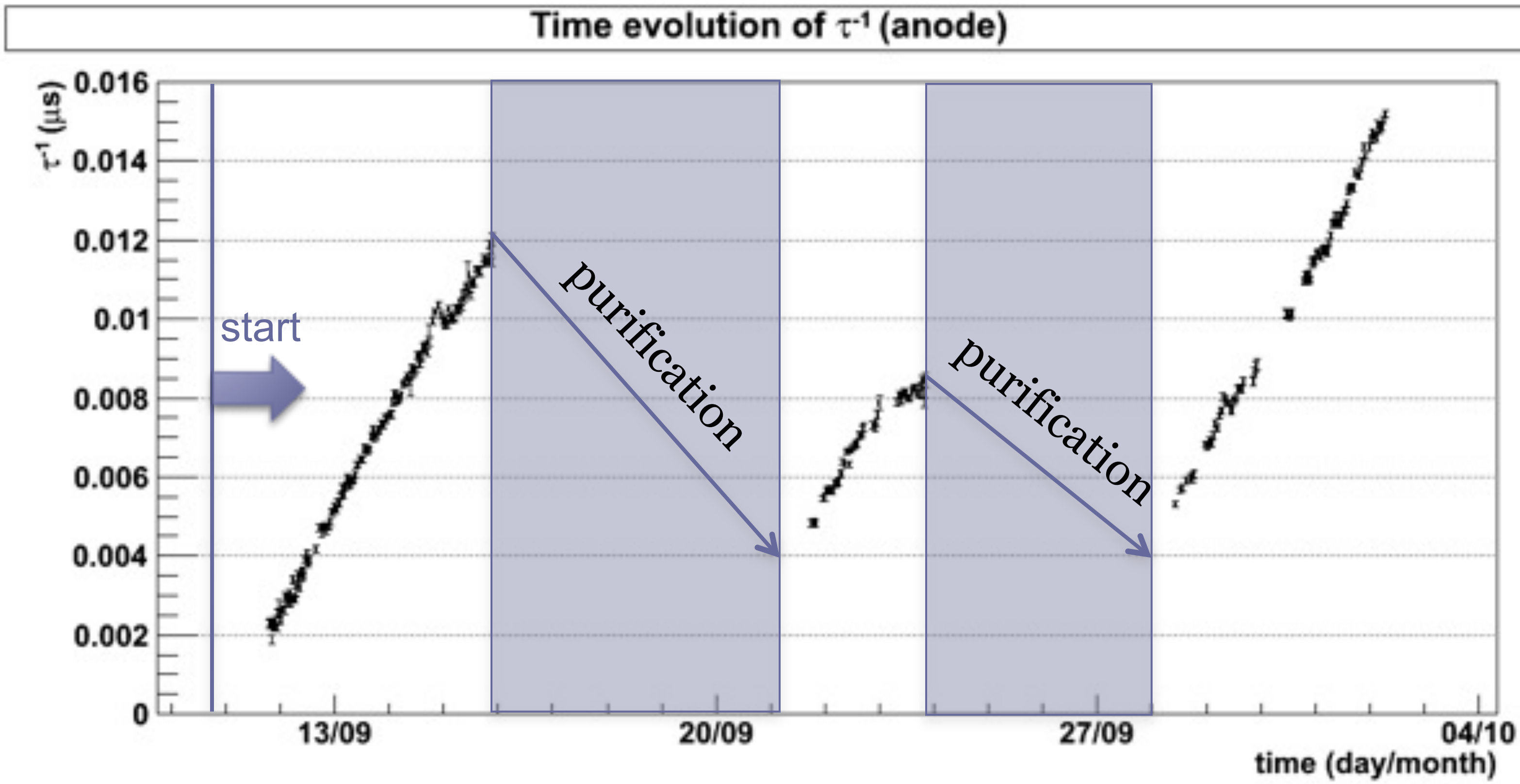
Operation mode: double phase argon, 1 bar, 87 K
data has been taken during three weeks



Purity monitoring during the run

cosmic muon data used to determine the LAr purity

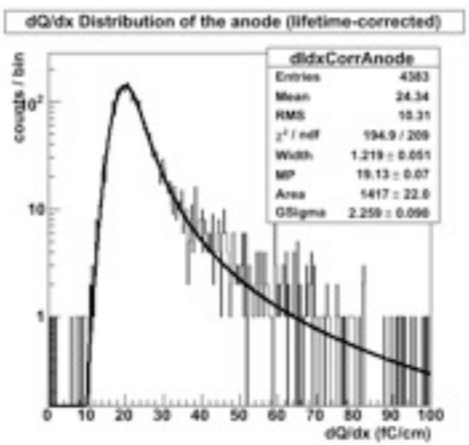
$$[O_2]_{eq}(ppb) \approx 300\ \tau^{-1}\ (\mu s^{-1})$$

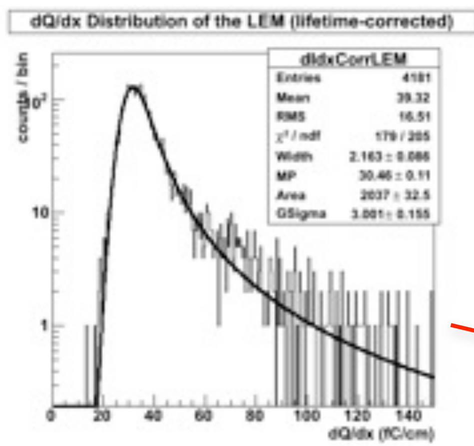


- very good initial purity (<0.6 ppb)
- purification system works as expected!

Results

dQ/dx distribution of long muon tracks, fitted with a Gauss convoluted Landau distribution:

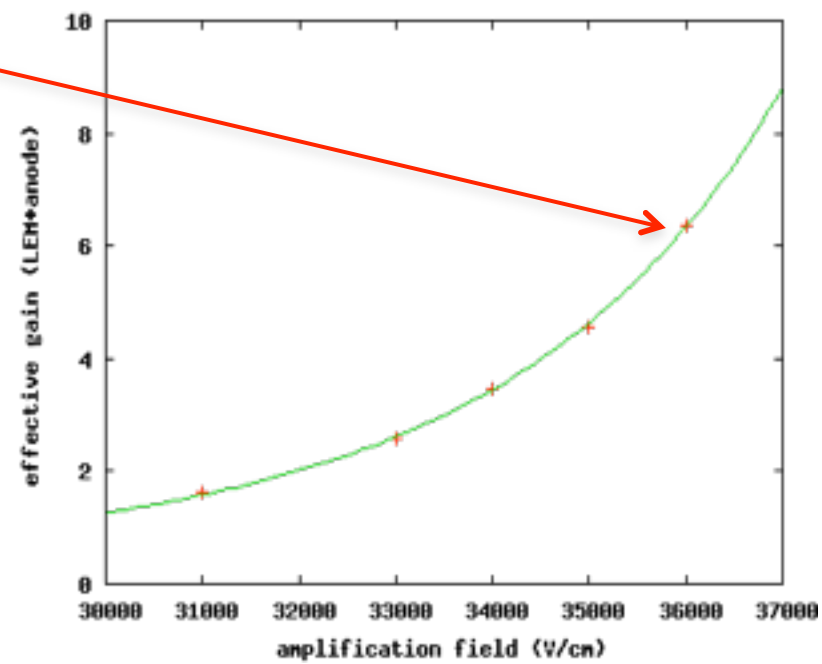




in LAr a MIP releases 2.1 MeV/cm

→ ionization charge after recombination (drift field ≈500 V/cm)

dQ/dx≈10 fC/cm



Results:

energy resolution ≈ 12%

total mean value = 64 fC/cm

→ **achieved gain ≈ 6.4**

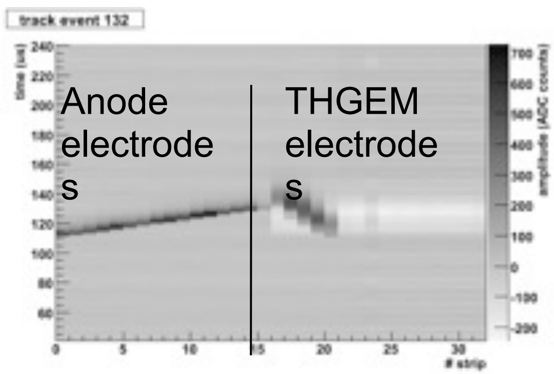
Conclusion

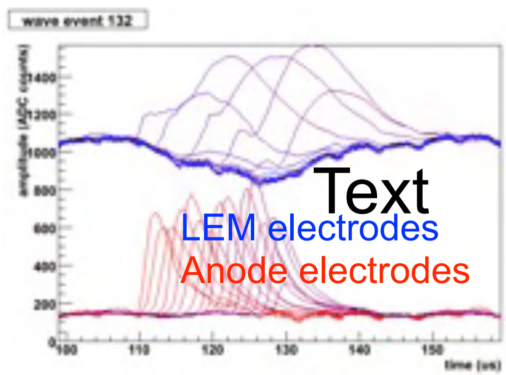
- Successful construction and operation of a 3 liter double phase pure Argon LEM-TPC.
- Proof of working principle:
    - Drift of ionization charge up to 20 cm
    - Charge multiplication in pure Argon gas (gain 6 with a 1 mm single stage LEM reached)
- Cosmic muon samples used to characterize the device

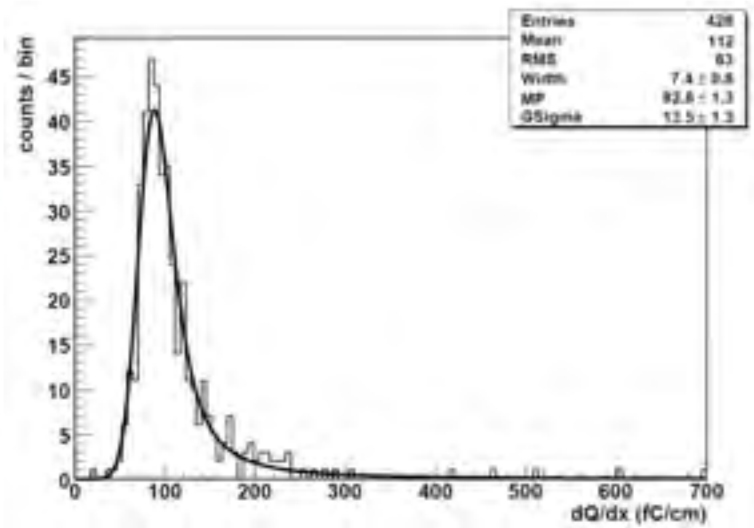
Future Plans

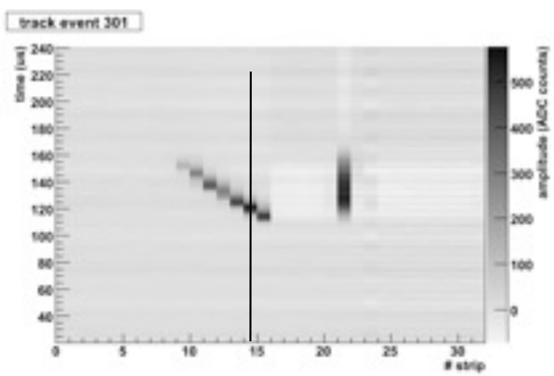
- Ongoing tests of different LEM geometries
- Design of a 80×80 cm^2 charge readout for ArDM

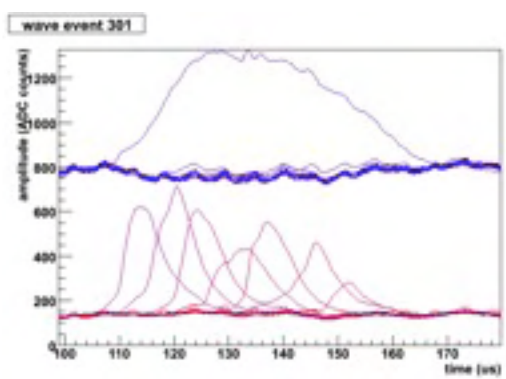
Backup slide: Operation of a double stage 1.6 mm LEM











Results:

energy resolution ≈ 16%
mean value (anode) = 112 fC/cm
achieved gain (anode) ≈ 10