Dual Phase LAr TPC

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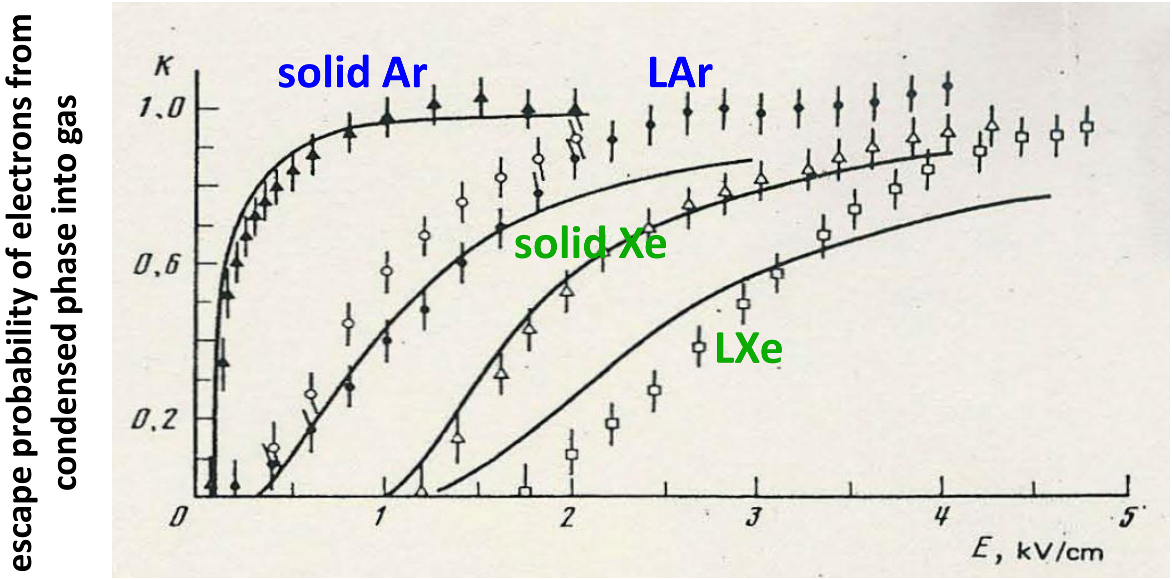
- **Dual phase LAr detectors**
- **The LAr LEM TPC concept**
- **A first 10x10 cm^2 prototype**
- **Towards a large area LEM TPC: a 40x76 cm^2 assembly**
    - **HV generation by an immersed Cockroft-Walton (Greinacher) voltage multiplier**
- **An improved 10x10 cm^2 prototype**
- **Plans for a 6x6x6 m^3 prototype**

Dual phase concept for LAr detector

- In 1968 Alvarez suggested the use of liquid noble gases as high spatial resolution detectors (low diffusion of electrons in liquid) , and as total absorption counters

- In 1970, to obviate to the unsuccessful attempts to achieve charge amplication in LAr, Dolgoshein proposed and successfully tested the main features of dual phase argon detectors



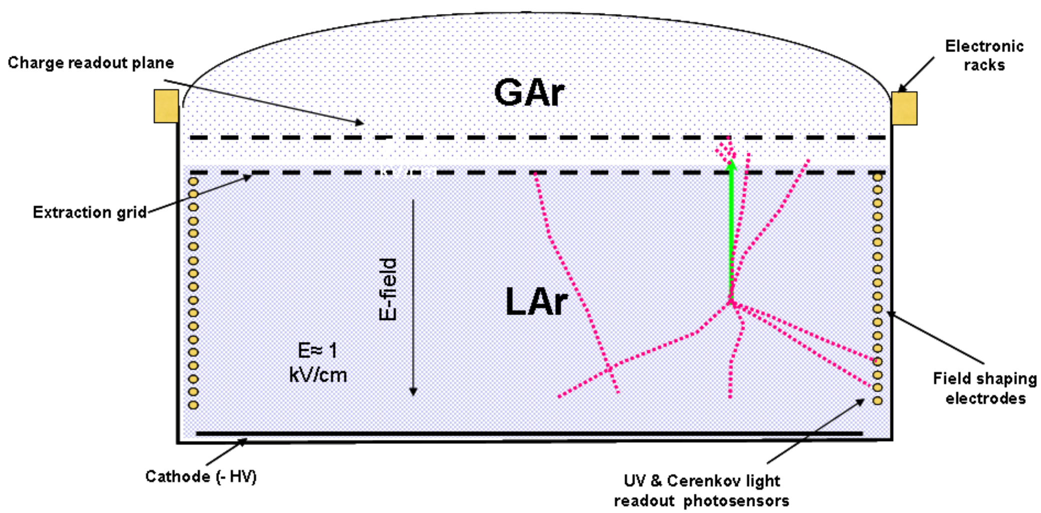
E.M.Gushchin et al.,
Sov. Phys. JETP 55 (1982) 860

- See A. Buzulutskov JINST 7 (2012) C02025 for a recent review

LAr LEM TPC

- **LAr LEM TPC**
  - **dual phase LAr TPC with ionization charge amplification in pure Ar gas**
  - Large Electron Multiplier (LEM), also known as Thick GEM
  - introduced by A. Rubbia, NO-VE Workshop, Venice 2003, hep-ph/0402110
  - **flawless reconstruction (also for low energy events e.g. Supernova) requires excellent signal to noise ratio and collection view provides best imaging**
  - **long drift paths (compensation for diffusion and charge attenuation)**
  - **reduced number of channels**

The GLACIER concept



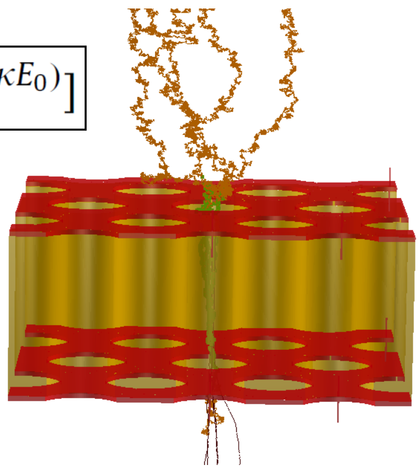
LAr LEM TPC Concept

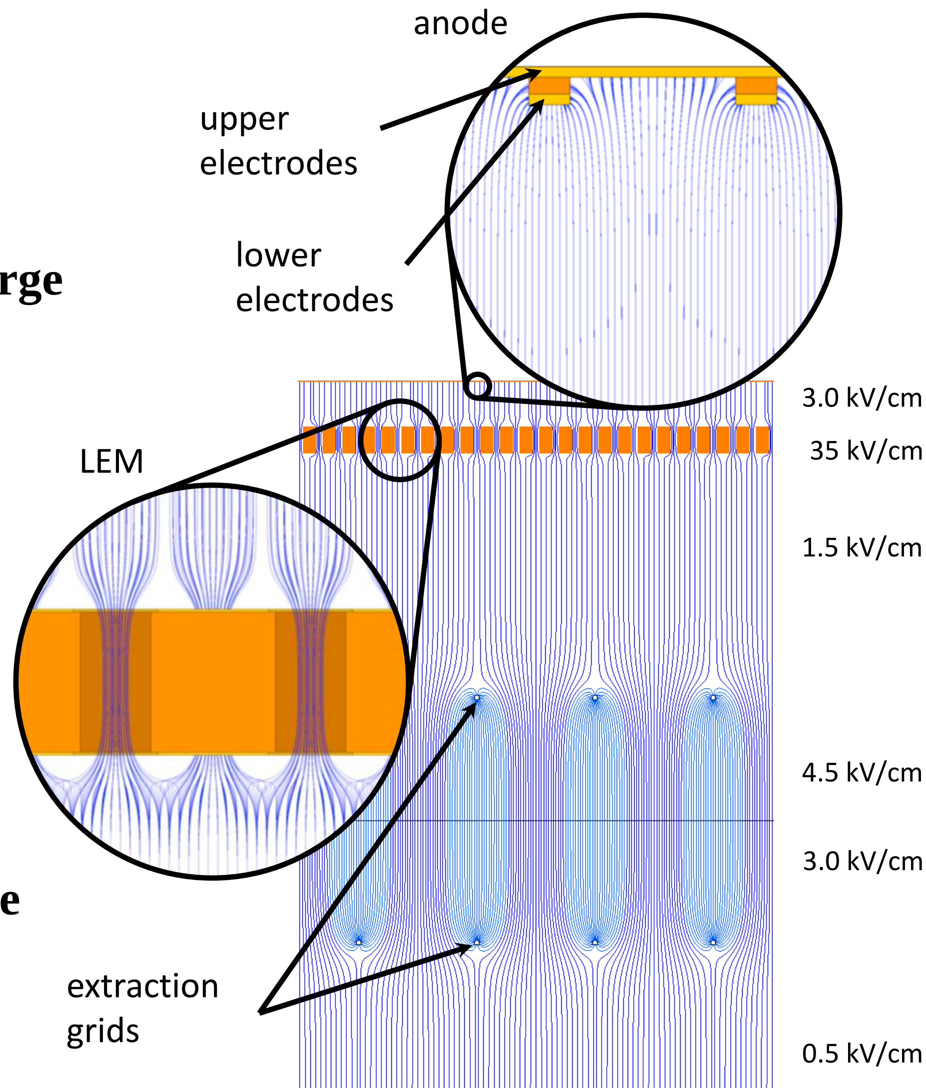
4. Charge collection on a 2D anode readout
(symmetric unipolar signals with two orthogonal views)

3. Charge multiplication in the holes of the Large Electron Multiplier (LEM) in pure Ar gas

$$G_{eff} \equiv T\exp[A\rho x e^{-B\rho/(\kappa E_0)}]$$

Garfield simulation of an electron avalanche

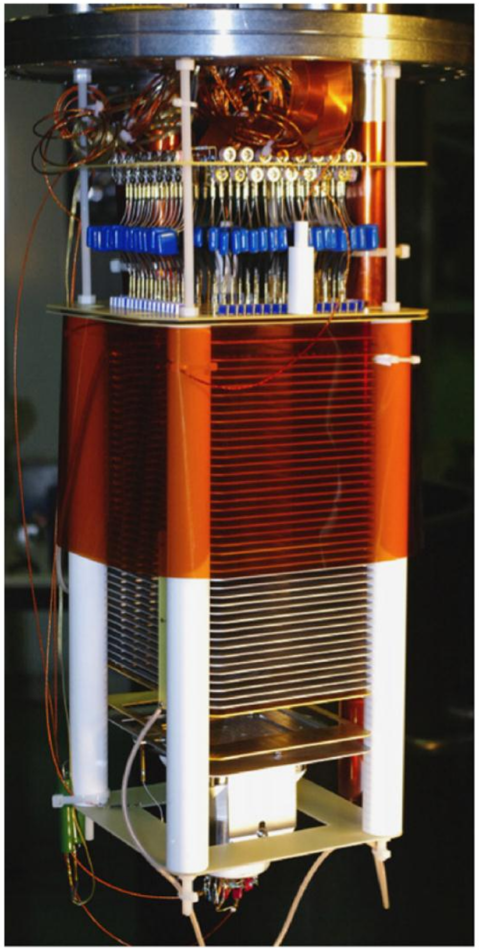


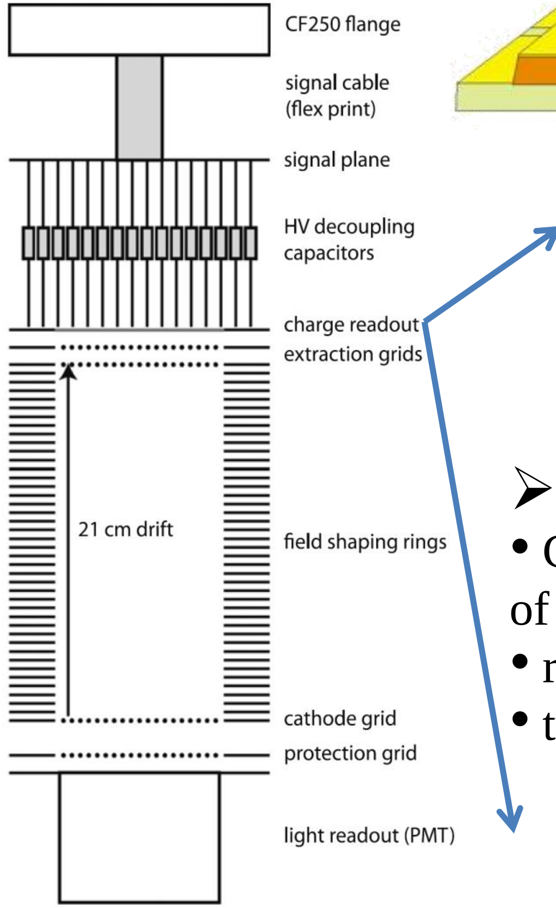


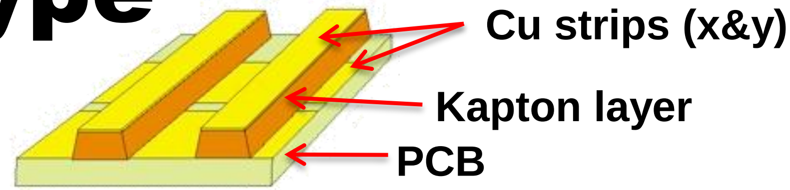
2. Drift electrons are efficiently emitted into the gas phase

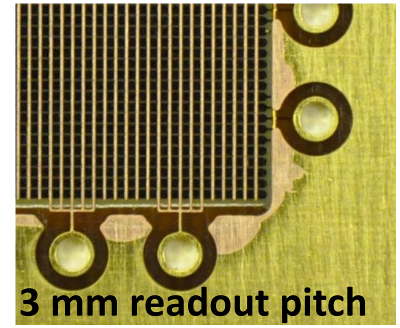
1. Ionization electrons drift towards the liquid argon surface

10x10 cm^2 prototype



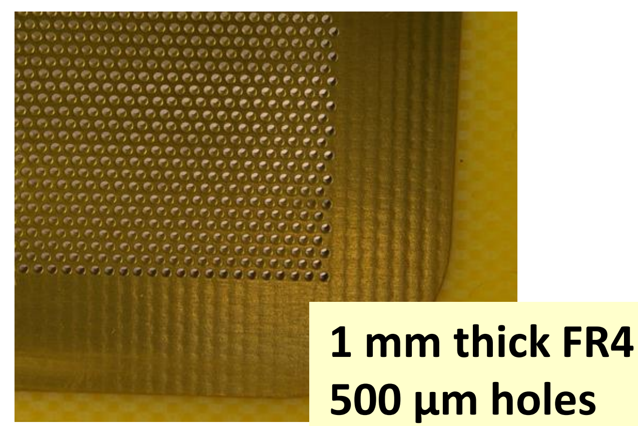






➢ **2D Projective anode readout**
- Charge is equally collected on two sets of strips (views)
- readout independent of multiplication
- two collection views (unipolar signals)

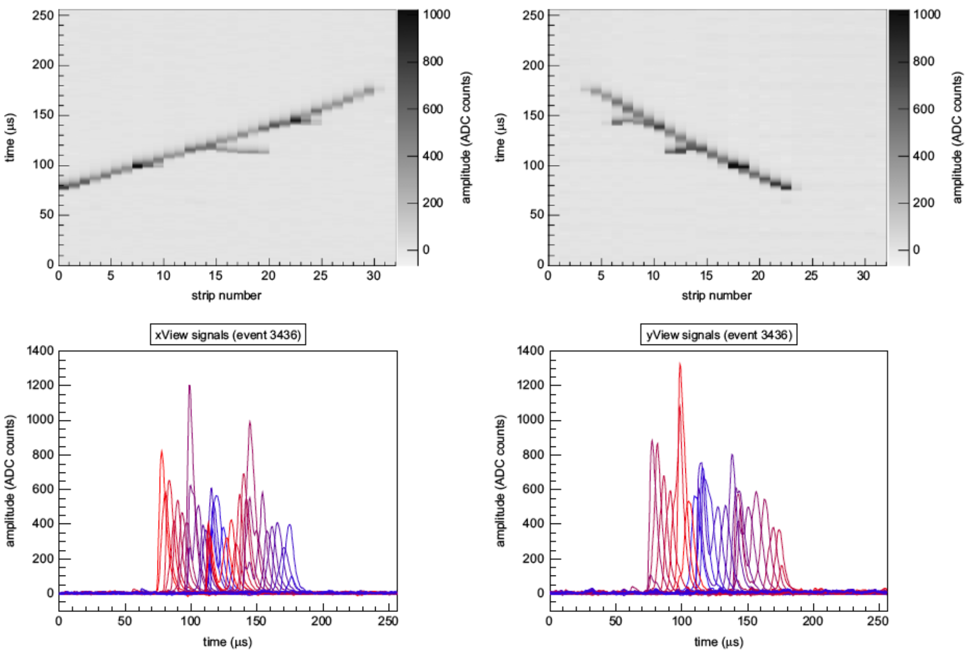
➢ **Large Electron Multiplier (LEM)**
- Macroscopic Gas hole Multiplier (=Thick GEM)
- more robust than GEMs (cryogenic temperatures, discharge resistant)
- manufactured with standard PCB techniques



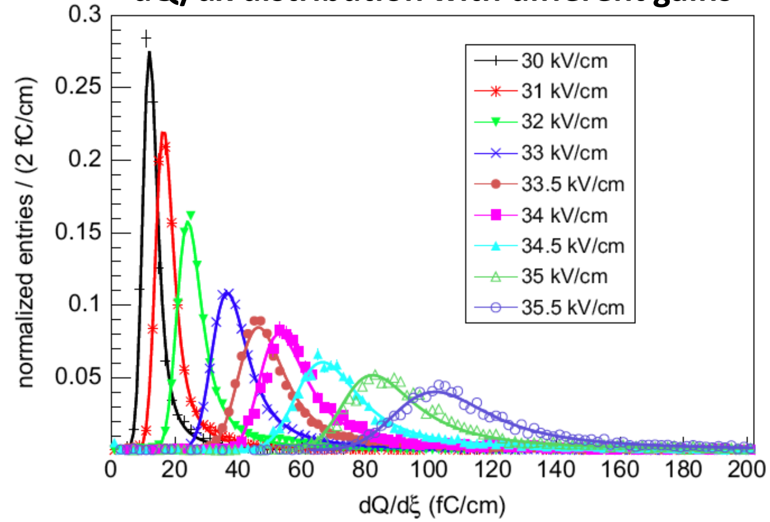
Proof of principle with 10x10 cm^2 prototype

A. Badertscher, et al., NIM A 641 (2011) 48

typical cosmic muon event

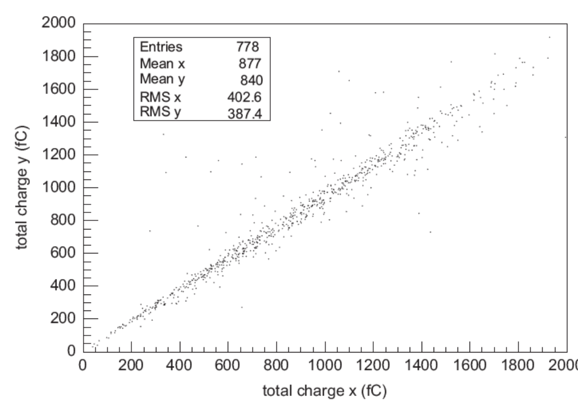


dQ/dx distribution with different gains

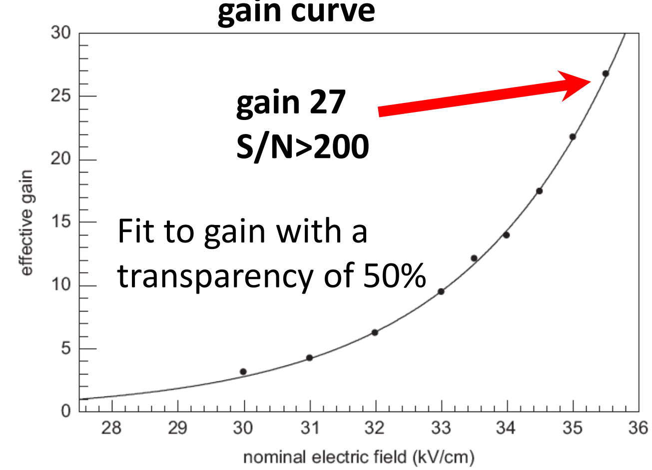


charge sharing test of the 2D anode

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

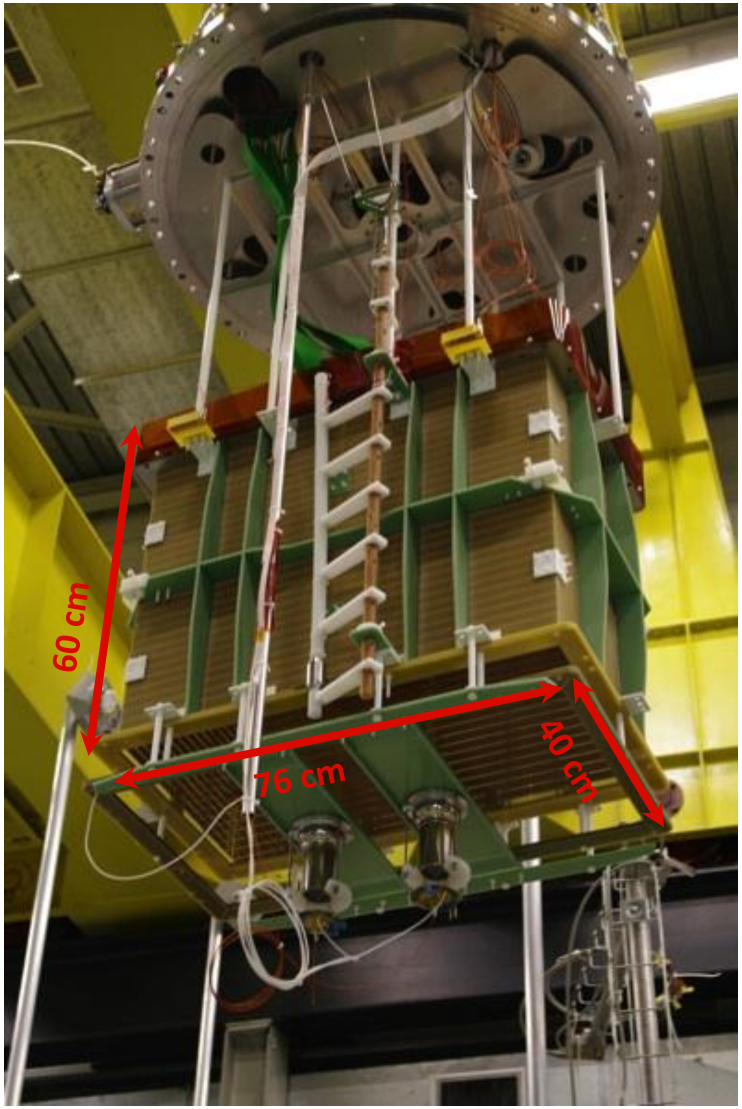


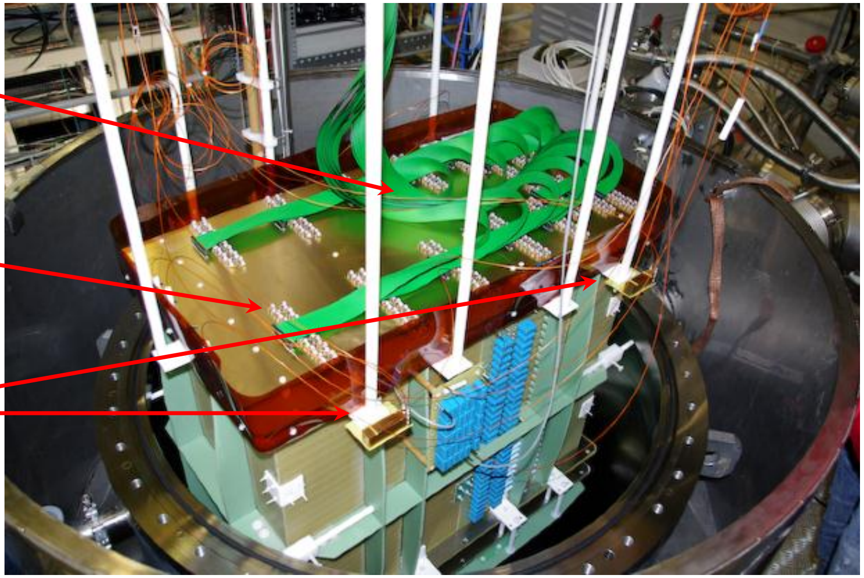
gain curve



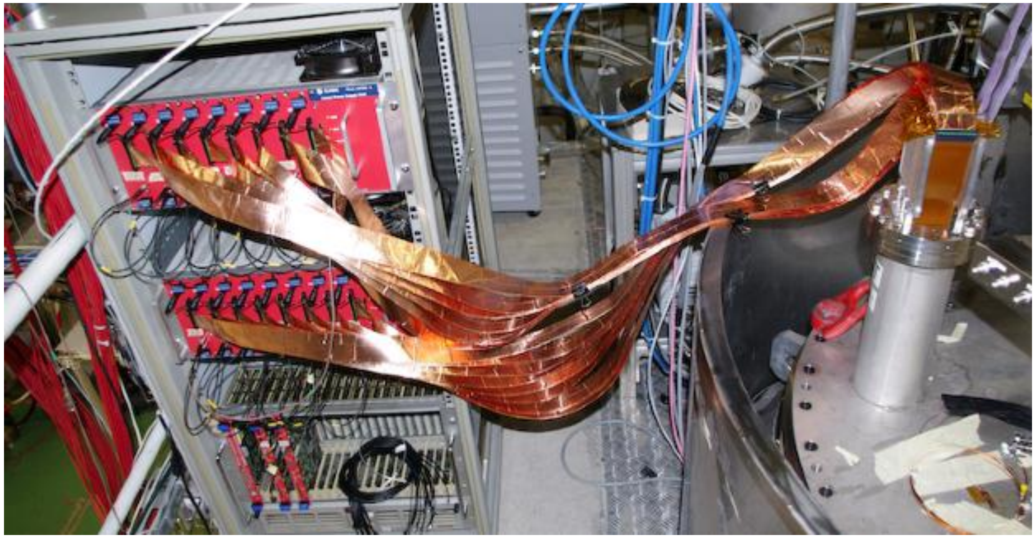
Towards a large area readout

detector fully assembled



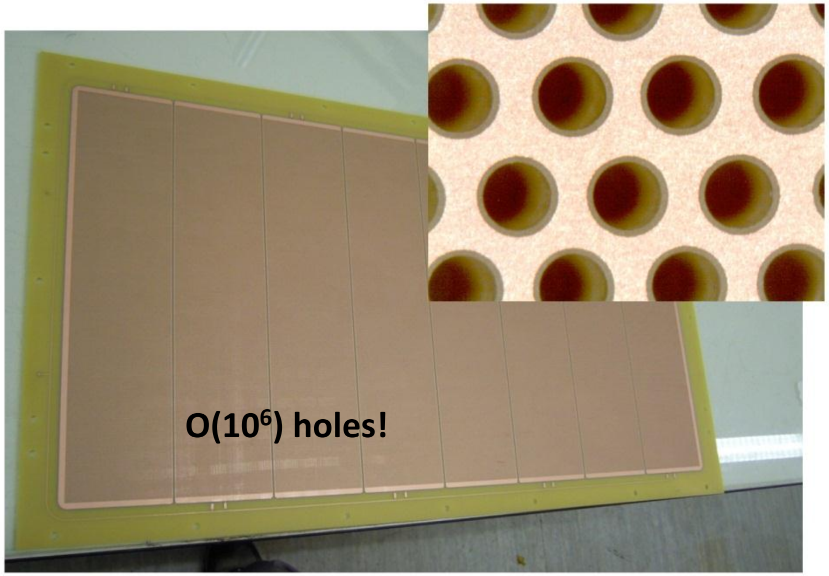


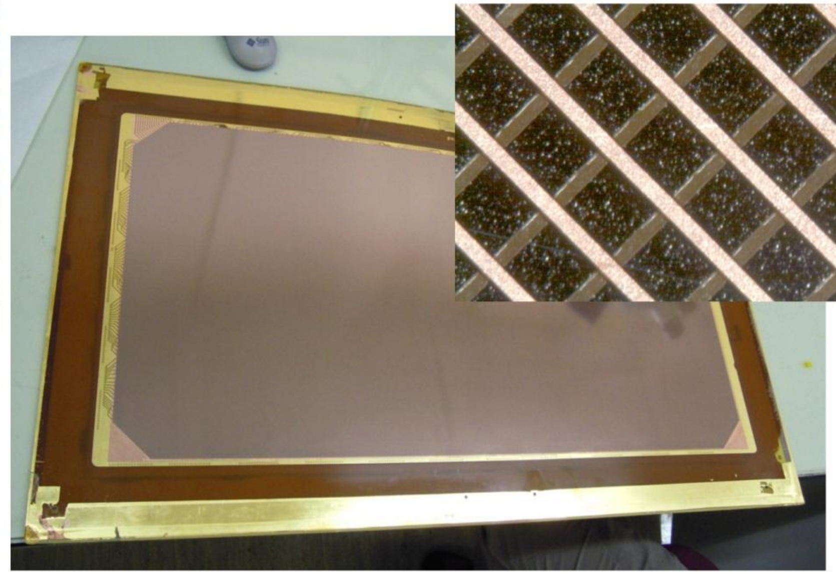
Readout through the CAEN SY2791 system



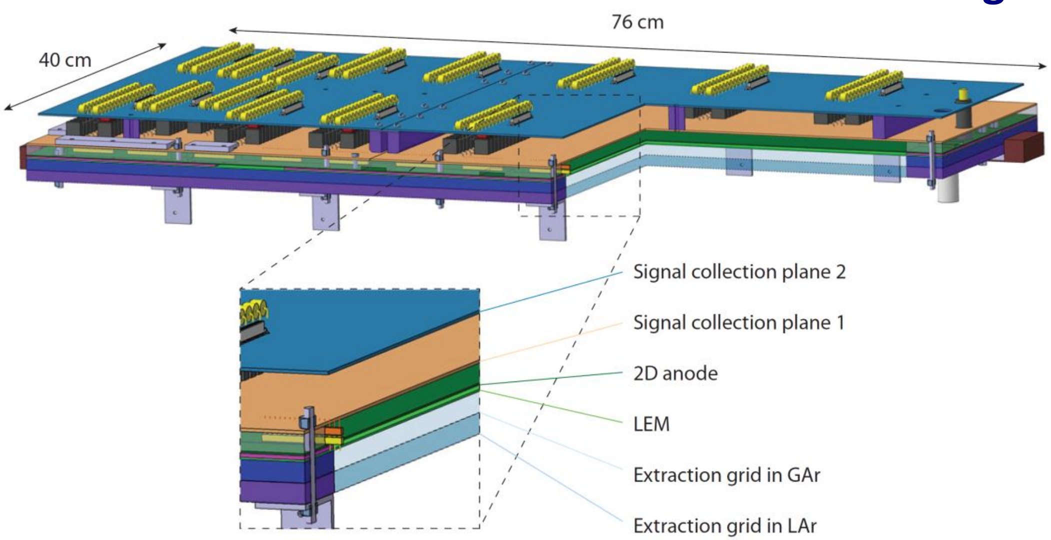
A. Badertscher et al., JINST 7 (2012) P08026
A. Badertscher et al., arXiv:1301.4817

40 x 76 cm^2 readout assembly





So far largest area LEM/2D anode produced

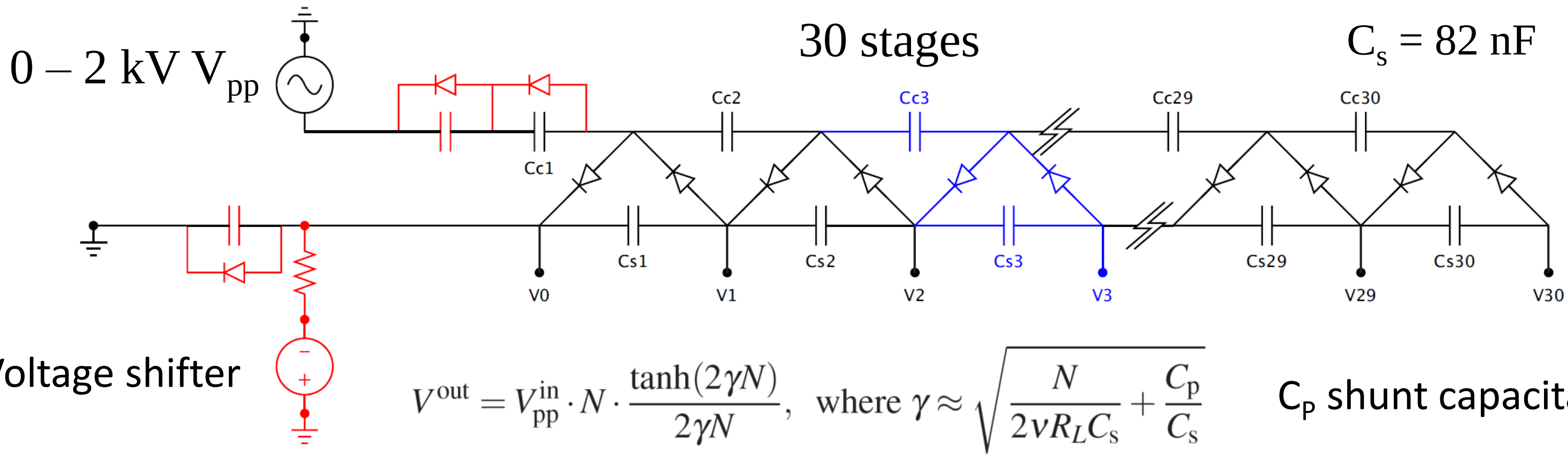


	Distance to the stage above (cm)
Signal collection plane 2	–
Signal collection plane 1	2
2D anode	1
LEM (top electrode)	0.2
LEM (bottom electrode)	0.1
Extraction grid in GAr	1
Extraction grid in LAr	1

HV generation

30 stages

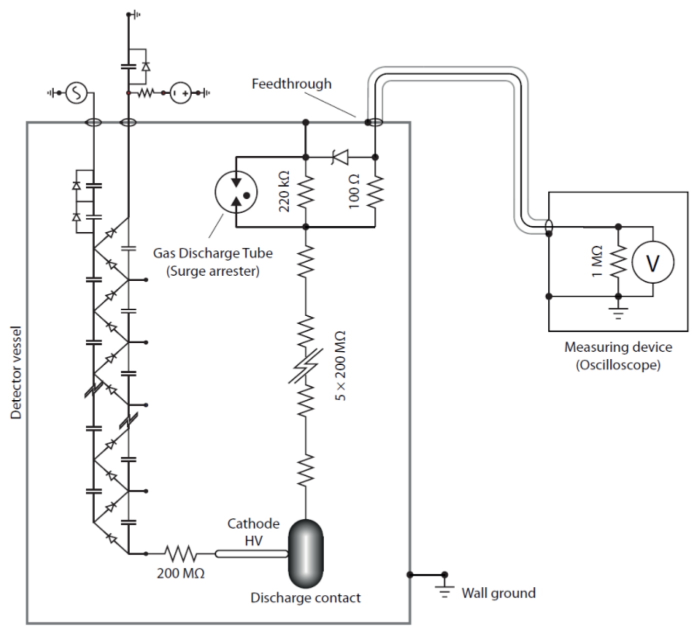
$C_s = 82$ nF

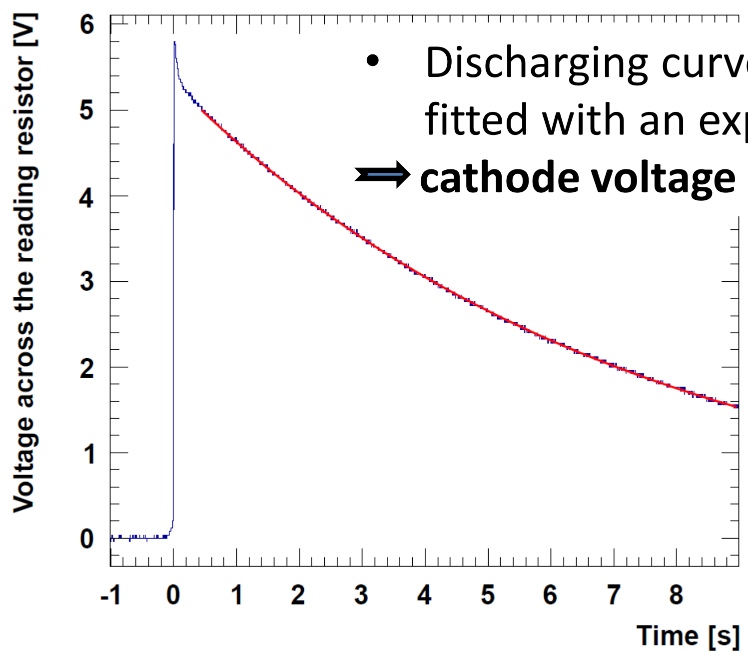


Voltage shifter

$$V^{\text{out}} = V_{\text{pp}}^{\text{in}} \cdot N \cdot \frac{\tanh(2\gamma N)}{2\gamma N}, \quad \text{where } \gamma \approx \sqrt{\frac{N}{2\nu R_L C_s} + \frac{C_p}{C_s}}$$

C_p shunt capacitance





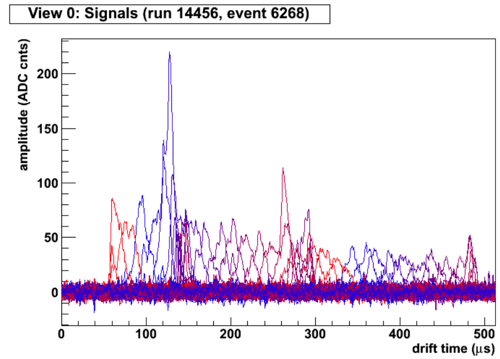
- Discharging curve for 1400 Vpp fitted with an exponential curve

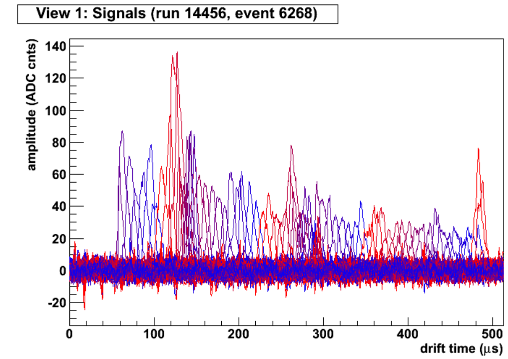
➡ **cathode voltage of 35.3 ± 0.9 kV**

Operation of a 40 x 76 cm^2 assembly

Detector operated for the first time in October 2011 during more than 1 month

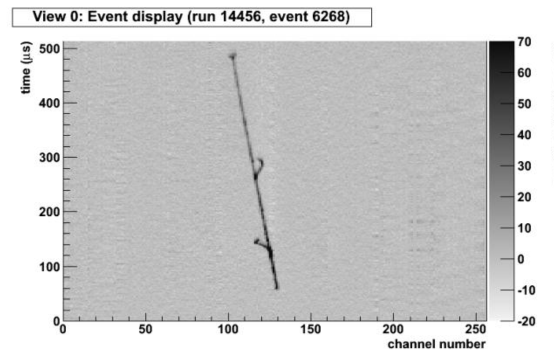
- The events shown here were recorded after...
- optimizing the field configuration (mainly the amplification field of the LEM)
- improving the LAr purity

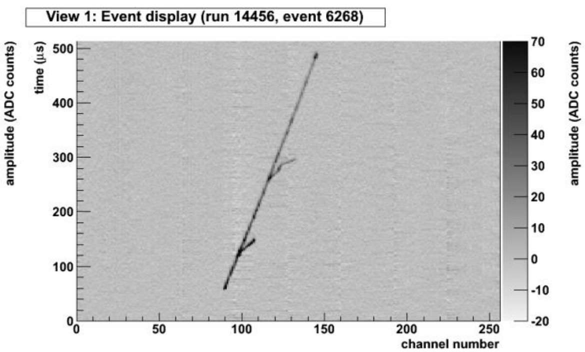


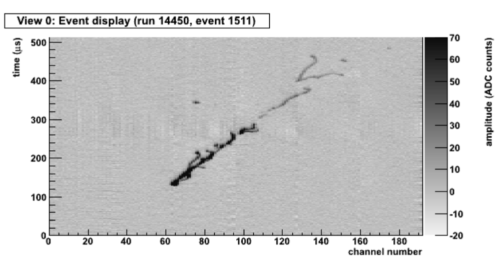


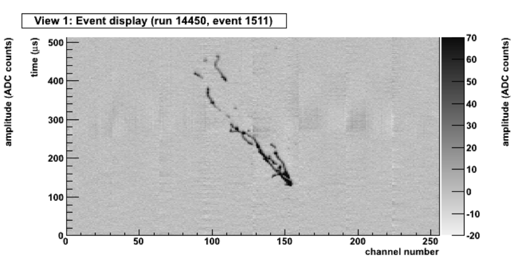
Field configuration

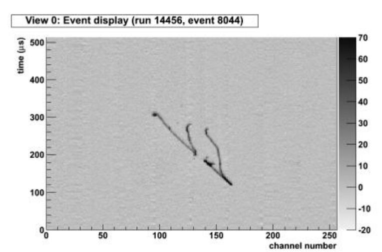
LEM-Anode	1800 V/cm
LEM	**35 kV/cm**
grid-LEM	600 V/cm
extraction	2300 V/cm
drift	400 V/cm

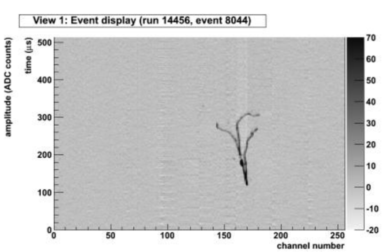






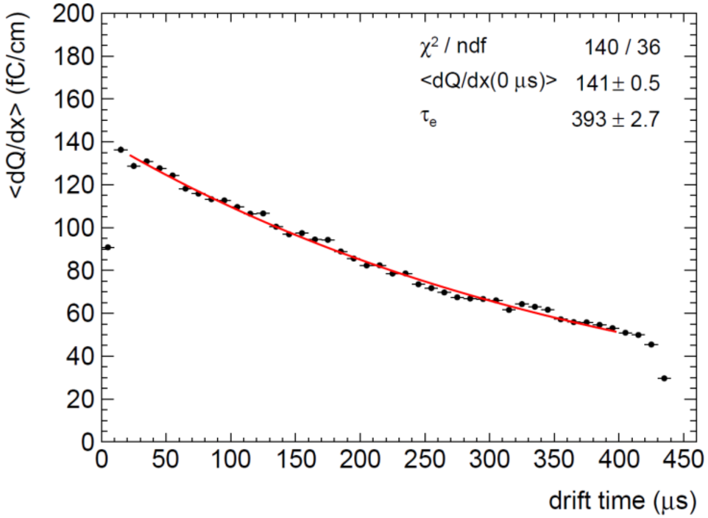




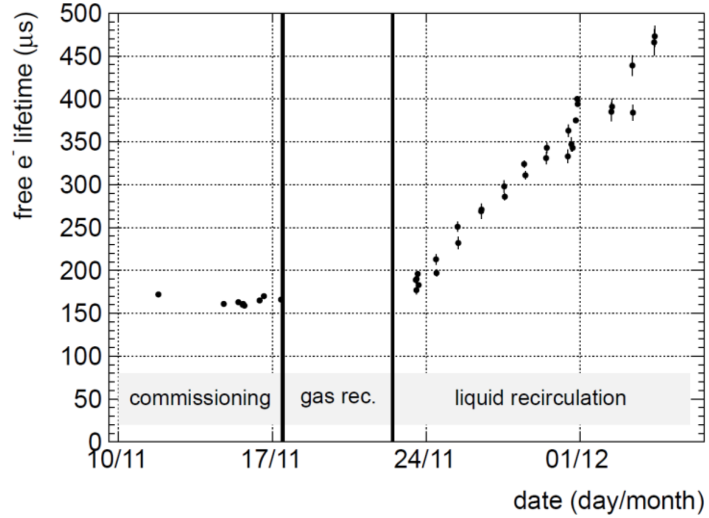


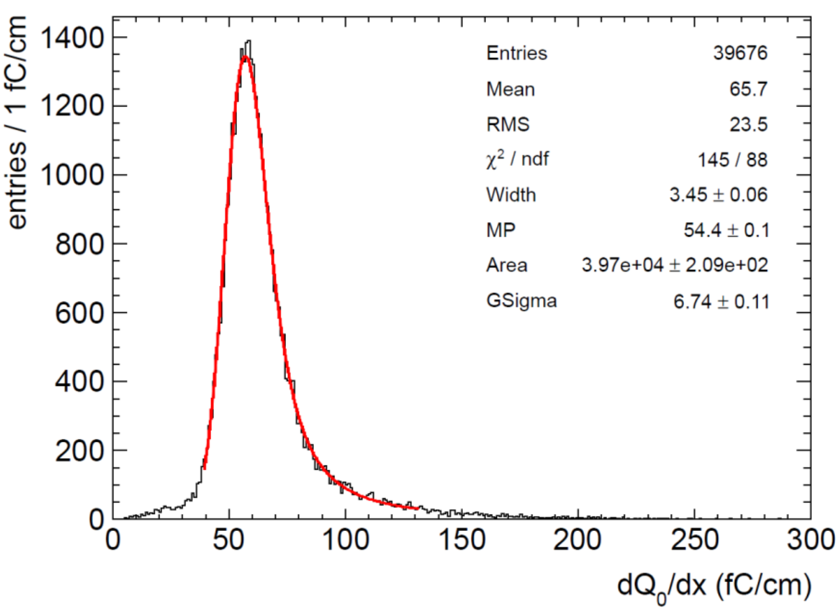
Results: signal to noise and gain

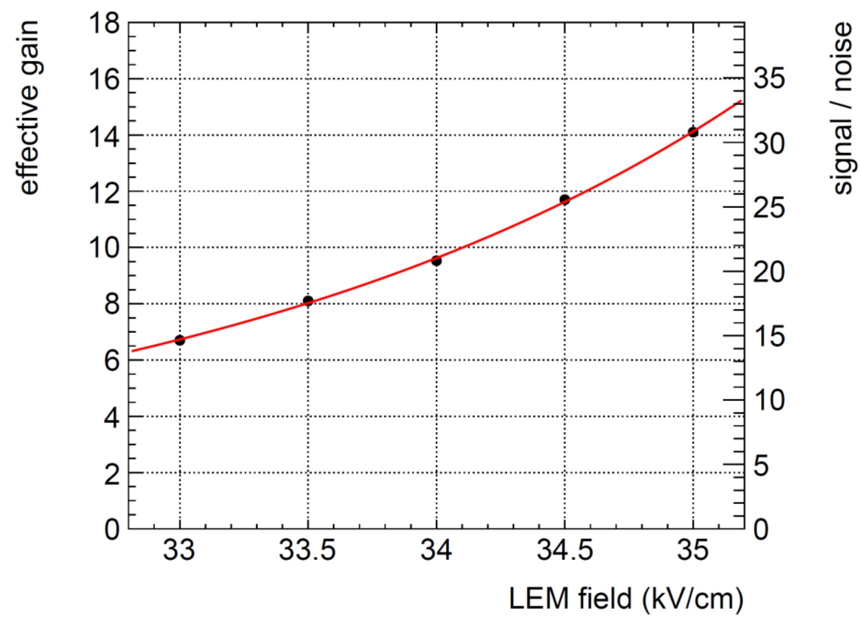
free electron lifetime



purity evolution



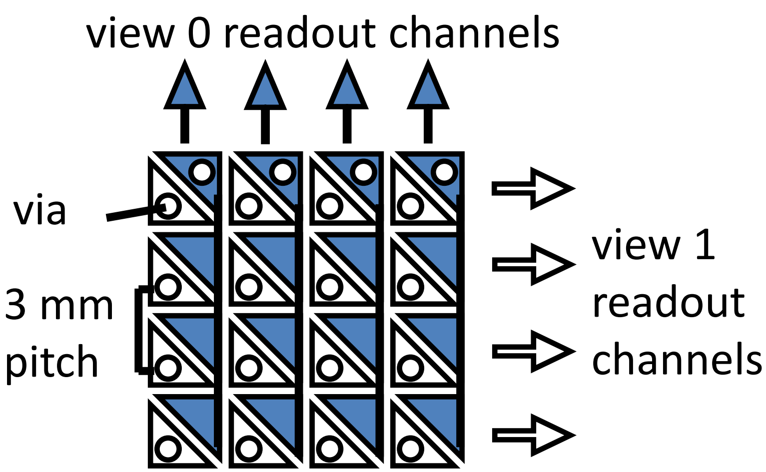




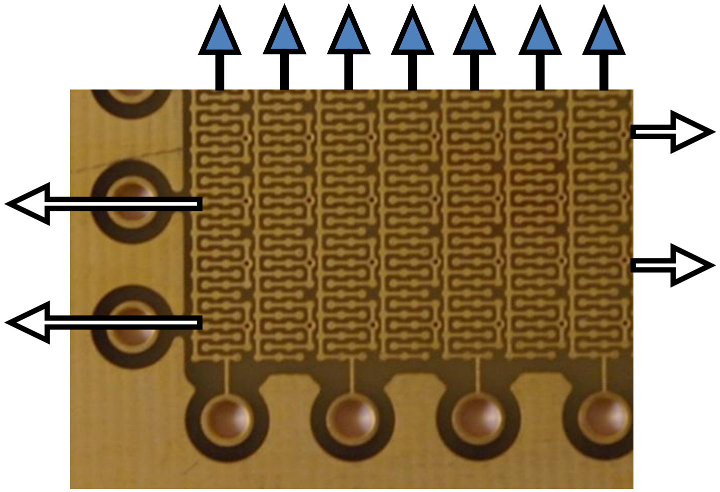
An improved 10x10 cm² prototype

- **Single extraction grid (smaller absolute voltages, better transparency)**
- **Anode at ground (no internal decoupling capacitors)**
- **New simplified readout**
- **Readout capacitance**
  - Readout capacitance of Kapton-type anode **≈600 pF/m**
  - capacitance reduction needed, due to noise requirements...
- **Mass production**
  - simple PCB preferable to Multilayer Kapton

new readout: simple 2 layer PCB

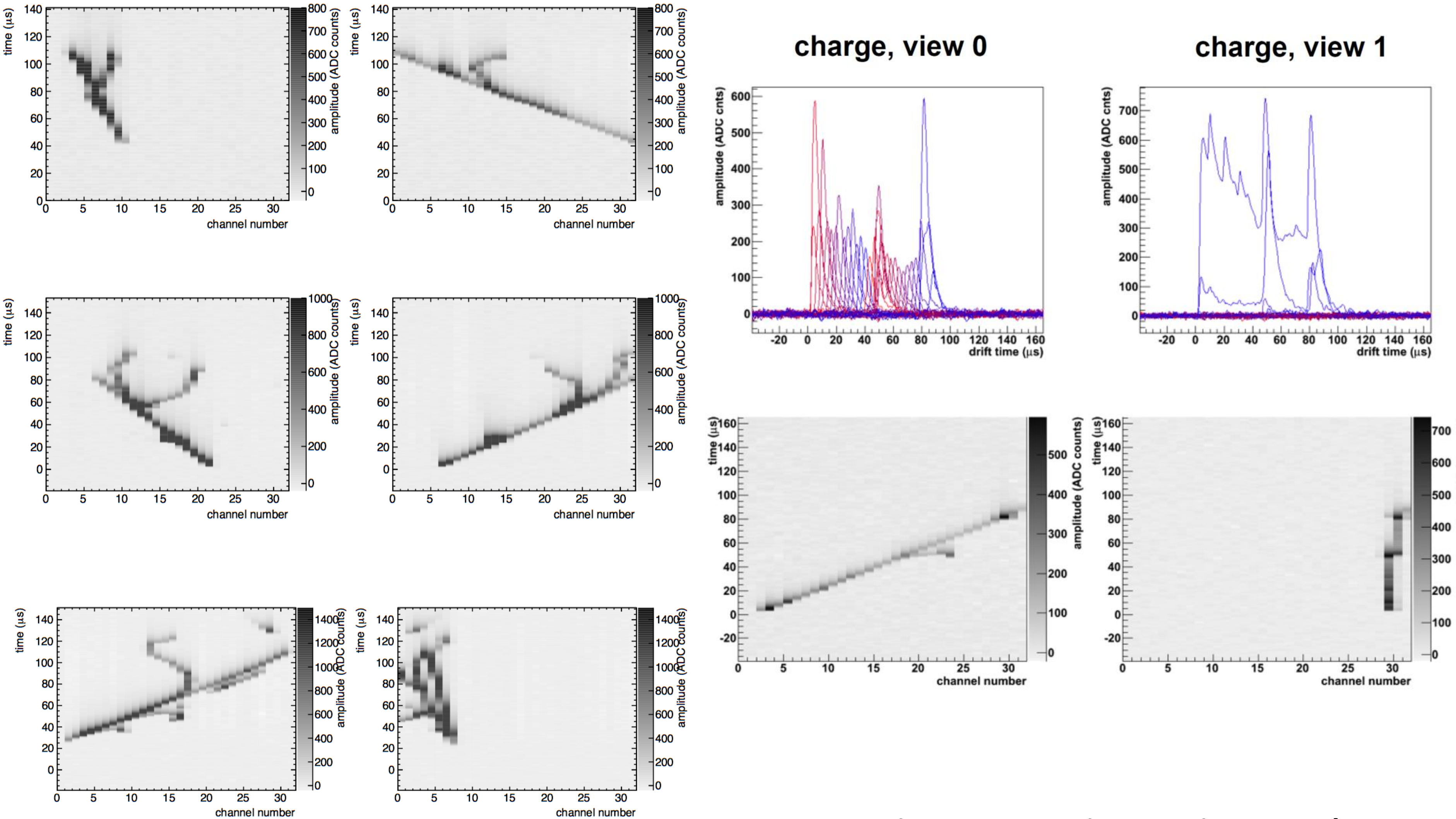


Realization with C≈200 pF/m



D. Lussi, TPC Symposium, Paris, December 2012

Event gallery (gain≈30)

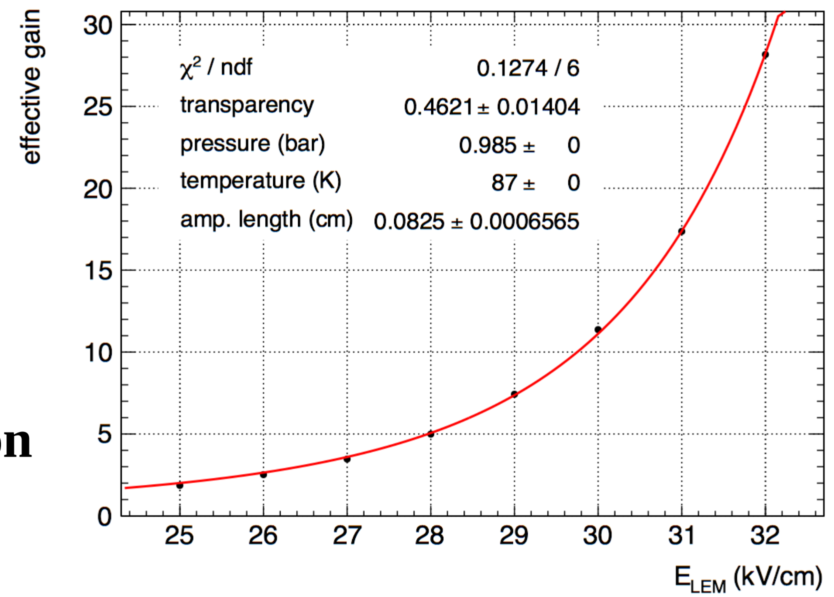


D. Lussi, TPC Symposium, Paris, December 2012

Results

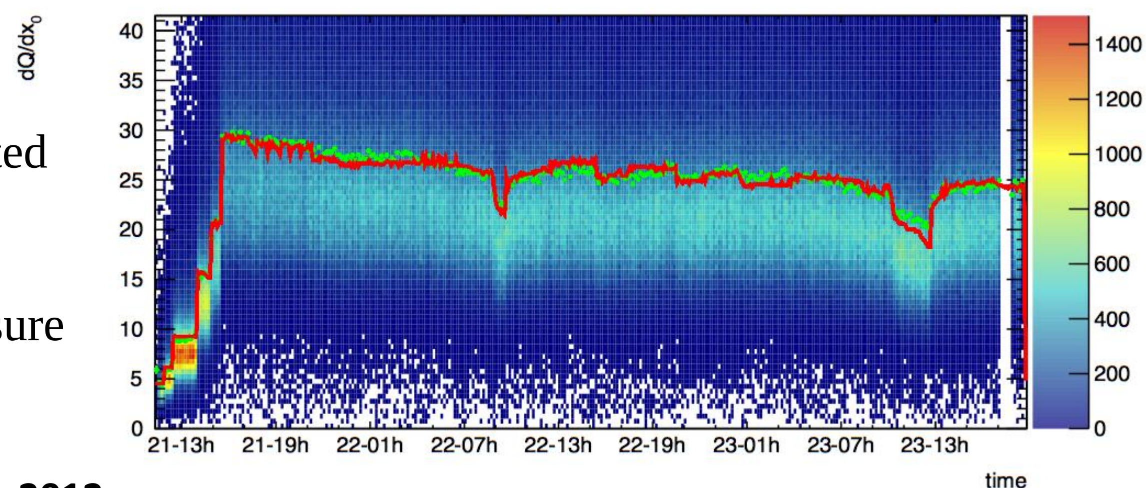
LEM field scan

- drift, extraction and induction fields were kept constant while increasing the LEM field
- 32 kV/cm could not be exceeded due to the onset of discharges
- the achieved gain of ≈30 confirms previous results



Stability run with optimal field configuration

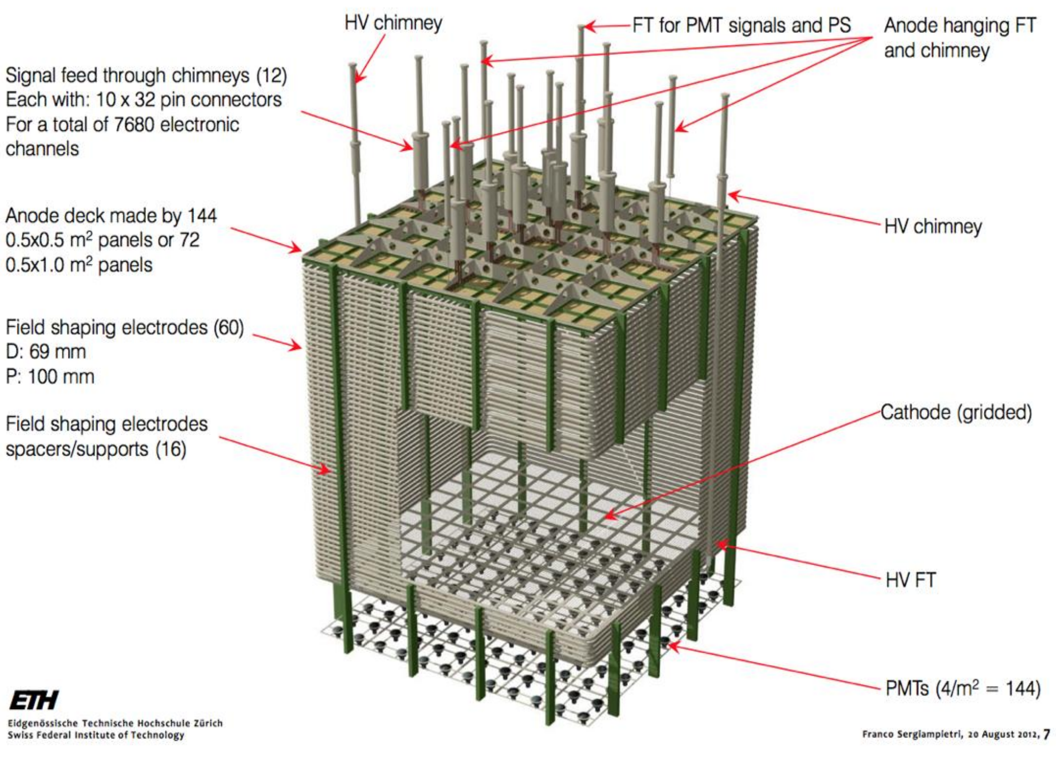
induction	5 kV/cm
LEM	28 kV/cm
extraction	2 kV/cm
drift	500 V/cm

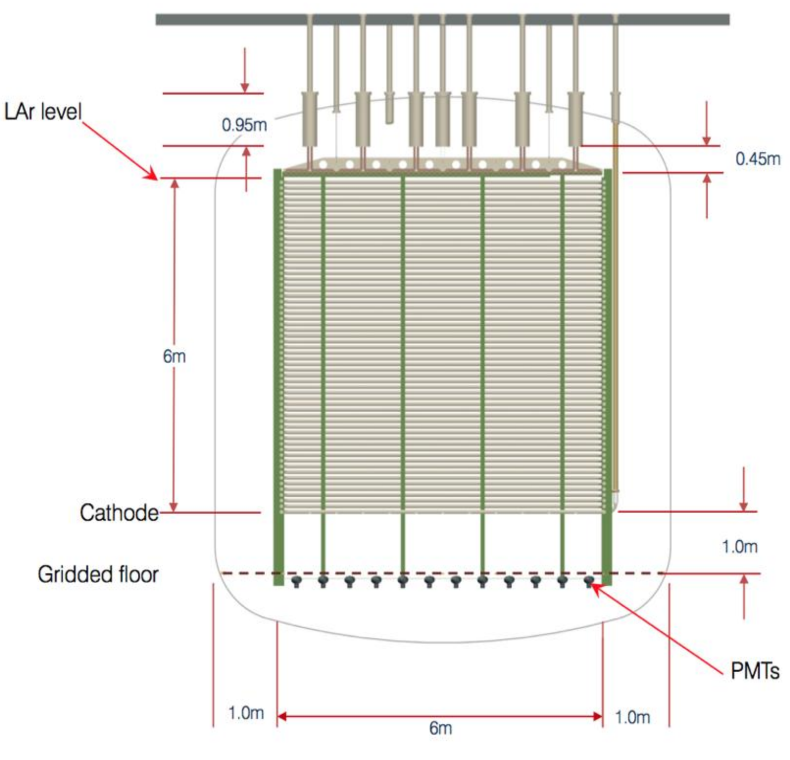


- the chamber was continuously operated during 54 hours / 3.5 M triggers
- no discharges with gain≈6
- tracked gain fluctuations due to pressure changes

LAGUNA prototype @CERN

- 6 x 6 x 6 m^3 prototype to be constructed and operated at CERN, as a prototype of the far detector double-phase TPC
- To be exposed to charged test beams
- Detector to be positioned in the North Area in an extension of the EHN1 building
- Timescale: proposal to be submitted in 2013 to CERN SPSC, if approved 6 x 6 x 6 m^3 could be operational around 2016





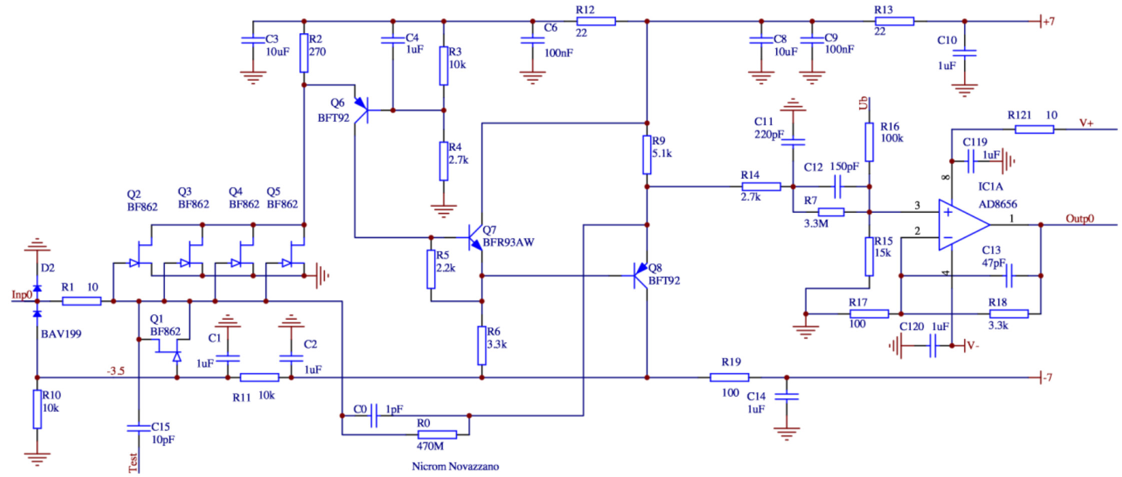
Conclusions

- **LAr LEM TPC: a technique to improve the quality of the signals of a LAr TPC**
  - for a better reconstruction of events in a LAr TPC
  - interesting applications for detection of below mip signals (dark matter…)
- **extensive prototyping on small scale detectors**
  - 10x10 cm^2: double phase LEM-TPC proof of principle
  - 40x76 cm^2: first large area device with compact and fully embedded double phase charge readout
  - an improved 10x10 cm^2 prototype
    - simplified 2D anode readout at ground!
- **next step is a 6x6x6 m^3 double phase LEM-TPC prototype with a total readout area of 36 m^2**

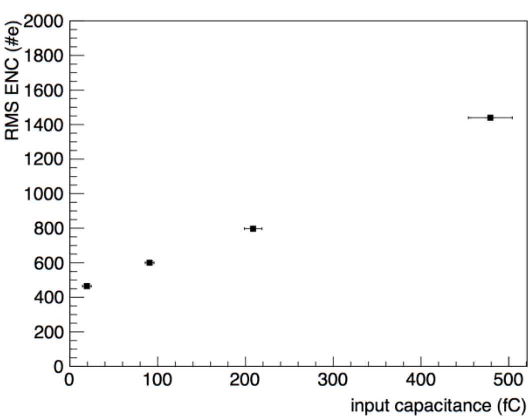
Backup

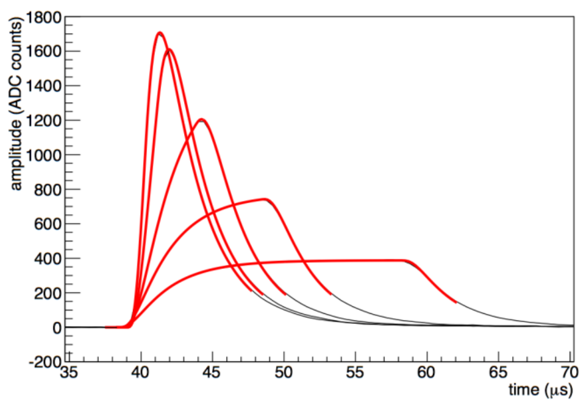
Readout electronics / ETHZ preamp

- Cascode design with 4 parallel JFETs at the input (C. Boiano et al. IEEE Trans. Nucl. Sci. 52 (2004) 1931)
- RC=470 µs feedback (C=1pF)
- RC-CR shaper with zero-pole sub. mechanism (no undershoot)
- over-voltage protection at input
- preamplifier is realized with discrete components
- two preamplifier circuits are implemented on a single 4-layer PCB



RMS ENC vs. input capacitance & shaping





performance summary

shaping time τ_D	$2.8 \pm 0.1\ \mu s$
shaping time τ_I	$0.45 \pm 0.02\ \mu s$
sensitivity	13.8 ± 0.4 mV/fC
open loop gain	$\approx 10^4$
linearity (0-180 fC)	$\pm 1\%$
ENC (RMS, $C \approx 200$ pF)	770 ± 30 electrons
S/N (1 fC, $C \approx 200$ pF)	8.1 ± 0.3