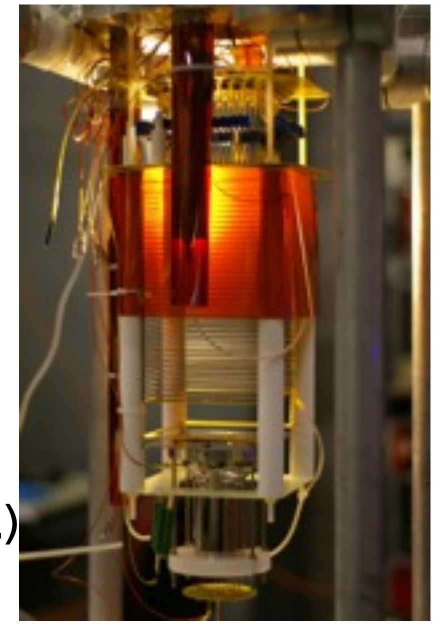
LBNO-DEMO (WA105)

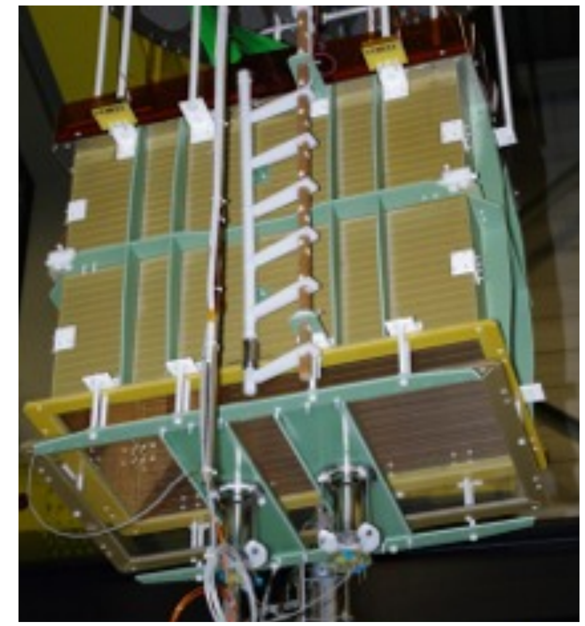
Lukas Epprecht (ETH Zurich)
on behalf of the LBNO-DEMO (WA105) collaboration

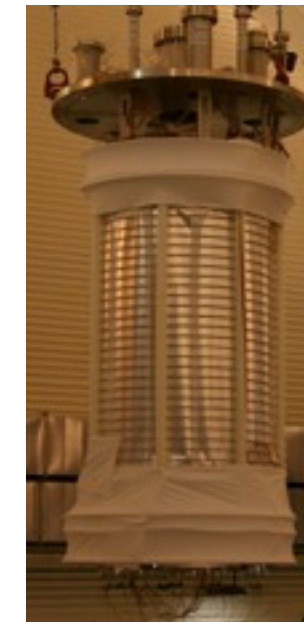
Why LBNO-DEMO (WA105)?

- We have developed successfully LAr double phase TPCs for a decade
- All concepts were demonstrated with prototypes of several sizes
- 3 l with 10x10 cm readout:
  - Small detector for fast turn around and detailed tests (e.g. optimization of LEM physical parameters)
    (C. Cantini et al. *JINST 9 (2014) P03017*,
    A. Badertscher et al. *NIM A641 (2011) p.48-57*, ...)
- 250 l with 80 x 40 cm readout
  - Successful scaling up from the smaller detector with the largest double phase charge readout ever built --> Proof of principle at m^3 scale
    (A. Badertscher et al. *JINST 8 (2013) P04012*)
- 1 ton detector (ArDM)
  - Full scale dark matter experiment running in the underground laboratory of Canfranc, Spain
    (A. Badertscher et al. *JINST 8 (2013) C09005*,
    A. Badertscher et al. *arXiv:1307.0117*, ...)
- In order to combine these researches, a detector of several tons is necessary

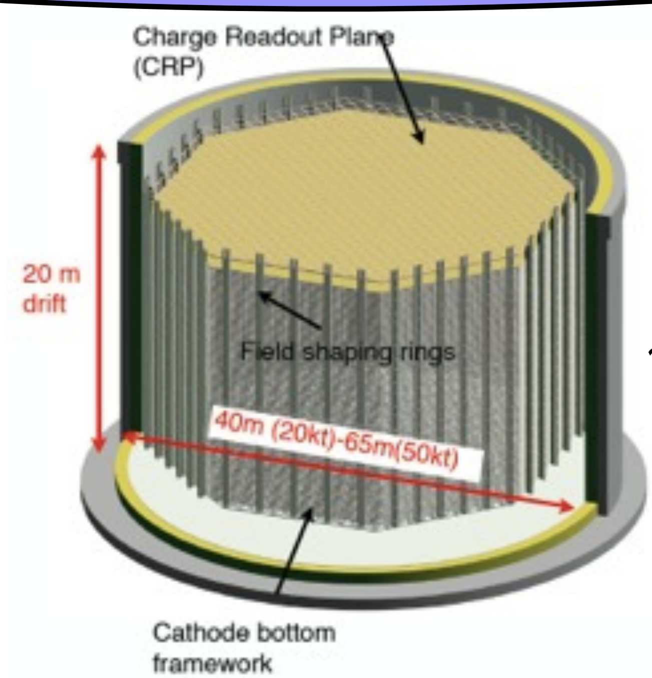
➡ **The WA105 program contains a 300 t detector and a first prototype of about 20 tons**


~3 l


~250 l


~1 t

?



~50 kt

Why LBNO-DEMO (WA105)?

Double phase LAr TPCs are the state of the art detectors to be used for affordable giant neutrino detectors using liquid noble gases

With WA105 we are demonstrating the scalability of the double phase LAr TPC to large detectors

The main challenges to be tackled are:

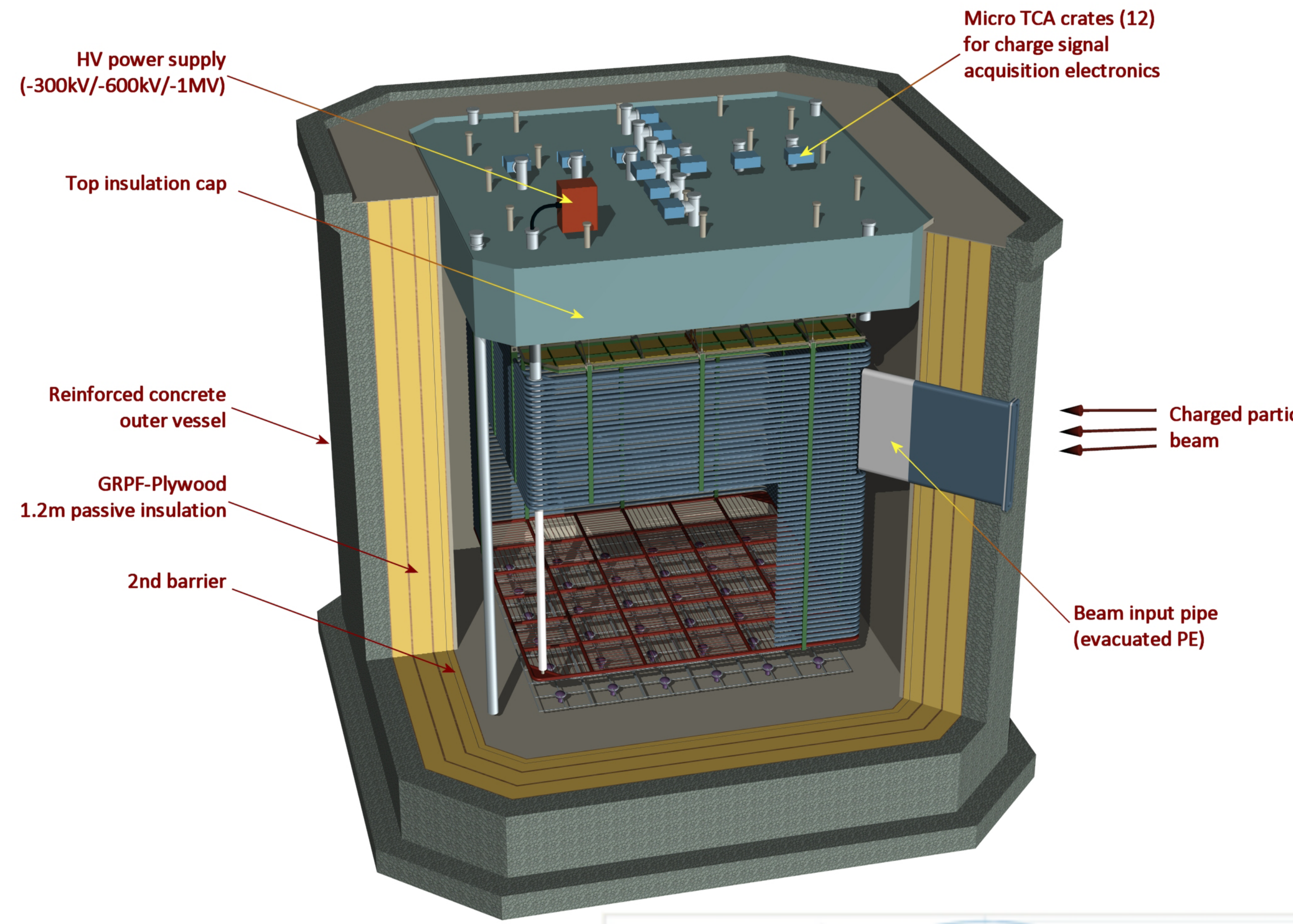
- Efficient charge readout
- Very long drifts (up to 20 m)
- Purity of LAr in non evacuated large volumes
- Very high voltage (MV)
- Efficient front-end electronics with low noise
  - accessible/upgradable cold electronics
- UV scintillation light readout system

With the LBNO-Demo (WA105) we will have a detector of the right scale (300 t) to test all these requirements

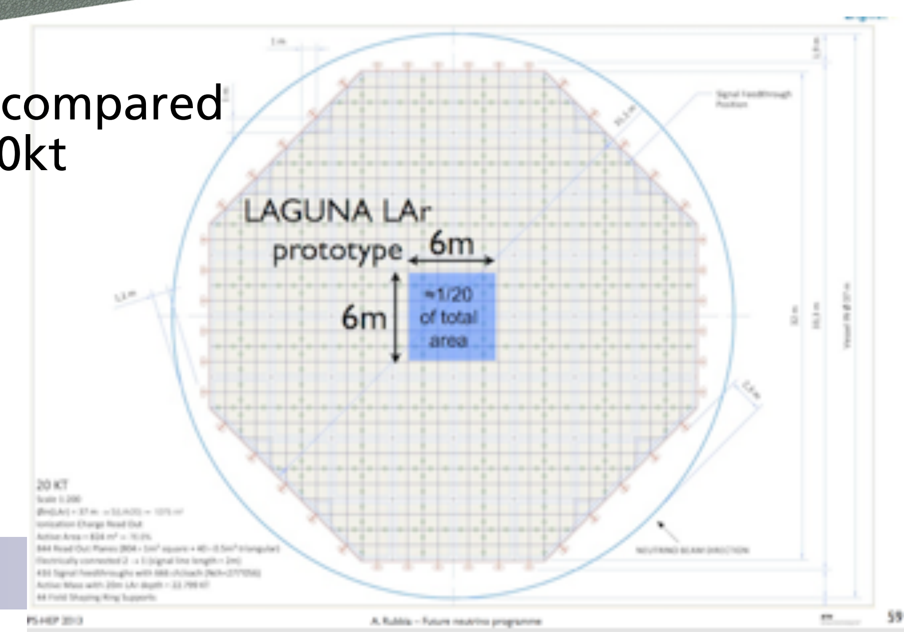
LBNO-DEMO (WA105)

Configuration

- $6x6x6\ m^3$ active volume
  - Tank dimensions of the inner vessel: $8.1 \times 8.1 \times 8.1\ m^3$
- Double Phase TPC with Charge Amplification and particle reconstruction
- 2D-collection Readout Anode
  - Large are readout with minimized dead area
- Exposition to 1-20 GeV/c charged hadron beam
- Completely scalable design for detectors, bigger than 50kt!
- Use of membrane technology for cryostat (non evacuated vessel)
- HV of 300-600 kV



LBNO-DEMO compared to GLACIER 20kt



Technical design report

Technical Design Report

for large-scale neutrino detectors prototyping

and phased performance assessment

in view of a long-baseline oscillation experiment

The LBNO-DEMO (WA105) Collaboration

- Technical design report submitted to CERN SPSC in April 2014 (SPSC-TDR-004-2014)
- **The Committee supports the technical goals of the Double Phase Liquid Argon (DLAr)-TPC program and considers it as the WA105 priority for the forthcoming years**

LBNO-DEMO (WA105)

- LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux
- OMEGA Ecole Polytechnique/CNRS-IN2P3
- UPMC, Université Paris Diderot, CNRS/IN2P3, Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE)
- APC, AstroParticule et Cosmologie, Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Observatoire de Paris, Sorbonne Paris Cité
- IRFU, CEA Saclay, Gif-sur-Yvette
- Université Claude Bernard Lyon 1, IPN Lyon

- University of Glasgow
- University College London

- University of Jyväskylä
- University of Oulu
- Rockplan Ltd

- Horia Hulubei National Institute (IFIN-HH)
- University of Bucharest

- University of Geneva, Section de Physique
- ETH Zürich

- INFN-Sezione di Pisa

- CERN

- Institut de Fisica d'Altes Energies (IFAE), Bellaterra (Barcelona)
- CIEMAT

- Faculty of Physics, St.Kliment Ohridski University of Sofia

- Institute for Nuclear Research of the Russian Academy of Sciences, Moscow

- High Energy Accelerator Research Organization (KEK)

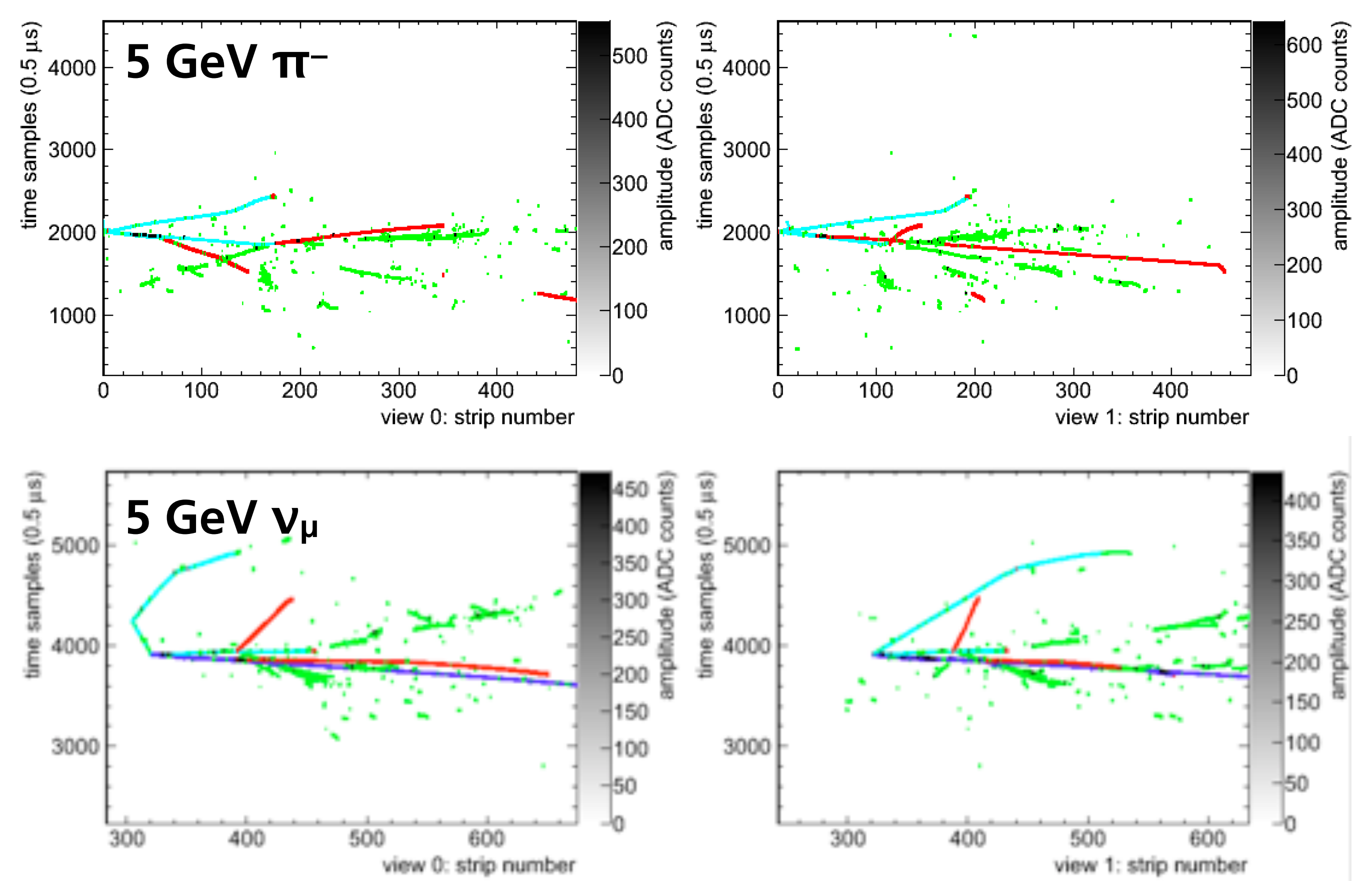
Scientific motivation

LBNO-DEMO will be installed in a charged hadron beam
→Well defined primary particles at a given energy!

<u>Main points of focus:</u>

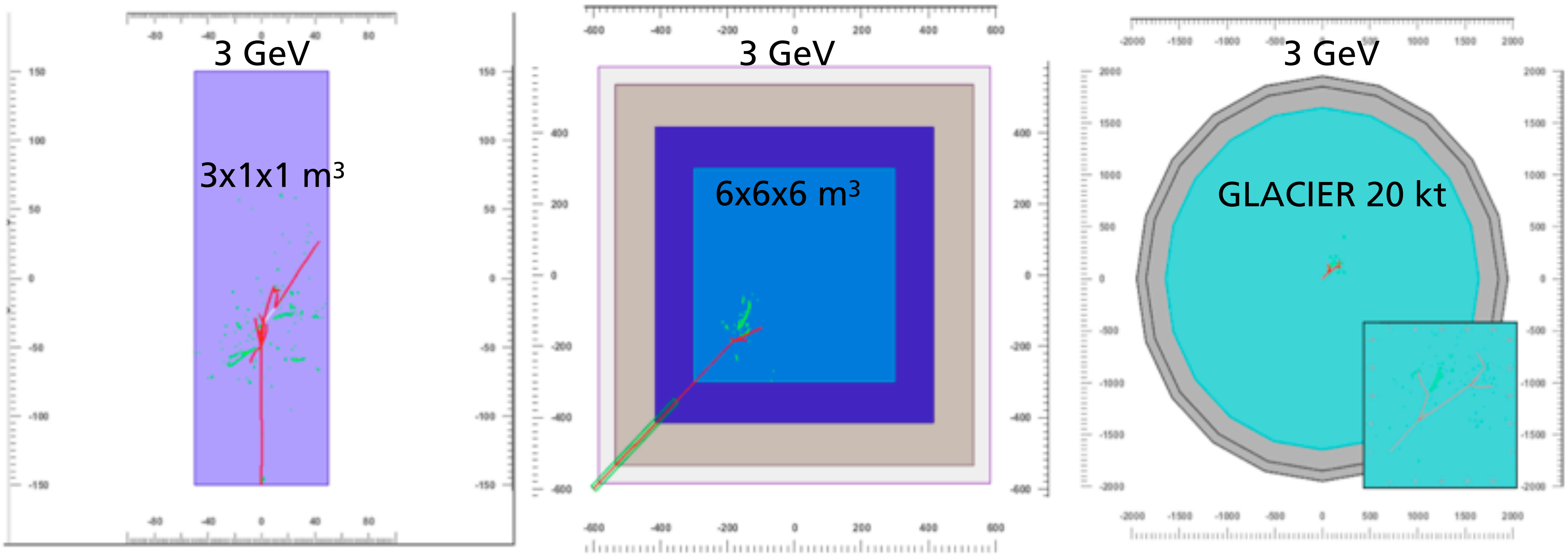
- Development of automatic event reconstruction
- Test of NC background rejection algorithm on “ve free“ events
- Cross section measurements of charged pions and protons with Argon nuclei
  - Big rate of pions is important
- Calorimetric performance

pions, electrons/positrons, protons, muons

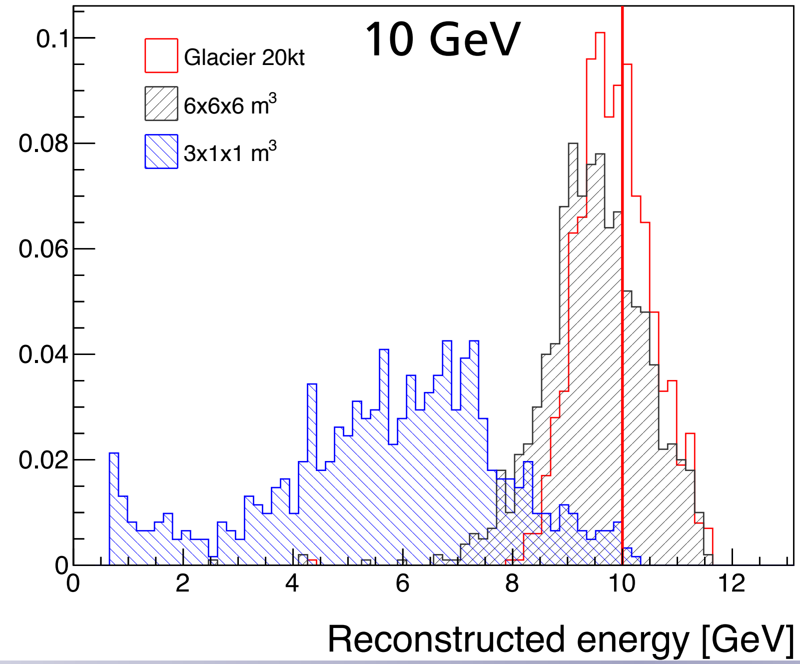


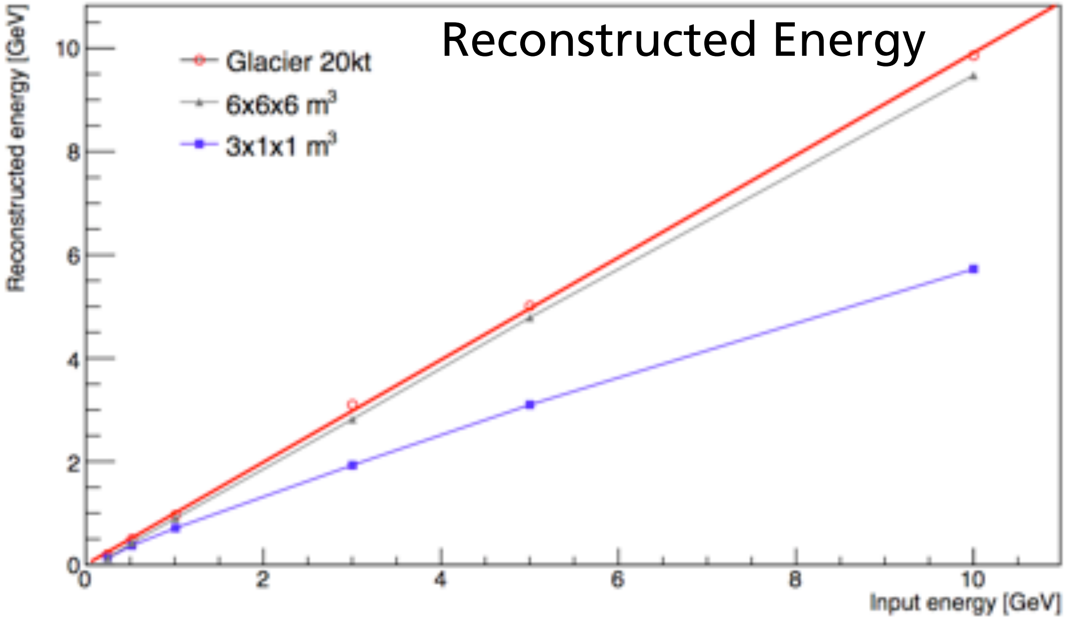
Scientific motivation

LBNO-DEMO will be large enough to contain the full showers!

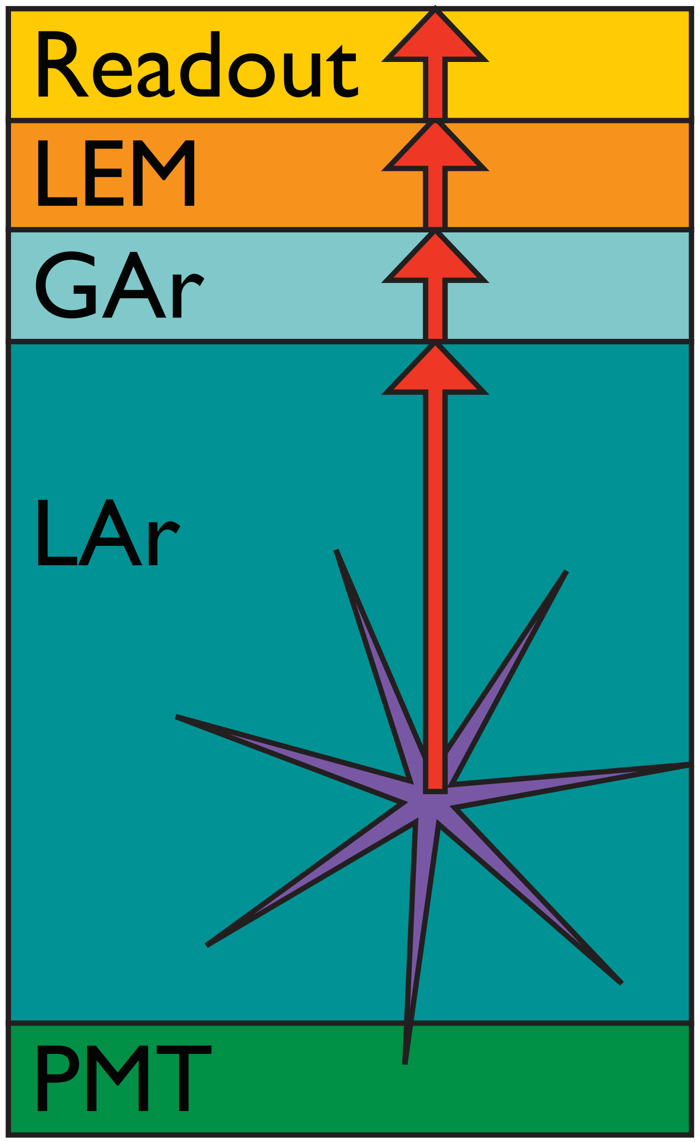


- WA105 will be large enough to contain the complete shower
- Energy resolution is similar to a 20kt detector
- First LAr TPC in a test beam to be able to do so





What is "Double Phase"



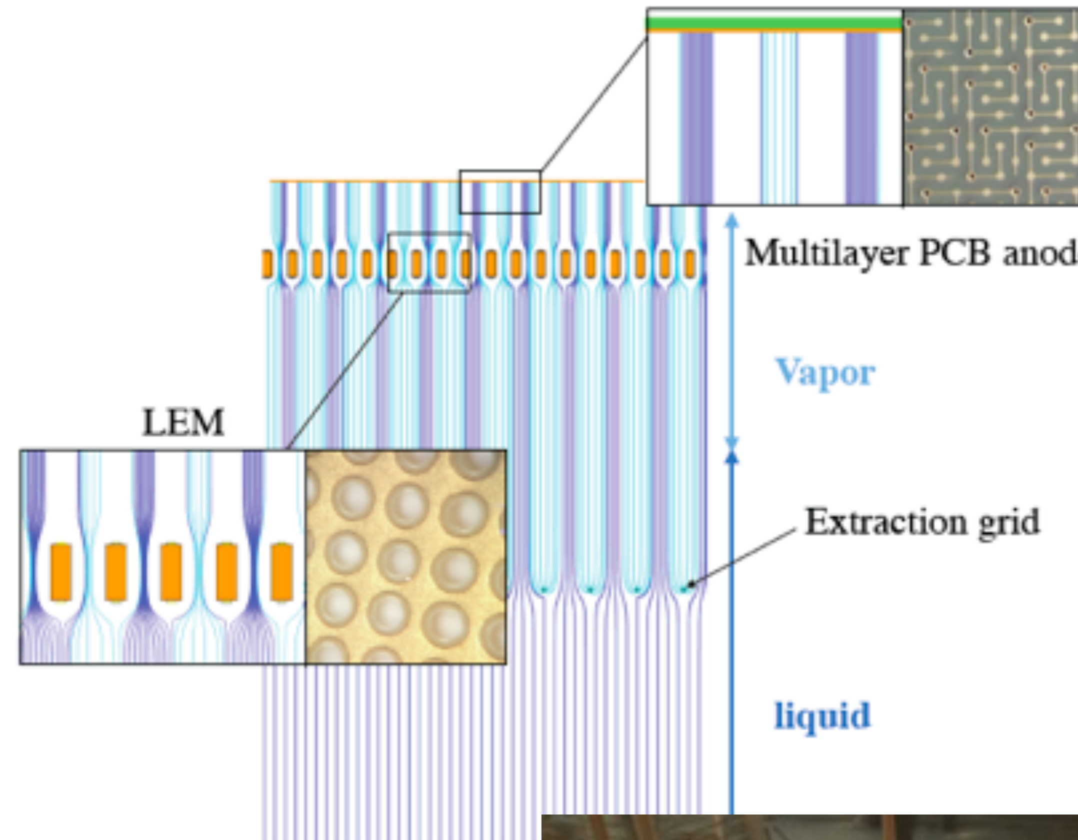
- The interaction of a particle with the LAr causes ionization charge
  - Applying an electric field, the electrons will drift towards the anode
- The existence of impurities in the liquid argon will reduce the number of electrons, arriving at the readout anode, proportionally to the drift time
  - In order to compensate the losses and to increase the signal to noise ratio, the arriving electrons have to be multiplied
- Multiplication cannot be done in liquid argon
  - We need to extract the electrons and use the well known techniques of avalanche multiplication in gas

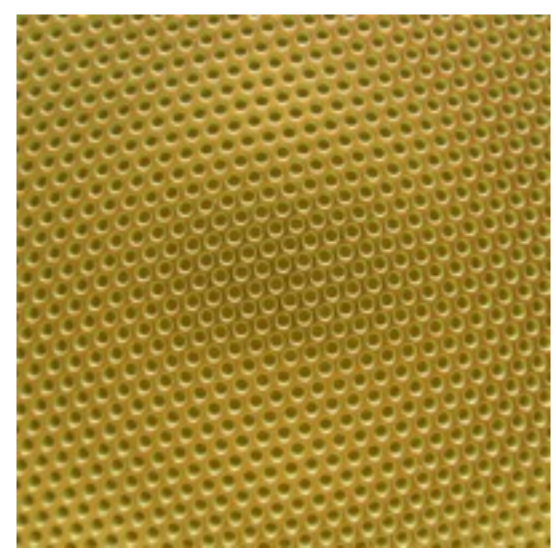
In the last decade we developed the LAr LEM TPC, evolving from the well known GEM detectors and adapted the special requirements in dense, pure argon gas

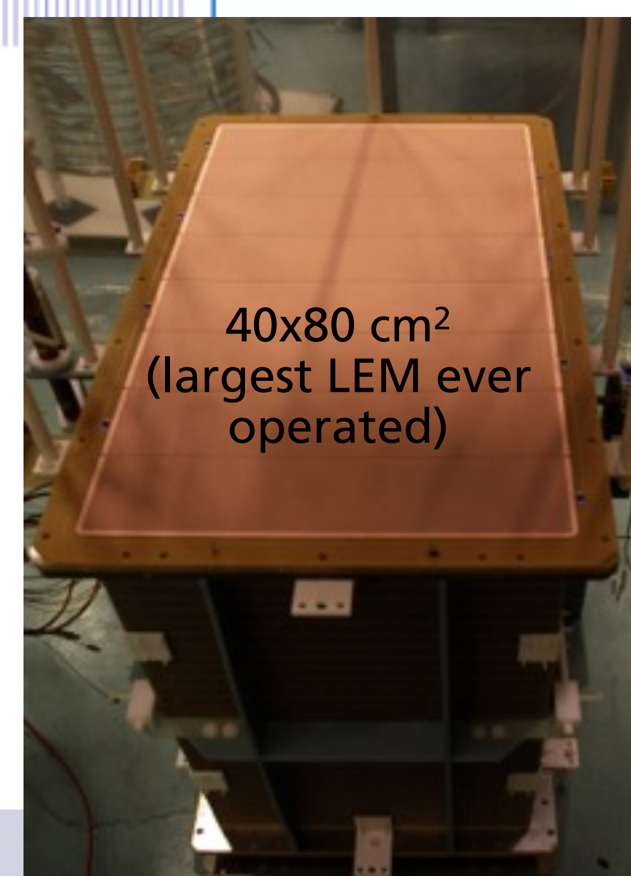
A. Rubbia *hep-ph/0402110*, A. Badertscher et al. *arXiv:0811.3384*, A. Badertscher et al. *NIM A641 (2011) p.48-57*, A. Badertscher et al. *NIM A617 (2010) p.188-192*, A. Badertscher et al. *JINST 7 (2012) P08026*, A. Badertscher et al. *JINST 8 (2013) P04012*, C. Cantini et al. *JINST 9 (2014) P03017*

The Charge Readout

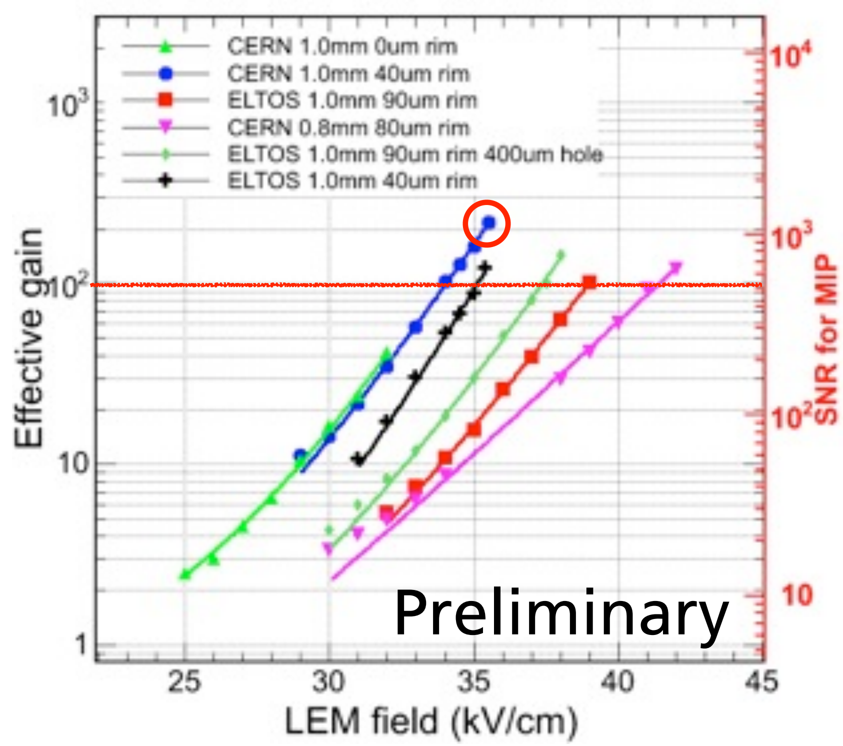
- The electrons drift up in the LAr
- In order to overcome the surface tension of the liquid surface, the electric field over the phase transition is increased with the help of an extraction grid
- In the gas they drift to the LEM holes where there is high electric field (>30 kV/cm)
- By ionizing additional argon atoms, the charge is multiplied
- This electron cloud is read out in two dimensions on the anode
  - There is no induction plane necessary!
- LEM and anode are produced by standard pcb-board techniques

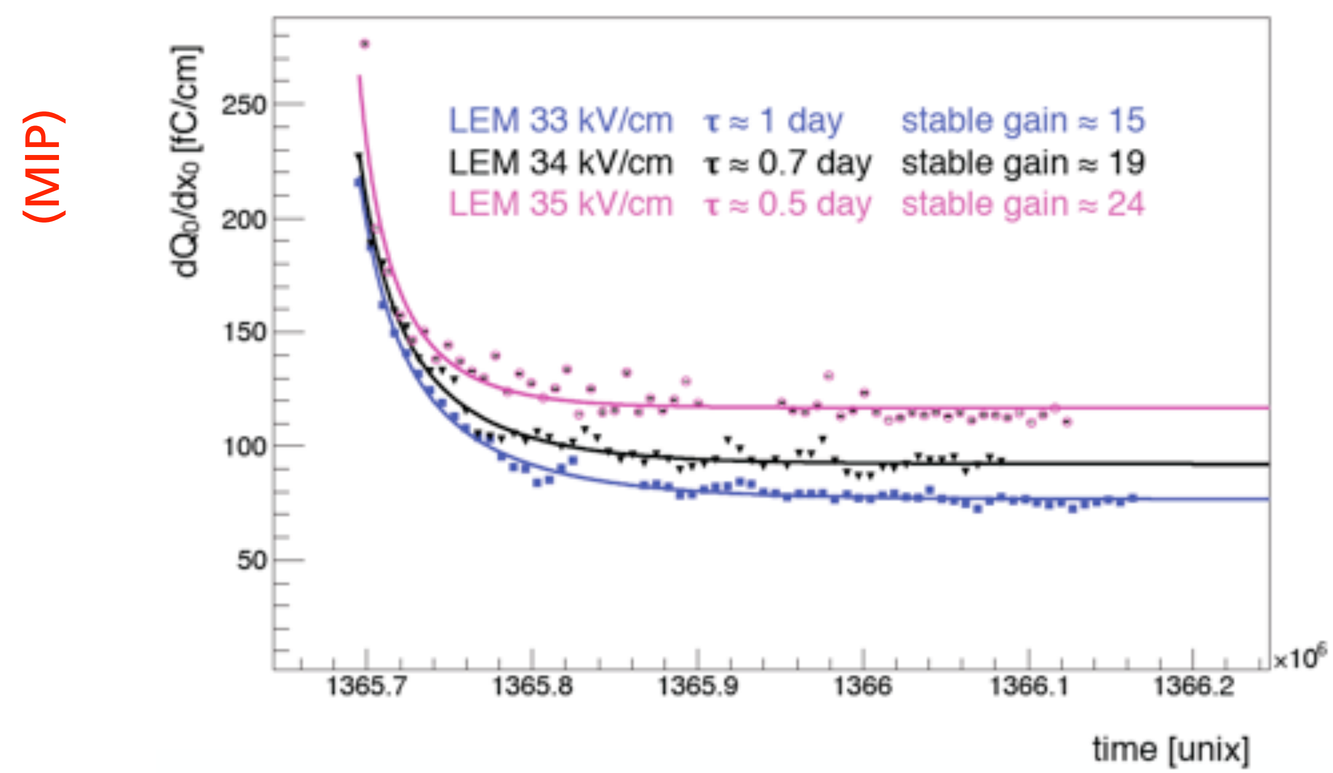






Performance

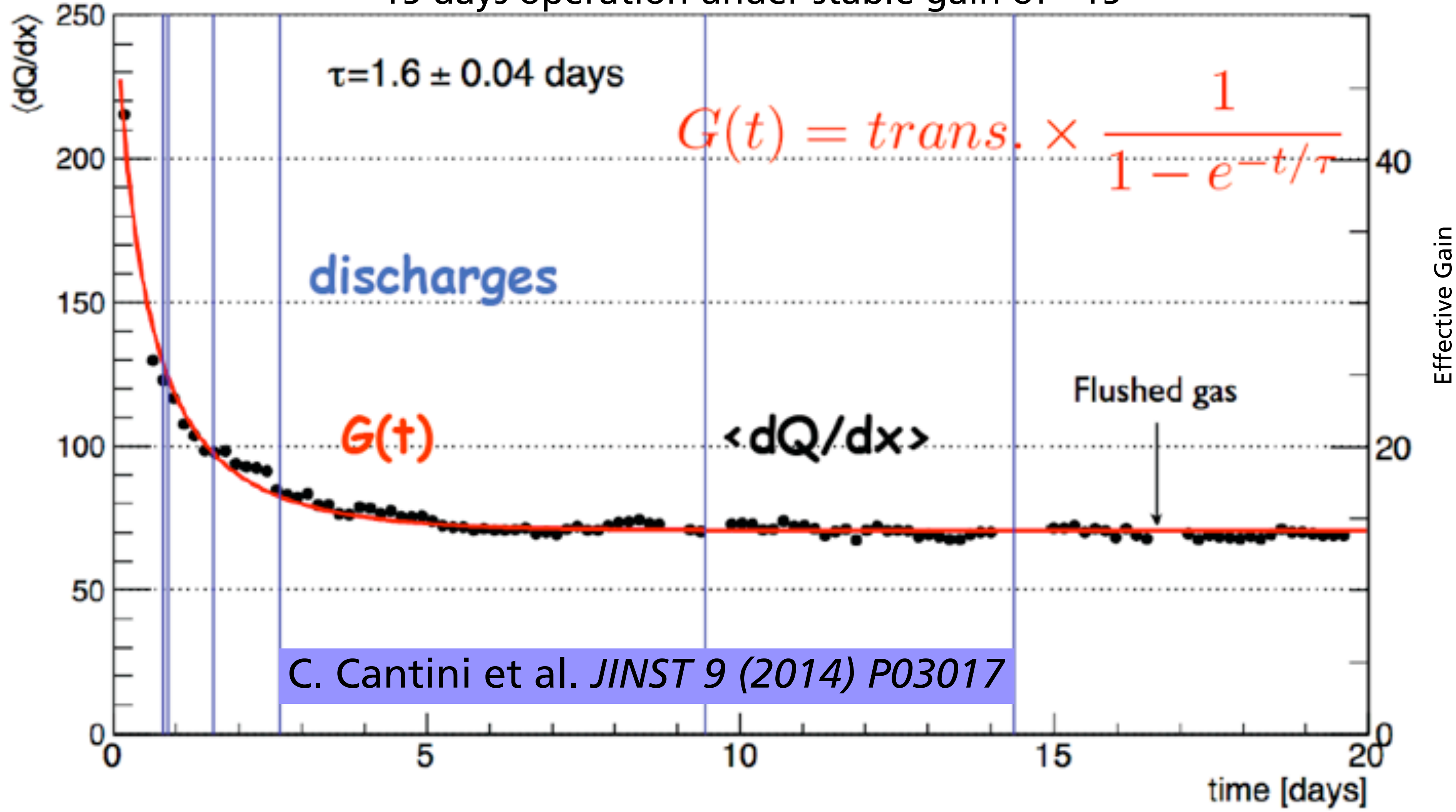




- Compared to a single phase detector, a double phase LEM has an excellent signal to noise ratio
- We achieved a maximum gain of more than 100! (Preliminary)
  - Gain of >90 published (C. Cantini et al. *JINST 9 (2014) P03017)*
- Depending on the electric field over the LEM, the time until a stable gain is reached changes
  - Initial gain is decreasing due to charging up effects in the LEM holes
- The charging up is well understood and totally reproducible
- Stable gain for several weeks!

Gain stability

~15 days operation under stable gain of ~15

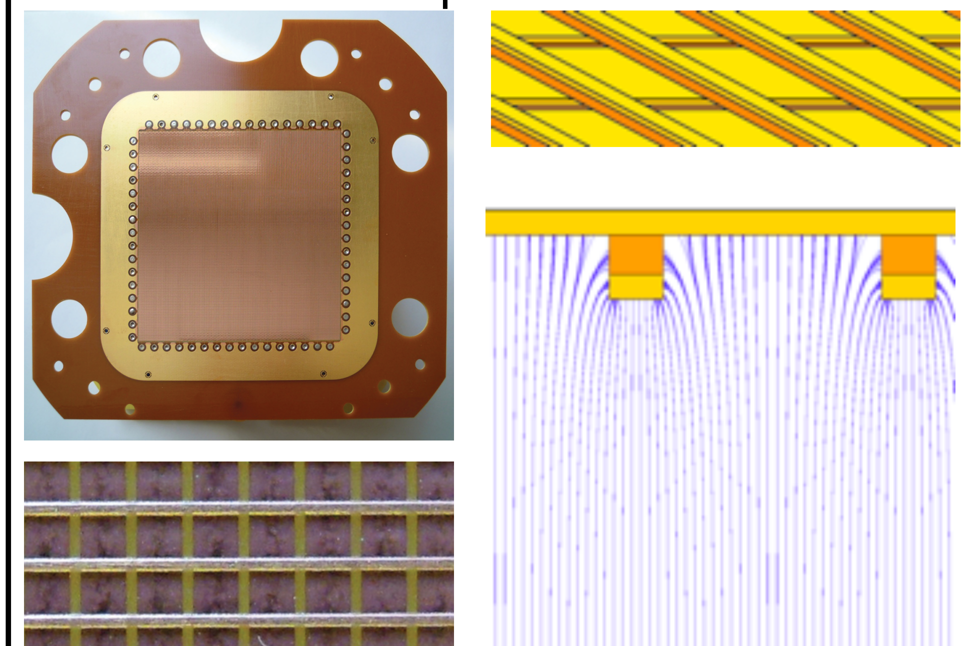


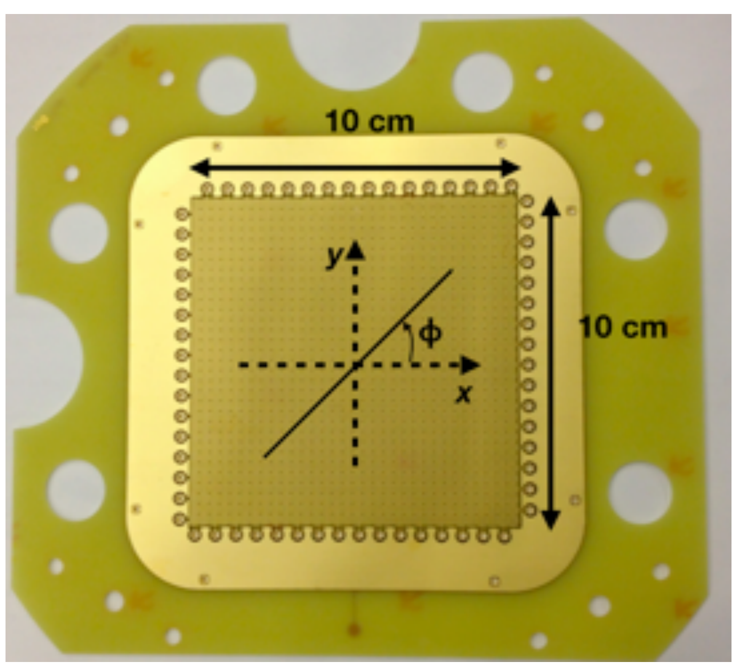
- dQ/dx corrected for pressure variations
- Discharges are local and do not affect the long term stability of the gain
- In total, only 6 discharges were observed over the entire test
- Once the LEM has charged up (~1.6 days) the gain stays stable

Anode details

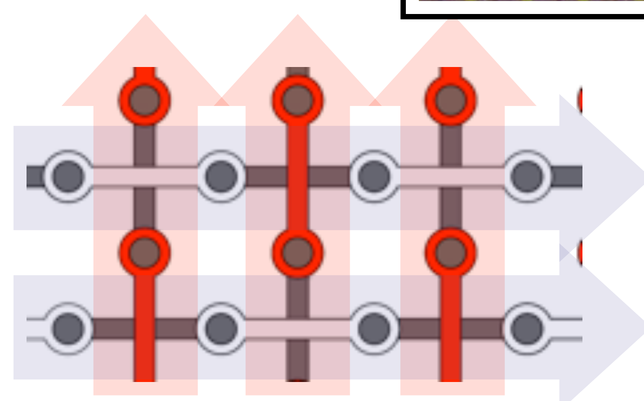
- Several types of 2D-Readout Anodes have been tested
- First solution contained multiple layers of Kapton and copper
- New solution is based on double side coated PCB board in order to reduce the capacitance
- Several types were tested, focusing on
  - Charge sharing
  - Invariance on direction
  - Capacity
- All measurements with 10 x 10 cm^2 CRP

Old Kapton anode

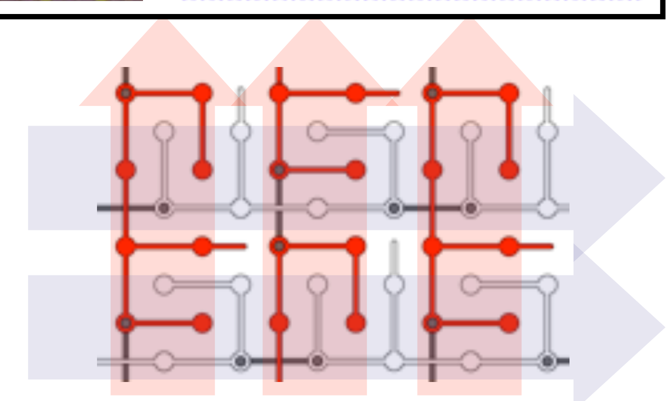




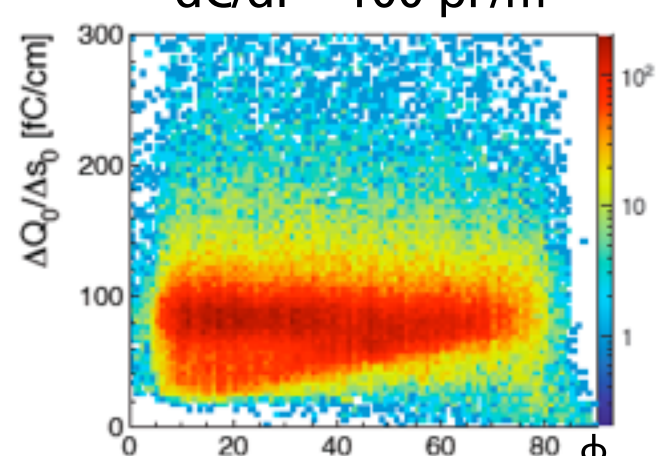
C Cantini et al 2014 JINST 9 P03017

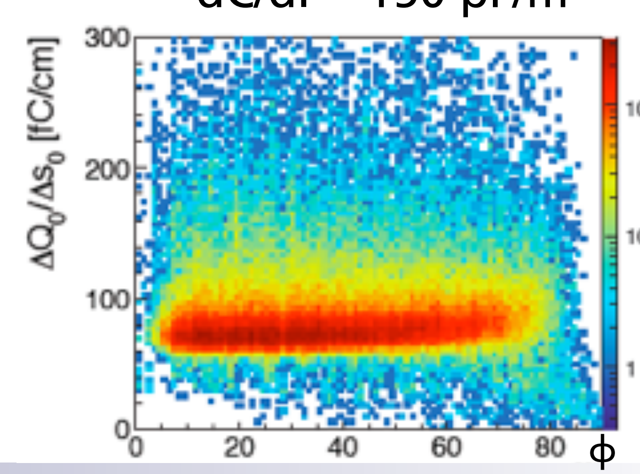


dC/dl ~ 100 pF/m



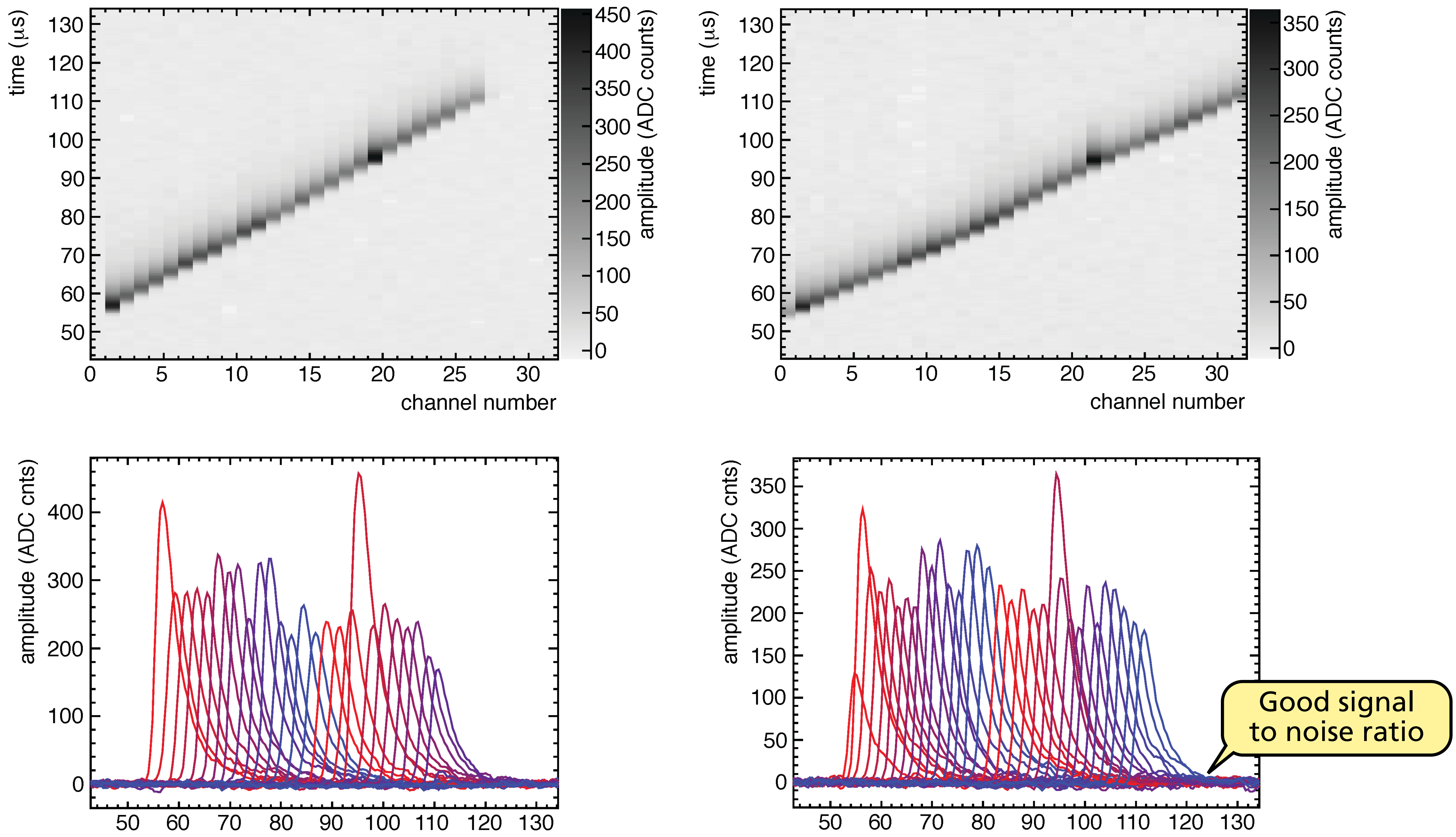
dC/dl ~ 150 pF/m





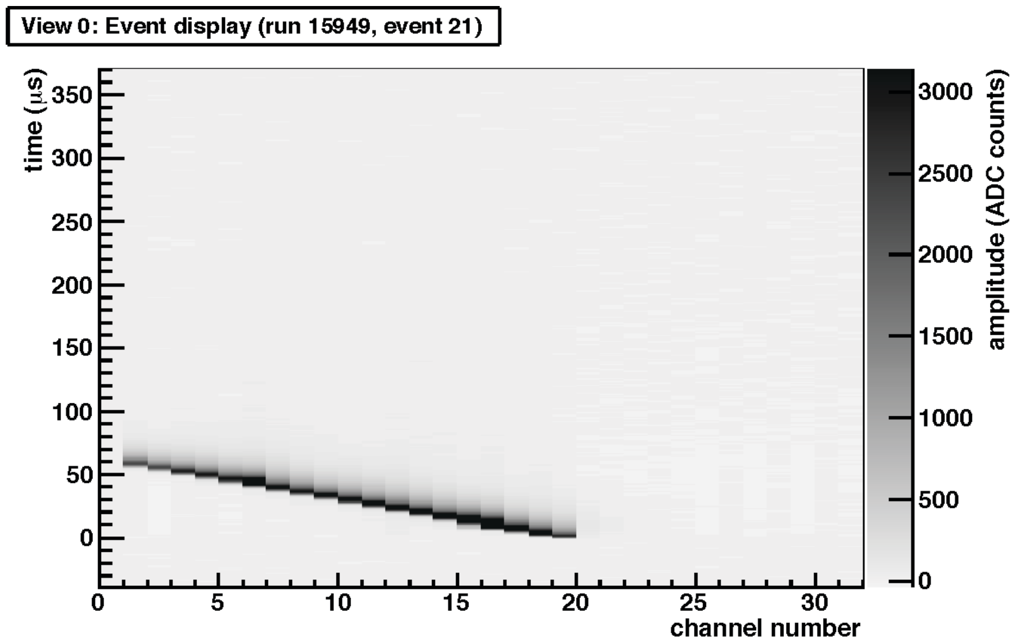
LEM: Event at effective gain of ~20

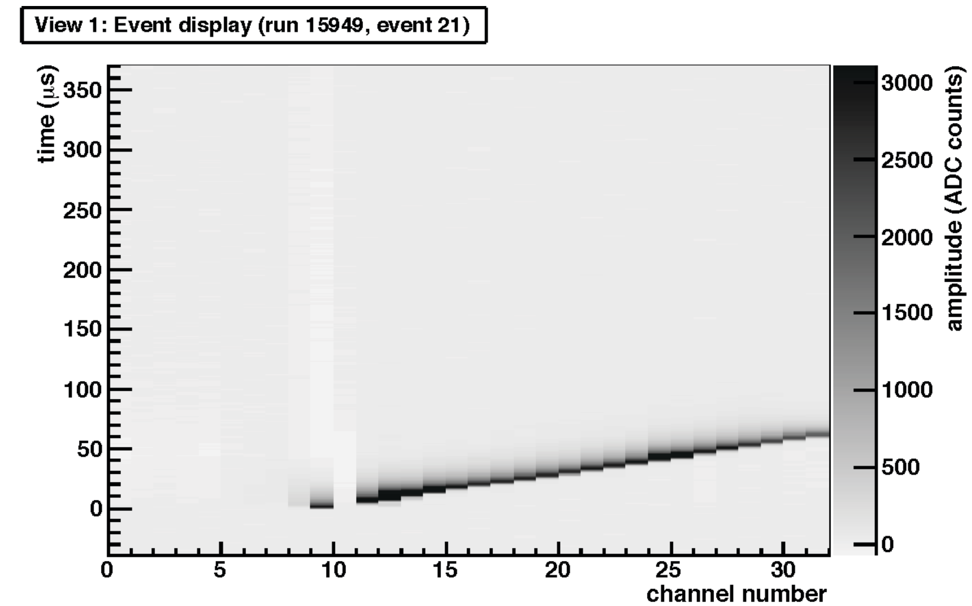
LEM: 33 kV/cm, induction: 5 kV/cm, extraction: 2 kV/cm, drift 0.5 kV/cm

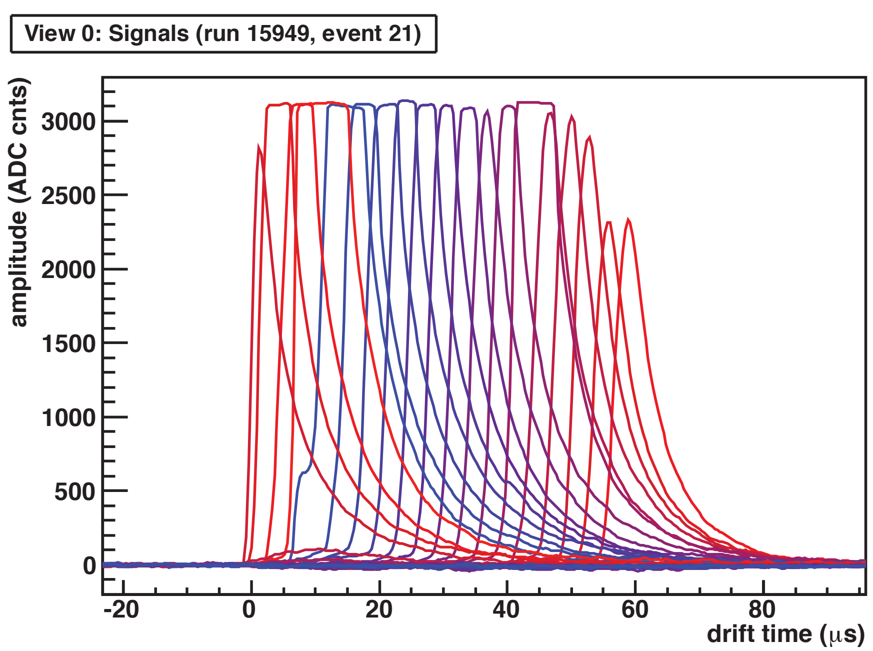


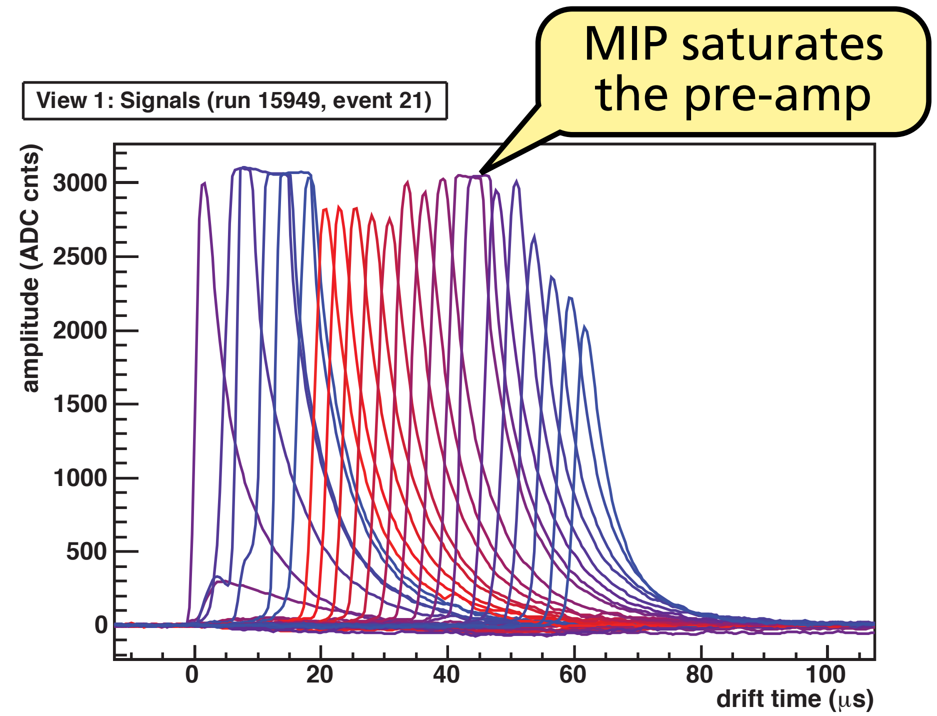
LEM: Event at highest gain of >90

LEM: 35 kV/cm, induction: 5 kV/cm, extraction: 2 kV/cm, drift: 0.5 kV/cm





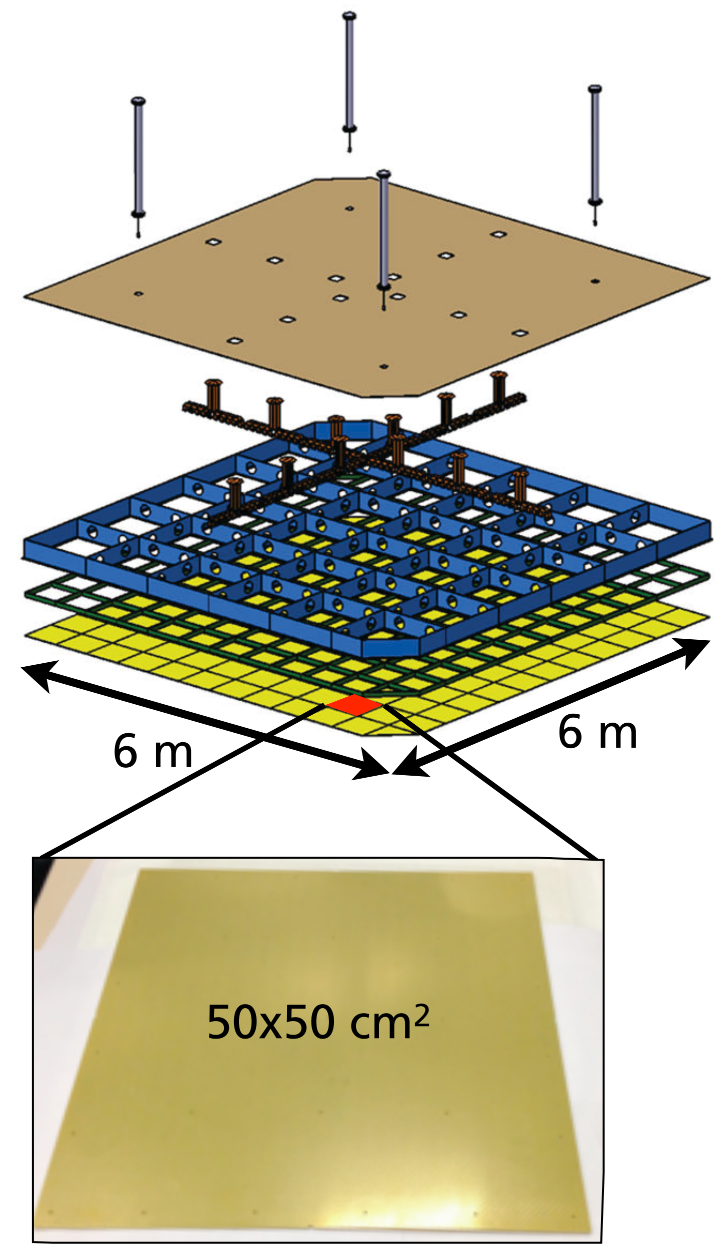


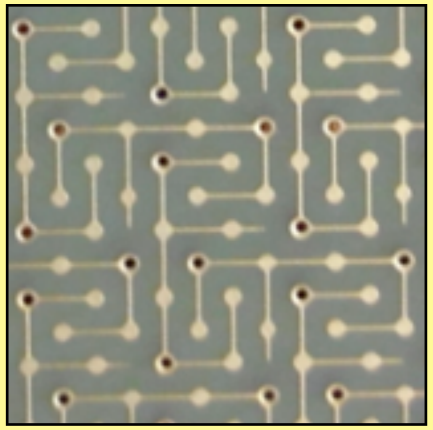
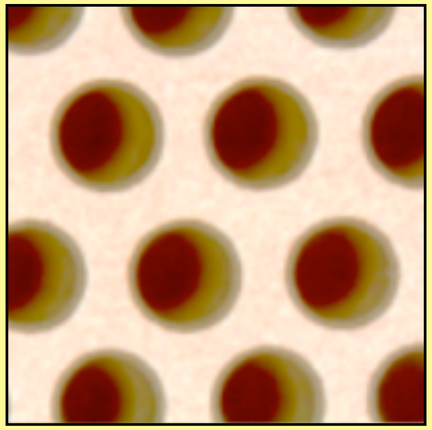
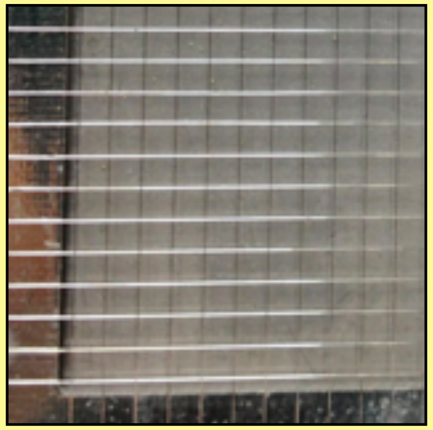


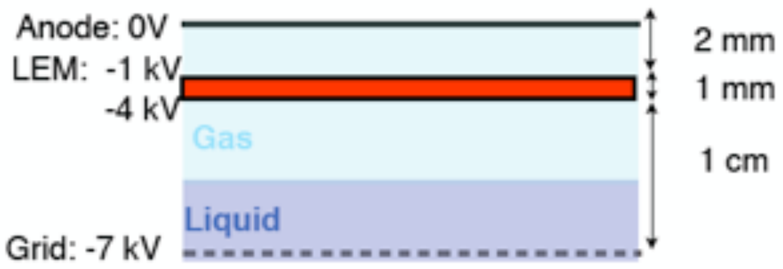
In future versions dynamic range of the preamp will be adapted to the gain.
--> Non-linear behavior to adapt to a wide dynamic range

Charge Readout Panel (CRP)

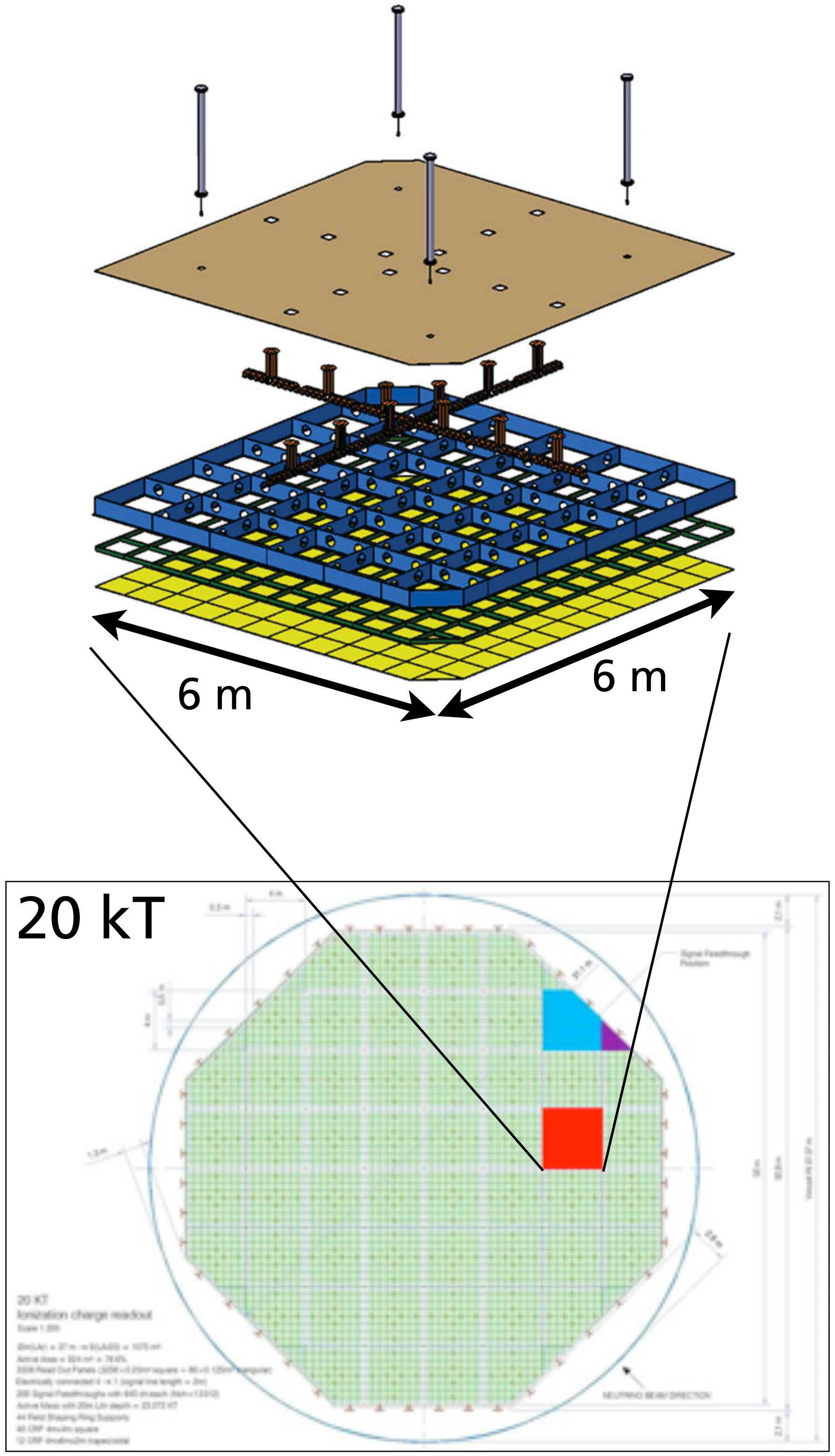
- Extrapolation to a 6 x 6 m^2 panel
- Panel contains several layers
  - 2D-directional readout anode
  - Charge multiplication device (LEM)
  - Extraction grid
- Single extraction grid for the complete area
- CRP is built of 144 LEM and Anode planes, fixed together to a rigid body
- Total of ~7700 channel
  - Detector is subdivided in 4 quarters of 3x3 m^2



Double PCB Anode	LEM	Extraction Grid
		



Extrapolation to multi-kton detectors

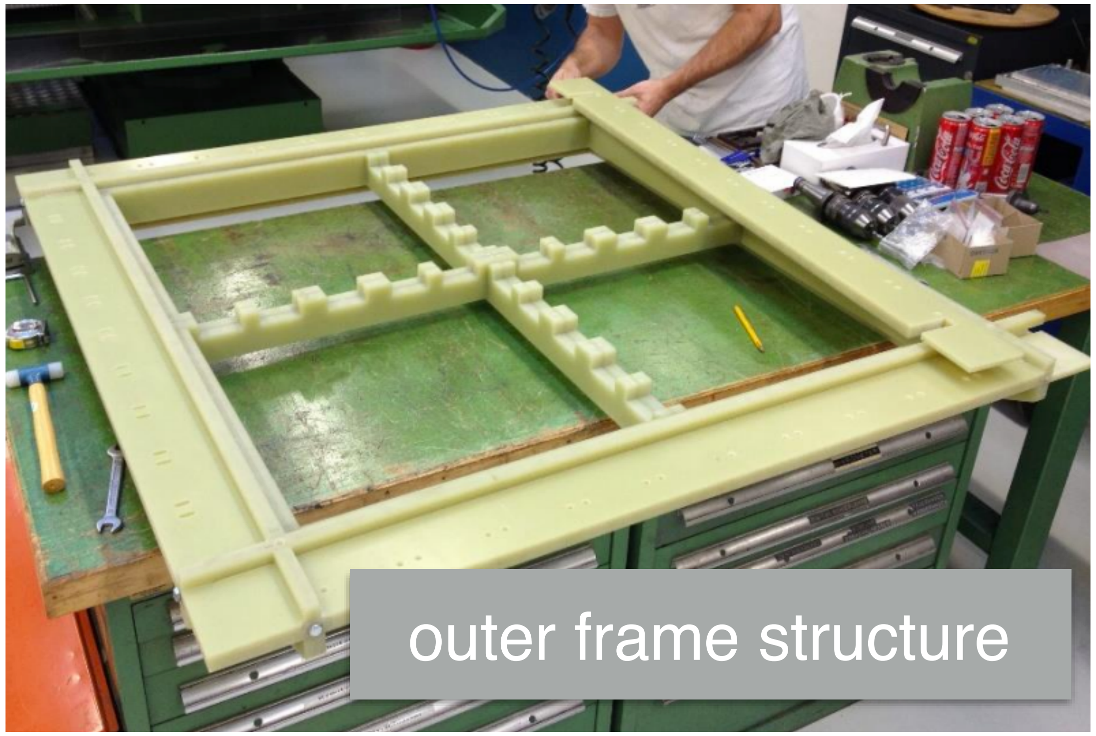


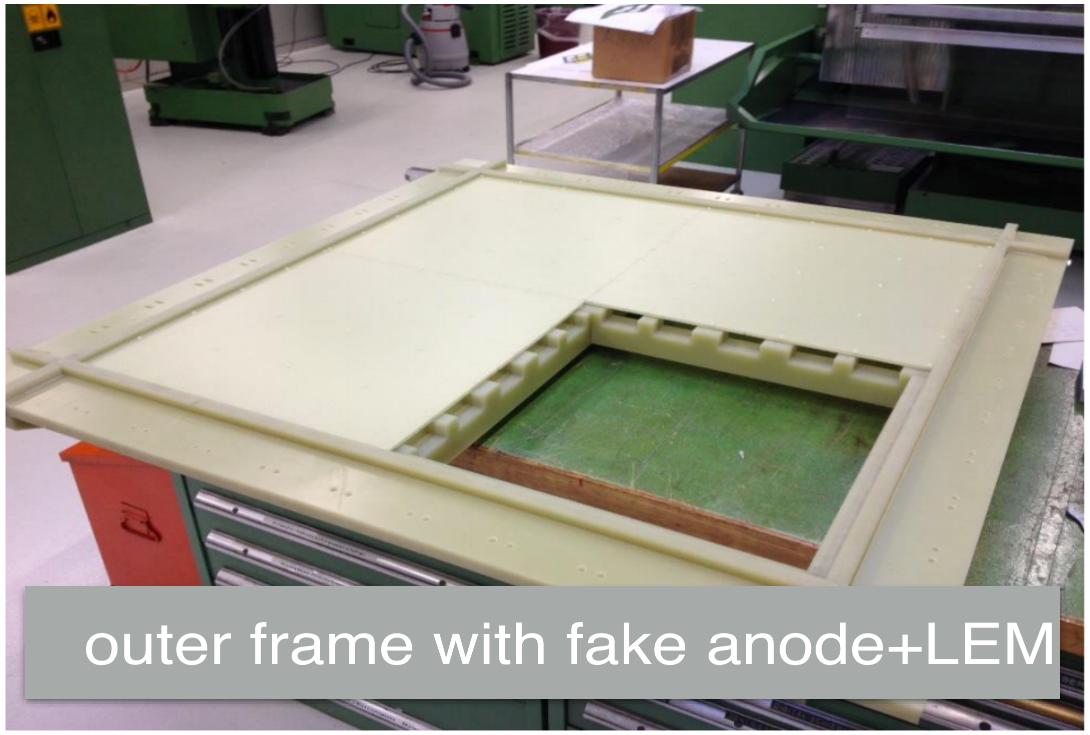
Each panel is an independent detector!

- We will be capable to quantify the performance of the solution <u>used for all upcoming detector generations of the LAGUNA/LBNO program</u>

- Charge Readout Panel (CRP) is suspended independently from the detector roof
  - Position with respect to Argon surface can be adjusted in height and planarity
- The LBNO-DEMO CRP consists of a single panel of 6x6 m^2
- The proposed CRPs for GLACIER will be similar (4x4 m^2)
  - Construction and design will be identical

CRP: Mechanical Mockup



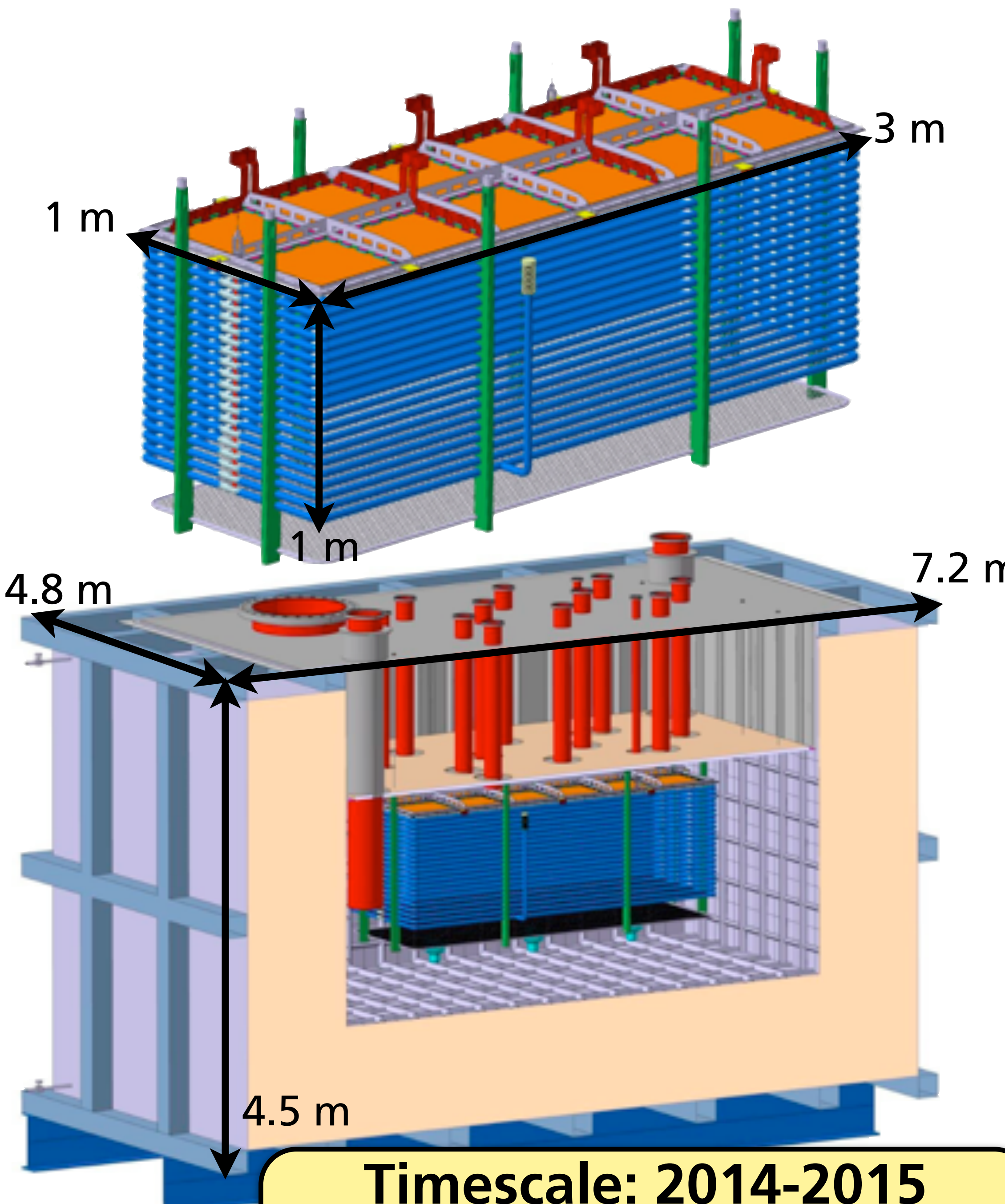


- Mockup of 1 m^2
- 1280 wires in total (640 in x and 640 in y)
- Precisely soldered on a PCB wire holder with pitch of 3 mm
- Each PCB wire holder hosts 32 wires and is tensioned individual

3x1x1 m³ detector

Between the largest existing double-phase LAr Detector of 1 ton (ArDM) and the LBNO-DEMO detector an intermediate solution (3x1x1 m³) is presently under construction:

- We are building a 3x1x1 m³ prototype detector
  - Active volume: 3 m³
  - Total volume of LAr: 17 m³ (~20 t)
  - Double phase operation with a single, large CRP of 3 m²
- The goal of this prototype is:
  - First use of the membrane technology
  - Cold electronics
  - Readout of large area CRPs
  - Liquid handling, cooling and purification
  - Software development for reconstruction and particle identification



Timescale: 2014-2015

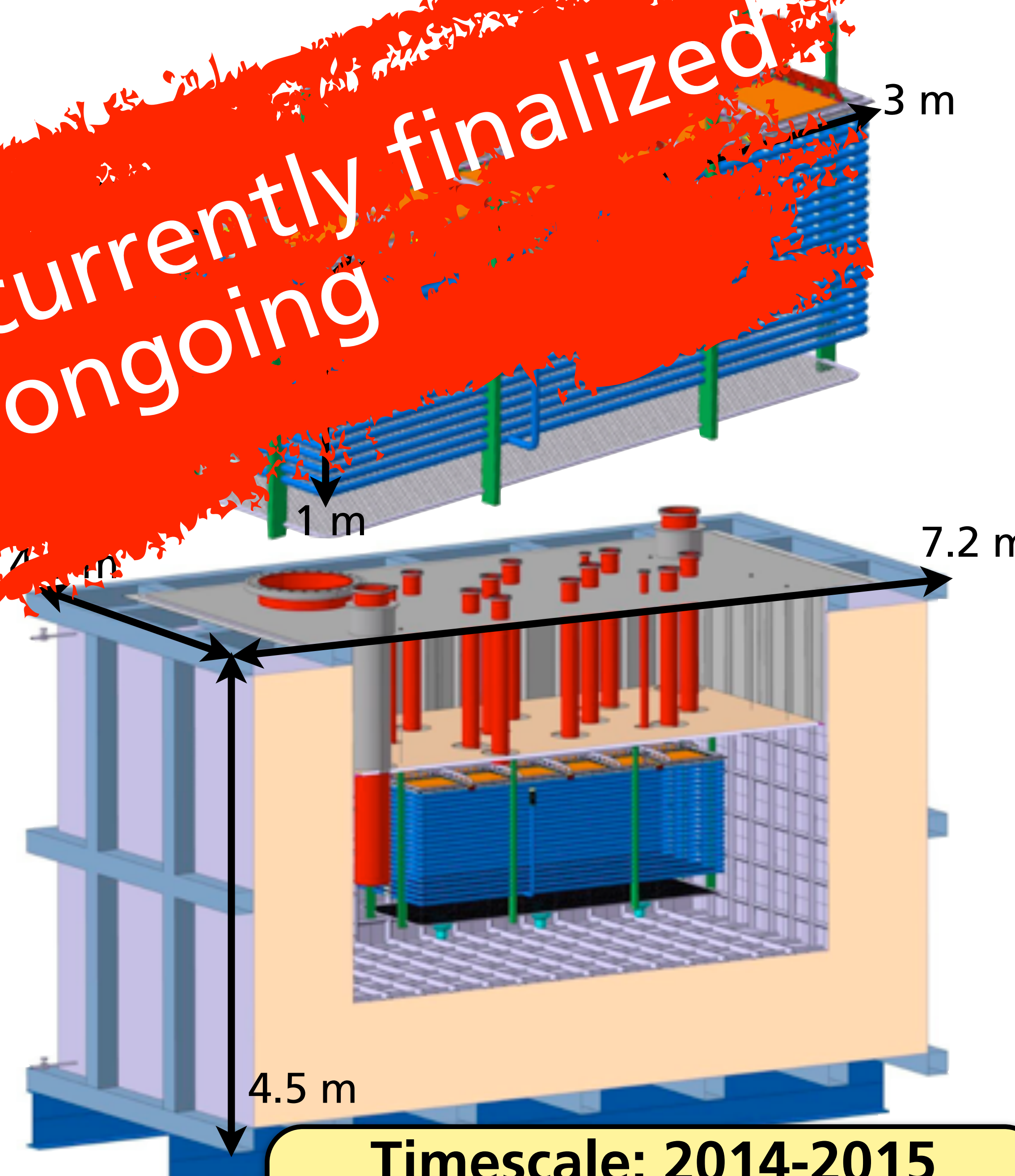
Cost in the order of 1 M€

3x1x1 m³ detector

Between the largest existing double-phase LAr Detector of 1 ton (ArDM) and the LBNO-DEMO detector an intermediate solution (3x1x1 m³) is presently under construction:

- We are building a 3x1x1 m³ prototype detector
  - Active volume: 3 m³
  - Total volume of LAr: 17 m³ (~20 t…
  - Double phase operat… large CRP of 3 m²
- The…
  - First … …nology
  - Co…
  - Read… large area CRPs
  - Liquid handling, cooling and purification
  - Software development for reconstruction and particle identification

Technical drawings are currently finalized
The work is ongoing



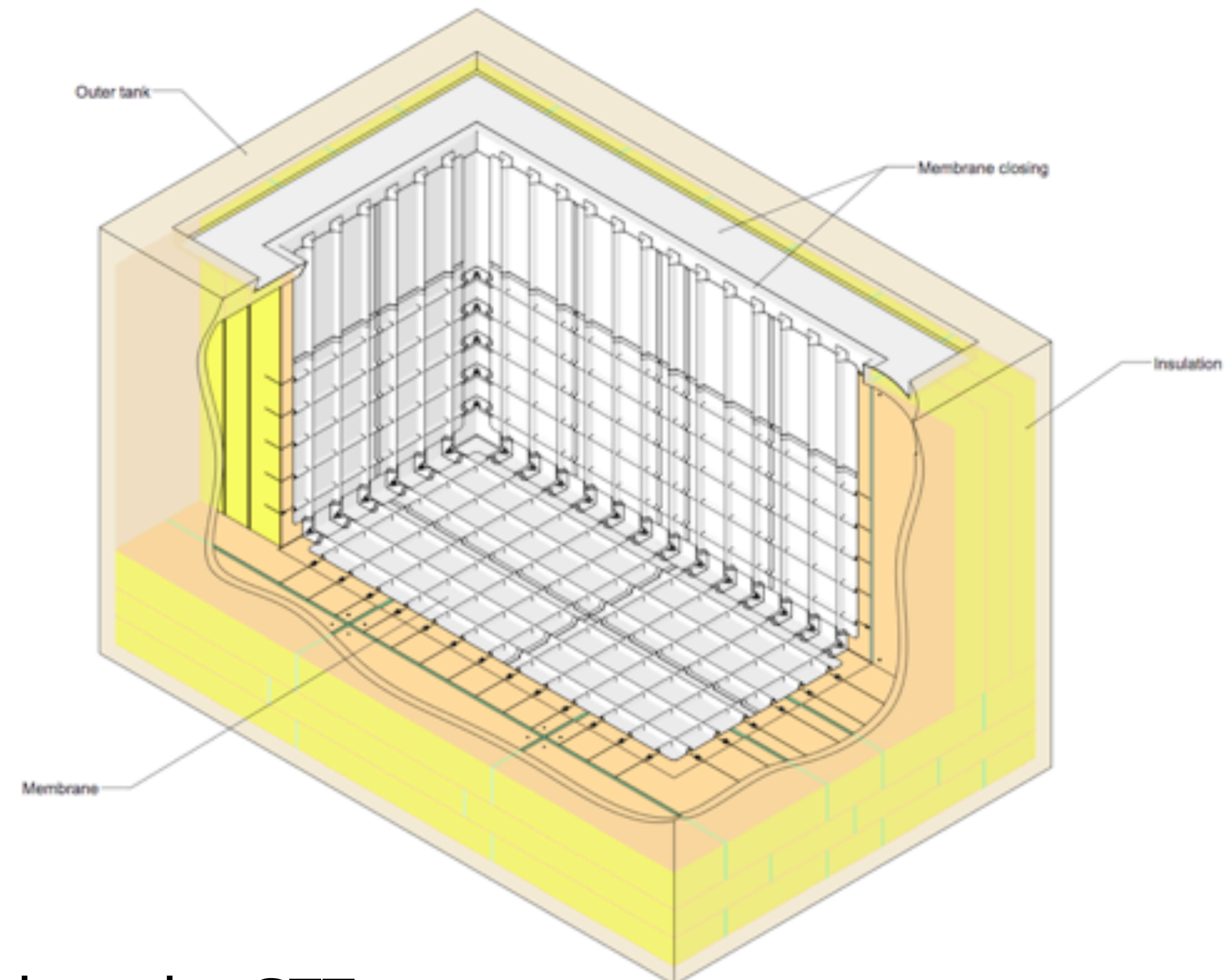
Timescale: 2014-2015

Cost in the order of 1 M€

Membrane technology

GTT	Technical	AP448-RT-CDC-00001
	TECHNICAL OFFER FOR THE LAGUNA THERMAL INSULATION SOLUTION	Revision : 012
		15/01/2013
	Scope of Works	Page : 10 / 10

- Very high requirements on tightness (10^{-9} mbar l / s)
- "Top cap" has to be removable
  - It can be welded up to 5 times
- Inner dimensions of the cryostat: 3.0 * 4.8 * 2.4 m^3 (height x length x width)
- Outer size of cryostat: 4.9 * 7.2 * 4.8 m^3



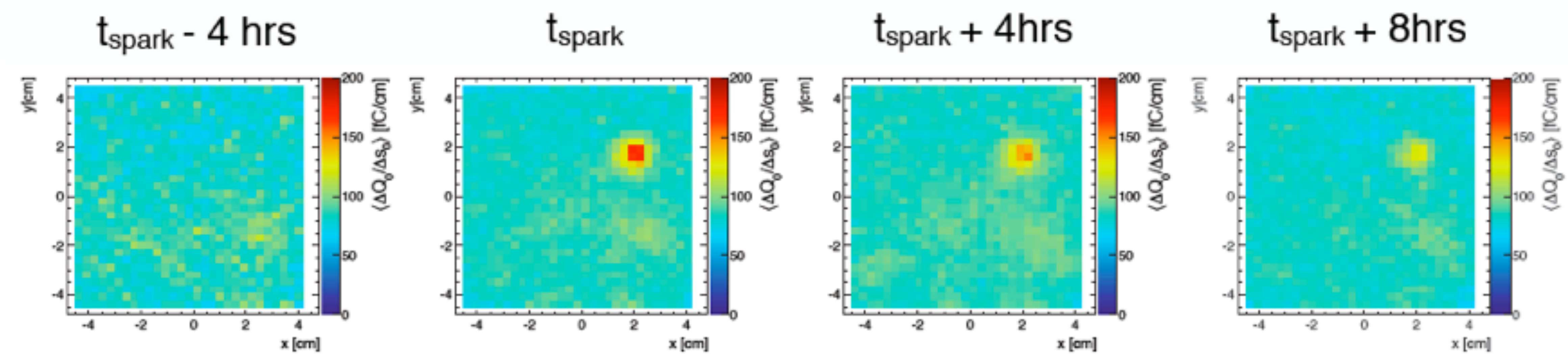
- Feasibility study for 3x1x1 tank was carried out by GTT
  - Document includes detailed drawing, pricing, installation sequence and time schedule
- The tender is currently ongoing
- 17 m^3 membrane tank to be ready for first cool down in spring 2015

Conclusion and Outlook

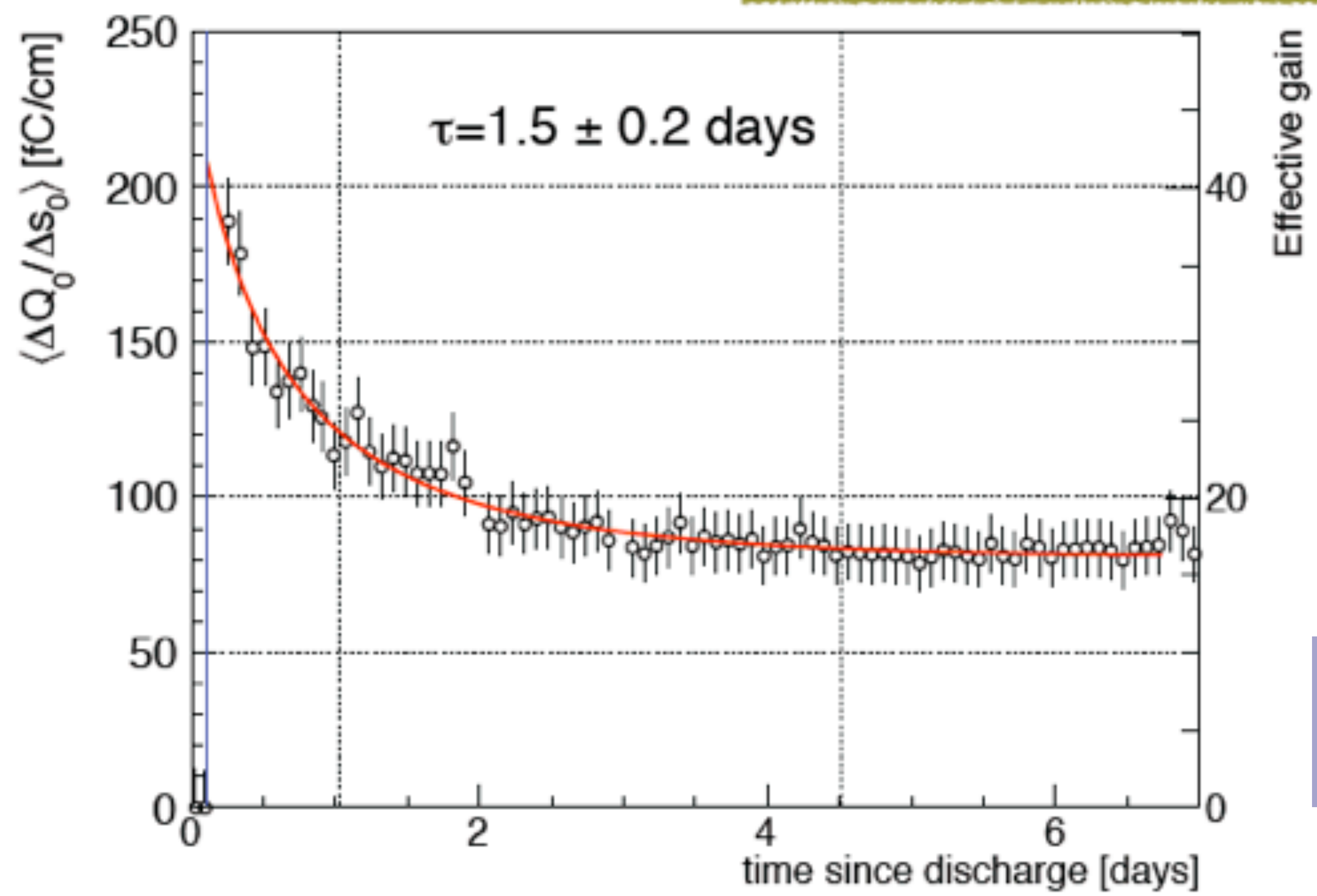
- WA105 will be the first LAr Double Phase detector which can contain complete physics events, coming from a test beam
- With the huge progress on the R&D for an efficient and stable charge readout we are able to design the final, large CRP detector used for all Double Phase LAr detectors defined by the LAGUNA-LBNO design study
- 3x1x1 and WA105 will be the first detectors benefiting of this design
- **WA105 is proposed, approved and supported by CERN!**
- We have a well defined plan to build the 3x1x1 m^3 detector over a time scale of one year until first commissioning
- 3x1x1 will give us important feedback on the technologies, important for WA105 and all future detectors

Backup

Discharges

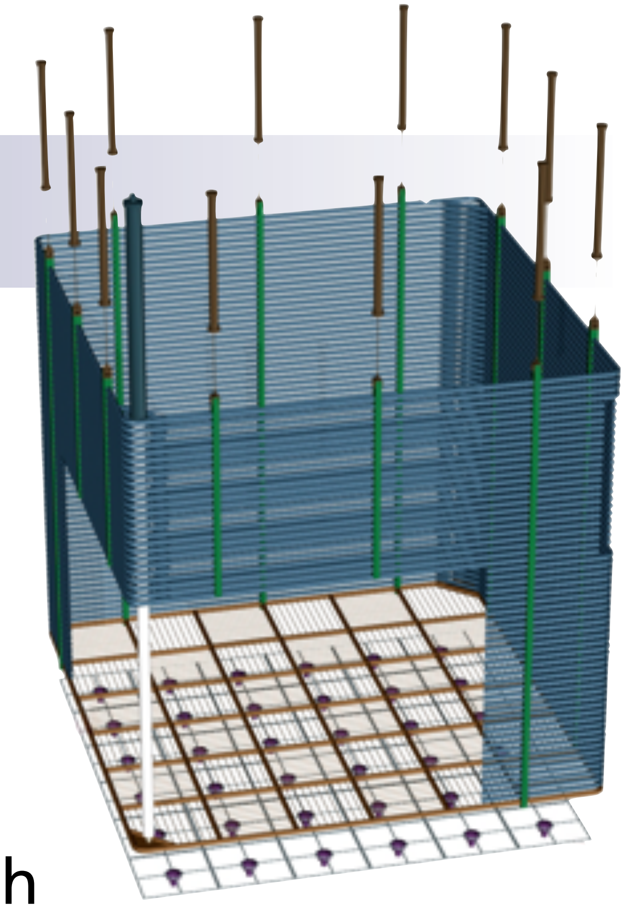


Same behaviour is observed locally!



S. Murphy,
RD51 collaboration meeting
CERN Feb. 7 2014

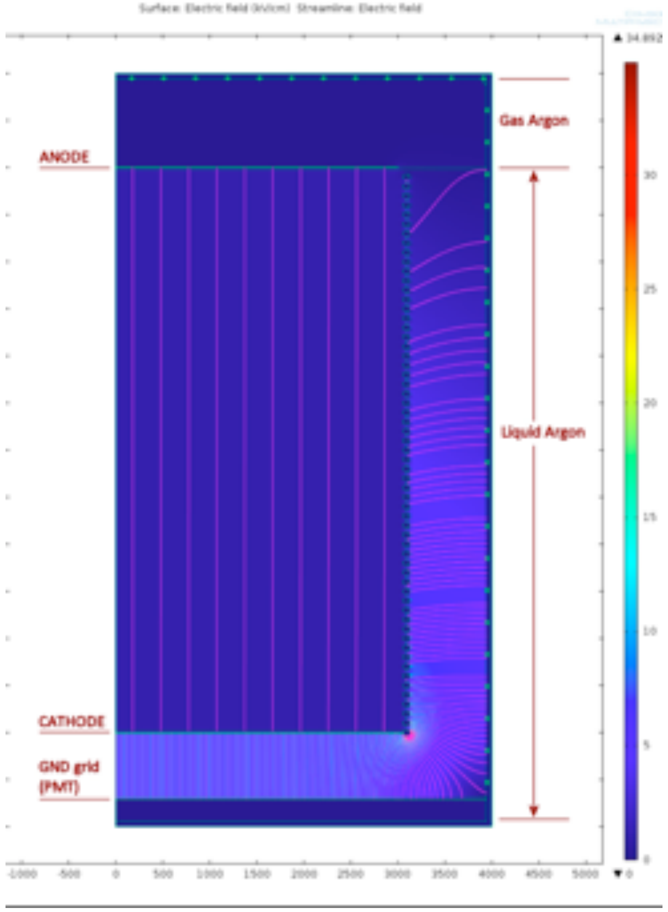
Drift Cage

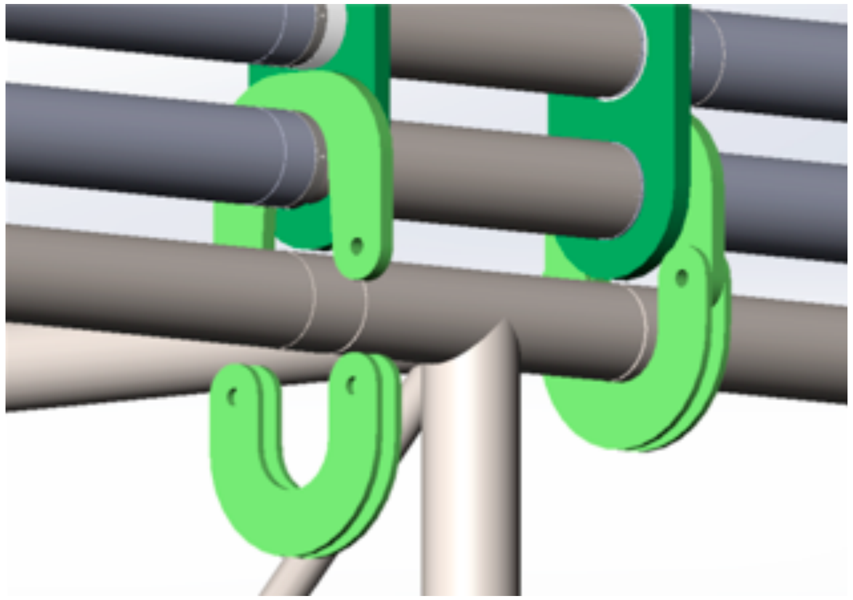


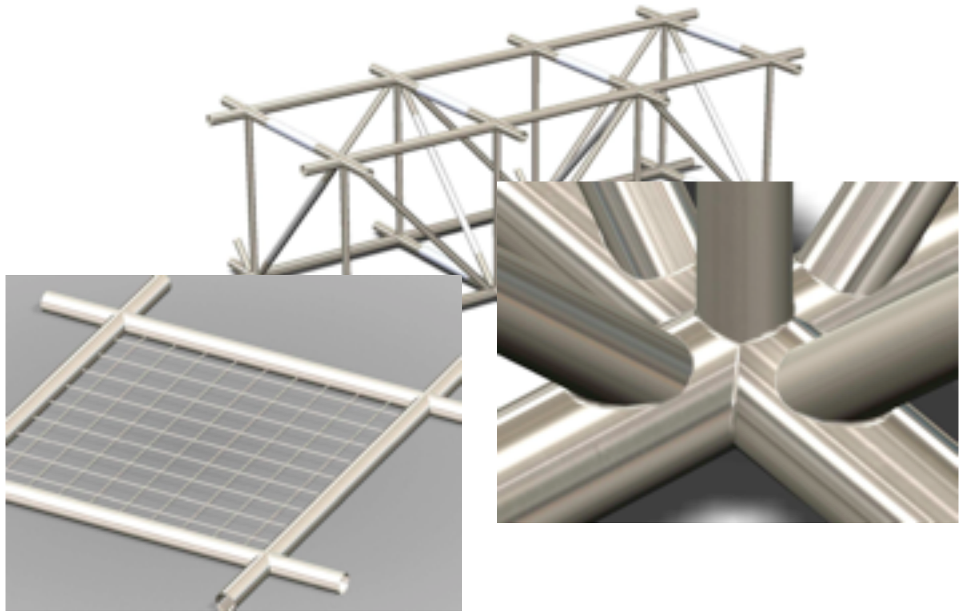
- Homogeneous drift field created by field cage
  - Drift field of 1 kV/cm i.e. 600 kV on cathode

- Cage is hanging from the tank roof
  - 60 tubes of ~70 mm diameter and a pitch of 100 mm
  - Supporting structure is made with 16 “FR4-chains“

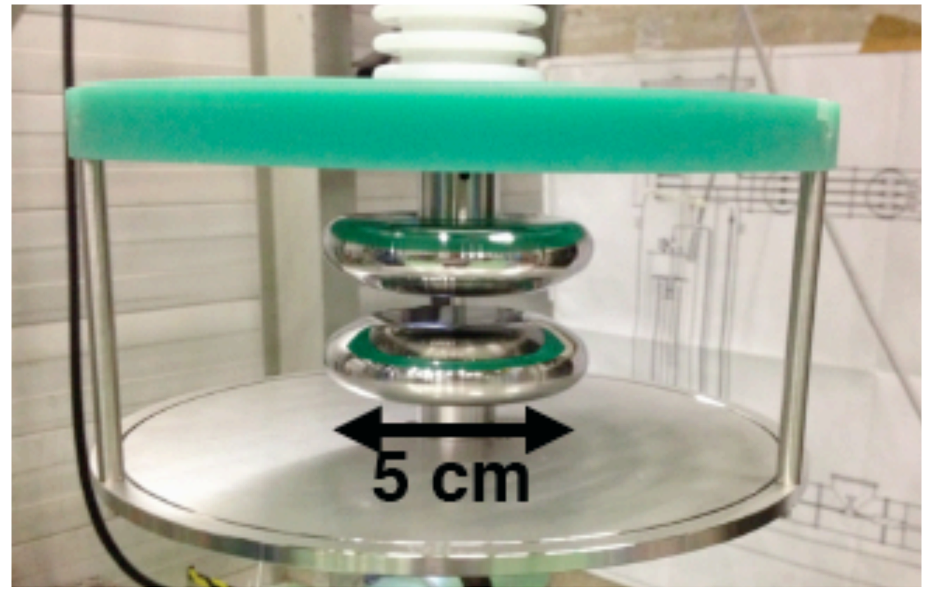
- Cathode
  - Steel tubes with pitch of 500 mm
  - 5 mm wire mesh with pitch of 50 mm
  - 80% transparency

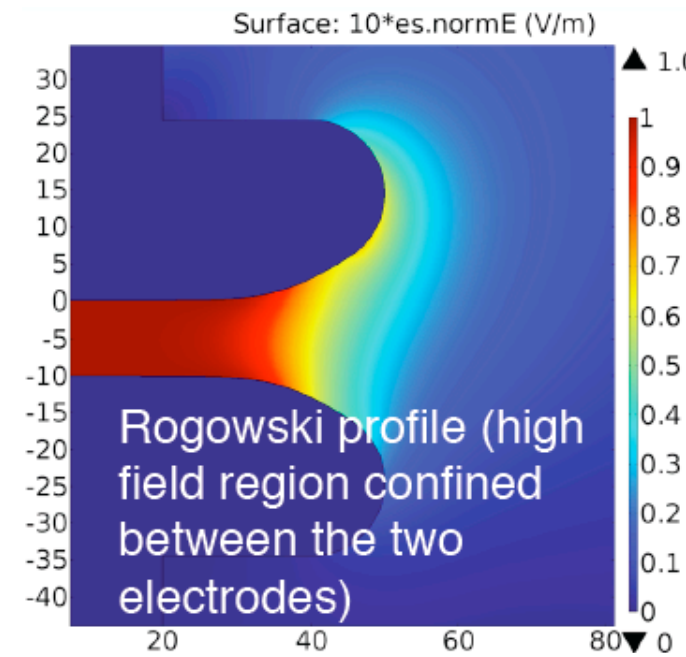






High voltage R&D test

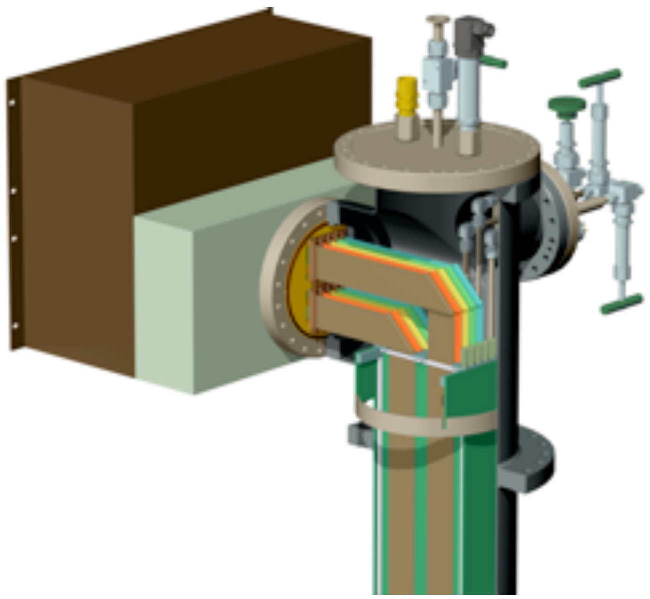


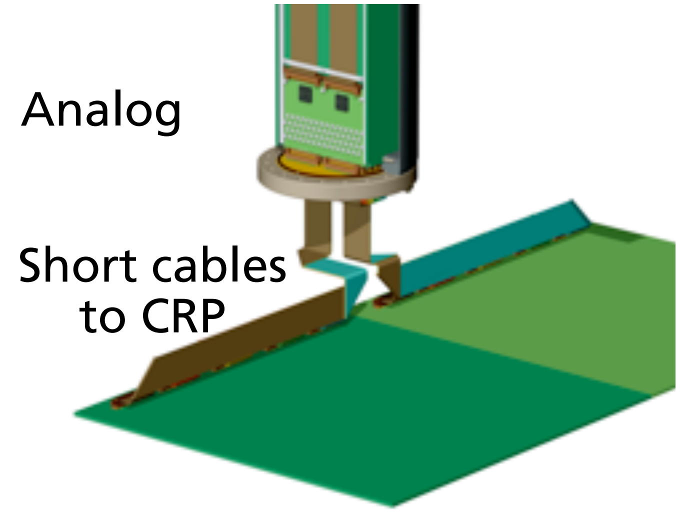


- Dielectric rigidity of argon was tested up to 100 kV/cm over 1 cm (away from boiling point)
- Discharge around 40 kV/cm at boiling point
  - arXiv:1401.2777
- New HV power supply for up to 300 kV is ordered
- Further tests will address the effect of impurities on rigidity

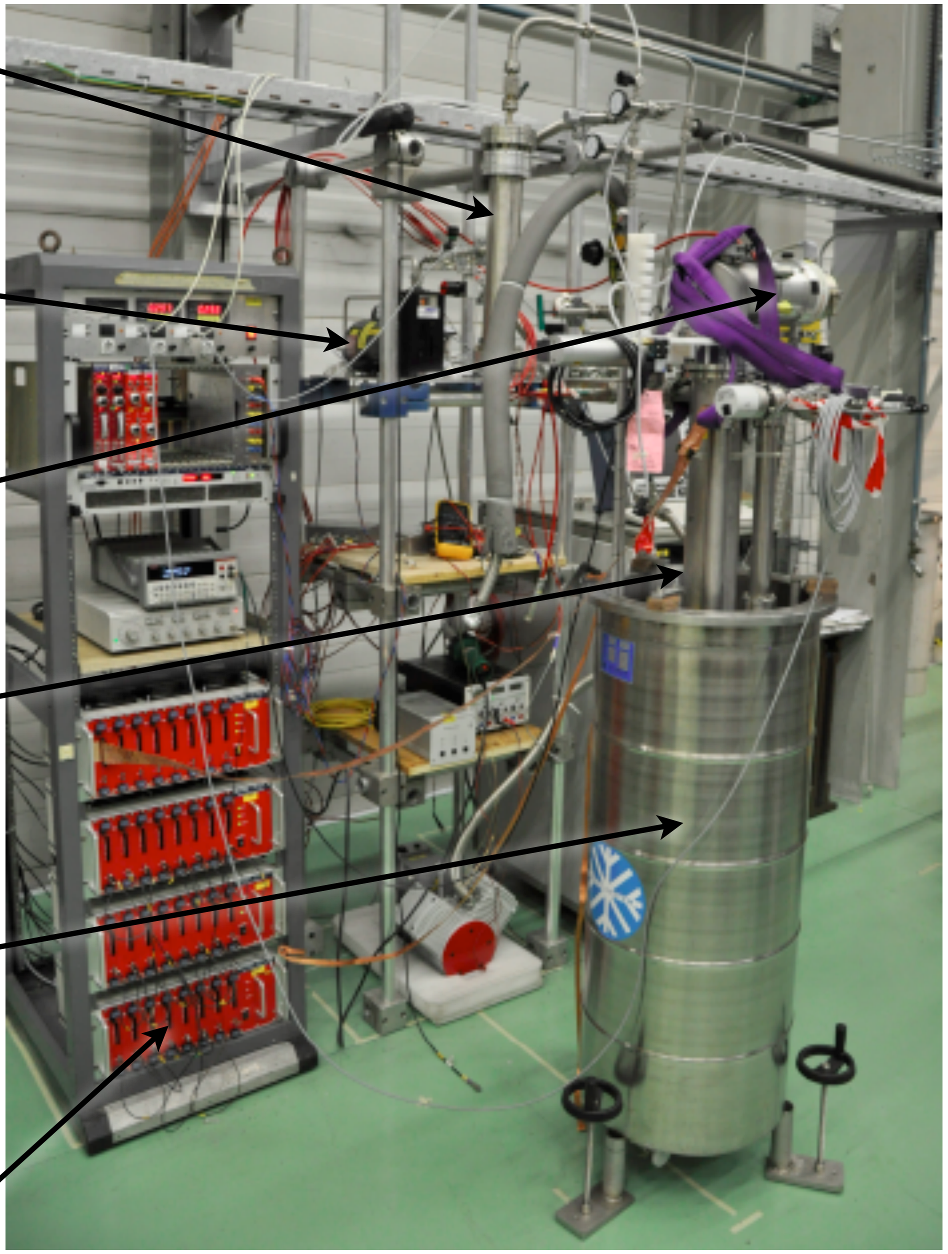
Front-end and DAQ readout

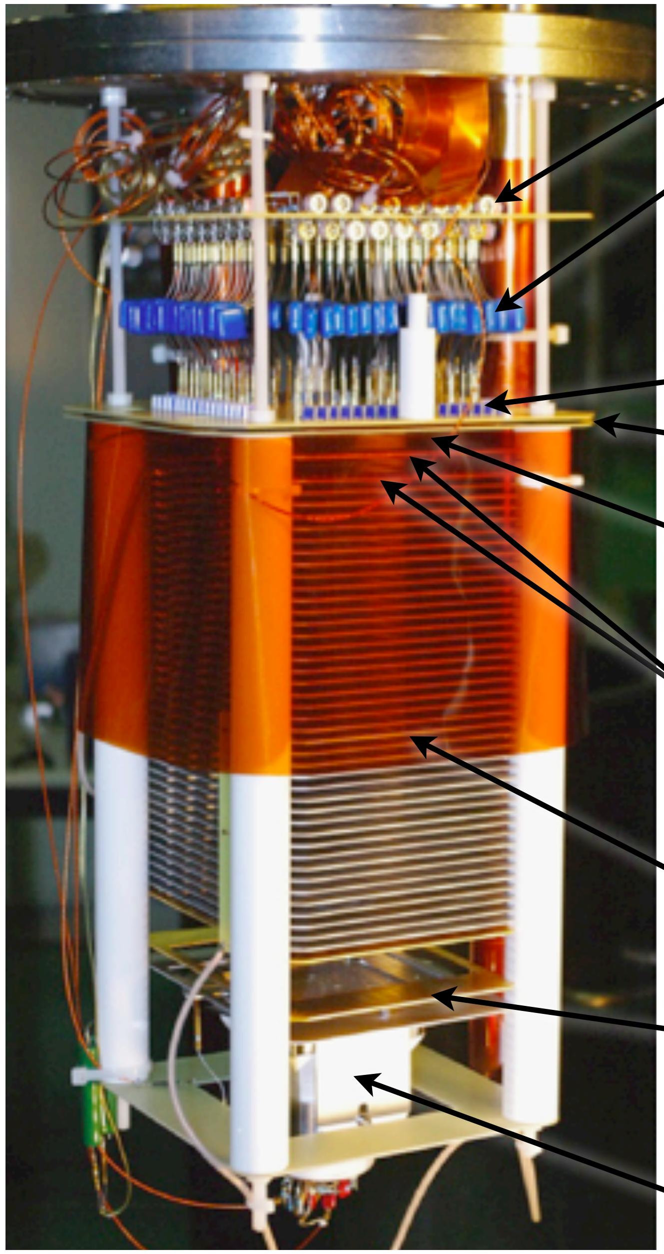
- In order to reduce the cable length and the electronic noise, the analog part of the readout electronic is close to the CRP
- Each chimney hosts 640 channels
- Cards of 64 channels each can be exchanged during operation without having to open the vessel
- Operation temperature of chips around 100 K
- Total of about 18 mK/ch of heat
- Extended dynamic range by double slope gain
- DAQ by Gigabit Ethernet
- Prototype is under preparation



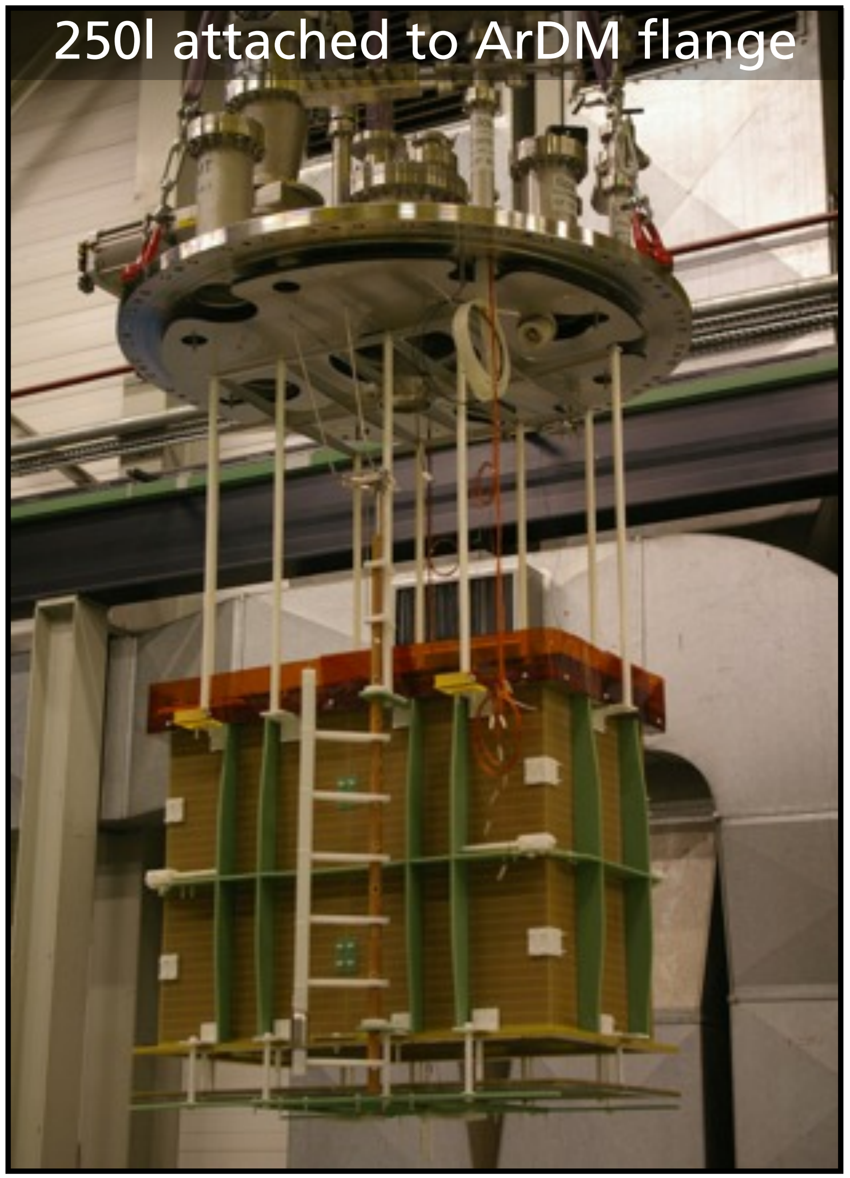


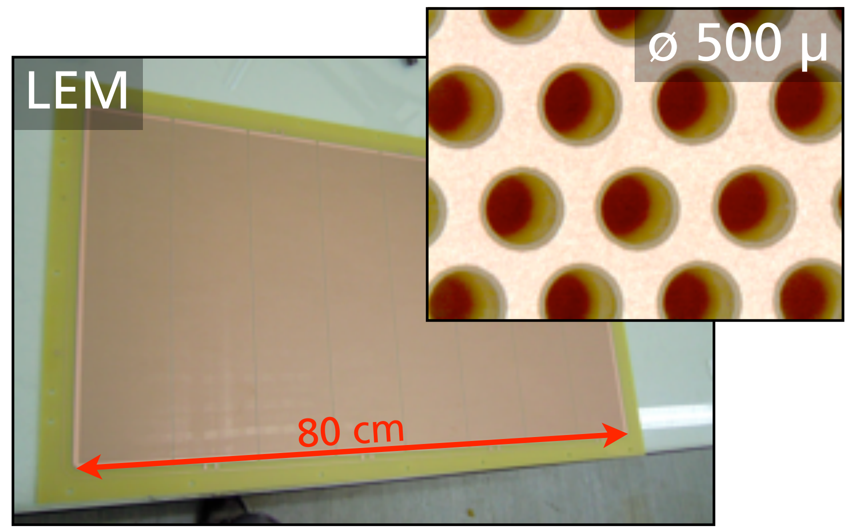
The 3l-Setup @ CERN

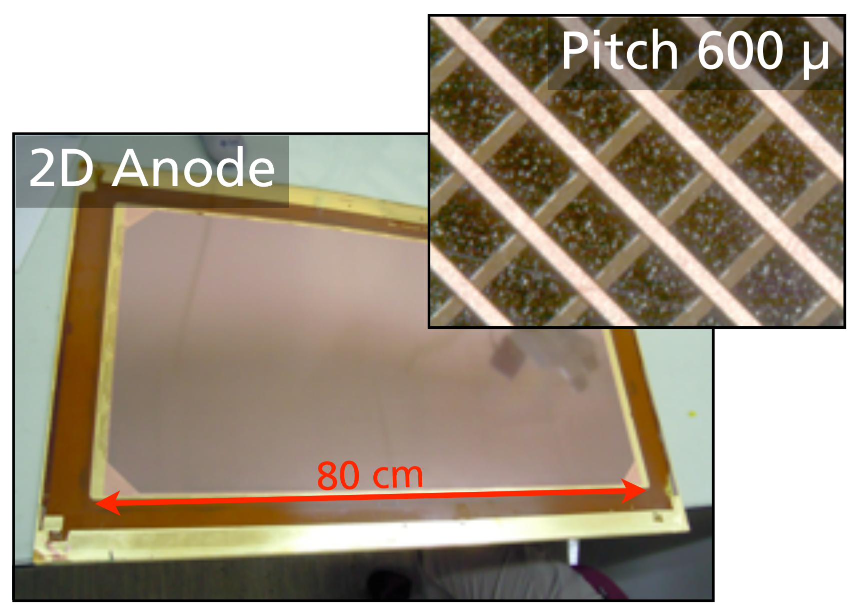




250l: Test of largest LEM ever built







A. Badertscher et al. JINST 8 (2013)P04012

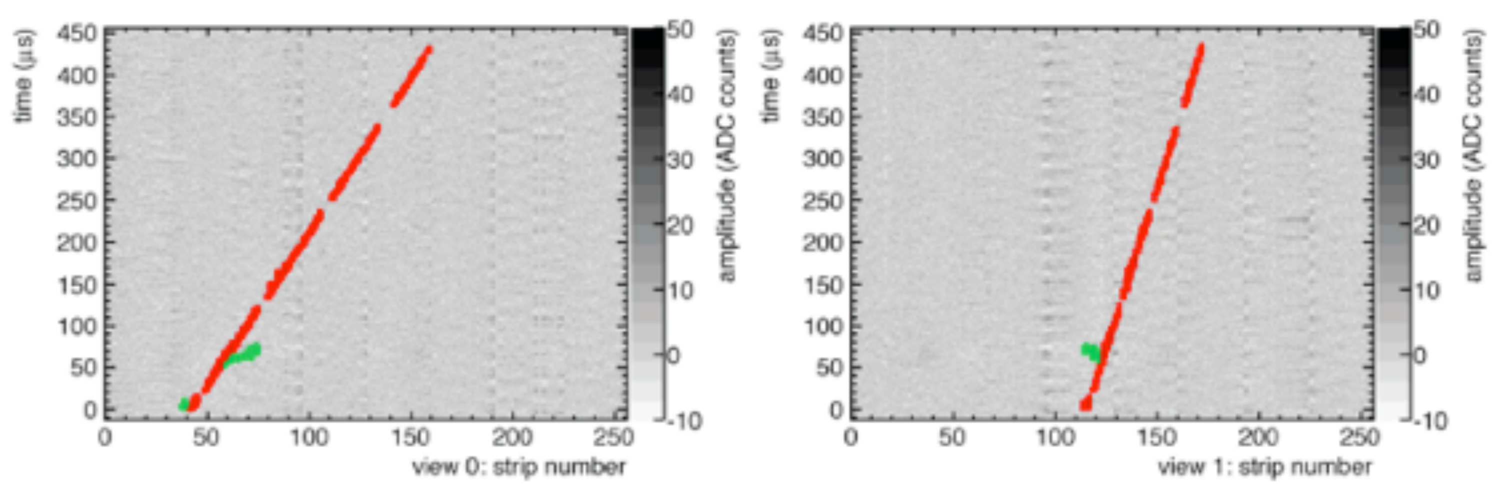
- Biggest LEM and 2D anode ever built (80 x 40 cm)
  - For WA105 they will be 50 x 50 cm
- LEM segmented in 8 parts to decrease capacitance
- Anode views 45° to possible incoming beam
- 512 channels
- Test was performed in the ArDM vessel at CERN
- Beside the actual detector, new cryogenics and electronics were tested

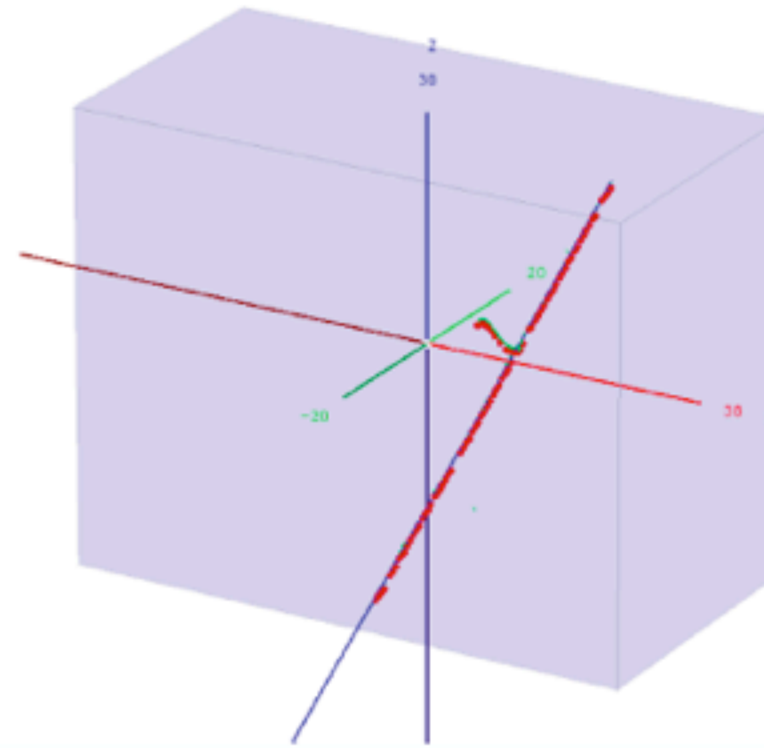
Results from the 250l setup

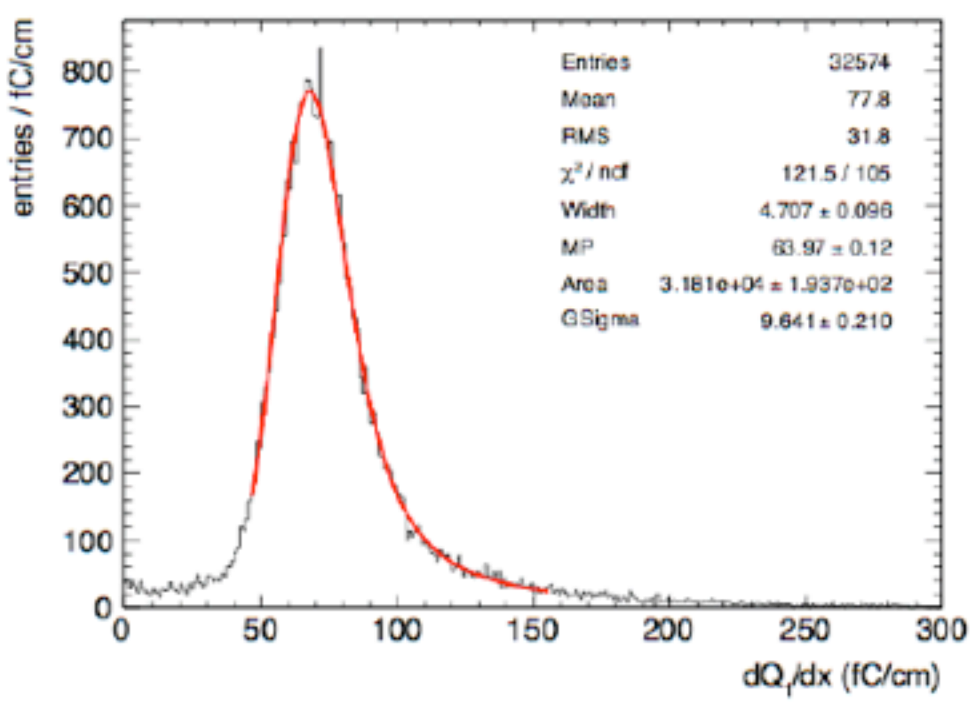
We have operated the detector for the first time in October 2011 during more than 1 month.

Operated under controlled pressure: 1023±1 mbar A. Badertscher et al. JINST 8 (2013)P04012,

delta ray identified and reconstructed in 3D!







Effective gain:
$(dQ/dx_{view0} + dQ/dx_{view1})/dQ/dx_{MIP}$ (≈10fC/cm)

<dQ/dx>=146 fC/cm
➡effective gain≈14.6, (S/N≈30)
charge sharing between the two collection views:
$(Q_1-Q_0)/(Q_1+Q_0)\approx 8\%$