WA105

Double phase charge readout system and construction of the WA105-3x1x1 double phase Liquid Argon TPC

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Institute for Particle Physics, ETH Zurich

on behalf of
WA105 collaboration

NNN 2015, Stony Brook, 23-28 Oct 2015

The double phase LAr LEM TPC

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

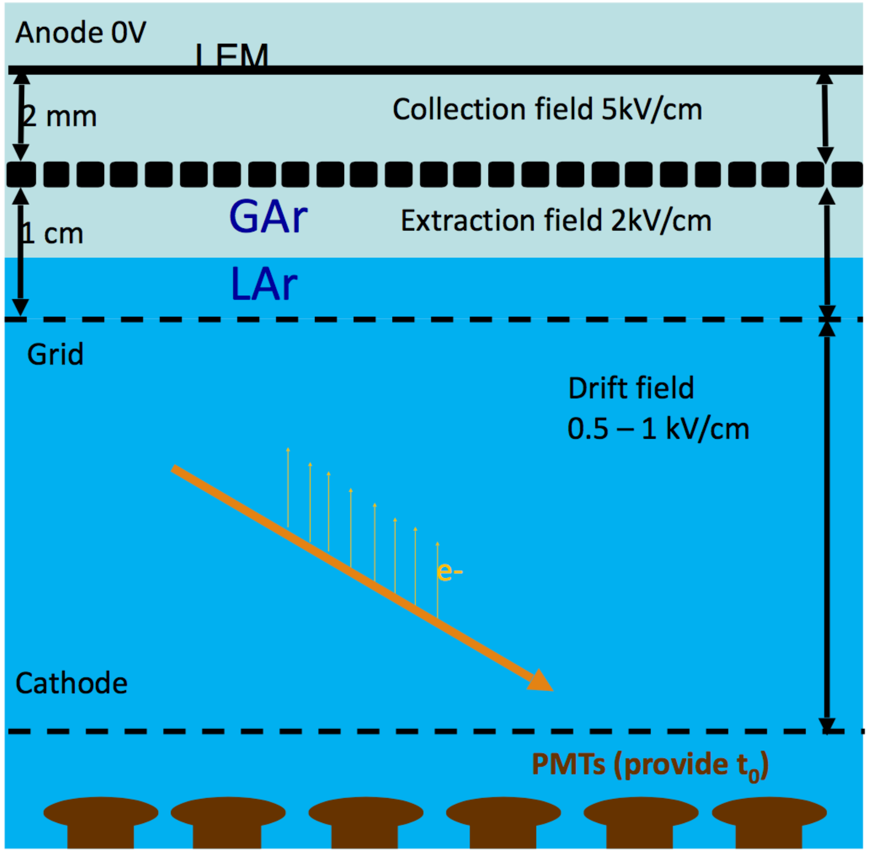
3.) Charge multiplication in the holes of the Large Electron Multiplier (LEM) with adjustable gain

2.) Drift electrons are efficiently extracted into the gas phase

1.) Ionisation electrons drift towards the liquid argon surface

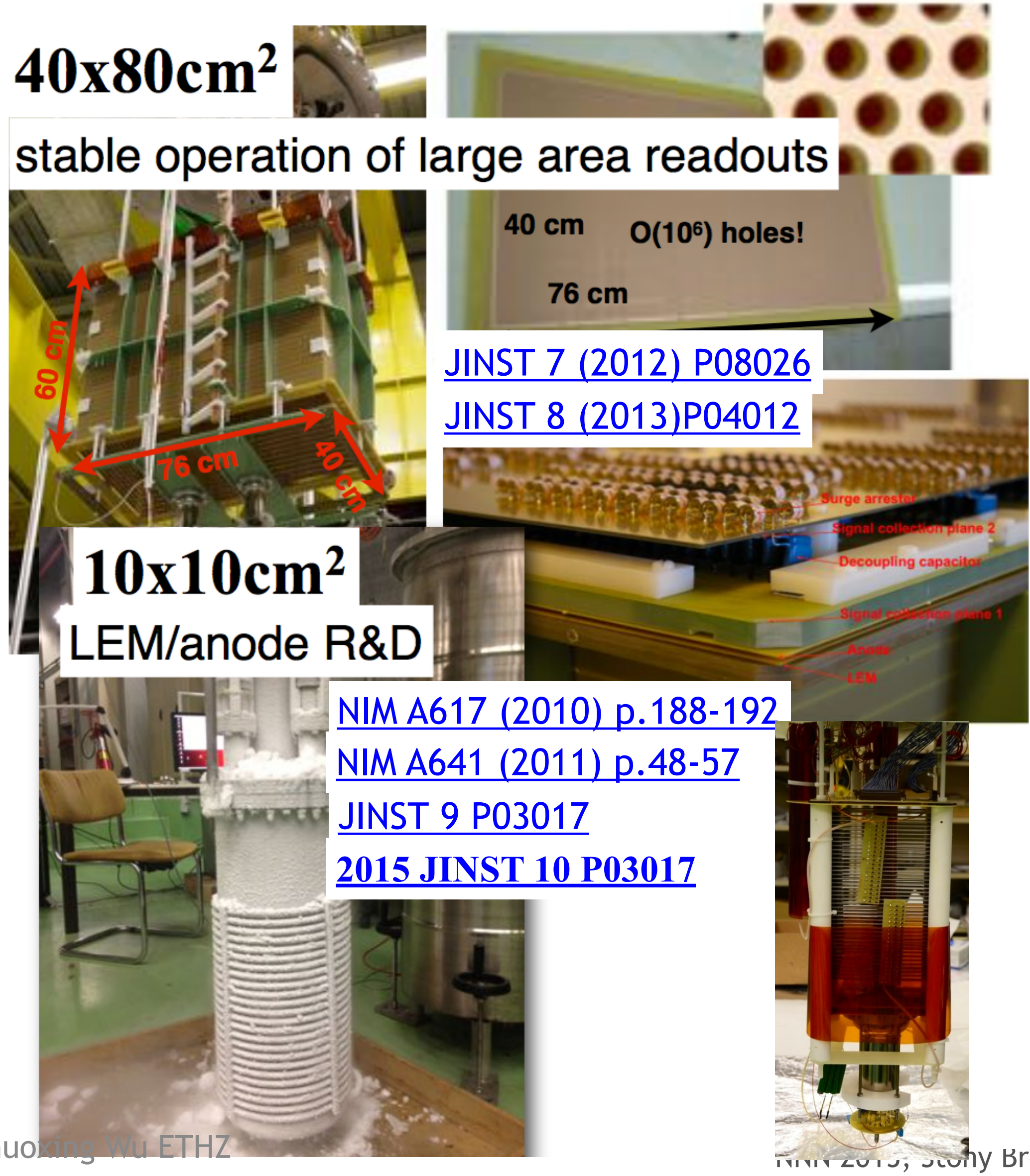
For MIPs:
- 10 fC/cm – ~10 k e^- for each strip (3 mm pitch,2 views) – SNR of 10 (noise of 1000 e^-)
- SNR of 100 – gain of 20 is needed

Concept of double-phase LAr TPC (Not to scale)



Double phase LAr TPC as a results of many years R&D

supporting R&D activities on smaller prototypes



40x80cm^2

stable operation of large area readouts

JINST 7 (2012) P08026
JINST 8 (2013)P04012

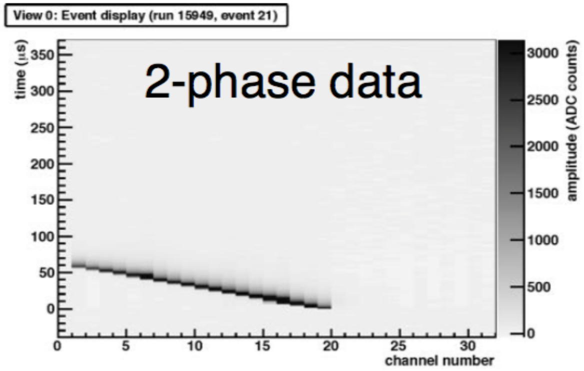
10x10cm^2

LEM/anode R&D

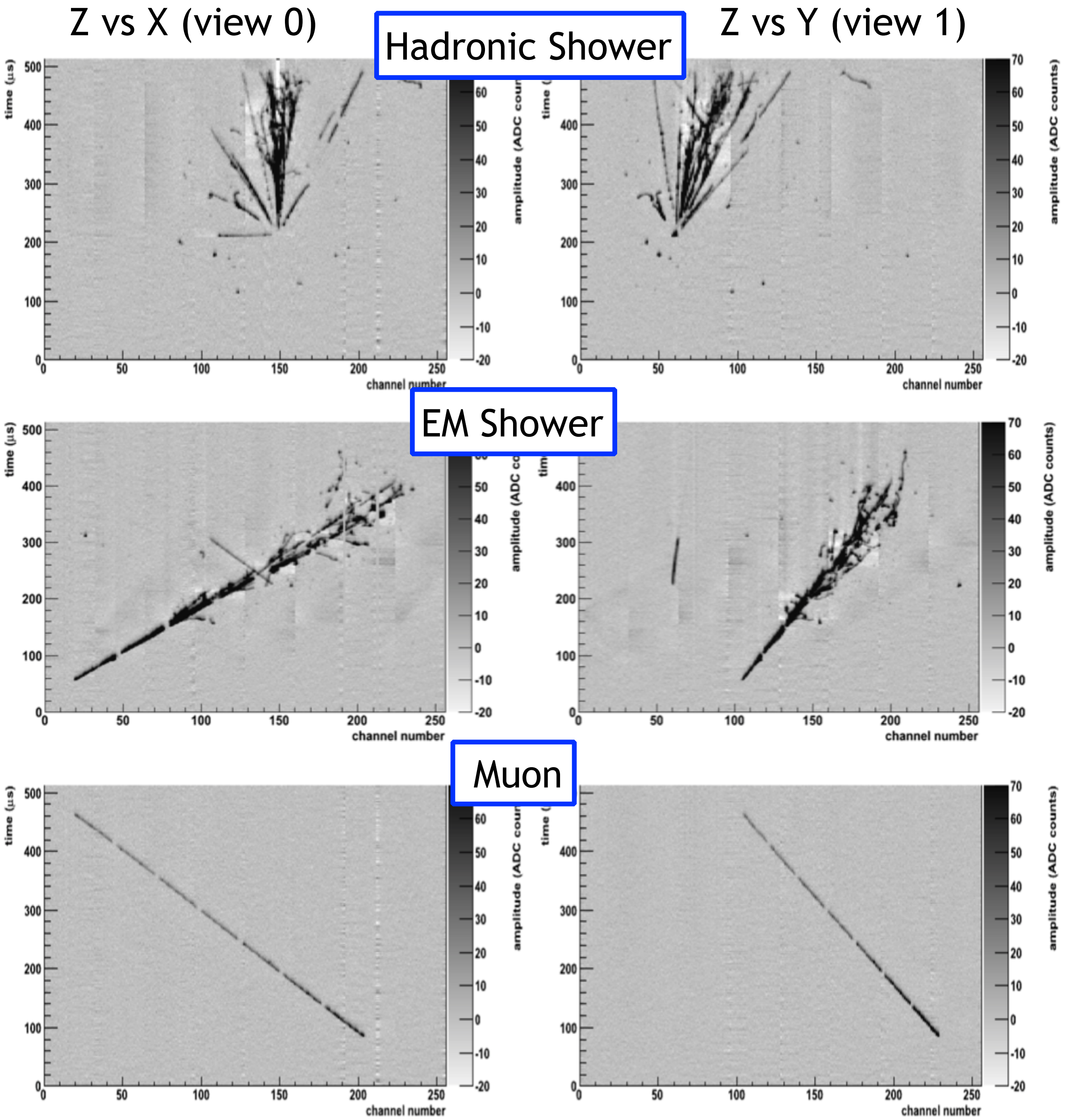
NIM A617 (2010) p.188-192
NIM A641 (2011) p.48-57
JINST 9 P03017
2015 JINST 10 P03017

ArDM 1ton

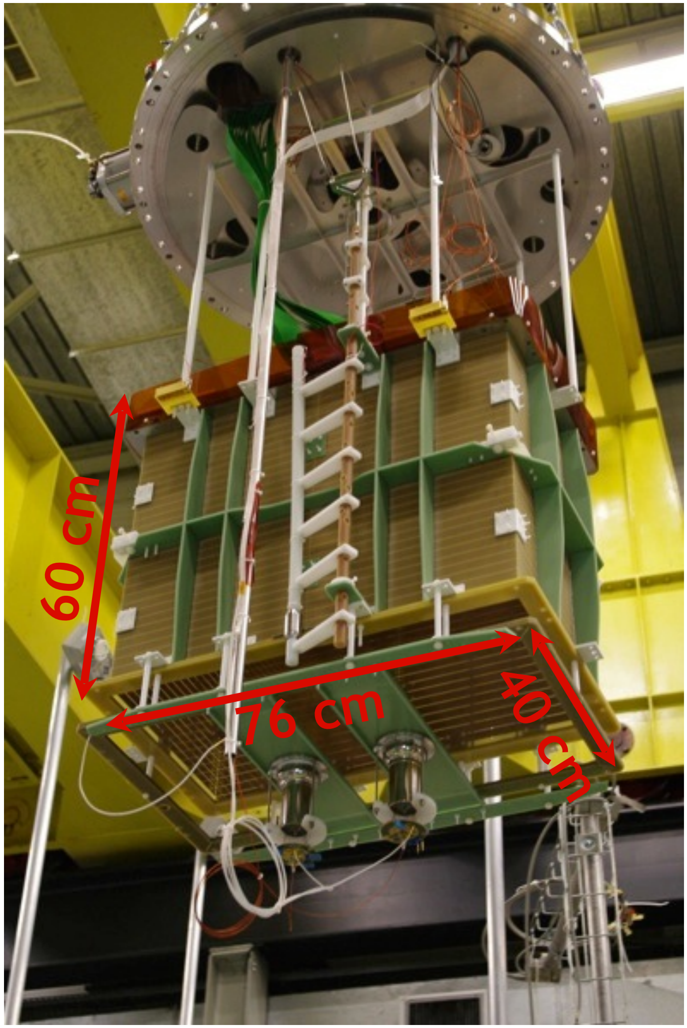
-light readout
-**Operating underground**



Events from double phase LAr LEM TPC

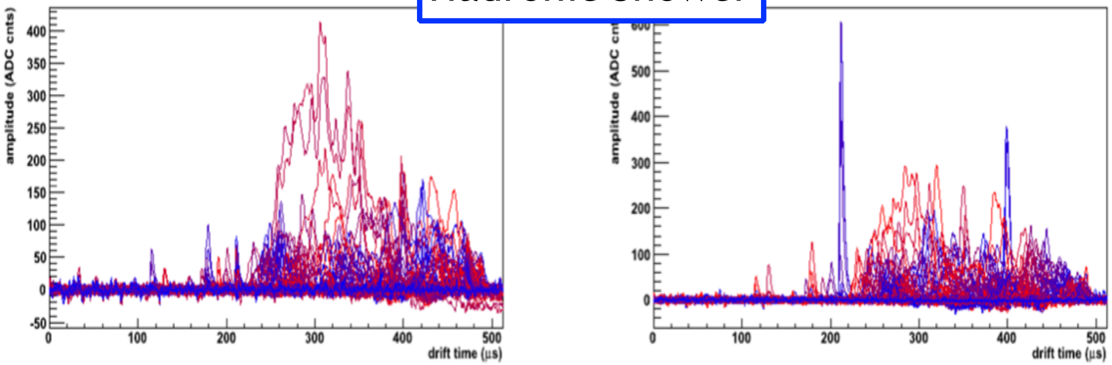


40x76x60 cm^3 LAr LEM TPC
(250L fiducial volume,
1 ton total mass)

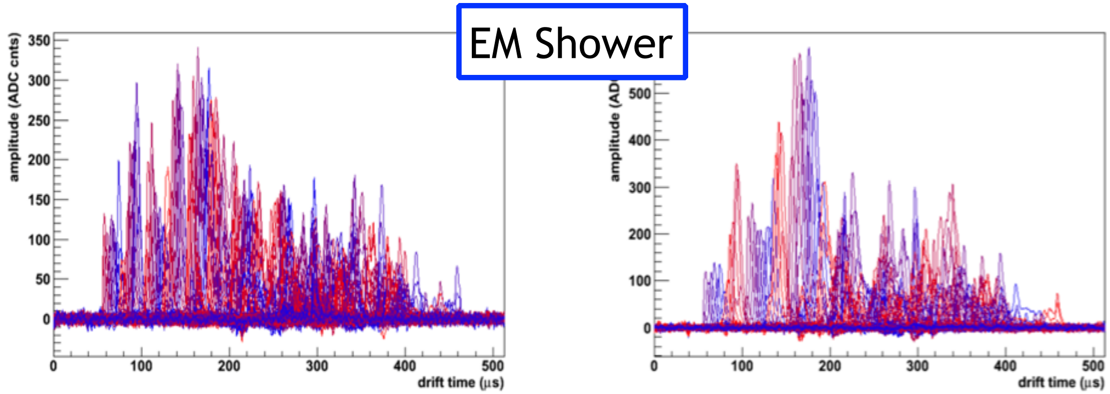


Events from double phase LAr LEM TPC

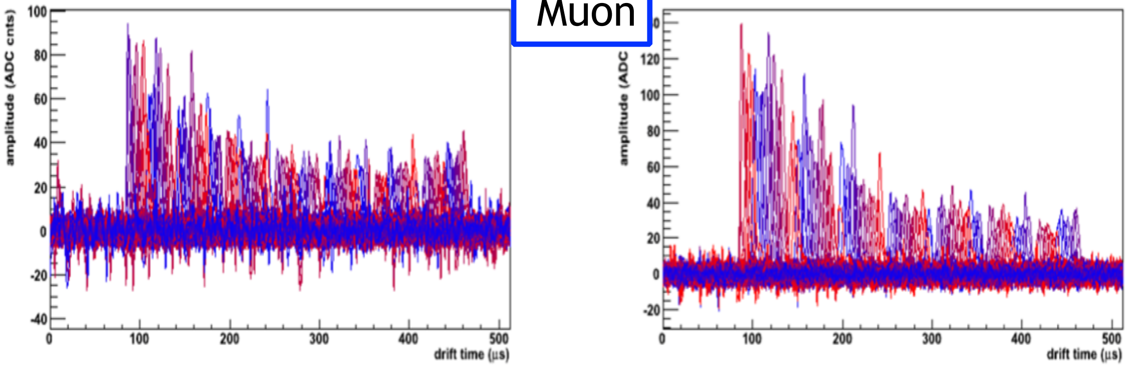
Hadronic Shower



EM Shower



Muon



40x76x60 cm^3 LAr LEM TPC
(250L fiducial volume,
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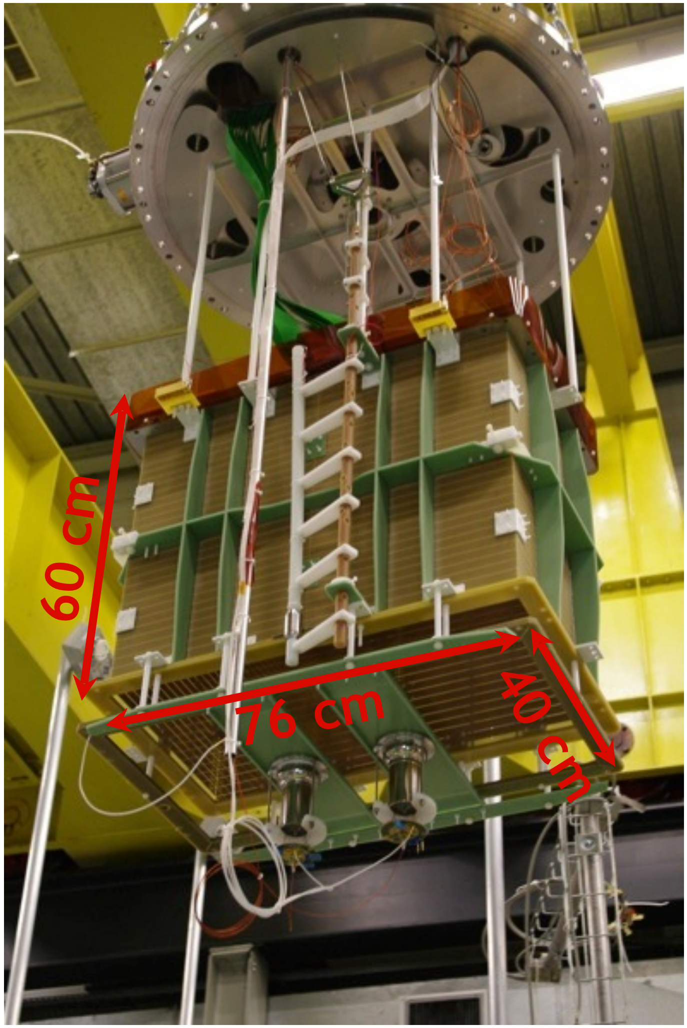
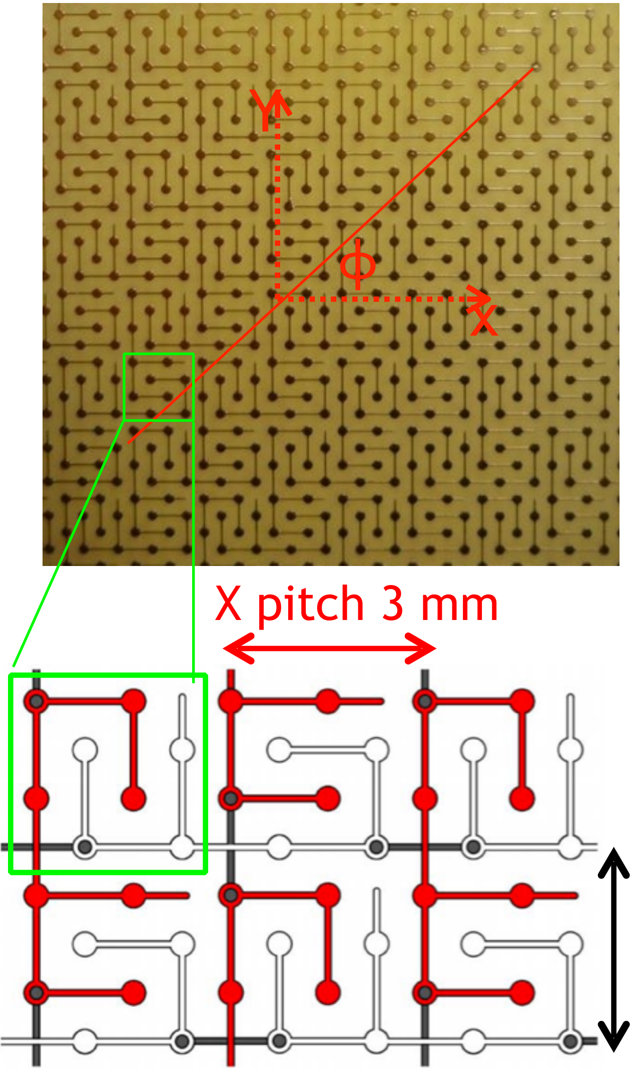


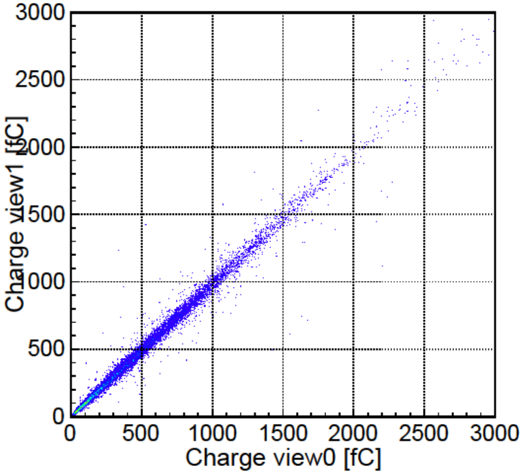
Design of the low capacitance 2D anode

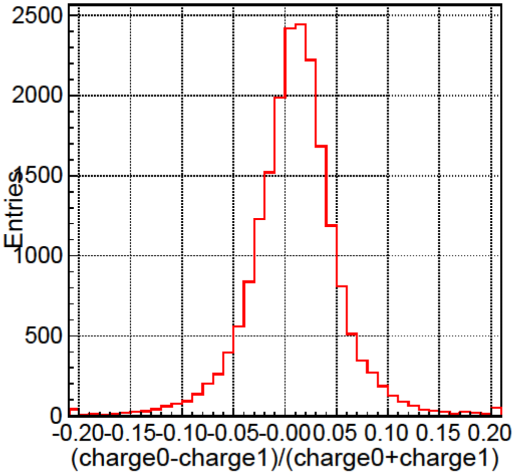


Y pitch
3 mm

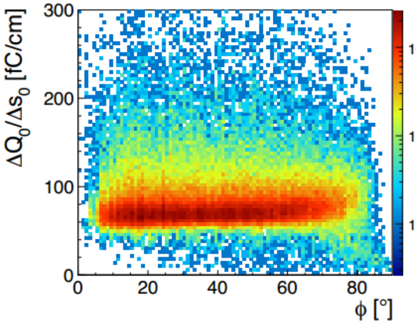
dC/dl~150 pF/m

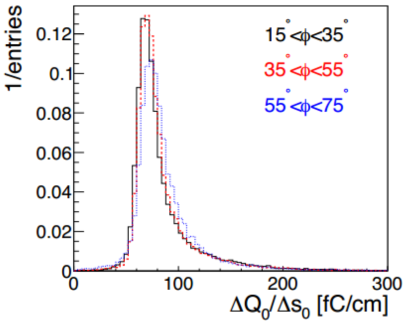
Fully X-Y symmetric:

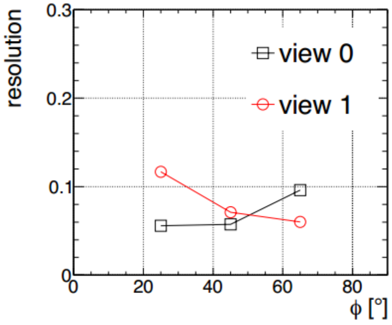




Uniform response to all tracks:

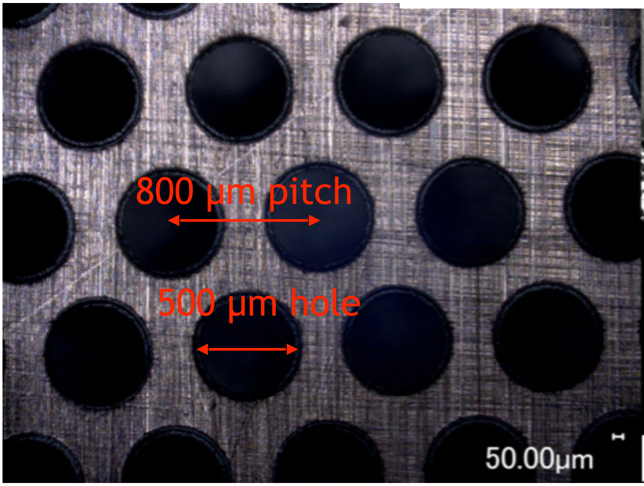


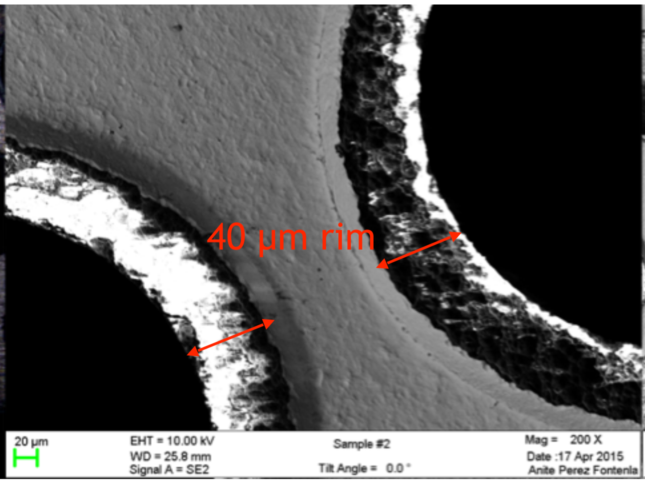


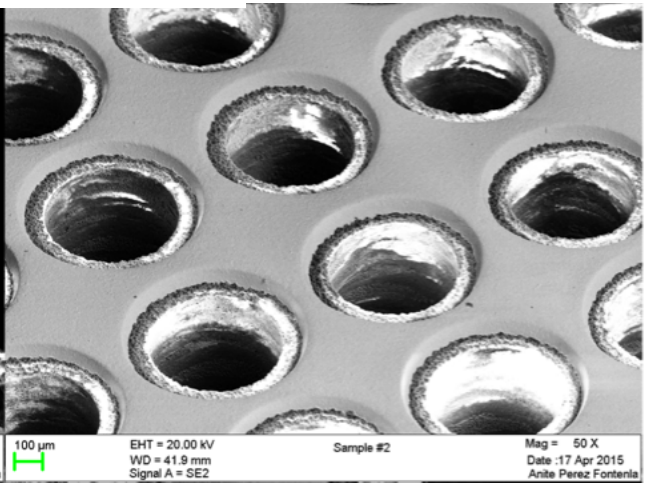


JINST 9 P03017

Optimisation of LEM parameters on 10x10 cm^2 LEM in double phase operations





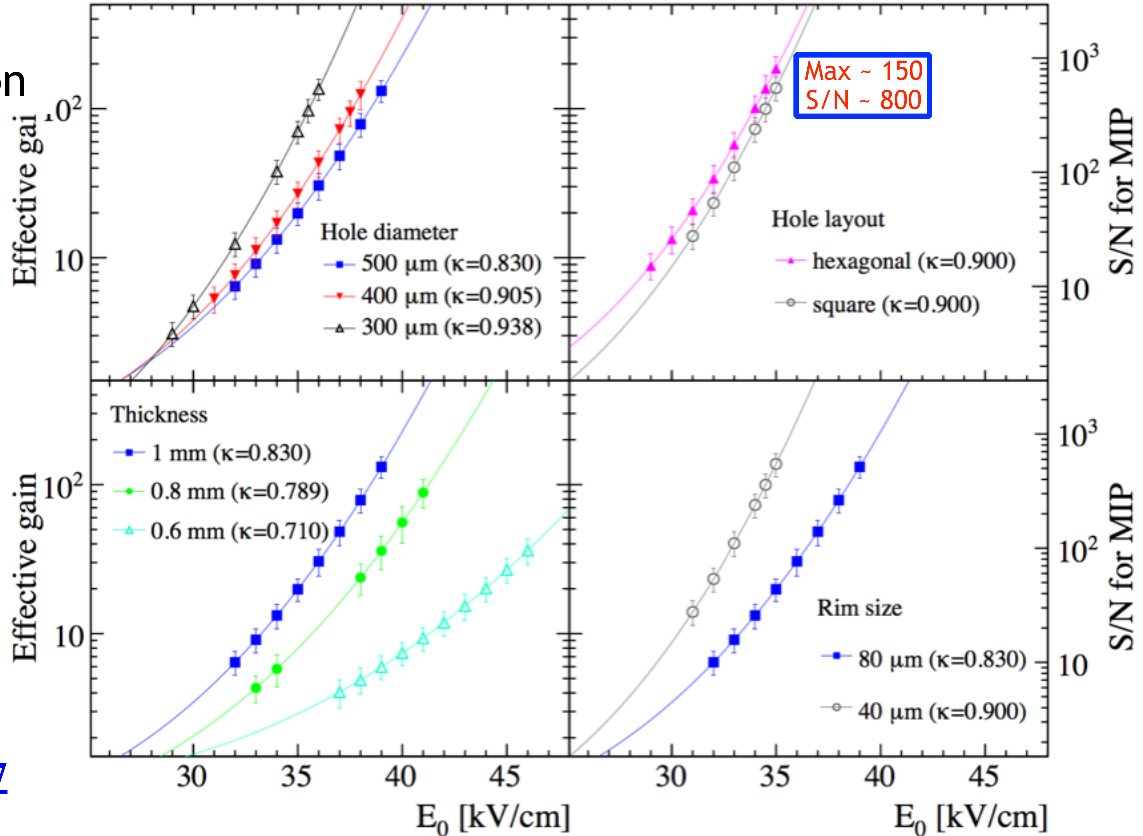


LEM gain and maximal gain depends on

- Rim size
- Thickness of FR4
- Hole diameter
- Geometry of hole layout

Optimised values

- 40 µm rim
- 1 mm FR4 thickness
- 500 µm diameter hole
- 800 µm hole pitch and hexagonal layout



Max ~ 150
S/N ~ 800

2015 JINST 10 P03017

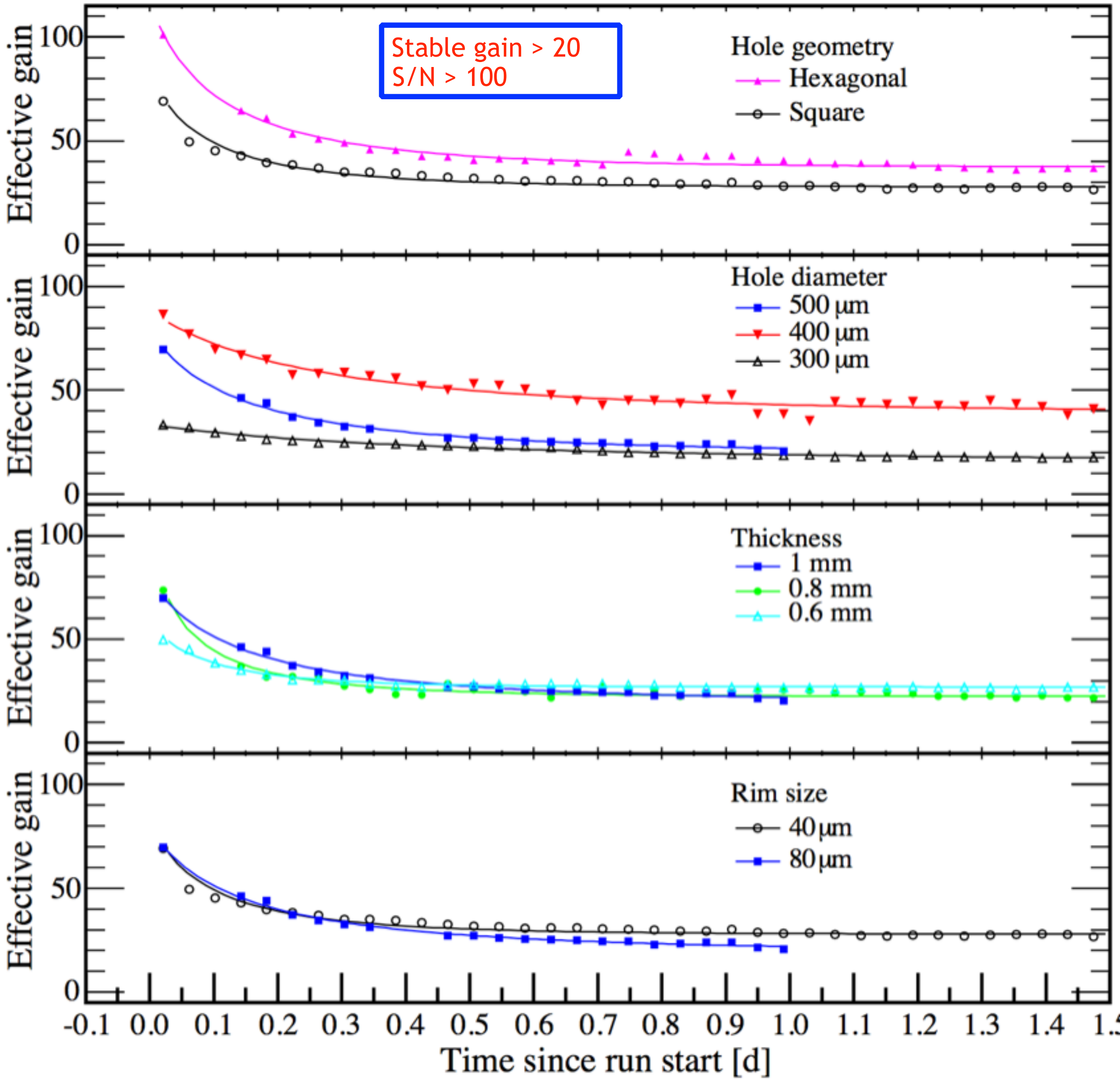
10x10 cm^2 LEM charging-up behaviours in double phase operations

"discharge free" operation mode in cold pure argon gas

Parameter	Value	LEM	E_0 [kV/cm]	Run-time [hrs]	No. of discharges
geometry	hexagonal	3	34	110	0
	square	5	34	52	0
hole	500 μm	2	38	24	0
	400 μm	4	37	50	2
	300 μm	6	33.5	75	3
thickness	1 mm	2	38	24	0
	0.8 mm	1	42	82	0
	0.6 mm	7	46	95	1
rim size	80 μm	2	38	24	0
	40 μm	5	34	52	0

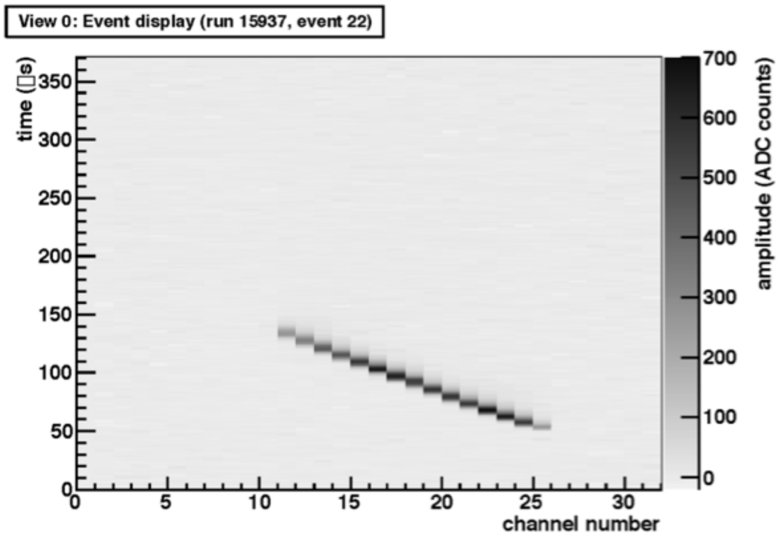
2015 JINST 10 P03017

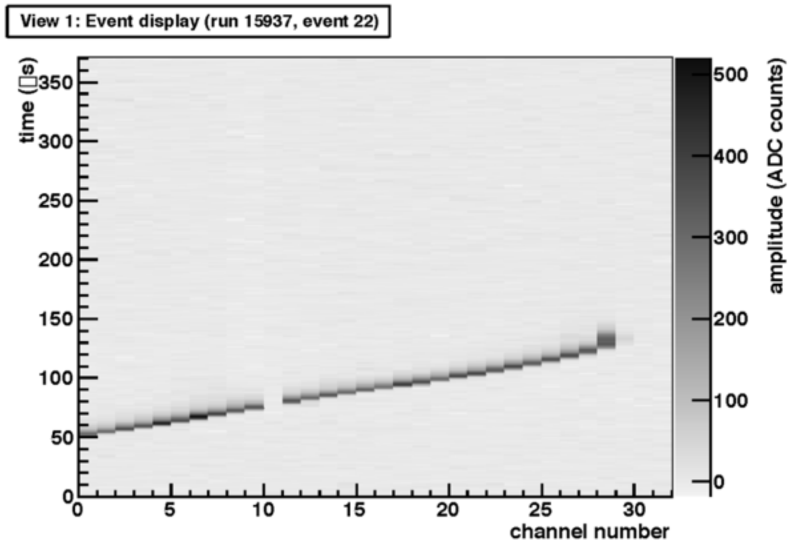
Stable gain over 20

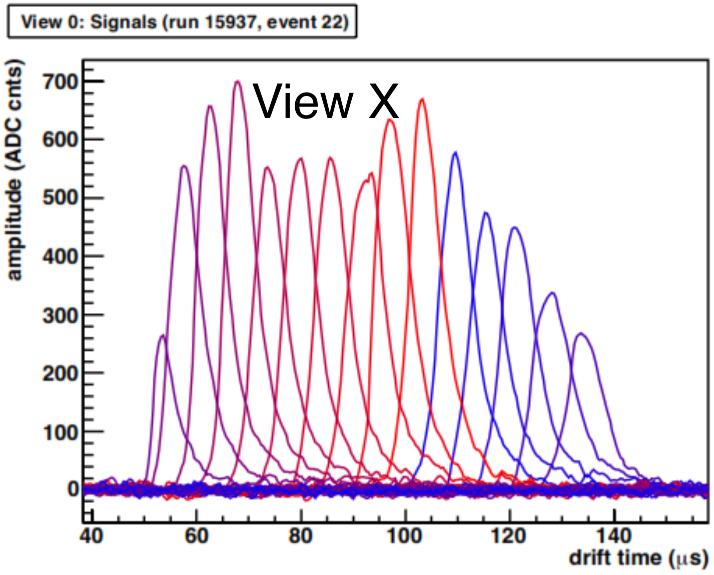


Stable gain > 20
S/N > 100

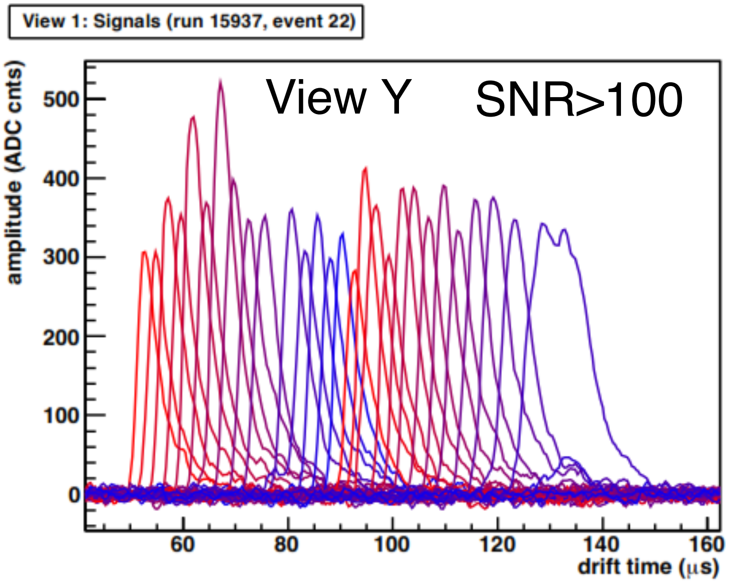
Cosmic event in double phase TPC at effective gain~20


View 0: Event display (run 15937, event 22)


View 1: Event display (run 15937, event 22)


View 0: Signals (run 15937, event 22)

View X

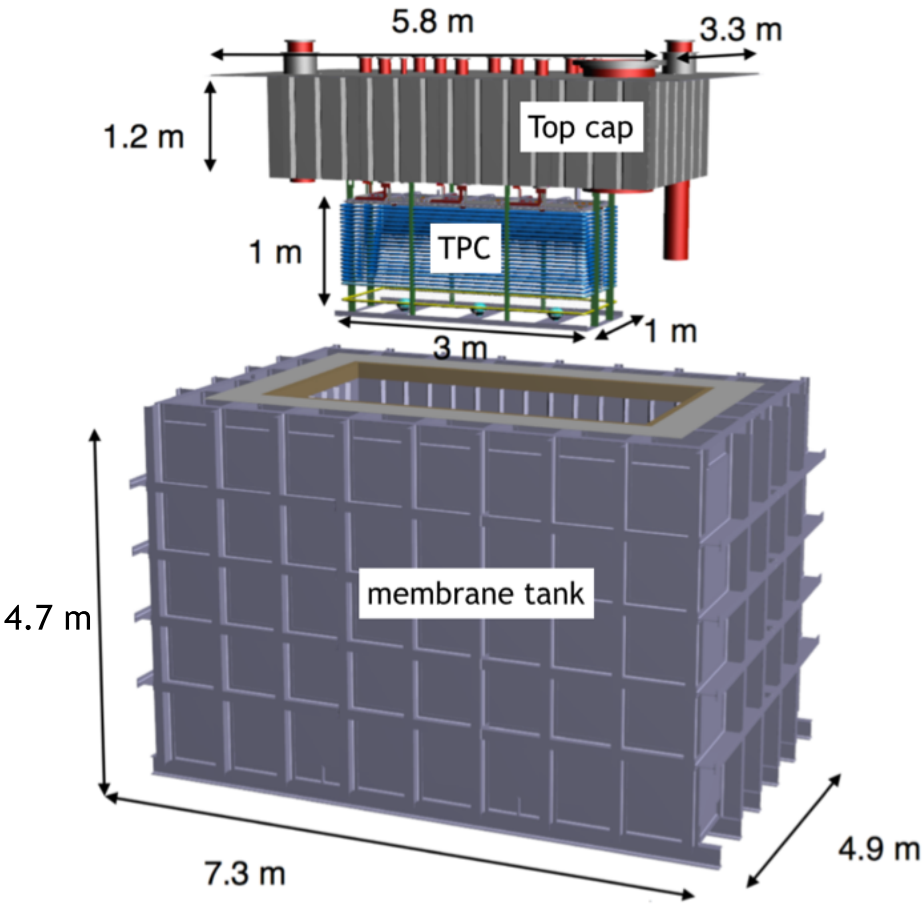

View 1: Signals (run 15937, event 22)

View Y SNR>100

The WA105 experiment at CERN
— double phase LAr LEM TPC demonstrators

DLAr-proto

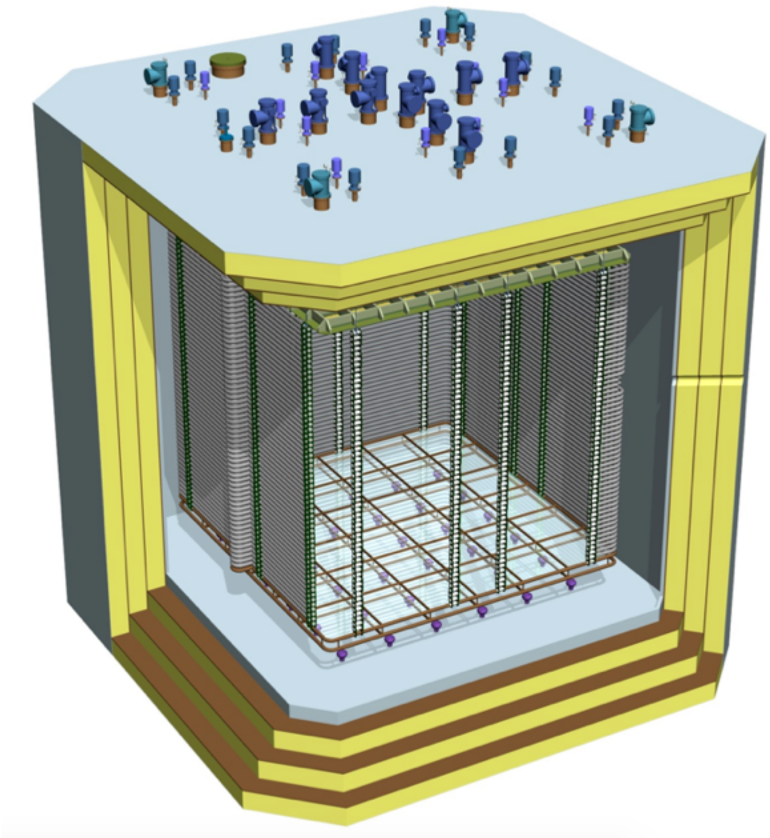
$3 \times 1 \times 1\ m^3$ active (24 ton LAr total)



Timescale: 2015-2016

DLAr

$6 \times 6 \times 6\ m^3$ active (700 ton LAr total)

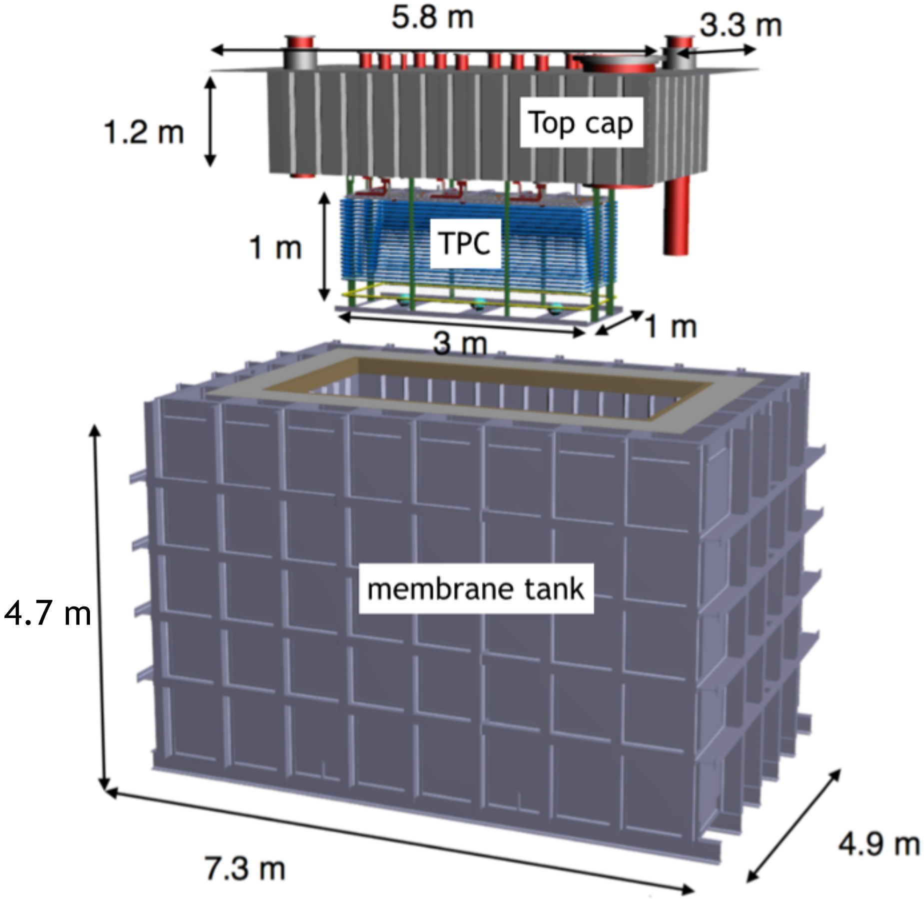


Timescale: 2016-2019

See talk by Sara Bolognesi

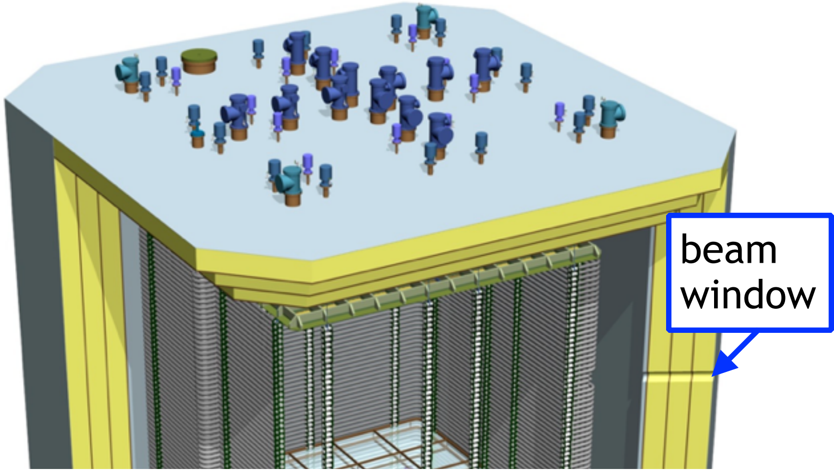
The WA105 experiment at CERN
— double phase LAr LEM TPC demonstrators

- cosmic trigger only
- scaling up to 24 ton mass
- intermediate step towards 3x3 m^2 CRP

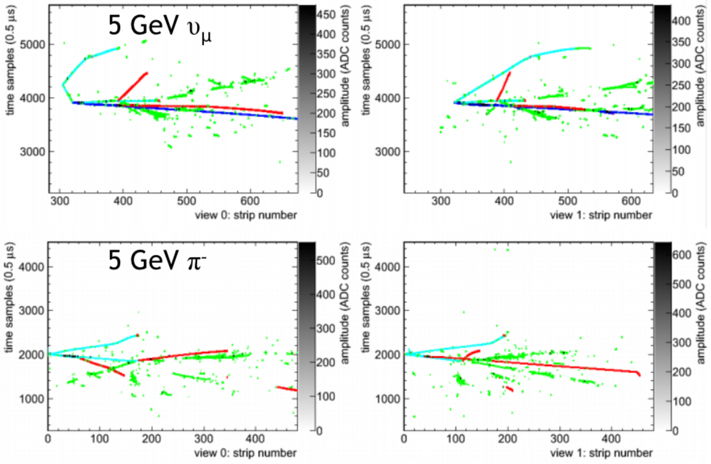


Timescale: 2015-2016

- beam test data
- many interesting physics topics
- basic readout 3x3 m^2 CRP



pions, electrons/positrons, protons, muons

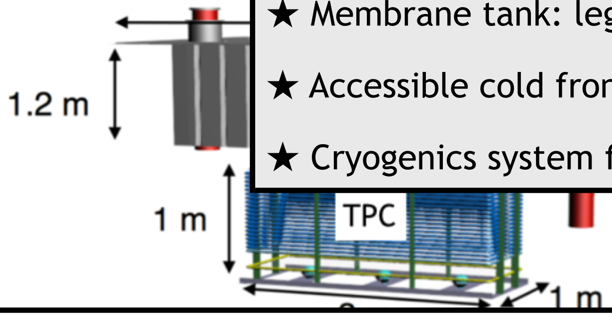


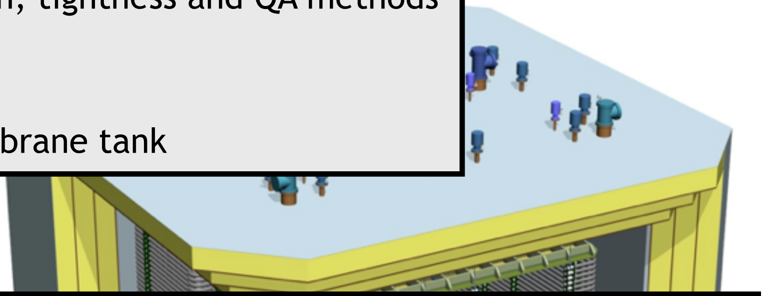
See talk by Sara Bolognesi

The WA105 experiment at CERN

— double phase LAr LEM TPC demonstrators

- ★ LEMs and anode: design, purchase, cleaning and QA
- ★ Chimneys, FT and slow control sensors
- ★ Membrane tank: legal aspects, construction, tightness and QA methods
- ★ Accessible cold front-end electronics
- ★ Cryogenics system for non-evacuated membrane tank



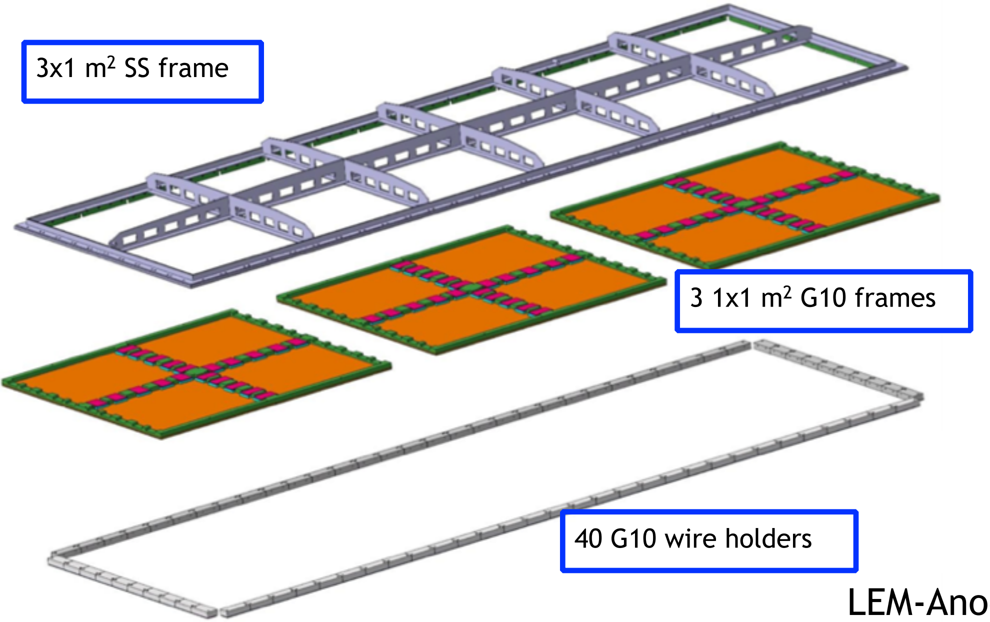


- ✓ **First GTT constructed cryostat for LAr**
- ✓ **Fully engineered versions of many detector components** with pre- production and direct implementation (installation details and ancillary services)
- ✓ **First overview of the complete system integration** set up full chains for Quality Assessment, construction, installation and commissioning
- ✓**Anticipate legal and practical aspects** related to procurement, costs and schedule verification

- ✳ Large hanging field cage structure
- ✳ Large cathode structure with controlled sagging
- ✳ Very high voltage generation and feedthrough
- ✳ Large area (36 m^2) charge readout
- ✳ Long drift (e- diffusion, LAr purity ..)
- ✳ Test beam data (calibration, reconstruction, fully contained events, x-sections, etc...)
- ✳ Long term stability of UV scintillation light readout over long distance
- ✳ Underground construction method

See talk by Sara Bolognesi

The 3x1 m^2 CRP

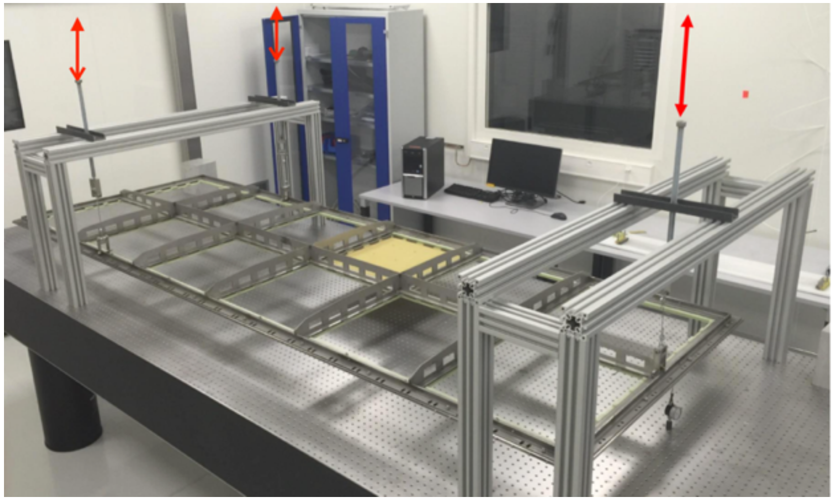


3x1 m^2 SS frame

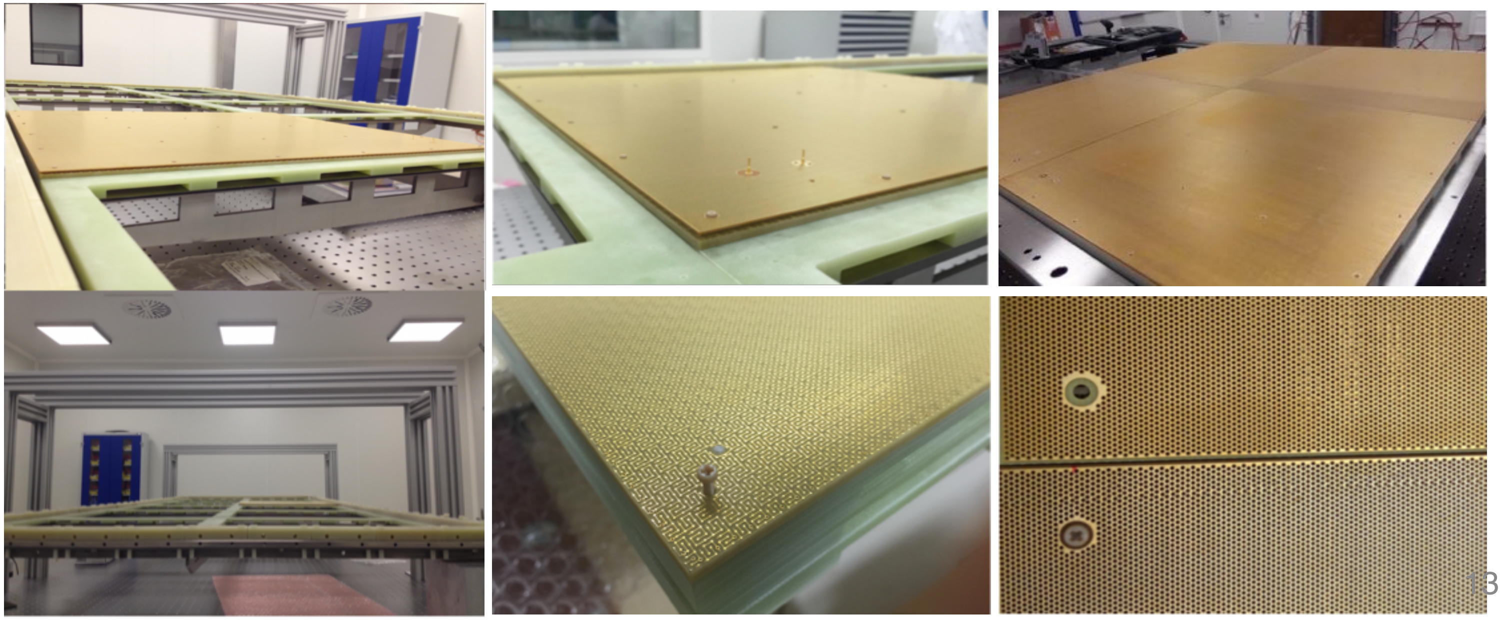
3 1x1 m^2 G10 frames

40 G10 wire holders

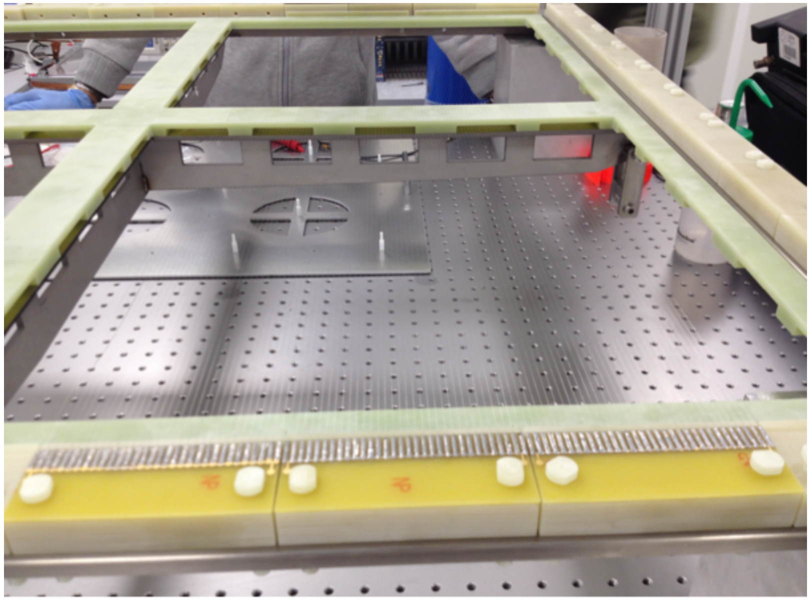
CRP is hang through 3 points



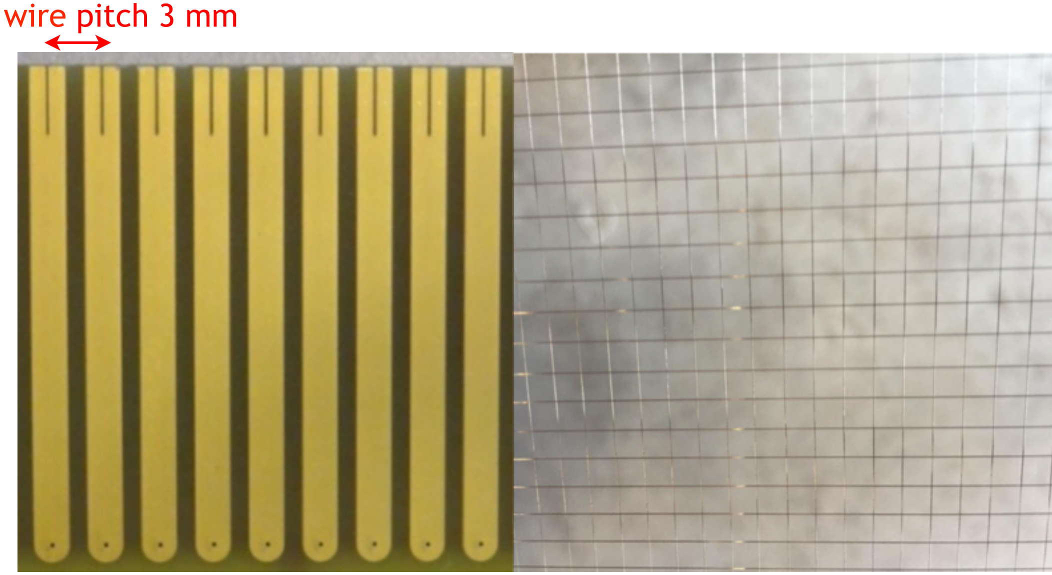
LEM-Anode assemble

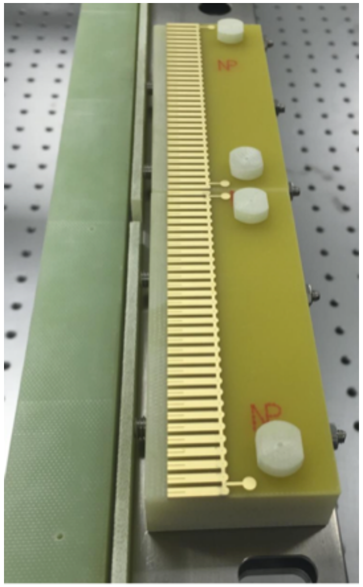


The 3x1 m^2 CRP

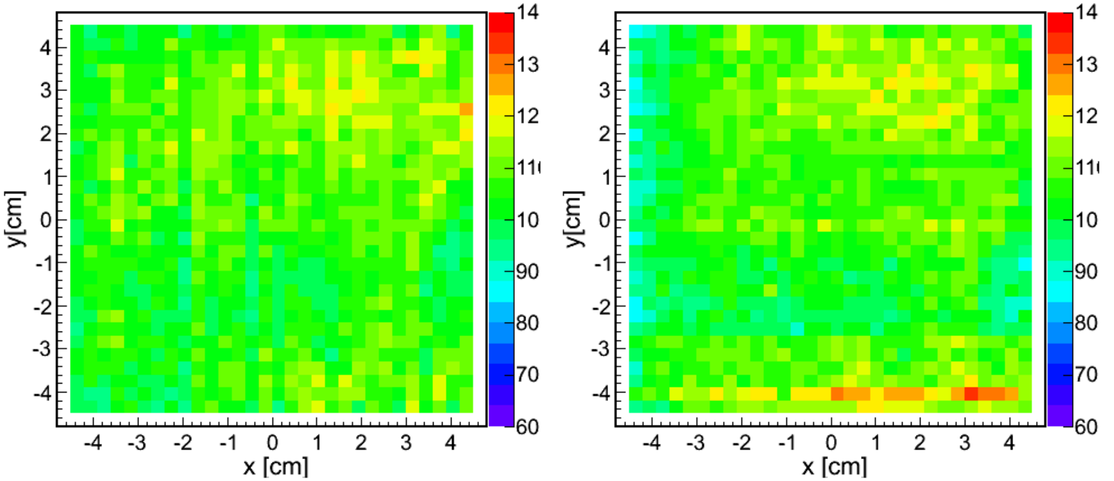


Wire soldering PCB and extraction grid



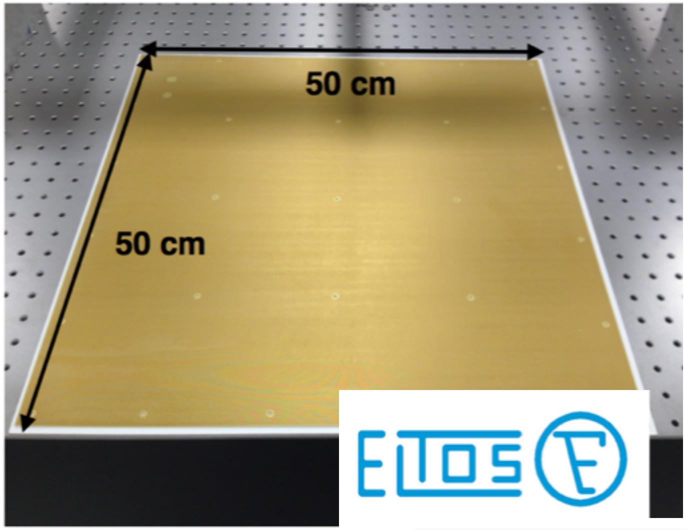


Good alignment ensures gain uniformity

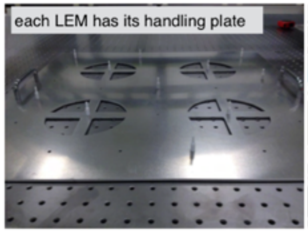


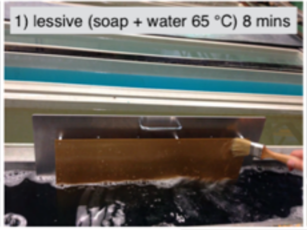
50x50 cm^2 LEM quality assurance – production and cleaning

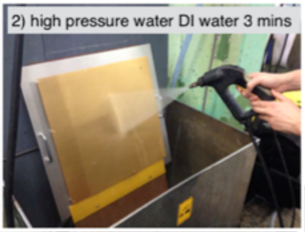
production from ELTOS
(or other PCB company)

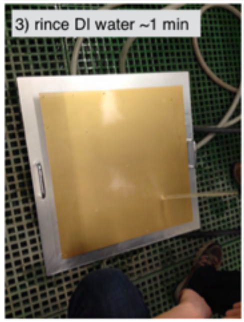


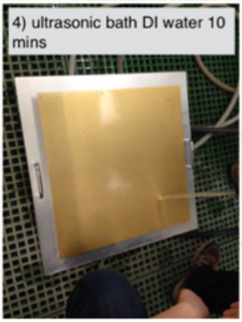
Cleaning, polymerization, HV test and storage at CERN

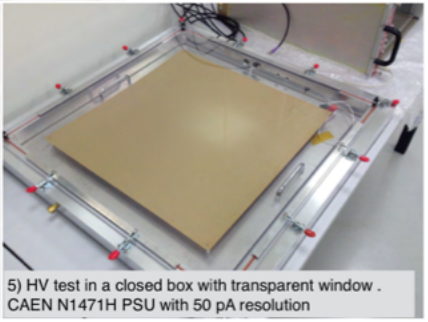

each LEM has its handling plate


1) lessive (soap + water 65 °C) 8 mins


2) high pressure water DI water 3 mins

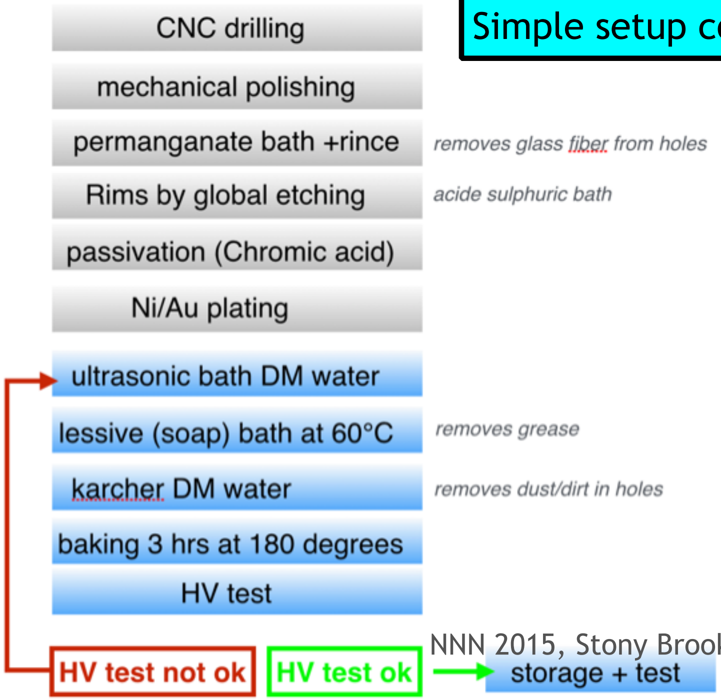

3) rince DI water ~1 min


4) ultrasonic bath DI water 10 mins


5) HV test in a closed box with transparent window . CAEN N1471H PSU with 50 pA resolution


6) storage in custom made box designed to hold 20 LEMs with their handling plates.

Simple setup could be built easily in another lab



ELTOS

- CNC drilling
- mechanical polishing
- permanganate bath +rince — *removes glass fiber from holes*
- Rims by global etching — *acide sulphuric bath*
- passivation (Chromic acid)
- Ni/Au plating

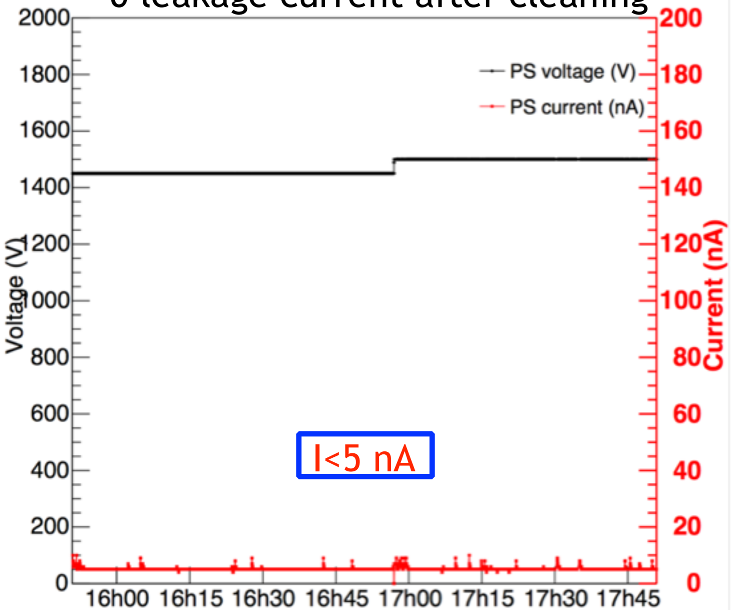
CERN

- ultrasonic bath DM water
- lessive (soap) bath at 60°C — *removes grease*
- karcher DM water — *removes dust/dirt in holes*
- baking 3 hrs at 180 degrees
- HV test

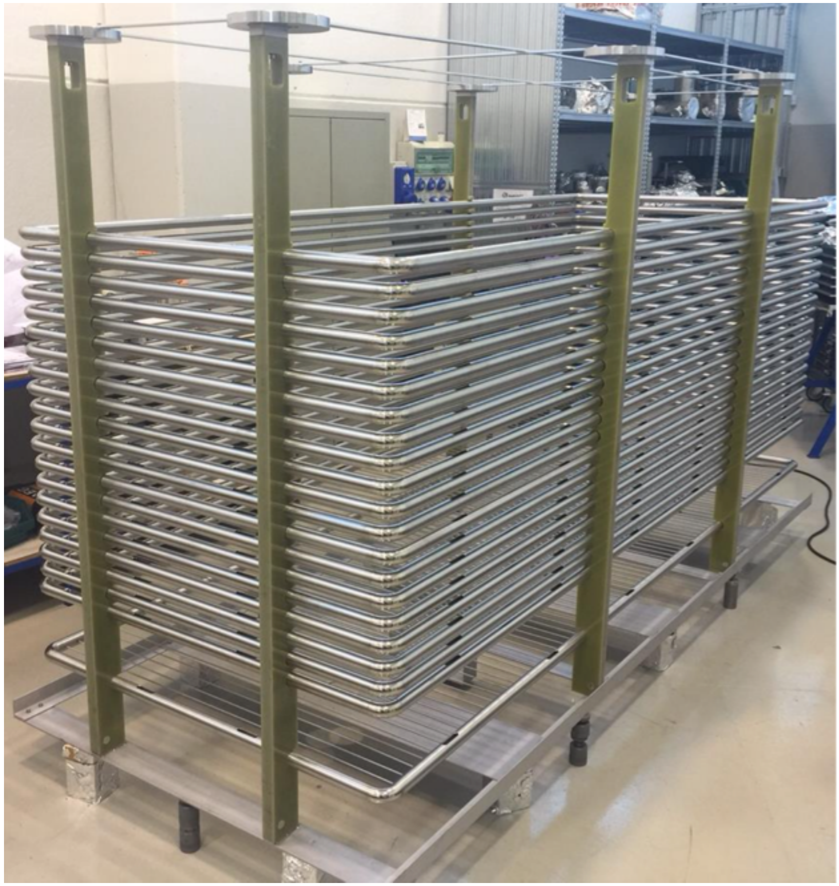
HV test not ok → ultrasonic bath DM water

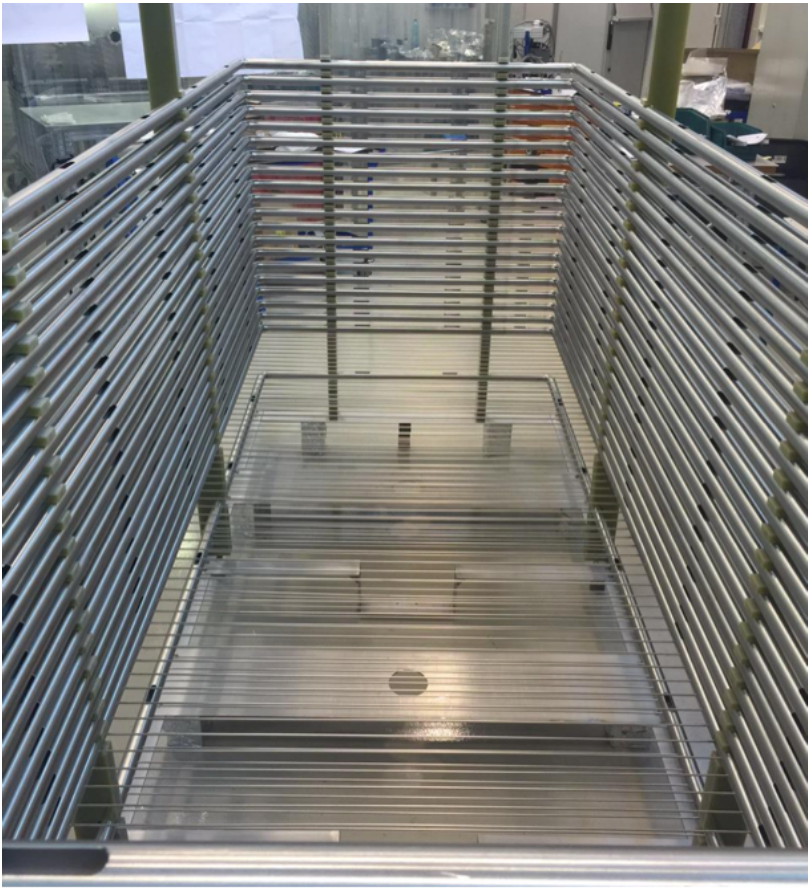
HV test ok → storage + test

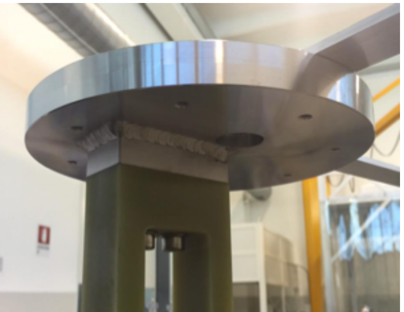
~ 0 leakage current after cleaning

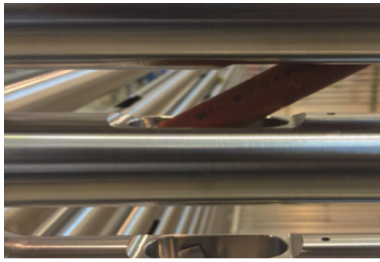


The drift cage for WA105-3x1x1



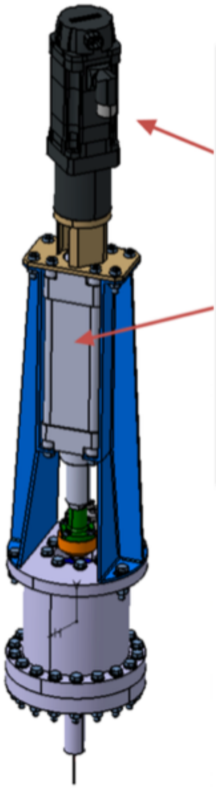


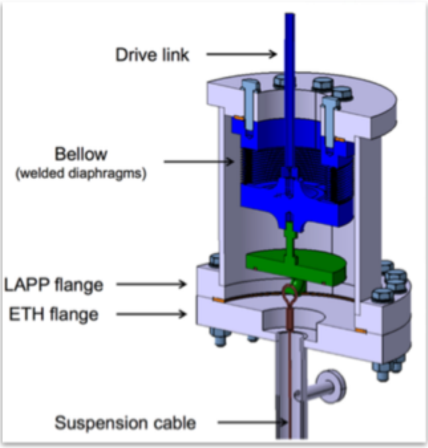


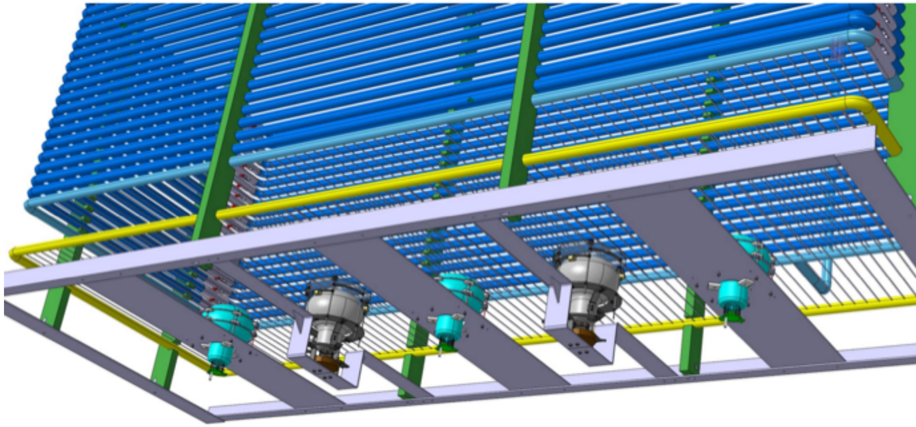


CRP hanging system and light readout

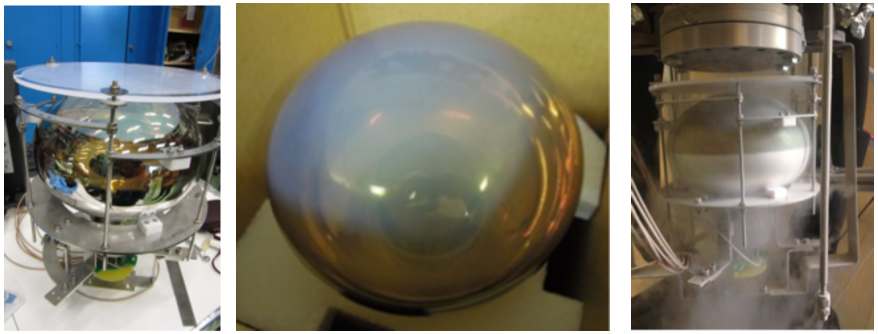
3 hanging points allowing dynamic adjustment w.r.t LAr level with sub-mm precision



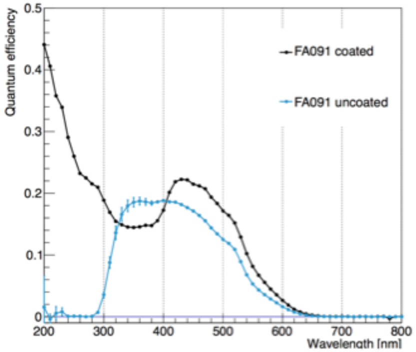




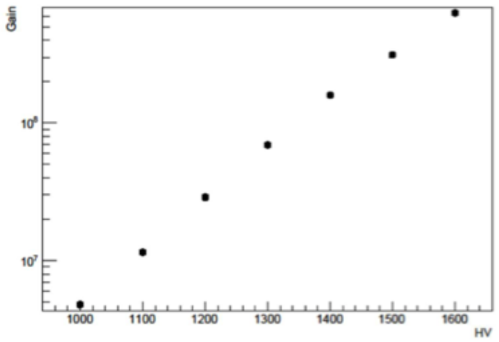
5 TPB coated Hamamatsu 8’’ R5912-02MOD PMTs



quantum efficiency



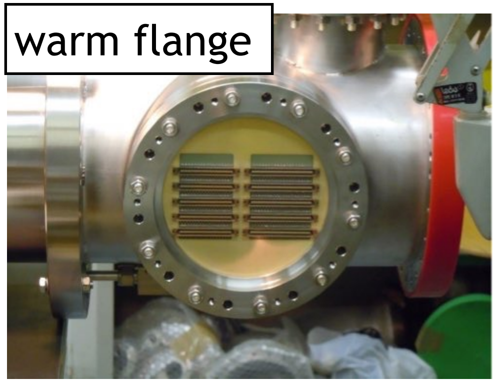
gain



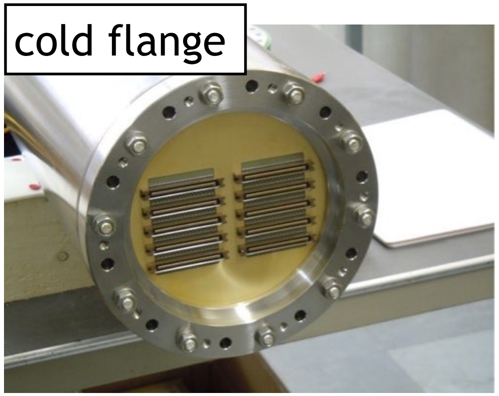
Signal feedthrough chimney for extractable cold FE electronics

First SFT prototype

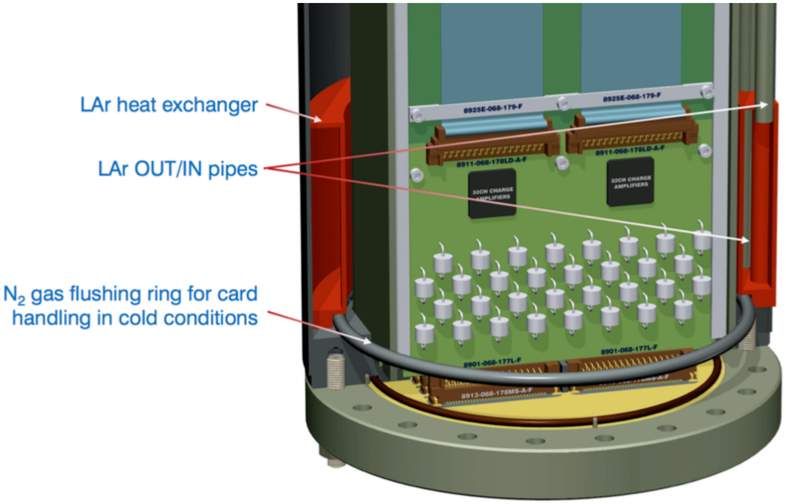
warm flange



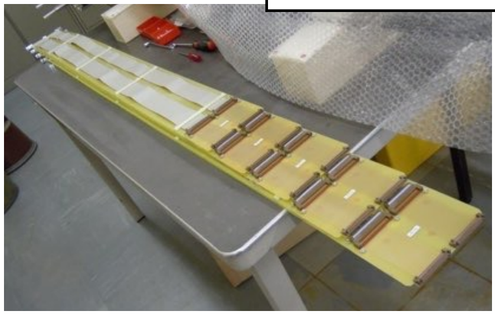
cold flange



- ASIC preamps in cold as close as possible to the anode (~50 cm cable).
- Fixed on insertable cards thus can be accessed without opening the detector.
- 1 chimney has 5 cards and reads 320 channels.



card insertion from top

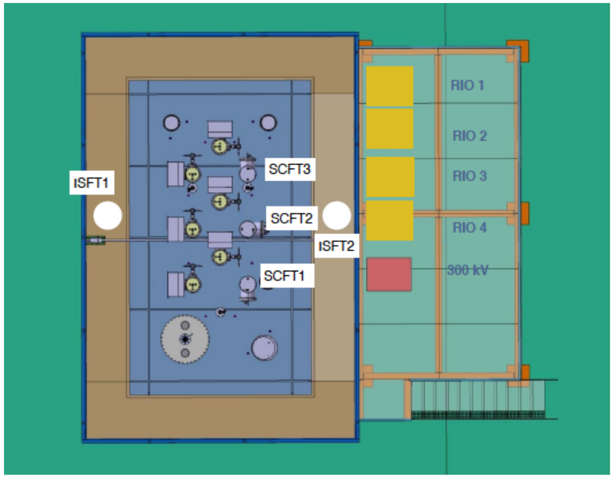


First SFT prototype tested OK, rest 5 under production

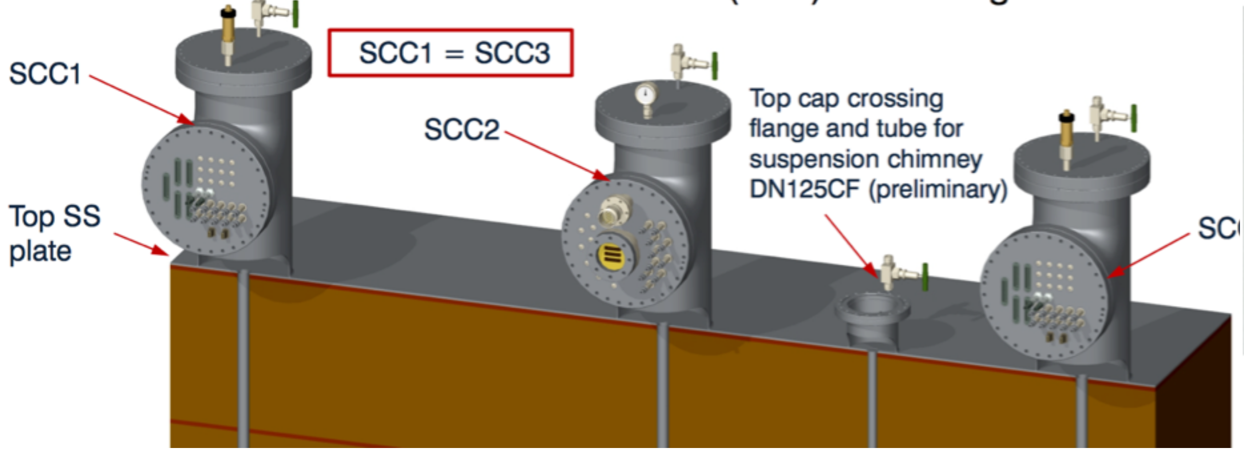
Slow control system

NI modules

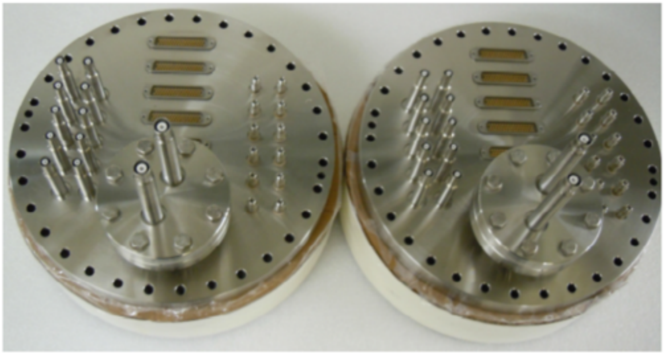
Slow control racks



Slow control and calibration (SSC) feedthroughs



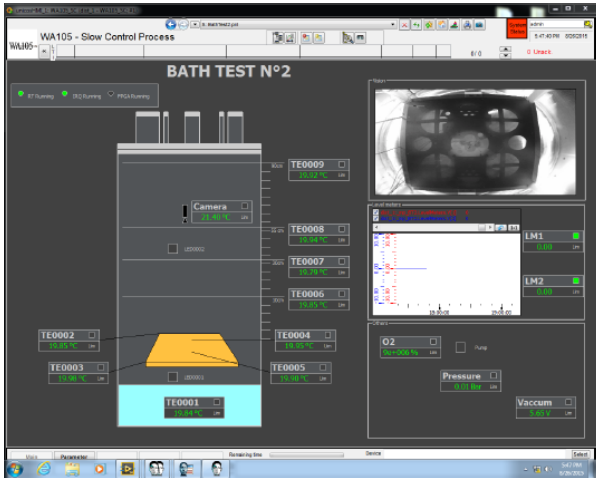
Slow control feedthroughs



See poster by Cosimo Cantini

Slow control system phased approach

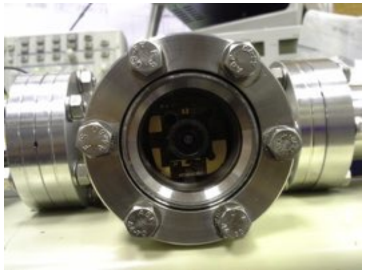
Temperature monitoring
Photogrammetric measure

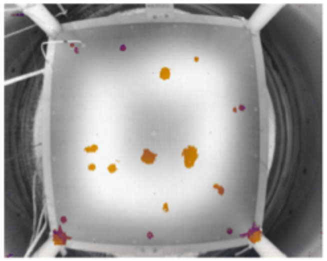

WA105 - Slow Control Process

BATH TEST N°2

Camera 21.40 °C
TE0009 19.92 °C
TE0008 19.94 °C
TE0007 19.79 °C
TE0006 19.85 °C
TE0002 19.85 °C
TE0004 19.95 °C
TE0003 19.98 °C
TE0005 19.90 °C
TE0001 19.84 °C
LM1 0.00
LM2 0.00
O2 9e+006 %
Pressure 0.01 Bar
Vaccum 5.65 V

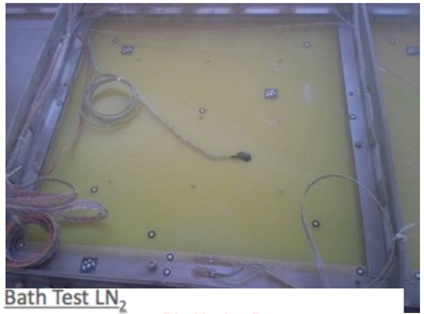
Image processing

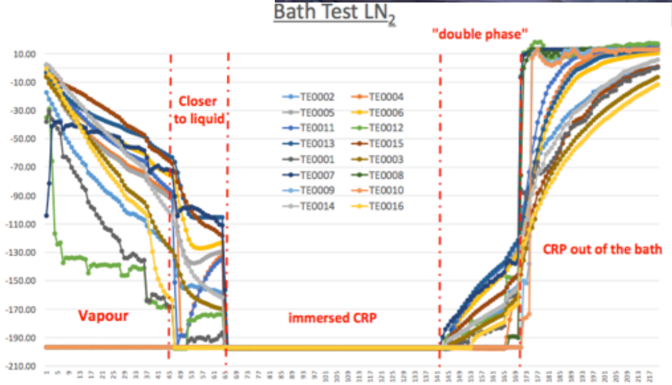


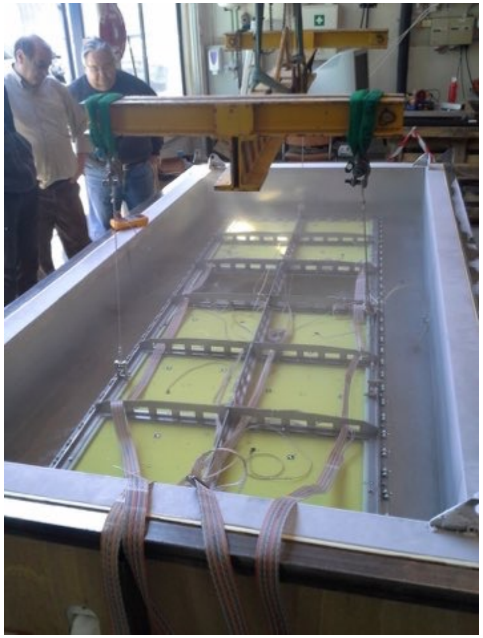


See poster by Cosimo Cantini

Cold test of 3x1 m2 CRP

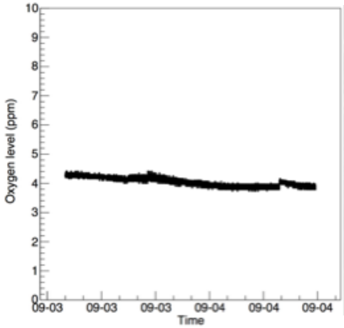


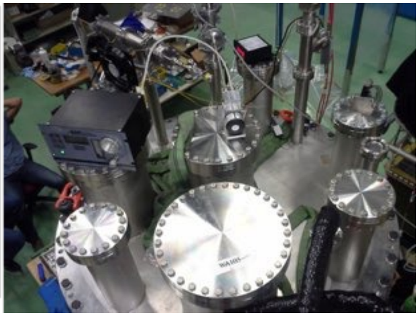




Cold test of 50x50 cm2 LEM

Monitor Purity over long time

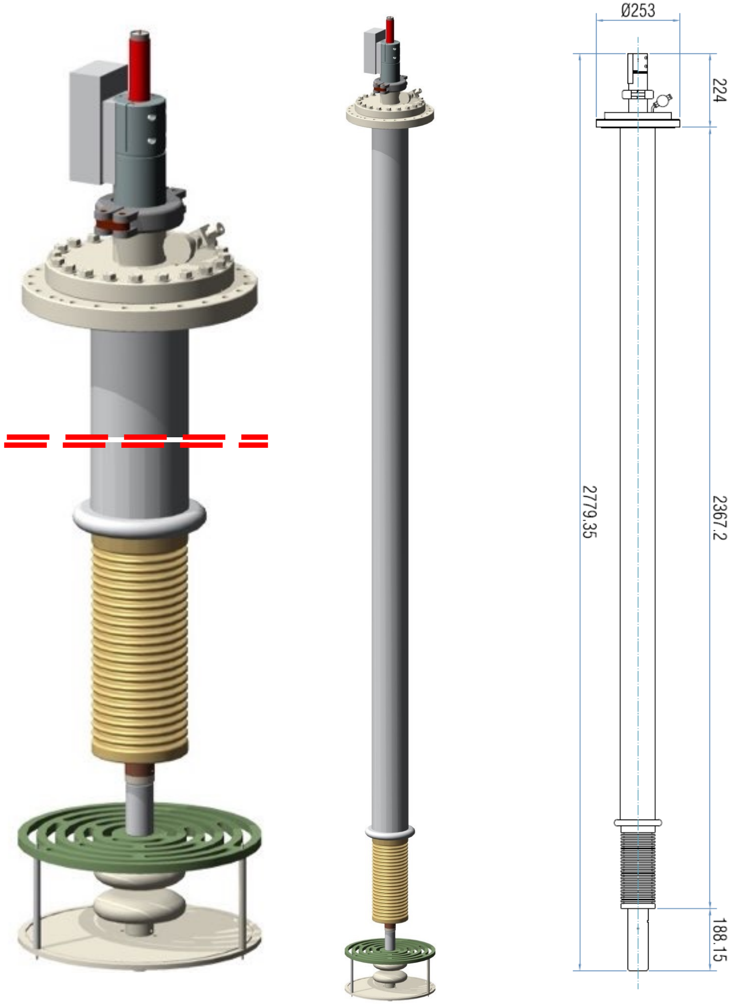




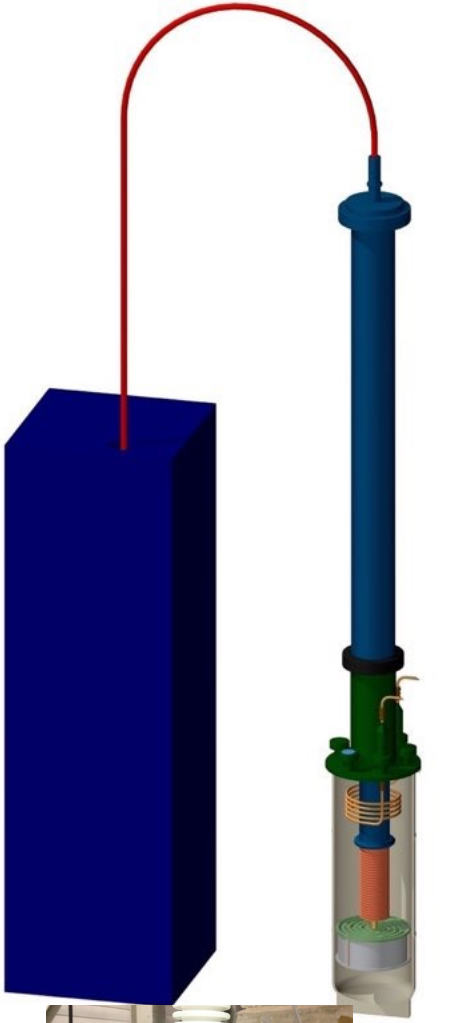
HV system and feedthrough

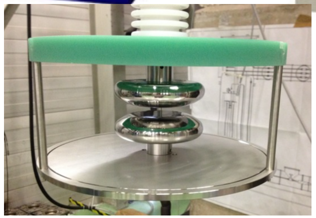
Heinzinger 300kV PS

300kV HV FT



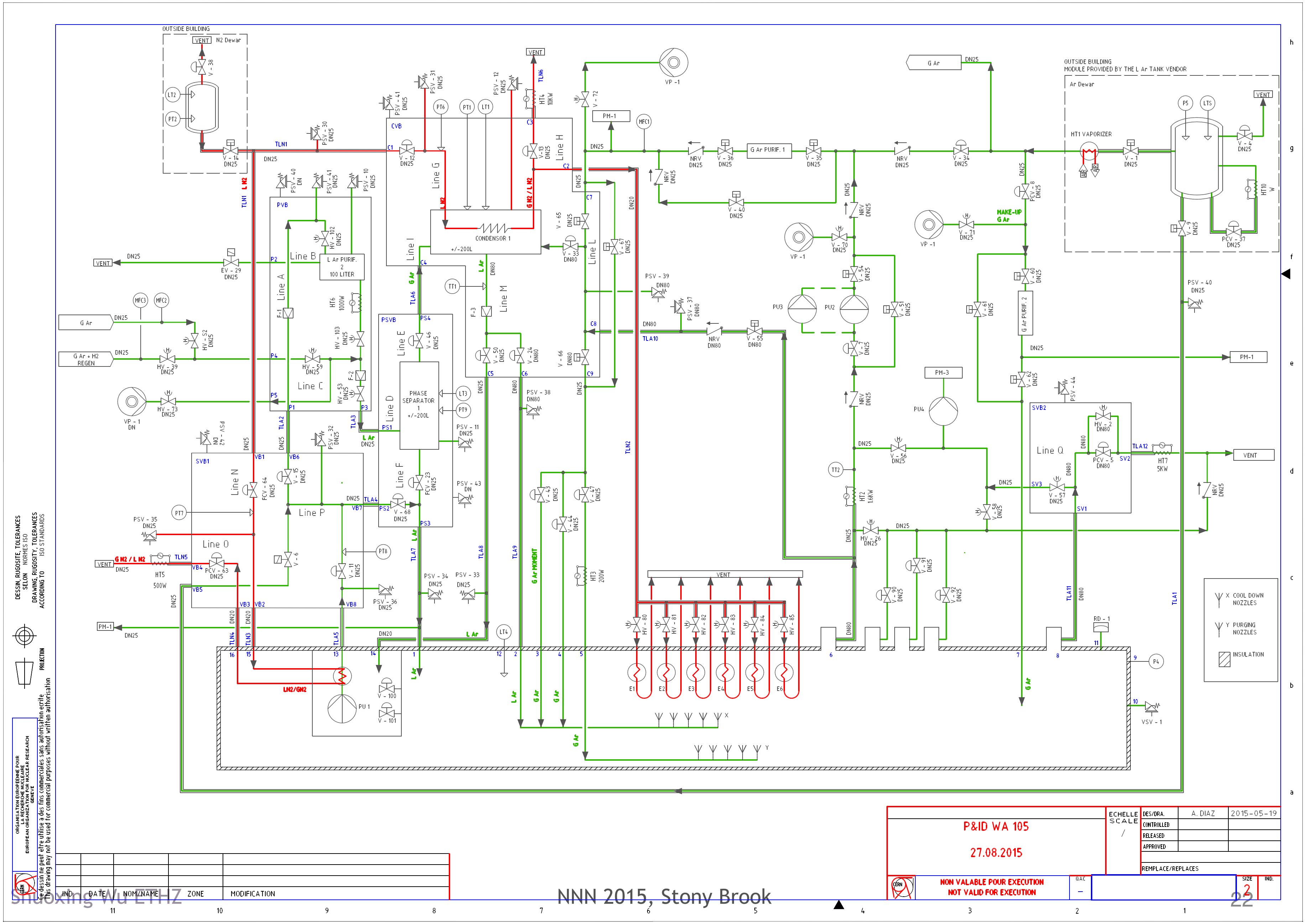
Planned HV test



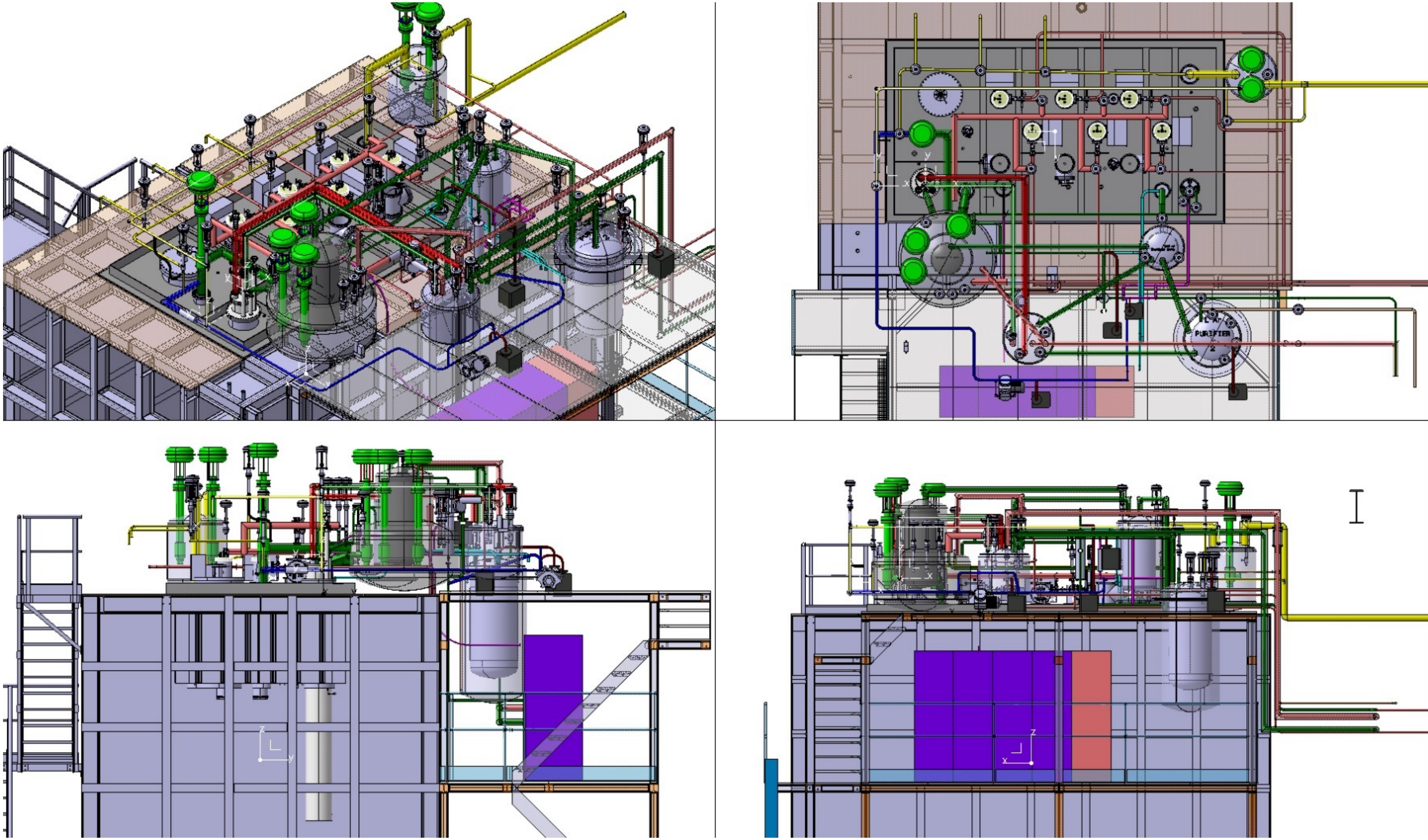


HV FT under construction, expected delivery end of November

Cryogenics system specially designed for the membrane tank and double phase readout



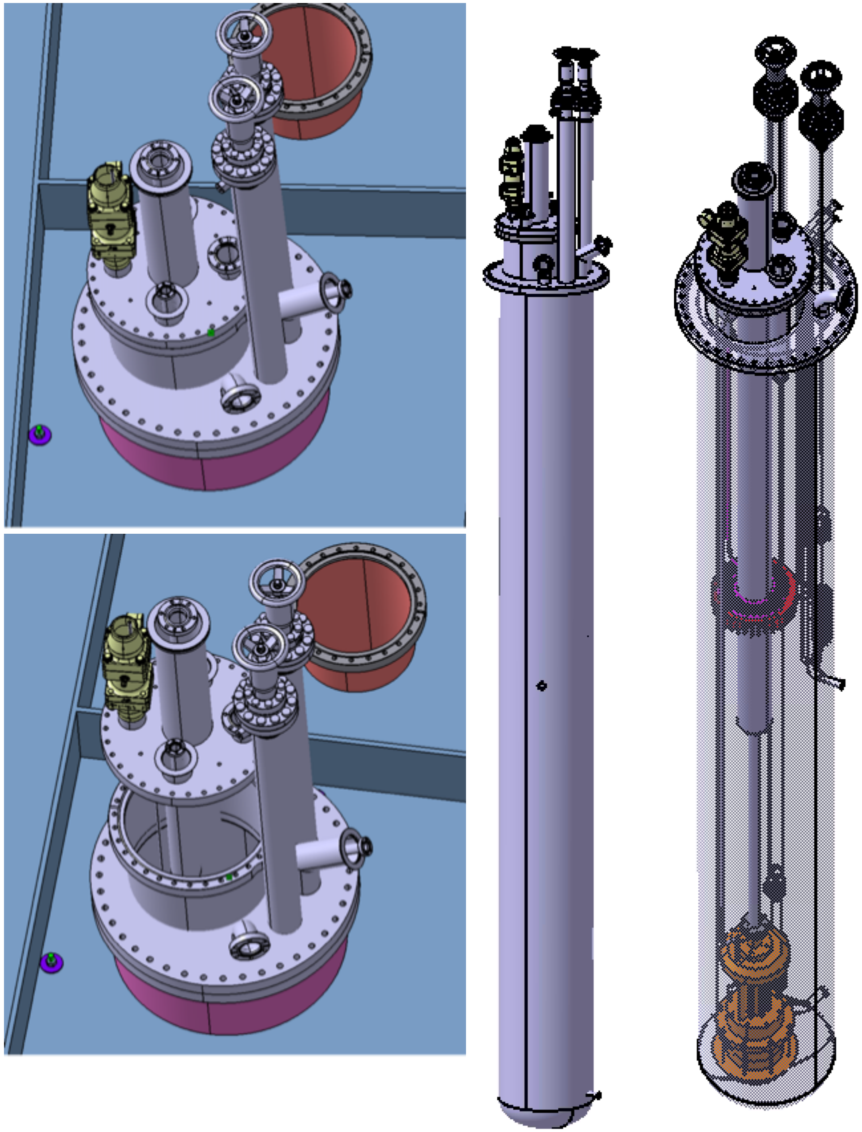
External cryogenics system



Expected installation April 2016

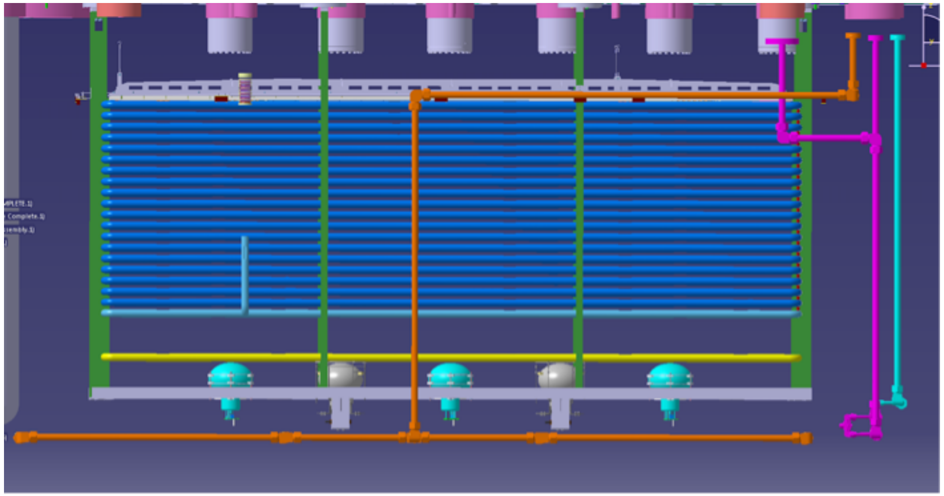
Internal cryogenics system

Extractable LAr pumping system



LAr pump and control system

Internal purging and cooling system



Design finished, place order soon

Summary

❖ Double phase LAr TPC technology has many benefits in terms of signal to noise ratio, long drift distance, larger fiducial volume, etc.

❖ We have successfully optimised the charge readout system based on many double phase operations of the 3L setup:

– the low capacitance (150 pF/m) readout anode meets the requirements on energy resolution, charge sharing, etc.

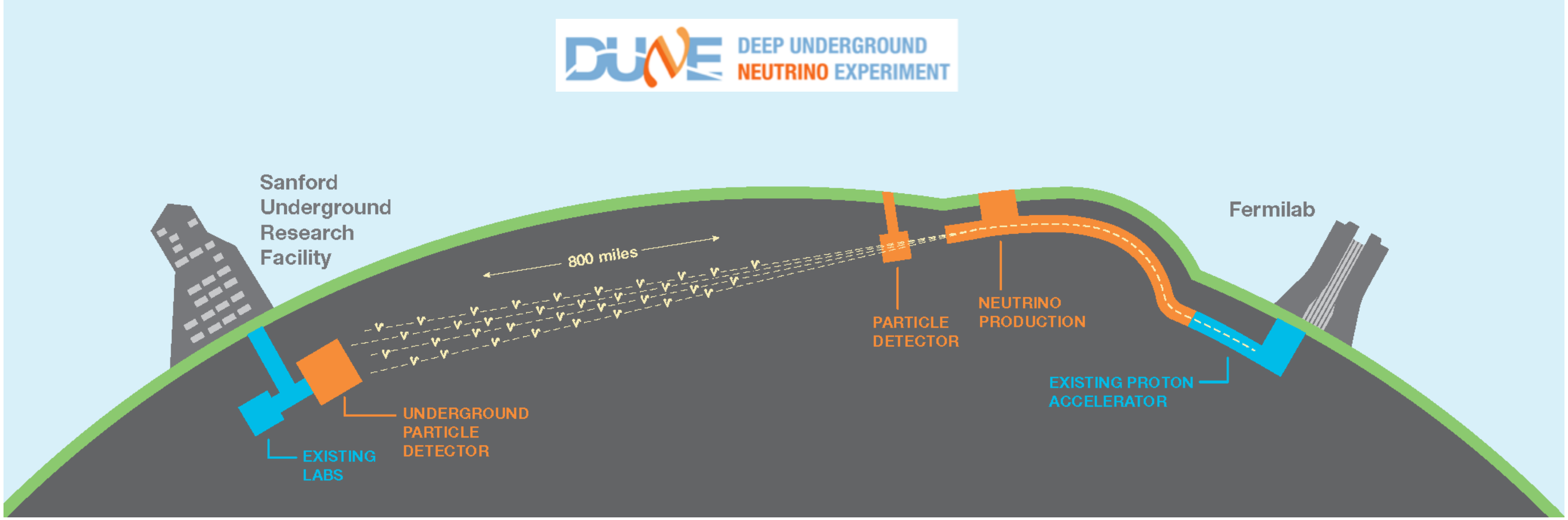
– the 10x10 cm^2 LEMs have a known behaviour and works at a stable gain over 20 at a very low discharge rate < 1 per day.

❖ The WA105 experiment is aimed to demonstrate the double phase LAr TPC technology in 300 ton active mass scale.

❖ Rapid progress has been made for the WA105-3x1x1 DLAr-proto which will pave the way towards the WA105-6x6x6 DLAr in many technical aspects.

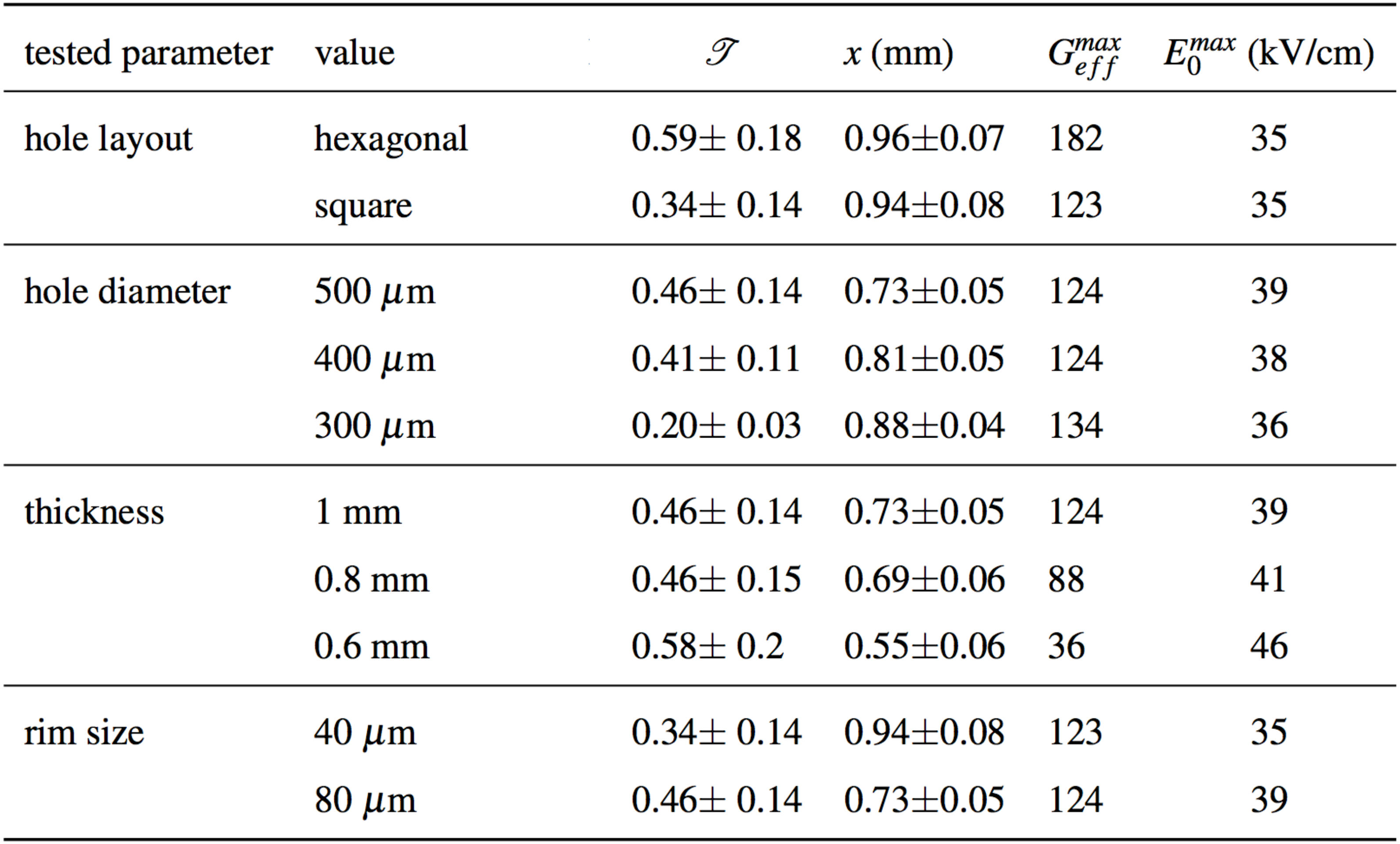
Thank you for your attention!

Deep Underground Neutrino Experiment (DUNE)



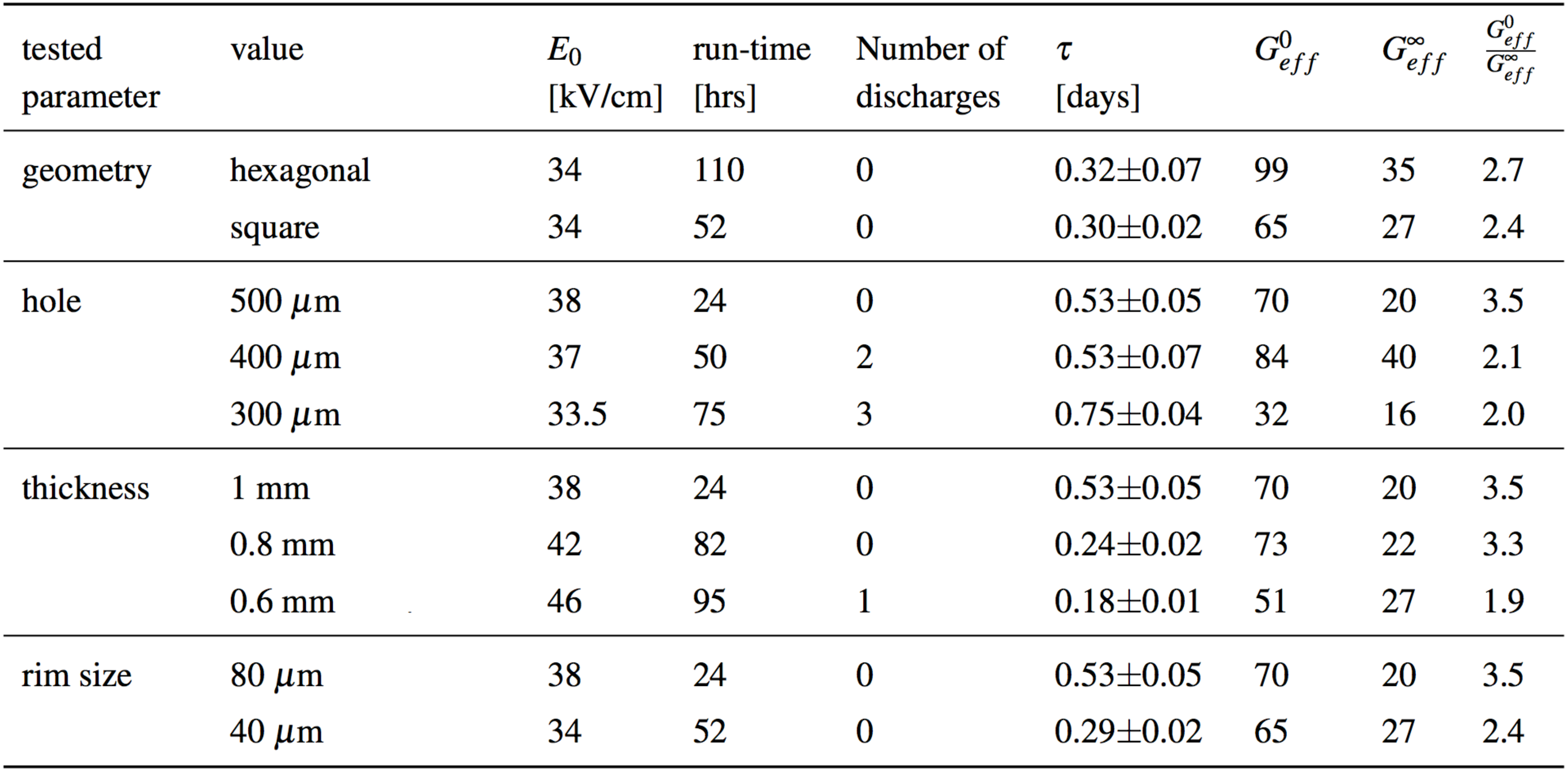
DUNE physics potential:

1. Accelerator based neutrino physics
   - Mass Hierarchy determination — over 5σ level over full δ_{CP} range for an exposure of 300 kt·MW·year, corresponding to 7 years' data with a 40-kt LAr detector and a 1.07-MW 80-GeV beam.
   - δ_{CP} measurement — 3σ sensitivity for 75% of δ_{CP} values at an exposure of 1320 kt·MW·year.
     — 5σ sensitivity for 50% of δ_{CP} values at an exposure of 810 kt·MW·year.
   - Sterile neutrino
2. Neutrino astronomy:
   - Solar neutrino
   - Atmosphere neutrino
   - Super-nova neutrino
3. Proton decay search



tested parameter	value	$\mathscr{T}$	x (mm)	G_{eff}^{max}	E_0^{max} (kV/cm)
hole layout	hexagonal	0.59± 0.18	0.96±0.07	182	35
	square	0.34± 0.14	0.94±0.08	123	35
hole diameter	500 μm	0.46± 0.14	0.73±0.05	124	39
	400 μm	0.41± 0.11	0.81±0.05	124	38
	300 μm	0.20± 0.03	0.88±0.04	134	36
thickness	1 mm	0.46± 0.14	0.73±0.05	124	39
	0.8 mm	0.46± 0.15	0.69±0.06	88	41
	0.6 mm	0.58± 0.2	0.55±0.06	36	46
rim size	40 μm	0.34± 0.14	0.94±0.08	123	35
	80 μm	0.46± 0.14	0.73±0.05	124	39

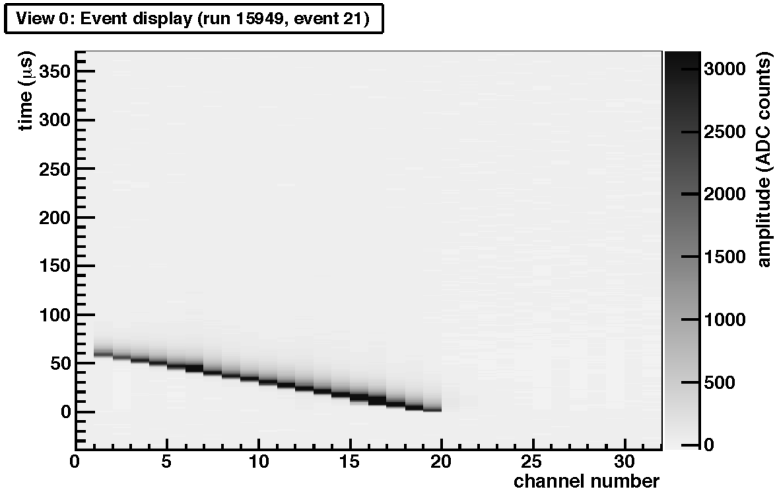
arXiv:1412:4402



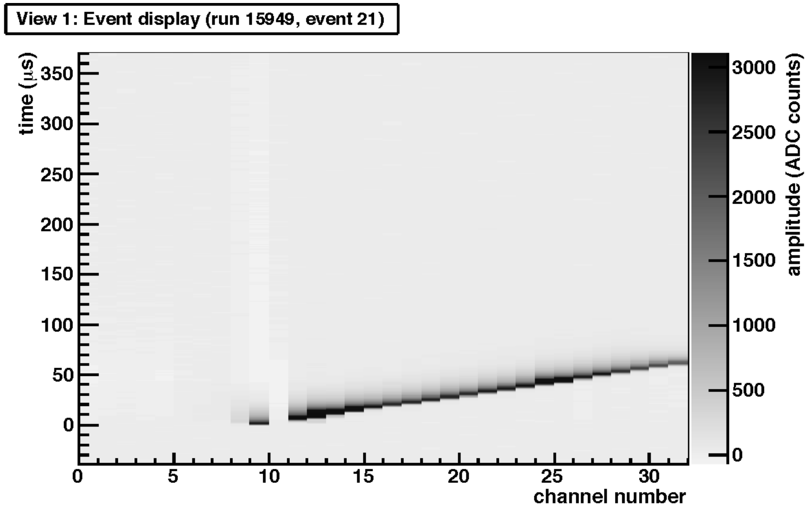
tested parameter	value	E_0 [kV/cm]	run-time [hrs]	Number of discharges	τ [days]	G^0_{eff}	G^∞_{eff}	$\frac{G^0_{eff}}{G^\infty_{eff}}$
geometry	hexagonal	34	110	0	0.32±0.07	99	35	2.7
	square	34	52	0	0.30±0.02	65	27	2.4
hole	500 μm	38	24	0	0.53±0.05	70	20	3.5
	400 μm	37	50	2	0.53±0.07	84	40	2.1
	300 μm	33.5	75	3	0.75±0.04	32	16	2.0
thickness	1 mm	38	24	0	0.53±0.05	70	20	3.5
	0.8 mm	42	82	0	0.24±0.02	73	22	3.3
	0.6 mm	46	95	1	0.18±0.01	51	27	1.9
rim size	80 μm	38	24	0	0.53±0.05	70	20	3.5
	40 μm	34	52	0	0.29±0.02	65	27	2.4

arXiv:1412:4402

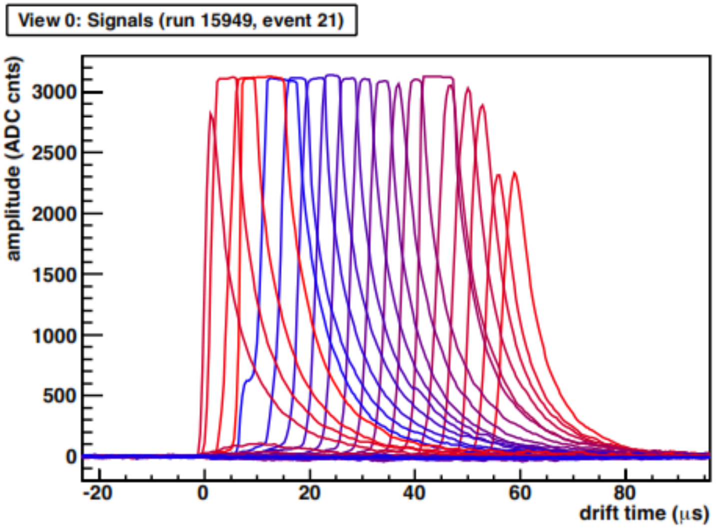
Cosmic event in double phase TPC at effective gain ~ 150



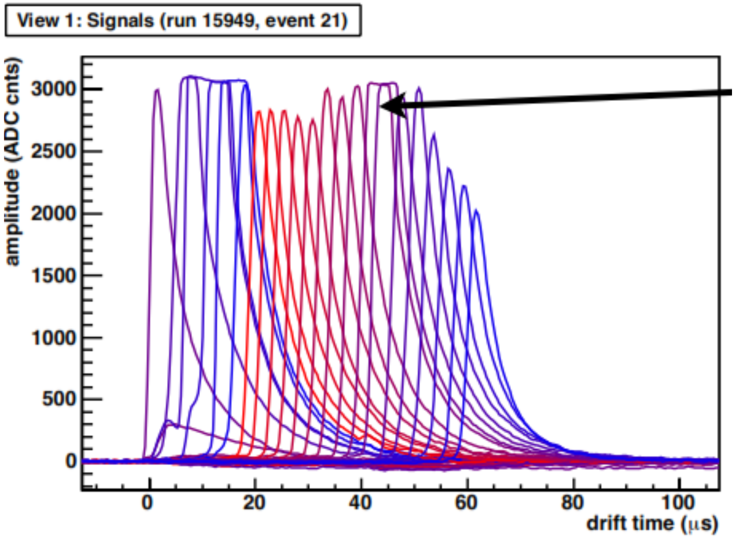
View 0: Event display (run 15949, event 21)



View 1: Event display (run 15949, event 21)



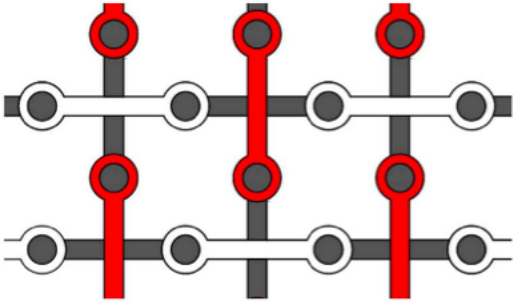
View 0: Signals (run 15949, event 21)



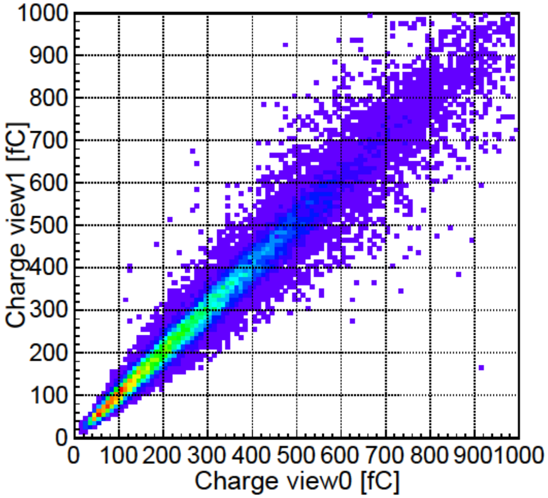
View 1: Signals (run 15949, event 21)

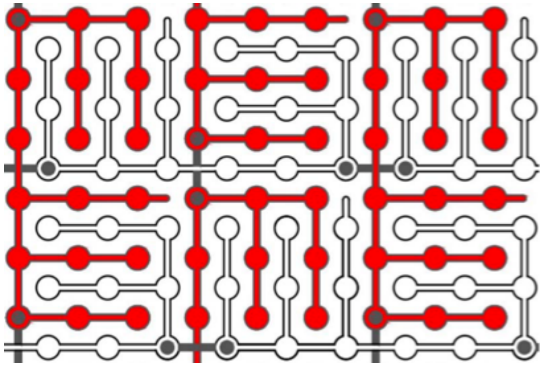
saturation
of the pre-amp

Other anodes tested

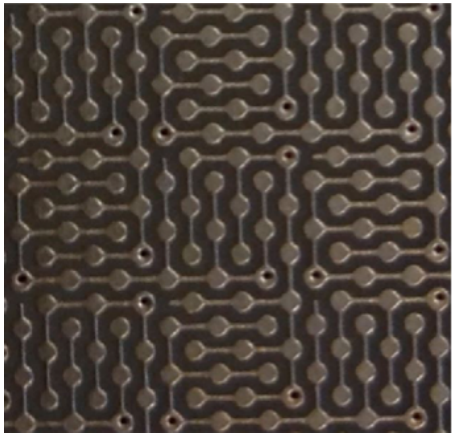


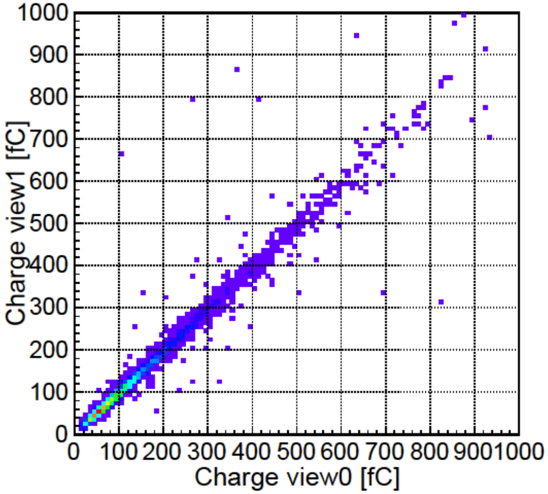
dC/dl~100 pF/m



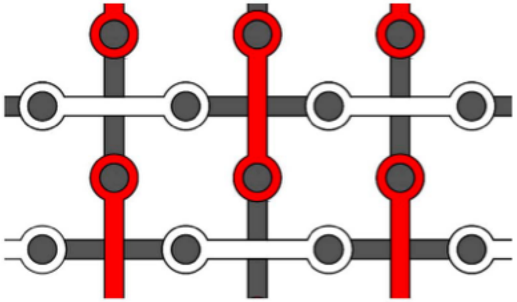


dC/dl~250 pF/m

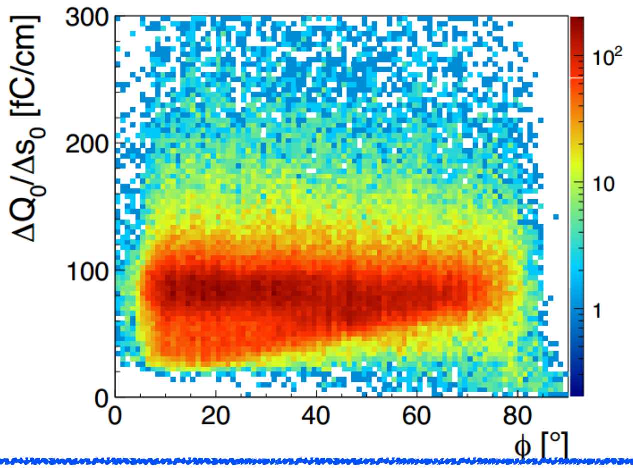


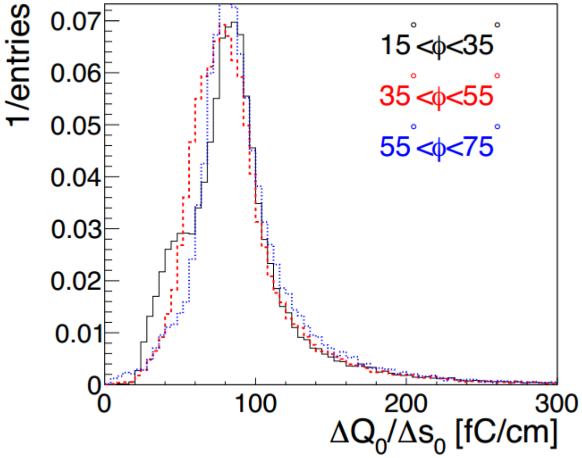


Other anodes tested



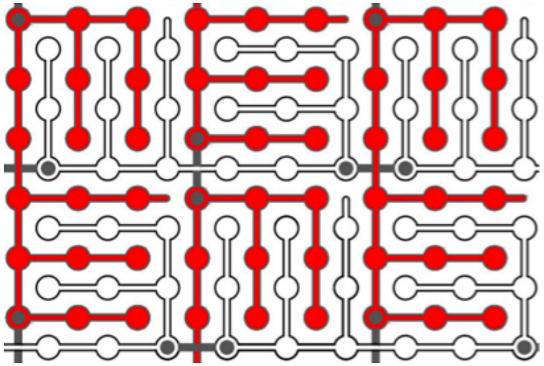
dC/dl~100 pF/m



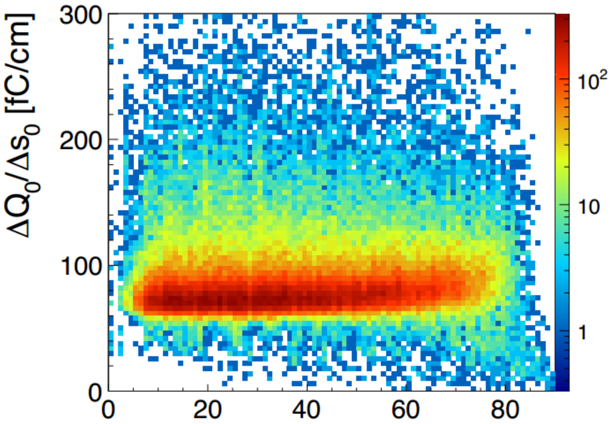


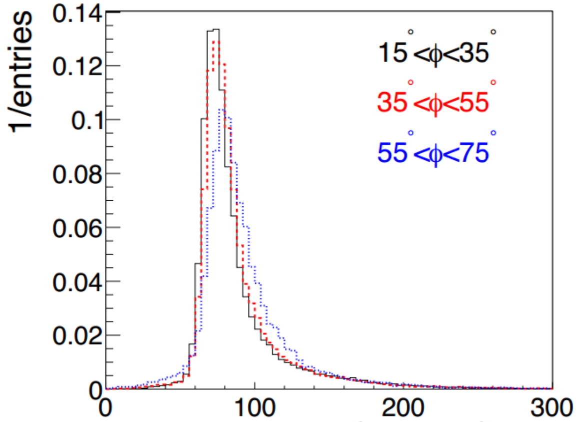
Pattern too loose, non uniform charge collection between strips

JINST 9 P03017



dC/dl~250 pF/m



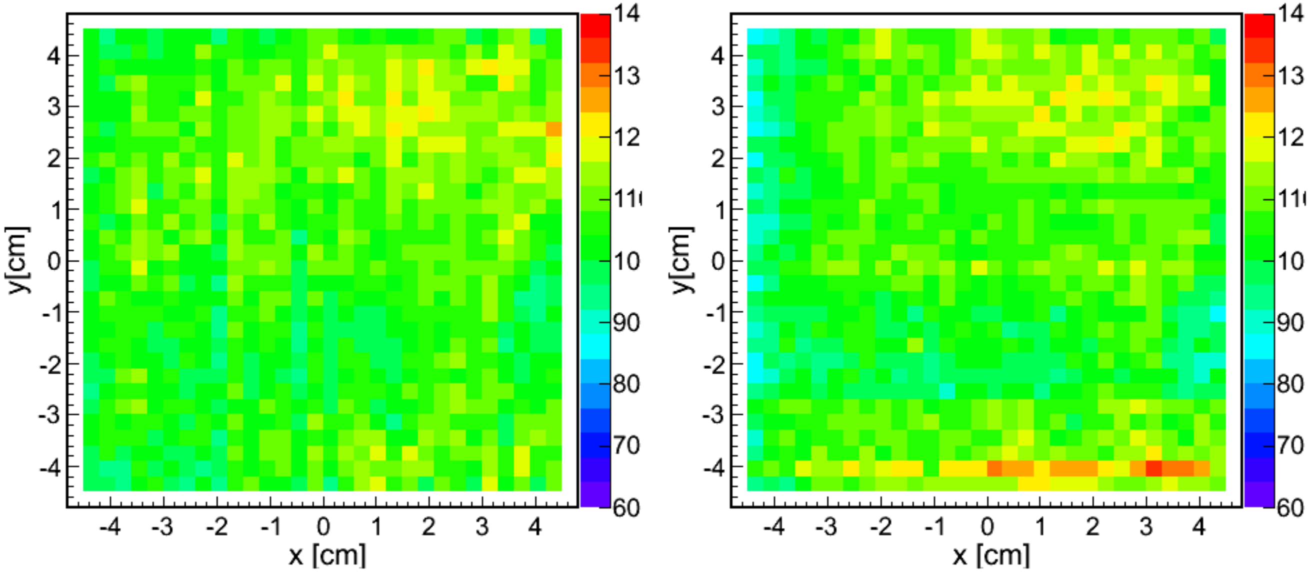


Compatible performance as 150 pF/m anode, but has higher capacitance

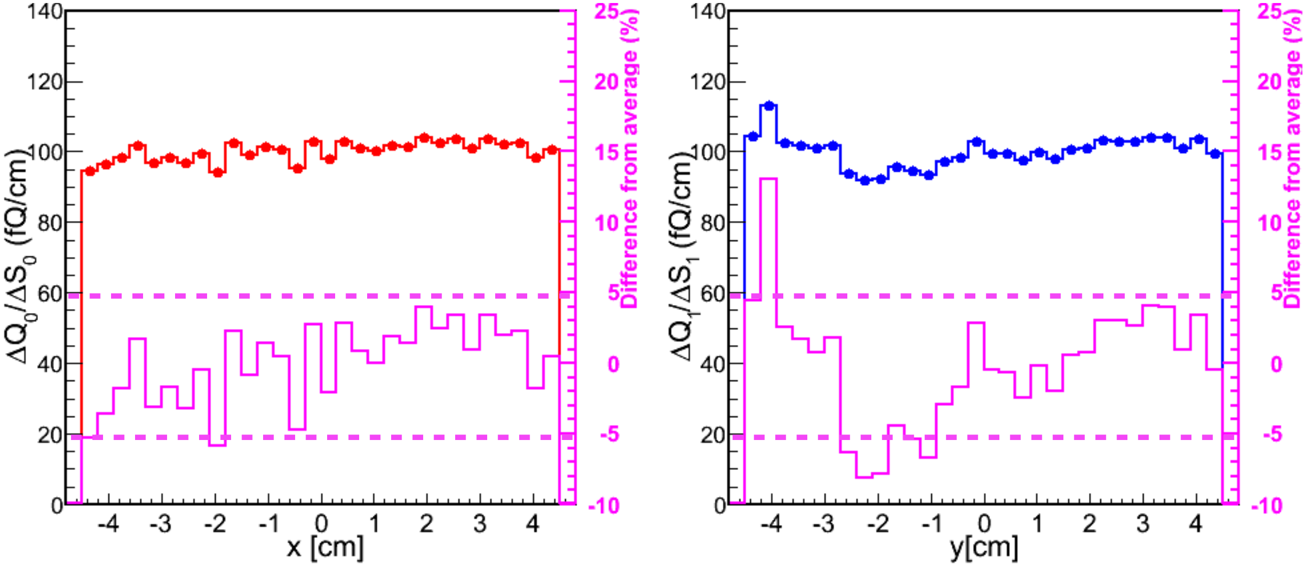
Gain uniformity

View 0 View 1

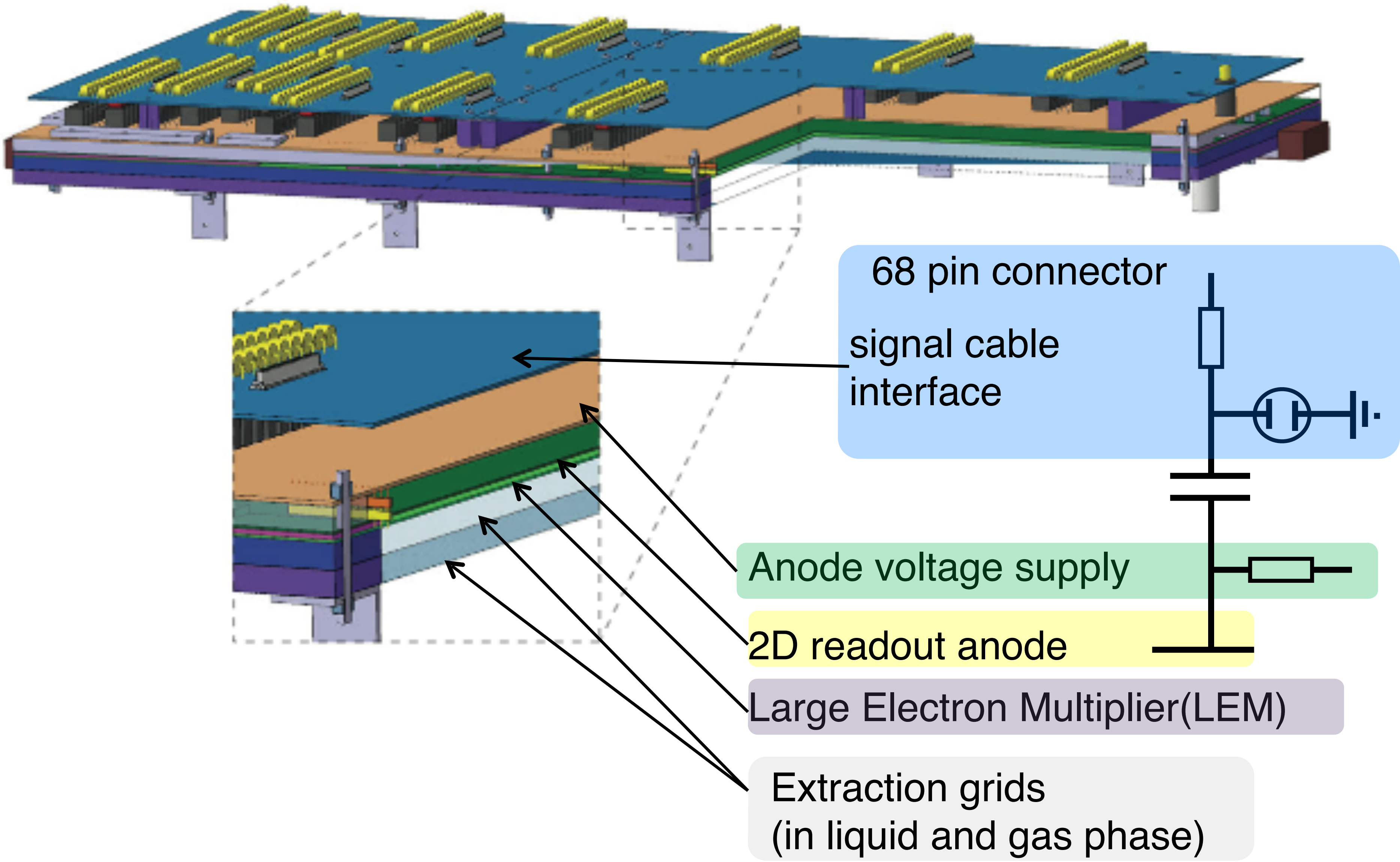
<dQ/dx> (fC/cm) (normalized to 100 fC/cm):



Projections on X and Y axis:



Compact charge readout design



68 pin connector

signal cable interface

Anode voltage supply

2D readout anode

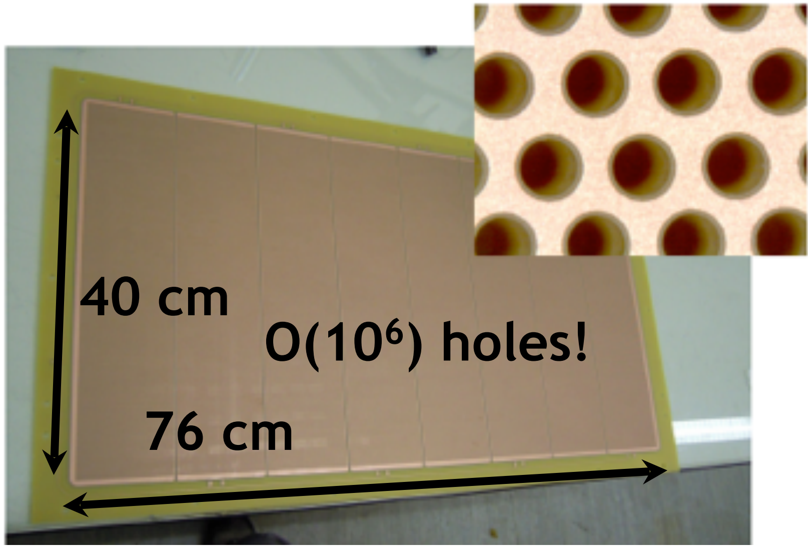
Large Electron Multiplier(LEM)

Extraction grids
(in liquid and gas phase)

Towards a large area readout: the 40x76 cm^2 prototype

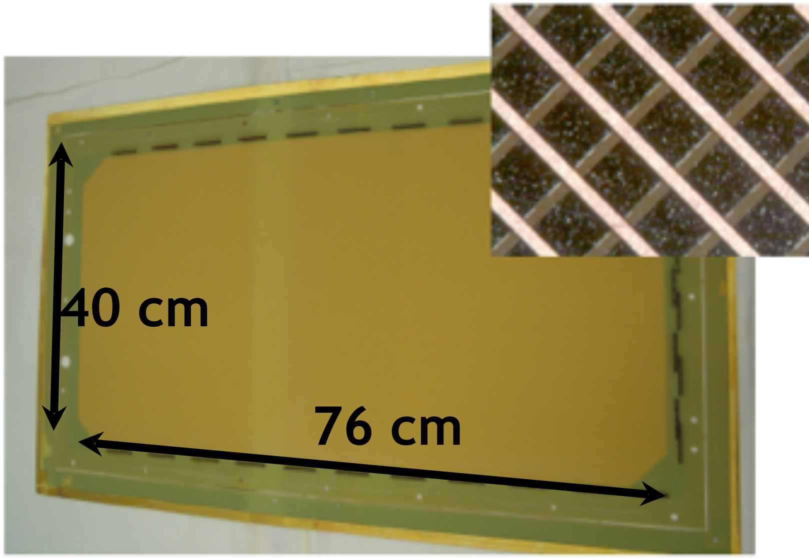
Large Electron Multiplier (LEM)

- Macroscopic gas hole multiplier (Thick GEM)
- more robust than GEMs (cryogenic temperatures, discharge resistant)
- manufactured with standard PCB techniques
- Large area coverable by 50x50 cm^2 modules
- Light quenching within the holes



2D projective anode readout

- Charge equally collected on two sets of strips (views)
- Readout independent of multiplication
- Signals have the same shape for both views:
  -two collection views (unipolar signals)
  -no induction view (bipolar signals) as in the case of a LAr-TPC with induction wires

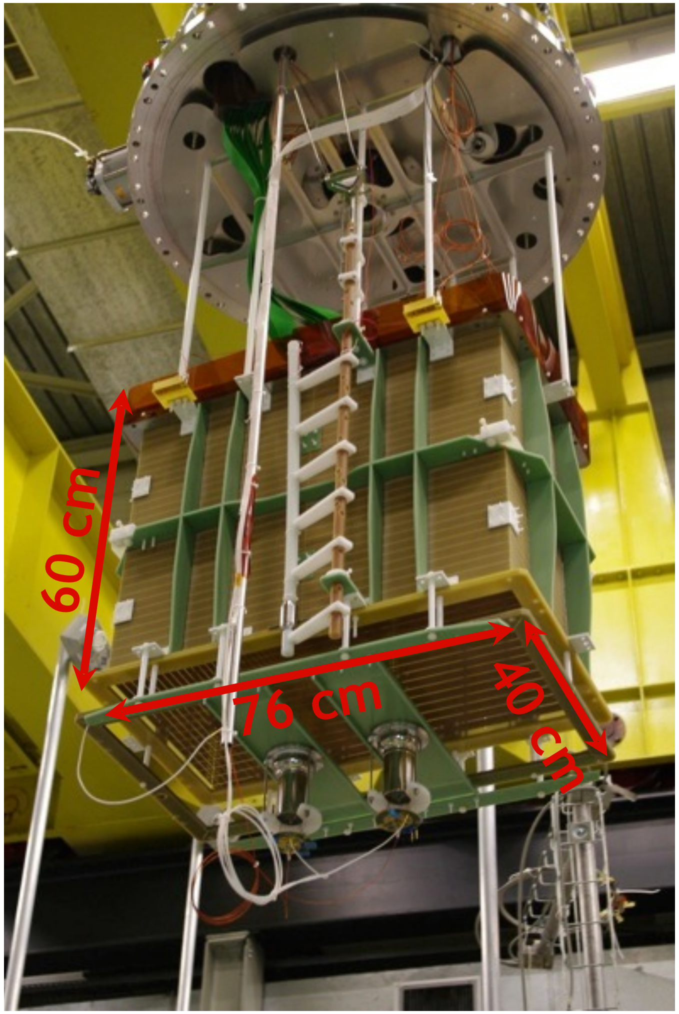


So far largest area LEM/2D anode produced

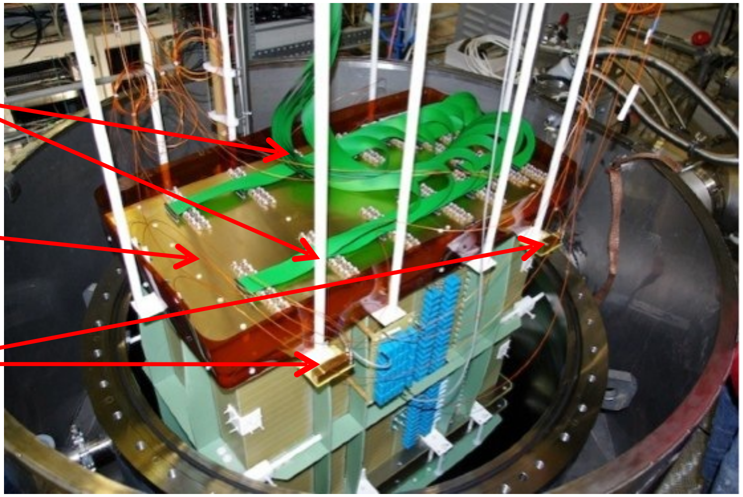
Large area readout: the 40x76 cm^2 prototype

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

detector fully assembled



going into the ArDM cryostat

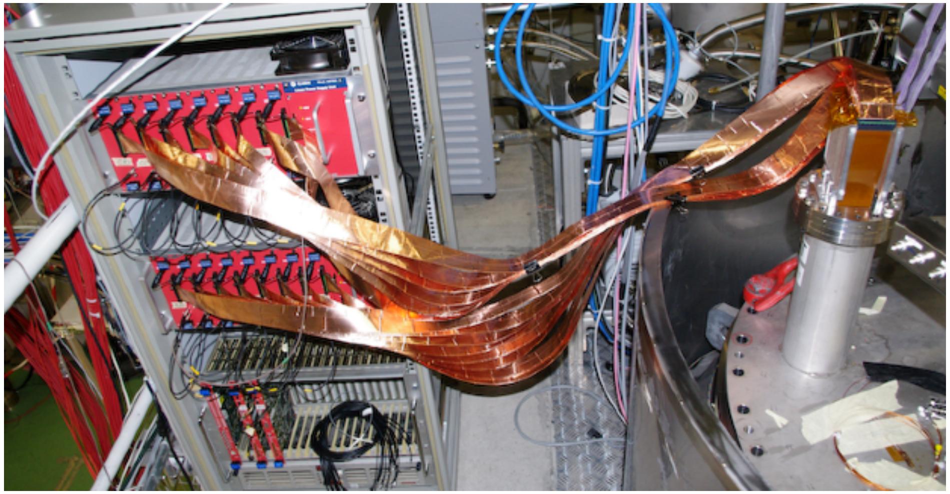


16 signal cables

charge readout sandwich

4 capacitive level meters

Final connection to the CAEN DAQ system



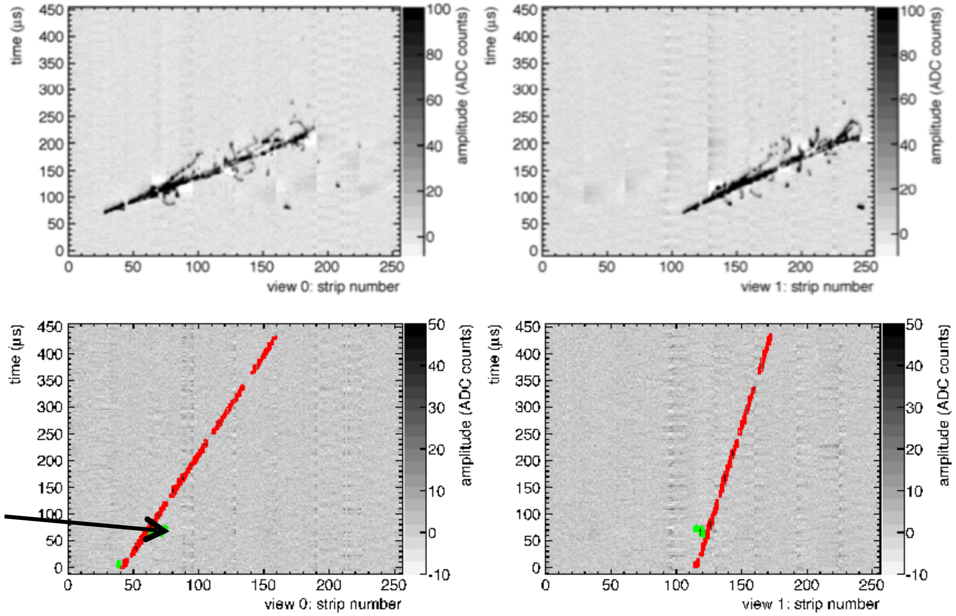
Results from the 40x76 cm^2 prototype

We have operated the detector for the first time in October 2011 for more than 1 month under controlled pressure: 1023±1 mbar

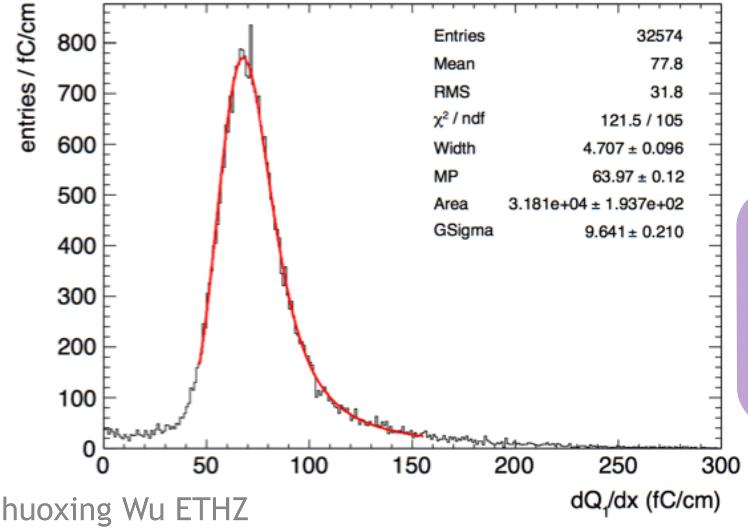
A. Badertscher et al. JINST 8 (2013) P04012

Optimized field configurations:

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



delta ray identified and reconstructed



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:
$(Q_1-Q_0)/(Q_1+Q_0)$≈8%