Double phase Liquid Argon LEM TPC

Shuoxing Wu
Institute for Particle Physics, ETH Zurich

on behalf of
WA105 collaboration

NNN 2016, IHEP Beijing, 3-5 Nov 2016

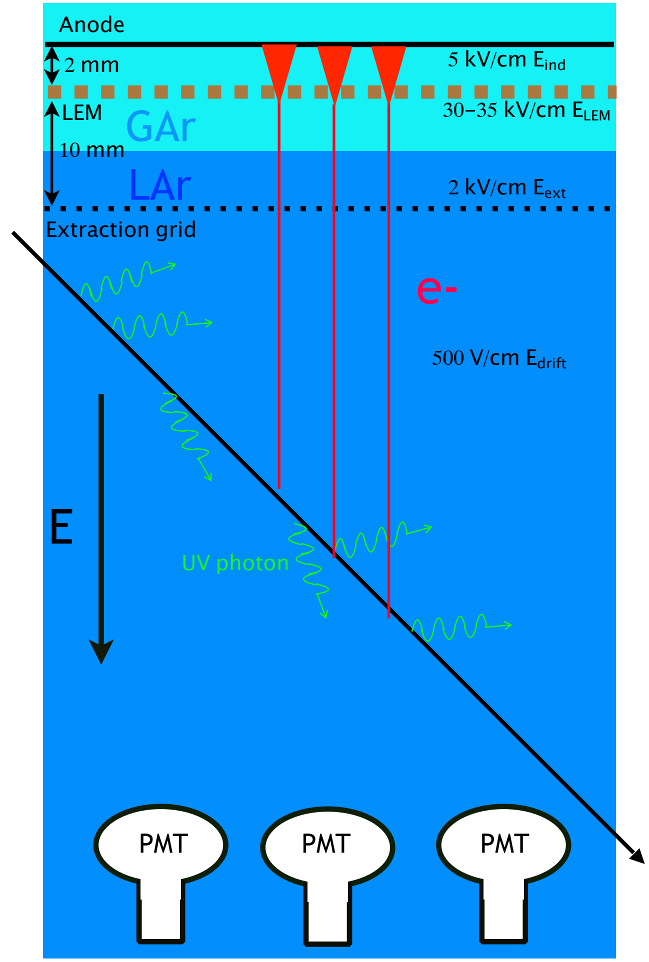
The double phase LAr LEM TPC

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 (20-100)

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

1.) Ionisation electrons drift towards the liquid argon surface

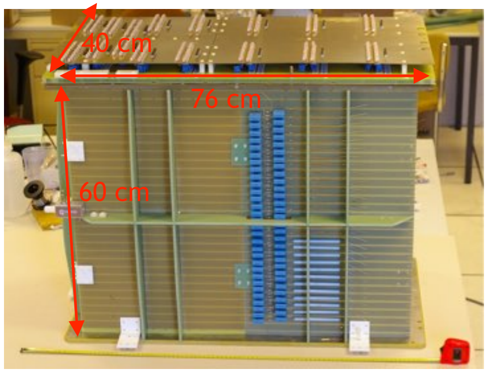


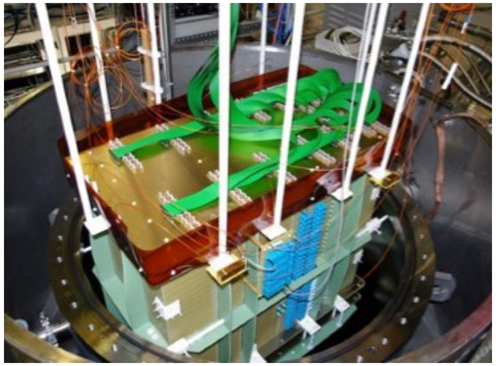
For MIPs:

- 10 fC/cm @ 500 V/cm E_{drift} — ~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
- SNR~10 for 12 m drift with 3 ms e^- lifetime

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

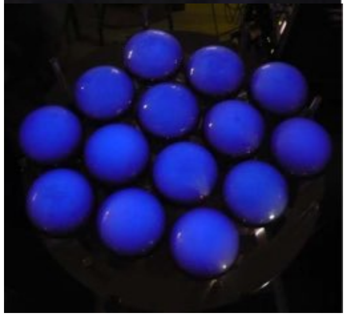
250L chamber@CERN:
stable large area charge amplification/readout





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

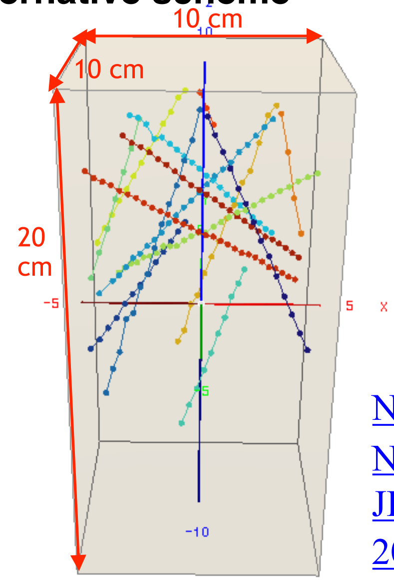
ArDM-1T@Canfranc lab:
- **LAr scintillation light detection**
- **Underground operation**



J.Phys.Conf.Ser. 39 (2006) 129-132

JINST 5 (2010) P11003

3L chamber@CERN:
- **proof of principle**
- **anode/LEM optimisation and alternative scheme**



NIM A617 (2010) p.188-192

NIM A641 (2011) p.48-57

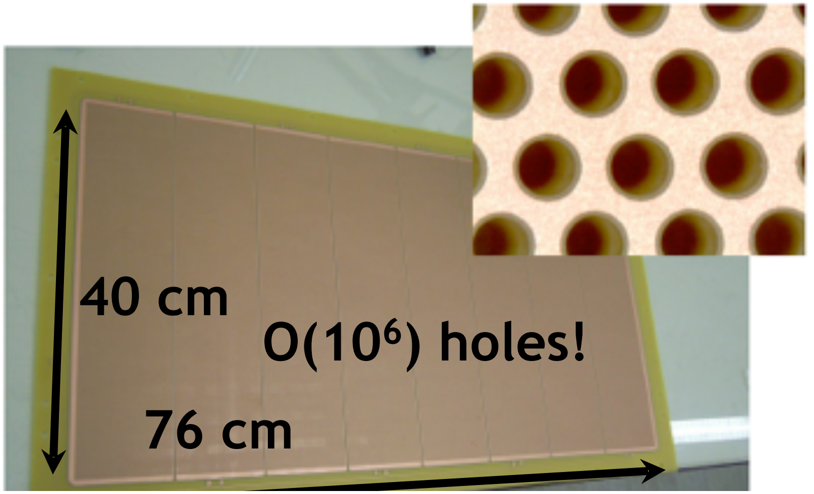
JINST 9 P03017

2015 JINST 10 P03017

Large area readout: the 40x76 cm^2 prototype

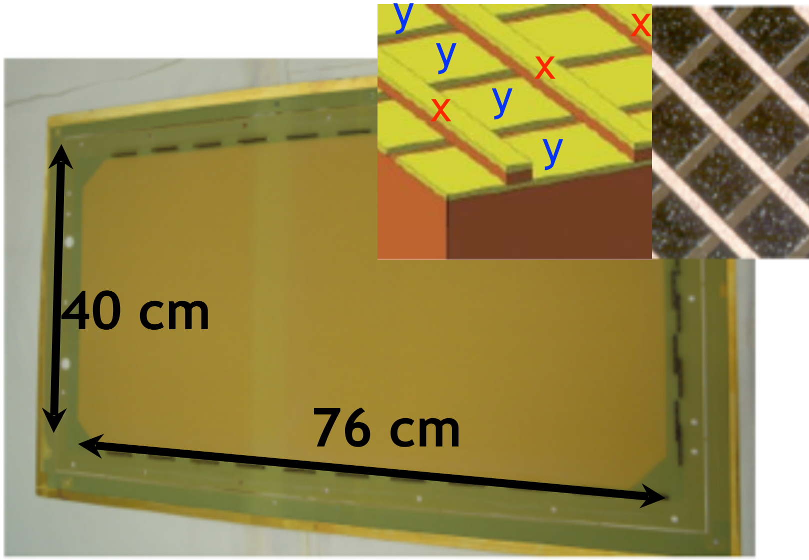
Large Electron Multiplier (LEM)

- Macroscopic gas hole multiplier (Thick GEM)
- more robust than GEMs (cryogenic temperatures, discharge resistant)
- manufactured with standard PCB techniques
- Light quenching inside the holes



2D projective anode readout

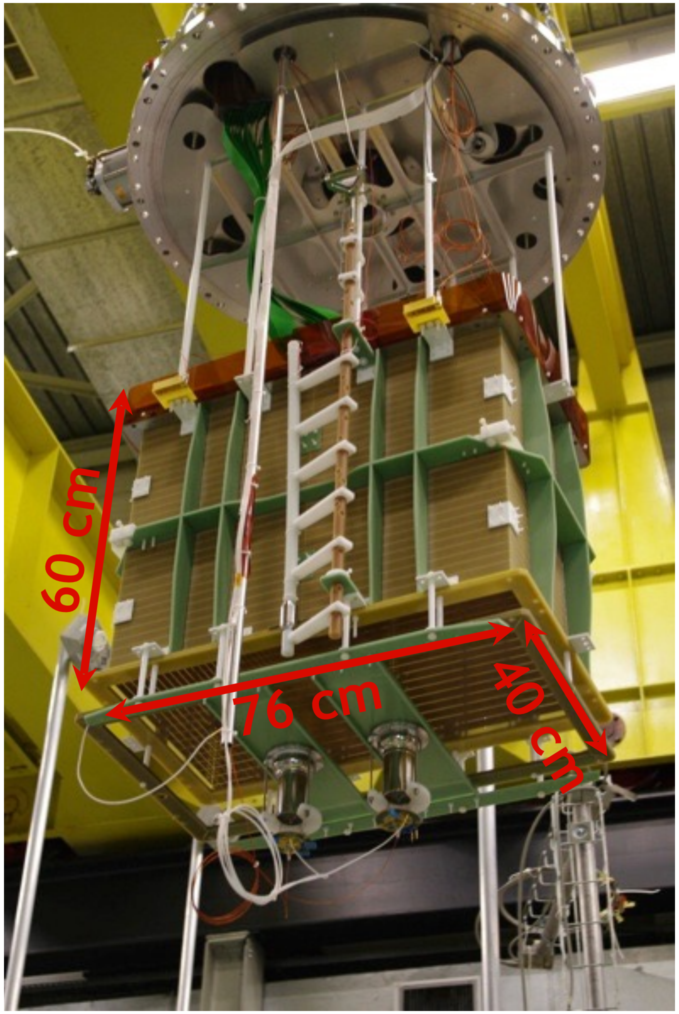
- Charge equally collected on two sets of strips (views)
- Two views separated by 50 um Kapton layer
- Readout independent of multiplication
- Signals have the same shape for both views:
  - two collection views (unipolar signals)
  - no induction view (bipolar signals) as in the case of a LAr-TPC with induction wires



So far largest area LEM/2D anode produced (larger than 50x50 cm2 panels)

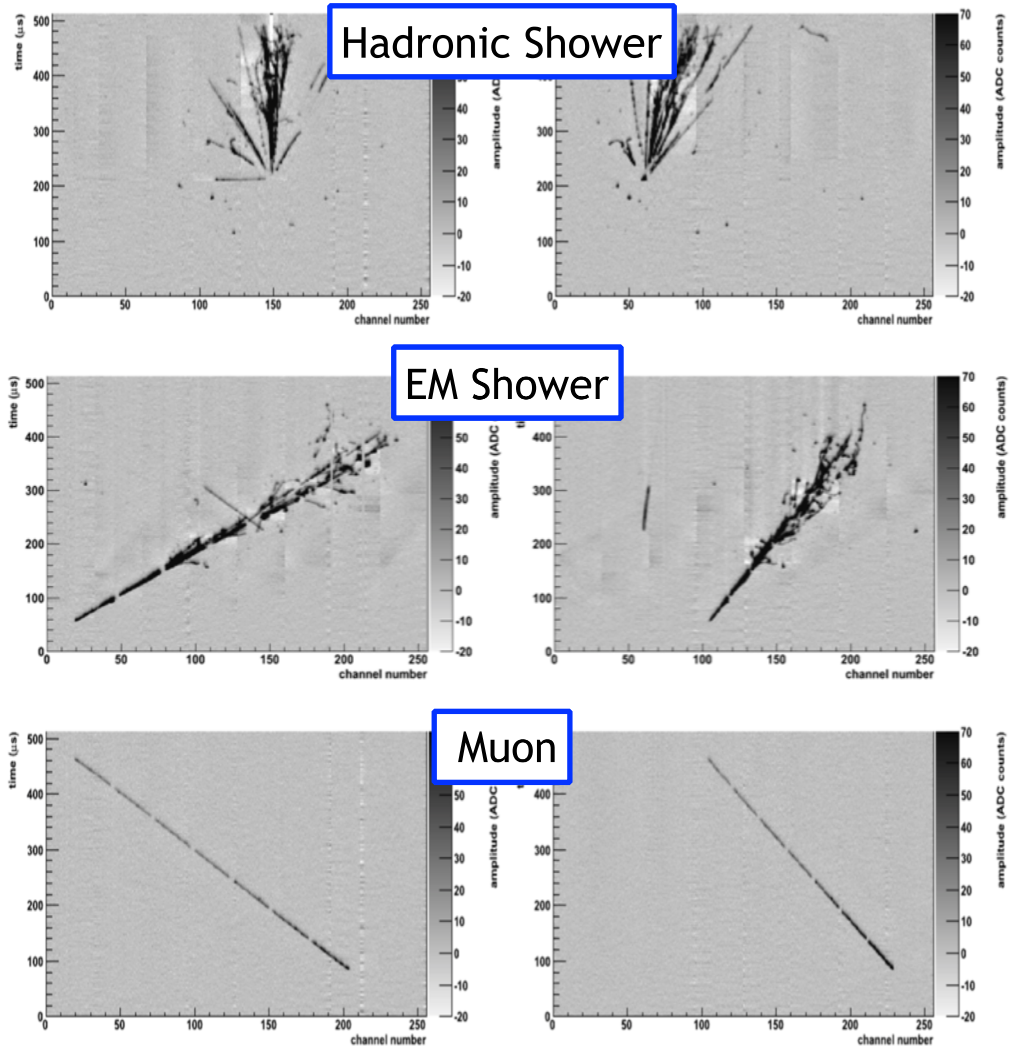
Large area readout: the 40x76 cm^2 prototype

detector fully assembled inside ArDM dewar



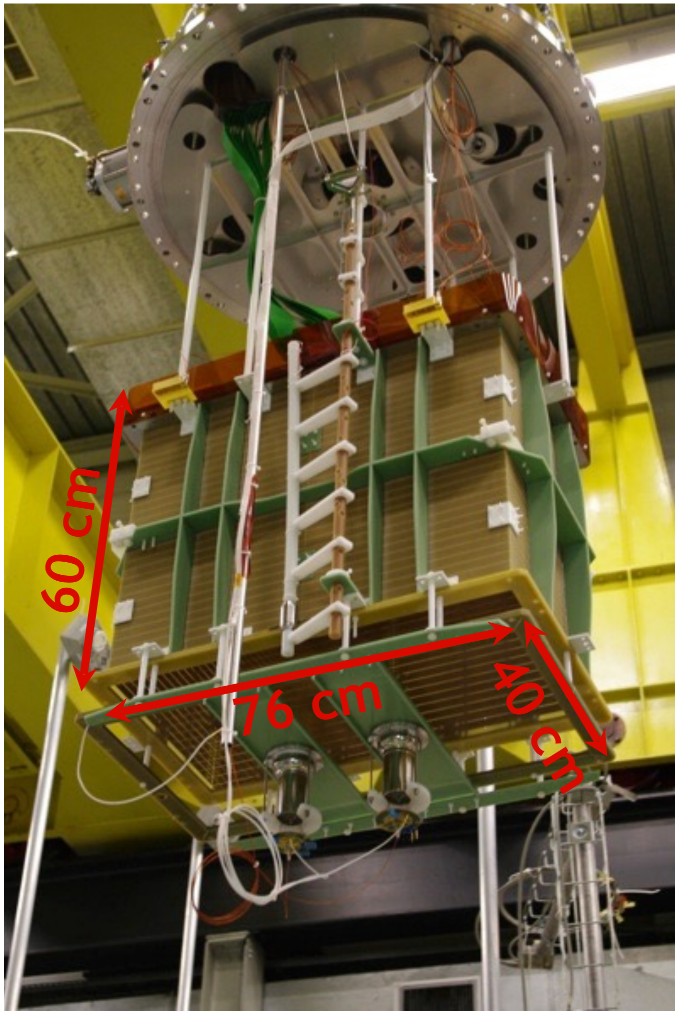
Two collection views:

z vs. x (view 0) z vs y (view 1)



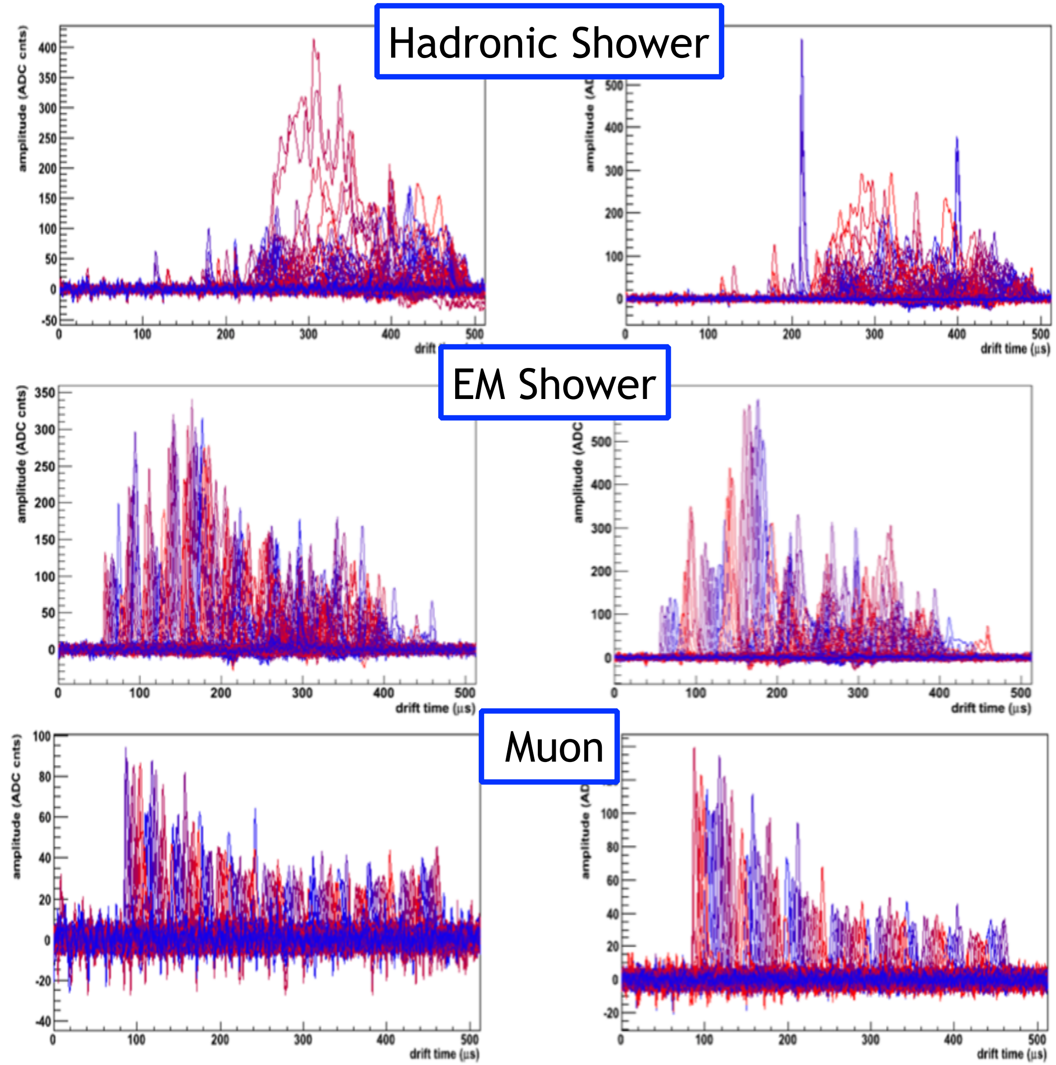
Large area readout: the 40x76 cm² prototype

detector fully assembled inside ArDM dewar



Two collection views:

waveforms (view 0) waveforms (view 1)



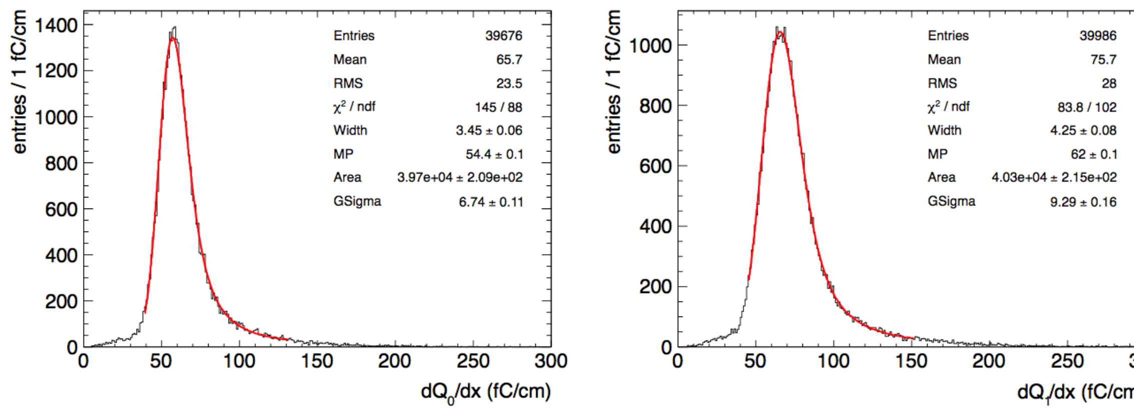
Results from the 40x76 cm² prototype

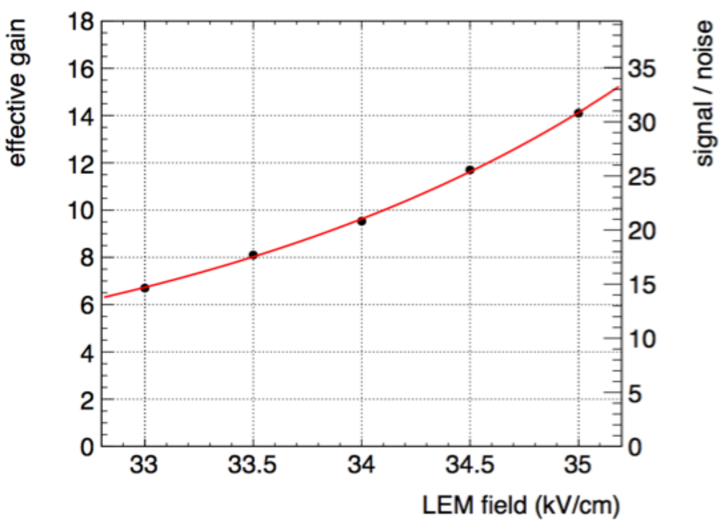
The detector was for the first time stably operated for more than 1 month (Oct. 2011) under controlled pressure: 1023±1 mbar

Optimized field configurations:

LEM-Anode	1800 V/cm
LEM	**35 kV/cm**
LEM-grid	600 V/cm
extraction	2300 V/cm
drift	500 V/cm

Reconstructed muon dQ/dx distribution





Effective gain:

$(<dQ_0/dx_0> + <dQ_1/dx_1>)/dQ/dx_{MIP}$ (≈10fC/cm)

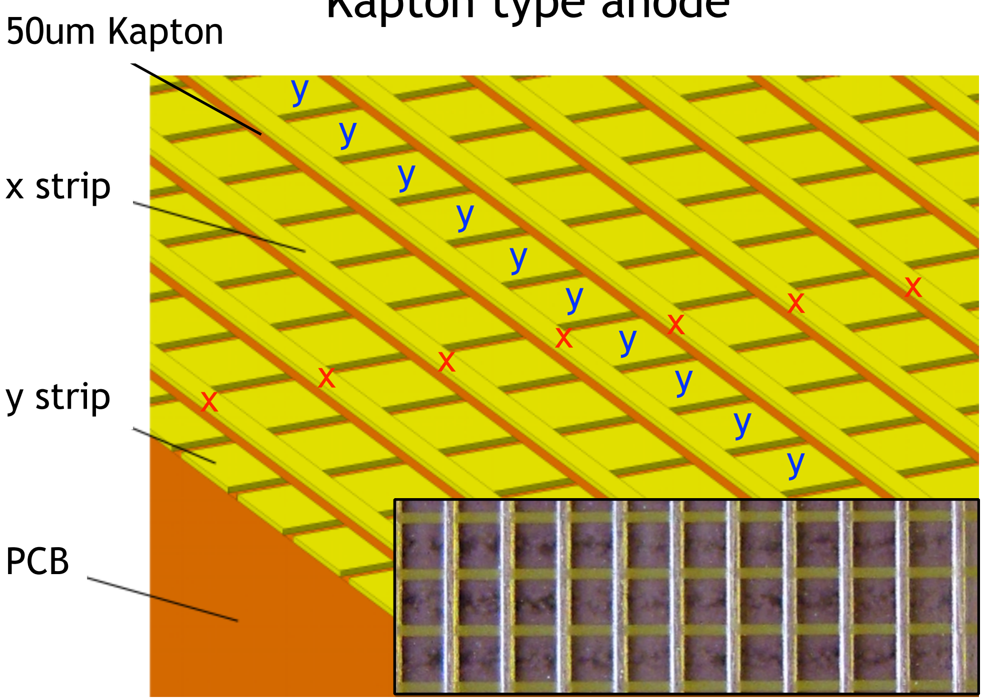
<dQ/dx>=146 fC/cm

->effective gain≈14.6, (S/N≈30)

charge sharing between the two collection views: $(Q_1-Q_0)/(Q_1+Q_0)$≈8%

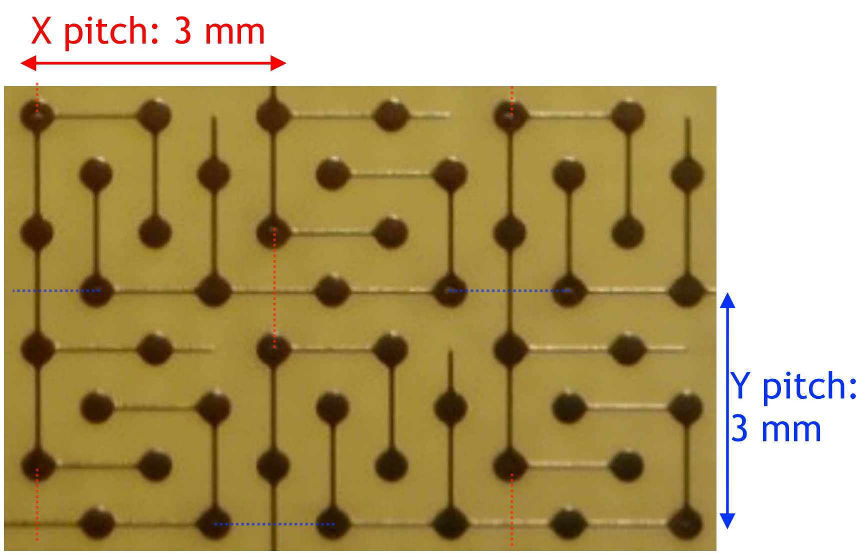
Low capacitance 2D anode for large area readout

"Proof of principle" Kapton type anode



- 2 views separated by a 50 um Kapton
- Inter-strip capacitance ~ 600 pF/m
  (input capacitance 1.8 nF for 3 m as DUNE)
- Non-industry production method
  (CERN TS/DEM workshop)

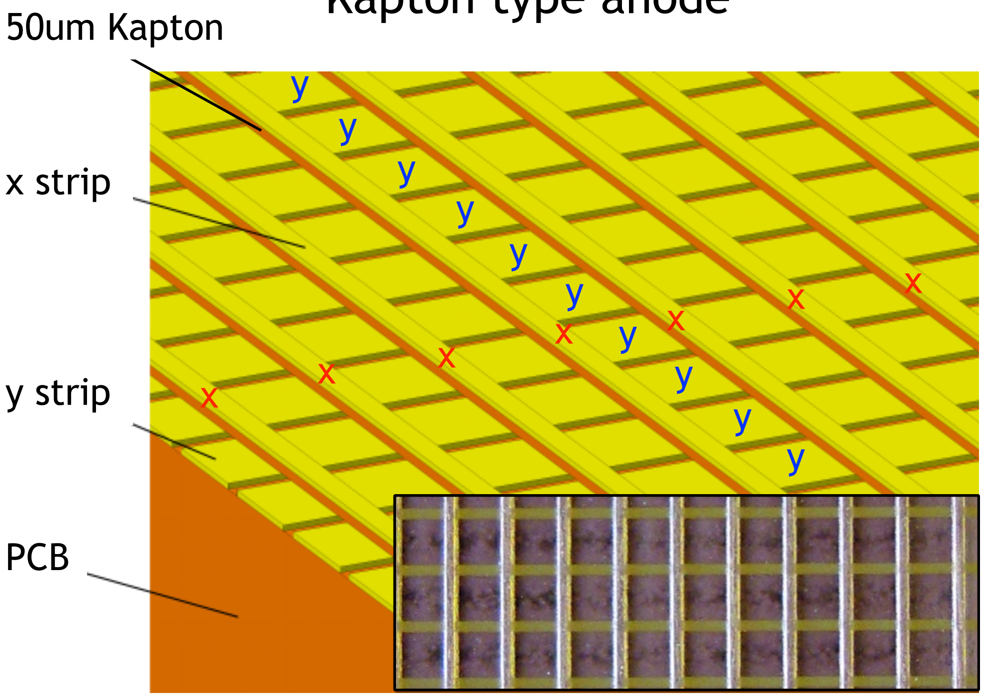
PCB type anode



- 2 views on the same layer
- Inter-strip capacitance ~ 150 pF/m
  (input capacitance 450 pF for 3 m as DUNE)
- Industry production method
  (standard PCB technique)

Low capacitance 2D anode for large area readout

"Proof of principle" Kapton type anode



- 2 views separated by a 50 um Kapton
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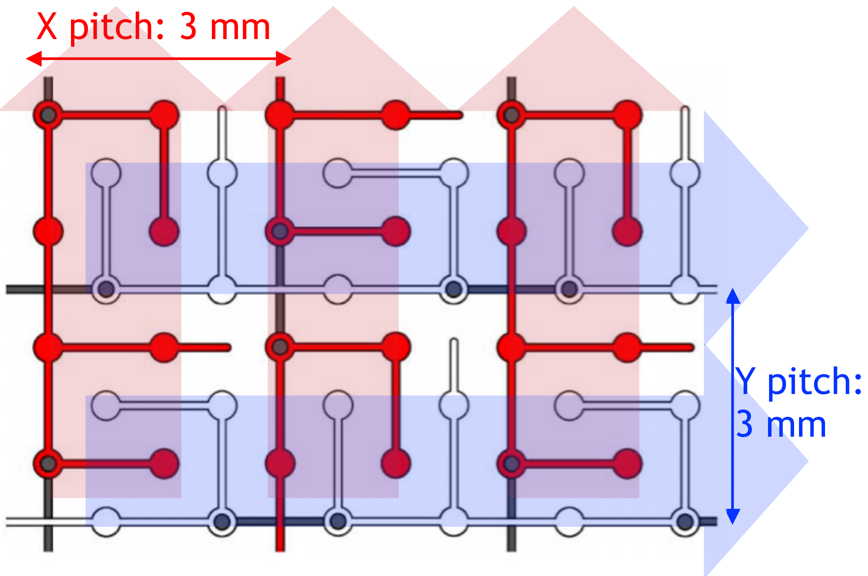
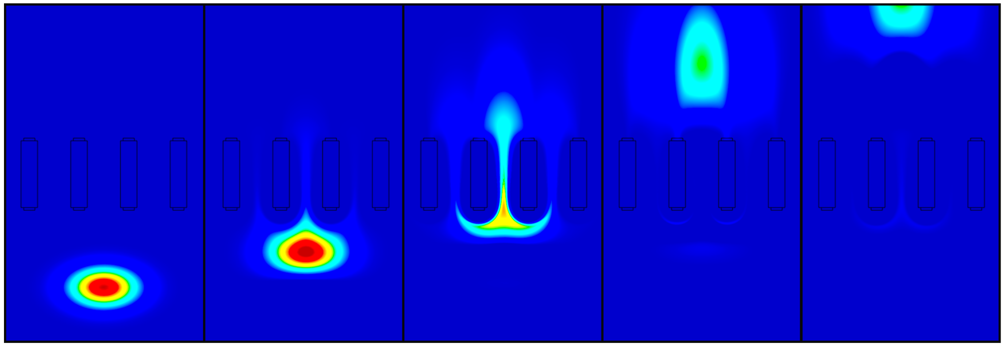


Two critical parameters:

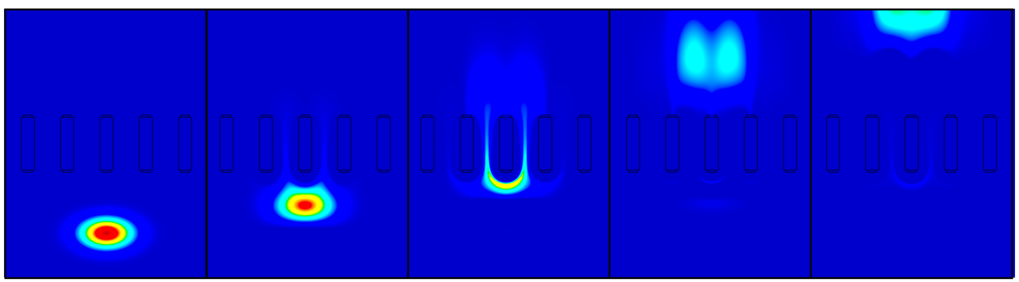
1. maximal separation between 2 strips inside the same view is 1.5 mm.
2. maximal separation between 2 strips from 2 views is 0.75 mm.

Electron cloud size simulation

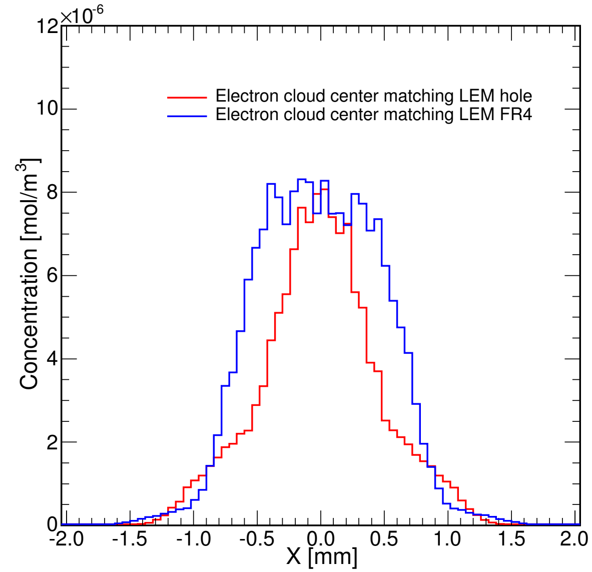
Electrons entering one LEM hole:



Electrons entering two LEM holes:

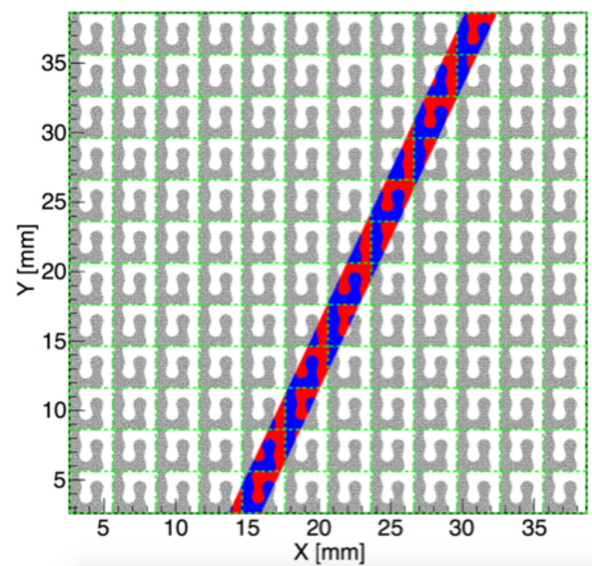


Electron concentration transverse projection:



cloud size: 2-3 mm

2 mm wide track:

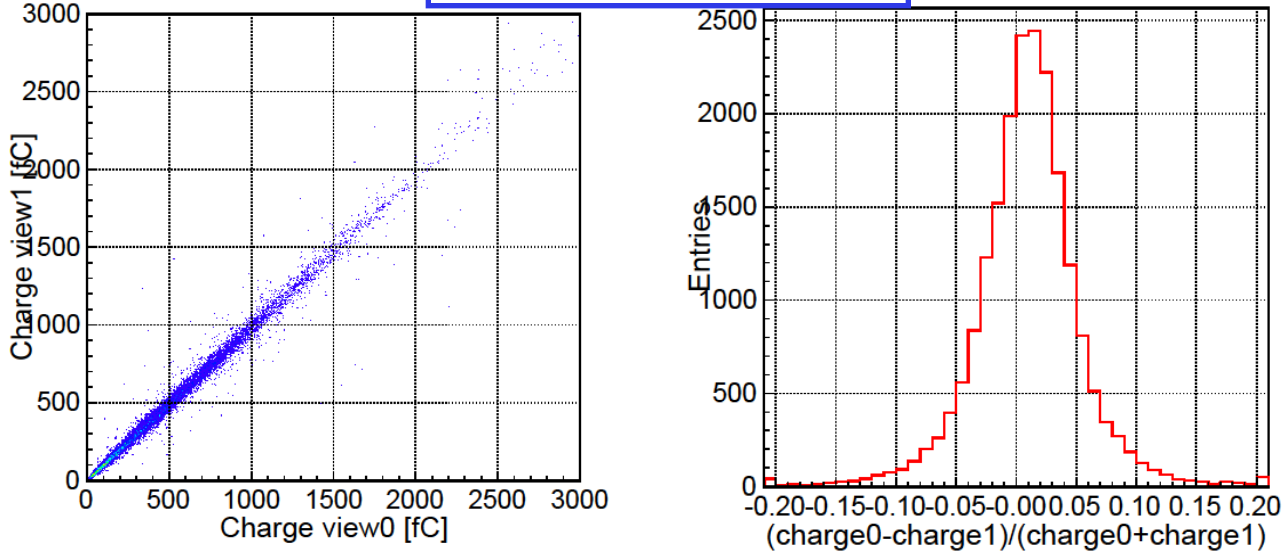


anode design requirements:

1. cloud size > maximal separation (diff views)
   — charge sharing symmetry between 2 views.
2. cloud size > maximal separation (same view)
   — strips see equal signal (good resolution).

Anode performance in 3L chamber

Fully X-Y symmetric:



Mean: 0.009

RMS: 0.043

Uniform response to track azimuth angles:

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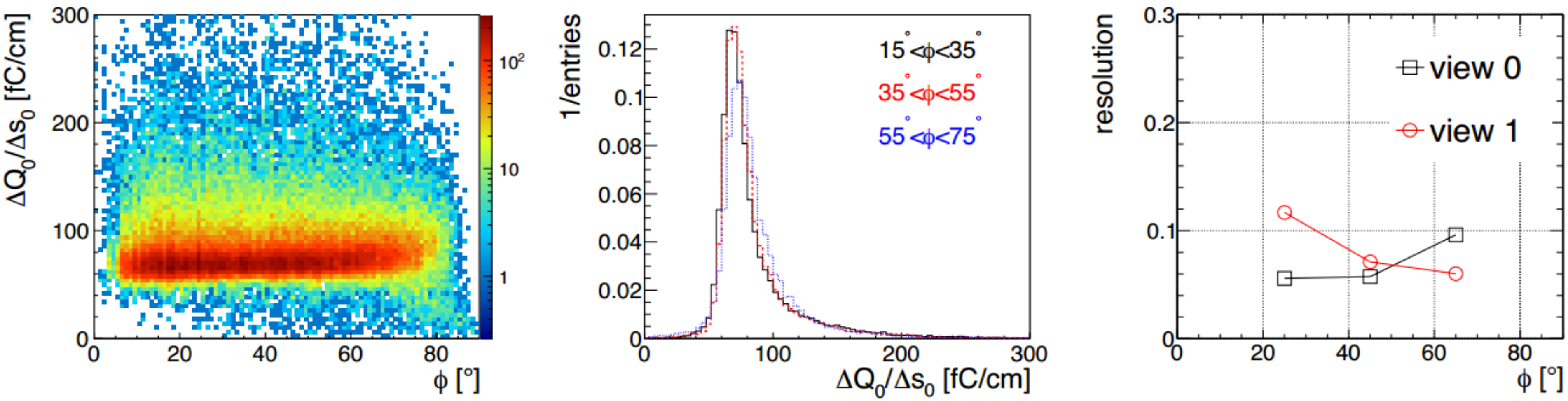
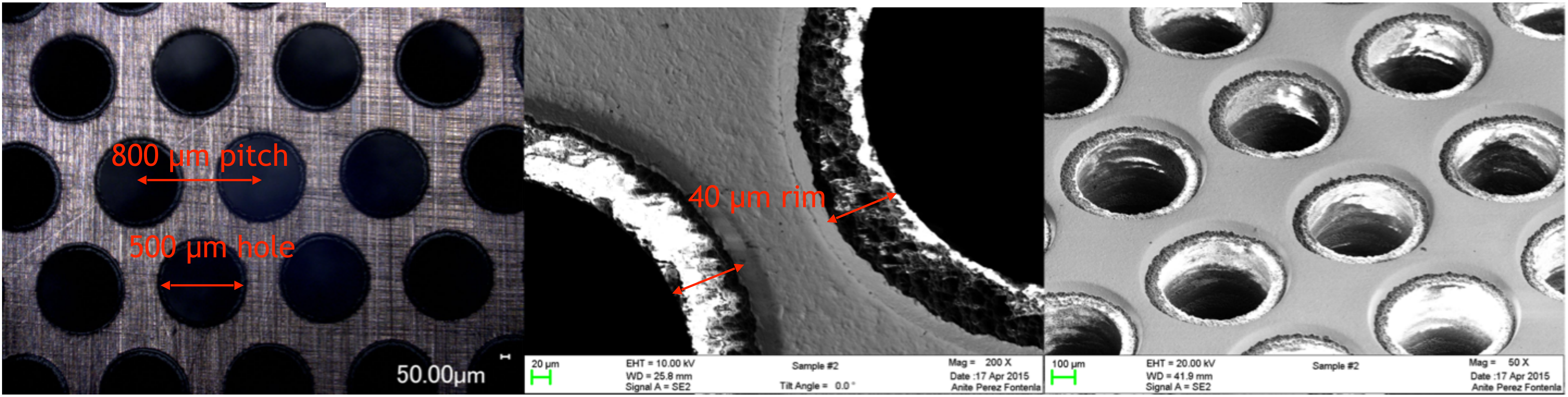


Optimisation of LEM parameters on 10x10 cm^2 LEM in double phase operations



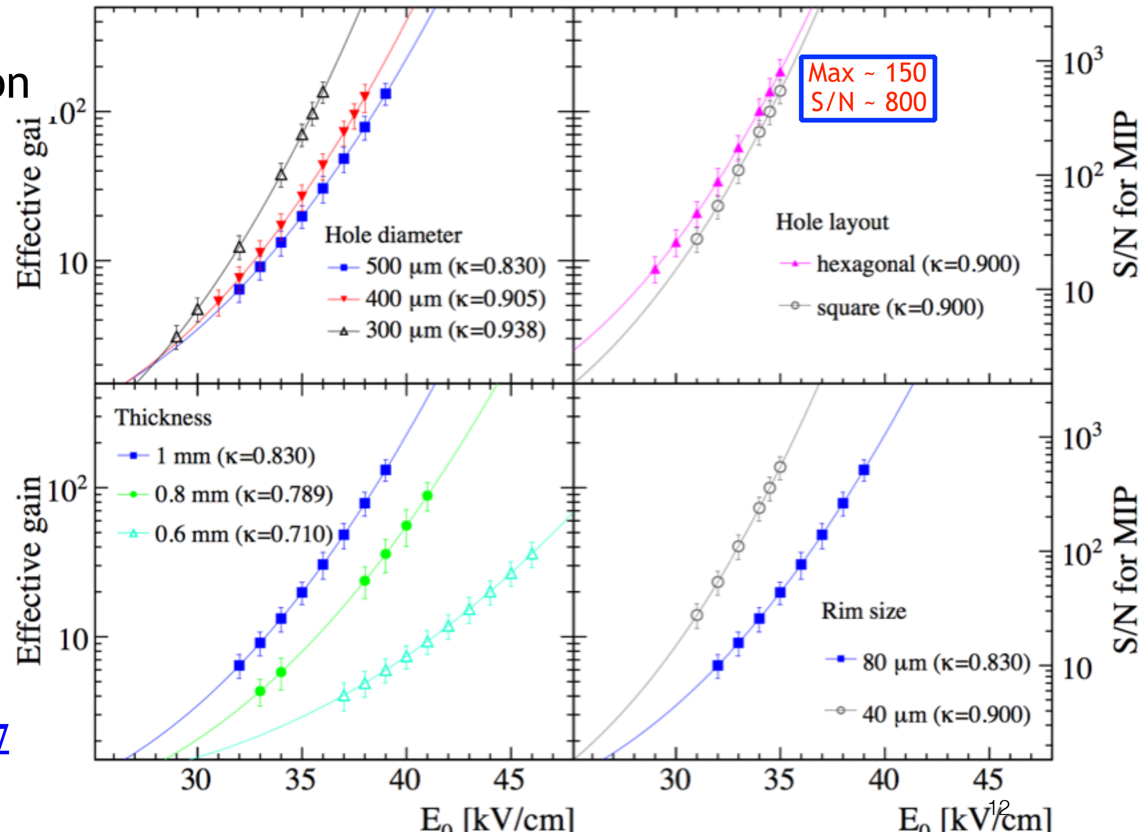
LEM gain and maximal gain depends on

- 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

[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

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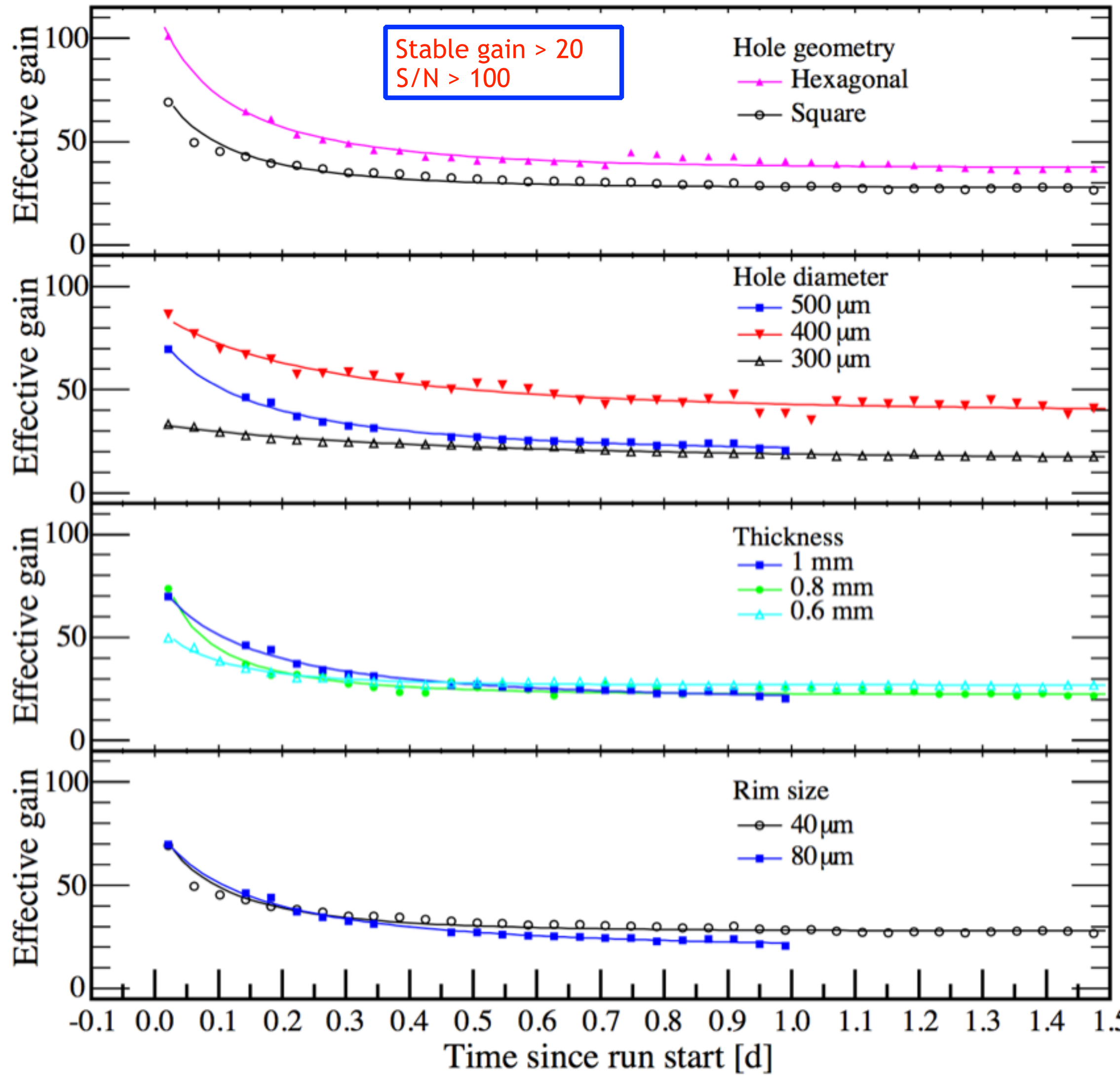
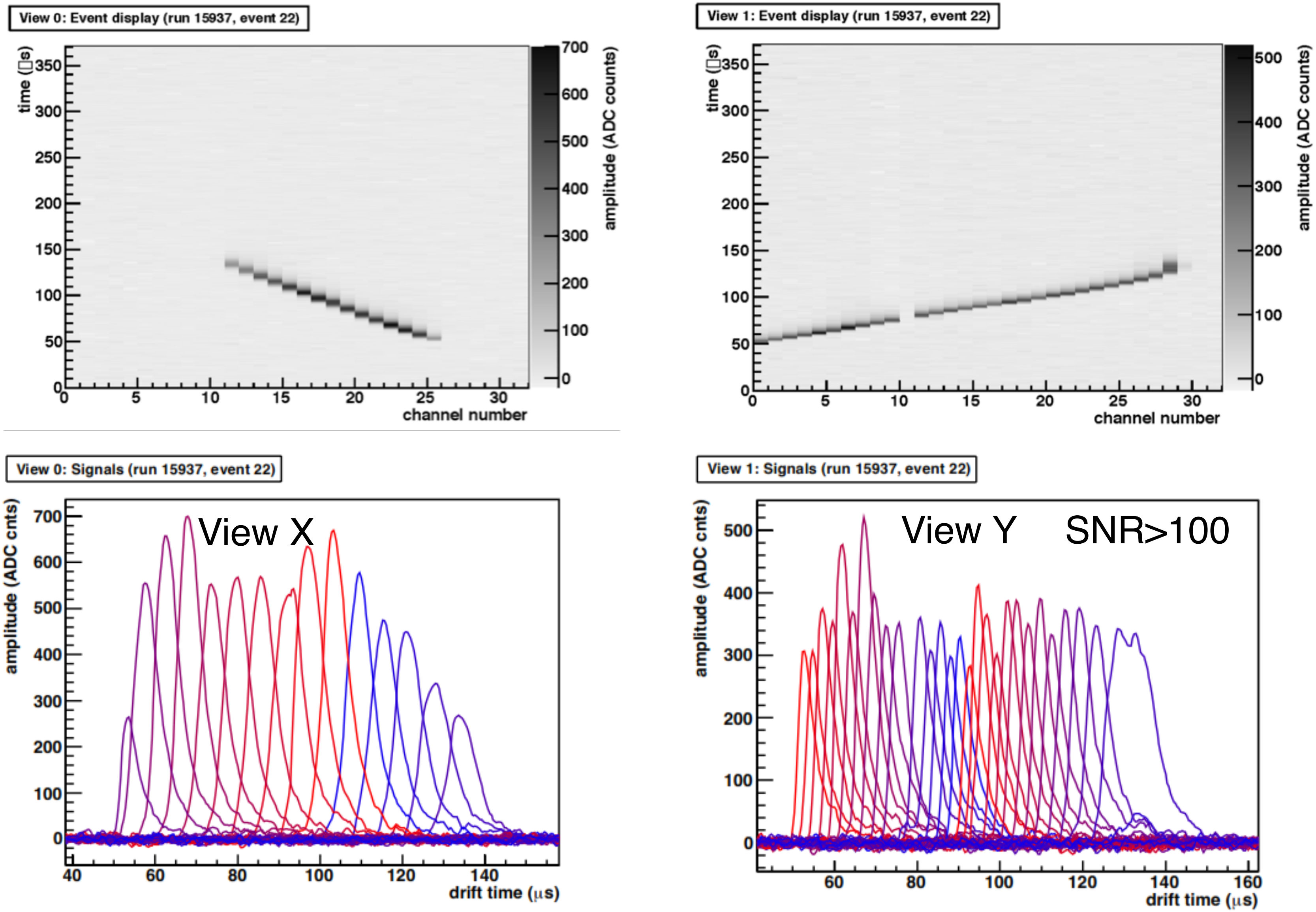
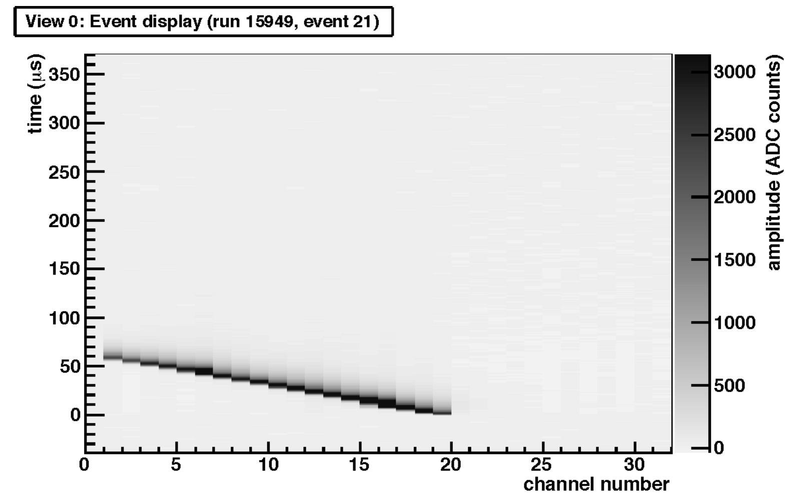
Stable gain over 20

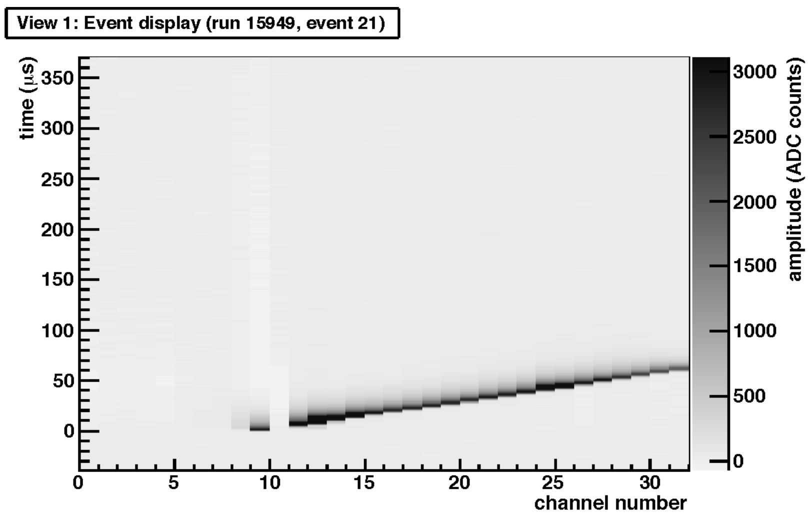


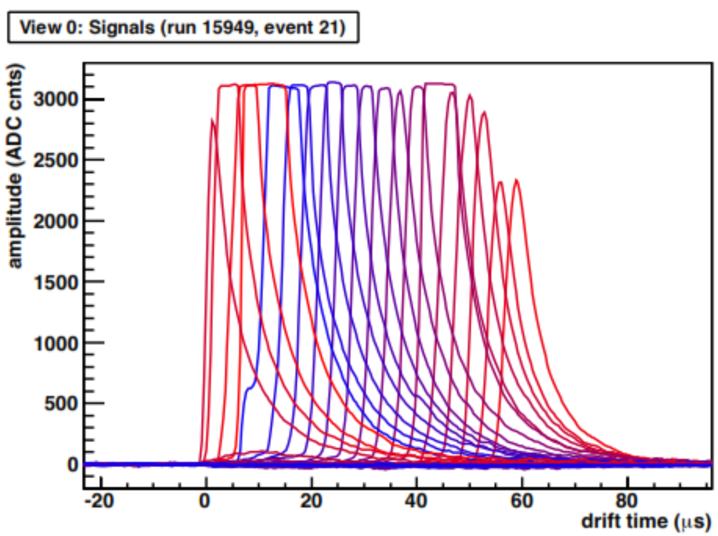
Cosmic event in double phase TPC at effective gain~20

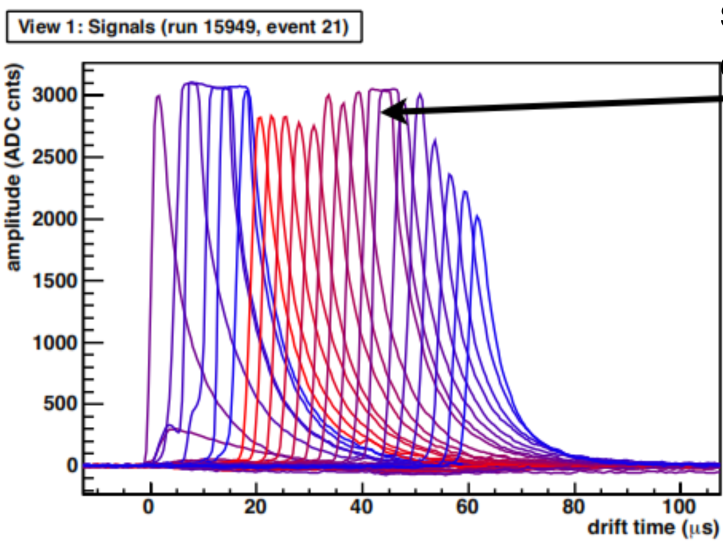


Cosmic event in double phase TPC at effective gain ~ 150





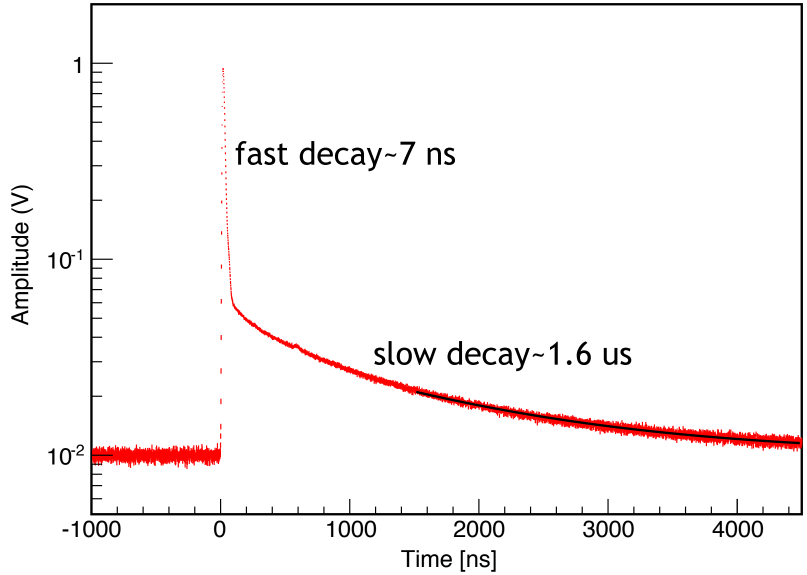




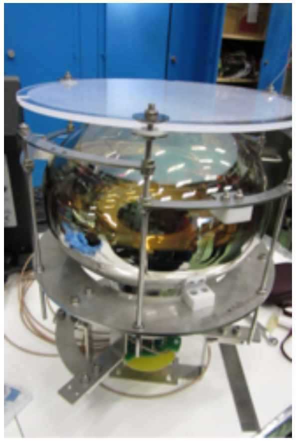
saturation
of the pre-amp

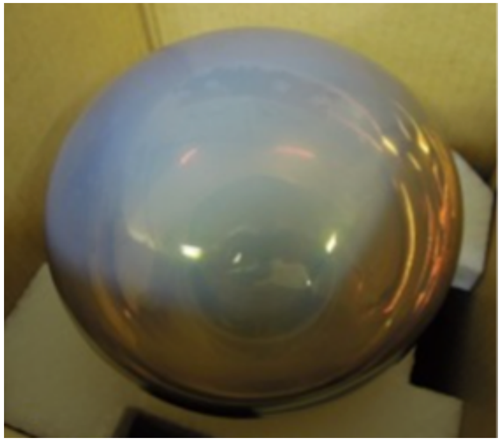
LAr scintillation light detection

LAr scintillation light:



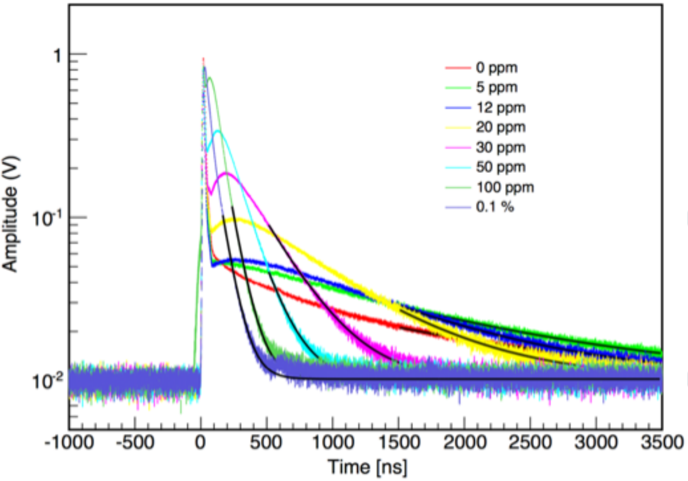
PMT coated with wavelength shifter TPB:



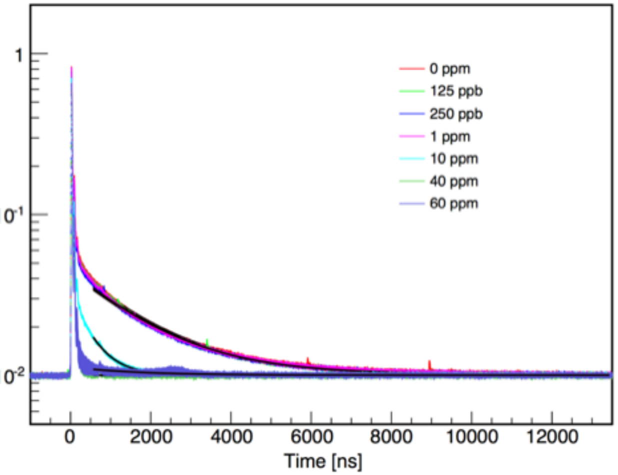


Slow component as a tool for LAr purity check:

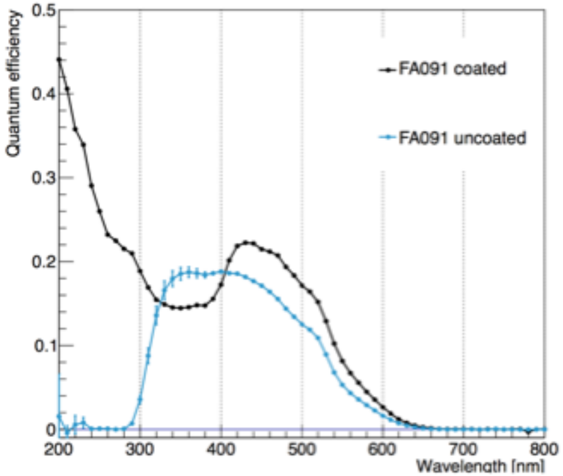
xenon:

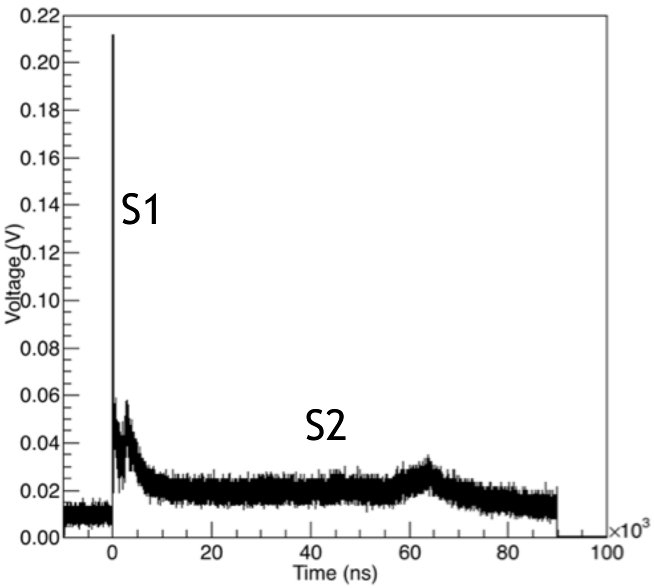


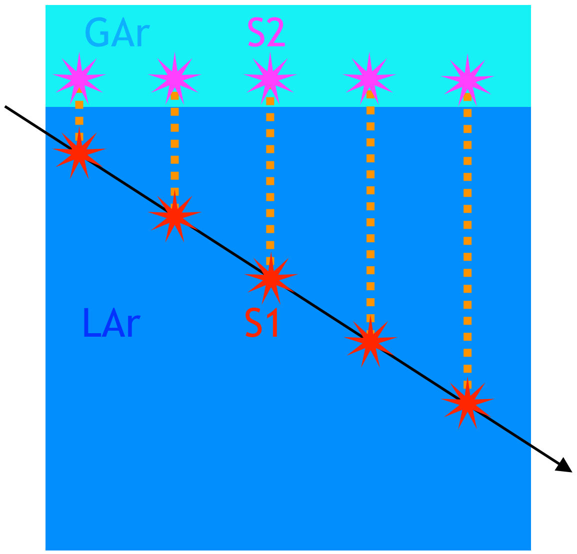
methane:



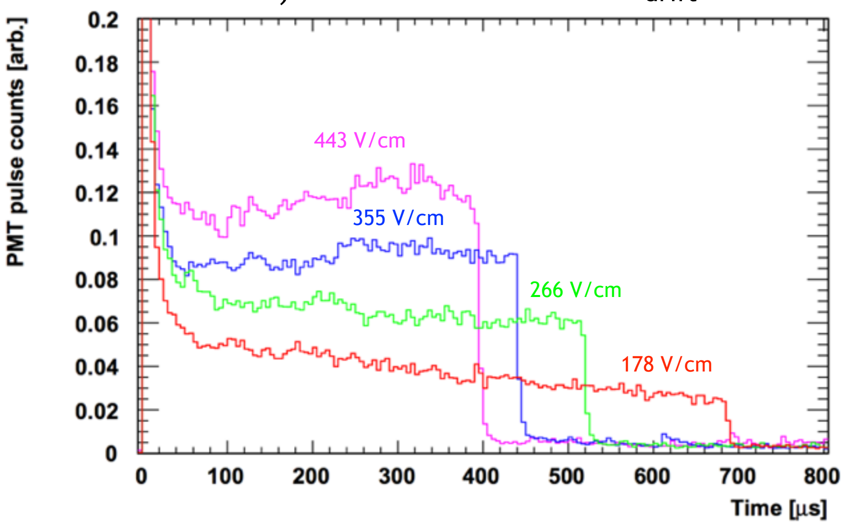
quantum efficiency:



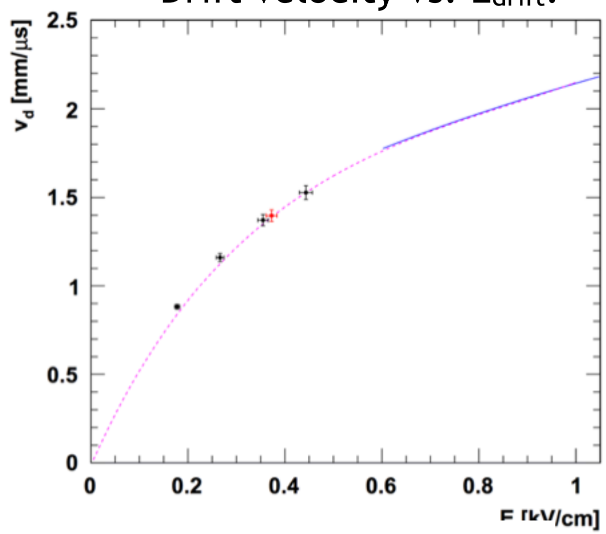




S1,S2 mean trace vs. E_{drift}:



Drift velocity vs. E_{drift}:

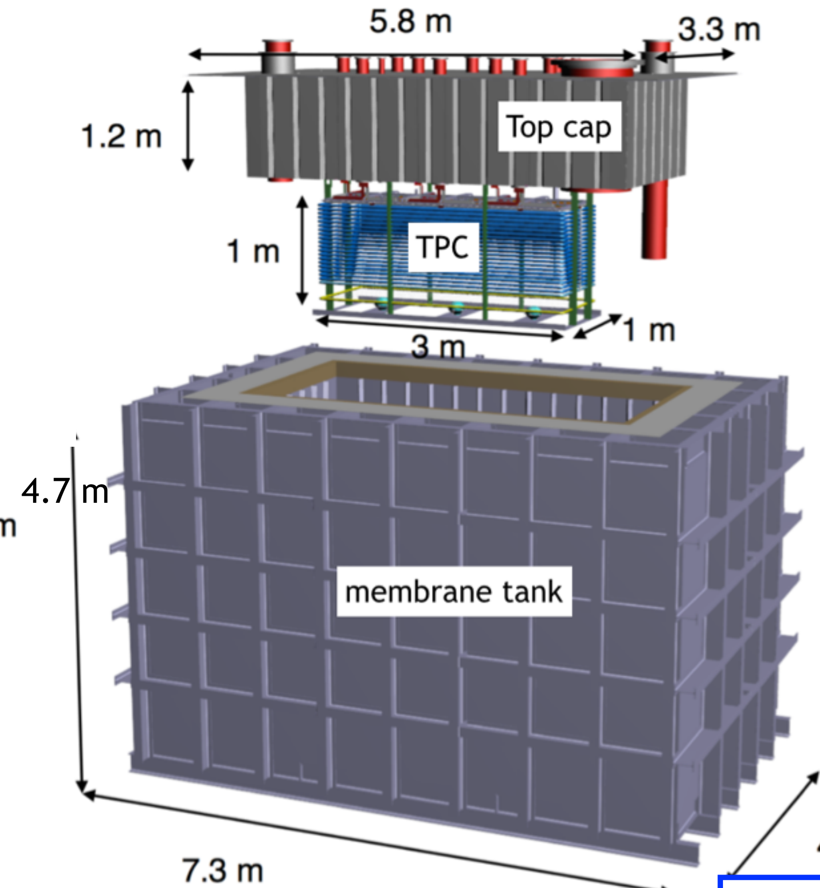


JINST 7 (2012) P08026

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

DLAr-proto
3x1x1 m^3 active (24 ton LAr total)

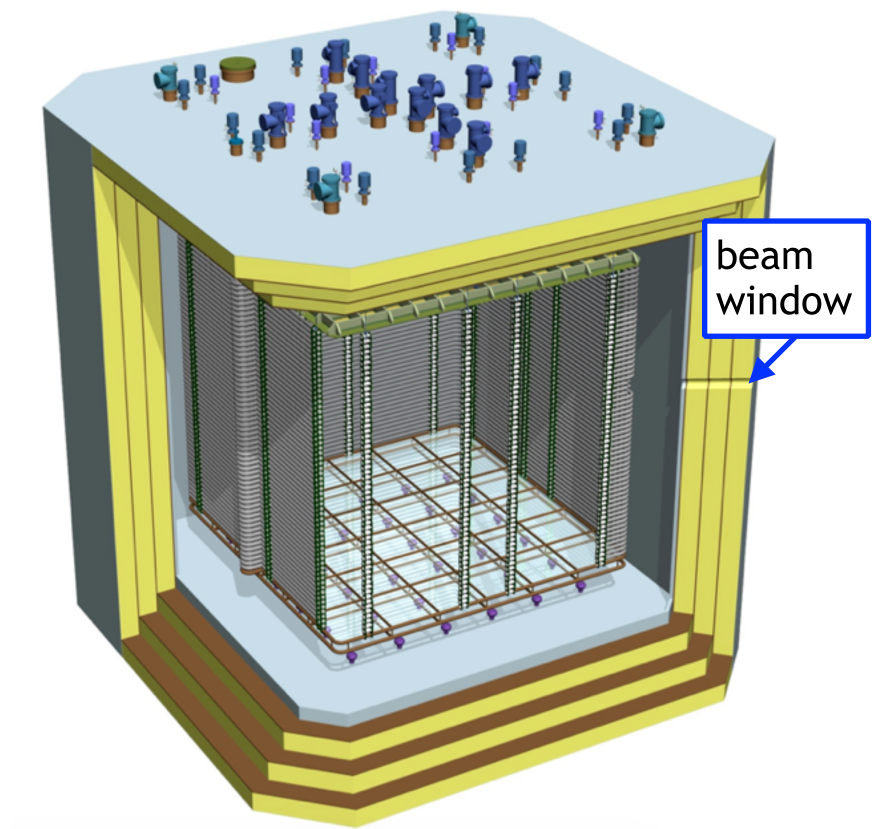
- cosmic trigger only
- scaling up to 24 ton mass
- intermediate step towards 3x3 m^2 CRP



Operation November 2016

DLAr (ProtoDUNE-DP)
6x6x6 m^3 active (700 ton LAr total)

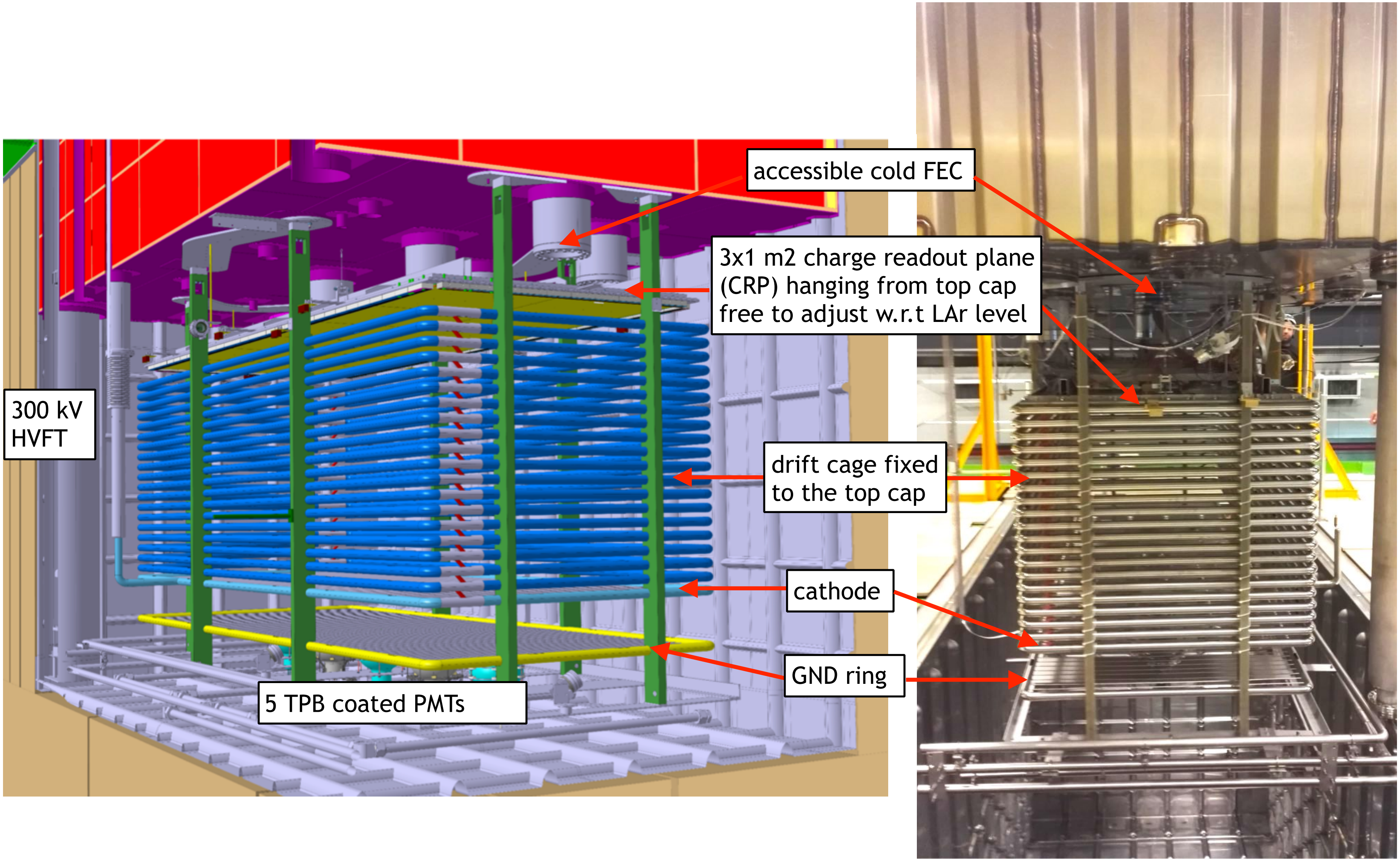
- beam test data (CERN SPS)
- many interesting physics topics
- basic readout 3x3 m^2 CRP



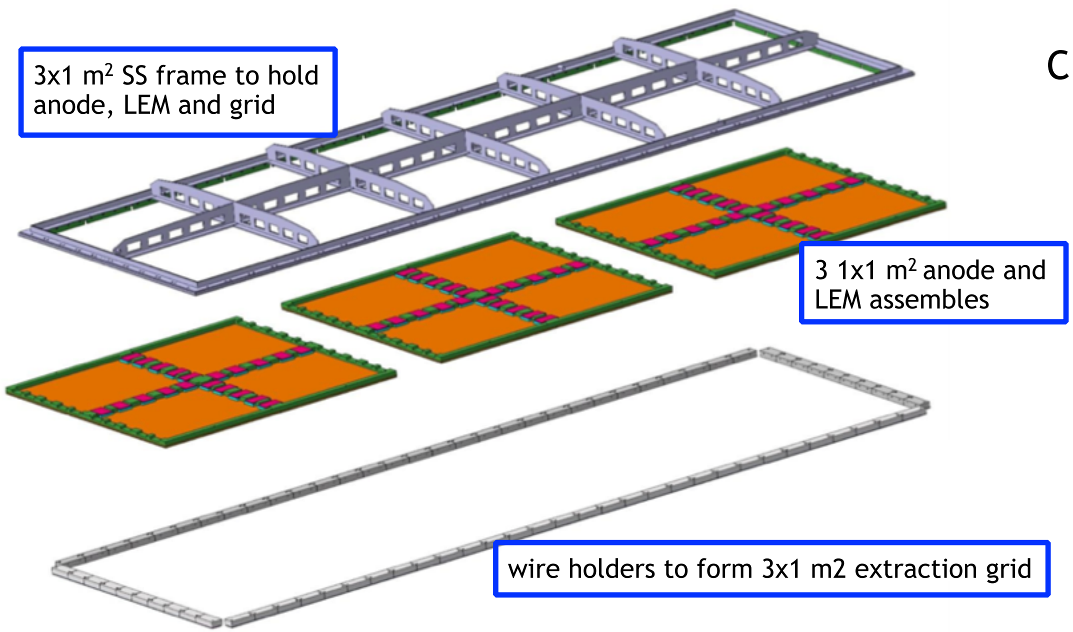
Detailed progress will be reported on Saturday talk

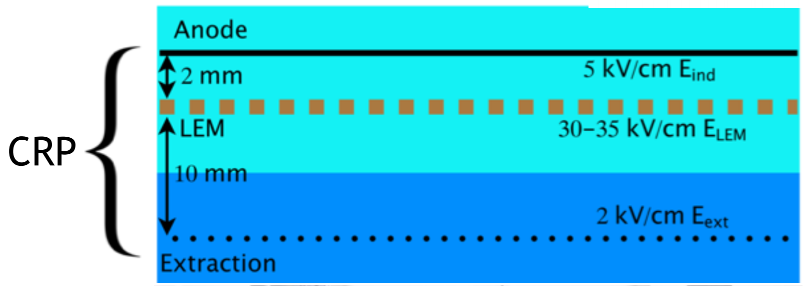
Timescale: 2016-2019

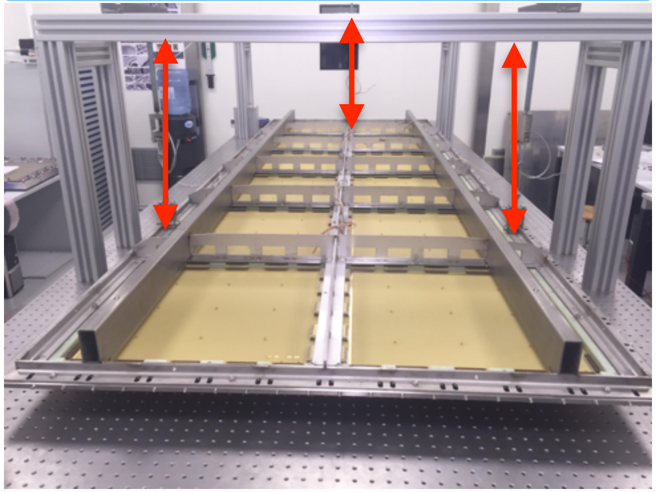
The WA105-3x1x1 prototype from design to reality



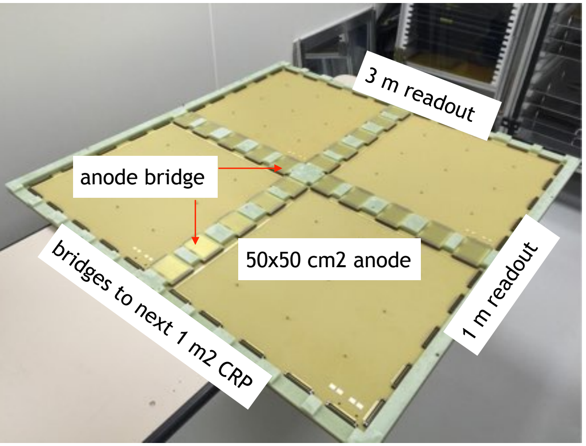
The 3x1 m² CRP



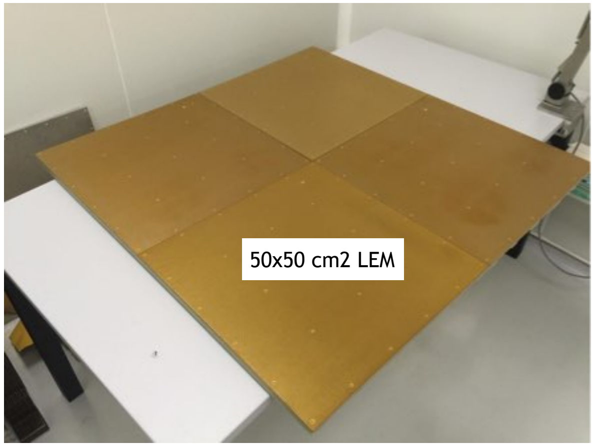




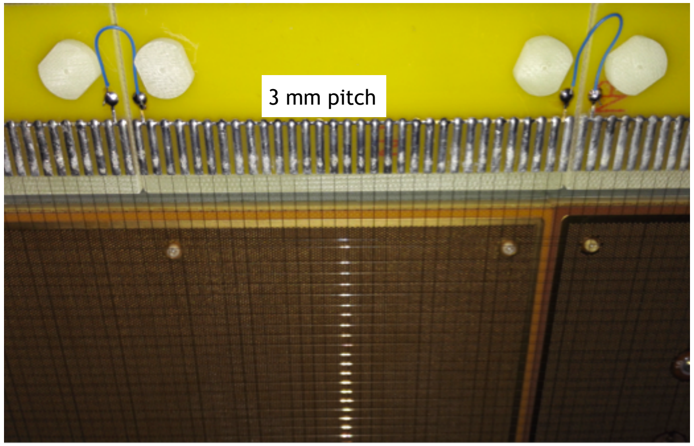
1x1 m2 top view



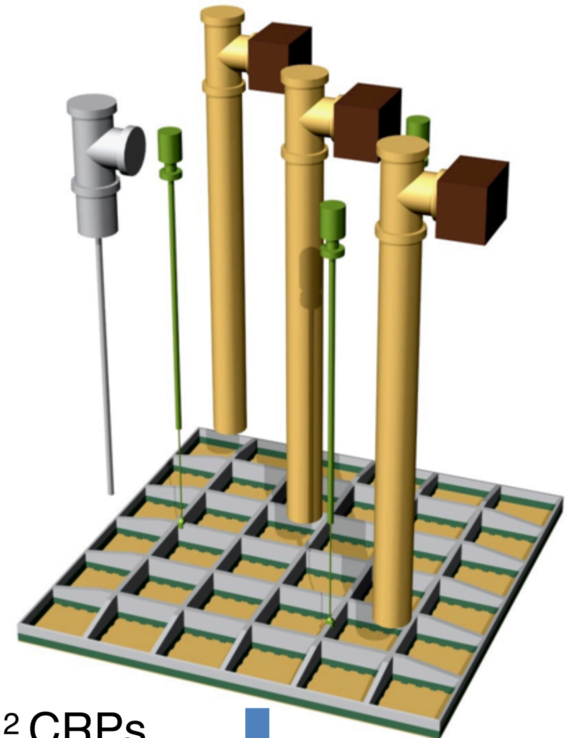
1x1 m2 bottom view

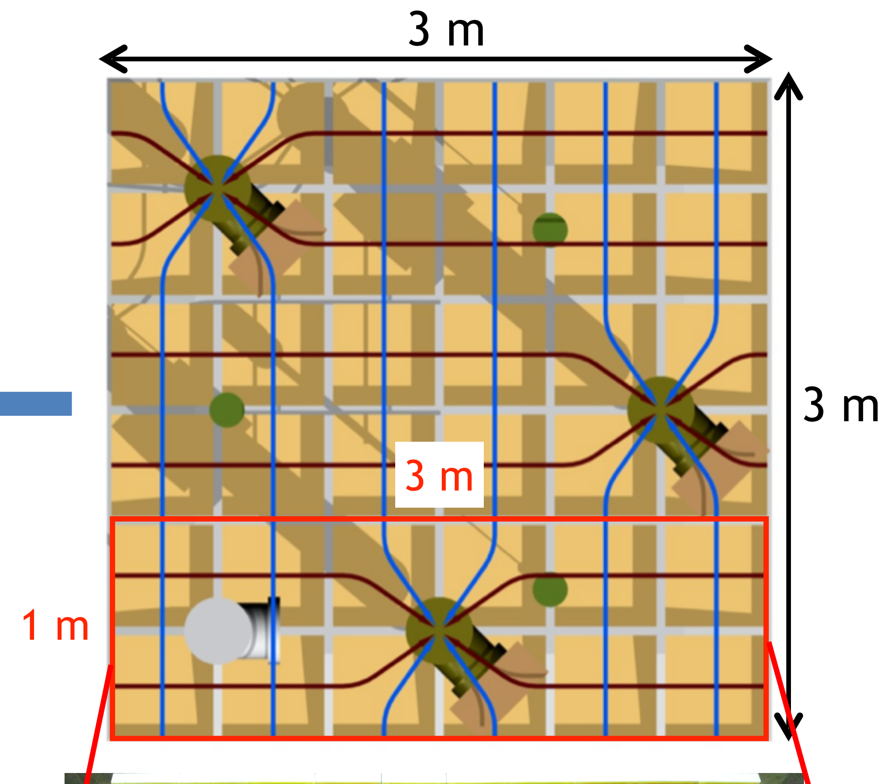


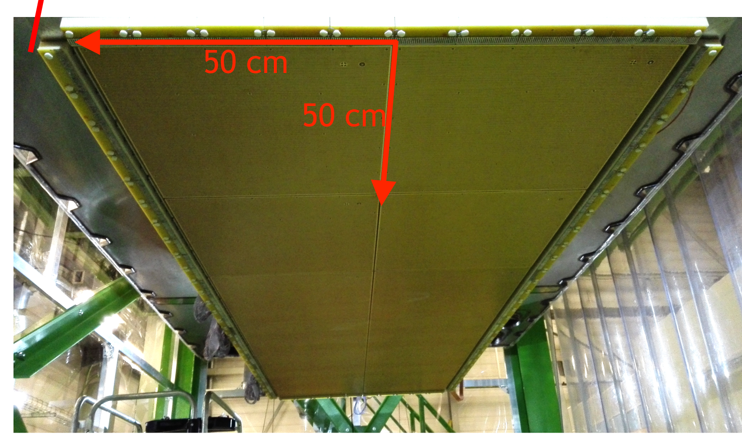
wire soldering pad and the grid



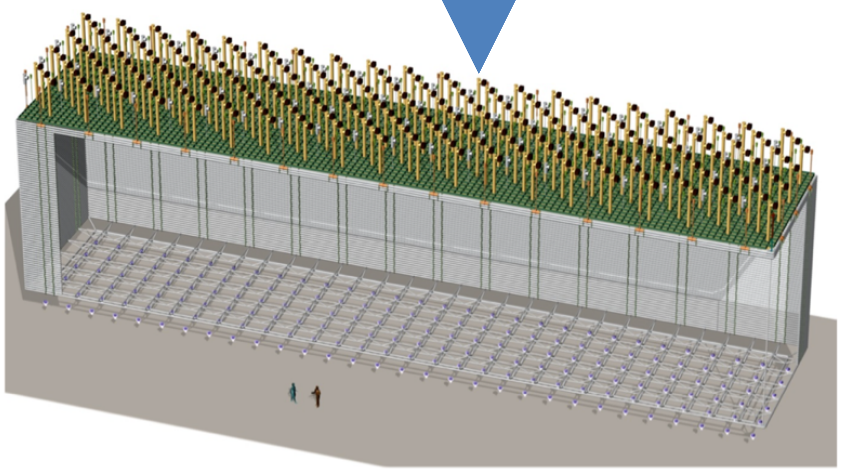
Scaling up to 3x3 m^2 CRP for DUNE







80 3x3 m^2 CRPs



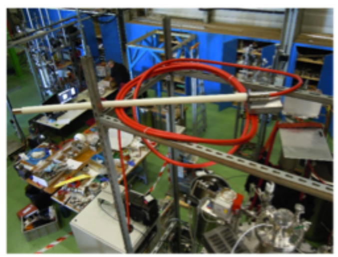
The WA105-3x1x1 HV system

HV generation:

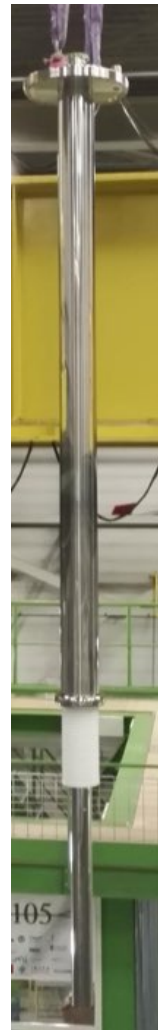
Heinzinger -300 kV

HV transport:

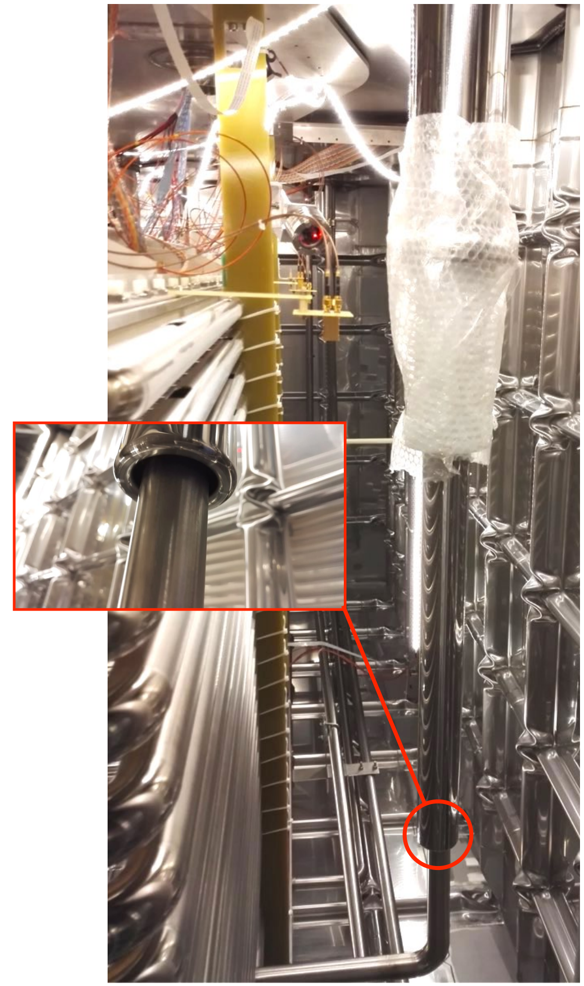
300 kV coaxial cable:



300 kV feedthrough:

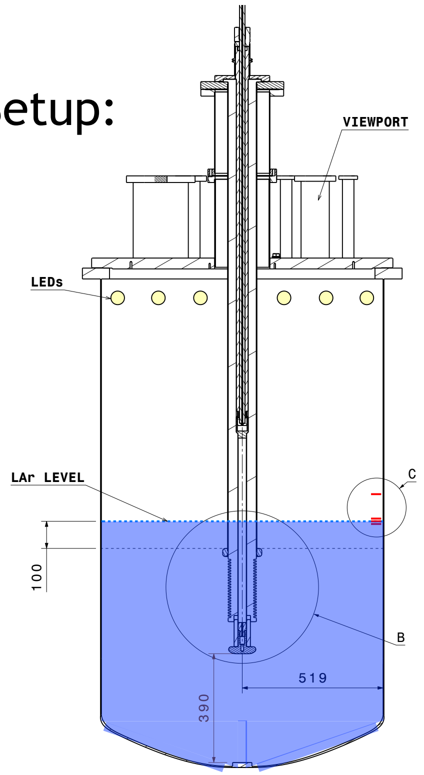


Connection to cathode:



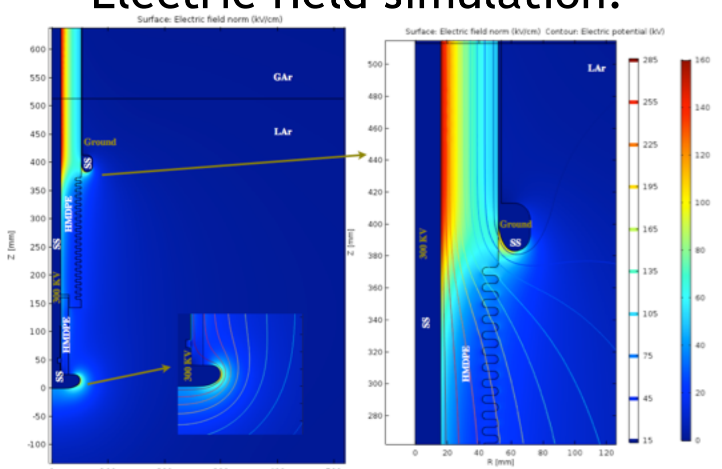
300 kV HVFT test

Setup:

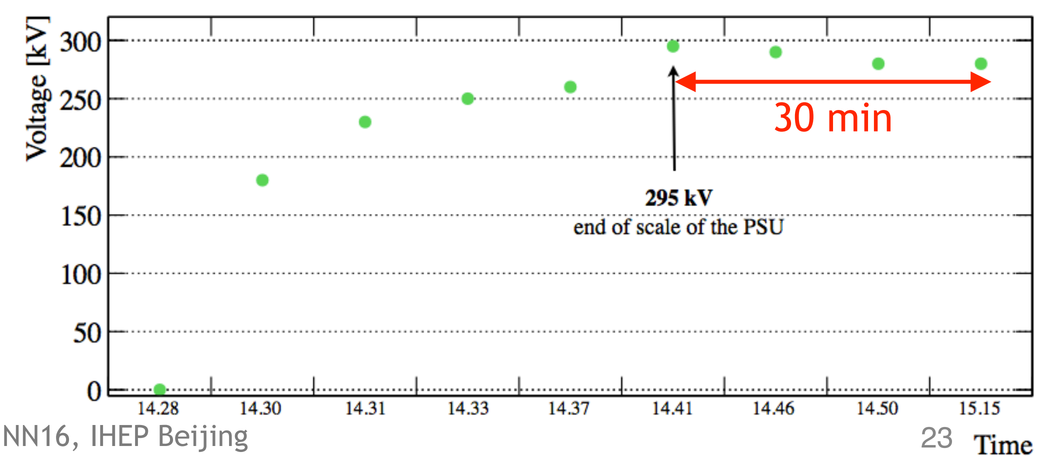


HV requirement for DP detectors:
WA105-6x6x6: -(300–600) kV
WA105-3x1x1: -(50–100) kV
DUNE-DP: -600 kV

Electric field simulation:



HV ramping-up history:



Summary

❖ Double phase LAr TPC technology has many benefits in terms of signal to noise ratio, long drift distance, etc. This technology has been demonstrated for large area charge readout.

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

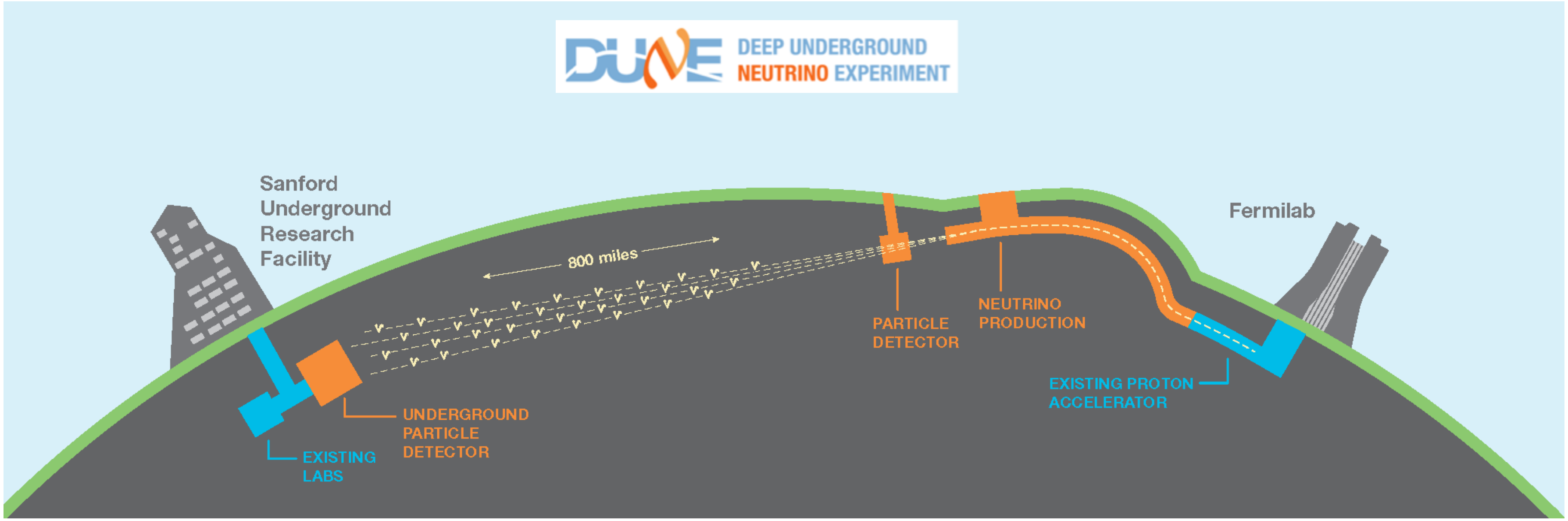
- the low capacitance (150 pF/m) readout anode meets the requirements on energy resolution, charge sharing, etc.
- the 10x10 cm^2 LEMs have a known behaviour and works at a stable gain over 20 at a very low discharge rate < 1 per day.

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

❖ Successful installation of WA105-3x1x1 DLAr-proto in a short time paves the way towards the WA105-6x6x6 DLAr in many technical aspects.

Thank you for your attention!

Deep Underground Neutrino Experiment (DUNE) WA105



DUNE physics potential:

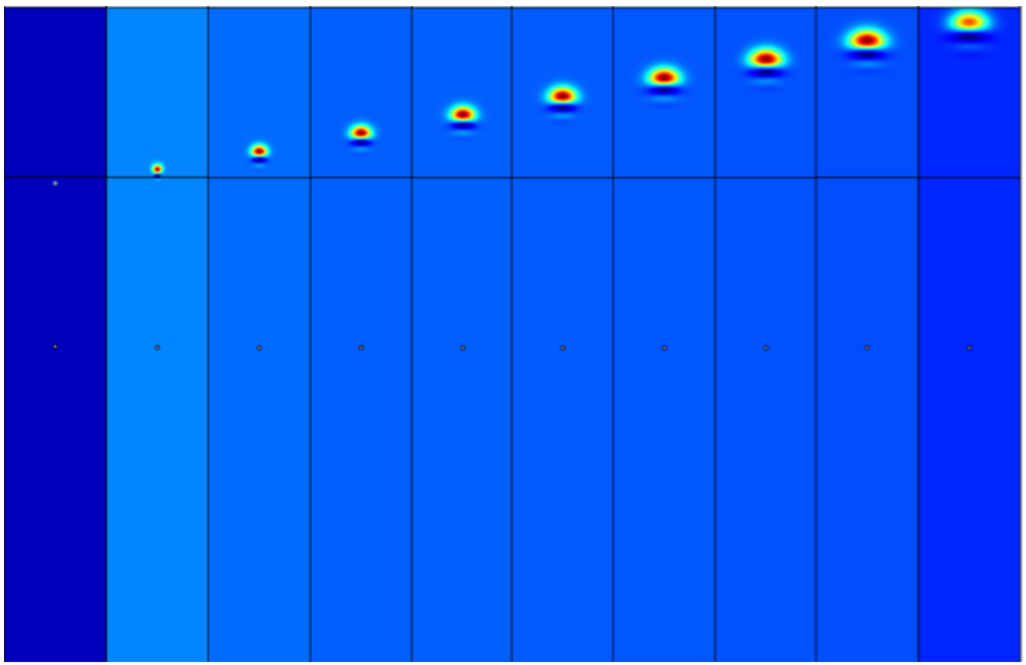
1. Accelerator based neutrino physics
   - Mass Hierarchy determination — over 5σ level over full δ_{CP} range for an exposure of 300 kt·MW·year, corresponding to 7 years' data with a 40-kt LAr detector and a 1.07-MW 80-GeV beam.
   - δ_{CP} measurement — 3σ sensitivity for 75% of δ_{CP} values at an 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

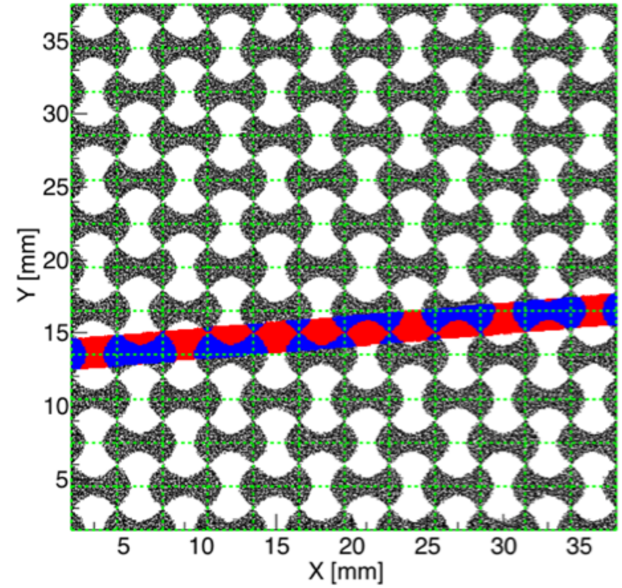
tested parameter	value	$\mathscr{T}$	x (mm)	G_{eff}^{max}	E_0^{max} (kV/cm)
hole layout	hexagonal	0.59± 0.18	0.96±0.07	182	35
	square	0.34± 0.14	0.94±0.08	123	35
hole diameter	500 μm	0.46± 0.14	0.73±0.05	124	39
	400 μm	0.41± 0.11	0.81±0.05	124	38
	300 μm	0.20± 0.03	0.88±0.04	134	36
thickness	1 mm	0.46± 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

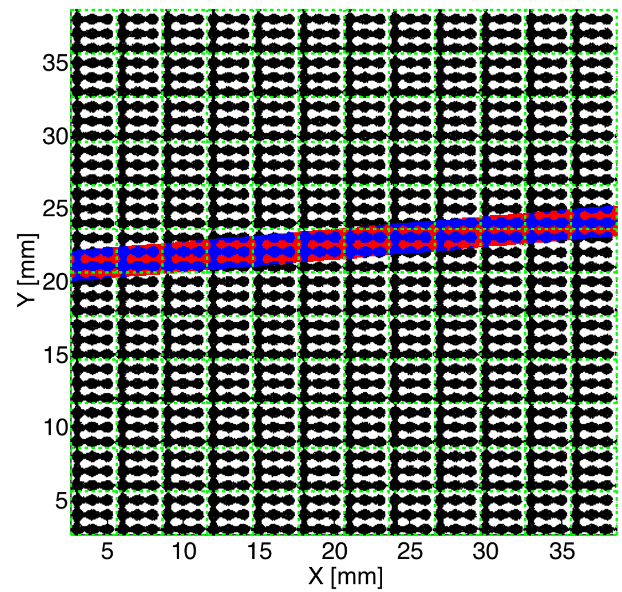
arXiv:1412:4402

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

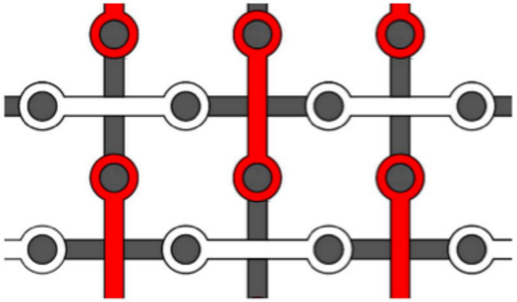
arXiv:1412:4402



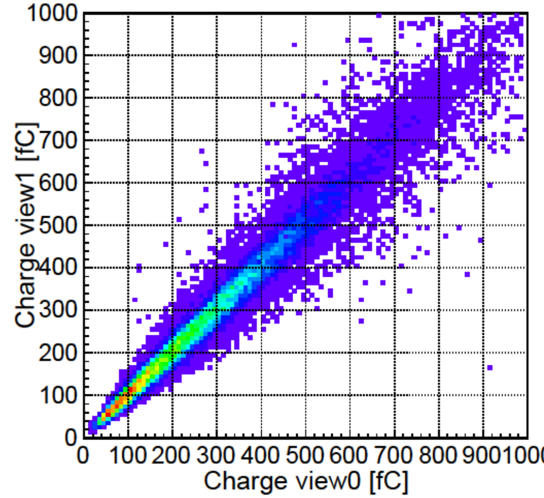

Y [mm]
35
30
25
20
15
10
5
5
10
15
20
25
30
35
X [mm]

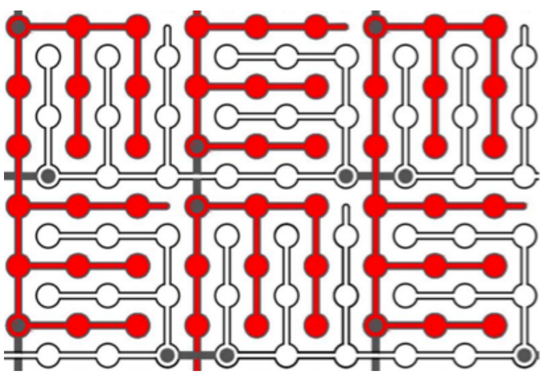

Y [mm]
35
30
25
20
15
10
5
5
10
15
20
25
30
35
X [mm]

Other anodes tested

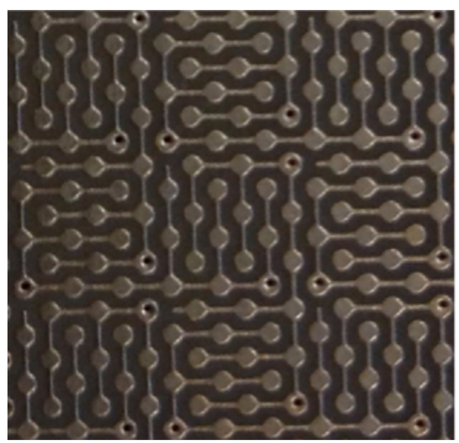


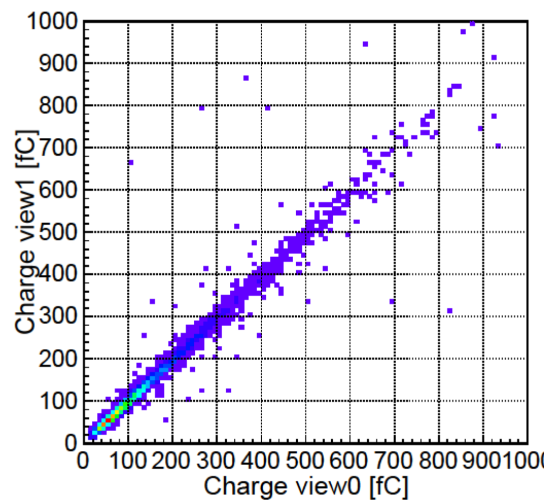
dC/dl~100 pF/m



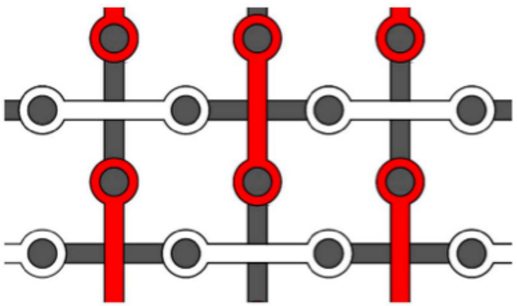


dC/dl~250 pF/m

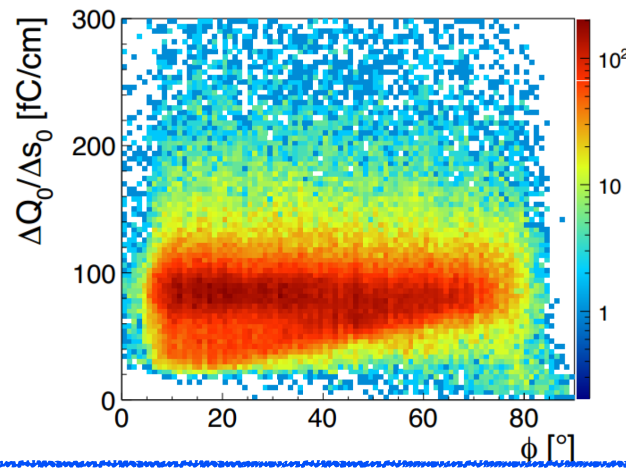


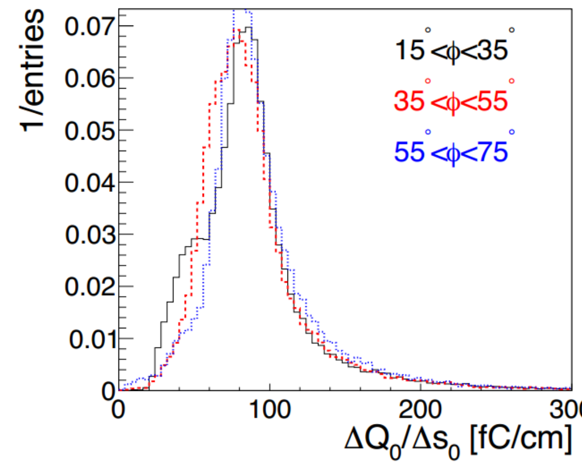


Other anodes tested



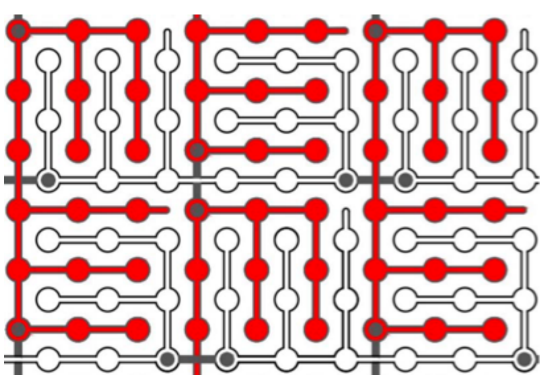
dC/dl~100 pF/m

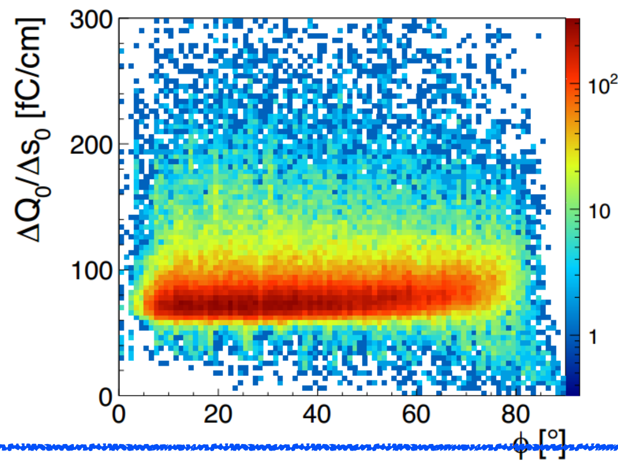


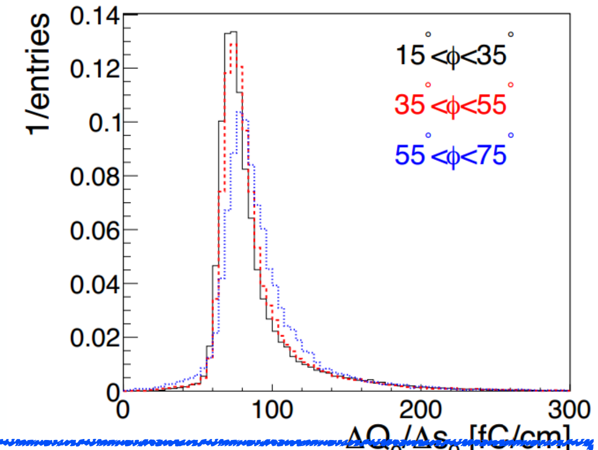


Pattern too loose, non uniform charge collection between strips

[JINST 9 P03017]







dC/dl~250 pF/m

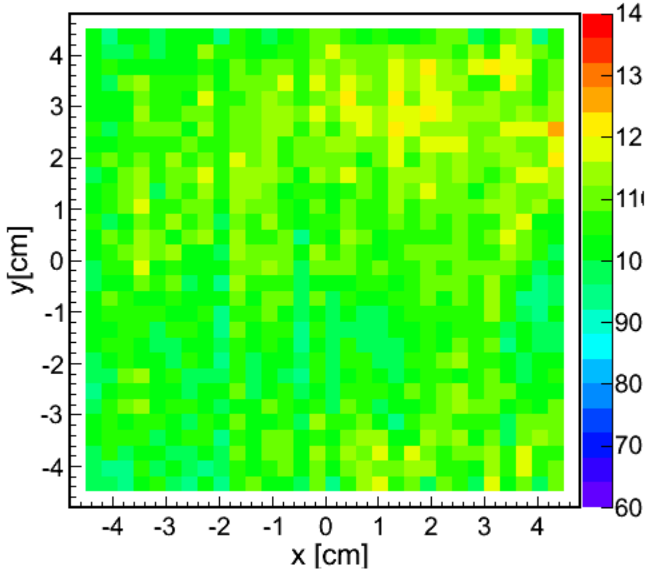
Compatible performance as 150 pF/m anode, but has higher capacitance

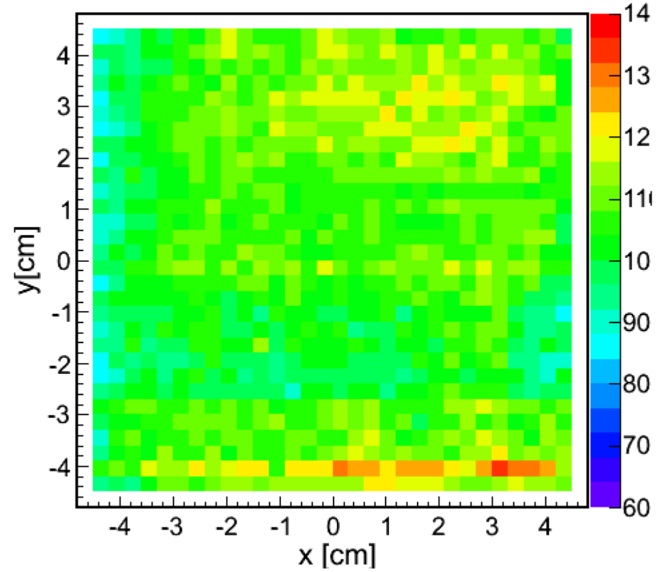
Gain uniformity

View 0

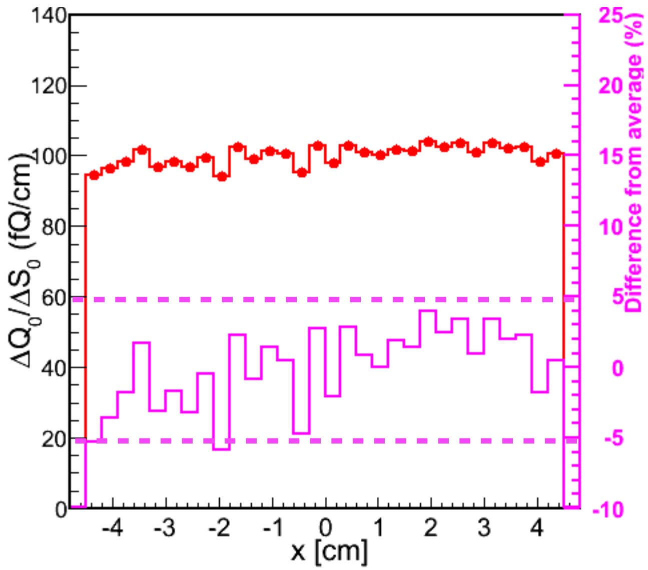
View 1

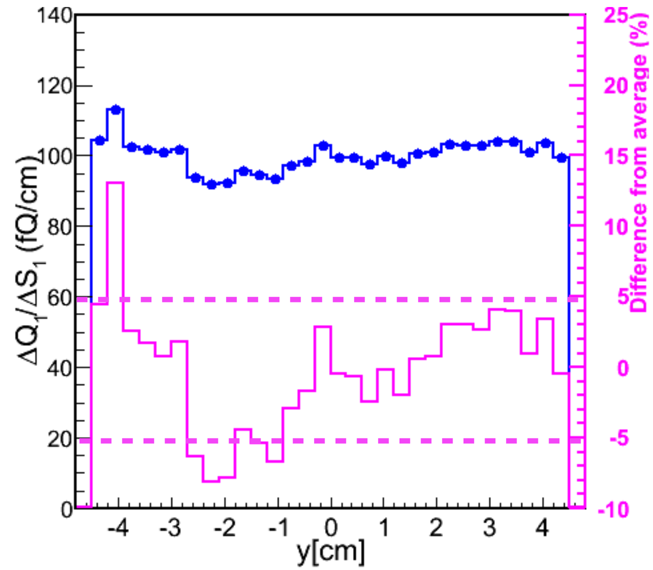
<dQ/dx> (fC/cm) (normalized to 100 fC/cm):



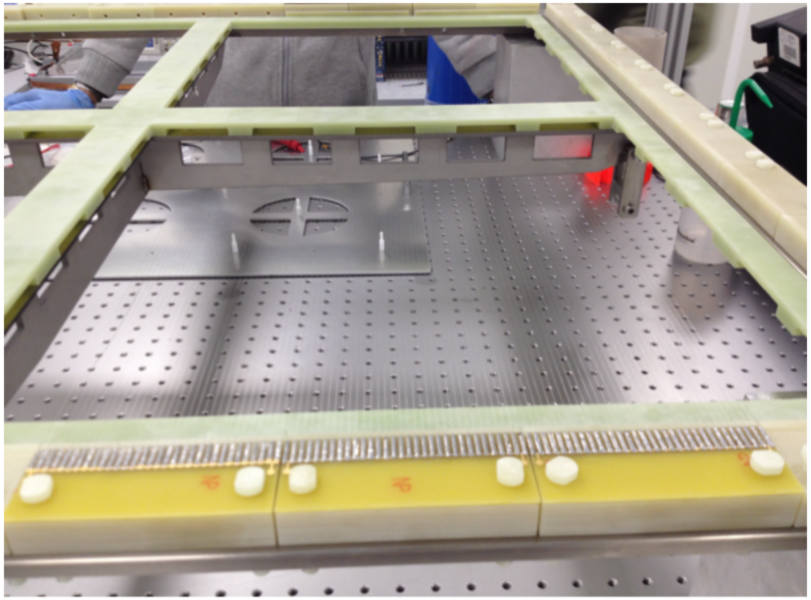


Projections on X and Y axis:

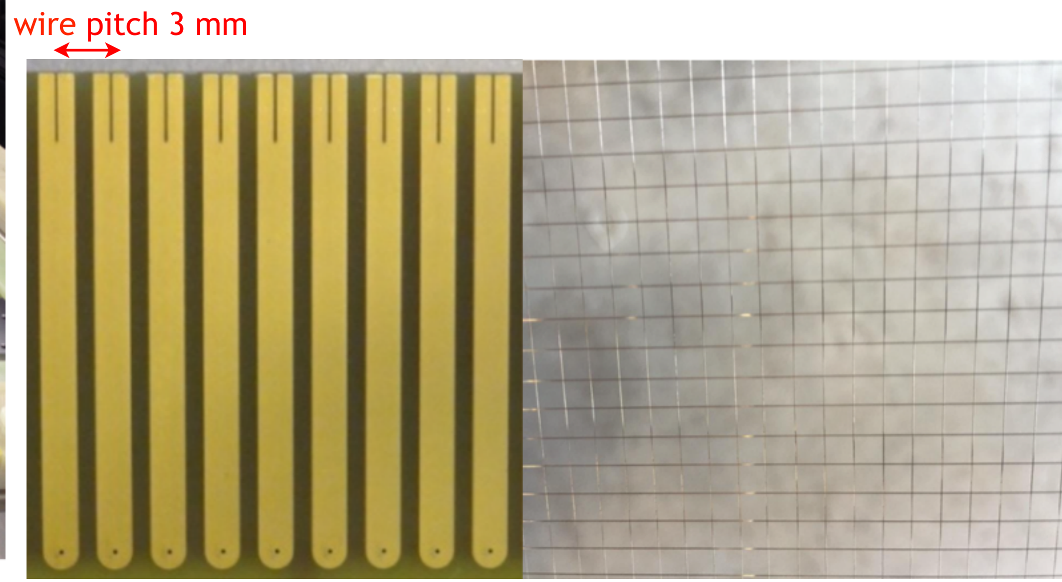


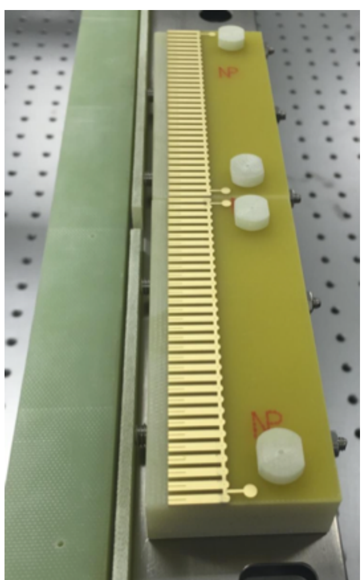


The 3x1 m^2 CRP

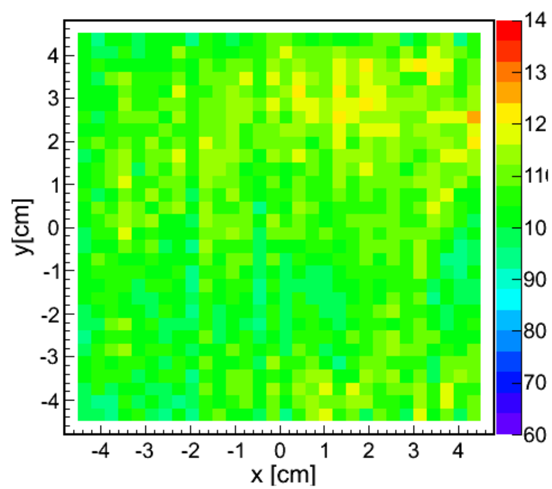


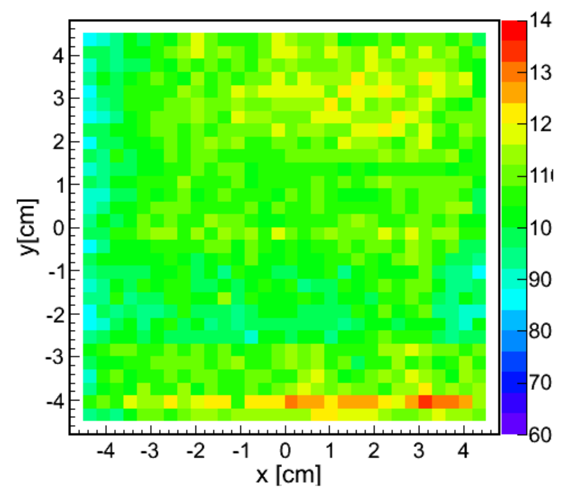
Wire soldering PCB and extraction grid



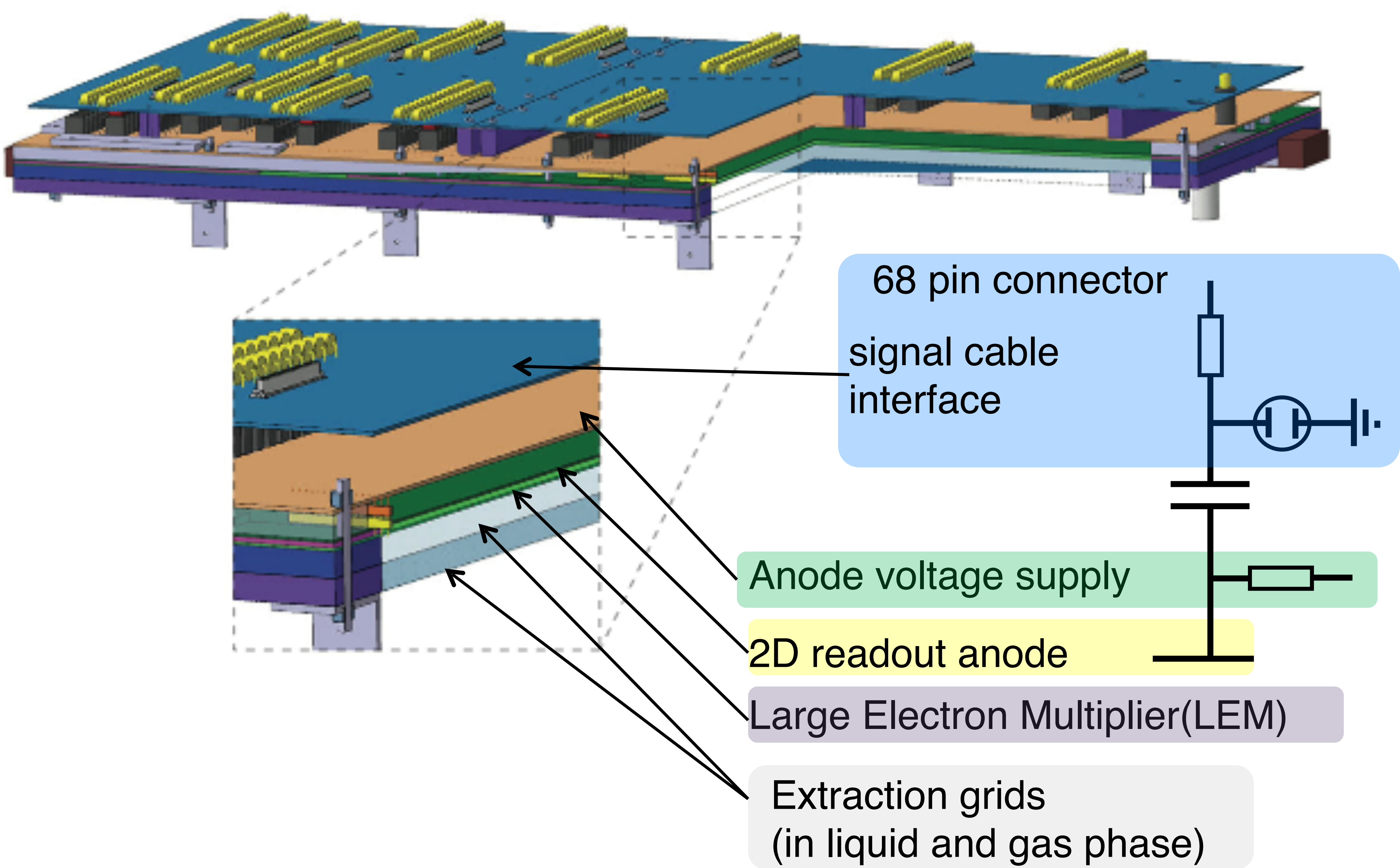


Good alignment ensures gain uniformity





Compact charge readout design



Large area readout: the 40x76 cm² prototype

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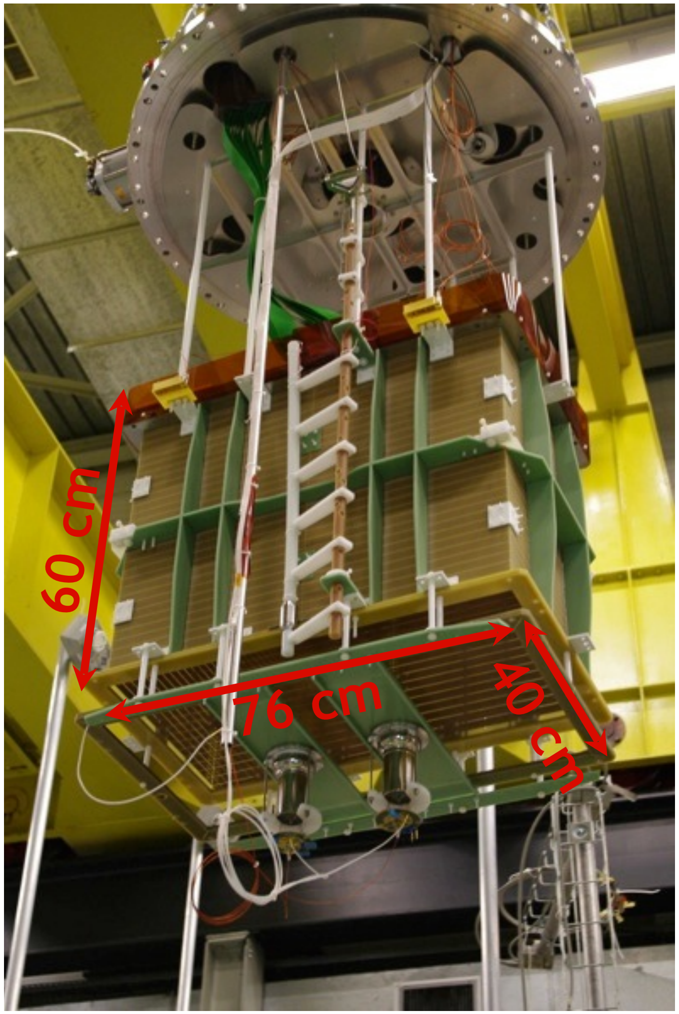
detector fully assembled

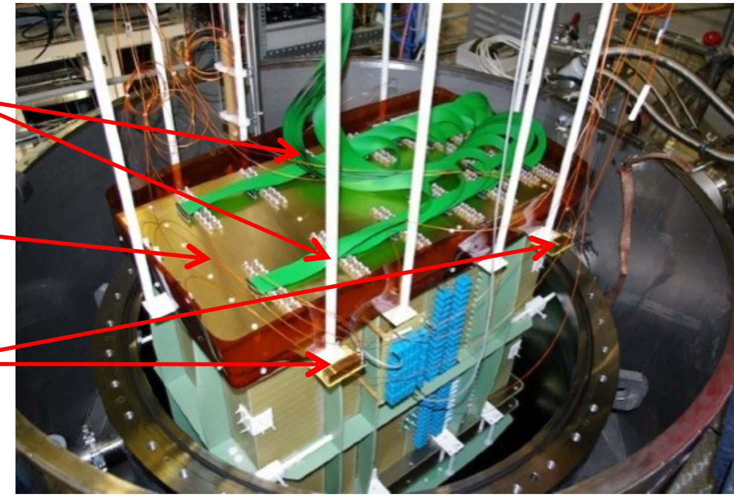


going into the ArDM cryostat

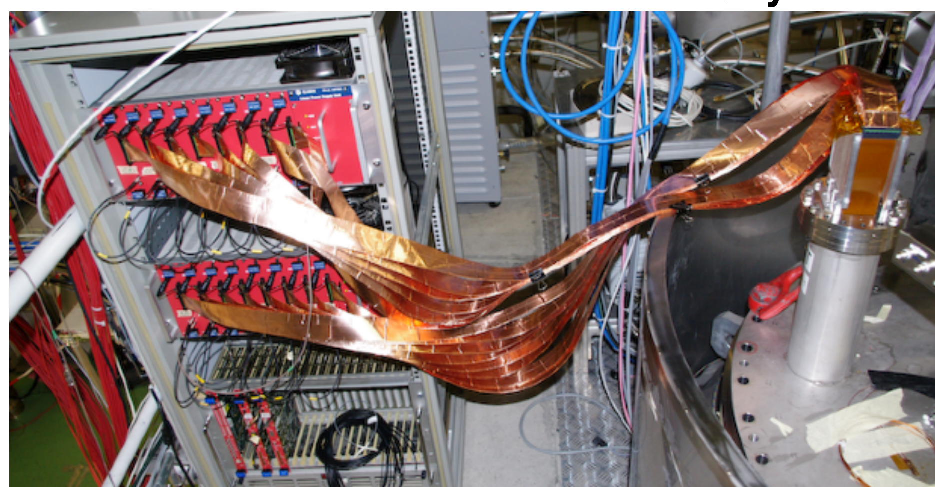
16 signal cables

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

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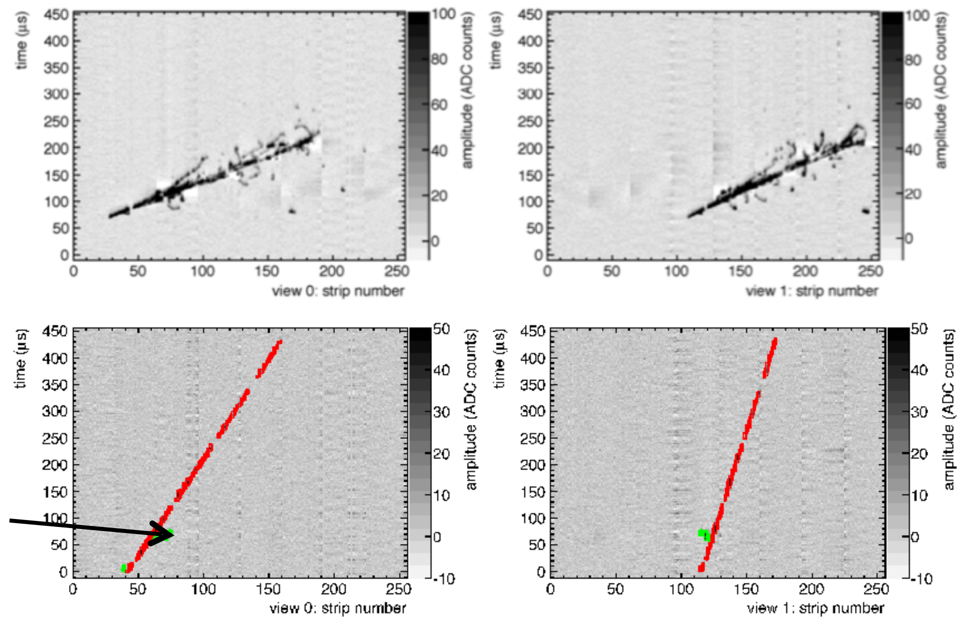
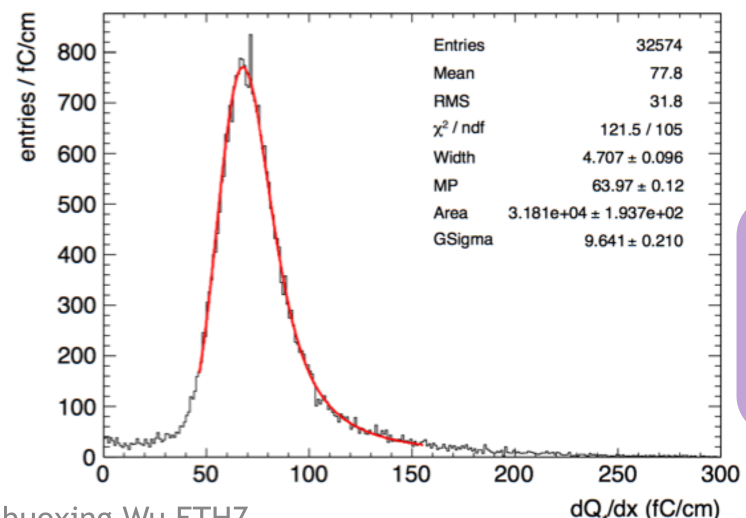
Optimized field configurations:

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%