LBNO-DEMO (WA105): a large demonstrator of the Liquid Argon double phase TPC

Sebastien Murphy ETHZ
on behalf of WA105

WIN2015 Heidelberg

DUNE

SURF (-1300 m)

✓**Measurement of CP-violating phase** (δ_{CP}) P5 goal of 3 sigma coverage of 75% of δCP phase space by 850-1300 kt-MW-years.

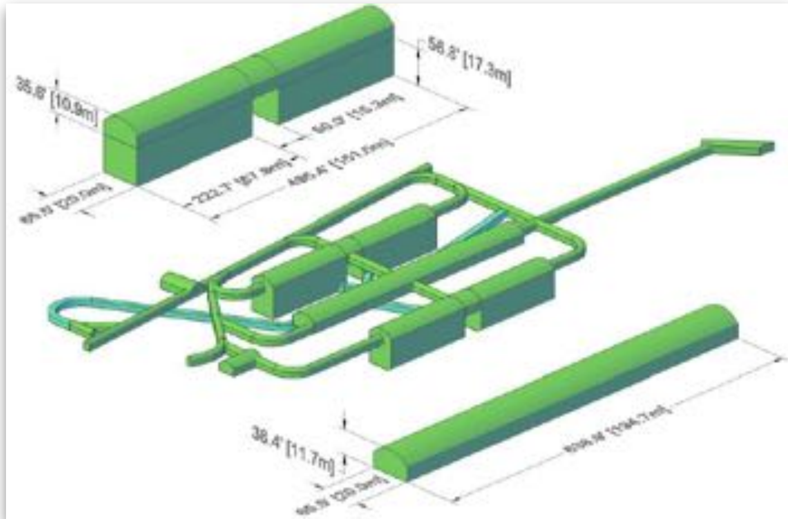
✓**5 sigma sensitivity to mass hierarchy** for all values of δCP by 400 kt-MW-years

✓**proton decay** (~4x10^{35} p->Kν => increase current limits of an order of magnitude)

✓**supernovae neutrino detection** (o(10’000) neutrino SN explosion @10kpc)

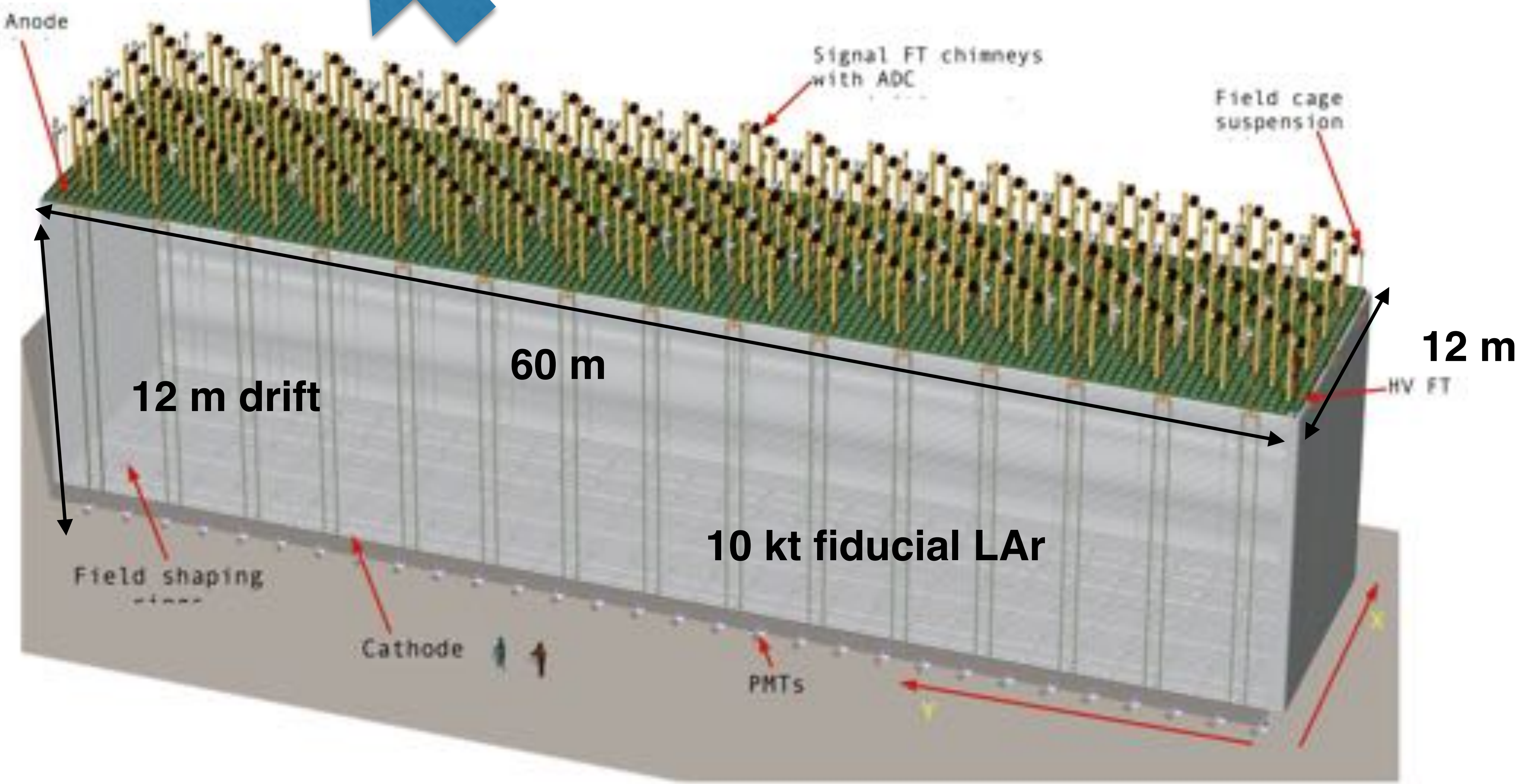
✓**and also:** precision measurement of neutrino oscillation parameters, test of 3-neutrino paradigm, nu_tau appearance, atmospheric neutrinos, precise x-section measurements in near detector,…

DUNE double phase far detector

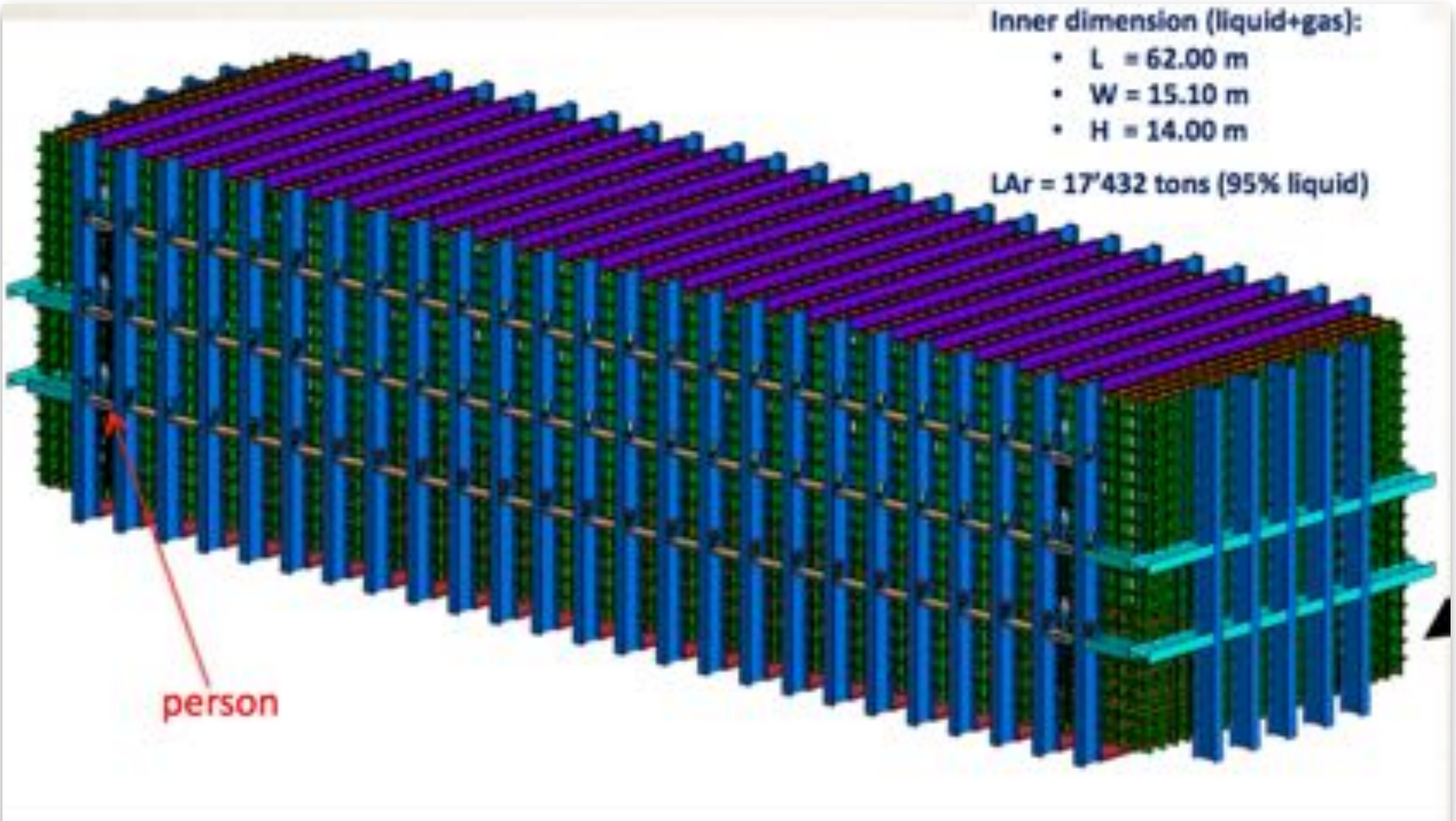


1.2 MW neutrino beam from FNAL to SURF underground laboratory with 40 kton Liquid Argon detector.

4 underground caverns with detector modules of 10 kton



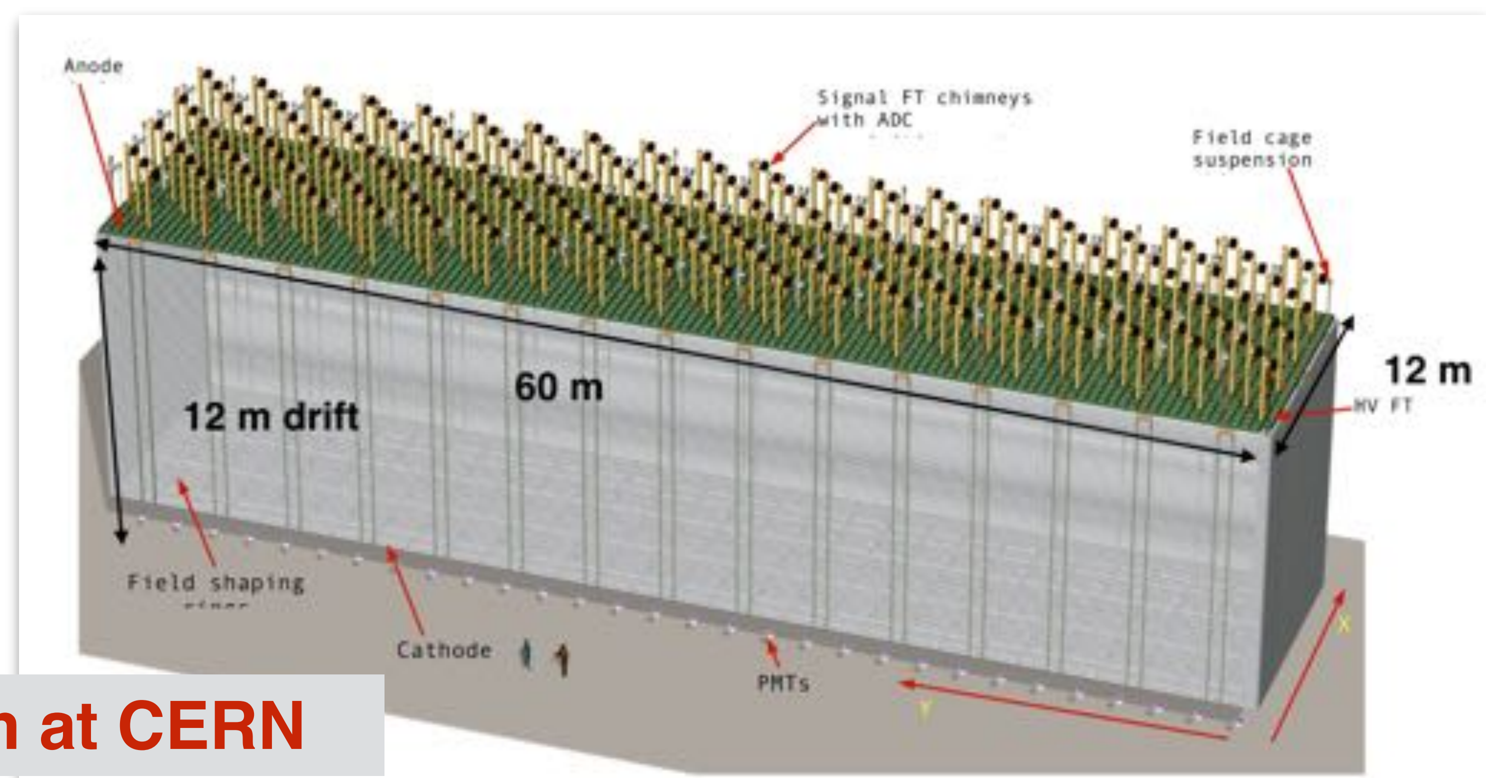
DUNE double phase far detector



A common cryostat design is being developed for both single and double phase technologies.

Ionisation signals amplified and detected in gaseous argon above the liquid surface

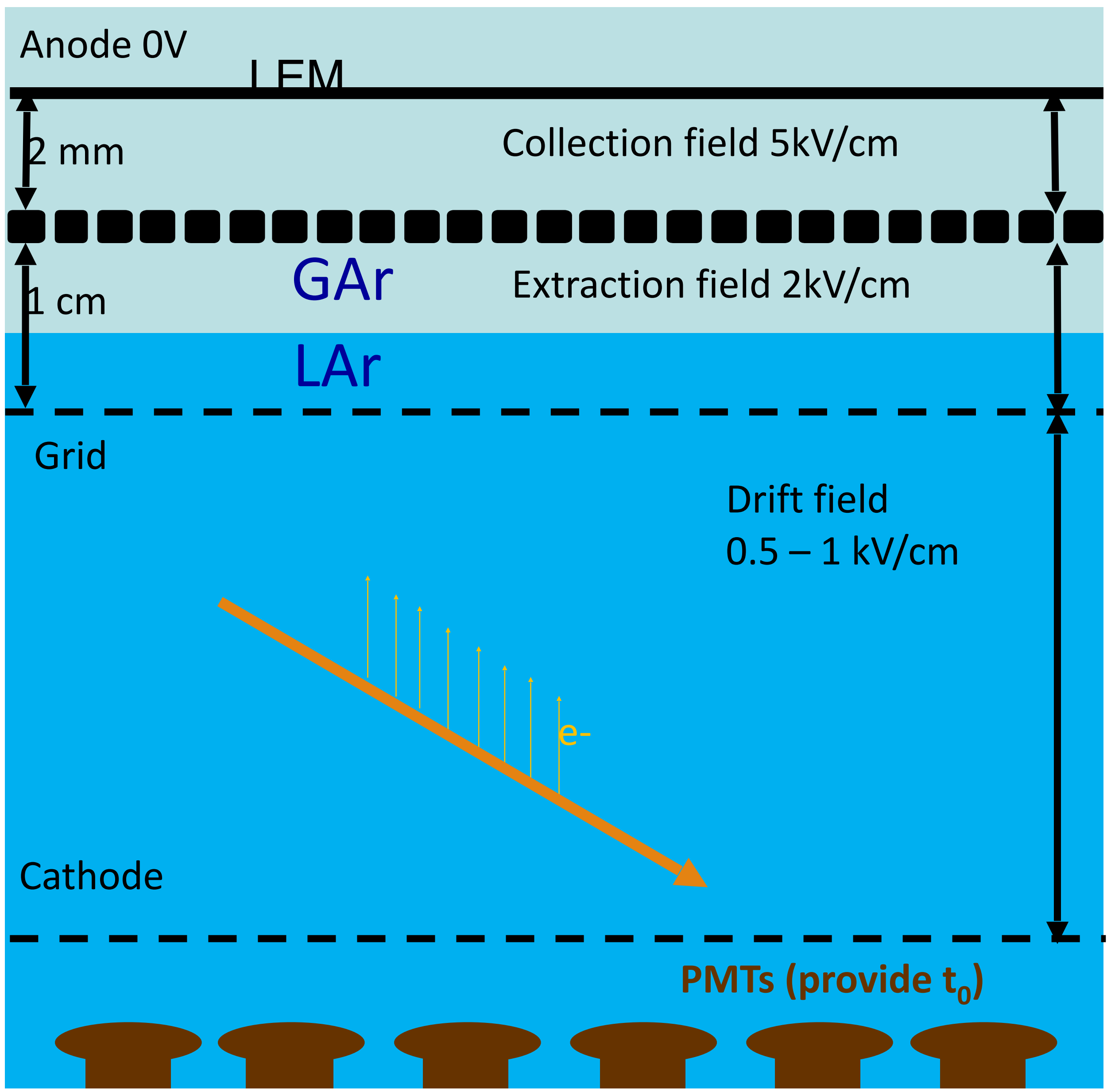
Allows finer readout pitch, lower energy thresholds and better pattern recognition



Will be tested by WA105 program at CERN

Large Double phase TPCs

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



Large scale LAr TPC for LB neutrino oscillation physics, astrophysics, and nucleon decay search (GUT physics)

- Single cryo-tank based on industrial LNG solution to house O(10) kton of LAr mass
- Double-phase for charge readout with amplification:
  - **Long drift distances**
  - **Low energy detection thresholds**
  - **readouts with only collection views**
  - **maximise active LAr volume whilst minimising the number of channels.**

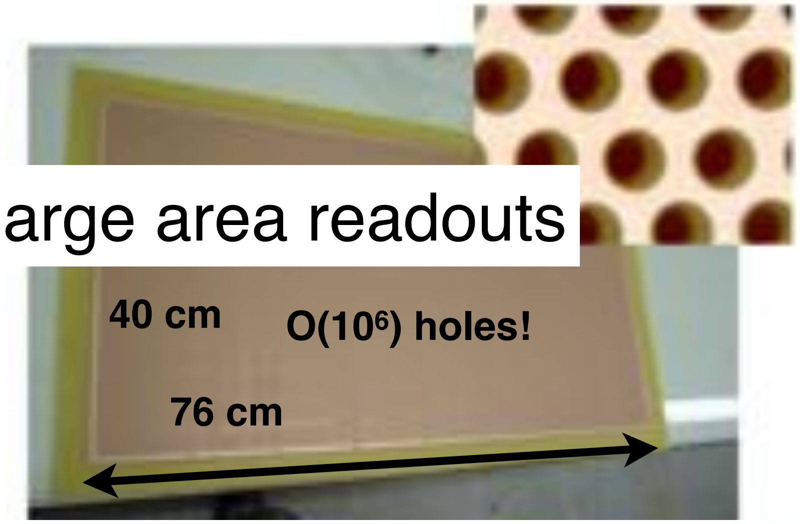
GLACIER concept. (A. Rubbia, Experiments for CP-violation: A giant liquid argon scintillation, Cherenkov and Charge imaging experiment? hep-ph/0402110.)

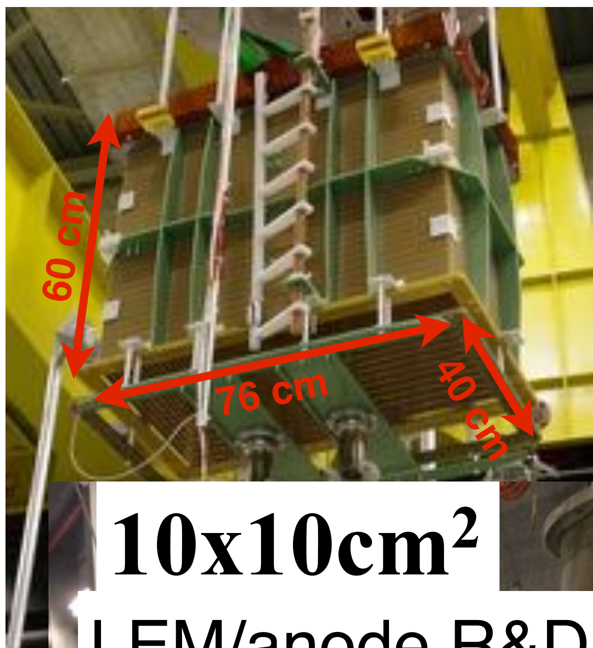
Double phase readout: many years of R&D

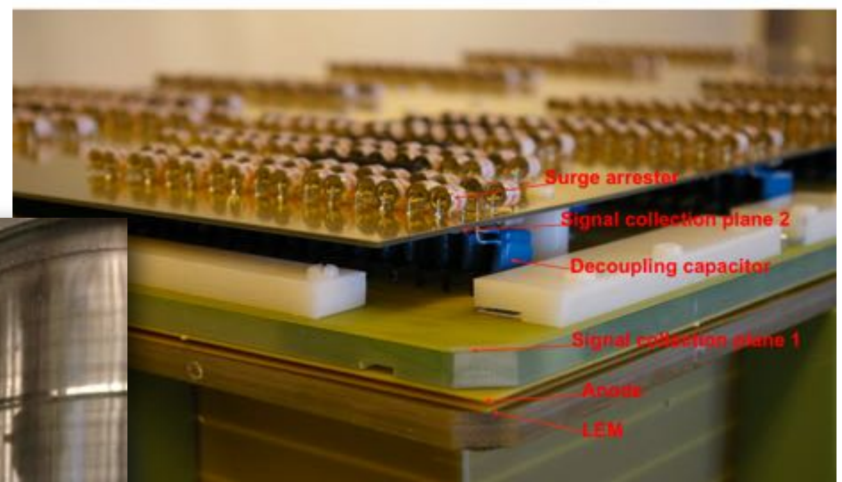
supporting R&D activities on smaller prototypes

40x80cm²

stable operation of large area readouts

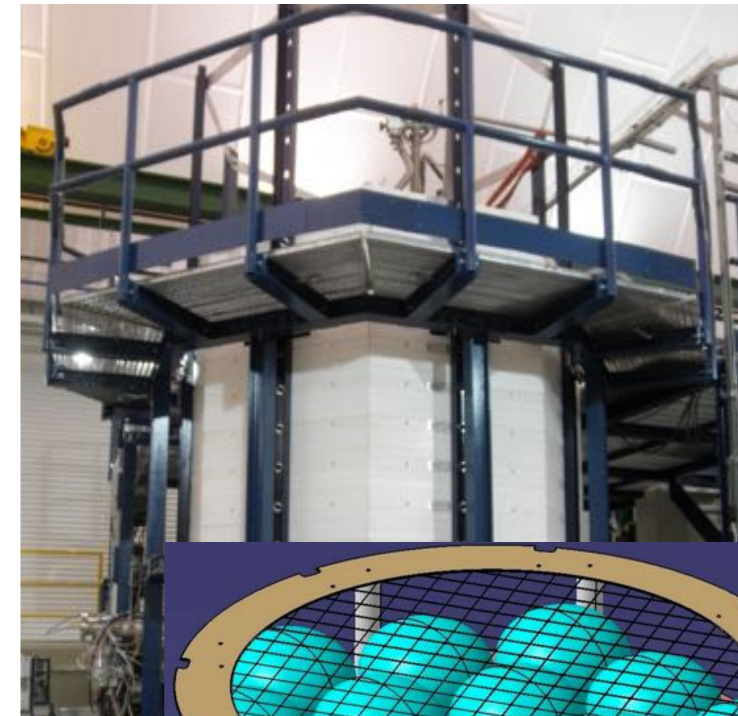






10x10cm²

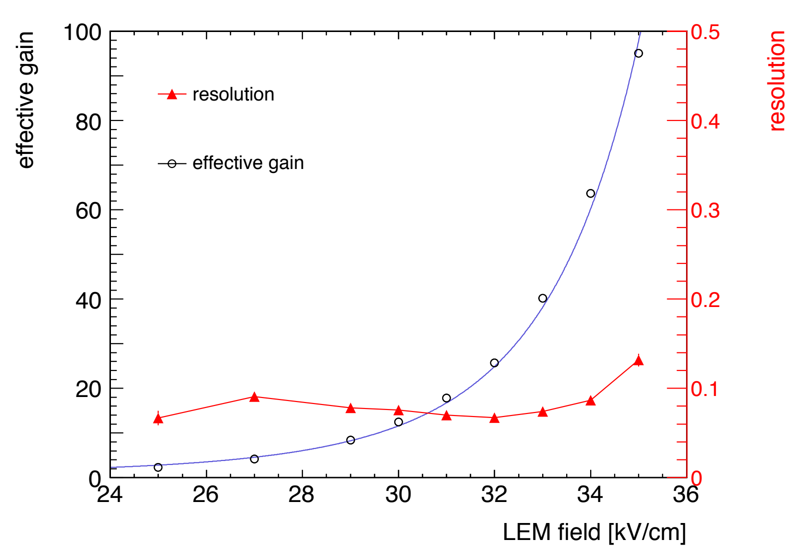
LEM/anode R&D

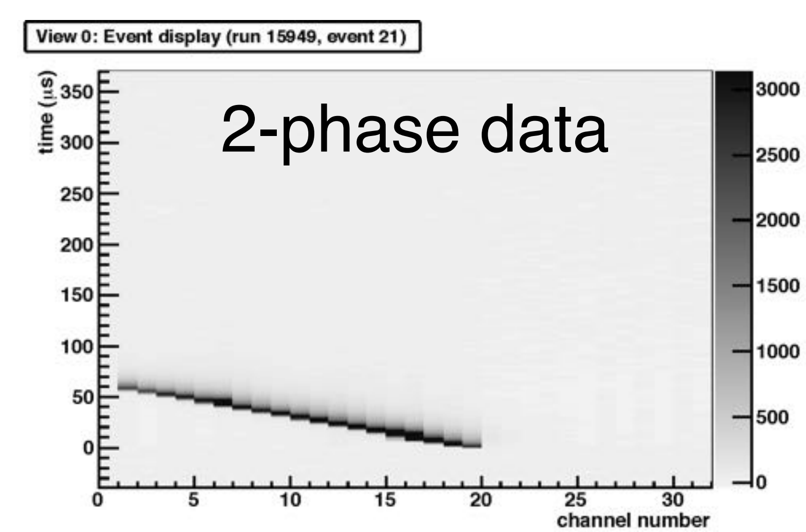


ArDM 1ton

-light readout

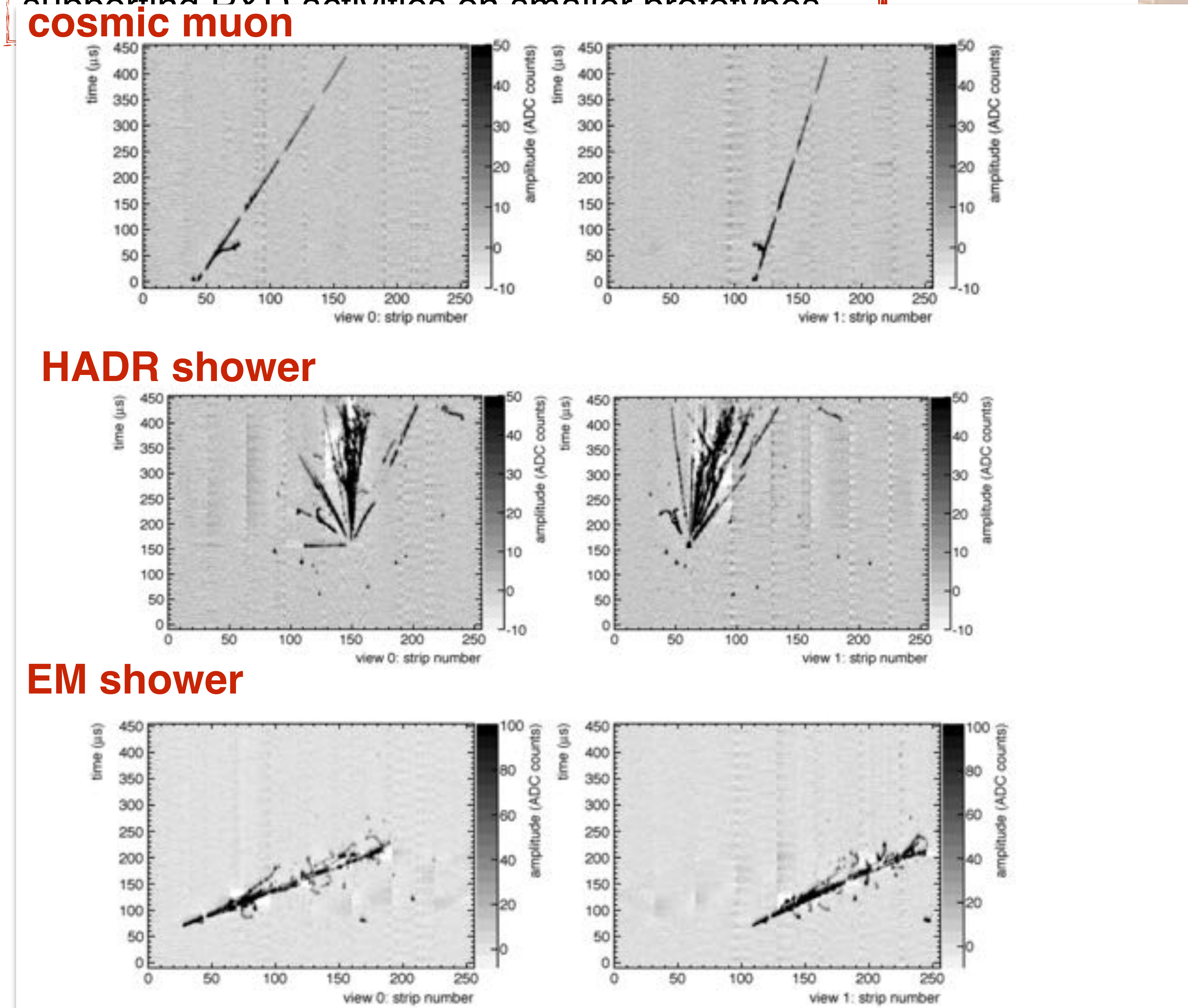
-**Operating underground**

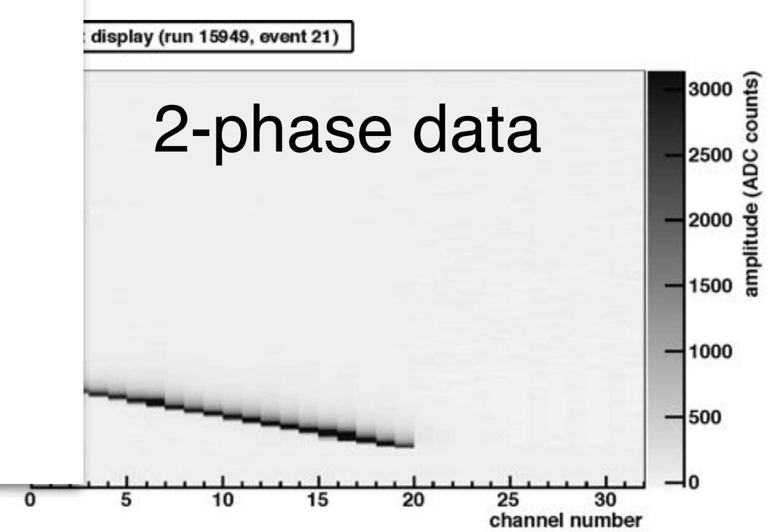




Double phase readout: many years of R&D

supporting R&D activities on smaller prototypes





24 26 28 30 32 34 36
LEM field [kV/cm]

The collaboration

WA105

22 institutes 122 physicists

UNIVERSITY of OULU

UNIVERSITÀ DI PISA

UCL

Sofia University St. Kliment Ohridski Bulgaria

CERN

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Ciemat
Centro de Investigaciones Energéticas, Medioambientale... ...gicas

KEK
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

UNIVERSITY OF JYVÄSKYLÄ

ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ РОССИЙСКОЙ АКАДЕМИИ НАУК
INSTITUTE FOR NUCLEAR RESEARCH OF RUSSIAN ACADEMY OF SCIENCES

Institut de Física d'Altes Energies IFAE

LPNHE PARIS

lapp

University of Glasgow

UNIVERSITÉ DE GENÈVE

cea SACLAY

ipnl

APC

IN2P3
INSTITUT NATIONAL DE PHYSIQUE NUCLÉAIRE ET DE PHYSIQUE DES PARTICULES

The WA105 6x6x6 m^3 demonstrator

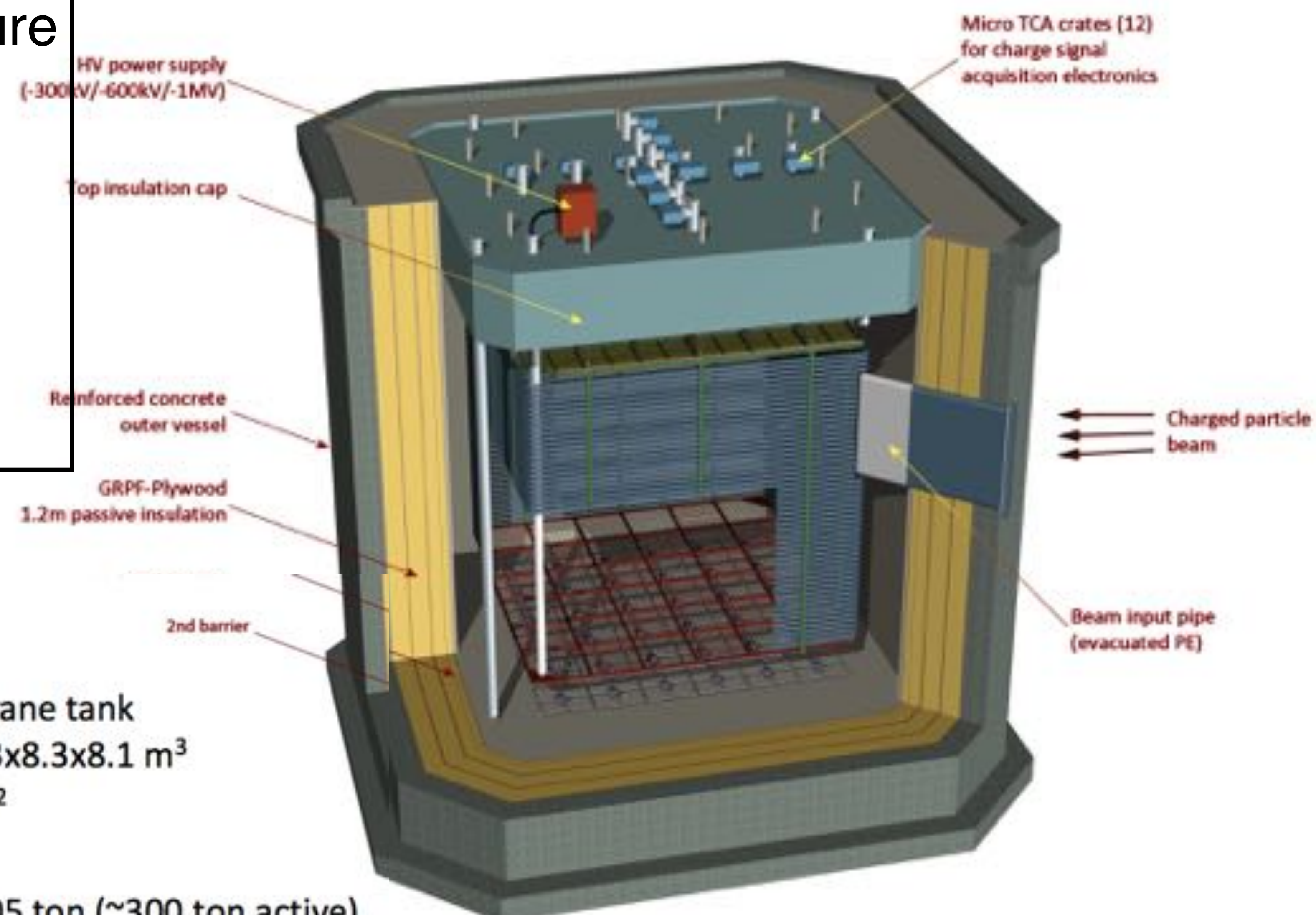
WA105

Build and operate a large scale prototype to demonstrate the feasibility of DLAr TPC design for O(10kt) detectors.

Technical proof-of-principle:

- ✳ Purity in non-evacuated tank
- ✳ Large hanging field cage structure
- ✳ Very high voltage generation
- ✳ Large area charge readout
- ✳ Accessible cold front-end electronics
- ✳ Long term stability of UV scintillation light readout

On the surface in a test beam

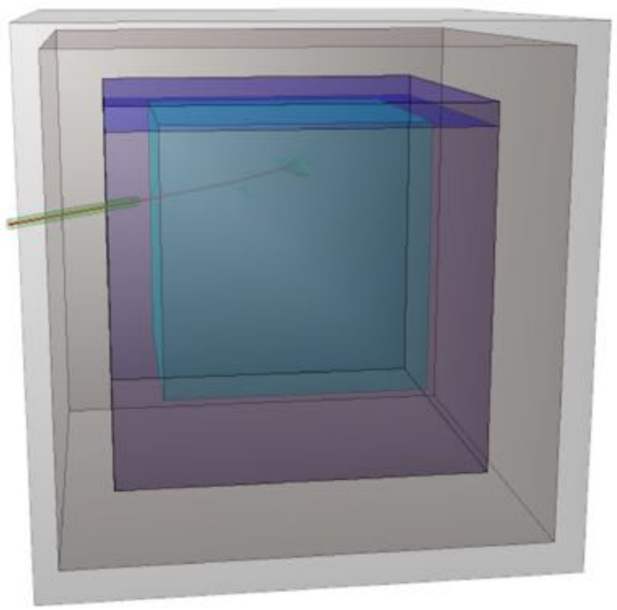


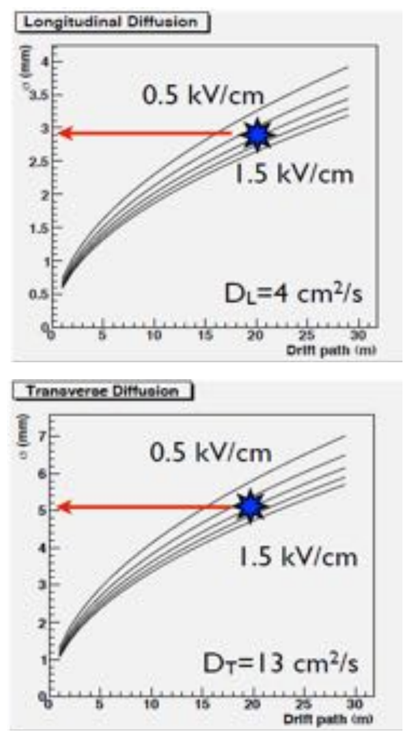
Some detector parameters:

- Insulated membrane tank
  → inner volume 8.3x8.3x8.1 m^3
- Active area 36 m^2
- Drift length 6 m
- Total LAr mass 705 ton (~300 ton active)
- Hanging field cage & readout plane
- # of signal channels: 7680 in 12 signal FT
- # of PMTs: 36

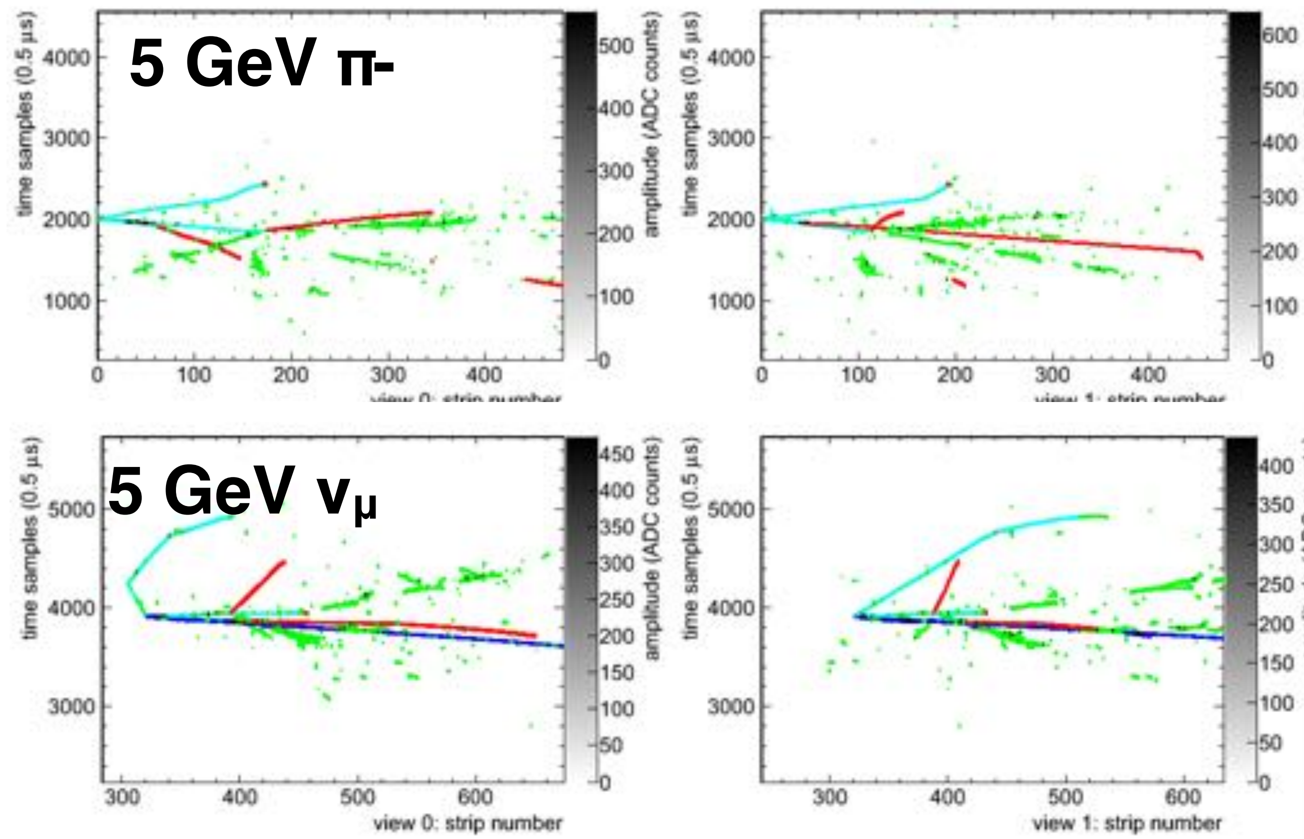
WA105: important Physics milestones

test reconstruction on fully contained events from charged particle beam (well defined primary particles and energies)





pions, electrons/positrons, protons, muons



- LAr TPC provide a fully active homogeneous medium
- High granularity 3x3 mm^2 ← two orders of magnitude better than most granular calorimeters
  - e.g., CALICE AHCAL prototype has 3x3 cm^2
- Additional handle from dE/dx

Opportunity to provide unprecedented measurements of hadronic shower development to HEP community

Some goals

- Development of automatic event **reconstruction**
- **test NC background rejection** algorithms on "ν_e free" events
- Charged **pions** and proton **cross-section** on Argon nuclei.

6x6x6 m^3 DLAr R&D goals: summary

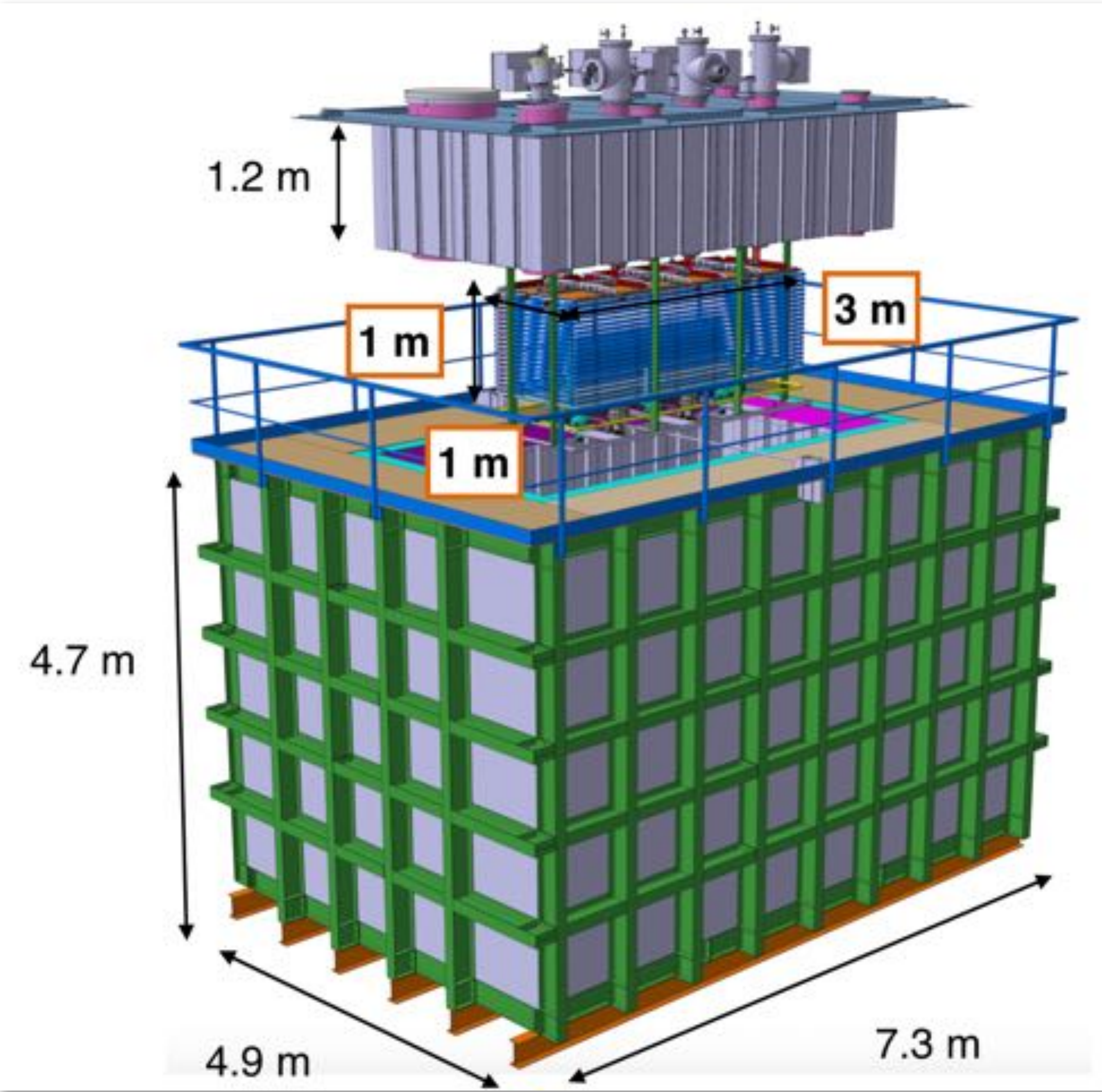
6x6x6m3 DLAr R&D goals: summary

Double phase LAr TPC validation:

1. Longest drift in LAr (up to 6m)
2. Ionisation e- transverse and longitudinal diffusion
3. e- attenuation and its compensation by charge multiplication with LEM operating in gas phase (LEM gain uniformity/stability/calibration)
4. HV operation in the range 300kV-600kV (or 0.5-1 kV/cm over 6m)
5. Validation of the corrugated membrane cryostat with passive insulation
6. ≤100ppt O2-equivalent impurities in LAr in such a tank
7. Low-noise accessible ionisation charge signal readout electronics operating at low temperature (~110K)
8. Reachable and optimisation of S/N ratio
9. Verification of possible effects of positive ions (surface! - n/a underground)
10. Robust light readout (UV aging resistant), immersed electronics
11. First calibration of a LAr TPC with beam e-/μ/hadrons

The WA105 3x1x1 m³

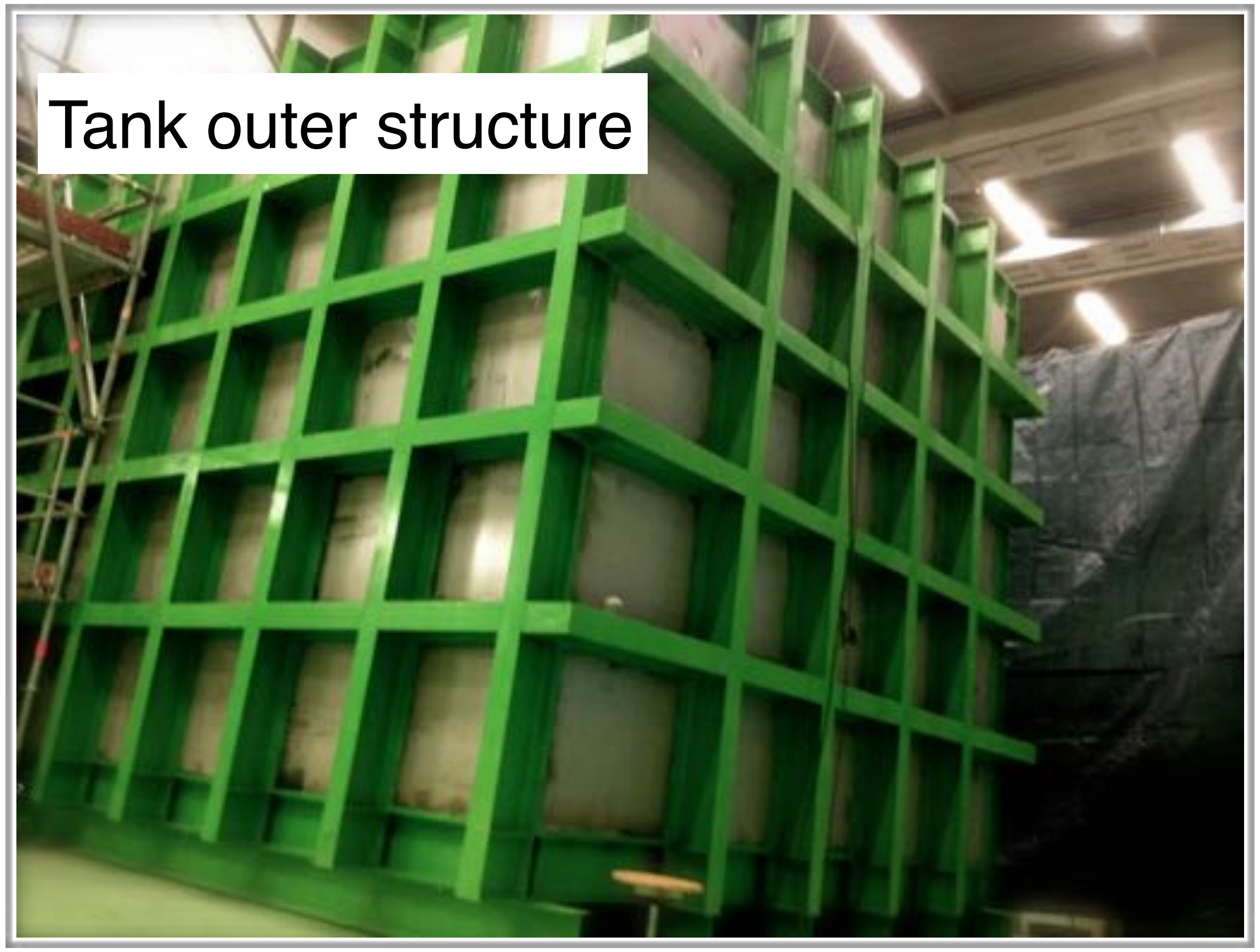
On a shorter time scale we are constructing a 3x1x1 m³ LAr TPC

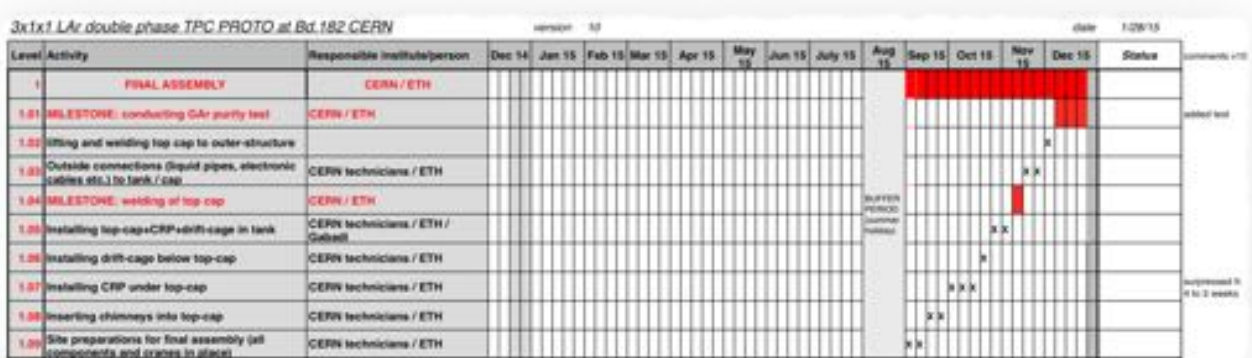


- ✓ **Fully engineered versions of many detector components** with pre-production and direct implementation (installation details and ancillary services)
- ✓ **First overview of the complete system integration**: set up full chains for Quality Assessment, construction, installation and commissioning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

WA105 prototypes - status

LAr-Proto (3x1x1 m³)



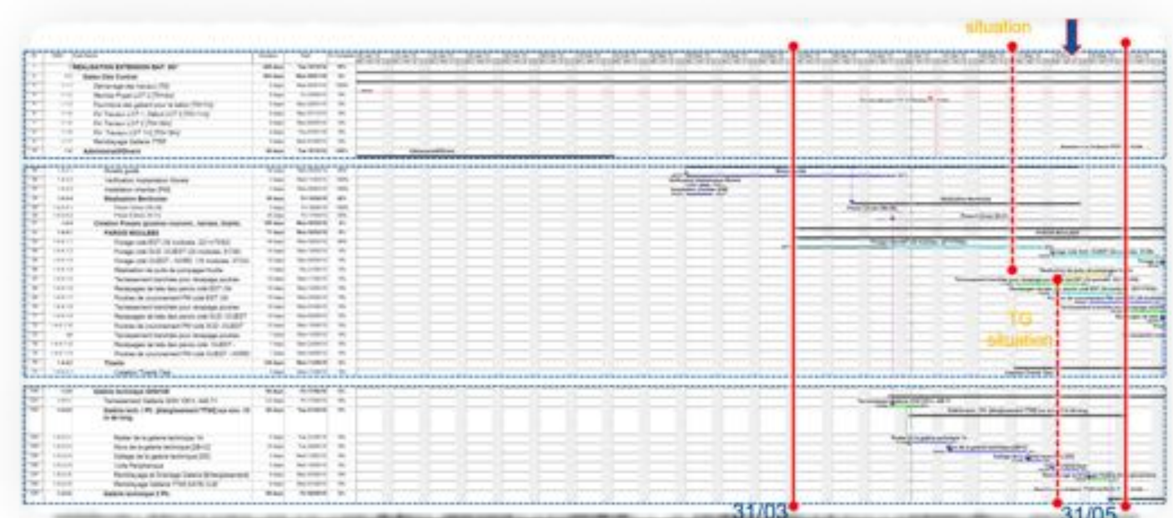


3x1x1 LAr double phase TPC PROTO at Bd.182 CERN

Level	Activity	Responsible institute/person
1	FINAL ASSEMBLY	CERN / ETH
1.01	MILESTONE: conducting GAr purity test	CERN / ETH
1.02	lifting and welding top cap to outer-structure	
1.03	Outside connections (liquid pipes, electronic cables etc.) to tank / cap	CERN technicians / ETH
1.04	MILESTONE: welding of top cap	CERN / ETH
1.05	Installing top-cap+CRP+drift-cage in tank	CERN technicians / ETH / Gabadi
1.06	Installing drift-cage below top-cap	CERN technicians / ETH
1.07	Installing CRP under top-cap	CERN technicians / ETH
1.08	Inserting chimneys into top-cap	CERN technicians / ETH
1.09	Site preparations for final assembly (all components and cranes in place)	CERN technicians / ETH

Detector installation end 2015

DLAr (6x6x6 m³)

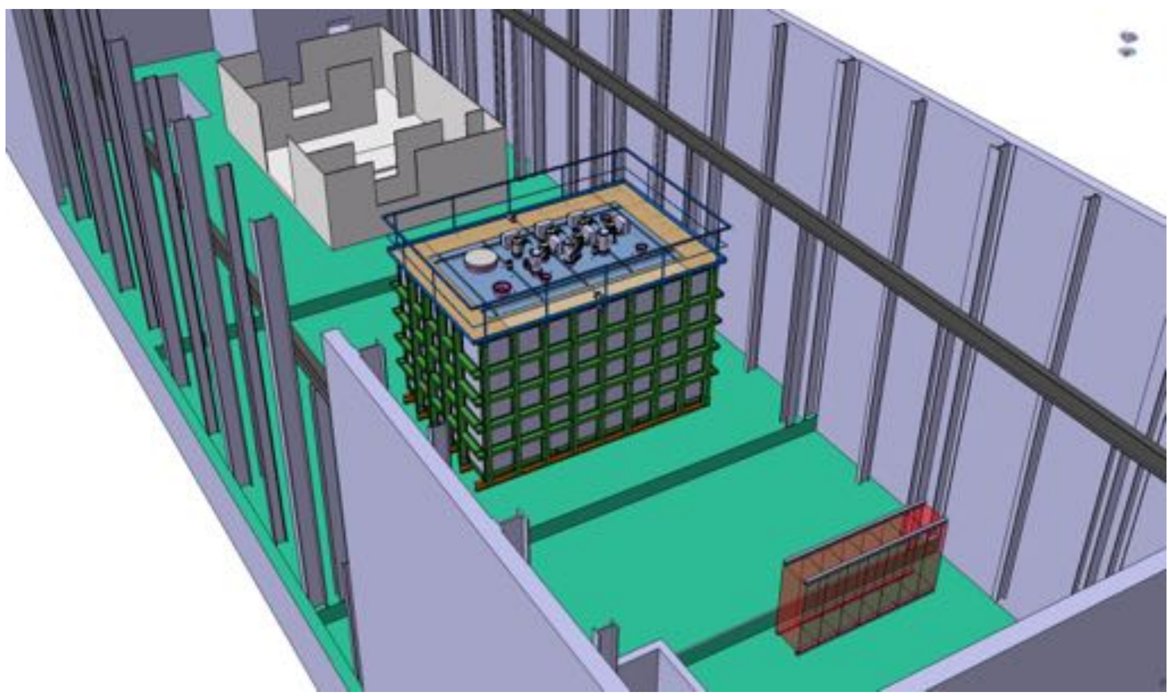


Detector installation 2017

WA105 prototypes - status

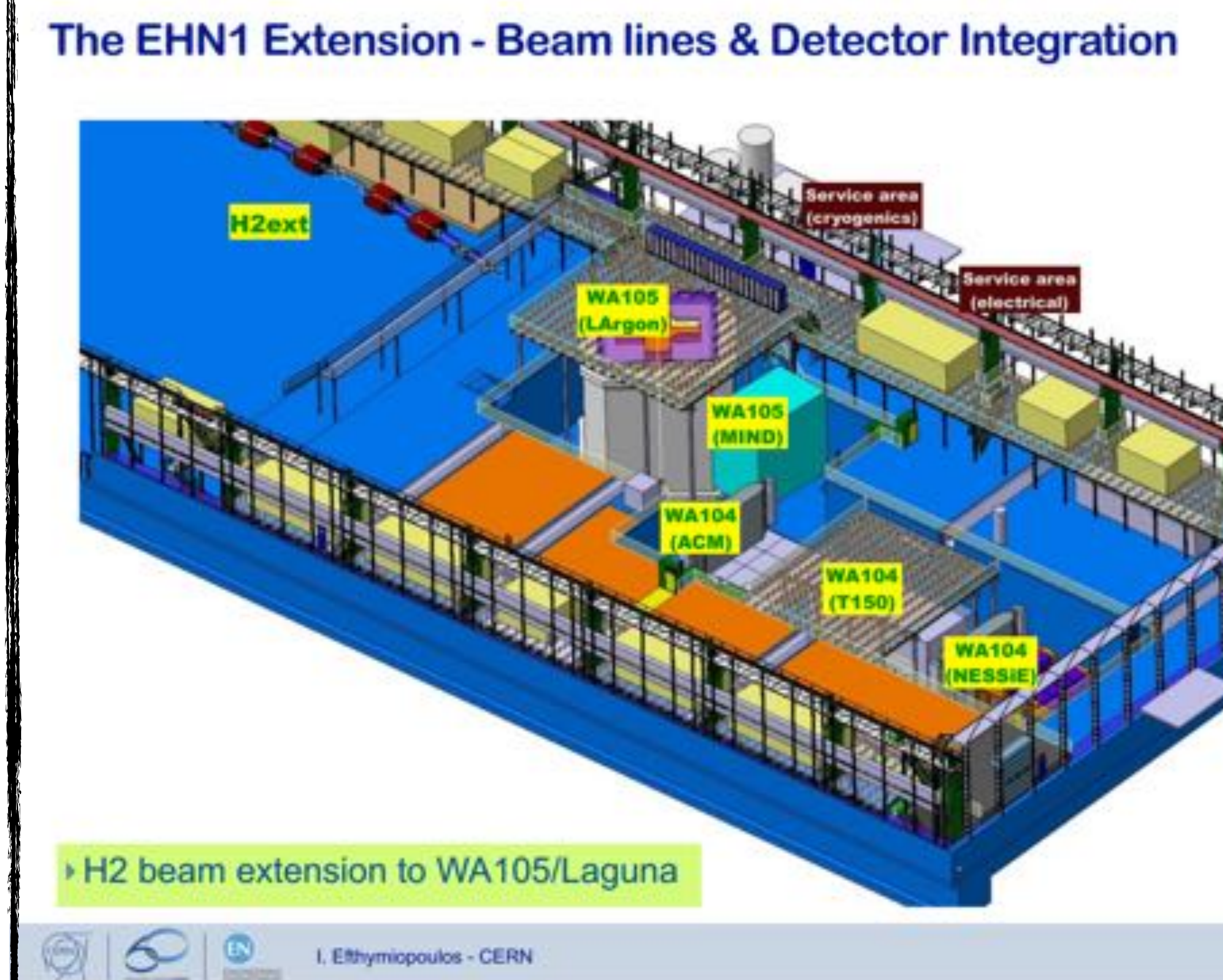
LAr-Proto (3x1x1 m³)

Tank outer structure



Detector installation end 2015

DLAr (6x6x6 m³)

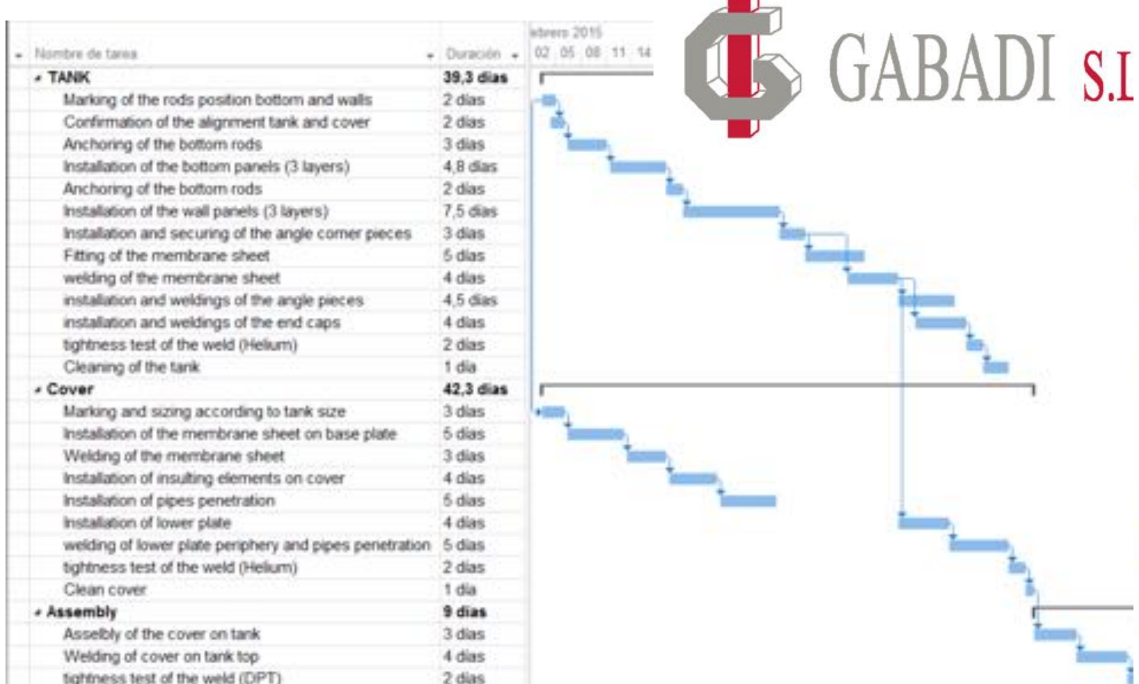


Detector installation 2017

Membrane tank

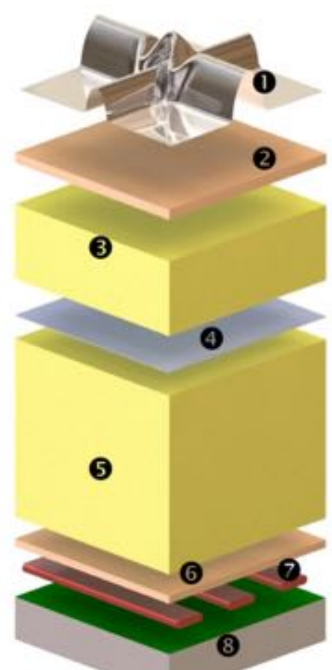
WA105

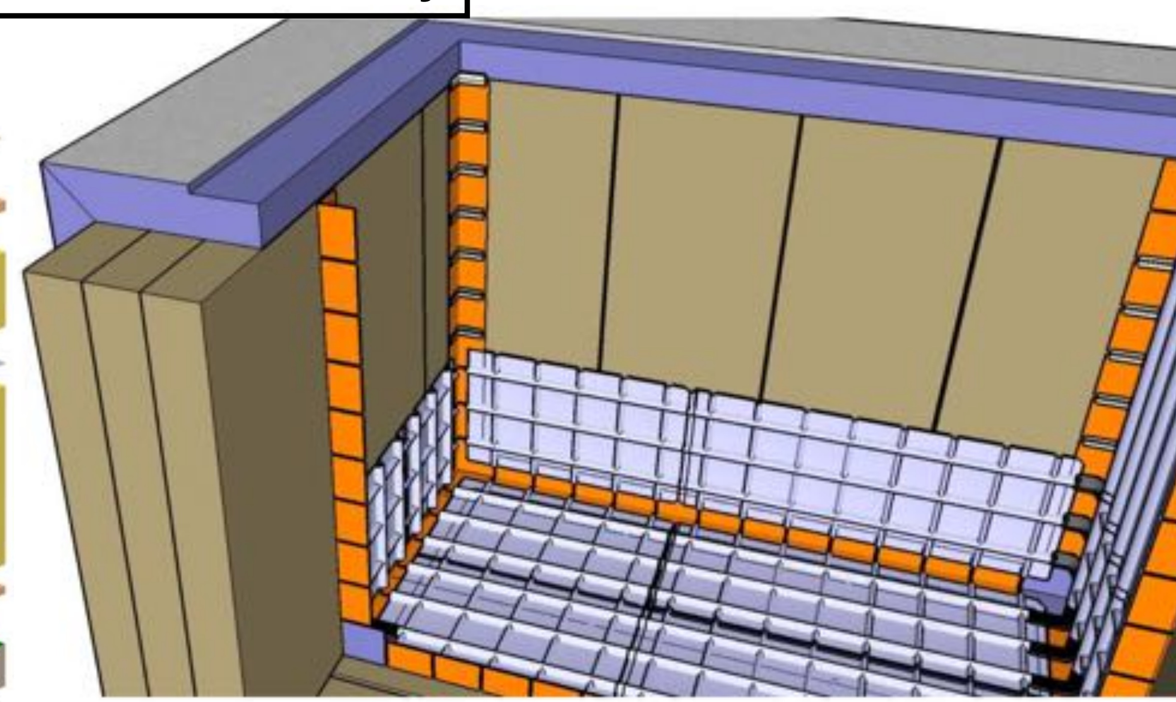
insulation and corrugated membrane panels installation in July



Nombre de tarea	Duración
TANK	**39,3 días**
Marking of the rods position bottom and walls	2 días
Confirmation of the alignment tank and cover	2 días
Anchoring of the bottom rods	3 días
Installation of the bottom panels (3 layers)	4,8 días
Anchoring of the bottom rods	2 días
Installation of the wall panels (3 layers)	7,5 días
Installation and securing of the angle corner pieces	3 días
Fitting of the membrane sheet	5 días
welding of the membrane sheet	4 días
installation and weldings of the angle pieces	4,5 días
installation and weldings of the end caps	4 días
tightness test of the weld (Helium)	2 días
Cleaning of the tank	1 día
Cover	**42,3 días**
Marking and sizing according to tank size	3 días
Installation of the membrane sheet on base plate	5 días
Welding of the membrane sheet	3 días
Installation of insulting elements on cover	4 días
Installation of pipes penetration	5 días
Installation of lower plate	4 días
welding of lower plate periphery and pipes penetration	5 días
tightness test of the weld (Helium)	2 días
Clean cover	1 día
Assembly	**9 días**
Asselbly of the cover on tank	3 días
Welding of cover on tank top	4 días
tightness test of the weld (DPT)	2 días

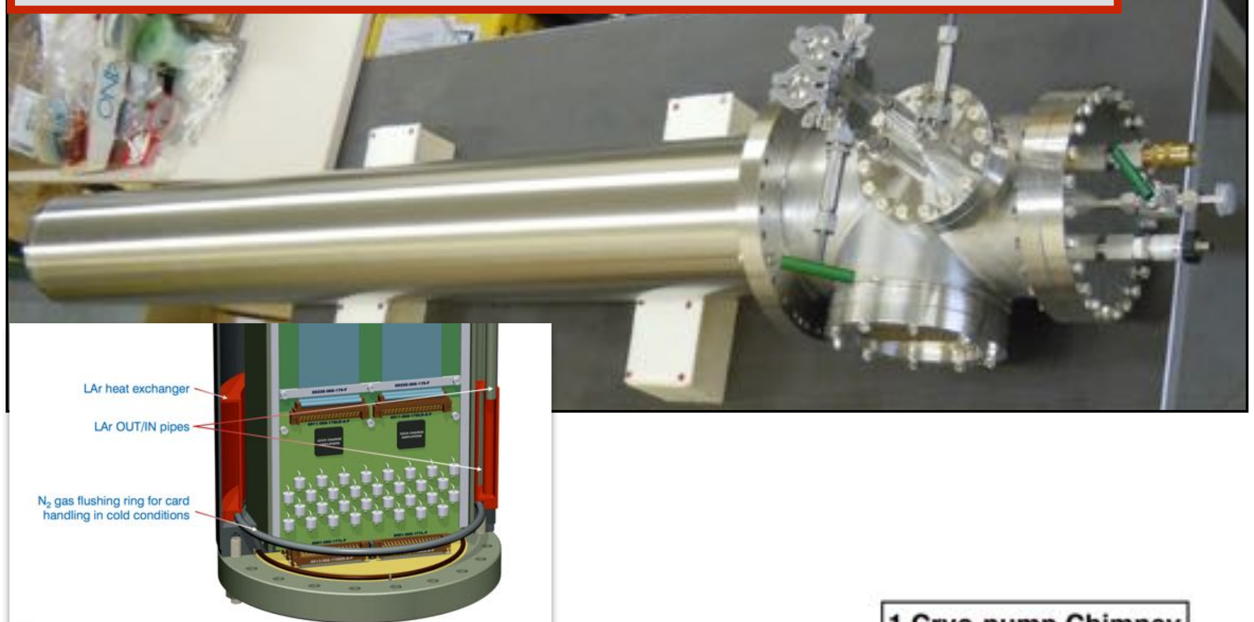
GABADI S.L

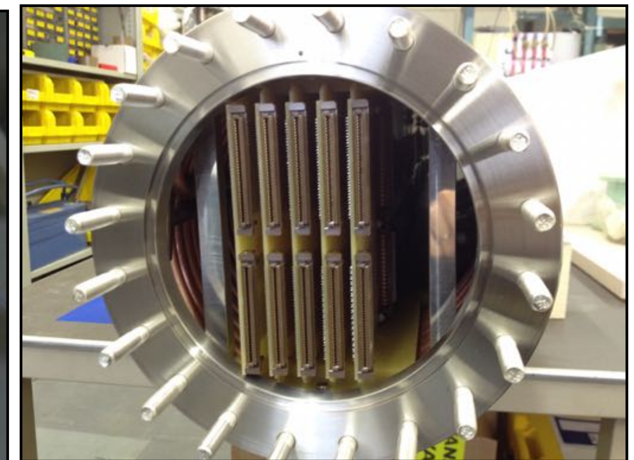


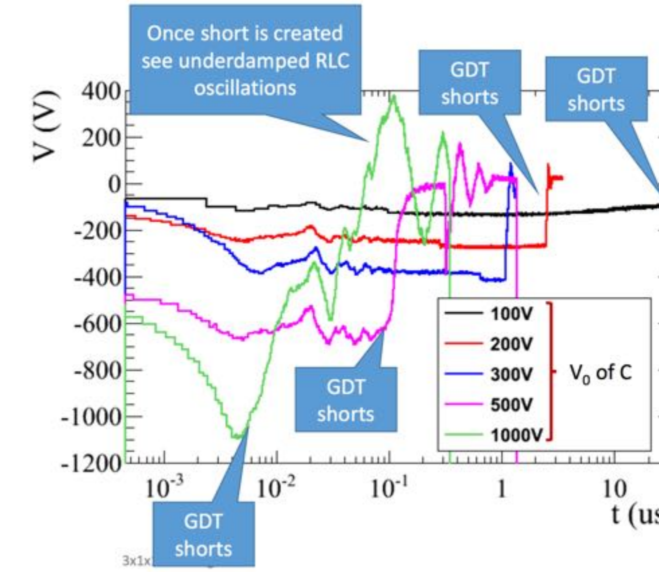


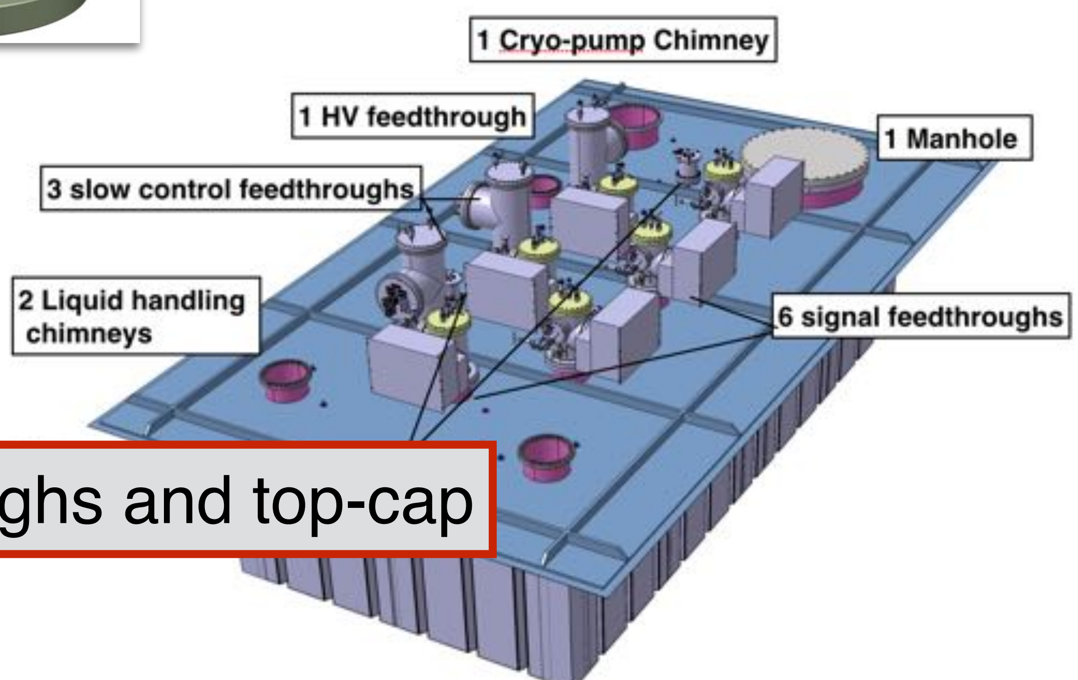
Ongoing work WA105 311 and 666

accessible cold front-end electronics

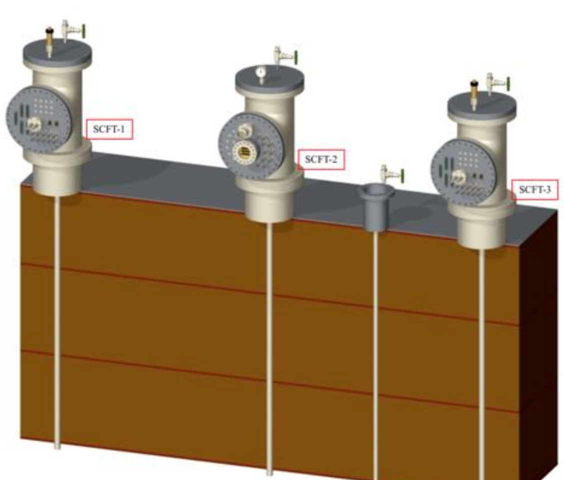


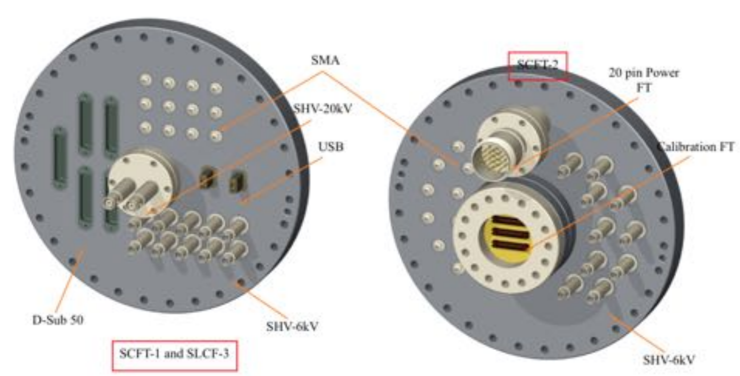




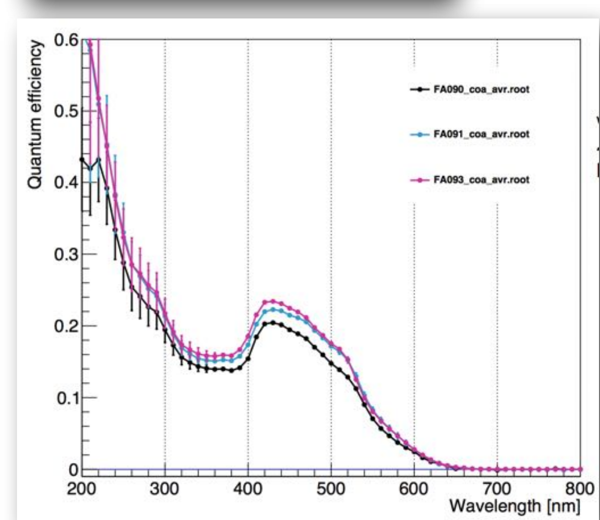


feedthroughs and top-cap

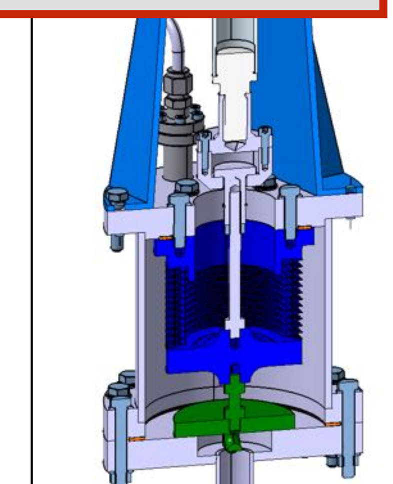


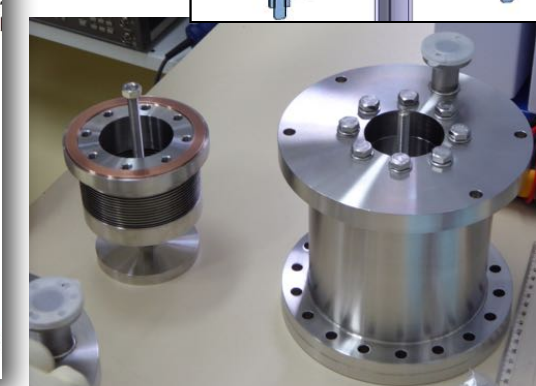


light readout



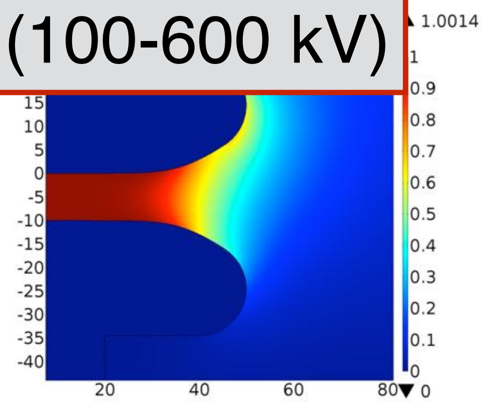
automatic levelling of CRP

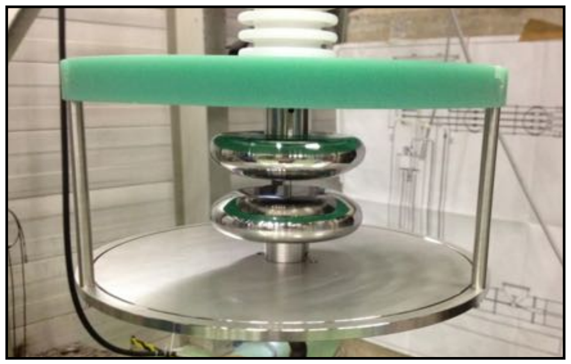


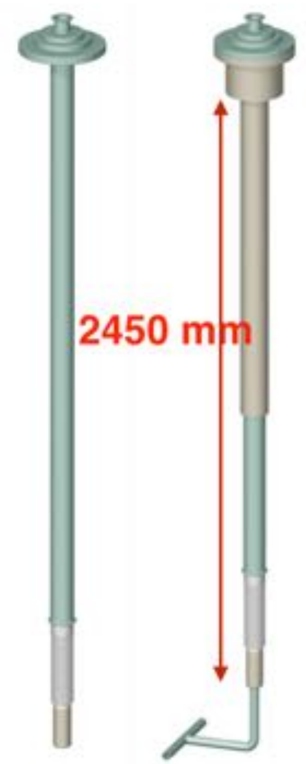


Ongoing work WA105 311 and 666

high voltage (100-600 kV)

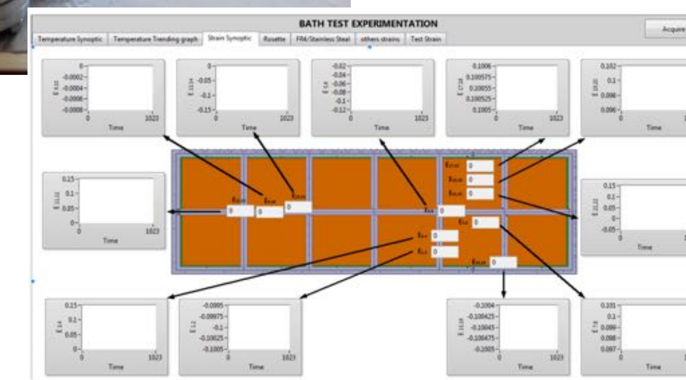




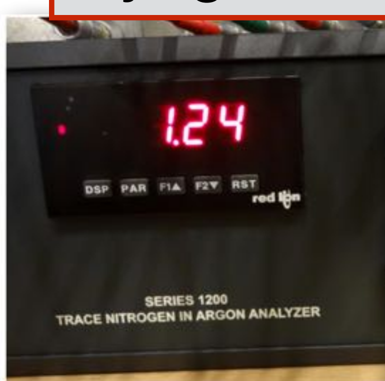


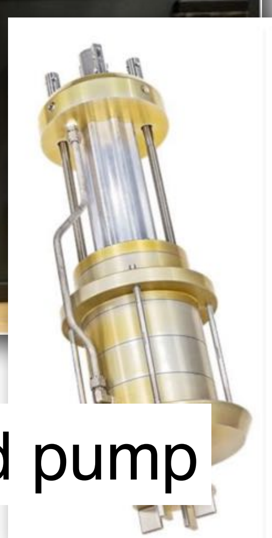
slow control & monitoring

cryo-camera

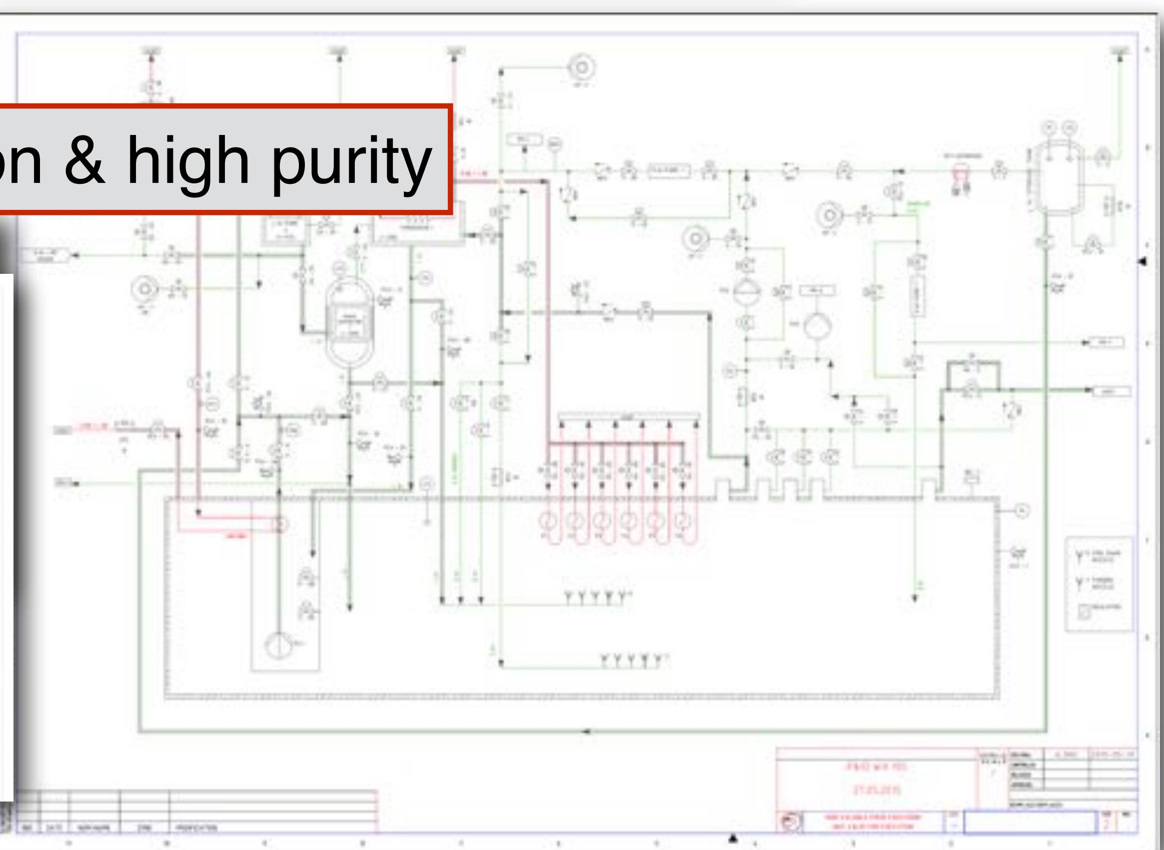


cryogenic installation & high purity

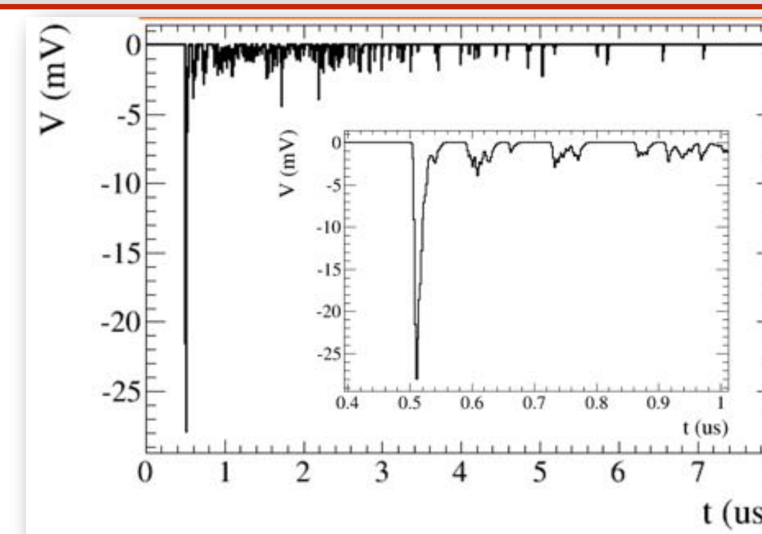




submerged pump

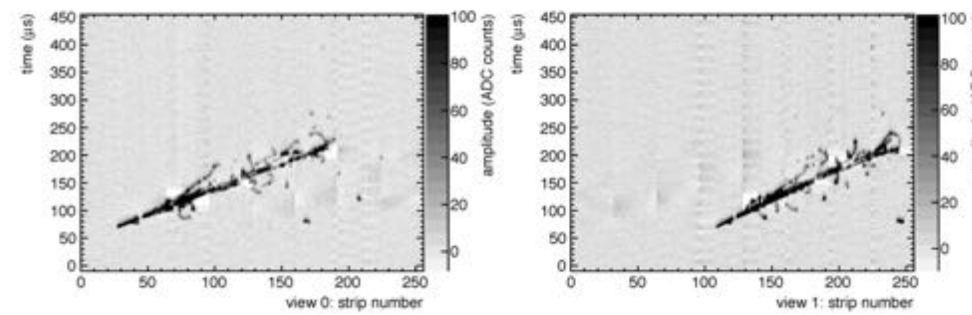


software
(simulations, DAQ, storage)



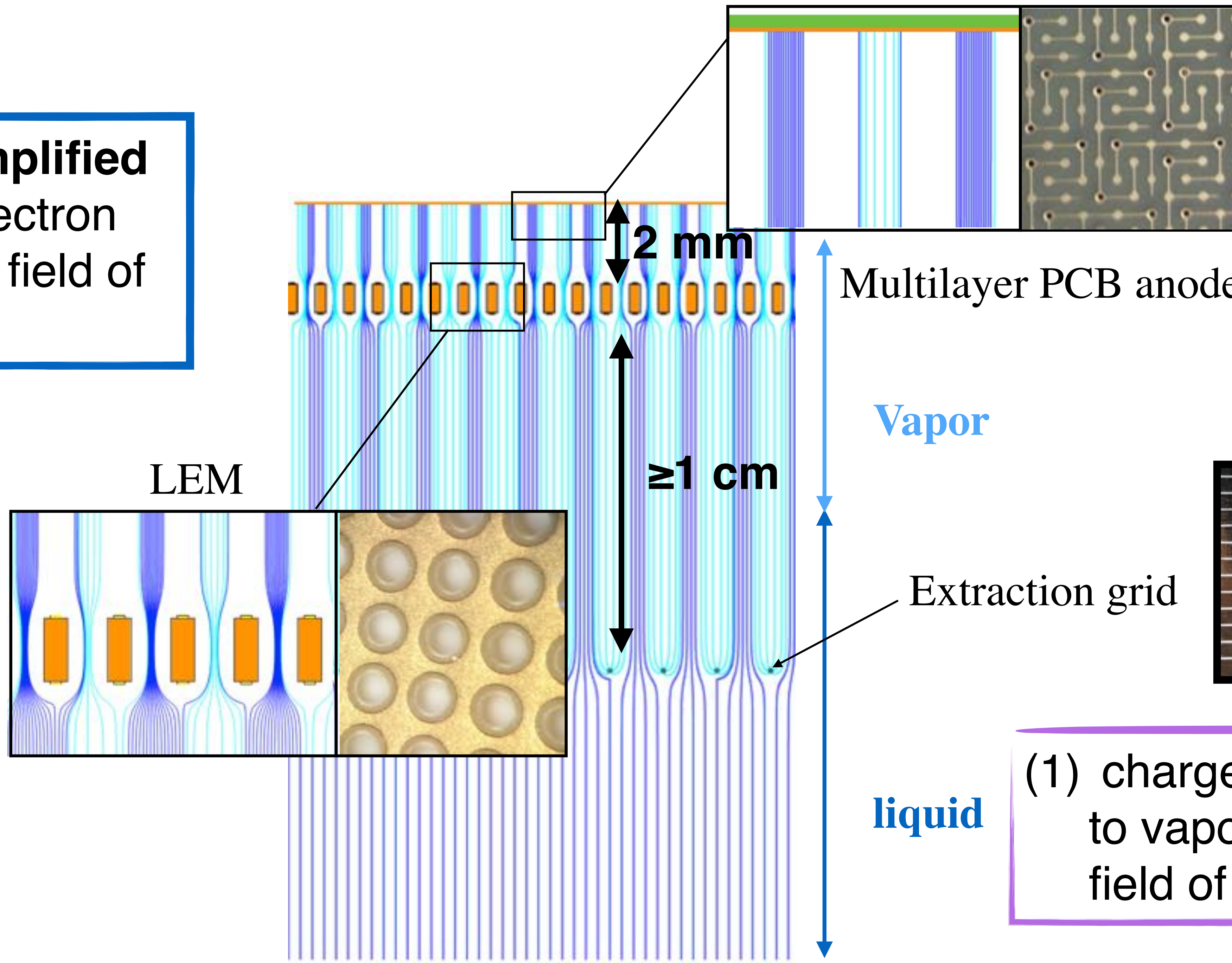
Amplification of charges in pure argon vapor

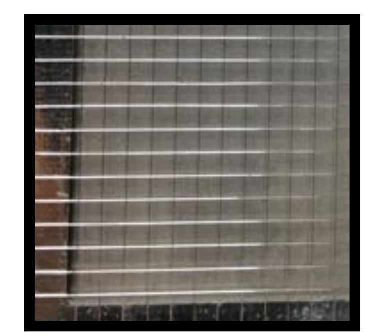
data collected on a 40x80 cm^2 DLAr TPC at CERN

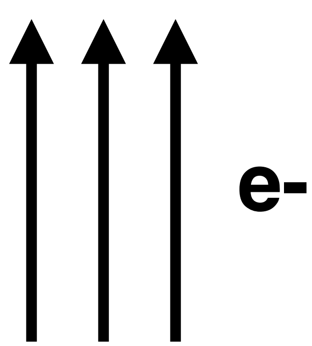


(3) charges **collected** on specially designed two view anode. Both views see the same amount of charge and have **identical signals**

(2) charges **amplified** in Large Electron Multiplier E field of ~30 kV/cm







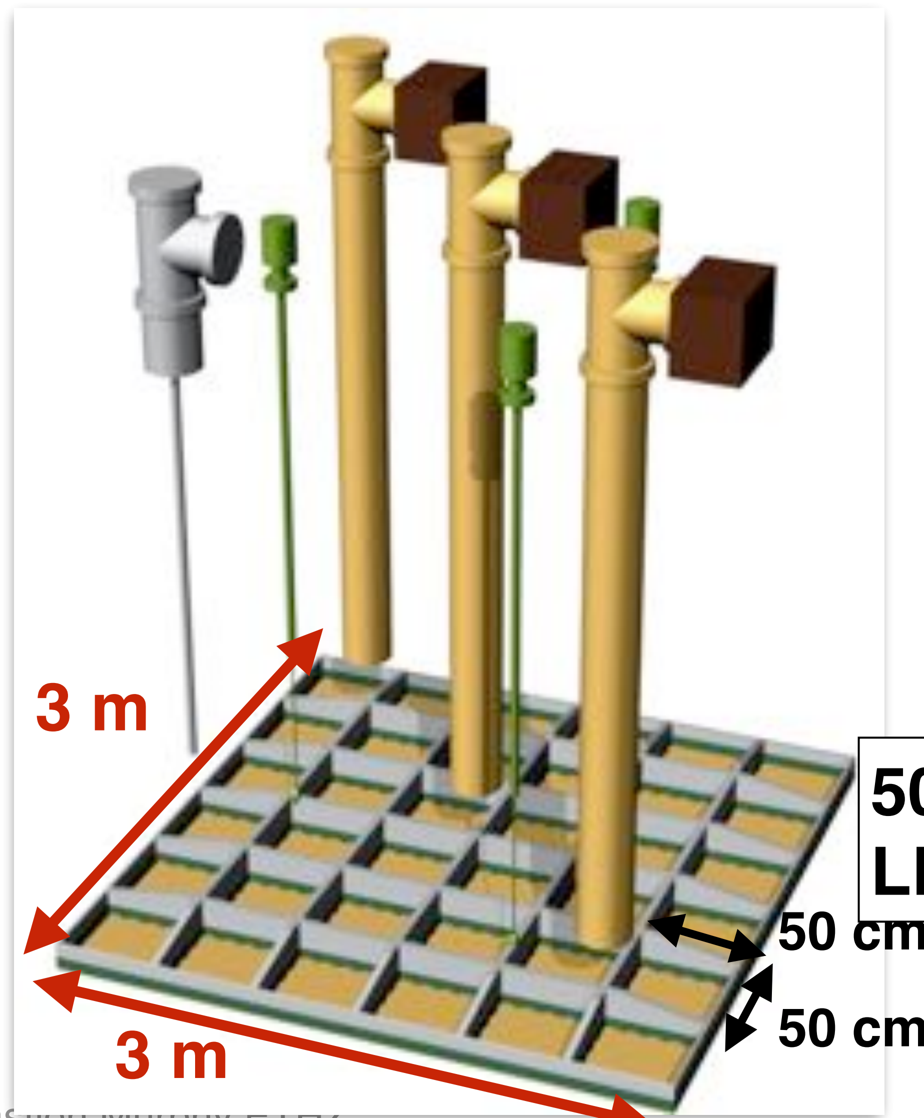
(1) charges **extracted** to vapor phase E field of ~2 kV/cm

The Charge Readout

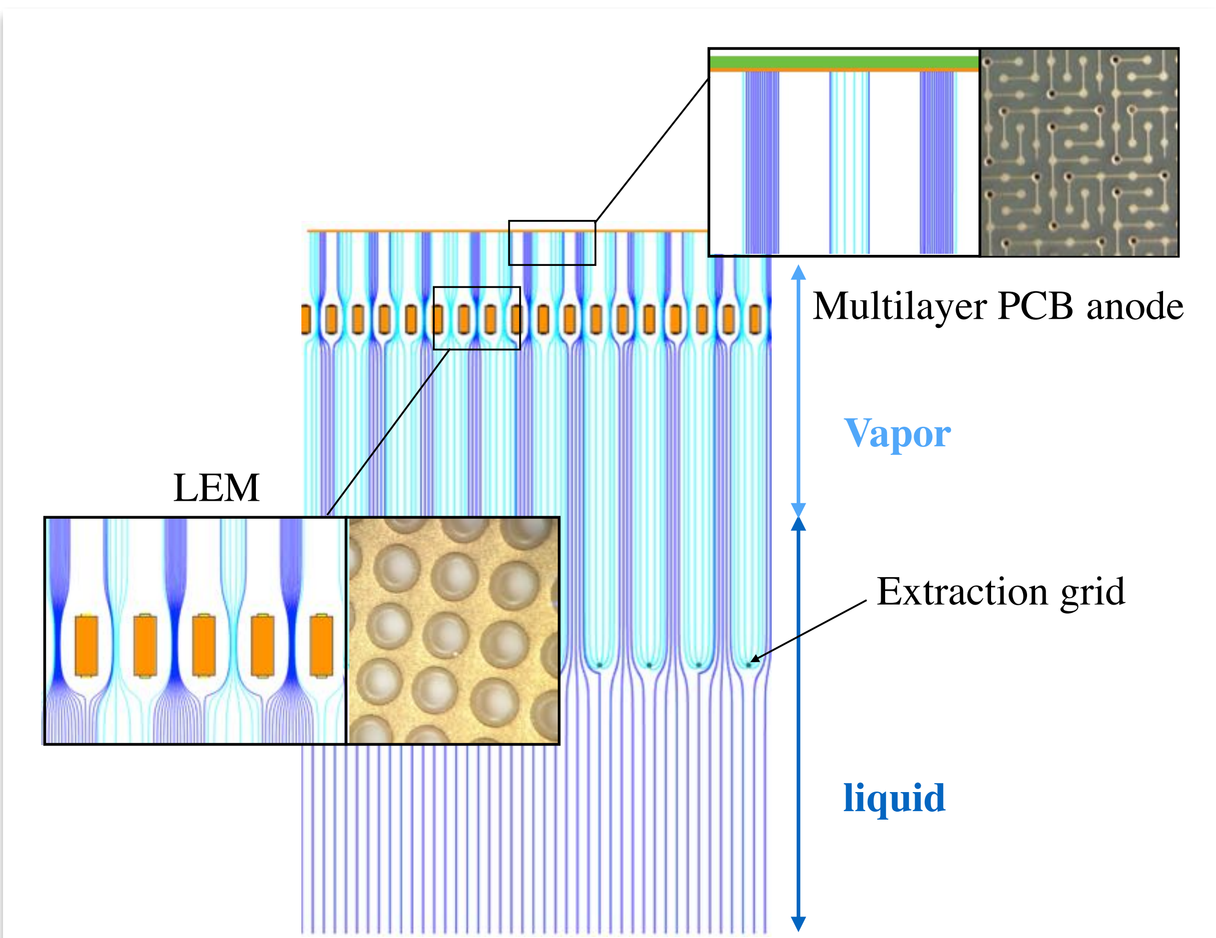
The extraction grid LEM and anodes are all combined in **independent modules of square meter scale** adjustable to the LAr level: **the charge readout plane (CRP)**

extraction grid-LEM and anode all in one single module

example of a 3x3 m² CRP



50x50 cm² LEM+anodes

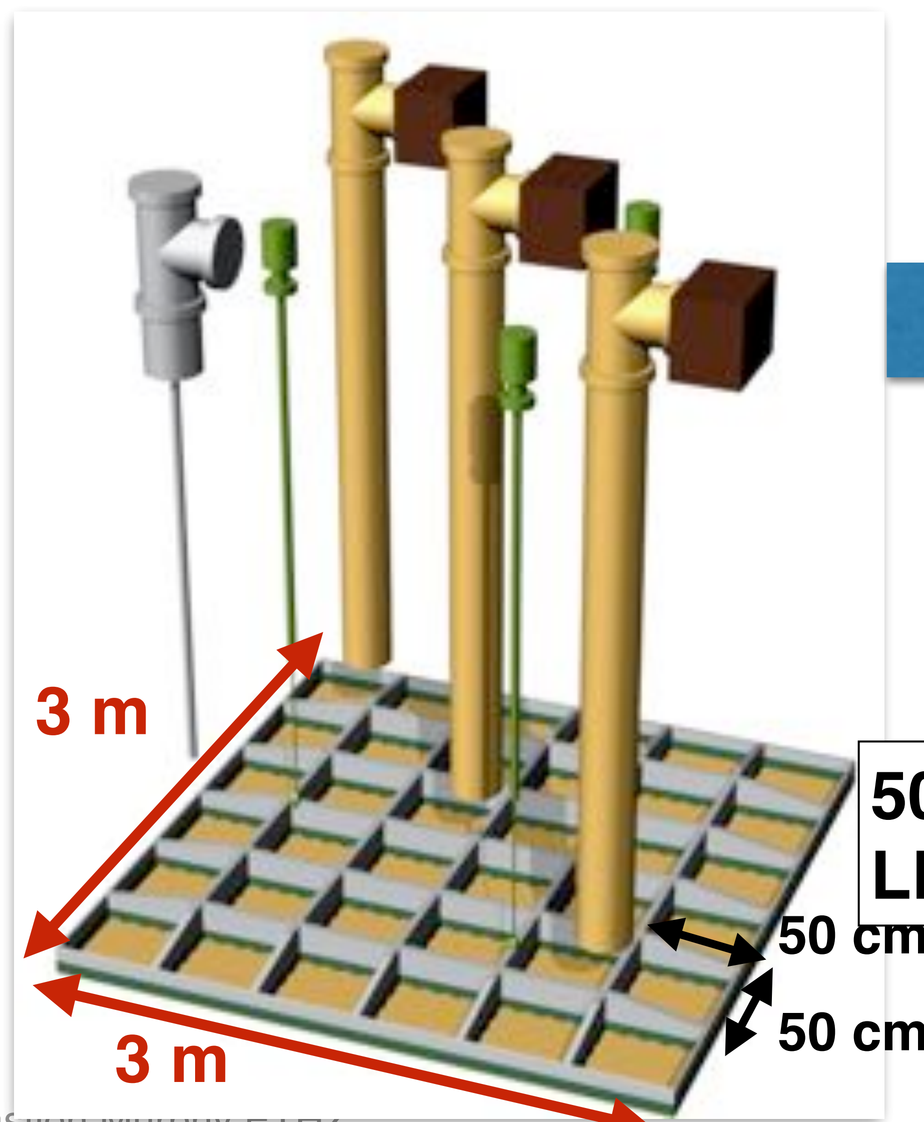


The detector: Charge Readout Plane

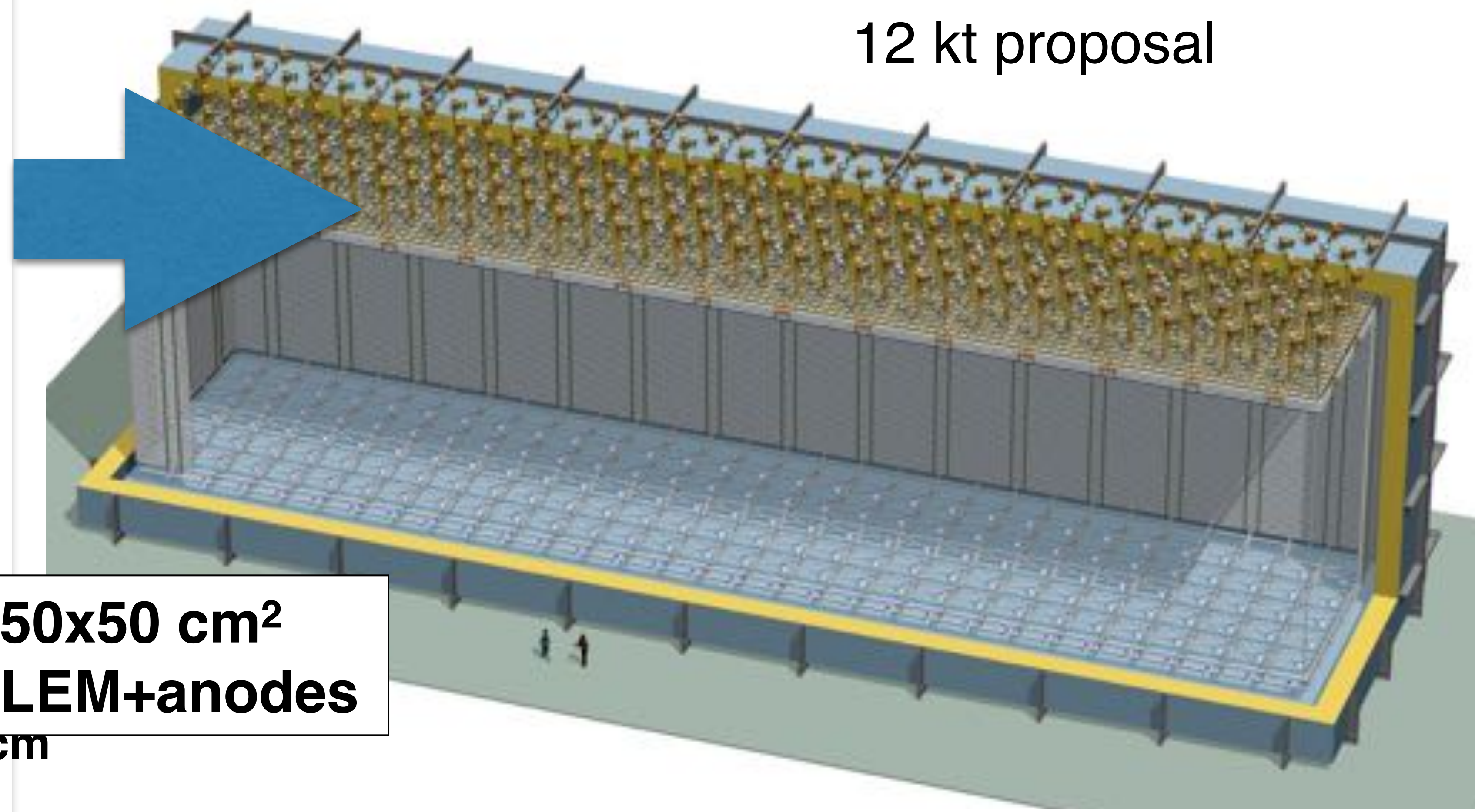
The extraction grid LEM and anodes are all combined in **independent modules of square meter scale** adjustable to the LAr level: **the charge readout plane (CRP)**

extraction grid-LEM and anode all in one single module

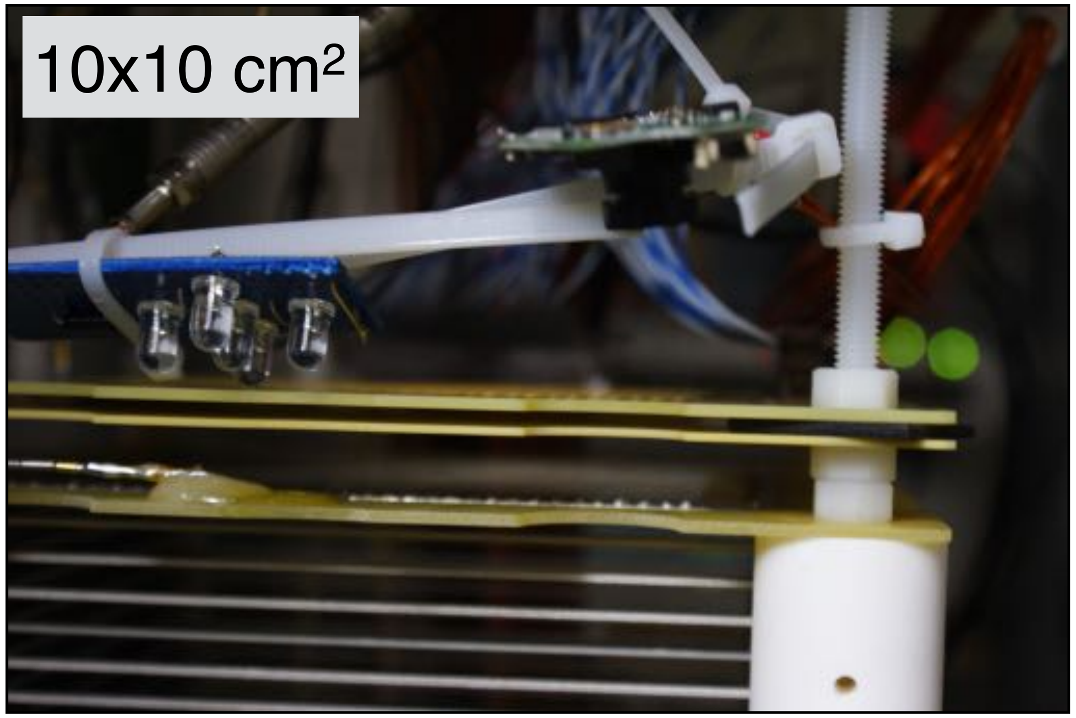
example of a 3x3 m² CRP

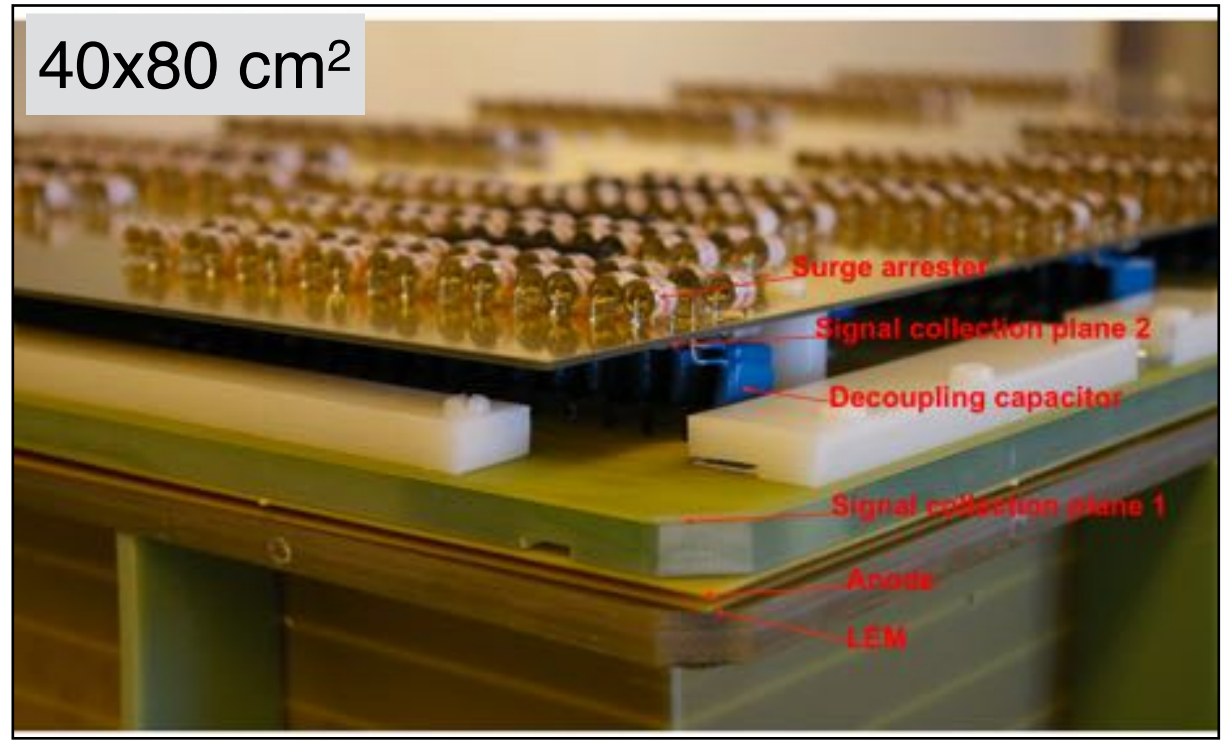


50x50 cm²
LEM+anodes

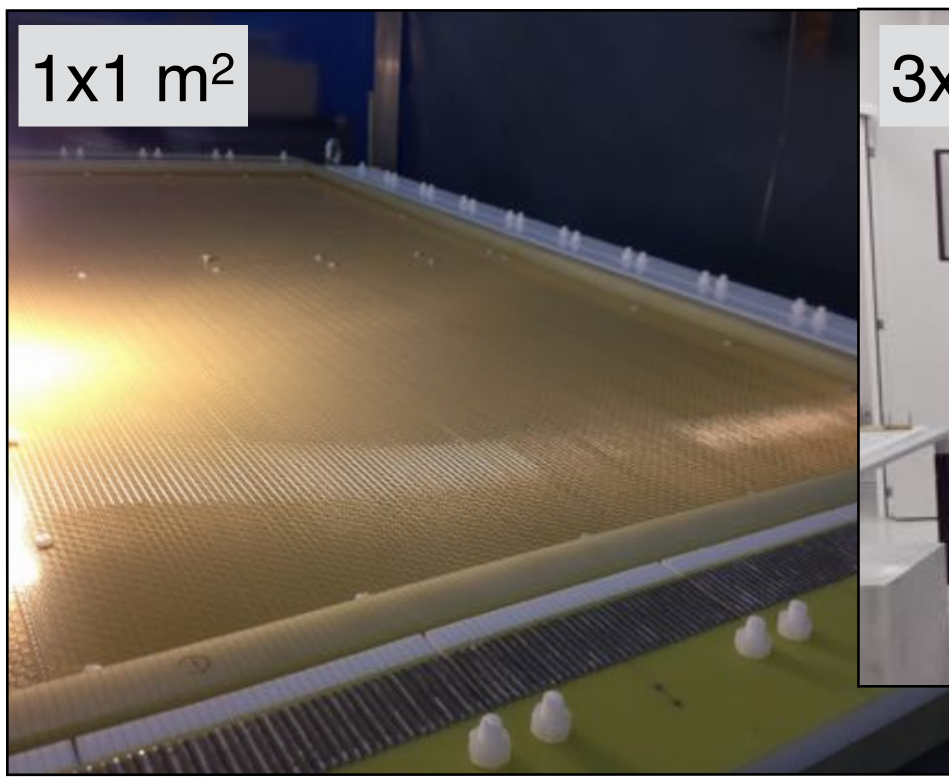


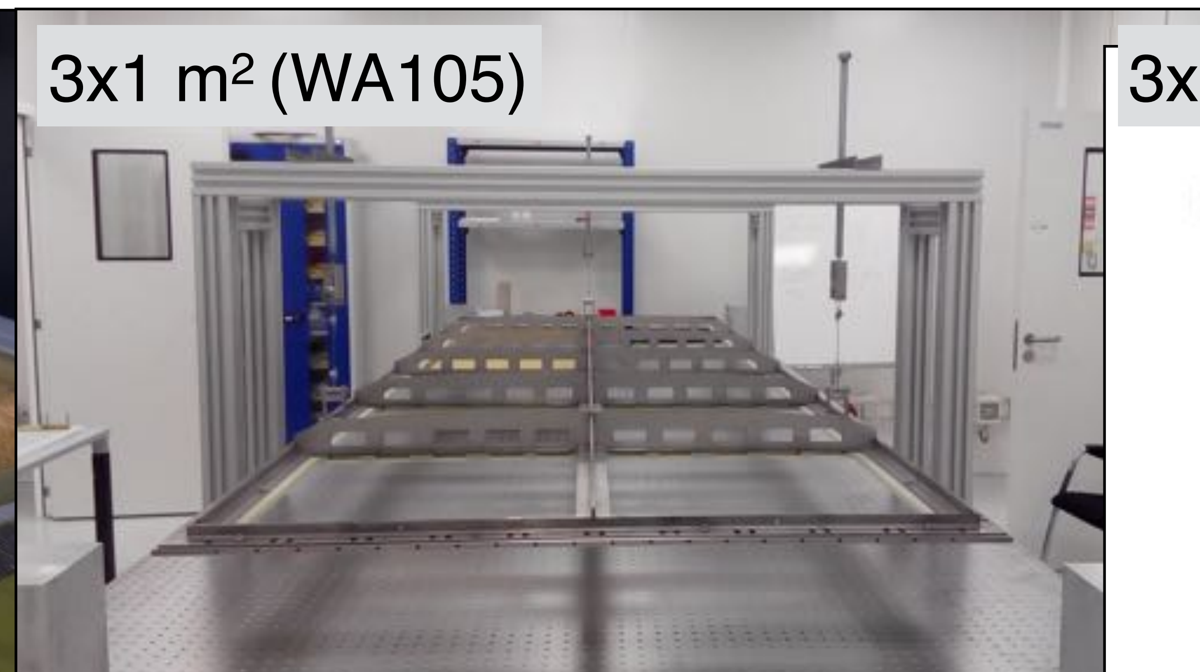
CRP- R&D towards increasing sizes

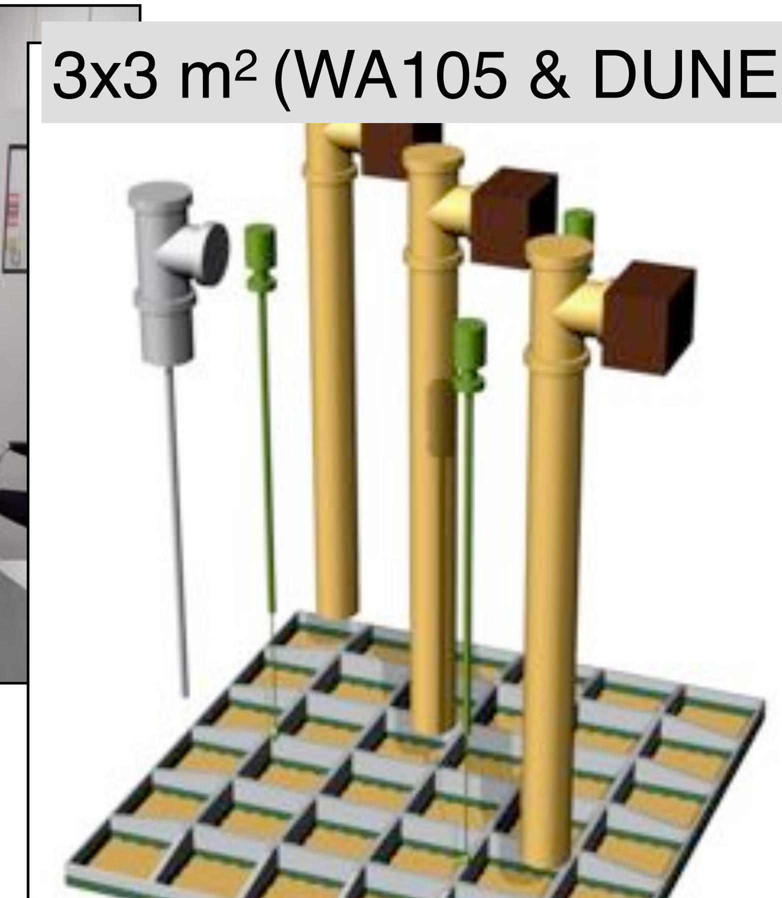

10x10 cm^2



40x80 cm^2

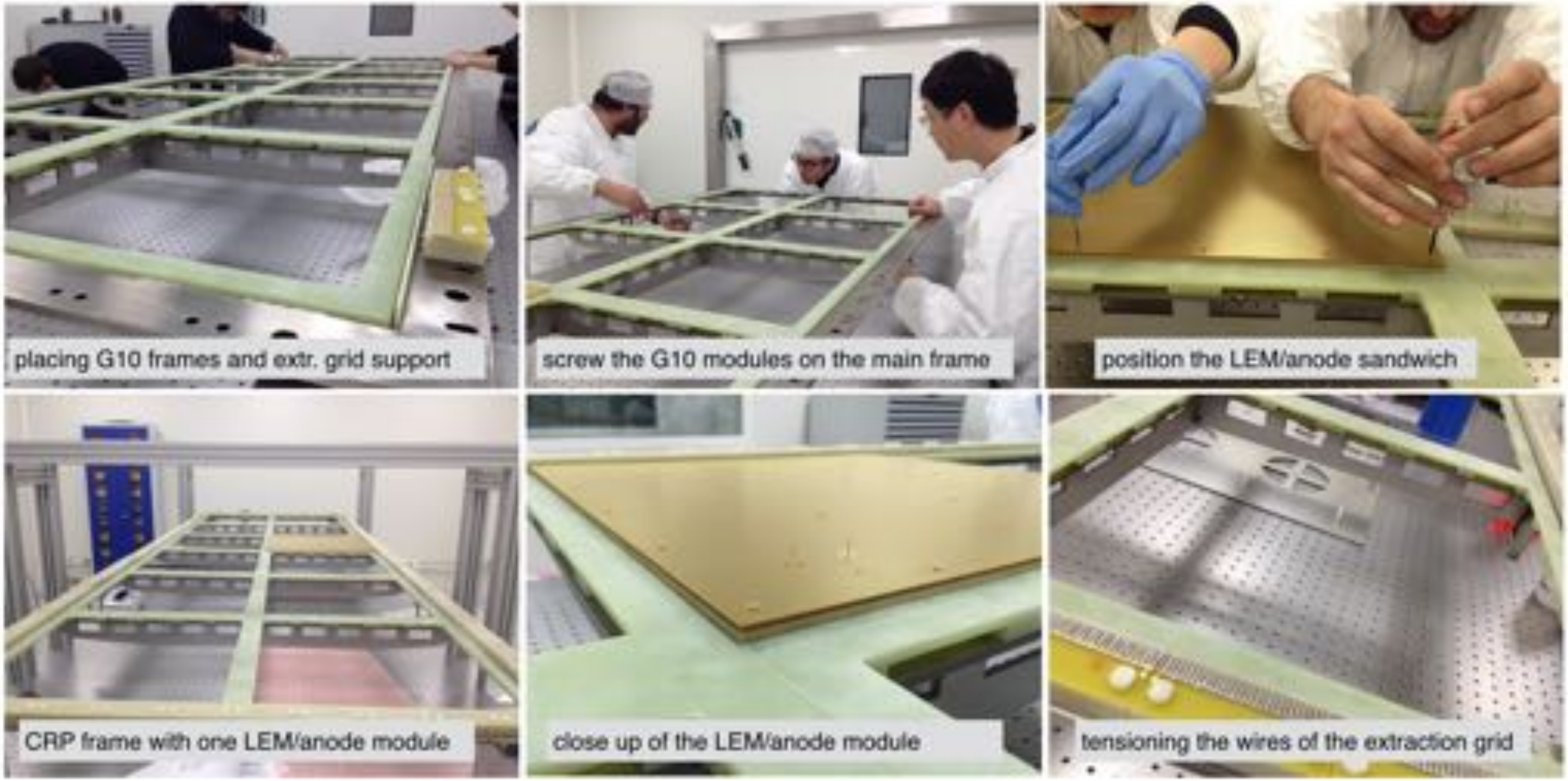

1x1 m^2


3x1 m^2 (WA105)

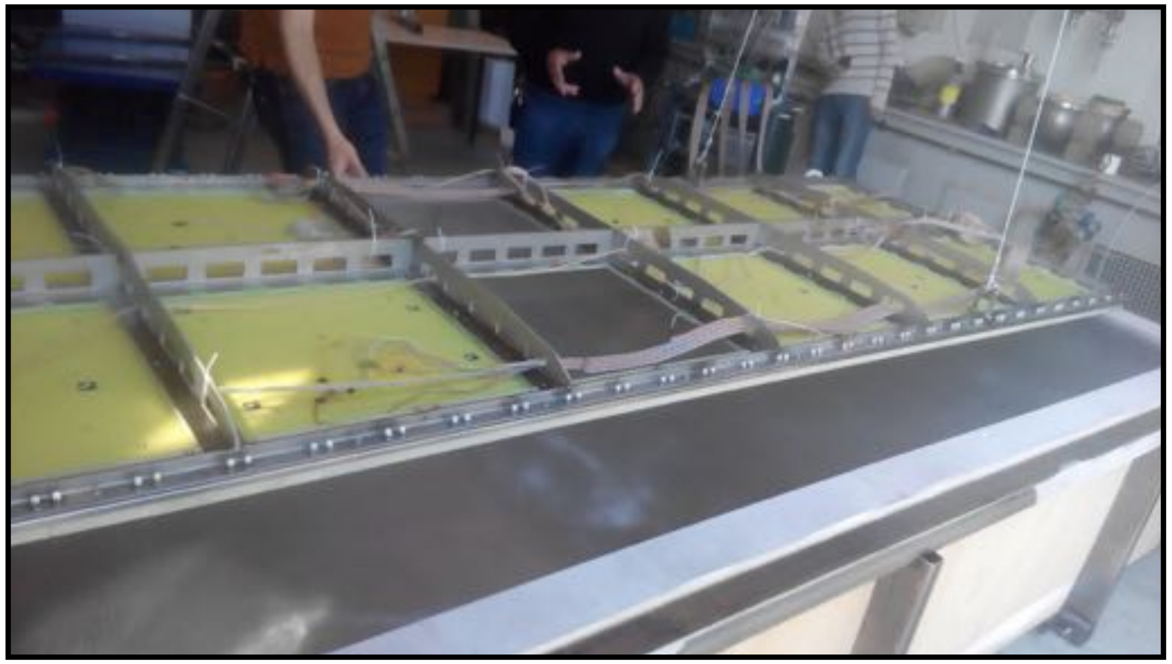

3x3 m^2 (WA105 & DUNE)

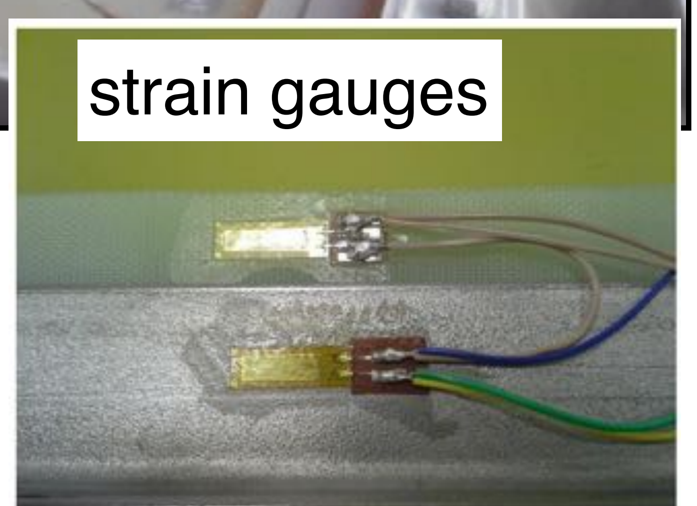
WA105 and DUNE CRPs are all composed of modules 50x50 cm2 LEMs and anodes

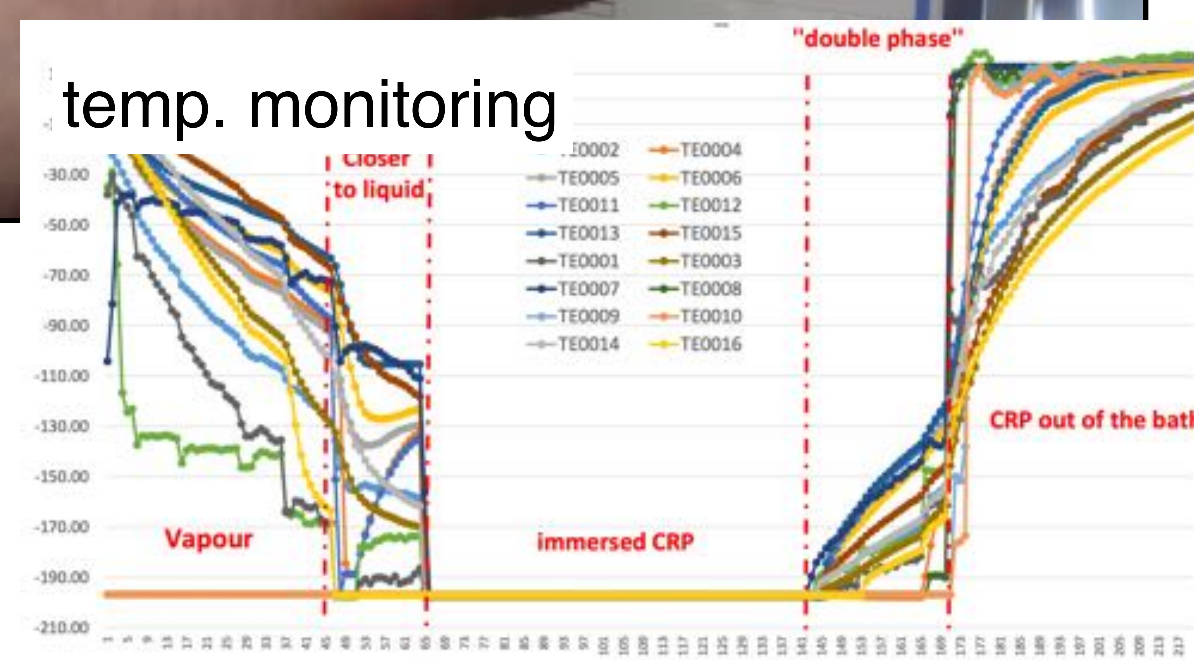
Assembly sequence on the CRP (3x1 m² CRP)



Tests in cold







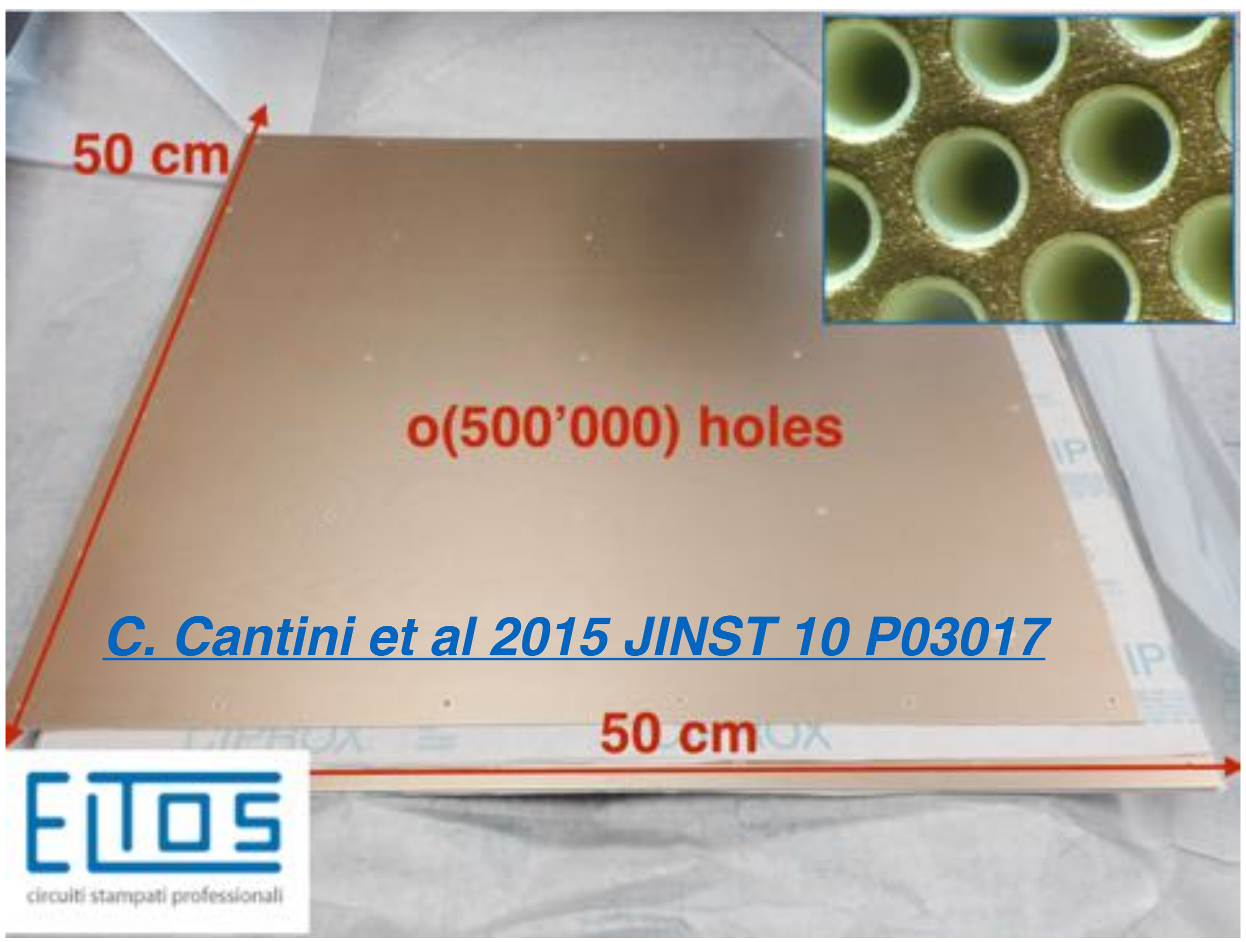
50x50 cm^2 LEM & ANODE

in the scope of the WA105 prototyping activities we have ordered and are testing 20 LEMs and 15 anodes from ELTOS.

Their design are the fruit of extensive R&D on smaller scale prototypes (10x10 cm^2 and 40x80 cm^2)

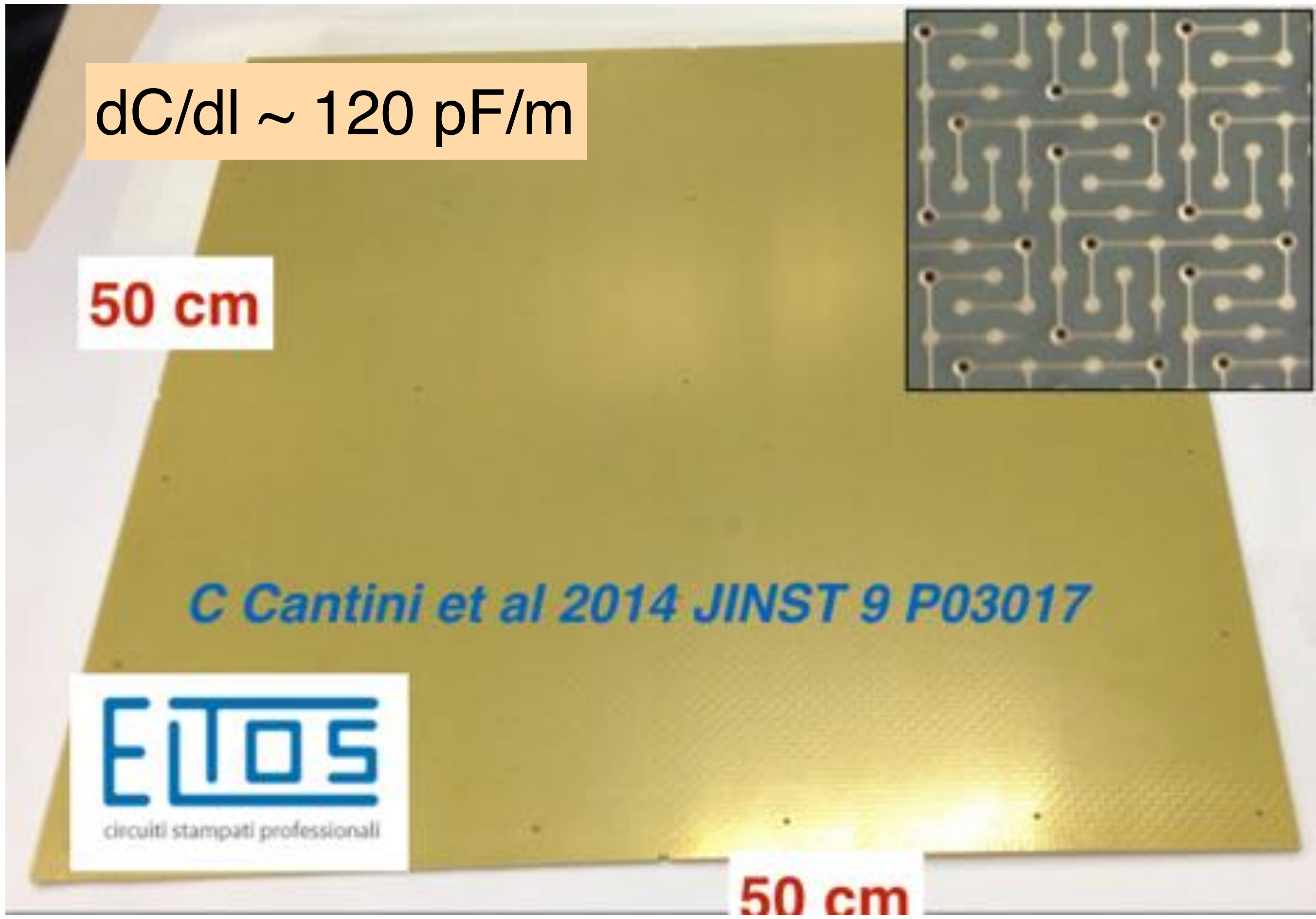
50x50 cm^2 LEM

-std PCB with o(150) holes/cm^2
-1 mm thick, 500 um ø holes, 40 um dielectric rim

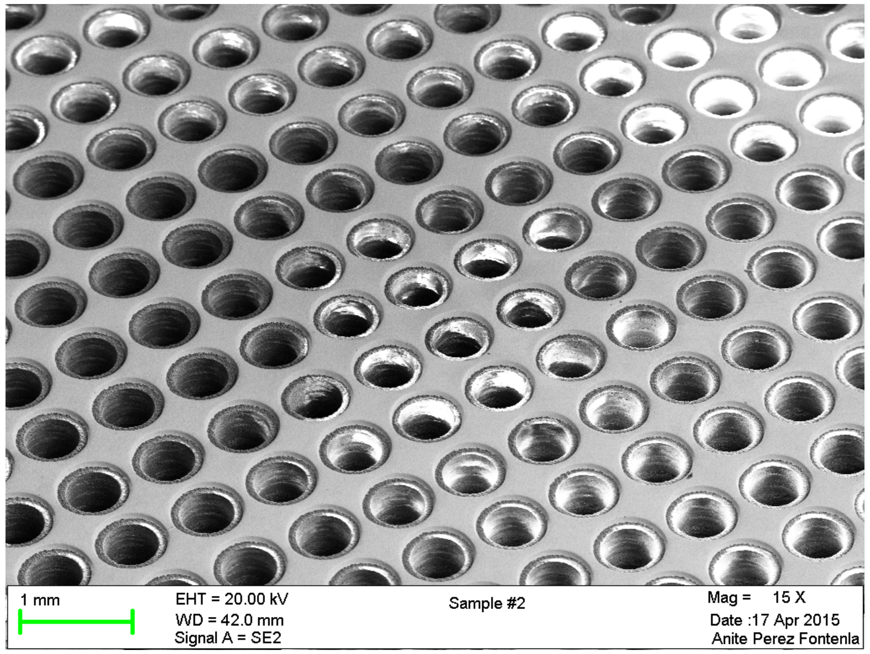


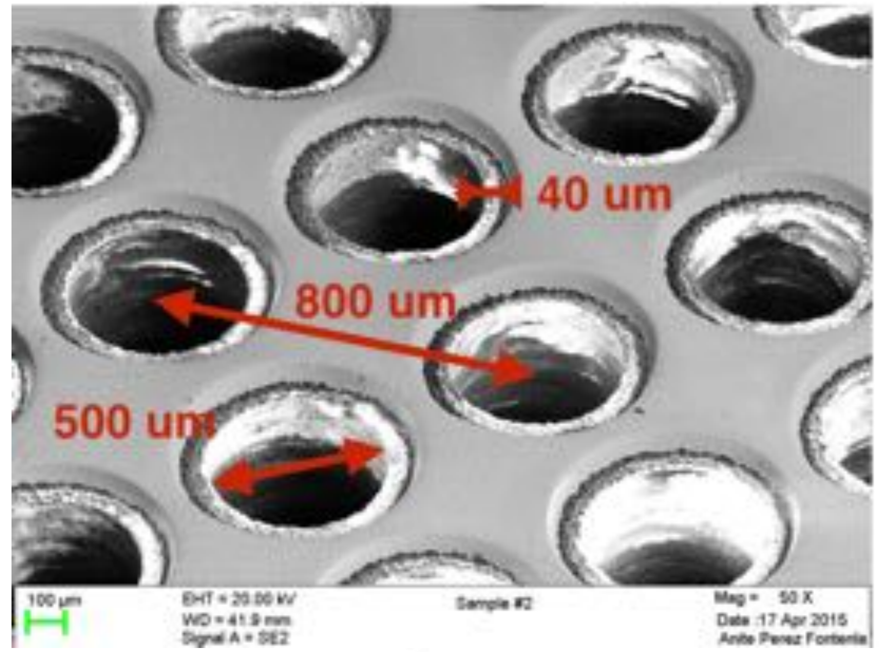
50x50 cm^2 Anode

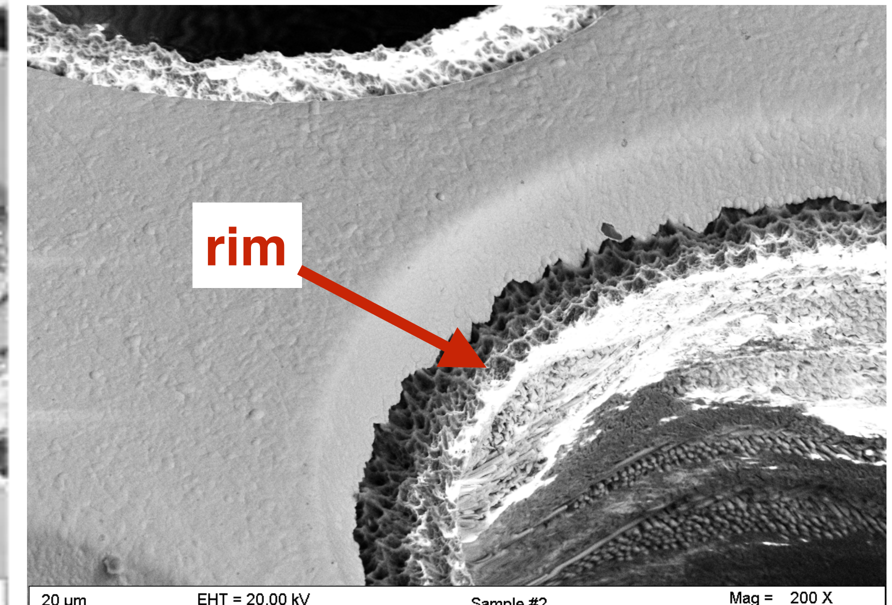
-optimised for long readout strip
-equal charge sharing on both views



LEM characterisation





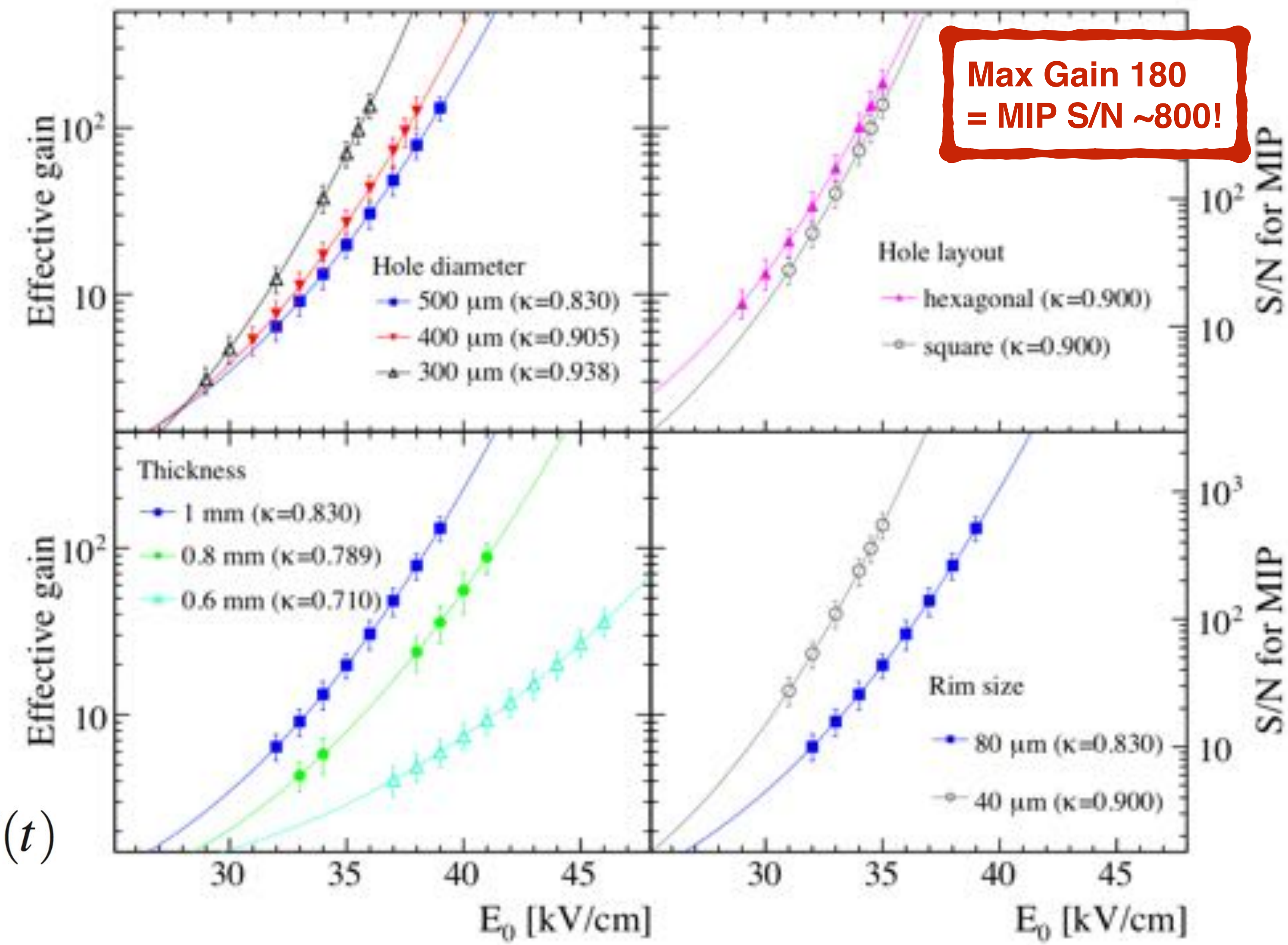


optimisation from 10x10 cm² LEMs in pure argon vapour

[*C. Cantini et al 2015 JINST 10 P03017*]()

effect of

- ✳rim size
- ✳hole diameter
- ✳hole layout
- ✳PCB thickness

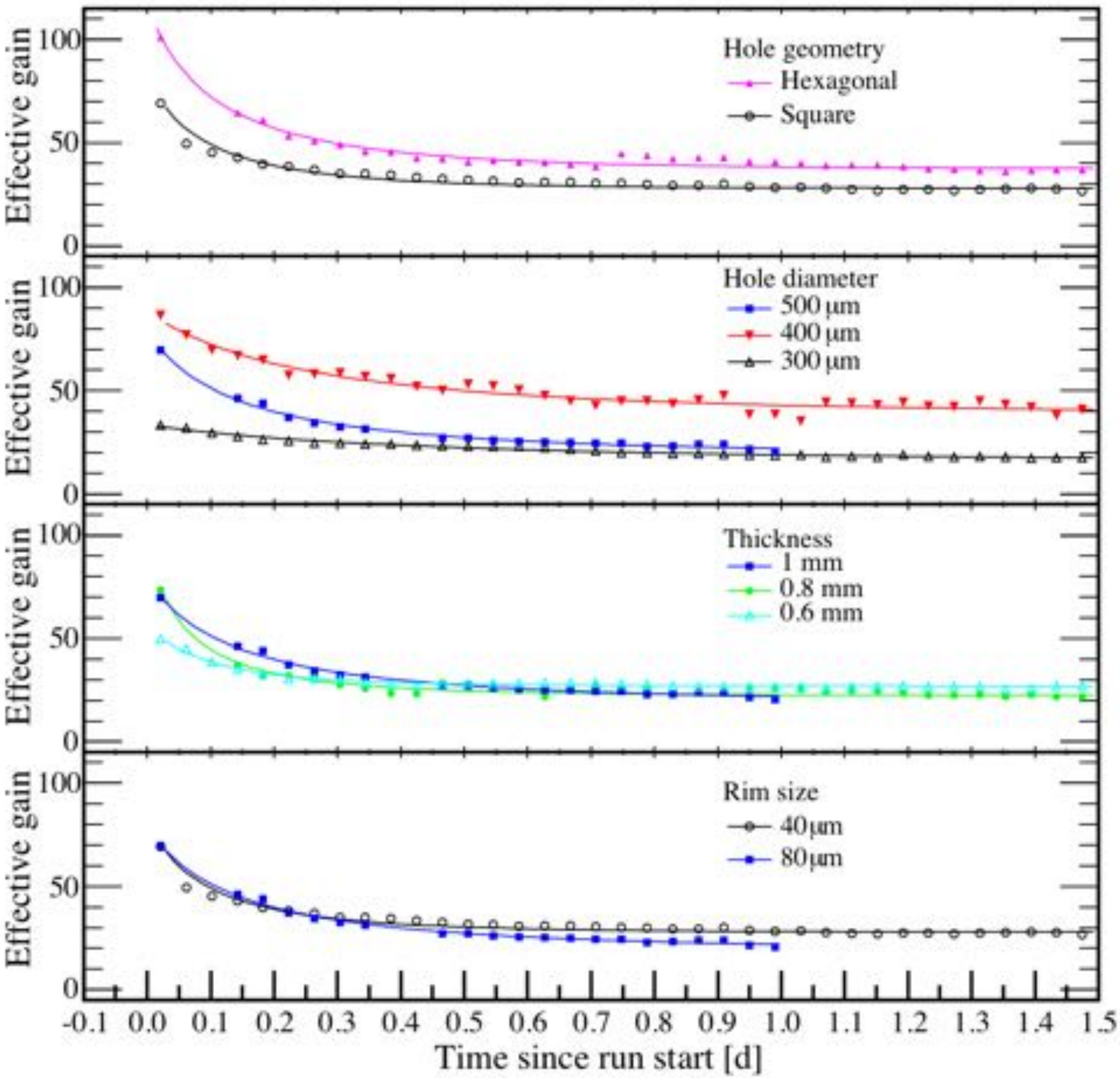


Fitting function:

$$G_{eff}(E,\rho,t) \equiv \mathscr{T} e^{\alpha(\rho,E)x} \times \mathscr{C}(t)$$

$$\alpha(\rho,E) = A\rho e^{-B\rho/E}$$

LEM gain stability



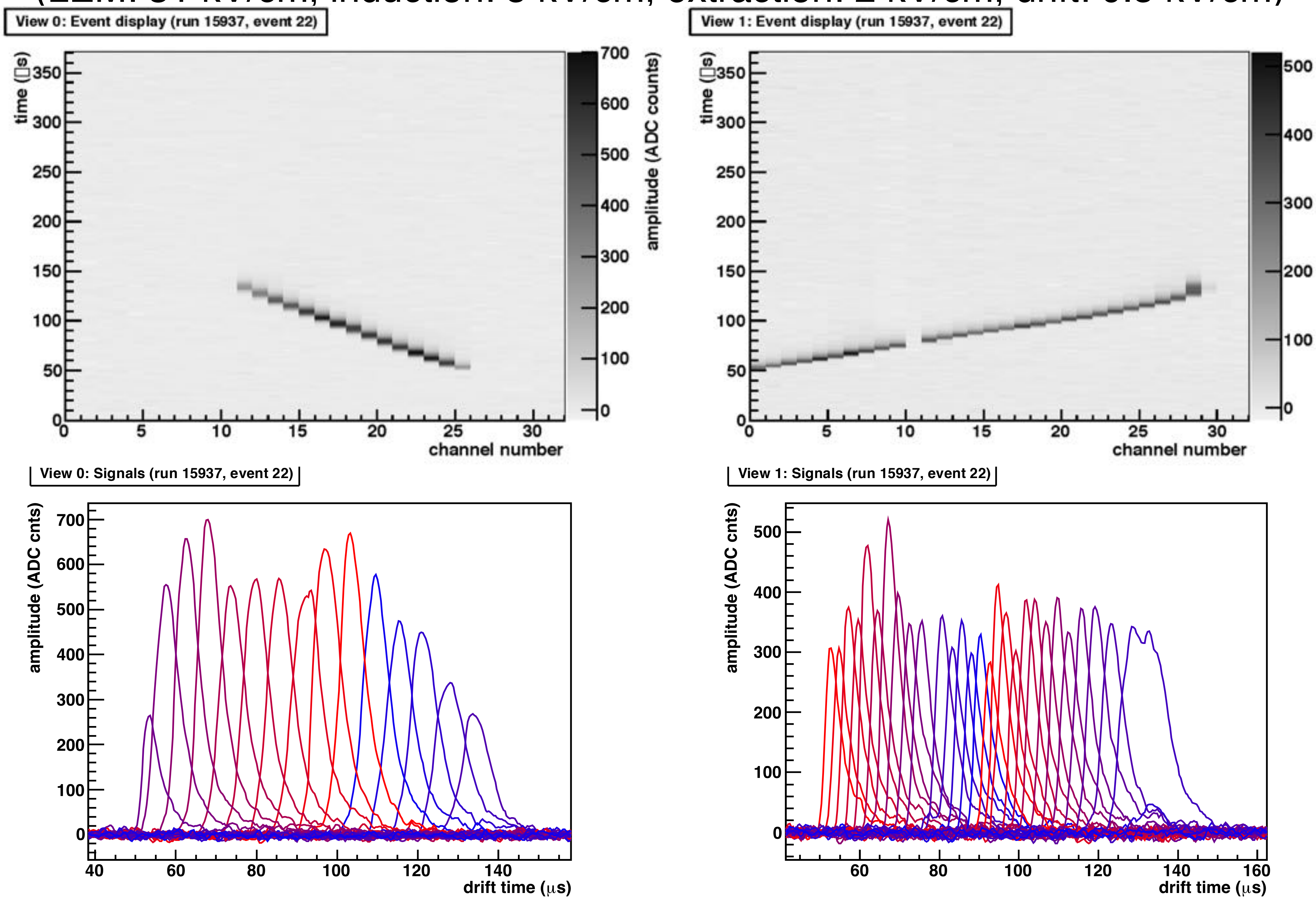
C. Cantini et al 2015 JINST 10 P03017

the LEMs have different charging up characteristics but all could be **operated stably at gains of at least 20**.

LEM gain stability

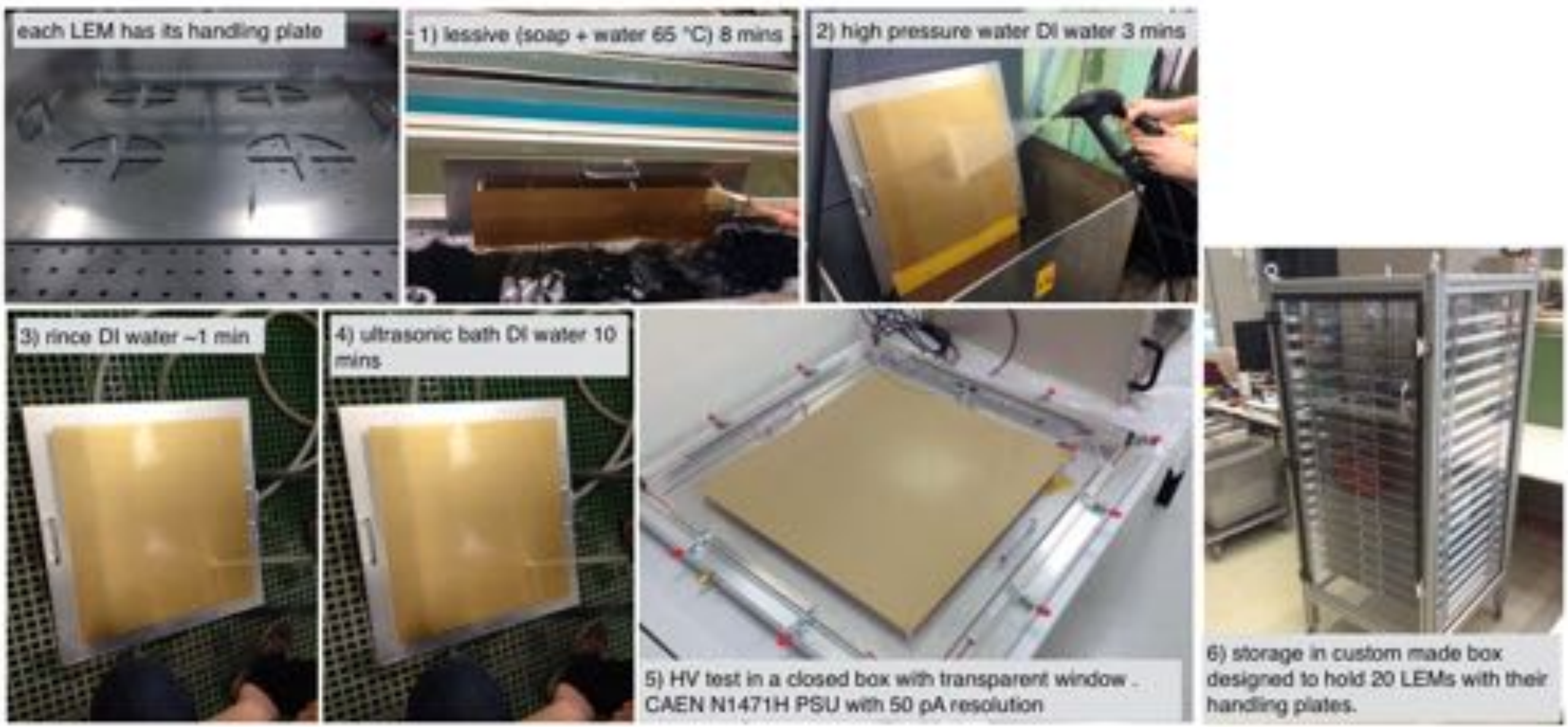
this is a MIP (data) event at gain of ~20 S/N

(LEM: 31 kV/cm, induction: 5 kV/cm, extraction: 2 kV/cm, drift: 0.5 kV/cm)



Large area LEMs

in the context of the WA105 3x1x1 m3 activities we have developed the complete chain for LEM validation from construction to installation. This includes shipping, cleaning, testing, QA, storage, etc…



Conclusion

- WA105 is **an approved CERN R&D program which will provide vital input for DUNE.** We have a set of **well defined technical and physics goals** to deliver which will have implications for the long baseline neutrino program.

- The **double phase readout is an extensively tested and proven technology.** that is now being scaled to the multi-square-meter area. It provides excellent S/N performance, hence low energy threshold, cost-effective etc..

- in the context of WA105 an intense effort is now been deployed to scale the double phase technology to relevant scales. **This includes the operation in the very near future of a 5 ton and 300 ton active volume demonstrators on the surface.**

- **A full Conceptual Design Report is available for a multi-10kt underground double phase LAr TPC**, developed in collaboration with Industrial Partners illustrating the construction sequences, cryogenic installation, safety issues, … all with a well defined costing.

Thank you!

Extra slides

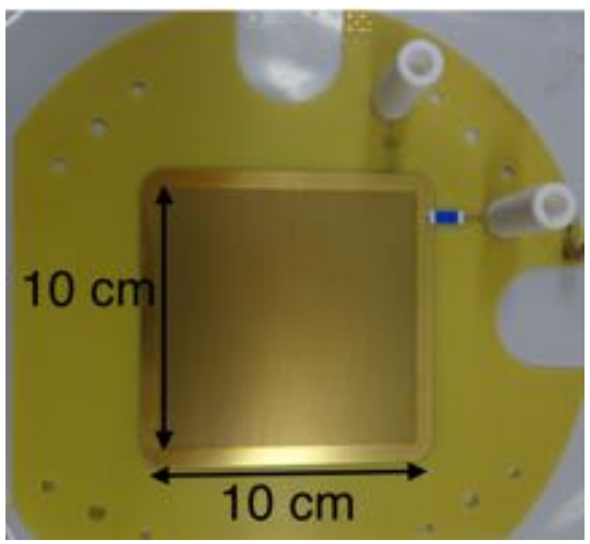
Developing square meter readout

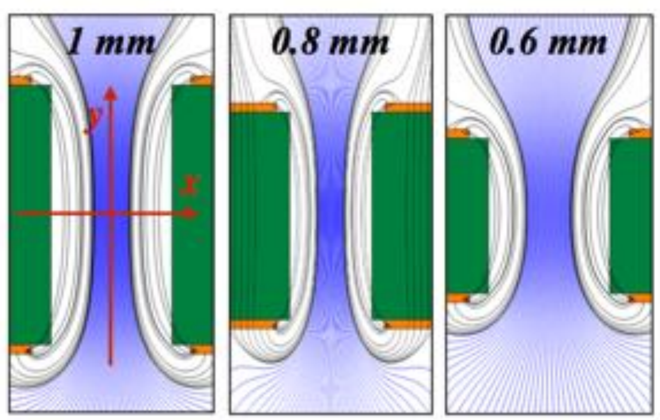
From the point of view of the readout the goals can be largely summarised as:

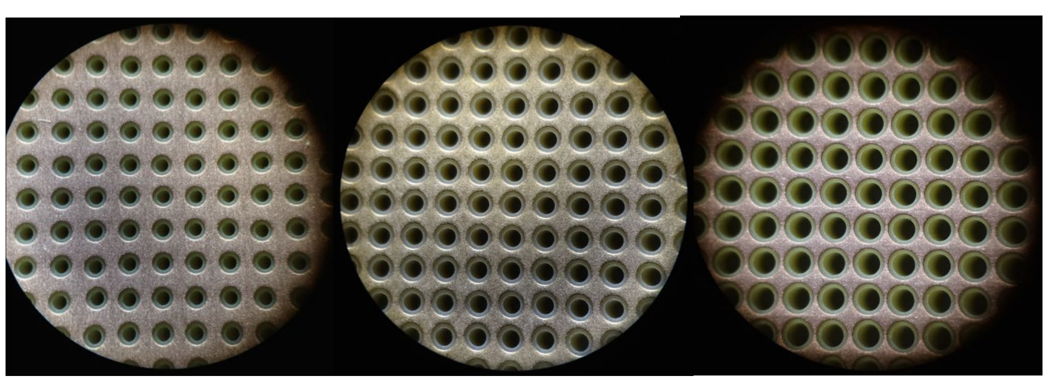
- we want to **amplify** the drifting charges by operating **50x50 cm² LEMs** in pure Argon vapor at 87K with the largest possible stable gain
- we want to readout the amplified charges on **meter long strips** with the lowest possible electronic noise.

a) LEM optimisation

C. Cantini et al 2015 JINST 10 P03017

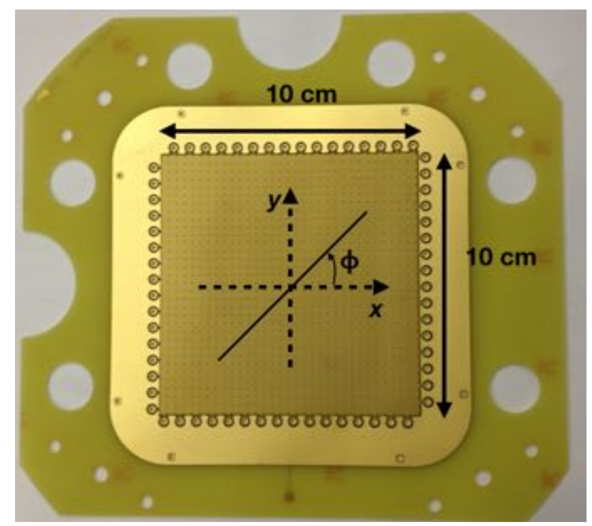


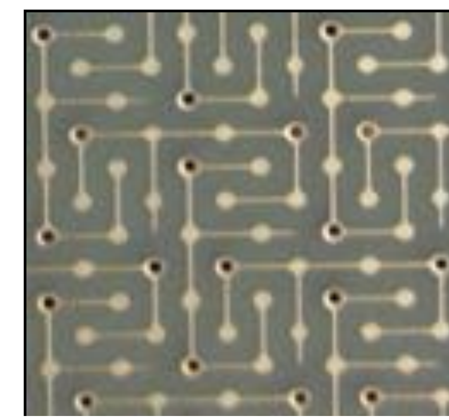




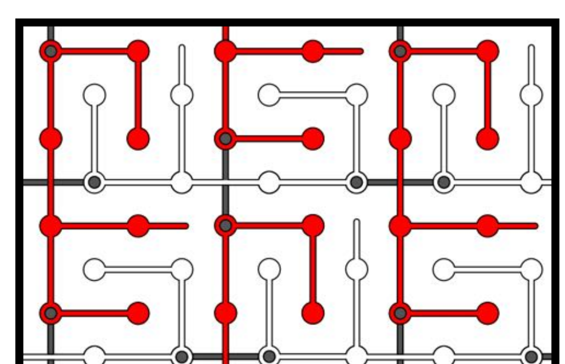
b) Anode optimisation

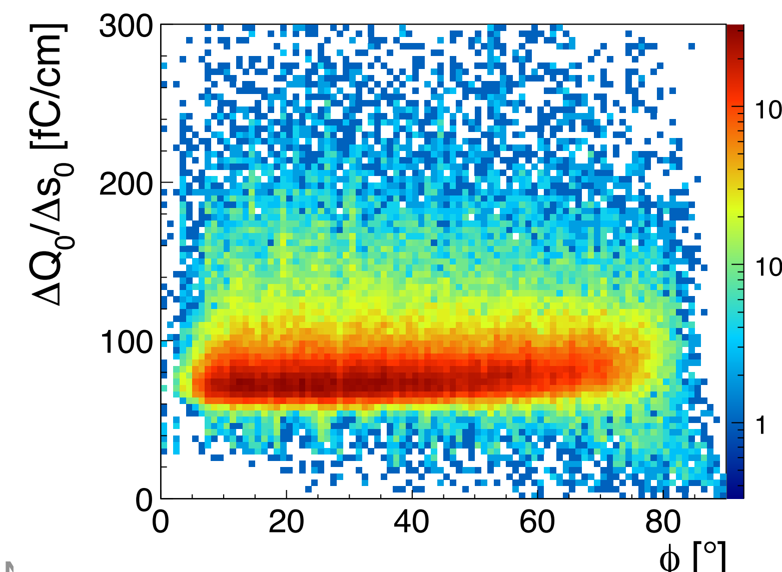
C Cantini et al 2014 JINST 9 P03017





dC/dl ~ 120 pF/m



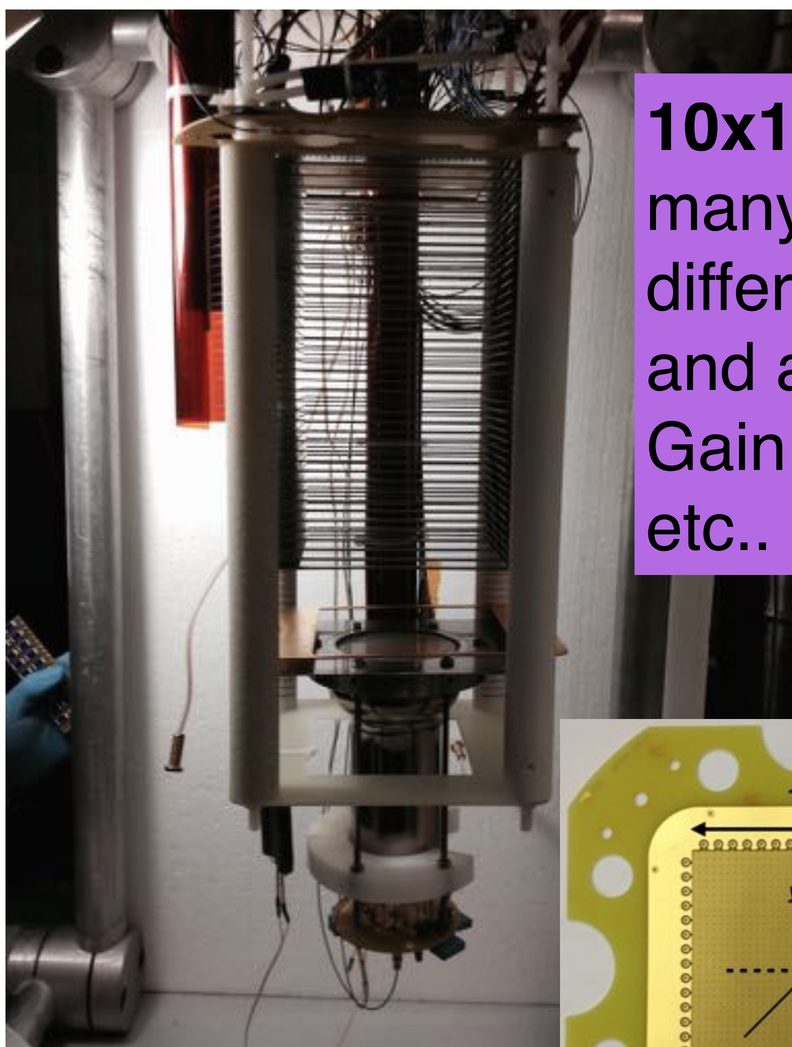


Developing square meter readout

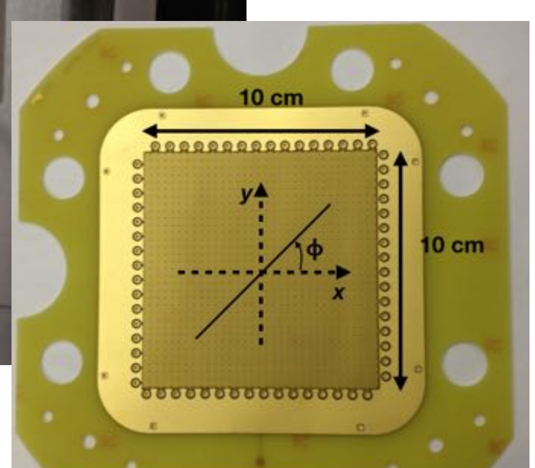
From the point of view of the readout the goals can be largely summarised as:

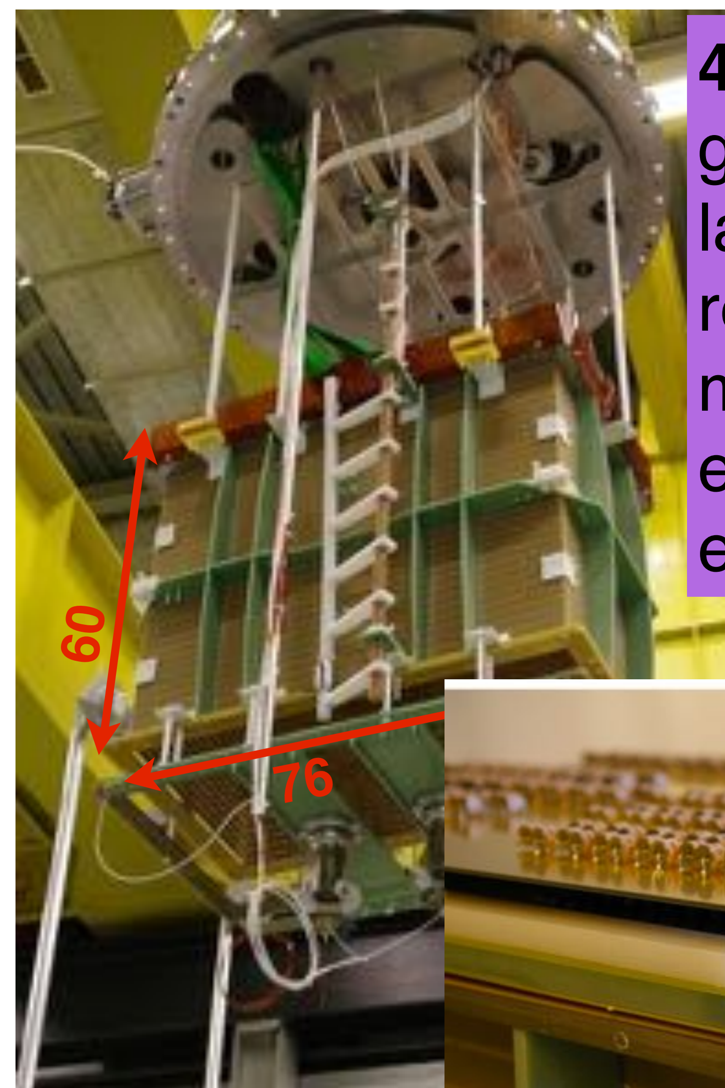
- we want to **amplify** the drifting charges by operating **50x50 cm^2 LEMs** in pure Argon vapor at 87K with the largest possible stable gain
- we want to readout the amplified charges on **meter long strips** with the lowest possible electronic noise.

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

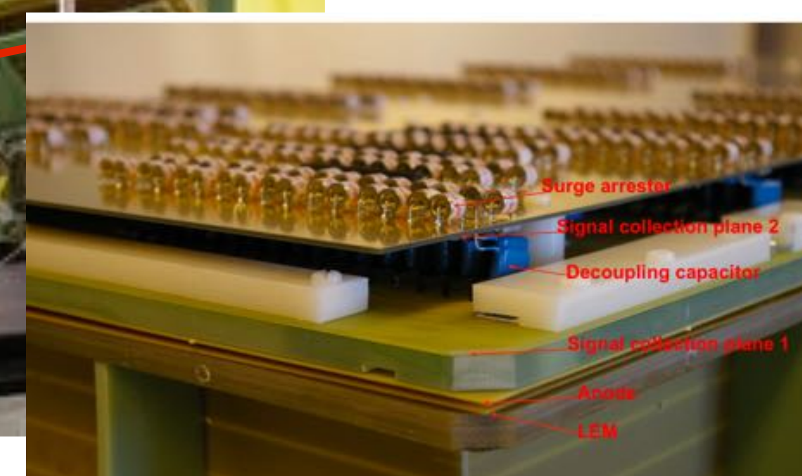


10x10 readouts
many test of different LEMs and anodes. Gain stability etc..

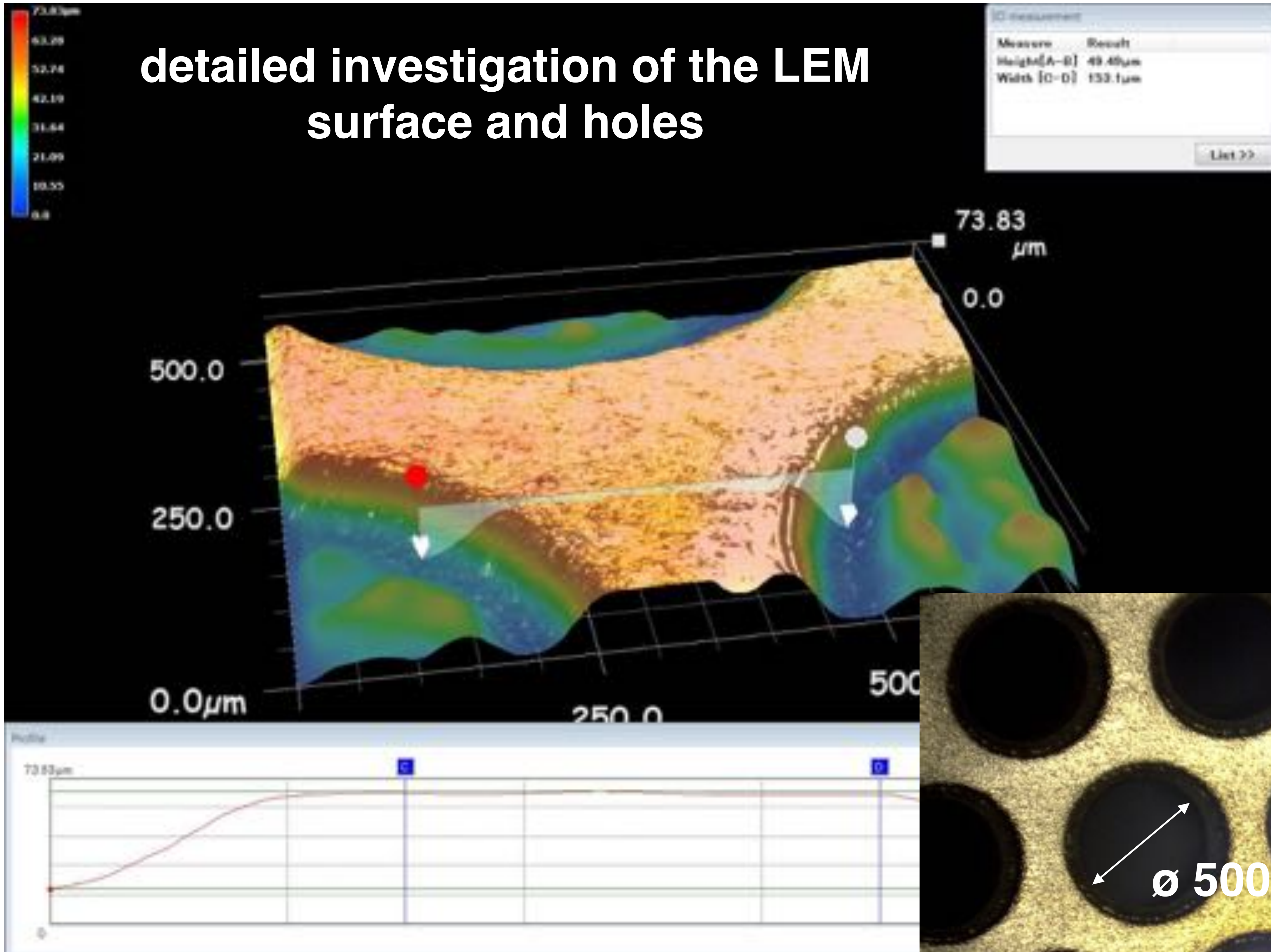


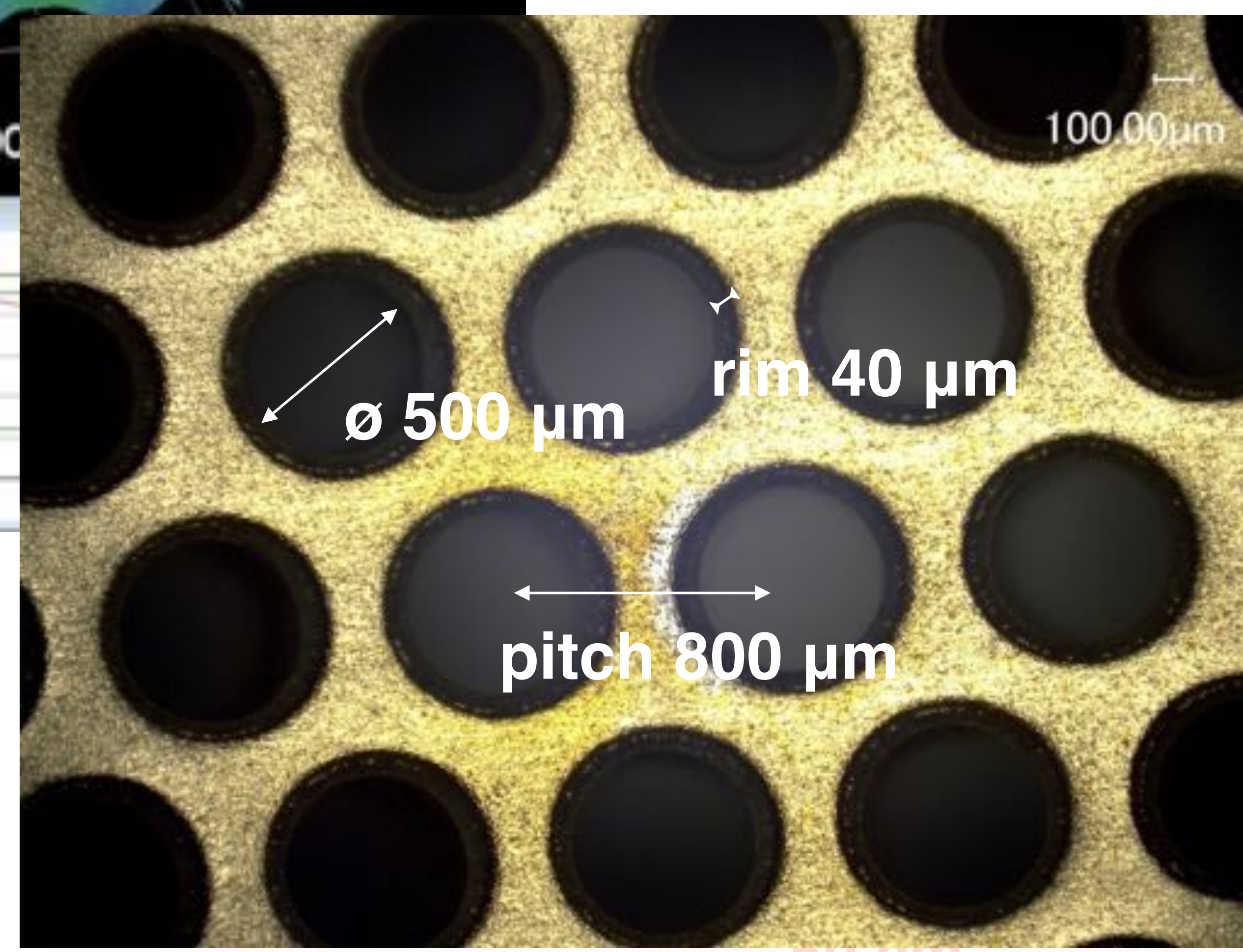


40x80 readout
gain behaviour on large areas.
reconstruction of more complex events (d-rays etc..)



50x50 cm^2 LEM & ANODE



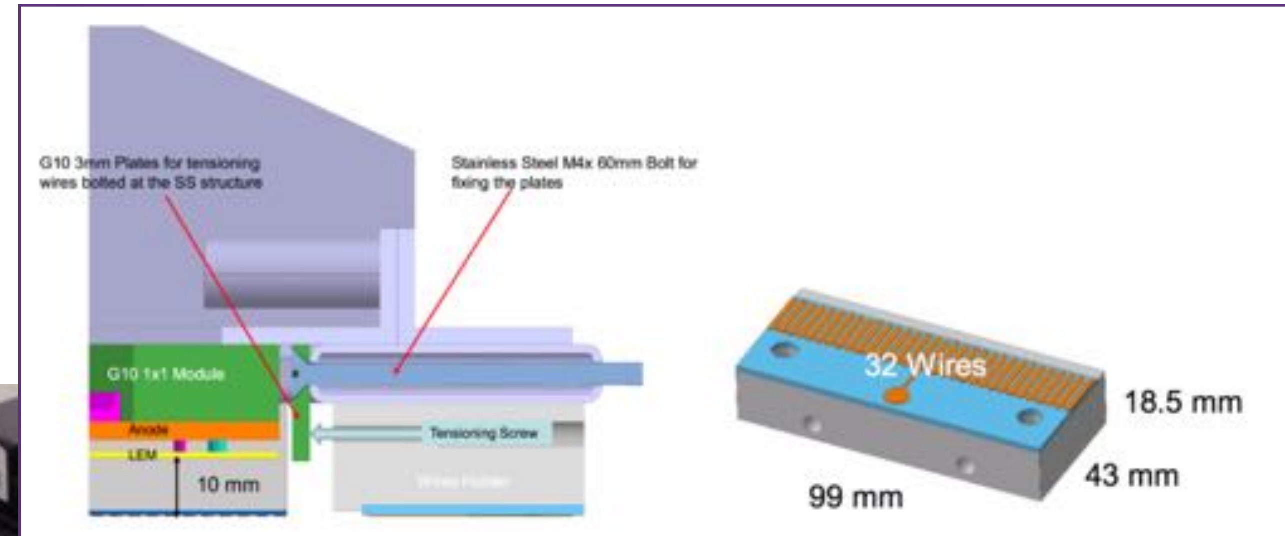


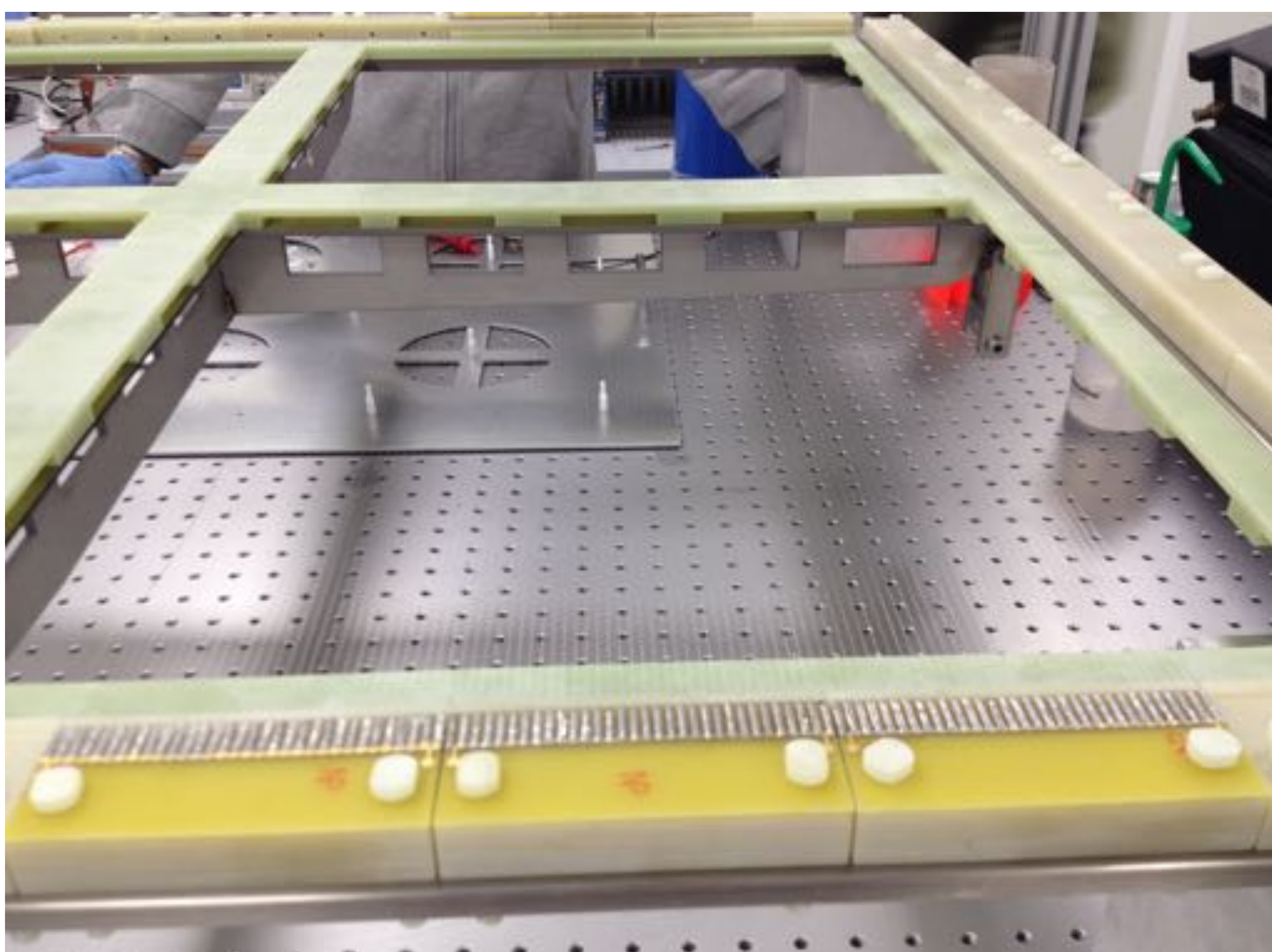
arxiv 1412.4402

The extraction grid

Charges need to be extracted from the liquid to the Ar vapour. Requires 2 kV/cm in the liquid, larger than the drift field of 500 V/cm.

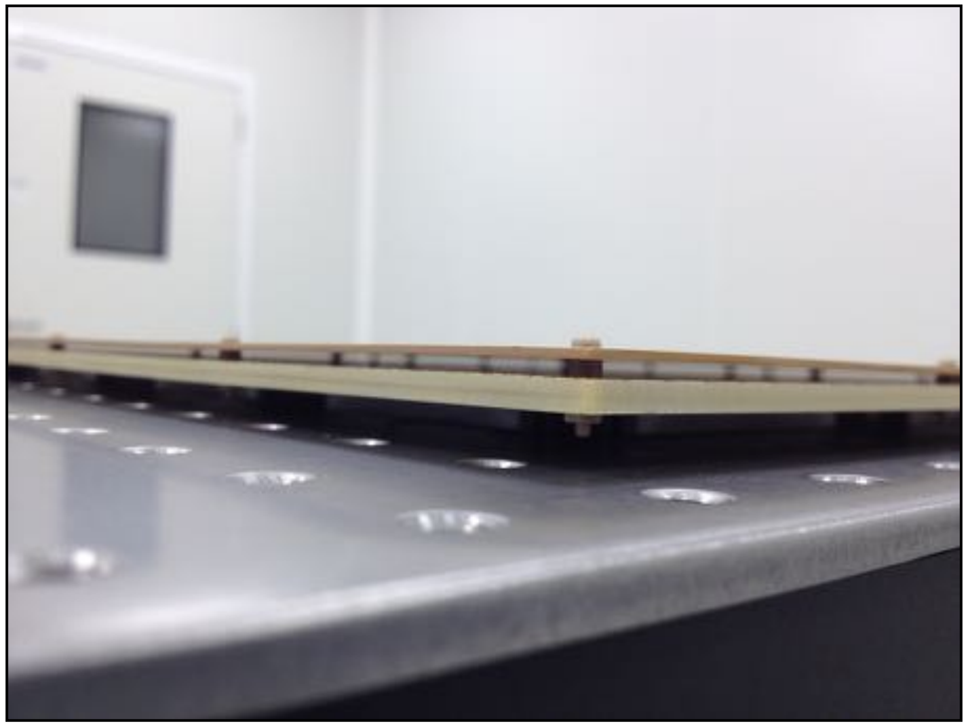
design 100 micron stainless wire with 3 mm pitch in x and y directions with dedicated tensioning system.

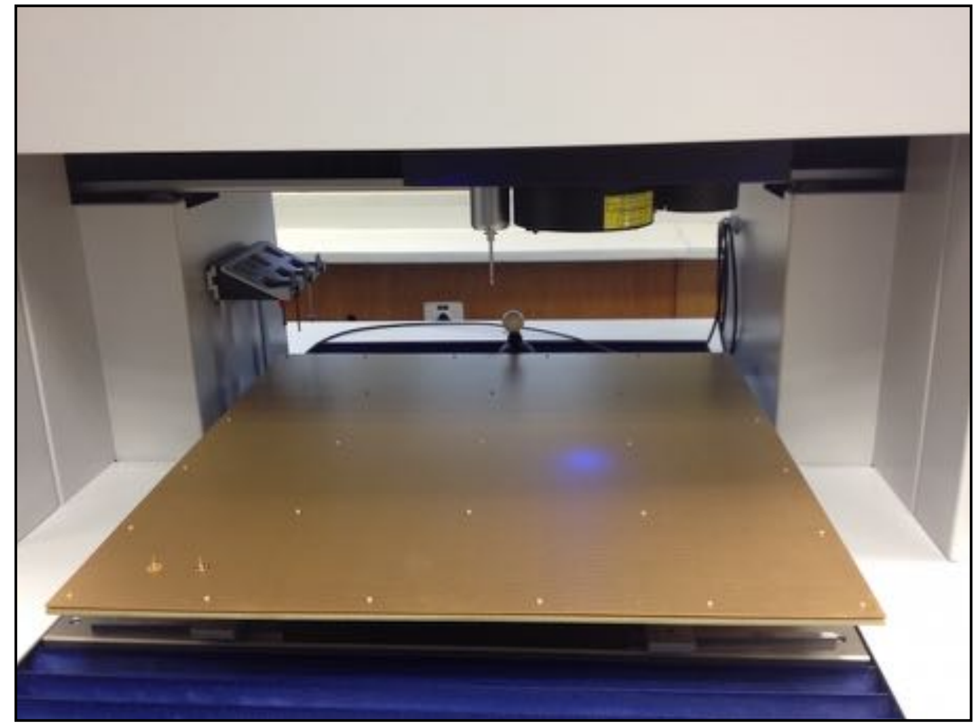


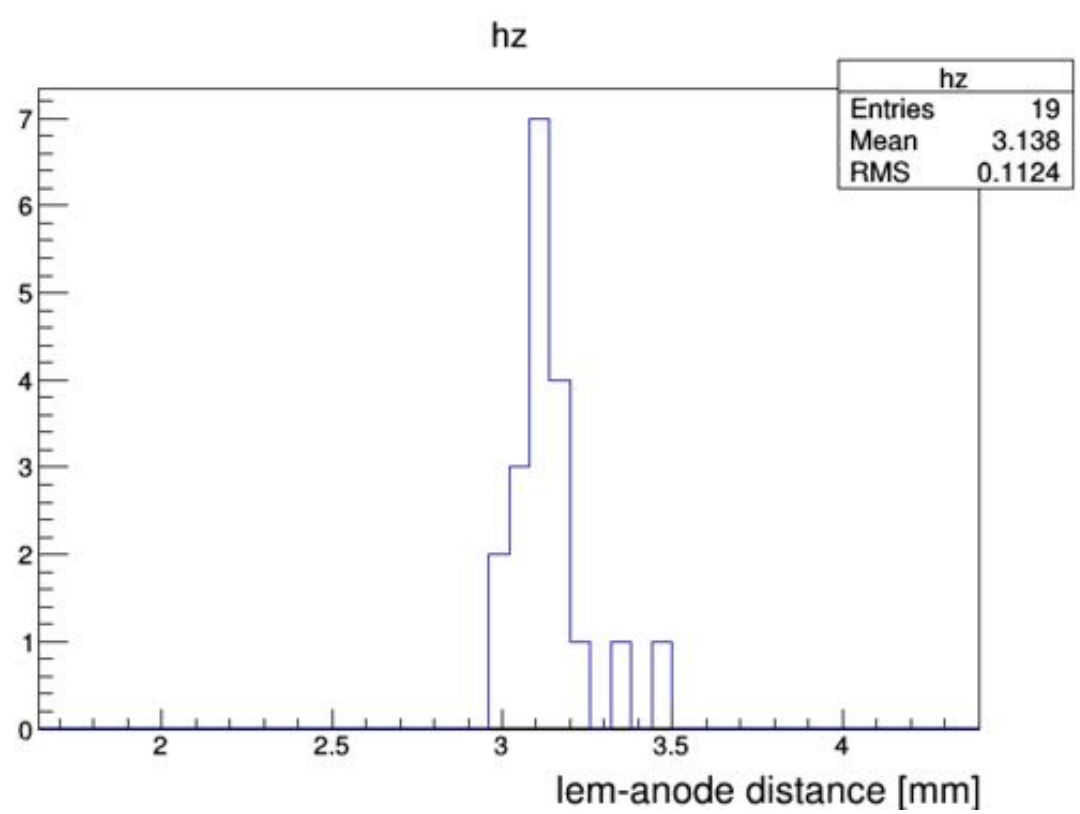


LEM + anode sandwich distance

distance between LEM & anode should be kept constant since it affects the gain. Here we had one module surveyed at the metrology lab. Planarity is within ~100 microns which is very acceptable in terms of gain variation (< 5 %).

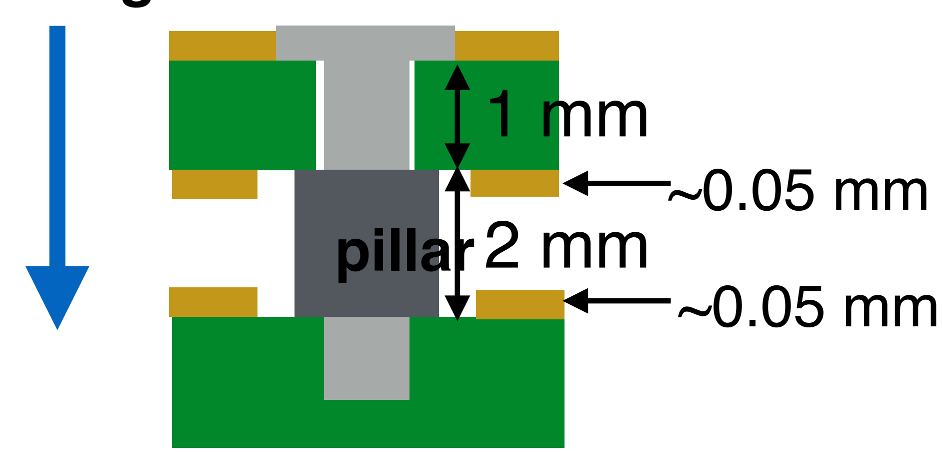




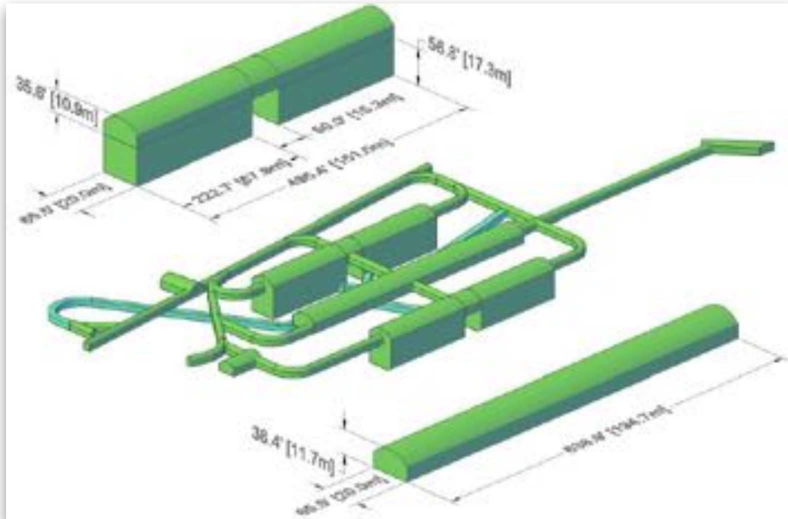


nominal ~ 2 (LEM-anode) + 1 (LEM thickness) + ~.05 mm ≈ **3.05 mm**

camera through LEM hole



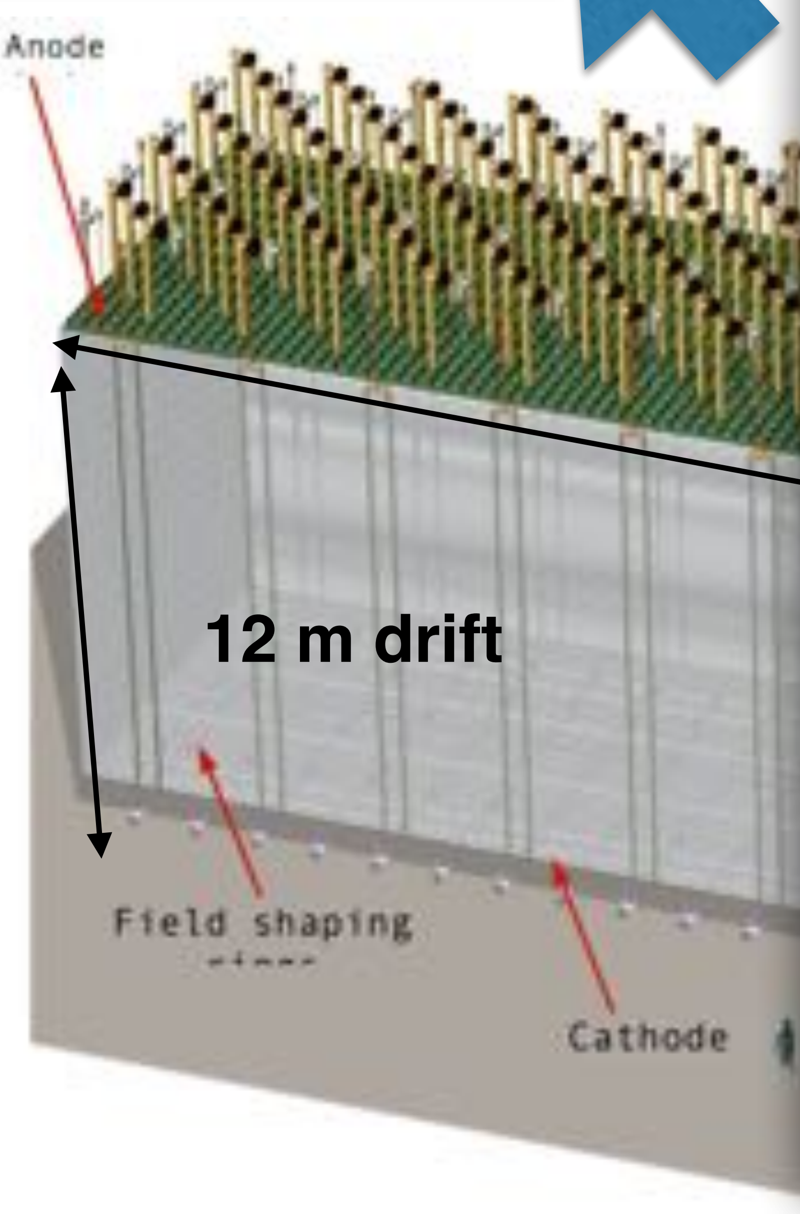
DUNE double phase far detector



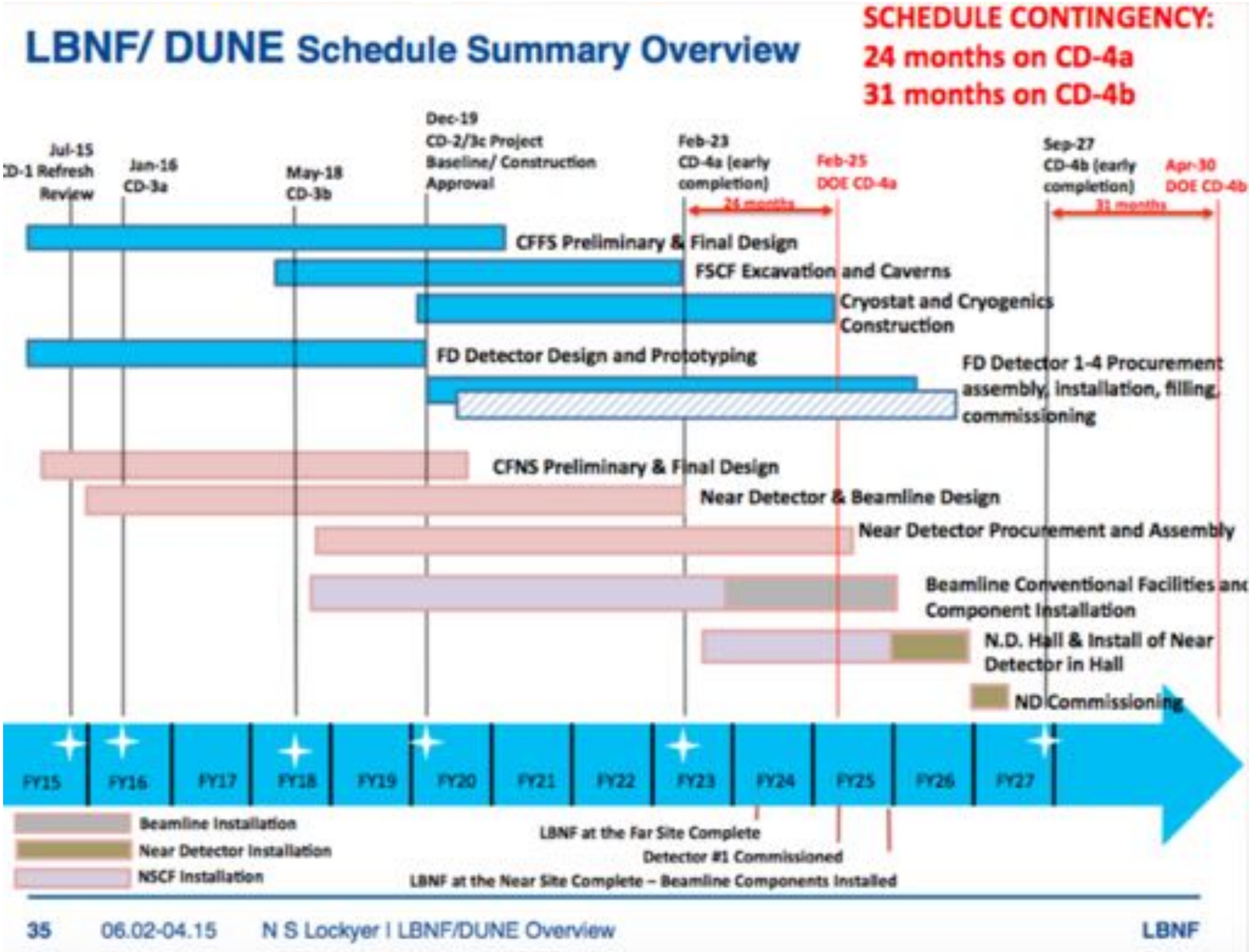
1.2 MW neutrino beam from FNAL to SURF underground laborato

4 underg

Active volume sizes	W = 12m	L = 60m	H = 12m
Active volume / LAr mass	8'640m^3	**12'096Ton**	
Number of field rings	60		
Field ring vertical spacing	200mm		
Field ring tube diameter	140mm		
Anode deck size	W = 12m	L = 60m	
Sub-Anode size	W = 3m	L = 3m	
Number of Sub-anodes	4 x 20 = **80**		
Number of CRP / sub-anode	36		
Total number of CRP	2880		
Number of LEM planes / sub-anode	36		
Total number of LEM planes	2880		
Number SFT chimneys / sub-anode	3		
Total number of SFT chimneys	**240**		
Number of read-out channels / SFT chimney	640		
Total number of read-out channels	**153'600**		
Number of Suspension FT / sub-anode	3		
Total number of Suspension FTs	**240**		
Number of Slow Control FT / sub-anode	1		
Total number of Slow Control FTs	**80**		
Number of HV feedthrough	1		
HV for vertical drift	**600 – 900 kV**		
Number of voltage degrader resistive chains	4		
Resistor value	100 MΩ		
Total number of resistors	300		
Total number of PMTs	**180** (1 / 4m^2)		



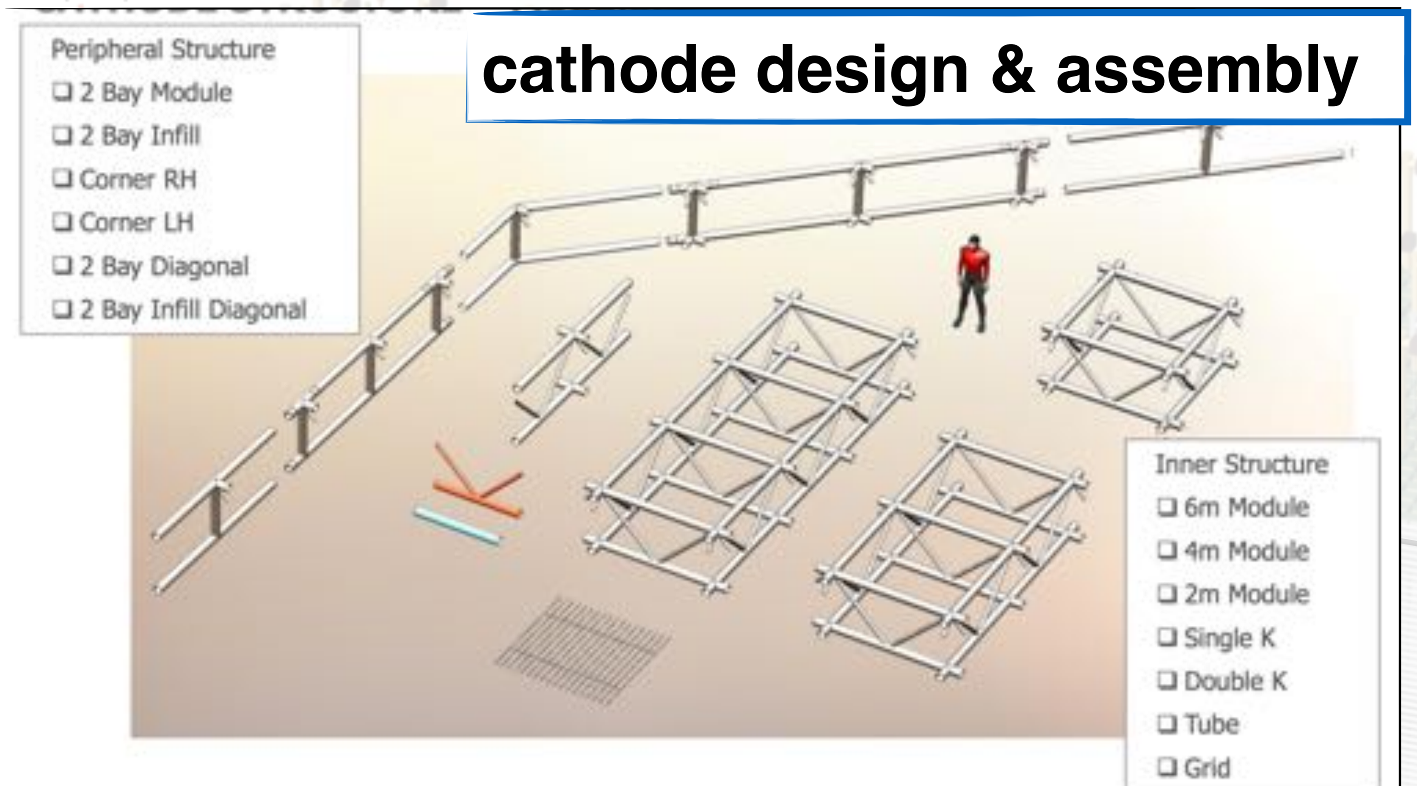
DUNE schedule



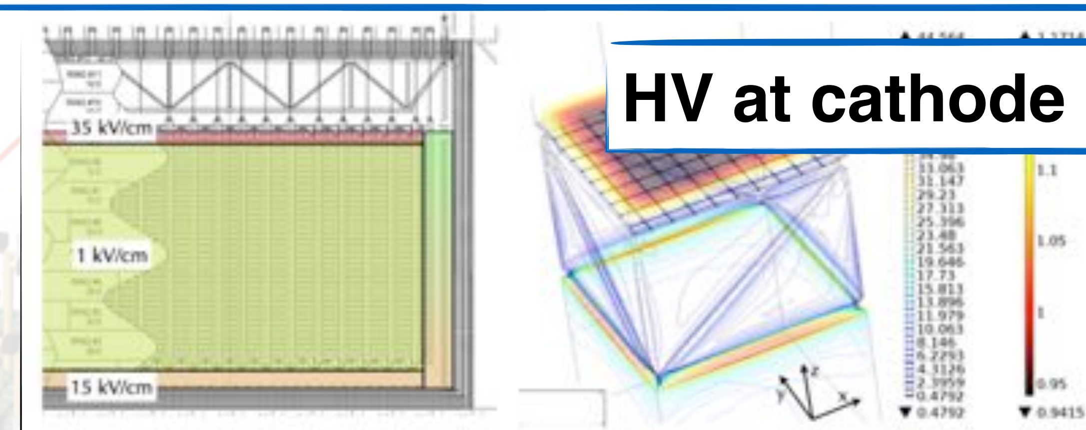
CRP for DUNE double phase far detector

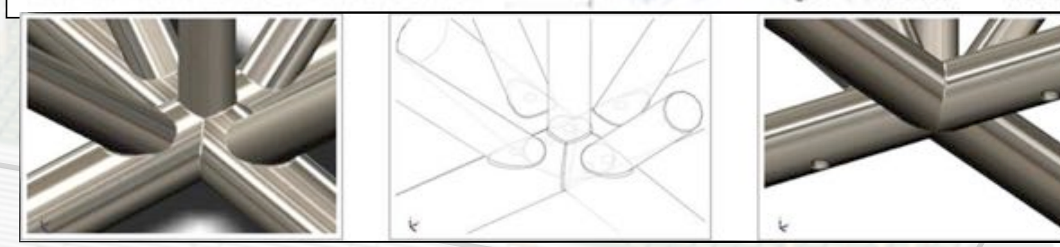
Many aspects have already been studied with industrial partners in the scope of LAGUNA

cathode design & assembly

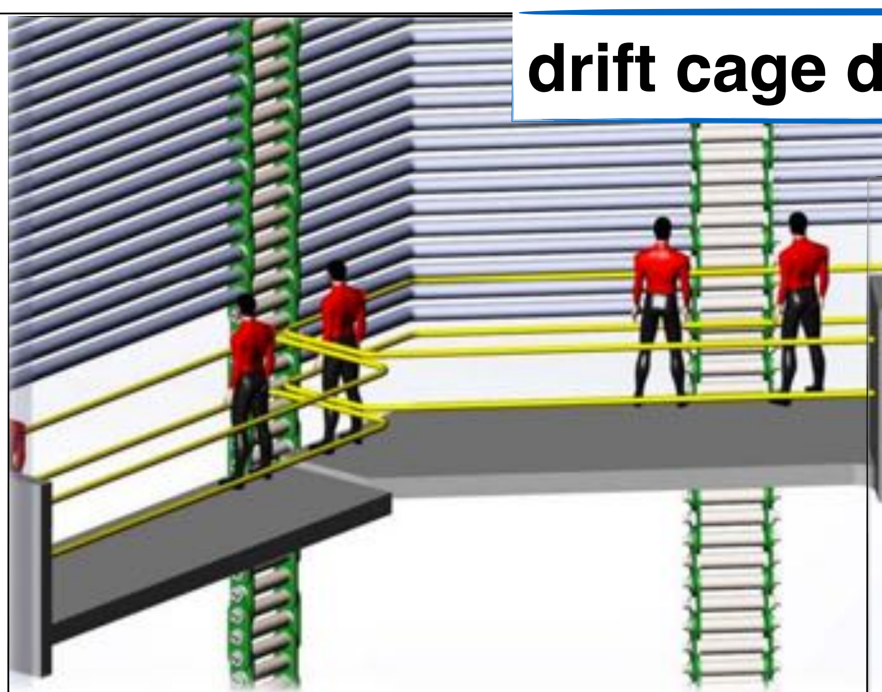


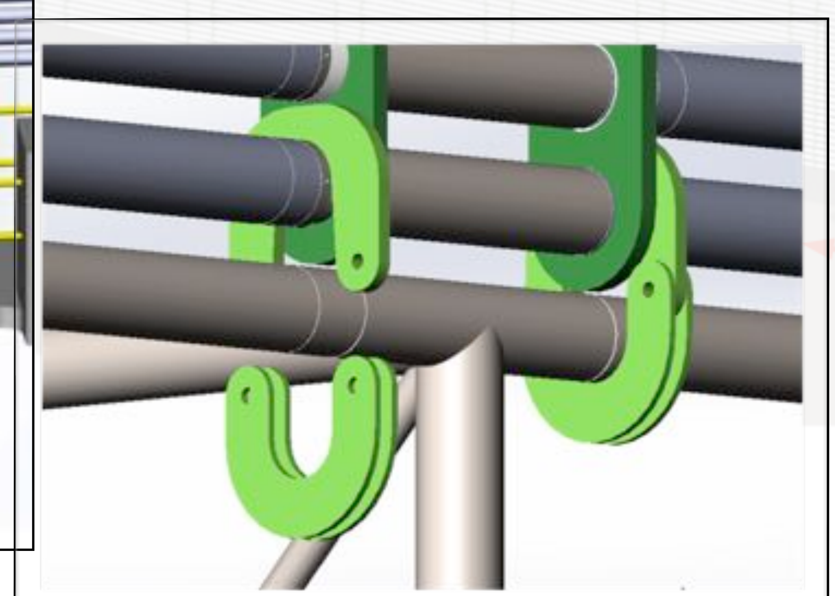
HV at cathode



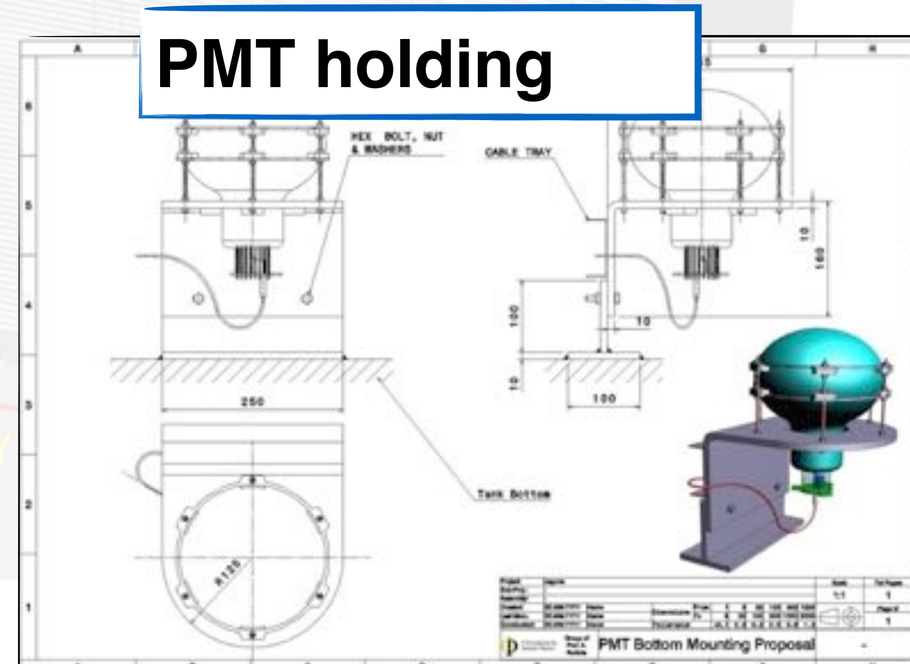


drift cage design & assembly

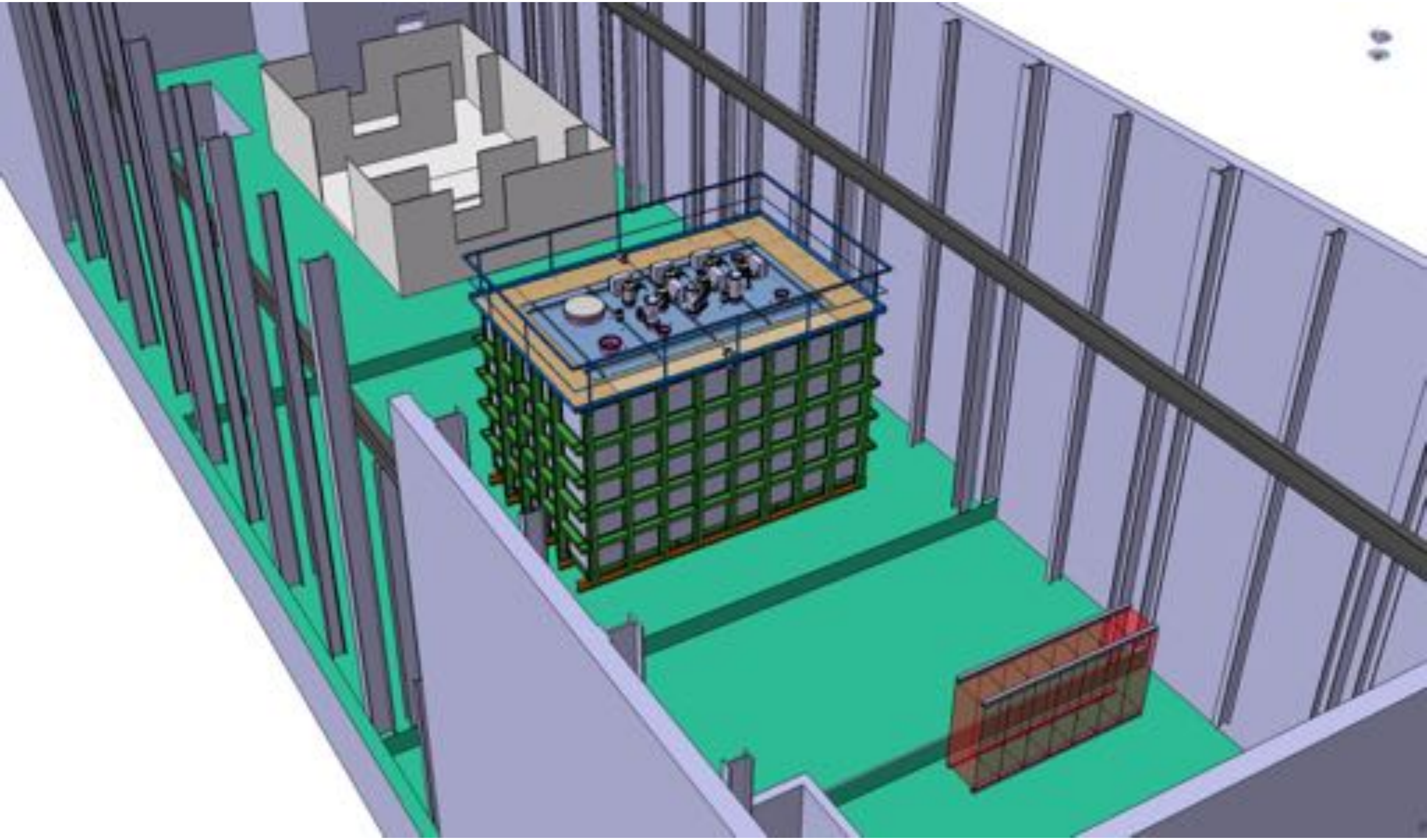




PMT holding

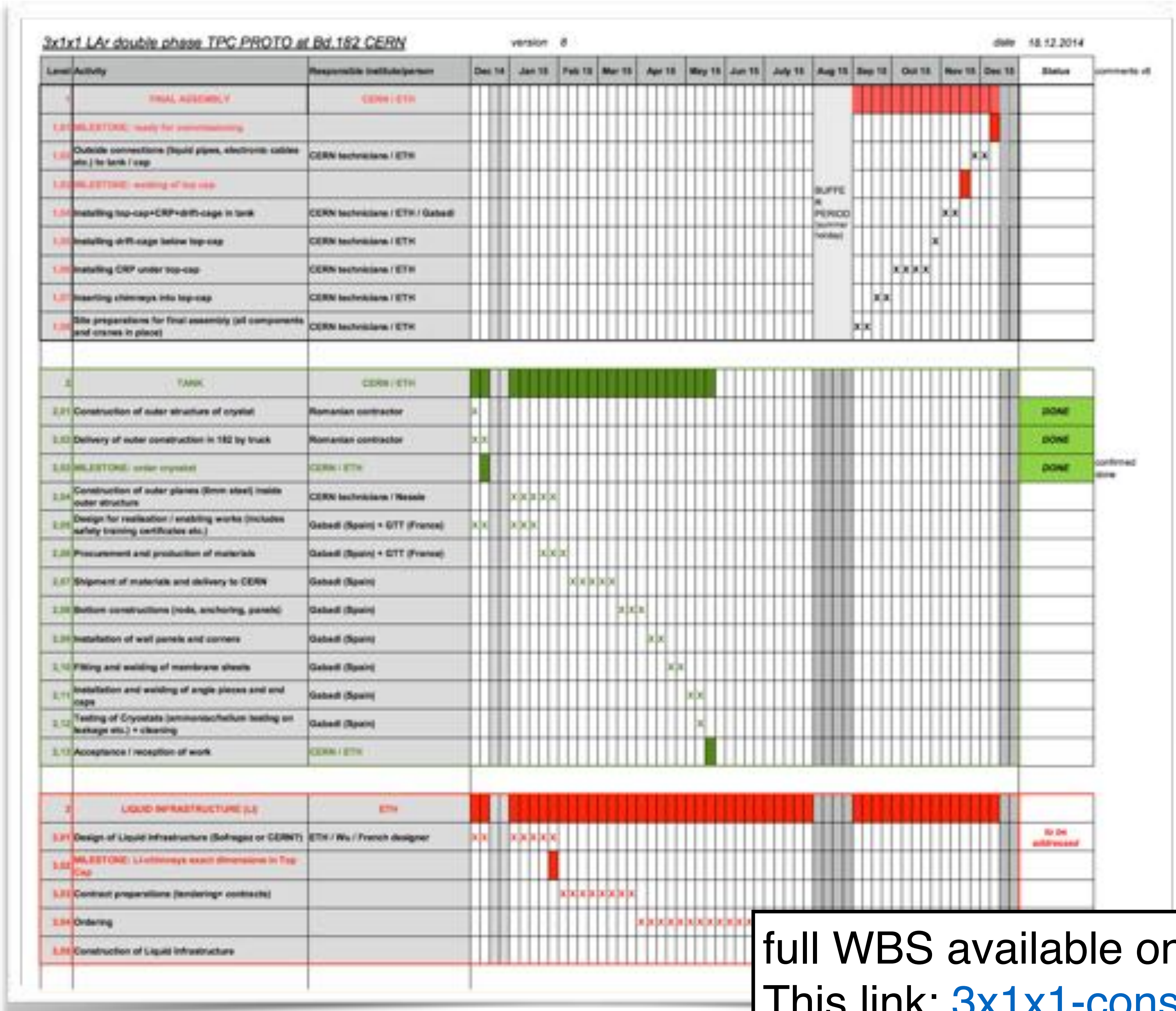


Lar Proto layout in building 182 at CERN



Installation schedule

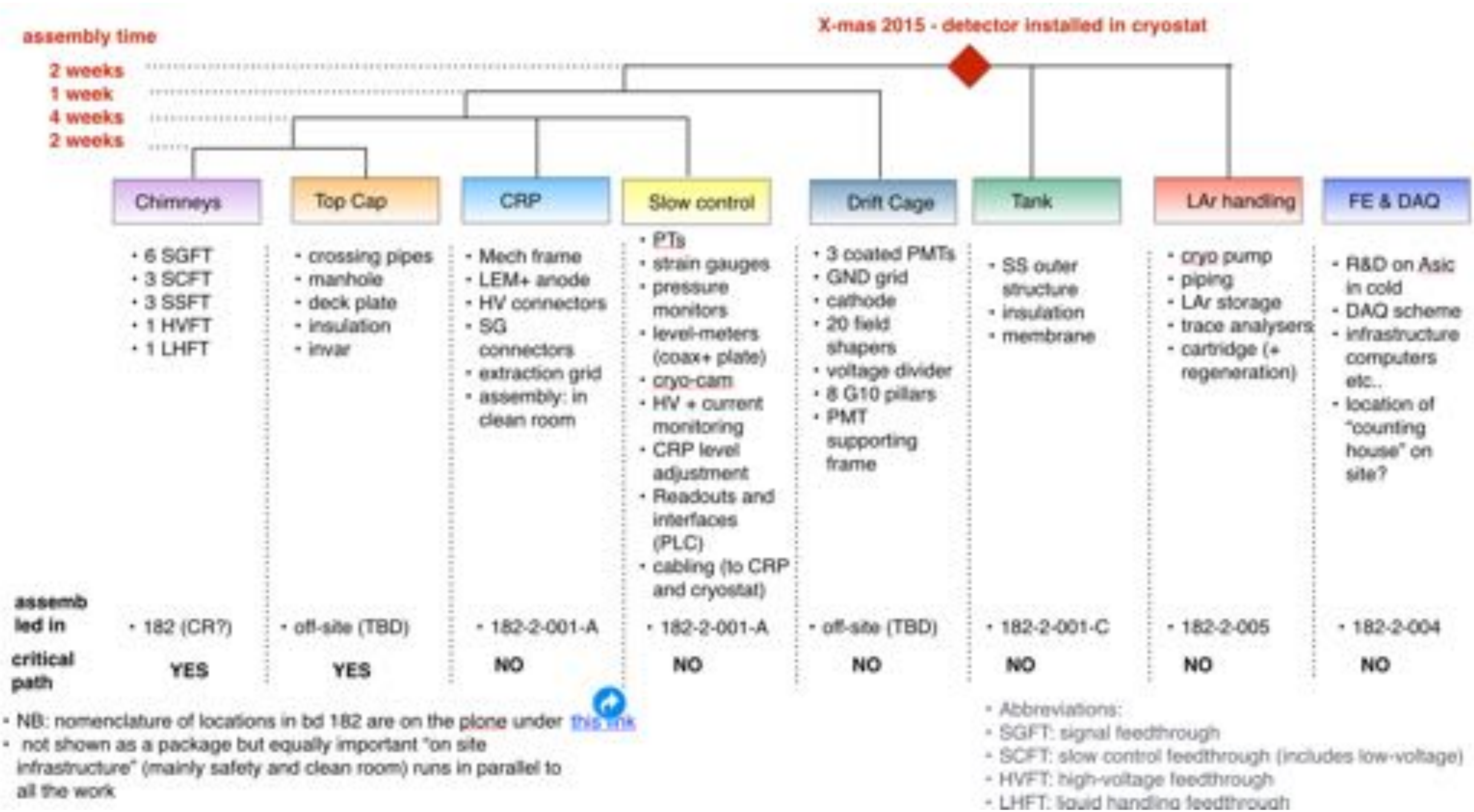
All Work Packages are decomposed in a one year WBS which is constantly checked and updated.



full WBS available on WA105 plone.
This link: [3x1x1-construction-plan]()

Work packages LAr Proto

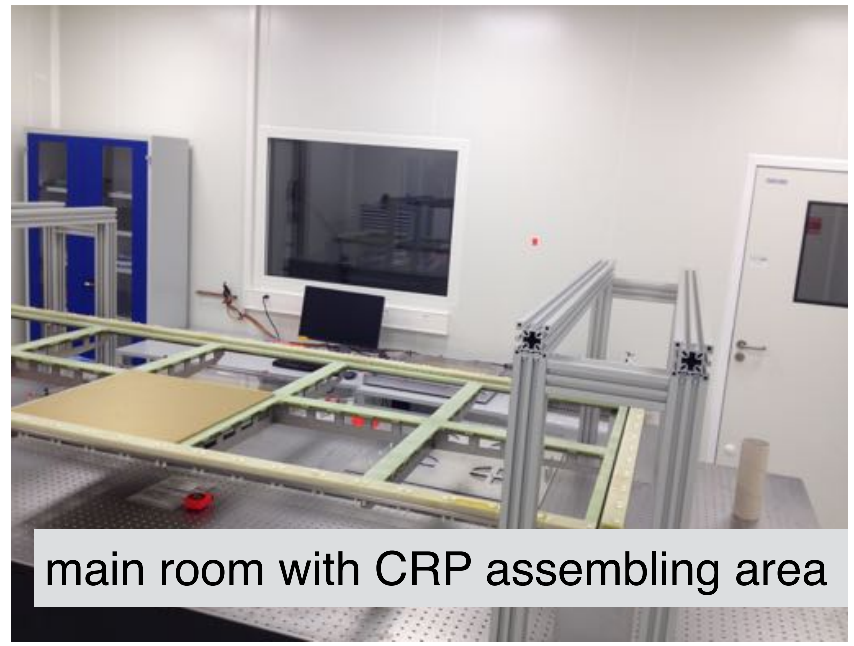
All activities decomposed in well identified Work Packages.



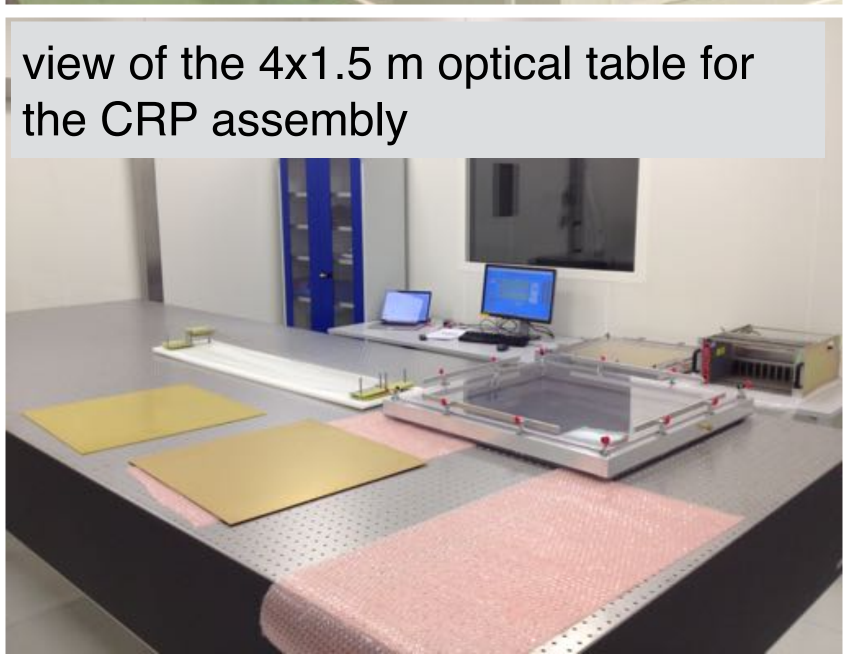
Clean room in b. 182

Fully operational with measured better than ISO 8 class.

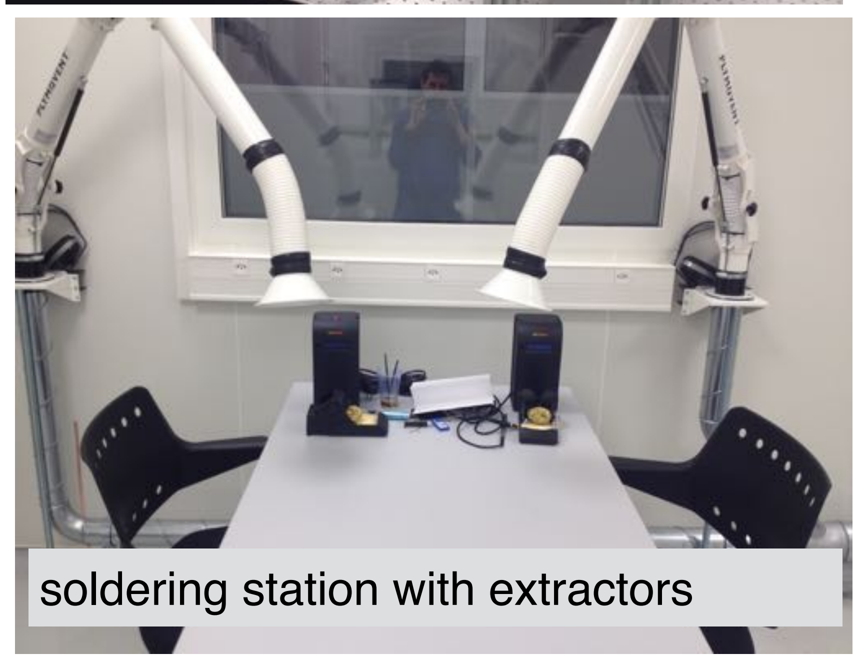
the clean room inside b. 182



main room with CRP assembling area



view of the 4x1.5 m optical table for the CRP assembly



soldering station with extractors

view of the soldering room

LEM procedure

WA105

CNC drilling

mechanical polishing

permanganate bath +rince — *removes glass fibber from holes*

Rims by global etching — *acide sulphuric bath*

passivation (Chromic acid)

Ni/Au plating

lessive (soap) bath at 68°C

ultrasonic bath DM water — *removes grease*

high pressure DM water — *removes dust/dirt in holes*

baking 4h 180°C (only once) or 1hr at 80°C (2nd,… iterations) — *polymerisation of the glass fibber (only 1st iteration) or drying*

HV test — *goal no discharges at 3.5 kV*

HV test not ok → ultrasonic bath DM water

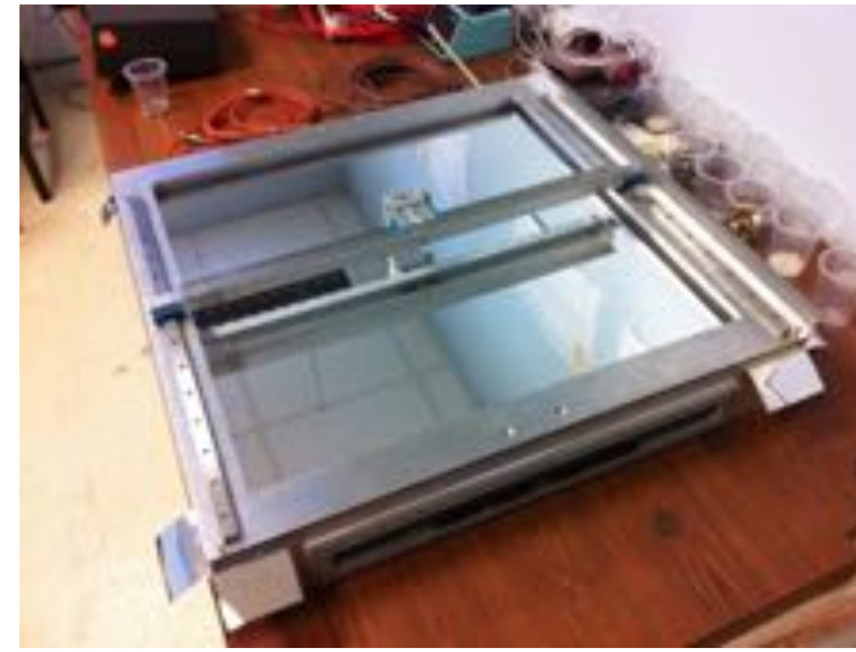
HV test ok → storage + test

- at ELTOS: one machine with 6 independent drills each capable of ~7 holes per second. They can drill 6 50x50 LEM in 24 hours. The timescale for the rest of the procedure depends on the organisation of production line.

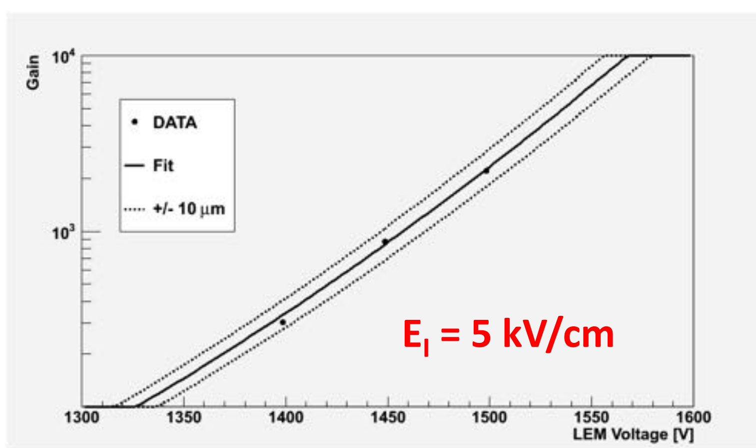
- Cleaning is done at CERN. procedure takes about 6hrs per LEM (mainly due to baking time)

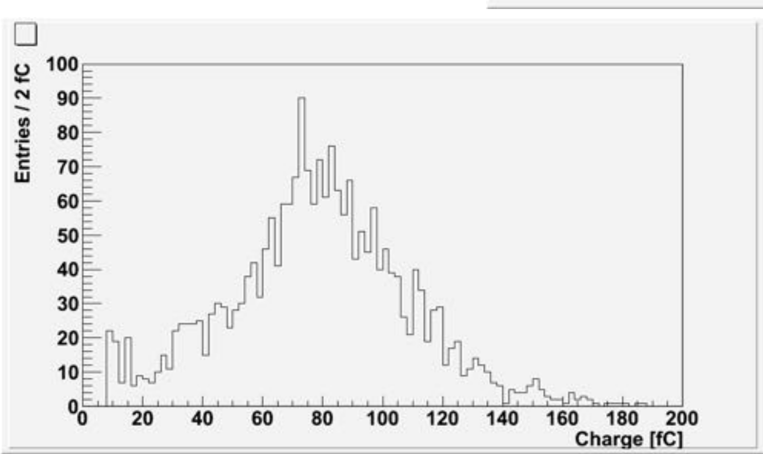
Gain characterisation of a 50x50 LEM

- **Test Chamber ready to be delivered to CERN on April 7th.**
- Electronic noise : ~ 0.2 fC / channel (T2K FEC).
- 0-suppression : × 70 reduction in data volume.
- All tests with 10 ×10 prototypes in Ar(95%)-iC_4H_{10} (5%) indicate that gains of ~10^3 can be reached allowing detectors to be calibrated with a ^{55}Fe source.

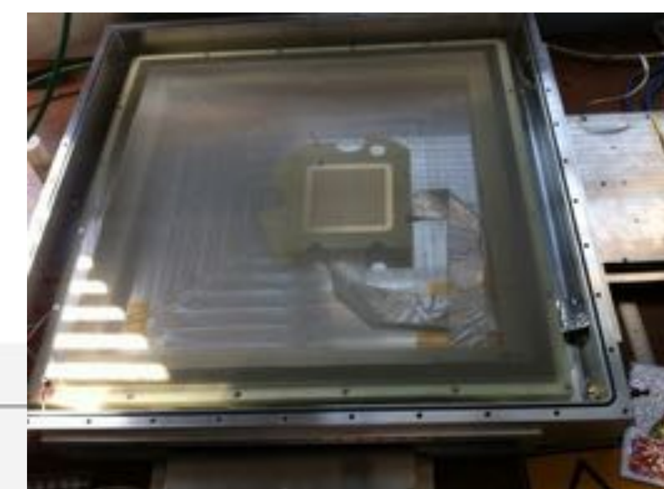


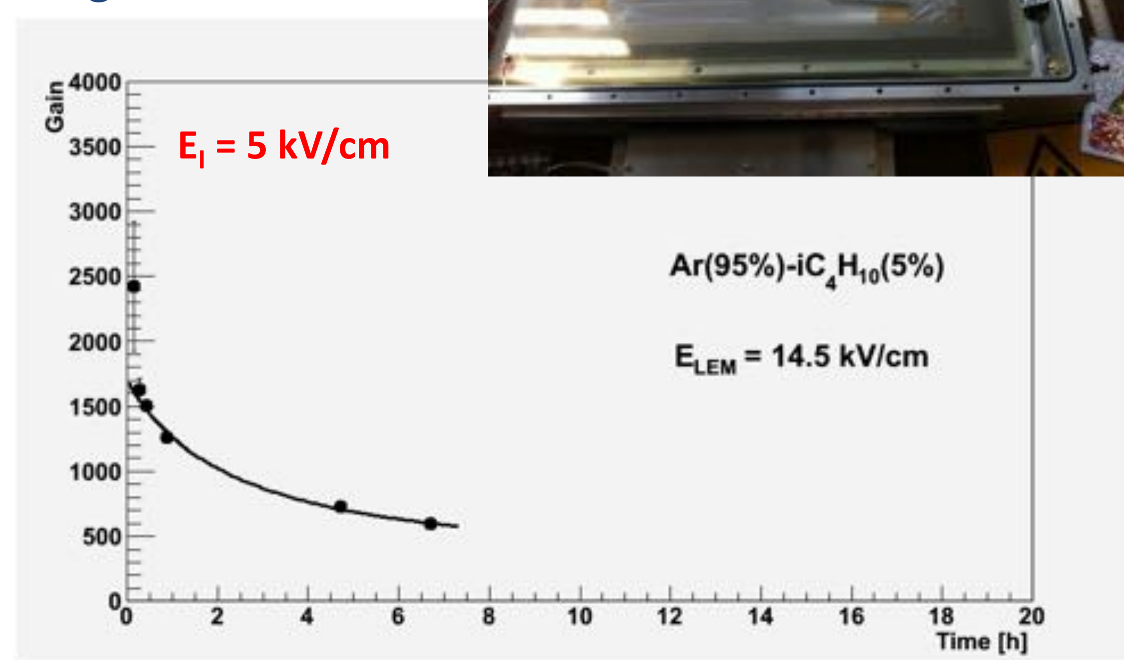
1mm LEM (ELTOS)
500 μm holes
80 μm rim
800 μm pitch
square



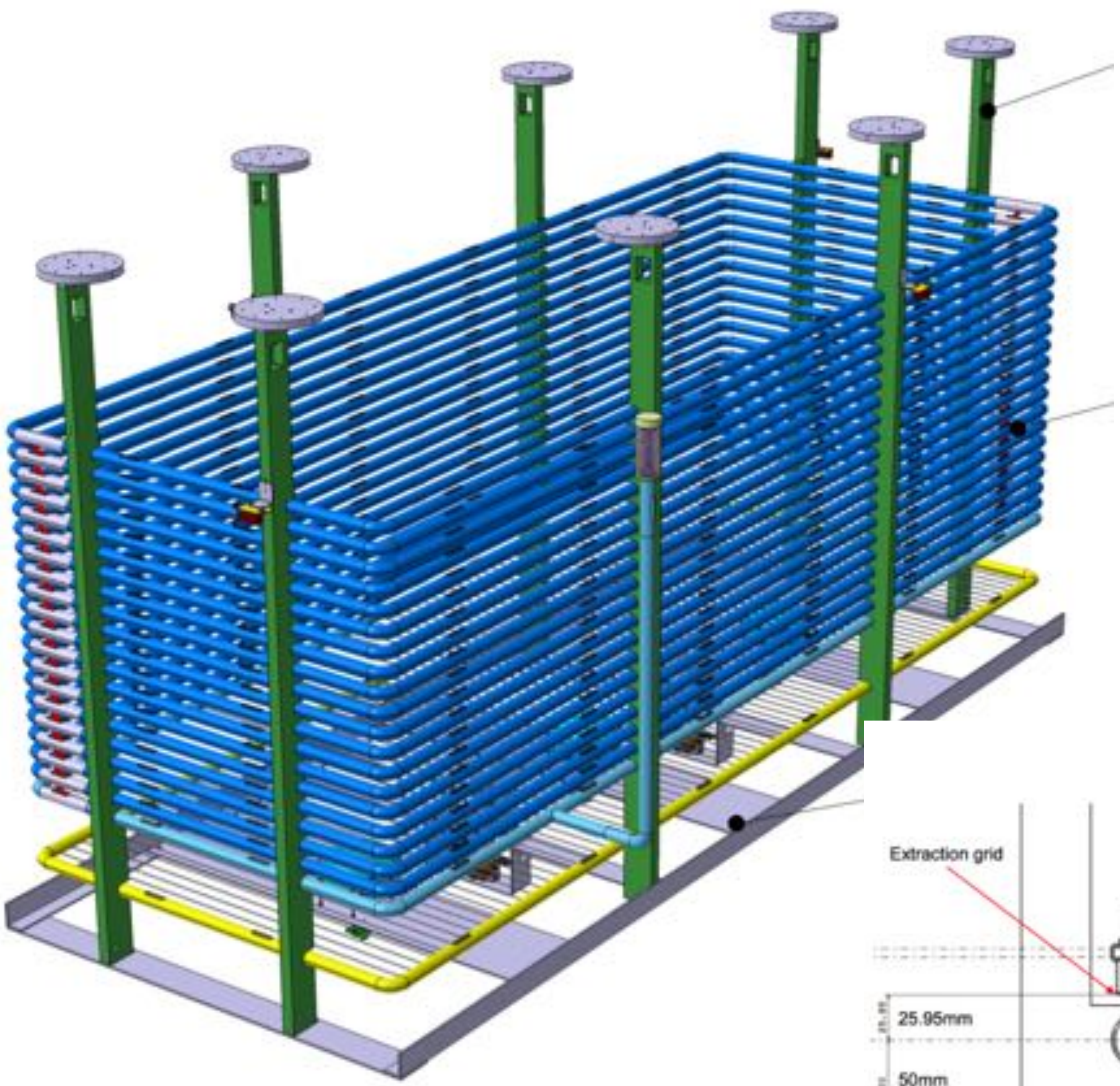


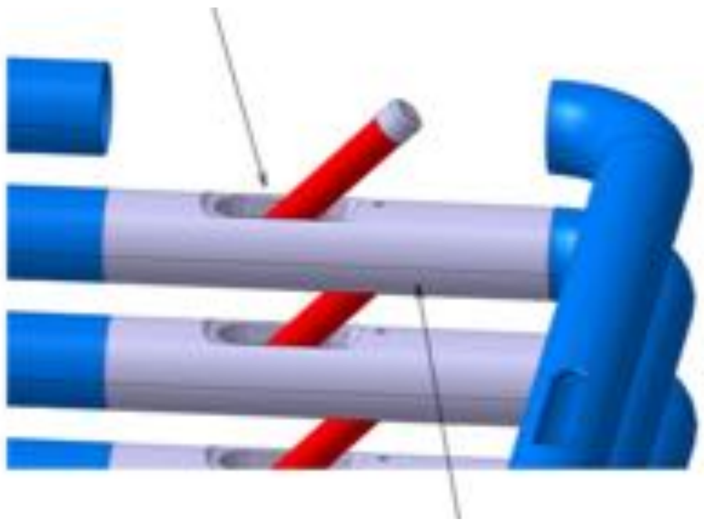
1mm LEM (ELTOS)
500 μm holes
40 μm rim
800 μm pitch
hexagonal

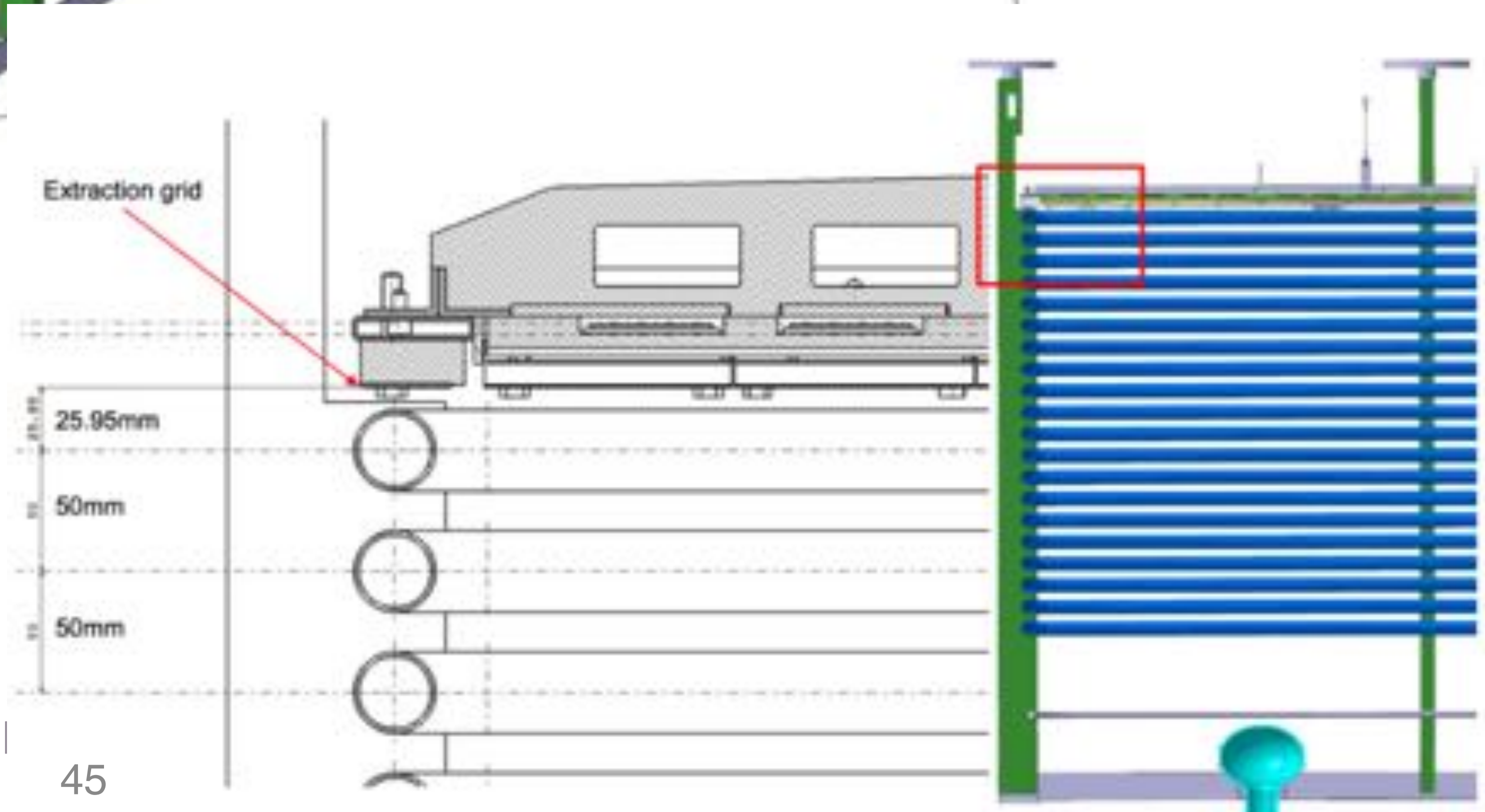




Drift Cage

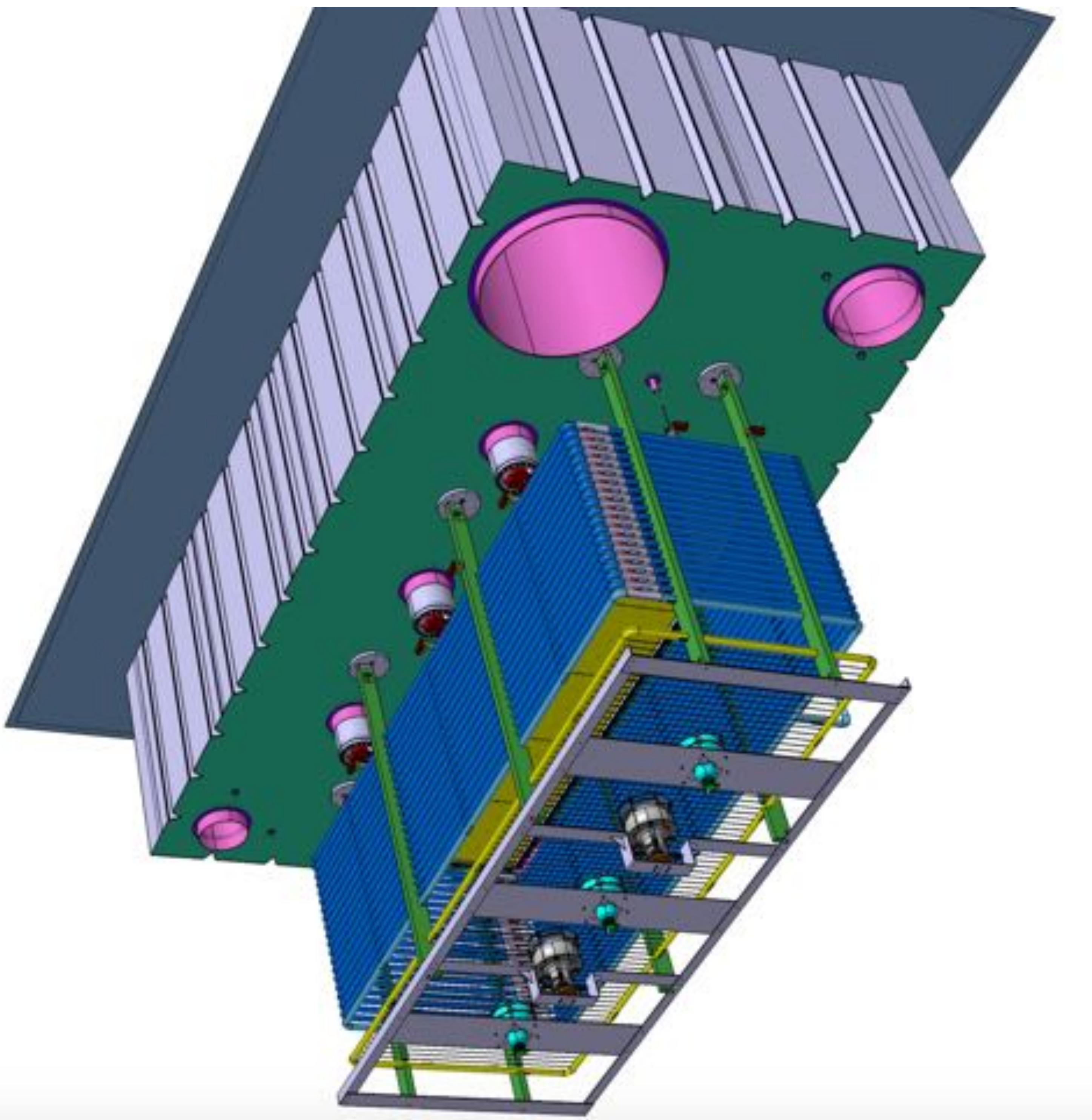


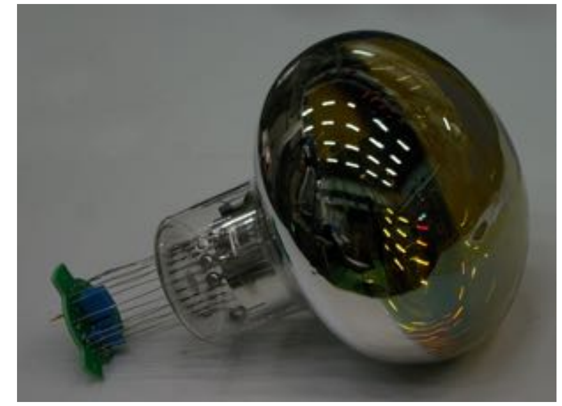


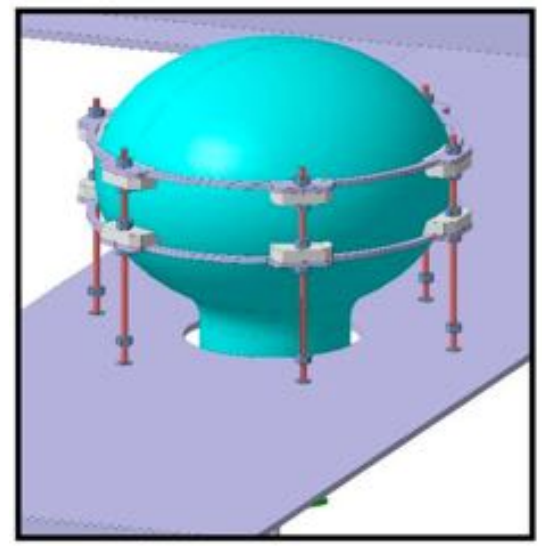


Light readout

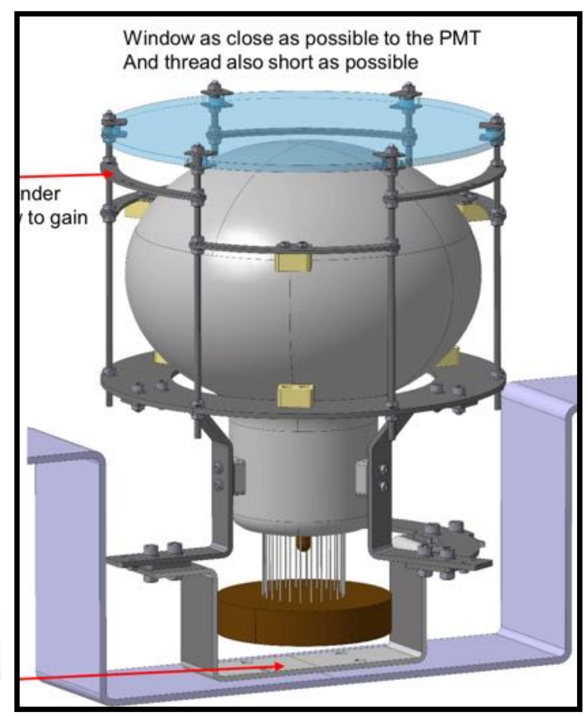
5 Hamamatsu 8” R5912 PMTs.







3 with same installation as ArDM.



2 with “Spanish installation”. acrylic window and single cable.