The Argon Dark Matter Experiment

on behalf of the ArDM collaboration
Lukas Epprecht

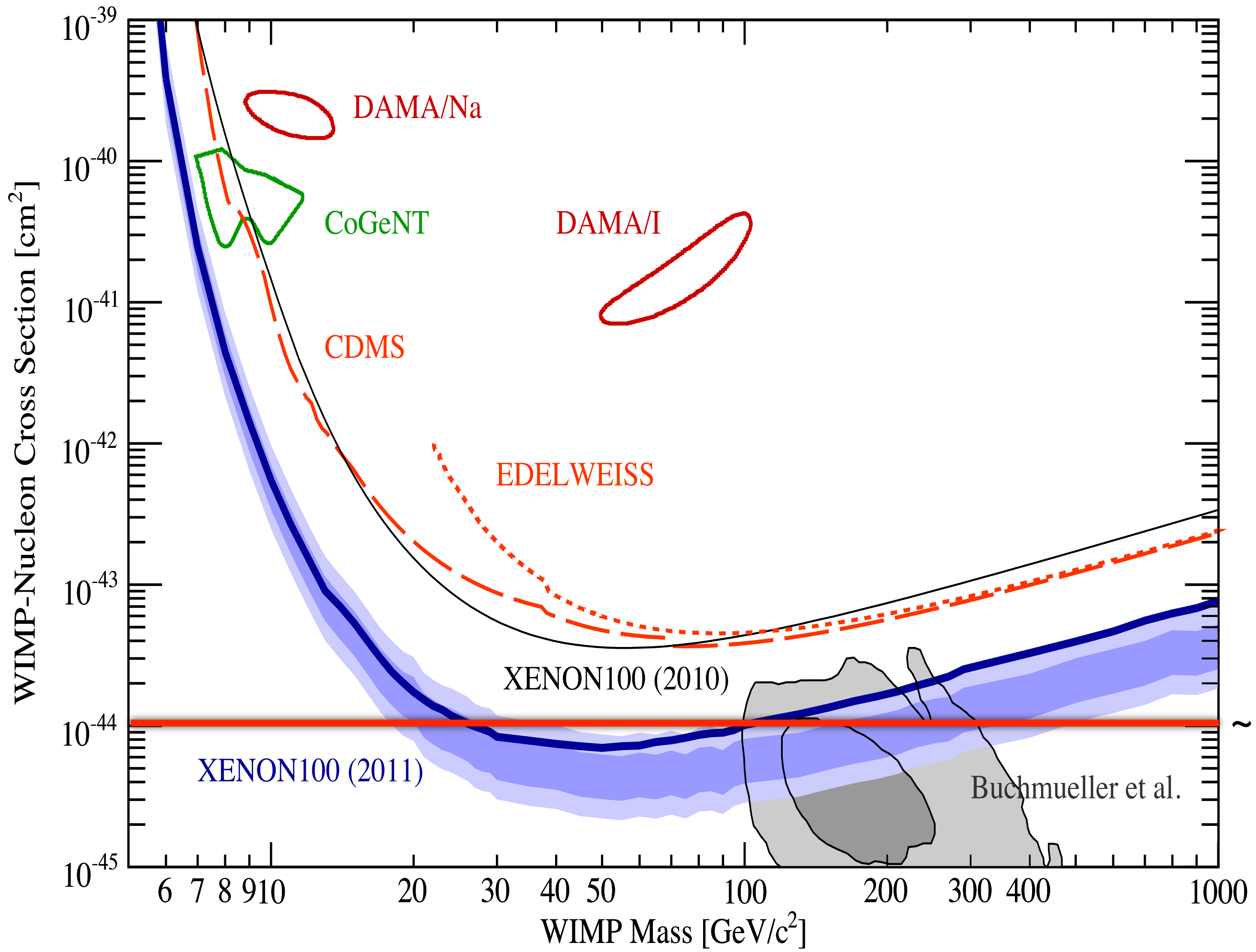
Why Argon for DM-Search?

- Long experience with noble elements (Ar & Xe) as detector medium by many groups
- Argon and Xenon provide different signature due to different recoil spectra
  --> Verification in case of a positive DM signal.
- High scintillation (Ar: 128 nm; Xe: 175 nm) and ionization yields (Ar: 15.75 eV; Xe: 12.13 eV)
- Scintillation via atomic excimer states
  --> good discrimination between nuclear and electron recoil by pulse shape discrimination and S1/S2
- Self shielding medium
- Good purity can be achieved by filtering out oxygen
  --> long drift of several meters possible
  --> detectors are scalable
- Event rejection with imaging TPC (multiple scattering, ...)
- Argon is a byproduct from air liquification
  --> Cheap ~1.5 $/l

BUT: ^{39}Ar is a β-emitter with Q = 565 keV and a half-life of τ=269 yrs. It's concentration in natural Ar is ~10^{-15} what leads to a rate of ~1 Hz/kg

- Rejection of 10^8 is needed.
- Depleted argon from underground wells can be used

What is the goal of sensitivity for ArDM?



~1 event / day / ton

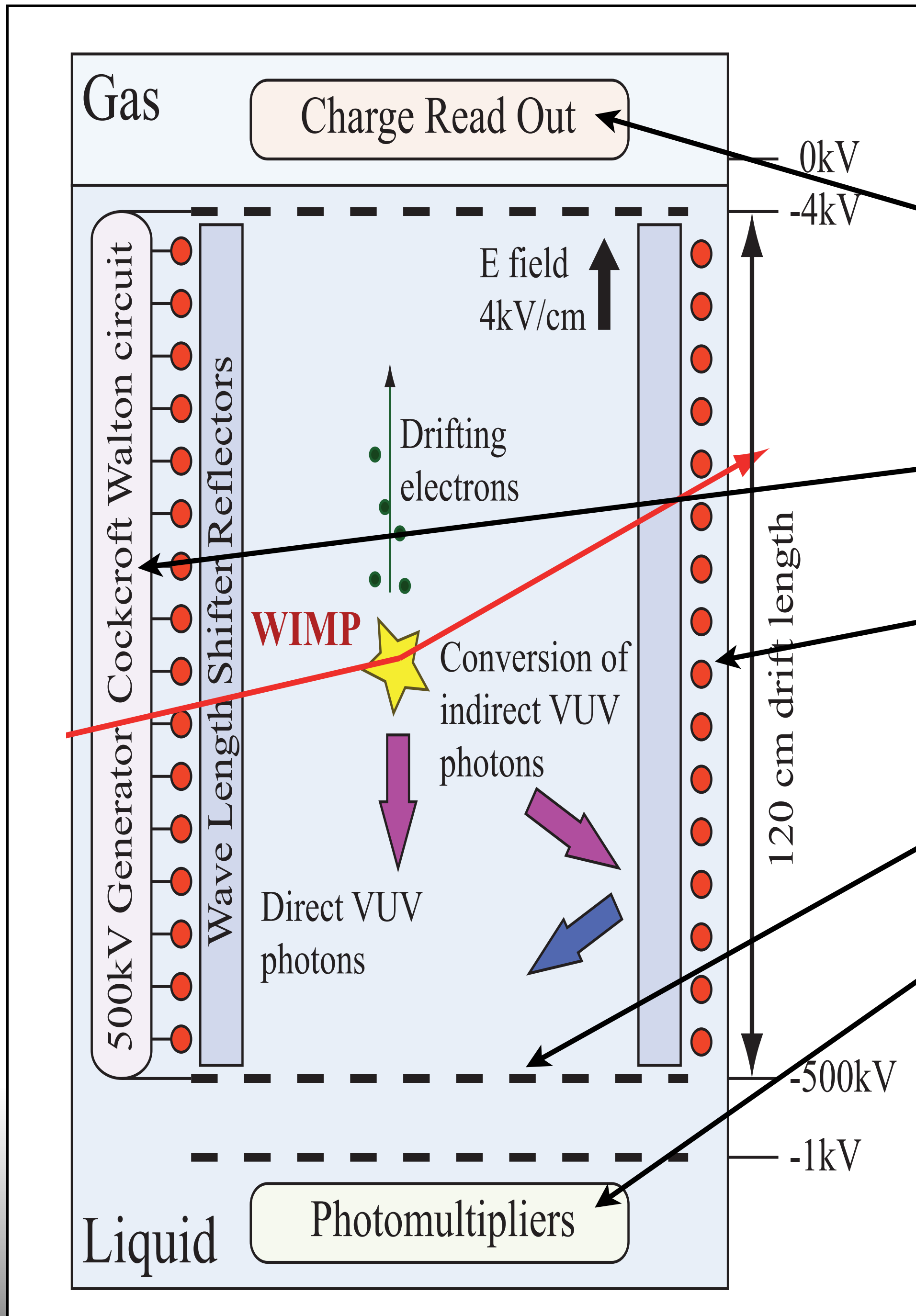
E. Aprile et al. (XENON100), arXiv:1104.2549v1

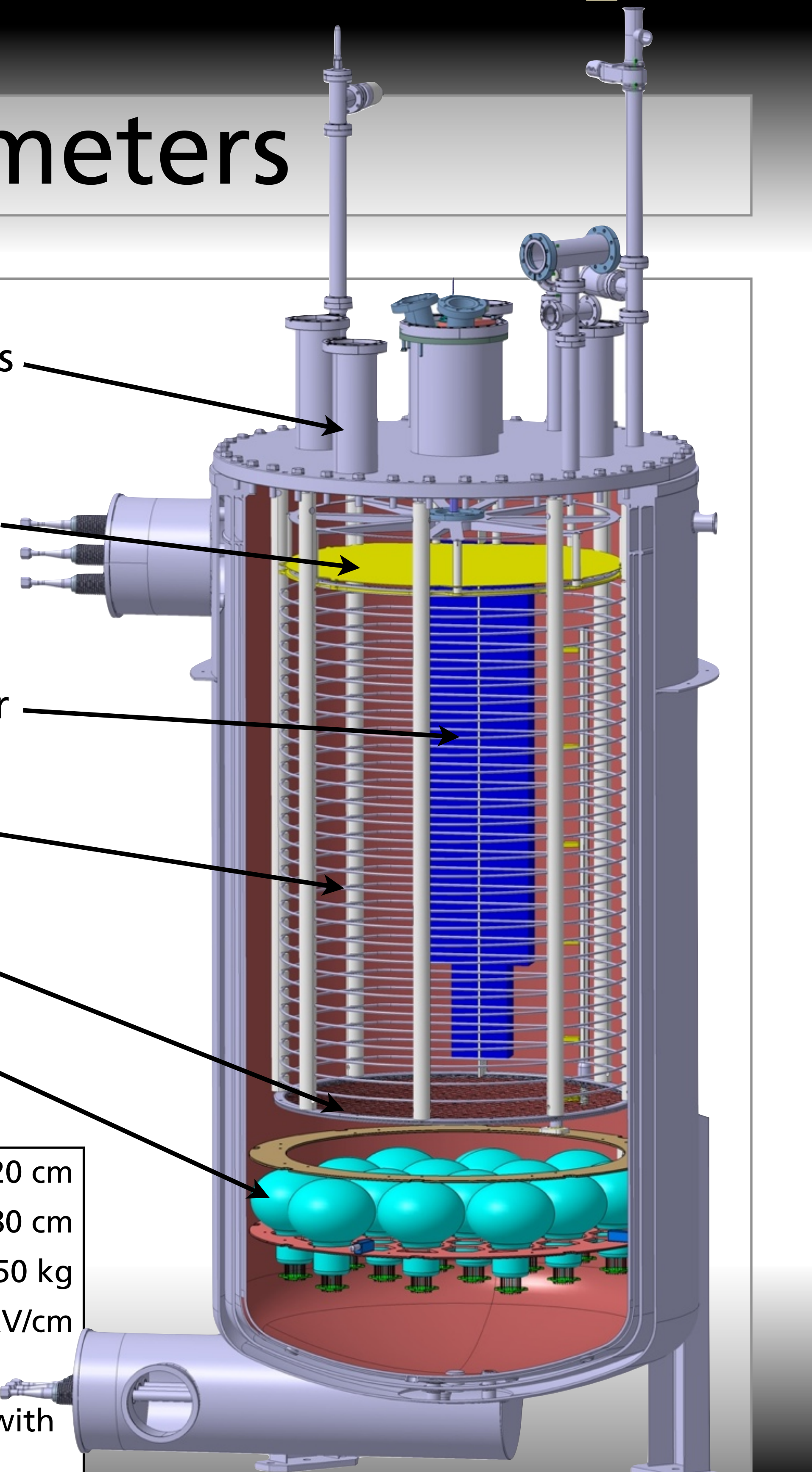
Expected signal for a threshold of ~30 keVr

Assumptions for calculations:

- Cross-section normalized to nucleon
  - → σ = 10–42 cm2 =10–6 pb
  - → MWIMP = 100 GeV
- Halo Model
  - → WIMP Density = 0.5 GeV/cm³
  - → vesc = 600 km/s
- Interaction
  - → Spin independent
  - → Engel Form factor

ArDM: Design Parameters





Total drift length:	120 cm
Diameter:	80 cm
Target:	850 kg
Drift field:	1–4 kV/cm
Shielding with 100 mm LAr	
Temperature control of detector with LAr cooling jacket	

Backgrounds:

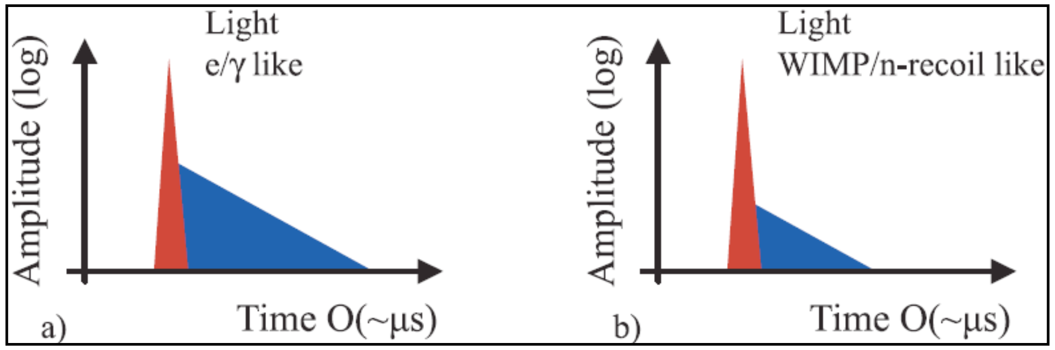
Gamma and Electrons:

Originating from:

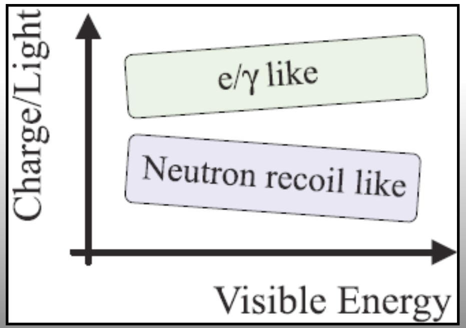
- U, TH, … contamination in detector material and surrounding rock
- Natural ^{39}Ar contamination in the detector

Rejection:

- Ratio of light coming from fast and slow decay of excited Ar molecule. (~ 5 ns vs. ~1.6 μs)



- Charge / light ratio



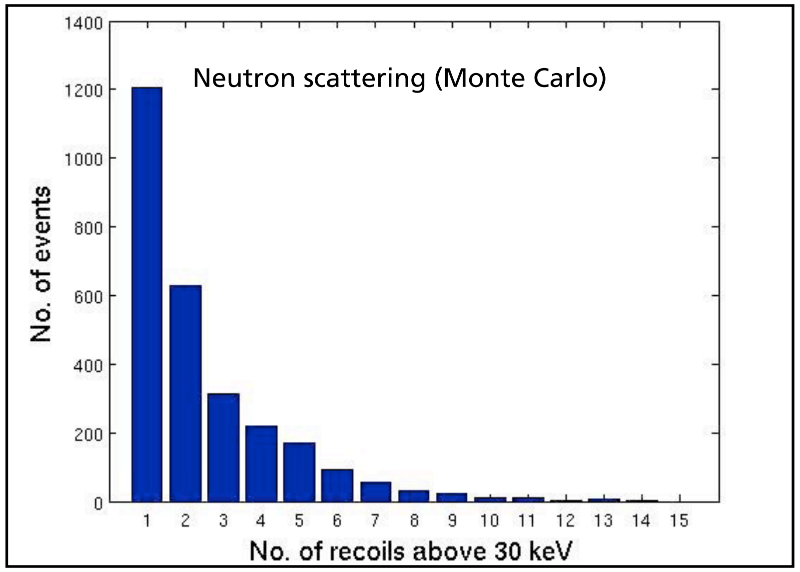
Neutrons:

Originating from:

- U, TH, … contamination in detector material
- Muon induced neutron background

Rejection:

- WIMPs have such a small cross section that they will scatter at most 1 time in the detector.



- External shield made out of 50 cm thick polyethylene wall

Expected Backgrounds in ArDM

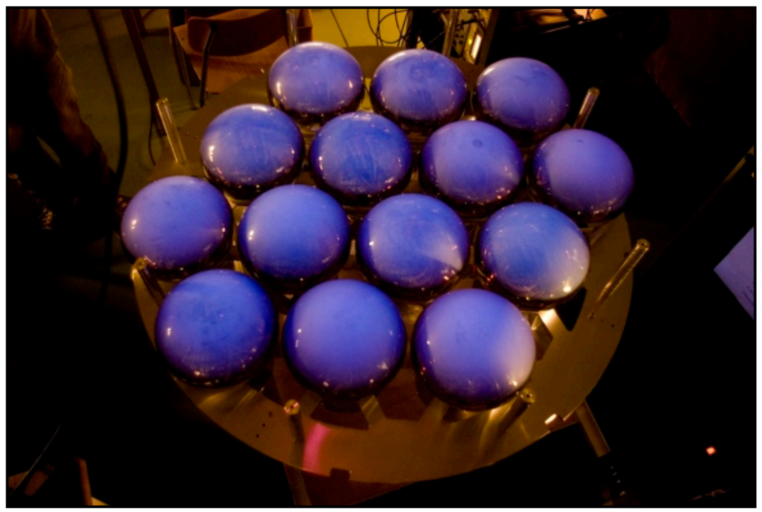
We assume:

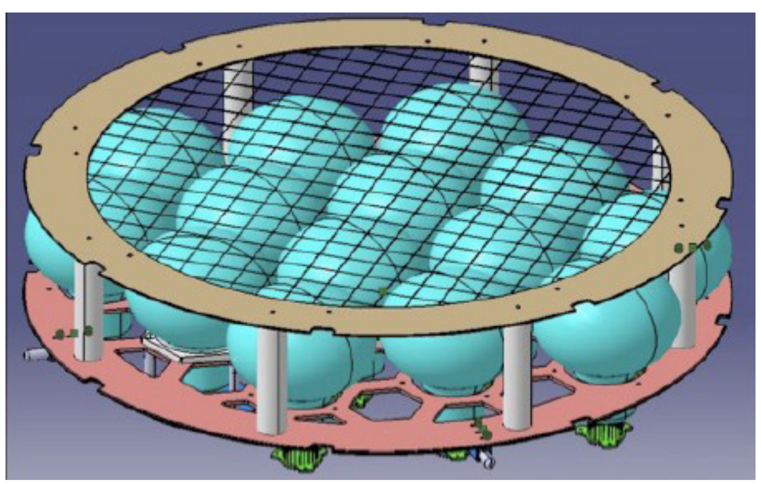
- 500 kg active mass after fiducialization.
- Background rejection: 10^7 (10^4 from PSD and 10^3 from S1/S2) for beta/gamma background
- Signal efficiency: 50%
- Neutrons from materials and neutron shield in place
- WIMP mass 100 GeV and xsec 10^{-44} cm^2
- Region of interest 30-100 keV

^{39}Ar [evt / day]	gamma [evt / day]	neutrons [evt / day]	background [evt / day]	WIMP rate [evt / day]
$1.5*10^6$	47'500	0.07	0.22	0.25

Light Readout System

Amsler et al. 2010 *JINST* 5 P11003





- Scintillation light in argon has 128 nm
- Glass is not transparent in VUV range

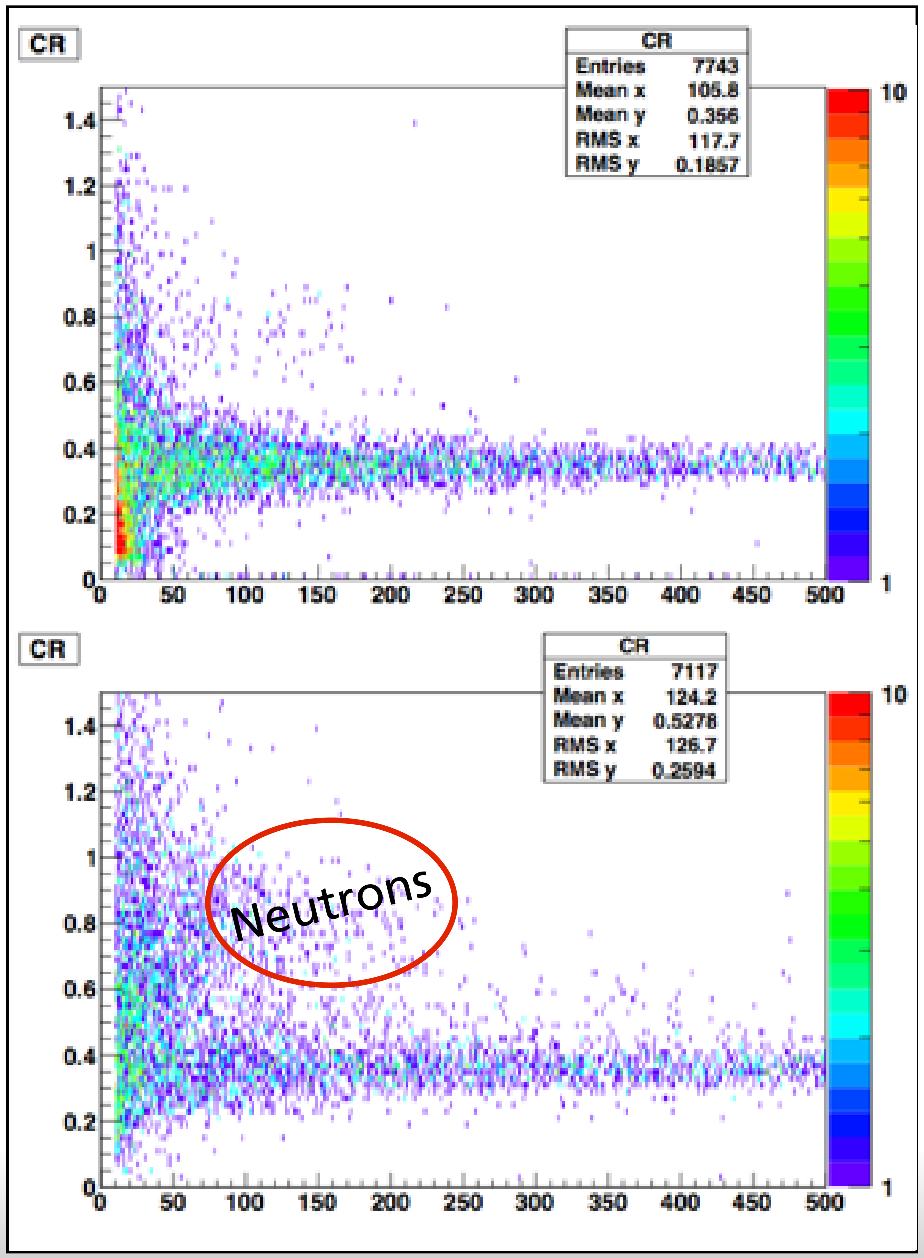
  →Wavelength shifter is needed
- Wavelength shifter: TPB (Tetra-phenyl-butadien)

  128 nm → 430 nm
- Coating of the PMTs in order to detect the direct light
- Coated reflector foil around fiducial volume to guide indirect light to the readout system

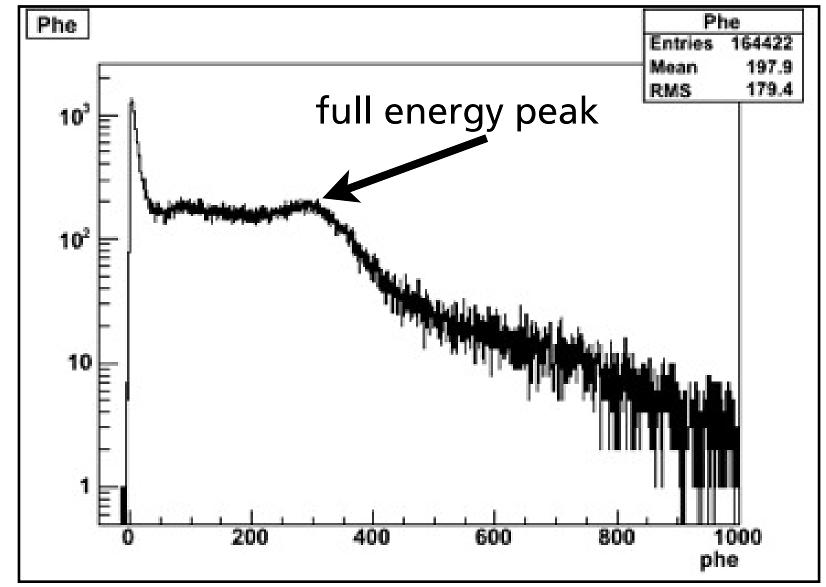
- 14 x 8 inch cryogenic low radioactivity PMT from Hamamatsu located at the bottom of the detector

New 3'' low back ground PMTs with QE >30% @ 420 nm (Hamamatsu R11065) currently tested at CERN
--> If positive up to 70 PMTs for ArDM light readout array

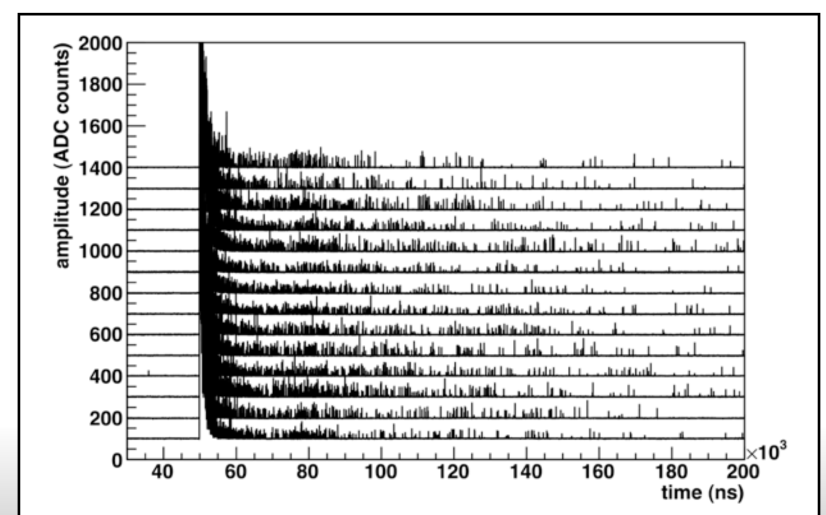
Results, achieved in Run on Surface @CERN



Measurements with Am Source

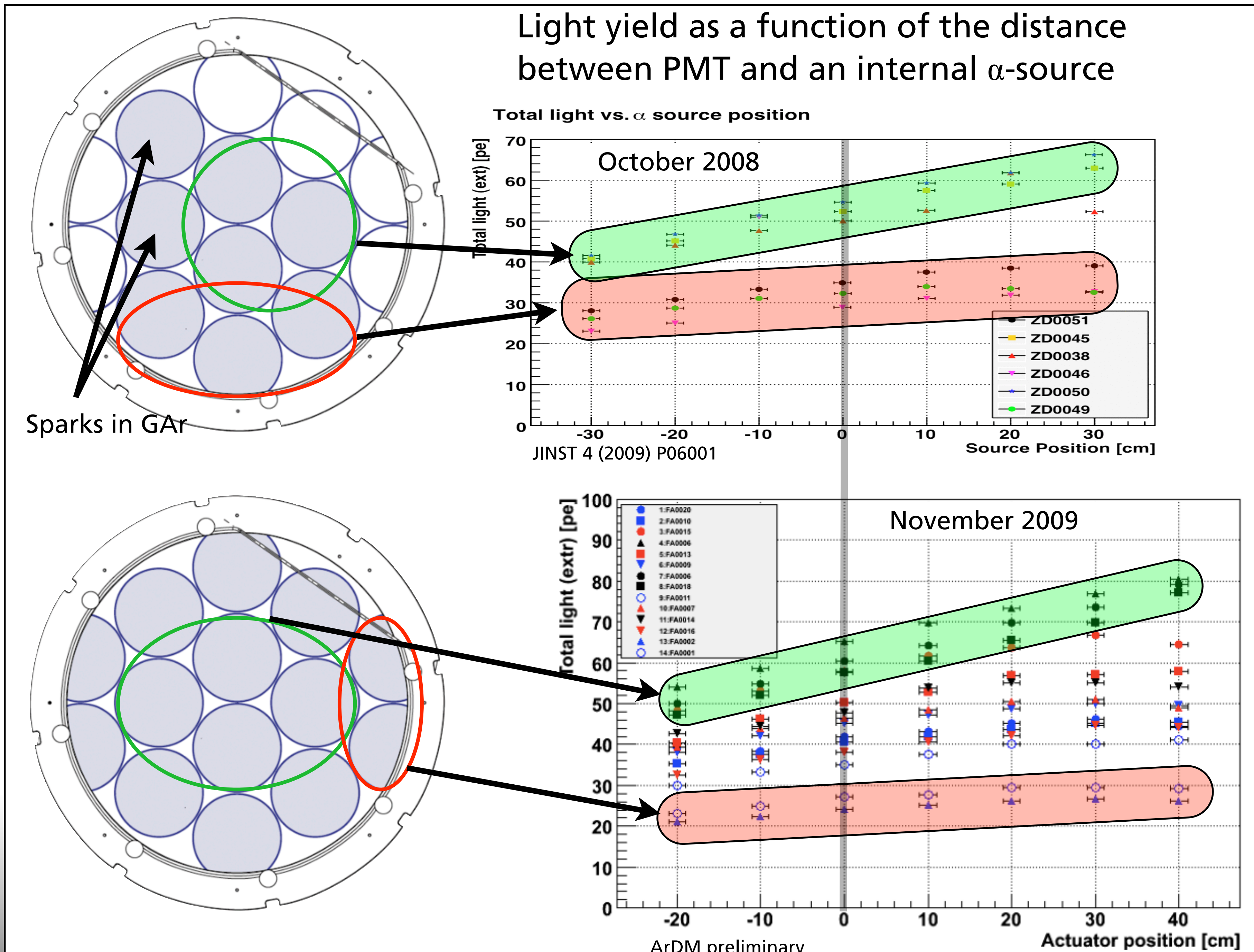


^{22}Na source, externally triggered



S1/S2 from crossing muons
(note timescale up to 200 μs!)

Measurements in Gas Argon with Final Light Readout (14 PMT)

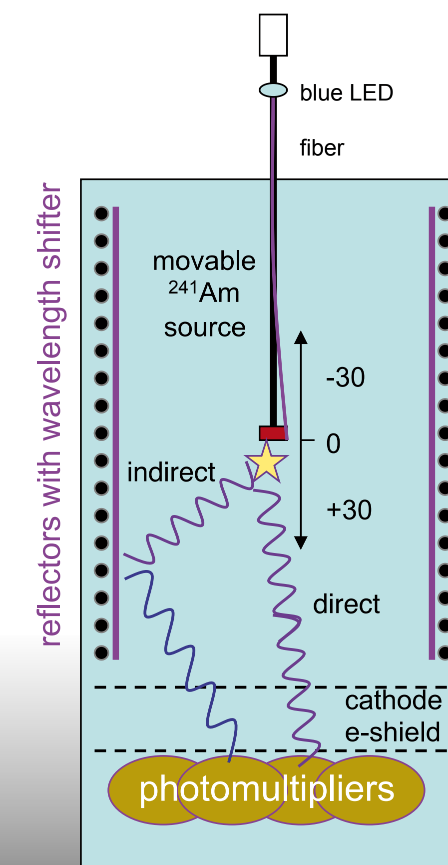


Results in comparison with earlier results with only 8 PMTs

All measurements in ultra pure GAr. (τ_2 > 3 μs)

NEW: All PMTs coated with wavelength shifter (TPB)

Slightly better light yield with new PMT's



Actual Charge Readout System

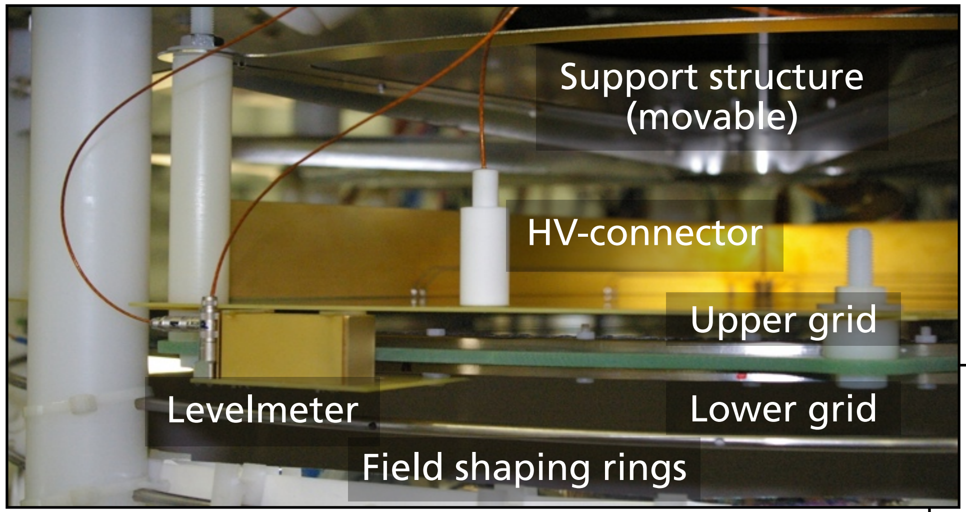
Temporary charge readout system, constructed as a single unit, containing an anode (32 channels) and 2 extraction grids.

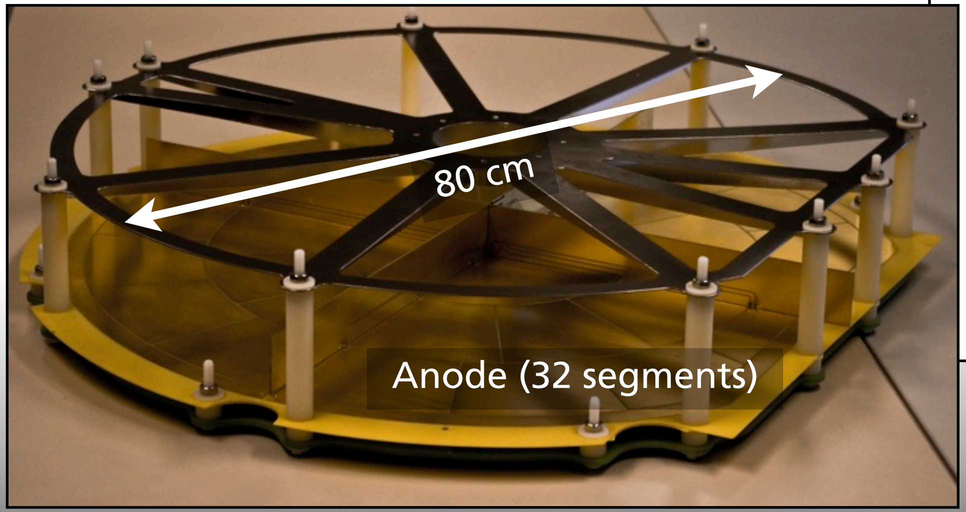
It covers all the fiducial volume with a diameter of 80 cm.

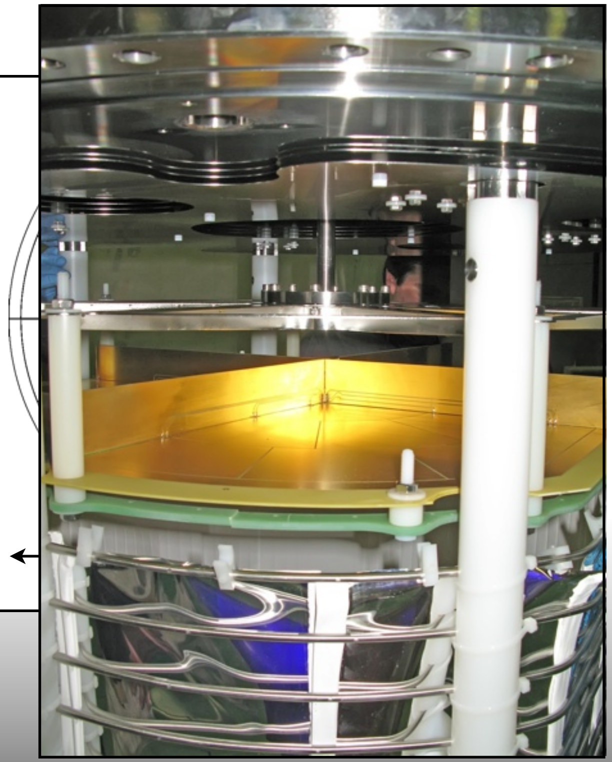
Segmented anode

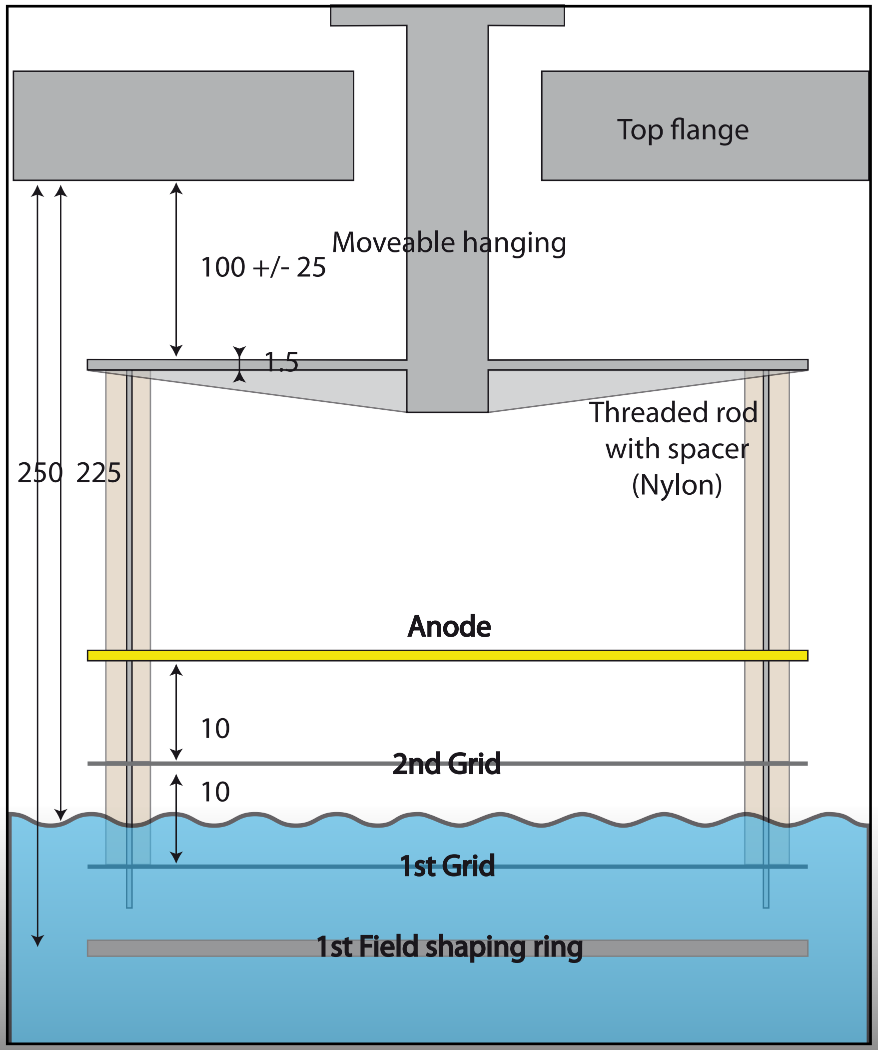
- Standard PCB technique
- 32 channels, capacitively read out
- Movable in z-direction
- Tilting possible in the plane
- Adjusting to the liquid level by 3 capacitive level meters

BUT: no amplification





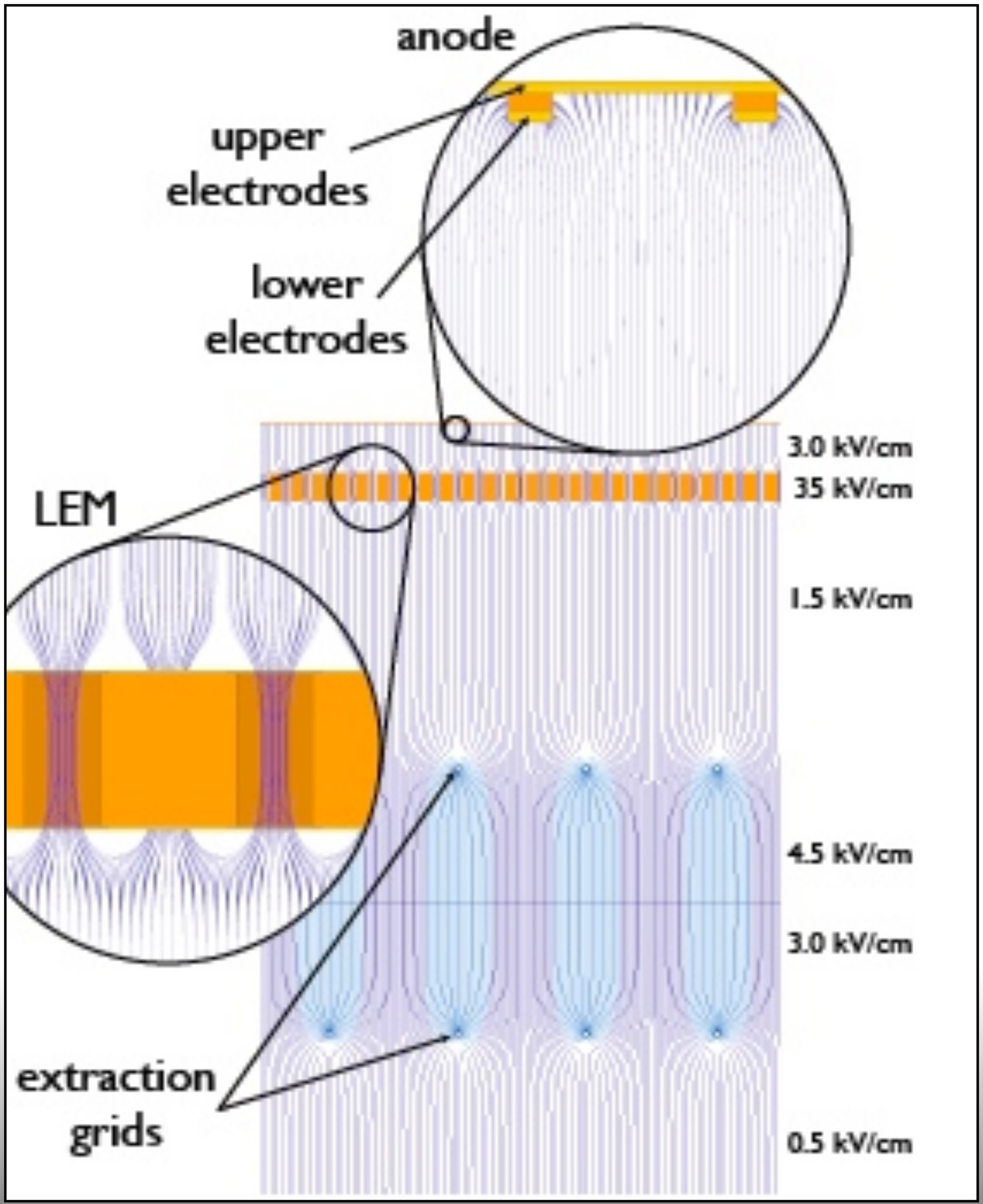




Charge Readout System

LEM (Large Electron Multiplier)

Badertscher et al., NIM A617 (2010) 188-192
Badertscher et al: NIM A 641 (2011) 48–57

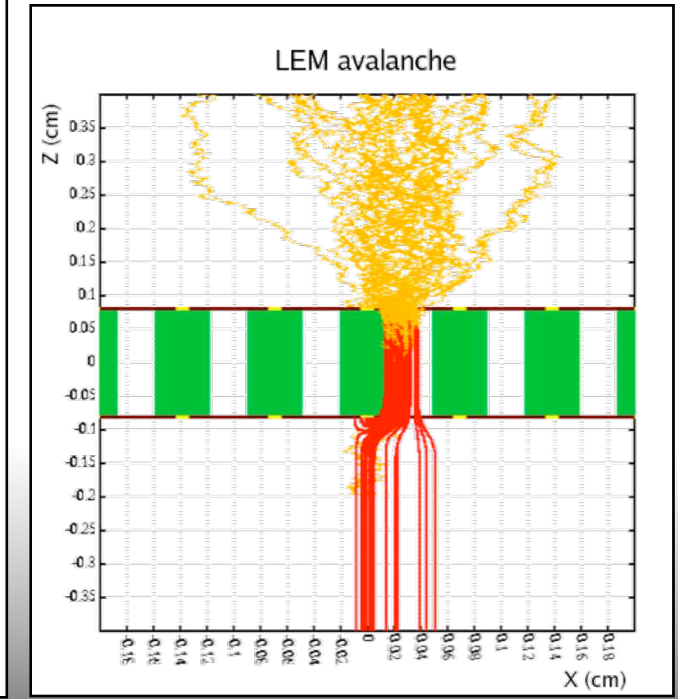


The charge readout system is developed at smaller scale with a 10 x 10 cm test setup, called "3l setup".

Goal of this R&D is to build large, mechanically robust charge multipliers in order to get an amplification of about a factor 1000, working in cold pure argon gas.

Principle of operation

- Electrons drift up in liquid
- 2 grids squeeze the field lines and electrons can pass the surface potential of the liquid
- In the high field of the LEM planes, an electron avalanche occurs. (multiplication factor: 10^2–10^3)
- Multiplied charge induces a signal in the anode
- Anode is read out in x and y direction



Details from the "3L Setup"

purification cartridge (home-made)

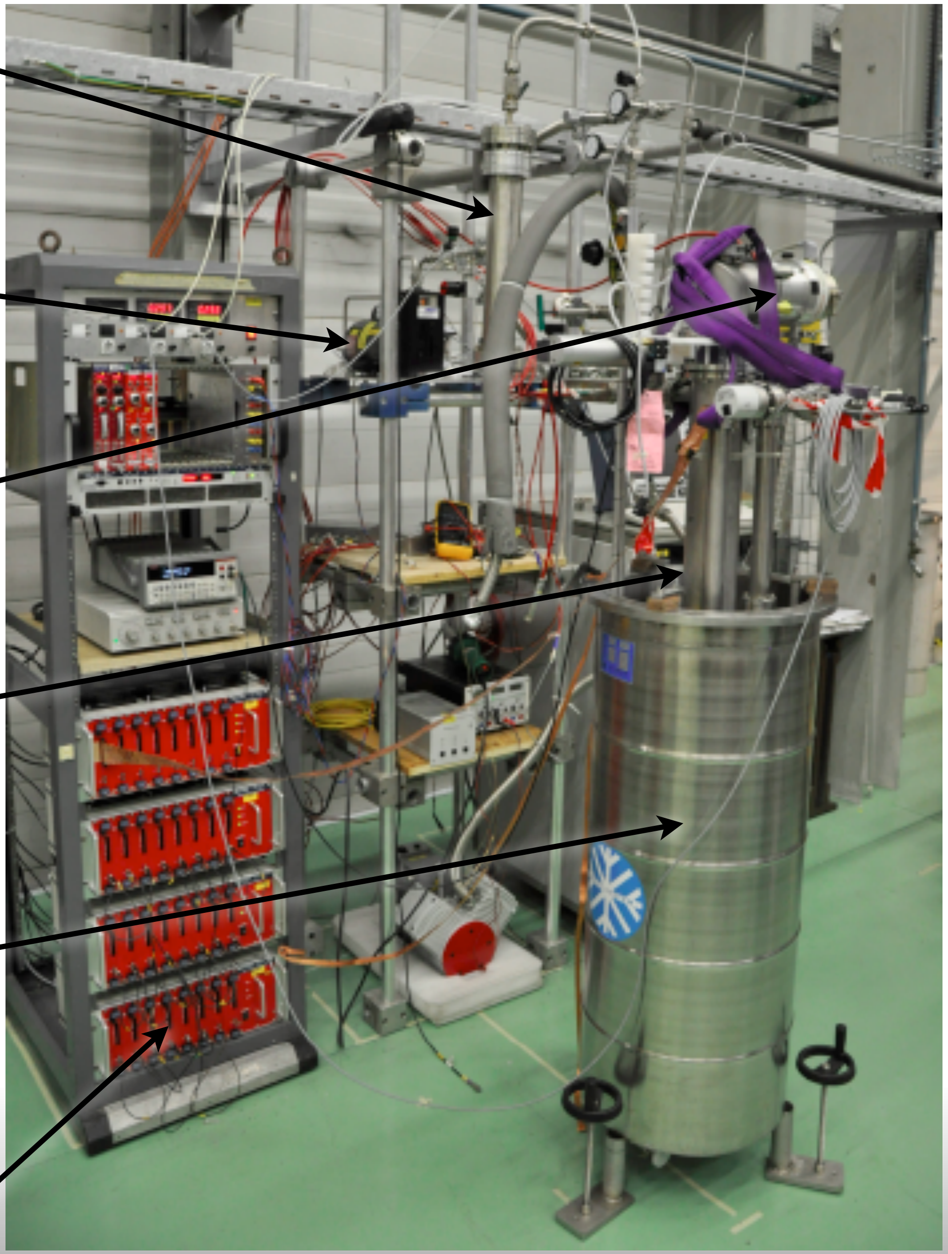
Argon purification system

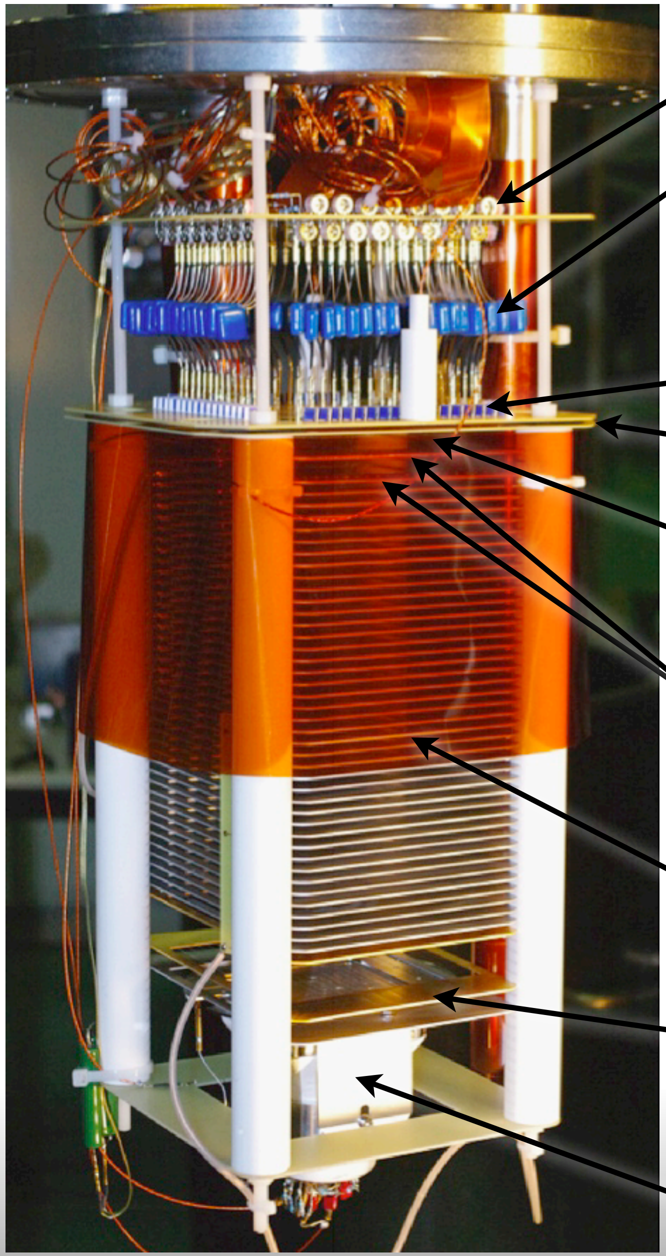
turbo pump

detector vessel

cryostat (open LAr cooling bath)

complete DAQ system for LAr TPC’s (ETHZ/CAEN)





Signal plane

Decoupling capacitors

HV-Resistors

2D anode

LEM

Extraction grids

Drift cage (10 x 10 x 10-30 cm)

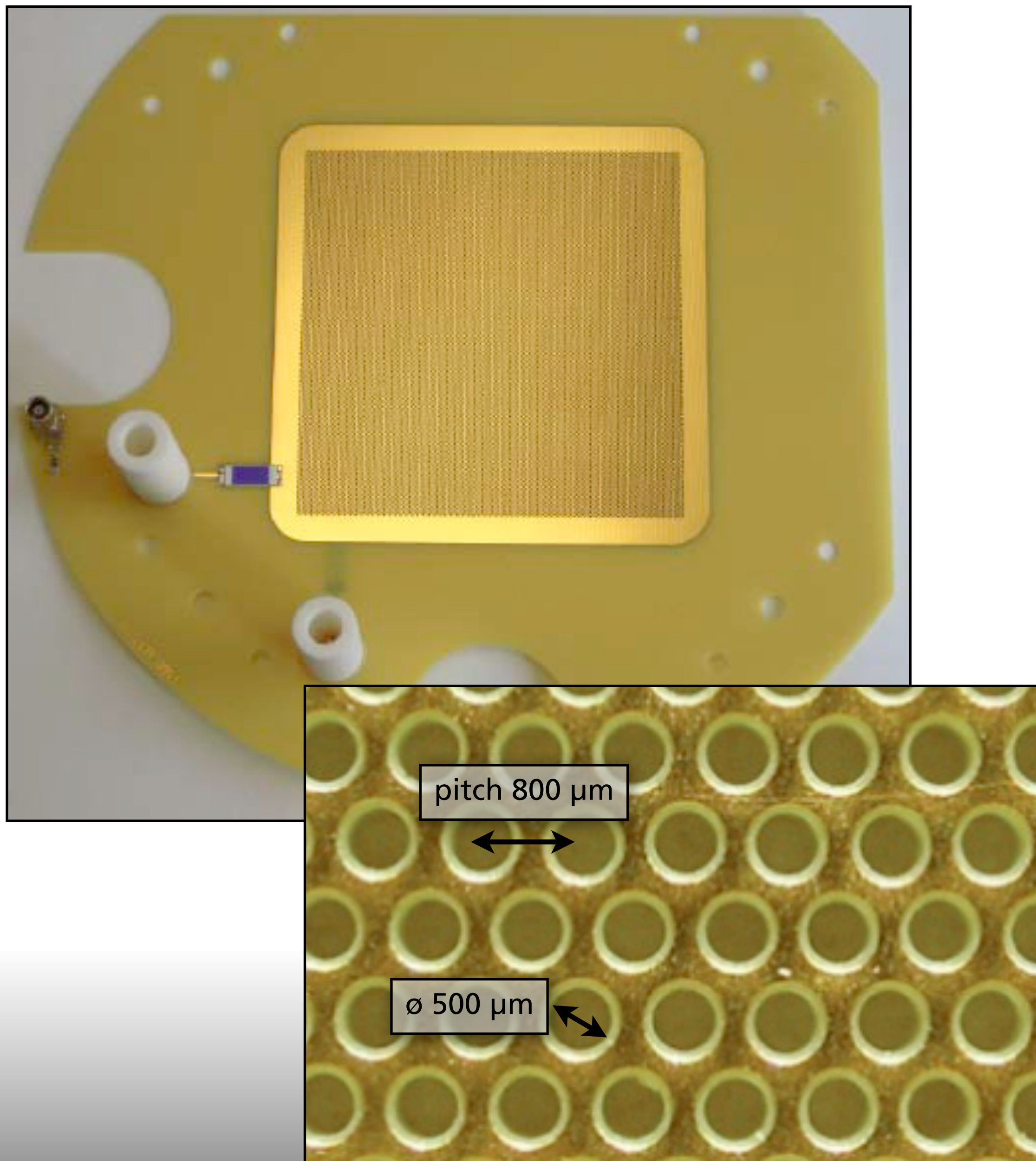
Cathode grid

PMT (Hamamatsu R11065)

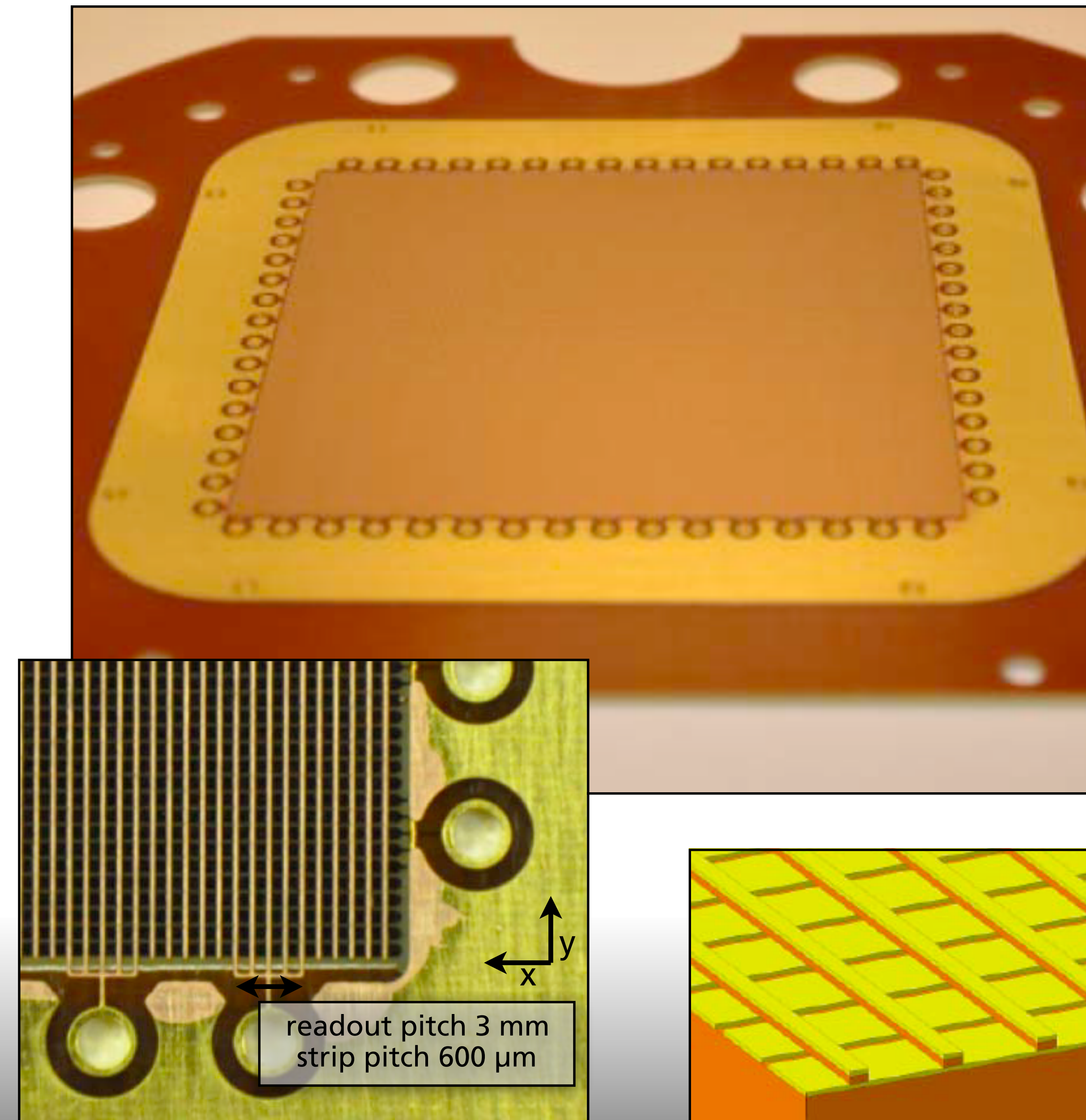
Details Charge Readout

Manufacturer: CERN TS/DEM group

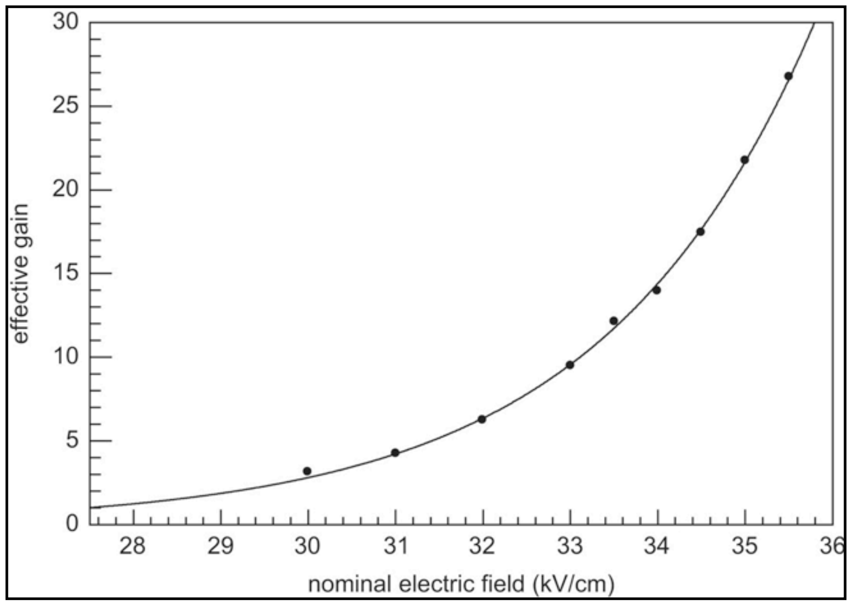
LEM
(10 x 10 x1 mm)



2D-Anode

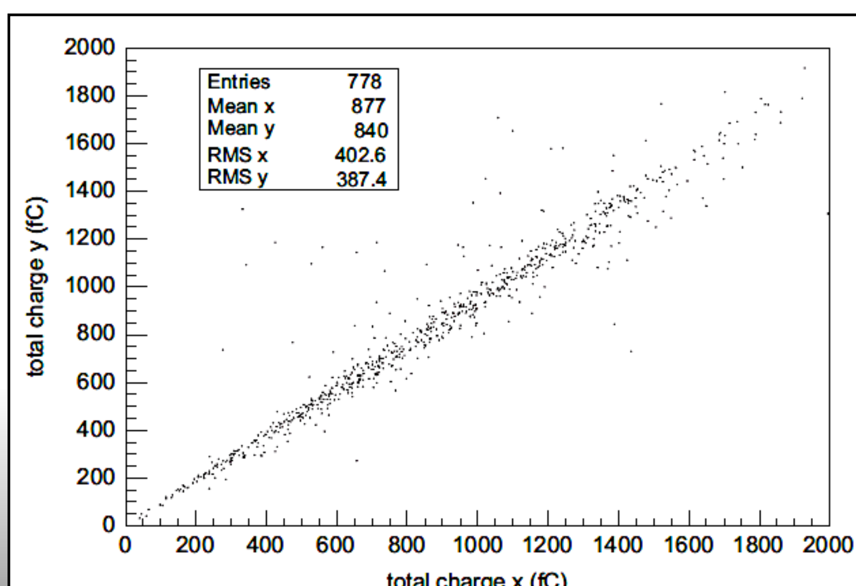


Performance of LEM



Effective gain vs electric field over single LEM

Calculated as the ratio of the total charge collected on x & y strips and the ionizisation charge deposited in the vessel (deposited charge by a MIP (electric field 500 V/cm) ~10 fC/cm)

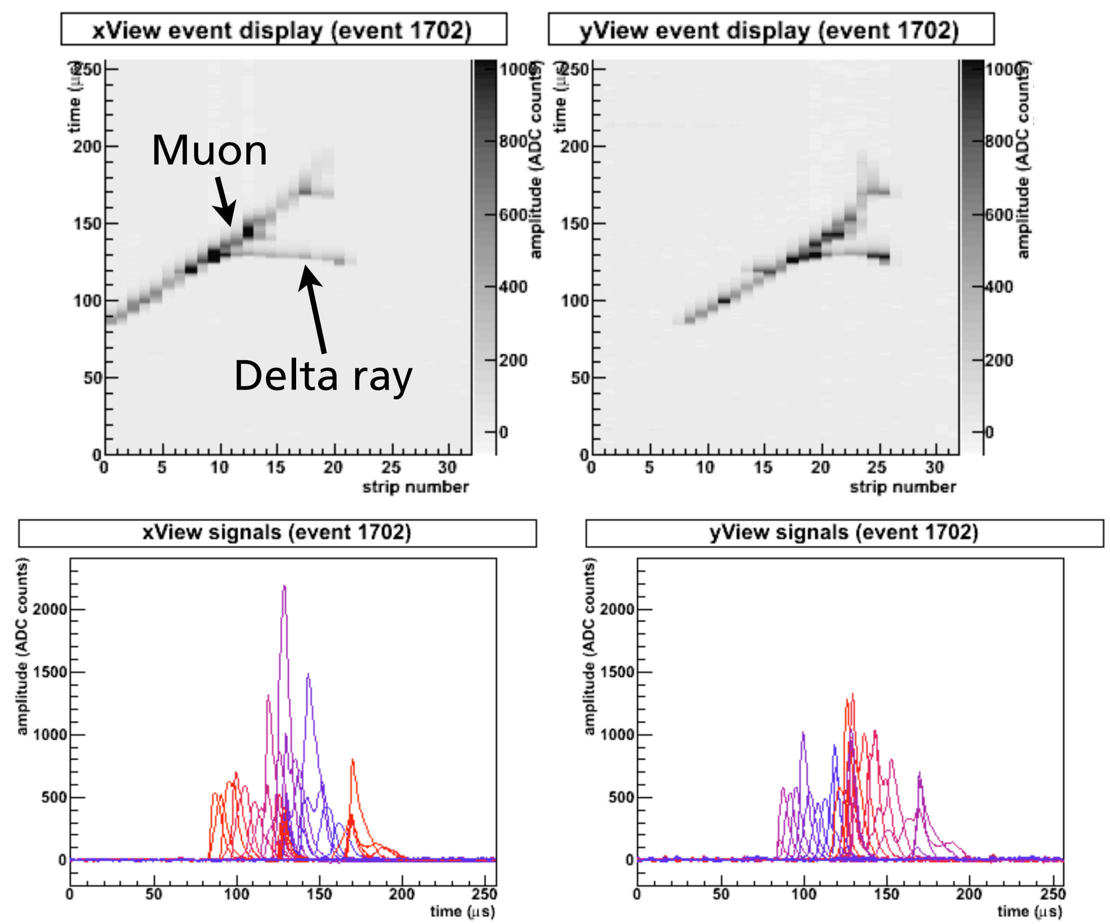


x-y charge sharing

geometry of anode strips is designed to distribute the charge equally on both strips

Crossing of a muon

Effective gain ~ 26



Badertscher et al: NIM A 641 (2011) 48–57

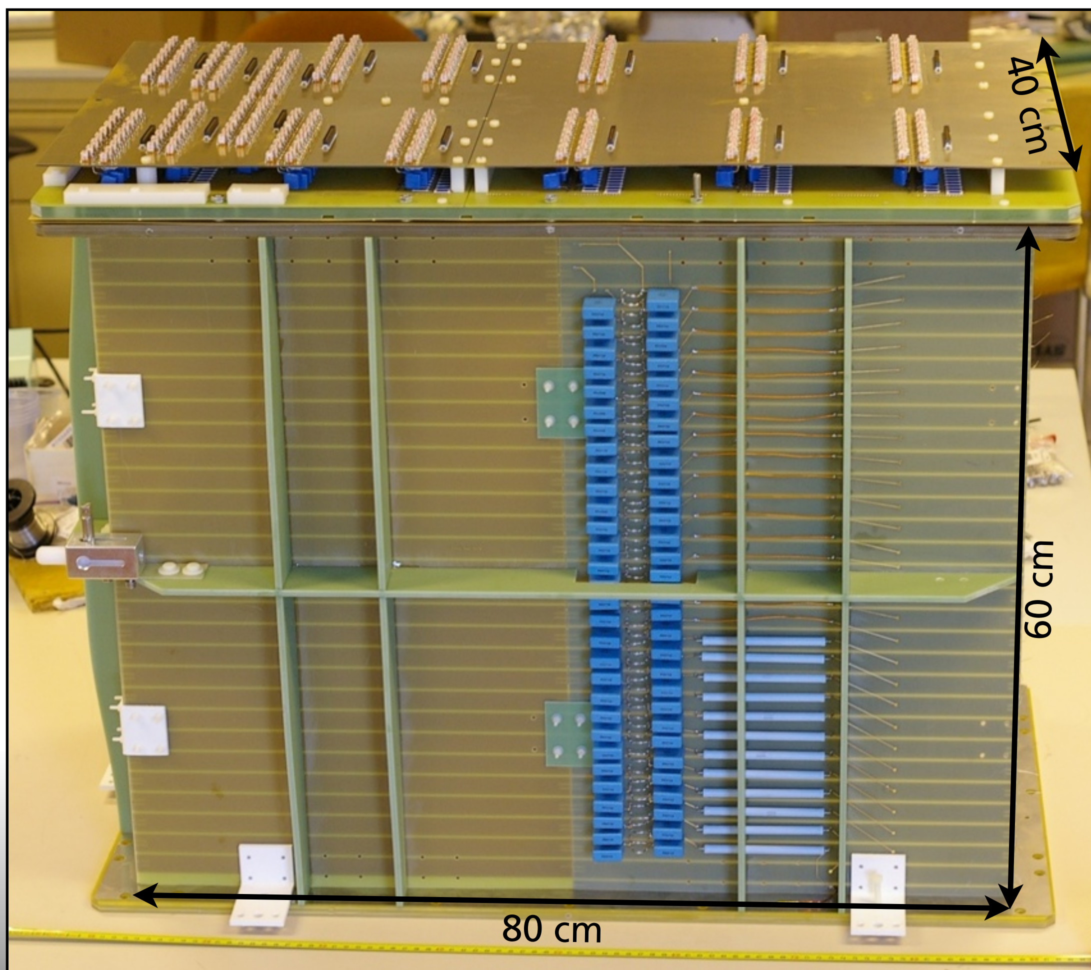
Next Step in Charge Readout R&D

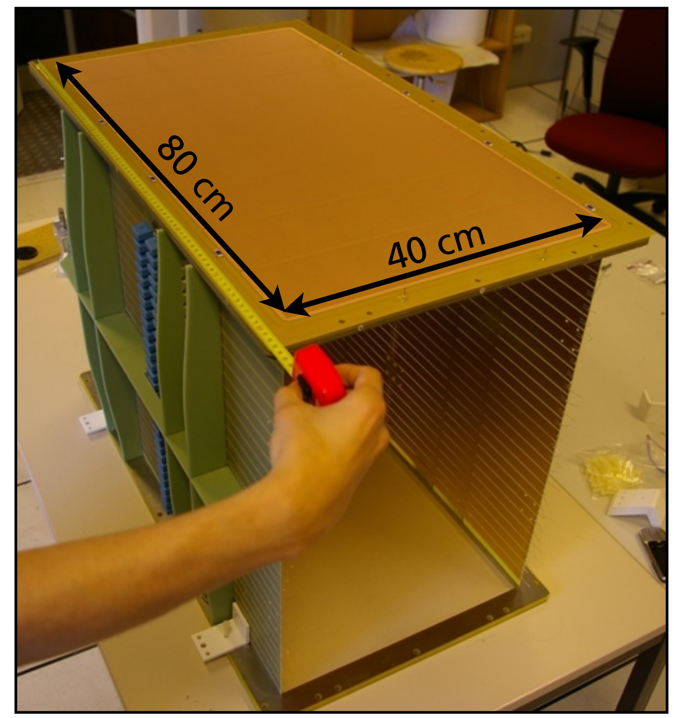
Manufacturer: Anode: CERN TS/DEM group; LEM: ELTOS

250l detector @ KEK (J-Parc P32)

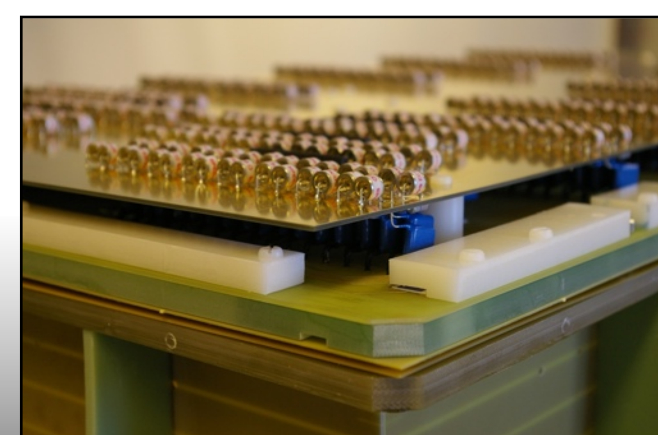
ETHZ-KEK-Iwate-Waseda

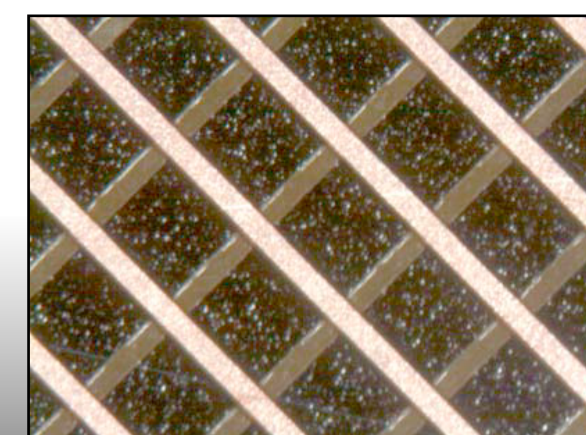
- Experiment with a double phase LAr TPC on a charged particle beam
- Drift cage 80 x 60 x 40 cm





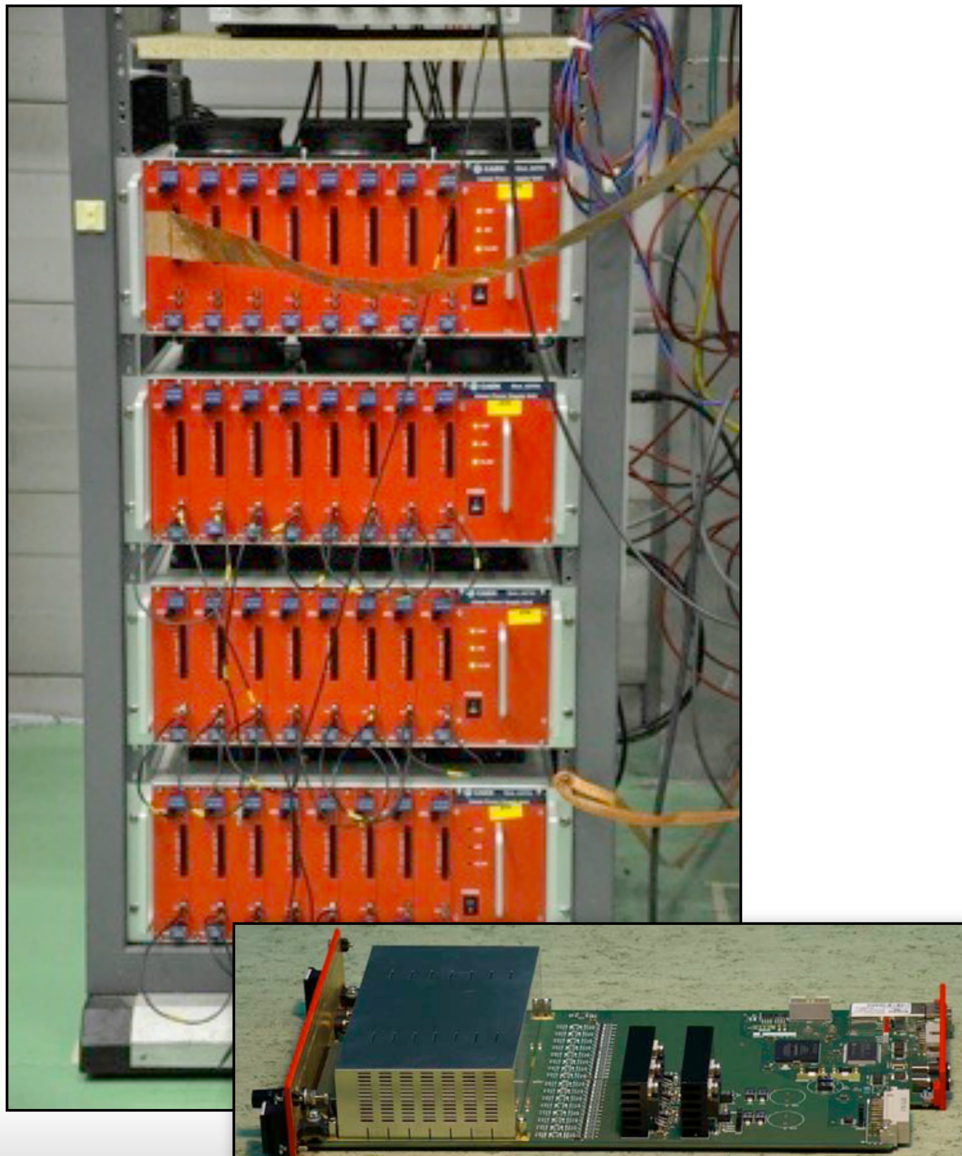
- Biggest LEM and 2D anode ever built (80 x 40 cm)
  - ~ half the size of final charge readout of ArDM
- LEM segmented in 8 parts to decrease capacitance
- Anode views 45° to incoming beam
- 512 channels





DAQ

Charge readout



CAEN SY2791

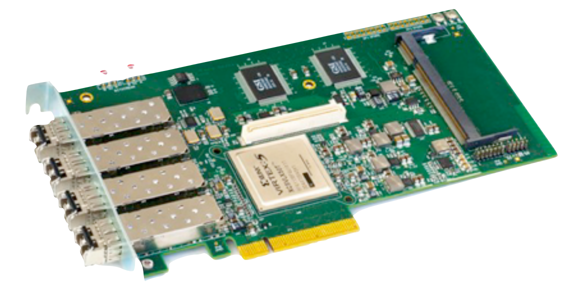
- CAEN, in collaboration with ETHZ
- 4 crates - 1024 channels
- 12 bit 2.5 MS/s flash ADCs + FPGA

Light readout

CAEN V1720

- VME based
- 3 boards currently available (24 ADC channels)
- 250MS/s 12bit 1.25MS/Ch (up to 10MS/Ch available)

DAQ-System



Readout Cards

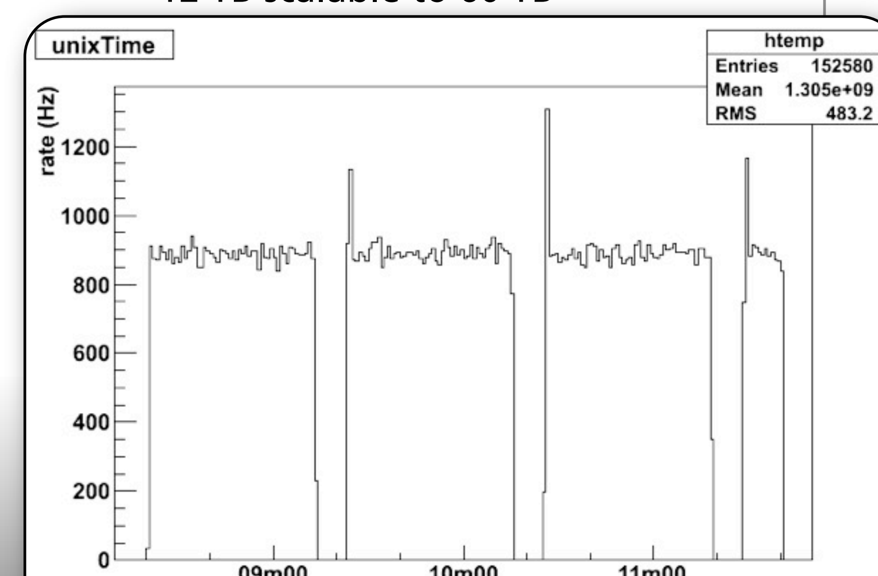
- 2 x CAEN A3818 PCI Express
- 4 optical links each, 95 MB/s per optical link

DAQ Computer

- 2 x DELL R510, 6 cores, 12 GB RAM

Storage

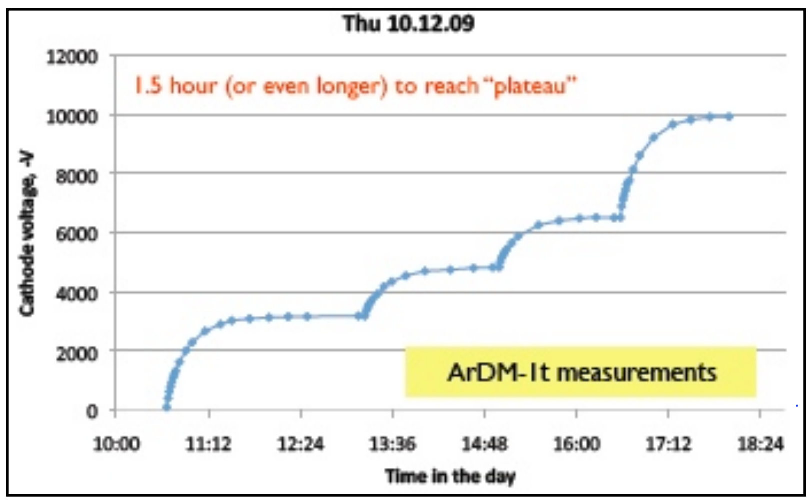
- LaCie 12Big, 12 TB scalable to 60 TB



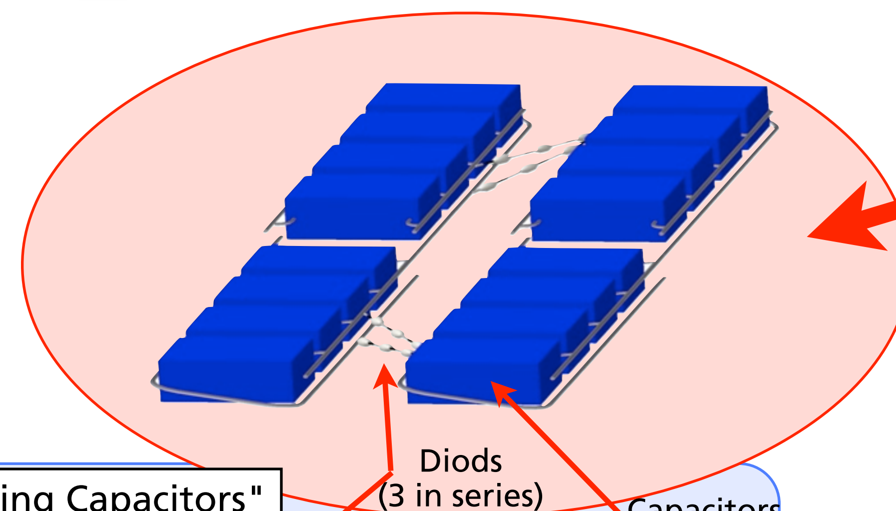
Performance: ~ 900 Hz!

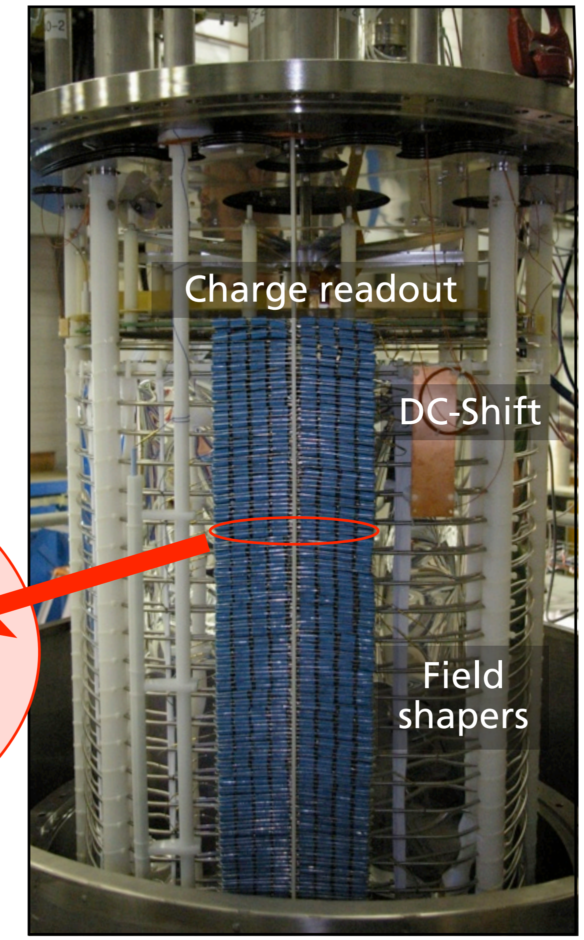
The High Voltage System of ArDM

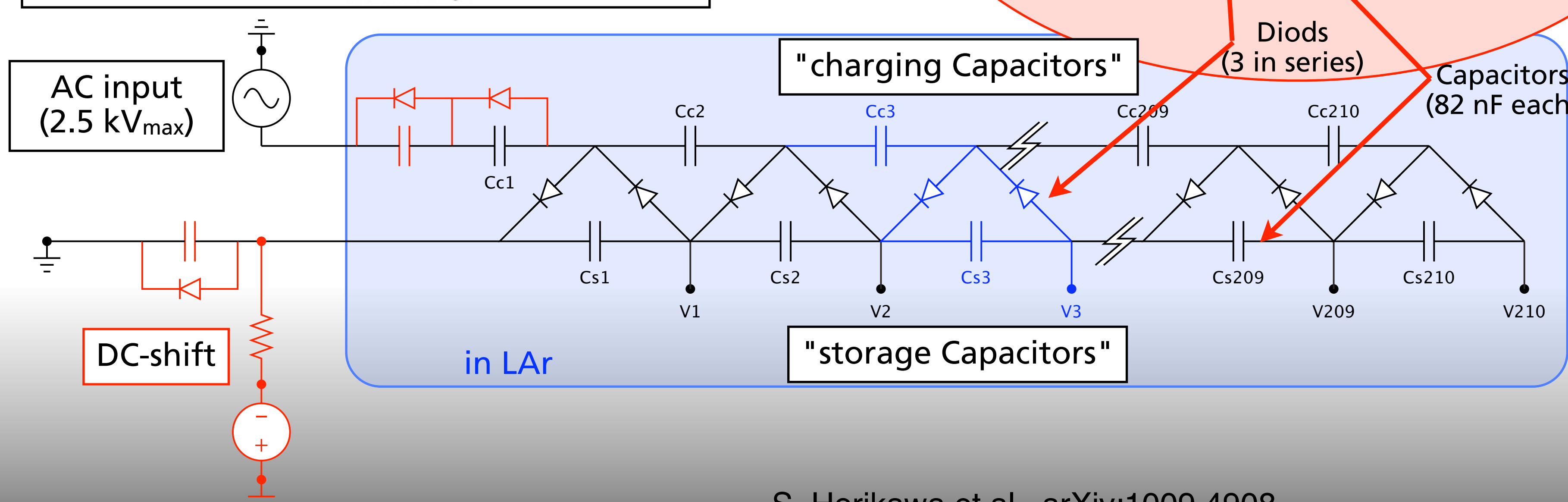
- Greinacher- / Cockcroft-Walton HV multiplier immersed in liquid argon (good insulator)
- 210 stages (1520 HV capacitors & 1260 avalanche diods)
- Low alternating input current (50 Hz; maximum $V_{pp(in)}$ ~ 2.5 kV)
- Ideally: $V_{out}(n)=n \times V_{in}$
- Starting voltage has to be negative
  - DC shift up to - 8 kV possible

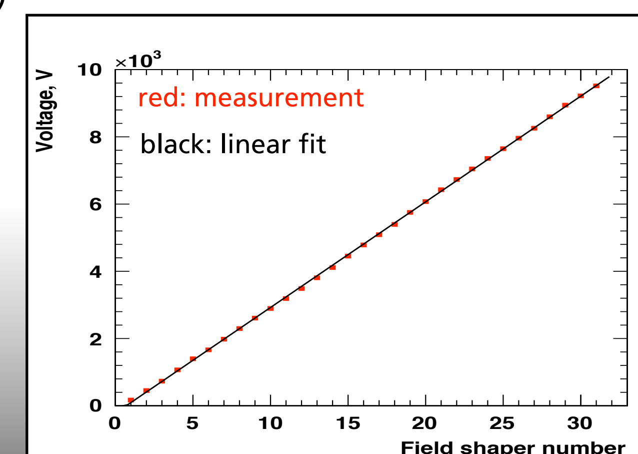


Tested up to 70 kV (600 V/cm)







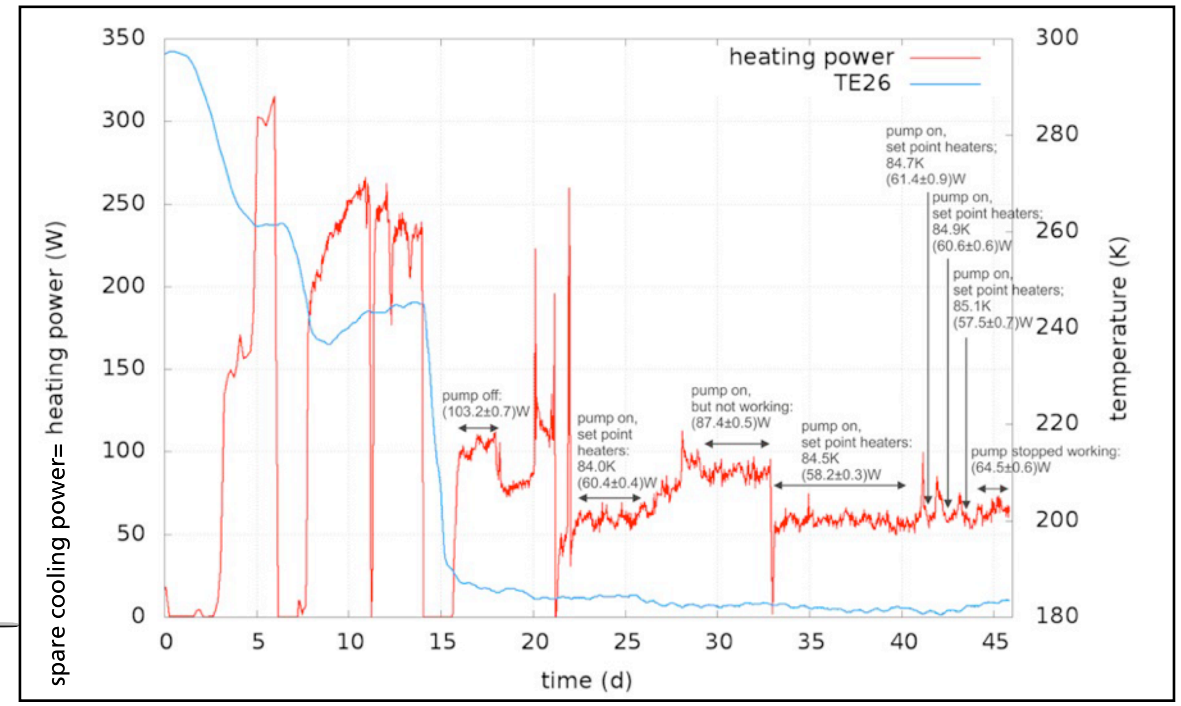


S. Horikawa et al., arXiv:1009.4908

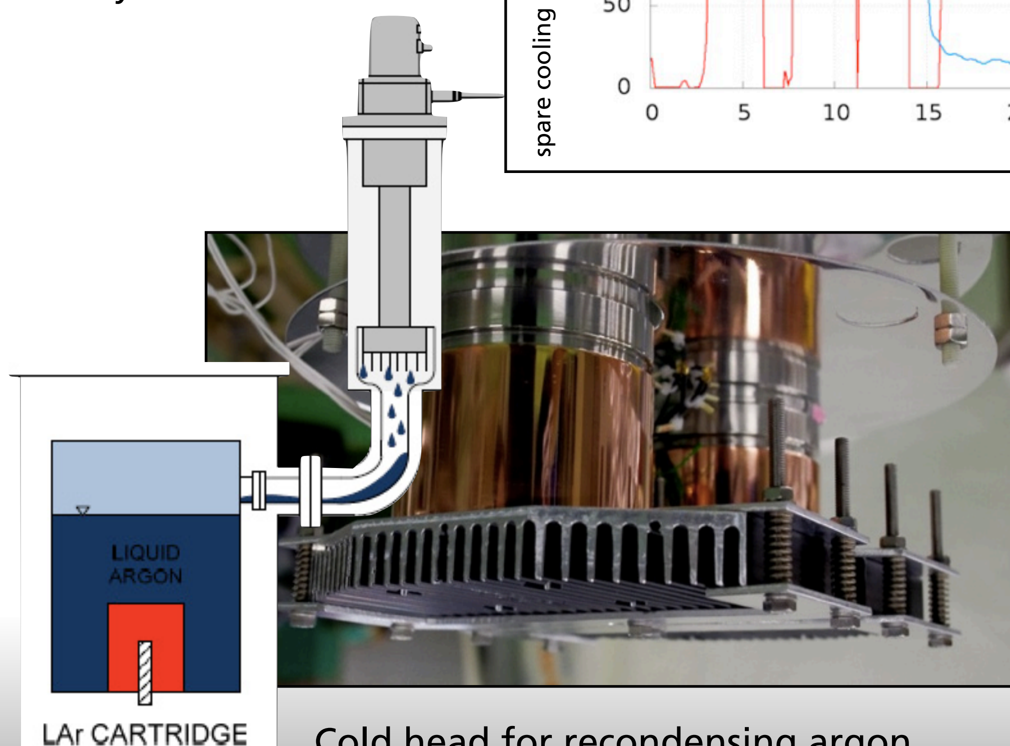
Cryogenics

ArDM is upgraded to a zero loss system

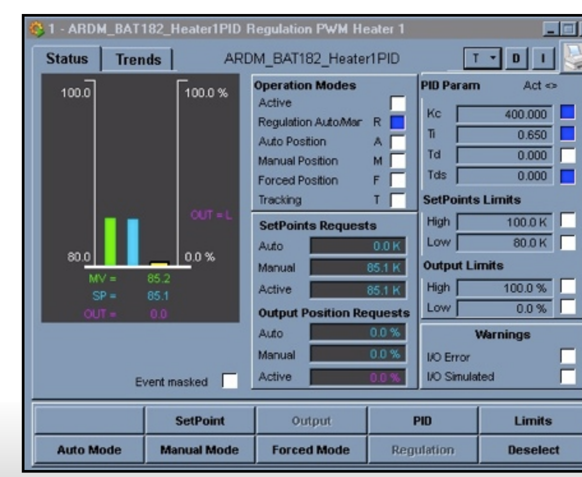
- All cryogenic processes (Insulation, cooling, recirculation, ...) controlled by PLC (Programmable Logic Controller)
- 2 Cryocooler with 300 W @ LAr temperature each (Cryomech AL300)
- Recondensation on cold heads
- Cooling power controlled by PID-controller in PLC system (pressure variations in cryostat < 5 mbar!)
- Cryostat and regeneration system insulated by independent vacuum insulations



PLC-System (incl. racks for DAQ and HV)
(under responsibility of CERN PH-DT group)



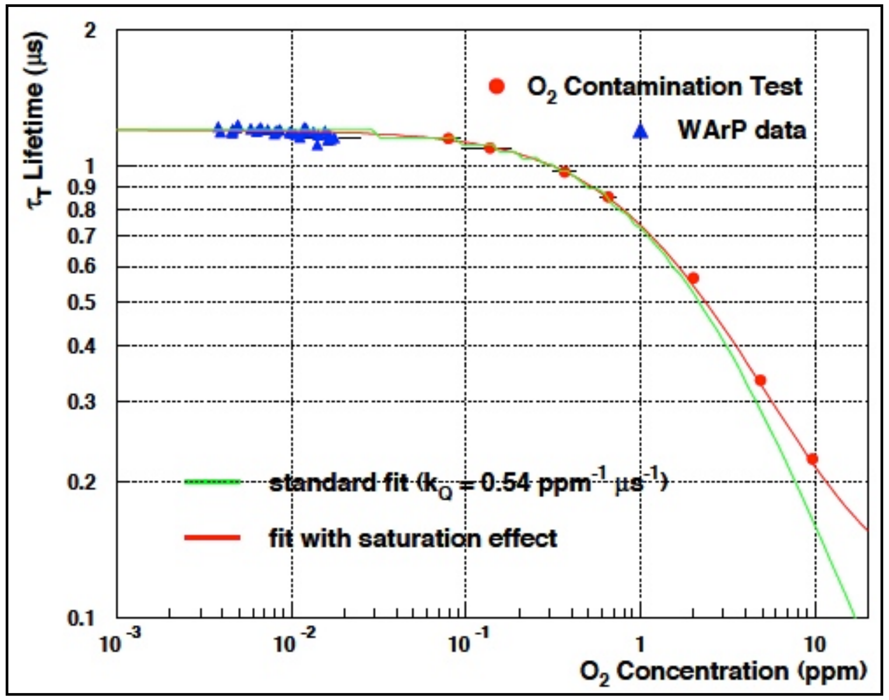
Cold head for recondensing argon
(Recondenser built by Criotec SA)



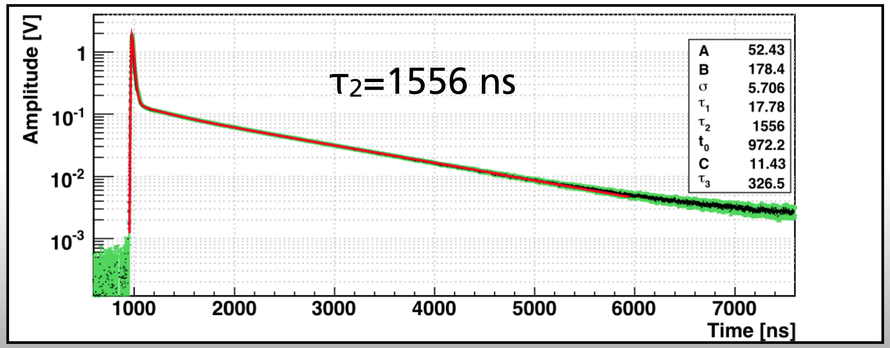
PID-Controller

Purity, a big issue for noble gas TPCs!

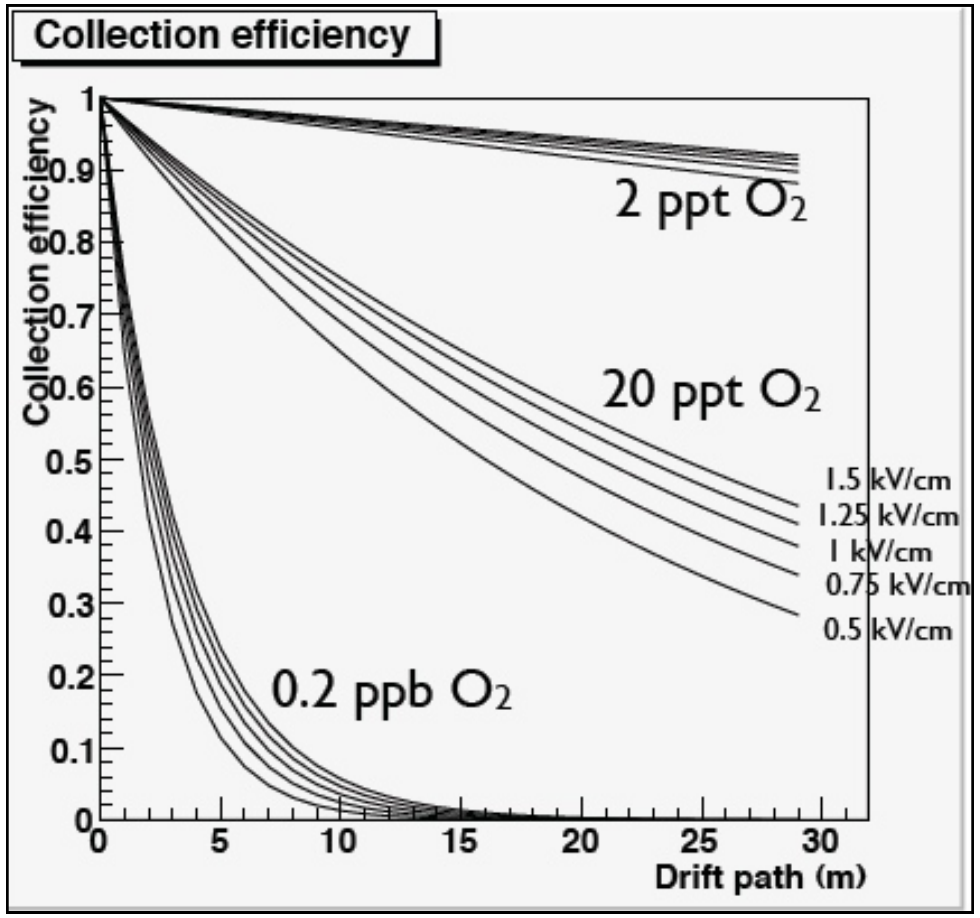
Drift of charge, as also the lifetime of excited states in argon, are strongly dependent on the amount of electro negative impurities in the noble gas.



R Acciarri *et al* 2010 *JINST* **5** P05003



Amsler et al. 2010 JINST 5 P11003



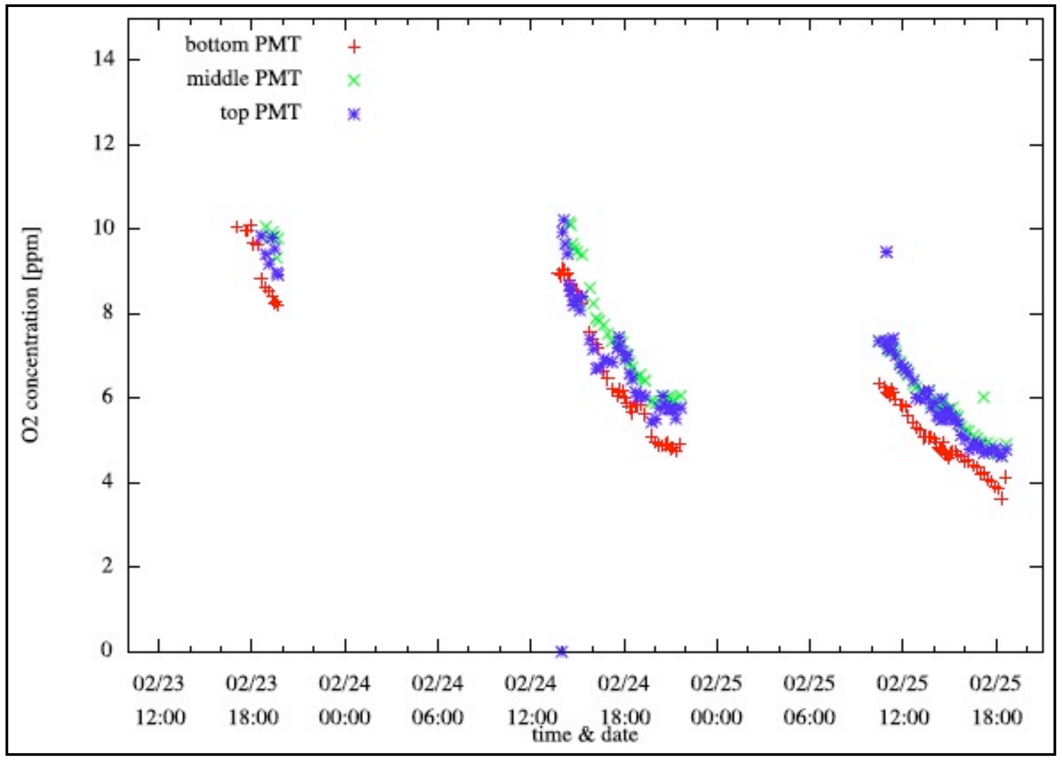
Lifetime of free charge in liquid argon: $\tau \approx \dfrac{300\mu s}{O_2(ppb)}$

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ETH Institute for Particle Physics

Results for cleaning Ar

Purging of non evacuated vessel with GAr



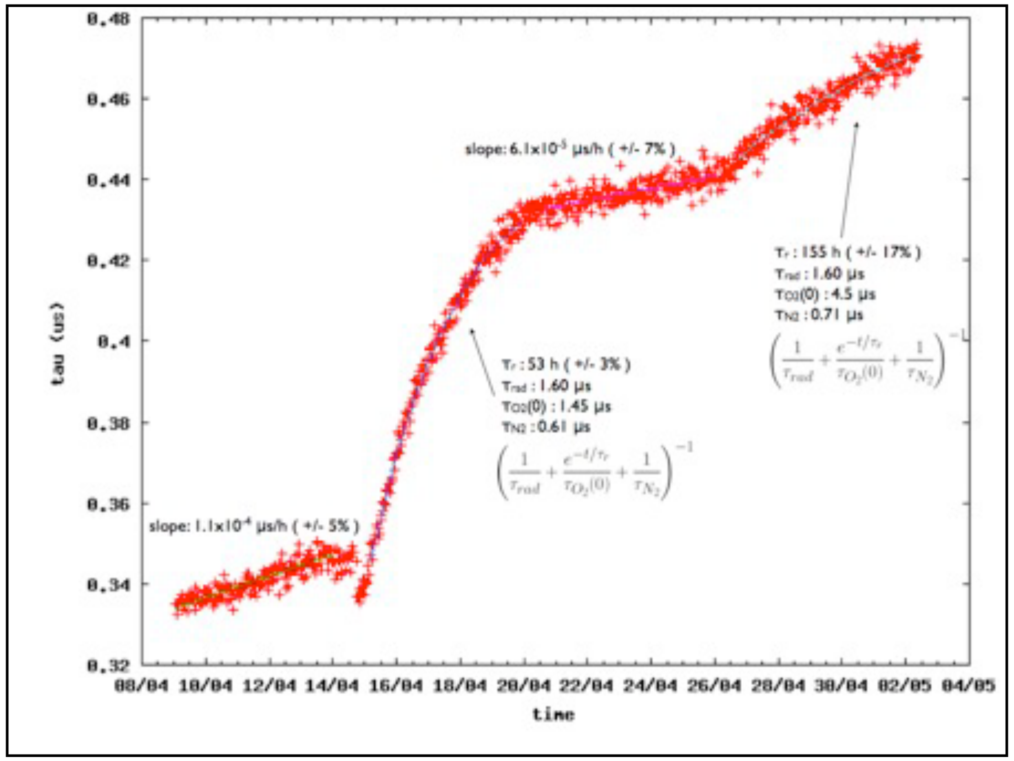
Curioni et al. arXiv:1009.4073v2

Purities down to a few ppm can be reached.

This test was performed in a 6 m^3 vessel with the background of building even bigger vessels that can't be evacuated.

(ETHZ, University of Liverpool)

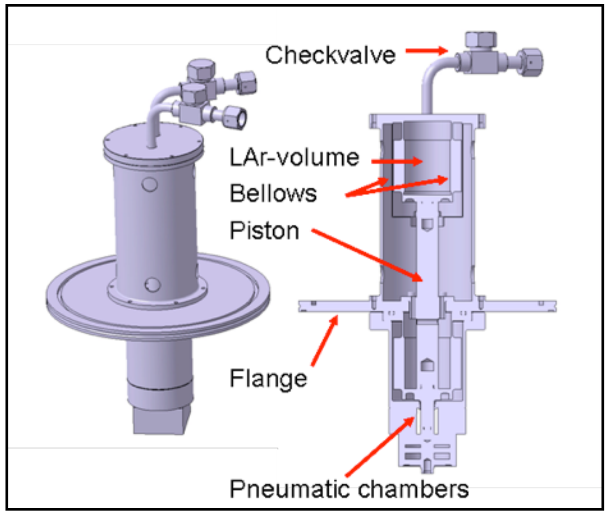
Purification of the LAr in ArDM



- For the first time the liquid recirculation of ArDM has been tested.
- Pump was running for several days with a constant flux of ~ 15 l/hr.
- This was done in a cryogenic test and the initial purity of the liquid was bad.
- Even though a lifetime of 1.6 µs was found for the scintillation light.

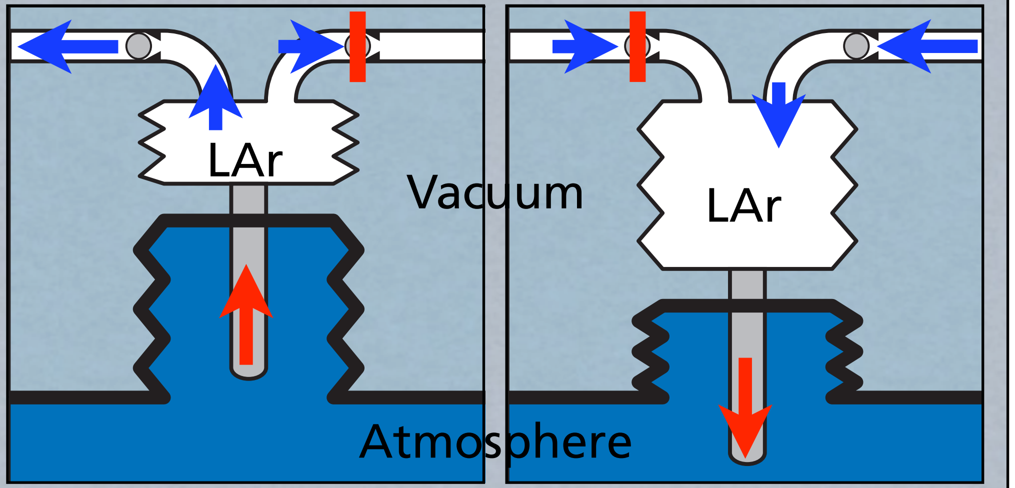
Liquid Gas Purification

In collaboration with Bieri Engineering



More powerful pump under construction
(increase of flux more than factor 2)

Bellow pump for LAr (up to 20 l / hr)

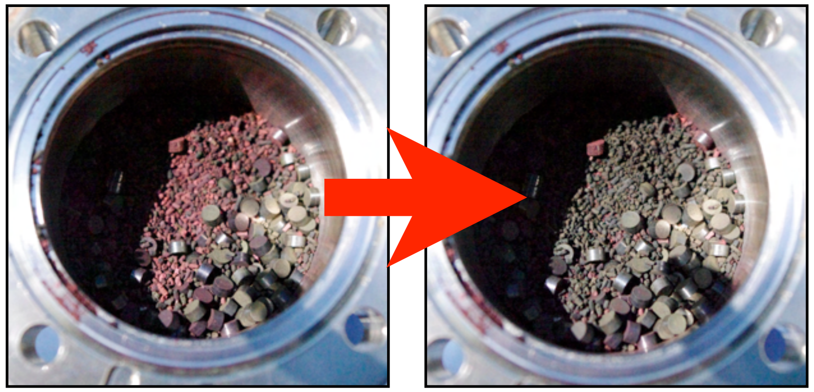


- Up to 20 l / hr
- Pneumatic actuation
- No abrasion
- No recirculation of GAr
- Limited lifetime due to membrane bellow

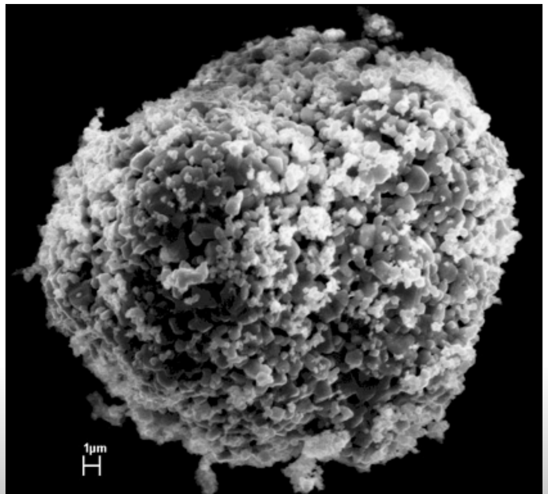
LAr cylinder containing copper cartridge (vacuum insulation removed)

Purification process:

- LAr floats through reduced copper oxide.
- Oxygen impurities oxidize copper and stay in the cartridge



activated copper (reddish) | after a few seconds exposed to air



Sintered copper "pellet"

Next steps for purification

After good experiences with gas purification in the 3l setup, we decided to install a similar system on ArDM.

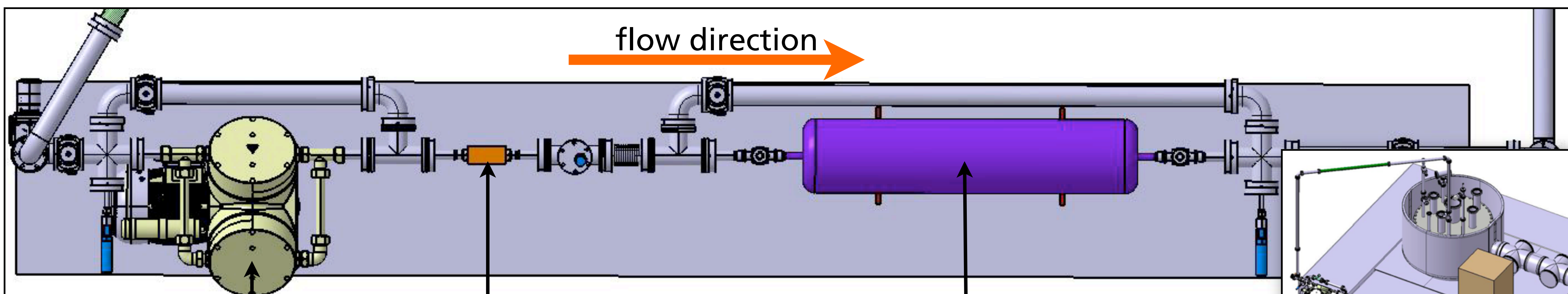
– Independent system from liquid recirculation
– ~ 150 l/min of GAr @ 300 K --> ~10 l LAr

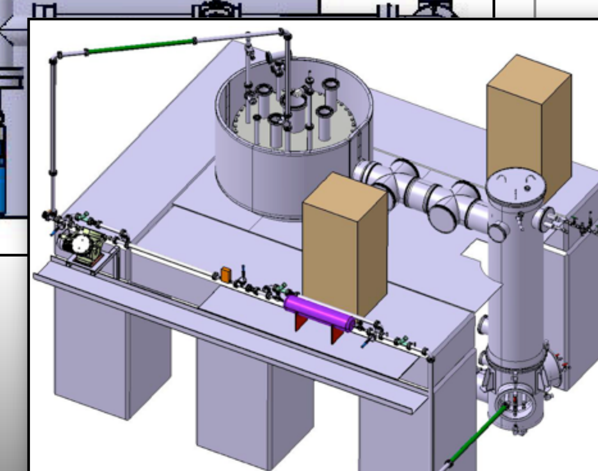
<u>Advantages</u>:

- Purification during cool down possible
- "Boil off" from argon doesn't only get recondensed but also purified
- Commercial SAES purification cartridge
- Possibility to attach gas analysis instruments
- Well known and less challenging technology

<u>Disadvantages</u>:

- Additional cooling power needed to cool down gas from room temperature to 80 K
- Much higher flux needed (1 l LAr ≈ 800 l GAr)





What's Coming Up?

LSC Scientific Committee
7th Meeting
October 7th and 8th, 2010
Canfranc Estación, Spain

Summary, Conclusions and Recommendations

CONCLUSIONS AND RECOMMENDATIONS

LoI -02-2005 (ArDM)

The Committee was pleased to receive the letter of intent (LoI) from the ArDM Collaboration. Large scale liquid Xe and liquid Ar dark matter experiments are running or being constructed at various underground laboratories worldwide. The ArDM one-ton liquid argon two-phase TPC can be competitive if deployed in time, and if the tests of some critical design components are successful. ArDM identifies nuclear recoil signals by the pulse shape and light/charge ratio. Compared with other

The Committee recommends the approval of the ArDM experiment for a period of four years. We also recommend that the Laboratory supply the requested platform and utilities (electrical power, cryogenics, gas lines, etc.) required for the experiment.

The Committee recommends that at the next meeting the Collaboration present results of the expected neutron background and sensitivity reach, for the different proposed phases.

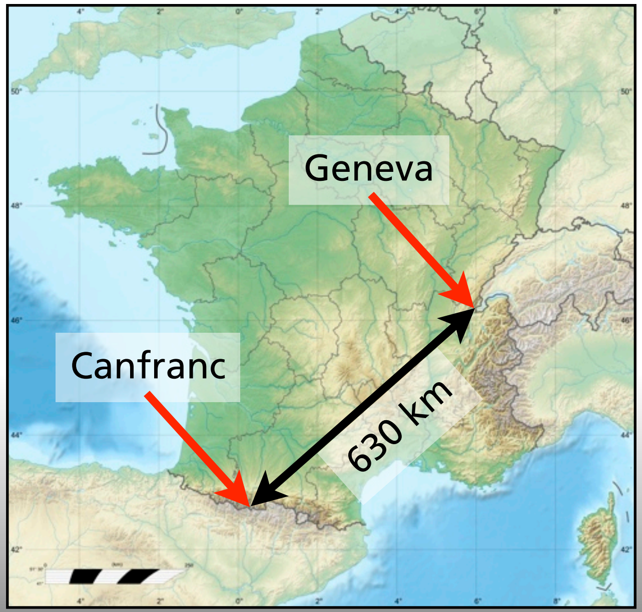
Approval for Underground Operation @ LSC

LSC (Laboratorio Subterráneo de Canfranc)

<u>LSC (Laboratorio Subterráneo de Canfranc)</u>

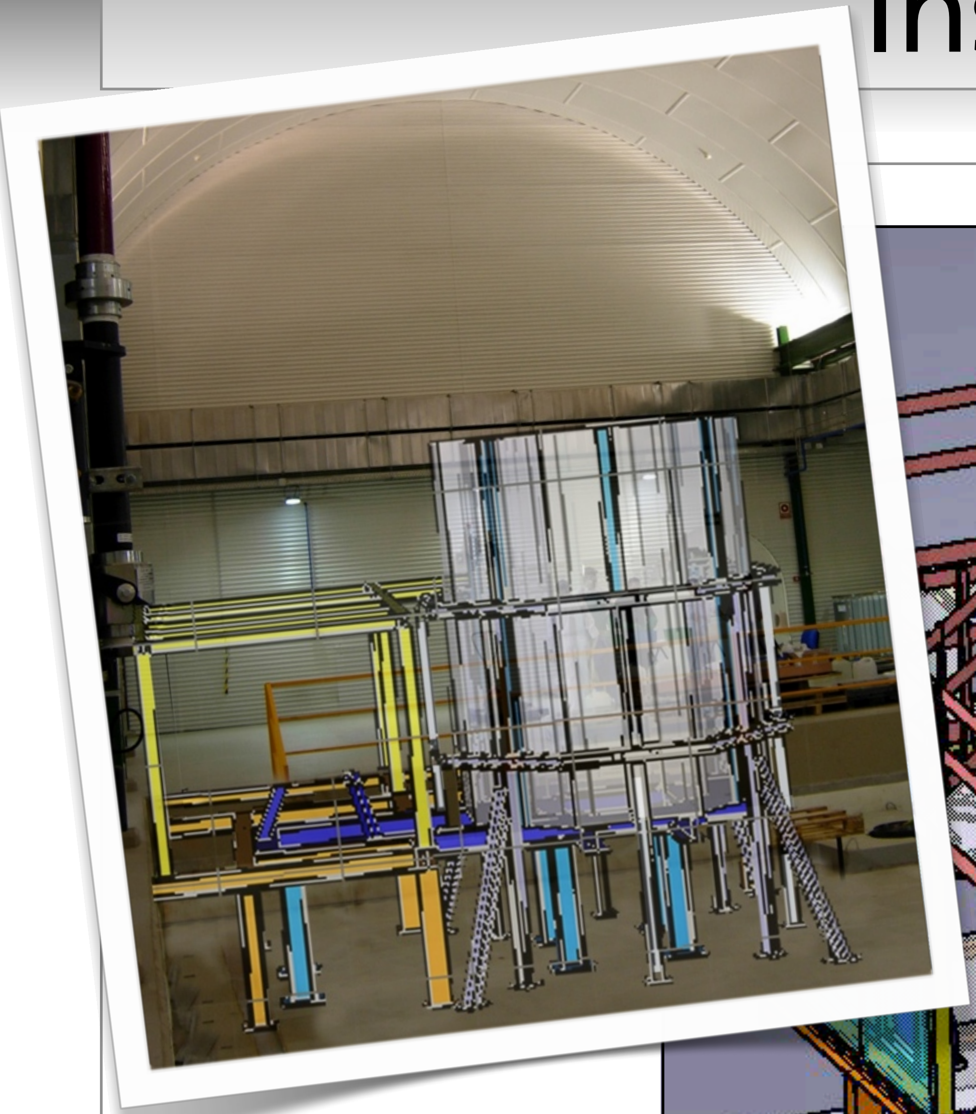
- Location: Somport tunnel between France and Spain
- Size of main hall: 40 × 15 × 10.5 m

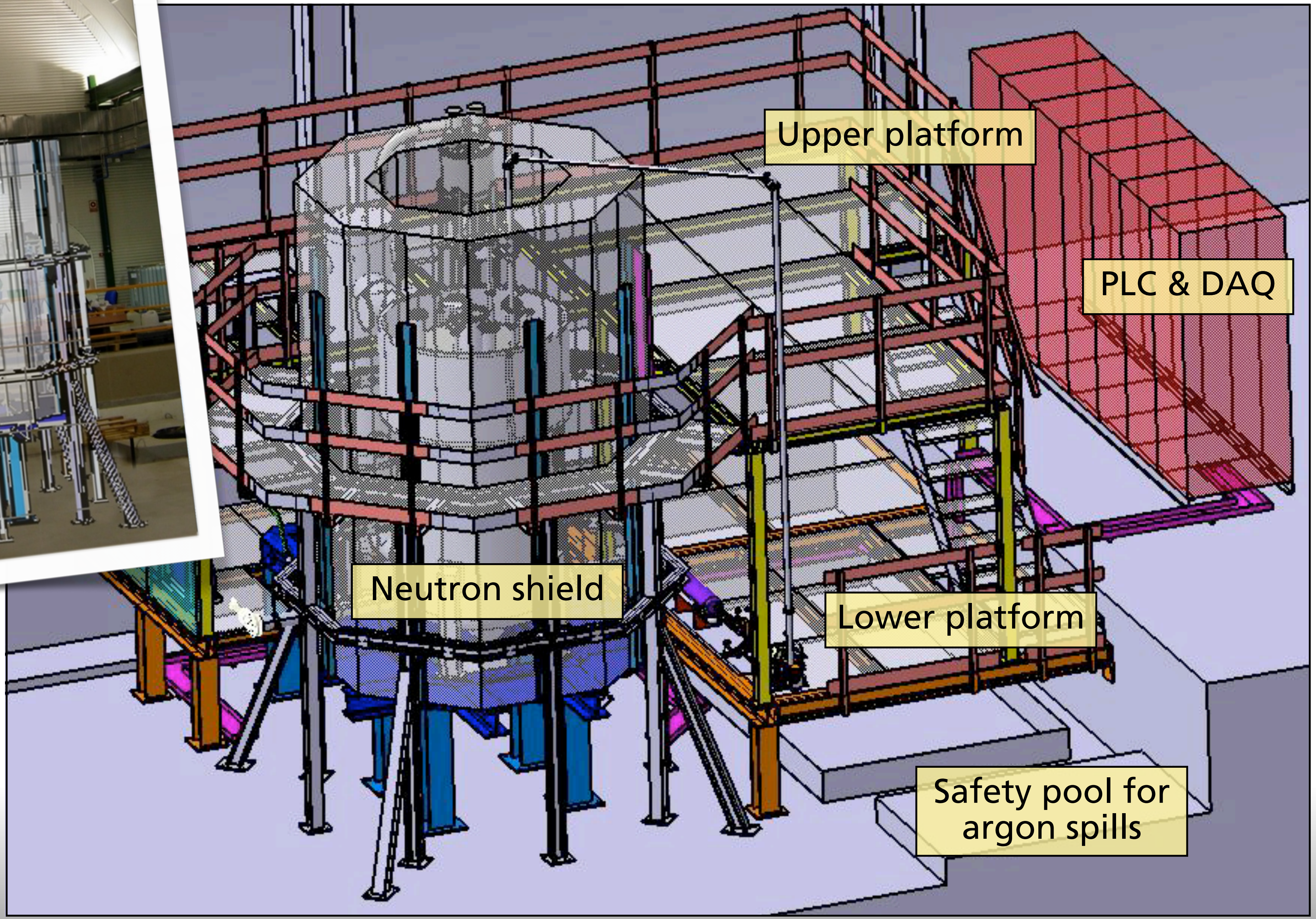
- 850 m deep under the Mount Tobazo (~ 2500 m.w.e; μ flux ≈ 2x10–7 μ/cm^2/s)
- Gamma flux ≈ 2x10–2 γ/cm^2/s
- Neutron flux ≈ 10–6 n/cm^2/s
- Radon ≈ 50-100 Bq/m^3



Installation at LSC

In collaboration with LSC

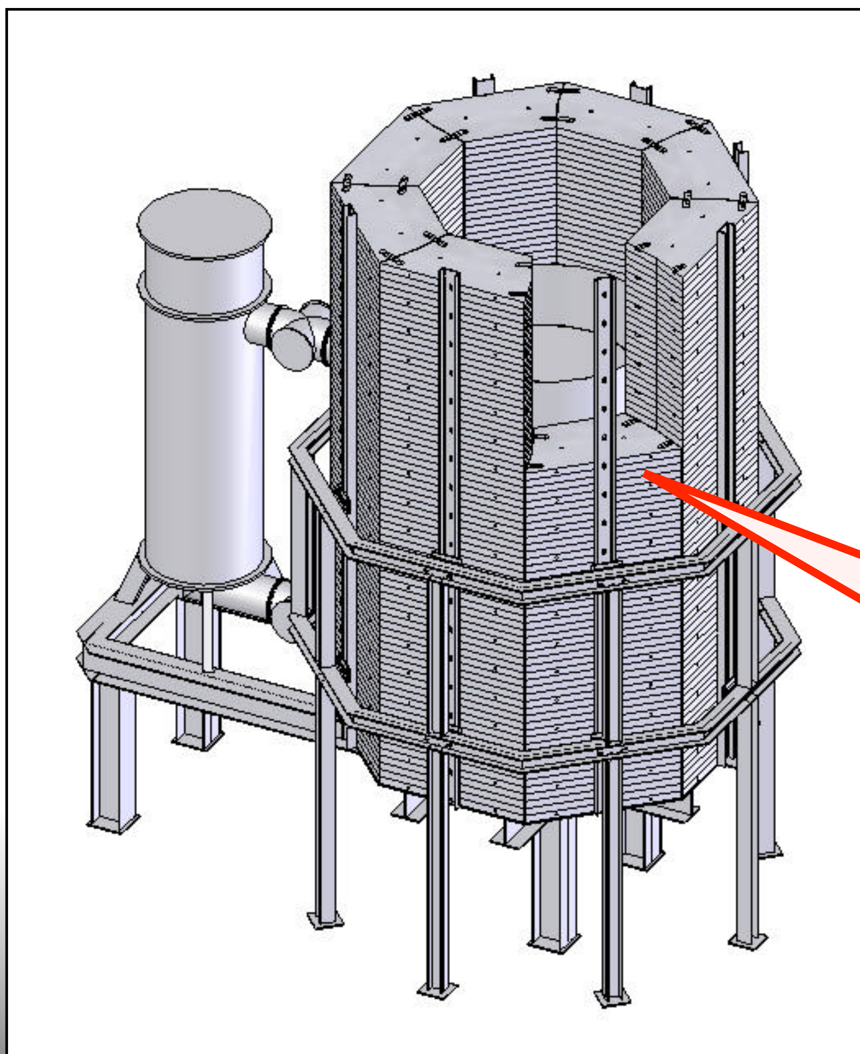


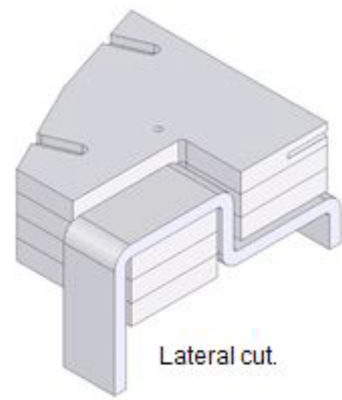


Neutron Shield

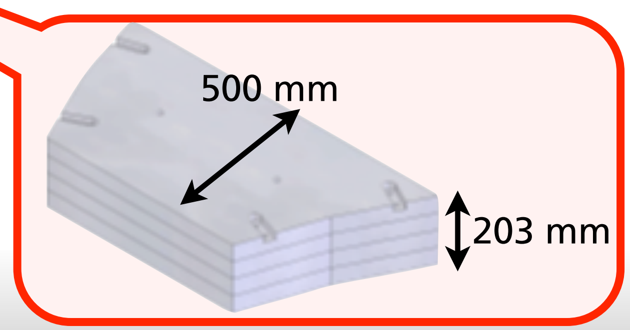
Under responsibility of CIEMAT group

- Material: polyethylene
- Radial thickness: 50 cm
- Octagon shape
- Total 600 slabls
- Blocks of ~ 20 cm height, clued together out of 4 slabs
- Total weight: ~17 tons (incl. cup and floor)





Cable feed through

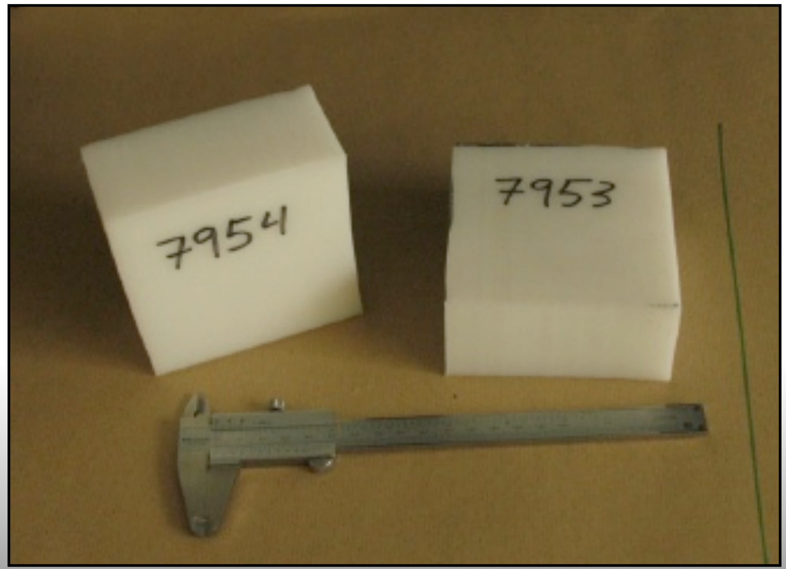


Ring of one slab height

Connection detail

Screening of Polyethylene

- Gamma activity was measured in two polyethylene samples.
- No radioactive contamination was found in any sample.
- No artificial radionuclides have been detected.
- No artificial radionuclides have been detected.



The letters AMD means minimum detectable activity.

MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat

RESULTADOS DE LAS DETERMINACIONES

INFORME N° 115/2011

TIPO DE MUESTRA: MUESTRAS DE PLANCHAS DE POLIETILENO
FECHA DE MUESTREO: 25 de Febrero de 2011
RESPONSABLE DEL MUESTREO: Luciano Romero Barajas

REF. MUESTRA	REF. LAB	CONCENTRACIÓN DE ACTIVIDAD ($Bq\ g^{-1}$)		AMD
CIEMAT-SOL-Polietileno AtCM-250211-1	7953	^{234}Th		1,06 E-03
		^{235}U		7,89 E-04
		^{226}Ra		3,86 E-04
		^{228}Ac		7,31 E-04
		^{208}Tl		1,82 E-04
		^{40}K		3,75 E-03
CIEMAT-SOL-Polietileno AtCM-250211-2	7954	^{234}Th		1,06 E-03
		^{235}U		7,88 E-04
		^{226}Ra		4,10 E-04
		^{228}Ac		7,17 E-04
		^{208}Tl		1,67 E-04
		^{40}K		3,70 E-03

(*) No se han detectado radionucleidos de origen artificial.

(**) La matriz de estas muestras no se ajustaba a ninguna de las geometrías establecidas en el Laboratorio de Medidas de Protección Radiológica para la medida directa por espectrometría gamma. Su análisis cuantitativo se ha realizado aplicando una calibración matemática en eficiencias mediante el código LabSOCS (Laboratory Sourceless Calibration Software, Canberra Inc., US Patent 6228664 B1). La densidad de ambas muestras se determinó experimentalmente. En el anexo de este informe se incluyen las características del detector de Ge empleado, (tipo BEGe, extendido en energía) y cuya caracterización fue realizada por el fabricante, así como las dimensiones de la geometría definida mediante el software de calibración matemática.

(***) La concentración de actividad de ^{226}Ra ha sido obtenida a través de su descendiente ^{214}Bi.

Madrid, 11 de Febrero de 2011.

Fdo: Nuria Navarro
Responsable Técnico.

Fdo: Alicia Álvarez,
Jefe del Laboratorio de Protección Radiológica

Este informe no deberá reproducirse parcialmente sin la aprobación por escrito del Laboratorio de Medidas de Protección Radiológica.

INFORME Nº 115 / 2011 Pág 1 de 1

FORMATO PT-SG-PR-46-3

Conclusion and Outlook

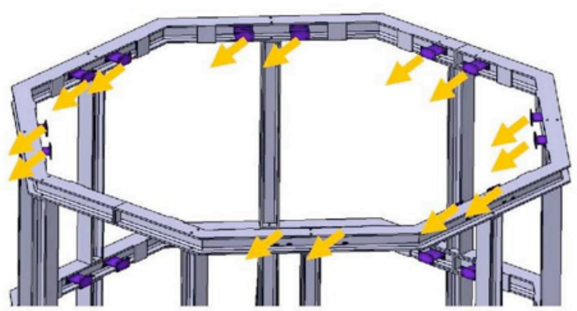
- ArDM has been commissioned successfully at CERN in several runs of up to 2 month
  - First results with light readout system (Amsler et al. 2010 JINST 5 P11003)
  - Analysis on nuclear recoil with Am-source ongoing
  - HV system tested up to 70 kV
  - S1/S2 discrimination with temporary anode (no amplification)
  - Prove of principle for liquid purification
  - Cryogenic system commissioned as "zero loss system"
  - DAQ upgraded
- R&D for light and charge readout on-going
  - Hamamatsu R11065 3" PMTs currently tested in different setups
  - Charge readout: Prove of principle with gain up to 30 (1 LEM only) in "3l setup"
  - Test with P32-chamber (40 x 80 cm^2 readout sandwich) next month @ CERN
- ArDM @ LSC
  - Platform under construction
  - Neutron shield designed and under construction @ CIEMAT

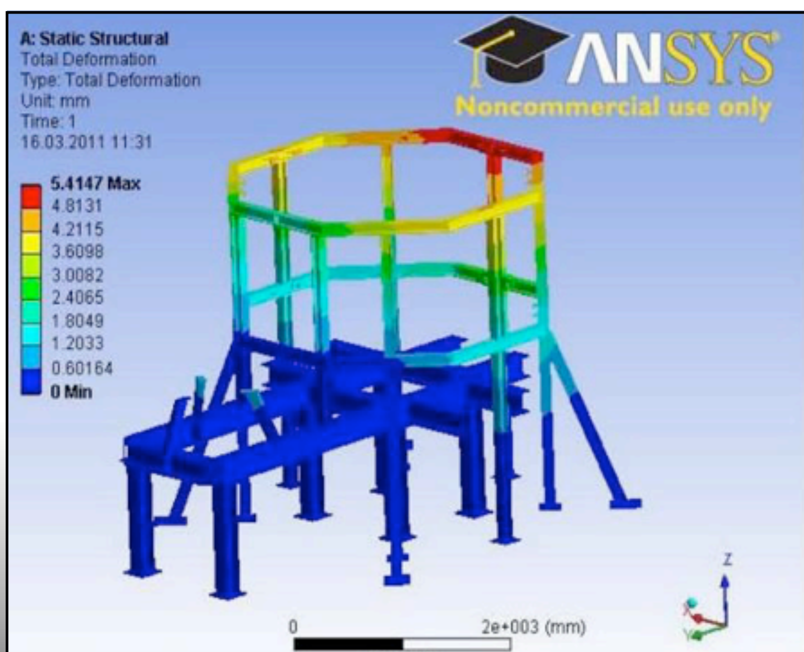
First run under ground and first measurements on ^{39}Ar background planned in the begin of 2012

BACKUP SLIDES

Dynamic Analysis of Earth Quakes

Static stress in case of an EQ with horizontal acceleration of 4 m/s^2





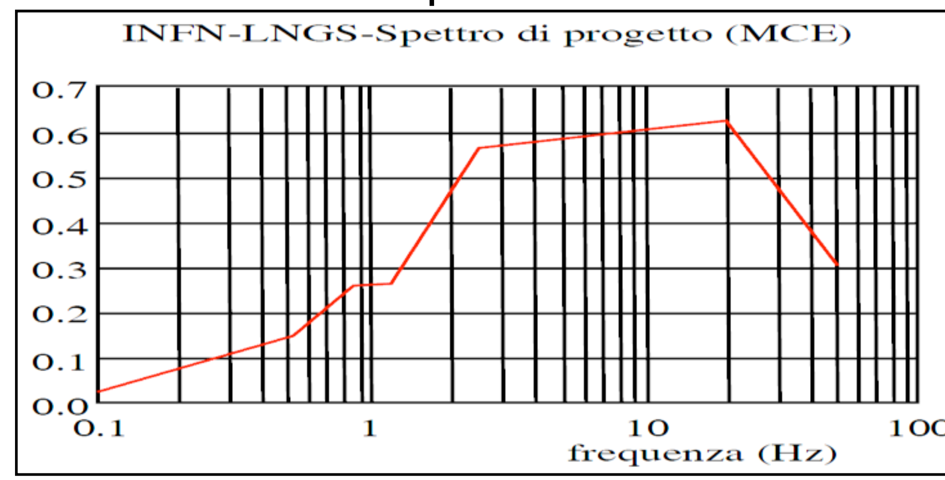
max. deformation: 5.5 mm

max. stress: 145 MPa

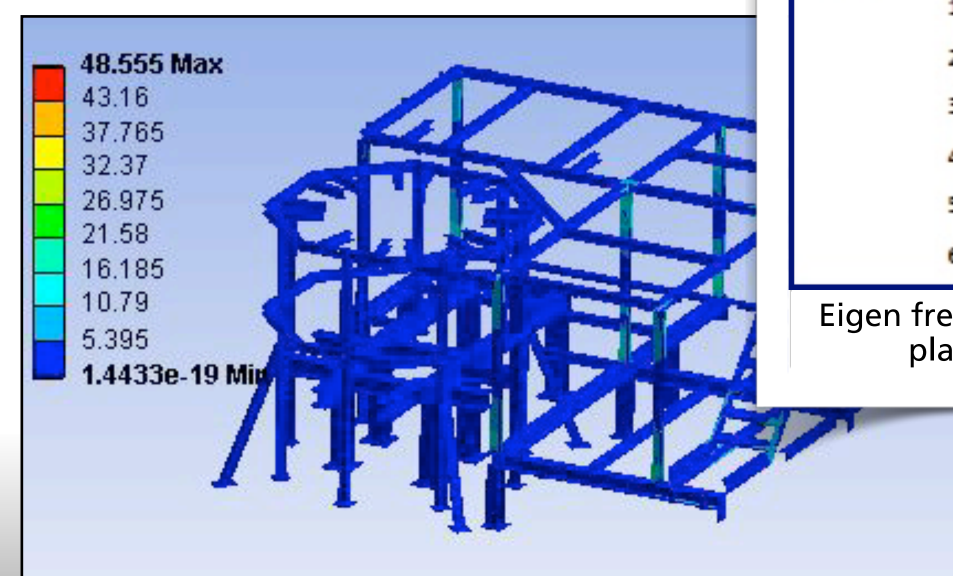
allowable stress: 235 MPa

➡safety factor 1.62

Acceleration response in all directions



Acceleration Response Spectrum corresponds to the Maximum Credible Earthquake (MCE) used for the seismic analysis of LNGS (Gran Sasso)



Maximum is in y-direction (48.6 MPa)
(x: 24 MPa; z: 5 MPa)

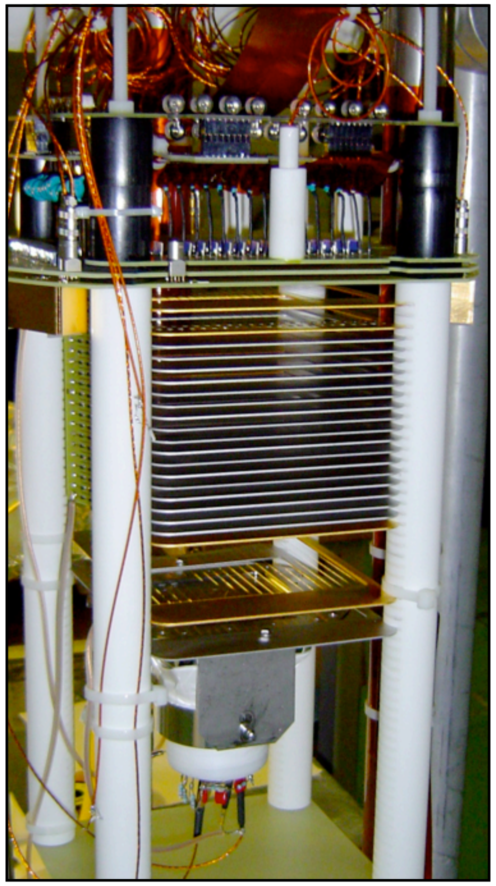
mode	f [hz]
1	10.477
2	13.497
3	18.855
4	20.601
5	20.913
6	22.816

Eigen freq. modes of platform

Alternative charge readout systems:

In collaboration with CERN RD51

LEM / THGEM

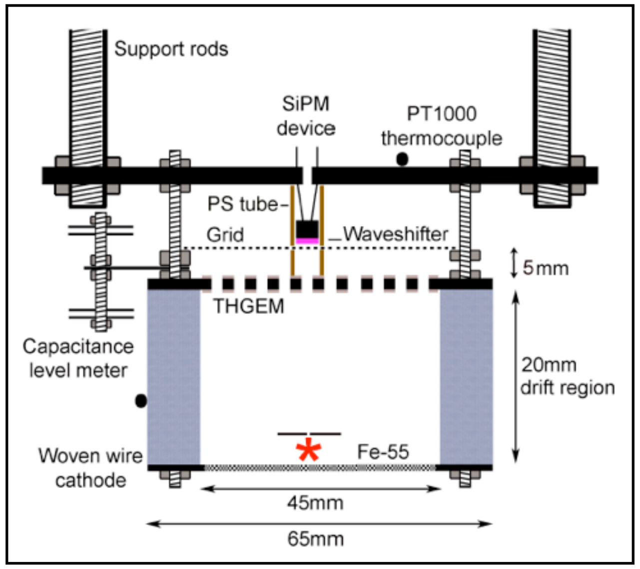


Badertscher et al., NIM A617 (2010) 188-192
Badertscher et al: NIM A 641 (2011) 48–57

MicroMegas

Saclay group
A. Delbart et al.,
GLA2010 workshop

Secondary scintillation from THGEM (optical readout)

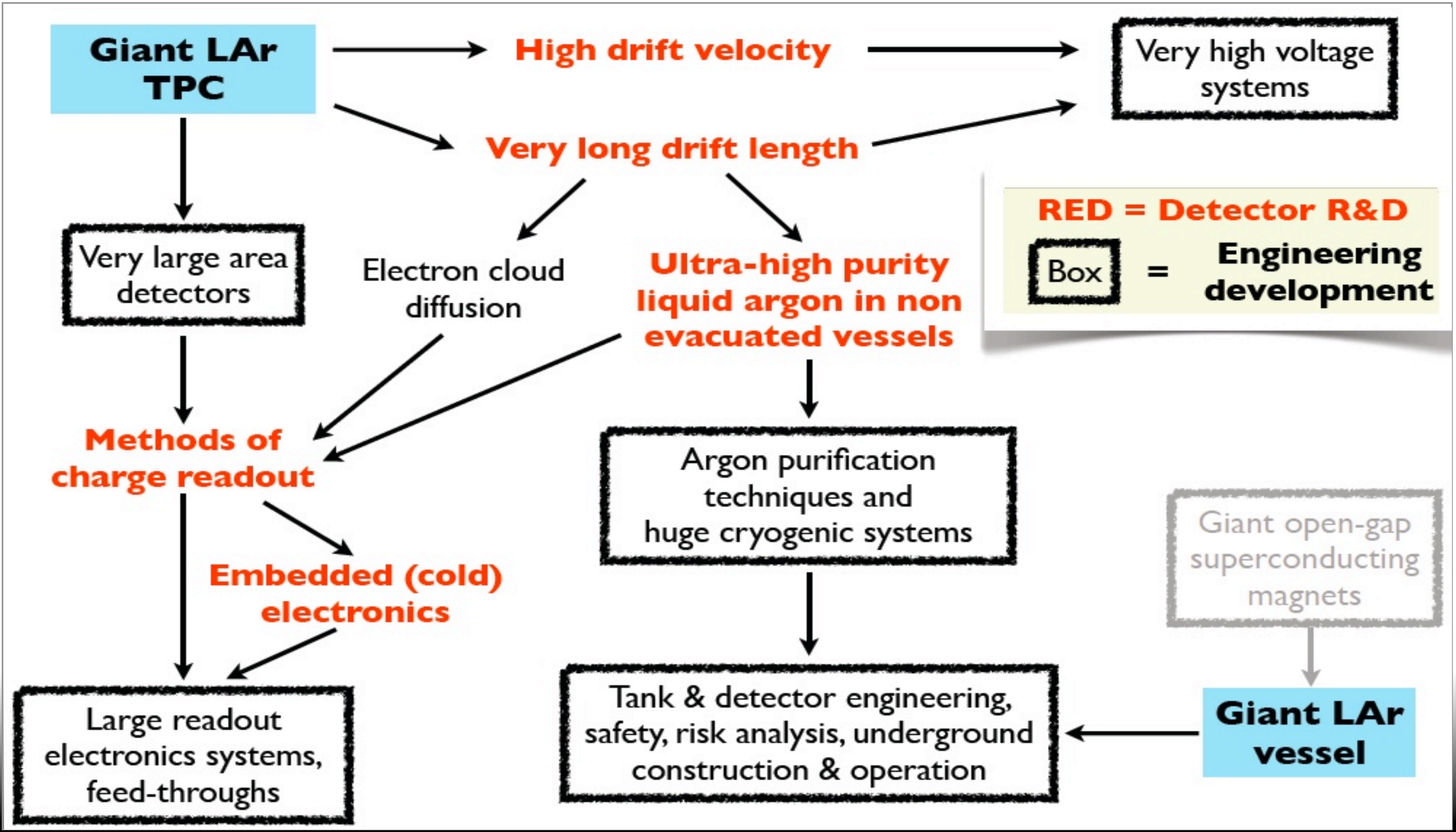


Sheffield group P K Lightfoot et al.,
JINST 4:P04002,2009

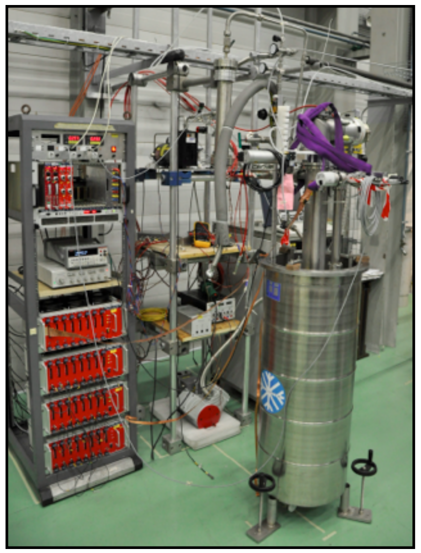
see also
A. Bondar et al.,
arXiv: 1005.5216
(May 28th 2010)

The R&D path to Giant LAr detectors

(A. Rubbia)



LAr-TPCs: Scale up

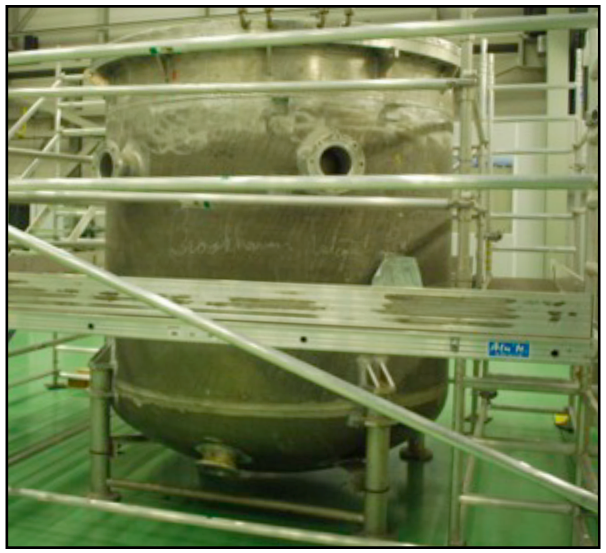


3l Setup @ CERN

(R&D charge readout)

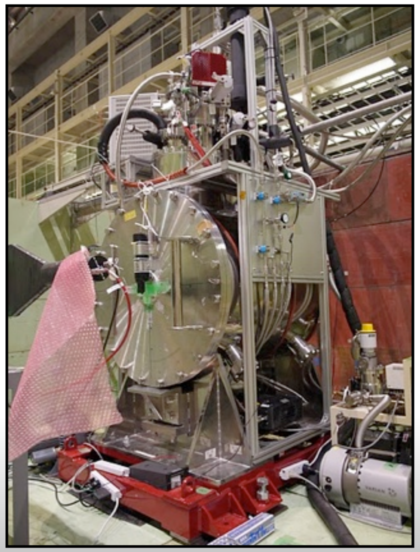
ArDM @ CERN --> LSC

(~1t LAr; Greinacher HV-Devise, large area readout, purification, …)



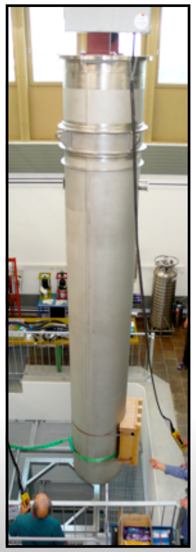
6m³ @ CERN

(R&D toward non evacuated vessels, charged particle test beam exposure in 2012)



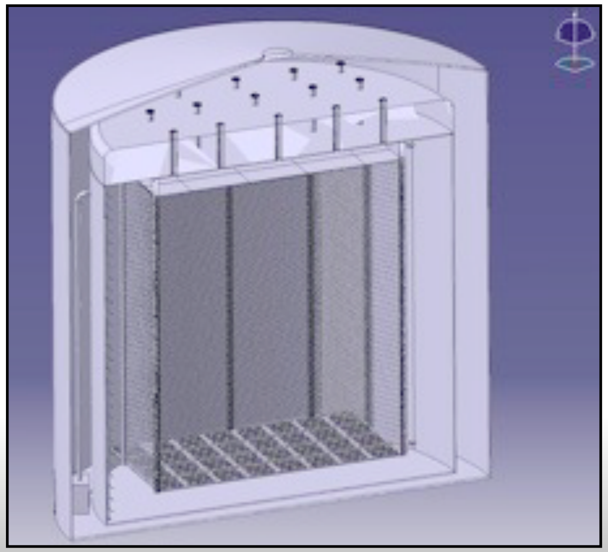
P32 @ JParc

(~0.4 t LAr; Pi-K test beam)



ArgonTube @ Bern

(long drift up to 5 m, HV-system, purity)

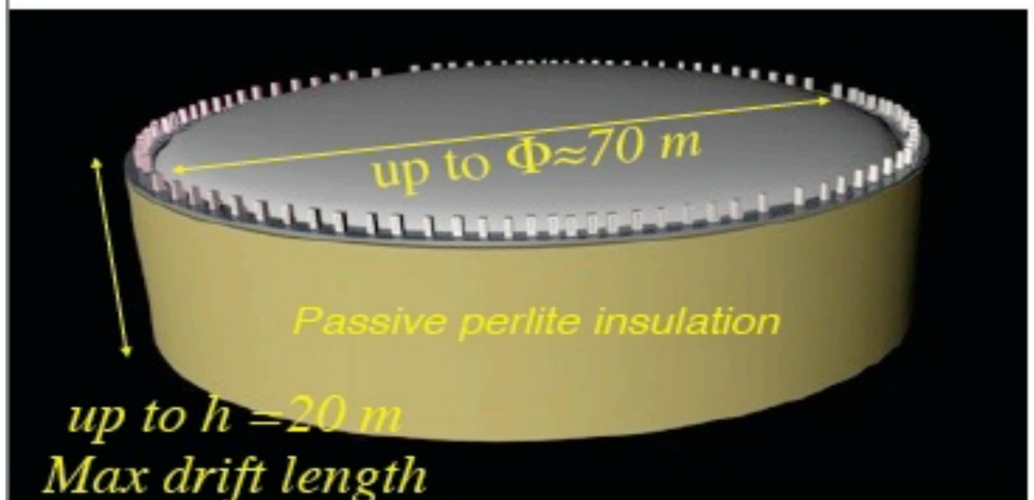


1 kton @ CERN

(full engineering demonstrator towards very large LAr-detectors with stand alone short baseline physics program)

GLACIER: Giant Liquid Ar Charge Imaging ExpeRiment

AR, hep-ph/0402110 (Venice 2003)



- Single module non-evacuable cryo-tank based on industrial LNG technology
- Cylindrical shape with excellent surface / volume ratio
- Simple, scalable detector design, possibly up to 100 kton
- Single very long vertical drift with full active mass
- A very large area LAr LEM-TPC for long drift paths
- Possibly immersed visible light readout for Cerenkov imaging
- Possibly immersed (high Tc) superconducting solenoid to obtain magnetized detector
- Reasonable excavation requirements (<250'000 m^3)

Design technical issues:

- Tank with passive insulation heat loss ≈ 80kW@LAr
- Very large area (≈3500m2) LEM/THGEM+anode with 3mm readout pitch, modular readout, strip length modulable, >=2.5x10^6 channels !
- Purification to < 10 ppt (O_2 equiv.) of bulk argon in large non-evacuable vessel, but excellent S/V ratio in vessel and time to purify before filling !
- Immersed HV Cockcroft-Walton for drift field (1 kV/cm) up to 2 MV → 10ms max drift time!
- Readout electronics (F/E; DAQ; network data flow & time stamp distrib.)
- WLS-coated 1000x 8" PMT and reflectors for DUV light detection

(Green: less challenging, Red: challenging)