STATUS OF ArDM

Alessandro Curioni - ETHZ
for the ArDM collaboration
GLA2011- Jyvaskyla
June 5-10 2011

OUTLINE

- Background information
- Status of ArDM-1ton: overview of the detector and recent progress
- Next steps: installation in LSC

Why LAr for direct DM searches

Noble liquids as Ar & Xe offer the possibility to have large instrumented volumes to detect WIMP-induced nuclear recoils, with low energy threshold and excellent background rejection capabilities

- Event rate in Ar less sensitive to energy threshold than in Xe [nuclear form factors]: 30 keVr break-even point for equal masses
- LAr from liquid air industry is cheap, easy to handle and purify, ton scale detectors are routinely built for - e.g. - neutrino physics
- In case of positive DM detection, Ar and Xe provide complementary information because of different recoil spectra [kinematics]
- Charge/light ratio and pulse shape of scintillation provide powerful discrimination against gamma and beta background [pulse shape not available in Xe]
- ^{39}Ar [β emitter, τ=269 yrs, Q=565keV, concentration ~10^{-15} in natural Ar] gives ~1 Hz/kg of natural Ar BUT:
- Enough rejection power may be available [$\geq 10^8$]
- Possibility to have Ar depleted of ^{39}Ar from underground wells

ArDM-1t

ArDM goal: 1-ton two-phase (gas & liquid) LAr detector with *independent* charge and light readout optimized for direct DM searches [high discrimination power against background, few keV energy threshold, designed for stable underground operation]

- Time projection chamber [TPC] readout for the charge produced by ionizing radiation, with sensitivity down to keV energy depositions and sub-millimeter position resolution using Large Electron Multipliers [LEM]. Fine segmentation helps background rejection through fiducial volume cuts, separate detection of multiple interactions within the same event.
- High voltage for drift field up to 3 kV/cm over 1.2 meter drift to detect ionization from highly quenched low energy nuclear recoils.
- Light readout of the prompt scintillation light using cryogenic photomultipliers immersed in LAr. Rejection of beta/gamma background from charge/light ratio and pulse shape discrimination.

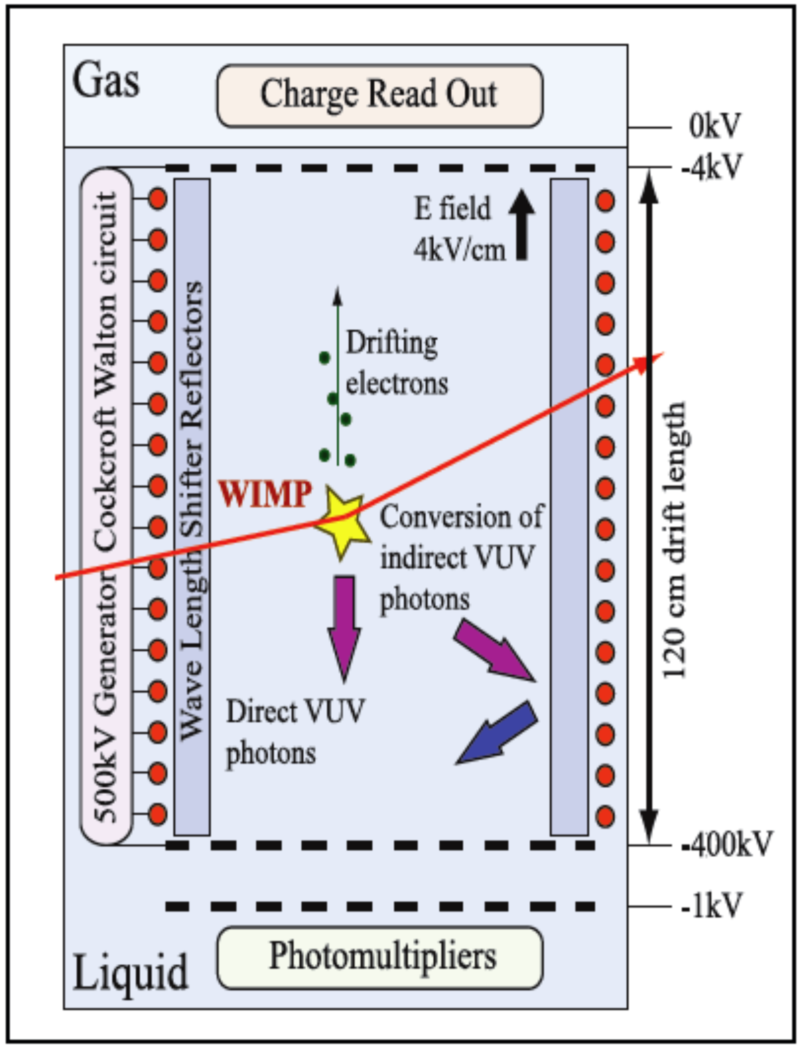
ArDM-1t

Phased approach:

a. Surface operation: build and commission 1-ton two-phase LArTPC at CERN, while pursuing separate R&D activities on specific topics[ends in 2010]
b. Underground operation Phase I: development of underground infrastructure, including shield system, science run using natural Ar [starts in 2011]
c. Underground operation Phase II: science run using depleted Ar [starts when sensitivity of science run with natural Ar is "^{39}Ar limited" AND a sufficient amount of ^{39}Ar depleted Ar is available. 2014?]

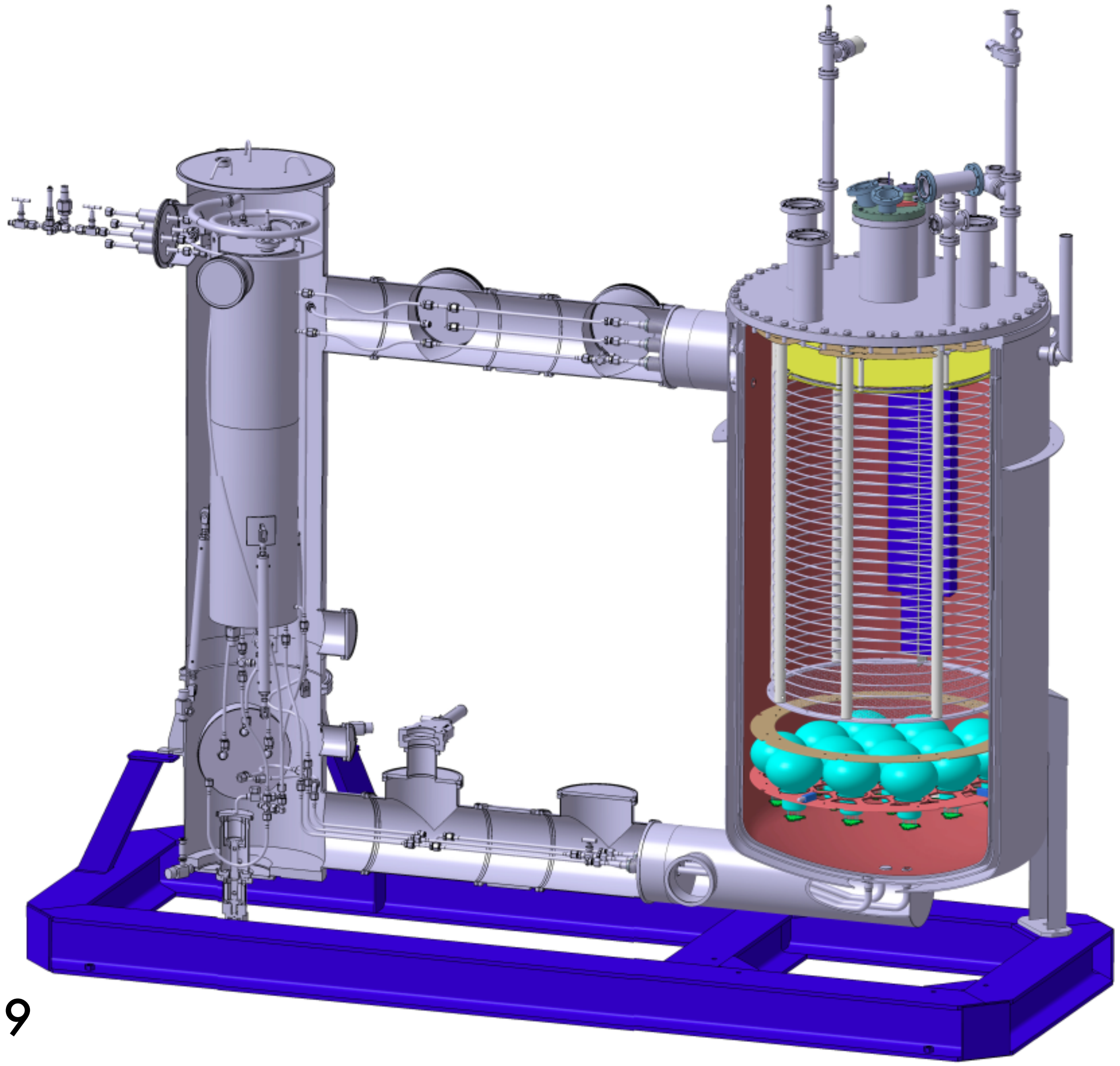
ArDM-1t

Working principle

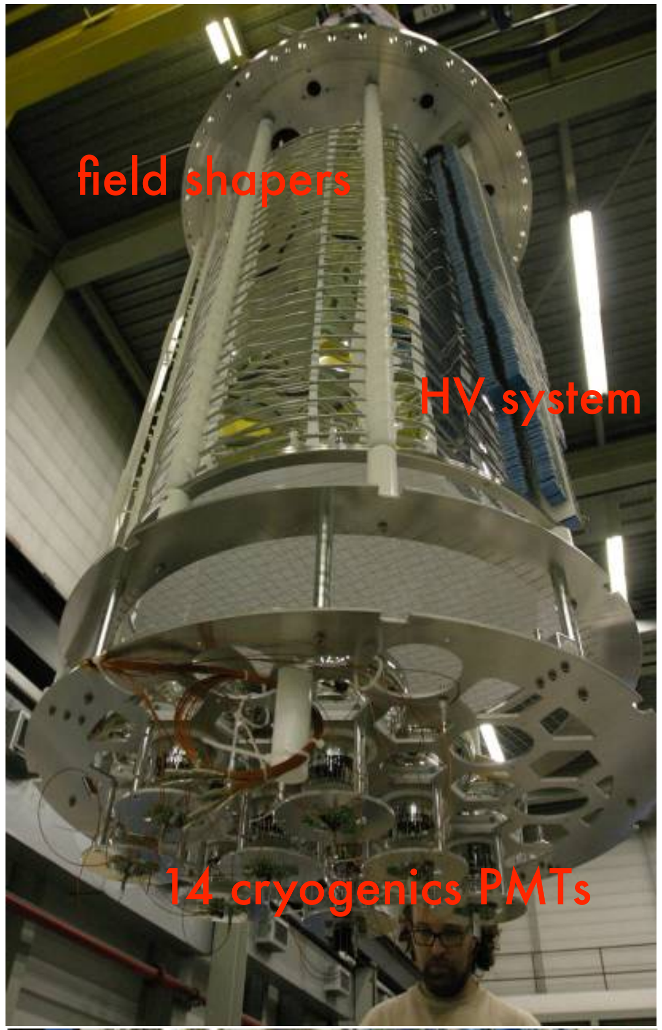


A.Rubbia, J.Phys.Conf.Ser.39 (2006) 129

Inner detector

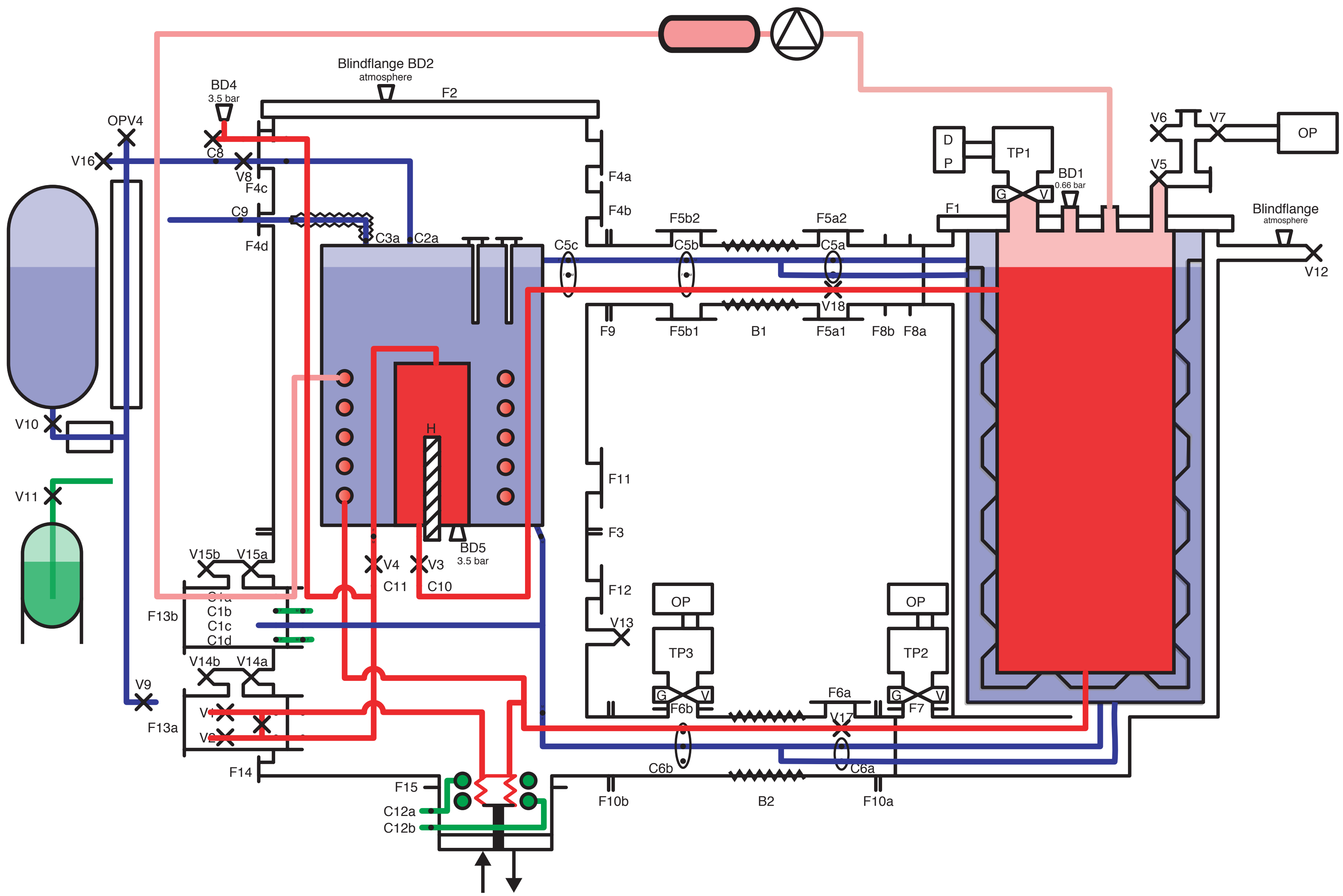


Cryogenic and purification circuit



ArDM cryogenics

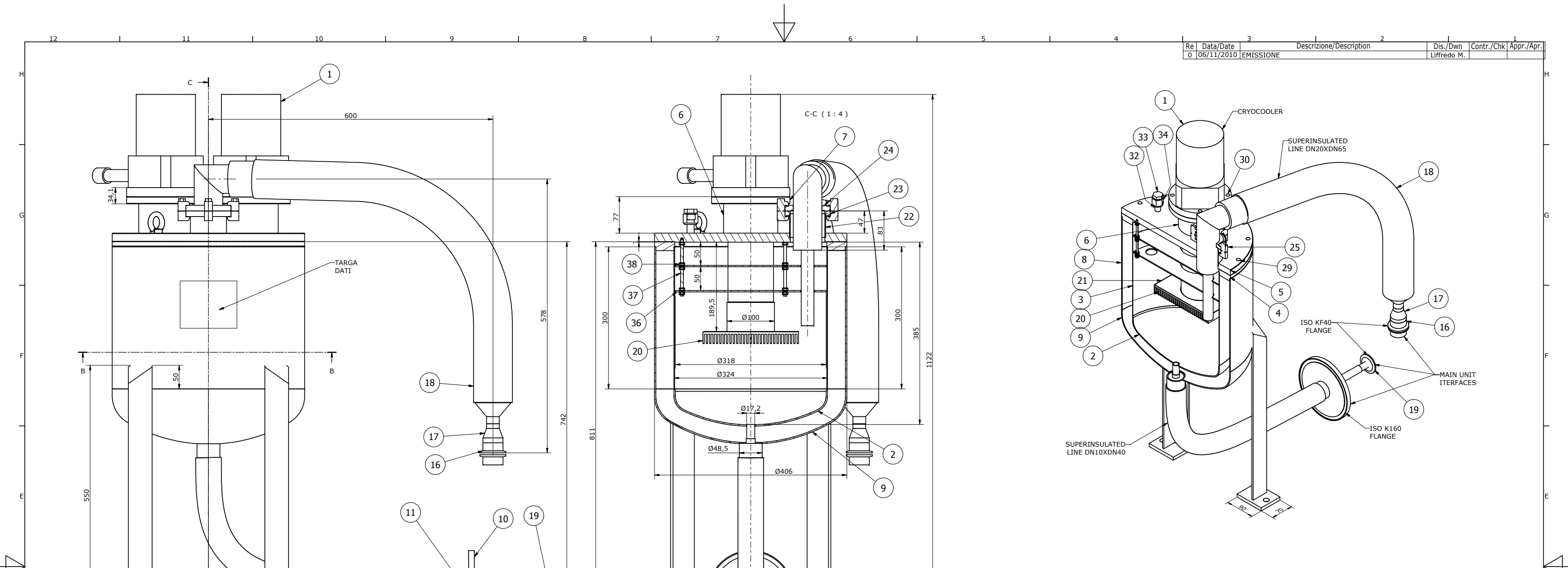
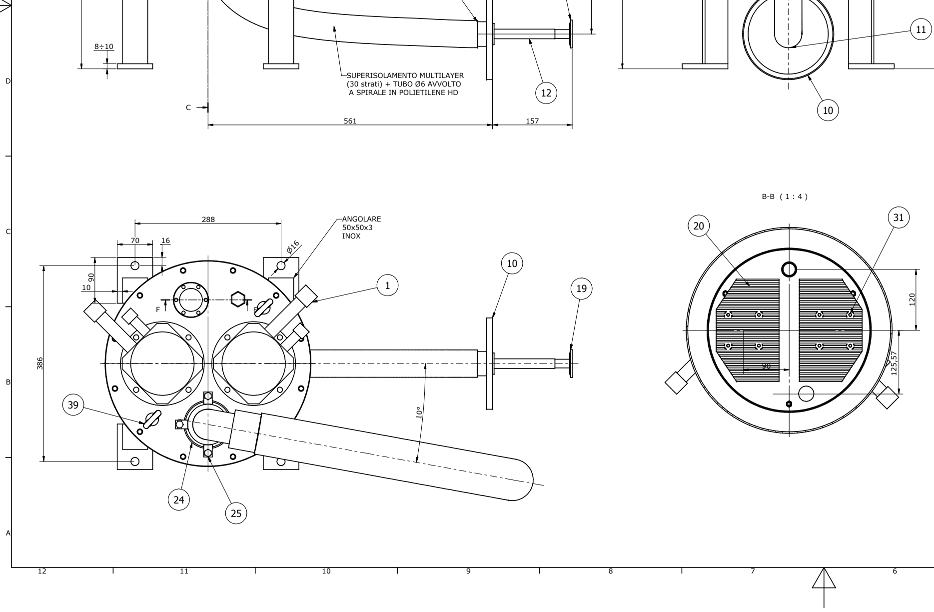
- until Dec 2010, LAr cooling bath open to atmosphere and automatically refilled through an electro-valve
- the cooling power needed for operation of ArDM was 400 W without any recirculation system



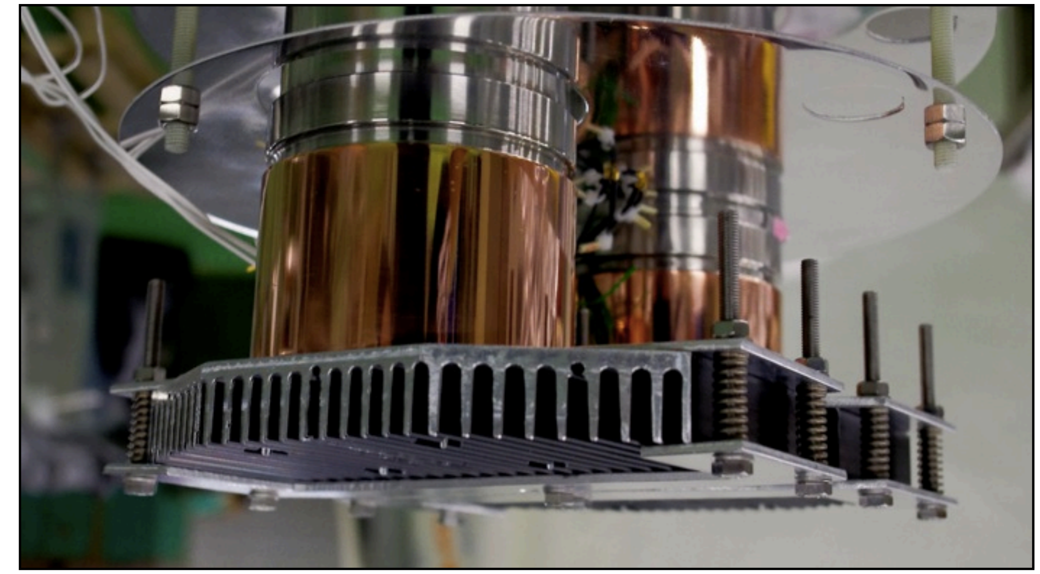
Cryogenics: cryocoolers

a. The cooling system of ArDM has been upgraded with a recondenser, with 600 W of cooling power provided by two GM cryocoolers [Cryomech AL300]. In this way we have a closed loop, zero loss system
b. The new system has been operated for over 7 weeks, providing a full characterization together with a stability test
c. The control of the cryocoolers/cryogenic system is fully integrated in the existing PLC
d. Reduced manpower requirements in operating ArDM
e. The system is safe: in case of failure of the cryocoolers, the LAr evaporates slowly [less than 100 L/day for the cooling bath and much less for the inner vessel] through the overpressure valves

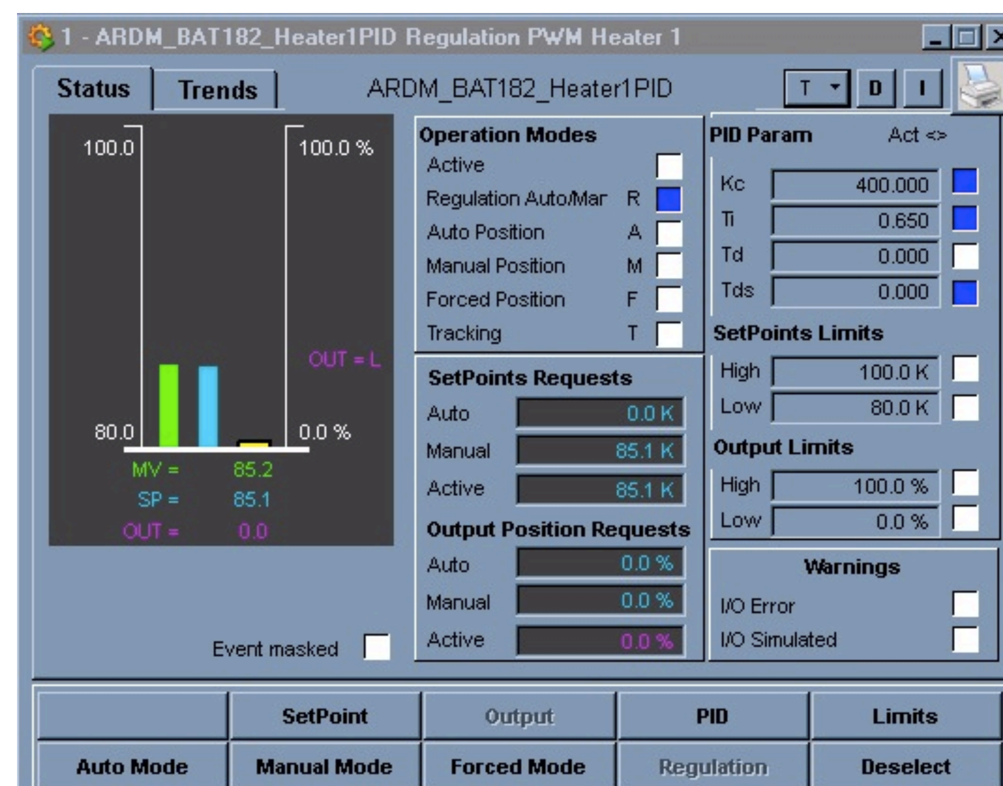
Cryogenics: cryocoolers

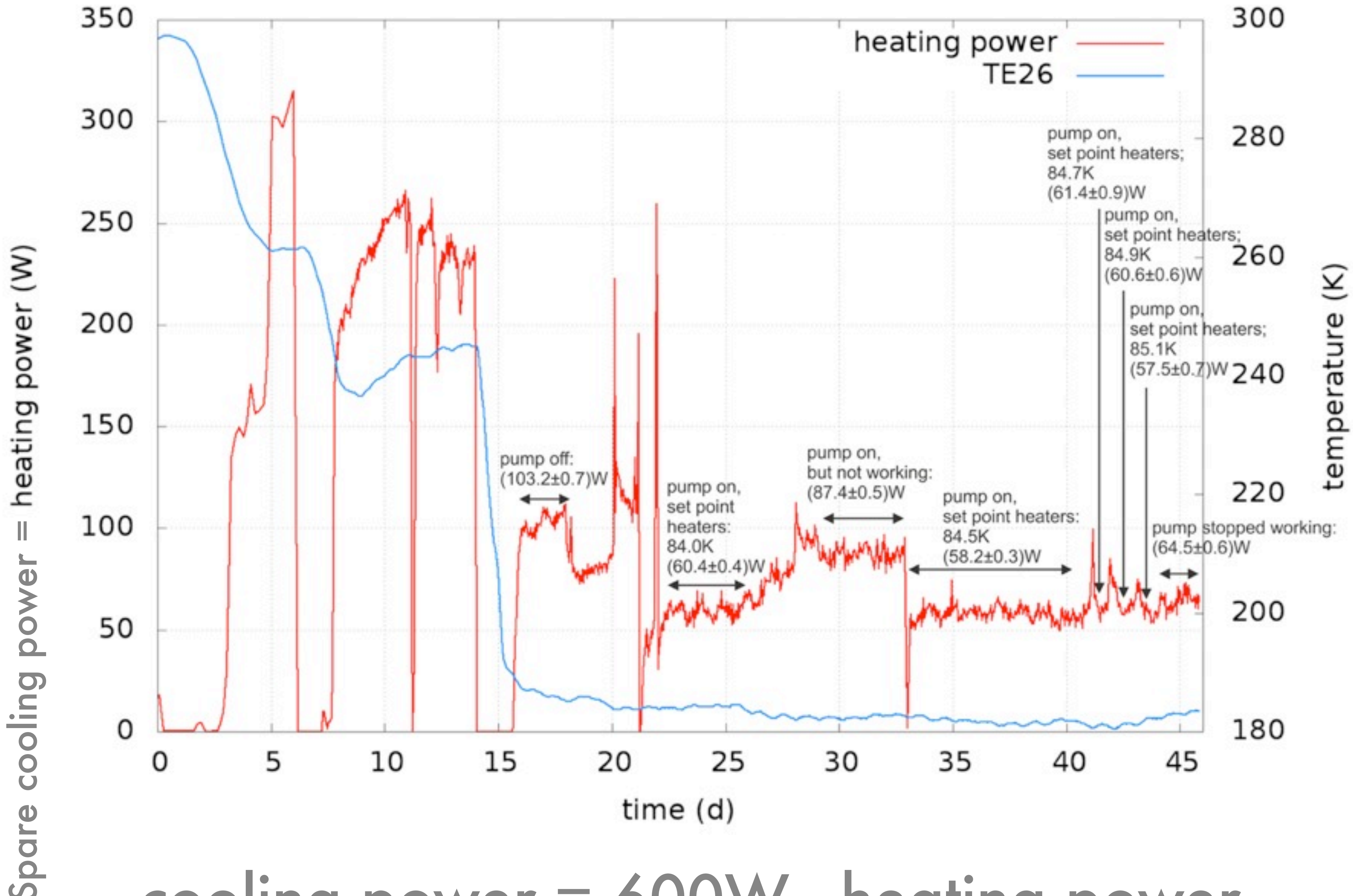
Recondenser unit built by Criotec



Cold heads, heat exchangers, heaters

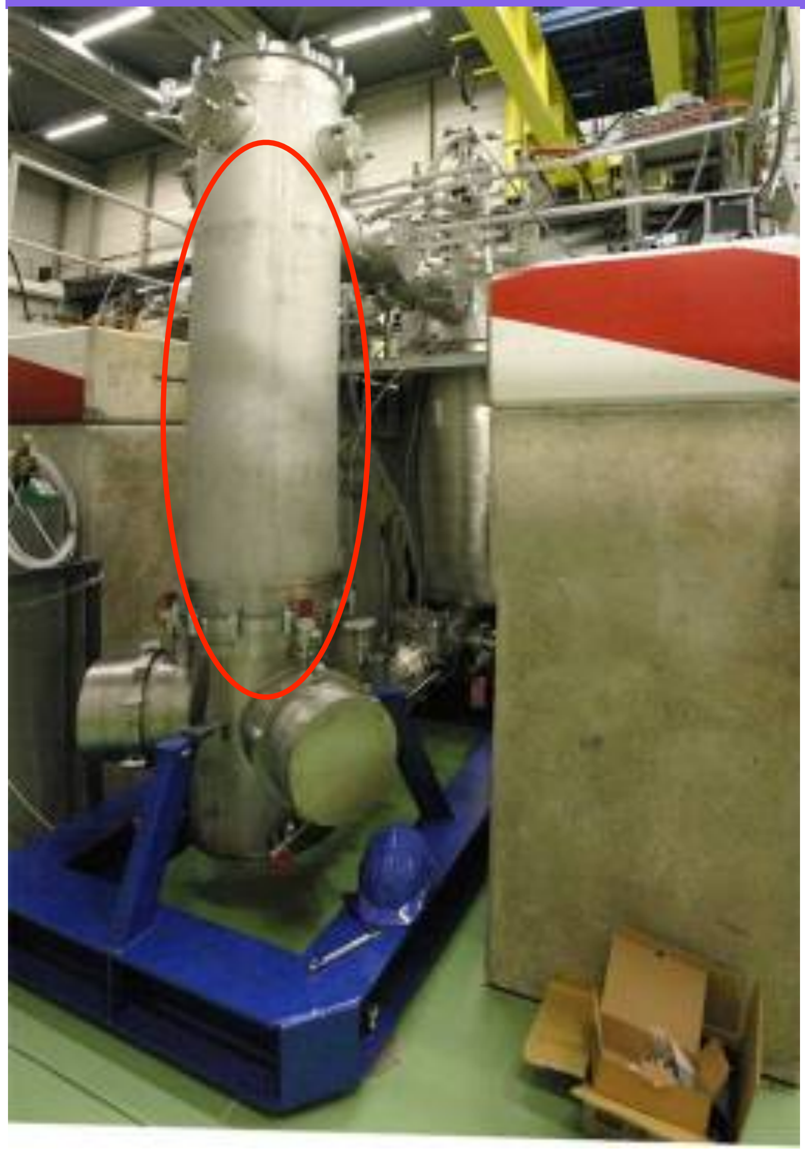


Cryogenics: cryocoolers

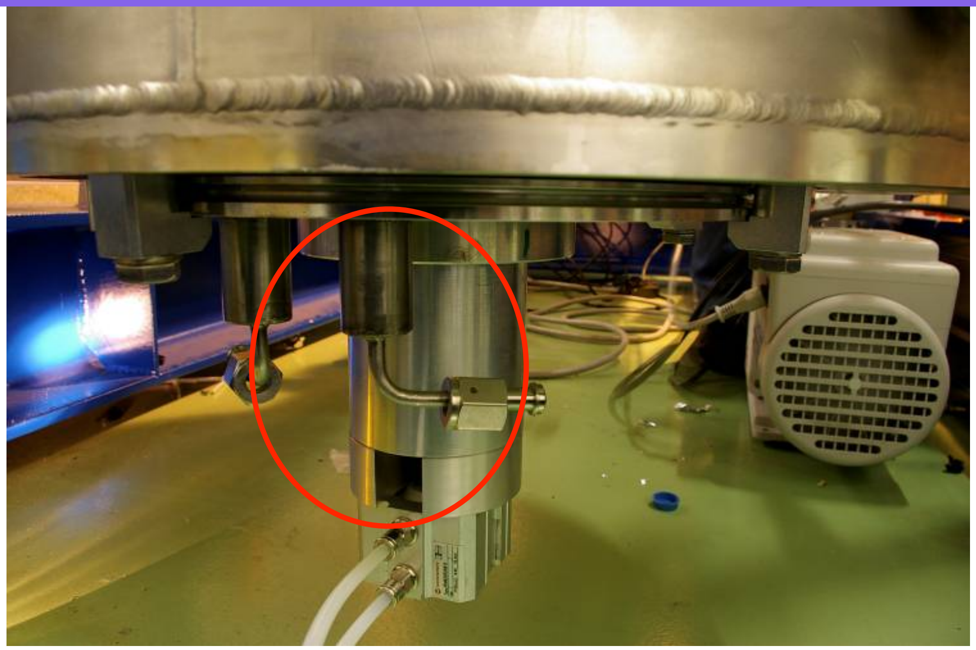


cooling power = 600W - heating power

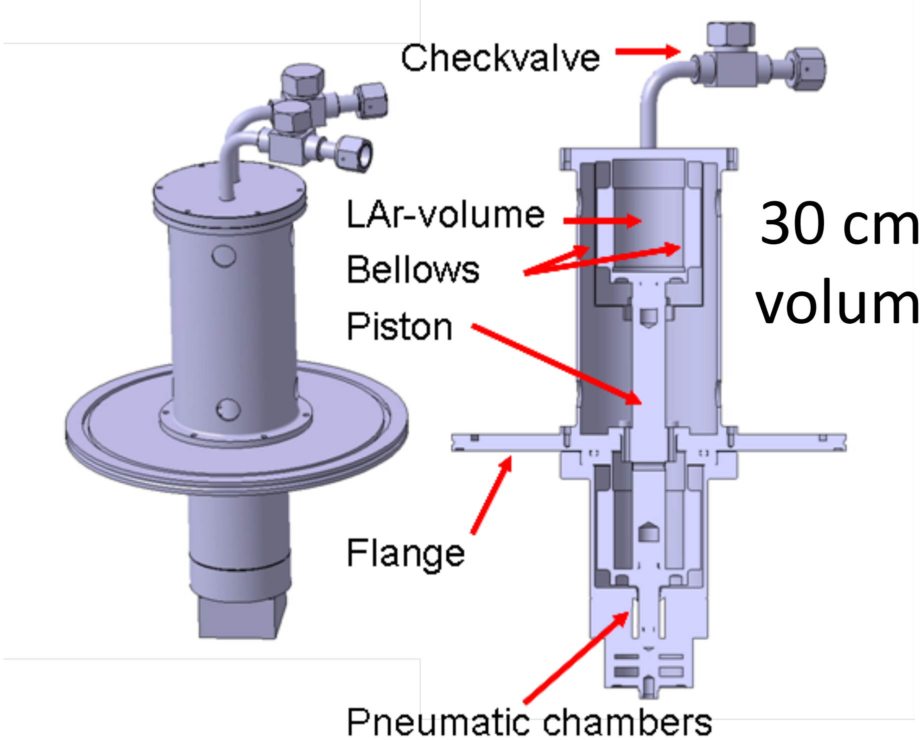
LAr purification



Recirculation and purification cartridge, vacuum insulated
The purification cartridge is regenerated in situ by flushing Ar/H2



Cryogenic bellow pump for LAr recirculation [up to 20 l/hr]

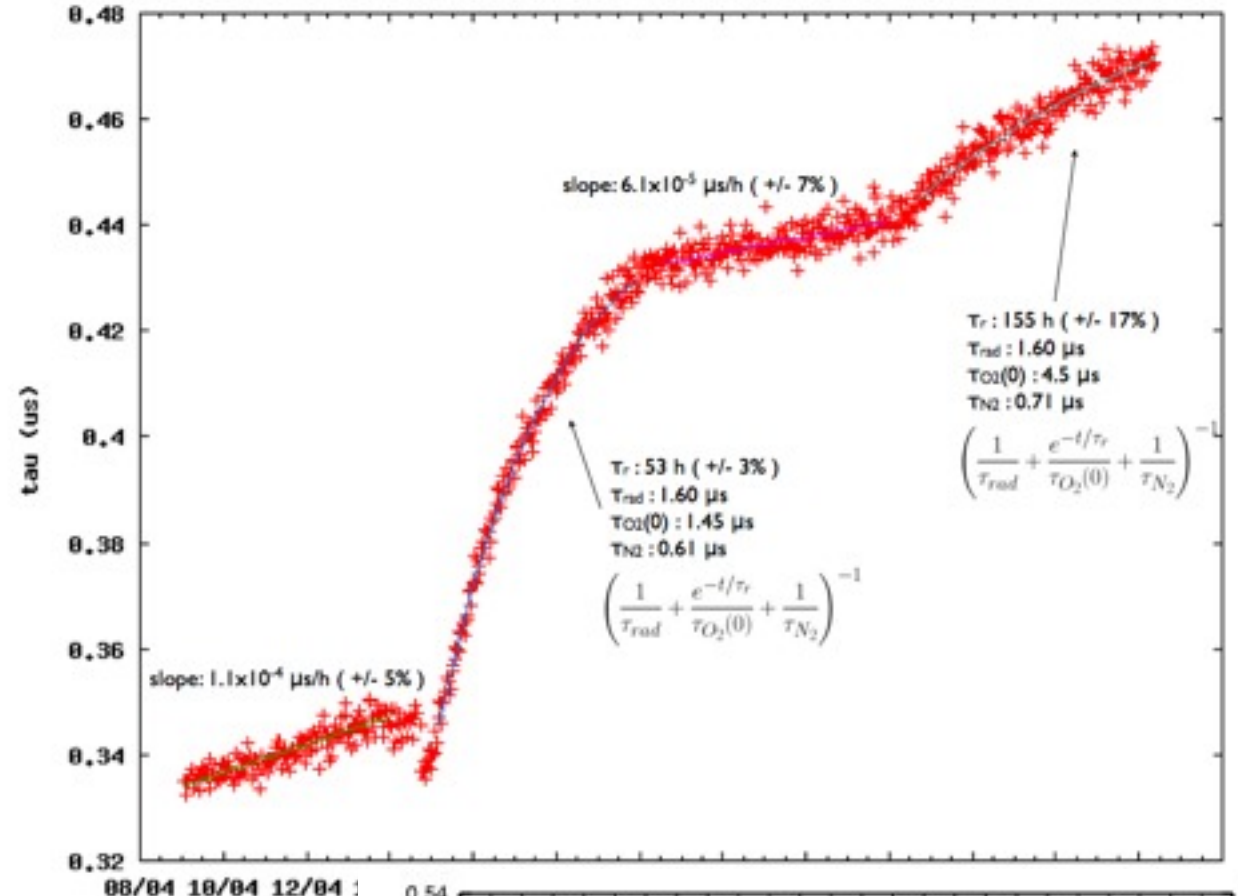


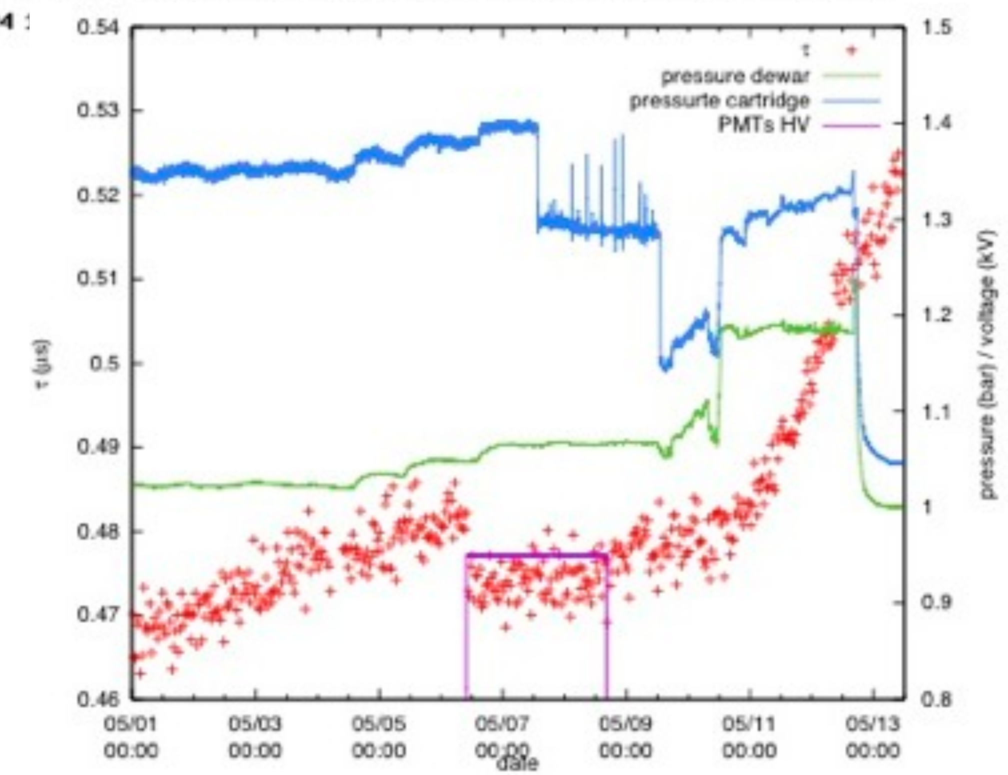
Pump "pumping"

Built in collaboration between Bieri Engineering and ETHZ

Cryogenics: LAr pump

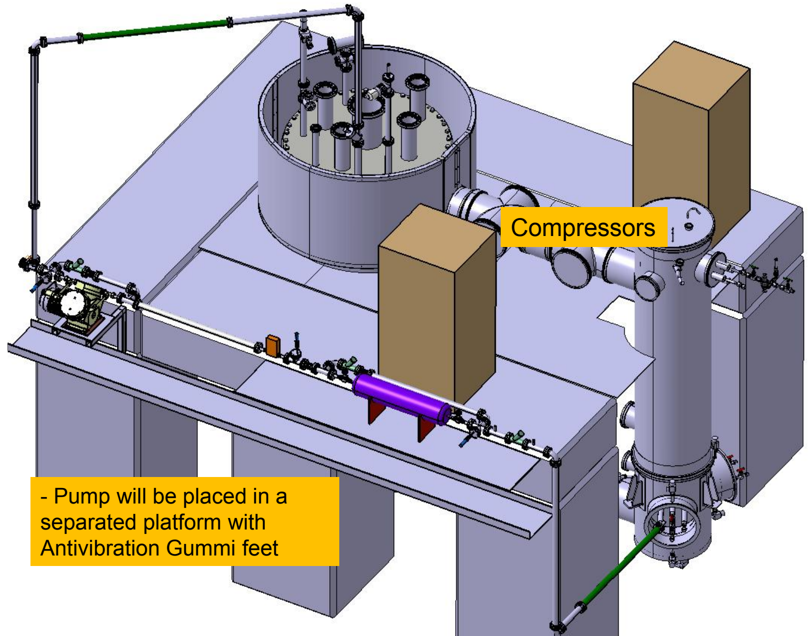
a. The pump is designed to drive the liquid argon through a purification cartridge [CuO, custom made]
b. During the cryogenic test, we have measured a stable flow of LAr of 10 lt/hr
c. Flow measured from evolution of LAr purity
d. An improved LAr pump is under construction

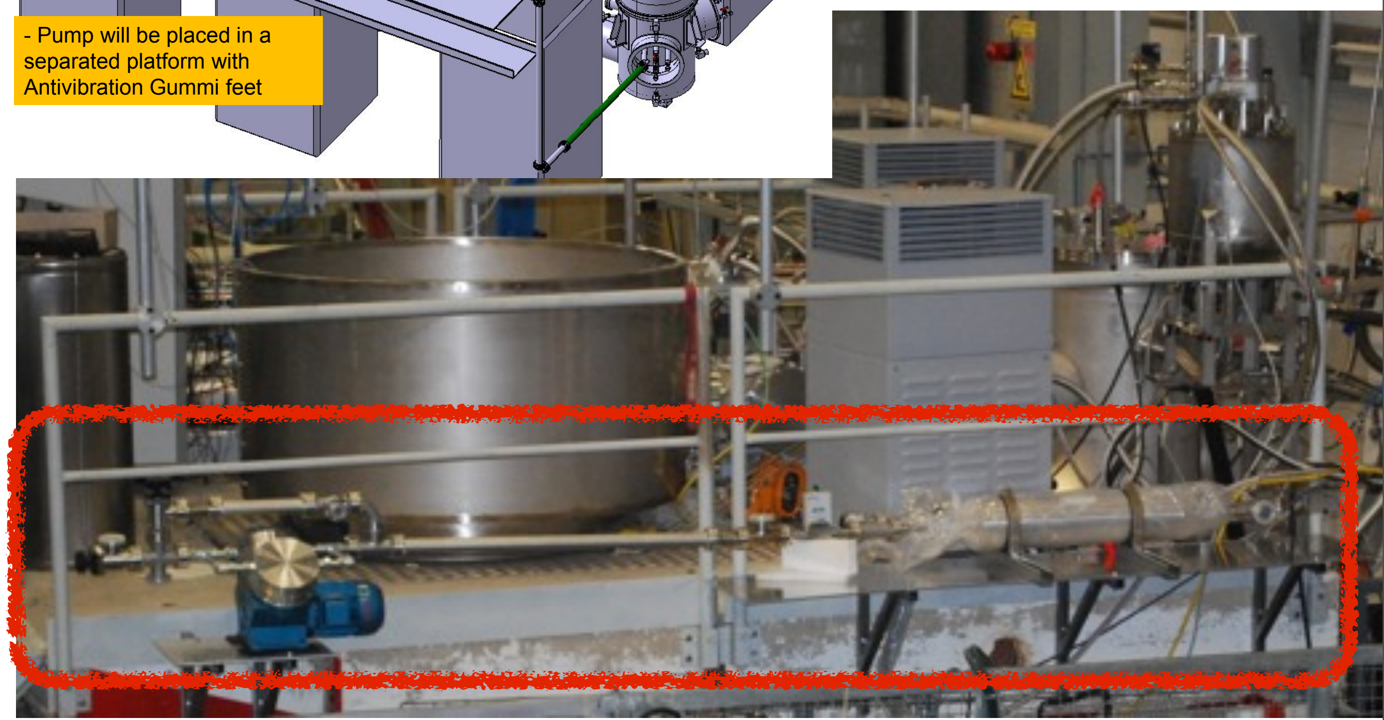


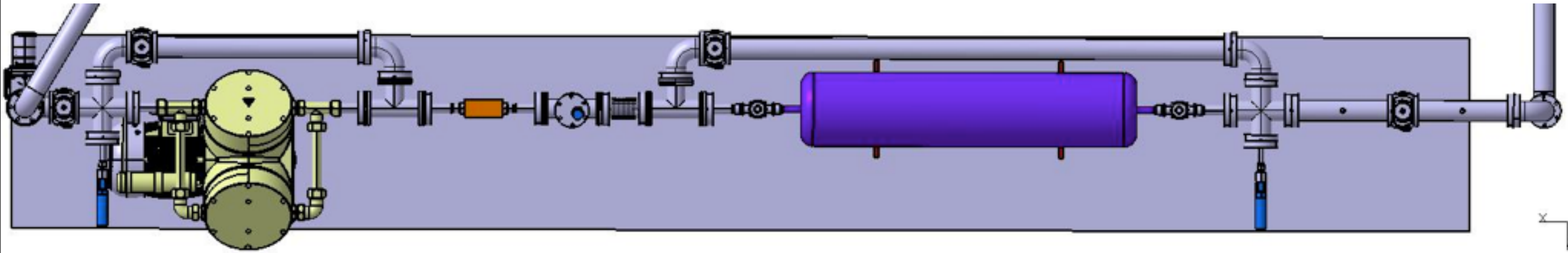


LAr purification

- KNF double membrane pump with leak rate better than 6E-6 mbar/lt sec
- All metal, high flow MKS flow meter
- SAES 4500 purification cartridge
- Controlled through the existing PLC
- Dimensioned to handle a flow of 150 lt/min of GAr [equivalent to 10 lt/hr of LAr]







ArDM slow control & safety

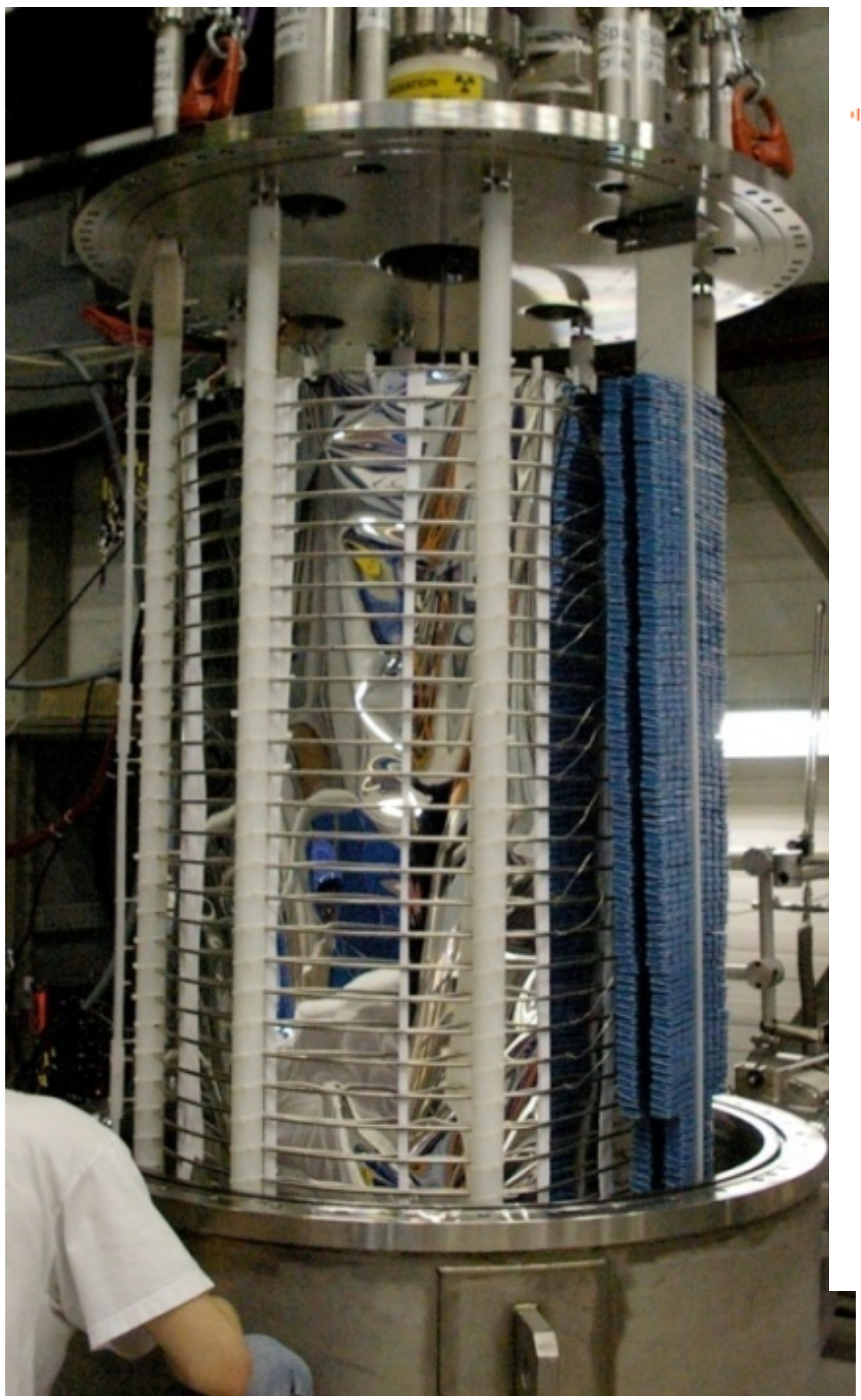
- Reviewed by the CERN Safety group
- Because no safety valves available on the market sufficiently leak tight, the pure LAr circuit is protected by two certified burst disks [burst pressure 0.6 bar]
- A PLC based control of the vacuum and cryogenic systems has been installed in 2010 and fully tested twice
- PMT HV and DAQ being included
- ALL ArDM electronics will be mounted in these 7 racks prior to shipping to LSC

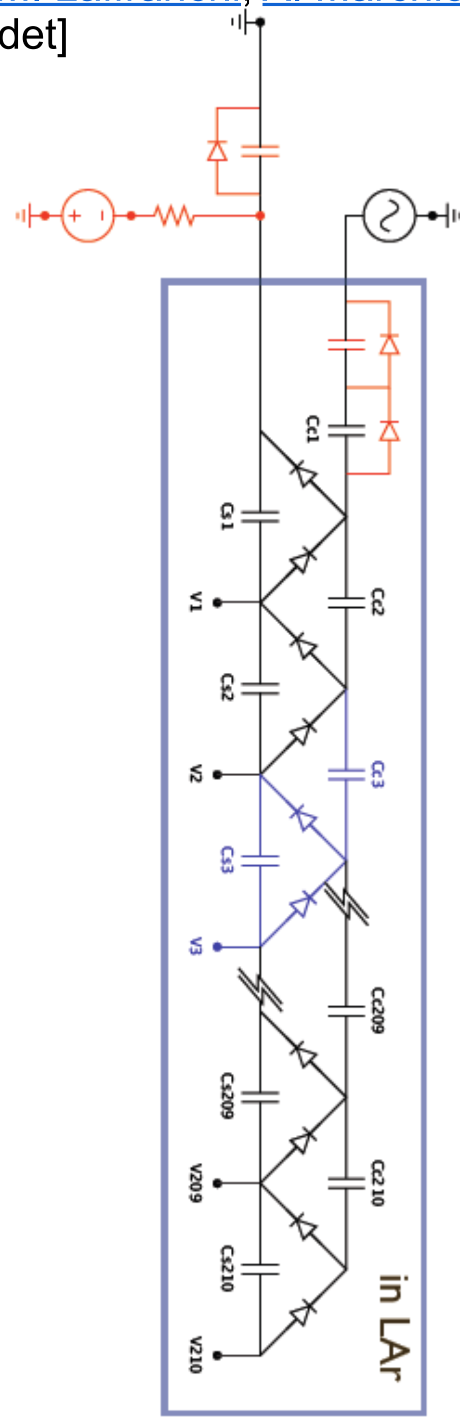
The PLC (programmable logic controller) approach gives a consistent way of handling the operation of ArDM-1t, good for safety but also in reducing the requirements in terms of manpower

ArDM-1t: HV System

Results presented at GLA2010 - see

Feasibility of high-voltage systems for a very long drift in liquid argon TPCs.
S. Horikawa, A. Badertscher, L. Kaufmann, M. Laffranchi, A. Marchionni, M. Messina, G. Natterer, A. Rubbia. Sep 2010. 8pp. Temporary entry e-Print: **arXiv:1009.4908** [physics.ins-det]

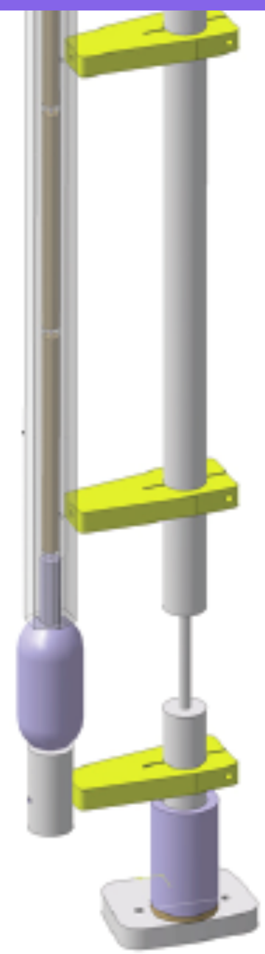


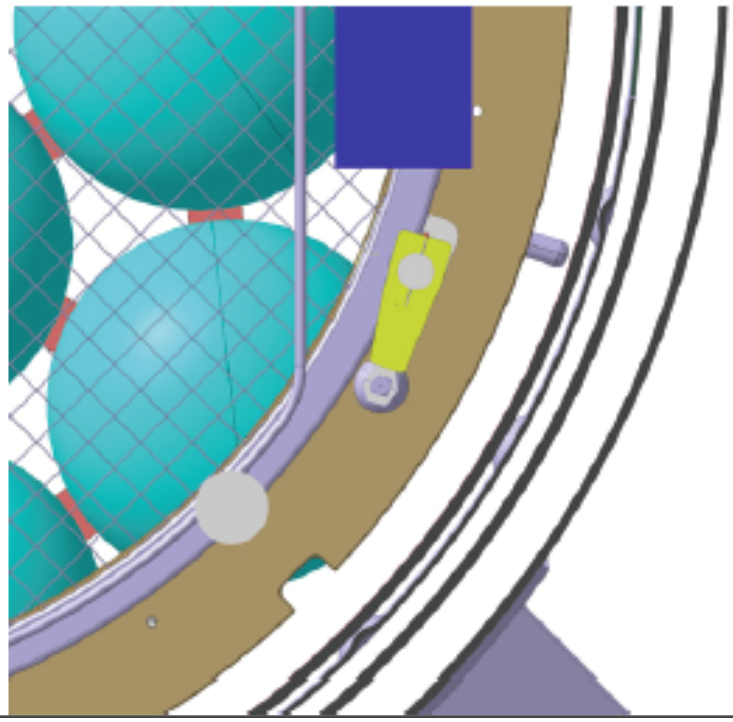


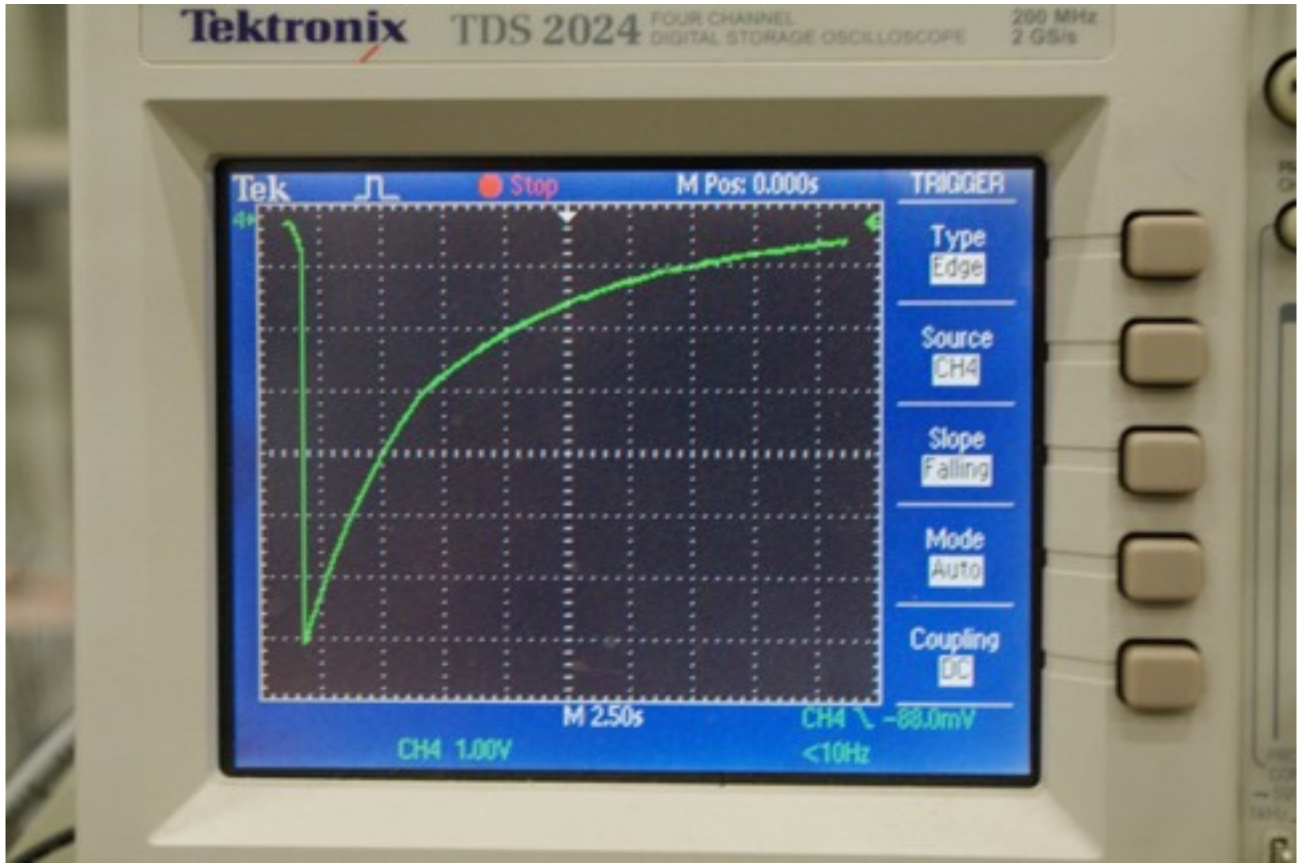
- 210 stages Cockroft-Walton [Greinacher] circuit
- 30 field shapers with 4 cm spacing
- 400 kV at cathode [3 kV/cm]
- good drift field linearity
- Rotary system for discharging
- tested up to 70 kV [0.6 kV/cm] in stable conditions and no particular training
- suffered one sparking at 80kV

ArDM-1t: HV System

rotary discharge system



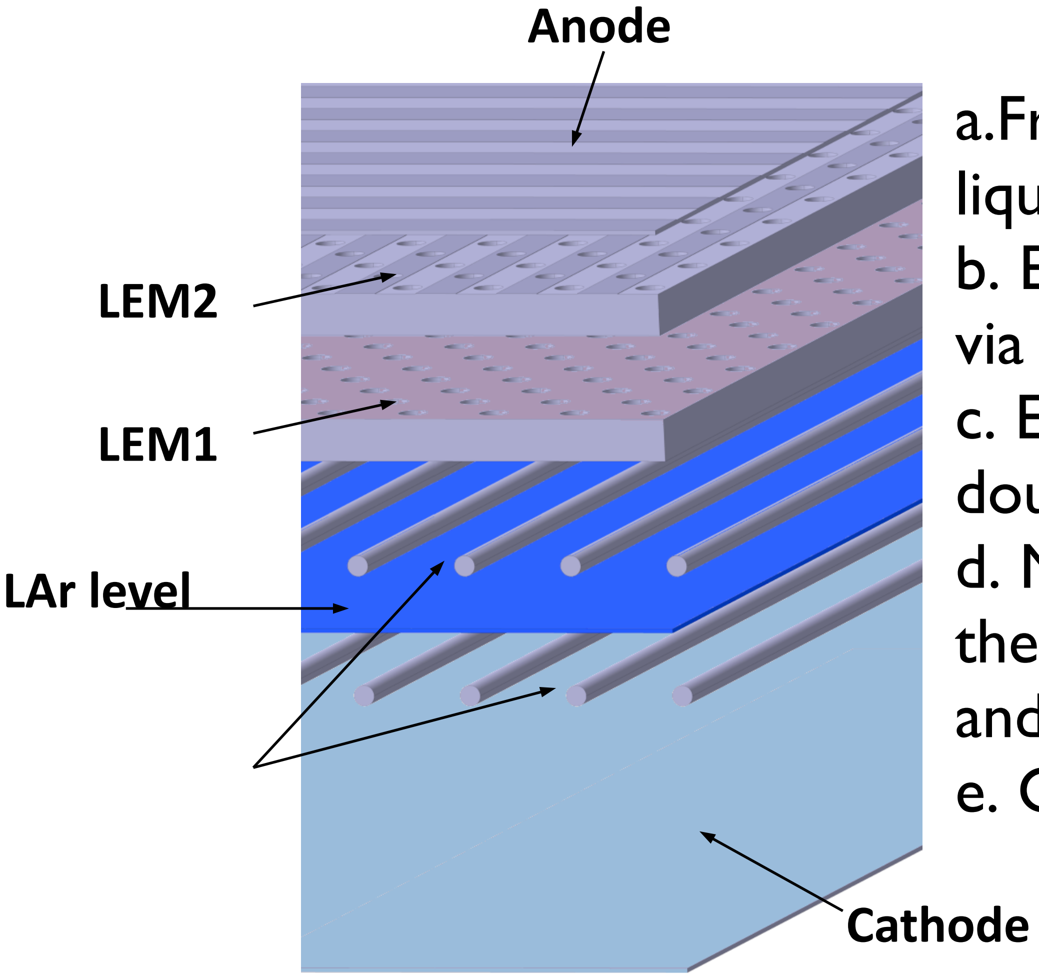




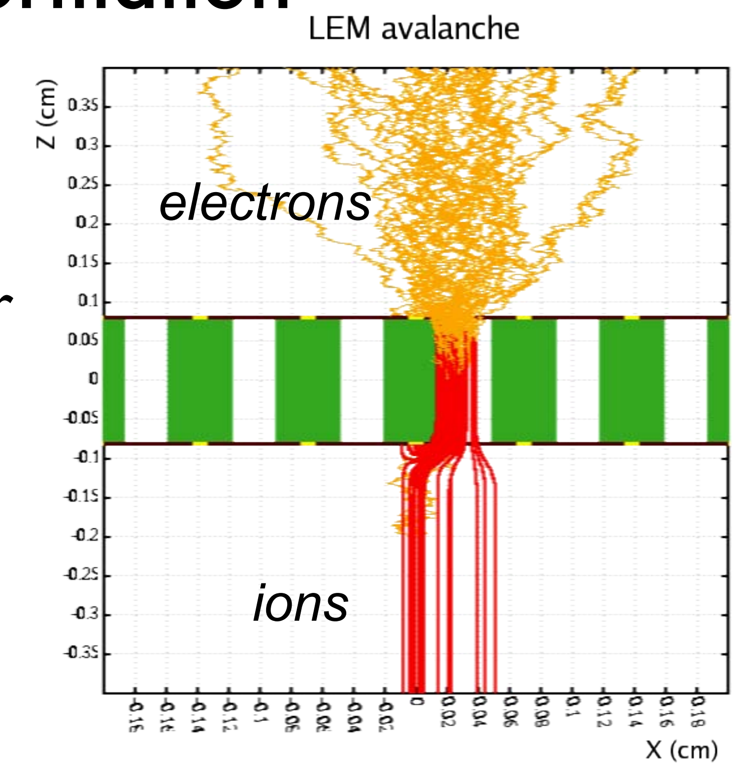
Discharge curve of the Greinacher [7 vertical divisions on the scope correspond to 70 kV]

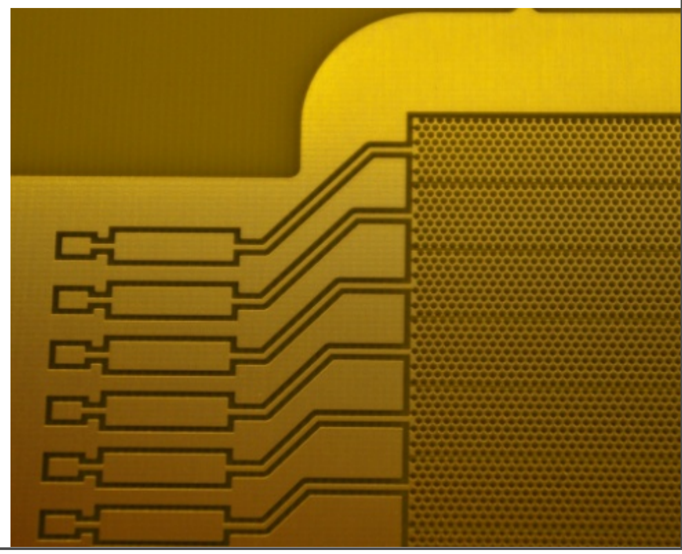
Charge readout: LEM

- ArDM is designed to operate like a double phase argon LEM-TPC, with amplification of the ionization charge by Large Electron Multipliers (LEM) in pure Ar gas
- It provides both tracking and calorimetric information



a. Free electrons drift in LAr towards liquid /vapor interface
b. Electrons are extracted to the vapor via extraction grids (E_{liq} > 2.5 kV/cm)
c. Electrons undergo multiplication in double stage LEM
d. Multiplied charge induces signals on the segmented electrodes of top LEM and anode
e. Or just on a 2D anode.





Charge readout: state-of-the-art

- A paper detailing the construction and operation of a single stage LEM (gain 30) plus 2D projective anode has been published
- Basic behavior of the device well understood
- Next step 1: test of 40x80 cm^2 LEM plus 2D projective anode
- Next step 2: test of 10x10 cm^2 double stage LEM to study the high gain needed in ArDM in realistic conditions [in theory, a 30^2=900 is possible]
- See Filippo's talk

Nuclear Instruments and Methods in Physics Research A 641 (2011) 48–57

Contents lists available at ScienceDirect

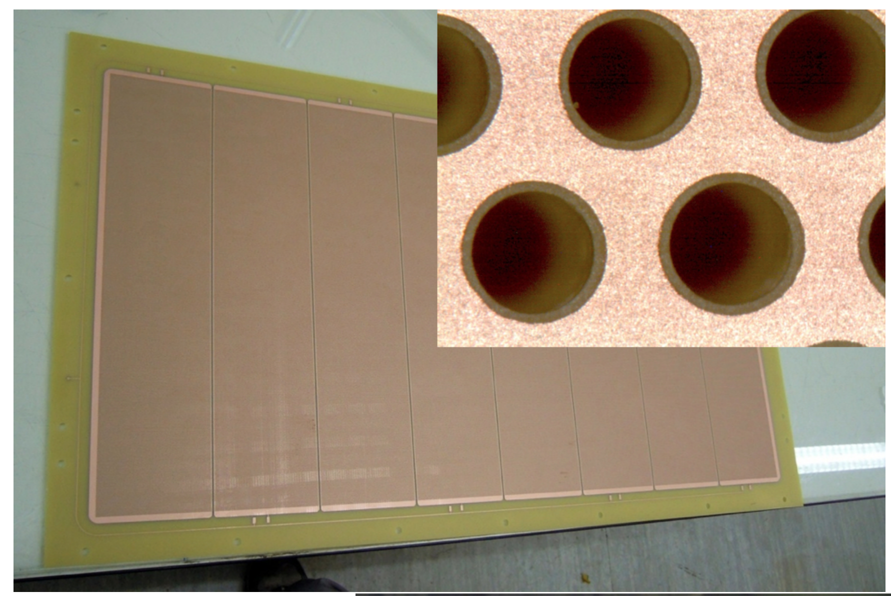
Nuclear Instruments and Methods in Physics Research A

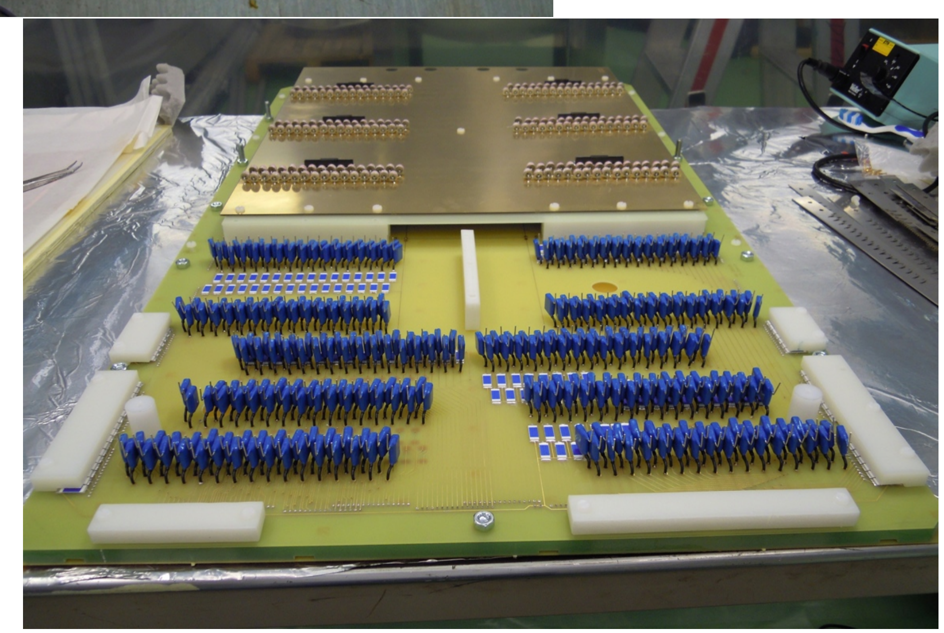
journal homepage: www.elsevier.com/locate/nima

First operation of a double phase LAr Large Electron Multiplier Time Projection Chamber with a 2D projective readout anode

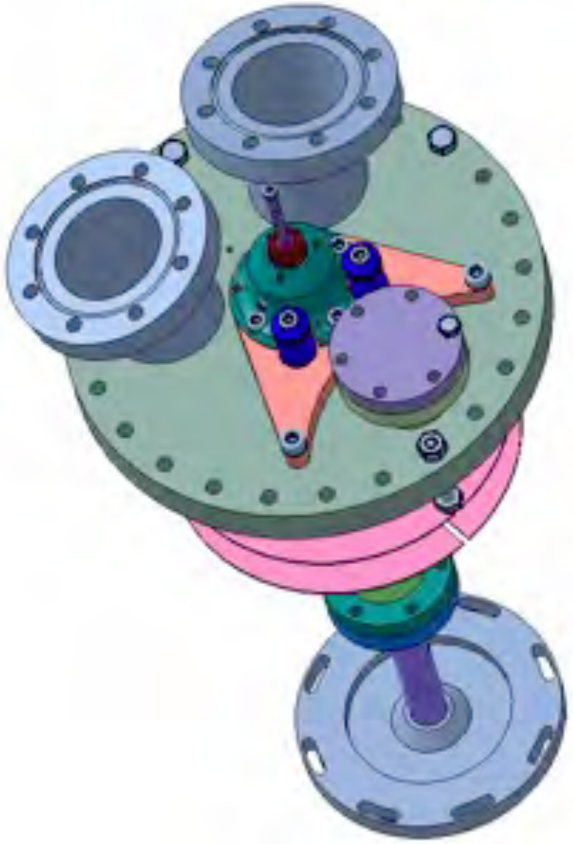
A. Badertscher, A. Curioni, L. Knecht, D. Lussi, A. Marchionni, G. Natterer, F. Resnati, A. Rubbia *, T. Viant

Institute for Particle Physics, ETH Zurich, 8093 Zurich, Switzerland

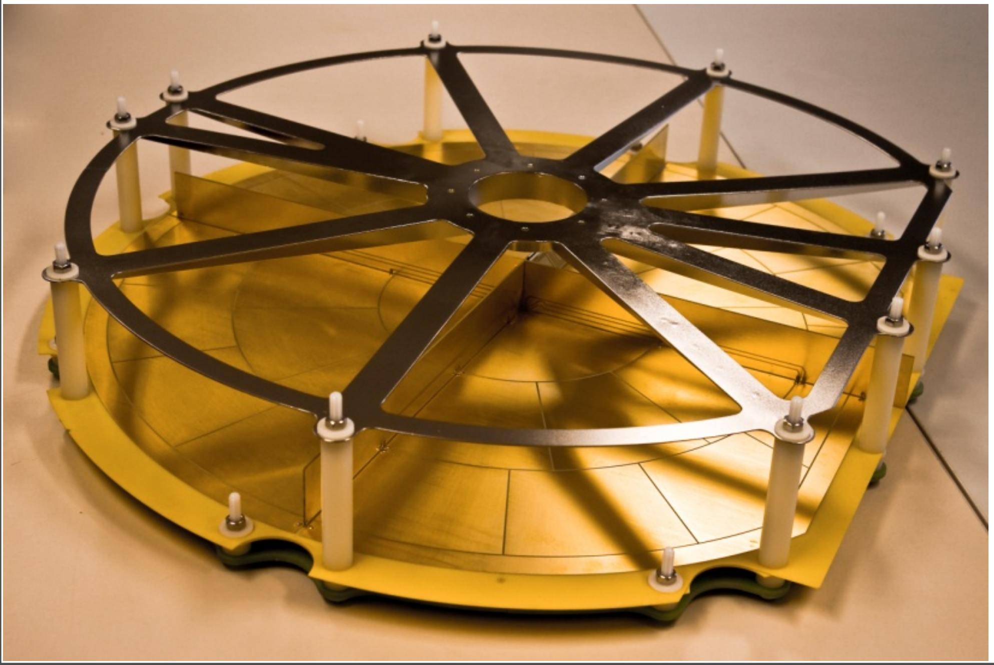


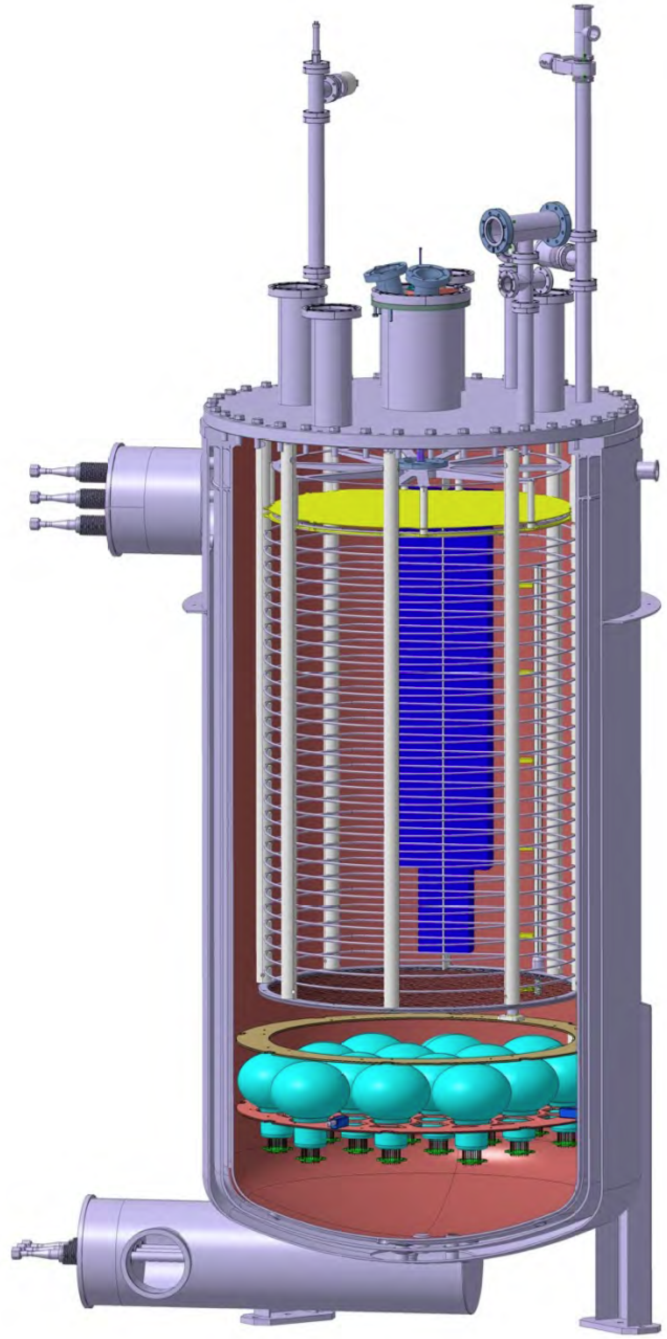


ArDM-1ton: temporary charge readout system



Adjustable 32 pad anode for first test of drift and charge extraction from liquid to gas phase. It also acts as a reflector for the 420 nm light, increasing the uniformity of the light yield.



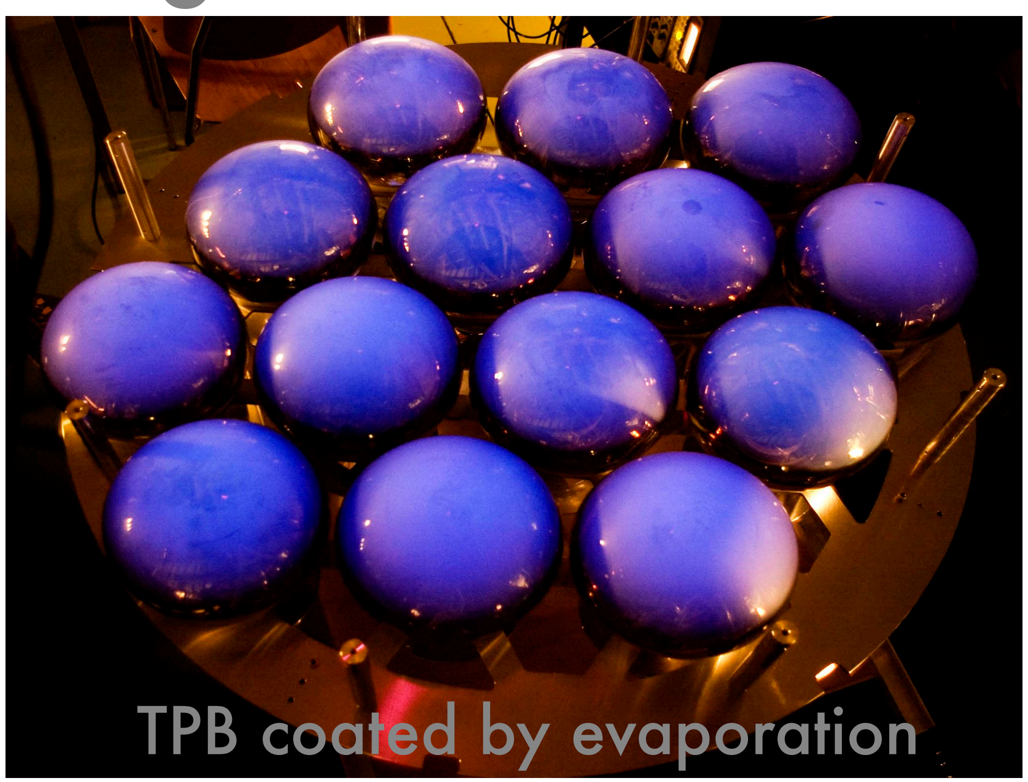


ArDM-1ton: light readout

Light readout for 1st LAr test

May 2009

Light readout now



14 low radioactivity Hamamatsu 8'' PMTs [R5912-02MOD]

Wavelength Shifter [WLS] reflector foils

results published in
V. Boccone et al. JINST 4 P06001 2009

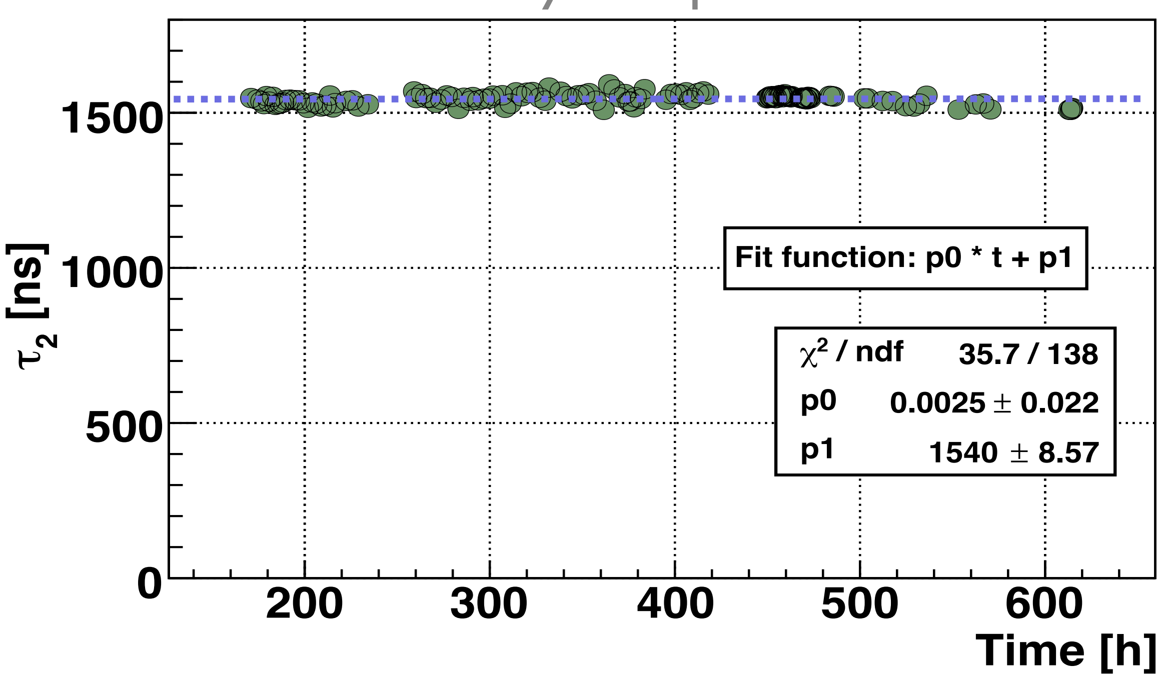
- LAr emission spectrum peaked at 128 nm
- use reflector foils coated with TPB in order to use standard bialkali PMTs
- TPB shifts to a mean wavelength of 430 nm
- 15 cylindrically arranged overlapping foils of TTX (120x25 cm^2) coated with 1.0 mg/cm^2 TPB by vacuum evaporation
- TTX is an aligned polytetrafluoroethylene (PTFE) fibrous cloth
- measured a reflection coefficient close to 97% at 430 nm

1st cool down and LAr test

- May 2009 - 4 weeks long run
- Goals:

a. Test cryogenic system [cool down and stable operation]
b. Achieve good LAr purity and stability
c. Commissioning and stable operation of light readout [7 PMTs] system in LAr
d. Preliminary measurement of light yield
e. Data reconstruction and benchmark of MC simulation

Lifetime of slow component of Ar scintillation light, sensitivity to impurities in Ar.



Most recent paper based on 2009 data

Jinst
PUBLISHED BY IOP PUBLISHING FOR SISSA
RECEIVED: *September 21, 2010*
ACCEPTED: *October 24, 2010*
PUBLISHED: *November 22, 2010*

First results on light readout from the 1-ton ArDM liquid argon detector for dark matter searches

The ArDM collaboration

C. Amsler,[a] A. Badertscher,[b] V. Boccone,[a] A. Bueno,[c] M.C. Carmona-Benitez,[c] W. Creus,[a] A. Curioni,[b] M. Daniel,[d] E.J. Dawe,[e] U. Degunda,[b] A. Gendotti,[b] L. Epprecht,[b] S. Horikawa,[b] L. Kaufmann,[b] L. Knecht,[b] M. Laffranchi,[b] C. Lazzaro,[b] P. K. Lightfoot,[e] D. Lussi,[b] J. Lozano,[c] A. Marchionni,[b] K. Mavrokoridis,[e] A. Melgarejo,[c] P. Mijakowski,[f] G. Natterer,[b] S. Navas-Concha,[c] P. Otyugova,[a] M. de Prado,[d] P. Przewlocki,[f] C. Regenfus,[a] F. Resnati,[b] M. Robinson,[e] J. Rochet,[a] L. Romero,[d] E. Rondio,[f] A. Rubbia,[b,1] L. Scotto-Lavina,[a] N.J.C. Spooner,[e] T. Strauss,[b] J. Ulbricht,[b] and T. Viant[b]

[a] *Physik-Institut, University of Zürich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland*
[b] *ETH Zurich, Institute for Particle Physics, CH-8093 Zürich, Switzerland*
[c] *University of Granada, Dpto. de Física Teórica y del Cosmos & C.A.F.P.E, Campus Fuente Nueva, 18071 Granada, Spain*
[d] *CIEMAT, Div. de Fisica de Particulas, Avda. Complutense, 22, E-28040, Madrid, Spain*
[e] *University of Sheffield, Department of Physics and Astronomy, Hicks Building, Hounsfield Road, Sheffield, S3 7RH, U.K.*
[f] *The Andrzej Soltan Institute for Nuclear Studies, Hoża 69, 00-681 Warsaw, Poland*

E-mail: andre.rubbia@cern.ch

ABSTRACT: ArDM-1t is the prototype for a next generation WIMP detector measuring both the scintillation light and the ionization charge from nuclear recoils in a 1-ton liquid argon target. The goal is to reach a minimum recoil energy of 30 keVr to detect recoiling nuclei. In this paper we describe the experimental concept and present results on the light detection system, tested for the first time in ArDM on the surface at CERN. With a preliminary and incomplete set of PMTs, the light yield at zero electric field is found to be between 0.3-0.5 phe/keVee depending on the position within the detector volume, confirming our expectations based on smaller detector setups.

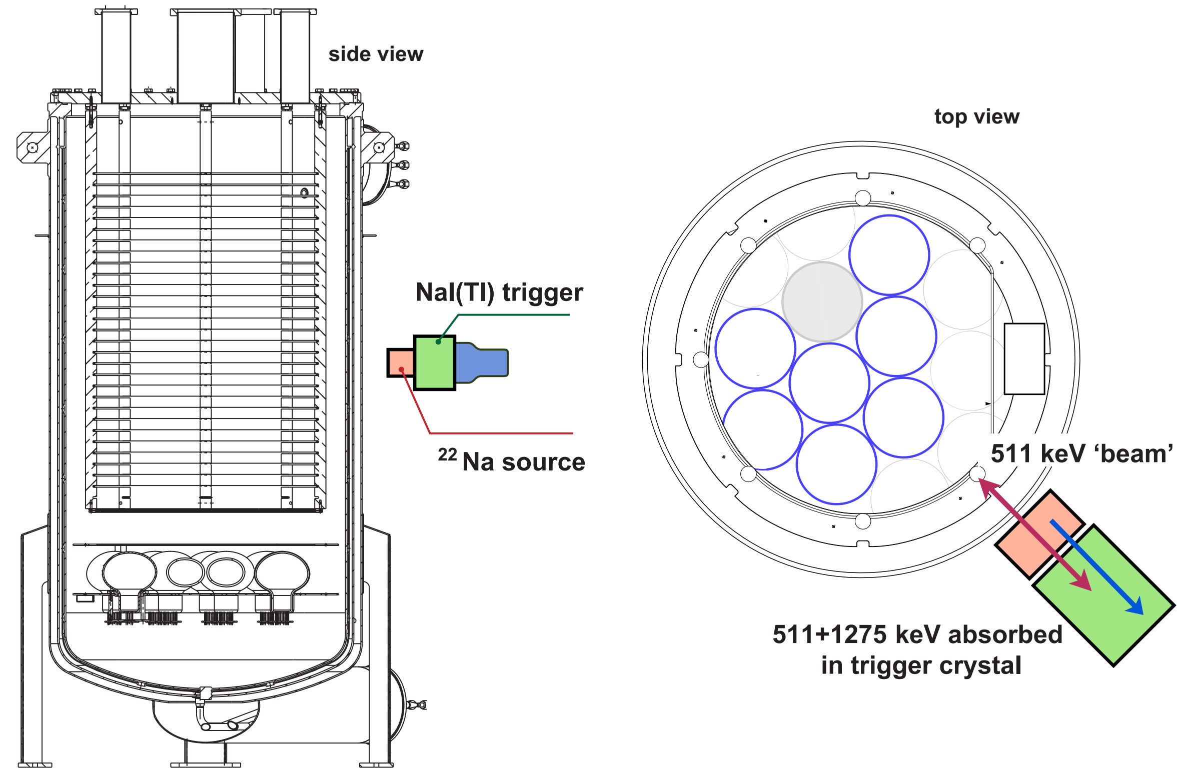
KEYWORDS: Photon detectors for UV, visible and IR photons (vacuum) (photomultipliers, HPDs, others); Large detector systems for particle and astroparticle physics; Liquid detectors

ARXIV EPRINT: 1009.3641

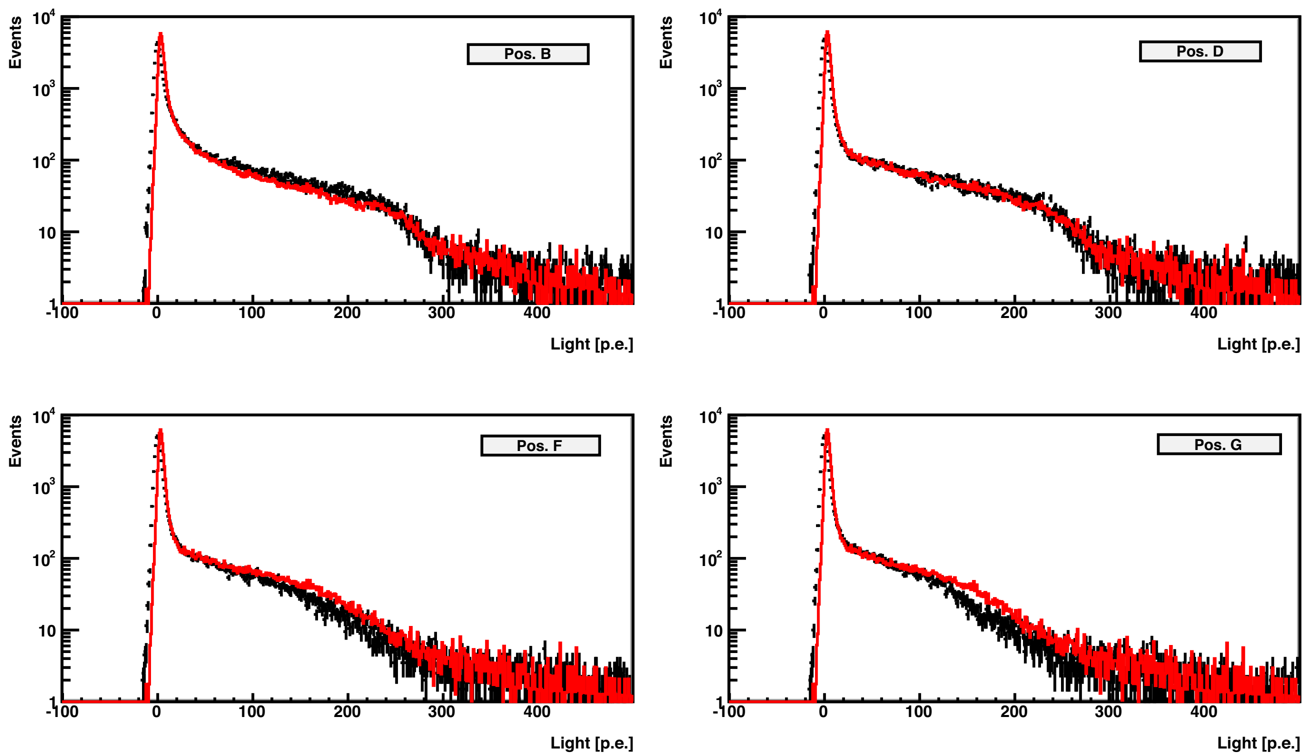
[1] Corresponding author.

1st cool down and LAr test

- calibration data taken with 511, 662, 1275 keV gamma rays and neutrons from AmBe - various trigger configurations [including external trigger]



- Data analysis and MC:

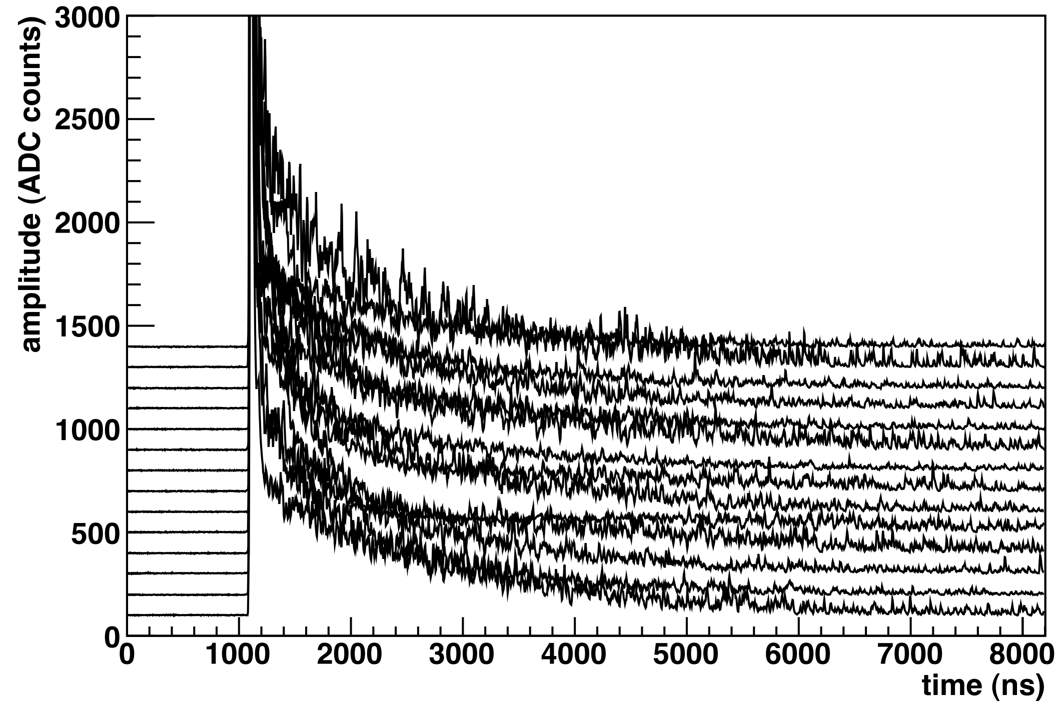


Noise 1.4 p.e.
Good agreement between data and MC
Light yield with 7 PMTs: approx 0.4 p.e. / Kevee

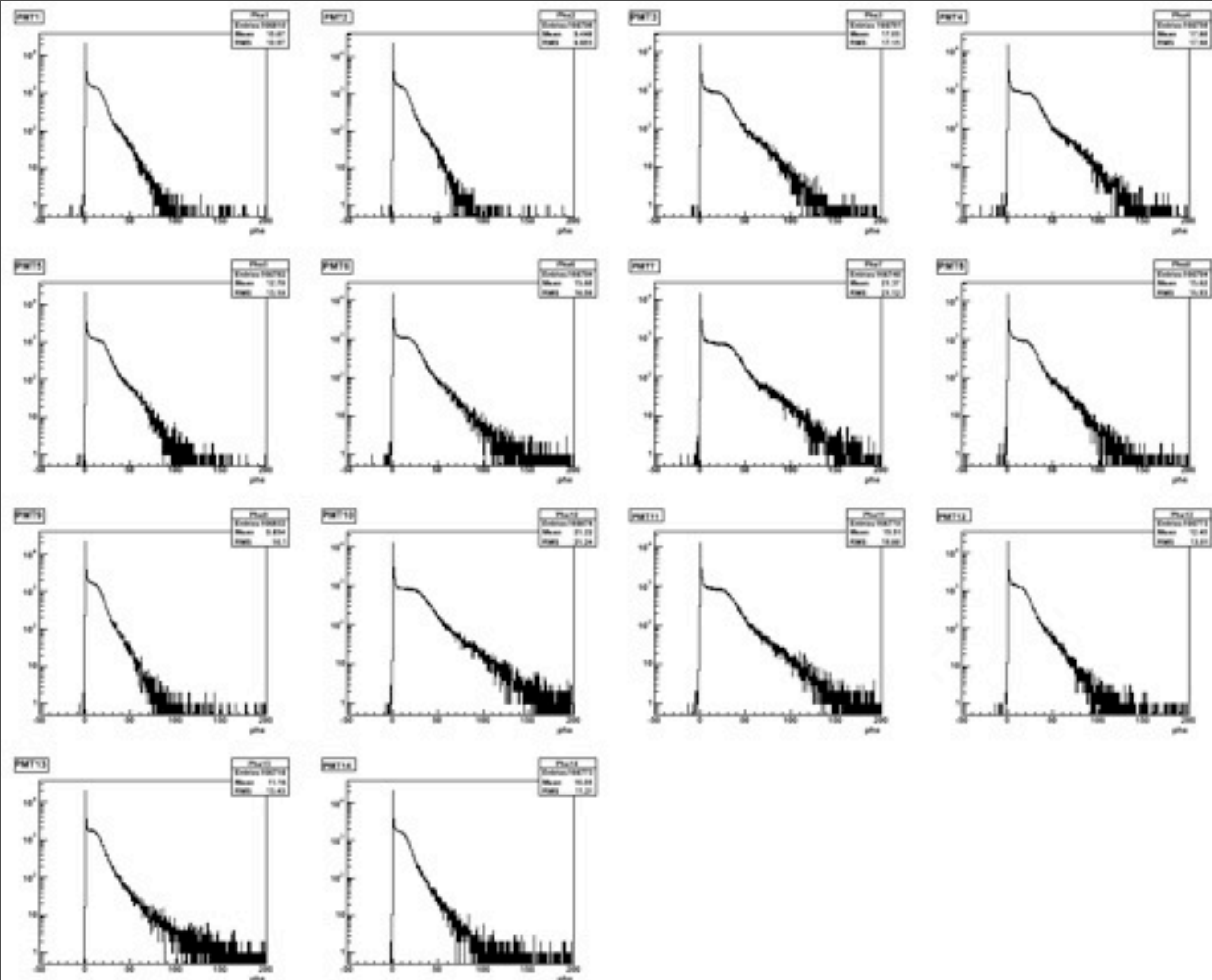
2nd cooldown - Oct 2010

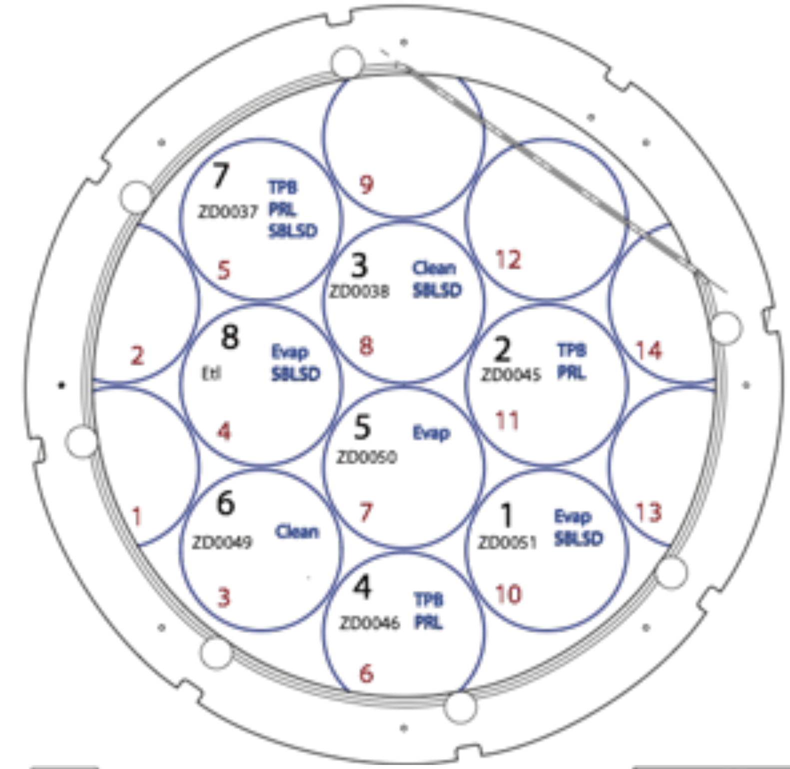
the main goals of this test were:

- measure the performance in LAr of completed light readout
- fully test new DAQ for light readout, including integration with charge DAQ
- run ArDM-1t using the recently completed PLC
- test charge extraction and detect S1/ S2
- collect several TB of data with external sources, mainly externally triggered, including AmBe data

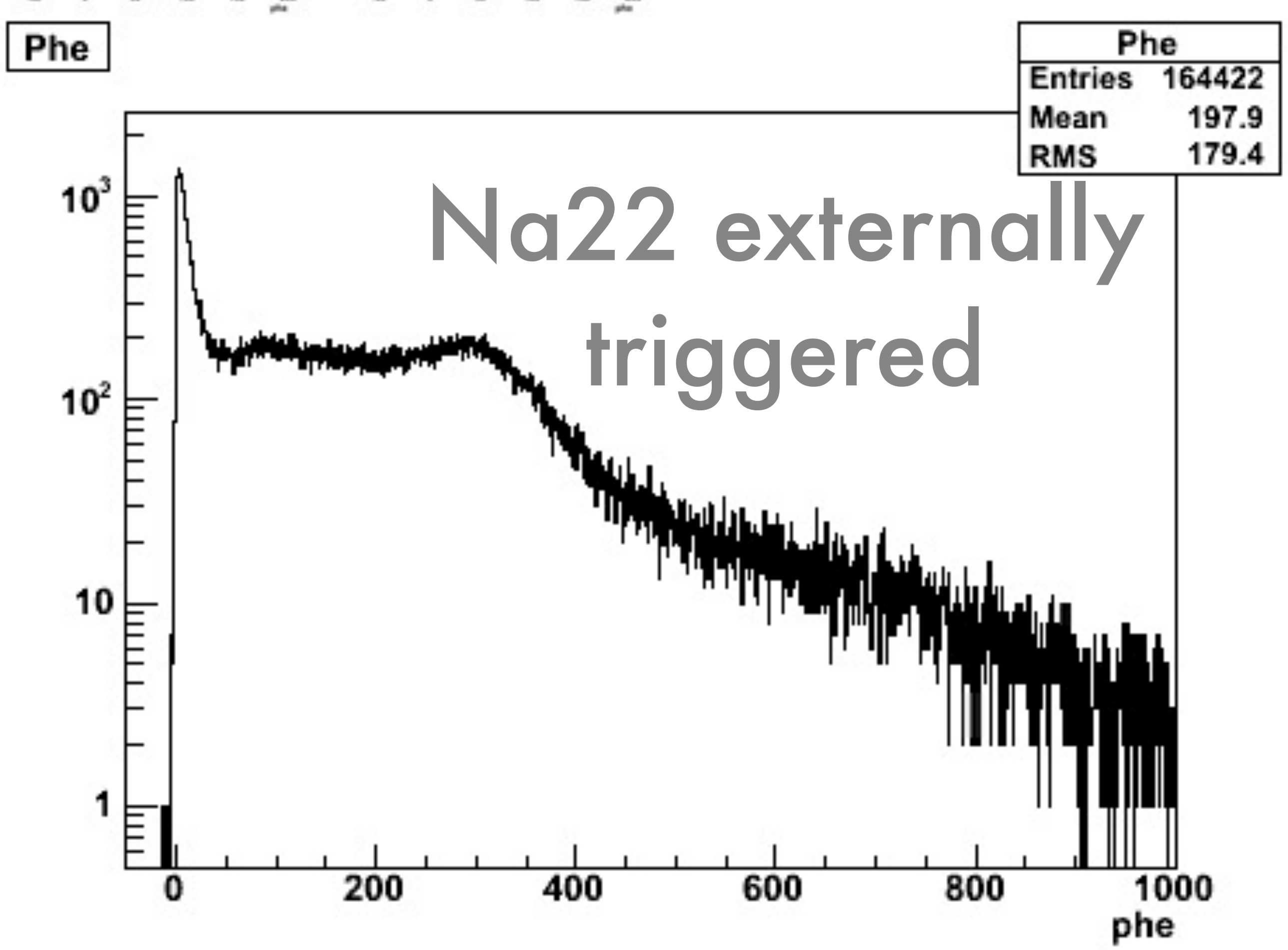


traces from the 14 PMTs
in ArDM-1t

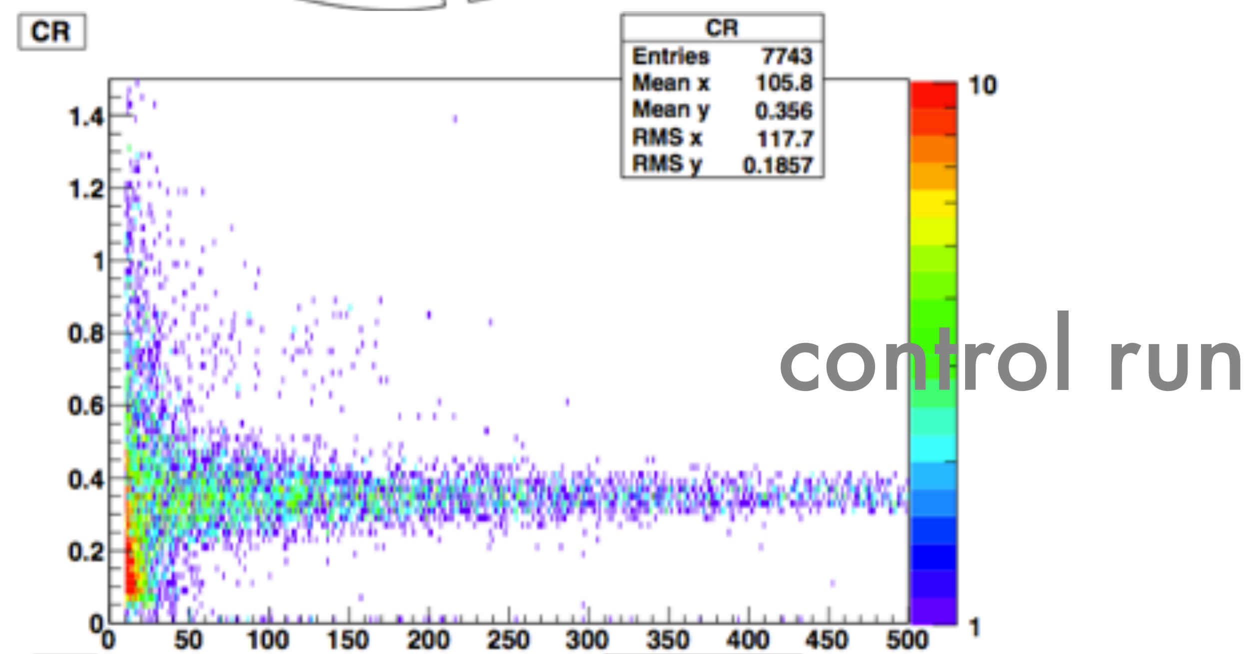




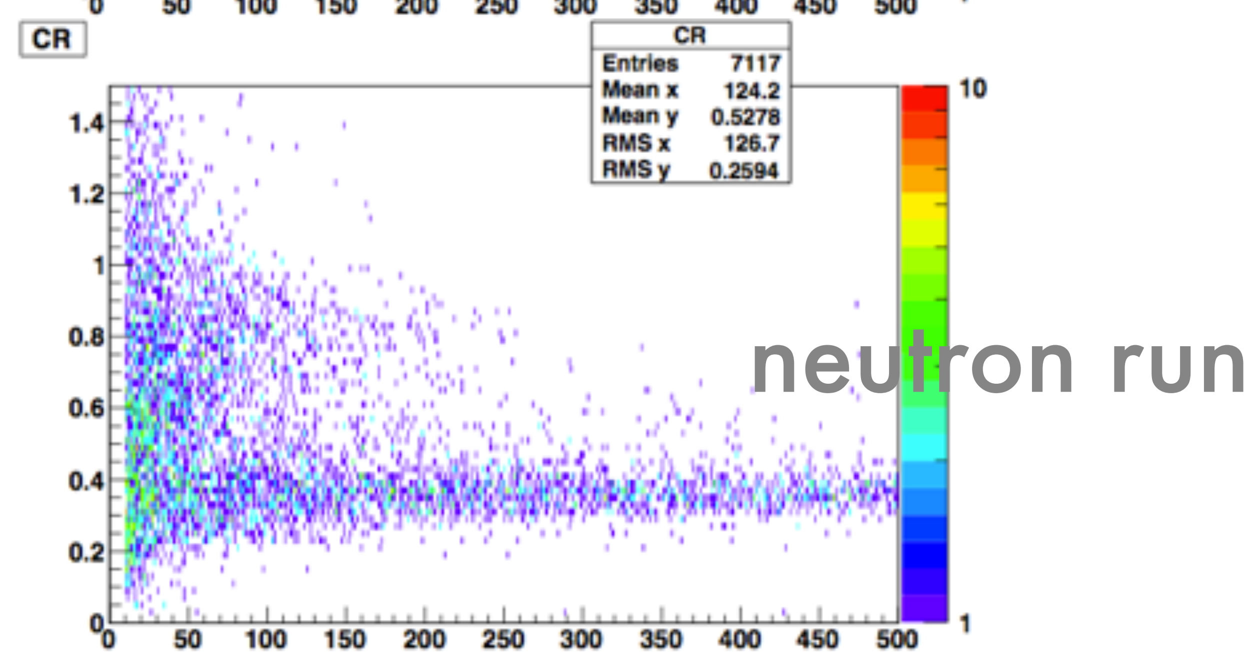
7 ZD0037 TPB PRL SBLSD
3 ZD0038 Clean SBLSD
8 Etl Evap SBLSD
2 ZD0045 TPB PRL
5 ZD0050 Evap
6 ZD0049 Clean
1 ZD0051 Evap SBLSD
4 ZD0046 TPB PRL



Phe
Entries 164422
Mean 197.9
RMS 179.4
Na22 externally triggered
phe



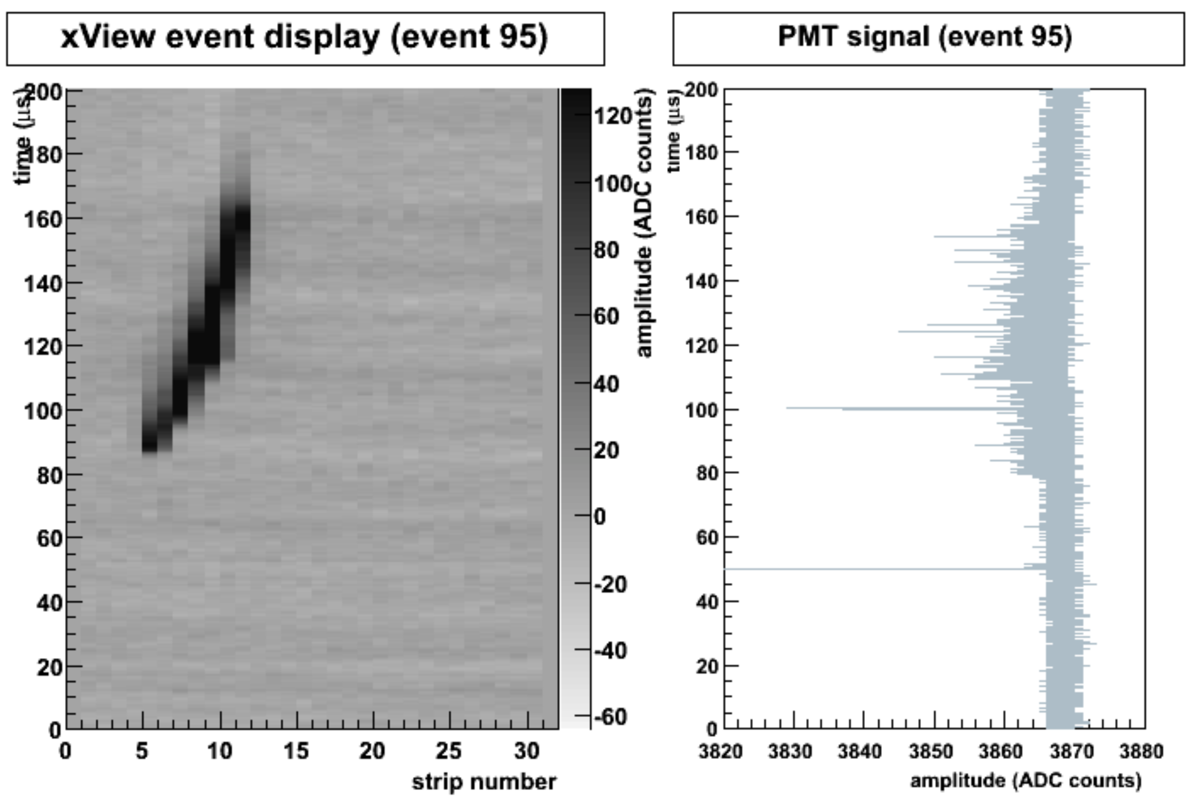
CR
Entries 7743
Mean x 105.8
Mean y 0.356
RMS x 117.7
RMS y 0.1857
control run

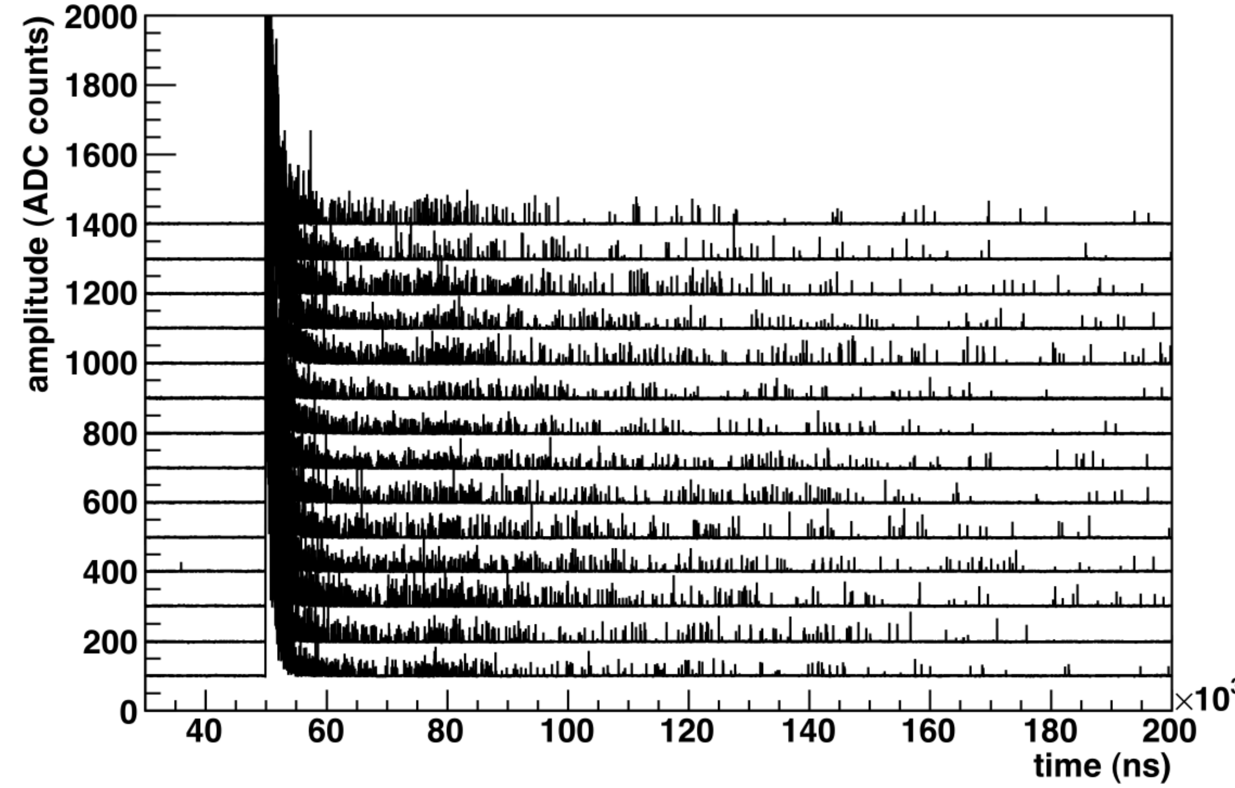


CR
Entries 7117
Mean x 124.2
Mean y 0.5278
RMS x 126.7
RMS y 0.2594
neutron run

2nd cooldown

S1/S2 and charge signal from the 3lt setup: same front-end electronics as ArDM-1t





S1/S2 signal from ArDM-1t triggered on muons crossing the detector top to bottom [note that time axis extends to 200 μs]

ArDM-1t: front-end electronics

Charge Readout

CAEN SY2791

4 crates - 1024 channels

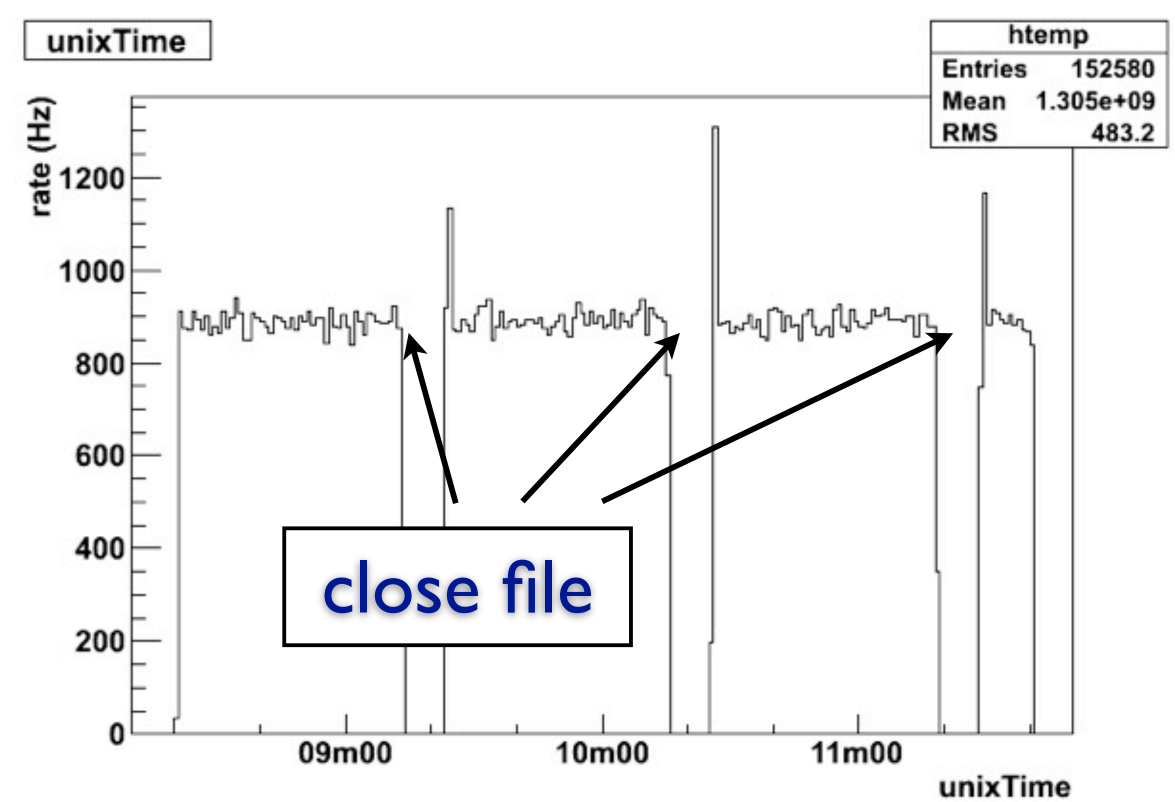
CAEN, in collaboration with ETHZ, developed A/D and DAQ system: 12 bit 2.5 MS/s flash ADCs + FPGA. Successfully tested and fully operational on small scale setups. 1000 readout channels available

Light Readout

- CAEN V1720 used in the most recent test of ArDM-1t - VME based, 250MS/s 12bit 1.25MS/Ch (up to 10MS/Ch available)
- good overall performance
- data taking at kHz rate
- 3 boards currently available (24 ADC channels)
- scalable, easy to modify firmware, already integrated with the existing DAQ for charge readout, reasonable cost

DAQ upgrade

- 2 CAEN A3818 PCI Express boards have been procured
- 4 optical links each, 95 MB/s per optical link
- one for the light readout, one for the charge readout
- new computers procured for DAQ - DELL R510, 6 cores, 12 GB RAM
- storage: LaCie 12Big, 12 TB scalable to 60 TB
- all installed in the ArDM electronics racks
- tested using the ArDM light readout, 3 TB of data written to disk
- implementation of algorithms for data compression and online data selection has started



NEW PMTs

- we expect - including a good performance of the side reflectors - ~1.2 p.e./keVee for the current light readout system with 14 R5912 8" PMTs
- this can be improved in a straightforward though expensive manner by replacing the PMTs with higher QE PMTs
- good options for an upgrade available on the market: Hamamatsu 3" R11065 have 30% QE or better at 420 nm

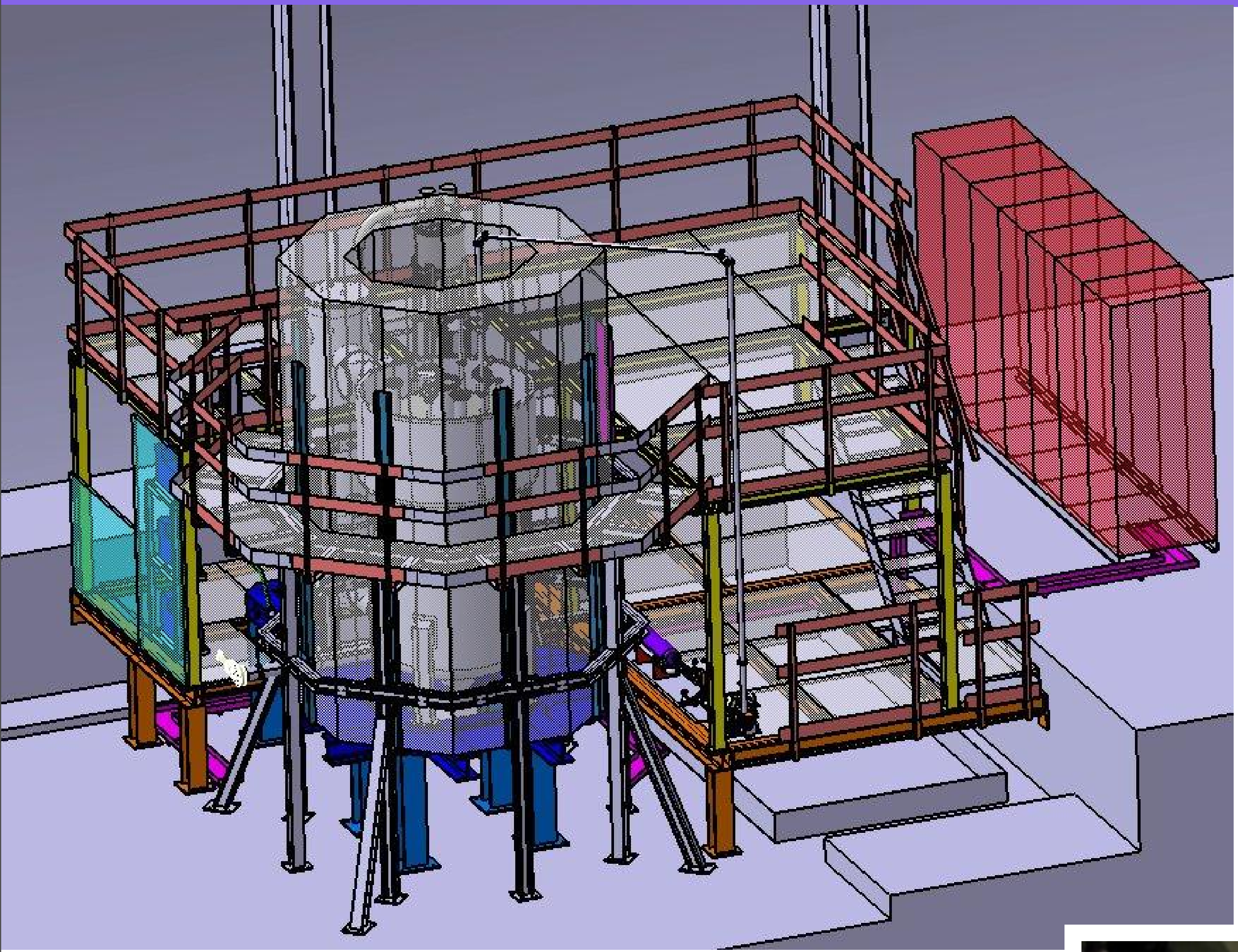
NEW PMTs

- 4 R11065 delivered to us by Hamamatsu in Oct 2010 and we had preliminary tests in the 3 lt / LEM setup
- a second setup for test in argon gas is now available
- 2 R11065 will be mounted for triggering purposes on the 250 lt chamber currently being asembled
- in order to cover the full area of ArDM-1t, cathode-side only, at least 61 PMTs will be needed
- the added number (x4.5) of HV and readout channels is manageable
- the photocatode coverage with the R11065 *decreases* by ~20% compared to the R5912 8" we have now
- in parallel: R&D on wavelength-shifters and coating

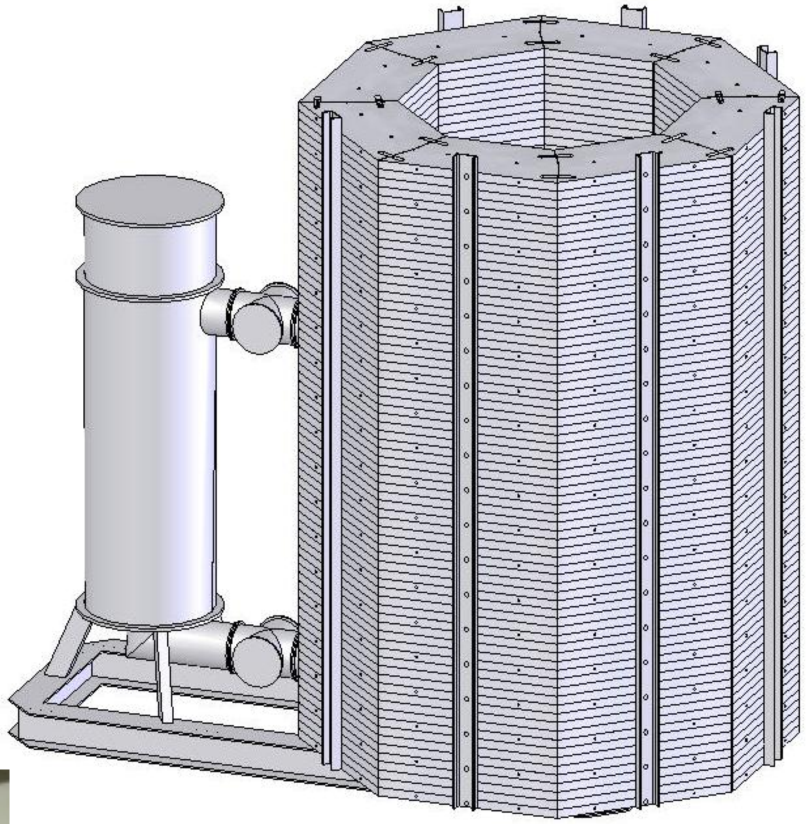
INSTALLATION IN LSC

In Oct 2010 ArDM has received approval for installation in Canfranc

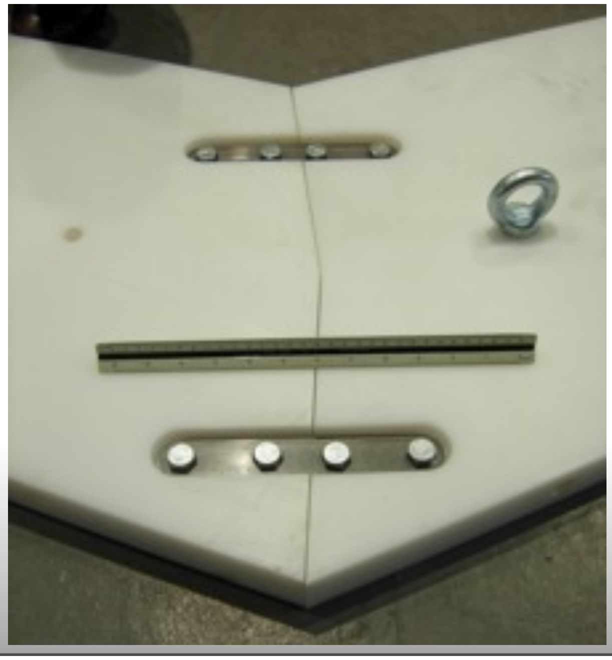
Support platform

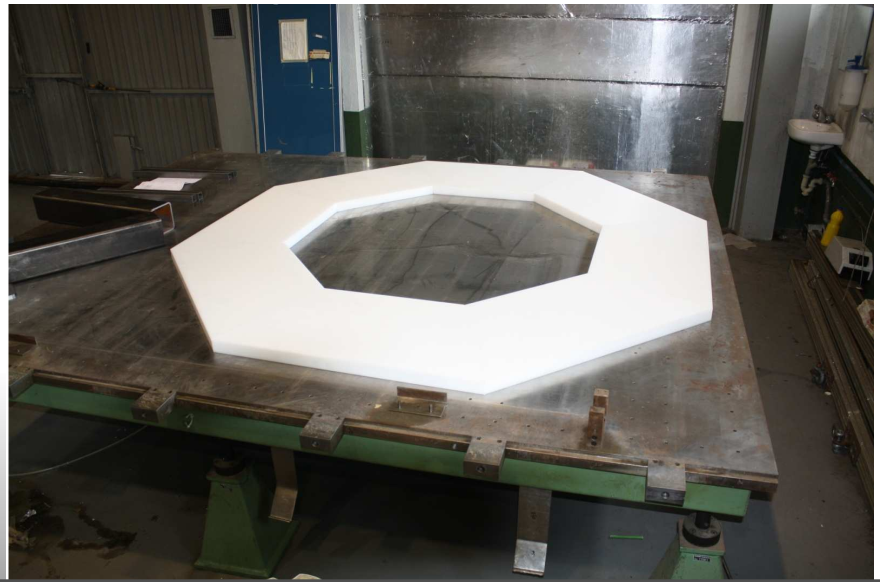


17 tons polyethylene neutron shield



3D model of the ArDM installation in LSC





Static analysis

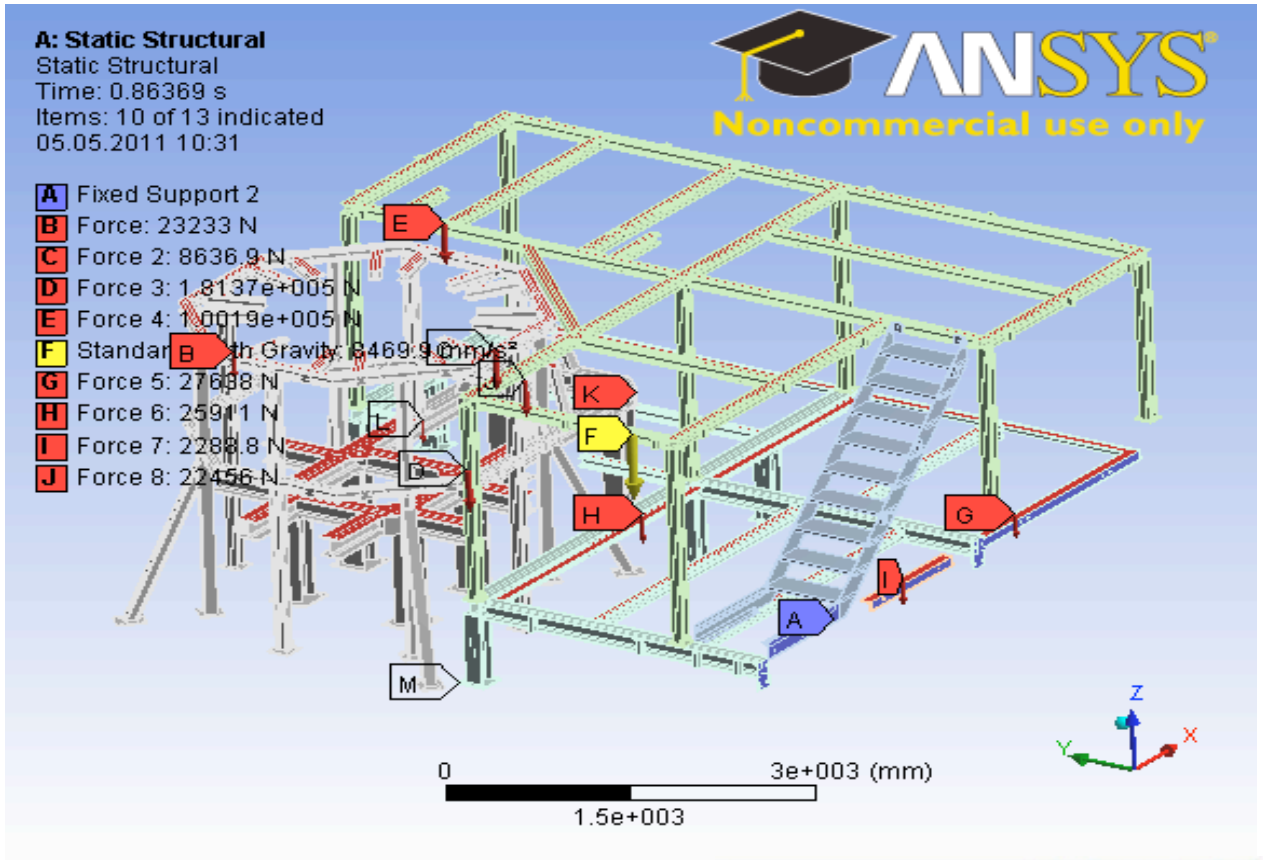


Fig.41 Loads at the structure for static analysis

Static seismic analysis

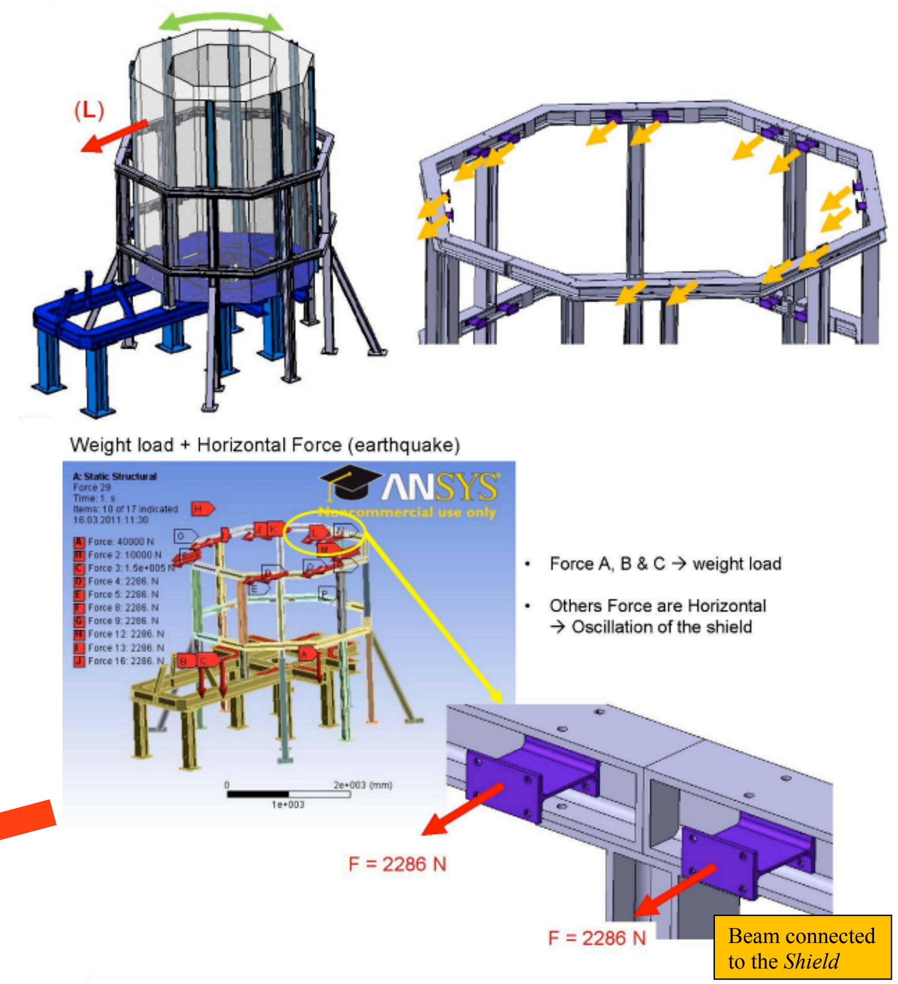


Fig. 44 Seismic Case

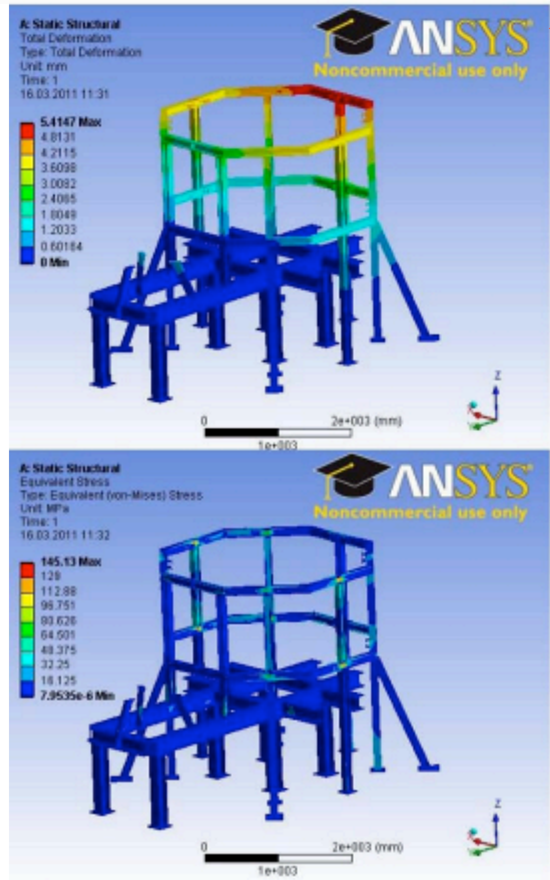


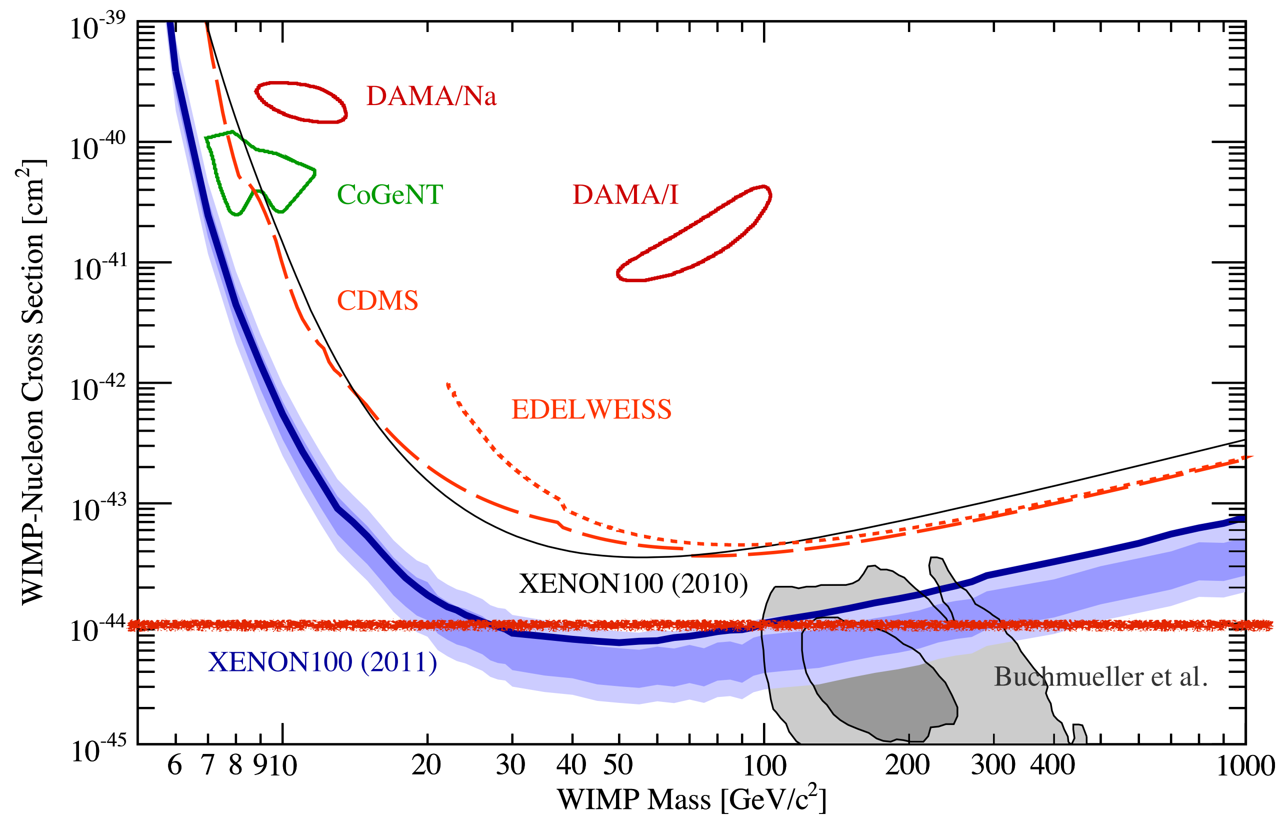
Fig. 45 Total Deformation and Equivalent (von-Mises) stress

Max deformation is 5.5 mm
Max stress 145 MPa
Allowable stress 235 MPa
Safety factor: 1.62

ArDM sensitivity

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



Ar39 [evt/day]	gamma [evt/day]	neutrons [evt/day]	background [evt/day]	WIMP rate [evt/day]
1.50E+06	47,500	0.07	0.22	0.25

CONCLUSIONS & OUTLOOK

- 1 ton Ar DM detector needed to be competitive with existing/soon to happen LXe DM experiment [XENON, LUX, XMASS] - 10^{-45} / 10^{-46} cm^2 xsec sensitivity
- Still unresolved issue of ^{39}Ar background
- ArDM-1t is our attempt to produce a significant direct Dark Matter search with a liquid Ar target
- Development phase at CERN completed. ArDM-1t works as dual phase LAr TPC with low energy threshold, ready for an underground phase
- Cryogenic system upgraded to a closed loop, zero loss system and tested

CONCLUSIONS & OUTLOOK

- Underground operation now needed to complete the development of ArDM-1t: mainly, low energy performance and background characterization
- This is what we proposed to LSC [Canfranc Laboratory] for 2011: ArDM was approved for installation in LSC in Oct 2010
- In the meantime, we will complete the upgrade of the light readout system and the R&D for the independent charge readout system
- The radiation shield is currently being produced, and will be ready by the end of 2011, when we plan to have a first Dark Matter run
- Within this schedule, ArDM has a good chance to produce relevant Dark Matter results