LAr activities - ETHZ group CERN / Zürich

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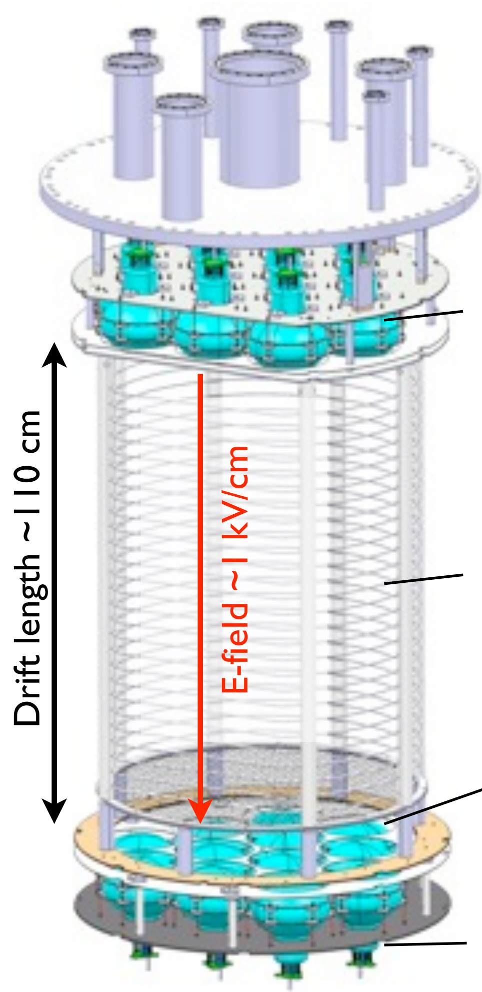
Menu:

- The ArDM experiment
  - Overview
  - Components
  - Current status
- R&D activities in the LAr sector
  - Charge read out
  - HV properties
  - VUV light detection
  - NR signal yields

The ArDM experiment

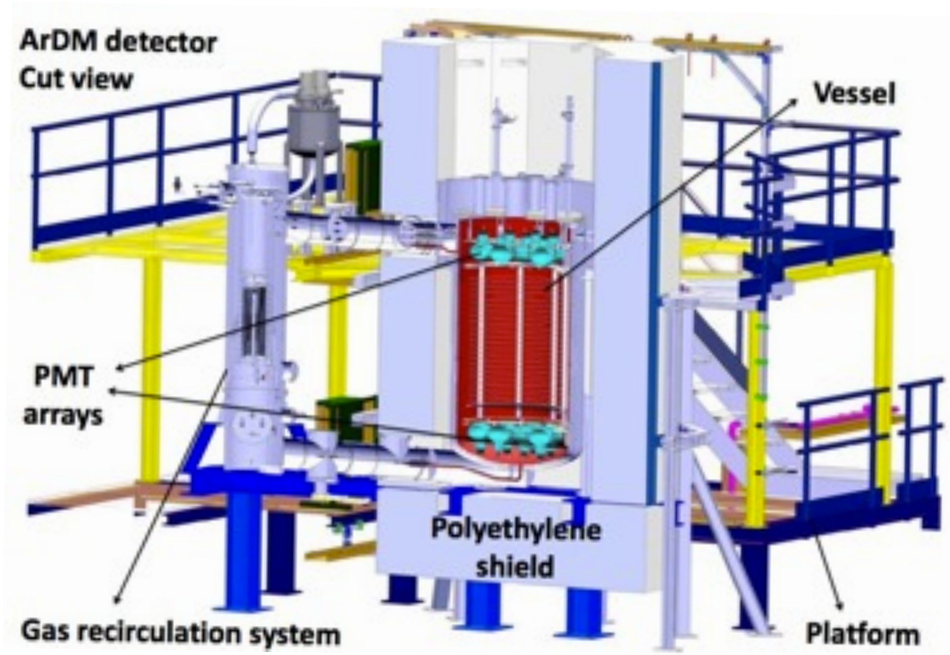
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
GOBIERNO DE ESPAÑA | MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

- Ton scale LAr detector (Ø80 cm x 120 cm)
- 850 kg active - 500 kg fiducial
- 30 keV_{nr} threshold
- Passive polyethylene neutron shielding



Installed at LSC (Spanish Pyrenees)

(Laboratorio Subterráneo de Canfranc, Spain)



- LAr and GAr purification through getters
- Fully PMT-based readout recording S1 / S2
- 2 x 12 x 8” cryogenic PMTs (Hamamatsu R5912-02MOD-LRI)
- PS + charge/light discrimination
- Tetratex® side reflectors coated with TPB
- Drift field: ~1 kV/cm => 100 kV VHV feedthrough

ArDM - explore LAr TPC technology at the low energy frontier

- Measure (spin-independent) WIMP recoil E-spectrum
- Prototype unit for large LAr detectors
- Modular design

Problem:

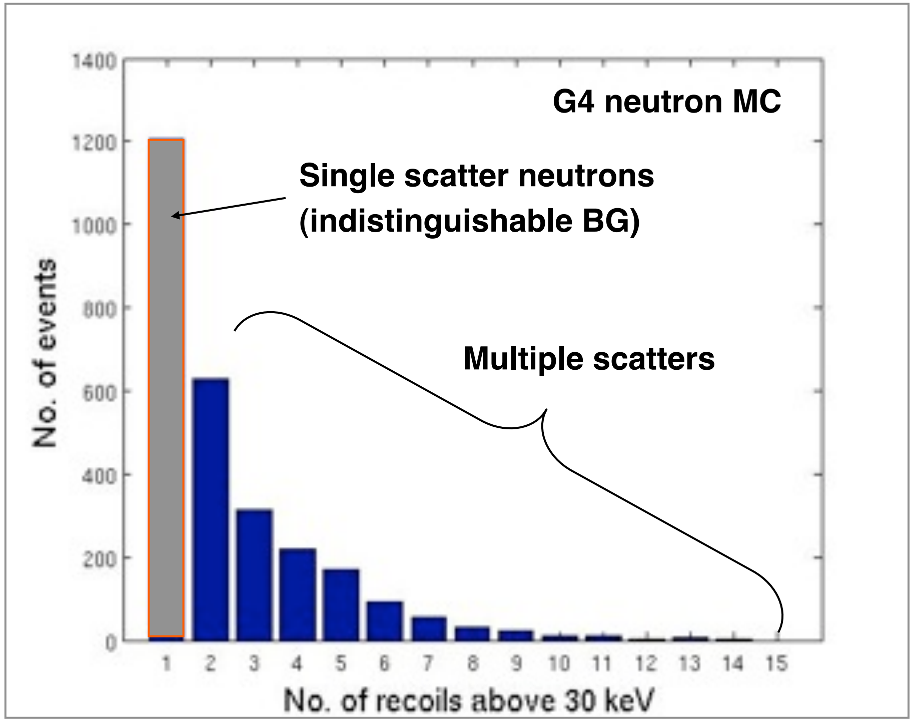
- Self activity of target (e.g. ^{39}Ar, β Q=565keV)
- Trigger rate

1Bq/dm^3 ≈ 10^8 /day/ton

Good:

LAr: X_0 = 14cm

- Self shielding (1t)
- Single neutron events (on statistical base)
- PSD + S1/S2 discrimination



- First task: Verifying these points
- Replacing components / additional shielding
- Selective triggers, data sparsification
- Depleted ^{39}Ar target

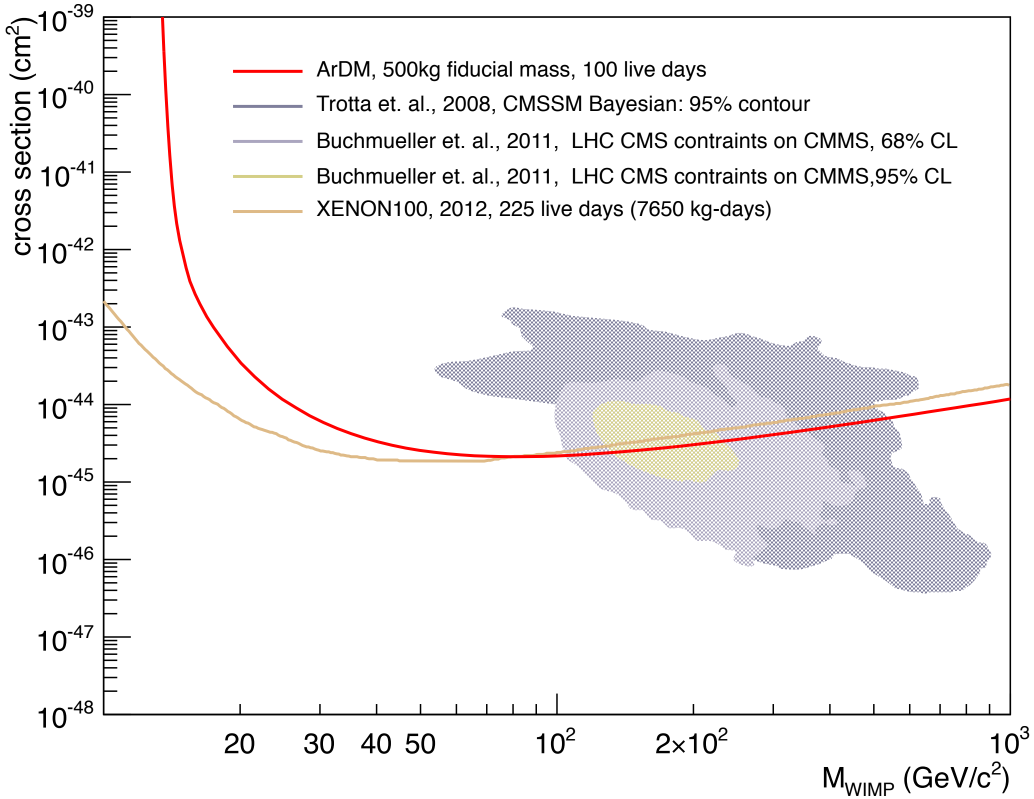
Challenging

Now in commissioning phase

Projected sensitivity

- Data analysis software for physics data is currently developed
- This includes involving analytical calculations of cross-sections, etc.
- Constraints given by experimental parameters like energy threshold, resolution and detection efficiency are implemented

Calculated by Dark Matter Online Tools



Assumed conditions

- fiducial volume : 500 kg LAr
- 100 live days of data taking
- energy threshold : 30 keV
- energy resolution : 23%
- detection efficiency : 50%
- total of 2.5 background events

Dark Matter Online Tools
http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/

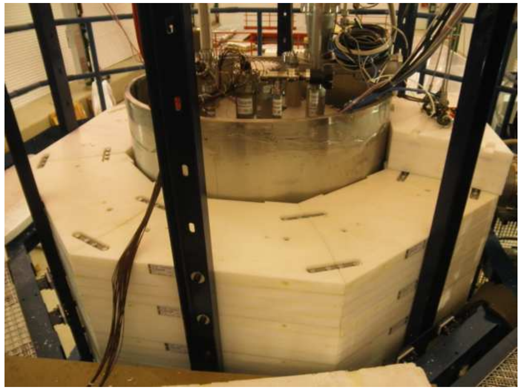
DMTools Dark Matter Limit Plot Generator
http://dmtools.brown.edu:8080/

Installation in LSC

Passive polyethylene neutron shield

Several 10s of tons

Bottom shield installation completed in September 2013



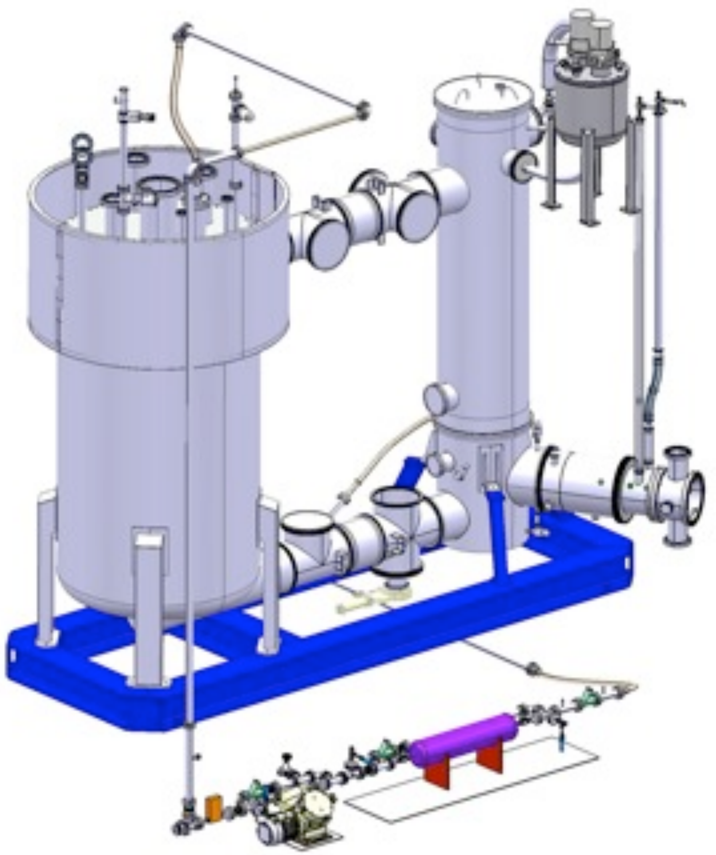
Lateral shields

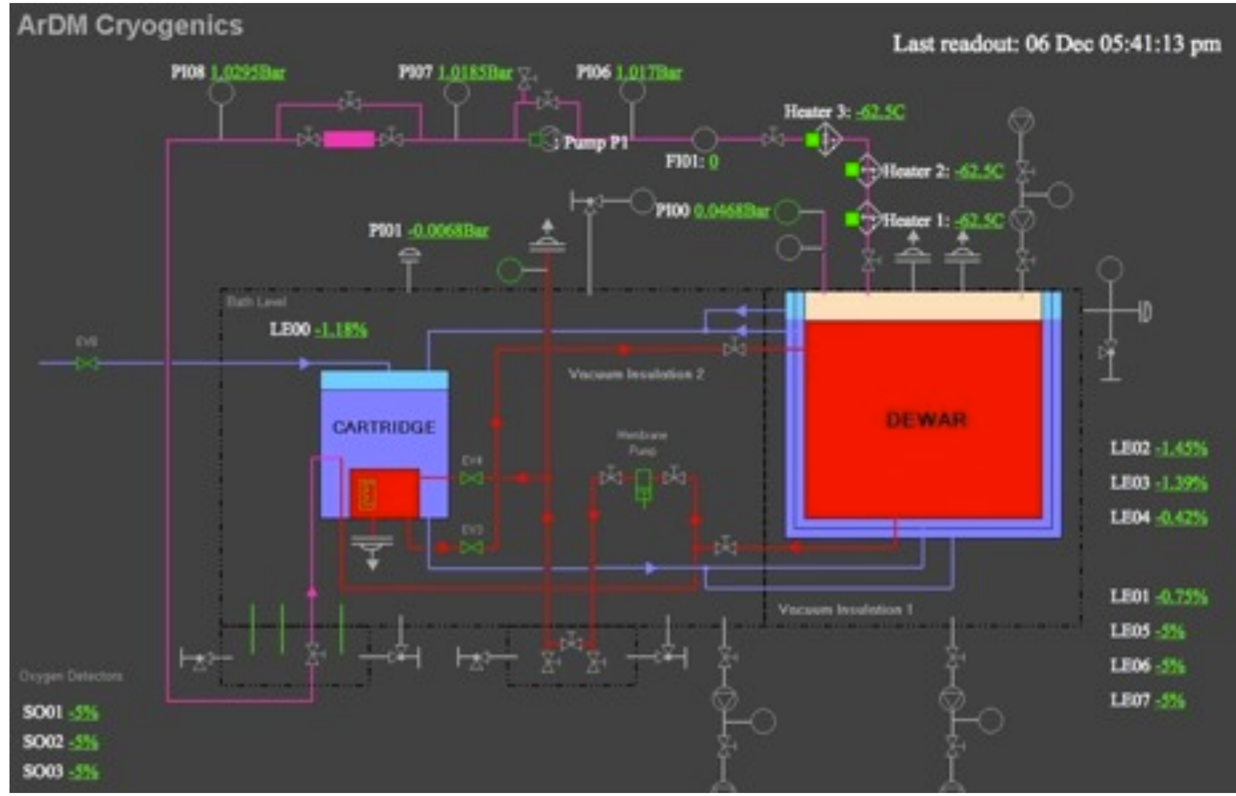
Only top shield remains to be installed

Cryogenic design

Bath design motivated by a modular design

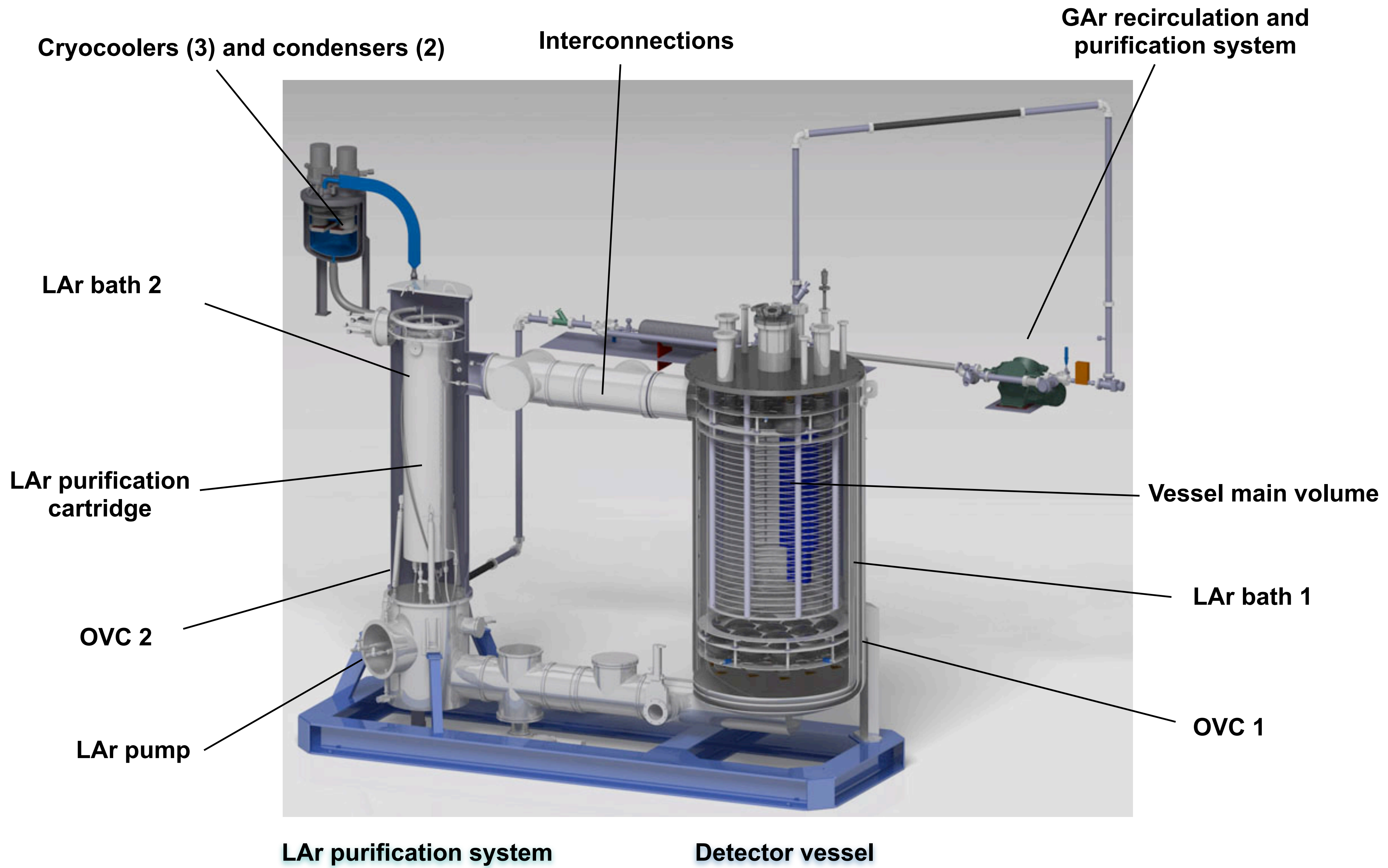
- **“clean” and “dirty” LAr volumes**
- **no direct heat load to the clean LAr**
- **bubble free ?**



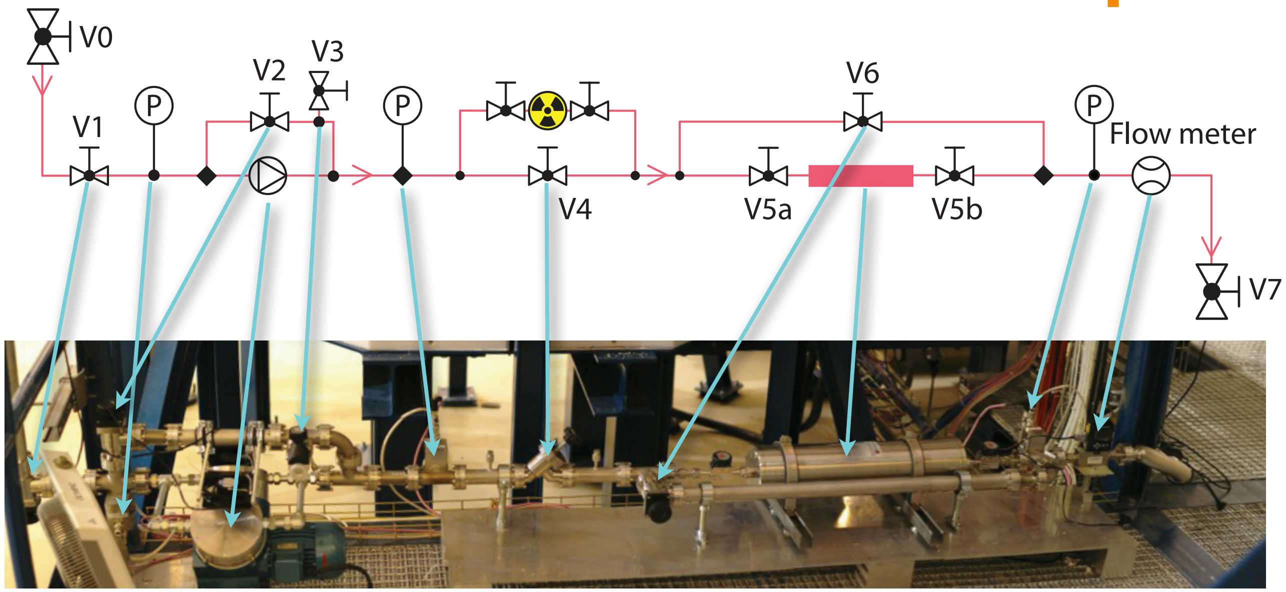


- **3 x 300-W Gifford-McMahon cryocoolers (Cryomech AL300)**
- **Heat influx from the environment ~350 W**
- **Third cryocooler for redundancy**

Cryogenic and vacuum components

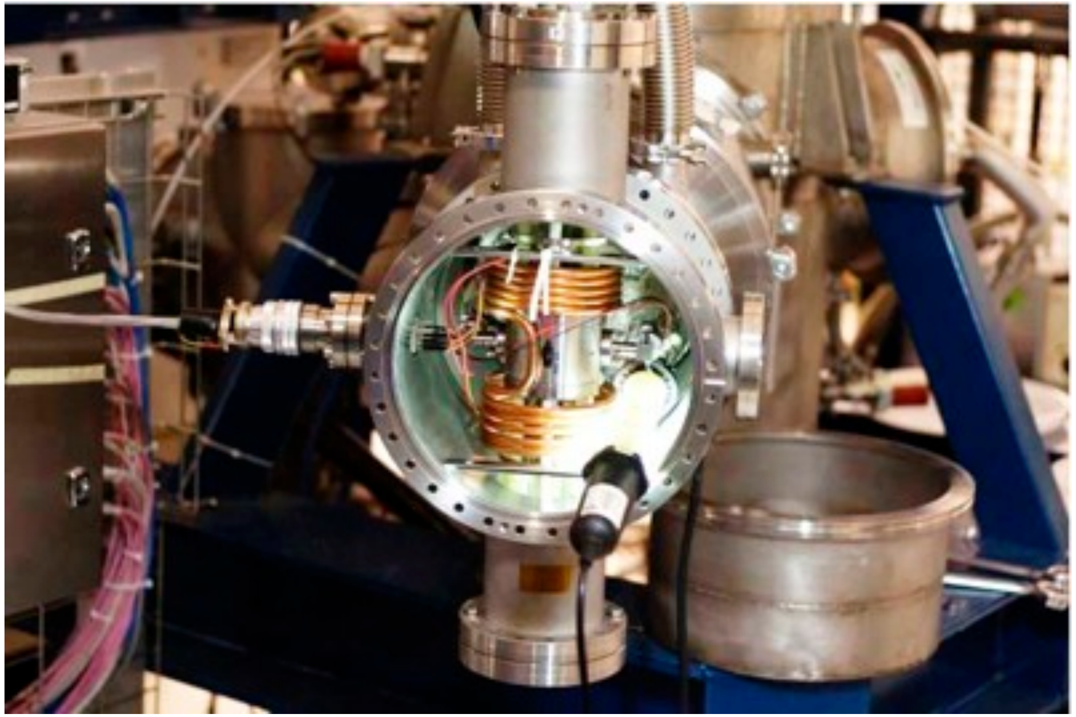


GAr and LAr purification



- Gaseous argon circulation system
- Pump speed ~80 slpm
- Recirculation time ~30 min (GAr op.)

Purification cartridge
SAES MicroTorr MC4500



- Liquid argon circulation system
- Cryogenic bellow piston pump
- Custom made (MEG experiment)
- Precooling
- Pump speed adjustable ~ 1...10 slpm
- CuO purification cartridge

PLC system - full experimental control

The PLC system provides the power management, the slow control and monitoring of the whole ArDM experiment

Central computer

UPS system

Distributing center

Sensor electronics

DAQ

Estimate of BG (^{39}Ar) rate in LAr : ~1 kHz

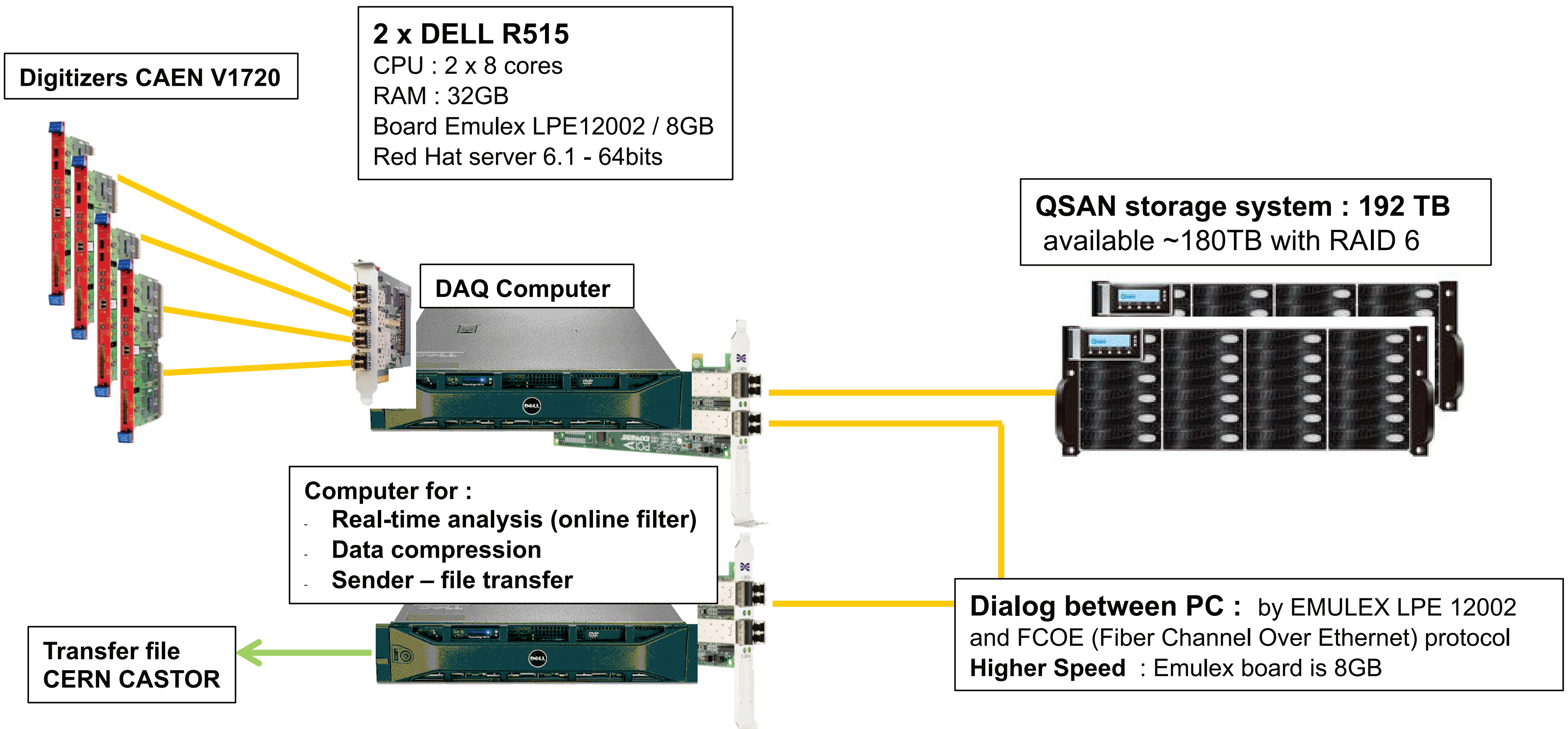
cf. 20–30 Hz of trig. in GAr

Data rate can amount to 100–200 MB/s

Recording of full waveform during a range of 4–8 μs is required

Upgraded scheme was tested in October 2013

Current DAQ configuration with four optical links



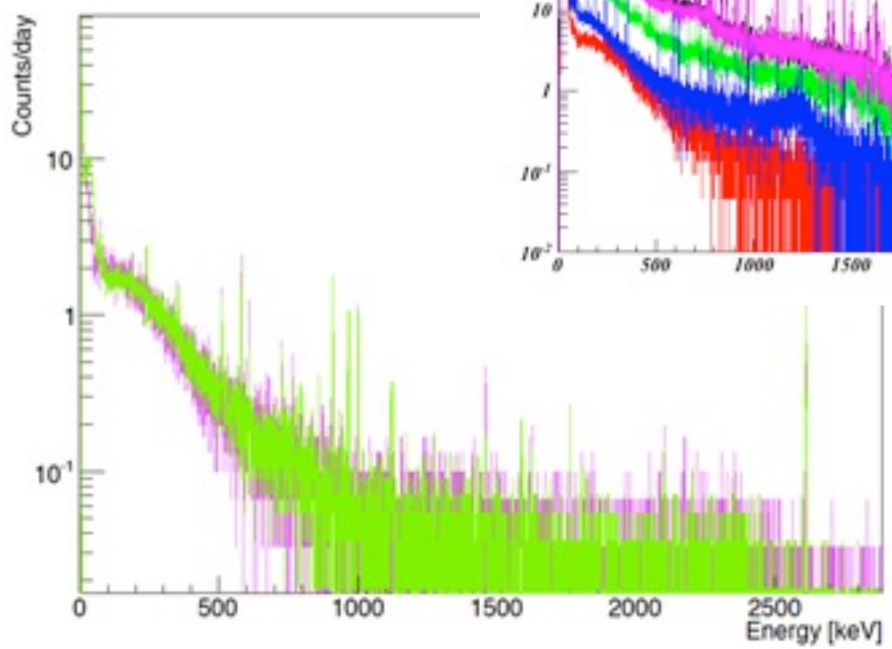
Storage system allows for continuous data taking of 22 days at 2 kHz trigger rate

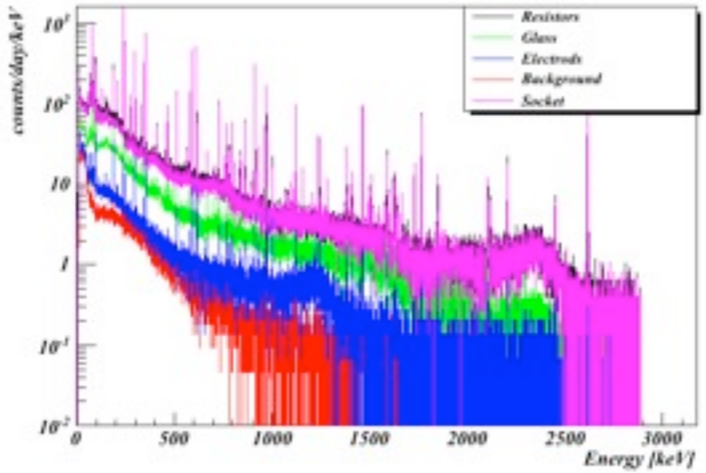
(x4 possible with lossless data compression)

- no sparsification planned for the moment

Material screening

Screening measurements done in Ge-Tobazo facility at LSC underground



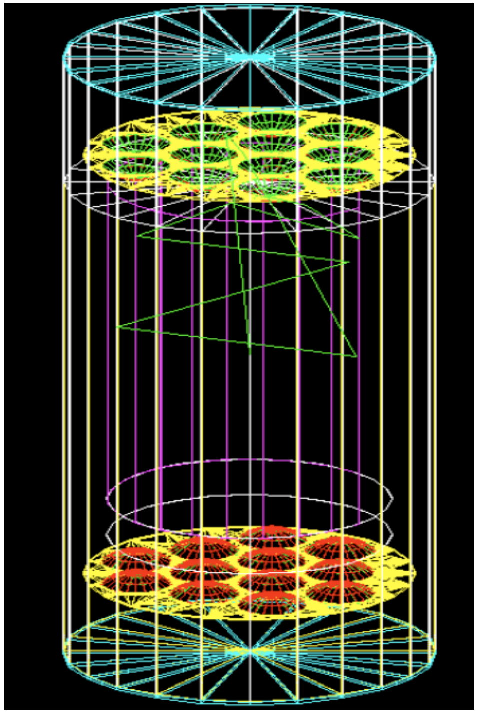


Measured spectrum for polyethylene (magenta)and BG (green)

Description	Quantity	Start	Stop	Days
PMT glass, Hamamatsu R5912-02MOD	746.7 g	03/08/2012	17/09/2012	45
PMT electrode part	197 g	17/09/2012	05/11/2012	49
HV resistors for drift cage	242.7 g	30/01/2013	20/02/2013	21
PMT base	1 unit	20/02/2013	11/04/2013	50
Polyethylene for PMT holder	63.2 g	11/04/2013	07/06/2013	57
Stainless steel for PMT holder	2072.1 g	07/06/2013	07/08/2013	61
Polyethylene for neutron shield	937.6 g	08/08/2013	10/09/2013	33
Perlite for top flange insulation	116.3 g	10/09/2013	20/09/2013	10

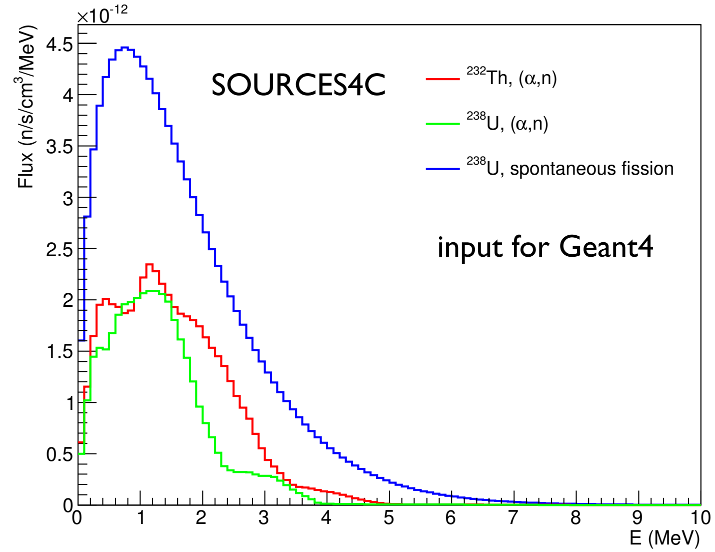
Monte Carlo Efforts

GEANT4

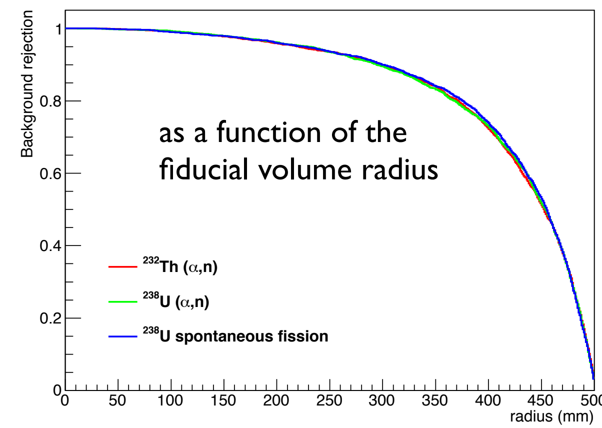


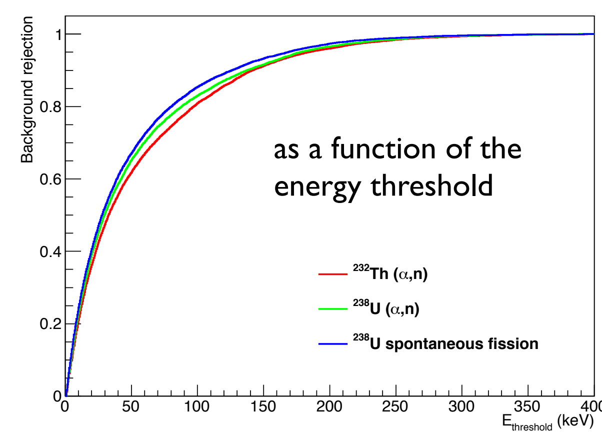
Expected energy spectra of the neutrons for 1 ppb contamination by the ^{238}U, ^{232}Th and ^{235}U in the stainless-steel vessel

neutron flux



BG rejection power

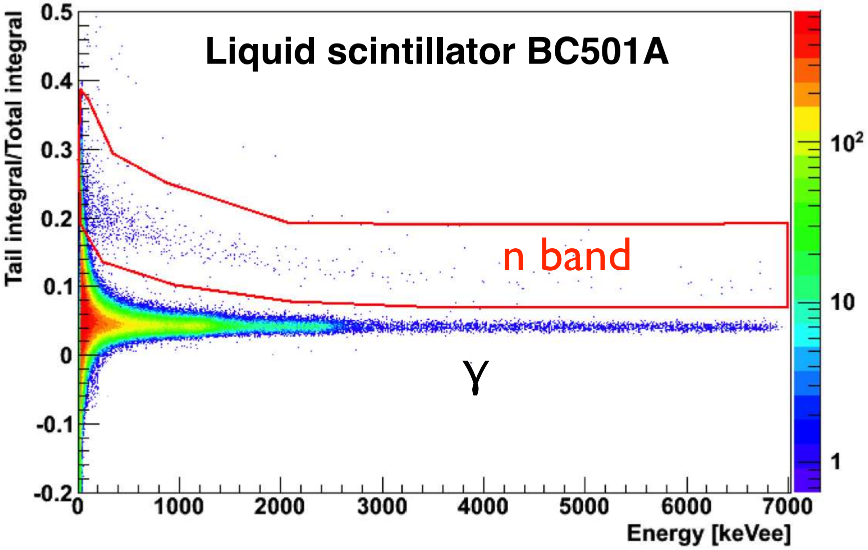




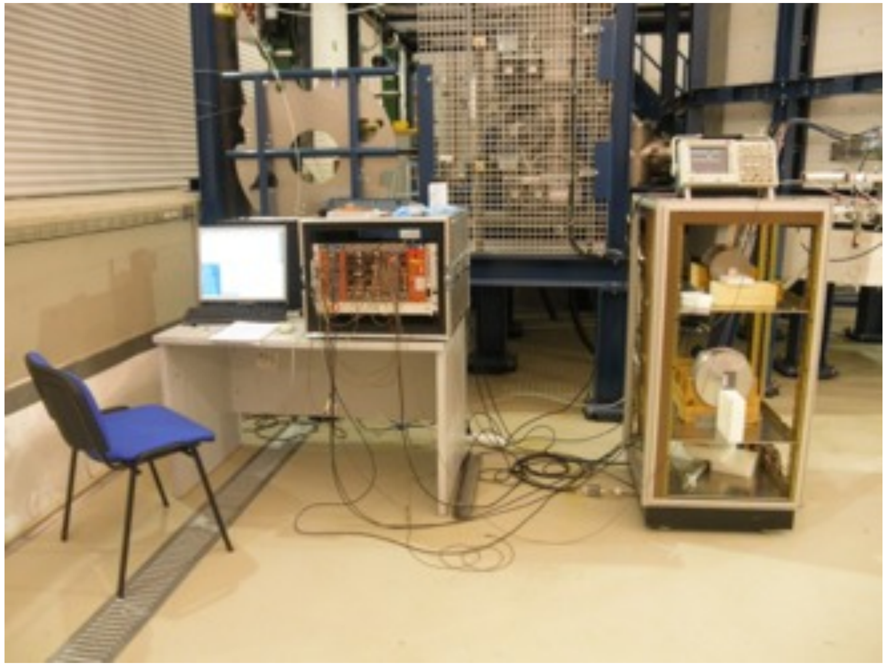
- Full detector geometry : PMTs, reflectors, TPB layers, support structure, 3-layer stainless steel vessel wall
- Ionization and scintillation processes in argon media (gas or liquid)
- Optical photon tracing involving all the optical processes :
    - wavelength shifting (conversion of VUV photons to visible)
    - definition of all the “optical surfaces” (refraction, reflection ...)
    - PMT response to visible photons

- Studies of BG events and discrimination efficiencies are under study

In-situ neutron BG measurement



Setup installed and under commissioning at LSC in Hall A

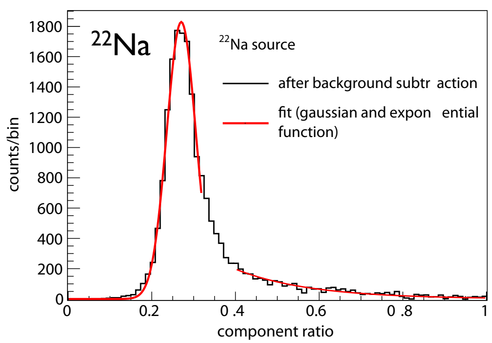


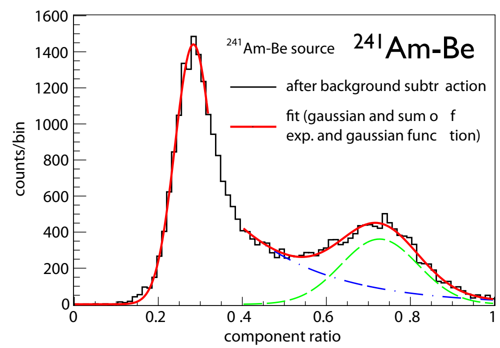
- Determine flux and spectrum
- Presently ongoing at the underground site
- Several months of measurements foreseen

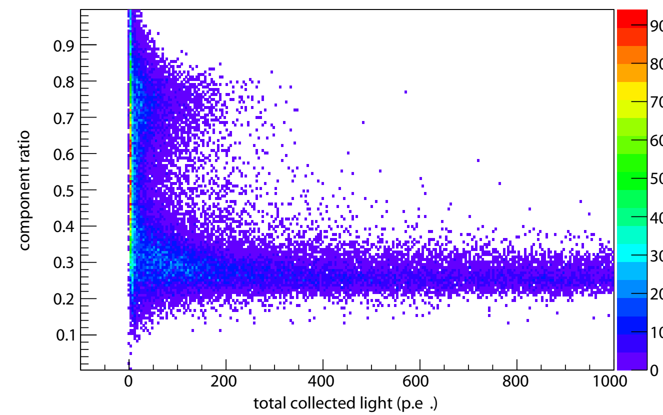
Results will be complemented with measurement using ^{3}He counters (CUNA collaboration)

PSD studies by component ratio

Measurement on surface at CERN
fraction of electronic recoil events (tagged 511-keV gamma from ^{22}Na source) misidentified as neutrons by PSD, which was tuned with the data taken with ^{241}Am-Be neutron source

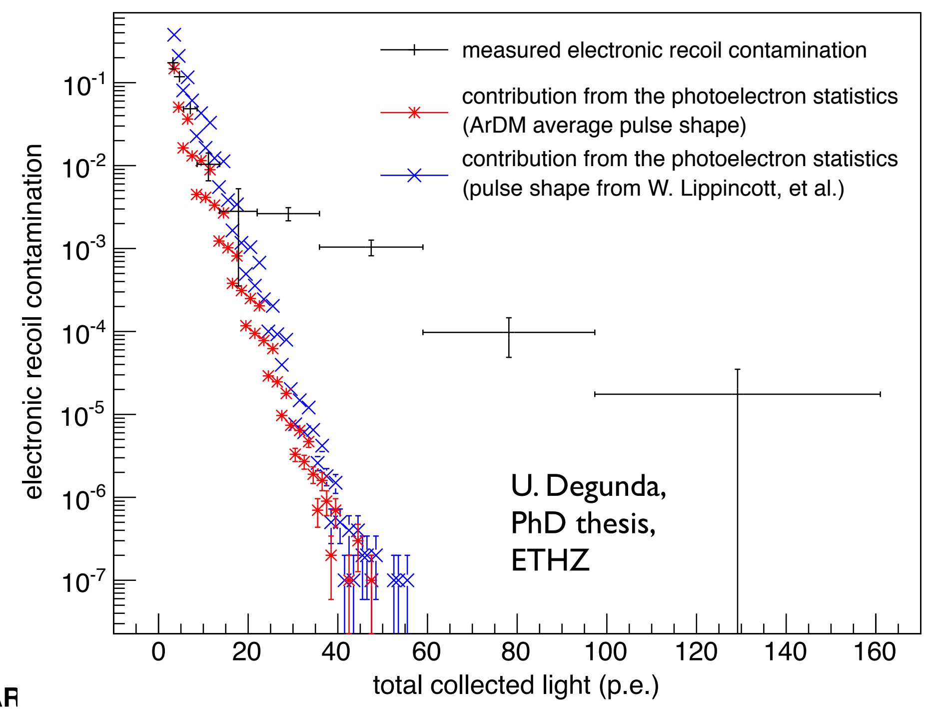


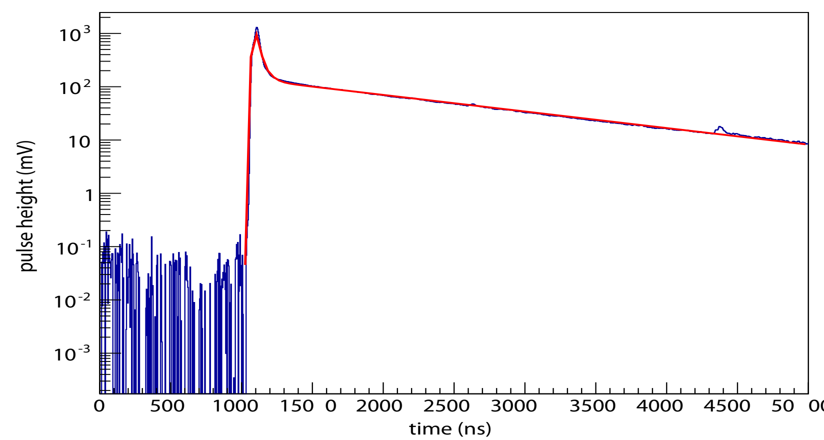




Averaged PMT signal in ArDM
for 511-keV gamma events (^{22}Na)

Data taken on surface at CERN



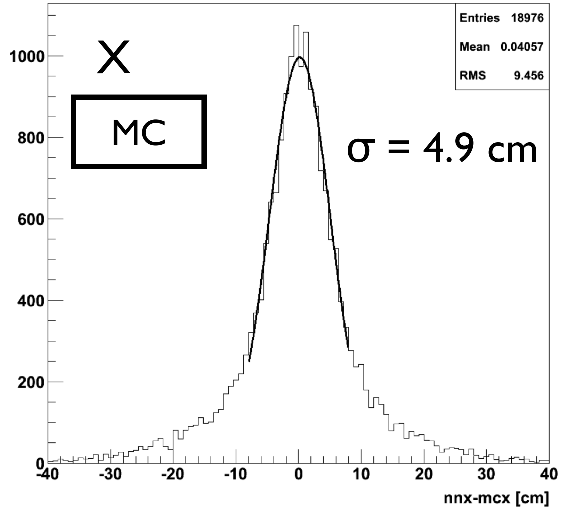


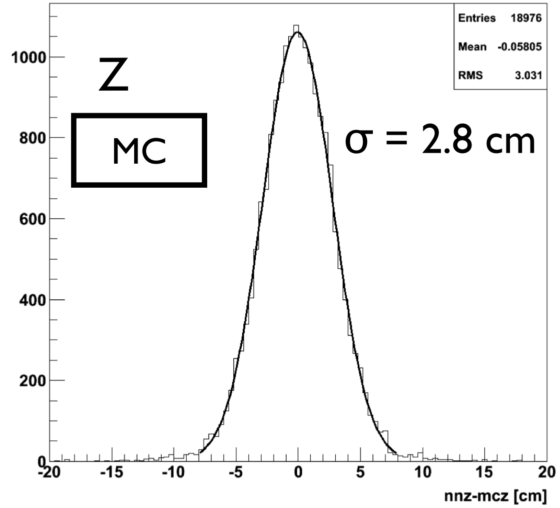
- Deviation from pe statistics
- Possible neutron contribution?
- To be measured underground

Towards physics analysis - 3D position reconstruction

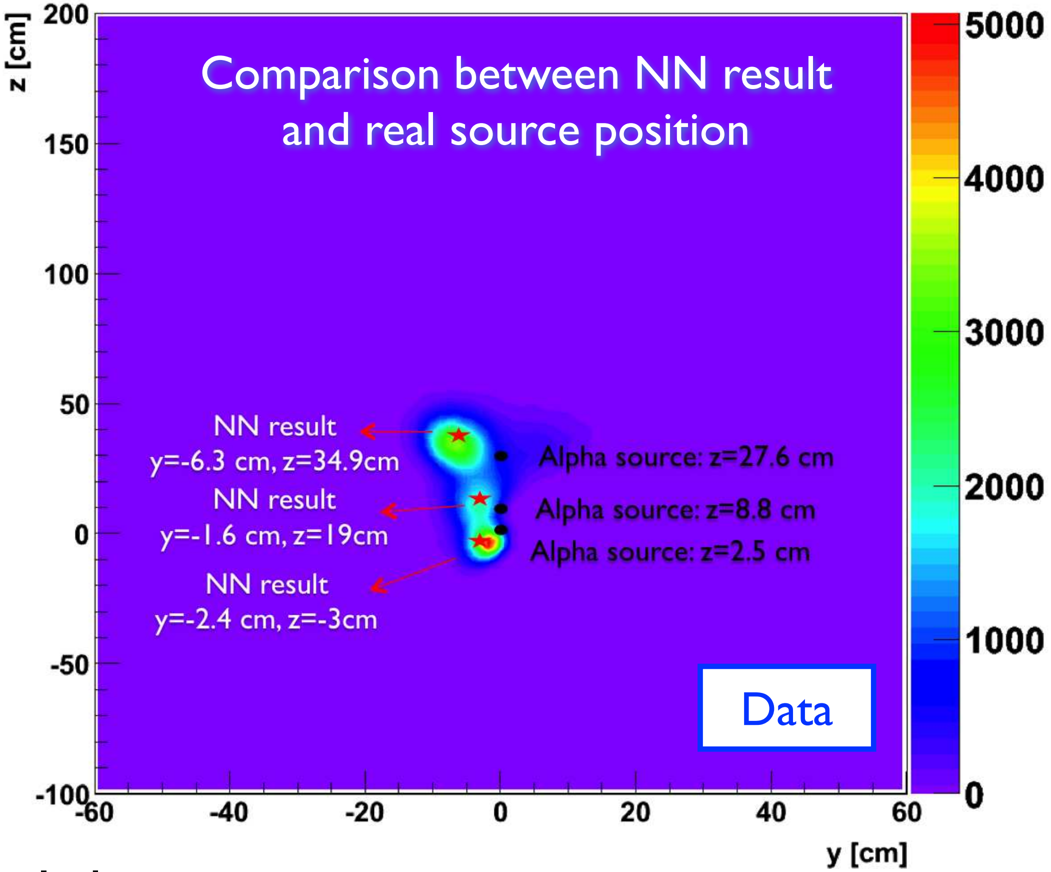
From the primary scintillation scintillation signal (S1) using neural network (NN)

Residual of the position reconstruction





3D reconstruction of the event position based only on the primary scintillation light (S1) with a precision of the order of centimeters is conceivable with NN



Ready for analysing LAr data

Improvements on the reco algorithm expected

Safety analysis & Quantitative Risk Assessment

To operate ArDM underground at LSC

In collaboration with colleagues from the Institute of Nuclear Technology-Radiation Protection, National Centre for Scientific Research “Demokritos”, Athens, Greece a qualitative risk analysis has been performed to identify the possible causes of Loss of Containment (LOC) of the liquid argon and hence its release to the laboratory atmosphere, the safety systems that are implemented in the design to inhibit such causes of LOCs and their failure modes, and the types of LOC such failures lead to.

The assessment indicates that all types of LOCs or Plant Damage States (PDS) may be grouped into 3 groups:

- **Plant Damage State I:** Failures in the installation resulting in the release of gaseous Ar (GAr) under conditions determined by the vessel design characteristics (burst discs).

- **Plant Damage State II:** A failure of the installation in such a way that results in a medium size break releasing of Liquid Ar (LAr) under conditions determined by the vessel design characteristics (burst discs pipe breaks).

- **Plant Damage State III:** A major failure of the argon vessel resulting in break (equivalent diameter 100mm to 500mm) releasing LAr.

“Only a catastrophic failure of the LAr vessel (PDS III) may pose serious health effects to the Lab personnel.”

“Generic frequencies for such catastrophic failure range between 10^{-4} ... 10^{-6}/year.”

Presently under evaluation by the LSC comittee

Outlook

- Installation work of the ArDM experiment basically finished
  (very last missing parts to be installed early next year)

- Extensive tests and evaluations were done with GAr over the last months/years

- The setup is ready for cryogenic operation (single phase, initial test required)

- Full ArDM safety file including a complete QRA submitted to the lab

- We are waiting now for the green light from LSC

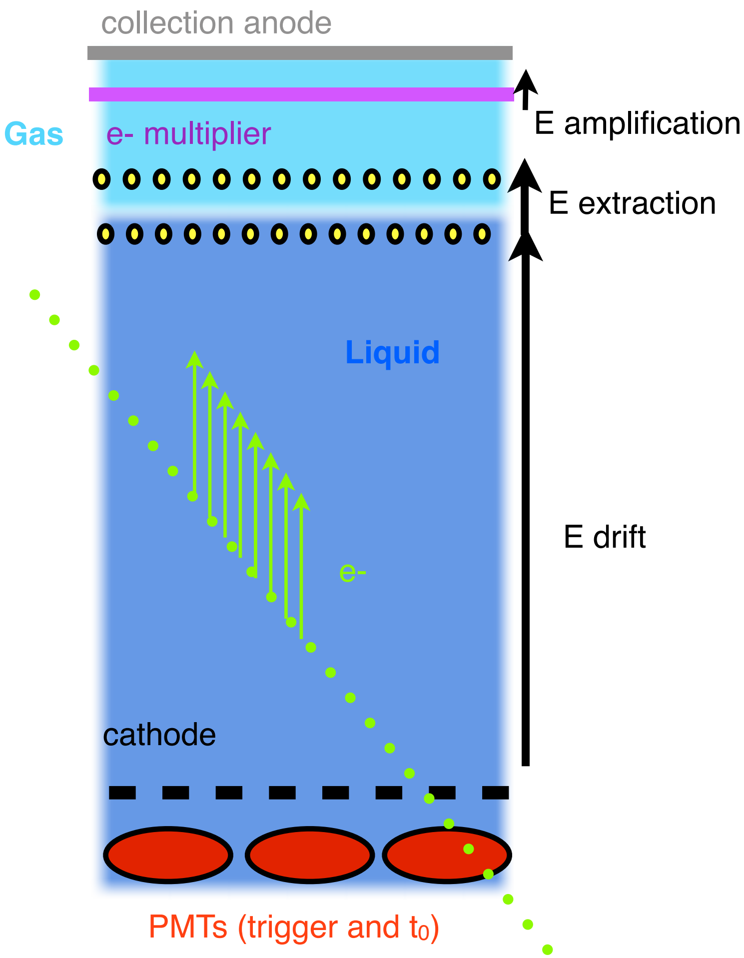
- We are ready to analyse physics data as soon as available

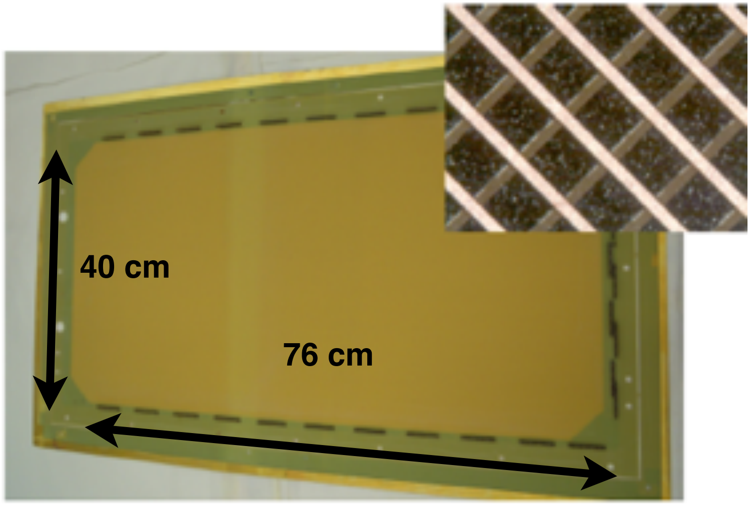
Commissioning run in single-phase

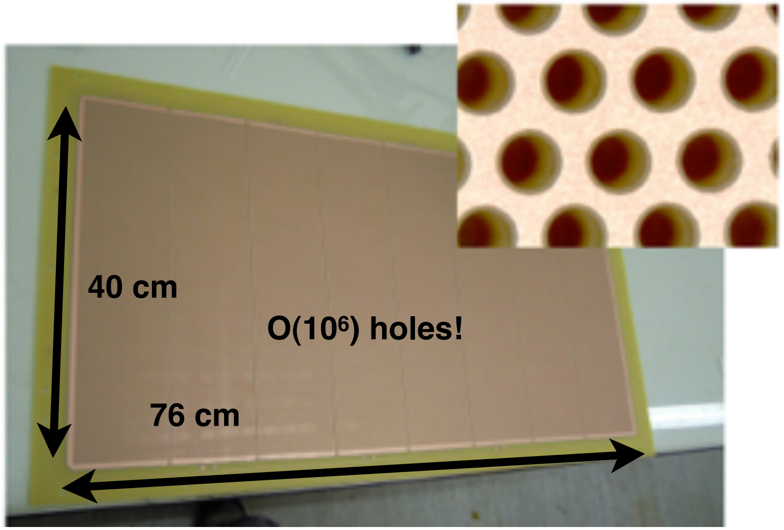
After the test of the liquefaction of argon in the LAr cooling bath (bath test):

- assess the light yield in cold
- measure the ^{39}Ar background and PSD rejection
- optimise the trigger rate and the reachable energy threshold (with S1 trigger)
- monitor the thermodynamic conditions of the cryogenic system
- evaluate the impact of the operation on the lab environment
- monitor the PMT stability
- assess the LAr purity
- test the LAr recirculation system

Large area charge readout - LAr TPC (R&D)





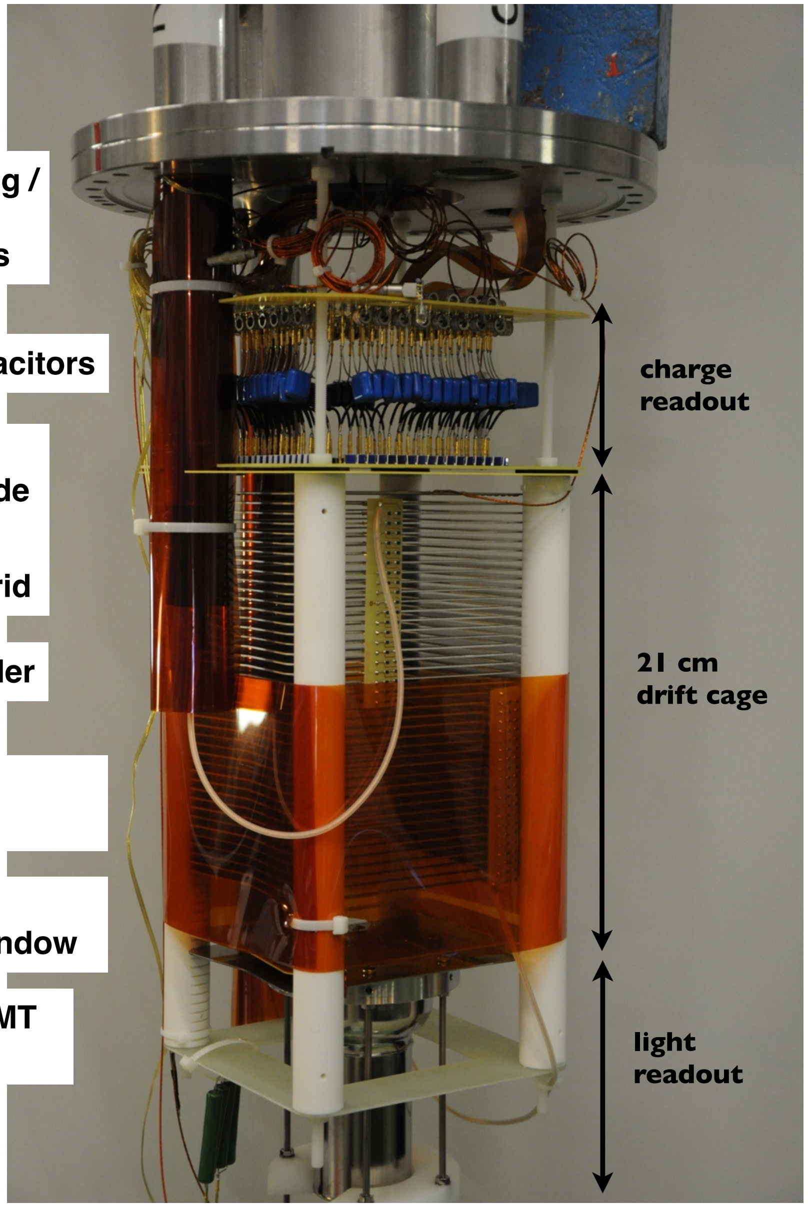


2008-2011: Proof of principle with 10x10 cm^2 double phase LAr LEM-TPC prototype:

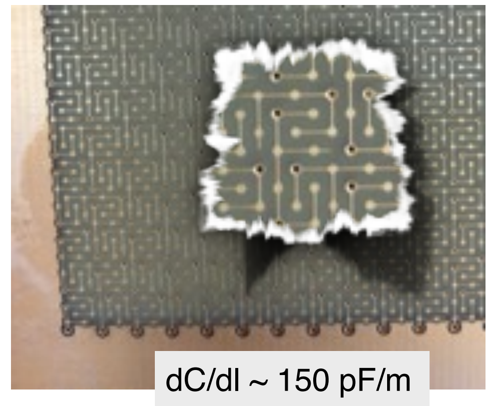
2011: First successful operation of a 40x80 cm^2 device

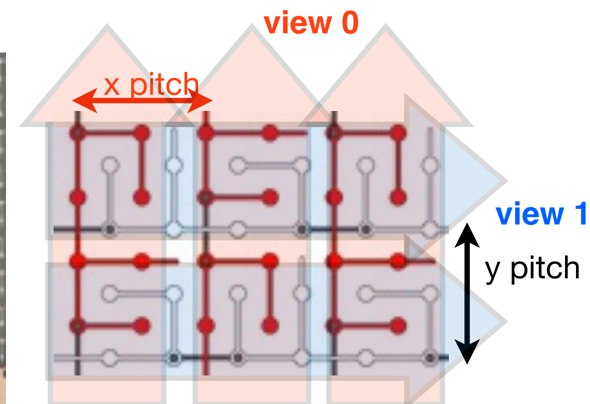
2012-2013: further R&D towards final, simplified charge readout for GLACIER:

10x10x20 cm^3 prototype for basic developments



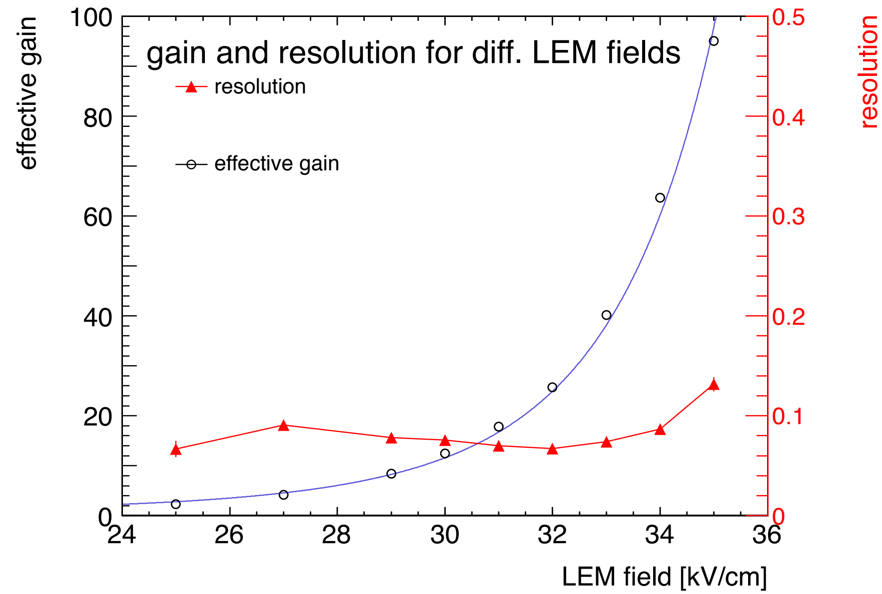
Anode developments





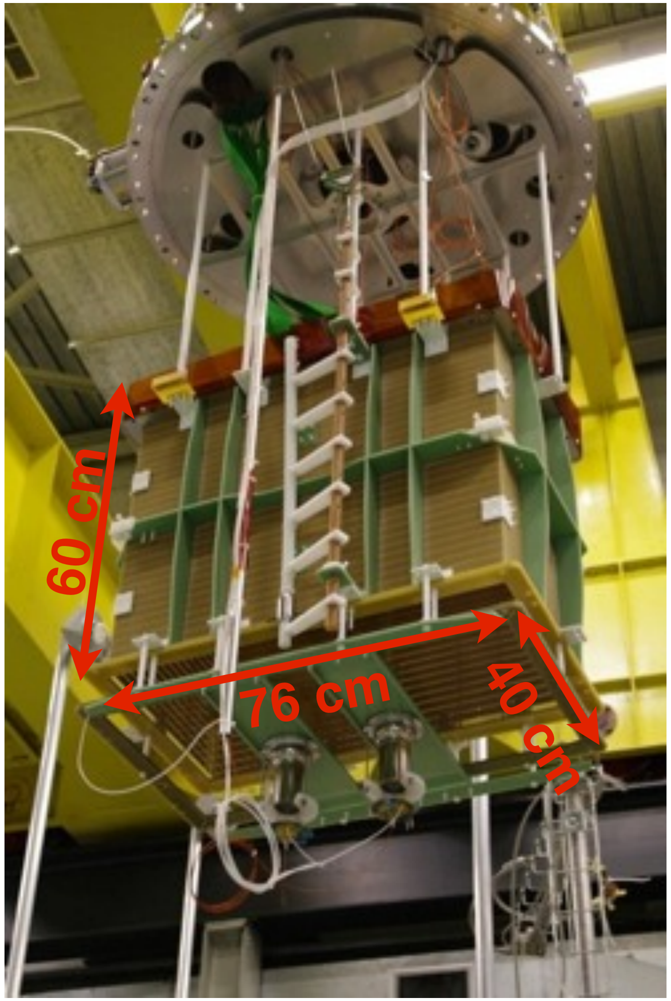
LEM E-field scan up to gain 90

onset of discharges @ gain > 90!

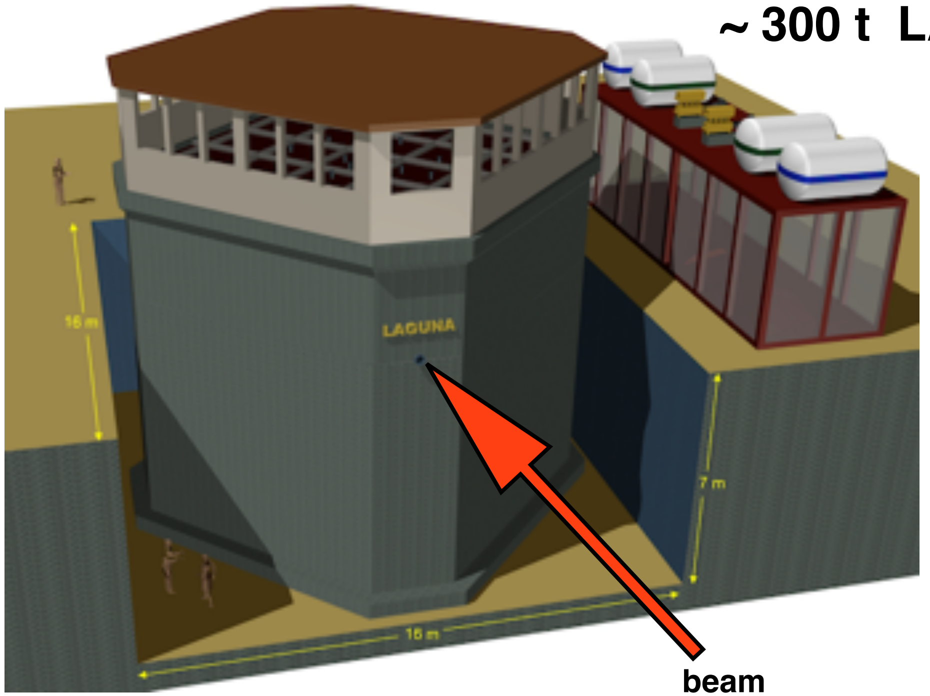


Upscaled prototypes

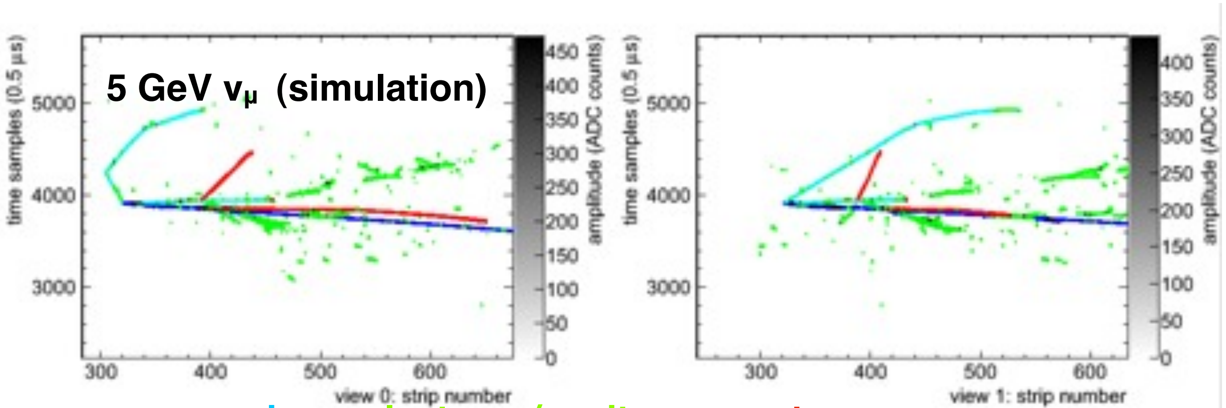
40x76 cm² prototype



6x6x6 m³ LBNO prototype WA105 @ CERN



Charged-particle test beam planned



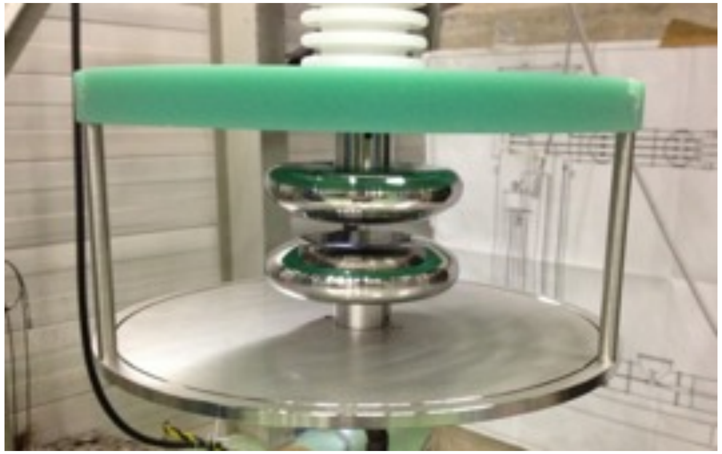
pions, electrons/positrons, protons, muons

Strong E-field properties of LAr (R&D project)

- Stability regions for the operation of LEM
- Long drift length

to get 0.5 or 1 kV/cm drift field =>
will test up to 600 kV at the cathode with the LBNO prototype

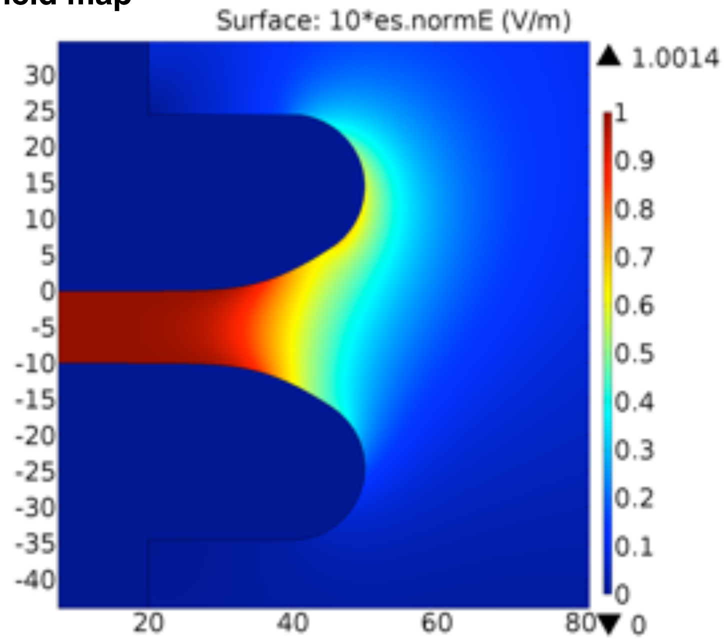
Polished electrodes shaped in Rogowski profiles (high field region confined between the two electrodes)



Significant R&D efforts ongoing for large HV systems for the drift field:

- Custom development of feedthroughs based on previous experience
- LAr dielectric rigidity versus distance between electrodes
- Bubble and LAr purity effects on discharges
- Argon ionisation and space charge effects
- Material effects

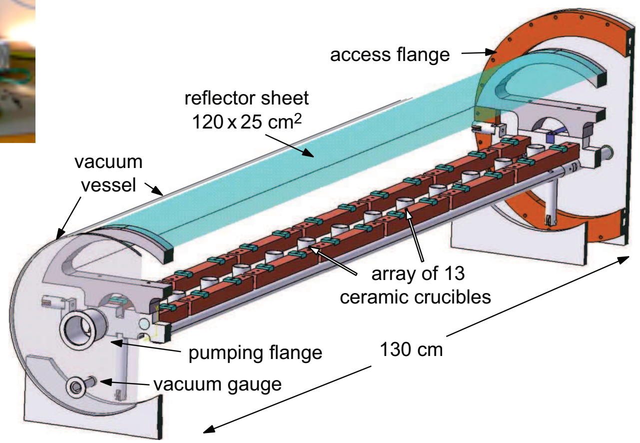
Field map

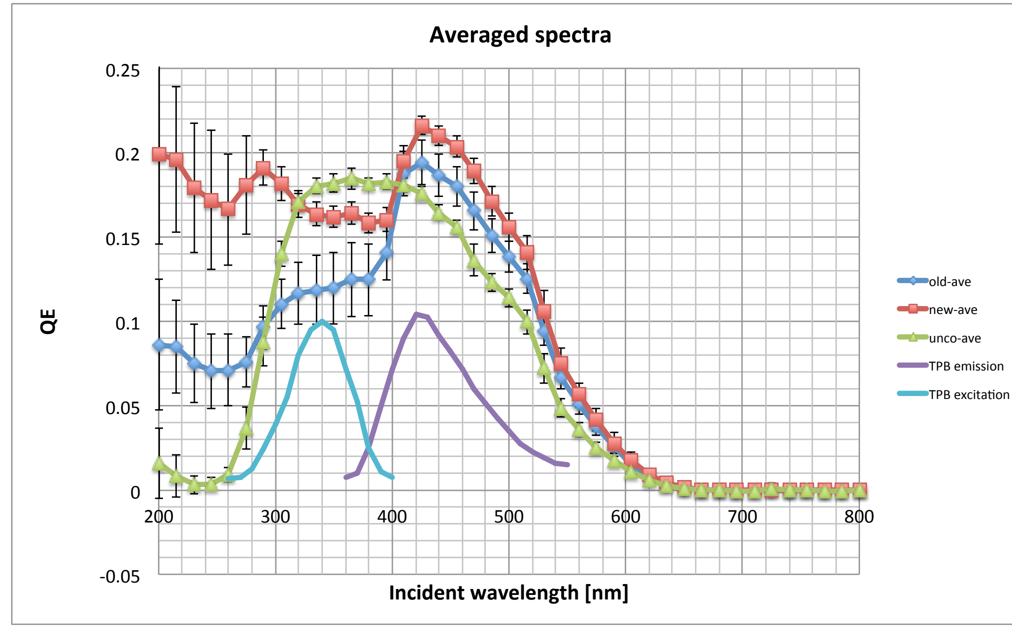


300 kV PS

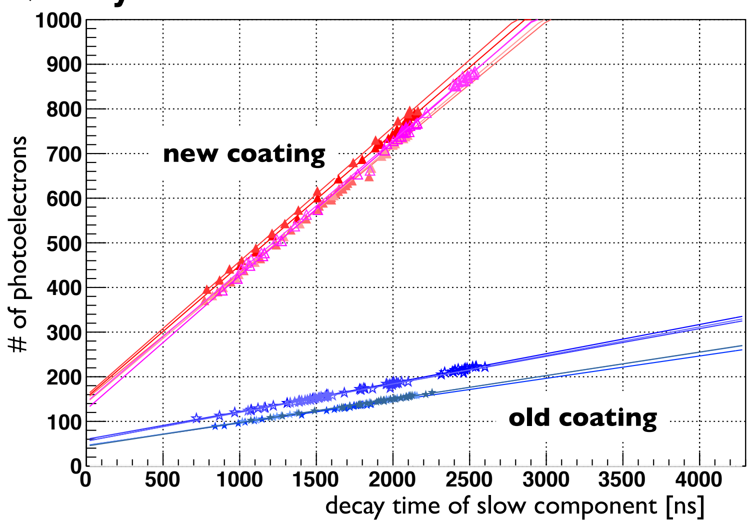
VUV cryogenic light detection (R&D)

- Coating technologies
- Substrate effects
- Test setups

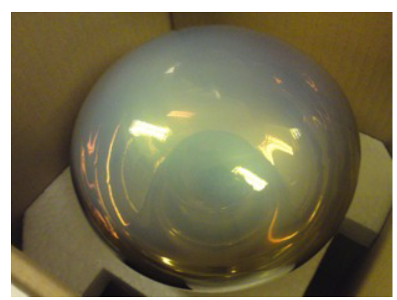




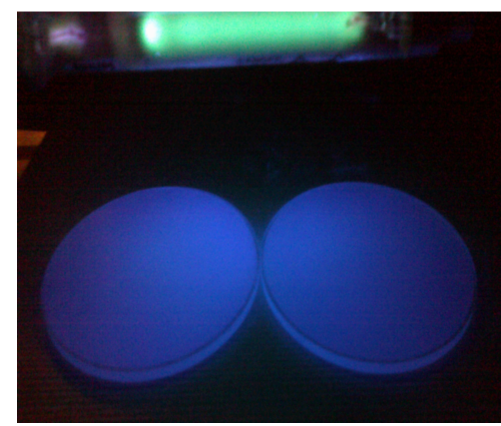
Quality control



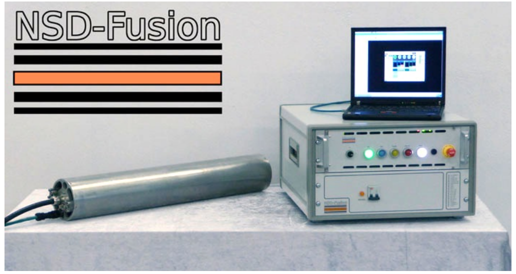
Freshly coated PMT



Optical inspection under UV



Nuclear recoil measurements in LAr @ CERN

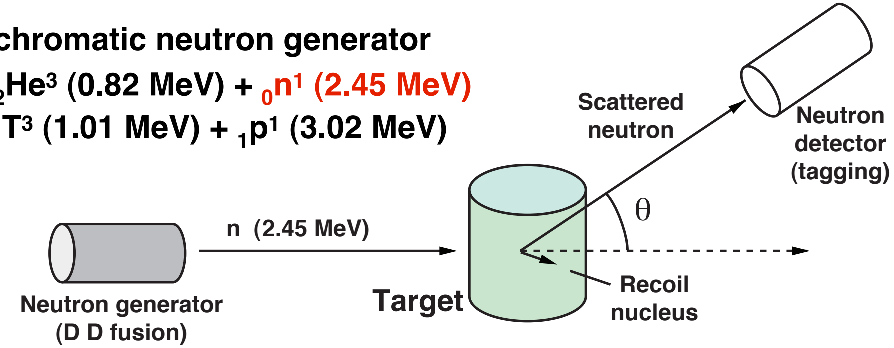


Monochromatic neutron generator

DD fusion -> $_1D^2 + {}_1D^2 \rightarrow {}_2He^3$ (0.82 MeV) + $_0n^1$ (2.45 MeV)

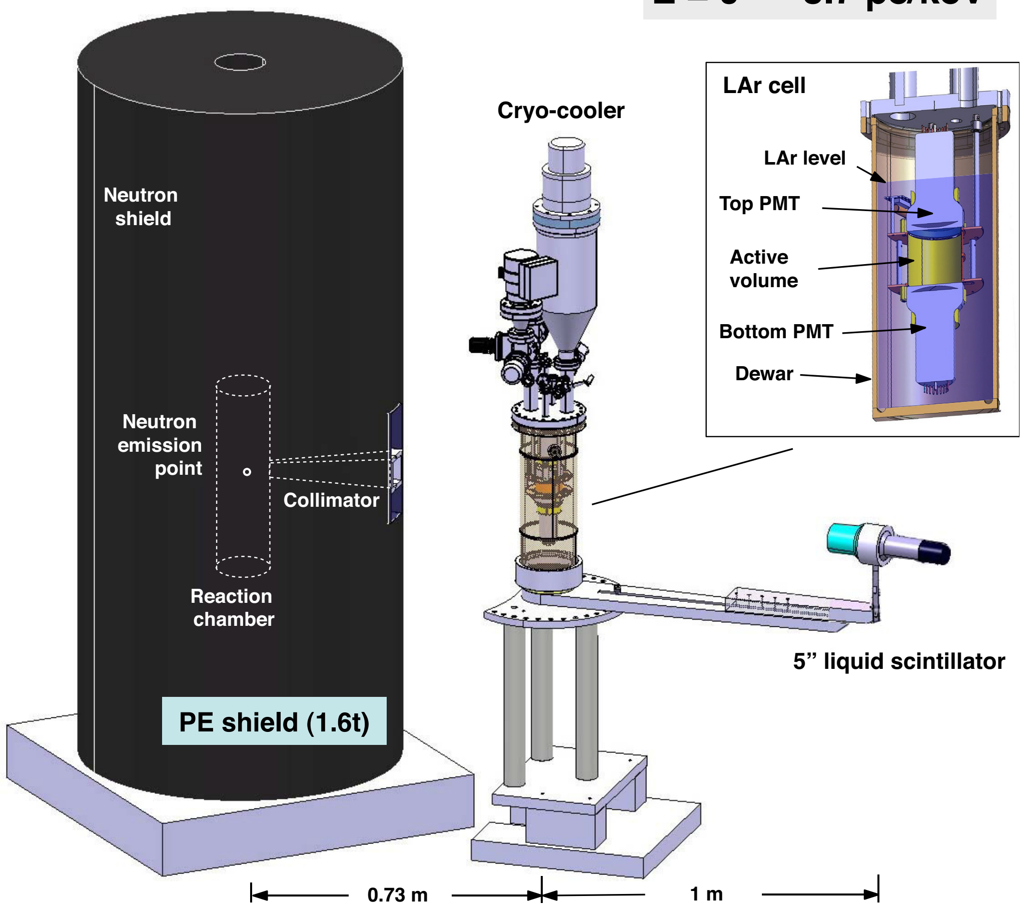
$_1D^2 + {}_1D^2 \rightarrow {}_1T^3$ (1.01 MeV) + $_1p^1$ (3.02 MeV)

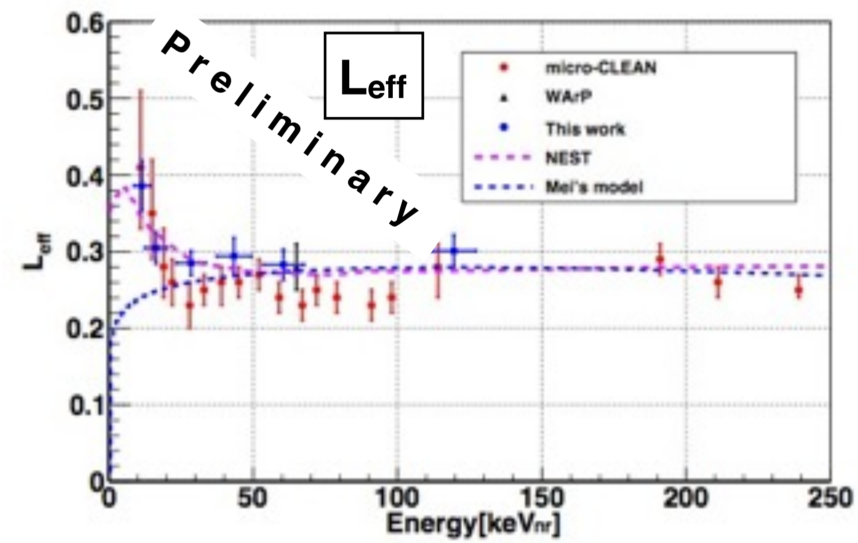
~ 10^6 n/s 4πsr
U_{max} = 120 kV,
I_{max} = 10 mA
Bremsstrahlung
shielded with 4mm Pb



Maximal energy transfer in LAr (central collision): 233 keVr

E = 0 ~3.7 pe/keV





- Desirable to measure towards lower energies (<10keV)
- Prepare a new cell with higher LY and E-field
- Availability of existing NG hardware unclear
- Other options? 10^9 n/s DD facility at TU Dresden

LAr summary

- ArDM clearly is one of the most pressing activities for us in the moment

- There is large progress and we should be close to underground operation with LAr

- In parallel R&D for large noble liquid TPC is pursued

- Main activities are

    - Charge readout with electron multipliers

    - HV properties of LAr

    - LAr scintillation light detection

    - Fundamental properties of LAr (NR yields)