The ArDM project at LSC

Installed at Laboratorio subterraneo de Canfranc (LSC), Spain

**ETHZ led collaboration with
CIEMAT, LSC, DS, CERN and others**

First ton scale LAr detector in double phase operation

Christian Regenfus - ETHZ

(On behalf of the ArDM collaboration)

Exploring the low energy frontier of the LAr technology at the ton scale

Content

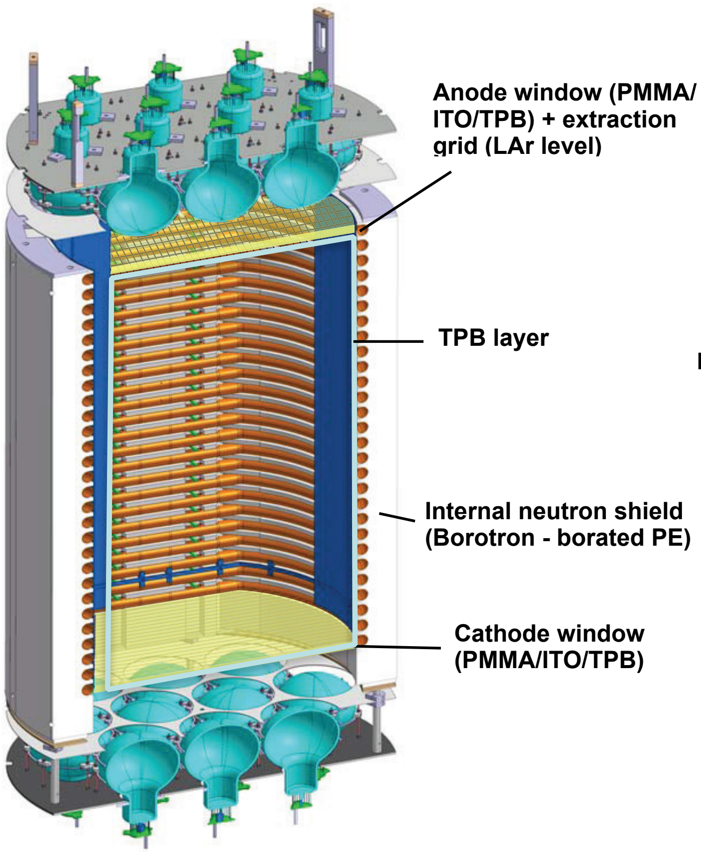
Major milestone achieved

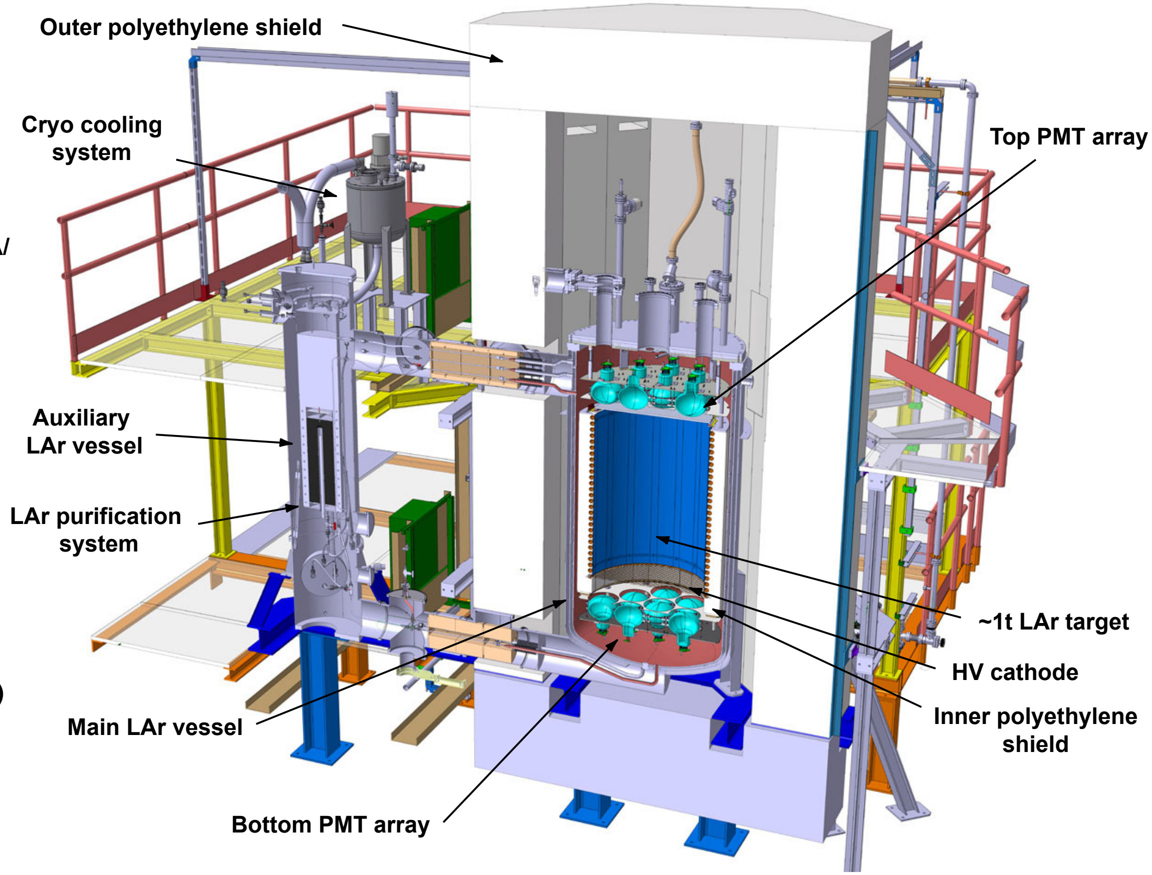
ArDM is running in dual phase mode

- Introduction
- Run I (single-phase) results
  - Low background goal confirmed
  - VUV yield <—> LAr purity
- Recent experimental upgrades
  - Towards dual-phase running
- Run II (dual-phase) started
  - Filling with cold boil off gas
  - LAr purity
  - First signals
- Ongoing activities
  - ArDM DART activities
- Conclusions

ArDM — a ton scale low background LAr facility at LSC

Now operating in dual-phase mode (2018)





Background recognition strategies:

- PSD and Ionization / scintillation ratio
- Localization: (fiducial volume, 3D imaging)
- Topology: (e.g. mult. elastic scatters from n)

- LAr mass: ~2t total, 850kg active, ~500kg fiducial
- Double phase, vertical TPC (0.1 – 1 kV/cm drift field)
- Cryogenic low radioactive 8" PMTs 12 + 12 (liquid and gas)
- Projected LY ~2pe / keV (@ LAr operation)
- Passive external neutron shield (~20t)
- Trigger rate / DAQ capability ~ kHz

A.Rubbia J.Phys.Conf.Ser 39:129-132,2006

Commissioning of ArDM, JCAP03 (2017) 003

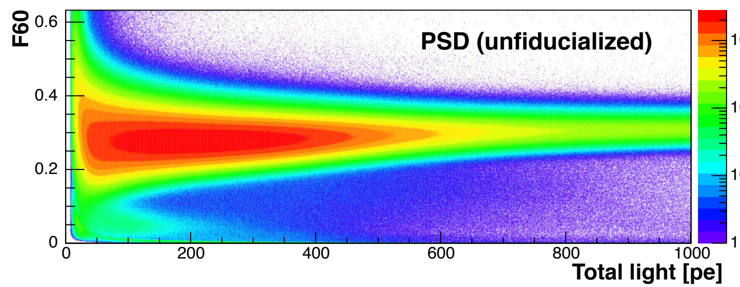
General status of ArDM

- **Experiment characterized from Run I data**
  - **Low background goal confirmed**
  - **VUV yield <—> LAr cleanliness**
  - **ER BG validation -> NR BG extrapolated**
  - **PSD verified**

Recent papers

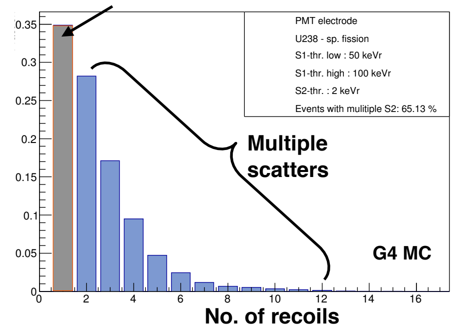
- **Commissioning of ArDM at LSC ….** JCAP, 03, 003 (2017)
- **Measurement of the attenuation length of argon scintillation light in the ArDM LAr TPC —** Astroparticle Physics 97,186 (2018)
- **Backgrounds and PSD in the ArDM liquid argon TPC** arXiv:1712.01932v1

- **Experimental upgrades driven by results**
  - **Internal (HV, field cage, liquid extraction)**
  - **Internal (filling circuit, gaseous recirculation)**



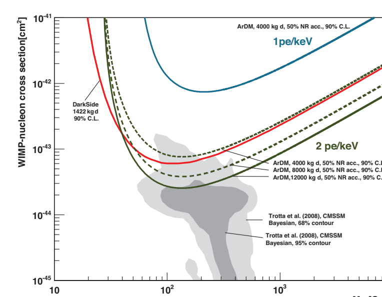
- **Run II in dual phase operation started recently**
  - **First operation of tonne scale LAr DM TPC**
  - **Verification of sensitivity and neutron IA**

Single scatter neutrons (indistinguishable BG)



ArDM is now integrated in the DS programme and the Global Argon Dark Matter Collaboration (GADMC)

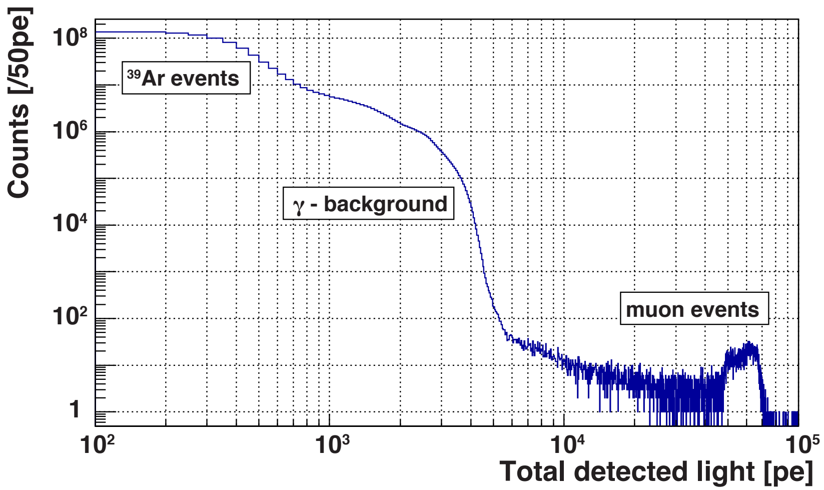
- **Facilities at LSC and CERN can be of great use for DS program**
- **Combining efforts towards future G2 and G3 facilities**
- **Future program of developments for DS20k strongly supported by LSC**
- **DepAr tests (DART/ArDM@LSC) planned for 2018 and beyond**



1 neutron event per ~20d expected

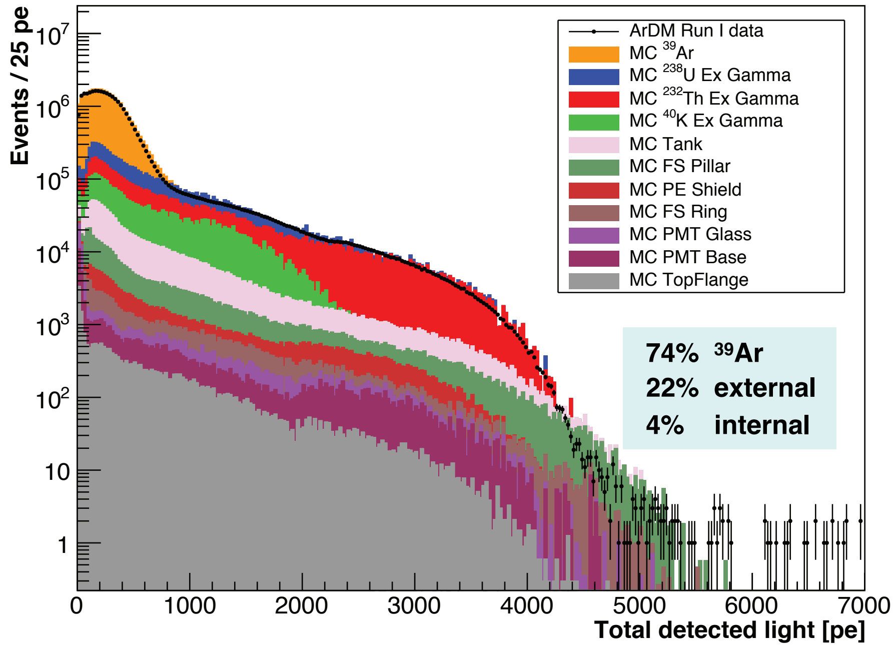
Results from RunI in single phase mode - Electron recoil BG

Experiment understood over many orders of magnitude



Cosmic muon rate at LSC ~3x10^{-3} (m^2 s)$^{-1}$

Commissioning of ArDM at LSC …. JCAP, 03, 003 (2017)



- Data well described by normalized MC spectra based on the material screening results + external BG
- => 1 neutron event per ~20d expected

Overall uncertainty 7%

Extracted ^{39}Ar specific activity 0.95 ± 0.05 Bq/kg

- => set BG free exposure frame

validates our low BG goals

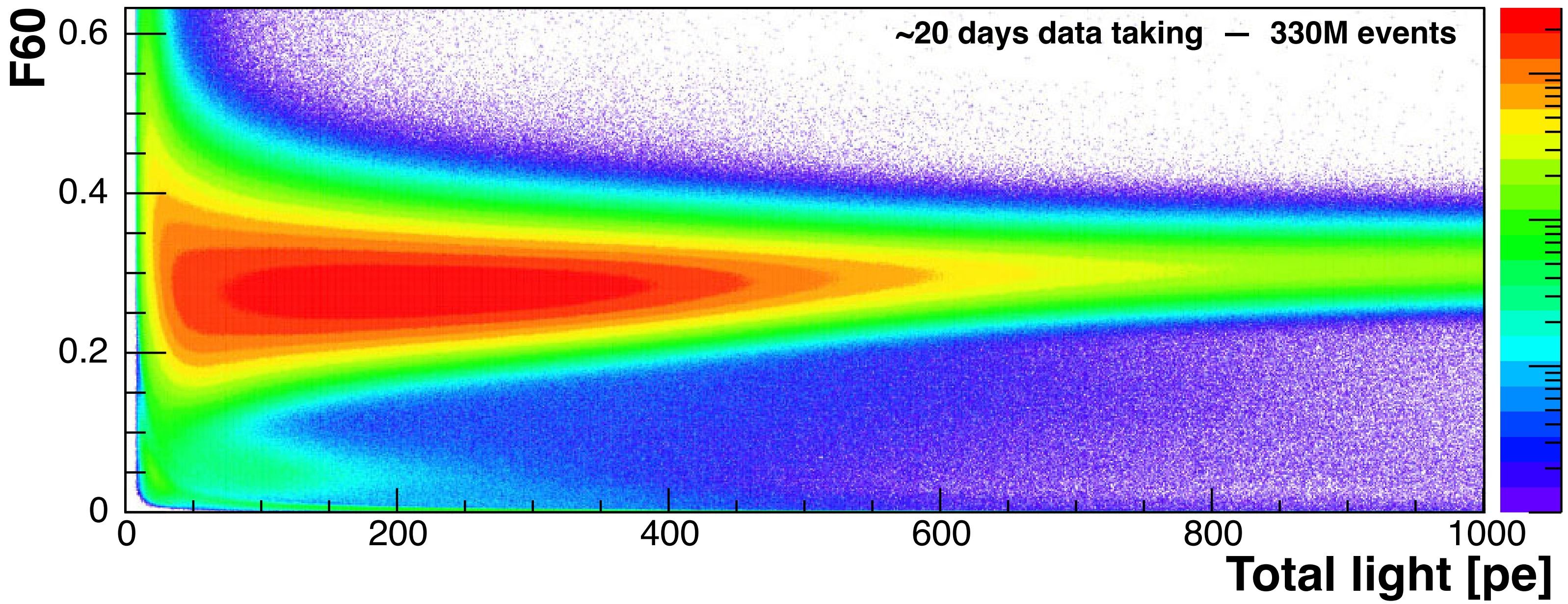
- Goal: Determine single scatter rate from n BG

Backgrounds and PSD in the ArDM liquid argon TPC arXiv:1712.01932v1

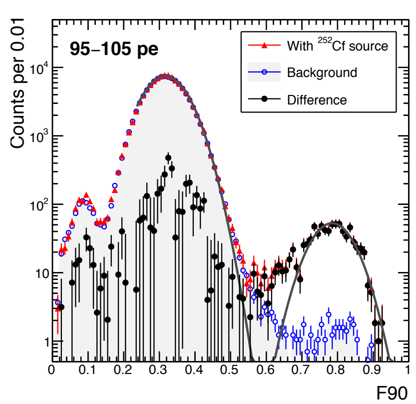
PSD with a ton scale LAr target

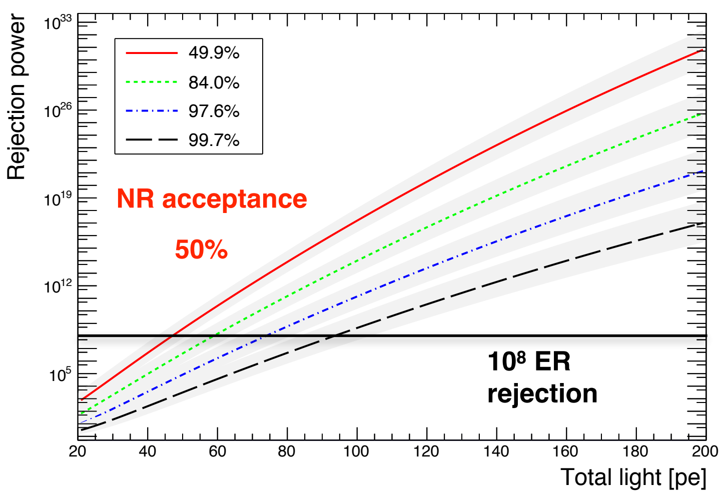
Run I data

Looking into one of the main features of LAr



Gaussian fit of neutron calibration data (slices)





Basic cuts only

Noise events removed

No fiducialization

Conform with gaussian PDF

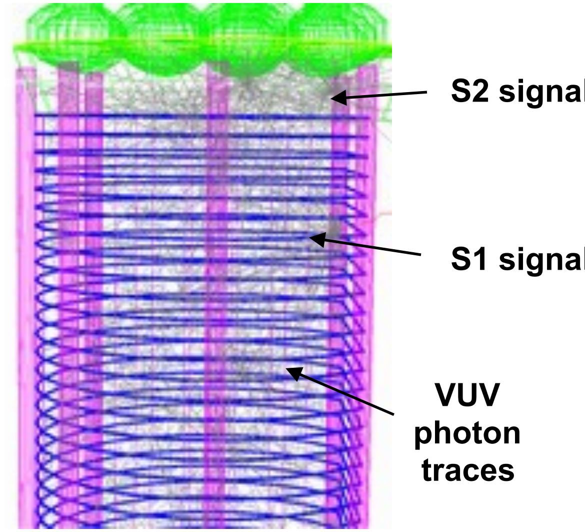
First demonstration of high background rejection by PSD at a ton-scale

Backgrounds and PSD in the ArDM liquid argon TPC arXiv:1712.01932v1

Understanding the LY in RunI

Scanning attenuation length λ_{VUV} and reflectivity $\mathcal{R}$

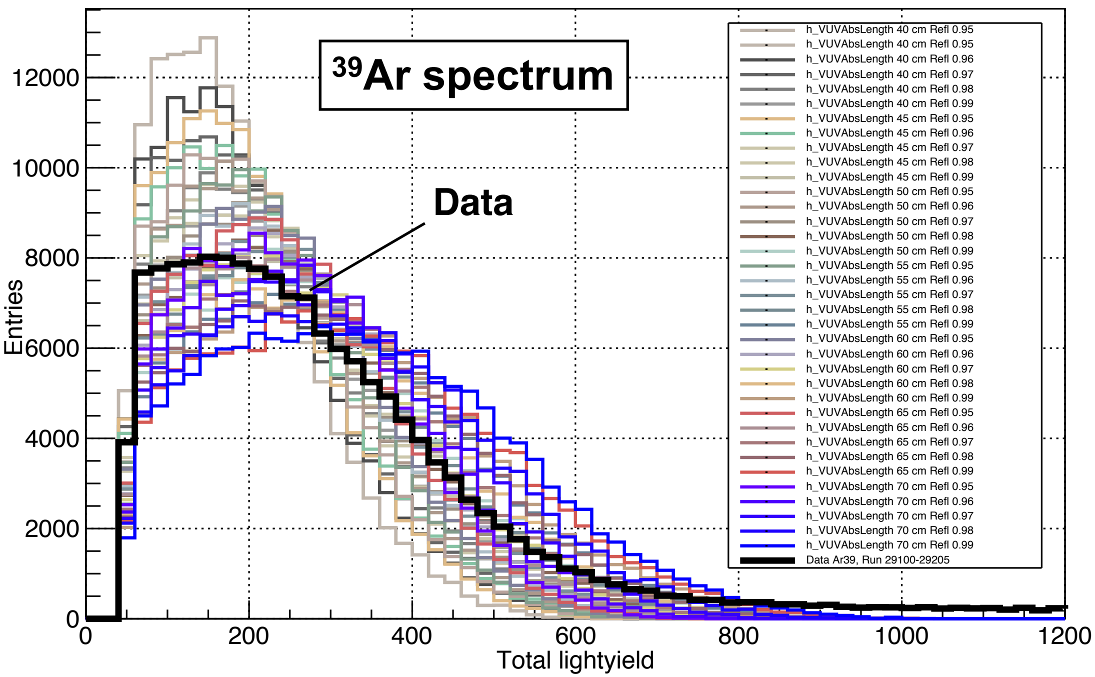
MC based on full light ray tracing



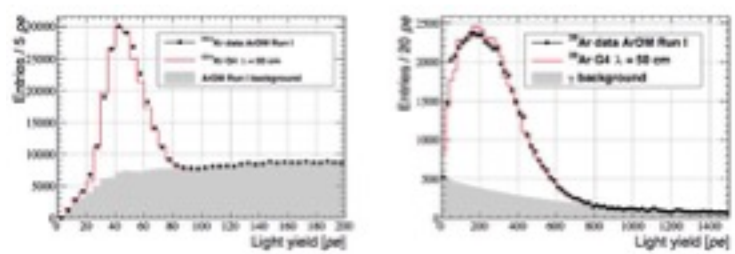
Optical parameters of the detector a priori not known

- **Most important parameters (λ and $\mathcal{R}$) are scanned**
- **Result understood in terms of VUV absorption of impurities**

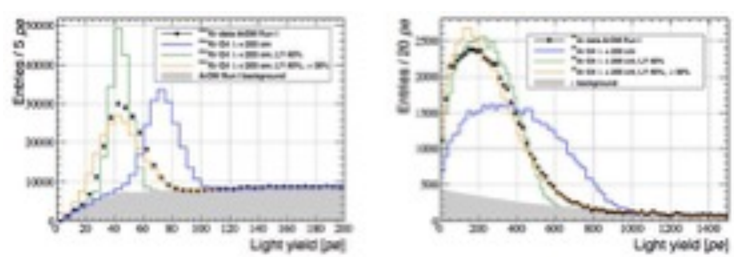
Example: ^{39}Ar spectrum, ^{83}Kr used for cross checks



Best fit λ = 50cm



To scrutinize the result λ = 200cm

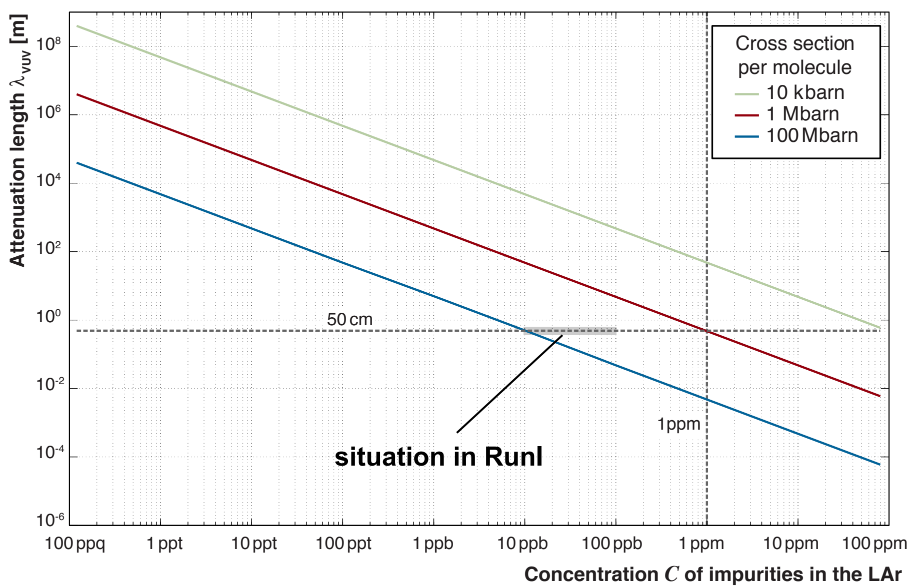


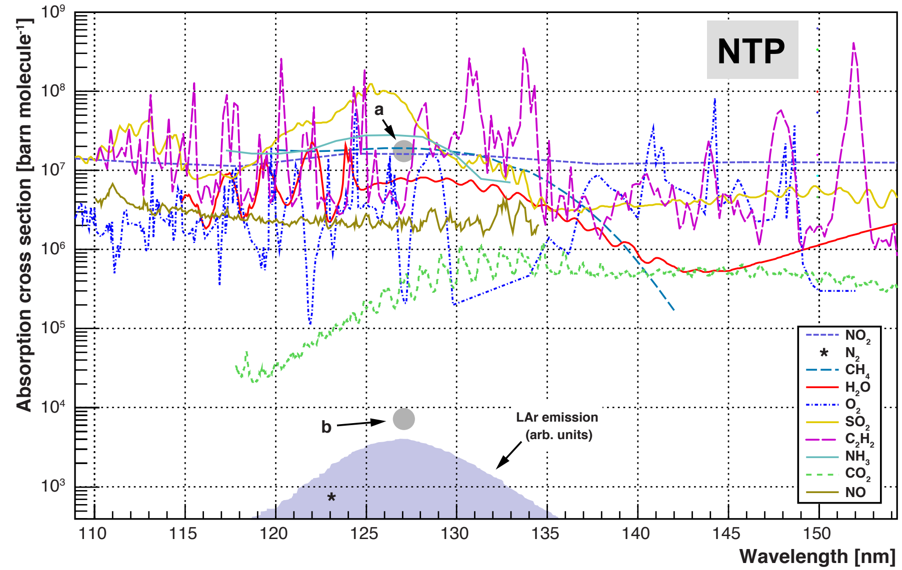
Data suggests an attenuation length of the VUV light of ~50 cm

Molecular VUV absorption cross sections

$$\lambda_{VUV} = \frac{1}{\sigma \cdot C \cdot n} \simeq \frac{476\,\mathrm{m}}{\sigma\,[\mathrm{Mbarn}] \cdot C\,[\mathrm{ppb}]}$$

Optical parameters at NTP can be transferred to the LAr environment (spectral blue shifts and line broadening)





Overlap integral with the LAr emission $\langle \sigma_{eff} \rangle = \int \sigma(\lambda + 7\,\mathrm{nm})\,\Phi(\lambda)\,d\lambda.$ **<- small energy shift due to the band structure of LAr (supported also by absorption spectra of Xe in Ar)**

	Molecule	$\langle \sigma_{eff} \rangle$ [Mbarn]	blue shifted	red shifted	C_{req} [ppb]
	NO_2	14	12	16	67
a	CH_4	9.8	1.8	18	97
	H_2O	4.4	1.1	7.8	220
	O_2	5.5	13	6.7	170
	SO_2	9.6	3.8	52	99
	C_2H_2	42	7.8	32	23
	NH_3	10	7.3	12	94
	CO_2	0.62	0.53	0.34	1.5k
	NO	2.5	2.4	2.2	380
b	N_2	0.007			135k
	Xe	35			27

- **Large target eases absorption studies**
- **More precise in dual phase mode**
- **Data explained by σ = 10-100 Mbarn and C = 10-100ppb**
- **100ppb CH_4 could explain the result**

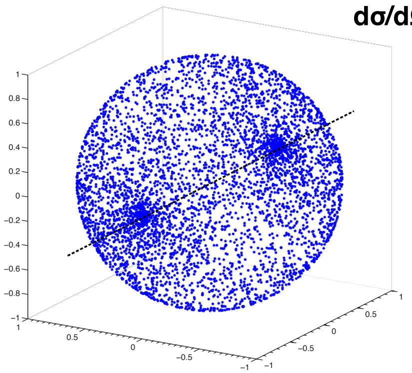
a) Methane in LAr, JINST 8 (2013) P12015 b) Nitrogen in LAr, JINST 8 (2013) P07011

Measurement of the attenuation length of argon scintillation light in the ArDM LAr TPC — Astroparticle Physics 97,186 (2018)

Minimal path lengths of VUV photons in a large LAr detector

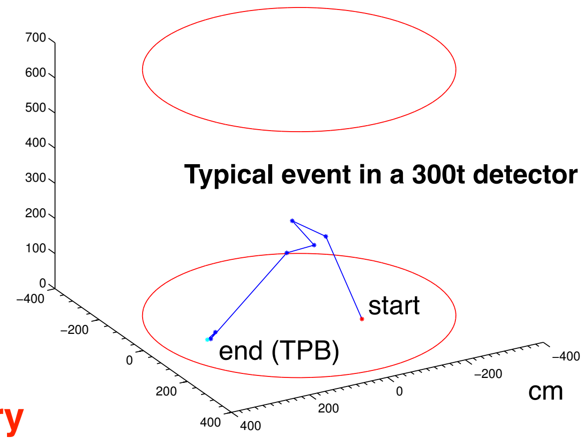
Rayleigh elastic scattering toy MC

Boosted in FW and BW directions
$d\sigma/d\Omega = 1+\cos(\theta)^2$

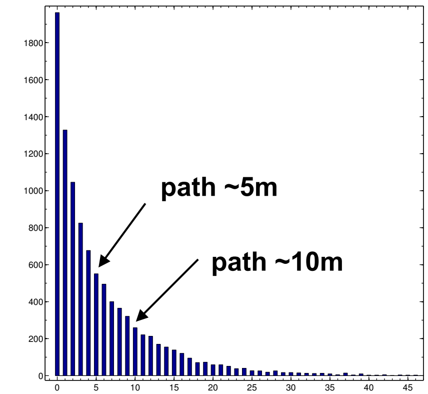


Preliminary

Setting the scale for purification needs

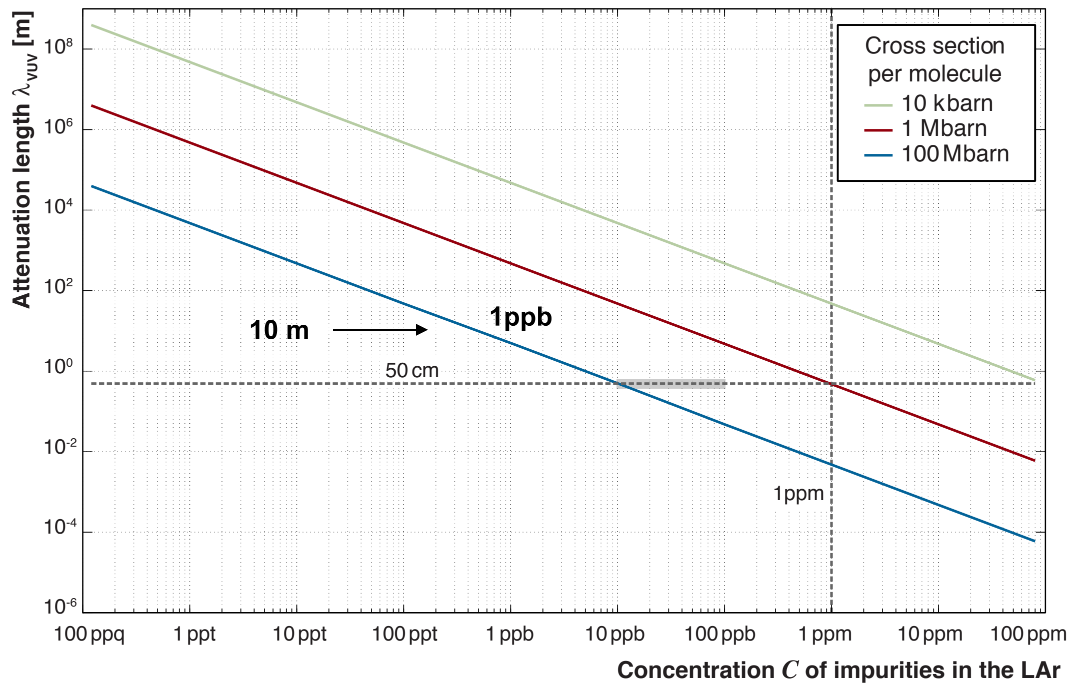


Number of scatterings



- **Value not well known (60 … 100cm)**
- **Simulation uses λ_{RAYVUV} = 100cm**
- **Cylindrical geometry (H ~ D)**

- **Mean path length for a 30t detector (3m):**
  - **180cm , ~2 scatter**
  - **-> 210cm for λ_{RAYVUV} = 60cm**
- **Mean path length for a 300t detector (7m):**
  - **570cm , ~6 scatter**
  - **-> 750cm for λ_{RAYVUV} = 60cm**



Better experimental confirmation of λ_{RAYVUV} desirable

Recent experimental upgrades

PMT arrays (remains same)

Assembled detector

Assembly

Assembly in low Rn environment
(Rn abatement system @ LSC)

Field cage

Final insertion

HV system components

HV feedthrough

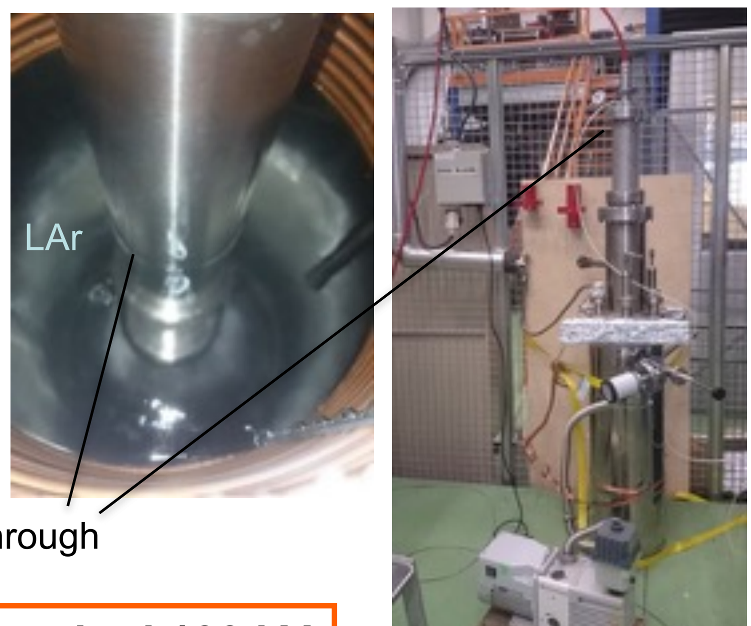
100-kV power supply

System capable of up to 100 kV is installed

- **Tested at CERN in LAr up to 100 kV**
- **Control software integrated into the ArDM SC**

- Nominal drift field in ArDM: 200 V/cm
→ ~22 kV at the cathode

Tests at CERN



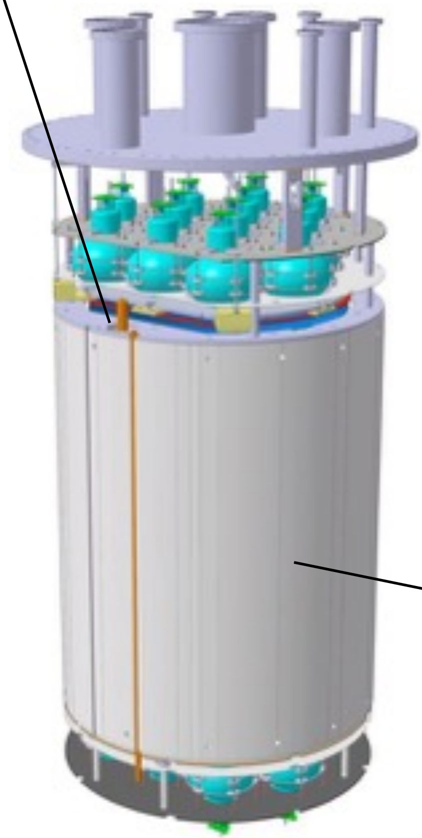
Feedthrough

Reached 100 kV

Installed HV FT

New detector layout

HV feedthrough
(crucial, designed for 100 kV)



4π VUV conversion
Neutron shield
Design contains no dead volumes

Top PMT array

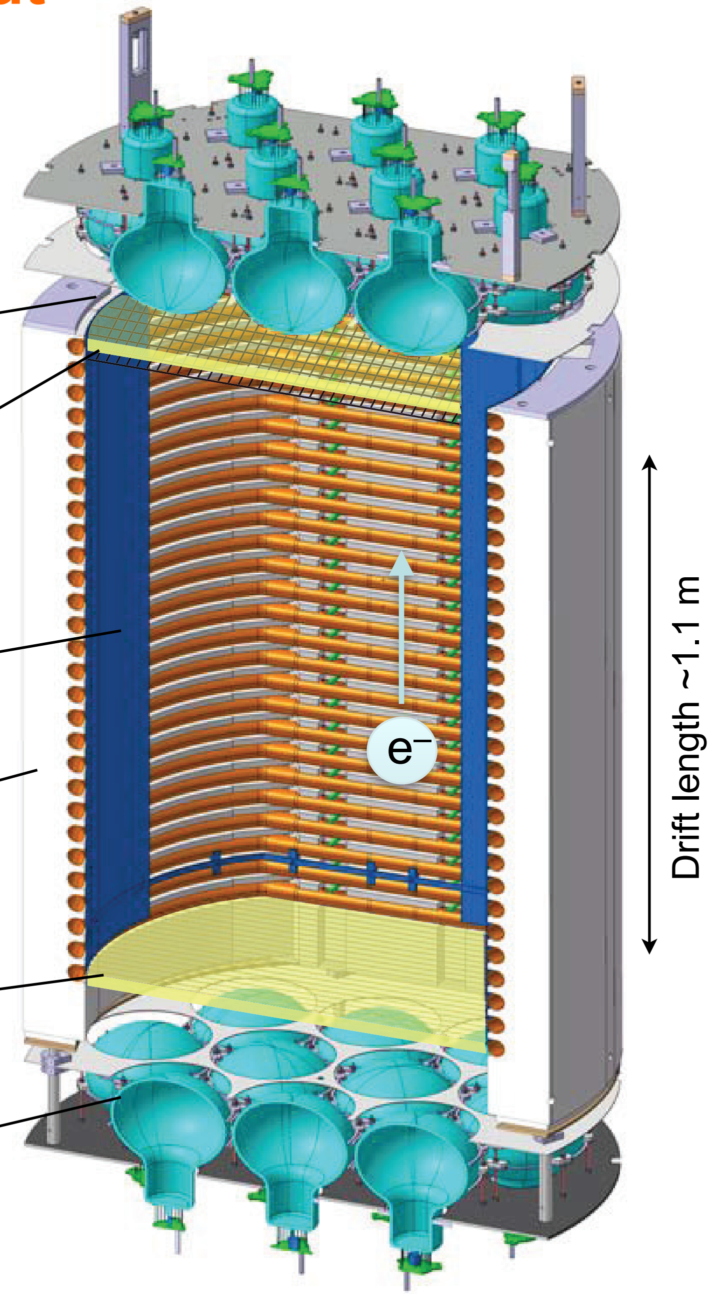
Anode window
PMMA/ITO/TPB
Extraction grid
LAr level

Drift cage lined with TPB coated 3M foil reflectors

Internal neutron shield
(Borotron, borated PE)

Cathode window
(PMMA/ITO/TPB)

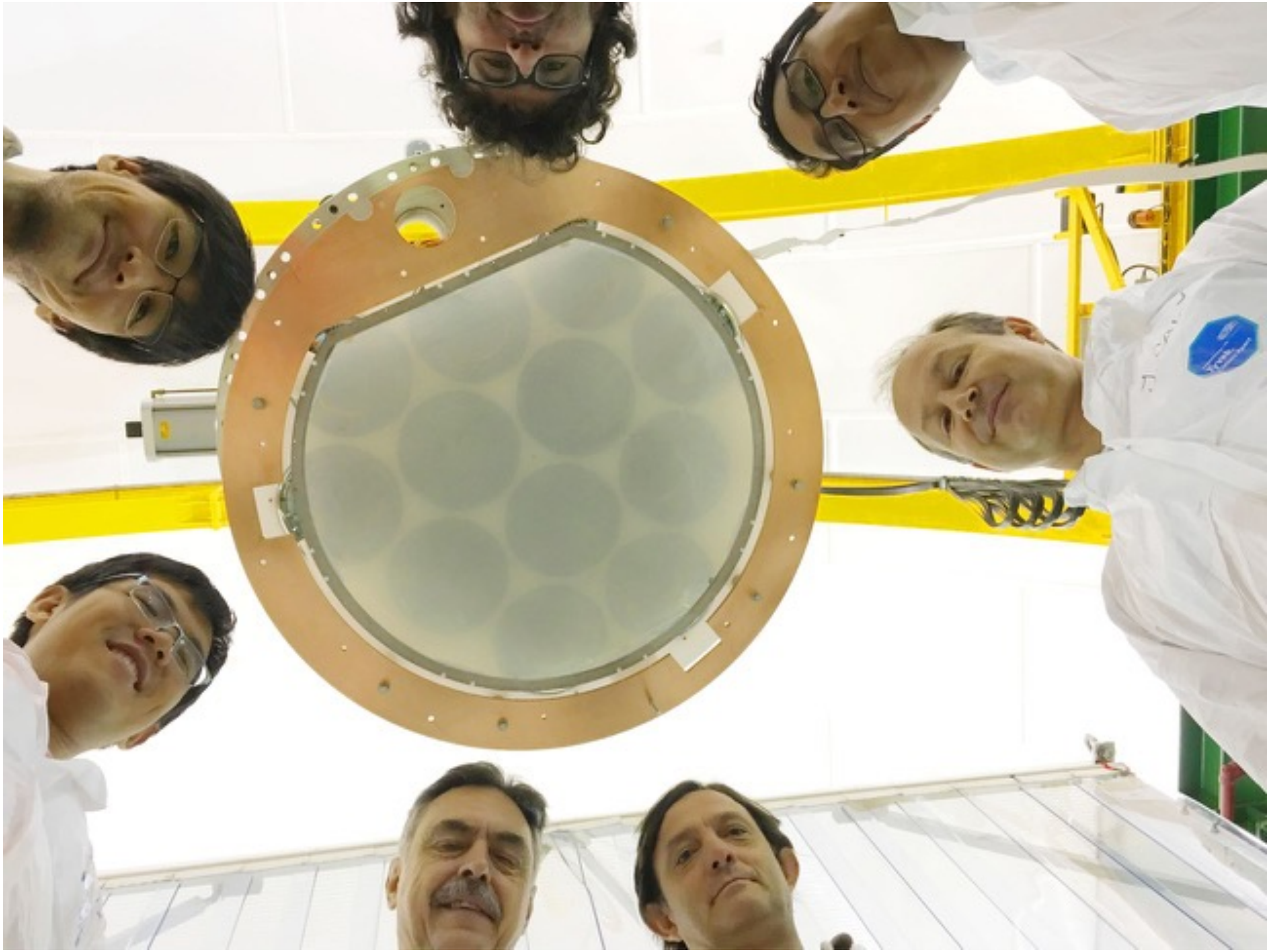
Bottom PMT array



Drift E-field ~200 V/cm

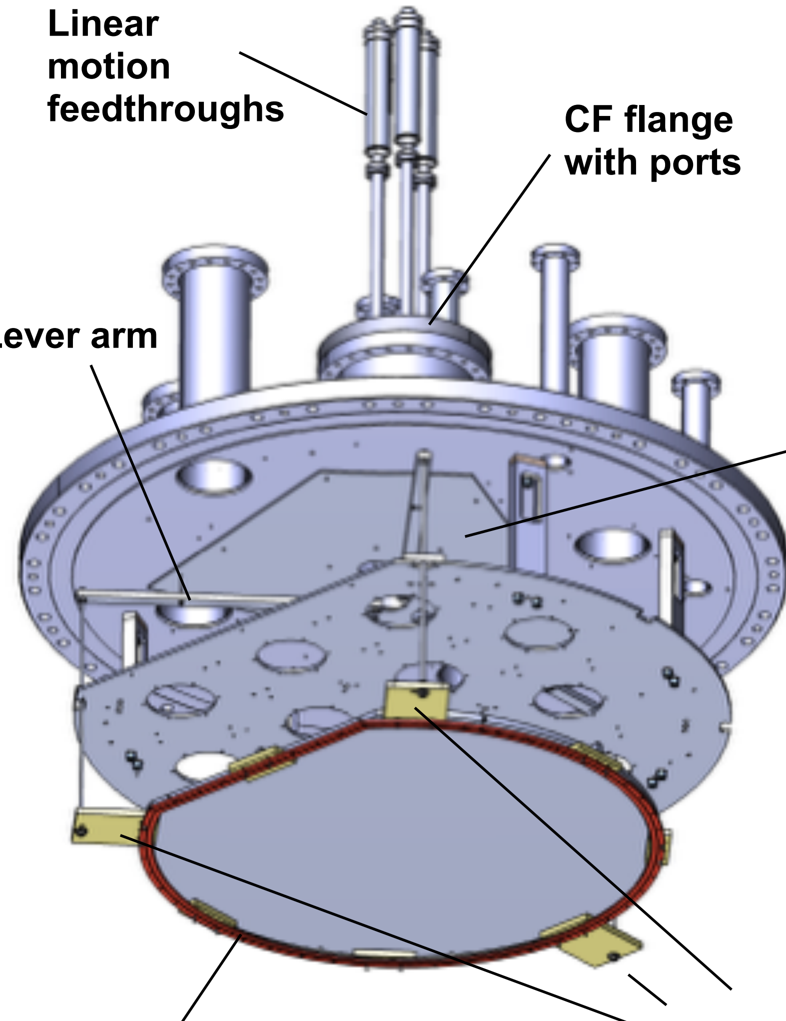
Cathode voltage <30 kV

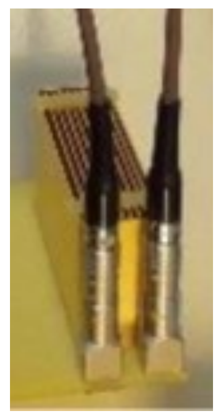
New ITO/TPB coated PMMA windows



Extraction grid-anode window assembly

Precision movable hanging system





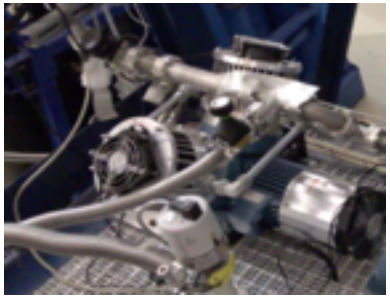
- Hanging at three points — independently movable by linear motion feedthroughs
- Position and horizontality of the extraction grid-anode assembly adjusted with respect to the LAr surface

Gaseous argon recirculation system

useful for both: gaseous or liquid phase

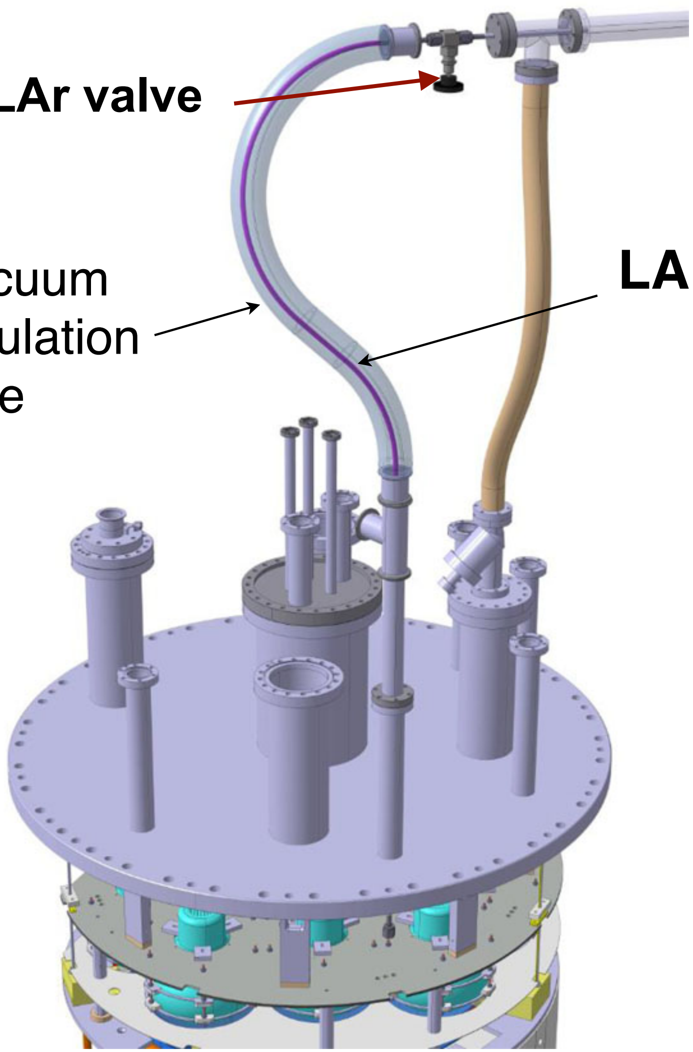
Accessible even while detector is cold

Double diaphragm gaseous Ar pump



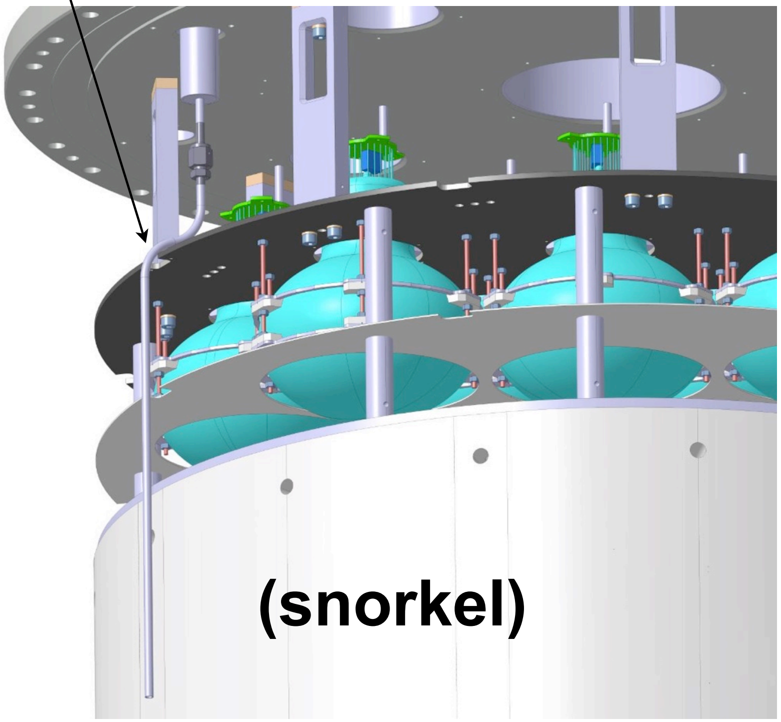
GAr/LAr valve

Gaseous argon recirculation circuit



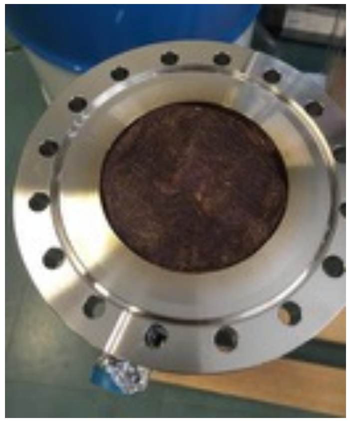
Vacuum insulation pipe

LAr extraction tube



Preparation of high flow purification cartridges

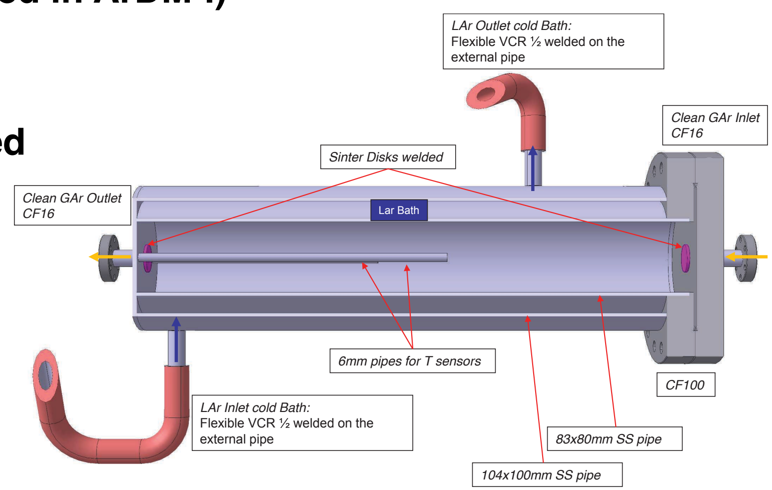
Preparation and filling of cartridge
Activated copper oxide filter preparations



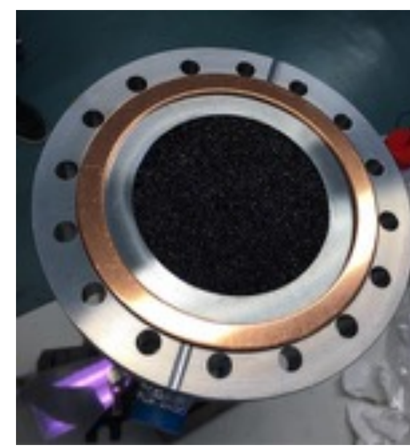
Activation setup

~ 12g H_2O produced

- **Low Rn emanation (measured in ArDM !)**
- **Impedance greatly reduced**
- **High purity copper employed**

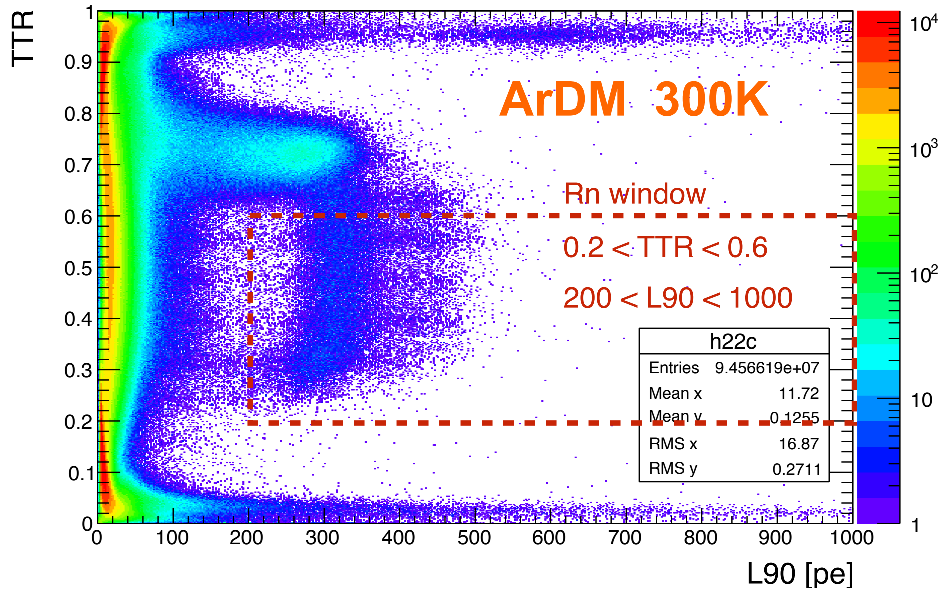


Charcoal cartridge
(ultra pure activated carbon)



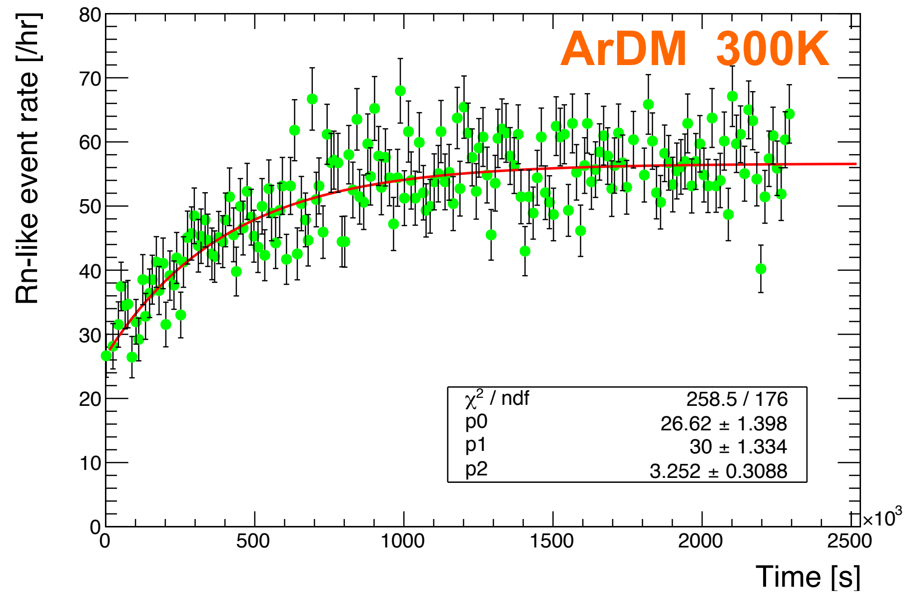
- **Internal T sensors**
- **Low impedance**
- **Active and passive cooling possible**

Rn emanation measurement

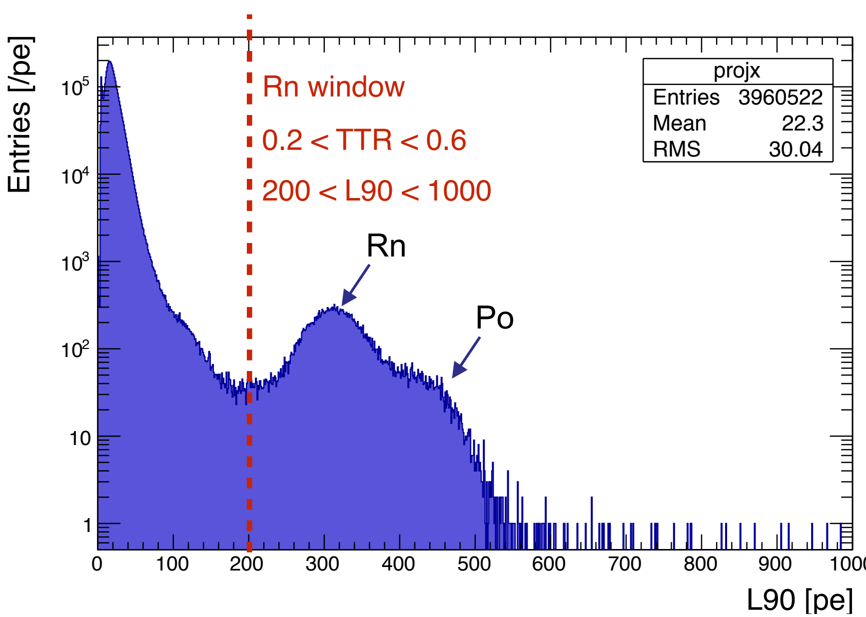


Warm gas data, **several months**

No purification – fast component light only



Rn-222 half life = 3.8 days, Fit : 3.2 ± 0.3 days



Upper limit of Rn (+ Po) event rate : ~0.06 mBq/L

Low emission rate of CuO_2 cartridge verified

Operation in dual-phase started - ArDM RunII (Jan 2018)

- **Experiment filled with LAr (Nov-Dec 2017)**
- **Internal purifying of LAr started ($\tau_{e^-} \sim 0.3ms$)**
- **Extraction system aligned**

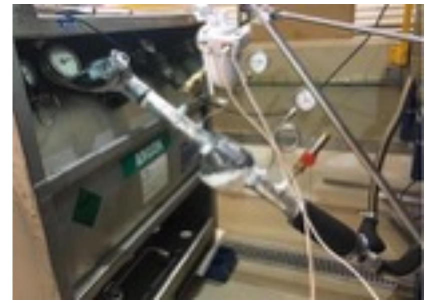
- **Experiment is running smoothly in 2-phase mode**
- **HV (30kV) operating flawlessly**
  - **E_{drift} 180V/cm, E_{extr} 2.8kV/cm, E_{S2} 4.2kV/cm**
  - **Increased E_{extr} 3.2kV/cm, E_{S2} 4.9kV/cm**

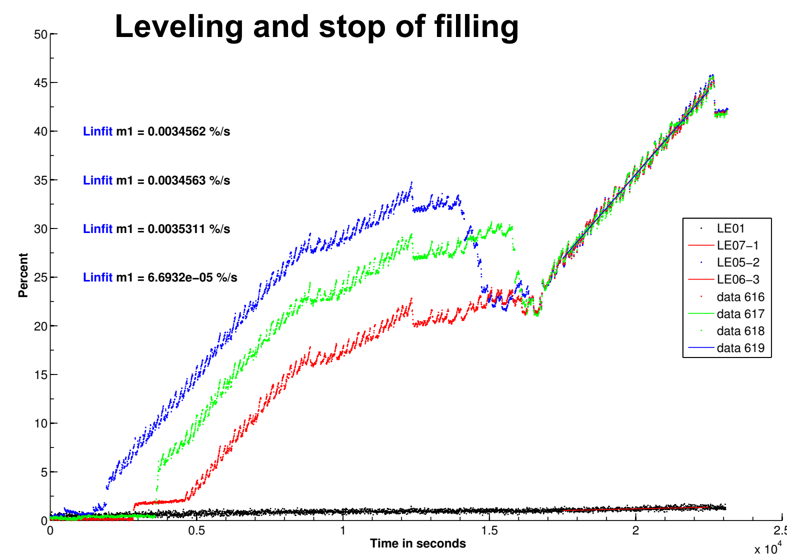
- **Trigger rate ~2.5kHz — challenging for DAQ**

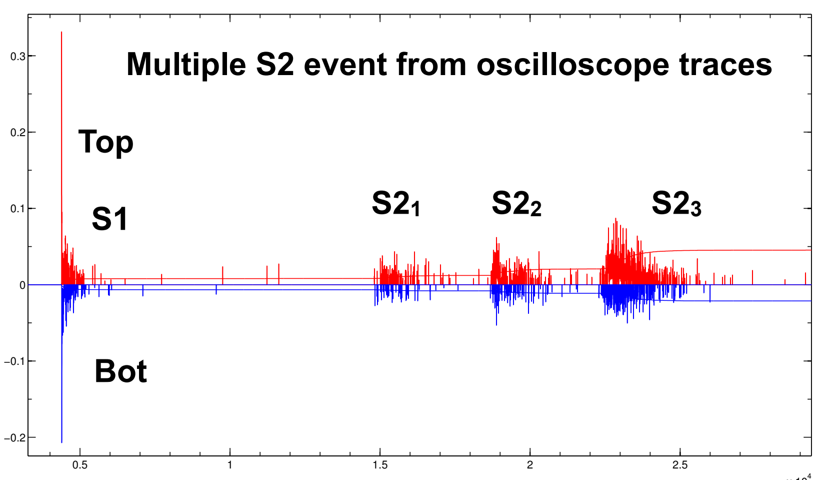
- **Data rate ~200 MByte/s**

- **No zero suppression — 4μs traces**

Filling with cold boil-off argon and filters

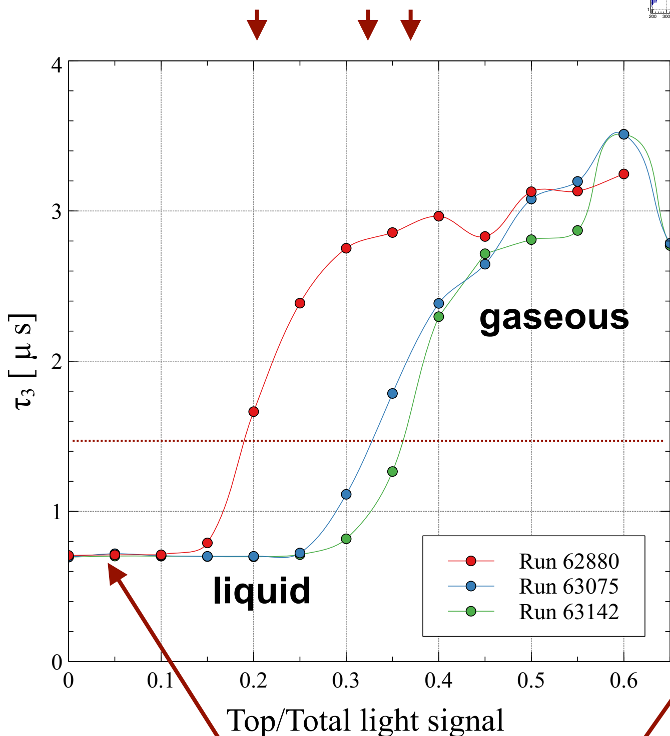


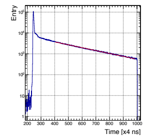




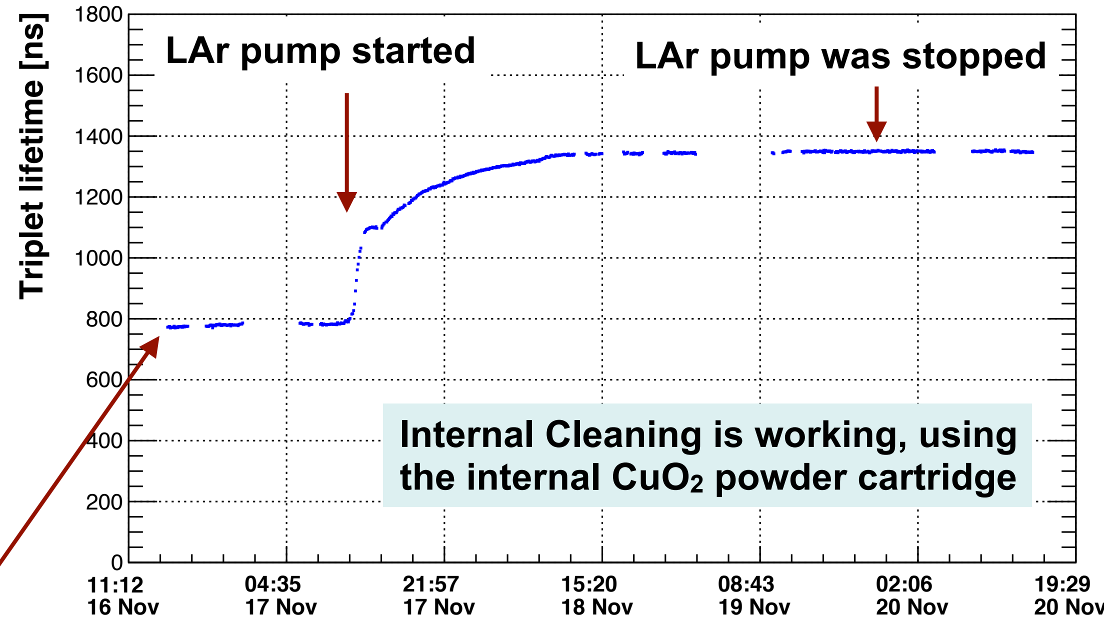
LAr purity — first assessment of the delivered quality (LINDE, Spain)

Different fill levels

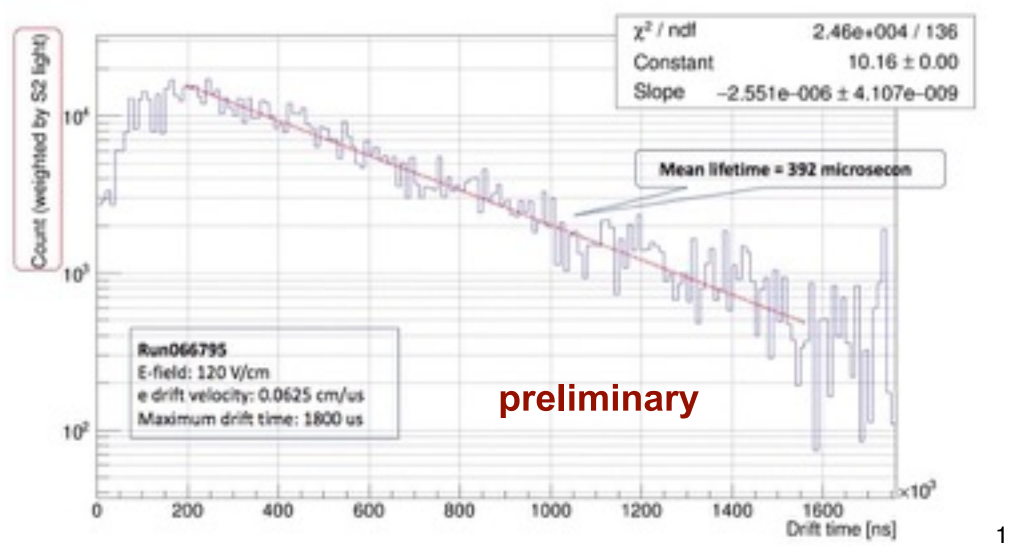




τ_2 analysis from exponential fit



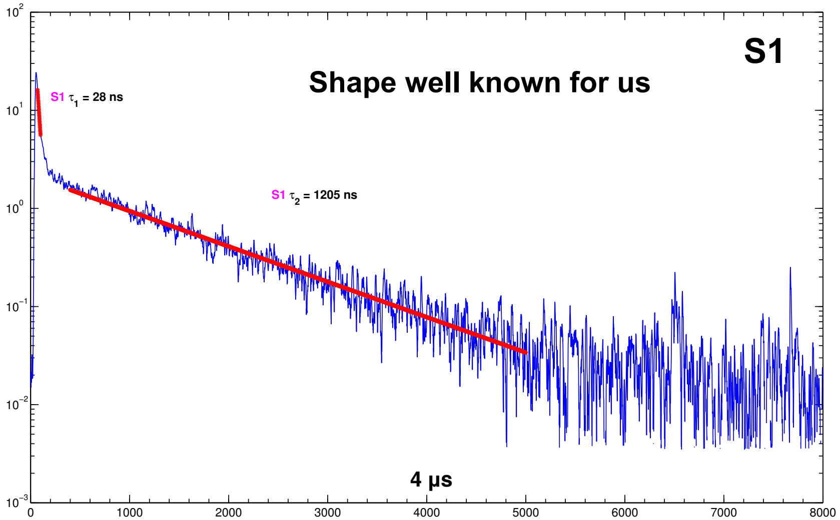
Delivered argon

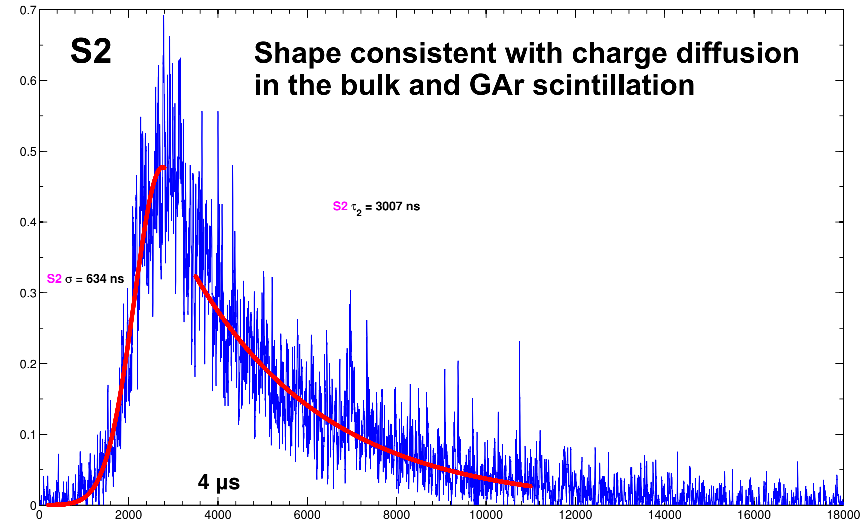


First feedback from e$^-$ lifetime (S2) ->

- Internal cleaning circuit efficient for oxygen equivalent impurities
- External purification circuit about to be commissioned

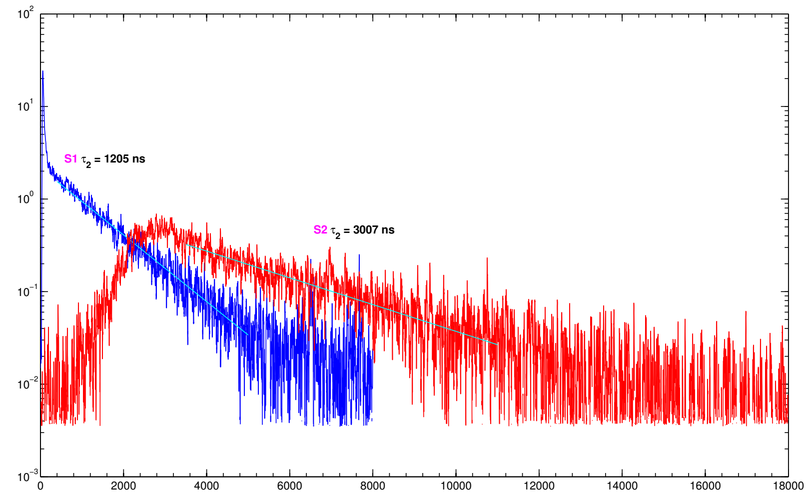
S1 and S2 mean pulse shapes



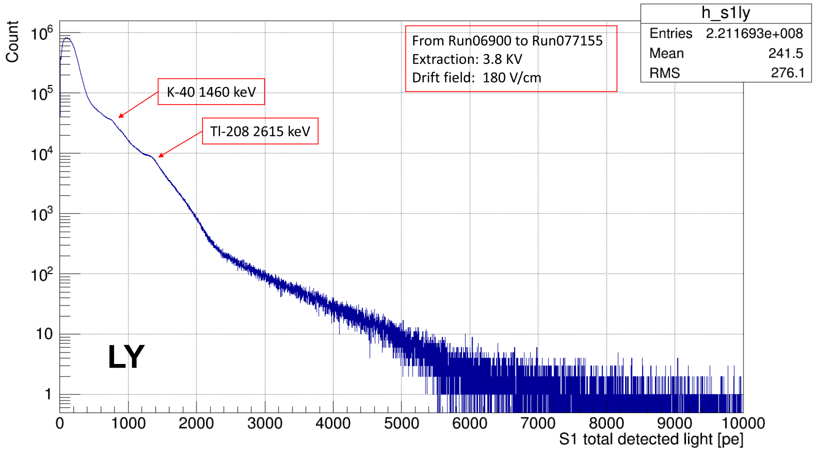


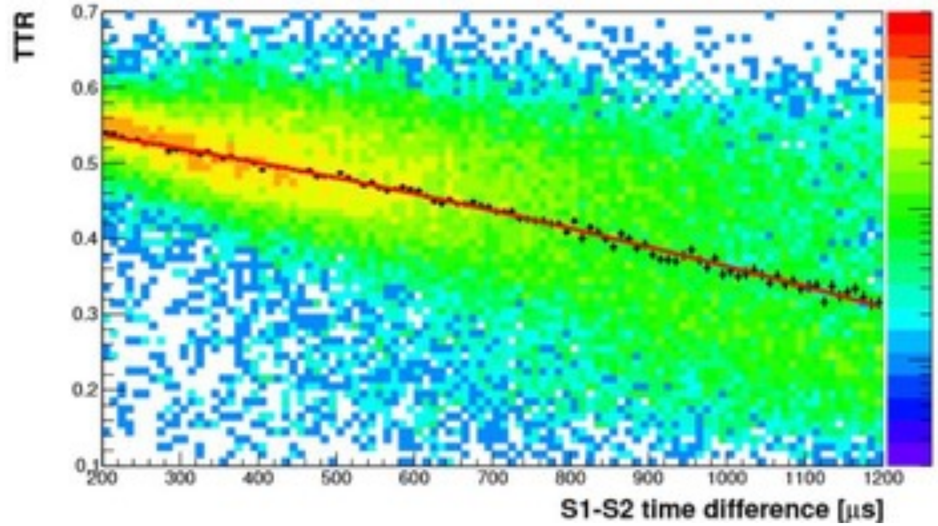
- Signals have to be classified offline
- Working on S1 S2 classifier (from shapes)
- Second step is event matching (efficiencies, correlations, energy resolution ..)

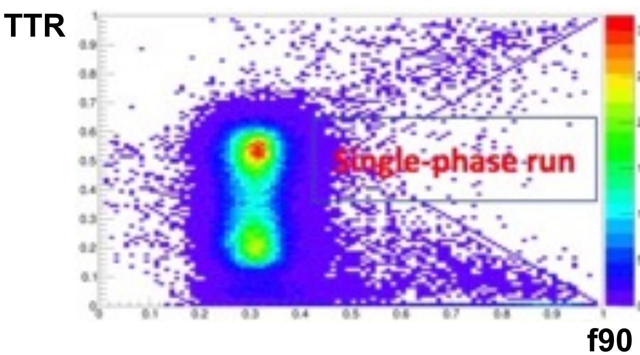
- Commission the external GAr filter system
- Verify trigger thresholds for S2 signals
- Once stable operating conditions:
- Calibration data with neutrons

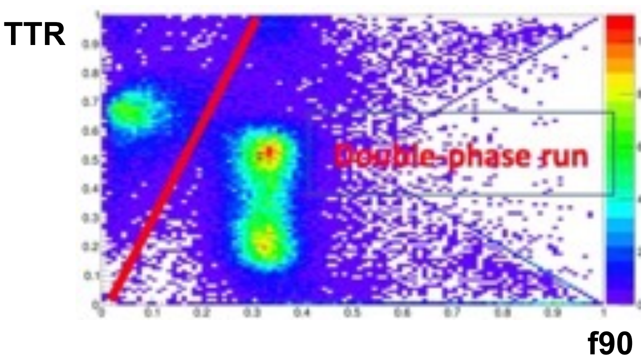


First very preliminary results of RunII data

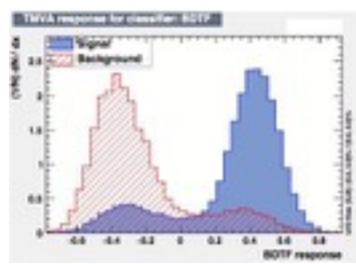




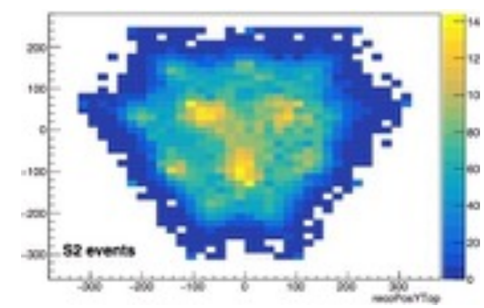


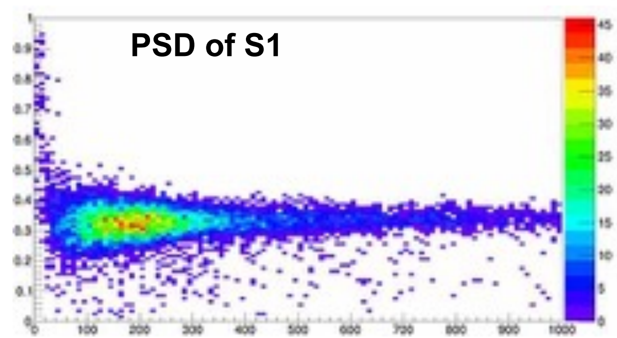


S1-S2 classification (BDT)



S2 Position reconstruction

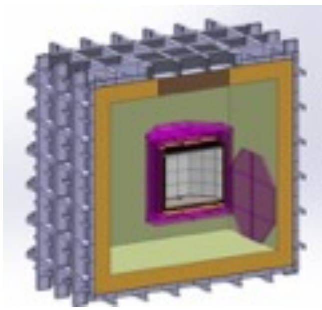




Many things work…

Future activities at LSC in the framework of the DS-20k project

- Substantial momentum created for the next generations LAr DM projects
- Unified program (DarkSide-50, DEAP-3600, MiniCLEAN, ArDM)
- Later-on a multi 100t detector (ARGO).



DS-20k experiment:

- 20-tonne fiducial volume dual-phase TPC at LNGS
- Underground argon operation
- Designed for exposure of 100 ton years
- Sensitivity: 1.2×10^{-47}cm^2 (1.1×10^{-46}cm^2) @ 1TeV/c^2 (10TeV/c^2)
- Free of radiogenic background.
- Set to start operating by 2021

ArDM is integrated as R&D facility into DarkSide 20k

Clone of ArDM vessel is existing at CERN on surface

Exploiting the ArDM infrastructure at LSC (and CERN) for R&D

- Ton scale test facilities
- <u>Characterization of DepAr (also large quantities) — DART</u>
- SiPMT based photo-detectors developments and tests
- Radon emanation measurements ………

DART goals

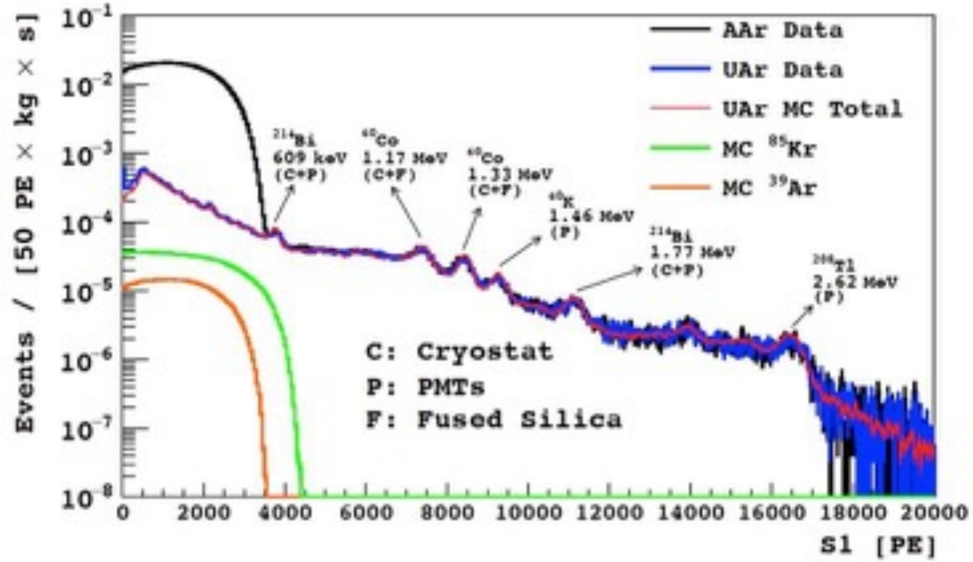
Activity measurement by fitting the β-spectra (of several radioactive traces)

The DS-50 measurement of AAr and UAr

Fitting spectral shapes

(0.73 ± 0.11) mBq/kg on

UAr radioactivity

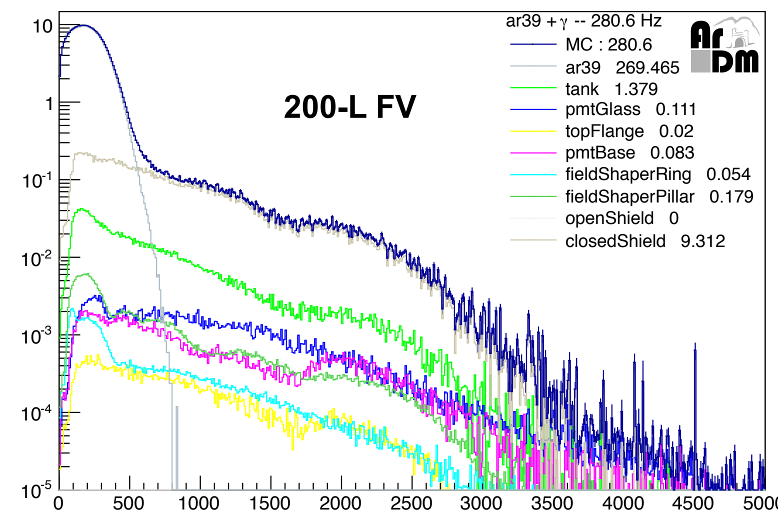


AAr ^{39}Ar and γ-Bkg in ArDM

Single phase (averaging) measurement

Crucial for the sensitivity is a good understanding of the gamma BG

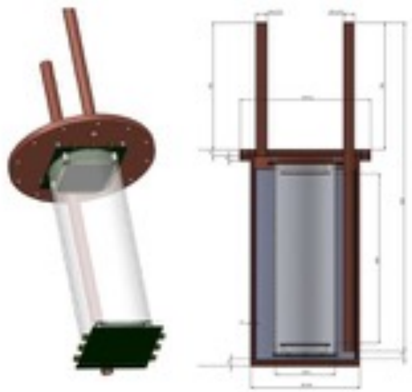
Improvement from dual phase data



1st step: Small 1L chamber in ArDM (operating in veto single phase mode)

HVFT will be removed

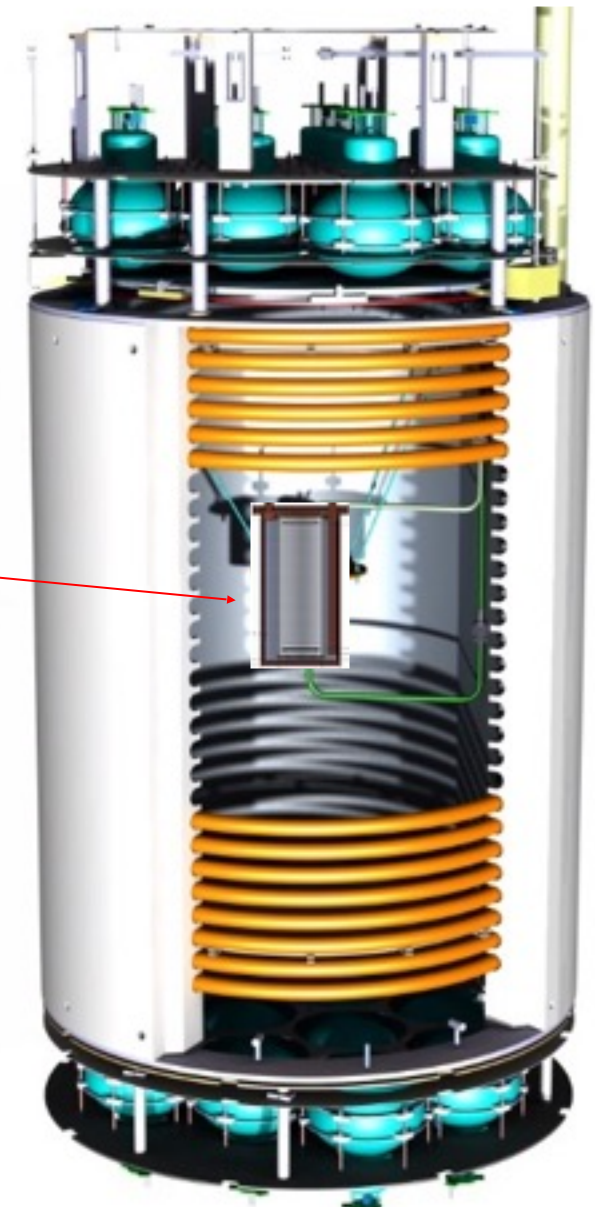
- Components under careful study of radiopurity requirements
- Also mechanical properties under revision (evacuateable)



SiPM read out
2x4 analog signals
Few SC lines

5x5 cm^2 low BG SiPMT arrays

Dart 1Ltr Chamber centered inside the main ArDM volume



Main components made from extra pure OFHC copper

Geant4 simulations

- BG sources: SiPM, PCB, copper, steel, external…
- Radioactive chains of ^{40}K, ^{232}Th, ^{238}U, ^{222}Rn

Expected sensitivity:

- UAr ~ 0.7 mBq/kg : 5σ ~0.2 weeks
- DAr ~ 0.07 mBq/kg : 3σ ~7.7 weeks

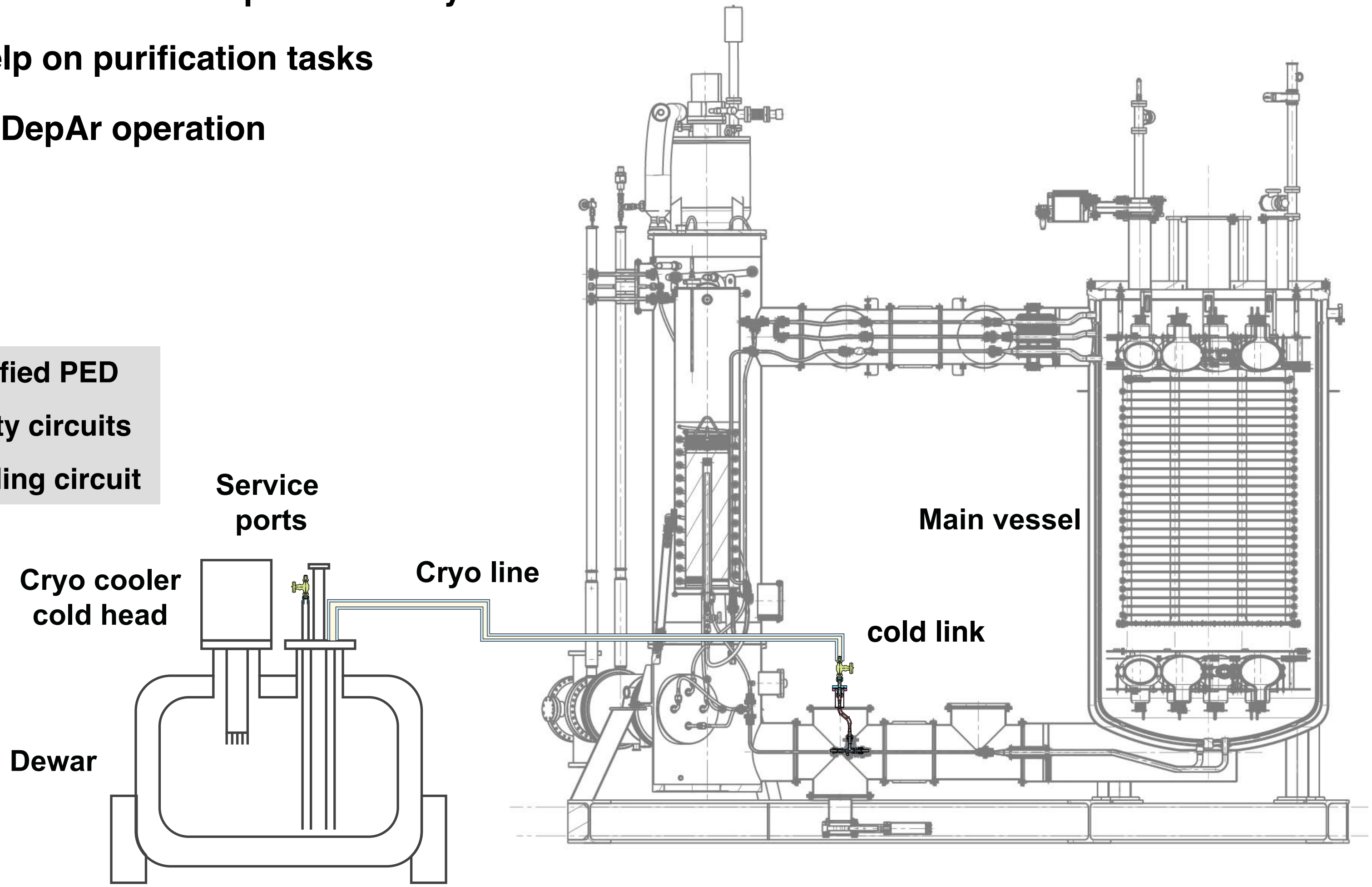
Ongoing activities: Recuperation dewar

- Important extension of the experimental setup
- Significantly decreases experimental turnover
- Ar is cleanest at the end of experimental cycles
- System can help on purification tasks
- Mandatory for DepAr operation

Under test at CERN
Installation soon at LSC

Fully safety certified PED
Includes all safety circuits
Stand alone cooling circuit

wessington cryogenics



Outlook: experimental program - main Objectives

- **Operation of a ton scale LAr target in dual phase mode**
- **Explore the limits for WIMP searches (BG, PSD…)**
- **3D reconstruction of events (multiple interactions)**
- **Fiducialization capabilities and effects on PSD, BG, signal**
- **How well can neutron multiple scatter be recognized (major milestone)?**
- **And hence the neutron single scatter rate be determined**
- **Explore the S2 parameter space - gain in E resolution**

- **Prepare the ArDM facility for depleted argon studies (DART)**
- **Design for 1L chamber finished / procurement of components ongoing**
- **Measurements will start at CERN in parallel to activities at LSC**
- **Later, higher sensitivity can be reached with large DAr target — need UAr**

Expect valuable information from the tonne-scale for next generation facilities