

A new method to measure ultra-low isotope contamination in liquid argon

Pablo García Abia

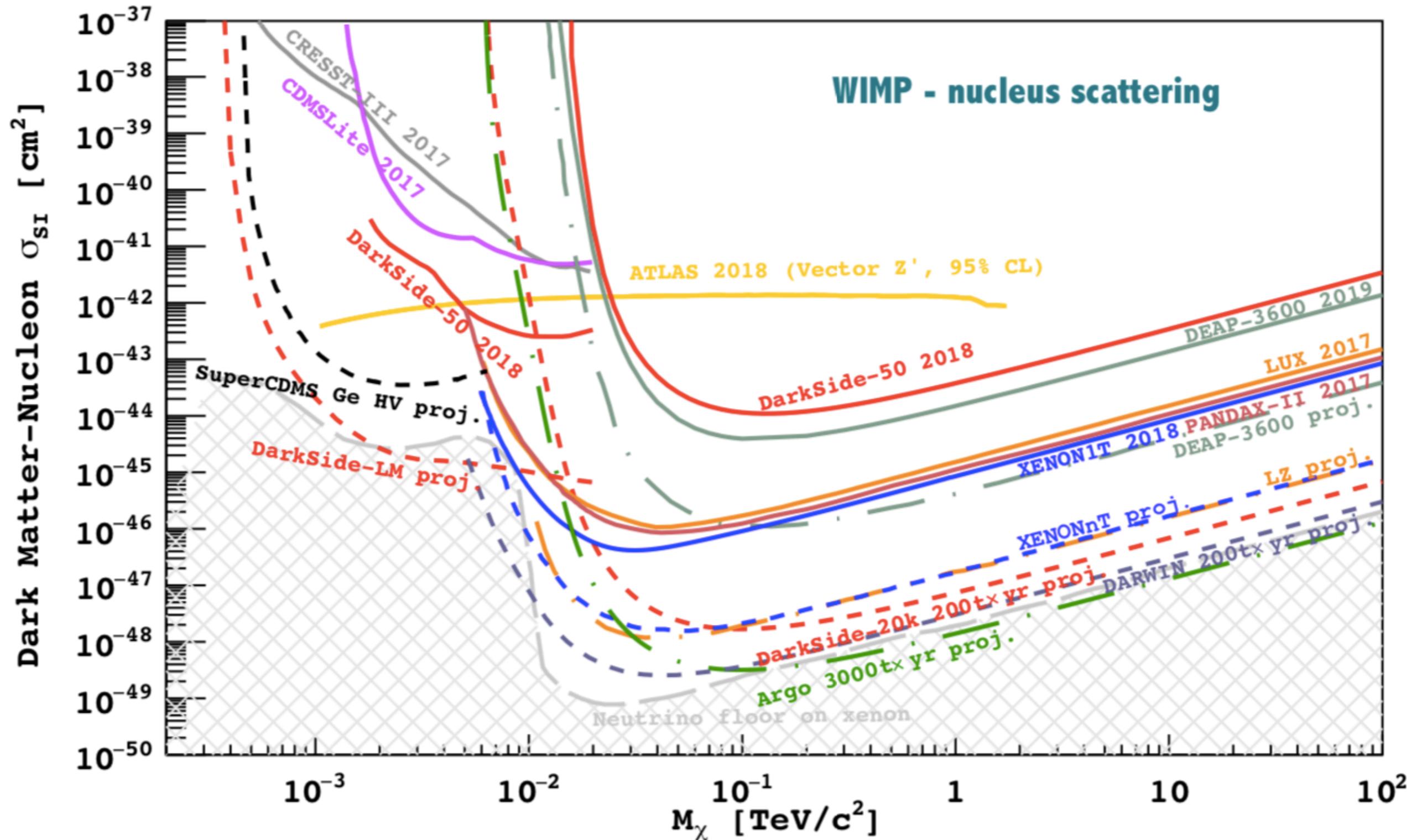
On behalf of the **DarkSide** and **ArDM** Collaborations



The role of underground argon in direct dark matter search

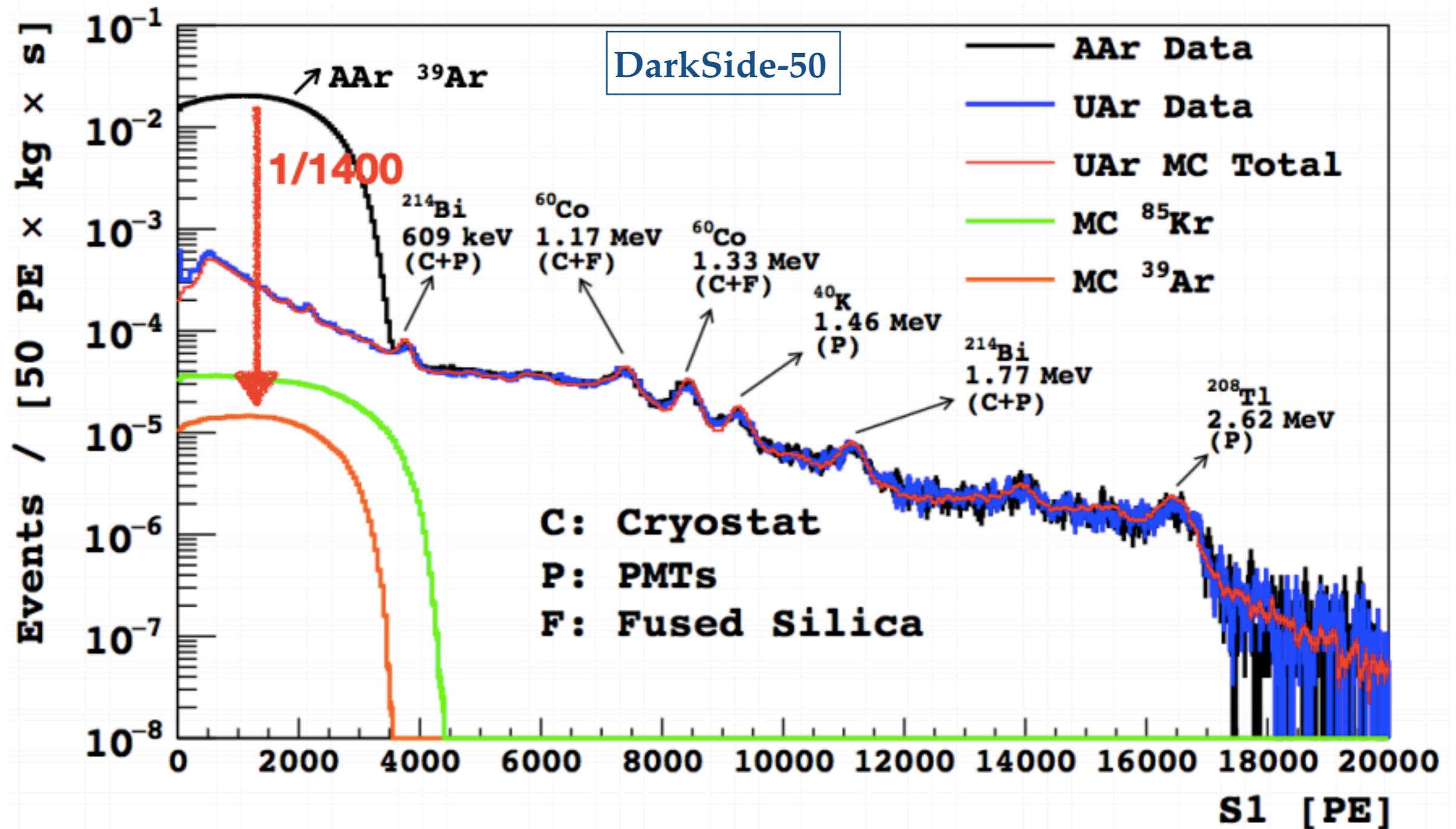
- Today, Xe rules.
- Ar competitive for high target mass and low background.
- Future Ar-based experiments will use underground argon (**UAr**).
- Measuring the concentration of ^{39}Ar in UAr is crucial: **DArT**.

Spin-independent DM-nucleon cross section 90% C.L. exclusion limits / sensitivity curves



Argon has a naturally occurring β emitting isotope, ^{39}Ar

Activity 1 Bq/kg in AAr, 0.73 mBq/kg in DS-50 UAr



Global Argon DM Collaboration

Next generation direct DM search experiments will operate with **underground Ar** and **radio-pure materials** to maximise the discovery potential. Light sensitivity and coverage enhanced with Si photomultipliers (**SiPMs**).

Current experiments: DarkSide-50, DEAP-3600, ArDM, MiniClean

Future experiments: DarkSide-20k (50 t), ARGO (300 t)

Laboratories: LNGS, SNOLAB, LSC. Strong support from CERN.

59 institutions, 420 researchers, 14 countries: Brazil, Canada, China, France, Greece, Russia, Italy, Mexico, Poland, Romania, Spain, Switzerland, UK, USA.

GADMC event at the Canadian Embassy

Madrid (Spain), May 2019



Similar events were previously
held in Rome and Paris



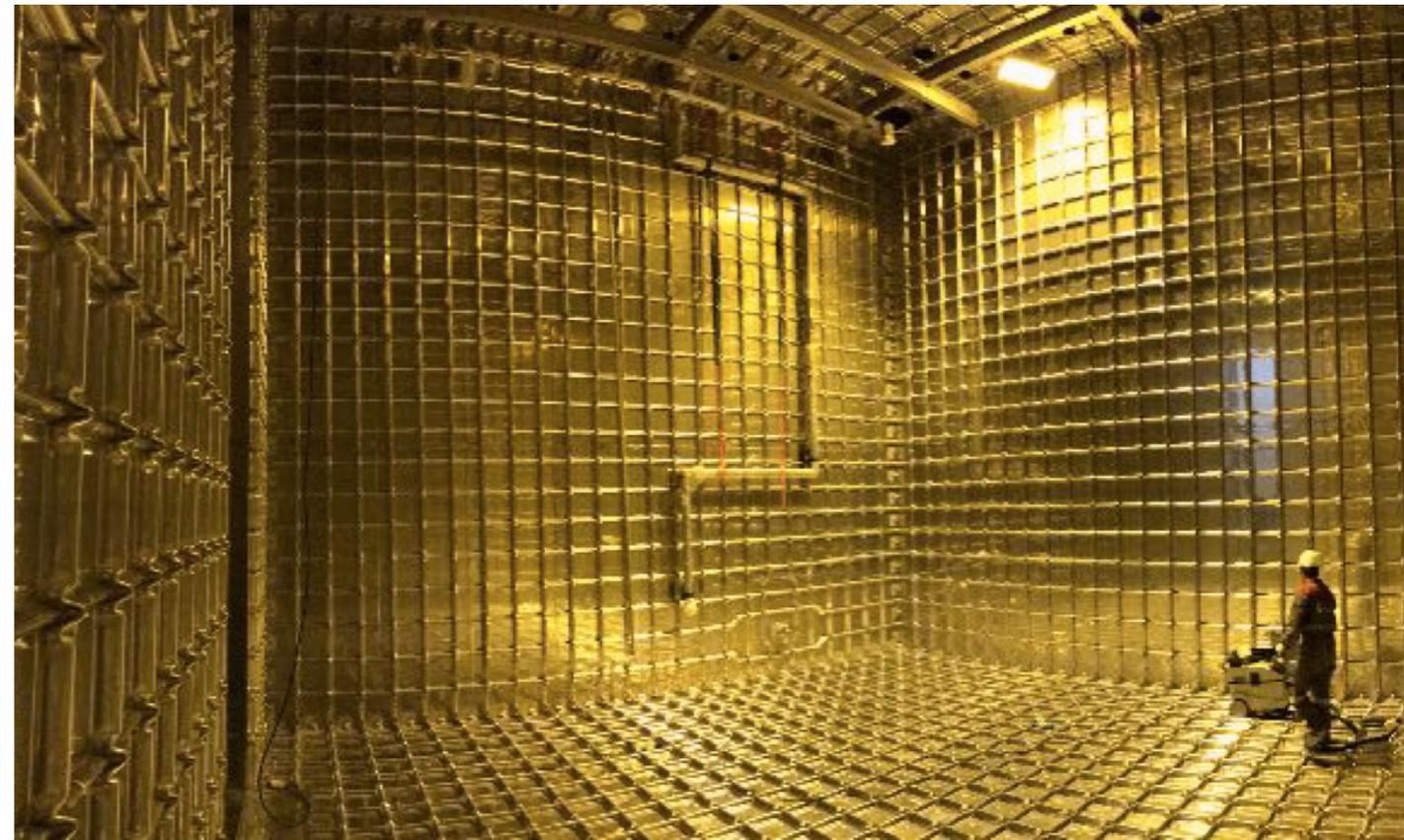
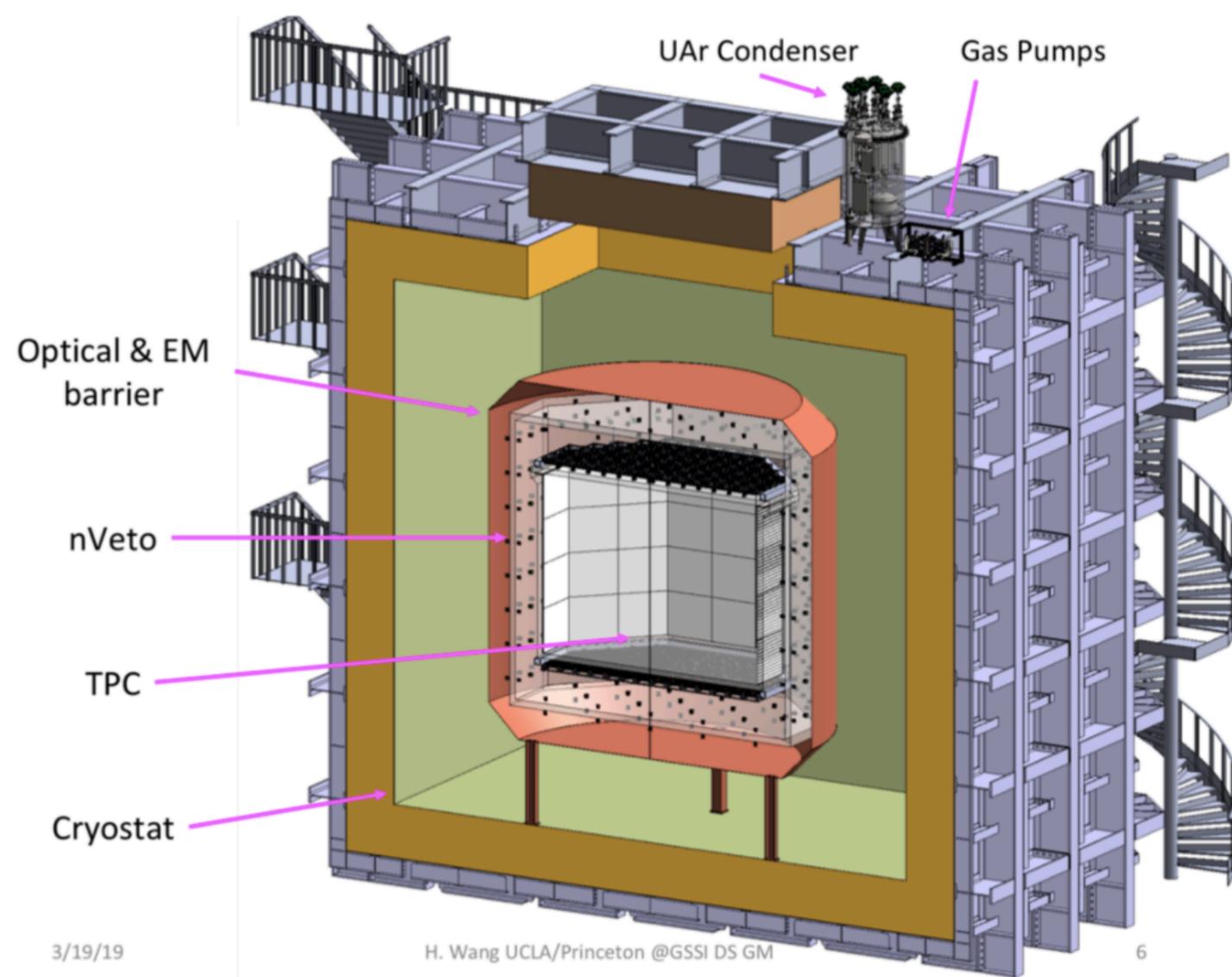
DarkSide-20k in a nutshell

50 tonne LAr active volume:
underground argon, 8200 PDMs
(SiPM), ultra radio-pure materials.

No organic liquid scintillators at
LNGS: new active veto (Acrylic + Gd).

New cryostat (proto-DUNE like):
passive veto (AAr)

DS-Proto: 1 tonne prototype (CERN).



Low radioactivity UAr for DS-20k

Assuming ^{39}Ar depletion factor 1400 (DS-50):

- 10^8 ER events expected in 100 tonne·y exposure.
- PSD: 10^9 discrimination power for NR/ER.

Lower depletion factor expected (air leak in DS-50 UAr).

DarkSide-20k physics goals at reach with just UAr.

URANIA plant will extract the UAr from the Kinder-Morgan facility in Cortez (Colorado, USA).

ARIA (Sardinia, Italy) will chemically purify the UAr to detector grade.

Crucial to measure the depletion factor of ^{39}Ar in UAr.

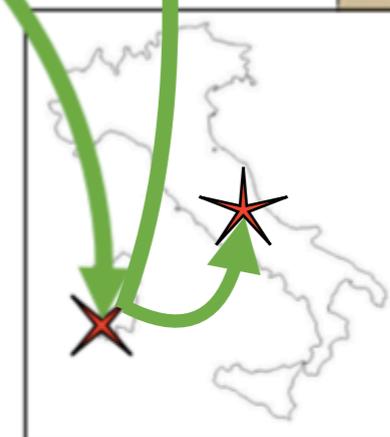
Ar extraction and purification



Characterisation: DArT
Measurement of the ^{39}Ar depletion factor



UAr transported via boat
for final purification at Aria



Production: Urania

- Commercial-scale plant to extract UAr
- Located in Southwestern Colorado
- UAr extracted from CO_2 well gas at the tonne scale
250 kg/day → 90 tonne/year

Purification: Aria

- 350 m tall cryogenic distillation column to purify UAr and isotopically separate argon and other elements
- Located in refurbished carbon mine shaft in Sardinia, Italy
- Will chemically purify the UAr for DS-20k to detector grade

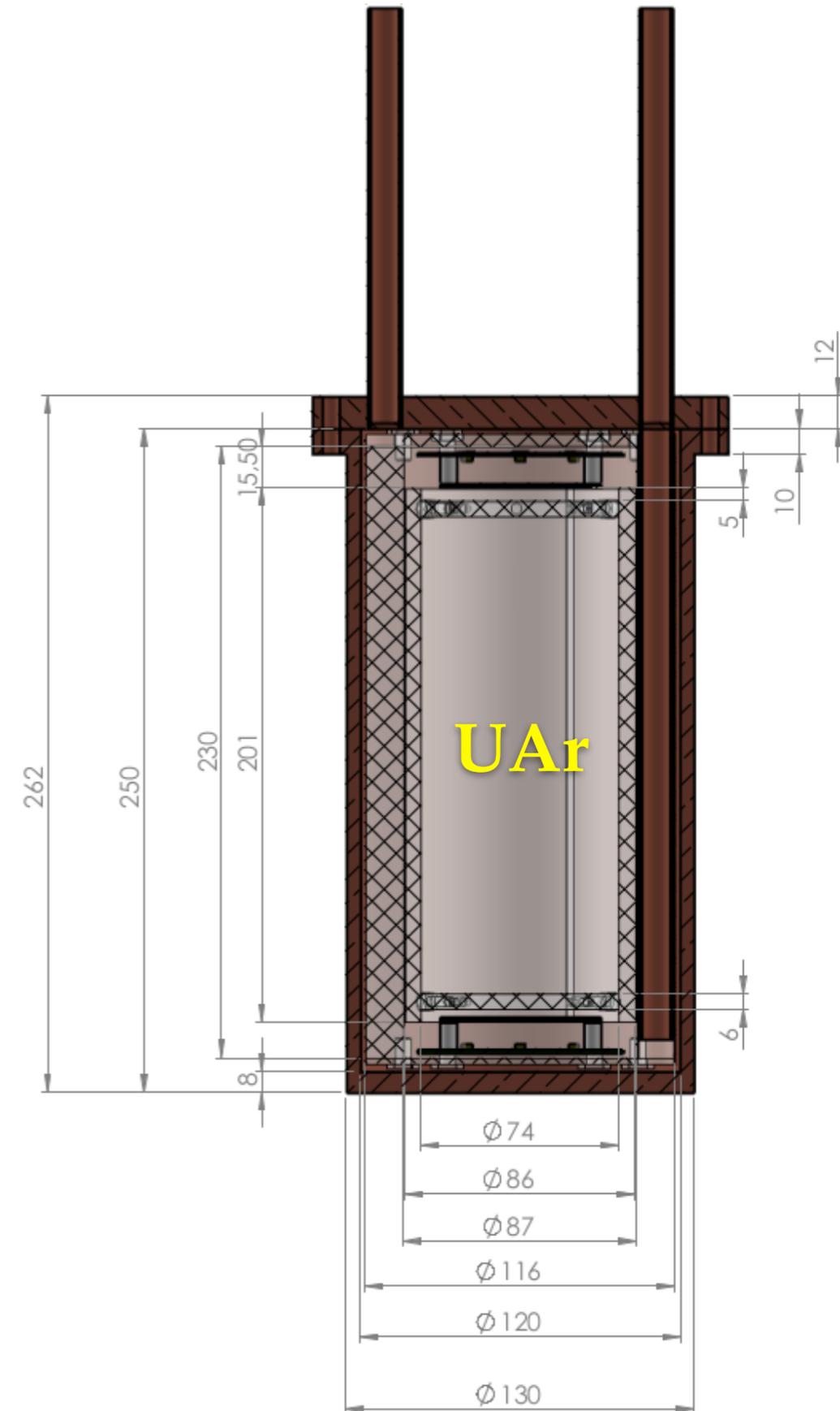
DArT: measuring ^{39}Ar in UAr

DArT is a small low-background detector designed to measure the ^{39}Ar depletion factor of different underground argon batches (URANIA+ARIA):

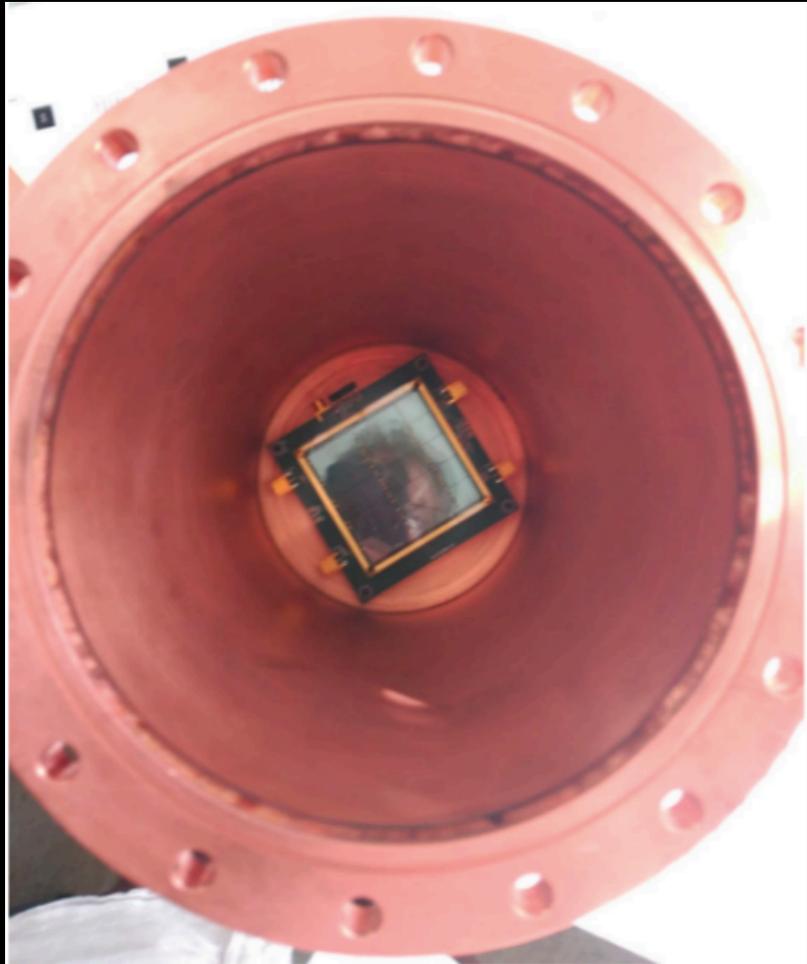
99.99% OFHC Cu cylinder, 1 ℓ active volume,
PMMA support structure with TPB coating,
Readout two PDMs (1 cm² SiPMs) from DS-20k
(DArTeye).

Background (γ): internal (from detector materials),
and external (from surrounding rock).

It will be located at **LSC** inside ArDM, LAr TPC
(850 kg AAr) to be used as active veto.



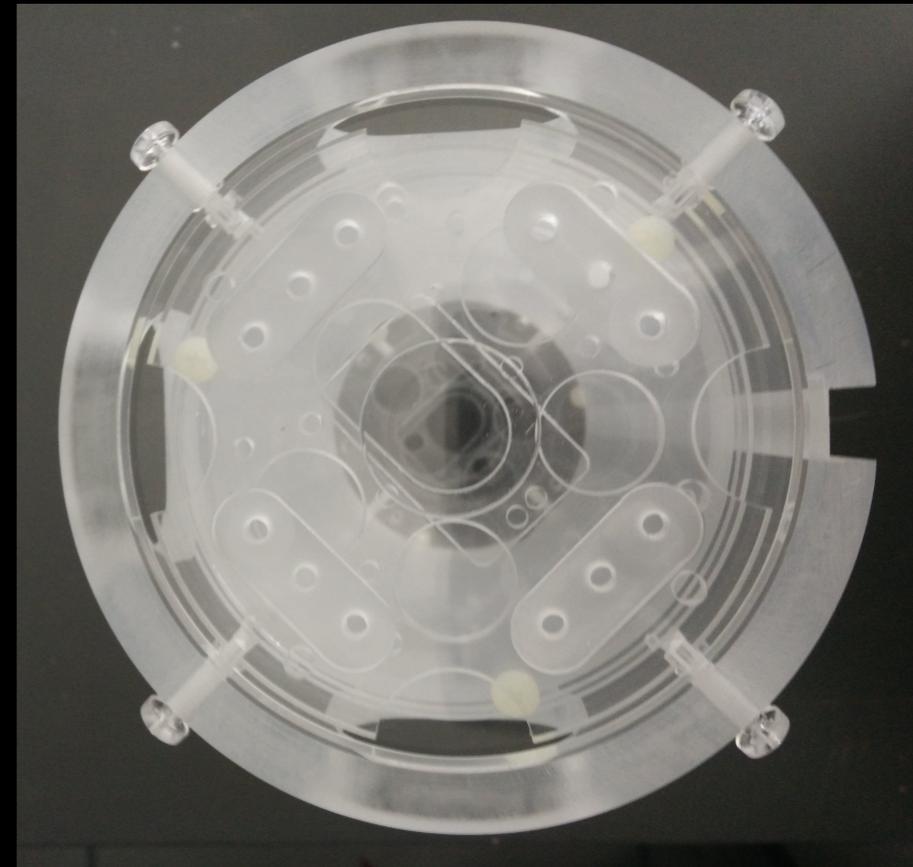
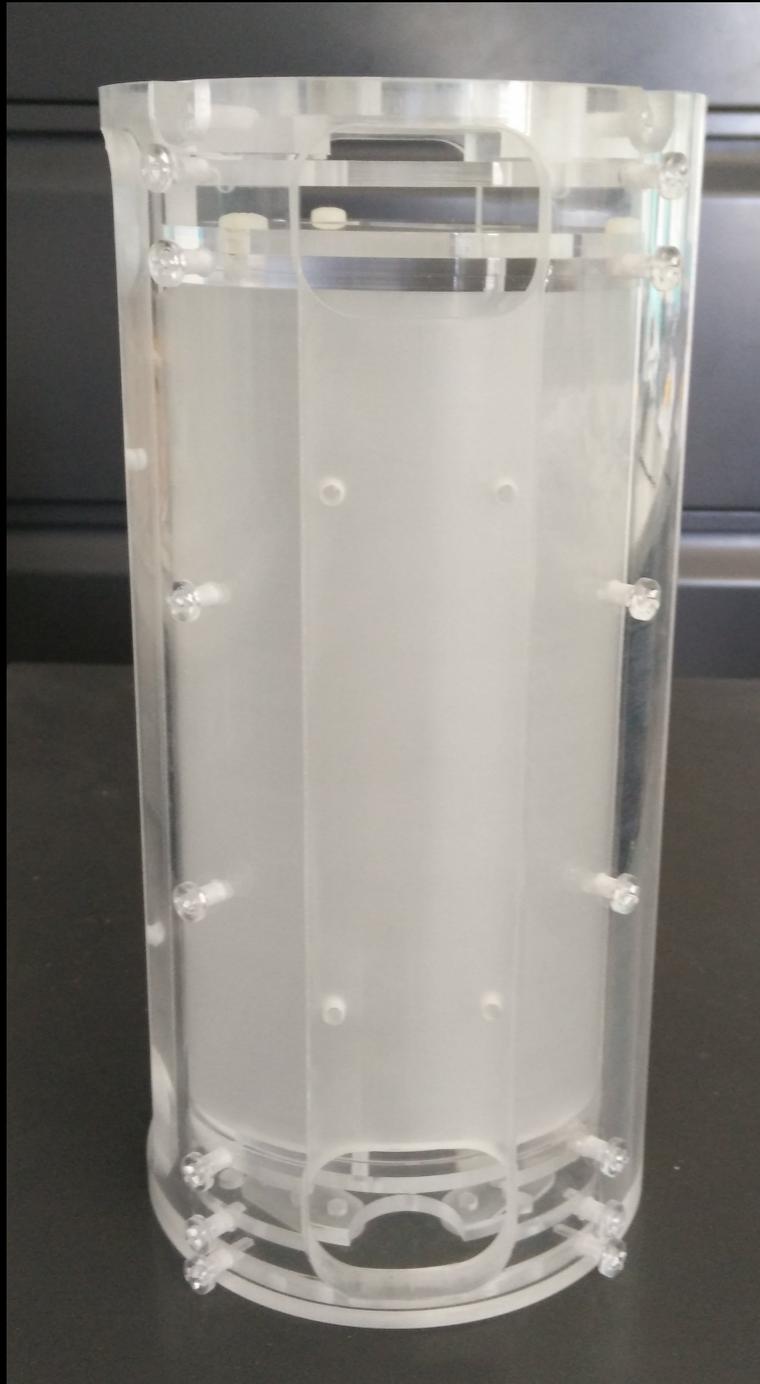
Copper vessel (Cagliari+CIEMAT)



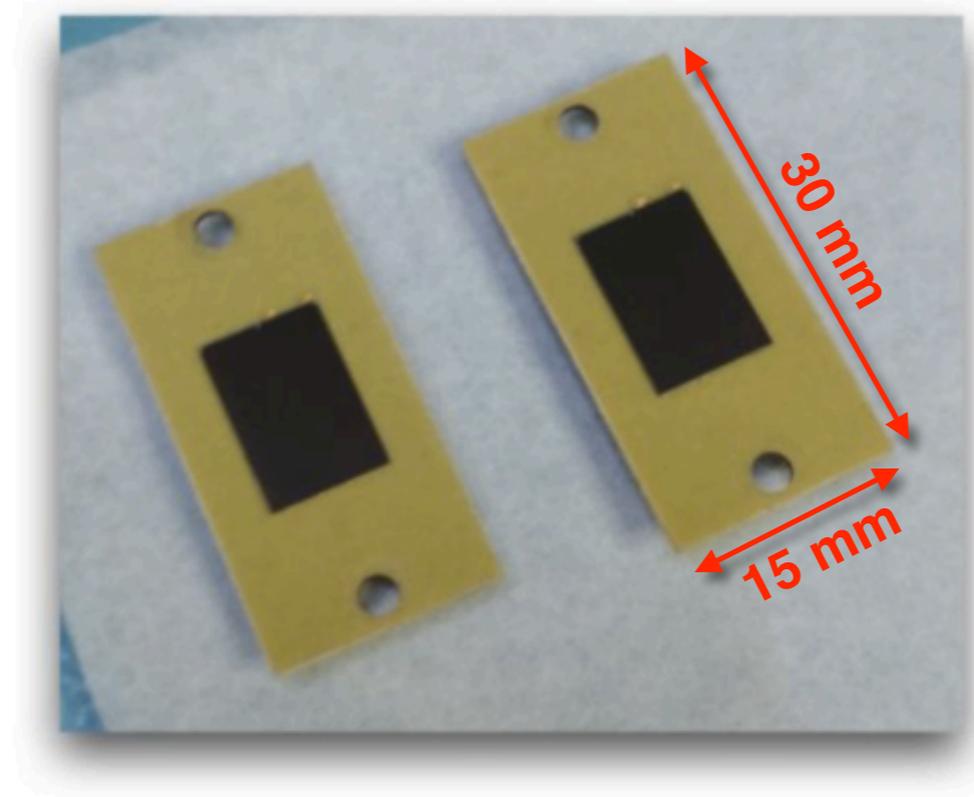
Vacuum and cryogenic tests (CIEMAT)



DEAP-3600 acrylic (Carleton U.)

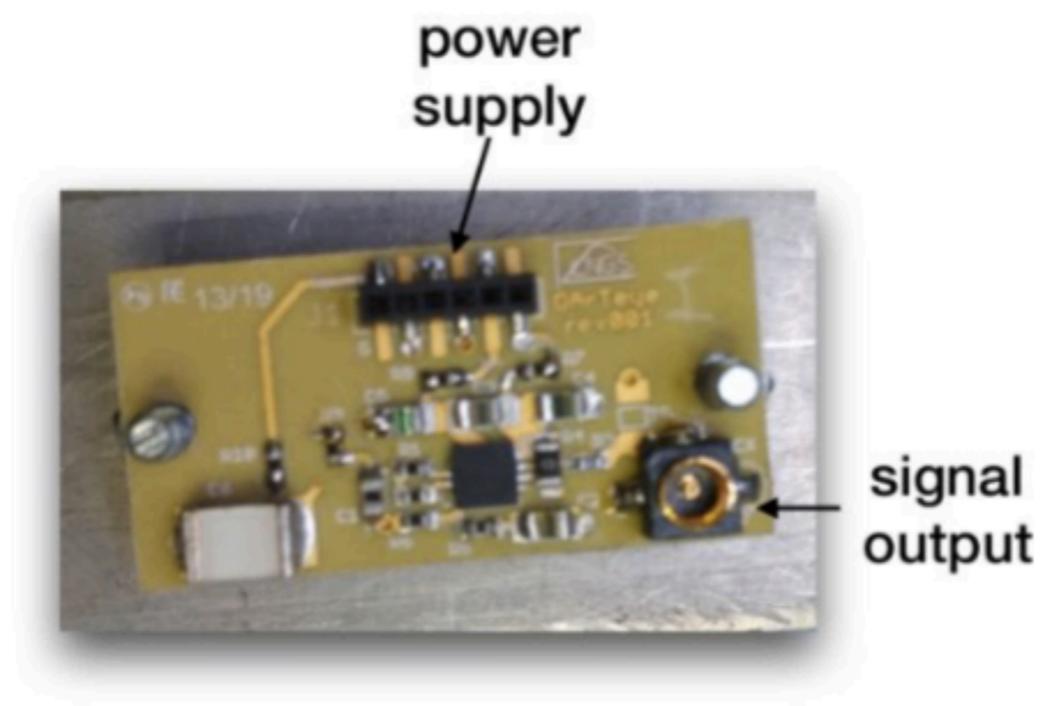


DArTeye: the DArT readout (LNGS)



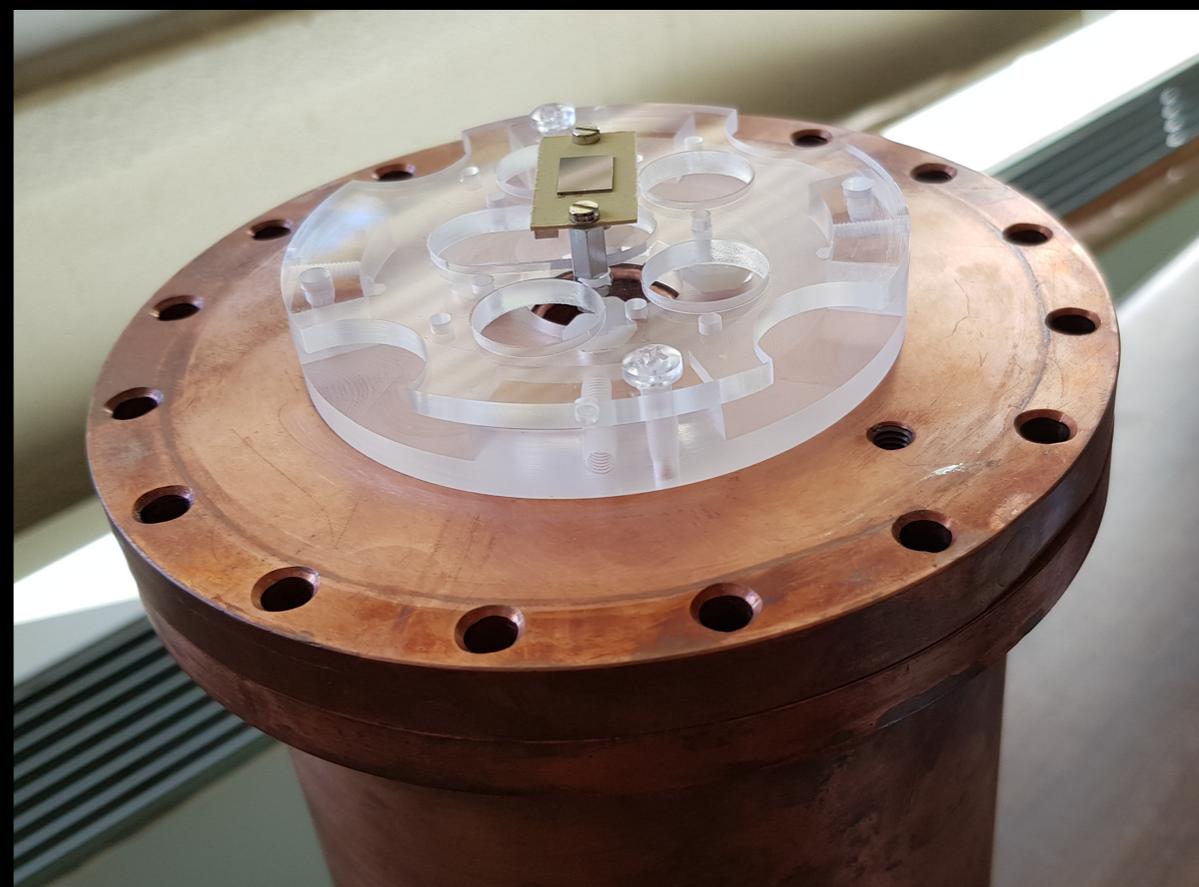
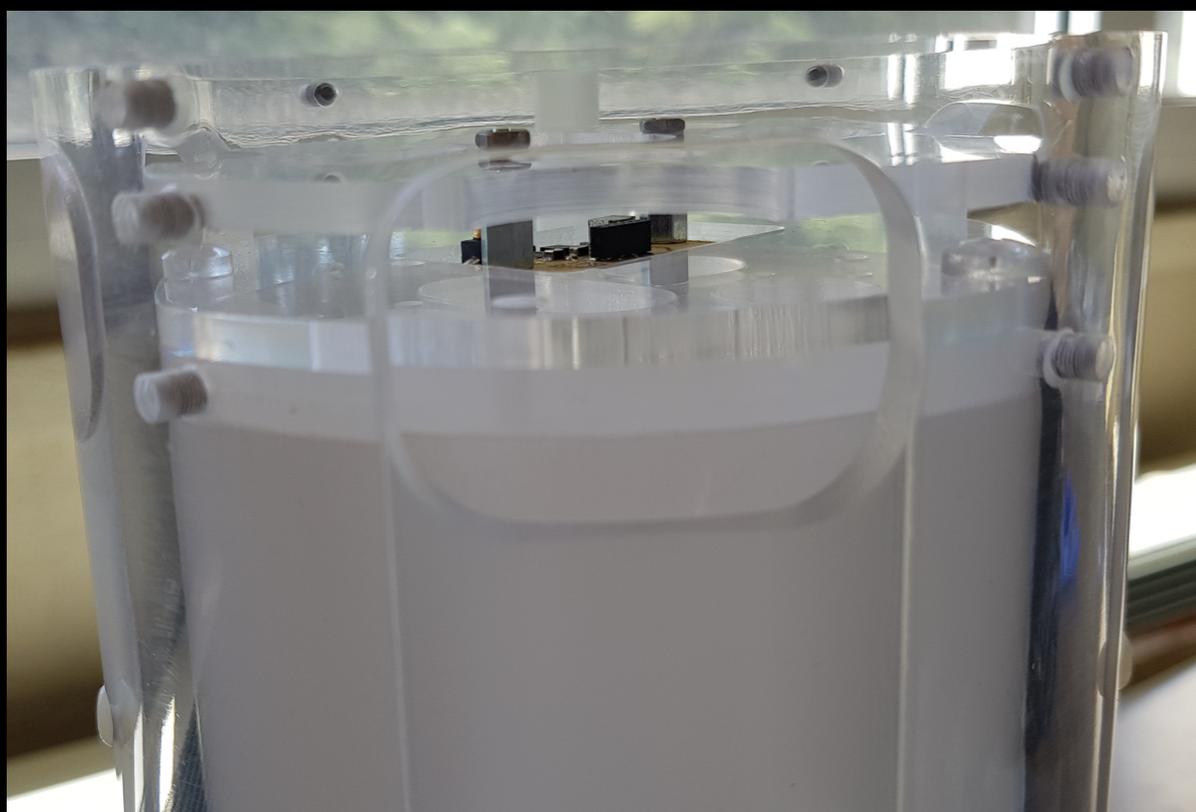
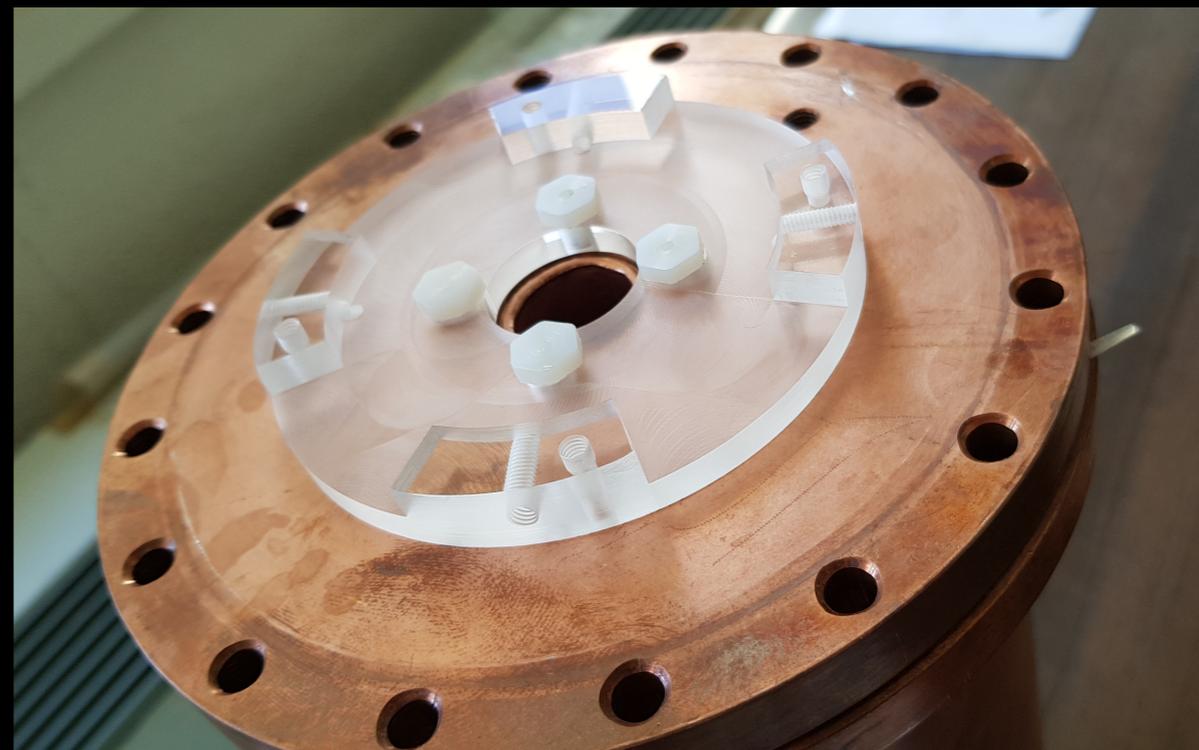
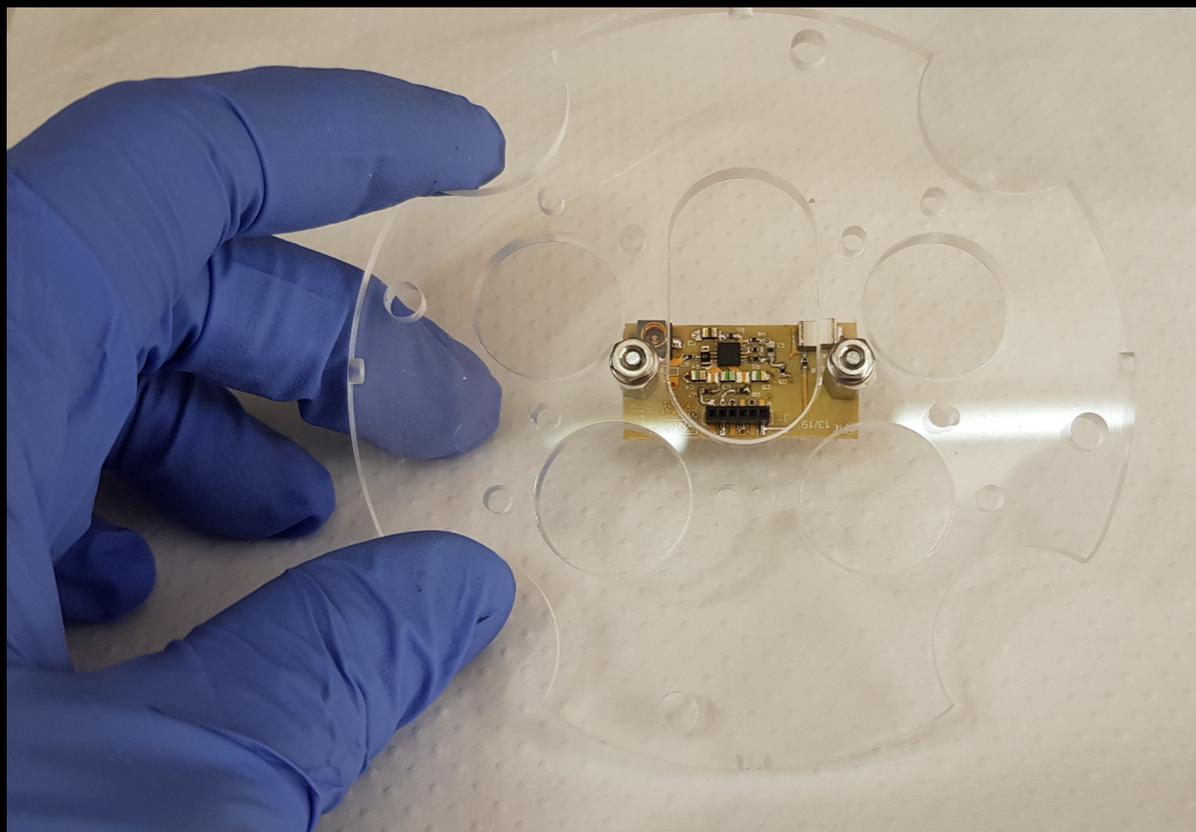
SiPM:
cell size 25 μm
 $R_q = 10 \text{ M}\Omega$
doping x3

design: LNGS
components: Cagliari
assembly: LNGS
wire bonding: PU

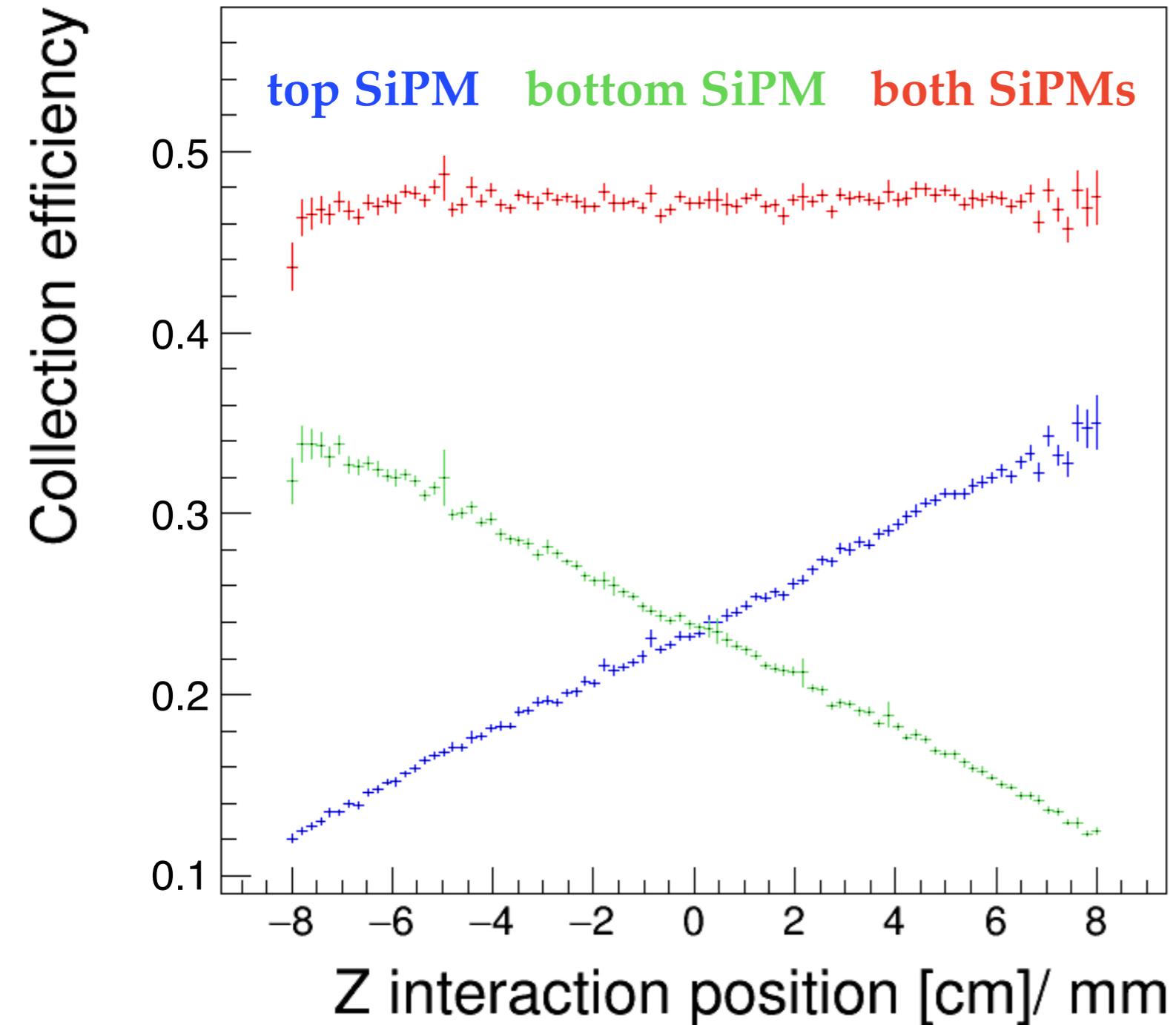


devices:
1. not radiopure
2. radiopure

DArTeye in DArT



Light collection efficiency



Collection efficiency 48%,
10 PE/keV with PDE 0.4.

High collection uniformity.

DArT in ArDM

Insertion of DArT in ArDM.
Use ArDM target as veto.

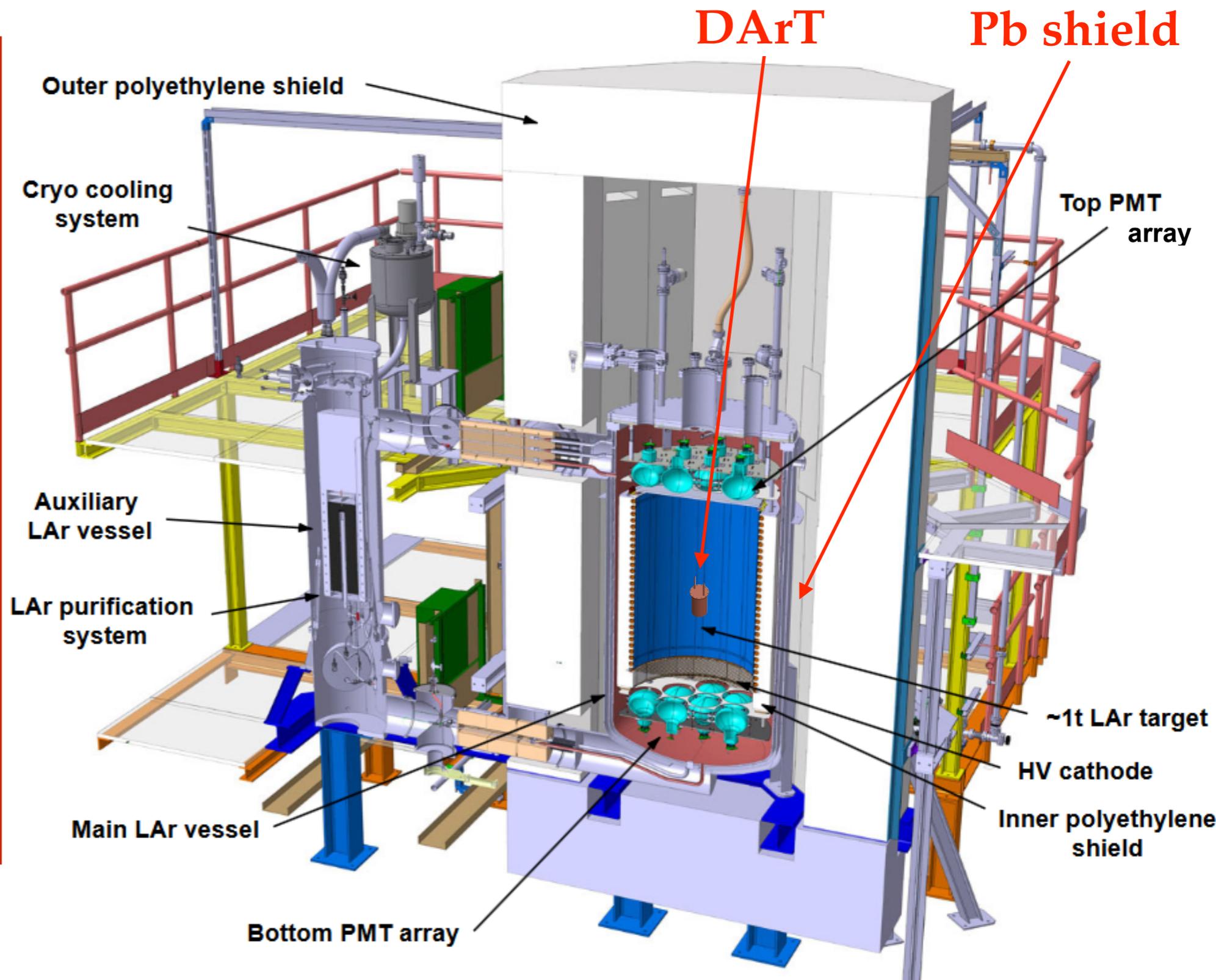
ArDM in single phase.

New flanges top/bottom
for the new 13 PMTs.

Use spare DAQ channels.

Dissipated power and
condensation heat to be
absorbed by the ArDM
cryogenic system.

Test of the gas system at
CIEMAT (Madrid)



ArDM in Hall A (LSC)



Event rates

Expected number of ^{39}Ar events in 1 week:

~ 4×10^8 in ArDM (610 Hz from AAr, 1 Bq/kg),

~620 in DArT (1 ℓ) - UAr, 0.73 mBq/kg (from DS-50),

~85 in DArT (1 ℓ) - UAr, 0.10 mBq/kg (depletion factor 10^4).

Rate expected in DArT: 0.4 Hz from internal background events (w/o veto) plus 1 Hz from ^{39}Ar events (AAr, w/o threshold).

Rate in ArDM: 1.5 kHz from ^{39}Ar and background events.

Readout: CAEN digitisers, MIDAS software. System originally developed for DEP-3600 (by the TRIUMF group), then used for DarkSide-Proto. Final setup under development.

Analysis of events in DArT

Background events: γ from the detector materials and the surrounding rock deposit energy in either ArDM, or DArT, or both.

The energy deposited in **ArDM** is used to tag (veto) background events:

$$E_{\text{ardm}} > 10 \text{ keV}$$

The region of interest (**ROI**) for signal events is defined using the energy deposited in **DArT**:

$$E_{\text{dart}} < 600 \text{ keV}$$

Events in the ROI with $E_{\text{ardm}} < 10 \text{ keV}$ (i.e. **untagged** in ArDM) are the actual background events.

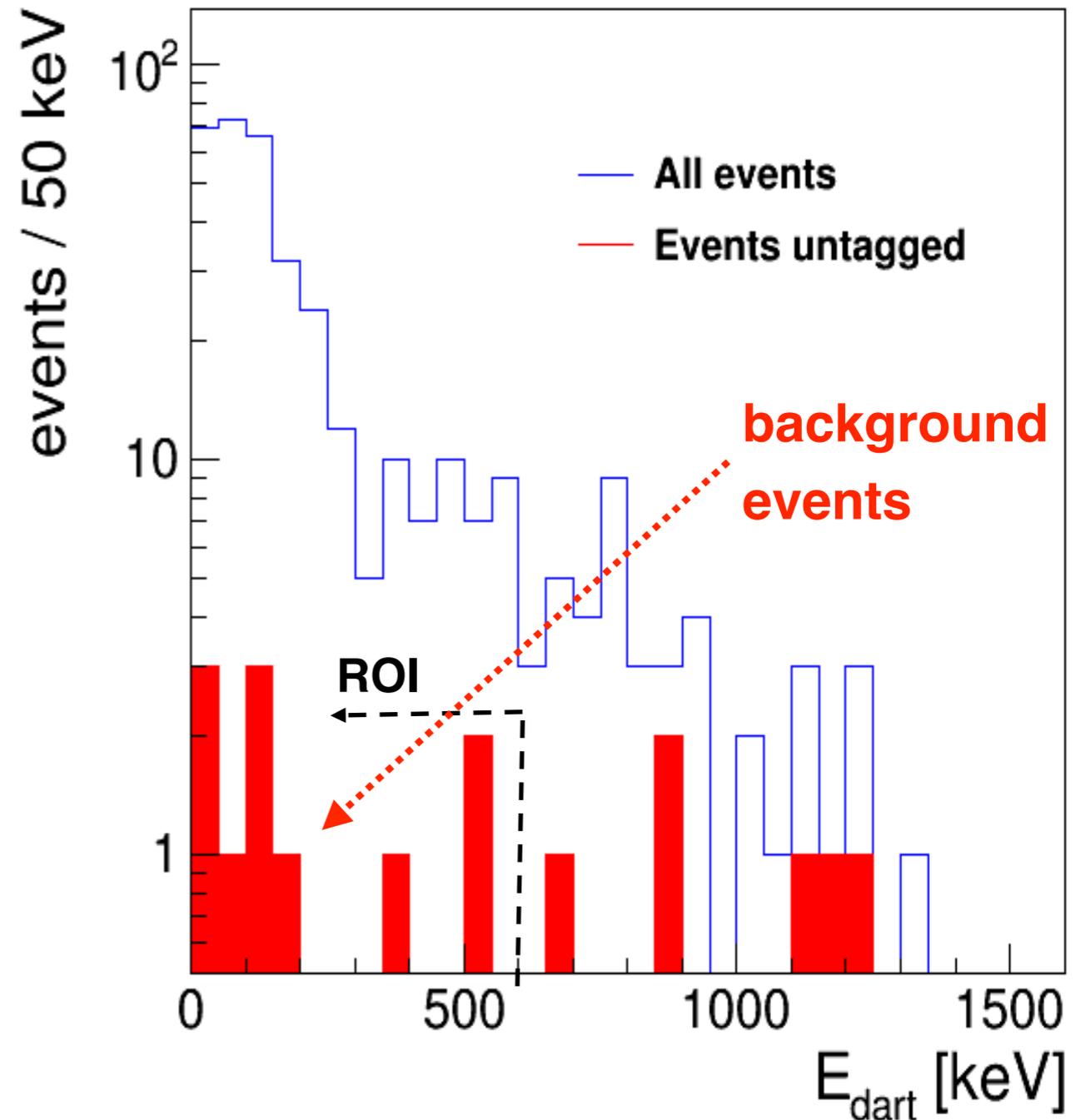
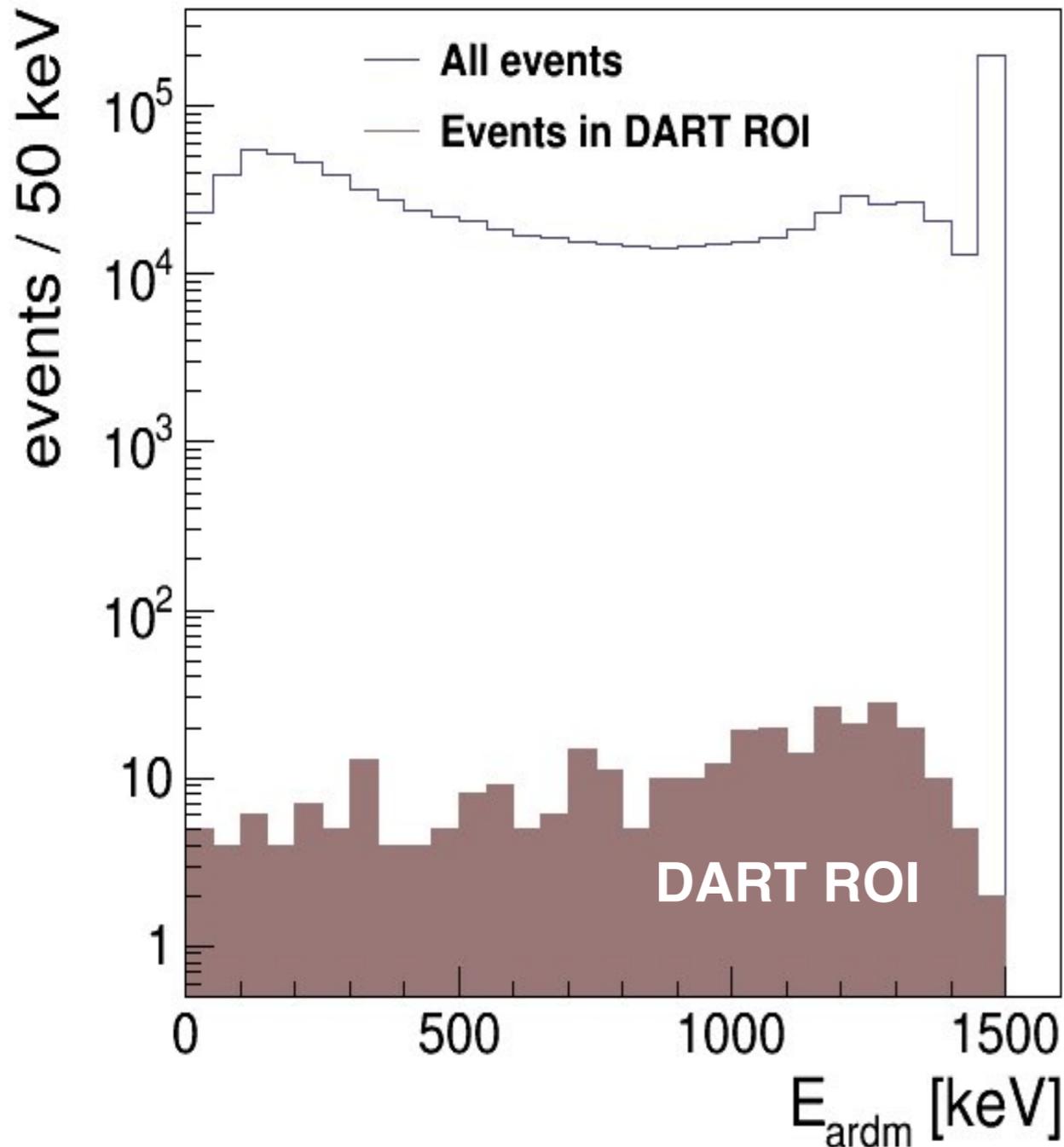
Full ArDM and DArT simulation, geometries and materials (Geant4).

Example

Background from the cryostat

Untagged: $E_{\text{ardm}} < 10 \text{ keV}$ (veto) ROI: $0 < E_{\text{dart}} < 600 \text{ keV}$

Events from ^{40}K : 900k in ArDM, 324 in DArT ROI, 11 untagged.



Background events per week

Internal background from radio-impurities in the materials.

Flux ($\gamma/\text{cm}^2 \text{ s}$) of the dominant external backgrounds [1]:

^{238}U 0.72, ^{232}Th 0.13, ^{40}K 0.05

[1] ArDM Collaboration, *Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC*, arXiv:1712.01932 (2017).

Signal events: 620

Signal-to-background ratio:

Naked = 0.06

Internal background in ROI

| Material | events / week | Untagged events / week |
|---------------|---------------|------------------------|
| DArT Cu | 17 | 6 |
| Arlon SiPM | 40 | 23 |
| Acrylic | 9 | 4 |
| ArDM cryostat | 3164 | 218 |
| ArDM PMTs | 1053 | 43 |

External background in ROI

| Configuration | events / week | untagged events / week |
|---------------|---------------|------------------------|
| Naked | 118 k | 10020 |
| Total naked | 122 k | 10300 |

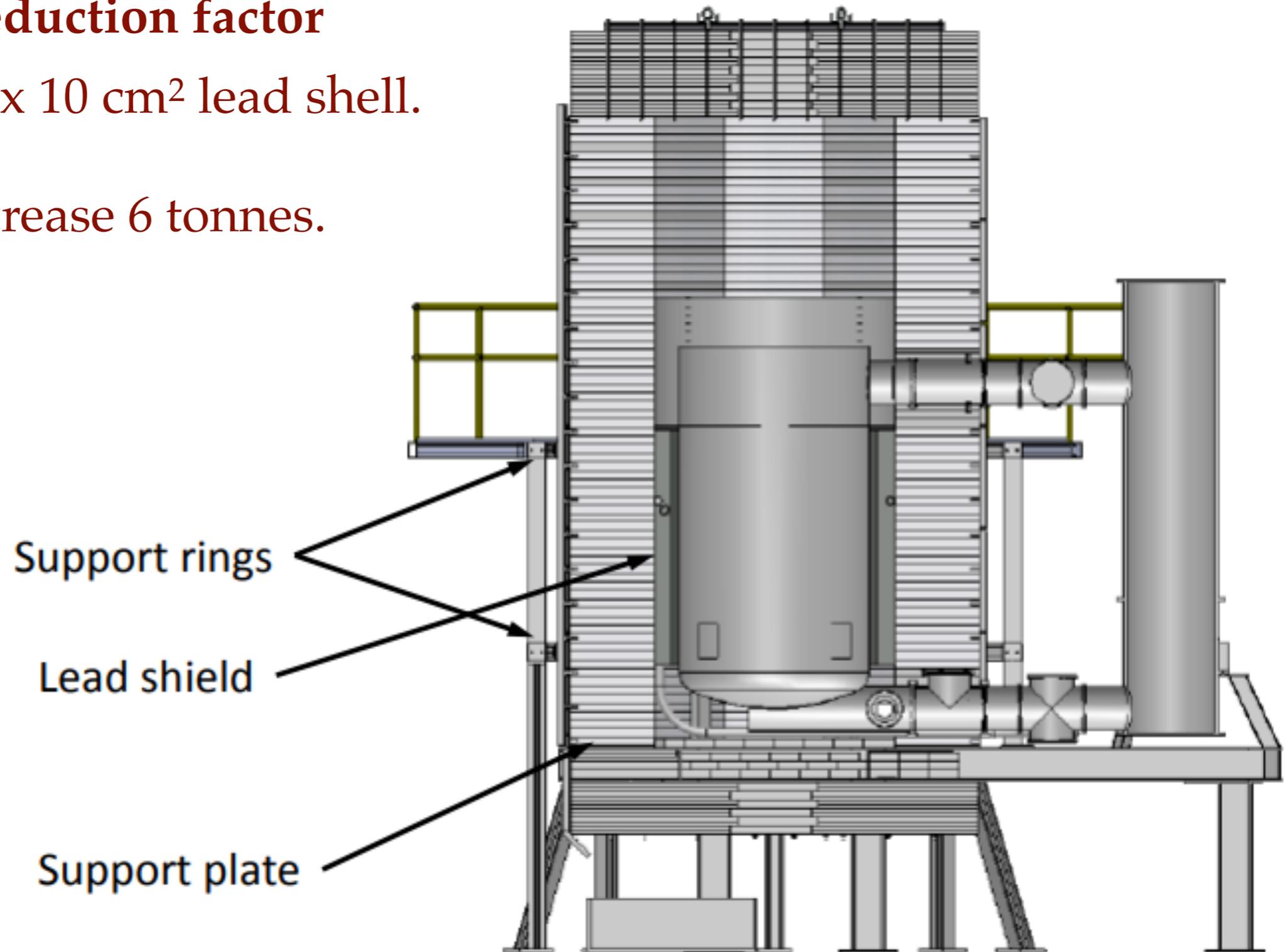
Huge external background

Pb shield against γ background

Background reduction factor

~50 with a 140 x 10 cm² lead shell.

Weight will increase 6 tonnes.



Background events per week

Internal background from radio-impurities in the materials.

Flux ($\gamma / \text{cm}^2 \text{ s}$) of the dominant external backgrounds [1]:

^{238}U 0.72, ^{232}Th 0.13, ^{40}K 0.05

[1] ArDM Collaboration, *Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC*, arXiv:1712.01932 (2017).

Signal events: 620

Signal-to-background ratio:

Naked = 0.06

Shielded = 1.33

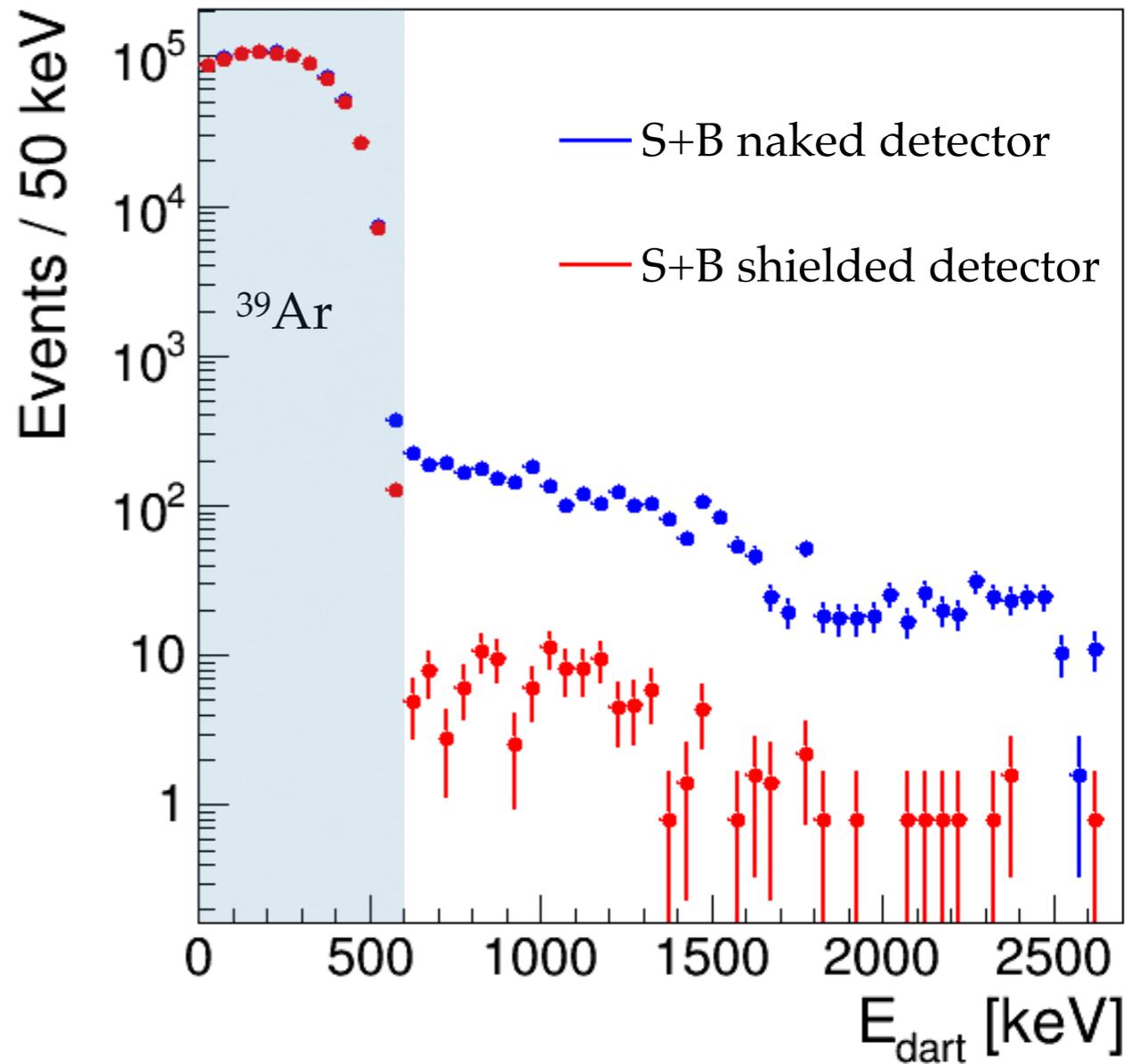
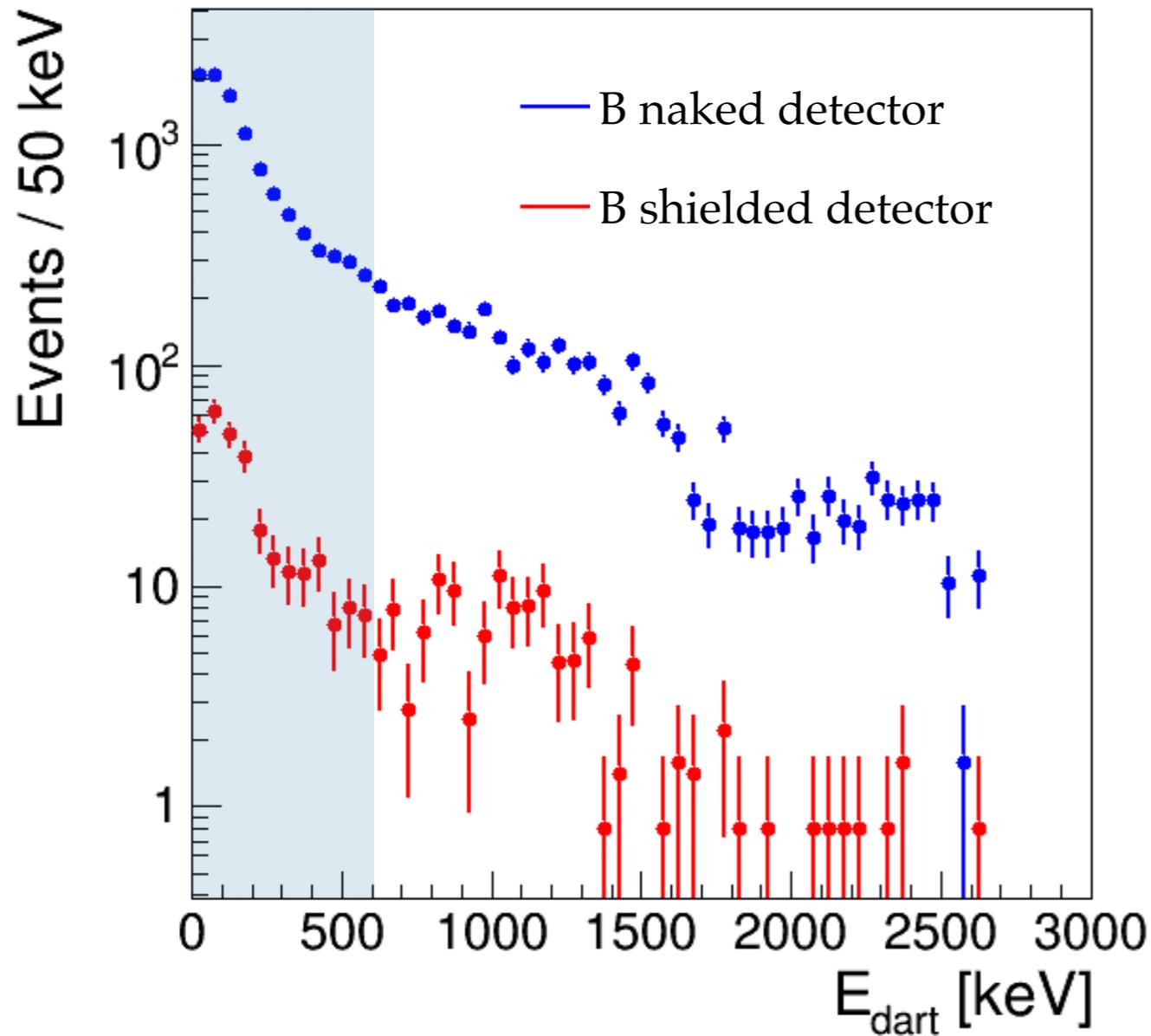
Internal background in ROI

| Material | events / week | Untagged events / week |
|---------------|---------------|------------------------|
| DArT Cu | 17 | 6 |
| Arlon SiPM | 40 | 23 |
| Acrylic | 9 | 4 |
| ArDM cryostat | 3164 | 218 |
| ArDM PMTs | 1053 | 43 |
| Pb shell | 150 | 16 |

External background in ROI

| Configuration | events / week | untagged events / week |
|----------------|---------------|------------------------|
| Naked | 118 k | 10020 |
| Total naked | 122 k | 10300 |
| Shielded | 2.6 k | 156 |
| Total shielded | 7.2 k | 466 |

Expected spectra in DArT



Sensitivity from a fit:

$$d = n_S S + n_B B$$

| Depletion factor with respect to AAr | statistical uncertainty without lead [%] | statistical uncertainty with lead [%] |
|---|---|--|
| 10 | 0.5 | 0.4 |
| 100 | 2.5 | 1.3 |
| DS-50 1400 | 20.3 | 6.7 |
| 14000 | / | 41.1 |

EDArT detector

Update of DArT detector (**Enhanced DArT**), in order to increase the sensitivity to depleted Ar (<0.1 mBq/kg).

Dual-phase detector with an active volume of 10 ℓ UAr:
~6000 events per week.

The ^{39}Ar signal would produce a single ionisation track in the detector. With a DP detector, multi-scattering events can be removed.

Expected performance for depleted Ar:

S/B from 1.3 to 5, statistical uncertainty from 20% to 4%.

Details (mechanics, readout, etc.) must be carefully studied.

Outlook

Underground argon will be key to the physics programmes of DarkSide-20k and ARGO.

DArT will measure the concentration ^{39}Ar in UAr for depletion factors exceeding the current measurements ($\times 1400$ for DS-50).

Very high depletion factors may require a DP detector: EDArT.

DArT will be installed in LSC and commissioned in Q4 2019.

In the long term, DArT will stay at LSC as a facility of the laboratory.