Measuring the ^{39}Ar depletion factor with DART

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

Low Radioactivity Underground Argon Workshop
PNNL (Richland, USA), 20 March 2018

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

EXCELENCIA MARÍA DE MAEZTU

cfp CIEMAT física de partículas

What is DART?

Next generation direct DM search experiments, like **DarkSide** (DS-50 now, DS-20k in 2021, Argo/GADMC in a longer term), will operate with liquid UAr to maximise the DM discovery potential.
[talk by W. Bonivento on Monday morning]

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

DART is a small experiment designed to measure this depletion factor:

- Integrates ArDM detector at LSC (Spain), and DarkSide at LNGS (SiPMs, UAr).
- Signal is ^{39}Ar decays, background is internal (γ from detector materials), and external (from surrounding rock).
- Small chamber (1 ℓ UAr) inside ArDM (850 ℓ AAr) used as veto.

Goal of DART

Measure the **depletion factor of ^{39}Ar in UAr** (2018).

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

~4×10^8 in ArDM (610 Hz from AAr, 1 Bq/kg),
~440 in 1 kg UAr (0.73 mBq/kg from DS-50),
~44 in DART for a depletion factor 10^4 (long term).

Background expected is few thousand γ events per week.

Ongoing:

- Mechanical design, electronics, cryogenic system, material procurement.
- Simulation of internal and external γ background, and optical response of the detector.

DART in ArDM

Insertion of active small chamber in ArDM.
Use ArDM target as VETO (single phase).

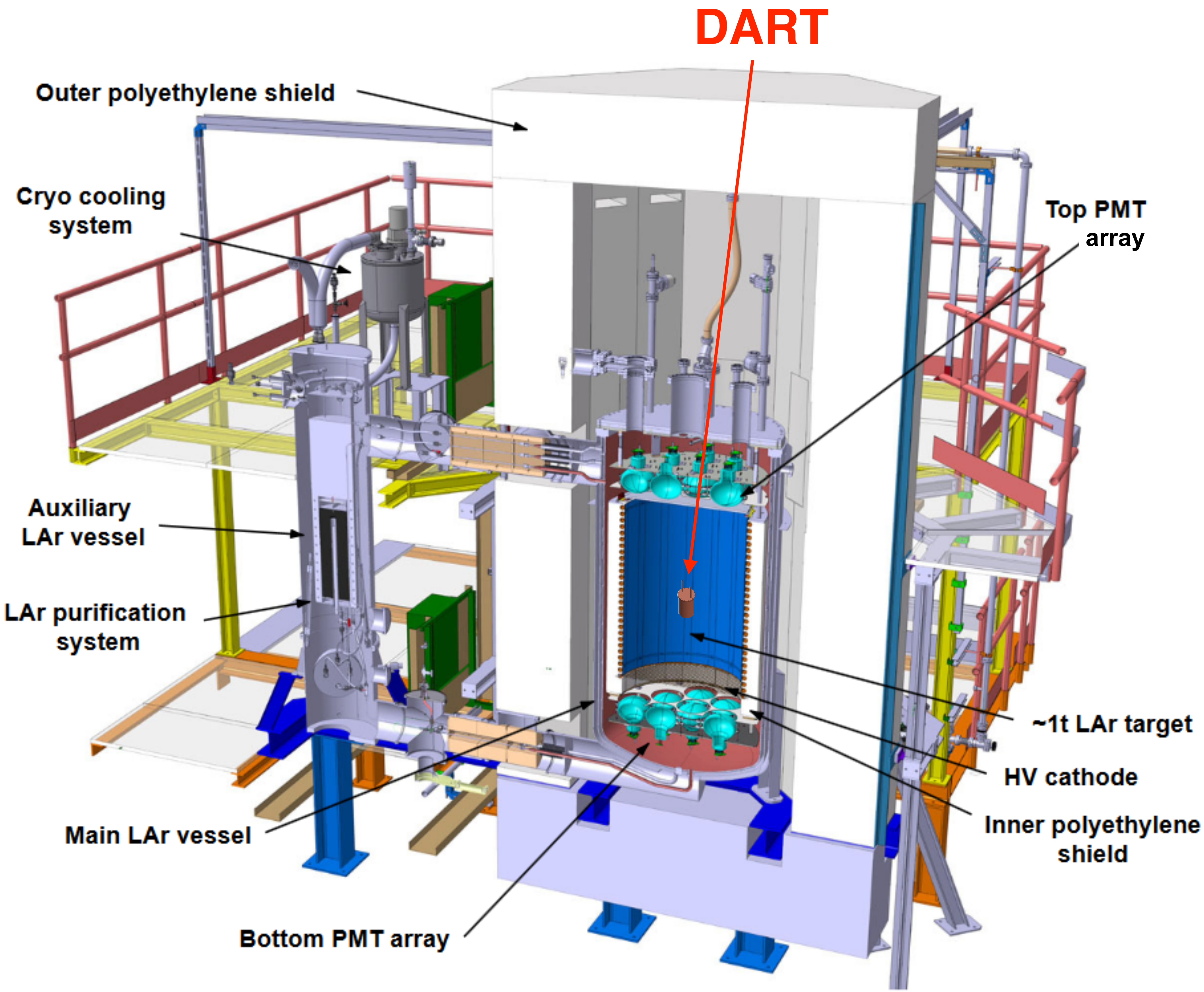
ArDM in single phase

Use existing flanges on top

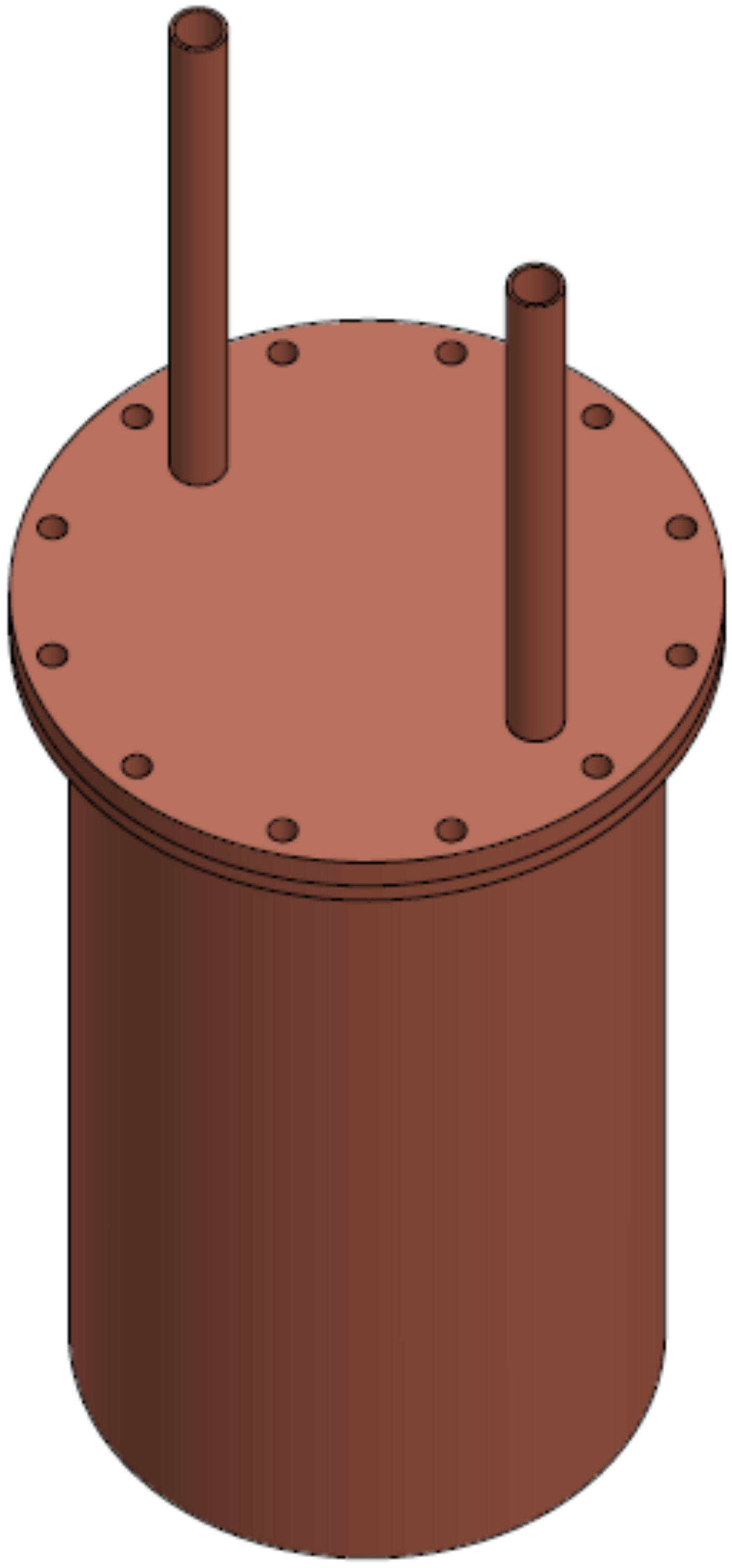
Use spare DAQ channels

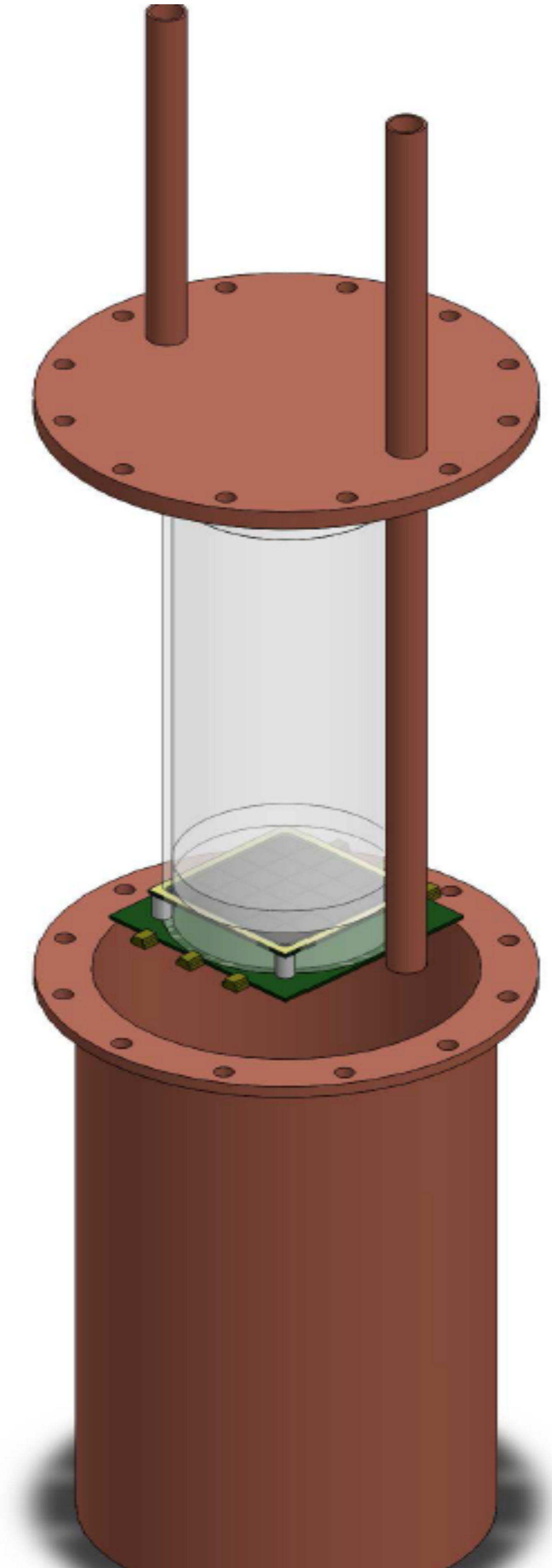
Dissipated power and condensation heat to be absorbed by ArDM cryogenic system

Thermodynamic stability to be tested at CERN



Mechanical design





Mechanical design

Vessel: 99.99% OFHC copper ~7 kg.

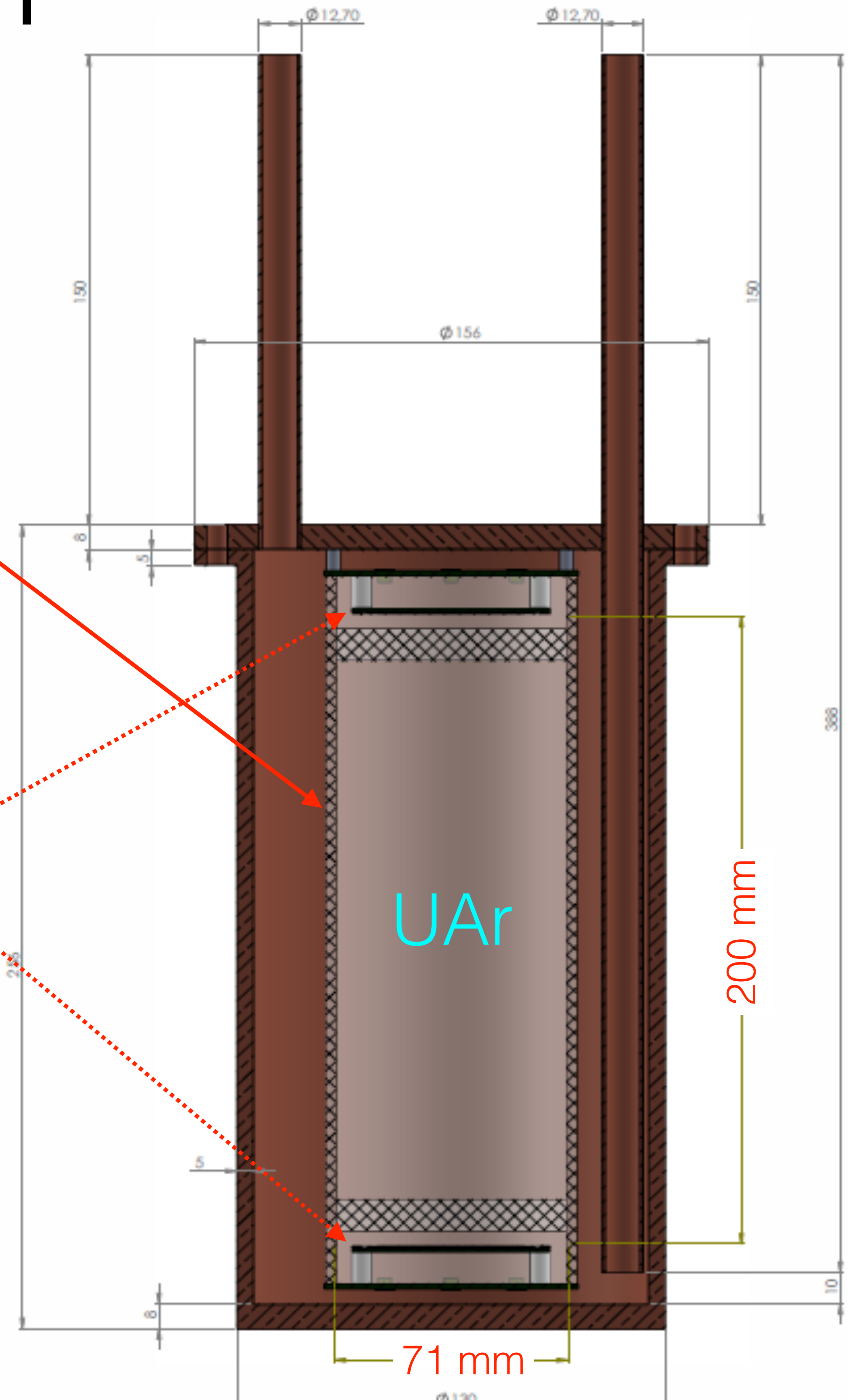
PMMA cylindrical support structure: 2-halves cylinder, 2x6 mm-thickness plates (~200 g), with TPB coating.

Reflector: 3M foil outside the PMMA cylinder.

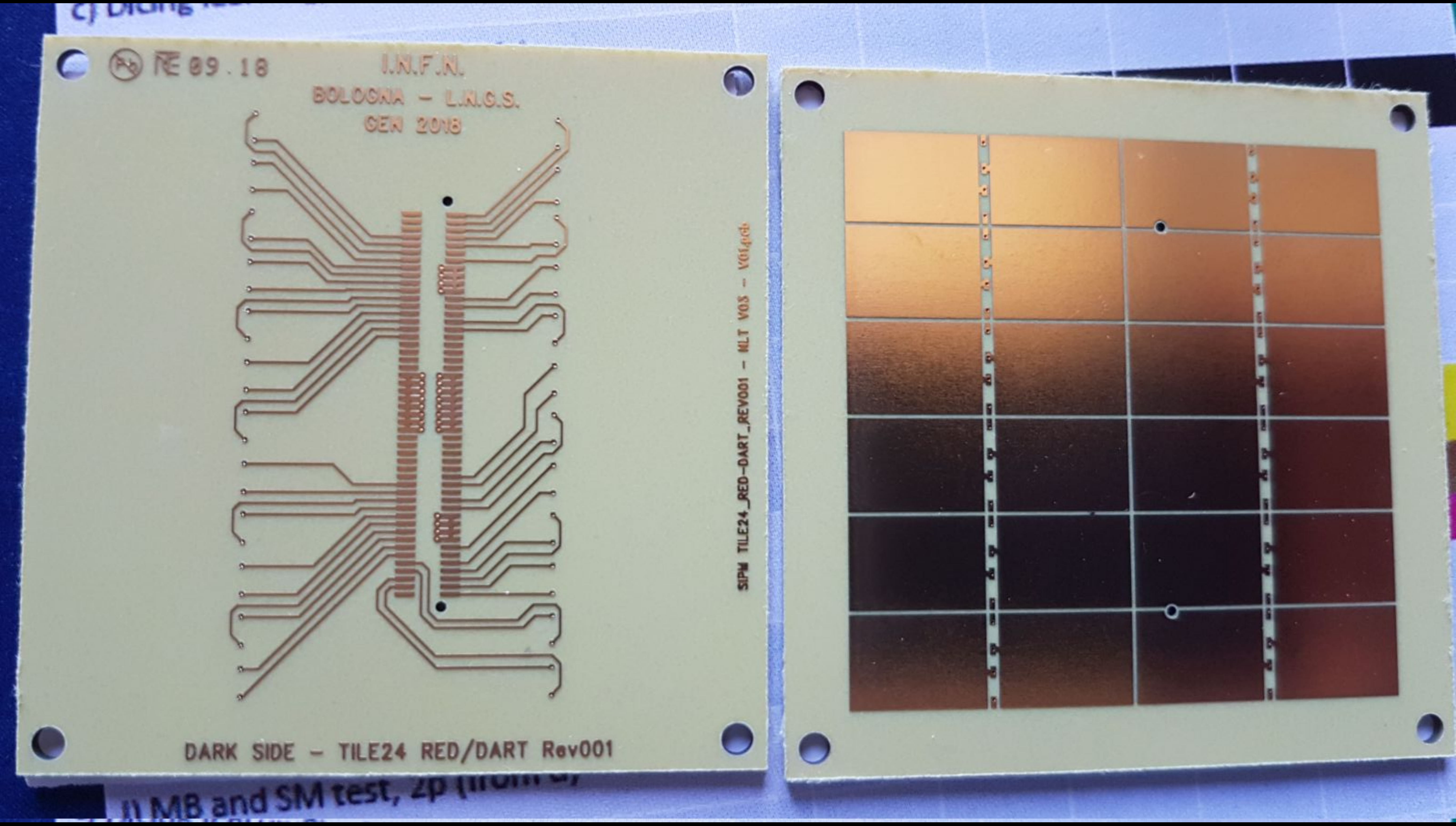
Light collection: 2 SiPM tiles (from DarkSide).

Maximum internal volume ~2.6 ℓ.

Liquid UAr volume ~0.8 ℓ (from DS-50).



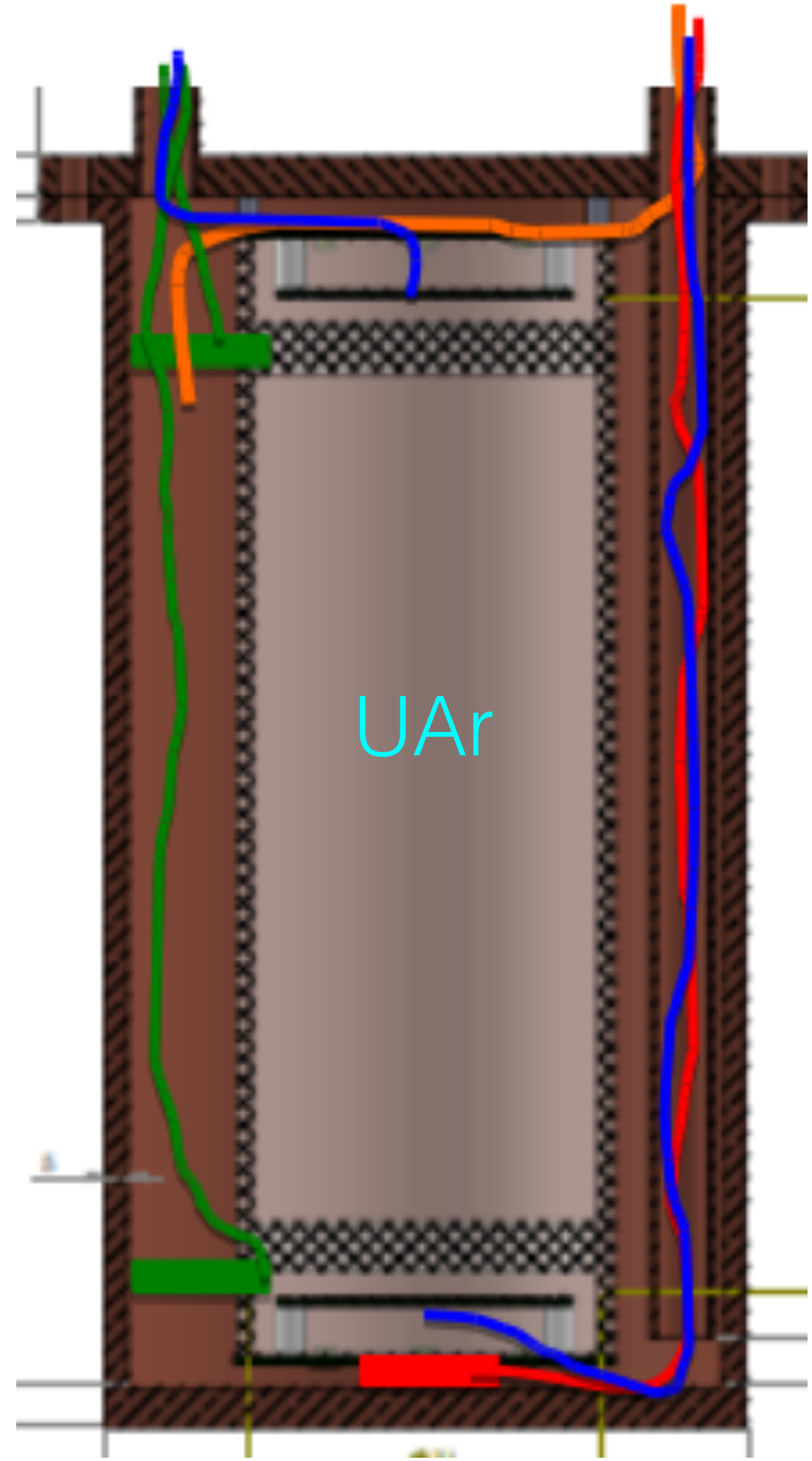
DarkSide tile for DART



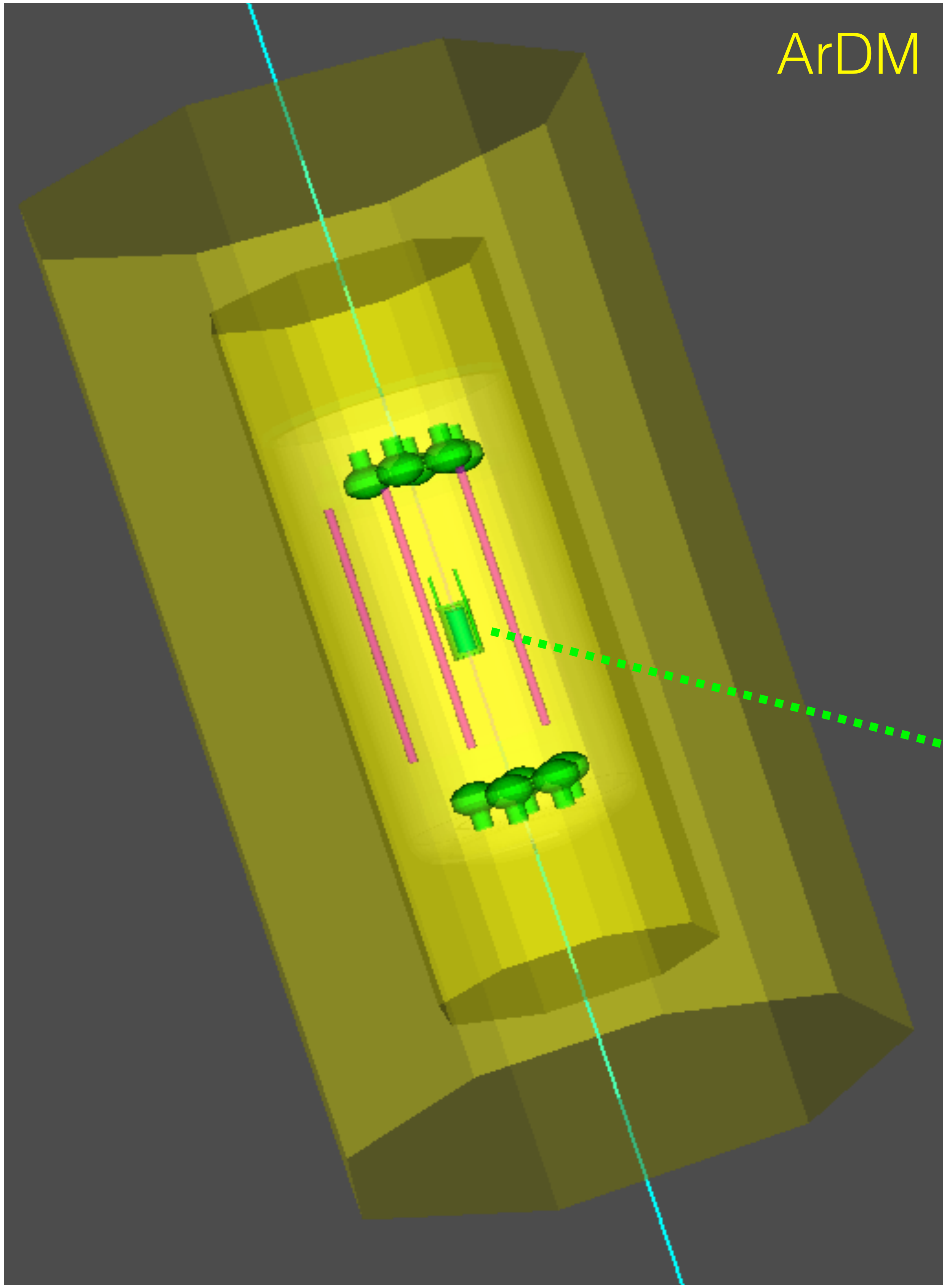
Services (sketch)

Two service pipes (Cu):

- SiPMs electrical connections.
- Heater (Ar recovery)
- Temperature sensors (top and bottom).
- Optical fiber (calibration).

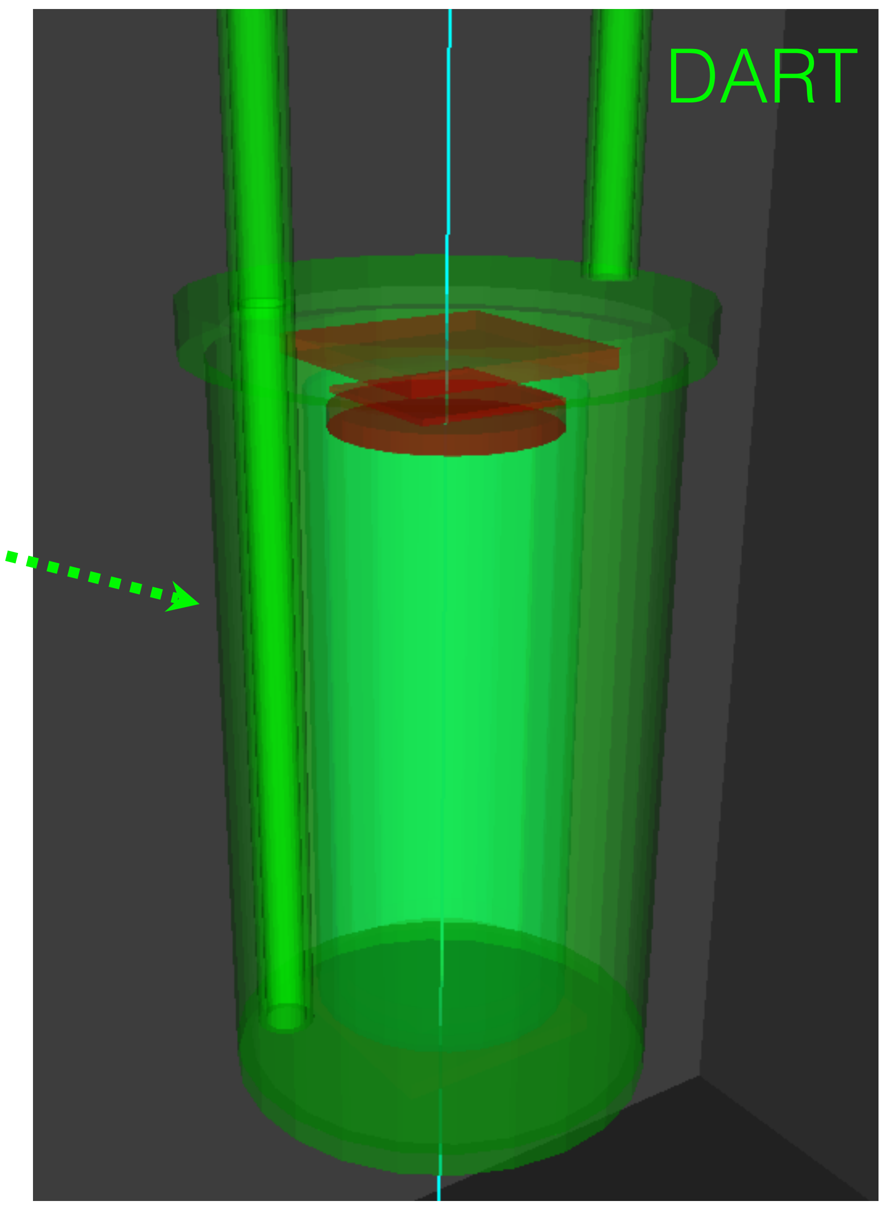


Simulation with Geant4



Full ArDM and DART simulation, geometries and materials:

PMMA, TPB, SiPM and reflector.

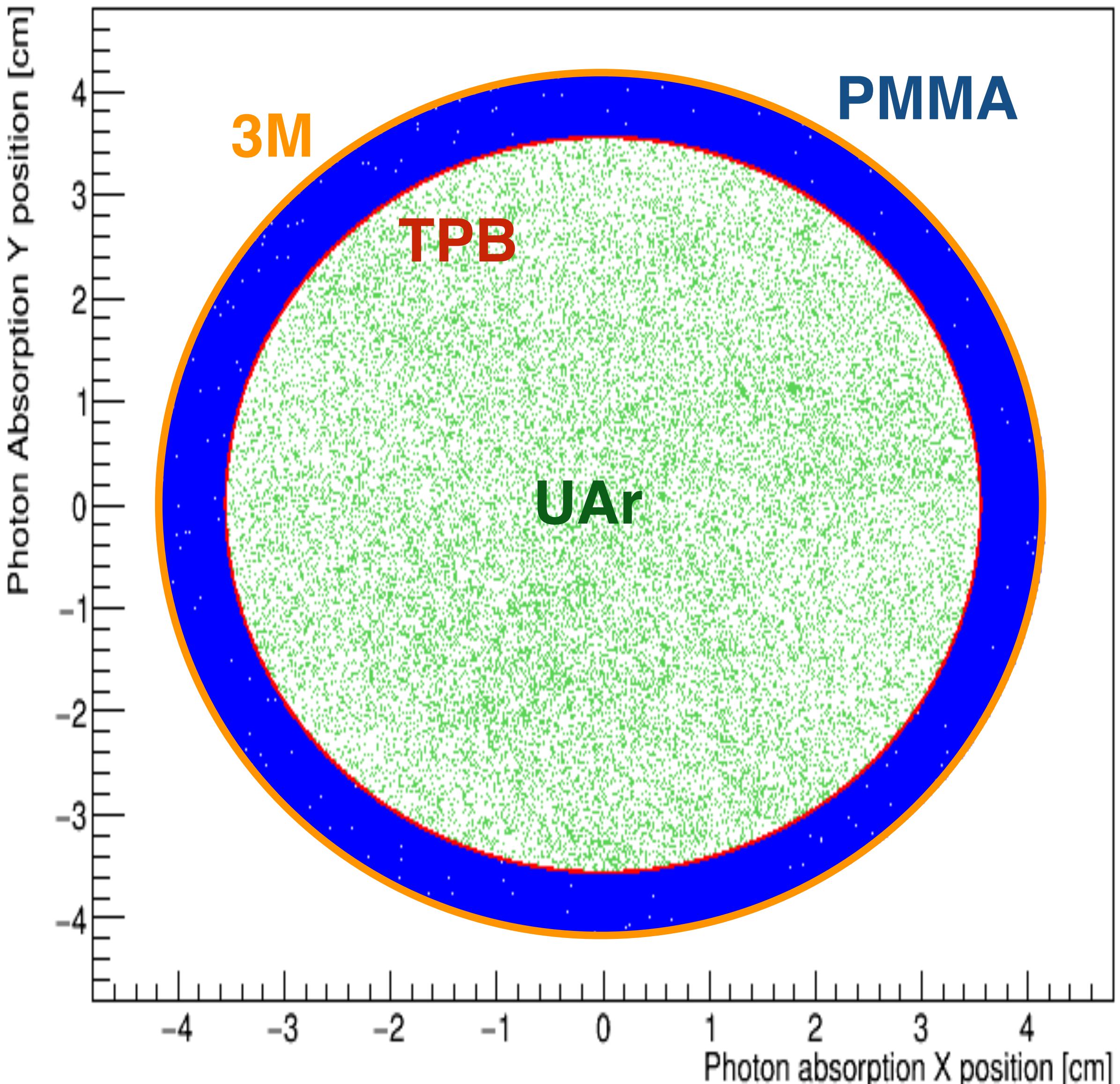


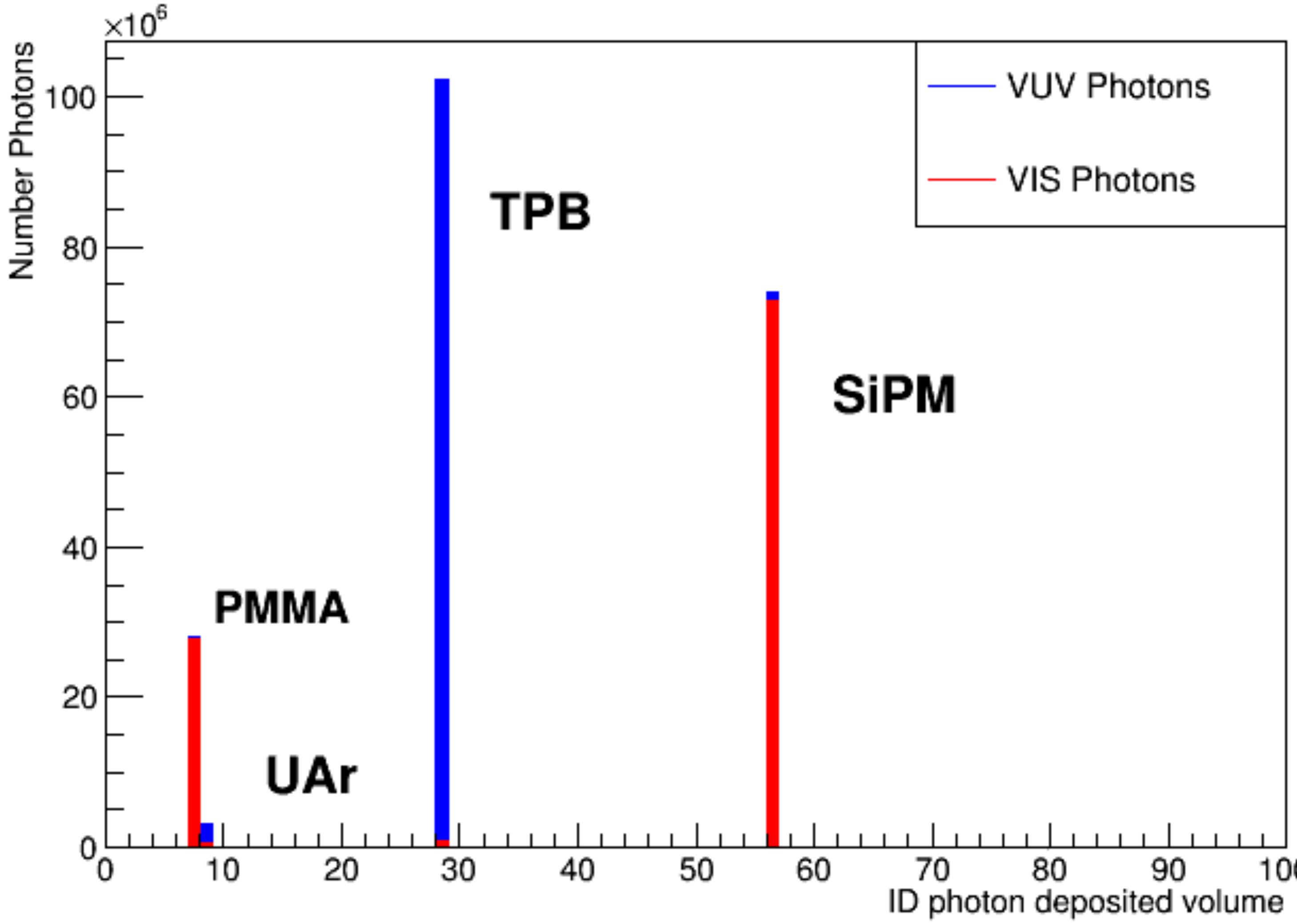
Optical simulation in DART

Based on the simulation code of the DarkSide-50 experiment.

Simulated ^{39}Ar events in the UAr active volume to tune the properties of optical materials and interfaces.

SiPM PDE not considered at this level.

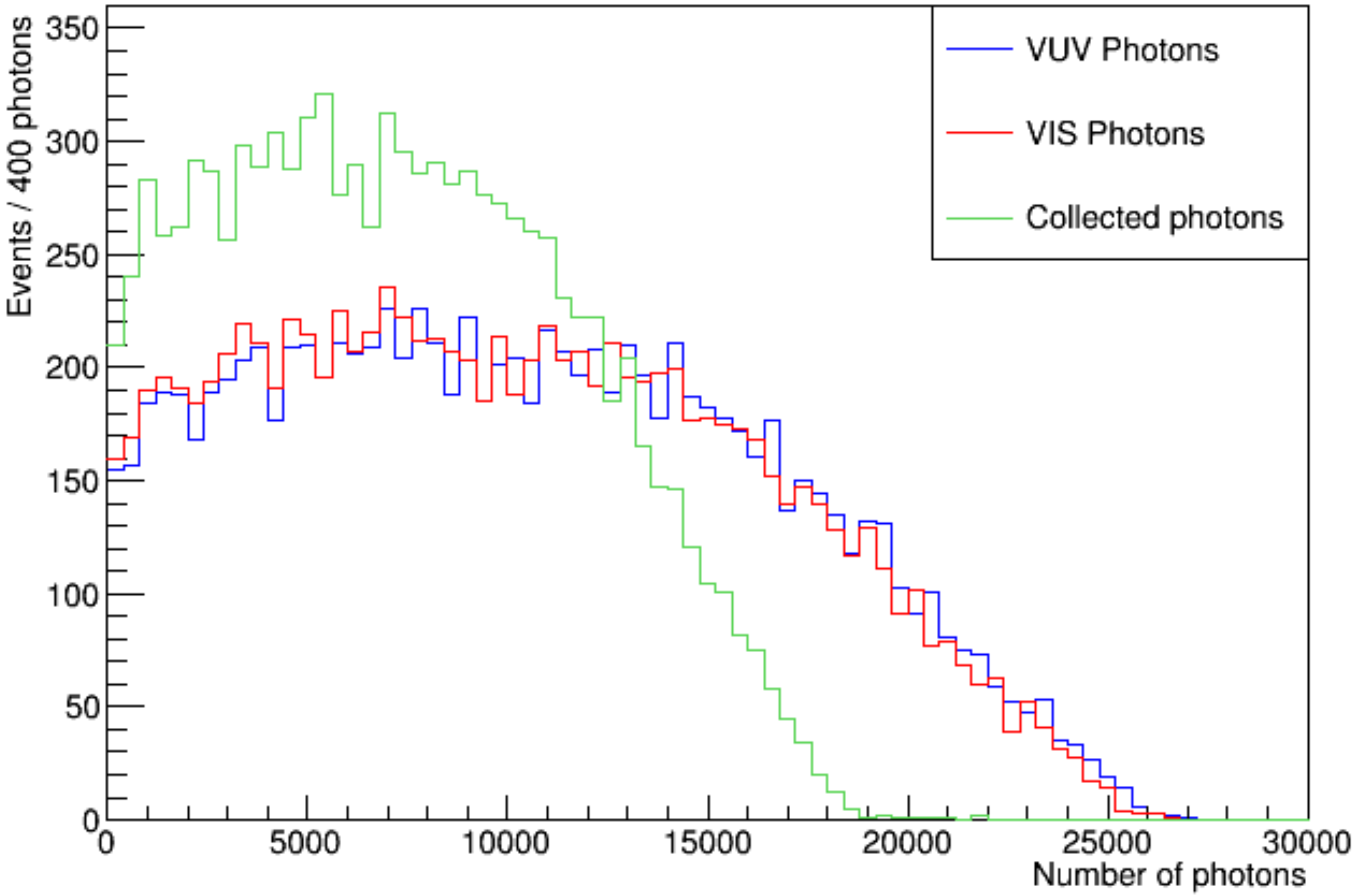




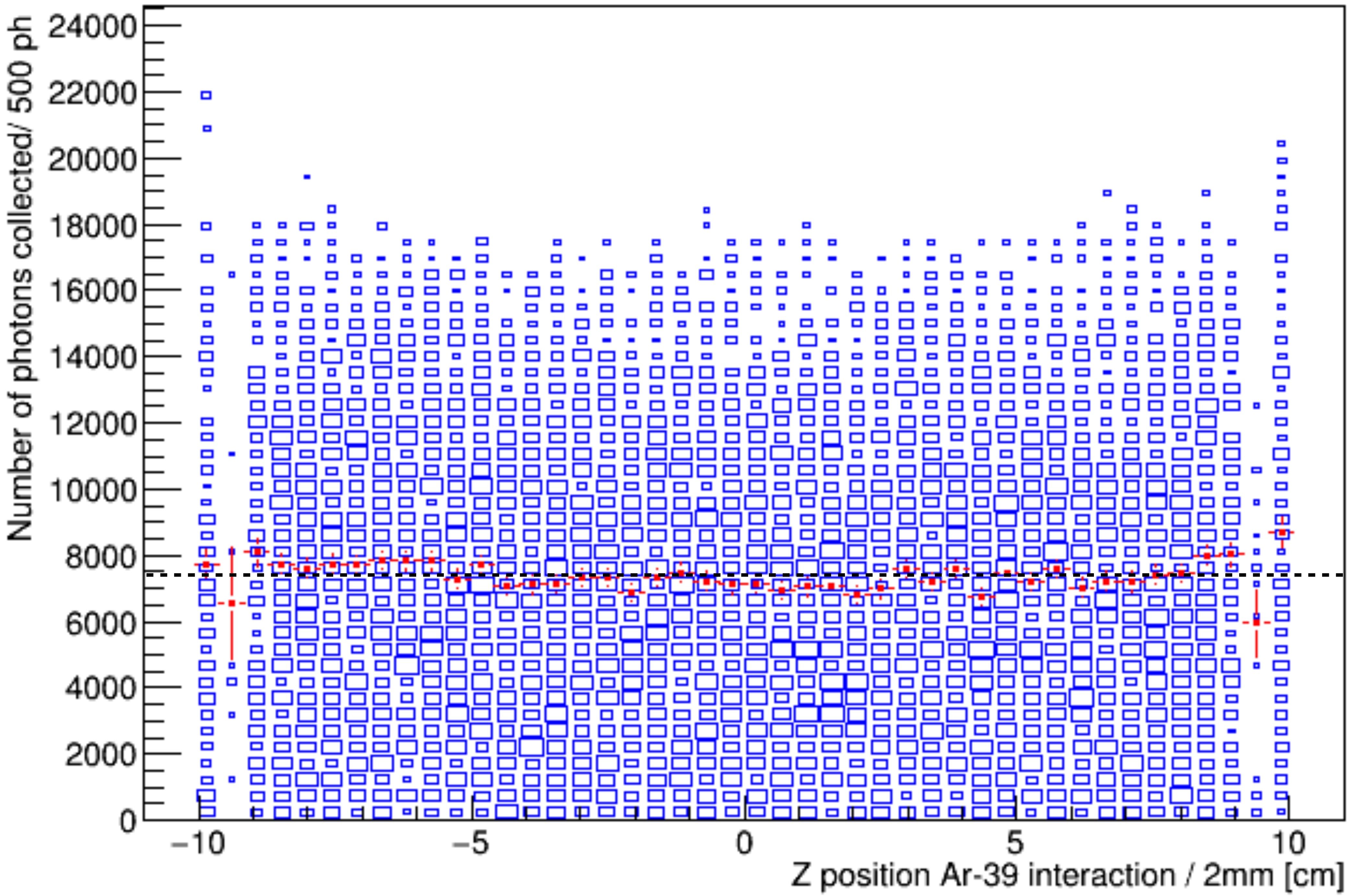
Photons produced and collected

High average number of photons per event (in both SiPMs):

VUV ≈ 10.5 k,   Visible ≈ 10 k,   collected ≈ 7 k → **efficiency ≈ 70%**



Average number of collected photons (top+bottom) slightly higher for ^{39}Ar decays closer to SiPM planes.
Uniform response expected for DART.



Analysis of events in DART

Background events (ɣ) from the detector materials and from the surrounding rock deposit energy in ArDM, DART, or both.

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

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

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

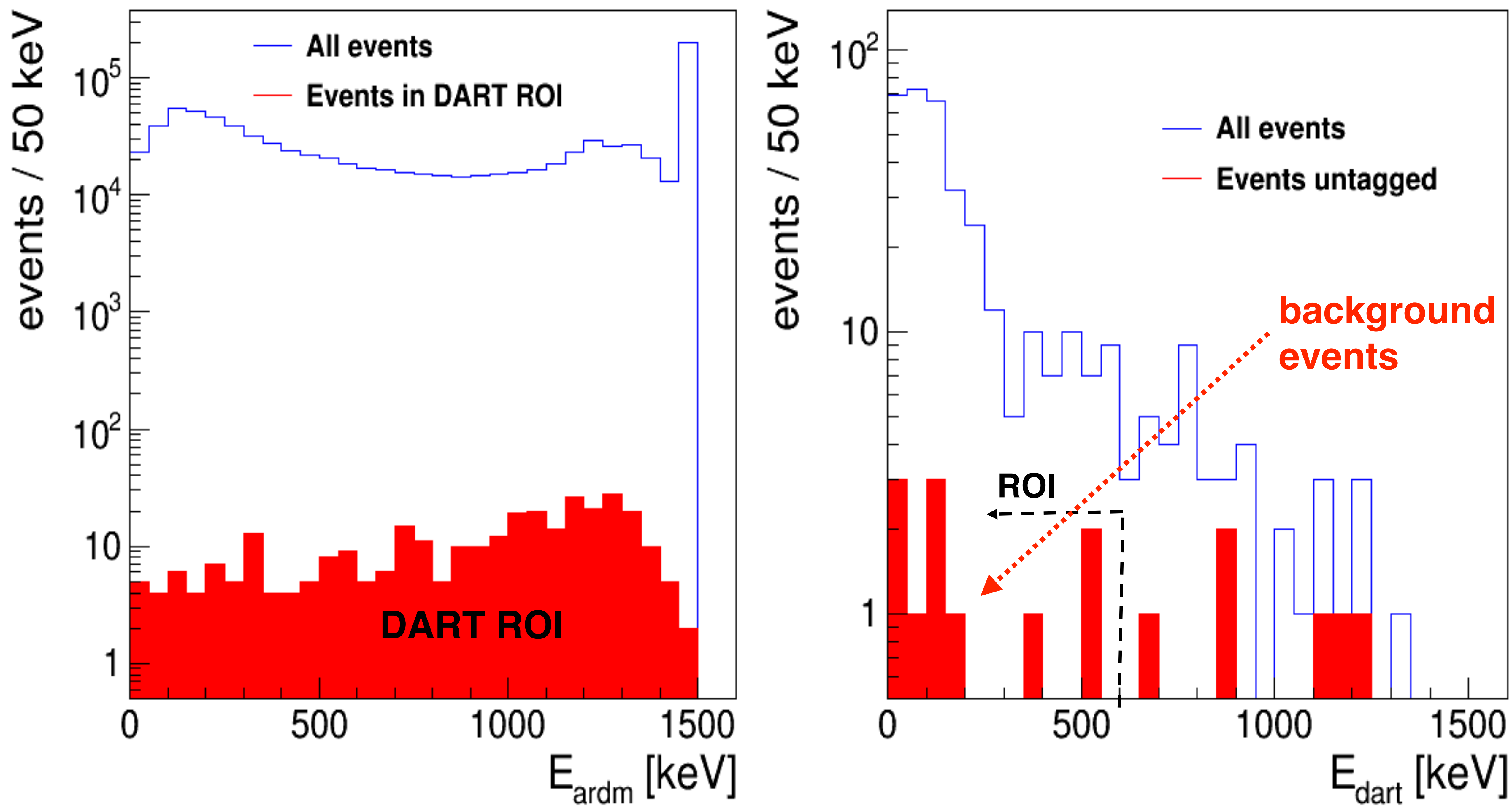
$$\mathbf{E_{dart} < 600\ keV}$$

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

Background from the cryostat

Example

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



ArDM materials radio-impurities

ɣ background mainly from SS cryostat and PMTs [B. Montes Ph.D. thesis].

Contributions from ^{238}U, ^{232}Th, ^{40}K and ^{60}Co measured with HPGe at LSC.

Sample	^{238}U [ppb]	^{235}U [ppb]	^{232}Th [ppb]	^{40}K [ppb]	^{60}Co [kru]
PMT glass	51.7±0.3	0.70±0.02	28.3±0.5	1.7±0.07	<0.2
PMT metal	14.7±0.3	0.71±0.04	18.4±0.7	12±0.4	–
PMT base	746±1	9.0±0.1	2720±10	64±0.7	–
SS struct	0.257±0.002	<0.05	1.57±0.01	<0.04	1.24±0.01
SS clamp	<0.6	1.0±0.3	<3	<0.1	2.0±0.2
SS rod	<2	1.18±0.08	<6	0.18±0.01	0.76±0.02
PE clamp	2.85±0.05	<0.2	23.3±0.6	0.3±0.07	<0.5
PE shield	0.34±0.06	<0.03	2.41±0.03	0.06±0.01	<0.06
HVres	118±1	1.92±0.02	466±1	6.7±0.06	–

ArDM collaboration, J. Calvo et al., "Commissioning of the ArDM experiment at the Canfranc underground laboratory: first steps towards a tonne-scale liquid argon time projection chamber for Dark Matter searches," JCAP 2017 (2017) 003.

DART materials radio-impurities

Cu (NEXT): measurements from Ge γ-ray spectroscopy and GDMS.

^{238}U 0.012, ^{232}Th 0.004, ^{40}K 0.06 and ^{60}Co 0.04 mBq/kg.

Assuming activities in Arlon (mBq/kg):
3 for ^{238}U and 0.3 for ^{232}Th

AVERAGES		232 Th				238 U			
PNNL Sample ID	Description	ppt	+/- stdev	µBq/kg	+/- stdev	ppt	+/- stdev	µBq/kg	+/- stdev
2017-38-1	Arlon85NT_0200	58.6	6.7	237	27	169	4	2103	51
2017-38-2	Arlon55NT_0040	43.2	5.3	175	21	267	15	3322	184
2017-38-3	Arlon55NT_0200	64.9	10.6	263	43	245	7	3055	92
2017-38-4	Arlon85NT_0040	22.8	1.5	92.3	5.9	114	3	1420	40

New measurements indicate higher activities for Arlon:
100 mBq/kg, yielding ~300 events/week.

Under investigation.

Internal background in ROI

Background from radio-impurities in the materials.

Material	events/week	Untagged events/week
DART Cu	40	10
DART PCB	100	50
ArDM cryostat	2500	90
ArDM PMTs	3000	60
Total	5640	210

External background in ROI

Flux (γ/cm^2 s) of the dominant external backgrounds [1]:

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

ArDM PE surface 43 m^2.

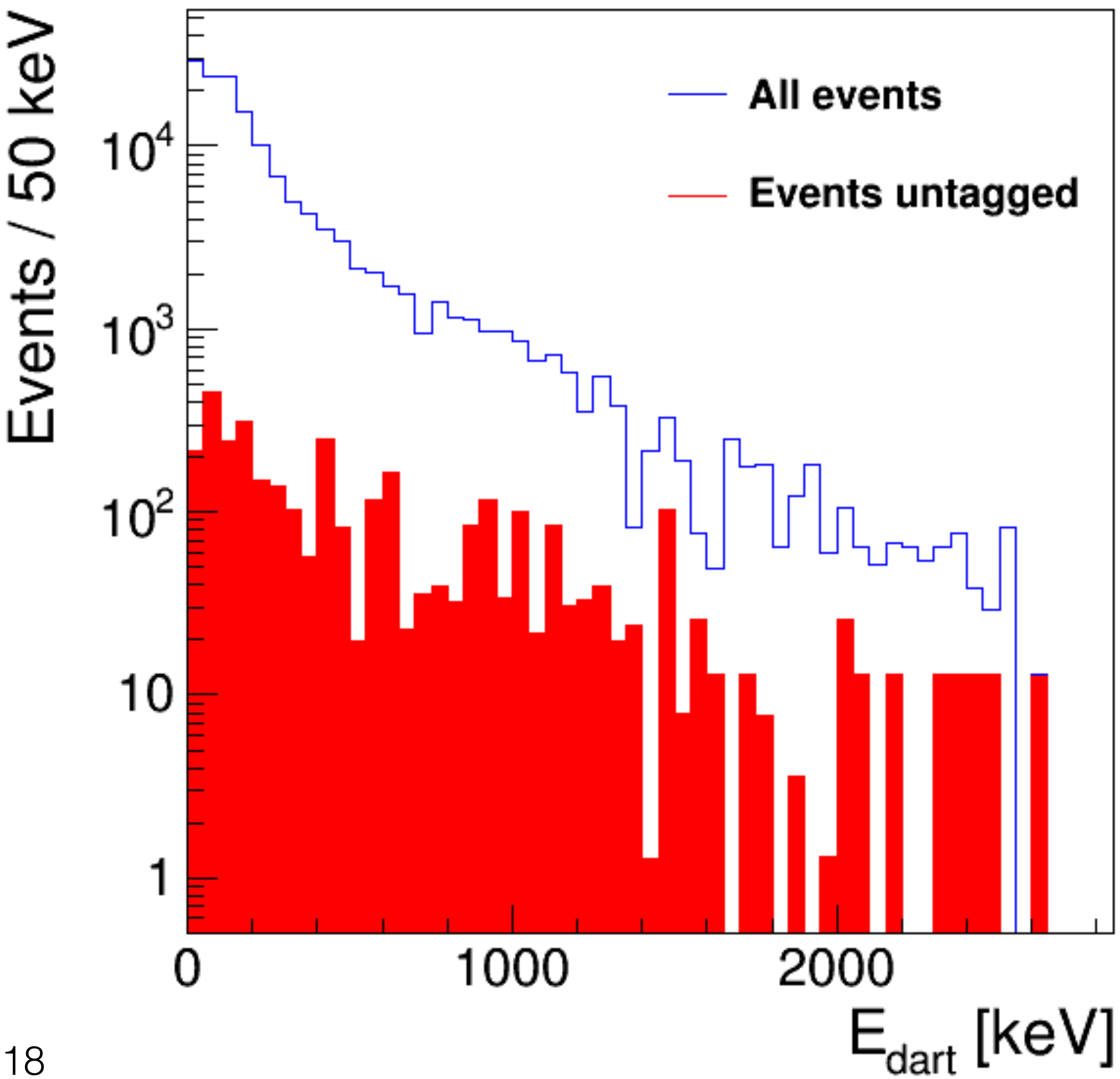
Radionuclide	events/week	untagged events/week
^{238}U-chain	76 k	1330
^{232}Th-chain	23 k	280
^{40}K	27 k	390
Total	126 k	2000

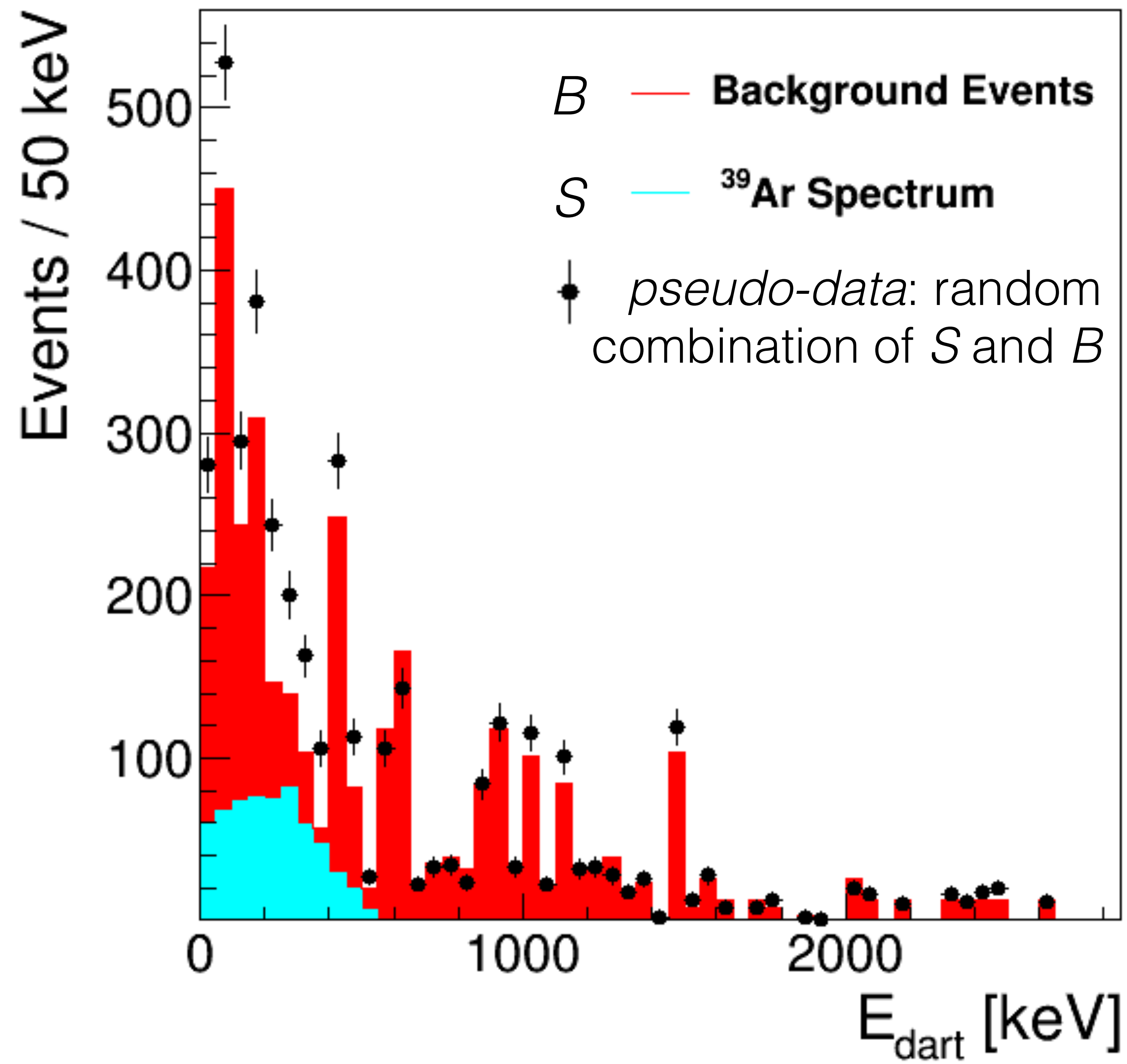
[1] ArDM Collaboration, *Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC*, arXiv:1712.01932 (2017).

Signal and background spectra

Events per week: (full spectrum)

internal	=	270
external	=	3040
signal (^{39}Ar)	=	600





^{39}Ar expected sensitivity in 1 week

Events per week: (full spectrum)

internal = 270
external = 3040
signal (^{39}Ar) = 600

$$d = n_s \cdot S + n_b \cdot B$$

UAr, 0.73 mBq/kg:

n_s = 620 ± 60

n_b = 3300 ± 70

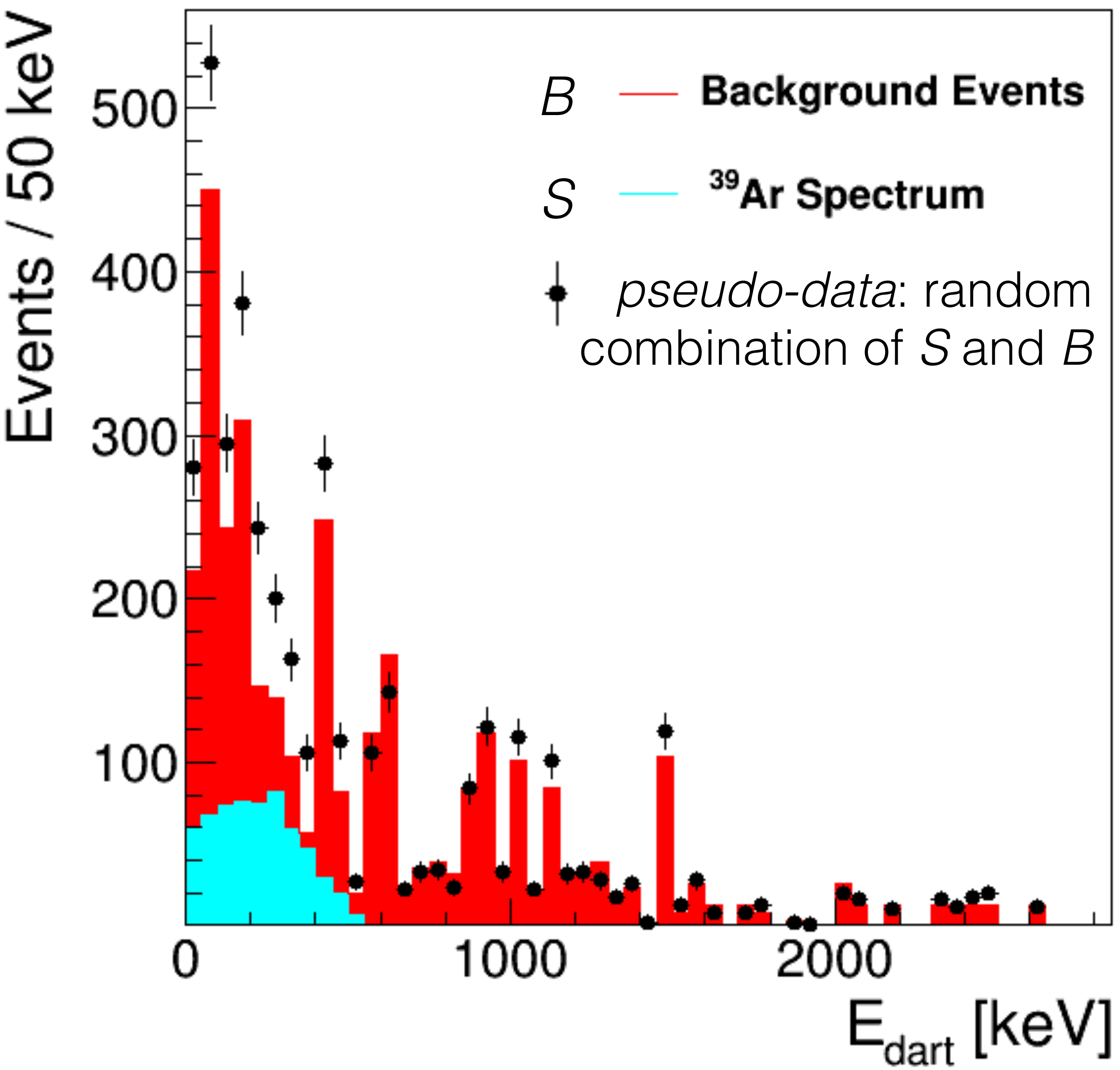
σ ≈ 10

DAr, 0.07 mBq/kg:

n_s = 70 ± 50

n_b = 3300 ± 80

σ ≈ 1.3 !!



Proper sensitivities are being calculated with optical simulations.

External background

Origin of external background events leaving a signal in DART.

Most events come from the side.

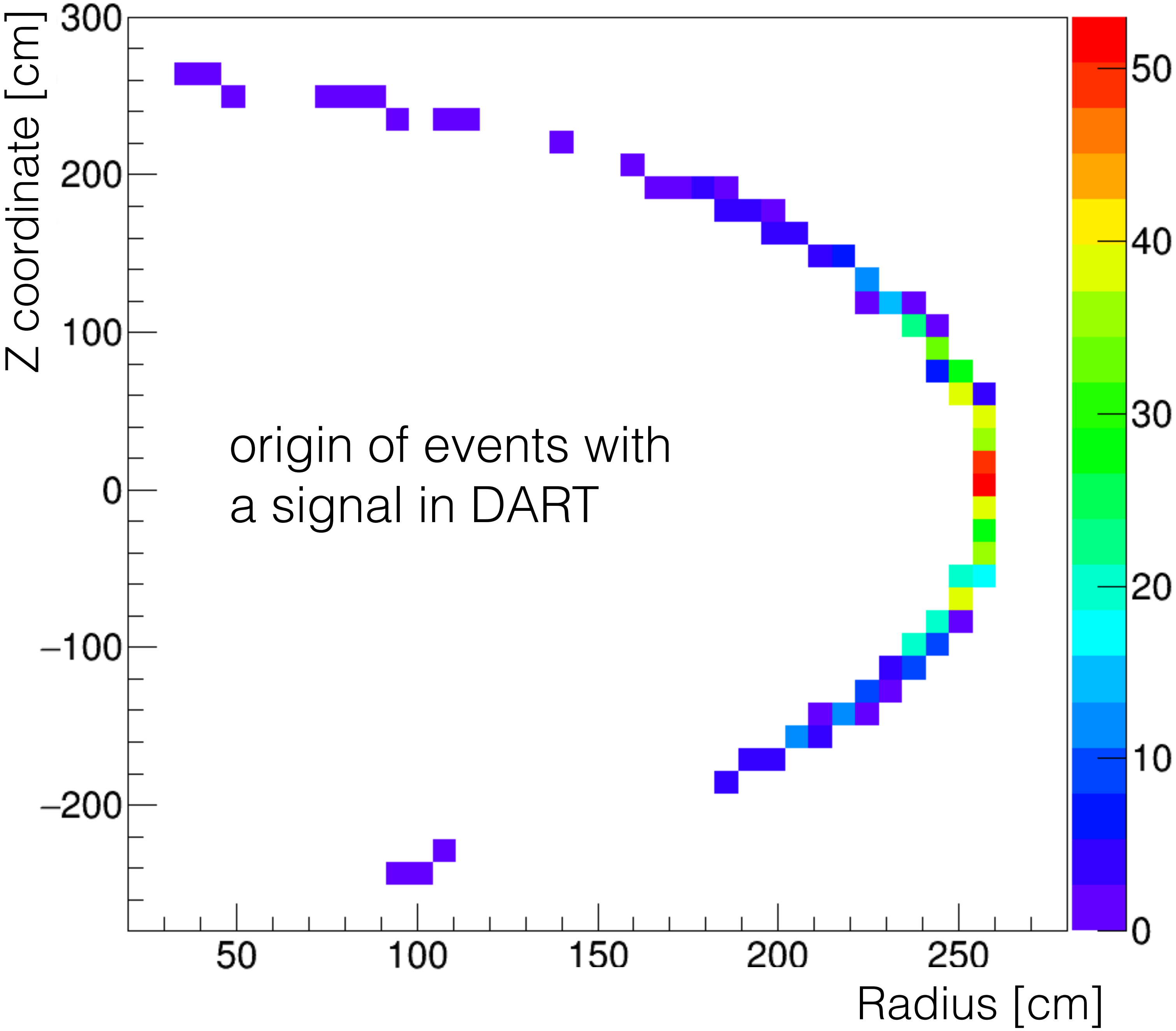
Considering the use of a lead shielding to reduce the external background.

DAr, 0.07 mBq/kg:

$n_s = 70 \pm 50$

$n_b = 3300 \pm 80$

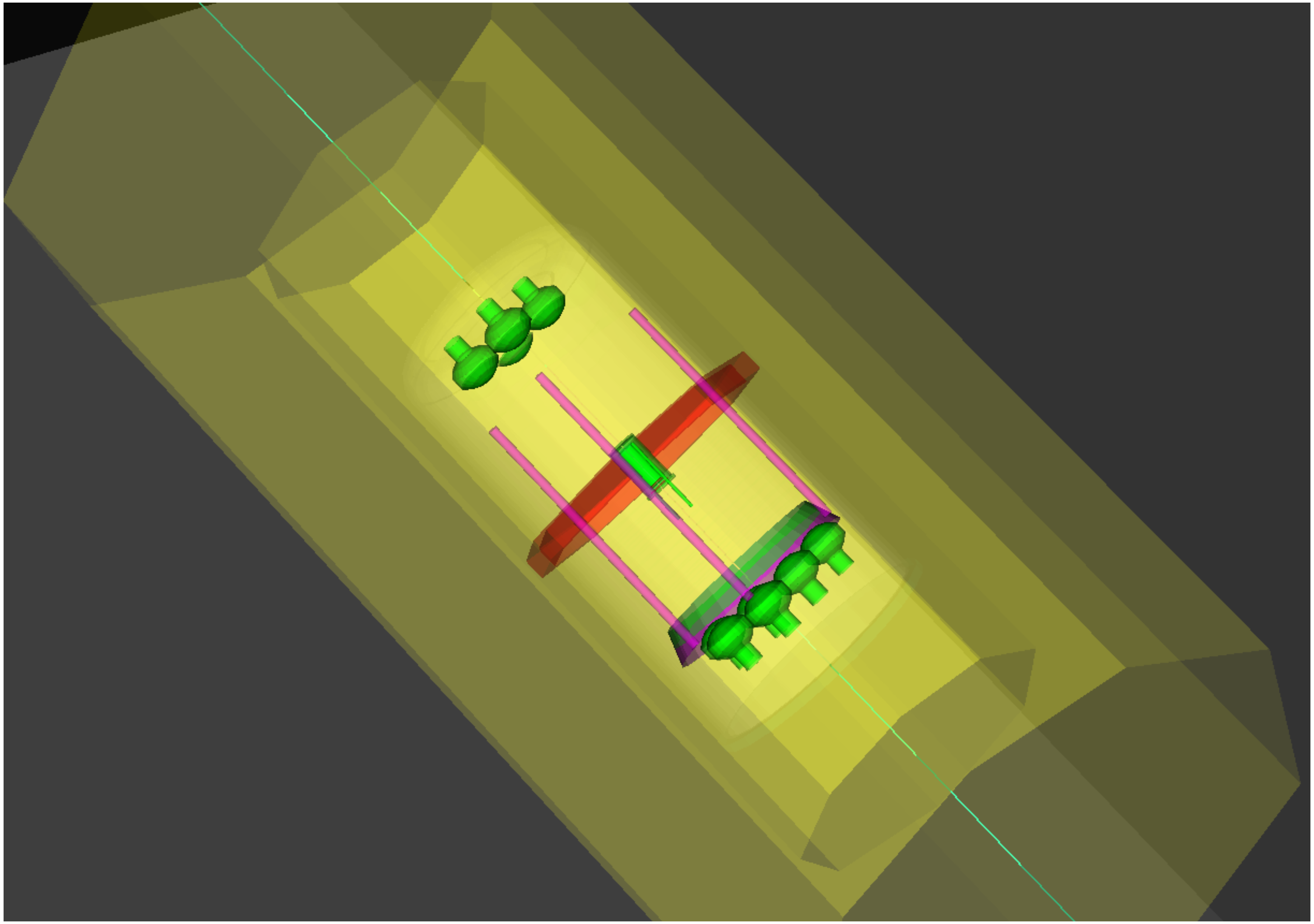
$\sigma \approx 1.3$!!



Lead belt shielding

Initial tests: 10 cm height, 7 cm width, Pb belt centred around DART.

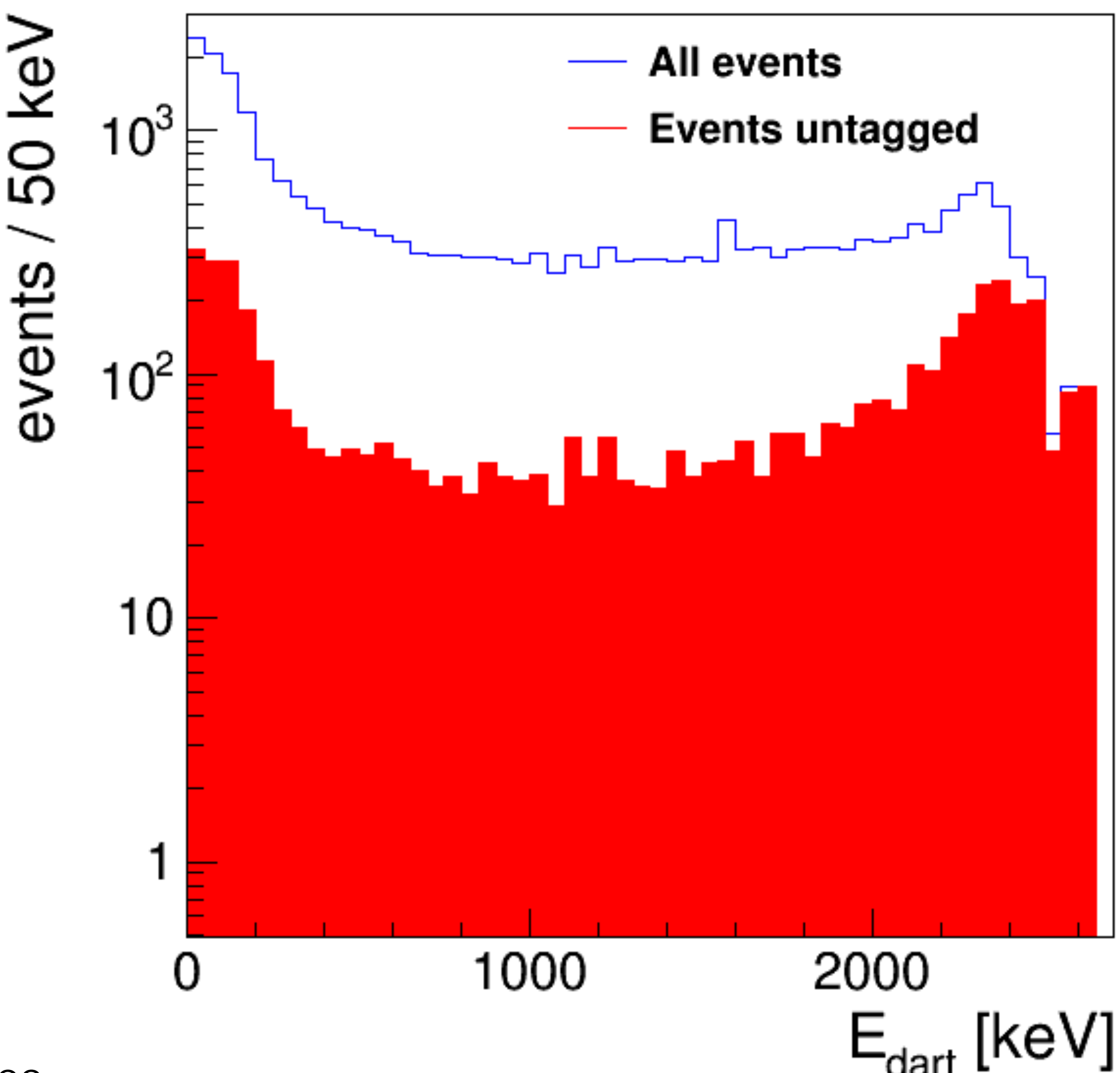
Shoot 1 MeV and 2.6 MeV γ from outside ArDM straight into DART.

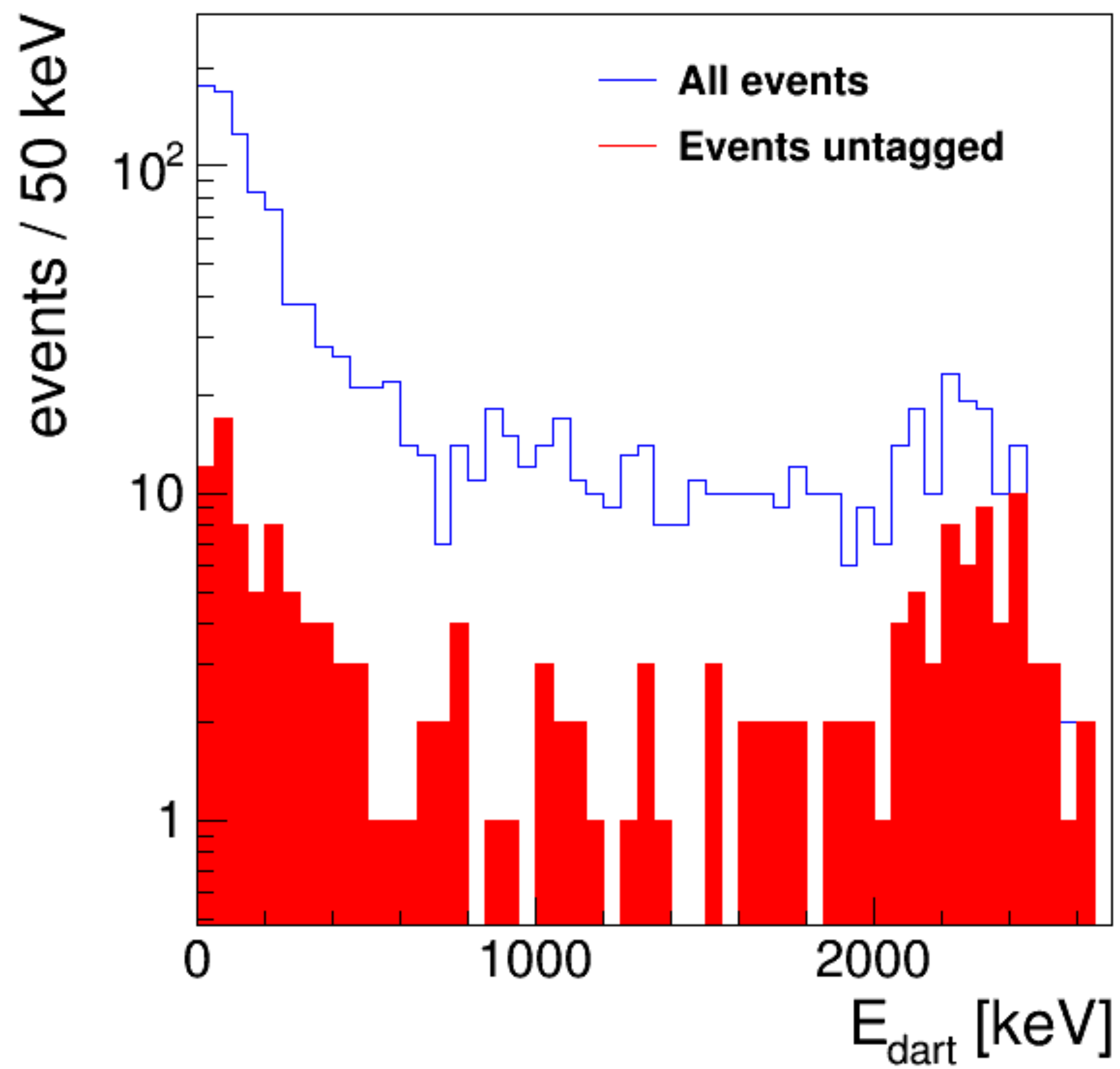


Shielding impact for 2.6 MeV γ

without Pb: in ROI 11k, untagged 1.6k - with Pb: in ROI 800, untagged 70

Background reduction factor **≈ 20**. Sensitivity for DAr: **σ ≈ 4** in one week !





Outlook

Thorough simulation studies of background, including the optical response of the detector.

Finalising the mechanical design and technical drawings.
TDR in preparation.

Next two months: decision on shielding, chamber construction (CIEMAT), and testing (ArDM clone at CERN), delivery of SiPMs.

Around summer: DART assembly with radio-pure electronics and final installation in the Canfranc Underground Laboratory (LSC).

Q4 2018: Data taking, analysis, and results.

Long term: optimise setup for higher depletion factors.