Argo

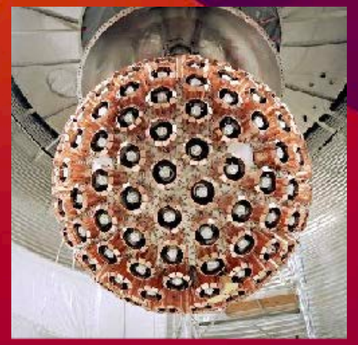
Presentation to P5 Committee
SLAC Townhall, May 2-5, 2023

Cristiano Galbiati | Princeton University and Gran Sasso Science Institute | May 3, 2023

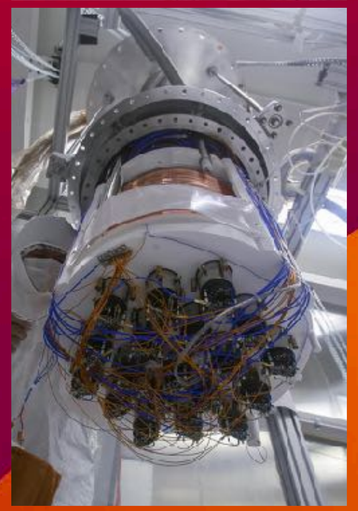
Since 2017

The Global Argon Dark Matter Collaboration (GADMC)

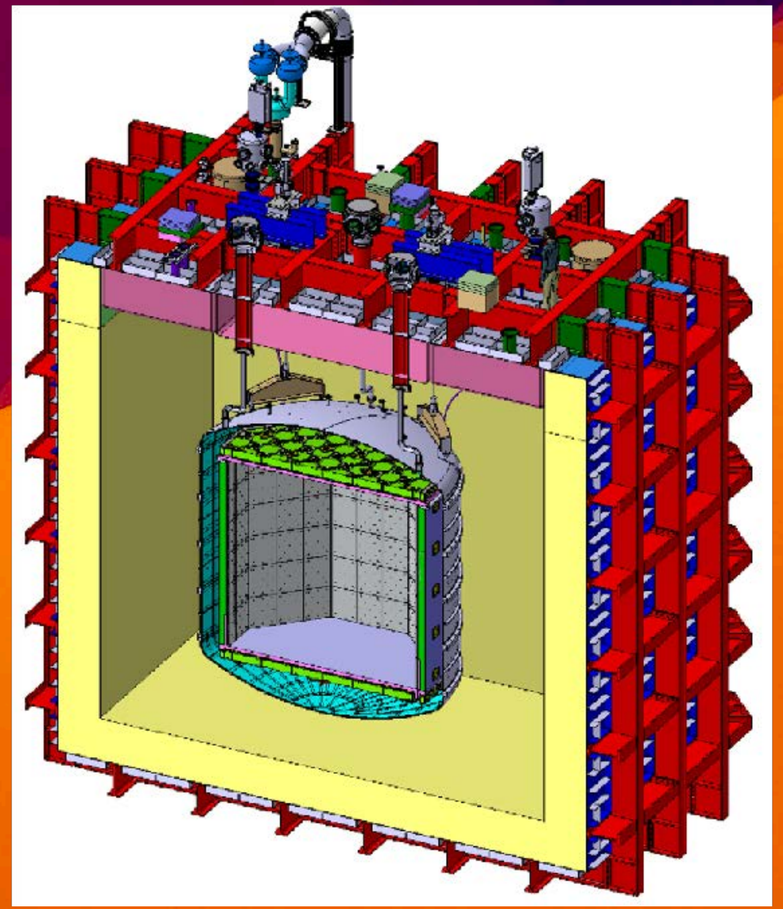
GADMC brings together more than 400 scientists committed to explore heavy (and light) dark matter to the neutrino fog and beyond



DEAP-3600

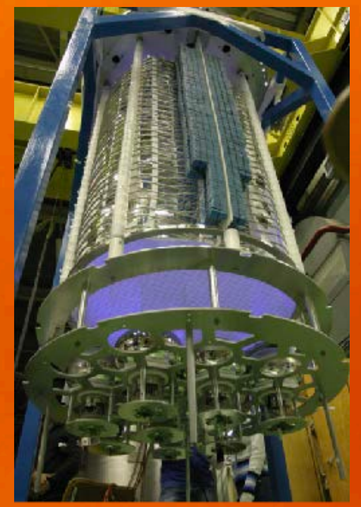


DarkSide-50



MiniCLEAN

ARDM



The Global Argon Dark Matter Collaboration

With many thanks for support to:

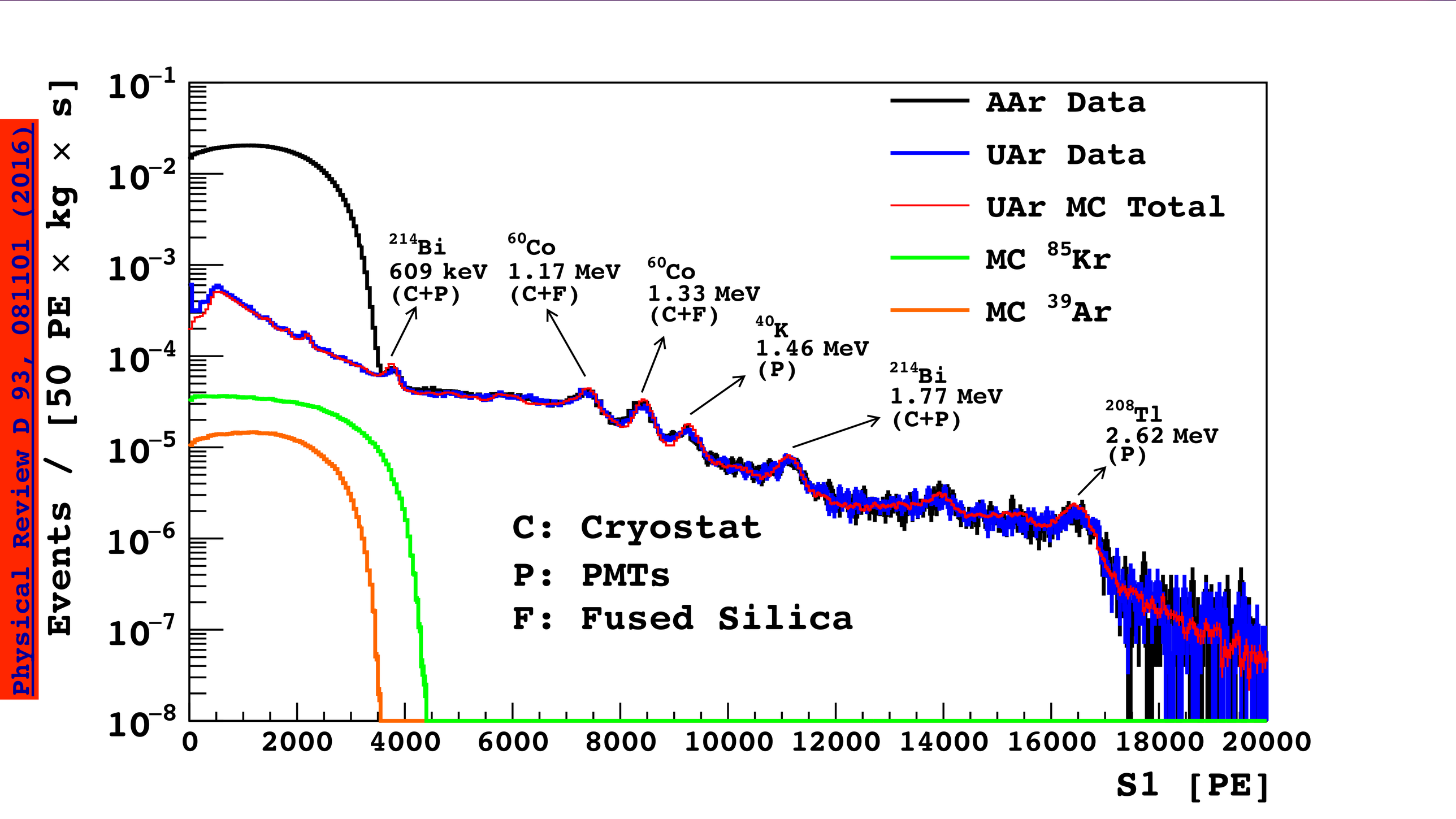
- CFI and NSERC (Canada)
- IN2P3 (France)
- INFN and MIUR (Italy)
- STFC (UK)
- NSF and DOE (U.S.)
- Poland and Spain Ministries for Science and Education

ArDM
DarkSide-50
DEAP
MiniCLEAN

The Global Argon Dark Matter Collaboration

DS-20k
{20 t fid., 50 t full}
[ops 2026-]

Argo
{300 t fid., 400 ton full]}
[Third Generation, starting in earnest in the US during this P5 period]


Physical Review D 93, 081101 (2016)
Events / [50 PE × kg × s]
S1 [PE]
AAr Data
UAr Data
UAr MC Total
MC ^{85}Kr
MC ^{39}Ar
^{214}Bi 609 keV (C+P)
^{60}Co 1.17 MeV (C+F)
^{60}Co 1.33 MeV (C+F)
^{40}K 1.46 MeV (P)
^{214}Bi 1.77 MeV (C+P)
^{208}Tl 2.62 MeV (P)
C: Cryostat
P: PMTs
F: Fused Silica

European Physics Journal C 81, 823 (2021)

>9 orders of magnitude suppression of ER backgrounds

no deviation from statistical expectations

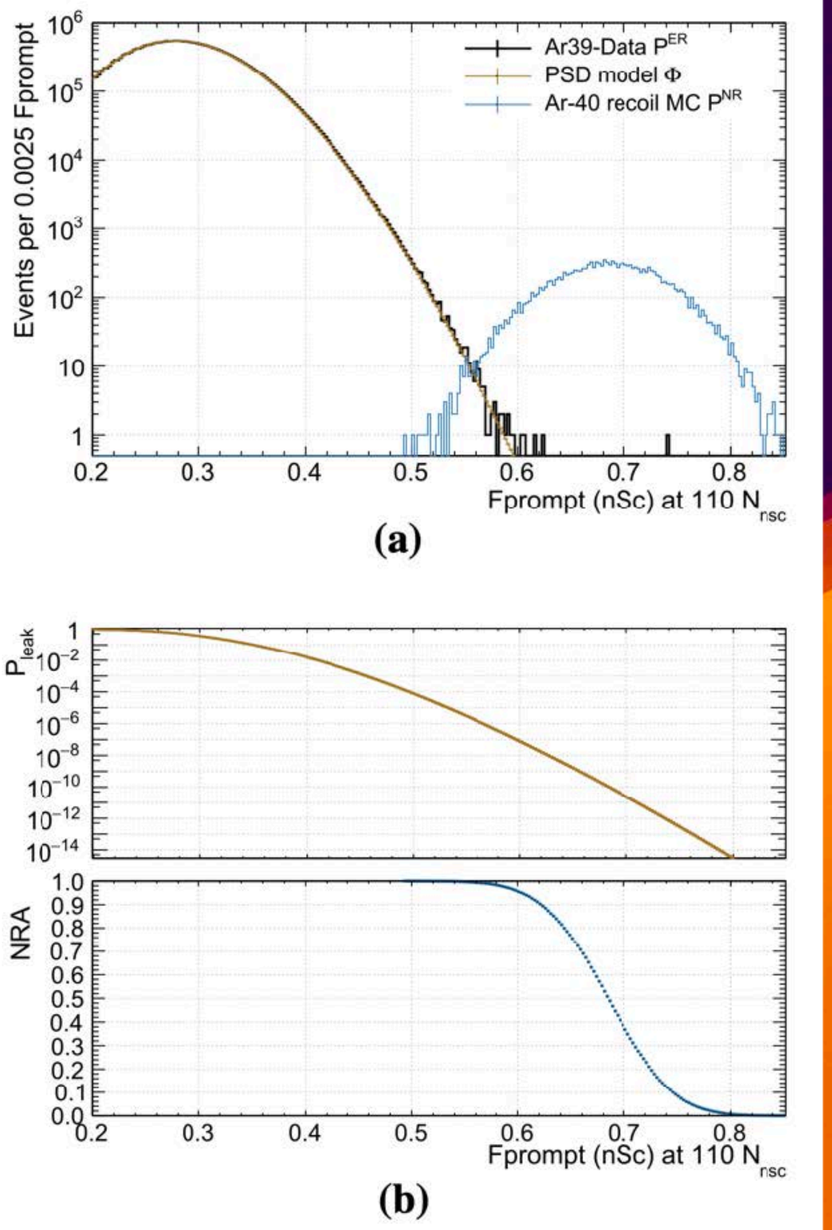
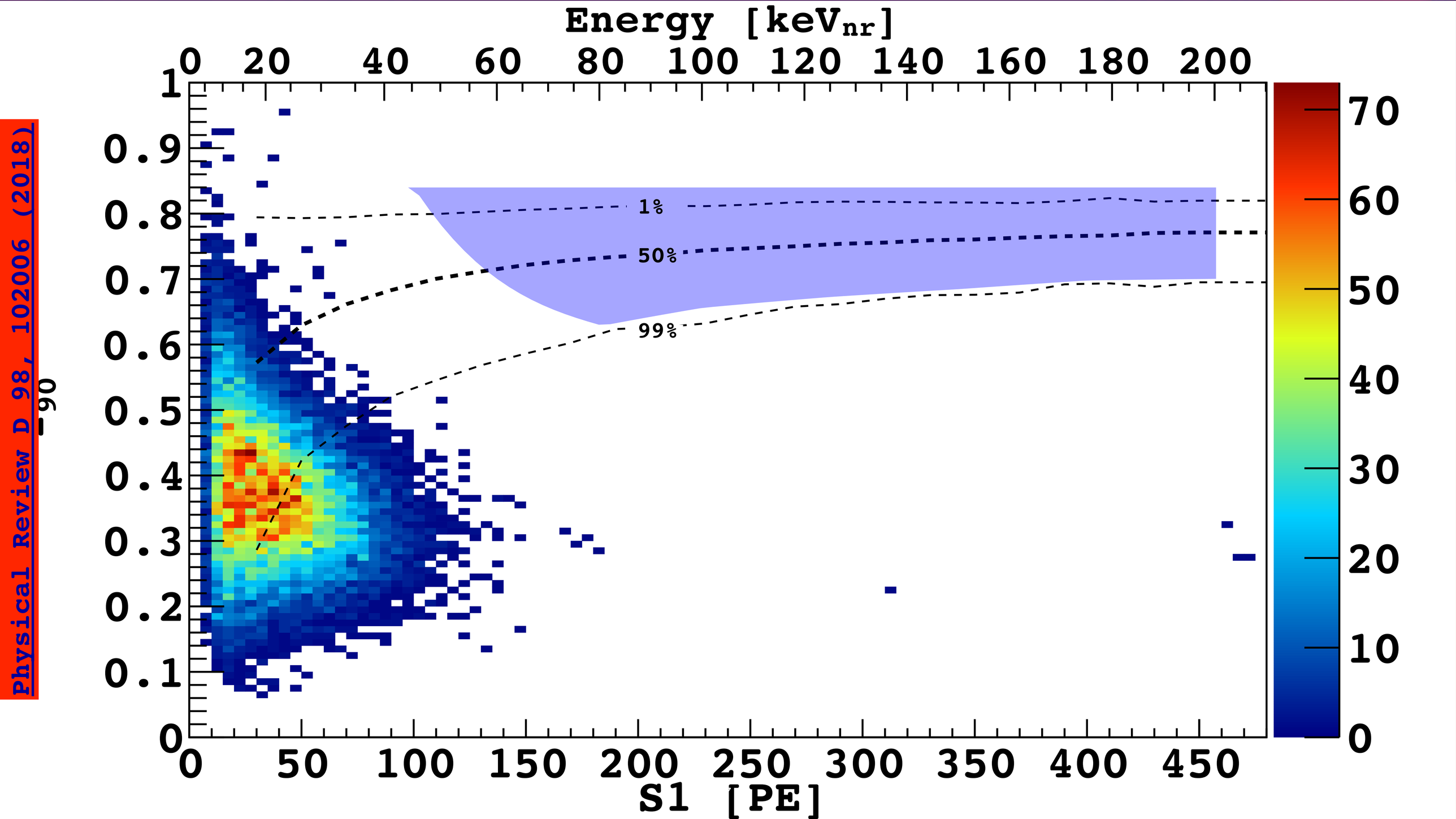


Fig. 4 **a** The $F_{\text{prompt}}^{\text{nsc}}$ distributions at $110\,N_{\text{nsc}}$ are shown for ^{39}Ar β events (background), together with the model fit, and for simulated ^{40}Ar recoil events (signal). **b** The background leakage probability (based on the fit model to ^{39}Ar data) and signal acceptance (based on signal MC) as a function of the PSD parameter is shown

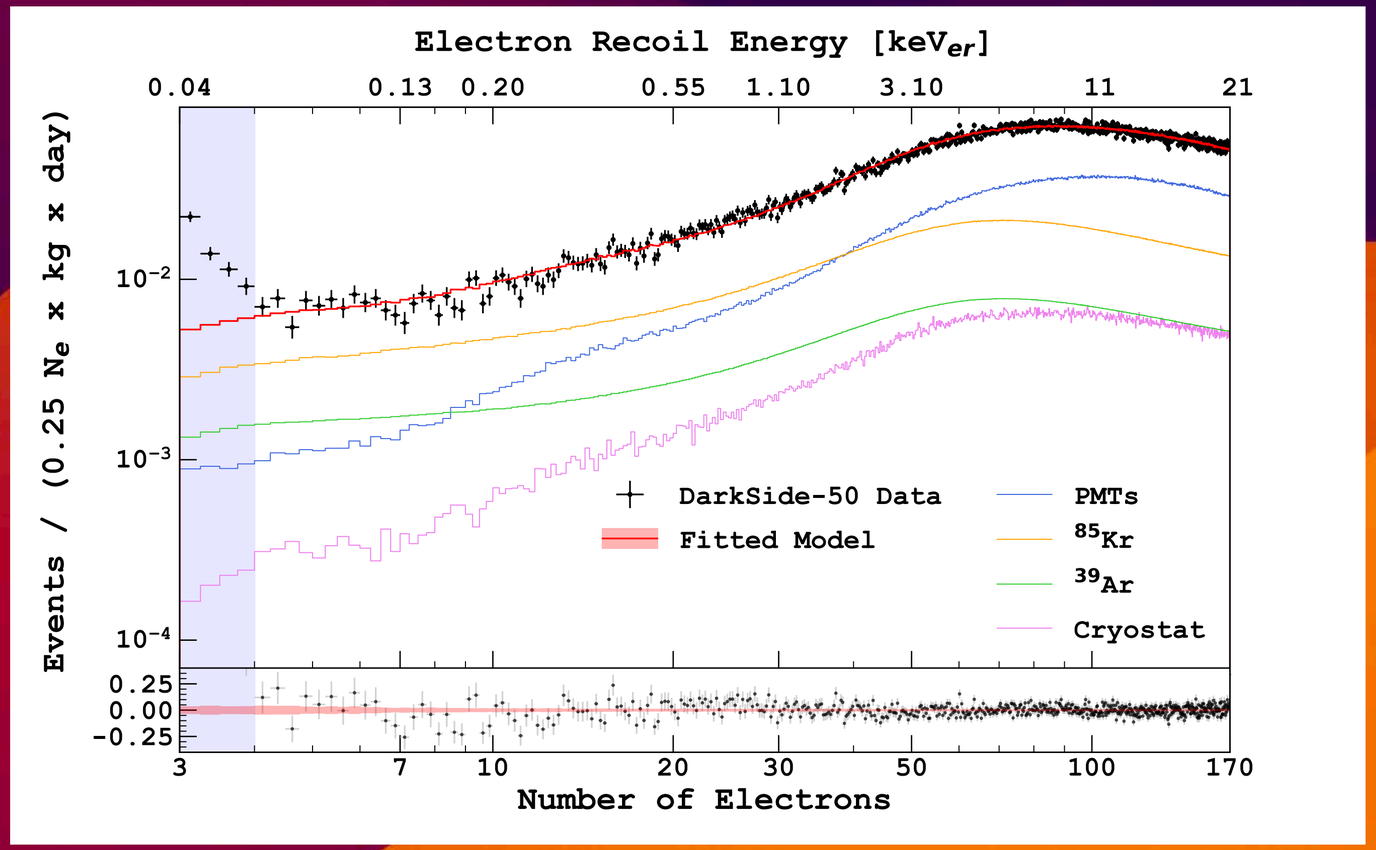
DEAP-3600 and DarkSide-50 have rejected more MIP's than expected in DarkSide-20k

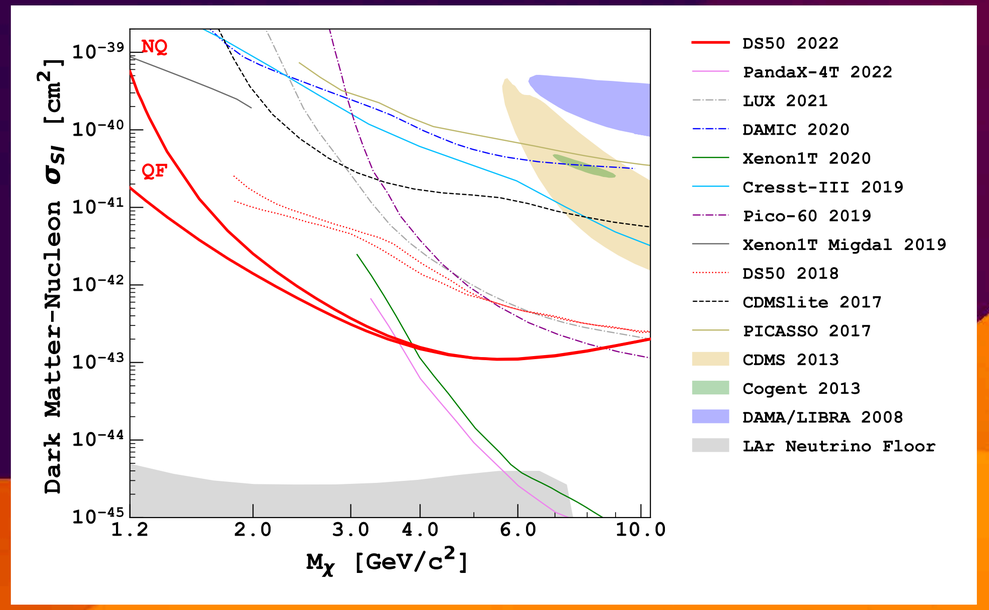
DEAP-3600 has rejected more MIP's than expected in Argo

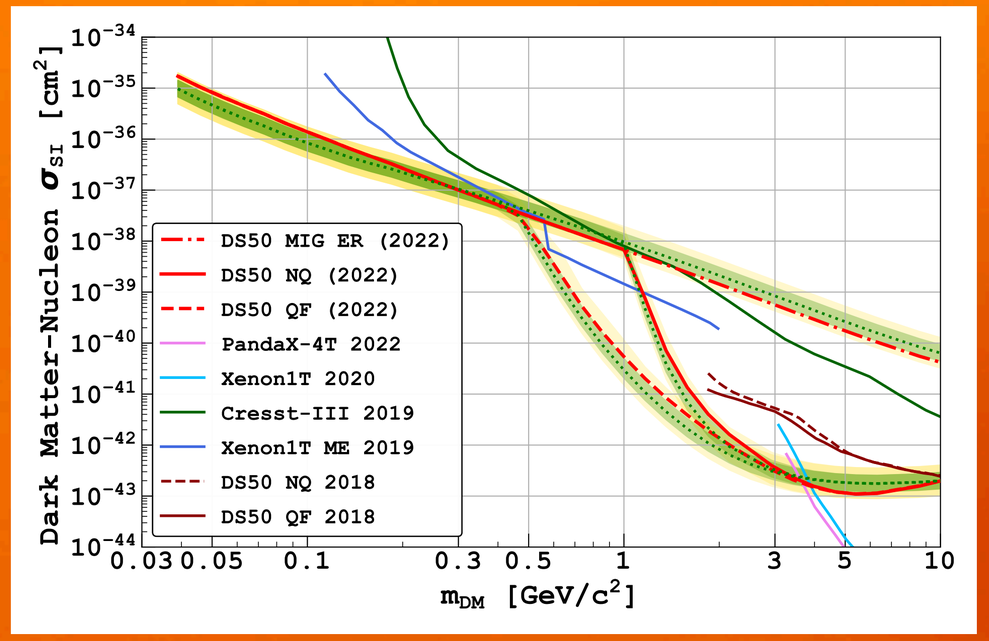

Energy [keV$_{nr}$]
0 20 40 60 80 100 120 140 160 180 200
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 50 100 150 200 250 300 350 400 450
S1 [PE]
log$_{10}$(S2$_b$/S1)
1%
50%
99%
70
60
50
40
30
20
10
0
Physical Review D 98, 102006 (2018)

Three world leading results in 2023, including first sterile neutrino dark matter direct detection search

Physical Review D 107, 063001 (2023)

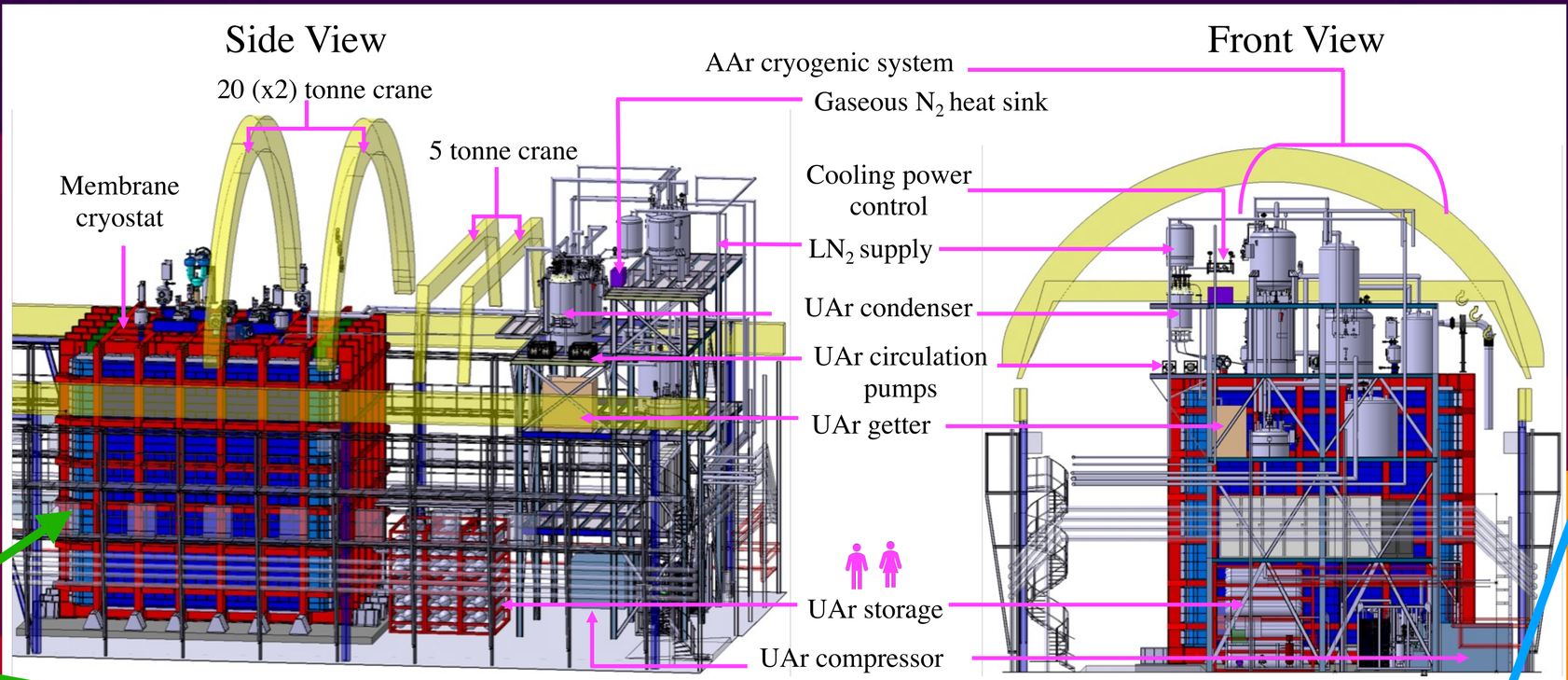


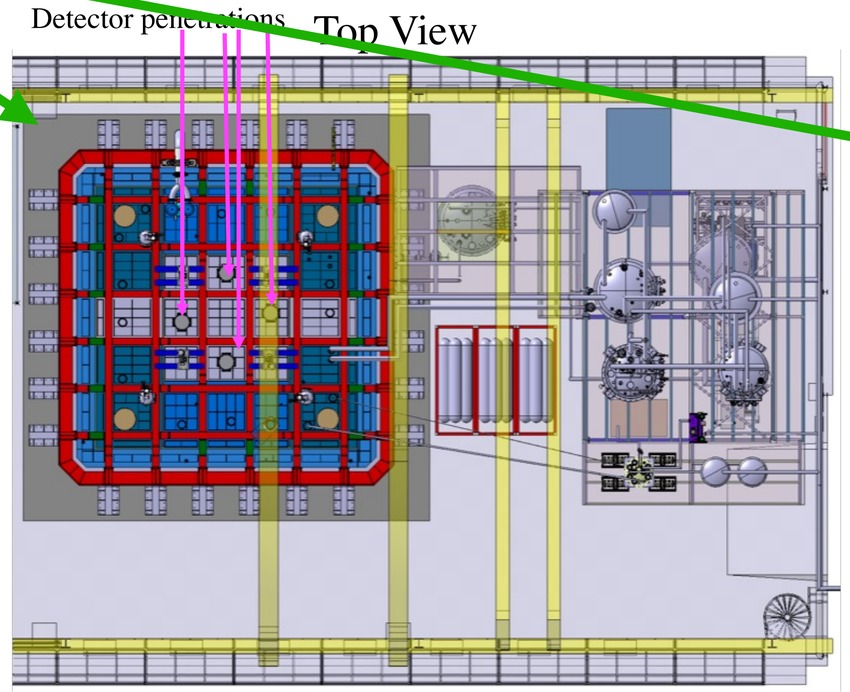


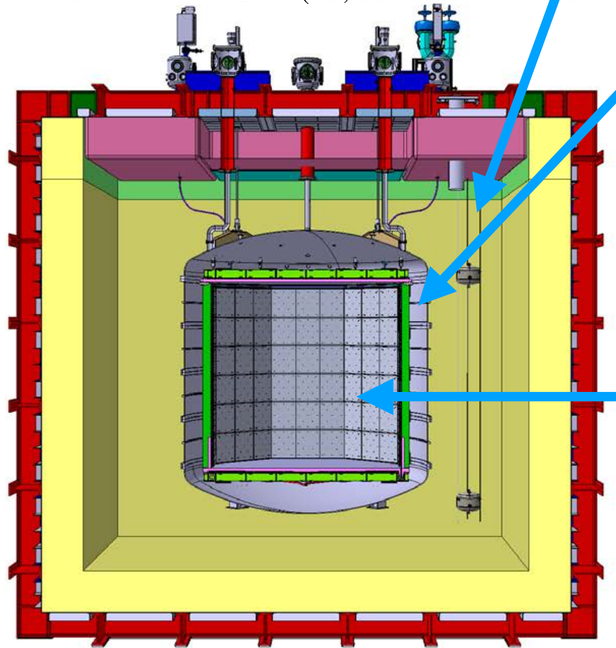


Physical Review Letters 130, 101001 (2023)

DUNE-like membrane cryostat



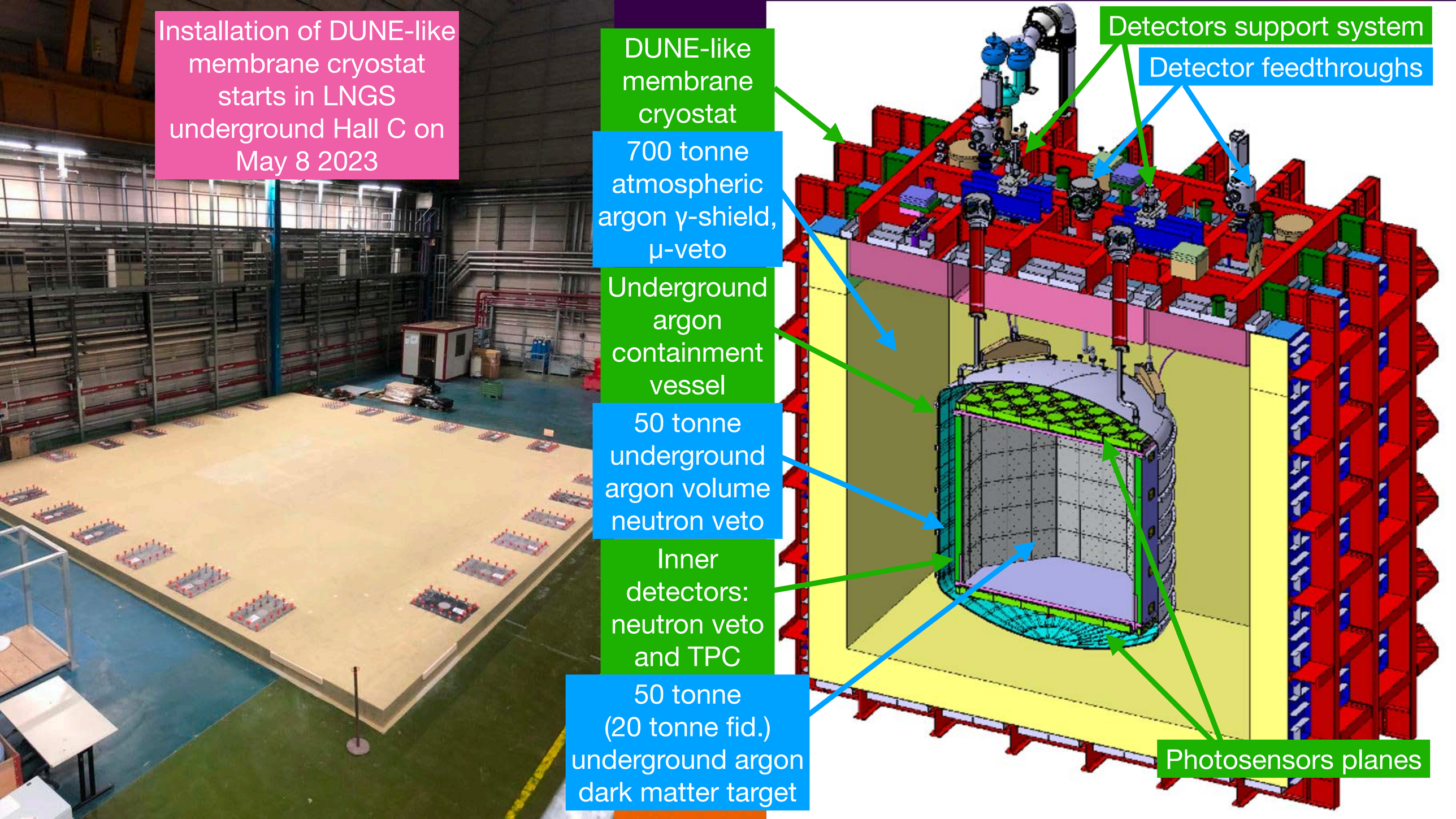




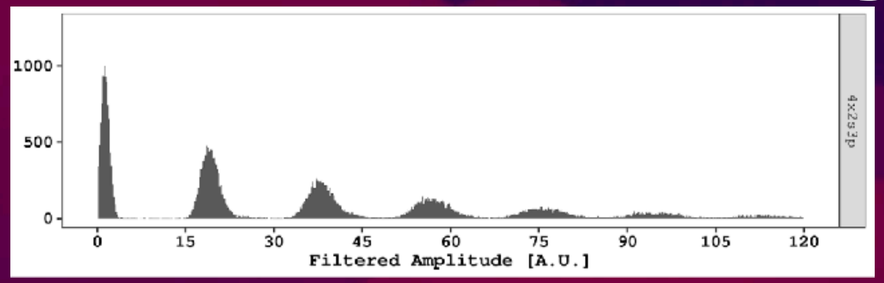
700 tonne atmospheric argon γ-shield, μ-veto

50 tonne underground argon volume neutron veto

50 tonne (20 tonne fid.) underground argon volume dark matter target


Installation of DUNE-like membrane cryostat starts in LNGS underground Hall C on May 8 2023
DUNE-like membrane cryostat
700 tonne atmospheric argon γ-shield, μ-veto
Underground argon containment vessel
50 tonne underground argon volume neutron veto
Inner detectors: neutron veto and TPC
50 tonne (20 tonne fid.) underground argon dark matter target
Detectors support system
Detector feedthroughs
Photosensors planes

Low-radioactivity, High Efficiency SiPMs

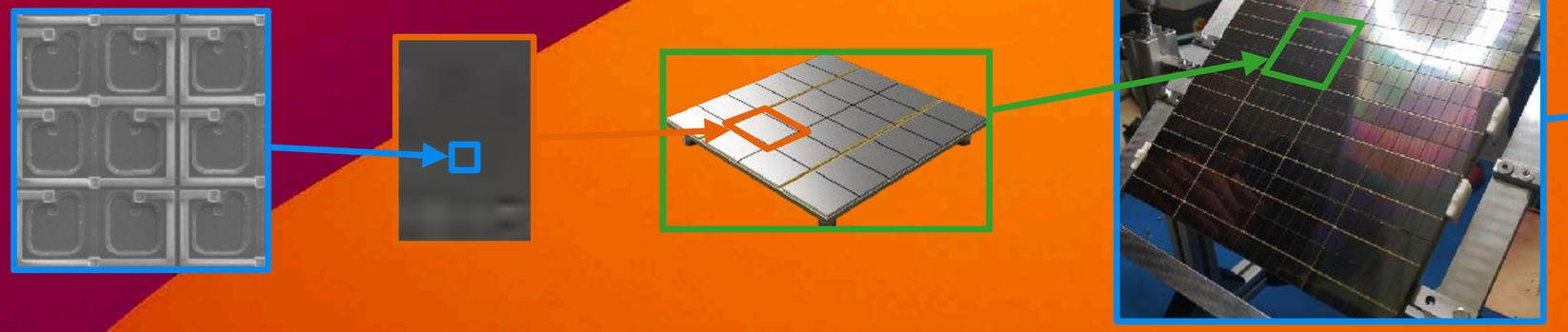


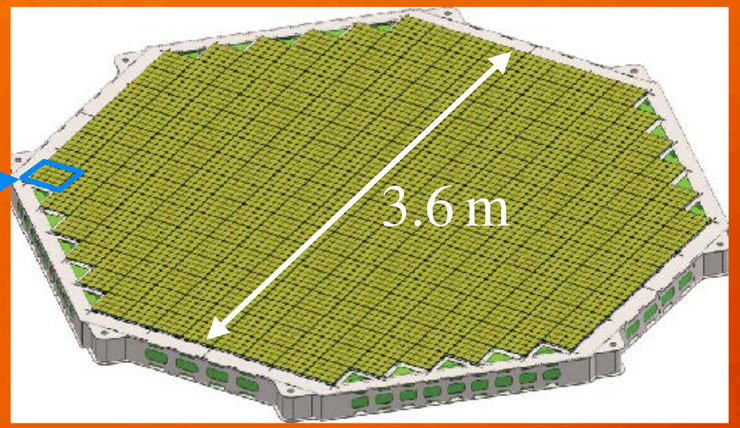
- Photon detection efficiency: **>40%** at 77 K
- Dark count rate: **<0.01 Hz/mm²** at 77 K
- SNR: **>8** for 10×10 cm² TPC PDU)

A new tool for particle physics: low-radioactivity, low-noise, high-efficiency SiPM arrays can cover large areas in a cost-effective manner

PDU packaging and assembly at
Nuova Officina Assergi (NOA) at LNGS

SPAD	**SiPM**	Tile (24 SiPM)	PDU (16 Tiles)	Optical Plane (264 PDUs)
$30 \times 30\,\mu\mathrm{m}^2$	$8 \times 12\,\mathrm{mm}^2$	$5 \times 5\,\mathrm{cm}^2$	$20 \times 20\,\mathrm{cm}^2$	$21\,\mathrm{m}^2$ in TPC, $5\,\mathrm{m}^2$ in Veto





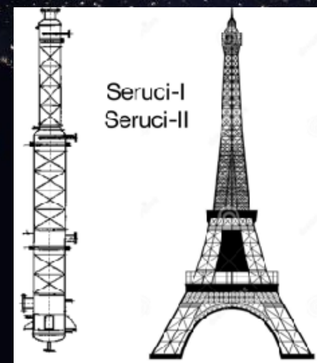
JINST 12, P09030 (2070)

Industrial Scale Underground Argon (UAr) Production

Production: Urania
Cortez, CO
Industrial scale extraction plant
Extraction rate: 250-330 kg/day
Production capability ≈ 120 t over two years
UAr purity: three-four nines

Production: Aria
Sardinia, Italy
Industrial scale extraction plant
350 m cryogenic distillation column
O(1 tonne)/day capability
UAr purity: > six nines
Ultimate goal: isotopic separation

DArT in ArDM
LSC, Spain
Facility for qualification of ^{39}Ar



ARGO: Key Elements of Conceptual Design

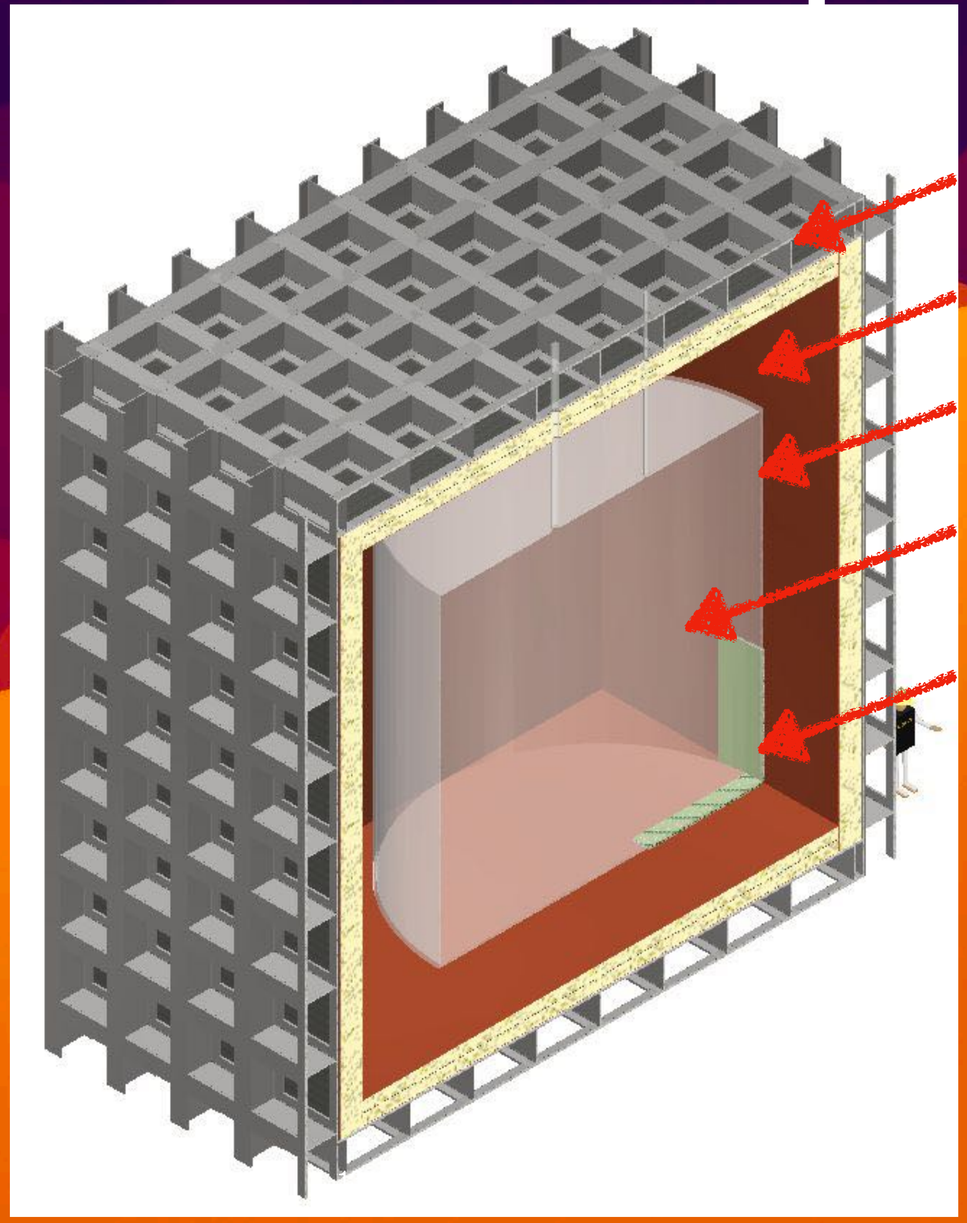
UAr Mass:

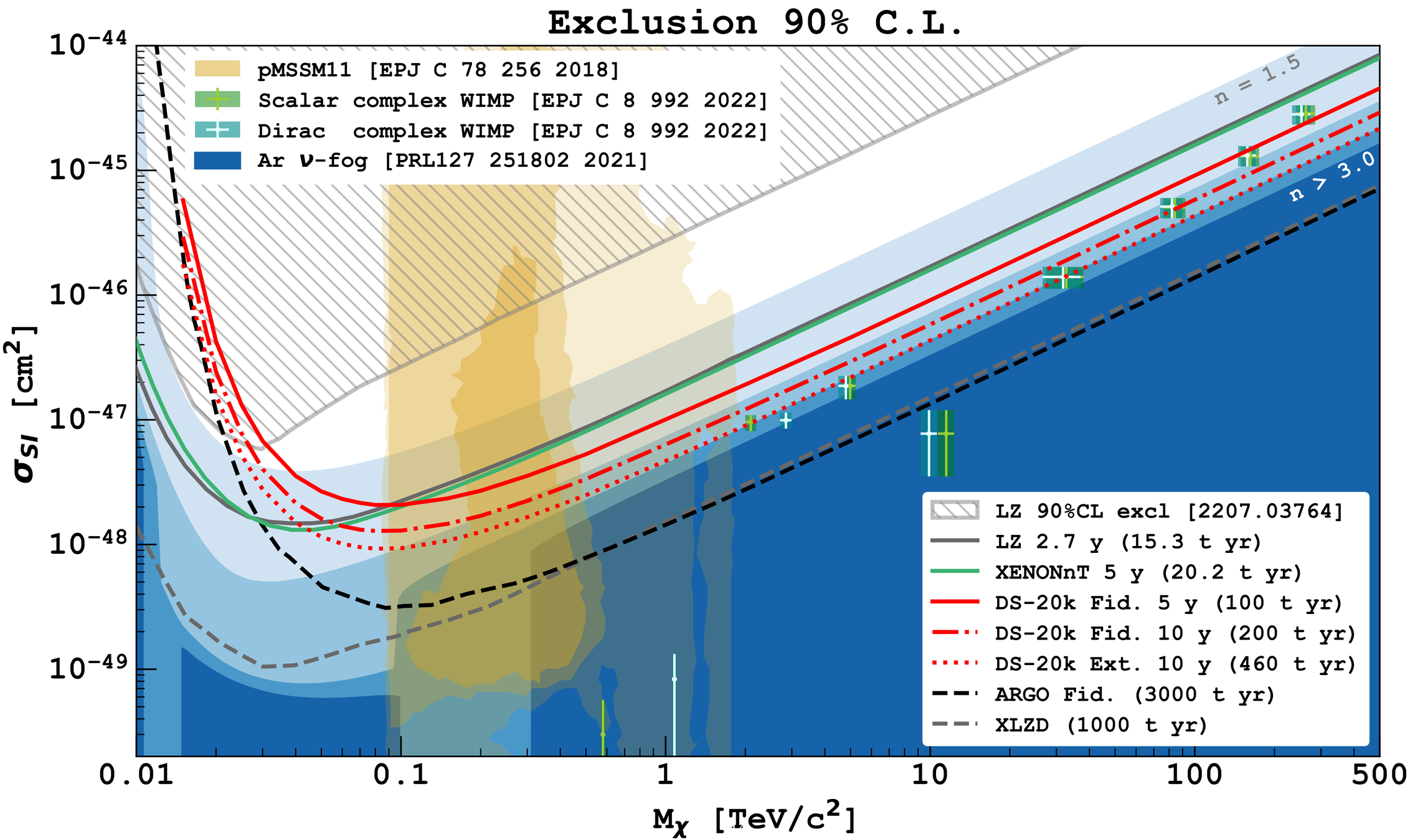
- total 400 tonnes;
- fiducial 300 tonnes.

SiPMs assemblies arranged as photon-to-digital converters (PDCs).

Data rates:

- operation 5k p.e./(m^2×s);
- calibration 100k p.e./(m^2×s).




Exclusion 90% C.L.
pMSSM11 [EPJ C 78 256 2018]
Scalar complex WIMP [EPJ C 8 992 2022]
Dirac complex WIMP [EPJ C 8 992 2022]
Ar ν-fog [PRL127 251802 2021]
n = 1.5
n > 3.0
LZ 90%CL excl [2207.03764]
LZ 2.7 y (15.3 t yr)
XENONnT 5 y (20.2 t yr)
DS-20k Fid. 5 y (100 t yr)
DS-20k Fid. 10 y (200 t yr)
DS-20k Ext. 10 y (460 t yr)
ARGO Fid. (3000 t yr)
XLZD (1000 t yr)
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
σ_{SI} [cm^2]
0.01
0.1
1
10
100
500
M_χ [TeV/c^2]

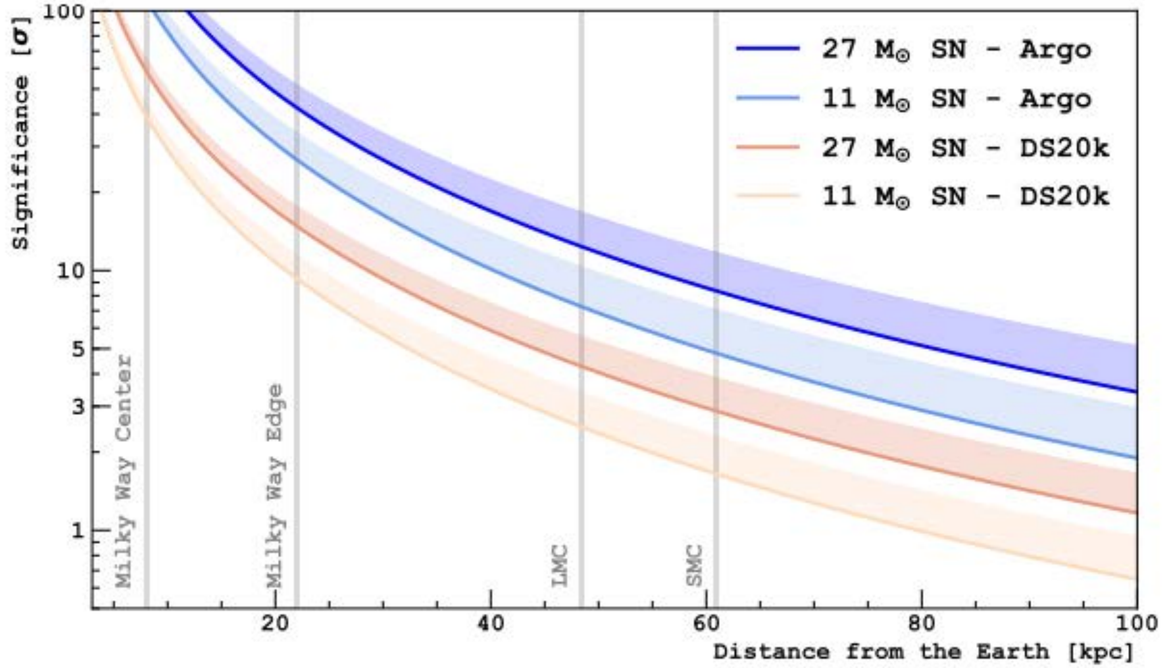
Solar and supernova neutrinos: DS-20k and Argo as neutrino observatories

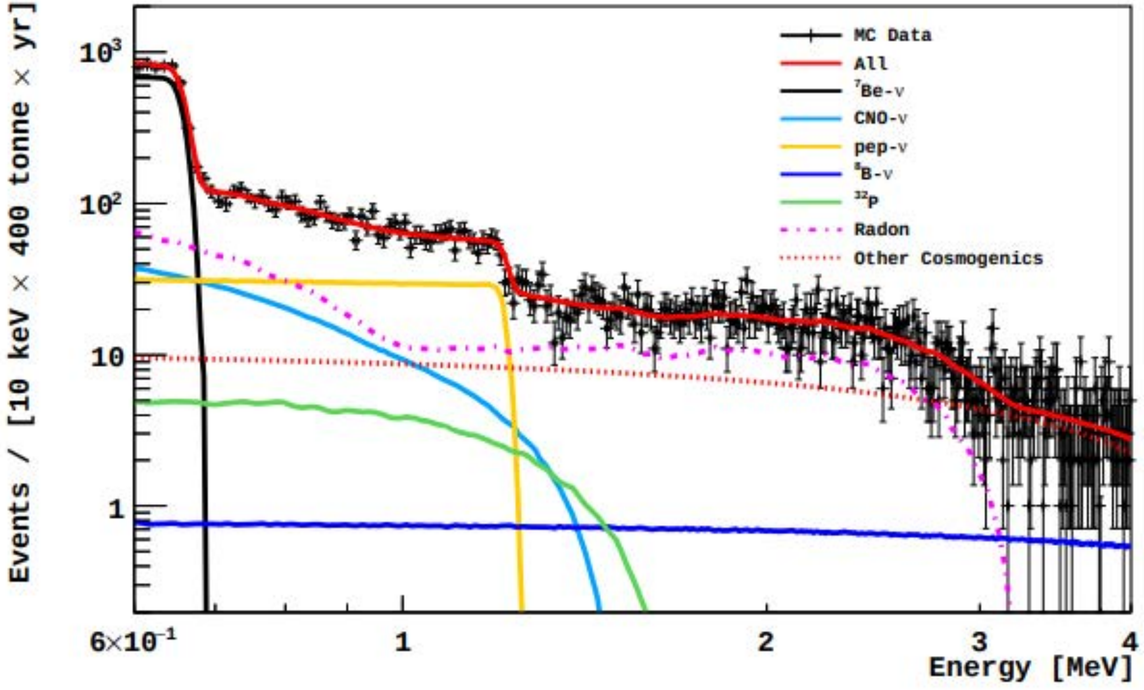
Core-collapse supernova neutrinos

Sensitivity to core-collapse supernova burst neutrinos beyond the Milky Way, with >3σ sensitivity to the neutronization burst

Solar neutrino measurements

High-precision solar neutrino measurements via electron-scattering and other channels; potential to resolve solar metallicity models





Argo: the Science Pillars

High Mass (>50 GeV/c^2): third-gen sensitivity to dark matter with complete suppression of electron recoils and any other instrumental background

- No extrapolation needed: thanks to planned use in Argo of underground argon suppressed in ^{39}Ar, the required background rejection was already demonstrated in the DEAP-3600 run (with atmospheric argon)

Solar and Supernova Neutrinos: great capability for complementary physics goals

Host Laboratory and Lead DOE Laboratory

For the host underground Laboratory, the two options under consideration are:

- SNOLAB (first option):
  - Argo would fit into the Cube Hall, current location of DEAP-3600;
- SURF / LBNF (second option).

Given the strong commonalities and history of collaboration, and in consideration of the physics connection with LBNF / DUNE, we feel Fermilab would be the natural lead DOE laboratory.

Key Assumptions

Roughly 25% of the total project cost, accounting for the cryostat, cryogenics, and UAr storage, has been assumed to be borne by the host underground Laboratory and/or the national funding agency(ies) of the host nation.

We expect to request the two funding agencies in the U.S., DOE and NSF, to bear a significant fraction (approximately, one half) of the 75% of the total project cost accounting for photodetectors, detector, and UAr extraction.

Point Estimate, Escalation, Contingency

The point estimate is of $202M in 2023 USD. The point estimate is based on a straightforward projection starting from the baseline of the DarkSide-20k project.

- This compares with a point estimate of $120M in 2023 USD for DarkSide-20k.

We assume a 3% inflation from 2024 to project completion.

Under this assumption, the point estimate increases to $258M in actual USD at the anticipated 2034 project completion date.

Based on prior experience with DarkSide-20k:

- Contingency for the US DOE is set at 50% of its project scope;
- Contingency for the US NSF is set at 35% of its project scope.

WBS Label	Intl. Agencies	USA DOE	USA NSF	Host Lab	Total
WBS 1 Photodetectors	**$73M**	**$17M**	**-**	**-**	**$90M**
WBS 1.1 Clean Room operations and personnel	$27M	-	-	-	$27M
WBS 1.2 PDU Test Facility	$6.5M	-	-	-	$6.5M
WBS 1.3 Phototetectors Development	$1.9M	-	-	-	$1.9M
WBS 1.4 TPC Photodetectors Production	$30M	$17M	-	-	$47M
WBS 1.5 Veto Photodetectors Production	$7.8M	-	-	-	$7.8M
WBS 2 Detector	**$15M**	**$28M**	**$5.2M**	**-**	**$49M**
WBS 2.1 Calibrations	$0.6M	-	-	-	$0.6M
WBS 2.2 Electronics and DAQ	$11M	-	-	-	$11M
WBS 2.3 Inner Detector	-	$23M	-	-	$23M
WBS 2.4 Materials	-	$5M	-	-	$5M
WBS 2.5 Offline	$1.1M	-	-	-	$1.1M
WBS 2.6 UAr Cryogenics	-	-	$5.2M	-	$5.2M
WBS 2.7 Veto	$2.1M	-	-	-	$2.1M
WBS 3 Infrastructure and Installation	**-**	**-**	**-**	**$34M**	**$34M**
WBS 3.1 AAr Cryogenics	-	-	-	$9.1M	$9.1M
WBS 3.2 Cryostat	-	-	-	$14M	$14M
WBS 3.3 Infrastructure Preparation	-	-	-	$3.8M	$3.8M
WBS 3.4 Installation	-	-	-	$7.6M	$7.6M
WBS 4 UAr Extraction Plant (Urania)	**-**	**-**	**$40M**	**$22M**	**$62M**
WBS 4.1 UAr Production	-	-	$34M	-	$34M
WBS 4.2 Urania relocation	-	-	$6.1M	-	$6.1M
WBS 4.3 Urania storage	-	-	-	$22M	$22M
WBS 5 UAr Purification (Aria)	**$11M**	**-**	**-**	**-**	**$11M**
WBS 5.1 Operations	$11M	-	-	-	$11M
WBS 6 Management Coordination	**$2.5M**	**$6.4M**	**$3.8M**	**-**	**$13M**
WBS 6.1 Project Management	$2.5M	$6.4M	$3.8M	-	$13M
Total	**$102M**	**$51M**	**$49M**	**$56M**	**$258M**
Contingency	**-**	**$26M**	**$17M**	**-**	**$43M**
Grand Total	**$102M**	**$77M**	**$66M**	**$57M**	**$301M**

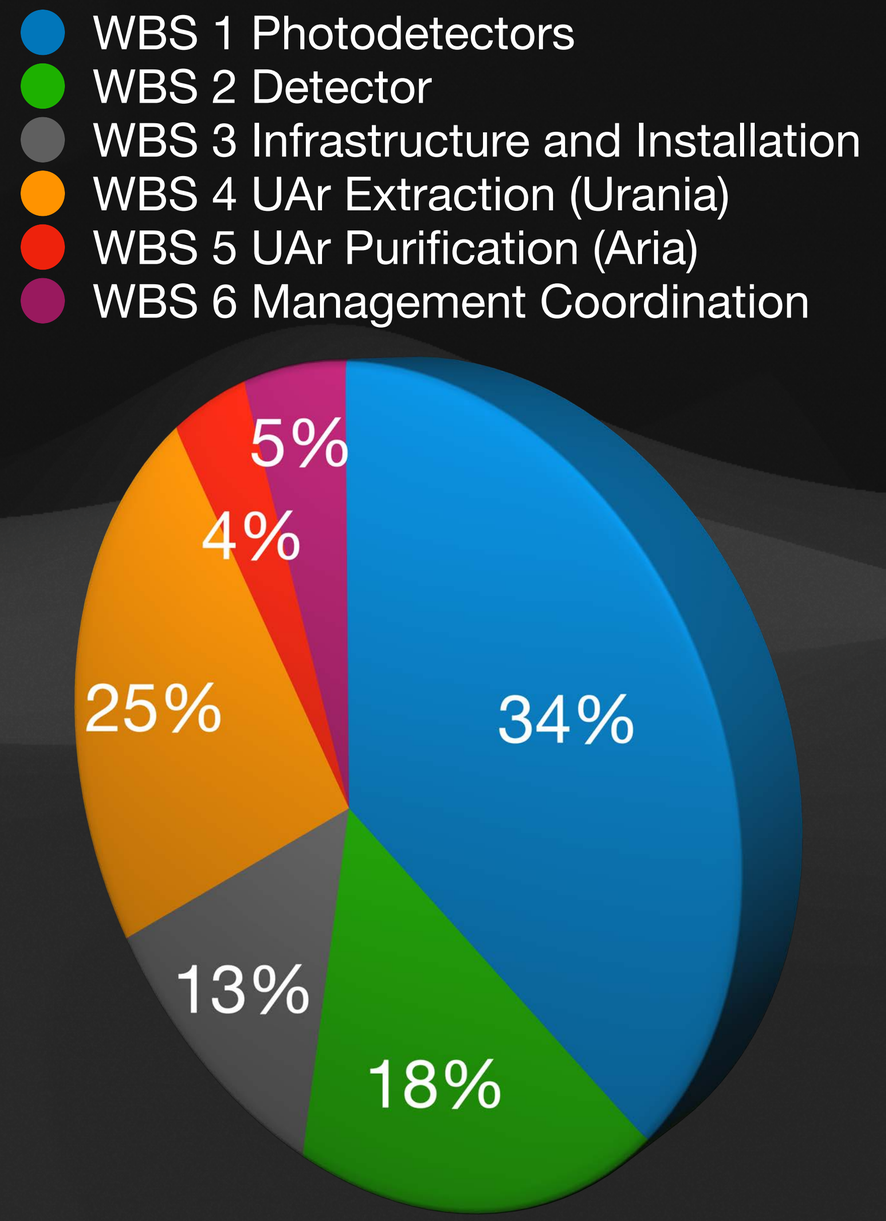
Table 6: Cost breakdown by WBS and Funding Agency (actual USD, accounting for constant 3% inflation rate from 2024 onwards, including contingency).

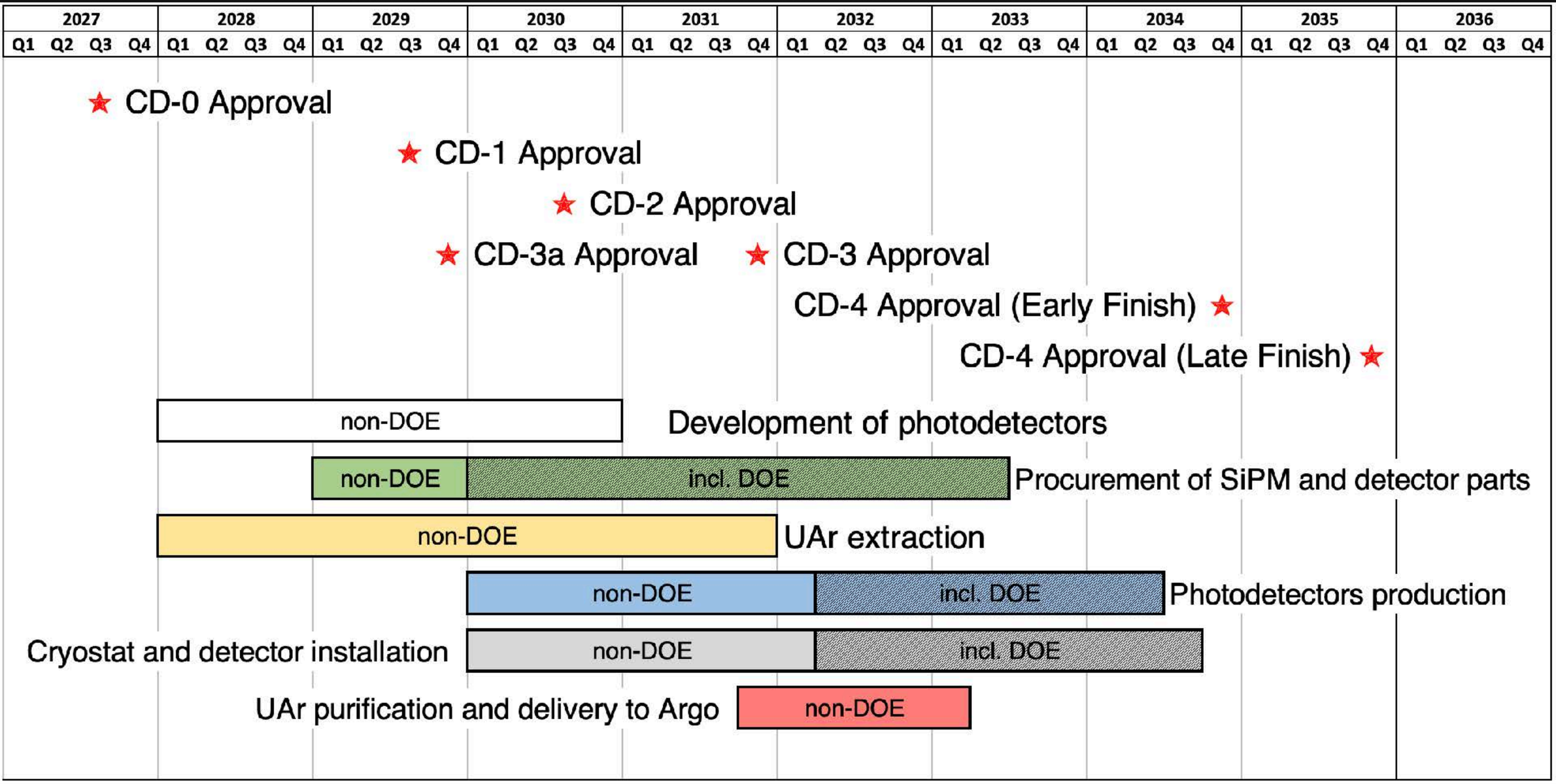
The Cost Drivers

The cost of the DUNE-like cryostat is based on the prior experience of the two units built at CERN and of that undergoing construction at LNGS.

Extraction and purification of the UAr will be performed with the Urania and Aria plants under construction for DarkSide-20k, without additional capital investments, at a rate of 100 tonne/yr.

Production of photosensors will also benefit from the prior investments made for DarkSide-20k. Cost of the 12,000 silicon wafers of custom-designed SiPMs is based on a firm quotation provided by the foundry that produced the wafers for DarkSide-20k.




2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
Q1 Q2 Q3 Q4
CD-0 Approval
CD-1 Approval
CD-2 Approval
CD-3a Approval
CD-3 Approval
CD-4 Approval (Early Finish)
CD-4 Approval (Late Finish)
non-DOE
Development of photodetectors
non-DOE
incl. DOE
Procurement of SiPM and detector parts
non-DOE
UAr extraction
non-DOE
incl. DOE
Photodetectors production
Cryostat and detector installation
non-DOE
incl. DOE
UAr purification and delivery to Argo
non-DOE

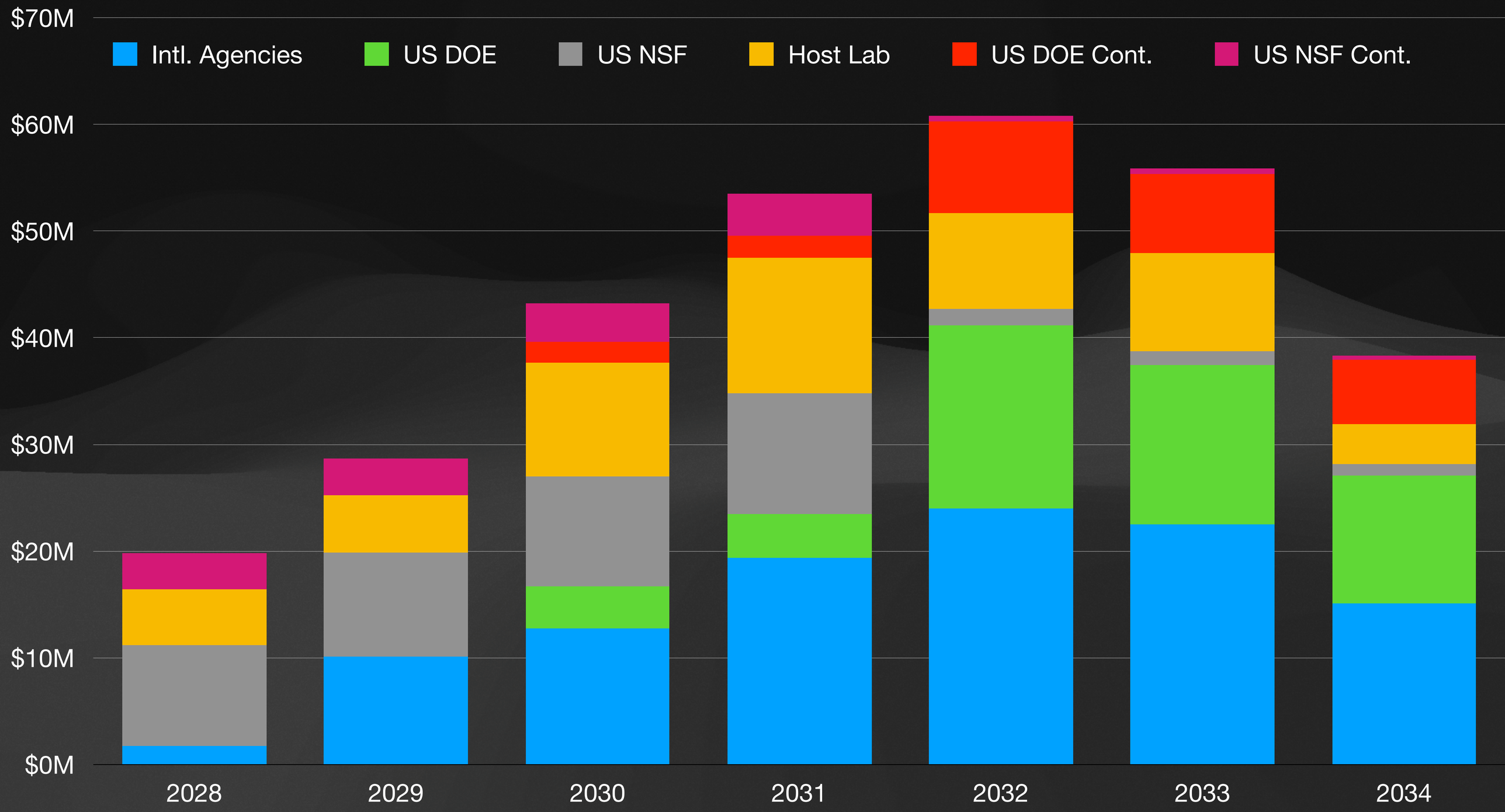


Chart 4: Argo cost profile by Funding Agency (actual USD, accounting for constant 3% inflation rate from 2024 onwards).

The Strategic Advantages

Top-notch sensitivity to dark matter and strong complementary physics program.

Limited costs for the US agencies:

- $77M fully burdened cost (incl. inflation and 50% contingency) for the US DOE;
- $66M fully burdened cost (incl. inflation and 50% contingency) for the US NSF.

Made possible by reliance on infrastructural investment for DarkSide-20k, thanks to:

- 15 years US-based program for underground argon extraction;
- 7 years program for bespoke SiPM and photosensors development;

Further investments in SiPM-based photosensors synergistic with US CHIPS act.

The End