ARGO and DEAP updates

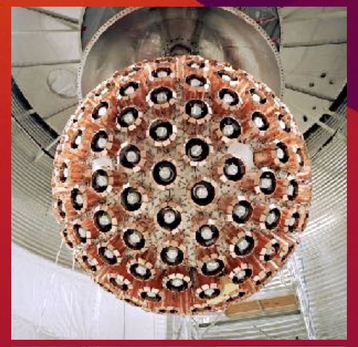
SEF Meeting @ SNOLAB
July 31, 2024

Mark Boulay Carleton University, Ottawa, Canada on behalf of GADMC, ARGO and DEAP | July 31, 2024

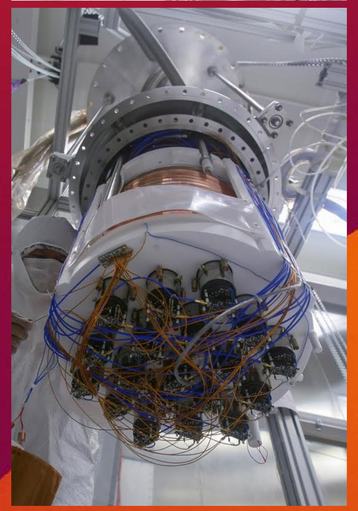
Since 2017

The Global Argon Dark Matter Collaboration (GADMC)

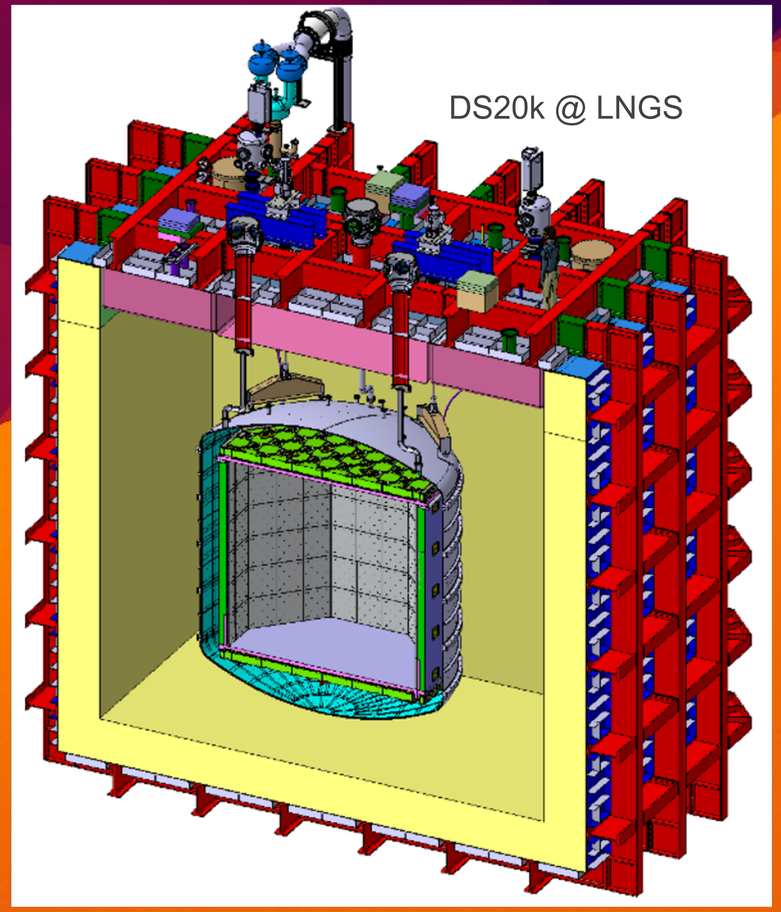
GADMC brings together more than 400 scientists committed to explore heavy (and light) dark matter to the neutrino fog and beyond



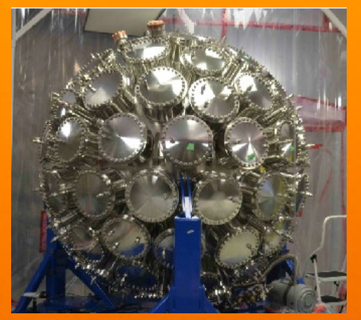
DEAP-3600



DarkSide-50



MiniCLEAN

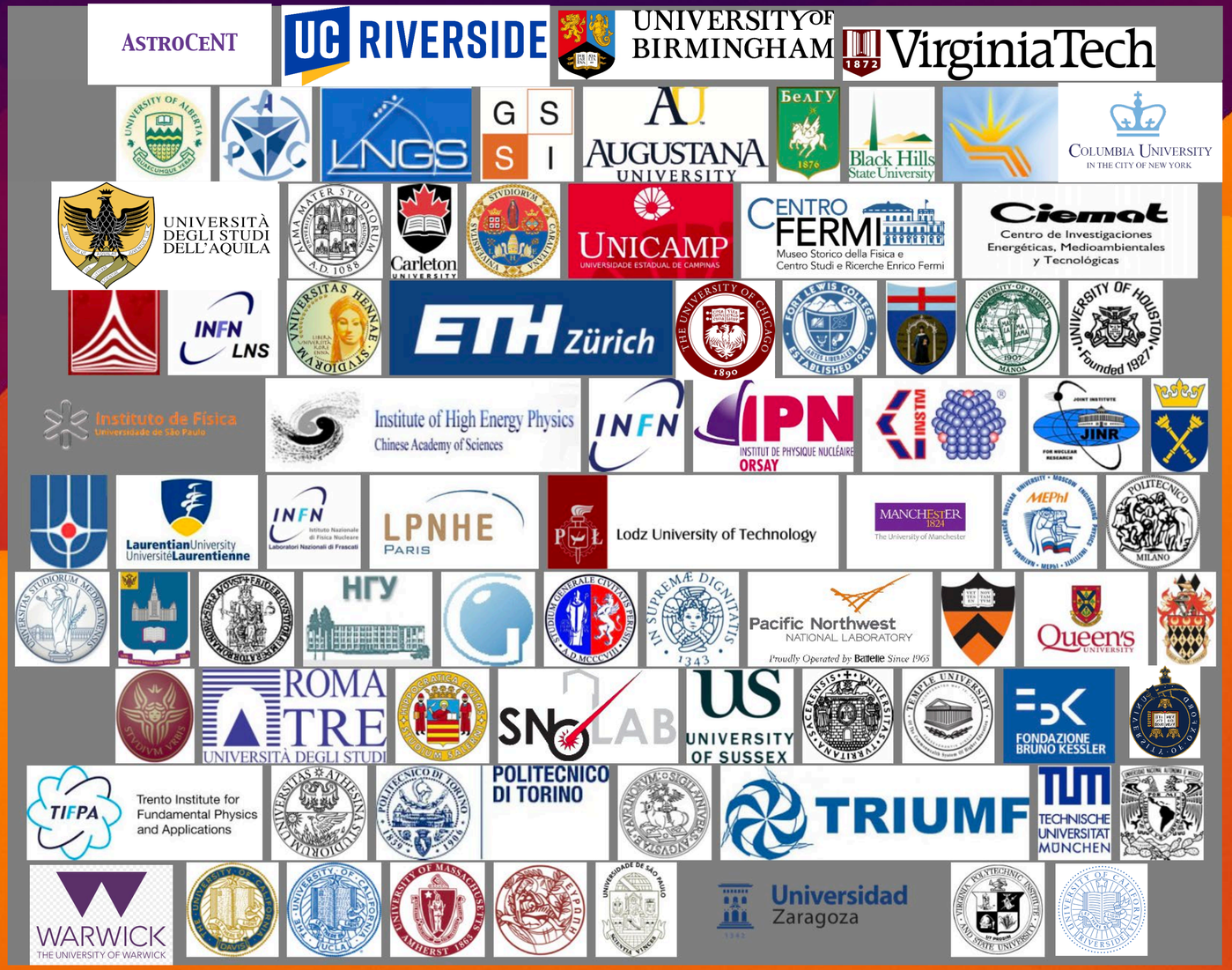


ARDM

The Global Argon Dark Matter Collaboration

With many thanks for support to:

- CFI and NSERC (Canada)
- IN2P3 (France)
- INFN (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 2027-]

ARGO
{300 t fid.,
400 ton full]}
[G3, concept development now, project early 2030’s]

Nuclear recoil vs β/γ discrimination and requirement for underground argon

•ionizing radiation leads to formation of excited dimers (Ar^*_2) in singlet or triplet states which lead to 128 nm scintillation photons

•Singlet and triplet lifetimes and intensity ratios are well-separated in argon

Net effect is powerful electron vs nuclear recoil PSD of ~10^9 using scintillation photon time distribution

Allows discrimination of β/γ events from nuclear recoils, including ^{39}Ar β decays (1 Bq/kg in ^{nat}Ar) for fiducial masses up to about 1 tonne (DEAP-3600 scale). Larger targets (DS20k and ARGO) require suppression of the ^{39}Ar isotope

Demonstration of low-activity (in ^{39}Ar) underground argon (UAr) performed with DS-50. Same extraction site in Colorado being developed to extract 120 tonnes of UAr for DS20k, and then planning for continued extraction for ARGO and other uses.

URANIA extraction plant status. All components constructed and in US; installation of site infrastructure in Colorado in progress.

>9 orders of magnitude suppression of ER backgrounds

no deviation from statistical expectations

DEAP result: Eur. Phys. J. C 81, 823 (2021)

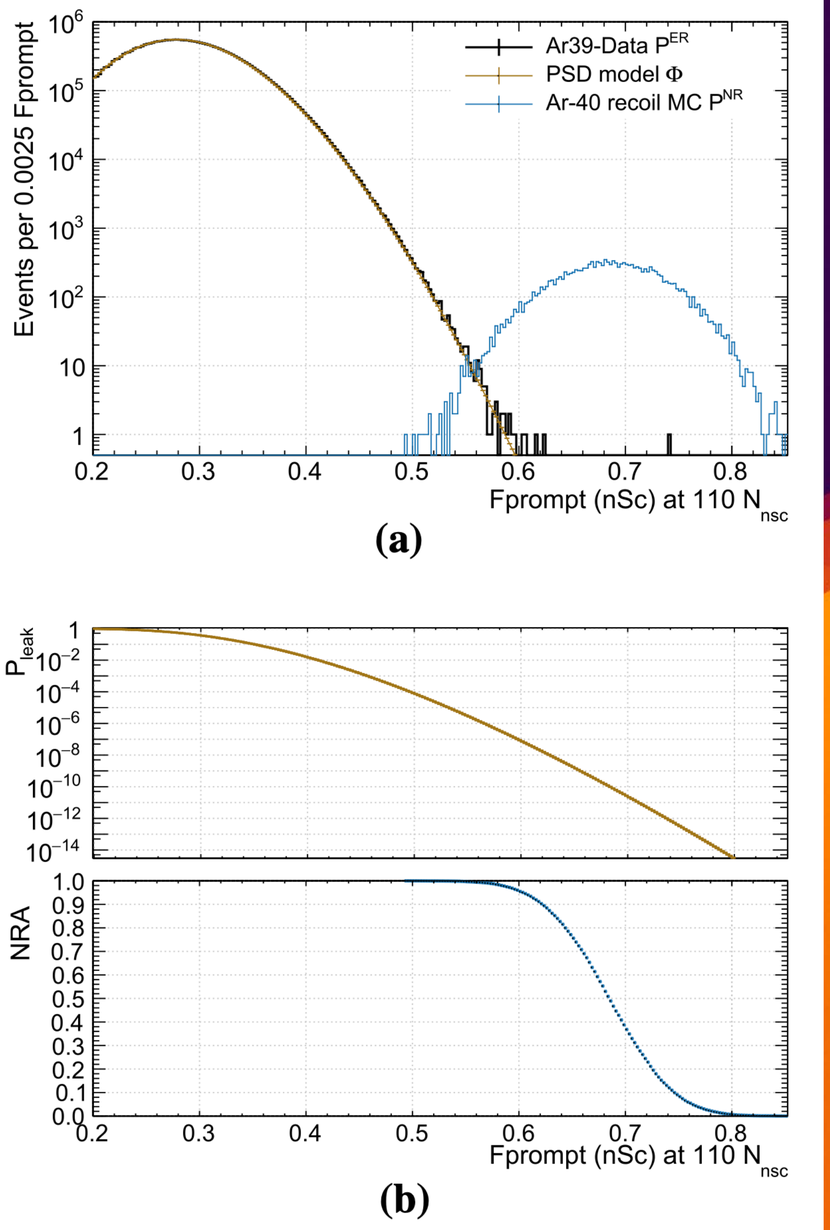
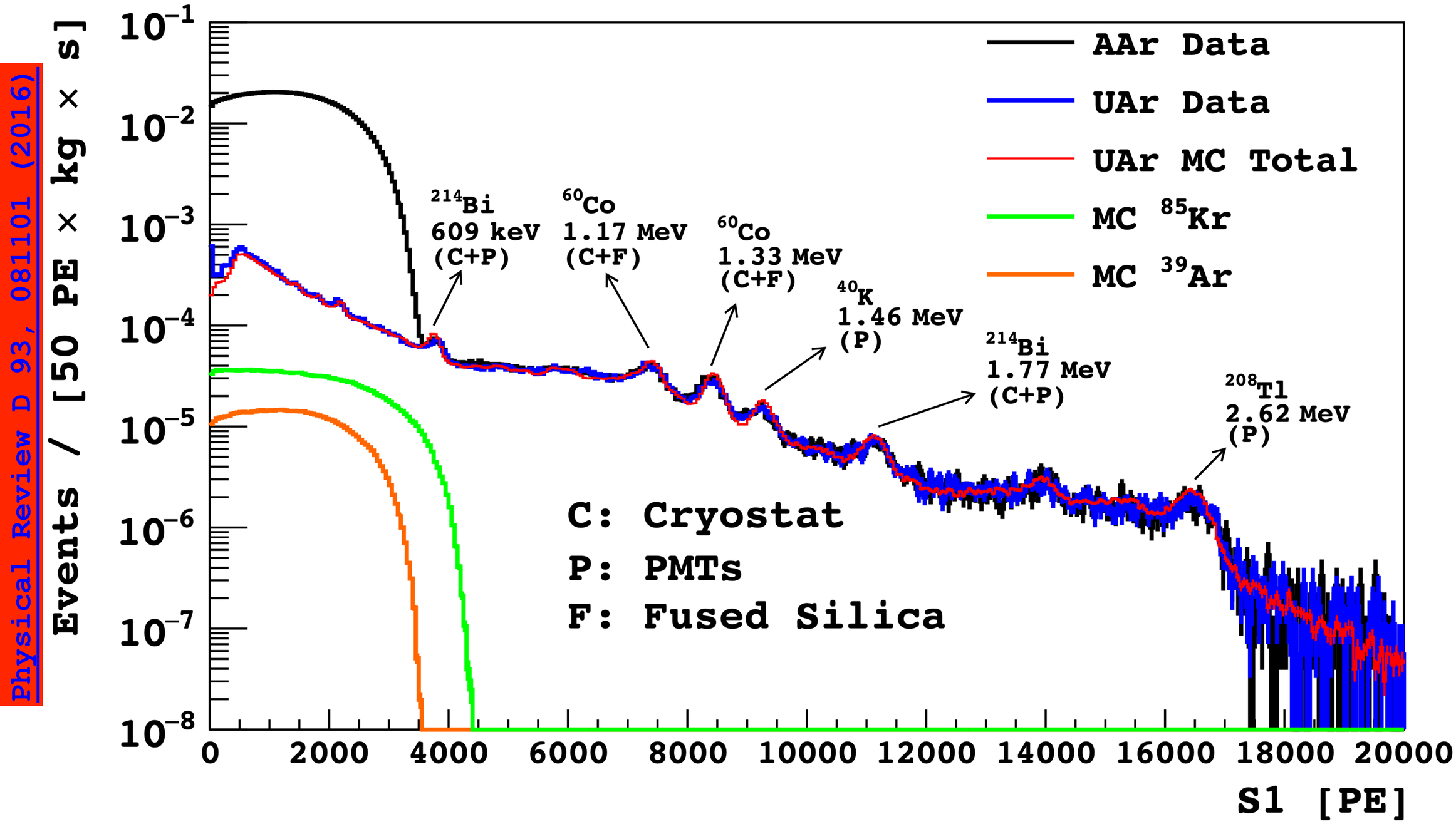


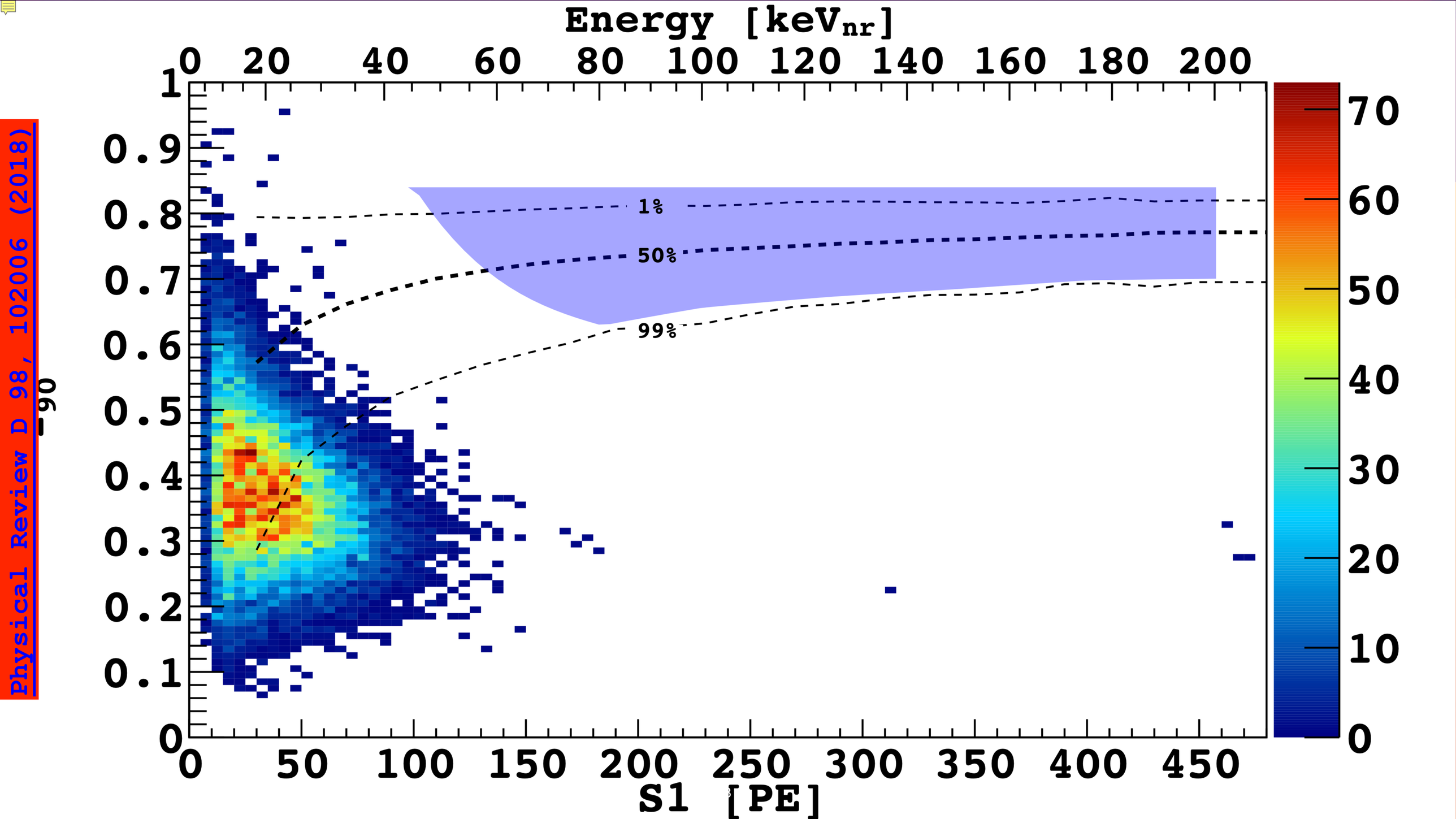
Fig. 4 **a** The F^{nsc}_{prompt} distributions at 110 N_{nsc} are shown for ^{39}Ar β events (background), together with the model fit, and for simulated ^{40}Ar recoil events (signal). **b** The background leakage probability (based on the fit model to ^{39}Ar data) and signal acceptance (based on 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 with use of Underground argon.

Development and demonstration of low-activity UAr use with DS-50 – enables the long-term program

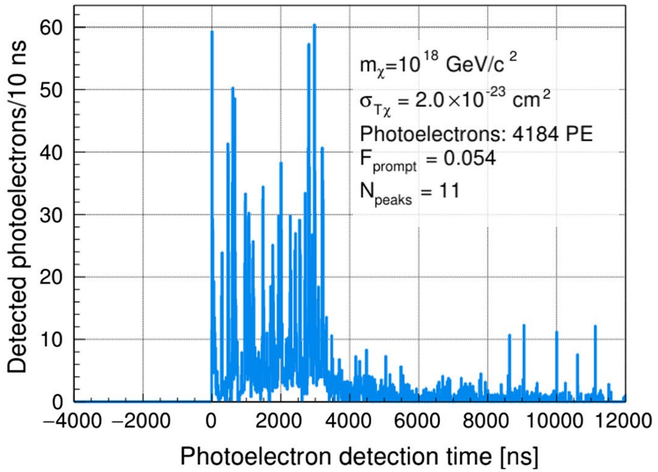


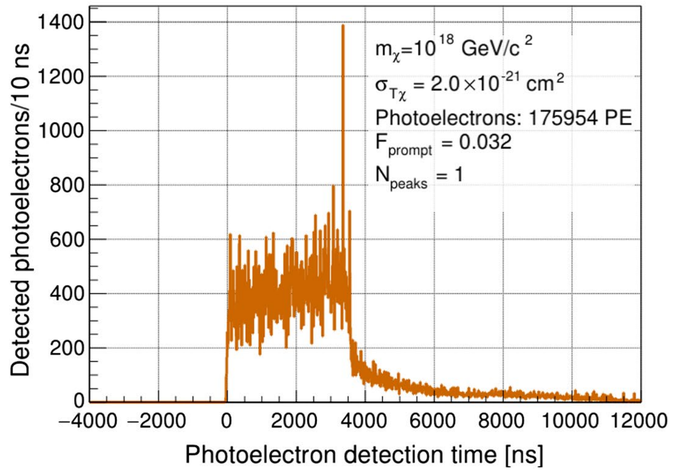

Energy [keV$_{nr}$]
0 20 40 60 80 100 120 140 160 180 200
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 50 100 150 200 250 300 350 400 450
S1 [PE]
log$_{10}$
70
60
50
40
30
20
10
0
1%
50%
99%
Physical Review D 98, 102006 (2018)

Constraints on Planck-Scale Mass Multi-scattering Dark Matter (DEAP 2022)

DM candidates with $\sigma_{\chi-n} \cong 10^{-25}$ cm^2 and mass $\gtrsim 10^{12}$ GeV/c^2 lose a negligible amount of energy in the scatterings with the Earth nuclei and can reach underground detectors.

- Event signature:
  - Contains multiple nuclear recoil scatters : produces multiple peaks in the signal
  - low F_{prompt}





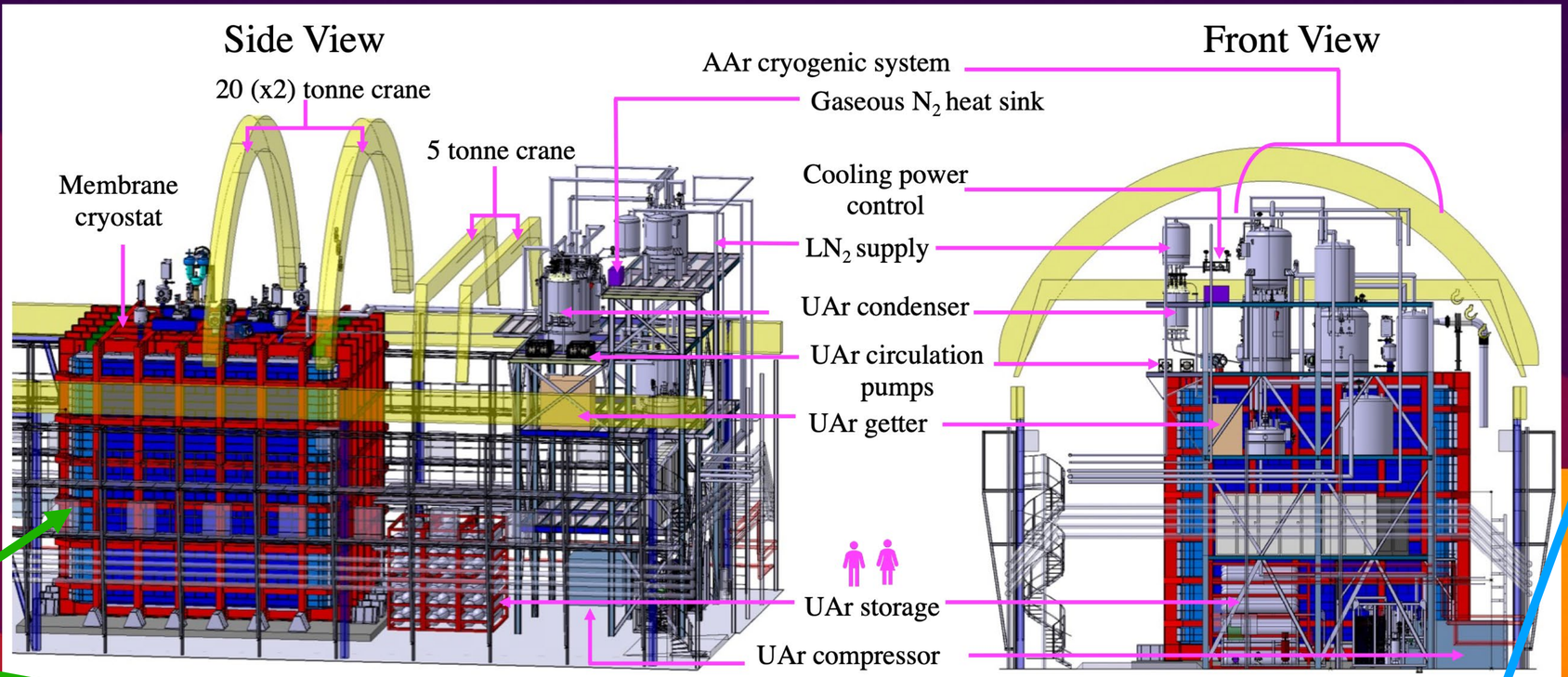
Simulated photoelectron time distribution

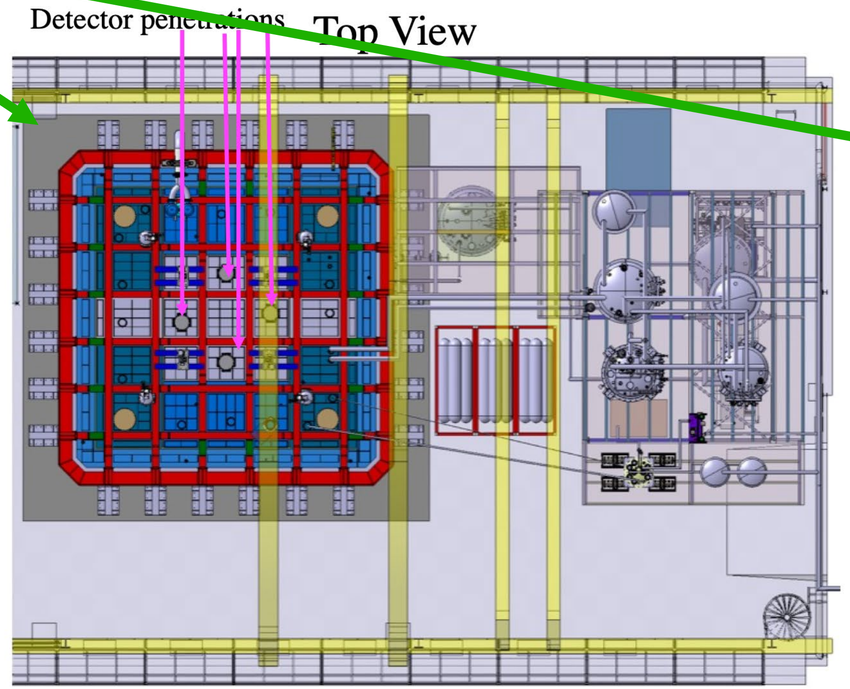
As cross-section increases, F_{prompt} decreases and number of dominant peaks starts to merge.

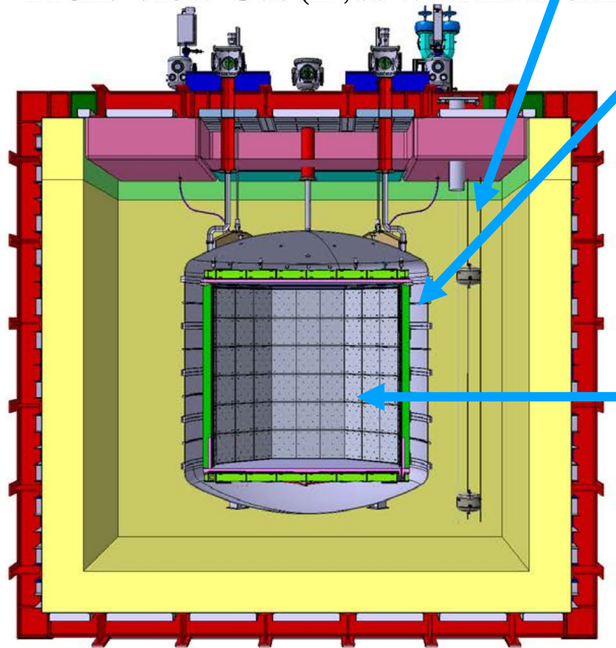
PRL 128 011801 (2022)

DS-20k @ LNGS

DUNE-like membrane cryostat





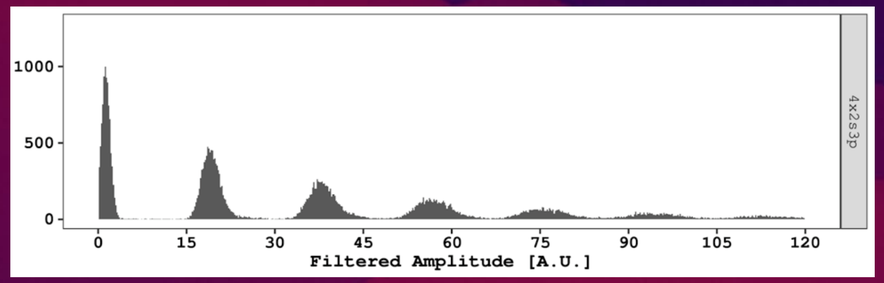


700 tonne atmospheric argon γ-shield, μ-veto

50 tonne underground argon volume neutron veto

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

Low-radioactivity, High Efficiency SiPMs DS20k

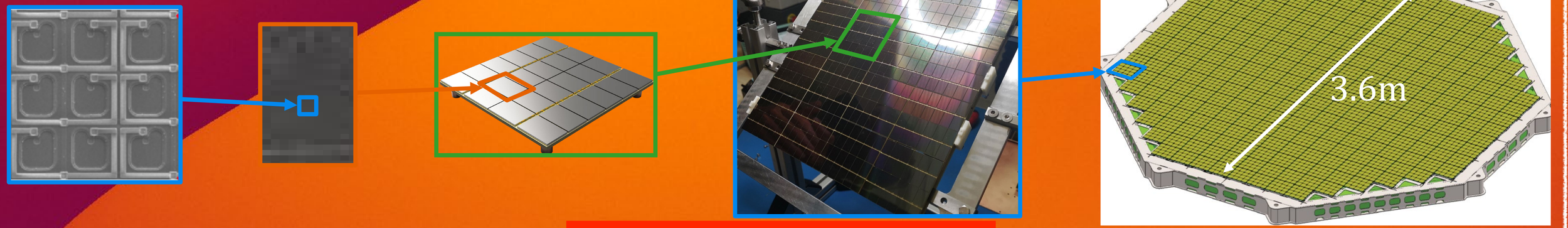


- Photon detection efficiency: **>40%** at 77 K
- Dark count rate: **<0.01 Hz/mm²** at 77 K
- SNR: **>8** for 10×10 cm² TPC PDU)

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



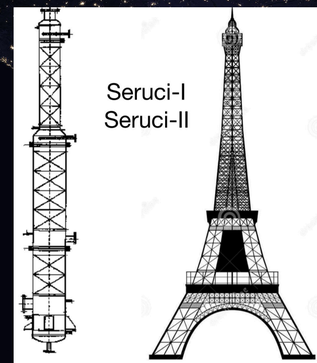
JINST 12, P09030 (2017)

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



Current Status

DS20k completion underway at LNGS

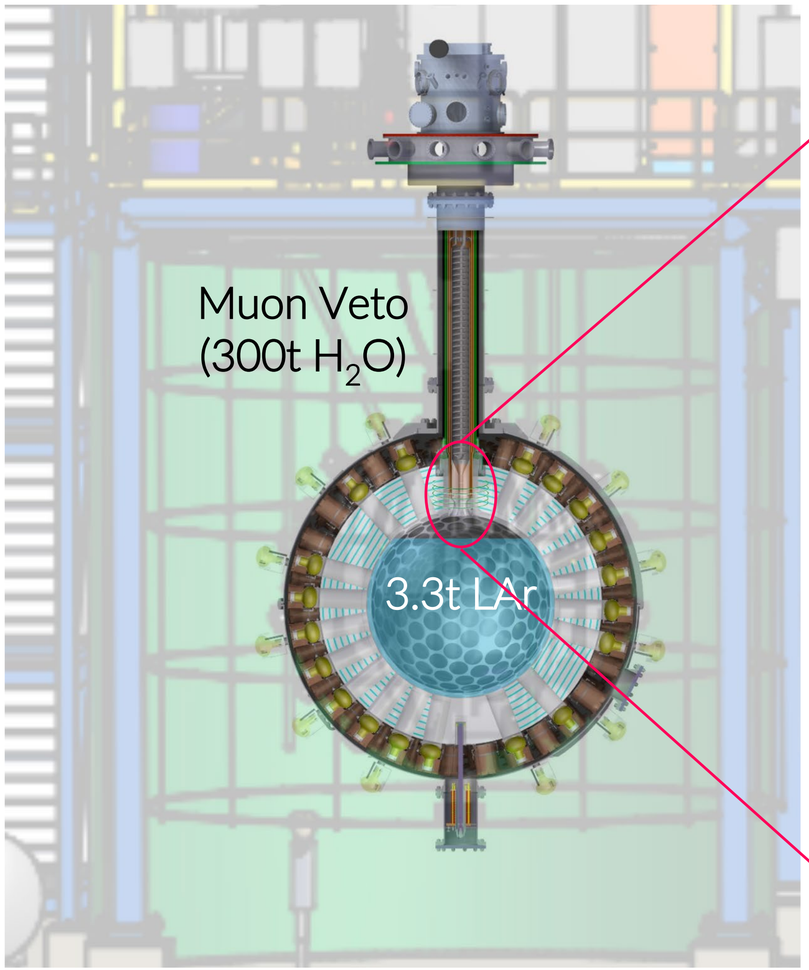
Installation of URANIA plant in Colorado with extraction starting 2025. Production of 120 tonnes over 2 years.

Completing upgrades of DEAP-3600 @ SNOLAB with new running starting later this year, for ~1.5 years (goal is background-free operation @ 10^{-46} cm^2 sensitivity)

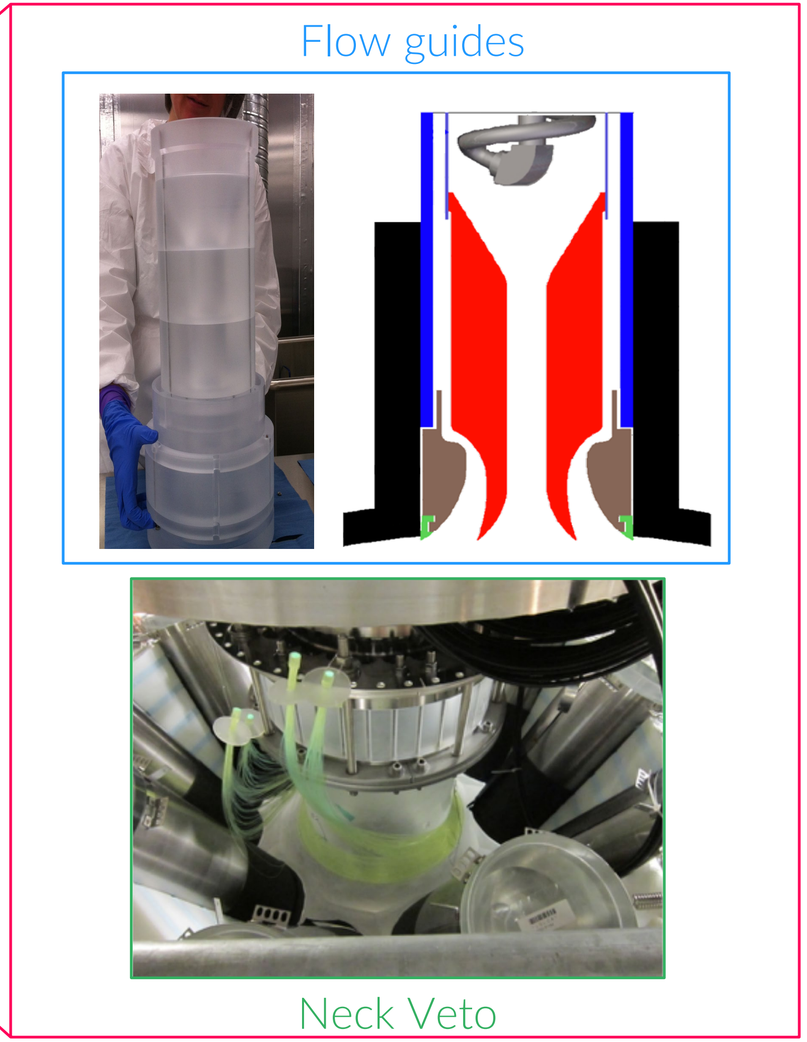
In parallel, developing concept for ARGO. Well-defined is goal of 300-tonne fiducial mass and 10-live year exposure. Currently working on detailed background budgets and TPC/single-phase concepts with preferred siting at SNOLAB.

DEAP-3600 detector upgrades

2016-2020 first physics running
2020-2024 upgrades development and installation
2024-2026 post-upgrade running



8.5 m shield tank in SNOLAB Cube Hall



DEAP-3600 Detector Upgrades

Upgrades are specially designed to remove neck alpha and dust alpha backgrounds

Dust Filtration

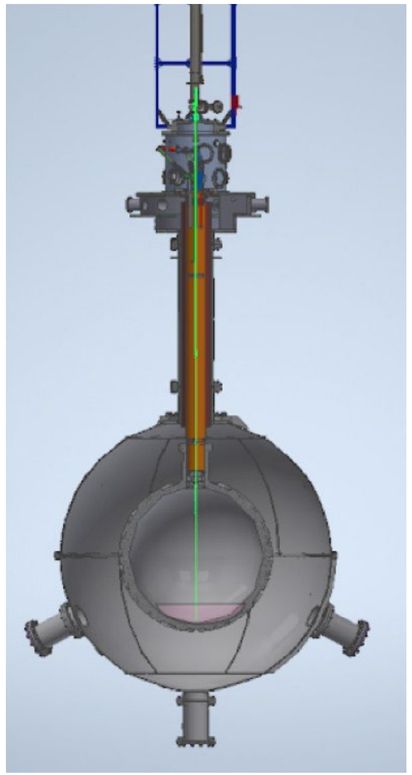
Deployment of vacuum jacketed stainless steel pipe through the neck of the detector ---- to remove liquid argon and allow filtration to remove dust

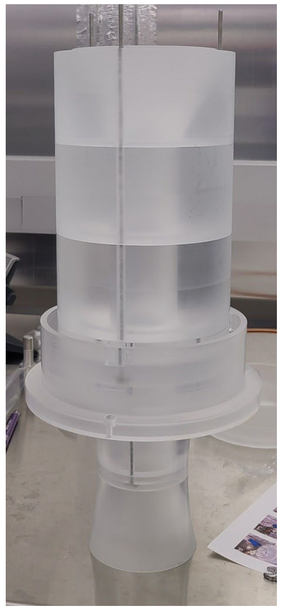
Removal of Neck alpha events

Flowguide Coating

Coat the flow guide surfaces with a “slow” wavelength shifter – custom pyrene/polymer film

Pyrene has a long decay time : neck alpha events will have lower F_{prompt} : use PSD to remove this background





Development of slow WLS NIM A 1034 16683 2022
Characterization JINST 16 P12029 2021

New runs upcoming

ARGO: Key Elements of Conceptual Design

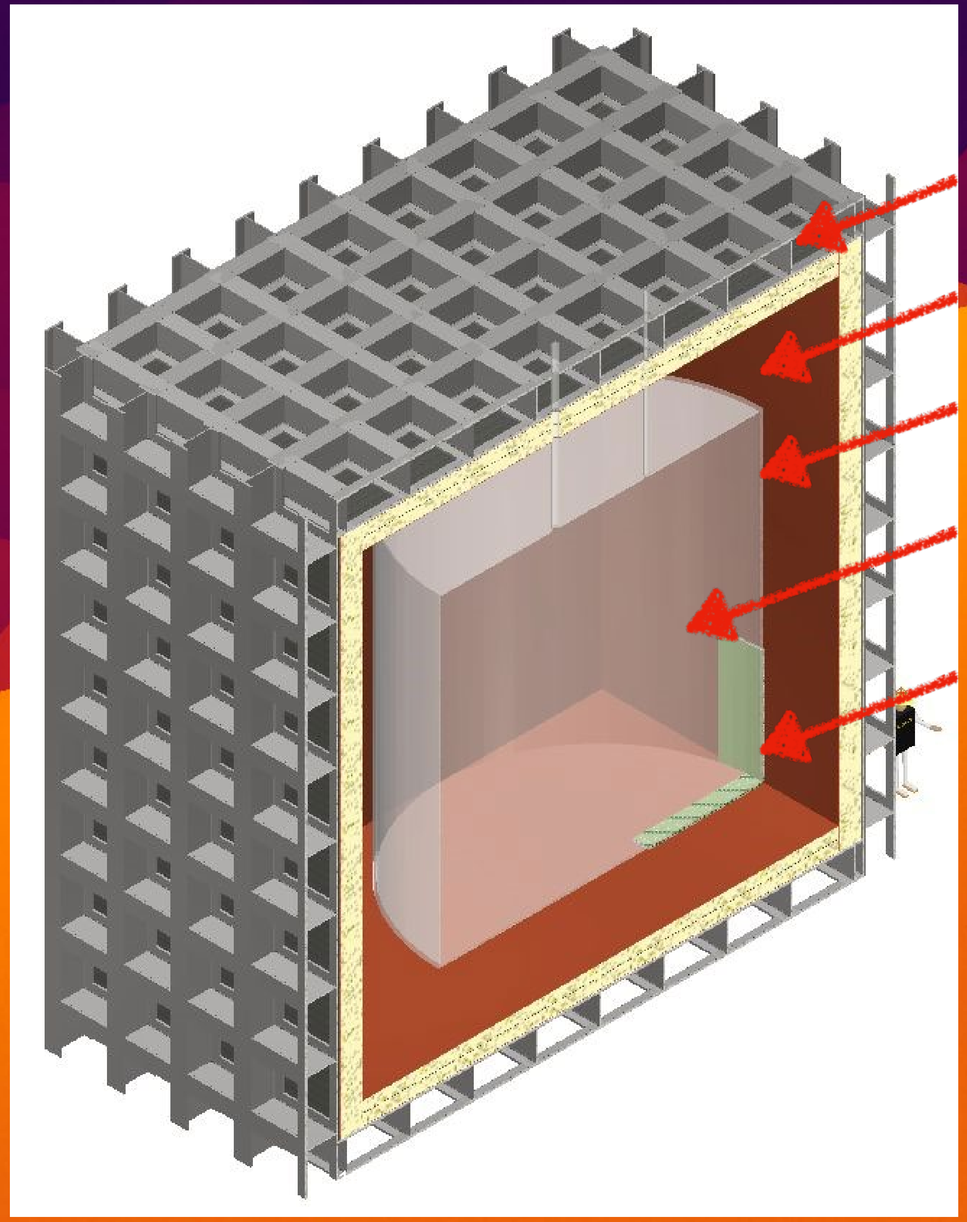
UAr Mass:

- 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).



Outer cryostat

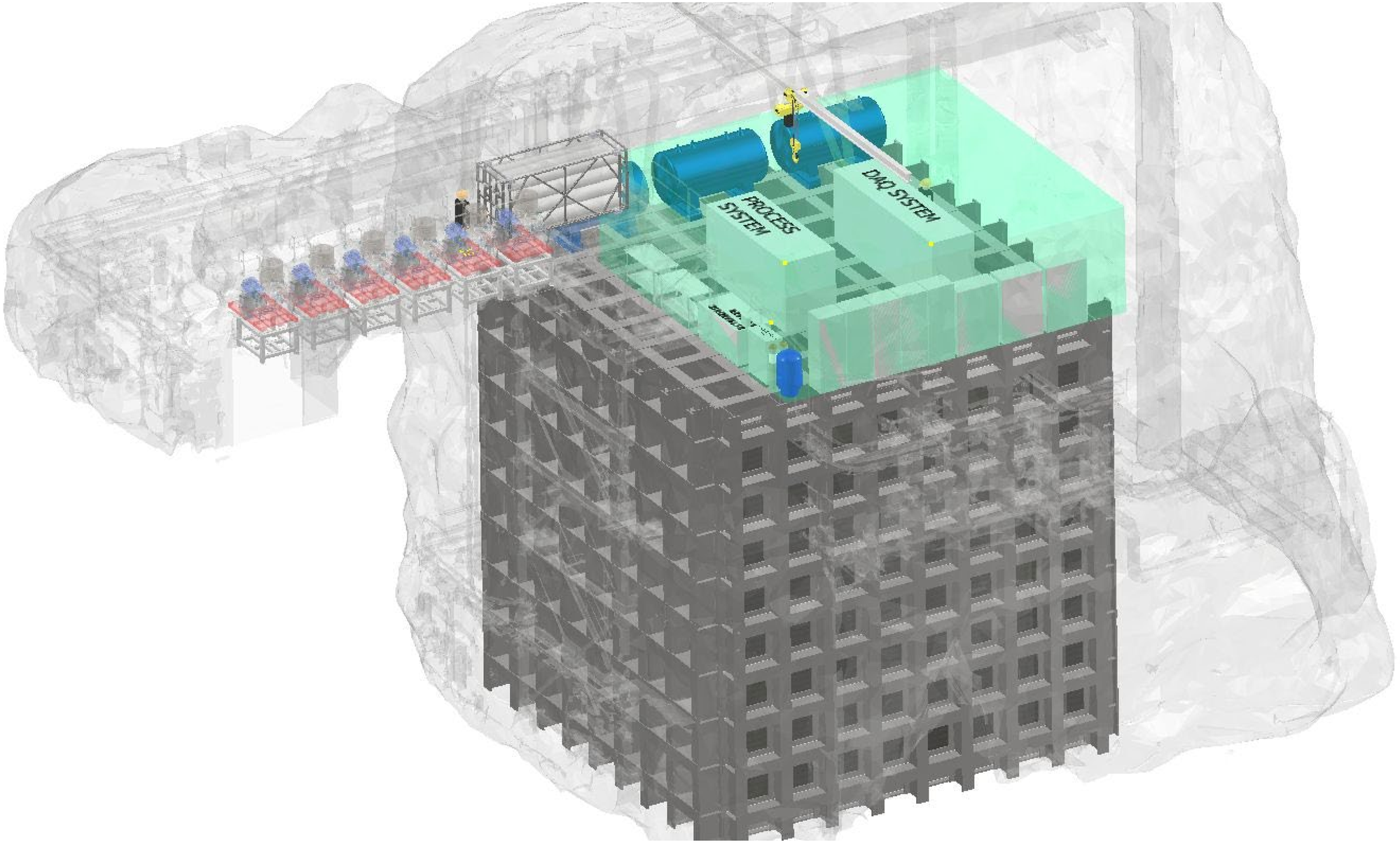
Liquid argon buffer

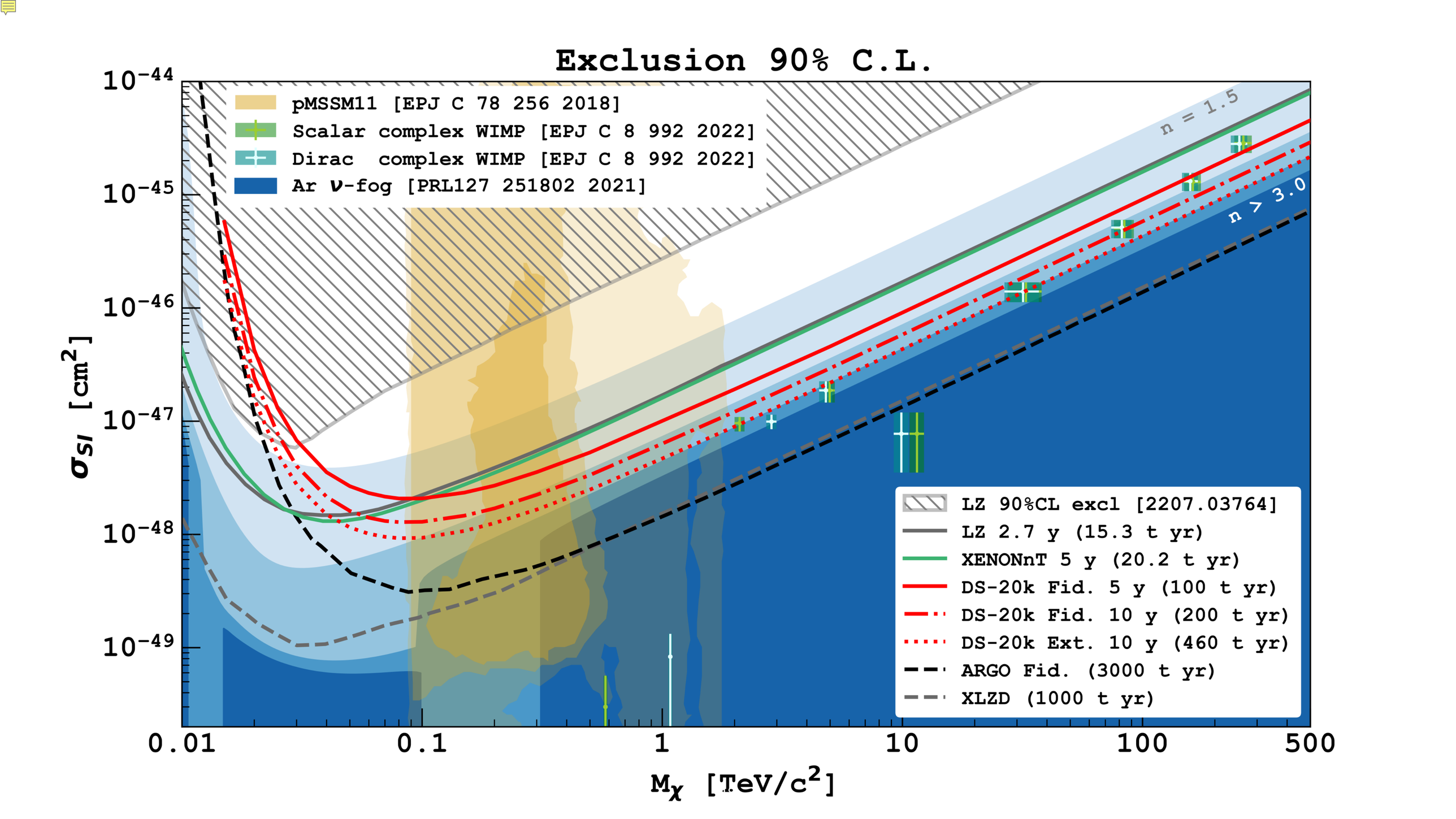
Ultrapure acrylic vessel (7m diameter and height)

400 tonnes low-radioactivity argon within acrylic vessel

250 m^2 PDCs covering full acrylic vessel surface

ARGO Concept in SNOLAB Cube Hall

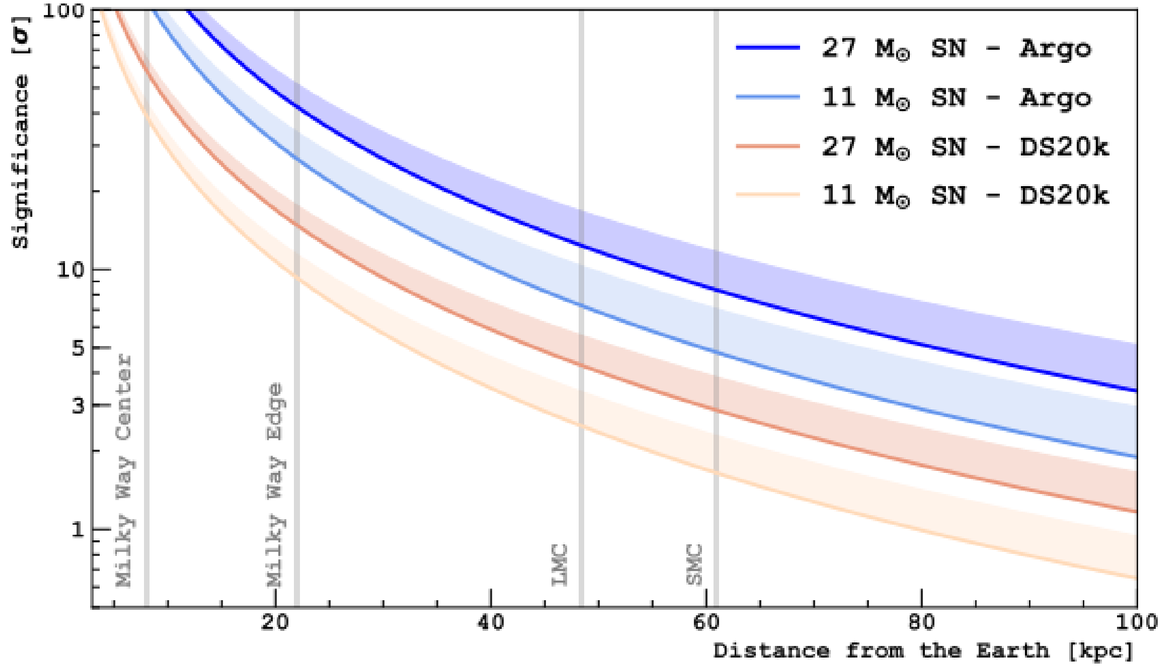


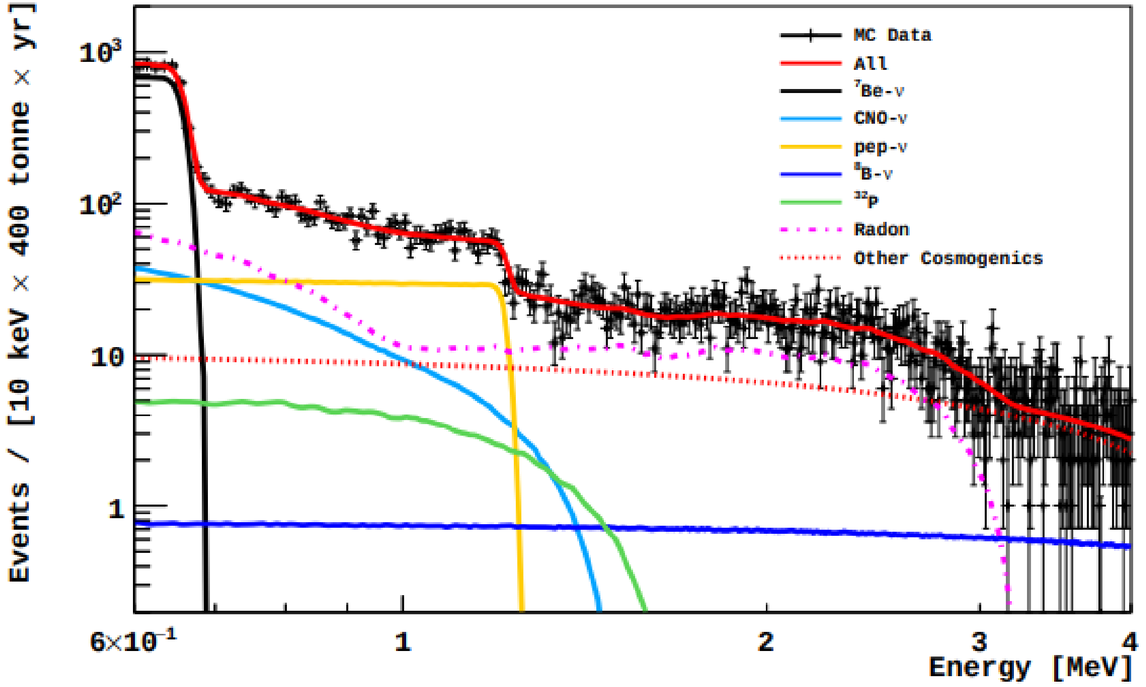

Exclusion 90% C.L.
pMSSM11 [EPJ C 78 256 2018]
Scalar complex WIMP [EPJ C 8 992 2022]
Dirac complex WIMP [EPJ C 8 992 2022]
Ar ν-fog [PRL127 251802 2021]
n = 1.5
n > 3.0
LZ 90%CL excl [2207.03764]
LZ 2.7 y (15.3 t yr)
XENONnT 5 y (20.2 t yr)
DS-20k Fid. 5 y (100 t yr)
DS-20k Fid. 10 y (200 t yr)
DS-20k 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

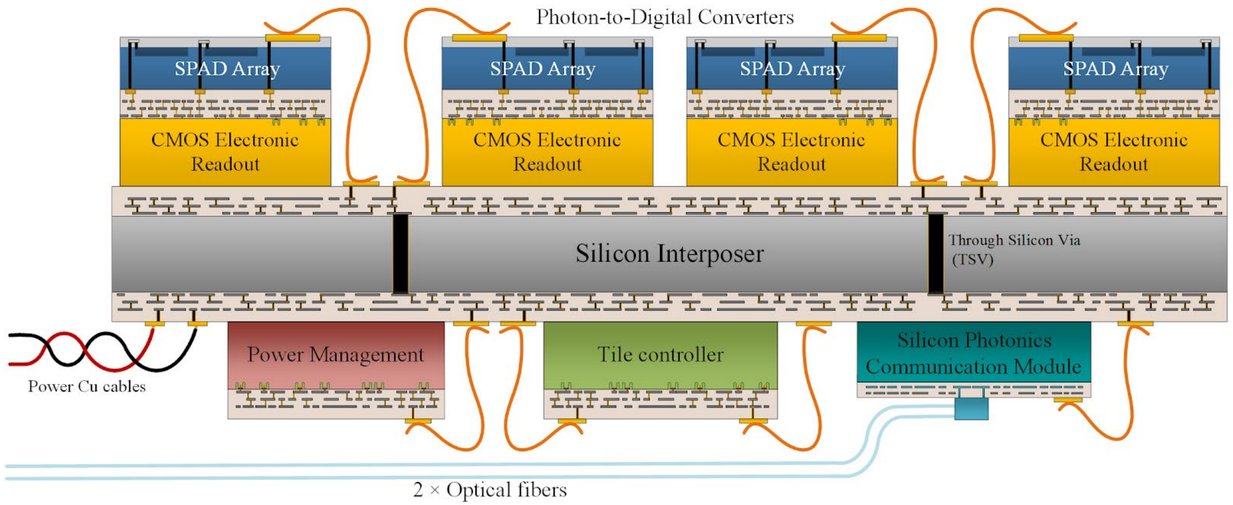
High Mass (>50 GeV/c^2): third-gen sensitivity to dark matter with complete suppression of electron recoils and any other instrumental background

- 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

GADMC preferred site is SNOLAB

Development of digital SiPMs for ARGO



Sherbrooke U.

PMT solution used in DEAP can't easily be scaled to ARGO due to both neutron backgrounds and thermal requirements

Digital solution can be scaled to several hundred m^2 and maintain low noise levels needed for PSD in argon

New proposal will combine continued development of this work at Sherbrooke and take advantage of efforts towards "2.5D" developments on a shorter timescale.

SPADs stacked onto electronics readout for very high fill factor and simple digital photon detection

Much simpler integration and readout

All-digital system not affected by electronic noise encountered in analog

Ability to reference individual SPADs, enable/disable as desired to control afterpulsing, remove noisy channels

Excellent time resolution (ns-scale) and spatial resolution (currently targeting ~3 mm) allows advanced vertex reconstruction and event ID for background rejection

Prototyping Facility / New CFI request

Testbed for future 4π digital SiPM systems and first demonstration of large area digital SiPMs and prototyping of DS-style TPC

- Fast timing and pixelation allows demonstration of position reconstruction and hit pattern ID of background events

- designed with calibration ports for low-background assay, in particular measurement of surface alpha contamination at the level of **10 microBq/m^2** (currently not possible anywhere else but required for DM and other experiments)

- will design in the possibility of assay of ^{42}Ar in underground argon (and by default assay of ^{39}Ar in UAr)

- will design for low gamma background, so that in the event a low-mass WIMP signal is seen in other experiments, we could reconfigure for a low-mass WIMP argon search for confirmation.

- 2025 CFI IF proposal / 2027-2030 prototyping at SNOLAB and Carleton + continued ARGO development

The ultimate deliverable is a final concept for ARGO that has been prototyped and risk-mitigated ready to move forward (around 2031)

Summary and Conclusion

Very active collaboration on liquid argon dark matter. Priority is completion of DS20k construction. Ongoing activity on conceptual design of ARGO.

DS-50 and DEAP-3600 still active on analysis and publications, including recent PRLs. New data upcoming with DEAP-3600 with goal of demonstrating high-sensitivity “background-free” operation now through ~2026.

Funded in Canada for development of ARGO concept. Work in progress; submitting both a formal LOI to SNOLAB this round and funding request in 2025 in Canada for (a) developing siting requirements and engineering for ARGO and (b) developing of a prototyping facility for ARGO, including digital SiPMs, that will replace DEAP-3600 around 2027 for operation 2027-2030. Approximate timeline is prototyping + design in place by 2030 to move ahead with ARGO project implementation.

SNOLAB is the collaboration’s preferred option.

The End