Development of ARGO

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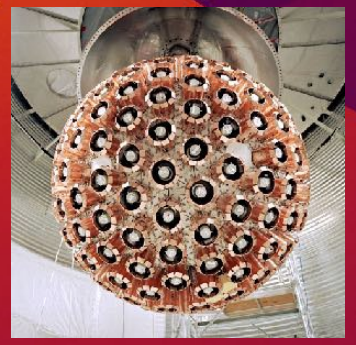
for the Global Argon Dark Matter Collaboration GADMC
(100 institutions in 14 countries)

and 2025 CFI IF Proponents
(Alberta, Canada Nuclear Laboratories, Carleton, Laurentian, LNGS, Naples, Queen's, Sherbrooke, TRIUMF)

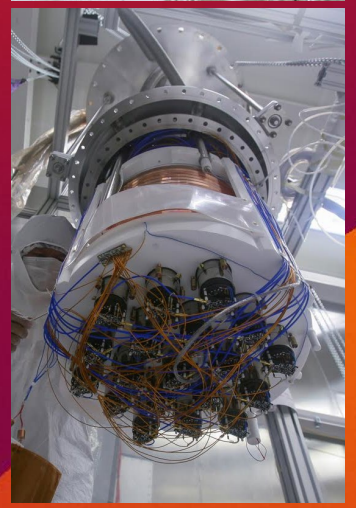
Since 2017

The Global Argon Dark Matter Collaboration (GADMC)

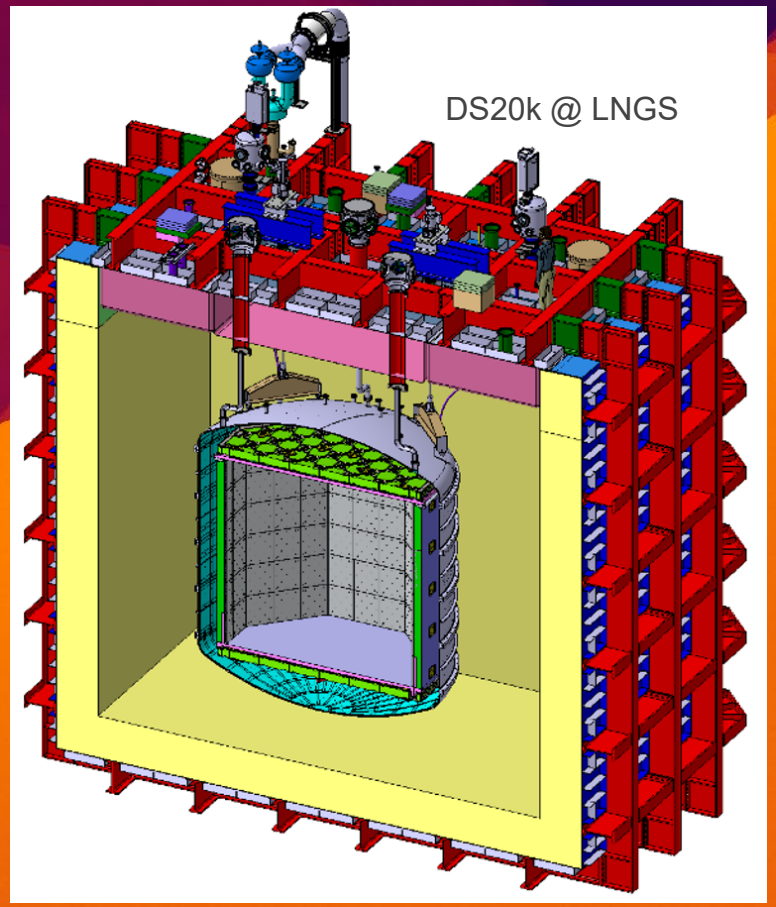
GADMC brings together more than 400 scientists committed to explore heavy (and light) dark matter to the neutrino fog and beyond



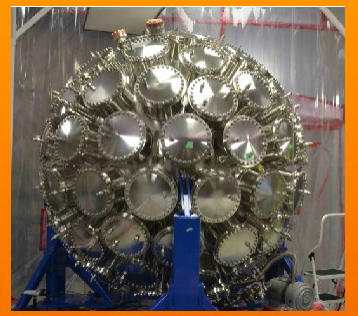
DEAP-3600



DarkSide-50



MiniCLEAN



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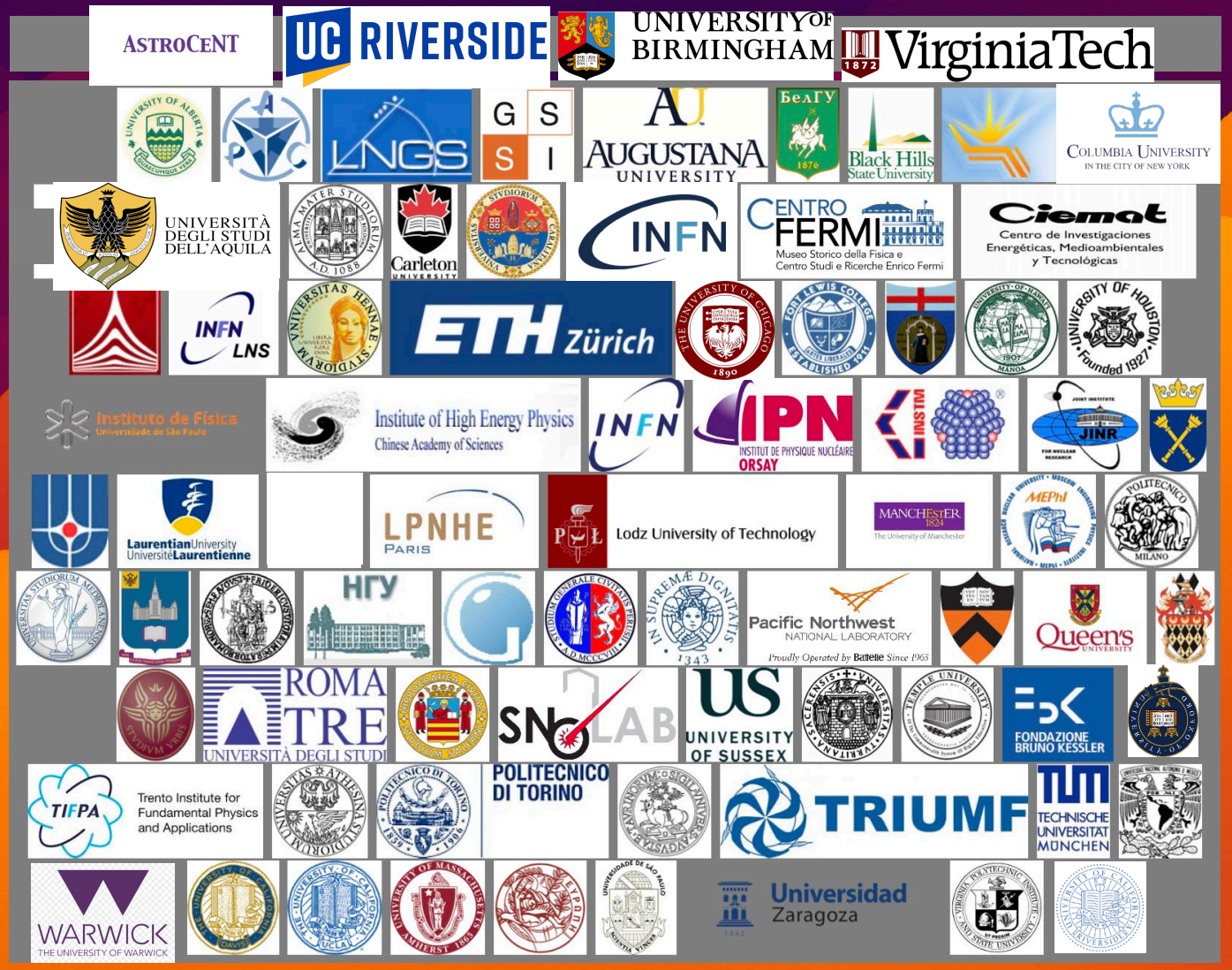
ARDM

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

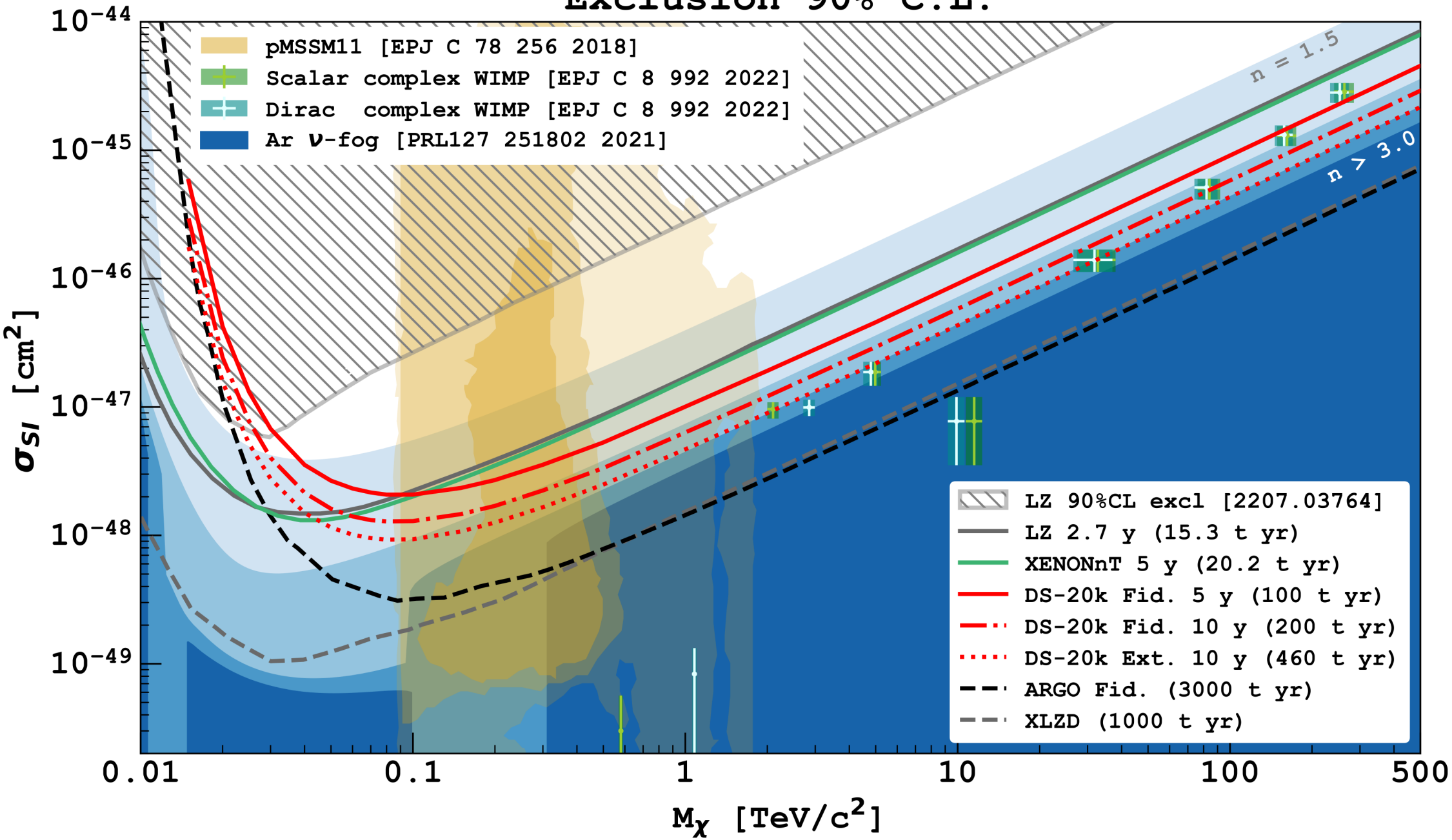


ArDM
DarkSide-50
DEAP
MiniCLEAN

The Global Argon Dark Matter Collaboration

DS-20k
{20 t fid.,
50 t full}
[ops 2028-]

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

Broad physics and technical program

- High-mass dark matter, highest sensitivity and instrumental background-free
- Solar neutrinos (intermediate energy through elastic scattering)
- Solar neutrinos (^{8}B through neutrino absorption)
- Multi-messenger astronomy
- Supernova sensitivity

  (and additional developments related to a 2025 CFI proposal, more later)

- ALARM – Field deployable border screening detector
- Pixelated digital photodetector development
- Low-mass dark matter “S2-only” (see Michela Lai’s talk)
- Cryogenic distillation of argon for removal of ^{39}Ar
- Exploring sensitivity to neutrinoless double beta decay

Timeline highlights of the argon program in Canada

Funded as NSERC SAP Project, funding 2006-2027. As DEAP-3600 until 2021, since then as GADMC program including DEAP-3600, DarkSide-20k and ARGO. Integrated NSERC funding $16M.

CFI NOF 2006, DEAP prototyping $580k (DEAP-1)

CFI LOF 2009, DEAP-3600 hardware $1M

CFI IF 2010, DEAP-3600 and SNO+ hardware, $26.4M, DM and double beta decay

…DEAP-3600 construction 2009-2016
…DEAP-3600 data collection 2016-2020
…DEAP-3600 hardware upgrades 2020 to 2024
…DEAP-3600 data collection 2025-2026 (after upgrades)

CFI IF 2017 and CFI JELF 2017, joint nEXO and ARGO (at the time DEAP-nT), DM and double beta decay, Noble Liquid Facility at Carleton and development of digital photodetectors at Sherbrooke. $10.1M
Strong synergy on technology development.

CFI IF 2020, DarkSide20k Canada and DEAP-3600 upgrades. $17.6M

SNOLAB Gateway-0 approval for ARGO (October 2024) and Gateway-1a approval (January 2025)

CFI IF 2025 application, ARGO development, $17M, photodetector development and prototyping, design

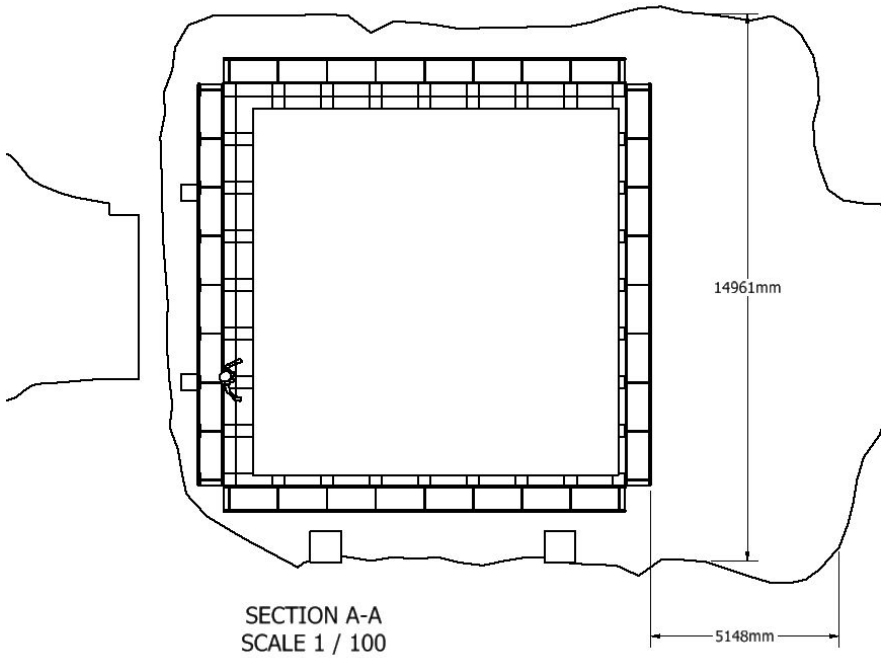
ARGO: Conceptual design

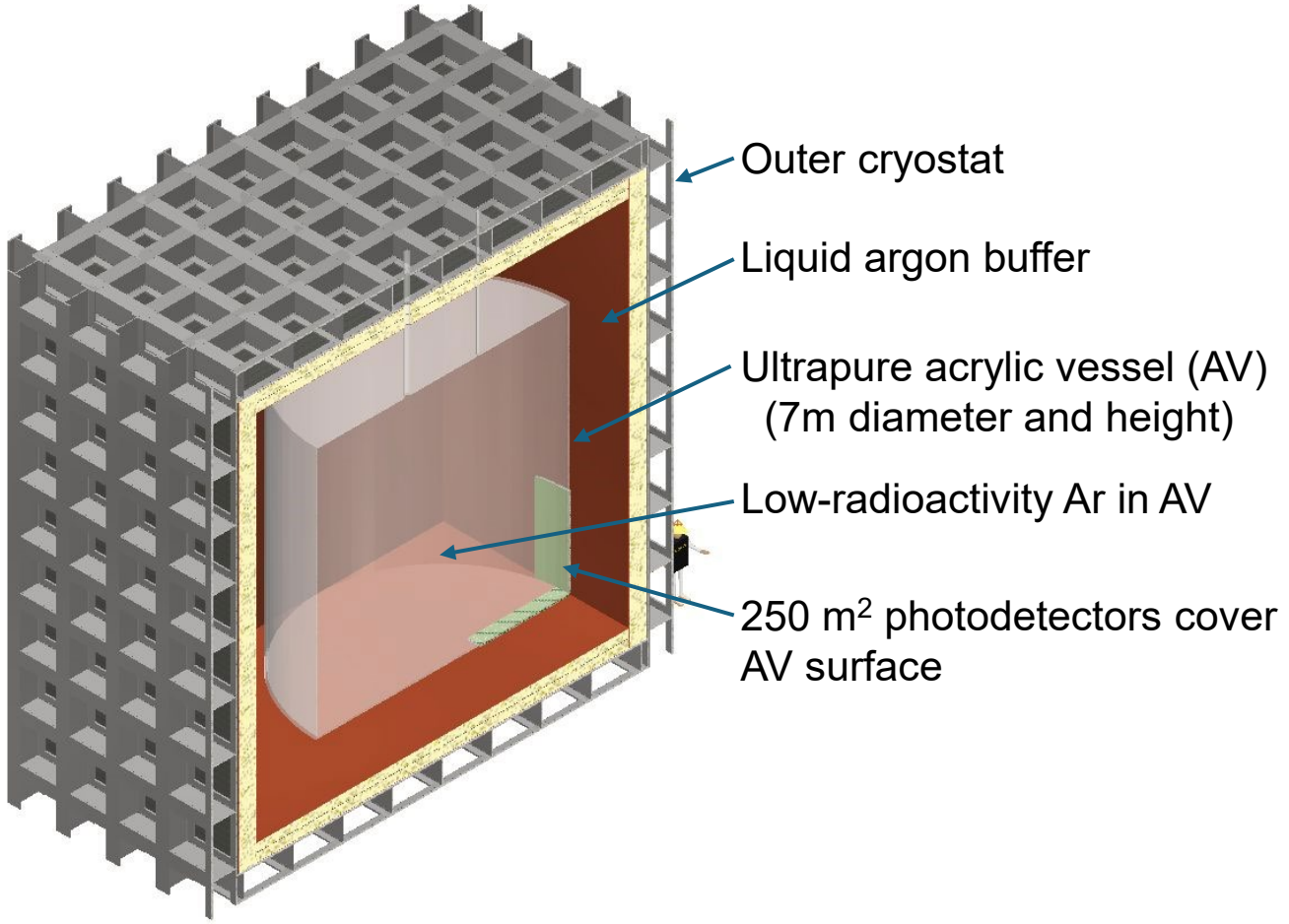
Low-radioactivity argon:
- total 400 tonnes, fiducial 300 tonnes

Pixelated digital photodetector readout

Preferred site: SNOLAB Cube Hall

Current focus in Canada is scintillation-only design, but configuration allows either this or TPC version.





Neutron backgrounds in ARGO – SNOLAB Cube Hall Detailed G4 simulation

ARGO detector geometry

World (norite rock) box: 50 m × 50 m× 50 m

room1 (air) box: 18.6 m (x) × 19.0 m (y) × 27.0 m (z)

protoDuneCryostat outershell (stainless steel)
box: 13 m × 13 m× 13 m, thickness :12.7 mm

protoDuneCryostat insulator (foam)
box : 12.9746 m × 12.9746 m × 12.9746 m, thickness: 1.2446 m

protoDuneCryostat innershell (stainless steel)
box: 10.5254 m × 10.5254 m× 10.5254 m, thickness : 12.7 mm

LAr (liquid argon)
box :10.5 m × 10.5 m× 10.5 m

SiPM Arrays

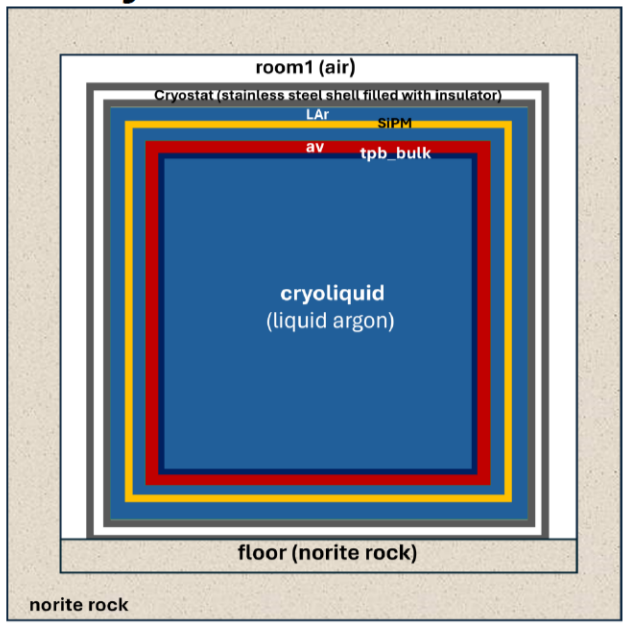
av (acrylic)
ρ_{max}: 3.675 m, h: 7.35 m, 15 cm thick

tpb_bulk (tpb)
ρ_{max}: 3.525 m, h: 7.05 m, 3 μm thick

cryoliquid (liquid argon)
ρ_{max} : 3.524997 m, h: 7.049994 m

floor (norite rock)

box: 18.6 m (x) × 19.0 m (y) × 7.0 m (z)



2-D cross-section of detector components (**standard geometry** in the simulation)

Mass : 381.43 tonnes
with density of argon = 1386 kg/m^3

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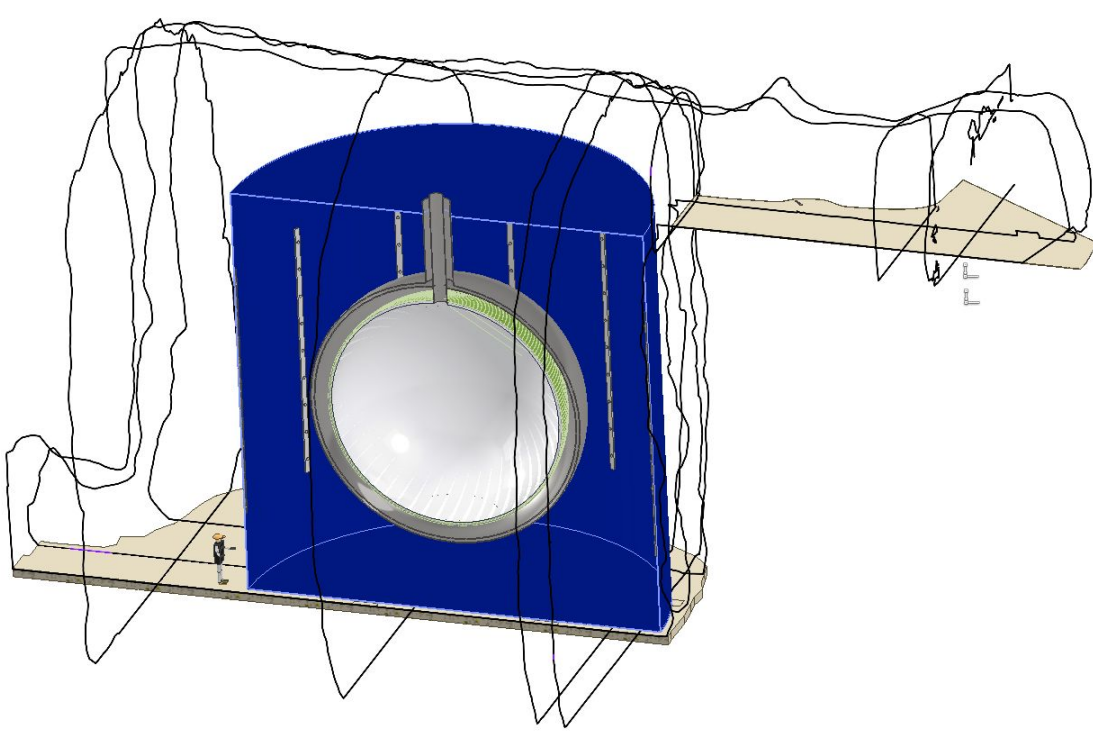
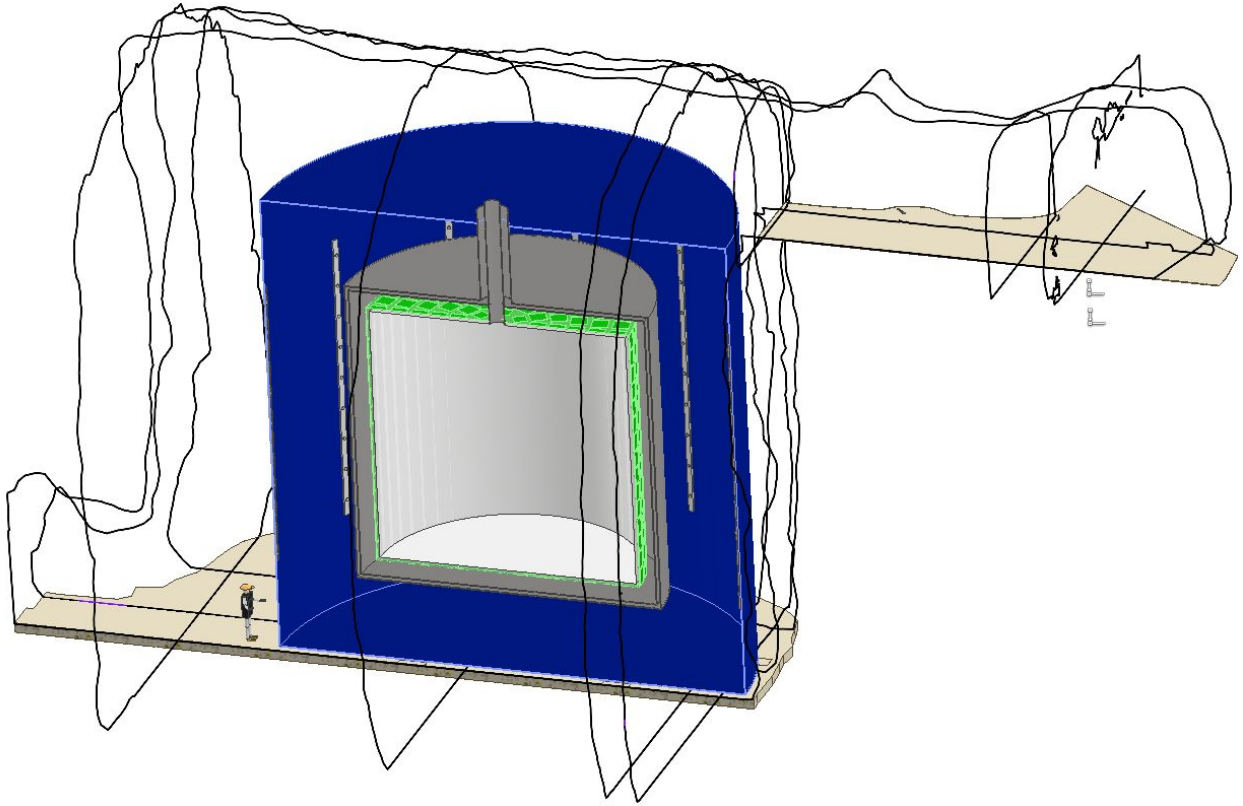
Find that no configuration results in less than around 100 neutron events in low-energy WIMP ROI, even changing acrylic thickness and flooding Cube Hall with water

New concepts being developed





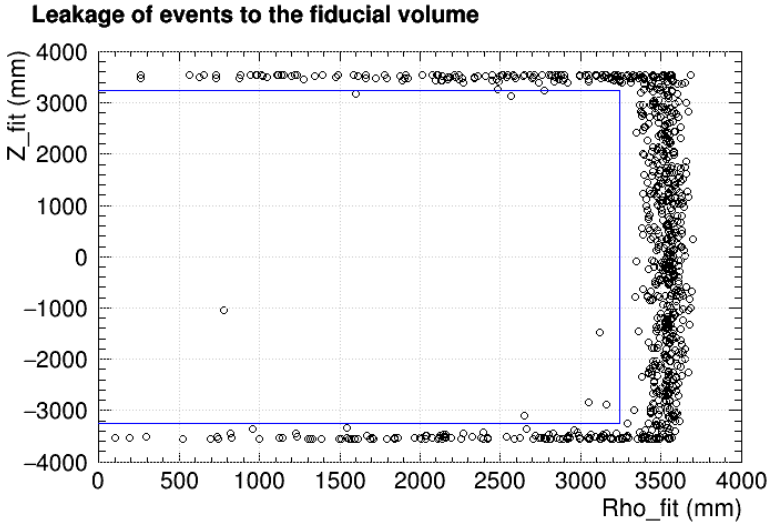
Increase inner dimension to reduce neutron backgrounds within fiducial volume; change protoDUNE-style cryostat to vacuum cryostat + large water shield to reduce external neutrons.

Backgrounds are being recalculated. Carrying two options for scintillation-only / TPC-style. Planning for full background table and publication this year.

Event reconstruction and ID with pixelated photodetectors

Detailed optical model of ARGO for simulation of position reconstruction and cluster ID algorithms.

Primary concern is the reduction of external or surface background events.

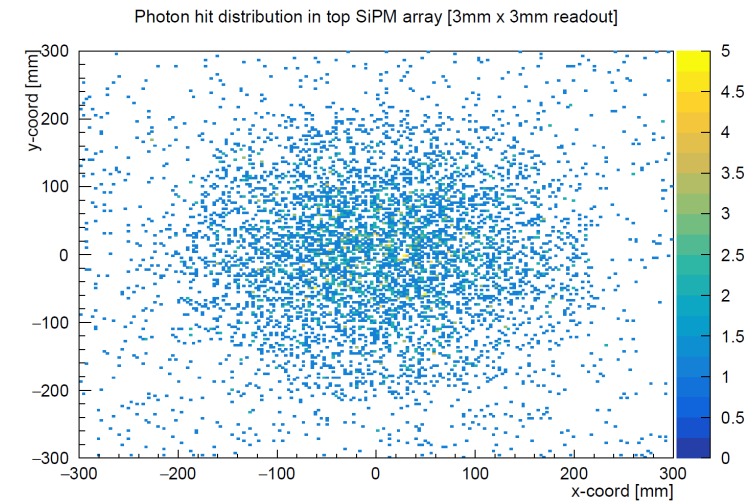


Left: Alpha-decays on ARGO inner detector surface

Time-based position reconstruction

Sets constraint on allowable surface ^{210}Po contamination and construction sequence

Work in progress



Left: hit pattern imaged onto pixelated photodetectors over 60x60 cm^2 area for surface events. Developing hit-pattern ID algorithms.

Reduction of 10^{-6} would allow setting target surface purity levels like those achieved in DEAP. Better than that can relax the surface activity requirement and simplify detector construction requirements. Work in progress.

2025 CFI Infrastructure Proposal

Proposal submitted in Feb 2025 for Nov 2025 Decision.

Main elements:

Development of pixelated digital photodetector array. Builds on past investments and combines Canadian and international effort.

Construction of a scintillation-only prototype (ARGOlite) using the above:
- $2m^2$ pixelated array
- installed in DEAP water shield tank at SNOLAB and uses DEAP cryogenic and argon purification
- Designed to be re-usable for Low-Mass WIMP search

Deployment of existing prototype TPC for concept studies (Naples)

Engineering design for ARGOlite and ARGO (2026 to 2031). Conceptual-level.

ALARM-2. Compact standalone LAr detector using the first pixelated readout tiles for Canadian Nuclear Labs (Chalk River). Nuclear materials screening. Funded by CNL with design effort by the collaboration.

Extension to existing SNOLAB distillation setup. Upgrade existing distillation test rig to a prototype 4-inch diameter distillation tower. Measurements enable design of a high-throughput rig that could supply ARGO.

Upgrade to facilities in Canada:
- new radon-free operation in Carleton cleanroom; new particulate imaging and deposition equipment
- new LAr test stand at Queen's
- FPGA farm at Sherbrooke to develop "Intelligent DAQ" readout

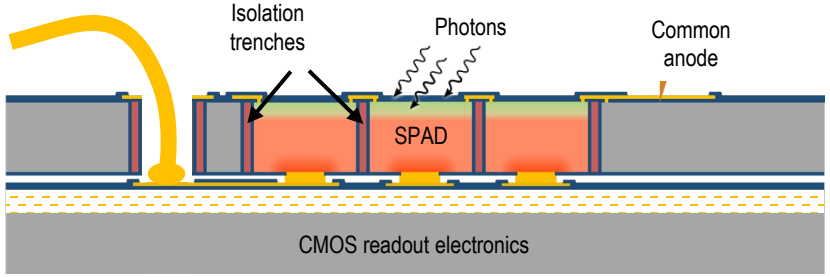
Two approaches for pixelated digital photodetectors (2025 CFI)

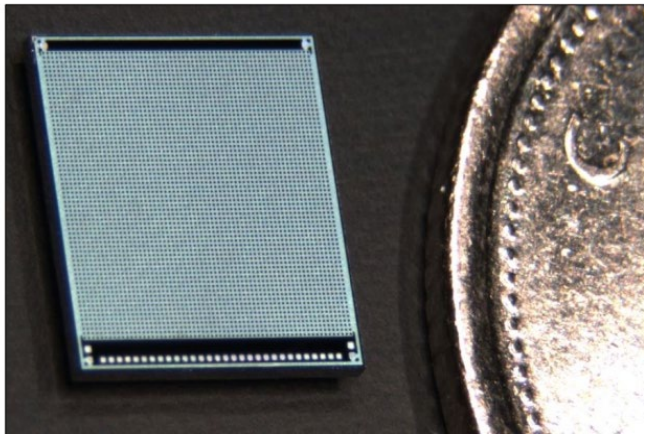
1: Full “photon-to-digital converter” PDC system (Sherbrooke)

Each SPAD is bonded (3D) to unique readout circuit; digital information is aggregated from the SPAD level and then pixelated. Most flexible.

2: ATARI “2.5d” system (LNGS and U. L’Aquila)

SPADs are aggregated on-plane into pixels, then each pixel is bonded to a readout circuit. Somewhat simpler implementation.

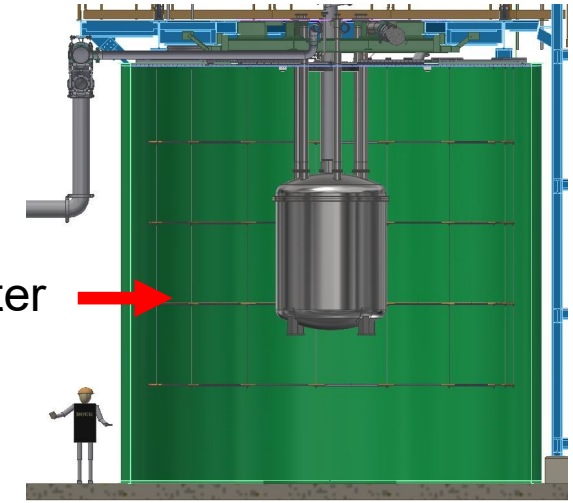




3D SPAD array (canadian 10¢ for reference) from Sherbrooke

- Evaluating both options within the and will produce a large array (2 m^2) for ARGOlite
- Output is similar: 3 mm pixels provide pixel_id, time of first photon and photon count as a digital stream
- TRIUMF providing integration and readout electronics

ARGOlite in the DEAP shield tank at SNOLAB



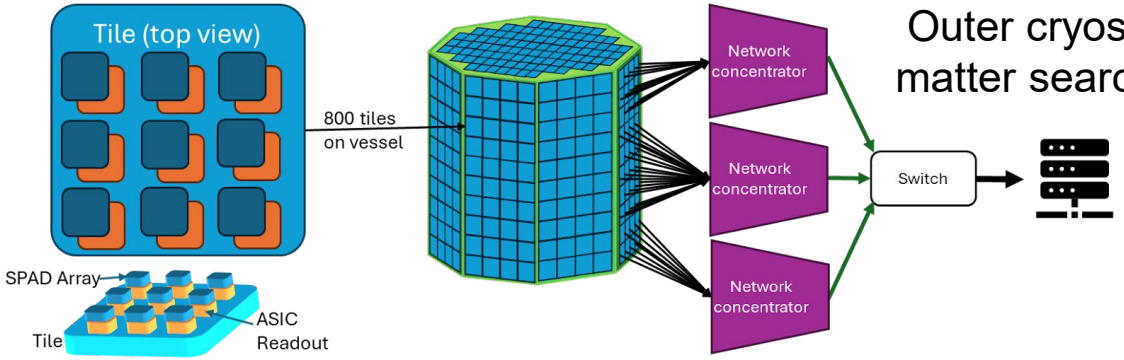
Re-uses the DEAP systems:
Cryogenics, Ar purification, shield tank, safety vent

Targets:
surface alpha assay at 10 mBq/m^2
^{42}Ar in argon (and ^{39}Ar)
direct material neutron rates, high sensitivity

demonstrate ER/NR PSD at 10^{-9}
demonstrate surface alpha rejection (combined) at 10^{-7} (or better)
Qualify the full optical detail for ARGO design
and determine threshold curve/physics performance.

Becomes general-purpose low-background assay infrastructure at SNOLAB after ARGO prototyping

Outer cryostat and infrastructure compatible with DS-LM for re-use in dark matter search experiment.



Isotopic purification

Proposed a 4-inch diameter, 20-m tall distillation column in 2025 CFI IF

In general, isotopic purity scales with column height and purification throughput scales with diameter

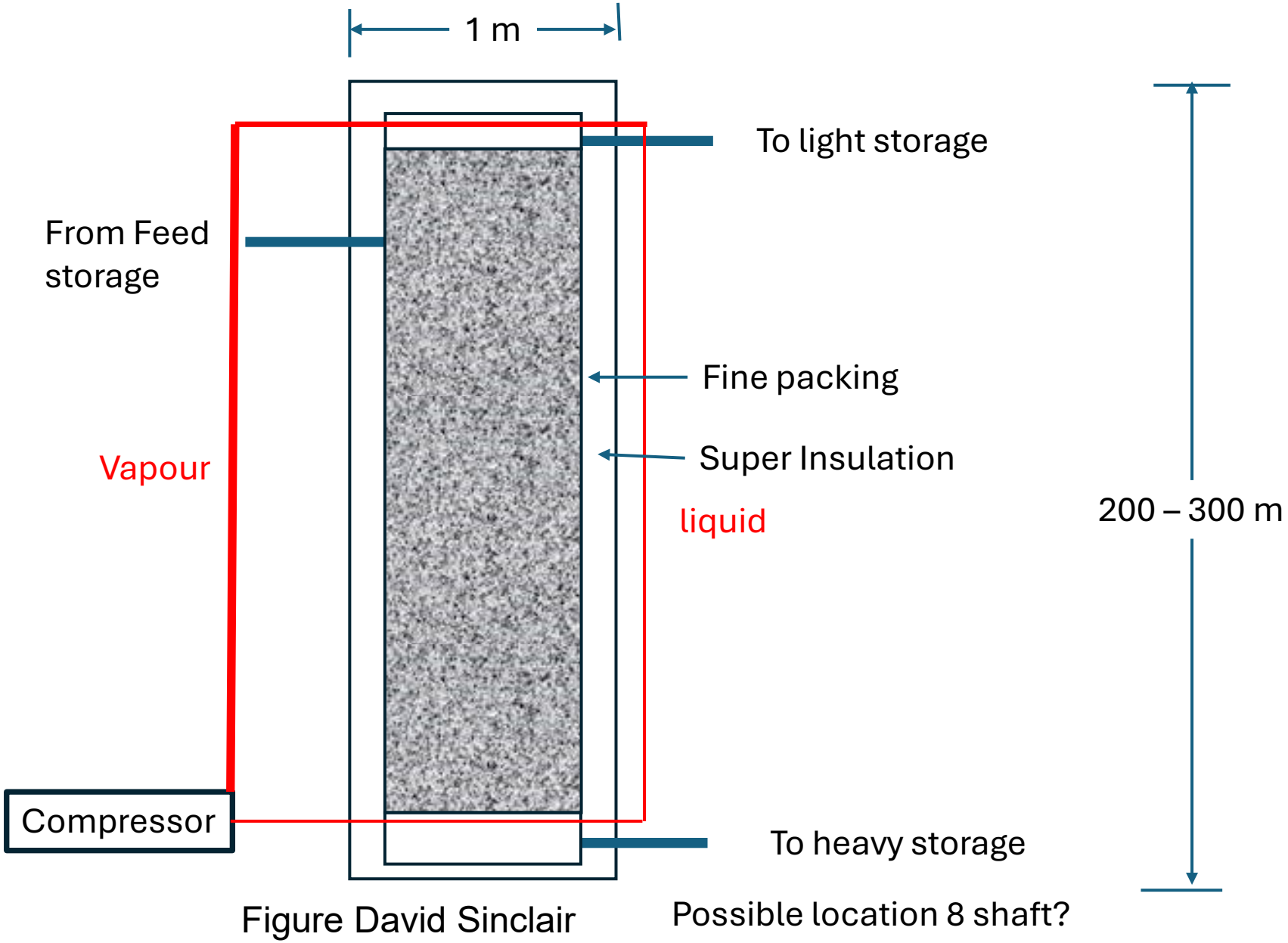
From earlier studies with the Xe-still, estimate that a 200 to 300 m tall column could provide a reduction factor of 100 to 1000 in ^{39}Ar. Column diameter can be scaled to 300 kg/day throughput.

Measurements with the proposed test column would allow detailed design and costing of full-scale column.

Test column provides around 15% reduction in ^{39}Ar for demonstration in ARGOlite.

Complementary to ARIA column in Sardinia that is critical for DarkSide-20k. ARIA designed for high isotopic purity at low rates (medical isotopes also could be used for DS-LM) and chemical purification at high rates. Large-scale column at SNOLAB would have medium purity but high throughput needed for ARGO.

Ar/Xe Enrichment Still (full-scale)



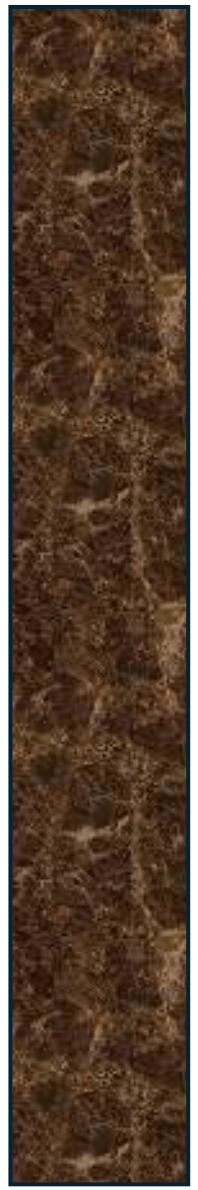


Figure David Sinclair

Neutrinoless Double Beta Decay

Considering options for neutrinoless double beta decay in ARGO program

Energy resolution in LAr is very good (around 2% in DEAP for high-energy gammas, dominated by systematics which could be improved)

Expect ~1-percent energy resolution in ARGO; remember 400 tonnes LAr with very low backgrounds

Can consider spiking the argon with candidate materials at the few percent level (10 tonnes or so)

Can also consider exploring concepts for neutrinoless double beta decay in ARGOlite

- dopants to convert photons to charge; or other candidate materials in LAr, including xenon
- operation of ARGOlite with LXe (currently designing the cooling system as part of the 2017 “Noble Facility” IF as a variable-temperature heat pipe that works with argon or xenon). For reference the DS-LM TPC within ARGOlite would hold 3 tonnes of LXe.
- can continue to take advantage of technical developments in Canada toward future project R&D

Summary

Broad and phased program targeting high-mass dark matter into the neutrino fog; includes shorter-term technology development and physics reach. Unique in low-background sensitivity.

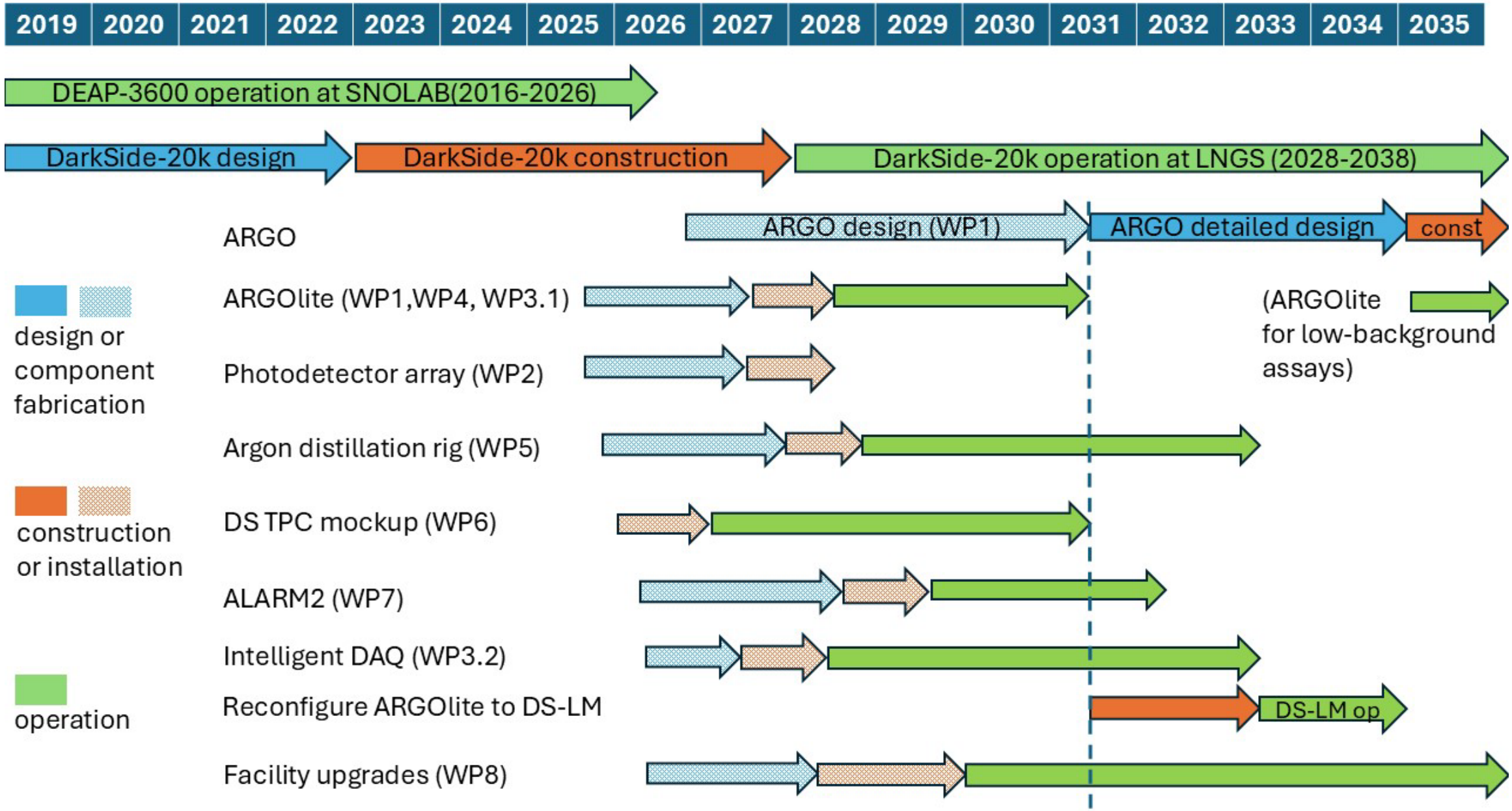
New prototyping facility ARGOlite at SNOLAB makes use of novel pixelated digital photodetectors, provides new assay capabilities and enables benchmarking ARGO design.

ARGOlite infrastructure requested in CFI IF 2025 is re-usable for low-mass WIMP search.

Possibility of using ARGOlite to study concepts for NDBD in argon, and operating with LXe for further development of the xenon NDBD program. Synergy around technical developments.

Items for the 15-year plan:

- Distillation column, possibly at 8 shaft
- Storage and logistics for 400 tonnes of low-radioactivity argon
- Possibility of radon-reduced air in the Cube Hall


2019
2020
2021
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DEAP-3600 operation at SNOLAB(2016-2026)
DarkSide-20k design
DarkSide-20k construction
DarkSide-20k operation at LNGS (2028-2038)
ARGO
ARGO design (WP1)
ARGO detailed design
const
ARGOlite (WP1,WP4, WP3.1)
(ARGOlite for low-background assays)
Photodetector array (WP2)
Argon distillation rig (WP5)
DS TPC mockup (WP6)
ALARM2 (WP7)
Intelligent DAQ (WP3.2)
Reconfigure ARGOlite to DS-LM
DS-LM op
Facility upgrades (WP8)
design or component fabrication
construction or installation
operation