Neutron Backgrounds for ARGO

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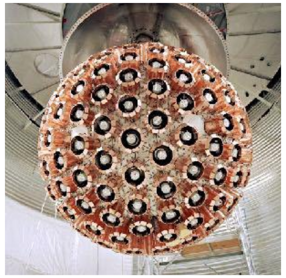
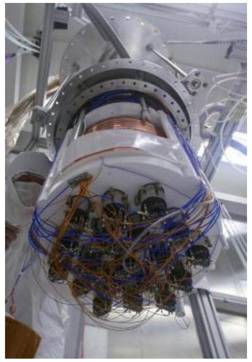
The Global Argon Dark Matter Collaboration formed in 2017



DEAP-3600



DarkSide-50

MiniCLEAN

ARDM

DarkSide20K

Brings together over 400 scientists from 100 institutes in 14 countries, **working on liquid argon detectors.**

Timeline

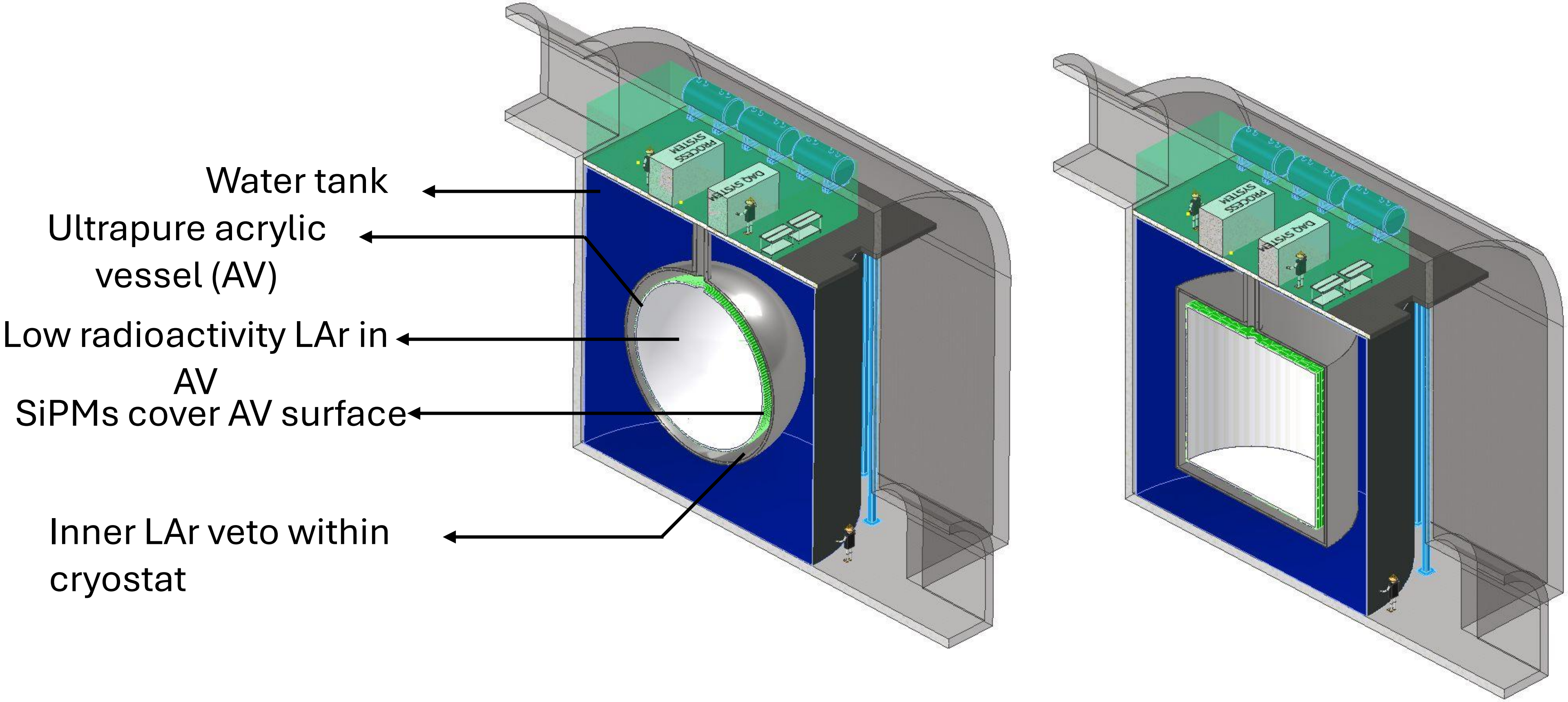
Currently running experiment:
DEAP-3600 at SNOLAB, Canada

New experiment under construction:

- DarkSide20K at LNGS, Italy
- 20 tonnes of fiducial mass

Next planned new experiment:
ARGO

ARGO Conceptual Design



Concept is being developed for the SNOLAB Cube Hall.

- Total 400 tonnes of underground liquid argon(LAr) **with 300 tonnes fiducial mass.**
- **250 m^2 of pixelated digital silicon photomultiplier (SiPM) readout,** covering full acrylic vessel outer surface.

Physics Program

Broad Physics Program

- Detect scintillation light generated when a dark matter particle (specifically, WIMP) elastically scatters off a ^{40}Ar nucleus, producing a nuclear recoil (NR).

$$\chi + {}^{40}Ar \rightarrow \chi + {}^{40}Ar$$

- Extensive sensitivity to neutrinos.

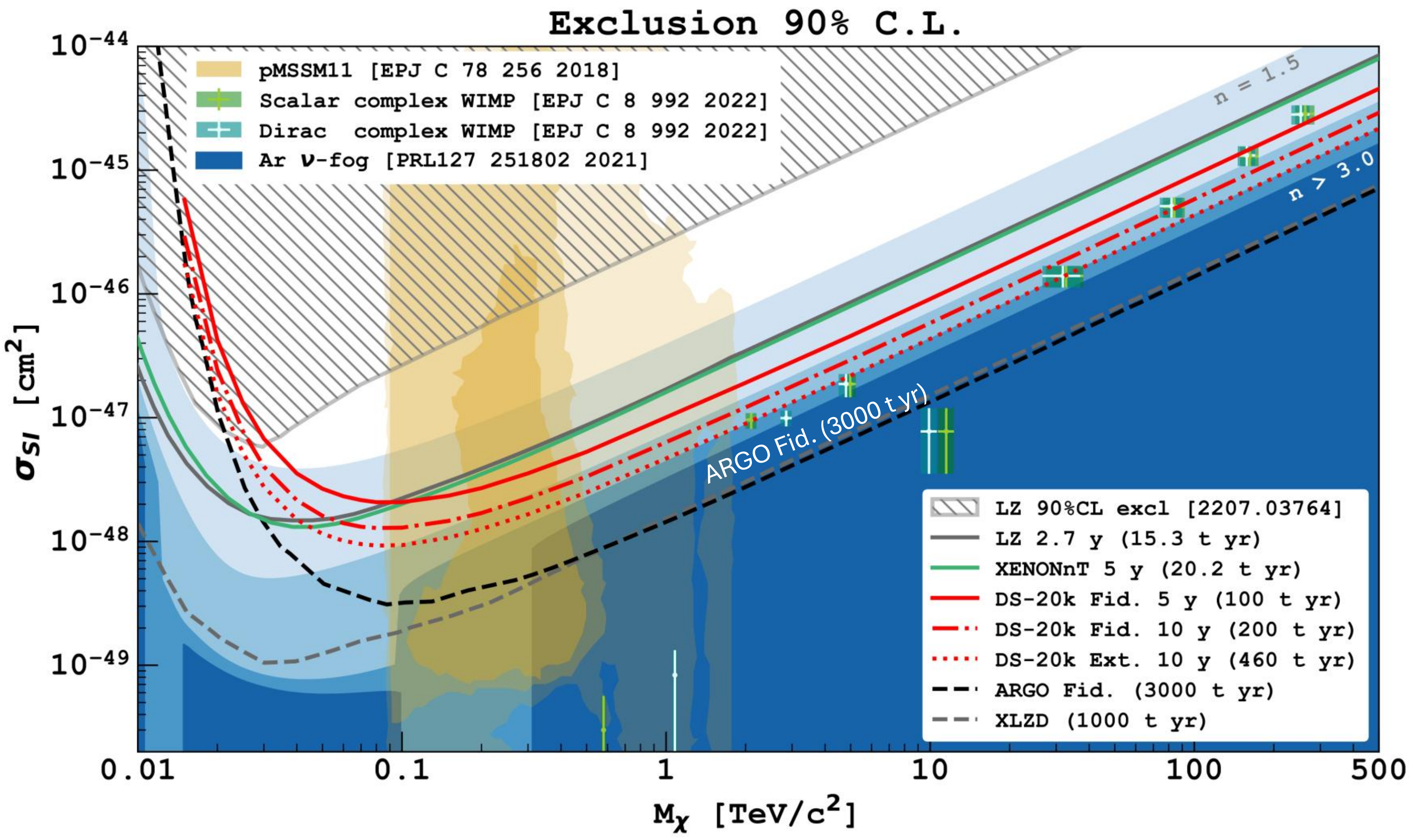
Challenges

- Detect an extremely small number of nuclear scatters ($\sim$1 event per 3000 tonne-year exposure).
- Suppress background events:
    - Electron recoil (ER) backgrounds from gamma-rays, beta-particles.
    - Nuclear recoil (NR) from neutrons, alpha -particles.

Reduction Strategy

- Underground liquid argon reduces beta decays from ^{39}Ar isotopes by approximately three order of magnitude.
- Pulse-shape discrimination (PSD) provides excellent separation between NR and ER events, with ER leakage probability less than one in a billion.
- Careful selection of radiopure material reduces the radiogenic neutron background to a negligible level.
- Building experiment 2 km underground at SNOLAB would significantly reduce cosmogenic neutron backgrounds. (similar to DEAP-3600 experiment)

Physics Program



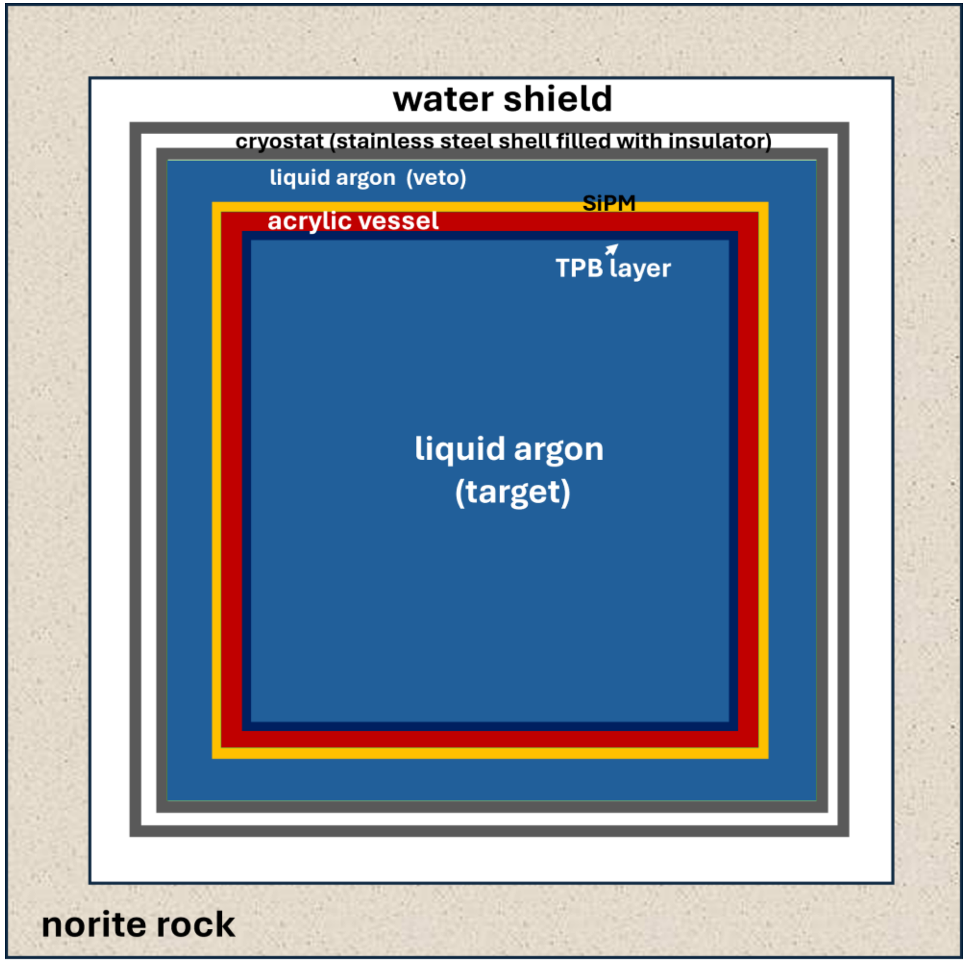
With ten years of data collection, ARGO is expected to achieve WIMP search sensitivity deep into ‘neutrino fog’.

Neutron Background Simulation

Goal:

Optimize detector design to achieve fewer than one neutron leaking into the region of interest (ROI) over 3000 tonne-year fiducial mass exposure.

- Detailed Monte Carlo simulation with RAT software built on GEANT4.
- No optical simulation since it's too CPU intensive; the effect of PSD cuts is estimated by tagging events with sufficient electron-recoil energy.



Key elements in ARGO Geometry used in simulation
https://rat.readthedocs.io/en/latest/overview.html

Radiogenic Neutron Backgrounds

U/Th contamination
↓
alpha particles emitted
↓
(α,n) reactions
↓
neutrons emitted
↓
nuclear recoils in detector

Component	Activity of Decay Chain					
	Unit	^{238}U upper	^{238}U mid	^{238}U lower	^{232}Th	^{235}U
protoDune-style cryostat	$\frac{mBq}{kg}$	4.2E+3	2.4E+3	1.7E+4	3.2E+3	1.9E+2
Vacuum cryostat	$\frac{mBq}{kg}$	6.4E-1	2.0E-1	4.0E-1	1.1E+0	3.0E-2
SiPM (only Silicon)	$\frac{uBq}{cm^2}$	1.6E-1	1.6E-1	3.2E+0	1.7E-1	7.4E-3
Acrylic vessel	ppb	3.8E-3	3.8E-3	0	6.7E-3	8.4E-4

Targeted radiopurity levels for detector components

Energy spectra for neutron are generated using:

- Neutron yield calculated by NeuCBOT tool (Neutron Calculator Based On TALYS) tools [Ref: NIMA 875 (2017) 57]
- Decay-chain activities taken from the above table.

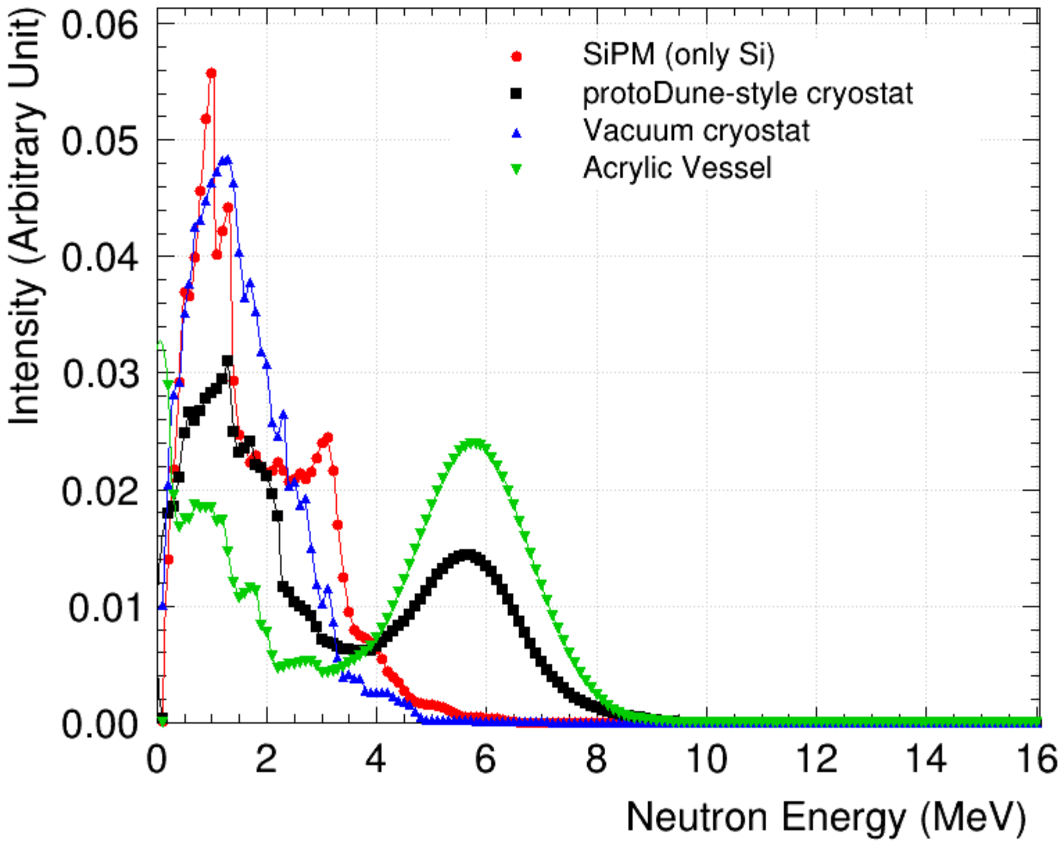
Detector Design and Neutron Energy Spectra

Design A

- 3 m thick water shield.
- 1.5 m thick LAr Veto within **protoDune-style cryostat (foam insulated steel)**
- AV Cylinder (ID Ø 7 m, height 7 m, 15 cm thick).

Design B

- 2 m thick water shield
- 1 m thick LAr Veto within **vacuum cryostat**
- AV Sphere (ID Ø 8 m, 10 cm thick).



The thicknesses of the water shield, LAr veto, and acrylic vessel (AV) were varied in the simulations to identify an optimal shield configuration that minimizes neutron background leakage into the ROI.

Analysis Overview

Step 1 : Simulated neutron events in the detector geometry.

Step 2 : Select remaining events within ROI, (15 -35) $keV_{ee.}$

Step 3 : Simulated the LAr veto ; provided further identification of neutrons.

Step 4 : Application of fiducial cut.

Leakage of radiogenic neutron background
within ROI for 3000 tonne-year exposure.

Results

Source of radiogenic neutron	Neutron Leakage in WIMP ROI (3000 tonne-year)	
	Design A	Design B
Norite Rock	< 0.13 (95% C.L.)	< 0.2 (95% C.L.)
Cryostat	42 ± 17.6	0.78 ± 0.09
SiPM (Si only)	0.06 ± 0.03	0.105 ± 0.002
Acrylic Vessel	0.72 ± 0.32	0.58 ± 0.02
Total	**43 ± 18**	**1.5 ± 0.2**

- In the Cube Hall, with the detector Design B radiogenic neutron background is low enough (approximately one neutron event).
- The Design B benefits from the custom-made vacuum cryostat.
- Identified optimized shielding configuration: 2 m water shield, 10 cm thick AV and 1 m thick LAr veto.

Summary

- ARGO is the next planned experiment of the Global Argon Dark Matter Collaboration.

- Conceptual detector design is considering for the SNOLAB, Canada.

- **Detector design is nearing completion:**
  - Defined targeted radiopurity of different detector components .
  - Optimized shielding configuration.

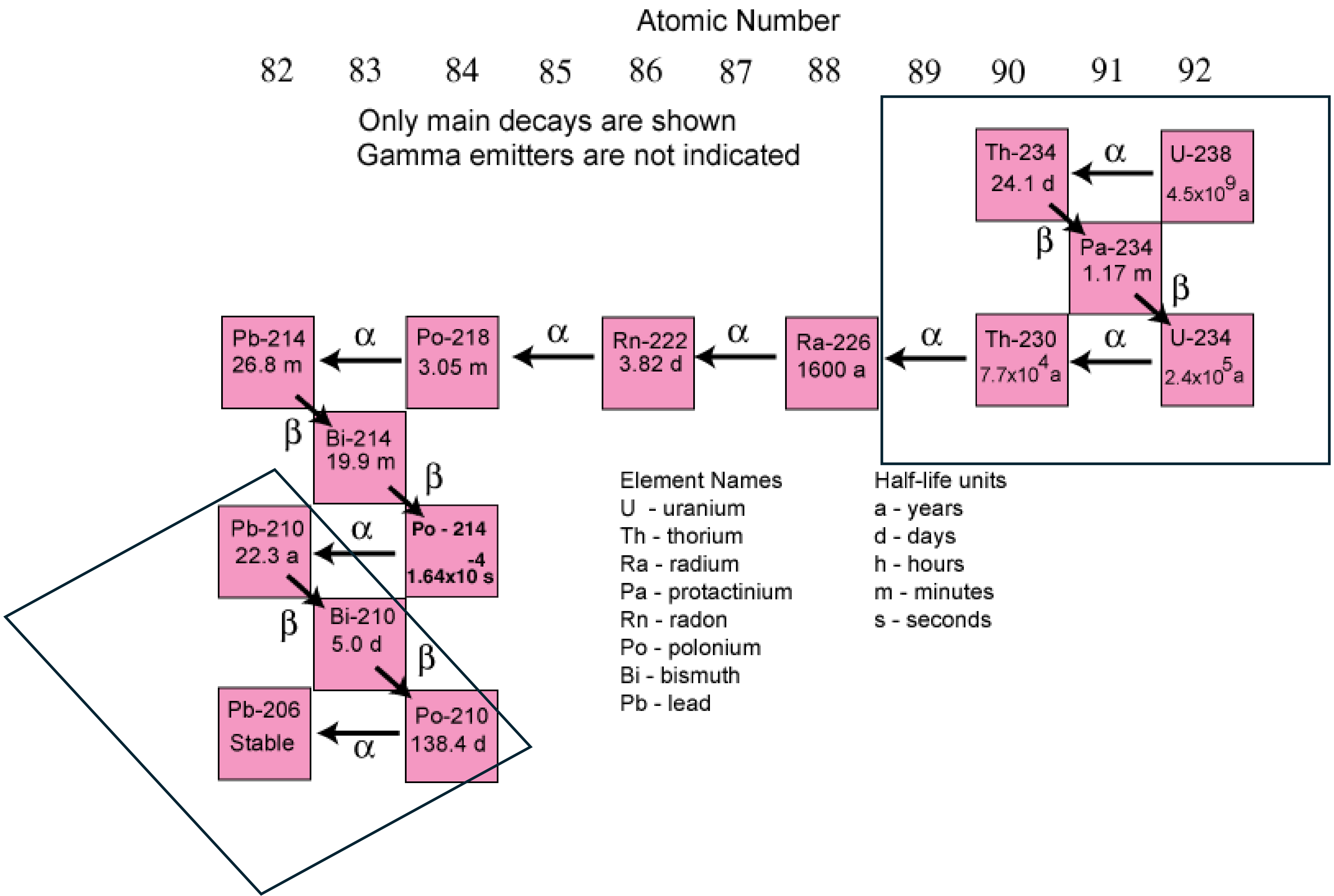
- **Completing the design paper.**

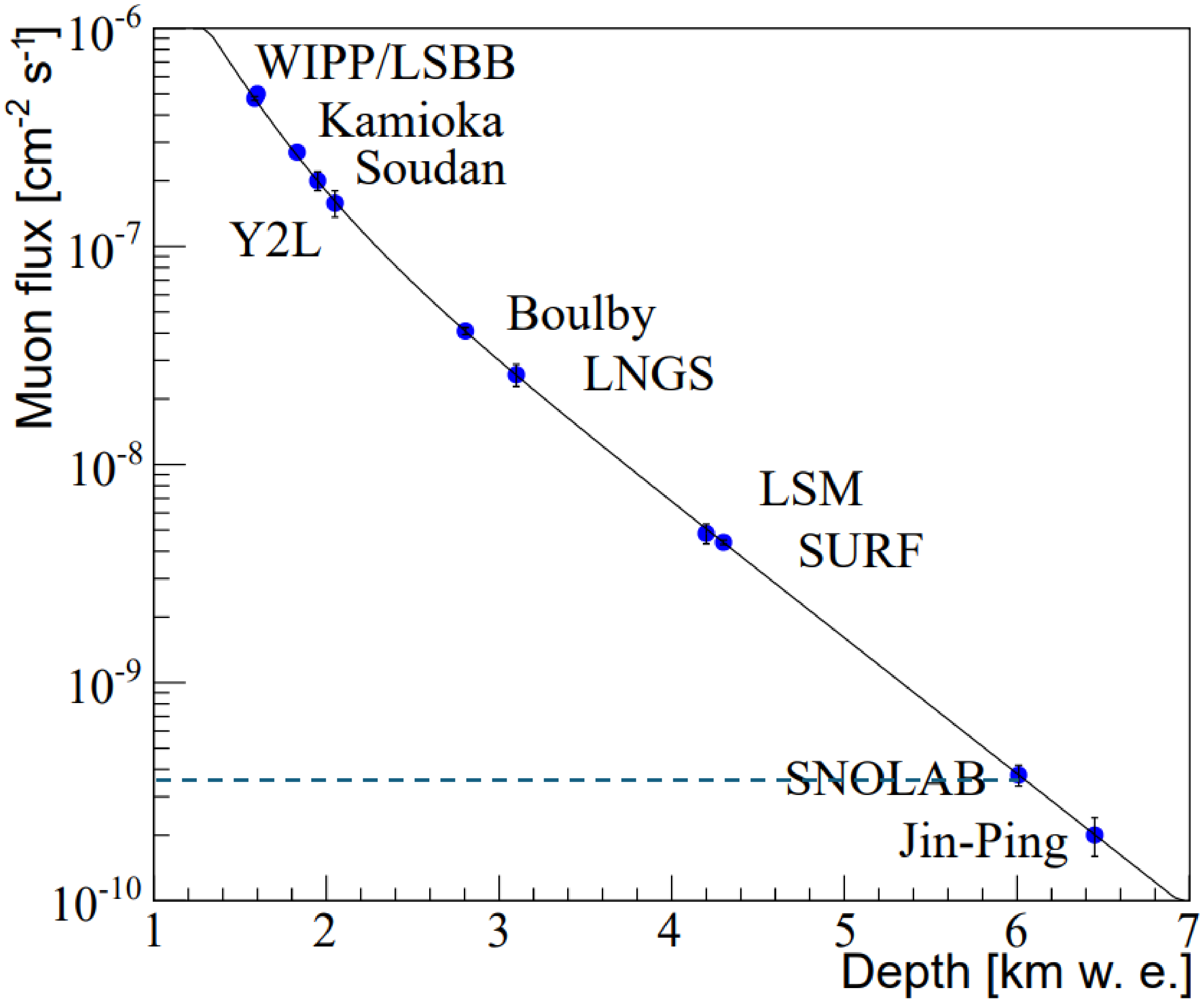
- **ARGO has the best discovery sensitivity to high mass dark matter** and **excellent sensitivity to neutrinos through several channels**.

Thank You!

Additional Slides

The Uranium-238 Decay Chain




Muon flux [cm-2 s-1]
10-6
10-7
10-8
10-9
10-10
WIPP/LSBB
Kamioka
Soudan
Y2L
Boulby
LNGS
LSM
SURF
SNOLAB
Jin-Ping
1
2
3
4
5
6
7
Depth [km w. e.]