Darkside 20k and the GADMC

Aksel Hallin

Future Projects Workshop

SNOLAB, July 2019

Global Argon Dark Matter Collaboration

Darkside +

DEAP +

ArDM +

MiniClean

350 Researchers from 80 Institutes

First project: DS20k at Gran Sasso

Goal: Pursue Dark Matter through the neutrino floor

DS20k makes the next generation physics measurement. It vets and enables the technology for Argo

Argo at SNOLAB

GADMC will pursue a program to reach below the neutrino floor with argon. Argon has several good properties:

- Unsurpassed discrimination between signal (nuclear recoils(NR)) and electromagnetic (EM) backgrounds. Based on DEAP3600 data, this will surpass 10^9
- TPC provides high resolution position reconstruction
- LAr provides excellent sensitivity in the region of WIMP masses above 30 GeV/c^2 using single or two phase detection with direct light observation for the rejection of EM events
- Ability to achieve very low radon backgrounds (160 nBq/kg of ^{222}Rn, 2.6 nBq/kg of ^{220}Rn in DEAP)

Two step programme: DS20k in next few years, followed by Argo (300 tons)

Why Liquid Noble gases?

Scaleable
High Purity
Liquid Scintillators

Table 1. Properties of Liquid Argon and Liquid Xenon in comparison to standard scintillators.

Property	*Argon*	*Xenon*	*NaI*	*Plastic (NE102 or equiv.)*
Atomic No. (Z)	18	54	46.5	5.6
Atomic weight (A)	39.95	131.3	(23/127)	(1/12)
Maximum recoil energy (% of incident n energy)	9.5	3.0	16/3 in Na/I respectively	100/28 in H/C
Boiling point (K $^\circ$)	87.3	165	> 300	> 300
Density (g/cc)	1.4	3.0	3.67	1.03
Electron mobility (cm2/v*s)	400	2200	n/a	n/a
Ion drift velocity at 1kV/cm (mm/μs)	2.2	2.4	n/a	n/a
Energy resolution (FWHM @ 662 keV) scint. only (%)	8%	8%	6.5%	$\approx$ 50%
Energy resolution, ionization+scintillation (%)	4 expected	4 (1.2 possible?)	(6.5)	$\approx$ 50
Scintillation wave length (nm) and PMT used	128 (w/λ shifter, fast PMT)	175 (quartz window PMT)	415 (regular PMT)	425 (fast PMT)
Scintillation yield (# scintillation photons/MeV)	40000	42000	38000	10000
Fast decay time (ns)	7 (25% light)	4.3	230	3
Slow decay time (ns)	1500 (75% light)	22(100% in $\leqslant$22ns)	n/a	n/a
(n,γ) propensity	medium	high	high	medium
Neutron activation	medium	high	high	none
Cost ($/gram)	$\approx$ 0.002	$\approx$ 1.5	$\approx$ 0.5	$\approx$ 0.15

Table 2. Liquid noble gas physical properties including radioactivity.

Element	Z	A	Liquid density (g/cc)	Boiling point (K)	Photon yield (γ/keV)	Triplet decay time	Emission Wavelength (nm)	Radio activity
He	2	4.00	0.13	4.2	22	13(s)	80	None
Ne	10	20.18	1.2	27.1	32	15(μs)	78	None
Ar	18	39.95	1.4	87.3	40	1.5(μs)	128	^{39}Ar 1Bq/kg
Kr	36	83.80	2.4	119.9	49	85(ns)	148	^{85}Kr 1MBq/kg
Xe	54	131.30	3.1	165.0	64	22(ns)	175	^{136}Xe $<$ 10uBq/kg

J A Nikkel et al 2012 JINST 7 C03007

Why Argon?

Incredibly good PSD: allows 3000 kg of normal argon

Exceptional radioactivity and chemistry

Relatively inexpensive: sources of underground argon

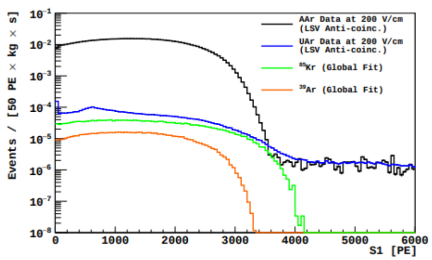
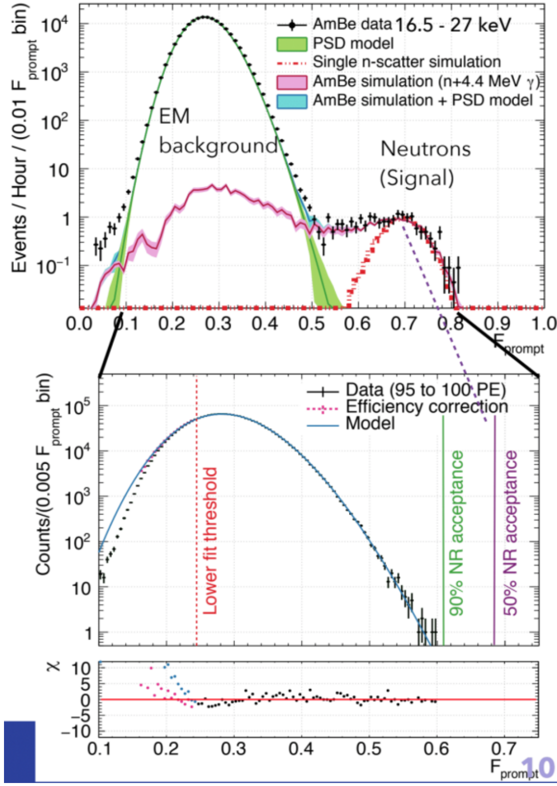


FIG. 1. Live-time normalized S1 pulse integral spectra from single-scatter events in AAr (black) and UAr (blue) taken with 200 V/cm drift field. Also shown are the ^{85}Kr (green) and ^{39}Ar (orange) levels as inferred from a MC fit. Note the peak in the lowest bin of the UAr spectrum, which is due to ^{37}Ar from cosmic-ray activation. The peak at ~600 PE is due to γ-ray Compton backscatters.



Phys. Rev. D 93, 081101 (2016)

Why do Argon if people are doing Xenon

Technically quite differe … n light,
radon chemistry, radiati

Coherent Neutrino Scat … erate
high energy nuclear rec

Solar neutrinos can ger

Different physics of WIM … ospin
Yaguna (JCAP, 2019)

Science (SNO Phases,

In the U.S., the 2014 report of the Particle Physics Project Prioritization Panel (P5) "Building for Discovery - Strategic Plan for U.S. Particle Physics in the Global Context" [42] states: *The experimental challenge of discovery and characterization of dark matter interactions with ordinary matter requires a multi-generational suite of progressively more sensitive and ambitious direct detection experiments. This is a highly competitive, rapidly evolving field with excellent potential for discovery. The second-generation direct detection experiments are ready to be designed and built, and should include the search for axions, and the search for low-mass (<10 GeV) and high-mass WIMPs. Several experiments are needed using multiple target materials to search the available spin-independent and spin-dependent parameter space.*

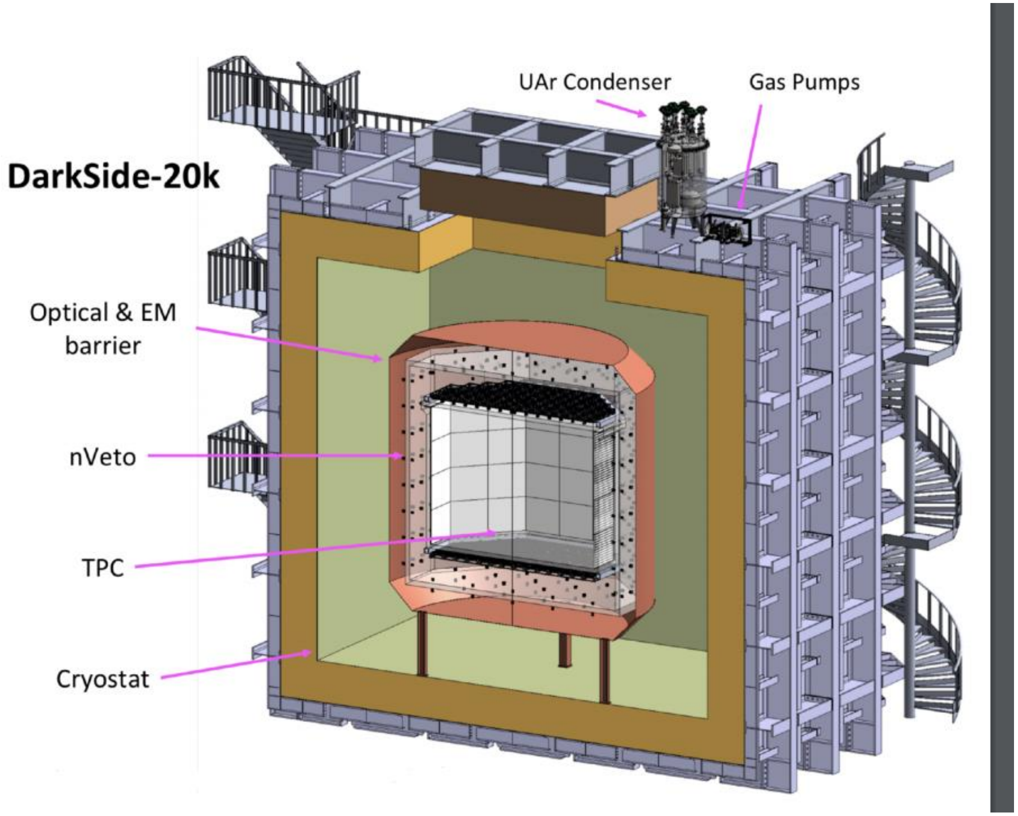
P5 recommends: *Recommendation 20: Support one or more third-generation (G3) direct detection experiments, guided by the results of the preceding searches. Seek a globally complementary program and increased international partnership in G3 experiments.*

In Europe, the "European Astroparticle Physics Strategy 2017-2026" [43] authored by the "Astroparticle Physics European Consortium" (APPEC) states: *Medium-scale Dark Matter and neutrino experiments: APPEC considers as its core assets the diverse, often ultra-precise and invariably ingenious suite of medium-scale laboratory experiments targeted at the discovery of extremely rare processes. These include experiments to detect the scattering of Dark Matter particles and neutrinoless double-beta decay, and direct measurement of neutrino mass using single-beta decay. Collectively, these searches must be pursued to the level of discovery, unless prevented by an irreducible background or an unrealistically high demand for capital investment.*

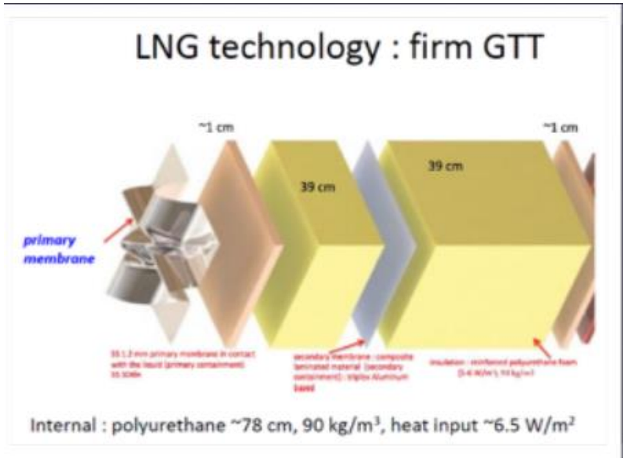
APPEC then adds: *For masses in excess of a few GeV, the best sensitivity to WIMPs is reached with detectors that use ultra-pure liquid noble-gas targets; such detectors include XENON1T (using 3.5 tons of xenon) and DEAP (using 3.6 tons of argon), which both started operating in 2016. Their sensitivity can be further enhanced by increasing the target mass. A suite of smaller-scale experiments is exploring, in particular, low-mass WIMPs and other Dark Matter hypotheses such as those based on dark photons and axions.*

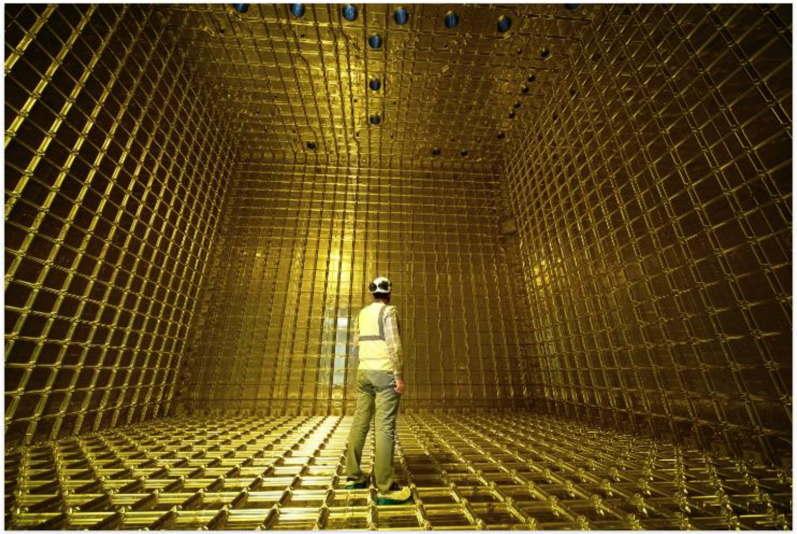
And it concludes: *APPEC encourages the continuation of a diverse and vibrant programme (including experiments as well as detector R&D) searching for WIMPs and non-WIMP Dark Matter. With its global partners, APPEC aims to converge around 2019 on a strategy aimed at realising worldwide at least one 'ultimate' Dark Matter detector based on xenon (in the order of 50 tons) and one based on argon (in the order of 300 tons), as advocated respectively by DARWIN and Argo.*

Darkside 20k



Darkside 20k Cryostat





Inside one of the protoDUNE detectors, currently under construction at CERN (Image: Max Brice/CERN)

TPC

All acrylic!

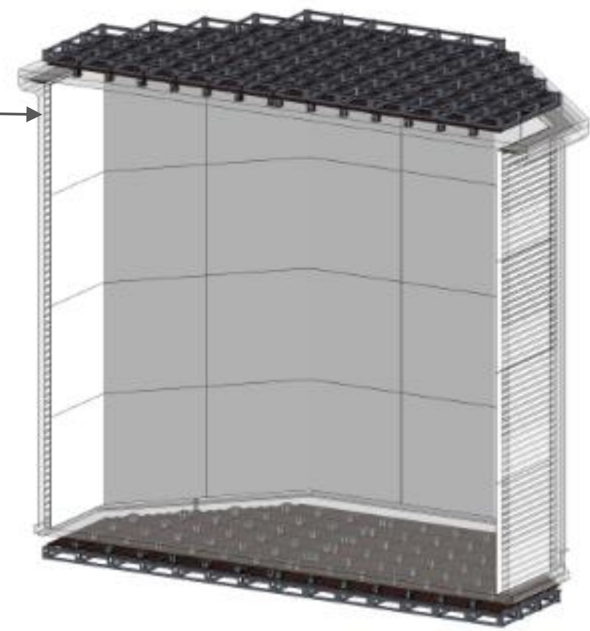
Grid and vapour space at top of TPC

Clevios coating for conductors (anode, cathode, field cage)

TPB coatings for WLS, reflector panels for optical isolation.

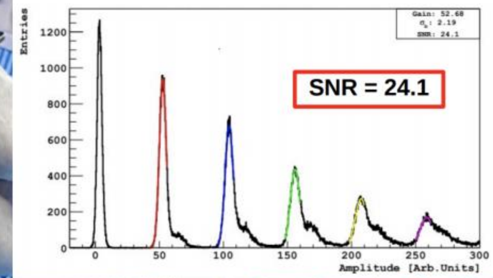
Acrylic allows light out and provides some shielding between sensors and argon. No material except tpb/acrylic in contact with Underground argon

Significant Canadian contribution



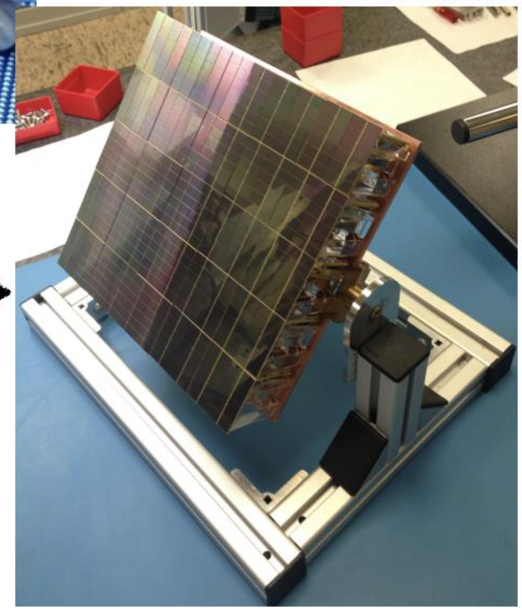
SiPMs as the photosensors

- Compact, increase the coverage
- PDE ~50%
- Good performance at LAr temperatures
- SiPM customization for cryogenic temperatures (FBK)
- SiPM Mass production (LFoundry)
- Packaging of the tiles and the cold electronics (NOA, L'Aquila)
- Full production chain largely funded by Regione Abruzzo, Italy



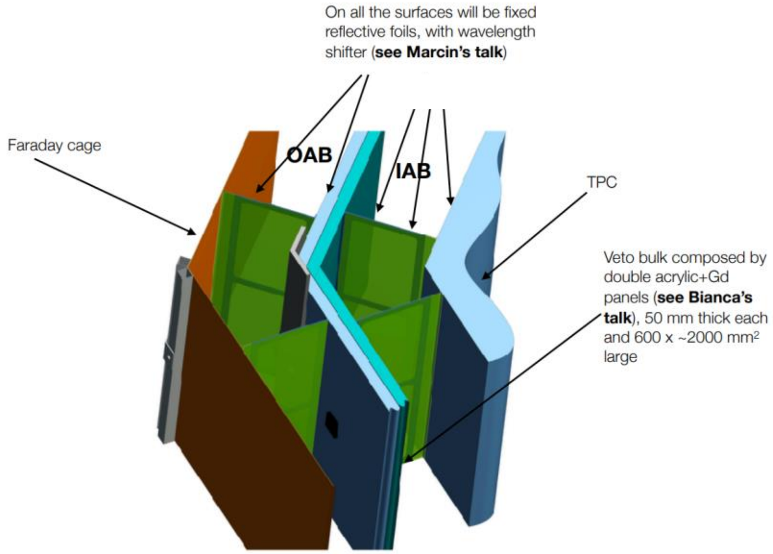
5cm x 5cm

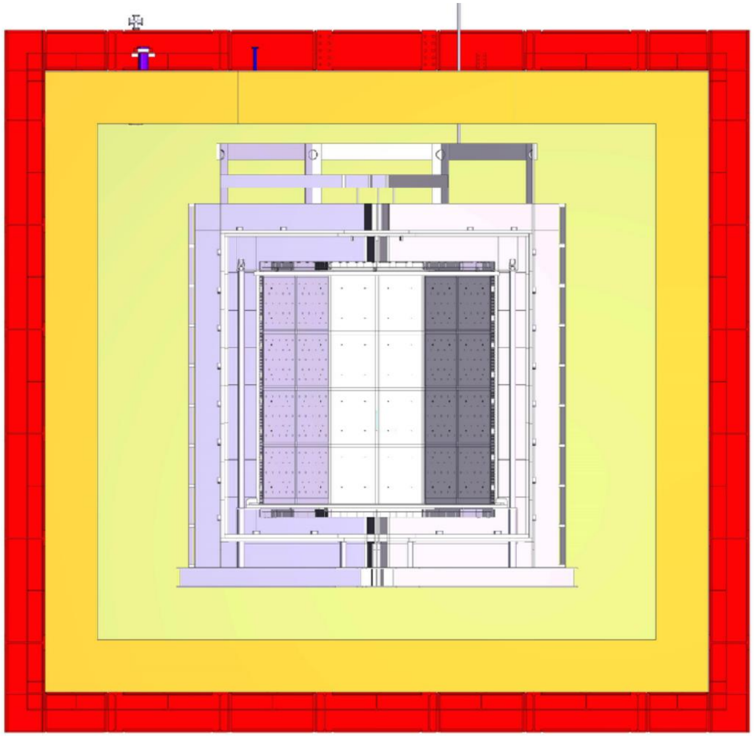
25 PDMs in one motherboard



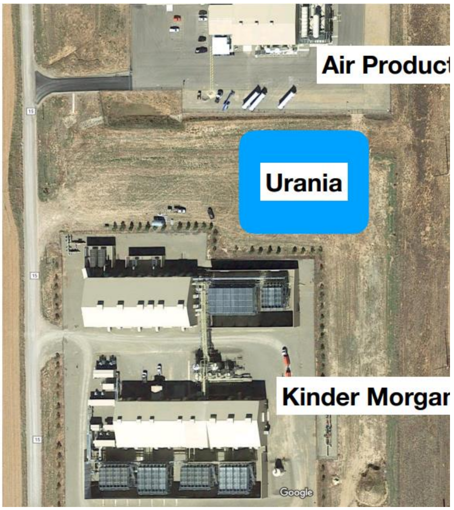
Lower radioactivity compared with PMTs.
Canadian CFI+ Triumf+DAQ

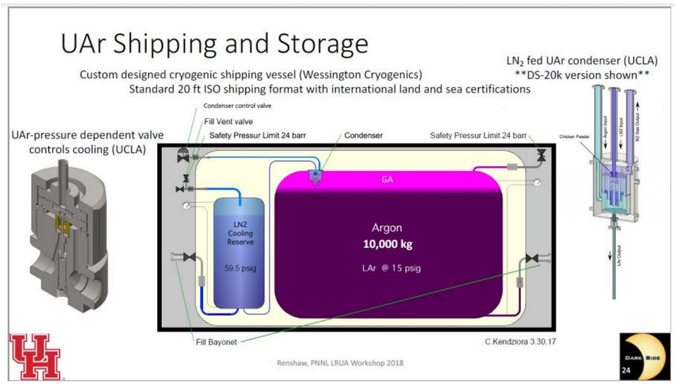
Veto Detector: atmospheric liquid argon



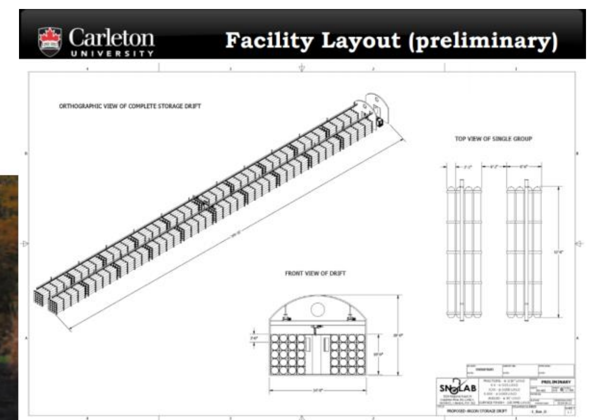


Underground Argon: Urania and Aria

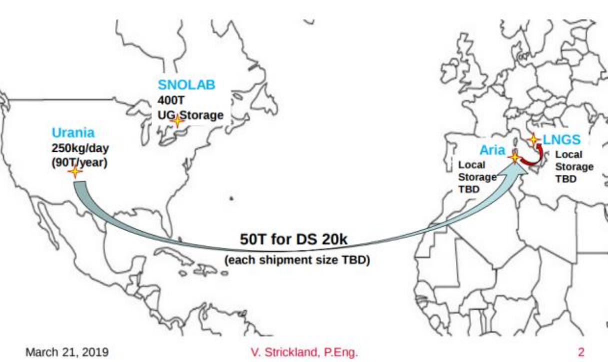




Argus for Argo?



Commercially available ABS/ISO skids (MEGCs)



Planning for Argo

Scaling up for Argo:

- Cryostat is suitable
- TPC / Acrylic
- SiPMs
- Veto Detector
- Underground Argon (already planning for Argo)

Canadian Contributions

Acrylic TPC

TPB/Clevios coating (with Astrocent)

SiPM electronics

DAQ

Underground argon/transport/storage

Exclusion limits

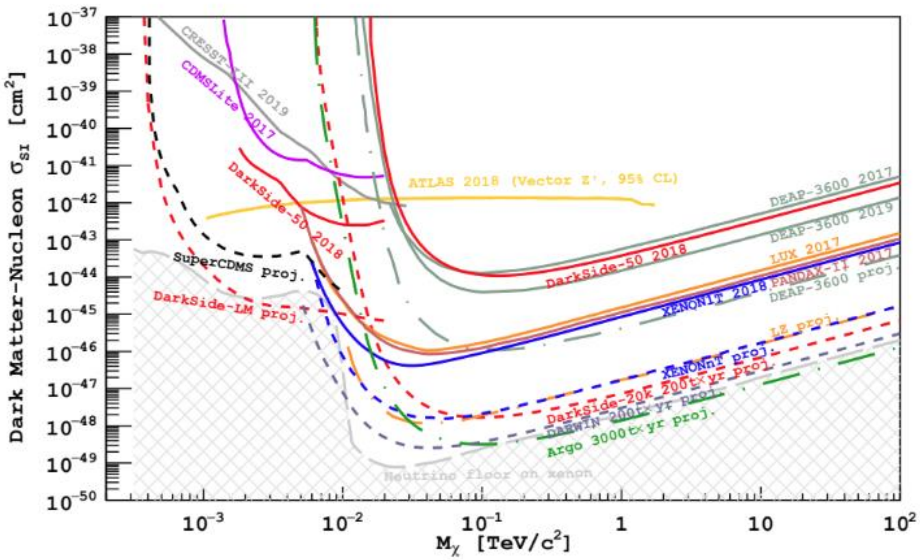


FIG. 2. 90 % C.L. exclusion limits showing leading results from direct (continuous lines, Ref. [6, 7, 9–12]) and accelerator-based dark matter searches (region above the yellow line [13]) compared with sensitivities of future germanium-, xenon-, and argon-based direct searches (dashed lines, Ref. [14–18] and this work). The "neutrino floor" curve follows the definition of Ref. [19]. The 95% C.L. limit from the ATLAS Experiment is shown for a benchmark model in which Dirac-fermion WIMPs interact with ordinary matter via a vector mediator[20] with coupling strengths to quarks, leptons and WIMPs of 0.25, 0.01, and 1, respectively.

Discovery Potential

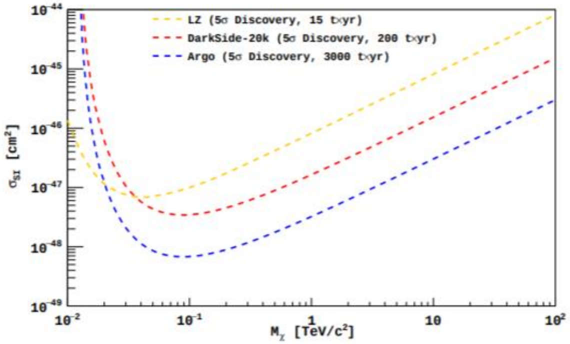


FIG. 2. 5σ discovery potential of the leading future noble liquid dark matter searches. See Tab. I for details and sources.

Experiment	Target	Threshold [keVr]	Exposure [t yr]	Source
LZ	LXe	4	15	[28]
DarkSide-20k	LAr	30	200	This work
DARWIN	LXe	7	200	[29]
Argo	LAr	30	3000	This work

TABLE I. Comparison of characteristics and expected performance of future LXe and liquid argon LAr direct detection dark matter experiments.