DarkSide-20k: Status and Prospects

DMUK
King's College London
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DarkSide-20k: Overview

Global Argon Dark Matter Collaboration (GADMC)
Comprised of 400+ people across 14 countries.

DarkSide-20k: Overview

UK groups building 25% of silicon detector readout, characterisation and installation.

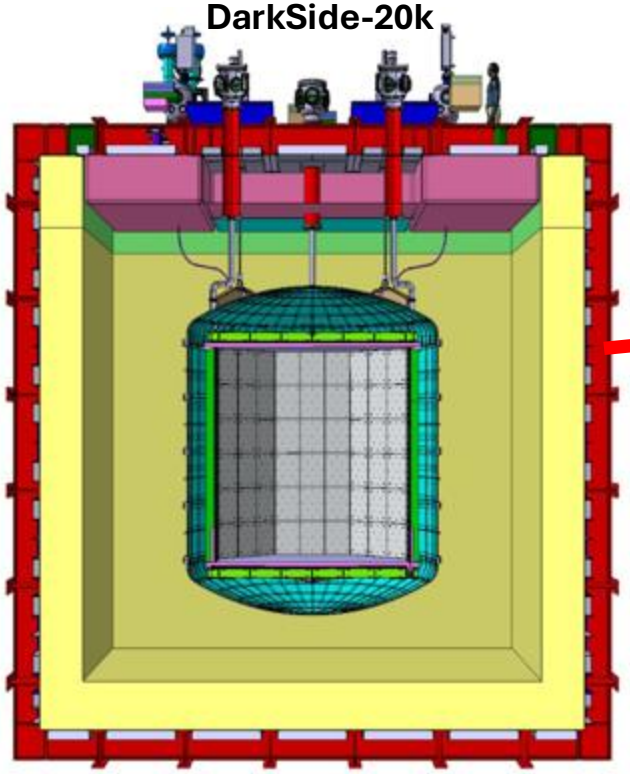
MiniCLEAN

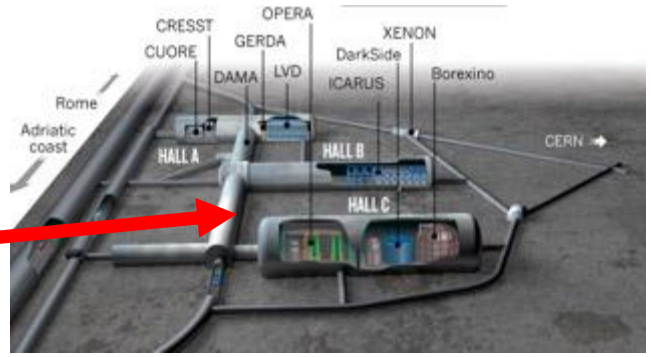
DarkSide-50

ArDM

DEAP-3600

DarkSide-20k

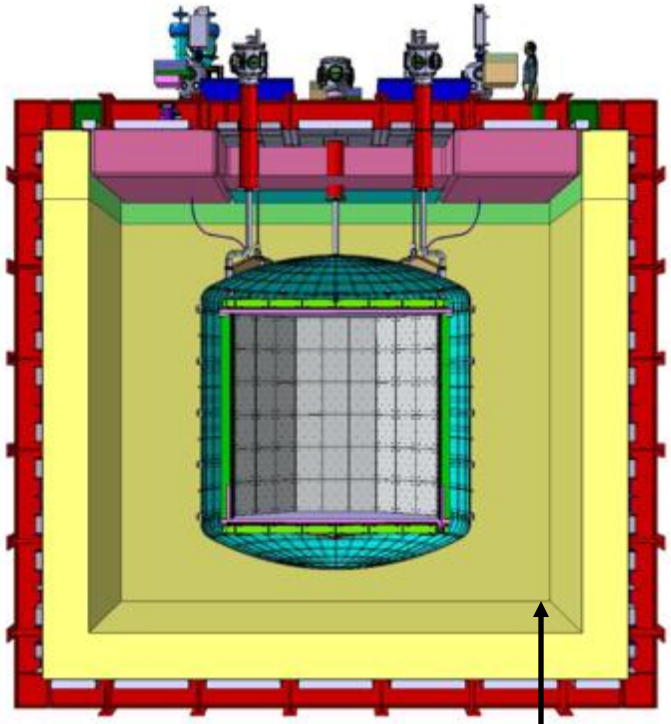




- **LAr dual-phase TPC** experiment designed to detect the scattering interaction of WIMPs from the dark matter halo.
- **50t underground Argon**(UAr).
- Light readout: **27m^2 cryogenic low-noise SiPMs**.
- Nominal runtime of 10 years.
- at least 250--500 tn yr exposure

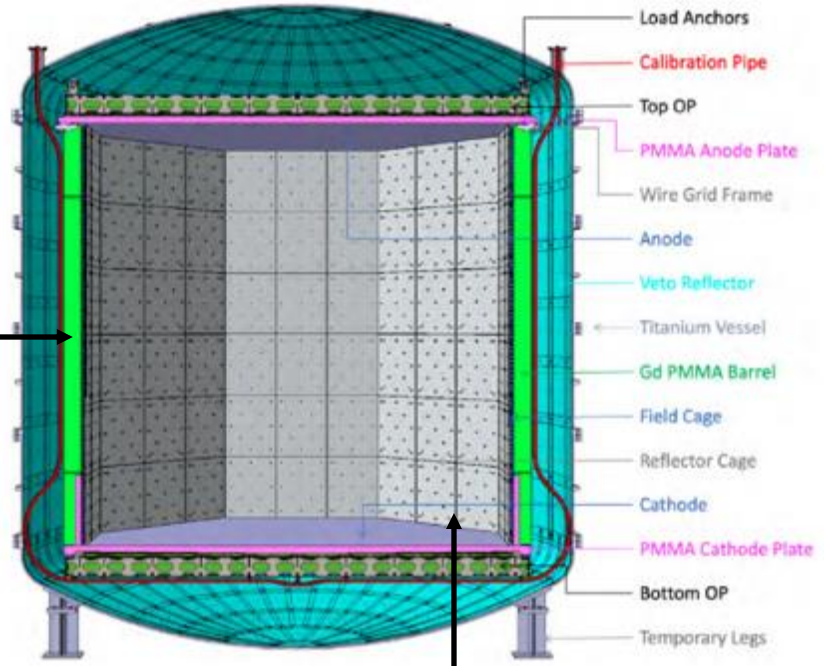
- Located in **Hall C** at **LNGS**, Italy at a depth of 1400m (**3400m water equivalent**).
- DarkSide-20k installation has started with the **protoDUNE-like cryostat**.
- TPC components in production.
- **Installation of UK Photodetectors starting in 2025.**
- **Construction is complete and commissioning runs in 2026.**
- **Physics data is planned to start in 2027.**

DarkSide-20k: Detector Structure



Neutron (inner) Veto

- 32 t of UAr.
- Enclosed in Stainless Steel vessel and HDPE neutron shield.
- Equipped with SiPMs covering 5 m^2 from UK groups.
- Light yield: 2 PE/keV.



Cosmogenic (Outer) Veto

- 650 t of Atmospheric Argon (AAr)
- Membrane "ProtoDUNE-like" cryostat 8x8x8 m^3
- Sparsely instrumented with SiPMs.

Dual-phase TPC

- 50 t of UAr (20 t fiducial).
- Two optical planes covering 21 m^2.
- S1 and S2 yield is 10 PE/keV and 20 PE/e^- respectively.

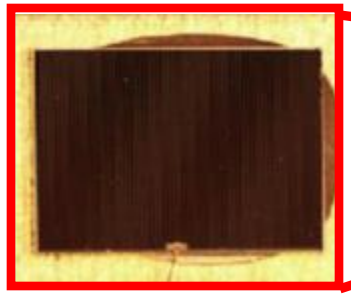
DarkSide-20k: Light Readout with SiPMs

TPC Plane, Neutron & cosmic Veto

Photo Detector Unit (PDU)

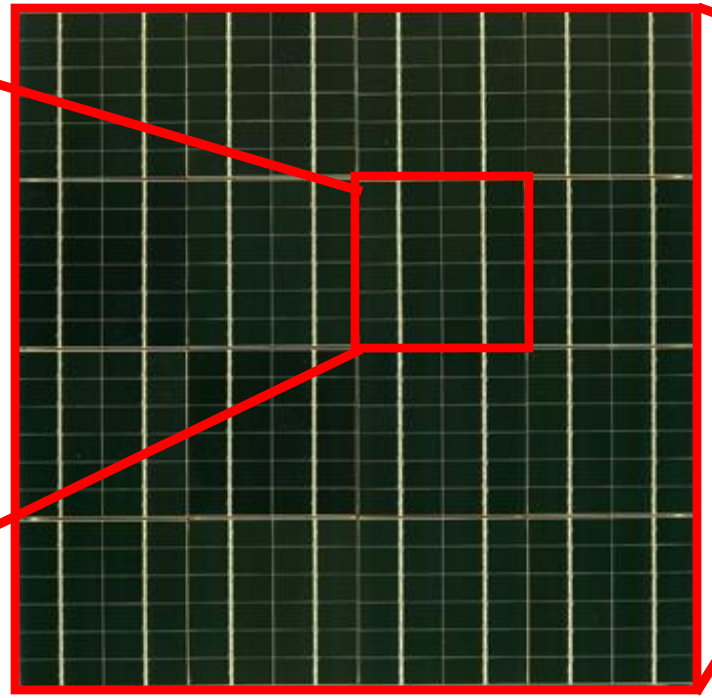
Photodetector Module (PDM)

SiPM

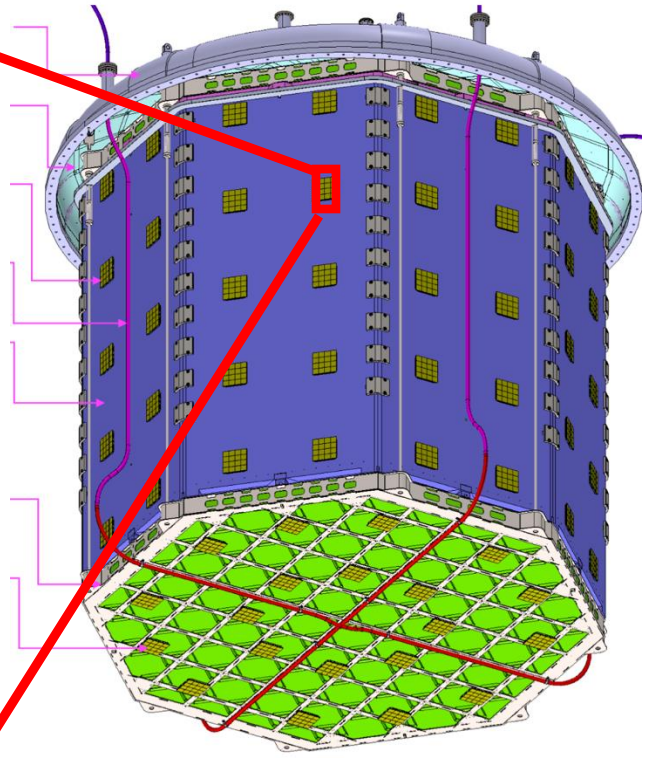


~1 cm^2
95k SPADs ~25-30 μm^2

5 x 5 cm^2
24 SiPMs + FEB



20 x 20 cm^2
16 PDMs + Motherboard



TPC: 528 PDUs
Vetos: 150 PDUs

Custom cryogenic SiPMs developed in collaboration with Fondazione Bruno Kessler (FBK), in Italy.

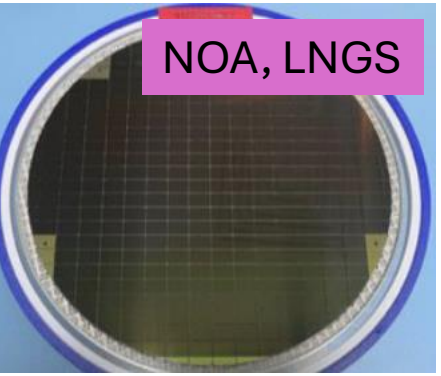
- Photon detection efficiency (PDE) ~45%
- Low dark-count rate < 0.01 Hz/mm^2 at 77 k (7 VoV)
- Timing resolution ~ 10 ns (TPC) < 30 ns (veto)
- SNR > 8 (TPC) >5 (veto)

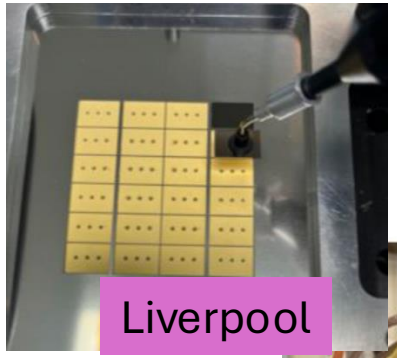
1 large PCB controls bias to individual tiles and sums signals from each quadrant.
4 channels per PDU, less cables means less radioactivity.

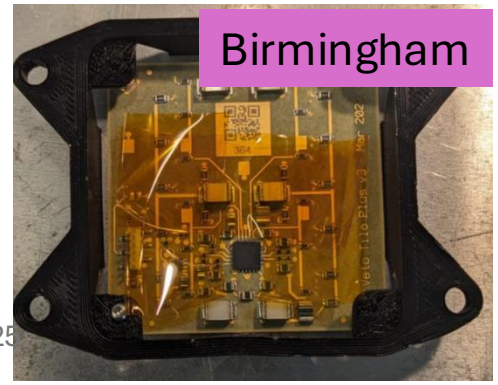
DarkSide-UK: Veto Photodetector Module

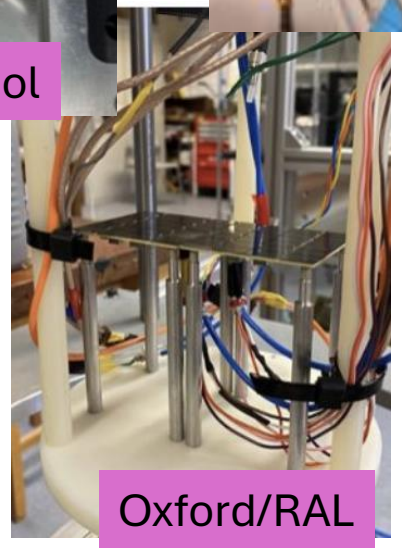
Silicon wafers Cryoprobed and Diced → PCB population → SiPM Die Attach & Wire Bonding → PDM Cryogenic Characterisation → PDU Assembly and Integration → PDU Cryogenic Characterisation

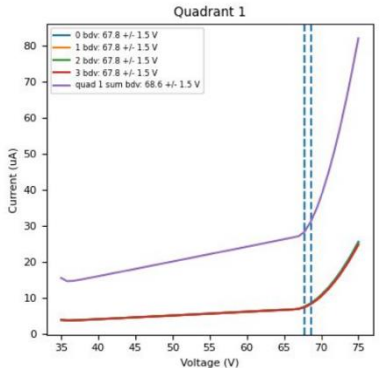
UK groups building 25% of silicon detector readout, characterisation and installation.

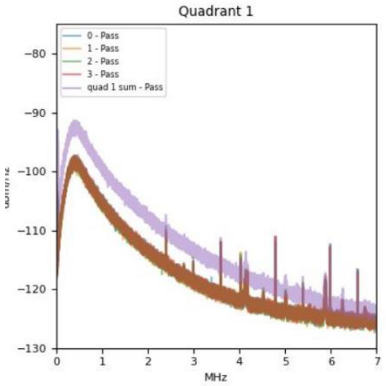


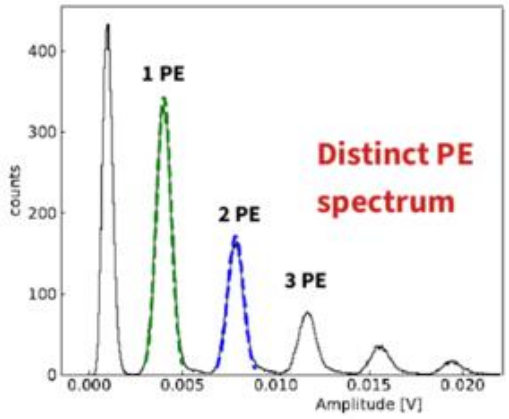


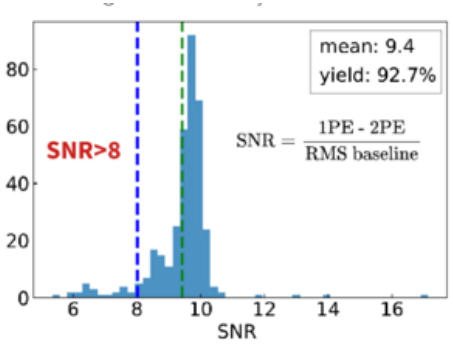












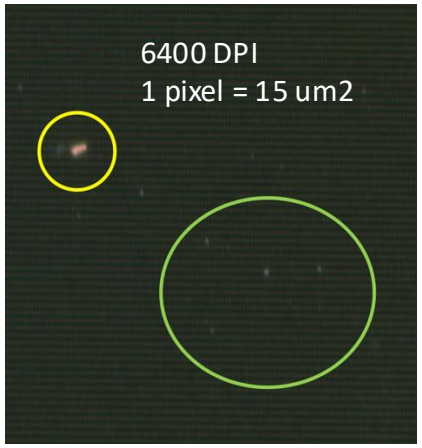
DarkSide-UK: Veto Photodetector Unit

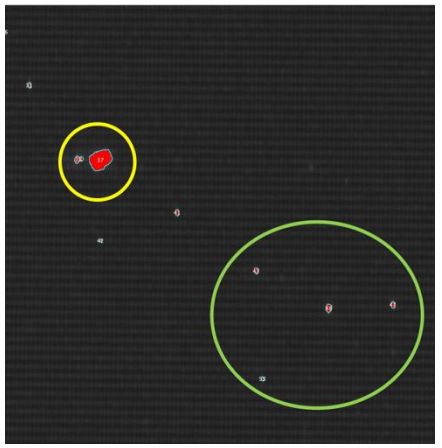
Silicon wafers Cryoprobed and Diced → PCB population → SiPM Die Attach & Wire Bonding → PDM Cryogenic Characterisation → PDU Assembly and Integration → PDU Cryogenic Characterisation

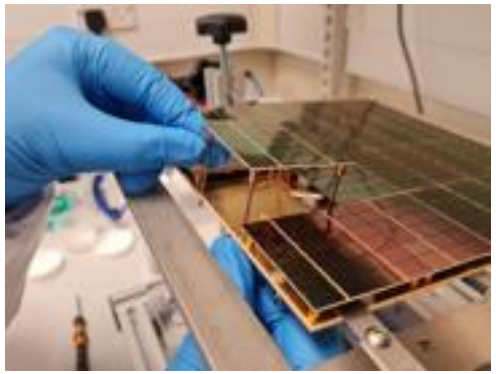
UK groups building 25% of silicon detector readout, characterisation and installation.

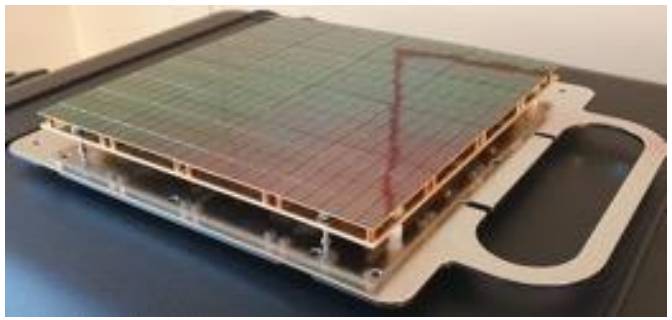
PDM/PDU Assembly and Testing

- 1.4k SiPM wafers cryoprobed in Italy (94% yield).
- QA/QC for dust counting, signal-to-noise, charge response, breakdown voltage and electronic noise
- PDM production is 50% complete (meets >80% yield requirement).
- 150 PDU required to be built by UK groups.
- PDU production is 11% complete, to schedule and on budget.

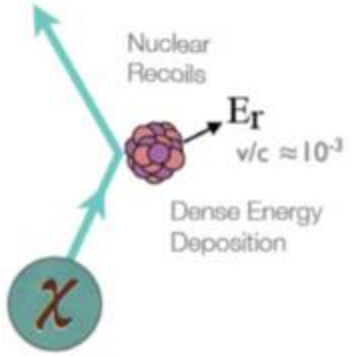








DarkSide-20k: WIMP signal and backgrounds



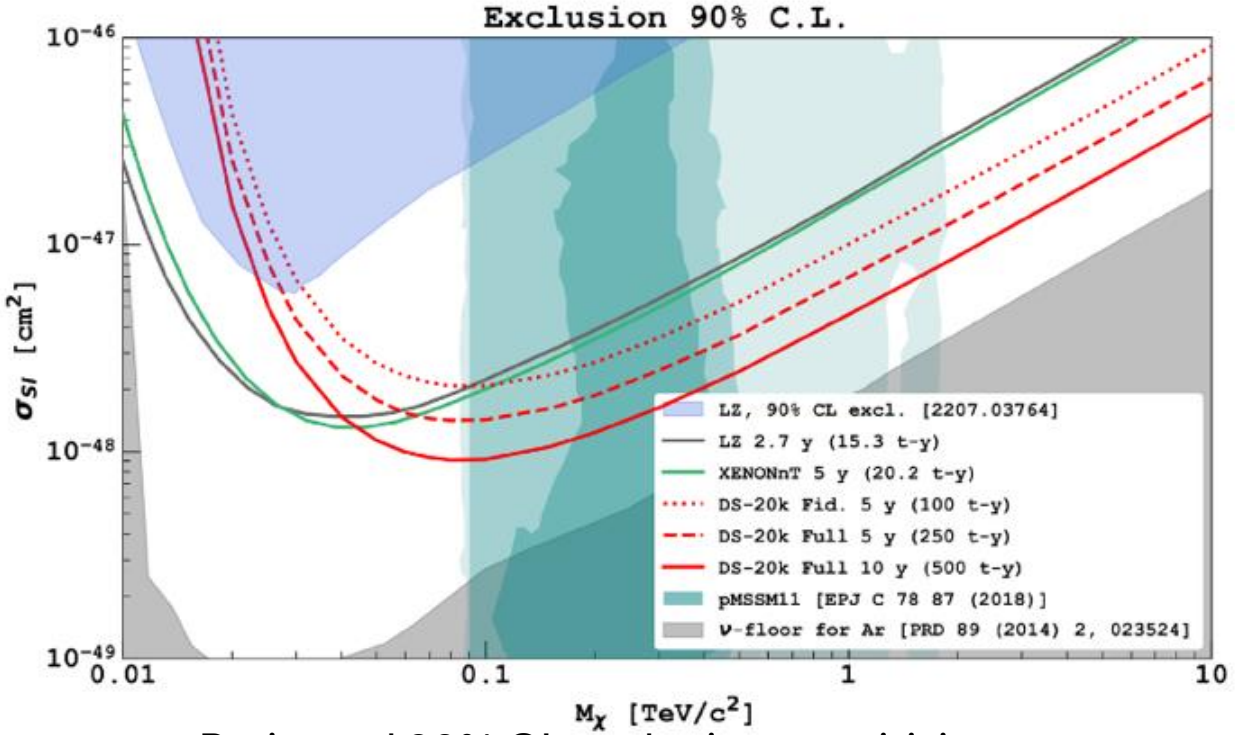
- Single scatter NR event
- Energy recoil between 1 and 100 keV

Background requirements for 10-year exposure:

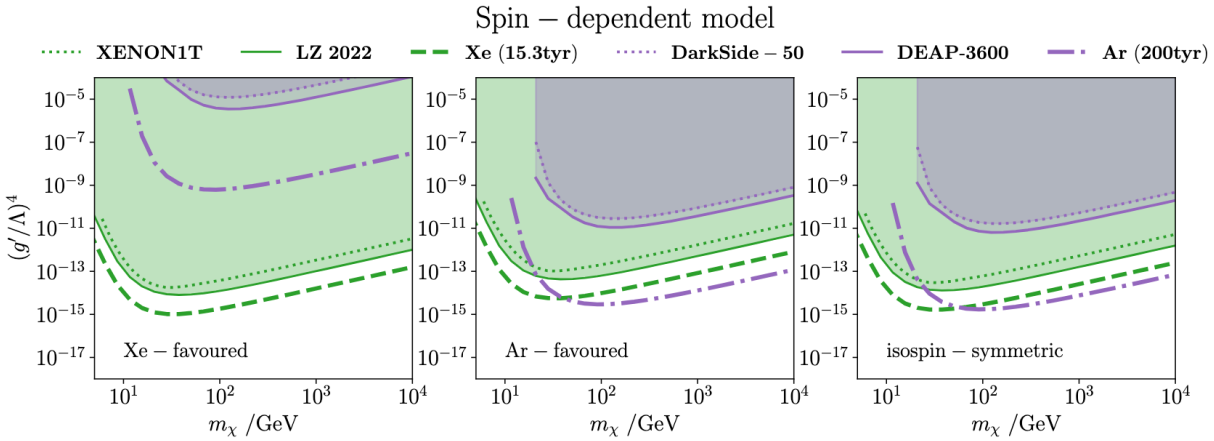
- <0.1 neutrons surviving veto
- <0.05 from β and γ

Background Source	Mitigation strategy
Ar^{39} β decay	Underground Argon + pulse shape discrimination
γ from rock and γ,e from material	Pulse shape discrimination + material selection
Radiogenic neutron (α, n) reaction in detector material	Material screening and selection, TPC fiducial volume and Neutron Veto to reject neutron signal
Surface Contamination due to Rn progeny	Surface cleaning, reducing air exposure and handling in Rn controlled environments
Muon induced background	Cosmic Veto
Neutrino coherent scatter	Irreducible

DarkSide-20k: High Mass WIMP sensitivity



Projected 90% CL exclusion sensitivity to spin-independent WIMP-nucleon scattering cross-section: **7.4 × 10^{-48} cm^2** for **1 TeV/c^2** WIMP with **250 - 500 tn yr exposure.**



The SD model, which is canonically considered invisible to argon target experiments is not.

Even in the isospin-conserving case, our projections show DarkSide-20k will be more sensitive than xenon for SD interactions for $m_\chi > 100$ GeV.

The Global Argon Dark Matter Collaboration. DarkSide-20k Technical Design Report. Rapp. tech. INFN, 2021

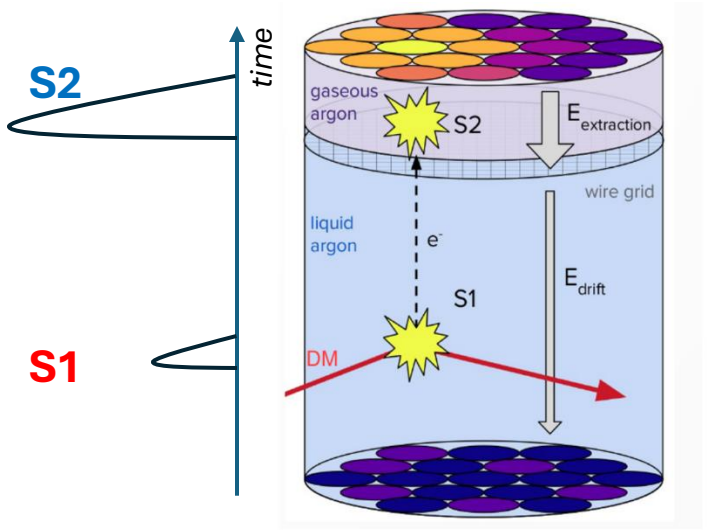
Isospin-violating dark matter at liquid noble detectors: new constraints, future projections, and an exploration of target complementarity: https://arxiv.org/pdf/2302.05458

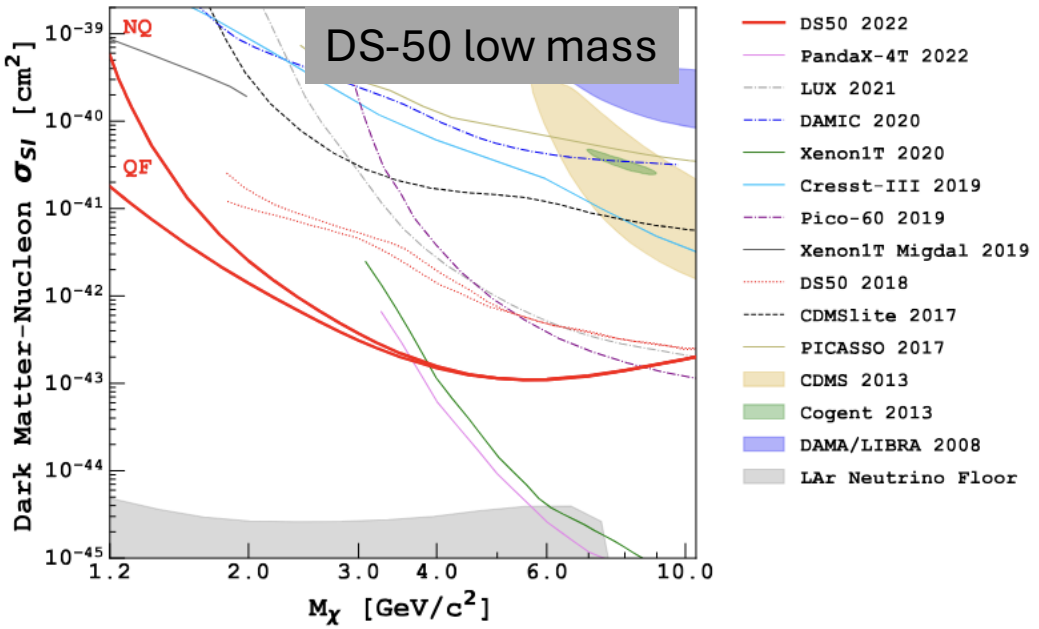
The DarkSide-20k Collaboration. DarkSide-20k sensitivity to light dark matter particles. *Commun Phys* **7**, 422 (2024). https://doi.org/10.1038/s42005-024-01896-z

To Low Mass WIMPs

Ionisation Signal (S2)-Only Analysis

- Dual-phase TPC drifts and extracts single ionisation electrons in the gas with **near 100% efficiency**.
- Signal amplified a further **x20** exploiting electroluminescence in the gas phase.
- By exploiting S2 signal, Darkside-20k can reach **sub-keV** recoil energy thresholds.





DarkSide-20k: Low mass analysis background model

Spurious electrons rereleased trapped electrons.

Extrapolated from DS50 data.

Conservative fit
Fit from N_e=4

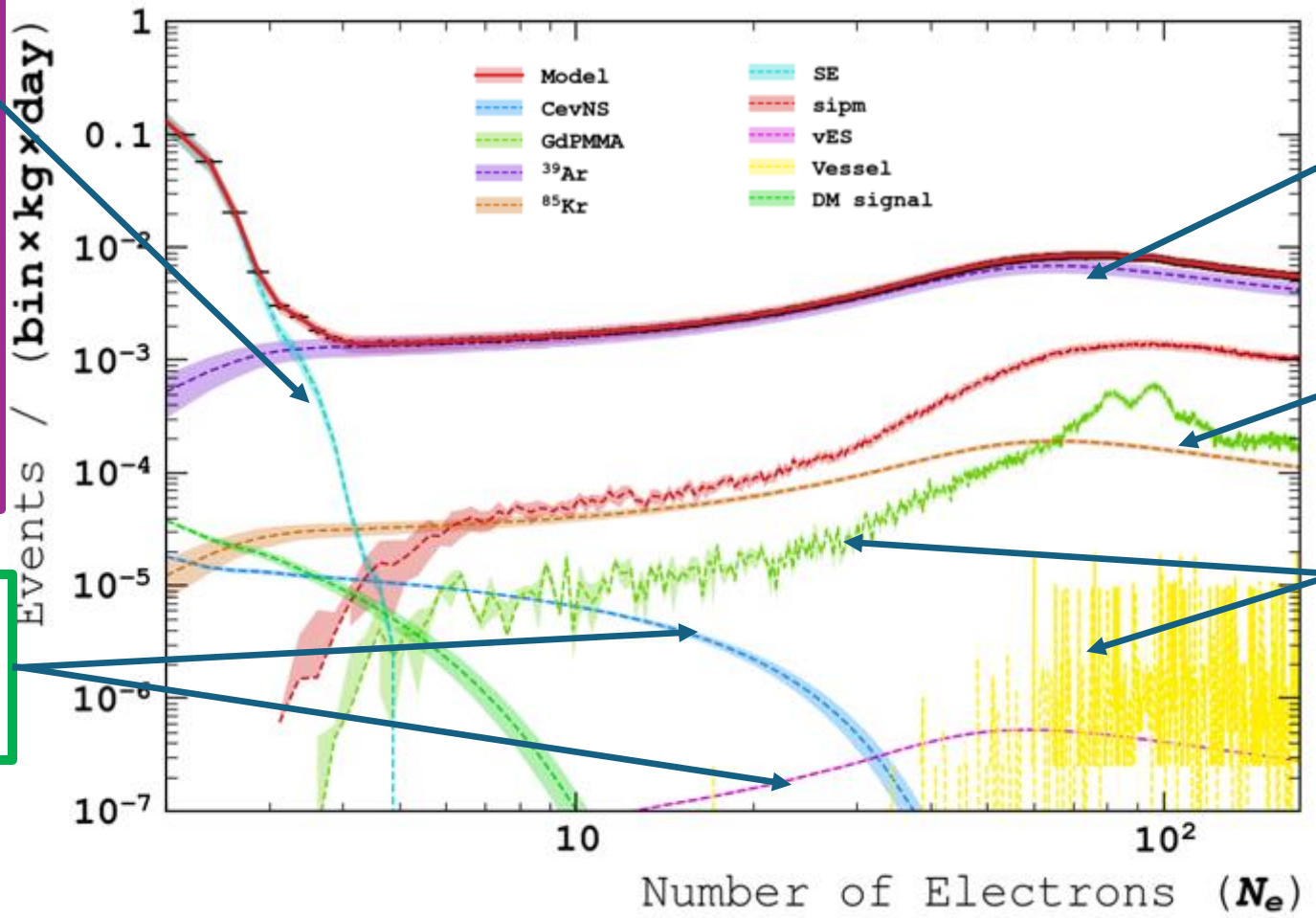
Ultimate fit
Fit from N_e=2

LAr intrinsic background

Neutrino Background

External γ

Spurious electron



^{39}Ar
Same activity as DS50
0.73 mBq/kg

^{85}Kr
Reduced activity w.r.t DS50
1.9 x 10^{-2} mBq/kg

Radio-pure stainless-steel vessel and SS structure from new material assay

Neutrinos
^{7}Be, ^{15}O, pep, ^{8}B, hep.

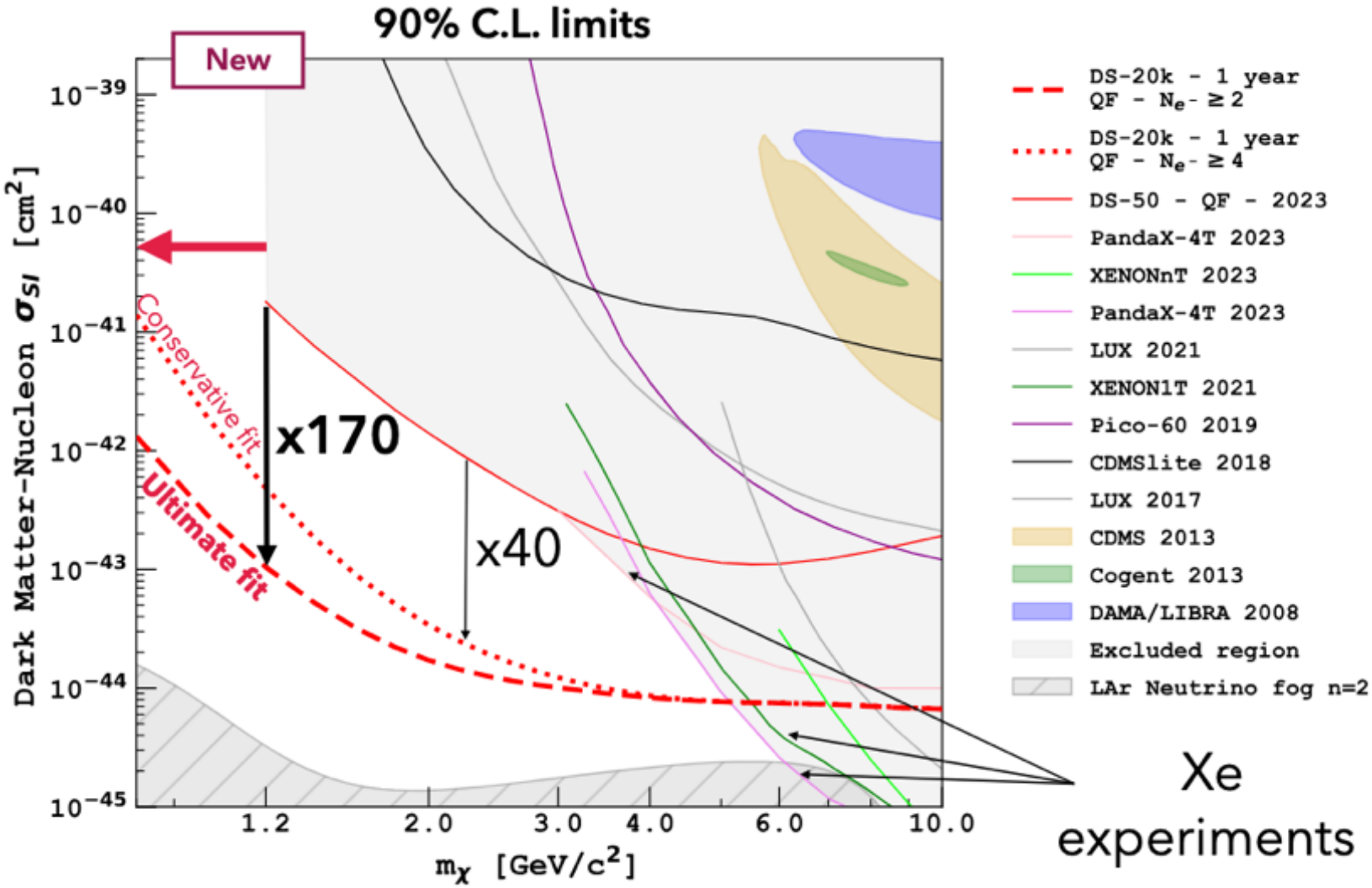
Radio-contaminant	Activity (Bq) TPC	PDMs	SS vessel
^{238}U up	16.1	38.8	21
^{238}U mid	11.5	18.4	8.8
^{238}U low	16.4	449	62
^{232}Th	4.2	17.8	33
^{235}U	0.7	1.8	1.0
^{137}Cs	2.5	2.9	5.0
^{60}Co	2.0	5.1	13
^{40}K	102	269	49

The DarkSide-20k Collaboration. DarkSide-20k sensitivity to light dark matter particles. *Commun Phys* **7**, 422 (2024). https://doi.org/10.1038/s42005-024-01896-z

DarkSide-20k: Low mass WIMPs sensitivity (GeV/c^2)

Assuming 1 year of data taking

DarkSidw-20k will lead the low mass WIMP- search below $m_\chi \approx 5$ GeV/c^2



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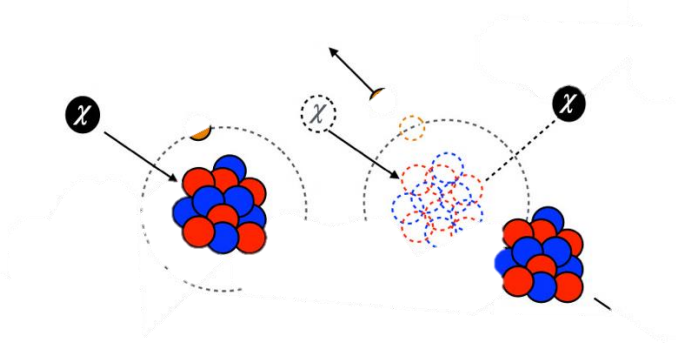
DarkSide-20k: Low mass WIMPs sensitivity (GeV/c^2)

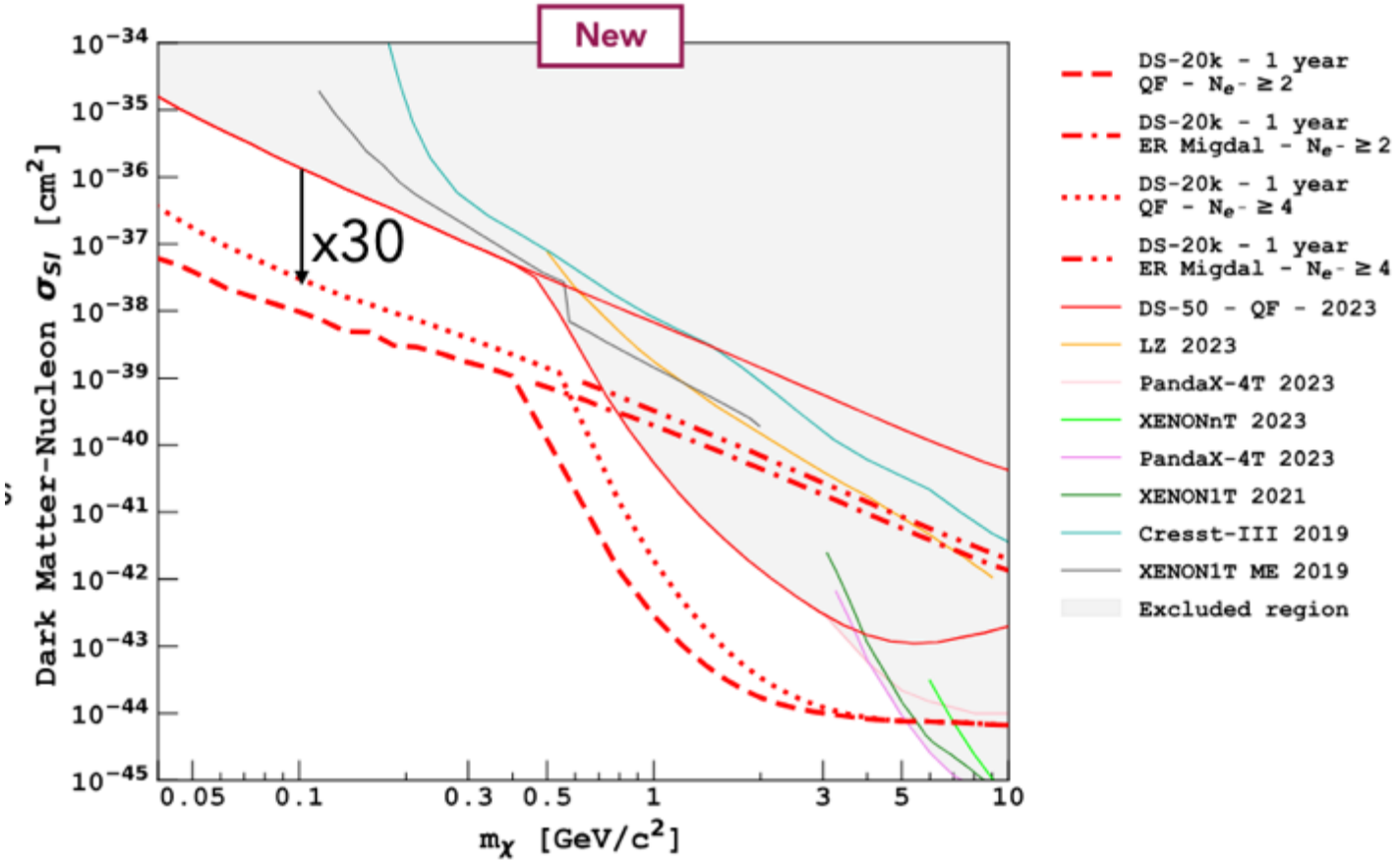
Including Migdal Effect



After nuclear recoil, the surrounding electron cloud gets accelerated, releasing de-excitation ionisation.

Including Migdal, the most stringent limits between 40 MeV/c^2 and 5 GeV/c^2.

Projects >**1 order of magnitude improvement** with respect to current experiments.



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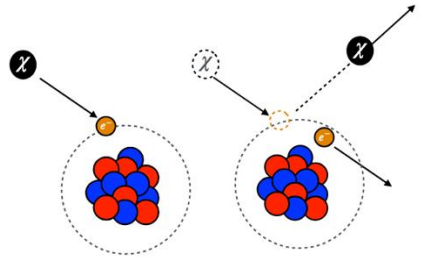
DarkSide-20k: Light Dark Matter (MeV/c^2)

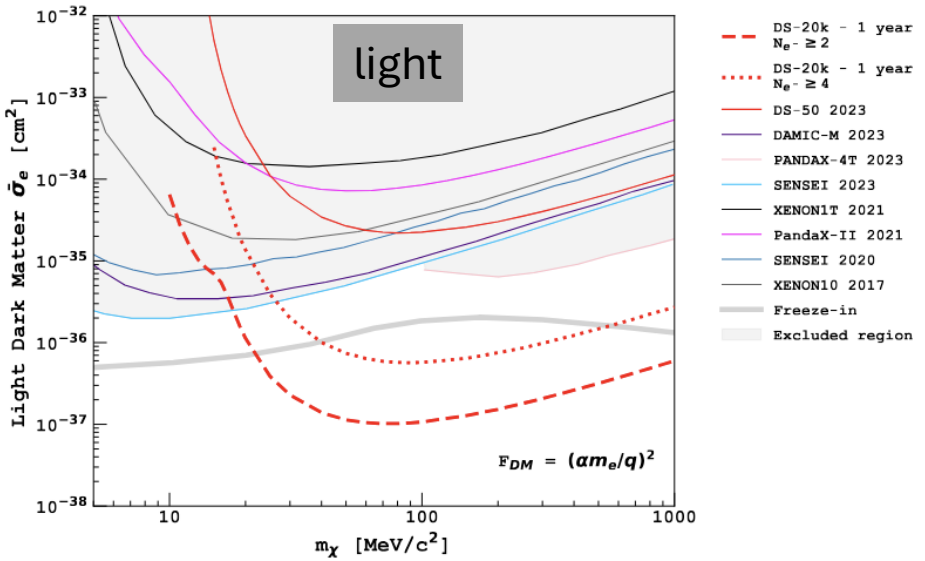


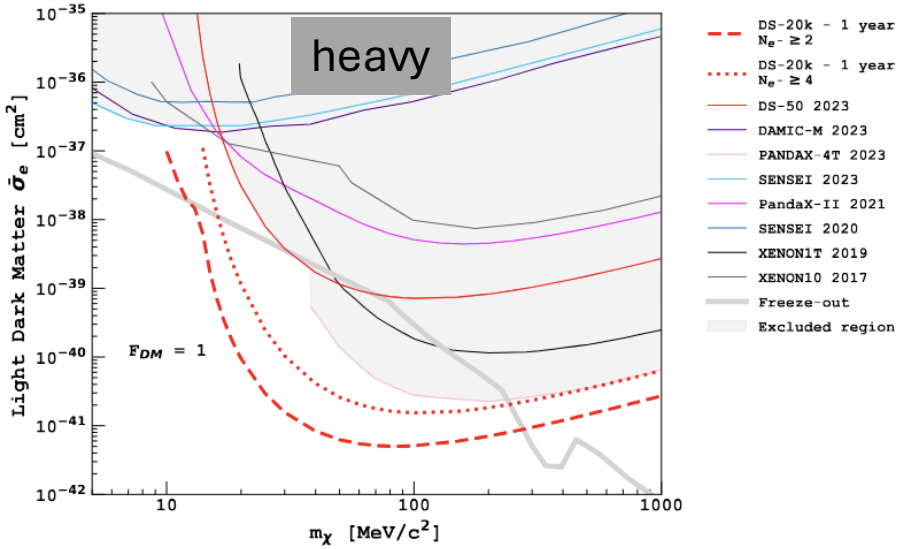
Elastic scattering of Atomic Electrons

Light dark matter can be sub-GeV fermion or scalar boson interacting atomic electrons via a vector mediator.

Mediator can be light ($m_{med} << m_\chi$) or heavy ($m_{med} >> m_\chi$)

Projects >**1 order of magnitude improvement** with respect to current experiments.





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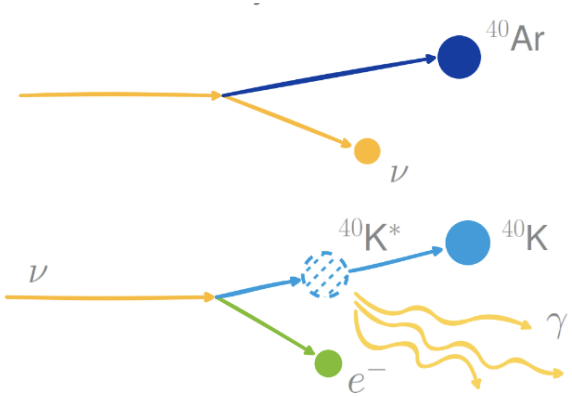
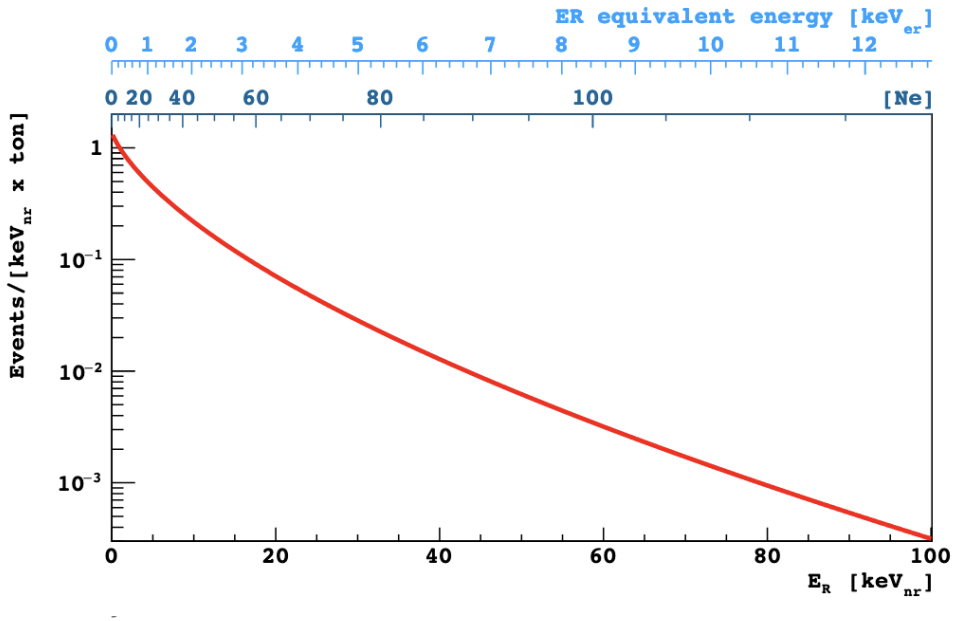
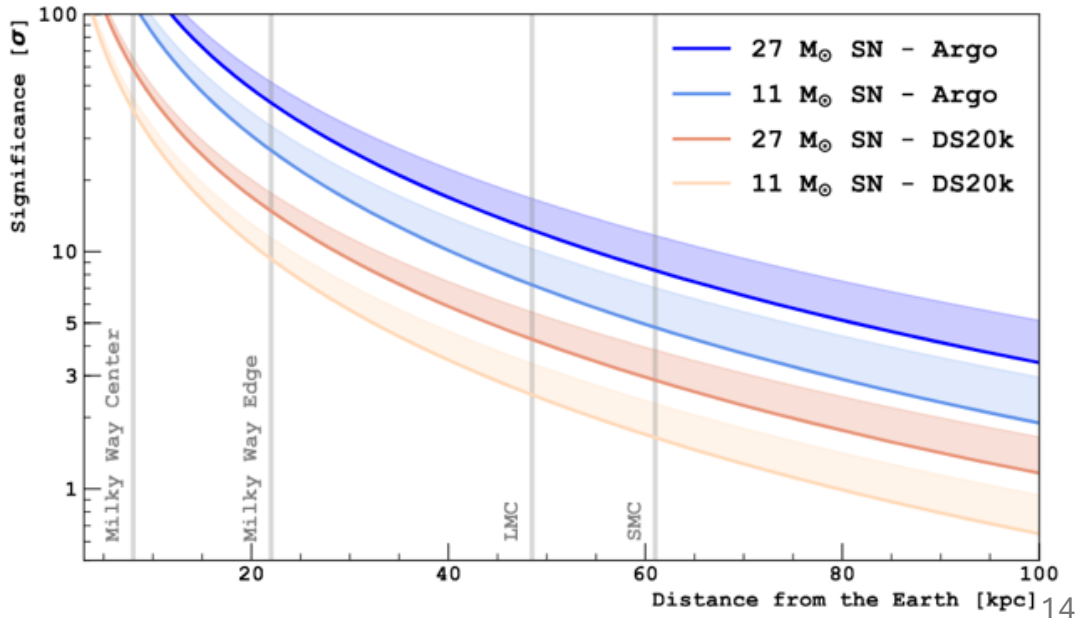
DarkSide-20k: Astrophysical multi-messaging

- DS-20k will join the **SuperNova Early Warning System 2.0** (SNEWS2.0)
- DarkSide-20k will be sensitive to **core-collapse supernova neutrinos** through the **coherent elastic neutrino-nucleus scattering** and **charge currents**.
- Backgrounds from detector bulk, ^{39}Ar and single electrons.



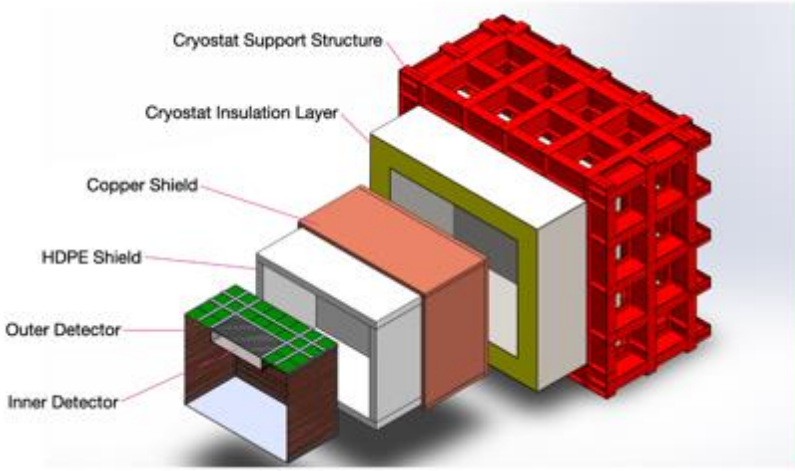


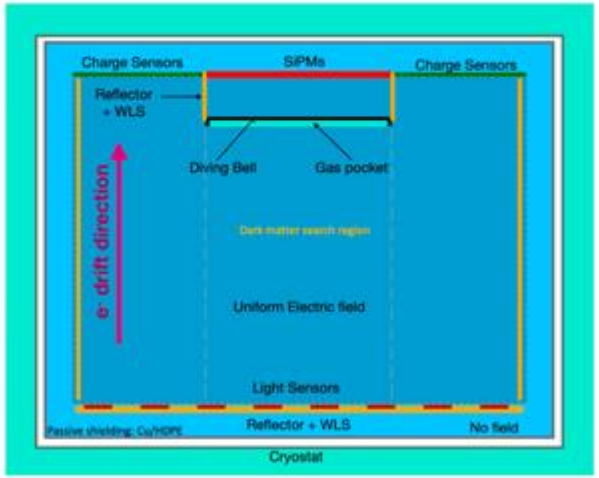


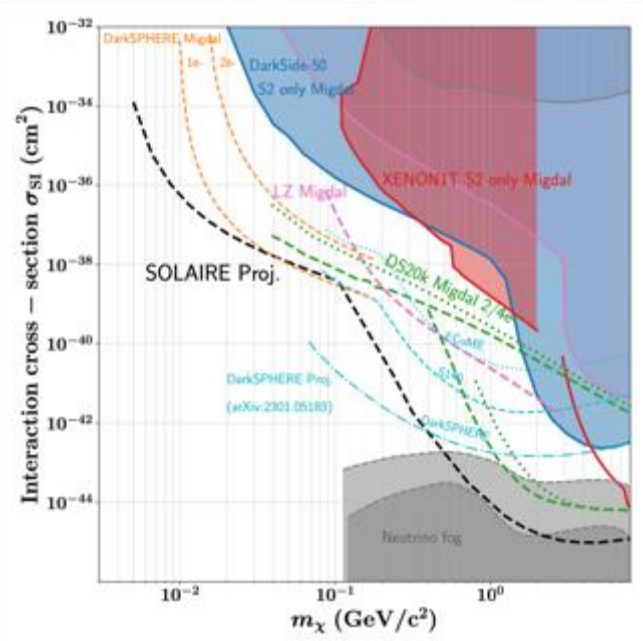
Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos - arXiv:2011.07819

SOLAIRE

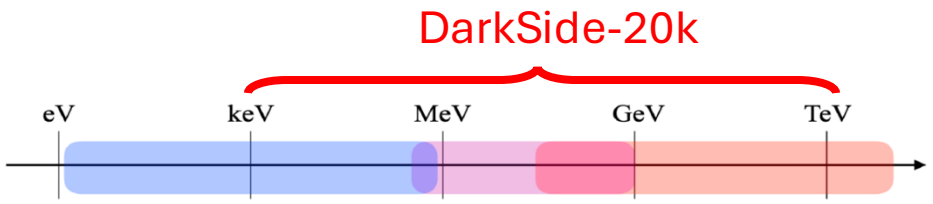
- **Boulby Underground Laboratory**: Hosted in the UK with contributions from 25 institutes across 10 countries.
- **UK institutes**: Boulby Lab, Daresbury, Edinburgh, Imperial, KCL, Liverpool, Manchester, Oxford, QMUL, RAL, RHUL, Warwick
- **Detector Design**: World-leading sensitivity to MeV–GeV dark matter with a 9-ton UAr target and 60 m^3 cryostat.
- **Future Prospects**: Awaiting funding approval, construction planned for 2025, with transformative low-mass dark matter searches anticipated.
- **Data Taking:** Ultimate physics by 2030.







Conclusion

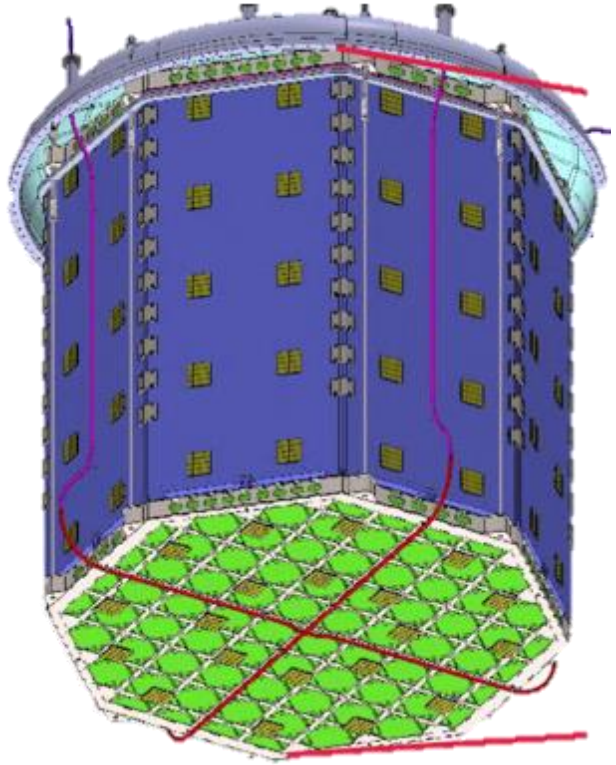


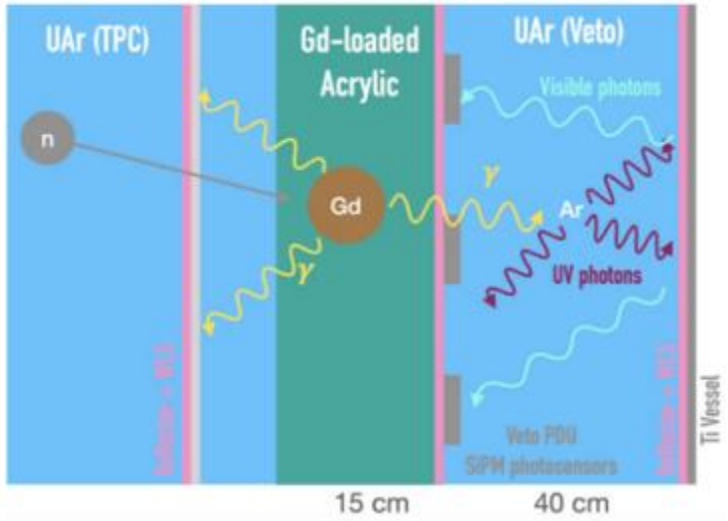
- **DarkSide-20k**
  - Wide-reaching physics: looks at a range of dark matter models at a range of proposed masses.
  - Key contributions: PDU production (25%), testing, background mitigation, tooling, and instrumentation.
  - Expanding the science program and preparing for data-taking.
- **SOLAIRE**
  - Manchester is leading the proposal, design, and construction of a world-leading low-mass dark matter detector in the UK.

Backup

Neutron Veto

- Neutrons are moderated in the acrylic shell and then captured on Hydrogen.
- Hydrogen emits gammas of 2.2 MeV and interact with the argon in the Neutron veto.
- LAr scintillation light is shifted and detected by 120 PDUs.





Systematic uncertainties

New

	Source uncertainty	Affected components
Amplitude	5% on the exposure	All
	15% on ^{39}Ar activity	^{39}Ar
	15% on ^{85}Kr activity	^{85}Kr
	20% on SE normalization	SE
	10% on activity from PDMs	PDMs
	10% on activity from the vessel	Vessel
	10% on activity from the TPC	TPC
	10% on neutrinos normalization	Neutrinos
Shape	atomic exchange and screening	^{39}Ar
	atomic exchange and screening	^{85}Kr
	1% on the ^{39}Ar-decay Q-value	^{39}Ar
	0.4% on the ^{85}Kr-decay Q-value	^{85}Kr
	SE modelling	SE
	ER ionization response	All backgrounds but CEνNS, SE
	NR ionization response	WIMP, CEνNS

Main bkg components and **ER ionization yield → Dominant systematic uncertainties & constrained by the fit**

SOLAIRE: Detector Concept

- Innovative wall-less TPC design
  - Reduced material near central DM search region.
- Dual and single-phase LAr volumes.
  - Gas pocket created with diving bell instrumented with DS20k SiPMs.
  - Single electric field to drift electrons throughout volume.