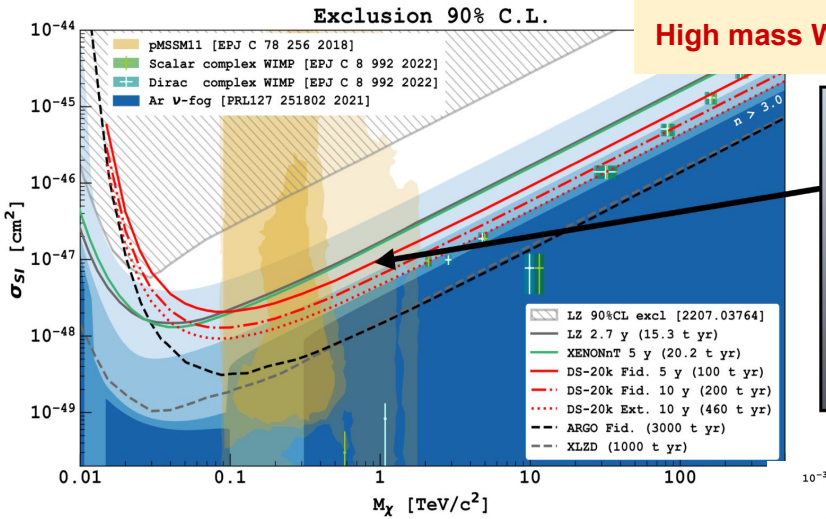
DarkSide-20k

UK ESPPU Input to Nov. 4 Drafting Session
Oct. 21, 2024

DarkSide-20k: Key Physics Deliverables

DarkSide-20k will have **world-leading sensitivity to WIMP and non-WIMP dark matter candidates for masses from keV to >>TeV scale,** as well as astrophysical neutrino sources. Construction at LNGS underway now, followed by a decade of operations from 2027. DarkSide-20k status and reach were presented by A. Kemp at the ECFA-UK Durham Meeting (Sept.'24): https://conference.ippp.dur.ac.uk/event/1357/contributions/7731/attachments/6134/8254/ECFA_DarkSide20k_Sept2024.pdf

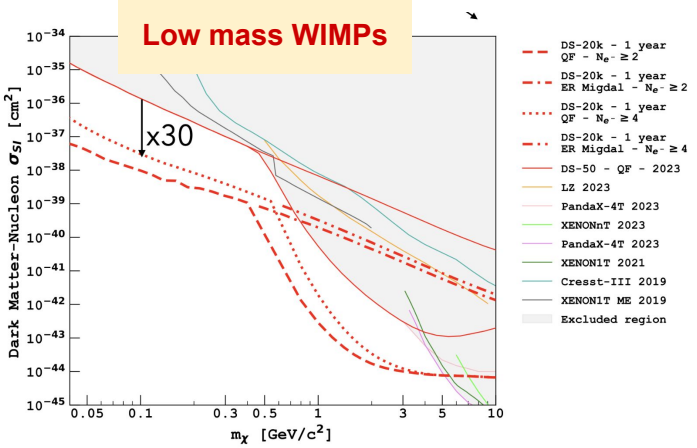
High mass WIMPs



Projected sensitivity to spin-independent WIMP-nucleon scattering cross section: 7.4 x 10^{-48} cm^2 for a 1 TeV/c^2 WIMP.

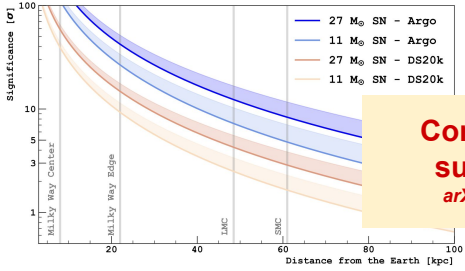
200 tonne-years exposure.

Low mass WIMPs

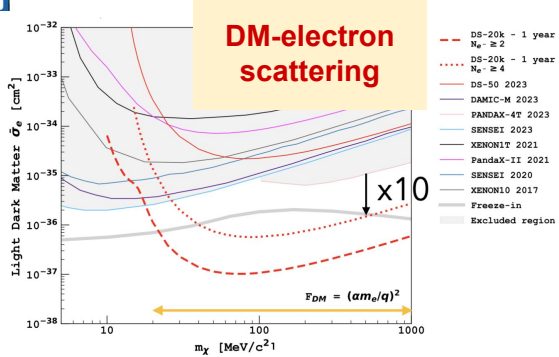


Core-collapse supernovae

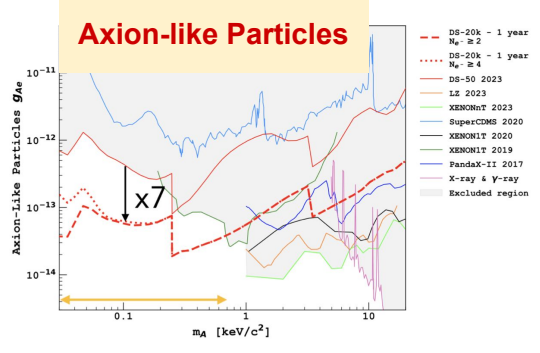
arXiv:2011.07819



DM-electron scattering



Axion-like Particles



DarkSide-20k: Key Physics Deliverables

Summary of key physics deliverables and comparison to current state-of-the-art:

- DarkSide-20k will have world-leading sensitivity to WIMP and non-WIMP dark matter candidates for masses from the keV [1] to Planck-scale [5] during its run period.
    - With 20 t-yr exposure (1 year of running, in a restricted fiducial volume), DarkSide-20k will improve upon the current world-leading constraints (which are from the predecessor DarkSide-50) on keV [2], MeV [3], and GeV [4] mass dark matter candidates by up to two orders of magnitude [1]. These candidates span a broad range of models beyond WIMPs, from warm dark matter to hidden sectors to asymmetric dark matter.
      [1] https://arxiv.org/abs/2407.05813, under review Nature Communications; [2] *Phys.Rev.Lett.* 130 (2023) 101001;
      [3] *Phys.Rev.Lett.* 130 (2023) 101002; [4] *Phys.Rev.D* 107 (2023) 6, 6; [5] *Phys.Rev.Lett.* 128 (2022) 1, 011801
    - With 100 tonne-years years of exposure (5 years running), DarkSide-20k will improve upon the current world-leading constraints for WIMP dark matter by more than an order of magnitude in the mass range beyond kinematic reach of LHC (TeV-scale)
- Supernova and solar neutrinos: DarkSide-20k will measure 100s of events from a ‘standard candle’ galactic supernova, and 10k solar neutrino events per 100 tonne-year, enabling unprecedented low-energy neutrino interaction statistics for oscillation and BSM studies.

List the project's main advantages compared to competitor projects:

- Background-free WIMP-mass range dark matter search strategy enabled by part-per-billion particle ID in argon (reducing the impact of background modeling)
- Large target exposures enabled by relatively low-cost Ar mean technology and search strategy continue to be scalable, to the kT scale
- Kinematic advantage of lighter target for sensitivity to dark matter particle candidates lighter than WIMPs
- Beyond the simplest ‘spherical cow’ models, having searches with multiple target nuclei enables enhanced discoverability, i.e. for non-universal neutron/proton couplings [6]. [6] *Eur.Phys.J.C 83 (2023) 10, 914*

Main risks/obstacles for realisation of physics goals: large-scale deployment of novel technology (SiPMs, UAr); achieving background goals

DarkSide-20k: Location / Timeline / Prioritisation

Location for the project: DarkSide-20k is under construction at Gran Sasso National Laboratory (LNGS) in Italy. Major UK contributions– 7 m^2 of novel SiPM array readout– leveraging silicon detector construction/testing infrastructure across 8 UK institutes.

Prioritised by 1) 2019 STFC Dark Matter Review, 2) 2020 PPRP (initiating UK project funding), 3) 2024 STFC decision to fund installation phase activities through 2026; and, internationally, 4) 2019 ESPPU, 5) 2023 APPEC Roadmap and 6) 2024 US P5 Process: In the baseline P5 programme, prioritised for support of construction, operations and research at same level as LZ, SuperCDMS, XENONnT.

Exploring the Quantum Universe

Figure 1 – Program and Timeline in Baseline Scenario (B)

Index: Operation Construction R&D, Research P: Primary S: Secondary

§ Possible acceleration/expansion for more favorable budget situations

P5 Report

Science Experiments									
Timeline	2024 – 2034	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
		Science Drivers						
LHC			P	P		P	P	
LZ, XENONnT				P				
NOvA/T2K		P				S		
SBN		P				S		
DESI/DESI-II		S		S	P			P
Belle II				S		S	P	
SuperCDMS				P				
Rubin/LSST & DESC		S		S	P			P
Mu2e							P	
DarkSide-20k				P				
HL-LHC			P	P		P	P	
DUNE Phase I		P				S	S	S
CMB-S4		S		S	P			P
CTA				S				P
G3 Dark Matter §		S		P				
IceCube-Gen2		P		S				P
DUNE FD3		P				S	S	S
DUNE MCND		P				S	S	
Higgs factory §	30		P	S		P	P	

DarkSide-20k: UK Involvement

Area(s) of UK involvement

- Hardware: UK is already substantially involved in production, testing, delivery and commissioning of 25% of the silicon instrumentation for detector. UK L2 and L3 WBS management roles in photodetectors, background est./mitigation, DAQ.
- Analysis: broad science programme exploitation – focus on dark matter beyond WIMPs, and, light simulations, grid computing solutions, sensitivity studies for neutrino physics programme (non-standard neutrino interactions, supernova…)

Significant leadership within collaboration: Deputy Spokesperson; Collaboration Boards; L2, L3 management roles in project WBS.

Total number of FTE /year required for construction/operation. What is the expected UK FTE?

We anticipate the UK involvement continuing at the current level, which is 45 members (32.6 FTE/yr). Current composition of UK FTE:

- Current PhD students: 14
- Senior Members (academics/senior fellows / senior core staff / postdocs): 10 (averaging 6.3 FTE/yr total) / 3 (averaging 0.5 FTE/yr total) / 7 (4.5 FTE/yr total)
- Technicians: 6 (5 FTE/yr total)
- Engineers: 5 (2.3 FTE/yr total)

Estimate of financial costs (provide separate numbers for R+D phase, construction phase and operations phase)

The STFC has invested 3.2M in the construction of DarkSide-20k to date. Funding of UK members beyond STFC in the past 5 years totals ~4M, from 3 UKRI and Royal Society Fellowships, as well as 3 Marie Curie postdoctoral fellowships. The international DarkSide-20k project is a ~120M GBP construction project funded by INFN, CFI, NSF, DOE, STFC, IN2P3, CIEMAT, FAPESP, IHEP.

Does your project plan dedicated submission(s) for the ESPPU? The Global Argon Dark Matter Collaboration will make a submission to the ESPPU.

Main message for UK input *to ESPPU*: strong support for direct detection science, complementary to energy frontier accelerators, is essential in **any** future scenario!

DarkSide-20k: Environmental Cost Estimates

Environmental cost of operation per year (in units of tonnes of CO_2 equivalent):

- The cryogenics system is designed to maximise efficiency by using heat exchange, thus the steady-state operations power requirement is approx. 10.5 kW of cryogenic cooling power.
- The major power usage is 90 kW for the DAQ computers in the control room, 10 kW for the electronics on top of the cryostat, and 27 kW for the AAr cryogenic plant as from extrapolation of the data of Proto-Dune.

With the conservative assumption of 100% up-time, using the conversion of 0.2071 kg CO_2e per kWh, this is 247.1 t/y CO_2e.

Environmental cost of construction (in units of tonnes of CO_2 equivalent):

- The project construction required no new excavation, no new buildings, and transportation of detector components was by ship and truck.
- The estimated value is therefore based on the power consumption of the Rn abatement and air circulation inside the cryostat during installation, which is 50 kW, and the 12.5 kW required during the LAr fill.

With the conservative assumption of 100% up-time, using the conversion of 0.2071 kg CO_2e per kWh, this is 112.3 t/y CO_2e, for the one year of installation operations inside the cryostat and LAr fill.