Project 6: Development of Low-Mass Dark Matter Searches with the DarkSide-20k Experiment

RAL/PPD PhD Open Day
19th February 2025

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RAL/University of Manchester

Science and Technology Facilities Council
Particle Physics

DARKSIDE

MANCHESTER 1824
The University of Manchester

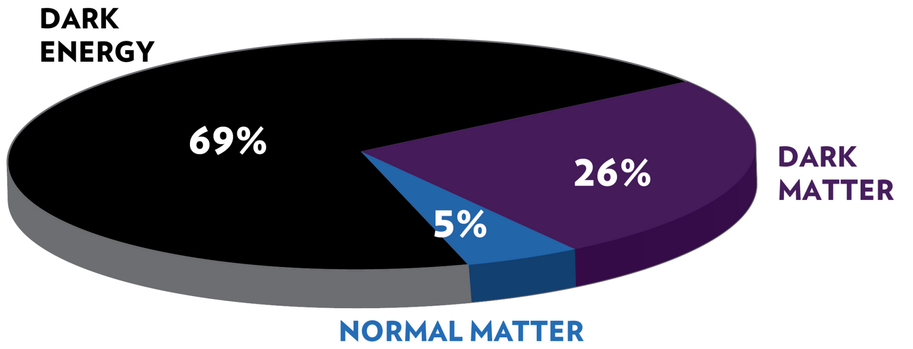
The Project

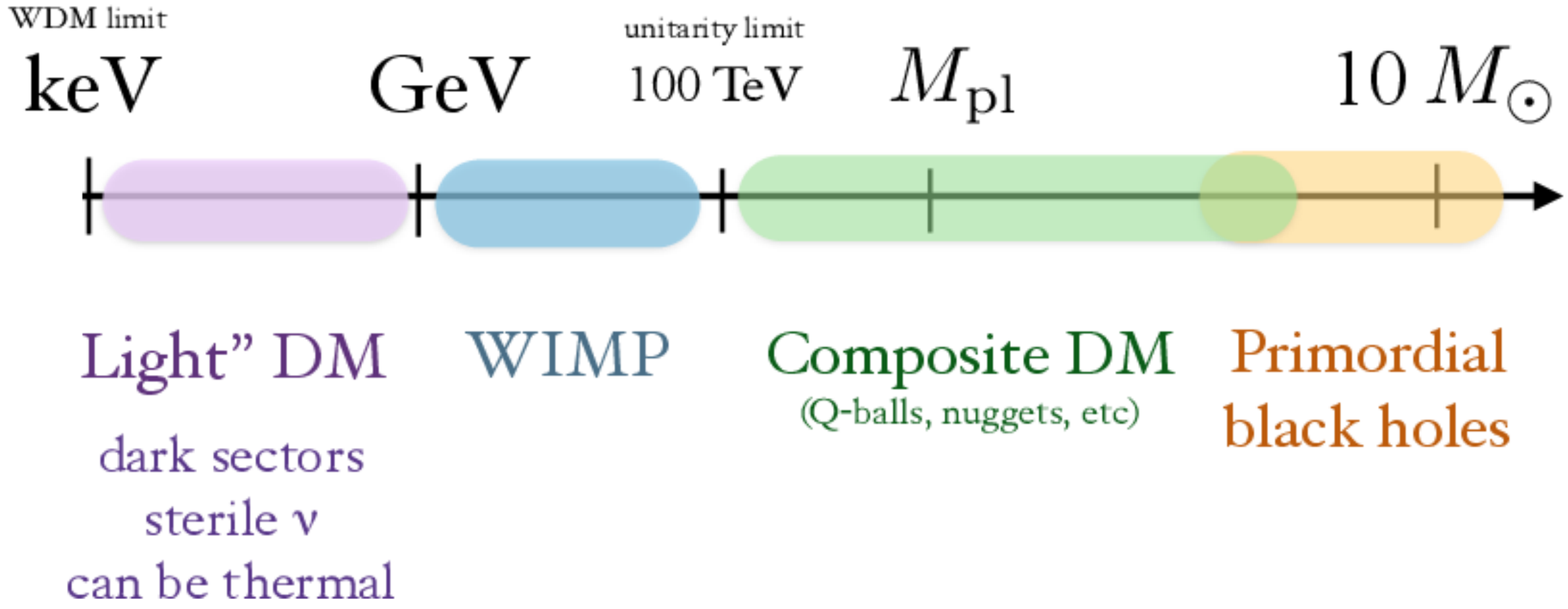
At a glance, you will...

- Take part in the characterisation and calibration of the **novel silicon photosensors** custom-designed for the DarkSide-20k dark matter experiment (which are being built here at RAL!)
- Actively participate in the installation and commissioning of the detector **on-site at LNGS.**
- Directly contribute to the **very first** dark matter search in DarkSide-20k!
- Play a pivotal role in developing new ideas to enhance and expand the search for a range of **low-mass** dark matter candidates.

The Challenge

Mass Scale of Dark Matter (Not to Scale)





Dark Matter Particles span a vast parameter space!

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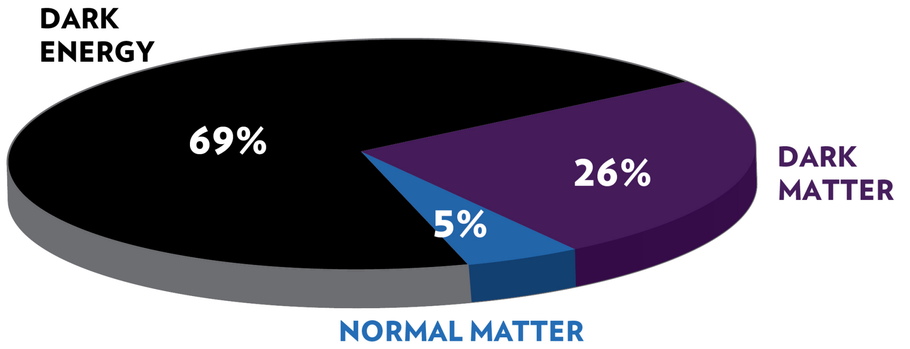
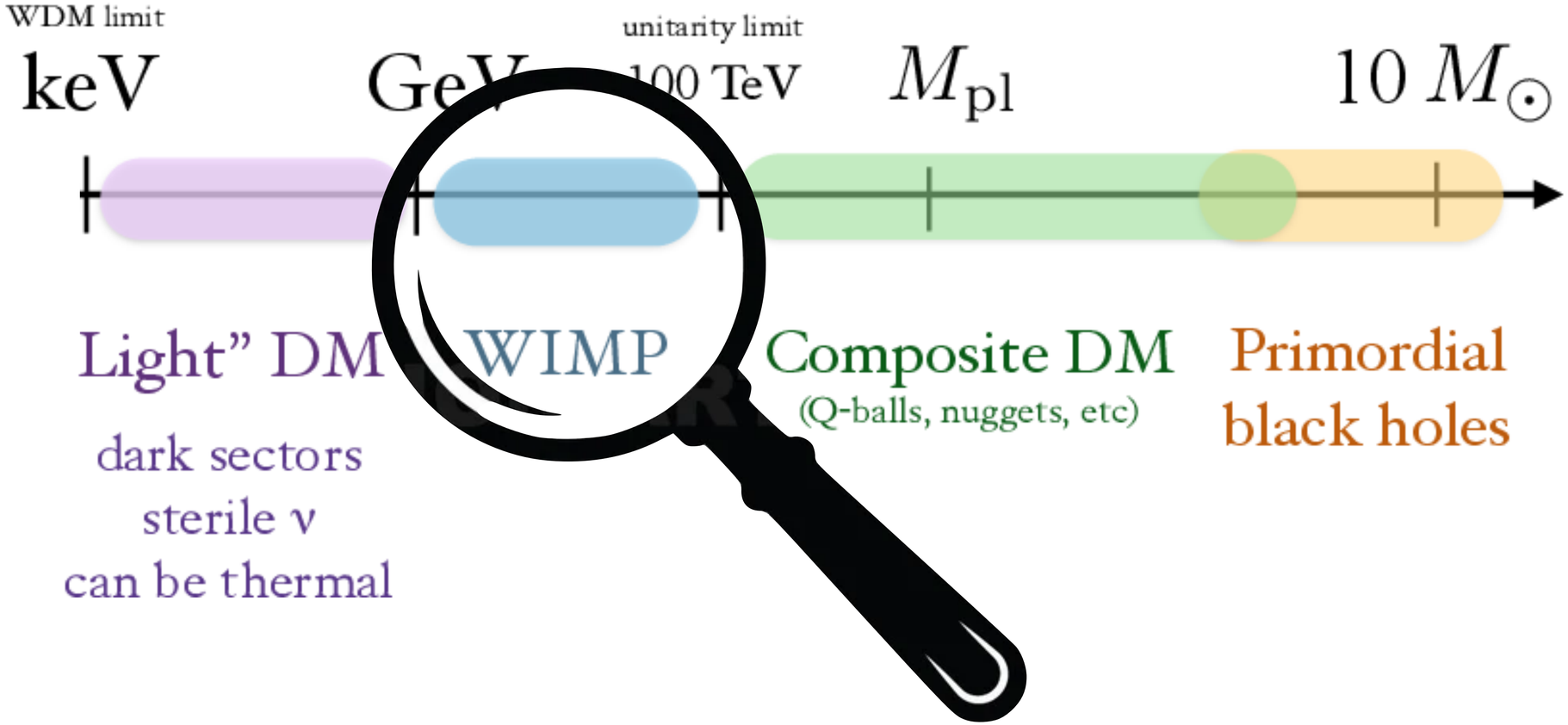




Dark Matter Particles span a vast parameter space!

DarkSide-20k: Overview

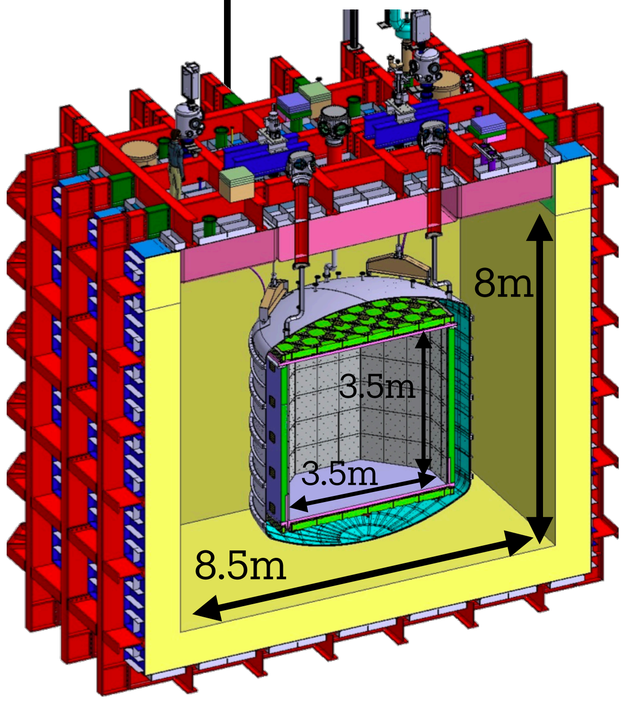
Global Argon Dark Matter Collaboration (GADMC) comprised of 400+ people across 14 countries.

June 2023 DarkSide-20k Collaboration Meeting at LNGS

DarkSide-20k: Detector

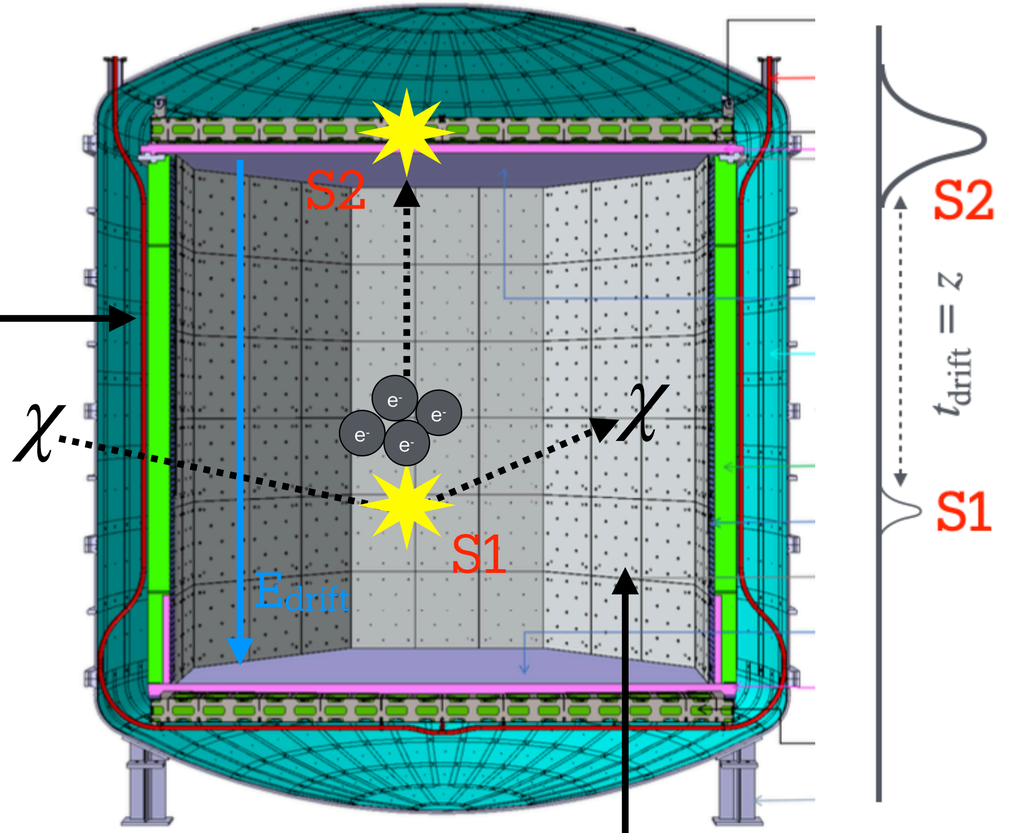
Cosmogenic (Outer) Veto:

- 650t Atmospheric Argon.
- Instrumented with Silicon Photomultipliers (SiPMs) with sparse coverage.



Neutron (Inner) Veto:

- Enclosed in Stainless Steel (SS) vessel. Plastic neutron shield surrounding SS.
- 35t Underground Argon.
- PMMA (acrylic) barrel.
- Instrumented with SiPMs; UK building 7 m^2.



Dual-Phase TPC:

- 50t Underground Argon. Instrumented with 2x Optical Plates of SiPM arrays with 21 m^2 coverage.

DarkSide-20k: Status

Construction at LNGS well underway:

- ✓ Cryostat and infrastructures in LNGS Hall C complete.
- ✓ Cryogenics system operating in Hall C.
- ✓ TPC components in production.
- ✓ Installation of UK photodetectors starting late 2025.
- ✓ Construction complete 2026: data-taking from 2027.

UK groups building 7m^2 of Silicon Detector Readout, Production, and Installation, including here at RAL!

Do go and see the Cleanroom tour today if you can!

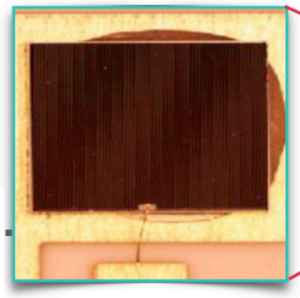
DarkSide-20k located in Hall C at LNGS, Italy (3400 m.w.e)

Cryostat complete in Hall C (LNGS)

Cryogenics System running in Hall C

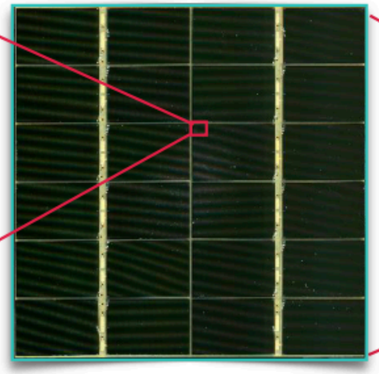
DarkSide-20k: Light Readout with SiPMs

Silicon Photomultiplier (SiPM)



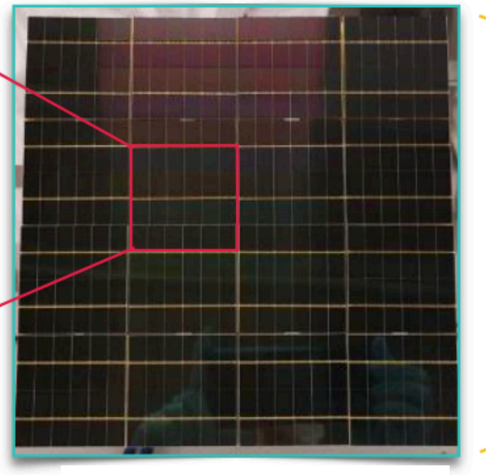
1 cm^2
95k Single Photon Avalanche Diodes

Photodetector Module (PDM)

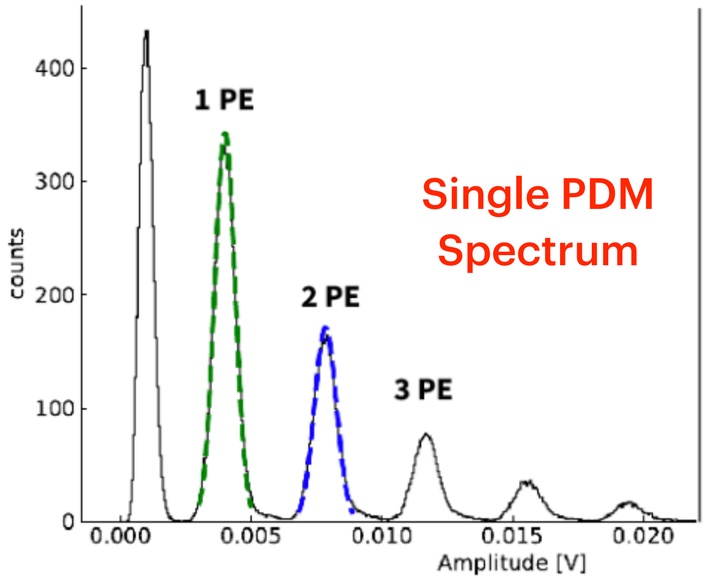


5x5 cm^2; 24 SiPMs + Front-End Electronics

Photodetector Unit (PDU)



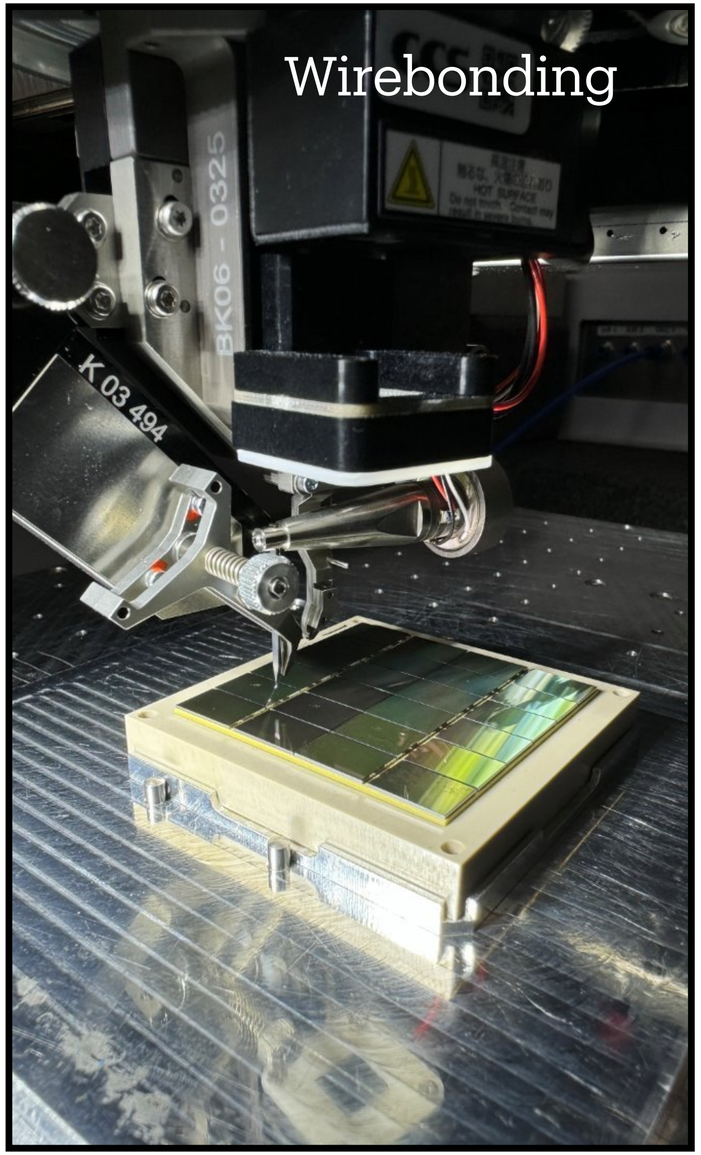
20 x 20 cm^2; 16 PDMs + Motherboard

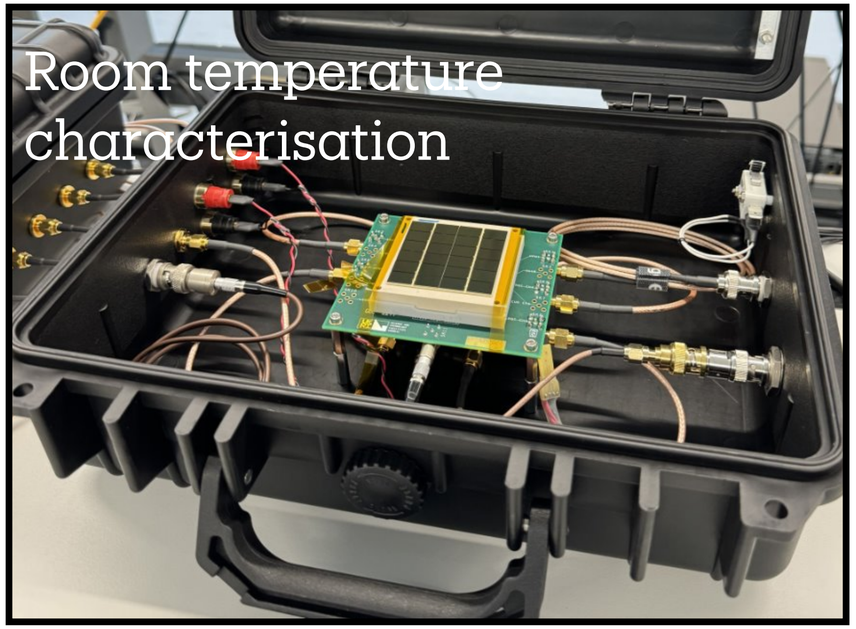


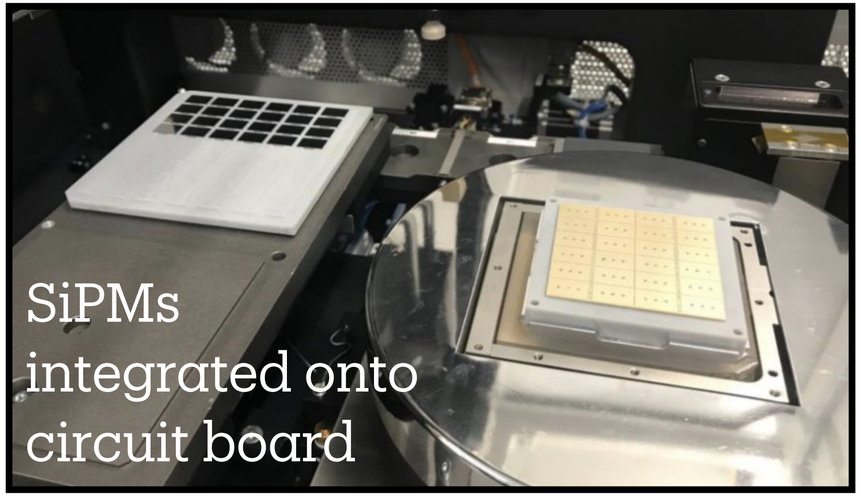
First dark matter experiment to be fully instrumented with SiPMs!

Why SiPMs? Lower noise; lower radioactivity; higher photon detection efficiency; and excellent single photon resolution compared to traditional photomultiplier tubes (PMTs).

DarkSide-20k: PDM Assembly & Testing @ RAL!

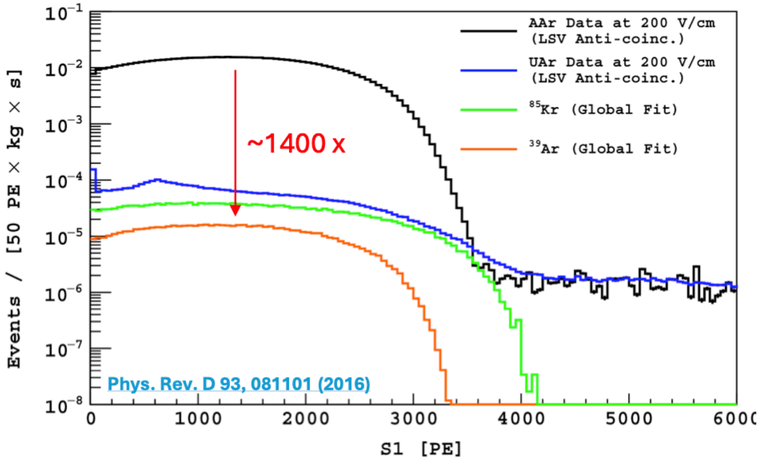






DarkSide-20k: How we will know if we found Dark Matter?

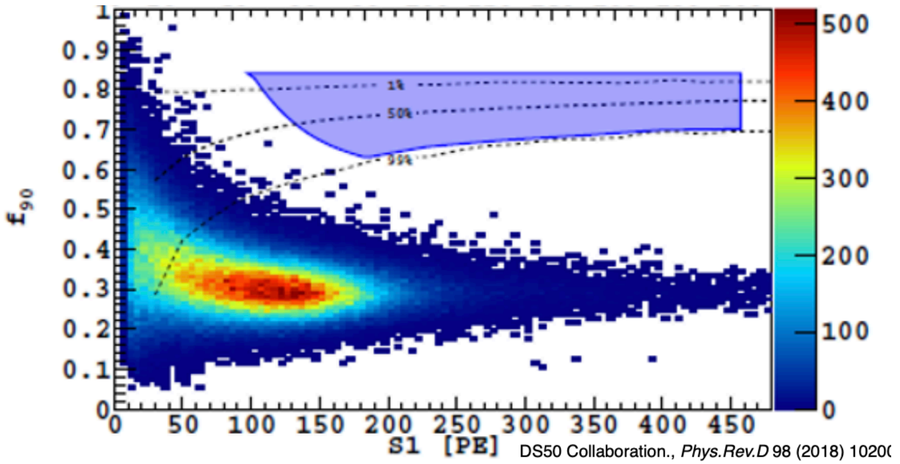
1) Underground Argon



Atmospheric Argon has ^{39}Ar radioactive isotope with high activity of 1 Bq/kg: high electron recoil background rate.

^{39}Ar Depletion factor ~1400!

2) Pulse-Shape Discrimination (PSD)

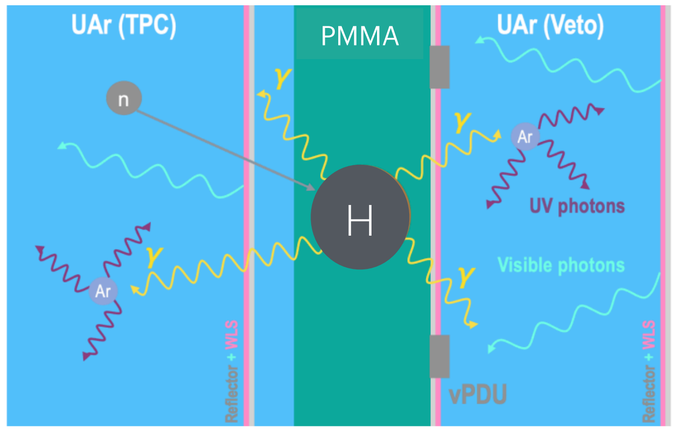


Major Argon advantage: Strong background discrimination.

Electron recoils (background) and nuclear recoils (signal) produce very different pulse shapes. Can use pulse shapes to discriminate between them.

World-leading PSD demonstrated ~10^{10} electron recoil rejection power.

3) Neutron Tagging



Neutrons most dangerous background for WIMP search.

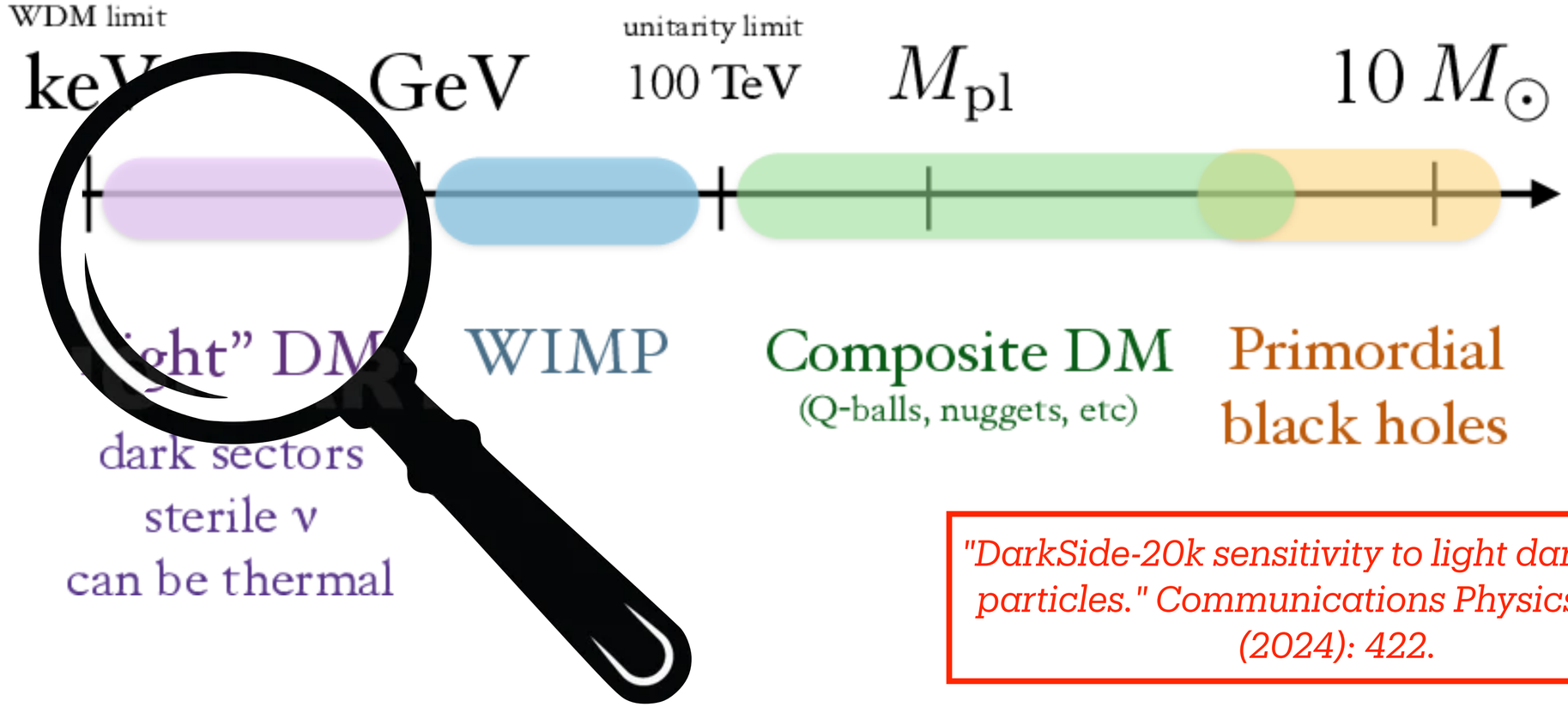
However, we expect WIMPs to interact only once, unlike neutrons which will interact several times.

Thermal neutron capture produces high energy gamma: use as veto signal! .

<0.1 neutron WIMP-like event in 200 tonne-years.

It's not all about WIMPs...

DarkSide-20k has potential to search for **both** lighter and heavier dark matter candidates!



"DarkSide-20k sensitivity to light dark matter particles." Communications Physics 7, no. 1 (2024): 422.

Dark Matter Particles span a vast parameter space!

Low-Mass Searches have their own challenges!

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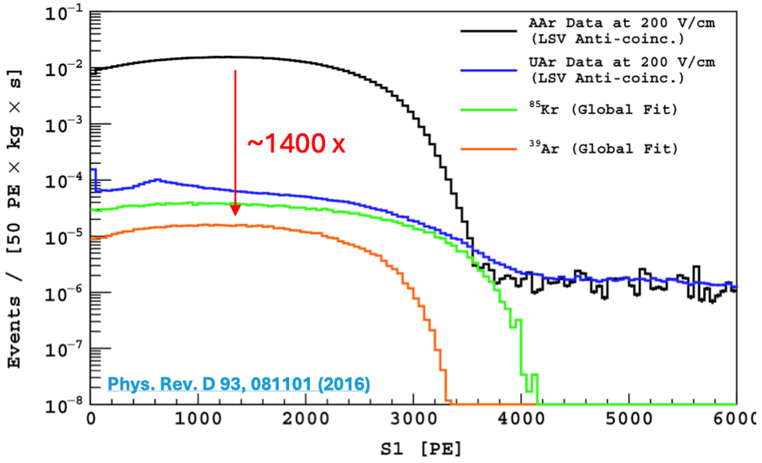

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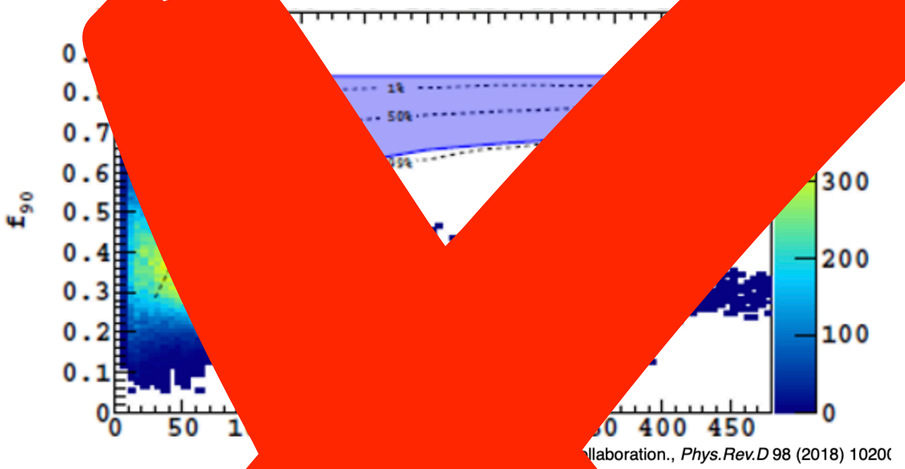

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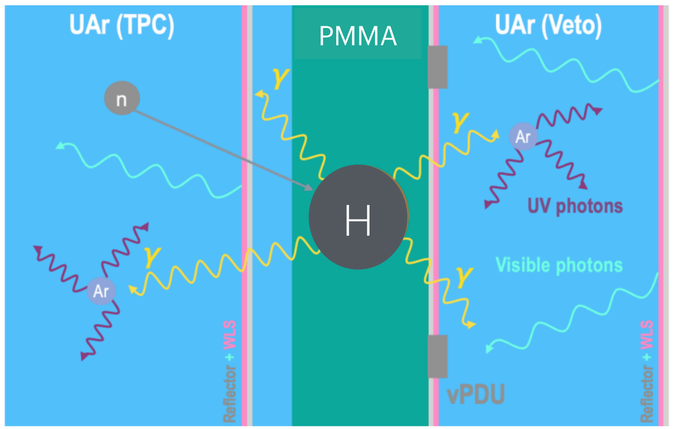

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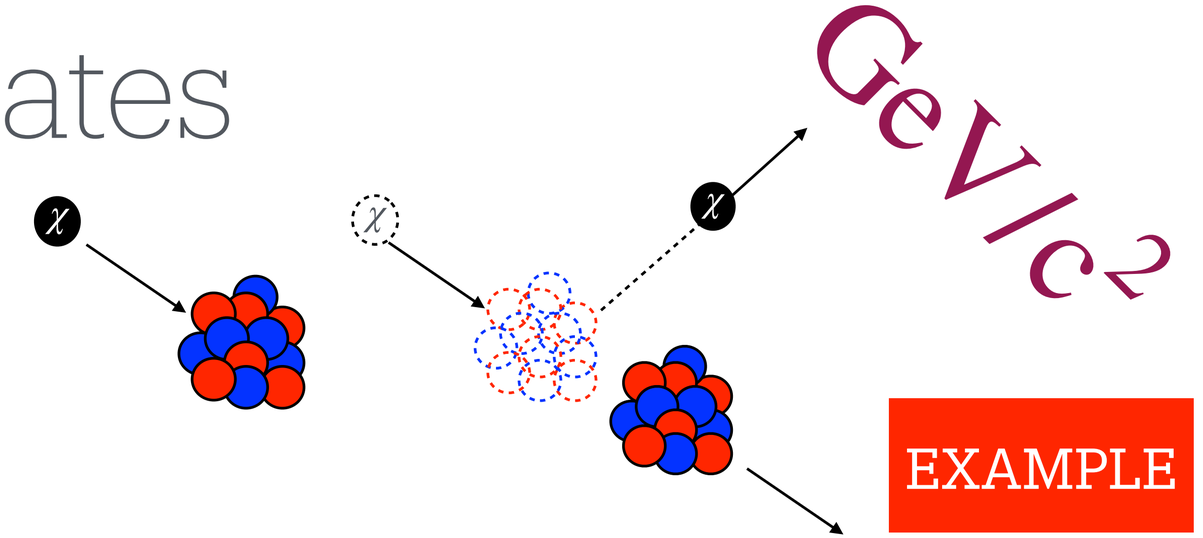
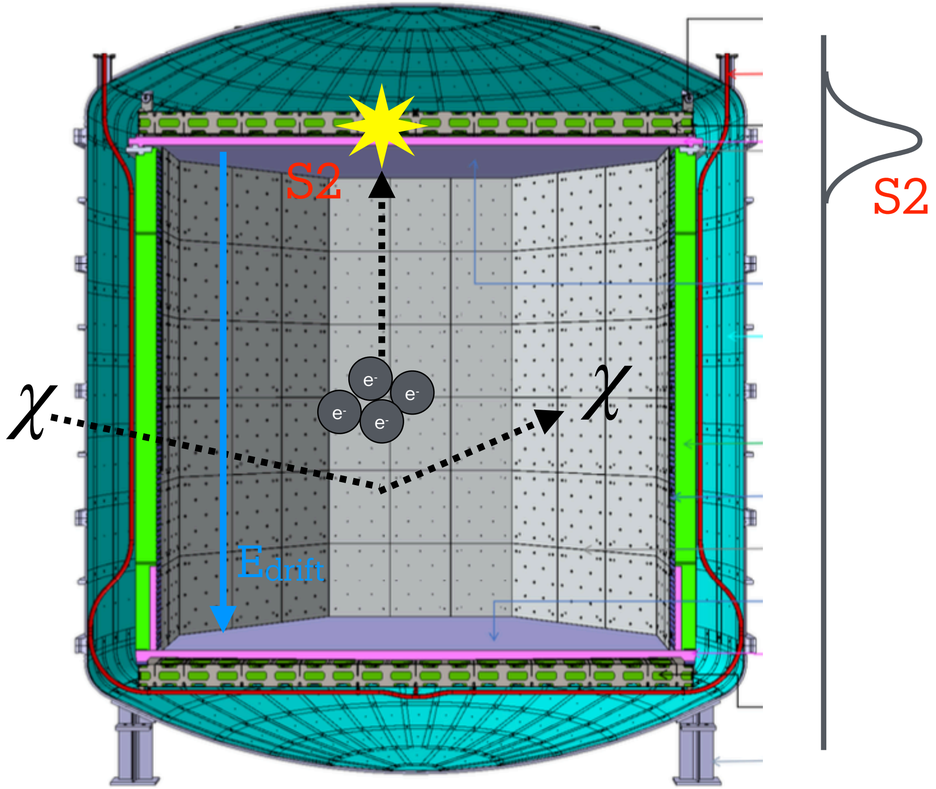
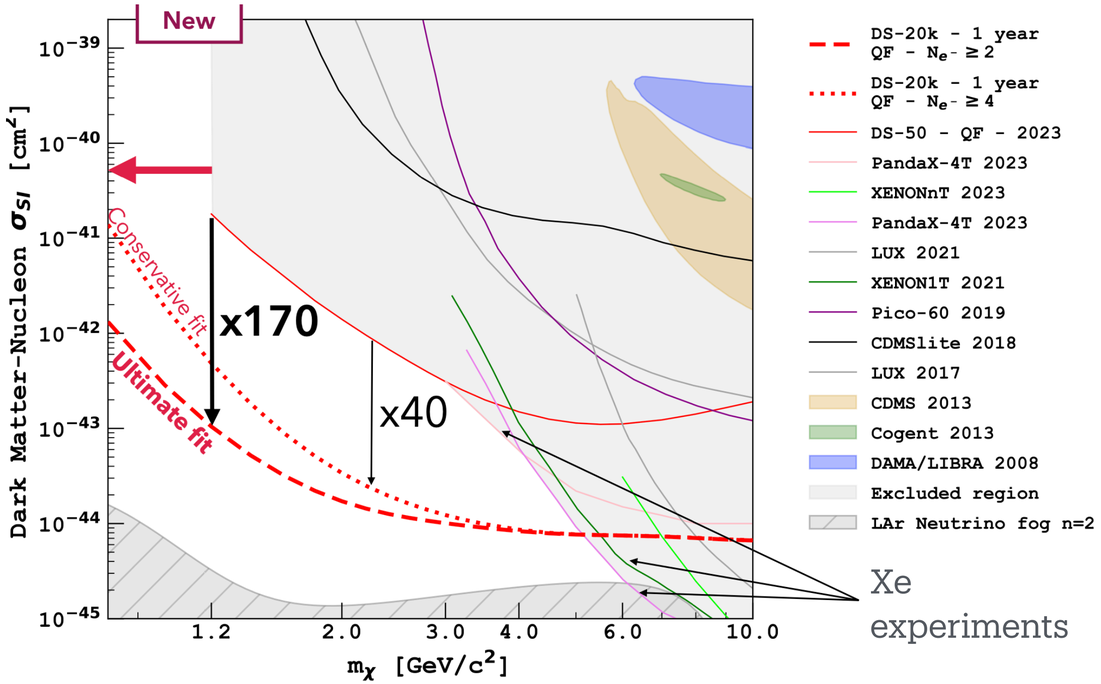
Nuclear Recoil Final States

Dual-phase TPC design drifts and extracts single ionisation electrons in gas with near-100% efficiency—signal amplified a further x20 exploiting electroluminescence in the gas phase.







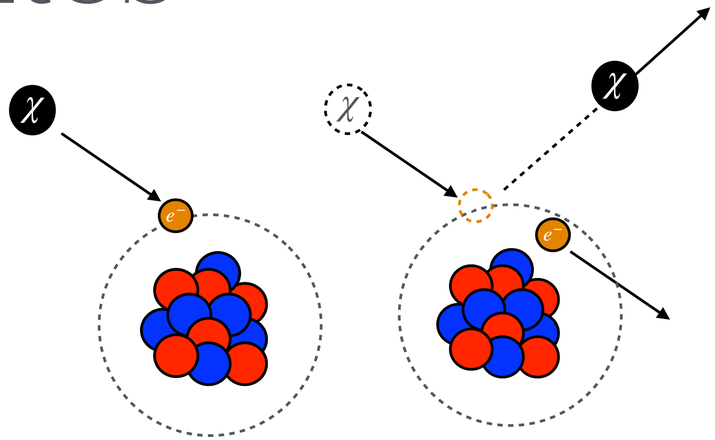
By exploiting ionisation signal (S2) only, DarkSide-20k can reach sub-keV recoil energy thresholds.

Electron Recoil Final States

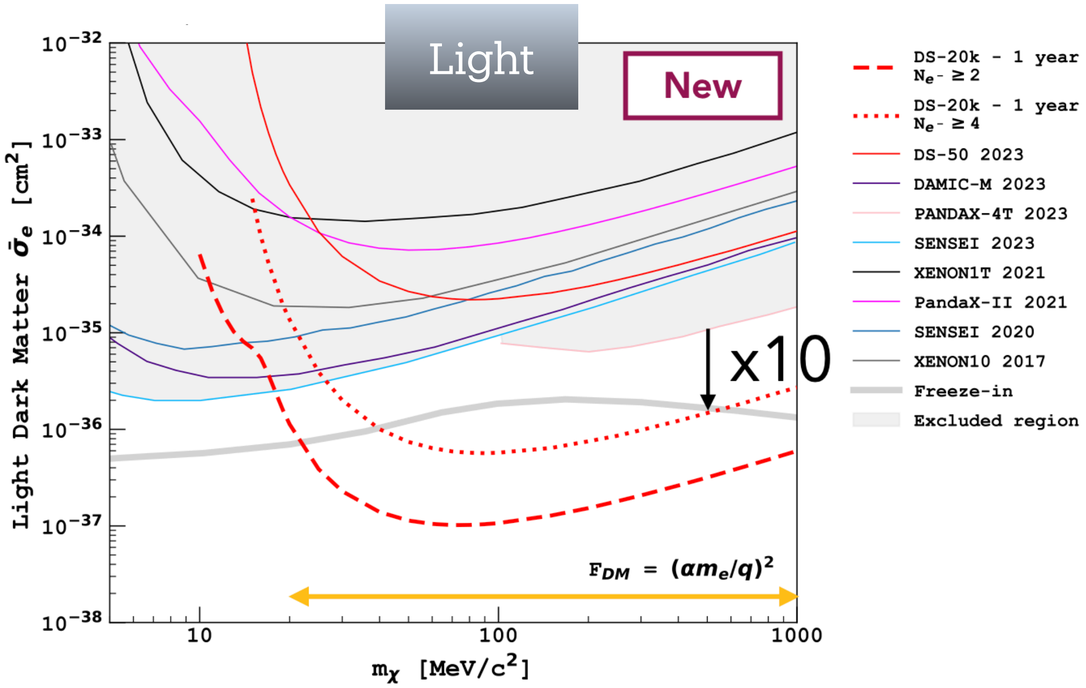
MeV/c2

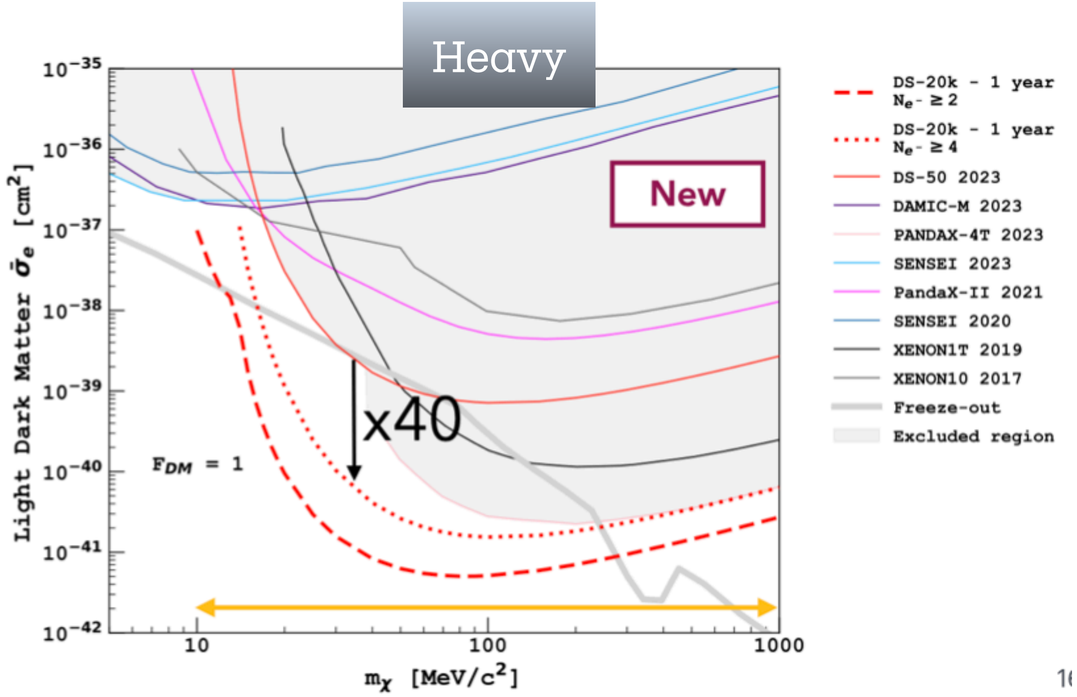
Elastic scattering off atomic electrons: interaction of sub-GeV DM fermion/scalar boson via vector mediator.

Mediator can be light $(m_{\text{med}} \ll m_{\chi})$ or heavy $(m_{\text{med}} \gg m_{\chi})$.



EXAMPLE





Summary

DarkSide-20k is a **hugely ambitious** project with **vast physics potential**: you will be joining the collaboration at undoubtedly the **most exciting time**!

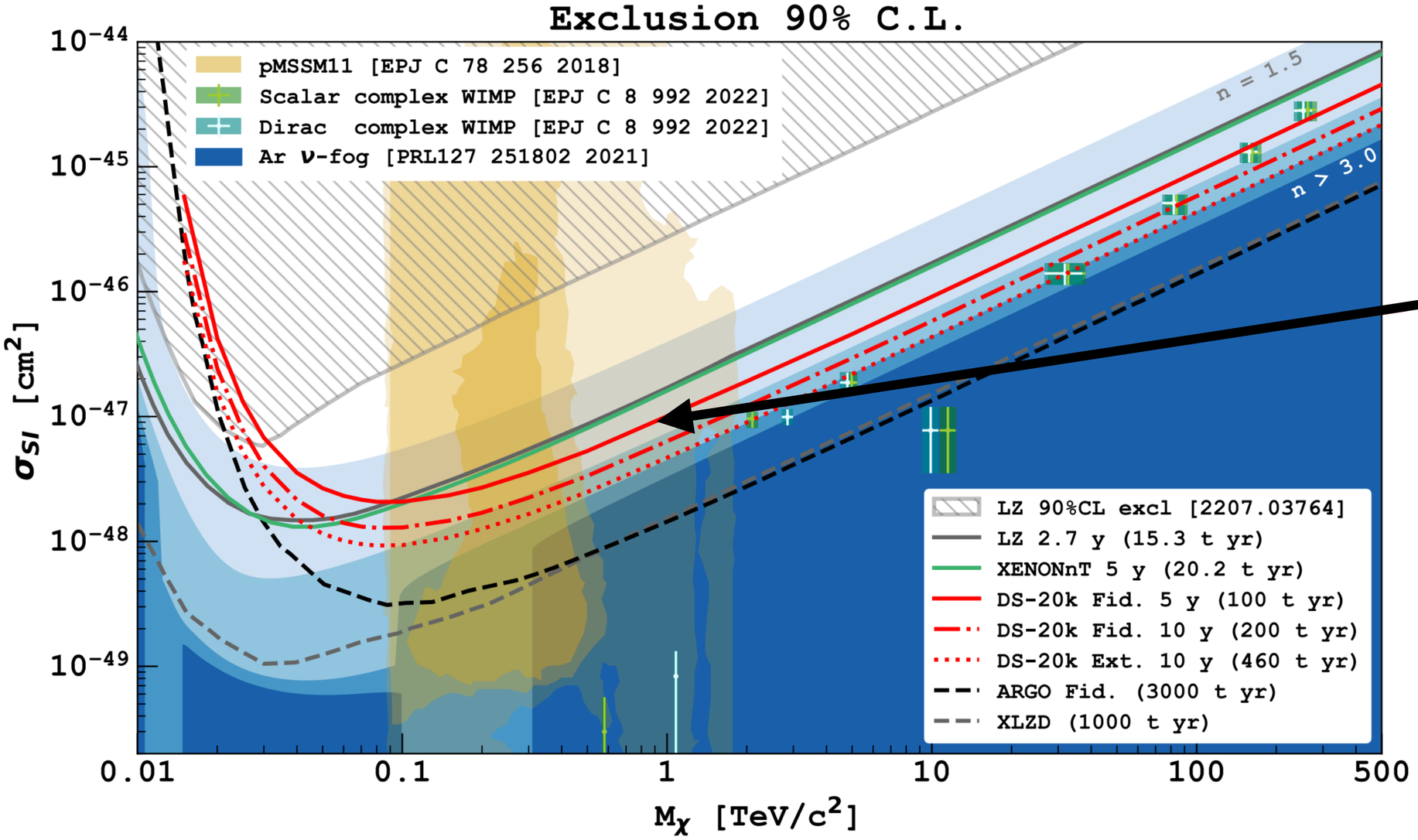
Time will be spent between RAL, Manchester, and LNGS: **ample opportunities** for networking and training.

A good **mix of hardware and software** experience, with **plenty of outputs** (papers, conference opportunities).

The project is not set in stone: we want to capitalise on opportunities for new ideas, based on what **you** find interesting!

Back Up

DarkSide-20k: High-Mass WIMP Sensitivity



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.