NON-STANDARD DARK MATTER SEARCHES WITH DARKSIDE

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UNIVERSITY OF LIVERPOOL ANNUAL HEP MEETING

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INTRODUCTION

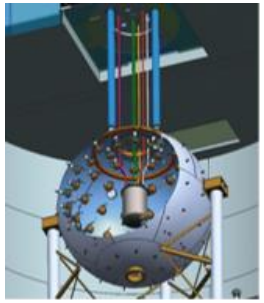
- This month I started as a postdoc here at Liverpool
  - Primarily working on T2K -> See Sam's talk earlier today

- Previously I was at the University of Manchester
  - Carried out both my undergrad MPhys and PhD there

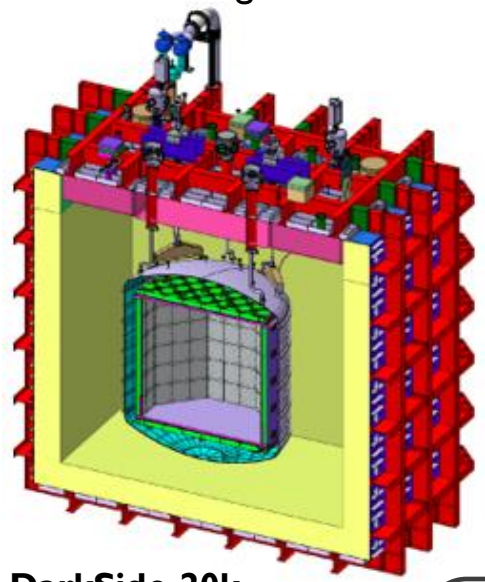
- PhD focus was direct detection dark matter, working within DarkSide
  - DS-UK including both Manchester and Liverpool involved in producing and testing SiPM sensors for the veto of DarkSide-20k
  - My work was primarily focused on broadening the sensitivity of the experiments, extending to lower masses, non-standard DM interactions etc
  - This will be the focus of my talk today

DARKSIDE PROGRAM

LAr dual phase direct detection experiments designed to detect WIMP scattering interactions from the dark matter halo, located 1400m underground lab. at LNGS, Italy



DarkSide-50
0.03 tyr exposure
2013-2018

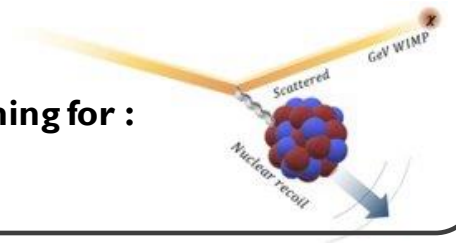


DarkSide-20k
200 tyr exposure
2026 +

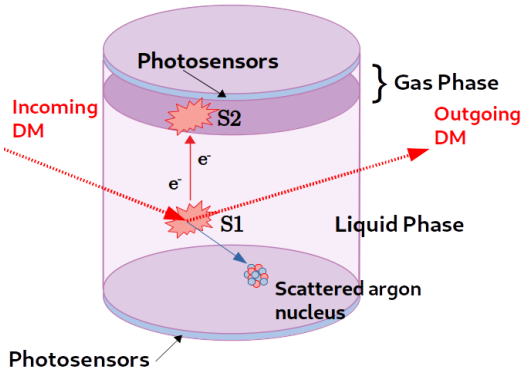
ARGO
3000 tyr exposure
2030s +
High mass focus

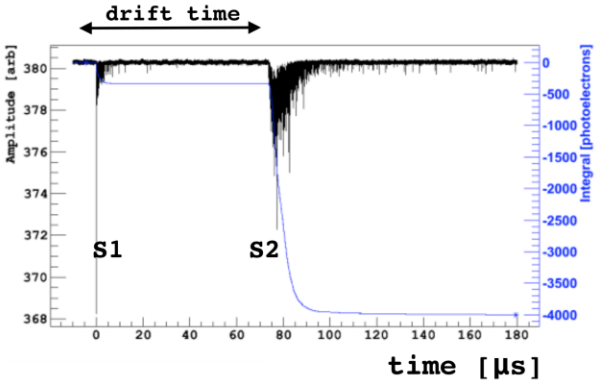
DarkSide-LowMass
Proposed 1 tyr exposure
Low mass (sub GeV)

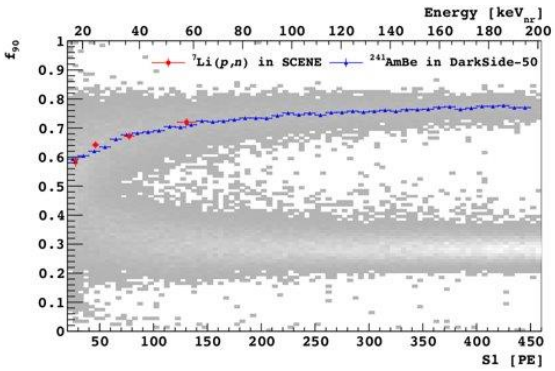
Searching for :



LAR TPC PRINCIPLES



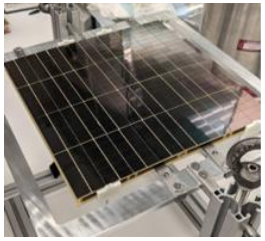


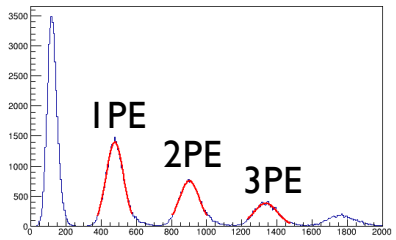


- DM-nucleus interaction creates initial scintillation pulse (S1) and secondary ionisation pulse (S2)
- Seen by photosensors on top and bottom of the TPC
- Use the S1-S2 time difference to measure Z position of event, and the S2 light distribution to determine XY position: 3D reconstruction
- Pulse shape discrimination can be used to discriminate between NR and ER signals due to the difference in decay constants between triplet and singlet states

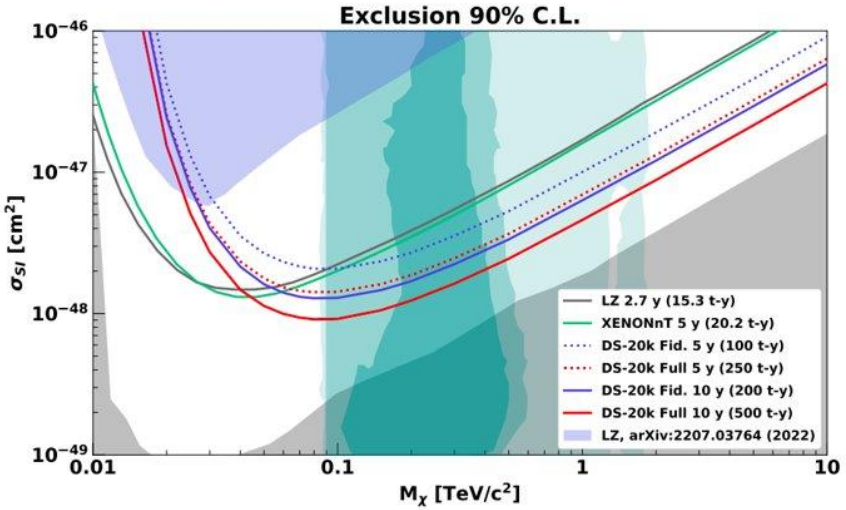
MY WORK

- Hardware
  - Characterisation of SiPM sensors for the TPC of DarkSide-20k in Naples
  - Assembly and testing of SiPM sensors for the veto volume of DarkSide-20k in Manchester



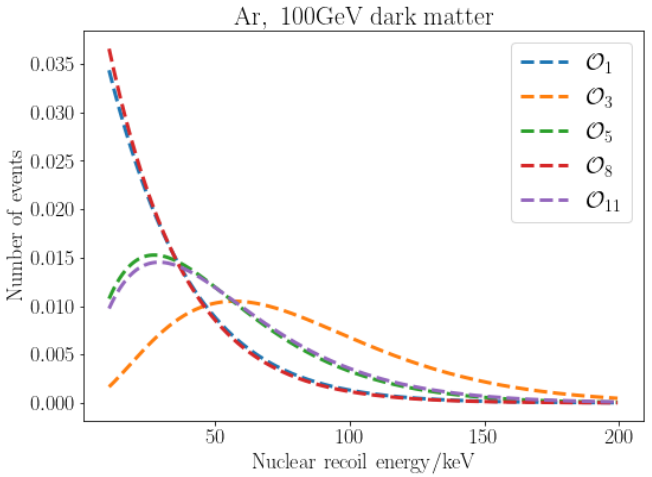


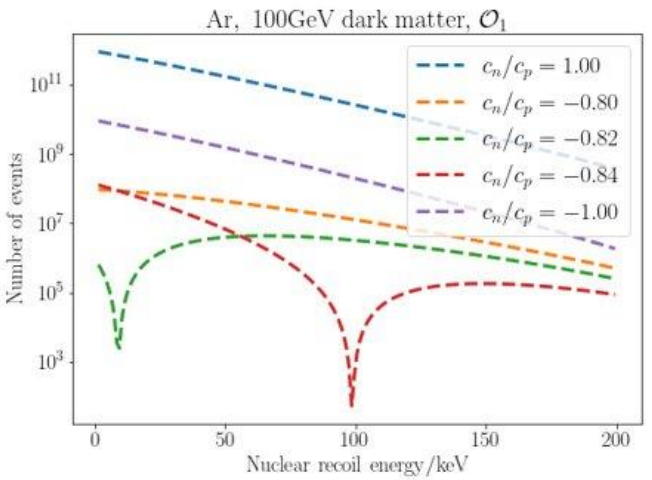
- Analysis and projected sensitivities
  - How can we extend beyond the standard GeV-TeV sensitivity to SI interactions?



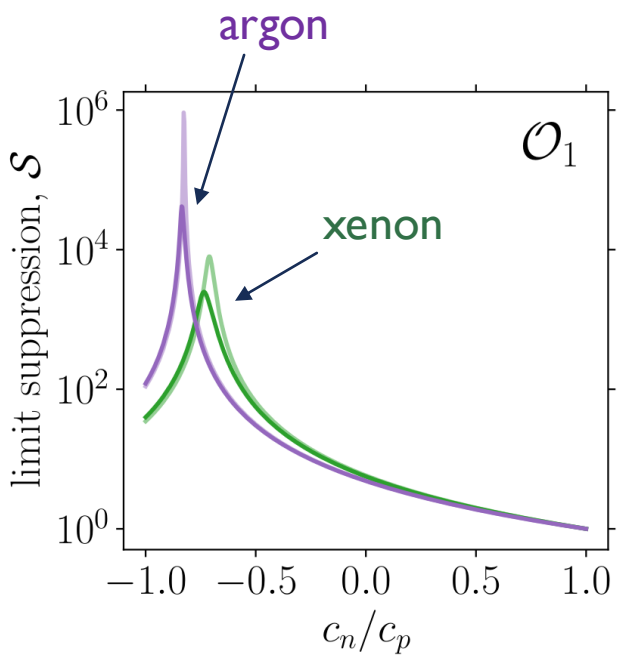
NON-STANDARD INTERACTIONS

- Extend beyond the usual assumptions of a spin-independent momentum-independent interaction
- Use an EFT framework for potential DM interactions which have dependencies on spin, momentum and velocity
- Allow the coupling to the proton and neutron to be different (isospin violation)
- Both the **spectral shape** of the signal, and the **signal strength** can be dramatically changed – are we sensitive to these interactions?
- We can build more complex models from a combination of the EFT operators

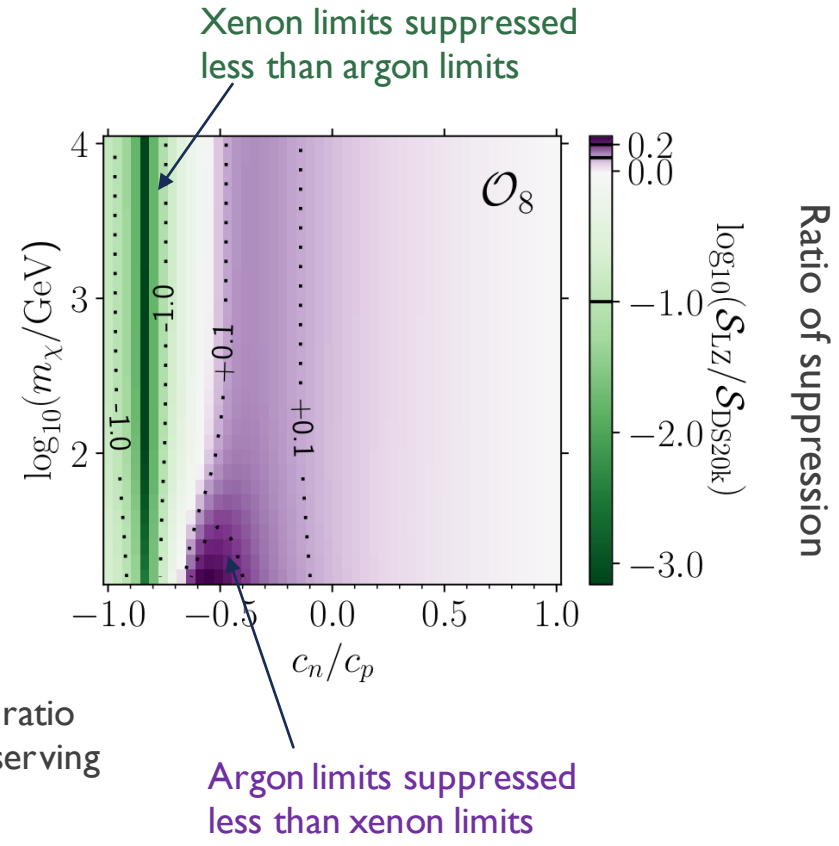




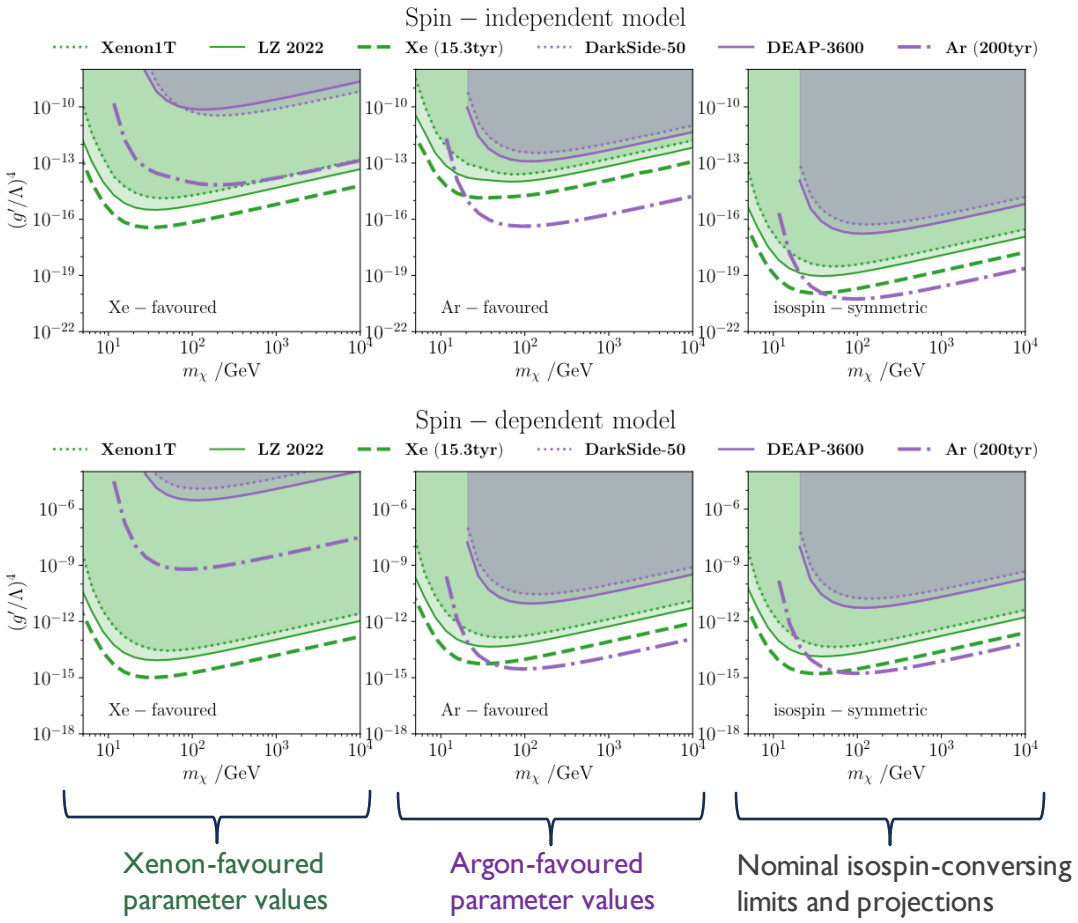
ISOSPIN-VIOLATING DARK MATTER



Experimental sensitivity at a specific coupling ratio compared to the sensitivity to the isospin-conserving dark matter interaction



EFFECT ON EXPERIMENTAL CONSTRAINTS

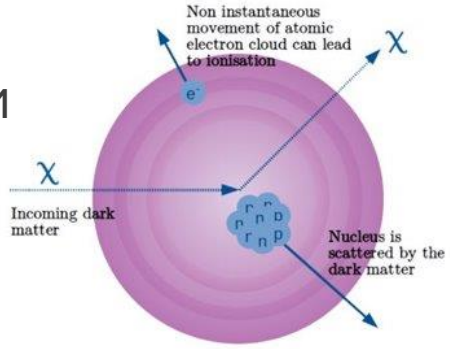


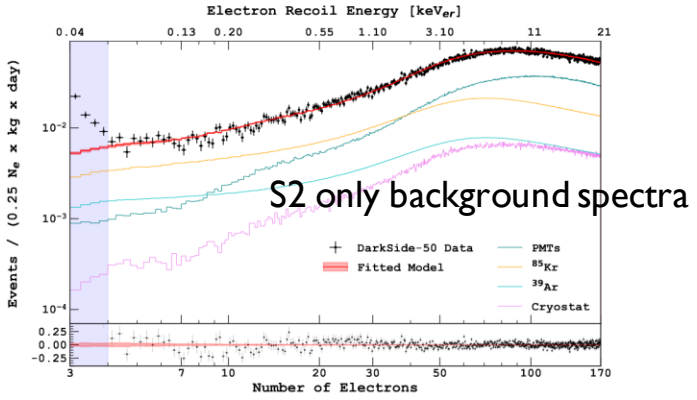
Look at specific Ar-favoured and Xe-favoured points to investigate how these experimental constraints and projections can be suppressed and those from different targets can swap order.

Study can be found here - arXiv:2302.05458 (currently under review by EPJC)

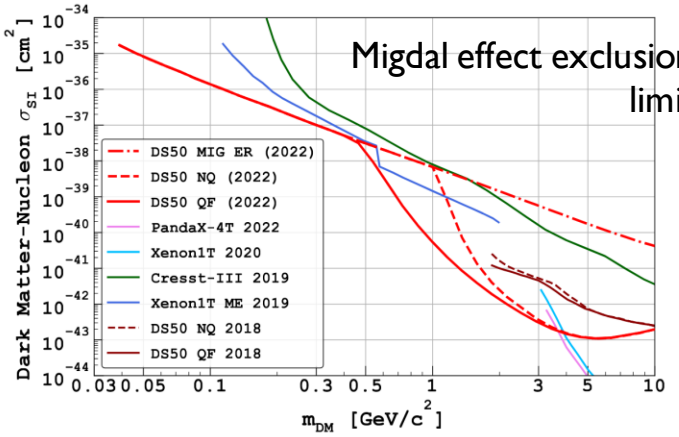
LOW MASS ANALYSIS WITH DARKSIDE-50

- Nominal sensitivity is in the 10 GeV- multi TeV dark matter mass range
- Using only the S2 (ionisation) pulse, can access much lower energy events at the expense of higher backgrounds -> sensitivity down to ~1 GeV
- Use the Migdal effect to reach even lower masses (additional EM signal) -> 40 MeV
- arXiv:2207.11966 , arXiv:2207.11967





S2 only background spectra

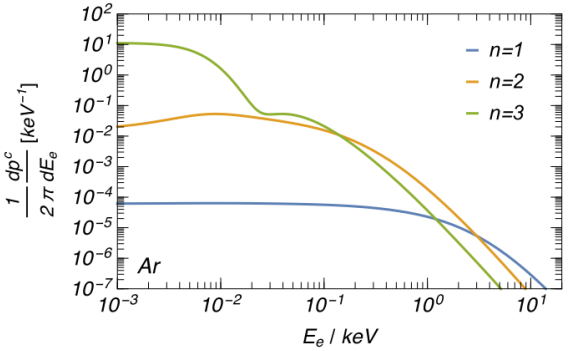


Migdal effect exclusion limit

MIGDAL EFFECT IN NON-STANDARD INTERACTIONS

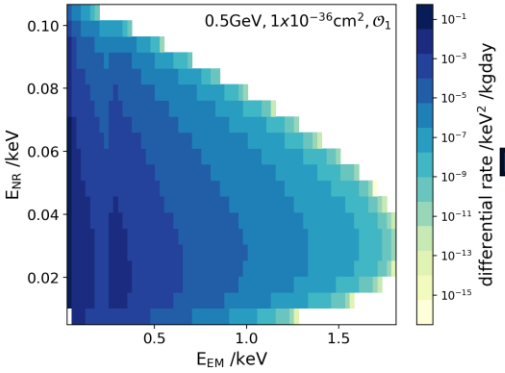
- Migdal effect expected to occur in a fraction of NR events: ionisation due to a lack of instantaneous movement of the electron cloud, and subsequent de-excitation
- This additional EM deposit can be observed as well as the NR signal, giving a boost to the total observable energy

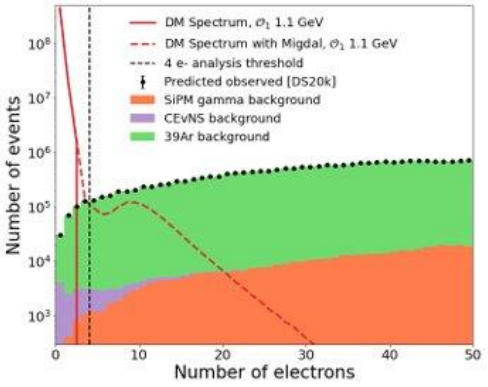
$$\frac{d^2R}{dE_{\rm nr}\,dE_{\rm er}} = \frac{dR_{\rm nr}}{dE_{\rm nr}}\frac{1}{2\pi}\sum_{n,\ell}\frac{dp^c_{q_e}(n\ell \to E_{\rm er})}{dE_{\rm er}}$$



Ionisation probability for each sub-shell from Ibe et al

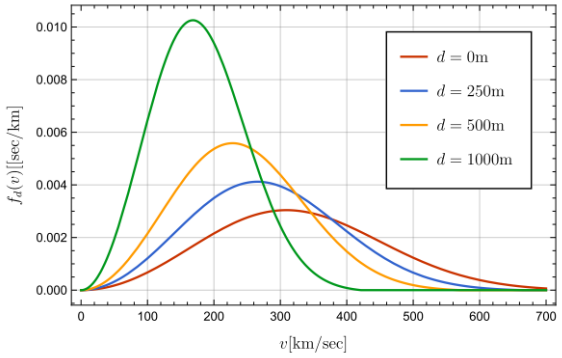
- Study carried out comparing Xe and Ar experiments using public information to re-cast Migdal limits in terms of other interactions, and carry out projections





EARTH SHIELDING EFFECTS

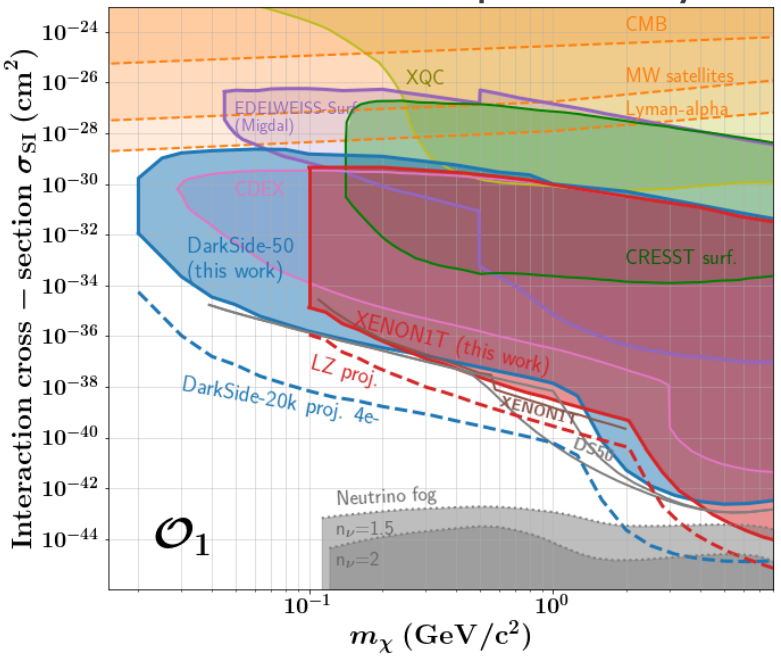
- At high cross-sections, there is a non-negligible chance of dark matter interactions within the atmosphere and earth before reaching the underground detector
- At some point we will lose sensitivity



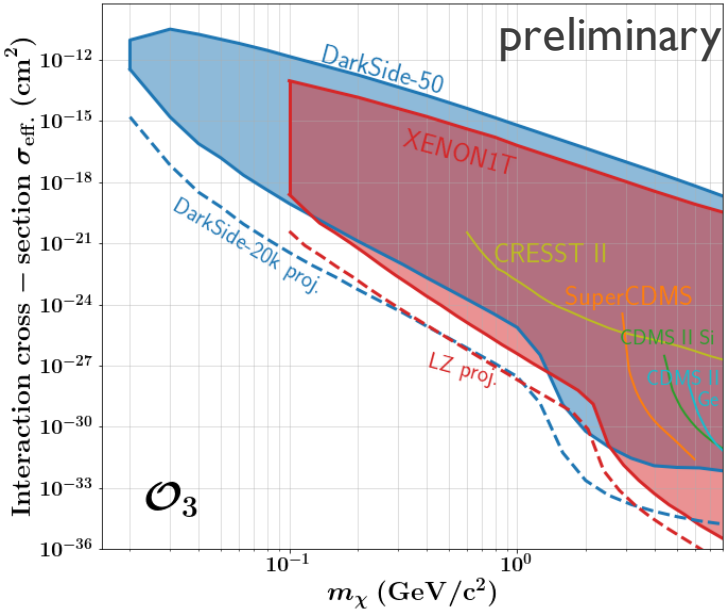
Velocity distribution of dark matter reaching the detector

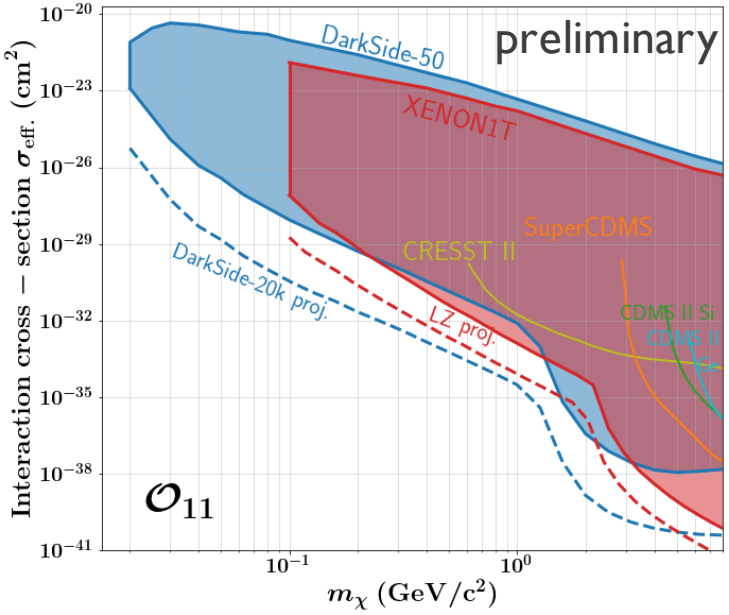
(taken from arXiv:1802.04764)

preliminary



NON-STANDARD INTERACTIONS IN THE LOW MASS REGION





- Main take away: DarkSide sensitive to lots of physics beyond GeV-TeV scale DM with isospin-conversing spin- and momentum-independent interaction
- Useful to have experiments with different targets to negate the effects of blind spots and disentangle dark matter parameters post-discovery

WHAT WILL I BE WORKING ON AT LIVERPOOL

- Primarily working on T2K
- Near detector upgrade :
  - The ND280 upgrade includes super-FGD, high angle TPCs, time of flight planes
  - Combined with an increase in neutrino beam power
  - There will be data taken with the upgraded detector in the near future
  - Will be working on cross-section measurements
- Will be working also in the HyperK calibration group on the UKLI system