DarkSide-20k Sensitivity to **Spin-Dependent** Dark Matter within the NREFT Framework

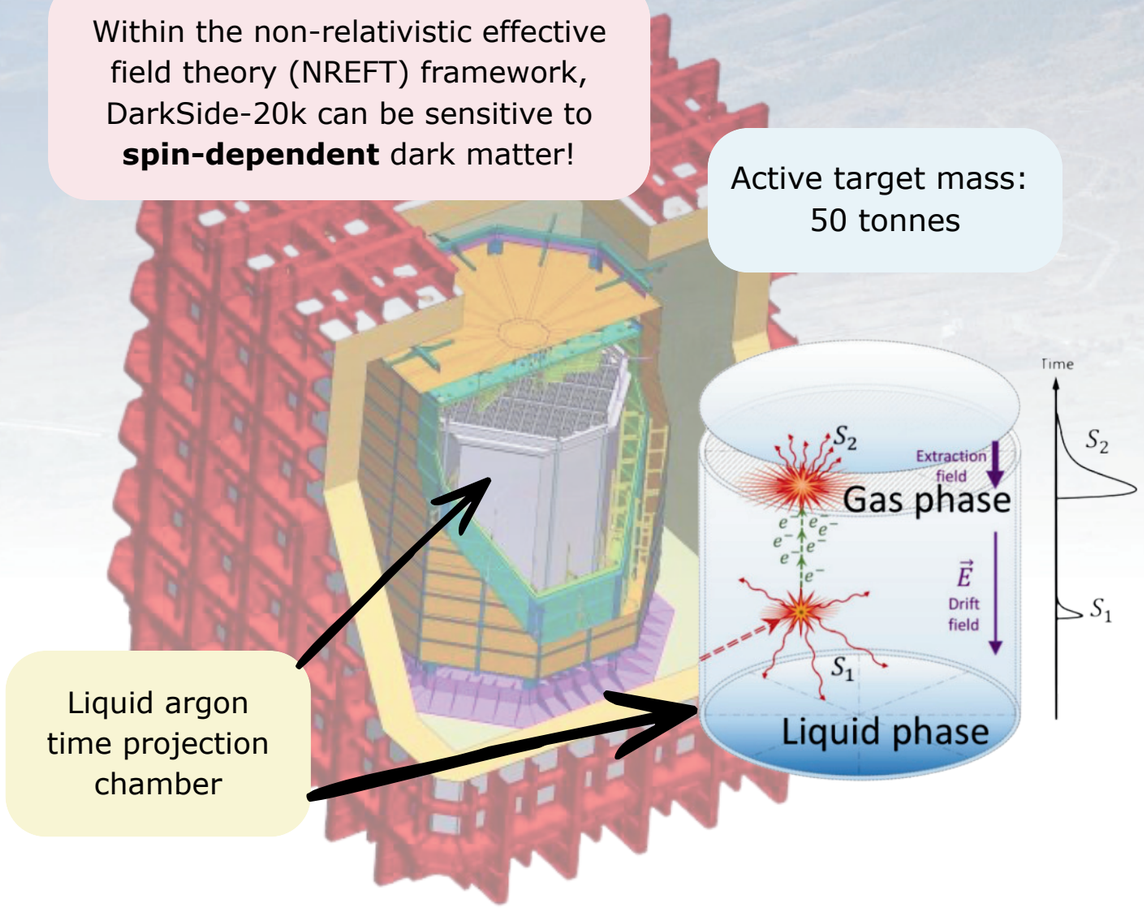
IOP Joint APP and HEPP Annual Conference 2026
Author: Saulė Pigulevičiūtė
Supervisors: Prof. Darren D. Price, Dr. Ashlea Kemp

Science and Technology Facilities Council
Particle Physics

1. DarkSide-20k

Within the non-relativistic effective field theory (NREFT) framework, DarkSide-20k can be sensitive to **spin-dependent** dark matter!

Active target mass: 50 tonnes



Liquid argon time projection chamber

2. Interactions between DM and nucleus: before...

Spin-independent (SI)

- Standard benchmark for direct DM searches.
- DarkSide-50 - driving sensitivity at GeV-scale.
- DarkSide-20k - will lead sensitivity in near future.

Spin-dependent (SD)

- ^{40}Ar - no spin.
- Canonical operator O_4 vanishes.
- No sensitivity for LAr detectors.

3. ...and after: non-relativistic effective field theory

$$L = \sum_N \sum_i c_i^N O_i \chi^+ \chi^- N^+ N^-$$

- Describes all possible dark matter - nucleus axial-vector interactions.
- Massive DarkSide-20k exposure results in observable nuclear recoil signals arising from contributions from non-canonical SD operators.

SI
$\mathcal{O}_1 = \mathbb{1}_\chi \mathbb{1}_N$
$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times v^\perp\right) \mathbb{1}_\chi$

SD
$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$
$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times v^\perp\right) \mathbb{1}_N$
$\mathcal{O}_6 = \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right)$
$\mathcal{O}_7 = \vec{S}_N \cdot v^\perp \mathbb{1}_\chi$
$\mathcal{O}_8 = \vec{S}_\chi \cdot v^\perp \mathbb{1}_N$
$\mathcal{O}_9 = i\vec{S}_\chi \left(\vec{S}_N \times \frac{\vec{q}}{m_N}\right)$
$\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N} \mathbb{1}_\chi$
$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N} \mathbb{1}_N$

4. Parametrisation

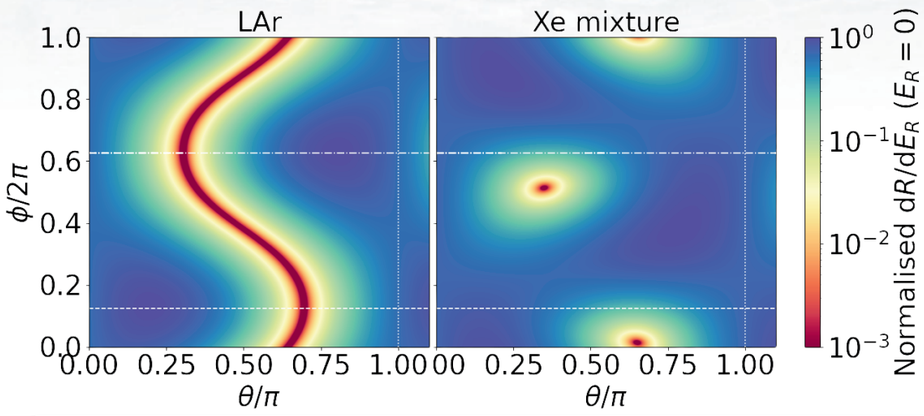
- θ: **L-handed** and **R-handed** quark interactions;
- ϕ: **up-type** and **down-type R-handed** couplings;
- g'^2 / Λ^2: overall **interaction strength**.

Isospin is preserved in two scenarios:

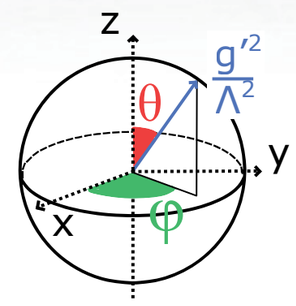
$\theta = k\pi; \phi \in [0, 2\pi]; k \in \mathbb{Z}$;

$\phi = \pi/4 + k\pi; \theta \in [0, 2\pi]; k \in \mathbb{Z}$

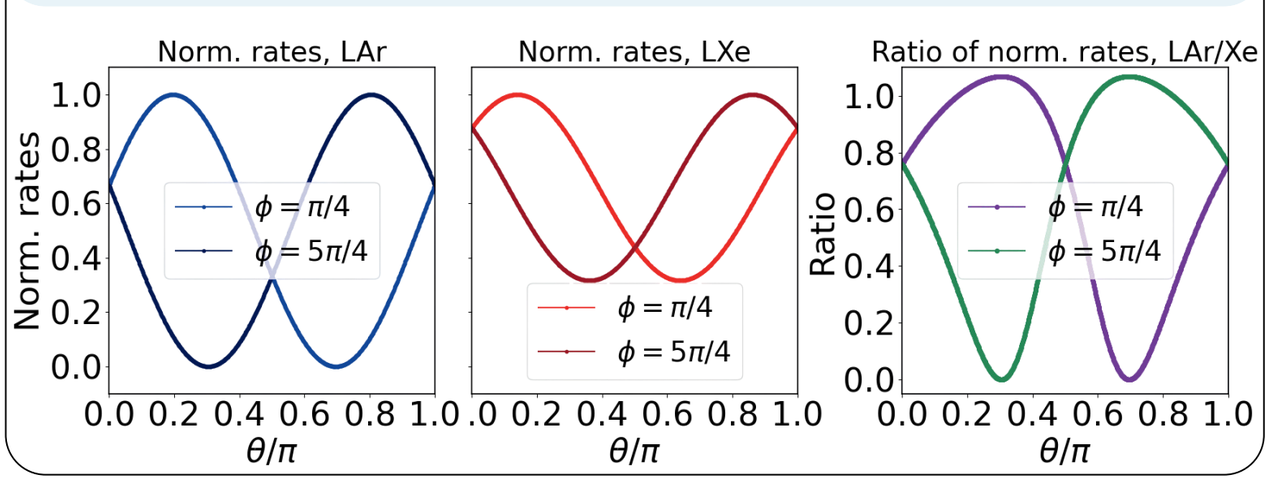
Normalised recoil spectra dependence on the full range of θ and ϕ parameters:



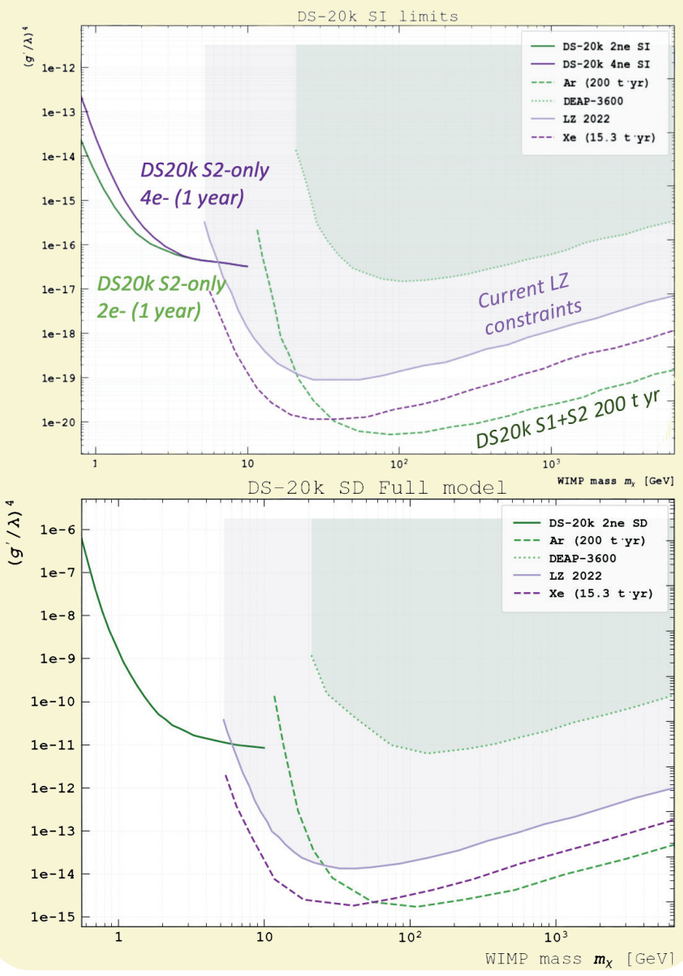
Parametrisation sphere:



Predicted sensitivity of argon (left) and xenon (middle) detectors for a varying θ; relative argon sensitivity w.r.t. xenon is shown on the right:



5. Reinterpretation within NREFT:



Conclusions

Because of a huge exposure, DarkSide-20k can be competitive in spin-dependent dark matter detection within the non-relativistic effective field theory framework.

Future work

Future work will include reinterpreting other direct dark matter experiments sensitivity in the NREFT framework and comparing them against DarkSide-20k sensitivity projections.

Acknowledgements

I would like to thank my supervisors prof. Darren D. Price and Dr. Ashlea Kemp for guiding the project and providing valuable feedback. This work was carried out by prof. Darren D. Price, Dr. Ellen Sandford, Dr. Ash Ritchie-Yates, Conner Roberts, Andrzej Gawdzik and Haoxiang Zhan. I would like to thank them for ongoing support.

References

[1] Roberts, C., Price, D. D. (2025, Nov 20). Sensitivity to spin dependent interactions: Ds20k prospects. https://agenda.infn.it/event/48469/contributions/280280/.

[2] Cheek, A., Price, D. D., & Sandford, E. M. (2023). Isospin-violating dark matter at liquid noble detectors: new constraints, future projections, and an exploration of target complementarity. The European Physical Journal C, 83(10), 914.