Ab-initio WIMP-Nucleus Scattering

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Introduction

- The nature of dark matter remains unknown is to this day.
- One of the more accepted hypotheses for dark matter is that it is a Weakly Interacting Massive Particle (WIMP).
- A way to look for WIMPs is direct detection, in which detectors look for recoil events caused by the scattering of nuclei by incoming dark matter particles.

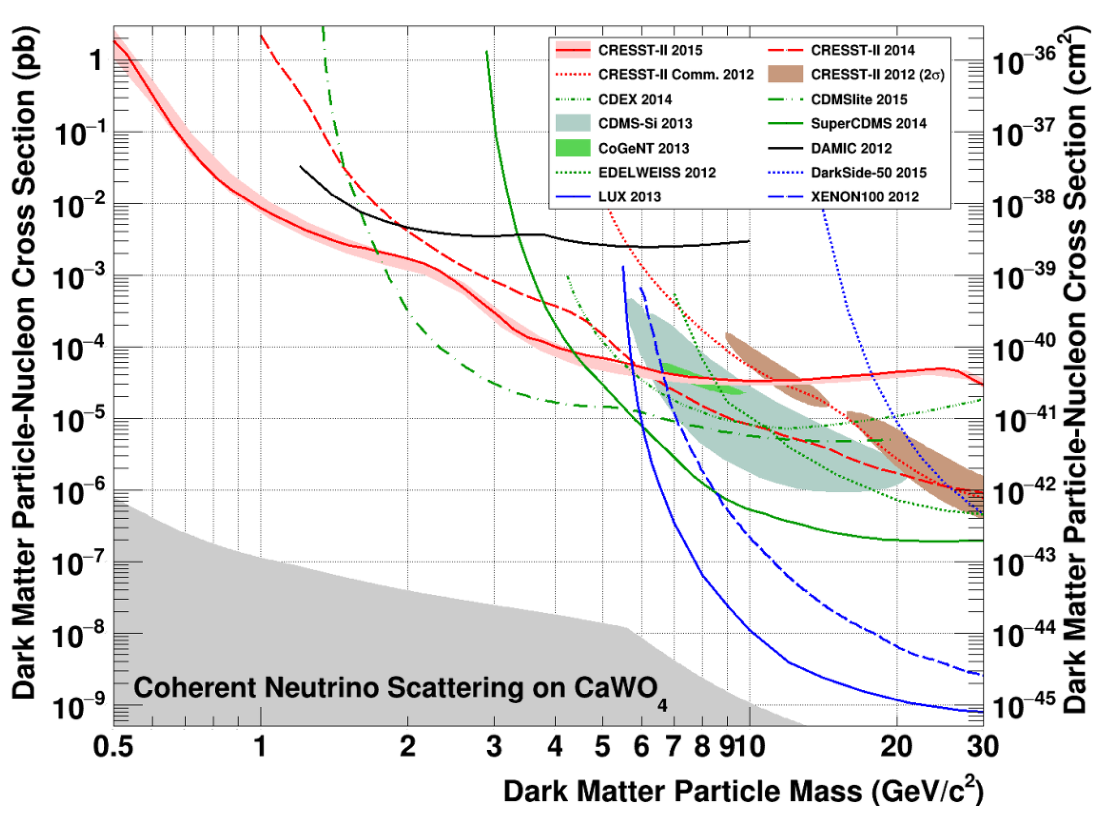


Figure 1. Upper limits set on the dark matter-nucleon cross-sections by direct detection experiments, as a function of the dark matter mass. Plot taken from [1].

To help guide experiments, we would like to compute observables such as cross-sections. We achieve this using an ab-initio (from the ground up) framework to compute nuclear response functions.

Non-Relativistic Effective Field Theory

- We first need a description of the WIMP-nucleus interaction.
- Go to an Effective Field Theory (EFT), build the most general Hamiltonian obeying Galilean invariance and momentum conservation:

$$\hat{\mathcal{H}}_{\chi N} = \sum_{i=0}^{A} \sum_{\tau=0,1} \sum_{j} c_j^{\tau} \hat{\mathcal{O}}_j^{(i)} t_{(i)}^{\tau} \quad (1)$$

This allows us to write any observable in terms of two sets of response functions:

- Dark matter response functions $R_m^{\tau\tau'}$, which are determined by the c_j^{τ}.
- Nuclear response functions $W_m^{\tau\tau'}$. These are dependent on the target nucleus and are calculated using ab-initio methods in our case.

Ab-Initio Calculations

- One of the problems in doing ab-initio nuclear physics calculations is the size of the Hamiltonians that need to be diagonalized.
- Modern methods such as the IMSRG can simplify the Hamiltonians enough to make ab-initio calculations possible.

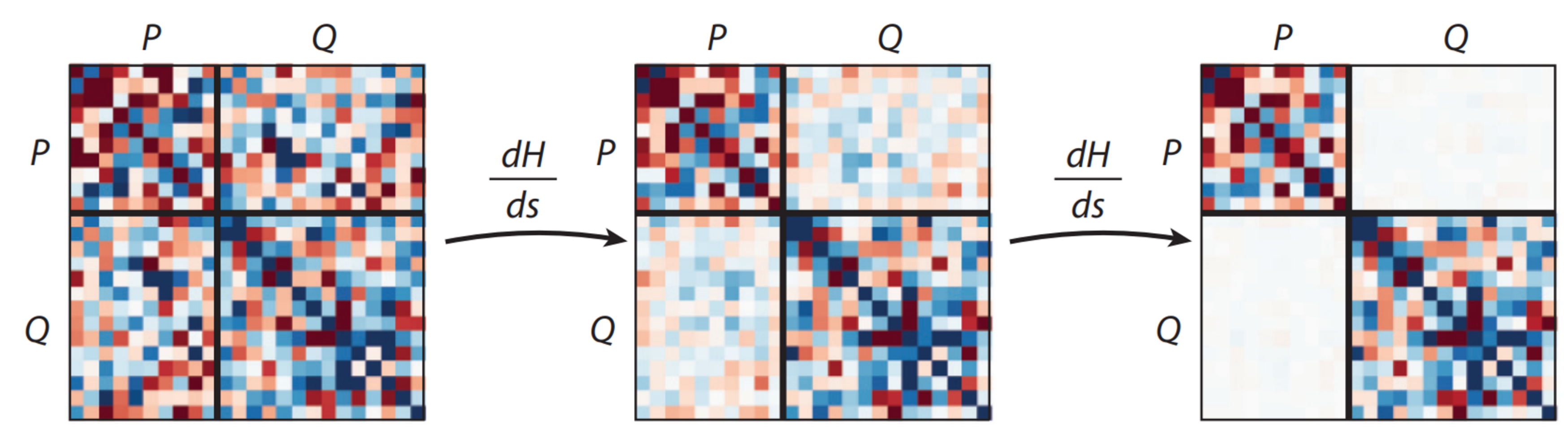


Figure 2. Evolution of the Hamiltonian towards a block-diagonal form using the IMSRG. Figure taken from [2].

Comparison With Chiral Effective Field Theory

- Another way to get a general WIMP-nucleus interaction is by using Chiral EFT. This is the primary approach, and also considering NREFT provides a better prediction.
- We can compare some of the $W_m^{\tau\tau'}$ between our results and previous results that use this EFT.

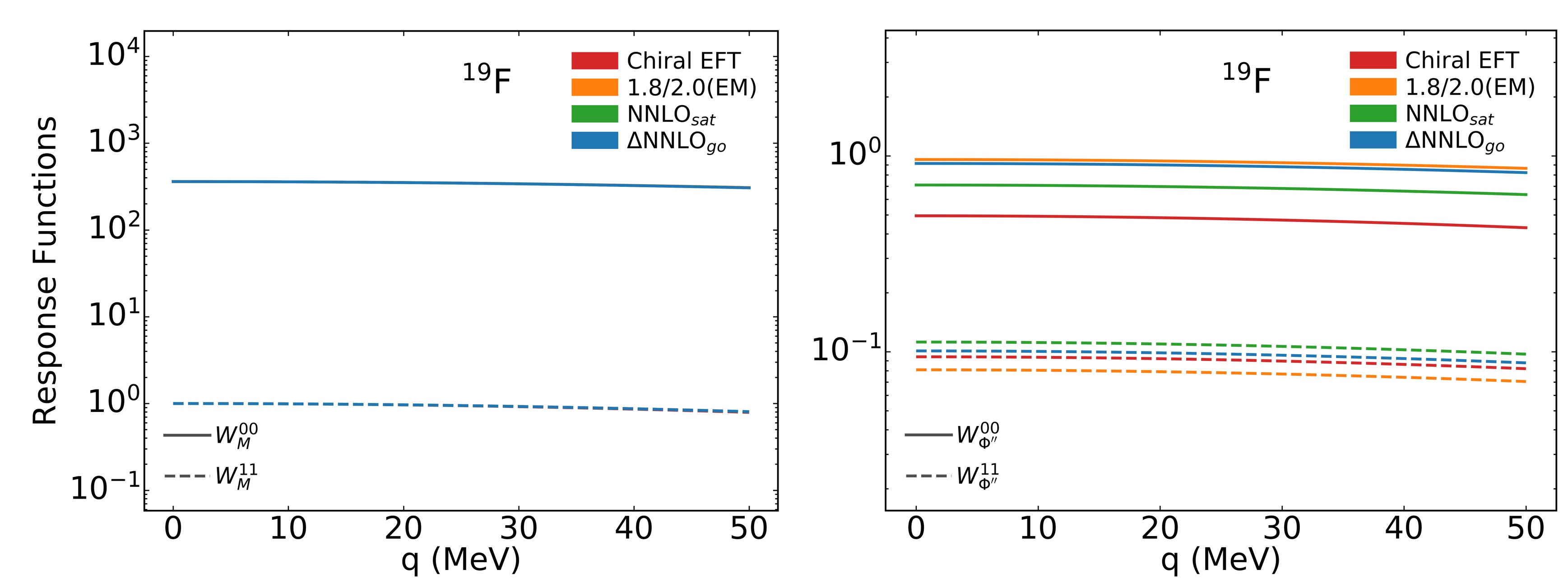


Figure 3. Comparison of two different $W_m^{\tau\tau'}$ with Chiral EFT. The last 3 labels in the legend are our calculations, done with different Nucleon-Nucleon interactions. We see the first response function agrees well with Chiral EFT, while there are small differences for the second.

Computing Scattering Cross-Sections

- From the response functions, we can compute observables like cross-sections.
- These are compared to existing results from phenomenological calculations that use the nuclear shell model.

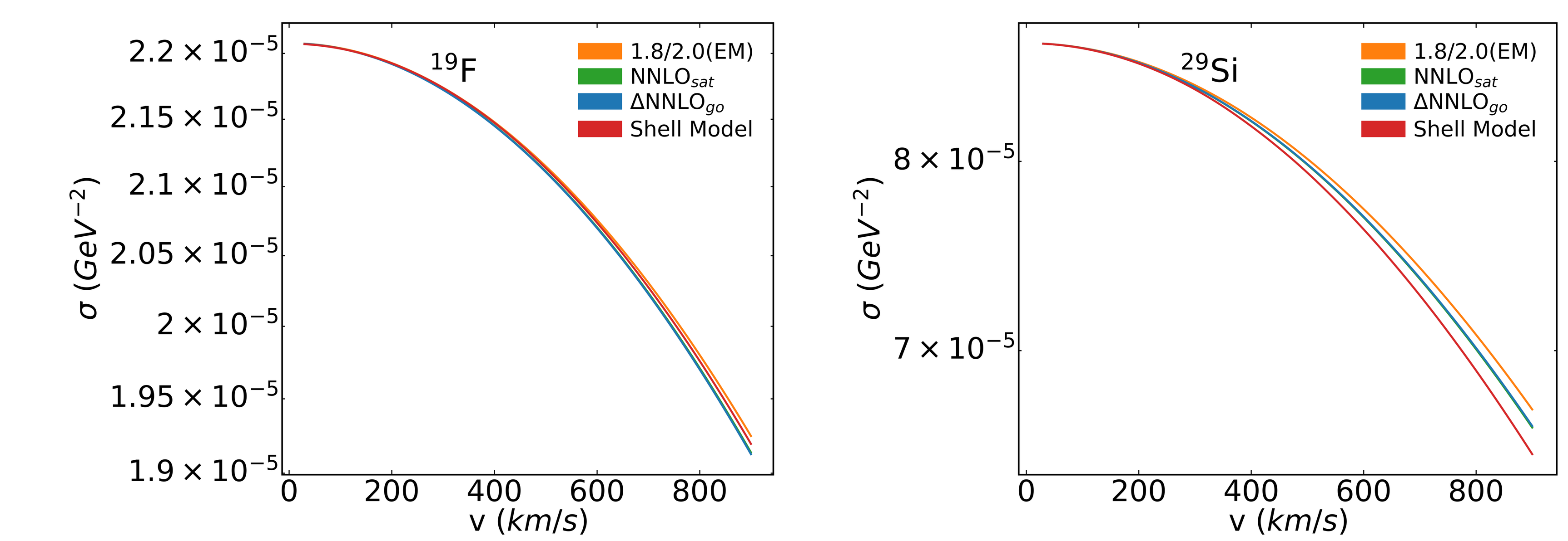
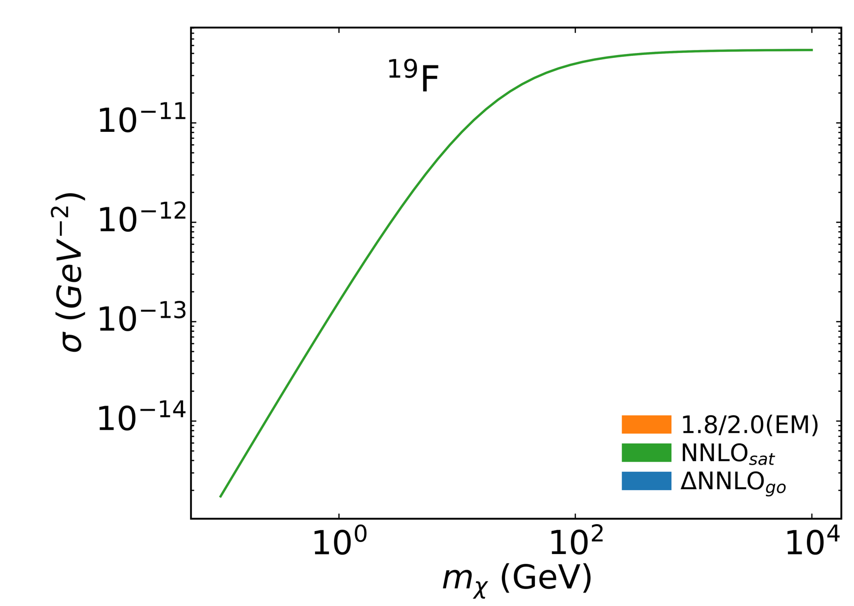


Figure 4. Total cross-sections of different targets, compared with phenomenological calculations (in red). For these targets, ab-initio and phenomenological calculations agree well.

As a Function of WIMP Mass



- We can also predict what the cross-section should be as a function of WIMP mass.
- This is more readily compared to exclusion plots presented by experiments.

Conclusion and next steps

- We are able to compute observables of WIMP-nucleus scattering using ab-initio methods, and results agree with the phenomenological approach.
- This will be extended for heavier elements, such as Xenon and Germanium.

Acknowledgements

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[1] Jochen Schieck, G Angloher, A Bento, C Bucci, L Canonica, X Defay, A Erb, N Ferreiro Iachellini, P Gorla, A Guetlein, et al. Direct dark matter search with the cresst ii experiment. *arXiv preprint arXiv:1611.02113*, 2016.

[2] S Ragnar Stroberg, Heiko Hergert, Scott K Bogner, and Jason D Holt. Nonempirical interactions for the nuclear shell model: an update. *Annual Review of Nuclear and Particle Science*, 69:307–362, 2019.