Bringing Light into the Darkness

First-principle Calculations of Dark Matter Scattering off Light Nuclei

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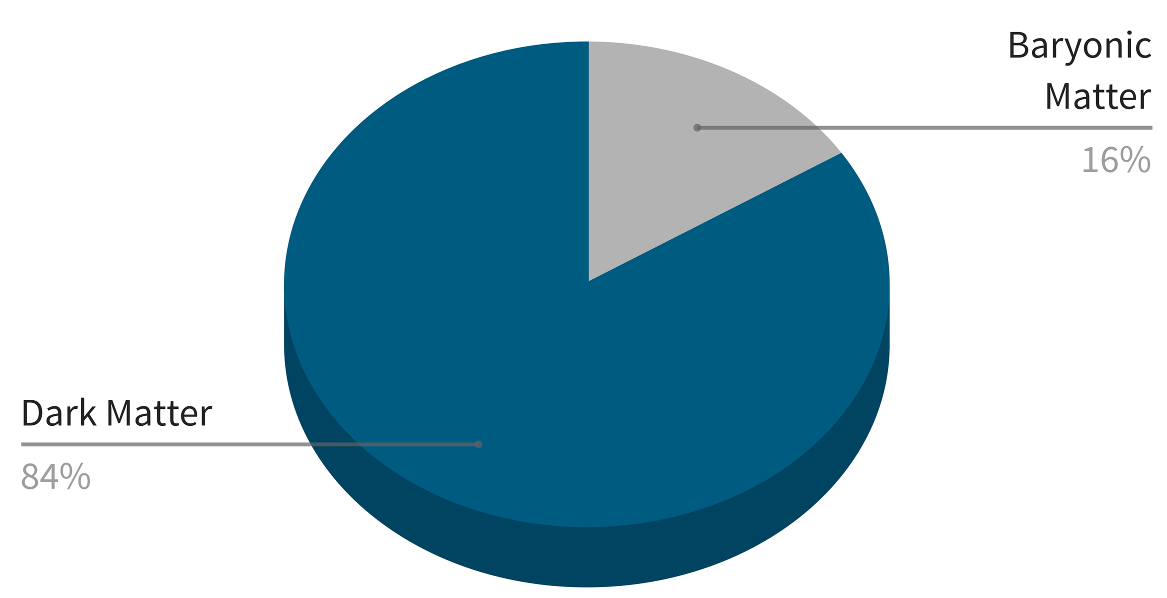
What do we know so far?

Whether we look at velocity distribution of galaxies, gravitational lensing effects or use cosmological models to explain observations made by the Hubble telescope, we find multiple independent pieces of evidence that something is missing: *we do not observe sufficient 'visible' mass in order to explain these macroscopic effects*.
This means either our understanding of gravity is fundamentally flawed, even in the classical regime where it should hold true, or there exists so-called **Dark Matter** (DM) which has to be described by theories **Beyond the Standard Model** (BSM) of particle physics.

Cosmological Matter Distribution



Experimental Searches

Direct Detection (low-energy)

- *LUX, PandaX, XENON, ⋯ (DM-Xenon scattering)*
- *(Proposed) NEWS, BNL (DM-H, He scattering)*

Indirect Detection (high-energy)

- *IceCube, ⋯ (DM annihilation)*

Collider Search (high-energy)

- *LHC, ⋯ (DM creation)*

The General Concept

→ Non-zero measurement in current experiments would confirm existence of DM candidate

→ Describe **complementary experiments** to **identify nature of DM**

→ Relate **recoil rates** of direct detection experiments to BSM theories

→ **Accurate and precise description** needed to **disentangle different BSM theories**

⇒ **Systematically describe DM-nucleus scattering** through **Effective Field Theories** (EFTs)

How to Compute 'Scattering'?

Direct detection experiments measure recoil rates which are defined as the convolution of nuclear **response functions** $\mathcal{F}_T$ and the DM velocity distribution f_χ

$$\frac{\mathrm{d}R_T}{\mathrm{d}q^2} \propto \frac{A_T^2}{m_T}\frac{\rho_\chi}{m_\chi}\int_{v_\chi^{(\mathrm{min})}}^{v_\chi^{(\mathrm{esc})}} \mathrm{d}^3\vec{v}_\chi \frac{1}{v_\chi} f_\chi(|\vec{v}_\chi|)\, |\mathcal{F}_T(\vec{q}(\vec{v}_\chi))|^2 \,,$$

with ρ_χ, m_χ, m_T and A_T the DM density distribution, DM mass, target mass and target atomic number. These response functions can be described as a matrix element of exchange momentum dependent DM currents $\hat{J}_\chi(\vec{q})$ between nuclear wave functions ψ_T

$$|\mathcal{F}_T(\vec{q})|^2 \propto \frac{1}{m_T^2 m_\chi^2 A_T^2}\left|\left\langle \psi_T \,\middle|\, \hat{J}_\chi(\vec{q}) \,\middle|\, \psi_T \right\rangle\right|^2 .$$

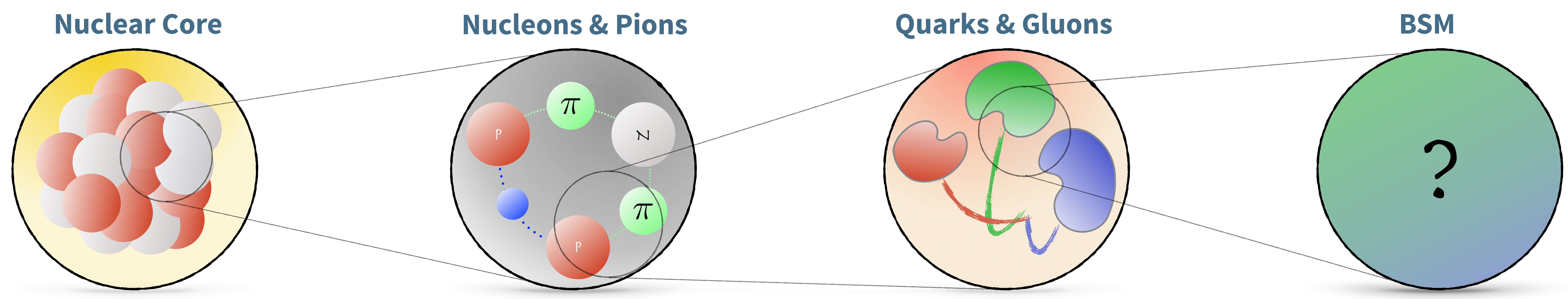
Quick summary of used methods

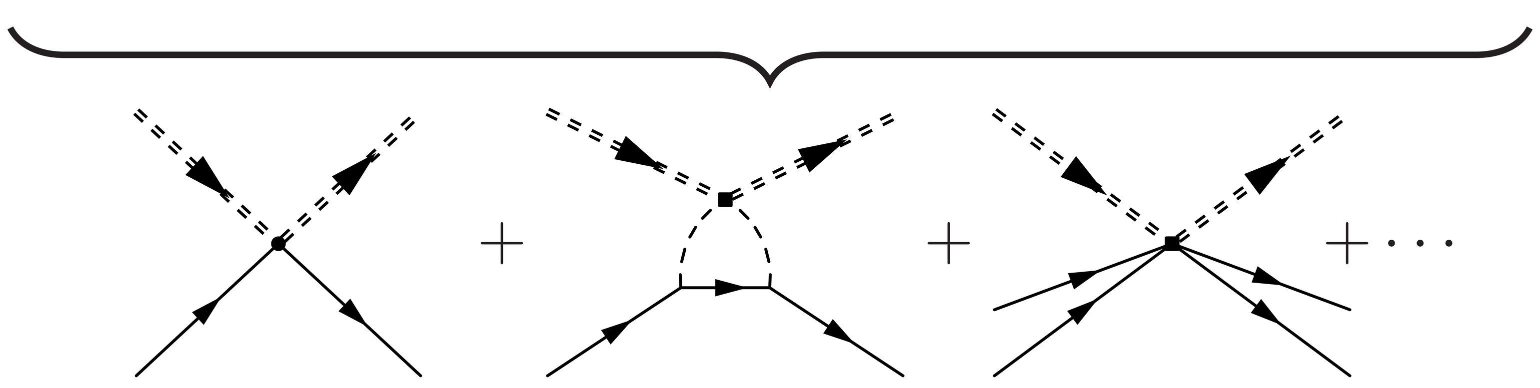
→ We describe the DM current operators as well as nuclear wave functions by **Chiral Perturbation Theory** (χPT)

→ Our solutions for light nuclei (^{2}H, ^{3}H and ^{3}He) are obtained by solving the Schrödinger and Faddeev equations

→ Our uncertainty estimates are based on chiral order-by-order comparisons of extracted matrix elements

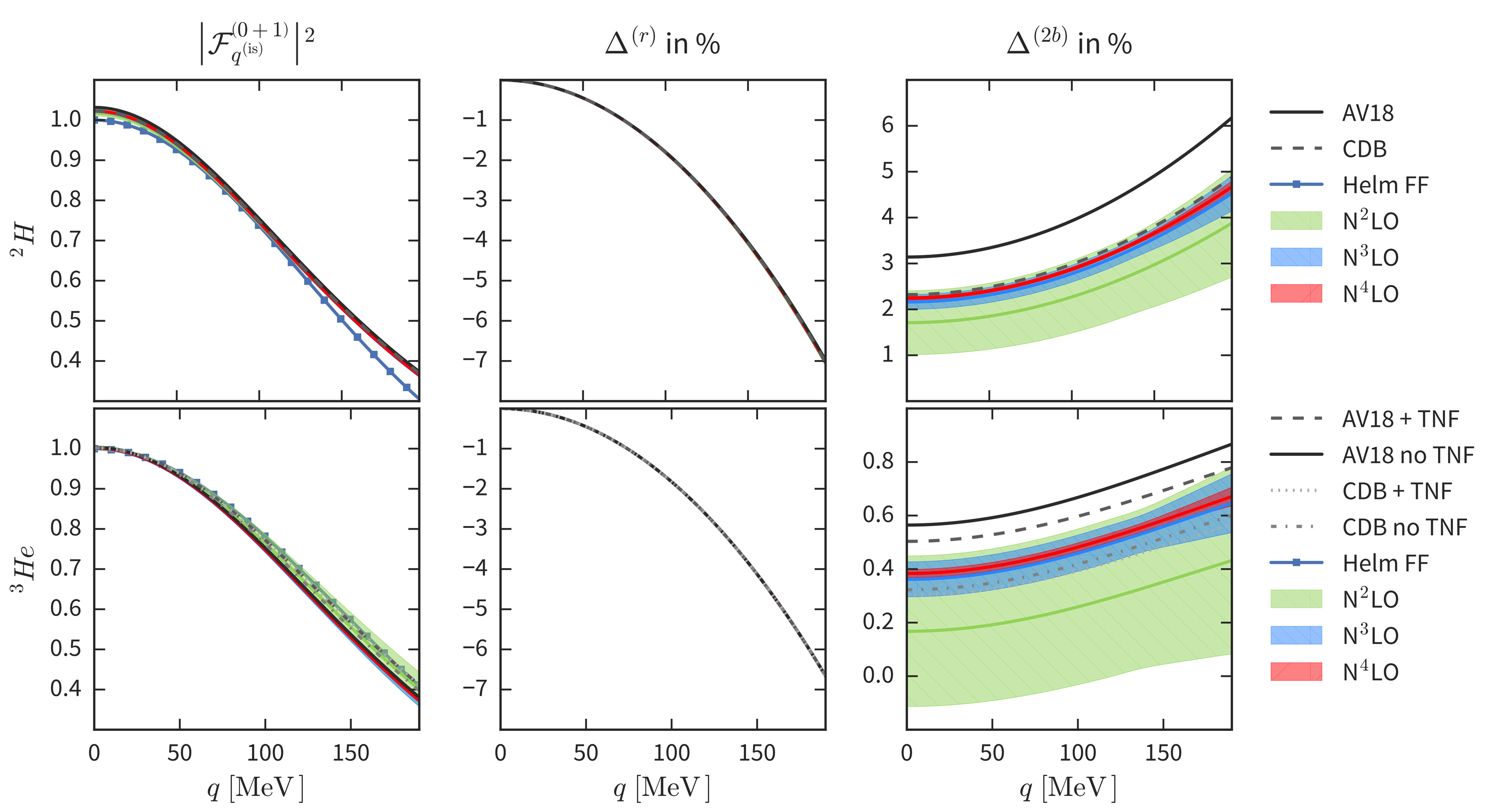
Bridging the Scales: From Experiment to BSM





$$\longleftrightarrow \quad \mathcal{L}_\chi = \bar\chi\chi\left(c_u\, m_u\, \bar u u + c_d\, m_d\, \bar d d + c_s\, m_s\, \bar s s + c_G\, \alpha_s G^a_{\mu\nu} G^{\mu\nu\, a}\right)$$

Our Results



We present response functions for DM scattering off ^{2}H and ^{3}He for different phenomenological and chiral wave functions. The uncertainty estimate is based on self-consistent convergence analysis (**not cutoff variation**).

→ $\mathcal{F}_{q^{(is)}}^{(0+1)}$ – Response function for isoscalar LO + NLO DM-nucleon interactions

→ $\Delta^{(r)}$ – NLO corrections by pion loop

→ $\Delta^{(2b)}$ – Two-nucleon NLO corrections

Get the Paper

If you are interested in this work or are curious about the references, feel free to follow the link (inSPIRE).