ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Impact of nuclear structure on nuclear responses to WIMP elastic scattering

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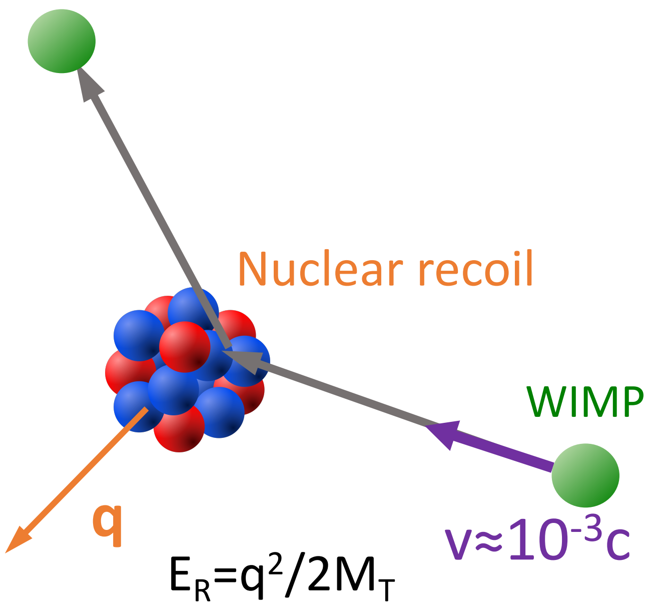
WIMP Direct Detection

Elastic scattering of a WIMP with a target nucleus



$$\frac{dR}{dE_R} \propto \int v\, d^3v \sum_{ij} \sum_{N,N'=p,n} f_v(\vec{v}) \; R(\vec{v},q)_{ij}^{(N,N')} \; F(q)_{ij}^{(N,N')}$$

Differential scattering (interaction) rate

DM Velocity Distribution

Particle Physics

Nuclear Structure

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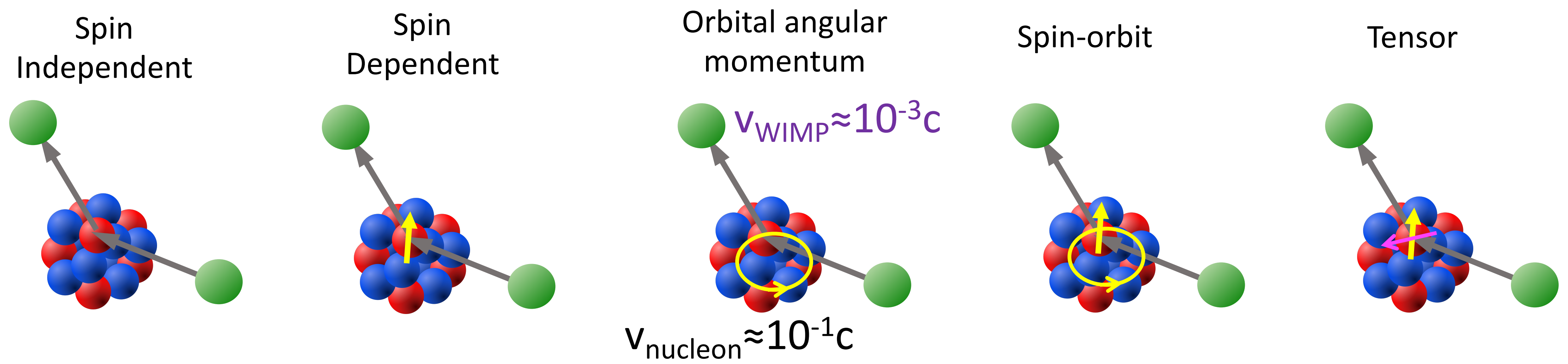
Nuclear response functions

Interaction channels

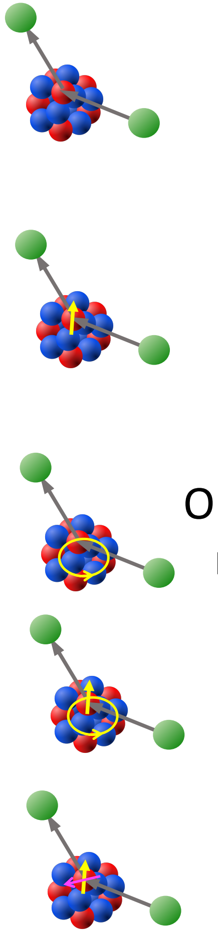


Fitzpatrick et al, JCAP **004**, 1302 (2013)

NREFT

Response $\times \left[\frac{4\pi}{2J_i+1}\right]^{-1}$	Leading Multipole	Long-wavelength Limit	Response Type
$\sum_{J=0,2,\ldots}^{\infty} \vert\langle J_i \vert\vert M_{JM} \vert\vert J_i\rangle\vert^2$	$M_{00}(q\vec{x}_i)$	$\frac{1}{\sqrt{4\pi}} 1(i)$	M_{JM} : Charge
$\sum_{J=1,3,\ldots}^{\infty} \vert\langle J_i \vert\vert \Sigma''_{JM} \vert\vert J_i\rangle\vert^2$	$\Sigma''_{1M}(q\vec{x}_i)$	$\frac{1}{2\sqrt{3\pi}} \sigma_{1M}(i)$	L^5_{JM} : Axial Longitudinal
$\sum_{J=1,3,\ldots}^{\infty} \vert\langle J_i \vert\vert \Sigma'_{JM} \vert\vert J_i\rangle\vert^2$	$\Sigma'_{1M}(q\vec{x}_i)$	$\frac{1}{\sqrt{6\pi}} \sigma_{1M}(i)$	T^{el5}_{JM} : Axial Transverse Electric
$\sum_{J=1,3,\ldots}^{\infty} \vert\langle J_i \vert\vert \frac{q}{m_N}\Delta_{JM} \vert\vert J_i\rangle\vert^2$	$\frac{q}{m_N}\Delta_{1M}(q\vec{x}_i)$	$-\frac{q}{2m_N\sqrt{6\pi}} \ell_{1M}(i)$	T^{mag}_{JM} : Transverse Magnetic
$\sum_{J=0,2,\ldots}^{\infty} \vert\langle J_i \vert\vert \frac{q}{m_N}\Phi''_{JM} \vert\vert J_i\rangle\vert^2$	$\frac{q}{m_N}\Phi''_{00}(q\vec{x}_i)$	$-\frac{q}{3m_N\sqrt{4\pi}} \vec{\sigma}(i)\cdot\vec{\ell}(i)$	L_{JM} : Longitudinal
	$\frac{q}{m_N}\Phi''_{2M}(q\vec{x}_i)$	$-\frac{q}{m_N\sqrt{30\pi}} [x_i \otimes (\vec{\sigma}(i)\times\frac{1}{i}\vec{\nabla})_1]_{2M}$	
$\sum_{J=2,4,\ldots}^{\infty} \vert\langle J_i \vert\vert \frac{q}{m_N}\tilde{\Phi}'_{JM} \vert\vert J_i\rangle\vert^2$	$\frac{q}{m_N}\tilde{\Phi}'_{2M}(q\vec{x}_i)$	$-\frac{q}{m_N\sqrt{20\pi}} [x_i \otimes (\vec{\sigma}(i)\times\frac{1}{i}\vec{\nabla})_1]_{2M}$	T^{el}_{JM} : Transverse Electric

Nuclear ground-state



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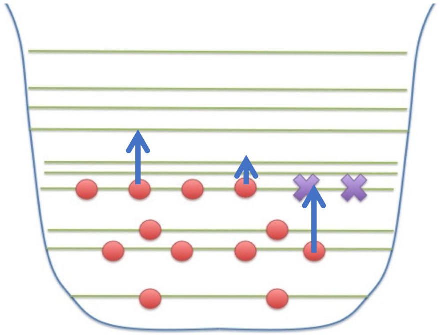
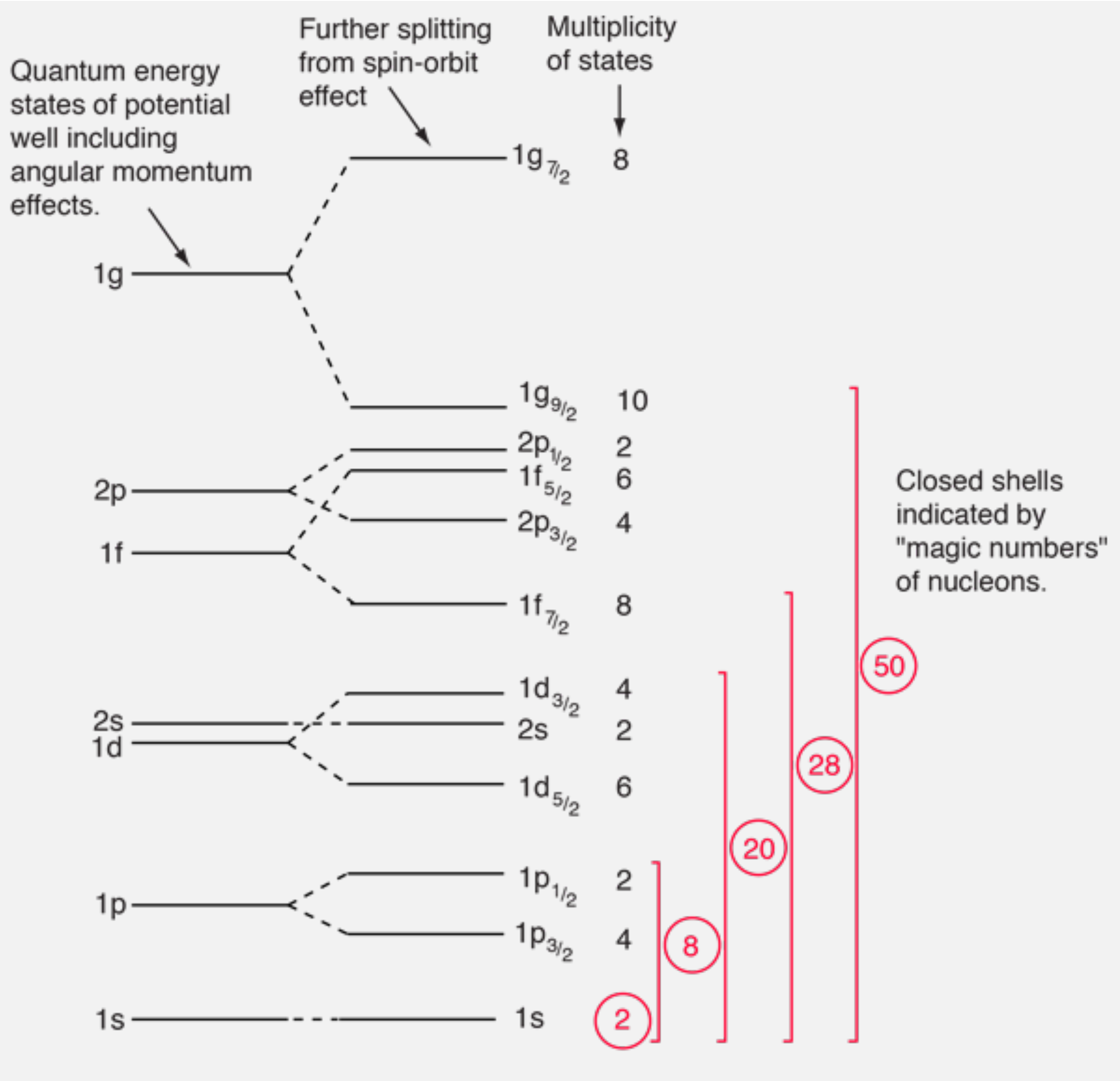
Nuclear Shell-Model

Configuration interaction

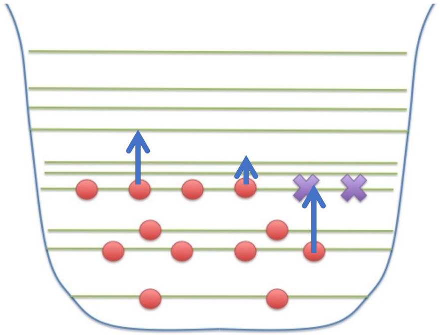
$|g.s.\rangle = \sum_{\alpha} C_{\alpha}$ |  ⟩



Nuclear Shell-Model

Configuration interaction

$$|g.s.\rangle = \sum_\alpha C_\alpha \Big|$$

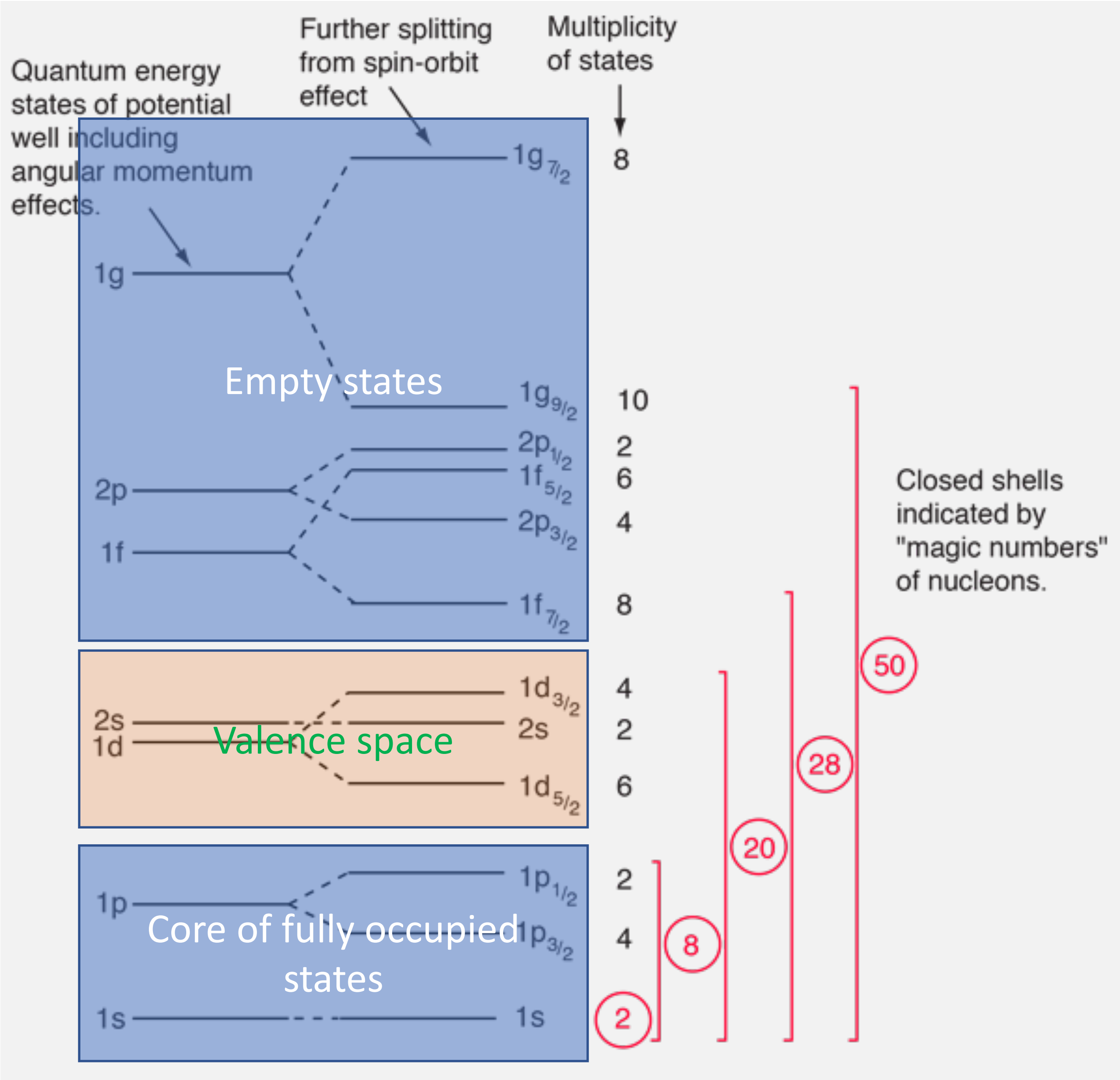


$\Big\rangle$

Uncertainties due to

- Valence space
- Nuclear Hamiltonian

How do they affect nuclear response functions for WIMP Direct Detection?



NREFT

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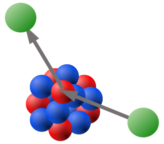
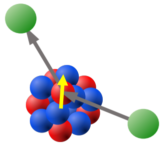
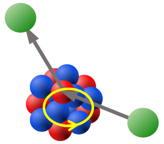
Nuclear ground-state



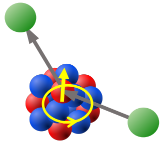
Spin Independent



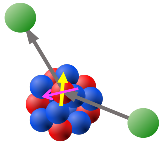
Spin Dependent



Orbital angular momentum



Spin-orbit



Tensor

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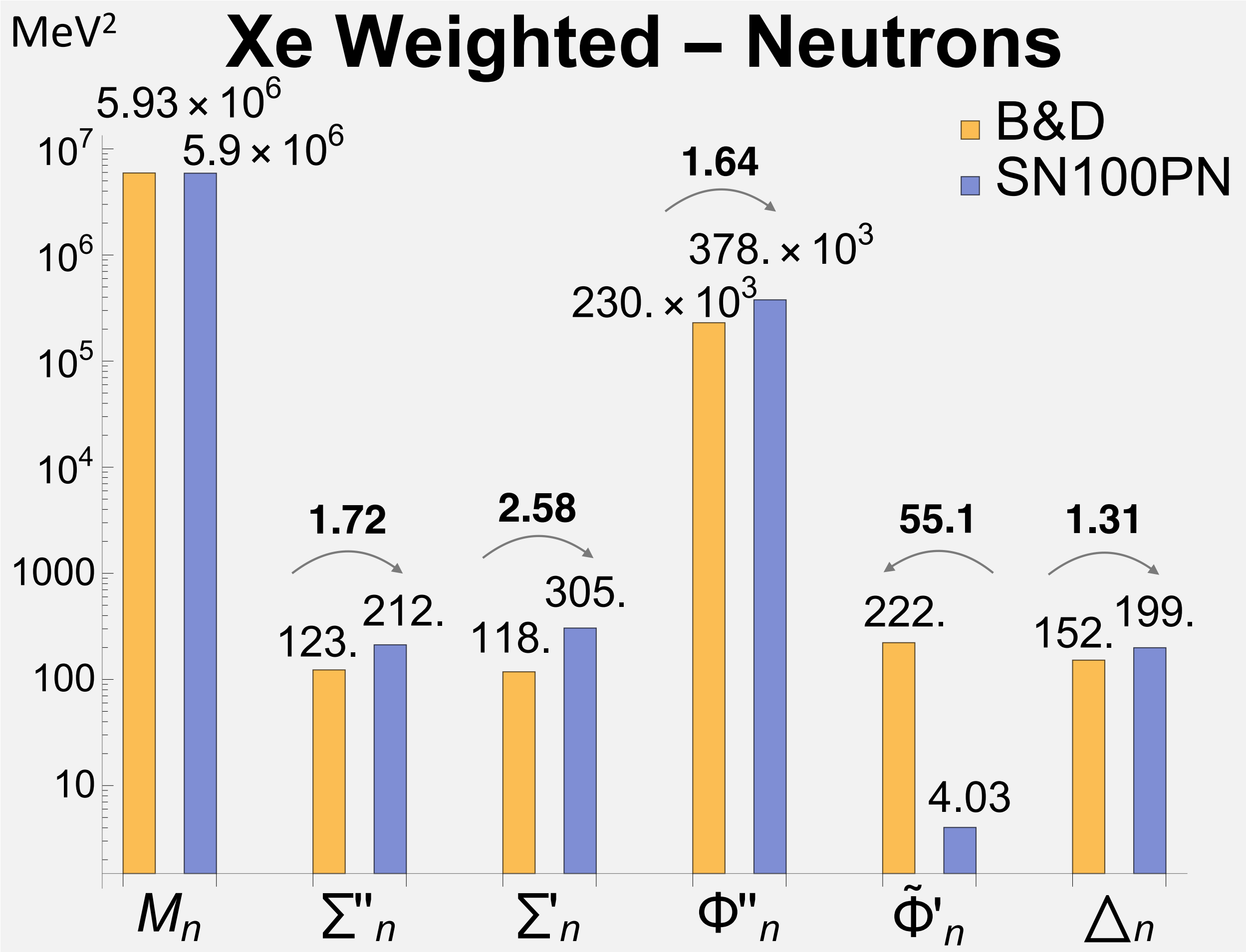
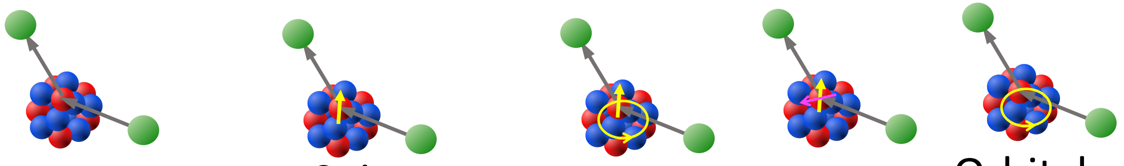
Nuclear response functions





$$\int_0^{100\ MeV} \frac{q\,dq}{2} \frac{4\pi}{2J_i+1} \sum_{J=0}^{2J_i+1} |\langle J_i || X_{J,N} || J_i \rangle|^2$$

$$X \equiv M, \Sigma', \Sigma'', \phi'', \tilde{\phi}', \Delta \qquad N \equiv p, n$$

$^{128,129,130,131,132,134,136}Xe$

Weighted by isotopic abundance

Conclusions and future work

- Role of ground-state nuclear structure in WIMP-nucleus interaction with Shell-Model (configuration interaction)
- Orbital angular momentum and spin-orbit contributions (in addition to SI and SD)
- Uncertainty in sub-dominant channels due to nuclear Hamiltonian
- Effect on 2-body currents (Sam Thompson)
- Rate calculations for BSM models (Nav Krishnan, Raghda A. Khaleq)
- (Beyond) Mean-Field description instead of Shell Model (Raghda A. Khaleq)


R.A. Khaleq


S. Thompson


N. Krishnan


A. Stuchbery


G. Busoni

Nuclear response functions

$$\int_0^{100\ MeV} \frac{q\,dq}{2} \frac{4\pi}{2J_i+1} \sum_{J=0}^{2J_i+1} |\langle J_i || X_{J,N} || J_i\rangle|^2$$

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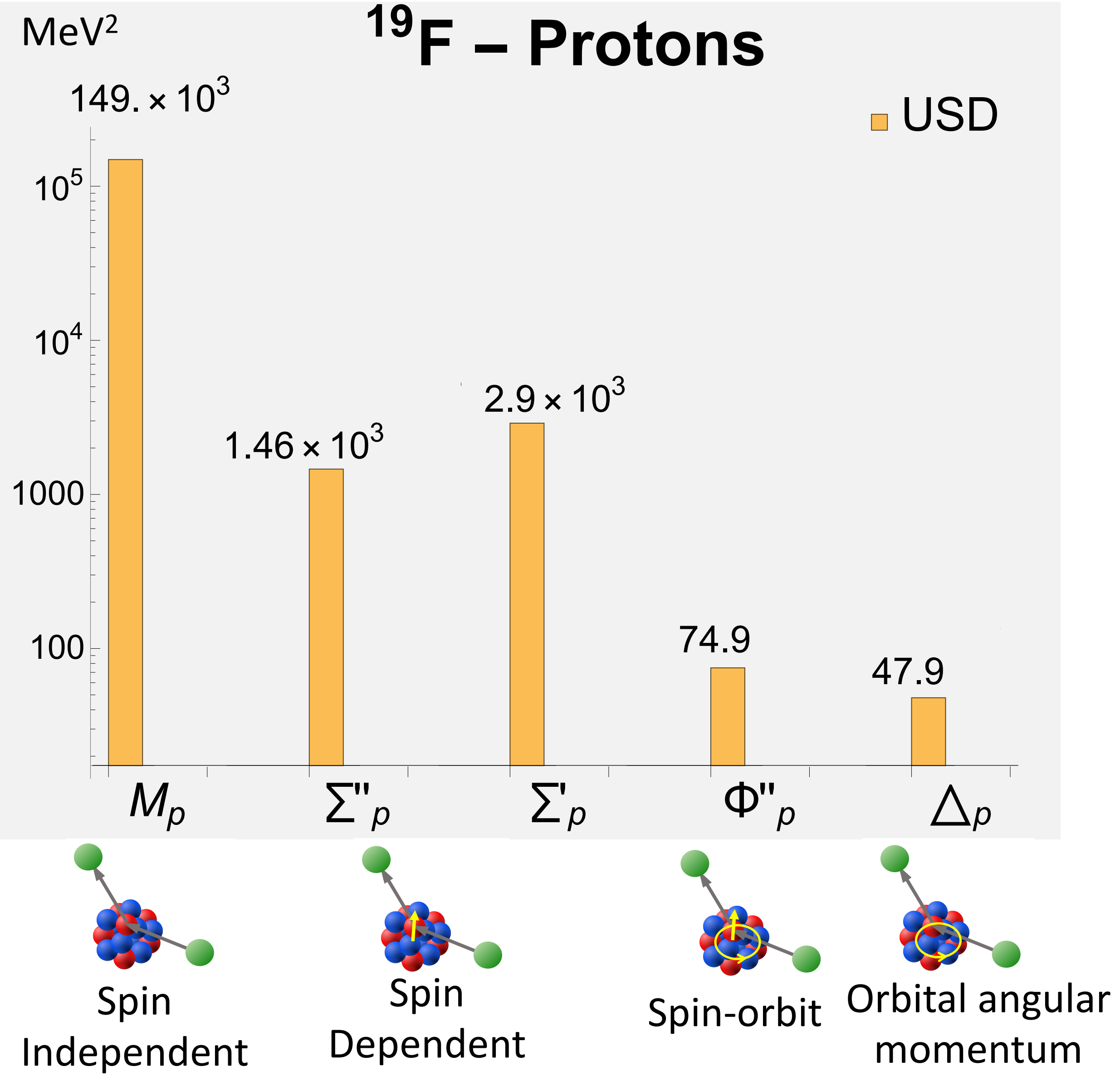

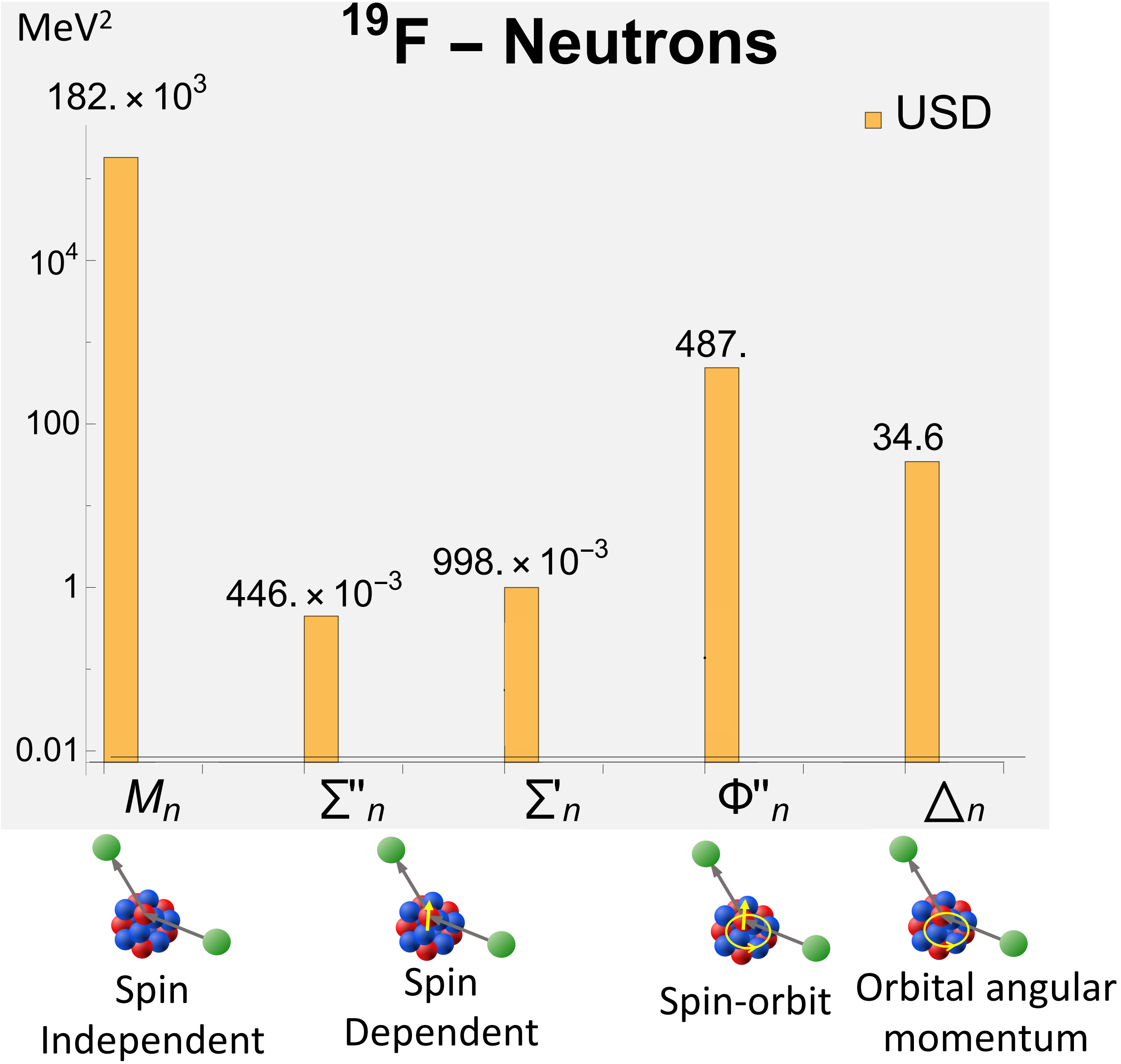

Nuclear response functions

$$\int_0^{100\ MeV} \frac{q\,dq}{2} \frac{4\pi}{2J_i+1} \sum_{J=0}^{2J_i+1} |\langle J_i||X_{J,N}||J_i\rangle|^2$$

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