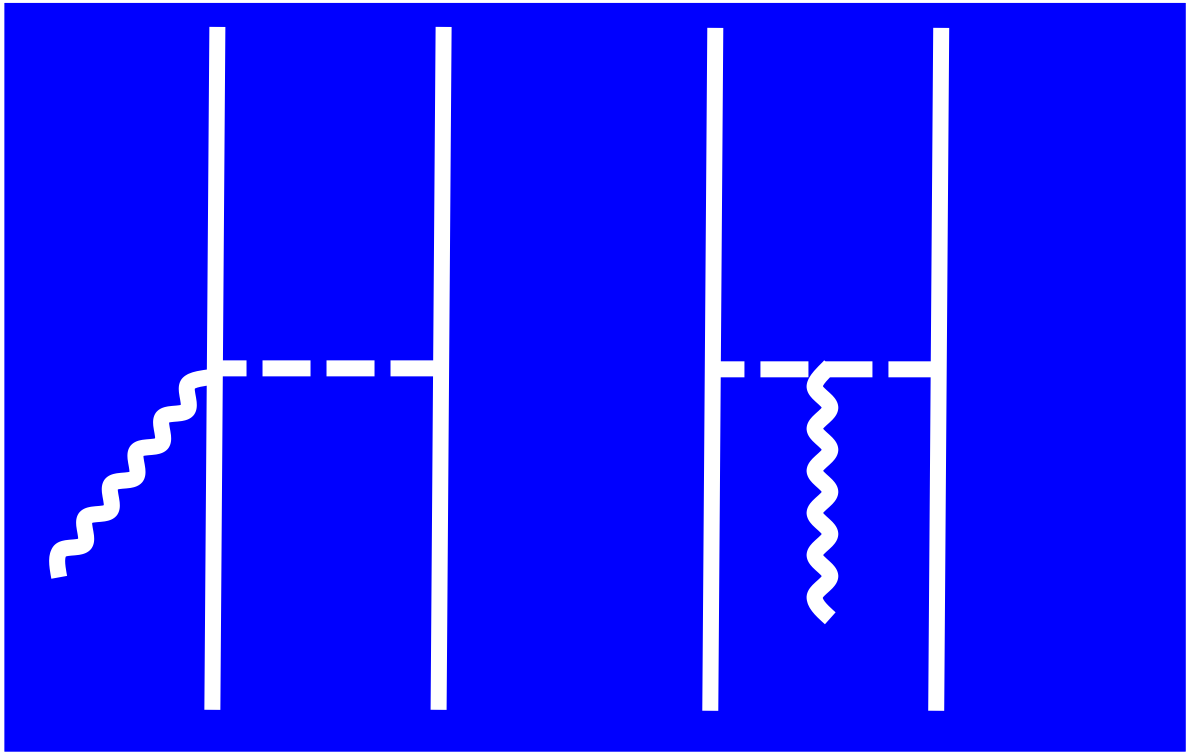
Two-Body Currents in Nuclei: Multipole Decomposition



Oscar Javier Hernandez

And with:
Sonia Bacca

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Two-body currents arise from the requirement of current conservation

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$$\Rightarrow \quad J(x) = J_{[1]}(x) + J_{[2]}(x) + \cdots$$

Two-body currents can be ordered via Chiral EFT expansion,

$$J_{[2]}(x) = J_{NLO}(x) + J_{\mathrm{N^2LO}}(x) + J_{\mathrm{N^3LO}}(x)$$

Two-body currents improve the accuracy of calculations in different fields

Nuclear Physics

Precision Atomic Physics

Astrophysics

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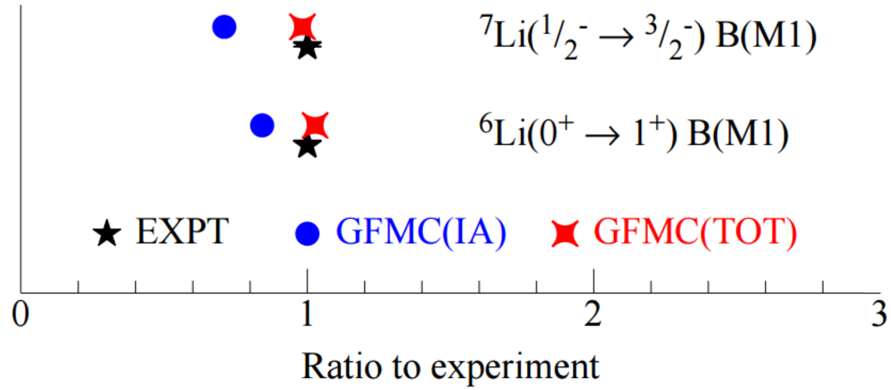
Magnetic moments of light nuclei



S. Pastore, S.C. Pieper, R. Schiavilla, R. Wiringa, Phys. Rev. C87, 035503 (2013)

Two-body currents improve the accuracy of calculations in different fields

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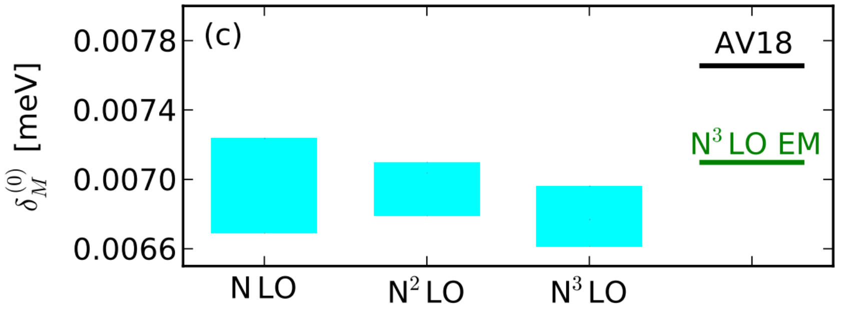
Bands increase from $\mathrm{N^2LO}$ to $\mathrm{N^3LO}$ due to missing MEC



O. J. Hernandez, C. Ji, S. Bacca, N. N. Dinur, and N. Barnea, Phys. Lett. B., vol. 736, pp. 344-349, 2014.

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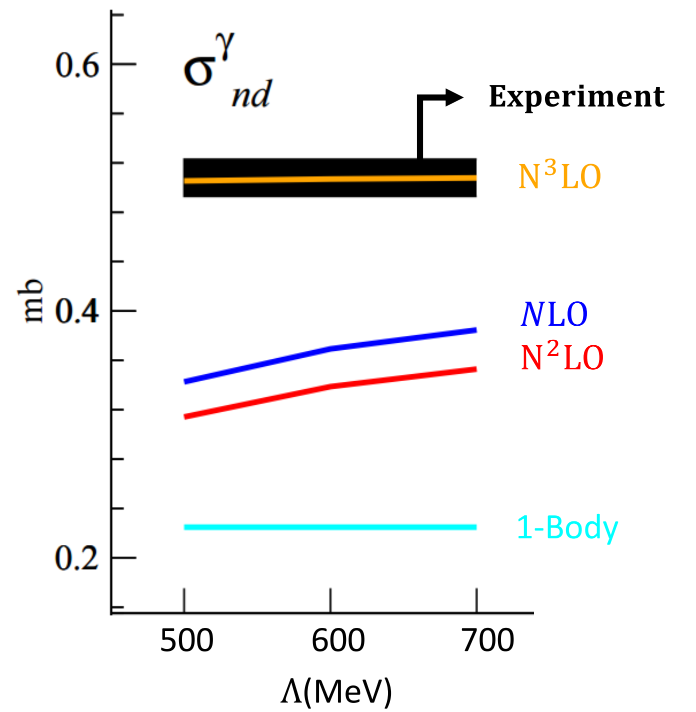
$\mathrm{np} \rightarrow d\gamma$ radiative capture process



Adapted from L. Girlanda, *et al.* EPJ Web of Conferences 3, 01004 (2010)

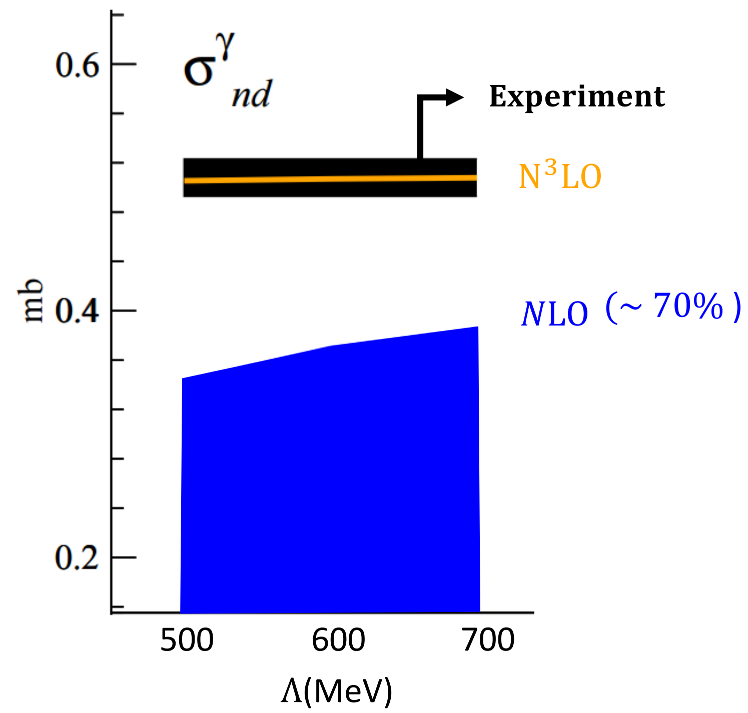
Motivation

Nuclear Physics

Precision Atomic Physics

Astrophysics

np → $d\gamma$ radiative capture process



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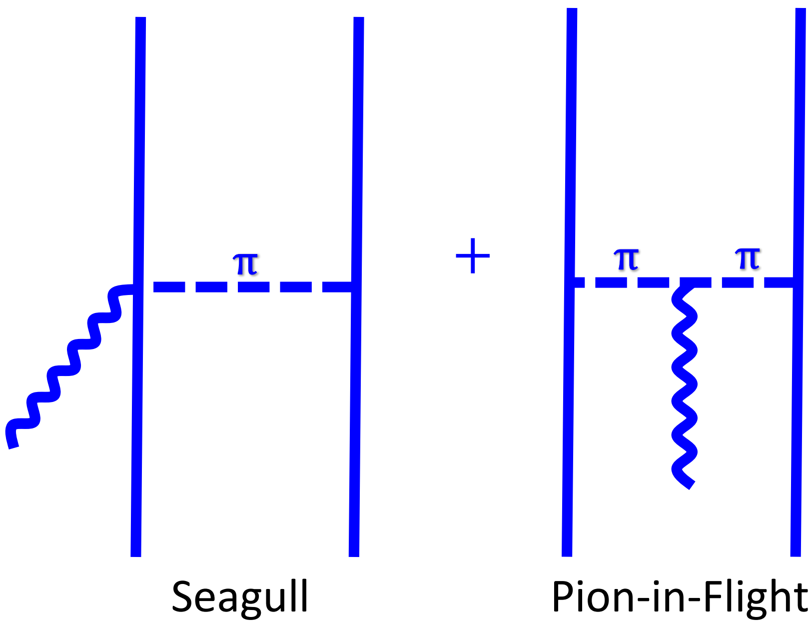
We have calculated the multipole decomposition of the current



$\boldsymbol{q} \rightarrow$ Photon momentum

$\boldsymbol{r} = \boldsymbol{r_1} - \boldsymbol{r_2}$ $\boldsymbol{R} = \frac{\mathbf{1}}{\mathbf{2}}(\boldsymbol{r_1} + \boldsymbol{r_2})$

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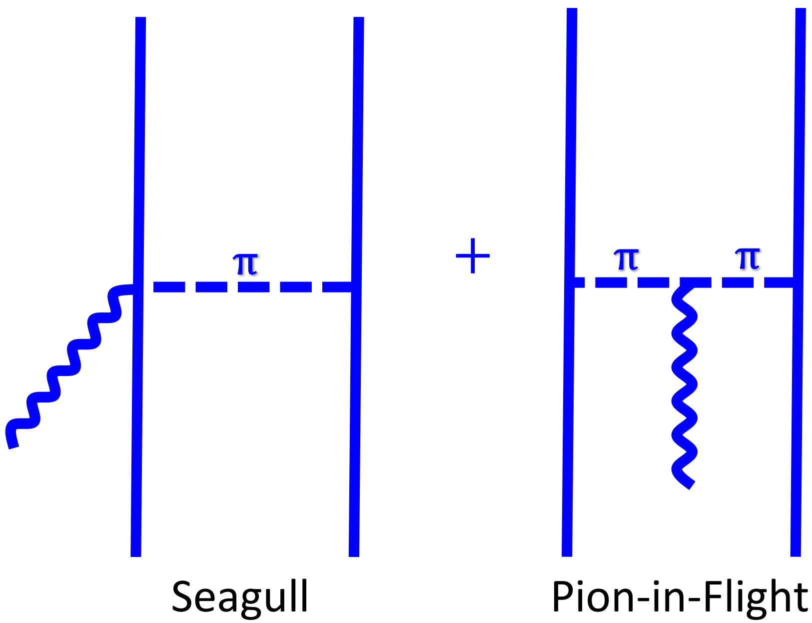

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$$\boldsymbol{J}(\boldsymbol{q},\boldsymbol{r},\boldsymbol{R}) = -\frac{ieg_A^2}{F_\pi^2} G_E^V(q^2)(\tau_1 \times \tau_2)_z[\boldsymbol{A}_{Seagull}(\boldsymbol{q},\boldsymbol{r},\boldsymbol{R}) + \boldsymbol{A}_\pi(\boldsymbol{q},\boldsymbol{r},\boldsymbol{R})]$$

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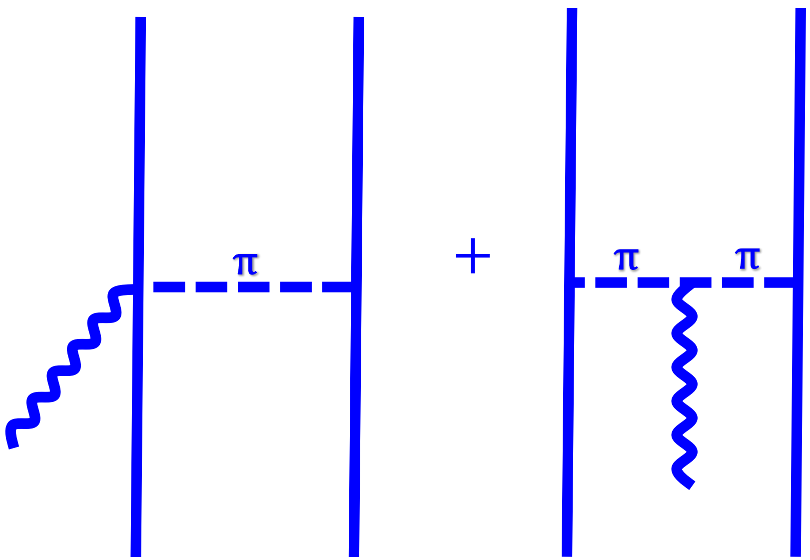

Seagull Pion-in-Flight

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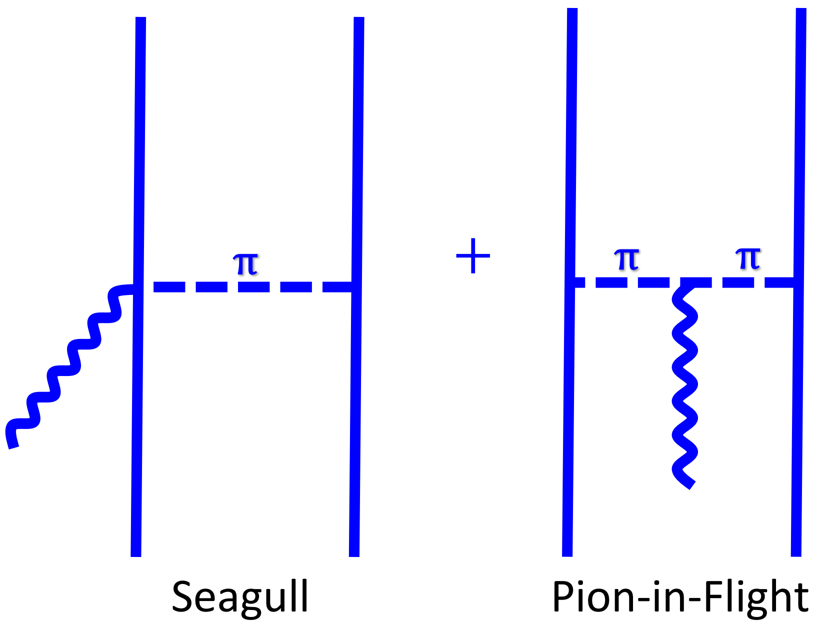
$$\boldsymbol{J}(\boldsymbol{q},\boldsymbol{r},\boldsymbol{R}) = \sum_{J\mu\ell} J_{J\ell}^{\mu}(q,\boldsymbol{r},\boldsymbol{R})\boldsymbol{Y}_{J\ell}^{\mu *}(\hat{q}) \qquad J_{J\ell}^{\mu}(q,\boldsymbol{r},\boldsymbol{R}) = \int d\hat{q}\, \boldsymbol{J}(\boldsymbol{q},\boldsymbol{r},\boldsymbol{R}) \cdot \boldsymbol{Y}_{J\ell}^{\mu}(\hat{q})$$

We have extracted the NLO M1 operator



$$J_{JJ}^{\mu}(q,\boldsymbol{r},\boldsymbol{R}) = 4\pi i^{J} T_{J\mu}^{mag}(q,\boldsymbol{r},\boldsymbol{R})$$

$$\mu_{NLO}^{[2]}(\boldsymbol{r},\boldsymbol{R}) \propto \lim_{q\to 0}\left(\frac{J_{11}^{\mu}(q,\boldsymbol{r},\boldsymbol{R})}{q}\right)$$

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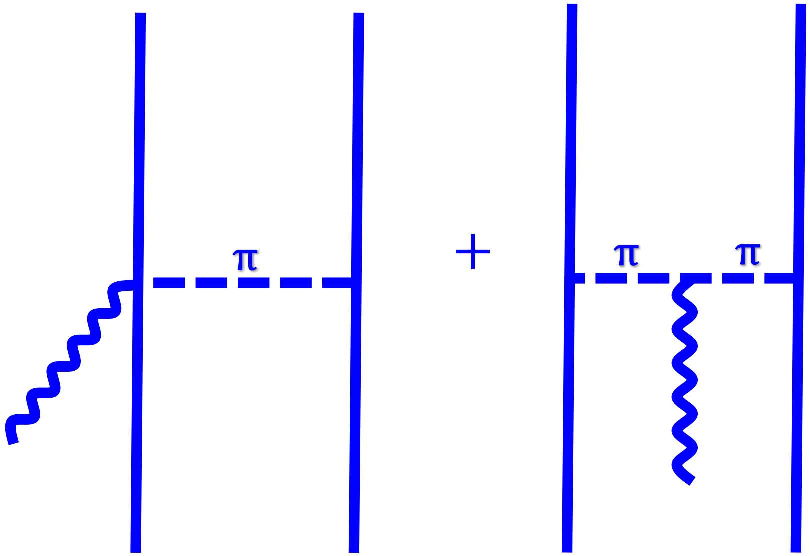

Seagull Pion-in-Flight

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In the case of the deuteron, with no CM-dependence,

$$\boldsymbol{\mu} = \boldsymbol{\mu}^{[1]} + \boldsymbol{\mu}_{NLO}^{[2]}$$

$$\boldsymbol{\mu}_{NLO}^{[2]}(\boldsymbol{r}) = -\frac{e g_A^2 m_\pi}{8\pi F_\pi^2}(\tau_1 \times \tau_2)_z\left[\left(1+\frac{1}{m_\pi r}\right)\left((\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2)\cdot\hat{r}\right)\hat{r} - (\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2)\right] e^{-m_\pi r}$$

We calculate the effect of the NLO currents on M1-isovector observables for the deuteron:

$$\chi_M = \frac{1}{2\pi^2}\int \frac{\sigma_M(\omega)}{\omega^2}\, d\omega$$

$$\sigma_M(\omega) = \frac{4\pi^2\alpha}{3}\,\omega\, R_M(\omega)$$

$$R_M(\omega) = \frac{1}{2J_0+1}\sum_N |\langle N|\mu|N_0\rangle|^2 \delta(E_N - E_0 - \omega)$$

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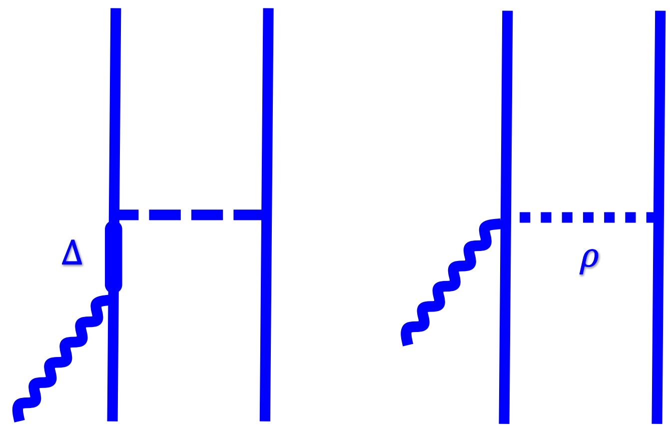


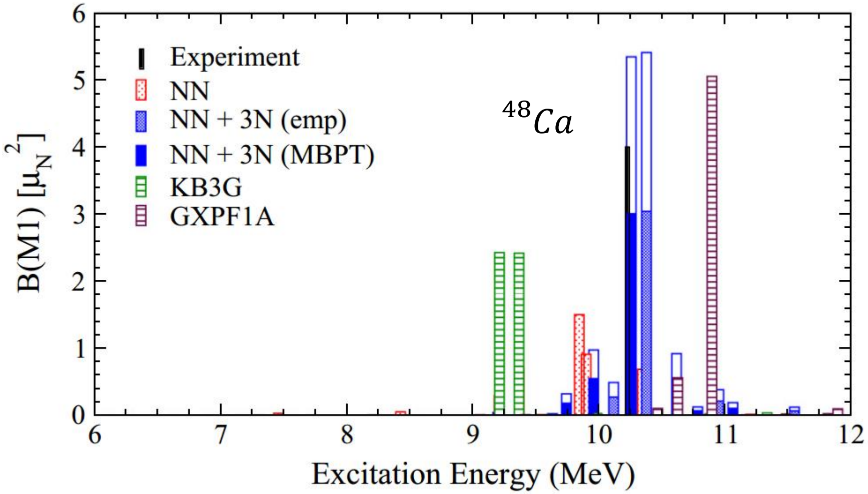
	Potential	χ_M (1-Body) [fm^3]	Current	χ_M (+ 2–Body) [fm^3]	% Difference
Arenhövel [1]	Bonn	0.0620	NLO+ρ	0.0681	10%
Our Work	N3LO	0.0684	NLO	0.0758	11%
Our Work	AV18	0.0679	NLO	0.0753	11%
Friar [2]	AV18	0.0678	NLO+Δ	0.0774	14%

* Calculations carried out in harmonic oscillator basis

In the future, we will apply these currents to other nuclei

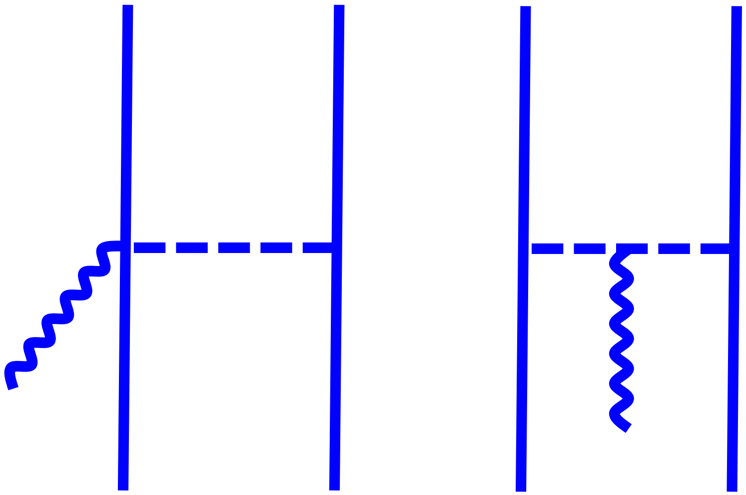
- Nuclear structure corrections to muonic atoms and HF splitting

- Exploration of the M1 transition strengths in medium mass nuclei



J.D Holt *et. al.* Phys. Rev. C 90, 024312 (2014)

Thank you!



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Nir Barnea

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[1] H. Arenhovel and M. Sanzone, Few Bod. Sys., Photodisintegration of the Deuteron, (1991).
[2] J. Friar and G.L. Payne, Phys. Rev. C 56 619 (1997)