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LATTICE21

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Towards robust constraints on nuclear effective field theory from lattice QCD

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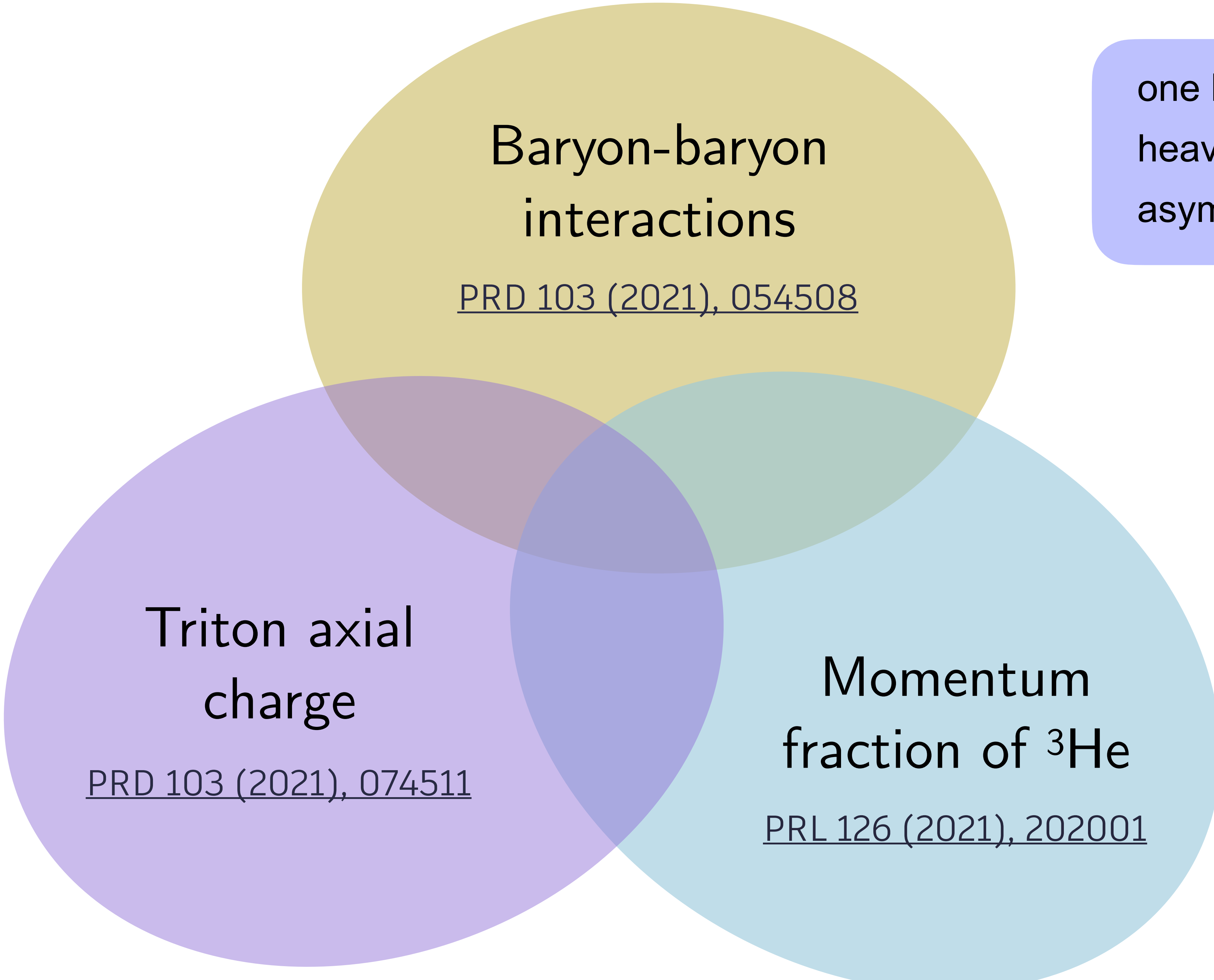
NPLQCD

Silas R. Beane, Emmanuel Chang, Zohreh Davoudi, William Detmold, David J. Murphy, Patrick Oare, Kostas Orginos, Assumpta Parreño, Martin J. Savage, Phiala E. Shanahan, Michael L. Wagman, Frank Winter

Matching lattice QCD to EFT



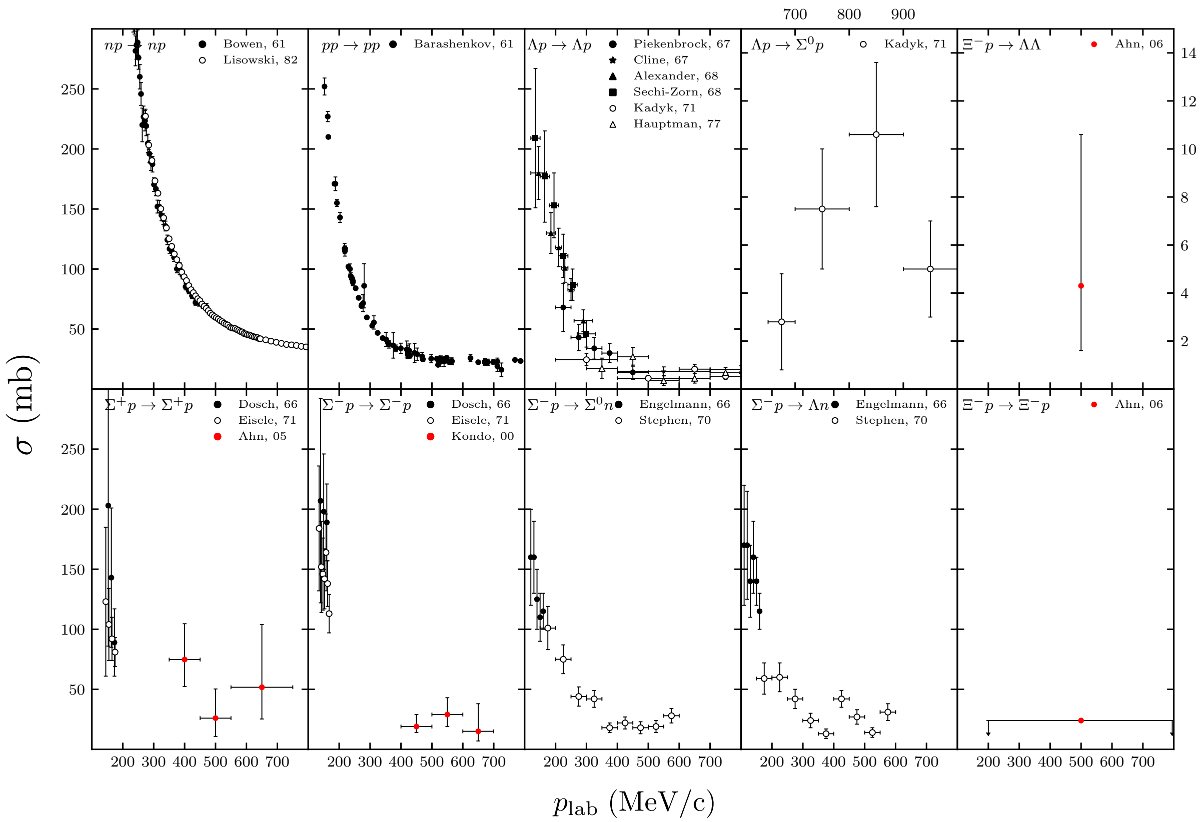
- one lattice spacing
- heavier-than-physical quark masses
- asymmetric correlation functions

see Michael Wagman talk in 45 min

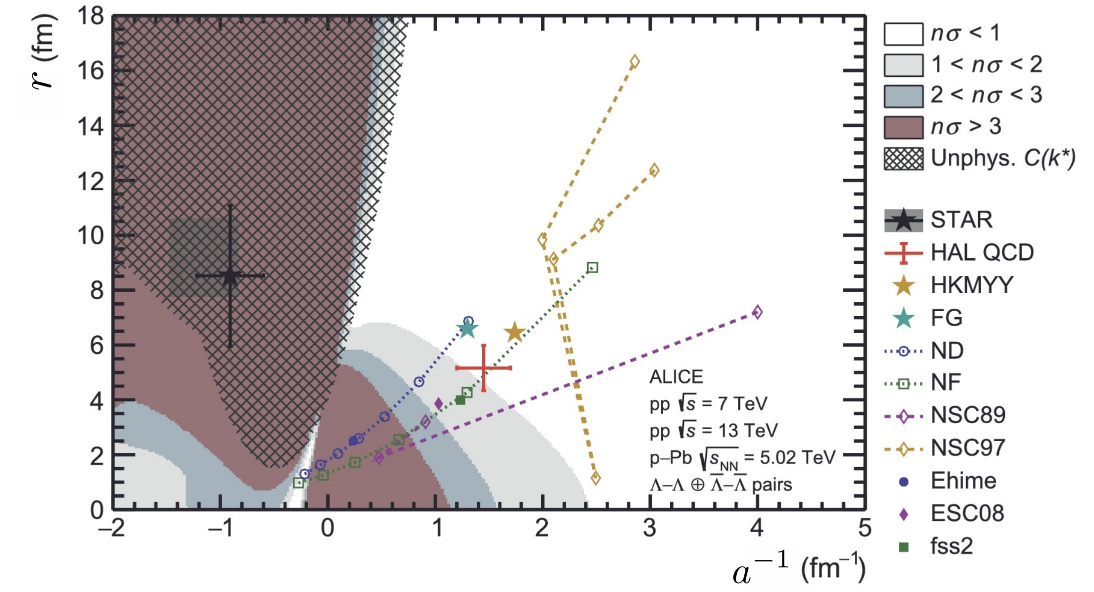
See review: Davoudi et al, Phys. Rept. 900 (2021), 1

Baryon-baryon interactions

Illa et al. [NPLQCD], PRD 103 (2021), 054508



updated from Dover and Feshbach, Ann. Phys. 198 (1990)



ALICE Collaboration, PLB 797 (2019)

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{8}_s \oplus \mathbf{1} \oplus \overline{\mathbf{10}} \oplus \mathbf{10} \oplus \mathbf{8}_a$$

Wagman et al. [NPLQCD], PRD 96 (2017)

$$m_u = m_d = m_s$$

$$m_\pi = m_K \sim 806 \text{ MeV}$$

$\mathbf{27}$ $\overline{\mathbf{10}}$ $\mathbf{10}$ $\mathbf{8}_a$

Illa et al. [NPLQCD], PRD 103 (2021)

$$m_u = m_d \neq m_s$$

$$m_\pi \sim 450 \text{ MeV}, \; m_K \sim 600 \text{ MeV}$$

$NN, \Sigma N, \Sigma\Sigma, \Xi\Sigma, \Xi\Xi$

NN $\Sigma N, \Xi\Xi$ ΞN

Baryon-baryon interactions

Illa et al. [NPLQCD], PRD 103 (2021), 054508

$\mathcal{L}_{BB}^{(\not\pi)}$

$\xrightarrow[\text{LO}]{SU(3)}$ $c_1, \ldots, c_6 \quad (c^{(27)}, \ldots, c^{(8_a)})$

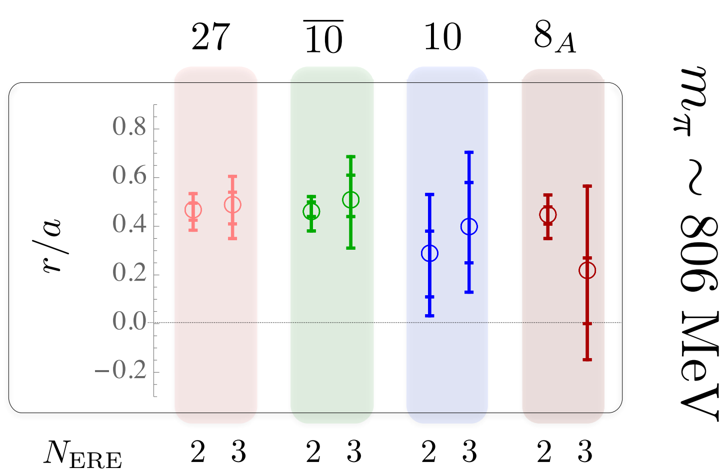
Savage and Wise, PRD 53 (1996)

$\xrightarrow{\text{NLO}}$ $\tilde{c}_1, \ldots, \tilde{c}_6 \quad (\tilde{c}^{(27)}, \ldots, \tilde{c}^{(8_a)}) + c_1^\chi, \ldots, c_{12}^\chi \quad \cancel{SU(3)}$

Petschauer and Kaiser, NPA 916 (2013)

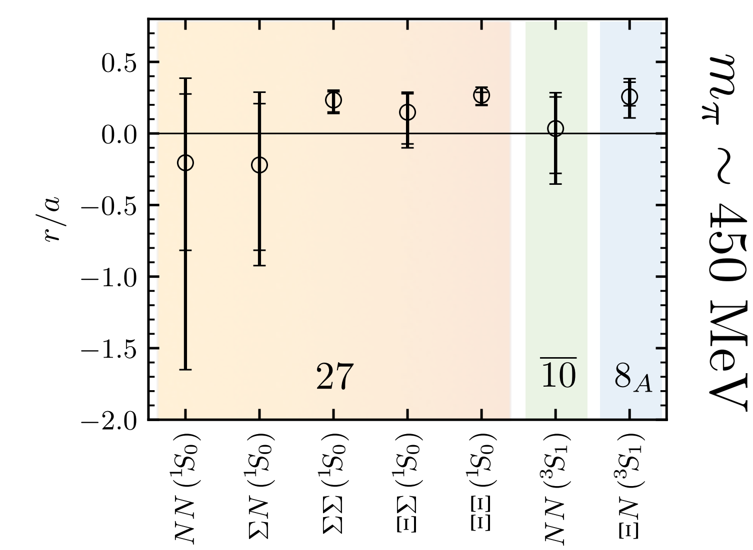
$\xrightarrow[\text{large } N_c]{SU(6)}$ a, b

Kaplan and Savage, PLB 365 (1996)



$c^\chi_{B_1B_2}(m_K^2 - m_\pi^2)$

$$\left[-\frac{1}{a_{B_1B_2}} + \mu\right]^{-1} = \frac{\overline{M}_{B_1B_2}}{2\pi}\left(c^{(\text{irrep})} + \boldsymbol{c}^\chi_{B_1B_2}\right)$$



Kaplan, Savage and Wise, PLB 424 (1998) NPB 534 (1998)

van Kolck, NPA 645 (1999)

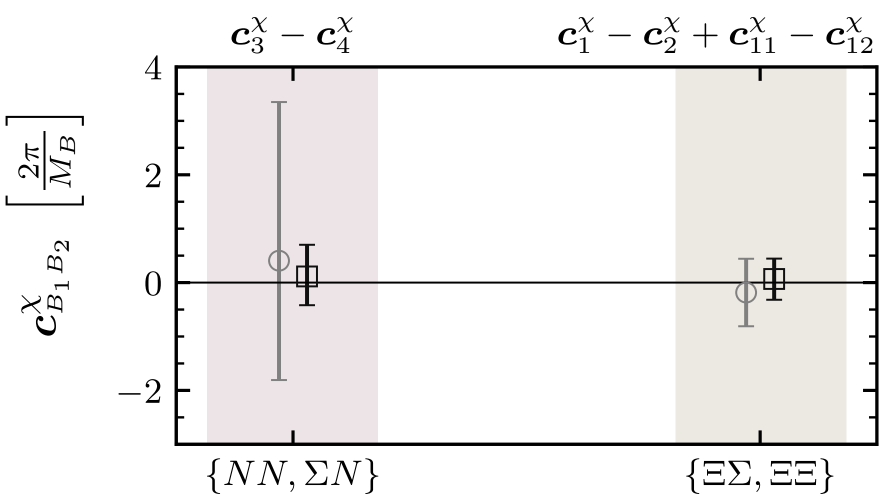
Baryon-baryon interactions

Illa et al. [NPLQCD], PRD 103 (2021), 054508

~~$SU(3)$~~ coefficients

$$\left\{ \begin{array}{l} NN : c^{(27)} + 4(\boldsymbol{c}_3^\chi - \boldsymbol{c}_4^\chi) \\ \Sigma N : c^{(27)} + 2(\boldsymbol{c}_3^\chi - \boldsymbol{c}_4^\chi) \end{array} \right\}$$

$$\left\{ \begin{array}{l} \Xi\Sigma : c^{(27)} + 2(\boldsymbol{c}_1^\chi - \boldsymbol{c}_2^\chi + \boldsymbol{c}_{11}^\chi - \boldsymbol{c}_{12}^\chi) \\ \Xi\Xi : c^{(27)} + 4(\boldsymbol{c}_1^\chi - \boldsymbol{c}_2^\chi + \boldsymbol{c}_{11}^\chi - \boldsymbol{c}_{12}^\chi) \end{array} \right\}$$



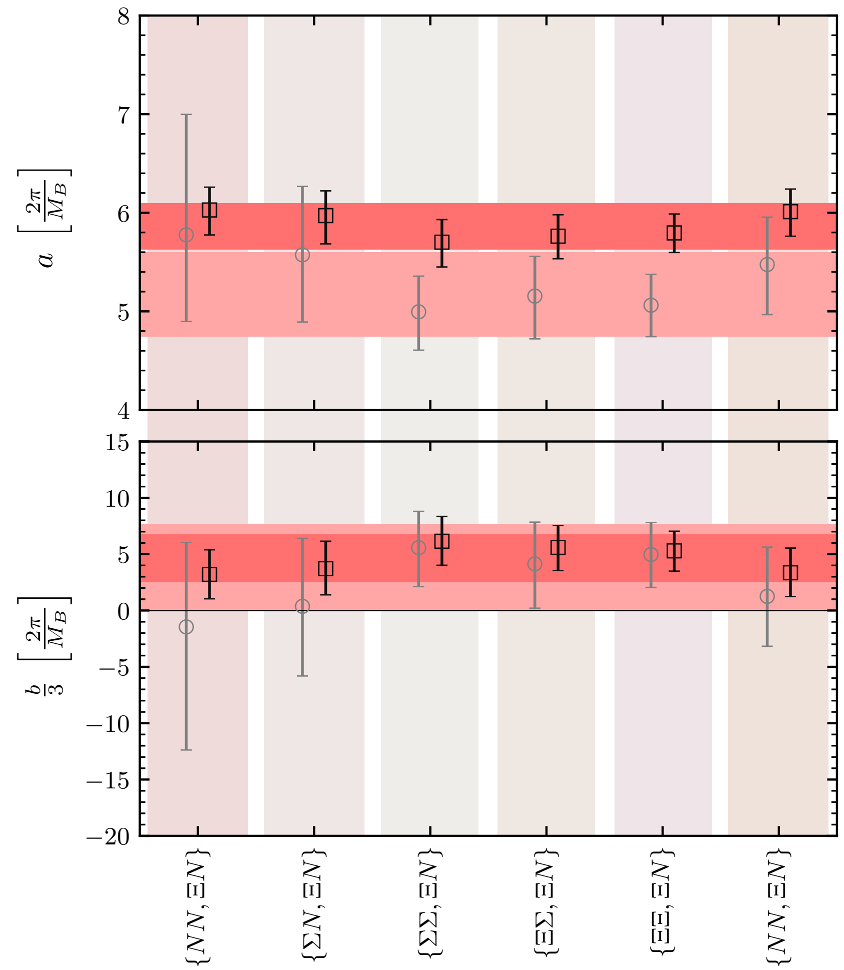
$$c^{(27)} = 2a - \frac{2b}{27}$$

$$c^{(\overline{10})} = 2a - \frac{2b}{27}$$

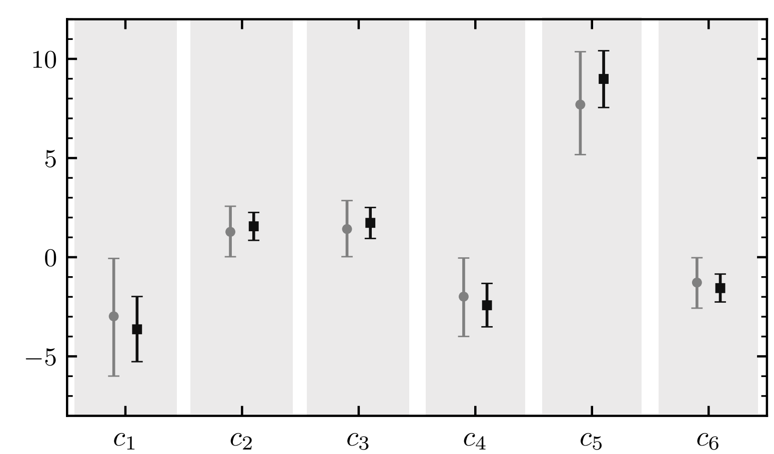
$$c^{(10)} = 2a + \frac{14b}{27}$$

$$c^{(8_a)} = 2a + \frac{2b}{27}$$

$SU(6)$ coefficients



$SU(3)$ coefficients



Baryon-baryon interactions

Illa et al. [NPLQCD], PRD 103 (2021), 054508

~~$SU(3)$~~ coefficients

$$\left\{ NN : c^{(27)} + 4(c_3^{\chi} - c_4^{\chi}) \right\}$$
$$\left\{ \Sigma N : c^{(27)} + 2(c_3^{\chi} - c_4^{\chi}) \right\}$$

$$\left\{ \Xi\Sigma : c^{(27)} + 2(c_1^{\chi} - c_2^{\chi} + c_{11}^{\chi} - c_{12}^{\chi}) \right\}$$
$$\left\{ \Xi\Xi : c^{(27)} + 4(c_1^{\chi} - c_2^{\chi} + c_{11}^{\chi} - c_{12}^{\chi}) \right\}$$

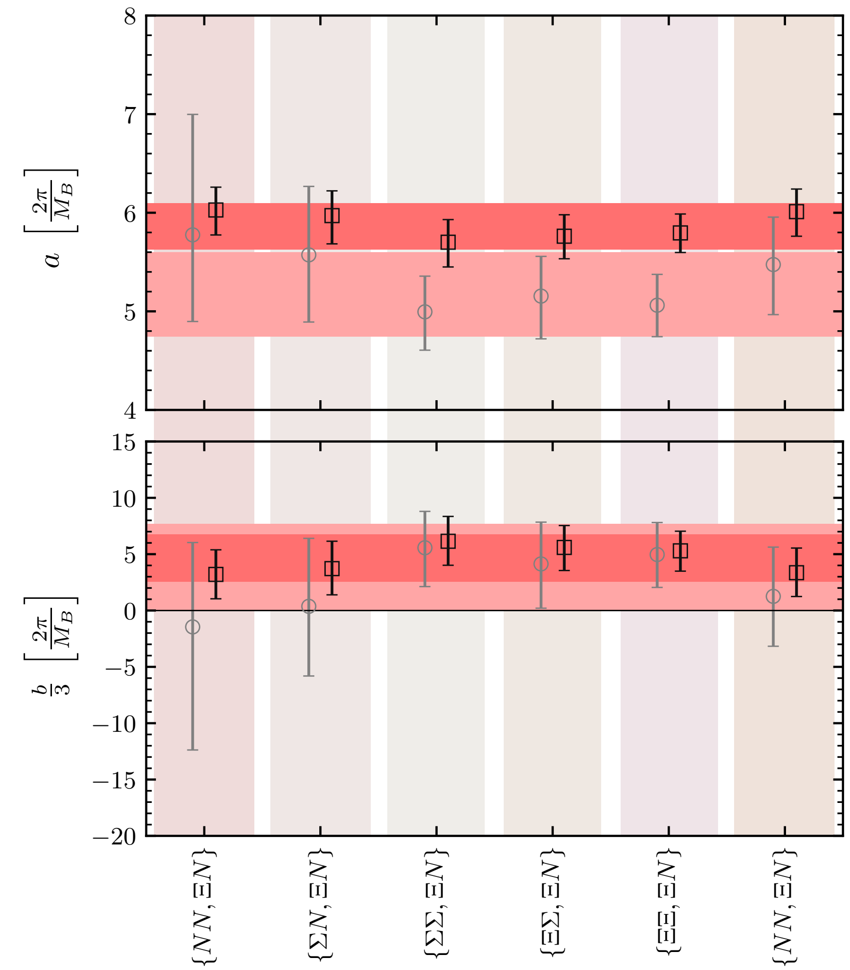
$$c^{(27)} = 2a - \frac{2b}{27}$$

$$c^{(\overline{10})} = 2a - \frac{2b}{27}$$

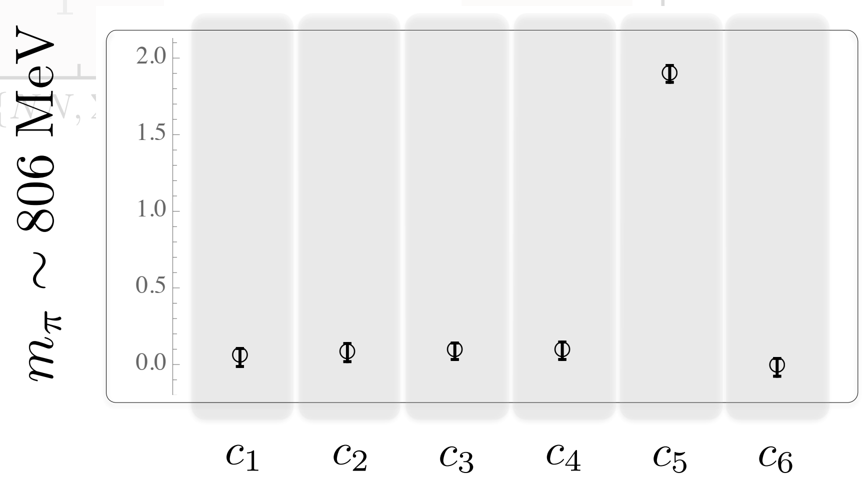
$$c^{(10)} = 2a + \frac{14b}{27}$$

$$c^{(8_a)} = 2a + \frac{2b}{27}$$

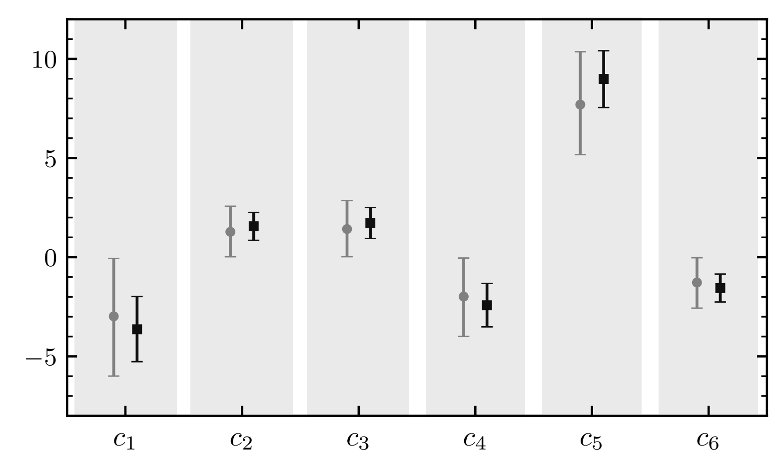
$SU(6)$ coefficients



Wagman et al. [NPLQCD], PRD 96 (2017)



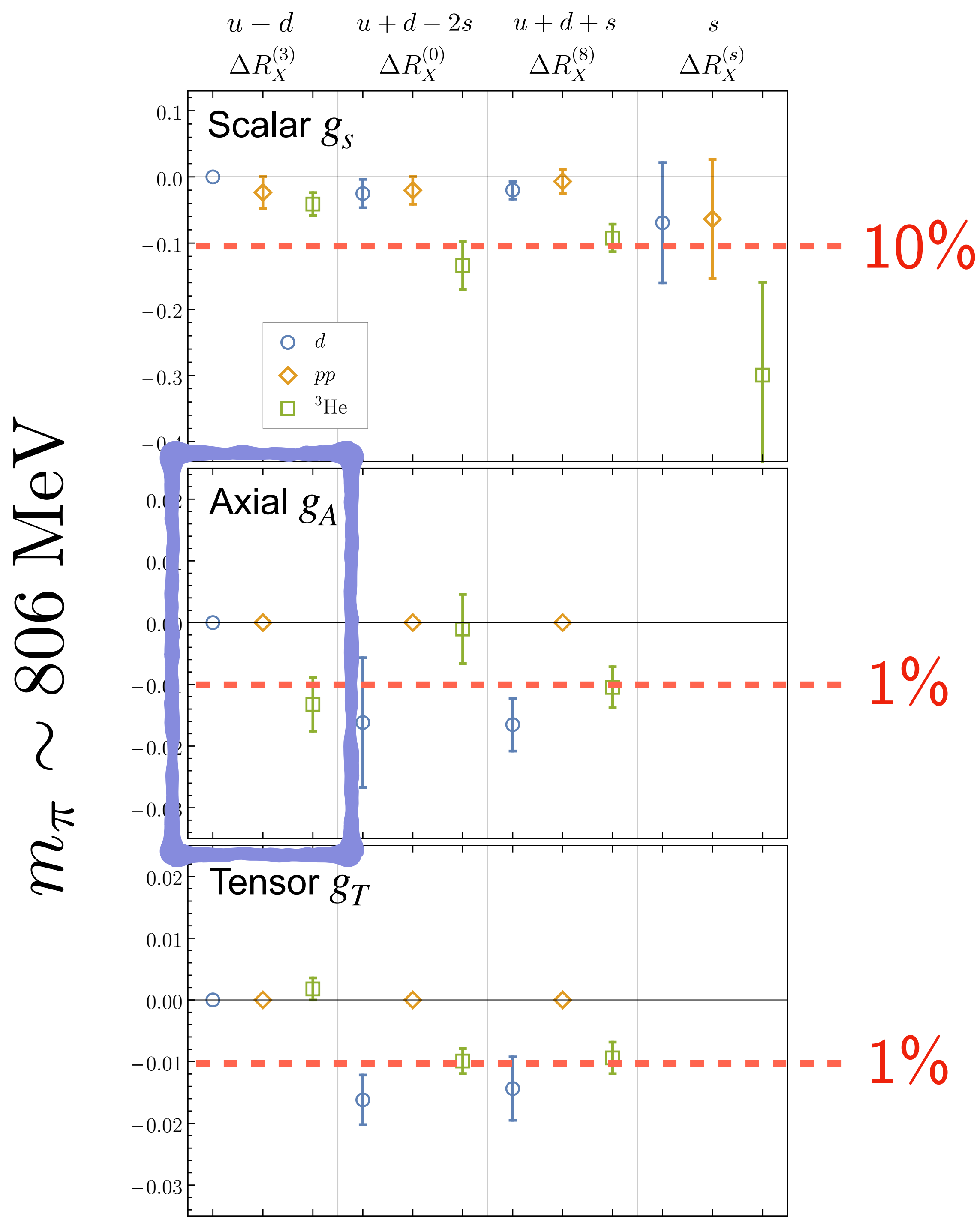
$SU(3)$
coefficients
$SU(16)$



Triton axial charge

Parreño et al. [NPLQCD], PRD 103 (2021), 074511

Nuclear effects computed from first principles



Chang et al. [NPLQCD], PRL 120 (2018)

These effects are not negligible

↓

Important for detectors that use heavy nuclei

↓

Match A=2,3,... to larger nuclei via EFT and many-body techniques

Barnea et al., PRL 114 (2015)

Contessi et al., PLB 772 (2017)

Bansal et al., PRC 98 (2018)

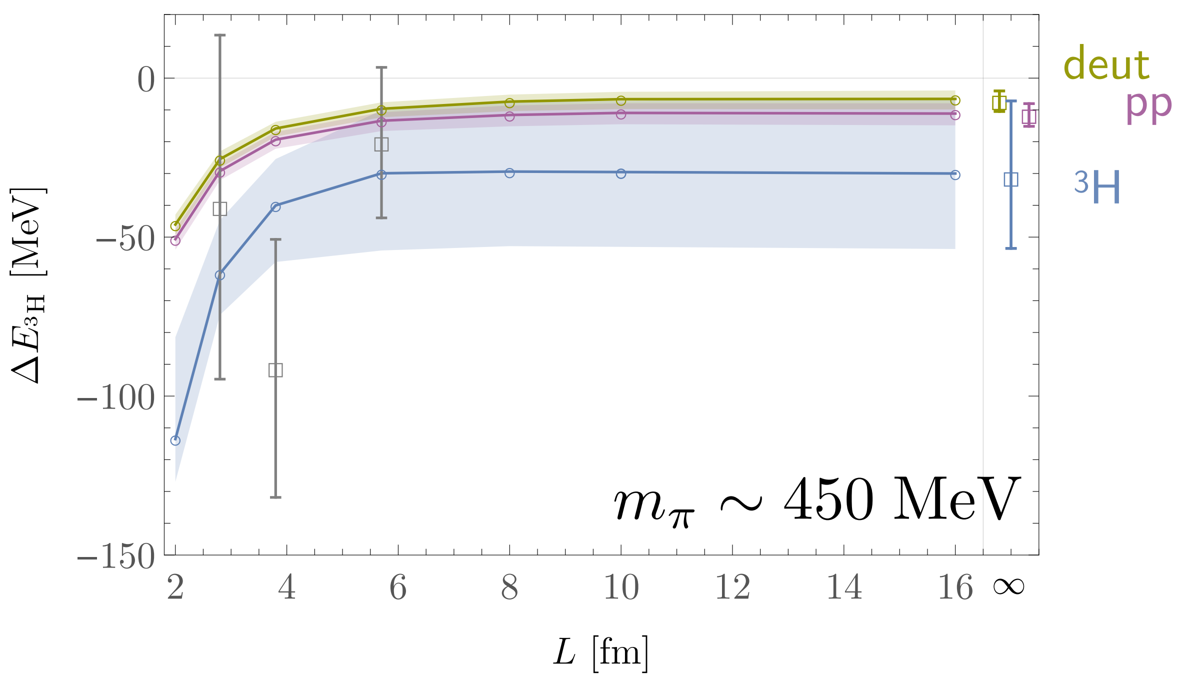
Triton axial charge

Parreño et al. [NPLQCD], PRD 103 (2021), 074511

Use $\not\pi$EFT to extrapolate to infinite-volume

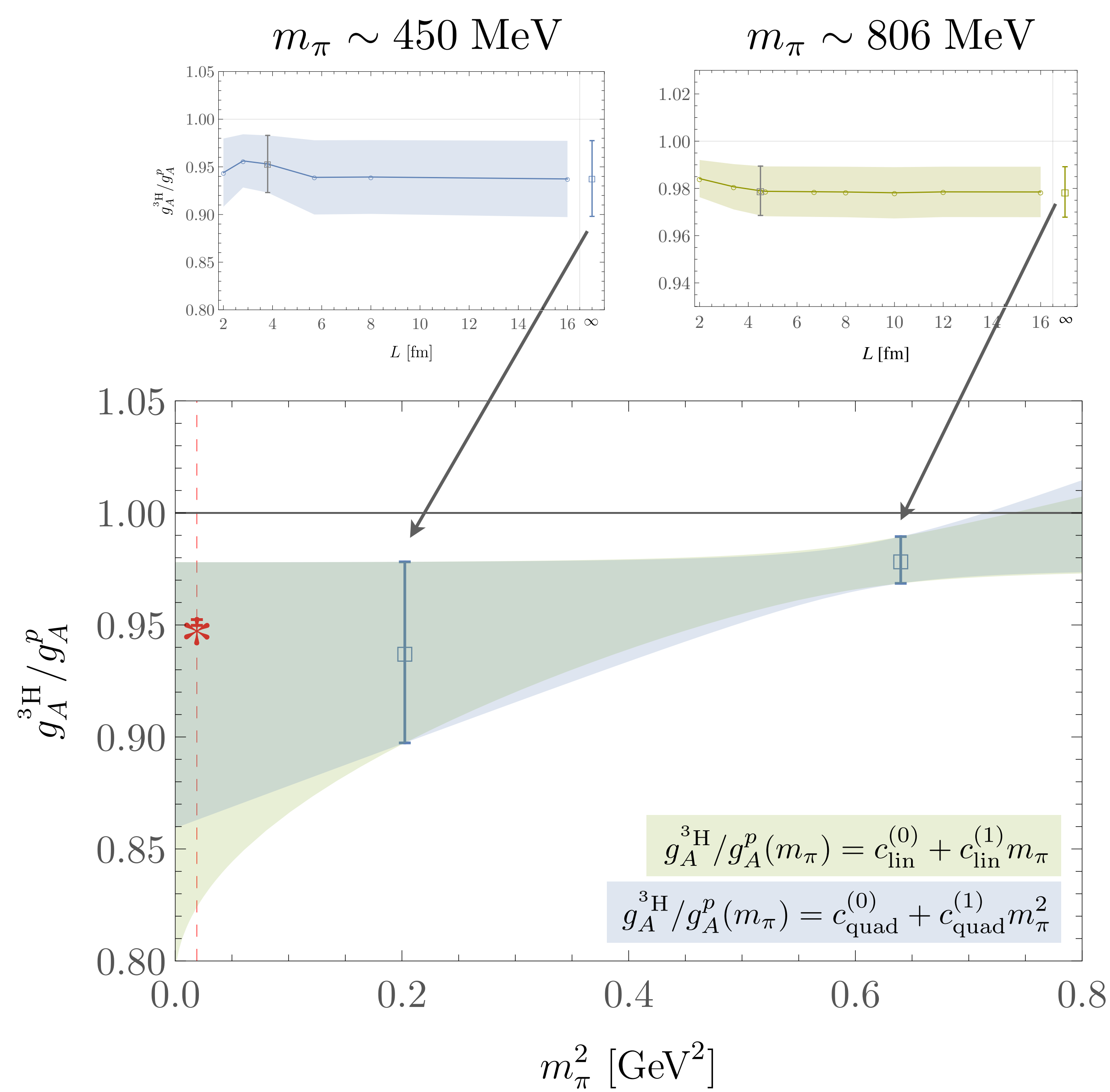
Eliyahu, Bazak and Barnea, PRC 102 (2020)

Detmold and Shanahan, PRD 103 (2021)



$$\langle \mathbf{GT} \rangle = g_A^{^3\mathrm{H}} / g_A^p$$

2-body LEC $L_{1,A}$



$$g_A^{^3\mathrm{H}} / g_A^p \Big|_{\mathrm{latt}} = 0.91^{(+0.07)}_{(-0.09)}$$

$$\updownarrow$$

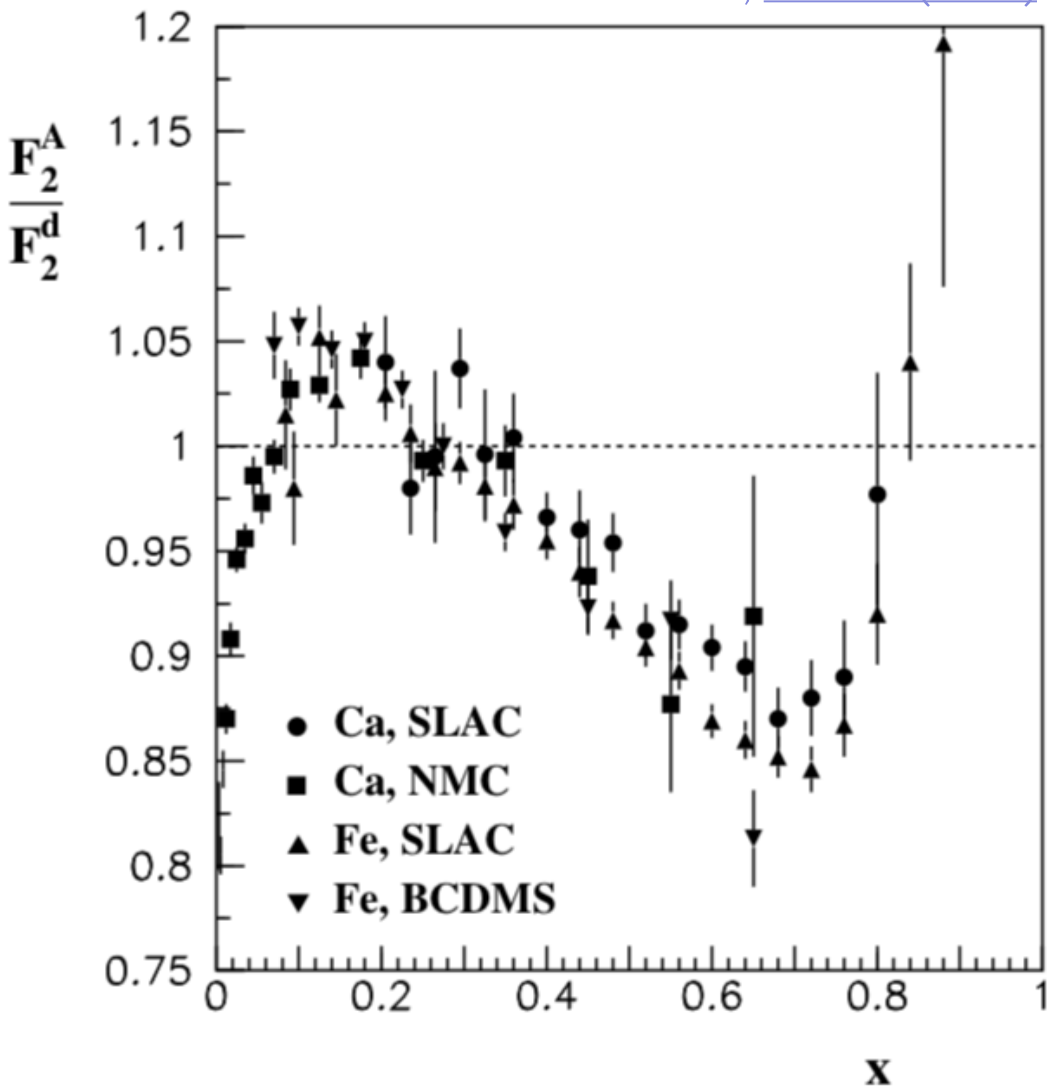
$$g_A^{^3\mathrm{H}} / g_A^p \Big|_{\mathrm{exp}} = 0.9511(13)$$

Momentum fraction of ^{3}He

Detmold et al. [NPLQCD], PRL 126 (2021), 202001

Nuclear effects computed from first principles

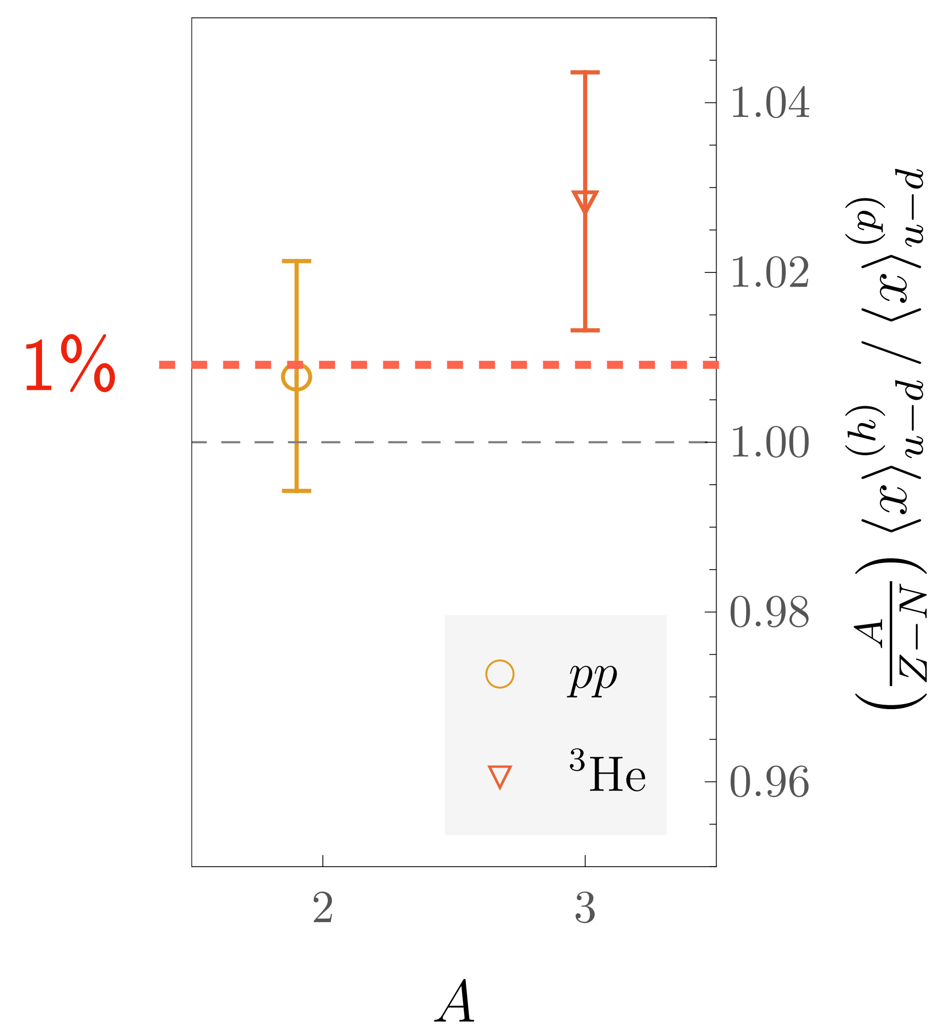
EMC Collaboration, PLB 123 (1983)



integrating

(easier for lattice calculations)

$m_\pi \sim 806$ MeV



$$F_2(x,Q^2) = \sum_q x\, e_q^2 \left[q(x,Q^2) + \overline{q}(x,Q^2)\right]$$

$$\langle x \rangle_q^{(h)} = \int_{-1}^{1} dx\; x\, q^{(h)}(x,Q^2)$$

Momentum fraction of ^{3}He

Detmold et al. [NPLQCD], PRL 126 (2021), 202001

Chen and Detmold, PLB 625 (2005)

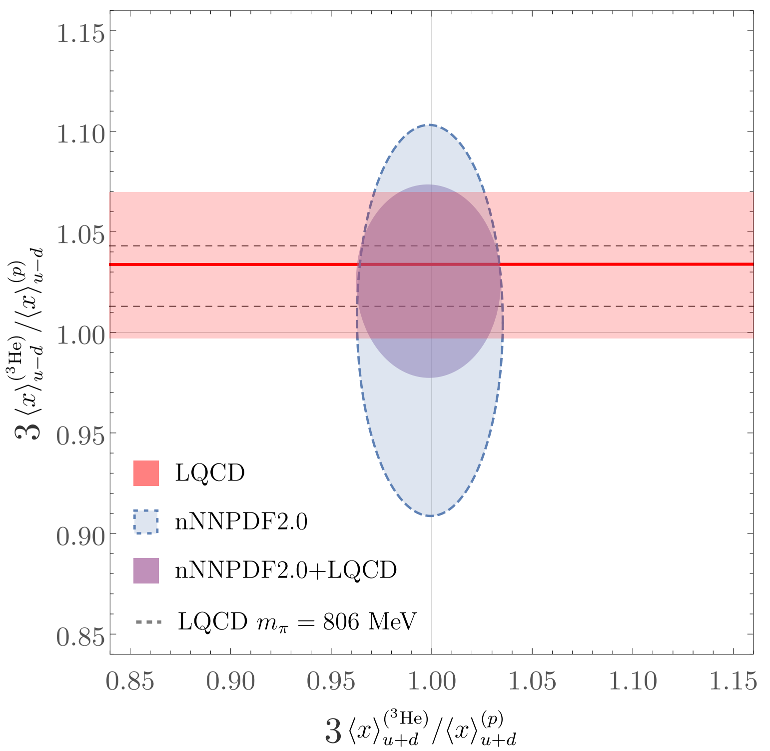
Extrapolate to the physical point:

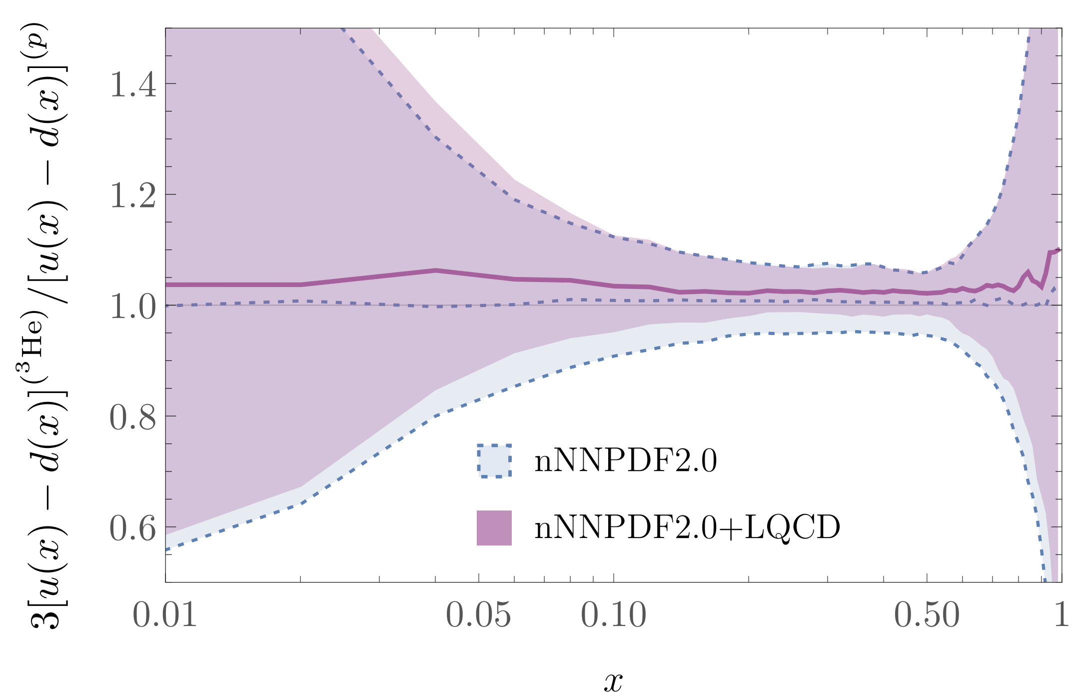
$$\alpha_{3,2}\mathcal{G}_3(^3\mathrm{He}) = \frac{1}{3}\left(3\frac{\langle x\rangle^{(^3\mathrm{He})}_{u-d}}{\langle x\rangle^{(p)}_{u-d}} - 1\right)\langle x\rangle^{(p)}_{u-d}$$

Combine with experimental data from global fits provided by nNNPDF2.0

Ball et al. [NNPDF], NPB 855 (2012)

Abdul Khalek, Ethier, Rojo, van Weelden, JHEP 09 (2020)





Conclusions

- We can use LQCD to reach systems that are difficult for experimentalist (like strange systems) and learn about the symmetries (more clearly visible at heavy quark masses)

- LQCD is able to reproduce the triton axial charge as well as the helium momentum fraction, indicating that first-principles calculations are possible, but still need closer-to-physical values for the quark masses

Thank you