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Extracting few-body matrix elements from lattice QCD

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IQuS
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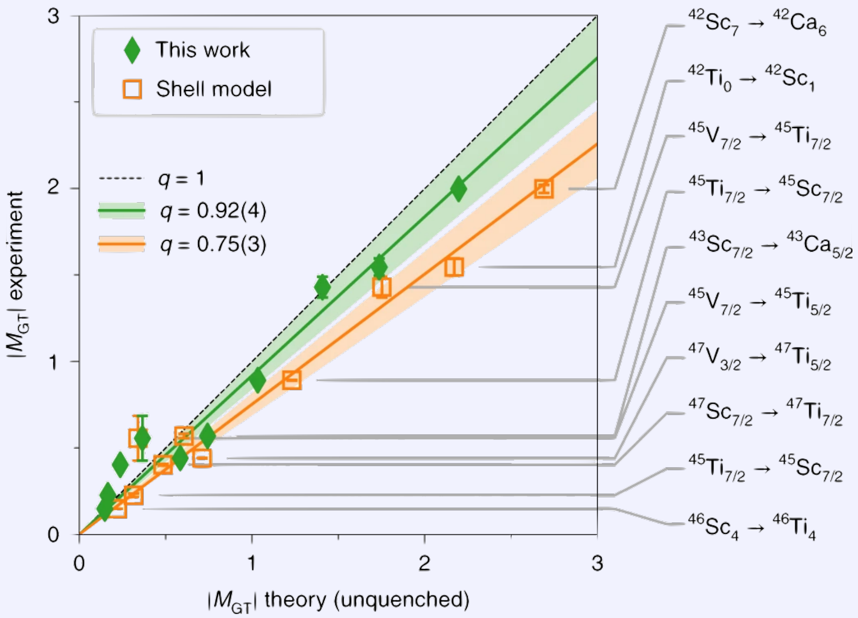
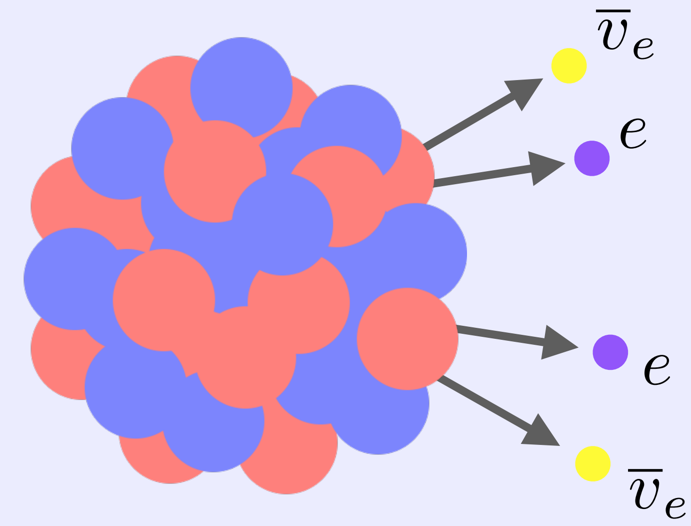
UNIVERSITY of WASHINGTON

Quenching of axial charge



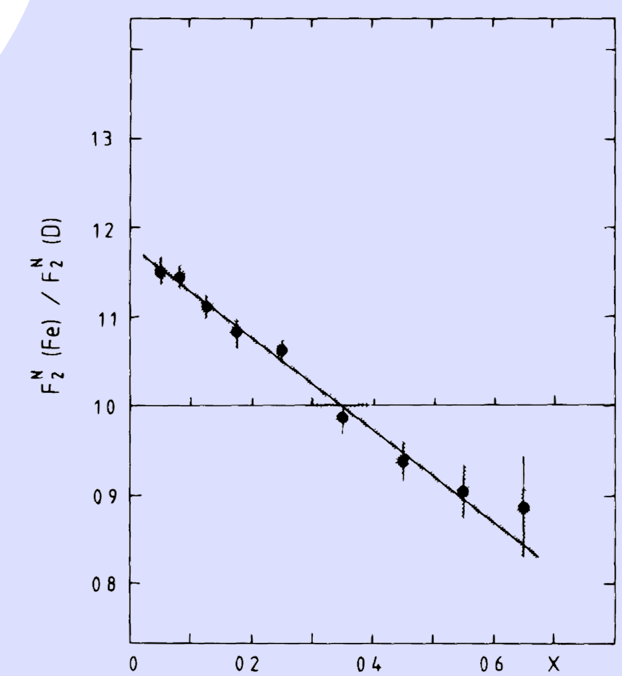
Gysbers et al., Nature Phys. 15 (2019)

Double-β decay

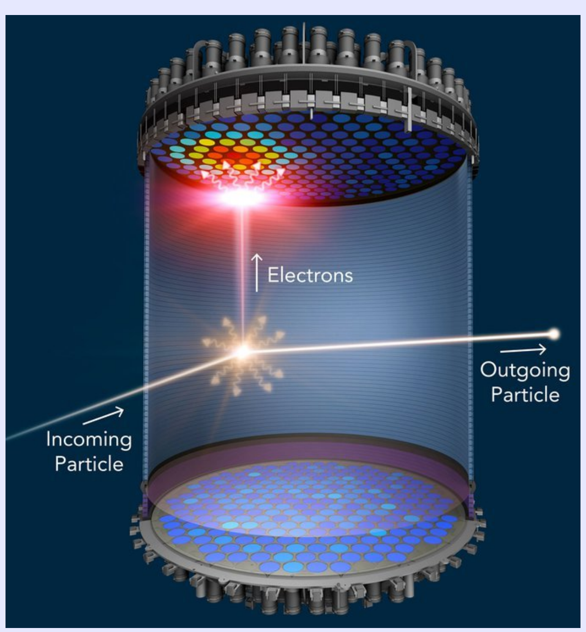


Nuclear matrix elements

EMC effect



EMC Collaboration, PLB 123 (1983)



Interaction with dark matter

SLAC National Accelerator Laboratory

Nuclear physics with lattice QCD

NPLQCD

Spectroscopy

Σ^- in dense nuclear matter
PRL 109 (2012), 172001

Light-nuclei spectrum
PRD 87 (2013), 034506

Charged multi-hadron systems with lattice QCD+QED
PRD 103 (2021), 054504 + QCDSF Collaboration

Baryon-baryon interactions
PRD 96 (2017), 114510, PRD 103 (2021), 054508

Variational study of two nucleons
arXiv:2108.10835

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

Matrix elements

$np \to d\gamma$ radiative capture process
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Momentum fraction of ^{3}He
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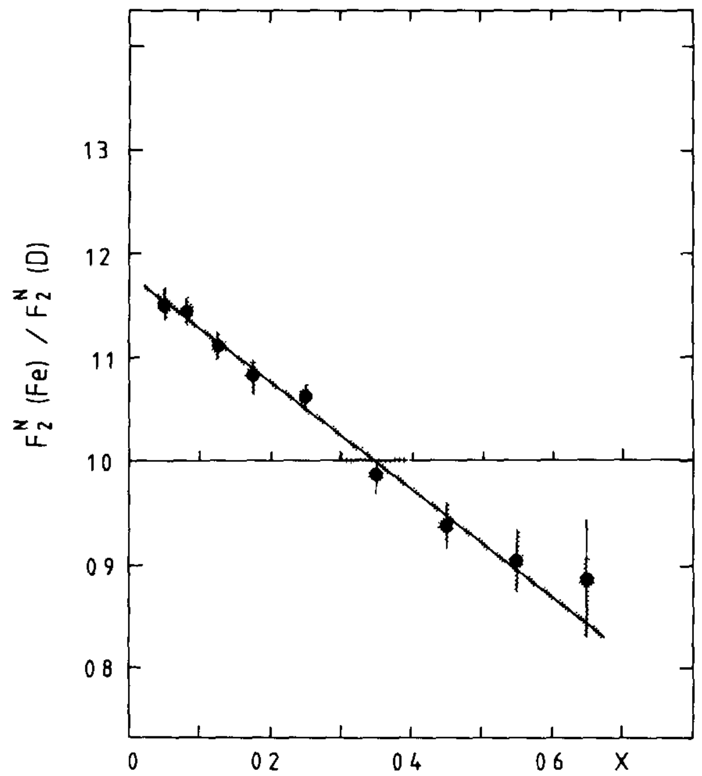
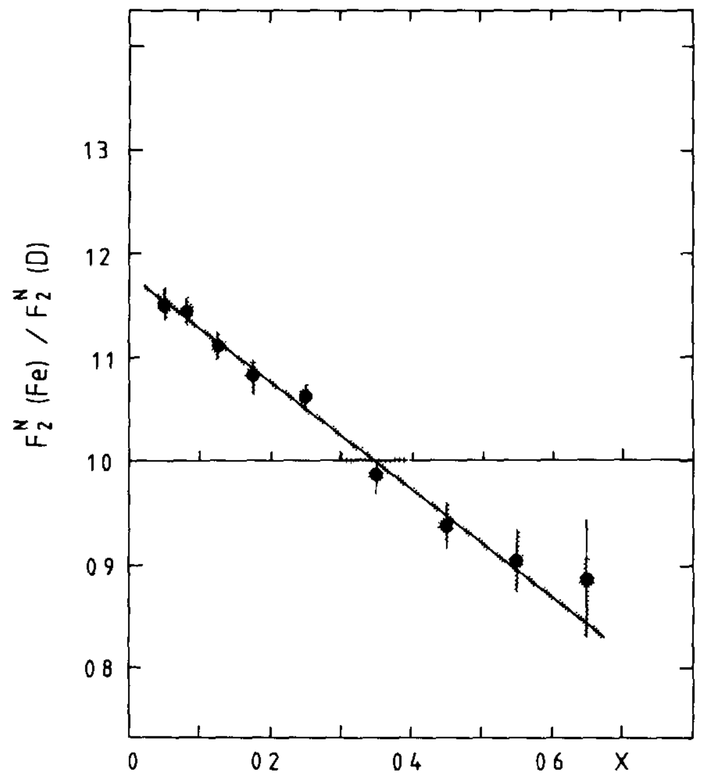


EMC Collaboration, PLB 123 (1983)

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

parton distribution function

Momentum fraction of ^{3}He



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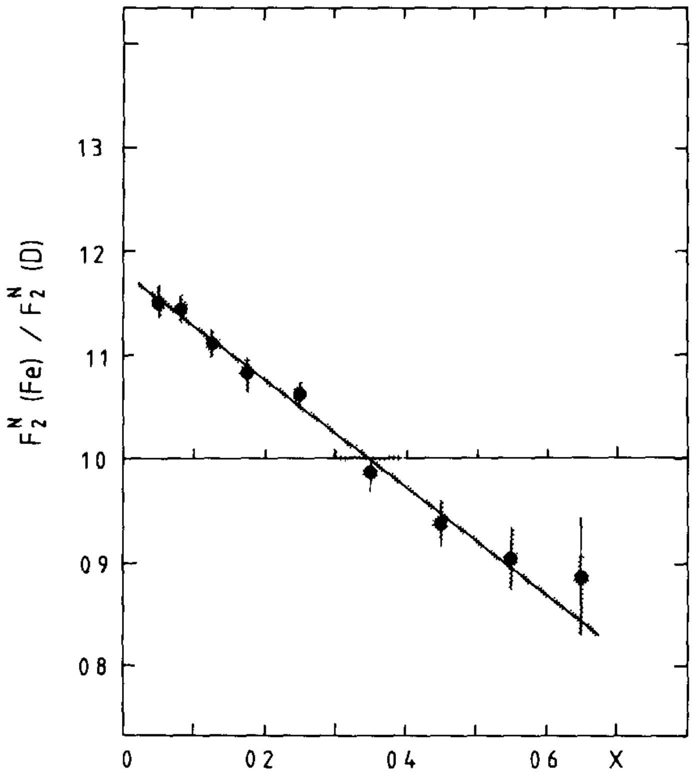

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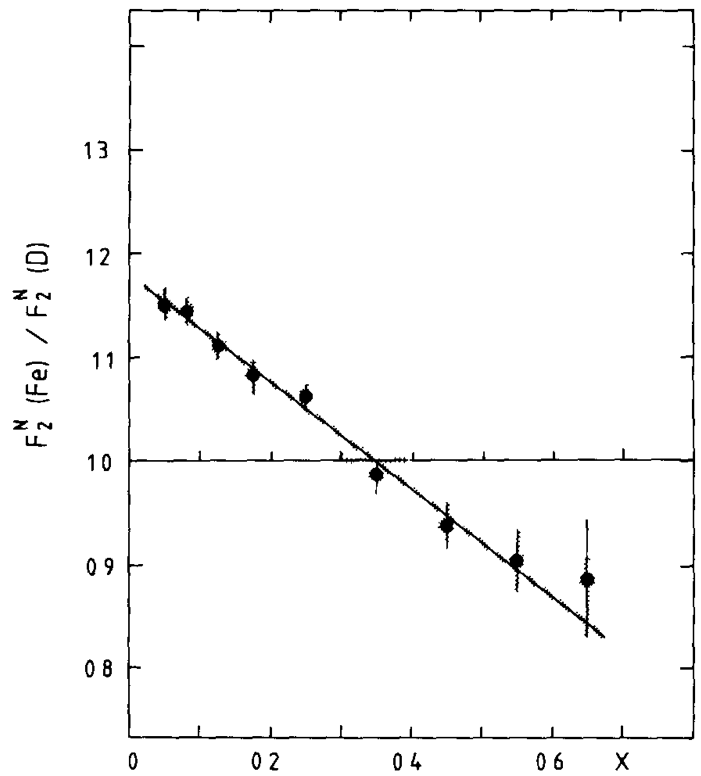
Much easier to compute the moments of PDFs:

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

Momentum fraction of ^{3}He



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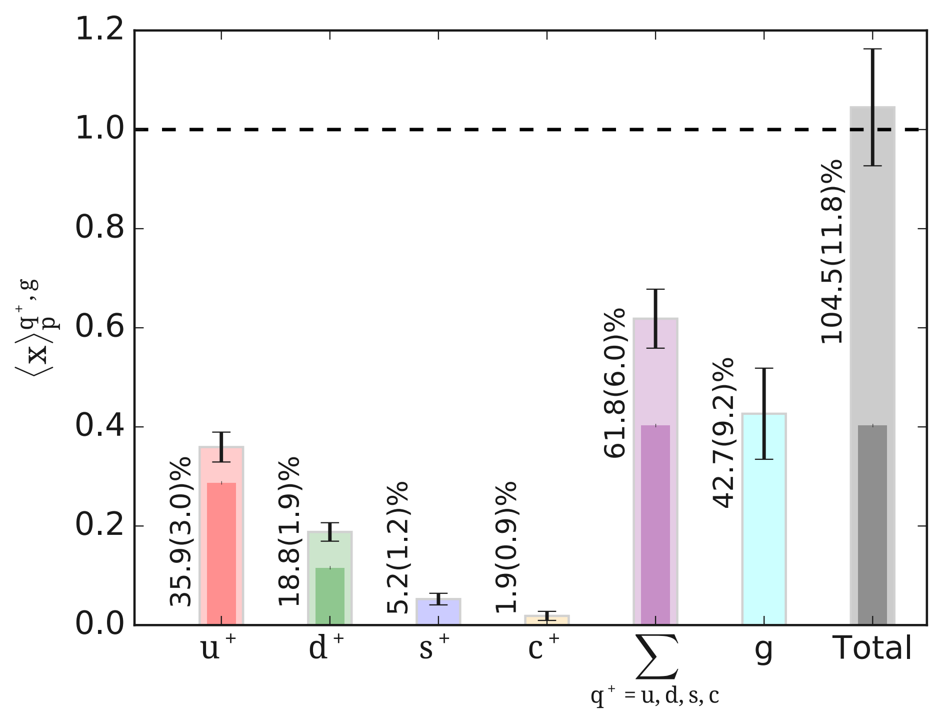

Full flavor decomposition of the proton momentum fraction at the physical point

Alexandrou et al. [ETMC], PRD 101 (2020)

Momentum fraction of ^{3}He

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

Observing EMC effects on the moments for light nuclei

Ensemble parameters: $m_u = m_d = m_s$ $\quad m_\pi \sim 806$ MeV

$a \sim 0.145$ fm $\quad L = 32 \sim 4.6$ fm

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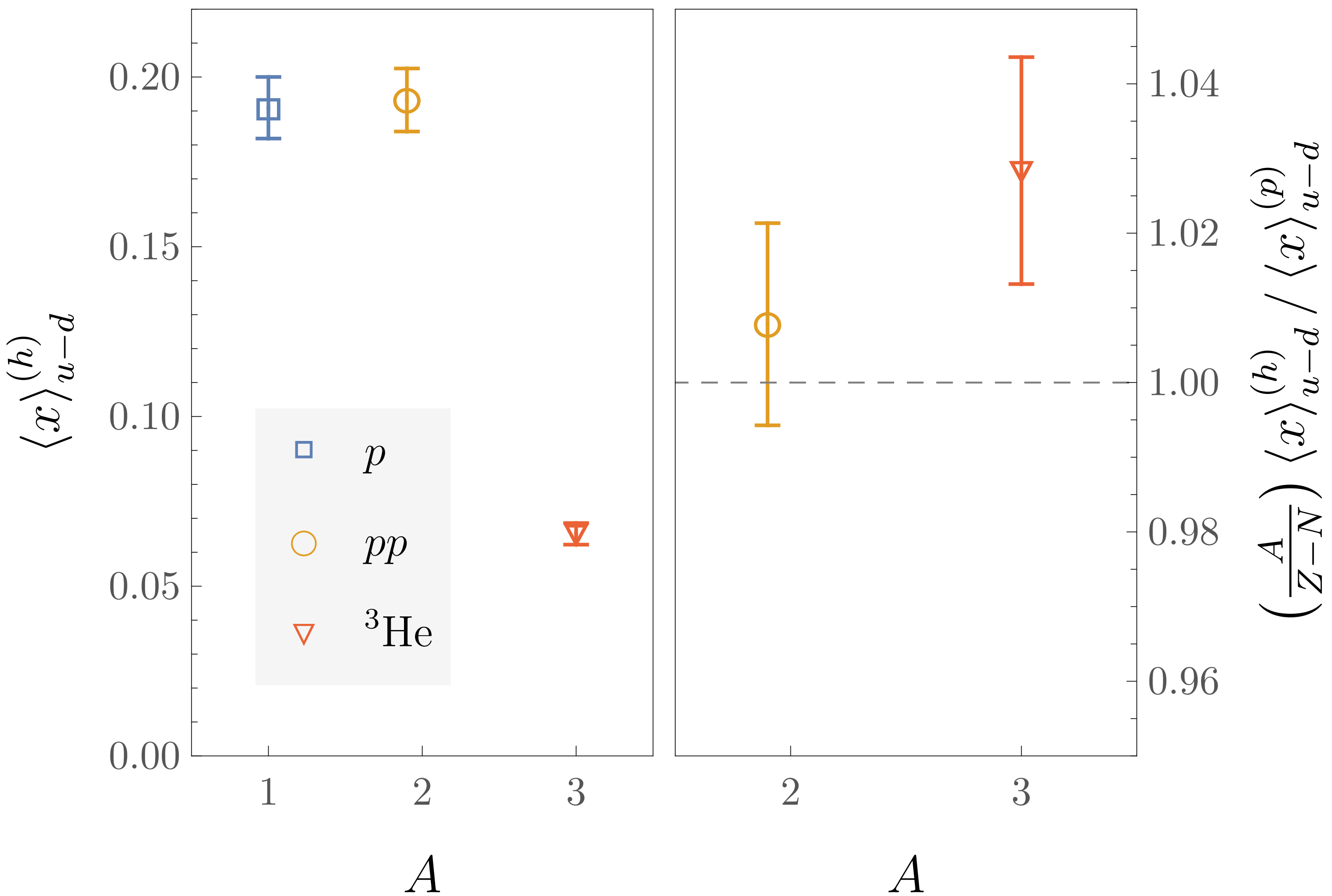

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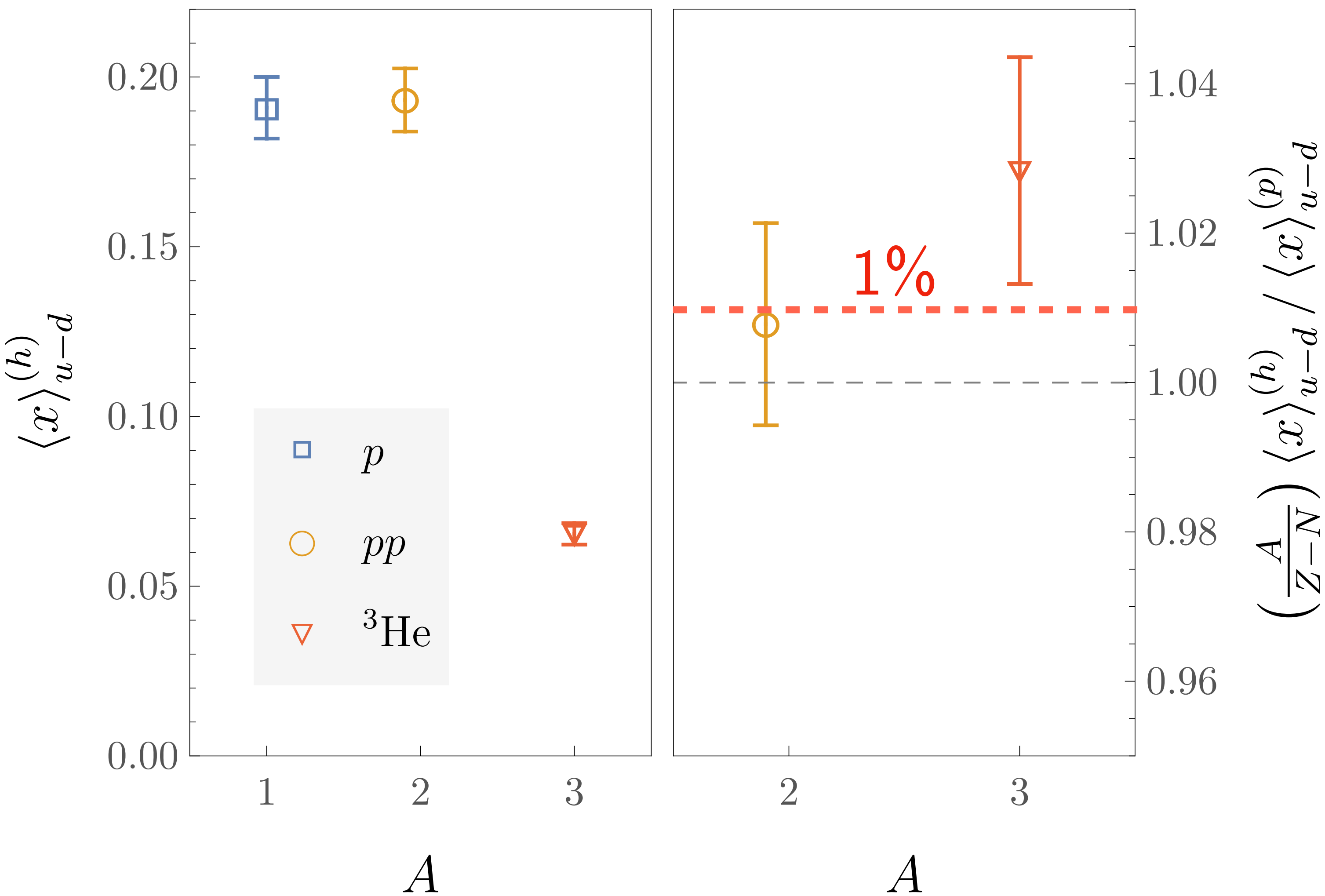

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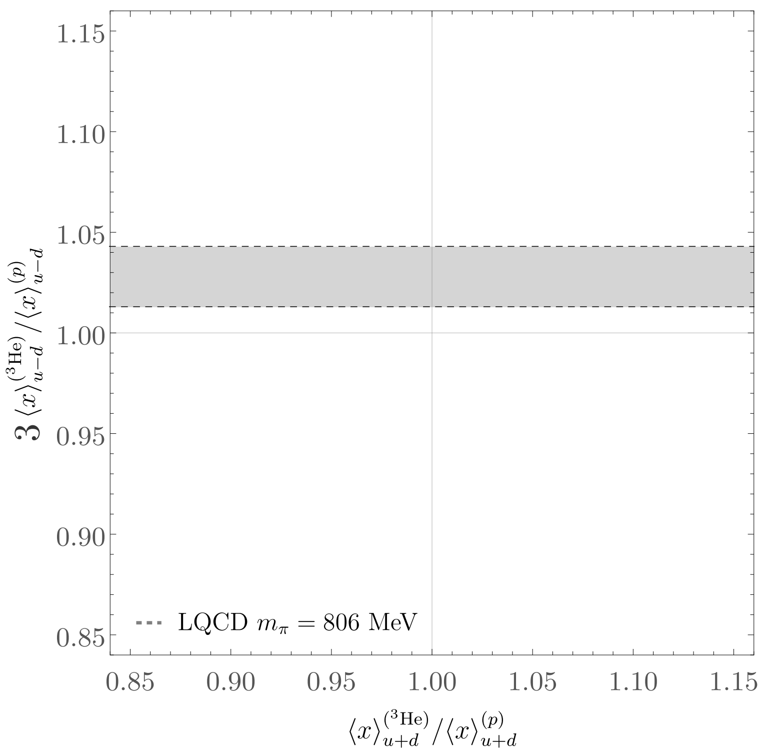

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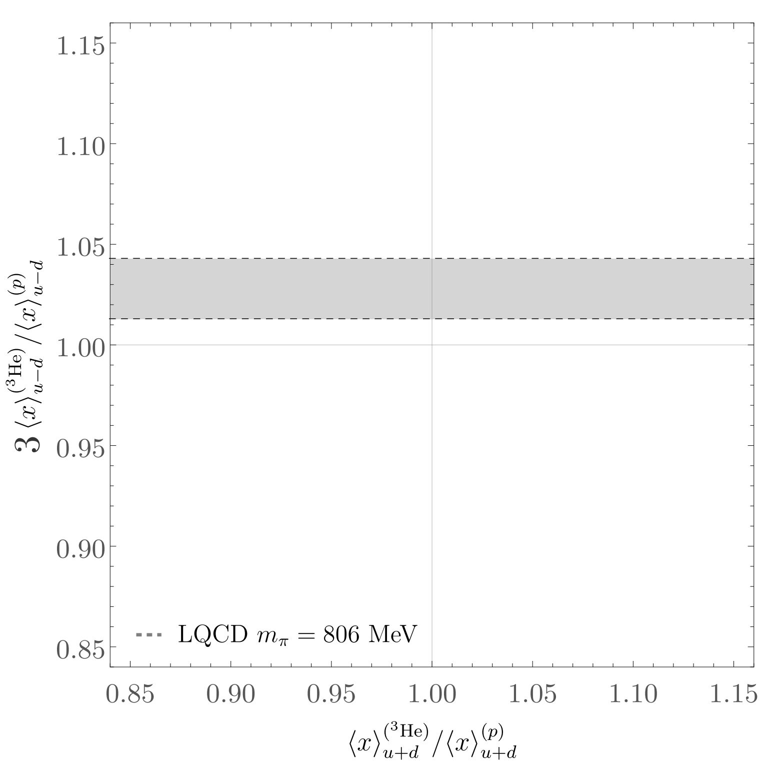
Chen and Detmold, PLB 625 (2005)



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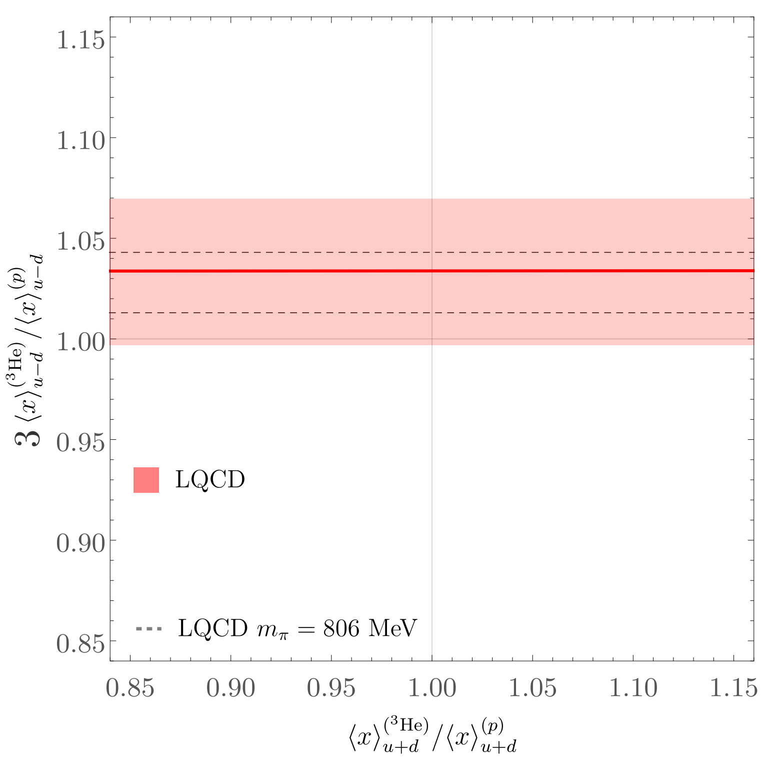

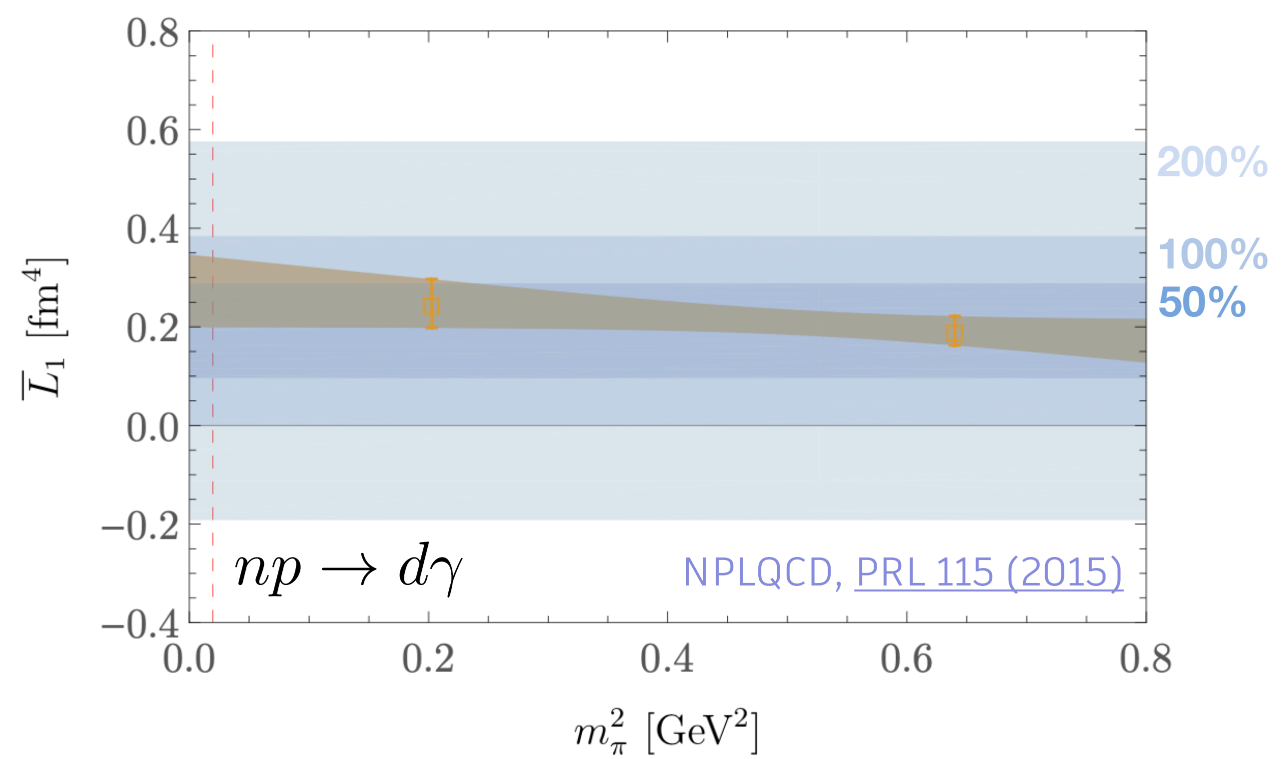

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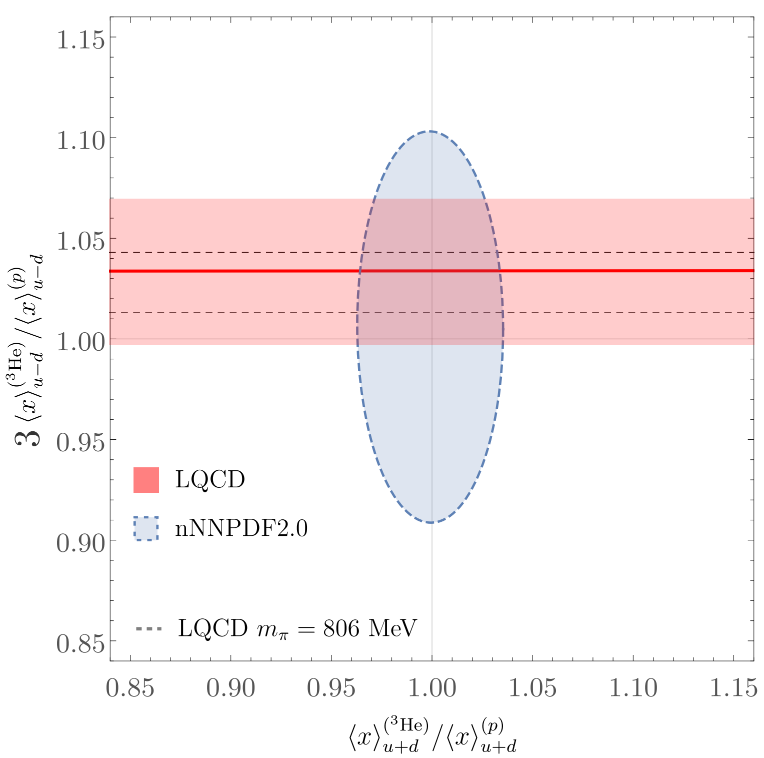
Combine with experimental data from global fits provided by nNNPDF2.0

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

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



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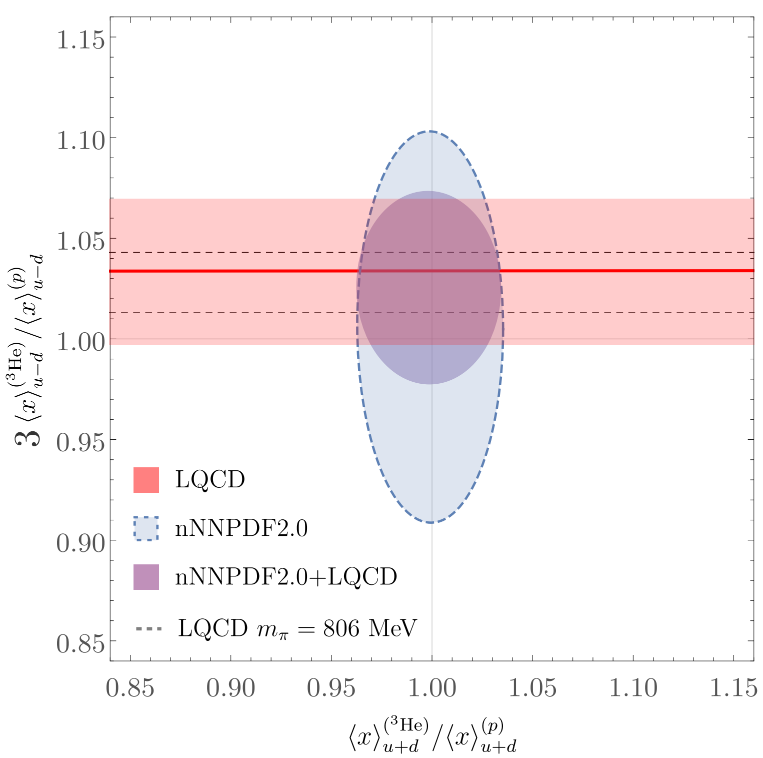

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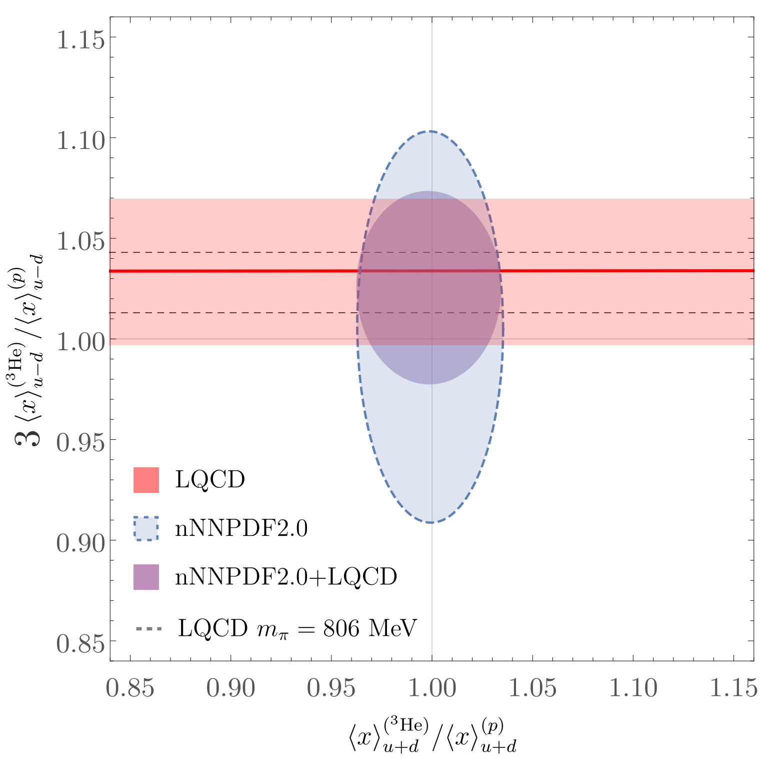
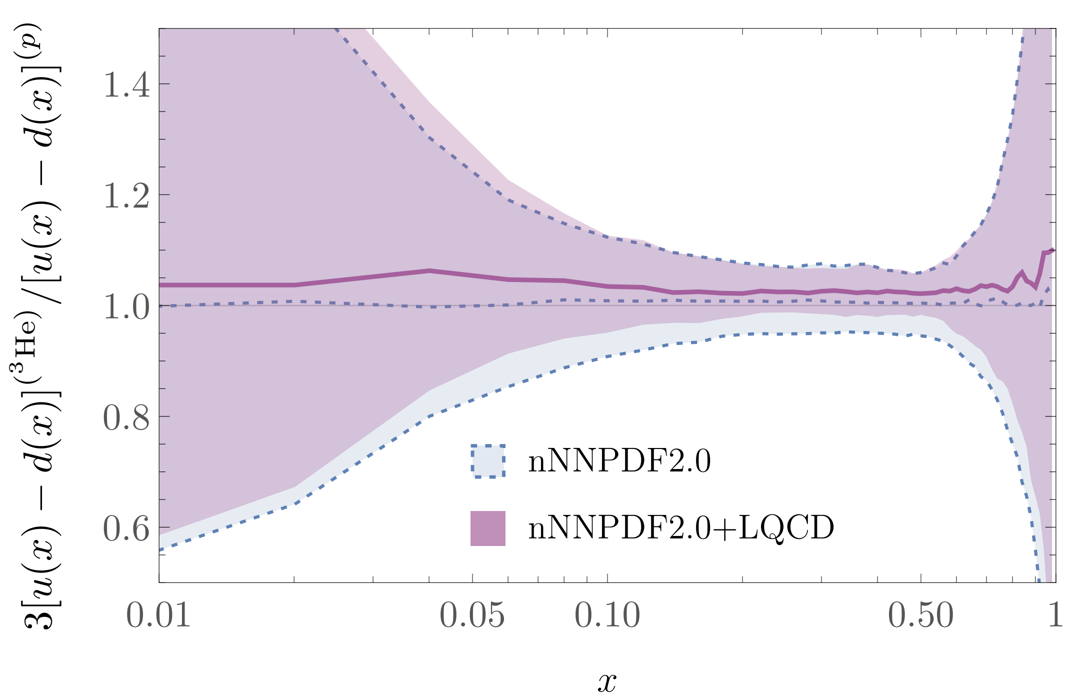
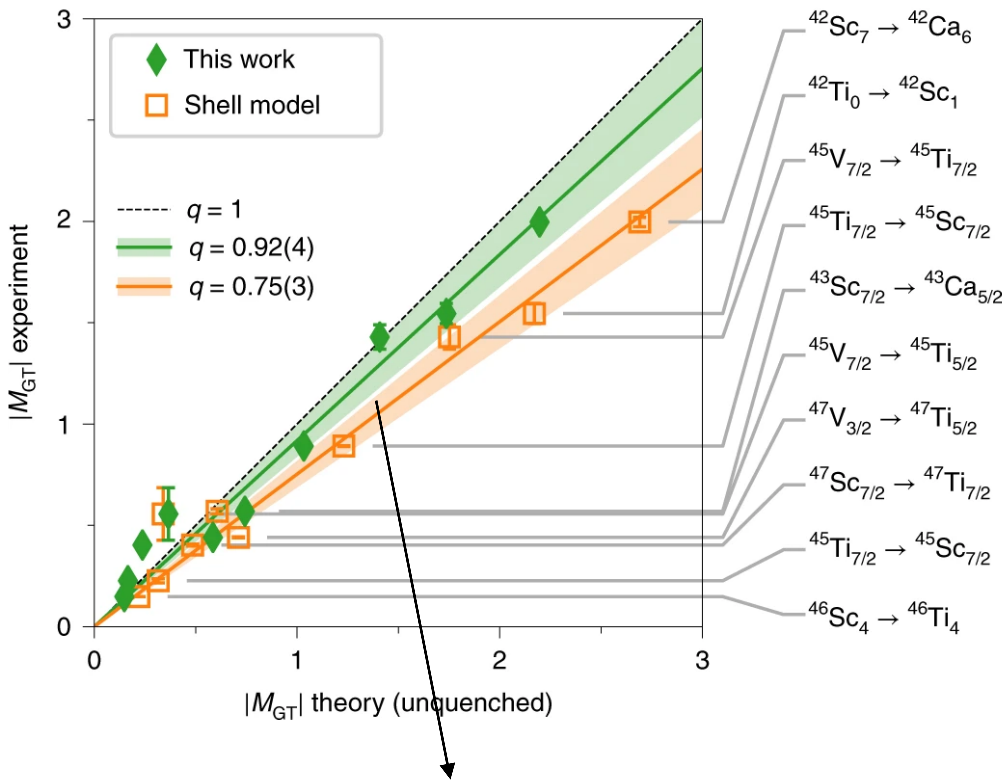




Triton axial charge

P. Gysbers et al., Nature Phys. 15 (2019)



Including nuclear correlations and
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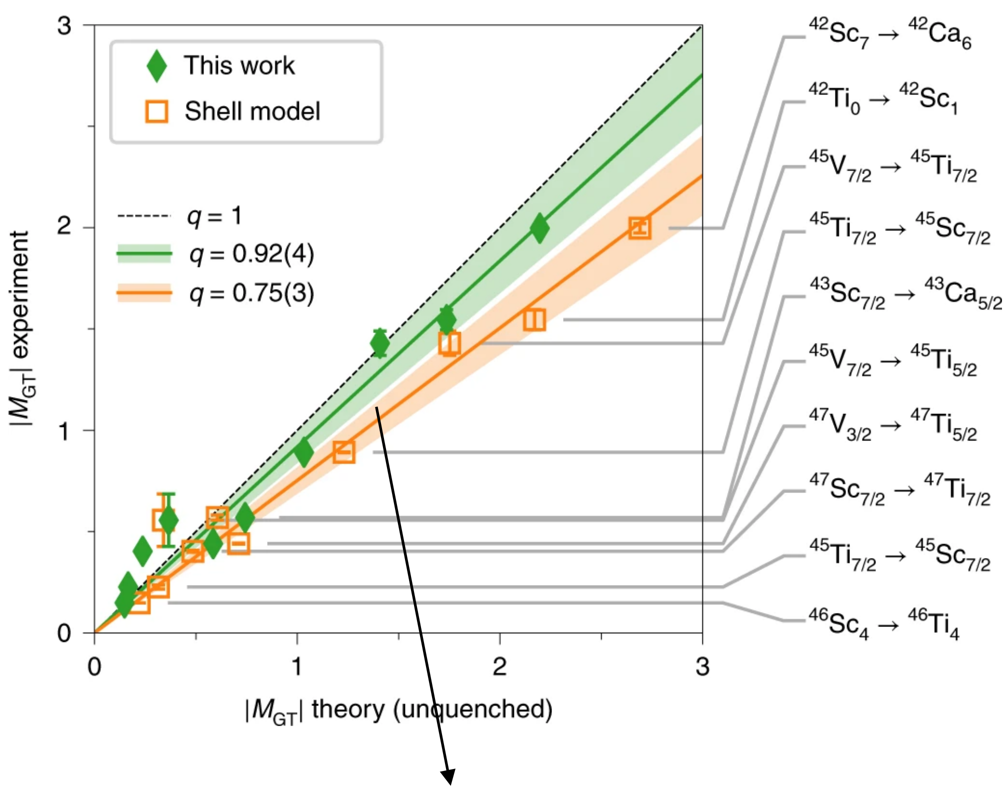

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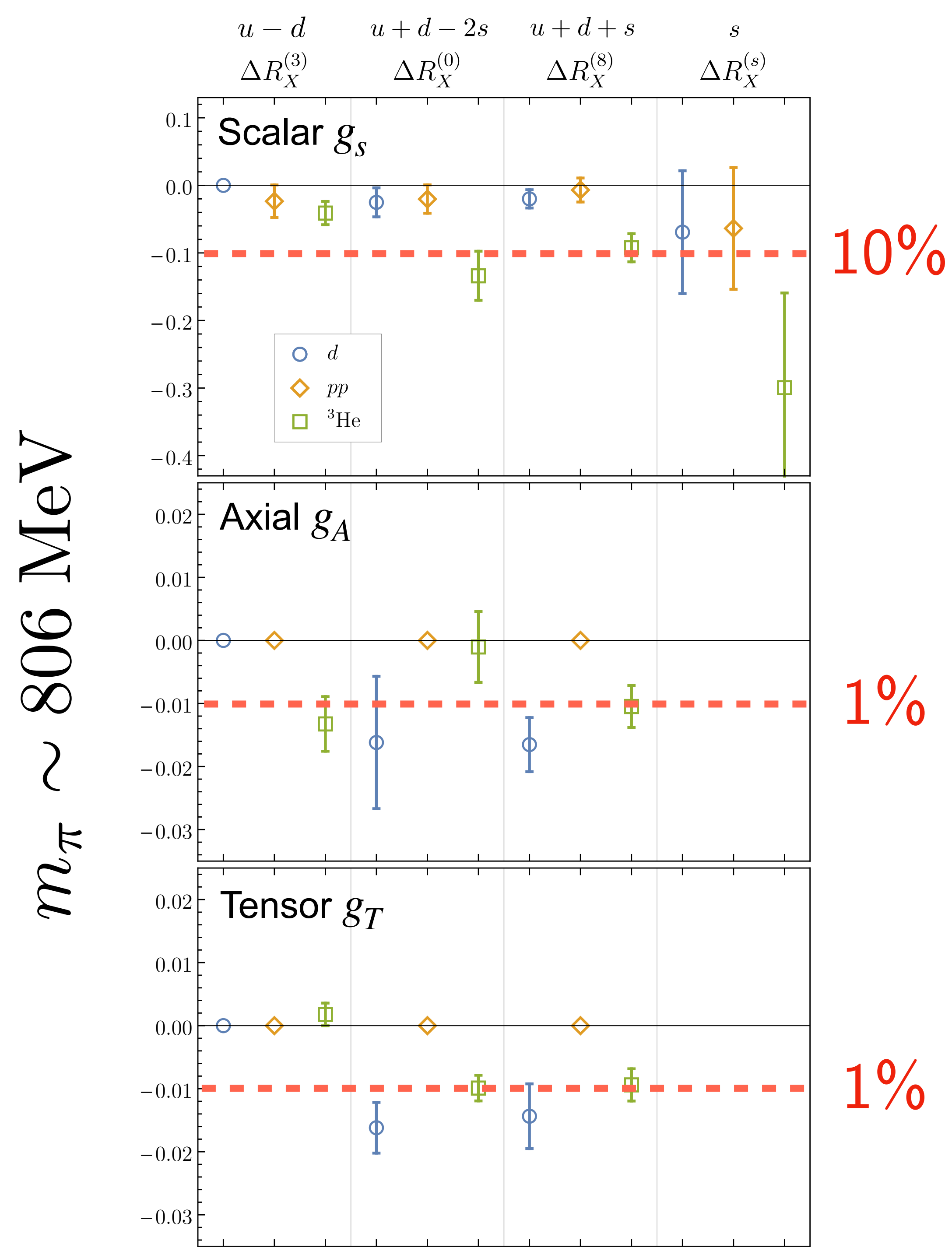

Chang et al. [NPLQCD], PRL 120 (2018)

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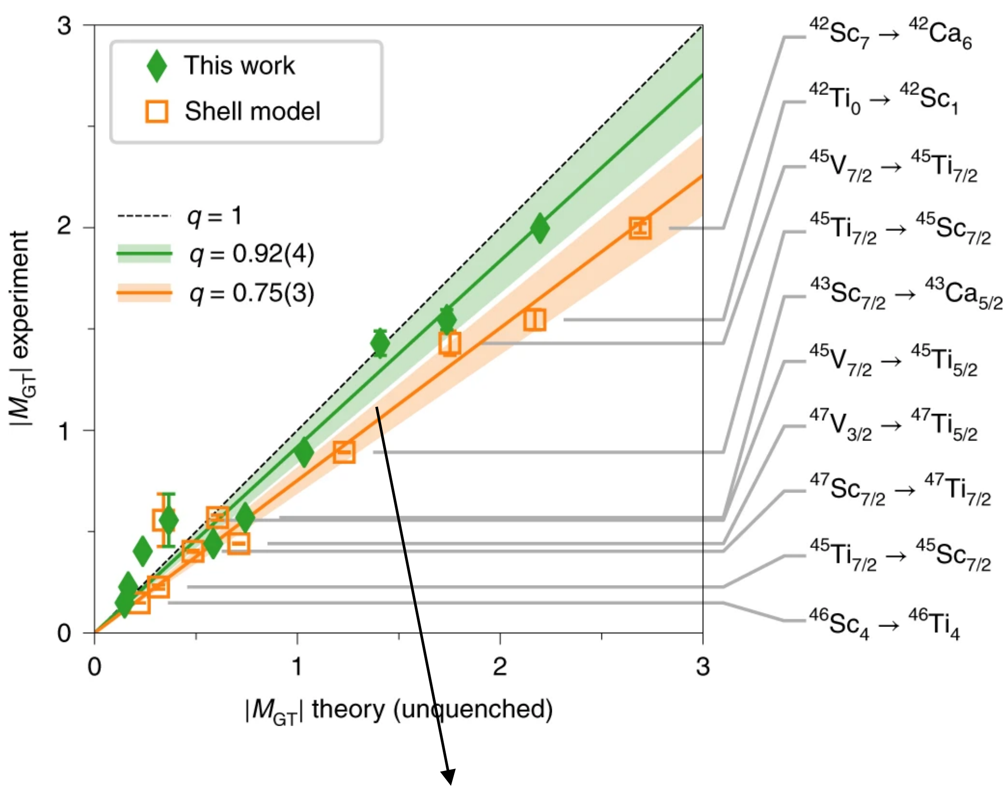

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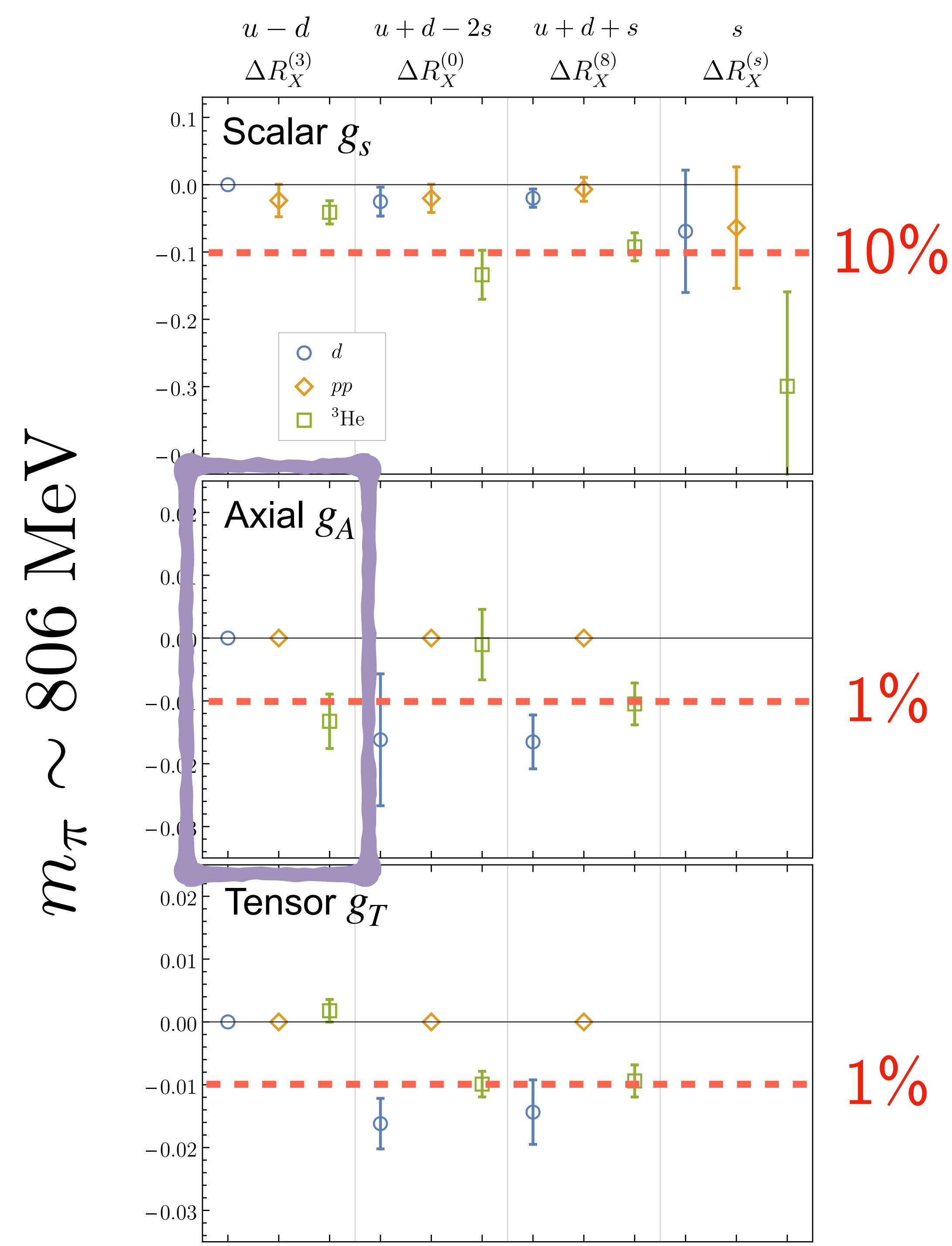

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Parreño et al. [NPLQCD]
PRD 103 (2021), 074511

Ensemble parameters: $m_u = m_d \neq m_s$ $m_\pi \sim 450\ \mathrm{MeV}$

$a \sim 0.1167\ \mathrm{fm}$ $L = 32 \sim 3.7\ \mathrm{fm}$

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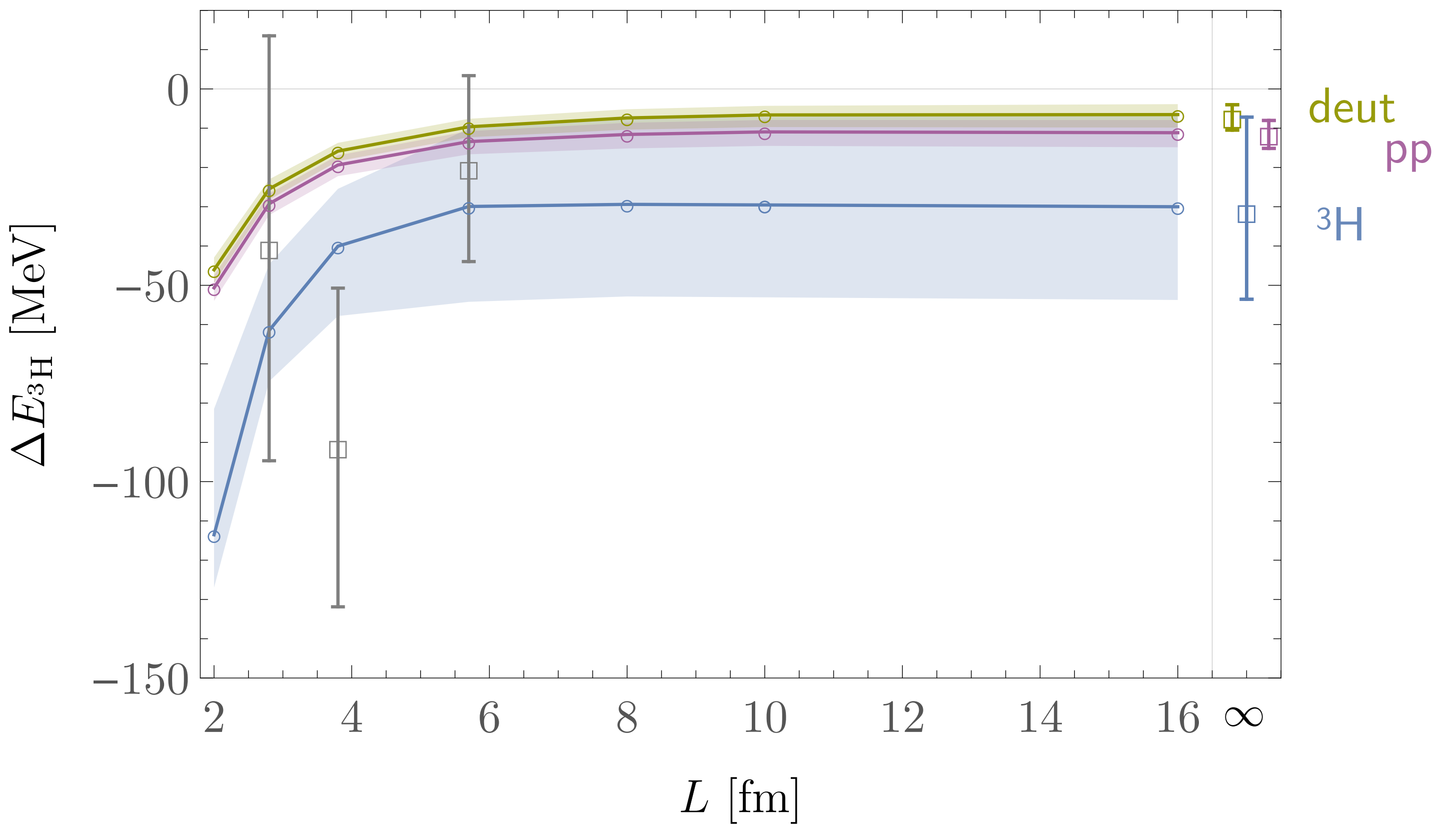
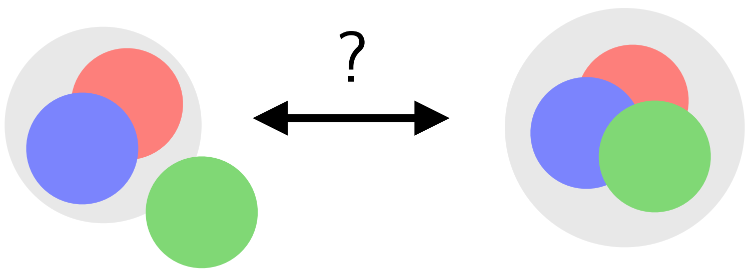
First, we have to determine the ground-state energy of ^{3}H



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

Eliyahu, Bazak and Barnea, PRC 102 (2020)
Detmold and Shanahan, PRD 103 (2021)



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Then we can compute the Gamow-Teller matrix element $\langle \mathbf{GT} \rangle = g_A^{^3\mathrm{H}} / g_A^p$

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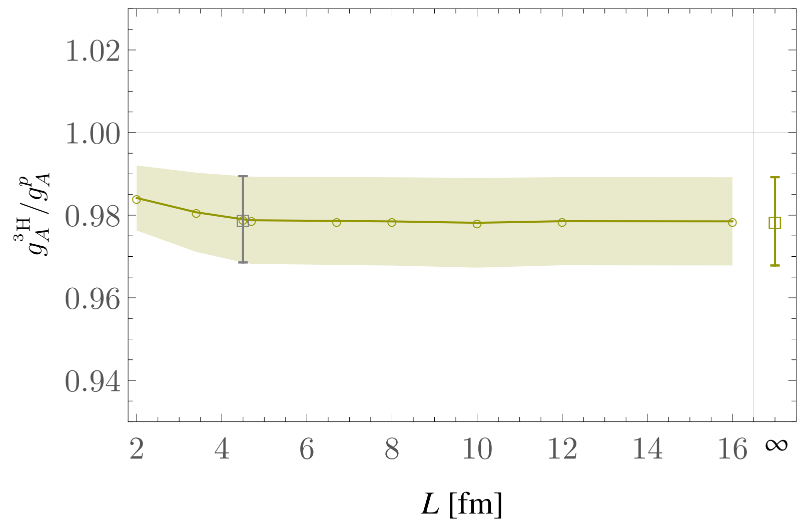

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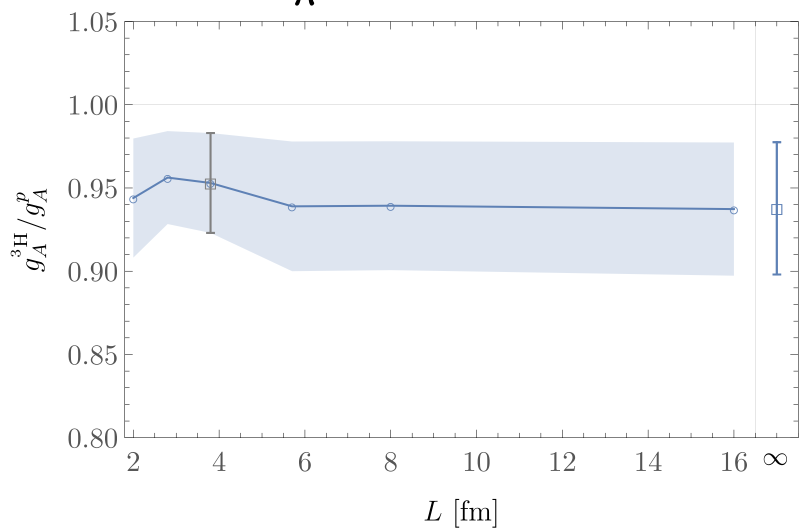

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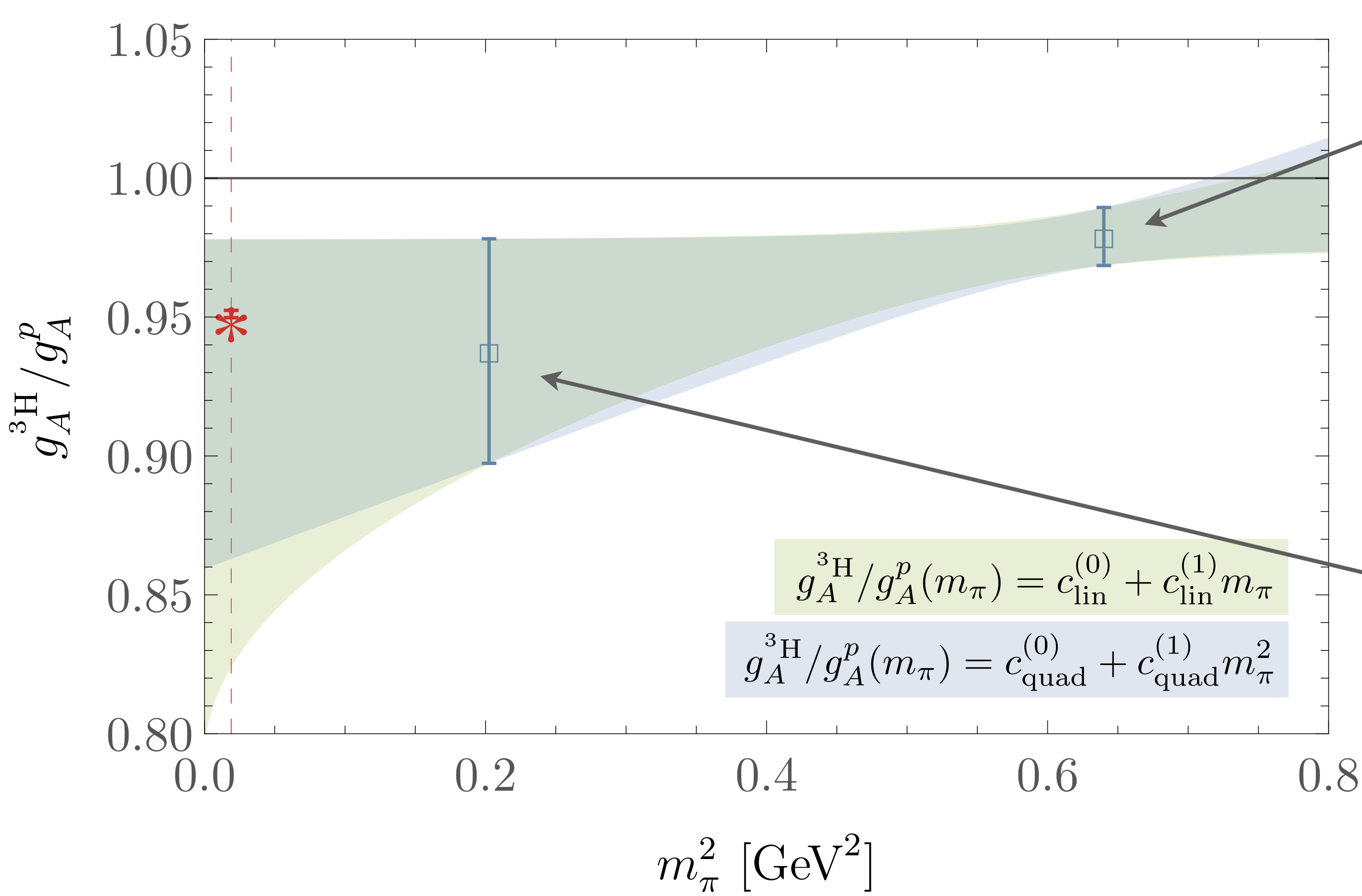

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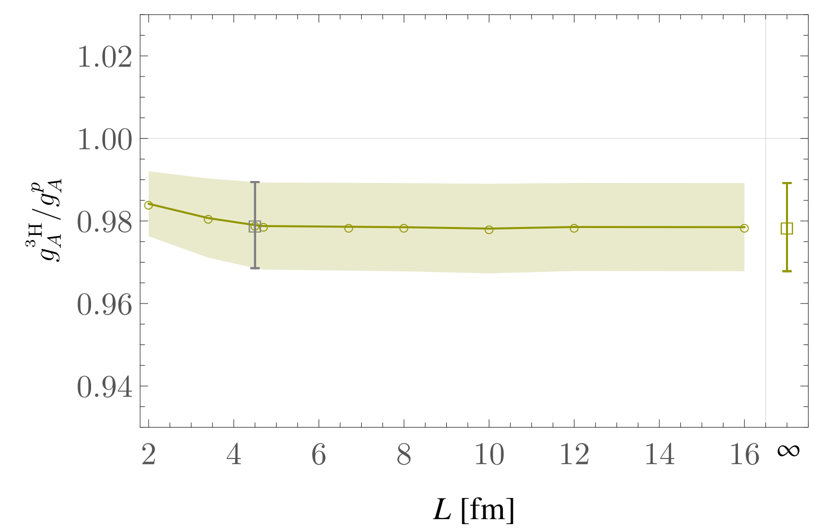

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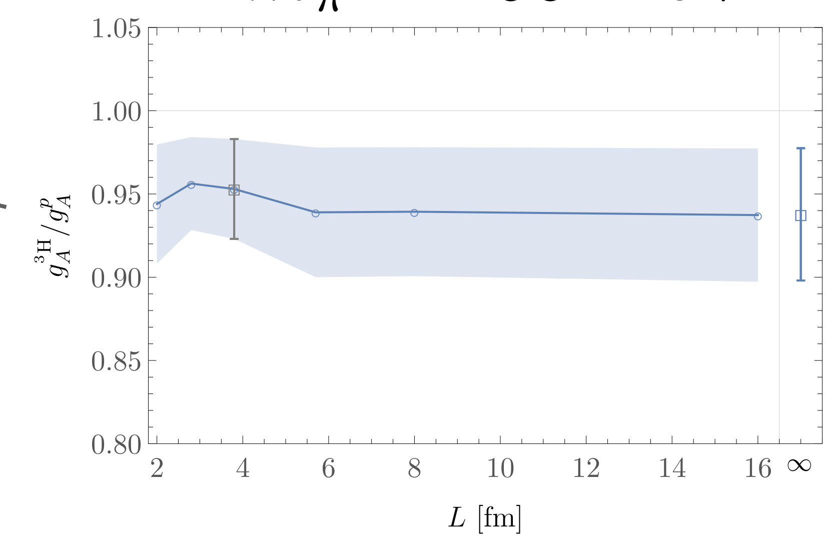

Conclusions

- 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

- While lattice calculations are only able to reach light nuclei ($A \leq 4$), they can be used to reach larger systems with EFTs and many-body techniques Barnea et al., PRL 114 (2015)
Contessi et al., PLB 772 (2017)
Bansal et al., PRC 98 (2018)

Thank you!