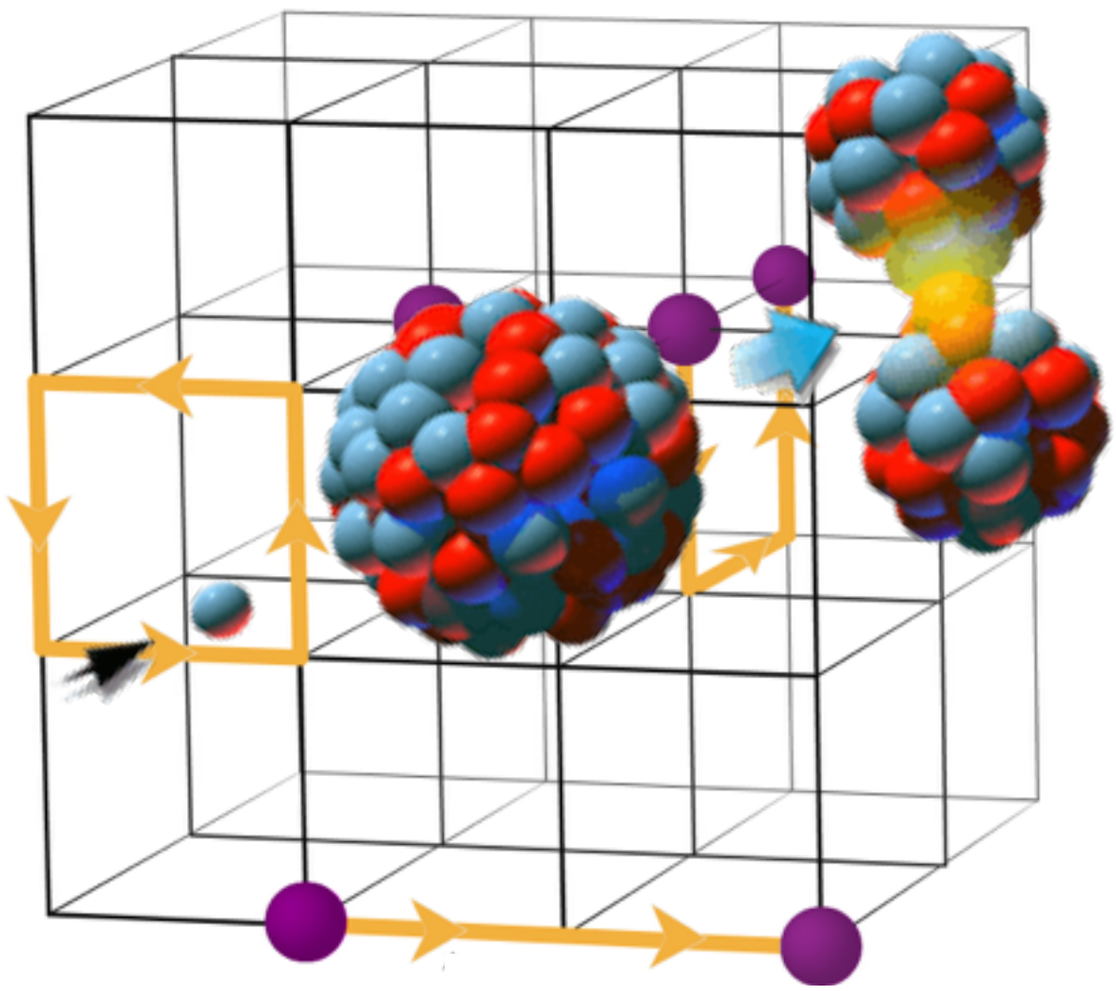
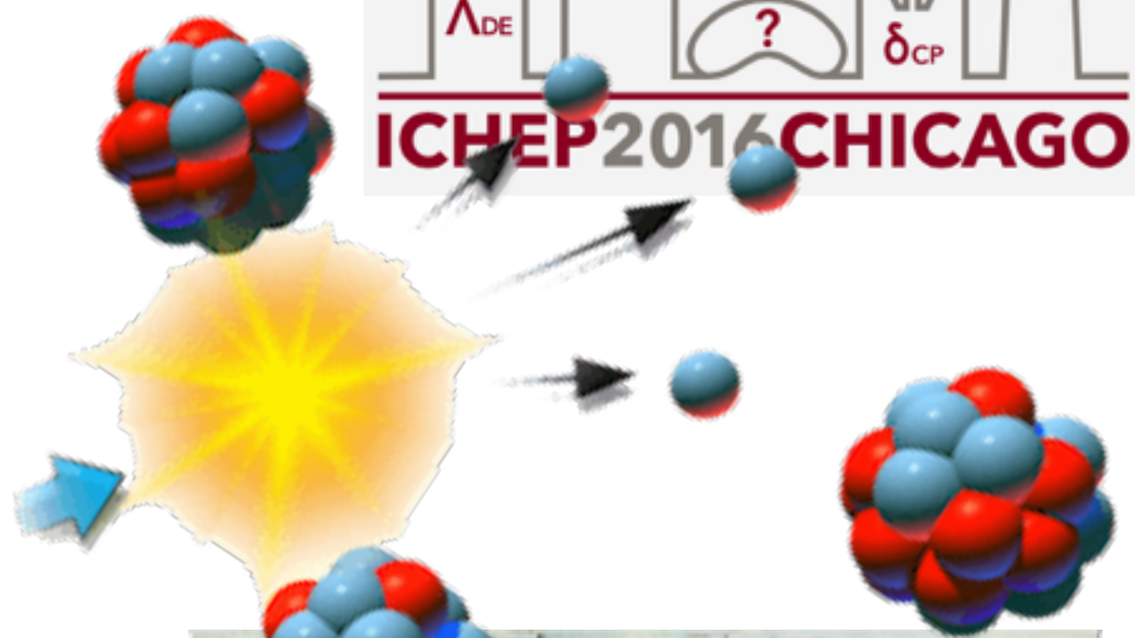
Axial Current Matrix Elements in Light Nuclei from Lattice QCD

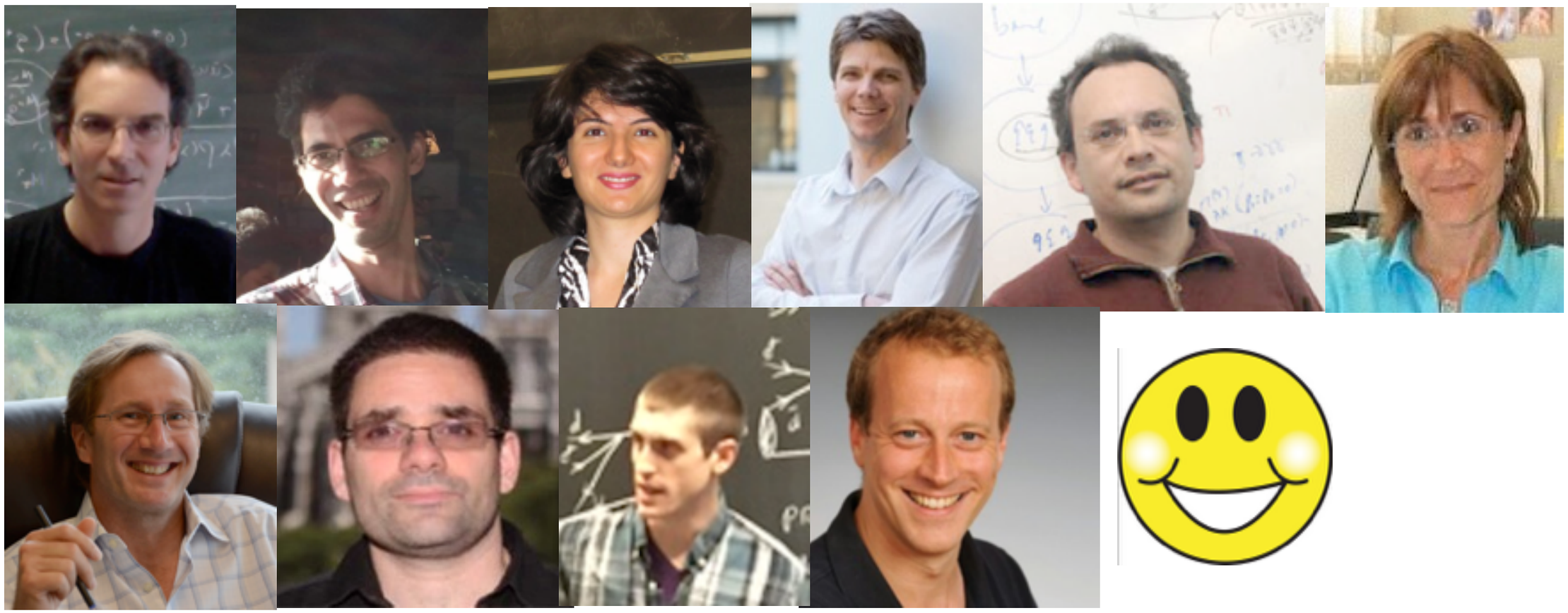




Martin J Savage

on behalf of the NPLQCD Collaboration

INSTITUTE for NUCLEAR THEORY



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Martin Savage (INT)
Frank Winter (JLab)
Jonas Wilhelm (Geissen)

Emmanuel Chang (INT)
William Detmold (MIT)
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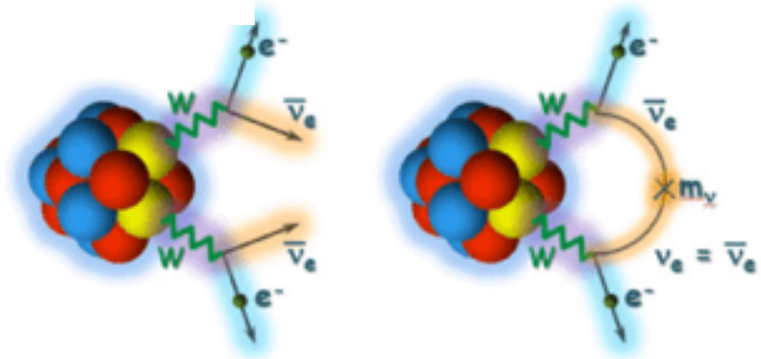
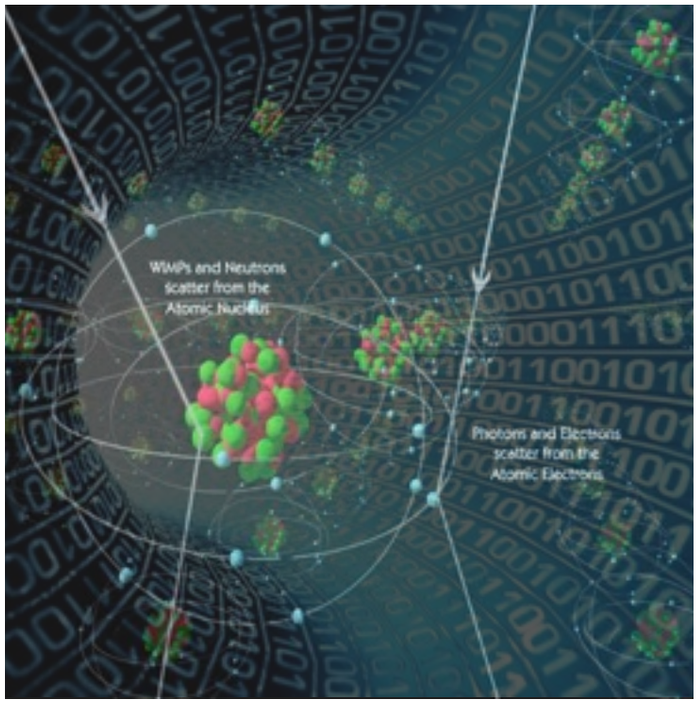
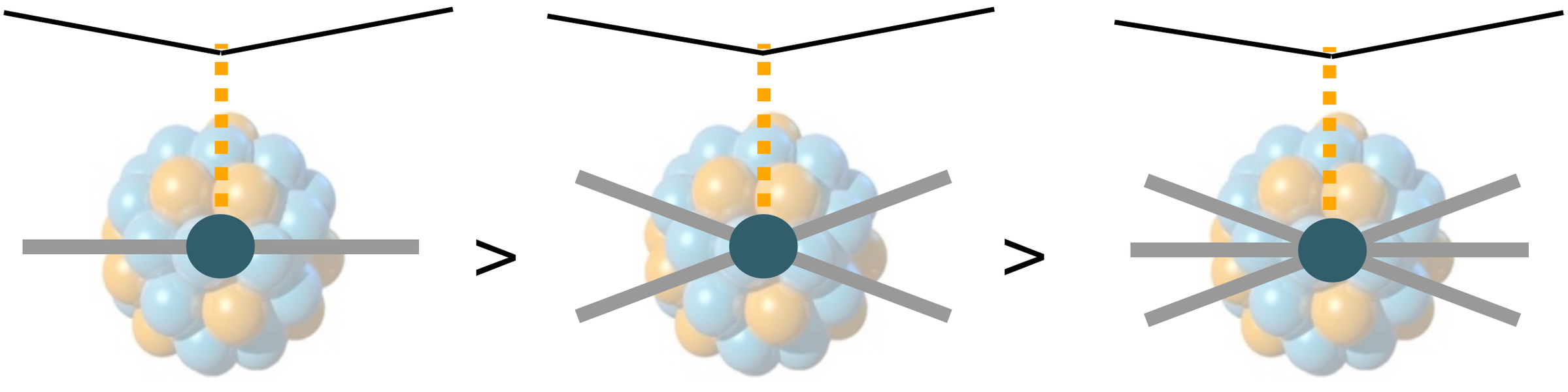
Past Collaborators
Saul Cohen
Pari Junnarkar
Huey-Wen Lin
Aaron Torok
Tom Luu
Andre Walker-Loud

Nuclear Matrix Elements

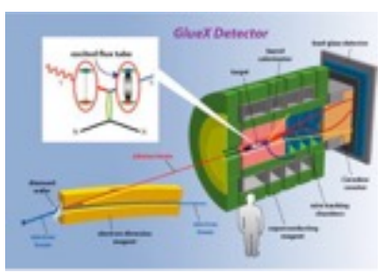


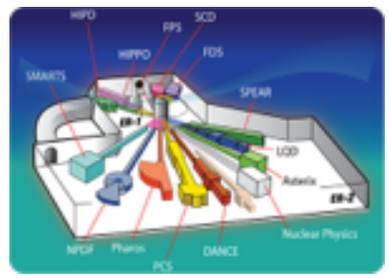


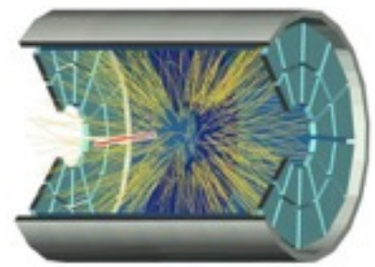
ν, e, μ, X - JLab, ν-experiments, DUNE, DM, edm, …

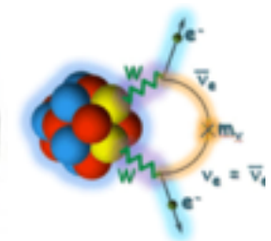


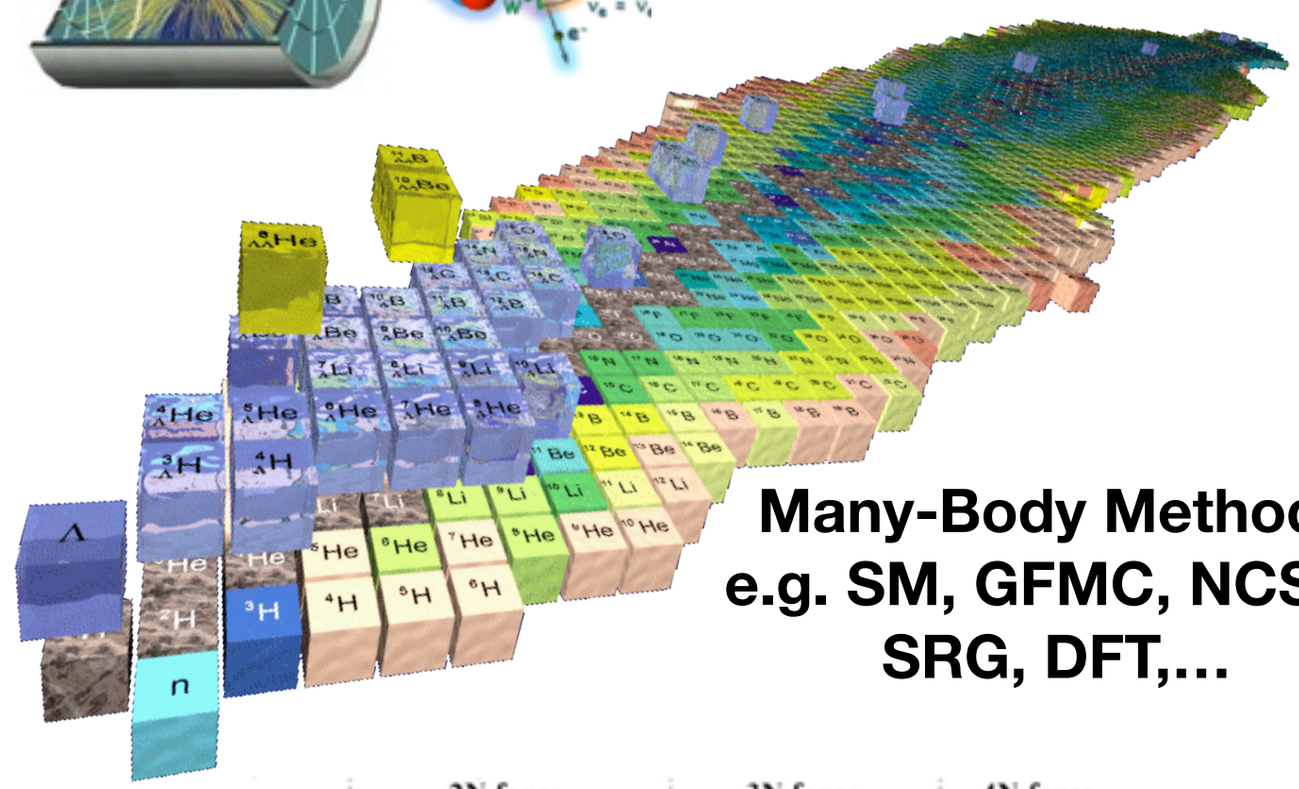
Low-Energy Nuclear Physics



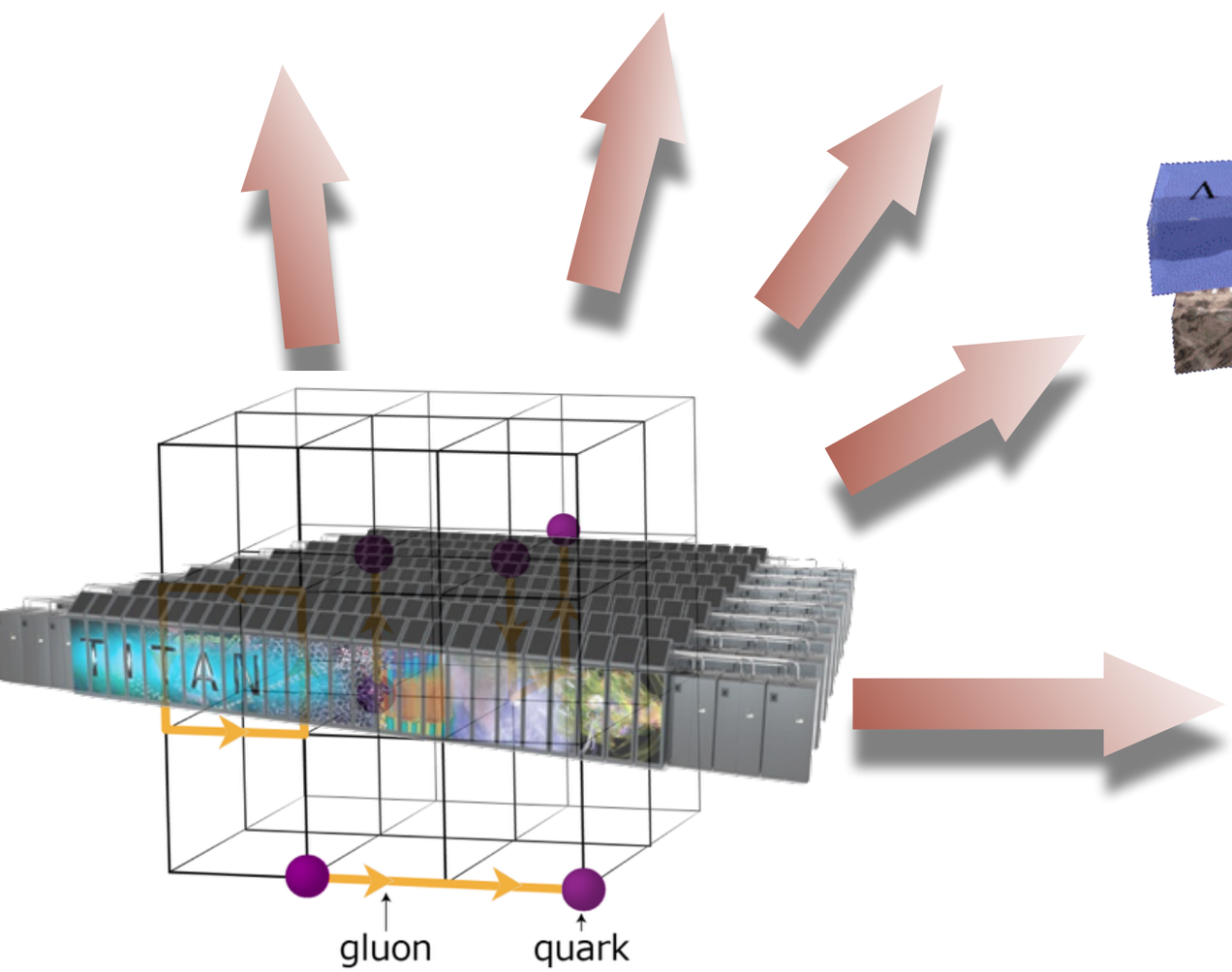


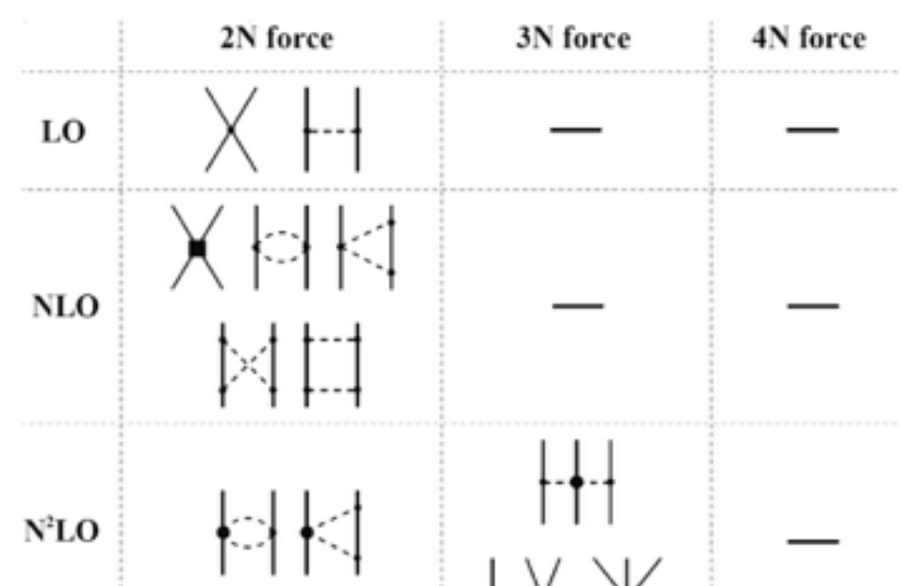




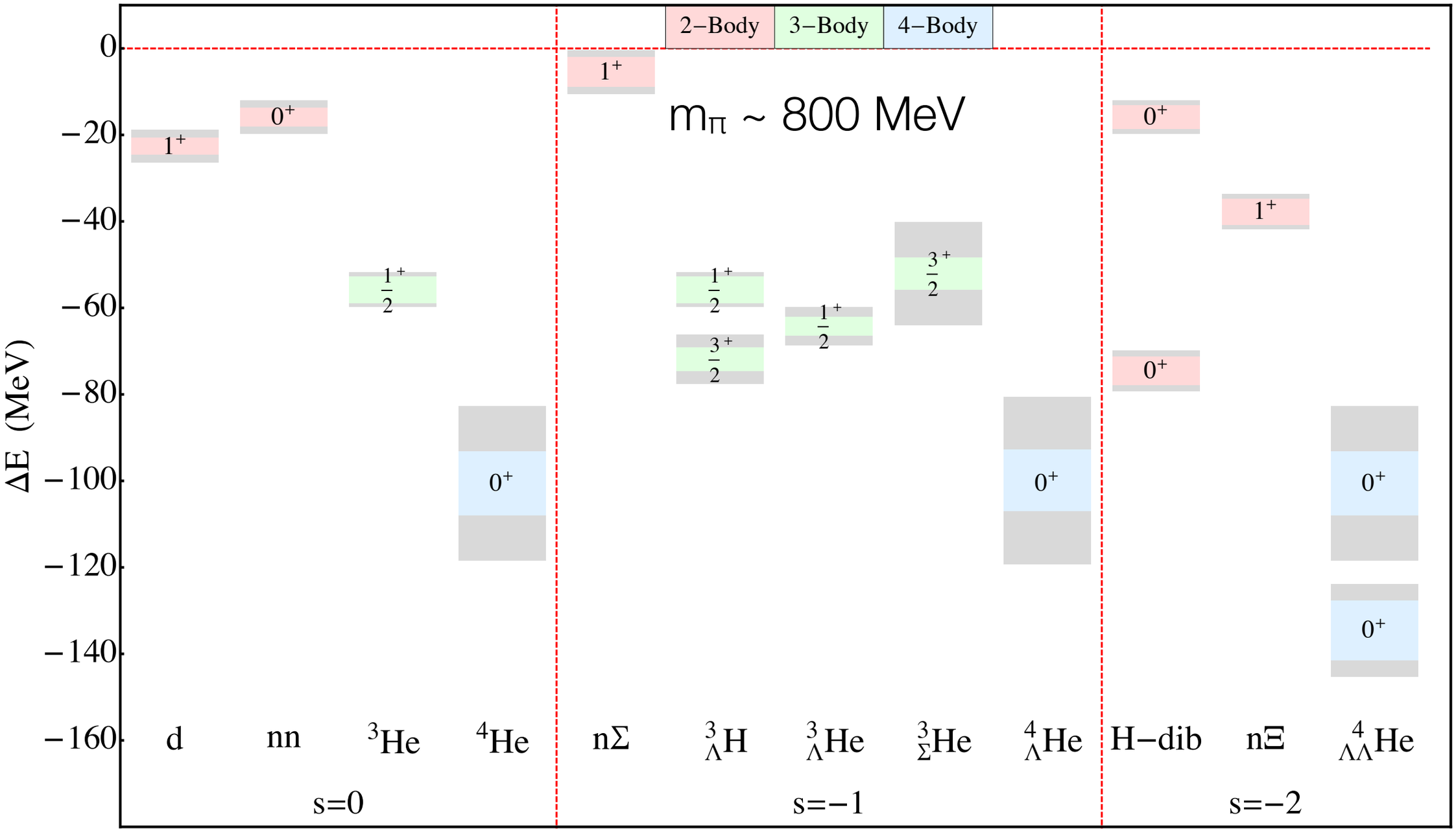


Many-Body Methods e.g. SM, GFMC, NCSM, SRG, DFT,…



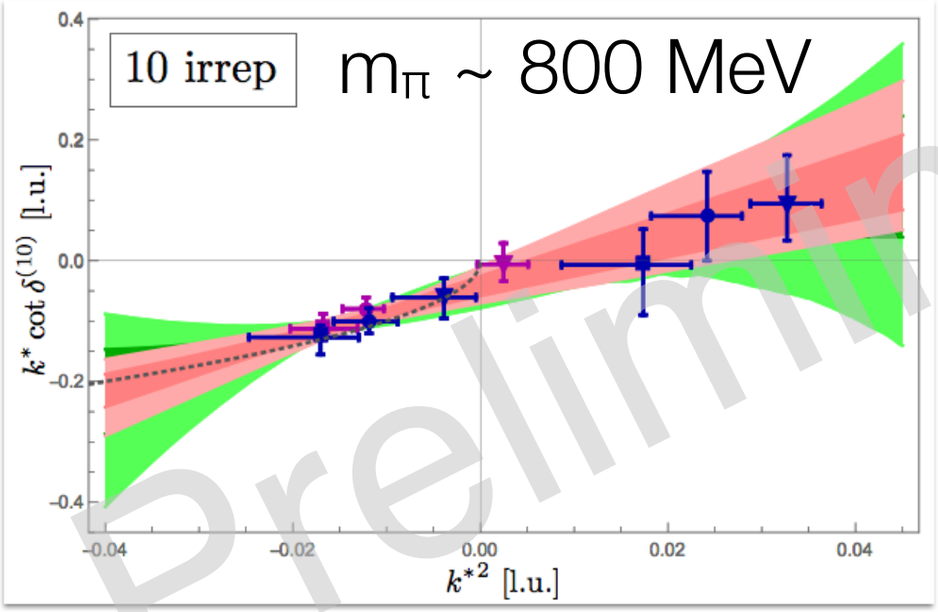


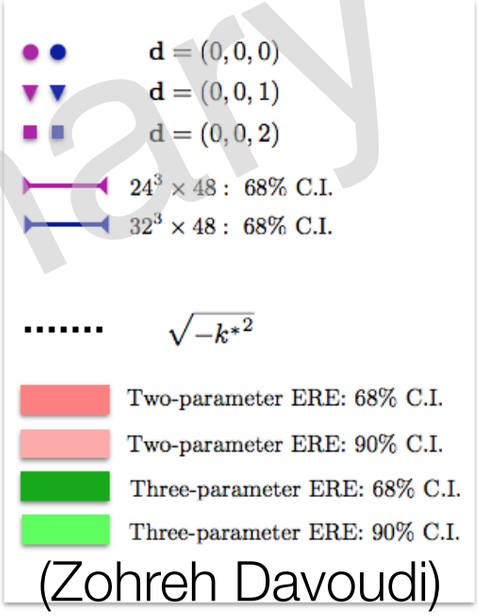
Nuclei from QCD



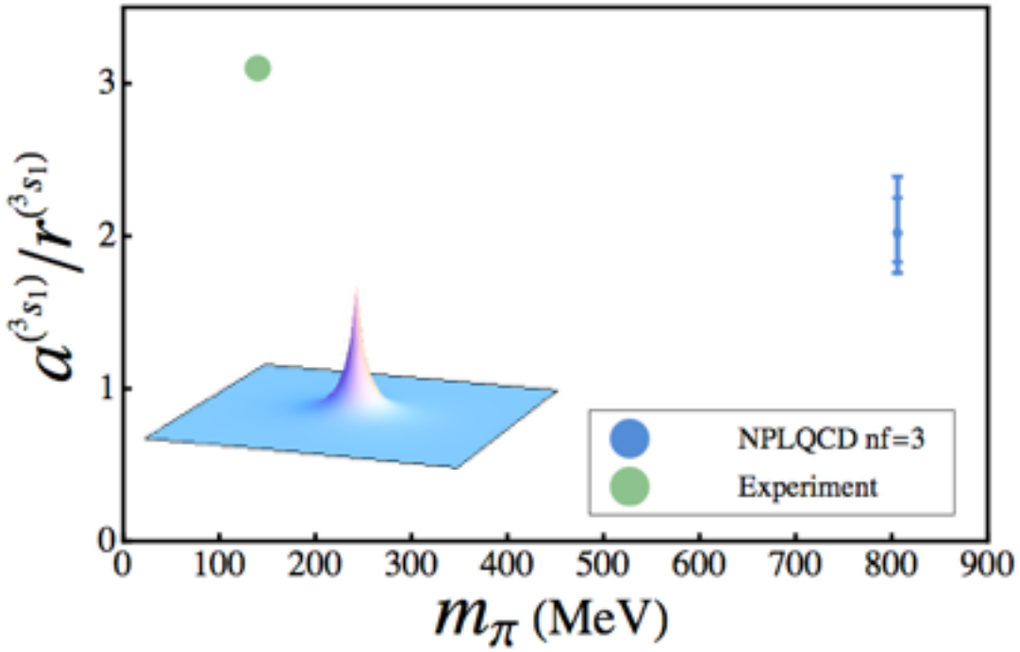
Beane *et al* (NPLQCD), Phys.Rev. D87 (2013) 3, 034506, Phys.Rev. C88 (2013) 2, 024003

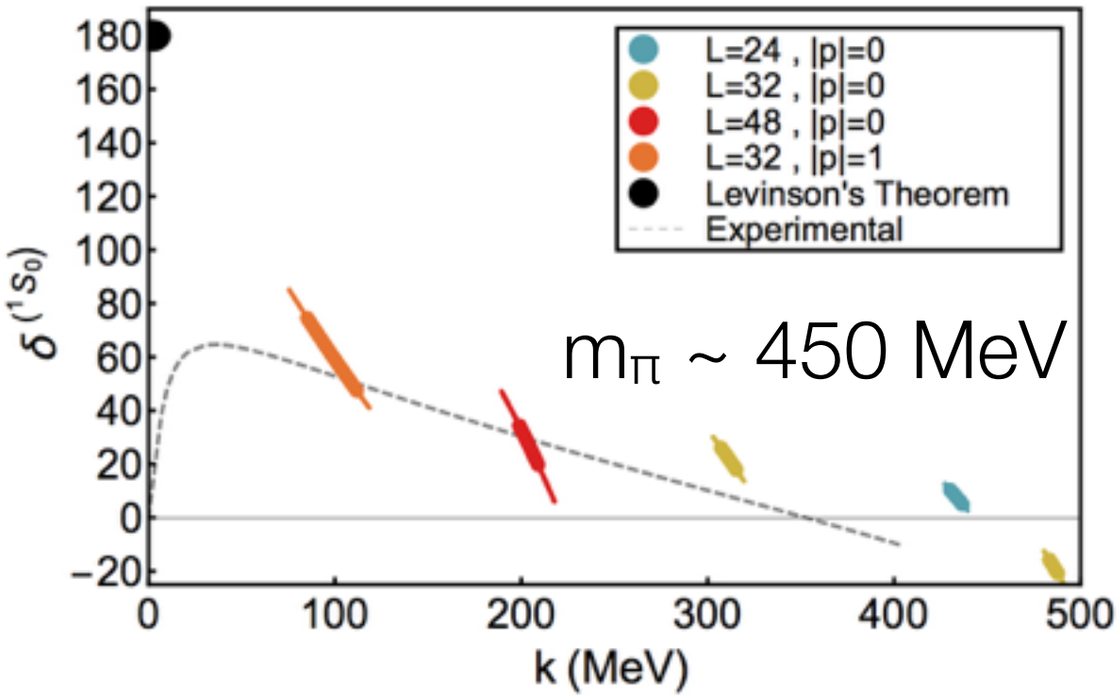
NN Interactions
NPLQCD





(Zohreh Davoudi)

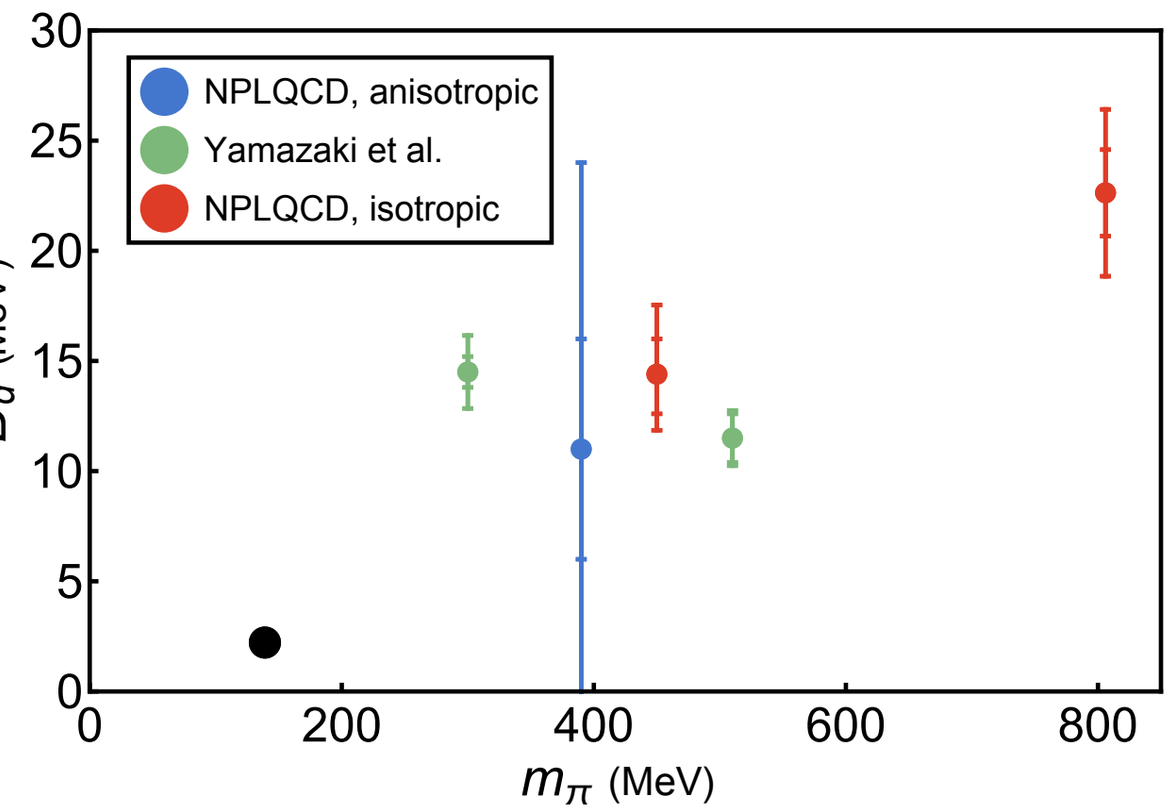


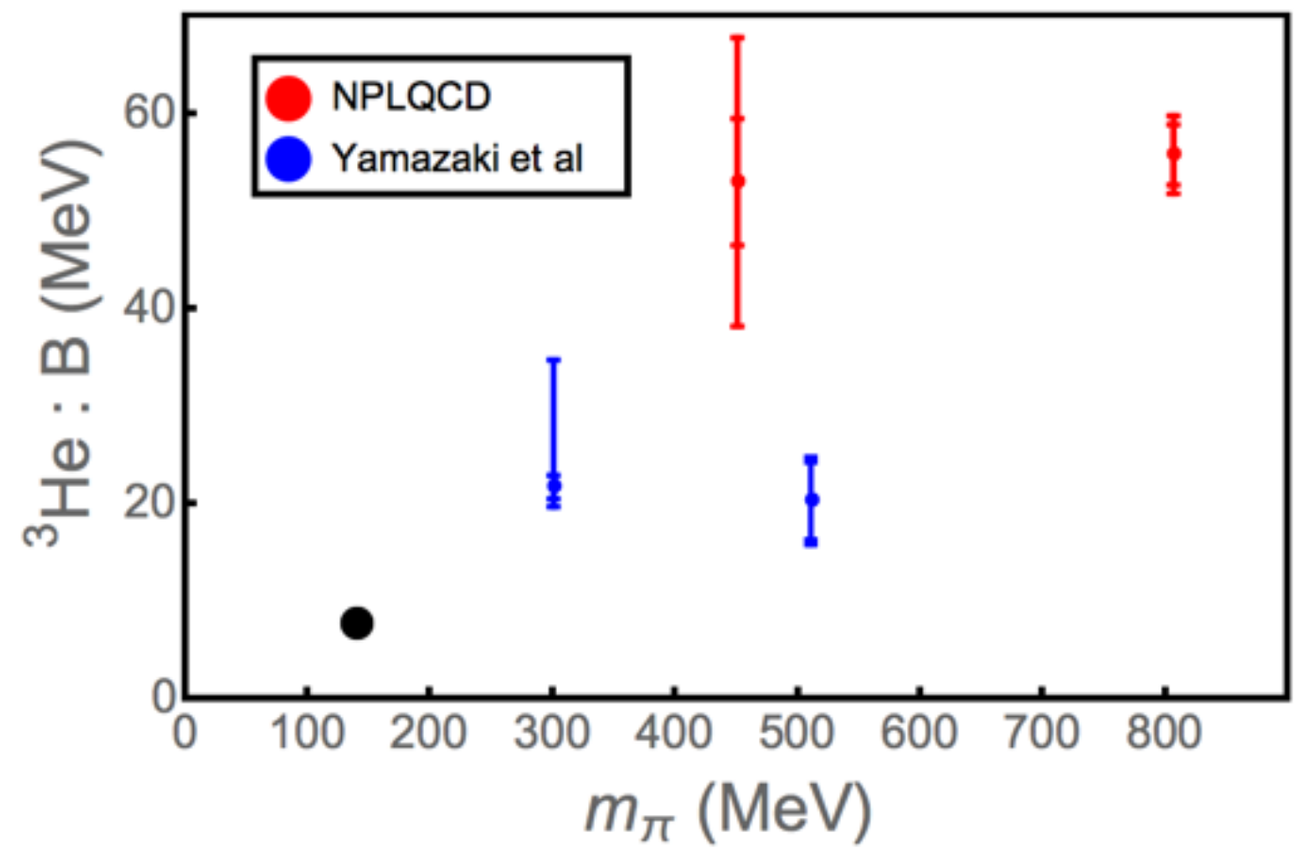


Deuteron appears to be unnatural but not finely-tuned ??
Generic feature of YM with n_f=3

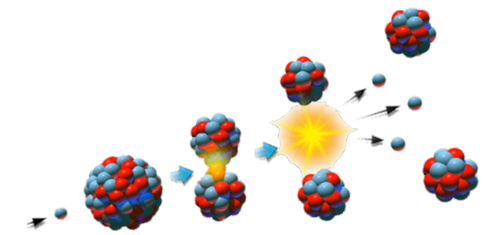
Kostas Orginos, et al (NPLQCD) Phys.Rev. D92 (2015) no.11, 114512

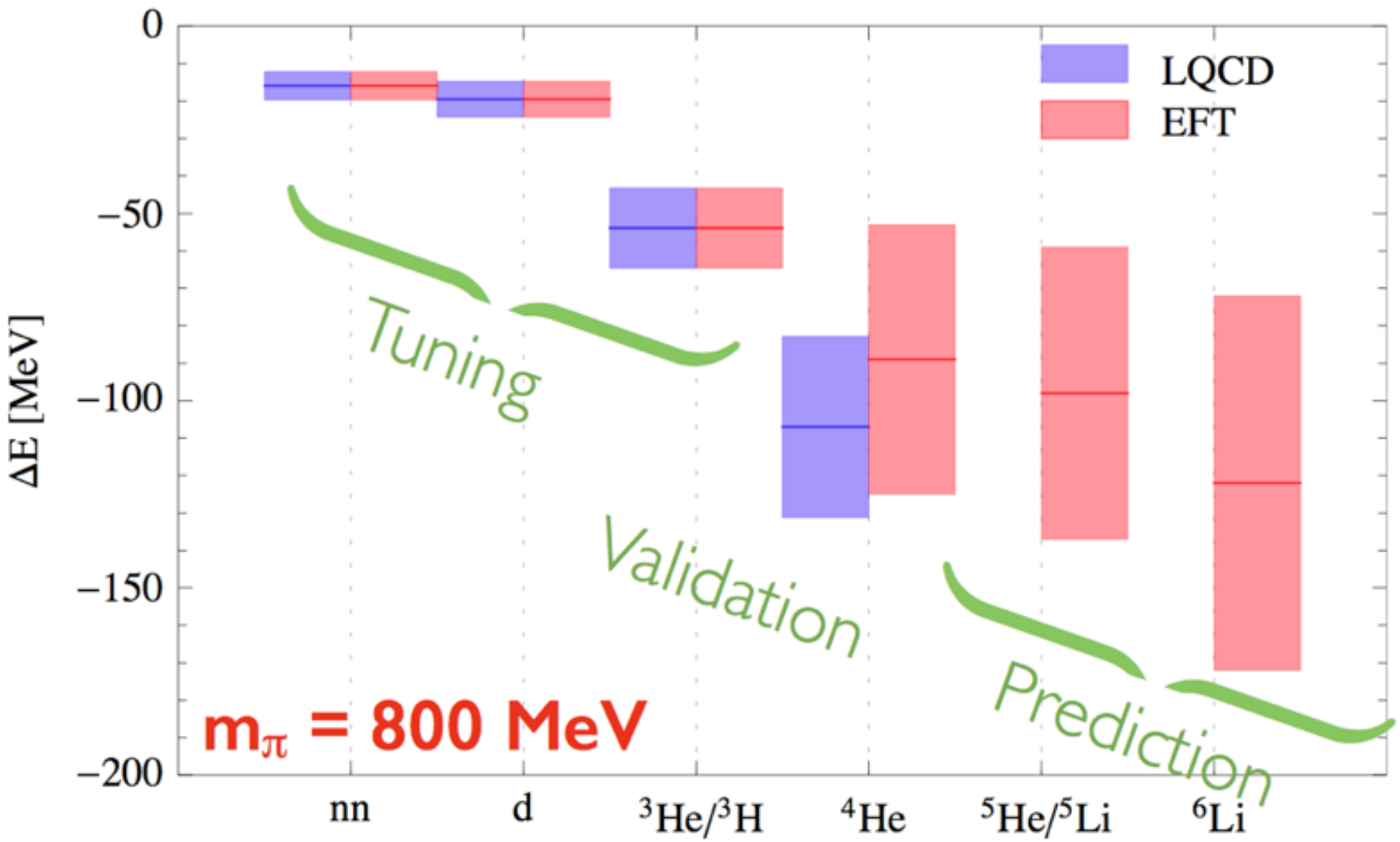
Light Nuclei : Quark Mass Effects





The Periodic Table as a function of the quark masses



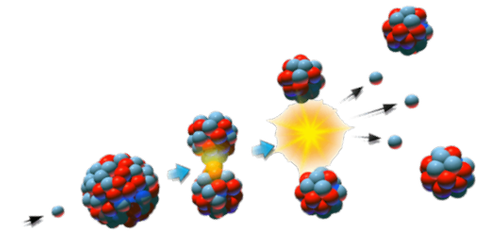


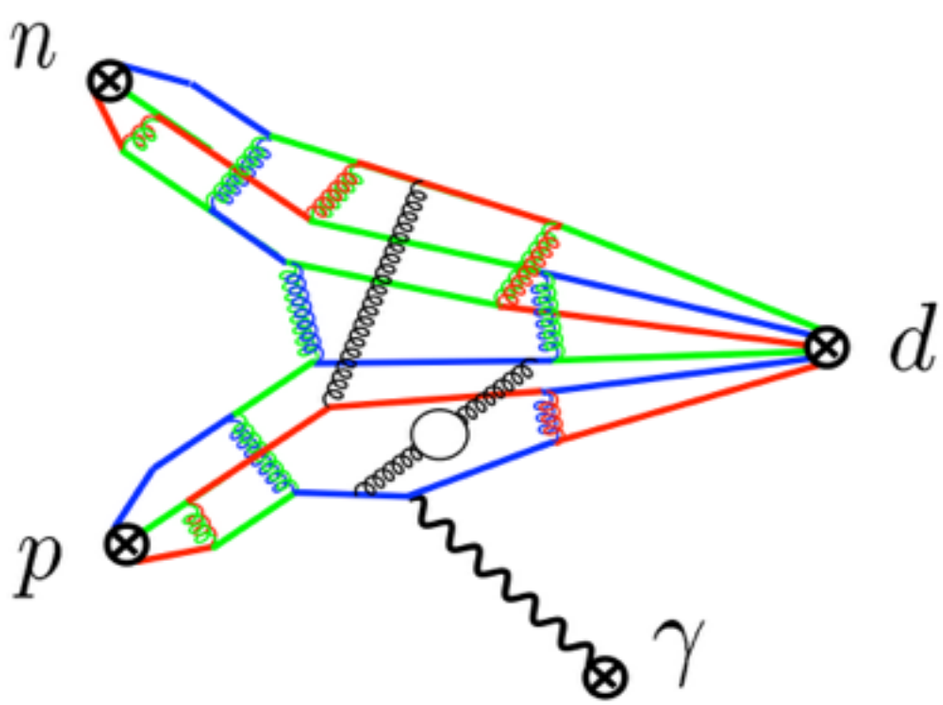
Enhances the scope of the Lattice Calculations

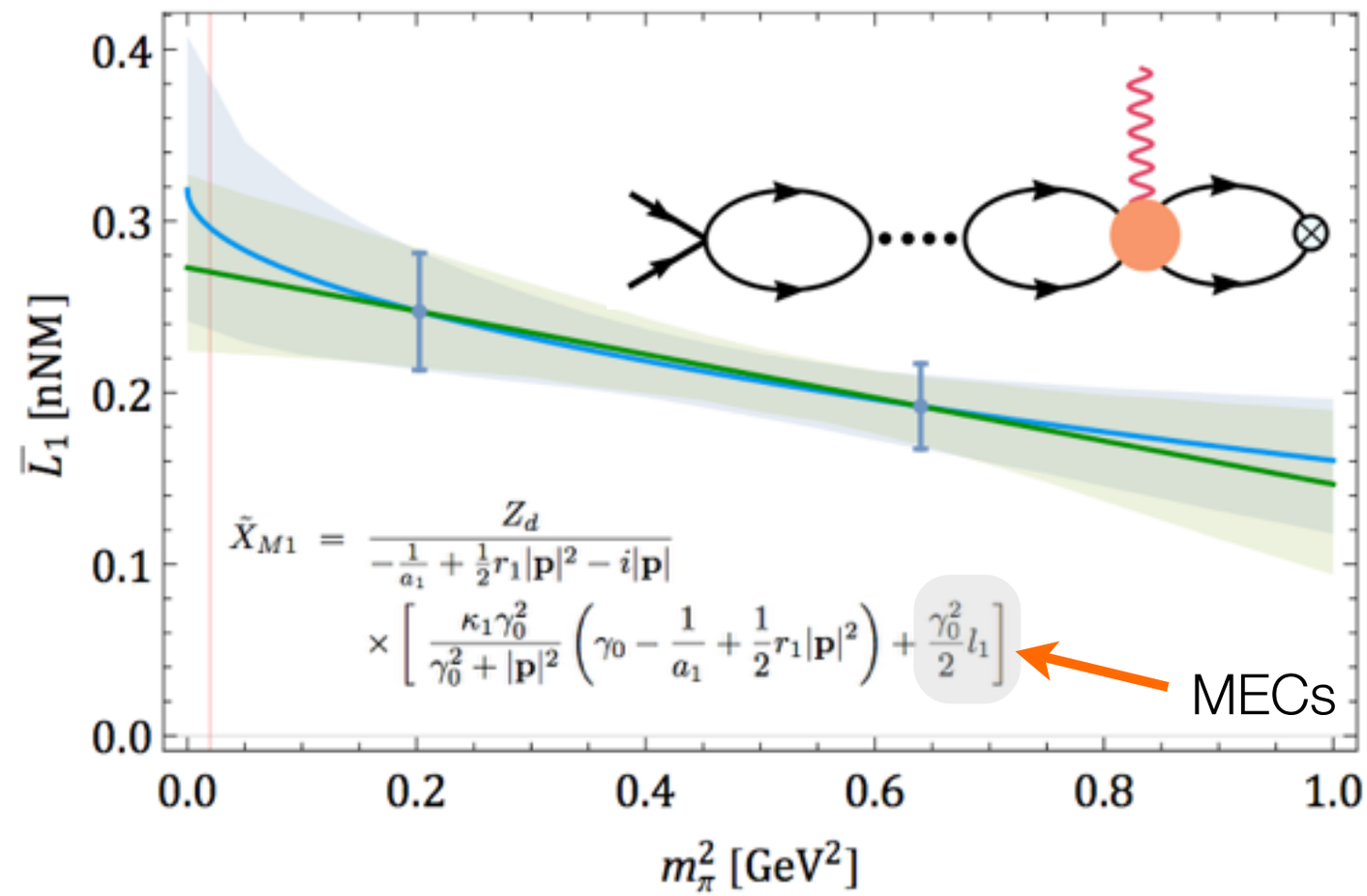
Effective Field Theory for Lattice Nuclei , N. Barnea et al, Nov 20, 2013. 5 pp. , Phys. Rev. Lett. 114 (2015) 5, 052501

First Inelastic Nuclear Reaction :

$$np \to d\gamma$$







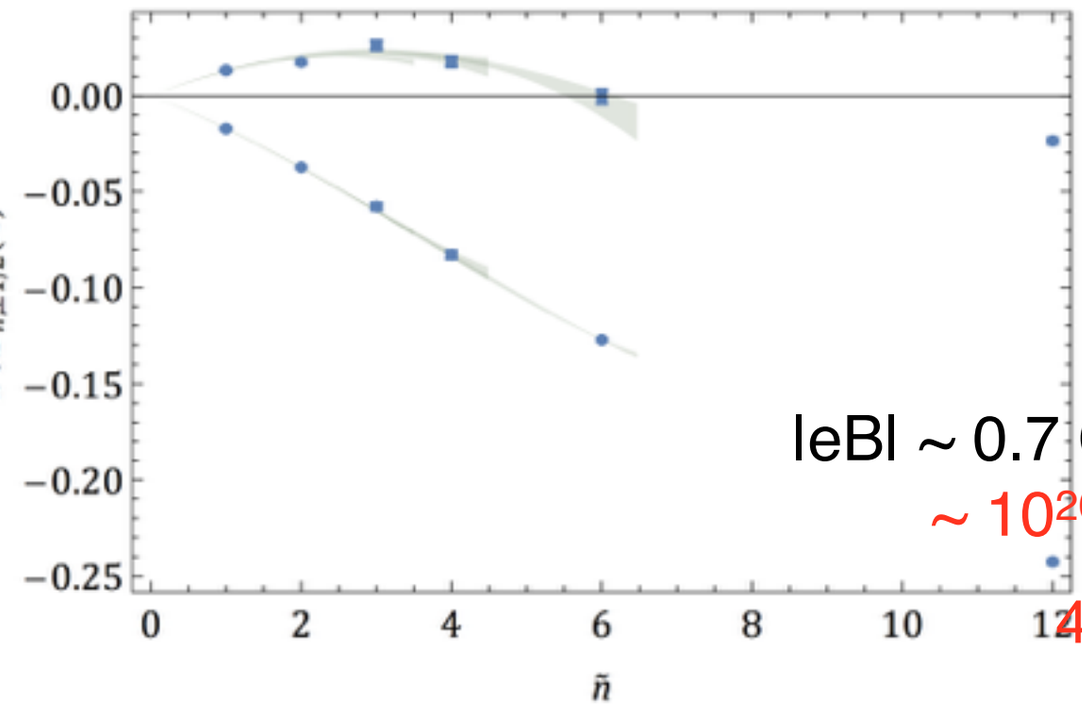
physical point:

σ^{LQCD} = 334.9(5.3) mb $\quad v = 2,200$ m/s

σ^{expt} = 334.2(0.5) mb [306 mb single nucleons alone]

Ab Initio Calculation of the np → dγ Radiative Capture Process, NPLQCD, Phys. Rev. Lett. 115 (2015) 13, 132001

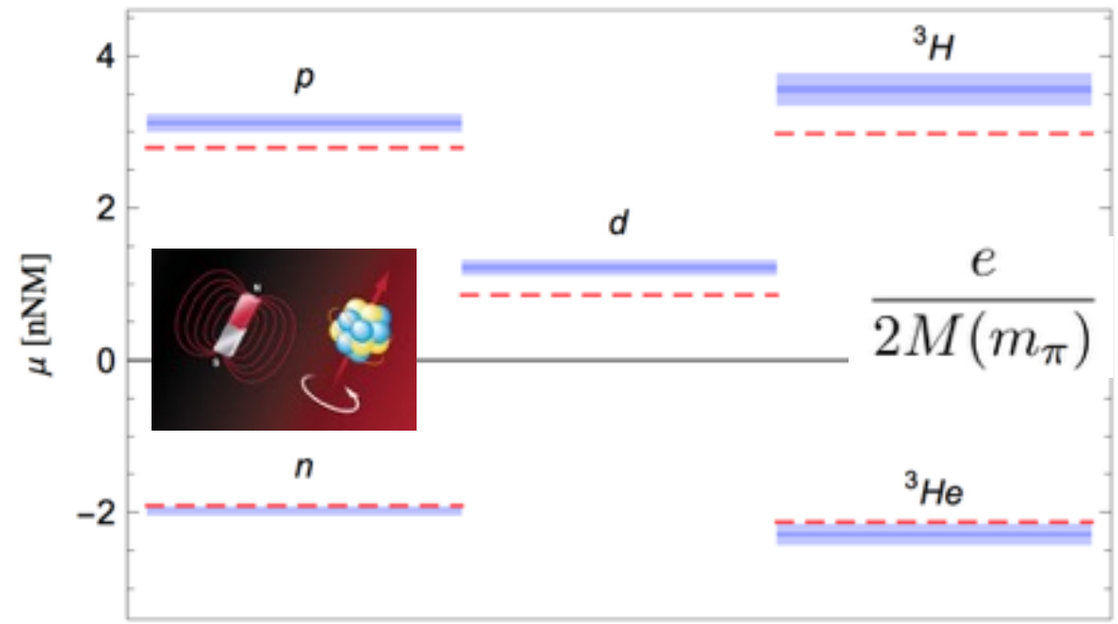
Magnetic Moments
Neutron Spin States

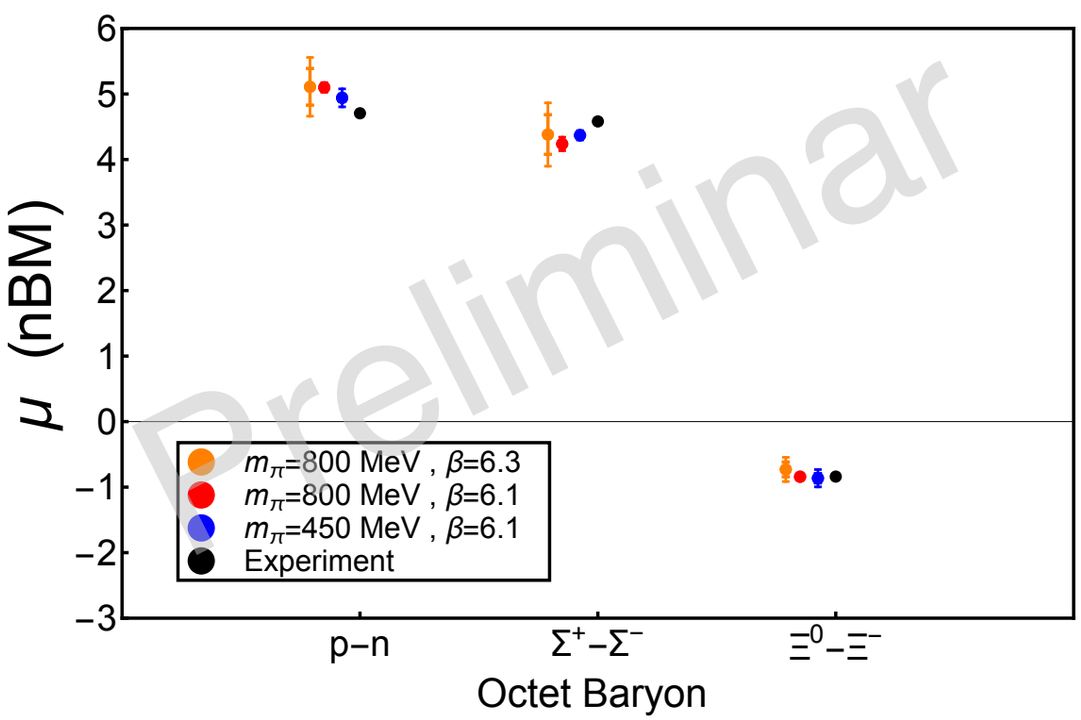


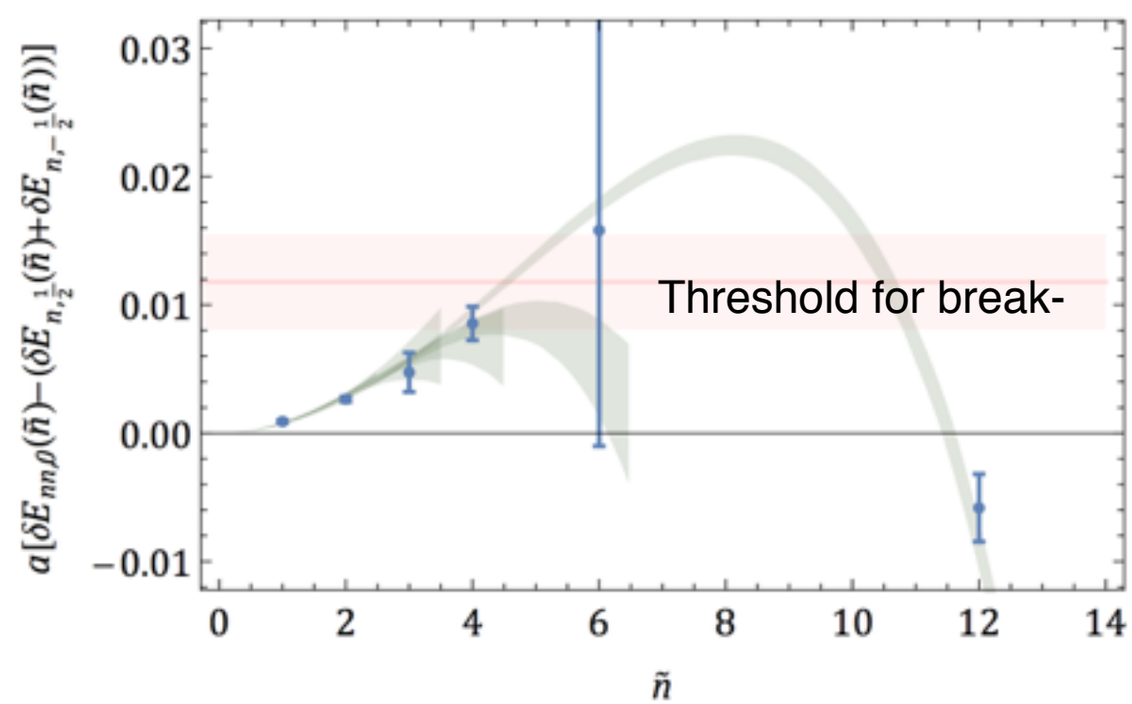
leBl ~ 0.7 GeV²

~ 10^{20} Gauss

400 MeV

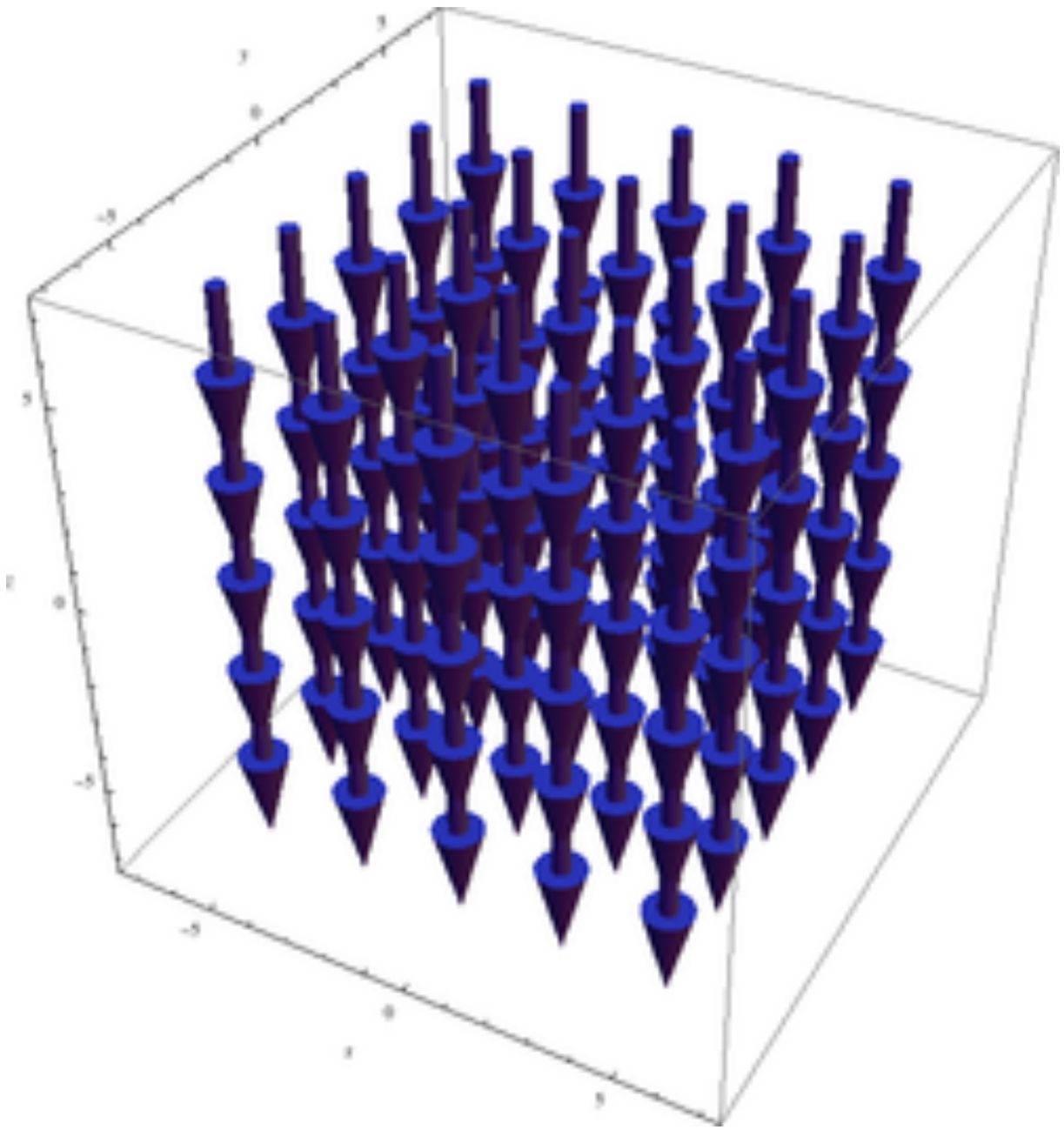






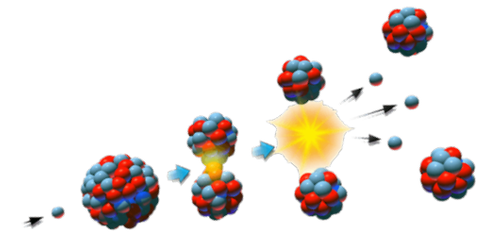
NPLQCD, Phys.Rev.Lett. 113 (2014) no.25, 252001 and Phys.Rev. D92 (2015) no.11, 114502

Axial-Current Matrix Elements



Uniform
Spacetime Independent
Axial Background Field
$W^a_\mu \rightarrow W^3_z$

Axial-Current Matrix Elements

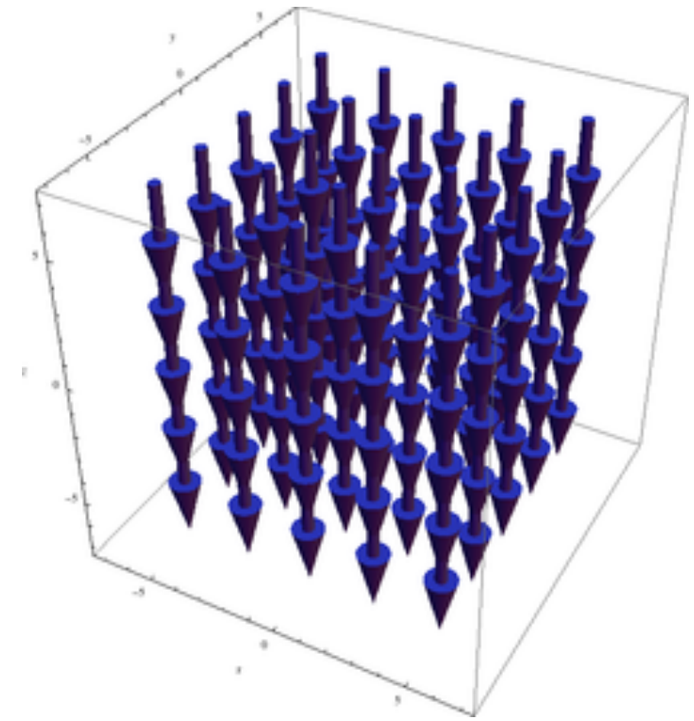


Formalism developed in

Electroweak matrix elements in the two nucleon sector from lattice QCD

William Detmold, MJS

Nucl. Phys. A743 (2004) 170-193



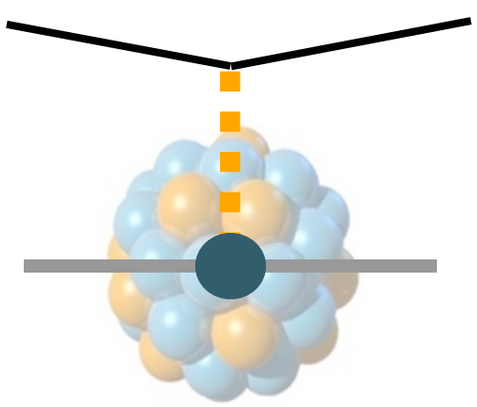
quark-level interactions

$$\delta\mathcal{L} = -\frac{1}{2} g W \left(\overline{u}\gamma^z\gamma_5 u - \overline{d}\gamma^z\gamma_5 d\right)$$

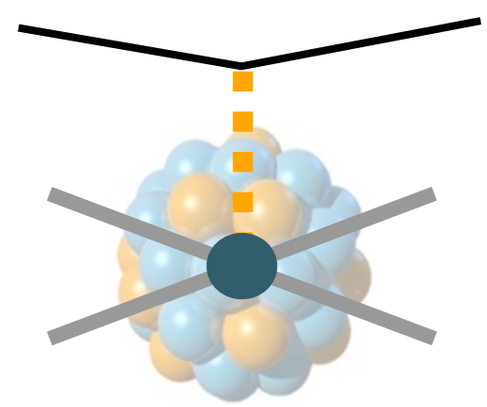
hadronic-level interactions

$$\delta\mathcal{L} = -gW\,\frac{g_A}{2}\,N^\dagger\sigma^z\tau^3 N \;-\; \frac{gW\;l_{1,A}}{2M\sqrt{r_1 r_3}}\left[t_3^\dagger s_3 + \text{h.c.}\right] \;+\; \ldots$$

single-nucleon interaction

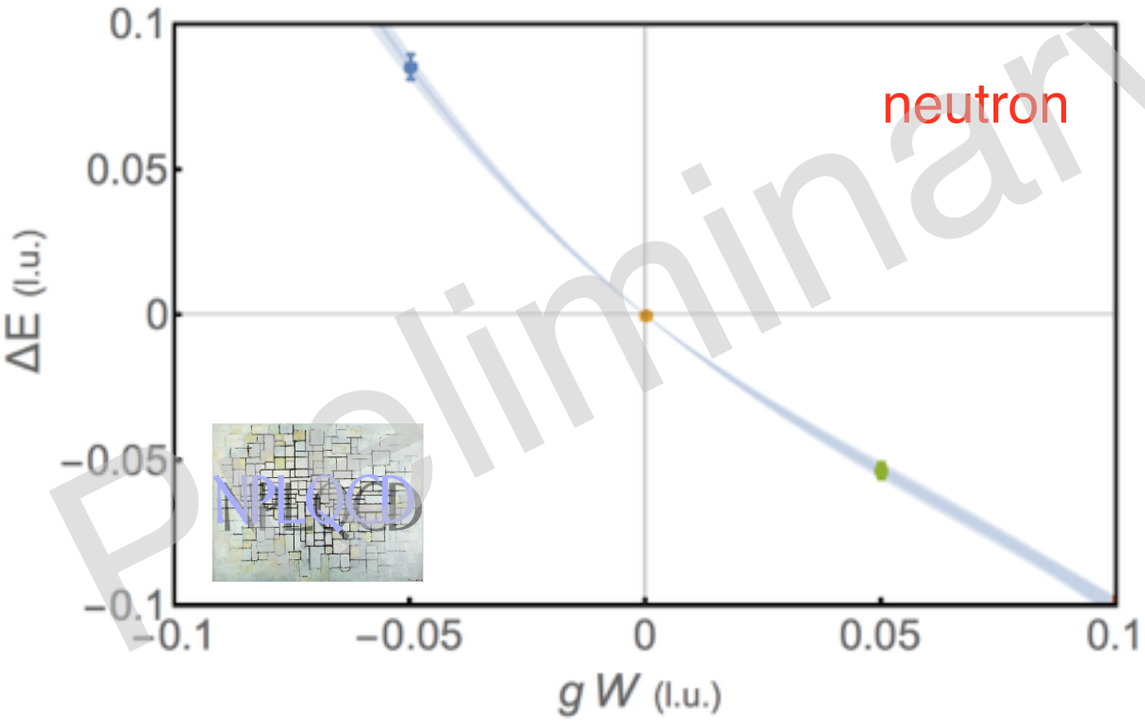


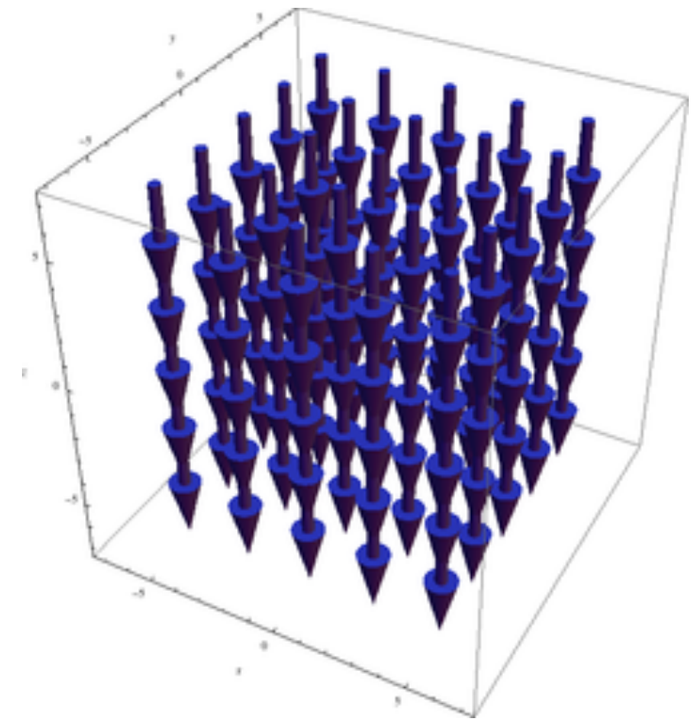
leading two-nucleon interaction

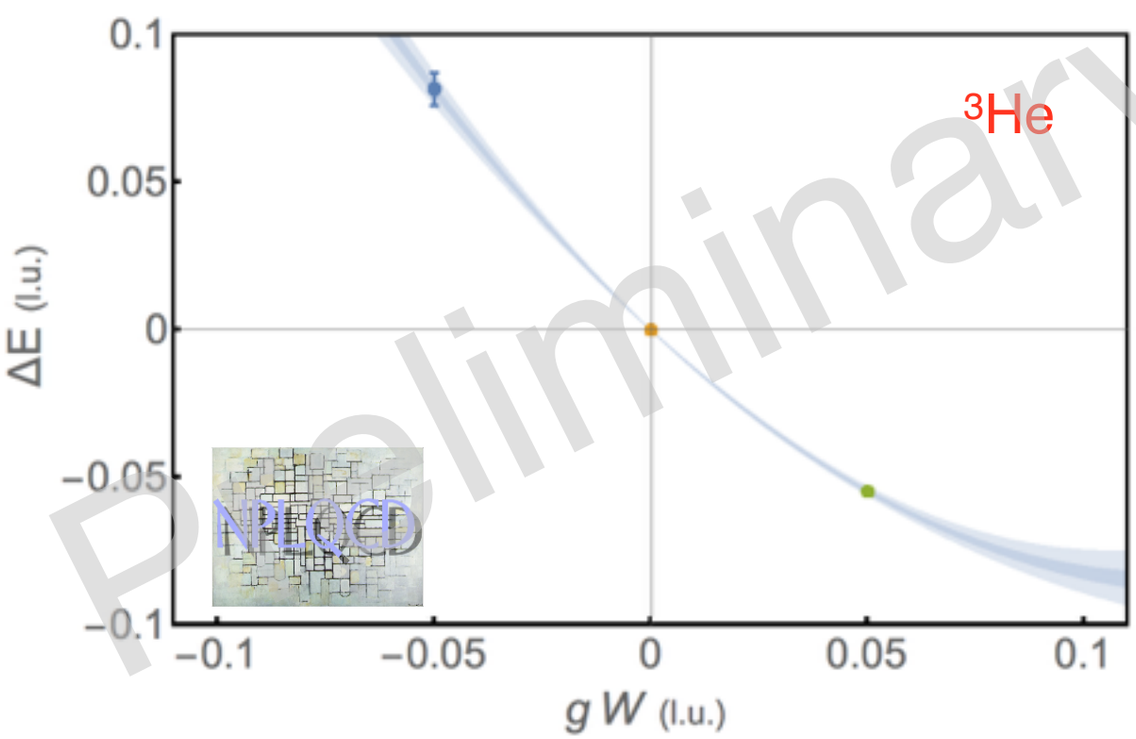


Axial-Current Matrix Elements

$M_\pi \sim 800$ MeV





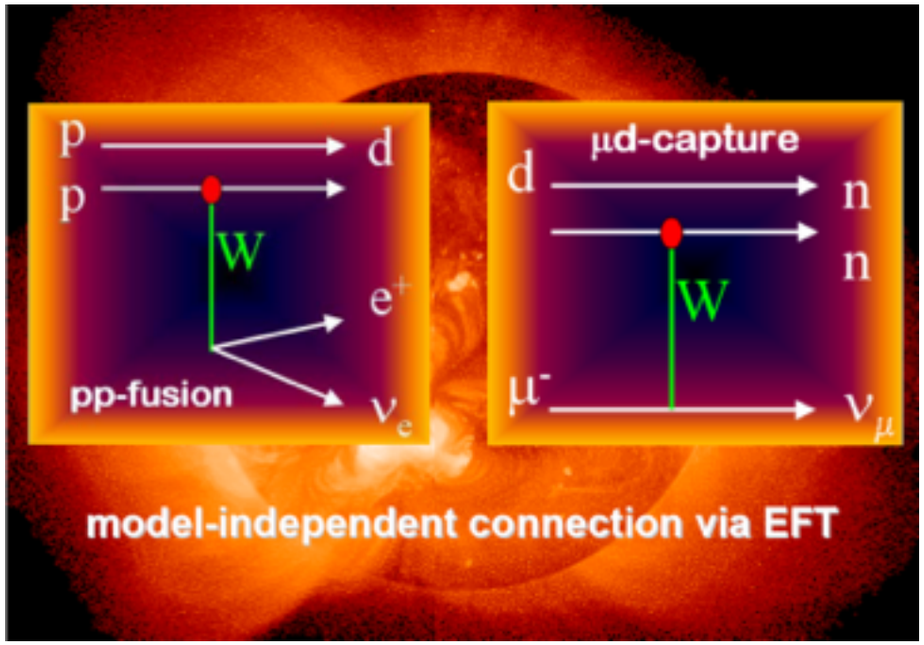


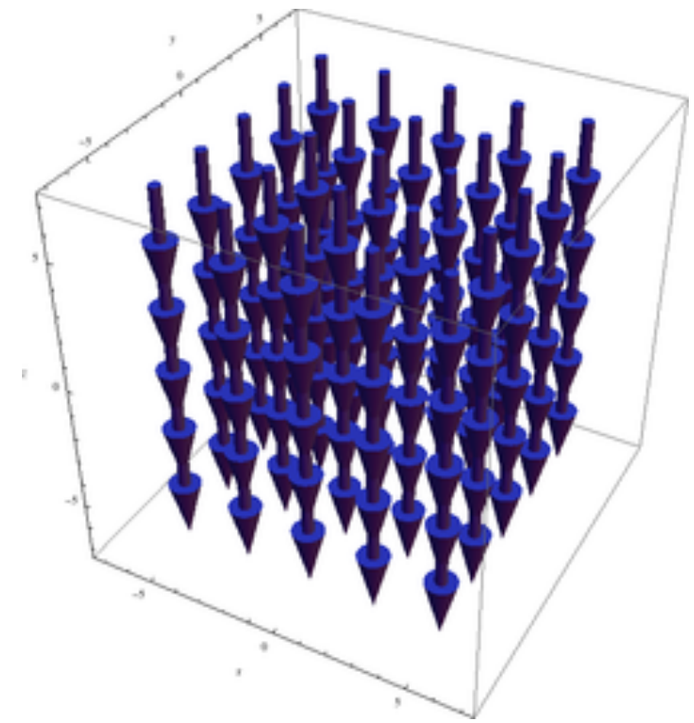
p : $g_A \sim 1.2$

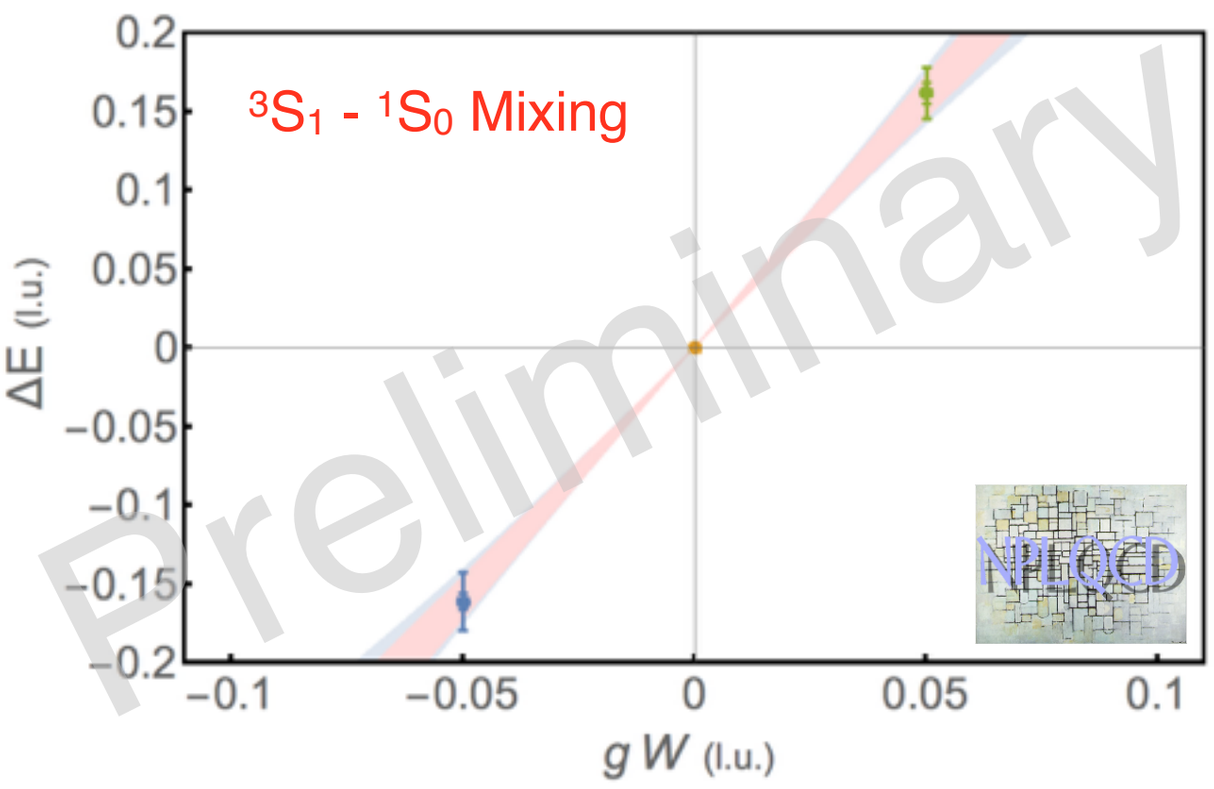
^{3}He : $g_A \sim 1.2$

Axial-Current Matrix Elements

$M_\pi \sim 800$ MeV



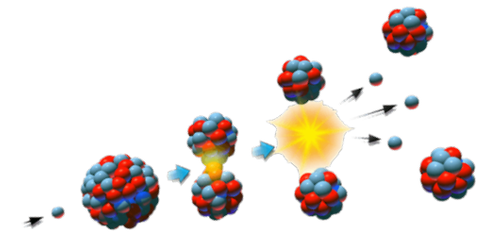


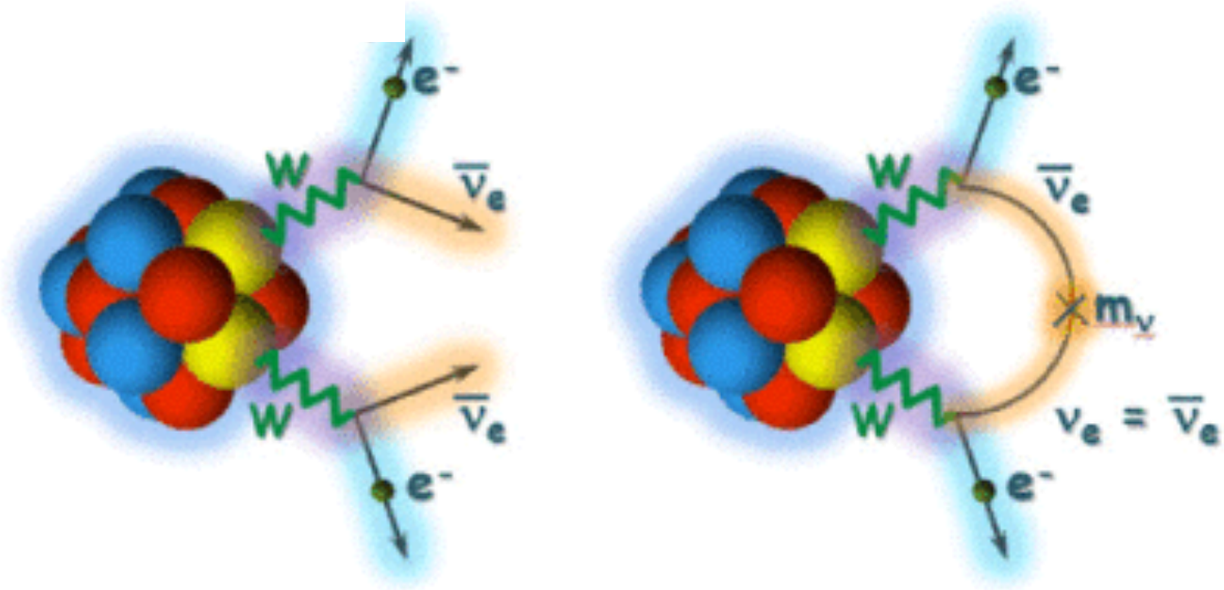


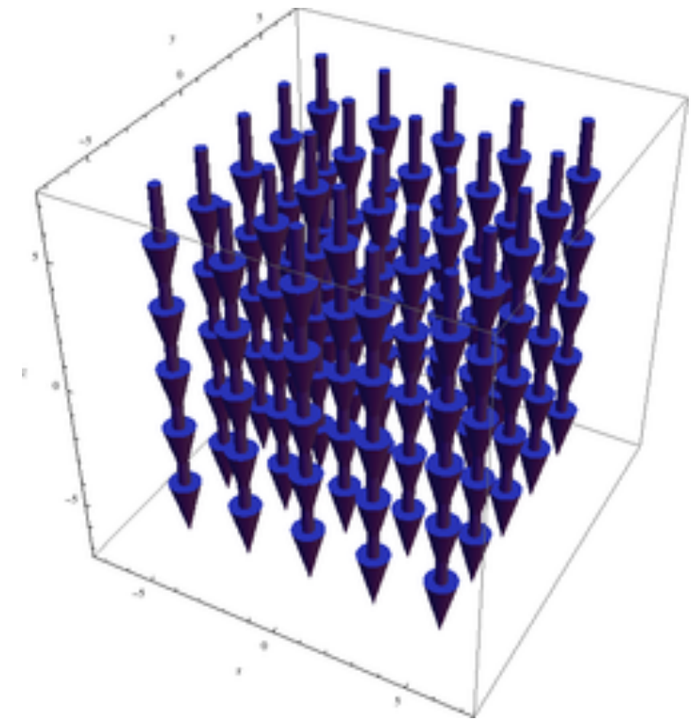
Extract the correlated two-nucleon interaction with axial field : L_{1A}

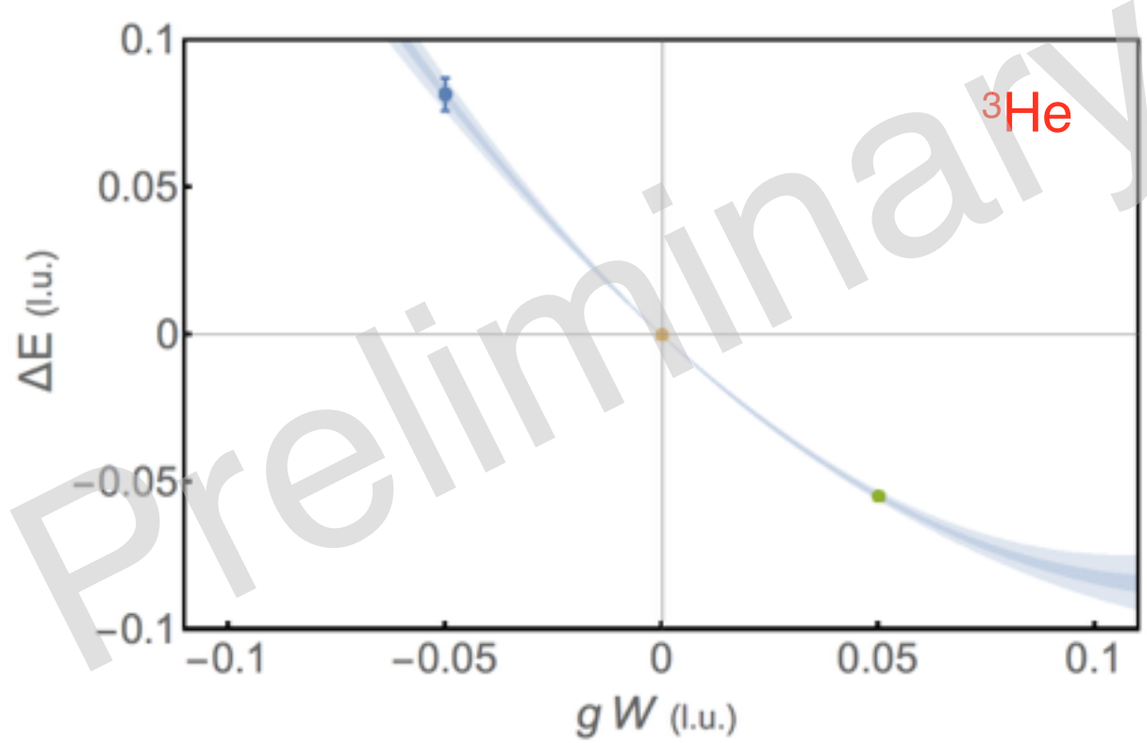
(aka - meson-exchange currents)

Axial Polarizabilities and 0νββ-decay rates





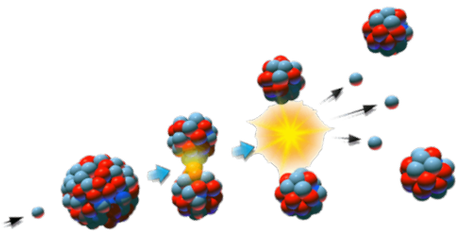




Curvature determined by Axial Polarizabilities.

Long-distance contribution to 0νββ-decay matrix elements

Summary and Outlook



- Lattice QCD of light nuclei and Interactions is underway
- Background field methods are valuable tools for electroweak and DM matrix elements,
  - e.g. **Zohreh Davoudi, William Detmold, Phys.Rev. D92 (2015) no.7, 074506**
- Axial current ME's are being calculated in light nuclei
  - refine chiral nuclear forces used in nuclear many-body calculations
- Axial polarizabilities important for 0νββ-decay matrix element calculations

FIN