New NCSM results for exotic nuclear moments, exotic nuclei, sub-leading 3N interactions

EMMI Workshop and 52nd International Workshop on Gross Properties of Nuclei and Nuclear Excitations: Challenges in effective field theory descriptions of nuclei

Hirschegg, January 18 - 24, 2026

Petr Navratil

TRIUMF

Collaborators:

Kostas Kravvaris (LLNL), Sofia Quaglioni (LLNL), G. Hupin (IJCLab), Lotta Jokiniemi (TU Darmstadt), Stephan Foster (TRIUMF/McMaster), Kia Boon Ng (TRIUMF), Stephan Malbrunot (TRIUMF), Lan Cheng (Johns Hopkins), Georgios Palkanoglou (TRIUMF)

2026-01-22

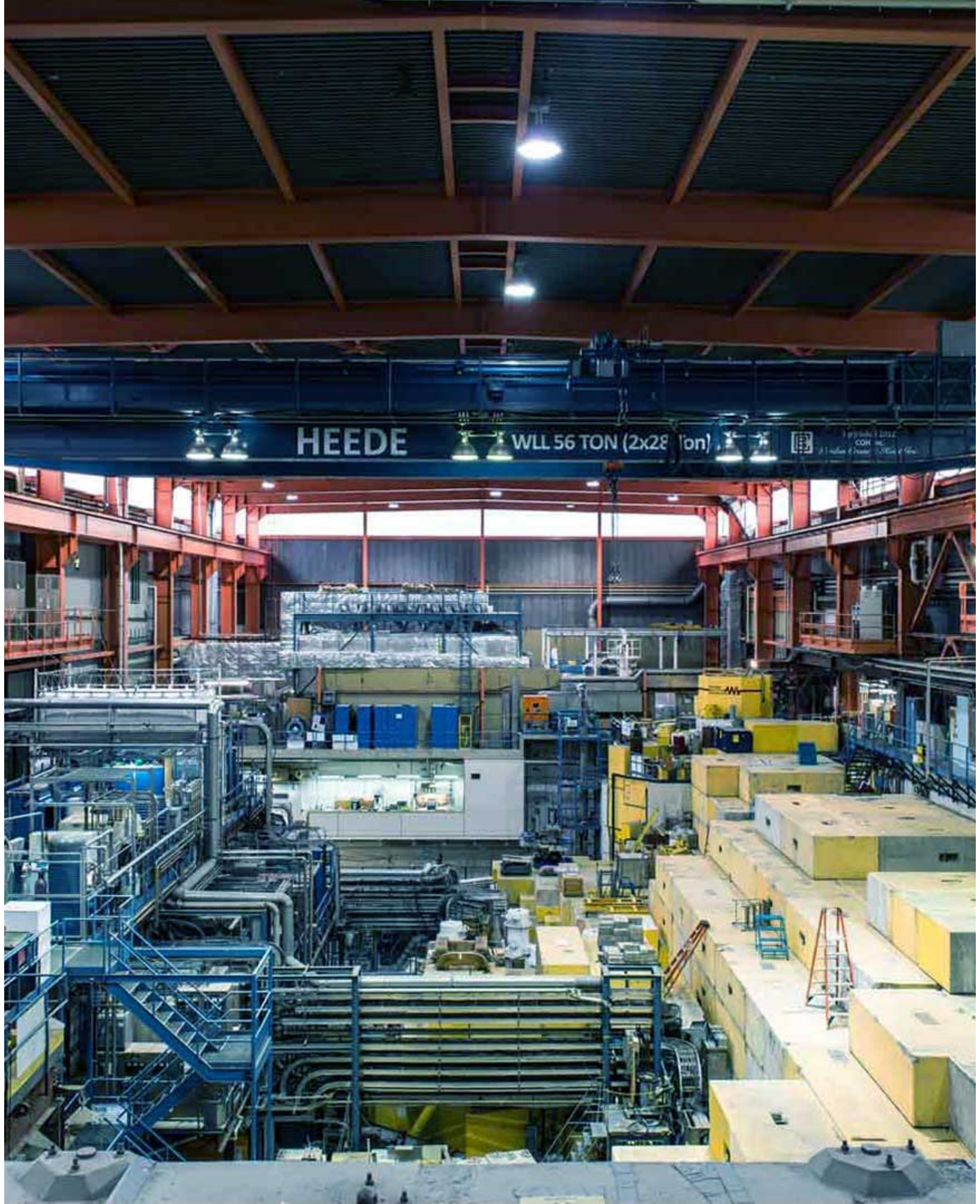
Discovery, accelerated

Outline

- Introduction – *ab initio* nuclear theory – no-core shell model (NCSM)
- Precision chiral EFT Hamiltonian with a sub-leading 3N interaction term
- *Ab initio* calculations of parity-violating moments
  - Experimental limits on the Schiff moment of ^{19}F
- Borromean halo nucleus ^{11}Li within NCSM (prerequisite for $^{11}Li \sim {}^{9}Li + n + n$)
- Enhanced short-range 3N interaction with two-pion exchange – results for ^{3}H
- Conclusions

Sub-leading 3N interactions

Ab initio nuclear theory - no-core shell model (NCSM)



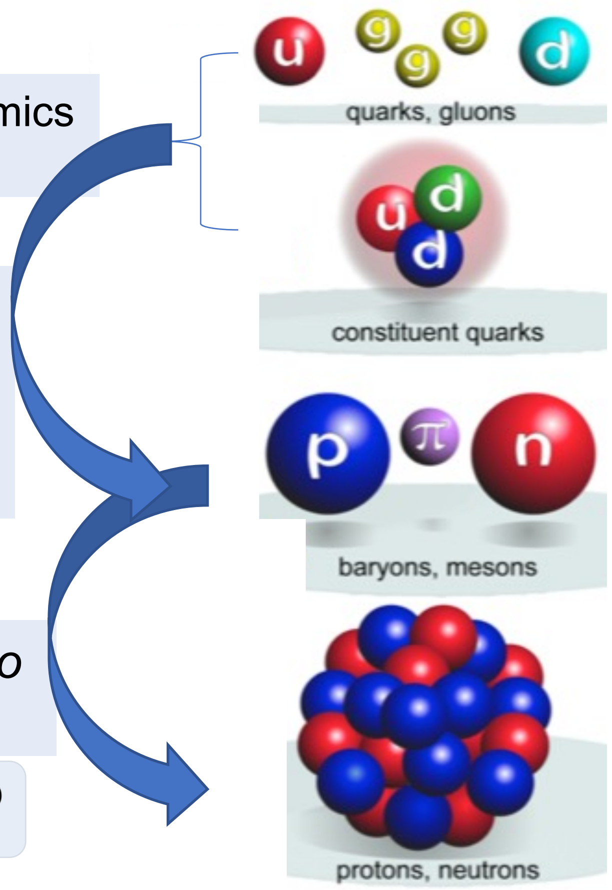
First principles or *ab initio* nuclear theory

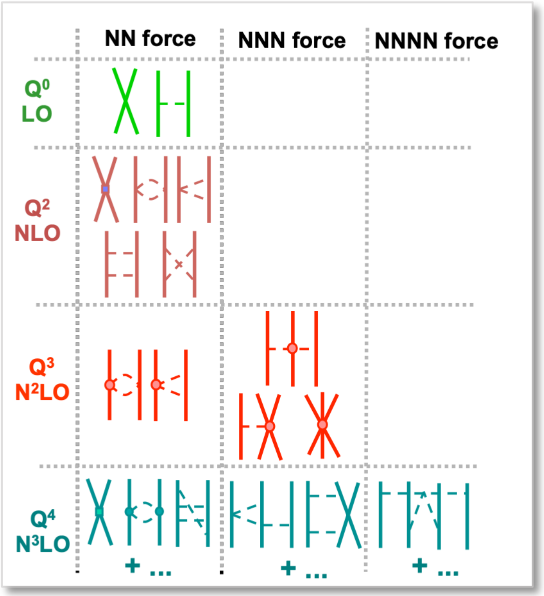
Quantum Chromodynamics (QCD)

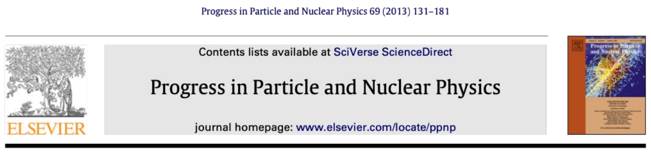
Chiral Effective Field Theory (parameters fitted to NN data)

Many-body *ab initio* nuclear theory

$$H\,\Psi^{(A)} = E\,\Psi^{(A)}$$

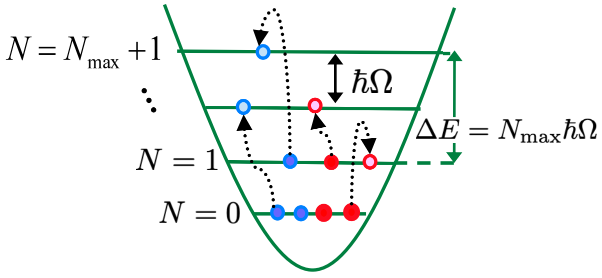


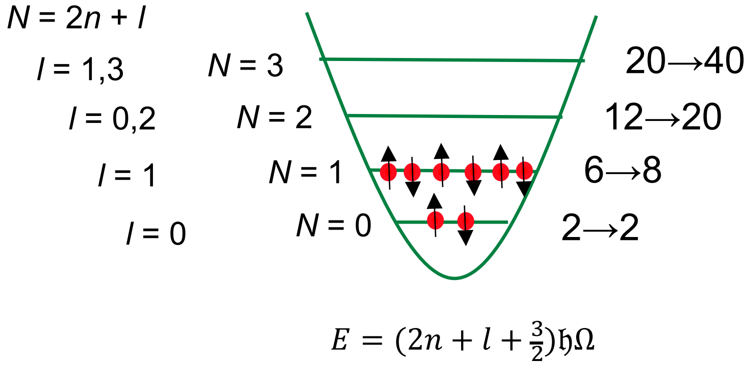



Progress in Particle and Nuclear Physics 69 (2013) 131–181
Contents lists available at SciVerse ScienceDirect
Progress in Particle and Nuclear Physics
journal homepage: www.elsevier.com/locate/ppnp
ELSEVIER
Review
Ab initio no core shell model
Bruce R. Barrett[a], Petr Navrátil[b], James P. Vary[c,*]

Conceptually simplest *ab initio* method: No-Core Shell Model (NCSM)

- Basis expansion method (CI)
  - Harmonic oscillator (HO) basis truncated in a particular way (N_{max})
    - HO frequency variational parameter
  - Why HO basis?
    - Lowest filled HO shells match magic numbers of light nuclei (2, 8, 20 – ^{4}He, ^{16}O, ^{40}Ca)
    - Equivalent description in relative(Jacobi)-coordinate and Slater determinant basis – nuclei self-bound, $[H,P_{CM}]=0$
      - Exact factorization of CM and intrinsic eigenfunctions at each N_{max}

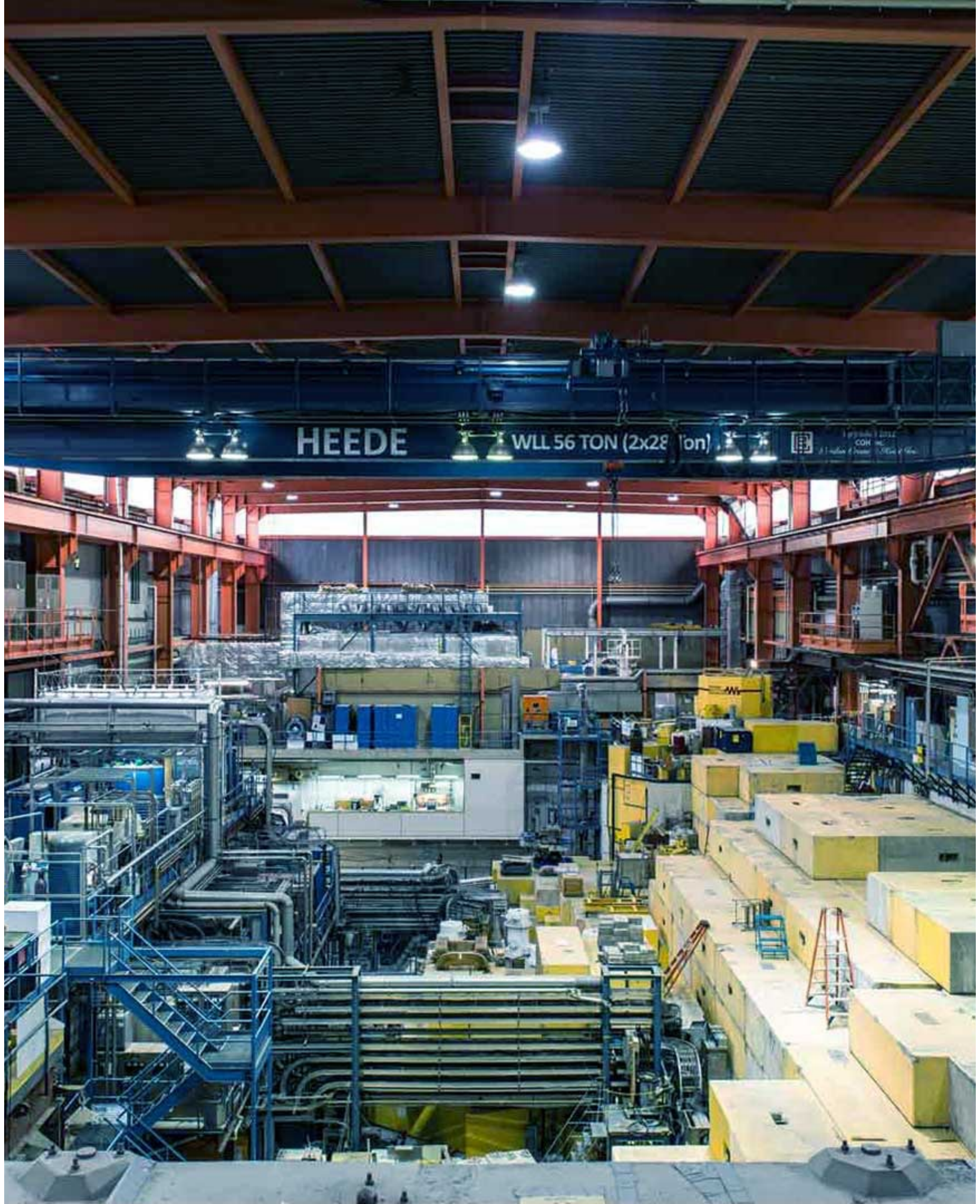




$$\Psi^A = \sum_{N=0}^{N_{\text{max}}} \sum_i c_{Ni} \Phi_{Ni}^{HO}(\vec{\eta}_1, \vec{\eta}_2, \ldots, \vec{\eta}_{A-1})$$

$$\Psi_{\text{SD}}^A = \sum_{N=0}^{N_{\text{max}}} \sum_j c_{Nj}^{\text{SD}} \Phi_{\text{SD}\,Nj}^{HO}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_A) = \Psi^A \varphi_{000}(\vec{R}_{CM})$$

Precision chiral EFT Hamiltonian with a sub-leading 3N interaction term



Precision chiral EFT Hamiltonian with LECs determined in few-nucleon systems

- NN N^{4}LO 500 interaction by Entem-Machleidt-Nosyk (2017)
- 3N N^{2}LO plus a sub-leading spin-orbit enhancing term with a new LEC (E_7) – Girlanda 2011
  - local/non-local regulator
  - **The Hamiltonian fully determined in *A*=2, *A*=3,4, and ^{6}Li systems**
    - Nucleon–nucleon scattering, deuteron properties, ^{3}H and ^{4}He binding energy, ^{3}H half life
    - New LEC (E_7) fitted to improve excitation levels in ^{6}Li
  - Denoted as NN N^{4}LO + 3N$_{\text{lnlE7}}$

PHYSICAL REVIEW C **101**, 014318 (2020)

Novel chiral Hamiltonian and observables in light and medium-mass nuclei

V. Somà,[1,*] P. Navrátil,[2,†] F. Raimondi,[3,4,‡] C. Barbieri,[4,§] and T. Duguet[1,5,‖]

PHYSICAL REVIEW C, VOLUME 60, 034001

Phenomenological spin-orbit three-body force

A. Kievsky*

$$V = \sum_{i\neq j\neq k} (E_1 + E_2\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j + E_3\boldsymbol{\sigma}_i\cdot\boldsymbol{\sigma}_j + E_4\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j\boldsymbol{\sigma}_i\cdot\boldsymbol{\sigma}_j)\left[Z_0''(r_{ij}) + 2\frac{Z_0'(r_{ij})}{r_{ij}}\right]Z_0(r_{ik})$$
$$+ (E_5 + E_6\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j)S_{ij}\left[Z_0''(r_{ij}) - \frac{Z_0'(r_{ij})}{r_{ij}}\right]Z_0(r_{ik}) + (E_7 + E_8\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_k)(\mathbf{L}\cdot\mathbf{S})_{ij}\frac{Z_0'(r_{ij})}{r_{ij}}Z_0(r_{ik})$$
$$+ [(E_9 + E_{10}\boldsymbol{\tau}_j\cdot\boldsymbol{\tau}_k)\boldsymbol{\sigma}_j\cdot\hat{\mathbf{r}}_{ij}\boldsymbol{\sigma}_k\cdot\hat{\mathbf{r}}_{ik} + (E_{11} + E_{12}\boldsymbol{\tau}_j\cdot\boldsymbol{\tau}_k + E_{13}\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j)\boldsymbol{\sigma}_k\cdot\hat{\mathbf{r}}_{ij}\boldsymbol{\sigma}_j\cdot\hat{\mathbf{r}}_{ik}]Z_0'(r_{ij})Z_0'(r_{ik})$$

$$Z_0(r;\Lambda) = \int \frac{d\mathbf{p}}{(2\pi)^3} e^{i\mathbf{p}\cdot\mathbf{r}} F(\mathbf{p}^2;\Lambda)$$

PHYSICAL REVIEW C **84**, 014001 (2011)

Subleading contributions to the three-nucleon contact interaction

L. Girlanda,[1] A. Kievsky,[2] and M. Viviani[2]

PHYSICAL REVIEW C **102**, 019903(E) (2020)

Erratum: Subleading contributions to the three-nucleon contact interaction [Phys. Rev. C 84, 014001 (2011)]

L. Girlanda, A. Kievsky, and M. Viviani

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- Successfully applied to ^{7}Be(p,γ)^{8}B and muon capture on ^{6}Li, ^{12}C, and ^{16}O
- Applied here for
  - ^{19}F structure and exotic moments
  - ^{11}Li structure

Physics Letters B 845 (2023) 138156

Contents lists available at ScienceDirect

Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

Ab initio informed evaluation of the radiative capture of protons on ^{7}Be

K. Kravvaris[a,*], P. Navrátil[b], S. Quaglioni[a], C. Hebborn[c,a], G. Hupin[d]

PHYSICAL REVIEW C **109**, 065501 (2024)

Muon capture on ^{6}Li, ^{12}C, and ^{16}O from *ab initio* nuclear theory

Lotta Jokiniemi[1,*] Petr Navrátil[1,2,†] Jenni Kotila[3,4,5,‡] and Kostas Kravvaris[6,§]

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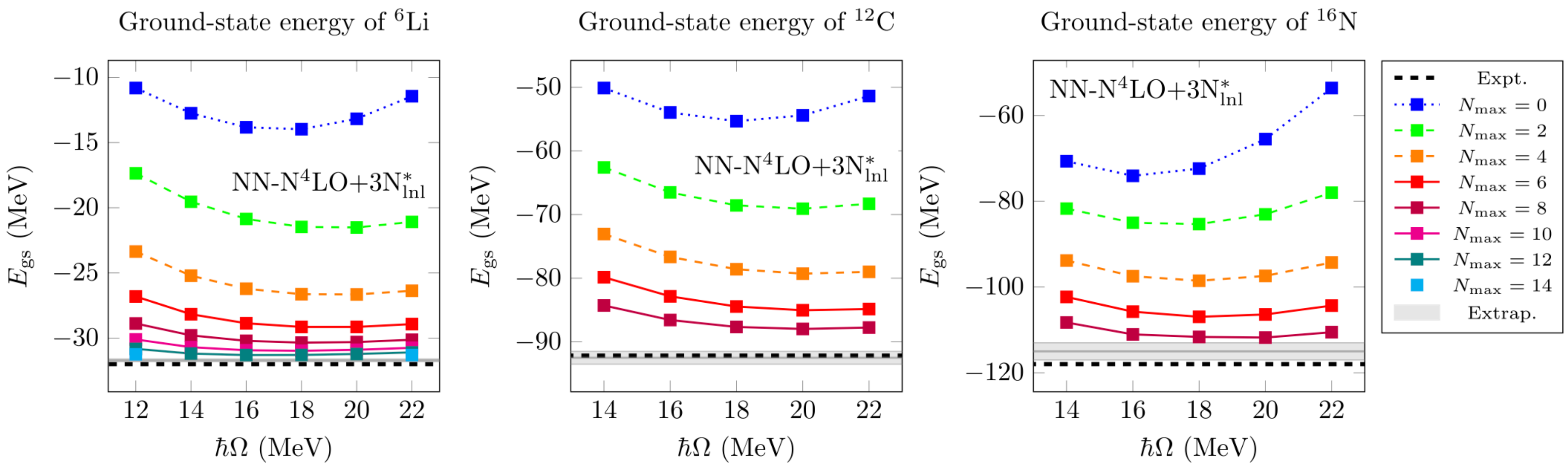
Describes well ground-state energies & excitation levels of light nuclei



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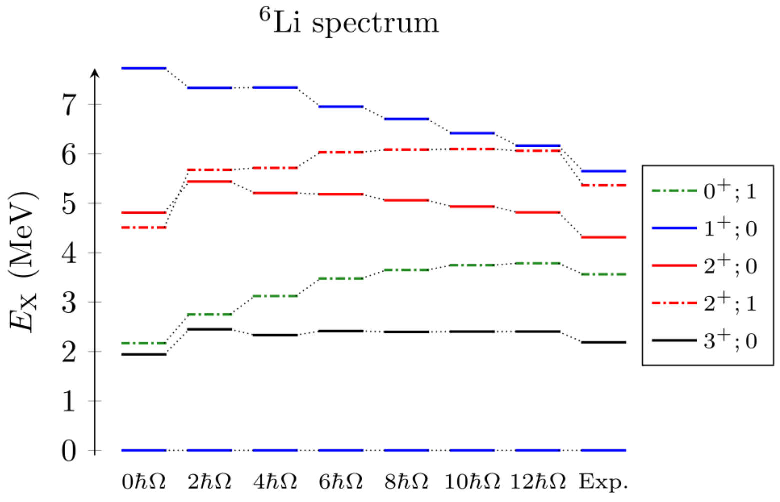

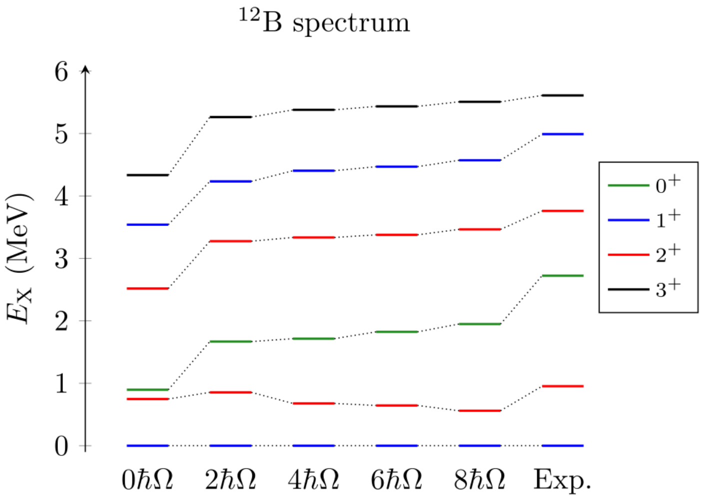

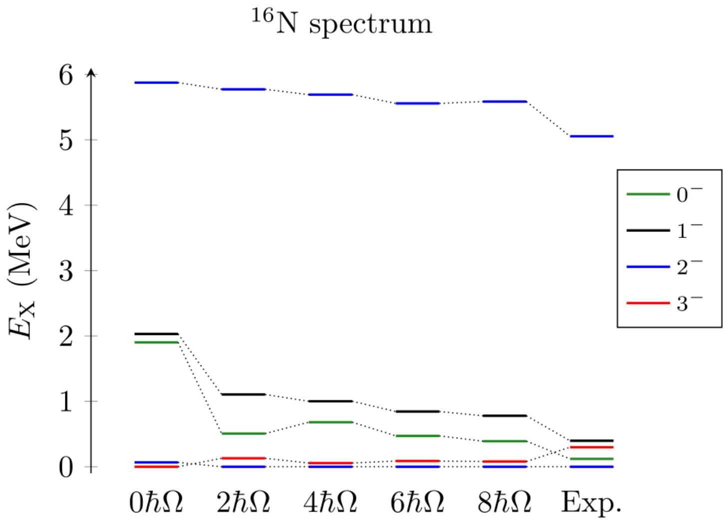

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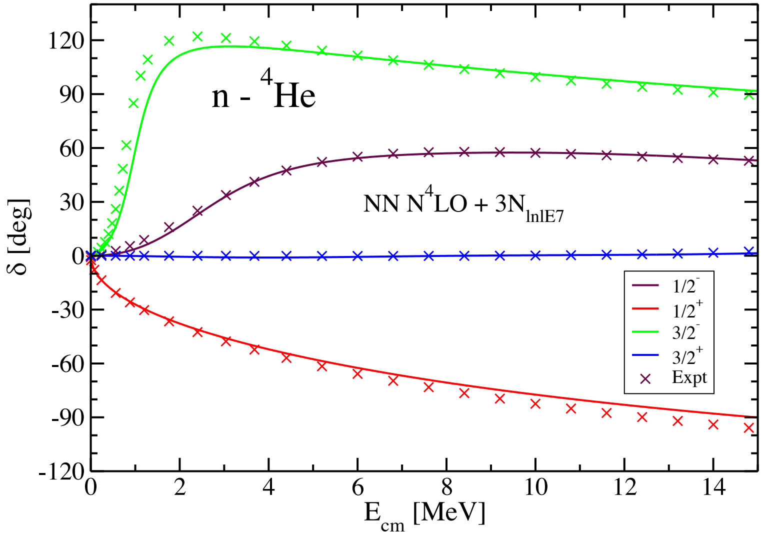
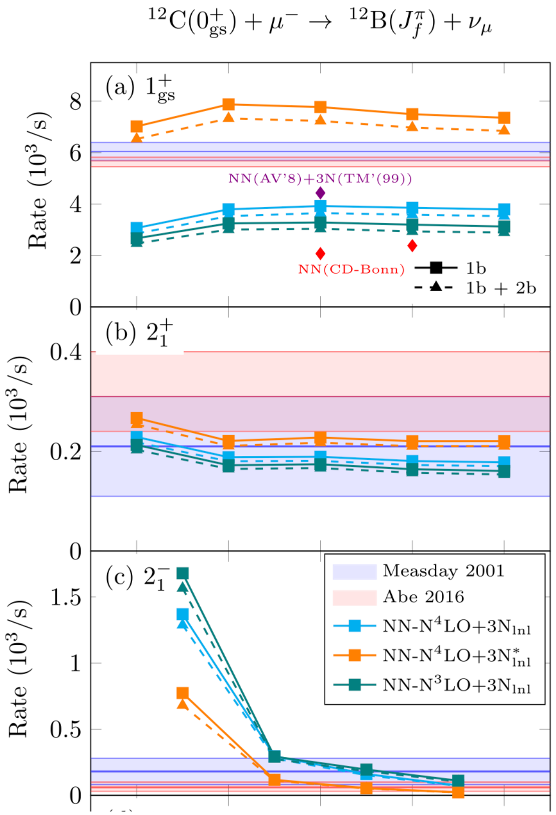
Improvement for ^{5}He *P*-wave resonances, ^{12}C muon capture rate compared to other interactions





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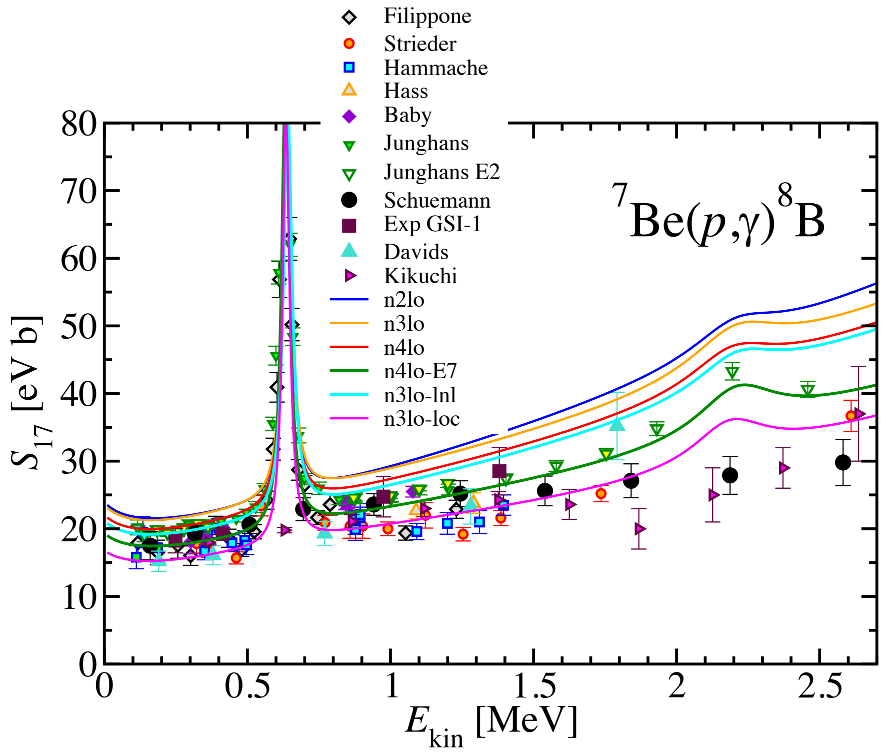
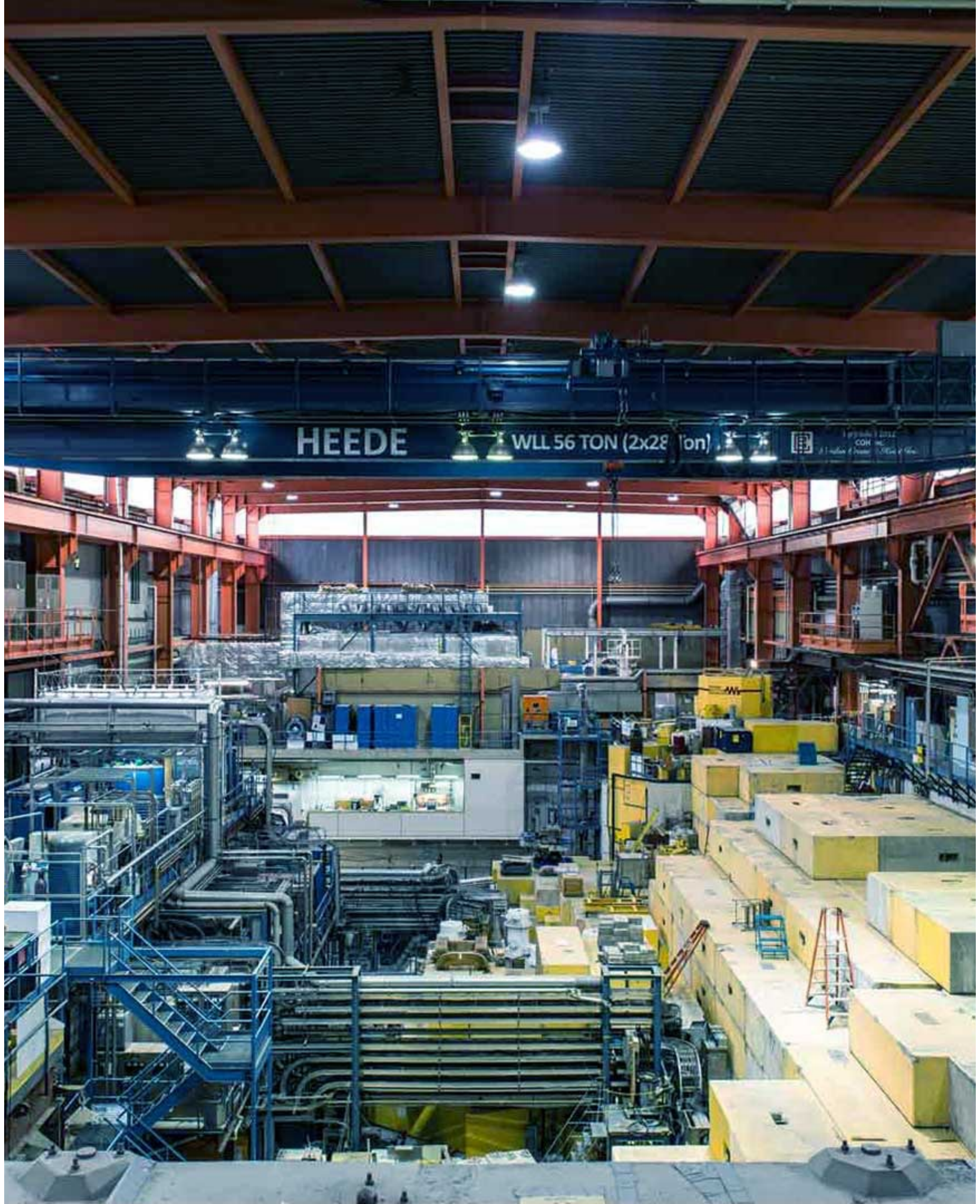
Improvement for $^7Be(p,\gamma)^8B$ S-factor compared to other interactions



Ab initio calculations
of parity-violating moments

Anapole moment
Electric dipole moment
Nuclear Schiff moment



Discovery,
accelerated

Why investigate the electric dipole moment (EDM) and nuclear Schiff moment (NSM)?

- Unsolved problem in physics: matter-antimatter asymmetry of the universe
- Standard model predicts some CP violation, not enough to explain this asymmetry
- The EDM and nuclear Schiff moment is a promising probe for CP violation beyond the standard model, as well as CP violating QCD $\bar{\theta}$ parameter

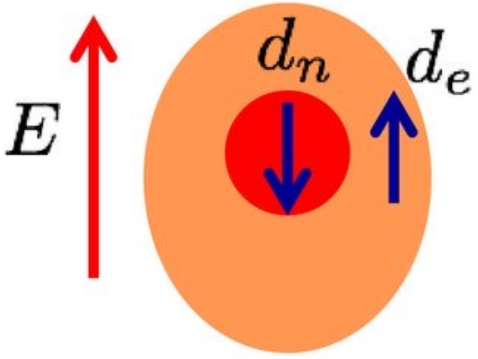
Proposal to measure ^{8}Li EDM in ion trap at ISOLDE

- Nuclear EDMs can be measured in storage rings (CERN feasibility study: arXiv:1912.07881)
- Nuclear Schiff moments can be measured using (radioactive) molecules

Nuclear Schiff moment measurements planned in $^{227}ThF^{+}$, RaF, and FrAg molecules

To understand the nuclear EDM and Schiff moment, nuclear structure effects must be understood

What is the nuclear Schiff moment?



Schiff Moment

$$\vec{S} = \frac{\langle e r^2 \vec{r} \rangle}{10} - \frac{\langle r^2 \rangle \langle e \vec{r} \rangle}{6}$$

Leonard Schiff's Theorem (1963):

- Any permanent dipole moment of the nucleus is perfectly shielded by its electron cloud
- True for point-like nuclei, non-relativistic electrons

However, the "Schiff moment" is not shielded by this effect

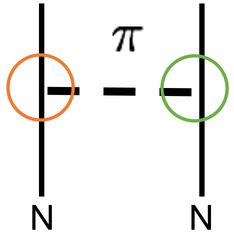
- Zero for point-like, spherical nuclei
- Arises from deformations in the nucleus or its constituent nucleons
- Very large in nuclei with both a quadrupole and octupole deformation

Look for heavy nuclei with large quadrupole and octupole deformations!

Slide by Matthew R. Dietrich (ANL)

Parity violating (PV) and parity & time-reversal (PTV) violating nucleon-nucleon (NN) interaction

- Anapole moment arises due to PV NN interaction (weak force - imaginary), EDM and Schiff moment due to PTV NN interaction (real)
- Parity non-conserving PV or PTV V_{NN}^{PNC} interaction
  - Conserves total angular momentum *I*
  - Mixes opposite parities
  - Has isoscalar, isovector and isotensor components
  - Admixes unnatural parity states in the ground state



$$|\psi_{\mathrm{gs}}\ I\rangle = |\psi_{\mathrm{gs}}\ I^{\pi}\rangle + \sum_j |\psi_j\ I^{-\pi}\rangle \times \frac{1}{E_{\mathrm{gs}} - E_j} \langle \psi_j\ I^{-\pi} | V_{\mathrm{NN}}^{\mathrm{PNC}} | \psi_{\mathrm{gs}}\ I^{\pi} \rangle$$

ANNALS OF PHYSICS 124, 449–495 (1980)

Unified Treatment of the Parity Violating Nuclear Force

BERTRAND DESPLANQUES*

Institut de Physique Nucleaire, Division de Physique Théorique, 91406 Orsay Cedex—France

JOHN F. DONOGHUE†

Center for Theoretical Physics, Laboratory for Nuclear Science and Physics Department, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

AND

BARRY R. HOLSTEIN

Physics Division, National Science Foundation, Washington, D. C. 20550

PHYSICAL REVIEW C 70, 055501 (2004)

P- and T-odd two-nucleon interaction and the deuteron electric dipole moment

C.-P. Liu* and R. G. E. Timmermans†

frontiers in Physics

REVIEW
published: 21 July 2020
doi: 10.3389/fphy.2020.00218

Parity- and Time-Reversal-Violating Nuclear Forces

Jordy de Vries[1,2], Evgeny Epelbaum[3], Luca Girlanda[4,5], Alex Gnech[6], Emanuele Mereghetti[7] and Michele Viviani[8]*

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$$|\psi_{\rm gs}\, I\rangle = |\psi_{\rm gs}\, I^{\pi}\rangle + \sum_j |\psi_j\, I^{-\pi}\rangle \times \frac{1}{E_{\rm gs} - E_j} \langle \psi_j\, I^{-\pi} | V_{\rm NN}^{\rm PNC} | \psi_{\rm gs}\, I^{\pi}\rangle$$

- EDM and Schiff moment operators

$$\hat{D}_z = \frac{e}{2} \sum_{i=1}^{A} (1 + \tau_i^z)\, z_i$$

$$\boldsymbol{S} = \frac{e}{10} \sum_{i=1}^{Z} \left(r_i^2 \boldsymbol{r}_i - \frac{5}{3} \langle r^2 \rangle_{\rm ch} \boldsymbol{r}_i \right)$$

- EDM and Schiff moment calculation
  - Nuclear EDM is dominated by and the Schiff moment determined by the polarization contribution:

$$D^{(pol)} = \langle \psi_{\rm gs}\, I^{\pi} | \hat{D}_z | \psi_{\rm gs}\, I \rangle + c.c. \qquad S = \langle \psi_{\rm gs}\, I^{\pi} | \boldsymbol{S} | \psi_{\rm gs}\, I \rangle + c.c.$$

NCSM applications to parity-violating moments:
How to calculate the sum of intermediate unnatural parity states?

$$|\psi_{\rm gs}\ I\rangle = |\psi_{\rm gs}\ I^{\pi}\rangle + \sum_j |\psi_j\ I^{-\pi}\rangle \frac{1}{E_{\rm gs}-E_j}\langle\psi_j\ I^{-\pi}|V_{\rm NN}^{\rm PNC}|\psi_{\rm gs}\ I^{\pi}\rangle$$

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Sum over all possible intermediate states

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- Solving Schroedinger equation with inhomogeneous term

$$(E_{\rm gs} - H)|\psi_{\rm gs}\; I\rangle = V_{\rm NN}^{\rm PNC}|\psi_{\rm gs}\; I^{\pi}\rangle$$

- To invert this equation, we apply the Lanczos algorithm

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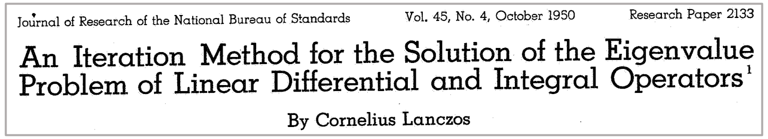
- To invert this equation, we apply the Lanczos algorithm
  — Bring matrix to tri-diagonal form ($\mathbf{v}_1$, $\mathbf{v}_2$ … orthonormal, H Hermitian)

$$\begin{aligned} H\mathbf{v}_1 &= \alpha_1\mathbf{v}_1 + \beta_1\mathbf{v}_2 \\ H\mathbf{v}_2 &= \beta_1\mathbf{v}_1 + \alpha_2\mathbf{v}_2 + \beta_2\mathbf{v}_3 \\ H\mathbf{v}_3 &= \beta_2\mathbf{v}_2 + \alpha_3\mathbf{v}_3 + \beta_3\mathbf{v}_4 \\ H\mathbf{v}_4 &= \beta_3\mathbf{v}_3 + \alpha_4\mathbf{v}_4 + \beta_4\mathbf{v}_5 \end{aligned}$$


Journal of Research of the National Bureau of Standards Vol. 45, No. 4, October 1950 Research Paper 2133

An Iteration Method for the Solution of the Eigenvalue Problem of Linear Differential and Integral Operators[1]

By Cornelius Lanczos

  — n^{th} iteration computes $2n^{th}$ moment
  — Eigenvalues converge to extreme (largest in magnitude) values
  — ~ 150-200 iterations needed for 10 eigenvalues (even for 10^9 states)

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$$|\psi_{\rm gs}\ I\rangle = |\psi_{\rm gs}\ I^{\pi}\rangle + \sum_j |\psi_j\ I^{-\pi}\rangle \frac{1}{E_{\rm gs} - E_j} \langle \psi_j\ I^{-\pi}| V_{\rm NN}^{\rm PNC} |\psi_{\rm gs}\ I^{\pi}\rangle$$

- Solving Schroedinger equation with inhomogeneous term

$$(E_{\rm gs} - H)|\psi_{\rm gs}\ I\rangle = V_{\rm NN}^{\rm PNC}|\psi_{\rm gs}\ I^{\pi}\rangle$$

- To invert this equation, we apply the Lanczos algorithm

$$|\mathbf{v}_1\rangle = V_{\rm NN}^{\rm PNC}|\psi_{\rm gs}\ I^{\pi}\rangle$$

$$|\psi_{\rm gs}\ I\rangle \approx \sum_k g_k(E_0)|\mathbf{v}_k\rangle$$

~100 iterations

$$\hat{g}_1(\omega) = \cfrac{1}{\omega - \alpha_1 - \cfrac{\beta_1^2}{\omega - \alpha_2 - \cfrac{\beta_2^2}{\omega - \alpha_3 - \beta_3^2}}}$$

$\ddots$

J. Phys. A: Math., Nucl. Gen., Vol. 7, No. 17, 1974. Printed in Great Britain. © 1974

The inverse of a linear operator

Roger Haydock

Few-Body Systems 33, 259–276 (2003)
DOI 10.1007/s00601-003-0017-z

Few-Body Systems
Printed in Austria

Efficient Method for Lorentz Integral Transforms of Reaction Cross Sections

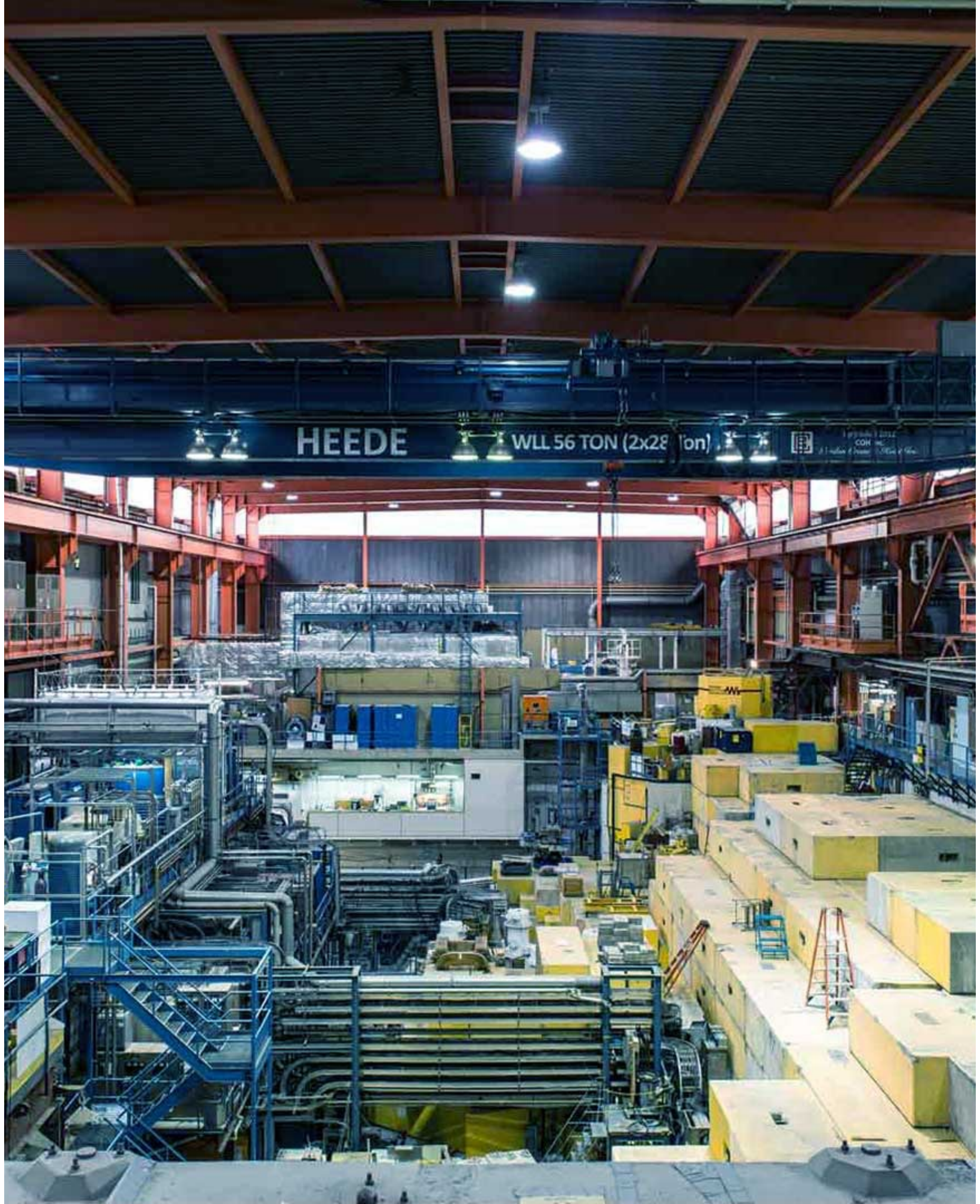
M. A. Marchisio[1], N. Barnea[2], W. Leidemann[1], and G. Orlandini[1]

Lanczos continued fraction method
or
Lanczos strength method

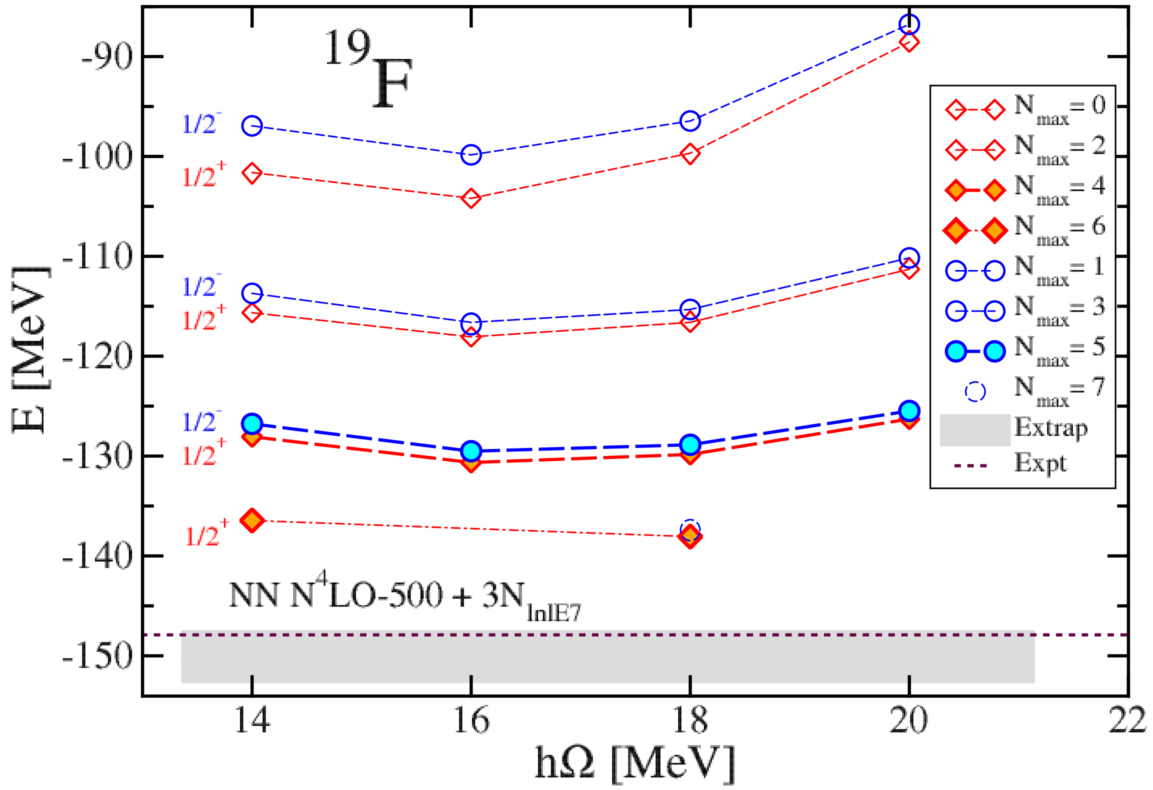
Ab initio calculations
of parity-violating moments:

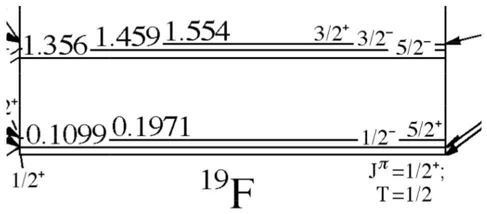
Experimental limits on the Schiff moment of ^{19}F

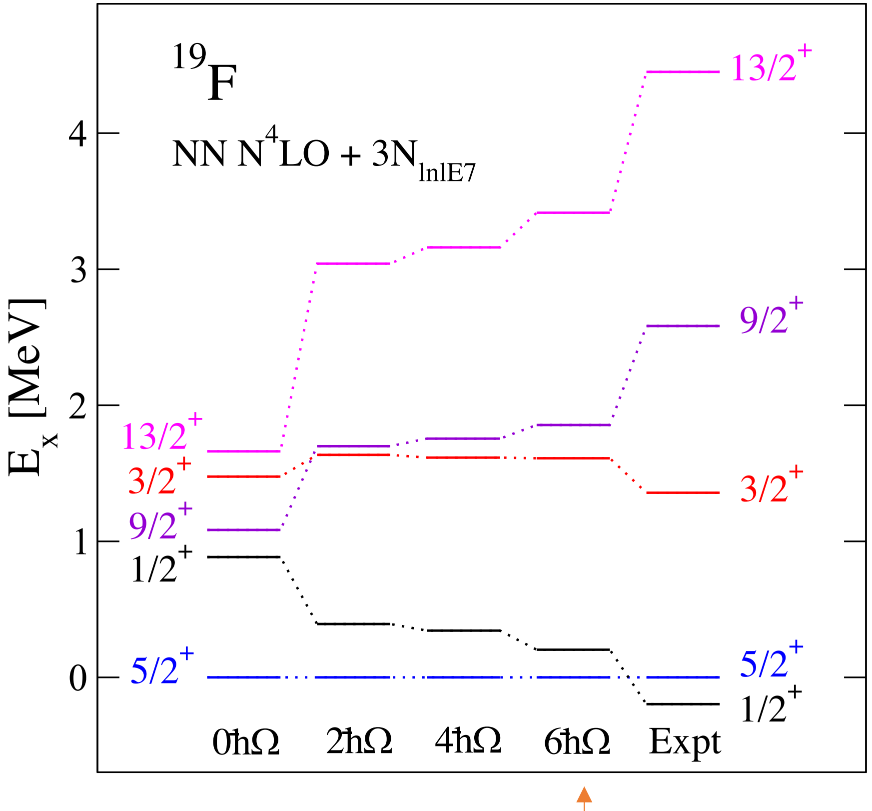
Anapole moment of ^{19}F



Large-scale NCSM calculations of ^{19}F

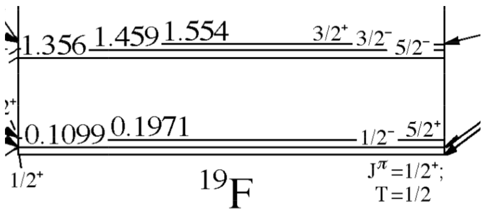


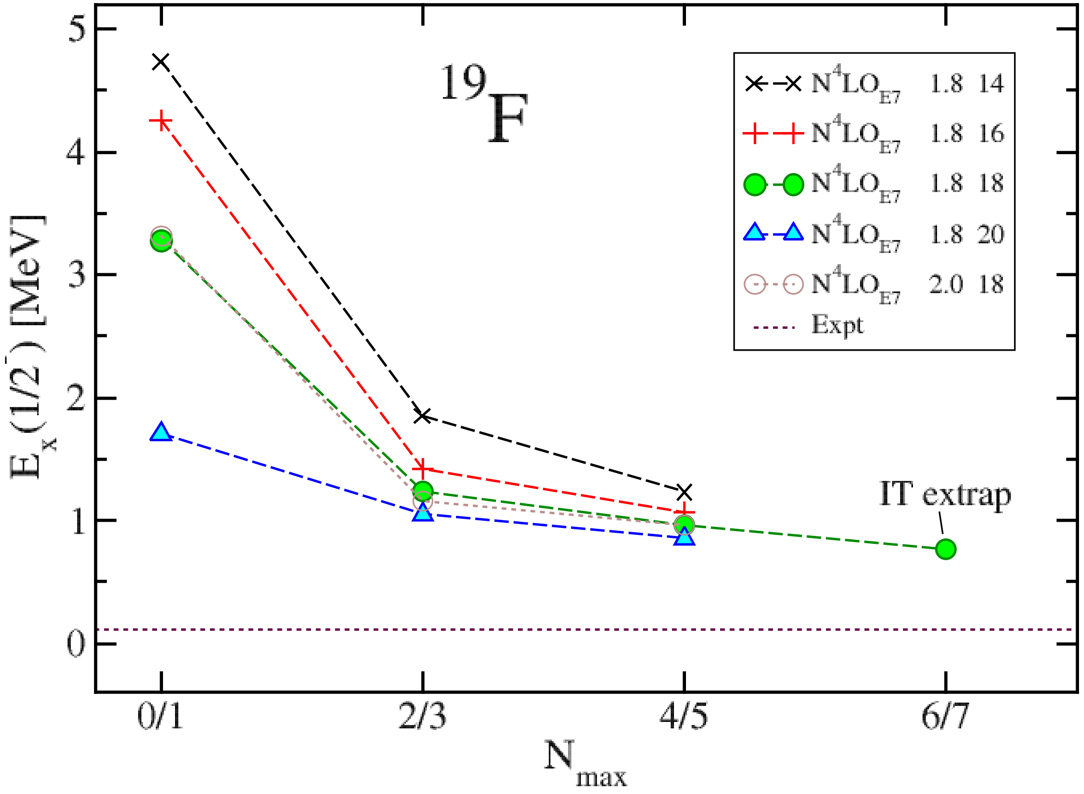




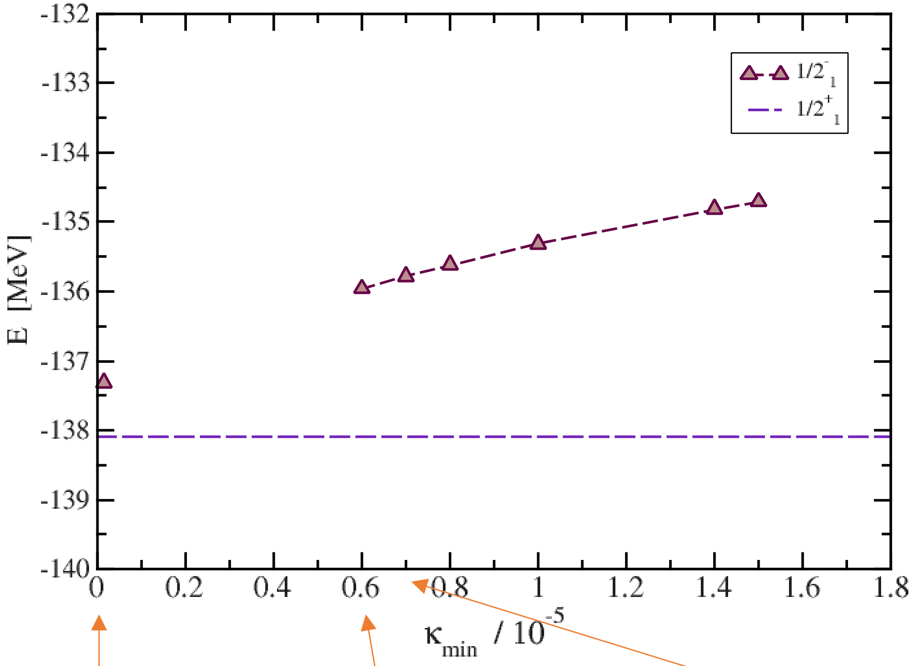
Basis dimension 1.35 billion

Large-scale NCSM calculations of ^{19}F





Importance-truncated NCSM @ N_{max} = 7



Basis dimension
8.48 billion

Inaccessible for
technical reasons

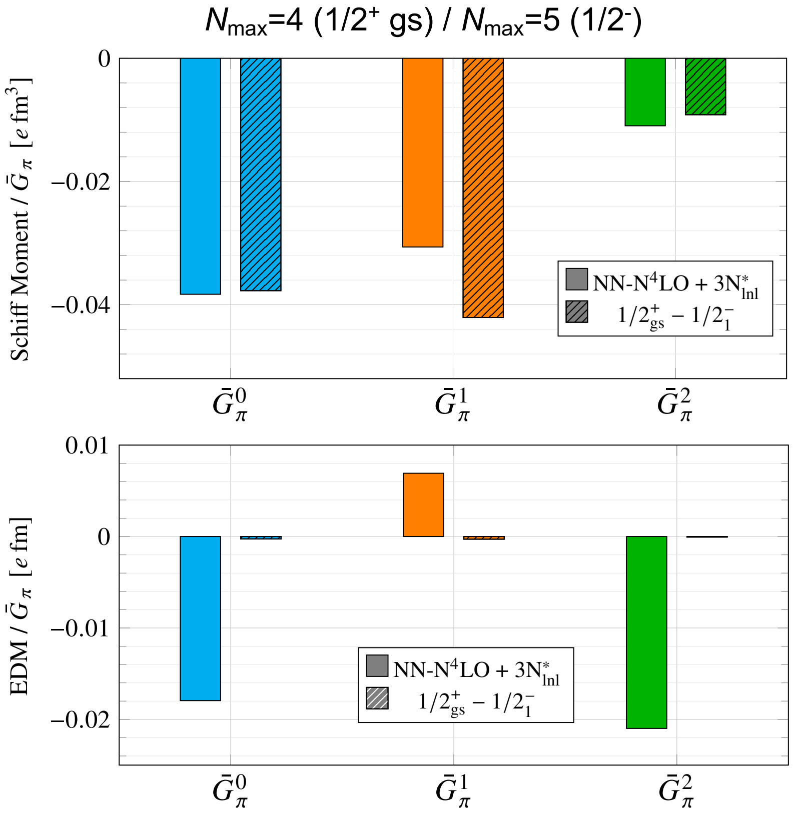
Basis dimension
812 million
=
Full N_{max}=5
+
623 million N=7 states

Basis dimension
702 million

Polynomial extrapolation
$\kappa_{\min} \to 0$

Nuclear Schiff moment and EDM of ^{19}F

Leading order PTV NN – one-pion exchange – isoscalar, isovector, isotensor contributions



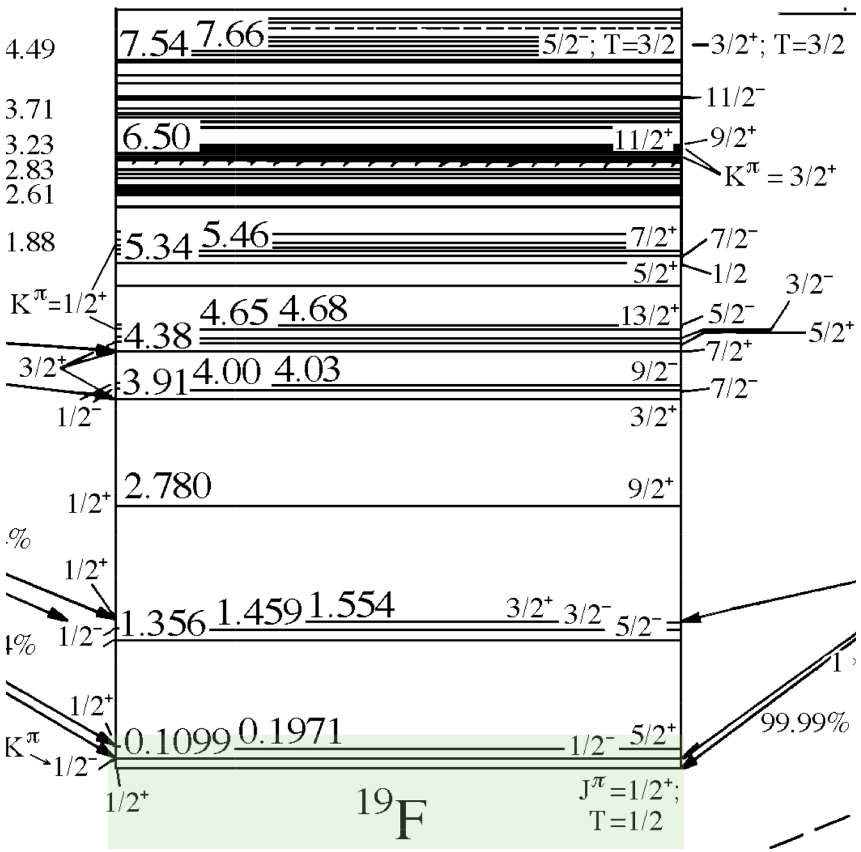
^{19}F Schiff moment enhanced due to the low-lying ½$^-$ state admixture to the ½$^+$ gs

$$S = \langle \psi_{gs}\, I^\pi | \boldsymbol{S} | \psi_{gs}\, I \rangle + c.c.$$

$$\boldsymbol{S} = \frac{e}{10}\sum_{i=1}^{Z}\left(r_i^2 \boldsymbol{r}_i - \frac{5}{3}\langle r^2\rangle_{\rm ch}\boldsymbol{r}_i\right)$$

$$|\psi_{gs}\, I\rangle = |\psi_{gs}\, I^\pi\rangle + \sum_j |\psi_j\, I^{-\pi}\rangle \times \frac{1}{E_{gs} - E_j}\langle \psi_j\, I^{-\pi} | V_{\rm NN}^{\rm PNC} | \psi_{gs}\, I^\pi\rangle$$

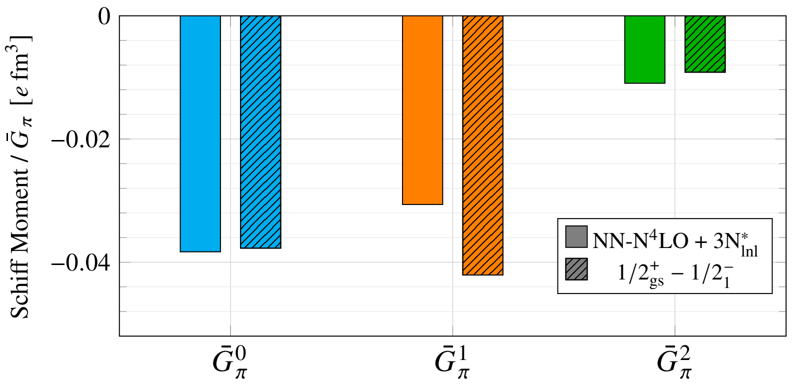
Calculated ½$^+$ state energy shifted to match the ½$^-_1$ excitation energy

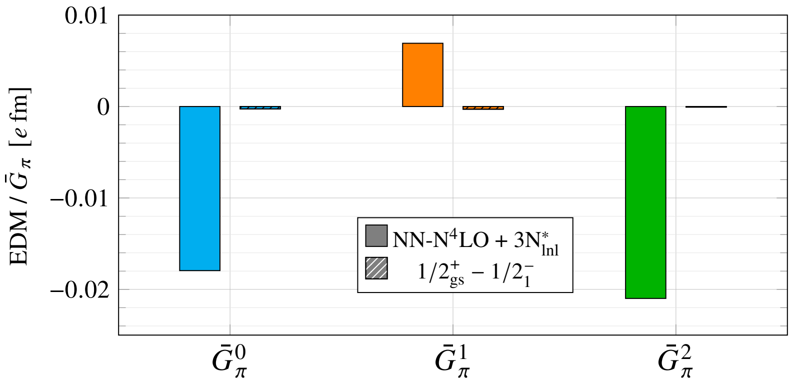


Nuclear Schiff moment and EDM of ^{19}F

Leading order PTV NN – one-pion exchange – isoscalar, isovector, isotensor contributions

$N_{\max}$=4 (1/2$^+$ gs) / $N_{\max}$=5 (1/2$^-$)





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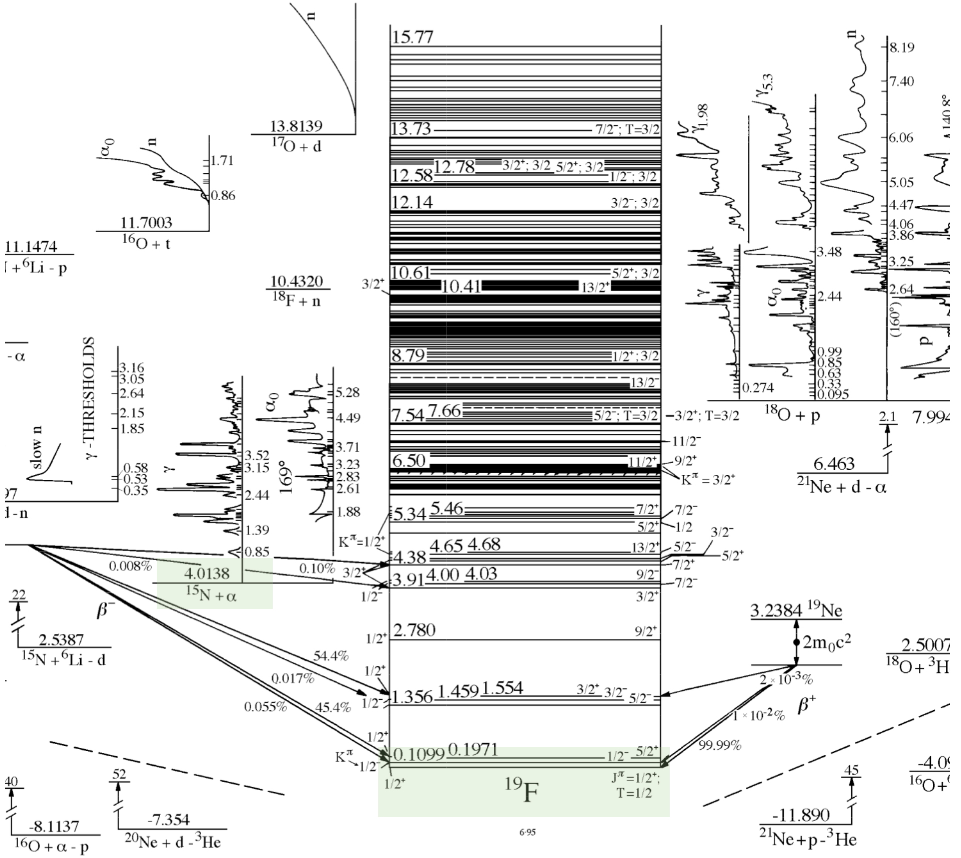

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Calculated ½$^+$ state energy shifted to match the ½$^-_1$ excitation energy

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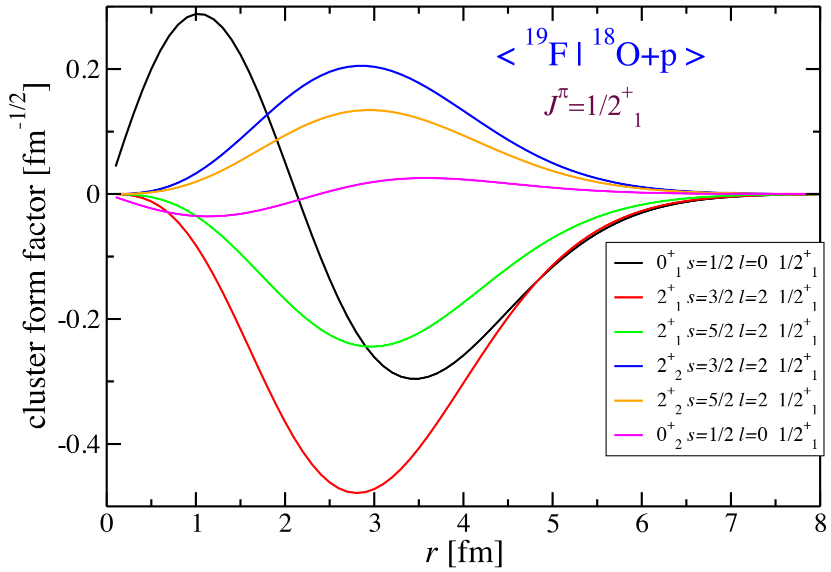
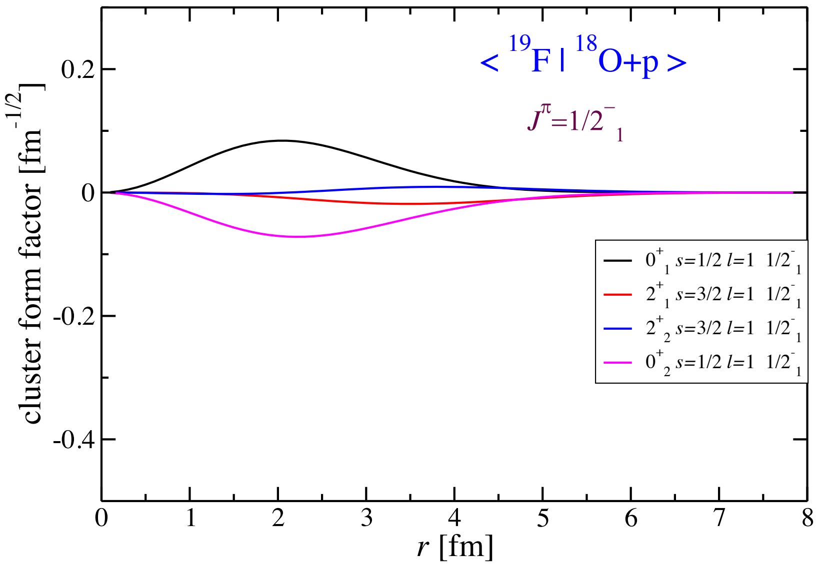
^{19}F Schiff moment dominated by the contribution of the lowest ½⁻ state
However, its contribution to the EDM of ^{19}F is negligible.

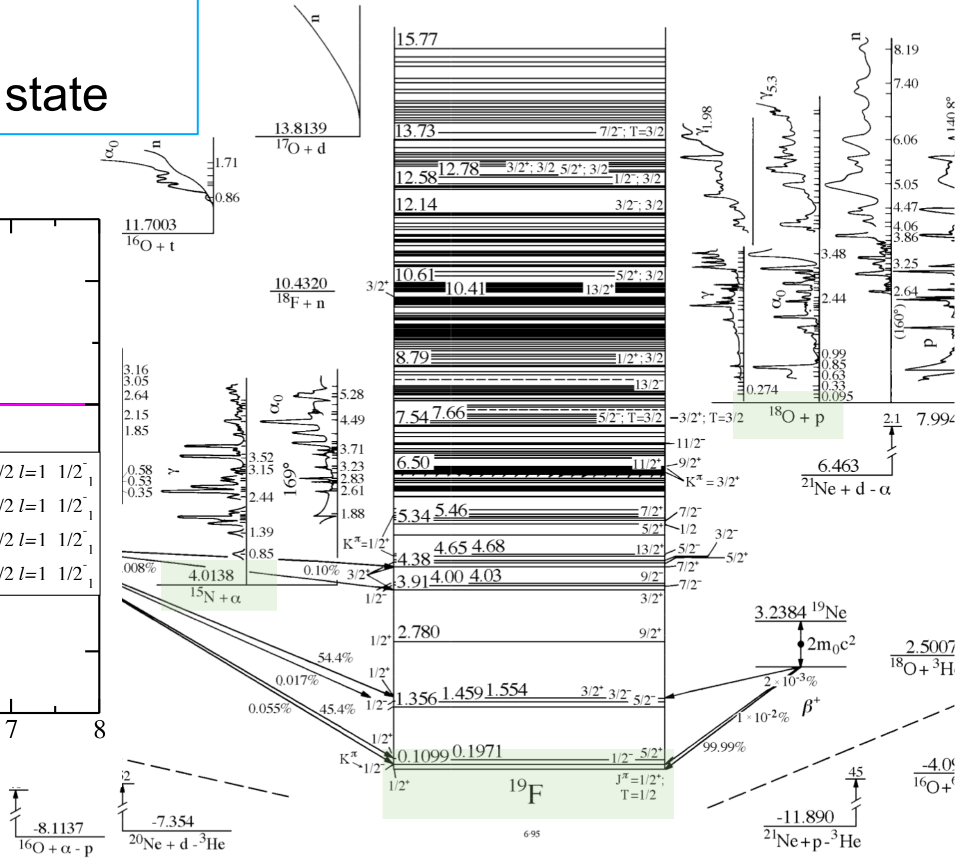
This is due to very different structure of the ½⁺ g.s. and the $½^{-}_{1}$ state



^{18}O+p (shell-model-like)



^{15}N+^{4}He – alpha-clustering



E1 matrix element small
S matrix element large due to the r^3 term

$$\widehat{D}_z = \frac{e}{2}\sum_{i=1}^{A}(1+\tau_i^z)\, z_i \qquad \boldsymbol{S} = \frac{e}{10}\sum_{i=1}^{Z}\left(r_i^2\boldsymbol{r}_i - \frac{5}{3}\langle r^2\rangle_{\rm ch}\boldsymbol{r}_i\right)$$

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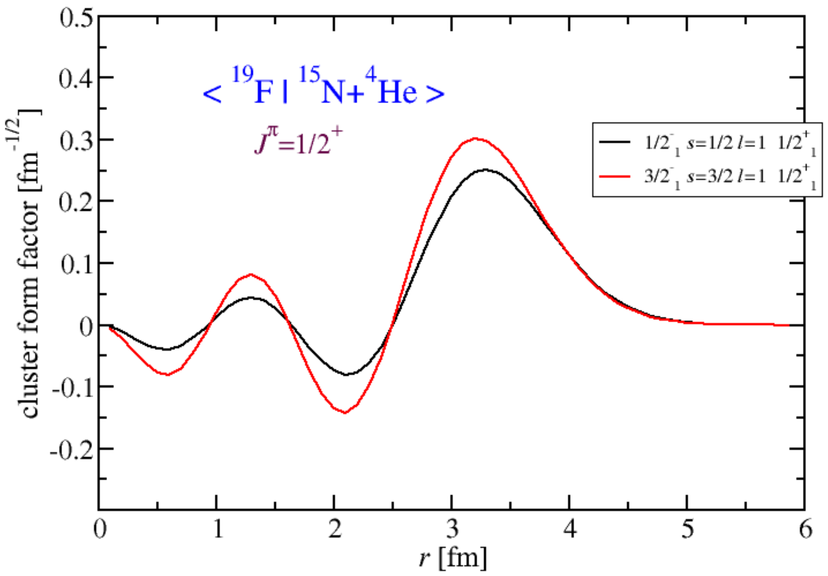

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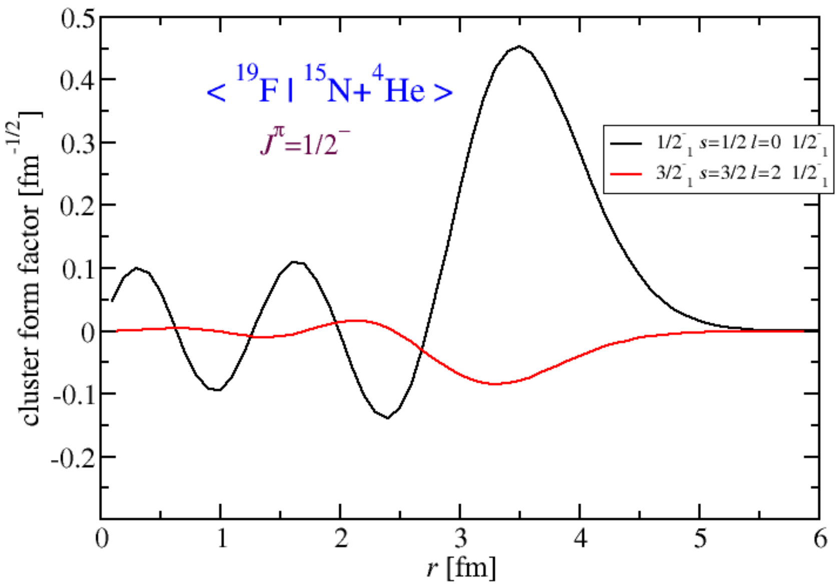

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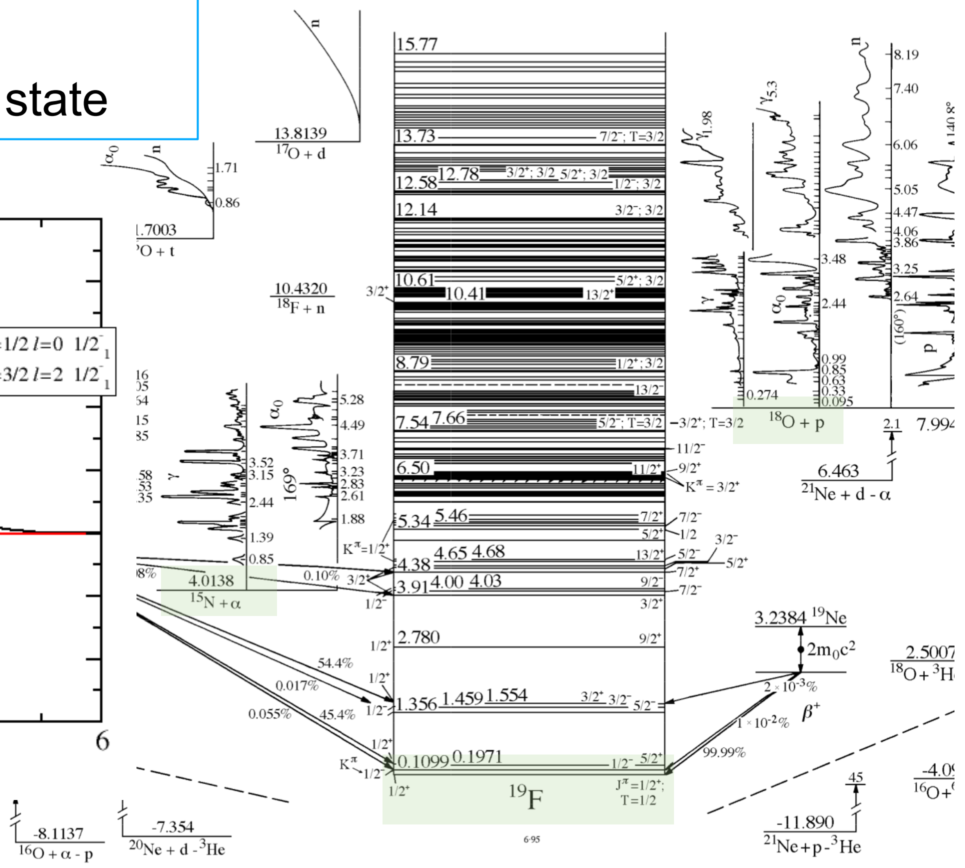

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Nuclear Schiff moment and EDM of ^{19}F

Recent JILA high-precision measurements of the **molecular electric dipole moment of $^{180}Hf^{19}F^+$**

in combination with **quantum-chemistry calculations** to evaluate the sensitivity of the hafnium monofluoride cation, **HfF^+, to the nuclear Schiff moment of ^{19}F**

and with ***ab initio* calculations of the ^{19}F nuclear Schiff moment**

allows to set an experimental limit on the PTV pion-nucleon-nucleon couplings.

$$\overline{G}_t^{\pi} = g\,\bar{g}_t \qquad (g \sim 13.5)$$

$$S(^{19}\mathrm{F}) = (-2.9\,g\bar{g}_0 - 2.4\,g\bar{g}_1 - 2.0\,g\bar{g}_2) \times 10^{-2}\ e\ \mathrm{fm}^3$$

Quantity	Limit
$\lvert\bar{g}_0\rvert$	2.3×10^{-8}
$\lvert\bar{g}_1\rvert$	2.8×10^{-8}
$\lvert\bar{g}_2\rvert$	3.3×10^{-8}

arXiv:2507.19811

Nuclear Schiff moment of the fluorine isotope ^{19}F

Kia Boon Ng,[1,*] Stephan Foster,[1,2] Lan Cheng,[3] Petr Navrátil,[1] and Stephan Malbrunot-Ettenauer[1,4]

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^{19}F Schiff moment comparable to ^{129}Xe Schiff moment calculated within the nuclear shell model

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PHYSICAL REVIEW C **102**, 065502 (2020)

Large-scale shell-model calculations of nuclear Schiff moments of ^{129}Xe and ^{199}Hg

Kota Yanase* and Noritaka Shimizu†

TABLE II. The NSM coefficients of ^{129}Xe in units of $10^{-2}e\,\mathrm{fm}^3$. Our final results are given in bold.

	a_0	a_1	a_2
IPM ($m_\pi \to \infty$)	−9.9	−9.9	−19.8
IPM	−4.6	−4.6	−9.2
LSSM (SN100PN, $m_\pi \to \infty$)	−8.7	−8.2	−15.8
LSSM (SNV, $m_\pi \to \infty$)	−8.6	−8.3	−16.2
LSSM (SN100PN)	−3.7	−4.1	−8.0
LSSM (SNV)	**−3.8**	**−4.1**	**−8.1**
IPM ($m_\pi \to \infty$) [35,36]	−11	−11	−22
IPM [38]	−6	−6	−12
RPA [38]	−0.8	−0.6	−0.9
PTSM [41]	0.05	−0.04	0.19
PTSM [42]	0.3	−0.1	0.4

Nuclear Schiff moment and EDM of ^{19}F

Recent JILA high-precision measurements of the **molecular electric dipole moment of $^{180}Hf^{19}F^+$**

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$$\overline{G}_t^{\pi} = g\,\bar{g}_t \qquad (g \sim 13.5)$$

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^{19}F Schiff moment comparable to ^{129}Xe Schiff moment calculated within the nuclear shell model

Still, the lighter mass of ^{19}F results in smaller coefficients for the πNN coupling terms than those in heavier and octupole-deformed nuclei such as ^{225}Ra and ^{227}Ac.

Nevertheless, the ^{19}F NSM can be computed using *ab initio* methods that provide a more detailed and reliable description of the nuclear structure than approaches typically used for heavier nuclei.

arXiv:2507.19811

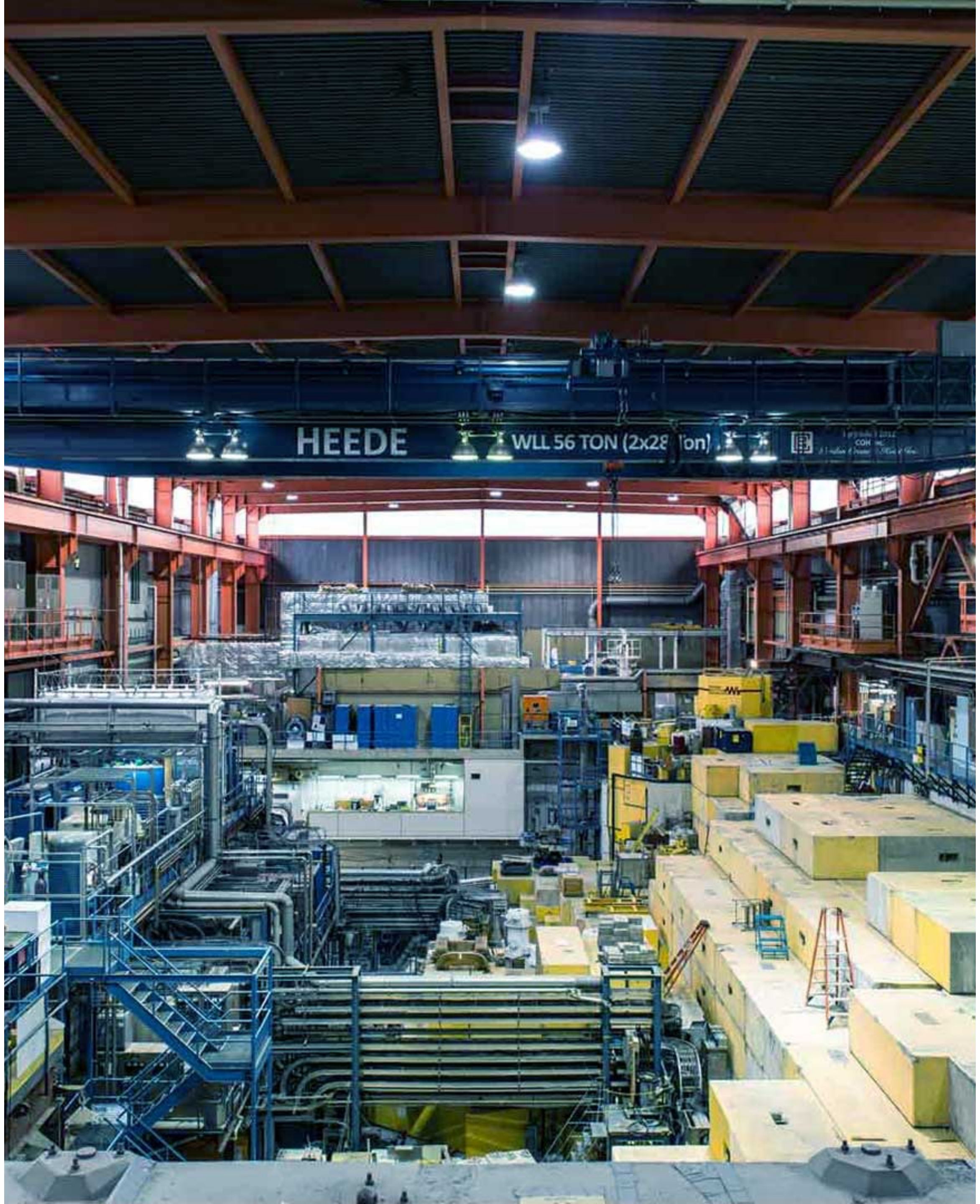
Nuclear Schiff moment of the fluorine isotope ^{19}F

Kia Boon Ng,[1,*] Stephan Foster,[1,2] Lan Cheng,[3] Petr Navrátil,[1] and Stephan Malbrunot-Ettenauer[1,4]

TRIUMF

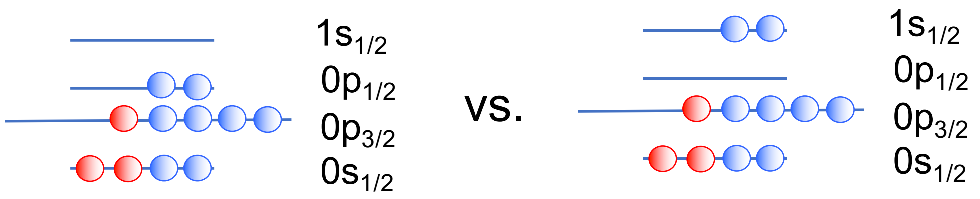
^{11}Li within NCSM

(prerequisite for $^{11}Li \sim {}^{9}Li + n + n$)

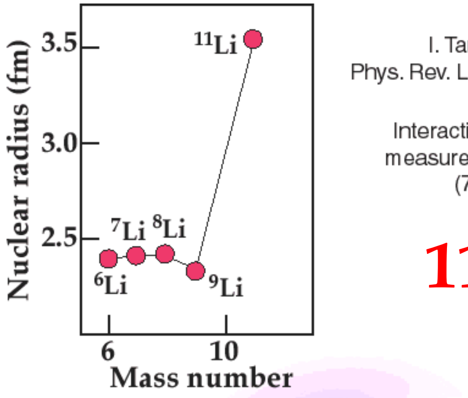


Discovery, accelerated

Borromean halo nucleus ^{11}Li



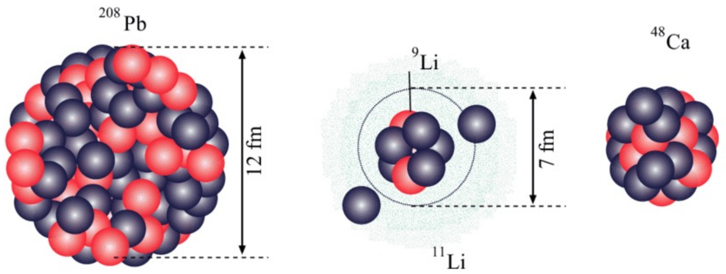
- Z=3, N=8
  - Very weakly bound: E_{th}=-0.3 MeV
    - Halo state – dominated by ^{9}Li+n+n in the *S*-wave
    - Configuration mixing, ^{9}Li ½- excited state plays a role
- Can we describe ^{11}Li in *ab initio* calculations?
  - Continuum must be included
  - What role does the 3N interaction play in the configuration mixing?
  - NCSMC needs to be applied – very challenging
  - The first step – large-scale NCSM



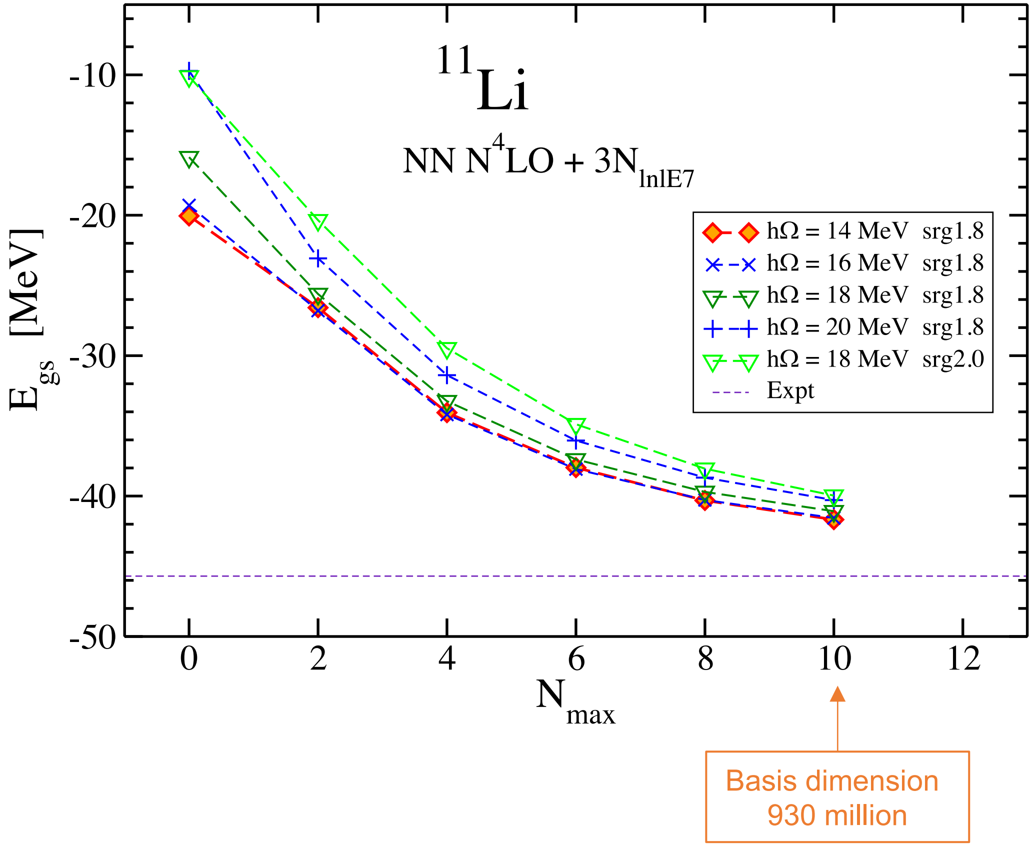
I. Tanihata et al.
Phys. Rev. Lett. 55, 2676 (1985)

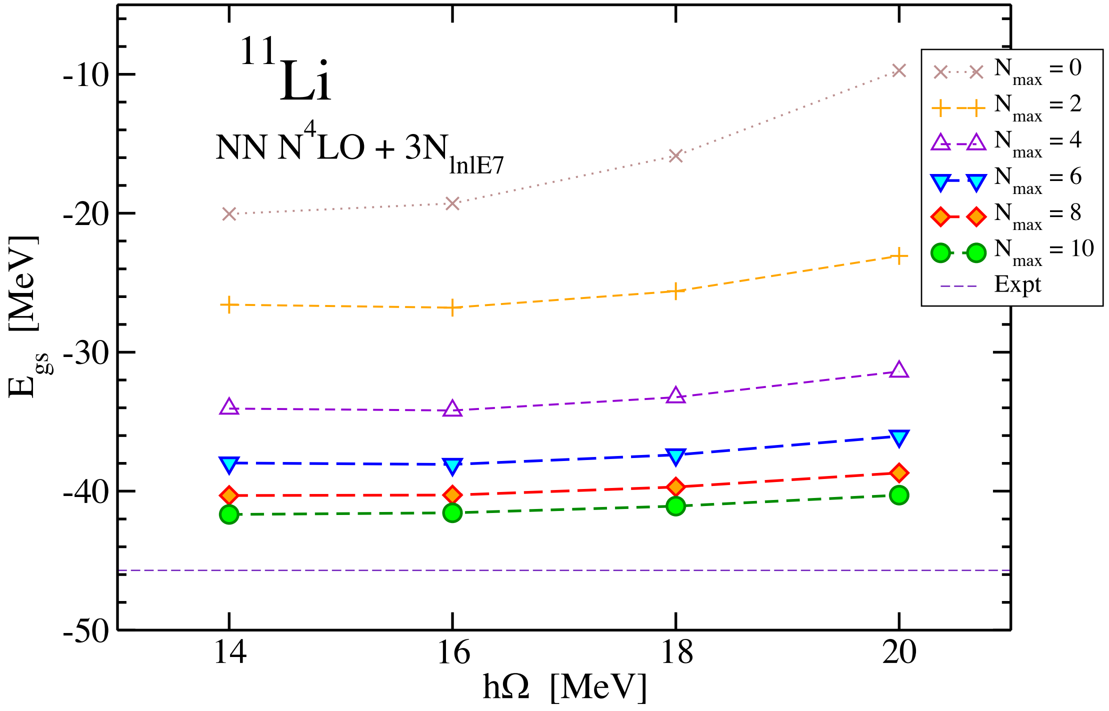
Interaction cross section measurements at Bevalac (790 MeV/u)

^{11}Li



Large-scale NCSM calculations of ^{11}Li





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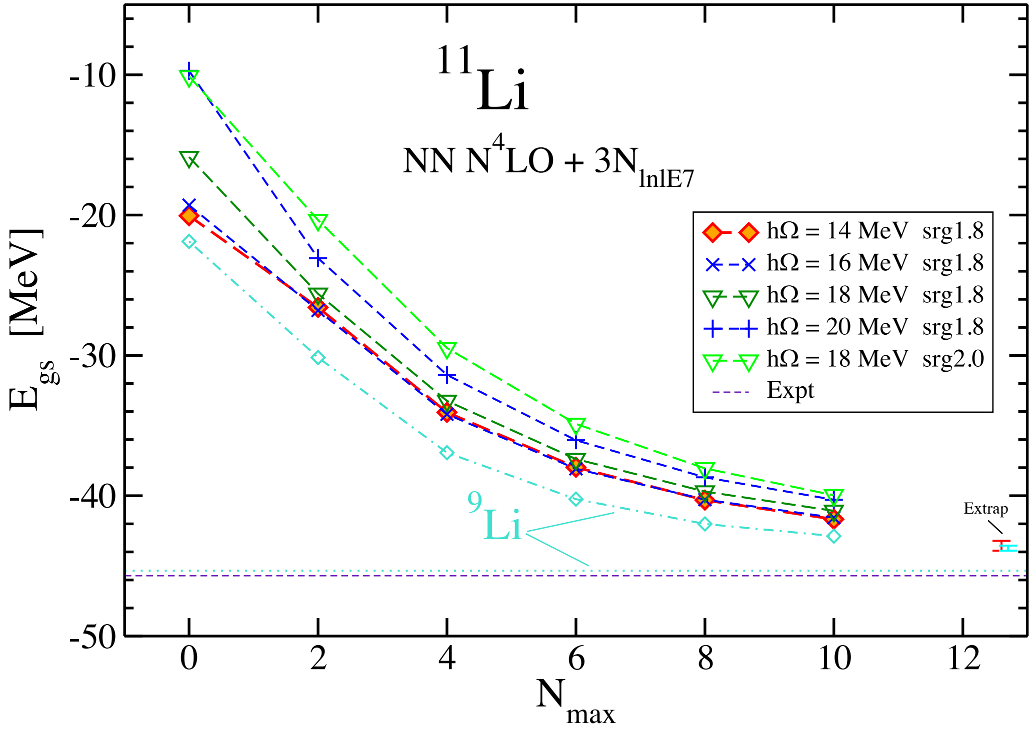

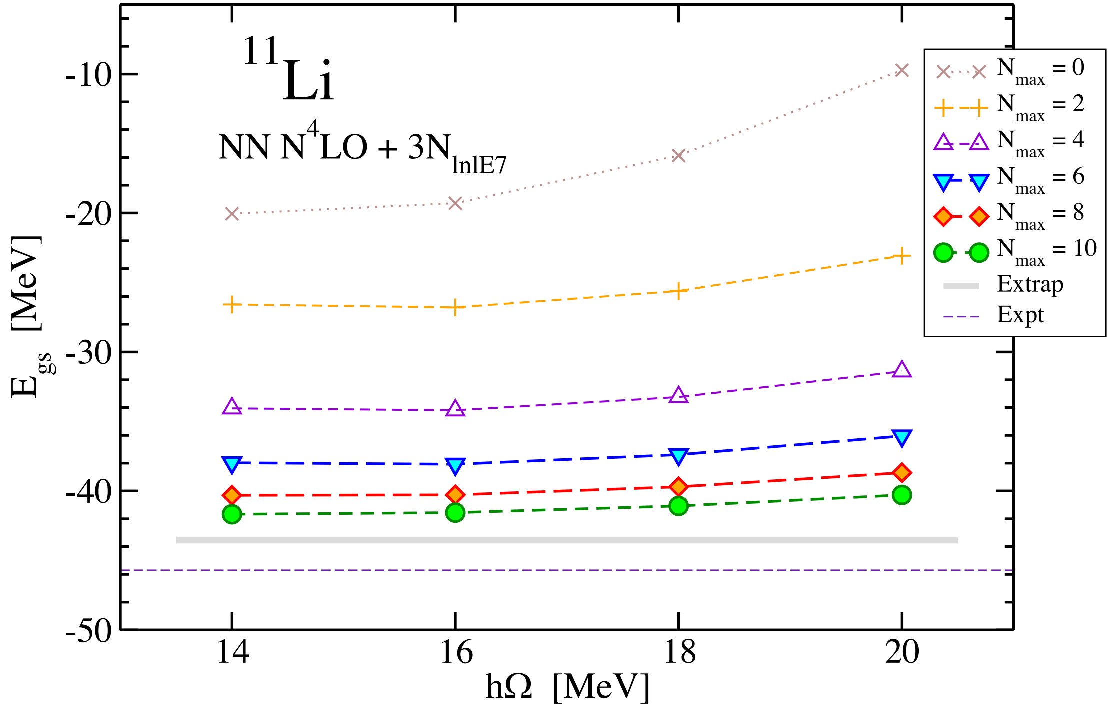

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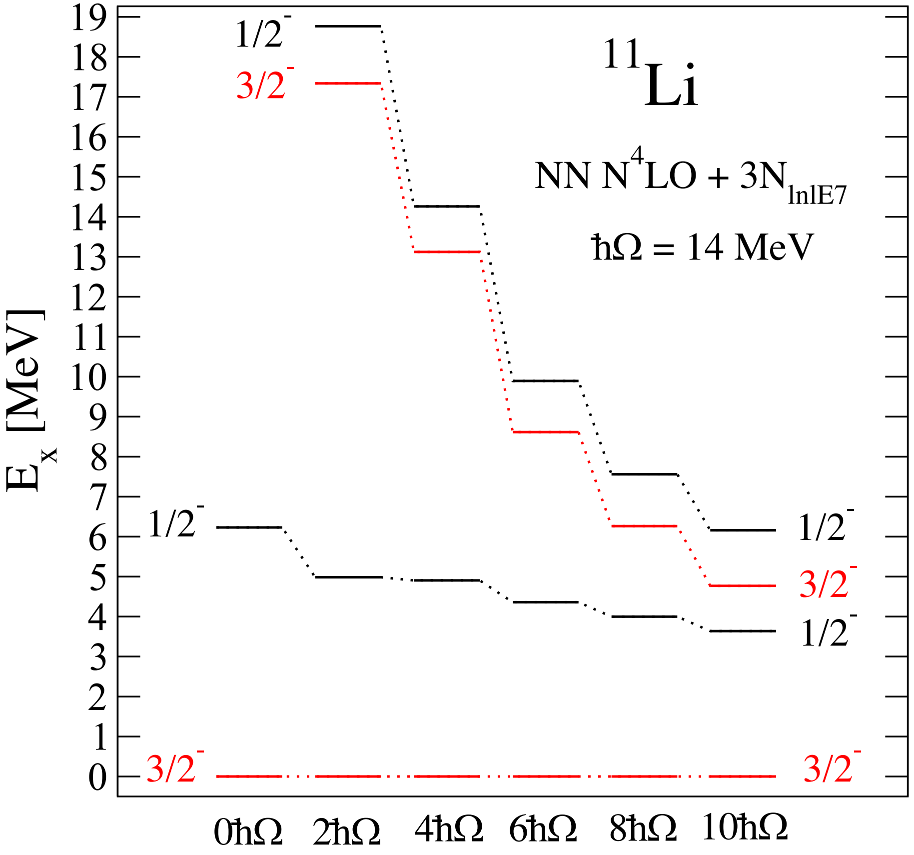
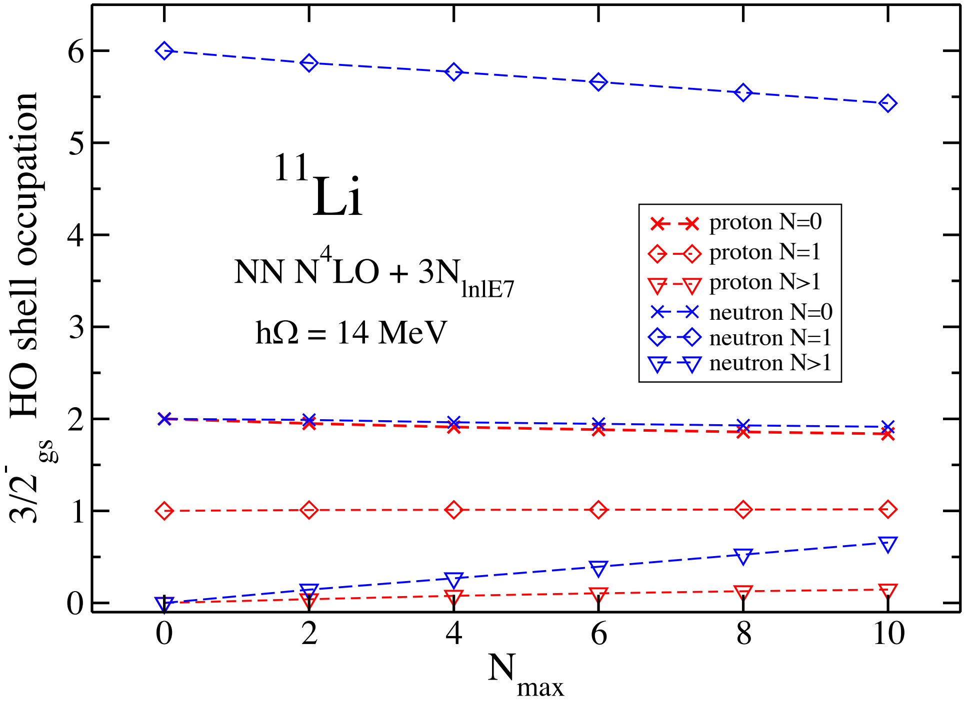


Preliminary



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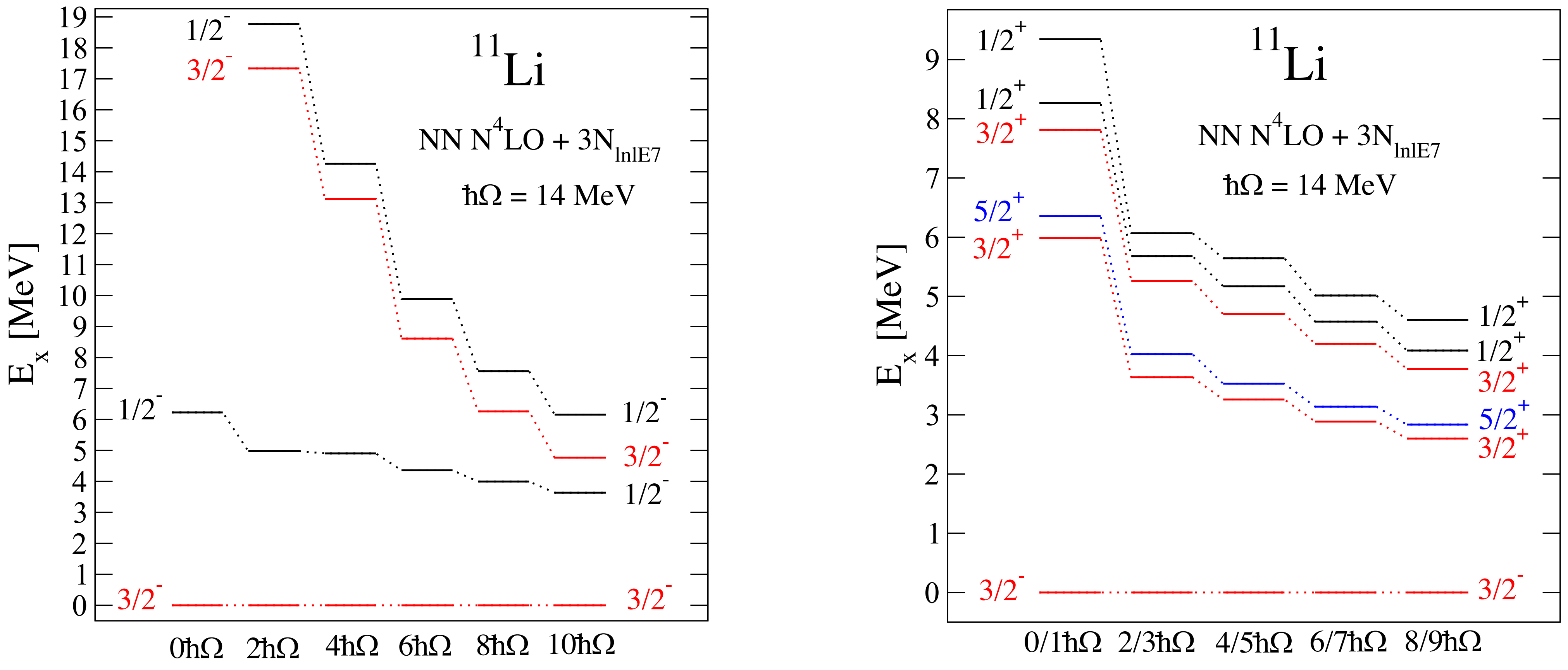

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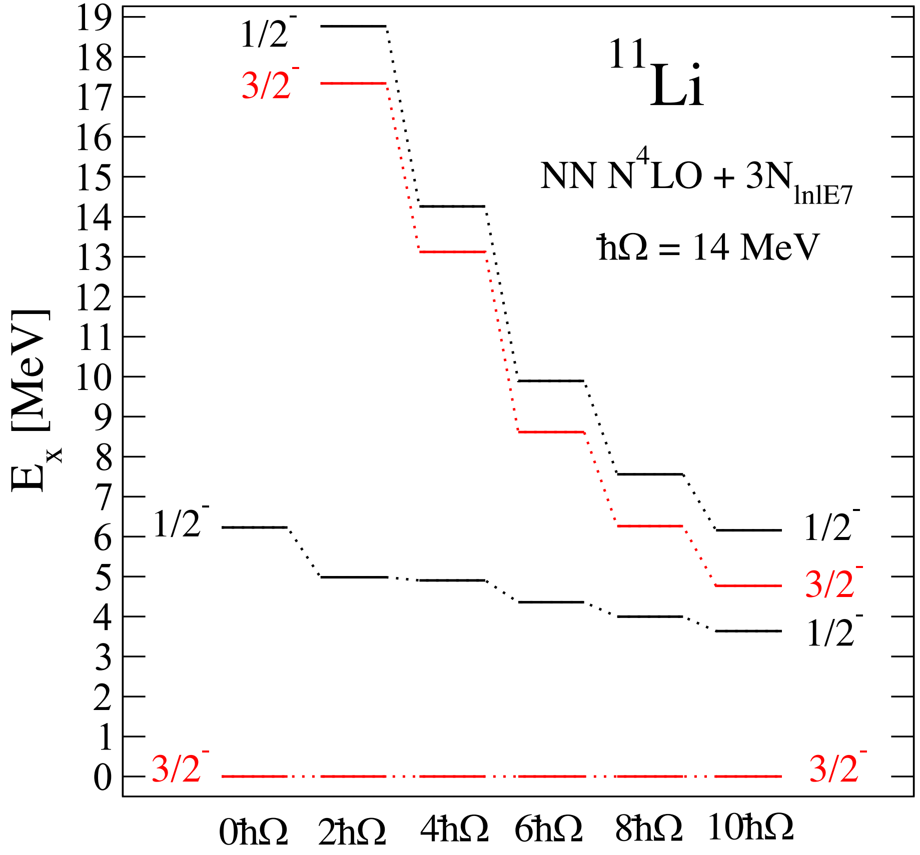
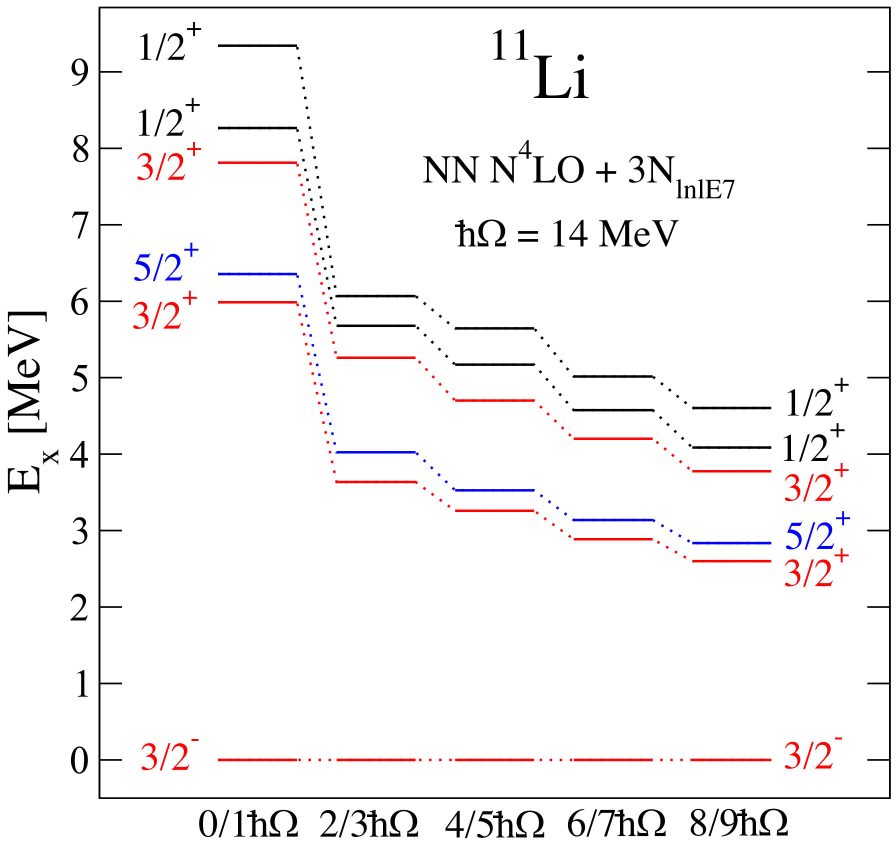
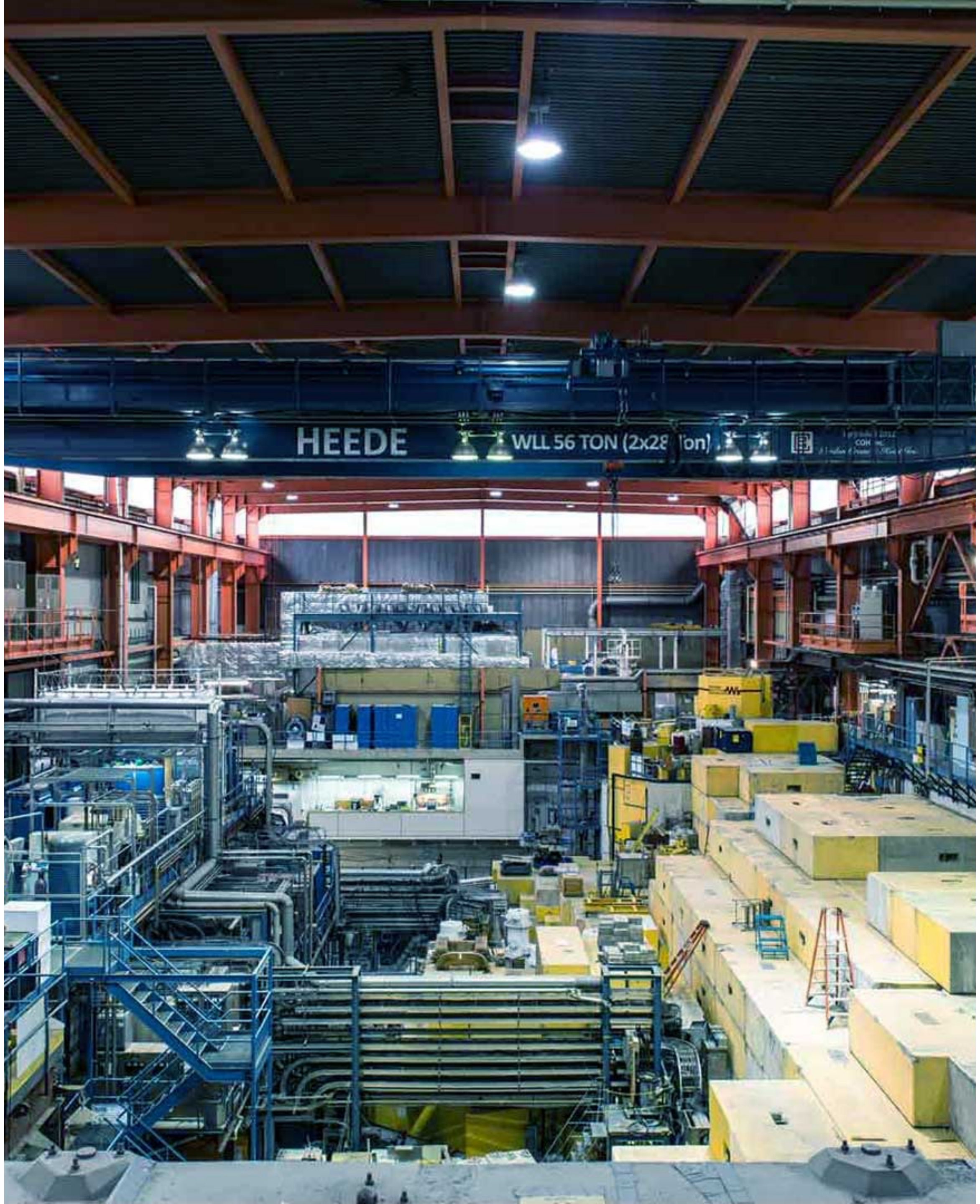




Next step – including continuum via NCSMC – ^{11}Li ~ ^{9}Li + n + n

Enhanced short-range 3N interaction with two-pion exchange

Results for ^{3}H



Discovery, accelerated

A new class of three-nucleon forces – enhanced sub-leading terms?

PHYSICAL REVIEW LETTERS **135**, 022501 (2025)

New Class of Three-Nucleon Forces and Their Implications

Vincenzo Cirigliano,[*] Maria Dawid,[†] Wouter Dekens,[‡] and Sanjay Reddy[§]

Closer look at enhanced three-nucleon forces

E. Epelbaum,[1] A. M. Gasparyan,[1] J. Gegelia,[1,2] D. Hog,[1] and H. Krebs[1]

arXiv:2512.14117

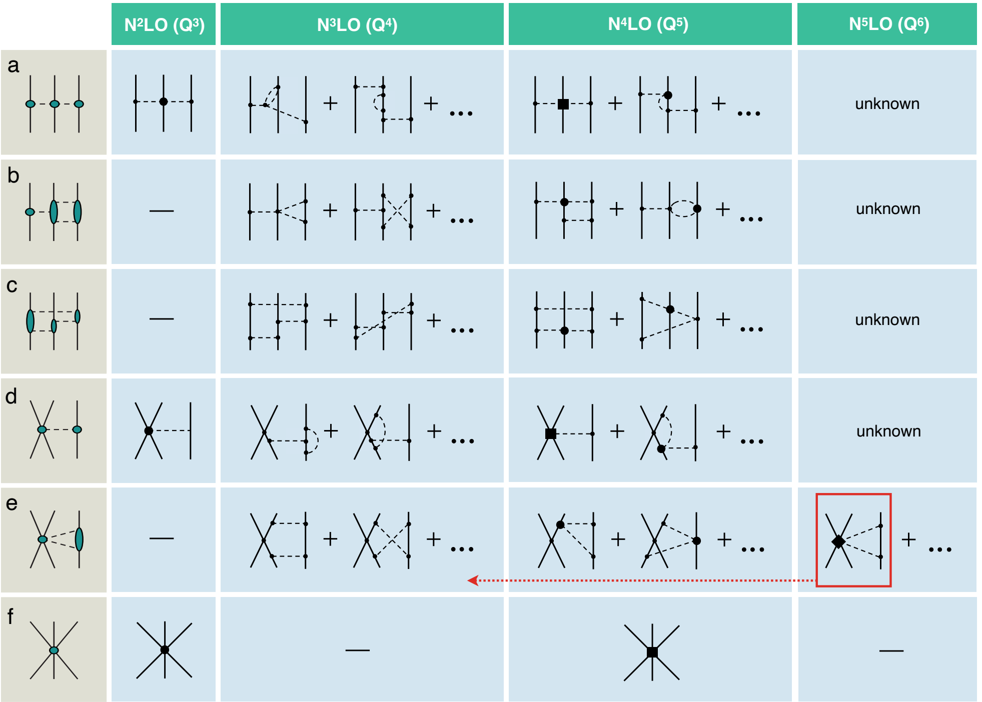
- Enhanced short-range 3N interaction with two-pion exchange

$$W_{D_2} = \sum_{i \neq j \neq k} \frac{9 g_A^2 D_2 m_\pi^3}{128 \pi f_\pi^4} \frac{(d_2^S + d_2^T \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j)}{d_2^S - 3 d_2^T} \mathcal{I}\left(\frac{q_k^2}{4 m_\pi^2}\right)$$

$$W_{F_2} = -\sum_{i \neq j \neq k} \frac{15 g_A^2 m_\pi^3}{16 \pi f_\pi^4} (f_2^S + f_2^T \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j) \mathcal{J}\left(\frac{q_k^2}{4 m_\pi^2}\right)$$

$$D_2 = \frac{c_{D_2}}{F_\pi^4} \quad \longleftarrow \quad D_2 = \frac{c_{D_2}}{F_\pi^2 \Lambda_\chi^2}$$

$$F_2 = \frac{c_{F_2}}{F_\pi^4} \qquad\qquad F_2 = \frac{c_{F_2}}{F_\pi^2 \Lambda_\chi^2}$$



Exploring quark mass dependent three-nucleon forces in medium-mass nuclei

Urban Vernik,[1,2,*] Kai Hebeler,[1,2,3,†] and Achim Schwenk[1,2,3,‡]

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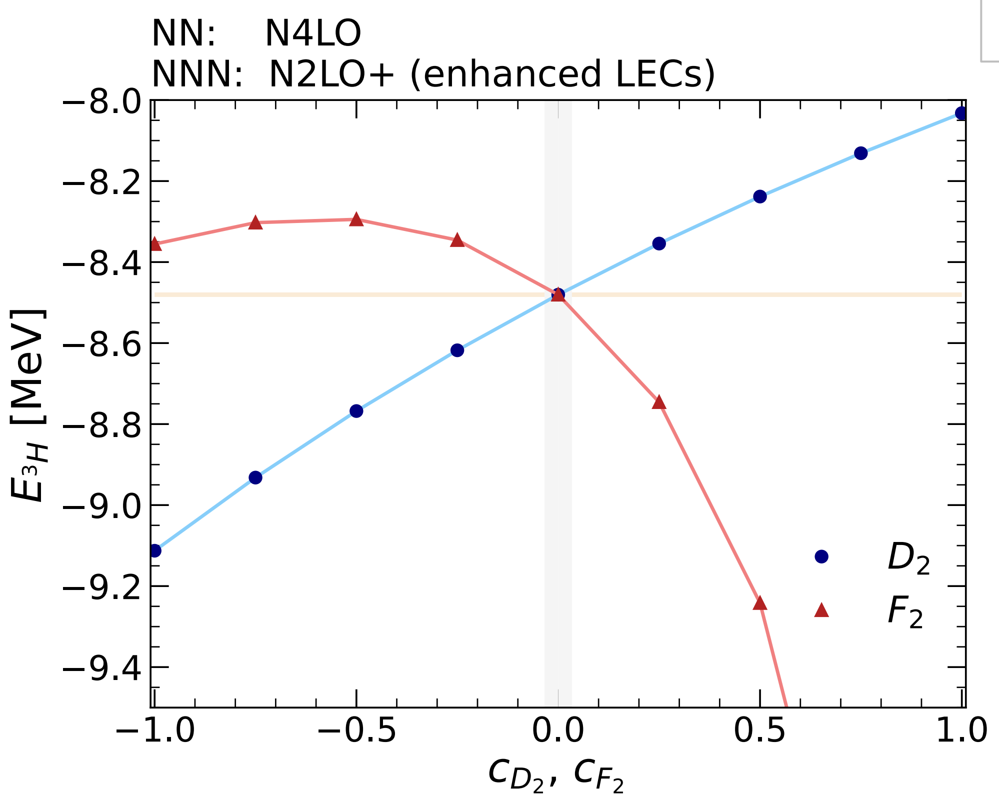
arXiv:2512.14117

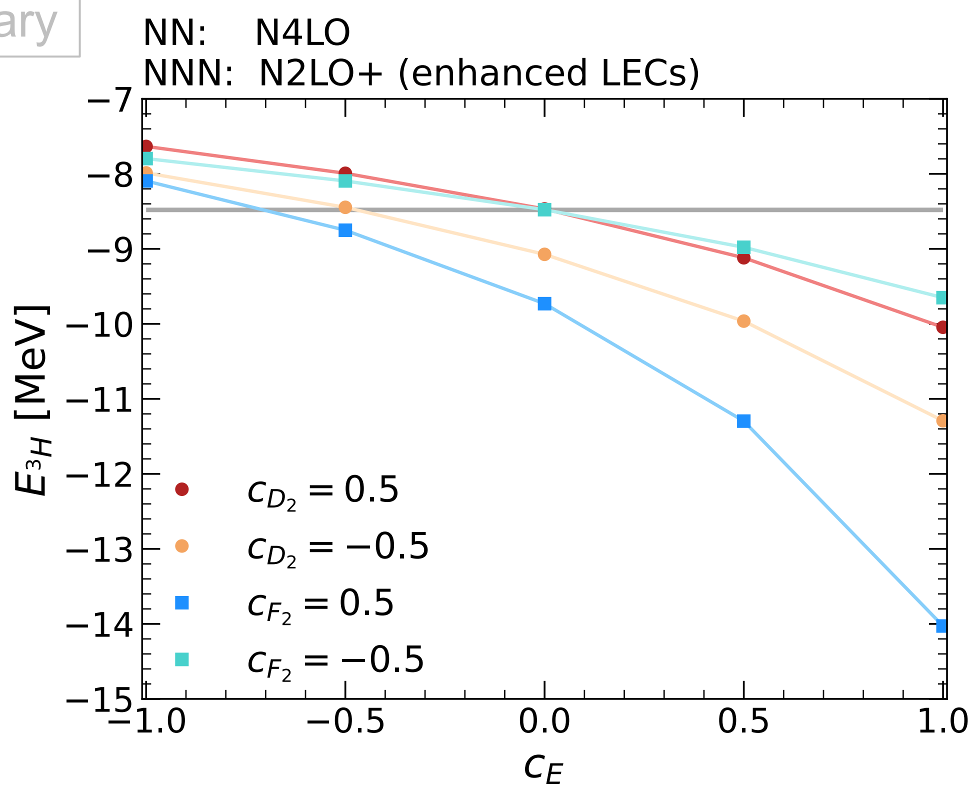
- Application to ^{3}H gs energy – Jacobi NCSM

Georgios Palkanoglou (TRIUMF)

Calculations for ^{4}He, p-shell nuclei in progress

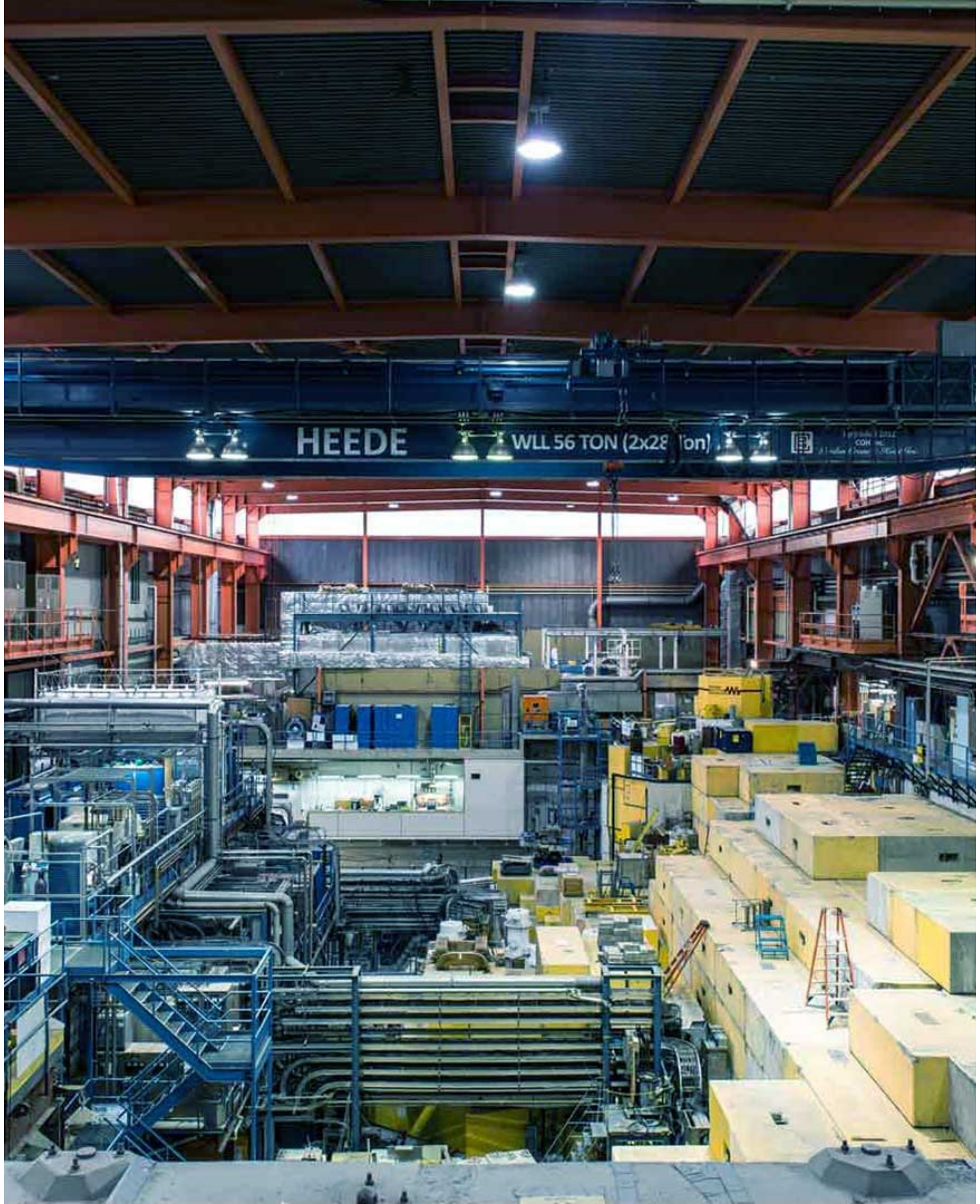
Preliminary





TRIUMF

Conclusions



Discovery, accelerated

Conclusions

- Sub-leading spin-orbit enhancing 3N interaction improves description of light nuclei
- Enhanced short-range 3N interaction with two-pion exchange applied to ^{3}H
  - Calculations for ^{4}He and p-shell nuclei in progress
- ^{19}F Schiff moment and EDM calculated in NCSM
  - Obtained experimental limits for PTV πNN couplings
- Nuclear structure of ^{11}Li investigated in NCSM
  - Relevant for new $^{11}Li(d,d')^{11}Li$ TRIUMF IRIS Experiment
  - Prerequisite for NCSMC $^{11}Li \sim {}^{9}Li + n + n$ study with three-body continuum