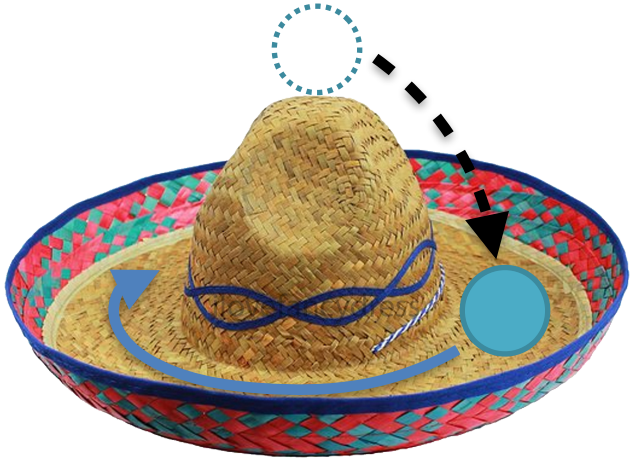
Symmetry breaking: spurious and spontaneous

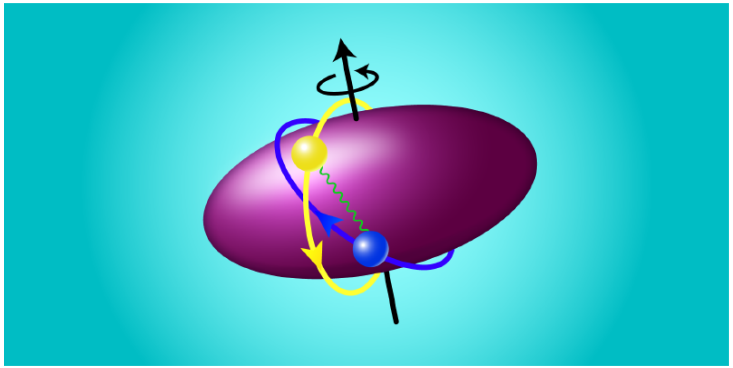


Ragnar Stroberg

TRIUMF PAINT25
Vancouver
February 26 2025

Part 1: The Spontaneous

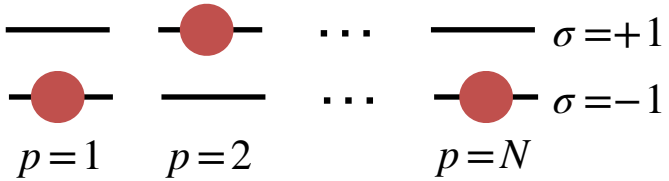
How should we treat deformed nuclei, from an ab initio point of view?



Use a deformed reference!!!!



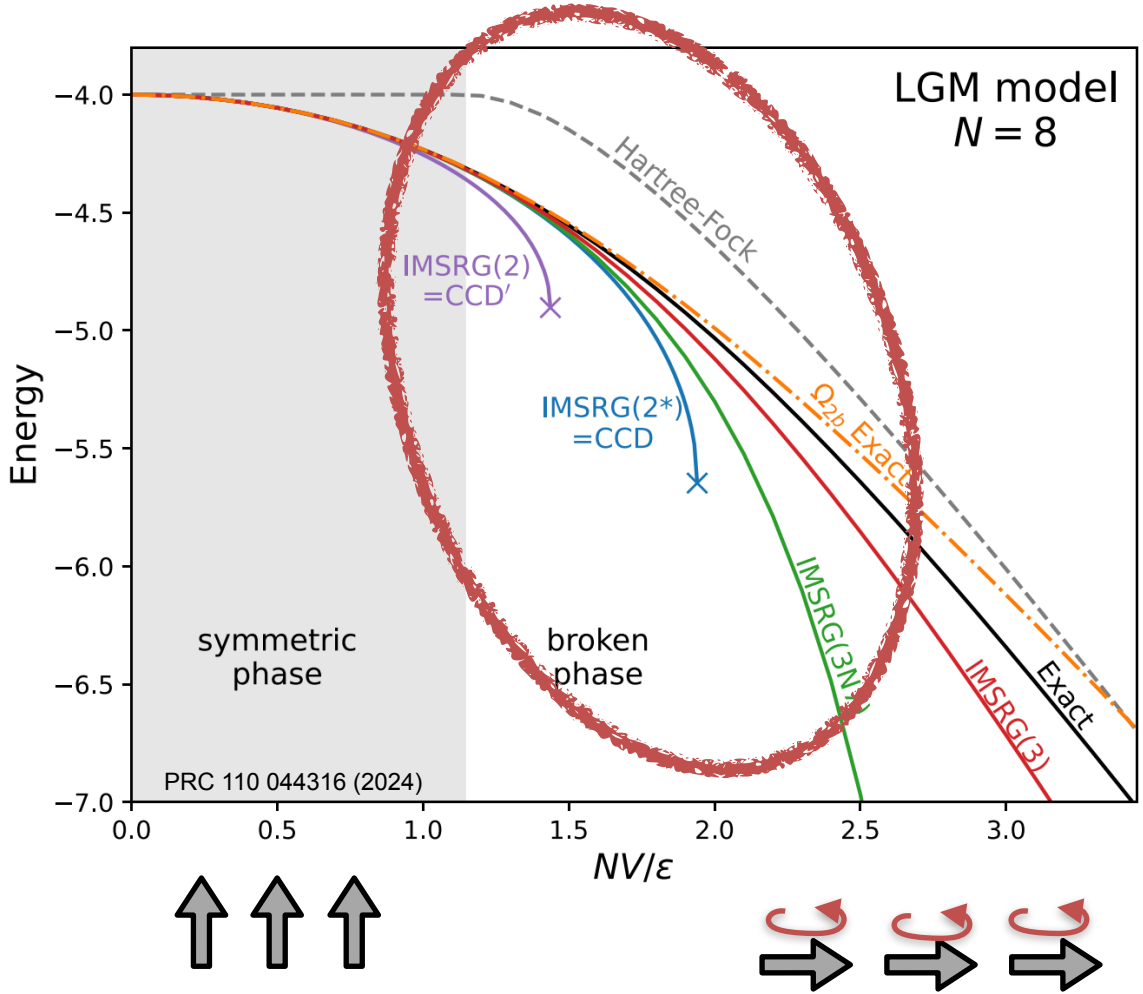

Lipkin-Glick-Meshkov model



$$H = \epsilon S_z + \frac{1}{2} V (S_+^2 + S_-^2)$$

$$S_z = \sum_{p\sigma} \sigma a^\dagger_{p\sigma} a_{p\sigma}$$

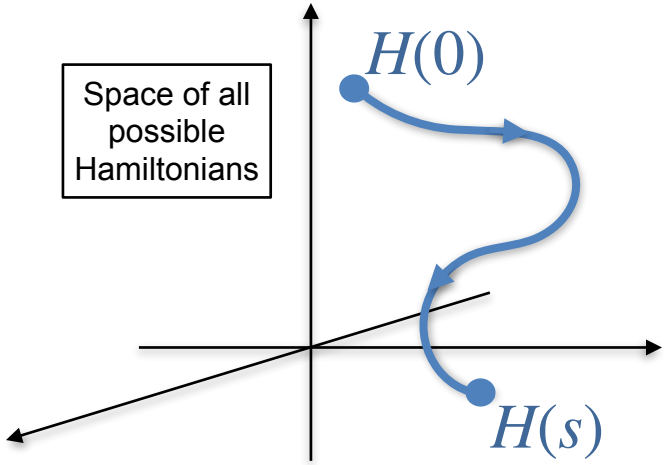
$$S_\pm = \frac{1}{2} \sum_{p\sigma} a^\dagger_{p\sigma} a^\dagger_{p'\sigma} a_{p-\sigma} a_{p'-\sigma}$$



IMSRG

$$H \rightarrow H(s) = U(s)HU^{\dagger}(s)$$

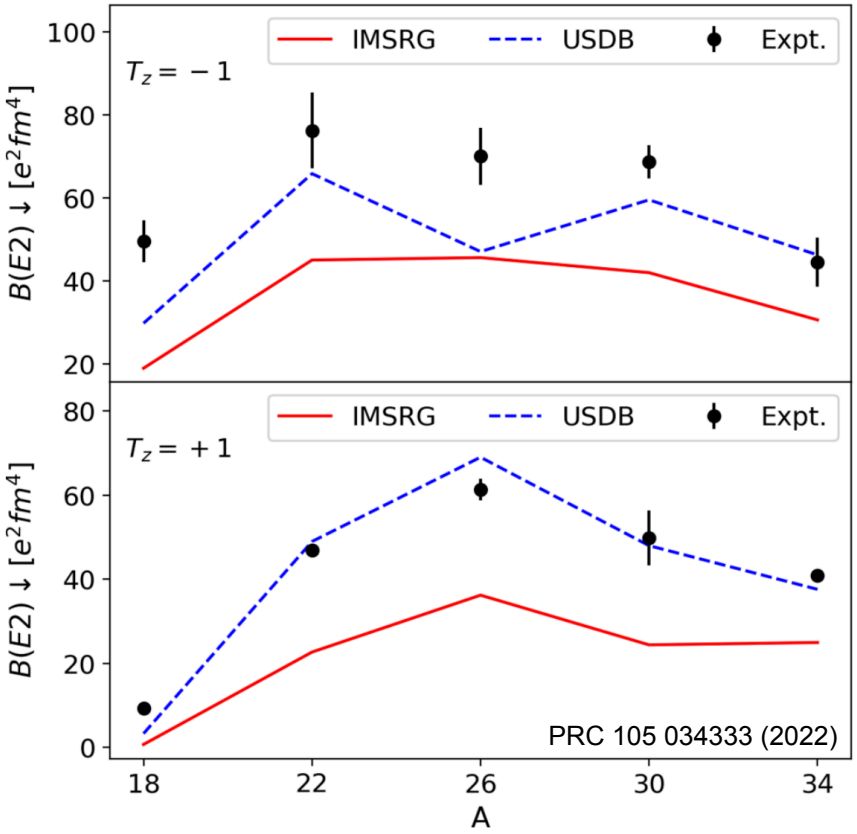
$$U(s) = e^{\Omega(s)}$$



$$H(s) = H + [\Omega, H] + \frac{1}{2!}[\Omega, [\Omega, H]] + \ldots$$

$$\mathcal{O}(s) = \mathcal{O} + [\Omega, \mathcal{O}] + \frac{1}{2!}[\Omega, [\Omega, \mathcal{O}]] + \ldots$$

Truncate all operators at NO2B level

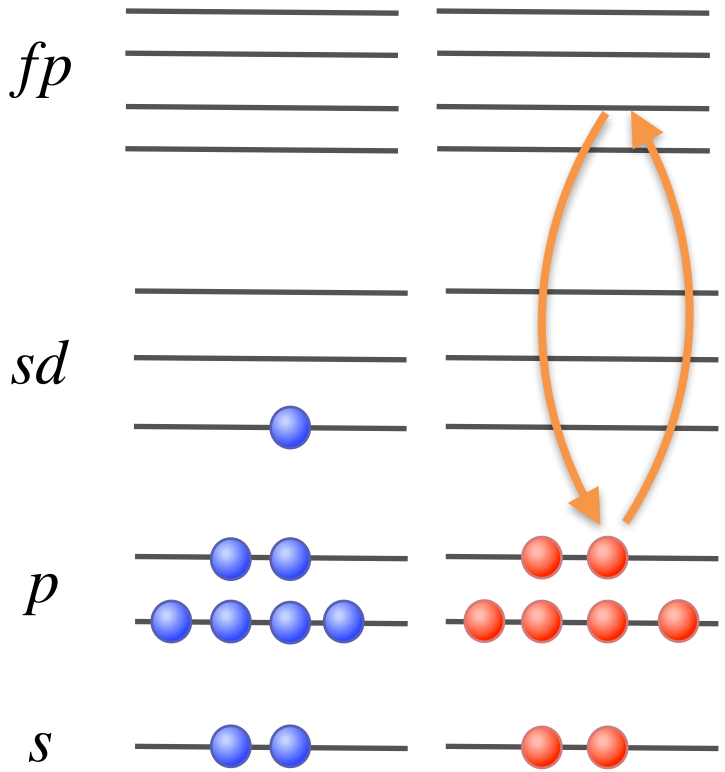


VS-IMSRG in *sd* shell underpredicts E2 transition strength by a factor ~2.

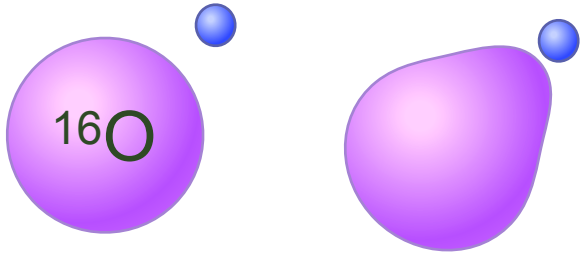
Phenomenologically, this is fixed by using **effective charges** $e_p \sim 1.5$, $e_n \sim 0.5$.

Effective charges should *emerge* from the VS-IMSRG transformation.

^{17}O



Effective charges: the lore



^{17}O ground state electric quadrupole moment:

Experiment: -2.558 e fm^2
VS-IMSRG: -1.40 e fm^2

^{17}O

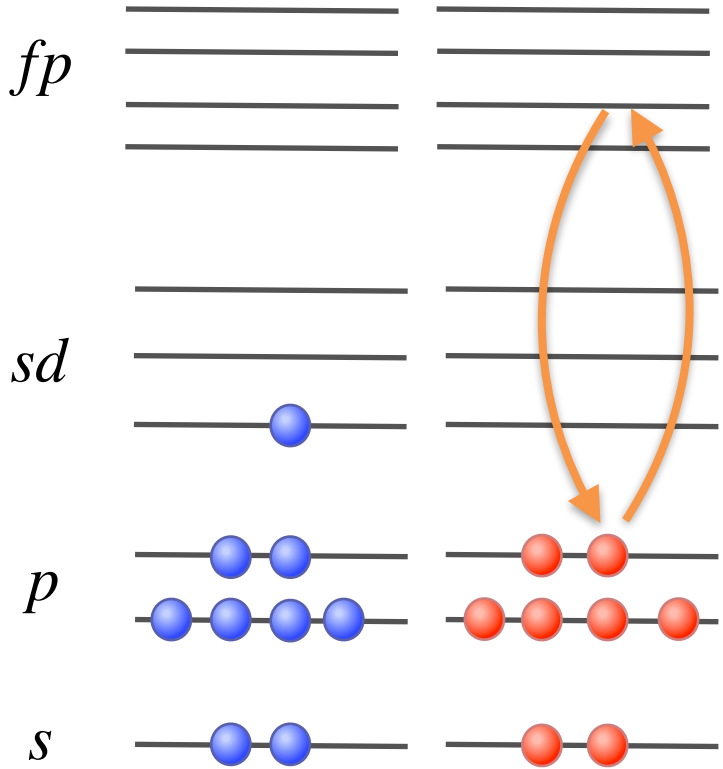
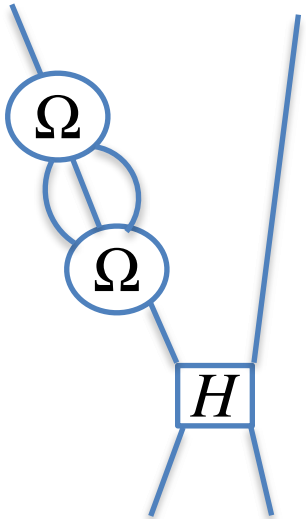


TABLE V. Effective charge for a $d_{5/2}$ nucleon above an ^{16}O core for different approximation schemes and interaction models. The model space is defined by $e_{\max} = 3$, $\hbar\omega = 16$ MeV. The last three columns give results of direct diagonalization truncated to $N_{\max}$ quanta of excitation.

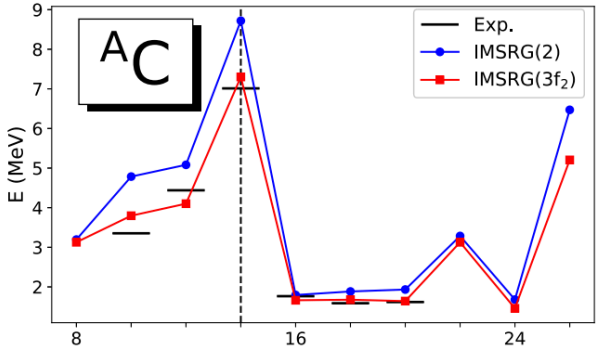
					VS-	CI $N_{\max}$		
int.		CP	TDA	RPA	IMSRG	2	4	6
$Q \cdot Q$	e_n	0.23	0.29	0.42	0.43	0.26	0.32	0.41
	e_p	1.25	1.31	1.44	1.49	1.30	1.37	1.46
NN	e_n	0.16	0.17	0.17	0.17	0.14	0.17	0.19
only	e_p	1.05	1.09	1.10	1.04	1.04	1.05	1.05
NN	e_n	0.24	0.31	0.33	0.26	0.20	0.23	0.29
$+3N$	e_p	1.07	1.16	1.19	1.02	1.04	1.05	1.05

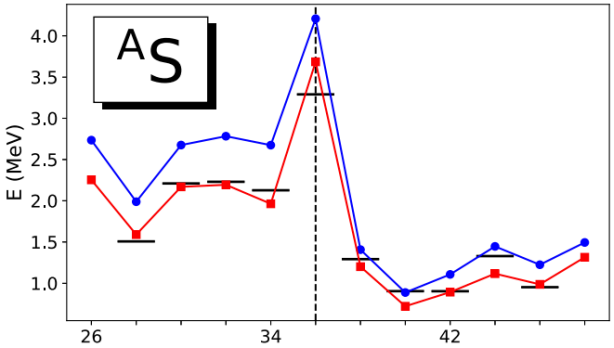
Going beyond IMSRG(2) with IMSRG($3f_2$)

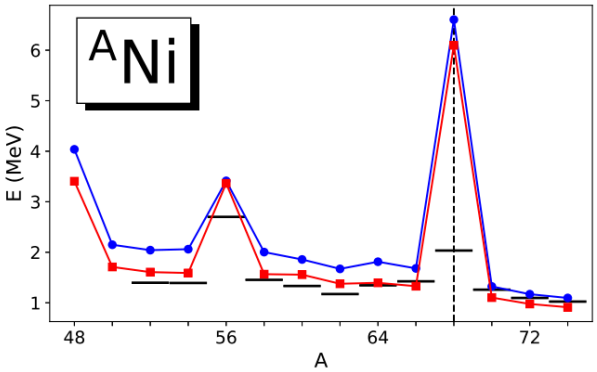
$$[\Omega, [\Omega, H]_{3b}]_{1b,2b}$$



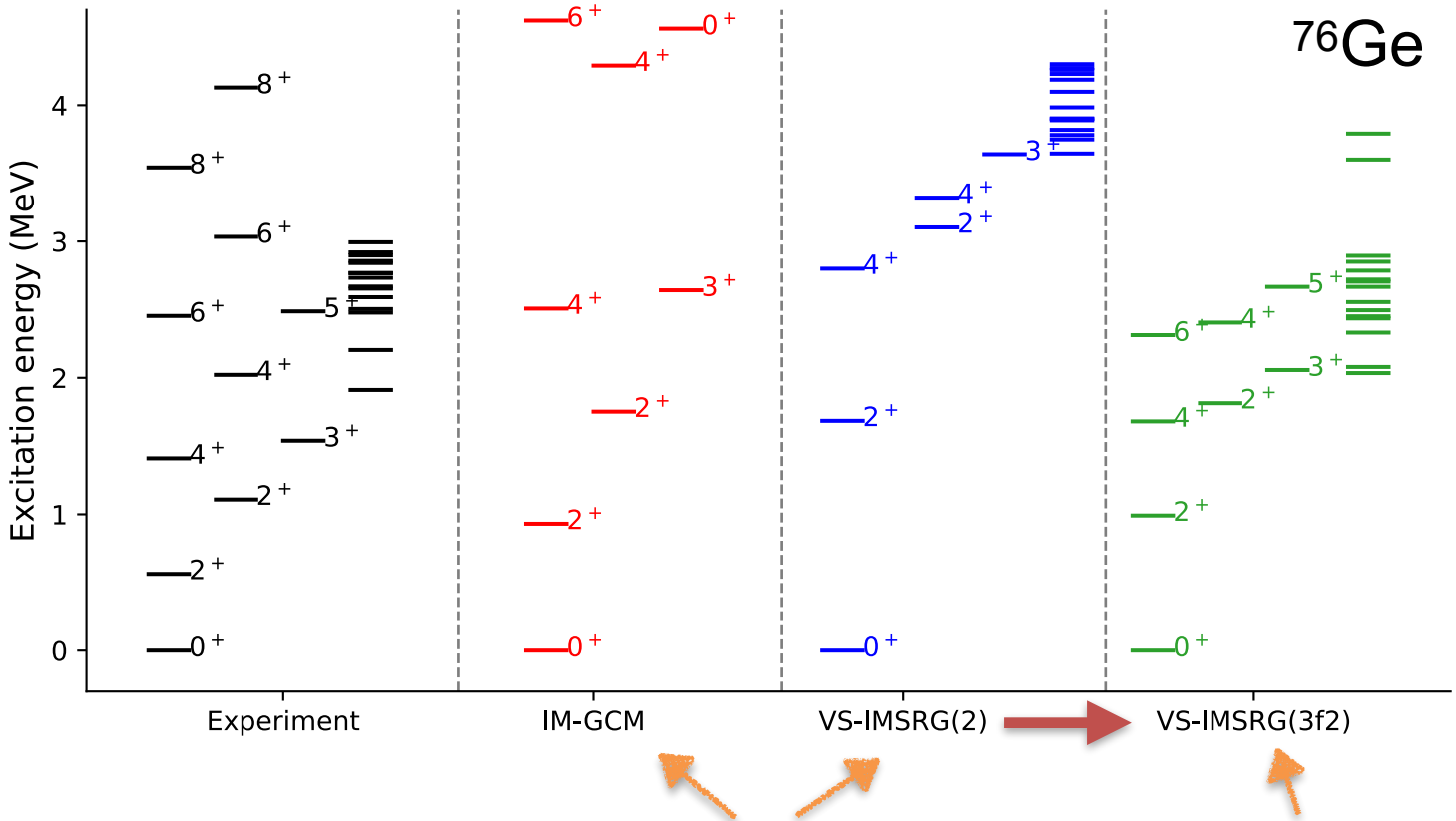
Will it work for E2s as well?







Bingcheng He
Notre Dame



[Preliminary]

different many-body methods, same input force

Better calculation, better agreement!

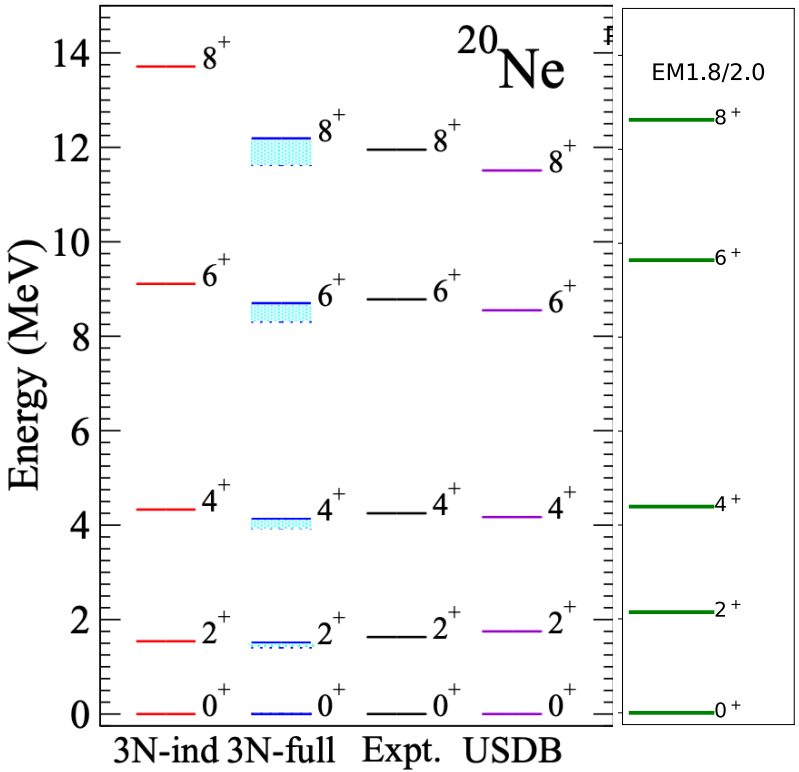
Good spectra ≠ good deformation

^{20}Ne

$B(E2; 2_1^+ \rightarrow 0_1^+)$

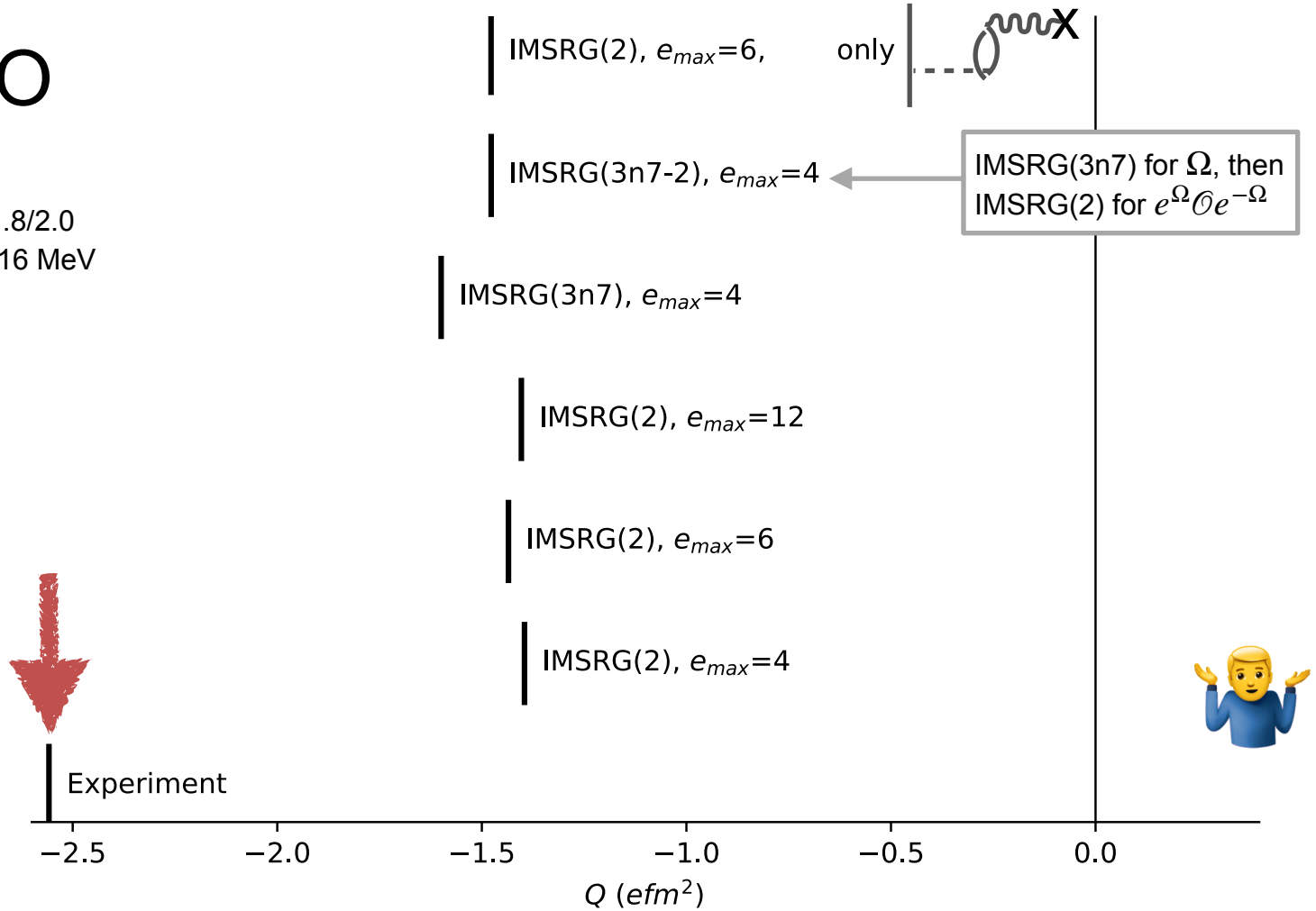
Experiment: 66 e²fm⁴ = 20 wu
R(4/2)=2.6

IMSRG(2): 29 e²fm⁴ = 9 wu
R(4/2) = 2.0 (with EM1.8/2.0)

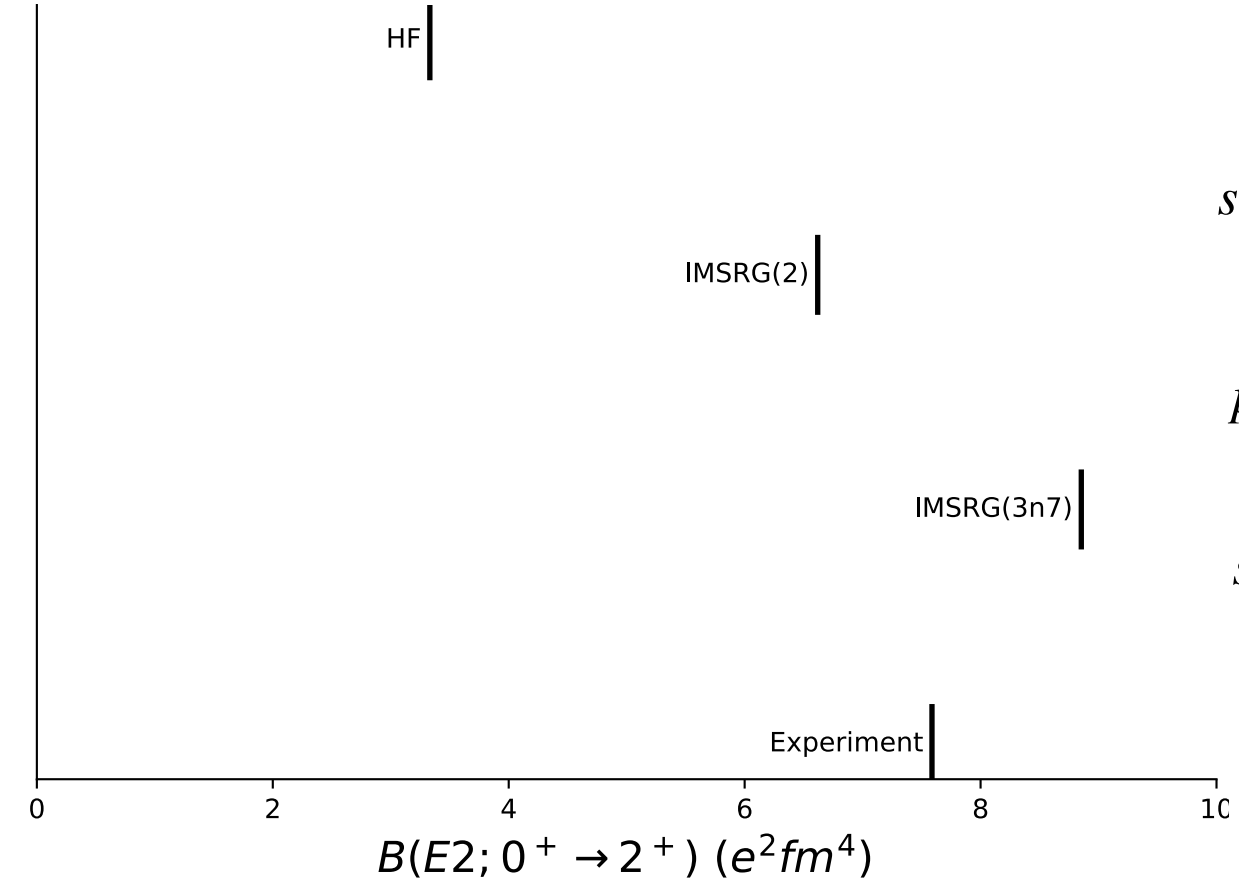


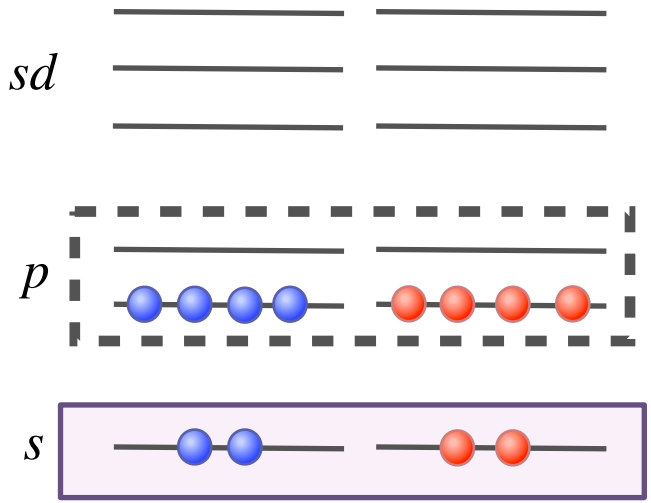
^{17}O

EM 1.8/2.0
$\hbar\omega$=16 MeV

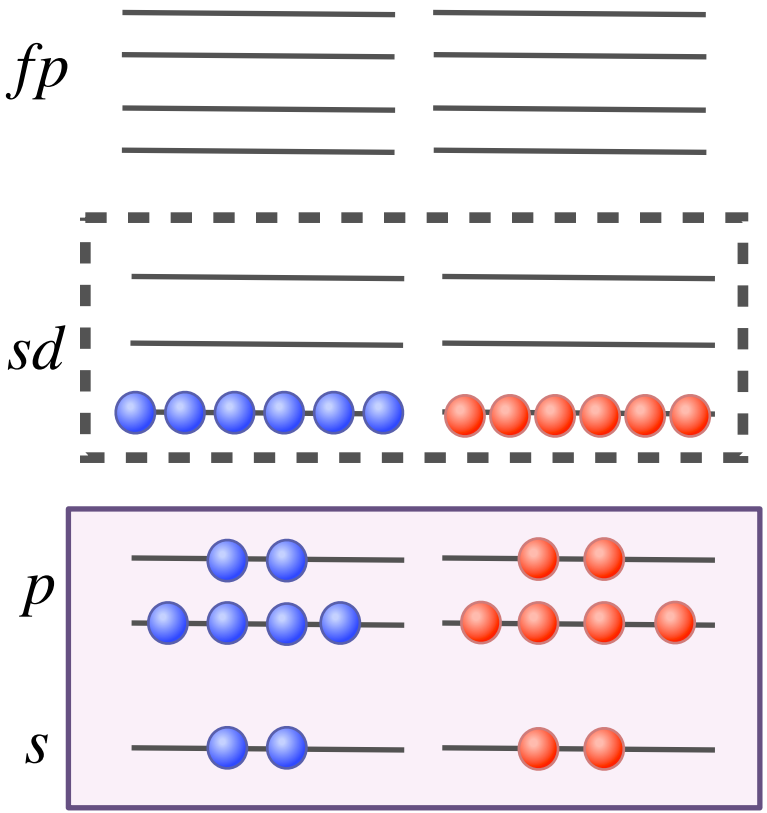


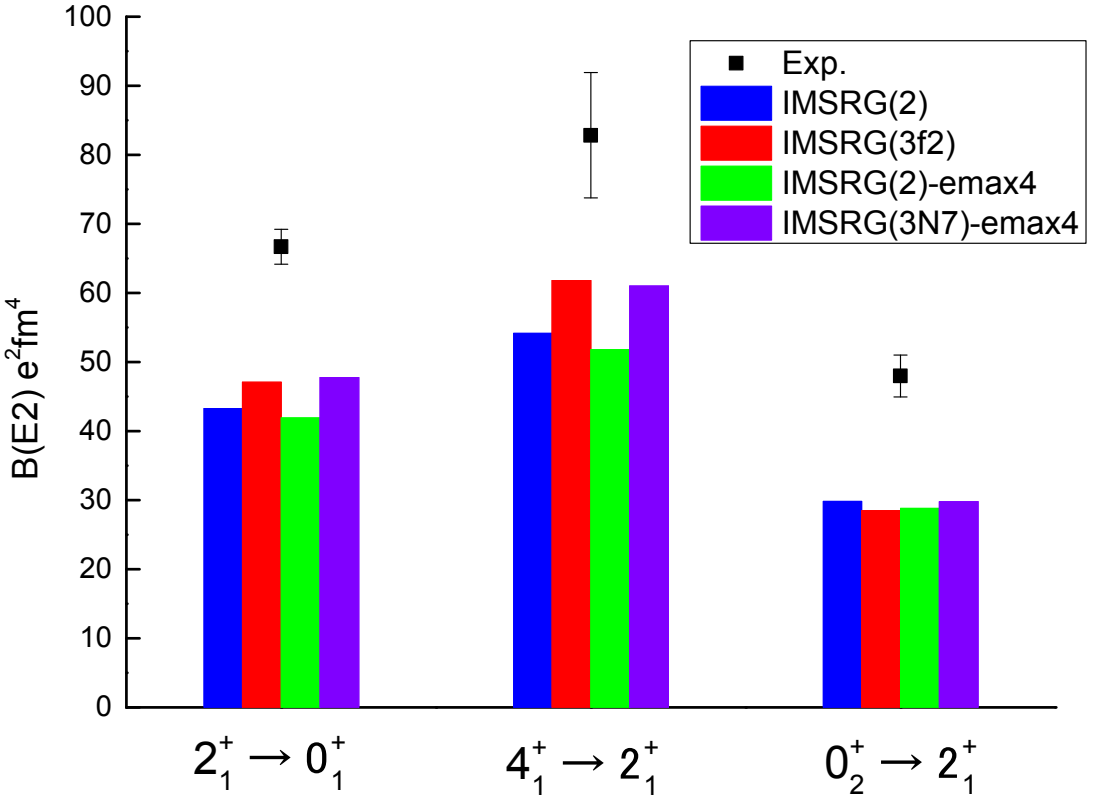
^{12}C


HF
IMSRG(2)
IMSRG(3n7)
Experiment
0
2
4
6
8
10
$B(E2; 0^+ \rightarrow 2^+)$ (e^2fm^4)


sd
p
s

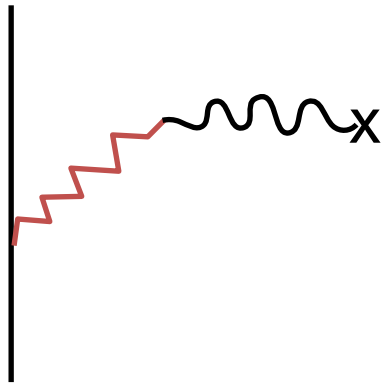
^{28}Si


fp
sd
p
s

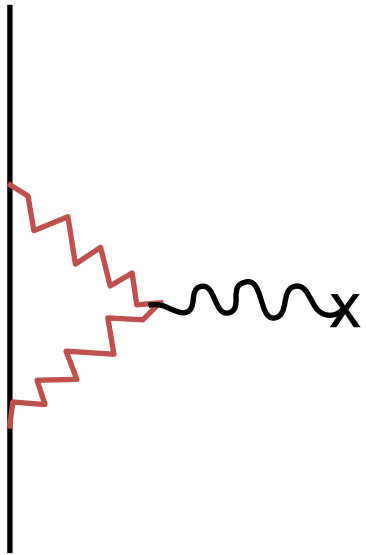

B(E2) e²fm⁴
100
90
80
70
60
50
40
30
20
10
0
Exp.
IMSRG(2)
IMSRG(3f2)
IMSRG(2)-emax4
IMSRG(3N7)-emax4
2₁⁺ → 0₁⁺
4₁⁺ → 2₁⁺
0₂⁺ → 2₁⁺

Where is the extra collectivity hiding??

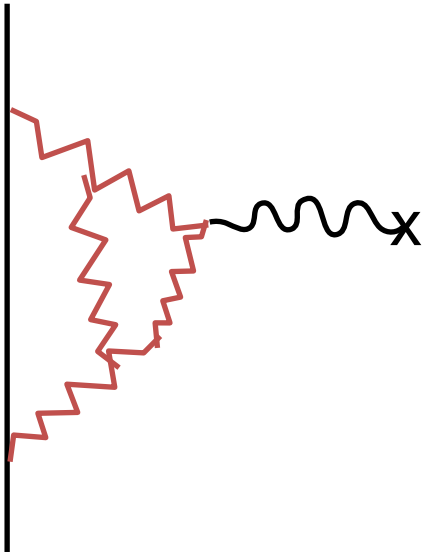
$[\Omega, \mathcal{O}]_1$



$[\Omega, [\Omega, \mathcal{O}]_2]_1$

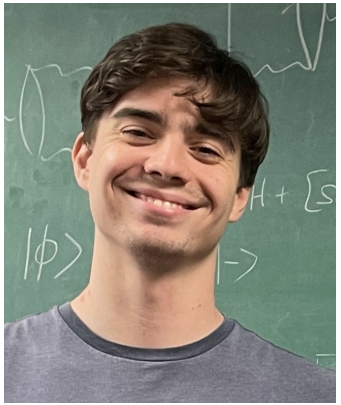


$[\Omega_3, [\Omega_3, \mathcal{O}]_3]_2]_1$



Part 2: The spurious

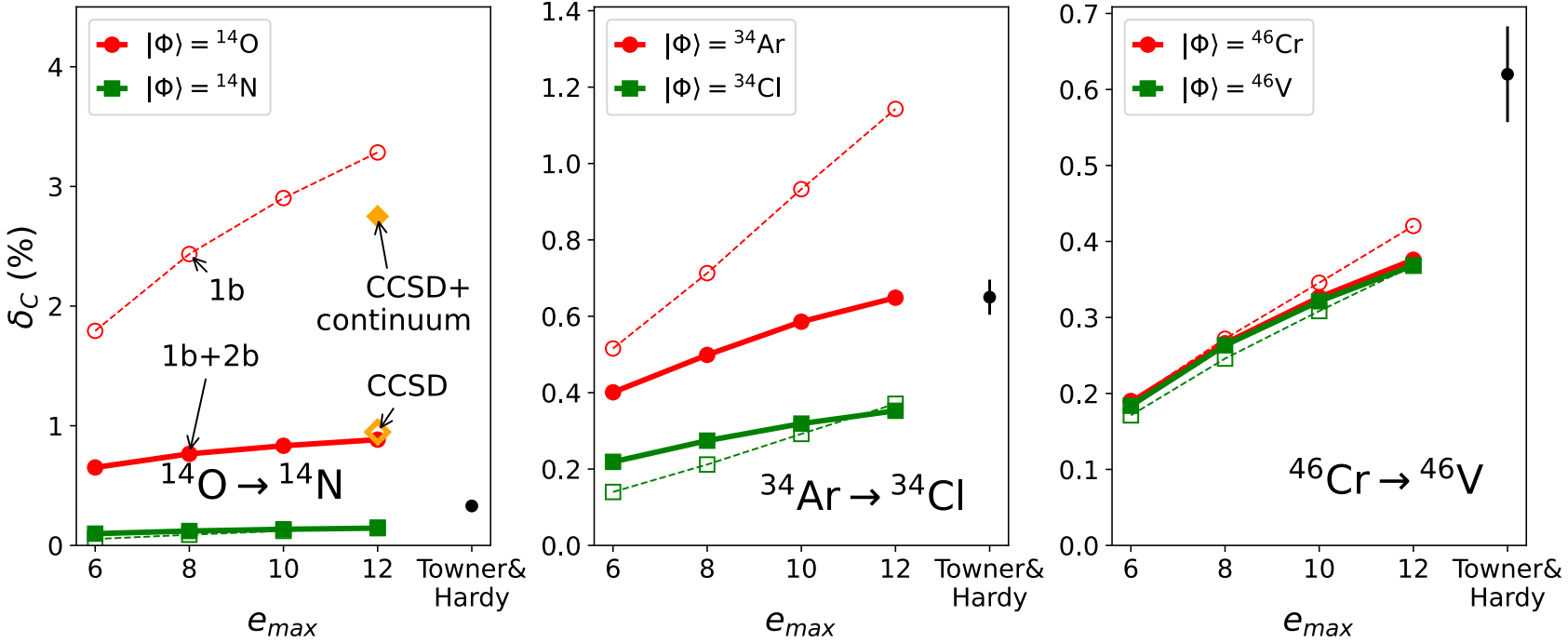
Isospin breaking relevant for calculations of the δ_C correction for superallowed β decays



arXiv 2412.10693

Alex Farren
REU student

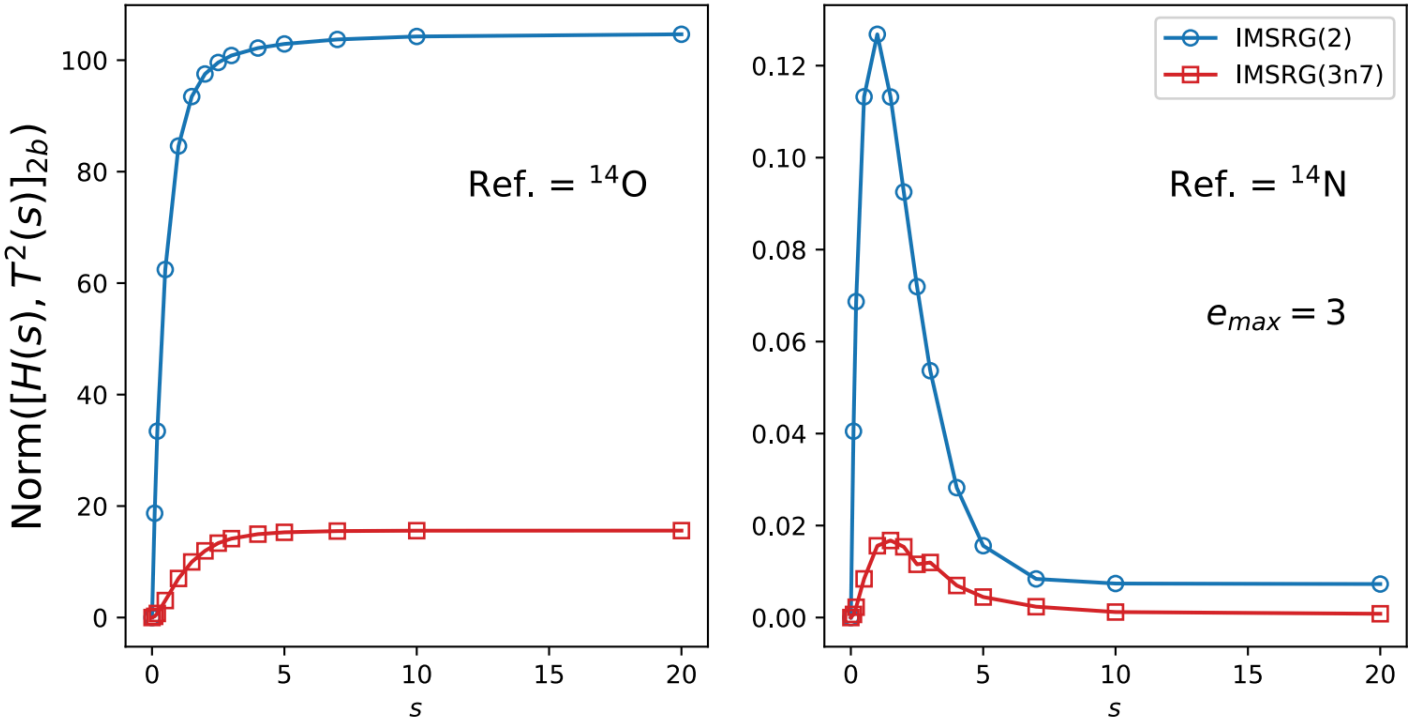
δ_C with the VS-IMSRG



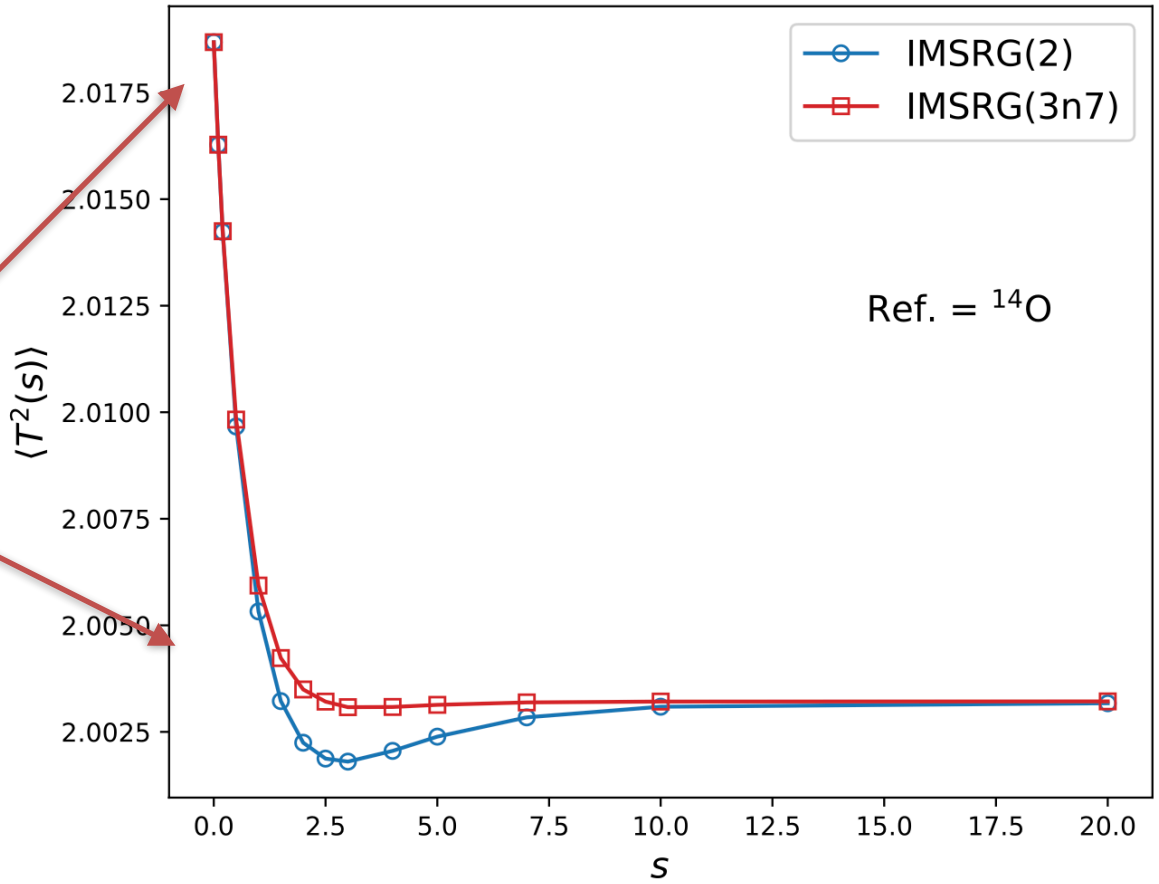
SRS, Particles 4 521 (2021)

Spurious isospin breaking

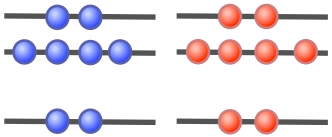
$[H(s), T^2(s)] = 0$ @ s=0 Toy isospin-conserving H

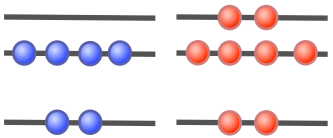


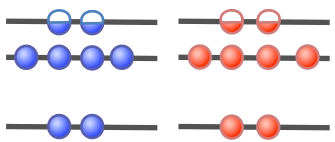
Hartree-Fock spuriously breaks T^2. Correlations from IMSRG tend to restore it.

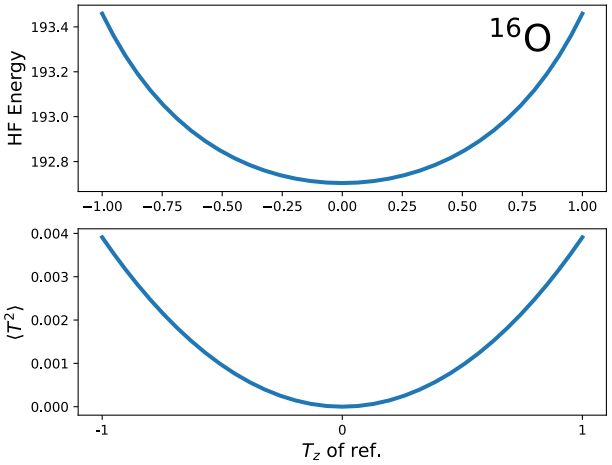


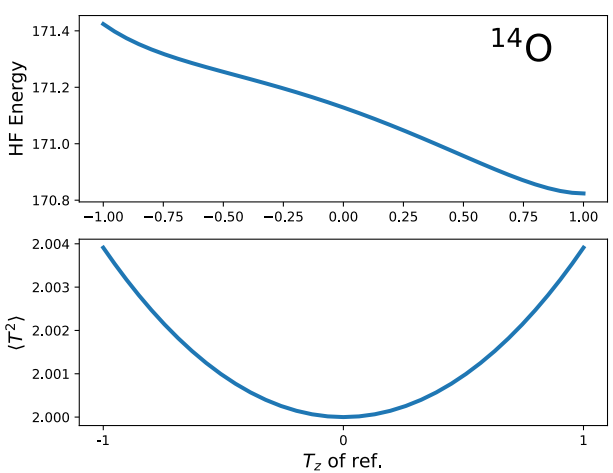
Spurious (spontaneous?) isospin breaking at the Hartree-Fock level

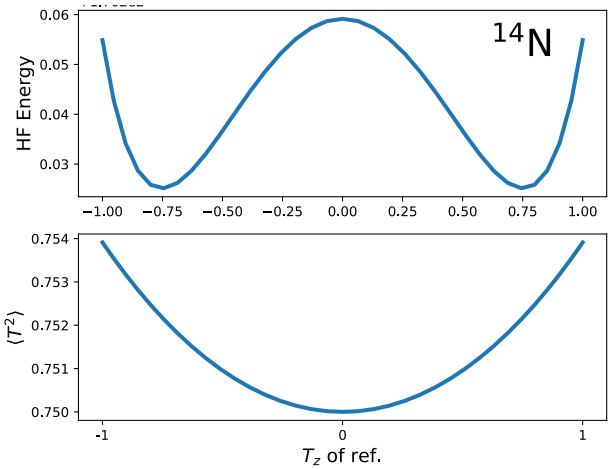










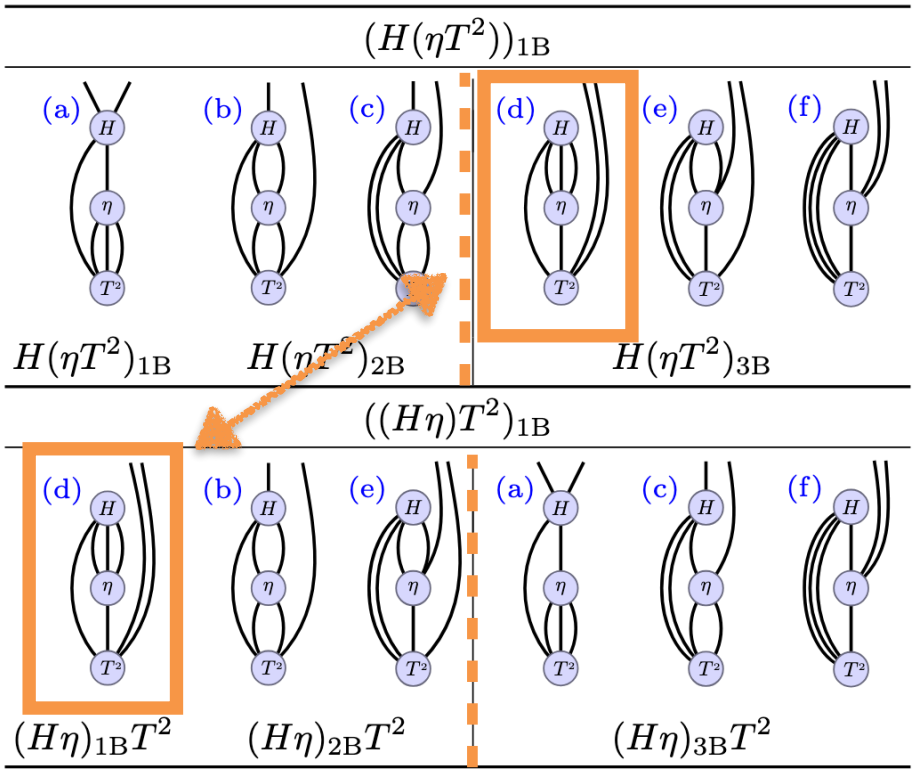


Spurious isospin breaking from IMSRG(2)

$$\frac{d}{ds}[H, T^2] = \big[\eta, [H, T^2]\big]$$

$$= \big[[\eta, H], T^2\big] + \big[H, [\eta, T^2]\big]$$

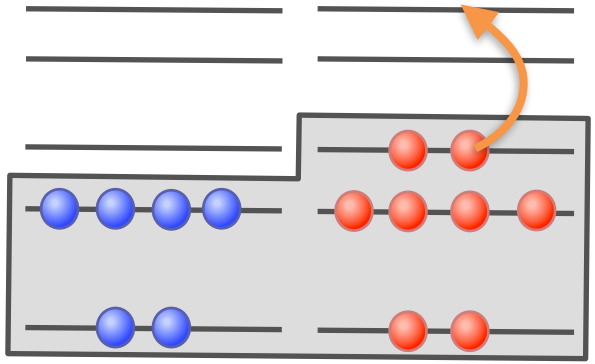
if initially $[H, T^2] = 0$, these should cancel.



Terms that need to cancel show up on opposite sides of the IMSRG(2) truncation. 😢

What can spoil $[\eta, T^2] = 0$?

$$H = H^{\mathrm{d}} + H^{\mathrm{od}} \qquad \eta = \frac{H^{\mathrm{od}}}{\Delta}$$



For a reference with $N \neq Z$
we can have

$$[T^2, H] = 0 \qquad [T^2, H^{\mathrm{d}}] \neq 0 \qquad [T^2, H^{\mathrm{od}}] \neq 0$$

This is remediated by using the same valence space for protons and neutrons.

$$|M_F|^2 = |M_F^{\text{iso}}|^2(1-\delta_C)$$

Isospin conserving interaction, plus Coulomb

δ_C (%)

Possible solution: compute with and without Coulomb and take the difference?

^{24}N

$= 0$

η	r no Cou					HF Coulomb	HF no Coul	HF Coulomb
Any	-4.441e-					4.441e-14	-2.220e-14	-0.0103

$\to \infty$

η	r no Cou					HF Coulomb	HF no Coul	HF Coulomb
SMW (EN)	-0.1847					-0.01399	5.264e-06	-0.01386
SMW (MP)	-0.1845					-0.01401	2.220e-14	-0.01385
SMa (EN)	-0.1847					-0.01399	5.351e-06	-0.01386
SMa (MP)	-0.1845					-0.01401	3.207e-09	-0.01385
SMit	-0.18505	-0.22166	-0.19787	-0.23760	SMit	-2.220e-14	-0.01401	4.441e-14	-0.01387
Iso SMW (EN)	-0.18441	-0.21589	-0.20684	-0.24581	Iso SMW (EN)	4.441e-14	-0.01331	-2.220e-14	-0.01325
Iso SMW (MP)	-0.18451	-0.21600	-0.20693	-0.24594	Iso SMW (MP)	4.441e-14	-0.01331	2.220e-14	-0.01326
Iso SMa (EN)	-0.18441	-0.21589	-0.20683	-0.24580	Iso SMa (EN)	2.220e-14	-0.01332	2.220e-14	-0.01325
Iso SMa (MP)	-0.18451	-0.21599	-0.20692	-0.24593	Iso SMa (MP)	4.441e-14	-0.01331	2.220e-14	-0.01326
Iso SMit	-0.18276	-0.21469	-0.20245	-0.24325	Iso SMit	-2.220e-14	-0.01334	6.661e-14	-0.01329

Summary

- Quantitative derivation of effective charges remains elusive.
- The standard core-polarization/PV coupling term is dominant, but doesn't seem to be enough.
- IMSRG(3) contributions don't seem to improve things significantly.
- There are multiple sources of spurious isospin breaking in the IMSRG workflow; many can be eliminated.
- Optimal procedure for δ_C is not yet clear.

PHY-2340834

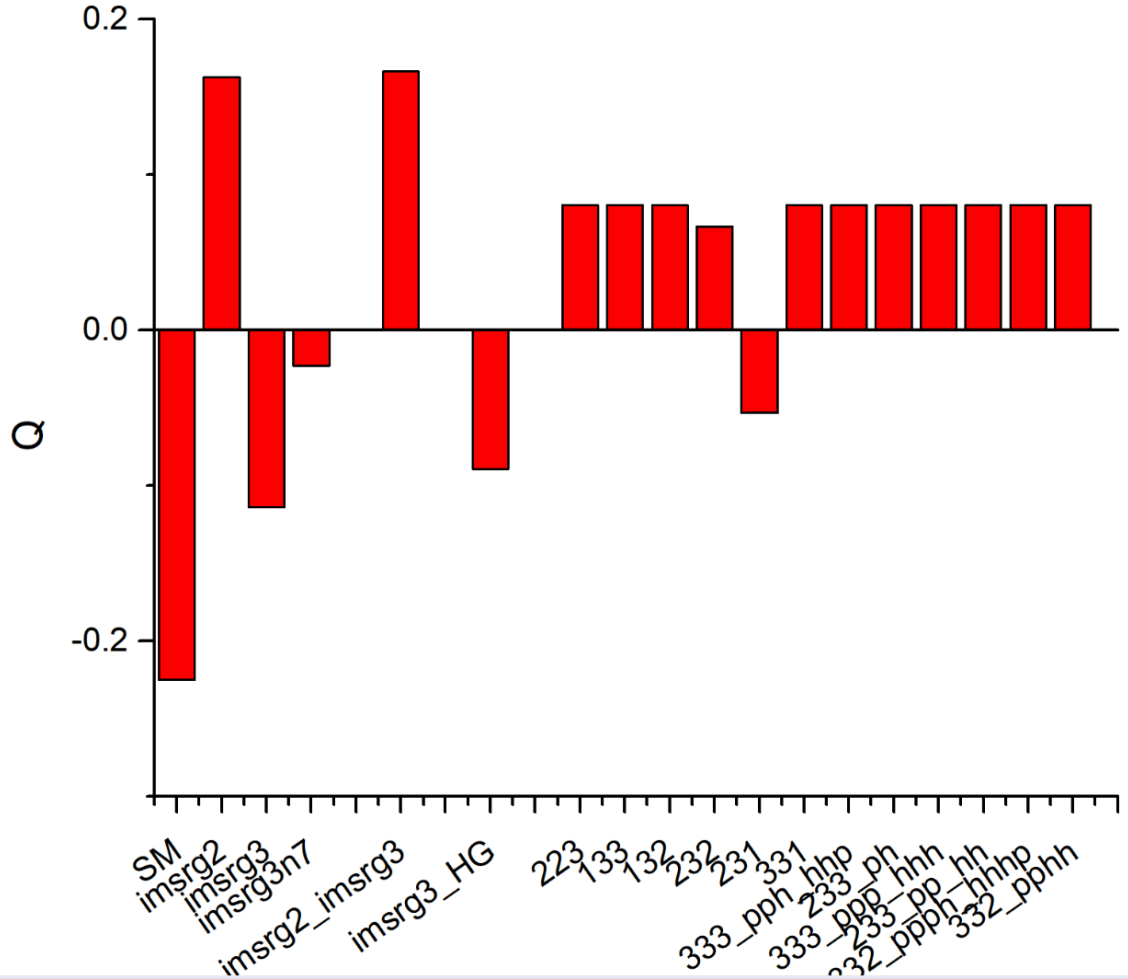
NUCLEI
Nuclear Computational Low-Energy Initiative

@NDB
Advancing Theory for Nuclear Double-Beta Decay

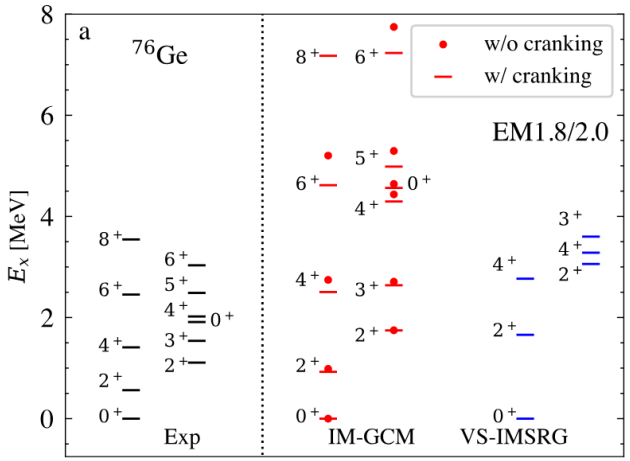
Additional slides

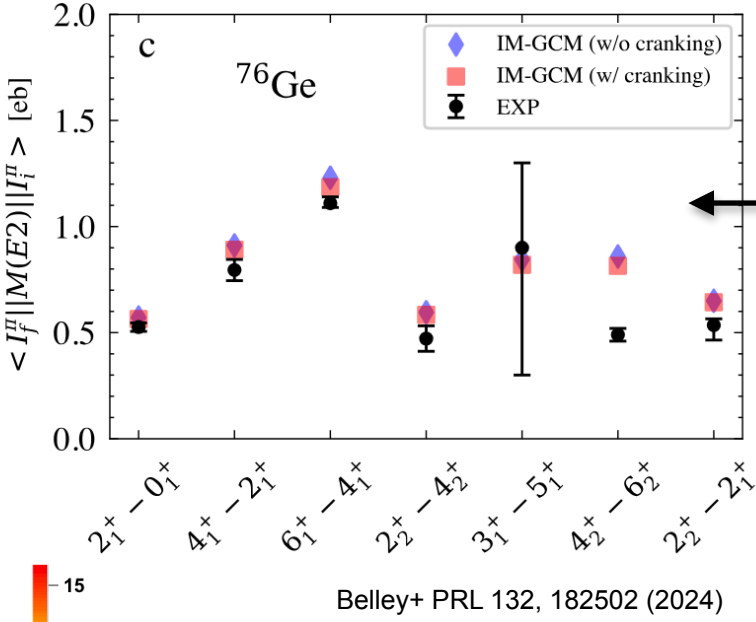
^{17}O

psd interaction, decouple sd valence space



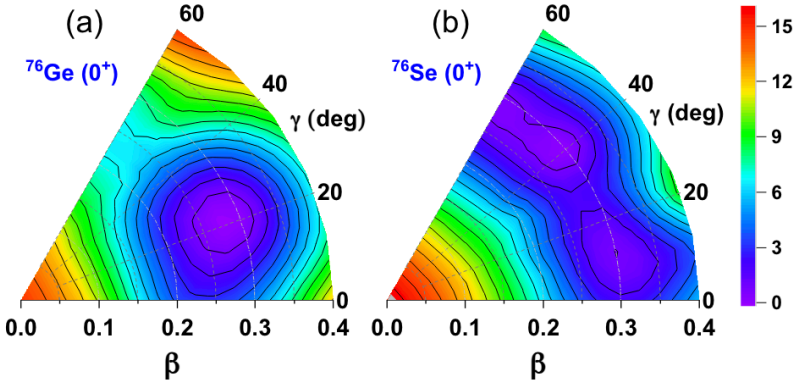
Don’t blame the forces!





IM-GCM with same interaction beautifully reproduces E2s.

Belley+ PRL 132, 182502 (2024)



VS-IMSRG spectrum is improved by incorporating intermediate 3-body operators. Will that also fix the E2s? (Probably not completely).