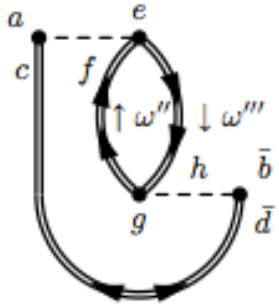
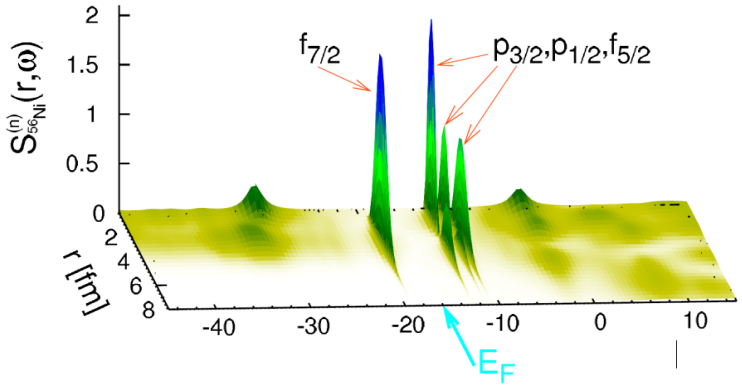
"Progress in Ab Initio Techniques in Nuclear Physics"
TRIUMF – February 21-23, 2013

Toward ab-initio predictions for mid-mass open shells

C. Barbieri





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Towards a unified description of nuclei

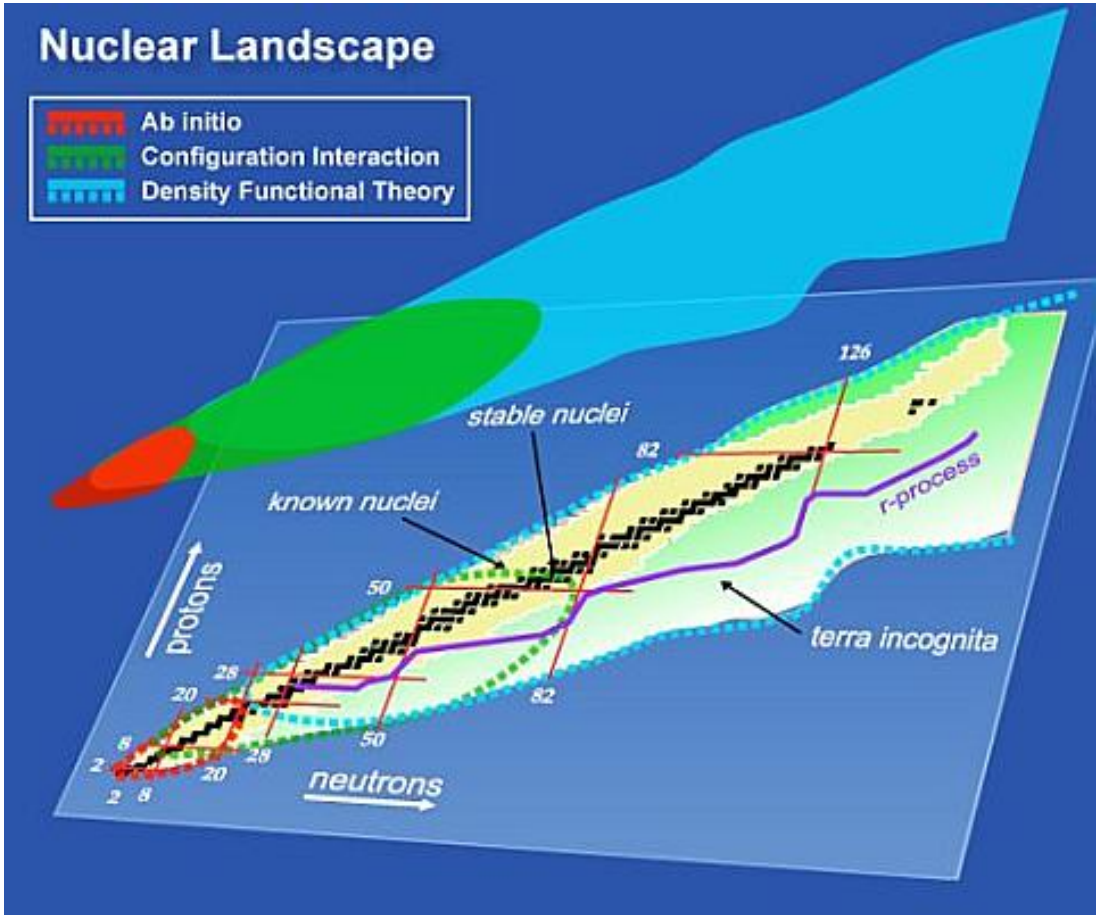
Open issues @ mid masses are:

→ Need of good nuclear Hamiltonians (3N forces mostly!)

→ Structure calculations are limited to closed-shells or A±1, A±2

→Ab-Initio link between structure and reactions.

(BUT calculations are GOOD!!!)



→ Green's functions can be naturally extended to: Scattering observable
Open shell nuclei

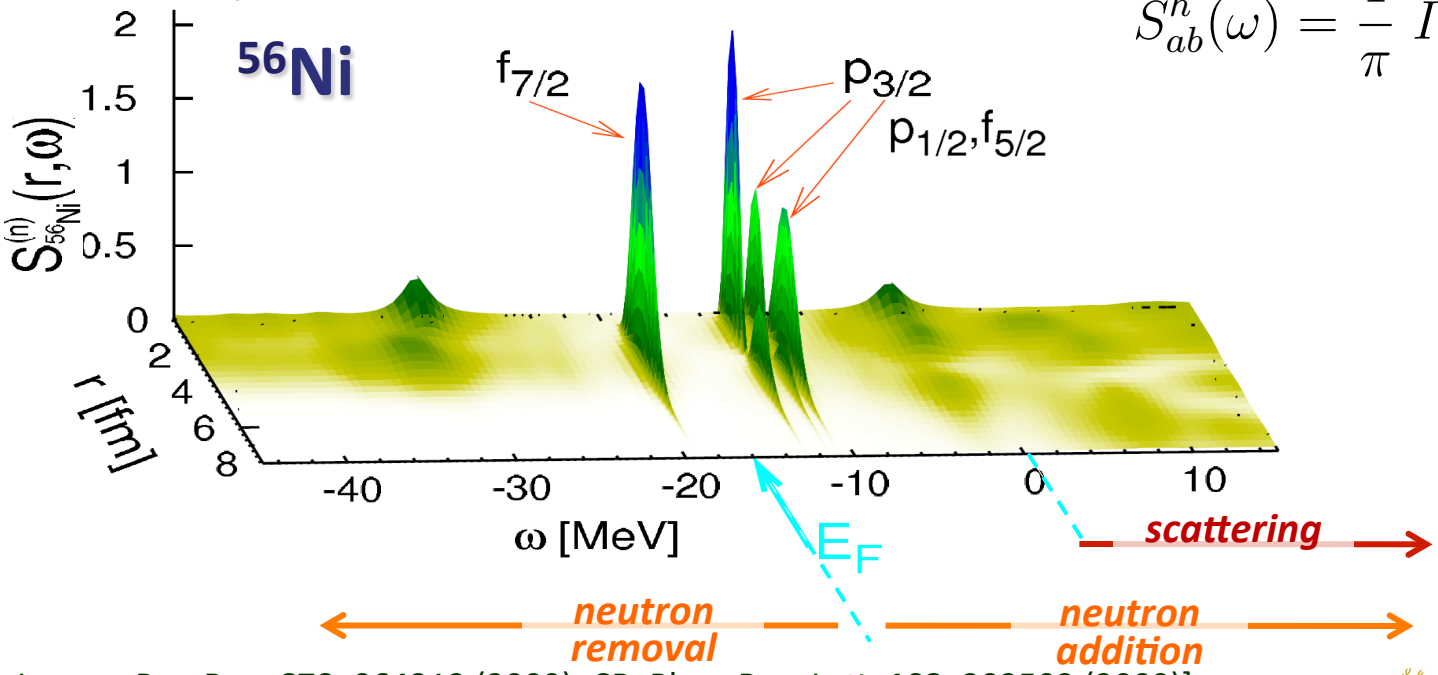
Green's functions in many-body theory

One-body Green's function (or propagator) describes the motion of quasi-particles and holes:

$$g_{\alpha\beta}(E) = \sum_n \frac{\langle \Psi_0^A | c_\alpha | \Psi_n^{A+1} \rangle \langle \Psi_n^{A+1} | c_\beta^\dagger | \Psi_0^A \rangle}{E - (E_n^{A+1} - E_0^A) + i\eta} + \sum_k \frac{\langle \Psi_0^A | c_\beta^\dagger | \Psi_k^{A-1} \rangle \langle \Psi_k^{A-1} | c_\alpha | \Psi_0^A \rangle}{E - (E_0^A - E_k^{A-1}) - i\eta}$$

…this contains all the structure information probed by nucleon transfer (spectral function):

$$S_{ab}^h(\omega) = \frac{1}{\pi}\, Im\, g_{ab}(\omega)$$



[CB, M.Hjorth-Jensen, Pys. Rev. C**79**, 064313 (2009); CB, Phys. Rev. Lett. **103**, 202502 (2009)]

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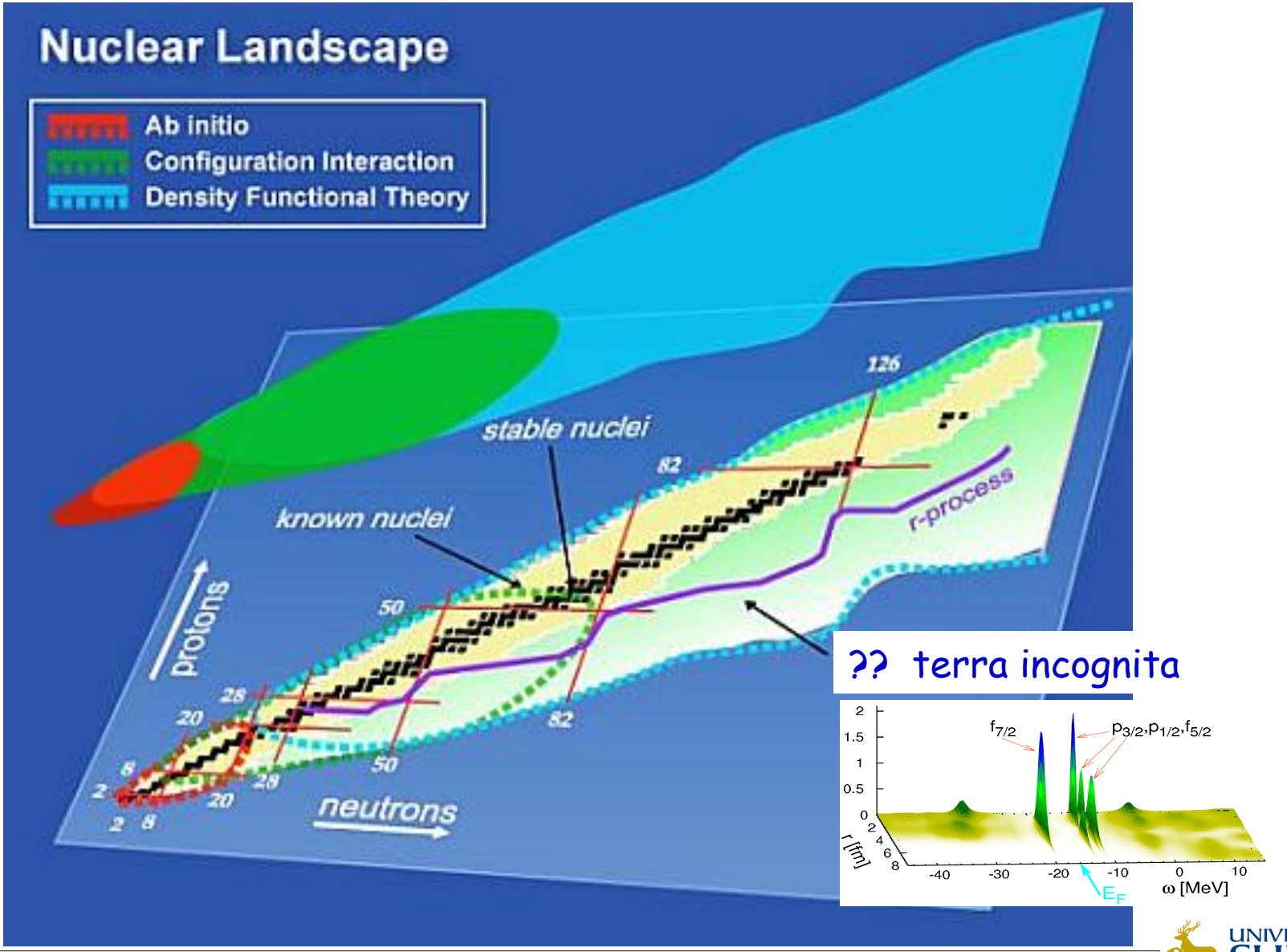
Towards a global description exotic structures…

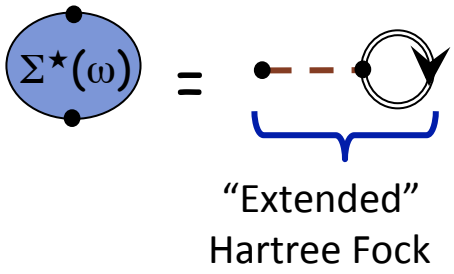


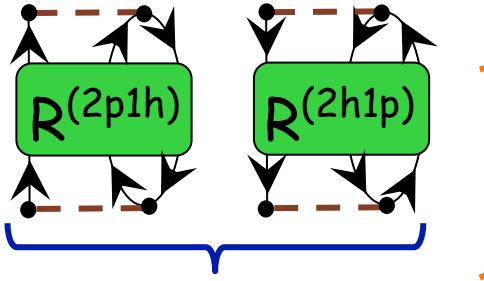
Calculating the spectral function:

FRPA, ADC(3), and the like…

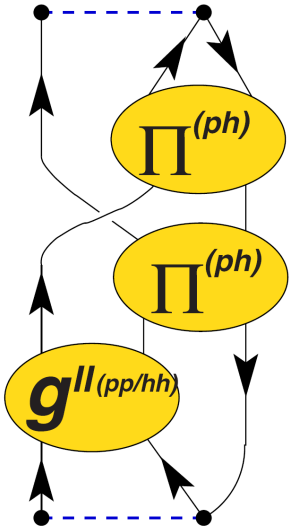
Faddeev-RPA in two words…

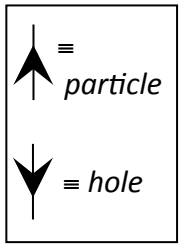
Self-energy (optical potential):





Faddeev-RPA:



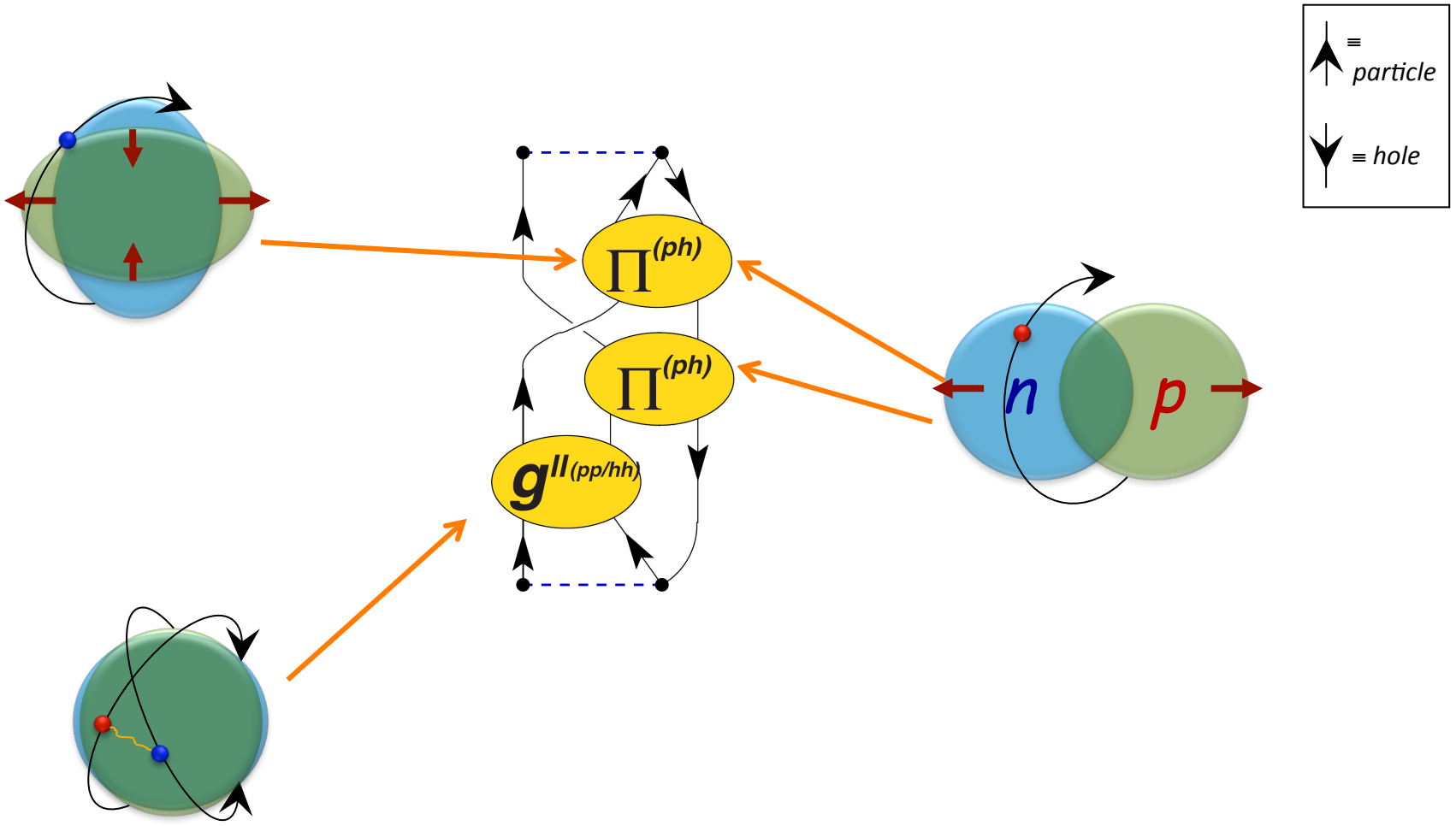


Phys.Rev.C63, 034313 (2001)
Phys.Rev.C65, 064313 (2002)
Phys.Rev.A76, 052503 (2007)

- A complete expansion requires *all types* of particle-vibration coupling:
  - ✓ $g^{II}(\omega)$ → pairing effects, two-nucleon transfer
  - ✓ $\Pi^{(ph)}(\omega)$ → collective motion, using RPA or beyond
  - ✓ Pauli exchange effects
- The Self-energy $\Sigma^{\star}(\omega)$ yields *both* single-particle states and scattering
- Finite nuclei:→ require high-performance computing

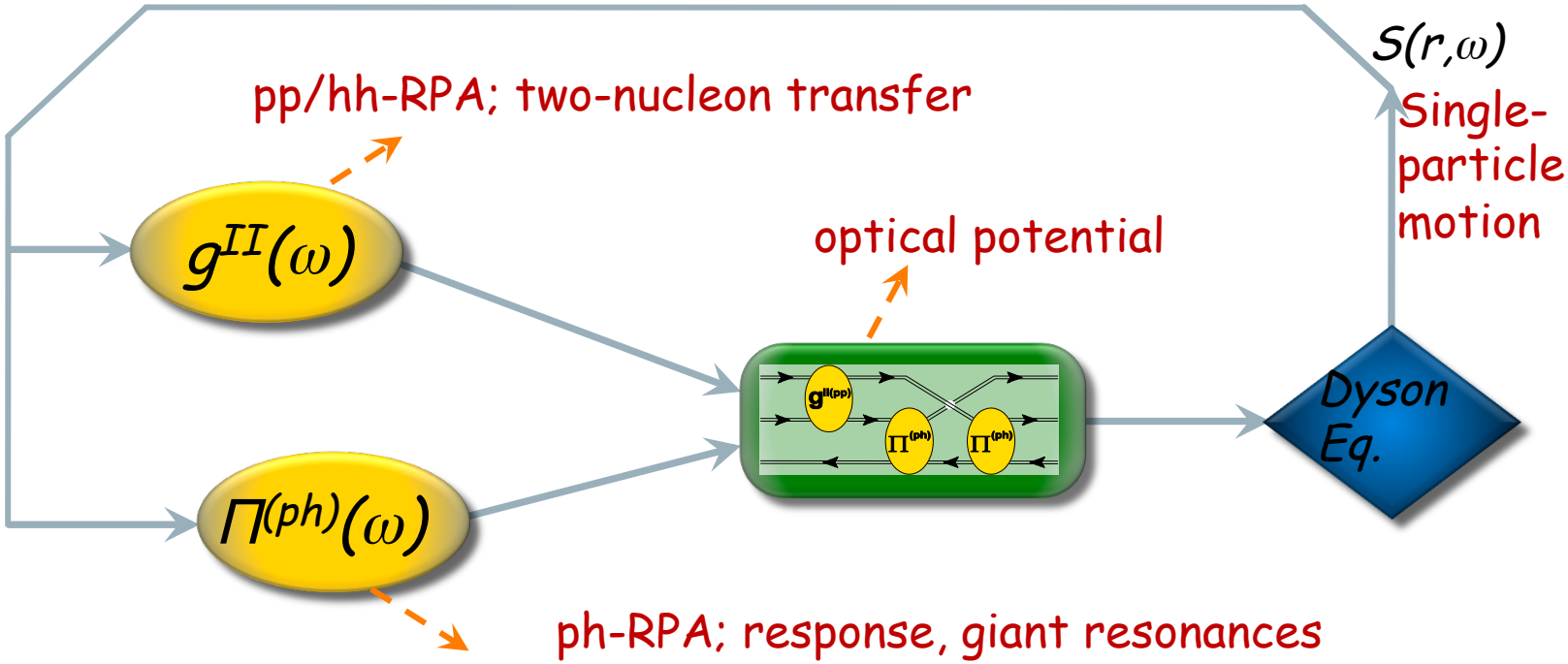
Faddeev-RPA in two words…

Particle vibration coupling is the main cause driving the distribution of particle strength—a least close to the Fermi surface…



Self-Consistent Green's Function Approach

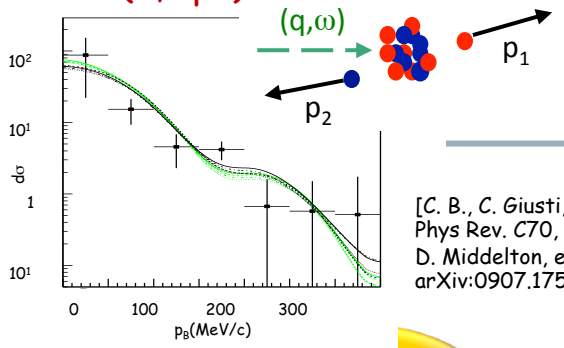
Why self-consistency ???



- Global picture of nuclear dynamics
- Reciprocal correlations among effective modes
- Guaranties *macroscopic conservation laws*

Self-Consistent Green's Function Approach

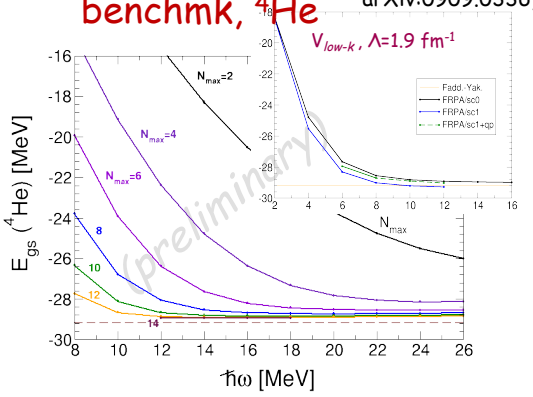
^{16}O(e,e'pn)^{14}N @ MAINZ



[C. B., C. Giusti, et al. Phys Rev. C70, 014606 (2004) D. Middelton, et al. arXiv:0907.1758; EPJA in print]

Binding energy benchmk, ^{4}He

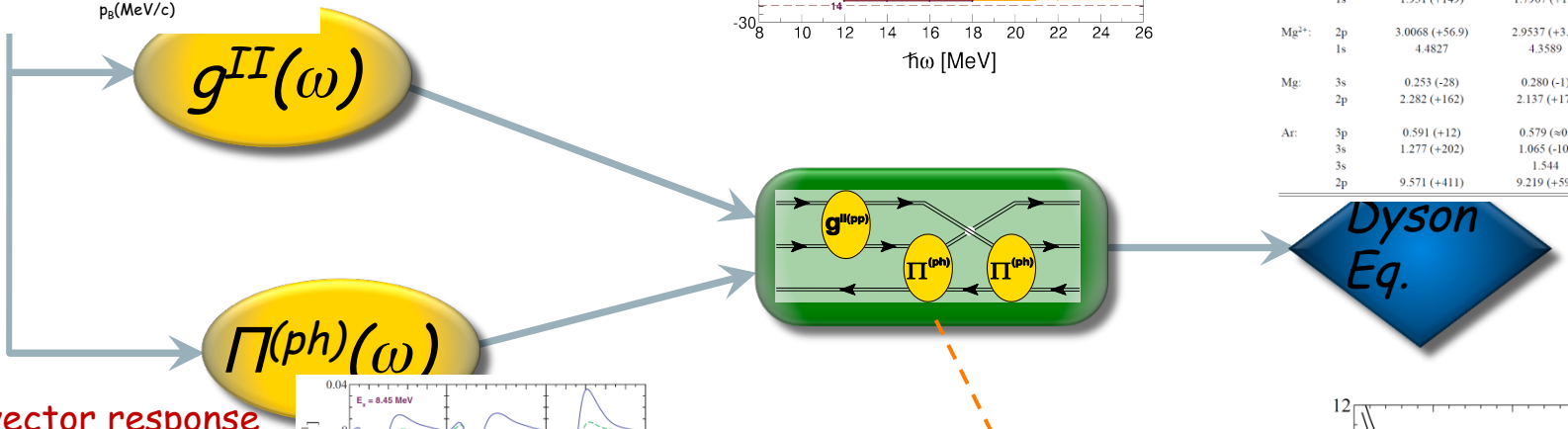
[C. B., arXiv:0909.0336]



Ionization energies/ affinities, in atoms

[CB, D. Van Neck, AIP Conf.Proc.1120,104 ('09) & in prep]

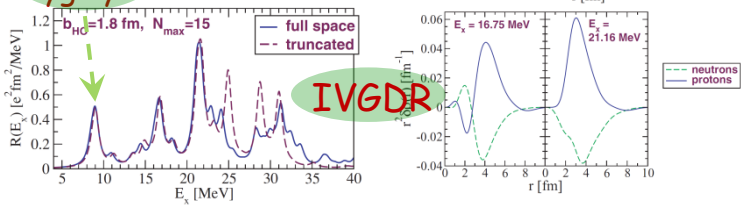
		Hartree-Fock	FRPAc	Experiment [16, 17]
He:	1s	0.918 (+14)	0.9008 (-2.9)	0.9037
Be^{2+}:	1s	5.6672 (+116)	5.6551 (-0.5)	5.6556
Be:	2s	0.3093 (-34)	0.3224 (-20.2)	0.3426
	1s	4.733 (+200)	4.5405 (+8)	4.533
Ne:	2p	0.852 (+57)	0.8037 (+11)	0.793
	1s	1.931 (+149)	1.7967 (+15)	1.782
Mg^{2+}:	2p	3.0068 (+56.9)	2.9537 (+3.8)	2.9499
	1s	4.4827	4.3589	
Mg:	3s	0.253 (-28)	0.280 (-1)	0.281
	2p	2.282 (+162)	2.137 (+17)	2.12
Ar:	3p	0.591 (+12)	0.579 (≈0)	0.579
	3s	1.277 (+202)	1.065 (-10)	1.075
	3s		1.544	
	2p	9.571 (+411)	9.219 (+59)	9.160



Isovector response for ^{32}Ar, ^{34}Ar

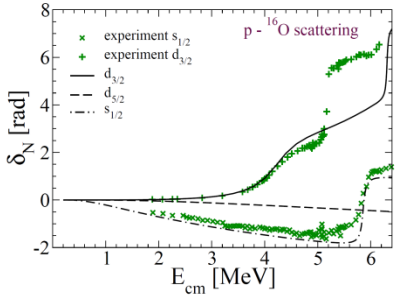
Proton Pygmy

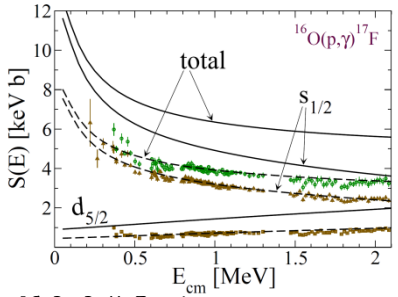
IVGDR



[C. B., K. Langanke, et al., Phys Rev. C77, 024304 (2008)]

^{16}O(p,γ)





[C. B., B. K. Jennings Nucl. Phys A758, 395c (2005) Phys Rev. C72, 014613 (2005)]

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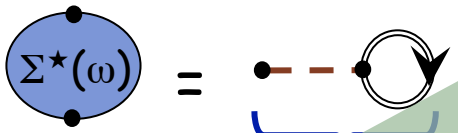
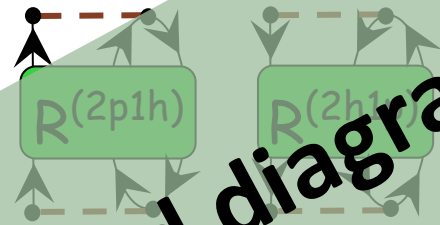
Faddeev-RPA in two words…

Self-energy (optical potential):

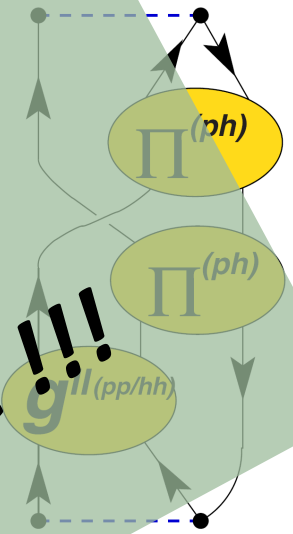


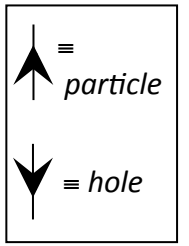
"Extended" Hartree Fock



≥ 2p1h/2h1p configurations

Faddeev-RPA:





All linked diagrams, so…

…it's size extensive !!!

Phys.Rev.C63, 034313 (2001)
Phys.Rev.C65, 064313 (2002)
Phys.Rev.A76, 052503 (2007)

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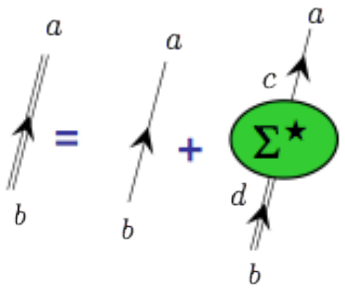
Dyson equation

- Propagators solves the Dyson equations

$$g_{ab}(\omega) = g^0_{ab}(\omega) + \sum_{cd} g^0_{ac}(\omega)\ \Sigma_{cd}(\omega)\ g_{db}(\omega)$$



- (Hole) single particle spectral function

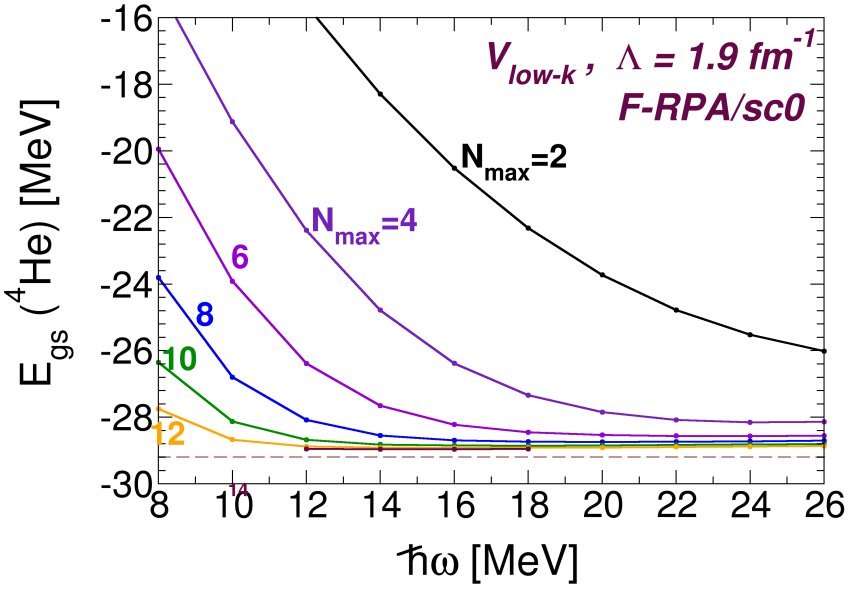
$$S^h_{ab}(\omega) = \frac{1}{\pi}\ Im\, g_{ab}(\omega) = \sum_k \langle \Psi^{A-1}_k | c_b | \Psi^A_0 \rangle \langle \Psi^A_0 | c^\dagger_a | \Psi^{A-1}_k \rangle\ \delta(\omega - (E^A_0 - E^{A-1}_k))$$

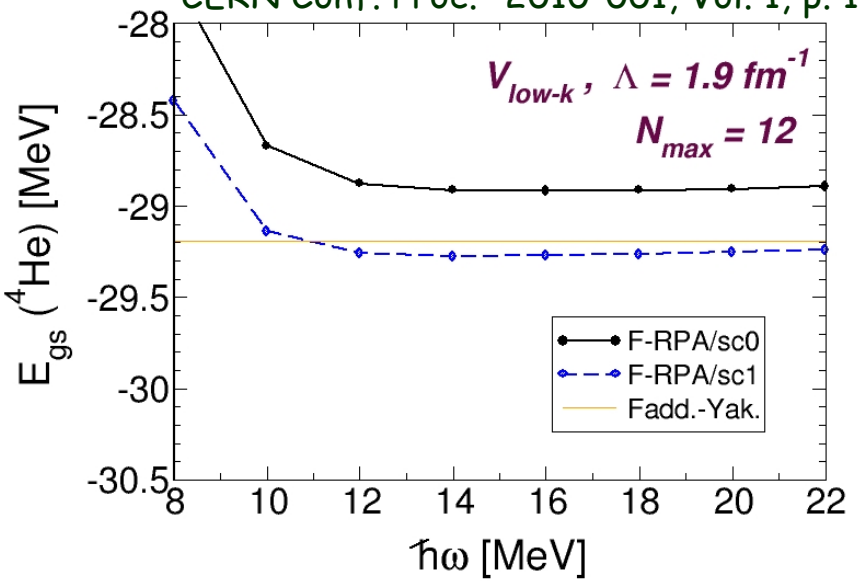
- Koltun sum rule (for 2N interactions):

$$\frac{1}{2} \sum_{ab} \int_{-\infty}^{E_F} (t_{ab} + \delta_{ab}\omega) S^h_{ab}(\omega)\ d\omega = \langle T \rangle + \langle V^{NN} \rangle$$

Accuracy of FRPA – ^{4}He binding energy

[C. B., arXiv:0909.0336;
CERN Conf. Proc. -2010-001, Vol. 1, p. 137]





➔ Self-consistent FRPA *compares well* with benchmark calculations on ^{4}He

	FRPA/sc0	FRPA/sc	Exact:
V_{low-k}:	-29.00(2)	-29.2 ±0.15	-29.19(5) (Fadd.-Yak.)

[Nogga et al., Phys. Rev. C70, 061002 (2004)]

self-consistency in the mean field only

estimates from different approx. to self-consistency

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Accuracy of FRPA – simple atoms/molecules

binding, eq. bond distances, → ionization energies (molecules)

		FTDAc	FRPAc	CCSD(T)	FCI	Expt.
H_2						
	E_0	−1.161	−1.161	−1.164	−1.164	−1.175
	r_{H-H}	0.757	0.757	0.761		0.741
	I	16.03	16.03	16.12		16.08
BeH_2						
	E_0	−15.831	−15.832	−15.835	−15.836	-
	r_{Be-H}	1.337	1.337	1.339		1.340
	I	11.78	11.76	11.89		-
HCl						
	E_0	−460.256	−460.255	−460.254		-
	r_{H-Cl}	1.297	1.293	1.290		1.275
	I	12.24	12.24	12.26		-
HF						
	E_0	−100.224	−100.228	−100.228	−100.231	-
	r_{H-F}	0.916	0.913	0.920		0.917
	I	15.70	15.54	15.42		16.12
H_2O						
	E_0	−76.240	−76.236	−76.241		-
	r_{H-O}	0.964	0.962	0.967		0.958
	Λ_{O-H-O}	102	102	102		104
	I	12.15	12.21	11.94		12.61

98-99% of correlation energy is recovered

[M. Degroote, D. van Neck, C. B. Phys. Rev. A 83, 042517 (2011); 85, 012501 (2012)]

		Hartree-Fock	Second order	FTDA	FRPA	Experiment [63,64]
He	1*s*	0.918(+14)	0.9012(−2.5)	0.9025(−1.2)	0.9008(−2.9)	0.9037
Be^{2+}	1*s*	5.6672(+116)	5.6542(−1.4)	5.6554(−0.2)	5.6551(−0.5)	5.6556
Be	2*s*	0.3093(−34)	0.3187(−23.9)	0.3237(−18.9)	0.3224(−20.2)	0.3426
	1*s*	4.733(+200)	4.5892(+56)	4.5439(+11)	4.5405(+8)	4.533
Ne	2*p*	0.852(+57)	0.752(−41)	0.8101(+17)	0.8037(+11)	0.793
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Mg	3*s*	0.253(−28)	0.267(−14)	0.272(−9)	0.280(−1)	0.281
	2*p*	2.282(+162)	2.117(−3)	2.141(+21)	2.137(+17)	2.12
Ar	3*p*	0.591(+12)	0.563(−16)	0.581(+2)	0.579(≈ 0)	0.579
	3*s*	1.277(+202)	1.111(+36)	1.087(+12)	1.065(−10)	1.075
	3*s*		1.840	1.578	1.544	
σ_{rms} [mH]		81.4	29.3	13.7	10.6	

← ionization energies (atoms)

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Three-nucleon interactions

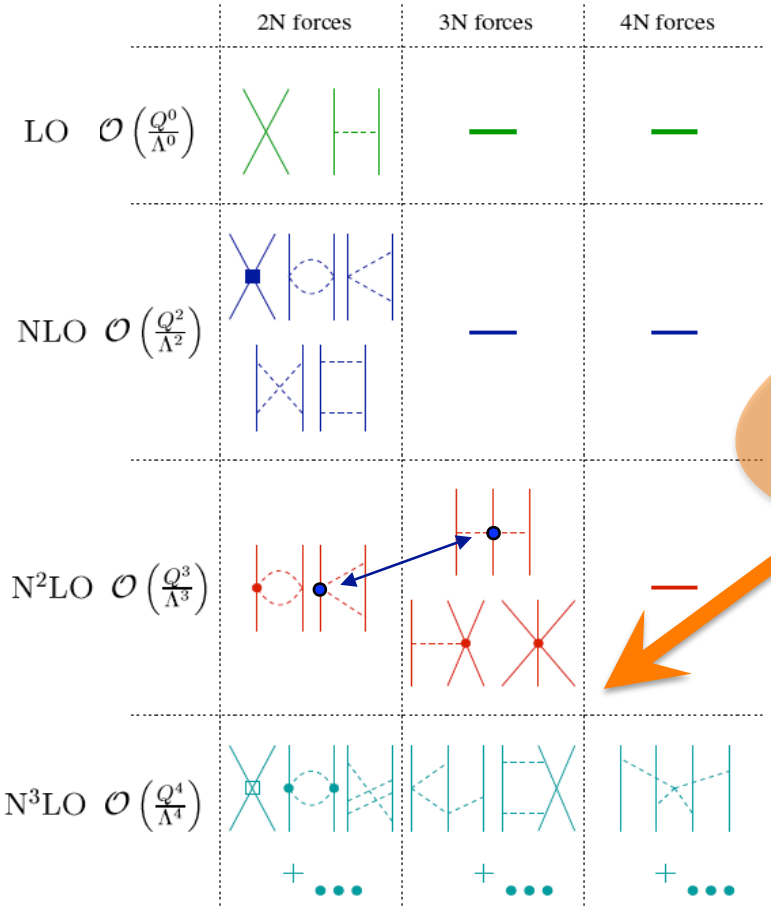
→ Added to self-energy as an effective 1N plus 2N force.

→ Correction to Koltun SR

A. Cipollone, P. Navratil, CB
arXiv:1211.3315 [nucl-th]

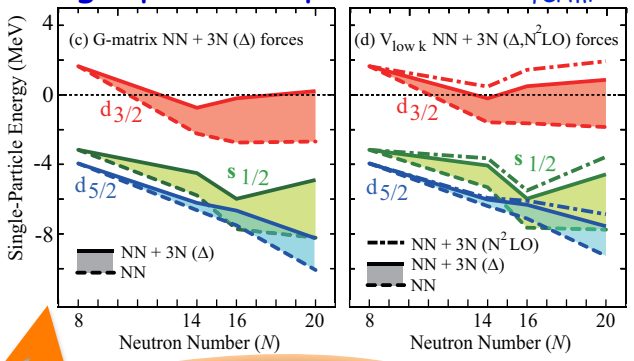
Modern realistic nuclear forces

Chiral EFT for nuclear forces:



(3NF arise naturally at N2LO)

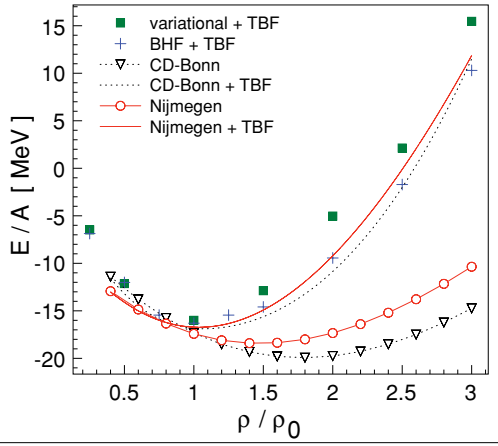
Single particle spectrum at E_{fermi}:



[T. Otsuka et al., Phys Rev. Lett **105**, 32501 (2010)]

Need at LEAST 3NF!!!
("cannot" do RNB physics without…)

Saturation of nuclear matter:



[V. Somà, Phys Rev. C **78**, 054003 (2008))]

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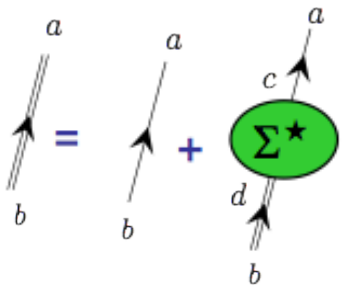
Dyson equation

- Propagators solves the Dyson equations

$$g_{ab}(\omega) = g^0_{ab}(\omega) + \sum_{cd} g^0_{ac}(\omega)\ \Sigma_{cd}(\omega)\ g_{db}(\omega)$$



- (Hole) single particle spectral function

$$S^h_{ab}(\omega) = \frac{1}{\pi}\ Im\, g_{ab}(\omega) = \sum_k \langle \Psi^{A-1}_k | c_b | \Psi^A_0 \rangle \langle \Psi^A_0 | c^\dagger_a | \Psi^{A-1}_k \rangle\ \delta(\omega - (E^A_0 - E^{A-1}_k))$$

- Koltun sum rule (for 2N interactions):

$$\frac{1}{2} \sum_{ab} \int_{-\infty}^{E_F} (t_{ab} + \delta_{ab}\omega) S^h_{ab}(\omega)\ d\omega = \langle T \rangle + \langle V^{NN} \rangle$$

Dyson equation

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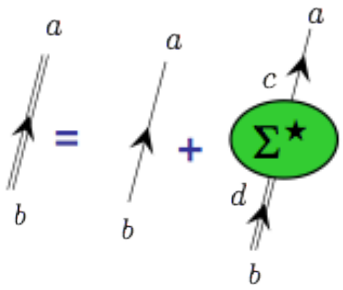


- (Hole) single particle spectral function

$$S^h_{ab}(\omega) = \frac{1}{\pi}\ Im\, g_{ab}(\omega) = \sum_k \langle \Psi^{A-1}_k | c_b | \Psi^A_0 \rangle \langle \Psi^A_0 | c^\dagger_a | \Psi^{A-1}_k \rangle\ \delta(\omega - (E^A_0 - E^{A-1}_k))$$

- Koltun sum rule (with NNN interactions):

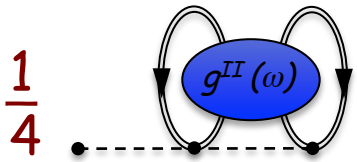
$$\frac{1}{2}\sum_{ab}\int_{-\infty}^{E_F} (t_{ab} + \delta_{ab}\omega) S^h_{ab}(\omega)\ d\omega = \langle T \rangle + \langle V^{NN} \rangle + \frac{3}{2}\langle V^{NNN} \rangle$$

$$\langle V^{NNN} \rangle \approx \frac{1}{6}$$

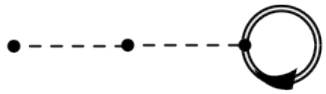
Inclusion of NNN forces

A. Carbone, A. Cipollone, CB, A. Rios, A Polls

- NNN forces can enter diagrams in three different ways:



Correction to external 1-Body interaction



Correction to *non-contracted* 2-Body interaction

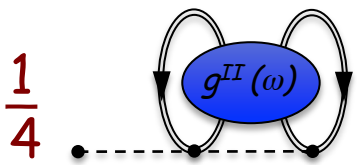
pure 3-Body contribution

- Contractions are with *fully correlated density matrices* (BEYOND a normal ordering…)

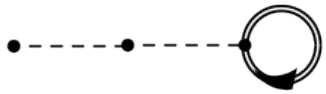
Inclusion of NNN forces

A. Carbone, A. Cipollone, CB, A. Rios, A Polls

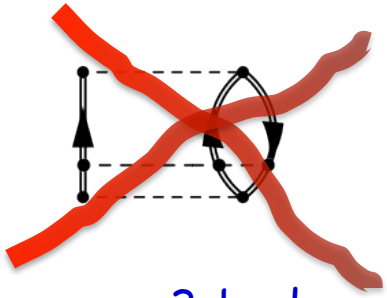
- NNN forces can enter diagrams in three different ways:



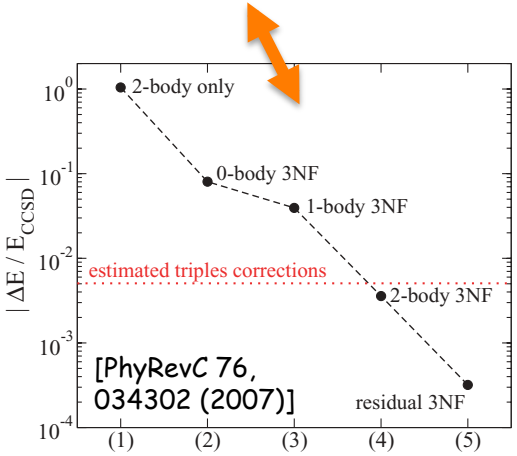
Correction to external 1-Body interaction



Correction to *non-contracted* 2-Body interaction



pure 3-body contribution (small)



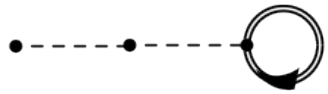
- Contractions are with *fully correlated density matrices* (BEYOND a normal ordering…)

Inclusion of NNN forces

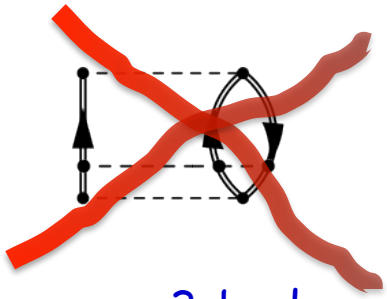
A. Carbone, A. Cipollone, CB, A. Rios, A Polls

- NNN forces can enter diagrams in three different ways:

Correction to external 1-Body interaction



Correction to *non-contracted* 2-Body interaction



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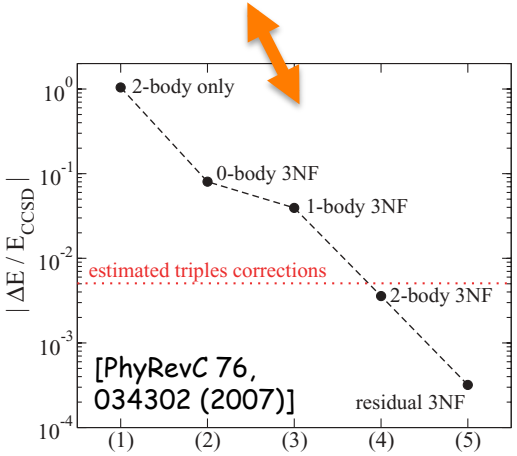

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A. Carbone, A. Cipollone, CB, A. Rios, A Polls

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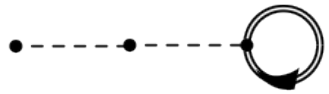
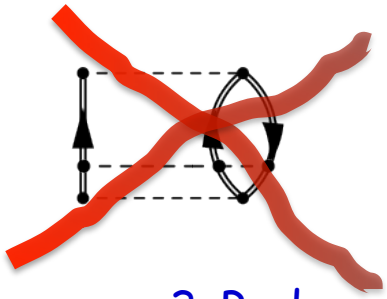
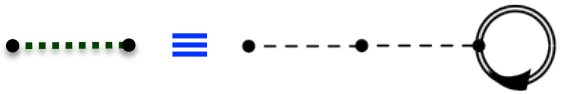


Correction to *non-contracted* 2-Body interaction



pure 3-Body contribution

BEWARE that defining:



and then:

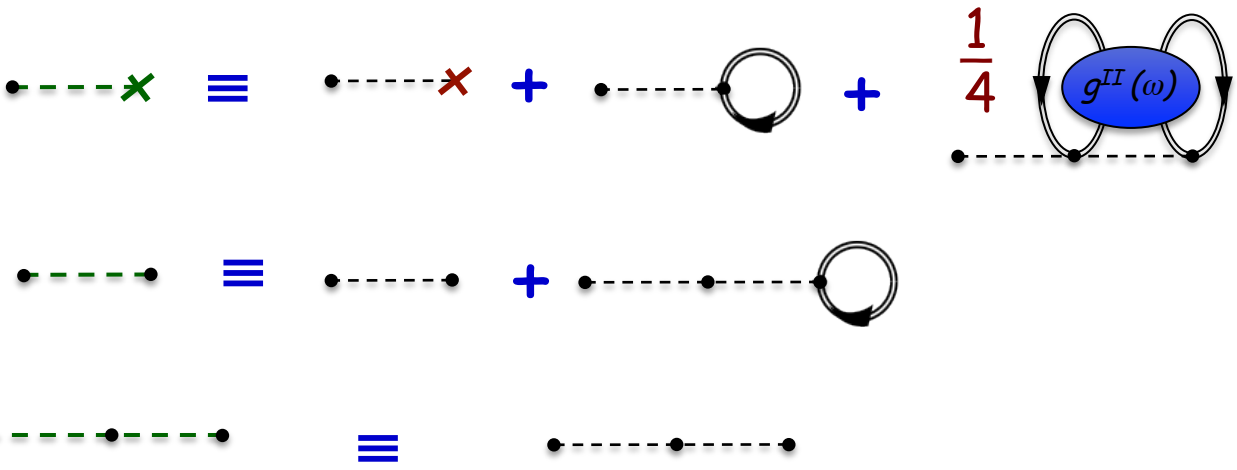
would *double count* the 1-body term.

Inclusion of NNN forces

A. Carbone, A. Cipollone, CB, A. Rios, A Polls

- NNN forces can enter diagrams in three different ways:

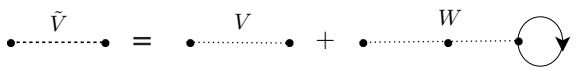
→ Define new 1- and 2-body interactions and use only interaction-irreducible diagrams



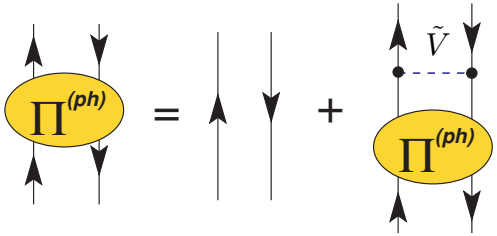
- Contractions are with *fully correlated density matrices* (BEYOND a normal ordering…)

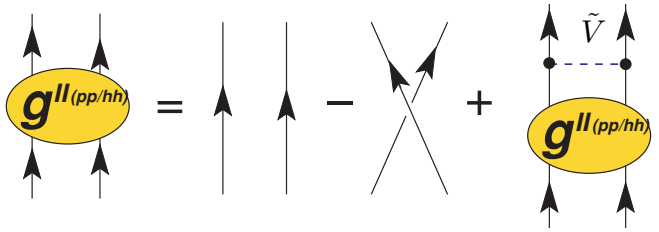
NNN forces in FRPA/FTDA formalism

A. Cipollone, CB, P. Navratil

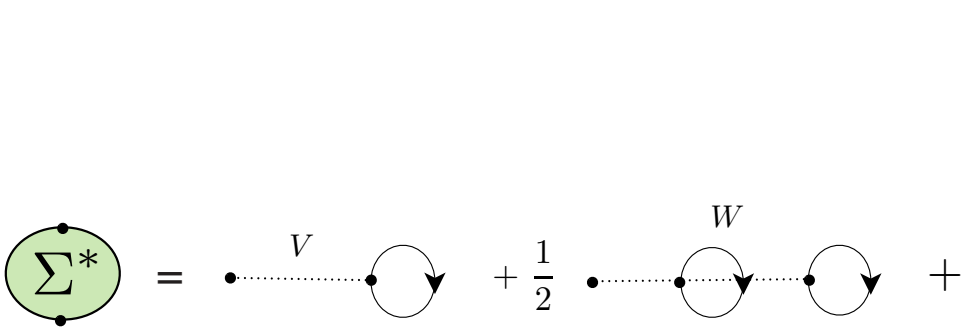
Use: 

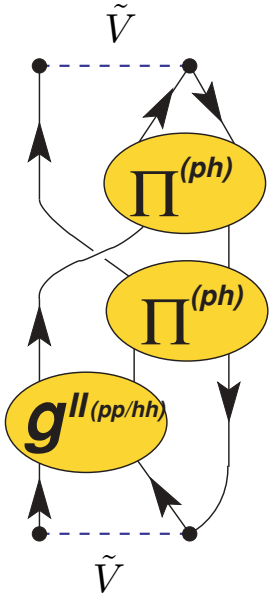
as 2-body potential in all V-irred. RPA/TDA summations





Then:





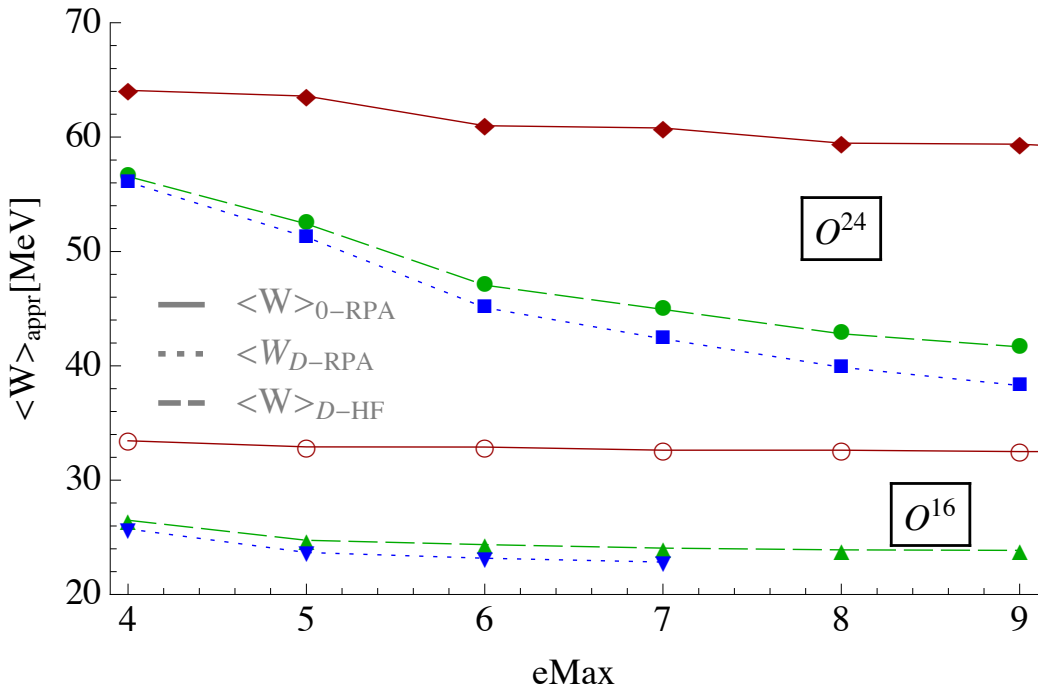
…approximations and some improvements still being assessed – this is all work in progress

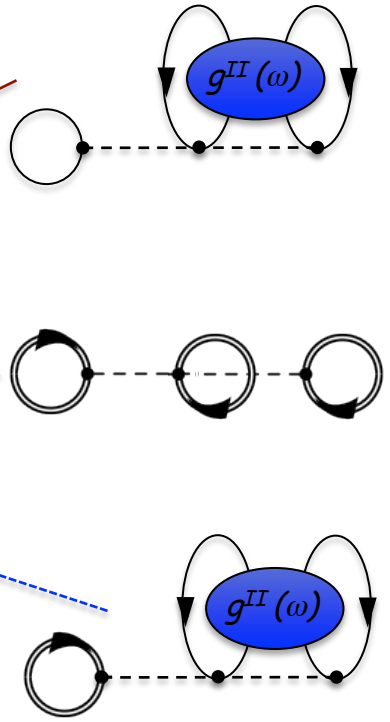
NNN forces in FRPA/FTDA formalism

A. Cipollone, CB, P. Navratil

Koltun sum rule requires a correction on the 3-bodypotential <W> :

$$\langle H \rangle = \sum_{\alpha\beta} \frac{1}{4\pi i} \int_{C\uparrow} d\omega \, [\, T_{\alpha\beta} + \omega \, \delta_{\alpha\beta} \,] \, g_{\alpha\beta}(\omega) - \frac{1}{2} \langle W \rangle$$

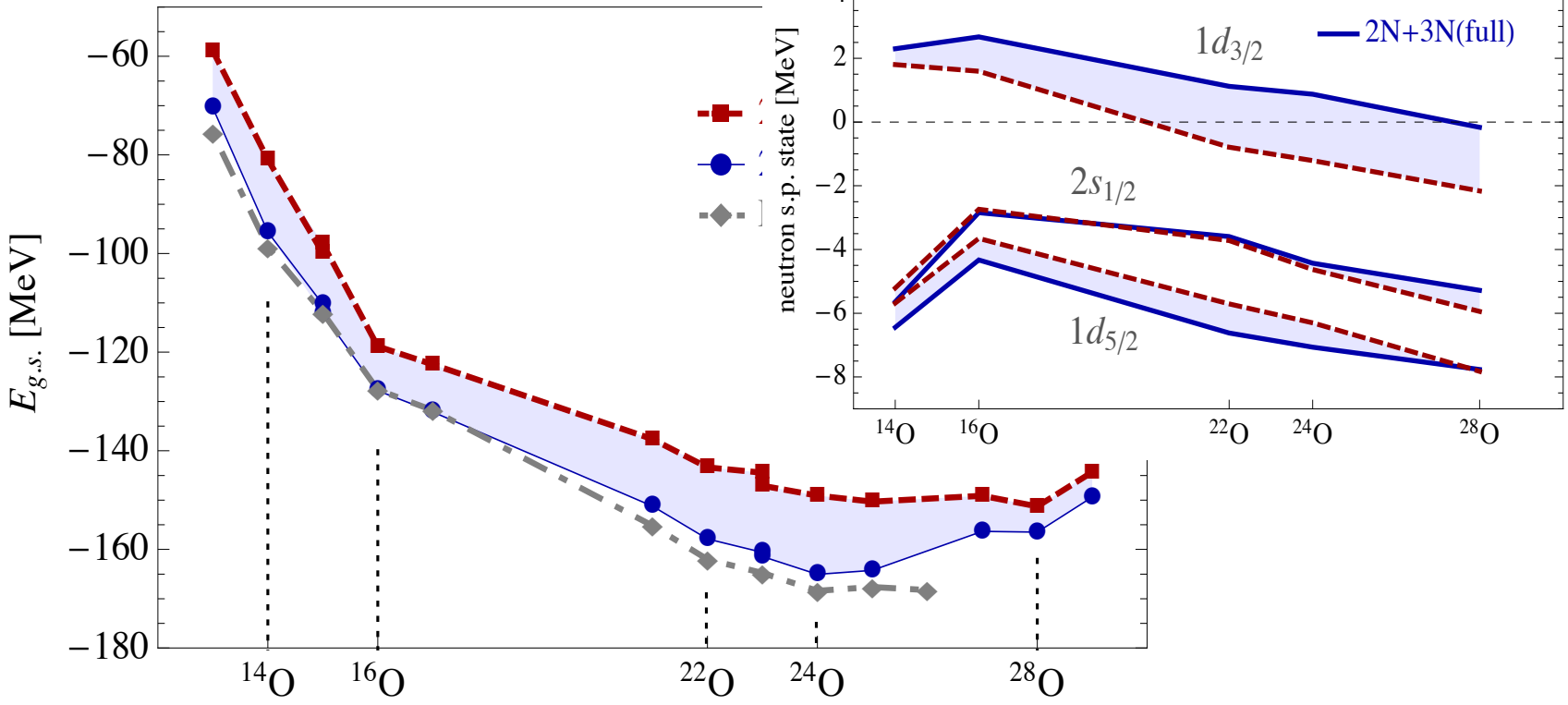




Oxygen isotopes with evolved chiral 3NF

A. Cipollone, CB, P. Navratil

Binding energy



CB, A. Cipollone, *et al.*, arXiv:1211.3315 [nucl-th]

N3LO (Λ = 500Mev/c) chiral NN interaction evolved to 2N + 3N forces (1.8fm^{-1})
N2LO (Λ = 400Mev/c) chiral 3N interaction evolved (1.8fm^{-1})

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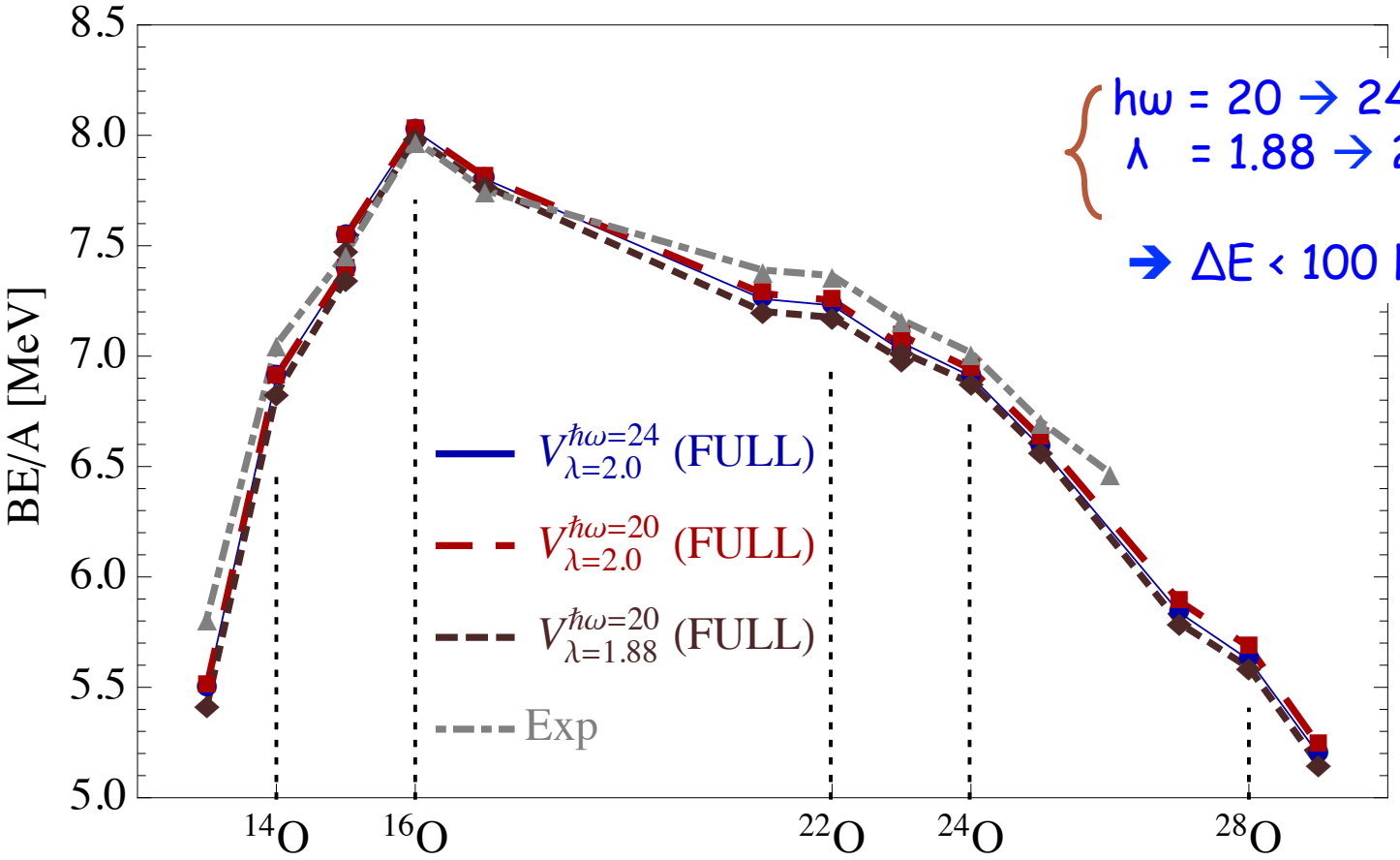
Oxygen isotopes with evolved chiral 3NF

A. Cipollone, CB, P. Navratil



hω = 20 → 24 MeV
Λ = 1.88 → 2.0 1/fm

➔ ΔE < 100 keV / A

N3LO (Λ = 500Mev/c) chiral NN interaction evolved to 2N + 3N forces
N2LO (Λ = 400Mev/c) chiral 3N interaction evolved

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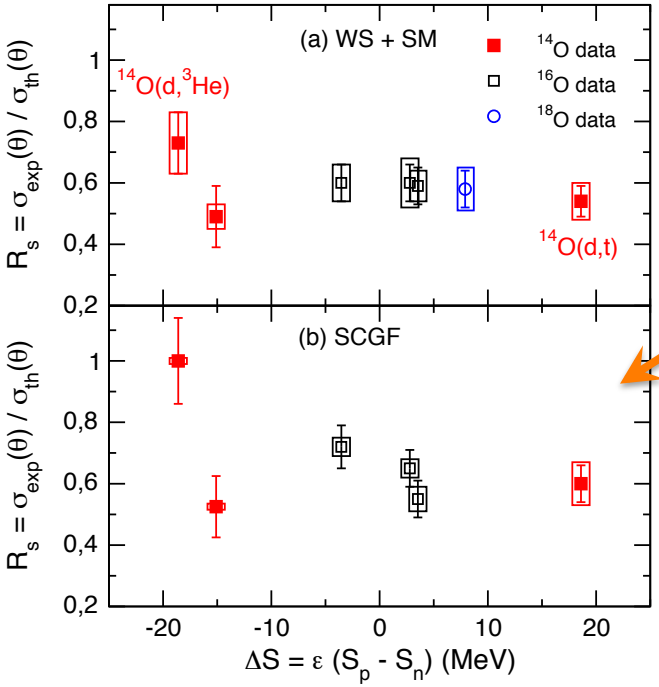
Overlap functions and spect. factors in ^{14}O

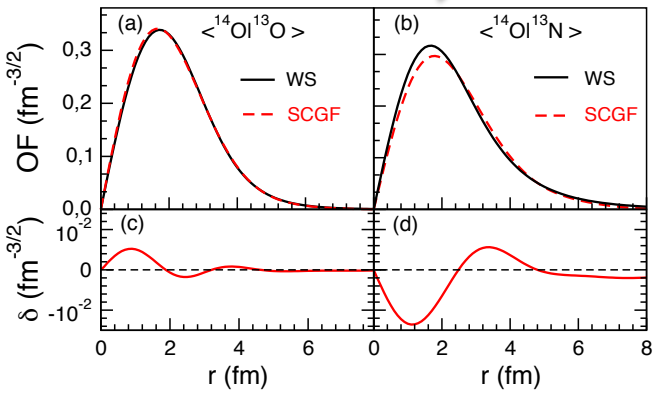
radii still too small !

TABLE 1. Predicted matter radii (in fm) for ^{16}O form SRG evolved 2N-only interactions and by including induced and full 3NF. Experiment are charge radii.

	2NF only	2+3NF(ind.)	2+3NF(full)	Experiment
^{16}O:	2.10	2. 41	2.38	2.718±0.210 [19]



After rescaling, the shape and results are the same as for phenoenological Woods-Saxon



F. Flavingny et al, CB, Phys. Rev. Lett. (2013)--in print

N3LO (Λ = 500Mev/c) chiral NN interaction evolved to 2N + 3N forces
N2LO (Λ = 400Mev/c) chiral 3N interaction evolved

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Approaching open-shells in the mid-mass region:

- ➔ Gorkov theory
- ➔ proof-of-principle results at 2nd order

V. Somà, T. Duguet, CB, Phys. Rev. C84, 046317 (2011)
arXiv:1208.2472 [nucl-th]

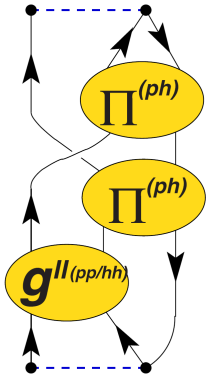
Applications to doubly-magic nuclei

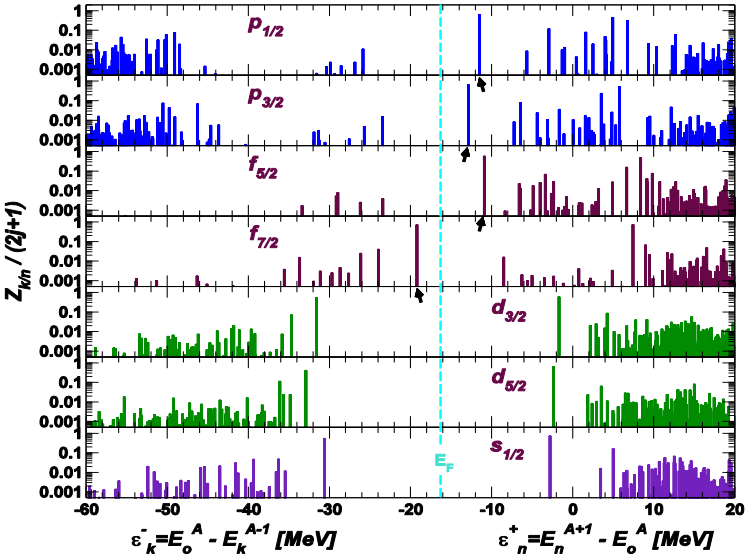
✺ Faddeev-RPA approximation for the self-energy

collective vibrations

particle-vibration coupling

[C.B. *et al*. 2001-2011]





✺ Successful in medium-mass doubly-magic systems

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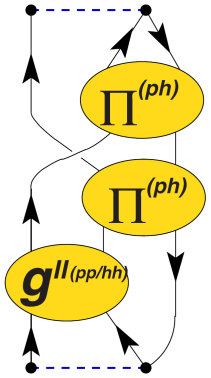

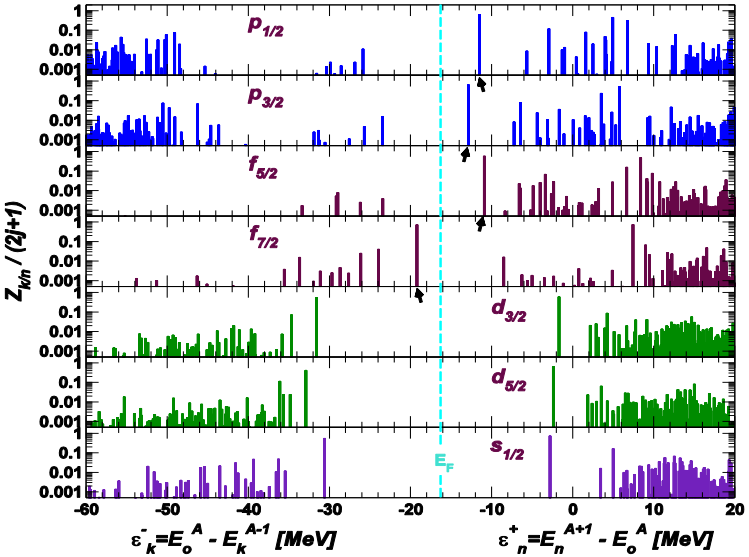

✺ Successful in medium-mass doubly-magic systems

→ Expansion breaks down when pairing instabilities appear

Explicit configuration mixing

Single-reference: Bogoliubov (Gorkov)

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Going to open-shells: Gorkov ansatz

[V. Somà, T. Duguet, CB, Pys. Rev. C84, 046317 (2011)]

✺ Ansatz $\quad \ldots \approx E_0^{N+2} - E_0^N \approx E_0^N - E_0^{N-2} \approx \ldots \approx 2\mu$

✺ Auxiliary many-body state $|\Psi_0\rangle \equiv \sum_N^{\text{even}} c_N \, |\psi_0^N\rangle$

↳ Mixes various particle numbers

↳ Introduce a "grand-canonical" potential $\Omega = H - \mu N$

⇒ $|\Psi_0\rangle$ minimizes $\Omega_0 = \langle\Psi_0|\Omega|\Psi_0\rangle$

under the constraint $N = \langle\Psi_0|N|\Psi_0\rangle$

⇒ $\Omega_0 = \sum_{N'} |c_{N'}|^2 \Omega_0^{N'} \approx E_0^N - \mu N$

Gorkov Green's functions and equations

[V. Somà, T. Duguet, CB, Pys. Rev. C84, 046317 (2011)]

✺ Set of 4 Green's functions

$$i\,G^{11}_{ab}(t,t') \equiv \langle\Psi_0|T\left\{a_a(t)a^\dagger_b(t')\right\}|\Psi_0\rangle \equiv$$

$$i\,G^{21}_{ab}(t,t') \equiv \langle\Psi_0|T\left\{\bar{a}^\dagger_a(t)a^\dagger_b(t')\right\}|\Psi_0\rangle \equiv$$

$$i\,G^{12}_{ab}(t,t') \equiv \langle\Psi_0|T\left\{a_a(t)\bar{a}_b(t')\right\}|\Psi_0\rangle \equiv$$

$$i\,G^{22}_{ab}(t,t') \equiv \langle\Psi_0|T\left\{\bar{a}^\dagger_a(t)\bar{a}_b(t')\right\}|\Psi_0\rangle \equiv$$

[Gorkov 1958]

$$\mathbf{G}_{ab}(\omega) = \mathbf{G}^{(0)}_{ab}(\omega) + \sum_{cd} \mathbf{G}^{(0)}_{ac}(\omega)\,\mathbf{\Sigma}^\star_{cd}(\omega)\,\mathbf{G}_{db}(\omega)$$

Gorkov equations

$$\mathbf{\Sigma}^\star_{ab}(\omega) \equiv \begin{pmatrix} \Sigma^{\star\,11}_{ab}(\omega) & \Sigma^{\star\,12}_{ab}(\omega) \\ \Sigma^{\star\,21}_{ab}(\omega) & \Sigma^{\star\,22}_{ab}(\omega) \end{pmatrix}$$

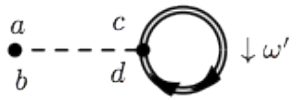
$$\mathbf{\Sigma}^\star_{ab}(\omega) \equiv \mathbf{\Sigma}_{ab}(\omega) - \mathbf{U}_{ab}$$

1st & 2nd order diagrams

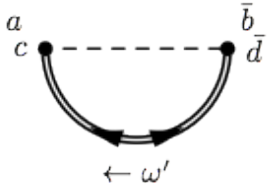
[V. Somà, T. Duguet, CB, Pys. Rev. C84, 046317 (2011)]

✺ 1st order ➟ energy-independent self-energy

$$\Sigma^{11\,(1)}_{ab} =$$

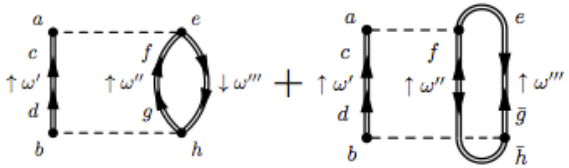


$$\Sigma^{12\,(1)}_{ab} =$$

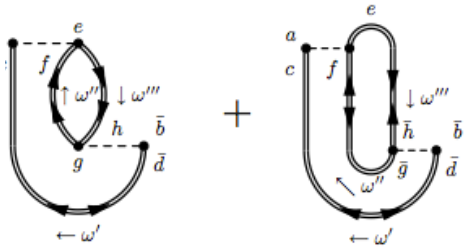


✺ 2nd order ➟ energy-dependent self-energy

$$\Sigma^{11\,(2)}_{ab}(\omega) =$$



$$\Sigma^{12\,(2)}_{ab}(\omega) =$$



✺ Gorkov equations ⟶ eigenvalue problem

$$\sum_b \begin{pmatrix} t_{ab} - \mu_{ab} + \Sigma^{11}_{ab}(\omega) & \Sigma^{12}_{ab}(\omega) \\ \Sigma^{21}_{ab}(\omega) & -t_{ab} + \mu_{ab} + \Sigma^{22}_{ab}(\omega) \end{pmatrix} \Bigg|_{\omega_k} \begin{pmatrix} \mathcal{U}^k_b \\ \mathcal{V}^k_b \end{pmatrix} = \omega_k \begin{pmatrix} \mathcal{U}^k_a \\ \mathcal{V}^k_a \end{pmatrix}$$

$$\mathcal{U}^{k*}_a \equiv \langle \Psi_k | \bar{a}^\dagger_a | \Psi_0 \rangle$$
$$\mathcal{V}^{k*}_a \equiv \langle \Psi_k | a_a | \Psi_0 \rangle$$

Espressions for 1st & 2nd order diagrams

[V. Somà, T. Duguet, CB, Phys. Rev. C84, 046317 (2011)]

Gorkov equations

[V. Somà, T. Duguet, CB, Pys. Rev. C84, 046317 (2011)]

$$\sum_b \begin{pmatrix} t_{ab} - \mu_{ab} + \Sigma^{11}_{ab}(\omega) & \Sigma^{12}_{ab}(\omega) \\ \Sigma^{21}_{ab}(\omega) & -t_{ab} + \mu_{ab} + \Sigma^{22}_{ab}(\omega) \end{pmatrix} \Bigg|_{\omega_k} \begin{pmatrix} \mathcal{U}^k_b \\ \mathcal{V}^k_b \end{pmatrix} = \omega_k \begin{pmatrix} \mathcal{U}^k_a \\ \mathcal{V}^k_a \end{pmatrix}$$

$$\begin{pmatrix} T - \mu + \Lambda & \tilde{h} & \mathcal{C} & -\mathcal{D}^\dagger \\ \tilde{h}^\dagger & -T + \mu - \Lambda & -\mathcal{D}^\dagger & \mathcal{C} \\ \mathcal{C}^\dagger & -\mathcal{D} & E & 0 \\ -\mathcal{D} & \mathcal{C}^\dagger & 0 & -E \end{pmatrix} \begin{pmatrix} \mathcal{U}^k \\ \mathcal{V}^k \\ \mathcal{W}_k \\ \mathcal{Z}_k \end{pmatrix} = \omega_k \begin{pmatrix} \mathcal{U}^k \\ \mathcal{V}^k \\ \mathcal{W}_k \\ \mathcal{Z}_k \end{pmatrix}$$

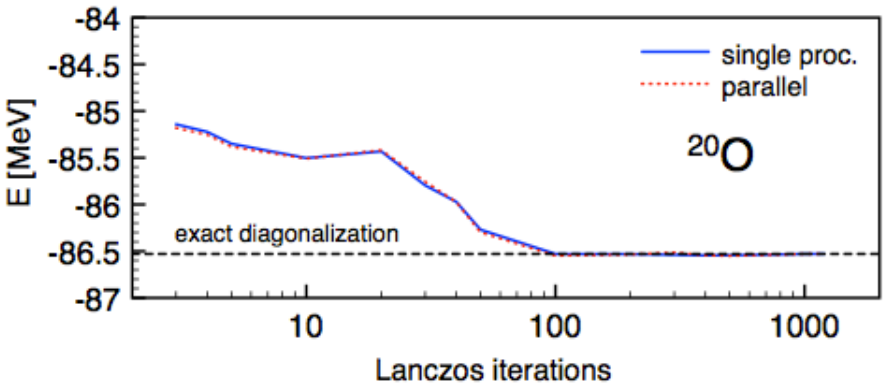
Energy *independent* eigenvalue problem

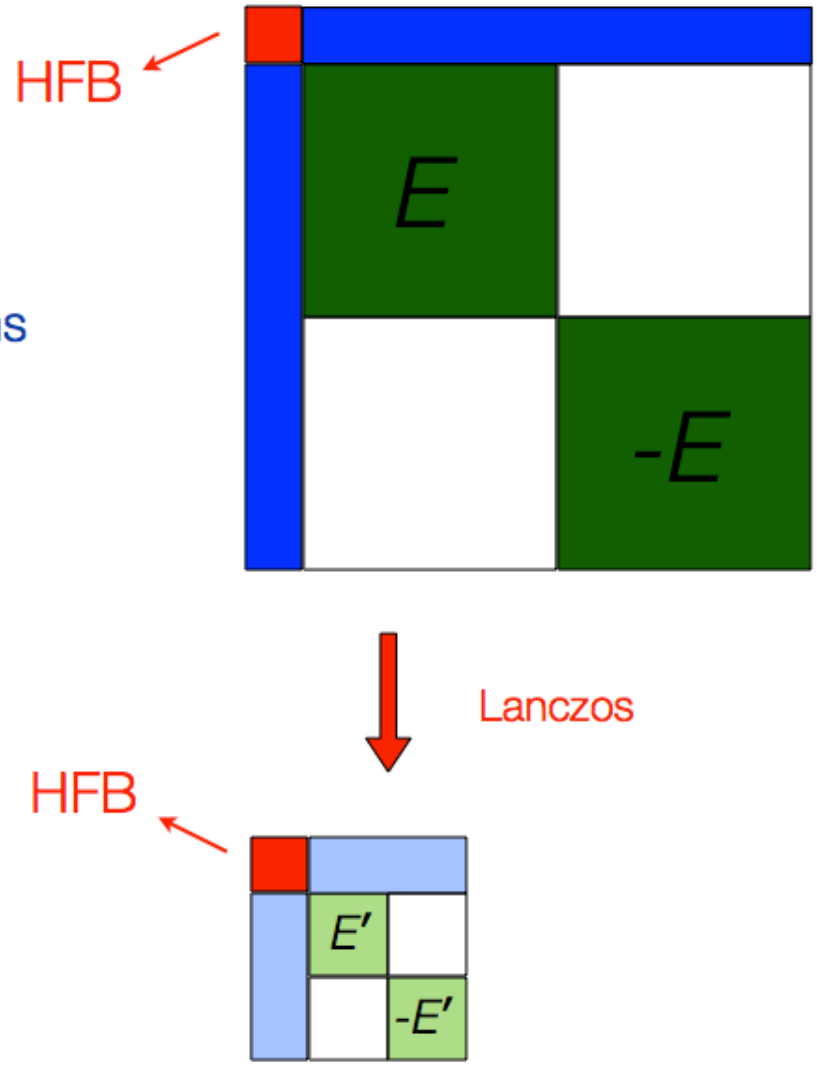
with the normalization condition $\sum_a \left[\left| \mathcal{U}^k_a \right|^2 + \left| \mathcal{V}^k_a \right|^2 \right] + \sum_{k_1 k_2 k_3} \left[\left| \mathcal{W}^{k_1 k_2 k_3}_k \right|^2 + \left| \mathcal{Z}^{k_1 k_2 k_3}_k \right|^2 \right] = 1$

Lanczos reduction of self-energy

$$\begin{pmatrix} T-\mu+\Lambda & \tilde{h} & \mathcal{C} & -\mathcal{D}^\dagger \\ \tilde{h}^\dagger & -T+\mu-\Lambda & -\mathcal{D}^\dagger & \mathcal{C} \\ \mathcal{C}^\dagger & -\mathcal{D} & E & 0 \\ -\mathcal{D} & \mathcal{C}^\dagger & 0 & -E \end{pmatrix} \begin{pmatrix} \mathcal{U}^k \\ \mathcal{V}^k \\ \mathcal{W}_k \\ \mathcal{Z}_k \end{pmatrix} = \omega_k \begin{pmatrix} \mathcal{U}^k \\ \mathcal{V}^k \\ \mathcal{W}_k \\ \mathcal{Z}_k \end{pmatrix}$$

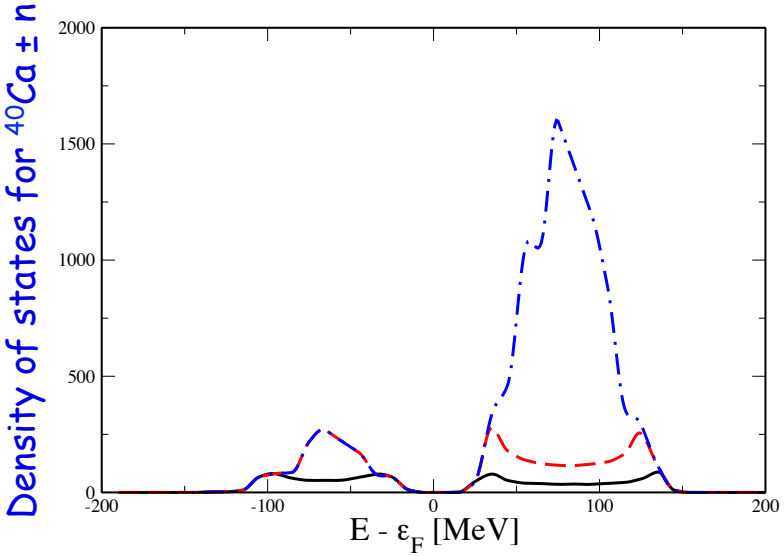
- Conserves moments of spectral functions
- Equivalent to exact diagonalization for $N_L \rightarrow$ dim(E)



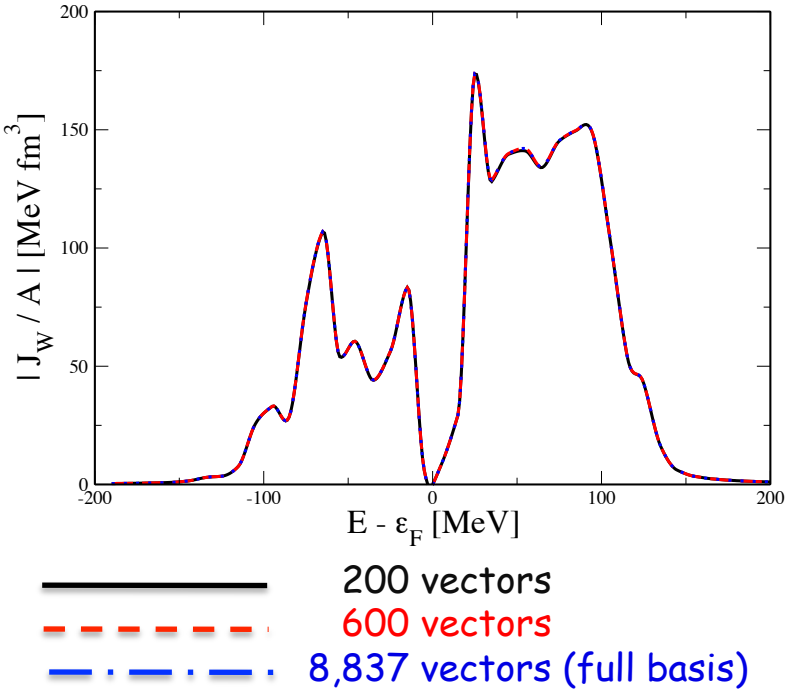


Application of Lanczos (example)

➔# of poles of the self-energy (== optical potential) are reduced without altering spectroscopic strength.



Volume integral of ^{40}Ca ± n optical potential in $f_{7/2}$ part. wave

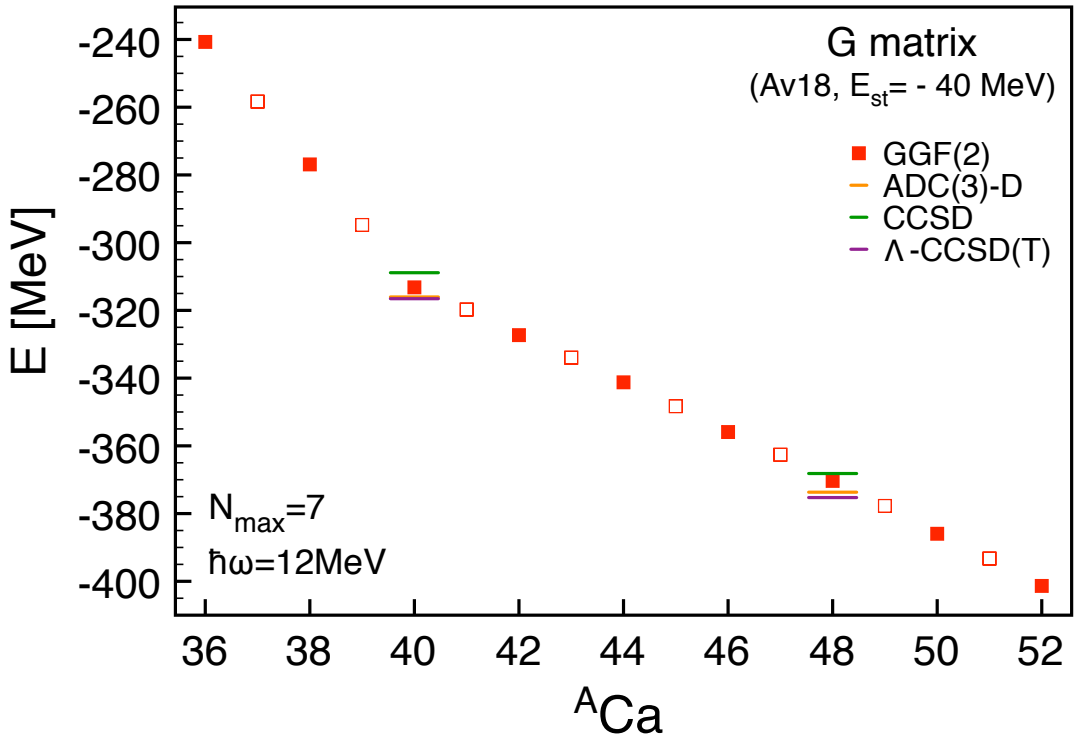


➔ Ground state energies converge with ≥ 200Lanczos vectors (10 osc. shells).

Binding energies

Somà, CB, Duguet, arXiv:1208.2472

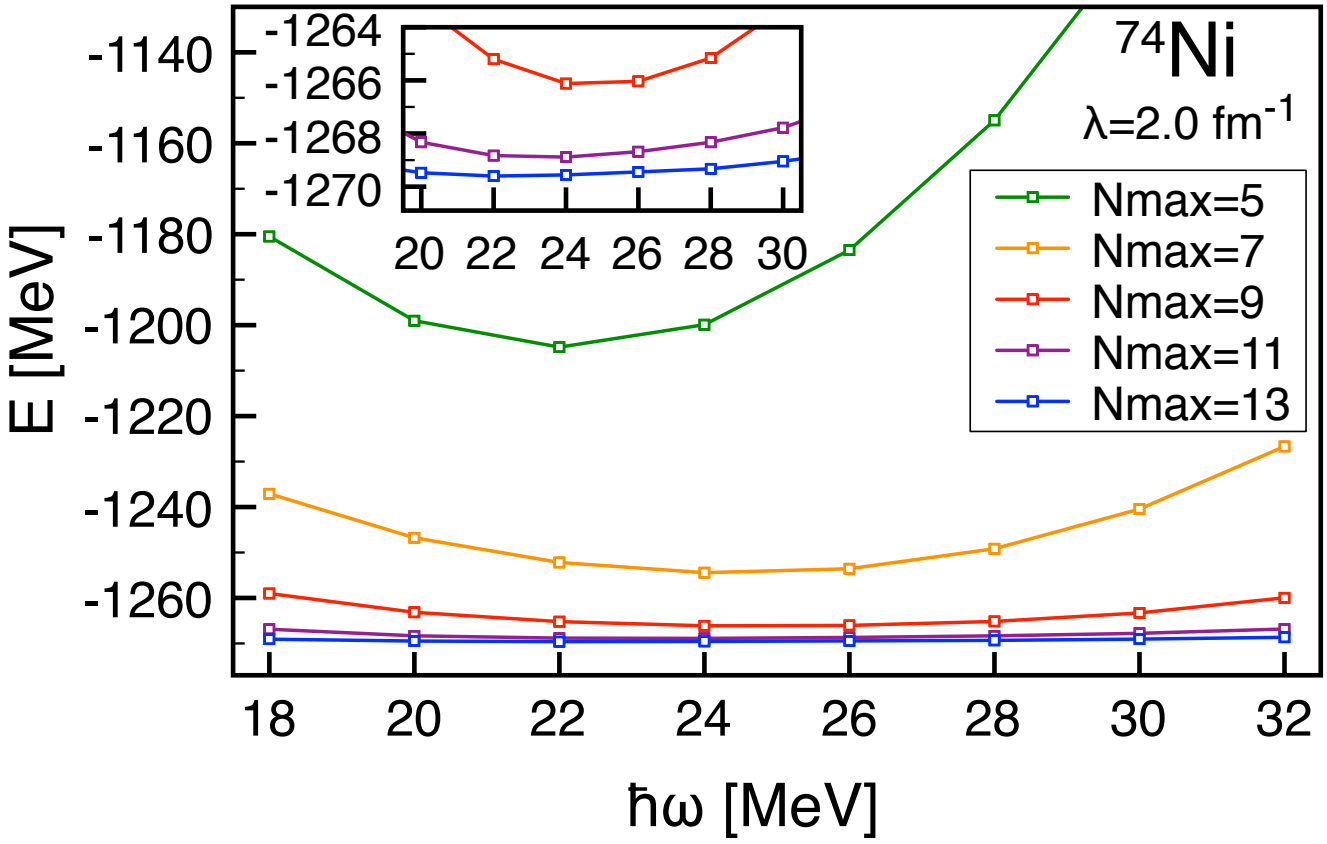
- Systematic along isotopic/isotonic chains has become available



- Accuracy is good (close to CCSD and FRPA) and improvable
- Systematic along isotopic/isotonic chains has become possible
- Of course, need proper interactions and (at least) NNN forces…

Binding energies

Somà, CB, Duguet, arXiv:1208.2472



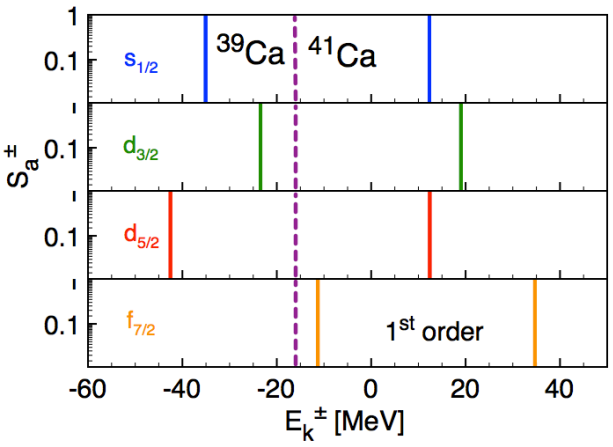
✺ Systematic along isotopic/isotonic chains has become possible

➟ Overbinding with A: traces need for (at least) NNN forces

➟ Effect of self-consistency is relevant; i.e. less bound than MBPT2

Spectral distribution

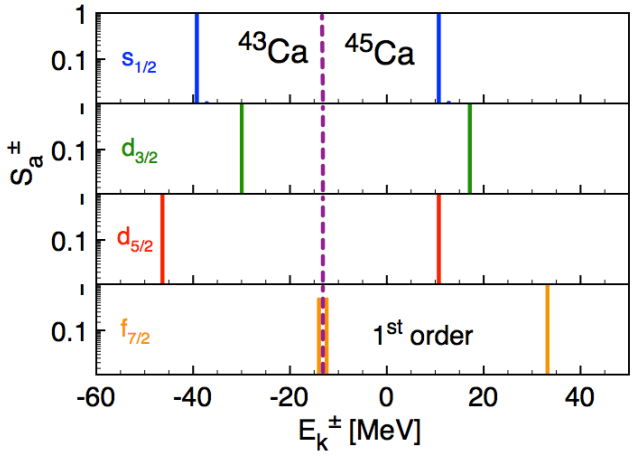
Dyson 1st order (HF)



Fragmentation

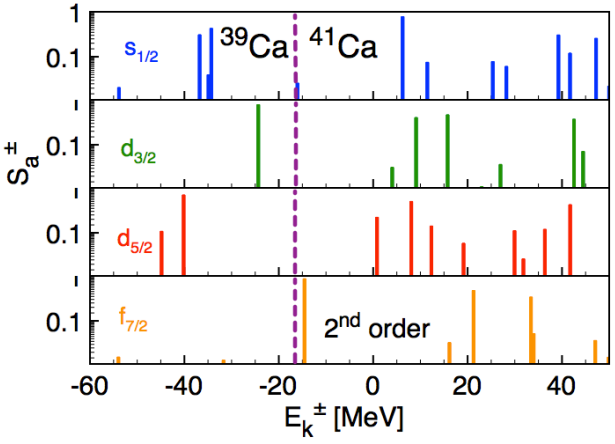
Static pairing

Gorkov 1st order (HFB)

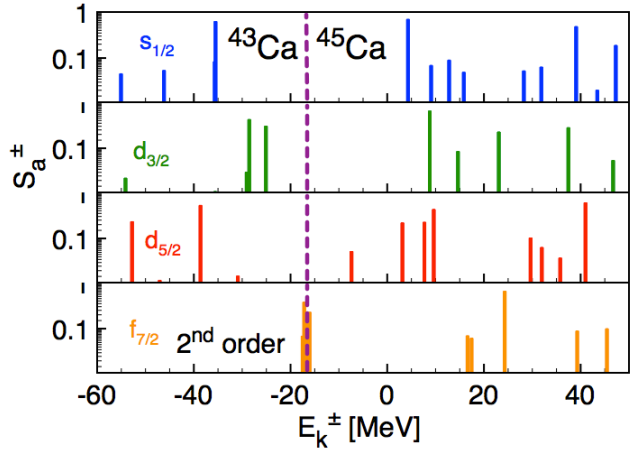


Dynamical fluctuations

Dyson 2nd order



Gorkov 2nd order



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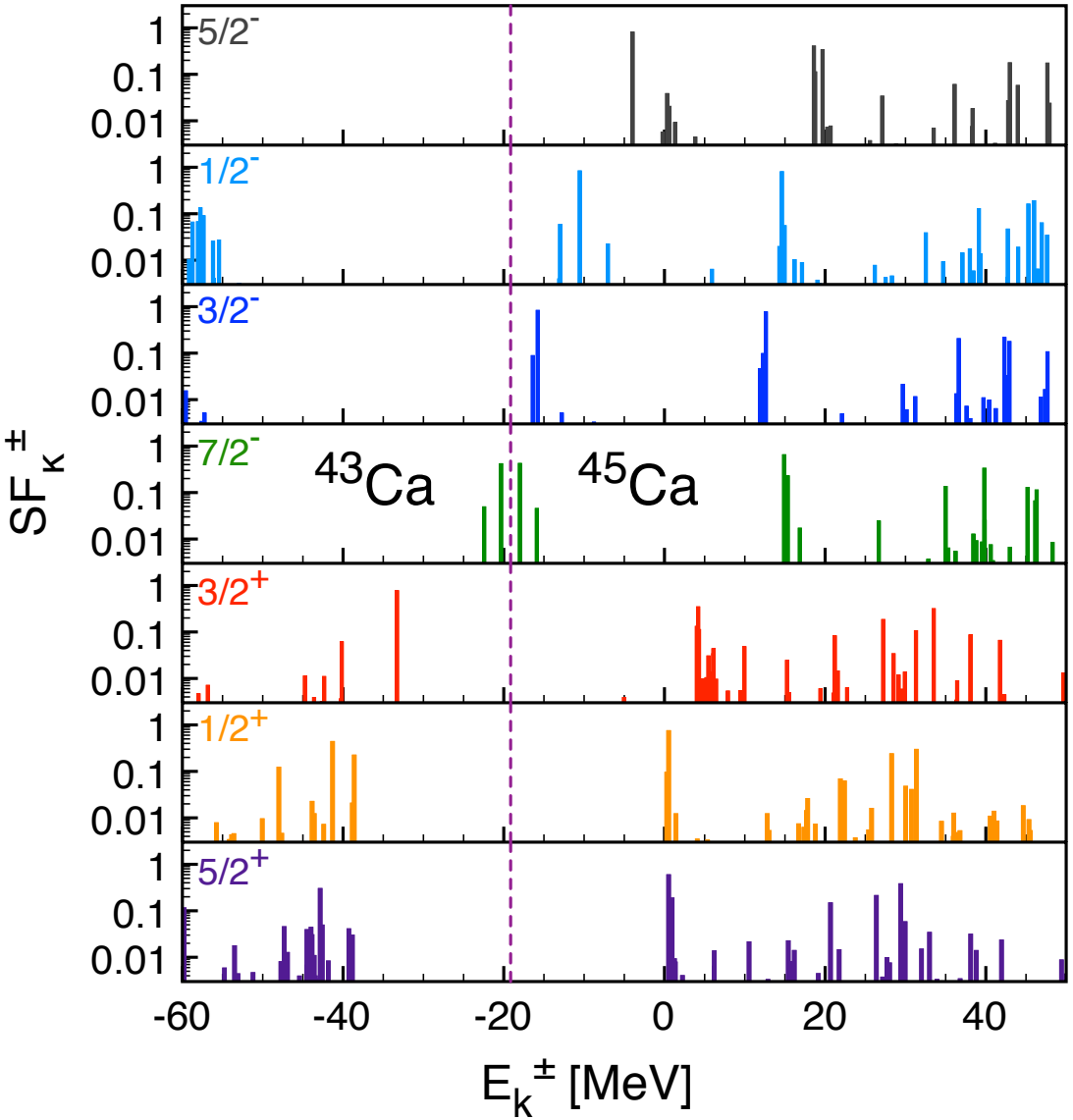
Spectral distribution

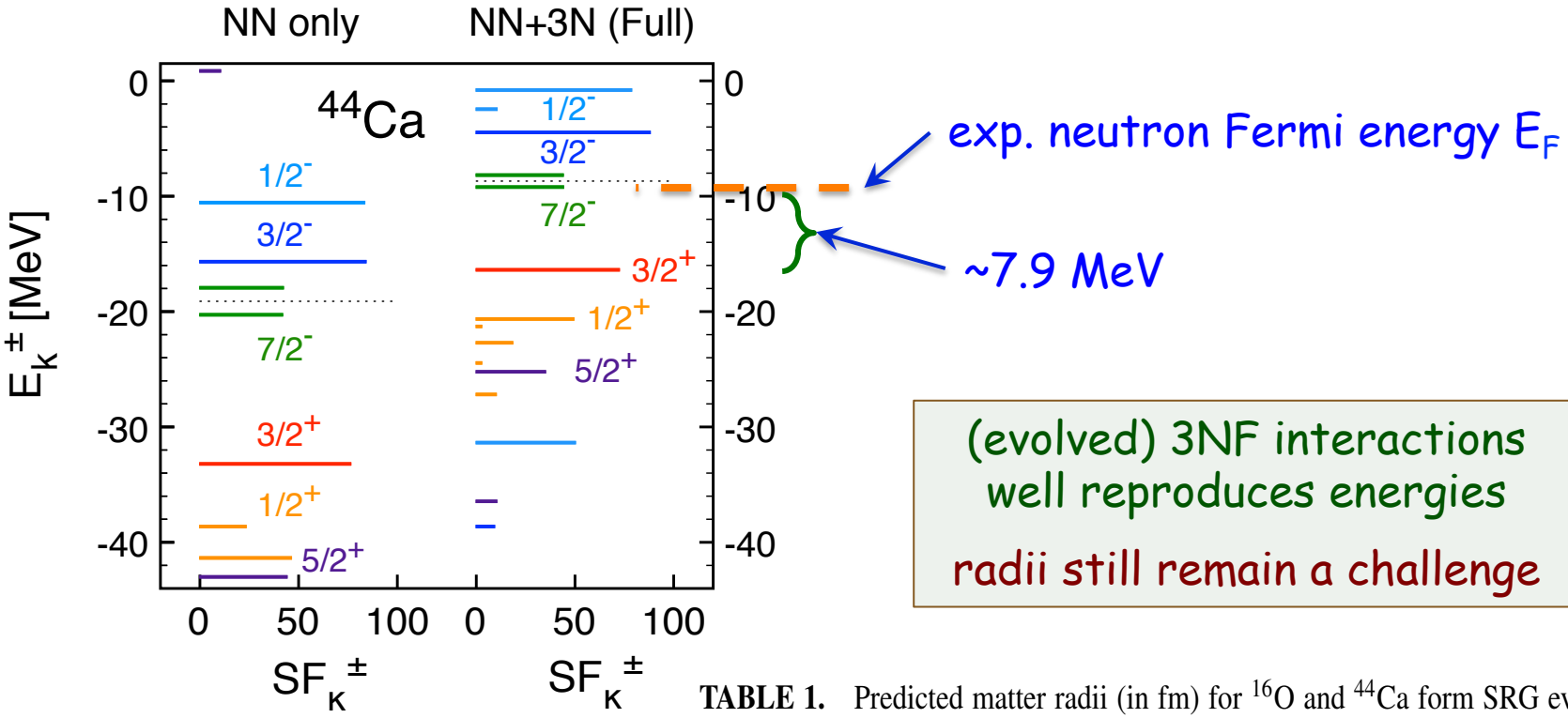
Somà, CB, Duguet, arXiv:1208.2472



➡ Gorkov-GF at 2nd order [or ADC(2)]

Evolved chiral 3NF and the Ca isotopes

A. Cipollone, CB, V.Somà, P. Navratil



(evolved) 3NF interactions well reproduces energies

radii still remain a challenge

CB *et al.*, arXiv:1211.3315 [nucl-th]

TABLE 1. Predicted matter radii (in fm) for ^{16}O and ^{44}Ca form SRG evolved 2N-only interactions and by including induced and full 3NF. Experiment are charge radii.

	2NF only	2+3NF(ind.)	2+3NF(full)	Experiment
^{16}O:	2.10	2. 41	2.38	2.718±0.210 [19]
^{44}Ca:	2.48	2.93	2.94	3.520±0.005 [20]

N3LO (Λ = 500Mev/c) chiral NN interaction evolved to 2N + 3N forces (2.0fm^{-1})
N2LO (Λ = 400Mev/c) chiral 3N interaction evolved (2.0fm^{-1})

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Conclusions

- Self-Consistent Green's Functions (SCGF), is a microscopic *ab-initio* method applicable to medium mass nuclei. *Greatest advantage* is the link to several (experimentally accessible) information.

- *Proof of principle calculations Gorgov theory are successful at 2nd order.* This de facto show that the approach is viable and opens a whole new path:

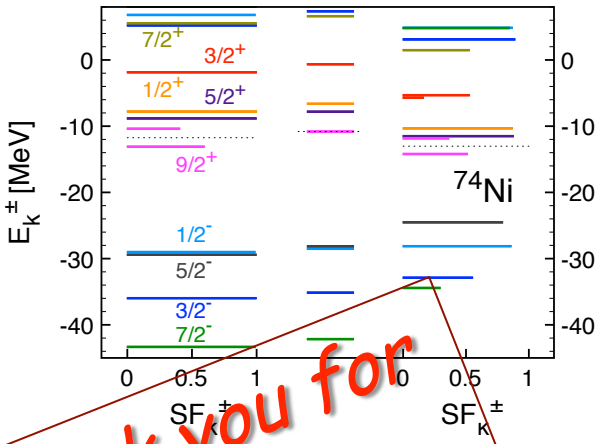
  → Open-shell nuclei (*many*, *not* previously approachable otherwise!).

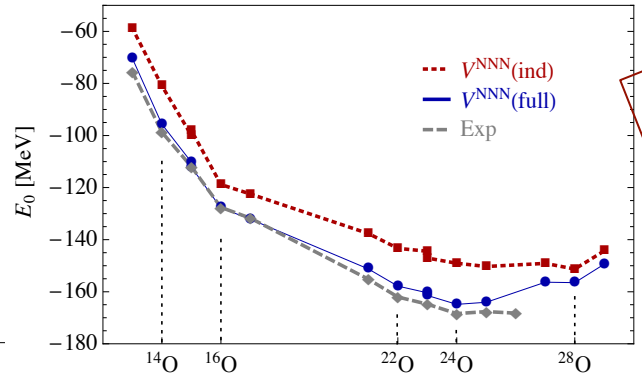
  → Reactions at driplines.

  → structure of next generation EDF.

- *Addition of* three nucleon forces (3NF) are feasible and underway.

  → This implies a step up in the accuracy of "ab-initio" calculations.





Thank you for your attention!!!

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