Near-degenerate systems in nuclear structure and quantum chemistry from ab initio many-body methods
ESNT, 30 March—2 April 2015

UNIVERSITY OF SURREY

Three-Body Forces and CI Effective Operators in Green's Function Theory

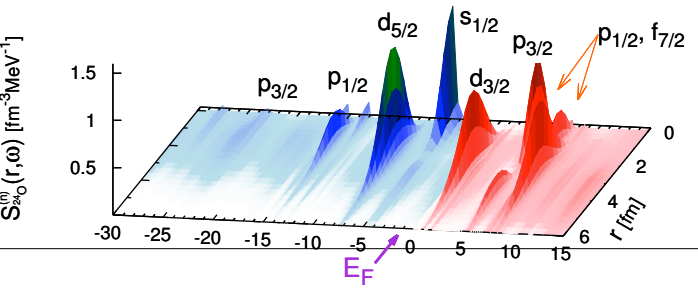
Carlo Barbieri — University of Surrey

Formalism and 3NF:
*Phys. Rev. C**63**, 034313 (2001),* *Phys. Rev. A**76**, 052503 (2007)*
*Phys. Rev. C**84**, 064317 (2011),* *Phys. Rev. C**88**, 054326 (2013)*

ab-initio & correlations: *Phys. Rev. C**89**, 061301R (2014)*
arXiv:1412.0491 [nucl-th] (2014)

CB, J. Phys.: Conf. Ser. **529,** 012005 (2014)

^{24}O:



Collaborators

A. Cipollone, A. Rios

V. Somà, T. Duguet

A. Carbone

P. Navratil

A. Polls

W.H. Dickhoff, S. Waldecker

D. Van Neck, M. Degroote

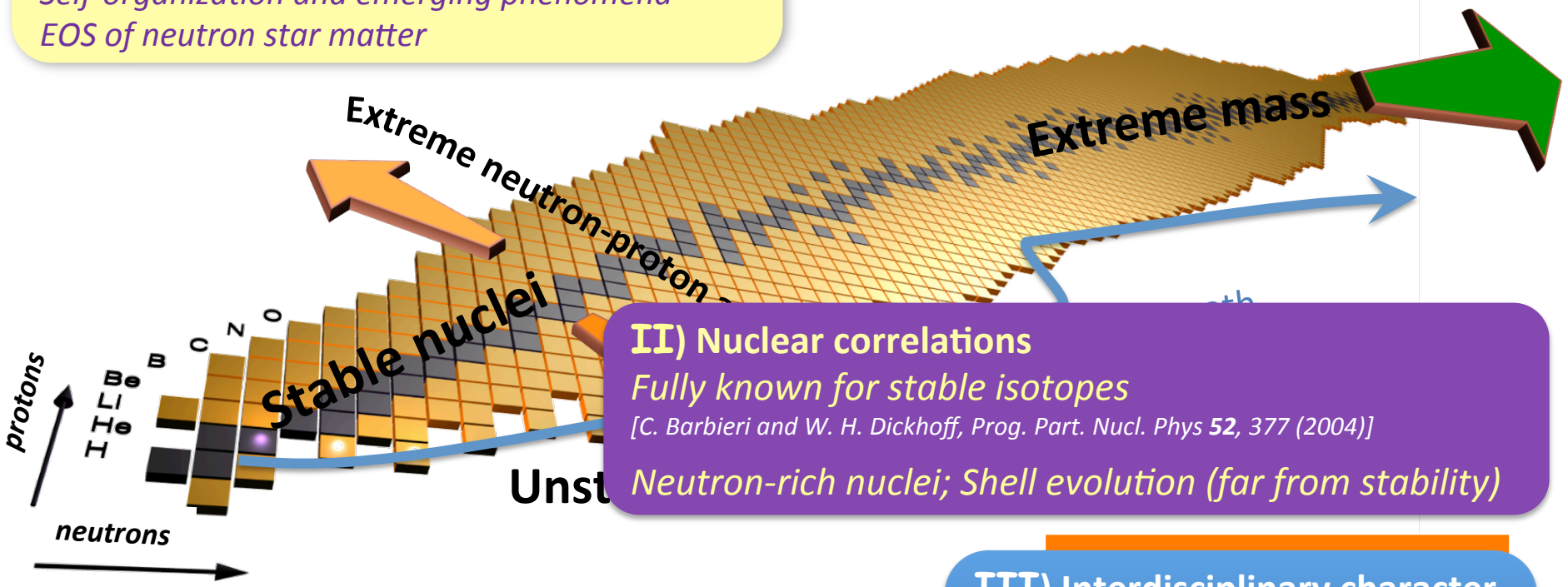
M. Hjorth-Jensen

Current Status of low-energy nuclear physics

Composite system of interacting fermions

Binding and limits of stability
Coexistence of individual and collective behaviors
Self-organization and emerging phenomena
EOS of neutron star matter

Experimental programs
RIKEN, FAIR, FRIB



II) Nuclear correlations

Fully known for stable isotopes
*[C. Barbieri and W. H. Dickhoff, Prog. Part. Nucl. Phys **52**, 377 (2004)]*

Neutron-rich nuclei; Shell evolution (far from stability)

I) Understanding the nuclear force

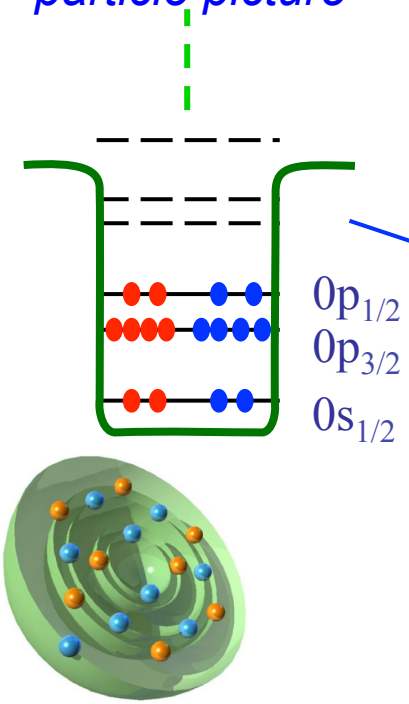
QCD-derived; 3-nucleon forces (3NFs)
First principle (ab-initio) predictions

III) Interdisciplinary character

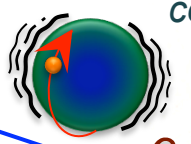
Astrophysics
Tests of the standard model
Other fermionic systems:
ultracold gasses; molecules;

Concept of correlations

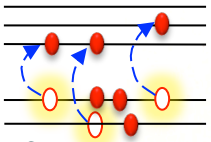
independent particle picture



Particle-vibration coupling (PV)



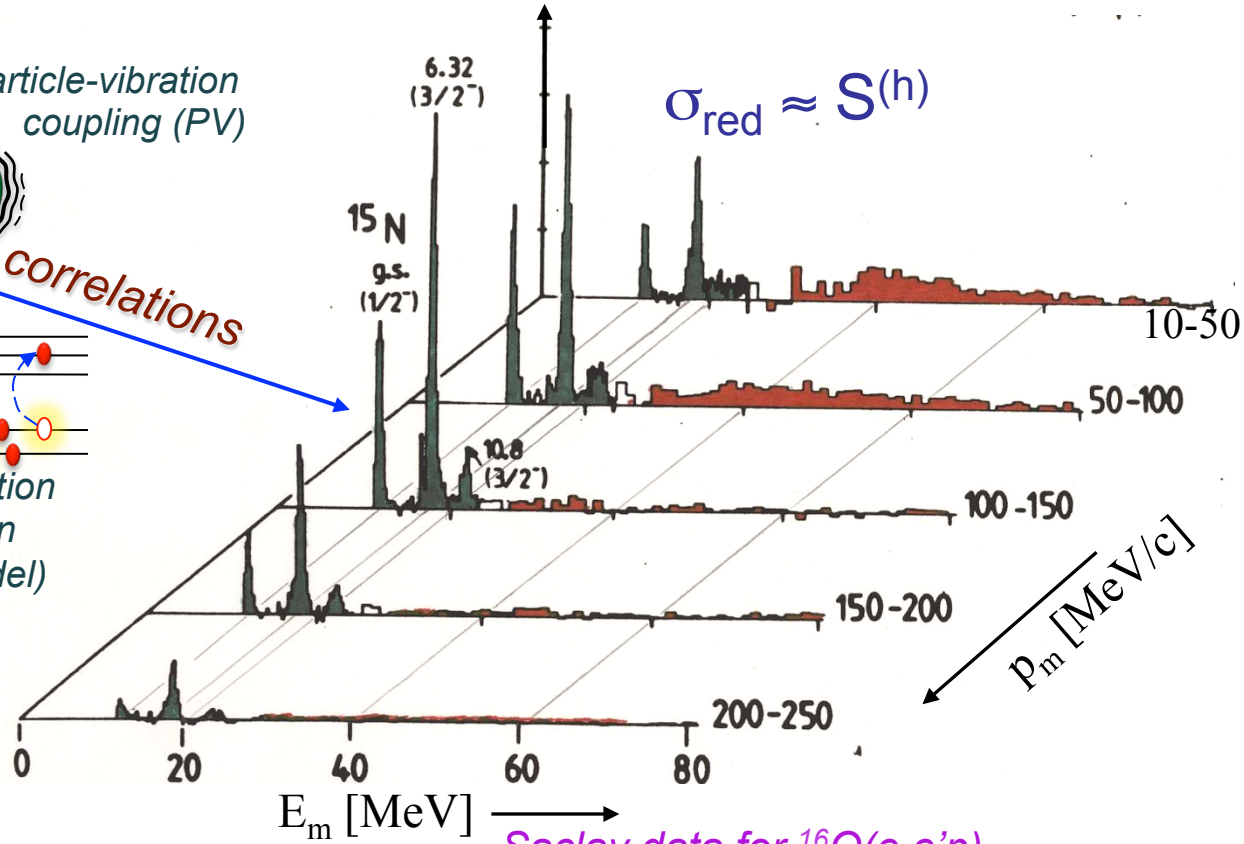
correlations



Configuration interaction (shell model)

Spectral function: distribution of momentum (p_m) and energies (E_m)

$\sigma_{red} \approx S^{(h)}$



Saclay data for $^{16}O(e,e'p)$

[Mougey et al., Nucl. Phys. A335, 35 (1980)]

*[CB and W. H. Dickhoff, Prog. Part. Nucl. Phys **52**, 377 (2004)]*

Concept of correlations

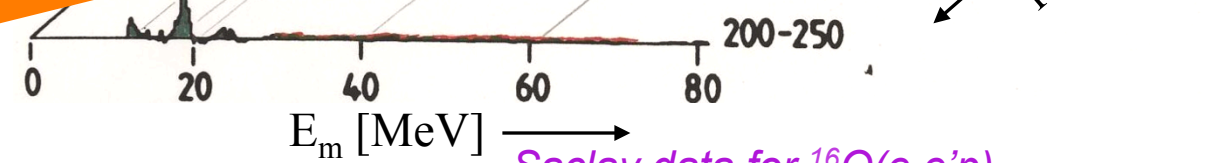
independent particle picture

Spectral function: distribution of momentum (p_m) and

Particle-vibration coupling

So far, fully characterised only for closed-shell and stable isotopes… (!)

[W. Dickhoff, CB, Prog. Part. Nucl. Phys. **52**, 377 (2004)]

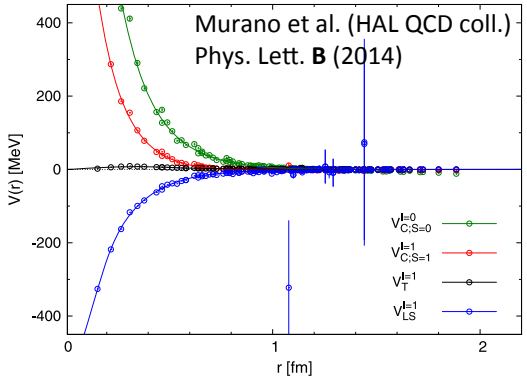


Saclay data for ^{16}O(e,e'p)
[Mougey et al., Nucl. Phys. A335, 35 (1980)]

*[CB and W. H. Dickhoff, Prog. Part. Nucl. Phys **52**, 377 (2004)]*

Nuclear forces in exotic nuclei

Nucleon interactions are very complex and difficult to handle



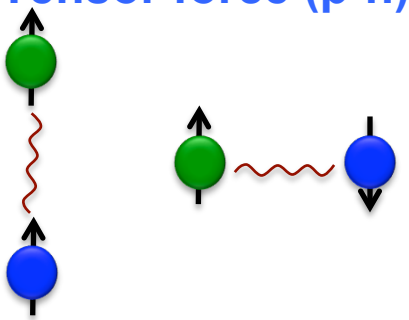
Change of regime from stable to dripline isotopes !

Symmetric matter:
N ≈ Z

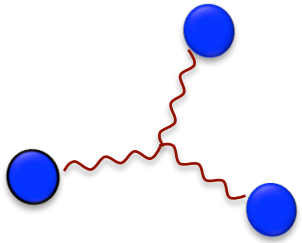
→

Neutron-rich matter (N ≫ Z):
- **Neutron star matter EoS**
- **Symmetry energy**

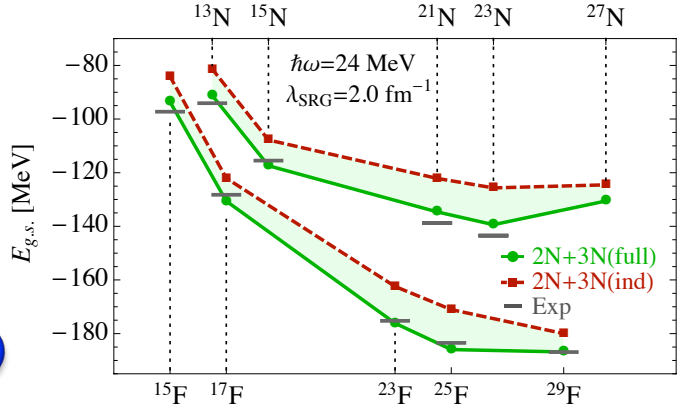
Tensor force (p-n)



Three-nucleon Force (3NF)



Driplines of nitrogen and fluorine isotopes



[A. Cipollone, CB, P. Navrátil, Phys. Rev. Lett. **111**, 062501 (2013)]

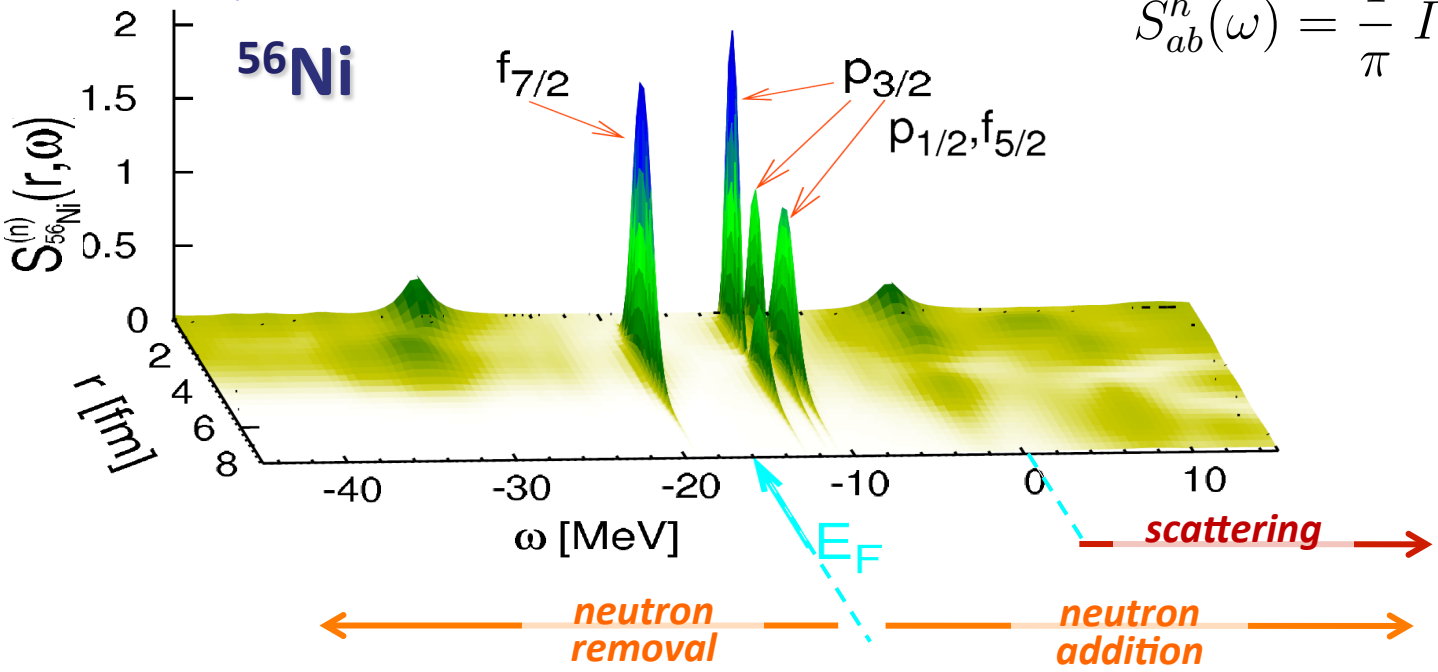
Example of spectral function ^{56}Ni

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):

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

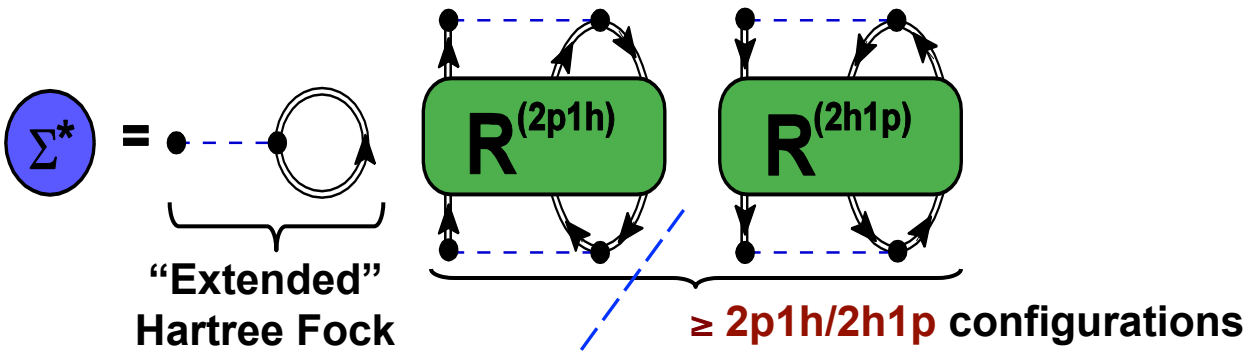


[CB, M.Hjorth-Jensen, Pys. Rev. C**79**, 064313 (2009); CB, Phys. Rev. Lett. **103**, 202502 (2009)]

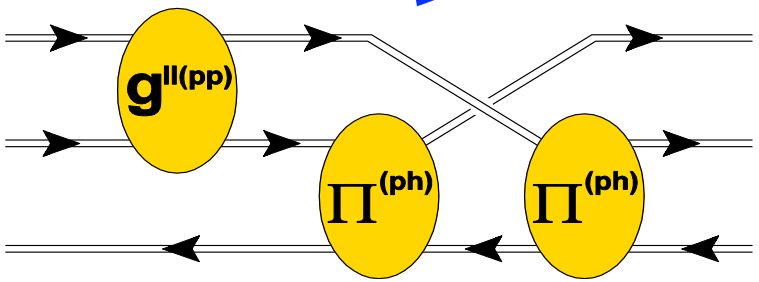
Ab-Initio SCGF approaches

Coupling single particle to collective modes

- Non perturbative expansion of the self-energy:



- Explicit correlations enter the "three-particle irreducible" propagators:

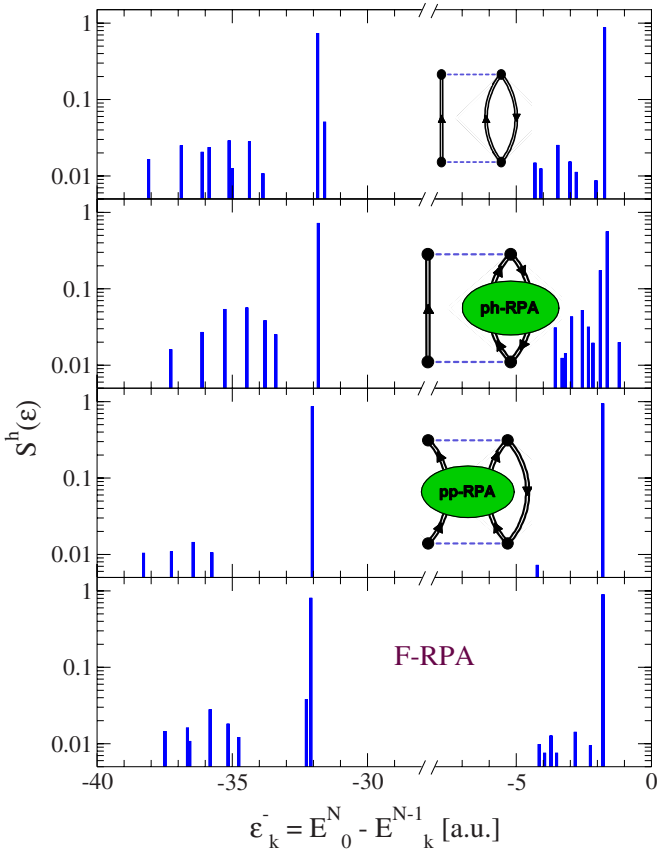


- Both pp/hh (ladder) and ph (ring) response included
- Pauli exchange at 2p1h/2h1p level

References: CB, et al.,
Phys. Rev. C63, 034313 (2001);
Phys. Rev. C65, 064313 (2002);
Phys. Rev. A76, 052503 (2007)

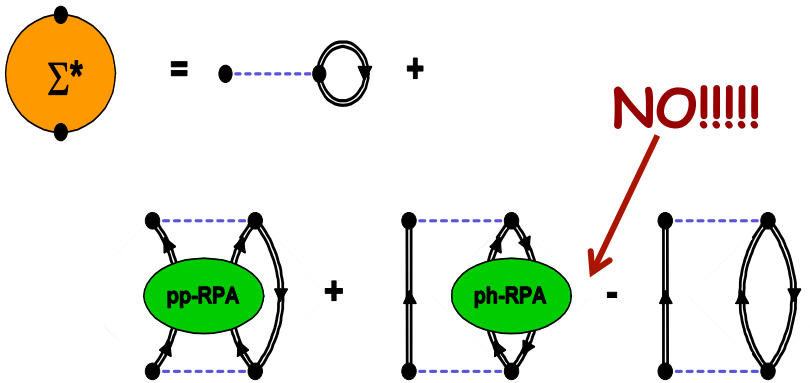
≡ particle
≡ hole

Ionization spectrum of Ne atom



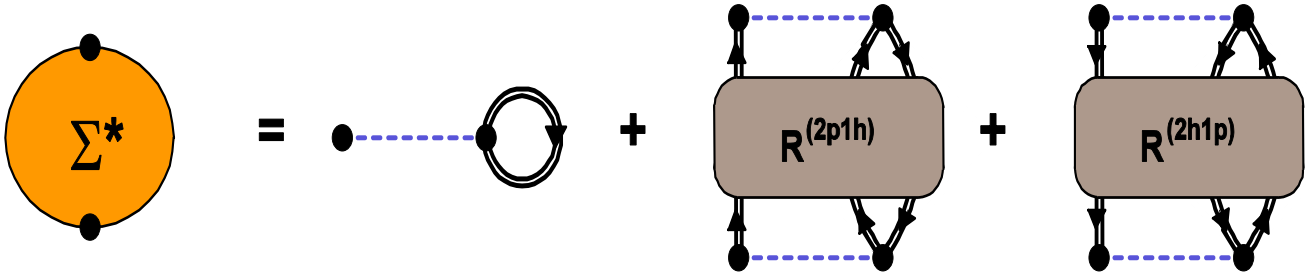
*Phys. Rev. A**76**, 052503 (2007)*

- Both pp and ph configurations are important
- In finite nuclei one need RPA to describe giant resonances
- CANNOT be simply added:

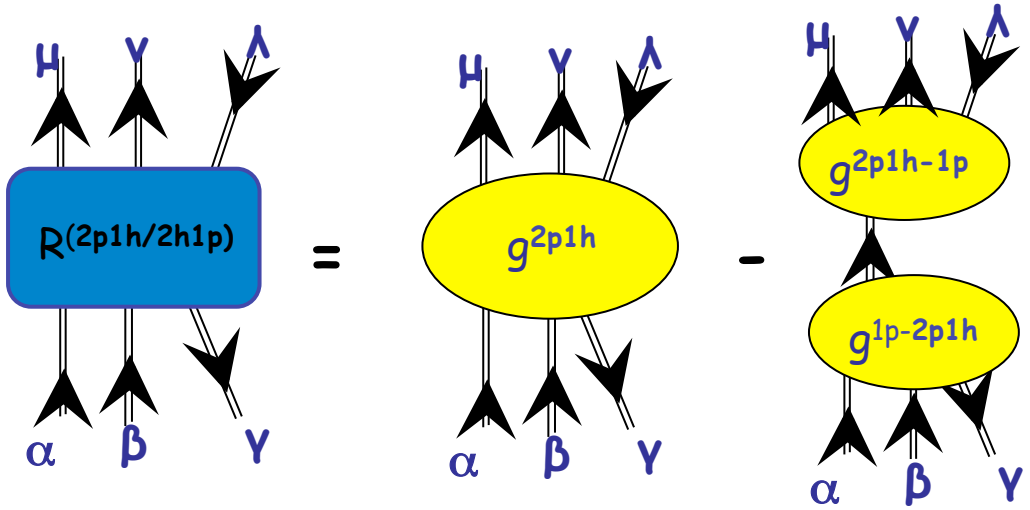


Faddeev RPA method

- Thus, to include both "ladder" and "ring" correlations one must calculate the full 2p1h/2h1p propagator



- In general this is exact if one can calculate the full 6-points Green's function (see lecture of Apr. 13th):



Faddeev RPA method

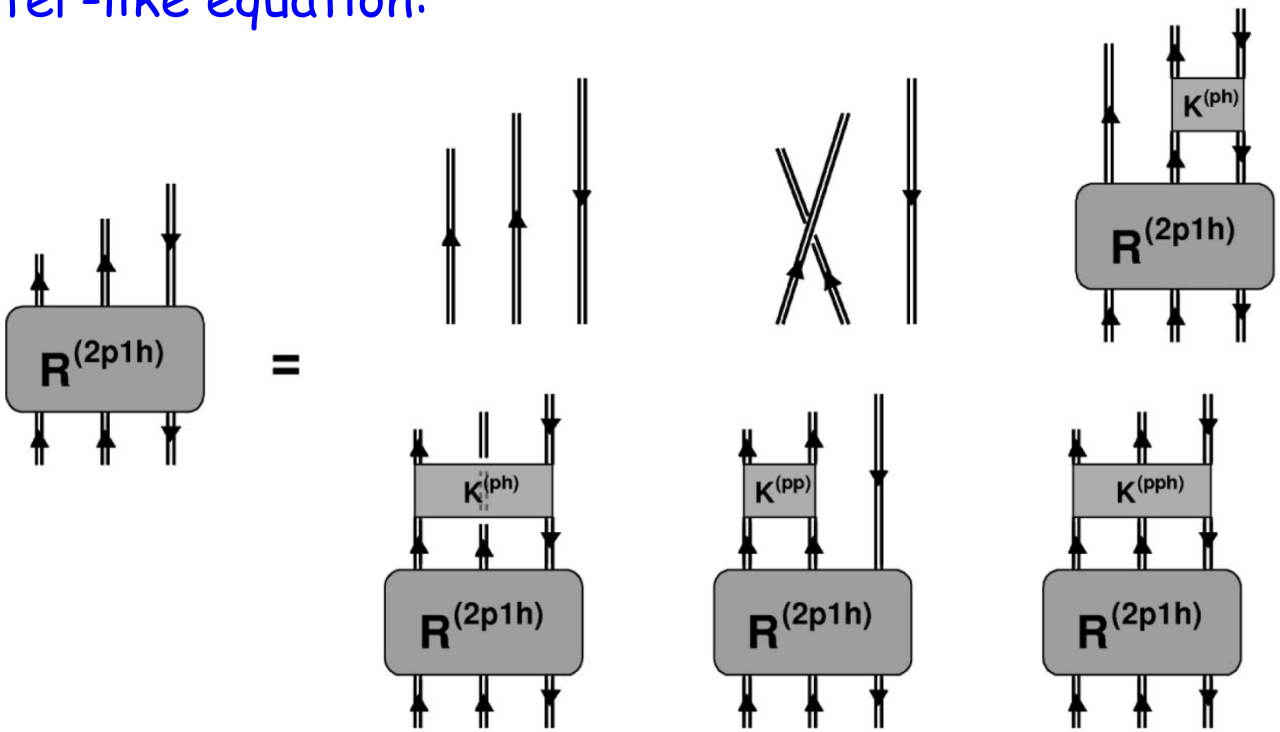
- The full 2p1h/2h1p polarization propagator also satisfies a Bethe-Salpeter-like equation:

$$
\begin{aligned}
R_{\alpha\beta\gamma,\mu\nu\lambda}(\omega_1,\omega_2,\omega_3) = {} & [g_{\alpha\mu}(\omega_1)g_{\beta\nu}(\omega_2) - g_{\beta\mu}(\omega_2)g_{\alpha\nu}(\omega_1)]g_{\lambda\gamma}(-\omega_3) \\
& + \Bigg(g_{\beta\beta_1}(\omega_2)g_{\gamma_1\gamma}(-\omega_3)V_{\beta_1\sigma,\gamma_1\rho}\int \frac{ds}{2\pi i} R_{\alpha\rho\sigma,\mu\nu\lambda}(\omega_1,s,\omega_2+\omega_3-s) \\
& + g_{\alpha\alpha_1}(\omega_1)g_{\gamma_1\gamma}(-\omega_3)V_{\alpha_1\sigma,\gamma_1\rho}\int \frac{ds}{2\pi i} R_{\rho\beta\sigma,\mu\nu\lambda}(s,\omega_2,\omega_1+\omega_3-s) \\
& + \frac{1}{2} g_{\alpha\alpha_1}(\omega_1)g_{\beta\beta_1}(\omega_2)V_{\alpha_1\beta_1,\rho\sigma}\int \frac{ds}{-2\pi i} R_{\rho\sigma\gamma,\mu\nu\lambda}(s,\omega_1+\omega_2-s,\omega_3) \Bigg)
\end{aligned}
$$

- However, this depends on 4-tmes (3 frequancies) and it is much more complicatde than the p-h Bethe-Salpeter.

Faddeev RPA method

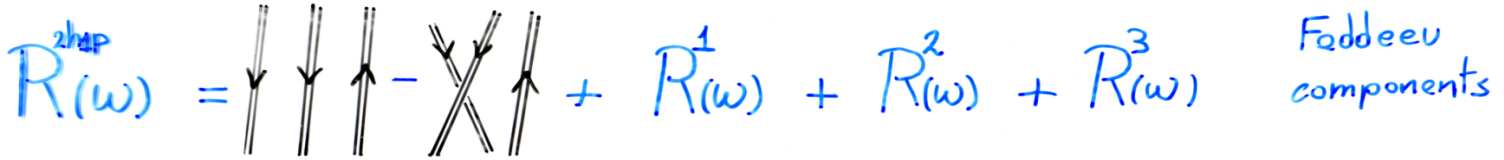
The full 2p1h/2h1p polarization propagator also satisfies a Bethe-Salpeter-like equation:

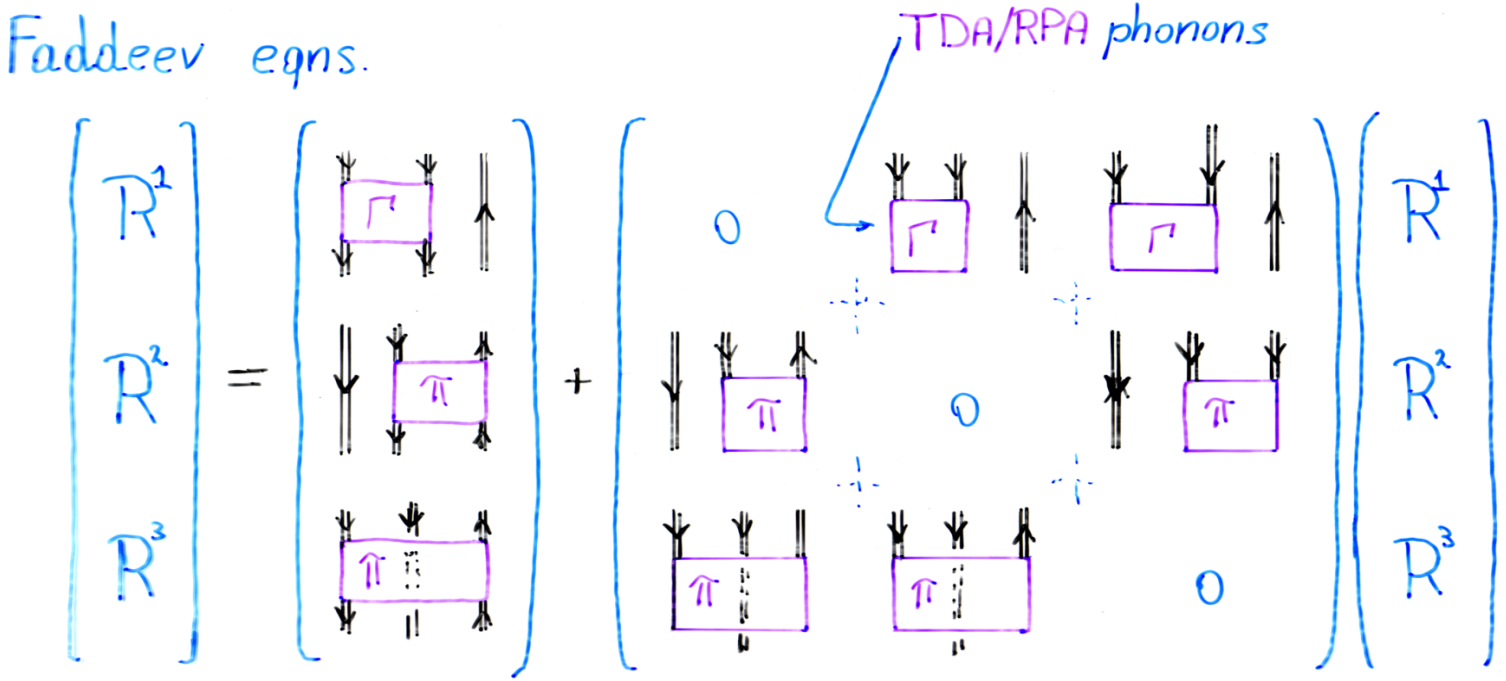


Strategy: solve each "pp" and "ph" channel separately, by solving the (simpler) DRPA equations. Then couple to a third line and mix the corresponding amplitudes ➔ Faddeev eqs.!!

Faddeev equations for the 2h1p motion

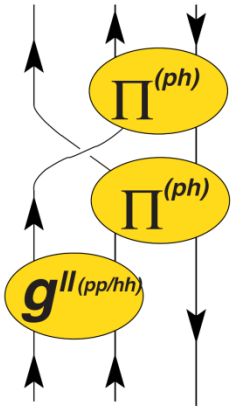
Strategy: solve each "pp" and "ph" channel separately, by solving the (simpler) DRPA equations. Then couple to a third line and mix the corresponding amplitudes ➔ Faddeev eqs.!!



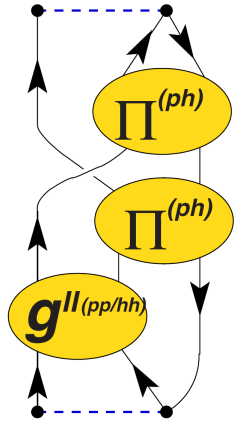


References: CB, et al., Phys. Rev. C63, 034313 (2001); Phys. Rev. A76, 052503 (2007)

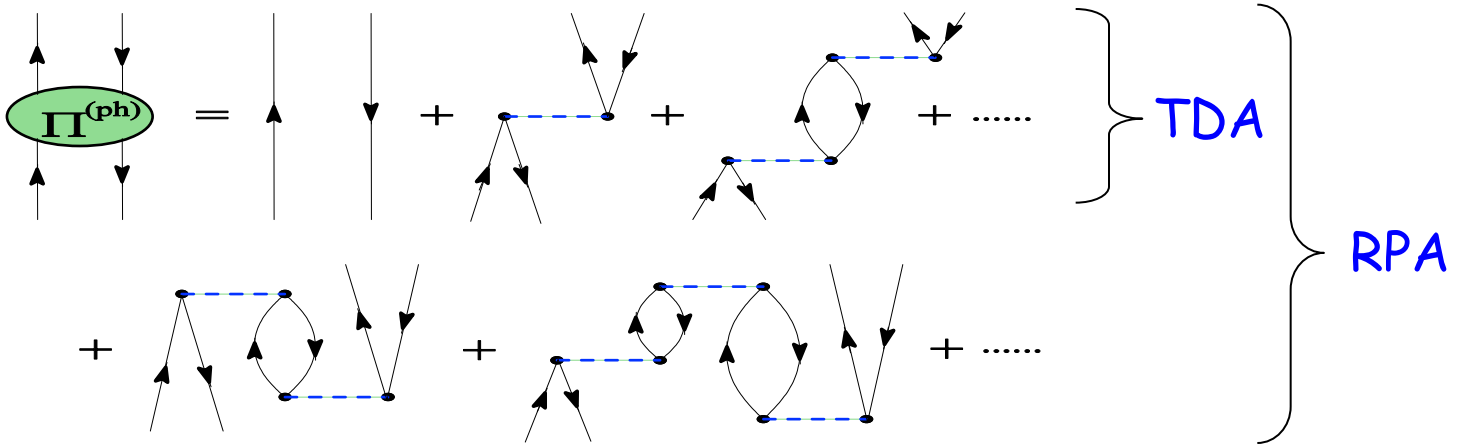
FRPA: Faddeev summation of RPA propagators



- Both pp/hh (ladder) and ph (ring) response included
- Pauli exchange at 2p1h/2h1p level
- All order summation through a set of Faddeev equations



where:

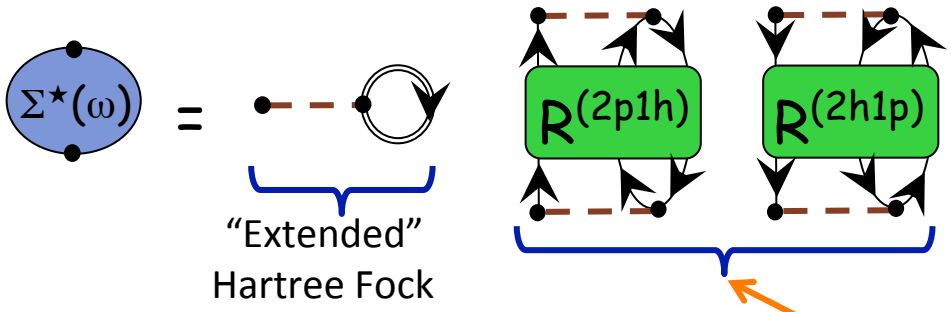


References: CB, et al., Phys. Rev. C63, 034313 (2001); Phys. Rev. A76, 052503 (2007)

The FRPA Method in Two Words

Particle vibration coupling is the main cause driving the distribution of particle strength—on both sides of the Fermi surface…

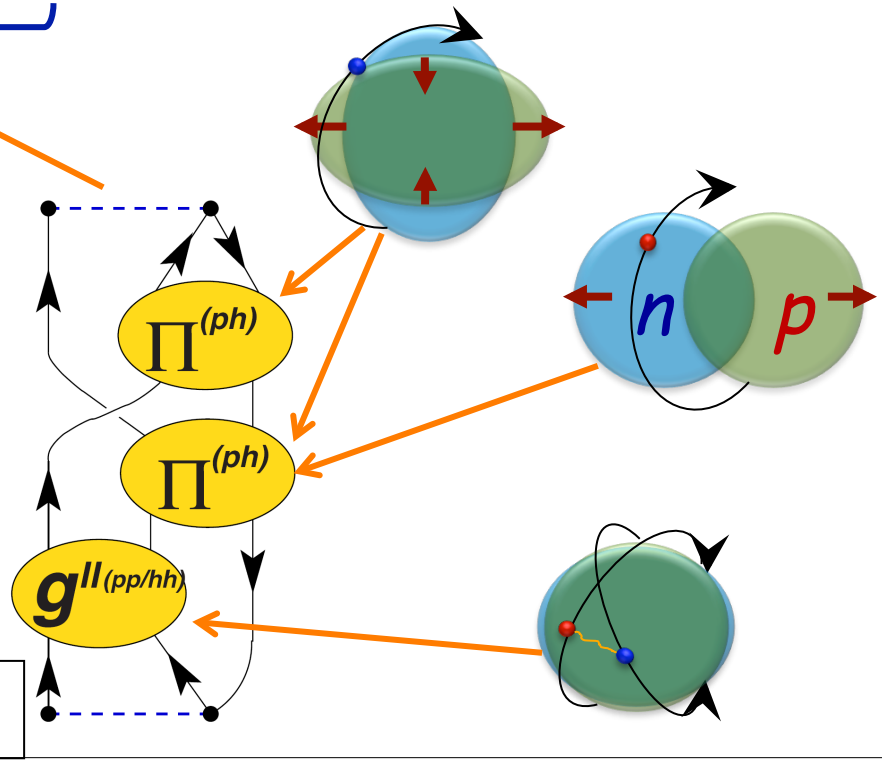
CB et al.,
*Phys. Rev. C**63**, 034313 (2001)*
*Phys. Rev. A**76**, 052503 (2007)*
*Phys. Rev. C**79**, 064313 (2009)*



- *A complete expansion requires <u>all types</u>* of particle-vibration coupling

  …these modes are all resummed exactly and to all orders in a *ab-initio* many-body expansion.

- The Self-energy Σ*(ω) yields *both* single-particle states and scattering



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

< 1% of tot. binding energy

binding energies (atoms)

	Hartree-Fock	FTDA	FRPA	CCSD	Experiment
He	−2.8617(+42.0)	−2.9028(+0.9)	−2.9029(+0.8)	−2.9039(−0.2)	−2.9037
Be^{2+}	−13.6117(+43.9)	−13.6559(−0.3)	−13.6559(−0.3)	−13.6561(−0.5)	−13.6556
Be	−14.5731(+94.3)	−14.6438(+23.6)	−14.6436(+23.8)	−14.6522(+15.2)	−14.6674
Ne	−128.5505(+387.8)	−128.9343(+4.0)	−128.9381(+0.2)	−128.9353(+3.0)	−128.9383
Mg^{2+}	−198.837(+444)	−199.226(−5)	−199.228(−7)	−199.225(−4)	−199.221
Mg	−199.616(+438)	−200.048(+6)	−200.052(+2)	−200.050(+4)	−200.054
Ar	−526.820(+724)	−527.543(+1)	−527.548(−4)	−527.536(+8)	−527.544
σ_{rms} [mH]	392	9.5(3.6)	9.5(3.4)	6.9(4.2)	

NB: energies in Hartree
errors in mHartree

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

Three-nucleon interactions

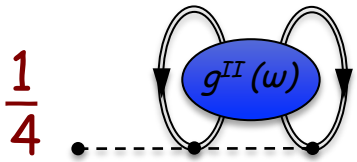
→ application to nuclei
→ need new formalism?

A. Carbone, A. Cipollone, CB, A. Rios, A. PollsPhys. Rev. C88, 054326 (2013).
A. Cipollone, CB, P. Navrátil, Phys. Rev. Lett. 111, 062501 (2013).

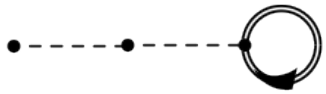
Inclusion of NNN forces

A. Carbone, CB, et al., Phys. Rev. C**88**, 054326 (2013)

- 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

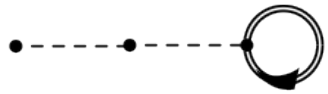
- Contractions are with *fully correlated density matrices* (BEYOND a normal ordering…)

Inclusion of NNN forces

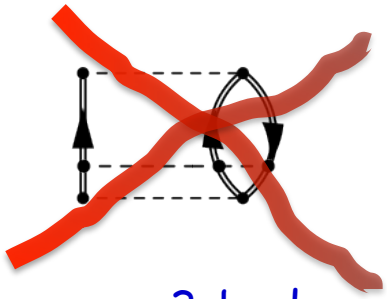
A. Carbone, CB, et al., Phys. Rev. C**88**, 054326 (2013)

- NNN forces can enter diagrams in three different ways:

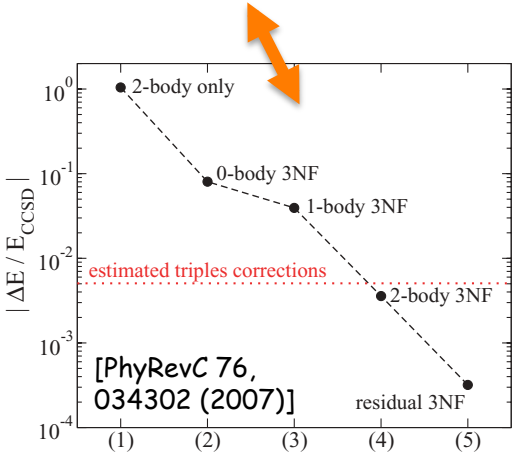
Correction to external 1-Body interaction



Correction to *non-contracted* 2-Body interaction



pure 3-body contribution (small)



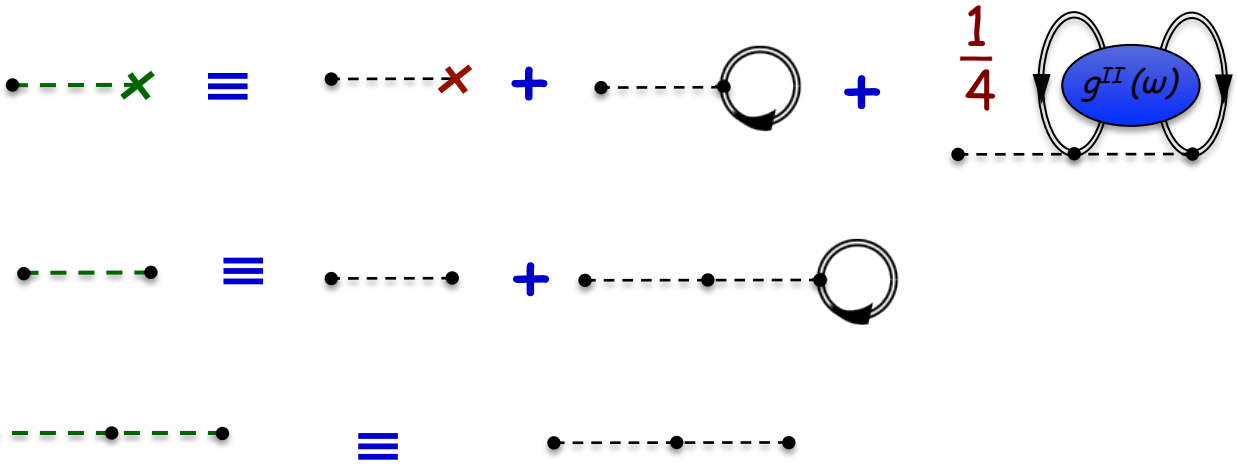
- Contractions are with *fully correlated density matrices* (BEYOND a normal ordering…)

Inclusion of NNN forces

A. Carbone, CB, et al., Phys. Rev. C**88**, 054326 (2013)

✺ NNN forces can enter diagrams in three different ways:

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

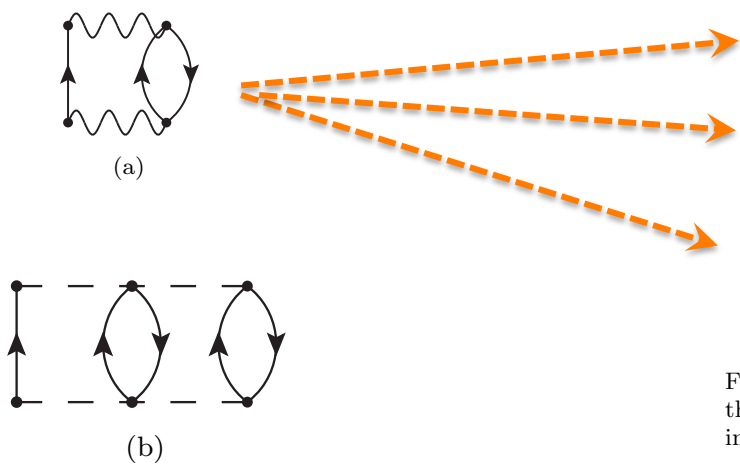


- Contractions are with *fully correlated density matrices* (BEYOND a normal ordering…)

Inclusion of NNN forces

A. Carbone, CB, et al., Phys. Rev. C**88**, 054326 (2013)

- Second order PT diagrams with 3BFs:



effectively:

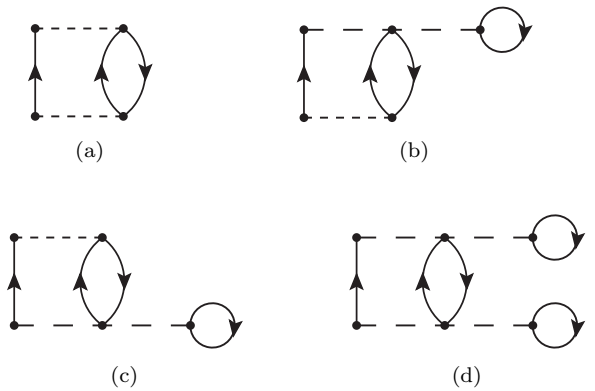
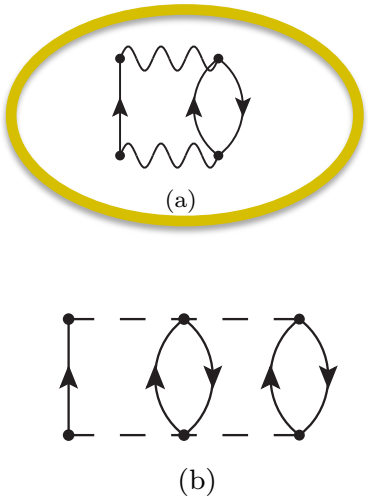


FIG. 4. The one *interaction irreducible* diagrams (a) and the three *interaction reducible* ones (b, c and d) that are contained in Fig. 3a.

Inclusion of NNN forces

A. Carbone, CB, et al., Phys. Rev. C**88**, 054326 (2013)

- Second order PT diagrams with 3BFs:



- Third order PT diagrams with 3BFs:

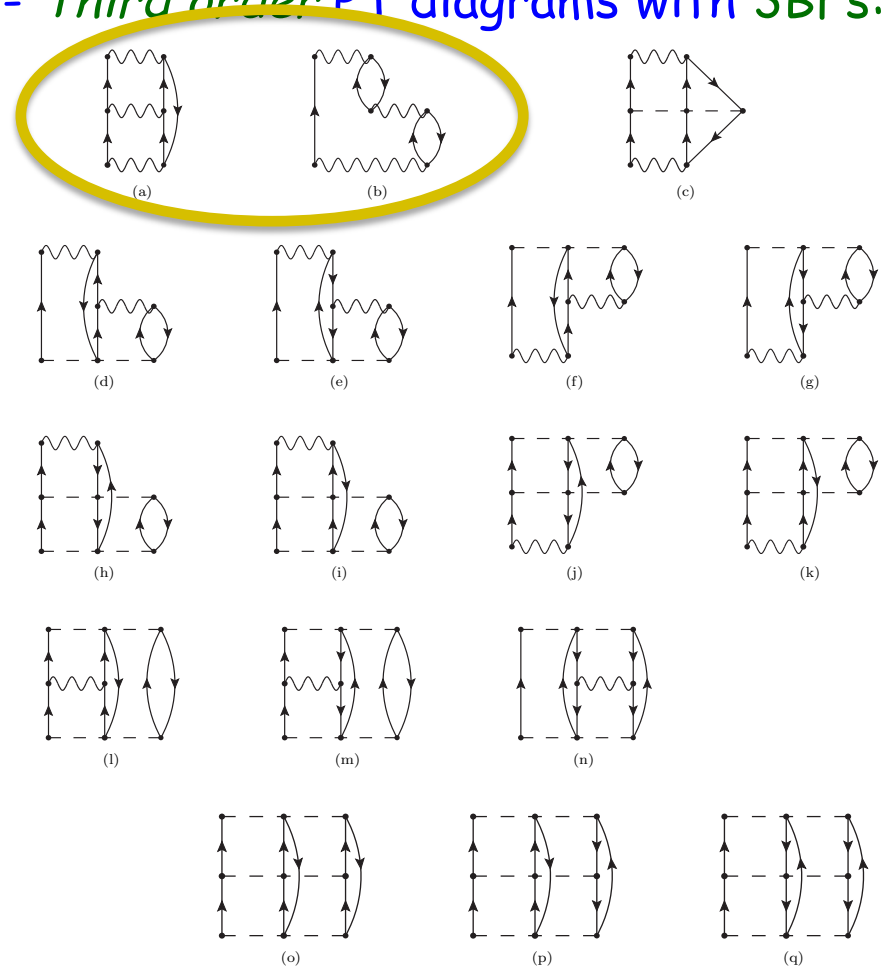
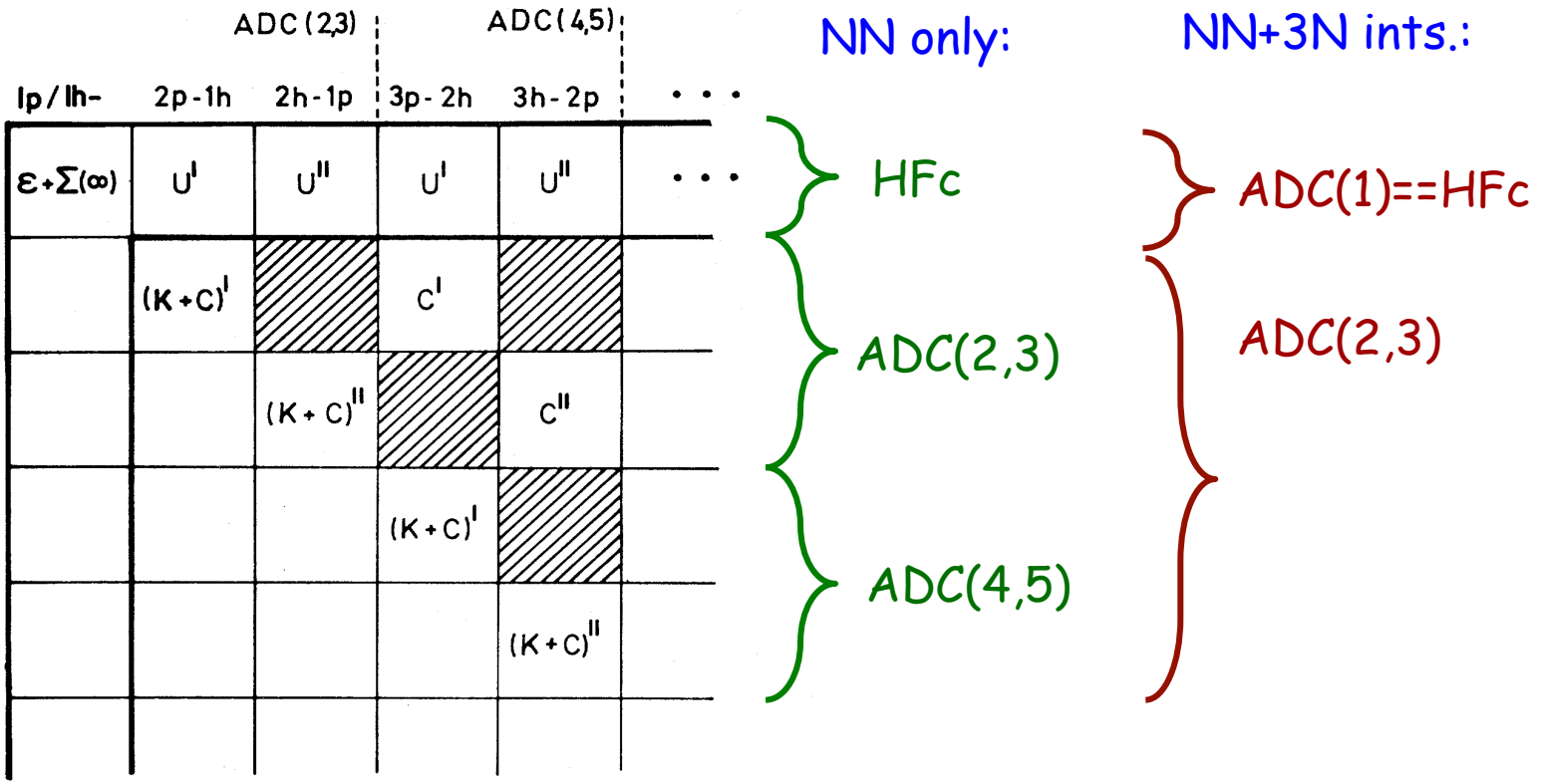


FIG. 5. 1PI, *skeleton* and *interaction irreducible* self-energy diagrams appearing at 3^{rd}-order in perturbative expansion (7), making use of the effective hamiltonian of Eq. (9).

ADC(n) schemes with 3-body interactions



➔ Adding many-body forces complicates the intermediate states at 3rd order! However, not all terms are equally relevant…

[F. Raimondi, CB, *in prep.*]

(Galitskii-Migdal-Boffi-) Koltun sumrule

- Koltun sum rule (with NNN interactions):

$$\sum_\alpha \frac{1}{\pi}\int_{-\infty}^{\epsilon_F} d\omega\, \omega\, \mathrm{Im}\, G_{\alpha\alpha}(\omega) = \langle \Psi_0^N|\hat{T}|\Psi_0^N\rangle + 2\langle \Psi_0^N|\hat{V}|\Psi_0^N\rangle + 3\langle \Psi_0^N|\hat{W}|\Psi_0^N\rangle$$

two-body three-body

- Thus, need an extra correction:

$$E_0^N = \frac{1}{3\pi}\int_{-\infty}^{\epsilon_F} \mathrm{d}\omega \sum_{\alpha\beta}(2T_{\alpha\beta}+\omega\delta_{\alpha\beta})\mathrm{Im}\, G_{\beta\alpha}(\omega) + \frac{1}{3}\langle \Psi_0^N|\widehat{V}|\Psi_0^N\rangle$$

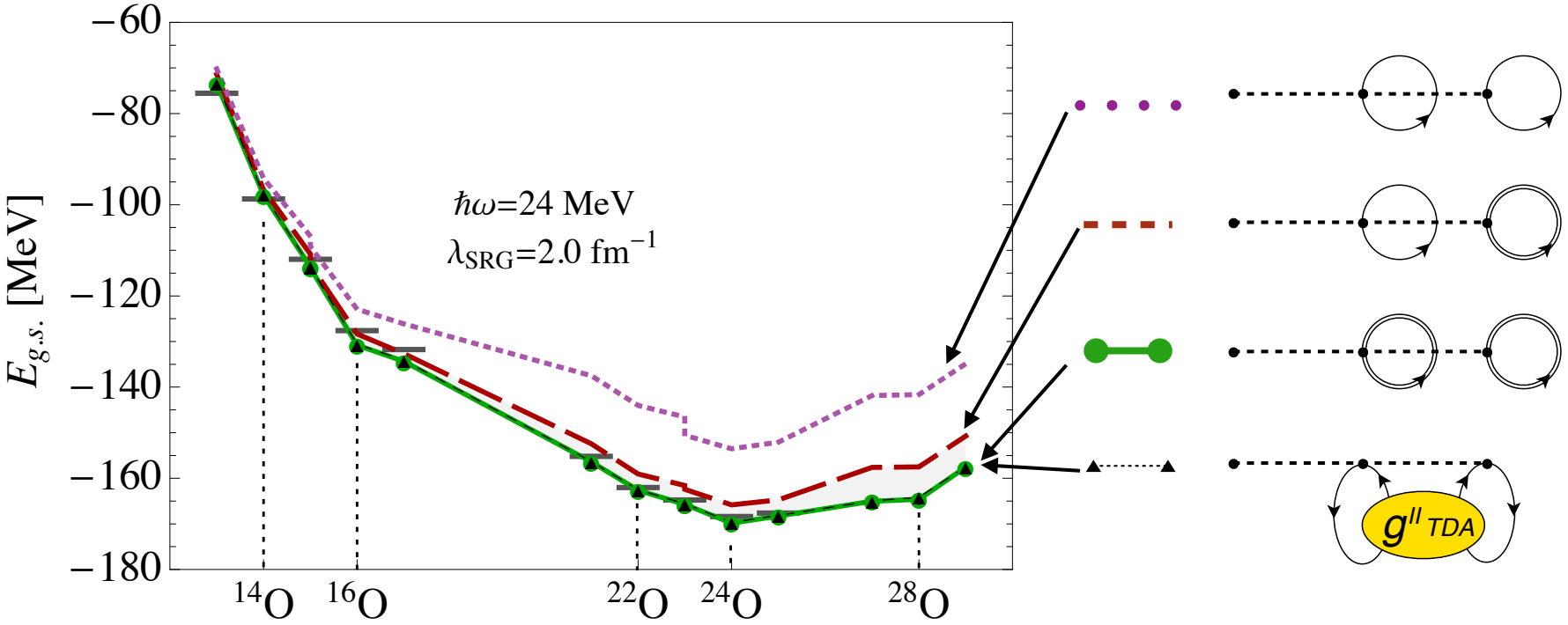
or

$$E_0^N = \frac{1}{2\pi}\int_{-\infty}^{\epsilon_F} \mathrm{d}\omega \sum_{\alpha\beta}(T_{\alpha\beta}+\omega\delta_{\alpha\beta})\mathrm{Im}\, G_{\beta\alpha}(\omega) - \frac{1}{2}\langle \Psi_0^N|\widehat{W}|\Psi_0^N\rangle$$

$\langle \Psi_0^N|\widehat{W}|\Psi_0^N\rangle \approx \frac{1}{6}$ 

3N forces in FRPA/FTDA formalism

→ Ladder contributions to static self-energy are negligible (in oxygen)

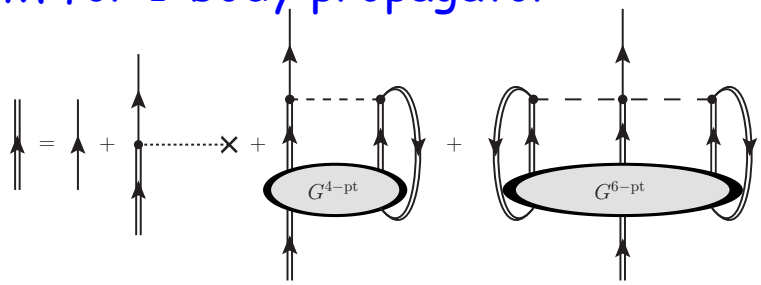


CB, *J. Phys.: Conf. Ser. 529, 012005 (2014)*

Equations of Motions with 3NF

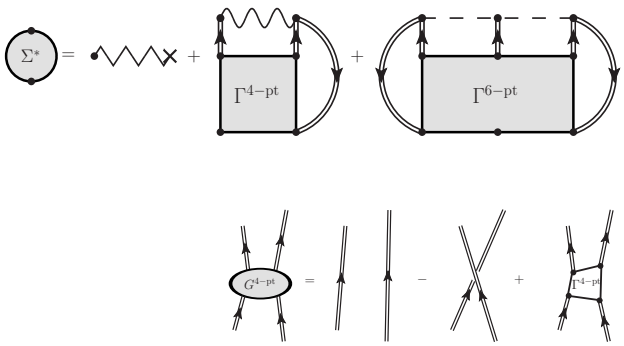
A. Carbone, CB, et al., Phys. Rev. C**88**, 054326 (2013)

- EOM for 1-body propagator:

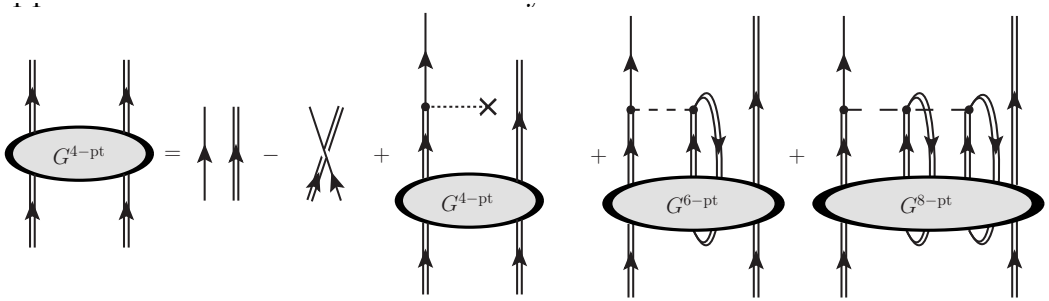


➔

irred. self-energy:



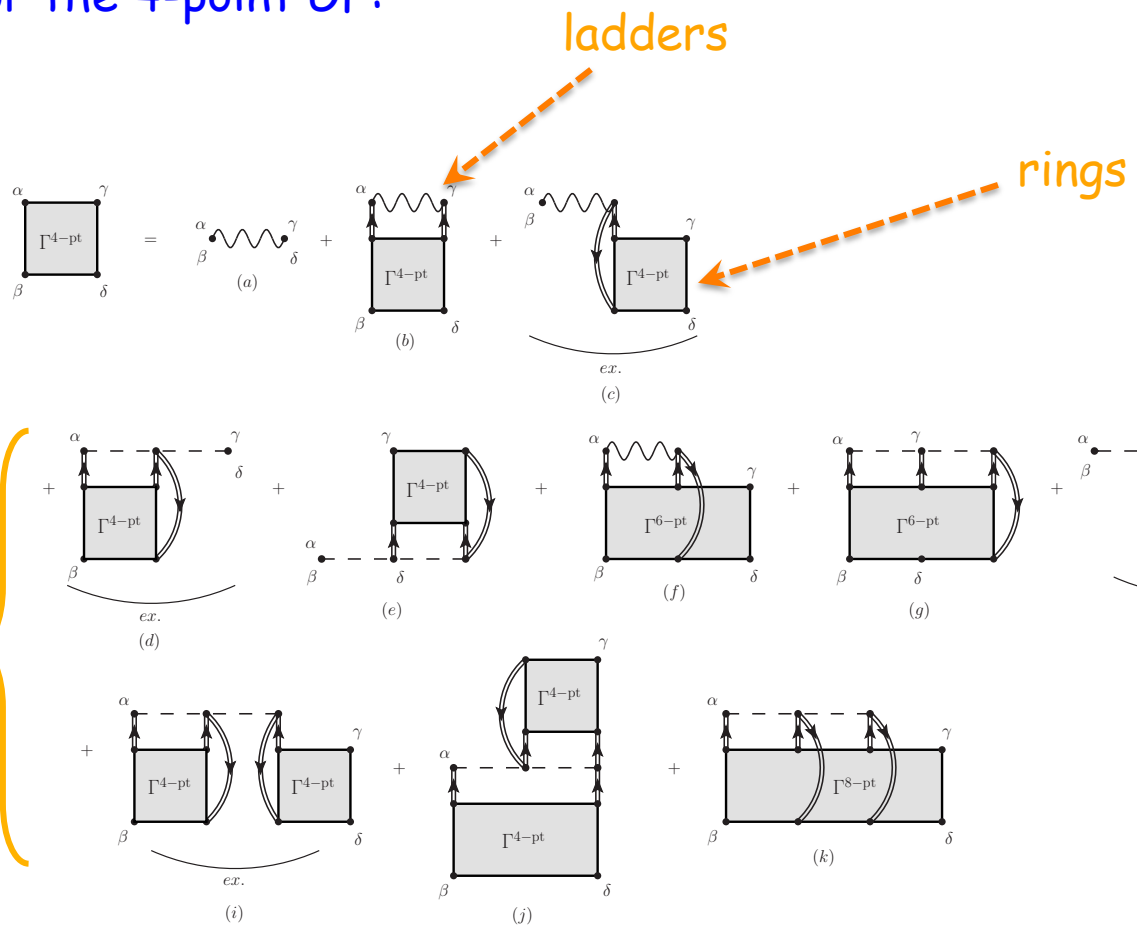
- EOM for 2-body propagator:



Equations of Motions with 3NF

A. Carbone, CB, et al., Phys. Rev. C**88**, 054326 (2013)

- SC equations for the 4-point GF:



Gorkov and symmetry breaking approaches

V. Somà, CB, T. Duguet, , Phys. Rev. C **89**, 024323 (2014)
V. Somà, CB, T. Duguet, Phys. Rev. C **87**, 011303R (2013)
V. Somà, T. Duguet, CB, Phys. Rev. C **84**, 064317 (2011)

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

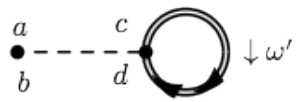
- Auxiliary many-body state $\quad |\Psi_0\rangle \equiv \sum_N^{\text{even}} c_N \, |\psi_0^N\rangle$

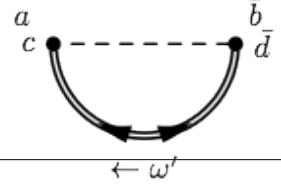
  → Mixes various particle numbers

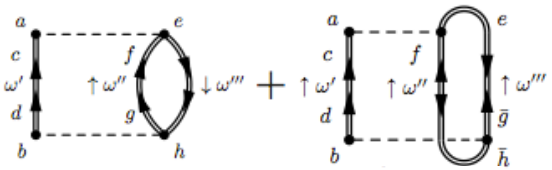
  → Introduce a "grand-canonical" potential $\quad \Omega = H - \mu N$

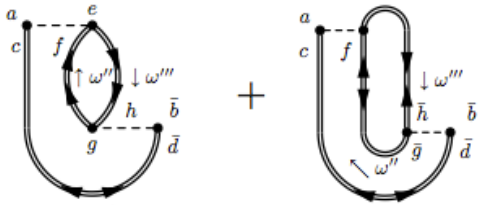
→ $|\Psi_0\rangle$ minimizes $\Omega_0 = \langle\Psi_0|\Omega|\Psi_0\rangle$ under the constraint $N = \langle\Psi_0|N|\Psi_0\rangle$

- This approach leads to the following Feynman diagrams:

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

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

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

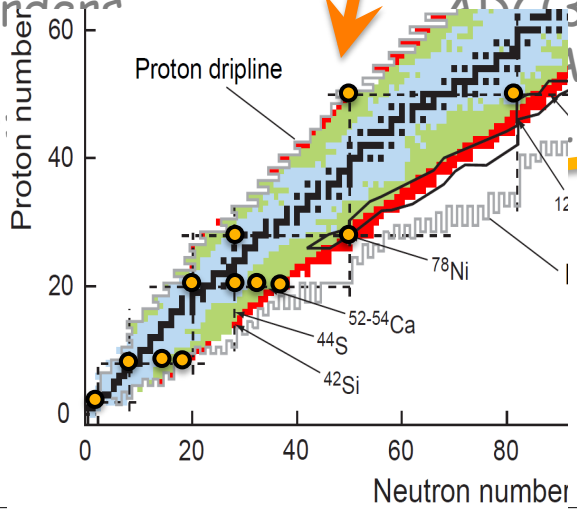
$\Sigma_{ab}^{12\,(2)}(\omega) =$ 

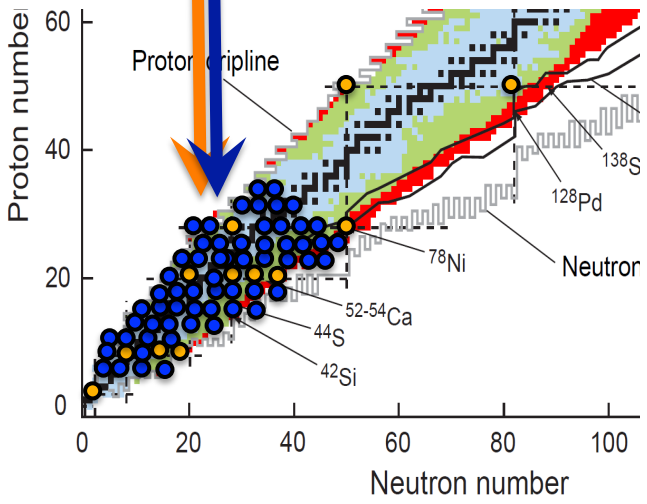
Approaches in GF theory

Truncation scheme:	Dyson formulation (closed shells)	Gorkov formulation (semi-magic)
1st order:	Hartree-Fock	HF-Bogolioubov
2nd order:	2nd order	2nd order (w/ pairing)
. . .	. . .	
3rd and all-orders sums, P-V coupling:	ADC(3) FRPA etc…	G-ADC(3) …work in progress

Approaches in GF theory

Truncation scheme:	Dyson formulation (closed shells)	Gorkov formulation (semi-magic)
1st order:	Hartree-Fock	HF-Bogolioubov
2nd order:	2nd order	2nd order (w/ pairing)
. . .	. . .	
3rd and all-orders sums, P-V coupling	ADC(3)	



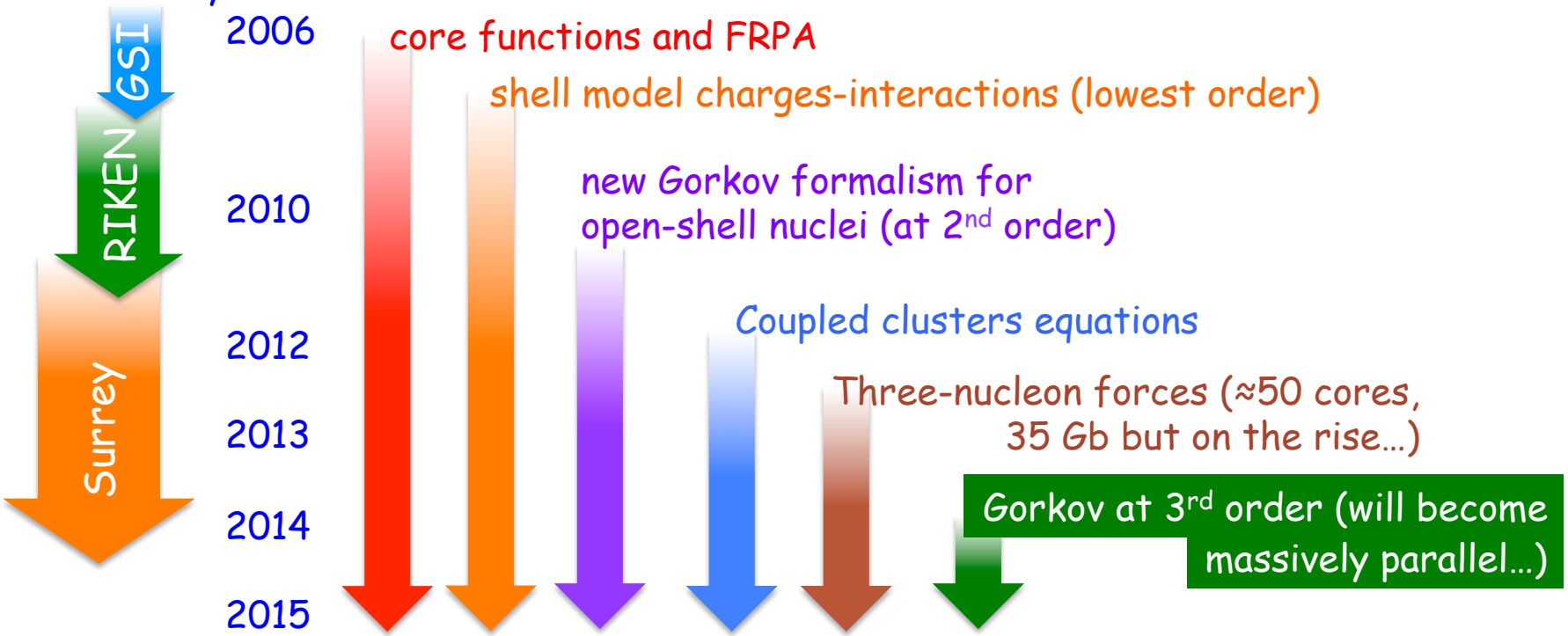


Ab-initio Nuclear Computation & BcDor code

BoccaDorata code:
(*C. Barbieri* 2006-14
V. Somà 2011-14
A. Cipollone 2012-13)

- Provides a *C++ class library* for handling many-body propagators (≈40,000 lines, OpenMPI based).
- Allows to solve for nuclear spectral functions, many-body propagators, RPA responses, coupled cluster equations and effective interaction/charges for the shell model.

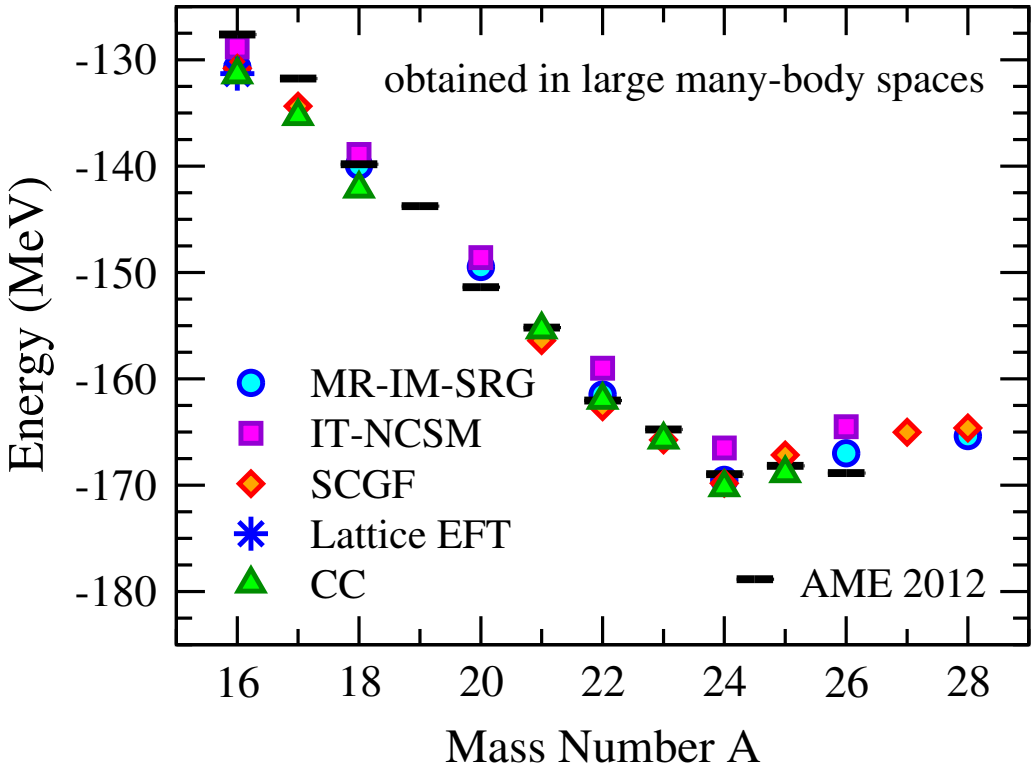
Code history:



… applications …

Results

Chiral Hamiltonians for the Oxygen chain



Benchmark with the same initial Hamiltonian

Oxygen dripline including chiral NN +3N forces correctly reproduced

confirmed in ab-initio calculations by different approaches,

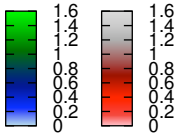
treating explicitly all nucleons as degrees of freedom

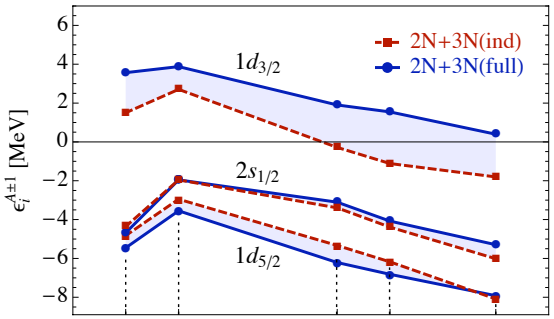
Pic. Credit:s
J.Menendez, J.Holt, et al, in prep.

Results from:
Hergert et al. PRL110 242501 (2013),
Cipollone et al. PRL111 062501 (2013),
Jansen et al. PRL113 142502 (2014)

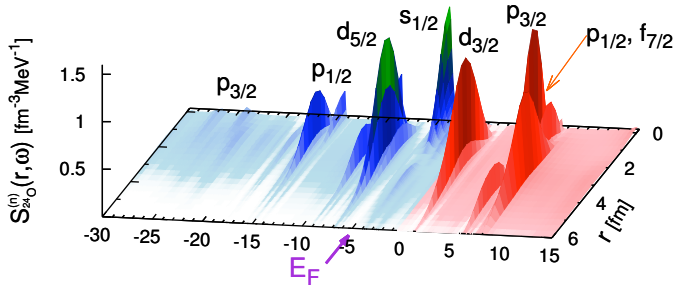
Neutron spectral function of Oxygens

A. Cipollone, CB P. Navrátil, *arXiv:1412.0491* (2014)

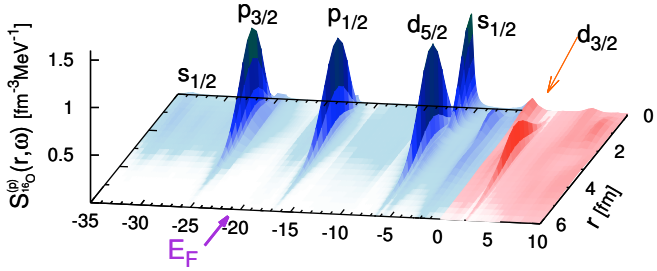




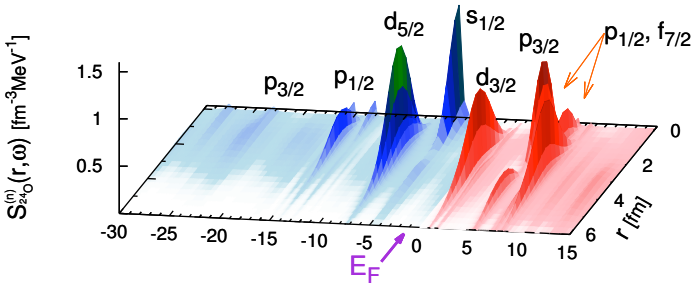
^{22}O:



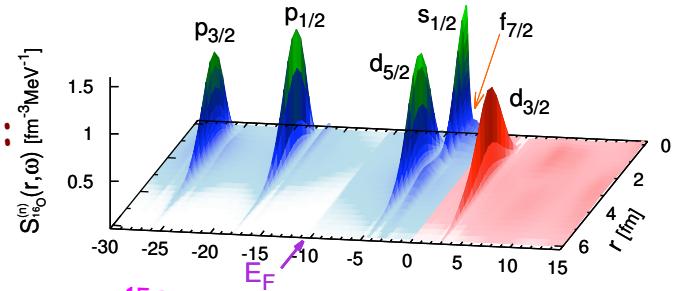
^{14}O:



^{24}O:

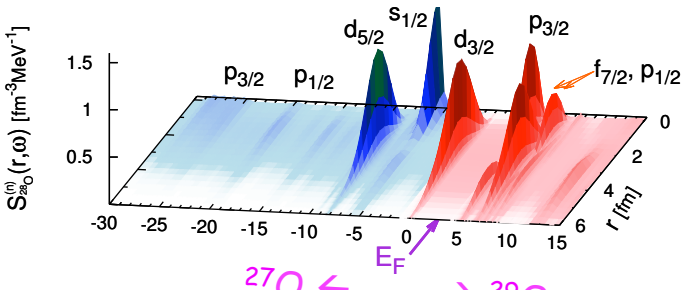


^{16}O:



$^{15}O \leftarrow$ $\rightarrow {}^{17}O$

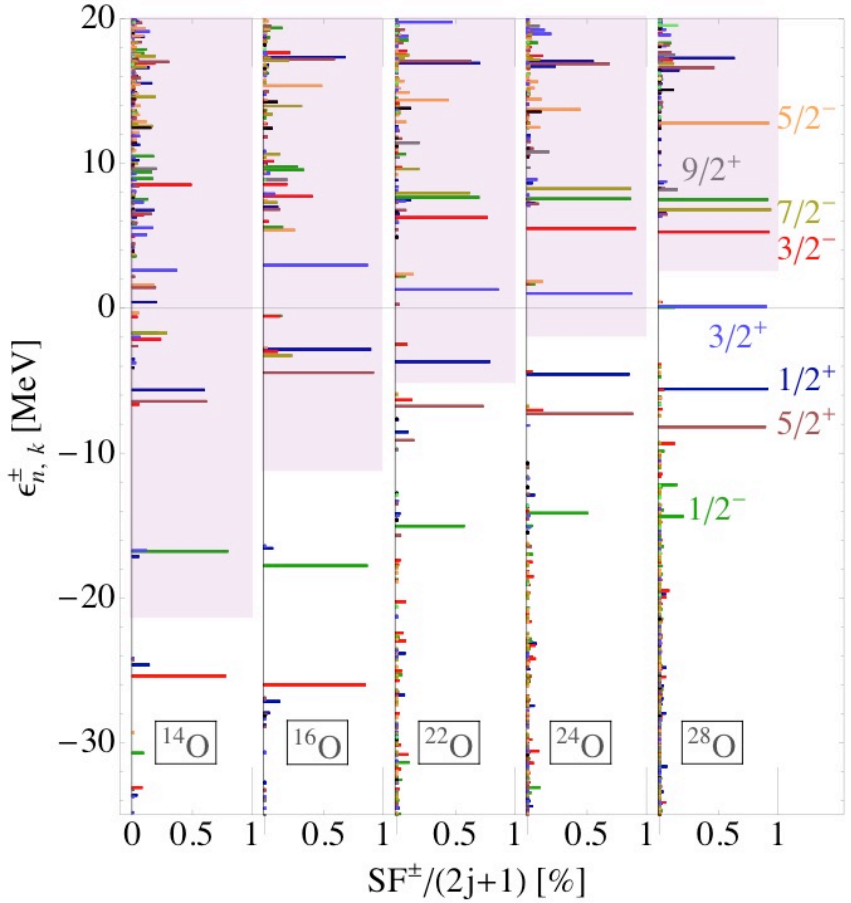
^{28}O:

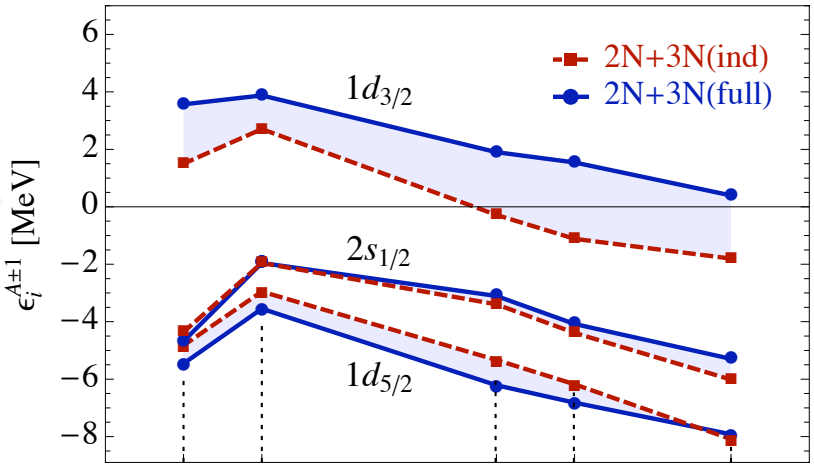


$^{27}O \leftarrow$ $\rightarrow {}^{29}O$

Results for the N-O-F chains

A. Cipollone, CB, P. Navrátil, Phys. Rev. Lett. **111**, 062501 (2013)
and arXiv:1412.0491 [nucl-th] (2014)





→ $d_{3/2}$ *raised* by genuine 3NF

→ cf. microscopic shell model [Otsuka et al, PRL**105**, 032501 (2010).]

Results for the N-O-F chains

A. Cipollone, CB, P. Navrátil, Phys. Rev. Lett. **111**, 062501 (2013)
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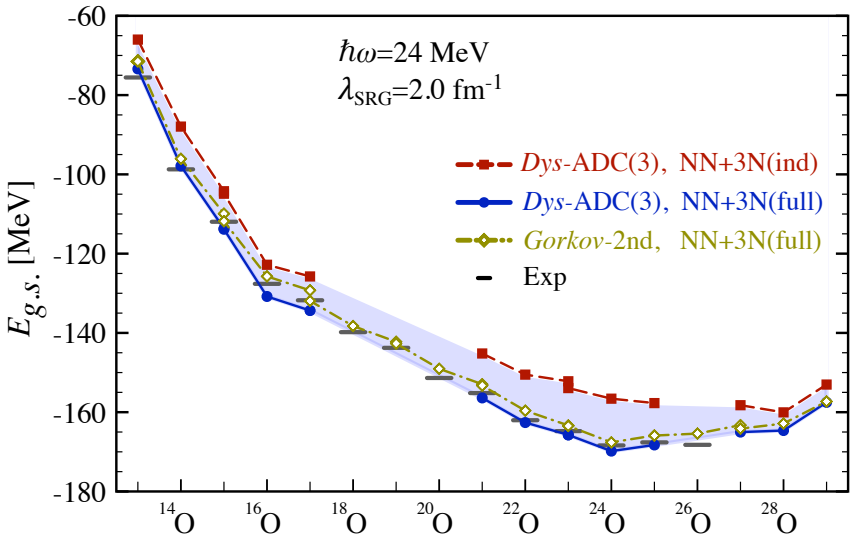

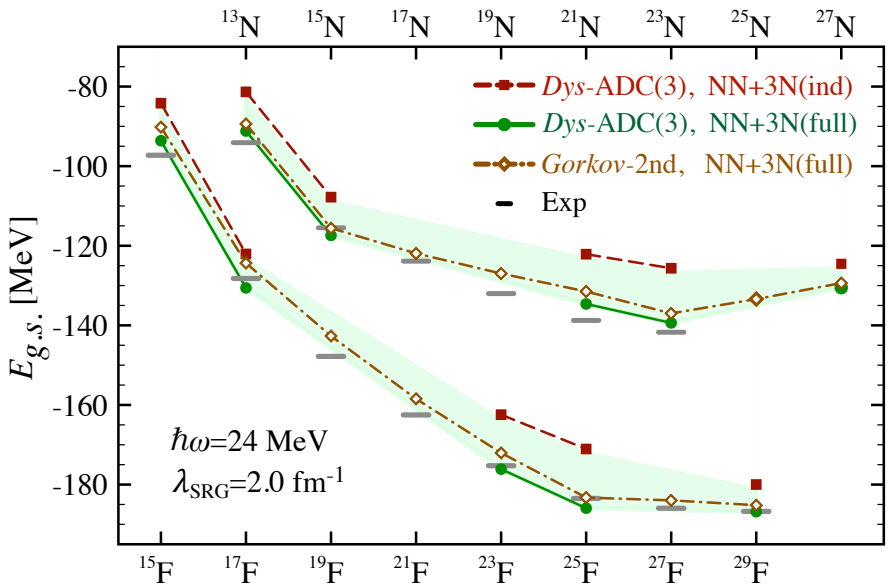

→ 3NF crucial for reproducing binding energies and driplines around oxygen

→ cf. microscopic shell model [Otsuka et al, PRL**105**, 032501 (2010).]

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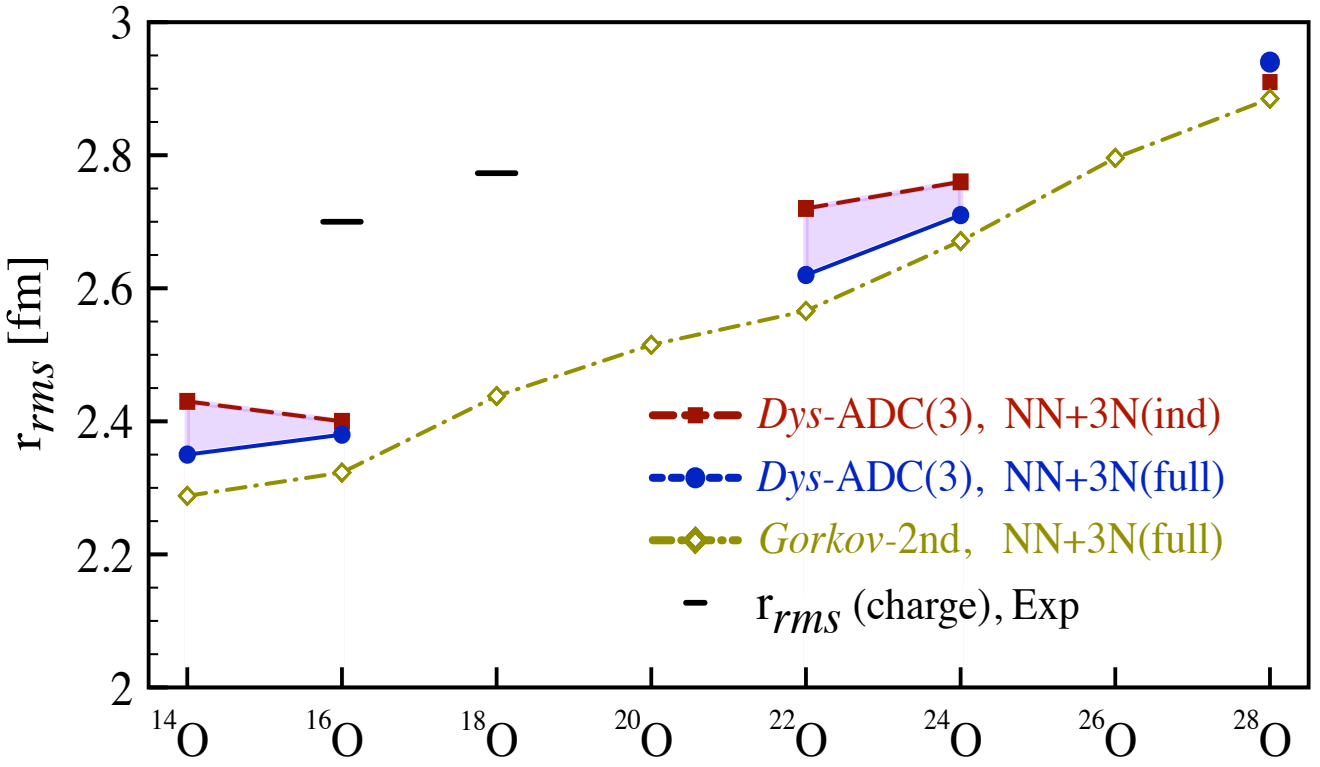
N3LO (Λ = 500Mev/c) chiral NN interaction evolved to 2N + 3N forces (2.0fm^{-1})
N2LO (Λ = 400Mev/c) chiral 3N interaction evolved (2.0fm^{-1})

Results for the oxygen chain

A. Cipollone, CB, P. Navrátil, arXiv:1412.0491 [nucl-th] (2014)



→ Single particle spectra slightly diluted and

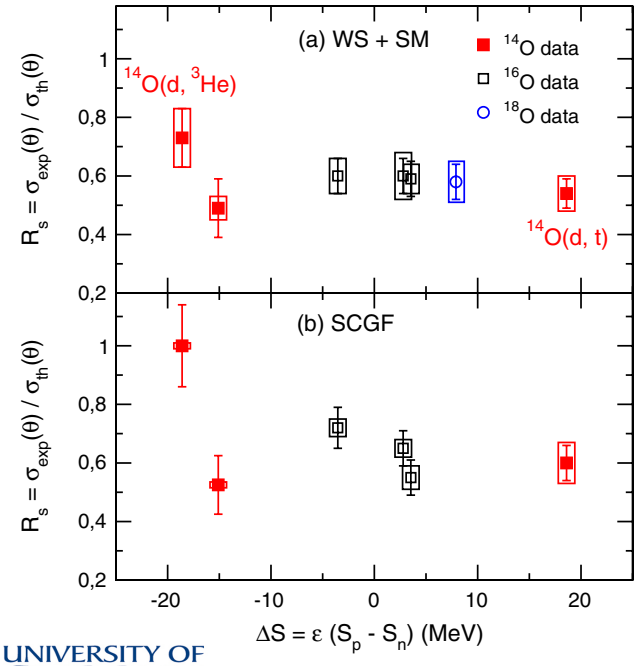
→ systematic underestimation of radii

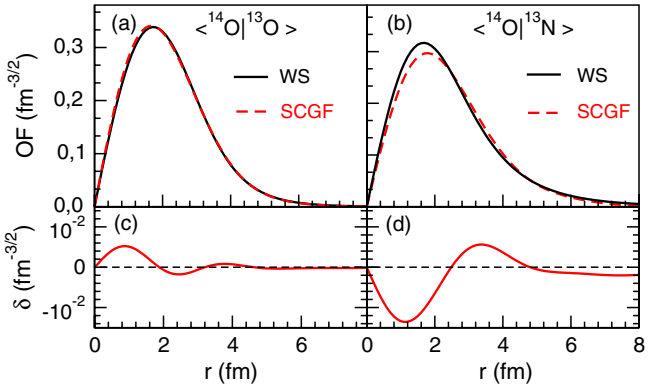
Single nucleon transfer in the oxygen chain

[F. Flavigny et al, PRL**110**, 122503 (2013)]

→ Analysis of $^{14}O(d,t)^{13}O$ and $^{14}O(d,^3He)^{13}N$ transfer reactions @ SPIRAL

Reaction	E^* (MeV)	J^π	R_{rms}^{HFB} (fm)	r_0 (fm)	C^2S_{exp} (WS)	C^2S_{th} $0p + 2\hbar\omega$	R_s (WS)	C^2S_{exp} (SCGF)	C^2S_{th} (SCGF)	R_s (SCGF)
^{14}O (d, t) ^{13}O	0.00	$3/2^-$	2.69	1.40	1.69 (17)(20)	3.15	0.54(5)(6)	1.89(19)(22)	3.17	0.60(6)(7)
^{14}O $(d, ^3He)$ ^{13}N	0.00	$1/2^-$	3.03	1.23	1.14(16)(15)	1.55	0.73(10)(10)	1.58(22)(2)	1.58	1.00(14)(1)
	3.50	$3/2^-$	2.77	1.12	0.94(19)(7)	1.90	0.49(10)(4)	1.00(20)(1)	1.90	0.53(10)(1)
^{16}O (d, t) ^{15}O	0.00	$1/2^-$	2.91	1.46	0.91(9)(8)	1.54	0.59(6)(5)	0.96(10)(7)	1.73	0.55(6)(4)
^{16}O $(d, ^3He)$ ^{15}N [19,20]	0.00	$1/2^-$	2.95	1.46	0.93(9)(9)	1.54	0.60(6)(6)	1.25(12)(5)	1.74	0.72(7)(3)
	6.32	$3/2^-$	2.80	1.31	1.83(18)(24)	3.07	0.60(6)(8)	2.24(22)(10)	3.45	0.65(6)(3)
^{18}O $(d, ^3He)$ ^{17}N [21]	0.00	$1/2^-$	2.91	1.46	0.92(9)(12)	1.58	0.58(6)(10)			





- Overlap functions and strengths from GF
- Rs independent of asymmetry

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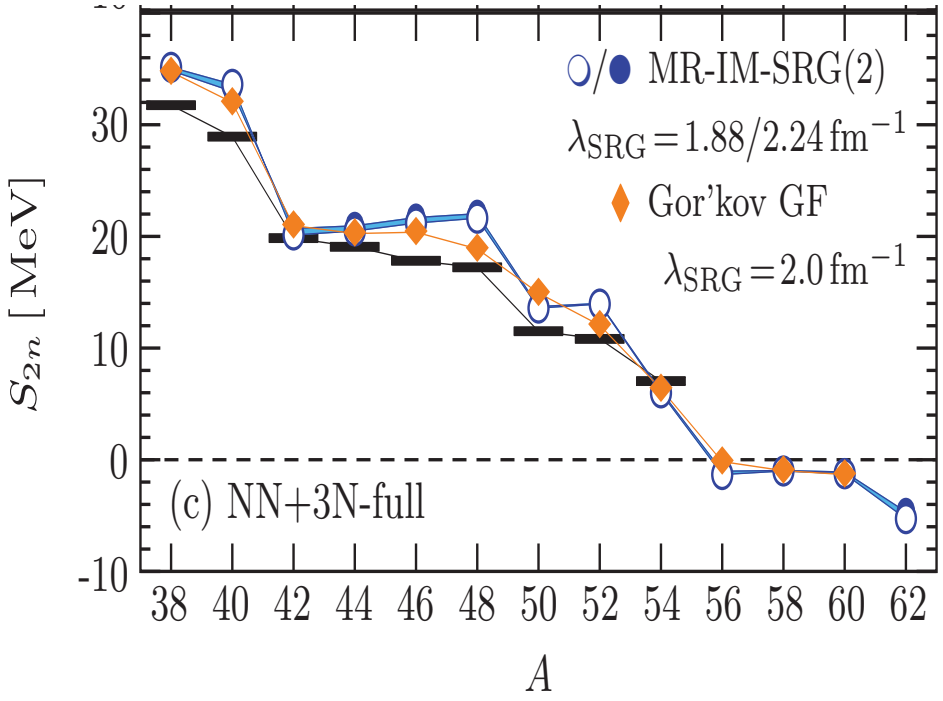
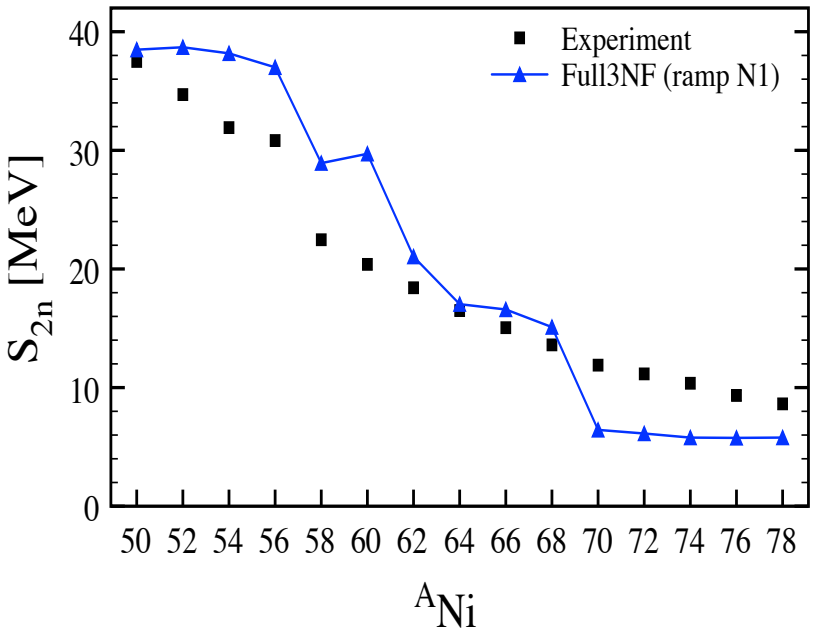
Ca and Ni isotopic chains

Hergert et al, PRC**90**, 041302(R) (2014)

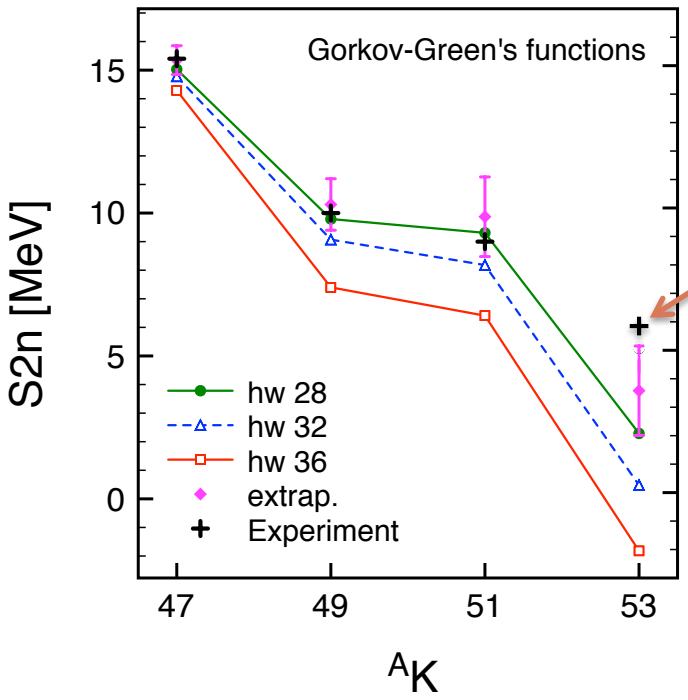




→ Large J in free space SRG matter (must pay attention to its convergence)

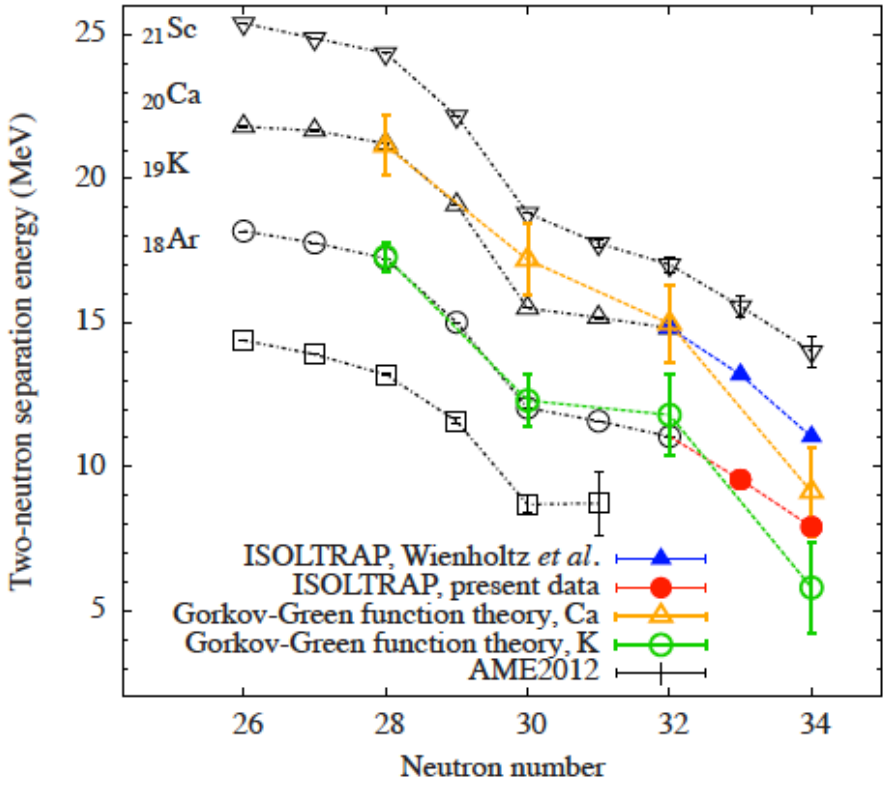
→ Overall conclusions regarding over binding and S_{2n} remain but details change

Two-neutron separation energies for neutron rich K isotopes



ISOLTRAP

M. Rosenbusch, et al., PRL (submitted).



→ *Error bar in predictions* are from extrapolating the many-body expansion to convergence of the model space.

Mapping Ab-Initio calculation into the shell model approach

Recent works through CCM and IMRSG:

Bogner et al Phys. Rev. Lett. 113, 142501 (2014)
Jansen et al Phys. Rev. Lett. 113, 142502 (2014)

✓ *works well for spectra*

Calculation of observables: need many-body corrections, to evolve operators, add electroweak currents, ect…

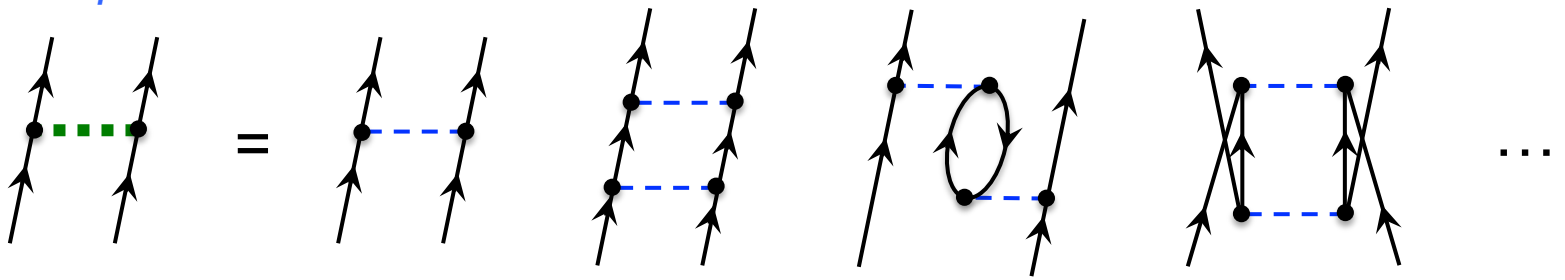
To have a look at the many-body and effects:

Extract vibration coupling form microscopic calculations…

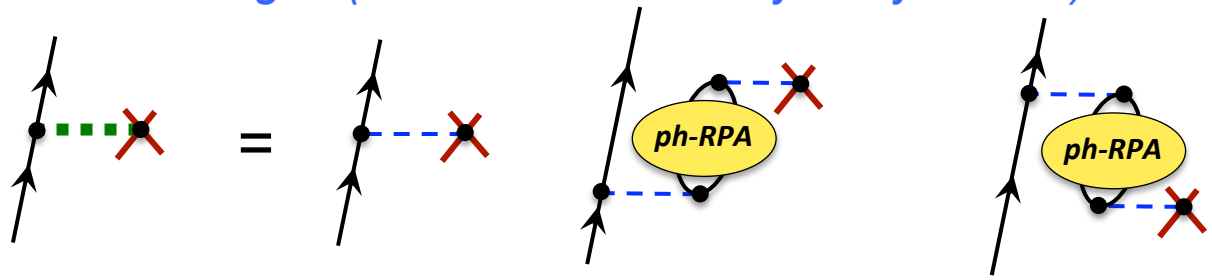
CB, T. Otsuka, in preparation

"traditional" MBPT approach

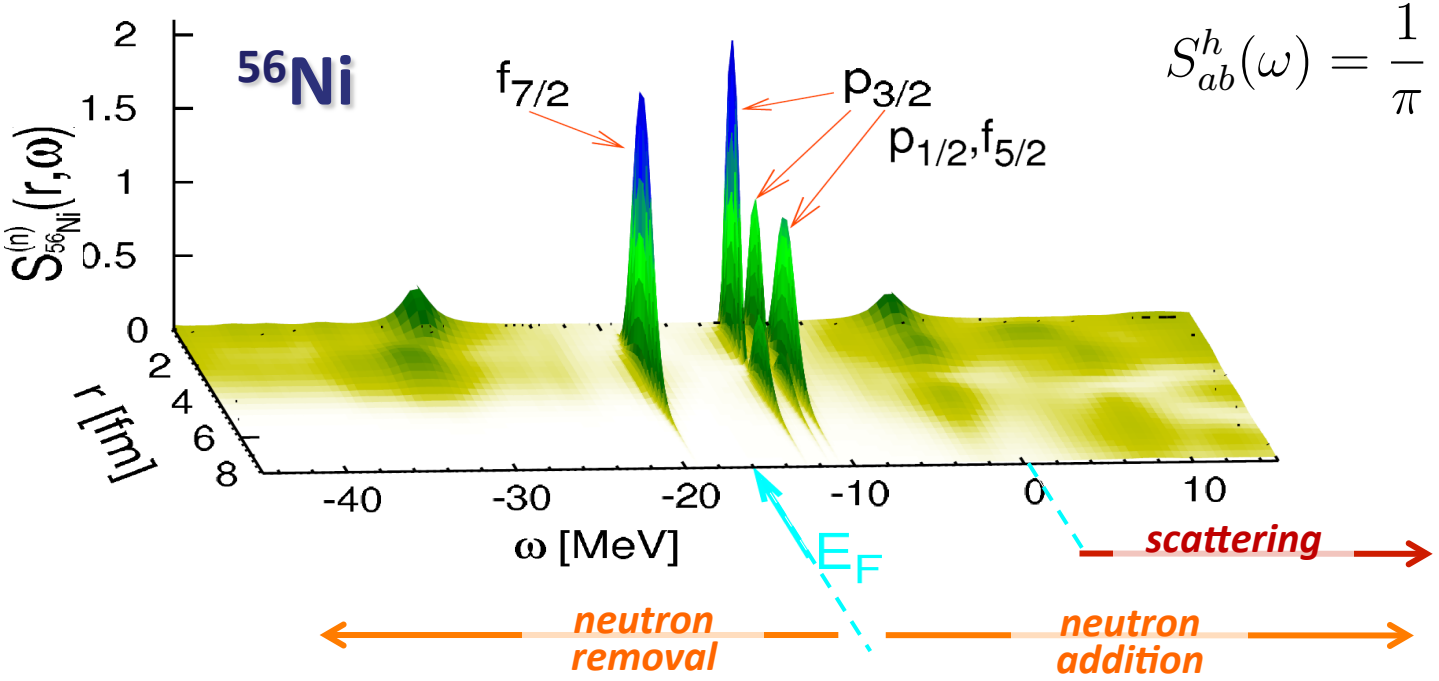
PT expansion of effective interactions:



Effective charges (estimate form many-body effects):



^{56}Ni neutron spectral function

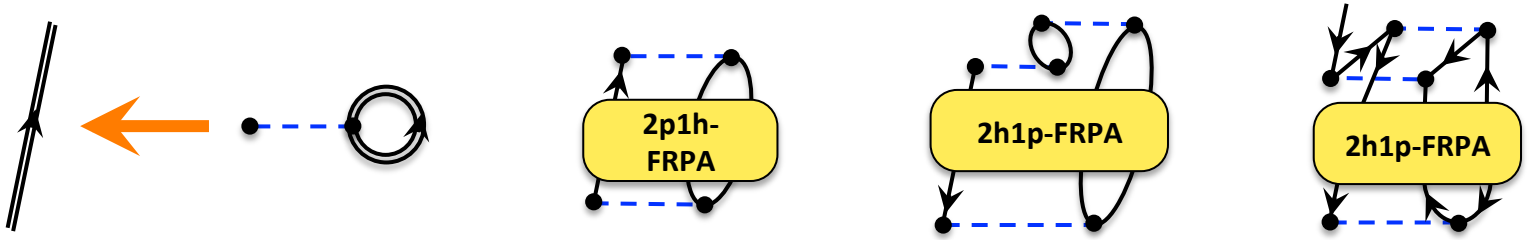


$$S^h_{ab}(\omega) = \frac{1}{\pi}\, Im\, g_{ab}(\omega)$$

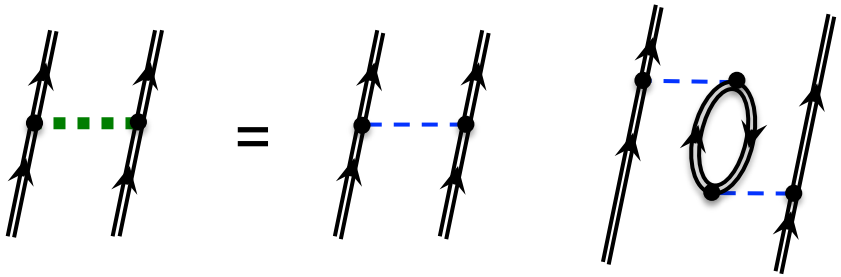
W. Dickhoff, CB, Prog. Part. Nucl. Phys. 53, 377 (2004)
CB, M.Hjorth-Jensen, Pys. Rev. C**79**, 064313 (2009)

"upgrade" using SCGF's spect. funct.

Dressed (self consistent) propagator:

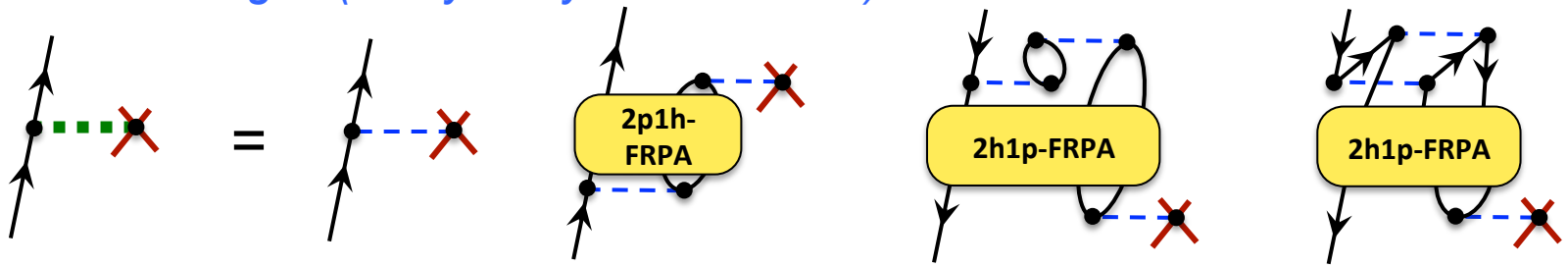


PT expansion of effective interactions:



… *but NO self-en insertions*

Effective charges (many-body contributions):

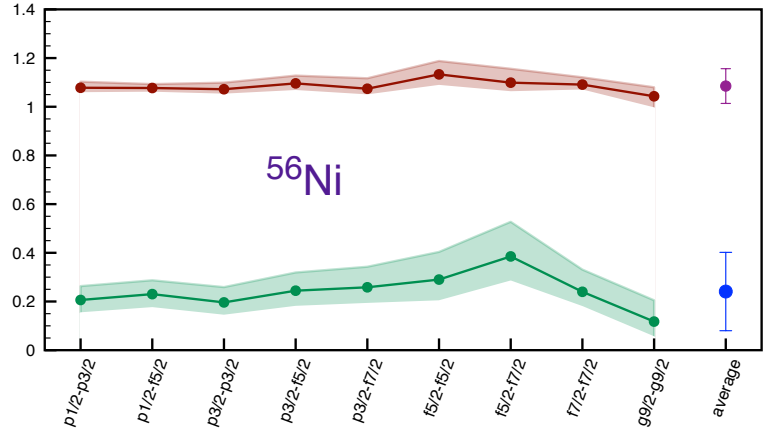


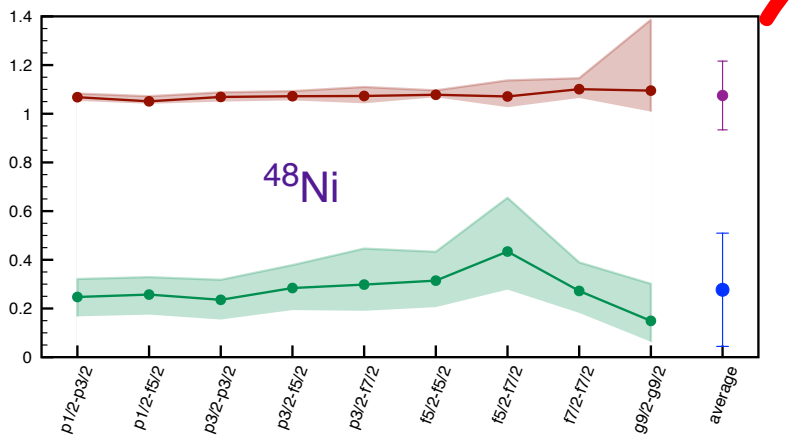
Some results – ^{A}Ni chain in $pfg_{9/2}$ shell

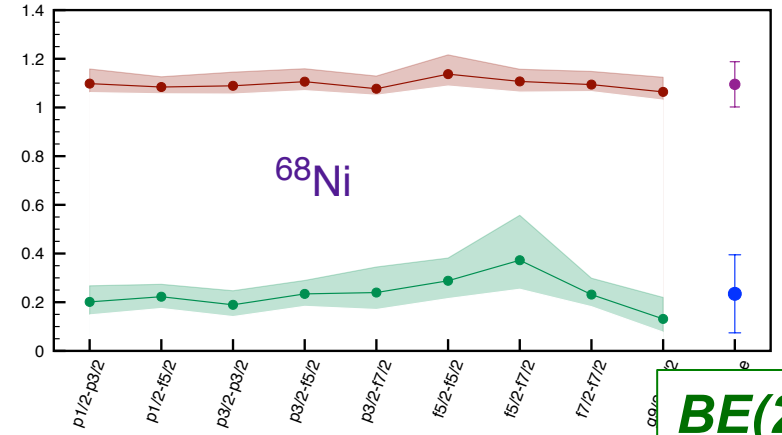
Interaction: NNLO-opt, AV18 (+Gmatrix)

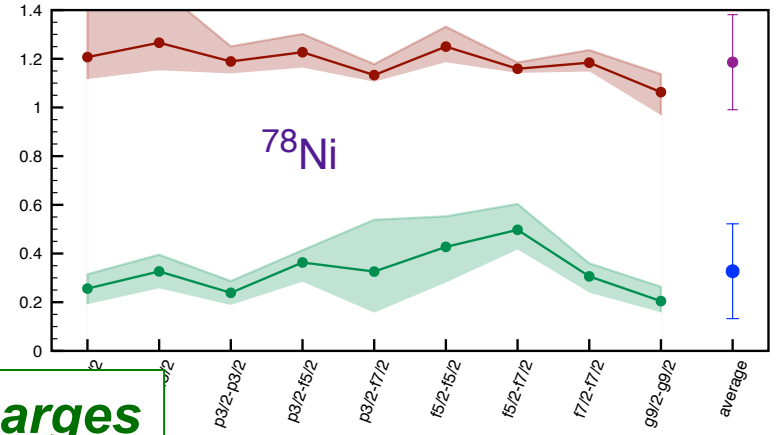
Single particle basis: HF

Preliminary









BE(2) charges

UNIVERSITY OF SURREY

CB, T. Otsuka, in preparation

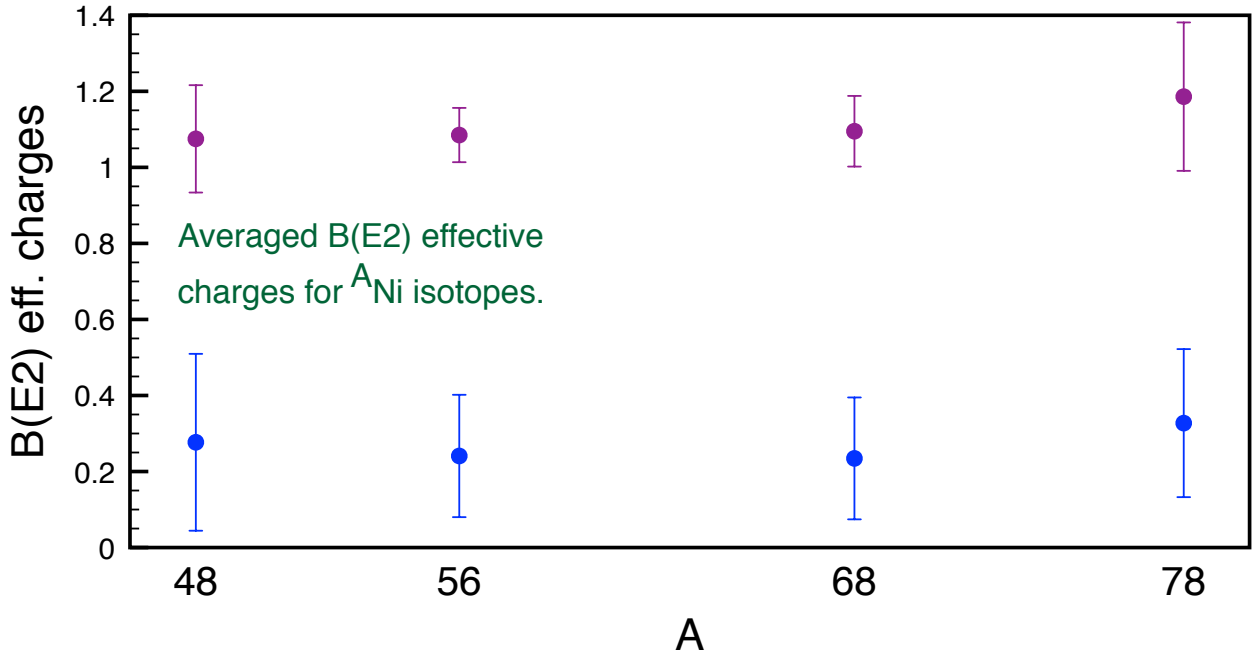
Some results – ^{A}Ni chain in $pfg_{9/2}$ shell

Interaction: NNLO-opt, AV18 (+Gmatrix)

Single particle basis: HF

Preliminary

Averaged charges



BE(2) charges

➔ *"predicted" charges are smaller than usual phenomenological ones*

➔ *NO higher order currents here -- just the many-body correction…*

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Some results – O and C chains

Interaction: N3LO(500) (+Gmatrix)

Single particle basis: HF or HFB

Preliminary

BE(2) charges

	C10	C22	O14	O16	O20
$\nu_{s1/2}$-$\nu_{d3/2}$:	0.142	0.094	-0.751	0.160	0.128
$\nu_{s1/2}$-$\nu_{d5/2}$:	0.226	0.125	0.261	0.214	0.181
$\nu_{d3/2}$-$\nu_{d3/2}$:	0.278	0.121	0.198	0.082	0.155
$\nu_{d3/2}$-$\nu_{d5/2}$:	0.320	0.137	0.249	0.274	0.214
$\nu_{d5/2}$-$\nu_{d5/2}$:	0.278	0.151	0.294	0.250	0.232
$\pi_{s1/2}$-$\pi_{d3/2}$:	1.131	1.051	0.594	1.105	1.078
$\pi_{s1/2}$-$\pi_{d5/2}$:	1.155	1.094	1.161	1.142	1.134
$\pi_{d3/2}$-$\pi_{d3/2}$:	1.061	1.054	1.441	0.976	1.070
$\pi_{d3/2}$-$\pi_{d5/2}$:	1.141	1.107	1.042	1.091	1.170
$\pi_{d5/2}$-$\pi_{d5/2}$:	1.161	1.077	1.139	1.107	1.099
$\nu_{p1/2}$-$\nu_{p3/2}$:	0.359	0.319	0.344	0.401	0.404
$\nu_{p3/2}$-$\nu_{p3/2}$:	0.315	0.247	0.367	0.316	0.307
$\pi_{p1/2}$-$\pi_{p3/2}$:	1.102	1.134	1.183	1.179	1.198
$\pi_{p3/2}$-$\pi_{p3/2}$:	1.128	1.103	1.075	1.056	1.082

➔ "predicted" charges are smaller than usual phenomenological ones

➔ NO higher order currents here -- just the many-body correction…

CB, T. Otsuka, in preparation

Conclusions

- What to did we learn about realistic chiral forces from ab-initio calculations ?

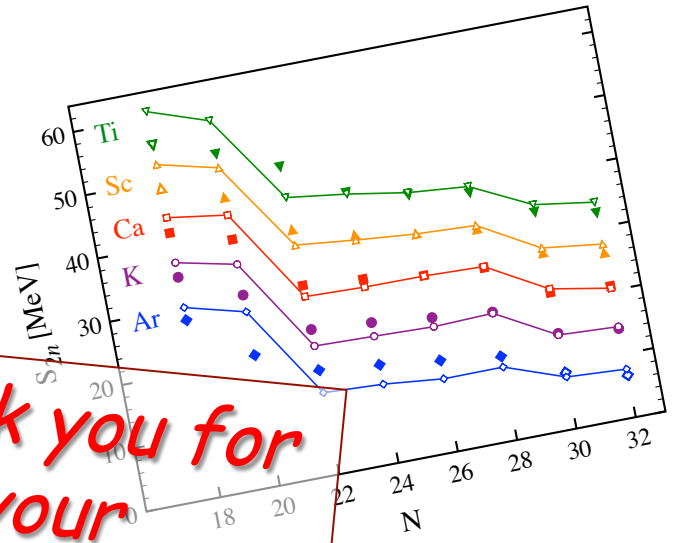
→ *Leading order 3NF are crucial to predict many important features that are observed experimentally (drip lines, saturation, orbit evolution, etc…)*

→ *Experimental binding is predicted accurately up to the lower sd shell (A≈30) but deteriorates for medium mass isotopes (Ca and above) with roughly 1 MeV/A over binding.*

→ *more short-range repulsion or fitting to mid masses will help [see NNLOsat, Evgeny talk, and new developments…].*

→ *Ab-initio optical potentials are a natutal 'by-product' of the SCGF method.*

→ *Earlier investigations of SCGF based optical potentials were very promising; it will now be crucial to apply it in modern ab-initio codes.*



Thank you for your attention!!!