Reaction and Structure of Exotic Nuclei
INT– 2-6 March 2015

Chiral 3NFs and elastic scattering in medium mass isotopes

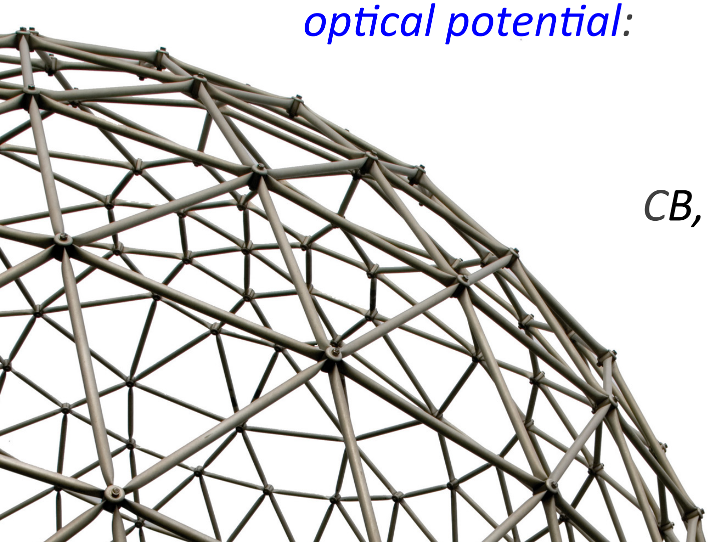
Carlo Barbieri — University of Surrey

Relevant papers:

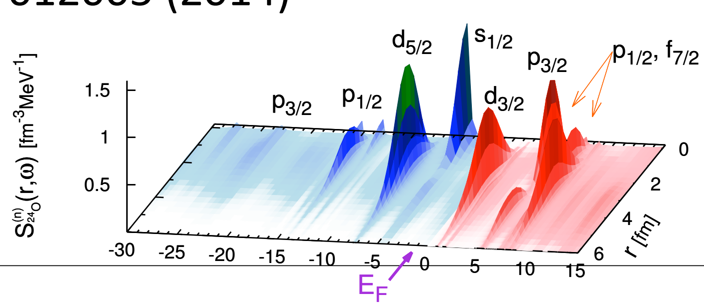
ab-initio & correlations: *Phys. Rev. C* ***89**, 061301R (2014)*
arXiv:1412.0491 [nucl-th] (2014)

optical potential: *Phys. Rev. C* ***72**, 014613 (2005)*
Phys. Rev. C ***84**, 034616 (2011)*

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



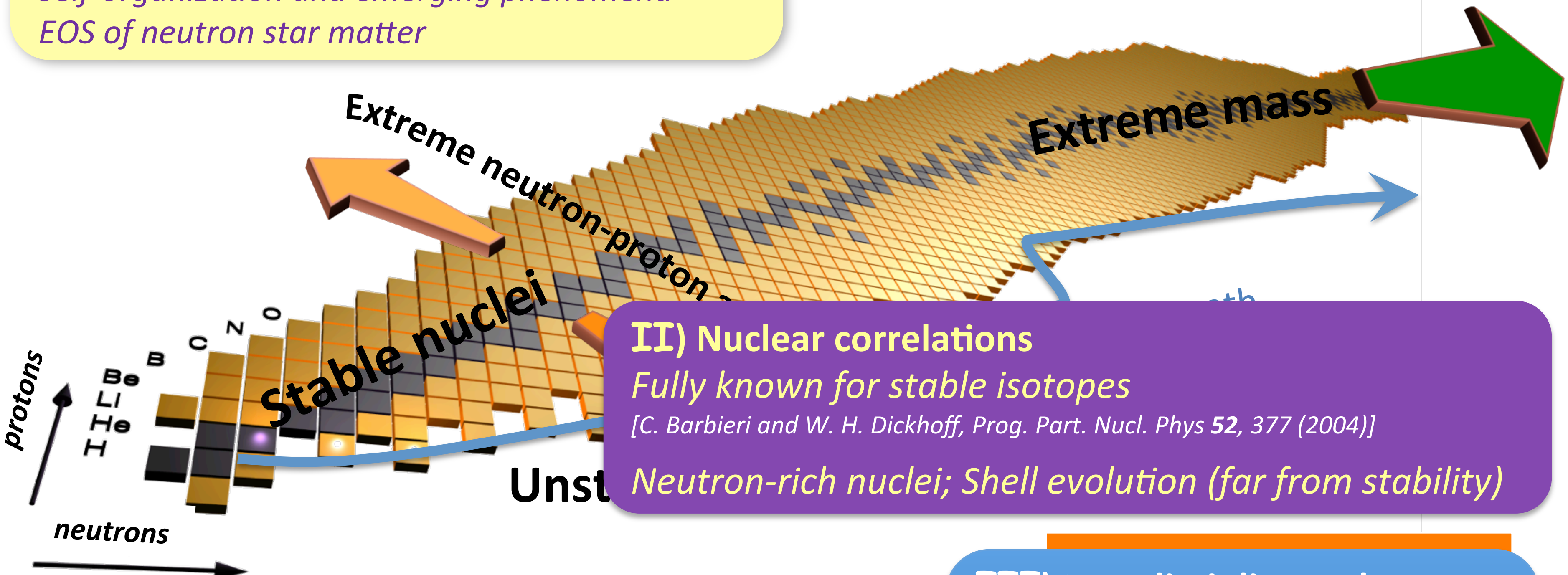
^{24}O:



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



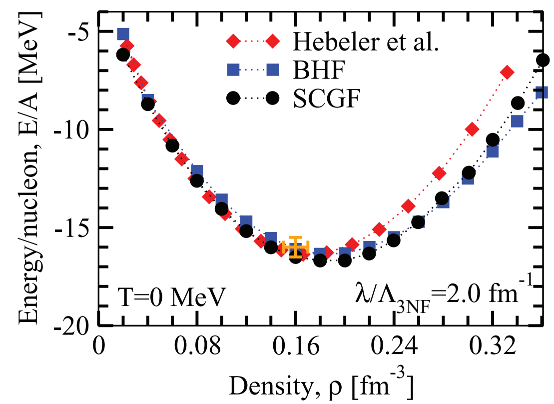
II) Nuclear correlations
Fully known for stable isotopes
*[C. Barbieri and W. H. Dickhoff, Prog. Part. Nucl. Phys **52**, 377 (2004)]*
Neutron-rich nuclei; Shell evolution (far from stability)

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;

Nuclear forces in exotic nuclei

[A. Carbone et al., Phy.s Rev. C **88**, 044302 (2013)]



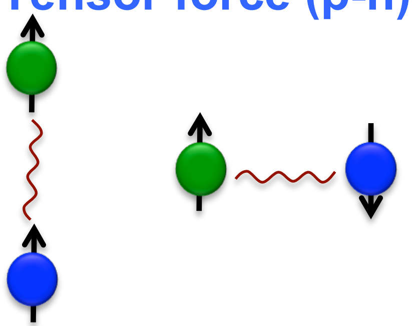
Nucleon interactions are very complex and difficult to handle

Change of regime from stable to dripline isotopes !

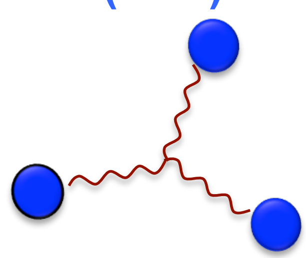
Symmetric matter:
N ≈ Z

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

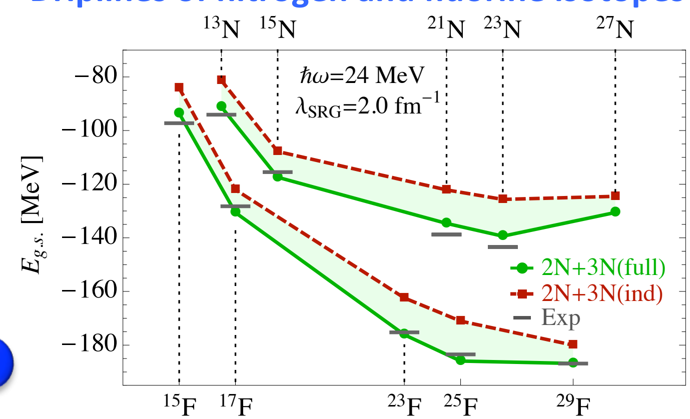
Tensor force (p-n)



Three-nucleon Force (3NF)



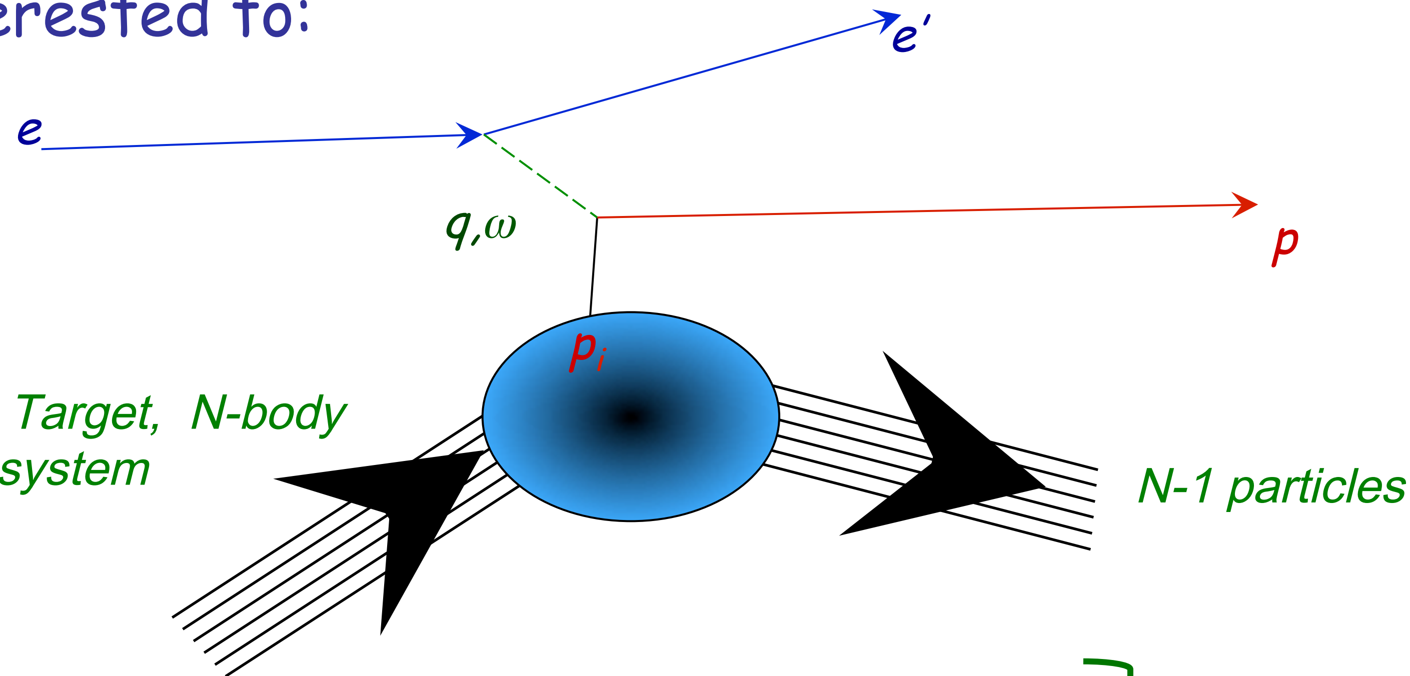
Driplines of nitrogen and fluorine isotopes



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

Spectroscopy via knock out reactions-basic idea

Use a probe (ANY probe) to eject the particle we are interested to:



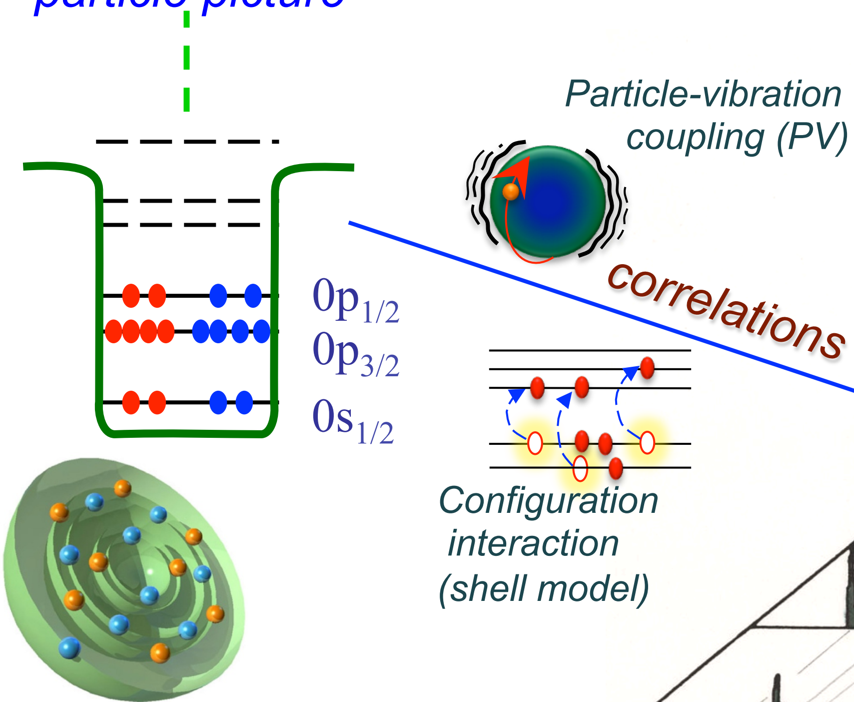
Basic idea:

- we know, e, e' and p
- "get" *energy and momentum* of p_i: $p_i = k_e' + k_p - k_e$
  $E_i = E_e' + E_p - E_e$

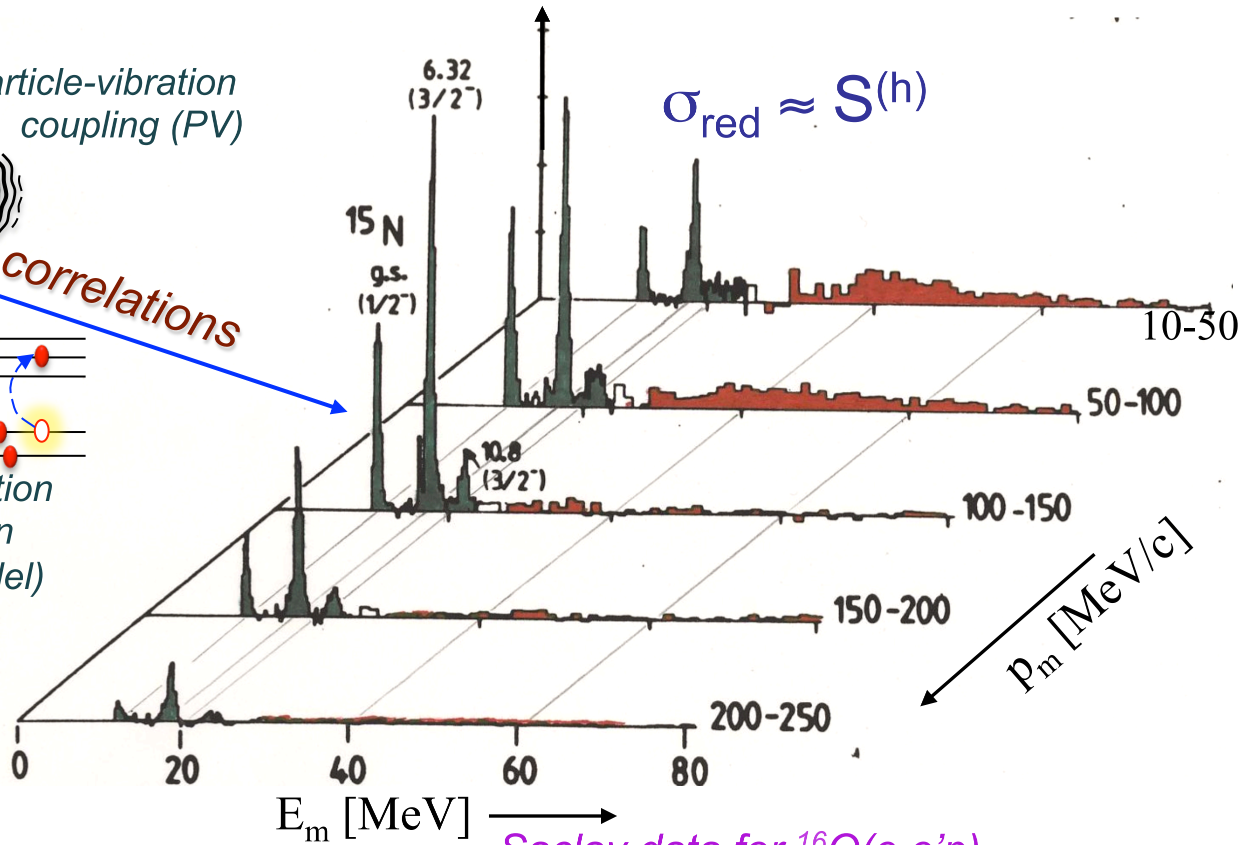
Better to choose large transferred momentum and weak probes!!!

Concept of correlations

independent particle picture



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



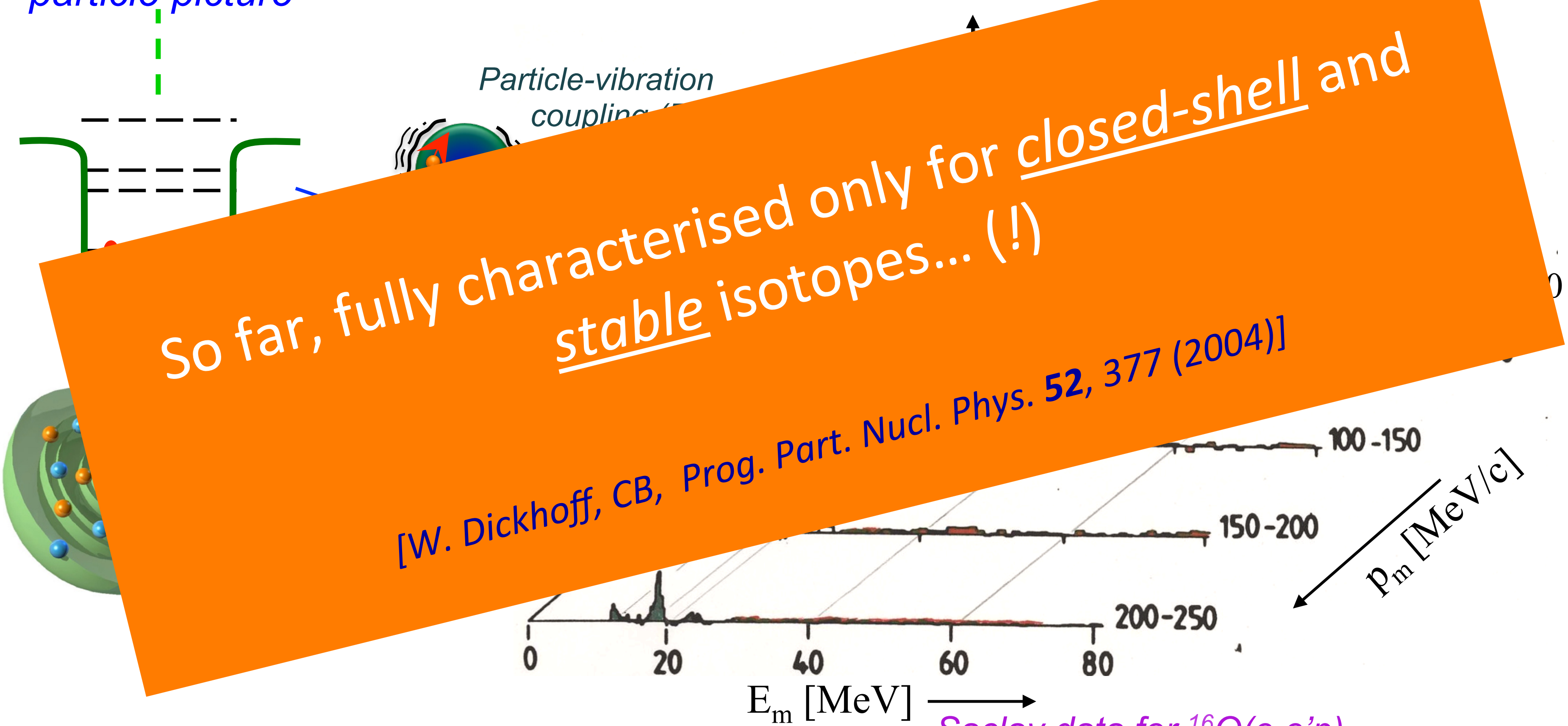
Saclay data for $^{16}O(e,e'p)$

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

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

Concept of correlations

Spectral function: distribution of momentum (p_m) and en...



So far, fully characterised only for <u>closed-shell</u> and <u>stable</u> 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)]*

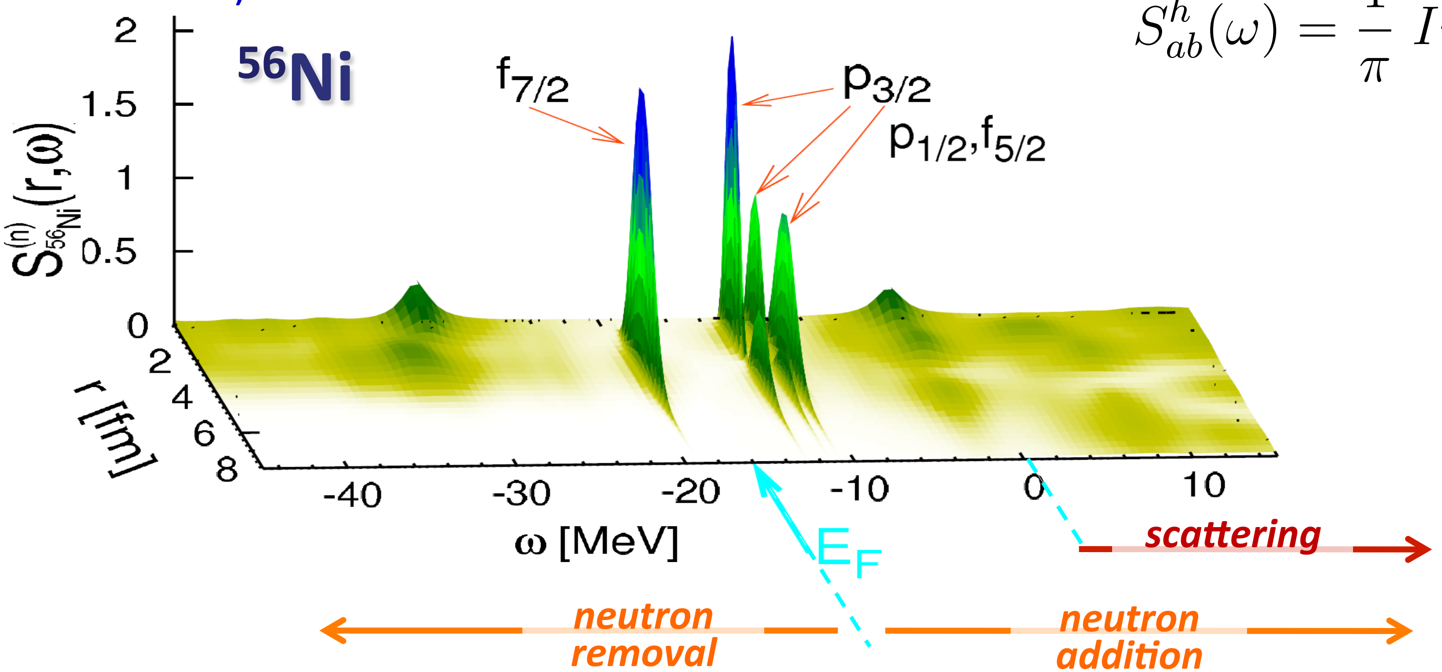
Example of spectral function ^{56}Ni

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 <u>all the structure information</u> probed by nucleon transfer (spectral function):

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



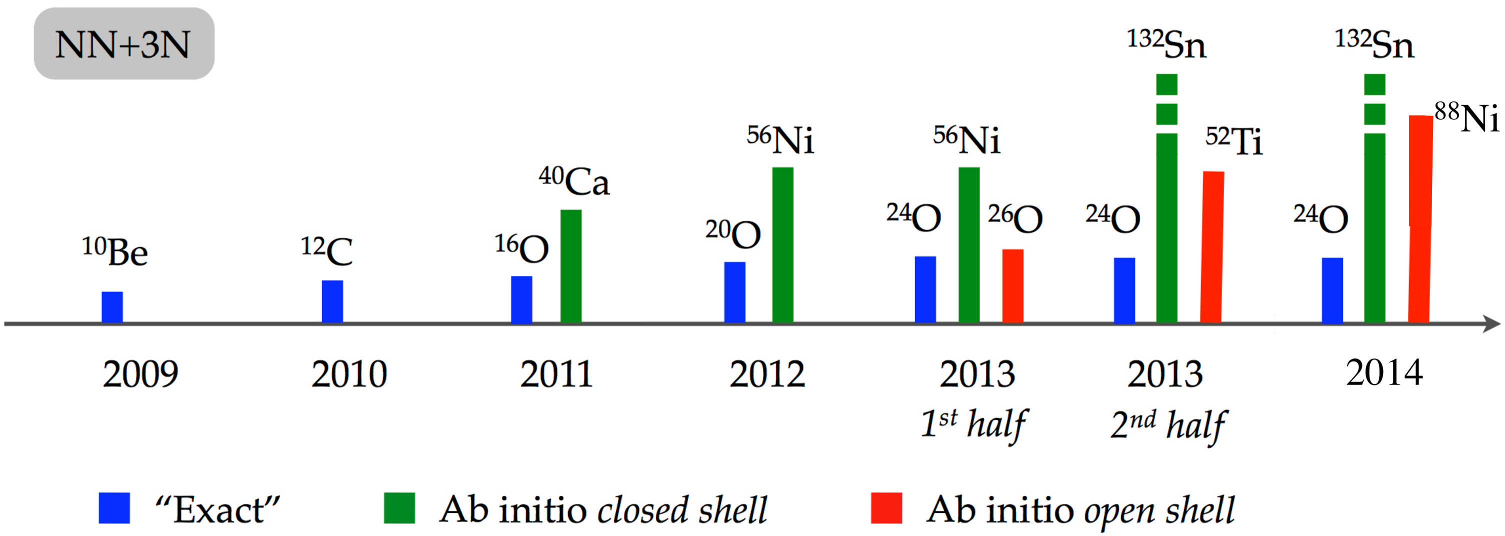
[CB, M.Hjorth-Jensen, Pys. Rev. C**79**, 064313 (2009); CB, Phys. Rev. Lett. **103**, 202502 (2009)]

Ab-Initio SCGF approaches

Reaching medium mass and neutron rich isotopes

➔ Degenerate system (open shells, deformations…)

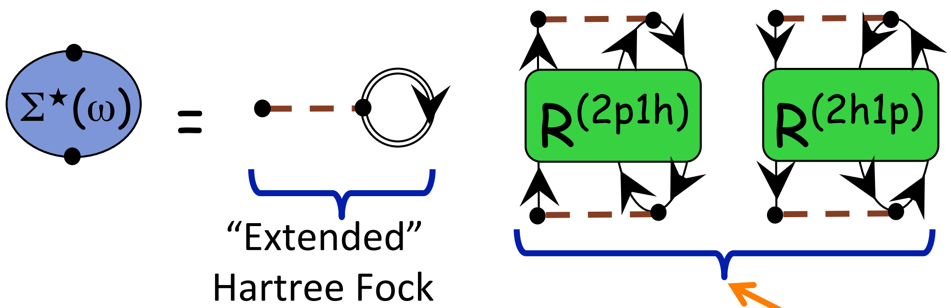
➔ Hamiltoninan, including three nucleon forces



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…

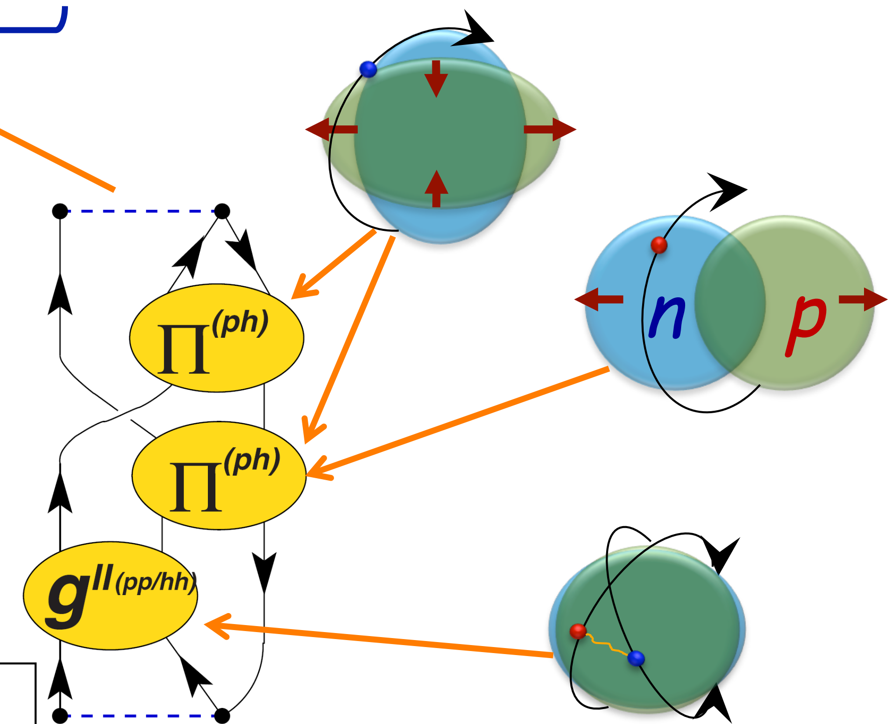
CB et al.,
Phys. Rev. C**63**, 034313 (2001)
Phys. Rev. A**76**, 052503 (2007)
Phys. Rev. C**79**, 064313 (2009)

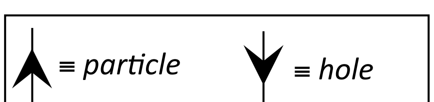


- *A complete expansion requires* ***all types*** of particle-vibration coupling

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

- The Self-energy $\Sigma^{\star}(\omega)$ yields *both* single-particle states and scattering





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

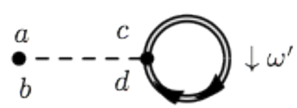
- Auxiliary many-body state $|\Psi_0\rangle \equiv \sum_N^{\text{even}} c_N \, |\psi_0^N\rangle$

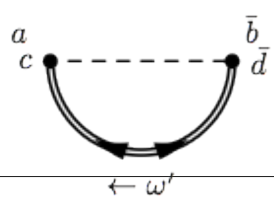
  → Mixes various particle numbers

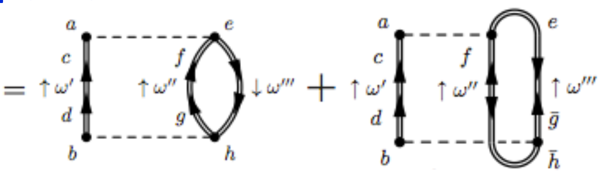
  → Introduce a "grand-canonical" potential $\Omega = H - \mu N$

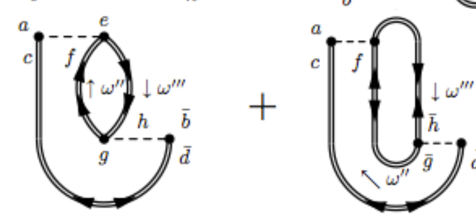
⟹ $|\Psi_0\rangle$ minimizes $\Omega_0 = \langle\Psi_0|\Omega|\Psi_0\rangle$ under the constraint $N = \langle\Psi_0|N|\Psi_0\rangle$

- This approach leads to the following Feynman diagrams:

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

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

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

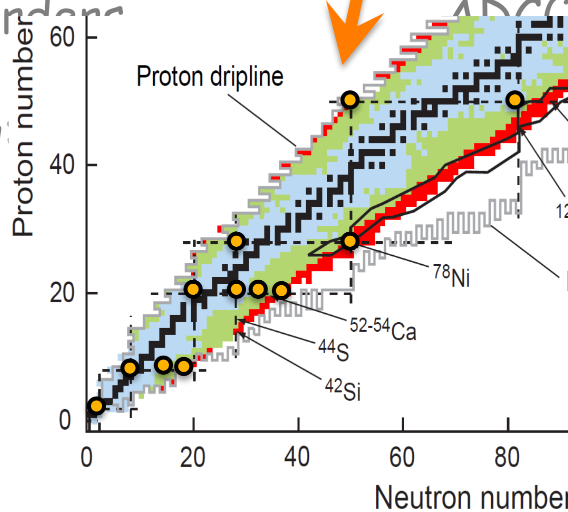
$\Sigma_{ab}^{12\,(2)}(\omega) =$ 

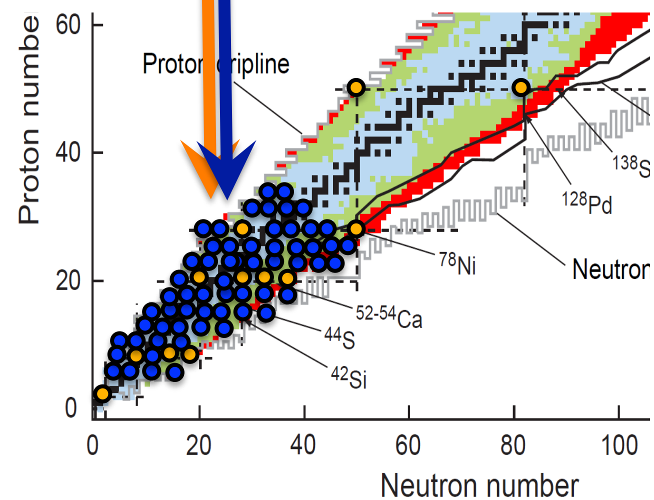
Approaches in GF theory

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)	



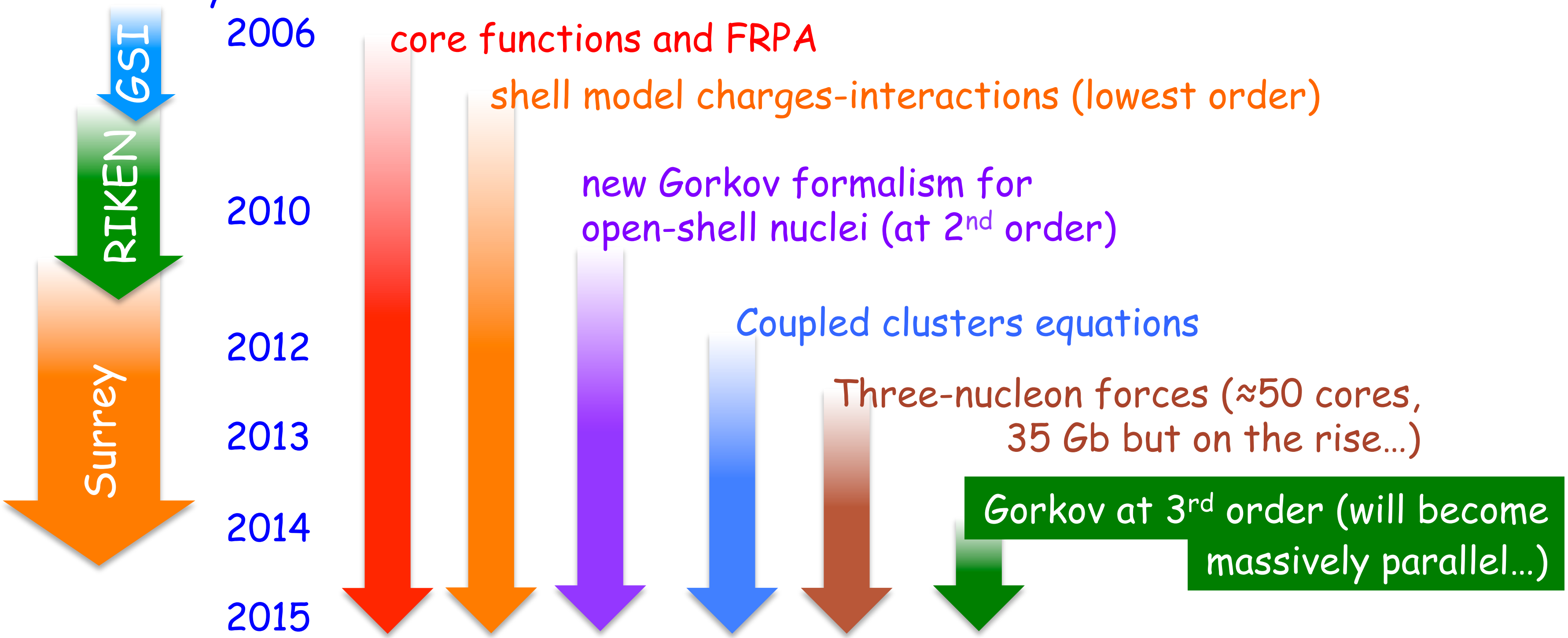


Ab-initio Nuclear Computation & BcDor code

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.

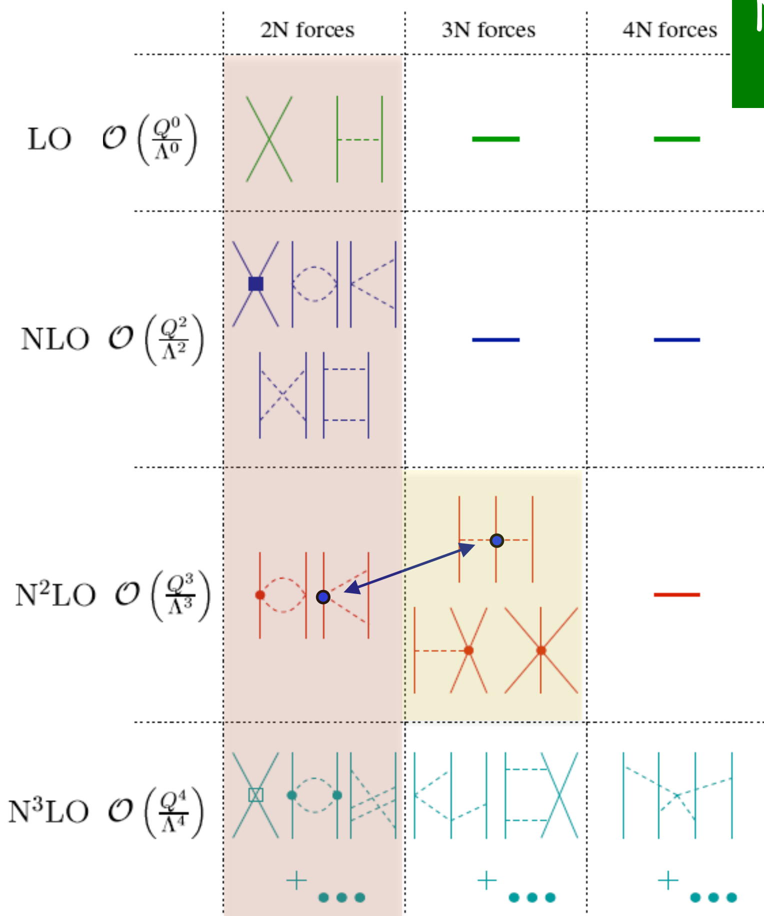
Code history:



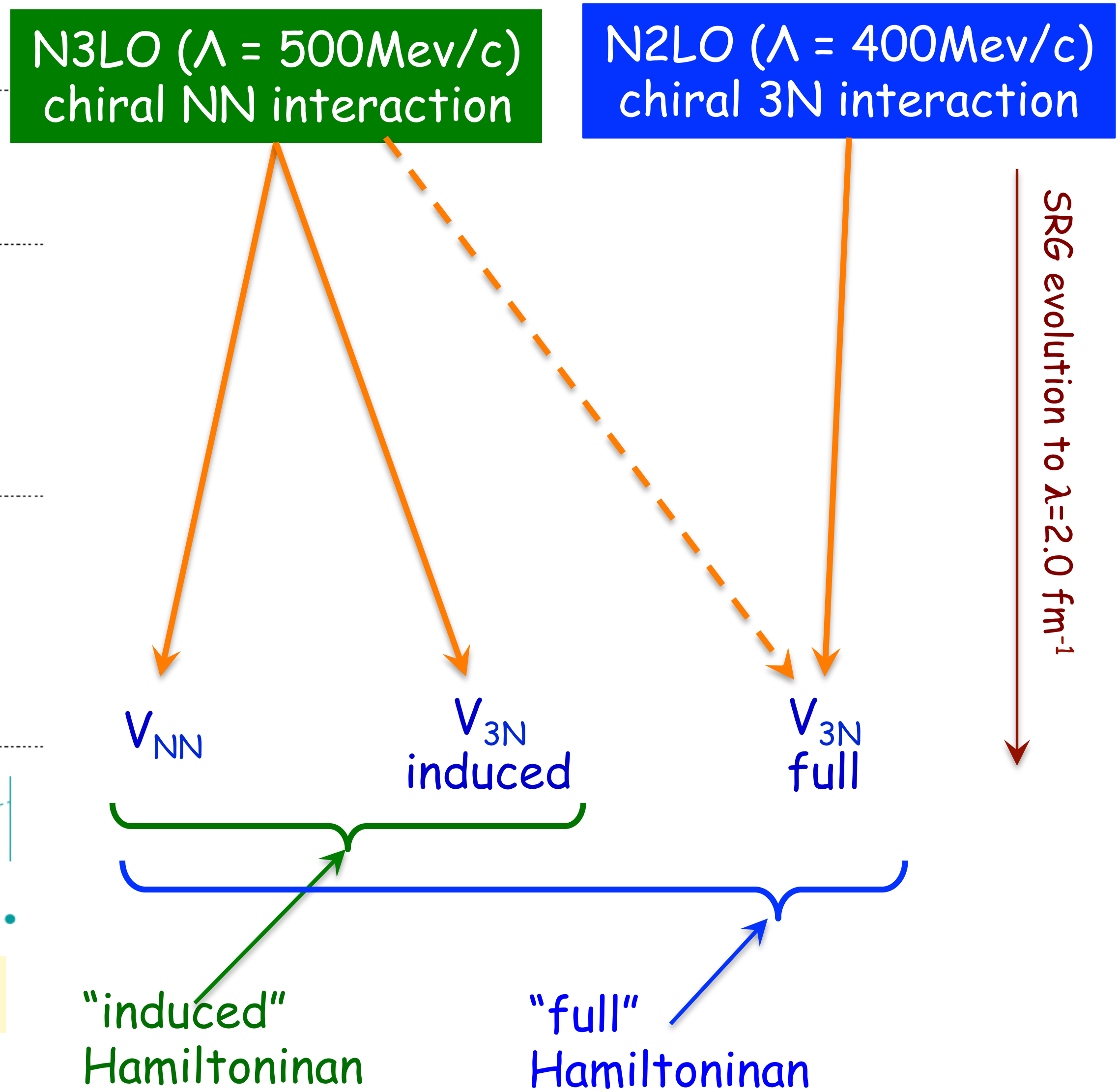
… applications …

Results

Chiral Nuclear forces - SRG evolved



(3NFs arise naturally at N2LO)



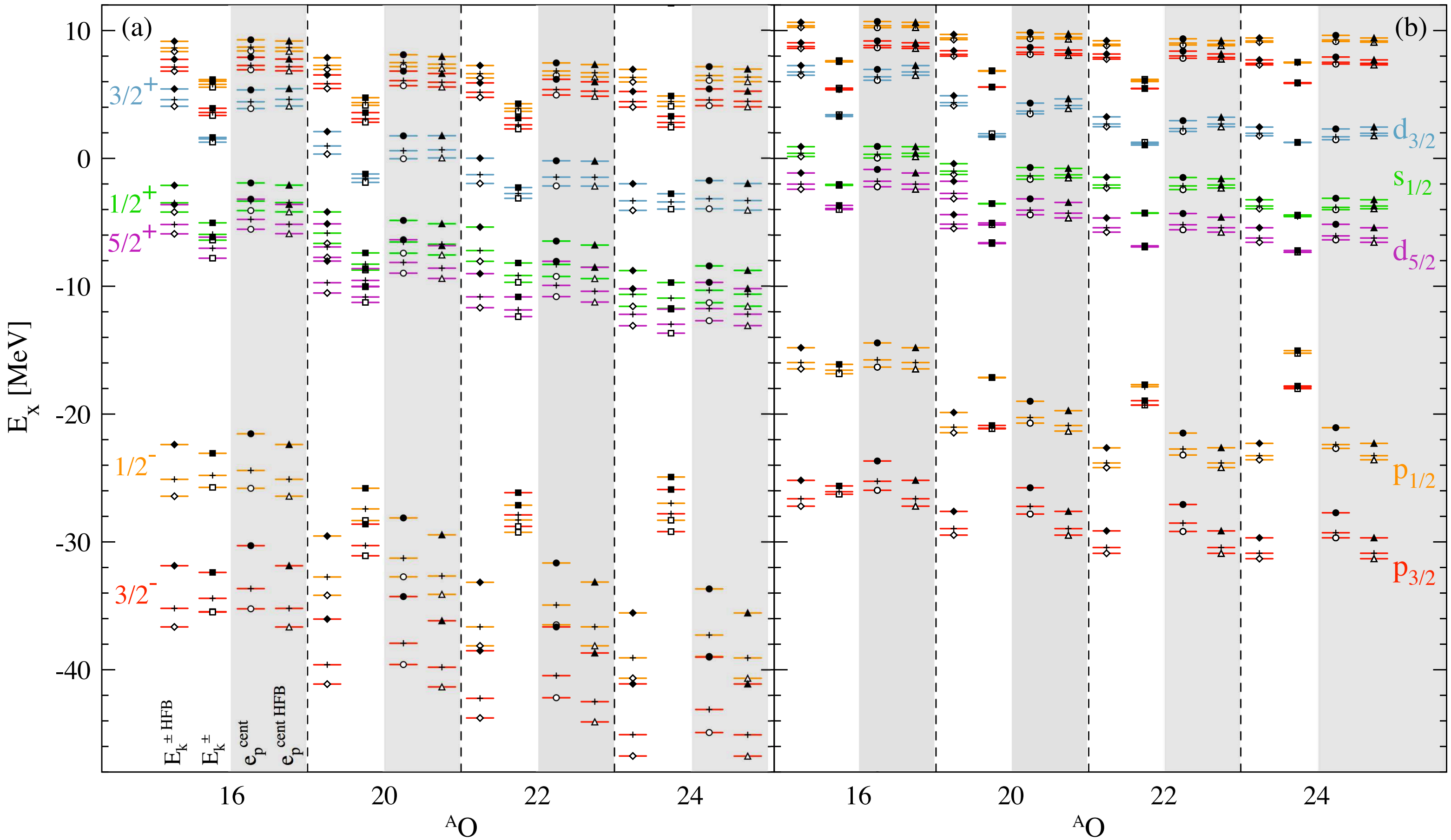
[Jurgenson, Navrátil, Furnstahl, Phys. Rev. Lett. **103**, 082501 (2009); Hebeler, Phys. Rev. C 85, 021002 (2012)]

Convergence of s.p. spectra w.r.t. SRG

Cutoff dependence is reduces, indicating good convergence of many-body truncation and many-body forces

arXiv:1411.1237 (2014)

✓only dominant s.p. states shown



NN terms (no induced 3NF) ← → NN+3NF fully included

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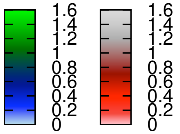
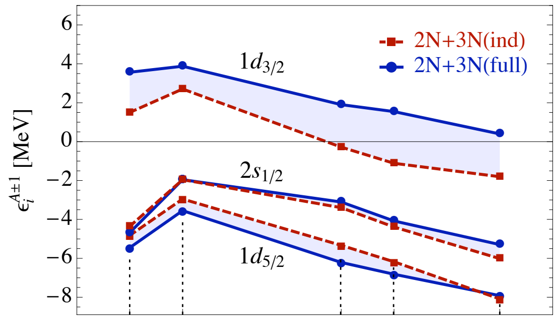
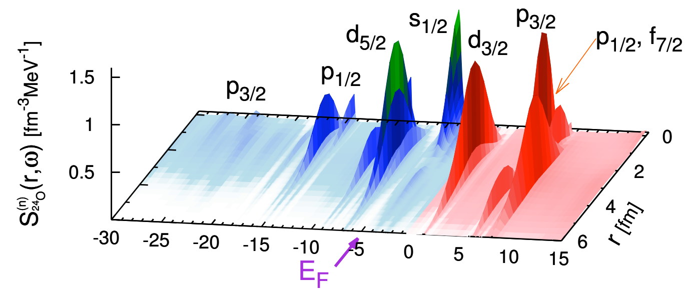
Neutron spectral function of Oxygens

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

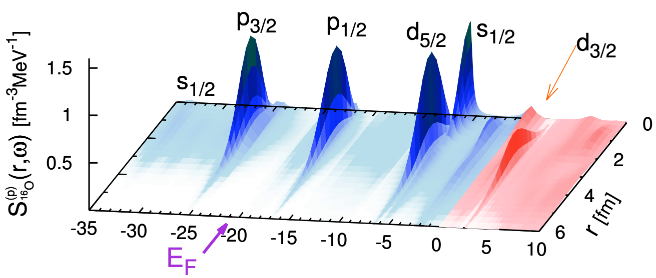




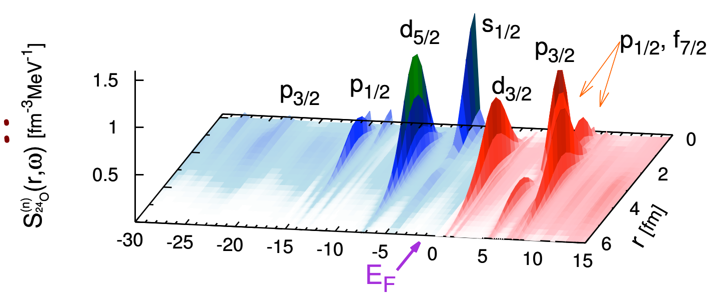
^{22}O:



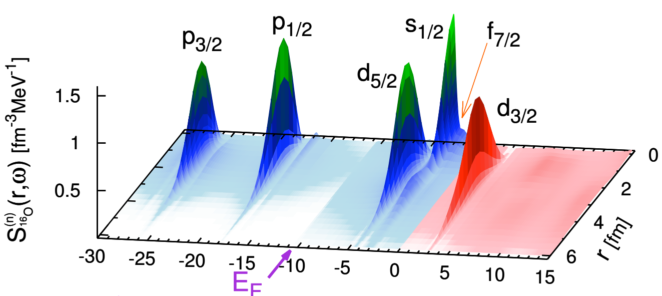
^{14}O:



^{24}O:

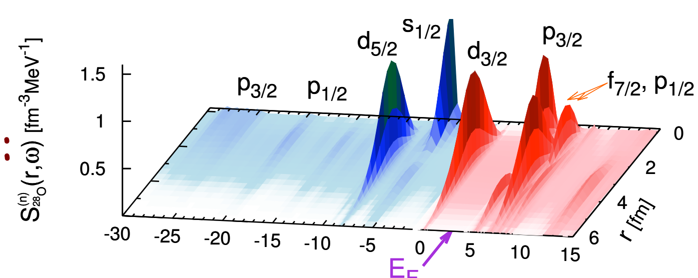


^{16}O:



^{15}O ← → ^{17}O

^{28}O:



^{27}O ← → ^{29}O

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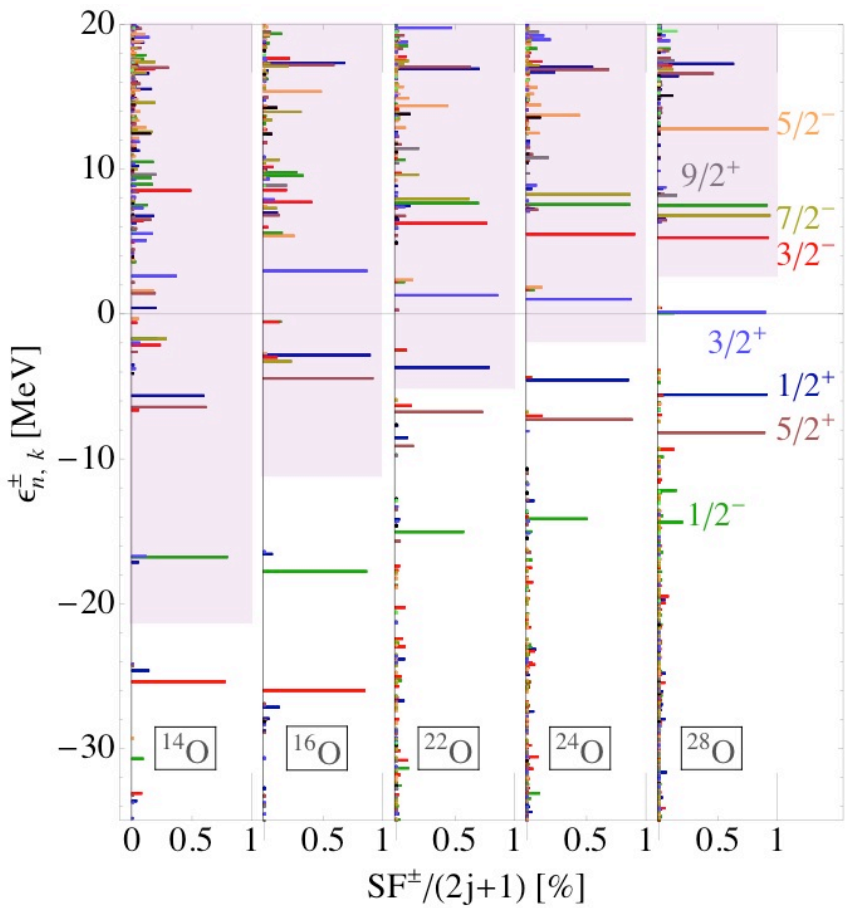
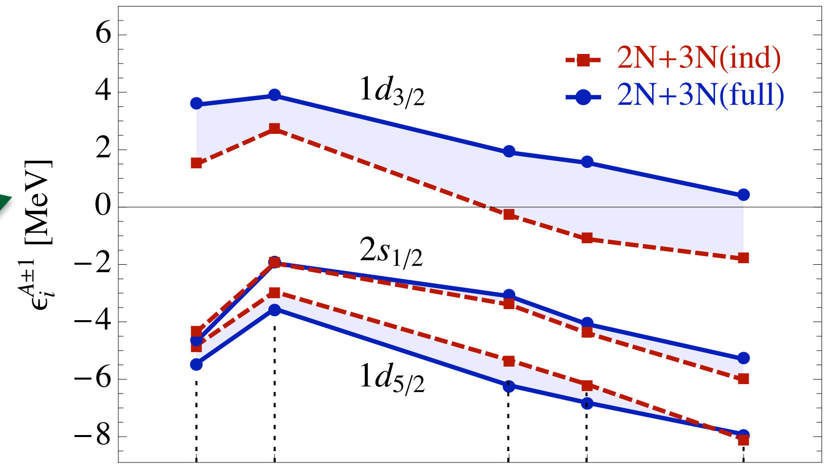
Results for the N-O-F chains

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).]

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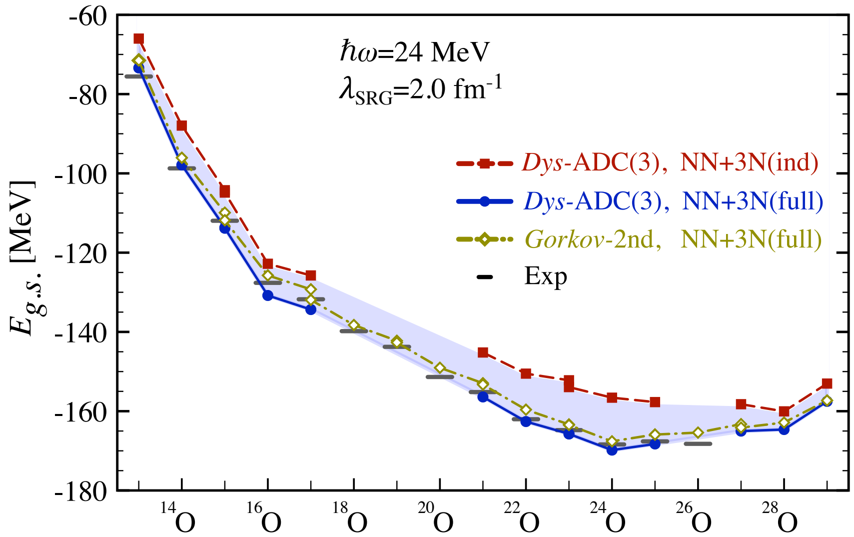
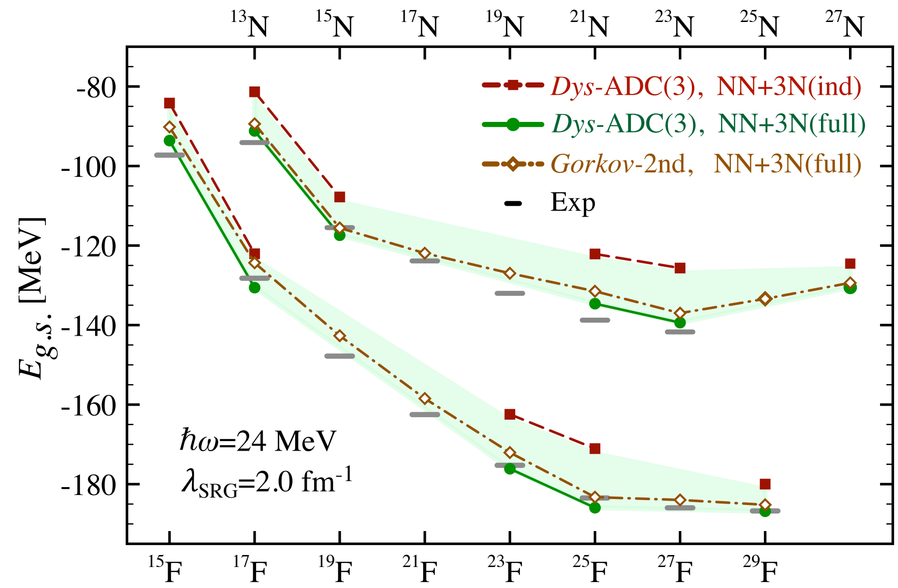




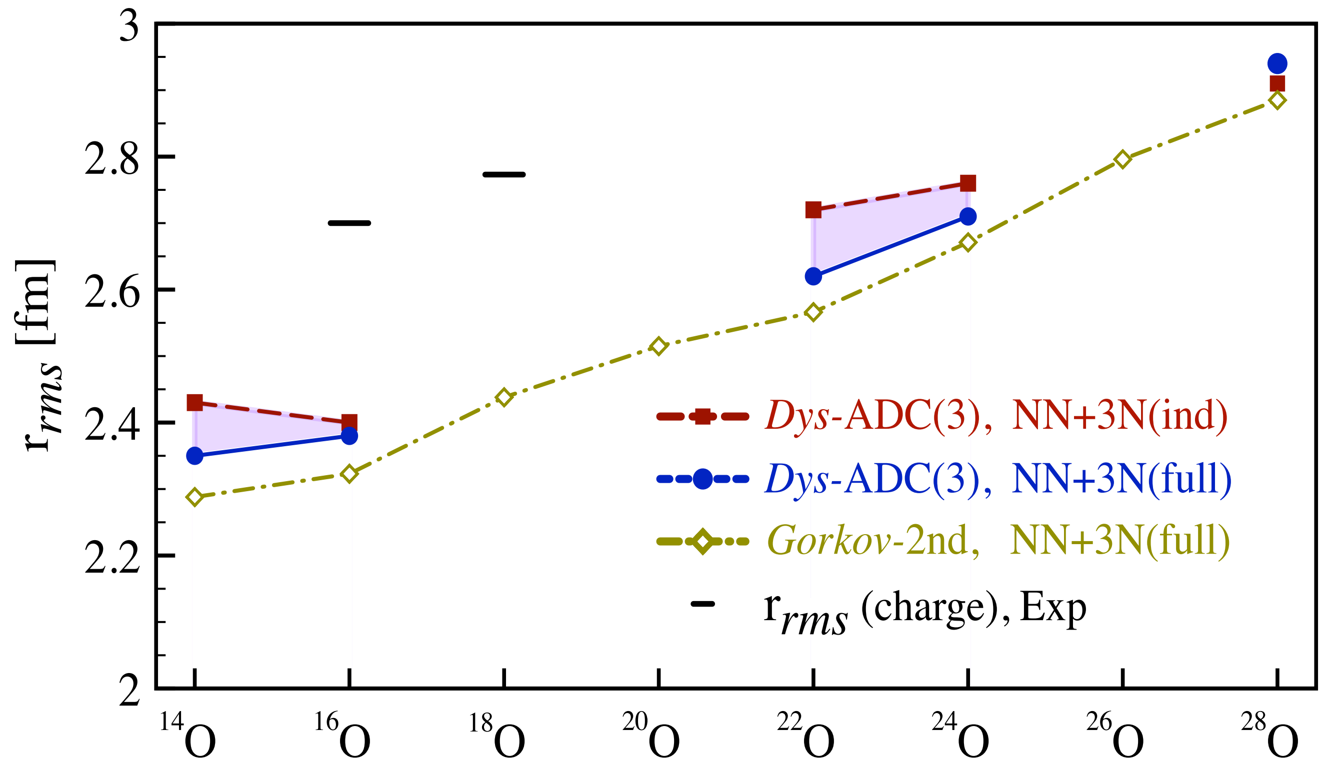
→ 3NF crucial for reproducing binding energies and driplines around oxygen

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

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)

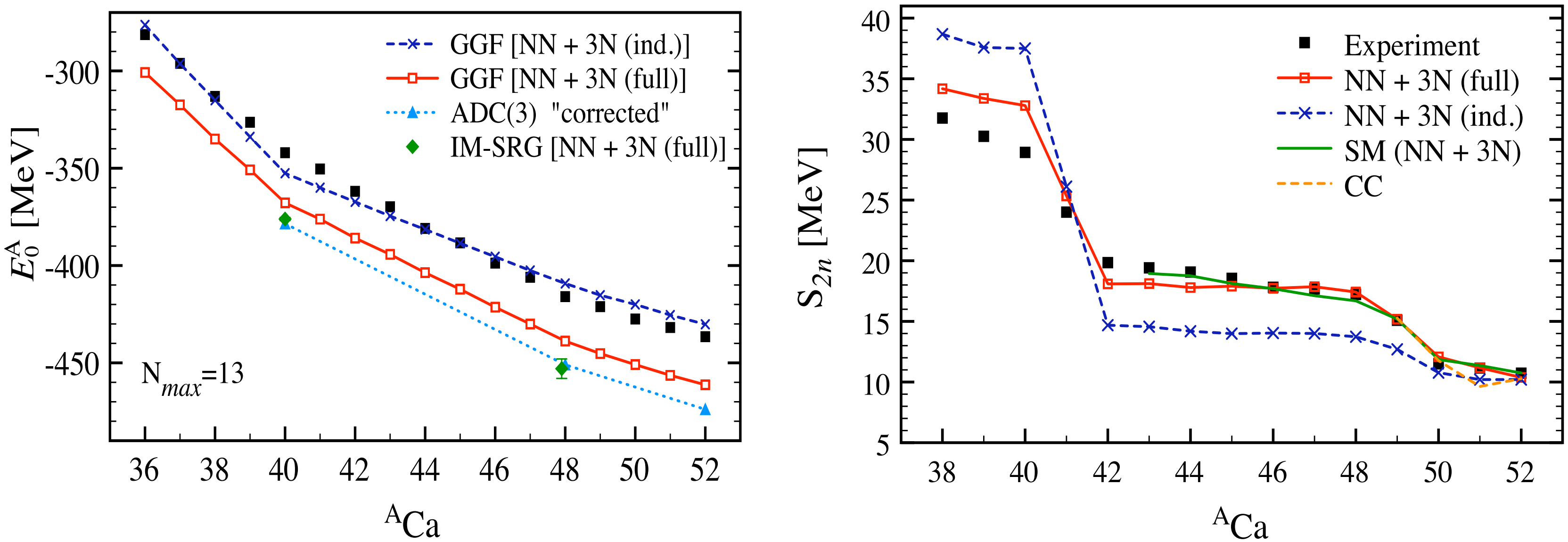


→ Single particle spectra slightly diluted and

→ systematic underestimation of radii

Calcium isotopic chain

Ab-initio calculation of the whole Ca: *induced* and full 3NF investigated



→ *induced* and full 3NF investigated

→ genuine (N2LO) 3NF needed to reproduce the energy curvature and S_{2n}

→ N=20 and Z=20 gaps overestimated!

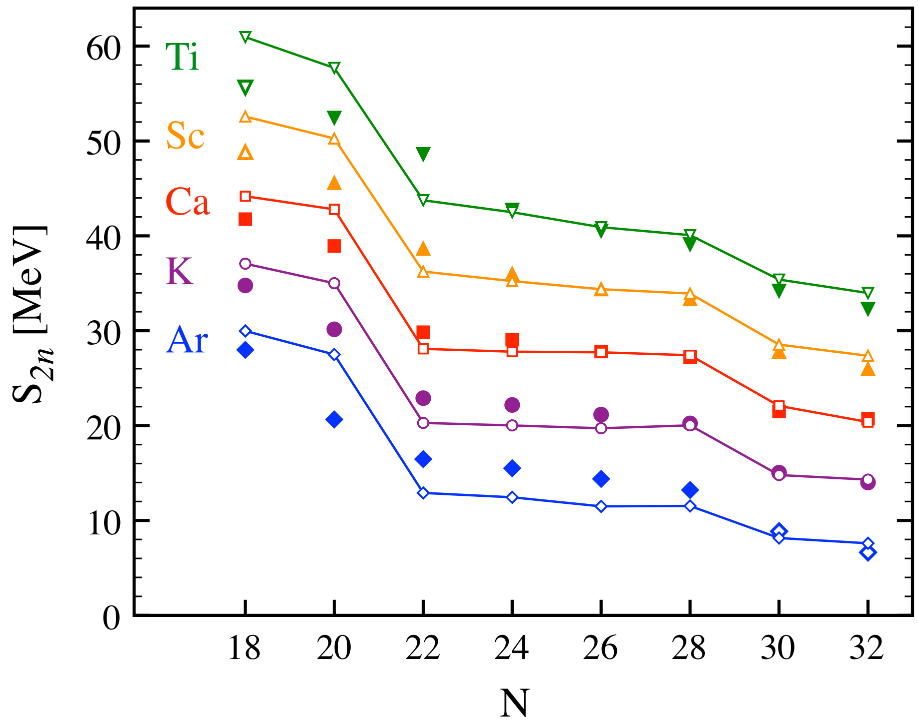
→ Full 3NF give a correct trend but over bind!

V. Somà, CB *et al.* Phys. Rev. C**89**, 061301R (2014)

Neighbouring Ar, K, Ca, Sc, and Ti chains

V. Somà, CB *et al.* Phys. Rev. C**89**, 061301R (2014)

Two-neutron separation energies predicted by chiral NN+3NF forces:



→ First *ab-initio* calculation over a contiguous portion of the nuclear chart—open shells are now possible through the Gorkov-GF formalism

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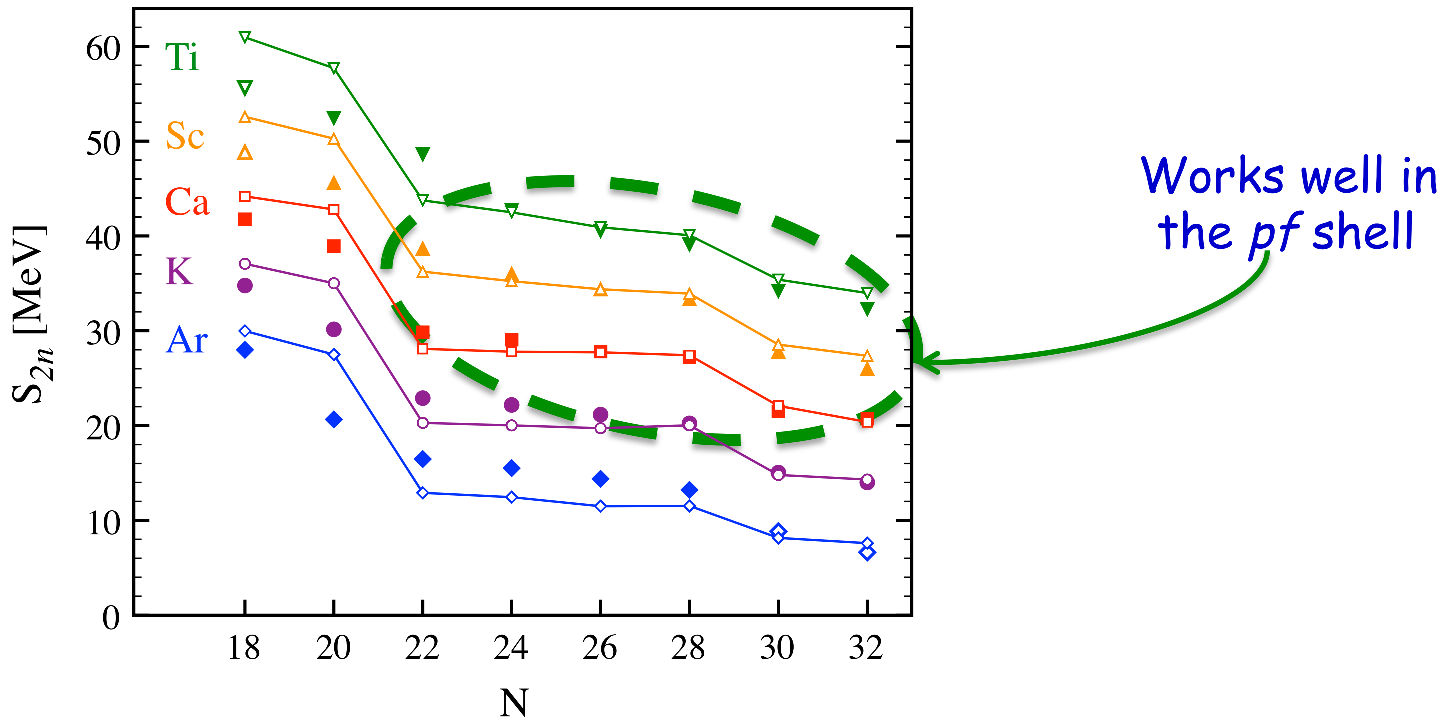

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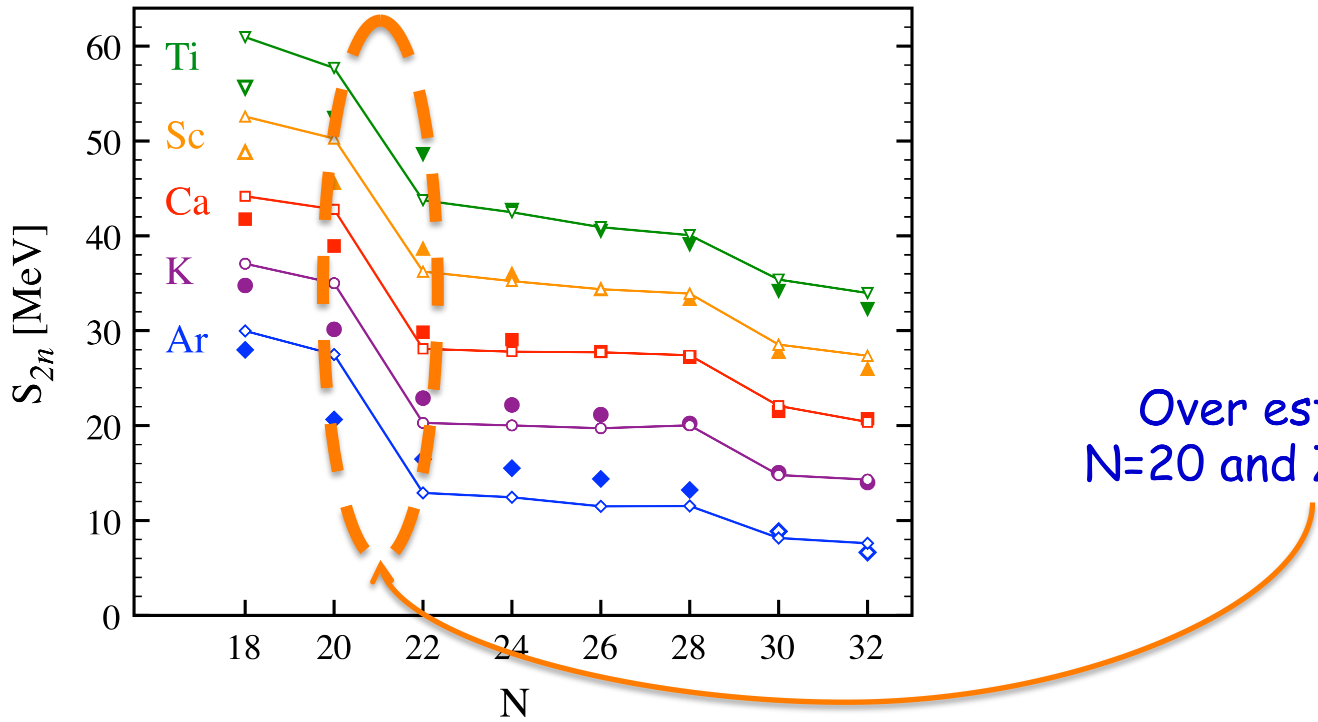

Over estimated
N=20 and Z=20 gaps

→ First *ab-initio* calculation over a contiguous portion of the nuclear chart—open shells are now possible through the Gorkov-GF formalism

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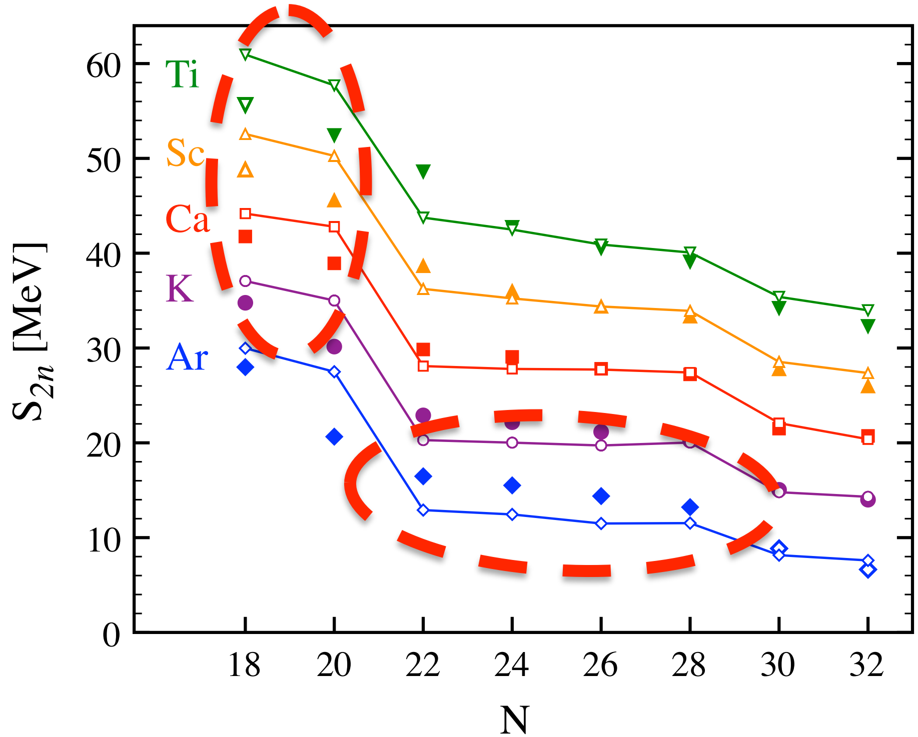


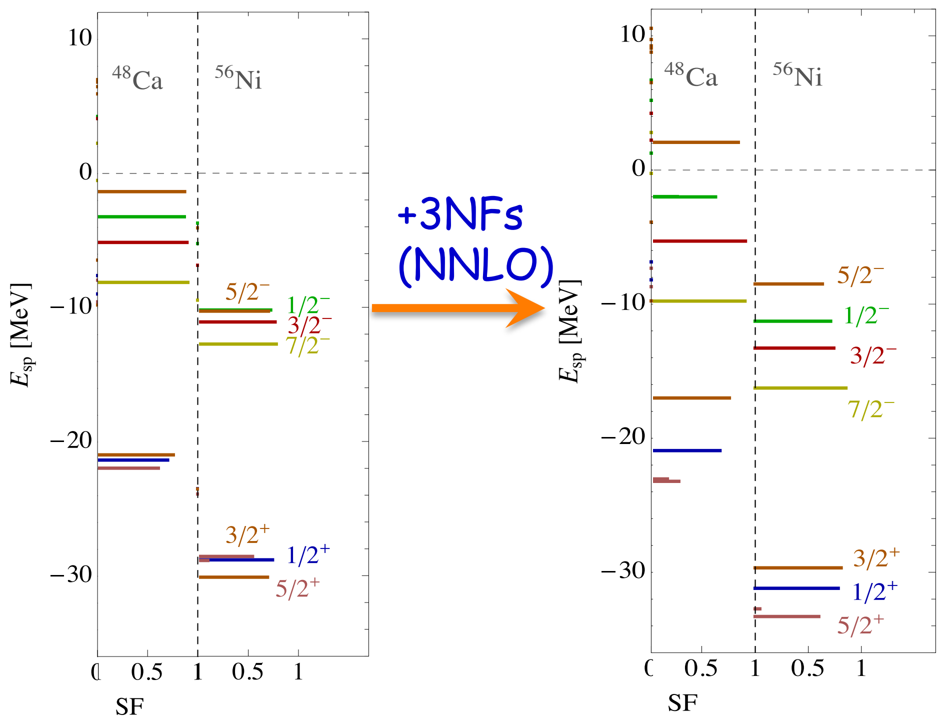
Lack of deformation due to quenched cross-shell quadrupole excitations

→ First *ab-initio* calculation over a contiguous portion of the nuclear chart—open shells are now possible through the Gorkov-GF formalism

The sd-pf shell gap

Neutron spectral distributions for ^{48}Ca and ^{56}Ni:

2N + 3NF (induced) | 2N + 3NF (FULL)

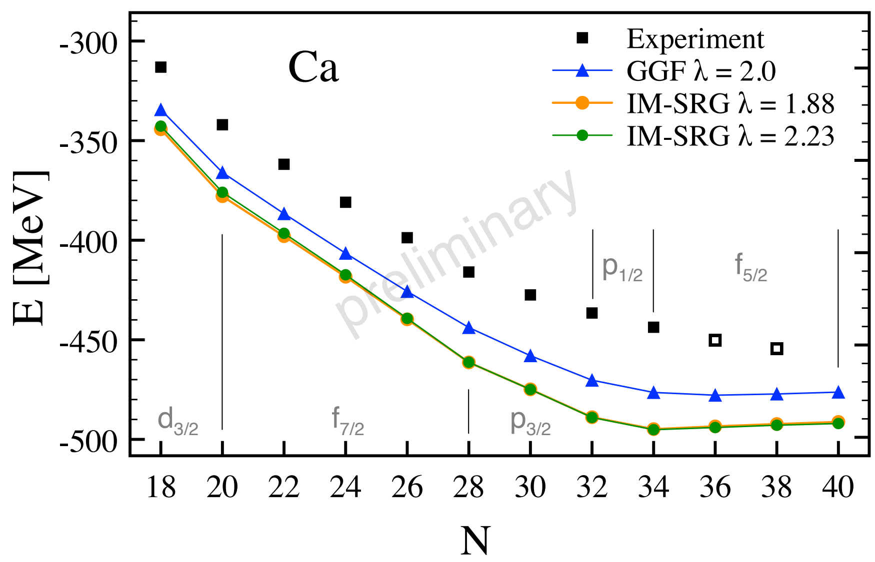


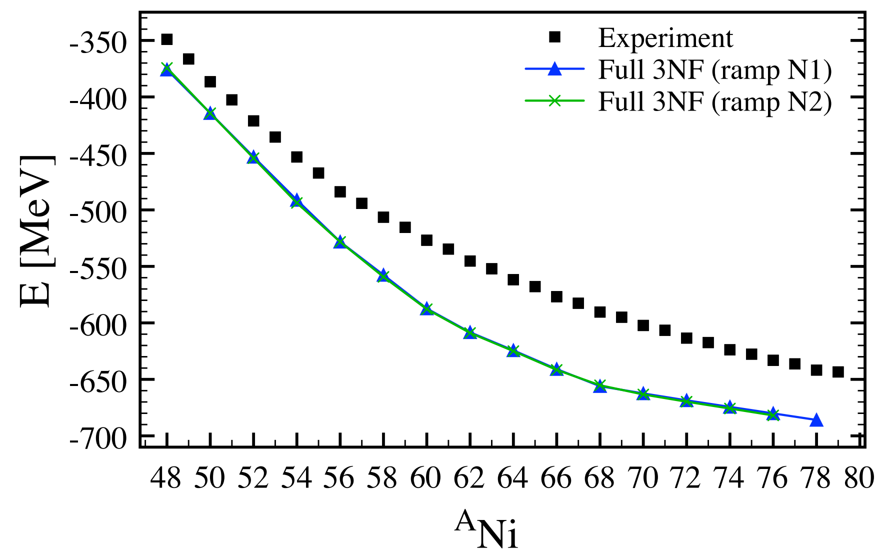
- *sd-pf separation is overestimated* <u>even</u> with leading order N2LO 3NF
- Correct increase of $p_{3/2}$-$f_{7/2}$ splitting (see Zuker 2003)

	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]

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

Ca and Ni isotopic chains





→ 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

IM-SRG results from H. Hergert

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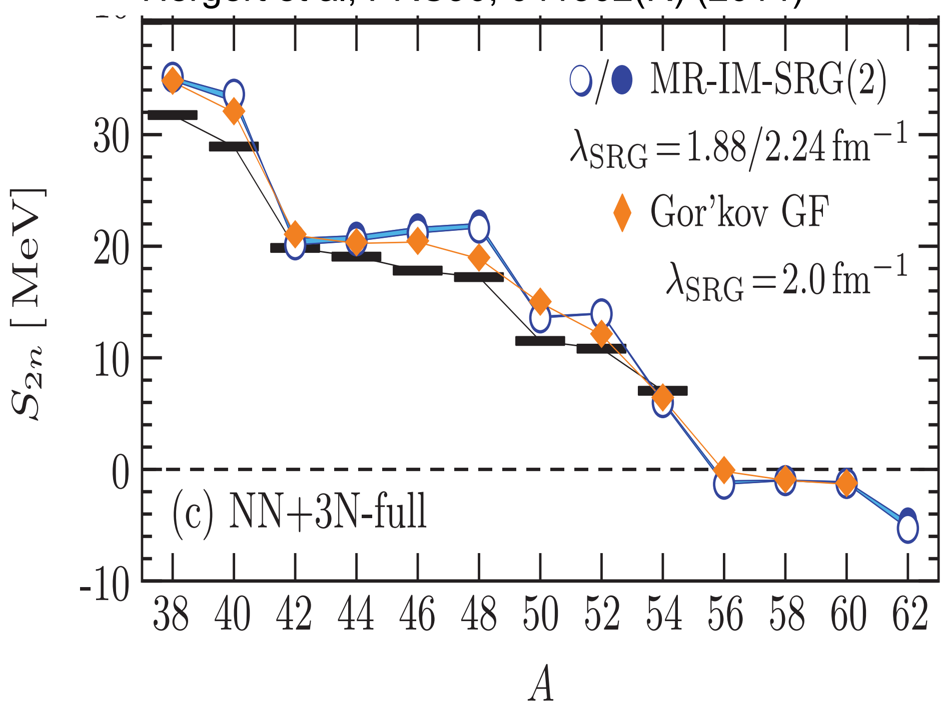
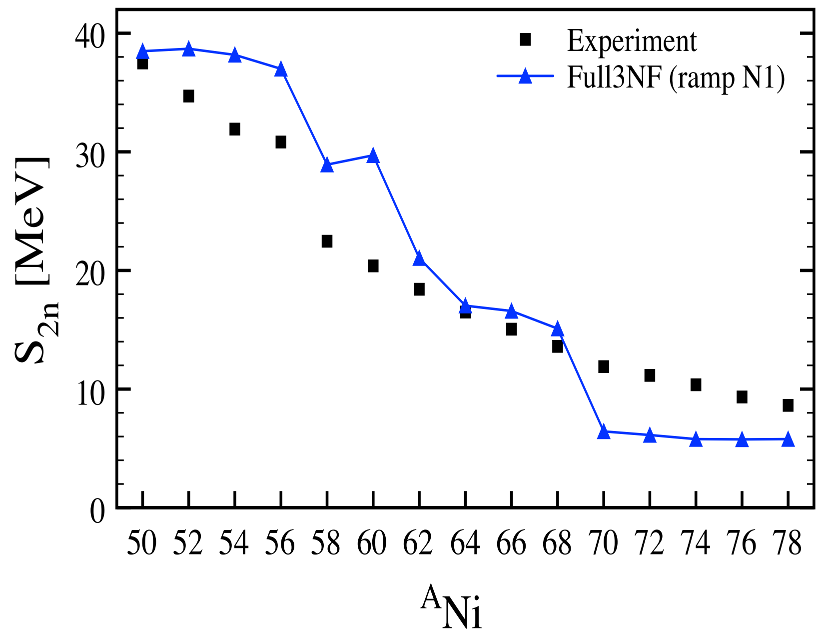
Ca and Ni isotopic chains

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

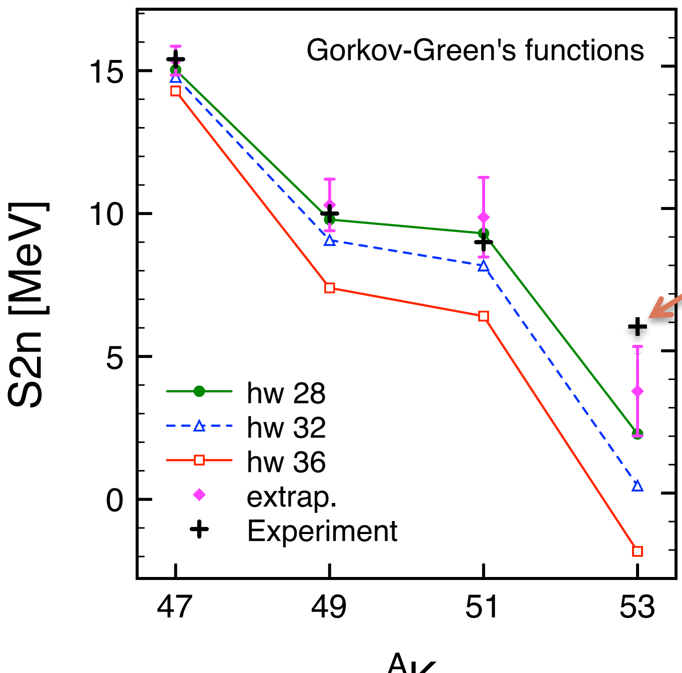




→ Large J in free space SRG matter (must pay attention to its convergence)

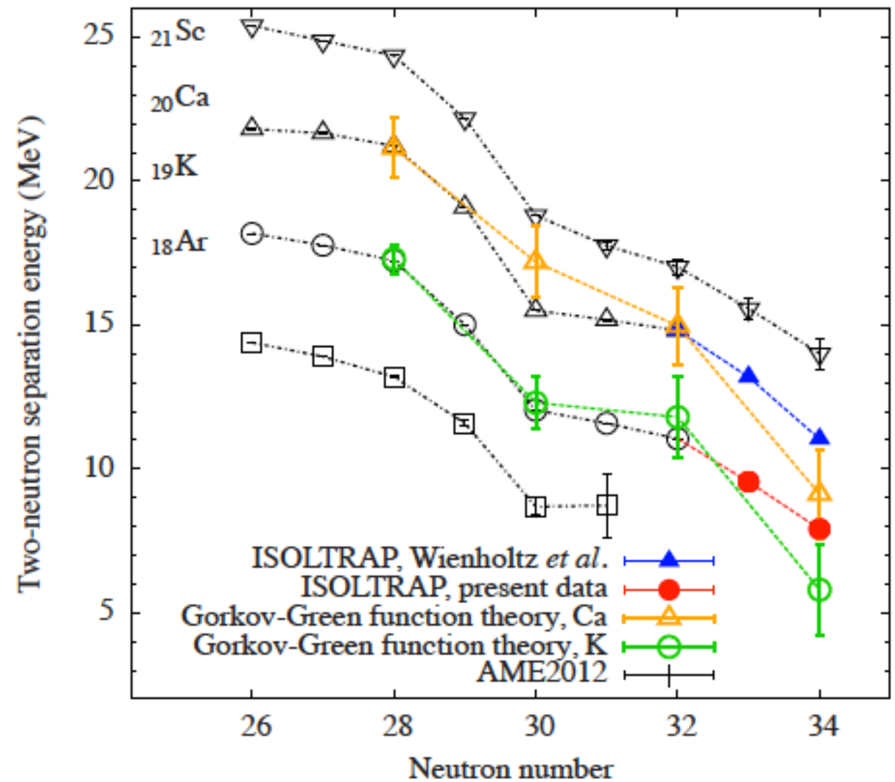
→ Overall conclusions regarding over binding and S_{2n} remain but details change

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.

Quenching of absolute spectroscopic factors

[CB, *Phys. Rev. Lett.* **103**, 202520 (2009)]

Overall quenching of *spectroscopic factors* is driven by:

SRC → *~10%*

part-vibr. coupling → *dominant*

"shell-model" → *in open shell*

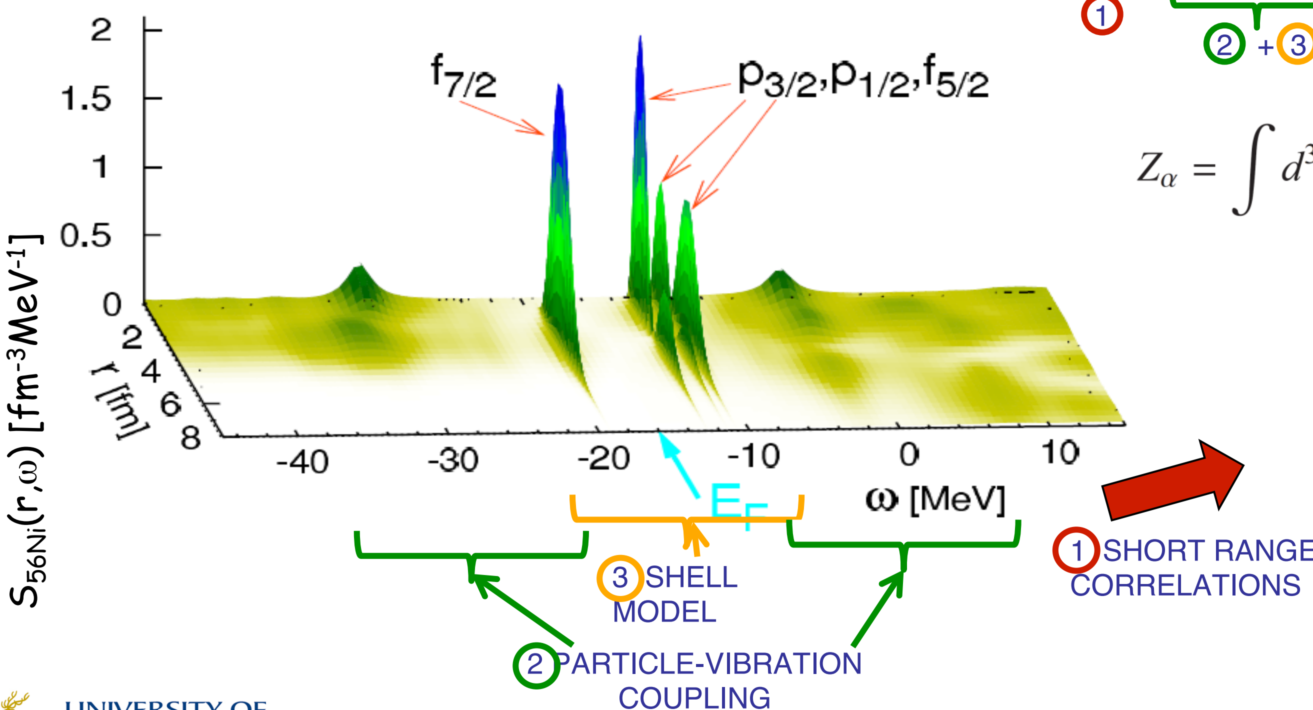
...with analogous conclusions for ^{48}Ca

	10 osc. shells FRPA (SRC)	full FRPA	FRPA $+\Delta Z_\alpha$	Exp. [30]	$1p0f$ space FRPA	SM	ΔZ_α
^{57}Ni:							
$\nu 1p_{1/2}$	0.96	0.63	0.61		0.79	0.77	-0.02
$\nu 0f_{5/2}$	0.95	0.59	0.55		0.79	0.75	-0.04
$\nu 1p_{3/2}$	0.95	0.65	0.62	0.58(11)	0.82	0.79	-0.03
^{55}Ni:							
$\nu 0f_{7/2}$	0.95	0.72	0.69		0.89	0.86	-0.03

^{57}Ni, ^{55}Ni

① (SRC column); ② + ③ (full FRPA, FRPA $+\Delta Z_\alpha$); ③ ($1p0f$ space FRPA, SM)

$$Z_\alpha = \int d^3r\, |\psi_\alpha^{overlap}(\mathbf{r})|^2 = \left.\frac{1}{1 - \frac{\partial \Sigma_{\hat\alpha\hat\alpha}(\omega)}{\partial\omega}}\right|_{\omega=\varepsilon_\alpha}$$



^{56}Ni

NN-N3LO(500)

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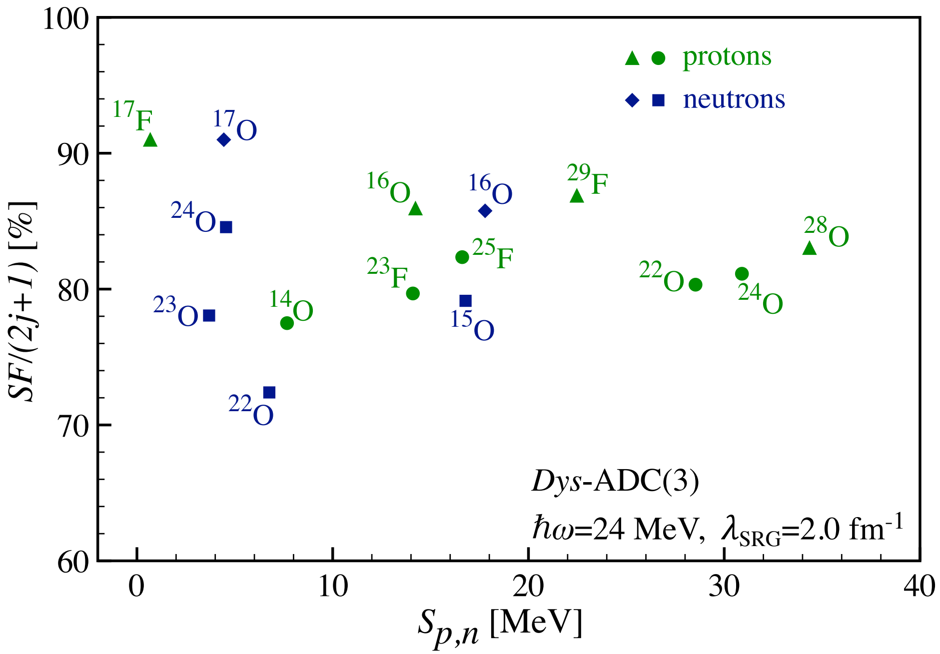
Z/N asymmetry dependence of SFs - Theory

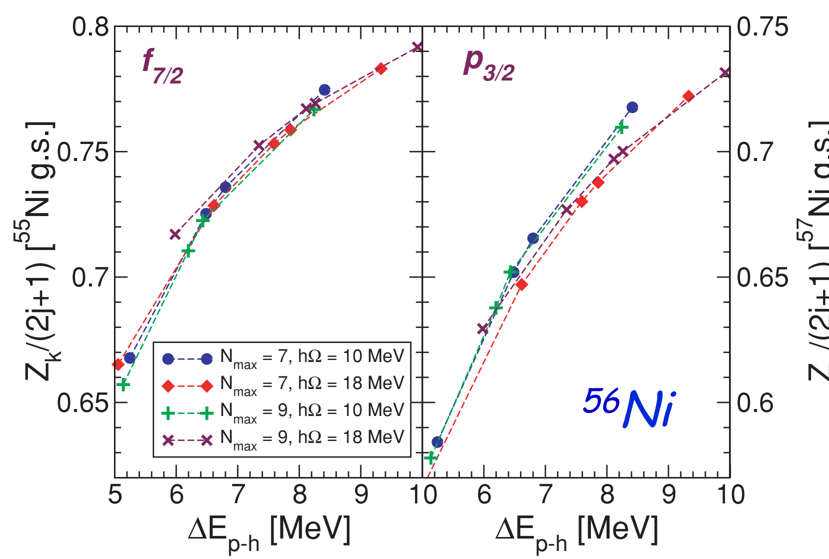
Ab-initio calculations explain the Z/N dependence but the effect is much lower than suggested by direct knockout

Effects of continuum become important at the driplines



arXiv:1412.0491 [nucl-th] (2014)

Spectroscopic factor are strongly correlated to p-h gaps:



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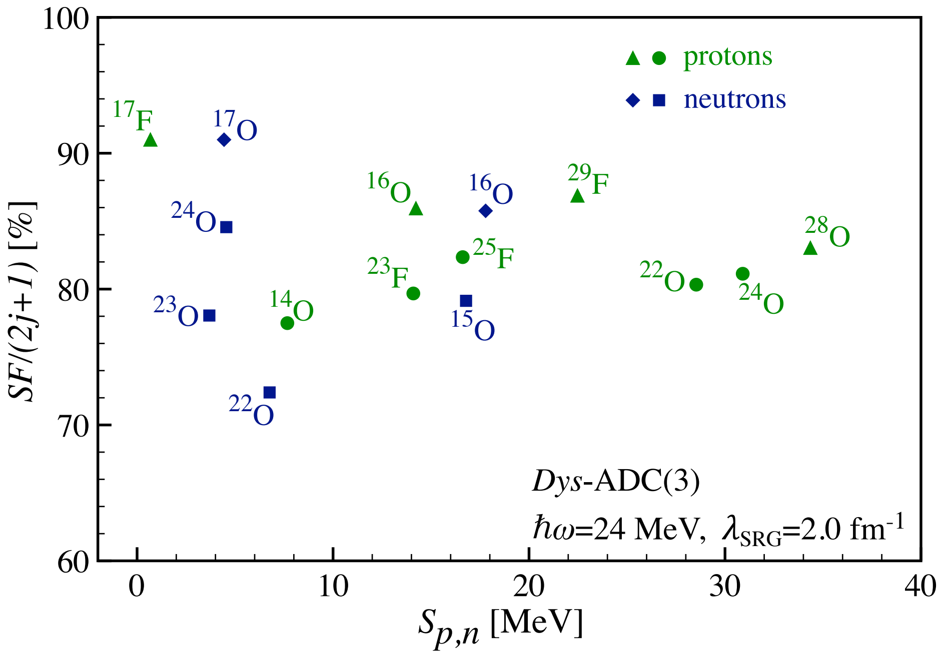
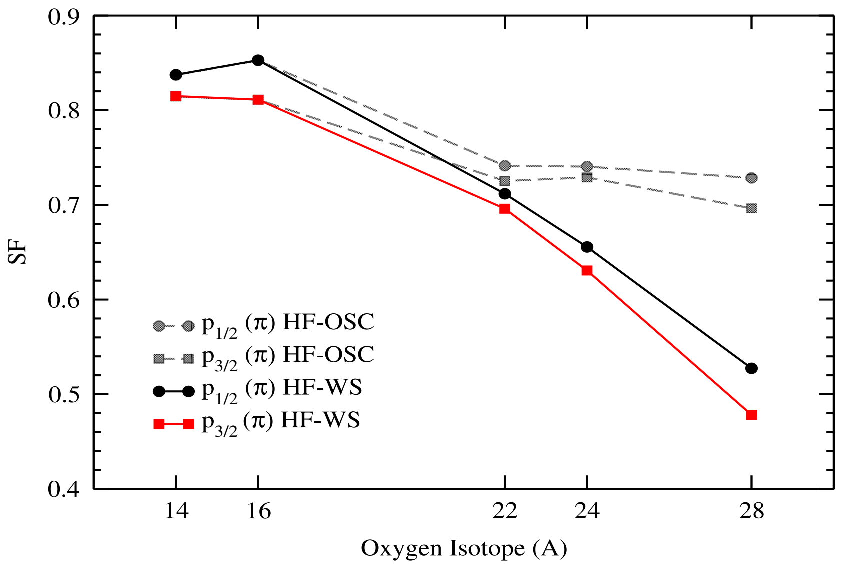


arXiv:1412.0491 [nucl-th] (2014)



[Hagen et al.
Phys. Rev. Lett. 107, 032501 (2011)]

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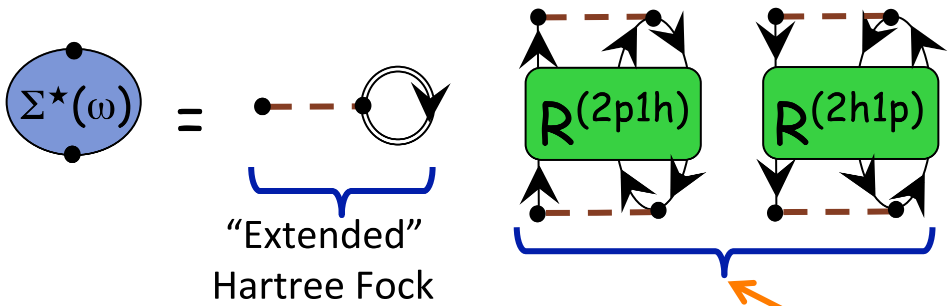
Optical Potentials Based on the Nuclear Self-energy

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…

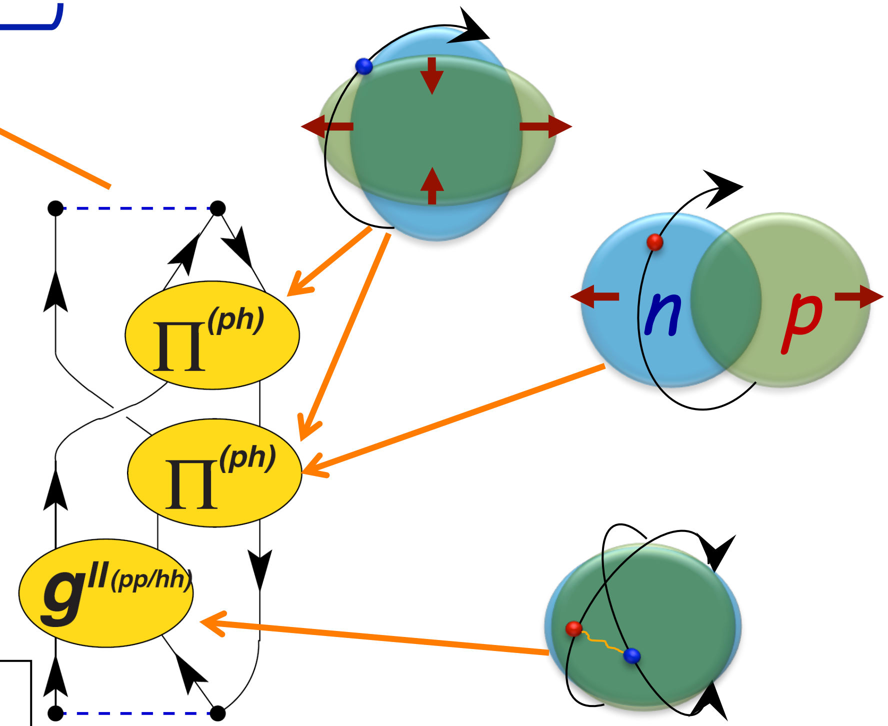
CB et al.,
*Phys. Rev. C**63**, 034313 (2001)*
*Phys. Rev. A**76**, 052503 (2007)*
*Phys. Rev. C**79**, 064313 (2009)*

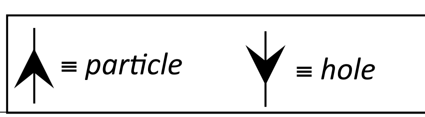


- *A complete expansion requires* ***all types*** of particle-vibration coupling

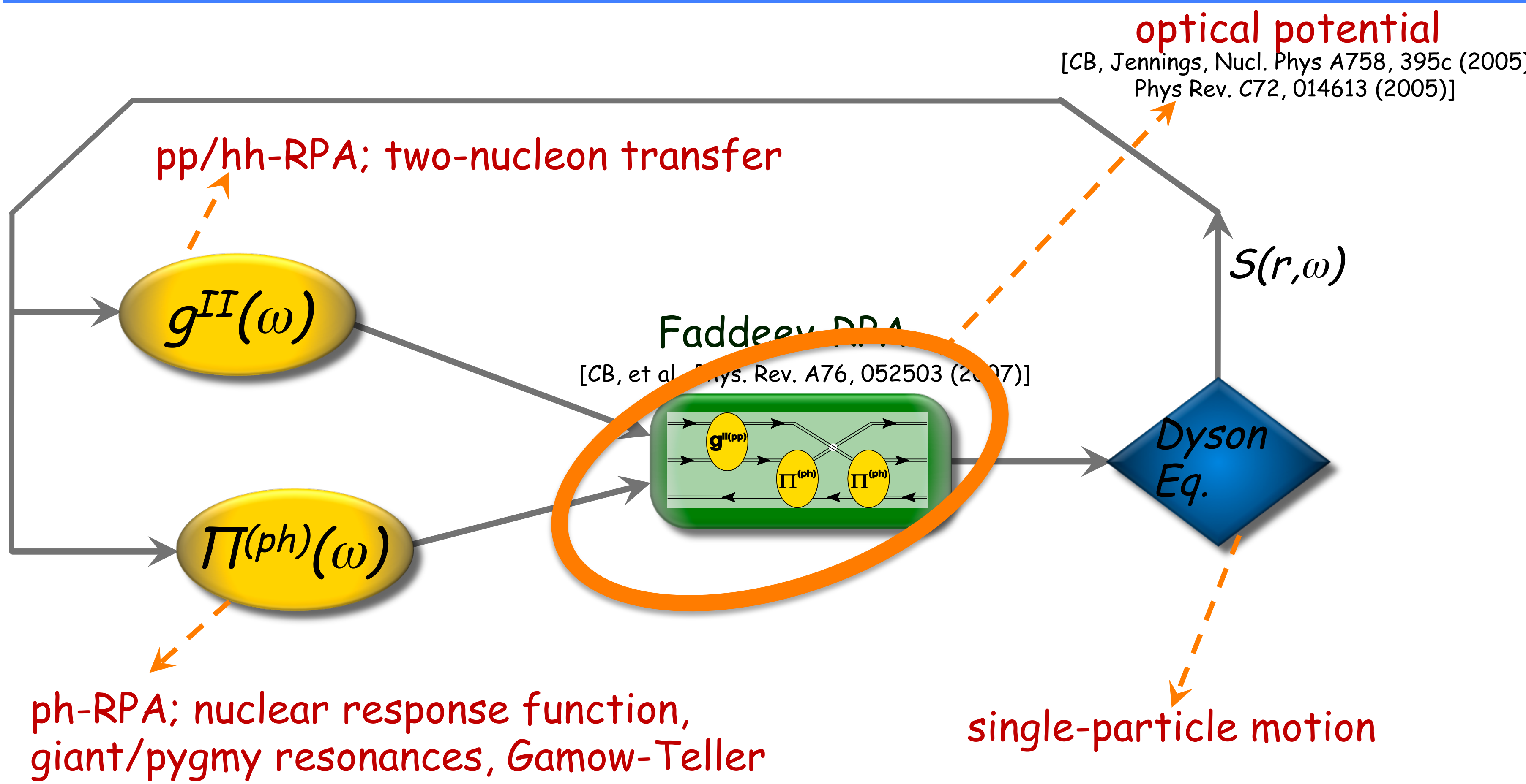
  …these modes are all resummed exactly and to all orders in a *ab-initio* many-body expansion.

- The Self-energy $\Sigma^{\star}(\omega)$ yields *both* single-particle states and scattering

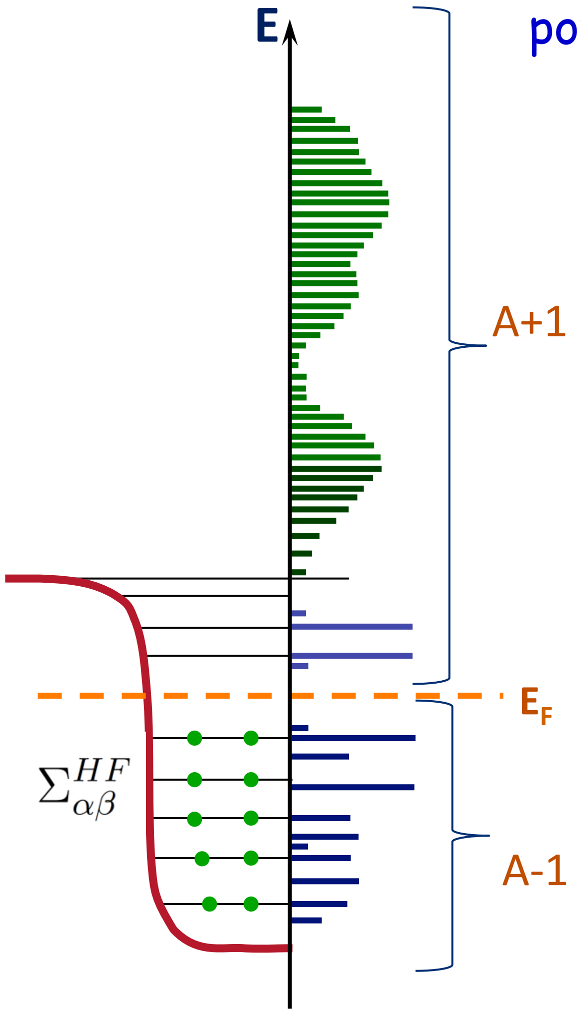




Self-Consistent Green's Function Approach



Nucleon-nucleus elastic scattering



The irreducible self-energy is a nucleon-nucleus optical potential [F. Capuzzi and C. Mahaux, Ann. Phys. (NY) **245**, 147 (1996), J. Escher and B. K. Jennings, Phys. Rev. C **66**, 034313 (2002)] :

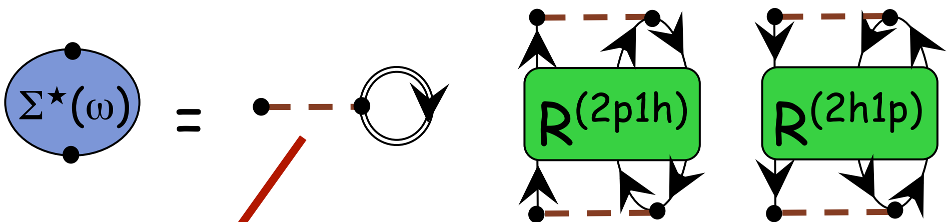
$$\Sigma^\star(\mathbf{r},\mathbf{r}';\varepsilon) = \Sigma^{HF}_{\alpha\beta} - \frac{1}{\pi}\int_{\varepsilon_T^>}^{\infty} dE' \, \frac{Im\,\Sigma^\star(\mathbf{r},\mathbf{r}';E')}{\varepsilon - E' + i\eta} + \frac{1}{\pi}\int_{-\infty}^{\varepsilon_T^<} dE' \, \frac{Im\,\Sigma^\star(\mathbf{r},\mathbf{r}';E')}{\varepsilon - E' - i\eta}$$

mean-field

resonances
beyond mean-field

➔ This provides *consistent* overlaps and scattering wave functions

Microscopic optical potential

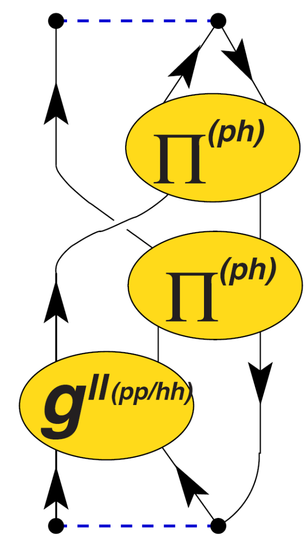


Transform h.o. basis
to k- or r- space and then
do scattering
→ NO NEED CONT. BASIS

$$\Sigma^{\mathrm{MF,Fadd}}_{lj}(k,k') = \sum_{n_\alpha,n_\beta\in\mathcal{P}} \phi_\alpha(k)\;\Sigma^{\mathrm{MF,Fadd}}_{lj,n_\alpha,n_\beta}\;\phi^*_\beta(k')$$

$$\Sigma^{(\mathrm{2p1h}),\mathrm{Fadd}}_{lj}(k,k') = \sum_{n_\alpha,n_\beta\in\mathcal{P}} \phi_\alpha(k)\left[\sum_{n+}\frac{\left(m^{n+}_\alpha\right)^*\; m^{n+}_\beta}{\omega-\varepsilon^{n+}_{lj}+i\eta}\right]\phi^*_\beta(k')$$

$$\Sigma^{(\mathrm{2h1p}),\mathrm{Fadd}}_{lj}(k,k') = \sum_{n_\alpha,n_\beta\in\mathcal{P}} \phi_\alpha(k)\left[\sum_{k-}\frac{\left(m^{k-}_\alpha\right)^*\; m^{k-}_\beta}{\omega-\varepsilon^{k-}_{lj}-i\eta}\right]\phi^*_\beta(k')$$



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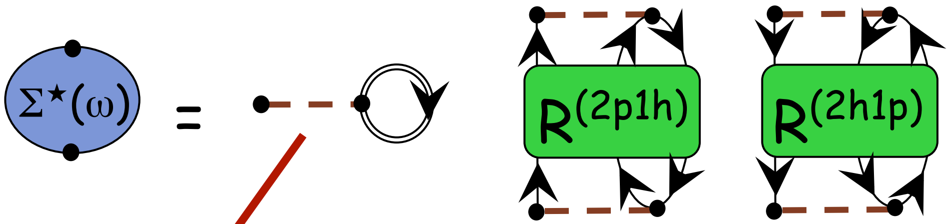
*CB, B. Jennings, Phys. Rev. C **72**, 014613 (2005)*

Microscopic optical potential



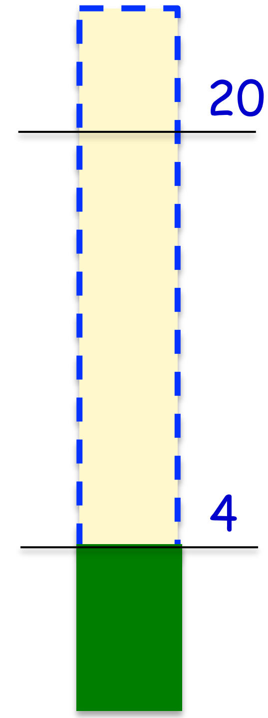
$$\Sigma_{lj}^{\mathrm{MF,Fadd}}(k,k') = \sum_{n_\alpha,n_\beta\in\mathcal{P}} \phi_\alpha(k)\ \Sigma_{lj,n_\alpha,n_\beta}^{\mathrm{MF,Fadd}}\ \phi_\beta^*(k')$$

$$\Sigma_{lj}^{(2p1h),\mathrm{Fadd}}(k,k') = \sum_{n_\alpha,n_\beta\in\mathcal{P}} \phi_\alpha(k)\left[\sum_{n+}\frac{\left(m_\alpha^{n+}\right)^*\ m_\beta^{n+}}{\omega-\varepsilon_{lj}^{n+}+i\eta}\right]\phi_\beta^*(k')$$

$$\Sigma_{lj}^{(2h1p),\mathrm{Fadd}}(k,k') = \sum_{n_\alpha,n_\beta\in\mathcal{P}} \phi_\alpha(k)\left[\sum_{k-}\frac{\left(m_\alpha^{k-}\right)^*\ m_\beta^{k-}}{\omega-\varepsilon_{lj}^{k-}-i\eta}\right]\phi_\beta^*(k')$$

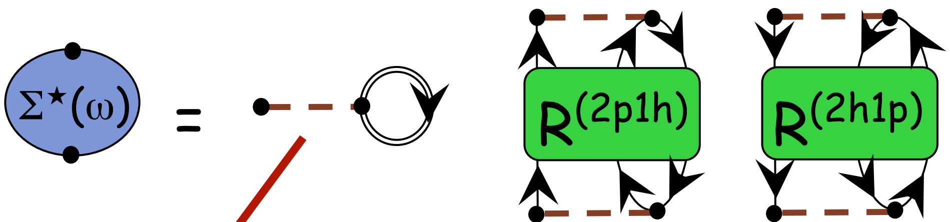
Transform h.o. basis
to k- or r- space and then
do scattering
→ NO NEED CONT. BASIS

In 2005:
- 4 h.o. shells
- Bonn-C



*CB, B. Jennings, Phys. Rev. C **72**, 014613 (2005)*

Microscopic optical potential



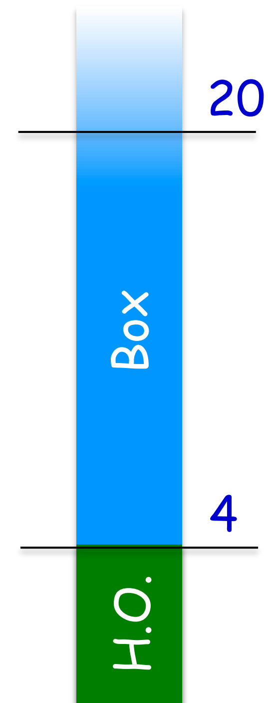
Transform h.o. basis
to k- or r- space and then
do scattering
→ NO NEED CONT. BASIS

In 2005: 4 h.o. shells, Bonn-C
→ COMPUTE MF IN A SPHERICAL BOX

$$\Sigma^{\mathrm{MF},I}_{lj}(k,k') = N^I_{lj}\,\Sigma^{\mathrm{MF,Fadd}}_{lj}(k,k') + \Sigma^{\mathrm{MF,Box}}_{1,lj}(k,k')$$

$$\Sigma^{\mathrm{MF},II}_{lj}(k,k') = N^{II}_{lj}\;\Sigma^{\mathrm{MF,Box}}_{lj}(k,k'),$$

$$\Sigma^{\star,I(II)}_{lj}(k,k';\omega) = \Sigma^{\mathrm{MF},I(II)}_{lj}(k,k') + \Sigma^{(2p1h),\mathrm{Fadd}}_{lj}(k,k';\omega) + \Sigma^{(2h1p),\mathrm{Fadd}}_{lj}(k,k';\omega).$$



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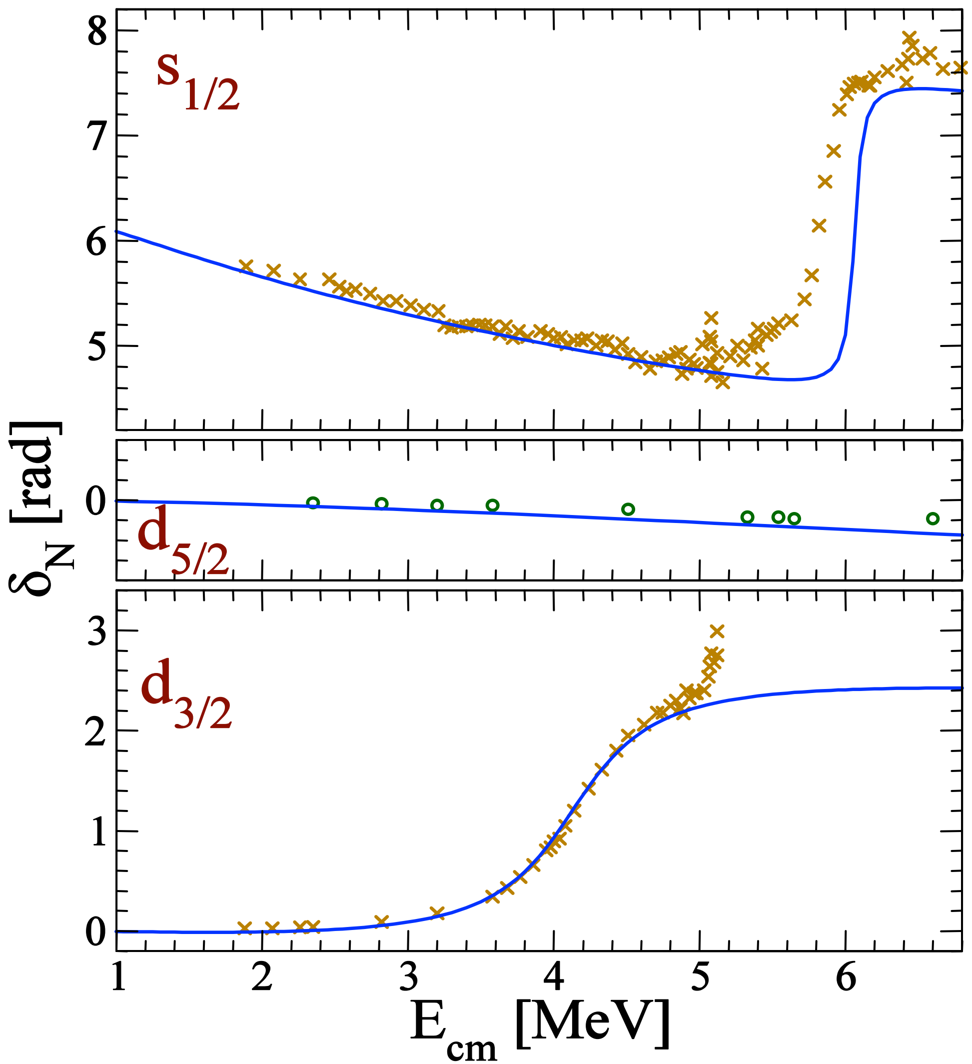
*CB, B. Jennings, Phys. Rev. C **72**, 014613 (2005)*

H. Müther, A. Polls, W. H. Dickhoff, Phys. Rev. C **49**, R17 ('94); **51**, 3040 ('95).

p-^{16}O phase shifts – positive parity waves

[C.B., B.Jennings,
Phys. Rev. C**72**, 014613 (2005)]



- AV18 interaction
- The phase shift are in agreement with the experiment!
- BUT does not reproduce phase shifts and bound state energies at the same time
  → need for improved H / 3NF
- Non-MF resonances "OK"

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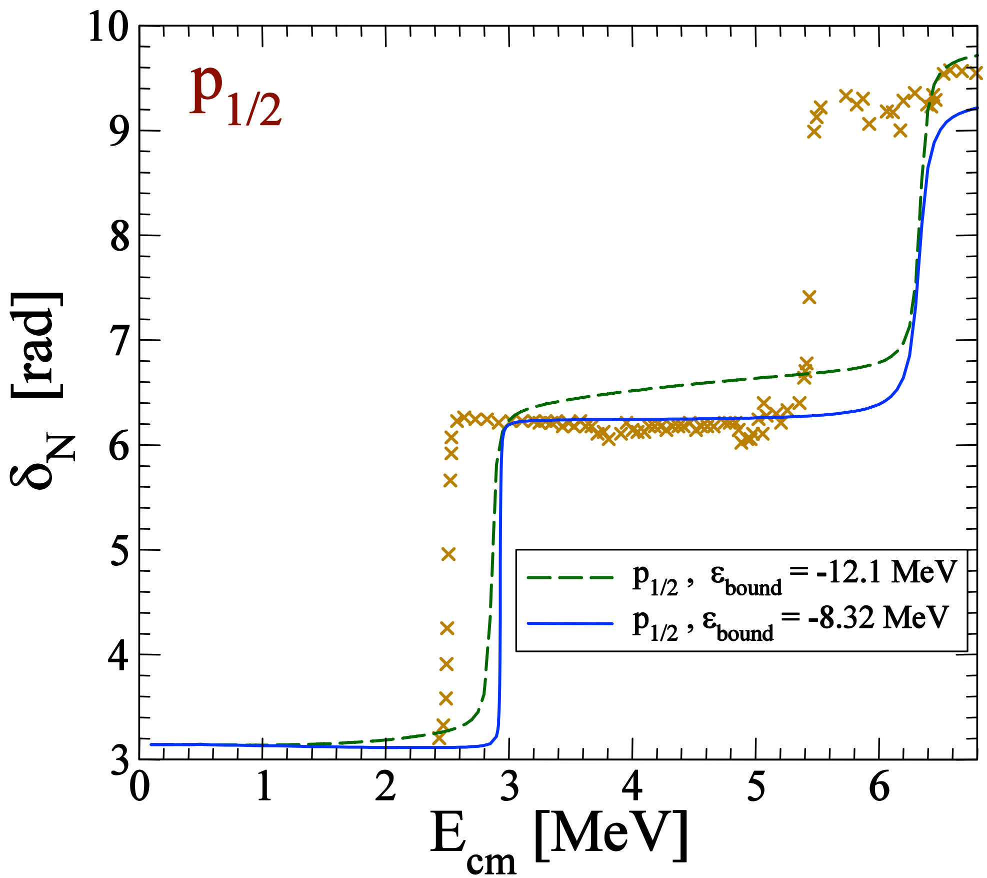
p-^{16}O phase shifts – l=1 waves



- For p waves: cannot describe separation energy and phase shift together… → need for improved H / 3NF (again!)

- To obtain the background phase shifts:

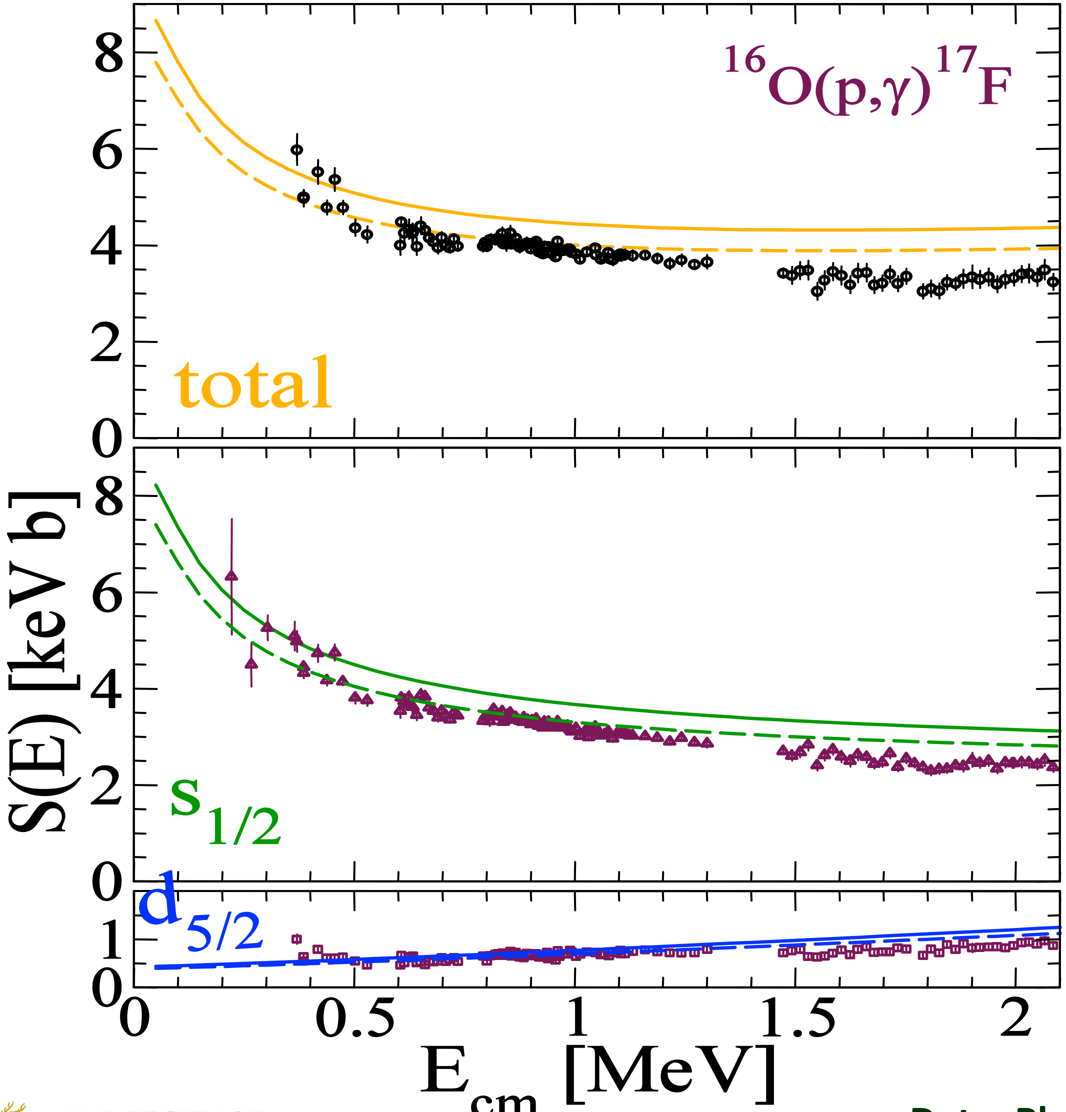
  $E_{p1/2}$ = -8.32 MeV

  $E_{p3/2}$ = -15.1 MeV

- Non-MF resonances

[C.B., B.Jennings, Phys. Rev. C**72**, 014613 (2005)]

Radiative capture



- astrophysical factor:

$$S(E) = Ee^{2\pi\eta}\sigma(E)$$

- At zero energy:

$$S(0) \approx 11.5 \ keV.b$$

CB, Jennings,
Nucl. Phys A758, 395c (2005)

Data: Phys. Rev. Lett. 79, 3837 ('97)

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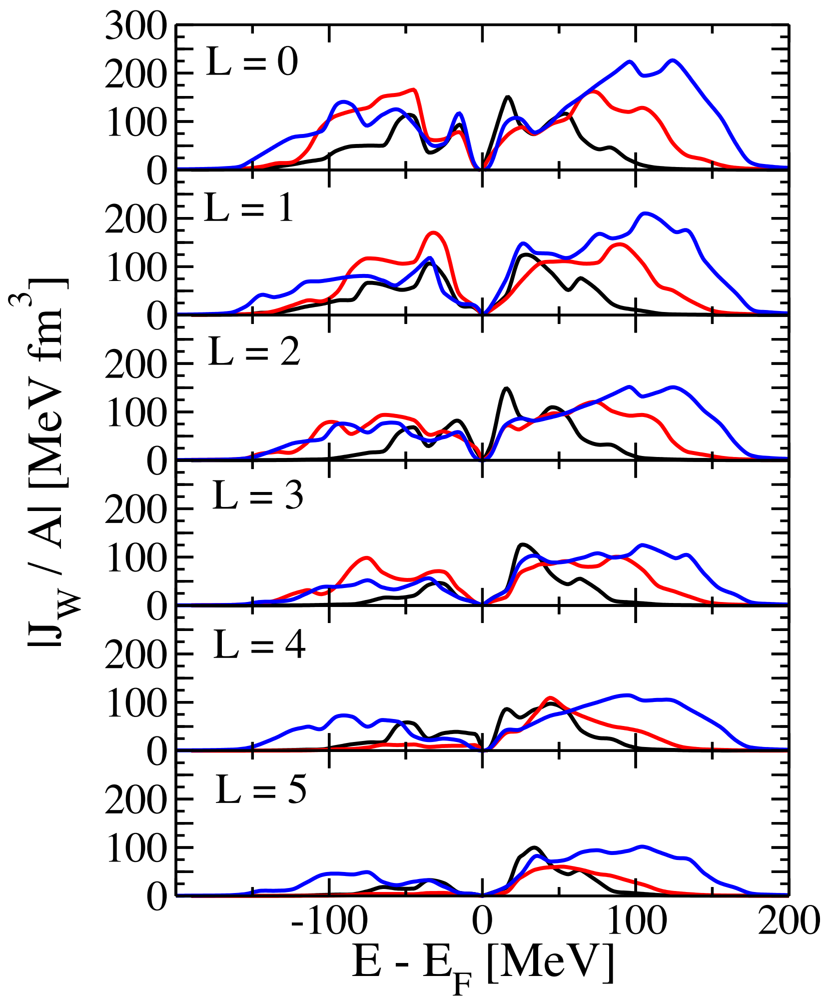
Convergence of Ab-Initio Calculated Optical Potentials



←J_w: volume integral over the imaginary opt. pot. (overall absorption)

n-^{48}Ca scattering calculated with the NN N3LO chiral interaction

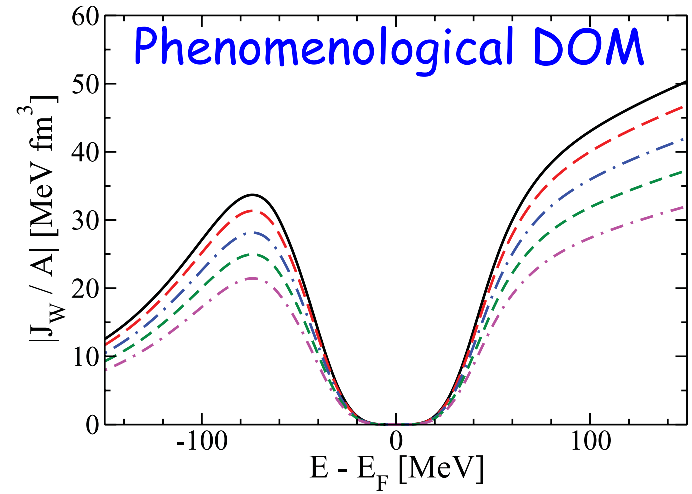
6 h.o. shells
8 h.o. shells
10 h.o. shells

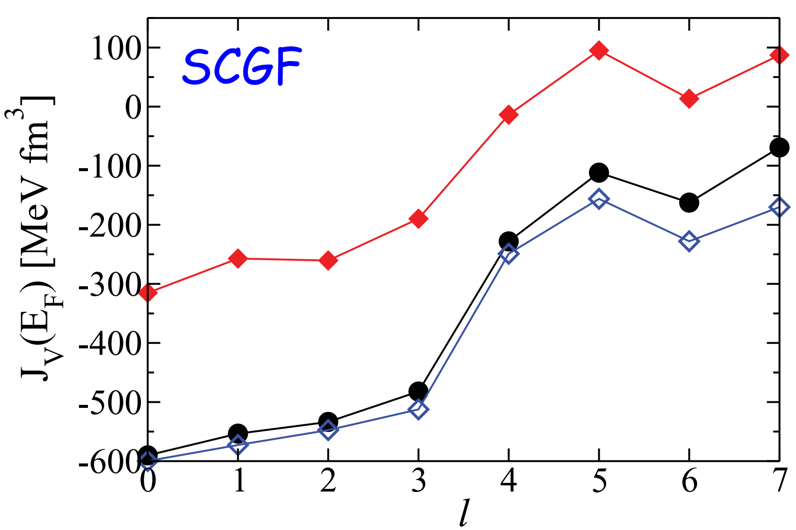
L-dependence and non locality

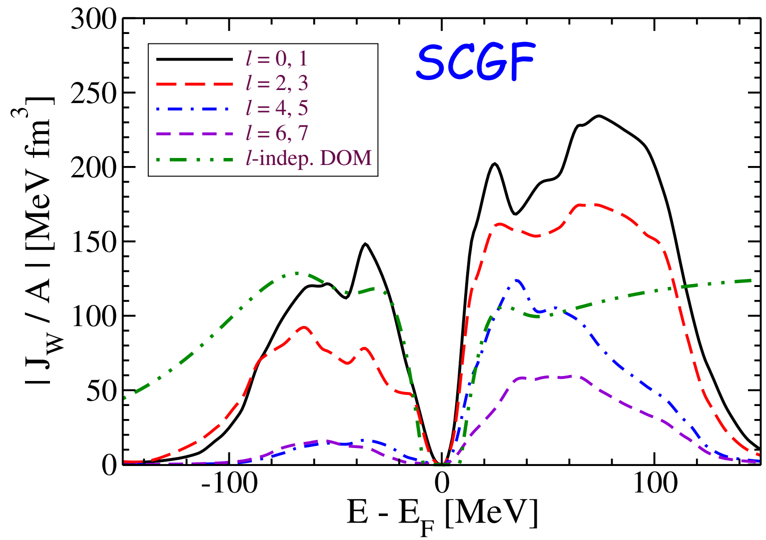
Volume integrals of central parts (real and imaginary):

$$J_W^\ell(E) = 4\pi \int dr r^2 \int dr' r'^2 \mathrm{Im}\ \Sigma_0^\ell(r, r'; E),$$

$$J_V^\ell(E) = 4\pi \int dr r^2 \int dr' r'^2 \mathrm{Re}\ \Sigma_0^\ell(r, r'; E).$$







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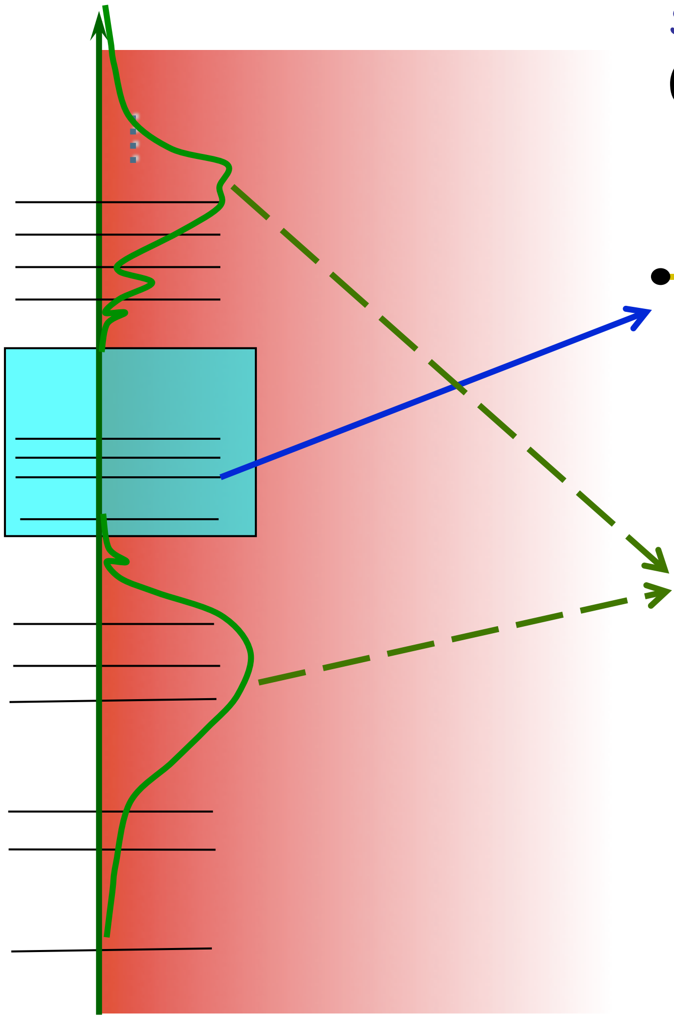
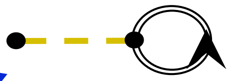
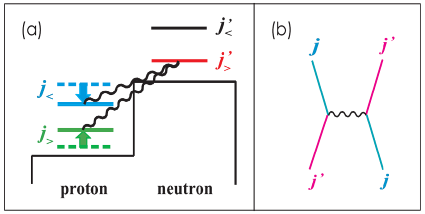
S. Waldecker, CB, W.Dickhoff – Phys. Rev. C84, 034616 (2011).

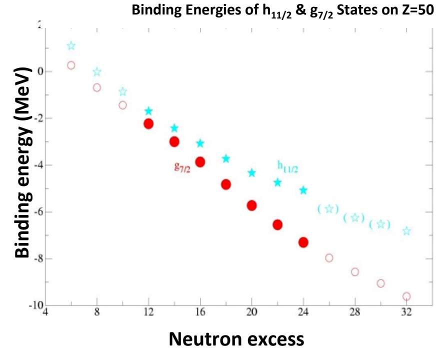
Correlations in sp energies and strengths



Single particle energies – driven by tensor + 3N force…
(see works by T. Otsuka PRL2005, 2010)



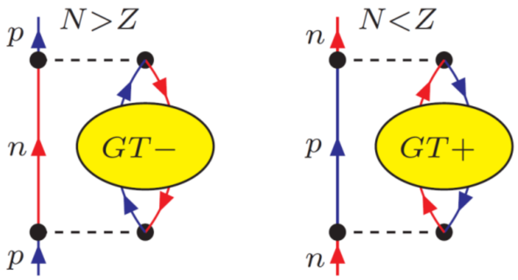




Quenching of spectral strength (spect. factor) – driven by coupling to collective modes…

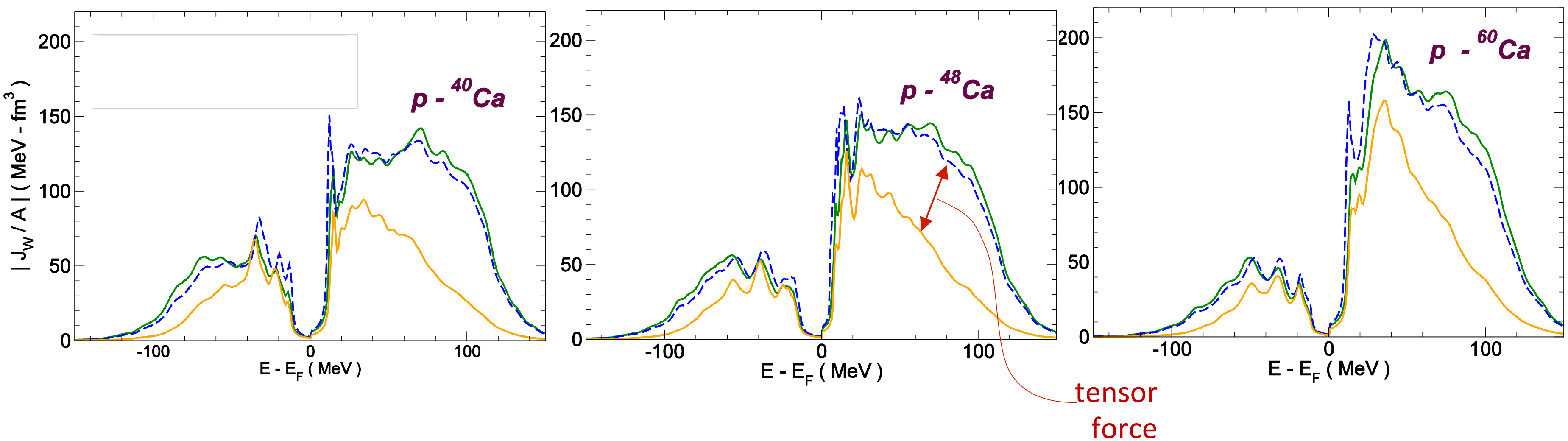
•Role of tensor force??

•Collective, charge exchange effects???



Microscopic Optical Potential from FRPA

- absorption away from E_F is enhanced by the tensor force
- little effects from charge exchange (e.g. p-^{48}Ca <-> n-^{48}Sc)



J_W: integral over the imaginary opt. pot (overall absorption)

Full FRPA result (w/ av18)
Charge-exchange d.o.f. suppressed
Tensor force suppressed

S. Waldecker, CB, W.Dickhoff – Phys. Rev. C84, 034616 (2011)

Collaborators

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P. Navratil

A. Polls

W.H. Dickhoff, S. Waldecker

D. Van Neck, M. Degroote

M. Hjorth-Jensen

Conclusions

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

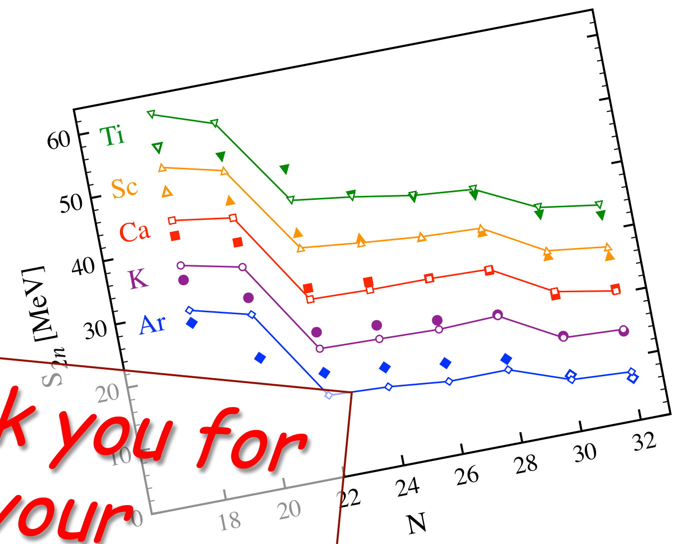
→ *Leading order 3NF are crucial to predict many important features that are observed experimentally (drip lines, saturation, orbit evolution, etc…)*

→ *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 talk, atc…].*

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

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



Thank you for your attention!!!