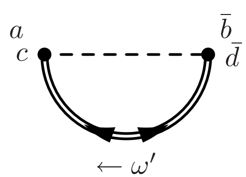
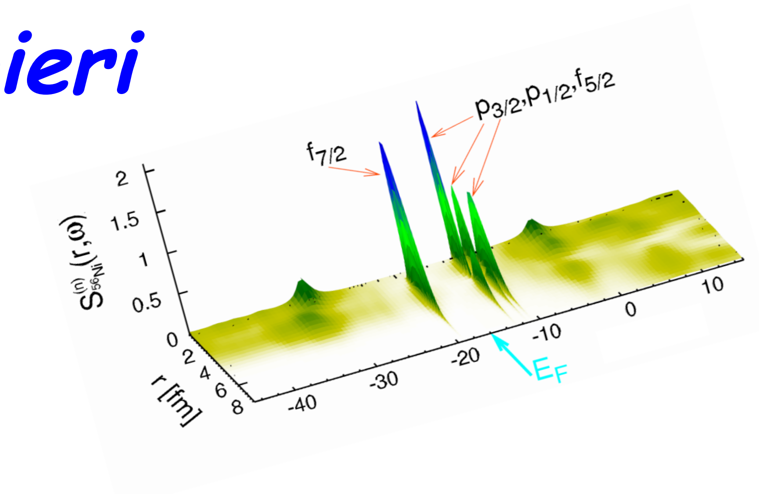
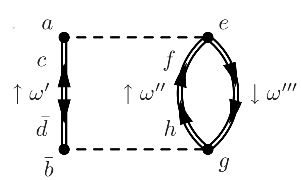
Interfaces between structure and reactions for rare isotopes and nuclear astrophysics ---- INT, Seattle, Aug. 8--Sept.2, 2011

Ab-initio Gorkov-Green's function calculations for open shell nuclei



C. Barbieri





Collaborators: V. Somà and T. Duguet

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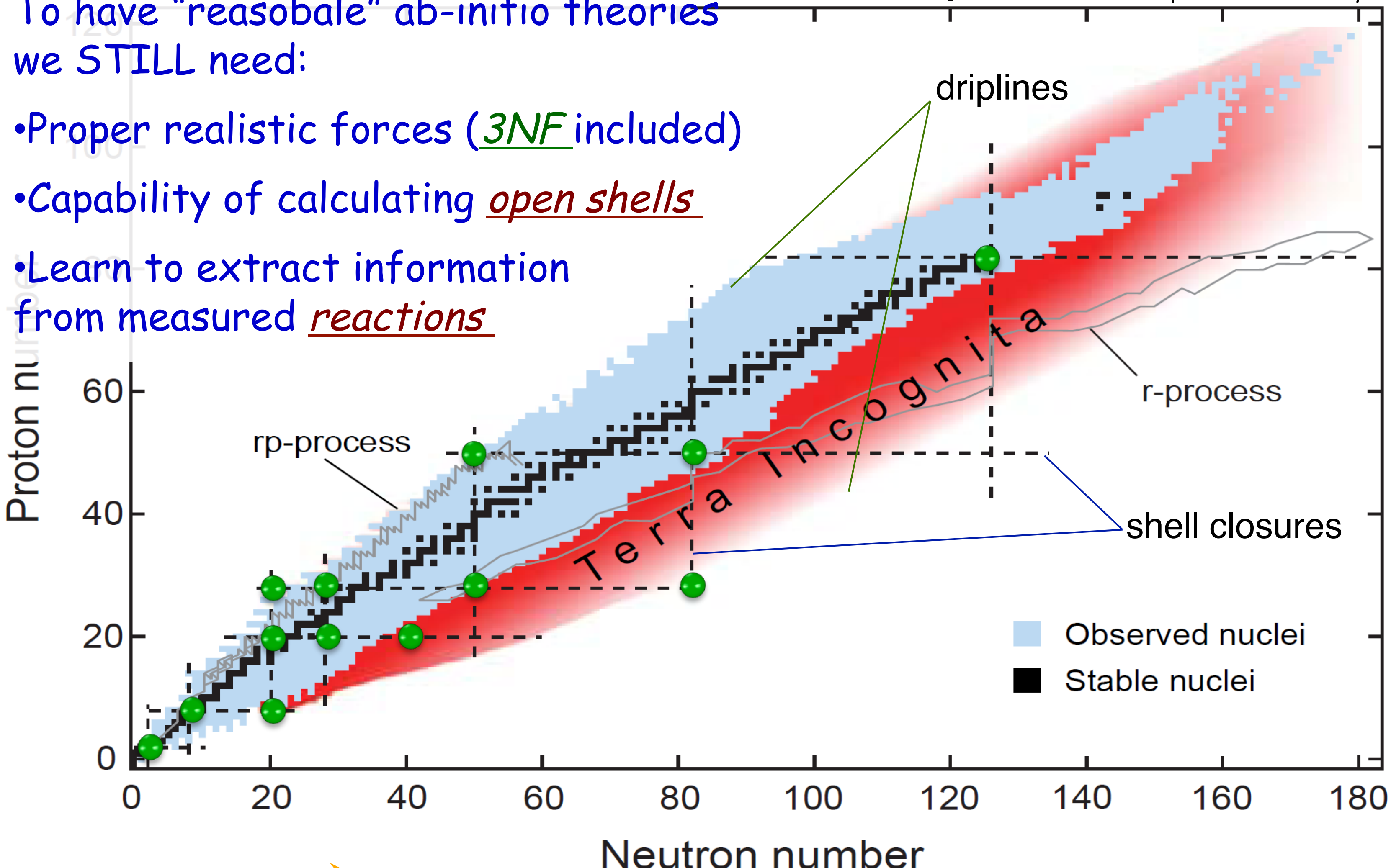
How to predict exotic isotopes?

[Picture credit: Isotope Science Facility MSUCL-1345]

To have "reasobale" ab-initio theories we STILL need:

- Proper realistic forces (3NF included)
- Capability of calculating *open shells*
- Learn to extract information from measured *reactions*



"reasonable": → not necessary convergent BUT *accurate enough, predictive* and *useful to an experimental program.*

State-of-the-art ab-initio nuclear structure theory

- Methods for an ab-initio description of *medium-mass* nuclei as of 2011

  (1) Coupled-cluster [Dean, Papenbrock, Hagen, ...]

  (2) In-medium similarity renormalization group [Tsukiyama, Bogner, Schwenk]

  (3) Self-consistent Dyson-Green's function (SCGF) [Barbieri, Dickhoff]

The present status is:

→Still in need of good nuclear Hamiltonians (3N forces mostly!)

→Only structure calculations and limited to closed-shells or A±1, A±2

(BUT calculations are GOOD!!!)

→ However, Green's functions can be extended to: Scattering observables
Open shell nuclei

Outline…

- Self-consistent Green's function in closed shells:

  - *Faddeev random-phase approximation (FRPA): ^{4}He benchmark*
    Scattering (N-A)

- Open shells: Gorkov-GF formalism

  - *G-SCGF formalism at 2nd order*
  - *Preliminary results*

- Applications: spectroscopic factors

- Applications: dispersive optical potentials
  - *S. Waldecker, CB, W. Dickhoff, arXiv:1105.4257*

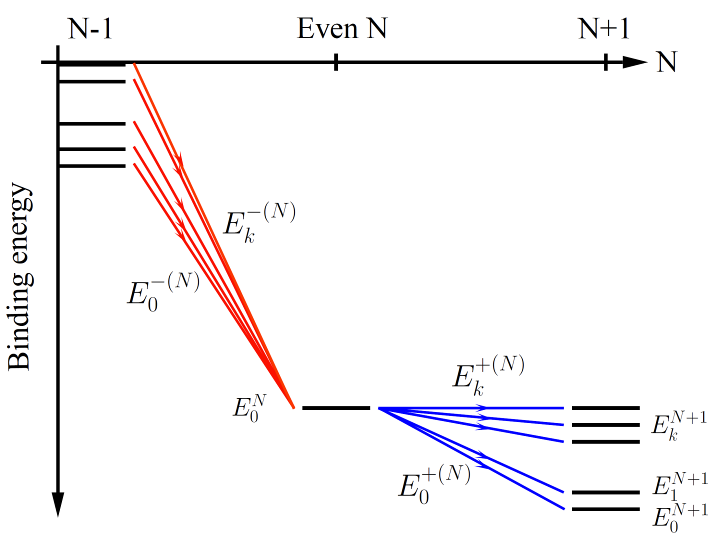
Concepts of Spectral Funstions
and
Many-Body Green's Functions

Green's functions in many-body theory

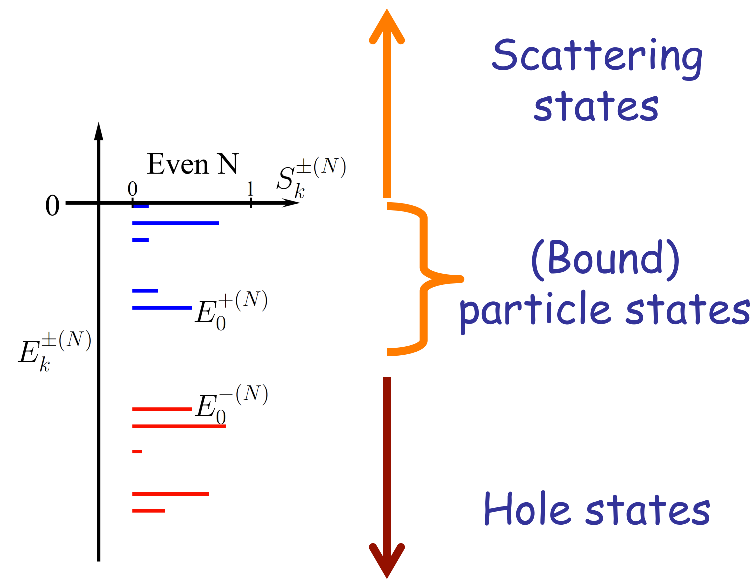
One-body Green's function (or propagator) describes the motion of quasi-particles and holes:

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

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



[pics. J. Sadoudi]



Separation energies and transfer strengths

Green's functions in many-body theory

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

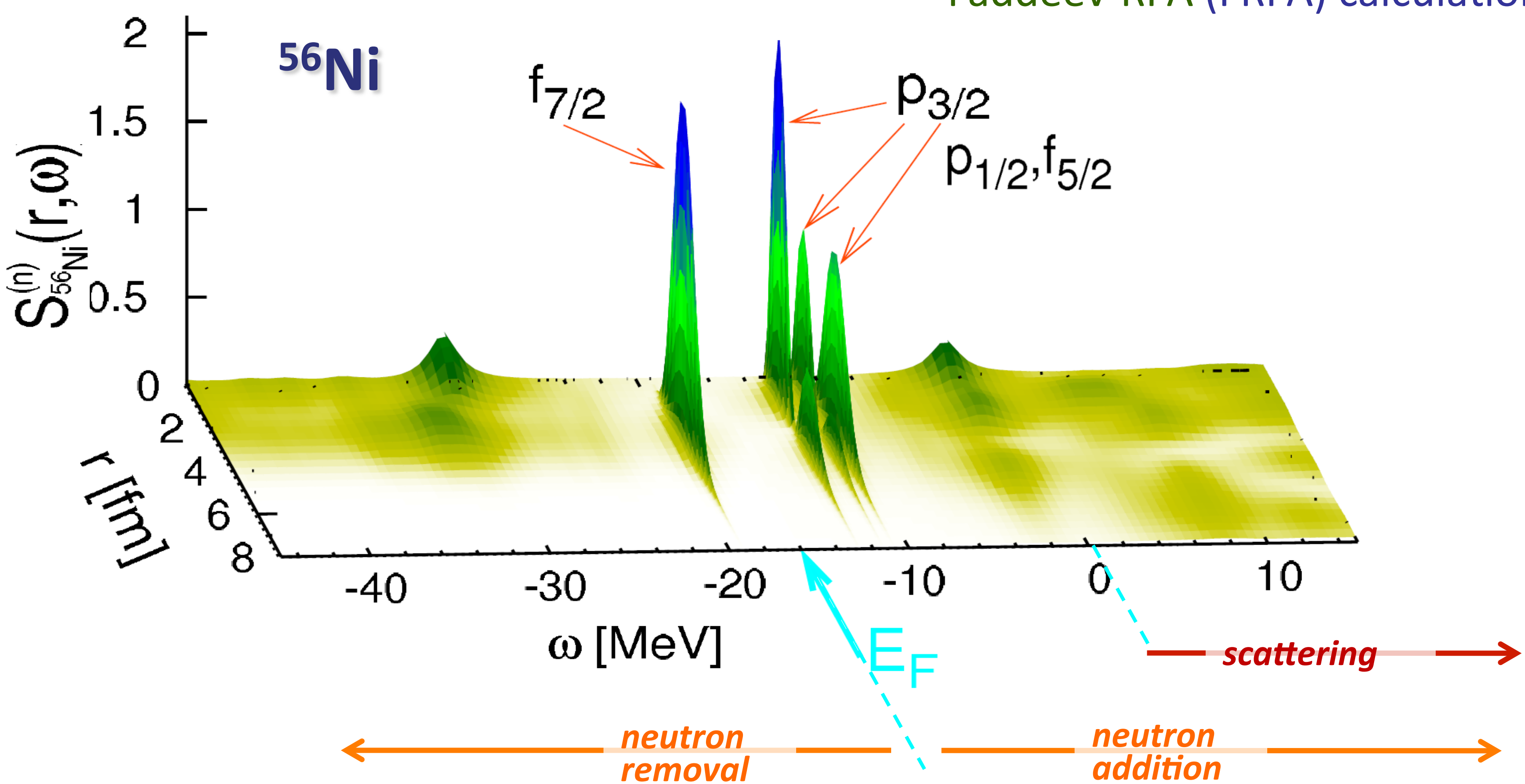
$$g_{\alpha\beta}(E) = \sum_n \frac{\langle\Psi_0^A|c_\alpha|\Psi_n^{A+1}\rangle\langle\Psi_n^{A+1}|c_\beta^\dagger|\Psi_0^A\rangle}{E-(E_n^{A+1}-E_0^A)+i\eta} + \sum_k \frac{\langle\Psi_0^A|c_\beta^\dagger|\Psi_k^{A-1}\rangle\langle\Psi_k^{A-1}|c_\alpha|\Psi_0^A\rangle}{E-(E_0^A-E_k^{A-1})-i\eta}$$

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

$$S(r,\omega) = \frac{\mp 1}{\pi}\mathrm{Im}\; g_{rr}(\omega) = \sum_n |\langle\Psi_n^{A\pm1}|c_r^{(+)}|\Psi_0^A\rangle|^2\,\delta(\omega \pm (E_0^A - E_n^{A\pm1}))$$

Spectral Function of ^{56}Ni

Faddeev-RPA (FRPA) calculations

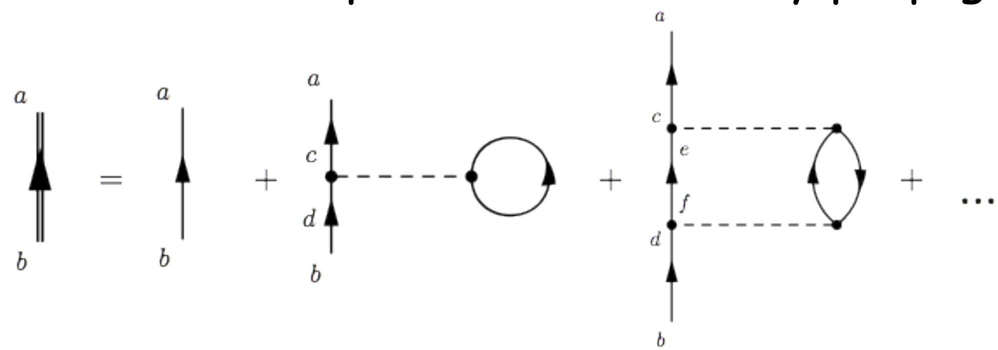


[CB, M.Hjorth-Jensen, Pys. Rev. C**79**, 064313 (2009)

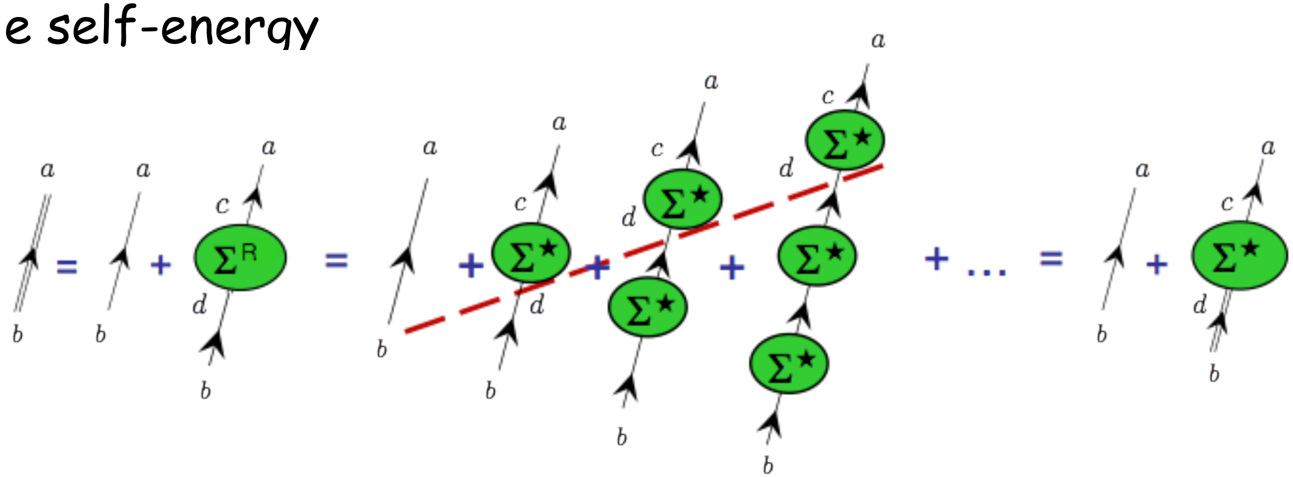
CB, Phys. Rev. Lett. **103**, 202502 (2009)]

Dyson equation & self-energy

✺ Perturbative expansion of one-body propagator



✺ Irreducible self-energy



✺ Dyson equation

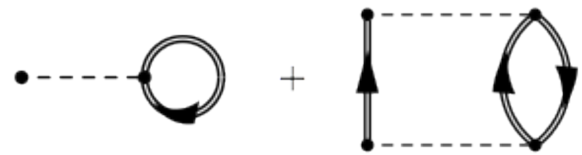
$$G_{ab}(\omega) = G^{(0)}_{ab}(\omega) + \sum_{cd} G^{(0)}_{ac}(\omega)\, \Sigma^\star_{cd}(\omega)\, G_{db}(\omega)$$

Solving the Dyson equation

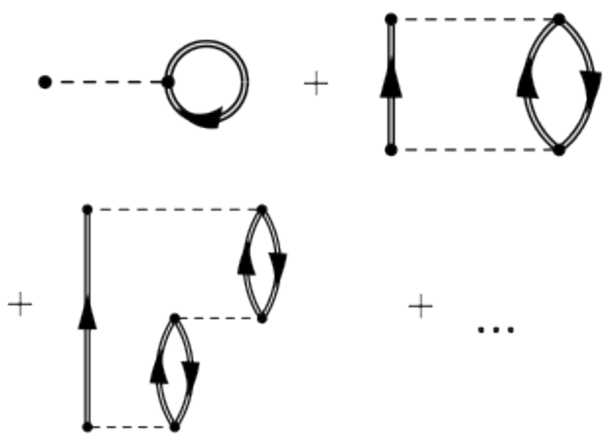
- Different approximations to the self-energy (**self-consistent** approaches)

➡ Hartree-Fock

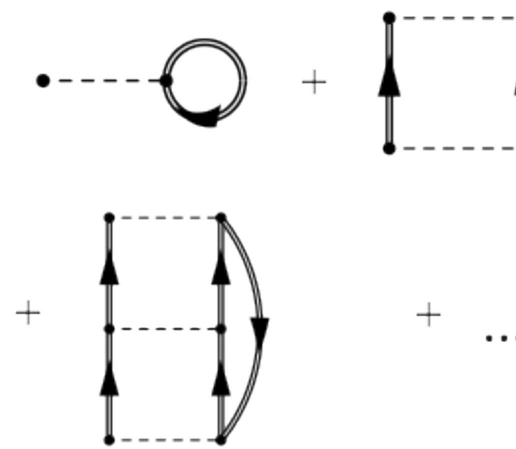
➡ Second order



➡ RPA



➡ Ladder (or T-matrix)



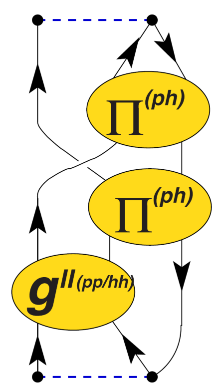
Applications to doubly-magic nuclei

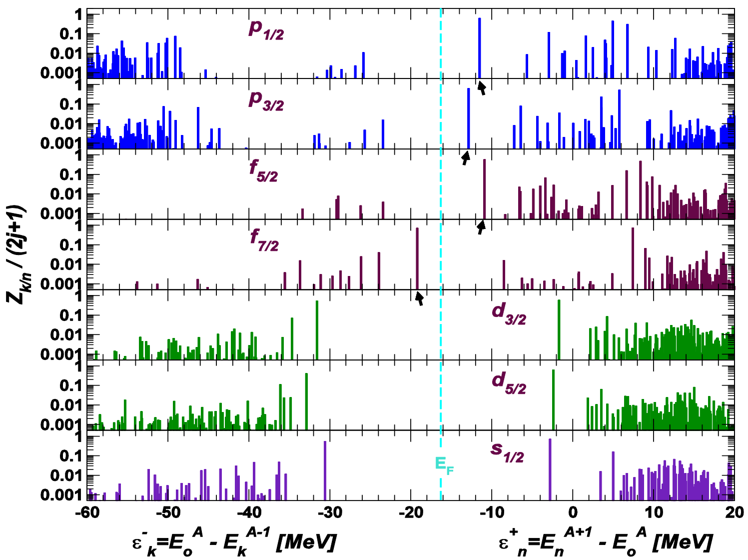
✳ Faddeev-RPA approximation for the self-energy

collective vibrations

particle-vibration coupling

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





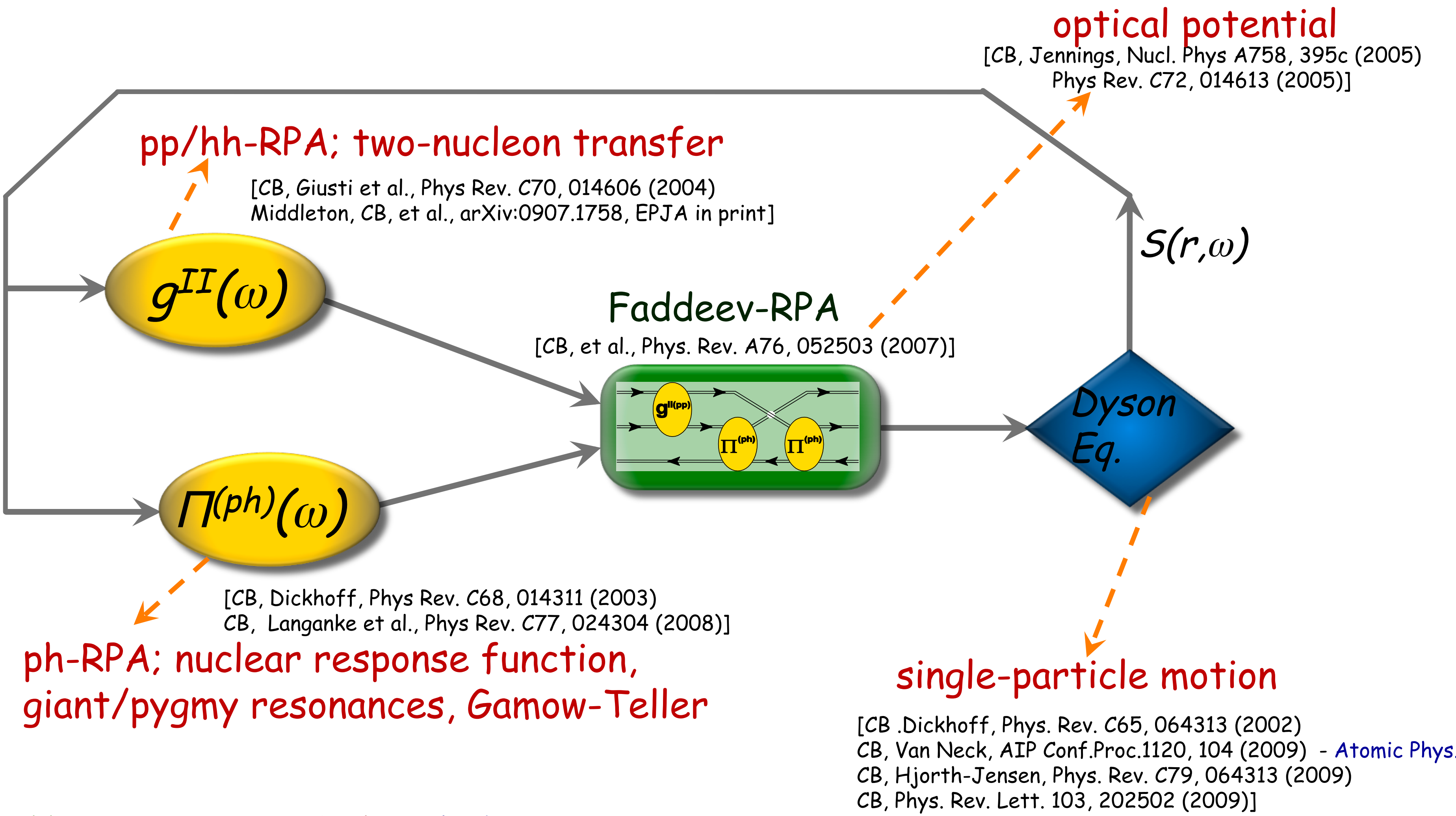
✳ Successful in medium-mass doubly-magic systems

Expansion breaks down when pairing instabilities appear

Explicit configuration mixing

Single-reference: Bogoliubov (Gorkov)

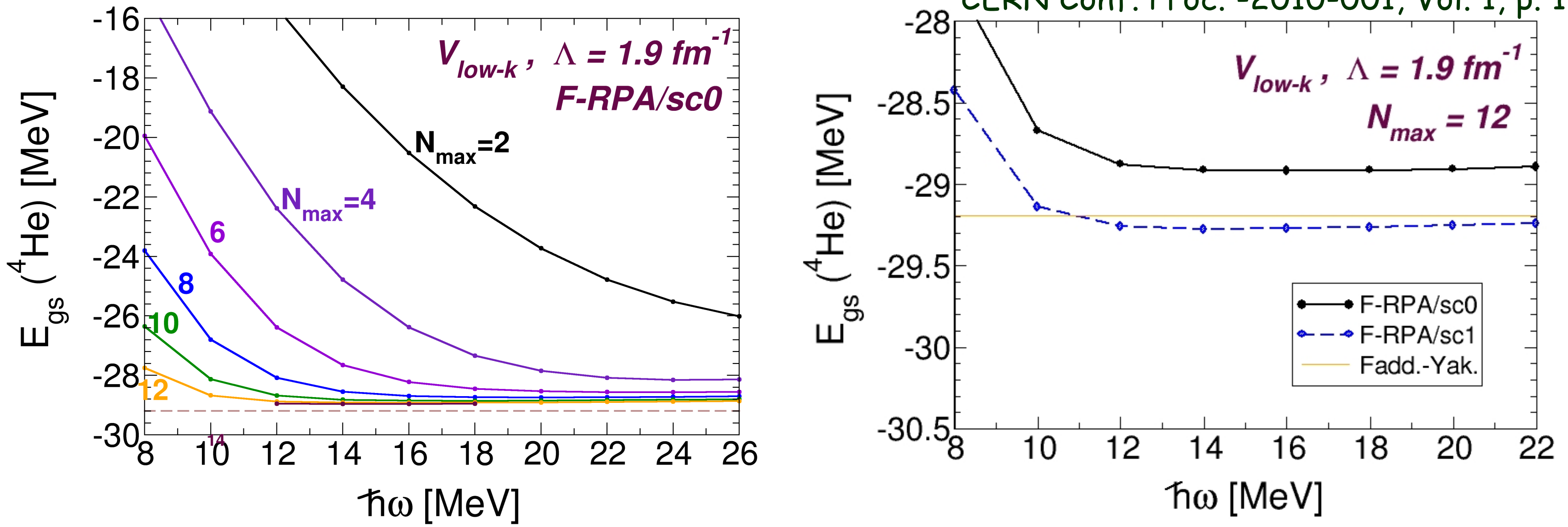
Self-Consistent Green's Function Approach



Faddeev-RPA is a *many-body* method:
- ✓random phase approx. (RPA) for collective vibrations
- ✓Faddeev eqs. for particle-vibration coupling

Binding Energy – ^{4}He Case

[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

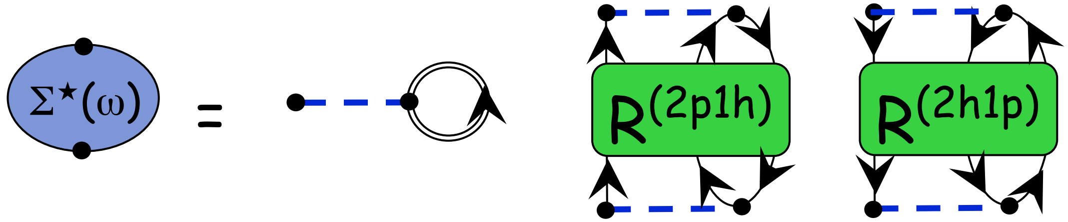
	FRPA/sc0	FRPA/sc	Exact:
V_{low-k}:	-29.00(2)	-29.2 ±0.15	-29.19(5) (Fadd.-Yak.)

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

self-consistency in the mean field only

estimates from different approx. to self-consistency

Comparison to CC benchmark



[C. B., arXiv:0909.0336;
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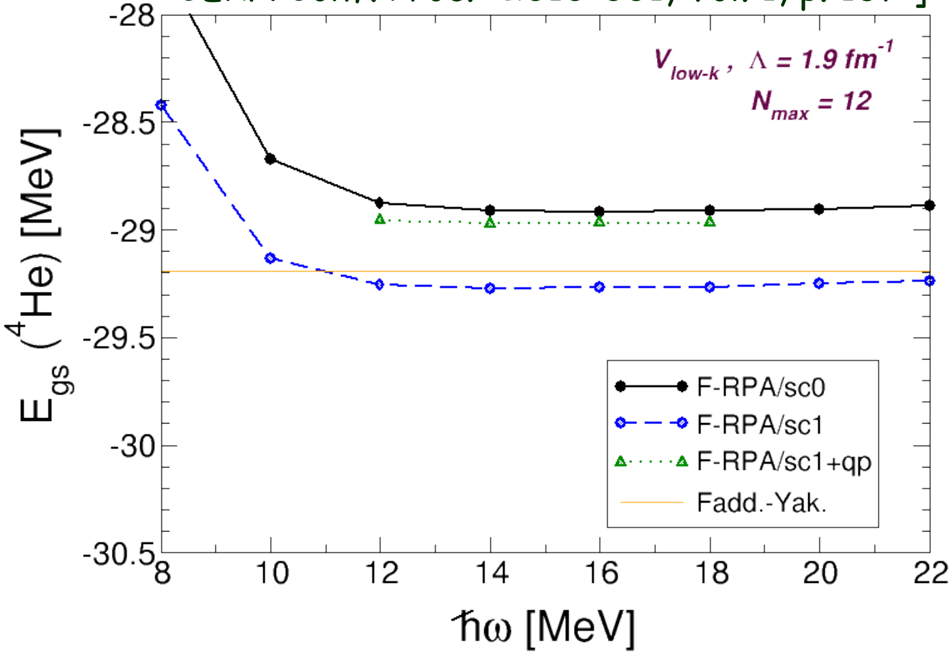
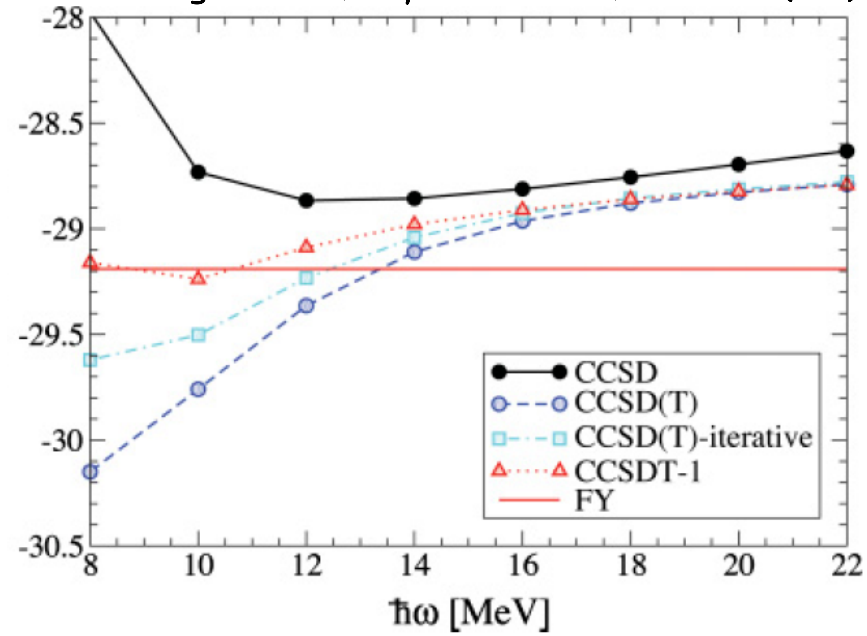


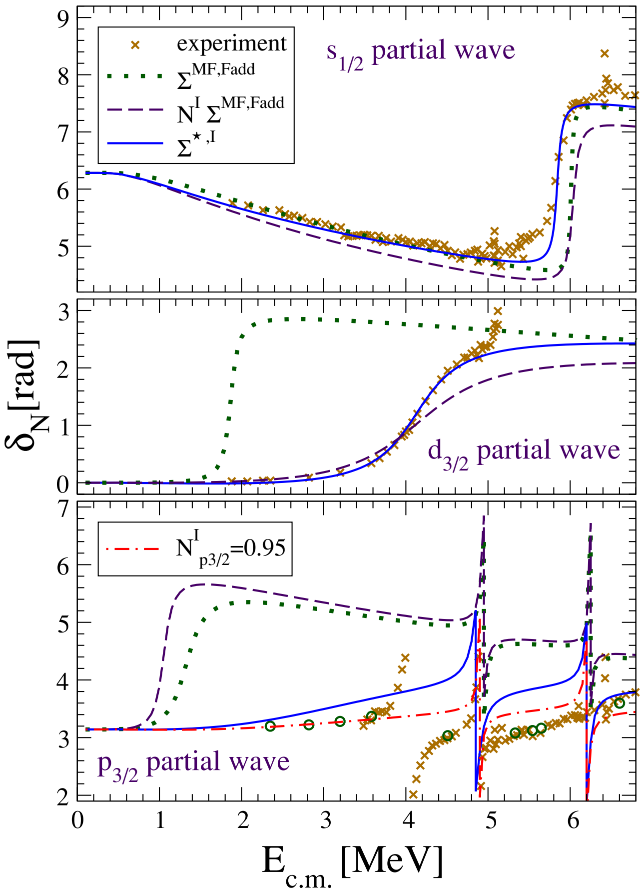
Coupled-Cluster benchmark,
G. Hagen et al, Phys. Rev. C76, 044305 ('07)



p-^{16}O phase shifts and <^{16}O|^{17}F> overlaps

- EITHER the phase shifts OR bound states can be made in agreement with the experiment! (with minor phen. corrections)
- BUT the calculation *did not* reproduce boht at the same time

→ need for improved Hamiltoninans / 3NF



- AV18 interaction
- Continuum is treated in full using momentum space
- *Non-MF resonances "OK"*

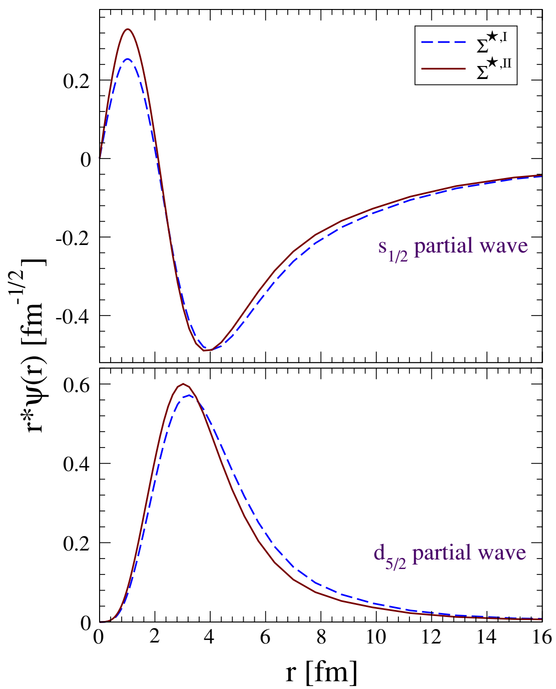


FIG. 6. (Color online) Radial part of the overlap wave functions between ^{16}O and the bound $d_{5/2}$ and $s_{1/2}$ states of ^{17}F.

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

Gorkov formalism: open shells

(CB, V. Somà, T. Duguet -- in completion)

Applications to doubly-magic nuclei

- Faddeev-RPA approximation for the self-energy

collective vibrations

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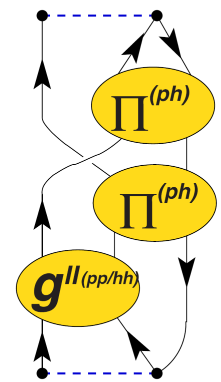
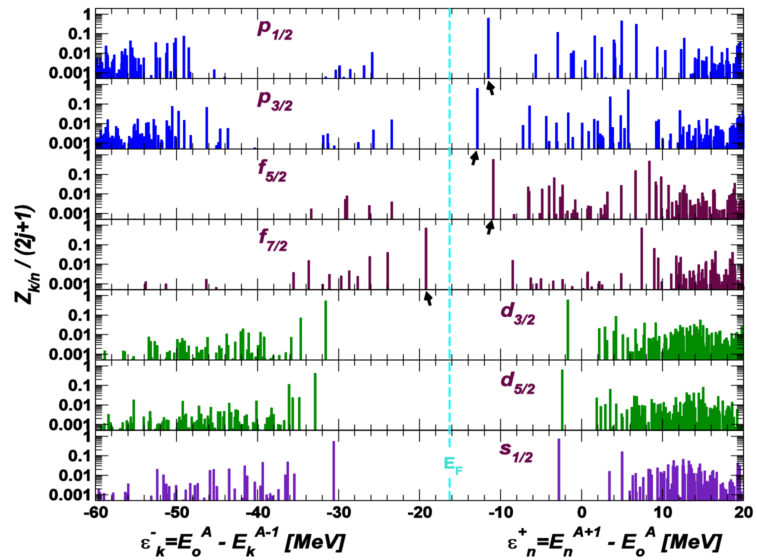
[C.B. *et al*. 2001-2011]





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Going to open-shells: Gorkov ansatz

- 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 $N = \langle \Psi_0 | N | \Psi_0 \rangle$

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

Gorkov Green's functions and equations

✳ 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

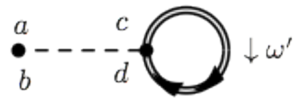
$$\mathbf{\Sigma}^\star_{ab}(\omega) \equiv \begin{pmatrix} \Sigma^{\star\,11}_{ab}(\omega) & \Sigma^{\star\,12}_{ab}(\omega) \\ \Sigma^{\star\,21}_{ab}(\omega) & \Sigma^{\star\,22}_{ab}(\omega) \end{pmatrix}$$

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

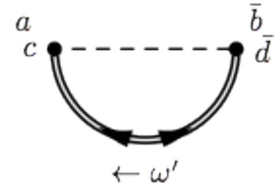
1^{st} & 2^{nd} order diagrams and eigenvalue problem

- 1st order ➟ energy-independent self-energy

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

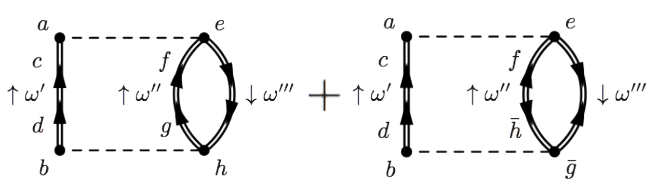


$\Sigma_{ab}^{12\,(1)} =$

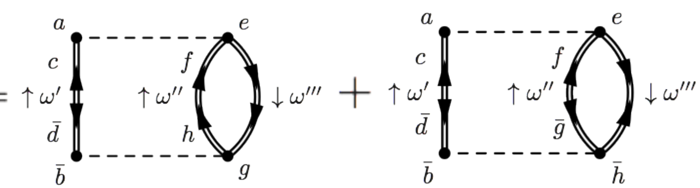


- 2nd order ➟ energy-dependent self-energy

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



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



- Gorkov equations ⟶ eigenvalue problem

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

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

Gorkov equations

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

⇓

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

Energy *independent* eigenvalue problem

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

Green's functions: important features

➟ *Self-consistent approach*

➟ *Direct connection to observables*

➟ *Improvability (diagrammatic expansion)*

➟ *Control over many-body requirements (conserving approximations)*

➟ *Possible connection to nuclear reactions (dispersive optical models)*

✺ *Drawbacks*

➟ *Technically and computationally involved*

Preliminary Gorgov results

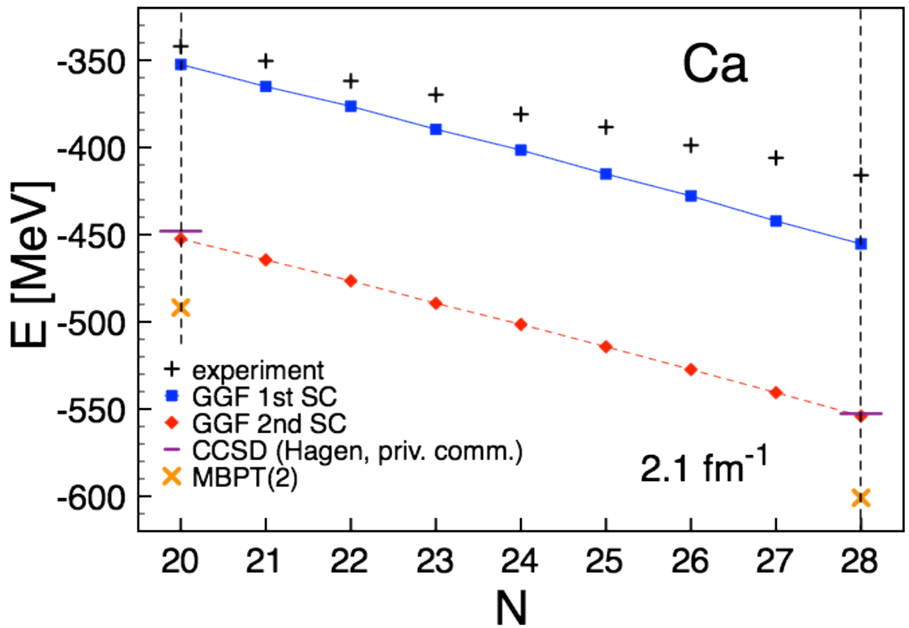
Results

- Calculations of $^{40-48}$Ca isotopes
  - Spherical HO basis (no-core): 7 shells, $\hbar\omega$ = 22 MeV (very preliminary!)
  - V_{low-k} from Ch-EFT N^{3}LO potential with cutoff Λ = 2.1 & 2.5 fm^{-1} [Entem and Machleidt 2003]
  - NN interaction only

- CEA-CCRT massively-parallel high-performance cluster
  - ~ 40 000 cores, ~ 300 Tflops total
  - Parallelized code
    - → Essential for converged self-consistent second-order calculations

Binding energies

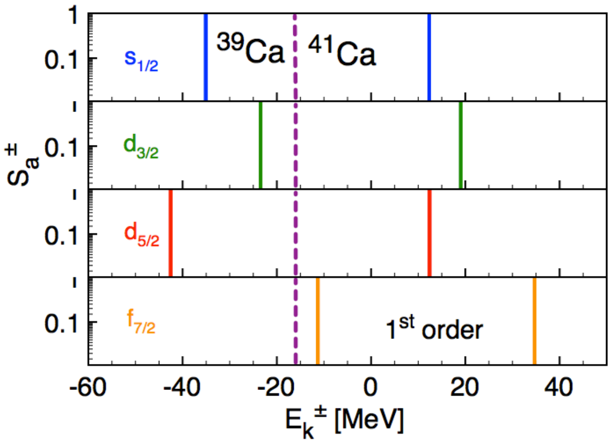
- Systematic along isotopic/isotonic chains has become available



- ➡ Correlation energy close to CCSD and FRPA (thorough comparison planed)
- ➡ Overbinding with A: traces need for (at least) NNN forces
- ➡ Effect of self-consistency significant; i.e. less bound than MBPT2

Spectral function

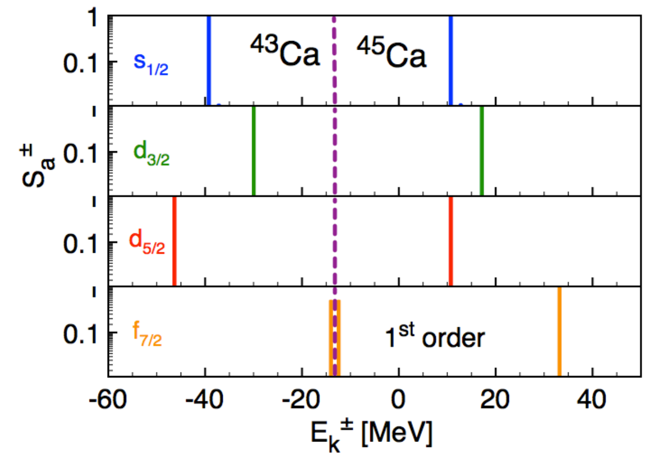
Dyson 1st order (HF)



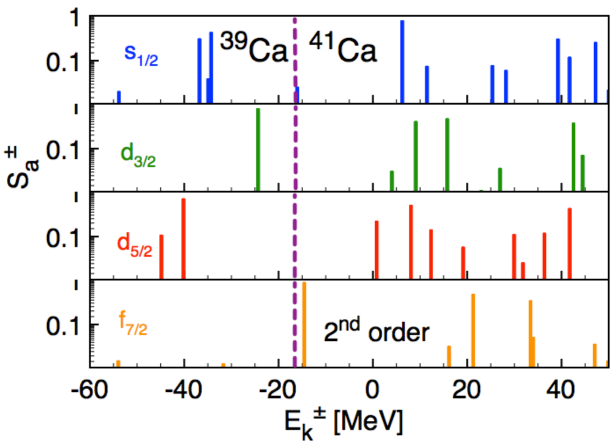
Fragmentation

Static pairing

Gorkov 1st order (HFB)

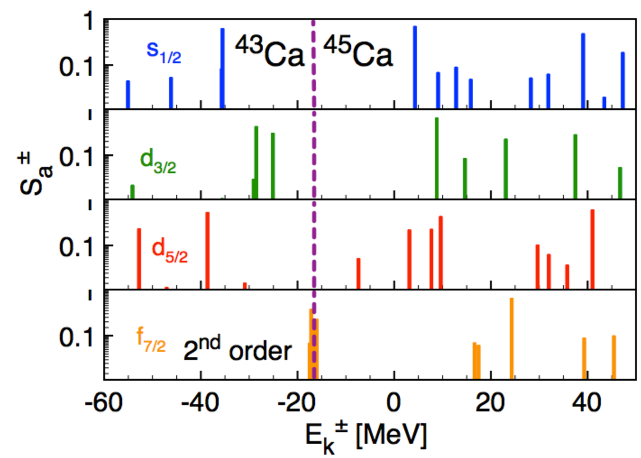


Dyson 2nd order



Dynamical fluctuations

Gorkov 2nd order

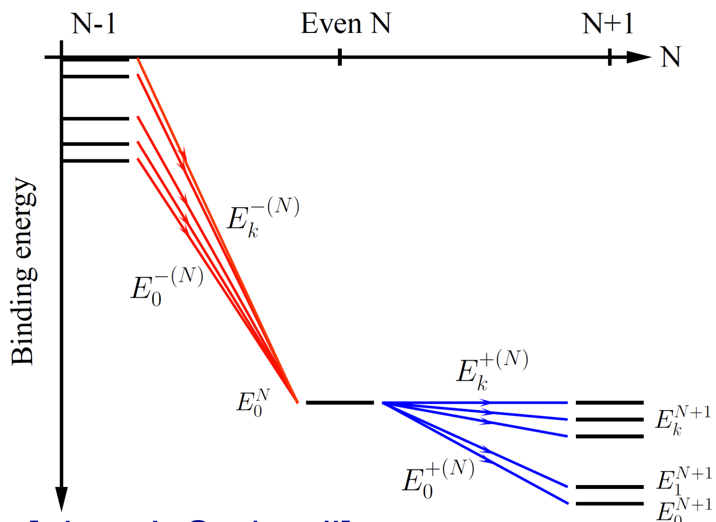


Shell structure evolution

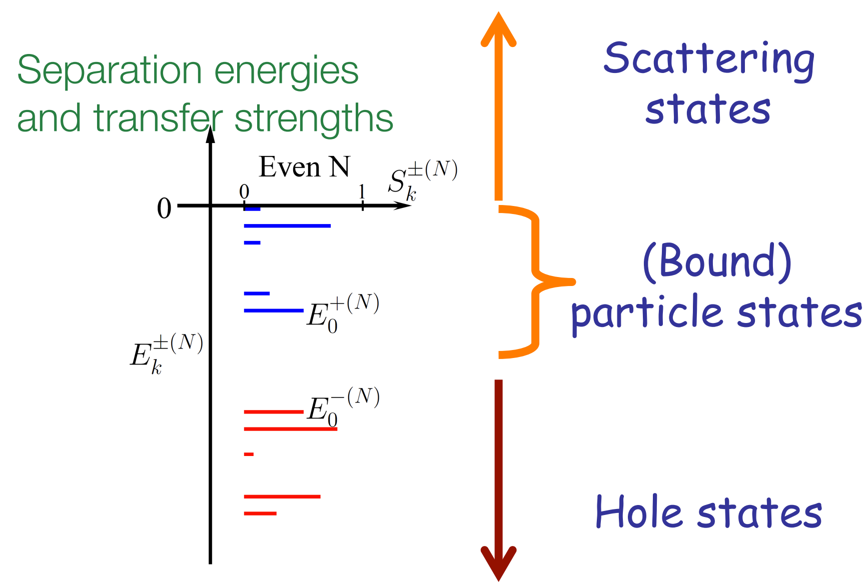
✷ ESPE collect fragmentation of "single-particle" strengths from both N±1

$$\epsilon_a^{cent} \equiv h_{ab}^{cent}\,\delta_{ab} = t_{aa} + \sum_{cd} \bar{V}_{acad}^{NN}\,\rho_{dc}^{[1]} + \sum_{cdef} \bar{V}_{acdaef}^{NNN}\,\rho_{efcd}^{[2]} \equiv \sum_k S_k^{+a} E_k^{+} + \sum_k S_k^{-a} E_k^{-}$$

[Baranger 1970, Duguet, CB, *et al.* 2011]



[pics. J. Sadoudi]



➟ ESPE not to be confused with quasiparticle peak

➟ Particularly true for low-lying state in open-shell due to pairing

Shell structure evolution

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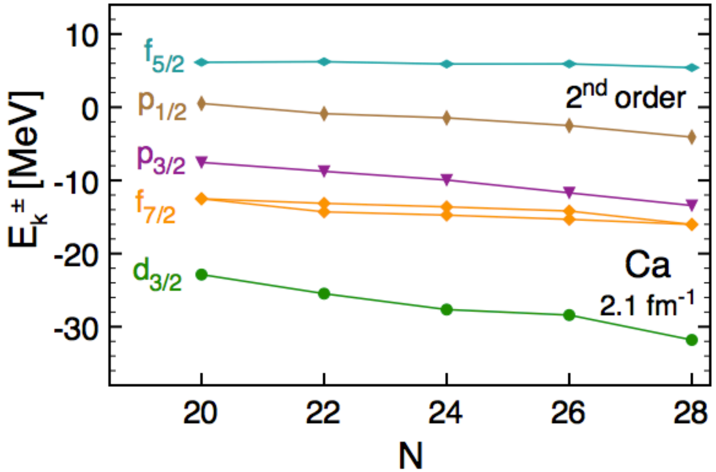
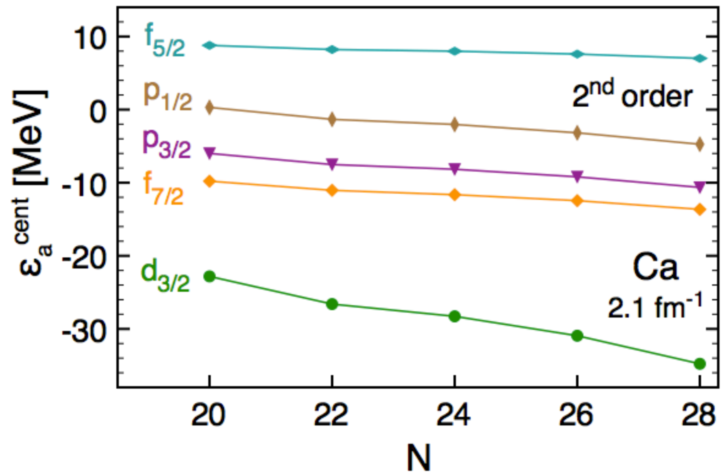
$$\epsilon_a^{cent} \equiv h_{ab}^{cent}\,\delta_{ab} = t_{aa} + \sum_{cd} \bar{V}_{acad}^{NN}\,\rho_{dc}^{[1]} + \sum_{cdef} \bar{V}_{acdaef}^{NNN}\,\rho_{efcd}^{[2]} \equiv \sum_k S_k^{+a} E_k^{+} + \sum_k S_k^{-a} E_k^{-}$$

[Baranger 1970, Duguet, CB, *et al*. 2011]

Quasiparticle peaks



Centroids

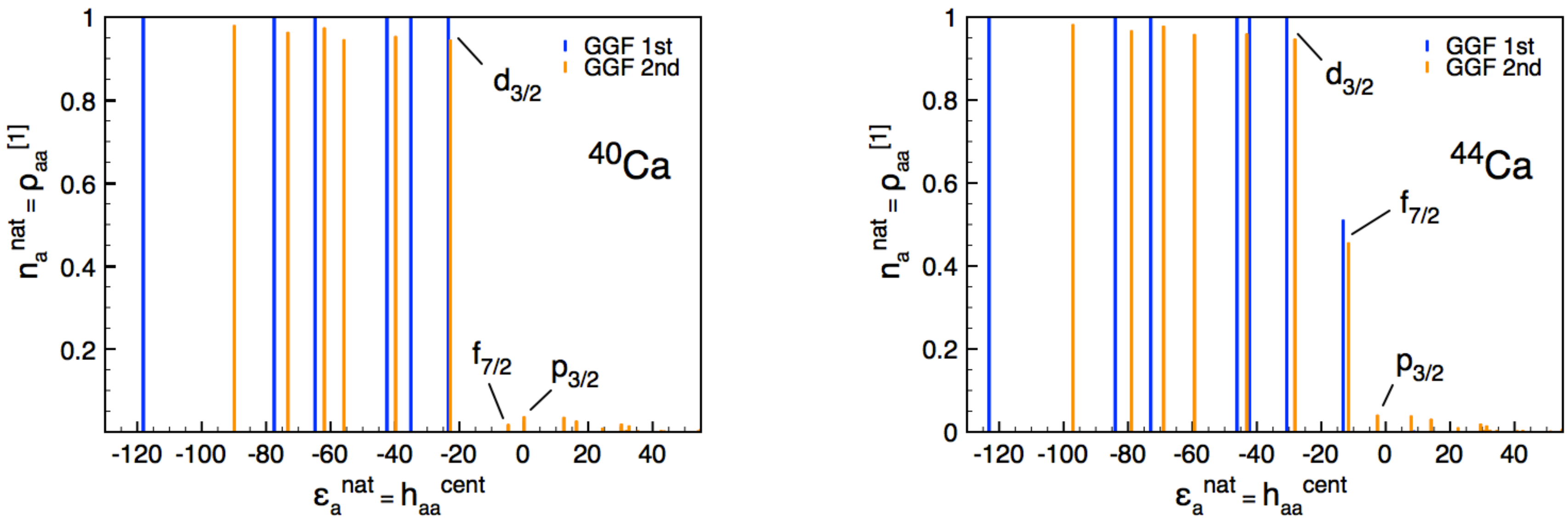


➟ ESPE not to be confused with quasiparticle peak

➟ Particularly true for low-lying state in open-shell due to pairing

Natural single-particle occupation

- Natural orbit a: $\rho_{ab}^{[1]} = n_a^{nat} \delta_{ab}$
- Associated energy: $\varepsilon_a^{nat} = h_{aa}^{cent}$



- Dynamical correlations similar for doubly-magic and semi-magic
- Static pairing essential to open-shells

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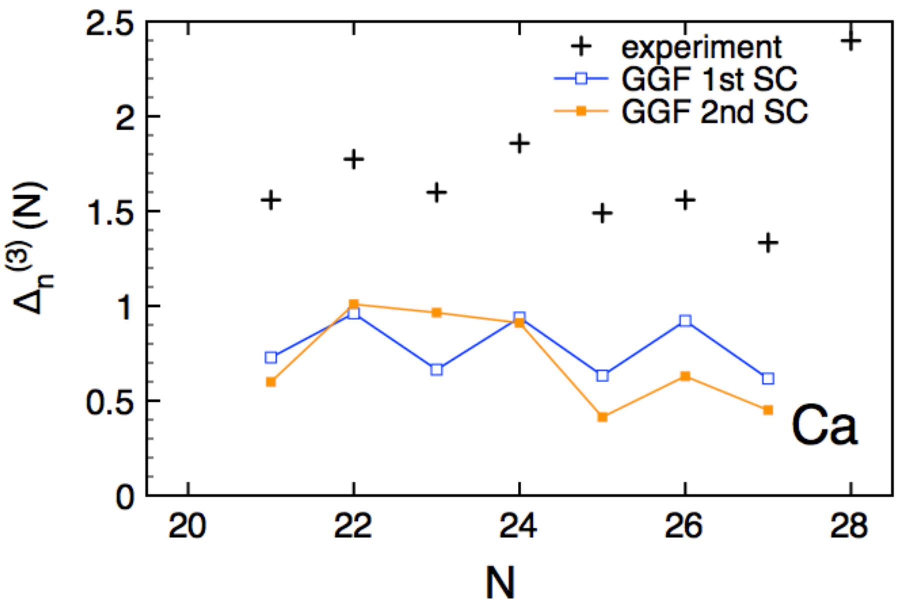
Pairing gaps

- Three-point mass differences

$$\Delta_n^{(3)}(N) = \frac{(-1)^N}{2} \frac{\partial \mu_n}{\partial N} + \Delta_n$$



➟ Systematic underestimation of experimental gaps

➟ Missing NNN in Σ^{11} changes picture qualitatively

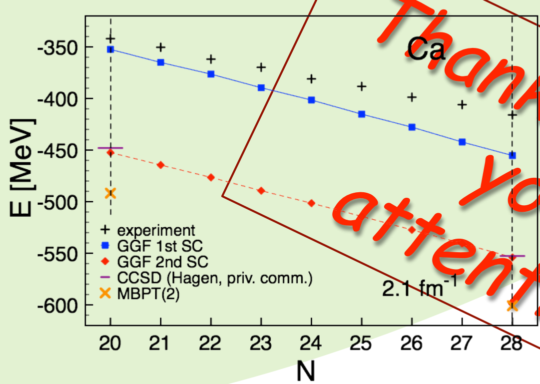
Summary

• Self-Consistent Green's Functions (SCGF), is a microscopic *ab-initio* method applicable to medium mass nuclei.

•The *greatest advantage* is the link to experimental information (→ spectroscopy)

• *The bigger challenges are:*
  - *Approach open-shells*
  - *Consistent description of structure and reactions*

•*SCGF* are the *optimal* choice
  - extension to Gorkov-formalism
    - →Open-shell nuclei
    - →Reactions at driplines
    - →structure of next generation EDF



Thank you for your attention!!!

• Three nucleon forces (3NF) are a *MUST* for accurate predictions of exotic isotopes.

Collaborators

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Quasiparticle states and spectroscopic factors

Dependence of Spect. Fact. from p-h gap

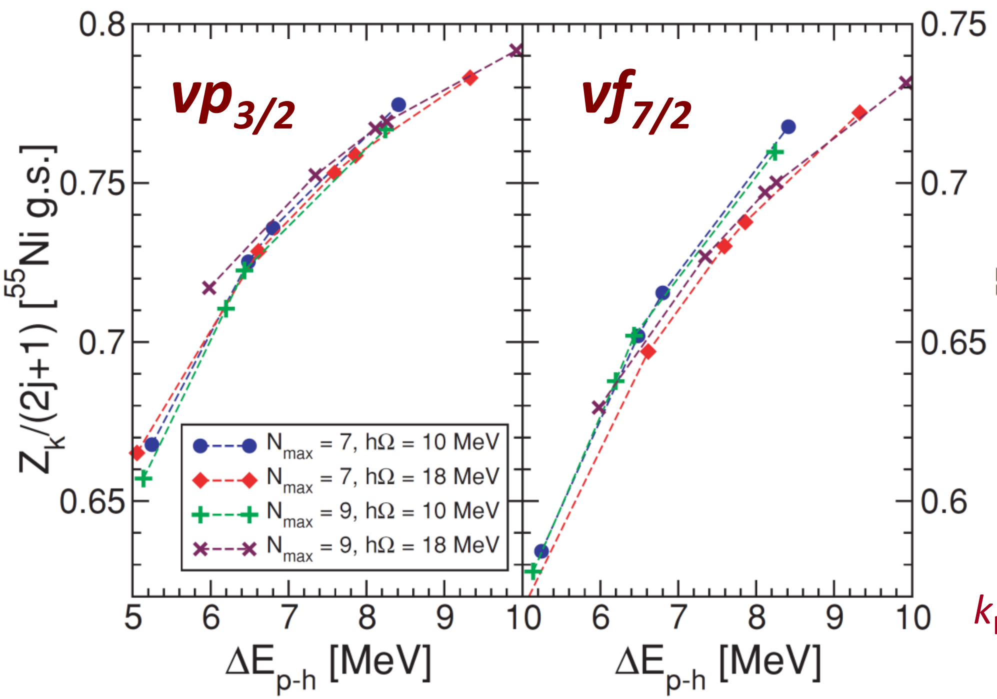
N3LO needs a monopole correction to fix the p-h gap:

$$\begin{cases} \Delta V^T_{fr} \rightarrow \Delta V^T_{fr} - (-1)^T \kappa_M , \\ \Delta V^T_{ff} \rightarrow \Delta V^T_{ff} - 1.5(1-T)\kappa_M , \end{cases}$$

$r \equiv p_{3/2}, p_{1/2}, f_{5/2}$

$f \equiv f_{7/2}$

Experimental Eph is found for k_M =0,57

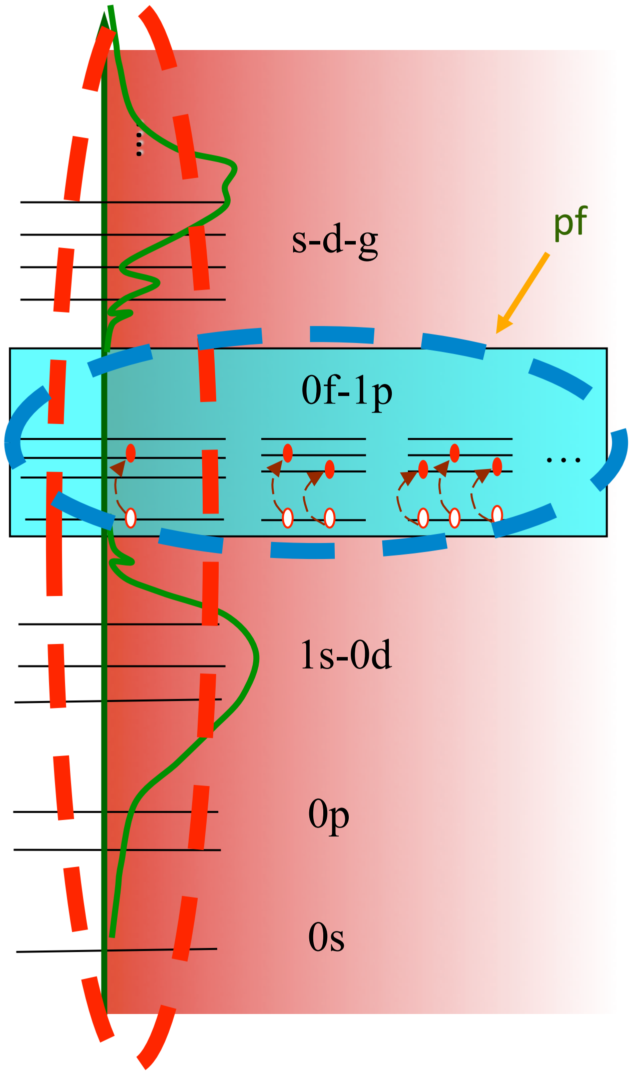


k_M = 0.4-0.7 MeV

small k_M ← → large k_M

N3LO interaction + monopole corr. **[CB, M.Hjorth-Jensen, Pys.Rev.C79, 064313 (2009)]**

Correlations & model space (RPA and SM)



Particle-vibration coupling dominates the quenching of spectroscopic factors

Relative strength among fragments requires shell-model approach

[see, e.g. Utsuno et al., AIP Conf. Proc. 1120, 81 (2009). Tsang et al., Phys. Rev. Lett. 102, 062501 (2009)]

		10 osc. shells			Exp. [30]	$1p0f$ space		
		FRPA (SRC)	full FRPA	FRPA $+\Delta Z_\alpha$		FRPA	SM	ΔZ_α
	^{57}Ni:							
^{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:							
^{55}Ni	$\nu 0f_{7/2}$	0.95	0.72	0.69		0.89	0.86	-0.03
	^{57}Cu:							
^{57}Cu	$\pi 1p_{1/2}$	0.96	0.66	0.62		0.80	0.76	-0.04
	$\pi 0f_{5/2}$	0.96	0.60	0.58		0.80	0.78	-0.02
	$\pi 1p_{3/2}$	0.96	0.67	0.65		0.81	0.79	-0.02
	^{55}Co:							
^{55}Co	$\pi 0f_{7/2}$	0.95	0.73	0.71		0.89	0.87	-0.02

[CB, Phys. Rev. Lett. ***103***, *202502 (2009)*]

Quenching of absolute spectroscopic factors

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

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

Overall quenching of *spectroscopic factors* is driven by:

SRC → *~10%*

part-vibr. coupling → *dominant*

"shell-model" → *in open shell*

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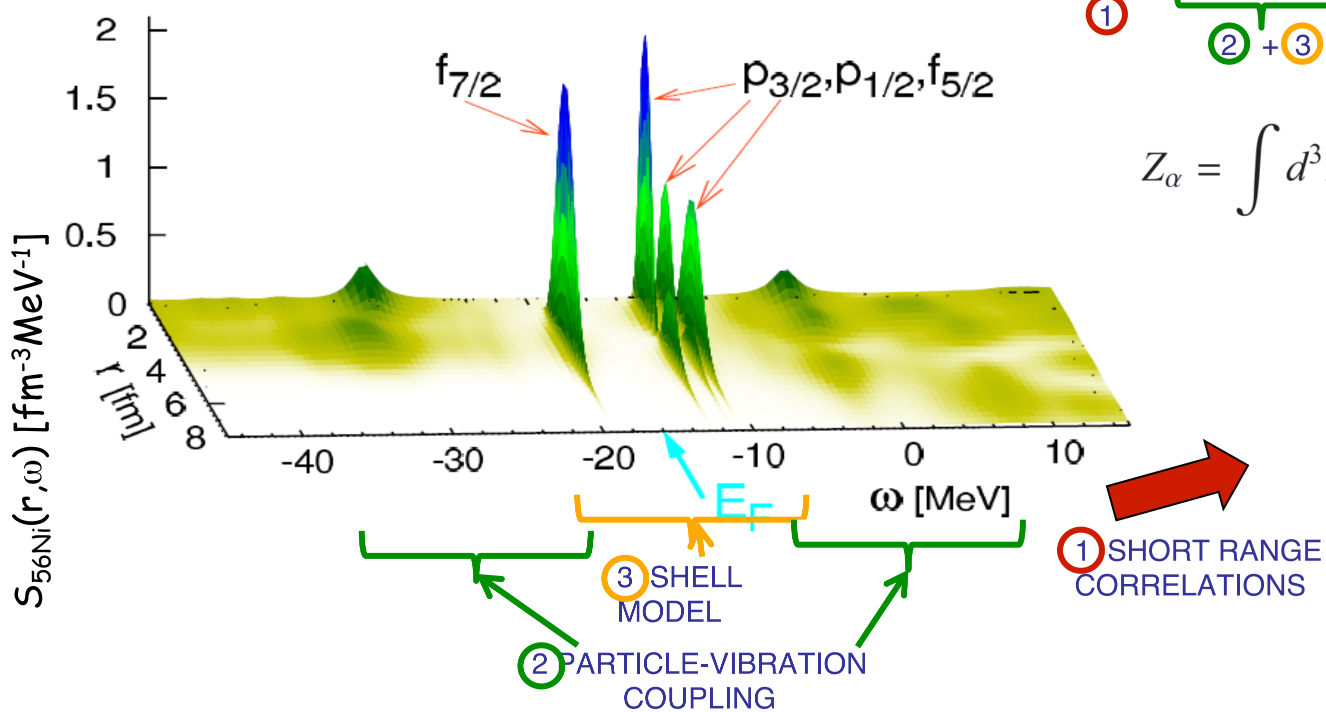
^{55}Ni:							
$\nu 0f_{7/2}$	0.95	0.72	0.69		0.89	0.86	-0.03

^{57}Ni, ^{55}Ni

① ②+③ ③

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



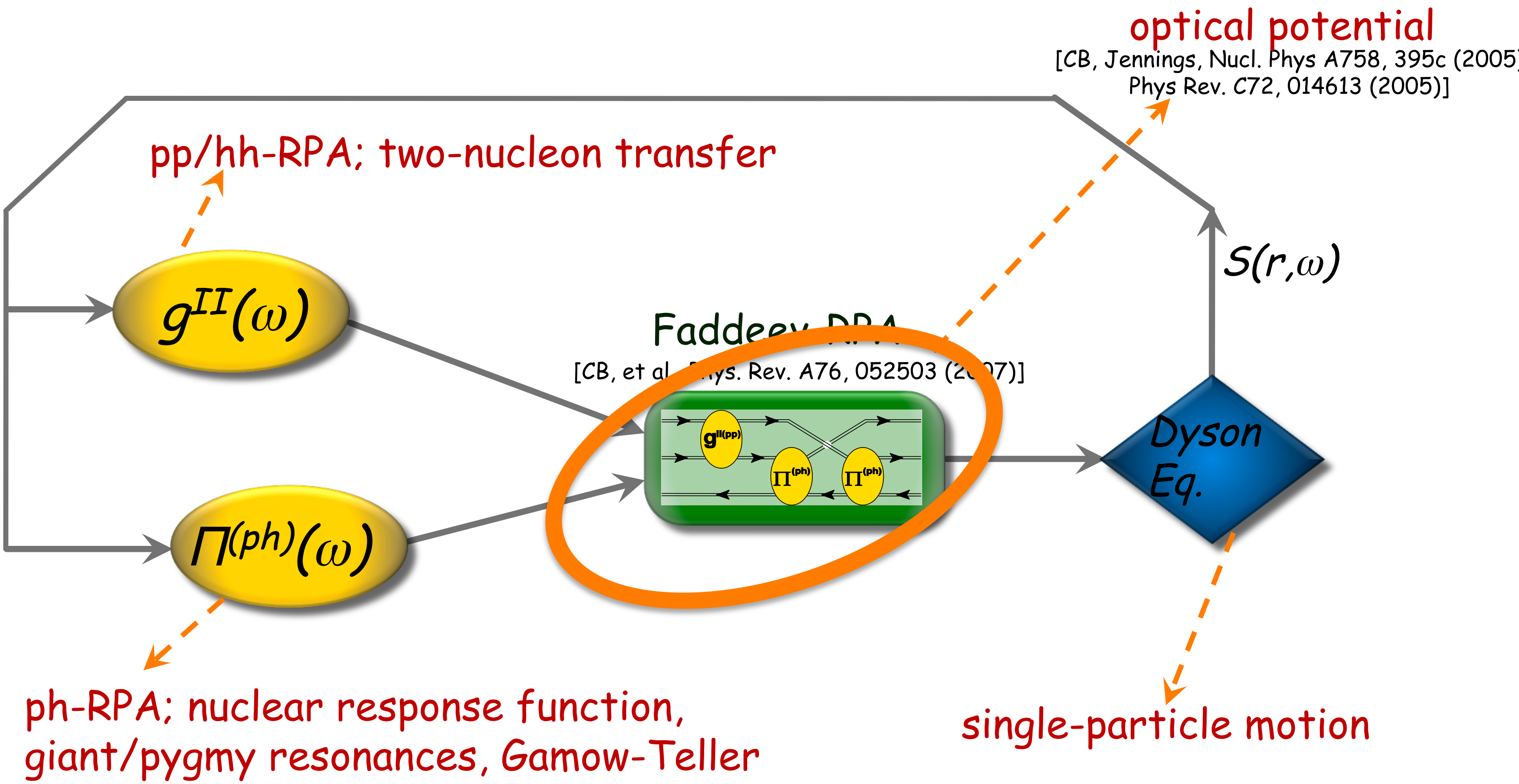
Optical Potentials Based on the Nuclear Self-energy

(CB, Jennings, and Waldecker, CB, Dickhoff)

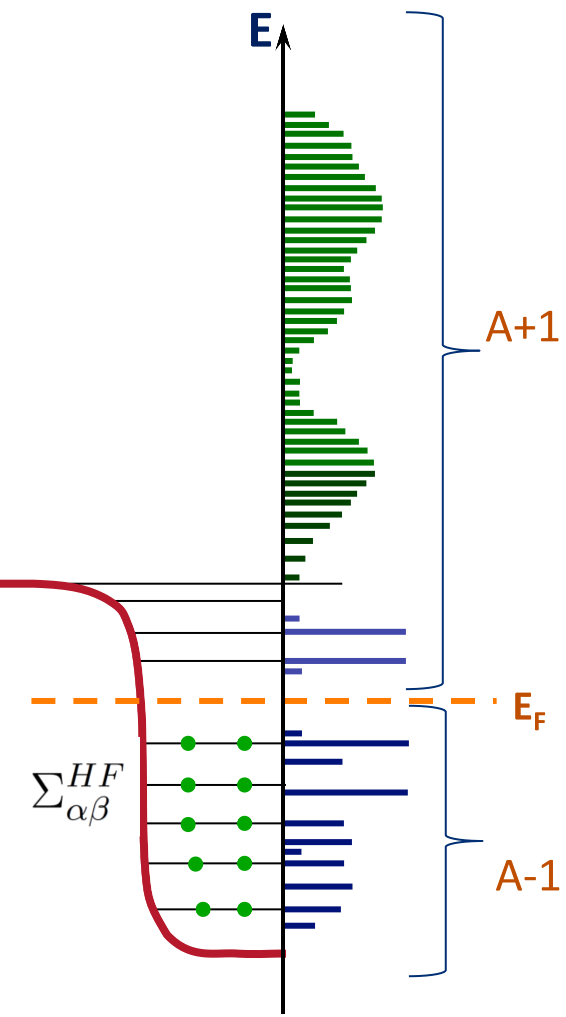
- Proton-^{16}O scattering
  [CB, B. Jennings, Phys. Rev. C**72**, 014613 (2005)]

- Optical model for the ^{A}Ca chain
  [S. Waldecker, CB, W. Dickhoff, arXiv:1105.4257]

Self-Consistent Green's Function Approach



Nucleon elastic scattering



The irreducible self-energy is a nucleon-nucleus optical potential [see e.g. Mahaux and Sartor, Adv. Nucl. Phys. 20, (1991)]

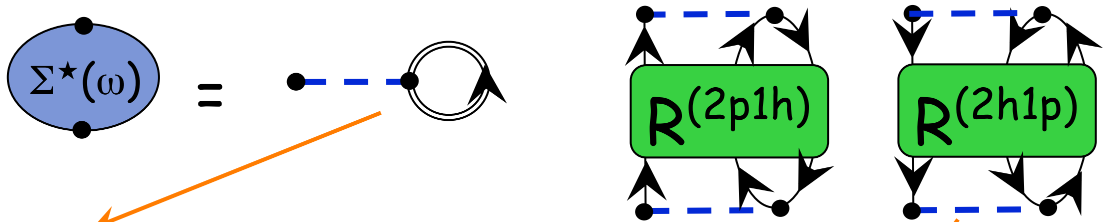
$$\Sigma^{\star}(\mathbf{r},\mathbf{r}';\varepsilon) = \Sigma^{HF}_{\alpha\beta} - \frac{1}{\pi}\int_{\varepsilon_T^{>}}^{\infty} dE' \, \frac{Im\ \Sigma^{\star}(\mathbf{r},\mathbf{r}';E')}{\varepsilon - E' + i\eta} + \frac{1}{\pi}\int_{-\infty}^{\varepsilon_T^{<}} dE' \, \frac{Im\ \Sigma^{\star}(\mathbf{r},\mathbf{r}';E')}{\varepsilon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

mean-field

resonances
beyond mean-field

➔ This provides *consistent* overlaps and scattering wave functions

FRPA self-energy is calculated in h.o. basis and re-expressed in k-space:



Correlated HF potential (cHF)

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

Non mean-field, part.-vib. coupling. etc…

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

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

Then one can solve for the scattering and spectroscopic factors

$$\frac{k^2}{2\mu}\psi(k) + \int_0^\infty dk' k'^2 \left\{ \Sigma_{lj}^{\star}(k,k';E_{\mathrm{c.m.}}) + V_{\mathrm{Coul.}}^{l}(k,k') \right\} \psi(k') \; = E_{\mathrm{c.m.}}\; \psi(k)$$

$$Z_{lj}^n = \int_0^\infty dk\; k^2 |\psi^n(k)|^2 = \left[1 - \langle \tilde{\psi}^n | \frac{d\Sigma_{lj}^{\star}}{d\omega} | \tilde{\psi}^n \rangle \Big|_{\omega = E_{\mathrm{c.m.}}^n} \right]^{-1}$$

Comparison of Calculated Microcopic and DOM Optical Potentials

Comparison to DOM potential, tone through volume integrals:

$$J^{\ell}_{W}(E) = 4\pi \int dr r^2 \int dr' r'^2 \mathrm{Im}\ \Sigma^{\ell}_{0}(r, r'; E)$$

$$J^{\ell}_{V}(E) = 4\pi \int dr r^2 \int dr' r'^2 \mathrm{Re}\ \Sigma^{\ell}_{0}(r, r'; E)$$

N-^{A}Ca scattering calculated with the chiral NN N3LO and AV18 interactions

For the local DOM $U(\boldsymbol{r}, \boldsymbol{r}') = U(r)\delta(\boldsymbol{r} - \boldsymbol{r}')$:

$$J^{\ell}_{U} = 4\pi \int dr\ r^2 \int dr' r'^2 U^{\ell}(r, r') = 4\pi \int U(r) r^2 dr = \int U(r)\ d\boldsymbol{r}\ ,$$

for any ℓ

[S. Waldecker, CB, W. Dickhoff]

Imaginary self-energy/optical pot. for ^{40}Ca

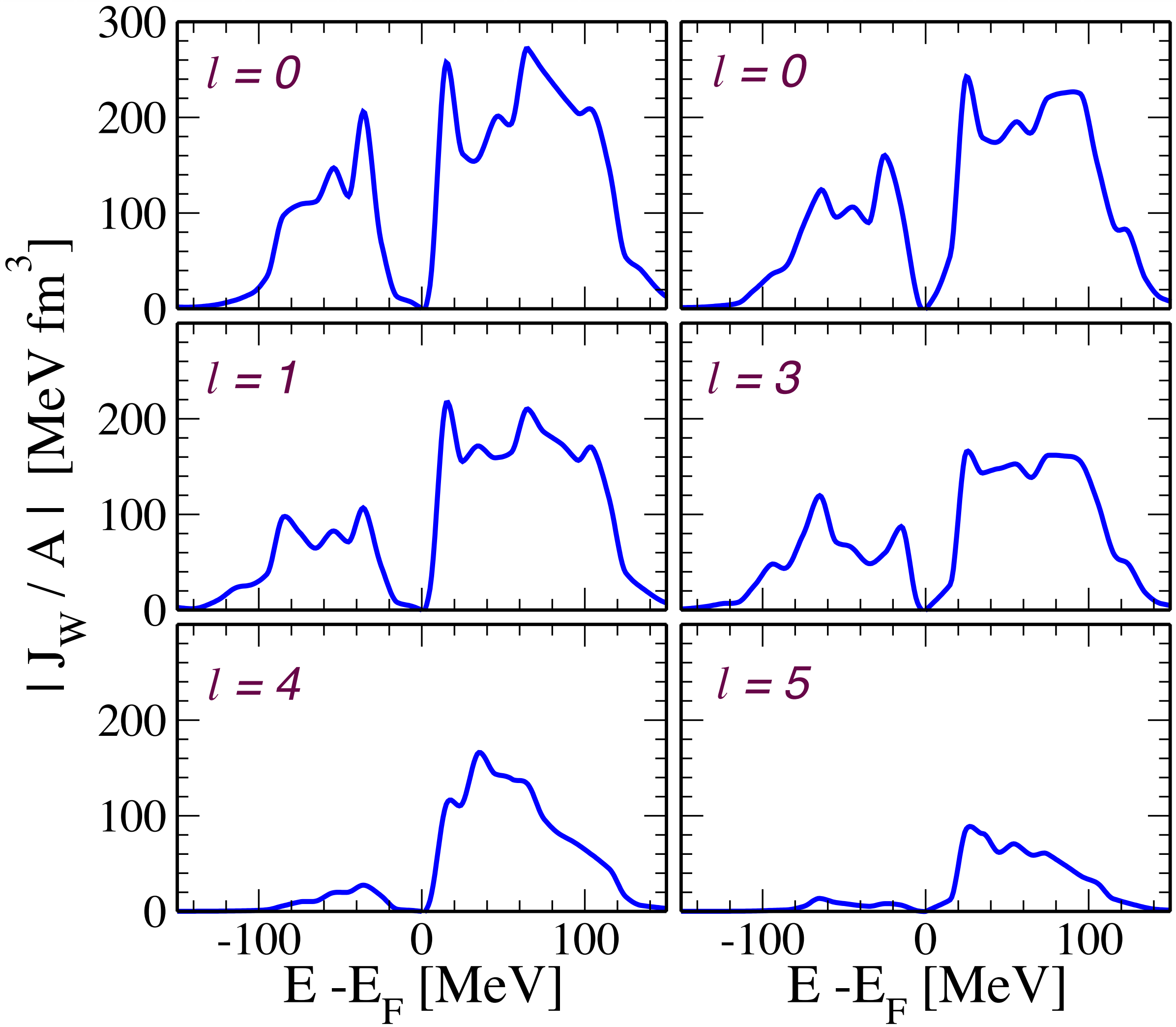


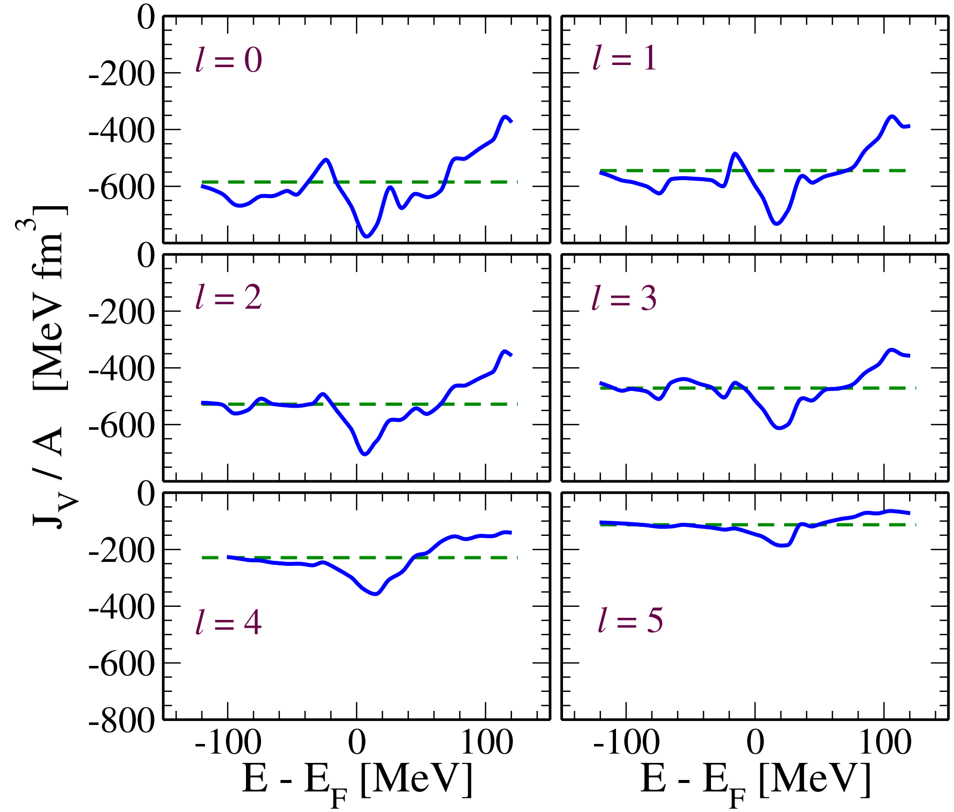
FIG. 6. Imaginary volume integral J_W^l of ^{40}Ca self-energy for neutrons with $\ell = 0 - 5$.

J_W gives the overall inelastic absorption

[S. Waldecker, CB, W. Dickhoff, arXiv:1105.4257]

Dispersive real parts J_V

FRPA



Volume Integrals of Re Σ_0^ℓ for neutrons in ^{40}Ca.
The horizontal, dashed lines are the volume integrals of $\Sigma_0^{\infty,\ell}(E_F)$.

FRPA

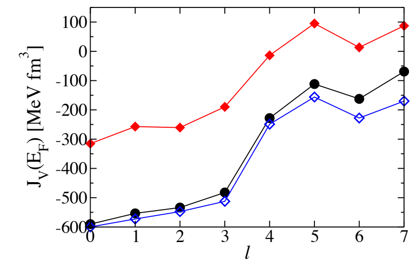
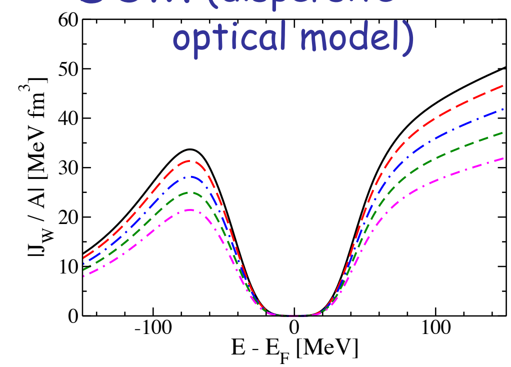


FIG. 8. Angular momentum dependence for the volume Integrals $J_F^\ell = J_V^\ell(E_F)$ of $\Sigma^{\infty,\ell}(E_F)$ excluding the contribution of the dynamic part of the self-energy. For each ℓ, results for protons are given by solid diamonds and neutrons by solid circles. Proton potentials are considerably less attractive due to the Coulomb energy. When the Coulomb interaction is suppressed (open diamonds) the proton results are close to the neutron results. The results shown are for ^{40}Ca using the AV18 interaction.

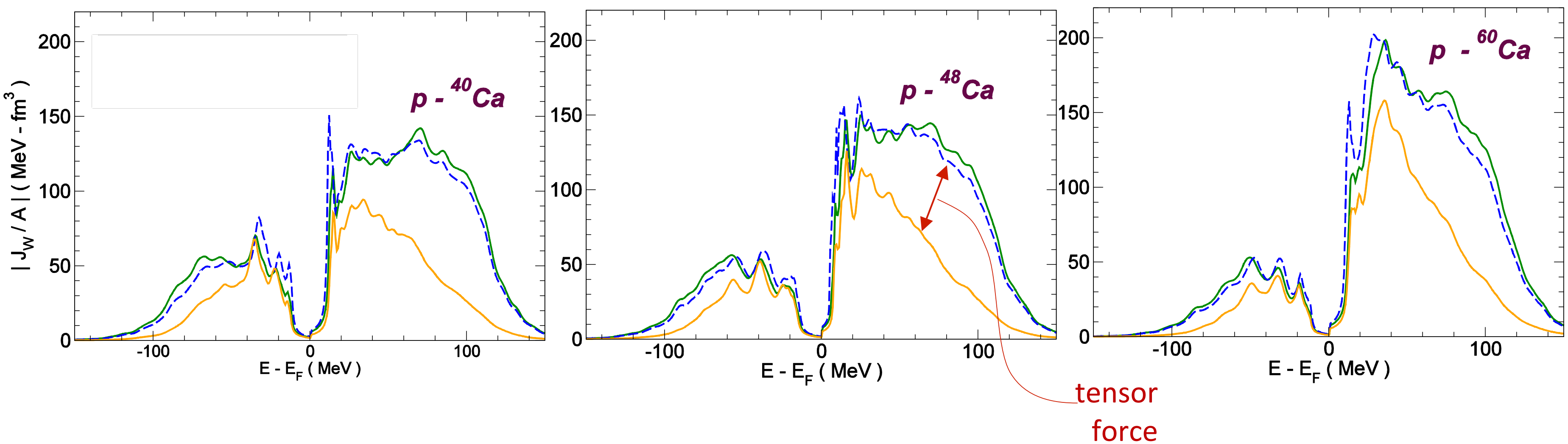
DOM (dispersive optical model)



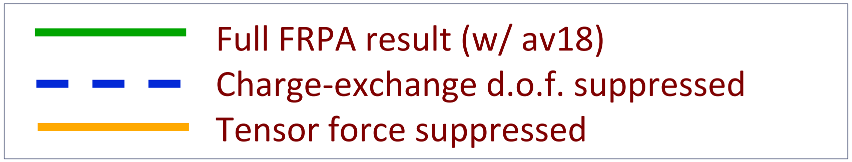
The OP must dependence on angular momentum!
→ non locality.

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)



[S. Waldecker, CB, W. Dickhoff, arXiv:1105.4257]

N/Z asymmetry dependence of J_W and tensor force contribution