LUND UNIVERSITY

Newton Fund

THE ROYAL SOCIETY

Optical potentials and knockout reactions from Green functions treatment

Andrea Idini

"Connecting Bound States to the Continuum"

Green functions many-body method

$$g_{\alpha\beta}(\omega + i\eta) = \sum_n \frac{\langle\psi_0^A|c_\alpha|\psi_n^{A+1}\rangle\langle\psi_n^{A+1}|c_\beta^+|\psi_0^A\rangle}{\omega - E_n^{A+1} + E_0^A + i\eta} + \sum_i \frac{\langle\psi_0^A|c_\alpha^+|\psi_i^{A-1}\rangle\langle\psi_i^{A-1}|c_\beta\,|\psi_0^A\rangle}{\omega - E_0^A + E_i^{A-1} - i\eta}$$

Källén–Lehmann spectral representation

Unperturbed case

$$g^0\,(\omega + i\eta) = \sum_i \frac{1}{E - \epsilon_i^{base} \pm i\eta}$$

Green function self-consistent methods find spectra of the Hamiltonian operator

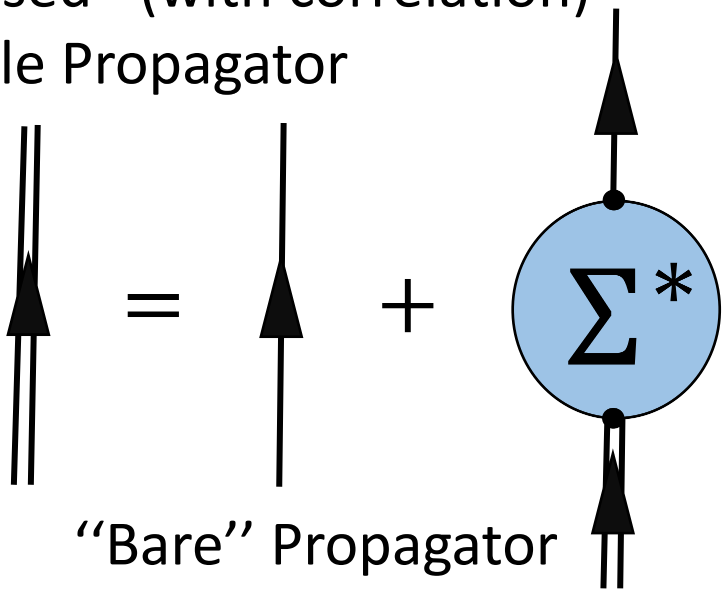
$$H(A) = T - T_{c.m.}(A+1) + V + W$$

Green functions many-body method

Dyson Equation

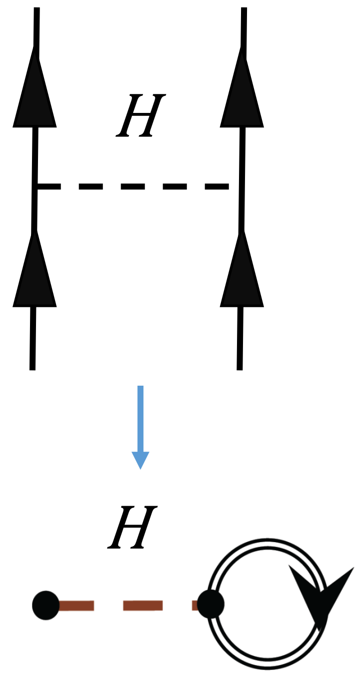
$$g(\omega+i\eta) = g^0(\omega+i\eta) + g^0(\omega+i\eta)\Sigma^*(\omega+i\eta)g(\omega+i\eta)$$

''Dressed'' (with correlation)
Particle Propagator



''Bare'' Propagator

$$H(A) = T - T_{c.m.}(A+1) + V + W$$



Green functions many-body method

Dyson Equation

$$g(\omega + i\eta) = g^0(\omega + i\eta) + g^0(\omega + i\eta)\Sigma^*(\omega + i\eta)g(\omega + i\eta)$$

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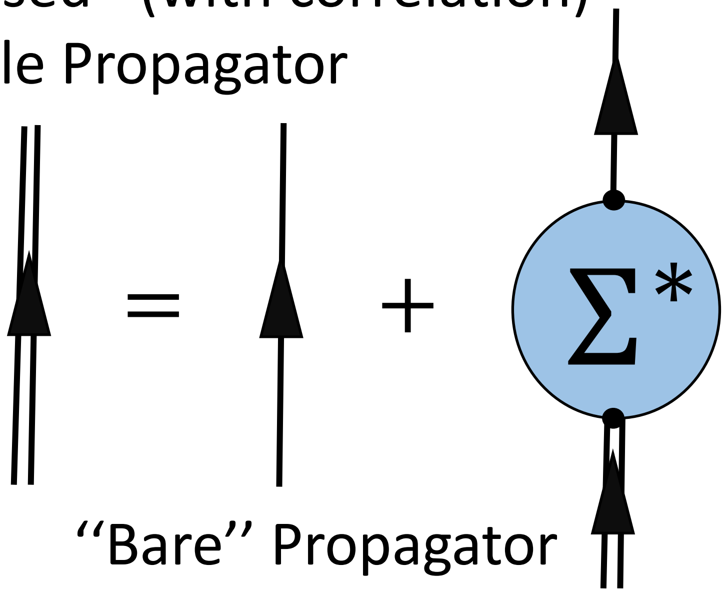


''Bare'' Propagator

Interaction between the particle and the system (physical choice)

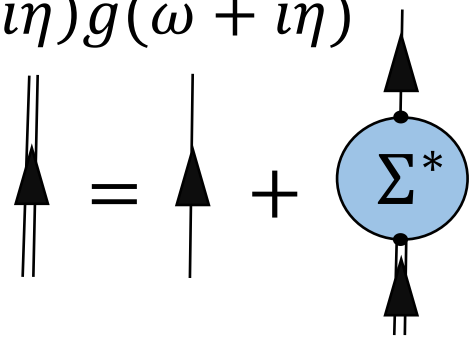
Fragments and **changes energy** of the ''bare'' state

$$\Sigma_{\alpha\beta}(\omega + i\eta) = \sum_r \frac{m_\alpha^r m_\beta^r}{\omega - E_r + i\eta}$$

Green functions many-body method

Dyson Equation

$$g(\omega + i\eta) = g^0(\omega + i\eta) + g^0(\omega + i\eta)\Sigma^*(\omega + i\eta) g(\omega + i\eta)$$



Equation of motion

$$\left(E + \frac{\hbar^2}{2m}\nabla_r^2\right) g(r, r';\, E, \Gamma) = \delta(r - r') + \int dr'' \Sigma^*(r, r''; E, \Gamma) g(r'', r; E, \Gamma)$$

Corresponding Hamiltonian

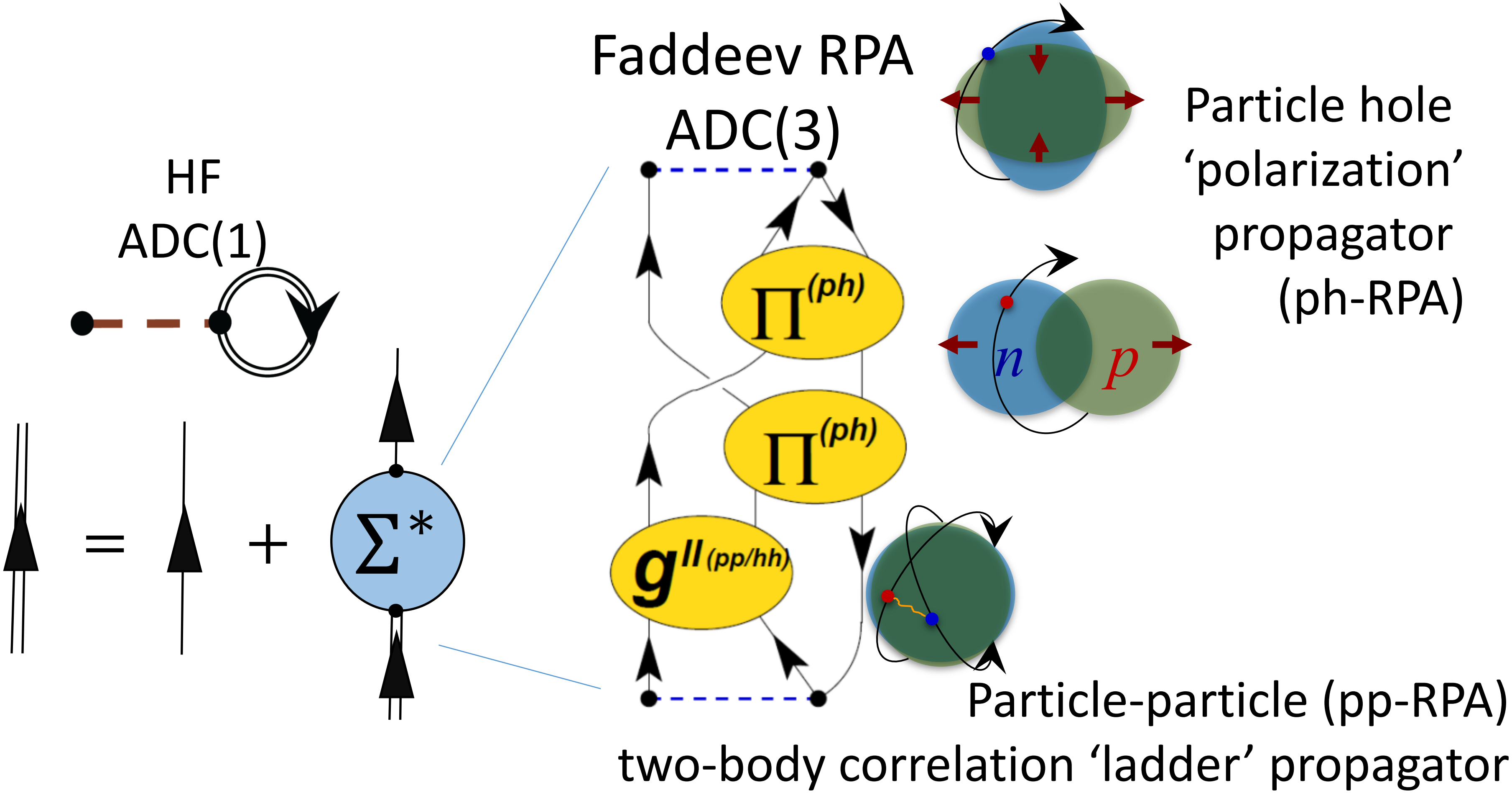
$$H(r, r') = -\frac{\hbar^2}{2m}\nabla_r^2 + \Sigma^*(r, r'; E, \Gamma)$$

Σ corresponds to the Feshbach's generalized optical potential

Escher & Jennings PRC66 034313 (2002)

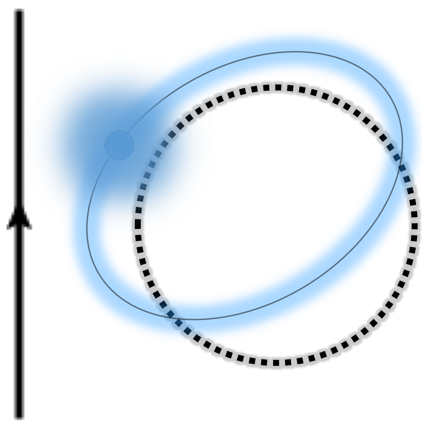
Hamiltonian method: self consistent Green functions

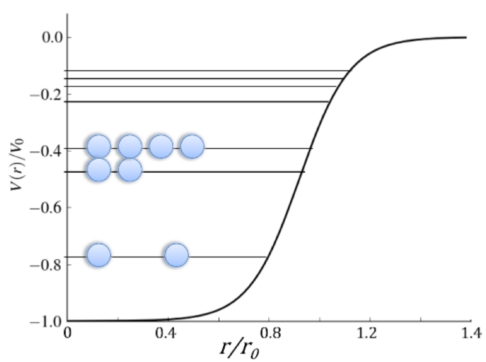
$$g(\omega + i\eta) = g^0(\omega + i\eta) + g^0(\omega + i\eta)\Sigma^*(\omega + i\eta)g(\omega + i\eta)$$



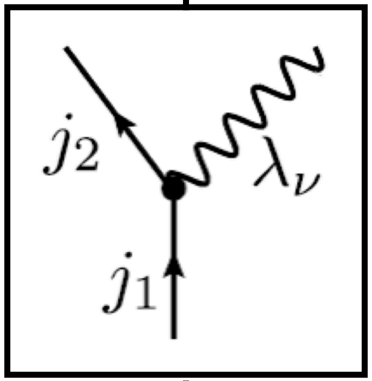
(Non) Hamiltonian method: nuclear field theory ansatz

Independent Particle

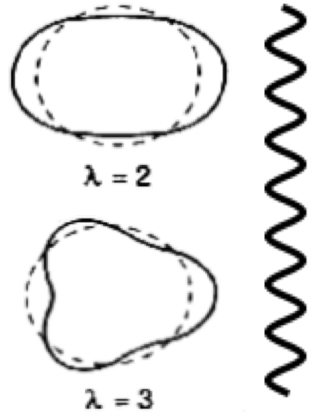


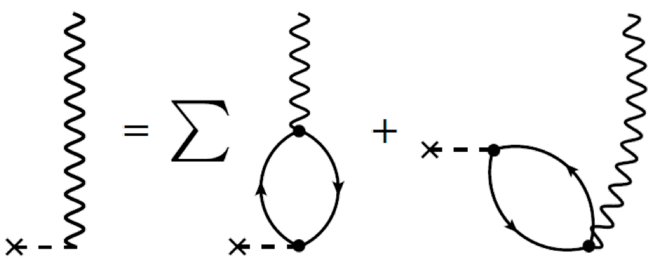


mean field



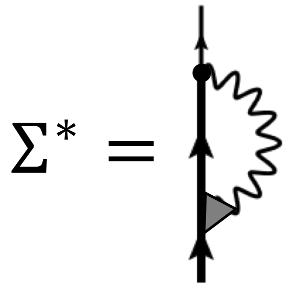
Collective Phonon

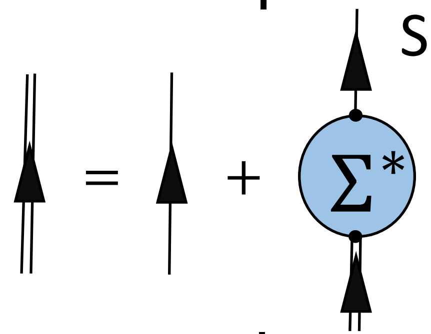




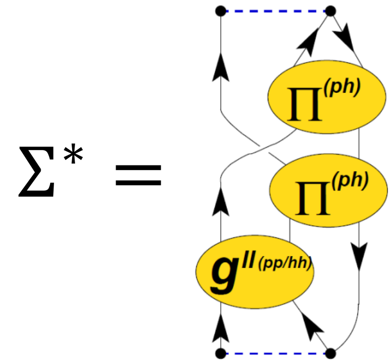
Random Phase Approximation

Nuclear Field Theory





Self Consistent Green Function

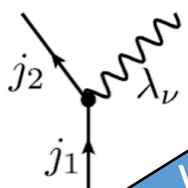


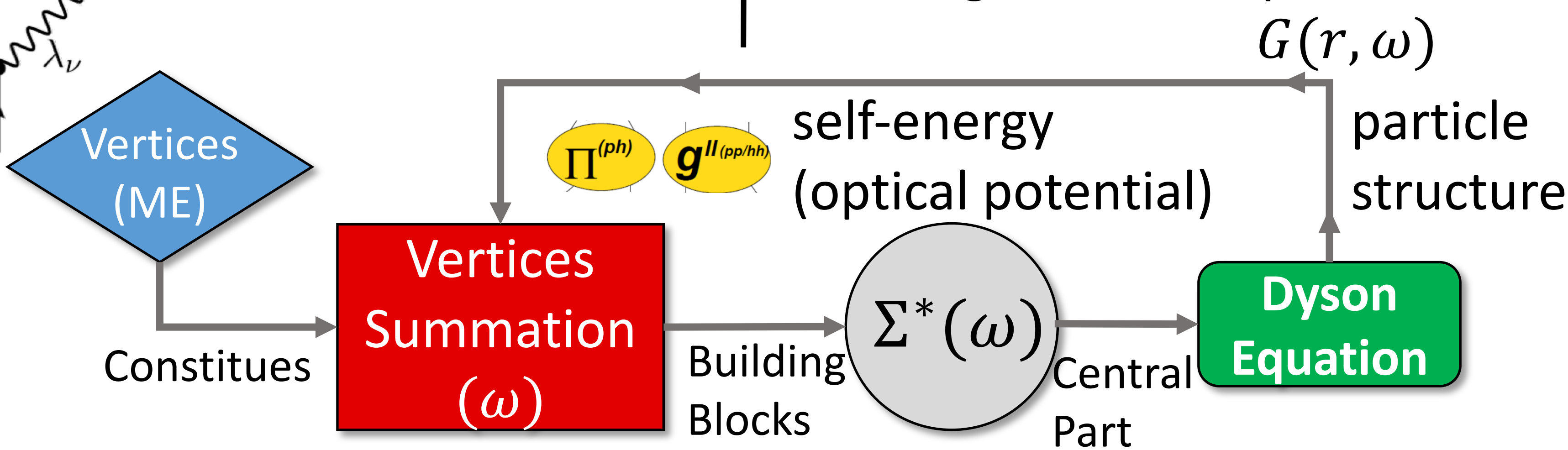
Coupling of physical quantities

Exploits different truncations

coupling from Hamiltonian matrix elements

Full single valence space

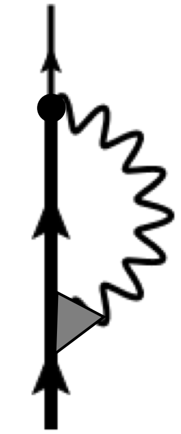




How the imaginary part arises in dissipative systems

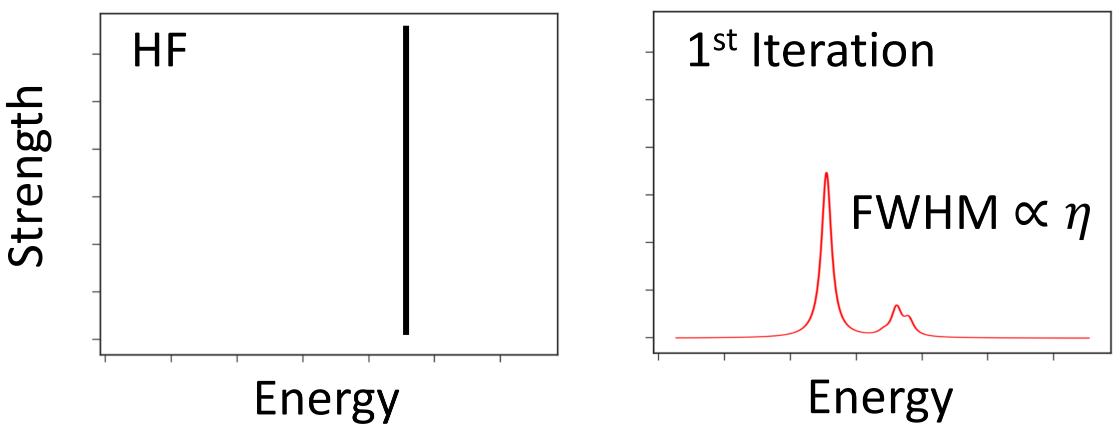
$$g_{\alpha\beta}(\omega + i\eta) = \left[\omega + i\eta - \Sigma_{\alpha\beta}(\omega + i\eta)\right]^{-1}$$

$$\Sigma_{\alpha\beta}(\omega + i\eta) = \sum_r \frac{m_\alpha^r(\omega) m_\beta^r(\omega)}{\omega - E_r + i\eta}$$



Complex roots of the Green function

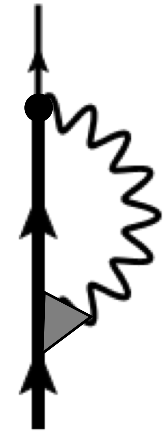
Implemented in NFT



How the imaginary part arises in dissipative systems

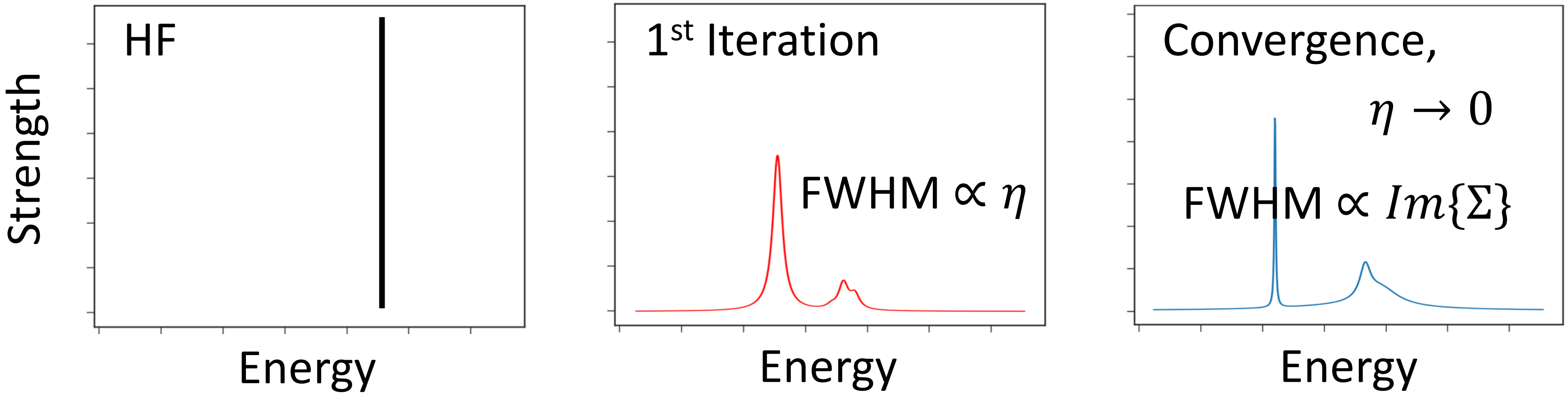
$$g_{\alpha\beta}(\omega + i\eta) = \left[\omega + i\eta - \Sigma_{\alpha\beta}(\omega + i\eta)\right]^{-1}$$

$$\Sigma_{\alpha\beta}(\omega + i\eta) = \sum_r \frac{m_\alpha^r(\omega) m_\beta^r(\omega)}{\omega - E_r + i\eta}$$

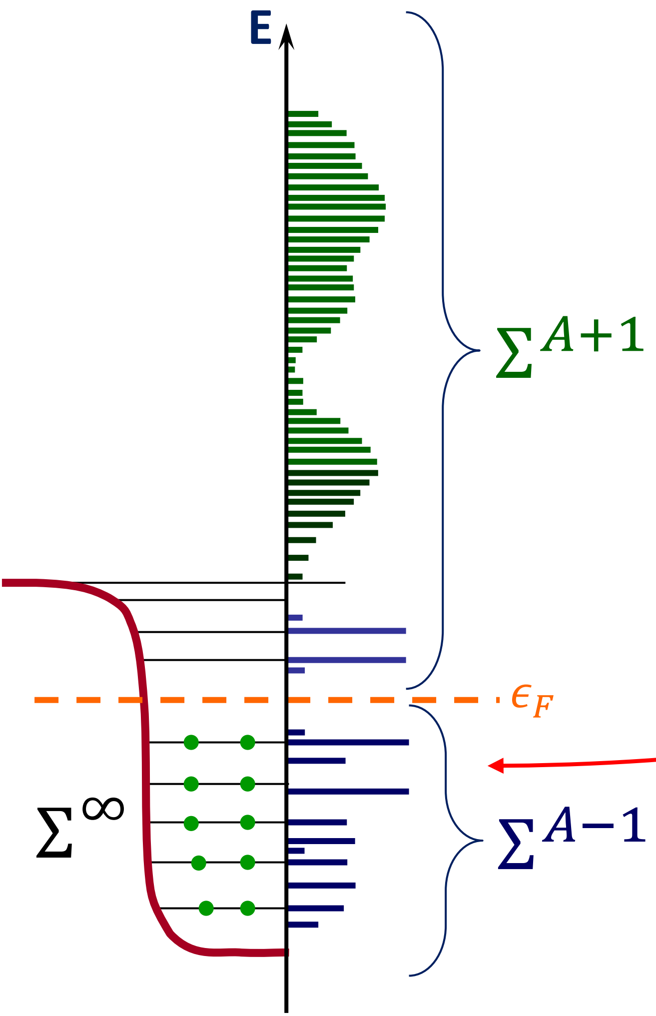


Complex roots of the Green function

Implemented in NFT



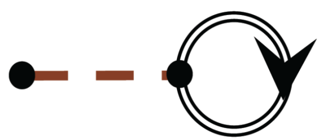
Nucleon elastic scattering



The irreducible self-energy is a nucleon-nucleus optical potential*

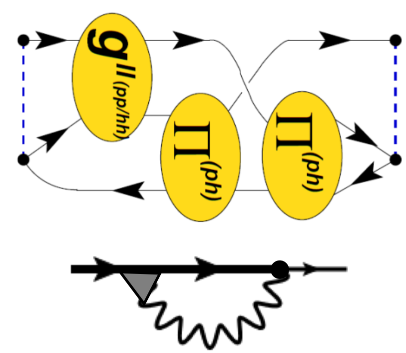
$$\Sigma^{*}_{\alpha\beta}(\omega + i\eta) = \Sigma^{\infty}_{\alpha\beta} + \sum_i \frac{m^i_\alpha \, m^{i*}_\beta}{\omega - \epsilon_i \pm i\eta}$$

correlated mean-field



resonances beyond mean-field

Correlations

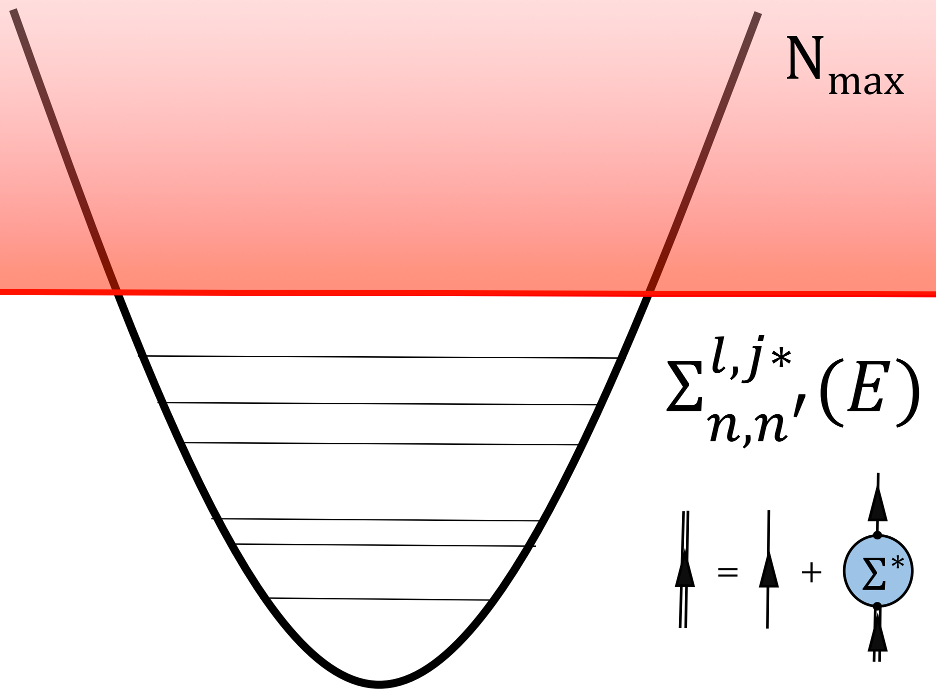


*Mahaux & Sartor, Adv. Nucl. Phys. 20 (1991), Escher & Jennings PRC66:034313 (2002)

- Solve Dyson equation in HO Space, find $\Sigma^{l,j*}_{n,n'}(E)$

- diagonalize in full continuum momentum space $\Sigma^{l,j*}(k,k',E)$

$$\frac{k^2}{2m}\psi_{l,j}(k) + \int dk' k'^2 \left(\Sigma^{l,j*}(k,k',E)\right)\psi_{l,j}(k') = \mathrm{E}\,\psi_{l,j}(k)$$

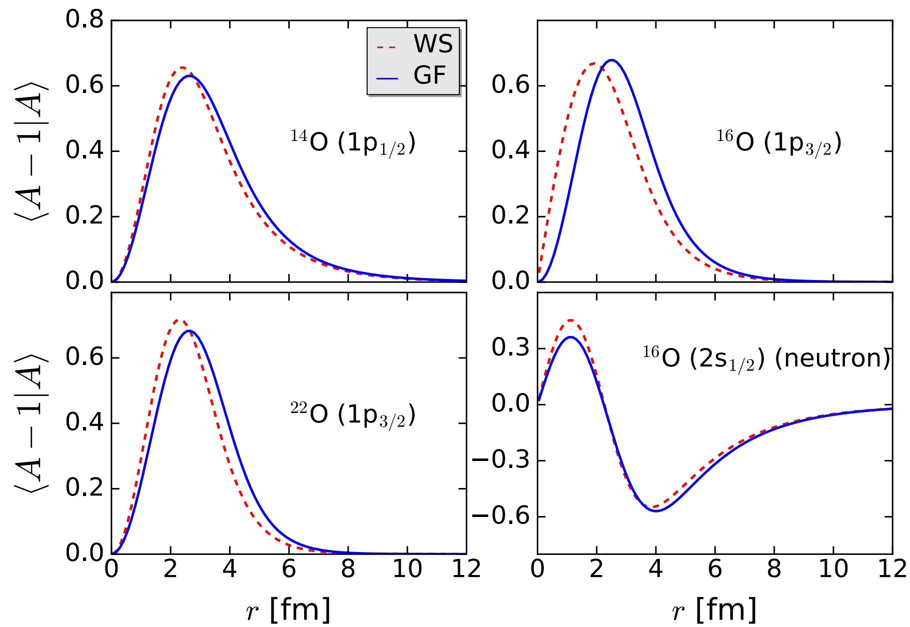


Knockout Spectroscopic Factors

$$\frac{k^2}{2m}\psi_{l,j}(k) + \int dk' k'^2 \left(\Sigma^{l,j*}(k,k',E)\right)\psi_{l,j}(k') = \mathrm{E}\,\psi_{l,j}(k)$$

$$SF = \left|\left\langle \mathbf{r}\,\Phi_n^{(A-1)} \middle| \Phi_{g.s.}^{A}\right\rangle\right|^2$$ Norm of overlap wavefunctions

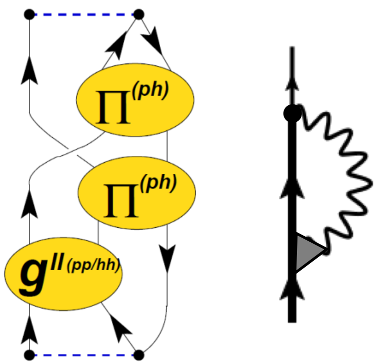
But also the shape of the overlap wavefunction!

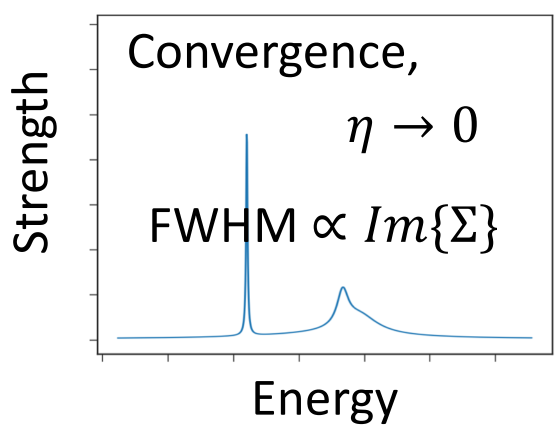


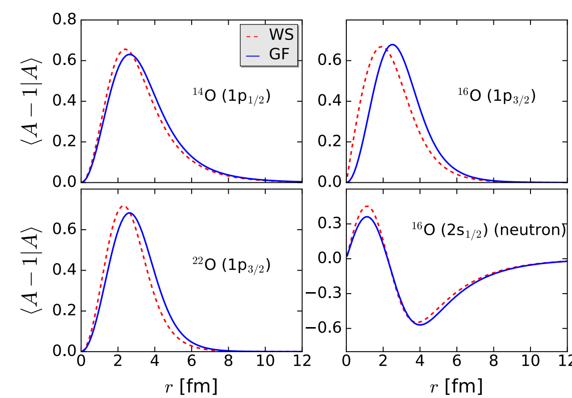
Collaboration with C. Bertulani

Conclusions (1)

- The non-local generalized optical potential corresponding to nuclear self energy can be calculated in several, different, ways.
- Imaginary part can arise spontaneously in non-hamiltonian cases.
- Reaction properties calculated from bound state description might differ from effective pure single-particle description.

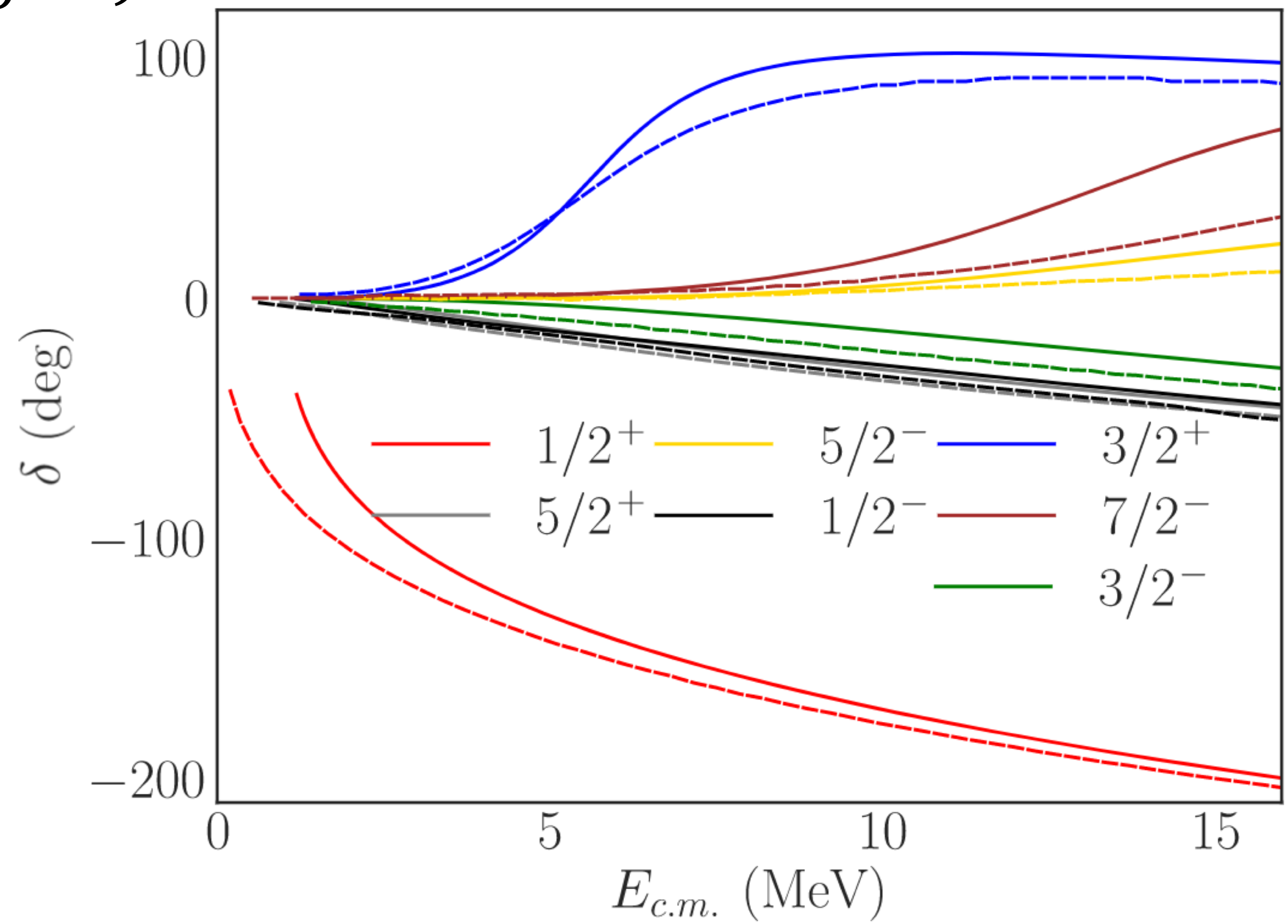




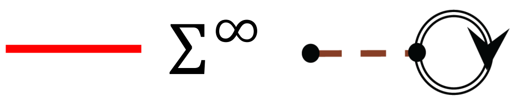


SRG-N^{3}LO, $\Lambda = 2.66\ \mathrm{fm}^{-1}$

$n + {}^{16}\mathrm{O}\ (g.s.)$

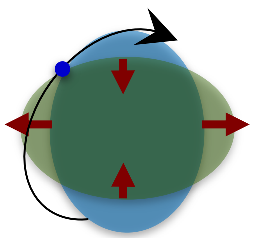


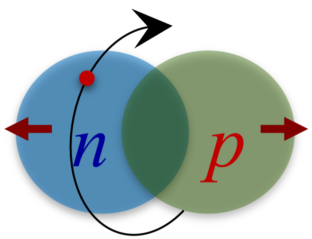
Navràtil, Roth, Quaglioni, PRC82, 034609 (2010)

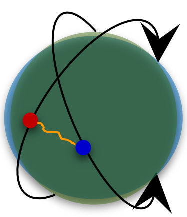


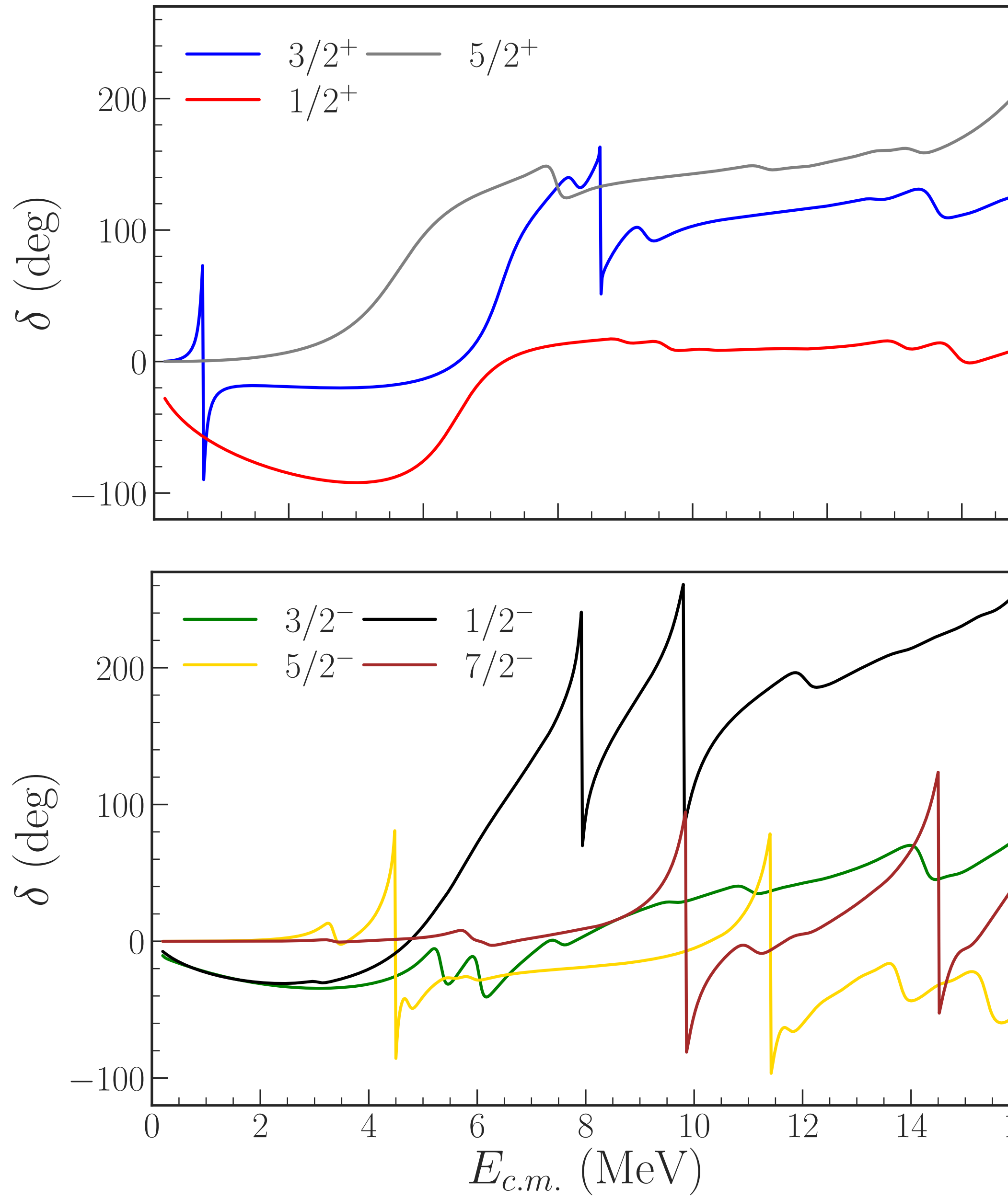
NNLO_{sat}

$n + {}^{16}\text{O}\ (g.s. + exc)$

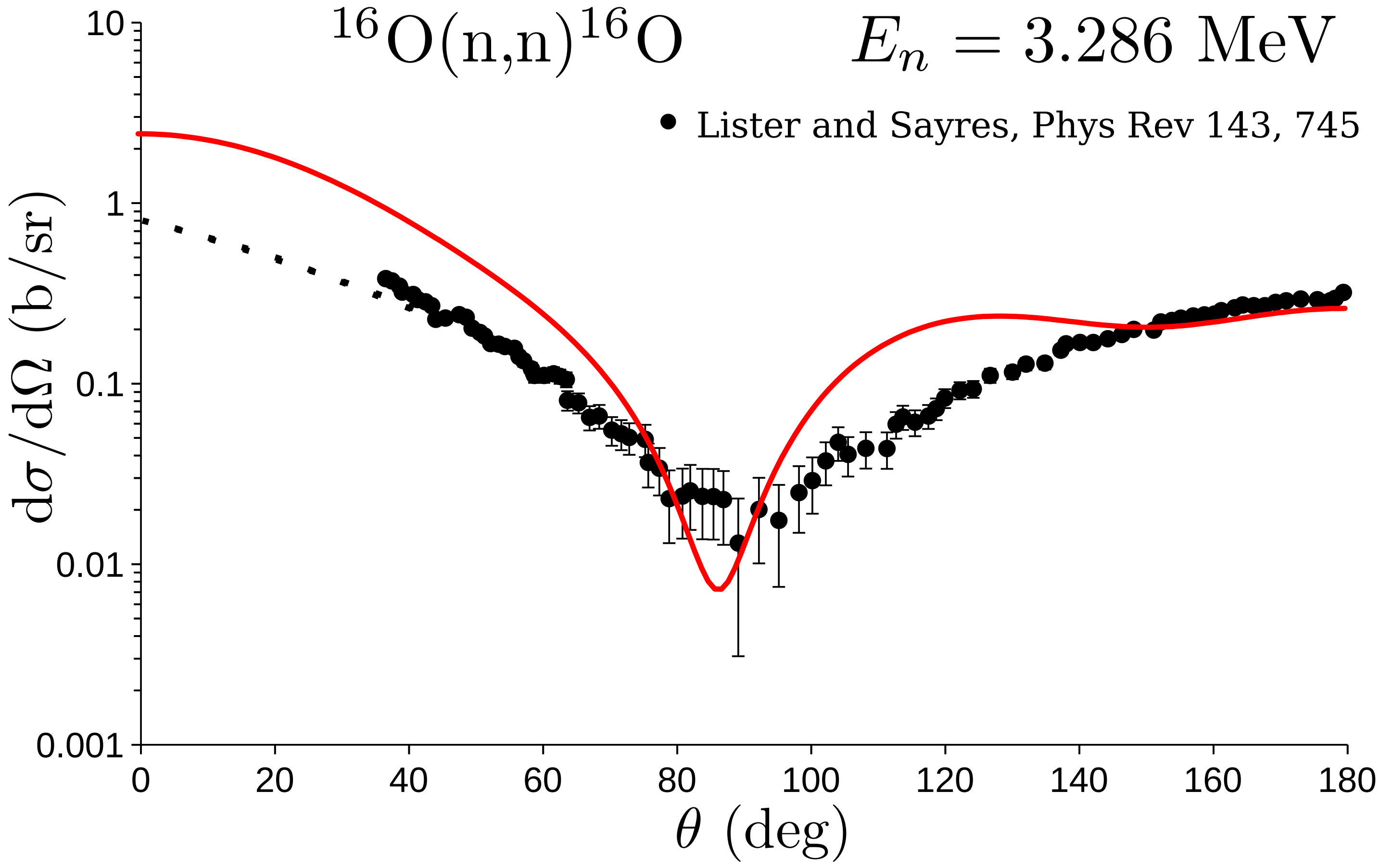


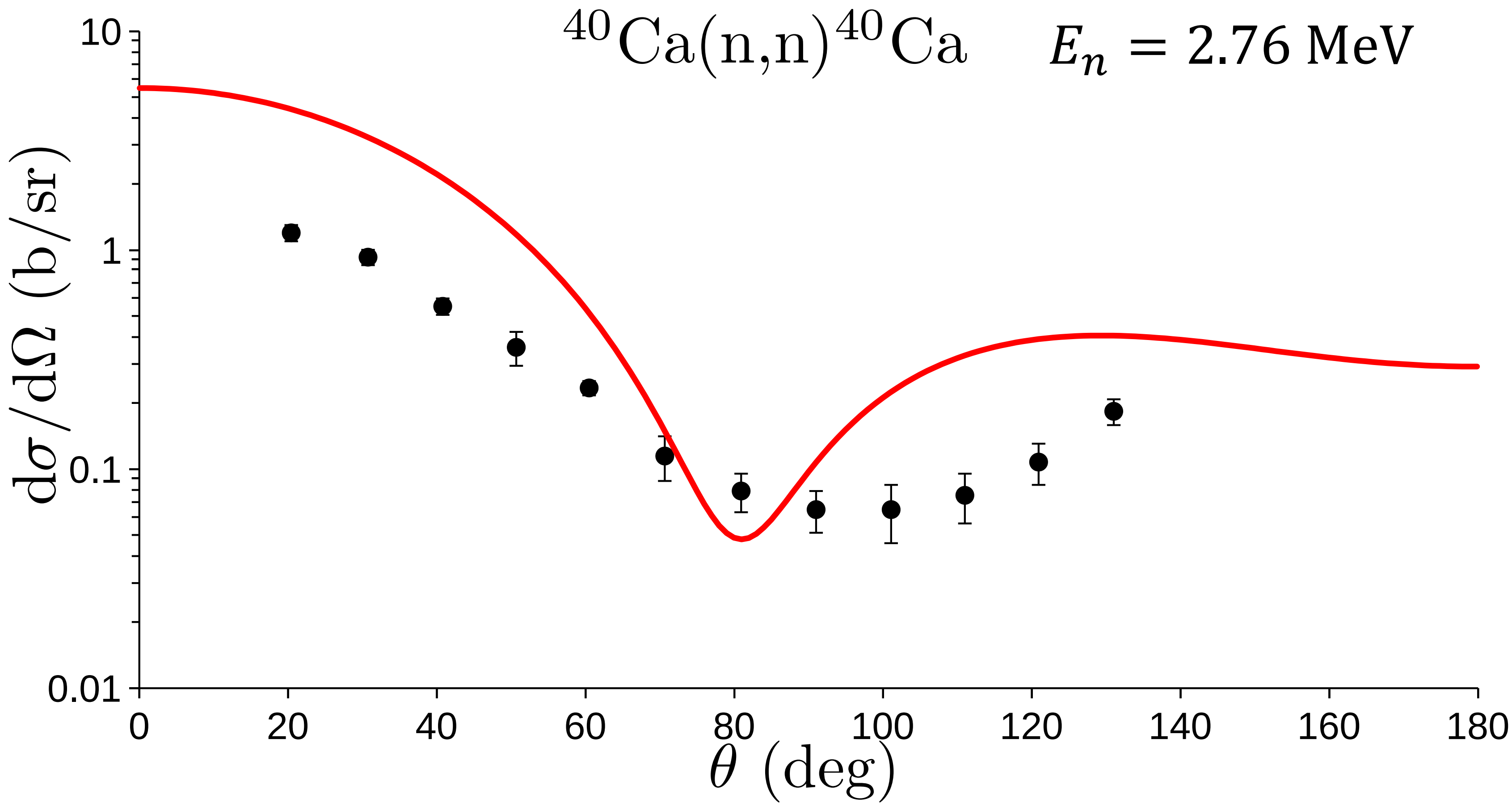






Using the ab initio optical potential for neutron elastic scattering on Oxygen

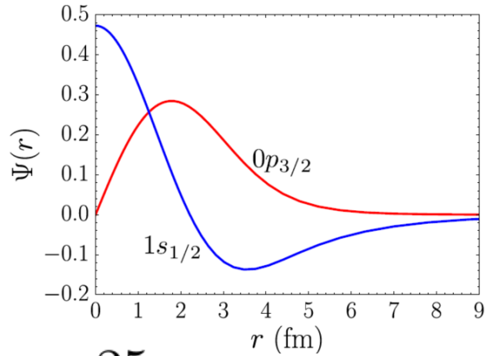




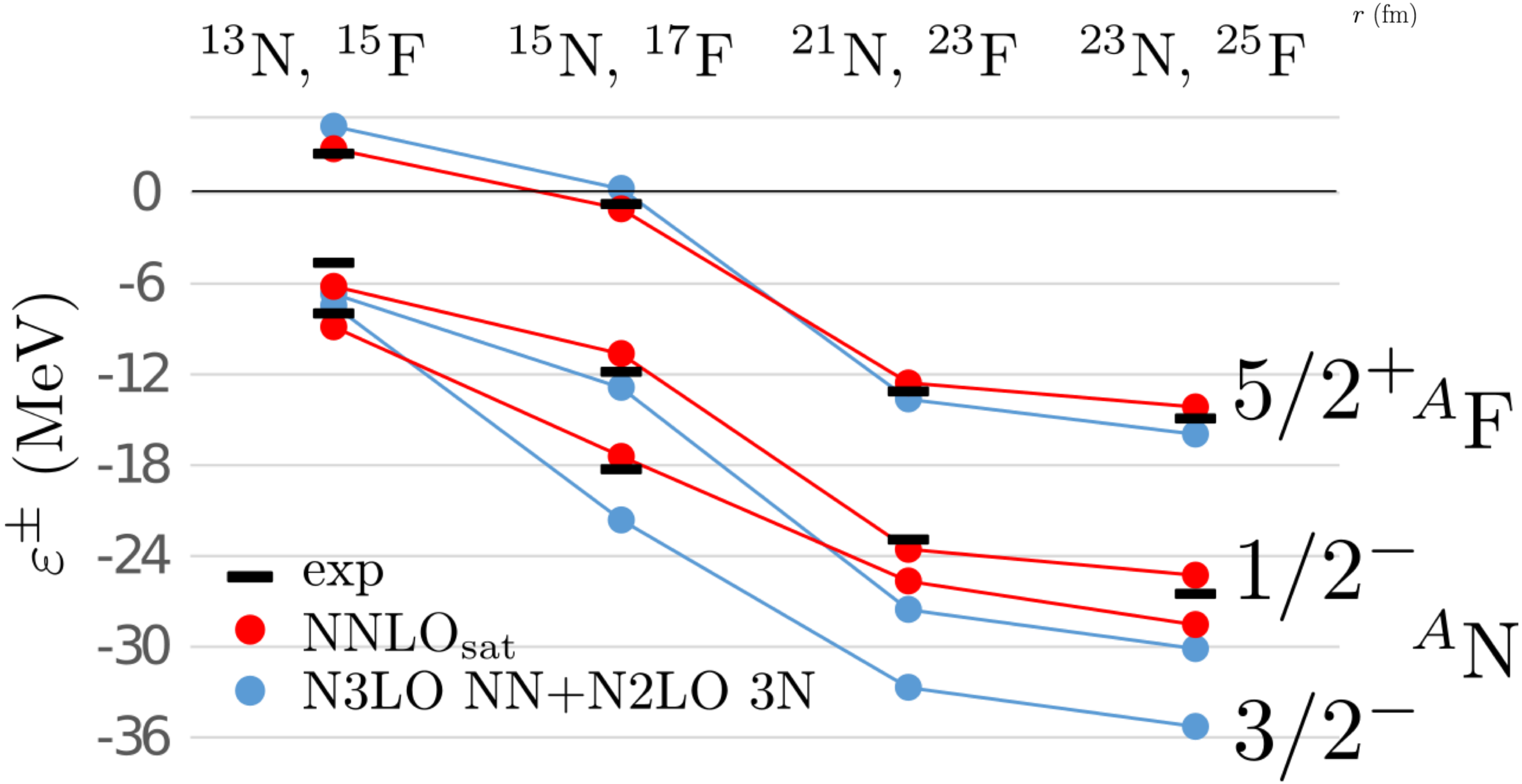
^{40}Ca(n,n)^{40}Ca
$E_n = 2.76$ MeV
10
1
0.1
0.01
dσ/dΩ (b/sr)
0
20
40
60
80
100
120
140
160
180
θ (deg)

Overlap function

$$\Psi_i(r) = \sqrt{A}\int dr_1 \ldots \cancel{r_i} \ldots dr_A \Phi^+_{(A-1)}(r_1, \ldots \cancel{r_i} \ldots, r_{A-1}) \Phi^+_{(A)}(r_1, \ldots, r_A)$$



Proton particle-hole gap

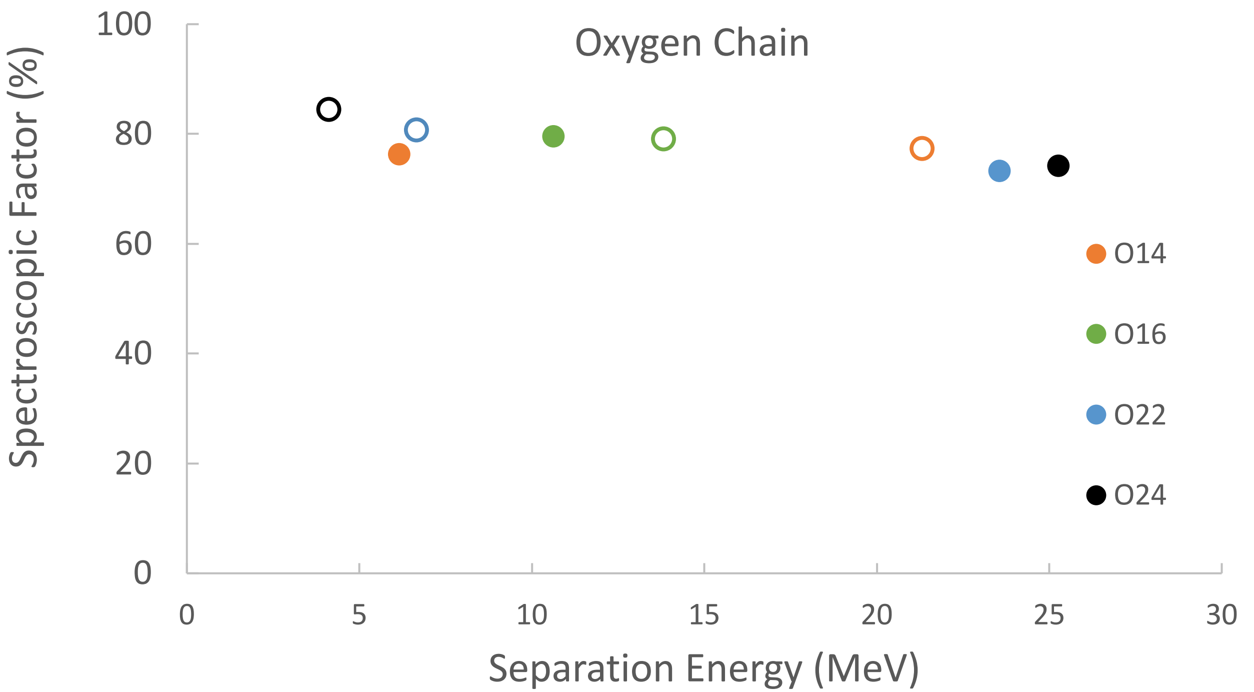


EM results from A. Cipollone PRC**92**, 014306 (2015)

Knockout Spectroscopic Factors

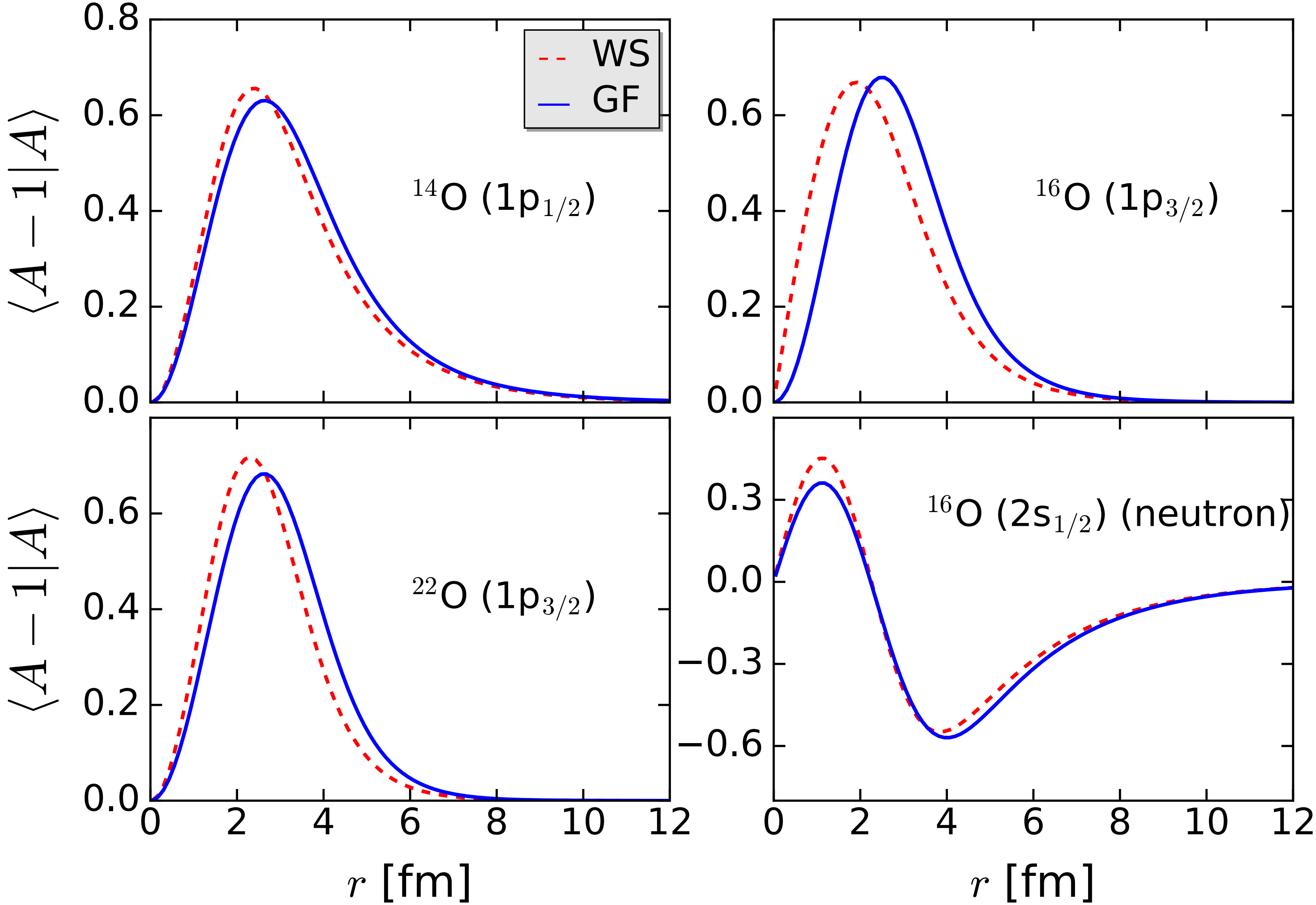
$$\frac{k^2}{2m}\psi_{l,j}(k) + \int dk' k'^2 \left(\Sigma^{l,j*}(k,k',E)\right)\psi_{l,j}(k') = \mathrm{E}\,\psi_{l,j}(k)$$

$$SF = \left|\left\langle \mathbf{r}\,\Phi_n^{(A-1)} \middle| \Phi_{g.s.}^A \right\rangle\right|^2$$ Calculated from overlap wavefunctions



open circles neutrons, closed protons

Overlap wavefunctions

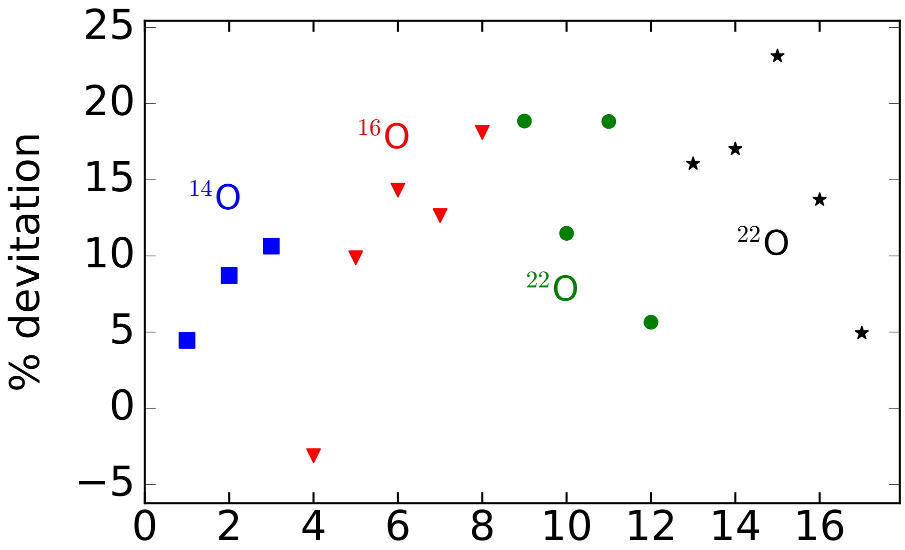


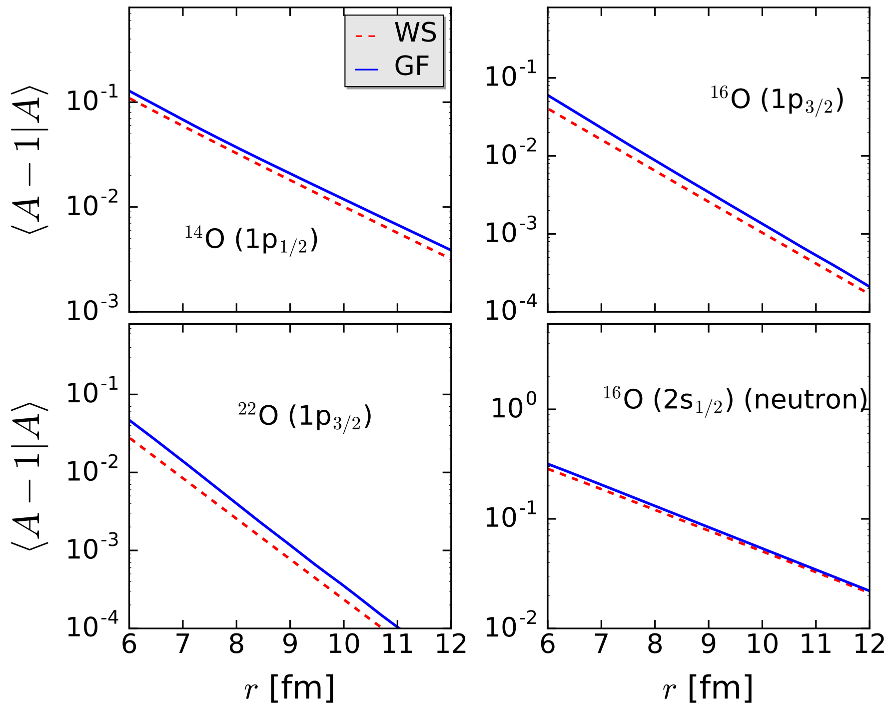
Collaboration with C. Bertulani

Nucleus (state)	E_B [MeV]	$\langle r^2 \rangle_{WS}^{1/2}$ [fm]	$\langle r^2 \rangle_{GF}^{1/2}$ [fm]	C_{WS} [fm$^{-1/2}$]	C_{GF} [fm$^{-1/2}$]	σ_{qf}^{WS} [mb]	σ_{qf}^{GF} [mb]	σ_{kn}^{WS} [mb]	σ_{kn}^{GF} [mb]	$C^2 S_{GF}$
^{14}O ($\pi 1p_{3/2}$)	8.877	2.856	2.961	6.785	7.172	27.38	28.60	27.19	27.42	0.548

σ_{qf}: 5% σ_{kn}: <1%

Deviation of quasifree (p, pn)
cross section calculation
for different wavefunctions
$(\sigma_{GF} - \sigma_{WS})/\sigma_{WS}$

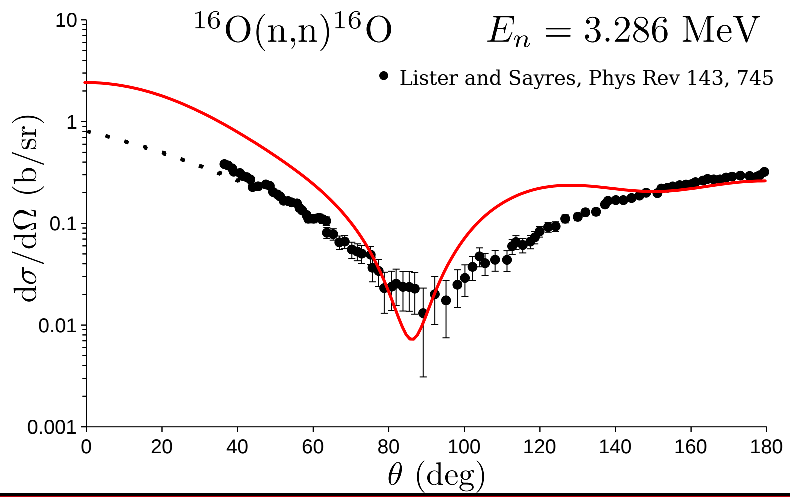


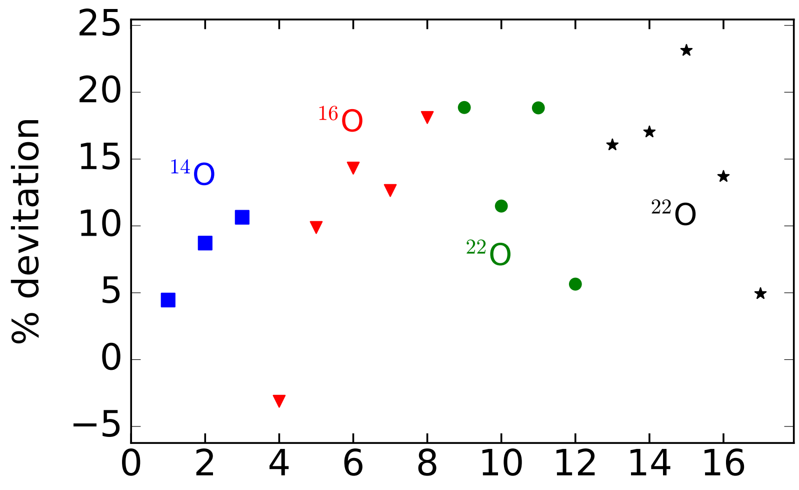


Collaboration with C. Bertulani

Conclusions and Perspectives

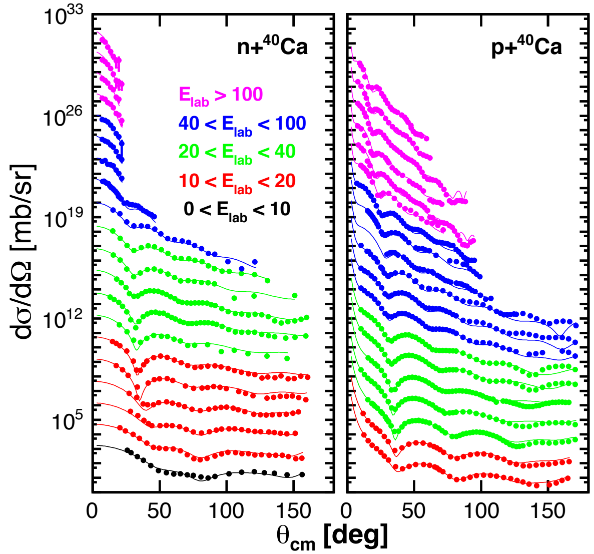
- We are developing an interesting tool to study nuclear reactions effectively.
  We have defined a non-local generalized optical potential corresponding to nuclear self energy.
- Spectroscopic Factors from ab-initio overlap wavefunctions differ from effective wood saxon. These do not seem to depend much on proton-neutron asymmetry



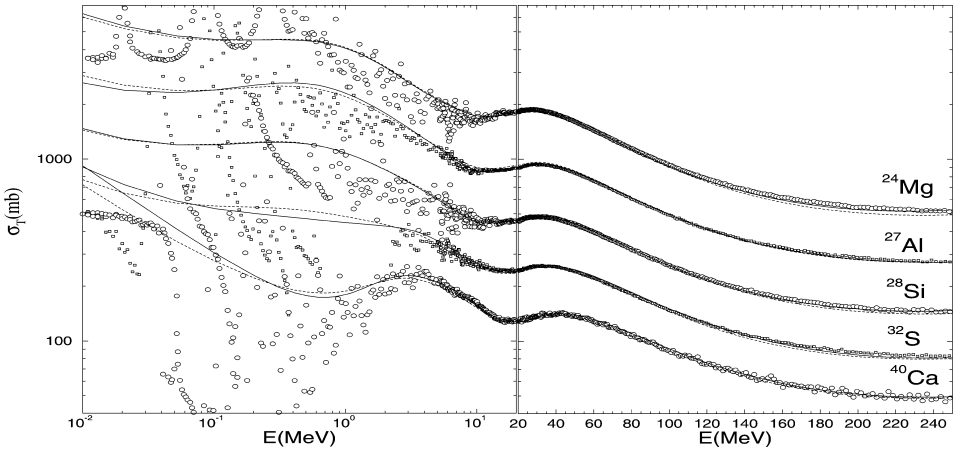


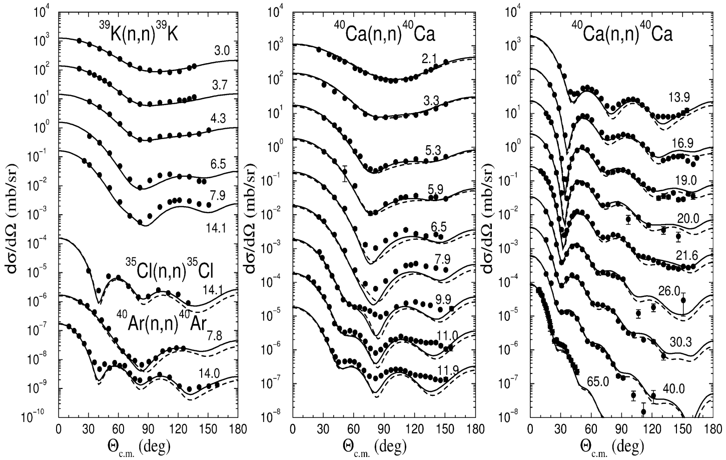
Why optical potentials?

- Optical potentials **reduce many-body complexity** decoupling structure contribution and reactions dynamics.
- Often fitted on elastic scattering data (locally or globally)
- A microscopic model is difficult but worth it



Dickhoff, Charity, Mahzoon, JPG44, 033001 (2017)





Koning, Delaroche, NPA713, 231 (2002)