Optical potentials and nucleon scattering from ab-initio Green function

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C. Barbieri

workshop on
Progress in Ab Initio Techniques in Nuclear Physics
TRIUMF, 28 Feb – 3 Mar

Idea

Objective: an effective, consistent description of structure and reactions with a single formalism.
(Hopefully) Predictive power of nuclear reactions measurements over a range of exotic isotopes.

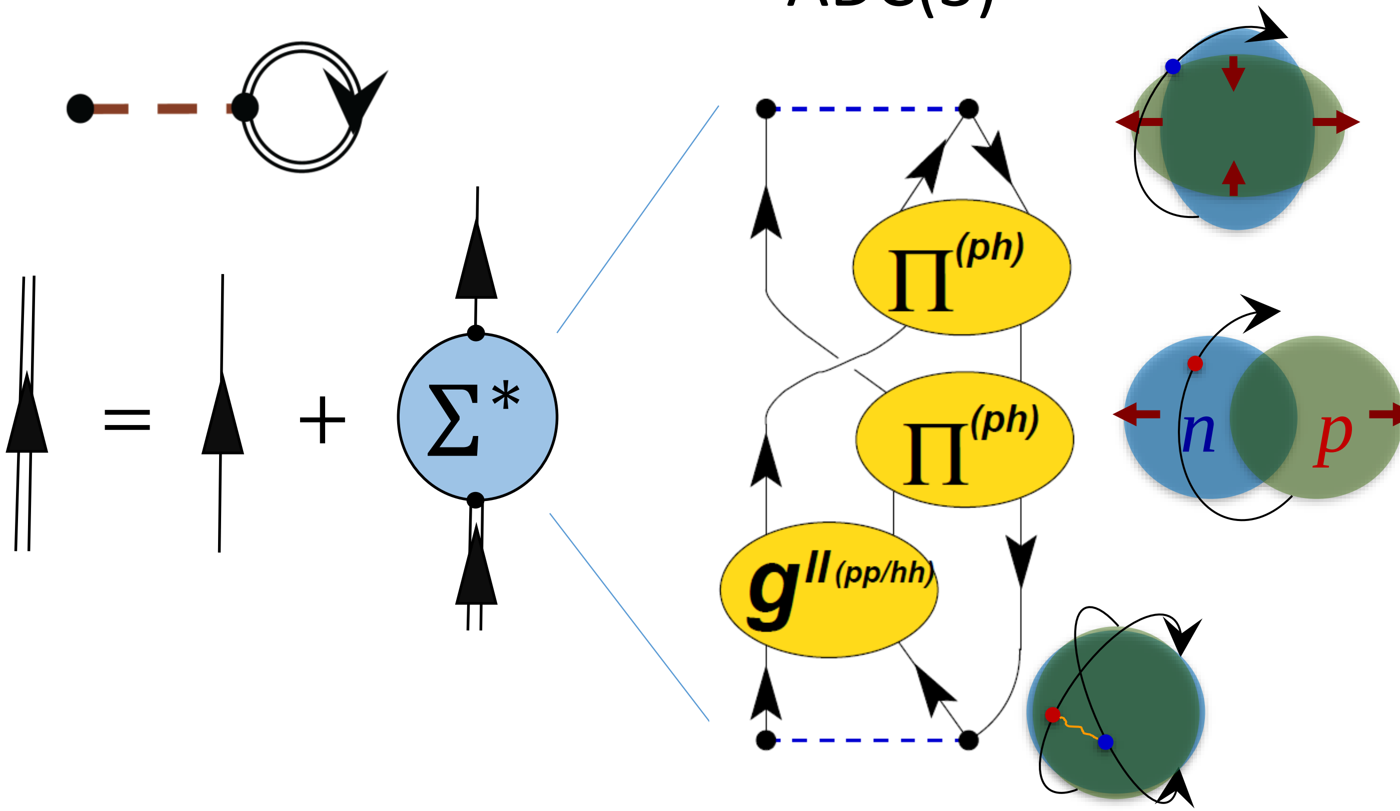
Method: Optical potential derived from Self Consistent Green Function and χEFT interactions.

1. reproduce nuclear bulk properties, i.e. binding energy and radii; ***NNLO**$_{sat}$*
2. use the same description to consistently generate an optical potential reproducing elastic scattering data.

Green Functions *(Dyson Equation)*

HF
ADC(1)

Faddeev RPA
ADC(3)



Particle hole
'polarization'
propagator
(ph-RPA)

Particle-particle (pp-RPA)
two-body correlation 'ladder' propagator

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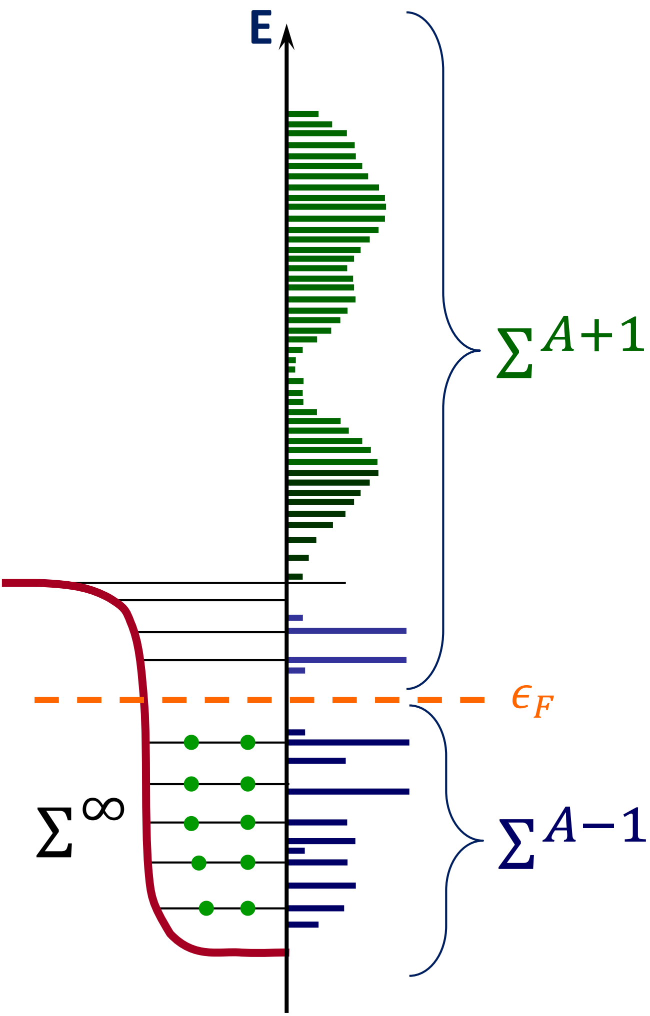
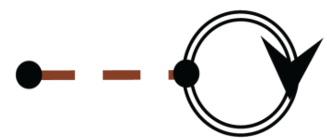
Nucleon elastic scattering



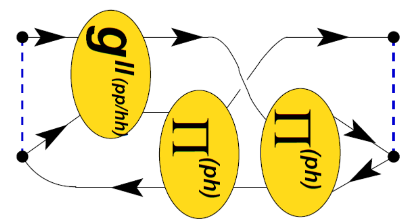
The irreducible self-energy is a nucleon-nucleus optical potential*

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

mean-field



resonances beyond mean-field



➔ This provides *consistent* many-body and scattering wave functions

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

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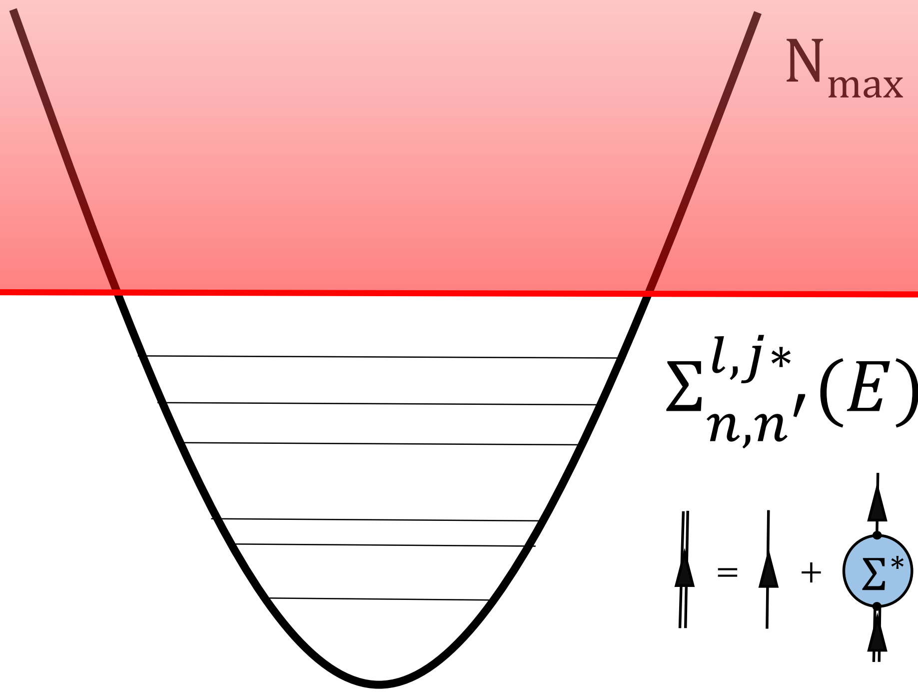
- Solve Dyson equation in HO Space, find $\Sigma^{l,j*}_{n,n'}(E)$

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

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



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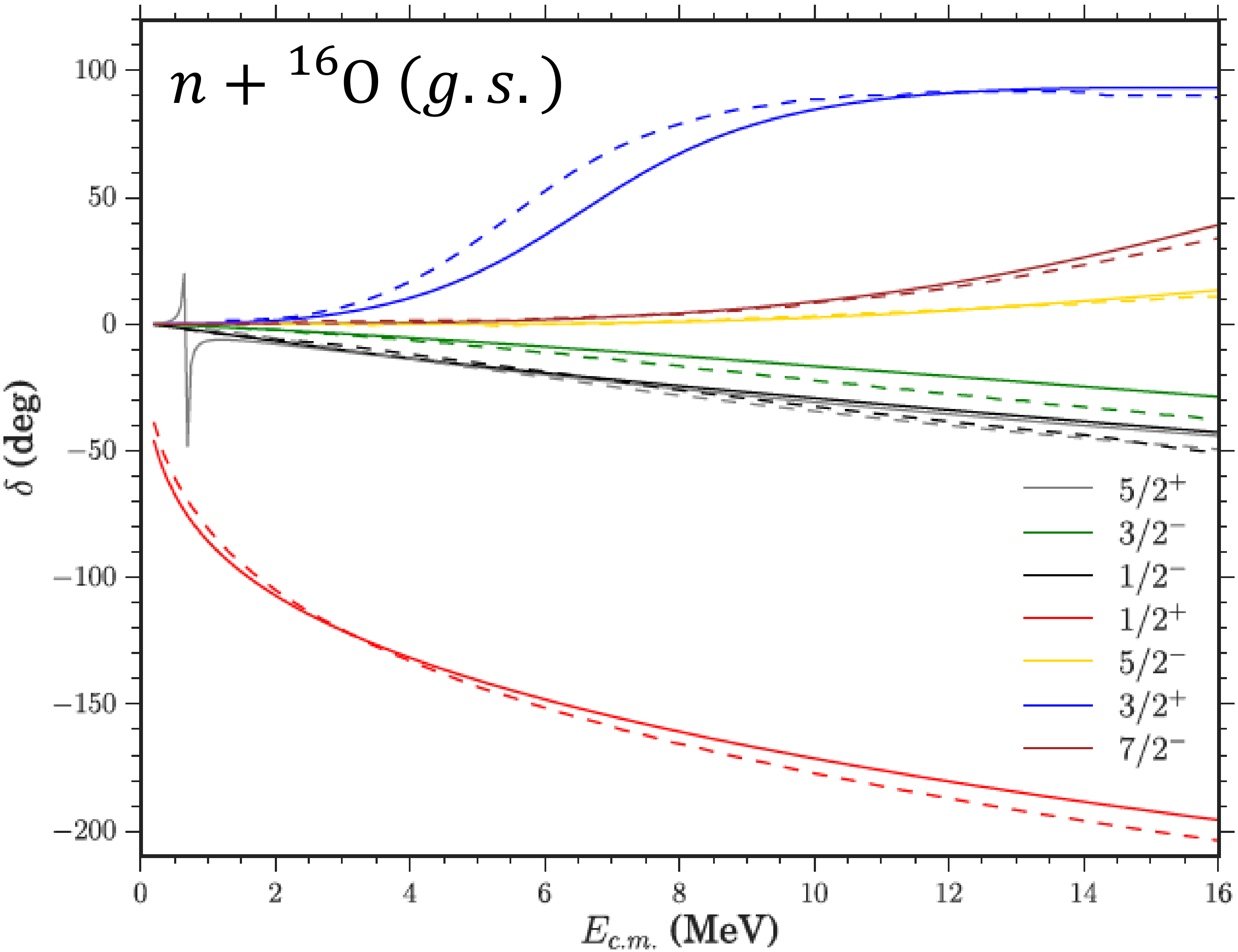
Freshly baked

RESULTS

arXiv:1612.01478 [nucl-th]

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



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

Σ^{∞}

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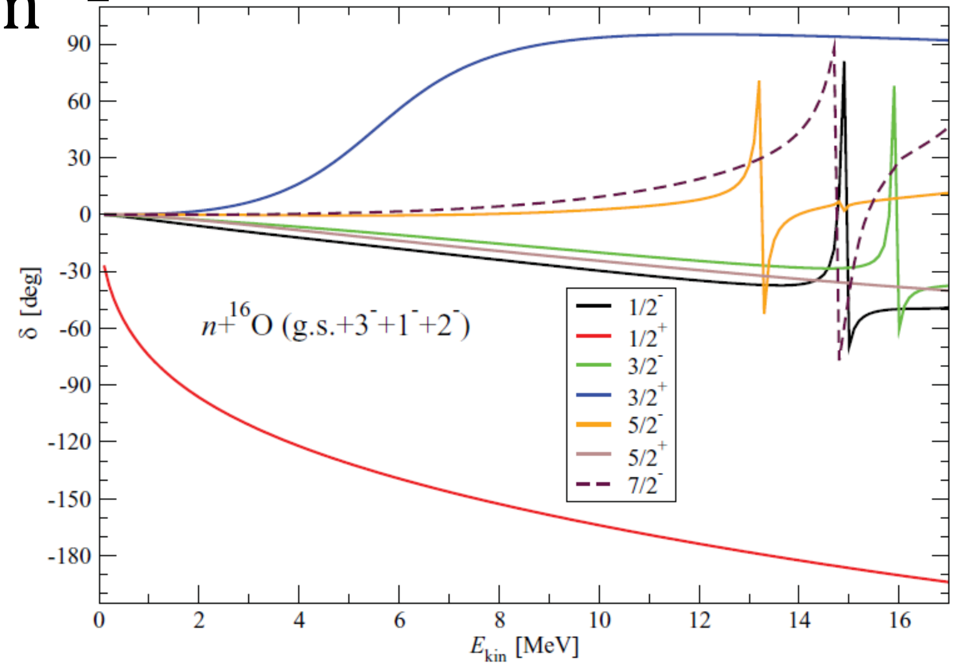
SRG-N^{3}LO, $\Lambda = 2.66\ \mathrm{fm}^{-1}$

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

$n + {}^{16}\mathrm{O}$



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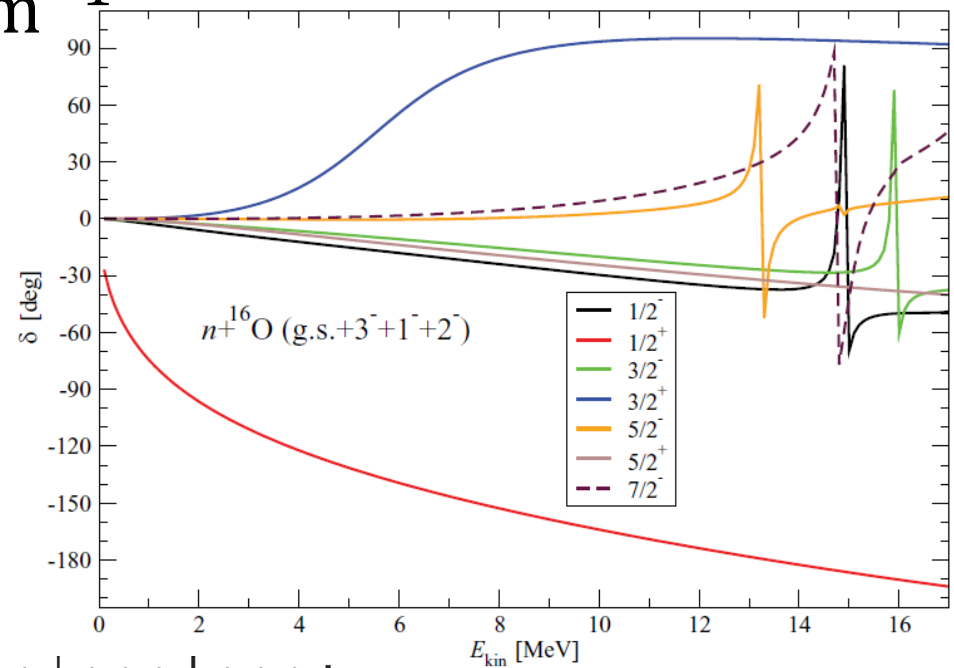

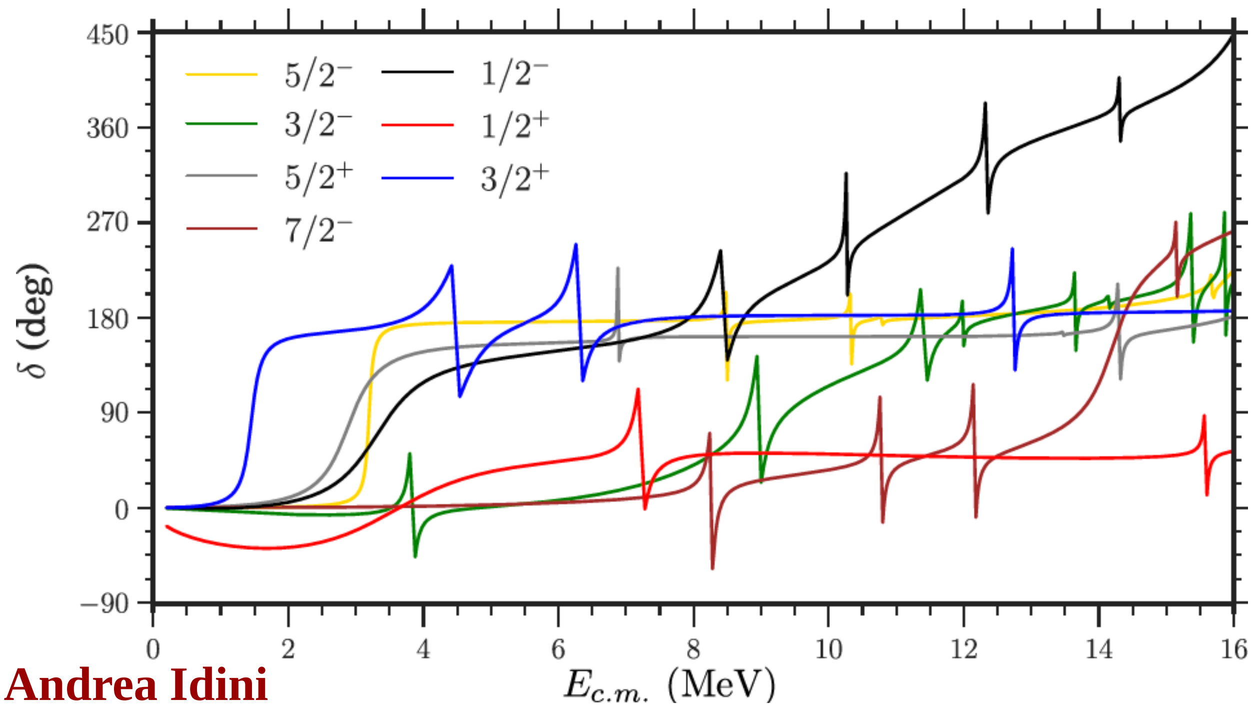

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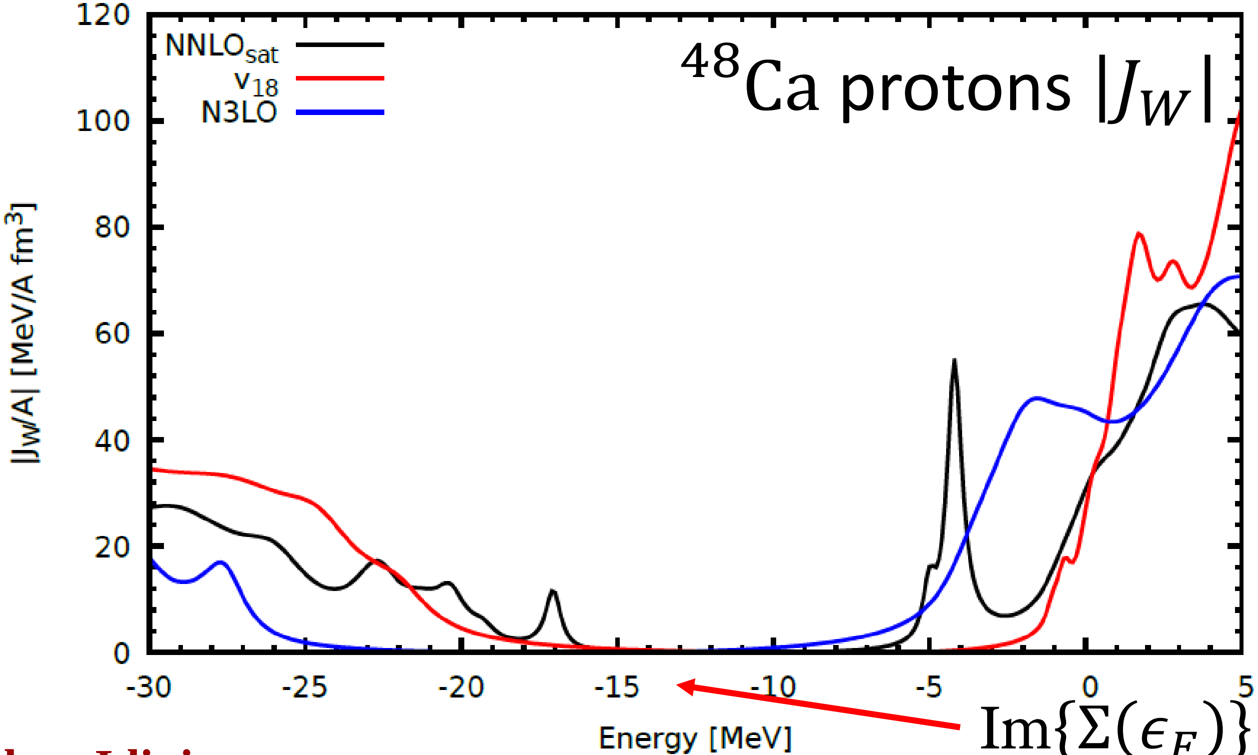
Volume integrals

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

Non local potential

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

$$\tilde{\Sigma}^{\ell j}_{n_a, n_b}(E) = \sum_r \frac{m^r_{n_a} m^r_{n_b}}{E - \varepsilon_r \pm i\eta}$$



$\mathrm{Im}\{\Sigma(\epsilon_F)\} = 0$

different Fermi energies and particle-hole gap for different interactions

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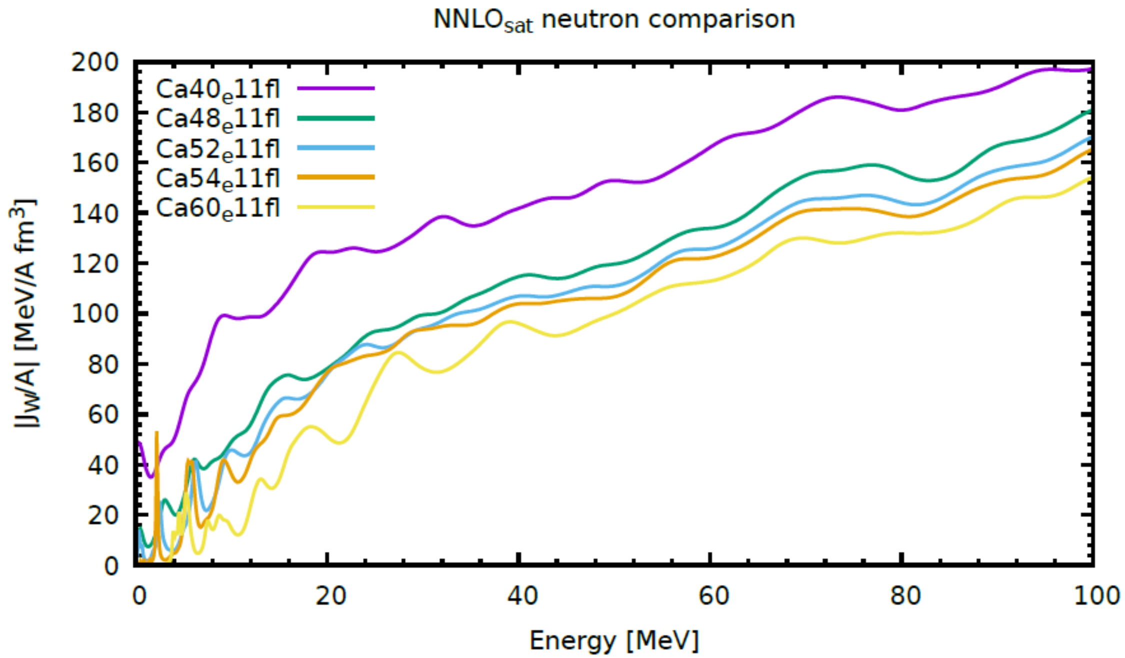
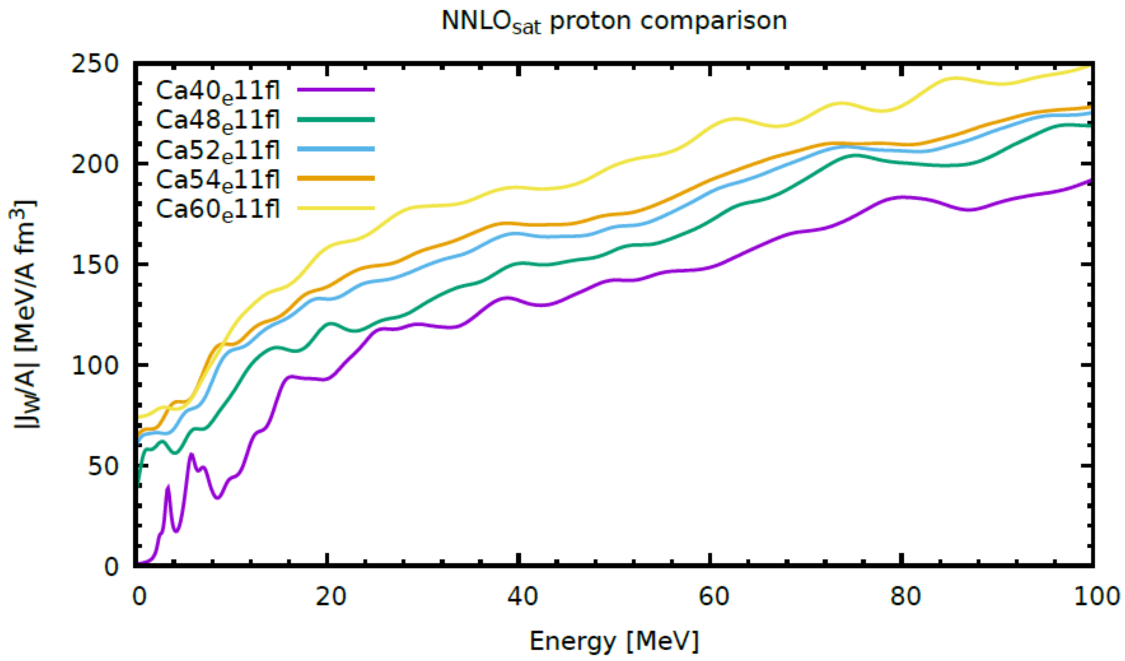
Ca isotopes

neutron and proton volume integrals of self energies.





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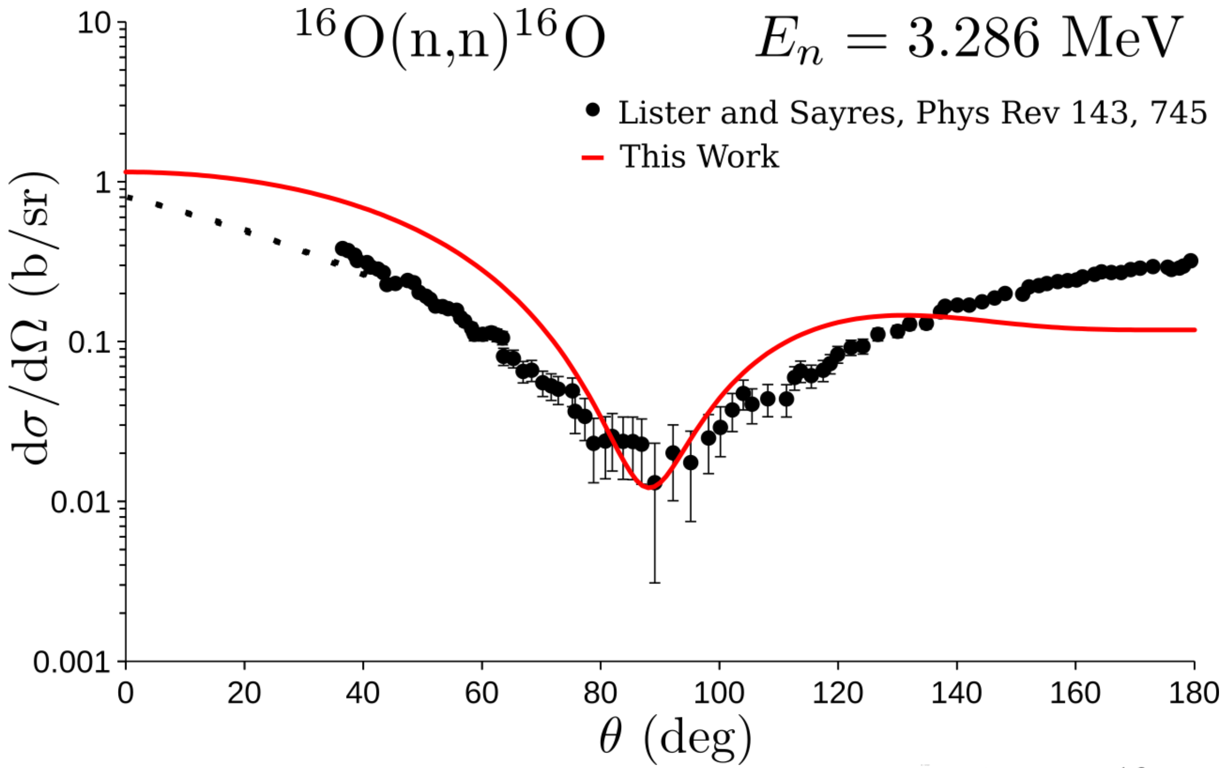

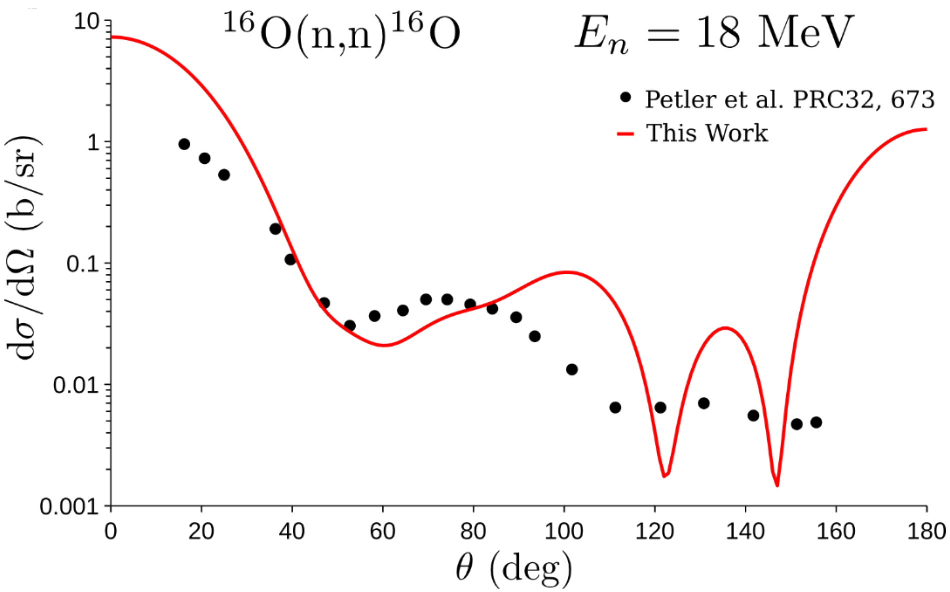

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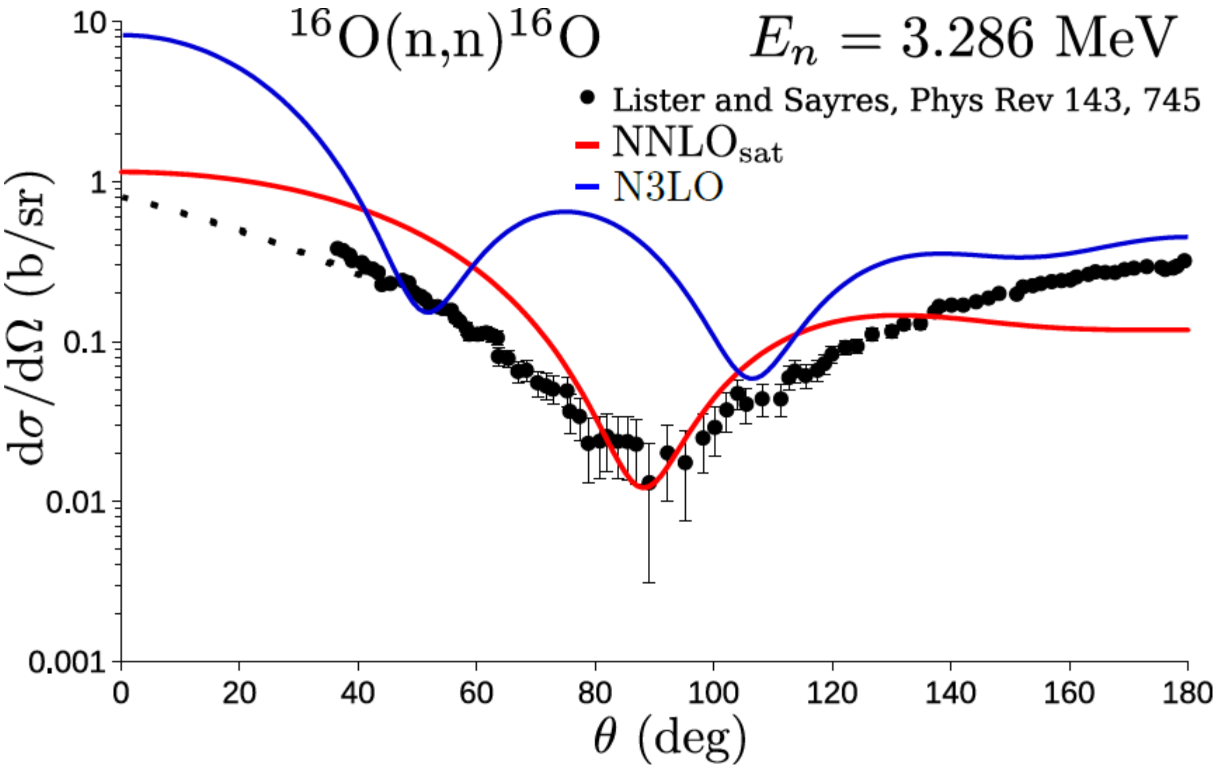

$^{16}O \langle r_p \rangle$

experiment	2.699±0.005 fm
$NNLO_{sat}$	2.734 fm
N3LO NN	2.354 fm

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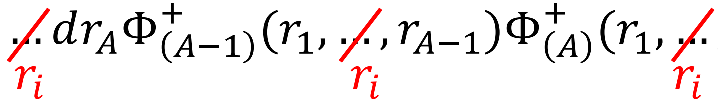
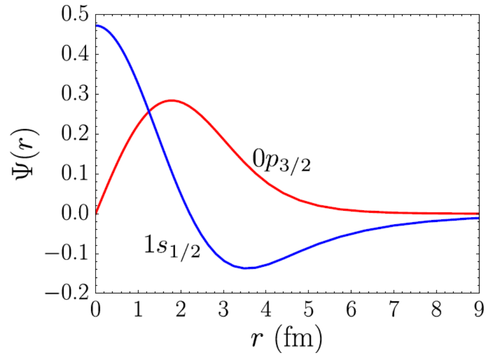
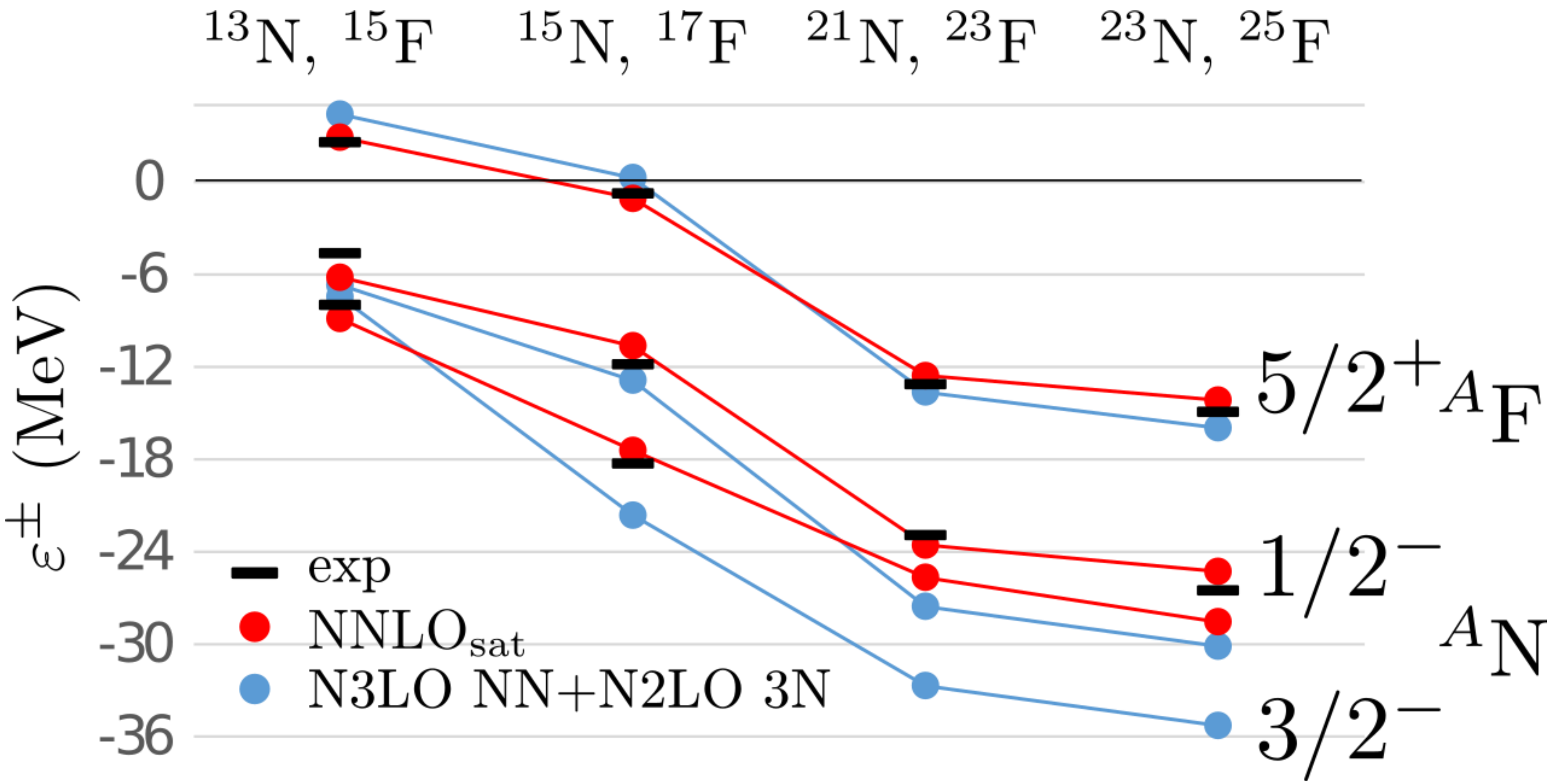
Overlap function

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







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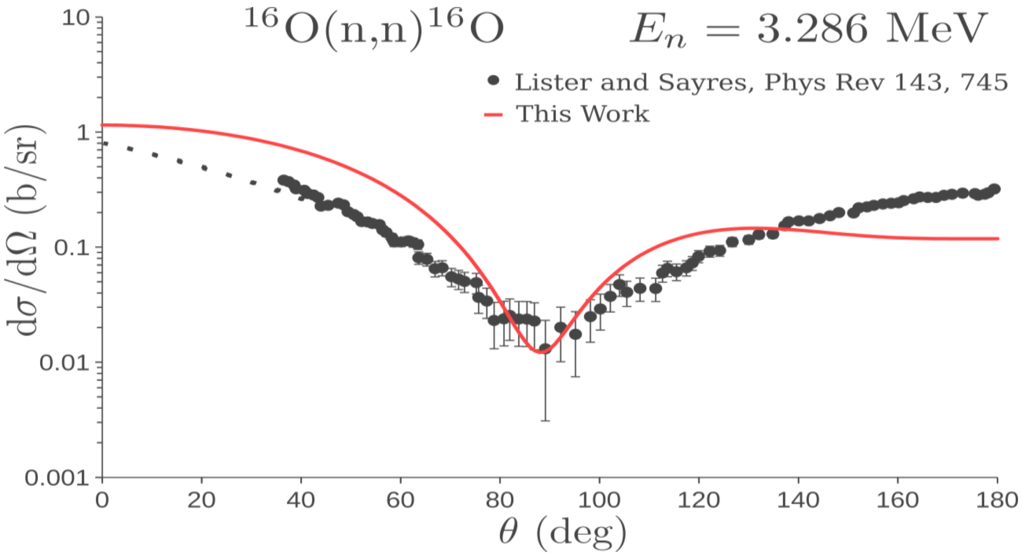
Conclusions and Perspectives

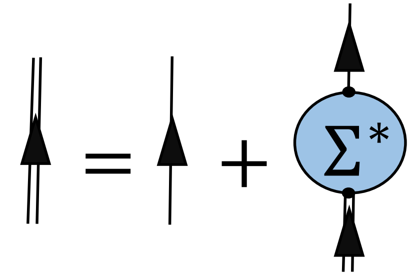
- We are developing an interesting tool to study nuclear reactions effectively.
  We have defined a non-local generalized optical potential corresponding to nuclear self energy.
- This tool is useful to probe properties of nuclear interactions.
- *Radii, saturation and bulk properties are fundamental!*



Why Green's Functions?

Dyson Equation

$$g_{\alpha\beta}(\omega) = g^0_{\alpha\beta}(\omega) + \sum_{\gamma\delta} g^0_{\alpha\gamma}(\omega)\Sigma^\star_{\gamma\delta}(\omega) g_{\delta\beta}(\omega)$$



Equation of motion

$$\left(E + \frac{\hbar^2}{2m}\nabla^2_r\right) G(\mathbf{r},\mathbf{r}';E) - \int d\mathbf{r}''\Sigma(\mathbf{r},\mathbf{r}'';E)G(\mathbf{r}'',\mathbf{r}';E) = \delta(\mathbf{r}-\mathbf{r}')$$

Corresponding Hamiltonian

$$\mathcal{H}_{\mathcal{M}}(\mathbf{r},\mathbf{r}') = -\frac{\hbar^2}{2m}\nabla^2_r\delta(\mathbf{r}-\mathbf{r}') + \Sigma(\mathbf{r},\mathbf{r}';E+i\epsilon)$$

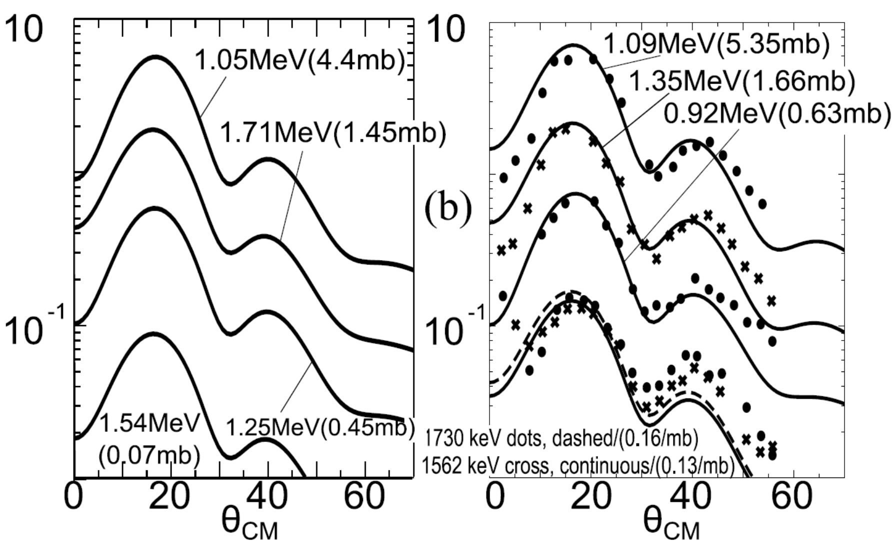
Σ corresponds to the Feshbach's generalized optical potential

Escher & Jennings PRC66 034313 (2002)

Why optical potentials?

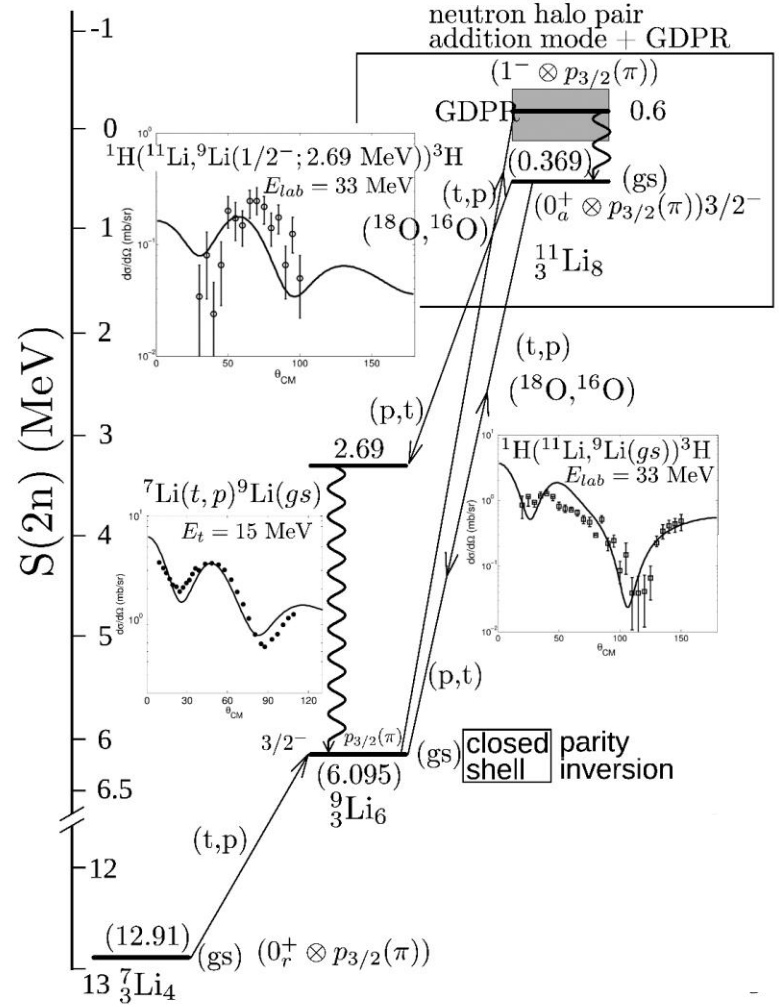
- Optical potentials **reduce many-body complexity** decoupling structure contribution and reactions dynamics.

1 particle transfer



A.I. et al. Phys. Rev. C **92**, 031304 (2015)

2 particle transfer



Broglia et al. *Phys. Scr.* **91** 06301* (2016)

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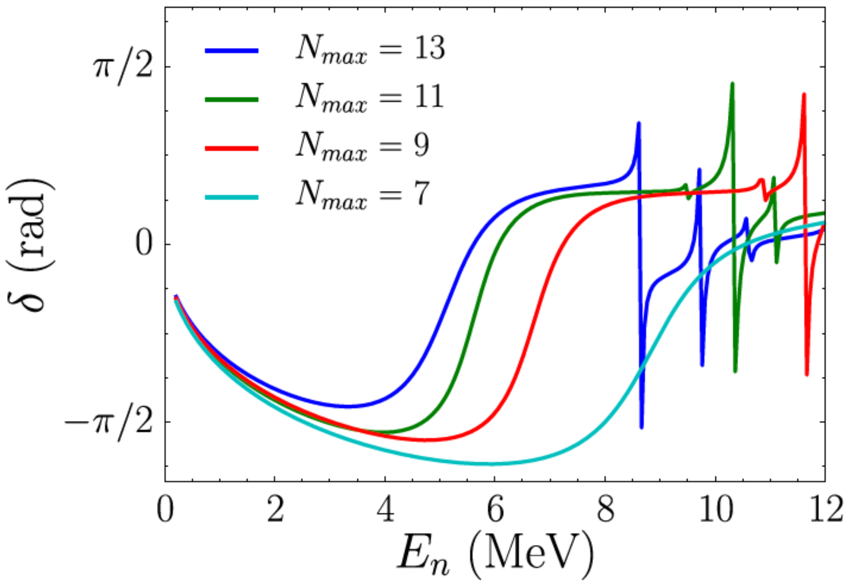

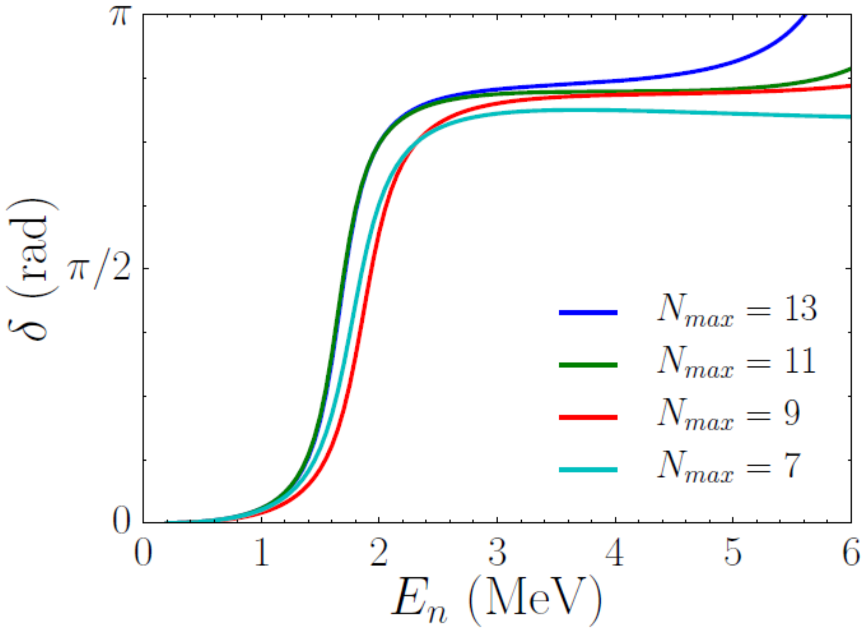

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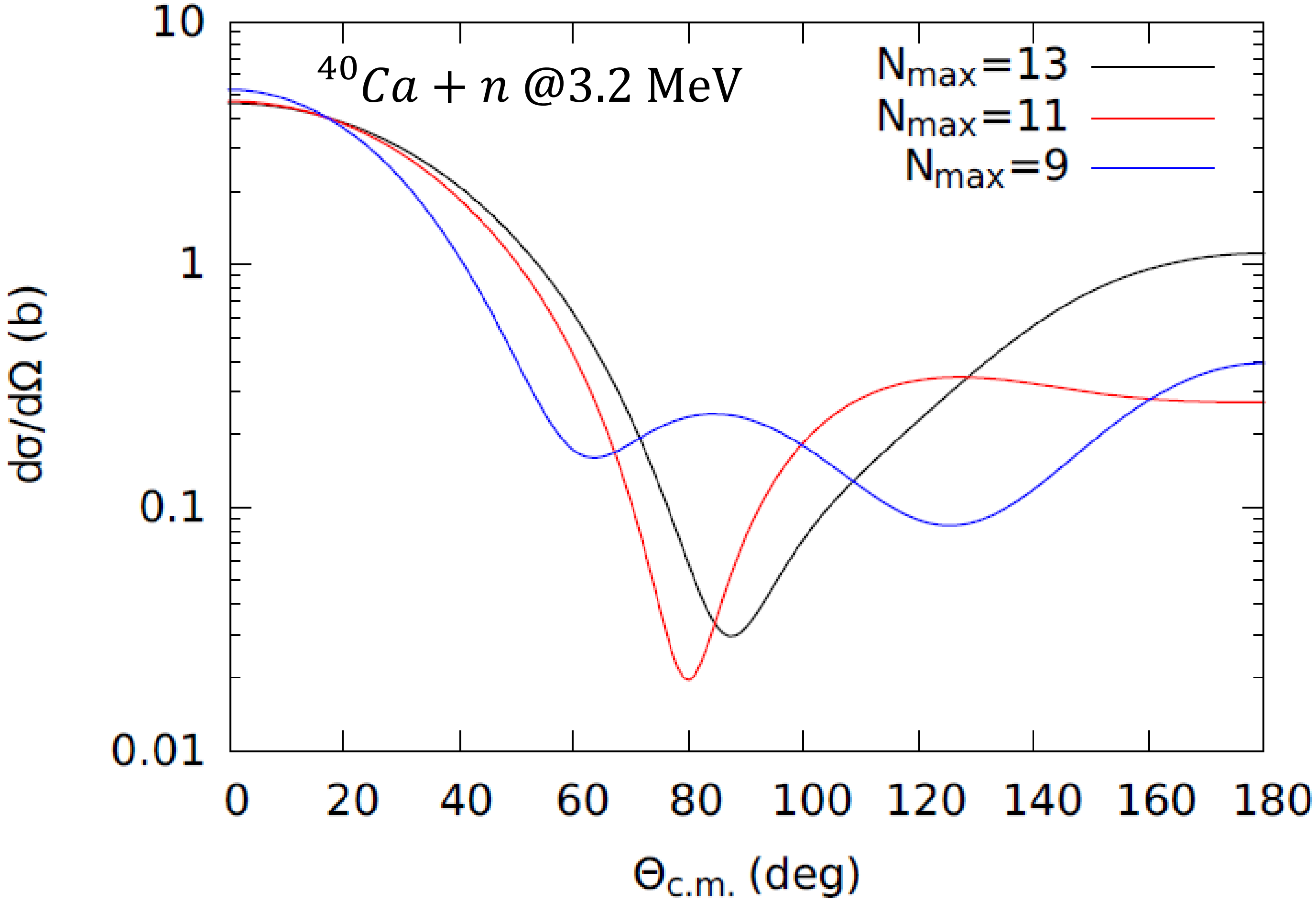
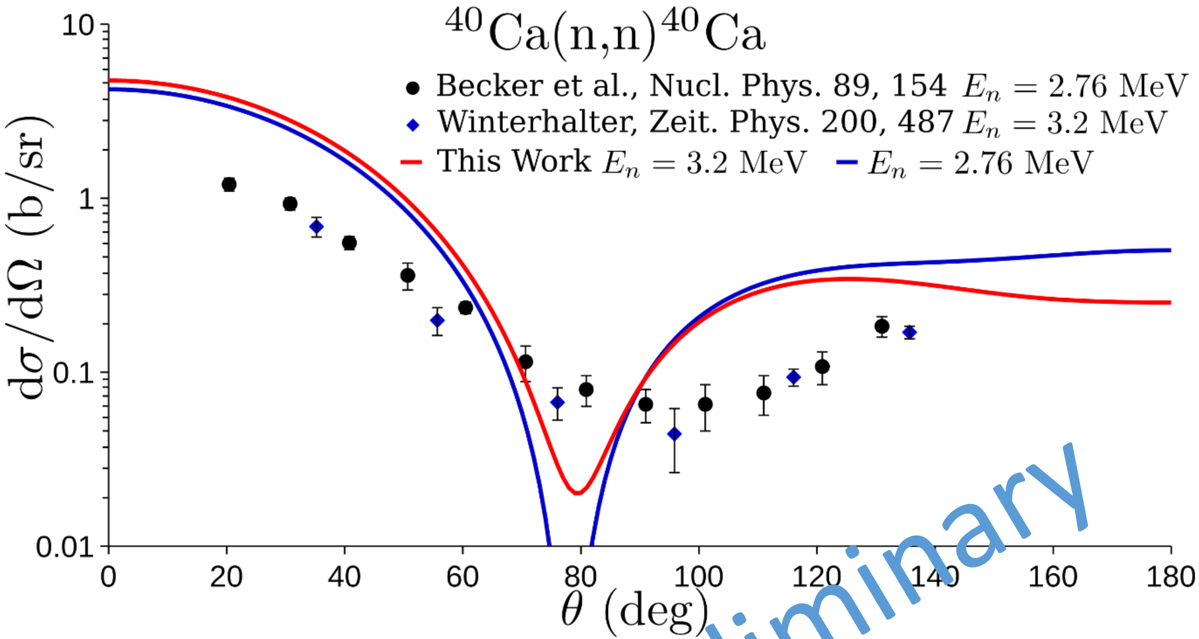
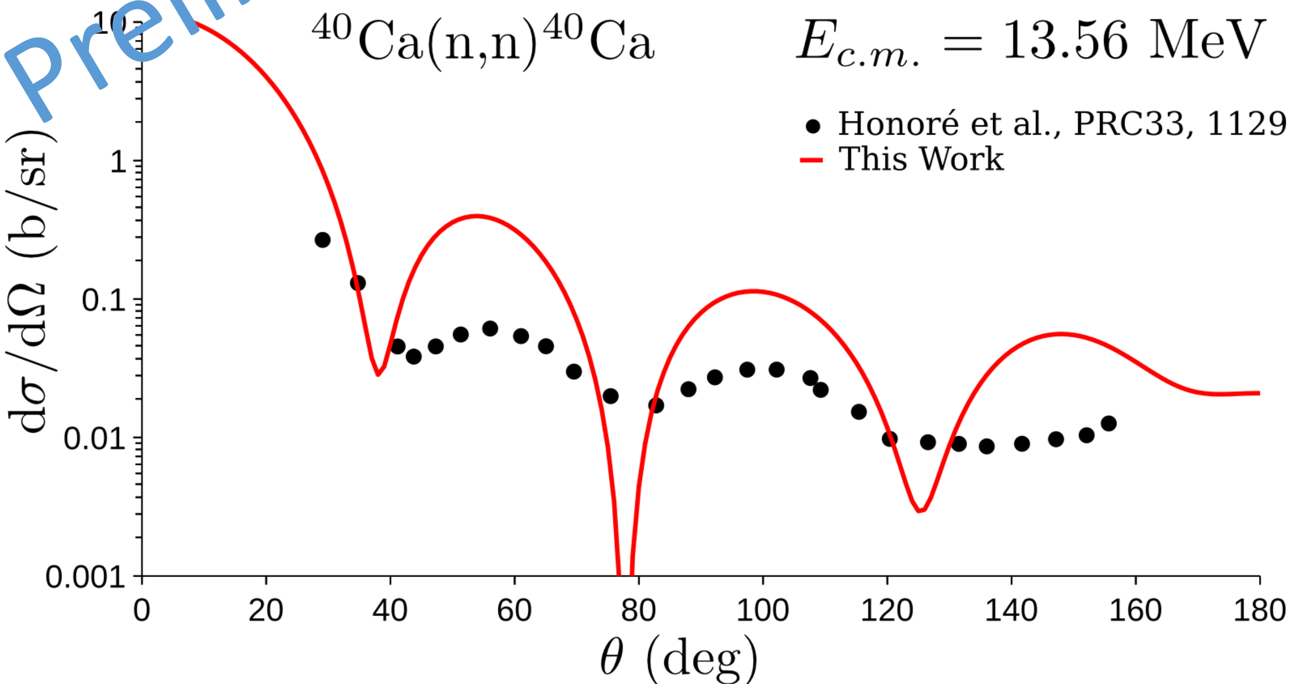


40Ca + n @3.2 MeV
Nmax=13
Nmax=11
Nmax=9
10
1
0.1
0.01
0
20
40
60
80
100
120
140
160
180
dσ/dΩ (b)
Θc.m. (deg)

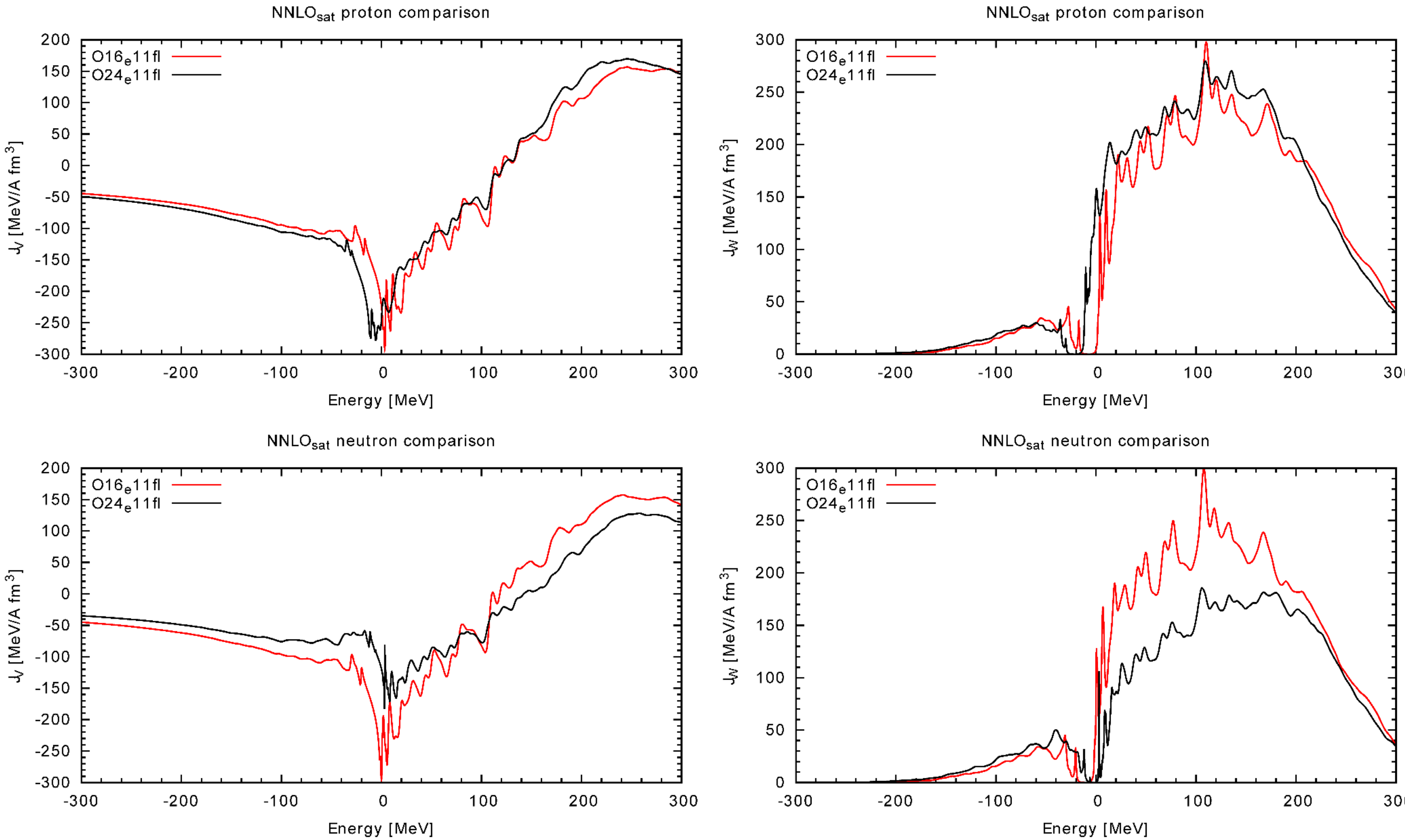


^{40}Ca(n,n)^{40}Ca
Becker et al., Nucl. Phys. 89, 154 $E_n = 2.76$ MeV
Winterhalter, Zeit. Phys. 200, 487 $E_n = 3.2$ MeV
This Work $E_n = 3.2$ MeV
$E_n = 2.76$ MeV
$d\sigma/d\Omega$ (b/sr)
θ (deg)



^{40}Ca(n,n)^{40}Ca
$E_{c.m.} = 13.56$ MeV
Honoré et al., PRC33, 1129
This Work
$d\sigma/d\Omega$ (b/sr)
θ (deg)

^{16}O and ^{24}O


NNLOsat proton comparison
O16e11fl
O24e11fl
JV [MeV/A fm3]
Energy [MeV]
NNLOsat proton comparison
O16e11fl
O24e11fl
JW [MeV/A fm3]
Energy [MeV]
NNLOsat neutron comparison
O16e11fl
O24e11fl
JV [MeV/A fm3]
Energy [MeV]
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Energy [MeV]