Gogny-based optical potential

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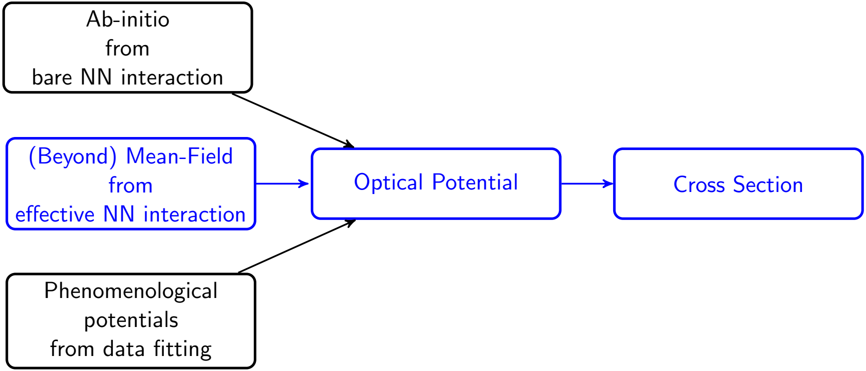
Microscopic ingredients for nuclear reaction codes (TALYS):

- Nuclear level densities — *S. Hilaire*
- γ-ray strength functions — *S. Péru*
- Preequilibrium — *M. Dupuis*
- Density and transition density — *S. Péru, N. Pillet*
- Optical Potential — *G. Blanchon*

TALYS: A.J. Koning, S. Hilaire, M. Duijvestijn, in Proceeding of the International Conference on Nuclear Data for Science and Technology-ND2007 (EDP Sciences, Paris, France, 2008), pp. 211–214

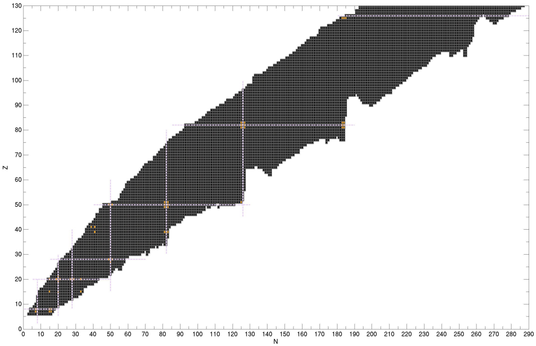


→ **Nuclear Structure Method for scattering**

N. Vinh Mau, Theory of nuclear structure (IAEA, Vienna) p. 931 (1970)

NSM & EDF extended reach

Spherical HF (∼10 nuclei)



G. Blanchon, M. Dupuis, H. Arellano, N. Vinh Mau, Phys. Rev. C (2015)

G. Blanchon, M. Dupuis, H. Arellano, Eur. Phys J. A, 51 12 (2015) 165

HF+RPA Potential

+

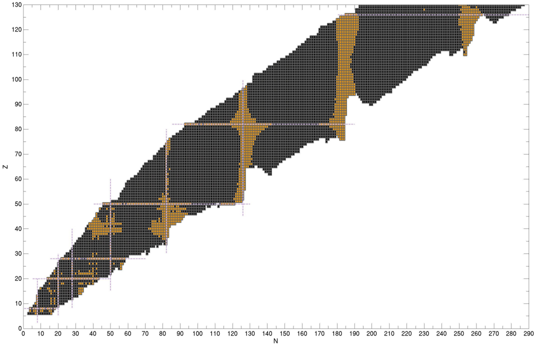
Integro-differential Schrödinger

⇓

Reaction Observables

NSM & EDF extended reach

Spherical HFB ($\sim$300 nuclei)



Collaboration with R. Bernard and S. Péru *(CEA,DAM,DIF)*

HFB+QRPA Potential

+

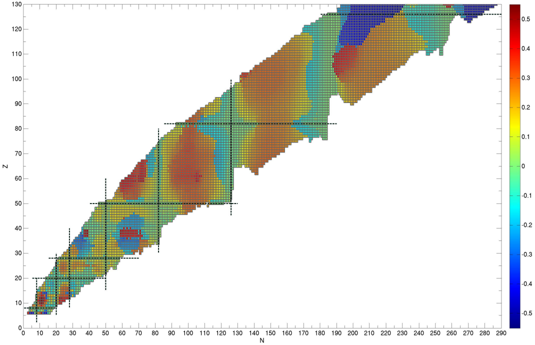
Nonlocal Coupled channels

$\Downarrow$

Reaction Observables

NSM & EDF extended reach

Deformed HFB (∼6000 nuclei)



Amine Nasri *PhD CEA,DAM,DIF*

"Non-local microscopic potentials for calculation of scattering observables of nucleons on deformed nuclei"

Collaboration with **H. Arellano**

HFB+QRPA deformed potential

+

Nonlocal Coupled channels

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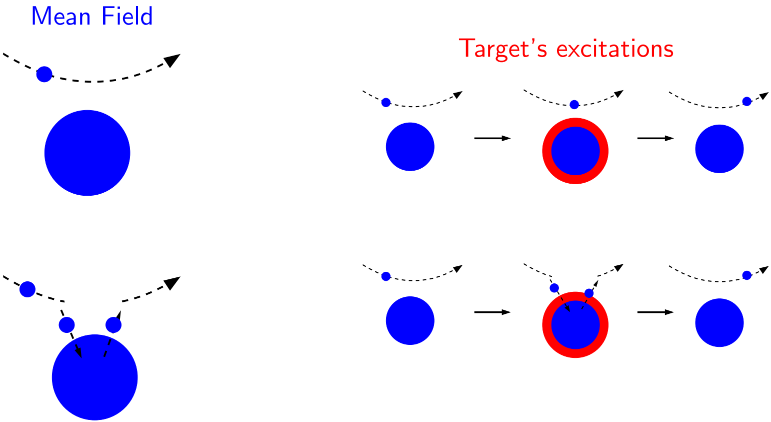
Reaction Observables

NUCLEAR STRUCTURE METHOD FOR SCATTERING

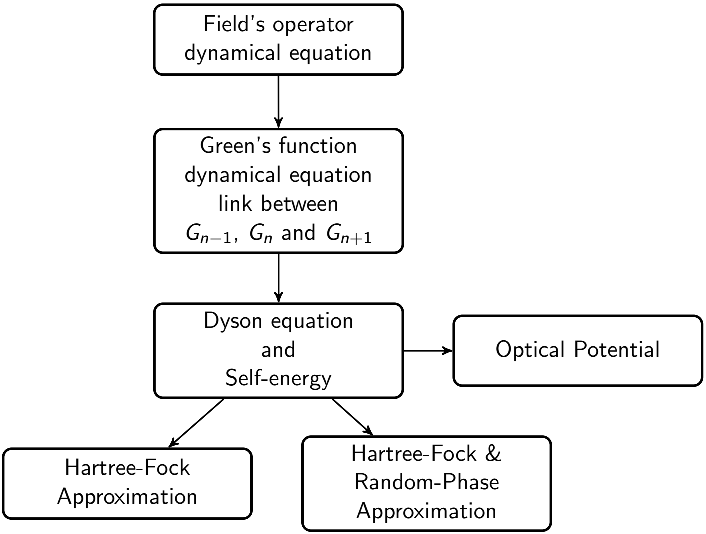
Nuclear Structure Method

$$V = V^{HF} + \Delta V^{RPA}$$



Limitation: No two-fold charge exchange (n, p, n) and (p, n, p) in the present version of NSM

From NN interaction to the optical potential

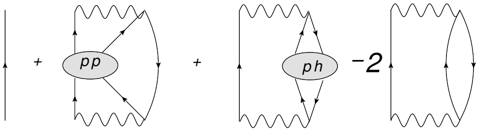


Nuclear Structure Method

Optical potential

$$V = V^{HF} + V^{PP} + V^{RPA} - 2V^{(2)}$$

Bare Interaction

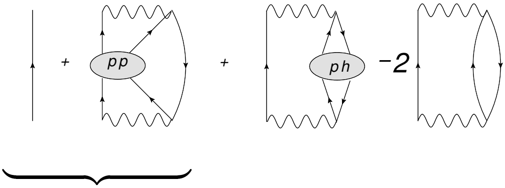


Nuclear Structure Method

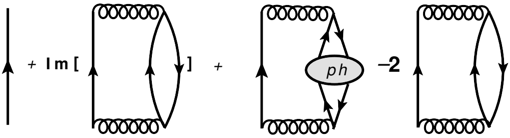
Optical potential

$$V = V^{HF} + V^{PP} + V^{RPA} - 2V^{(2)}$$

Bare Interaction



Effective Interaction



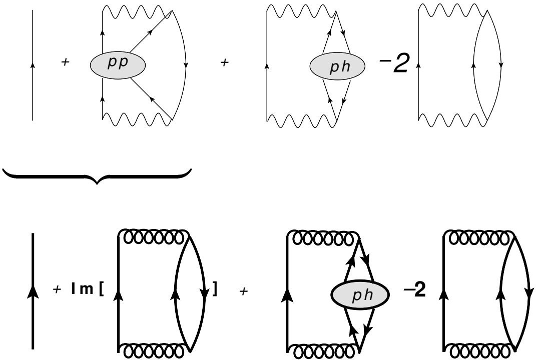
Nuclear Structure Method

Optical potential

$$V = V^{HF} + V^{PP} + V^{RPA} - 2V^{(2)}$$

Bare Interaction

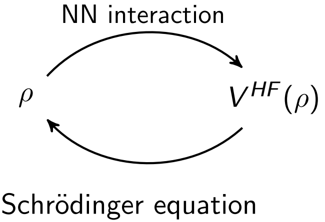
Gogny Interaction

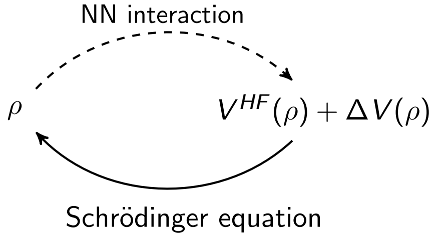


Gogny D1S interaction has been designed anticipating the inclusion of particle-vibration couplings

Issue : The resulting potential is not dispersive ...

Self-consistency





HF

- Coordinate representation
- Treatment of the continuum (SP resonances)

RPA

- Oscillator basis including 15 major shells
- Excited states up to $J = 8$ with both parities

Self energy $\rightarrow$ optical potential

The resulting potential is nonlocal, complex and energy dependent

Nonlocal potential & Schrödinger equation

Integro-differential Schrödinger equation

$$-\frac{\hbar^2}{2m}\left[\frac{d^2}{dr^2}-\frac{l(l+1)}{r^2}\right]u_{lj}(r)+\int dr' r\nu_{lj}(r,r';E)r' u_{jl}(r') = E\ u_{lj}(r)$$

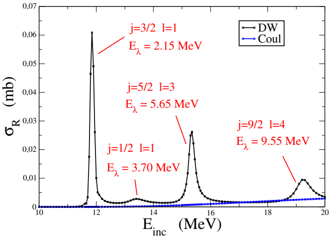
- Radial mesh
- Solution obtained by matrix inversion
- Connection to asymptotic $\rightarrow$ phaseshift $\rightarrow$ observables

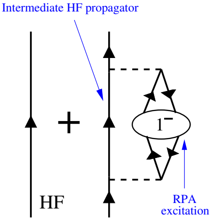
No use of local version

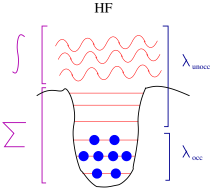
$$-\frac{\hbar^2}{2m}\left[\frac{d^2}{dr^2}-\frac{l(l+1)}{r^2}\right]u_{lj}(r)+\nu_{lj}(r;E)u_{jl}(r) = E\ u_{lj}(r)$$

Coupling to a single target excited state

- $p+^{40}Ca$ scattering
- Coupling to the first 1^- state of ^{40}Ca with $E_{1^-} = 9.7$ MeV

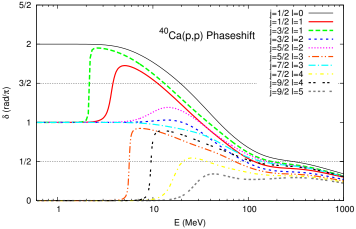






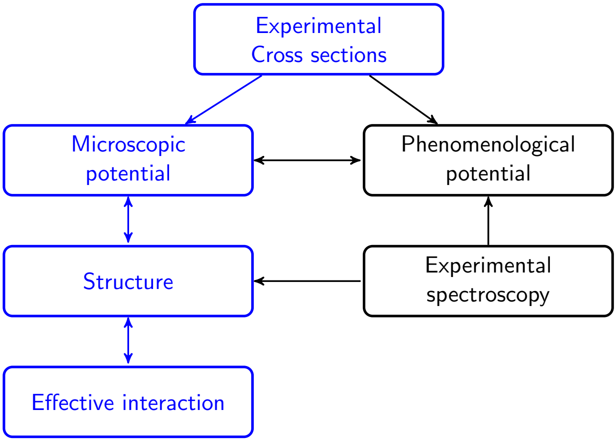
- **Importance of the intermediate single particle resonances**
- **Strong impact on reaction cross section**

- HF phaseshift



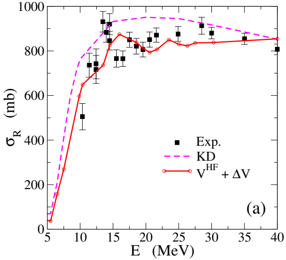
NUCLEON SCATTERING OFF N=Z TARGET NUCLEUS

Elastic scattering n/p + ^{40}Ca

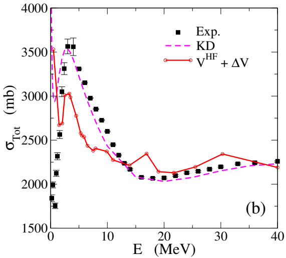


Integral cross sections n/p + ^{40}Ca

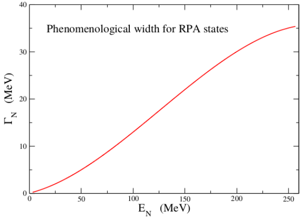
- p + ^{40}Ca



- n + ^{40}Ca

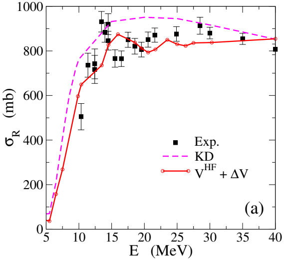


- Compound elastic from Haüser-Feshbach with Koning-Delaroche potential
- Use of phenomenological width for the excited states of the target.

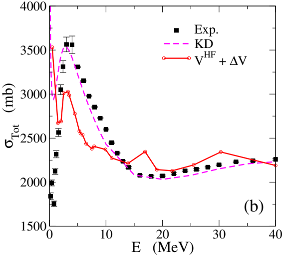


Integral cross sections   n/p + ^{40}Ca

- p + ^{40}Ca



- n + ^{40}Ca



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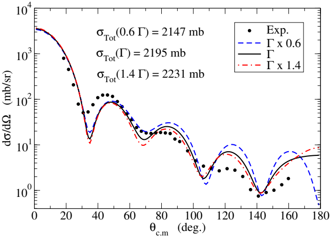
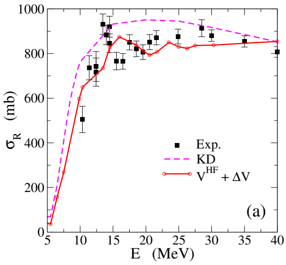


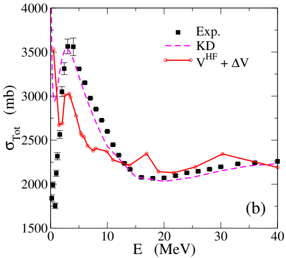
Width sensitivity (n+^{40}Ca @ 25 MeV)

Integral cross sections n/p + ^{40}Ca

- p + ^{40}Ca



- n + ^{40}Ca



- Compound elastic from Haüser-Feshbach with Koning-Delaroche potential

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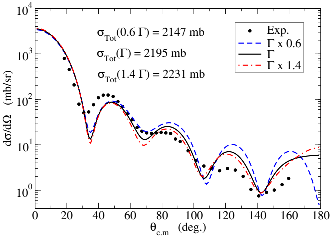
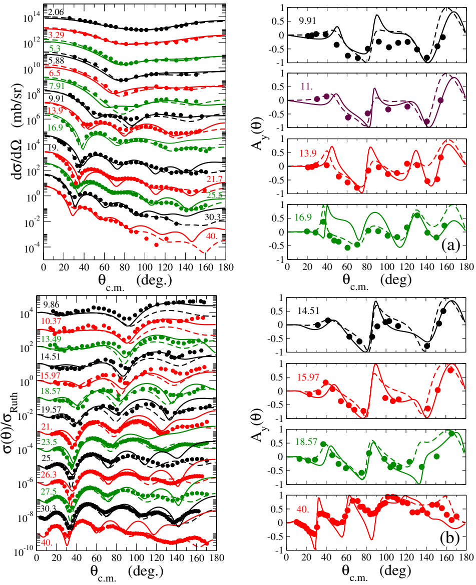


Width sensitivity (n+^{40}Ca @ 25 MeV)

- Perspective: microscopic determination of energy widths and shifts: 2p-2h coupling *(N. Pillet)*

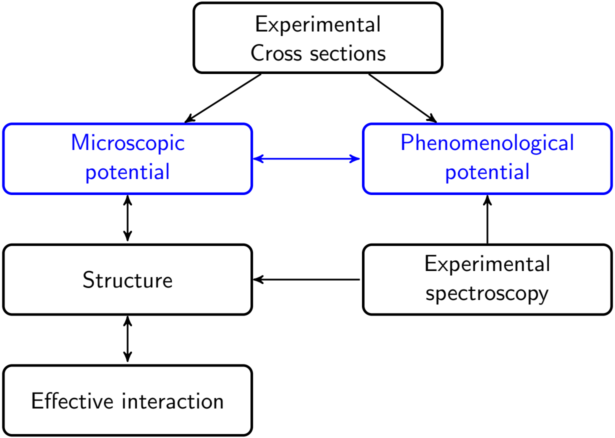
Cross section and Analyzing powers n/p+^{40}Ca



NSM (full line)
Koning-Delaroche (dashed line)

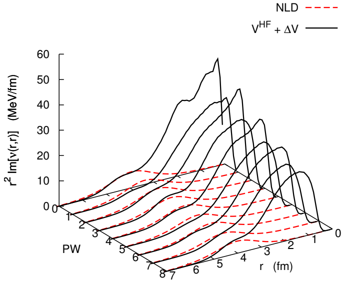
- Good agreement with cross section data below 30 MeV.
- In terms of energy regime, NSM is complementary to g-matrix approaches.
- Good agreement with analyzing powers data: correct behaviour of the "spin-orbit" term of the potential.
- Effective interaction fitted from structure data + fission barriers

Microscopic and phenomenological potentials



Potential for n + ^{40}Ca @ 10 MeV

- NSM potential
- Non Local Dispersive (NLD) potential fitted on all the available data for ^{40}Ca
  $\nu_{lj}(r,r') = \iint d\hat{\mathbf{r}} d\hat{\mathbf{r}}' \mathcal{Y}^m_{jl}(\hat{\mathbf{r}}) V(\mathbf{r},\mathbf{r'}) \mathcal{Y}^{m\dagger}_{jl}(\hat{\mathbf{r}}')$



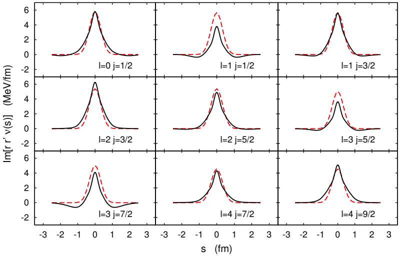
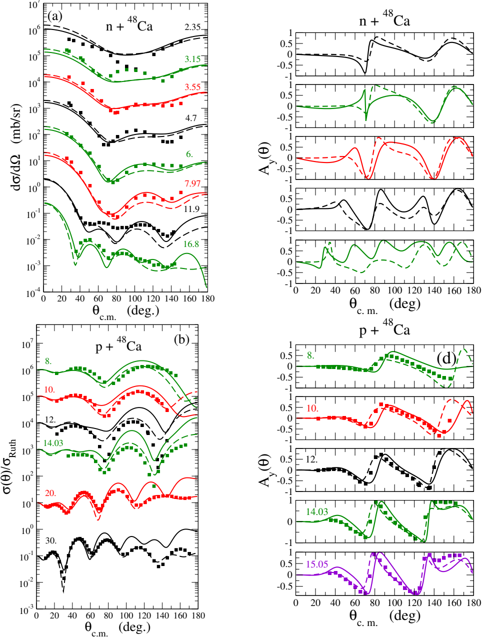


Figure : $s = |\mathbf{r} - \mathbf{r'}|$

NLD: *M.H. Mahzoon et al. , Phys. Rev. Lett. 112, 162503 (2014)*

NUCLEON SCATTERING OFF N>Z TARGET NUCLEUS

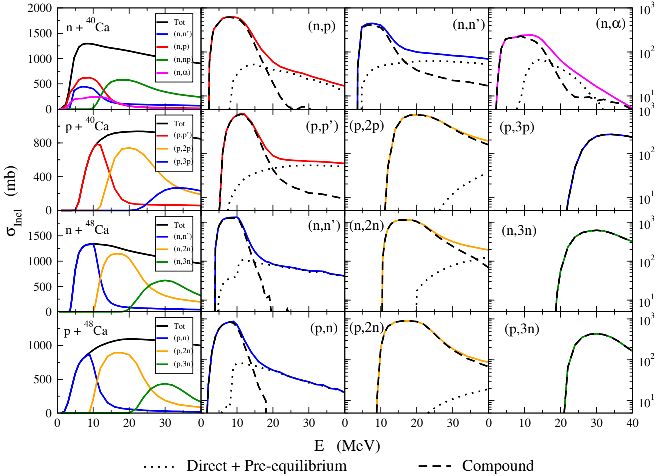
Cross section and Analyzing powers n/p+^{48}Ca



NSM (full line)
Koning-Delaroche (dashed line)

- Good agreement with cross section data for n + ^{48}Ca
- Lack of absorption for p + ^{48}Ca

TALYS

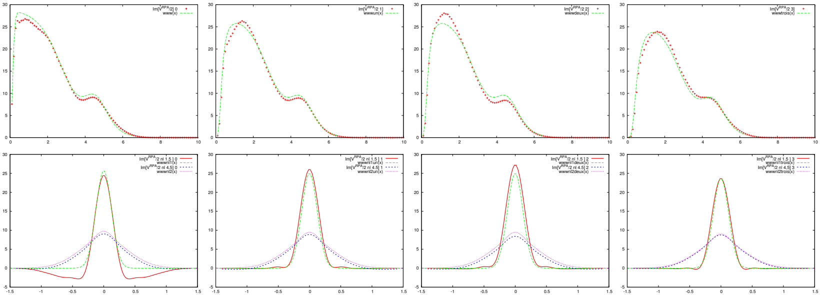


- NSM potential describes direct components
- Need for two-fold charge exchange (p, n, p)

PB-like equivalent of the imaginary NSM potential

p + ^{48}Ca :

$(0, 1/2)$ $(1, 1/2)$ $(1, 3/2)$ $(2, 3/2)$



Perey-Buck ansatz :

$$W^{n/p}(\mathbf{r},\mathbf{r'};E) = H(\mathbf{s},\beta_v)W_v^{n/p}(E)f(R,r_v,a_v) + 4H(\mathbf{s},\beta_s)W_s^{n/p}(E)a_s f'(R,r_s,a_s)$$

$$f(r,r_0,a) = \left[1+\exp\left(\frac{r-r_0A^{1/3}}{a}\right)\right]^{-1}$$ *WS form factor*

$$H(\mathbf{s},\beta) = \frac{1}{\pi^{3/2}\beta^3}\exp\left(-\left|\frac{\mathbf{s}}{\beta}\right|\right)$$ *Gaussian nonlocality*

with $R = (r+r')/2$ and $\mathbf{s} = \mathbf{r} - \mathbf{r'}$

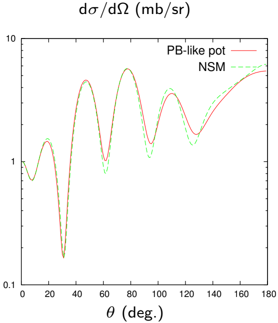
PB-like equivalent of the imaginary NSM potential

$$W^{n/p}(\mathbf{r},\mathbf{r'};E) \quad = \quad H(\mathbf{s},\beta_v)W_v^{n/p}(E)f(R,r_v,a_v)+4H(\mathbf{s},\beta_s)W_s^{n/p}(E)a_sf'(R,r_s,a_s)$$

Fit parameters :

r_v	r_s	a_v	a_s	β_v	β_s
0.78	1.254	0.49 (^{40}Ca) 0.78 (^{48}Ca)	0.44	0.35	1.1

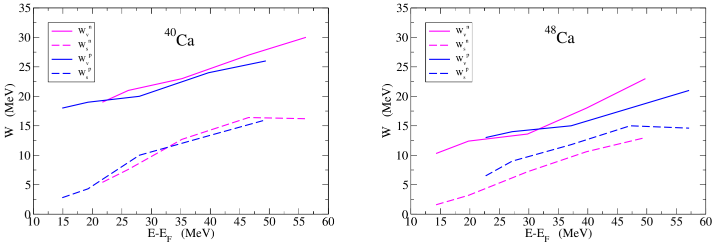
Check of reliability of the fit :



p + ^{48}Ca @ 30 MeV

PB-like equivalent of the imaginary NSM potential

Magnitudes :



- Lane consistency *(already discussed by Osterfeld)*
- Proton/neutron asymmetry of the target yields a bigger proton surface potential than the neutron one
- Volume imaginary potential decreases with asymmetry for protons and neutrons

NSM/Lane potential

Approximate method to recover proton absorption

Lane model assumes isospin symmetry in nuclei :

$$V^{(n/p)} = V_0 \pm \frac{(N-Z)}{2A} V_1 \quad \text{with} \quad V^{n/p}(E - E_F^{n/p})$$

in reality, one gets

$$V^n - V^p = \frac{N-Z}{A} V_1 - V_{cc}$$

V_{cc} : isospin non-conserving Coulomb corrections in the second order term

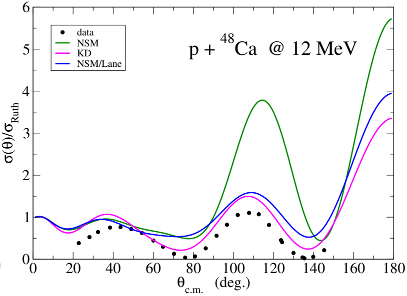
$V_{cc} \approx 0$ in the case of ^{40}Ca

$V^n(^{40}\text{Ca}) \approx V^p(^{40}\text{Ca}) \approx V_0^{FIT}(^{40}\text{Ca})$

and assuming NSM provides nice results for $n+^{48}$Ca scattering

$$\Downarrow$$

$$V^p_{NSM/Lane}(^{48}\text{Ca}) = 2V_0^{FIT}(^{48}\text{Ca}) - V^n_{NSM}(^{48}\text{Ca})$$



CONCLUSION

Conclusions

- Gogny interaction is connected to reaction observables
- Need for double-charge-exchange component in NSM
- Results on asymmetry *(submitted to EPJA)*
- Study of all doubly-closed-shell target nuclei *(in progress)*
- Account of pairing *(in progress)*

Potential based on effective interaction

Nuclear Structure Method

- N. Vinh Mau, Theory of nuclear structure (IAEA, Vienna 1970) p. 931.
- N. Vinh Mau, A. Bouyssy, NPA 257(2), 189 (1976).
- V. Bernard, N. Van Giai, NPA 327(2), 397 (1979).
- F. Osterfeld, J. Wambach, V.A. Madsen, PRC 23(1), 179 (1981).
- K. Mizuyama et al., PRC 86, 041603 (2012).
- Y. Xu et al., JPG 41, 015101 (2014).
- G. Blanchon, M. Dupuis, H. Arellano and N. Vinh Mau, PRC 91, 014616 (2015).
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- T. V. Nhan Hao et al., PRC 92, 014605 (2015).