# Asymmetry dependence of Gogny-based optical potential

G. Blanchon, R. Bernard, M. Dupuis, H. F. Arellano

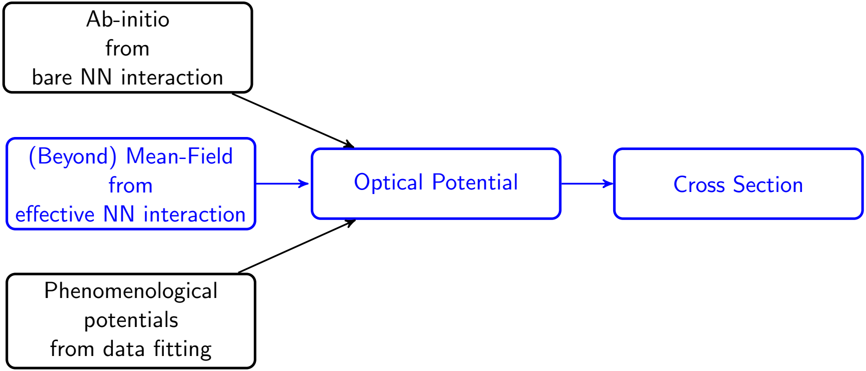
CEA,DAM,DIF F-91297 Arpajon, France

March 13-16 2017, INT, Seattle, USA

Microscopic ingredients for nuclear reaction codes (TALYS):

- Nuclear level densities — *S. Hilaire*
- $\gamma$-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*

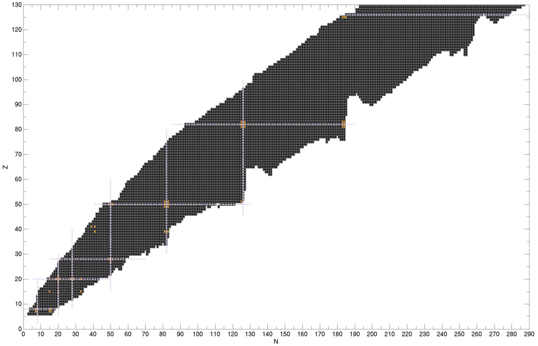



→ **Nuclear Structure Method for scattering**

*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

+

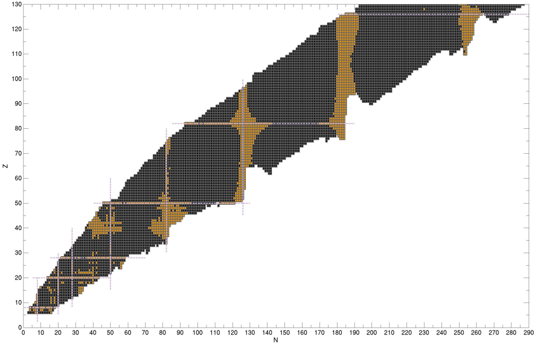
Integro-differential Schrödinger

⇓

Reaction Observables

# NSM & EDF extended reach

Spherical HFB (∼300 nuclei)




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

HFB+QRPA Potential

+

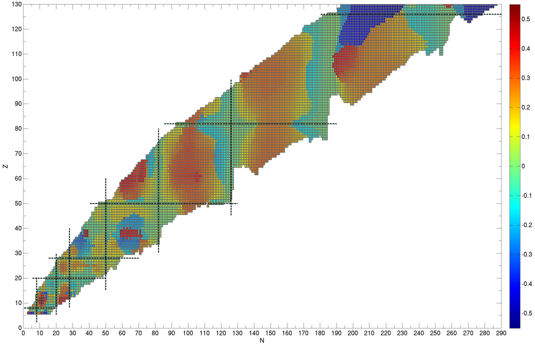
Nonlocal Coupled channels

⇓

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

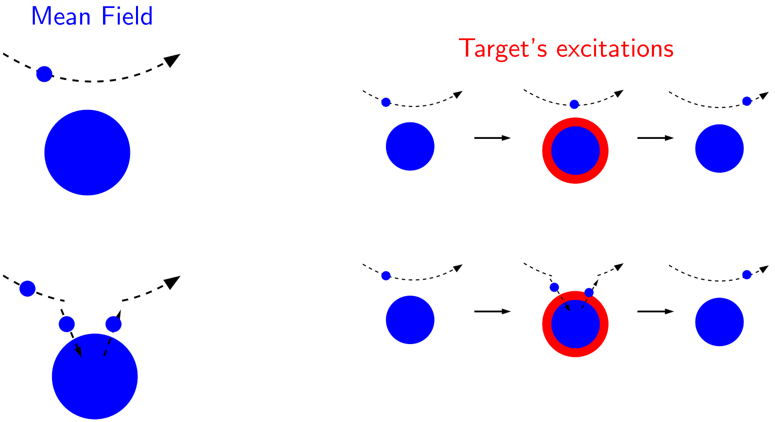
⇓

Reaction Observables

## NUCLEAR STRUCTURE METHOD FOR SCATTERING

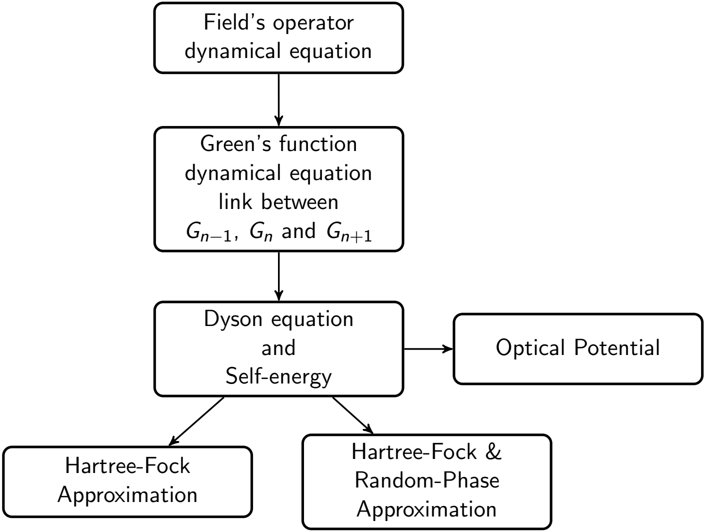
# Nuclear Structure Method

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




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

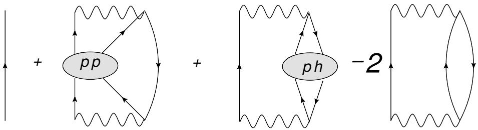


# Nuclear Structure Method

## Optical potential

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

Bare Interaction



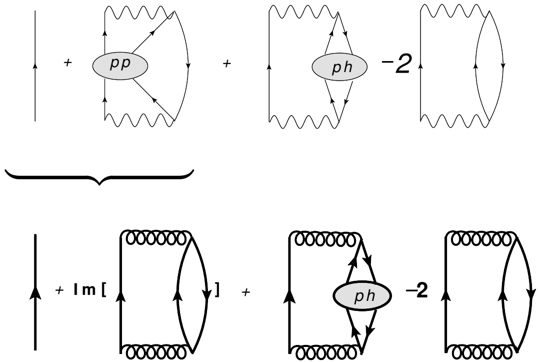
# Nuclear Structure Method

## Optical potential

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

Bare Interaction

Effective Interaction



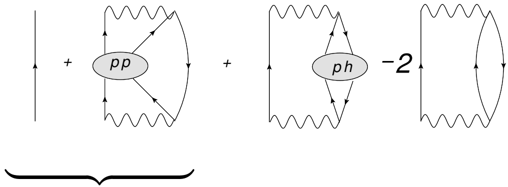
# Nuclear Structure Method



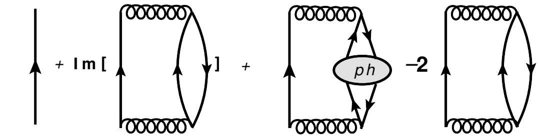
## Optical potential

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

Bare Interaction

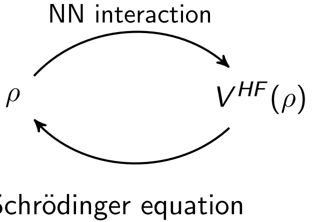


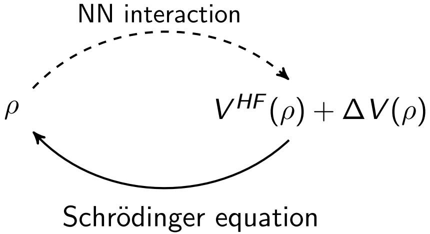

Gogny Interaction




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

# Self-consistency




**HF**

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

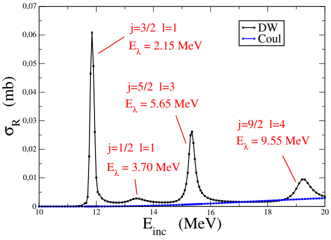
**RPA**

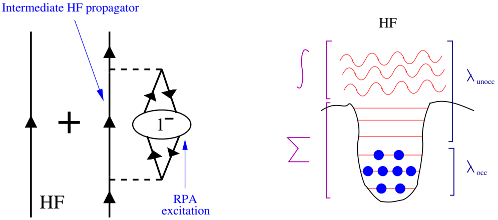
- Oscillator basis including 15 major shells
- Excited states up to $J = 8$ with both parities

**The resulting potential is nonlocal, complex and energy dependent**

# Coupling to a single target excited state

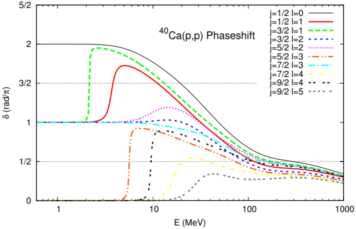
- $p + {}^{40}Ca$ scattering
- Coupling to the first $1^-$ state of ${}^{40}Ca$ with $E_{1^-} = 9.7$ MeV



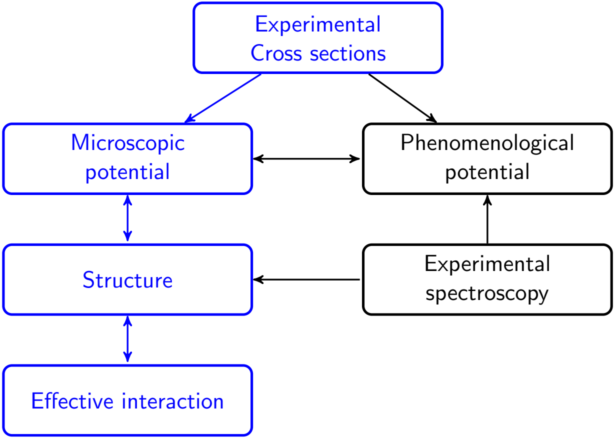

- Importance of the intermediate single particle resonances
- Strong impact on reaction cross section

- HF phaseshift



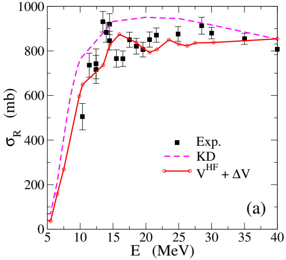
## NUCLEON SCATTERING OFF N=Z TARGET NUCLEUS

# Elastic scattering n/p + $^{40}$Ca

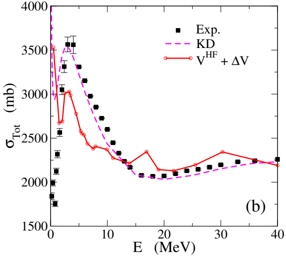


# Integral cross sections n/p + $^{40}$Ca

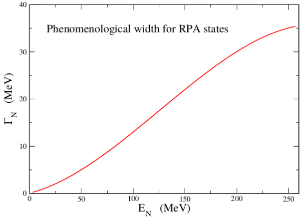
- p + $^{40}$Ca




- n + $^{40}$Ca

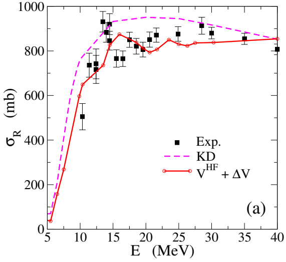



- Compound elastic from Haüser-Feshbach with Koning-Delaroche potential
- Use of phenomenological width for the excited states of the target.

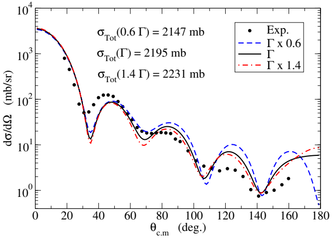


# Integral cross sections $n/p + {}^{40}Ca$

- $p + {}^{40}Ca$

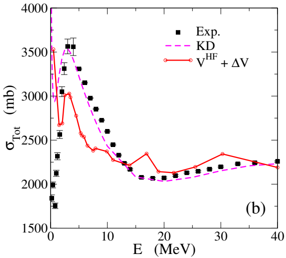



- Compound elastic from Haüser-Feshbach with Koning-Delaroche potential
- Use of phenomenological width for the excited states of the target.



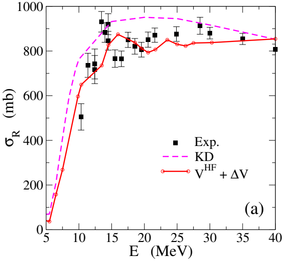

Width sensitivity ($n+{}^{40}Ca$ @ 25 MeV)

- $n + {}^{40}Ca$

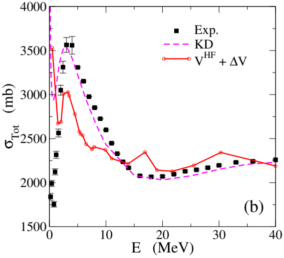


# Integral cross sections n/p + $^{40}$Ca

- p + $^{40}$Ca

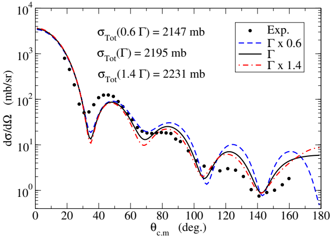



- n + $^{40}$Ca




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

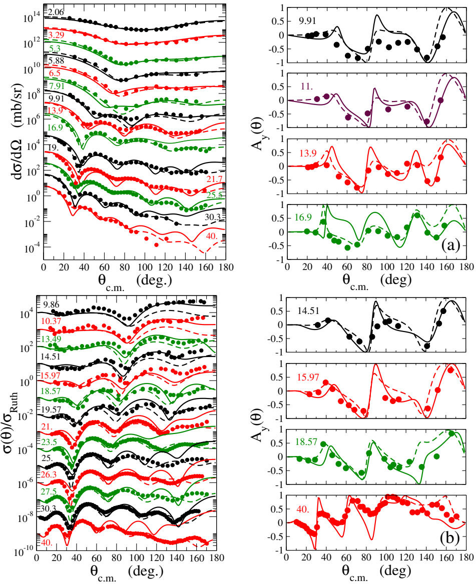
- Use of phenomenological width for the excited states of the target.




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

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

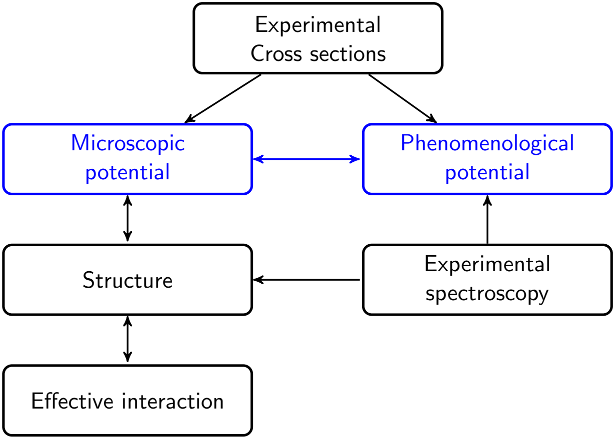
# Cross section and Analyzing powers n/p+$^{40}$Ca




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
  $\nu_{lj}(r, r') = \iint d\hat{\mathbf{r}} d\hat{\mathbf{r}}' \mathcal{Y}_{jl}^{m}(\hat{\mathbf{r}}) V(\mathbf{r}, \mathbf{r'}) \mathcal{Y}_{jl}^{m\dagger}(\hat{\mathbf{r}}')$

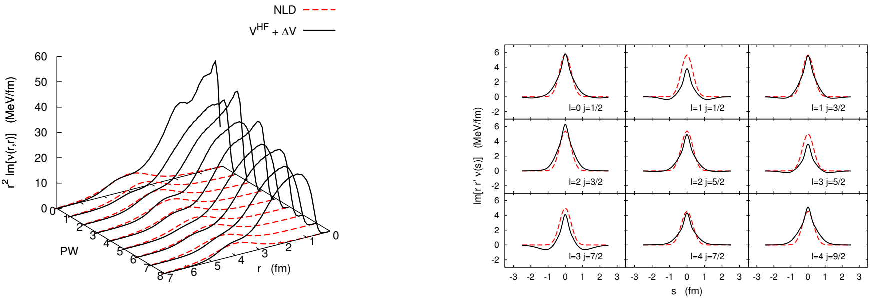
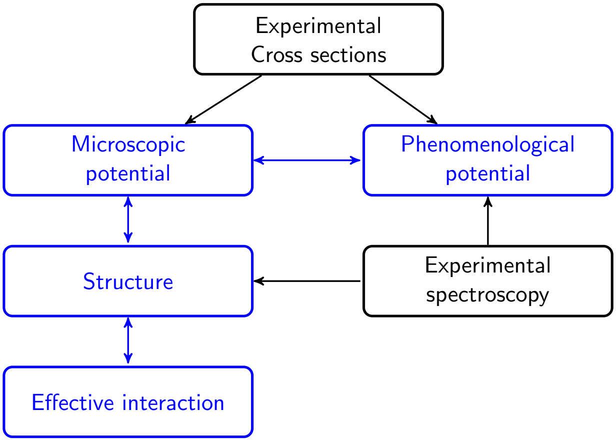



Figure : $s = |\mathbf{r} - \mathbf{r'}|$

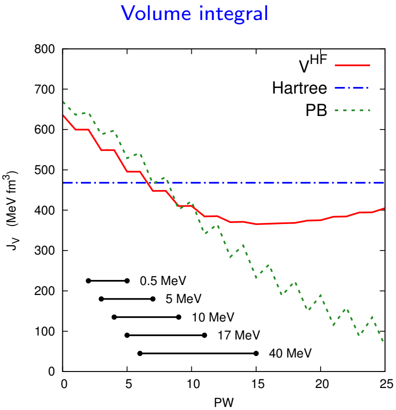
**NLD:** *M.H. Mahzoon et al. , Phys. Rev. Lett. 112, 162503 (2014)*

# Phenomenological potential and effective interaction



# Phenomenological potential and Gogny interaction

Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr\ r^2 \int dr' r'^2 \nu_{lj}(r, r')$

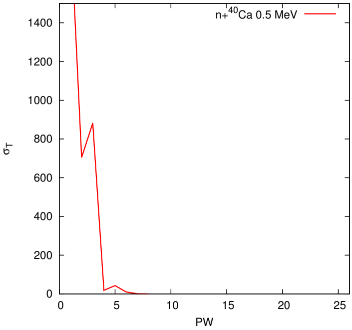



- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.

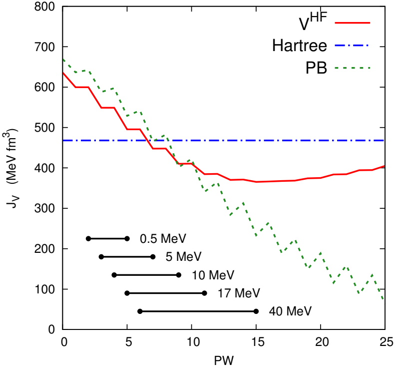
# Phenomenological potential and Gogny interaction

Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr\ r^2 \int dr' r'^2 \nu_{lj}(r, r')$

Total cross section




Volume integral

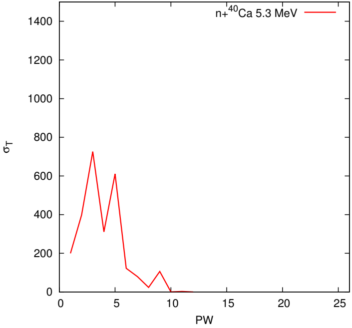



- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.

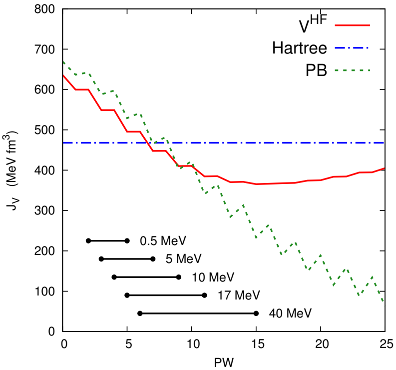
# Phenomenological potential and Gogny interaction

Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr\ r^2 \int dr' r'^2 \nu_{lj}(r, r')$

Total cross section




Volume integral

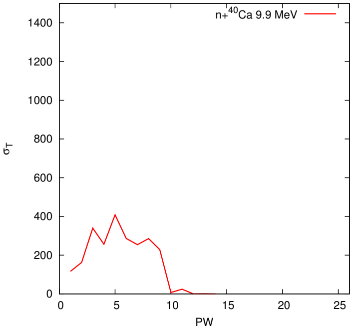



- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.

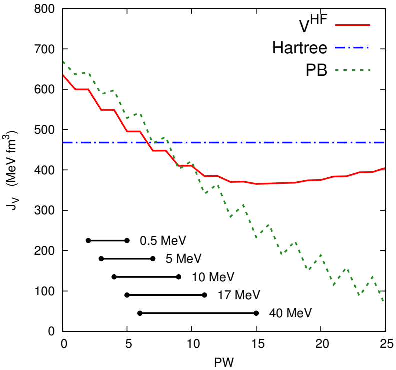
# Phenomenological potential and Gogny interaction

Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr\ r^2 \int dr' r'^2 \nu_{lj}(r, r')$

Total cross section




Volume integral

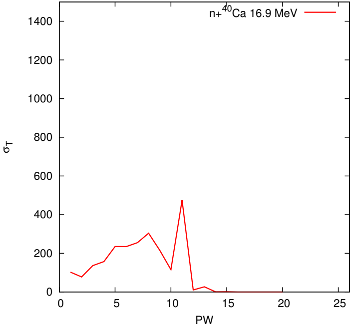



- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.

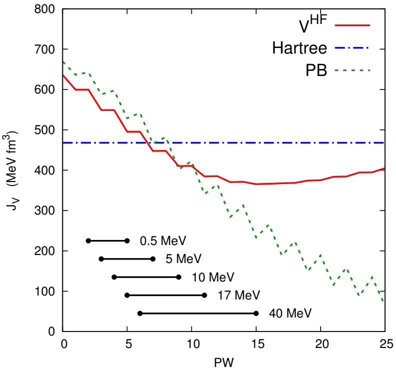
# Phenomenological potential and Gogny interaction

Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr\ r^2 \int dr' r'^2 \nu_{lj}(r, r')$

Total cross section




Volume integral

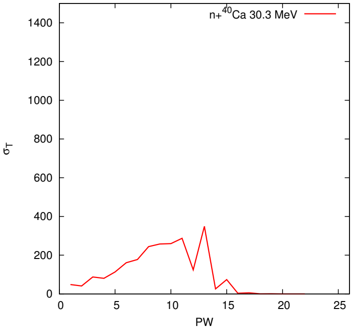



- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.

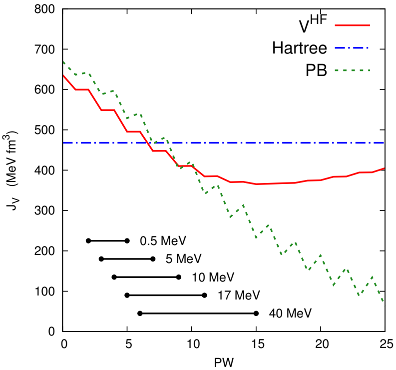
# Phenomenological potential and Gogny interaction

Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr\ r^2 \int dr' r'^2 \nu_{lj}(r, r')$

Total cross section




Volume integral

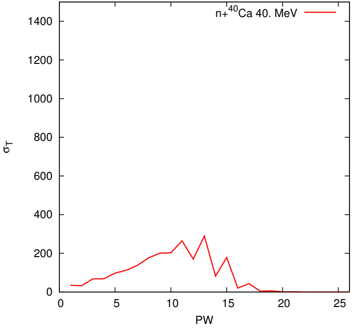



- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.

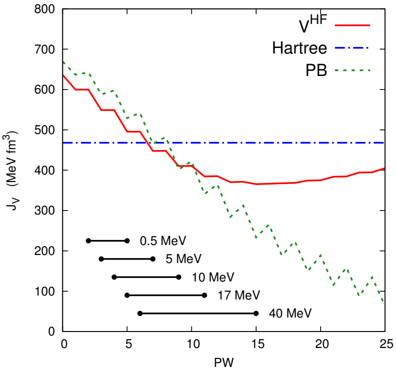
# Phenomenological potential and Gogny interaction

Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr \ r^2 \int dr' r'^2 \nu_{lj}(r, r')$

Total cross section



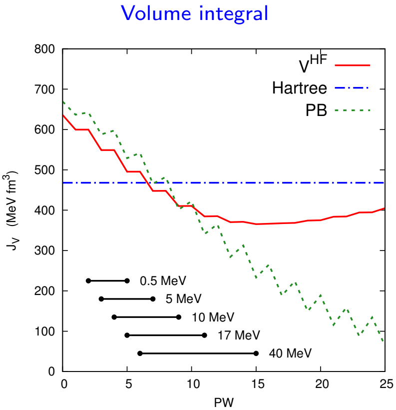

Volume integral




- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.

# Phenomenological potential and Gogny interaction

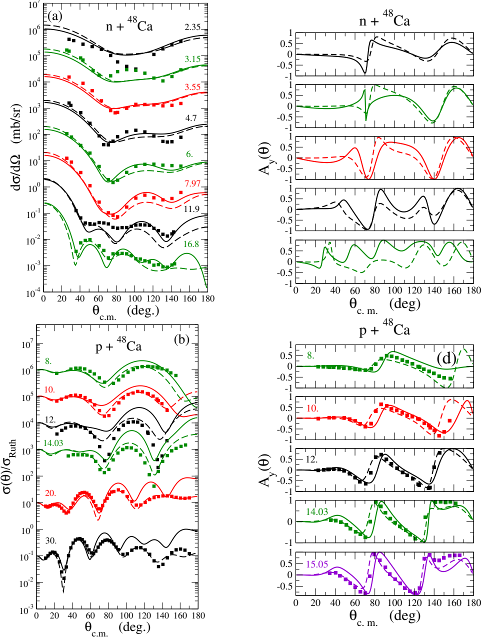
Volume integral: $J_V^{lj} = \frac{-4\pi}{A} \int dr\ r^2 \int dr' r'^2 \nu_{lj}(r, r')$




- **PB:** Perey Buck optical potential with gaussian non locality and energy independent.
- NSM limited to incident energies below about 30 MeV

# NUCLEON SCATTERING OFF N>Z TARGET NUCLEUS

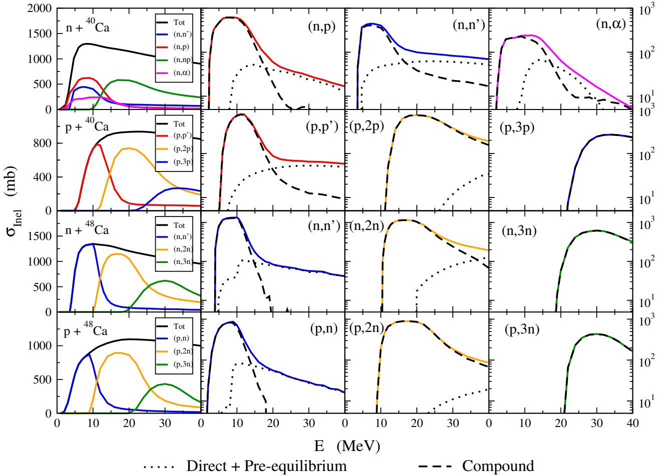
# Cross section and Analyzing powers n/p+$^{48}$Ca




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

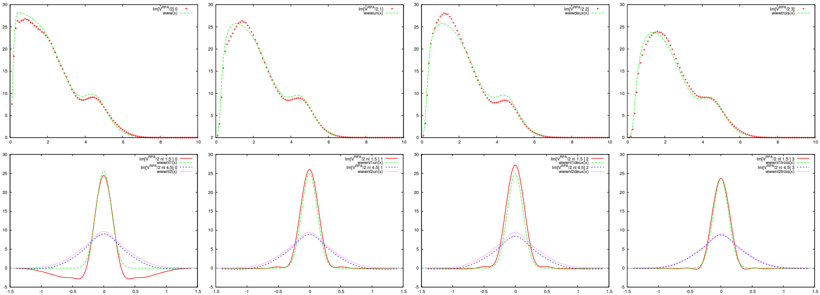



- NSM potential describes direct components
- Need for two-fold charge exchange $(p, n, p)$

# 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 $\mathbf{s}=\mathbf{r}-\mathbf{r'}$

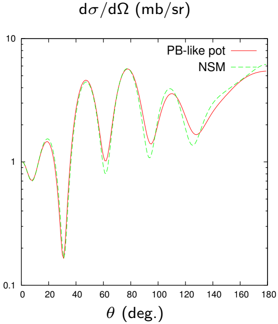
# PB-like equivalent of the imaginary NSM potential

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

**Fit parameters :**

| $r_v$ | $r_s$ | $a_v$ | $a_s$ | $\beta_v$ | $\beta_s$ |
|---|---|---|---|---|---|
| 0.78 | 1.254 | 0.49 ($^{40}$Ca) 0.78 ($^{48}$Ca) | 0.44 | 0.35 | 1.1 |

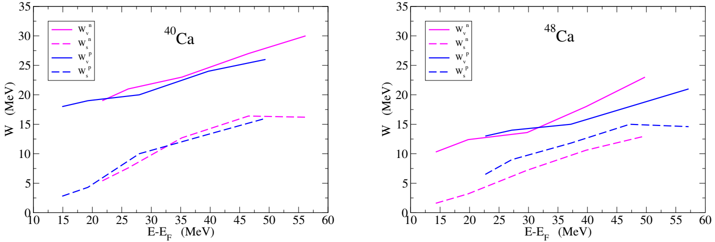
**Check of reliability of the fit :**




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

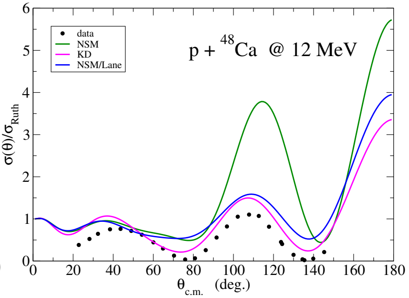
$V_{cc} \approx 0$ in the case of $^{40}$Ca

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

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

$$\Downarrow$$

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

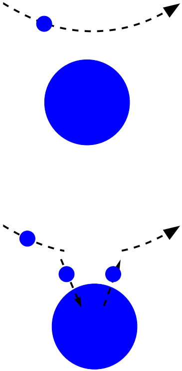


## NUCLEON SCATTERING OFF TARGET WITH PAIRING

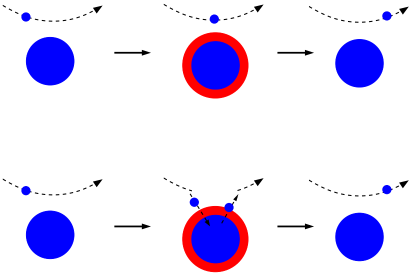
# NSM for spherical targets with pairing

$$V = V^{HFB} + \Delta V^{QRPA}$$

Mean Field

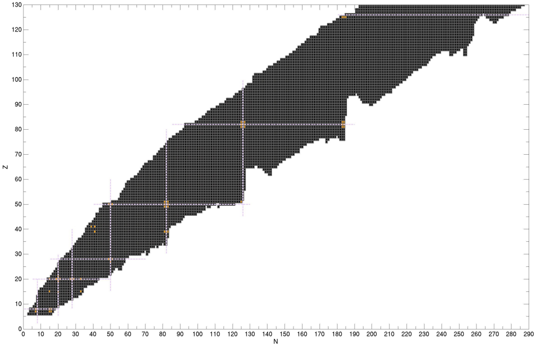


Target's excitations



# 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

\+

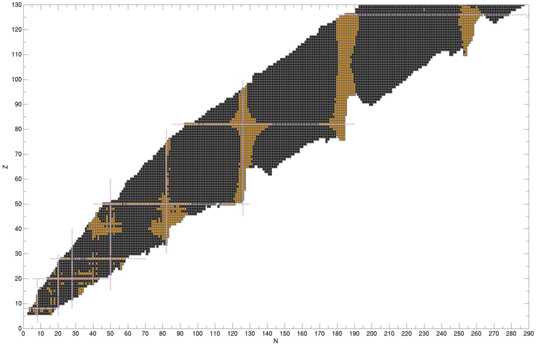
Integro-differential Schrödinger

⇓

Reaction Observables

# NSM & EDF extended reach

Spherical HFB (∼300 nuclei)




HFB+QRPA Potential

+

Nonlocal Coupled channels

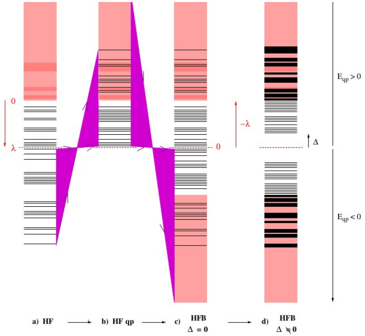
⇓

Reaction Observables

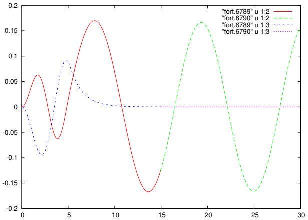
**Collaboration with R. Bernard and S. Péru** *(CEA,DAM,DIF)*

# HFB equations in coordinate representation

$$\int d^3\mathbf{r'} \sum_{\sigma'} \begin{pmatrix} h(\mathbf{r}\sigma, \mathbf{r'}\sigma') & \Delta(\mathbf{r}\sigma, \mathbf{r'}\sigma') \\ \Delta(\mathbf{r}\sigma, \mathbf{r'}\sigma') & -h(\mathbf{r}\sigma, \mathbf{r'}\sigma') \end{pmatrix} \begin{pmatrix} u(E, \mathbf{r'}\sigma') \\ v(E, \mathbf{r'}\sigma') \end{pmatrix} = \begin{pmatrix} E+\lambda & 0 \\ 0 & E-\lambda \end{pmatrix} \begin{pmatrix} u(E, \mathbf{r}\sigma) \\ v(E, \mathbf{r}\sigma) \end{pmatrix}$$




- HFB with D1S Gogny interaction in coordinate representation in a box with treatment of the continuum




- Effect of bound states on the cross section

**NEXT STEP:**

- Dressed mean field & pairing field using QRPA
- Application to scattering...

# 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).
- G. Blanchon, M. Dupuis, H. Arellano, Eur. Phys J. A, 51 12 (2015) 165
- T. V. Nhan Hao et al., PRC 92, 014605 (2015).