A new probe into three-nucleon-force effects on reaction observables

Research Center for Nuclear Physics (RCNP), Osaka University

Kosho Minomo

Collaborators

RCNP K. Yoshida, M. Kohno, K. Ogata

Kyushu University M. Toyokawa

This research was funded by ImPACT Program of Council for Science,Technology and Innovation (Cabinet Office, Government of Japan).

Direct Reactions with Exotic Beams 2016 (Halifax, Canada)

14 July 2016

Microscopic approach to many-body reactions

- ✓ Many-body nuclear direct reactions
- ✓ Microscopic reaction theory based on *NN* effective interactions (*g*-matrix)

  founded on multiple scattering theory

  K. M. Watson, RMP30, 565 (1958).

  M. Yahiro et al., PTP120, 767 (2008).

Realistic force (Chiral EFT) → *NN g*-matrix (Brueckner theory) → Many-body reactions (folding model, ...)

N^3LO 2NF
N^2LO 3NF

E. Epelbaum et al., NPA747, 362 (2005); RMP81, 1773 (2009)

There is no *ad hoc* parameter!

Microscopic reaction theory is enable us to investigate exotic structures and (effective) interactions.

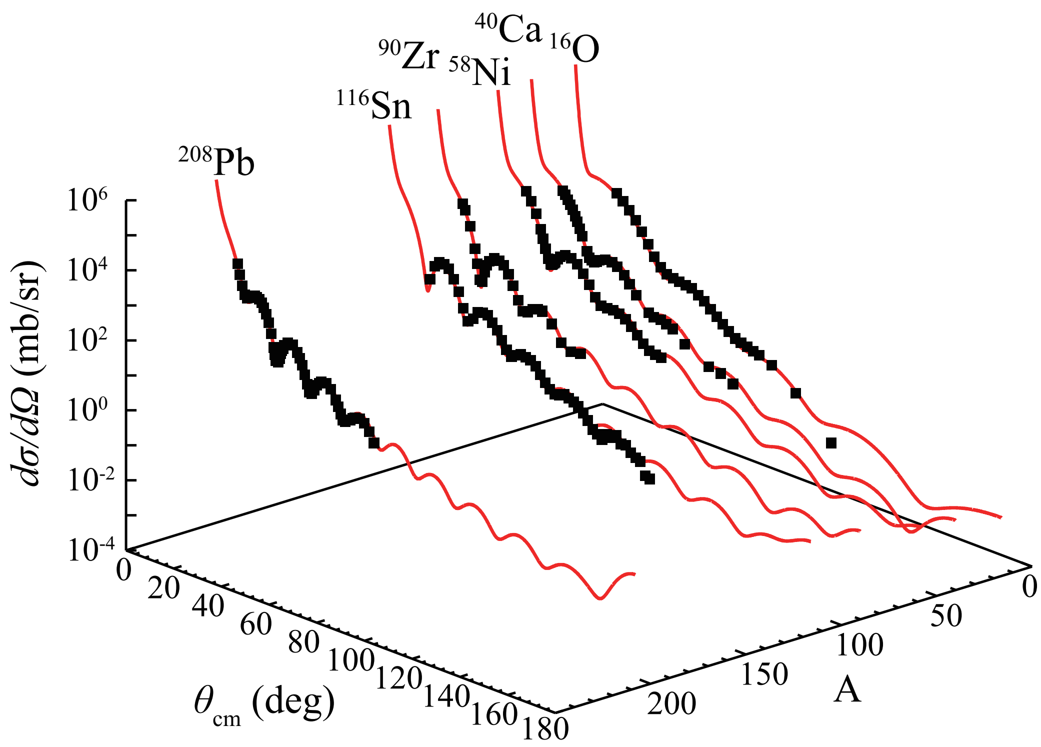
Elastic and inelastic scattering

Folding (microscopic coupled-channels) calculations

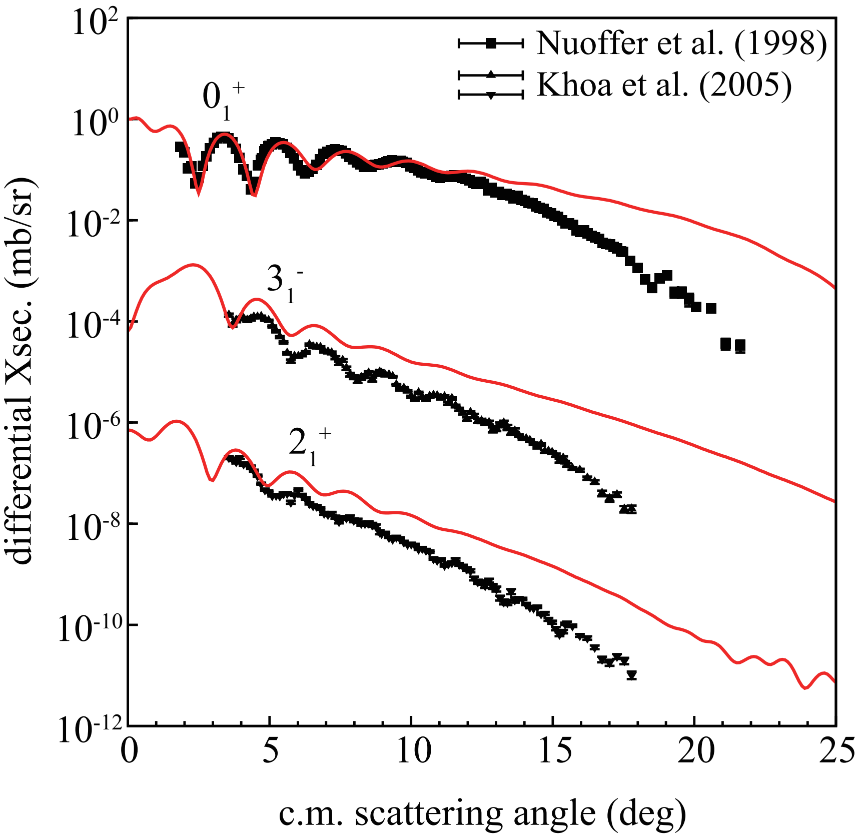
The nonlocality coming from knockon exchange process is localized.

KM et al., JPG37, 085011 (2010).

p-scattering@65MeV



^{16}O-^{16}O@70MeV/nucl.



Note: "usual" folding potential does not work at lower energies.

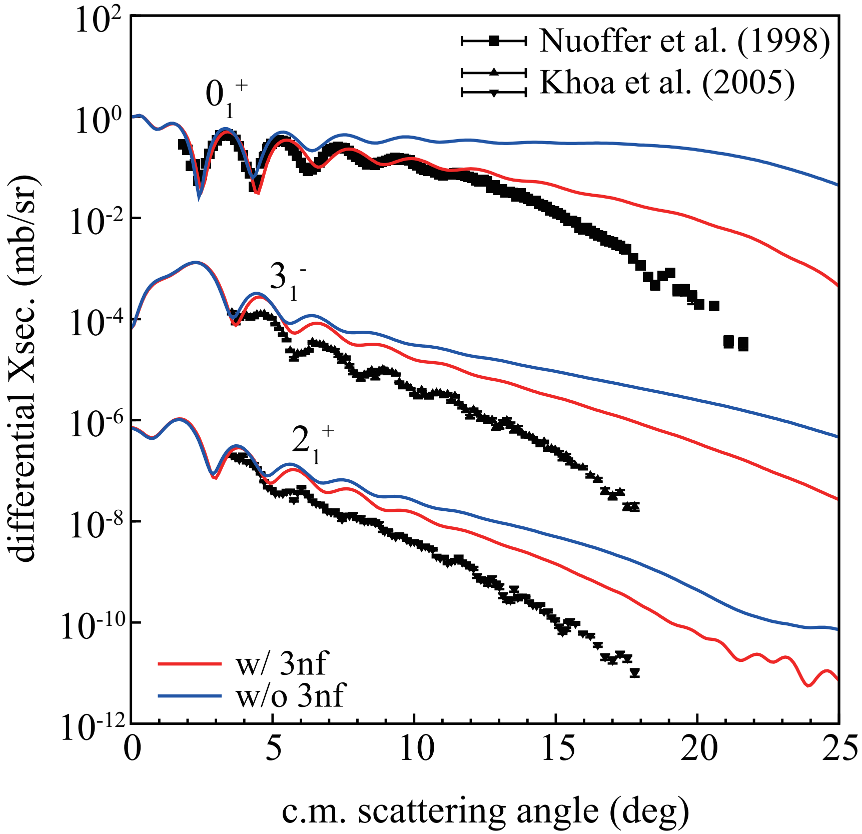
cf.) Dispersive folding model *J. Mueller et al., PRC83, 064605 (2011).*

3NF effects on scattering observables

Nucleus-nucleus scattering

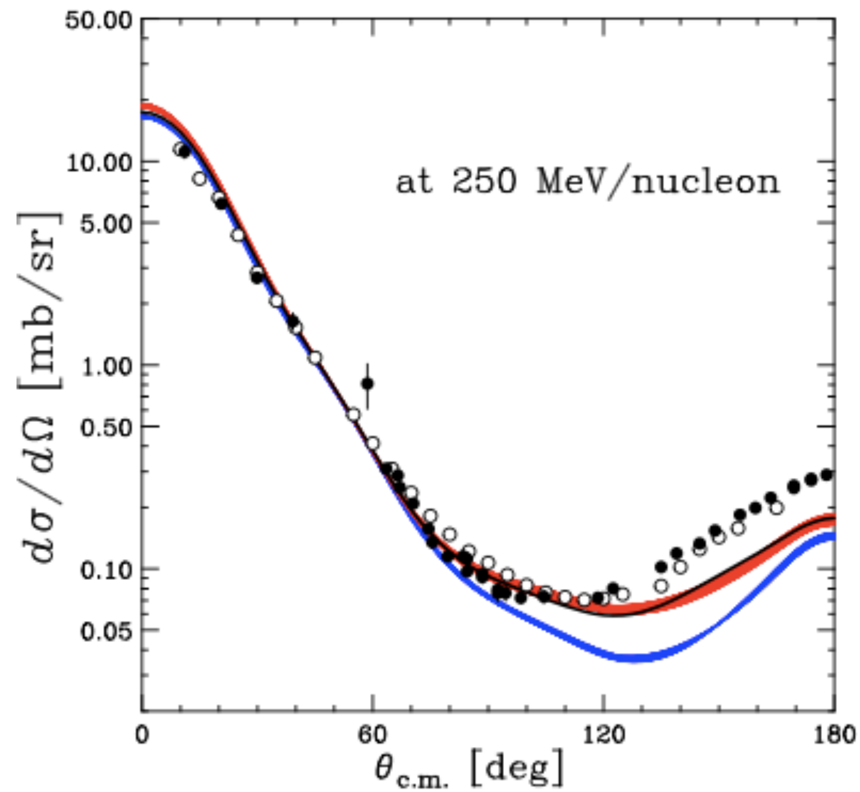
with the frozen density approx. ($\rho=\rho_P+\rho_T$)

KM et al., PRC93, 014607 (2016).



dp scattering

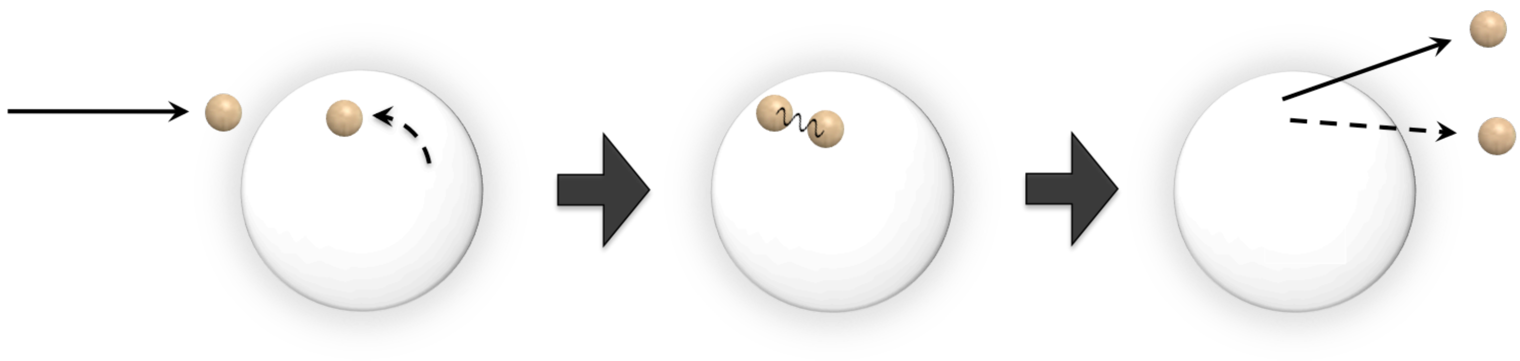
K. Sekiguchi et al., PRC89, 064007 (2014).



Can we investigate 3NF effects by using other reactions?

Knockout reactions as a probe into 3NF

Proton knockout reaction (*p*,2*p*)



(*p*,2*p*) reaction occurs in nuclear interior so that 3NF effects are probed through the density dependence of *g*-matrix.

<u>Motivations</u>

- ✓ Examine the microscopic approach to knockout reactions
- ✓ Investigate the 3NF effects on many-body reactions

Microscopic DWIA

- ✓ Transition matrix element in the distorted wave Impulse Approx.

$$T = \langle \chi^{(-)}_{1,\boldsymbol{k}_1} \chi^{(-)}_{2,\boldsymbol{k}_2} | g(\kappa', \kappa, \theta; E, \rho) | \chi^{(+)}_{0,\boldsymbol{k}_0} \varphi_{nlj} \rangle$$

$g(\kappa', \kappa, \theta; E, \rho)$: chiral *g*-matrix

$\chi^{(+)}_{0,\boldsymbol{k}_0}$, $\chi^{(-)}_{1,\boldsymbol{k}_1}$, and $\chi^{(-)}_{2,\boldsymbol{k}_2}$: distorted waves

φ_{nlj}: single particle wave function

Microscopic DWIA

✓ Transition matrix element in the distorted wave Impulse Approx.

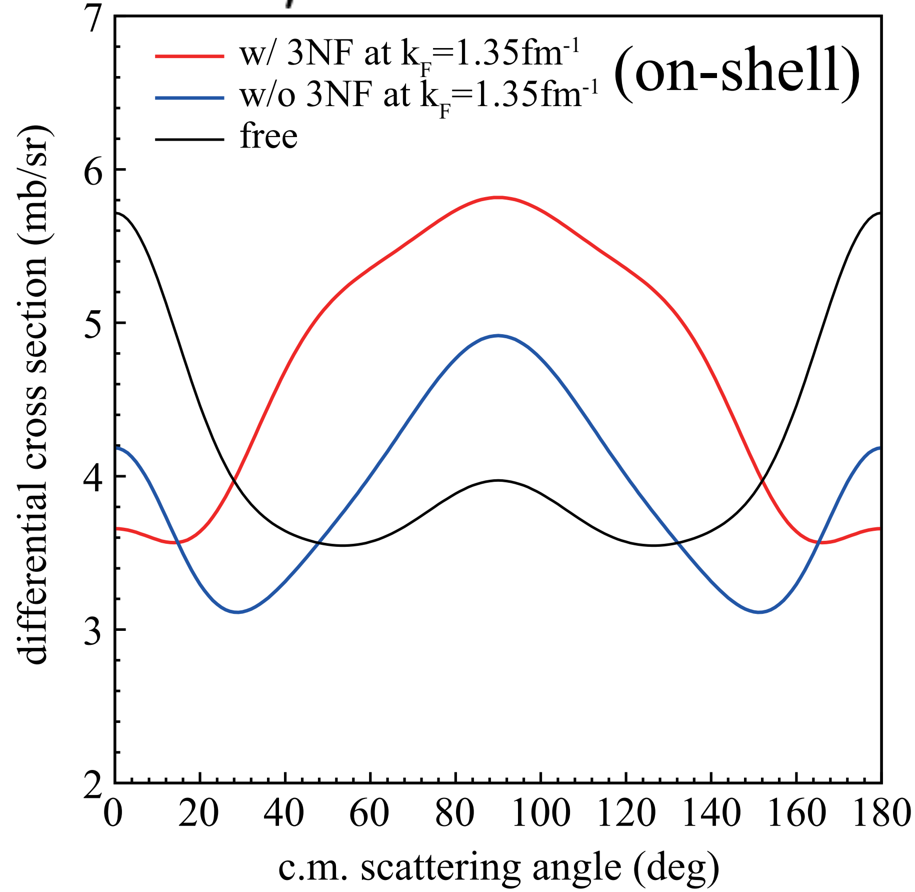
$$T = \langle \chi^{(-)}_{1,\boldsymbol{k}_1} \chi^{(-)}_{2,\boldsymbol{k}_2} | g(\kappa', \kappa, \theta; E, \rho) | \chi^{(+)}_{0,\boldsymbol{k}_0} \varphi_{nlj} \rangle$$

$g(\kappa', \kappa, \theta; E, \rho)$: chiral *g*-matrix

$\rho = 0.16\ \mathrm{fm}^{-3}$

Inmedium *pp* scattering@200MeV

$$\frac{d\sigma_{pp}}{d\Omega} \propto \left| g(\kappa', \kappa, \theta; E, \rho) \right|^2$$



3NF effects increase the *pp* cross section depending on the density.

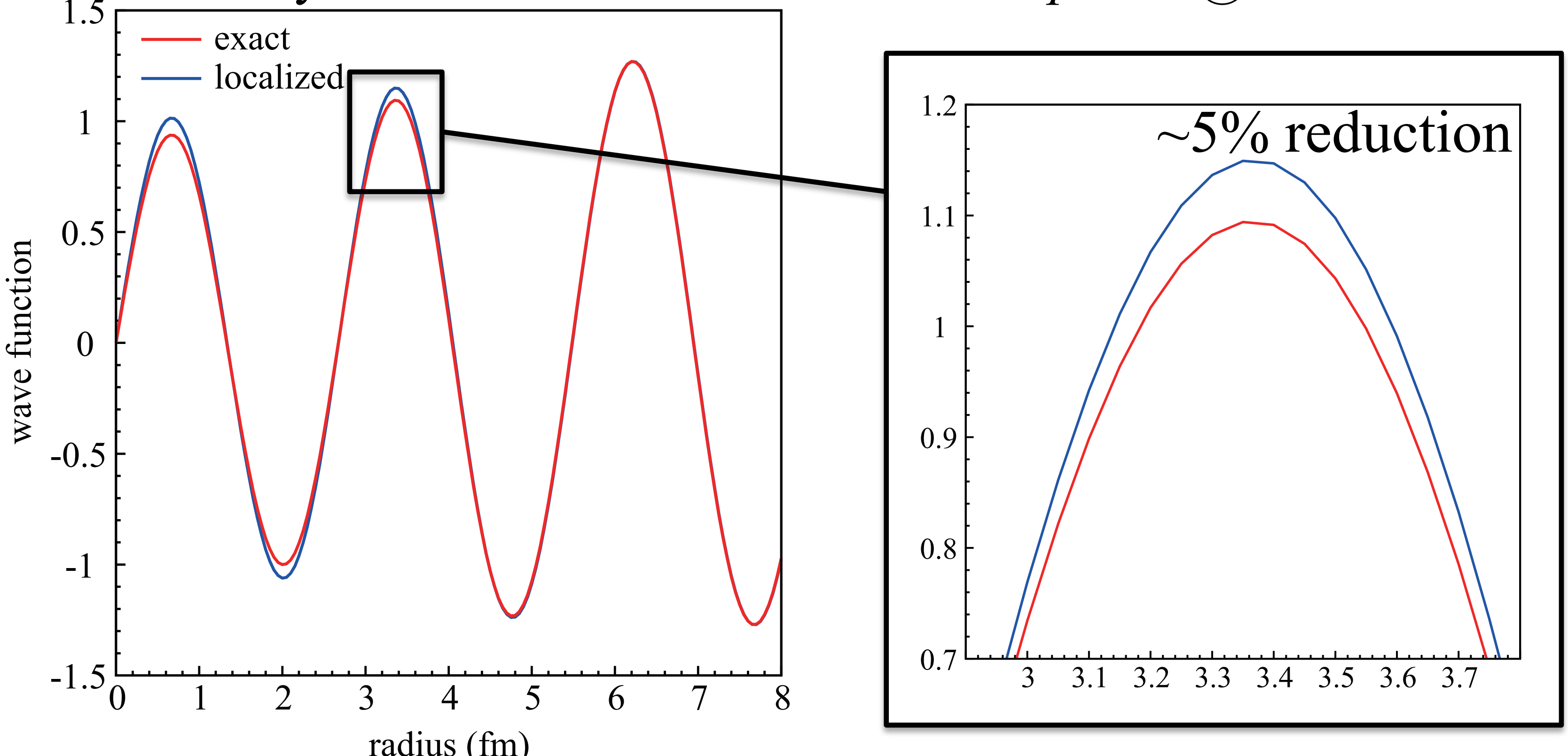
Microscopic DWIA

✓ Transition matrix element in the distorted wave Impulse Approx.

$$T = \langle \chi^{(-)}_{1,\boldsymbol{k}_1} \chi^{(-)}_{2,\boldsymbol{k}_2} | g(\kappa', \kappa, \theta; E, \rho) | \chi^{(+)}_{0,\boldsymbol{k}_0} \varphi_{nlj} \rangle$$

$\chi^{(+)}_{0,\boldsymbol{k}_0}$, $\chi^{(-)}_{1,\boldsymbol{k}_1}$, and $\chi^{(-)}_{2,\boldsymbol{k}_2}$: distorted waves calculated with nonlocal microscopic optical potentials

The Perey effect on L=0 wave function for p-^{40}Ca@100MeV



Microscopic DWIA

✓ Transition matrix element in the distorted wave Impulse Approx.

$$T = \langle \chi^{(-)}_{1,\boldsymbol{k}_1} \chi^{(-)}_{2,\boldsymbol{k}_2} | g(\kappa', \kappa, \theta; E, \rho) | \chi^{(+)}_{0,\boldsymbol{k}_0} \varphi_{nlj} \rangle$$

$g(\kappa', \kappa, \theta; E, \rho)$: chiral *g*-matrix

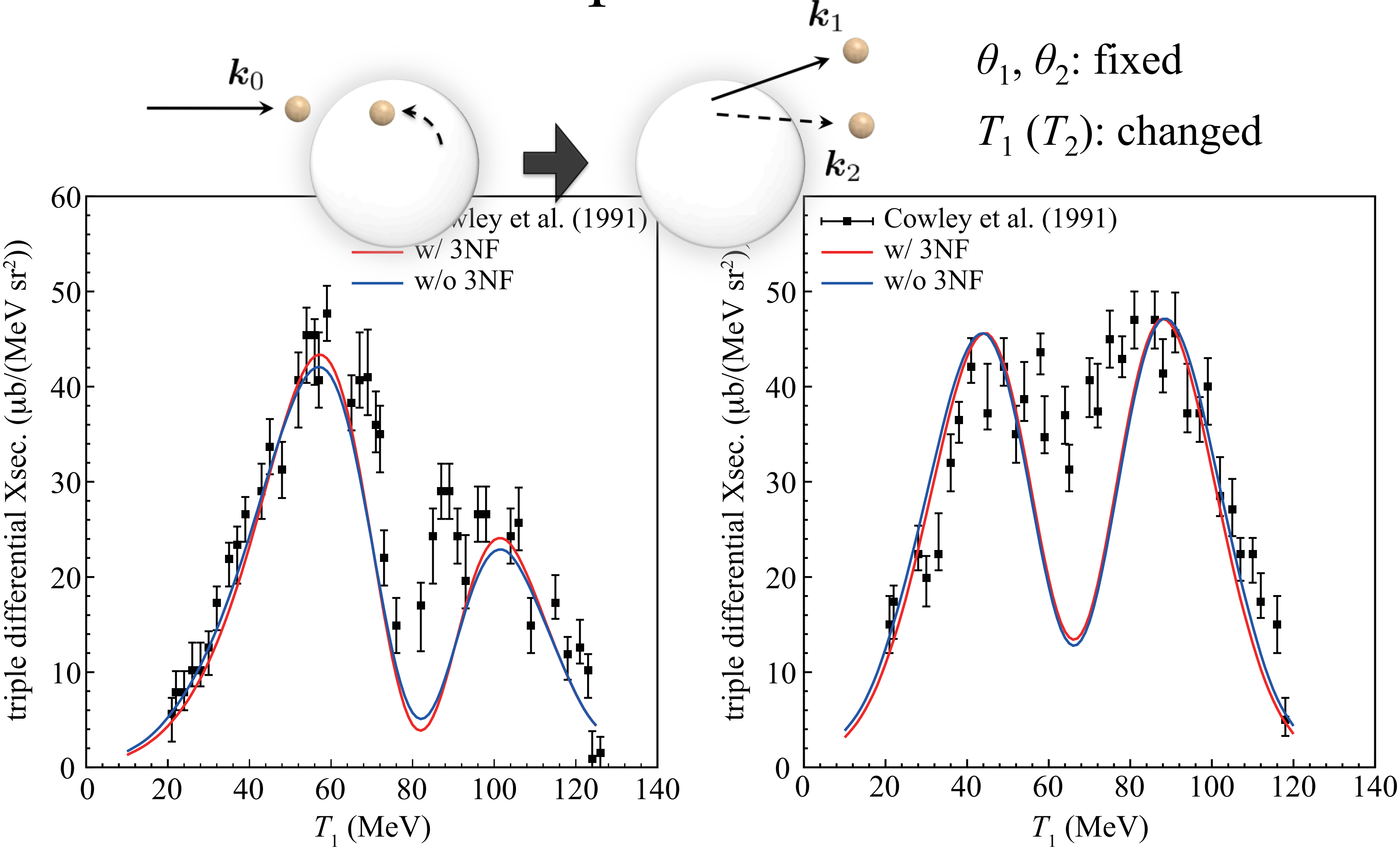
- ✓ medium effect
- ✓ off-shell properties

$\chi^{(+)}_{0,\boldsymbol{k}_0}$, $\chi^{(-)}_{1,\boldsymbol{k}_1}$, and $\chi^{(-)}_{2,\boldsymbol{k}_2}$: distorted waves calculated with nonlocal microscopic optical potentials

- ✓ Perey effect coming from knockon exchange process

φ_{nlj}: single particle wave function calculated by the Hartree-Fock method with the Gogny D1S force

Test of the present framework



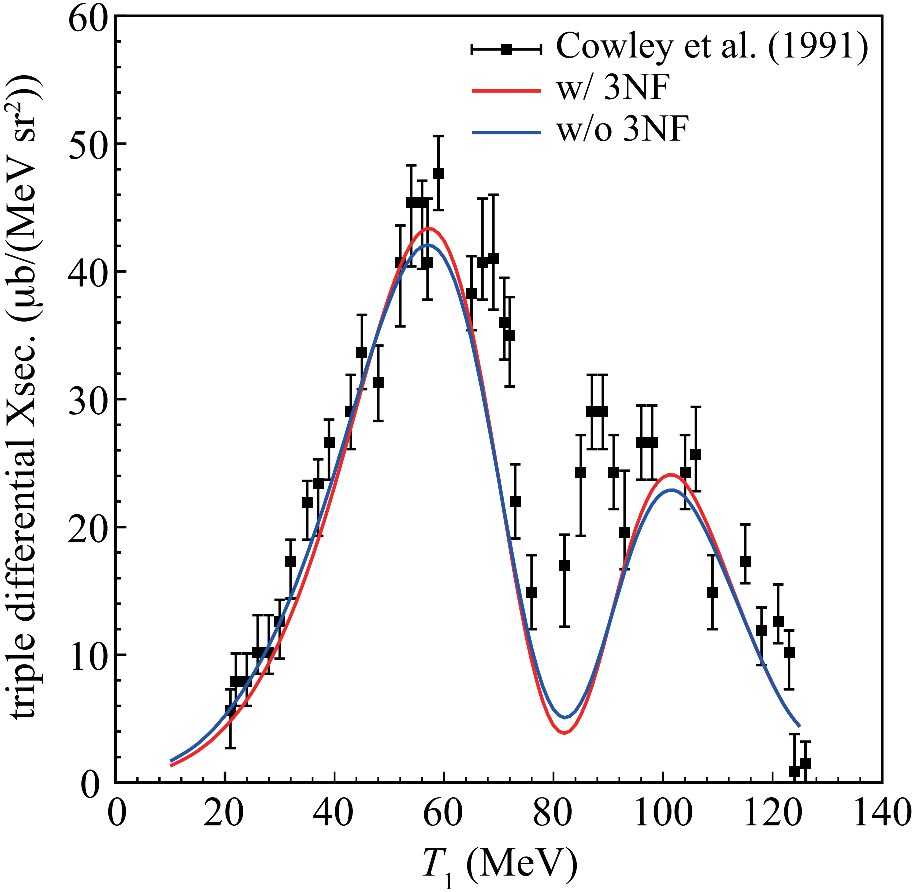
✓ The microscopic framework well reproduces the data.

✓ The 3NF effects are negligibly small.

Test of the present framework

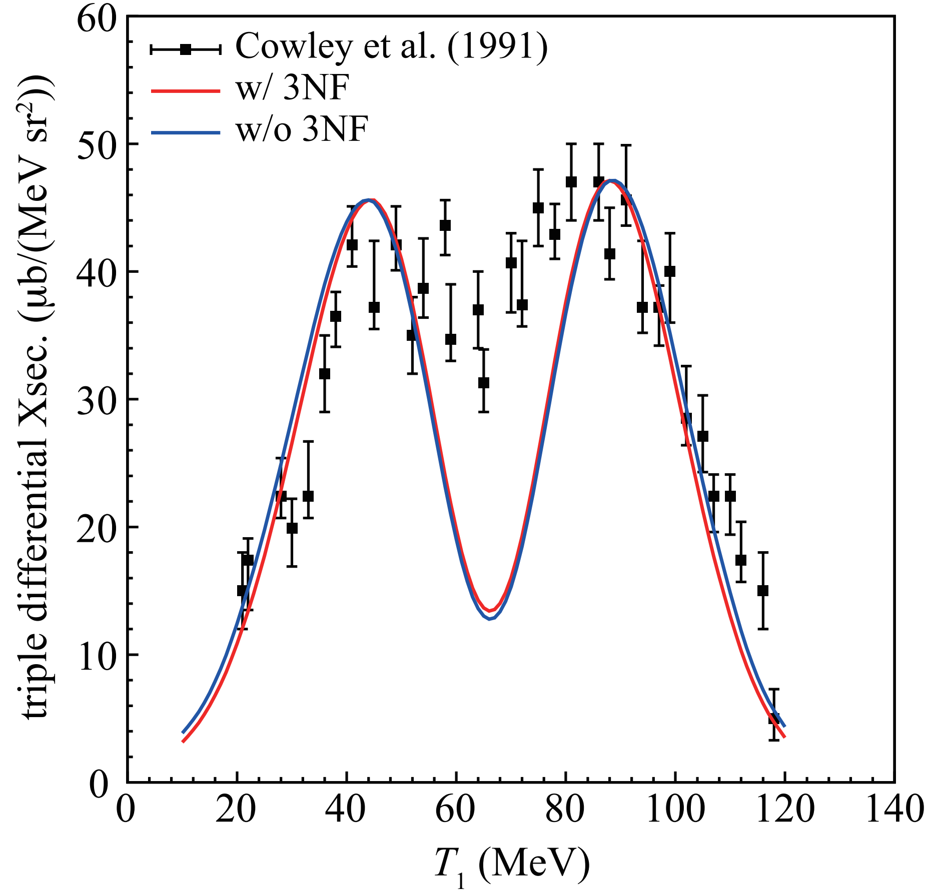
^{16}O(p,2p)^{15}N$_{\text{g.s.}}$@151MeV (0p1/2 orbit)

C^2S = 1.27 +/- 0.13 extracted from (e,e'p)



^{16}O(p,2p)^{15}N$^*_{6.32\text{MeV}}$@151MeV (0p3/2 orbit)

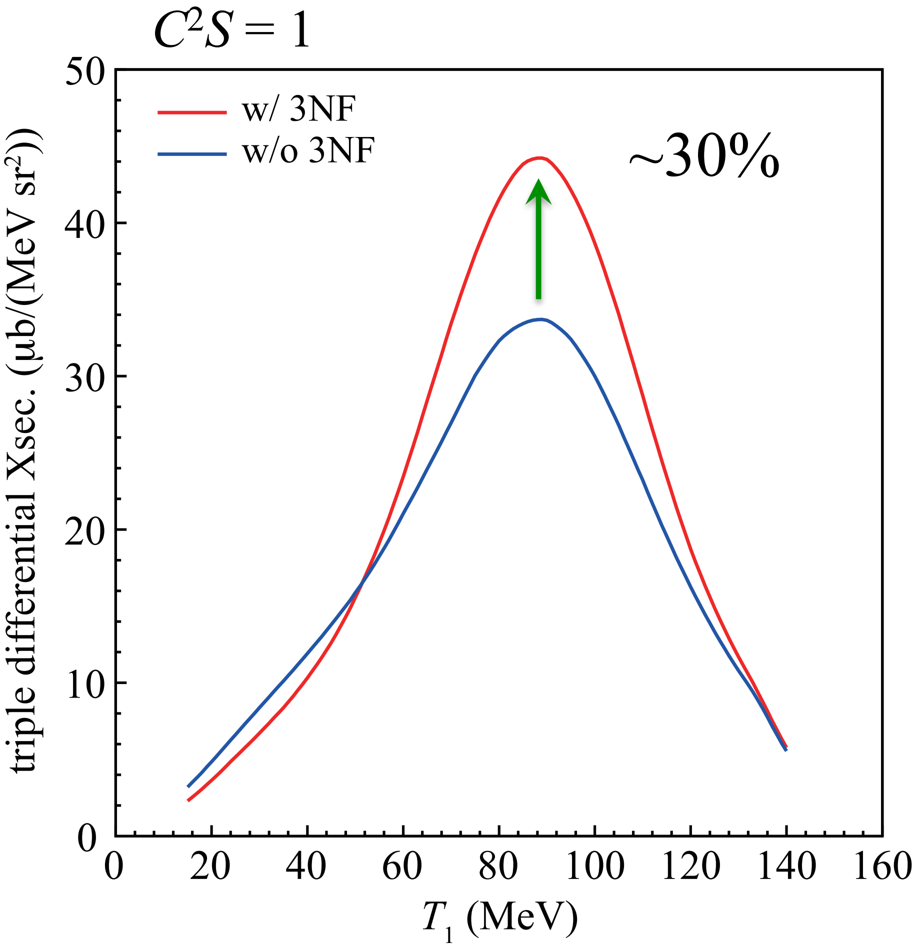
C^2S = 2.25 +/- 0.22 extracted from (e,e'p)



- ✓ The microscopic framework well reproduces the data.
- ✓ The 3NF effects are negligibly small.

Probing the 3NF effects

^{40}Ca(p,2p)^{39}K*@200MeV
(0s1/2 orbit)



- ✓ The 3NF effects enhance the cross sections near the peak.
- ✓ FWHM

  w/ 3NF: 57 MeV

  w/o 3NF: 67 MeV

cf.)

C^2S = 1.56 +/- 0.28 extracted from (p,2p)
Y. Yasuda et al., PRC81, 044315 (2010).

C^2S = 1.50 extracted from (e,$e'p$)
J. Mougey et al., NPA262, 461 (1976).

C^2S = 1.10
A. Fabrocini et al., PRC63, 044319 (2001).

C^2S = 1.56
C. Bisconti et al., PRC75, 054302 (2007).

(p,2p) reactions can be used to probe 3NF effects!

Summary and perspective

Summary

- ✓ Microscopic approach to many-body direct reactions based on chiral interactions
- ✓ Microscopic DWIA framework
- ✓ A possibility of probing the 3NF effects by using (p,2p) reaction

Perspective

- ✓ Spin observables $$\frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$$
- ✓ 3NF effects for T =3/2 state

Thank you very much for your attention!