Microscopic Approach to Scattering of Unstable Nuclei

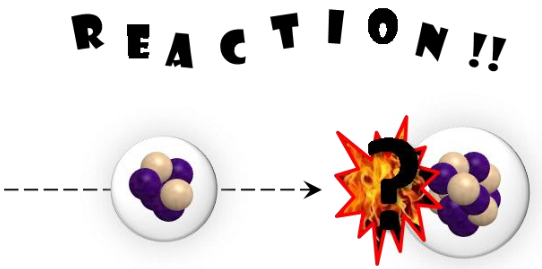
Kosho Minomo
K. Ogata, M. Kohno[A], Y. R. Sihimizu and M. Yahiro

Kyushu University, Kyushu Dental College[A]

2010/06/16

Introduction

The properties of nuclei are obtained by analysis of nuclear reaction.



- ☐ Conventional (phenomenological) approach

  Distorted wave Born approximation (DWBA), etc.

  An optical potential between projectile and target is necessary as an input.

- ☐ Features of experiments with unstable nuclei

  - ✓ The beam intensity is weak.
  - ✓ Unstable nuclei are fragile.

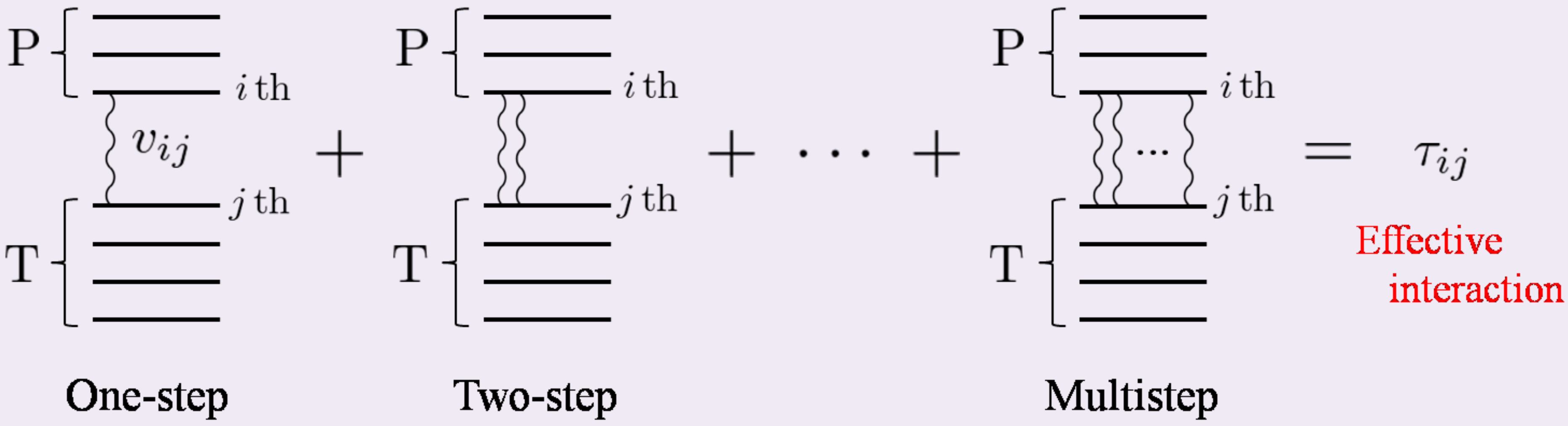
  An experiment with unstable nuclei is more difficult than that with stable nuclei so that one cannot construct an optical potential phenomenologically.

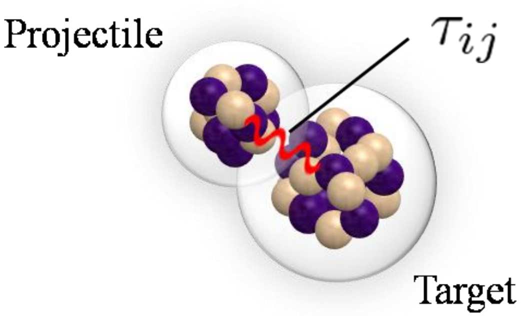
We must construct the microscopic reaction theory.

Schroedinger equation with resummation

✓ **Introduction an effective interaction**

Multistep of v_{ij} between i th nucleon in projectile and j th nucleon in target





✓ **Schrödinger equation with resummation**

$$\left[K + h_{\mathrm{P}} + h_{\mathrm{T}} + \sum_{i\in \mathrm{P}, j\in \mathrm{T}} \tau_{ij} - E \right] \Psi = 0$$

M. Yahiro, K. Minomo, K. Ogata, M. Kawai, Prog. Theor. Phys. No 120 Vol. 4 (2008), 767

Nucleon-nucleus scattering

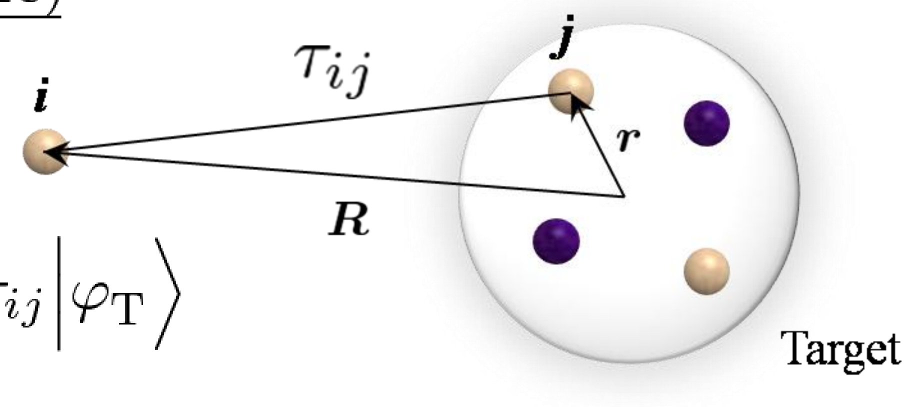
✓ **Schrödinger equation with resummation**

$$\left[K + h_{\mathrm{T}} + \sum_{j\in\mathrm{T}} \tau_j - E\right]\Psi = 0$$ (That KMT expression)

☐ Folding model

The equation for the relative motion $\chi(\boldsymbol{R})$

$$\left[K + U - E_{\mathrm{in}}\right]\chi(\boldsymbol{R}) = 0$$



Folding potential $U = \left\langle \varphi_{\mathrm{T}} \middle| \sum_{j\in\mathrm{T}} \tau_{ij} \middle| \varphi_{\mathrm{T}} \right\rangle$

$|\varphi_{\mathrm{T}}\rangle$ **:** ground-state wave function of the target

We obtain the localized folding potential with the Brieva-Rook (BR) method.

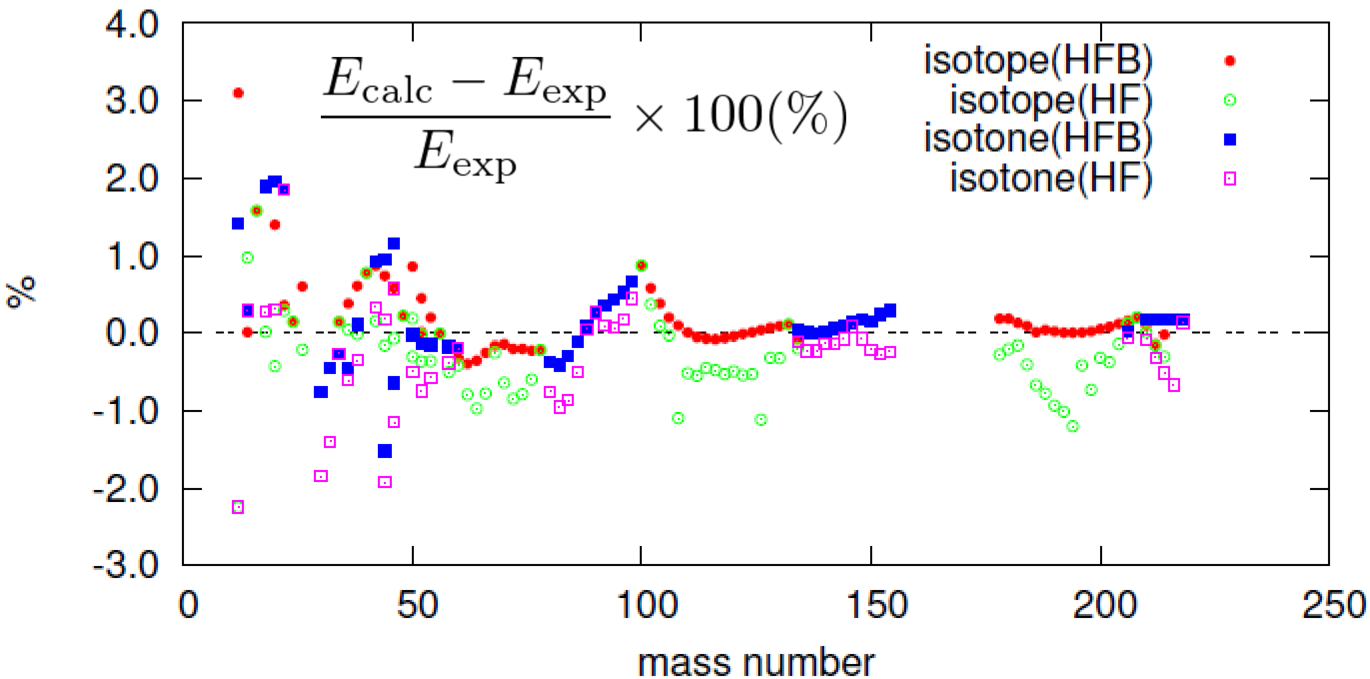
F. A. Brieva and J. R. Rook, Nucl. Phys. A **291**, 317 (1977).

Structure model

✓ **Hartree-Fock method with finite-range Gogny force**

It is applicable to obtain the ground-state wave function of all nuclei.

The properties of many stable nuclei such as the binding energy are well reproduced.



We find that this method is reliable.

Interaction for reaction dynamics

✓ **Melbourne *g*-matrix**

Two-body interaction which depends on the target density

K. Amos, P. J. Dortmans, H. V. von Geramb, S. Karataglidis and J. Raynal,
Adv. Nucl. Phys. **25**, 275 (2000).

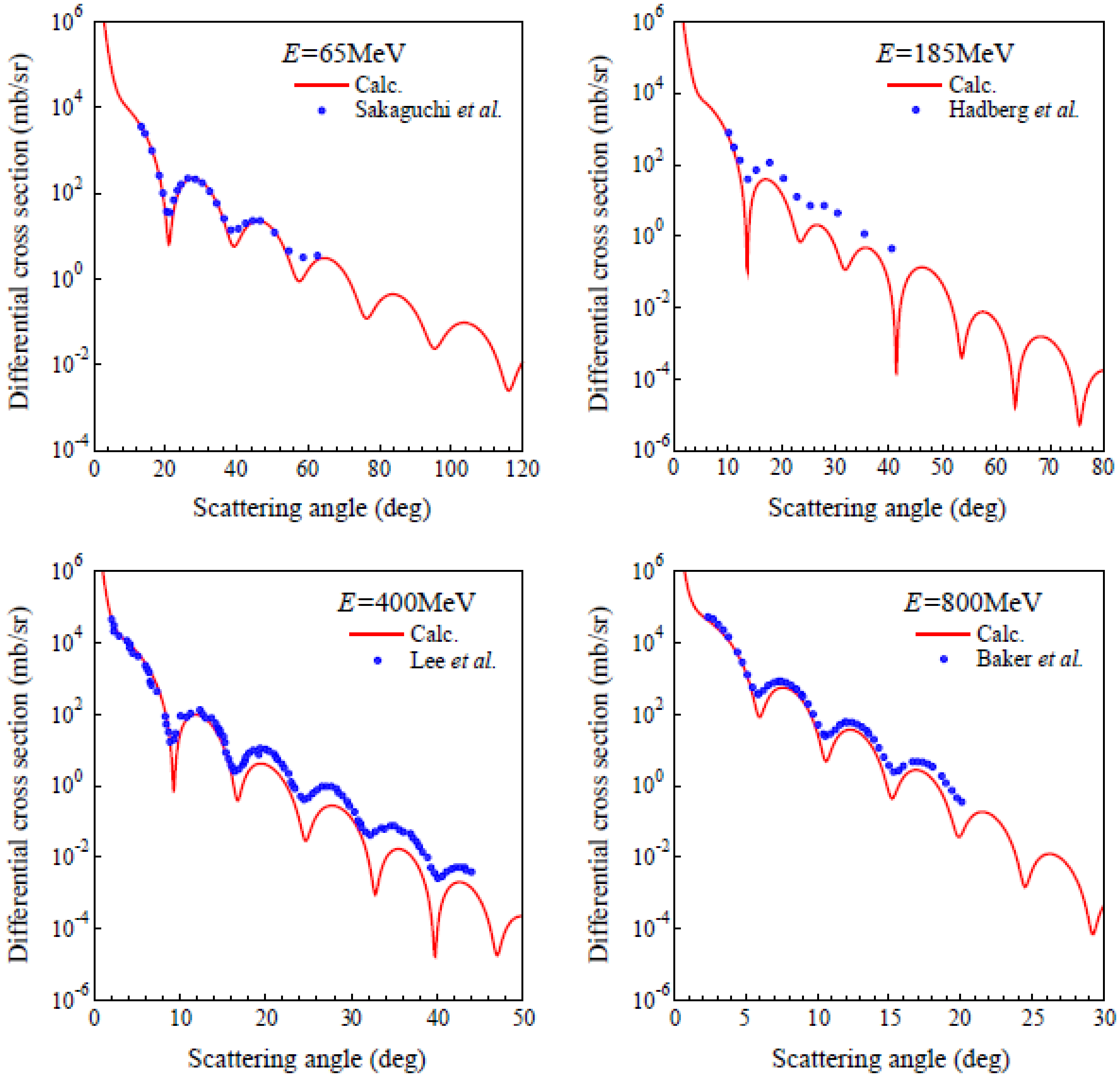
☐ The framework in this study

- HF method with Gogny force
- Melbourne *g*-matrix
- BR localization

Pure theoretical framework without any parameter

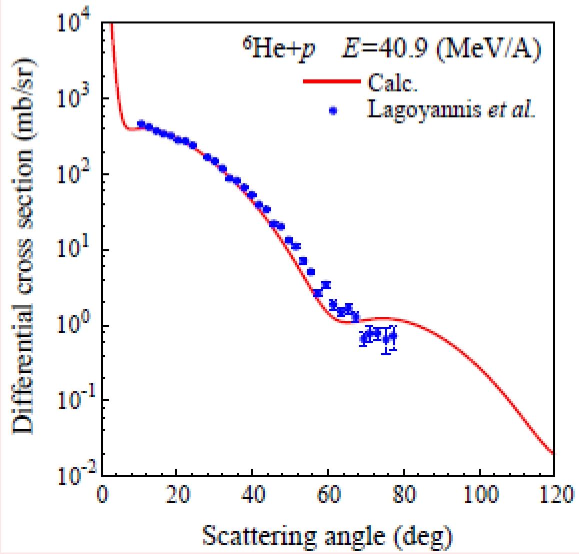
$p + {}^{90}Zr$ elastic scattering

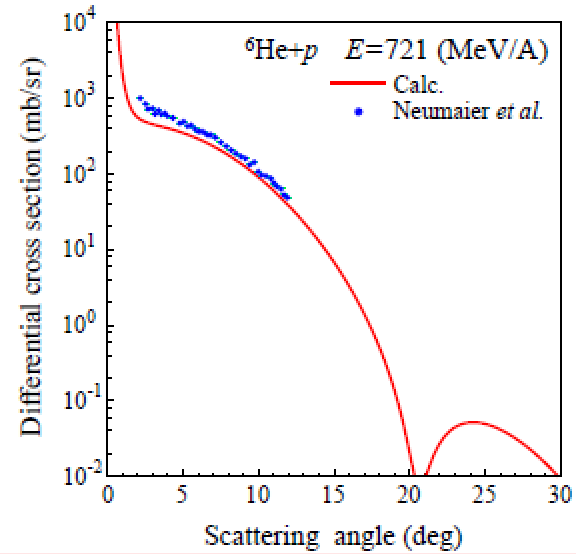
Stable nucleus
^{90}Zr



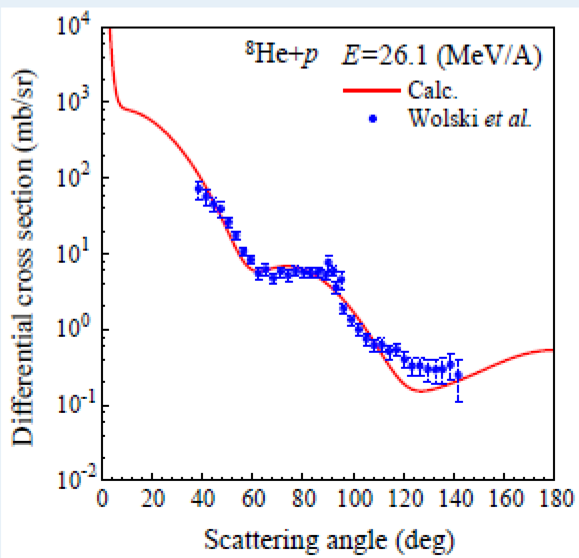
^{6,8}He+*p* elastic scattering

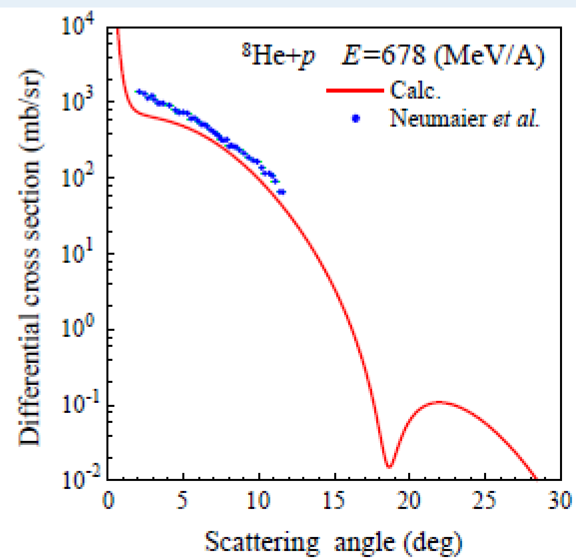
Unstable nucleus
^{6}He





Unstable nucleus
^{8}He



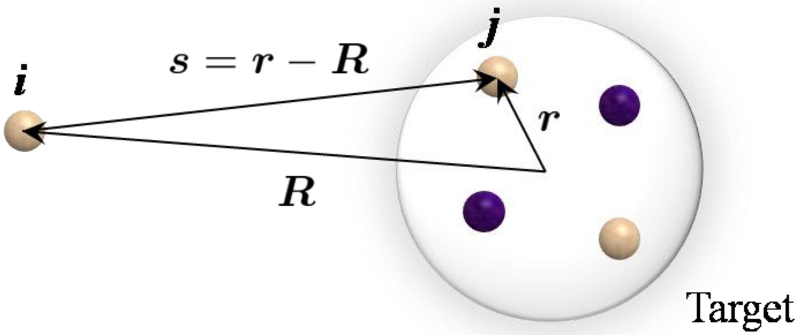


Non-locality and BR localization

In general, nucleon-nucleus potential has non-locality.

The definition of the equivalent local potential

$$U_{\rm loc}(\boldsymbol{R})\chi(\boldsymbol{R}) = \int U(\boldsymbol{R},\boldsymbol{r})\chi(\boldsymbol{r})d\boldsymbol{r}$$



With the BR localization, we obtain the approximate form of $U_{\rm loc}(\boldsymbol{R})$.

The essence of the BR localization is the local semi-classical approximation.

$$\chi(\boldsymbol{r}) = \chi(\boldsymbol{R}+\boldsymbol{s}) \approx \chi(\boldsymbol{R})e^{i\boldsymbol{k}(\boldsymbol{R})\cdot\boldsymbol{s}}$$

Local wave number: $\hbar k(\boldsymbol{R}) = \sqrt{2\mu(E - U_{\rm loc}(\boldsymbol{R}))}$

The BR localized potential is obtained by self-consistent calculation for $k(\boldsymbol{R})$.

The validity of BR localization

It is necessary to test the accuracy of the BR localization.

We have to solve the Schrödinger equations

Exact: $$\Big(T_{\boldsymbol{R}} - E\Big)\chi(\boldsymbol{R}) = \int U(\boldsymbol{R}, \boldsymbol{r})\chi(\boldsymbol{r})d\boldsymbol{r}$$

For only elastic scatterings, one can calculate the exact form.

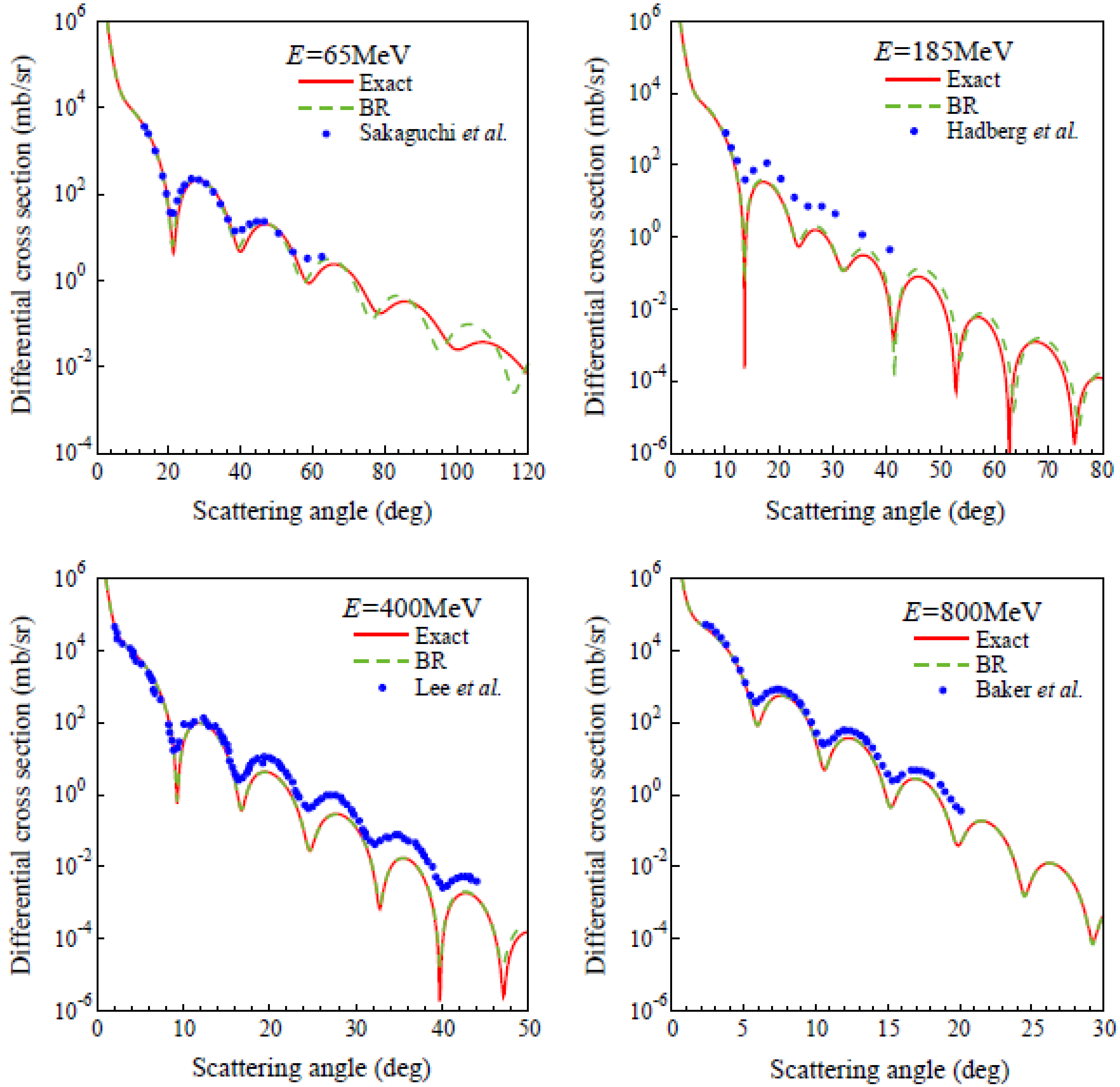
BR: $$\Big(T_{\boldsymbol{R}} + U_{\rm loc}(\boldsymbol{R}) - E\Big)\chi(\boldsymbol{R}) = 0$$

We tested the validity of the BR localization by comparison of the exact calculation and BR calculation.

K. Minomo, K. Ogata, M. Kohno, Y. R. Shimizu, and M. Yahiro, J. Phys. G (arXiv:nucl-th0911.1184)

Exact vs BR for $p+{}^{90}Zr$

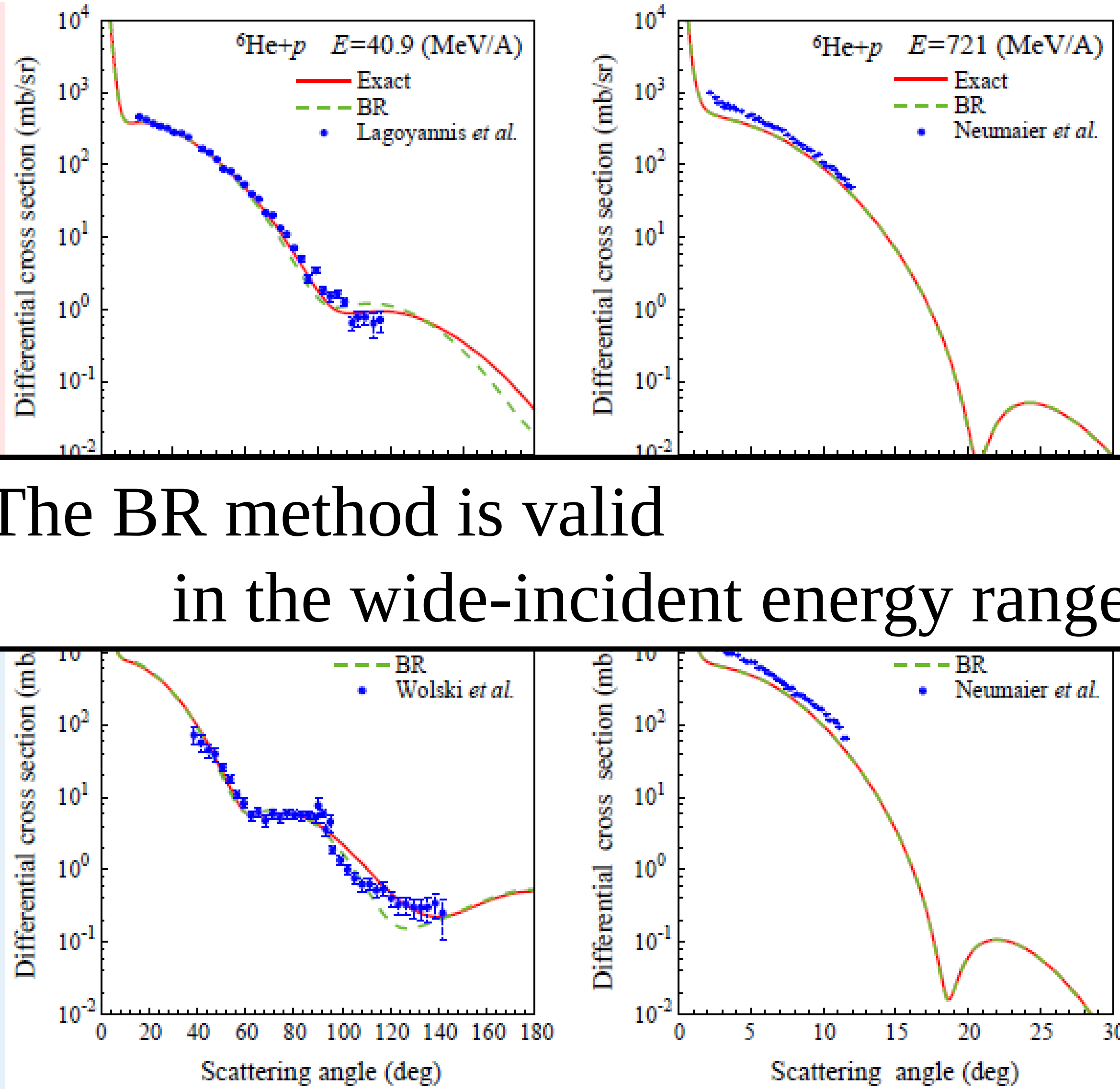
^{90}Zr



Exact vs BR for ^{6}He+p and ^{8}He+p

^{6}He

^{8}He



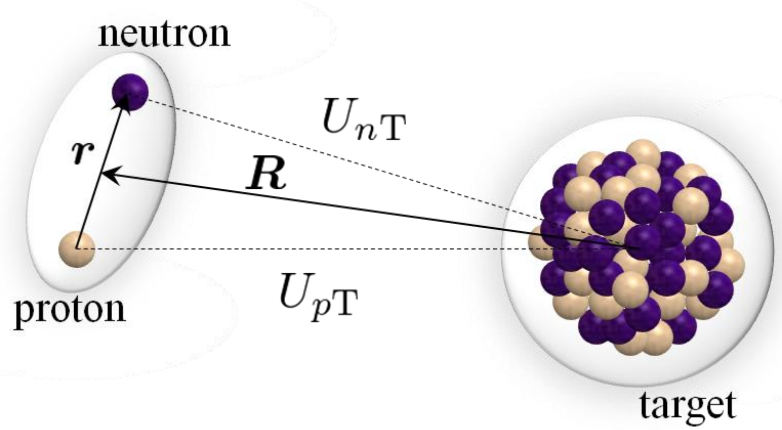
The BR method is valid
in the wide-incident energy range.

Application

☐ For deuteron induced reaction

$$\left[K + h_{pn} + h_{\mathrm{T}} + \sum_{j\in\mathrm{T}} \left(\tau_{pj} + \tau_{nj}\right) - E\right]\Psi = 0$$

<u>three-body model</u>



Optical potentials as an input

$$U_{p\mathrm{T}} = \left\langle \varphi_{\mathrm{T}} \middle| \sum_{j\in\mathrm{T}} \tau_{pj} \middle| \varphi_{\mathrm{T}} \right\rangle$$

$$U_{n\mathrm{T}} = \left\langle \varphi_{\mathrm{T}} \middle| \sum_{j\in\mathrm{T}} \tau_{nj} \middle| \varphi_{\mathrm{T}} \right\rangle$$

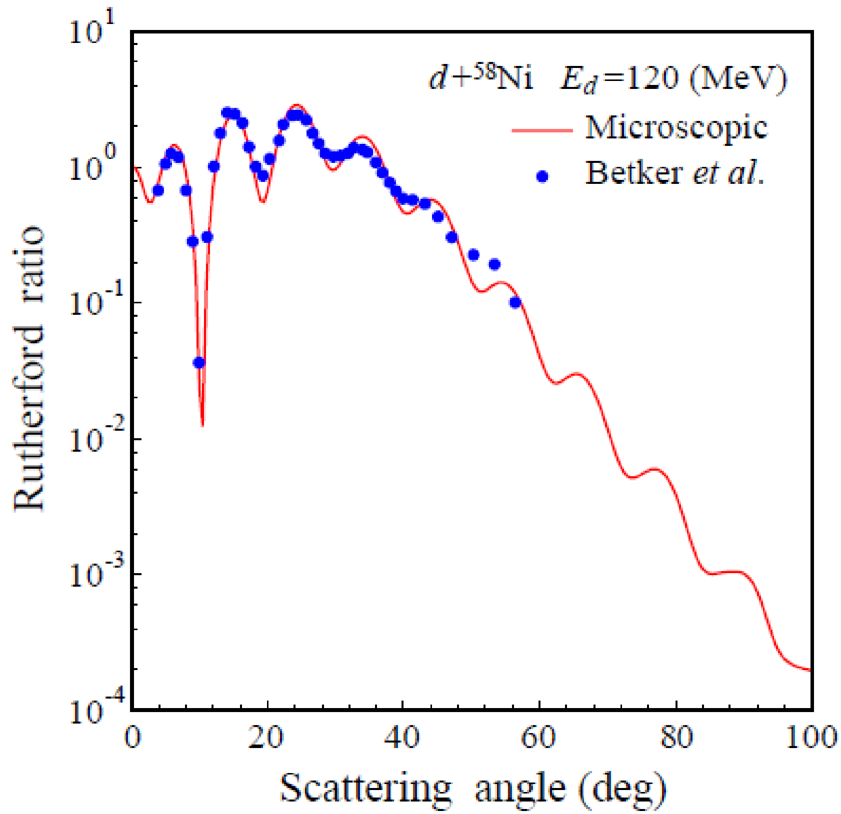
✓ ~~non-local potential~~ complicated

✓ localized potential（BR method） useful

✓ **Continuum-Discretized Coupled-Channels method (CDCC)**

It is a standard direct reaction theory to describe real and virtual breakup.

$d + {}^{58}$Ni elastic scattering



Our microscopic calculation reproduces the data.

A success of
Microscopic CDCC

in a case of scattering
with unstable nuclei

- ✓ ~~phenomenological potential~~ unavailable
- ✓ ~~non-local potential~~ complicated
- ✓ localized potential（BR method） useful

Summary

☐ Systematic description for nucleon-nucleus elastic scattering

We formulated Schrodinger equation with resummation.

- ✓ **Structure model**
  Hartree-Fock method with finite range Gogny force
- ✓ **Effective interaction for reaction dynamics**
  Melbourne g-matrix interaction is recommendable.
- ✓ **Localization**
  Brieva-Rook method is useful in a wide-incident energy region.

For nucleon elastic scattering from stable and unstable nucleus, we succeeded to reproduce the data with no free parameters.

☐ Application to the other reaction

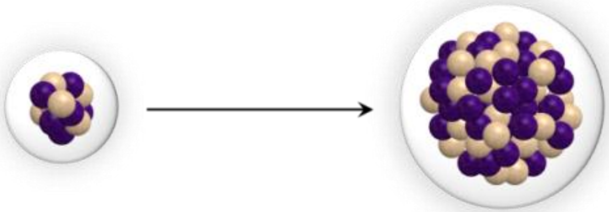
- ✓ **Framework of microscopic CDCC**
  Deuteron elastic scattering from ^{58}Ni is successful.

Future work

☐ Nucleus-nucleus scattering

Double folding potential

$$U = \left\langle \varphi_{\mathrm{P}}\varphi_{\mathrm{T}} \middle| \sum_{i\in \mathrm{P}, j\in \mathrm{T}} \tau_{ij} \middle| \varphi_{\mathrm{P}}\varphi_{\mathrm{T}} \right\rangle$$



☐ Descriptions of reaction process

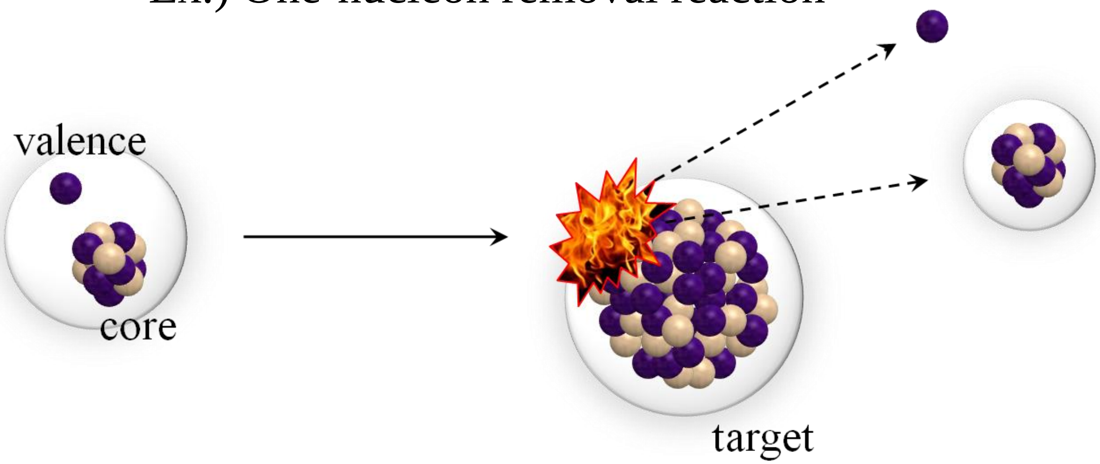
Microscopic CDCC

<u>three-body model</u>

✓ Single folding potential
between valence and target

✓ Double folding potential
between core and target

Ex.) One-nucleon removal reaction



Analysis of reactions with unstable nuclei ⇒ New insight