Determination of $^{8}B(p,\gamma)^{9}C$ Reaction Rate from ^{9}C Breakup

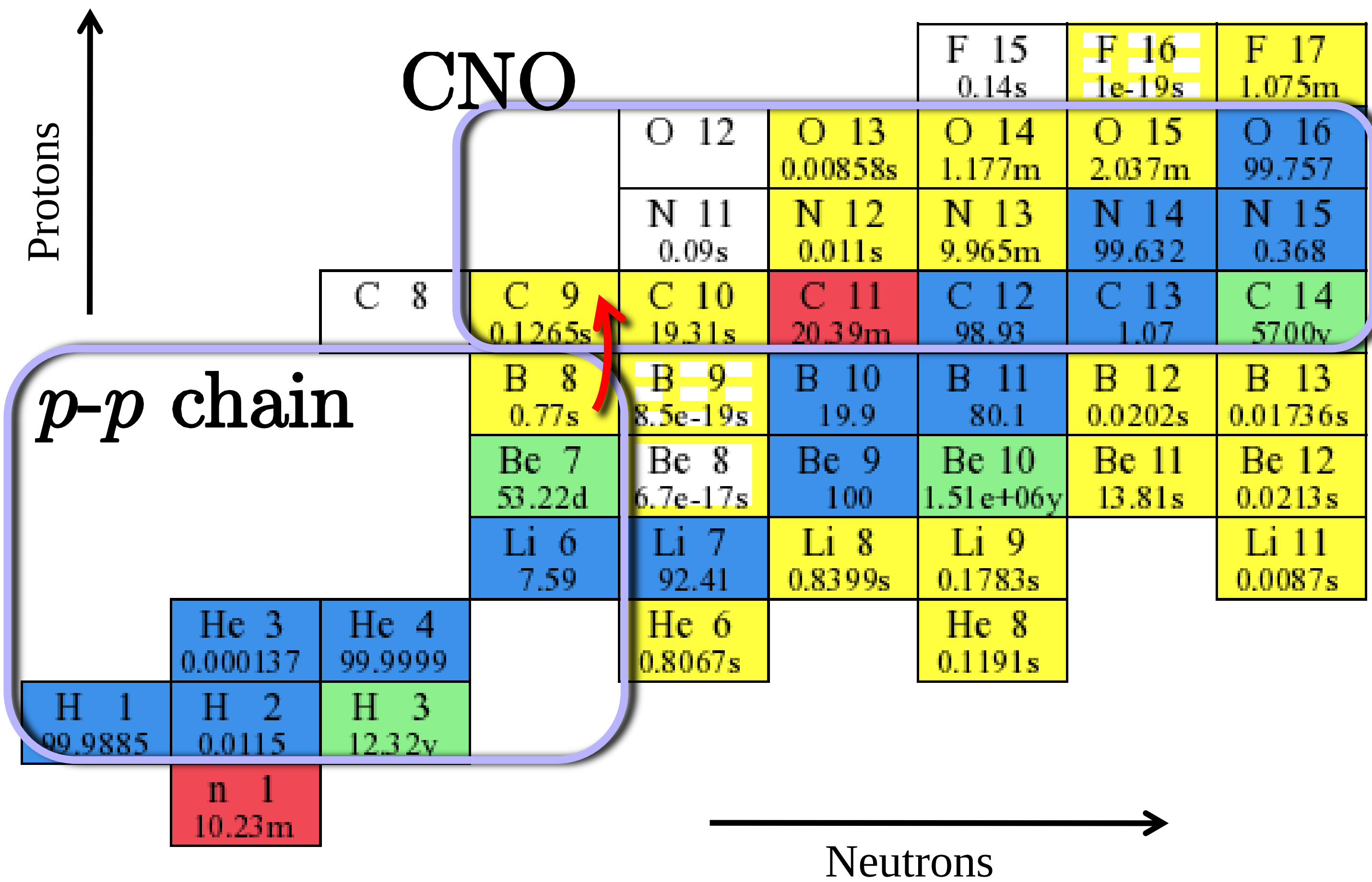
T. Fukui　　Dep. of Phys., Kyushu Univ.

K. Ogata, K. Minomo, M. Yahiro

KYUSHU UNIVERSITY

3/Aug./2011

Introduction



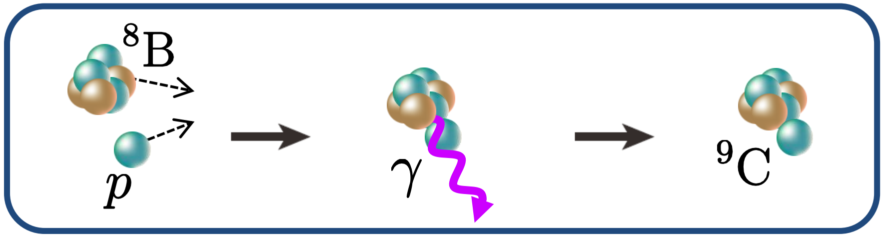
$$^{8}\mathrm{B}(p,\gamma)^{9}\mathrm{C}(\alpha,p)^{12}\mathrm{N}(p,\gamma)^{13}\mathrm{O}(\beta^{+}\nu)^{13}\mathrm{N}(p,\gamma)^{14}\mathrm{O}$$

$$\Rightarrow \; ^{12}\mathrm{C}(^{9}\mathrm{C},p\,^{8}\mathrm{B})^{12}\mathrm{C}$$

Introduction

Eλ transition cross section

$$\sigma_{\mathrm{E}\lambda} \propto \left| \left\langle I(\boldsymbol{r}) \middle| \hat{O}_{\mathrm{E}\lambda}(\boldsymbol{r}) \middle| \psi_{p\mathrm{B}}(\boldsymbol{r}) \right\rangle \right|^2$$

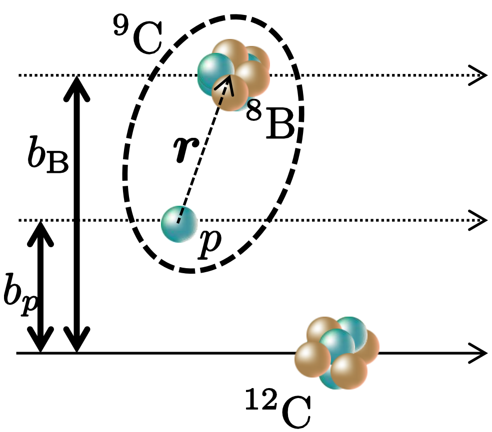


Overlap function

$$I(\boldsymbol{r}) \equiv \langle \phi_{\mathrm{C}}(\boldsymbol{r}, \xi_p, \xi_{\mathrm{B}}) | \phi_p(\xi_p)\phi_{\mathrm{B}}(\xi_{\mathrm{B}}) \rangle , \quad I(r) \xrightarrow{r \gg r_{\mathrm{N}}} \frac{CW(r)}{r}$$

Determine the C
from Breakup reaction: ^{12}C(^{9}C,p^{8}B)^{12}C

Peripheral Reaction !!



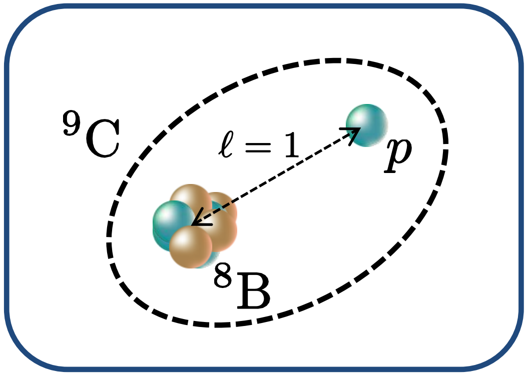
- If b_p is large, there will be no Breakup because of the short-rage property of Nuclear interaction.
- If b_{B} is small, there will be no Breakup because of the absorption.

Model

Channel Spin Decomposition

Ground state wave function

$$\phi_{\mathrm{C}}^{\mathrm{g.s.}}(\boldsymbol{r}) = \sum_{S=3/2,5/2} \frac{\varphi^{\mathrm{g.s.}}(r)}{r} \left[\left[\eta_{1/2} \otimes \Phi_2\right]_S \otimes Y_1(\hat{\boldsymbol{r}})\right]_{3/2,J_z}$$

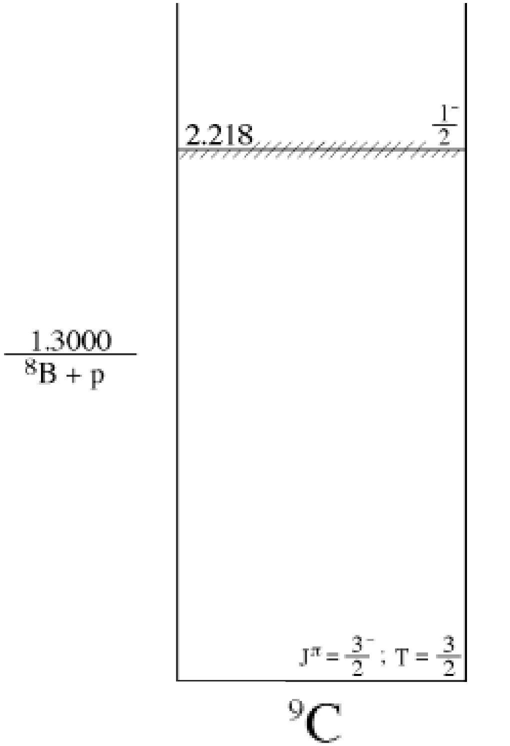


Resonance state wave function

$$\phi_{\mathrm{C}}^{\mathrm{res}}(\boldsymbol{r}) = \frac{\varphi^{\mathrm{res}}(r)}{r} \left[\left[\eta_{1/2} \otimes \Phi_2\right]_{3/2} \otimes Y_1(\hat{\boldsymbol{r}})\right]_{1/2,J_z}$$

S conservation

$$\sigma_{\mathrm{BU}} = S_{\mathrm{exp}}^{(3/2)} \sigma_{\mathrm{BU}}^{(3/2)} + S_{\mathrm{exp}}^{(5/2)} \sigma_{\mathrm{BU}}^{(5/2)}$$



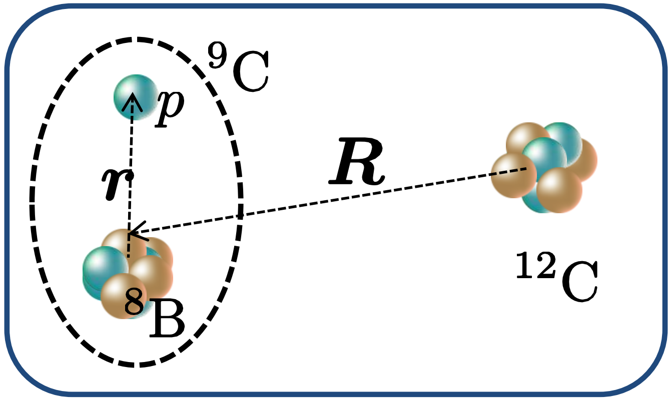
D.R. Tilley et al.
Nuclear Physics A 745 (2004) 155–362

Model CDCC (Continuum Discretized Coupled Channels) method

3-body Schrödinger eq.

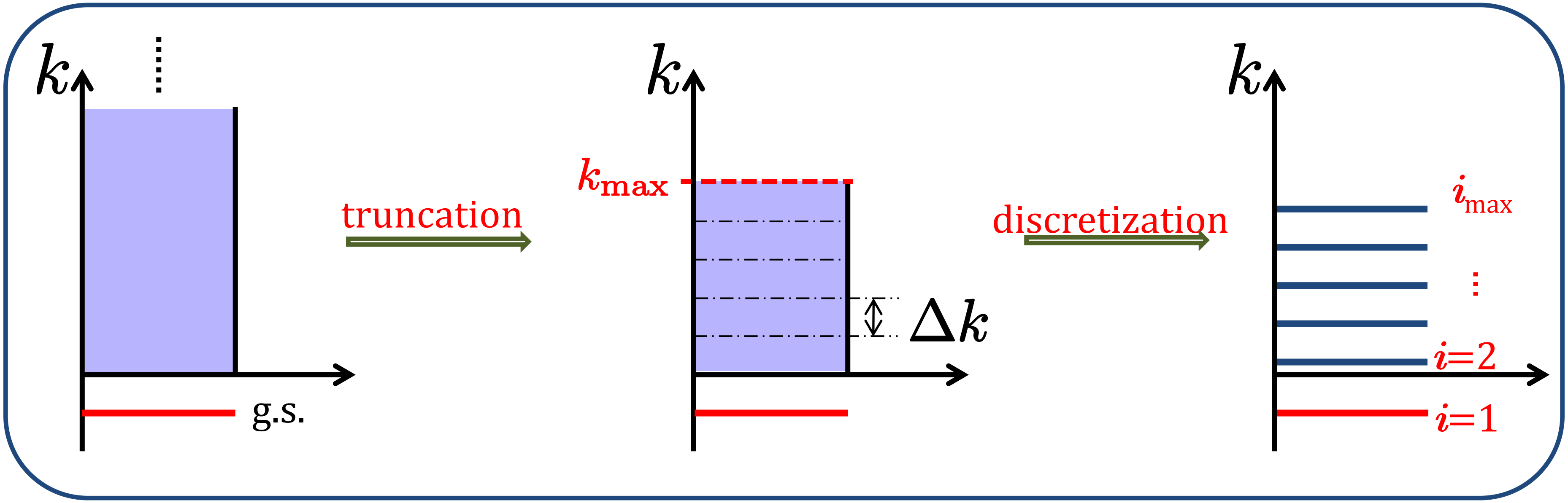
$$(H_{3b} - E)\Psi(\boldsymbol{r}, \boldsymbol{R}) = 0$$

$$H_{3b} = T_r + V_{p\mathrm{B}} + T_R + U_{p\mathrm{C}} + U_{\mathrm{BC}}$$

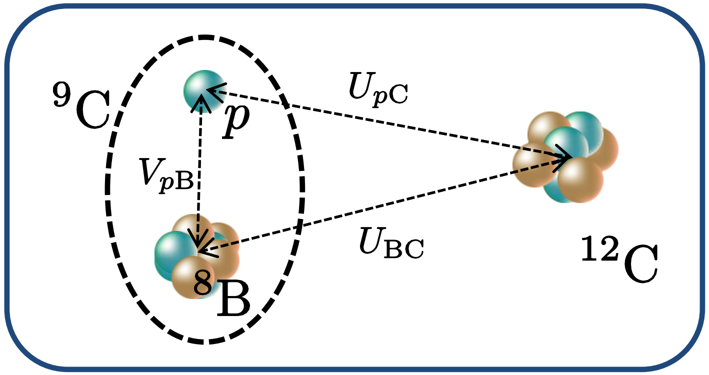


CDCC wave function

$$\Psi(\boldsymbol{r}, \boldsymbol{R}) = \phi_0\chi_0 + \int_0^\infty \phi_k\chi_k dk \quad \longrightarrow \quad \Psi^{\mathrm{CDCC}}(\boldsymbol{r}, \boldsymbol{R}) = \sum_{i}^{i_{\mathrm{max}}} \hat{\phi}_i\hat{\chi}_i$$



Model



^{9}C

- s, p, d, f - waves
- $k_{\mathrm{max}} = 0.6$ [fm^{-1}] ($E_{\mathrm{rel\text{-}max}} \sim 7.7$ [MeV])
- $\Delta k = 0.05$ [fm^{-1}]
- $V_{p\mathrm{B}}$: Woods-Saxon pot. reproducing B.E. (-1.3 MeV) & resonance

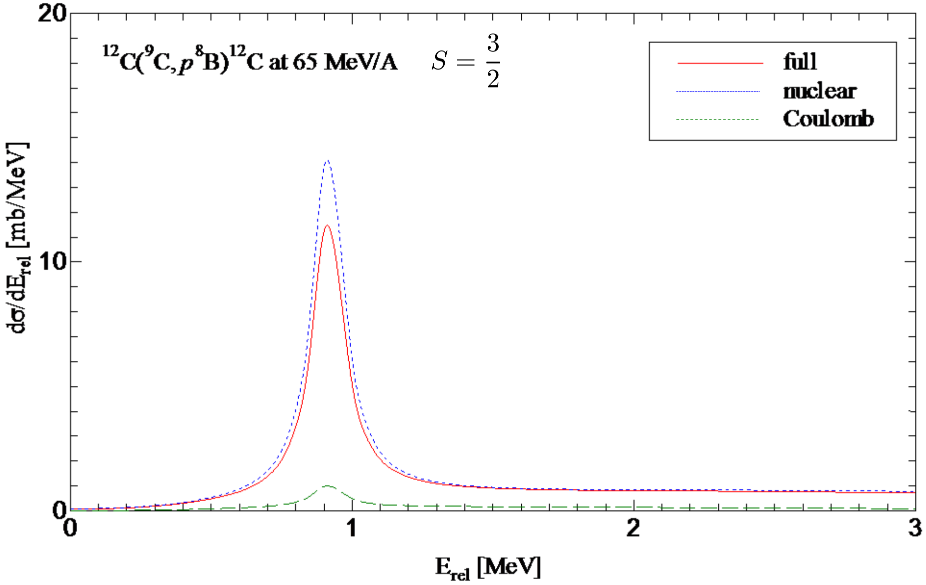
Distorting pot. : full microscopic folding model

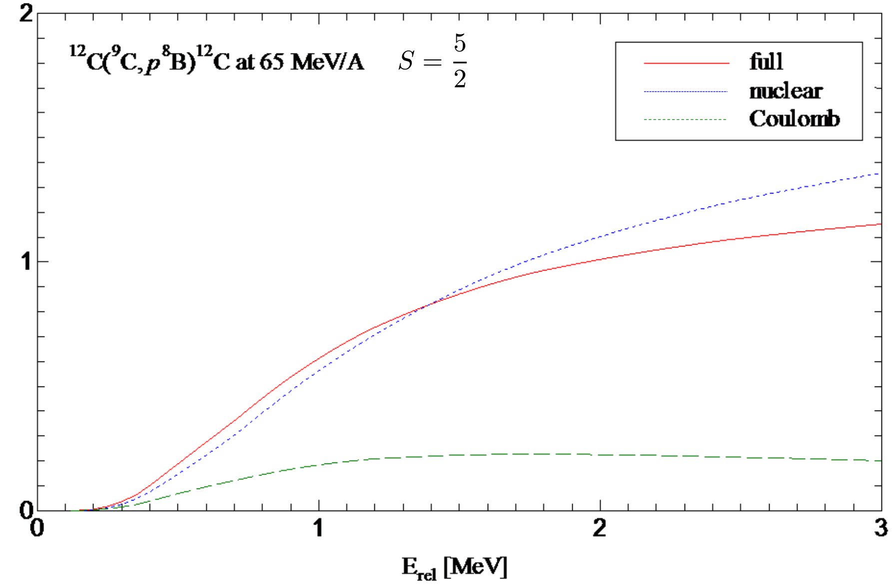
- $U_{p\mathrm{C}} = \int \rho_{\mathrm{C}}(\boldsymbol{r}_2) \sum_{i \in \mathrm{C}} g_i d\boldsymbol{r}_2$
- $U_{\mathrm{BC}} = \int \rho_{\mathrm{B}}(\boldsymbol{r}_1)\rho_{\mathrm{C}}(\boldsymbol{r}_2) \sum_{i \in \mathrm{B}, j \in \mathrm{C}} g_{ij} d\boldsymbol{r}_1 d\boldsymbol{r}_2$

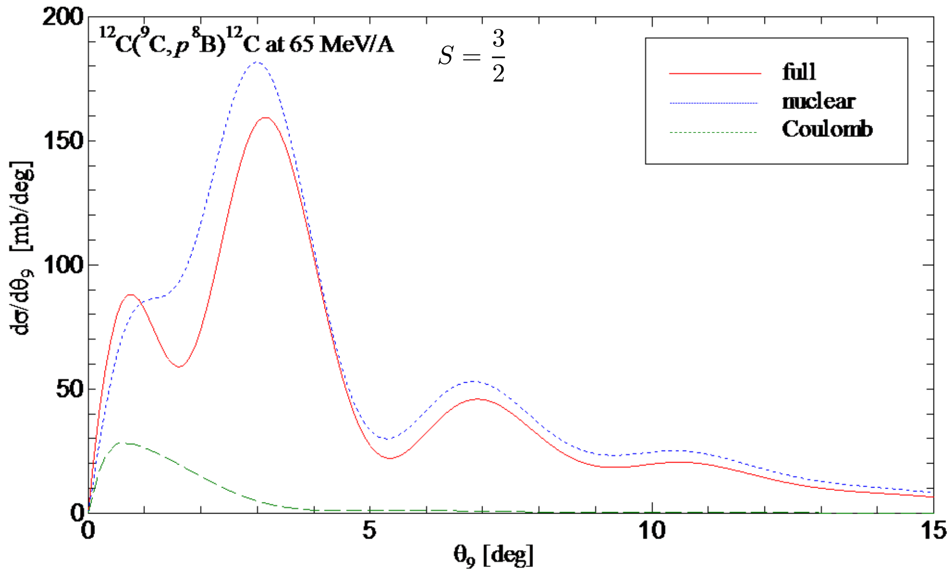
(*NN* interaction g_{ij} : Melbourne g-matrix

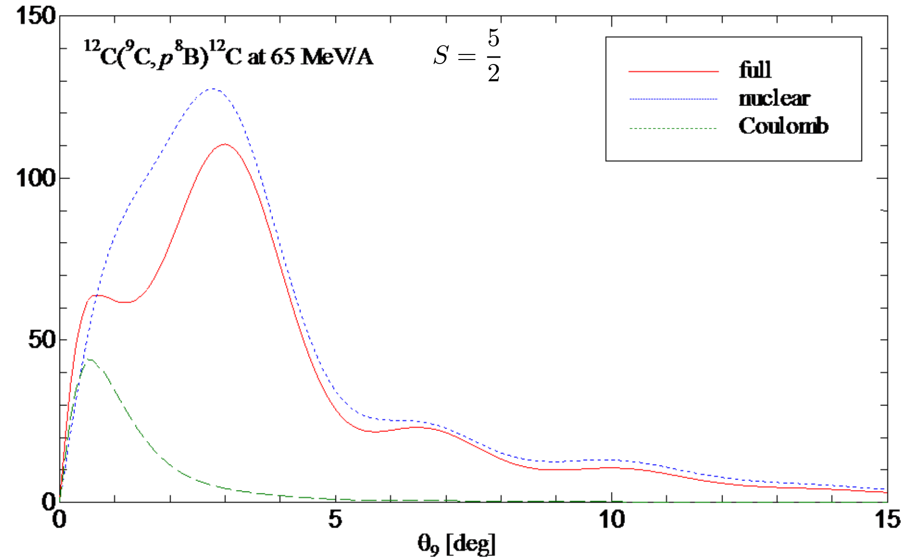
$\rho_{\mathrm{B}}, \rho_{\mathrm{C}}$: Hartree-Fock calc. with Gogny D1S)

Result Nuclear/Coulomb BU Effects







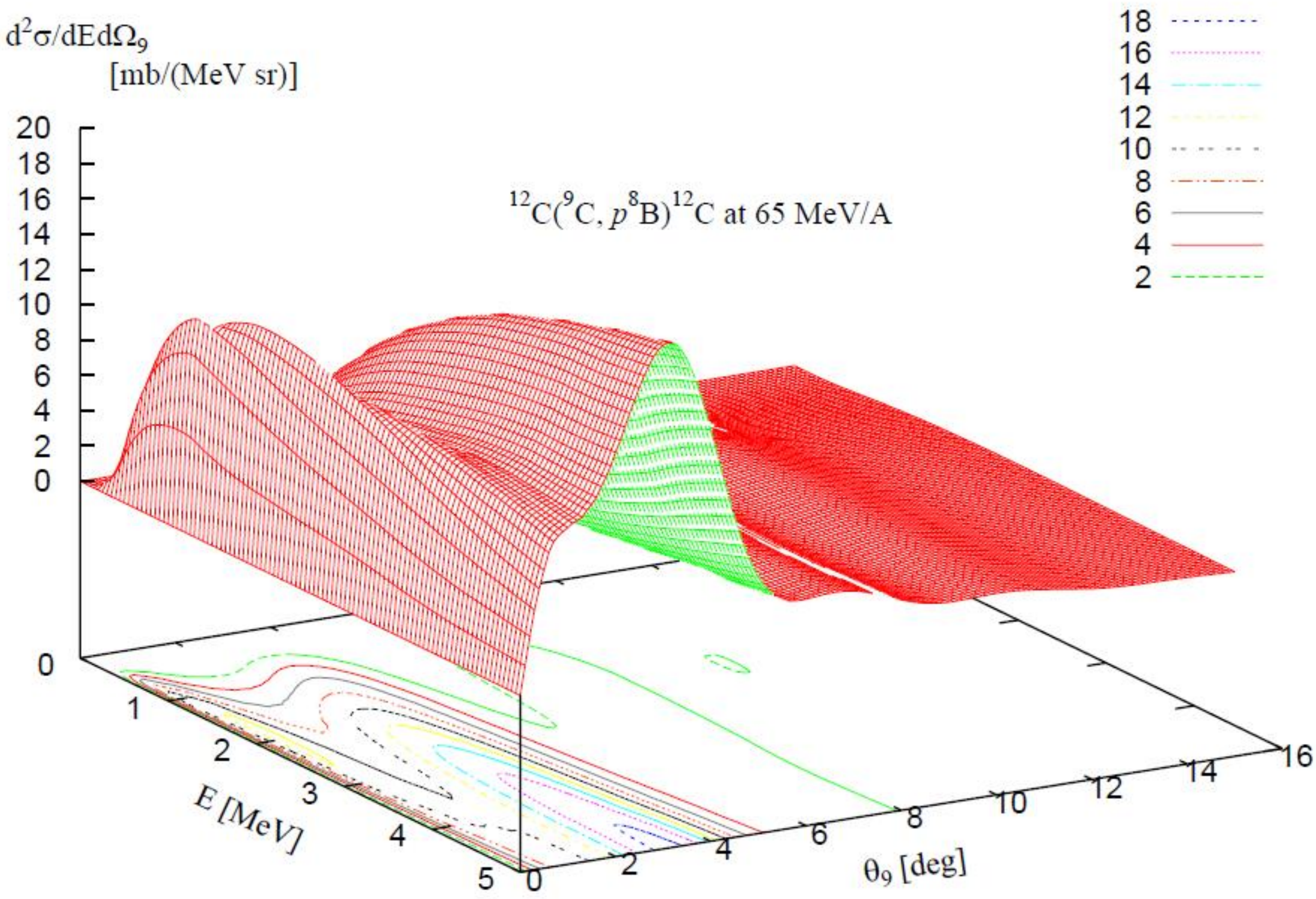


Summary

$^{12}\mathrm{C}(^{9}\mathrm{C},p^{8}\mathrm{B})^{12}\mathrm{C}$ at 65 MeV/A
is analyzed by CDCC.

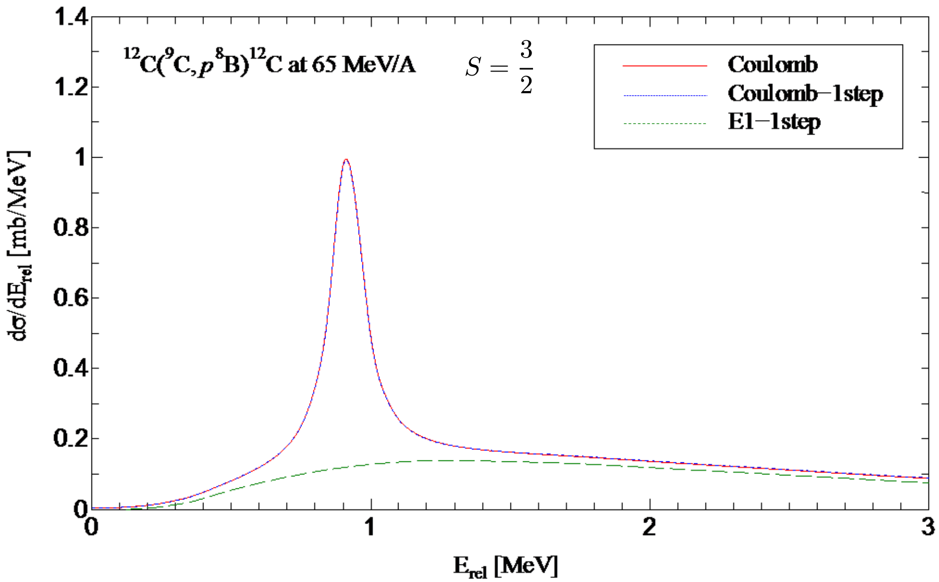
- Our CDCC calculation reproduces well the shape of breakup energy spectrum.
- ANC: $(C_{3/2})^2 = 0.115$ [fm^{-1}], $(C_{5/2})^2 = 0.247$ [fm^{-1}],
  $S_{18} = 12 \pm 1$ [eV-b].
- There is strong interference between Nuclear & Coulomb breakup.

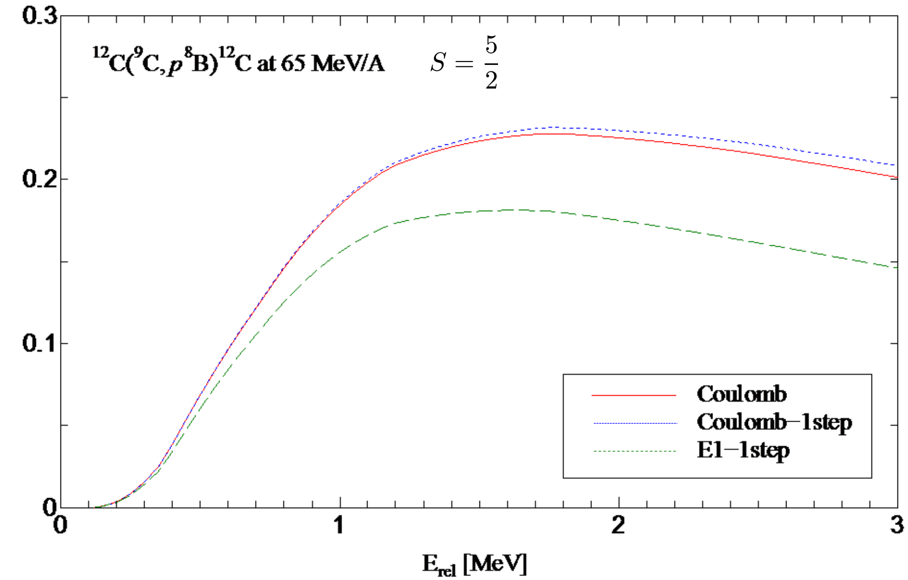
Double Differential Cross Section

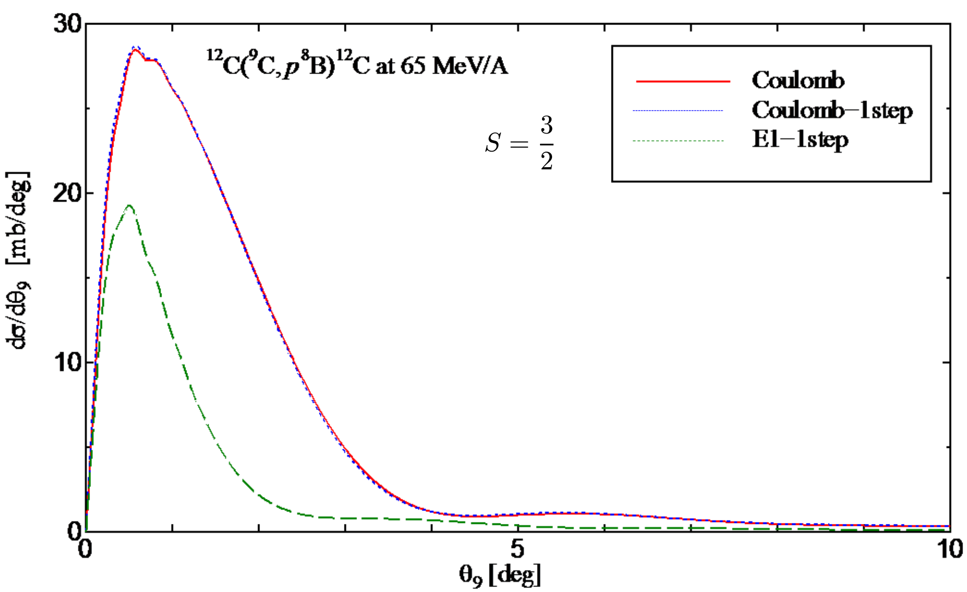


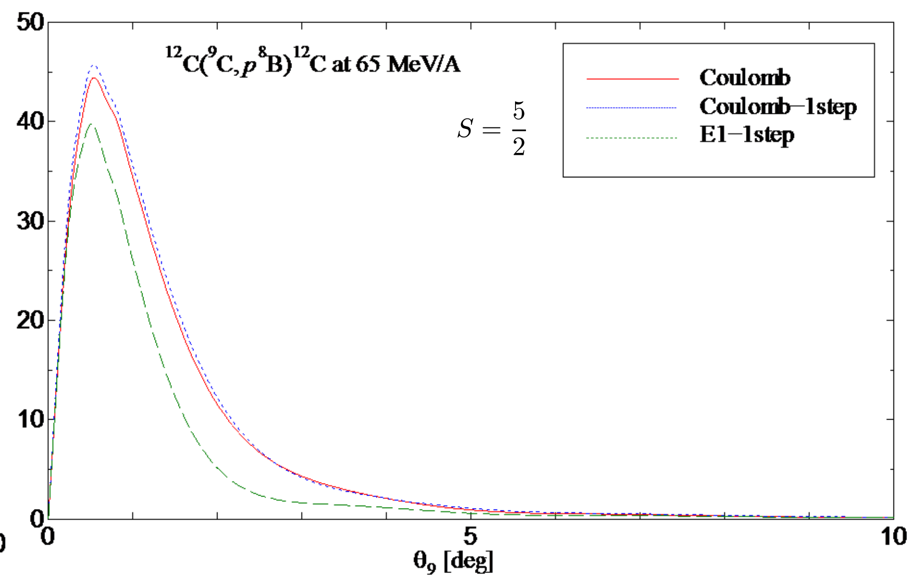
Result

Coulomb BU Multistep Effects





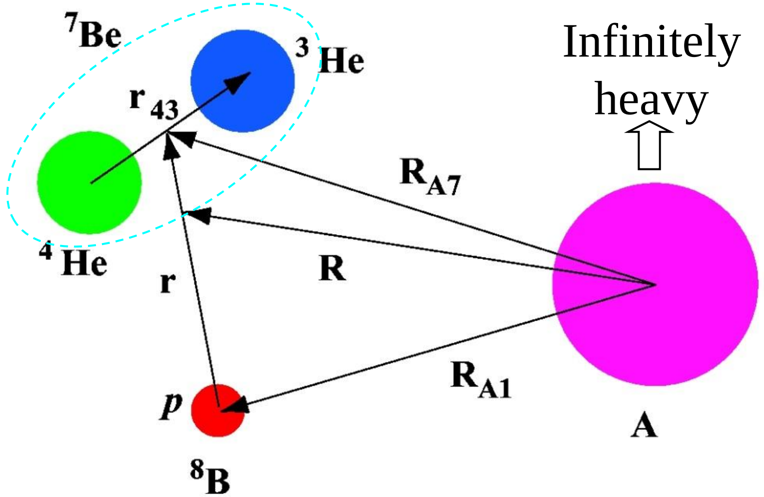




Three "new" aspects of our S_{17} paper

—— *KO, Hashimoto, Iseri, Kamimura, and Yahiro, PRC**73**, 024605 (2006).*

2) Reduction from 4-body breakup to 3-body breakup

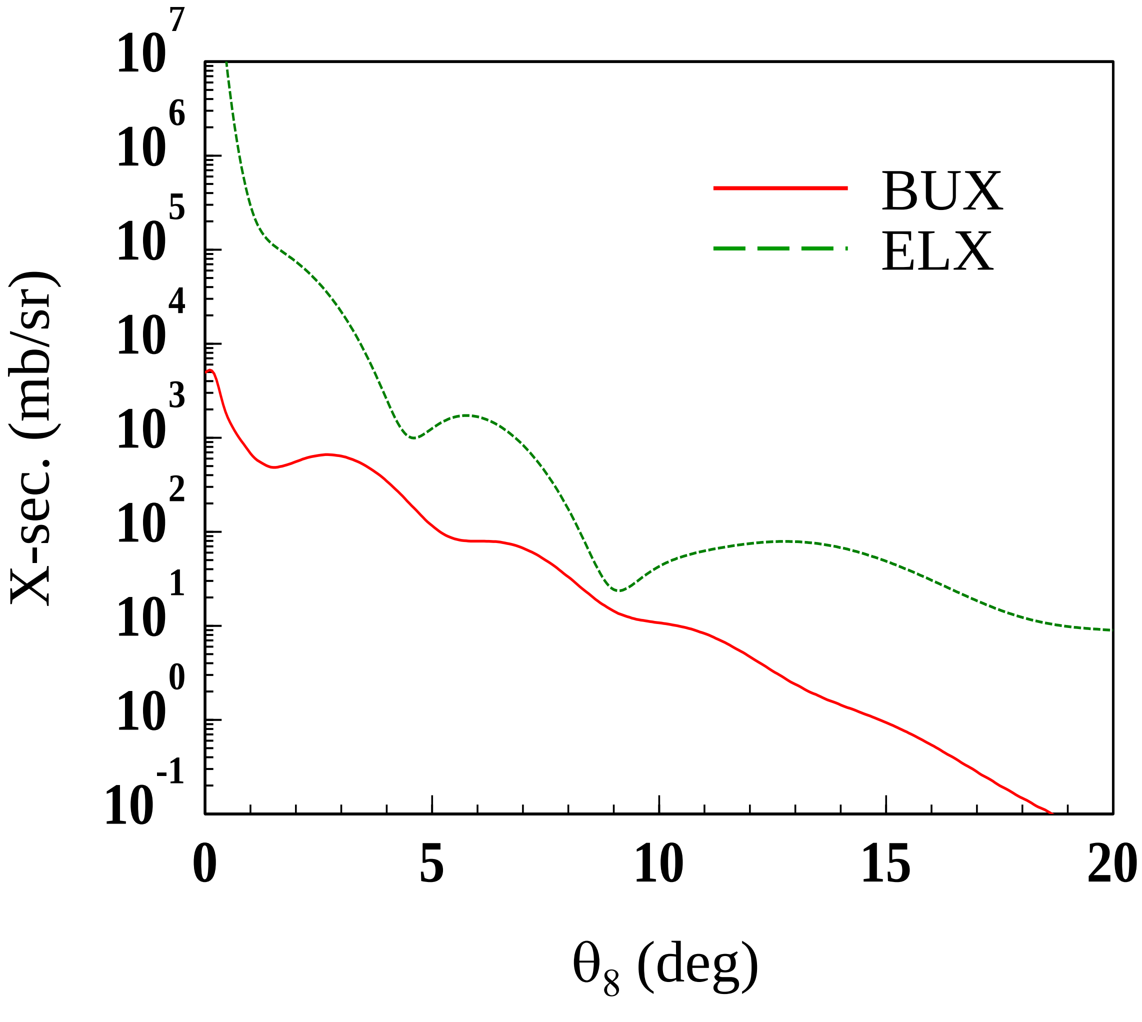


- **The triple-differential cross section for (^{8}B, ^{7}Be+p) is obtained by $C\,\rho\,|T|^2$ with** $\mathfrak{T} = \langle \chi_1 \chi_7 \phi_7^{(0)} | U_{A3} + U_{A4} + U_{A1} + V_{13} + V_{14} | \Psi_{\text{4-body}} \rangle$

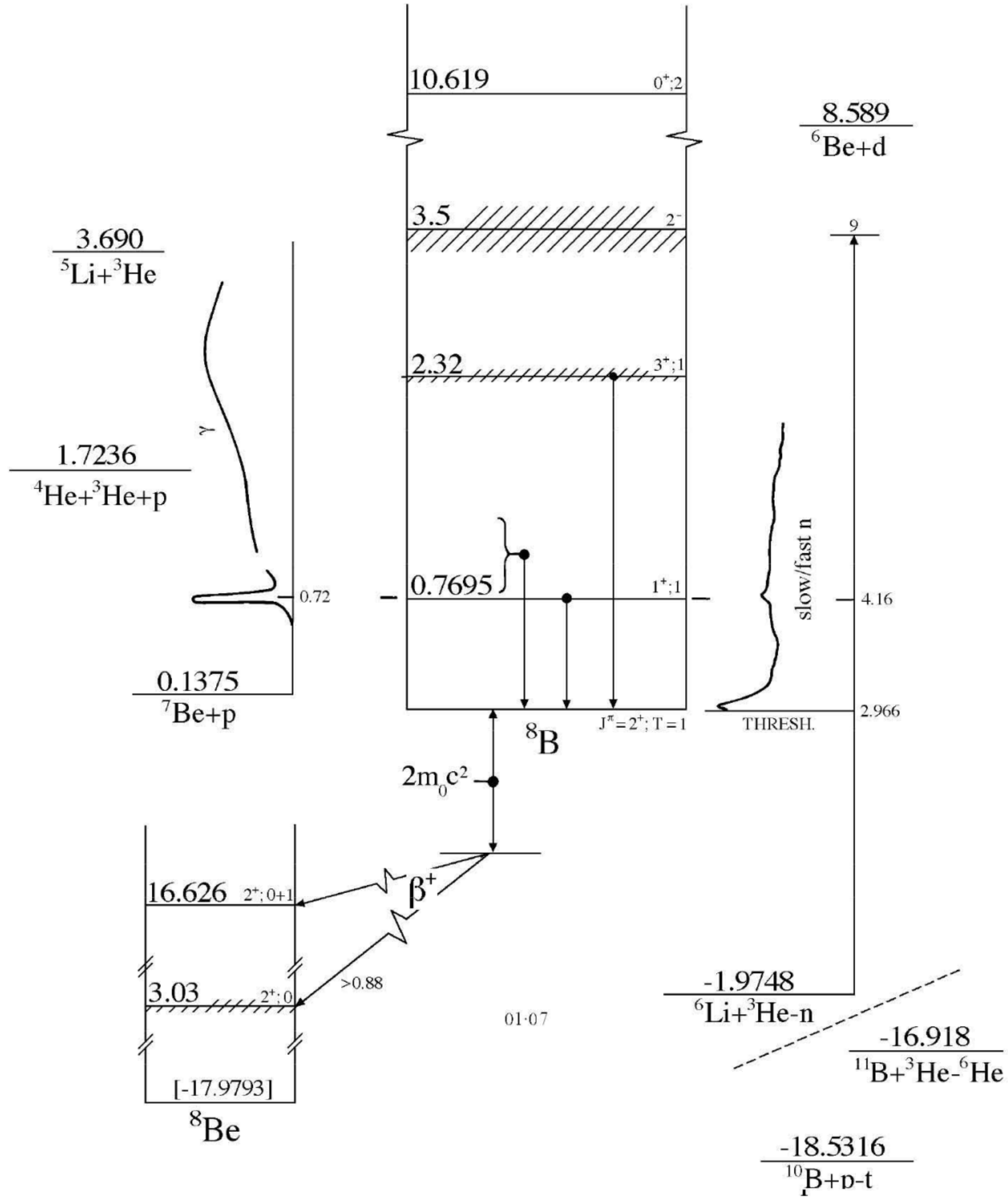
- **^{7}Be breakup cross section by ^{208}Pb turned out to be negligibly small for forward-scattering.** $\Rightarrow$

$$\begin{cases} U_{A3} + U_{A4} \approx \langle \phi_7^{(0)} | U_{A3} + U_{A4} | \phi_7^{(0)} \rangle \\ V_{13} + V_{14} \approx \langle \phi_7^{(0)} | V_{13} + V_{14} | \phi_7^{(0)} \rangle \end{cases}$$

^{8}B scattering from ^{9}Be at 100 A MeV



^{8}B Energy levels

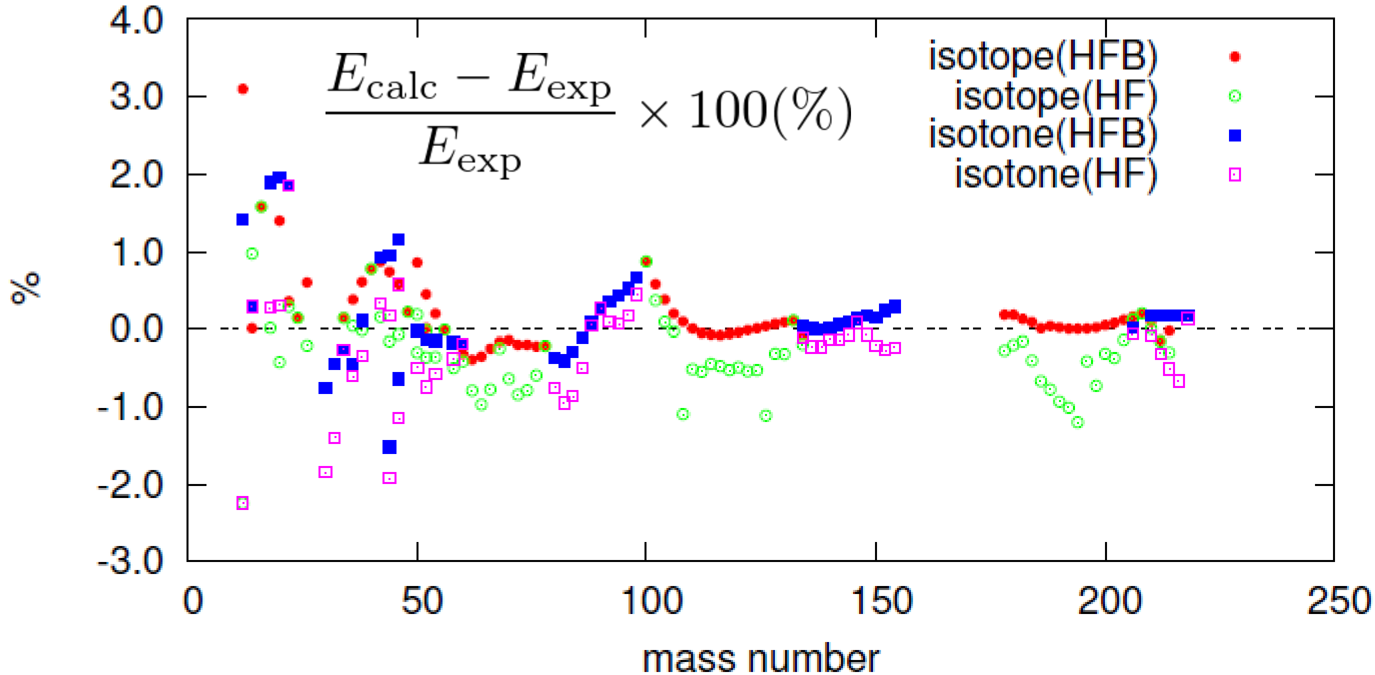


Structure model

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

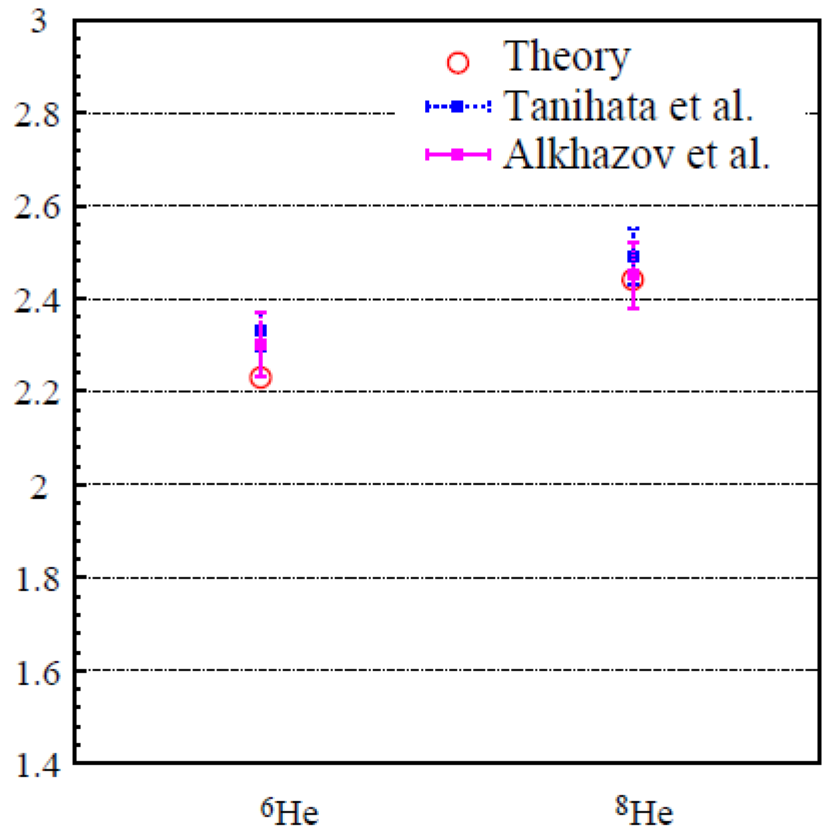
It is applicable to obtain the ground-state wave function of all nuclei.

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



We find that this method is reliable.

核半径(^6He, ^8He)


3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
Theory
Tanihata et al.
Alkhazov et al.
6He
8He