第2回実証的原子核物理学 (Feb. 22th-23th, 2012 at RCNP)

高エネルギー重イオン散乱における核反応ダイナミクスの分析

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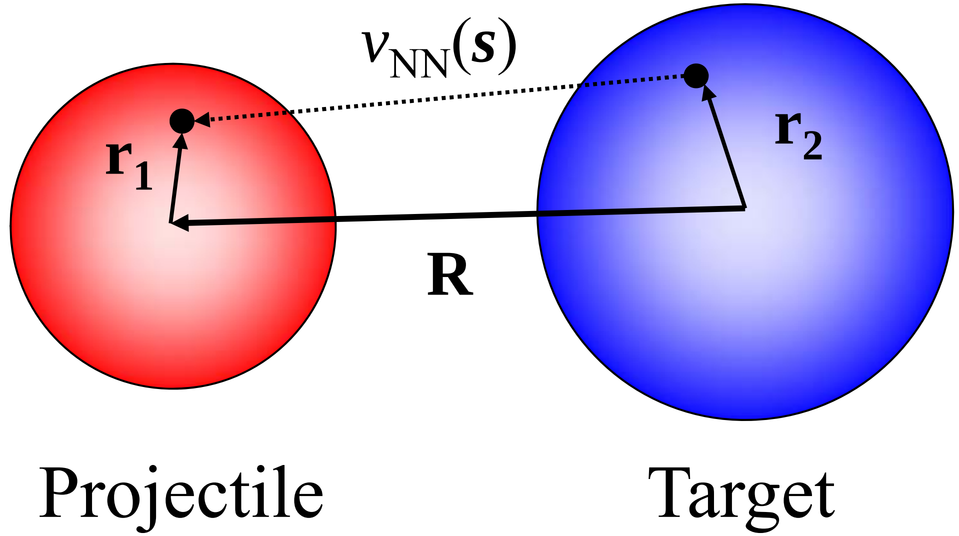
Contents

Double-Folding Model (DFM)



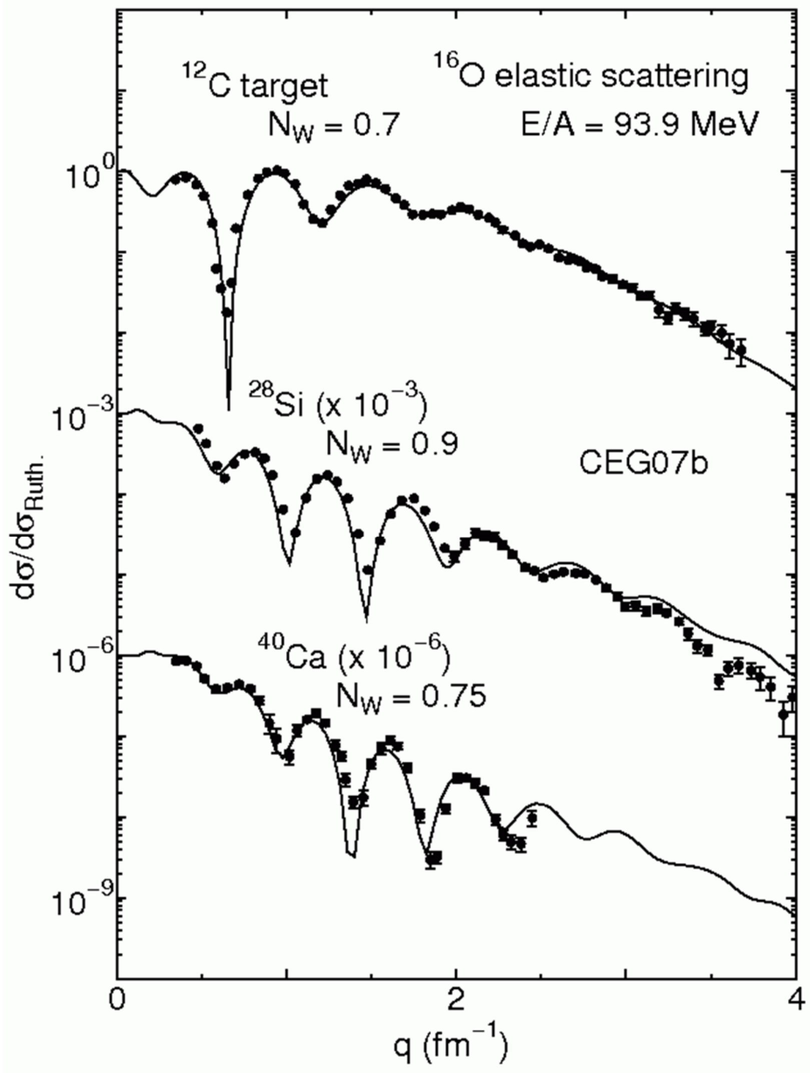
$$U_{DF}(\mathbf{R}) = \int \underbrace{\rho_1(\mathbf{r}_1)}\underbrace{\rho_2(\mathbf{r}_2)}_{\text{nucleon density}} \underbrace{v_{NN}(\mathbf{s};\rho,E)}_{\text{complex } G\text{-matrix interaction (CEG07)}} d\mathbf{r}_1 d\mathbf{r}_2$$

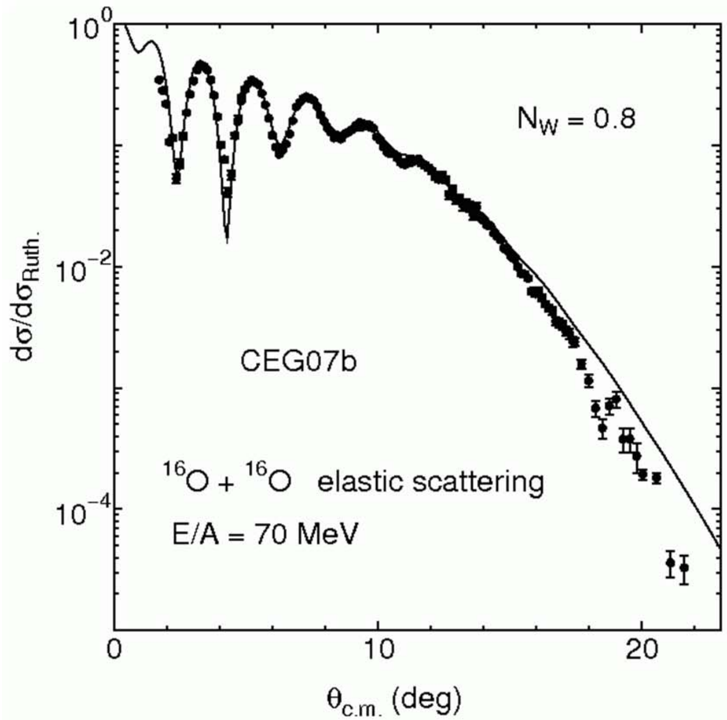
nucleon density

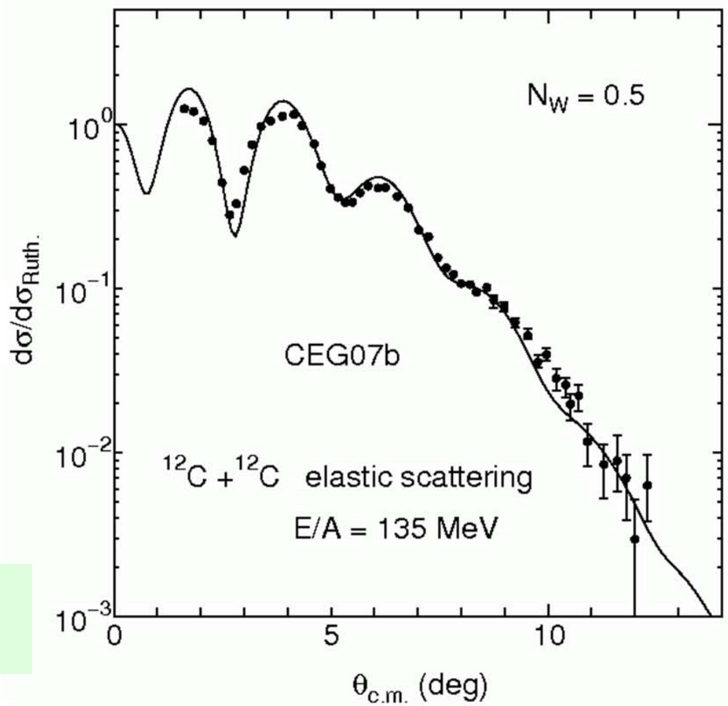
complex *G*-matrix interaction (CEG07)

***T. Furumoto**, Y. Sakuragi and Y. Yamamoto,*
(Phys. Rev. C.79 (2009) 011601(R)), ibid. 80 (2009) 044614)

Heavy-ion elastic scattering

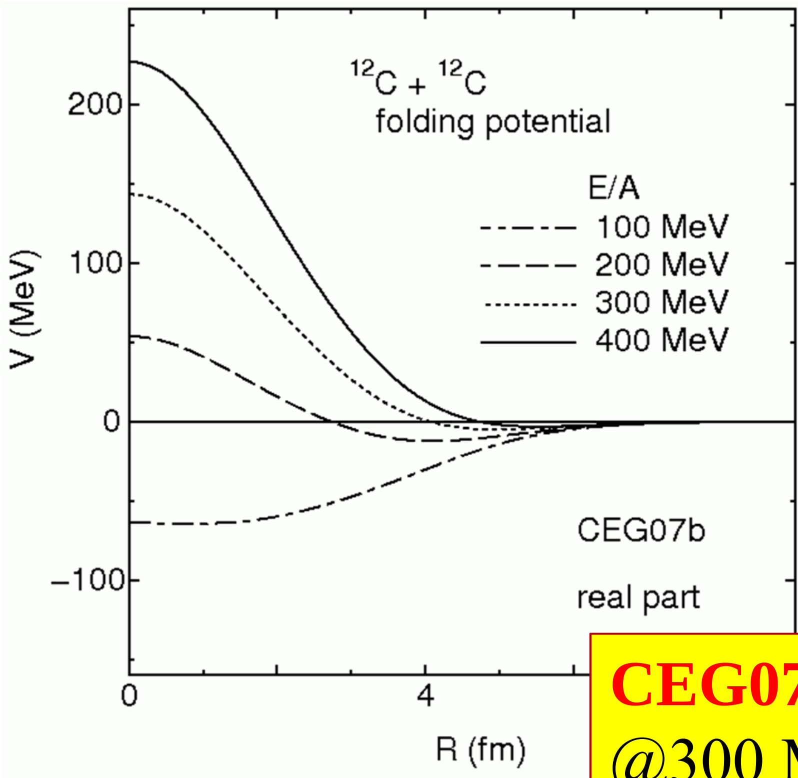




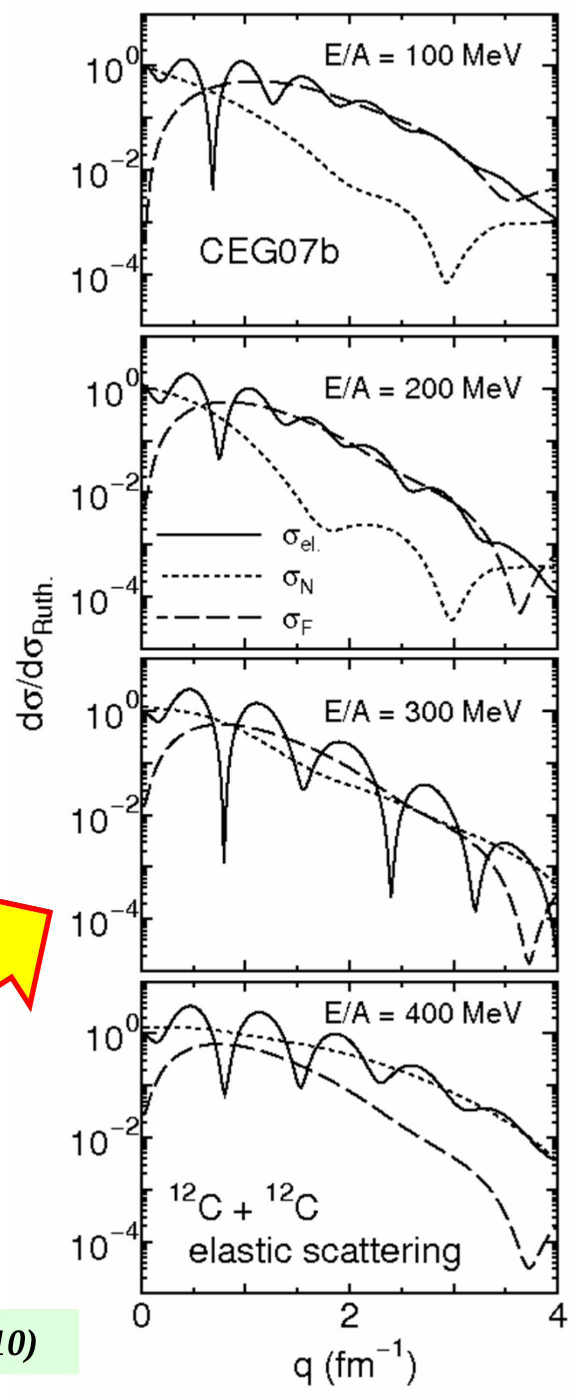


***T. Furumoto**, Y. Sakuragi and Y. Yamamoto,*
(Phys. Rev. C.79 (2009) 011601(R)), ibid. 80 (2009) 044614)

Prediction of repulsive potential for Heavy-ion High-energy scattering



CEG07b
@300 MeV/u



The strong interference appears.

T. Furumoto*, *Y. Sakuragi and Y. Yamamoto, Phys. Rev. C82, 044612 (2010)

Microscopic Coupled Channel (MCC) with CEG07

Coupled Channel equation

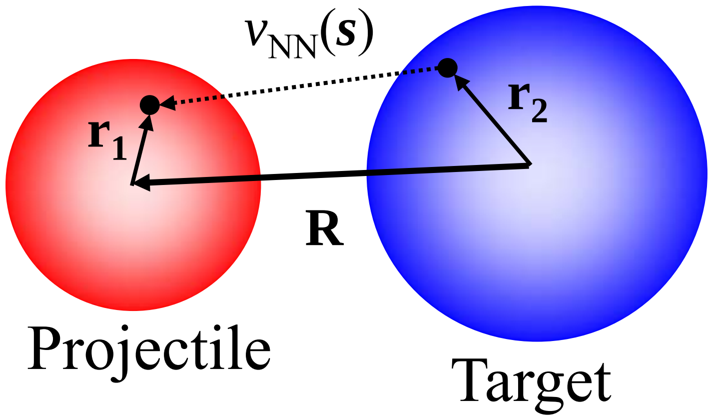
$$\left[T_R + U_{\alpha\alpha}(\mathbf{R}) - E_\alpha\right]\chi_\alpha(\mathbf{R}) = -\sum_{\beta\neq\alpha}^{N} U_{\alpha\beta}(\mathbf{R})\,\chi_\beta(\mathbf{R})$$

The diagonal and coupling potentials are derived from microscopic view point.

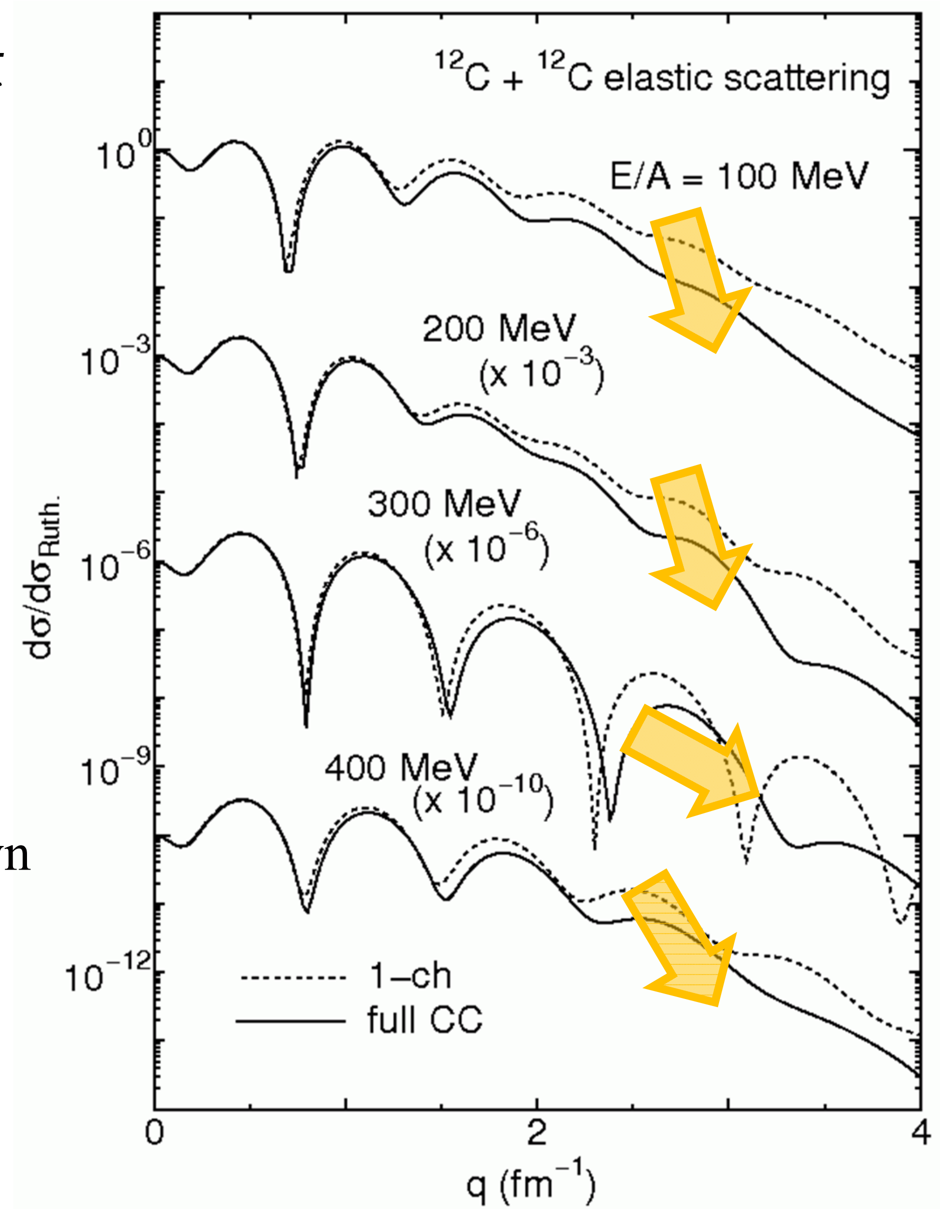
$$U_{\alpha\beta}(\mathbf{R}) = \int \underbrace{\rho_{ik}^{(P)}(\mathbf{r}_1)\rho_{jl}^{(T)}(\mathbf{r}_2)}_{\text{transition density}} \underbrace{\boxed{v_{NN}(\mathbf{s};\rho,E)}}_{\text{CEG07}}\, d\mathbf{r}_1 d\mathbf{r}_2$$

Transition density

$$\underline{\rho_{ik}(\mathbf{r})} = \left\langle \varphi_i(\xi) \middle| \sum_i \delta(\mathbf{r}_i - \mathbf{r}) \middle| \varphi_k(\xi) \right\rangle$$



Dynamic coupling effect on high-energy heavy-ion elastic scatterings



<u>T. Furumoto</u> and Y. Sakuragi, in preparation

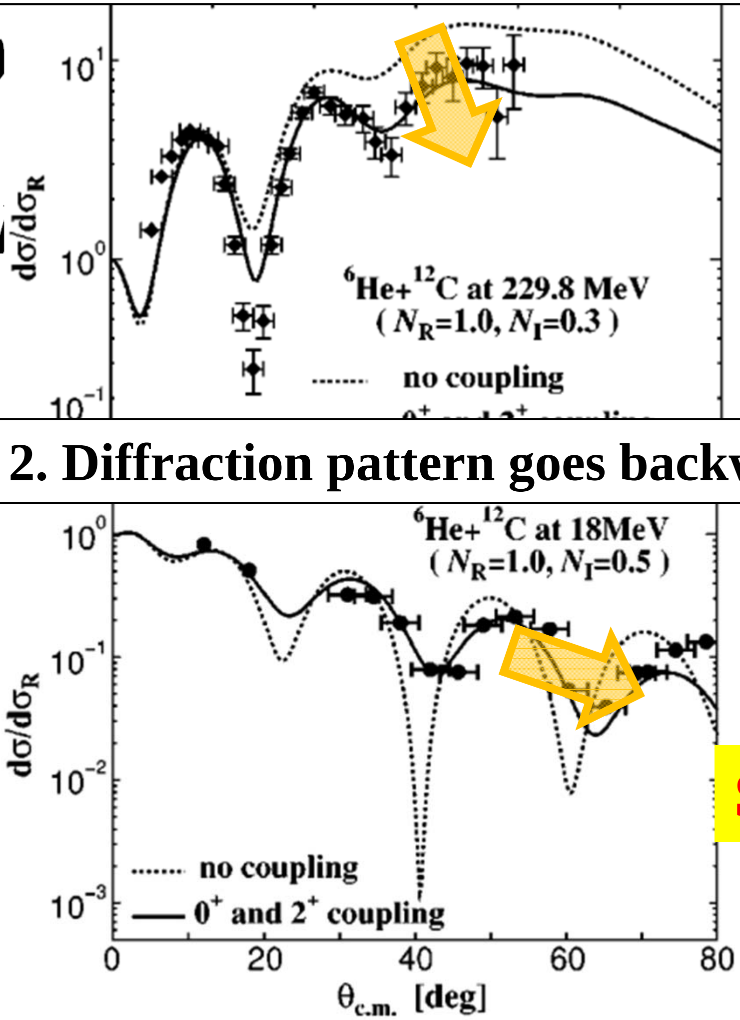
<u>The effect is clearly seen!</u>

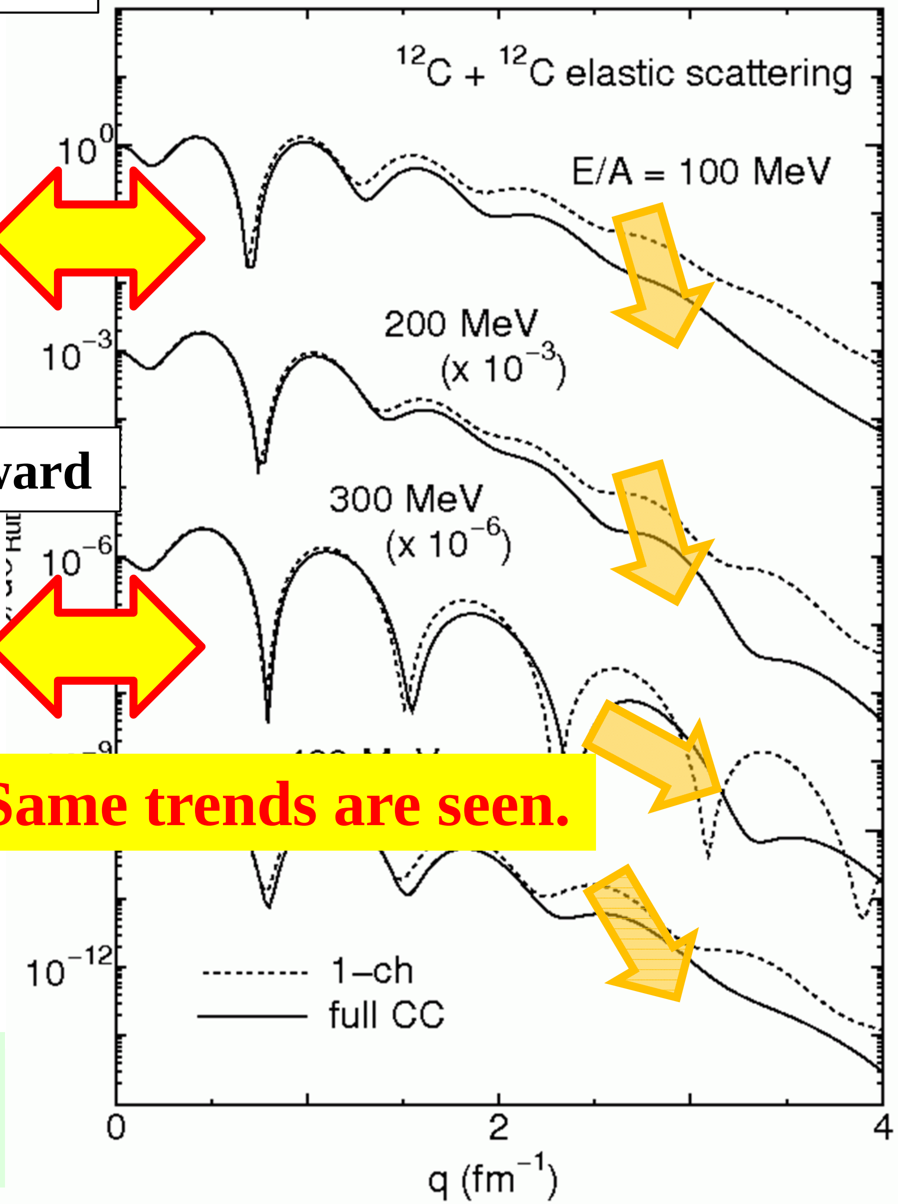
1. Backward cross section comes down

2. Diffraction pattern goes backward

1. Backward cross section comes down

2. Diffraction pattern goes backward





Same trends are seen.

T. Matsumoto, E. Hiyama, K. Ogata, Y. Iseri, M. Kamimura, S. Chiba, and M. Yahiro, (Phys. Rev. C.70 (2004) 061601(R)))

T. Furumoto and Y. Sakuragi, in preparation

Dynamical polarization potential (DPP)

Coupled Channel equation

$$\left[T_R + U_{\alpha\alpha}(\mathbf{R}) - E_\alpha\right]\chi_\alpha(\mathbf{R}) = -\sum_{\beta\neq\alpha}^{N} U_{\alpha\beta}(\mathbf{R})\ \chi_\beta(\mathbf{R})$$

$$\left[T_R + U_{\alpha\alpha}(\mathbf{R}) + \underline{\sum_{\beta\neq\alpha}^{N} U_{\alpha\beta}(\mathbf{R})\left(\chi_\beta(\mathbf{R})/\chi_\alpha(\mathbf{R})\right)} - E_\alpha\right]\chi_\alpha(\mathbf{R}) = 0$$

Coupling effect

Dynamical polarization potential (DPP)

$$\Delta U_{DPP}(\mathbf{R}) = \sum_{\beta\neq\alpha}^{N} U_{\alpha\beta}(\mathbf{R})\left(\chi_\beta(\mathbf{R})/\chi_\alpha(\mathbf{R})\right)$$

By partial wave expansion

$$\Delta U_{DPP}^{(J)}(R) = \sum_{\beta\neq\alpha}^{N} U_{\alpha\beta}(R)\left(\chi_\beta^{(J)}(R)/\chi_\alpha^{(J)}(R)\right)$$

Coupled Channel equation

$$\left[T_R + U_{\alpha\alpha}(\mathbf{R}) + \boxed{\sum_{\beta\neq\alpha} U_{\alpha\beta}(\mathbf{R}) \left(\chi_\beta(\mathbf{R}) / \chi_\alpha(\mathbf{R}) \right)} - E_\alpha \right] \chi_\alpha(\mathbf{R}) = 0$$

Dynamical polarization potential

$$\Delta U_{DPP}(\mathbf{R}) = \boxed{\sum_{\beta\neq\alpha} U_{\alpha\beta}(\mathbf{R}) \left(\chi_\beta(\mathbf{R}) / \chi_\alpha(\mathbf{R}) \right)}$$

$$= \sum_{\beta\neq\alpha} U_{\alpha\beta}(\mathbf{R}) \int G_\beta^{(+)}(\mathbf{R},\mathbf{R}') U_{\beta\alpha}(\mathbf{R}') \chi_\alpha(\mathbf{R}') d\mathbf{R}' / \chi_\alpha(\mathbf{R})$$

$$\left(G_\beta^{(+)} = \frac{1}{E_\beta - T_\beta - U_{\beta\beta} + i\varepsilon} \right)$$

Here, we assume that $U_{\alpha\beta}(\mathbf{R}) = (N_R + iN_I) V_{\alpha\beta}(\mathbf{R})$

$$\Delta U_{DPP}(\mathbf{R}) = (N_R + iN_I)^2 \sum_{\beta\neq\alpha} V_{\alpha\beta}(\mathbf{R}) \int G_\beta^{(+)}(\mathbf{R},\mathbf{R}') V_{\beta\alpha}(\mathbf{R}') \chi_\alpha(\mathbf{R}') d\mathbf{R}' / \chi_\alpha(\mathbf{R})$$

$$\Delta U_{DPP}(\mathbf{R}) = (N_R + iN_I)^2 \sum_{\beta\neq\alpha} V_{\alpha\beta}(\mathbf{R}) \int G_\beta^{(+)}(\mathbf{R},\mathbf{R}') V_{\beta\alpha}(\mathbf{R}') \chi_\alpha(\mathbf{R}') d\mathbf{R}' / \chi_\alpha(\mathbf{R})$$

$$= (N_R + iN_I)^2 (\Delta u + i\Delta w)$$

$$= \underbrace{(N_R^2 - N_I^2)\Delta u - 2N_R N_I \Delta w}_{\text{Real part}} + i\underbrace{\left\{2N_R N_I \Delta u + (N_R^2 - N_I^2)\Delta w\right\}}_{\text{Imaginary part}}$$

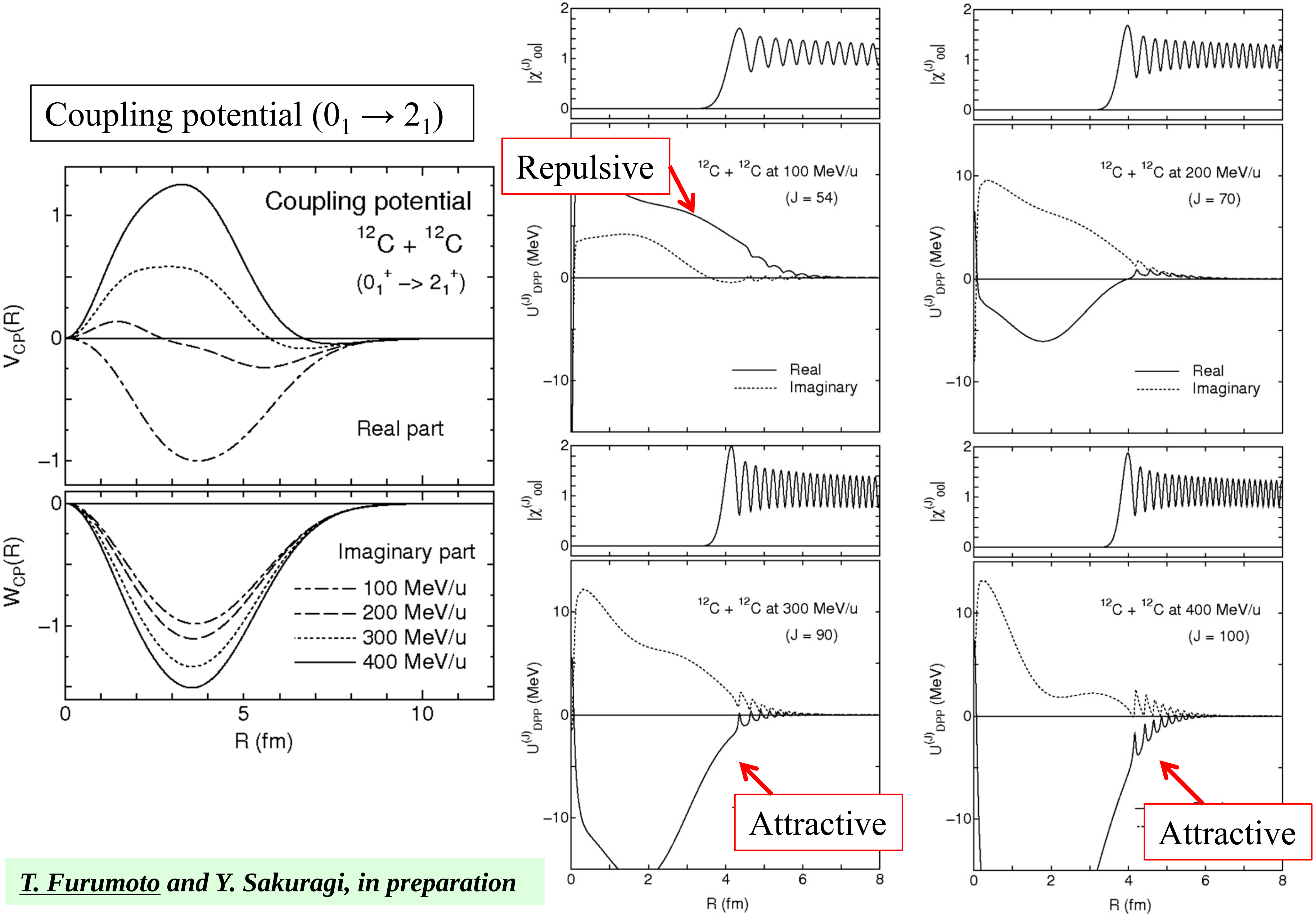
$$\Delta u + i\Delta w = \sum_{\beta\neq\alpha} V_{\alpha\beta}(\mathbf{R}) \int G_\beta^{(+)}(\mathbf{R},\mathbf{R}') V_{\beta\alpha}(\mathbf{R}') \chi_\alpha(\mathbf{R}') d\mathbf{R}' / \chi_\alpha(\mathbf{R})$$

$$\approx -\frac{ik}{8\pi E_{c.m.}} \sum_{\beta\neq\alpha} \sum_\lambda f_{\alpha\beta}^{(\lambda)}(R) \int_0^\infty dq q j_\lambda(qR) \int_0^\infty dx x^2 f_{\beta\alpha}^{(\lambda)}(x) j_\lambda(qx)$$

K.-I. Kubo and P.E.Hodgson, Nucl. Phys. A366 (1981) 320

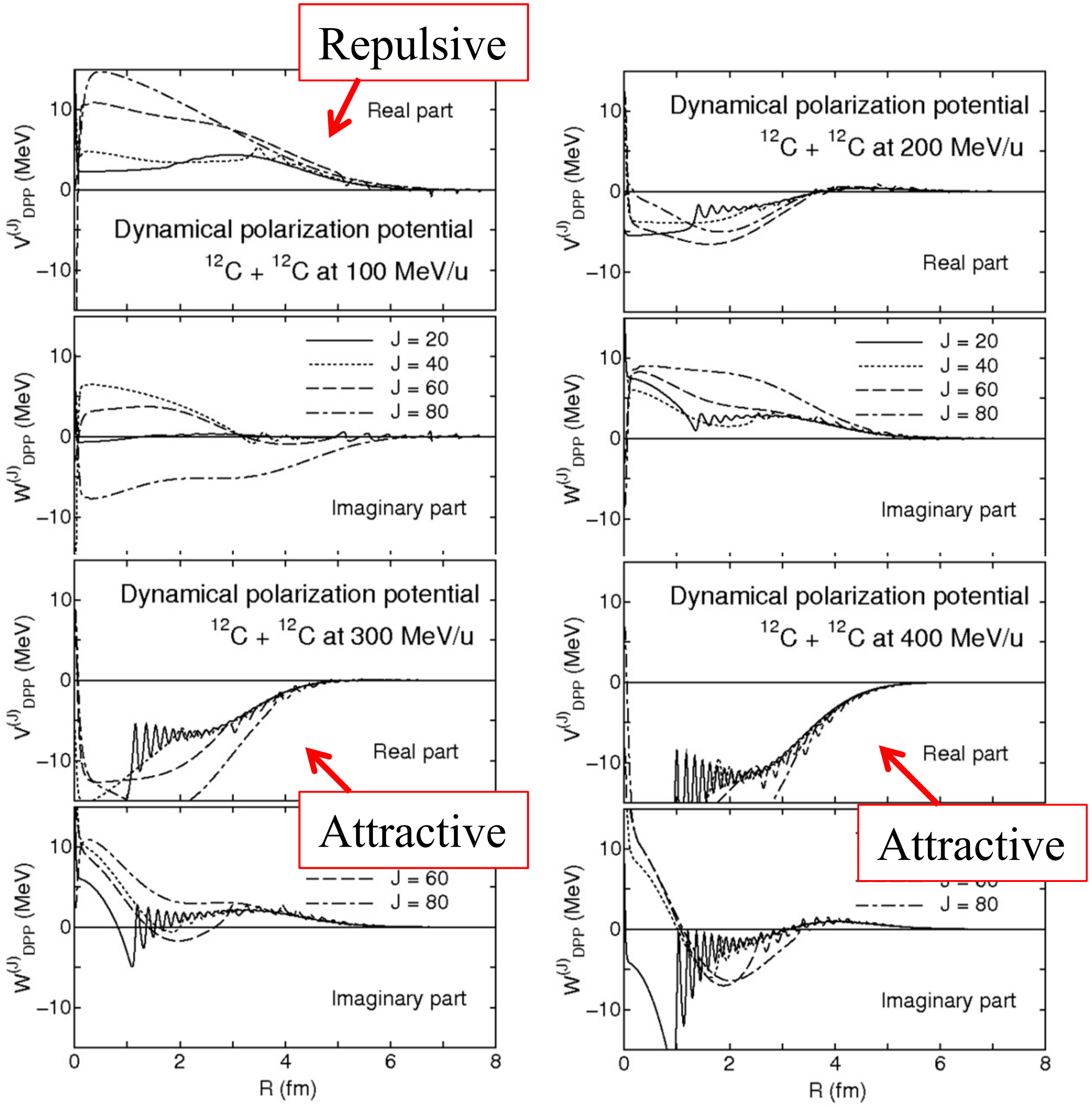
If $f_{\beta\alpha}^{(\lambda)}$ is real, $\left\{ \begin{array}{l} \Delta u = 0 \\ \Delta w < 0 \end{array} \right.$

Dynamical polarization potential (DPP)

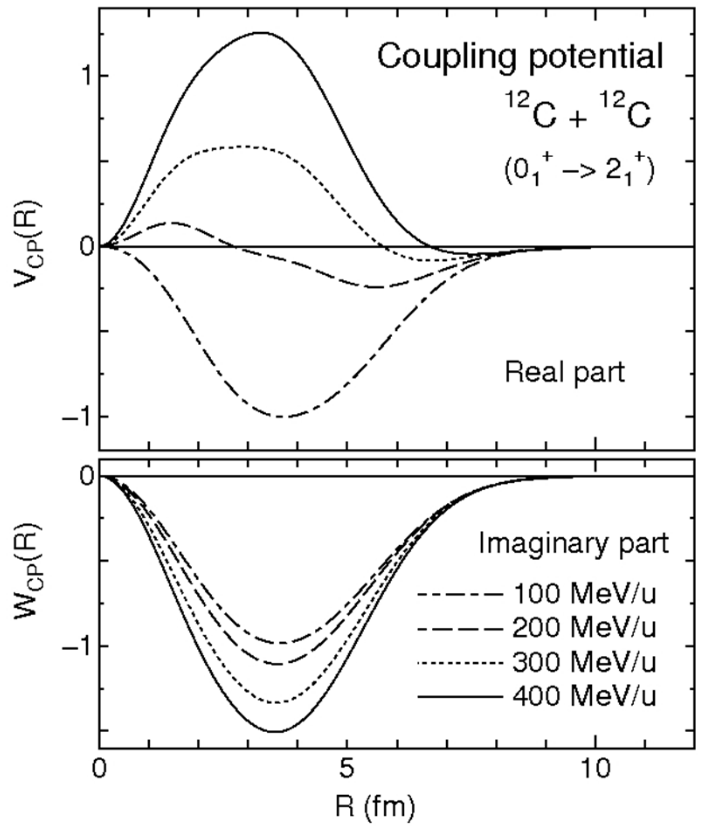


***T. Furumoto** and Y. Sakuragi, in preparation*

Dynamical polarization potential (DPP) for high-energy heavy-ion systems



Coupling potential ($0_1 \rightarrow 2_1$)



***T. Furumoto** and Y. Sakuragi, in preparation*

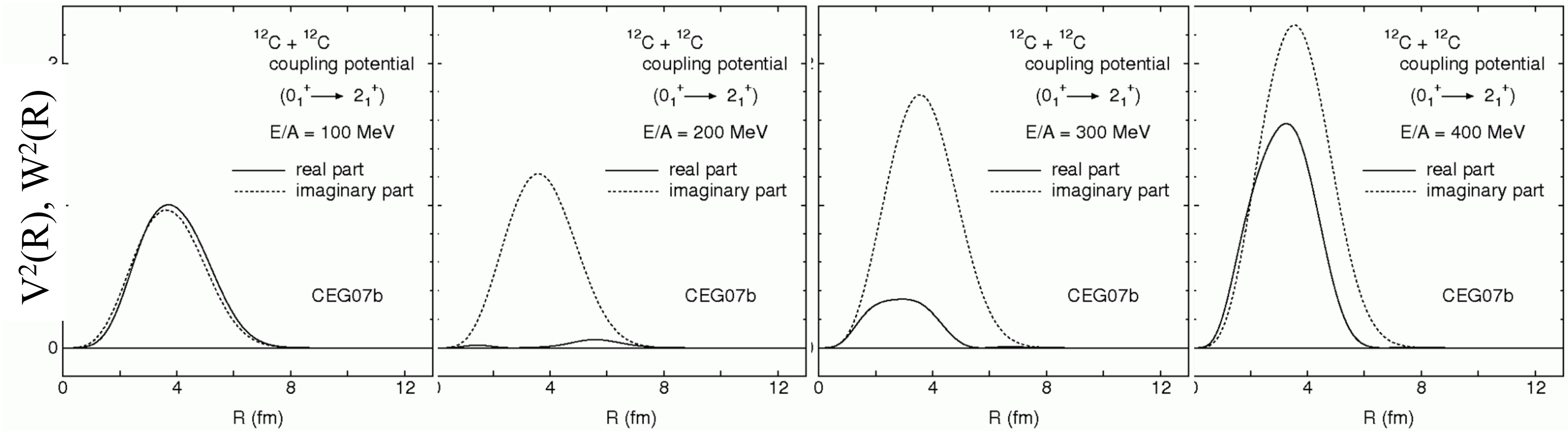
Role of imaginary part of coupling potential

- Complex coupling gives the large dynamical coupling effect.

- Coupling potential is derived as

$$U_{\alpha\beta}(\mathbf{R}) = \int \underbrace{\rho_{ik}^{(P)}(\mathbf{r}_1)\rho_{jl}^{(T)}(\mathbf{r}_2)}_{\text{transition density}} \underbrace{\boxed{v_{NN}(\mathbf{s};\rho,E)}}_{\text{CEG07}} d\mathbf{r}_1 d\mathbf{r}_2$$

At high energies, the imaginary part of coupling potential becomes larger than the real part



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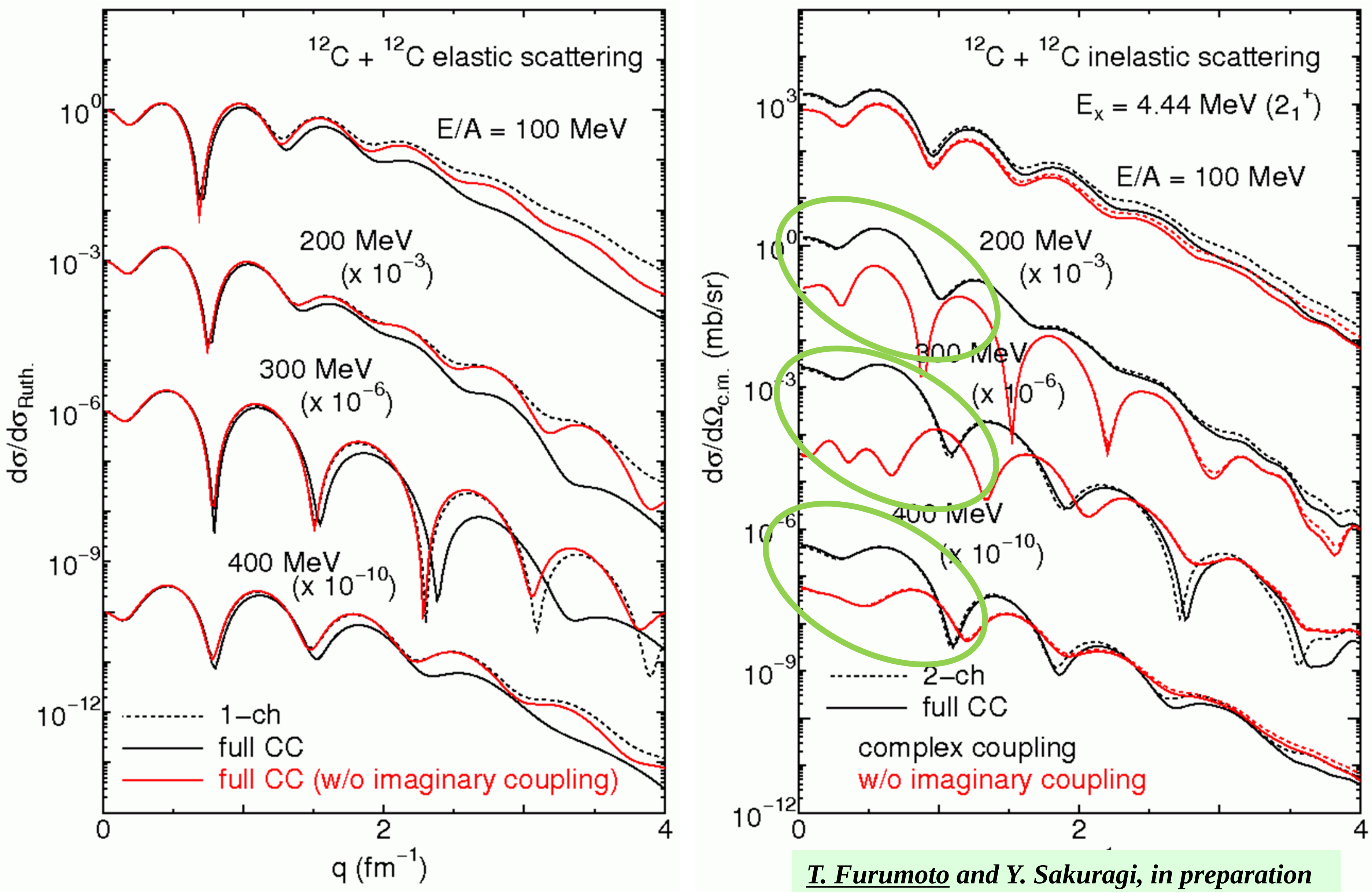
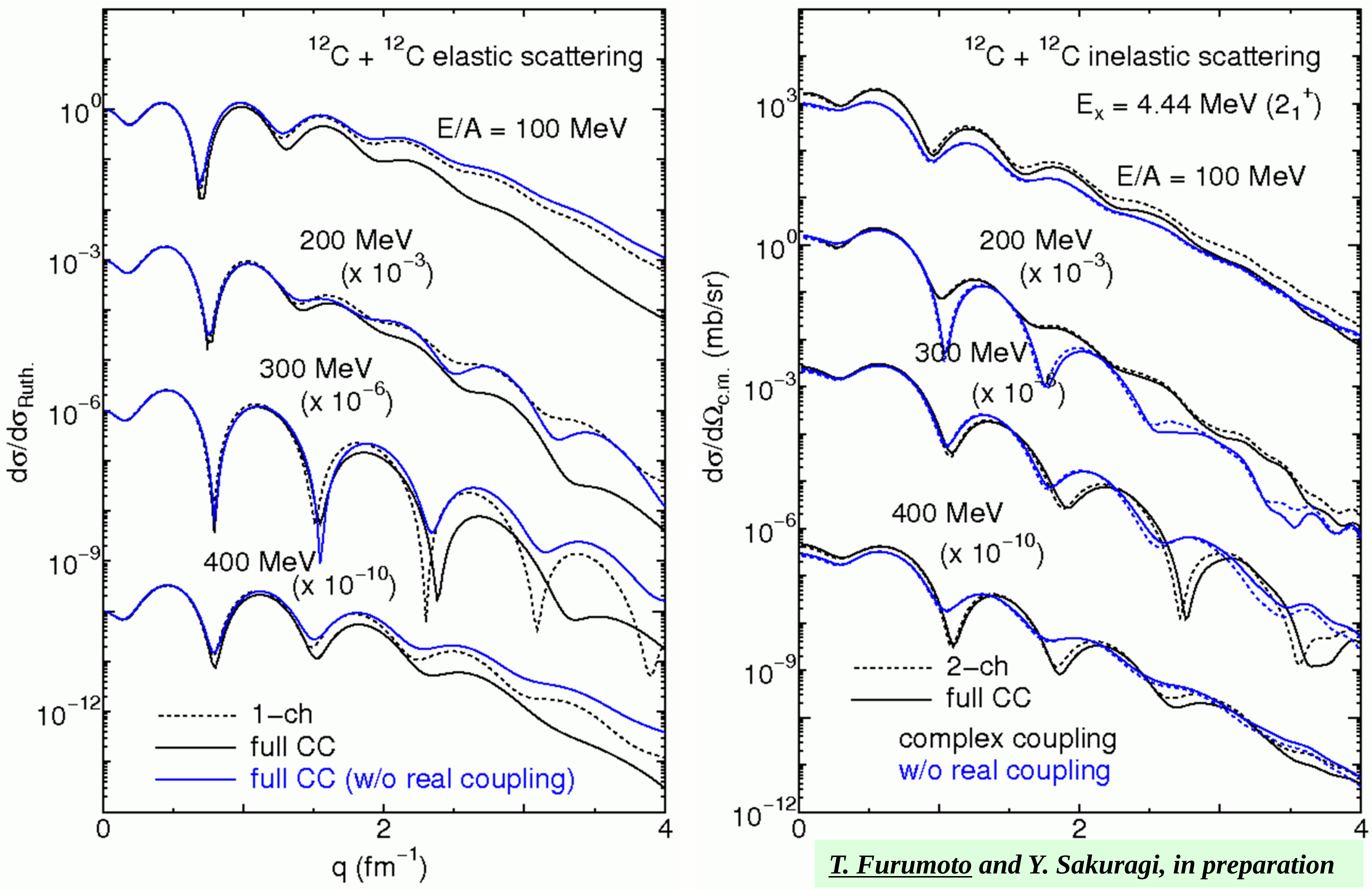
Effect of imaginary part of coupling potential



***T. Furumoto* and Y. Sakuragi, in preparation**

Effect of real part of coupling potential



<u>T. Furumoto</u> and Y. Sakuragi, in preparation

Summary

Dynamical coupling effect

- clearly seen in elastic scattering cross section, although the incident energy is high enough.

Dynamical polarization potential

- becomes from repulsive to attractive in energy evolution.
- due to the energy dependence of the coupling potential.

Role of imaginary part of coupling potential

- the imaginary part plays dominant role to inelastic scattering in high energy region (200-400 MeV/u).
- the inelastic cross section give a hint to know the imaginary part of coupling potential.