Three-Body Model Analysis of Subbarrier α Transfer Reaction

T. Fukui[1], K. Ogata[2], M. Yahiro[1]

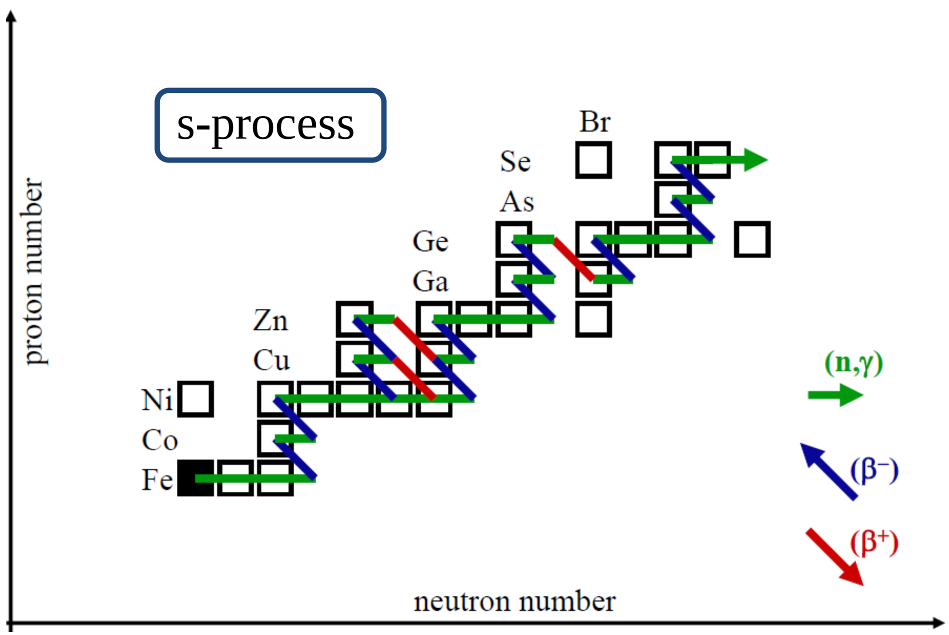
[1]*Kyushu University*
[2]*RCNP, Osaka University*

KYUSHU UNIVERSITY

24/Oct./2011

Introduction

Reaction rate of $^{13}C(\alpha,n)^{16}O$



from *Los Alamos National Laboratory*

$^{13}C(\alpha,n)^{16}O$

The main source of neutrons for the *s*-process in the AGB.

The astrophysical *S* factor of $^{13}C(\alpha,n)^{16}O$ was calculated:

$$S(0) = (2.5 \pm 0.7) \times 10^{6}\ [\mathrm{MeV} - \mathrm{b}].$$ [1]

This is **10 times smaller** than NACRE compilation[2]
and **a factor of 5 larger** than the work of S. Kubono *et al*[3].

1: E. D. Johnson *et al*., PRL **97**, 102701 (2006).
2: C. Angulo *et al*., NPA **653**, 3 (1999).
3: S. Kubono *et al*., PRL **90** 062501 (2003).

Introduction

Indirect method

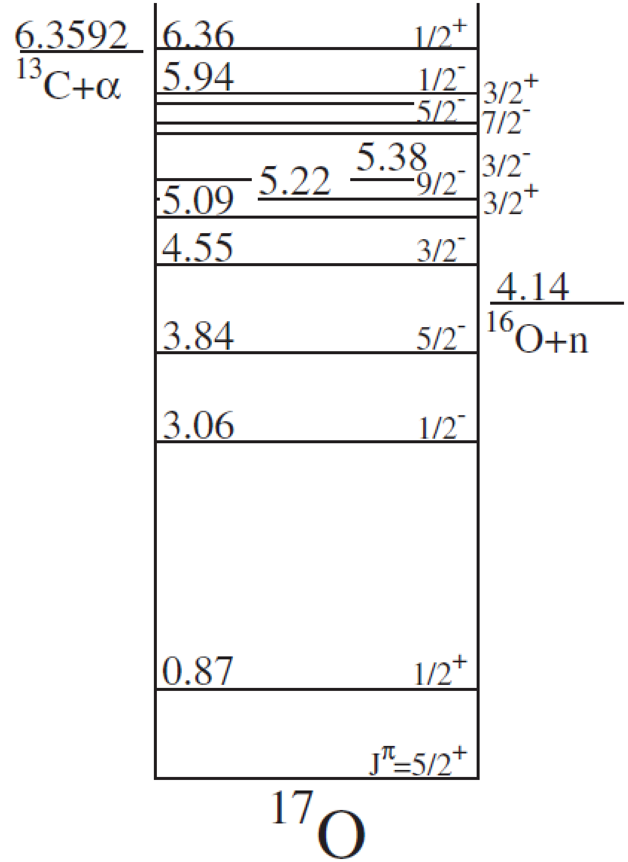
$$^{13}C(\alpha,n)^{16}O$$

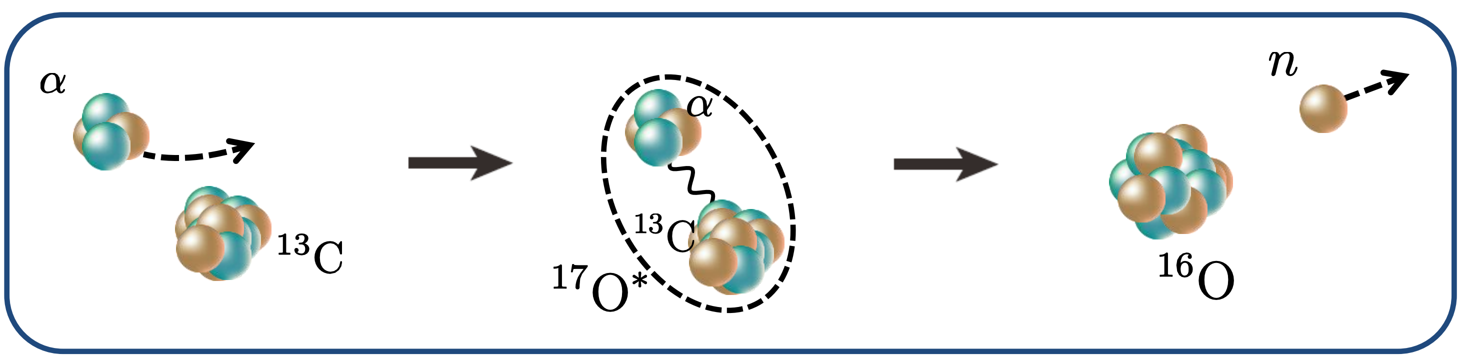
$$\alpha + {}^{13}C \rightarrow {}^{17}O^*$$

unknown

$$^{17}O^* \rightarrow {}^{16}O + n$$

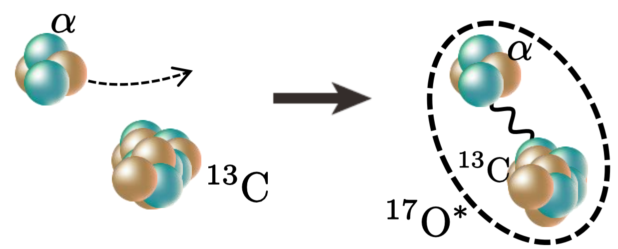
known





$\alpha + {}^{13}\mathrm{C} \longrightarrow {}^{17}\mathrm{O}^*$

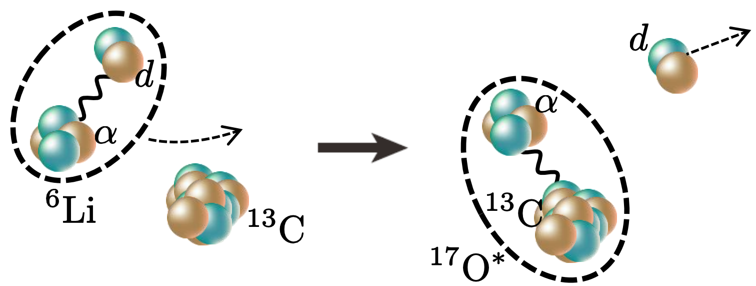
$$\sigma \propto \left| \left\langle I(\boldsymbol{r}) \left| \hat{V}(\boldsymbol{r}) \right| \psi_{\alpha\mathrm{C}}(\boldsymbol{r}) \right\rangle \right|^2$$



$$I(\boldsymbol{r}) \equiv \langle \phi_{\mathrm{O}}(\boldsymbol{r}, \xi_\alpha, \xi_{\mathrm{C}}) | \phi_\alpha(\xi_\alpha)\phi_{\mathrm{C}}(\xi_{\mathrm{C}}) \rangle ,$$

$$I(r) \xrightarrow{r \gg r_{\mathrm{N}}} \frac{CW(r)}{r}$$

Indirect



${}^{6}\mathrm{Li} + {}^{13}\mathrm{C} \longrightarrow {}^{17}\mathrm{O}^* + d\ (\mathrm{E_{in}} < \mathrm{V_{Coul}})$

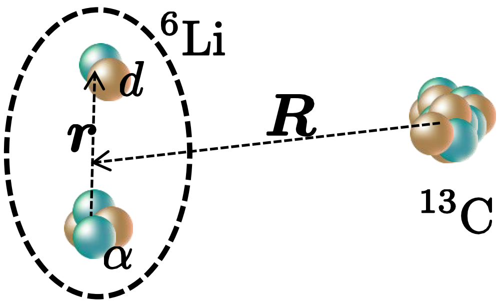
$$\sigma \propto \left| \left\langle I(\boldsymbol{r})\chi_{d\mathrm{O}}(\boldsymbol{R}_f) \left| \hat{V}_f(\boldsymbol{r}, \boldsymbol{R}_f) \right| \psi_{\alpha d}(\boldsymbol{r}_{\alpha d})\chi_{\mathrm{LiC}}(\boldsymbol{R}_i) \right\rangle \right|^2$$

Model CDCC (Continuum Discretized Coupled Channels) method

3-body Schrödinger eq.

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

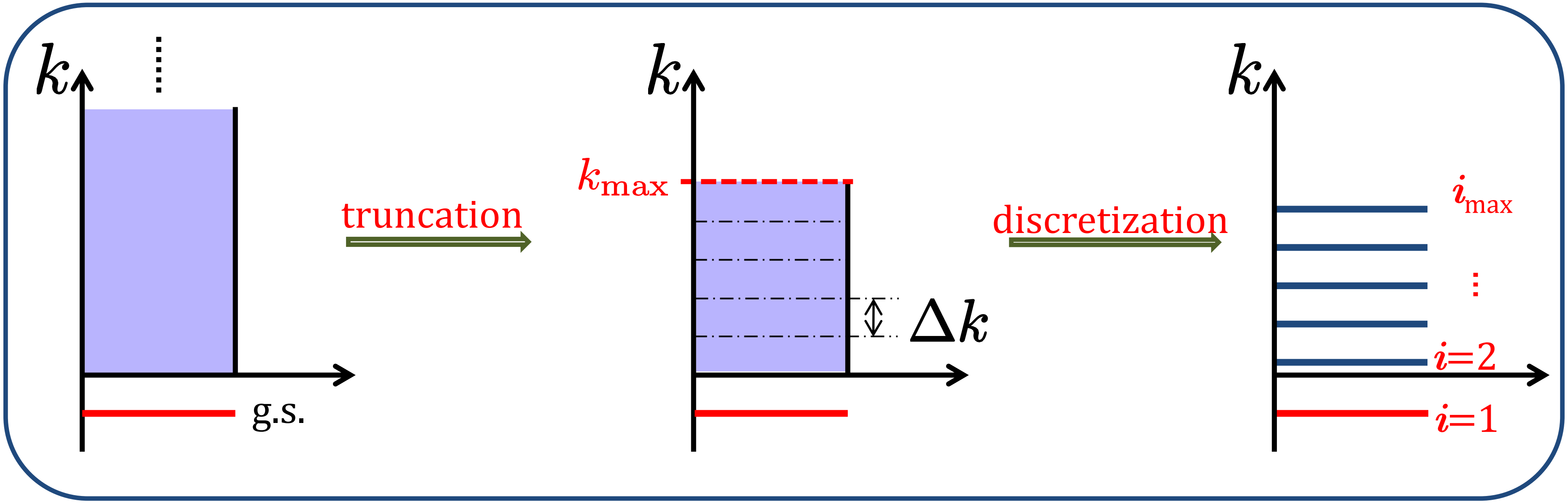
$$H_{3b} = T_r + V_{\alpha d} + T_R + U_{d\mathrm{C}} + U_{\alpha \mathrm{C}}$$



CDCC wave function

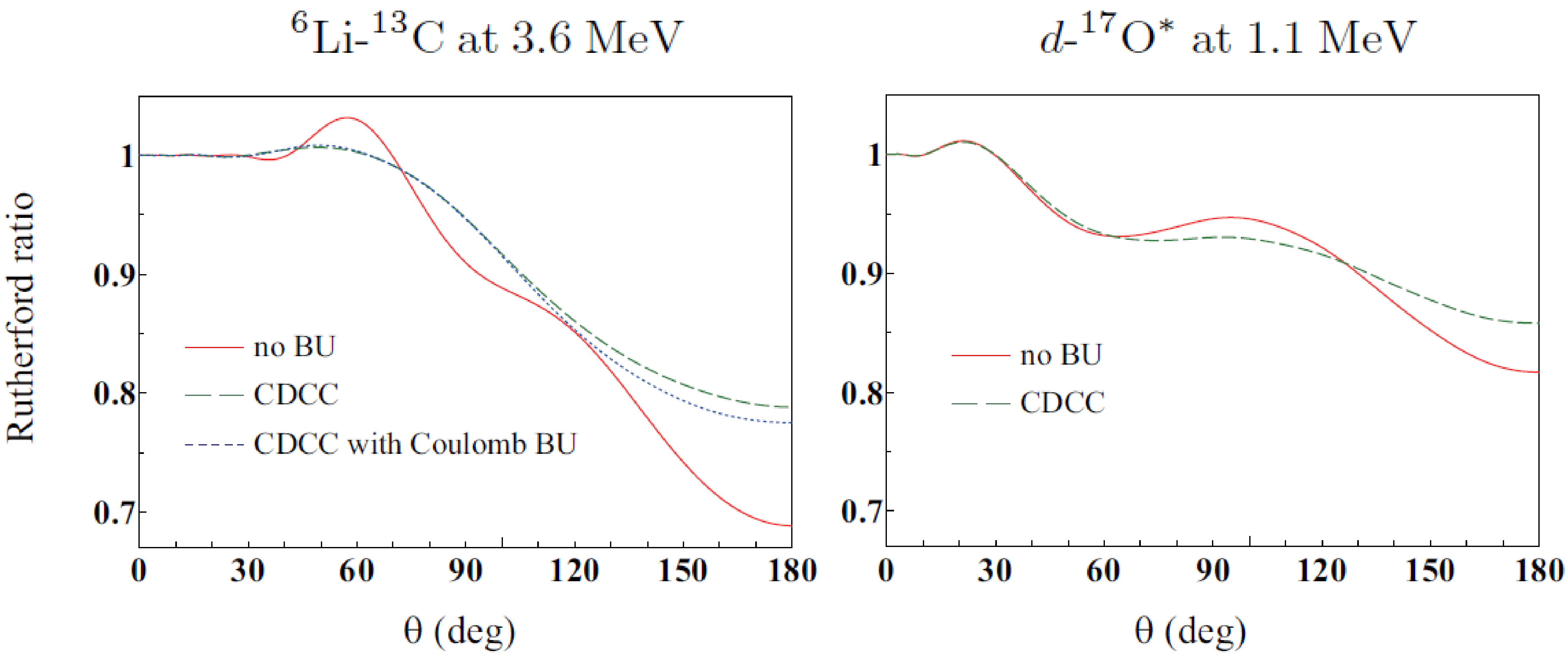
$$\Psi(\boldsymbol{r}, \boldsymbol{R}) = \phi_0(\boldsymbol{r})\chi_0(\boldsymbol{R}) + \int_0^{\infty} \phi(k, \boldsymbol{r})\chi(k, \boldsymbol{R})dk$$

$$\rightarrow \quad \Psi^{\mathrm{CDCC}}(\boldsymbol{r}, \boldsymbol{R}) = \sum_{i}^{i_{\max}} \hat{\phi}_i(\boldsymbol{r})\hat{\chi}_i(\boldsymbol{R})$$



Result

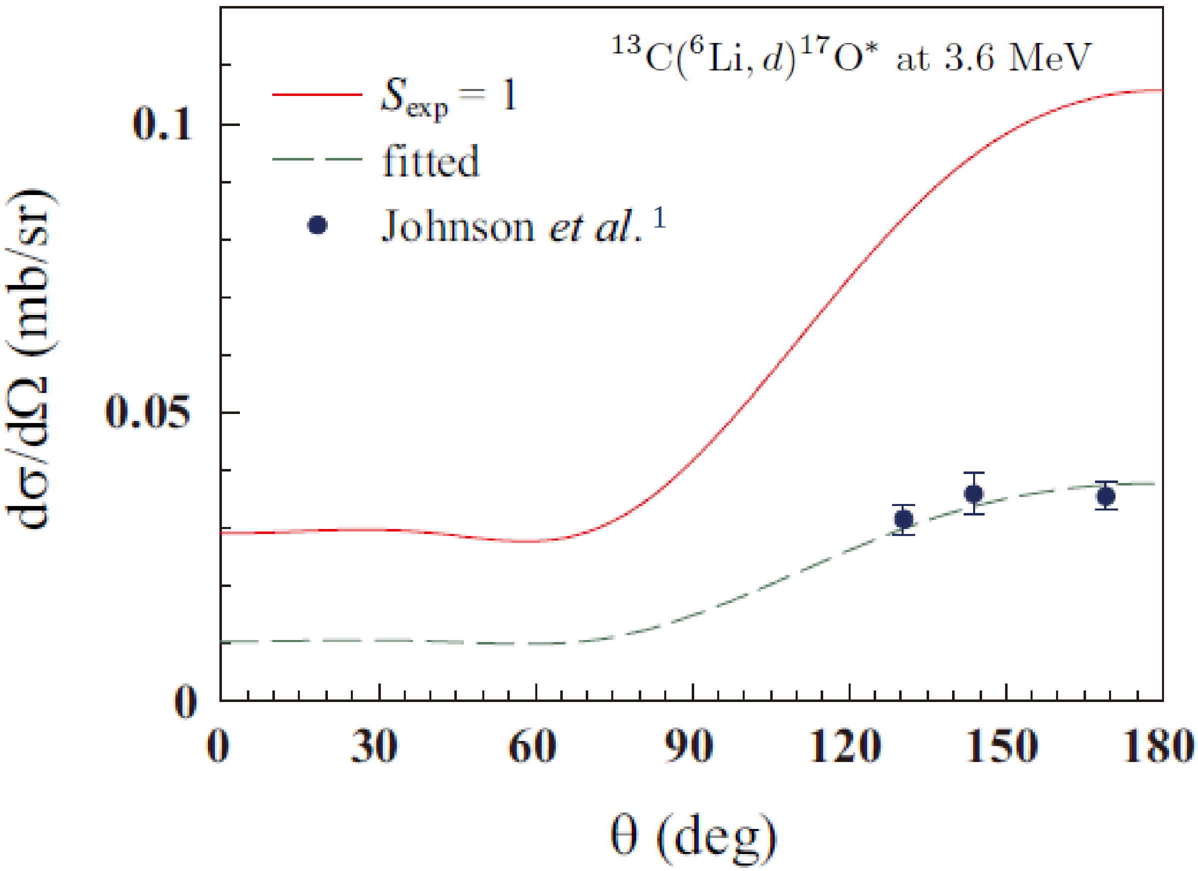
Elastic Cross Section



^{6}Li breakup is important.

^{17}O* breakup is negligible.

Transfer Cross Section & ANC



$$S_{exp} = 0.357$$
$$(C_{sp})^2 = 2.89\ \mathrm{fm}^{-1}$$
$$(C^2 = S_{exp}(C_{sp})^2)$$

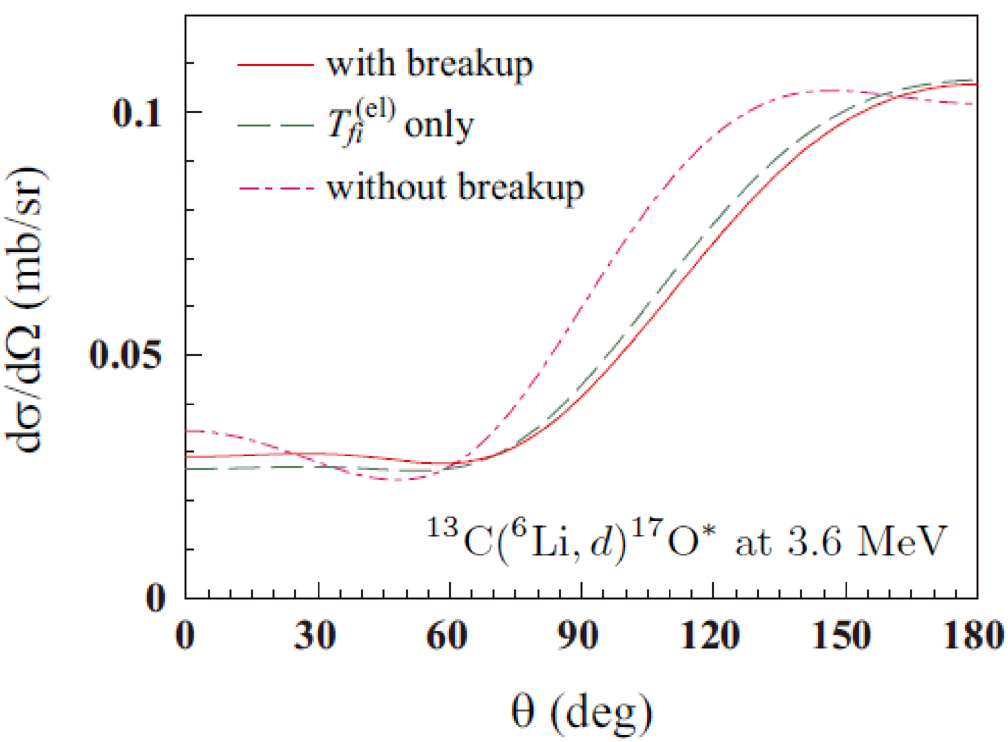
$$\text{ANC:}\ (C^{^{17}O^*}_{\alpha\,^{13}C})^2 = \begin{cases} 1.03 \pm 0.29\ \mathrm{fm}^{-1} & \text{(This work)} \\ 0.89 \pm 0.23\ \mathrm{fm}^{-1} & \text{(Previous work[1])} \end{cases}$$

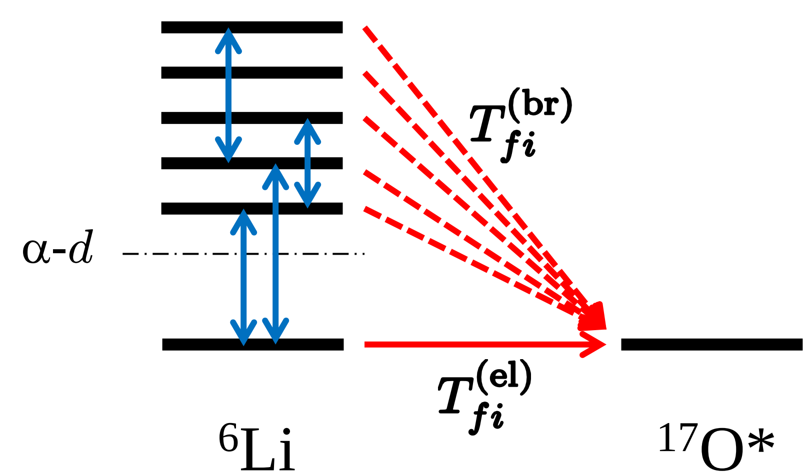
1: E. D. Johnson *et al.*, PRL **97**, 102701 (2006).

T-matrix

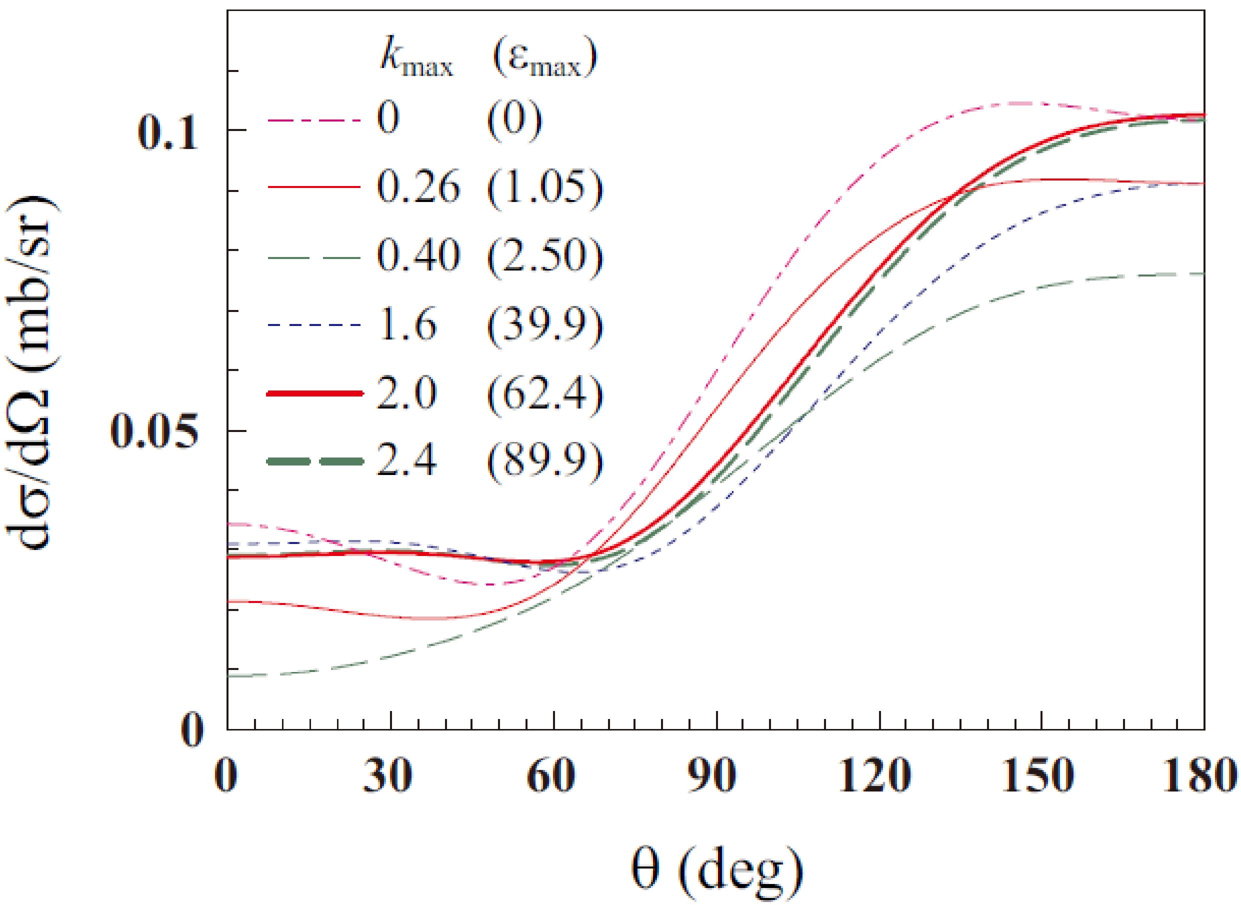
$$T_{fi} = T_{fi}^{(\mathrm{el})} + T_{fi}^{(\mathrm{br})}$$

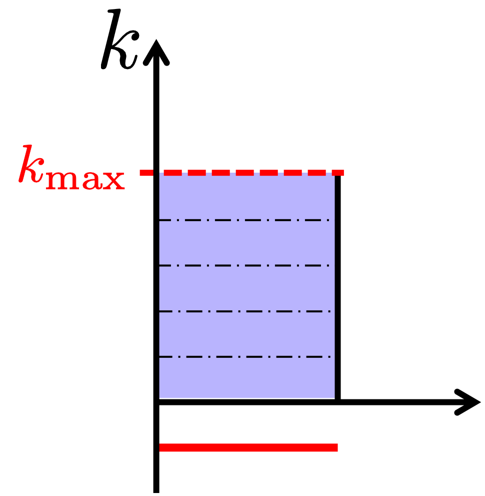
$$\left(\begin{aligned} T_{fi}^{(\mathrm{el})} &= \left\langle \Psi_f^{(-)} \left| V_{\mathrm{tr}} \right| \Psi_{\mathrm{el}}^{(+)} \right\rangle \\ T_{fi}^{(\mathrm{br})} &= \left\langle \Psi_f^{(-)} \left| V_{\mathrm{tr}} \right| \Psi_{\mathrm{br}}^{(+)} \right\rangle \end{aligned} \right)$$





$^{13}C(^{6}Li, d)^{17}O^{*}$ at 3.6 MeV





Summary

$^{13}C(^{6}Li,d)^{17}O^{*}$ at 3.6 MeV is analyzed with CDCC in order to determine the reaction rate of $^{13}C(\alpha,n)^{16}O$.

- ☝^{6}Li breakup is important for the subbarrier α transfer reaction, the back-coupling in particular.

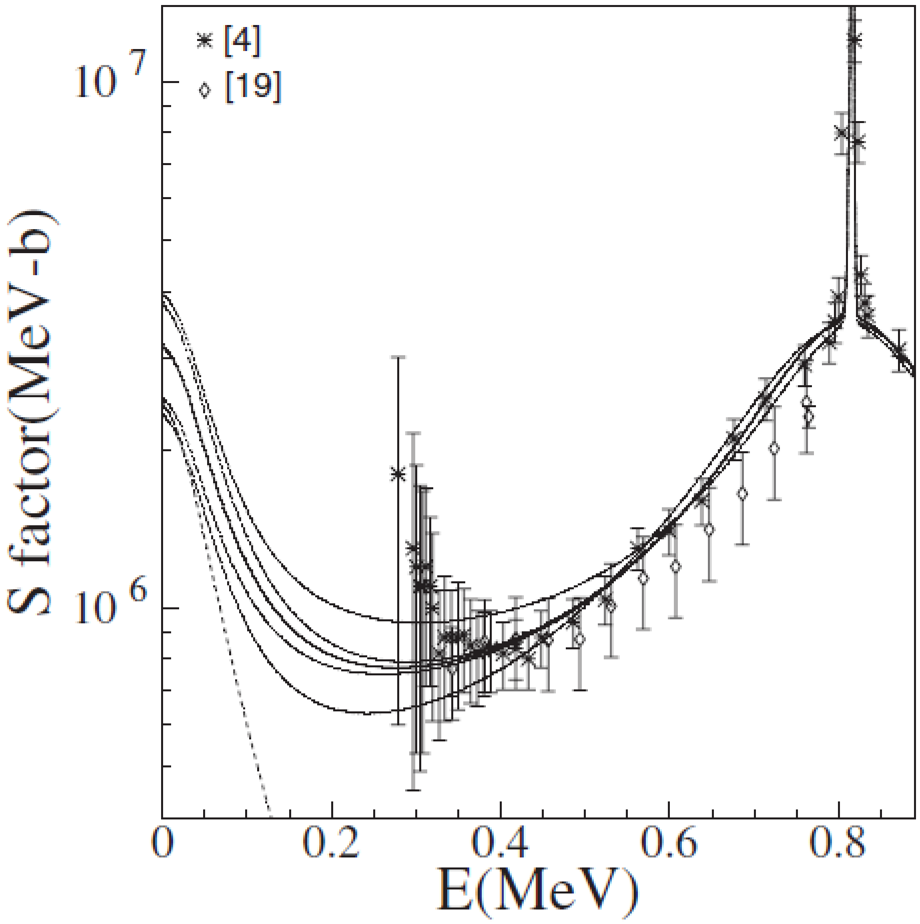
- ☝Our result is almost consistent with the previous result.

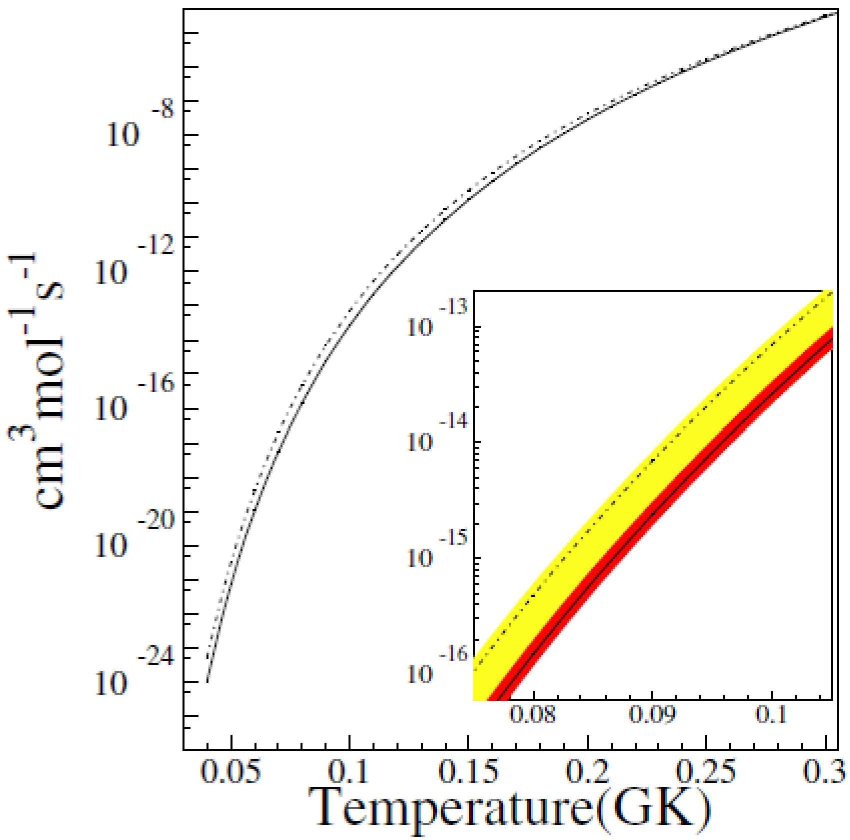
- ☝Other subbarrier α transfer reactions must be analyzed with CDCC in order to know the role of breakup channels.

$x + A \to b + B$ (through the subthreshold reso. F)

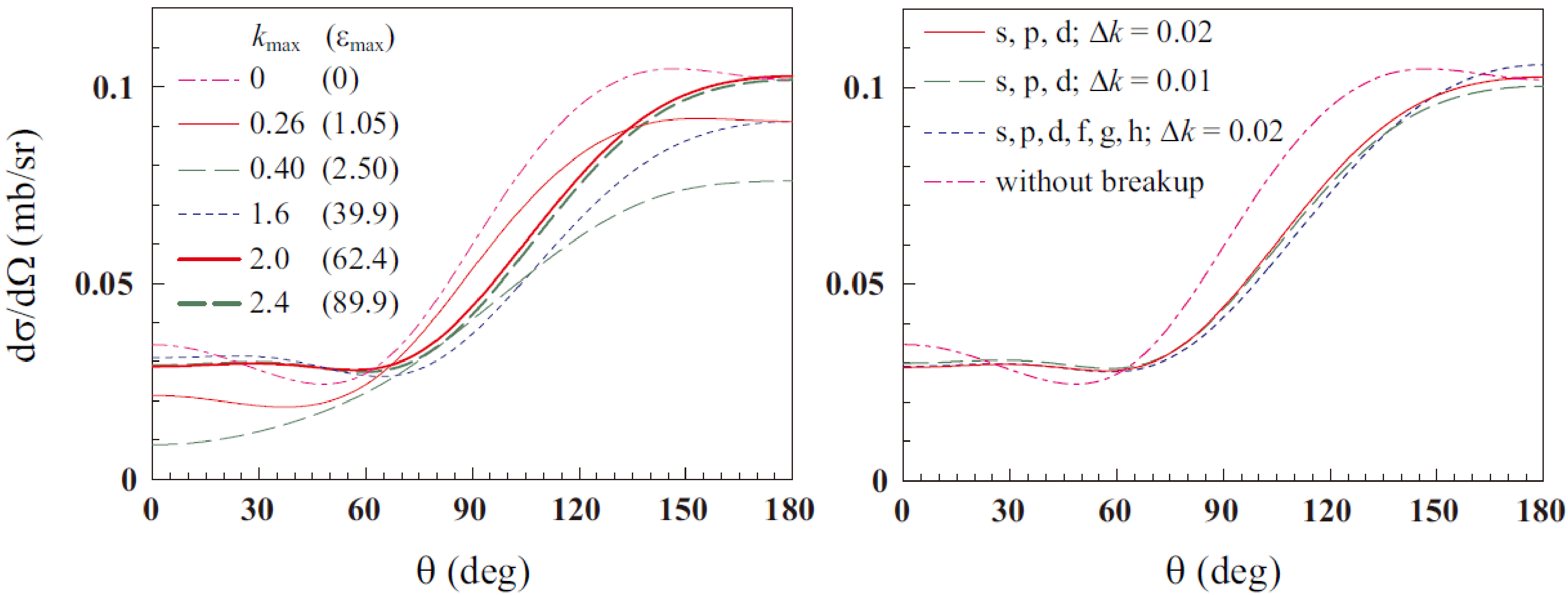
$$M = \frac{1}{2\sqrt{k_{xA}k_{bB}}}\sqrt{\frac{P_l(k_{xA}, r_0)}{\mu_{xA}r_0}}\tilde{W}_{-\eta,l+1/2}(2\kappa r_0)$$
$$\times \frac{\tilde{C}^F_{xA}\Gamma^{1/2}_{bB}(E_{bB}, r_0)}{E_{xA} + \varepsilon + i\Gamma_F(E_{bB}, r_0)/2}\exp(i\delta)$$

S factor & Reaction Rate

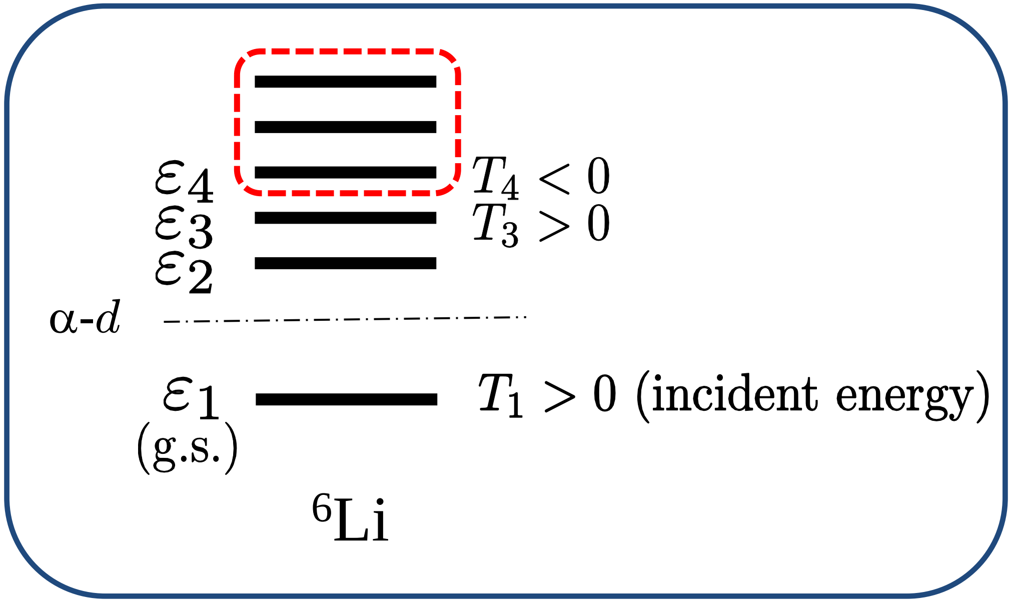




$^{13}C(^{6}Li, d)^{17}O^{*}$ at 3.6 MeV



Closed channel



$$\varepsilon_i + T_i = E(const.)$$

ε_i: internal energy
T_i: kinetic energy
E: total energy