Direct reaction studies with microscopic inputs for many-nucleon systems

… the number of the degrees of freedom excited is very small. … even in the transition between collective states, in which infinite number of transition processes are involved, only a few collective states participate.

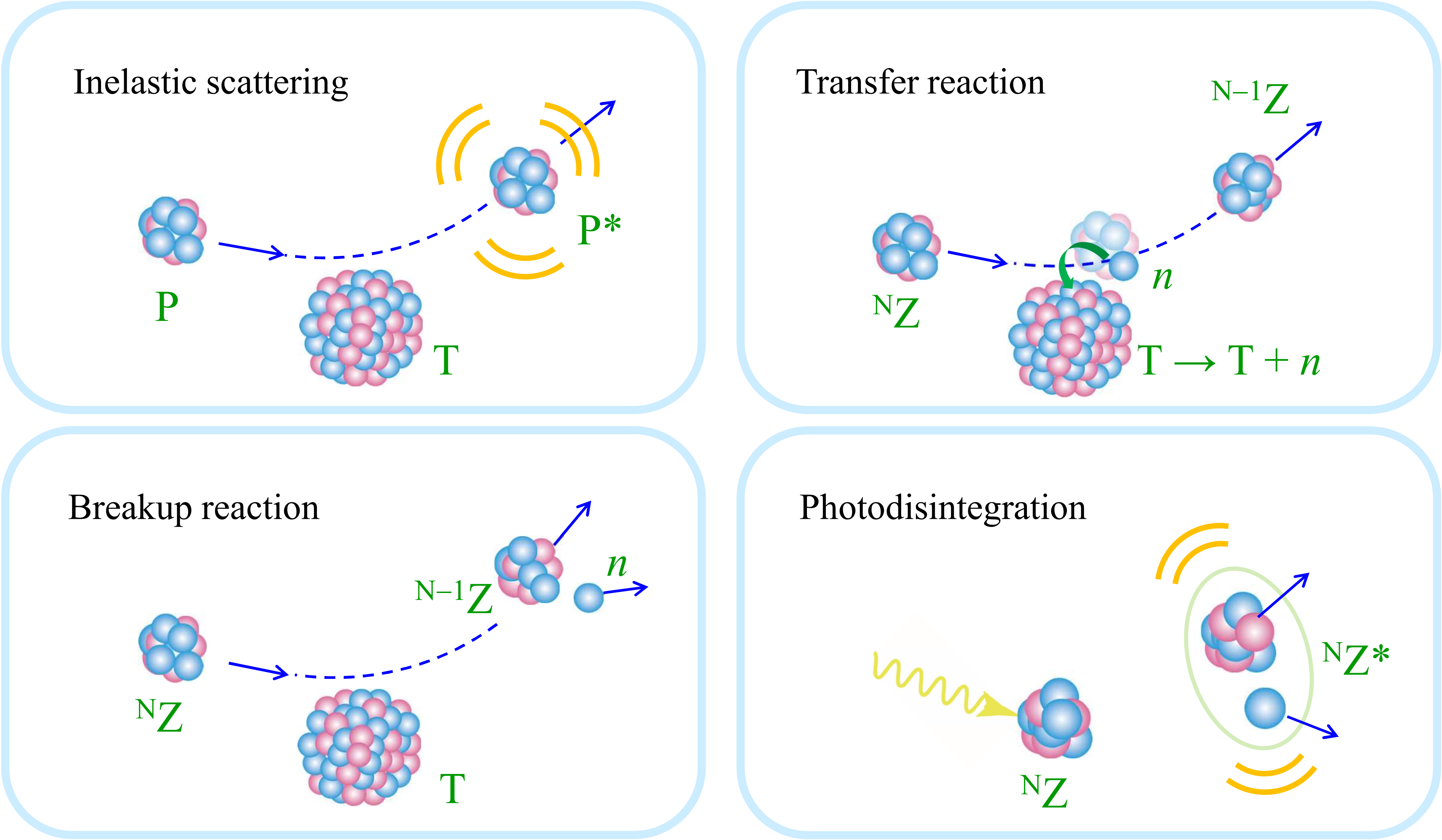
M. Kawai and S. Yoshida, "Nuclear Reaction Theories" (Asakura) p. 149 (Translated by KO).

Kazuyuki Ogata

Kyushu University

Microscopic, but not *ab initio*

Various nuclear reaction processes



What to do?

The probability of a reaction process is given by the absolute square of the transition matrix.

$$T_{\beta\alpha} = \left\langle \Phi_\beta^{\rm free} \left| V_\beta \right| \Psi_\alpha \right\rangle$$

$\Phi_\beta^{\rm free}$: Internal W.Fns. of the constituents and their free relative W.Fns.

V_β : Interactions between the constituents

Ψ_α : Exact W.Fn. of the system in the initial ($\neq$ incident) channel

Key: simplification of Ψ_α with keeping a microscopic picture

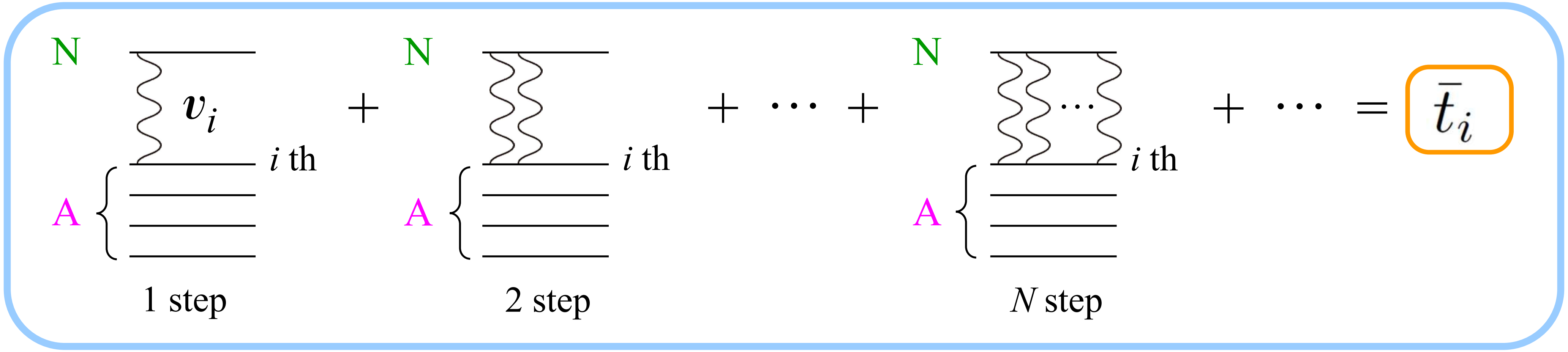
→ Multiple Scattering Theory (MST)

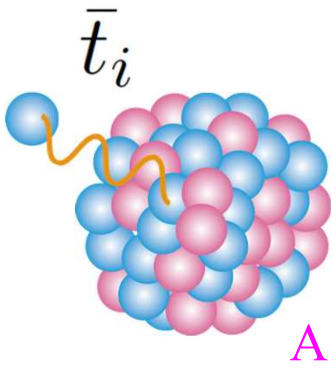
MST

Microscopic description of optical potentials

TABLE I. Optical-Model Parameters Neutrons

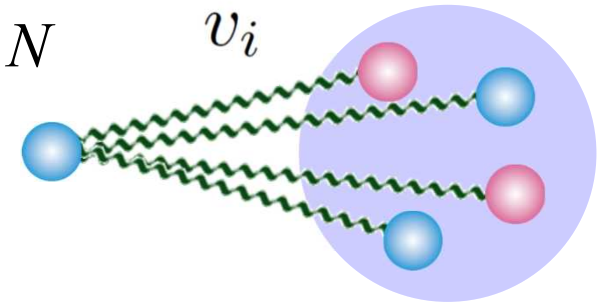
NUCLIDE	ENERGY	REAL POTENTIAL			VOL.IMAG. POTENTIAL			SURF.IMAG. POTENTIAL			SPIN-ORBIT POTENTIAL			ST	SR	FIT	NOTE	REF.
	(MEV)	V	R	A	W	RW	AW	WD	RD	AD	VSO	RSO	ASO					
AL	1.	40.	1.25*	0.65*				5.0G*	1.25*	0.98*	10.*	1.25*	0.65*	3520	1340	S3	15	GIL63
AL	1.5	47.4	1.25*	0.46				6.3G	1.25*	0.98*	10.*	1.25*	0.46	3204		S1	10	KOR68
AL	2.47	48.0	1.14	0.65				8.42	1.19	0.48*	8.0*	1.14	0.65	2530	1270	S2	2	HOL71
AL	3.00	47.9	1.13	0.72				7.35	1.08	0.48*	8.0*	1.13	0.72	2520	1250	S2	2	HOL71
AL	3.49	48.7	1.18	0.61				8.46	1.29	0.48*	8.0*	1.18	0.61	2360	1130	S1	2	HOL71
AL	4.00	49.1	1.20	0.62				7.99	1.26	0.48*	8.0*	1.20	0.62	2290	1090	S2	2	HOL71
AL	4.56	50.2	1.18	0.59				8.38	1.26	0.48*	8.0*	1.18	0.59	2060	1020	S1	2	HOL71
AL	6.09	47.8	1.20	0.67				8.23	1.23	0.48*	8.0*	1.20	0.67	1880	1070	S3	2	HOL71
AL	7.	45.5	1.25*	0.65*				9.5G	1.25*	0.98*	8.6	1.25*	0.65*			X3		BJO58
AL	7.05	49.1	1.20	0.68				7.90	1.20	0.48*	8.0*	1.20	0.68	1800	1040	S2	2	HOL71
AL	7.97	49.4	1.20	0.69				12.1	1.30	0.41	9.8	1.20	0.69			S1	2	BRA72





A. K. Kerman, H. McManus, and R. M. Thaler, Ann. Phys. (NY) **8**, 551 (1959).

MST description of nucleon-nucleus (NA) scattering



Difficult to handle

$$T = \sum_i v_i + \sum_i v_i G_0^{(+)} \sum_j v_j + \sum_i v_i G_0^{(+)} \sum_j v_j G_0^{(+)} \sum_k v_k + \ldots = \sum_i \Lambda_i$$

"free" propagator

Kinetic energy Op.

Hamiltoniam of A

$$G_0^{(+)} = \frac{1}{E - (T_{\mathrm{NA}} + H_{\mathrm{A}}) + i\eta}$$

Resummation (1/3)

$$\Lambda_i \equiv v_i + v_i G_0^{(+)} \sum_j v_j + v_i G_0^{(+)} \sum_j v_j G_0^{(+)} \sum_k v_k + \ldots$$

$$\Lambda_i = v_i + v_i G_0^{(+)} v_i + v_i G_0^{(+)} v_i G_0^{(+)} \sum_k v_k + \ldots$$

$$+ v_i G_0^{(+)} \sum_{j \neq i} v_j + v_i G_0^{(+)} \sum_{j \neq i} v_j G_0^{(+)} \sum_k v_k + \ldots$$

$$= v_i + v_i G_0^{(+)} \left(v_i + v_i G_0^{(+)} \sum_k v_k + \ldots \right)$$

$$+ v_i G_0^{(+)} \sum_{j \neq i} \left(v_j + v_j G_0^{(+)} \sum_k v_k + \ldots \right)$$

N interacts last with i

$$\Lambda_i = v_i + v_i G_0^{(+)} \Lambda_i + v_i G_0^{(+)} \sum_{j \neq i} \Lambda_j$$

N interacts last with $j \neq i$

Resummation (2/3)

$$\Lambda_i = v_i + v_i G_0^{(+)} \Lambda_i + v_i G_0^{(+)} \sum_{j \neq i} \Lambda_j$$

$$\Lambda_i = \frac{1}{1 - v_i G_0^{(+)}} v_i + \frac{1}{1 - v_i G_0^{(+)}} v_i G_0^{(+)} \sum_{j \neq i} \Lambda_j$$

$$\left(t_i = v_i + v_i G_0^{(+)} t_i \right) \qquad t_i \equiv \frac{1}{1 - v_i G_0^{(+)}} v_i \quad \Rightarrow \quad \Lambda_i = t_i + t_i G_0^{(+)} \sum_{j \neq i} \Lambda_j$$

T-matrix in terms of an effective interaction

$$T = \sum_i t_i + \sum_i t_i G_0^{(+)} \sum_{j \neq i} t_j + \sum_i t_i G_0^{(+)} \sum_{j \neq i} t_j G_0^{(+)} \sum_{k \neq j} t_k + \ldots$$

Resummation (3/3)

If the A-body W.Fn. is antisymmetrized, the label i has no specific meaning:

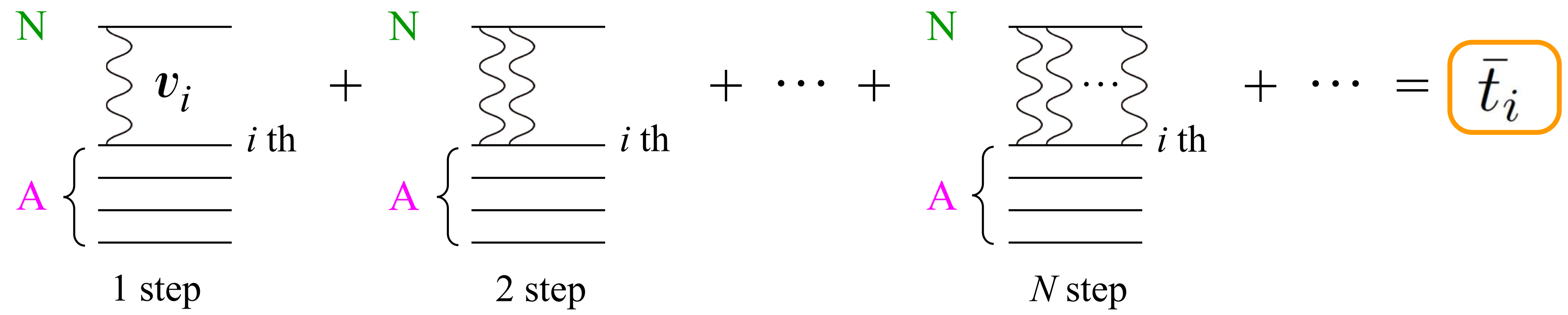
$$\sum_{j \neq i} t_j \to \frac{A-1}{A} \sum_j t_j \equiv \sum_j \bar{t}_j$$

$$T = \frac{A}{A-1} \bar{T}$$

$$\bar{T} \equiv \sum_i \bar{t}_i + \sum_i \bar{t}_i G_0^{(+)} \sum_j \bar{t}_j + \sum_i \bar{t}_i G_0^{(+)} \sum_j \bar{t}_j G_0^{(+)} \sum_k \bar{t}_k + \dots$$

One can use an effective interaction instead of the bare *NN* interaction.

Multiple Scattering Theory (MST)



$$\left(T_{\mathrm{NA}} + \sum_i v_i + H_{\mathrm{A}} - E\right)\Psi = 0 \quad \xrightarrow{\textit{Resummation}} \quad \left(T_{\mathrm{NA}} + \sum_i \bar{t}_i + H_{\mathrm{A}} - E\right)\bar{\Psi} = 0$$

Note: we have restricted the b.c.

$$T = \sum_i v_i + \sum_i v_i G_0^{(+)} \sum_j v_j + \ldots$$

$$\bar{t}_i = \frac{A-1}{A} t_i, \quad t_i = v_i + v_i G_0^{(+)} t_i$$

L. L. Foldy, Phys. Rev. **67**, 107 (1945); K. M. Watson, Phys. Rev. **89**, 115 (1953).
A. K. Kerman, H. McManus, and R. M. Thaler, Ann. Phys. (NY) **8**, 551 (1959).
M. Yahiro, K. Minomo, KO, and M. Kawai, PTP **120**, 767 (2008).

Impulse approximation to t

$$t_i = v_i + v_i \frac{1}{E - (T_{\rm NA} + H_{\rm A}) + i\eta} t_i$$

$$t_i = v_i + v_i \frac{1}{\boxed{E} - T_{\rm NA} - T_{i\rm A} \boxed{- H_{\rm B} - V_{i\rm B}} + i\eta} t_i$$

$$\approx E'$$

$$\boxed{t_i^{\rm IA} = v_i + v_i \frac{1}{E' - T_{\rm NA} - T_{i\rm A} + i\eta} t_i^{\rm IA}}$$

At high energies, the effect from the nucleons except the interacting one may be disregarded.

g matrix approximation to t

NN interaction is obtained by solving the Bethe-Goldstone Eq. assuming infinite nuclear matter of density ρ:

Pauli's Op.

$$g\left(\boldsymbol{q}',\boldsymbol{q};\boldsymbol{K}\right)=v\left(\boldsymbol{q}',\boldsymbol{q}\right)+\int d\boldsymbol{k}'\,v\left(\boldsymbol{q}',\boldsymbol{k}'\right)\frac{Q\left(\boldsymbol{k}',\boldsymbol{K};k_{\mathrm{F}}\right)}{E\left(\boldsymbol{k}_0,\boldsymbol{K}\right)-E\left(\boldsymbol{k}',\boldsymbol{K}\right)}g\left(\boldsymbol{k}',\boldsymbol{q};\boldsymbol{K}\right),$$

$$E\left(\boldsymbol{k}_0,\boldsymbol{K}\right)-E\left(\boldsymbol{k}',\boldsymbol{K}\right)=\frac{\hbar^2}{m}\left(k_0^2-k'^2\right)$$

$$+U\left(|\boldsymbol{k}_0+\boldsymbol{K}|\right)+U\left(|\boldsymbol{k}_0-\boldsymbol{K}|\right)-U\left(\left|\boldsymbol{k}'+\boldsymbol{K}\right|\right)-U\left(\left|\boldsymbol{k}'-\boldsymbol{K}\right|\right).$$

Auxiliary pot.

Elastic scattering

Microscopic optical potential with MST

$$\left[T_{\mathrm{NA}} + U^{\mathrm{dr}}(R) + U^{\mathrm{ex}}(R) - E_{\mathrm{cm}}\right] \chi(\boldsymbol{R}) = 0$$

Direct term:

Nuclear one-body density

$$U^{\mathrm{dr}}(R) = \frac{A-1}{A} \int g^{\mathrm{dr}}\left(s, k_{\mathrm{F}}\left(|\boldsymbol{R}+\boldsymbol{s}/2|\right)\right) \rho\left(|\boldsymbol{R}+\boldsymbol{s}|\right) d\boldsymbol{s},$$

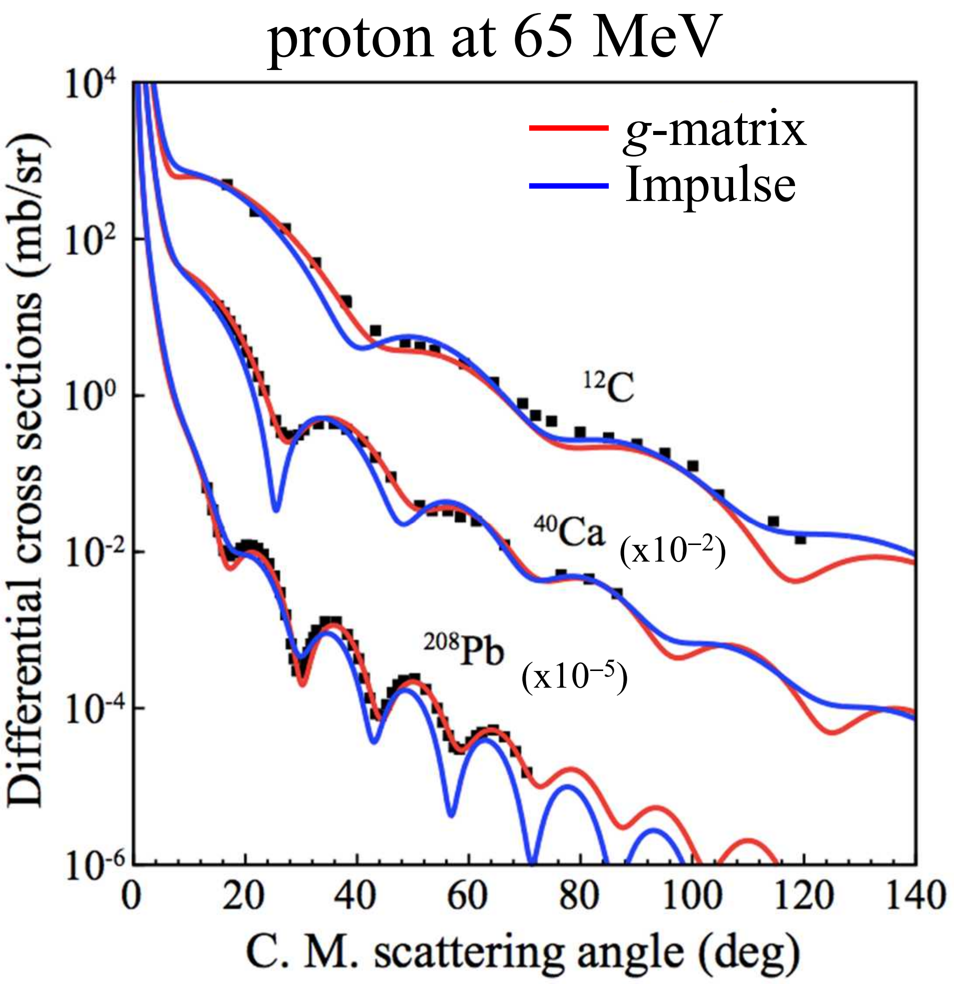
Knock-on exchange term with Brieva-Rook localization:

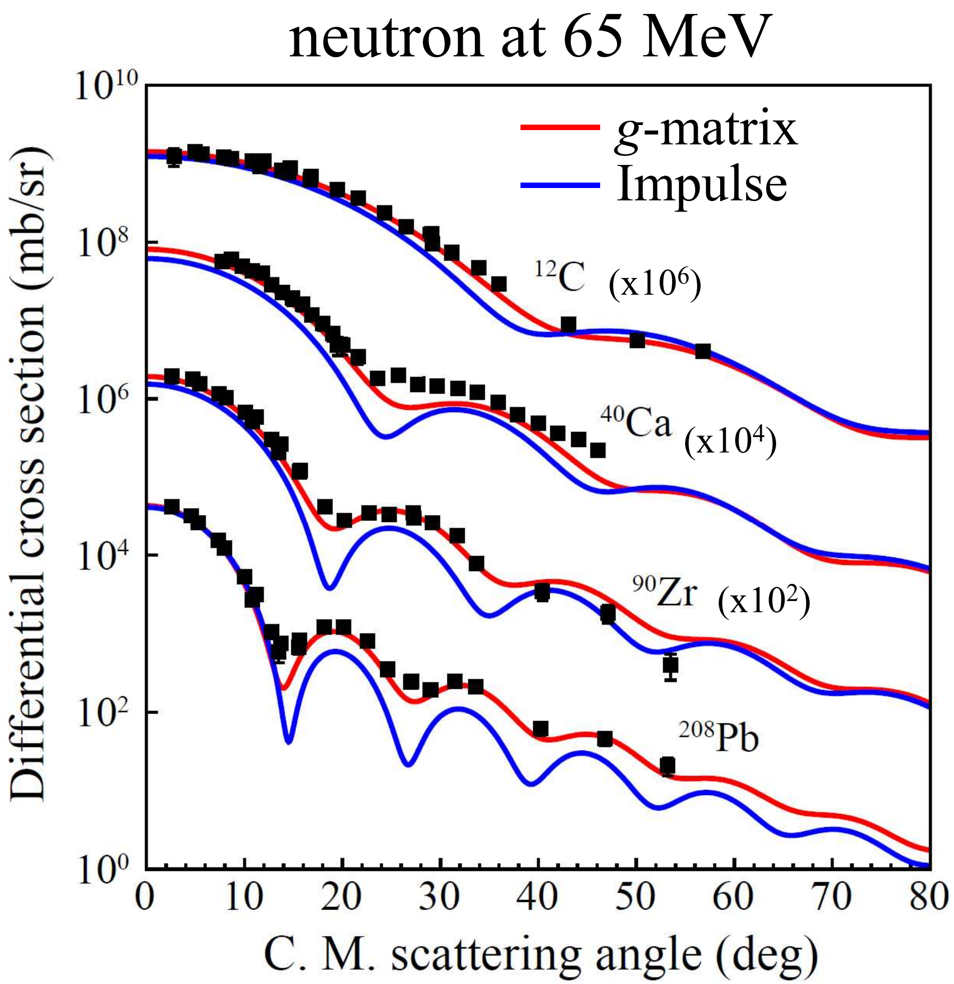
F. A. Brieva and J. R. Rook, Nucl. Phys. A 291, 317 (1977).

$$U^{\mathrm{ex}}(R) = \frac{A-1}{A} \int \frac{3 j_1\left(k_{\mathrm{F}}\left(|\boldsymbol{R}+\boldsymbol{s}/2|\right) s\right)}{k_{\mathrm{F}}\left(|\boldsymbol{R}+\boldsymbol{s}/2|\right) s} j_0\left(K(R)\, s\right)$$
$$\times\, g^{\mathrm{ex}}\left(s, k_{\mathrm{F}}\left(|\boldsymbol{R}+\boldsymbol{s}/2|\right)\right) \rho\left(|\boldsymbol{R}+\boldsymbol{s}/2|\right) d\boldsymbol{s}.$$

Nuclear one-body density

Application of MST to NA elastic scattering





cf. K. Amos+, Adv. Nucl. Phys. ***25****, 275 (2000).*
T. Furumoto+, PRC ***78****, 044610 (2008).*
M. Toyokawa+, PRC ***92****, 024618 (2015).*

Inelastic scattering

MST-based description of inelastic scattering

Hagino, Moro, and O, Prog. Part. Nucl. Phys. ***125****, 10395 (2022).*

$$\left(T_{\mathrm{NA}} + \sum_i \bar{t}_i + H_{\mathrm{A}} - E\right)\bar{\Psi} = 0$$

$$\bar{\Psi} = \sum_c \chi_c \phi_c^{\mathrm{A}} \qquad H_{\mathrm{A}}\phi_c^{\mathrm{A}} = \varepsilon_c \phi_c^{\mathrm{A}} \qquad \langle \phi_{c'}^{\mathrm{A}} | \phi_c^{\mathrm{A}} \rangle = \delta_{c'c}$$

Microscopic coupled-channel equations:

$$\left(T_{\mathrm{NA}} + \int \phi_c^{*\mathrm{A}} \sum_{i\in\mathrm{A}} \bar{t}_i \phi_c^{\mathrm{A}}\, d\xi_{\mathrm{A}} - E_c\right)\chi_c = -\sum_{c'\neq c}\left(\int \phi_c^{*\mathrm{A}} \sum_{i\in\mathrm{A}} \bar{t}_i \phi_{c'}^{\mathrm{A}}\, d\xi_{\mathrm{A}}\right)\chi_{c'}$$

Diagonal pot.

Coupling pot.

(Processes through channel *c*')

Coupled-Channel equations/potentials

Hagino, O, Moro, PPNP 125, 103951 (2022).

- CC Eqs.

$$\left[-\frac{\hbar^2}{2\mu}\frac{d^2}{dR^2}+\frac{\hbar^2}{2\mu}\frac{\left(L'\right)^2}{R^2}-E_{n'I'}\right]\chi^{(J_T)}_{c'c_0}(k_{n'I'},R)=-\sum_{c}U^{(J_T)}_{c'c}(R)\,\chi^{(J_T)}_{cc_0}(k_{nI},R)$$

- CC Pots.

$$U^{\mathrm{dr}}_{c'c,J_T}(R)=\int d\hat{\mathbf{R}}\sum_{m'_I m'_L}\langle I'm'_I L'm'_L|J_T M_T\rangle\, i^{-P'} i^{-L'} Y^*_{L'm'_L}(\hat{\mathbf{R}})$$
$$\times\sum_{m_I m_L}\langle I m_I l m_L|J_T M_T\rangle\, i^{P} i^{L} Y_{Lm_L}(\hat{\mathbf{R}})\sum_{\lambda\mu}\langle I m_I \lambda\mu|I'm'_I\rangle\,\mathcal{U}^{\mathrm{dr}}_{n'I'nI,\lambda}(\mathbf{R}),$$

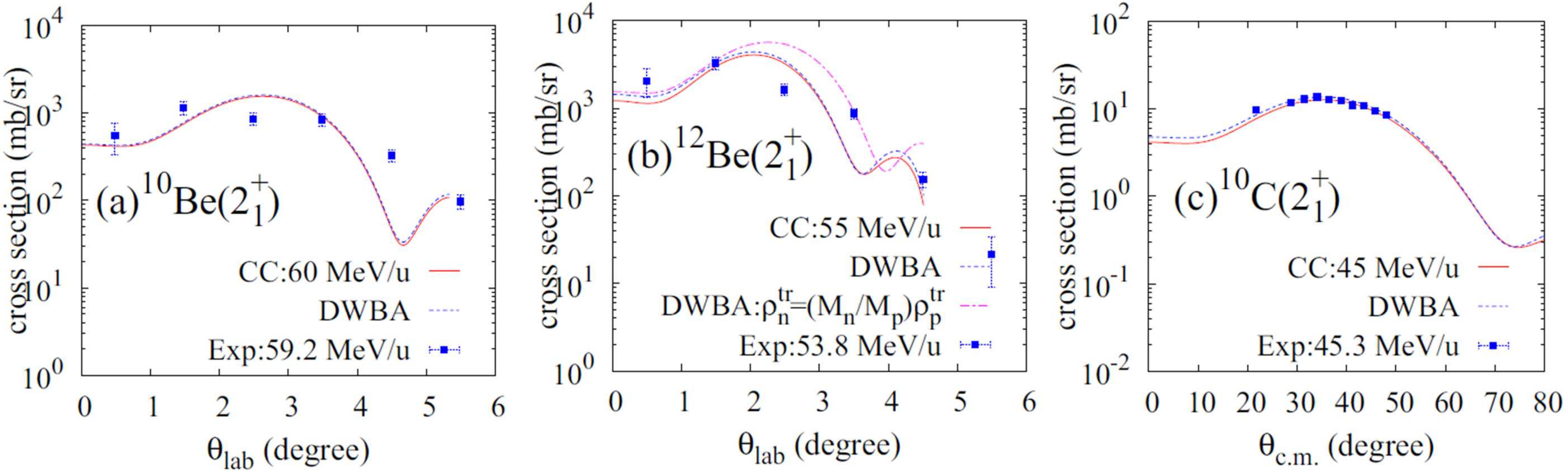
$$\mathcal{U}^{\mathrm{dr}}_{n'I'nI,\lambda}(\mathbf{R})\equiv\int\bar{g}^{\mathrm{dr}}\left(s,k_{\mathrm{F};n'I'nI}\left(|\mathbf{R}+\mathbf{s}/2|\right)\right)\rho^{\mathrm{tr}}_{n'I'nI,\lambda}(r_{\mathrm{A}})\,Y^*_{\lambda\mu}\left(\hat{\mathbf{r}}_{\mathrm{A}}\right)d\mathbf{r}_{\mathrm{A}}$$

One-body transition density

$$\rho^{\mathrm{tr}}_{n'I'm'_I nIm_I}(\mathbf{r}_{\mathrm{A}})\equiv\int\Phi^*_{n'I'm'_I}(\xi)\sum_{i=1}^{A}\delta(\mathbf{r}_i-\mathbf{r}_{\mathrm{A}})\,\Phi_{nIm_I}(\xi)\,d\xi=\sum_{\lambda\mu}\langle I m_I\lambda\mu|I'm'_I\rangle\rho^{\mathrm{tr}}_{n'I'nI,\lambda}(r_{\mathrm{A}})\,Y^*_{\lambda\mu}\left(\hat{\mathbf{r}}_{\mathrm{A}}\right)$$

Application to p-inelastic scattering off ^{10}Be, ^{12}Be, ^{10}C

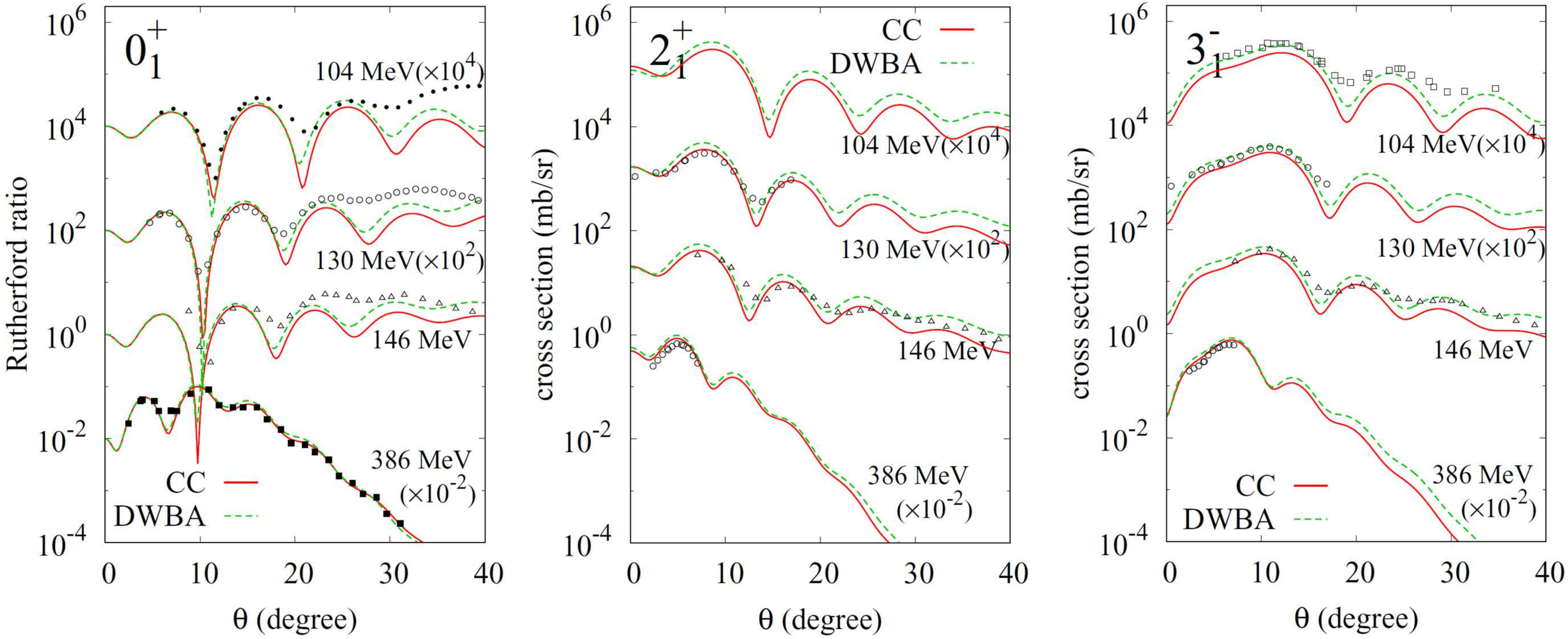
Kanada-En'yo and O, Phys. Rev. C 100, 064616 (2019).



AMD (Antisymmetrized Molecular Dynamics) densities are used.

Application to α-^{16}O scattering

Kanada-En'yo and O, Phys. Rev. C 99, 064608 (2019).



α-A CC pots. are obtained by folding NA CC pots. with a one-body density of α.

Breakup reaction

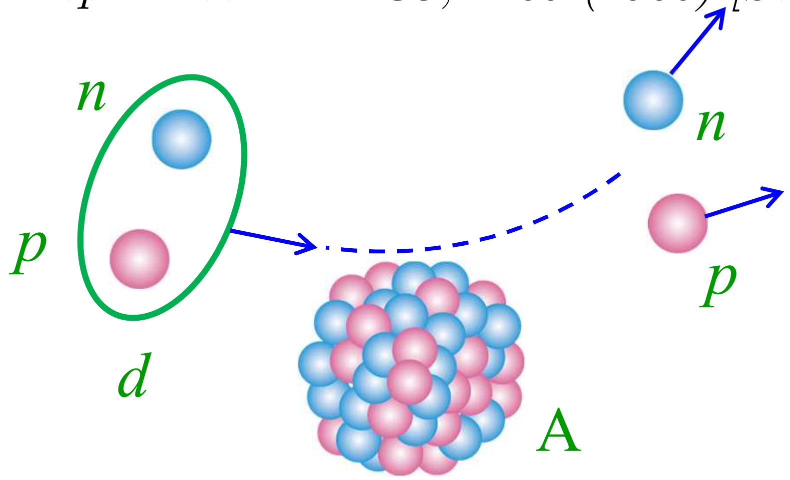
Two questions

1. ***Can we use a single Lippmann-Schwinger Eq.?***

2. ***How to implement the continuum st. of many-body system?***

The Faddeev theory

L. D. Faddeev, Zh. Eksp. Theor. Fiz. ***39****, 1459 (1960) [Sov. Phys. JETP* ***12****, 1014 (1961)].*



$$[E - K - V_{pn} - V_{pA} - V_{nA}]\,\Psi = 0, \quad \Psi = \Psi_d + \Psi_p + \Psi_n.$$

Faddeev Eqs.

$$[E - K - V_{pn}]\,\Psi_d = V_{pn}\left(\Psi_p + \Psi_n\right),$$

$$[E - K - V_{nA}]\,\Psi_n = V_{nA}\Psi_d + V_{nA}\Psi_p,$$

$$[E - K - V_{pA}]\,\Psi_p = V_{pA}\Psi_d + V_{pA}\Psi_n.$$

Three-body theory in a model space

N. Austern, M. Yahiro, and M. Kawai, Phys. Rev. Lett. ***63****, 2649 (1989);*
N. Austern, M. Kawai, and M. Yahiro, Phys. Rev. C ***53****, 314 (1996).*

$$[E - K - V_{pn} - V_{pA} - V_{nA}]\,\Psi = 0, \quad \Psi = \Psi_d + \Psi_p + \Psi_n.$$

Faddeev Eqs.

not pair int. but 3-body int.

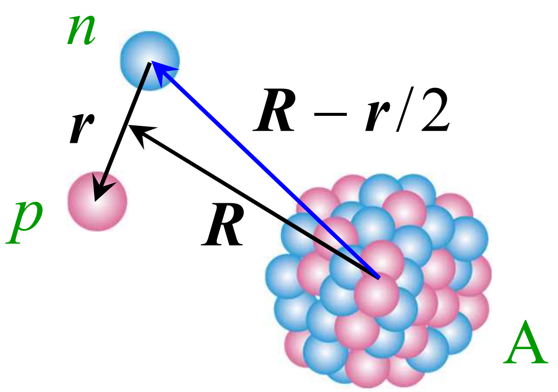
$$[E - K - V_{pn} - \mathcal{P}_{l_{\max}}(V_{nA} + V_{pA})\mathcal{P}_{l_{\max}}]\,\Psi_d = V_{pn}(\Psi_p + \Psi_n),$$

$$[E - K - V_{nA}]\,\Psi_n = (V_{nA} - \mathcal{P}_{l_{\max}} V_{nA} \mathcal{P}_{l_{\max}})\,\Psi_d + V_{nA}\Psi_p,$$

$$[E - K - V_{pA}]\,\Psi_p = (V_{pA} - \mathcal{P}_{l_{\max}} V_{pA} \mathcal{P}_{l_{\max}})\,\Psi_d + V_{pA}\Psi_n.$$

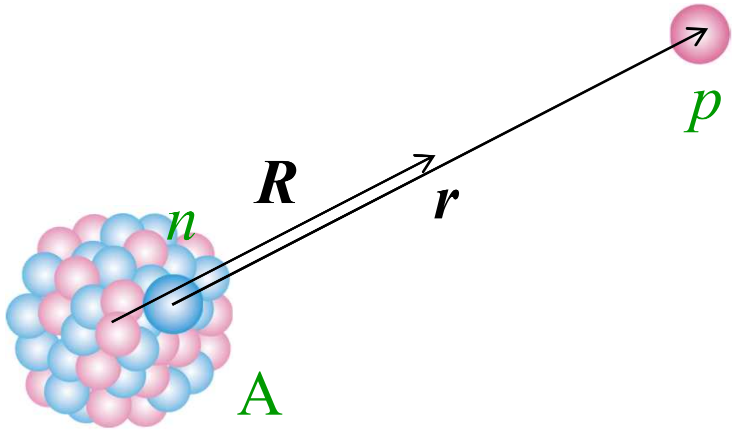
$$\mathcal{P}_{l_{\max}} = \int d\hat{\boldsymbol{r}}' \sum_{l \le l_{\max}} \sum_m Y_{lm}(\hat{\boldsymbol{r}})\, Y^*_{lm}(\hat{\boldsymbol{r}}')$$

$$\mathcal{P}_0 e^{-\mu(\boldsymbol{R}-\boldsymbol{r}/2)^2} \to e^{-\mu R^2} e^{-\mu r^2/4}$$



l-truncation

N. Austern, M. Yahiro, and M. Kawai, Phys. Rev. Lett. ***63****, 2649 (1989);*
N. Austern, M. Kawai, and M. Yahiro, Phys. Rev. C ***53****, 314 (1996).*



$$\mathcal{P}_{l_{\max}} = \int d\hat{\boldsymbol{r}}' \sum_{l \le l_{\max}} \sum_m Y_{lm}(\hat{\boldsymbol{r}}) Y^*_{lm}(\hat{\boldsymbol{r}}')$$

$\mathcal{P}_{l_{\max}}$ smears out $\hat{\boldsymbol{r}}$ with the resolution of $1/l_{\max}$.

[If $l_{\max} \to \infty$, it means $\delta(\hat{\boldsymbol{r}}' - \hat{\boldsymbol{r}})$.]

- We have no rearrangement-like channel in the asymptotic region because of $\mathcal{P}_{l_{\max}}$.
- As $l_{\max}$ increases, the coupling between the 1st Eq. and the other two becomes weaker.

Three-body theory in a model space

N. Austern, M. Yahiro, and M. Kawai, Phys. Rev. Lett. ***63****, 2649 (1989);*
N. Austern, M. Kawai, and M. Yahiro, Phys. Rev. C ***53****, 314 (1996).*

$$[E - K - V_{pn} - V_{pA} - V_{nA}]\,\Psi = 0, \quad \Psi = \Psi_d + \Psi_p + \Psi_n.$$

Faddeev Eqs.

not pair int. but 3-body int. → 0

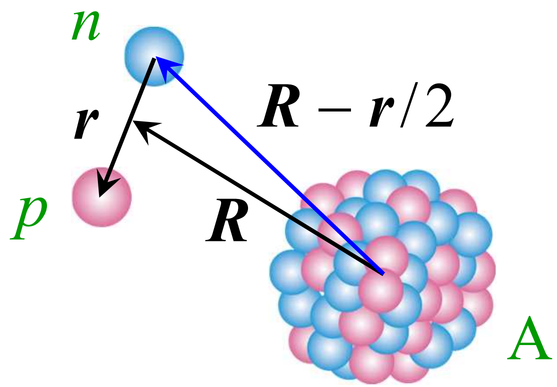
$$[E - K - V_{pn} - \mathcal{P}_{l_{\max}}(V_{nA} + V_{pA})\mathcal{P}_{l_{\max}}]\,\Psi_d = V_{pn}(\Psi_p + \Psi_n),$$

$$[E - K - V_{nA}]\,\Psi_n = (V_{nA} - \mathcal{P}_{l_{\max}} V_{nA} \mathcal{P}_{l_{\max}})\,\Psi_d + V_{nA}\Psi_p,$$

$$[E - K - V_{pA}]\,\Psi_p = (V_{pA} - \mathcal{P}_{l_{\max}} V_{pA} \mathcal{P}_{l_{\max}})\,\Psi_d + V_{pA}\Psi_n.$$

$$\mathcal{P}_{l_{\max}} = \int d\hat{\boldsymbol{r}}' \sum_{l \le l_{\max}} \sum_{m} Y_{lm}(\hat{\boldsymbol{r}})\, Y^*_{lm}(\hat{\boldsymbol{r}}')$$

$$\mathcal{P}_0 e^{-\mu(\boldsymbol{R}-\boldsymbol{r}/2)^2} \to e^{-\mu R^2} e^{-\mu r^2/4}$$



The Continuum-Discretized Coupled-Channels method

N. Austern, M. Yahiro, and M. Kawai, Phys. Rev. Lett. ***63****, 2649 (1989);*
N. Austern, M. Kawai, and M. Yahiro, Phys. Rev. C ***53****, 314 (1996).*

CDCC solves the following LS eq.:

$$\Psi^{\mathrm{CDCC}} = e^{i\boldsymbol{K}\cdot\boldsymbol{R}}\phi_d + \frac{1}{E - H_d + i\varepsilon}\mathcal{P}_{l_{\max}}\left(V_{nA} + V_{pA}\right)\mathcal{P}_{l_{\max}}\Psi^{\mathrm{CDCC}}.$$

CDCC gives a proper solution to a three-body scattering problem
if the solution converges with respect to l.

- Continuum-Discretization has nothing to do with the justification of CDCC.
- l-truncation allows one to truncate also r and k.
- Convergence for other quantities ($r_{\max}$, $k_{\max}$, etc.) must be confirmed.

Faddeev–Alt-Grassberger-Sandhas (FAGS) vs. CDCC

*N. J. Upadhyay, A. Deltuva, F. M. Nunes, PRC **85**, 054621 (2012).*

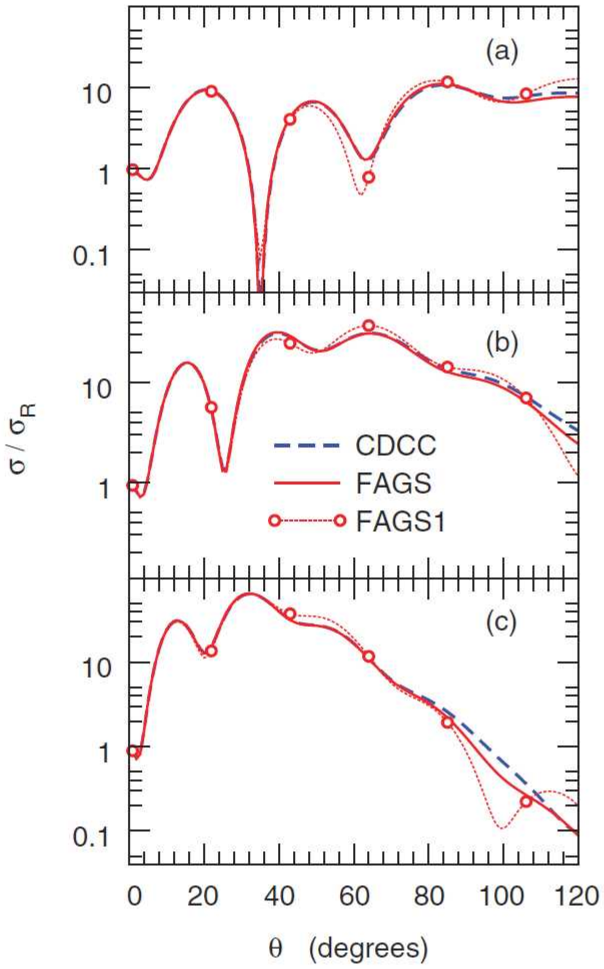


FIG. 2. (Color online) Elastic cross section for $d+^{10}$Be: (a) $E_d = 21.4$ MeV, (b) $E_d = 40.9$ MeV, and (c) $E_d = 71$ MeV.

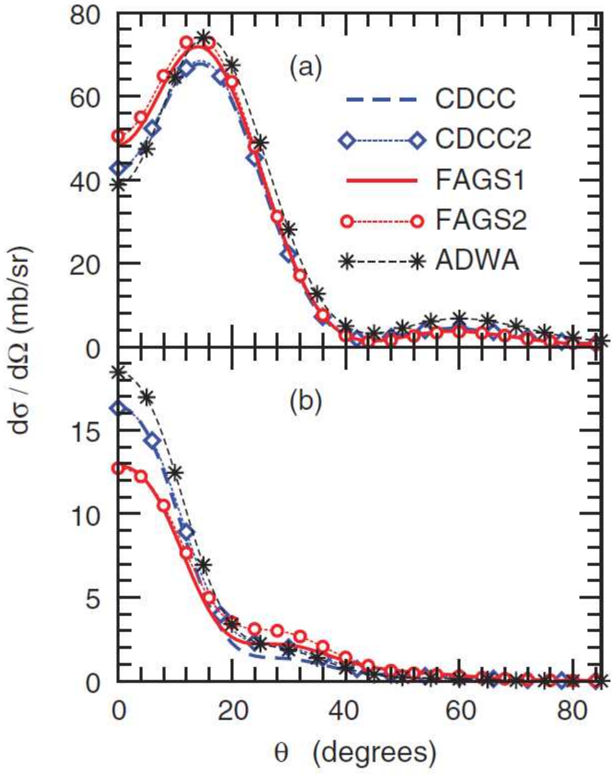


FIG. 6. (Color online) Angular distribution for ^{12}C$(d,p)^{13}$C: (a) $E_d = 12$ MeV and (b) $E_d = 56$ MeV.

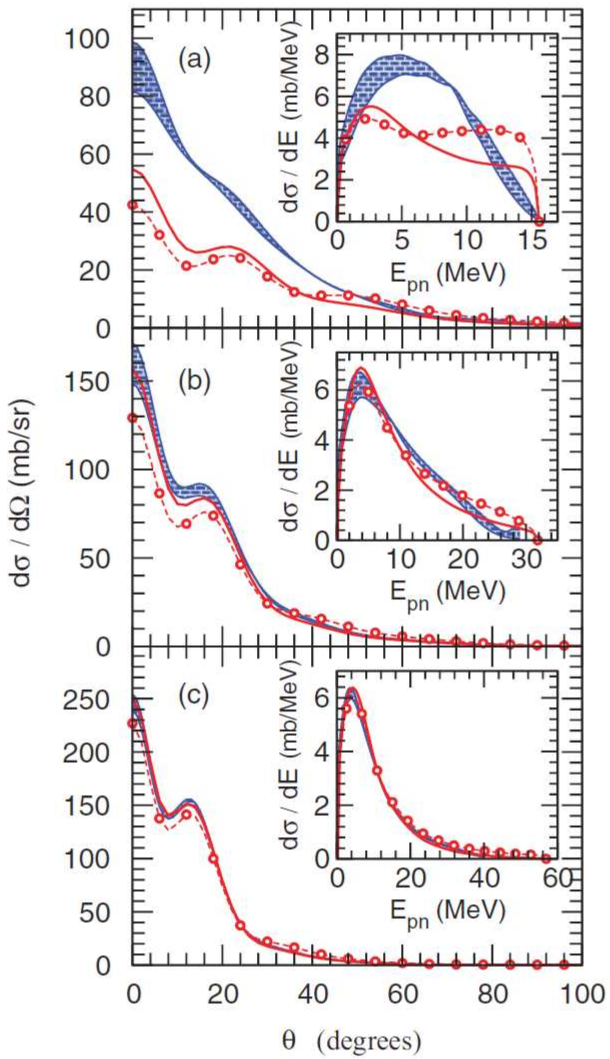
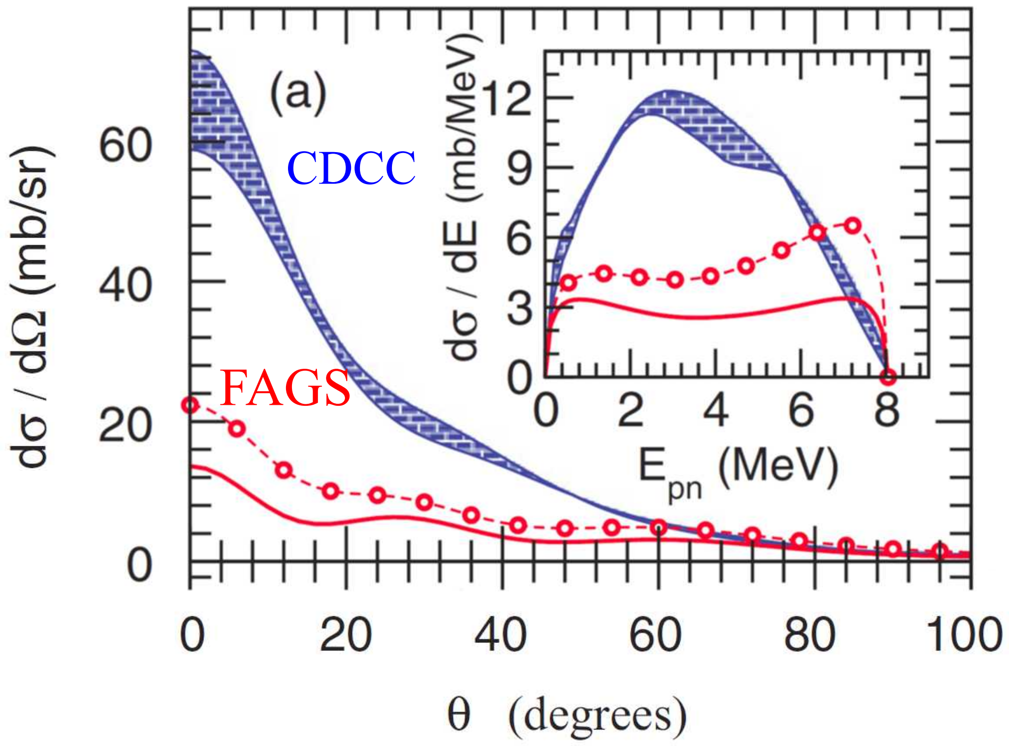


FIG. 8. (Color online) Breakup distributions for the ^{10}Be$(d,pn)^{10}$Be reaction at (a) $E_d = 21$ MeV, (b) $E_d = 40.9$ MeV, and (c) $E_d = 71$ MeV. Results for CDCC (hatched band), FAGS (solid), and FAGS1 (circles).

Applicability of CDCC to low energy BU process

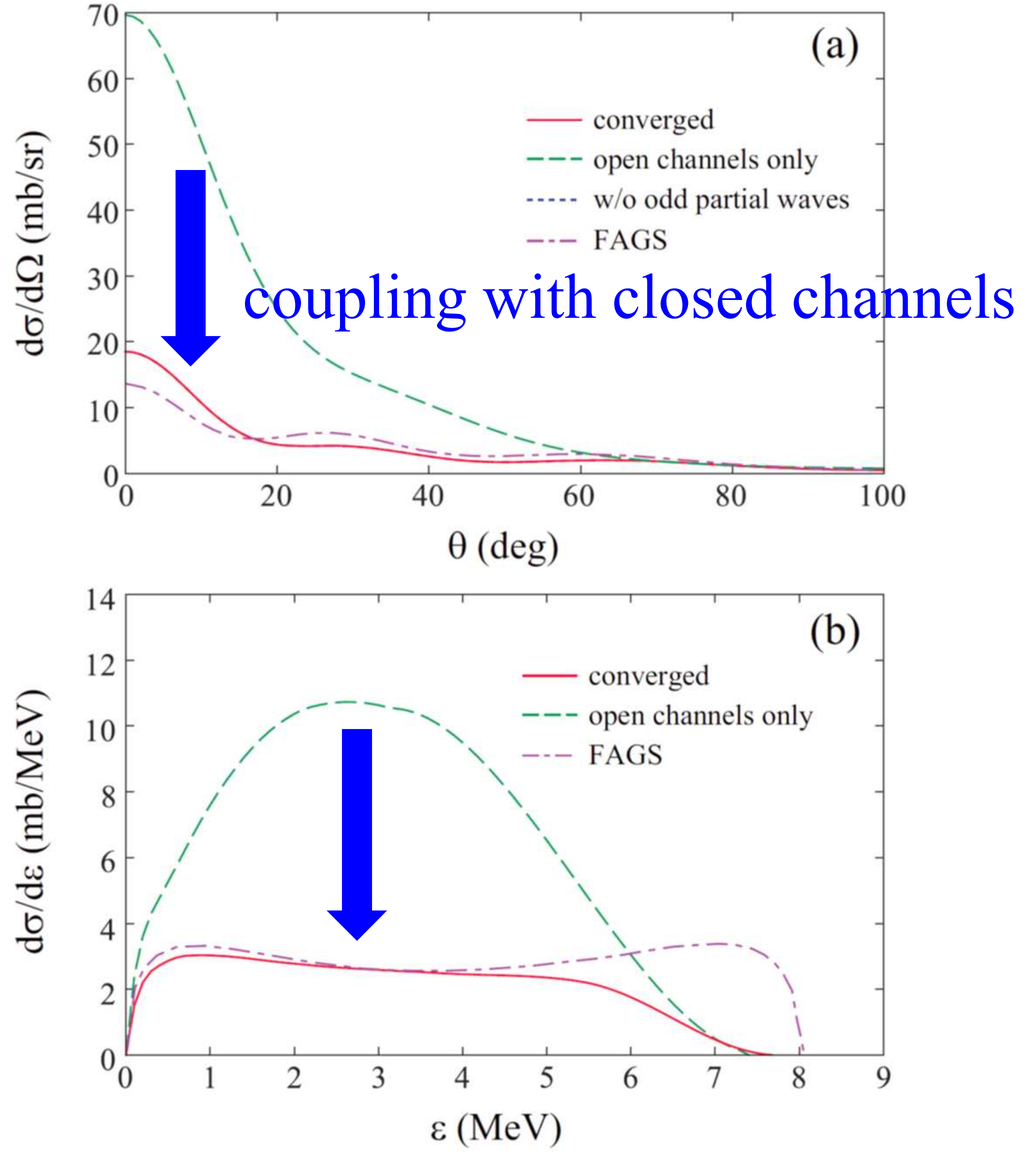
N. J. Upadhyay et al., PRC ***85****, 054621 (2012).*

$^{12}C(d,pn)^{12}C_{gs}$ at $E_d = 12$ MeV



CDCC severely overshoots the result of FAGS.

KO and K. Yoshida, PRC ***94****, 051603(R) (2016).*



Two questions

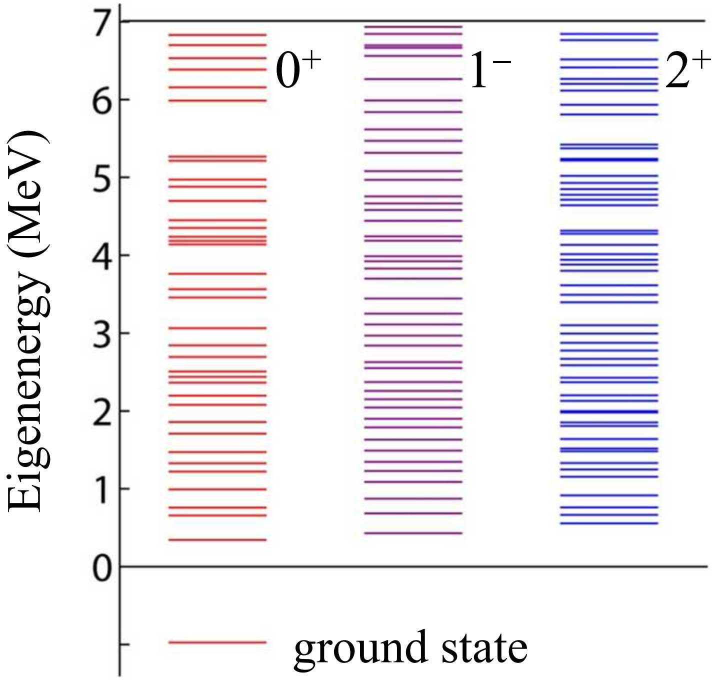
✓ 1. *Can we use a single Lippmann-Schwinger Eq.?*

2. *How to implement the continuum st. of many-body system?*

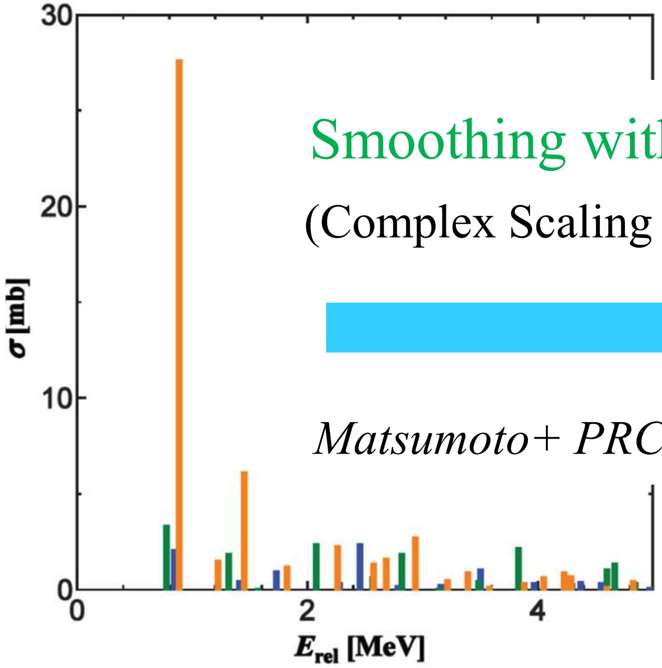
Gaussian Expansion Method (GEM) for ^{6}He

Yahiro+, Prog. Theor. Exp. Phys. 2012, 01A206.

Eigenstates of ^{6}He (= α+*n*+*n*)



Cross section to each state

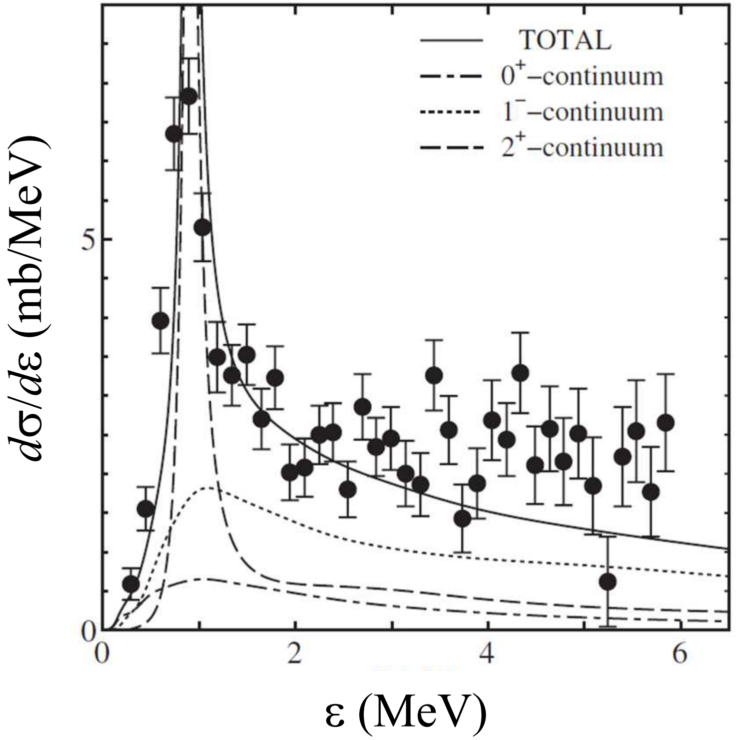


Smoothing with CSM

(Complex Scaling Method)

Matsumoto+ PRC82 ('10)

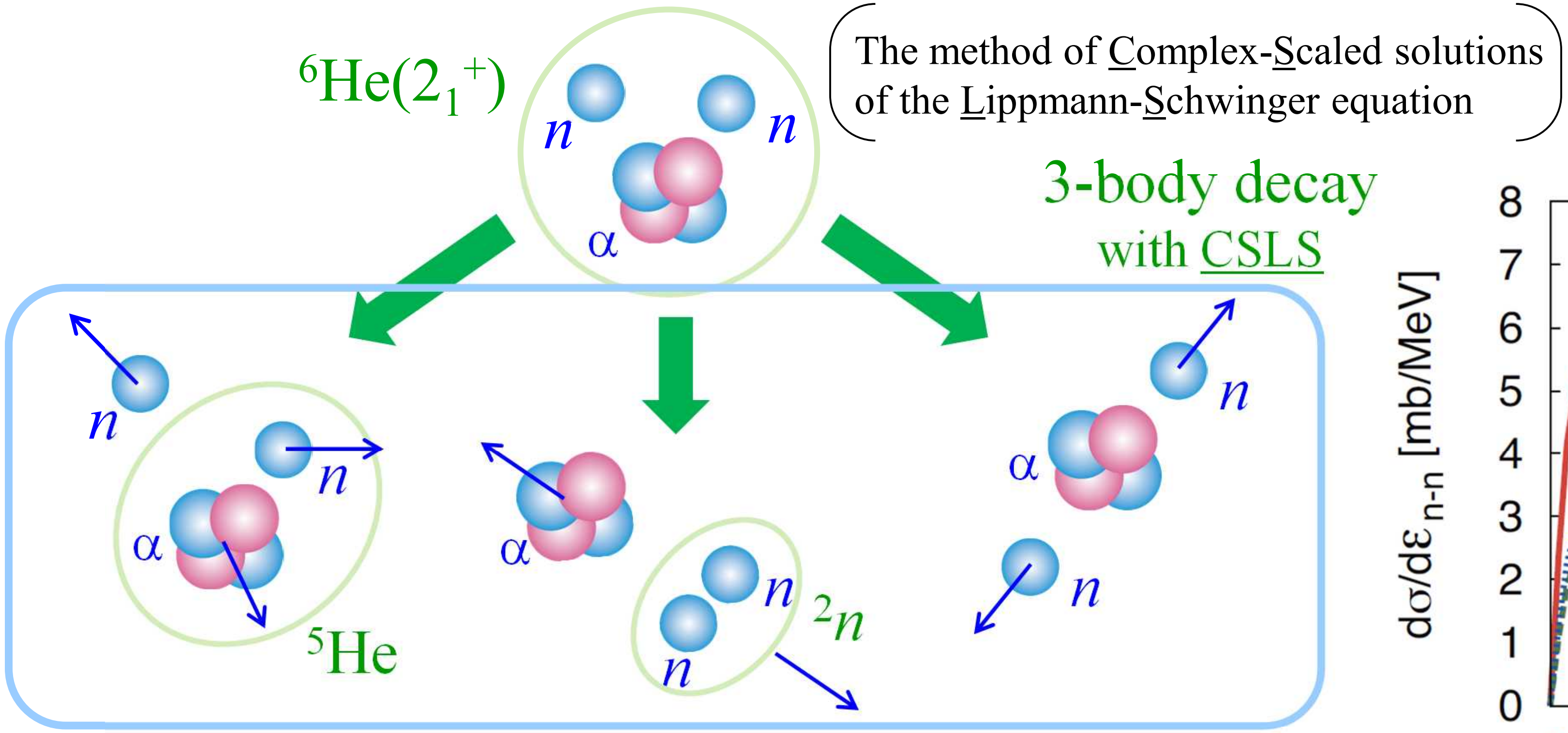
^{6}He → α+*n*+*n* BUX

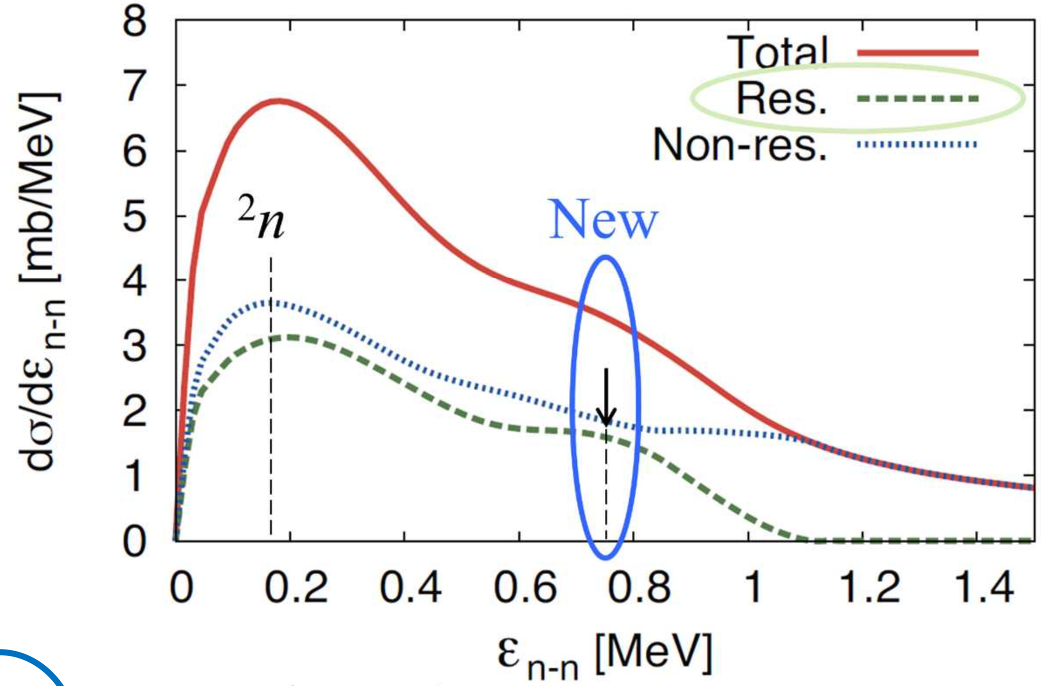


Hiyama+, Prog. Part. Nucl. Phys. 51, 223 (2003).

Specification of the final state

Kikuchi+ PTP122 ('09), PRC88 ('13)





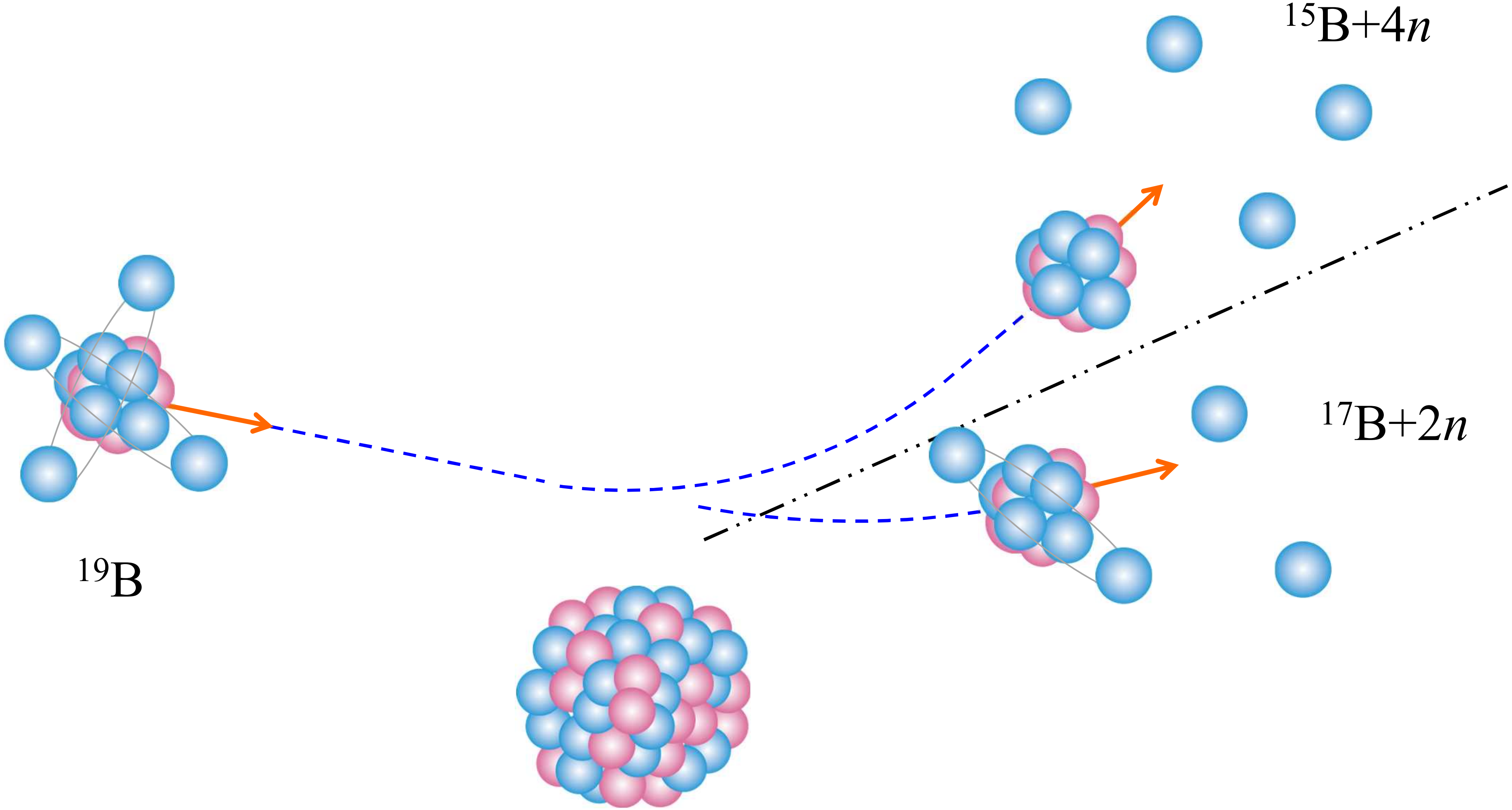
$$\left|\psi^{(+)}\right\rangle = |\phi_{\rm free}\rangle + \sum_n U^{-1}(\theta)\left|\Phi_n^\theta\right\rangle \frac{1}{\varepsilon - \varepsilon_n^\theta}\left\langle\tilde{\Phi}_n^\theta\right| U(\theta)\, V \left|\phi_{\rm free}\right\rangle$$

Eigenstate of a CS Hamiltonian

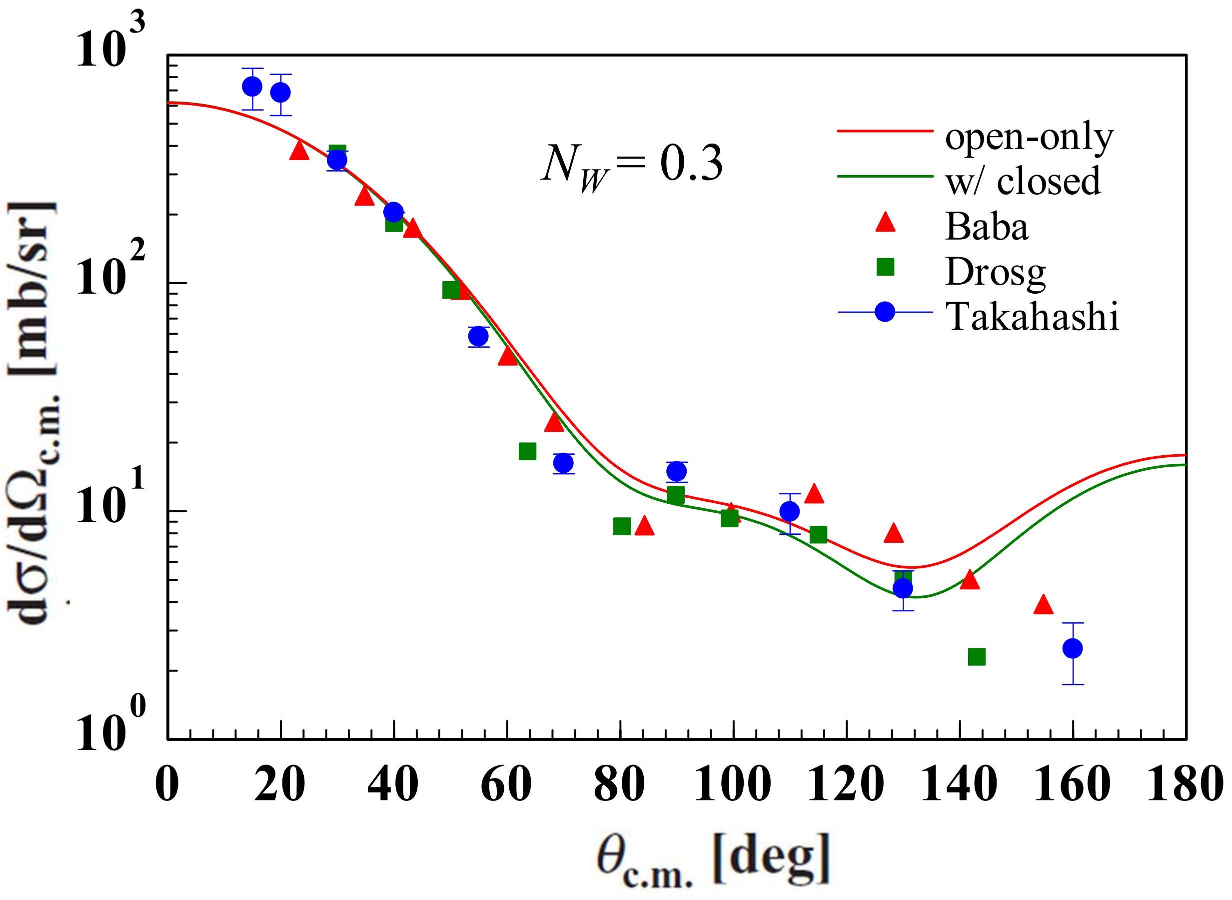
cf. A practical FS specification: Watanabe+ PRC103 ('21)

Possible future study

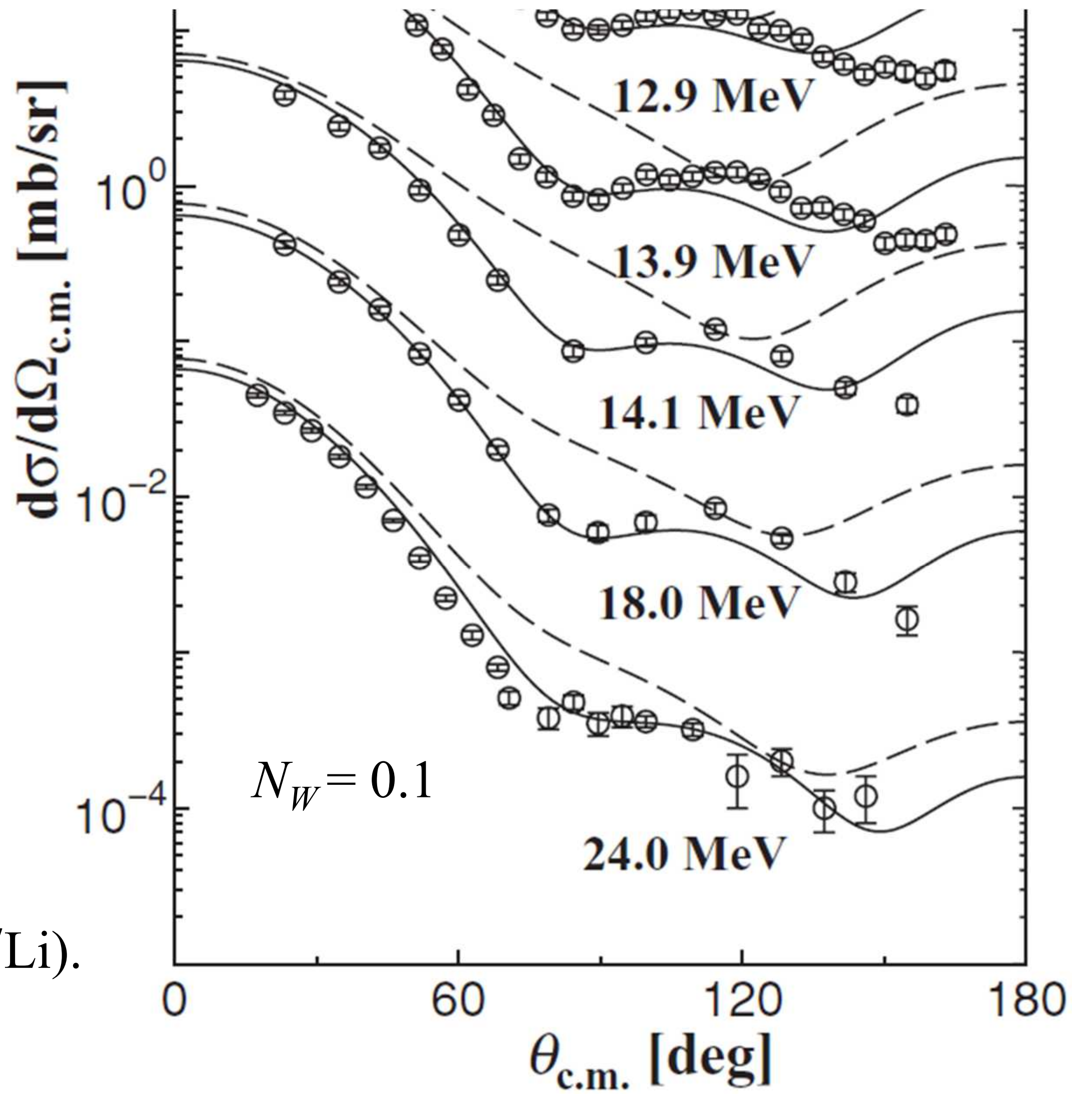
cf. Cook+, PRL124 ('20)



(My) 1st 4-body CDCC calc. for n-^{6}Li elas. scat.



Matsumoto+, PRC 83, 064611 (2011).

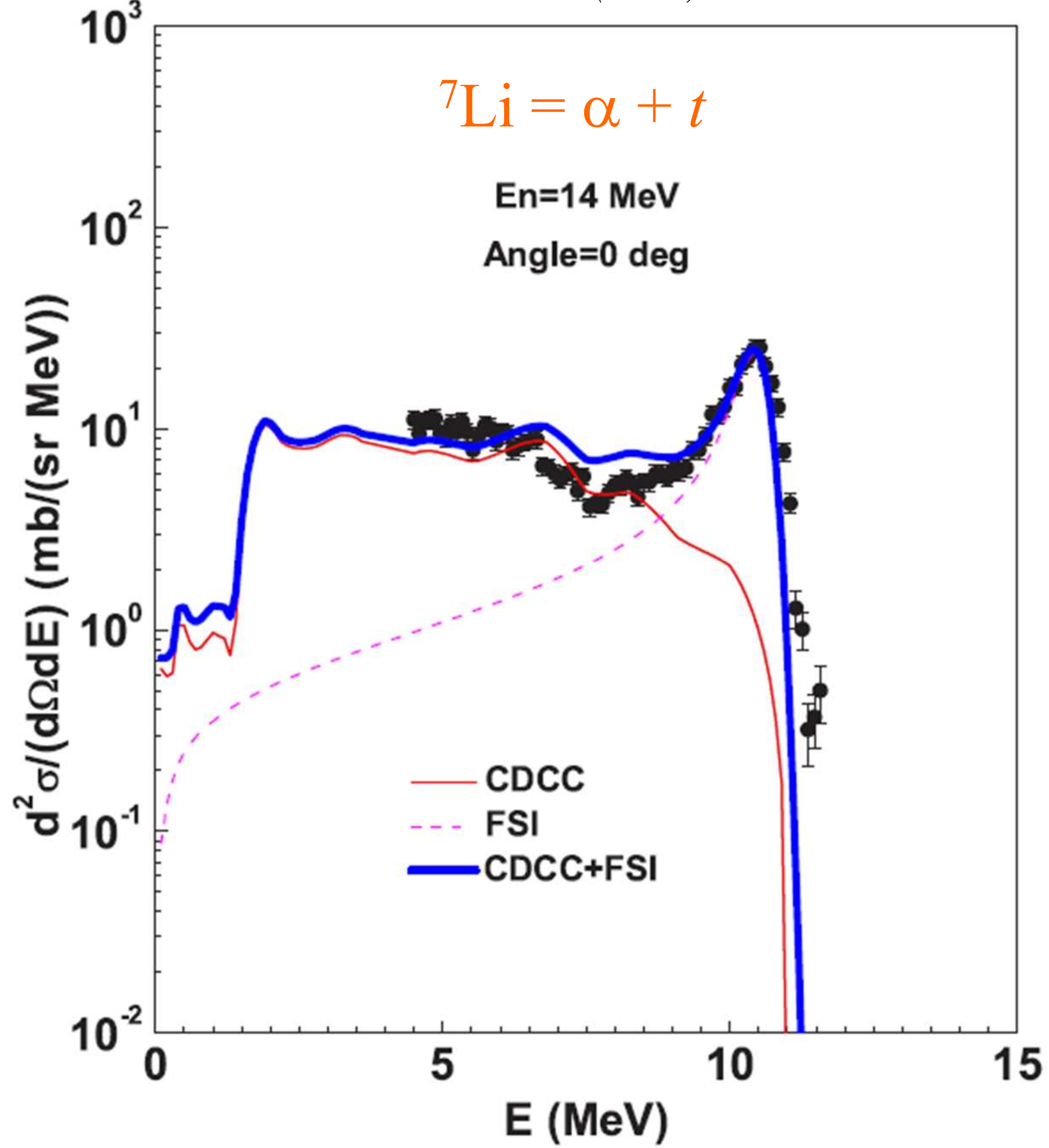


Physics case: t production around ITER

- ✓ In the preceding studies, $\alpha+d$ ($\alpha+t$) is assumed for ^{6}Li (^{7}Li).
- ✓ A simplified g-matrix int. (JLM) is employed, with a normalization of its imaginary part.

t production from n-^{7}Li reaction

Guo+, PRC 99, 034602 (2019).



How does the result change when ^{7}Li is described with α+*p*+*n*+*n*?

Note:

The specification of the final channel with CSLS is necessary.

Summary

- ✓ I have introduced an MST-based microscopic approach to nuclear reactions.
  - ✓ NN eff. int. is a key ingredient; g-matrix approach works quite well.
  - ✓ One-body transition densities, ideally with 3NF effect, are expected to be provided by B1 and B2 collaborators.
- ✓ CDCC, a possible alternative to Faddeev-AGS, is the key reaction model.
  - ✓ Its theoretical foundation was reviewed.
  - ✓ Specification of the final channel with CSLS is crucial.
- ✓ Description of t-production from N-^{6,7}Li is the first physics case of B3.
  - ✓ GEM-CDCC calc., in collaboration with Prof. Hiyama, is getting ready for N-^{6}Li.
  - ✓ A comparison using different W.Fns. will be performed in collaboration with Prof. W. Horiuchi (OMU).
  - ✓ After N-^{6}Li studies, we will consider how to proceed with ^{7}Li.