Theoretical study on multichannel breakup reactions

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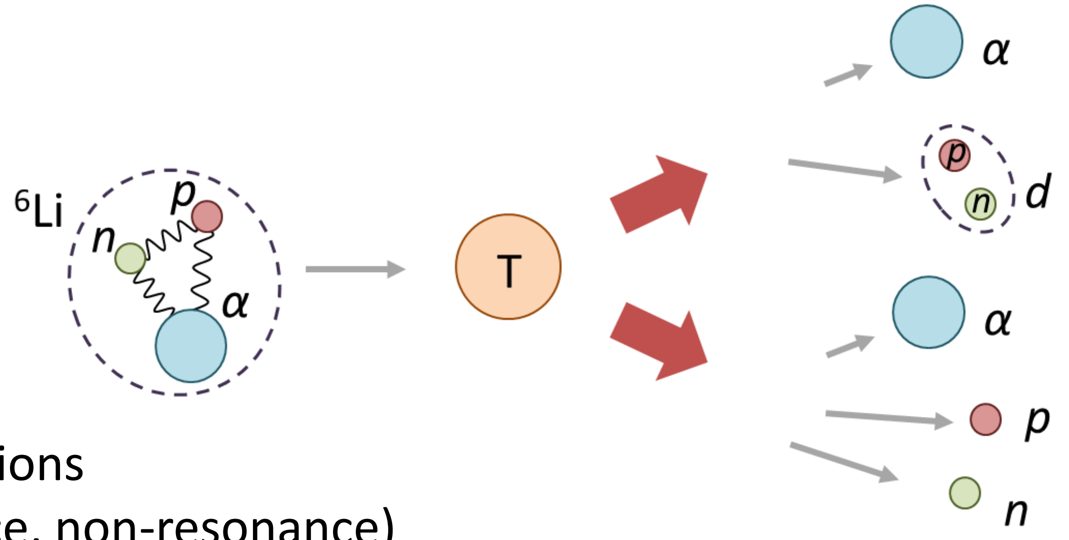


Key words

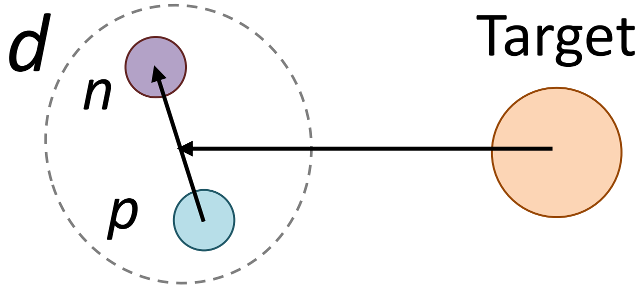
- Multichannel breakup reactions
- Continuum states (resonance, non-resonance)
- Discretized continuum states

2021/06/24

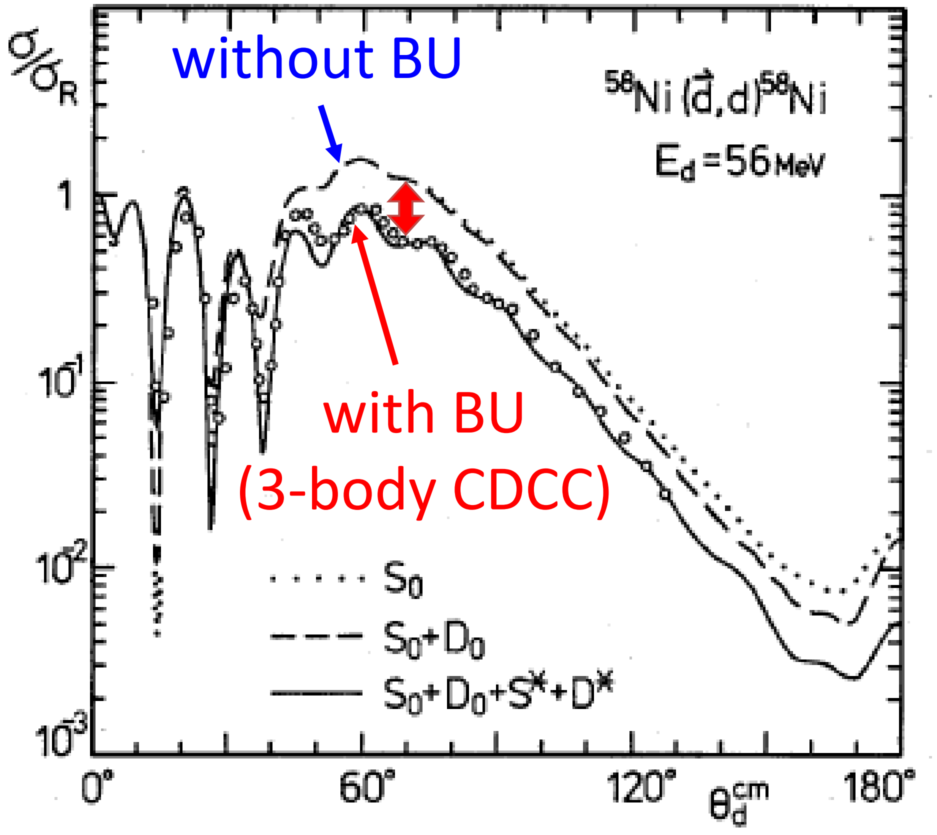
Reaction Seminar 2021 (Zoom)

CDCC: Continuum-Discretized Coupled-Channels

- ✓ CDCC is a fully quantum mechanical method for treating projectile-BU effects.
- ✓ CDCC was born as a theory for *d*-scattering ⇒ 3-body CDCC



Three-body CDCC has been widely applied and successful in describing many kinds of three-body reactions.



BU effects in elastic scattering

M. Yahiro, Y. Iseri, H. Kameyama, M. Kamimura, and M. Kawai, Prog. Theor. Phys. Suppl. No. 89 (1986), 32.

Development of CDCC

Three-body CDCC (1980s-)

Four-body CDCC (2004-)

T. Matsumoto, E. Hiyama, K. Ogata, Y. Iseri, M. Kamimura, S. Chiba, and M. Yahiro, Phys. Rev. C **70**, 061601(R) (2004).
I. J. Thompson, F. M. Nunes, and B. V. Danilin, Comput. Phys. Commun. **161**, 87 (2004).
M. Rodríguez-Gallardo, J. M. Arias, J. Gómez-Camacho, A. M. Moro, I. J. Thompson, and J. A. Tostevin, Phys. Rev. C **80**, 051601(R) (2009).
T. Matsumoto, K. Kat¯o, and M. Yahiro, Phys. Rev. C **82**, 051602(R) (2010).
P. Descouvemont, Phys. Rev. C **97**, 064607 (2018).

Three-body CDCC with core excitation (2014-)

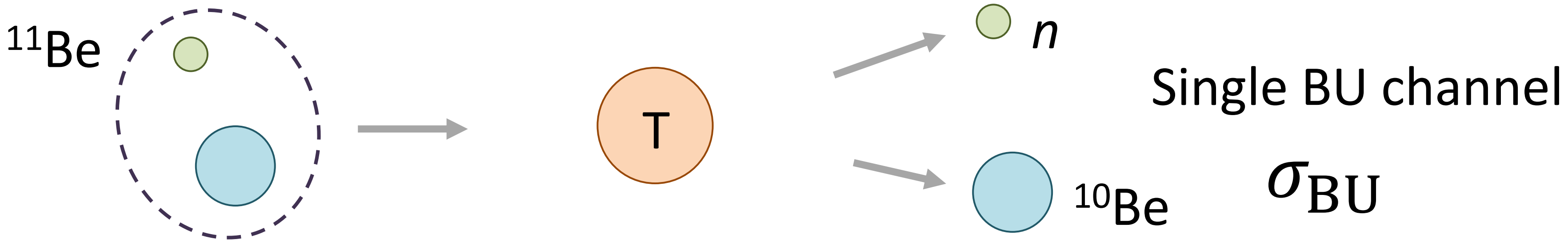
R. de Diego, J. M. Arias, J. A. Lay, and A. M. Moro, Phys. Rev. C **89**, 064609 (2014).
J. A. Lay, R. de Diego, R. Crespo, A. M. Moro, J.M. Arias, and R. C. Johnson, Phys. Rev. C **94**, 021602(R) (2016).
R. de Diego, R. Crespo, and A. M. Moro, Phys. Rev. C **95**, 044611 (2017).

These methods address breakup reactions including multi-breakup channels.

Multi-channel breakup reactions

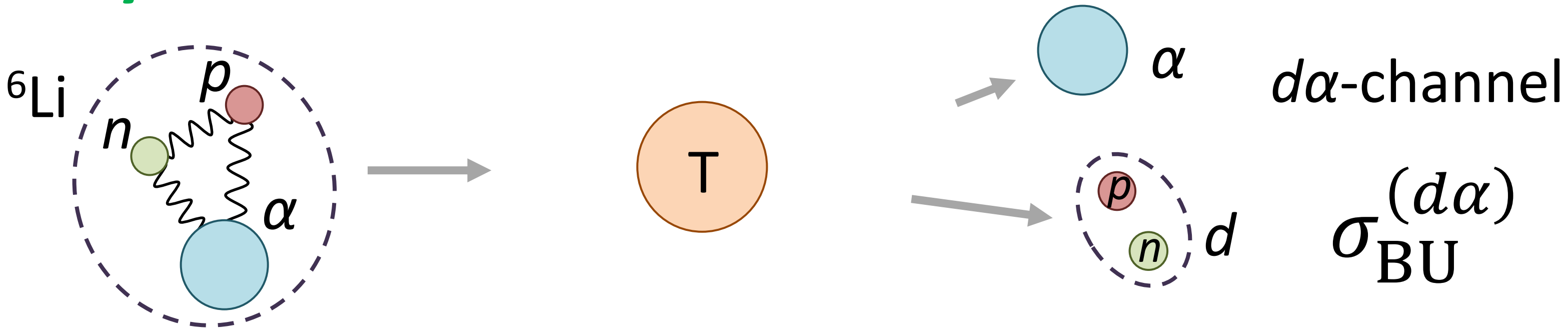
3-body BU reaction

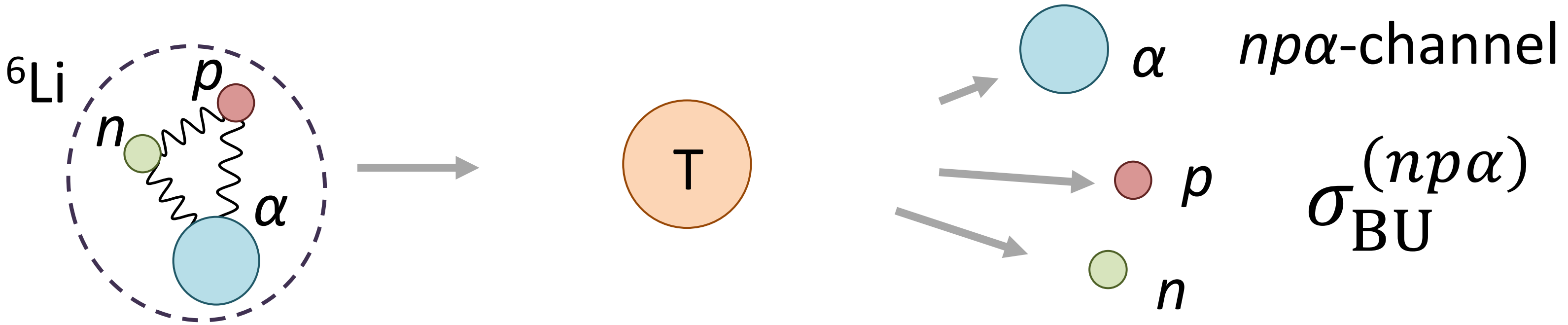
3-body CDCC: *M. Yahiro, Y. Iseri, H. Kameyama, M. Kamimura, and M. Kawai, Prog. Theor. Phys. Suppl. No. 89 (1986), 32.*



4-body BU reaction

4-body CDCC: *T. Matsumoto et al., PRC **70**, 061601(R) (2004).*





Multi-channel breakup reactions

3

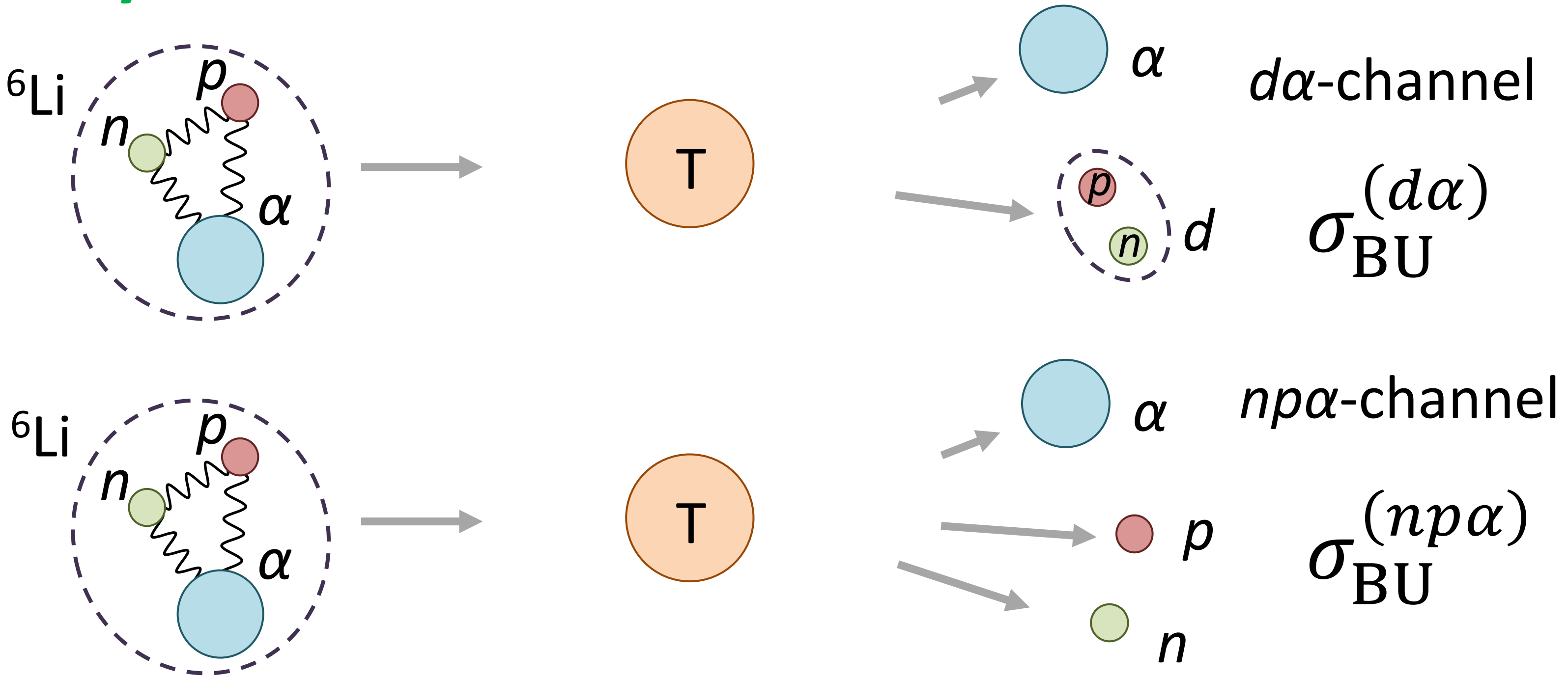
nd
32.

Dynamics of 4-body BU reaction is richer than that of 3-body BU reaction and its elucidation is important.

Each breakup cross section (BUX) provides useful information.

4-body BU reaction

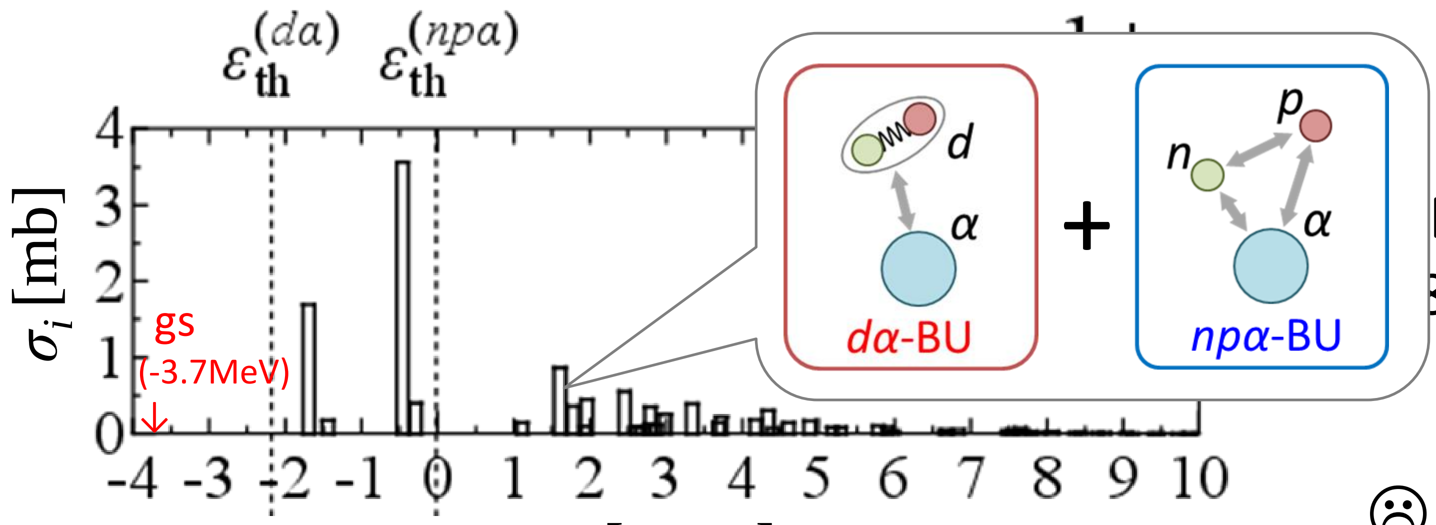
4-body CDCC: *T. Matsumoto et al., PRC* ***70****, 061601(R) (2004).*



Problem in four-body CDCC

☹ In four-body CDCC, a BUX is obtained as a mixture of different channels.

e.g.) Discretized BUX for ^{6}Li scattering



Bi (=n+p+α+^{209}Bi)

3 MeV

☹ Hard to obtain

(In principle)

We can decompose the discretized BUXs by taking an overlap between the discretized state and the exact continuum state.

3-body CDCC smoothing:
T. Matsumoto et al., Phys. Rev. C ***68****, 064607 (2003)*

→ Can we decompose BUXs easily?

Background & Purpose

Background

- ✓ If a projectile is a 3-body system（^{6}Li=n+p+α etc.）, the continuum states are often discretized in reaction calculations.
- ✓ These discretized states (Pseudostates) are obtained as a mixture of many kinds of channels.
- ✓ The discretized BUX thus obtained is also a mixture of many kinds of channels.

Note
Discretization is indispensable in CDCC

Purpose

We propose an approximate way of decomposing discretized BUXs into components of different channels.

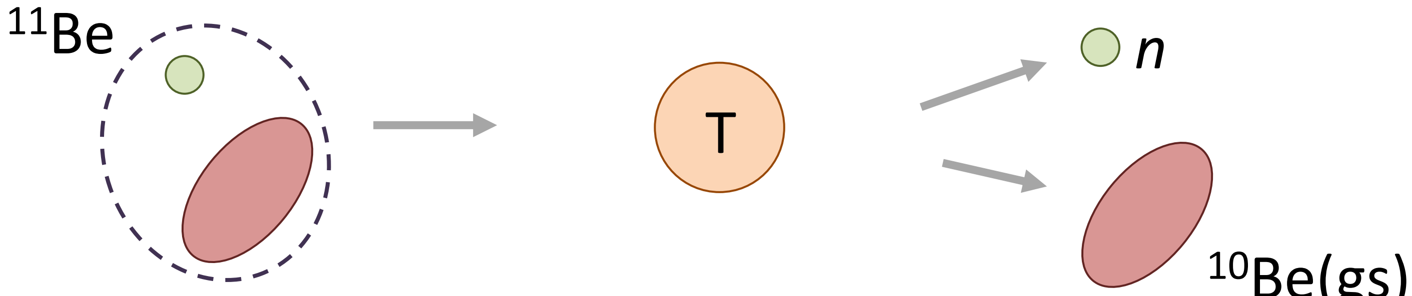
Model and Analysis

Simplifying the problem

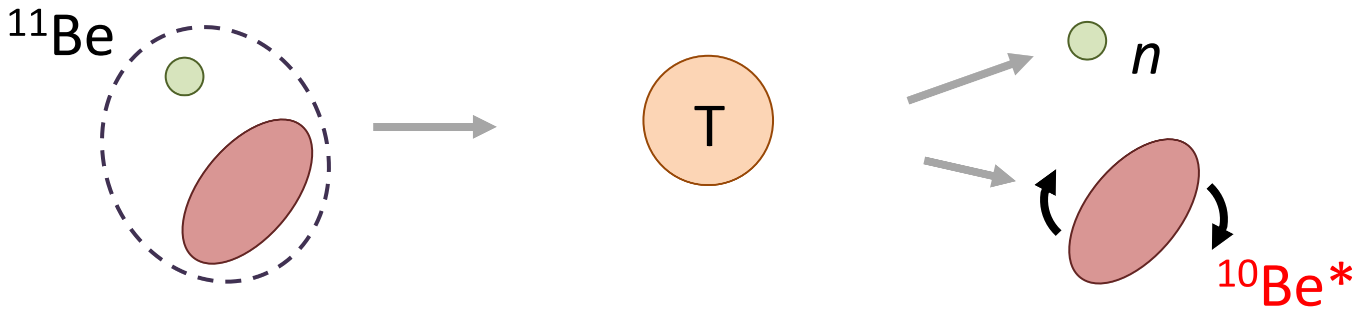
Before going to four-body scattering,
we consider three-body scattering with core excitation.

Core-excitation
R. Crespo, A Deltuva, and A. M. Moro, Phys. Rev. C ***83****, 044622 (2011).*

Core-ground channel



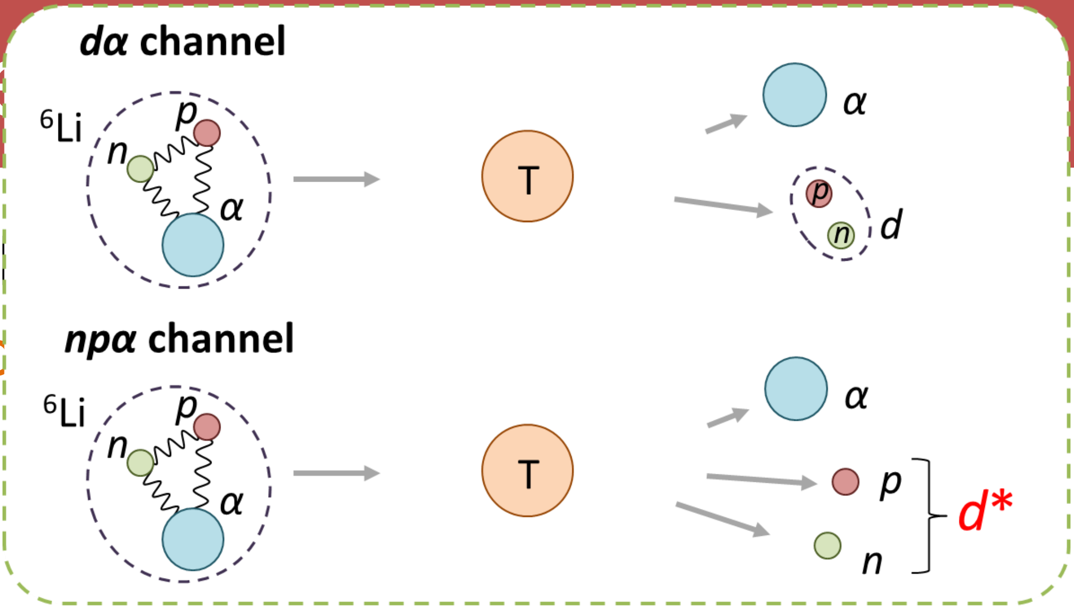
Core-excited channel



- Analogy to ^{6}Li scattering
  → Mixture of different channels
- Simple 2-body problem
  → We can easily obtain the exact continuum wave functions.

Exact vs Discretized

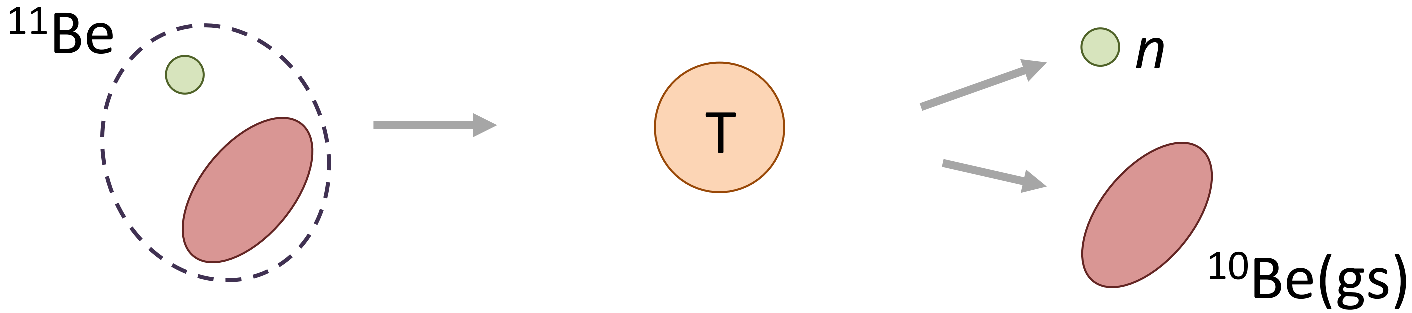
Simplifying the



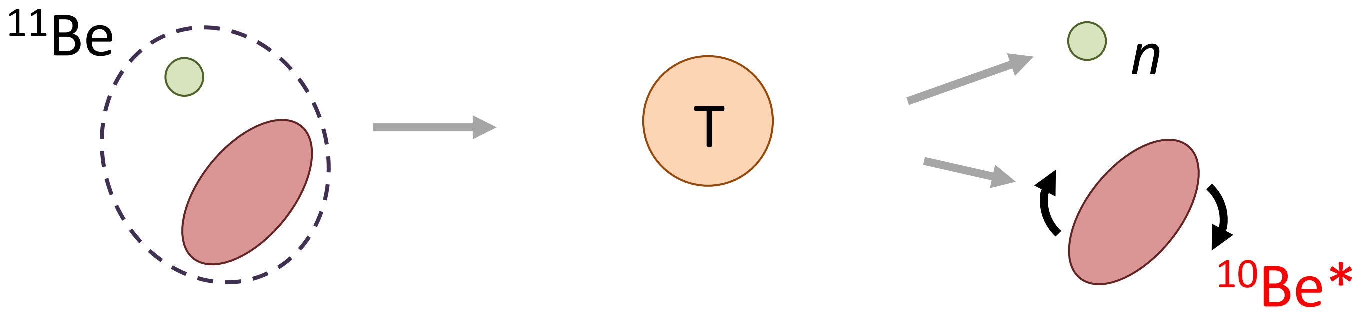
Core-excitation
R. Crespo, A Deltuva, and A. M. Moro, Phys. Rev. C ***83****, 044622 (2011).*

Before going to four-
we consider three-bo

Core-ground channel



Core-excited channel



- Analogy to ^{6}Li scattering
  → Mixture of different channels
- Simple 2-body problem
  → We can easily obtain the exact continuum wave functions.

Exact vs Discretized

Model Hamiltonian

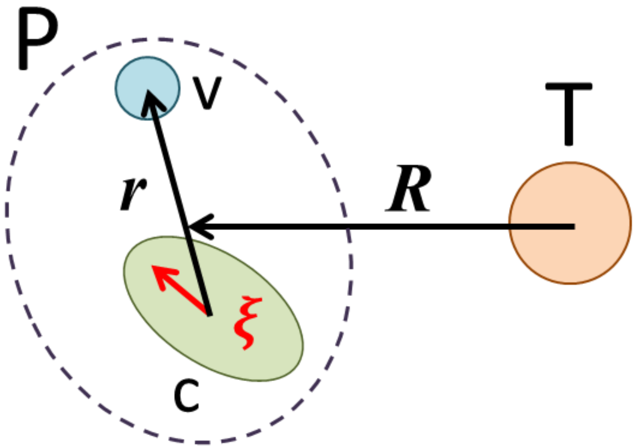
$$H_{\text{tot}} = K_{\boldsymbol{R}} + V_{\text{vT}}(R_{\text{vT}}) + V_{\text{cT}}(\boldsymbol{R}_{\text{cT}}, \xi) + h_{\text{P}}$$

$$h_{\text{P}} = K_{\boldsymbol{r}} + V(\boldsymbol{r}, \xi) + h_{\text{c}}(\xi)$$

DWBA with core excitation: A. M. Moro and R. Crespo, Phys. Rev. C ***85****, 054613 (2012).*
CDCC with core excitation: R. de Diego, J. M. Arias, J. A. Lay, and A. M. Moro, Phys. Rev. C 89, 064609 (2014).

✓ Projectile WF is constructed with the Particle Rotor Model

✓ Reaction part is solved by the distorted-wave Born Approximation (DWBA)



This model enables us to calculate both the exact (continuous) and the approximate (discretized) T-matrix elements.

Model setting (Hamiltonian)

$$H_{\rm tot} = K_{\boldsymbol{R}} + V_{\rm vT}(R_{\rm vT}) + V_{\rm cT}(\boldsymbol{R}_{\rm cT}, \xi) + h_{\rm P}$$

$$h_{\rm P} = K_{\boldsymbol{r}} + V(\boldsymbol{r}, \xi) + h_{\rm c}(\xi)$$

^{11}Be+*p* at 63.7 MeV/nucl.

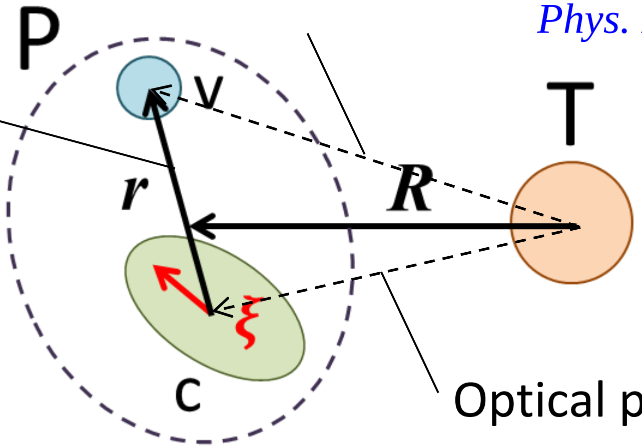
Gaussian: $V(r) = -45e^{-(r/1.484)^2}$

A. M. Moro and R. Crespo, Phys. Rev. C ***85****, 054613 (2012).*

WS Potential

F.M. Nunes et al., NPA609 43 (1996).

$$V_{\rm WS} = -54.45 \text{ MeV}$$
$$V_{\rm SO} = -8.50 \text{ MeV}$$
$$R = 2.483 \text{ fm}$$
$$a = 0.65 \text{ fm}$$



Optical potential

B. A. Watson et al., Phys. Rev. ***182****, 977 (1969).*

^{10}Be core

$$\beta_2 = 0.67, E(2+) = 3.368 \text{ MeV}$$

Model space

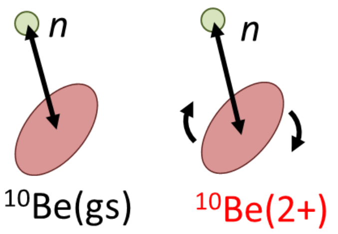
$$\ell = 0 - 3 \quad I = 0, 2$$

Discretized and Exact continuum states of projectile

- **Discretized continuum states** (with diagonalization)
  - ✓ Continuum states are automatically discretized
  - ✓ Specified by the state number n → Several channels are mixed

$$\widehat{\Psi}^{(n)}_{^{11}\mathrm{Be}}(\boldsymbol{r},\boldsymbol{\xi}) = \Phi_0(\boldsymbol{\xi})\hat{\psi}^{(n)}_0(\boldsymbol{r}) + \Phi_2(\boldsymbol{\xi})\hat{\psi}^{(n)}_2(\boldsymbol{r})$$

Gaussian Expansion Method (GEM)
E. Hiyama, Y. Kino, M. Kamimura, Prog. Part. Nucl. Phys. ***51****, 223 (2003).*



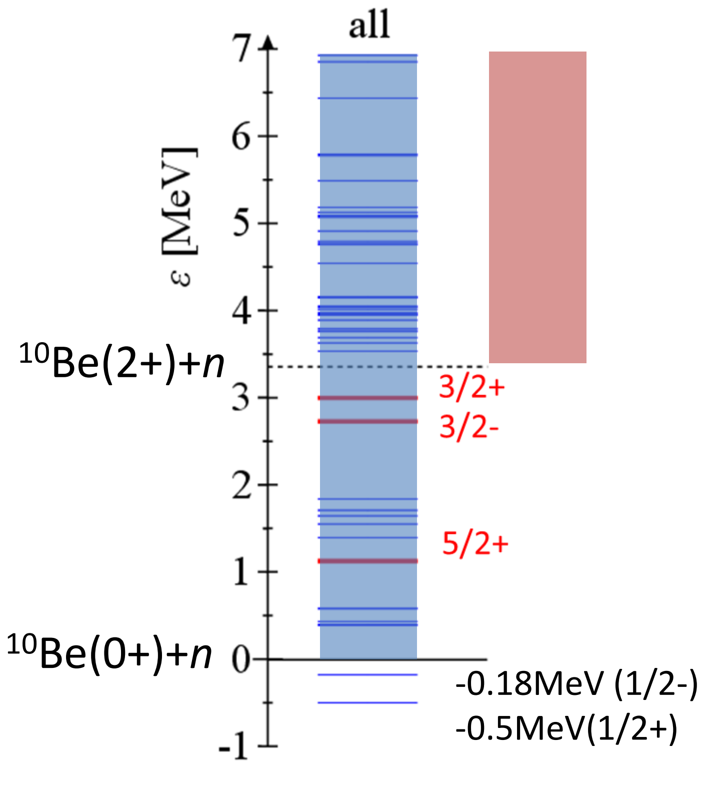
- **Exact continuum states** (with difference method)
  - ✓ $\mathrm{ch} = \{\varepsilon, I\}$ is specified before solving the scattering problem

$$\Psi^{(\mathrm{ch})}_{^{11}\mathrm{Be}}(\boldsymbol{r},\boldsymbol{\xi}) = \Phi_0(\boldsymbol{\xi})\psi^{(\mathrm{ch})}_0(\boldsymbol{r}) + \Phi_2(\boldsymbol{\xi})\psi^{(\mathrm{ch})}_2(\boldsymbol{r})$$

Boundary condition

$$\Psi^{(\varepsilon,I=0)}_{^{11}\mathrm{Be}}(\boldsymbol{r},\boldsymbol{\xi}) \to \Phi_0 e^{i\boldsymbol{k}\cdot\boldsymbol{r}} + \Phi_0 f_{00}(\theta)\frac{e^{ikr}}{r} + \Phi_2 f_{20}(\theta)\frac{e^{ik'r}}{r}$$

$$\Psi^{(\varepsilon,I=2)}_{^{11}\mathrm{Be}}(\boldsymbol{r},\boldsymbol{\xi}) \to \Phi_2 e^{i\boldsymbol{k}'\cdot\boldsymbol{r}} + \Phi_0 f_{02}(\theta)\frac{e^{ikr}}{r} + \Phi_2 f_{22}(\theta)\frac{e^{ik'r}}{r}$$



Energy spectrum of n+^{10}Be

Discretized and Exact *T*-matrix in DWBA

✓ For the present purpose, we take the Distorted Wave Born Approximation (DWBA).

A. M. Moro and R. Crespo, Phys. Rev. C ***85****, 054613 (2012).*

Discretized *T*-matrix（Approximate） ※ with diagonalization

$$\hat{T}_{fi} = \left\langle \chi^{(-)}_{\boldsymbol{K}'}(\boldsymbol{R})\hat{\Psi}_f(\boldsymbol{r},\xi) \middle| V_{vt}(R_{vt}) + V_{ct}(\boldsymbol{R}_{ct},\xi) \middle| \chi^{(+)}_{\boldsymbol{K}}(\boldsymbol{R})\Psi_i(\boldsymbol{r},\xi) \right\rangle$$

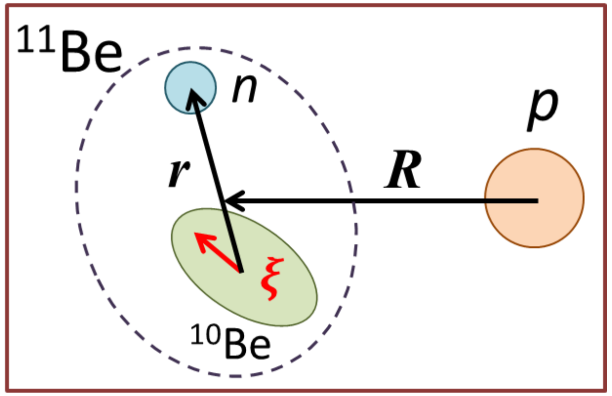
✓ $\hat{\sigma}^{(f)}_{\rm BU} \propto \left|\hat{T}_{fi}\right|^2$ is obtained.

compare

Continuum *T*-matrix（Exact） ※ with difference method

$$T_{fi}(\varepsilon) = \left\langle \chi^{(-)}_{\boldsymbol{K}'}(\boldsymbol{R})\Psi_{f[\varepsilon, I=0 \text{ or } 2]}(\boldsymbol{r},\xi) \middle| V_{vt}(R_{vt}) + V_{ct}(\boldsymbol{R}_{ct},\xi) \middle| \chi^{(+)}_{\boldsymbol{K}}(\boldsymbol{R})\Psi_i(\boldsymbol{r},\xi) \right\rangle$$

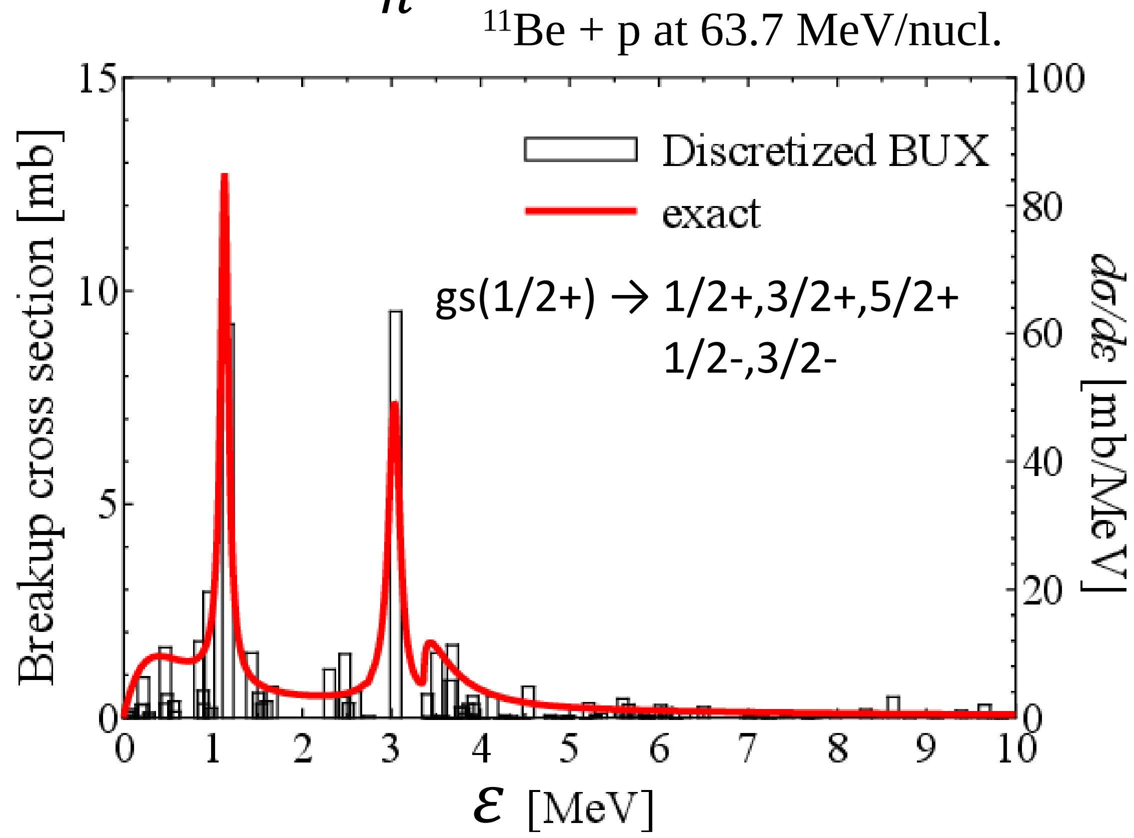
✓ $\dfrac{d\sigma^{(I=0)}_{\rm BU}}{d\varepsilon}, \dfrac{d\sigma^{(I=2)}_{\rm BU}}{d\varepsilon}$ are separately obtained.

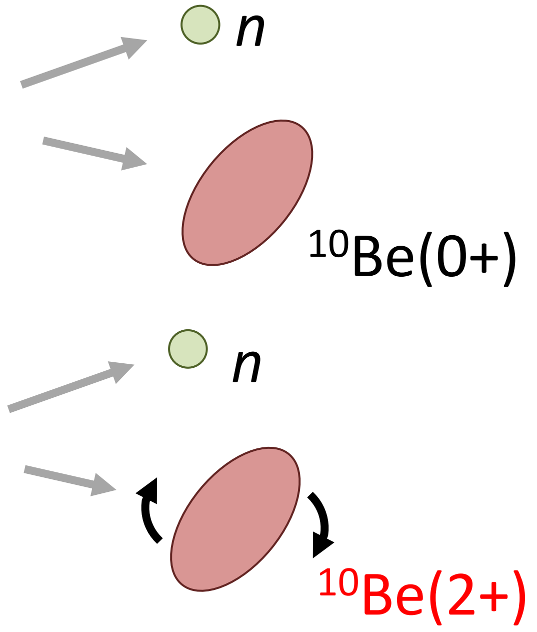


^{11}Be+*p* at 63.7 MeV/nucl.

Result 1 : Total BUX

$$\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})} = \sum_n \hat{\sigma}_n = 54.8\ \mathrm{mb} \qquad \sigma_{\mathrm{BU}}^{(\mathrm{tot})} = \int \frac{d\sigma}{d\varepsilon} d\varepsilon = 54.8\ \mathrm{mb}$$





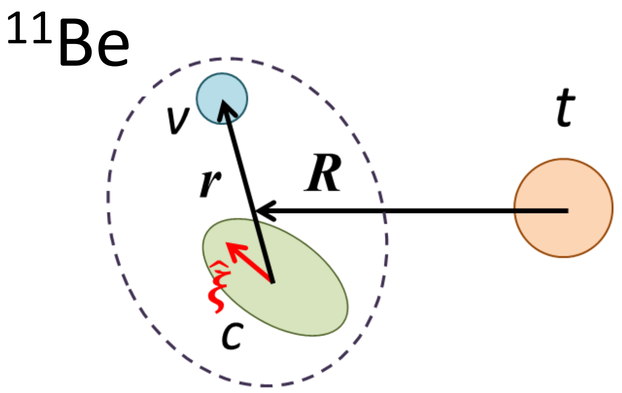
Components? $\sigma_{\mathrm{BU}}^{(0+)}$ & $\sigma_{\mathrm{BU}}^{(2+)}$

As for $\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})}$, we can obtain the same result. $\left(\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})} = \sigma_{\mathrm{BU}}^{(\mathrm{tot})}\right)$

How to separate $\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})}$? → Probability Separation "P-separation"

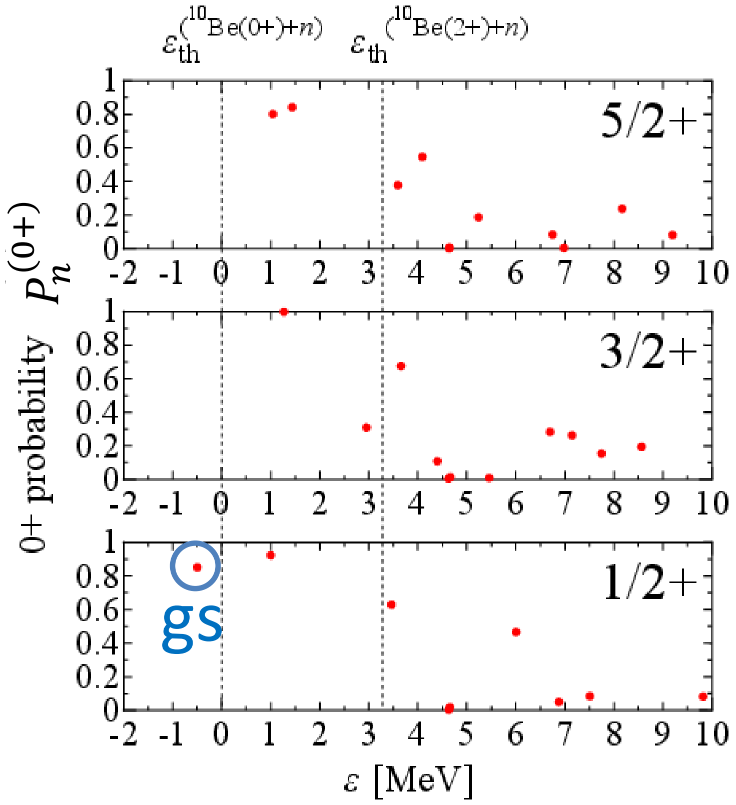
Projectile wf.

$$\widehat{\Psi}_{^{11}\mathrm{Be}}^{(n)}(\boldsymbol{r},\boldsymbol{\xi}) = \Phi_0(\boldsymbol{\xi})\hat{\psi}_0^{(n)}(\boldsymbol{r}) + \Phi_2(\boldsymbol{\xi})\hat{\psi}_2^{(n)}(\boldsymbol{r})$$



0+ probability

$$P_n^{(0+)} = \int d\boldsymbol{r} \left| \left\langle \Phi_0(\boldsymbol{\xi}) \middle| \widehat{\Psi}_{^{11}\mathrm{Be}}^{(n)}(\boldsymbol{r},\boldsymbol{\xi}) \right\rangle_{\xi} \right|^2$$



P-separation (Approx.)

$$\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})} = \Sigma_n \hat{\sigma}_n$$

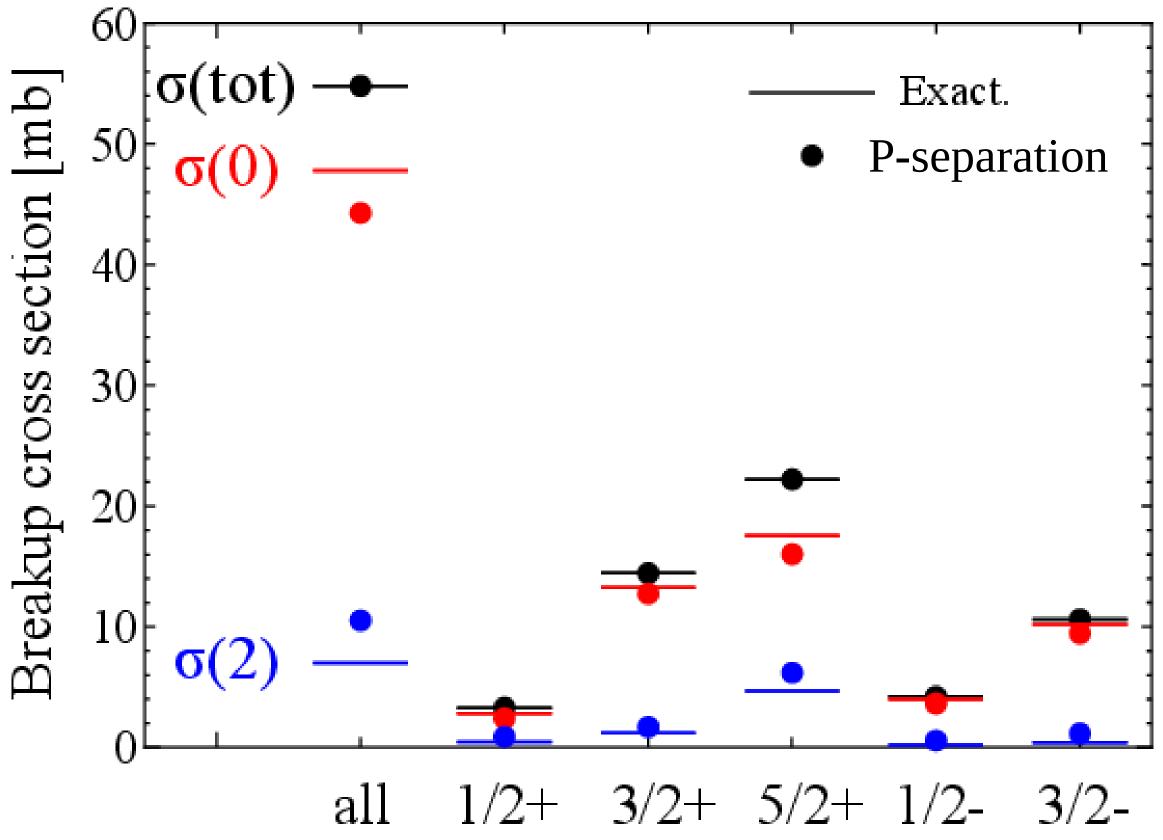
$$\hat{\sigma}_{\mathrm{BU}}^{(0+)} \approx \Sigma_n P_n^{(0+)} \hat{\sigma}_n$$

$$\hat{\sigma}_{\mathrm{BU}}^{(2+)} \approx \Sigma_n \left(1 - P_n^{(0+)}\right) \hat{\sigma}_n$$

$P_n^{(0+)} = 1$ for $\varepsilon_n \le \varepsilon_{\mathrm{th}}$

^{11}Be is not broken up into n+^{10}Be(2+) below $\varepsilon_{\mathrm{th}}$.

Result 2: Decomposition of discretized BUXs



DWBA analysis

^{11}Be+p at 63.7 MeV/nucl.

→ ^{10}Be(0+)+n+p

→ ^{10}Be(2+)+n+p

P-separation (Approx.)

$$\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})} = \Sigma_n \hat{\sigma}_n \qquad \left(P_n^{(0+)} = 1 \text{ for } \varepsilon_n \leq \varepsilon_{\mathrm{th}}\right)$$

$$\hat{\sigma}_{\mathrm{BU}}^{(0+)} \approx \Sigma_n P_n^{(0+)} \hat{\sigma}_n \qquad \hat{\sigma}_{\mathrm{BU}}^{(2+)} \approx \Sigma_n P_n^{(2+)} \hat{\sigma}_n$$

Almost identical

Exact solution

$$\sigma_{\mathrm{BU}}^{(\mathrm{tot})} = \int \frac{d\sigma}{d\varepsilon} d\varepsilon$$

$$\sigma_{\mathrm{BU}}^{(0+)} = \int \frac{d\sigma^{(0+)}}{d\varepsilon} d\varepsilon \qquad \sigma_{\mathrm{BU}}^{(2+)} = \int \frac{d\sigma^{(2+)}}{d\varepsilon} d\varepsilon$$

☺ Discretized BUXs ($\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})}$) are decomposed into each component ($\hat{\sigma}_{\mathrm{BU}}^{(0+)}$, $\hat{\sigma}_{\mathrm{BU}}^{(2+)}$) very well.

Validity of P-separation (Systematic analysis)

We perform a systematic analysis to validate the P-separation.

- ✓ The different configurations are prepared by changing V and/or ϵ_2.
- ✓ The potential is common for the ground and continuum states.

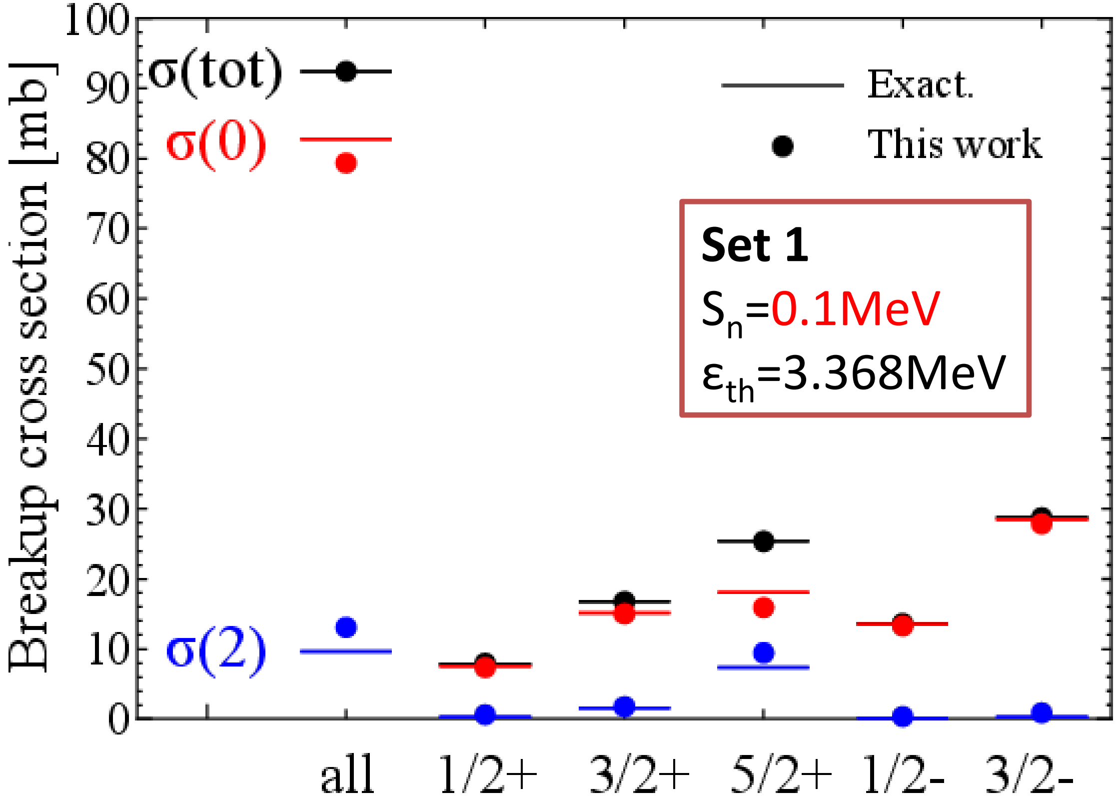
Table: Potential sets and the ground state properties

set	S_n	V_0	V_{so}	ϵ_2	$P_{gs}(0)$	$P_{gs}(2)$	
1	0.1	-51.924	-8.5	3.368	0.943	0.057	Weakly-bound gs
2	0.5	-54.45	-8.5	3.368	0.855	0.145	Original (done)
3	0.5	-52.988	-1.0	0.5	0.792	0.208	
4	1.0	-56.475	-8.5	3.368	0.788	0.212	
5	5.0	-67.059	-8.5	3.368	0.577	0.423	
6	5.0	-65.670	-1.0	0.5	0.545	0.455	Tightly-bound gs

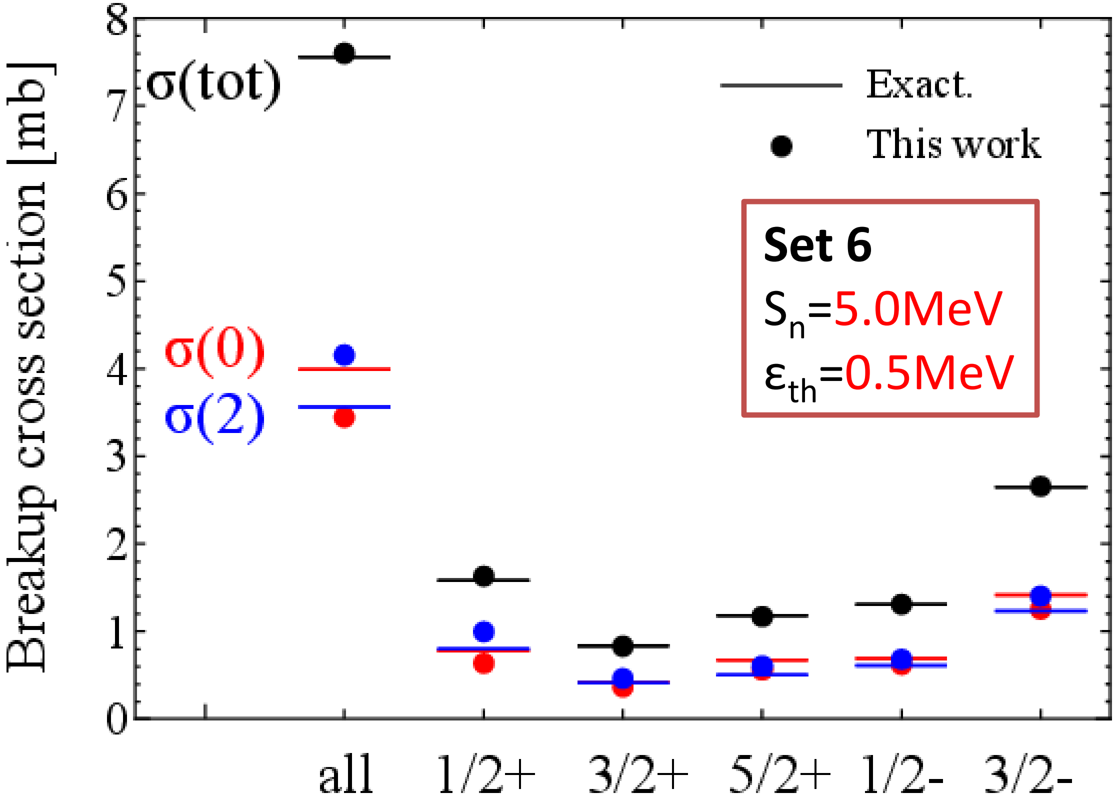
Potential: A. Deltuva et al., Phys. Rev. C 94, 044613 (2016)

Result 3 : Validity of the P-separation

Weakly binding



Tightly binding & Small ε_{th}



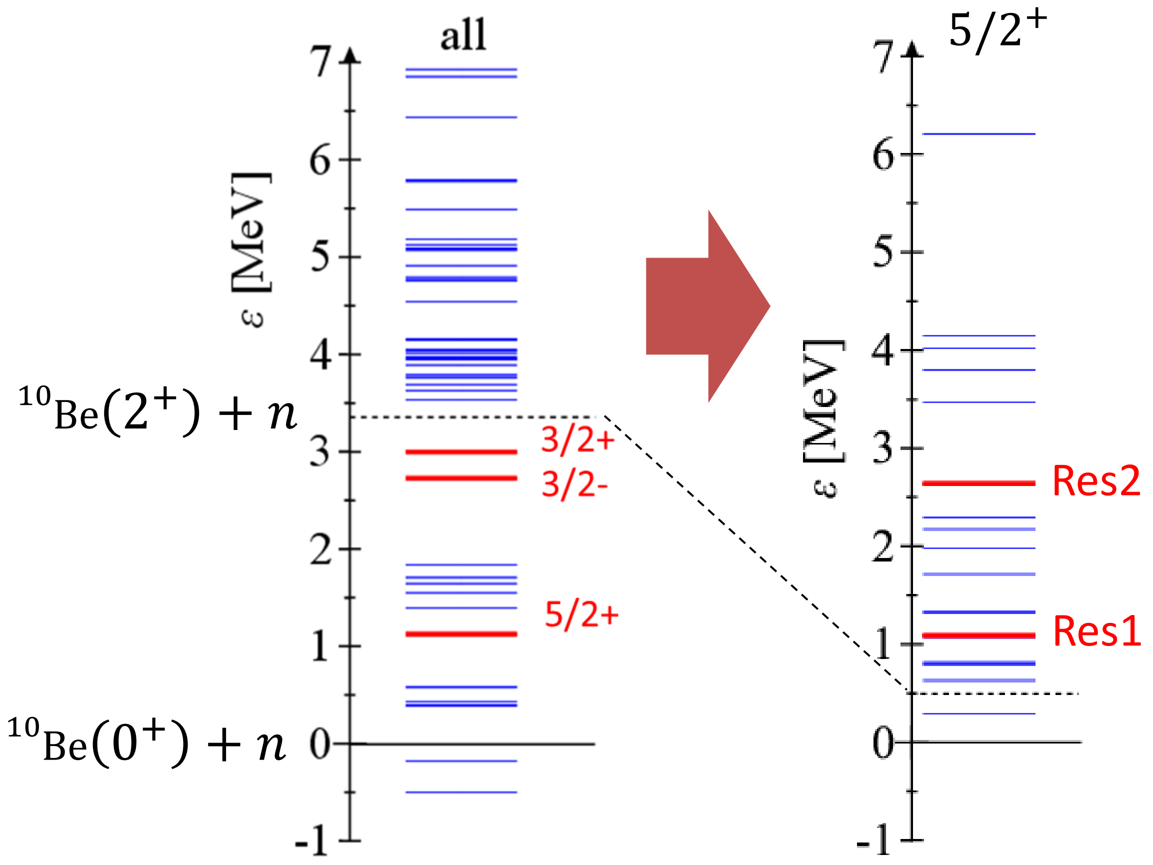
The P-separation works well regardless of the configurations.

Q. What will happen if the resonance(s) exists above ε_{th}?

So far

All the resonances appear below ε_{th}.

➢ The separation is trivial.



From now on

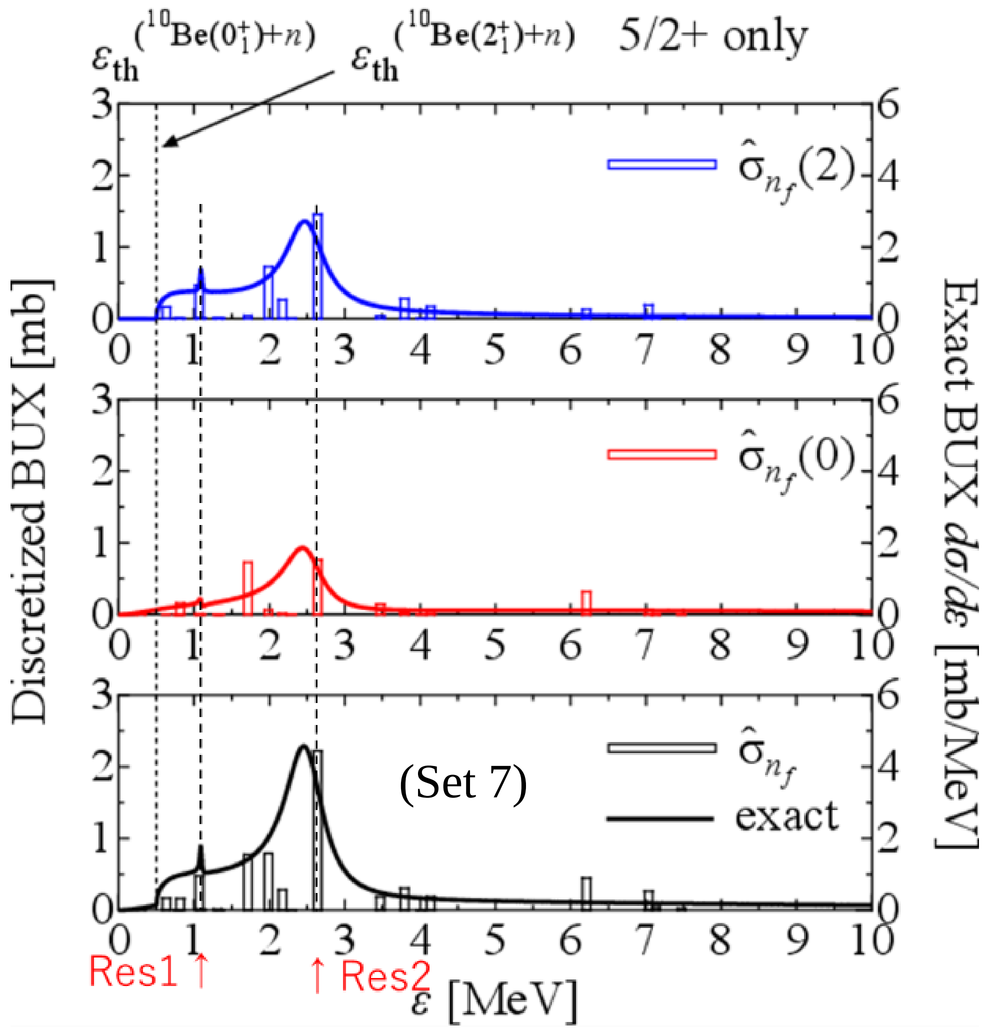
Is the P-separation still valid even if the resonance(s) exists above ε_{th}?

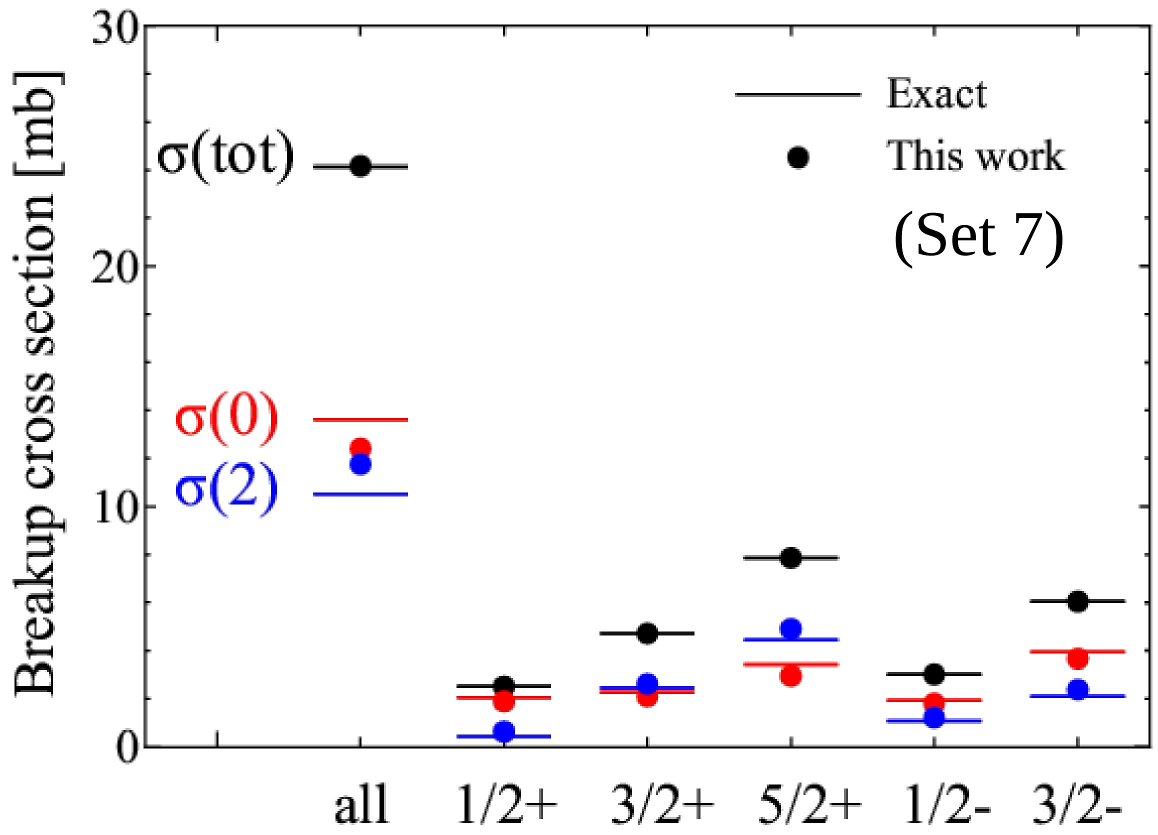
> To construct the resonances above ε_{th} in the 5/2+ state, we found that the deeper potential is necessary.

Depth : $V_0 = -54.45 \rightarrow -85.791$ MeV

Threshold : $\varepsilon_{th} = 3.368 \rightarrow 0.5$ MeV

P-separation with resonances above ε_{th}





✓ Two resonances make the characteristic peaks, respectively.

☺ The P-separation works well regardless of the resonance position.

Why P-separation works well? $P_n^{(0+)}$ vs $\Gamma_n^{(0+)}$

$P_n^{(0+)}$ ●
$\Gamma_n^{(0+)}$ ···□···

$\boldsymbol{P_n^{(0+)}}$ **:Proportion of the core-ground component**

$$P_n^{(0+)} \equiv \int d\boldsymbol{r} \left| \left\langle \Phi_0(\boldsymbol{\xi}) \middle| \widehat{\Psi}^{(n)}_{^{11}\mathrm{Be}}(\boldsymbol{r},\boldsymbol{\xi}) \right\rangle_{\xi} \right|^2$$

↑ Core-ground state ↑ n-th discretized state

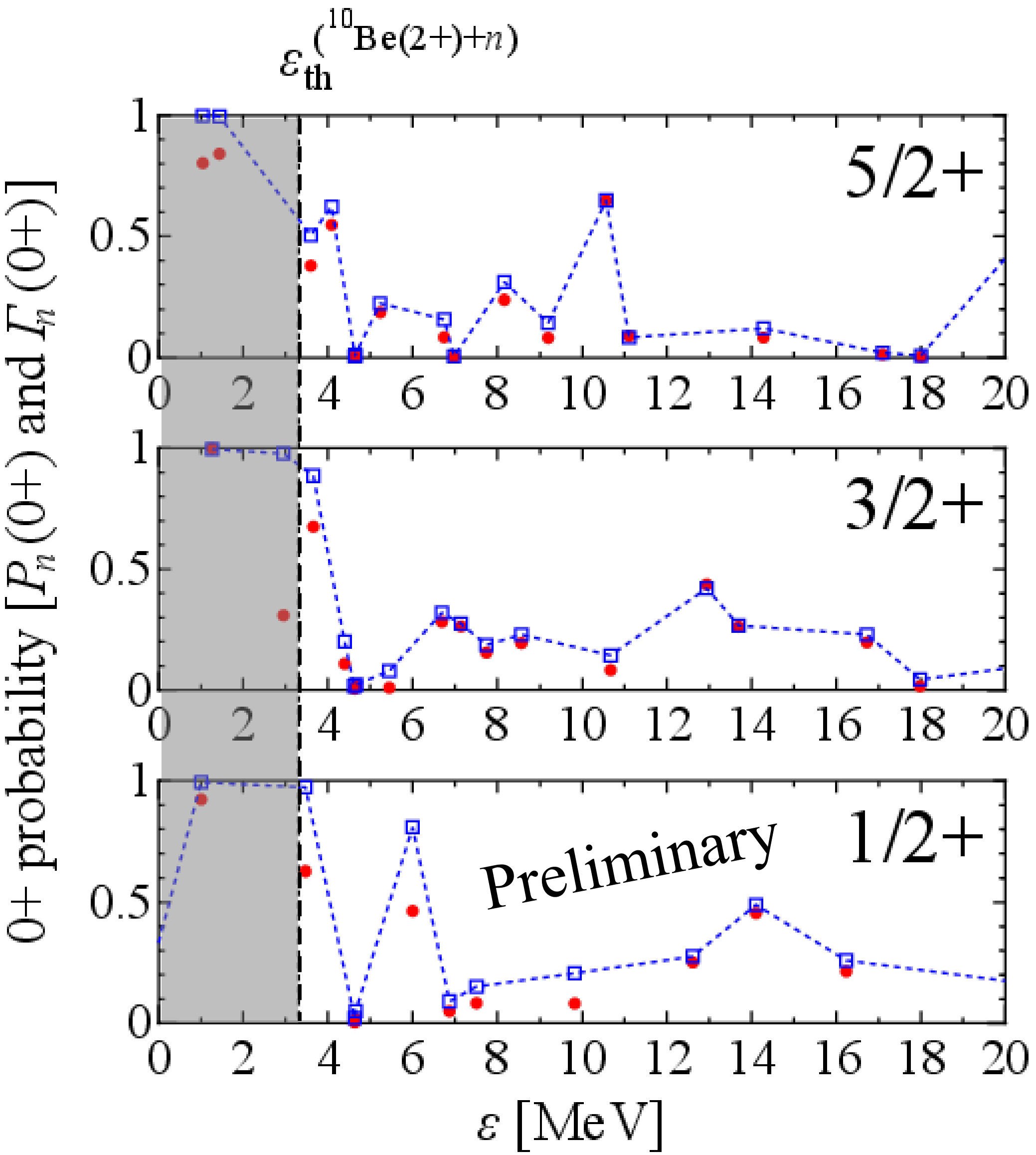
$$P_n^{(0+)} + P_n^{(2+)} = 1$$

$\boldsymbol{\Gamma_n^{(0+)}}$ **:Proportion of the core-ground channel**

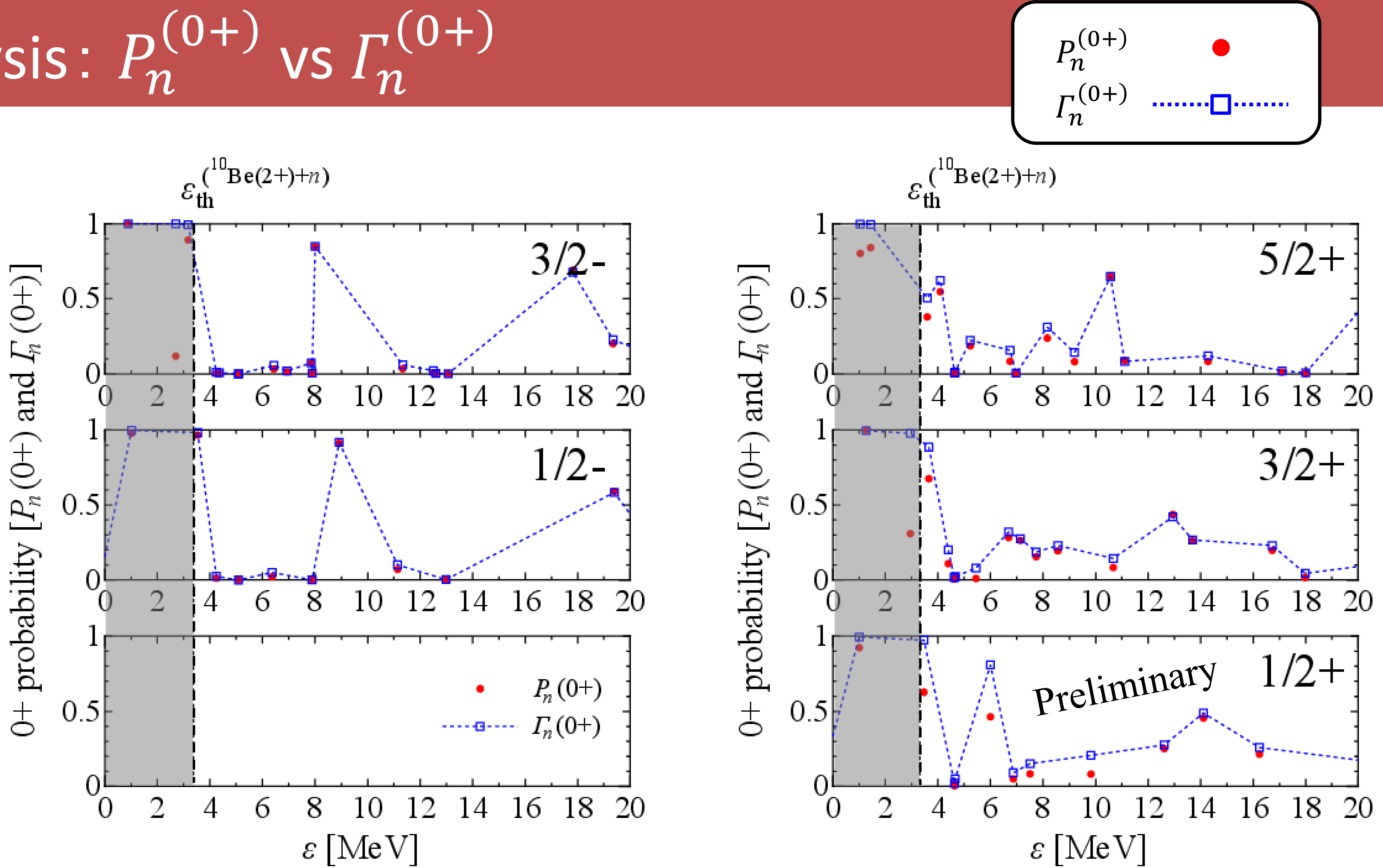
$$\Gamma_n^{(0+)} \equiv \int d\varepsilon \left| \left\langle \Psi_\varepsilon^{(lj,I=0)}(\boldsymbol{r},\boldsymbol{\xi}) \middle| \widehat{\Psi}^{(n)}_{^{11}\mathrm{Be}}(\boldsymbol{r},\boldsymbol{\xi}) \right\rangle \right|^2$$

↑ Exact continuum state ↑ n-th discretized state

$$\Gamma_n^{(0+)} + \Gamma_n^{(2+)} = 1$$

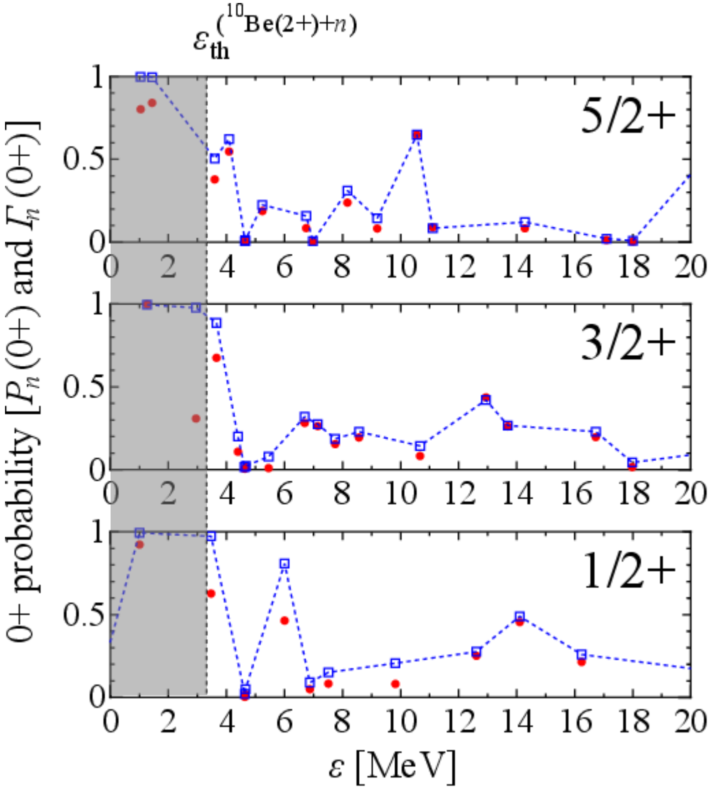


Analysis: $P_n^{(0+)}$ vs $\Gamma_n^{(0+)}$

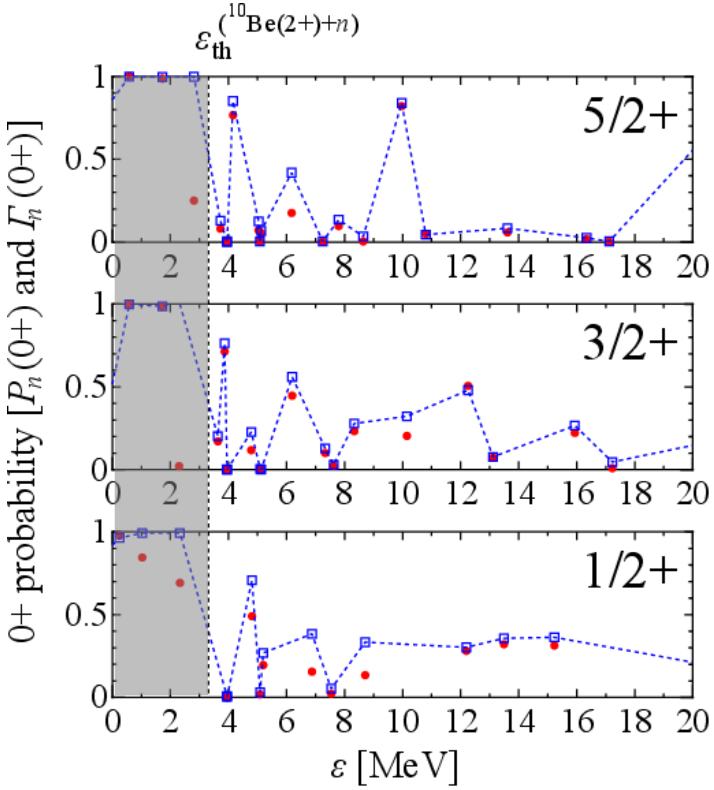


Different cases : $\Gamma_n^{(0+)}$ vs $P_n^{(0+)}$

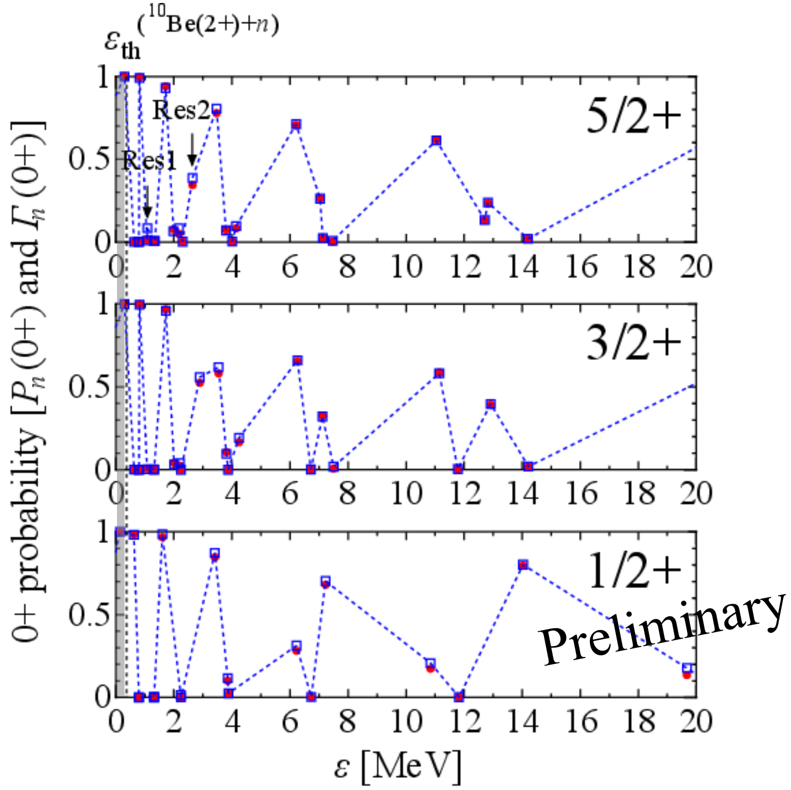
Set2 (original)



Set4（deeper *V*）



Set7 (deeper *V* & smaller ε_{th})



$P_n^{(0+)} \approx \Gamma_n^{(0+)}$ $(\varepsilon_n > \varepsilon_{th})$
is realized regardless of

- Potential parameters
- Deformation parameter β_2
- Basis parameters

Short summary

We have proposed an approximate treatment (P-separation)
for decomposing discretized BUXs.

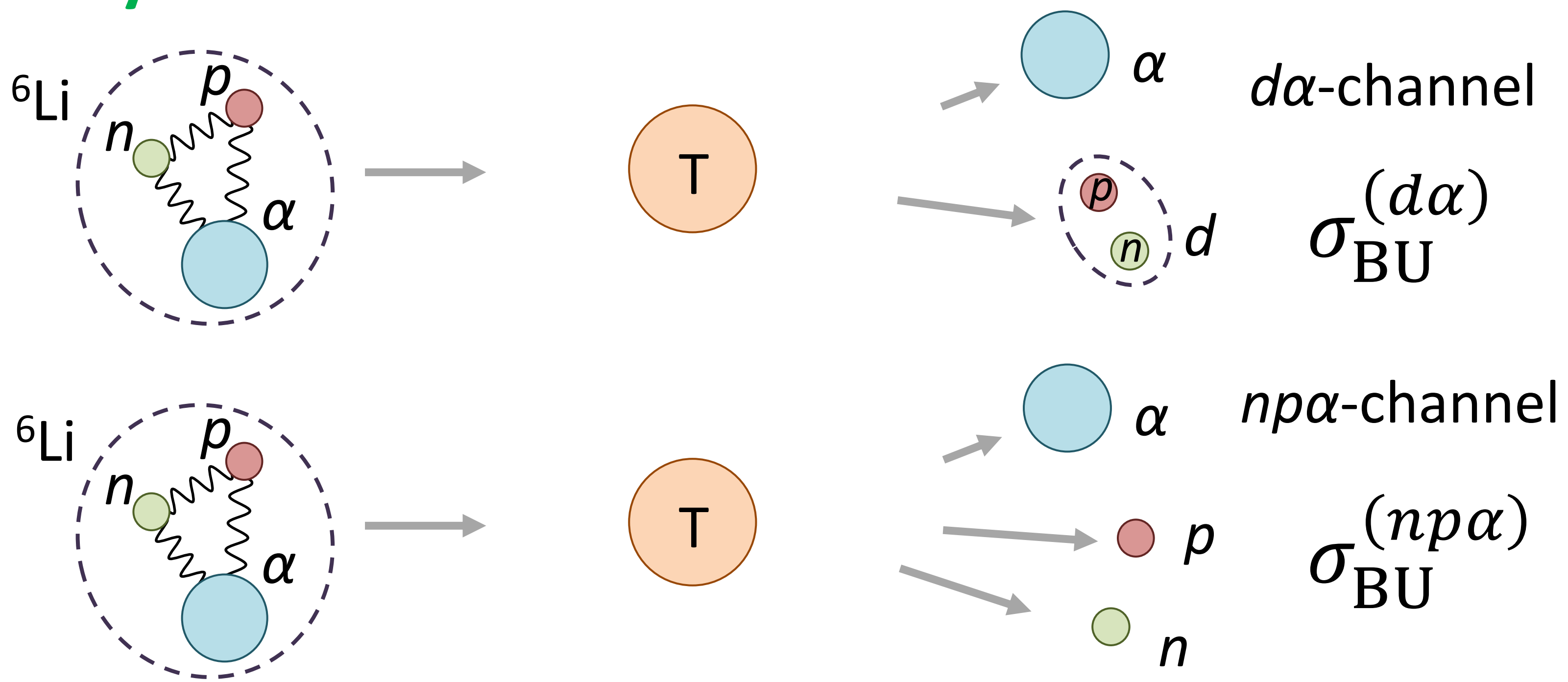
S. Watanabe, K. Ogata, and T. Matsumoto, PRC 103, L031601 (2021).

- ✓ We applied the P-separation to ^{11}Be scattering with core excitation.
  - ➢ ^{11}Be+T→^{10}Be(gs)+n+T and ^{11}Be+T→^{10}Be(2+)+n+T
- ✓ The P-separation reproduces the exact BUXs well regardless of the configurations and/or the resonance positions of ^{11}Be.
- ✓ We also found that $P_n^{(0+)} \approx \Gamma_n^{(0+)}$ is realized.

Application to four-body scattering

4-body BU reaction

4-body CDCC: *T. Matsumoto et al., PRC* ***70****, 061601(R) (2004).*



Application to four-body CDCC

We investigate dα- and npα-BUX of ^{6}Li scattering (n+p+α+T).

Low energy: ^{6}Li+^{208}Pb at 39 MeV

High energy: ^{6}Li+^{208}Pb at 210 MeV

Model

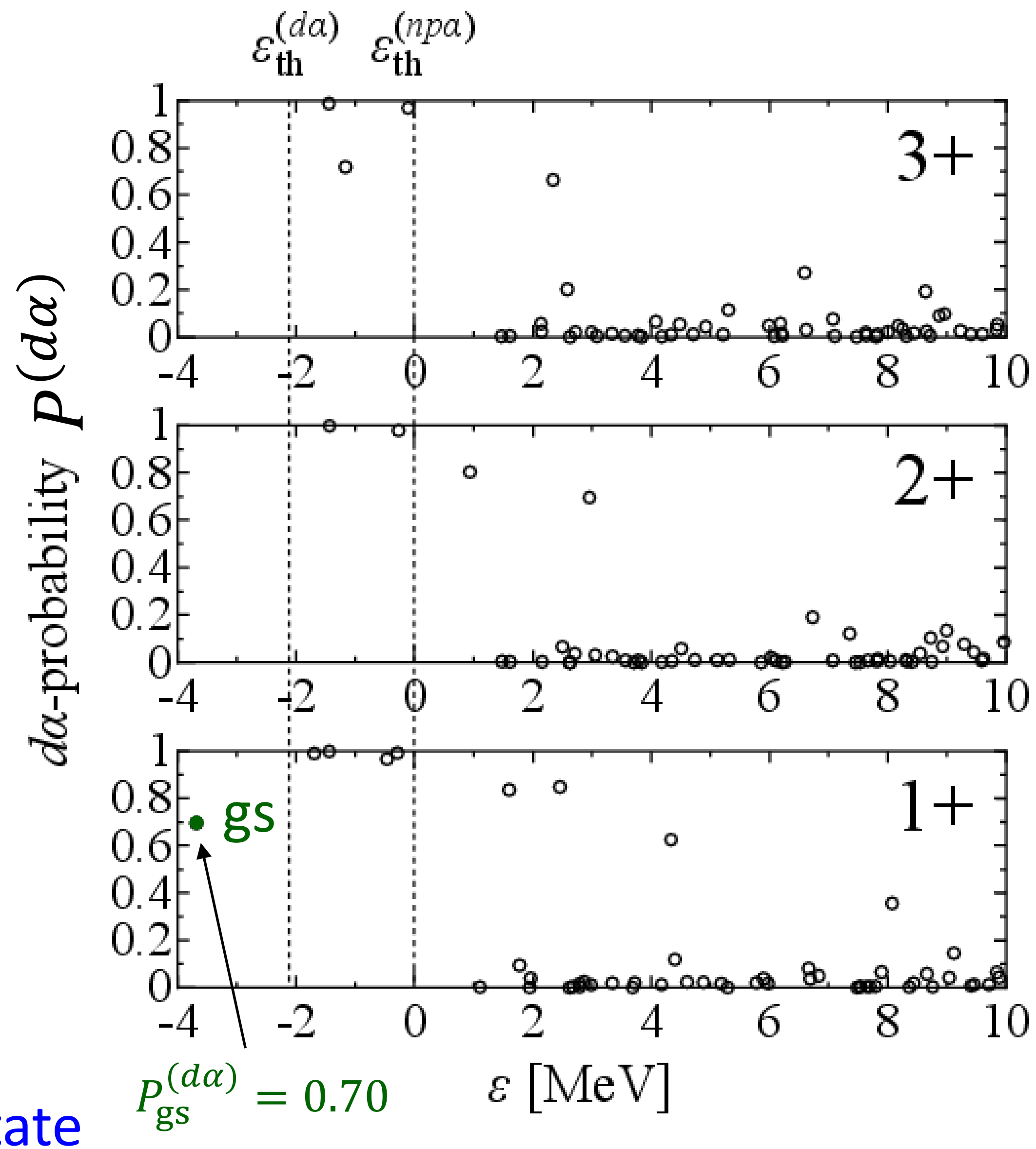
- ✓ 1+, 2+, and 3+ states are included
- ✓ Coulomb BU is neglected

Details: S. Watanabe et al., PRC ***92****, 044611 (2015).*

dα-probability

$$P_n^{(d\alpha)} = \int d\boldsymbol{r} \left| \left\langle \Phi_d(\boldsymbol{y}) \middle| \hat{\Psi}^{(n)}_{^6\mathrm{Li}}(\boldsymbol{r},\boldsymbol{y}) \right\rangle_{\boldsymbol{y}} \right|^2$$

Deuteron g.s.↑ ↑Three-body pseudostate



$d\alpha$-BUX $\hat{\sigma}_{\mathrm{BU}}^{(d\alpha)}$ and $np\alpha$-BUX $\hat{\sigma}_{\mathrm{BU}}^{(np\alpha)}$

^{6}Li+^{208}Pb scattering

	$\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})}$[mb]	$\hat{\sigma}_{\mathrm{BU}}^{(d\alpha)}$[mb]	$\hat{\sigma}_{\mathrm{BU}}^{(np\alpha)}$[mb]
39 MeV	68.7	45.3	23.4
210 MeV	137	89.9	47.1

$$\hat{\sigma}_{\mathrm{BU}}^{(d\alpha)} \approx 2\hat{\sigma}_{\mathrm{BU}}^{(np\alpha)}$$

Almost comparable

P-separation（Approx.）

$$\hat{\sigma}_{\mathrm{BU}}^{(\mathrm{tot})} = \Sigma_n \hat{\sigma}_n$$

$$\hat{\sigma}_{\mathrm{BU}}^{(d\alpha)} \approx \Sigma_n P_n^{(d\alpha)} \hat{\sigma}_n$$

$$\hat{\sigma}_{\mathrm{BU}}^{(np\alpha)} \approx \Sigma_n \left(1 - P_n^{(d\alpha)}\right) \hat{\sigma}_n$$

$$P_n^{(d\alpha)} = 1 \text{ for } \varepsilon_n \leq \varepsilon_{\mathrm{th}}^{(np\alpha)}$$

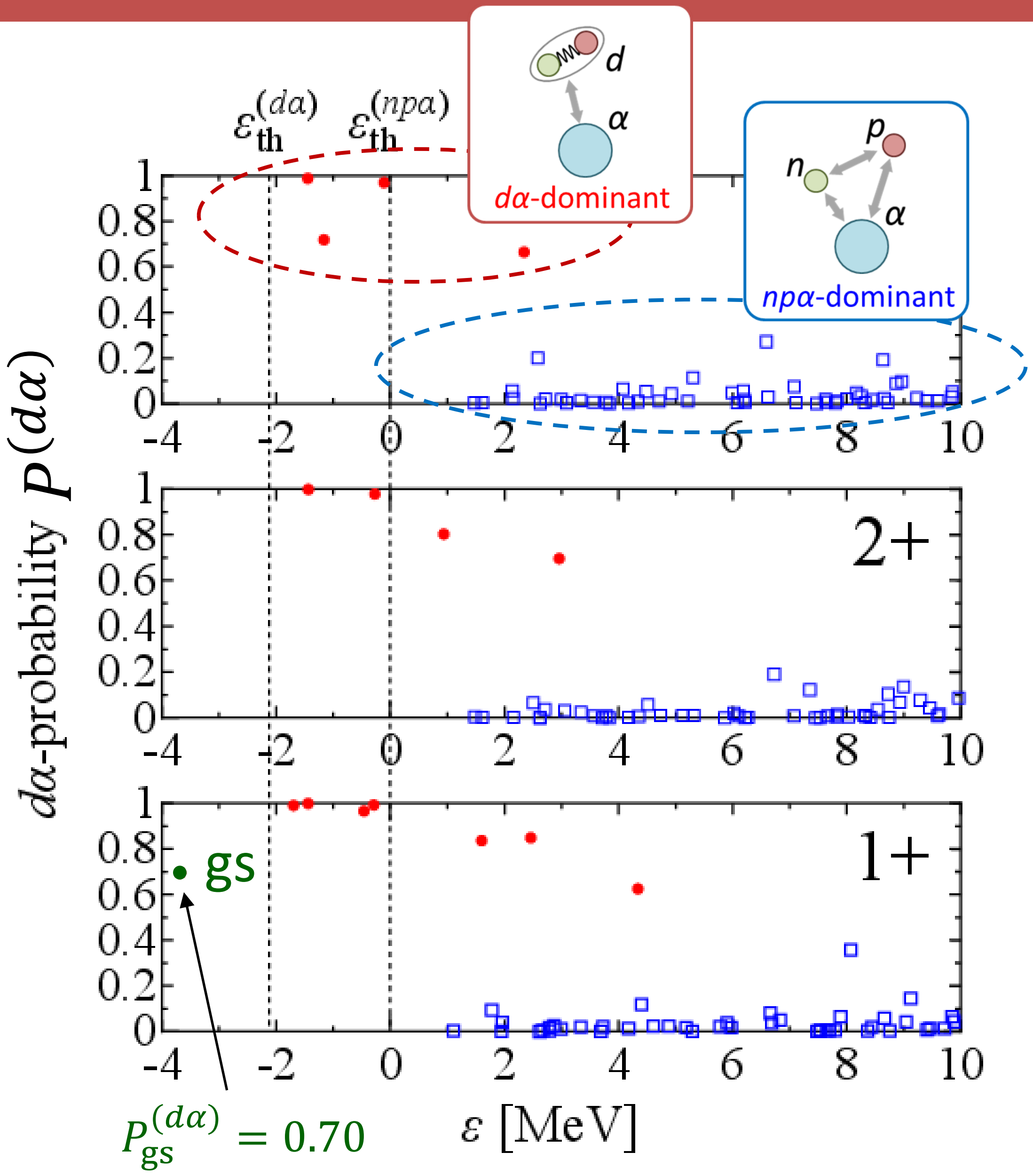
This appears to contradict with the findings in the previous work:

"four-body channel coupling is negligible in the elastic scattering"

(^{6}Li+T ↔ n+p+α+T)

*S. Watanabe et al., PRC **92**, 044611 (2015).*

Three- and four-body channel-coupling effect on the elastic scattering



S. Watanabe, T. Matsumoto, K. Ogata, and M. Yahiro, PRC ***92****, 044611 (2015).*

■ Categorize BU states

- ➢ *dα*-dominant state $|d\alpha\rangle_i$ 15 states

  $|\mathrm{BU}\rangle_i$ with $P_i^{(d\alpha)} > 0.5$

- ➢ *npα*-dominant state $|np\alpha\rangle_j$ 140 states

  $|\mathrm{BU}\rangle_j$ with $P_j^{(d\alpha)} \leq 0.5$

Note

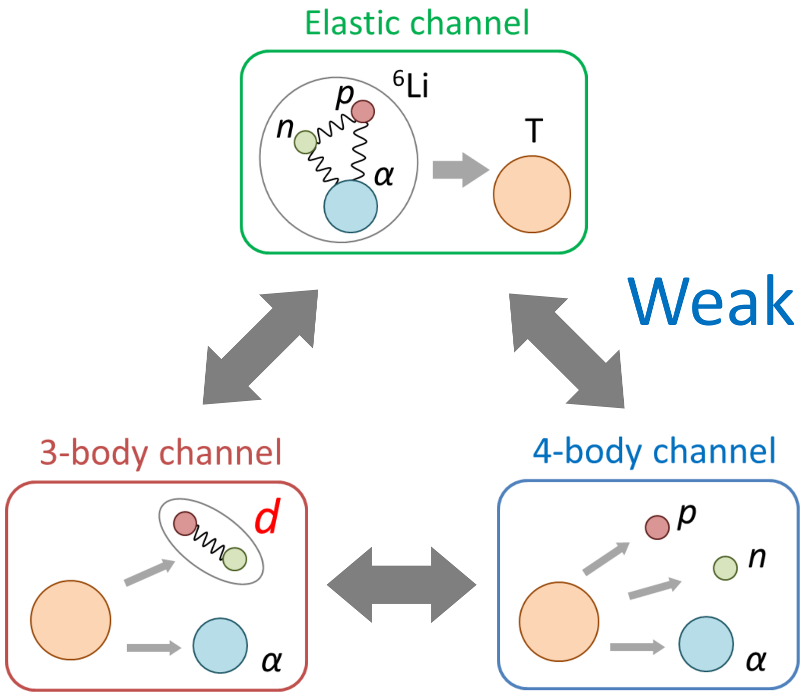
The number of npα-dominant states is much more than that of dα-dominant states.

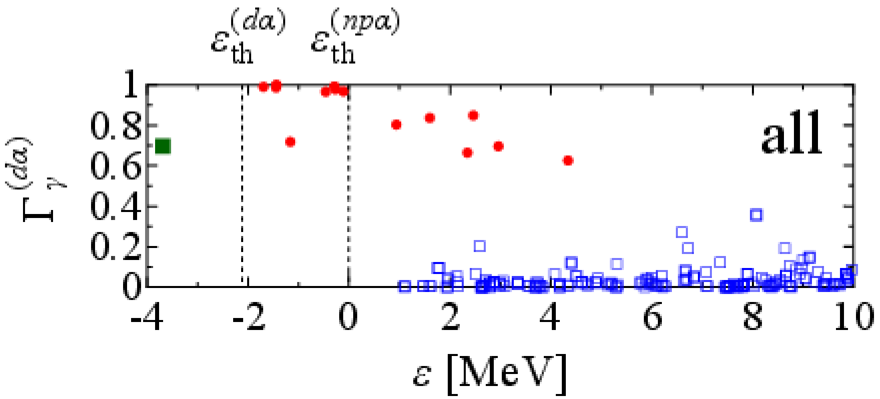
We investigate the channel-coupling effects by switching on and off

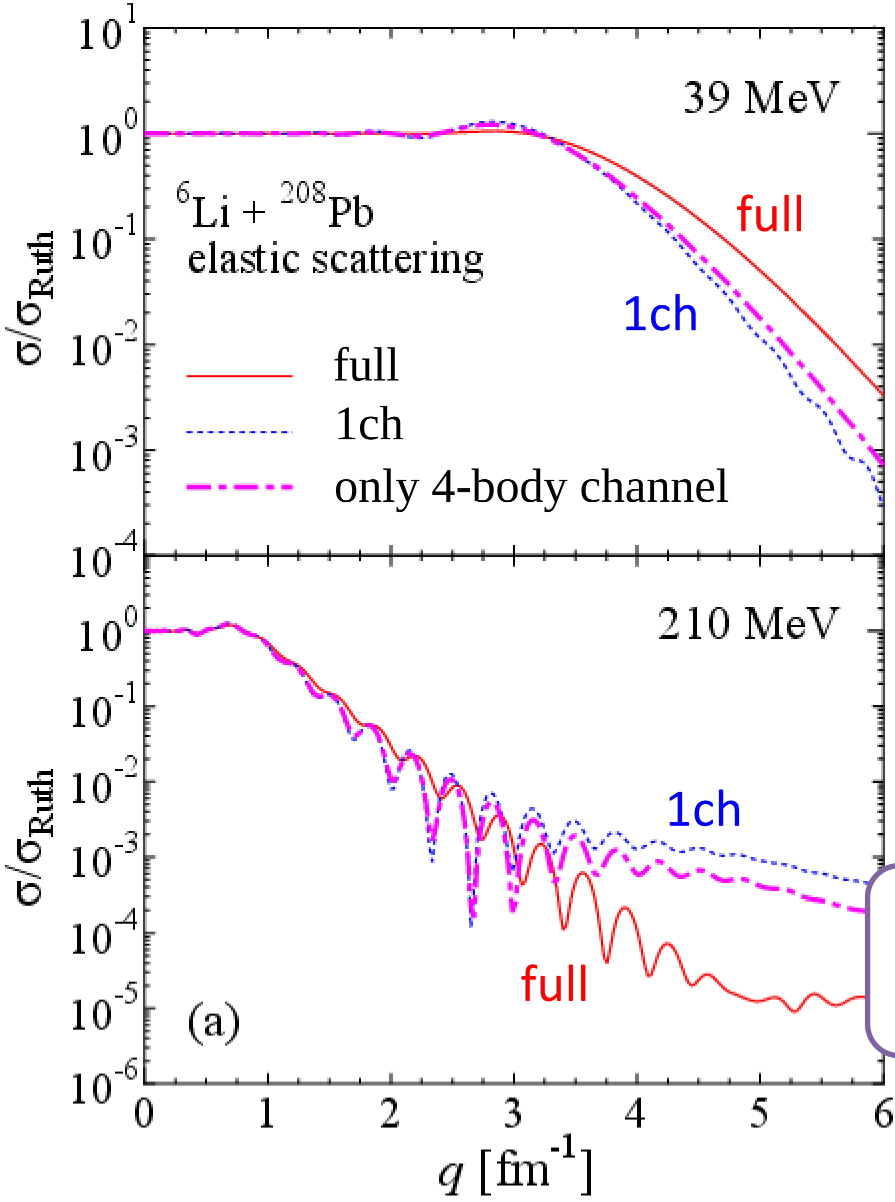
- three-body channel (^{6}Li+T↔n+p+α+T)
- four-body channel (^{6}Li+T↔n+p+α+T)

Four-body channel-coupling effect

Channel coupling



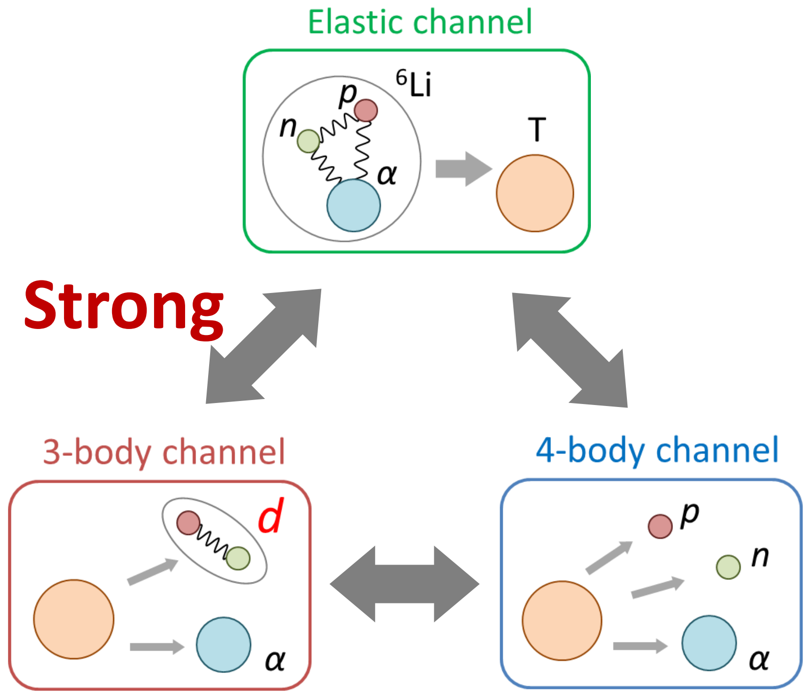


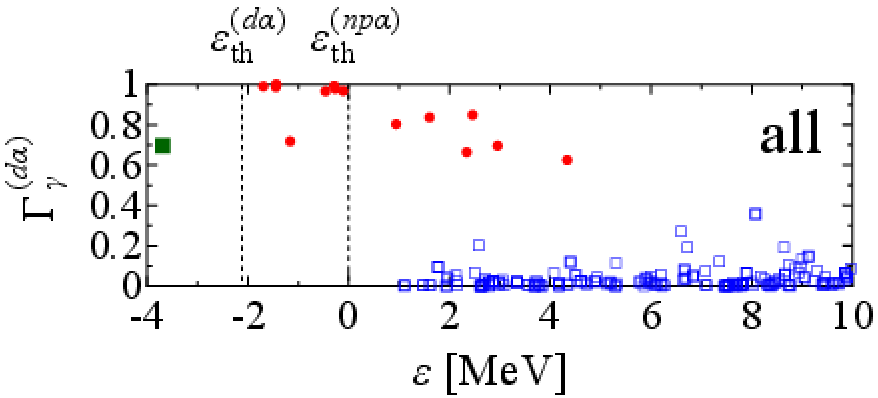


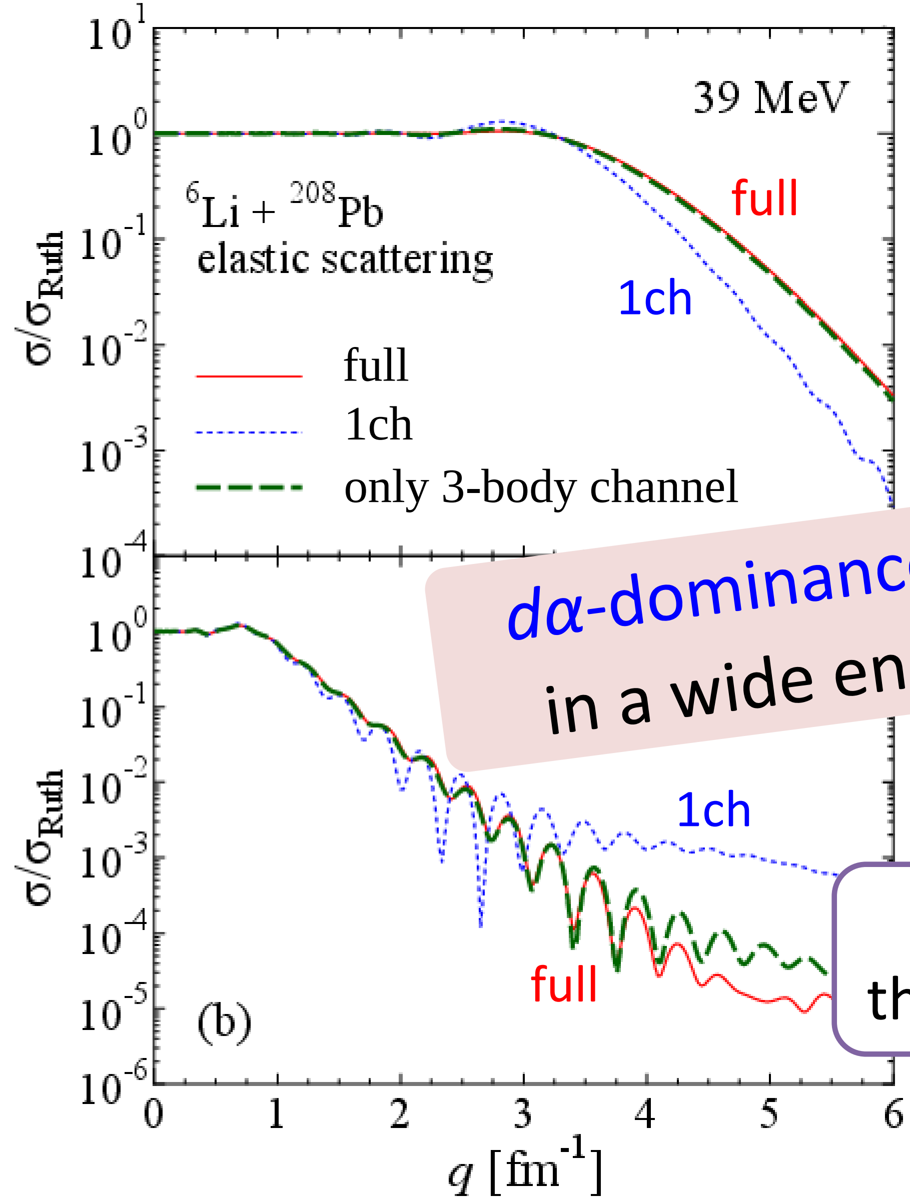
The results differ little from 1ch calculations.

Three-body channel-coupling effect

Channel coupling







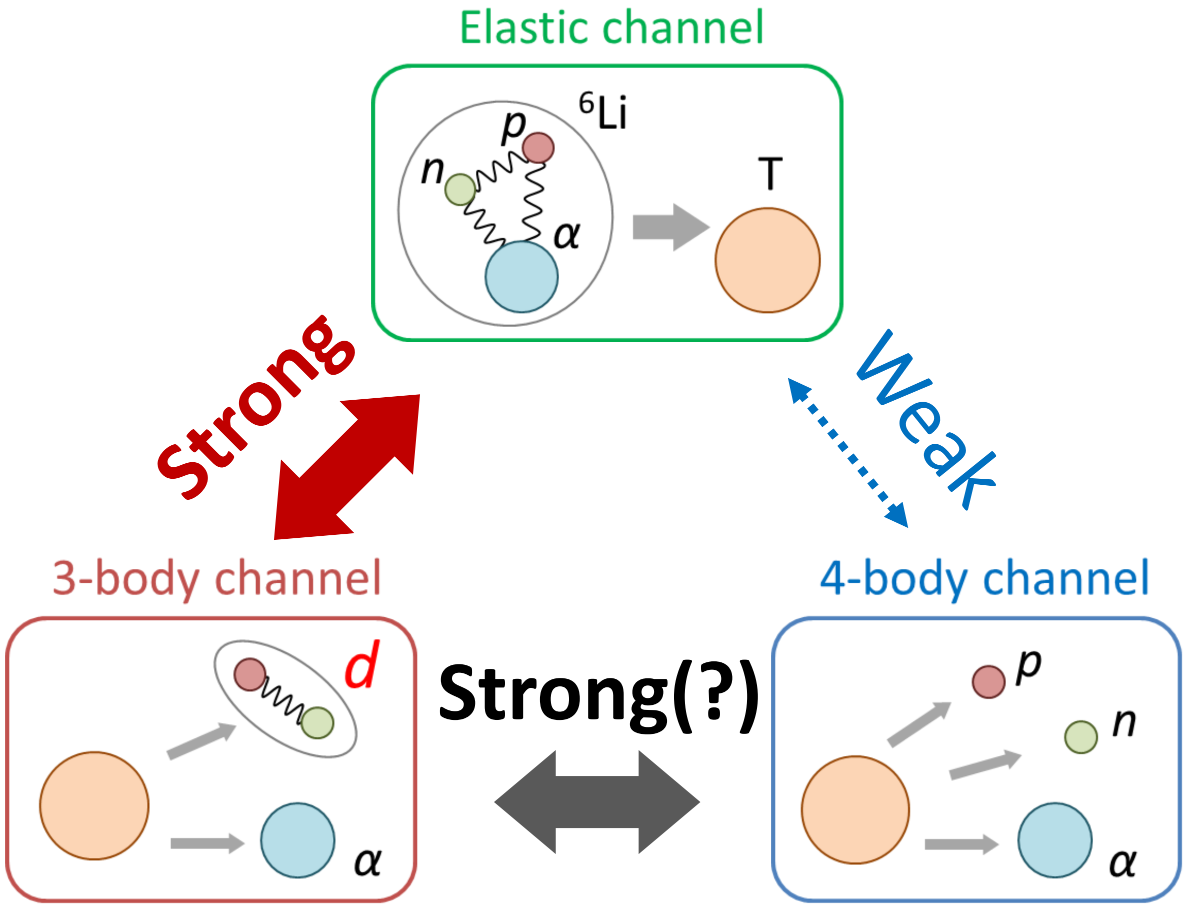
dα-dominance is realized in a wide energy range.

The results simulate the full calculations well.

Channel-coupling strength

What is happening in ^{6}Li scattering?

^{6}Li may be broken up into three particles after breaking up into two clusters.
(^{6}Li → d+α → n+p+α)



$$\sigma_{\mathrm{BU}}^{(d\alpha)} \approx 2\sigma_{\mathrm{BU}}^{(np\alpha)}$$

Summary

We have proposed an approximate treatment (P-separation) for decomposing discretized BUXs.

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✓ We applied the P-separation to ^{11}Be scattering with core excitation.

- ^{11}Be+T→^{10}Be(gs)+n+T→^{10}Be(2+)+n+T

✓ The P-separation reproduces the exact BUXs well regardless of the configurations and/or the resonance positions of ^{11}Be.

✓ We also found that $P_n^{(0+)} \approx \Gamma_n^{(0+)}$ is realized.

This method can be an alternative approach for decomposing discretized BUXs into components in four- or five-body scattering where the strict decomposition is hard to perform.