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Comparison between ^{9}Li and ^{10}Be nuclei from view point of nuclear structure and reaction

Takenori Furumoto

(Yokohama National University)

Collaborators
T. Suhara (Matsu College of Technology)
N. Itagaki (YITP, Kyoto Univ.)

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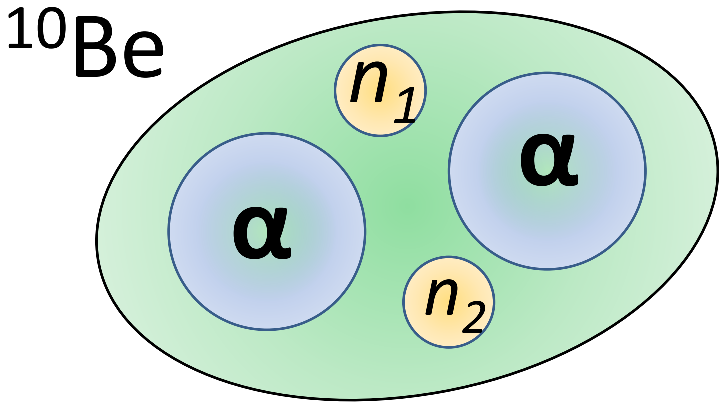
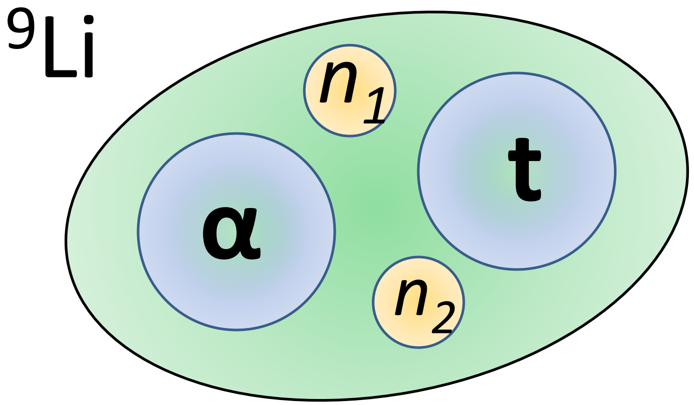
- ***Stochastic Multi-configuration mixing Method***
  - Excitation energy & Radius & Transition strength

- ***Microscopic Coupled Channel (MCC) Method with complex G-matrix interaction***
  - Channel Coupling (CC) effects

- ***Summary***

Comparison of ^{10}Be and ^{9}Li nuclei





The ^{10}Be and ^{9}Li nuclei are well described by assuming the α+α(t)+n+n 4-body cluster model.

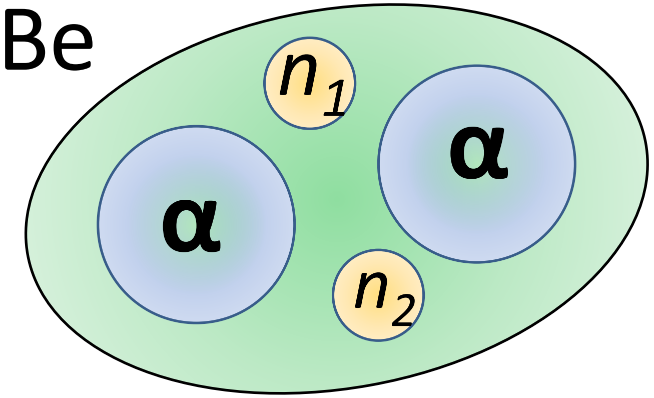
N. Itagaki and S. Okabe, PRC61, 044306 (2000),
K. Arai et. al., PTPS142, 97 (2001),
Y. En'yo and T. Suhara, PRC85, 024303 (2012), and so on.

The similarity of them is often discussed from the view point of **the nuclear structure**.

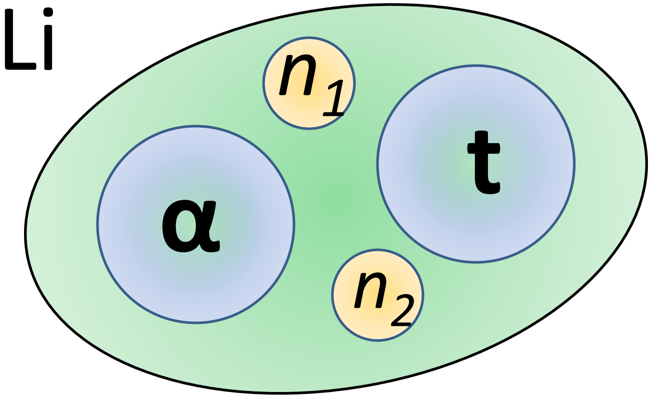
T. Suhara and Y. En'yo, PTP123, 303 (2010),
T. Furumoto, T. Suhara and N. Itagaki, PRC87, 064320 (2013)
Y. En'yo, arXiv 1604.01453 (2016)

Comparison of ^{10}Be and ^{9}Li nuclei

^{10}Be



^{9}Li



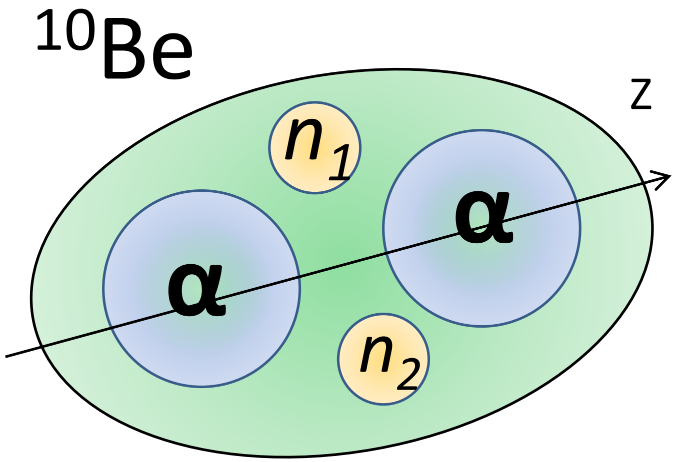
However, the similarity and/or dissimilarity of them are **NOT** discussed from the view point of **the nuclear reaction**.

- Mass is different

- Coulomb strength is different

⇨ We try it!

Formalism (Structure)



Brink model + Stochastic multi-configuration mixing

$$\Phi^{J^\pi M} = \sum_K \sum_i c_{i,K} \Psi_i^{J^\pi MK}$$

Randomly fixed

$$\Psi_i^{J^\pi MK} = P^\pi P^{JMK} [A\{\phi_\alpha(\mathbf{r}_1\mathbf{r}_2\mathbf{r}_3\mathbf{r}_4,\mathbf{R}_1)\phi_\alpha(\mathbf{r}_5\mathbf{r}_6\mathbf{r}_7\mathbf{r}_8,\mathbf{R}_2)\phi_{n_1}(\mathbf{r}_9,\mathbf{R}_3)\phi_{n_2}(\mathbf{r}_{10},\mathbf{R}_4)\}]$$

$$\phi(\mathbf{r}_j,\mathbf{R}_k) = \exp\left[-\nu\left(\mathbf{r}_j - \frac{\mathbf{R}_k}{\sqrt{\nu}}\right)^2\right]\chi_j$$

χ_j : spin and isospin parts

Hamiltonian

$$\hat{H} = \sum_{i=1}^{A} \hat{t}_i - \hat{T}_{c.m.} + \sum_{i>j}^{A} \hat{v}_{ij}$$

Effective *NN* interaction

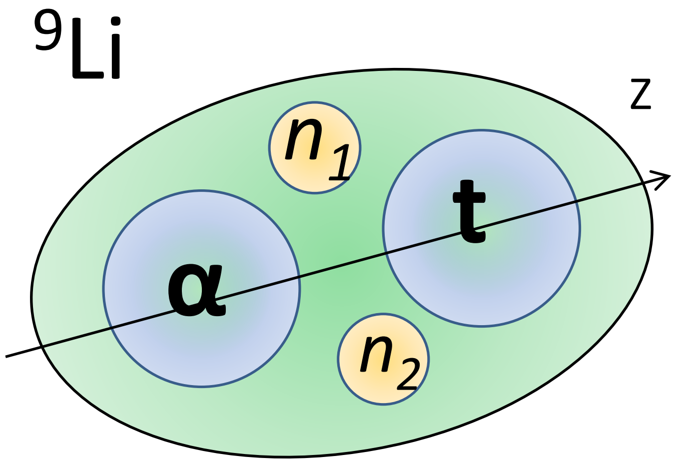
Central : Volkov No.2 (W=1-M)
LS : G3RS (V_{LS}=2000MeV)

$\nu = 0.235$

$M = 0.60$

$B = H = 0.08$

Formalism (Structure)



Brink model + Stochastic multi-configuration mixing

$$\Phi^{J^\pi M} = \sum_K \sum_i c_{i,K} \Psi_i^{J^\pi MK}$$

Randomly fixed

$$\Psi_i^{J^\pi MK} = P^\pi P^{JMK} [A\{\phi_\alpha(\mathbf{r}_1\mathbf{r}_2\mathbf{r}_3\mathbf{r}_4, \mathbf{R}_1)\phi_t(\mathbf{r}_5\mathbf{r}_6\mathbf{r}_7, \mathbf{R}_2)\phi_{n_1}(\mathbf{r}_8, \mathbf{R}_3)\phi_{n_2}(\mathbf{r}_9, \mathbf{R}_4)\}]$$

$$\phi(\mathbf{r}_j, \mathbf{R}_k) = \exp\left[-\nu\left(\mathbf{r}_j - \frac{\mathbf{R}_k}{\sqrt{\nu}}\right)^2\right]\chi_j$$

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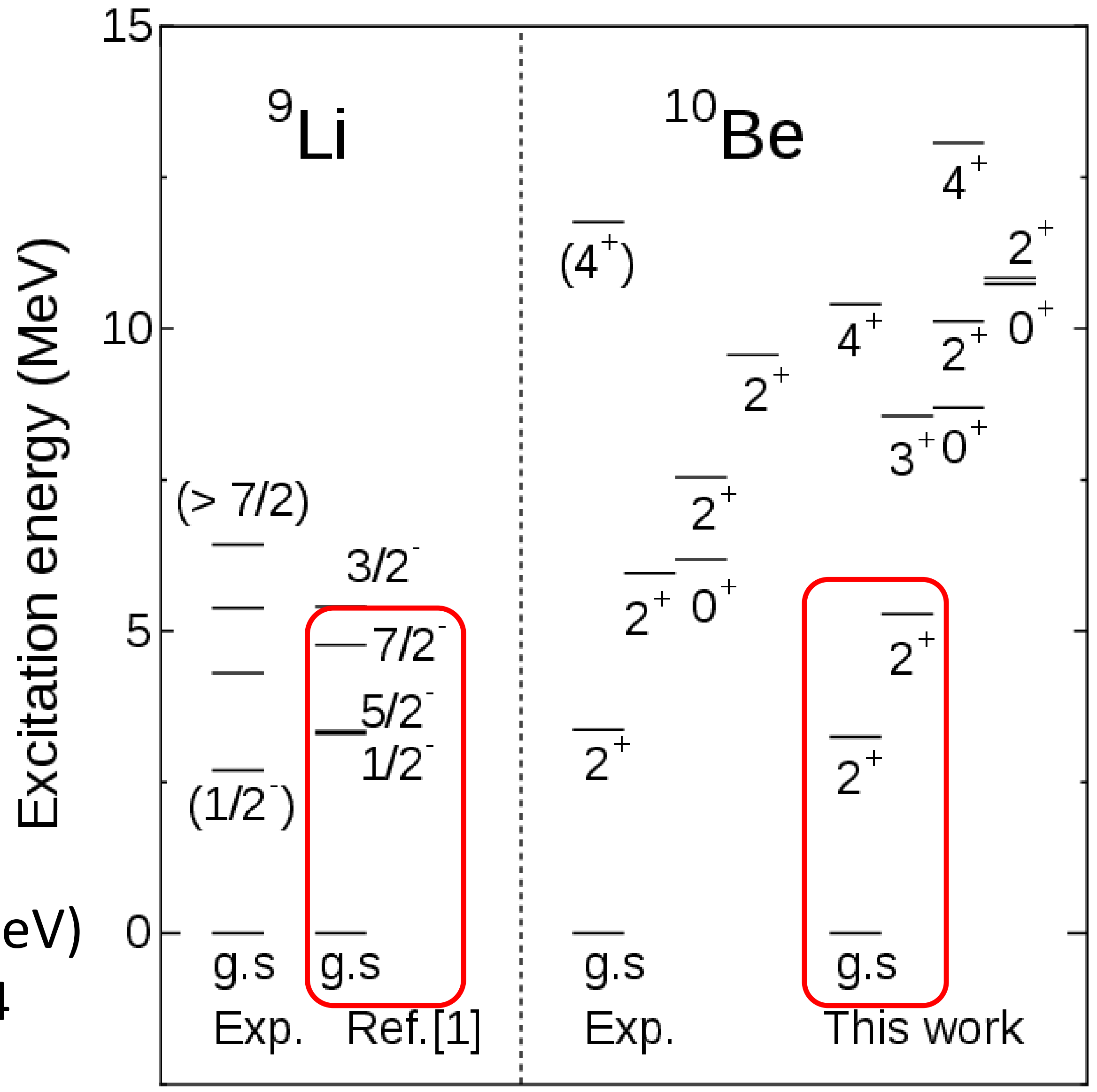
Excitation energy

BE (MeV)
-41.04



BE (MeV)
-62.74

Radius & transition strength

^{9}Li

Theory

Radius 2.459 fm

B(IS2) ($1/2_1 \rightarrow$g.s) 38.51 fm^4

($5/2_1 \rightarrow$g.s) 12.79 fm^4

($7/2_1 \rightarrow$g.s) 15.78 fm^4

Experiment

Radius 2.3-2.5 fm [1,2]

[1] I. Tanihata et al., PLB206, 592 (1998)
[2] A. V. Dobrovolsky et al., NPA766, 1 (2006)

^{10}Be

Theory

Radius 2.559 fm

B(IS2) ($2_1 \rightarrow$g.s) 46.84 fm^4

($2_2 \rightarrow$g.s) 0.3551 fm^4

B(E2) ($2_1 \rightarrow$g.s) 11.27 e^2fm^4

($2_1 \rightarrow 0_2$) 0.29 e^2fm^4

($2_2 \rightarrow$g.s) 0.7429 e^2fm^4

Experiment

Radius 2.3-2.5 fm [1,3,4]

B(E2) ($2_1 \rightarrow$g.s) 10.24 ± 0.97 e^2fm^4 [5]

($2_1 \rightarrow 0_2$) 0.64 ± 0.23 e^2fm^4 [5]

[3] E. Liatard et al., Europhys. Lett. 13, 401 (1990)
[4] R.E. Warner, et al., PRC64, 044611 (2001)
[5] F. Ajzenberg-Selvo and J.H. Kelley, NPA506, 1 (1990)

Formalism (Reaction)

Microscopic Coupled Channel (MCC)

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

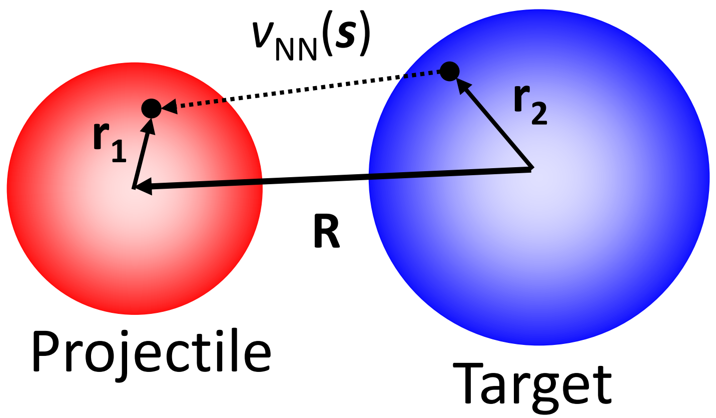
The diagonal and coupling potentials are derived from microscopic view point.

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

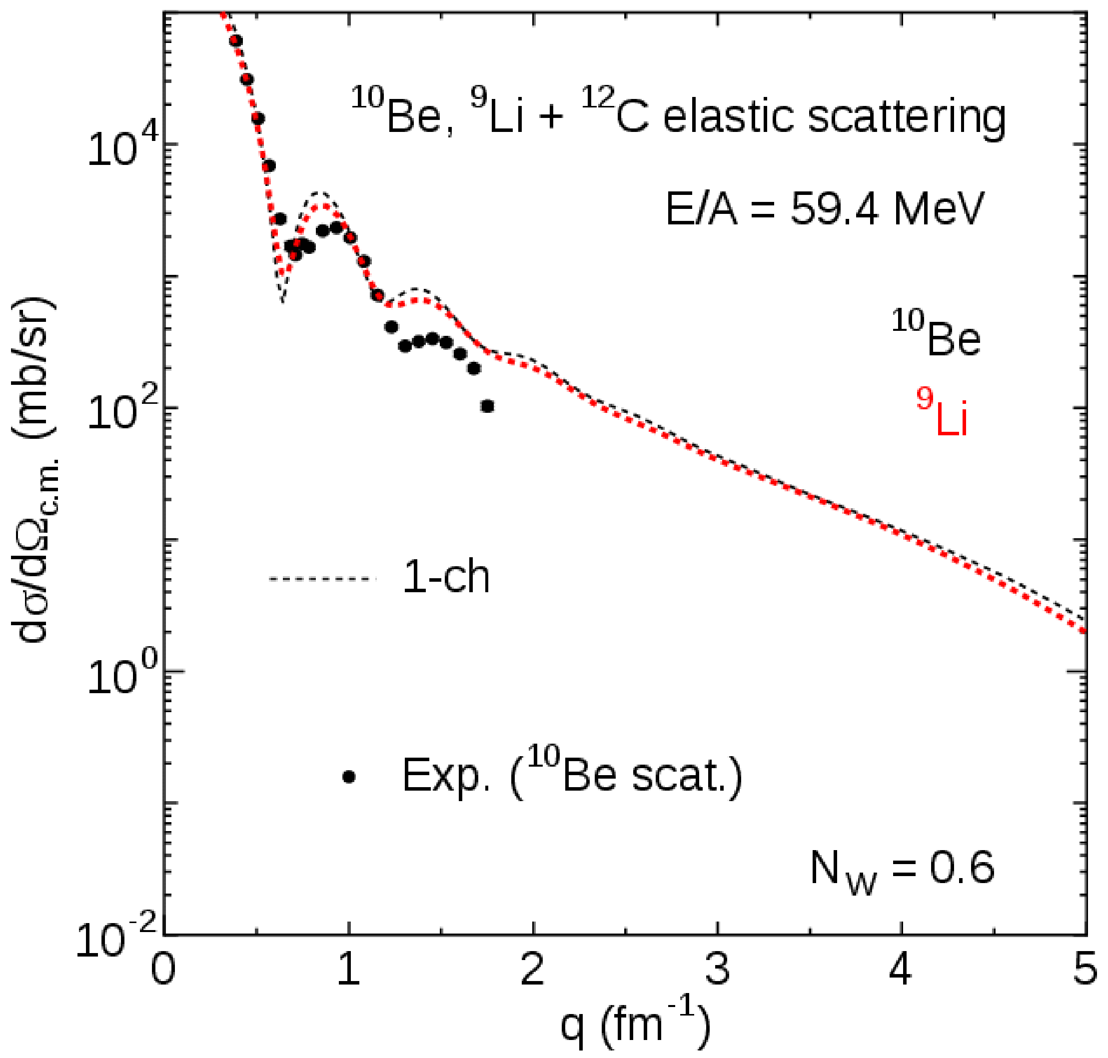
transition density　　　　MPa

Transition density

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

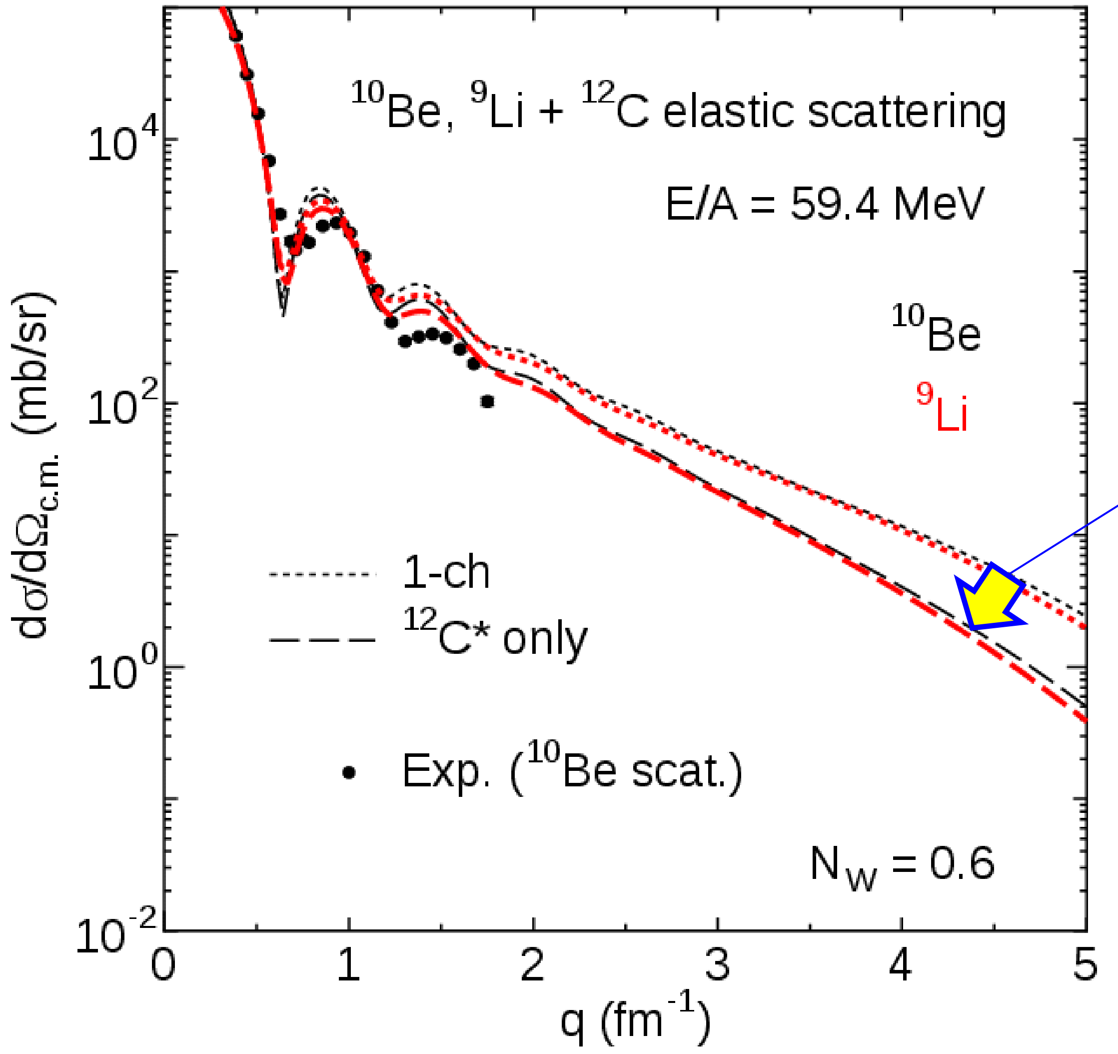


Elastic cross section of ^{9}Li, ^{10}Be + ^{12}C



$$U = V + iN_W W$$

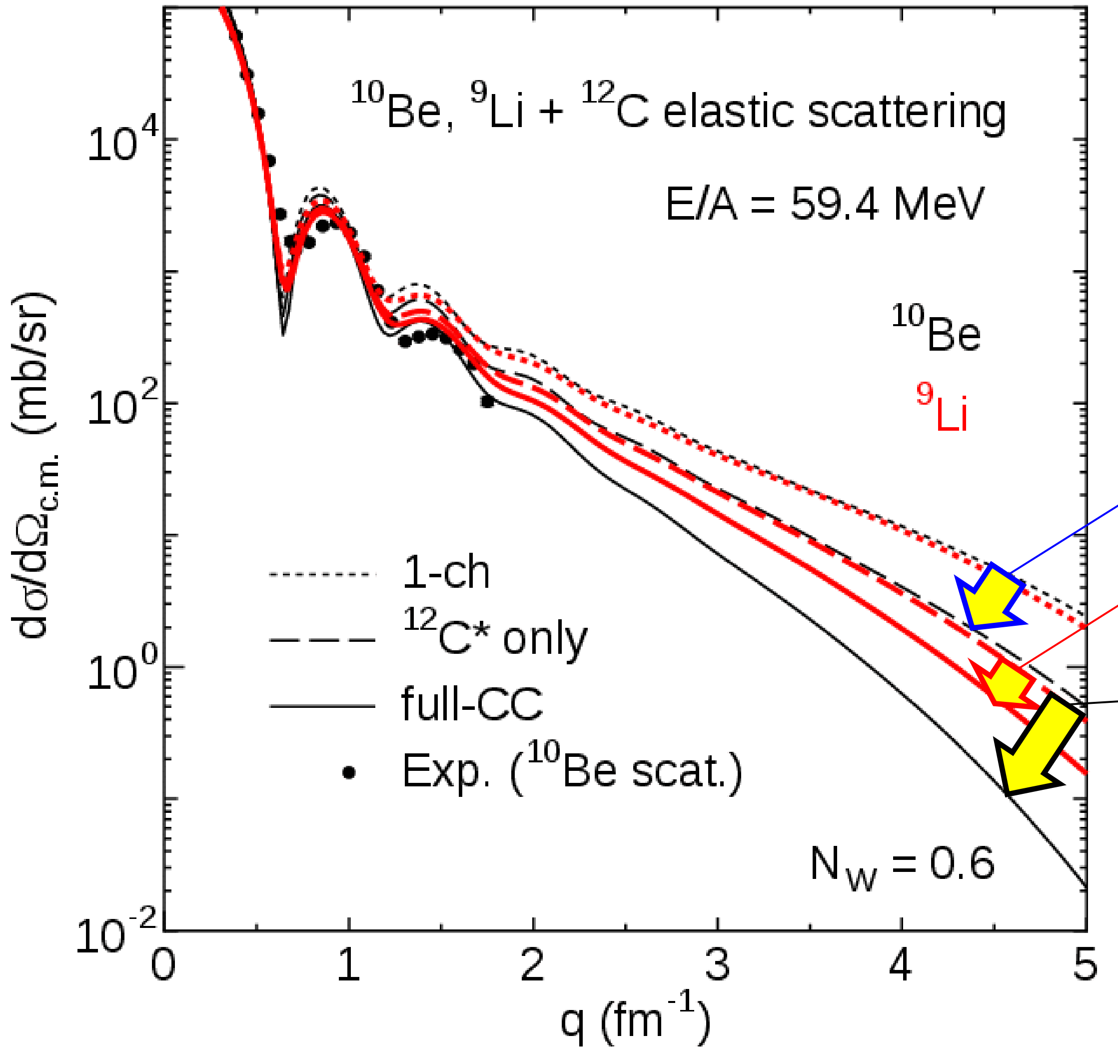
Elastic cross section of ^{9}Li, ^{10}Be + ^{12}C



^{12}C excitation

$$U = V + \underline{iN_W} W$$

Elastic cross section of ^{9}Li, ^{10}Be + ^{12}C



^{12}C excitation

^{9}Li excitation

^{10}Be excitation

$$U = V + iN_W W$$

Elastic channel, Coupling & Dynamical Polarization Potentials for ^{9}Li, ^{10}Be + ^{12}C systems

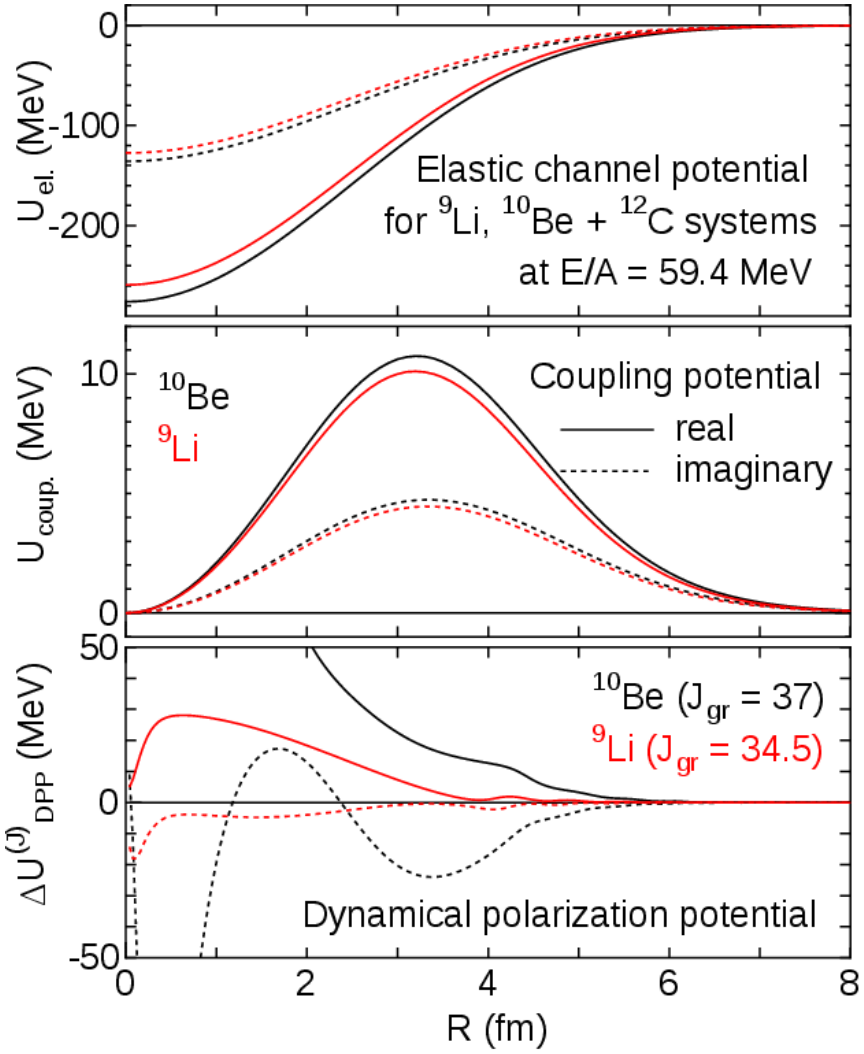
CC equation & Form Factor

$$[T_R - E_\alpha]\chi^{(J')}_{\alpha L}(R) = -\sum_{\alpha', L'} F^{(J')}_{\alpha L,\alpha' L'}(R)\chi^{(J')}_{\alpha' L'}(R), \qquad (8)$$

$$\begin{aligned} F^{(J')}_{\alpha L,\alpha' L'}(R) &\equiv F^{(J')}_{\alpha S(I_1 I_2)L,\alpha' S'(I_1' I_2')L'}(R) \\ &= \sum_\lambda i^{L+L'-\lambda}(-1)^{S+L'-J'-\lambda}\hat{L}\hat{L}'\,W(SLS'L' : J'\lambda) \\ &\quad \times (L0L'0|\lambda 0)U^{(\lambda)}_{\alpha S(I_1 I_2),\alpha' S'(I_1' I_2')}(R), \qquad (9)\end{aligned}$$

Dynamical Polarization Potential (DPP)

$$\Delta U^{(J)}_{\rm DPP}(R) = \sum_{\beta\neq 0, L'} F^{(J)}_{0J,\beta L'}(R)\chi^{(J)}_{\beta L'}(R)/\chi^{(J)}_{0J}(R), \qquad (14)$$



$$J_{gr} = b_{gr}\frac{\sqrt{2\mu E_{c.m.}}}{\hbar}$$

Summary

- Application of microscopic cluster and folding models to the ^{10}Be & ^{9}Li nuclei

- **Comparison with ^{9}Li & ^{10}Be nuclei**
  - **Similarity** : Radius, Binding energy, Transition strength
  - **Dissimilarity**: Channel coupling (CC) effect on the elastic cross section

- **The CC effect**
  - The dissimilarity is uncovered by **Dynamical Polarization Potential (DPP)**
  - **Angular momentum algebra** are important in the comparison with ^{9}Li & ^{10}Be scatterings

Back up

Formalism (Outline)

Our model consists of the **structure** and **reaction** parts

"Structure"

Brink model + Stochastic multi-configuration mixing

→ Biding energy
→ Radius
→ Transition strength

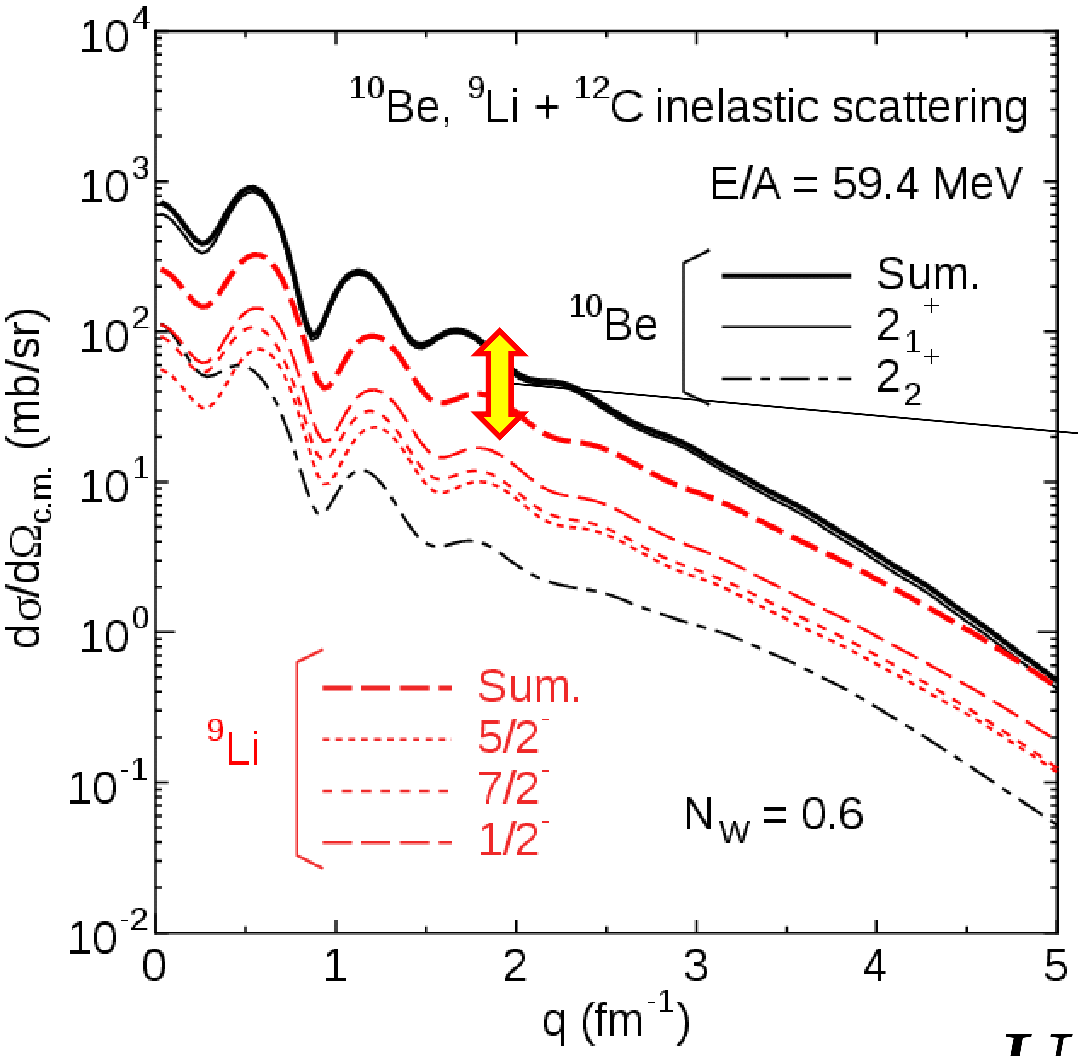
Transition density

"Reaction"

Microscopic Coupled Channel (MCC)

→ Cross section

Inelastic cross section of ^{9}Li, ^{10}Be + ^{12}C

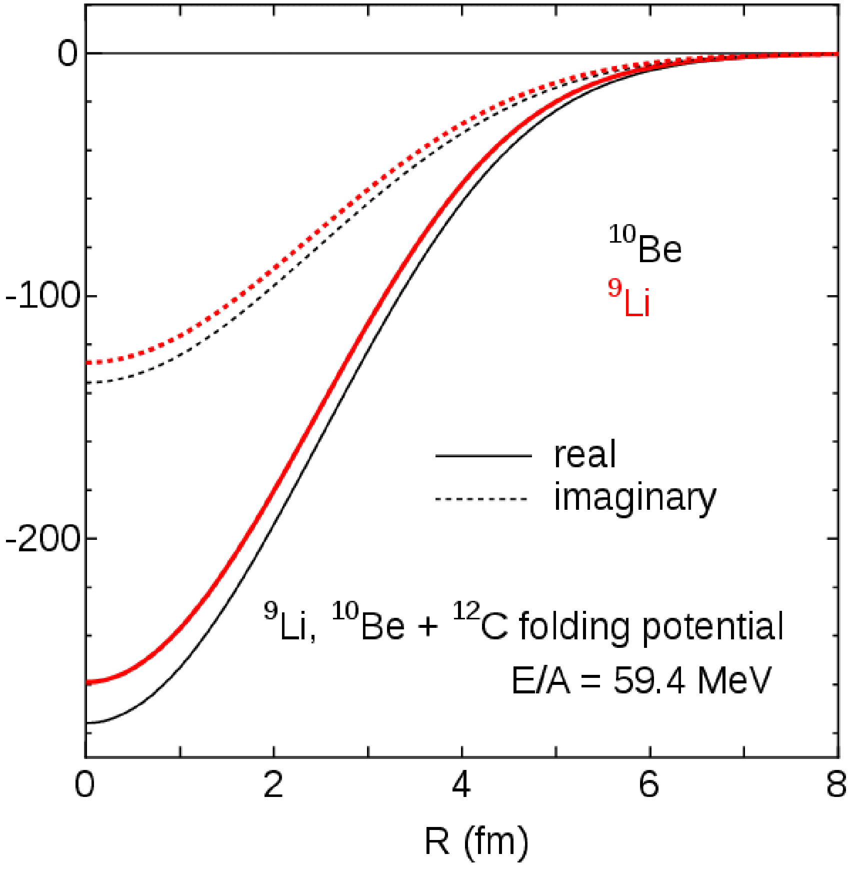


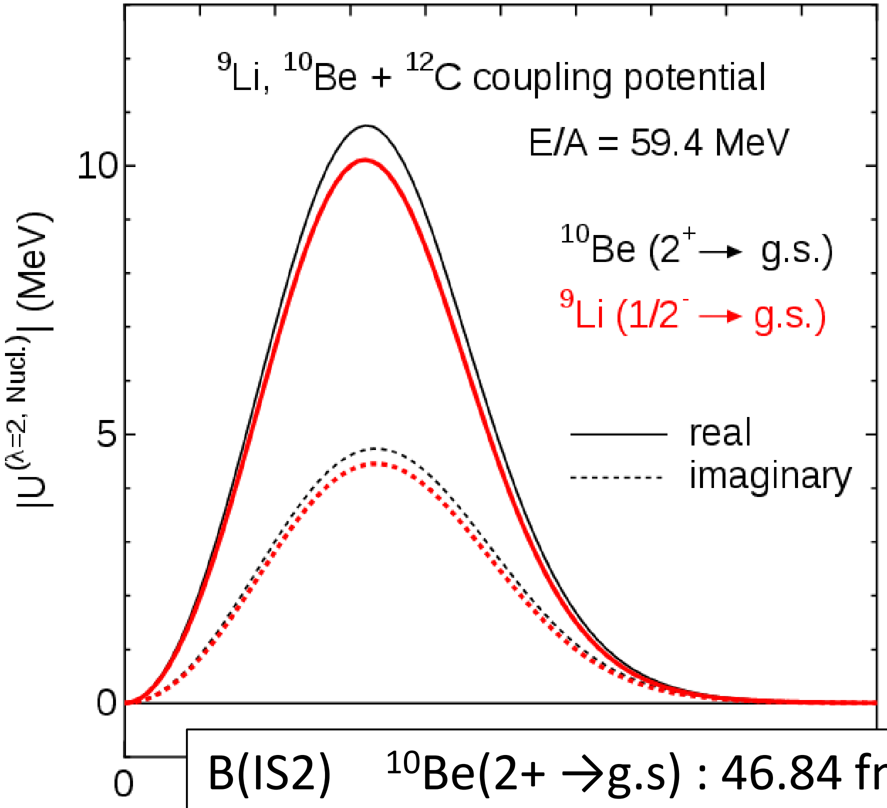
$\sigma(^{10}\mathrm{Be}) > \sigma(^{9}\mathrm{Li})$

Sum of B(IS2)
^{10}Be: 47.20 fm^4
^{9}Li : 67.08 fm^4

$$U = V + iN_W W$$

Potentials for ^{9}Li, ^{10}Be + ^{12}C systems





B(IS2) $^{10}Be(2+ \rightarrow g.s)$: 46.84 fm^4
^{9}Li (1/2 $\rightarrow$g.s): 38.51 fm^4

Elastic channel potential

Coupling potential

Dynamical Polarization Potential (DPP) for ^{9}Li, ^{10}Be + ^{12}C systems

CC equation & Form Factor

$$[T_R - E_\alpha]\chi_{\alpha L}^{(J')}(R) = -\sum_{\alpha',L'} F_{\alpha L,\alpha' L'}^{(J')}(R)\chi_{\alpha' L'}^{(J')}(R), \quad (8)$$

$$\begin{aligned} F_{\alpha L,\alpha' L'}^{(J')}(R) &\equiv F_{\alpha S(I_1 I_2)L,\alpha' S'(I_1' I_2')L'}^{(J')}(R) \\ &= \sum_\lambda i^{L+L'-\lambda}(-1)^{S+L'-J'-\lambda}\hat{L}\hat{L}'\, W(SLS'L' : J'\lambda) \\ &\quad \times (L0L'0|\lambda 0)U_{\alpha S(I_1 I_2),\alpha' S'(I_1' I_2')}^{(\lambda)}(R), \end{aligned} \quad (9)$$

Dynamical Polarization Potential (DPP)

$$\Delta U_{\rm DPP}^{(J)}(R) = \sum_{\beta\neq 0,L'} F_{0J,\beta L'}^{(J)}(R)\chi_{\beta L'}^{(J)}(R)/\chi_{0J}^{(J)}(R), \quad (14)$$

$$J_{gr} = b_{gr}\frac{\sqrt{2\mu E_{c.m.}}}{\hbar}$$