Microscopic analysis of α inelastic scattering on ^{12}C exciting to the 3α cluster state

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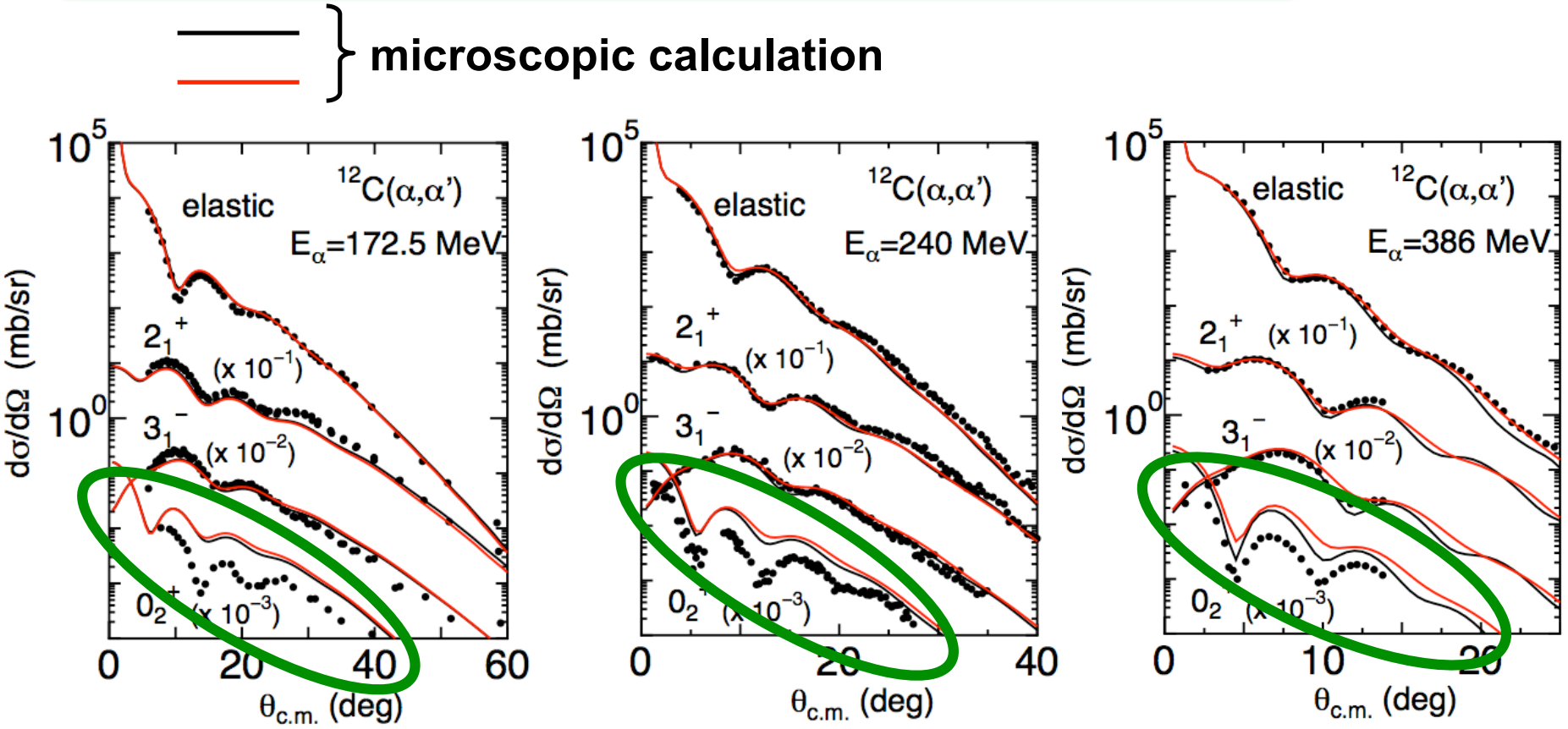
α inelastic scattering on ^{12}C



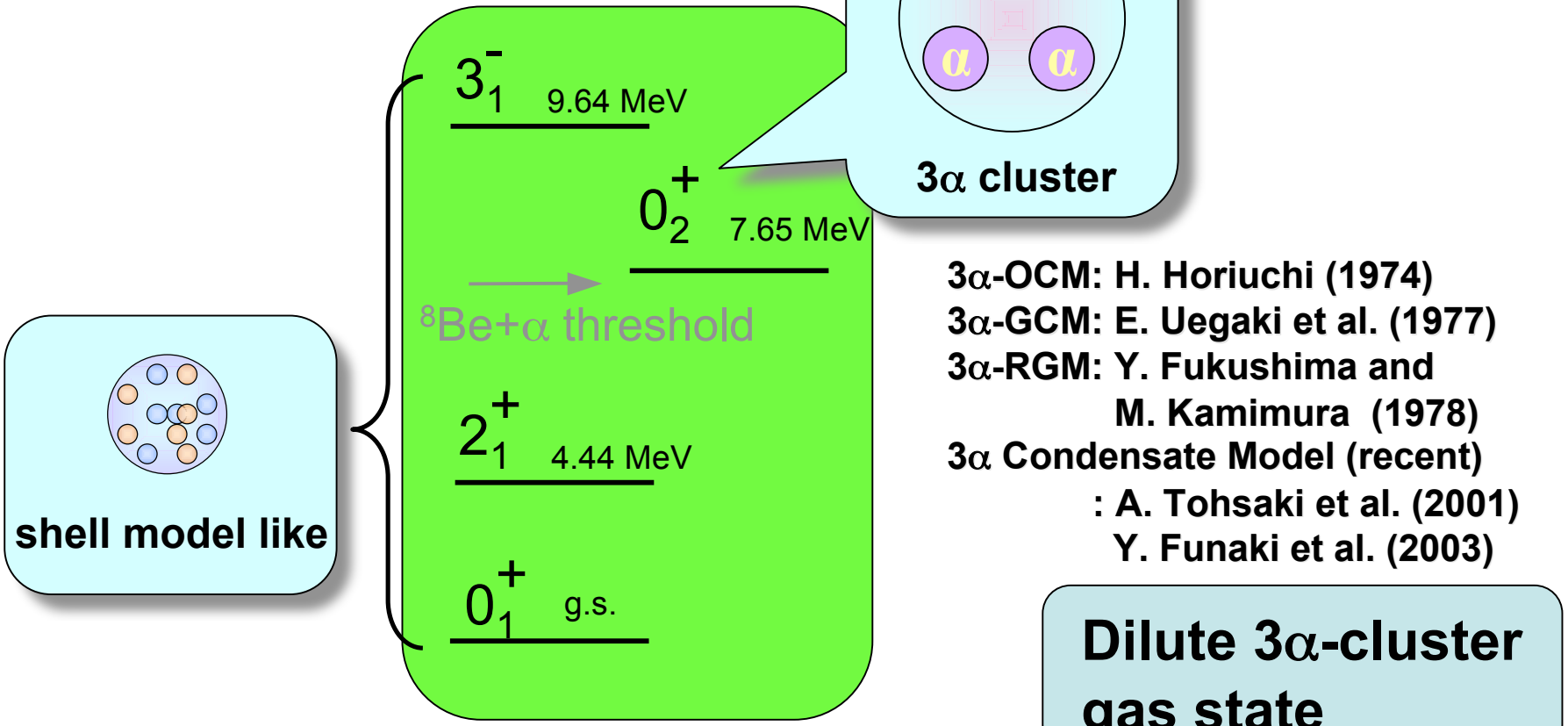
The elastic, 2_1^+ and 3_1^- channels are well reproduced by calculation.

However, the 0_2^+ channel cannot be reproduced.

Cluster structure in ^{12}C

^{12}C

Low-lying states



3α-OCM: H. Horiuchi (1974)
3α-GCM: E. Uegaki et al. (1977)
3α-RGM: Y. Fukushima and M. Kamimura (1978)
3α Condensate Model (recent) : A. Tohsaki et al. (2001) Y. Funaki et al. (2003)

Dilute 3α-cluster gas state

Reliable wfs of these states are obtained.

(semi-) Microscopic Coupled-Channel (MCC) method

Coupled-channel equation

$$\left[T_R + V_{ii}(R) - E_i \right] \chi_i(R) = -\sum_{j \neq i}^{N} V_{ij}(R)\, \chi_j(R) \qquad (i = 1 \sim N)$$

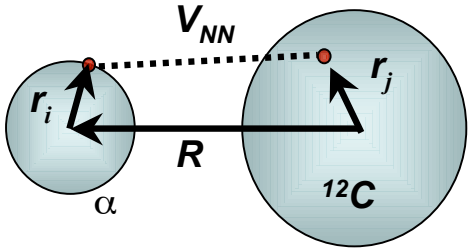
(semi-) microscopic α-^{12}C potential

Case 1: Double-folding model

$$V_{ij}(\vec{R}) = \int \rho_0^{(\alpha)}(\vec{r}_1)\, \rho_{ij}^{(^{12}C)}(\vec{r}_2)\, \boxed{v_{NN}(\vec{r}_1 + \vec{R} - \vec{r}_2)}\, d\vec{r}_1\, d\vec{r}_2$$

DDM3Y

$$U_{ij}(\vec{R}) = (N_R + iN_I) V_{ij}(\vec{R})$$

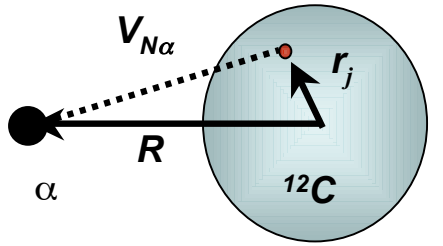


Case 2: N-α single-folding model

$$U_{ij}(\vec{R}) = \int \rho_{ij}^{(^{12}C)}(\vec{r})\; v_{N-\alpha}(\vec{R} - \vec{r})\; d\vec{r}$$

$$v_{N-\alpha}(\vec{R} - \vec{r}) = -V(1 + \beta_v \rho^{2/3}(\vec{r}))\, e^{-|\vec{R}-\vec{r}|^2/a_v} - iW(1 + \beta_w \rho^{2/3}(\vec{r}))\, e^{-|\vec{R}-\vec{r}|^2/a_w}$$

A. Kolomiets et al., PRC 61, 034312 (2000)



$V, \beta_v, a_v, W, \beta_w, a_w$ are determined to reproduce the elastic data.

Charge form factor of ^{12}C

Cal. Resonating Group Method (**RGM**)

$$\rho_{ij}^{(^{12}C)}(\vec{r}) \Leftrightarrow F(q)$$

M. Kamimura, Nucl. Phys. A 351, (1985) 456.

elastic $0_1^+ \rightarrow 2_1^+$ $0_1^+ \rightarrow 0_2^+$ $0_1^+ \rightarrow 3_1^-$

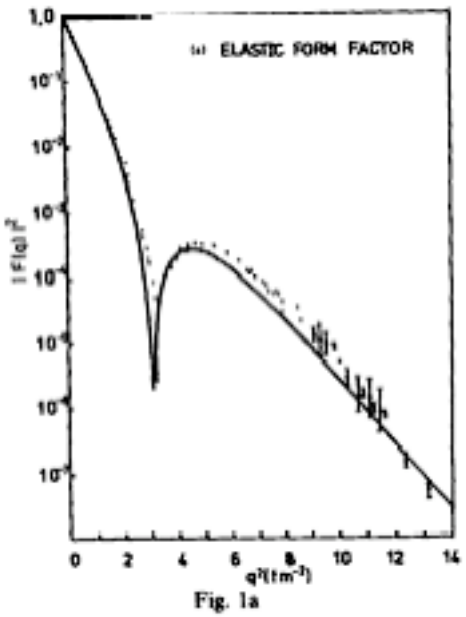


Fig. 1a

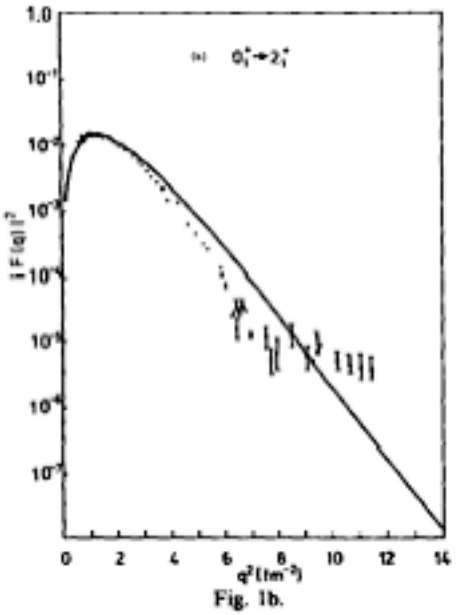


Fig. 1b.

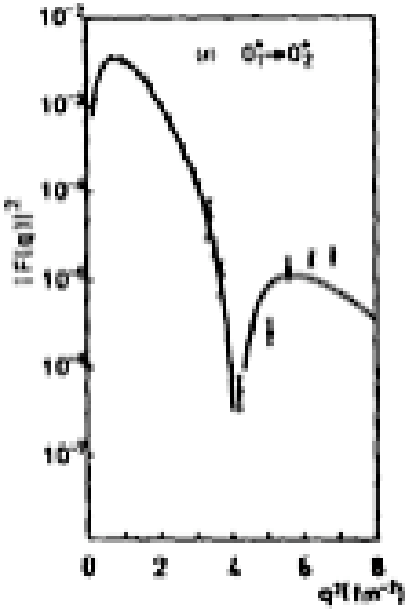
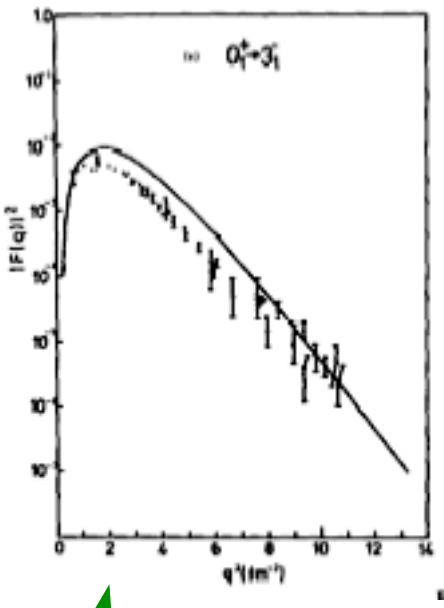


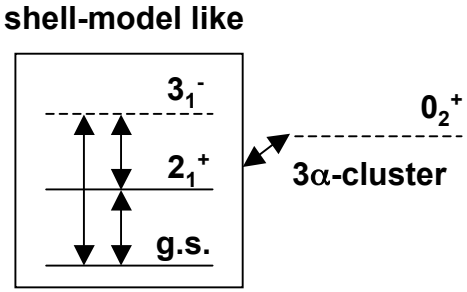
Fig. 1d.



Experimental charge form factors are well reproduced by the RGM calculation without normalization factor except for $0_1^+ \rightarrow 3_1^-$.

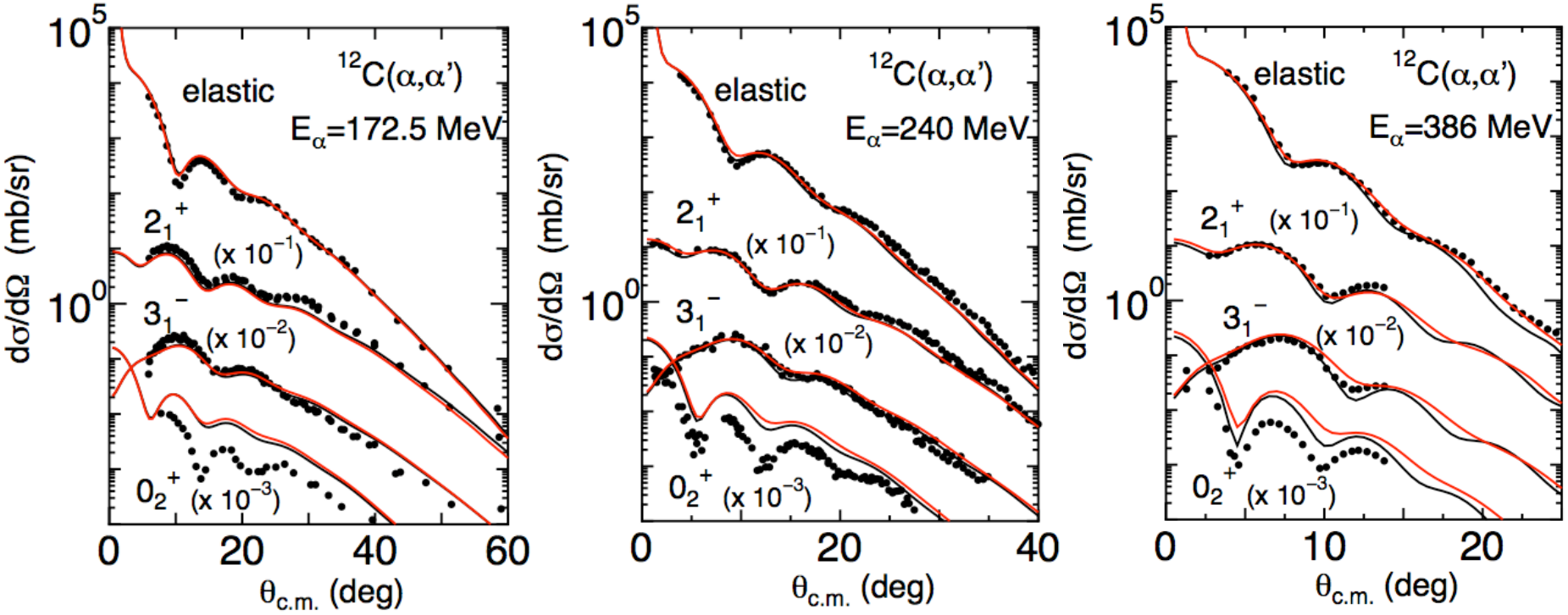
$$\rho_{3_1^- \leftarrow 0_1^+}^{(^{12}C)}(\vec{r}) \times 0.7$$

Results of the MCC calculations



DDM3Y

N-α SF



The elastic, 2_1^+ and 3_1^- channels are well reproduced by calculation.

However, the 0_2^+ channel cannot be reproduced.

Similar discrepancy

B. John et al., Phys. Rev. C68, 014305 (2003)

$^{12}C(\alpha, \alpha')$ at E_α=240 MeV

E0 transition strength to 0_2^+ was derived using the single-folding + collective model.

TABLE IV. Isoscalar $E0$ and $E1$ energy weighted sum-rule strengths for low-lying states in ^{12}C.

	Isoscalar EWSR (%)			
E_x(MeV); J^π	α Present work	^{3}He scattering analysis[a]	^{6}Li scattering analysis[b]	Electron scattering analysis[c]
7.65; 0^+	7.6±0.9	8.6	9.5	15
10.3; 0^+	6.9±0.9		5±1	
10.84; 1^-	0.08±0.02			

correct

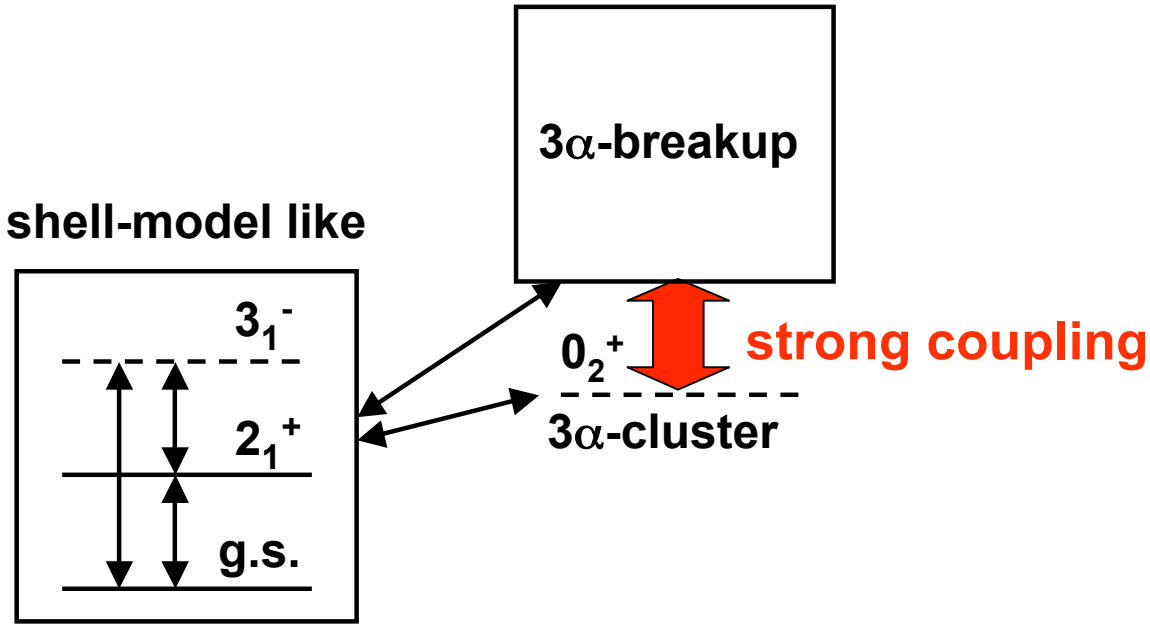
The strength derived from α inela. is about **a half** of the electron scat.

Transition density by collective model

$$\rho_{tr}(r) = \beta\left(3 + r\frac{d}{dr}\right)\rho_{gs}(r)$$

β is determined experimentally

A possible reason (?)

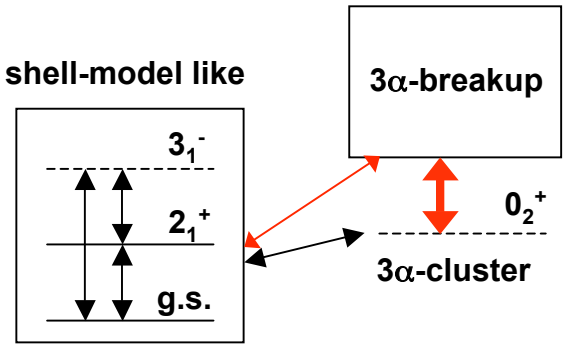


We include the 3α-breakup channels obtained by the RGM calculation.

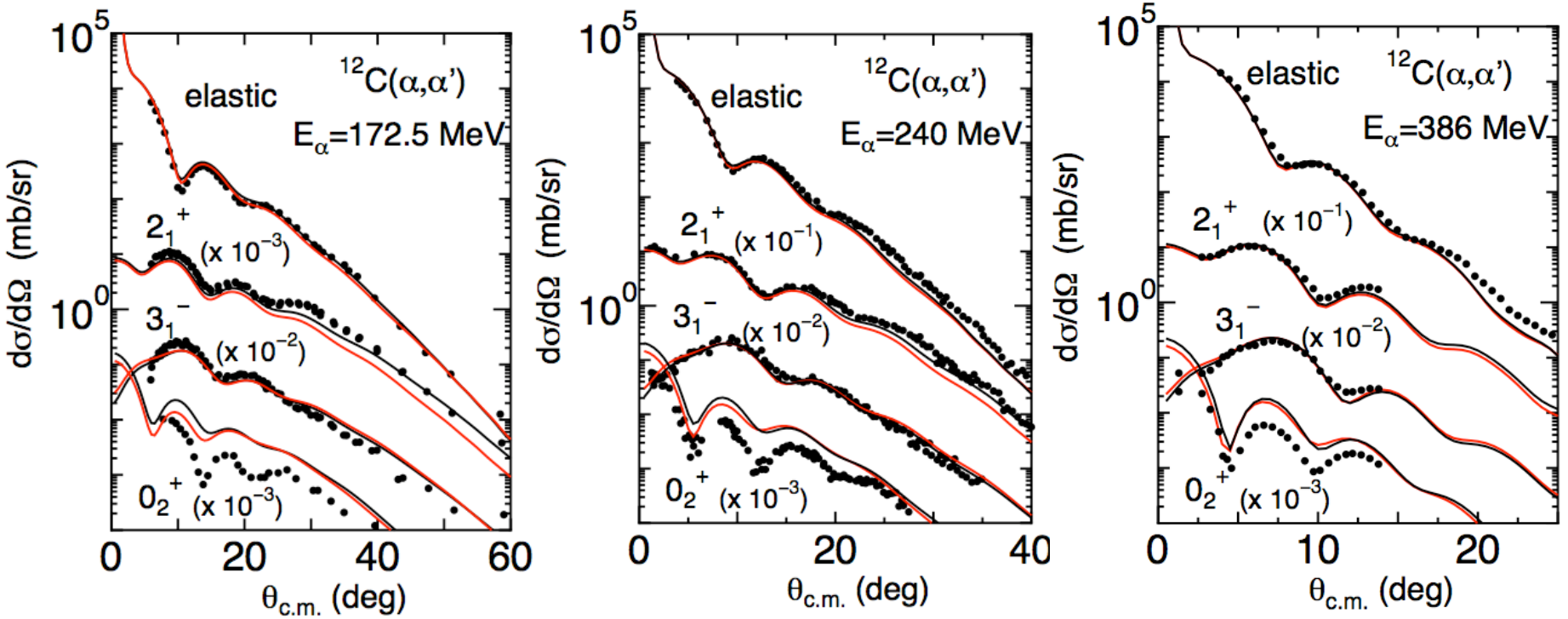
- two 0^+ pseudo-states
- two 2^+ pseudo-states
- 2_2^+ resonance state $B(E2;0_2^+ \rightarrow 2_2^+) \approx 25\ B(E2;0_1^+ \rightarrow 2_1^+)$

M. Kamimura, Nucl. Phys. A 351, (1985) 456.

Effect of breakup channels



DDM3Y

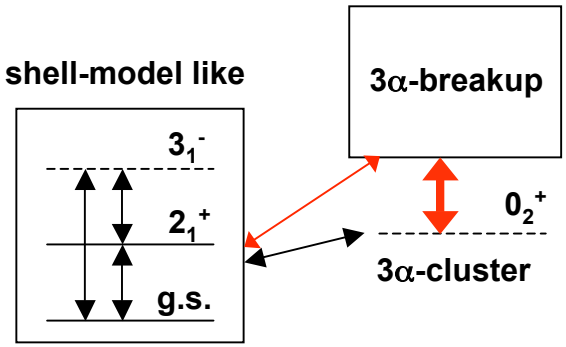


4-channel

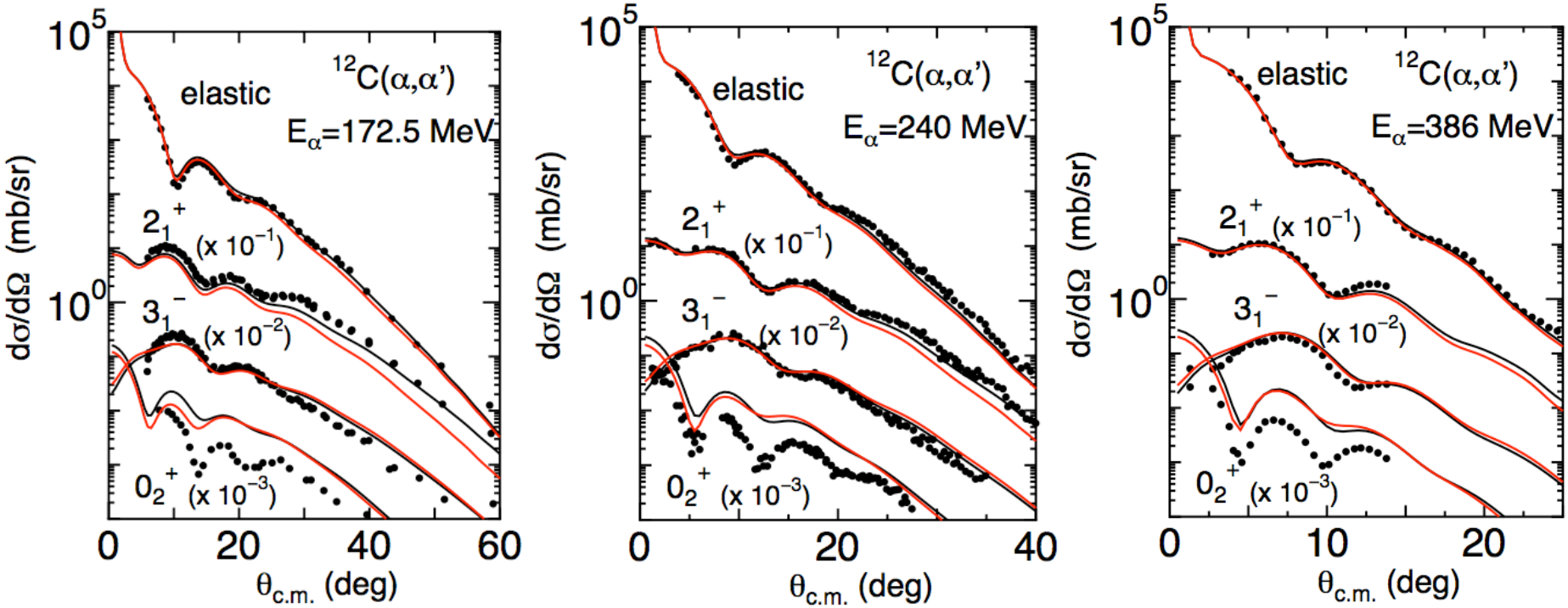
4-channel+breakup

NOT IMPROVED

Effect of breakup channels



N-α SF



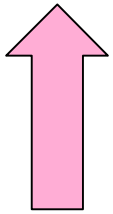
4-channel

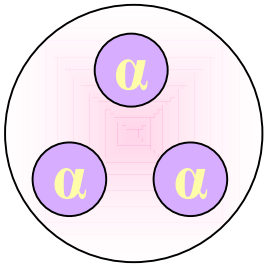
4-channel+breakup

NOT IMPROVED

The discrepancy is **not** due to the breakup effect.

Other possible reason is
the exotic structure of $^{12}C(0_2^+)$.
(well developed 3α cluster structure)



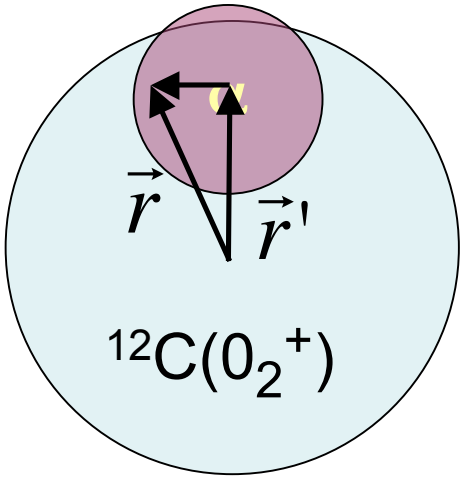


We should consider this fact.

In order to take it into account in the folding calculation,
we suggest the following procedure.
(N-α single-folding case)

Folding procedure for cluster state

Assumption



$$\rho_{ij}^{(^{12}C)}(\vec{r}) = \int \omega_{ij}^{(3\alpha)}(\vec{r}')\rho_0^{(\alpha)}(\vec{r}-\vec{r}')\,d\vec{r}'$$

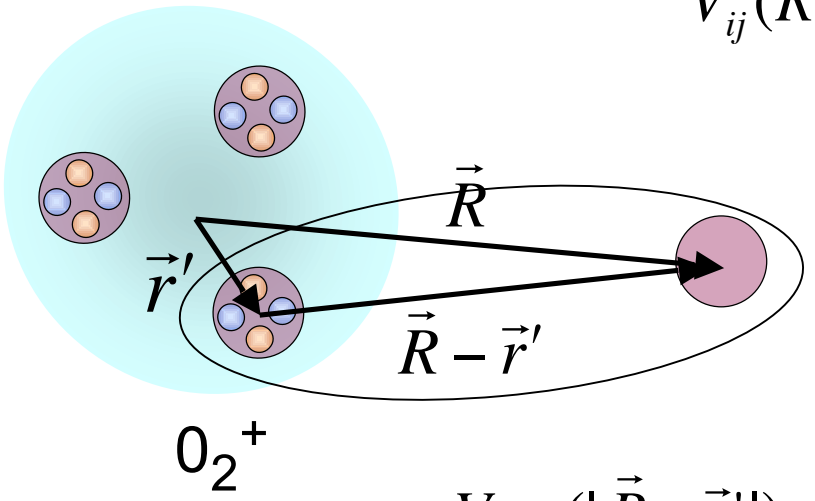
$\rho_0^{(\alpha)}(\vec{x})$: nucleon density of α-particle

$\omega_{ij}^{(3\alpha)}(\vec{r}')$: point α density in ^{12}C

Folding procedure for cluster state

$$\rho_{ij}^{(^{12}C)}(\vec{r}) = \int \omega_{ij}^{(3\alpha)}(\vec{r}')\rho_0^{(\alpha)}(\vec{r}-\vec{r}')\,d\vec{r}'$$

$$V_{ij}(\vec{R}) = \int \rho_{ij}^{(^{12}C)}(\vec{r})\ v_{N-\alpha}(|\vec{R}-\vec{r}\,|,\rho(\vec{r}))\ d\vec{r}$$



$$\rightarrow \int \omega_{ij}^{(3\alpha)}(\vec{r}')\ V_{\alpha-\alpha}(|\vec{R}-\vec{r}'|)\ d\vec{r}' \equiv V_{ij}^{(new)}(\vec{R})$$

α–α potential

$$V_{\alpha-\alpha}(|\vec{R}-\vec{r}'|) = \int \rho_0^{(\alpha)}(\vec{r}-\vec{r}')\,v_{N-\alpha}(|\vec{R}-\vec{r}\,|,\underbrace{\rho_0^{(\alpha)}(\vec{r}-\vec{r}')}_{\text{replaced}})dr$$

We also assume that $V_{\alpha-\alpha}(|\vec{R}-\vec{r}'|)$ has no density dependence because of the α gas-like structure.

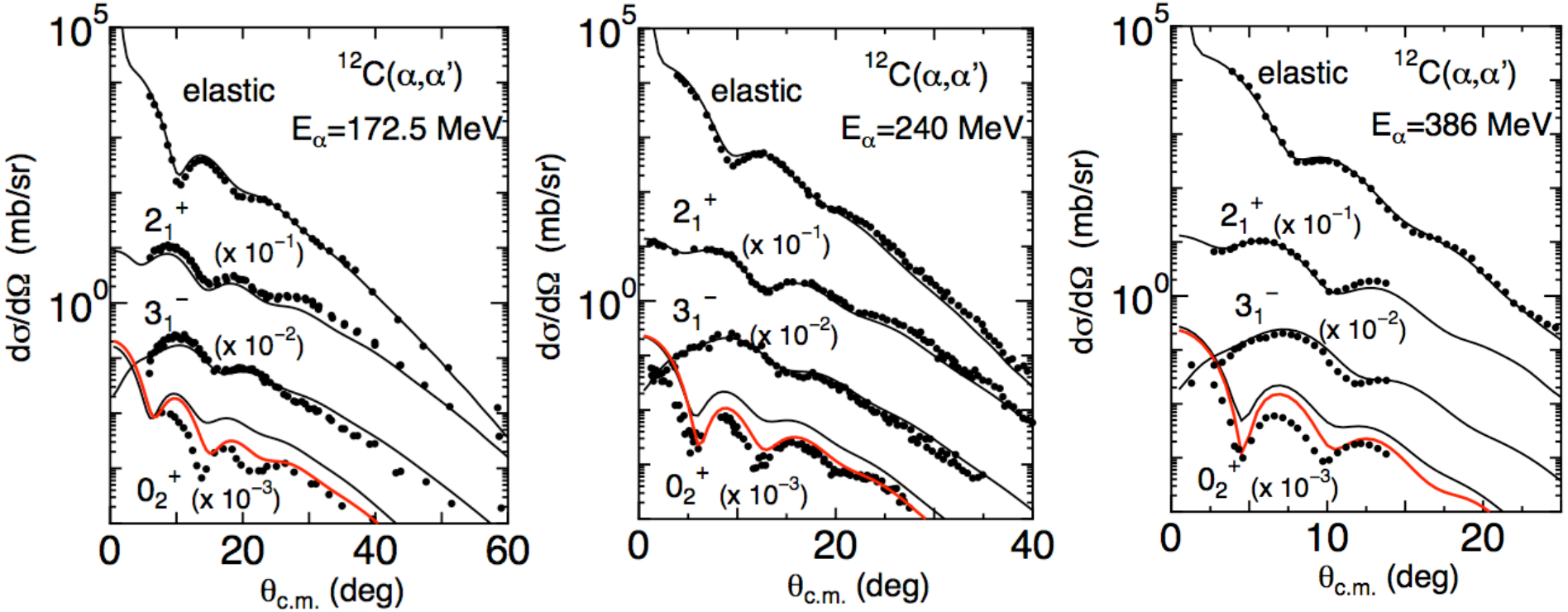
Note

If $v_{N-\alpha}(|\vec{R}-\vec{r}|,\rho(\vec{r}))$ has **no density dependence**,

$$V_{ij}^{(new)}(\vec{R}) = V_{ij}(\vec{R})$$

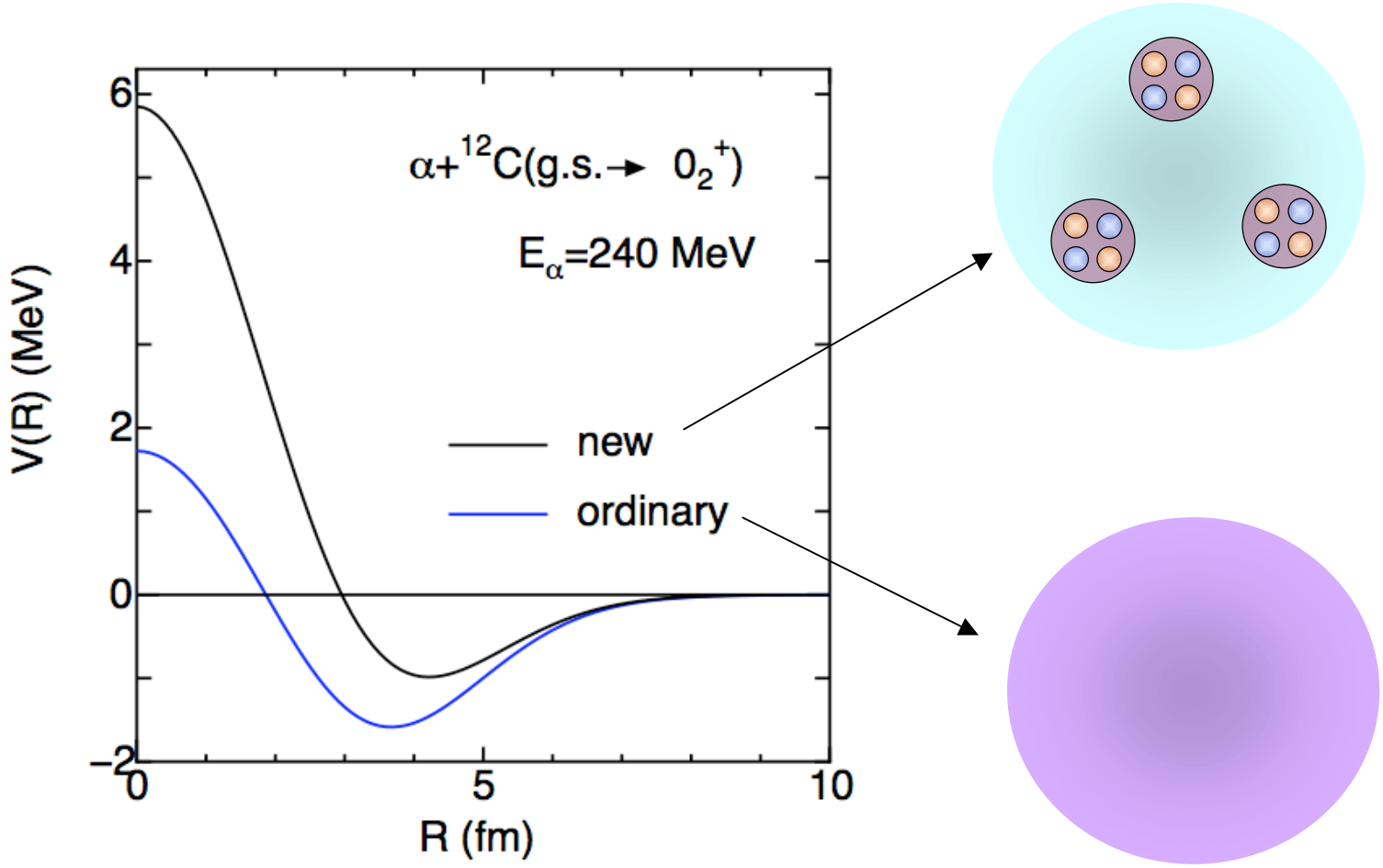
Results

present procedure
(2-channel calc.)



We obtain improved results.
More precise calculation is necessary.

Coupling potential



Summary

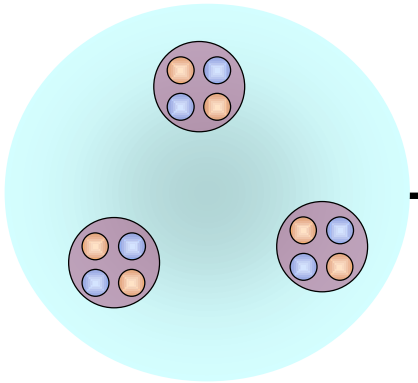
- ✓ α+^{12}C(0_2^+) inelastic differential cross section cannot be reproduced by (semi-) microscopic calculation, even though the breakup channels are included.

- ✓ We consider the cluster structure of ^{12}C(0_2^+) for the calculation of folding potential.

- ✓ We obtain **improved** results.
  (although the present results are very **preliminary**)

More precise calculation is necessary for $\omega_{ij}^{(3\alpha)}(\vec{r}')$
(e.g. OCM calc.)

Coupling term

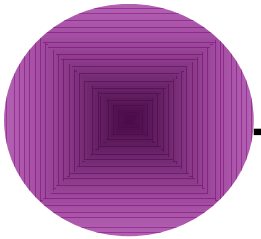


0_2^+

$V_{0_2^+}^{(new)}(\vec{R})$ **present procedure**

coupling term

$\frac{1}{2}\left(V_{0_2^+\leftarrow gs}(\vec{R}) + V_{0_2^+\leftarrow gs}^{(new)}(\vec{R})\right)$ **average**



g.s.

$V_{gs}(\vec{R})$ **ordinary procedure**