$\alpha + {}^2n + {}^2n$ cluster structure and ${}^2n$ breaking in ${}^8\mathrm{He}(0_2^+)$

Based on K. Nakagawa, Y. Kanada-En'yo, Phys. Rev. C **112**, 034309 (2025)

Kyoto University
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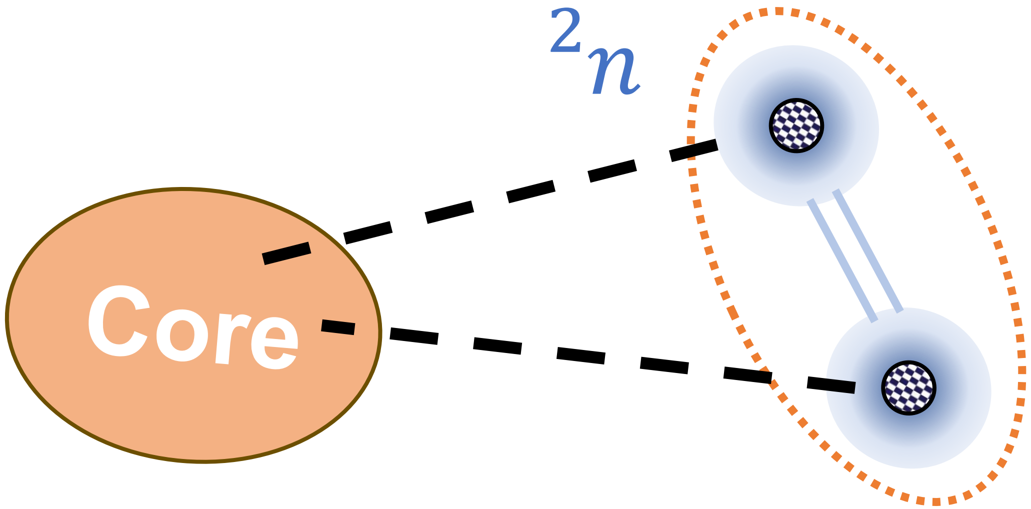
Dineutron Formation in Neutron-rich Nuclei

Dineutron (^{2}n): Neutron pair with strong spatial correlation ($2n$ are close)

- Appear in low-density region

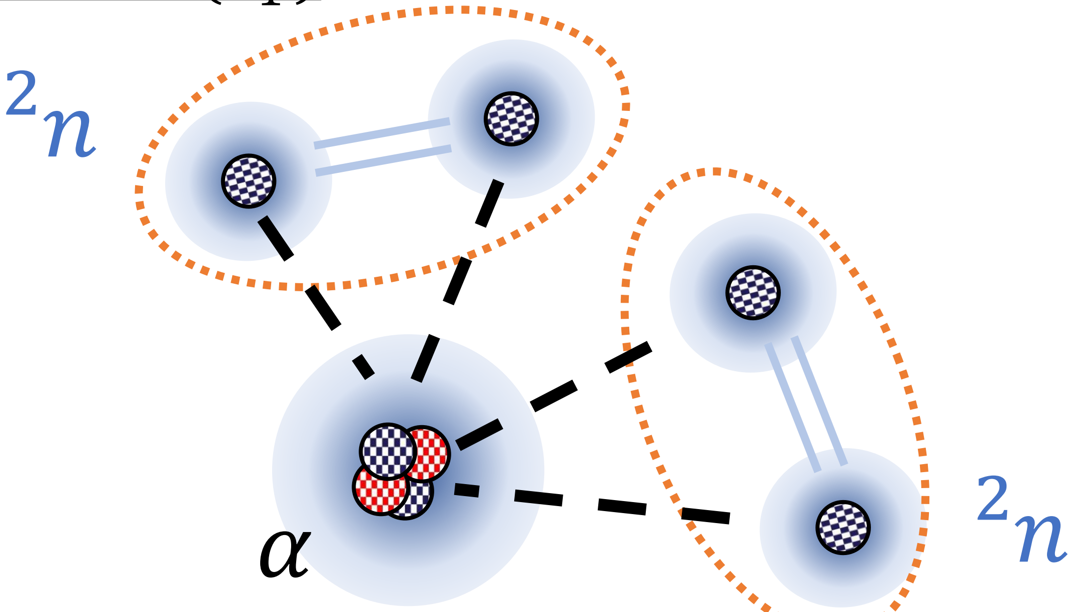
→ Typical on the surface of some neutron-rich nuclei

ex. 1: $2n$ halo



H. Esbensen, G. F. Bertsch, Nucl. Phys. A **542**, 2 (1992)
K. Hagino, *et al.* Phys. Rev. Lett. 99, 022506 (2007)

ex. 2: $^{8}\mathrm{He}(0_1^+)$



K. Hagino *et al.* Phys. Rev. C **77**, 054317 (2008)

Unique behavior in weakly-bound core+2,4-neutron systems

Dineutron Formation in Neutron-rich Nuclei

Dineutron (^{2}n): Neutron pair with strong spatial correlation ($2n$ are close)

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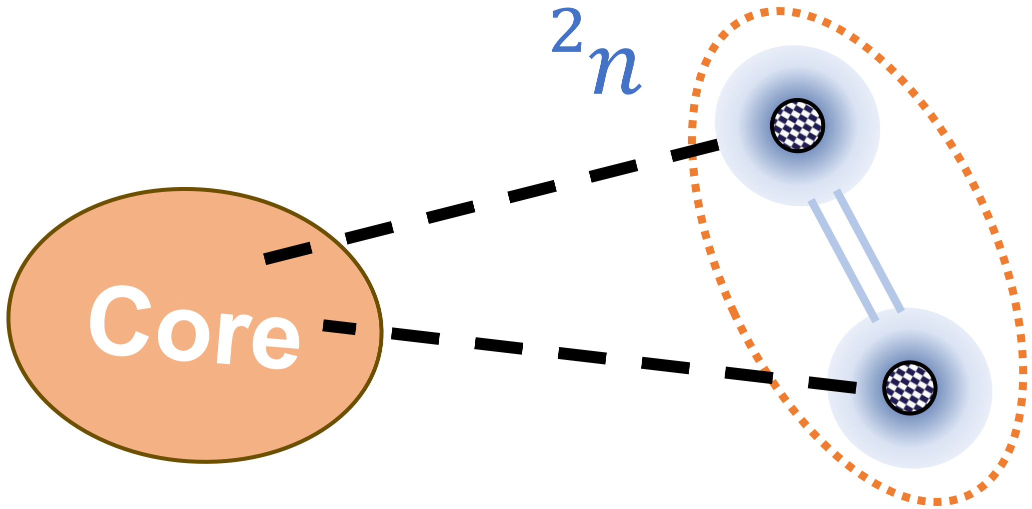
Excited state?

Larger radius
due to orthogonality

ex. 1: $2n$ halo



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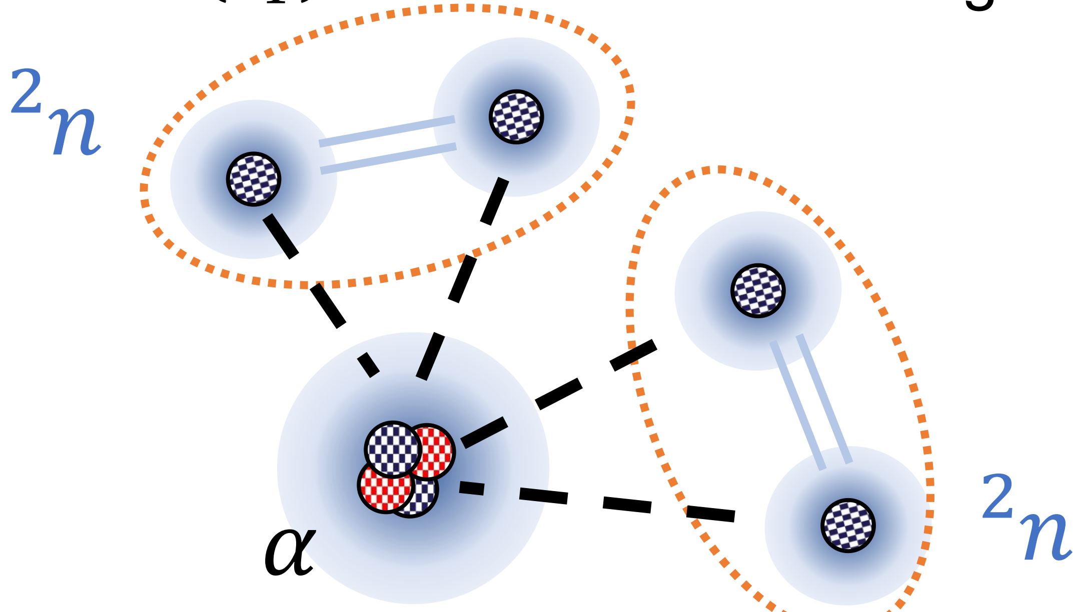

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Unique behavior in weakly-bound core+2,4-neutron systems

Observation of $^{8}\mathrm{He}(0_2^+)$ and its ^{2}n Clustering

Which state of $^{8}\mathrm{He}$? → The $\mathbf{0_2^+}$ state!

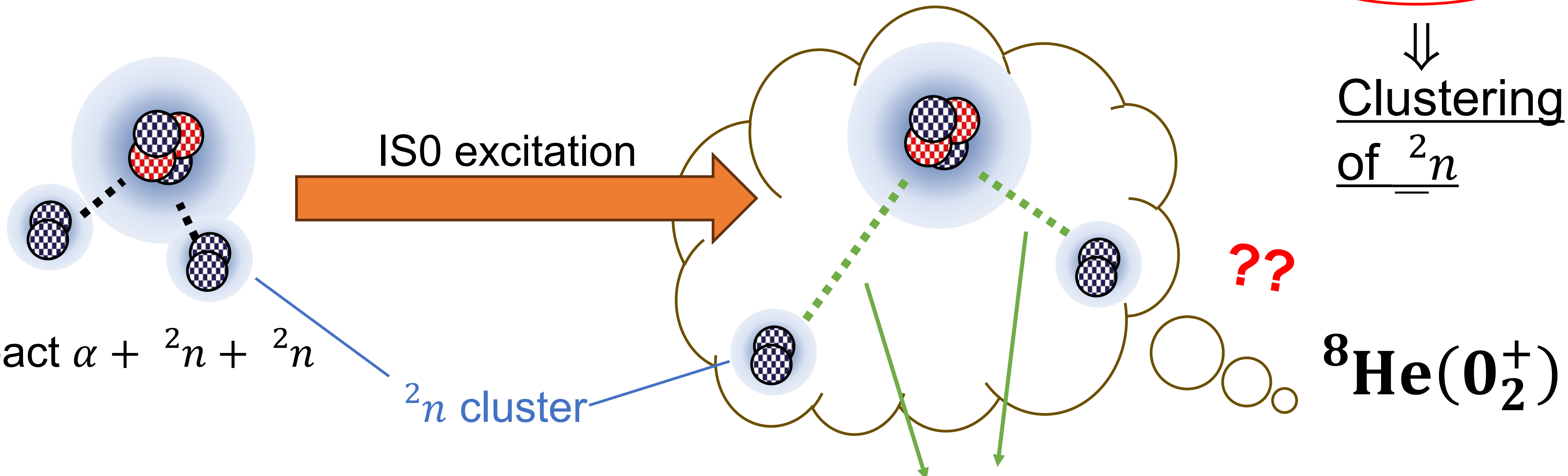
Z. H. Yang *et. al.* PRL **131**, 242501 (2023)

- First observation of $^{8}\mathrm{He}(0_2^+)$ via $^{12}\mathrm{C}(^{8}\mathrm{He},\ ^{8}\mathrm{He}^{*})$ in RIBF
- Isoscalar monopole (IS0) transition strength : $M(\mathrm{IS0}) = 11\ \mathrm{fm}^2$

large!

⇓

Clustering of ^{2}n



For analysis of $^{8}\mathrm{He}(0_2^+)$, it is necessary to describe relative motions between clusters

Purpose of this talk

- Verify rules of the ${}^{2}n$ clusters in ${}^{8}\mathrm{He}(0_2^+)$ focusing on
  - $\alpha + {}^{2}n + {}^{2}n$ 3-clusters & spatial correlation between clusters
  - ${}^{2}n$ cluster breaking ($\leftarrow 2n$ is not bound in the first place)

single particle w.f: $e^{-\nu(\boldsymbol{r}-\boldsymbol{R})^2}|\sigma_z\rangle|\tau_z\rangle$

- To this end, we apply a microscopic cluster model which can describe
  - relative motion between clusters
  - ${}^{2}n$ cluster breaking due to the spin-orbit force around the α cluster

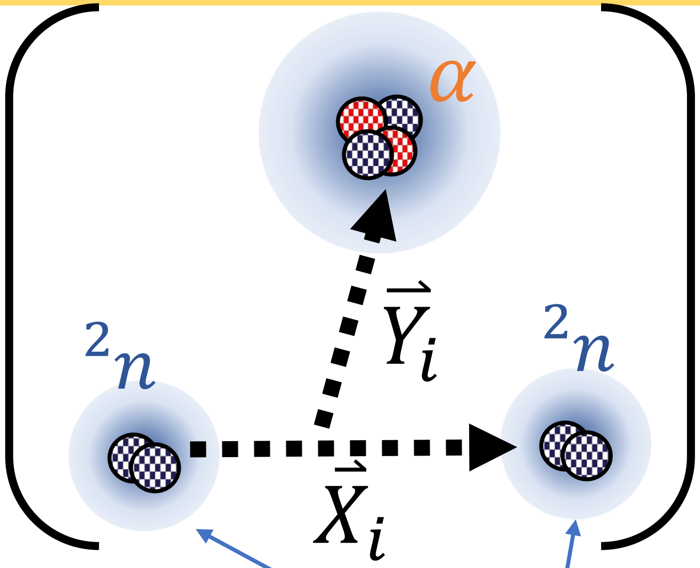
= expressed by shell-model-induced states

Methods

Description of the Relative Motions

$$\Psi(\,^{8}\mathrm{He}) = \sum_i \underline{c_i^{3B}} \det \left[\cdots \right]_i$$

weight coefficient



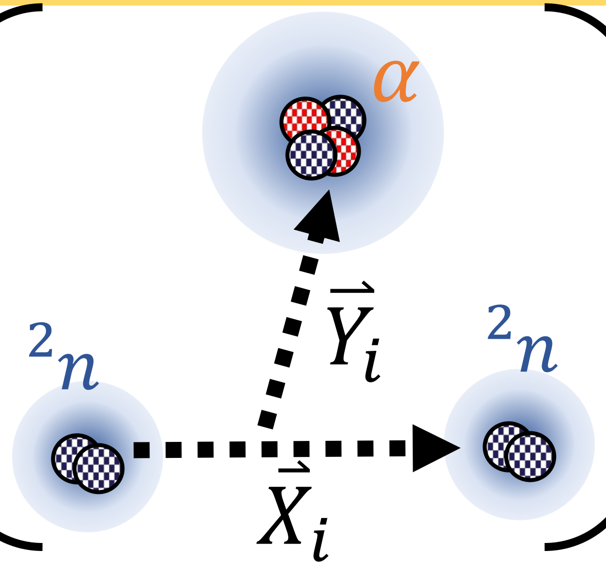
$$+\cdots$$

- $S = 0$
- common Gaussian center

- The relative motions between $\alpha + \,^{2}n + \,^{2}n$ clusters are described by superposing basis with various spatial configurations (GCM)

Description of the Relative Motions

$$\Psi(\,^{8}\mathrm{He}) = \sum_i \underbrace{c_i^{3B}}_{\text{weight coefficient}} \det \left[\vphantom{\sum} \right]_i$$

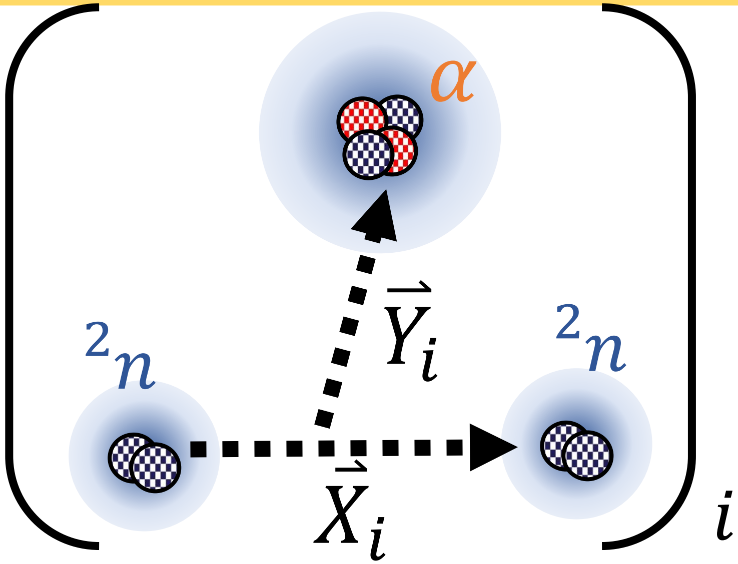


$$+ \cdots$$

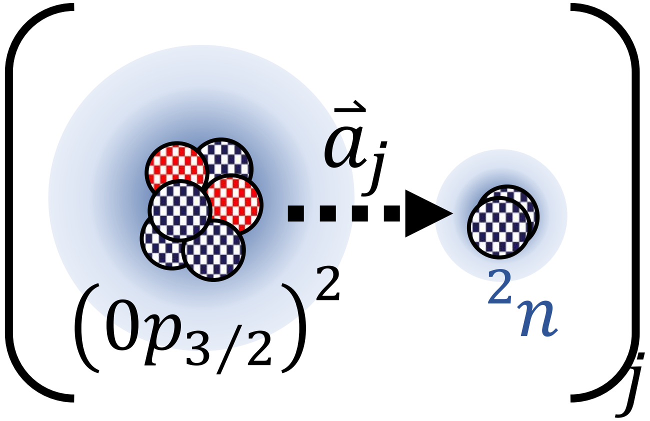
- The relative motions between $\alpha + {}^{2}n + {}^{2}n$ clusters are described by superposing basis with various spatial configurations (GCM)

Mixing cluster breaking configurations

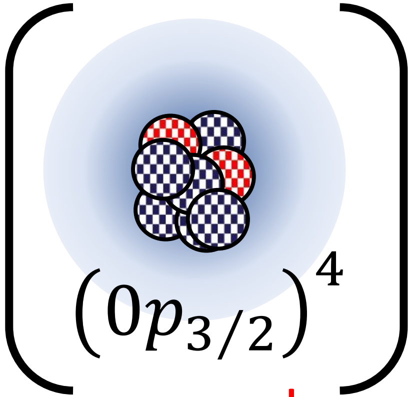
$$\Psi({}^{8}\mathrm{He}) = \sum_i c_i^{3B} \det$$



$$+ \sum_j c_j^{2B} \det$$



$$+ c^{1B} \det$$



2-body cluster

$p_{3/2}$-closure
=shell model state

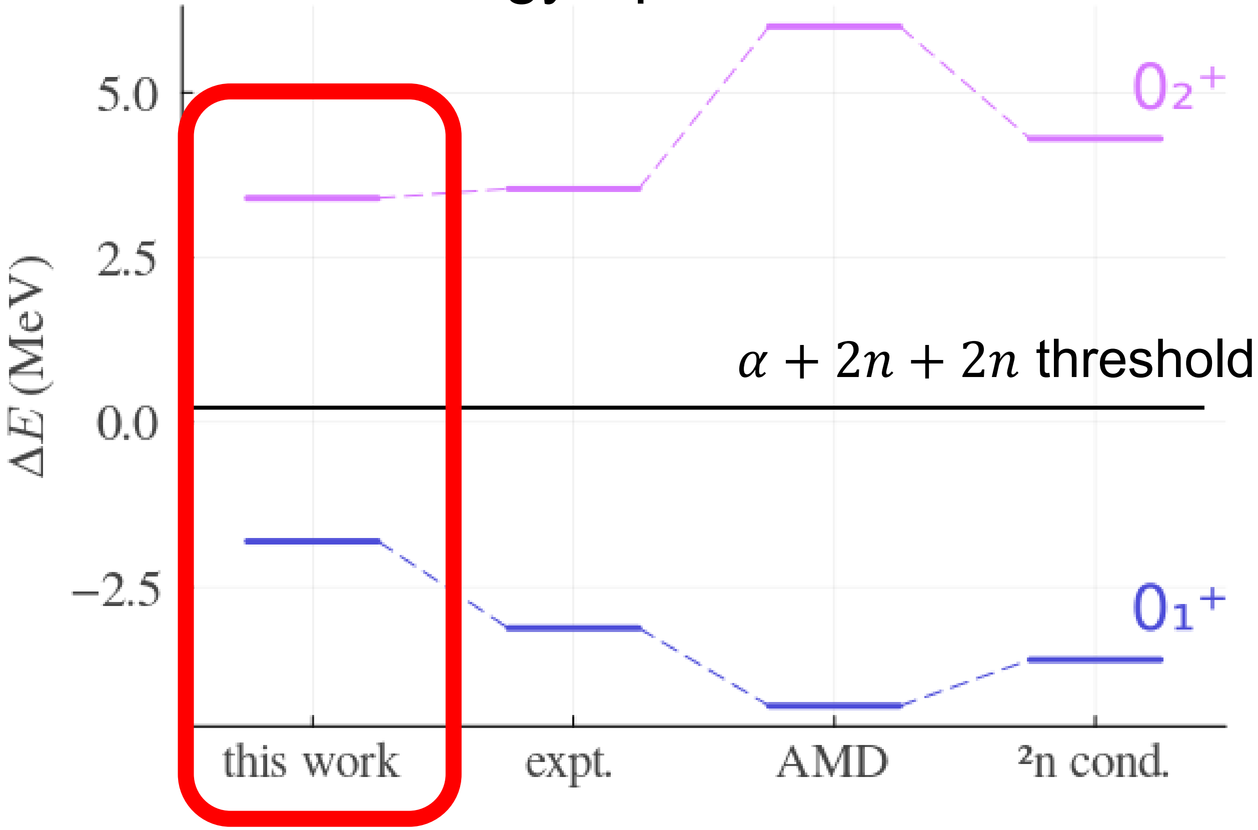
- Configuration mixing of $p_{3/2}$-subshell state = 1,2- ${}^{2}n$ cluster breaking

Results

Basic Results of our Calculation

Yang *et al.*, PRL **131**, 242501 (2023)
Kanada-En'yo, PRC **76**, 044323 (2007)
Kobayashi, Kanada-En'yo PRC **88**, 034321 (2013)

Energy Spectrum



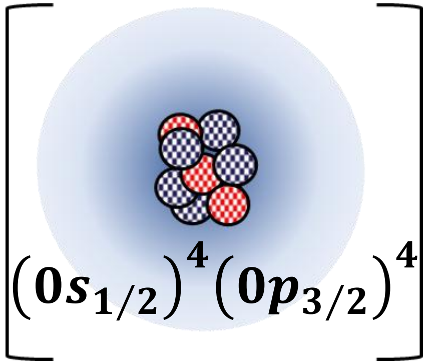
Radius & IS0 transition strength

	This work	Expt.	AMD	^2n cond.
$R_{rms}(0_1^+)$(fm)	2.40	2.52	2.24	2.49
$R_{rms}^p(0_1^+)$(fm)	1.89	1.788	1.76	1.93
$R_{rms}(0_2^+)$(fm)	3.91		2.73	4.67
$M(\mathrm{IS0})$ (fm^2)	7.75	$11^{+1.8}_{-2.3}$	7.3	10.3

- Overall results reproduced experimental or other theoretical studies well.
- Large radius and $M(IS0)$ → developments of cluster structures

Analysis of ^{2}n Breaking Components

- squared overlap of the $0p_{3/2}$ closure configuration ←

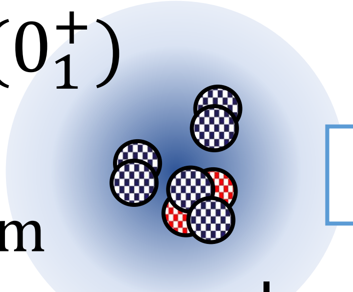


	0_1^+	0_2^+
overlap	0.487	0.086

large! ↑ small ↑

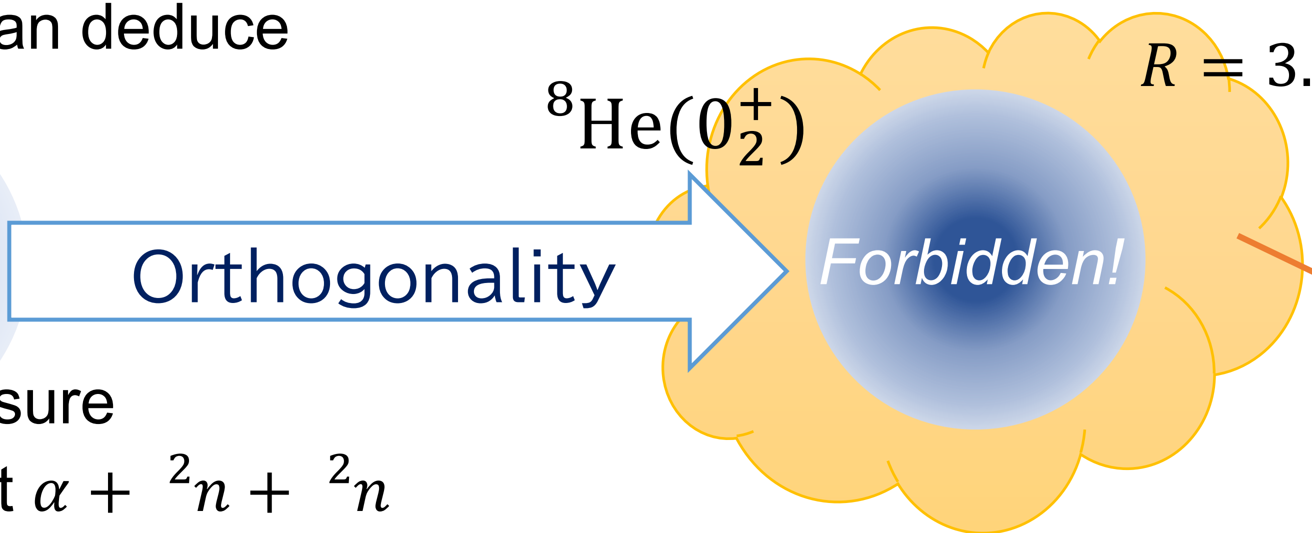
- From these results, we can deduce

$^{8}\mathrm{He}(0_1^+)$



$R = 2.40\ \mathrm{fm}$

- $p_{3/2}$-closure
- compact $\alpha + {}^{2}n + {}^{2}n$

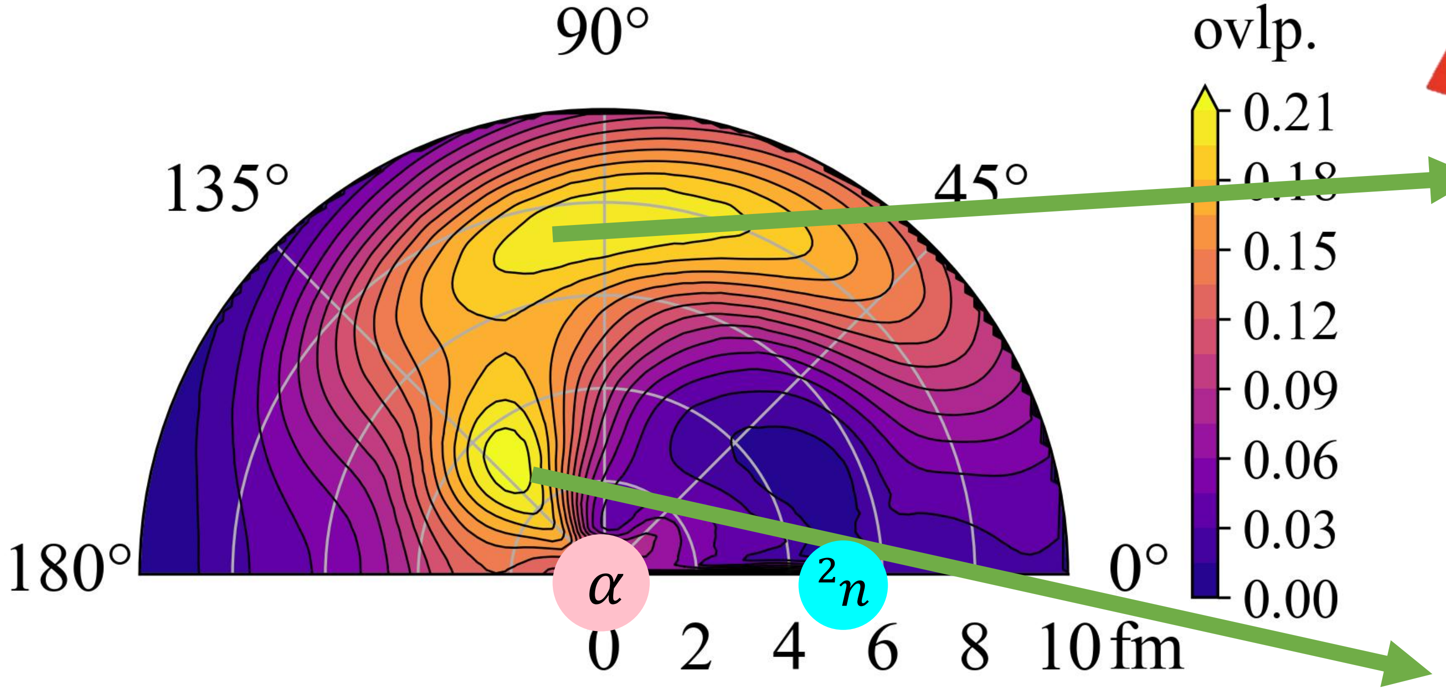


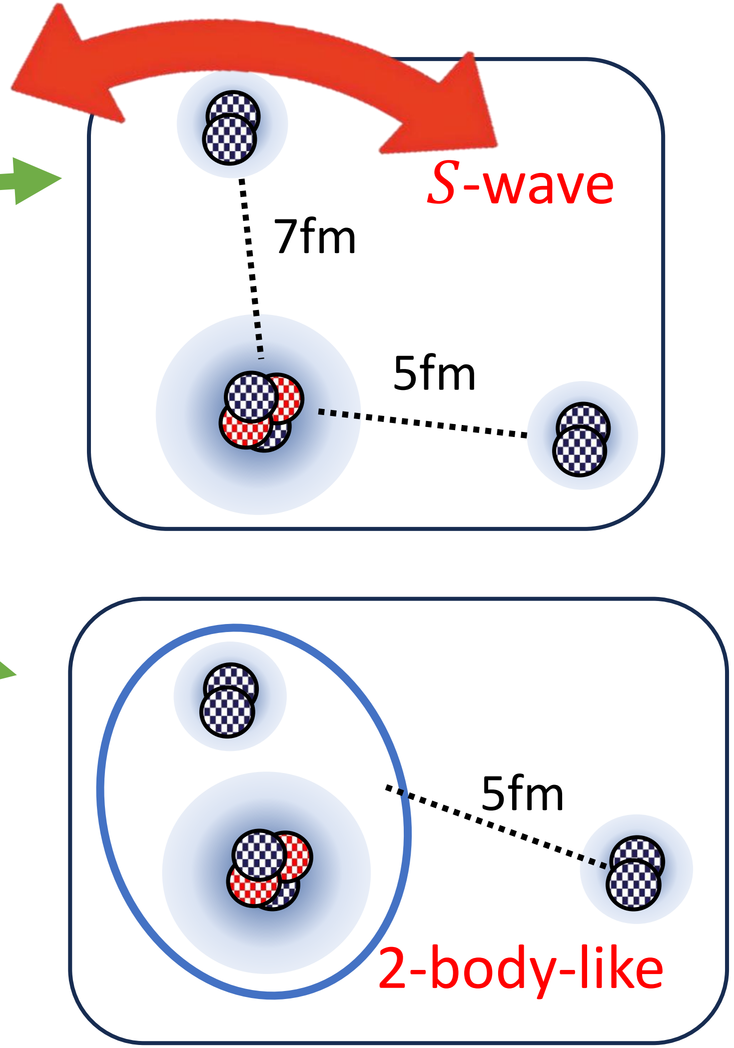
Cluster gas

→ What's next

^{2}n Cluster Spatial Distribution in $^{8}\mathrm{He}(0_2^+)$

Squared overlap with configurations with fixing the α and ^{2}n cluster





Dual cluster structure

- distinct 3-body clusters
- spatially correlated $(\alpha + {}^{2}n)$ + ^{2}n
  $\rightarrow$ related to 2-body cluster

Conclusions

- We analyze cluster structure in $^8\mathrm{He}(0_2^+)$
- Our model is focusing on
  - relative motion between $\alpha + {}^2n + {}^2n$ clusters
  - ${}^2n$ cluster breaking

- What we revealed:
  - 0_1^+: shell-model-like
  - 0_2^+: weakly-bound 2,3-body
  - Enlargement of $M(\mathrm{IS0})$