Universal three-body clustering in excited states of light nuclei

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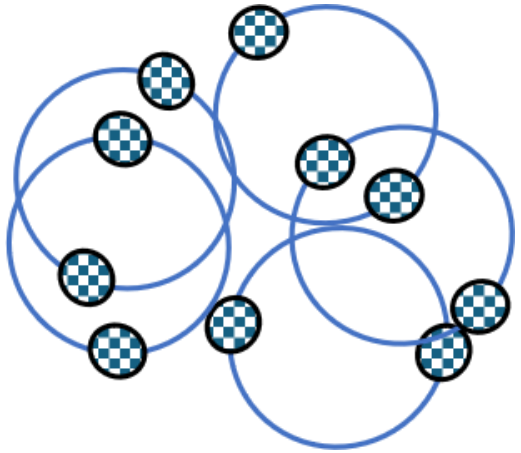
K. Nakagawa, Y. Kanada-En'yo, Phys. Rev. C **112**, 034309 (2025)

Pairing Size in Neutron Matter

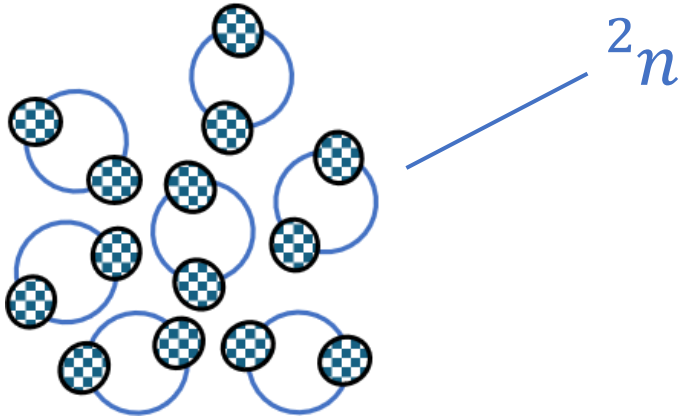
- (pair size / mean distance) changes with density
- In the low-density region, neutron pairs are clustered as dineutrons (^2n)

BCS



$\rho/\rho_0 > 0.1$

crossover



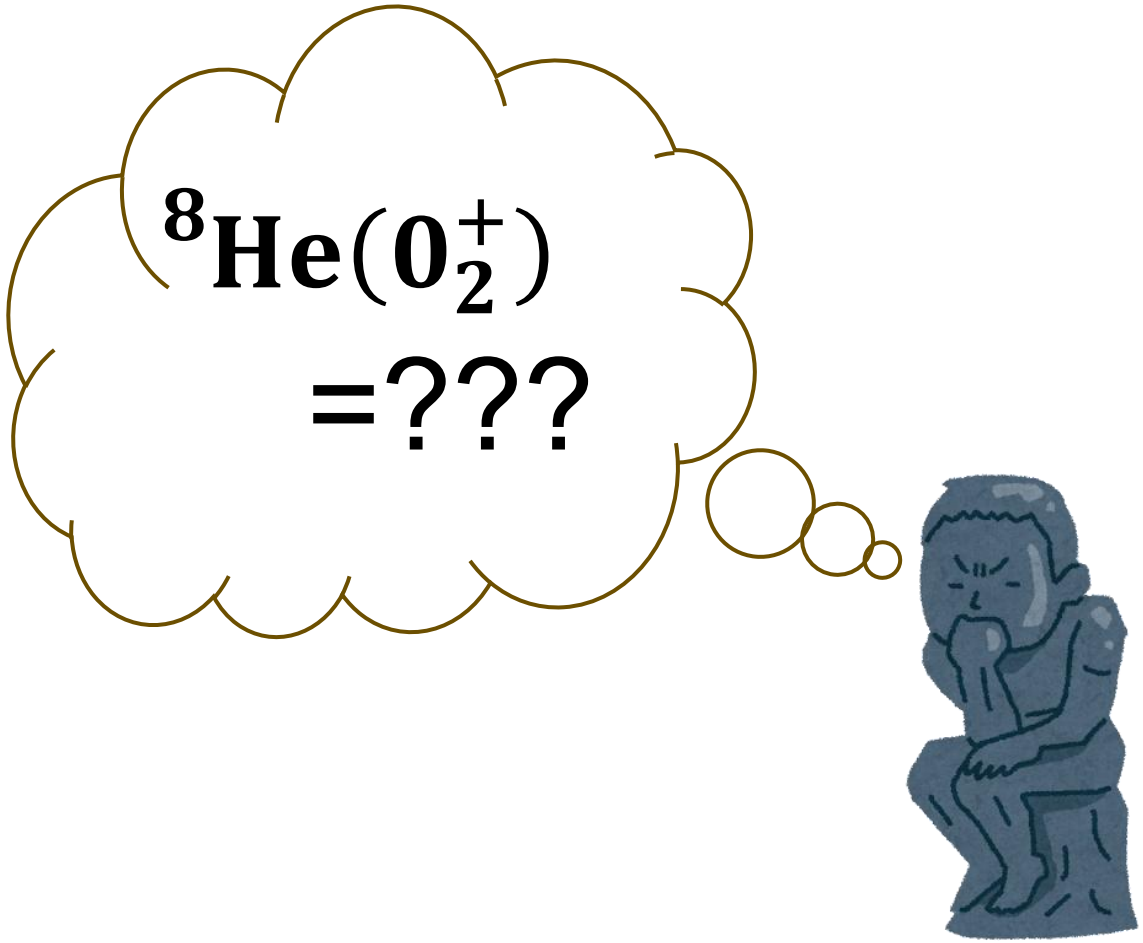
$\rho/\rho_0 \sim 10^{-4} - 0.1$

$\rho_0 \sim 0.16/\mathrm{fm}^{-3}$: saturation density

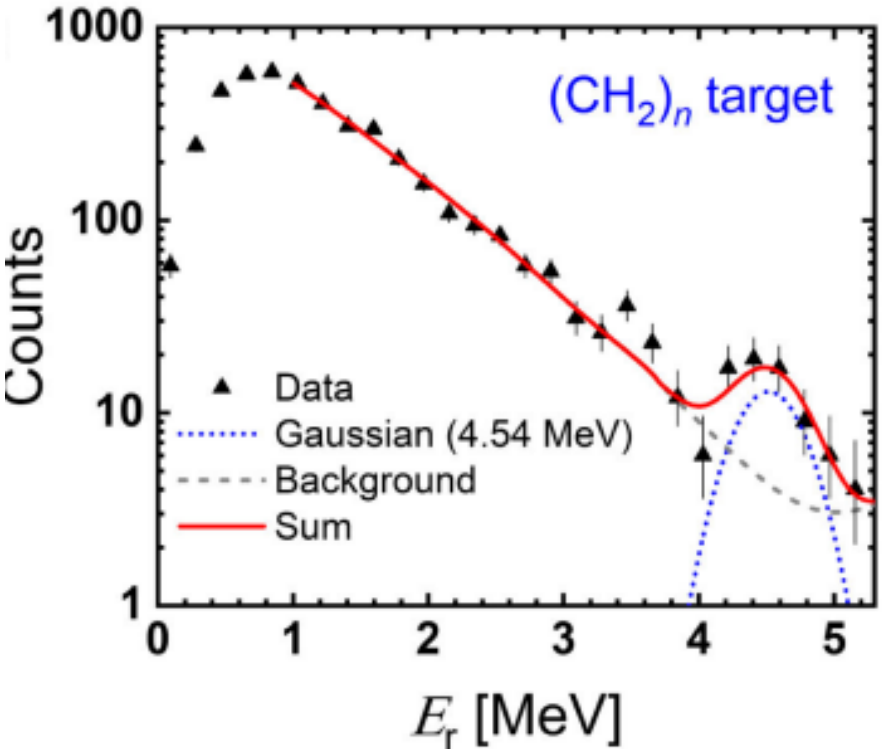
Experiment on $^{8}\mathrm{He}(0_2^+)$

- 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：$M(\mathrm{IS0}) = 11^{+1.8}_{-2.7}\ \mathrm{fm}^2$

large!



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



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

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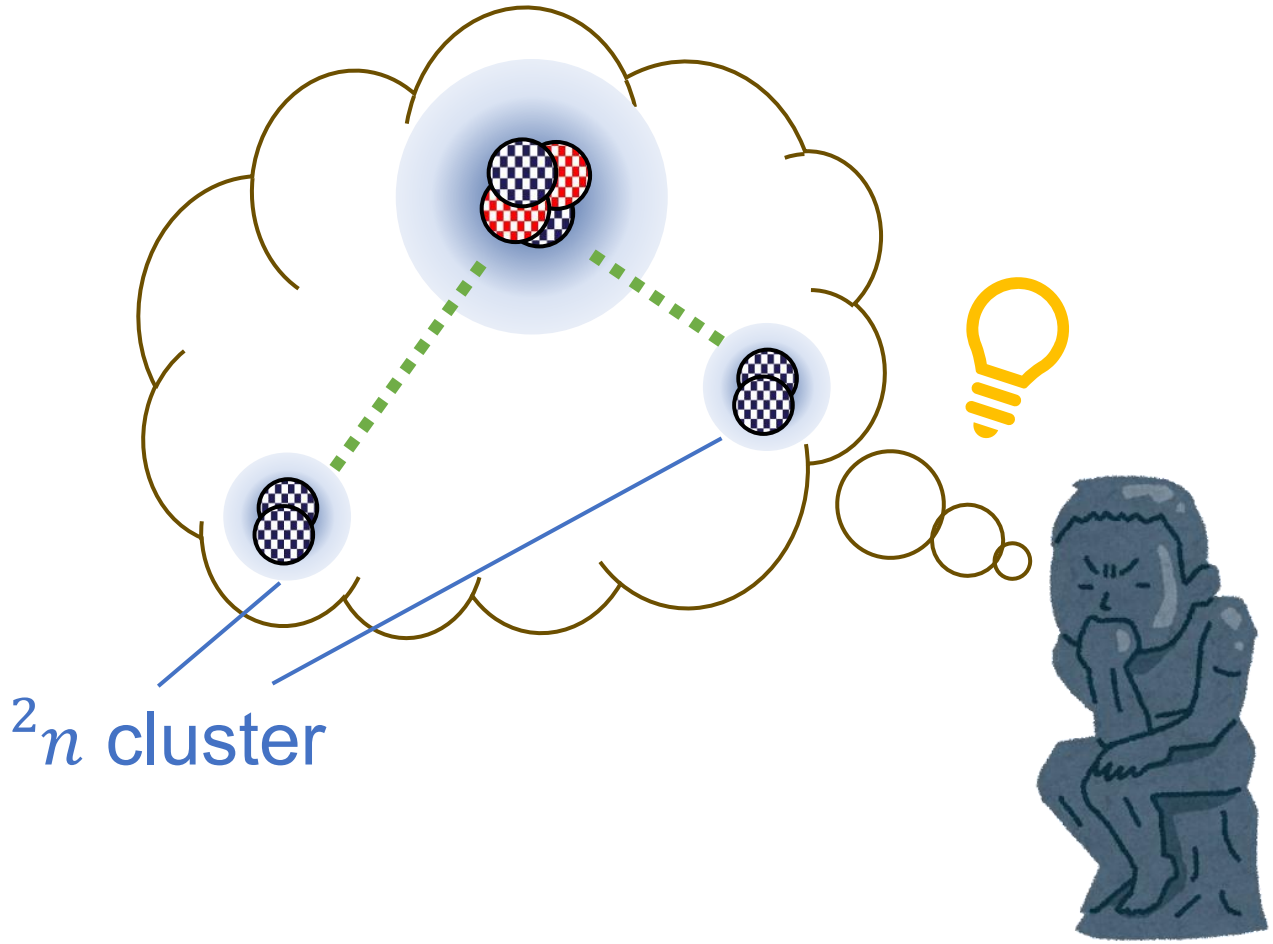
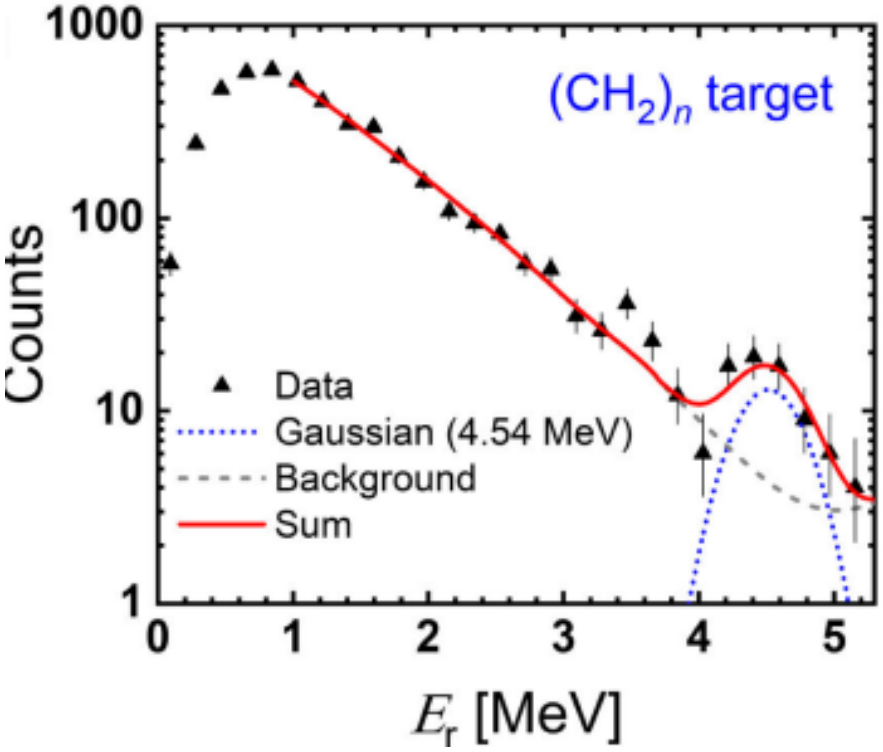
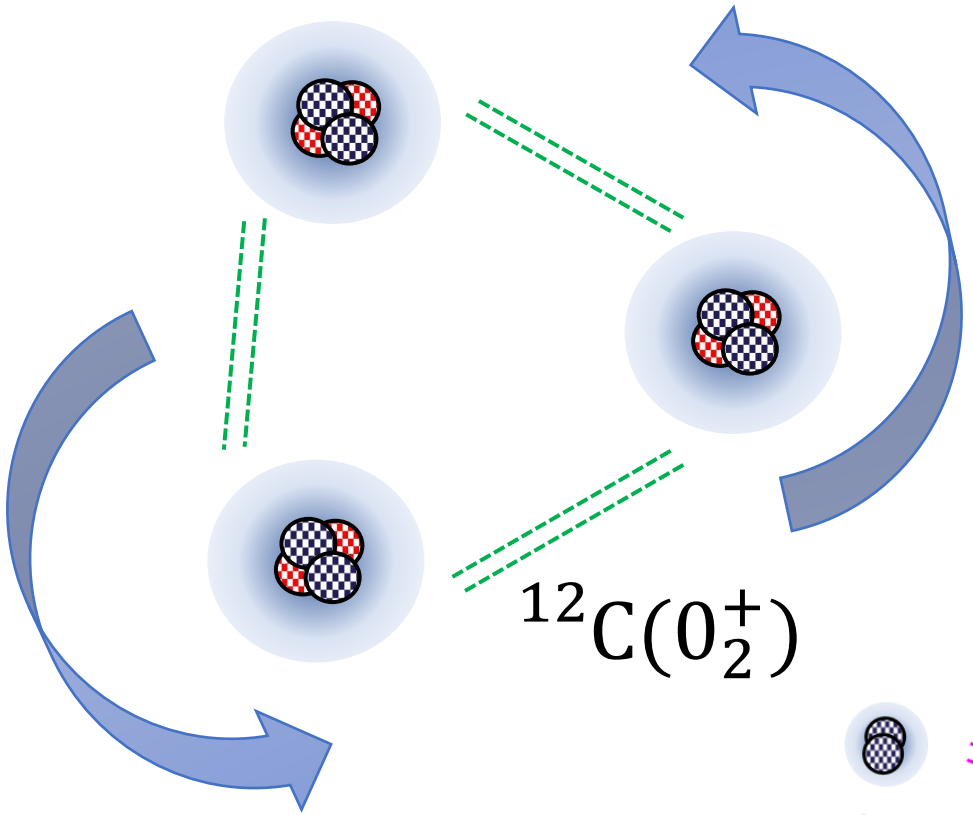


Z. H. Yang *et al.* PRL **131**, 242501 (2023)

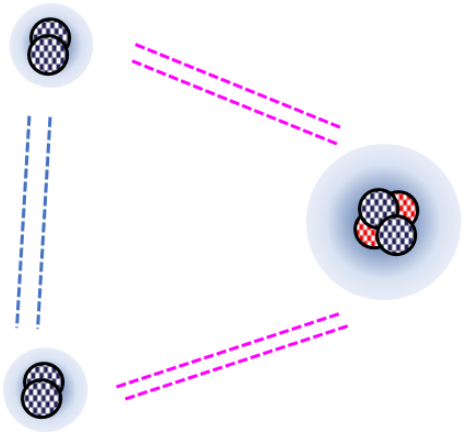


Similarity with 3α structure in $^{12}\mathrm{C}(0_2^+)$



- large ISO transition strength
  $M(\mathrm{IS0}) = 10.8\ \mathrm{fm}^2$

Structure of $^{12}\mathrm{C}(0_2^+)$
= weakly bound 3α in S-wave orbitals
"3-cluster gas"



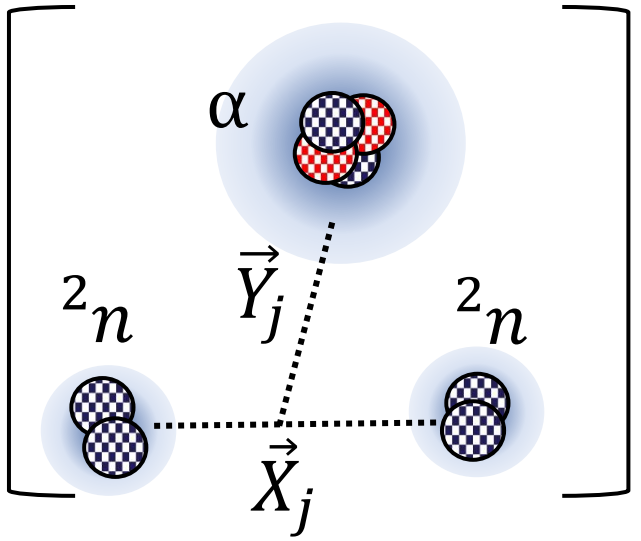
← also appear in $^{8}\mathrm{He}(0_2^+)$?

A. Tohsaki et al., Phys. Rev. Lett. 87, 192501 (2001)

Model Wave Functions

microscopic w.f. (Gaussian) focusing on inter-cluster correlations

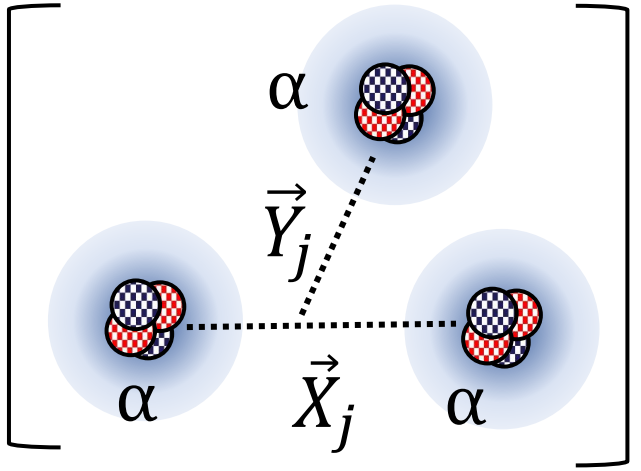
$$\Psi(^{8}\mathrm{He}) = \sum_j c_j^{(3)}$$



$+$ ^2n breaking

3-body clustering

$$\Psi(^{12}\mathrm{C}) = \sum_j c_j^{(3)}$$

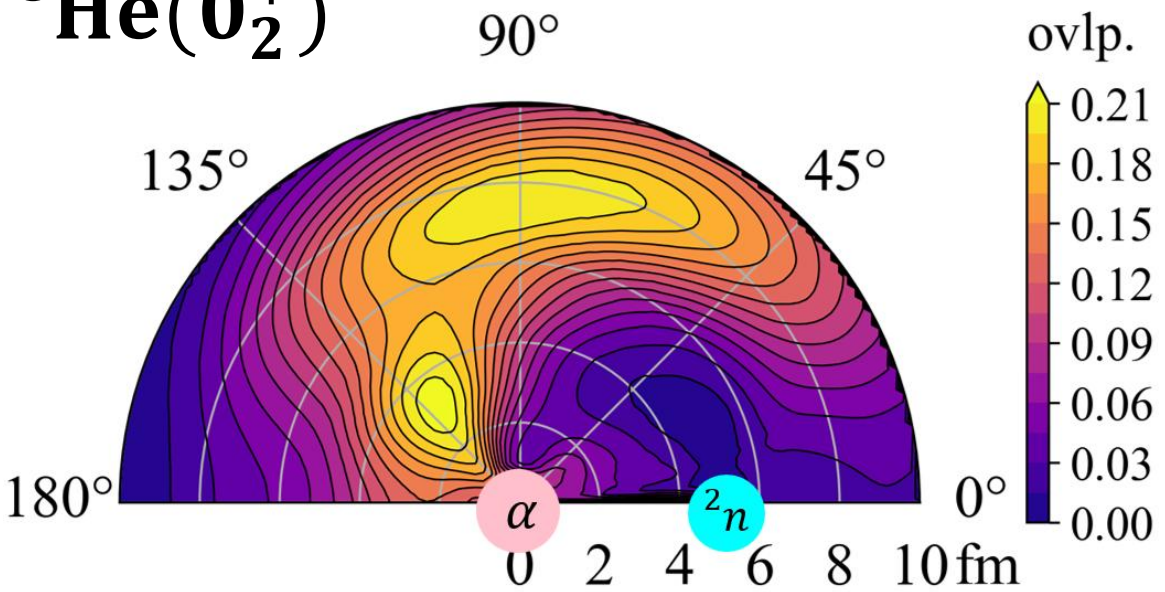


$+$ α breaking

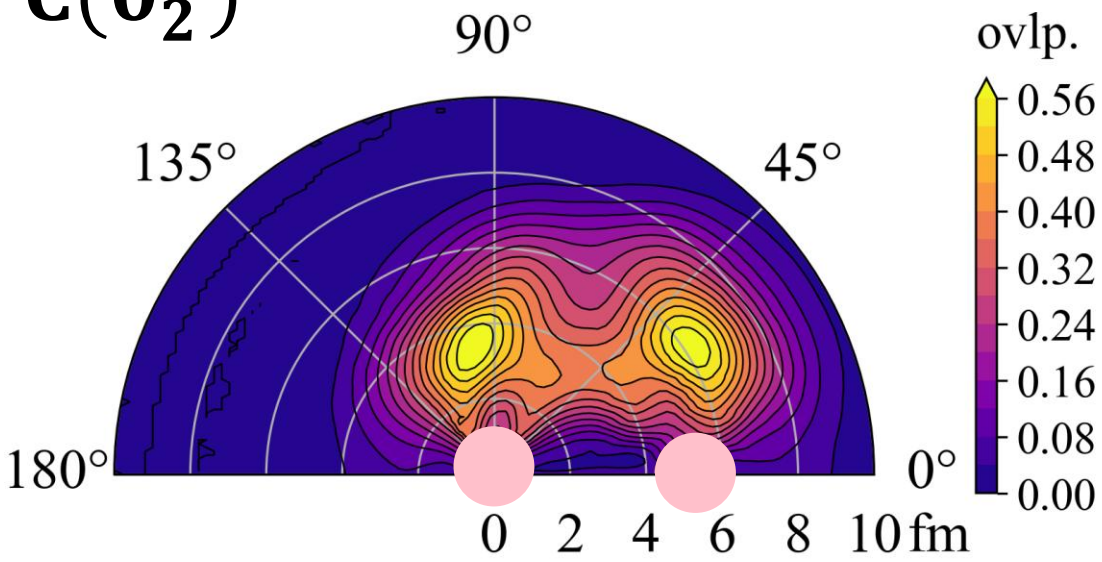
Cluster Spatial Distribution in $^{8}\mathrm{He}(0_2^+)$

^{2}n (α) cluster distribution when fixing the α and ^{2}n cluster

$^{8}\mathrm{He}(0_2^+)$



$^{12}\mathrm{C}(0_2^+)$



Dual cluster structure

- distinct $\alpha + {}^{2}n + {}^{2}n$ clusters $\cong$ S-wave 3α cluster structure
  - S-wave motion of ^{2}n cluster
- spatially correlated $(\alpha + {}^{2}n)$ + ^{2}n

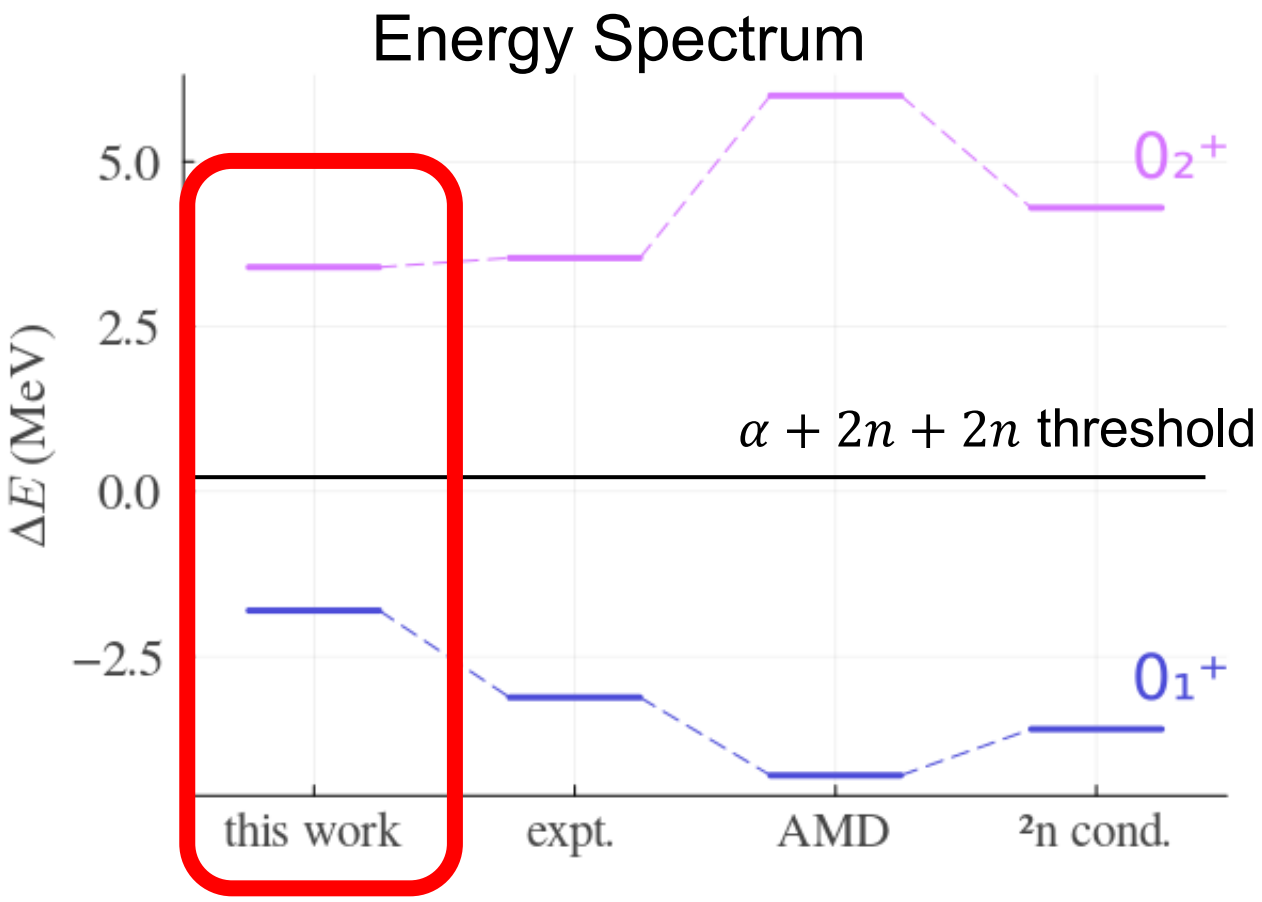
Conclusions

- Analysis of $^{8}\mathrm{He}(0_2^+)$ and $^{12}\mathrm{C}(0_2^+)$ by a microscopic cluster model
- Resemblances between $^{8}\mathrm{He}$ and $^{12}\mathrm{C}$: S-wave motions of 3-body clusters with some total scaling

→ independent of details of inter-cluster interactions

- Specific features of $^{8}\mathrm{He}$: mixing of $(\alpha + {}^{2}n) + {}^{2}n$ 2-body cluster states

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)

Radius & IS0 transition strength

	This work	Expt.	AMD	^2n cond.
$R_{rms}(0_1^+)$(fm)	2.40	2.52	2.24	2.49
$R^p_{rms}(0_1^+)$(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 agree with experimental data and other theoretical studies well.
- Large radius and $M(IS0)$ → development of cluster structures