Cluster features in ground and excited states of ^{12}C and ^{8}He

-- dineutron correlation in ^{8}He --

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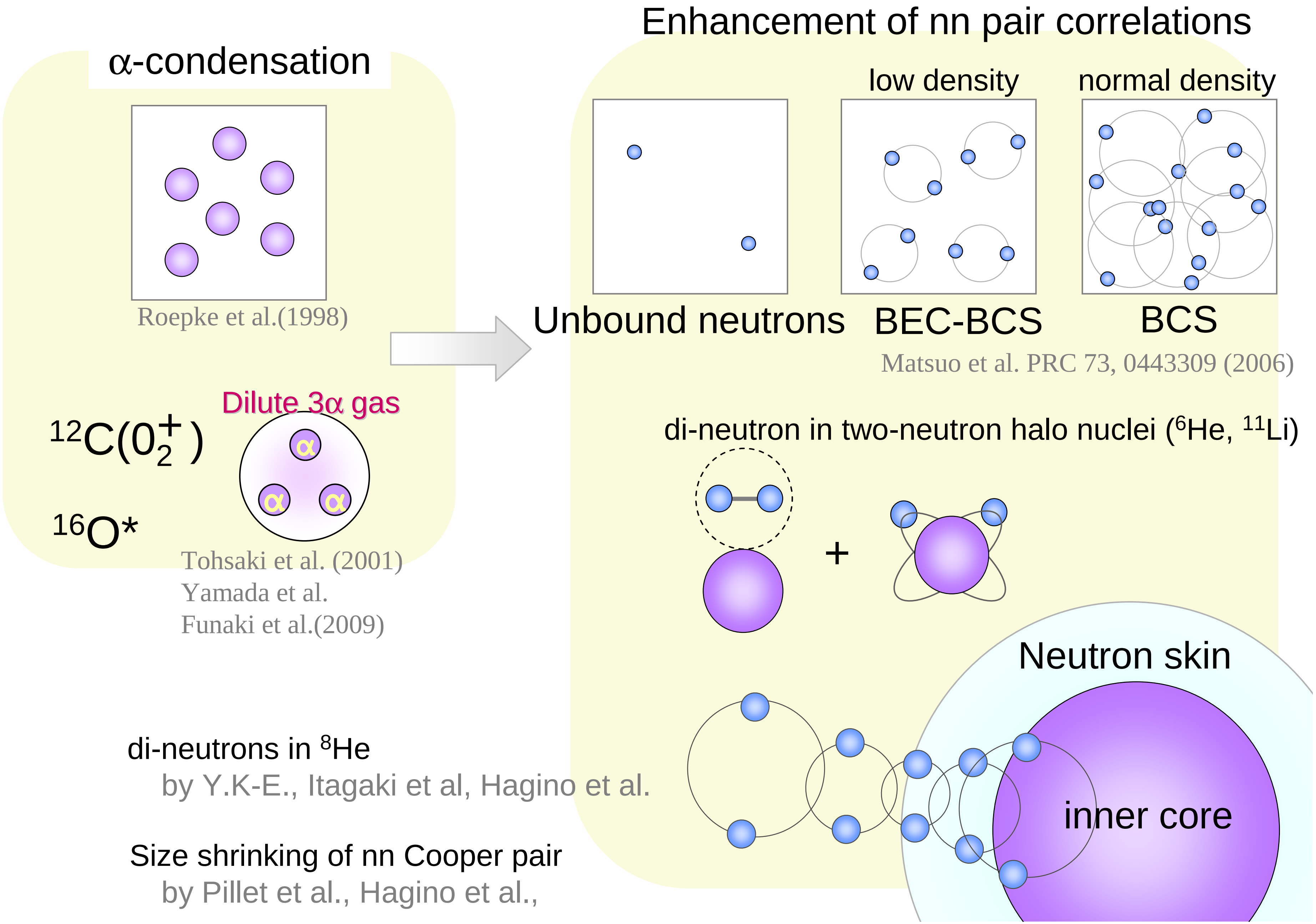
dineutron correlations (spin=0 S-wave nn pair)

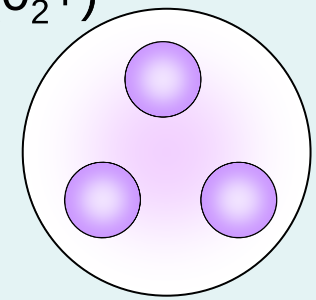


Two dineutrons in ^{8}He

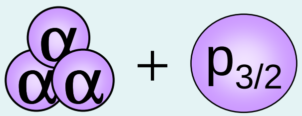
^{12}C

Dilute cluster gas

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

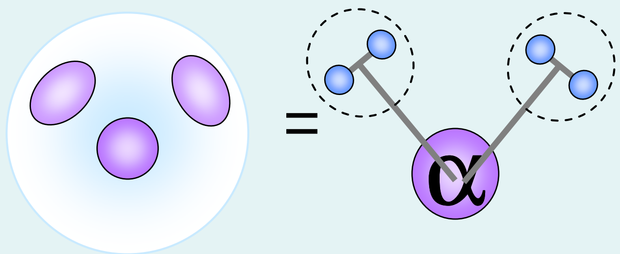


$^{12}C(0_1+)$

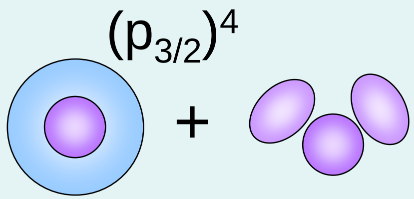


^{8}He

Excited
States ?



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



Today’s talk

1. He isotopes are calculated with a method of Antisymmetrized Molecular Dynamics(AMD).

2. Dineutron correlations are discussed by analyzing two-neutron density.

Formulation

AMD wave function

Wave function

$$\Phi = c\Phi_{\mathrm{AMD}} + c'\Phi'_{\mathrm{AMD}} + c''\Phi''_{\mathrm{AMD}} + \cdots$$

$$\Phi_{\mathrm{AMD}} = \mathcal{A}\{\varphi_1, \varphi_2, \cdots, \varphi_A\}$$

Slater det.

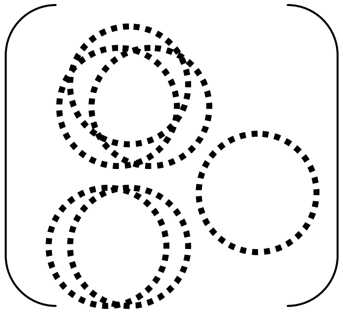
spatial Gaussian

$$\varphi_{\mathbf{i}} = \phi_{\mathbf{Z}_\mathbf{i}} \chi_{\mathbf{i}} \begin{cases} \phi_{\mathbf{Z}_\mathbf{i}}(\mathbf{r}_\mathbf{j}) \propto \exp\left[-\nu\left(\mathbf{r} - \dfrac{\mathbf{Z}_\mathbf{i}}{\sqrt{\nu}}\right)^2\right] \\ \chi_{\mathbf{i}} = \begin{pmatrix} \frac{1}{2} + \xi_{\mathbf{i}} \\ \frac{1}{2} - \xi_{\mathbf{i}} \end{pmatrix} \times (p \text{ or } n) \end{cases}$$

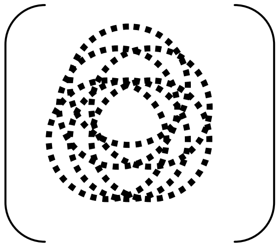
spin

isospin

Complex parameter $\mathbf{Z} = \{\mathbf{Z}_1, \mathbf{Z}_2, \cdots, \mathbf{Z}_A, \xi_1, \cdots, \xi_A\}$

det 

Cluster structure

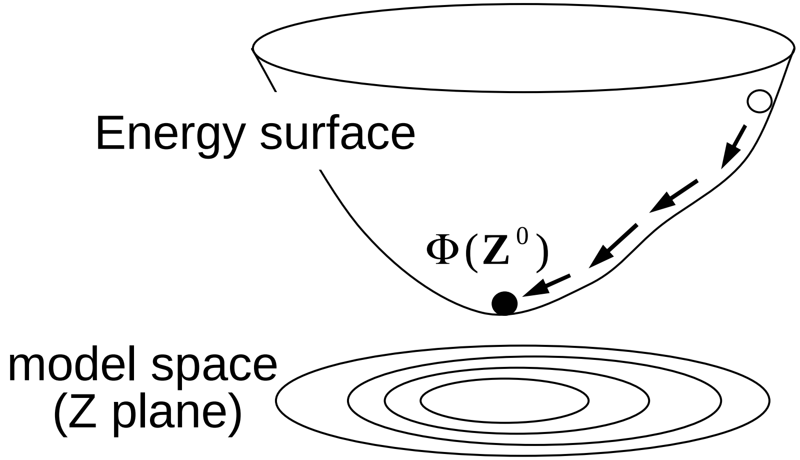
det 

Shell-model-like states

The wave function is equivalent to a simple version of FMD.
For Hamiltonain, we use phenomenological effective nuclear interactions.

Energy Variation

$$\delta \frac{\langle \Phi(\mathbf{Z}) | H | \Phi(\mathbf{Z}) \rangle}{\langle \Phi(\mathbf{Z}) | \Phi(\mathbf{Z}) \rangle} \equiv \delta E = 0$$



frictional cooling method

$$\frac{d\mathbf{Z}}{dt} = (\lambda + i\mu)\frac{1}{i\hbar}\frac{\partial E}{\partial \mathbf{Z}^*}$$

Constraint AMD & superposition $\approx$ AMD + GCM

Variation with Constraints

Principal quantum number $\langle a^+ a \rangle$ & “deformation” β

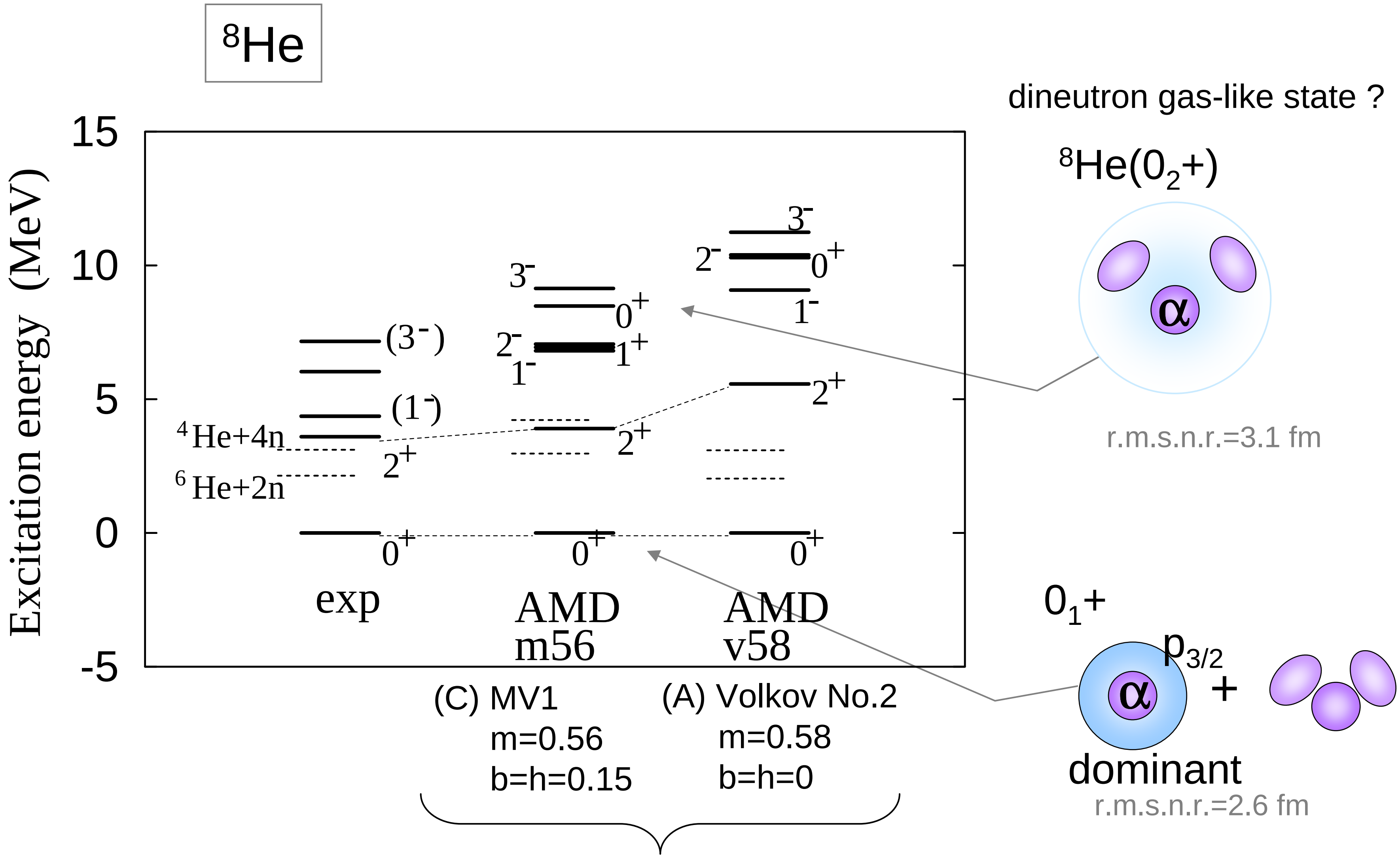
Then, superposition of basis wave functions.

50-100 basis wave functions

Multi configurations (MC) : beyond mean field approaches

Results of ^{8}He

AMD+GCM calc. for ^8He

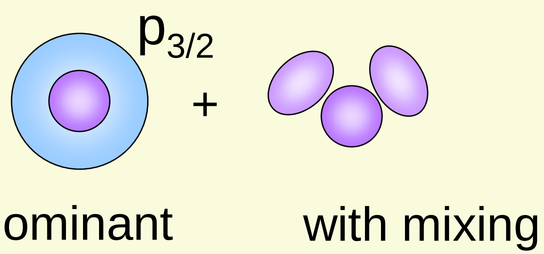


AMD+GCM

with effective N-N interactions(MV1, Volkov)

Dineutron correlation in 8He

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



Dominant p3/2 closure with a mixing of dineutron(S=0 pairs) correlations like SU(3)-limit,no spatially development. Weaker than 6He.

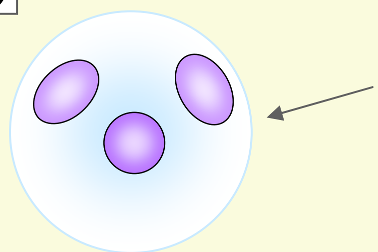
consistent with Itagaki et al. PRC78:017306,2008
inconsistent with ? Hagino et al. PRC77:054317,2008.

Breaking of p3/2 neutron shell has been discussed in recent experimental works.

Exp. L.V.Chulkov et al. NPA759,43(2005) 8He(p,pn)
N. Keeley et al., PLB646, 222(2007). 8He(p,t)6He
F. Skaza, et al. PRC73, 044301(2006). p(8He,d)

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

possible existence of the second 0+ state.



Spatially developed dineutron clusters
=Dineutron gas

No experimental data

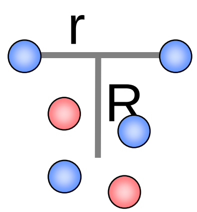
Analysis of dineutron correlations

Two-neutron density

Two-body density:

$$\rho^{(2)}(\mathbf{r},\mathbf{R}) \equiv \left\langle \sum_{i\neq j} \delta(\hat{\mathbf{r}}_i - \mathbf{r}_1)\delta(\hat{\mathbf{r}}_j - \mathbf{r}_2) \right\rangle$$

$$\mathbf{r} = \mathbf{r}_2 - \mathbf{r}_1, \quad \mathbf{R} = (\mathbf{r}_2 + \mathbf{r}_1)/2$$



S=0 and S=1 decomposition

$$\rho^{(2)}_{nn}(\mathbf{r},\mathbf{R}) \equiv \left\langle \sum_{i\neq j} \delta(\hat{\mathbf{r}}_i - \mathbf{r}_1)\delta(\hat{\mathbf{r}}_j - \mathbf{r}_2) \right\rangle \qquad \mathbf{r} = \mathbf{r}_2 - \mathbf{r}_1,\ \mathbf{R} = \frac{\mathbf{r}_1 + \mathbf{r}_2}{2}$$

$$= \rho^{(2)}_{nn,S=0}(\mathbf{r},\mathbf{R}) + \rho^{(2)}_{nn,S=1}(\mathbf{r},\mathbf{R})$$

$$\equiv \left\langle \sum_{i\neq j} P(S_{ij}=0)\delta(\hat{\mathbf{r}}_i - \mathbf{r}_1)\delta(\hat{\mathbf{r}}_j - \mathbf{r}_2) \right\rangle + \left\langle \sum_{i\neq j} P(S_{ij}=1)\delta(\hat{\mathbf{r}}_i - \mathbf{r}_1)\delta(\hat{\mathbf{r}}_j - \mathbf{r}_2) \right\rangle$$

Average of angles

$$\rho^{(2)}(r,R) \equiv \iint d\Omega_r d\Omega_R \rho^{(2)}(\mathbf{r},\mathbf{R})$$

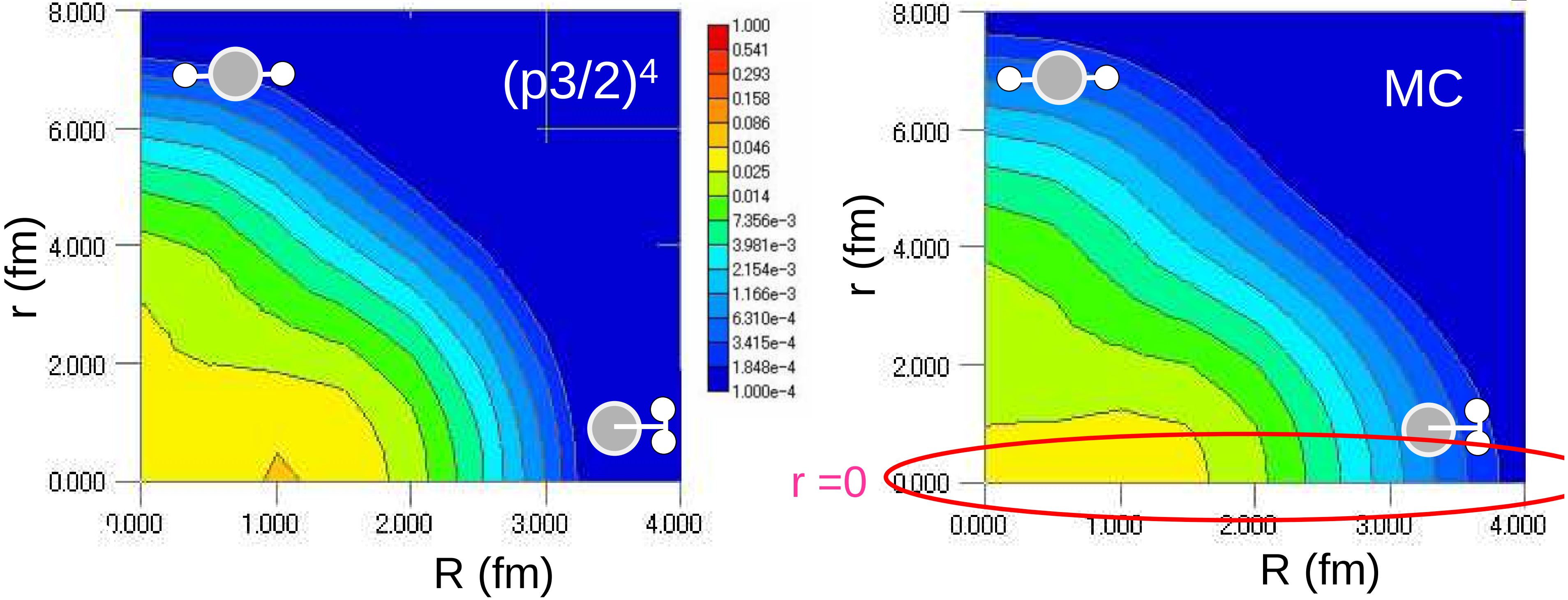
Two-neutron density in 8He

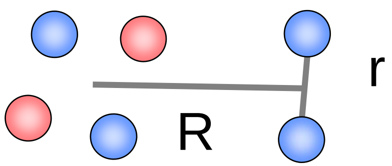
^{8}He

S=0 component $\rho^{(2)}_{nn,S=0}(r,R)$

Superposition of Sater determinants

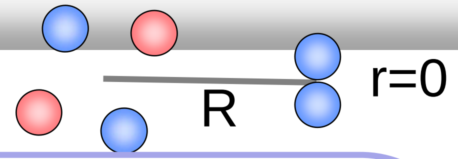
uncorrelated (p3/2)^4 → MC-AMD ^{8}He(0^+_1)





some enhancement of two-neutron density in R>3 fm region
-> dineutron correlations

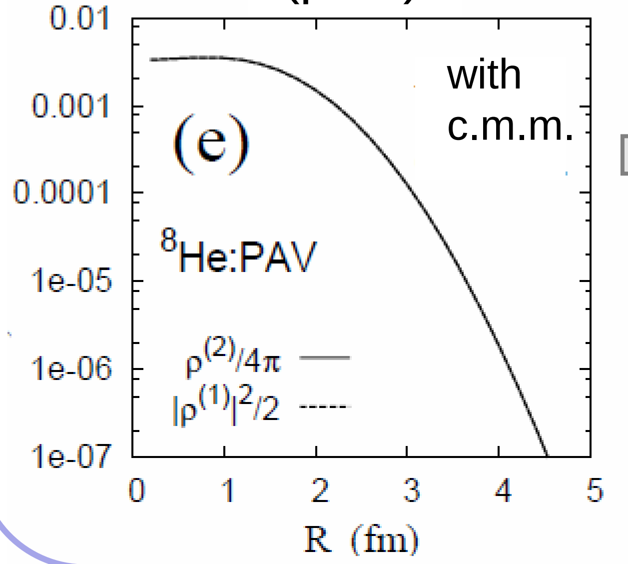
Tow-neutron density in 8He

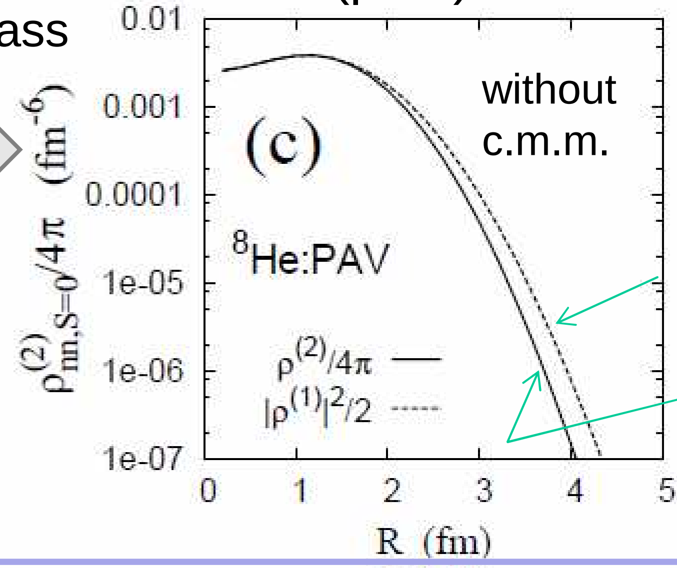


$$\rho^{(2)}_{nn,S=0}(r=0,R) \quad v.s. \quad \left(\rho^{(1)}_{nn,S=0}(R)\right)^2$$

uncorrelated

Extraction of center of mass motion





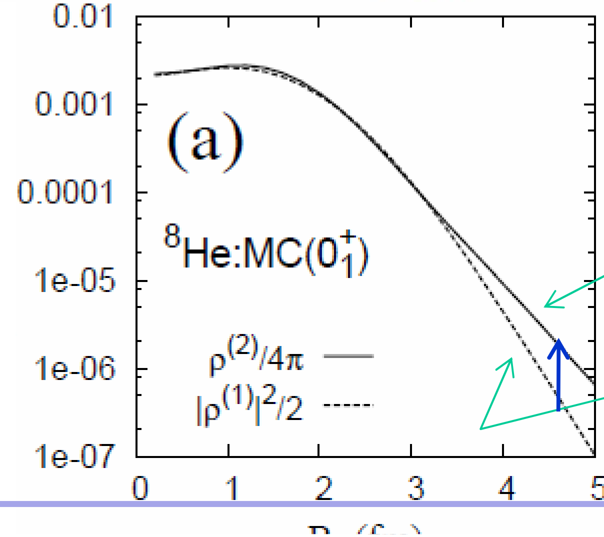
squared 1n density

2n density

MC wave functions:

If we can measure 1n density and 2n density, we will find enhancement of 2n density at surface region(R>4) compared with squared 1n density.

Recoil effect (i.e. extraction of c.m.m.) should be taken into accout.



MC-AMD

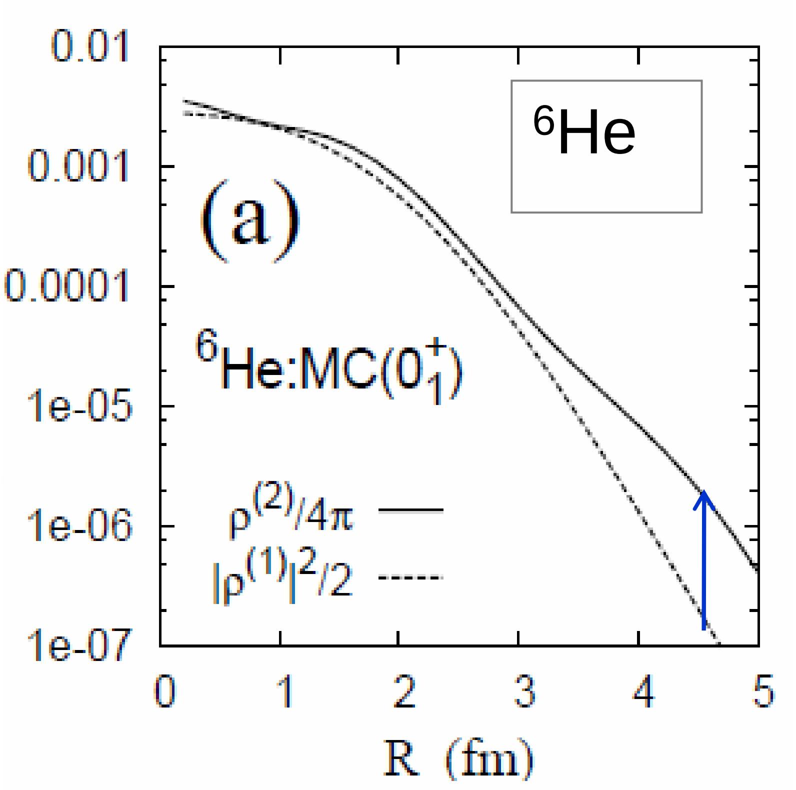
^{8}He($0^+{}_1$)

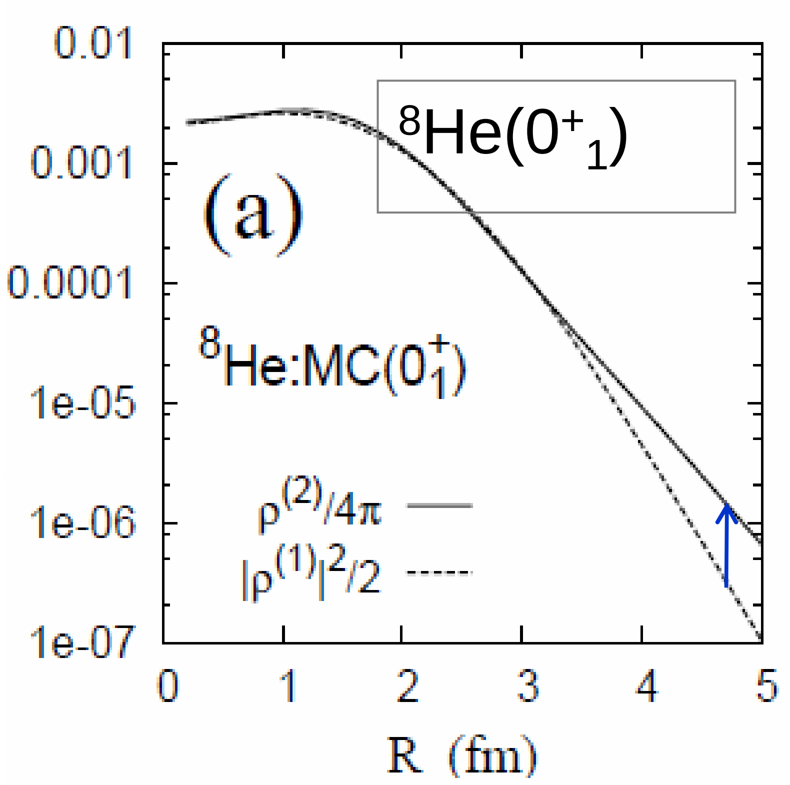
2n density

squared 1n density

Comparison with other nuclei

$$\rho^{(2)}_{nn,S=0}(r=0,R) \quad v.s. \quad \left(\rho^{(1)}_{nn,S=0}(r=0,R)\right)^2$$

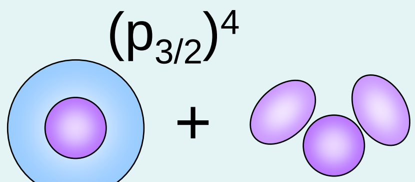




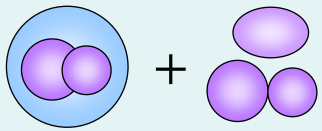
MV1(m=0.56,b=h=0.15)

Dineutron correlation in N=6 nuclei (preliminary)

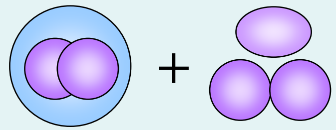
^{8}He(0_1+)

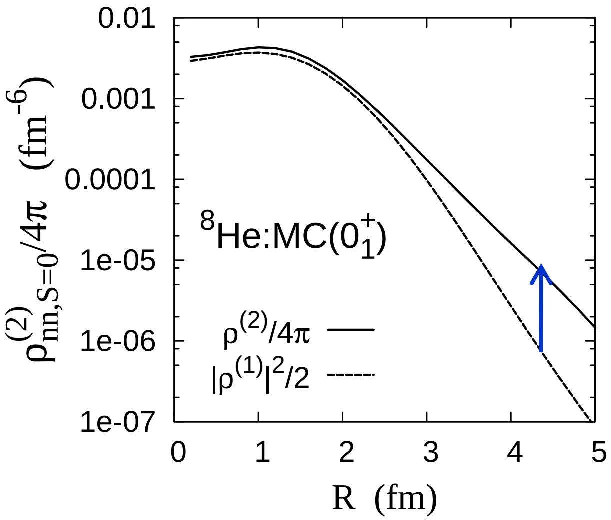


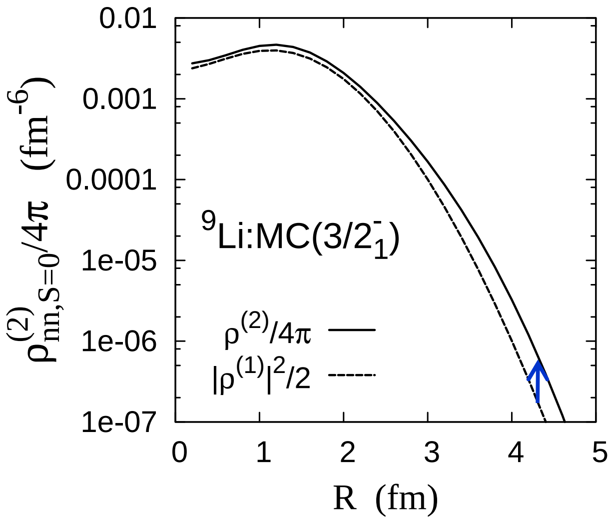
^{9}Li($3/2_1$-)

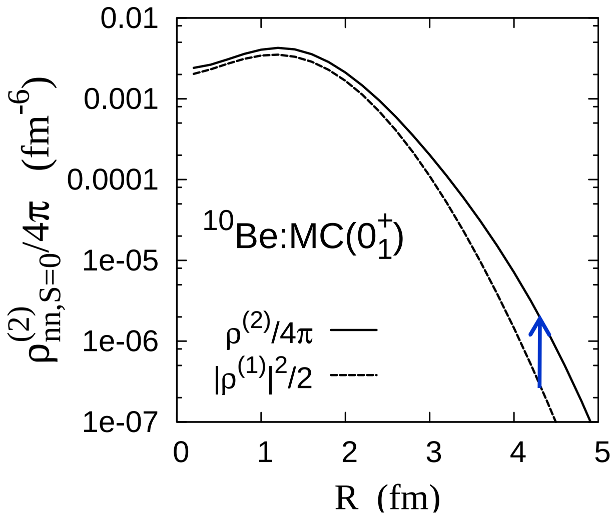


^{10}Be(0_1+)









V2(m=0.60,b=h=0.125)

Dineutron correlation can be discussed in two-neutron density at surface and also in relation with $(p3/2)^4$ component and mixing of $(p3/2)^2$ $(p1/2)^2$

Summary

Dineutron correlation in ^{8}He

Structure of He isotopes was studied with AMD+GCM
Dineutron structure in ^{8}He was analyzed

Results:
• Dineutron correlation in ^{8}He(g.s.) but weaker than ^{6}He(g.s.)
• Possible existence of ^{8}He(0_2+):
  α+2n+2n structure, dineutron gas ?
Future problems:
  Width of excited states. Effective nuclear force.

Analysis of dineutron correlations:
  two-neutron density can be a good probe.
Comparison of 2n density with squared 1n density
6He and 8He show an enhancement of 2n density at surface region(R>4) .

Future: We are now developing a new framework (extension of AMD) to investigate dineutron correlations. F. Kobayashi's poster yesterday.