^{14}Cの励起状態の構造

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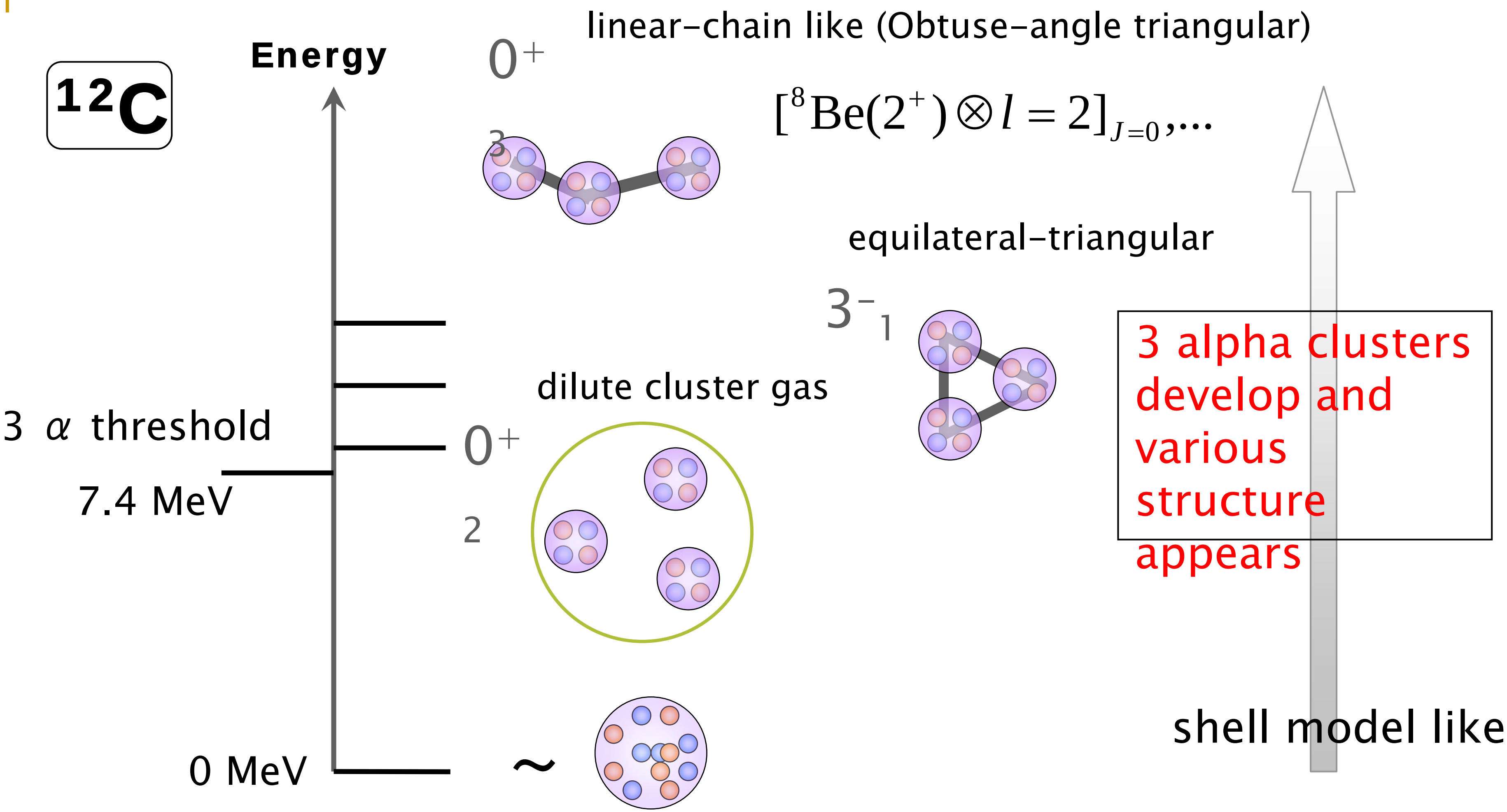
1. Introduction

- Motivation
- Methods

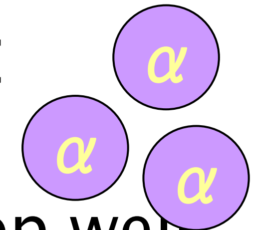
1. Introduction



E. Uegaki, et al. Prog. Theor. Phys. **57**, 1262 (1977)
M. Kamimura, et al. J. Phys. Soc. Jpn. **44** (1978), 225.
A. Tohsaki, et al. Phys. Rev. Lett. **87**, 192501 (2001)
Y. Kanada-En'yo, Prog. Theor. Phys. **117**, 655 (2007) etc

Motivation

^{12}C



In excited states of 12C, 3 alpha clusters develop well

How about excited states in 14C

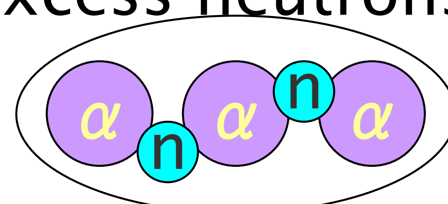
(14C is an unstable nucleus which 2 neutrons are added in to 12C)

- Do alpha clusters appear or disappear?
- If alpha clusters appear, what kind of structure do they have?

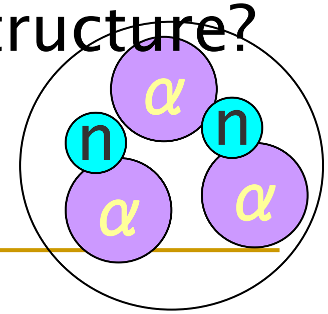
  Equilateral-triangular, Linear-chain, …

- What kind of effect do excess neutrons give structure?

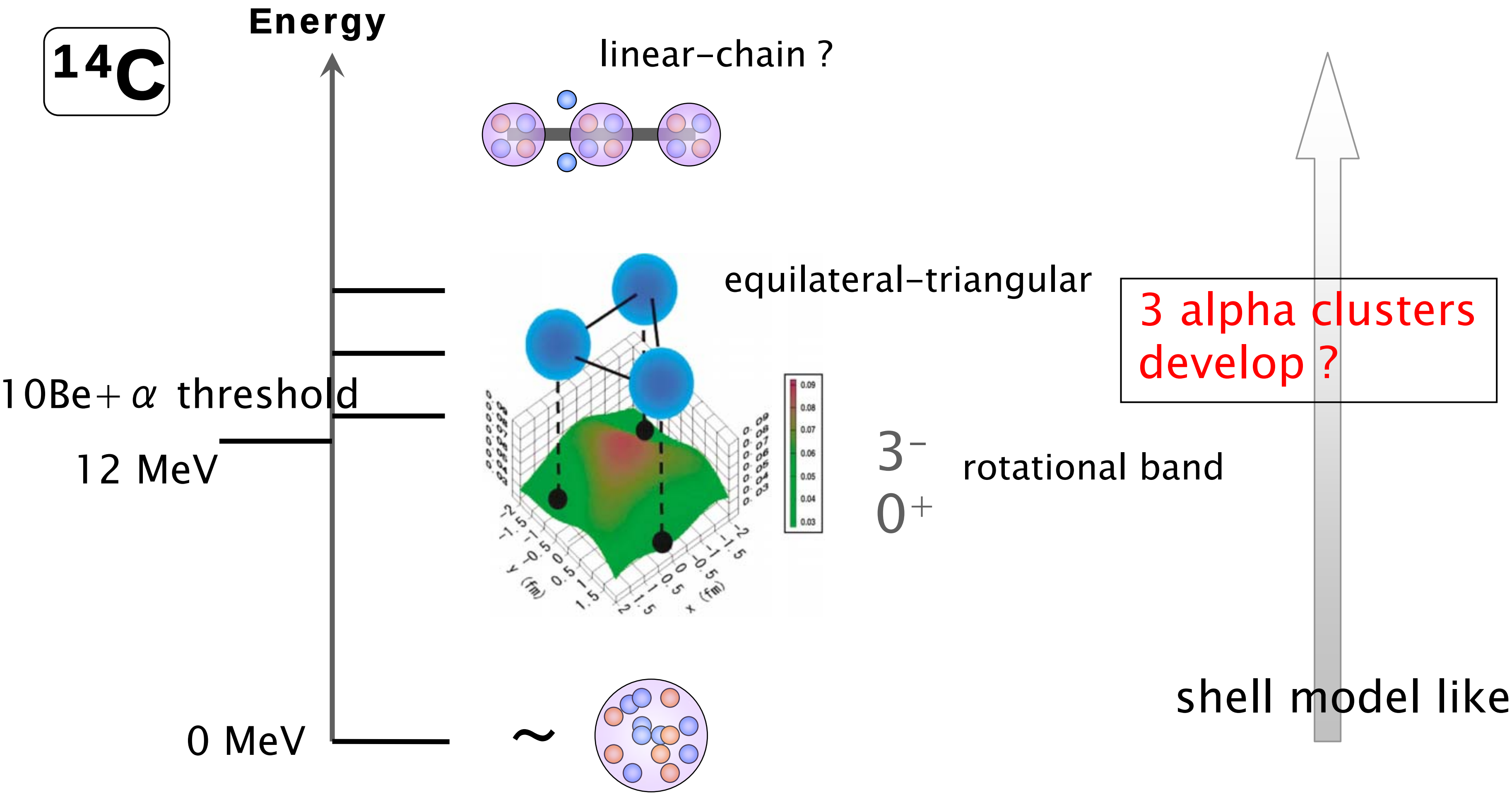
^{14}C



^{14}C



1. Introduction



N. Itagaki, et al, Phys. Rev. Lett. **92**, 142501 (2004)

1. Introduction

Aim

To know what kind structure appear in excited states of

It is expected that various structure appear from an analogy of 12C

Require to methods to use

More free from model assumption
Useful to describe various structure

Methods

AMD（Antisymmetrized Molecular Dynamics）
Constraint on the quadrupole deformation
Superposition (GCM)

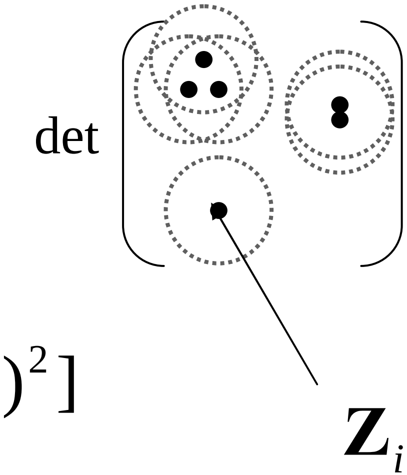
2. Methods

- AMD
- Constraint
- GCM
- Effective Hamiltonian

2. Methods

AMD（Antisymmetrized Molecular Dynamics）

a wave function of A-body system



$$\Phi_{\mathrm{AMD}} = \det[\varphi_1, \varphi_2, \Lambda\ , \varphi_{\mathrm{A}}]$$

spatial

$$\varphi_i = \phi(\mathbf{Z}_i)\chi(\boldsymbol{\xi}_i)$$

$$\phi(\mathbf{Z}_i) \propto \exp[-\nu(\mathbf{r} - \frac{\mathbf{Z}_i}{\sqrt{\nu}})^2]$$

$$\chi(\boldsymbol{\xi}_i) = \begin{pmatrix} \xi_{i\uparrow} \\ \xi_{i\downarrow} \end{pmatrix} \times (\mathrm{p}\ _{\mathrm{or}}\ \mathrm{n})$$

spin and isospin

Set of variational parameters

$$Z = \{\mathbf{Z}_i, \boldsymbol{\xi}_i\}$$

$\mathbf{Z}_i$: center of Gaussian wave packets

$\boldsymbol{\xi}_i$: spin direction

parameters are complex number

2. Methods

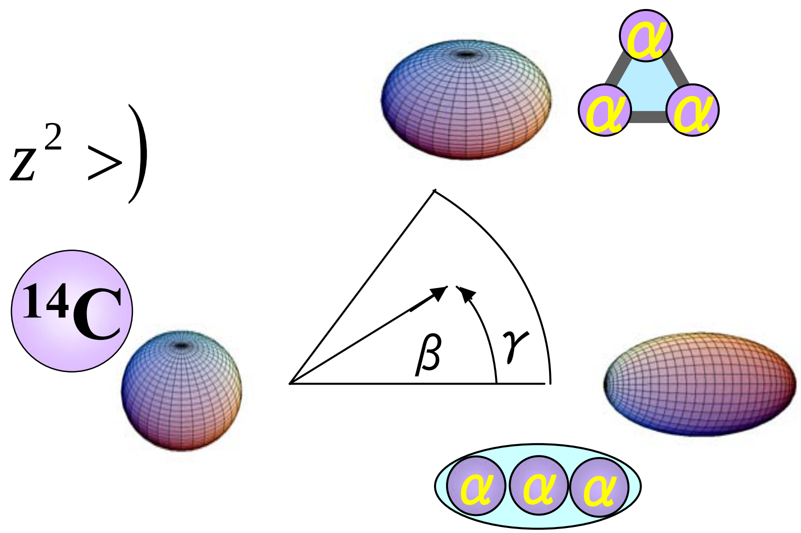
Constraints

The quadrupole deformation (β , γ)

$$\beta \cos\gamma = \frac{\sqrt{5\pi}}{3} \frac{2 < z^2 > - < x^2 > - < y^2 >}{R^2}$$

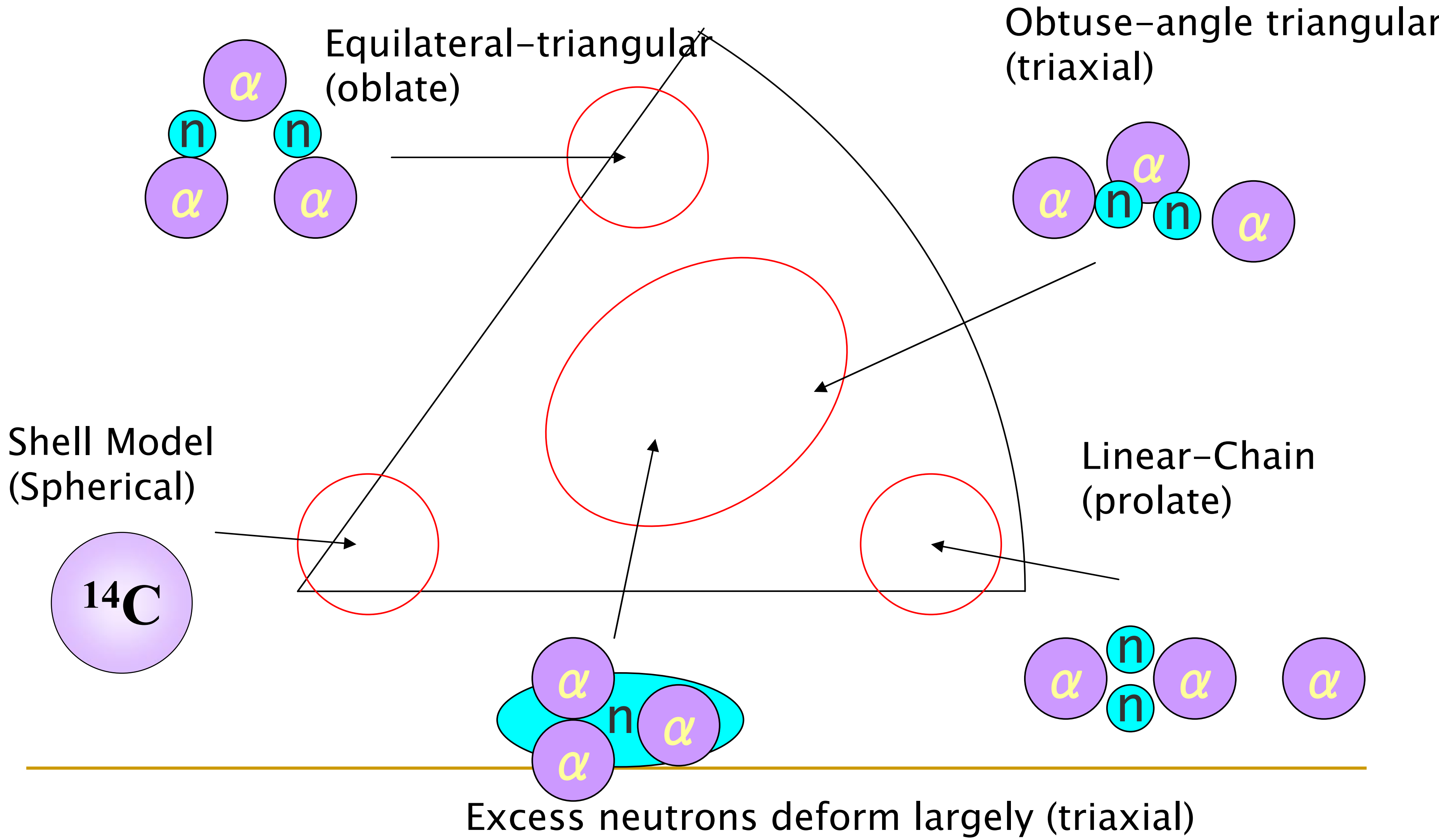
$$\beta \sin\gamma = \sqrt{\frac{5\pi}{3}} \frac{< x^2 > - < y^2 >}{R^2}$$

$$R^2 = \frac{5}{3}\left(< x^2 > + < y^2 > + < z^2 > \right)$$



2. Methods

Structures which are expected to appear on the (β 、γ) plan



GCM(Generator Coordinate Method)

States are described by a superposition of wave functions $\Phi(\alpha)$ using α as generator coordinates

$$\left|\Phi_k^{\mathrm{GCM}}\right\rangle = \int d\alpha\, f_k(\alpha) \left|\Phi(\alpha)\right\rangle$$

The weight functions $f_k(\alpha)$ are obtained by solving the Hill-Wheeler equation,

$$\int d\alpha \left\{ \left\langle \Phi(\alpha') \middle| H \middle| \Phi(\alpha) \right\rangle - E \left\langle \Phi(\alpha') \middle| \Phi(\alpha) \right\rangle \right\} f_k(\alpha) = 0$$

In this study, we adopted (β、γ) as the generator coordinat

Effective Hamiltonian

$$H^{\text{eff}} = \sum_{i} t_i - T_G + \sum_{i<j} v_{ij}^{\text{central}} + \sum_{i<j} v_{ij}^{\text{LS}} + \sum_{i<j} v_{ij}^{\text{Coulomb}}$$

The central force : The Volkov No.2 (0.6)

The LS force : The LS part of the G3RS

This effective Hamiltonian is same as Itagaki's work for C isotopes

N. Itagaki, et al, Phys. Rev. C. **64**, 014301 (2001)

N. Itagaki, et al, Phys. Rev. Lett. **92**, 142501 (2004)

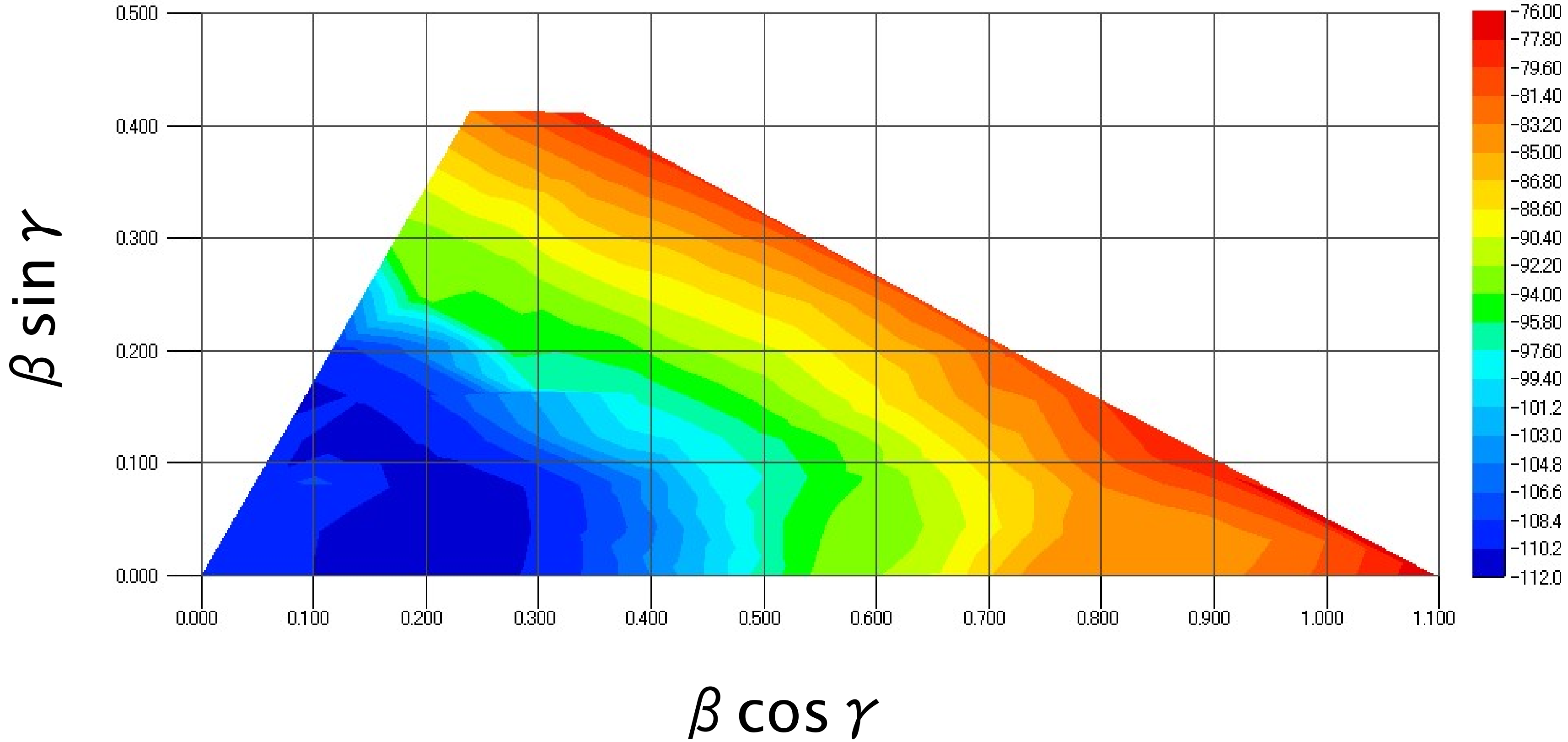
N. Itagaki, et al, Phys. Rev. C. **74**, 067304 (2006)

3. Results

- Energy Surface by Constrained AMD
- Structure of Intrinsic States
- Energy Levels

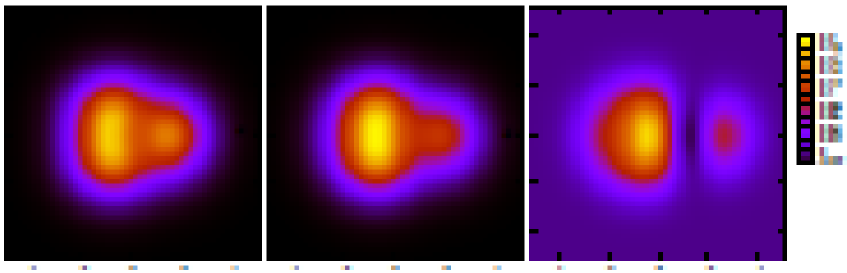
3. Results

The energy surface of 0^+

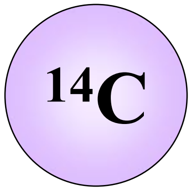


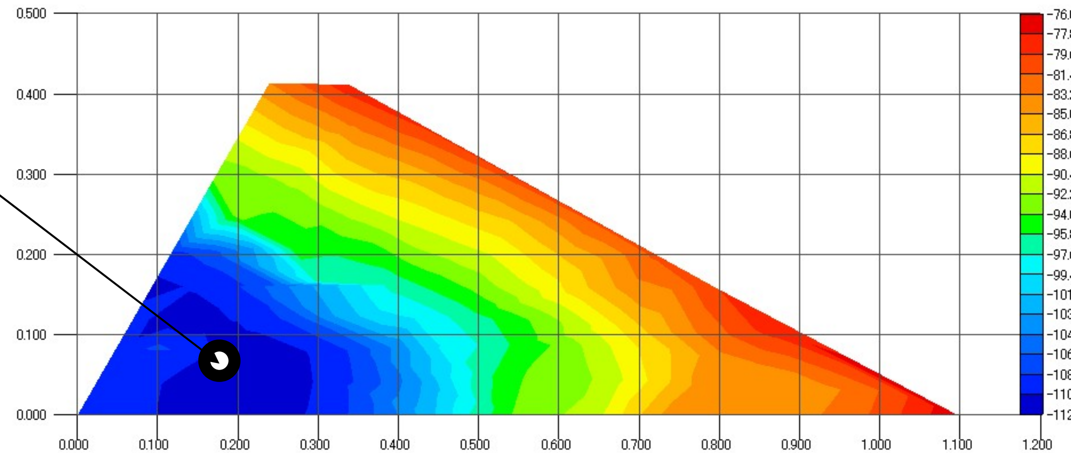
3. Results (Example of Structure)

p n n−p



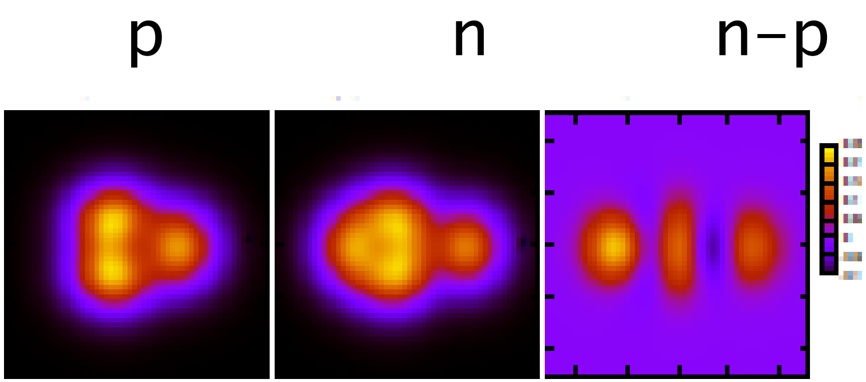
Shell model like



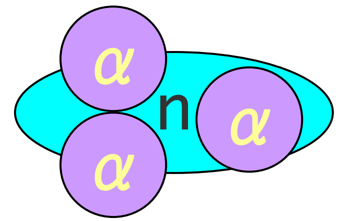


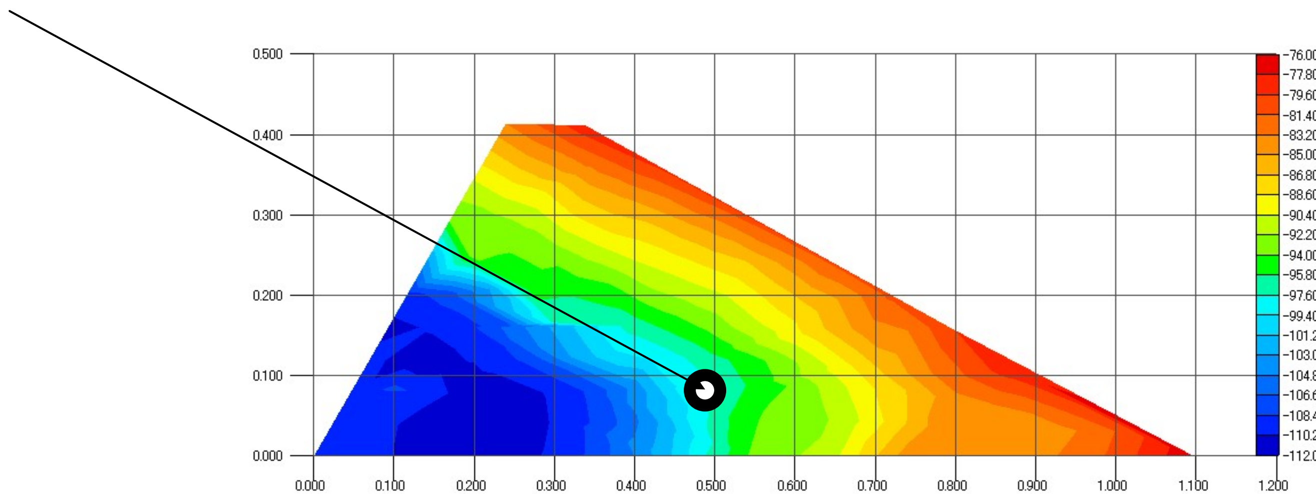
centers of Gaussian gather around the origin

3. Results (Example of Structure)



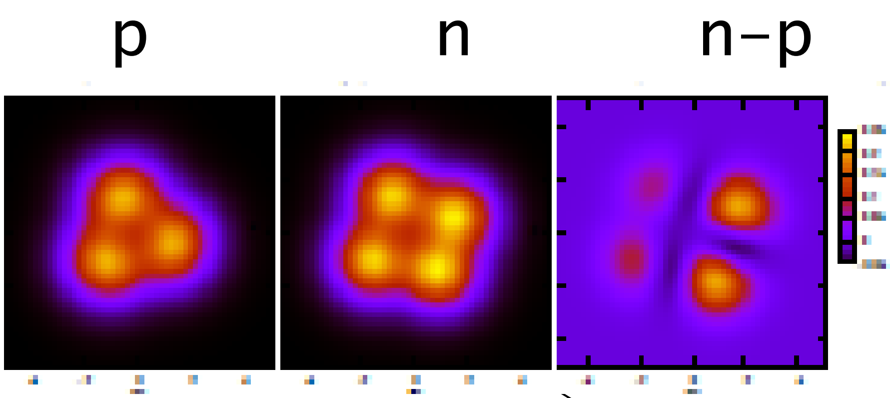
Triaxial
(Excess neutrons deform largely)



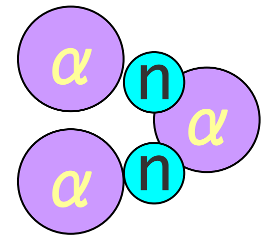


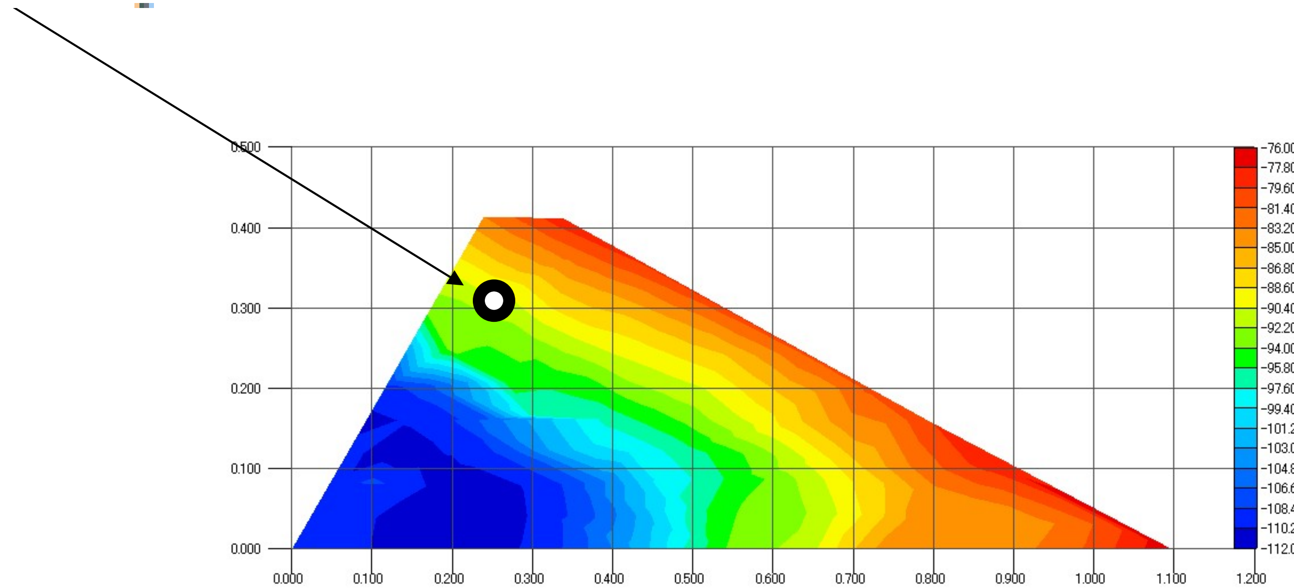
3 alpha clusters develop
excess neutrons occupy sd-like orbital between 8Be and an α cluste

3. Results (Example of Structure)



Equilateral−triangular
(oblate)

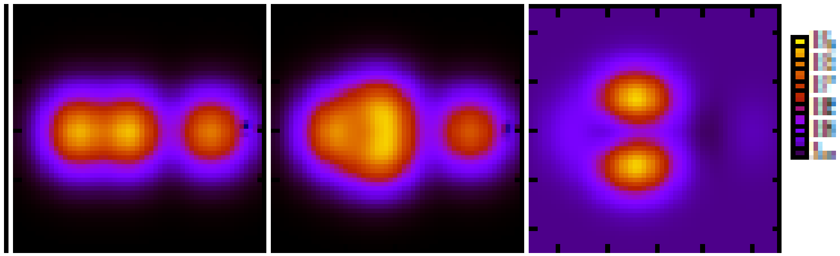




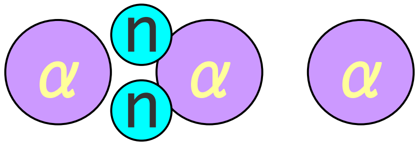
3 alpha clusters develop and have an equilateral−triangular shape

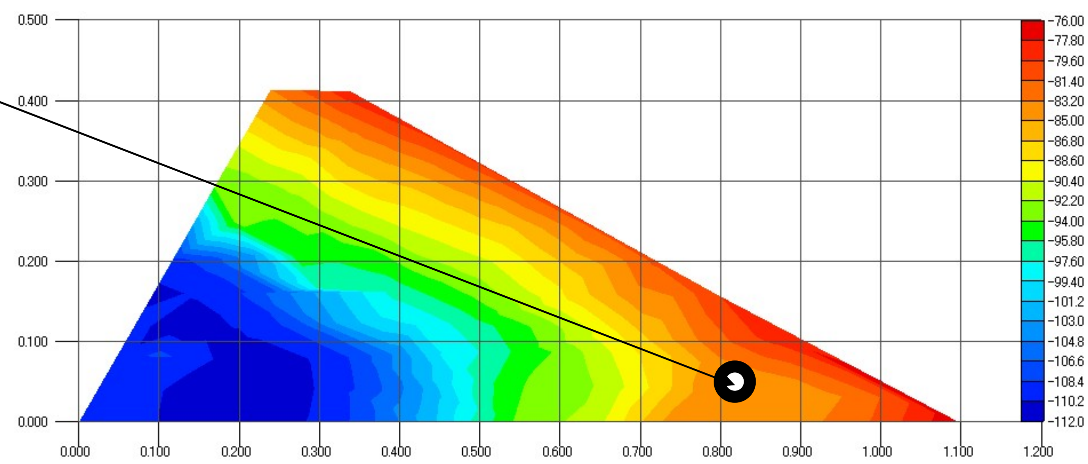
3. Results (Example of Structure)

p n n-p



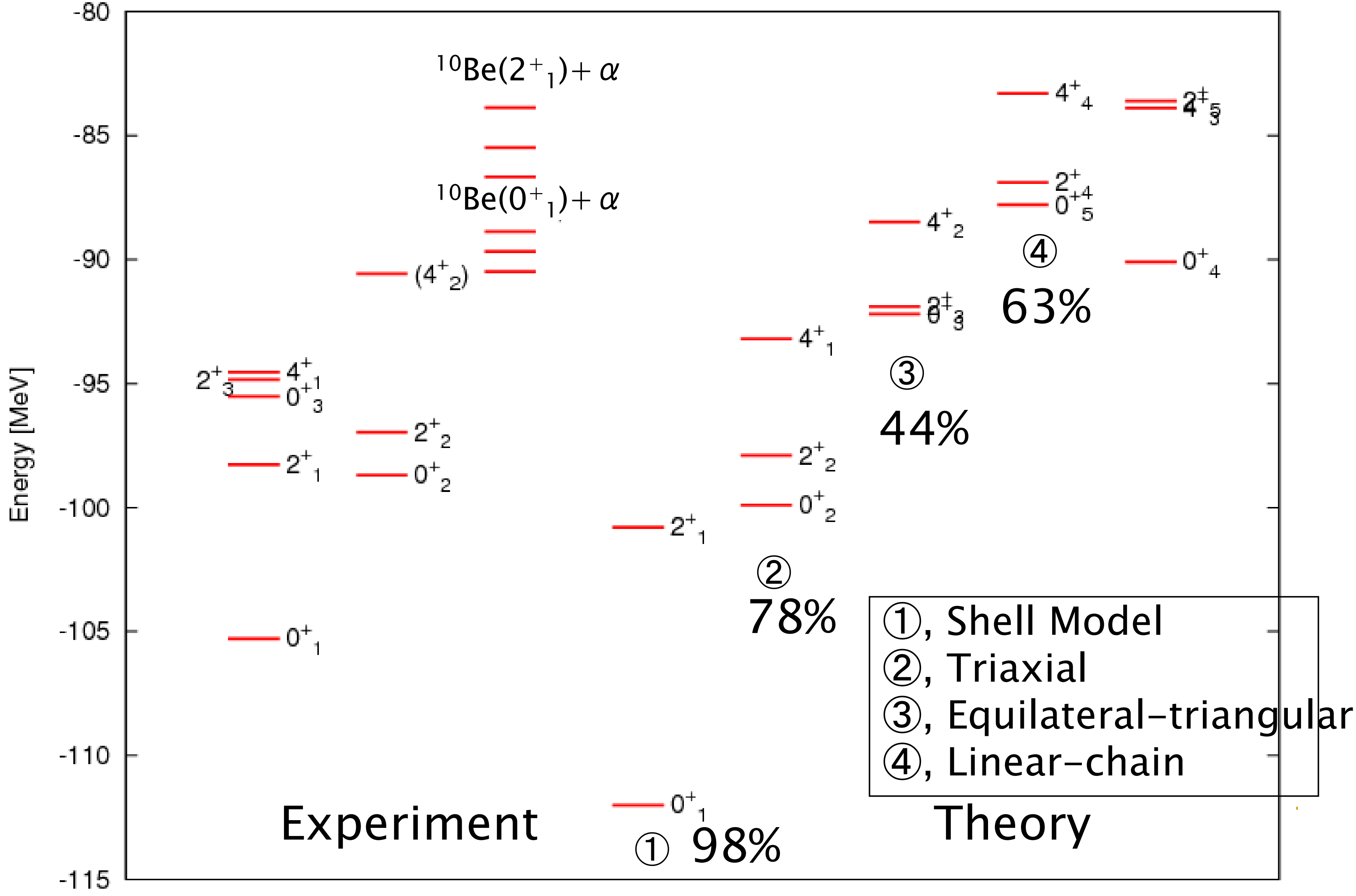
Linear-Chain (prolate)



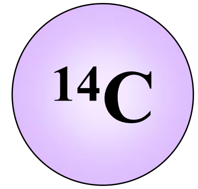


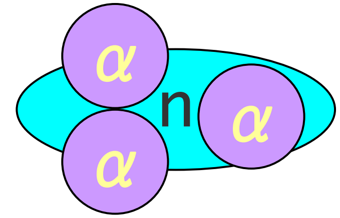
3 alpha clusters develop and have an linear-chain shape
10Be correlation exist

3. Results (The Energy Levels)



3. Results (Energy Levels)

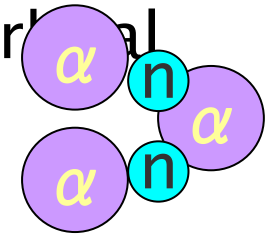




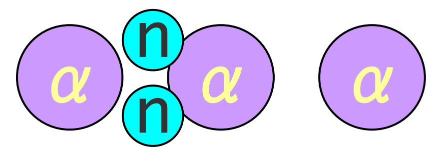
Characteristics

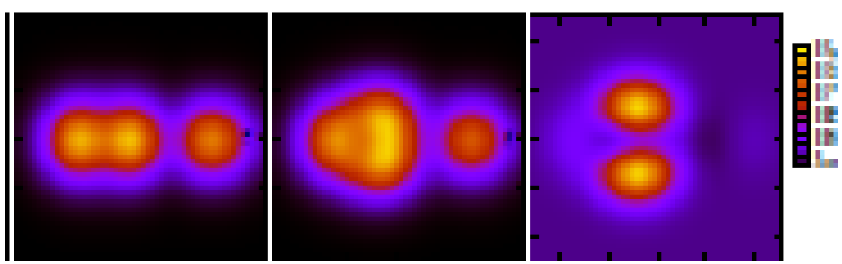
There are four bands

- The 0^+_1 band has shell model like structure
- In 0^+_2 band, excess neutrons occupy sd-like orbital between 8Be and an α cluster (excess neutrons deform largely)



- The 0^+_3 band has equilateral-triangular structure
- The 0^+_4 band has linear-chain structure 10Be correlation exist





4. 10Be correlation in linear-chain states in 14C

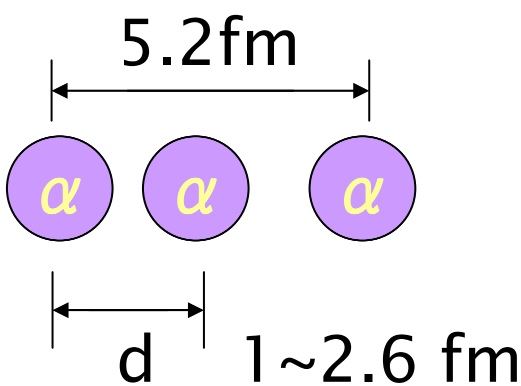
In linear-chain states, does 10Be correlation exist really?
Should excess neutrons move around the whole of 14C?
This calculation is an answer of these questions.

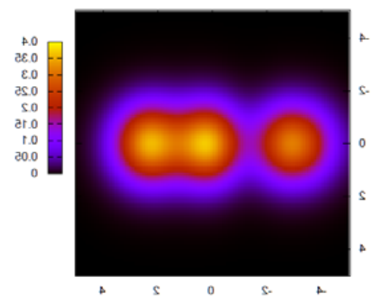
Linear-chain states are calculated in simple 3α linear-chain model in order to see 10Be correlatio

4. 10Be correlation in linear-chain states in 14C

Setting for simple 3α linear-chain model

- 3 α clusters have linear-chain structure
  - the length is fixed 5.2 fm
  - central α cluster moves 1~2.6 fm
- orbitals of excess neutrons are determined by variation



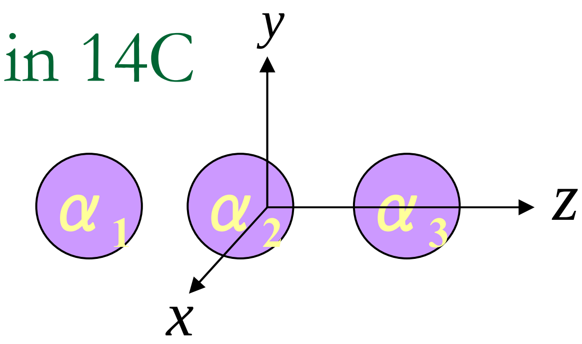


under these conditions, we calculate energy

after variation, if 10Be correlation exists,
energy minimum states should satisfy 2 conditions

- d << 2.6 fm (2α + α)
- excess neutrons gather around the 2α

4. 10Be correlation in linear-chain states in 14C



The wave function

(0S)^4

$$\Phi^+ = P^+ A[\phi_{\alpha_1}\phi_{\alpha_2}\phi_{\alpha_3}\varphi_{n_1}\varphi_{n_2}]$$

$$\varphi_{n_1} = \left\{C_{n_1,1}\left(p_x + ip_y\right)_1 + C_{n_1,2}\left(p_x + ip_y\right)_2 + C_{n_1,3}\left(p_x + ip_y\right)_3\right\}\left|n\uparrow\right\rangle$$

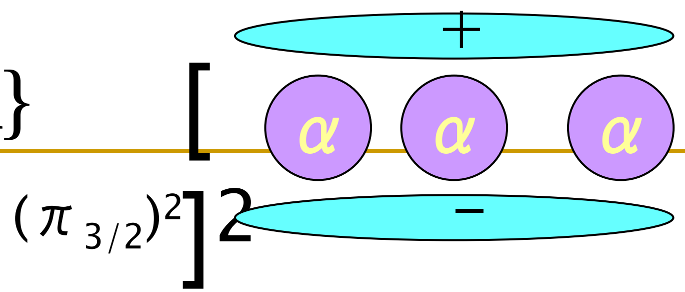
$$\varphi_{n_2} = \left\{C_{n_2,1}\left(p_x - ip_y\right)_1 + C_{n_2,2}\left(p_x - ip_y\right)_2 + C_{n_2,3}\left(p_x - ip_y\right)_3\right\}\left|n\downarrow\right\rangle$$

variation $\left\{C_{n_i,1}, C_{n_i,2}, C_{n_i,3}\right\}$ are determined by variation

We calculate also the case excess neutrons move around the whole of 3 α clusters (MO) to compare variation c

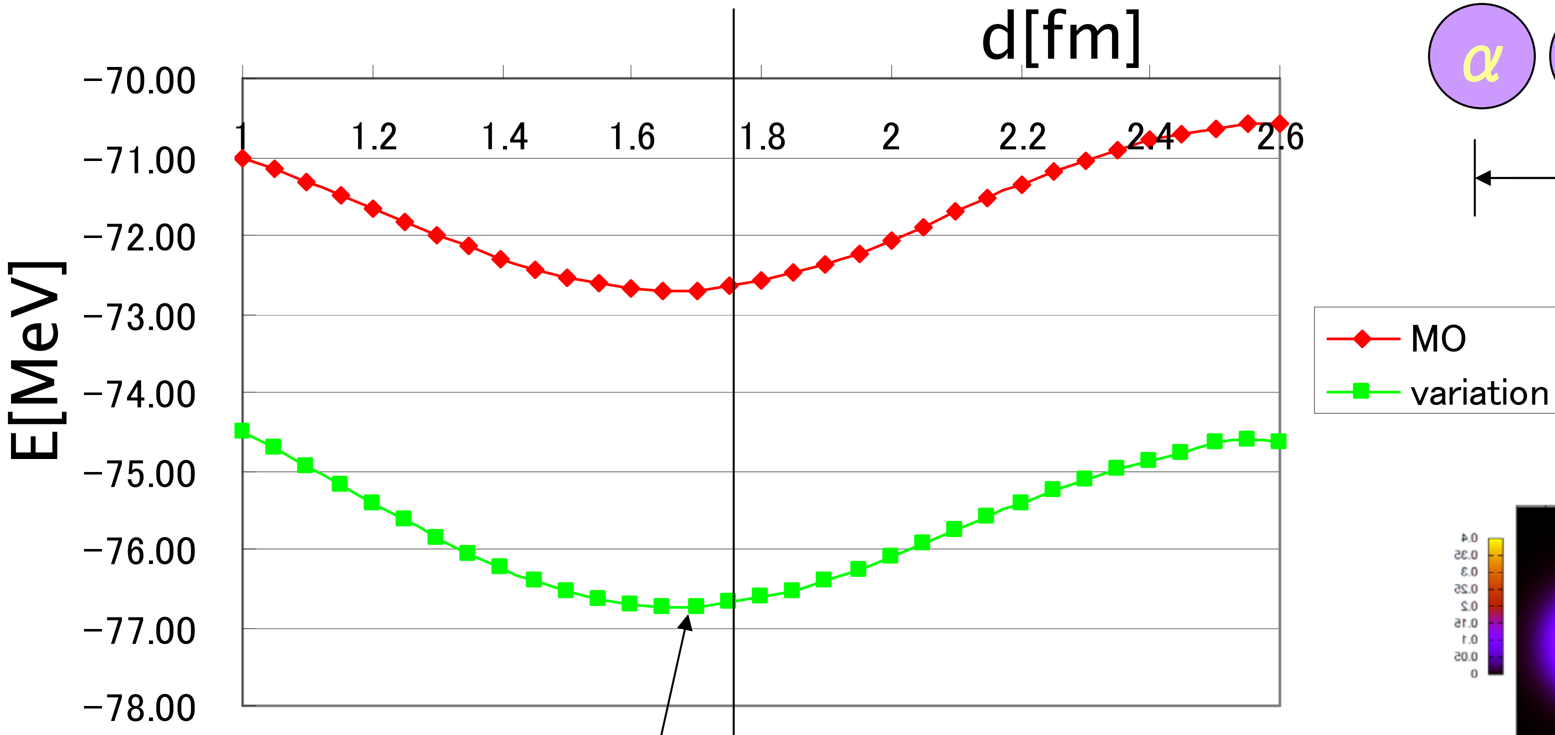
MO $\left\{C_{n_i,1}, C_{n_i,2}, C_{n_i,3}\right\} = \{1,1,1\}$

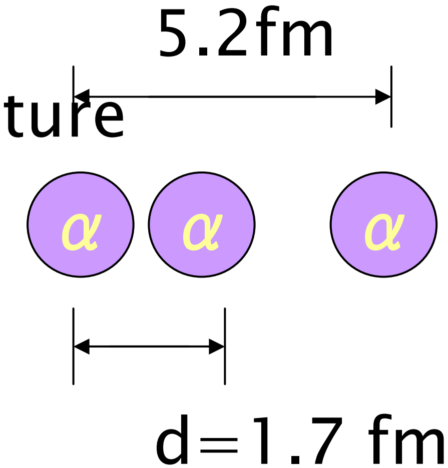
Equal weight

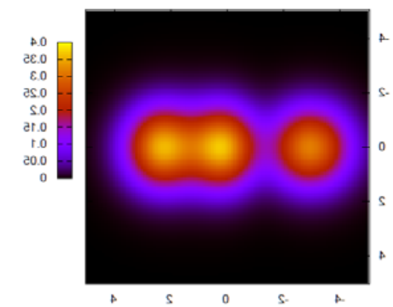


4. 10Be correlation in linear-chain states in14C

Energy of 14C which have linear-chain structure





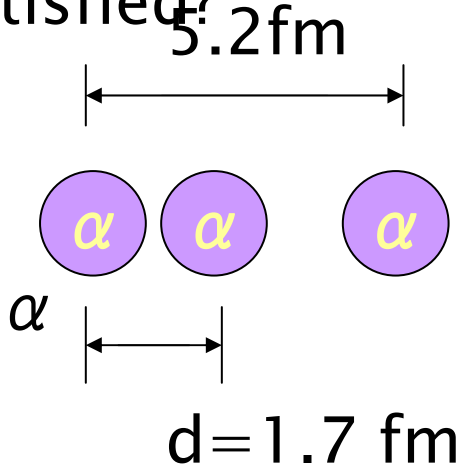


variation $\left\{C_{n_i,1}, C_{n_i,2}, C_{n_i,3}\right\} = \{1.0\,,3.9\,,0.6\}$

MO $\left\{C_{n_i,1}, C_{n_i,2}, C_{n_i,3}\right\} = \{1,1,1\}$

4. 10Be correlation in linear-chain states in14C

Are 2 conditions (10Be correlation exists) satisfied?



2 conditions

- d << 2.6fm (2α+ α)
- excess neutrons gather around the 2α

Calculated results

- d = 1.7 fm
- excess neutrons surely gather around the 2α

$$\left\{C_{n_i,1}, C_{n_i,2}, C_{n_i,3}\right\} = \{1.0\,, 3.9\,, 0.6\}$$

In linear chain states in 14C, 10Be correlation exist

5. Summary

5. Summary

Abstract

・Using AMD, we study structure of excited states in 14C

・We constrained the quadrupole deformation and superposed wave functions(GCM)

・In linear-chain states in 14C, we check 10Be correlation using simple 3α linear-chain model

Results

・There are 4 characteristic bands (Shell model, Triaxial, Equilateral-triangular, Linear-chain)

in excited states, 3 alpha clusters develop well

they have various structure

・10Be correlation exists in linear-chain states