Cluster structures of excited states in ^{14}C

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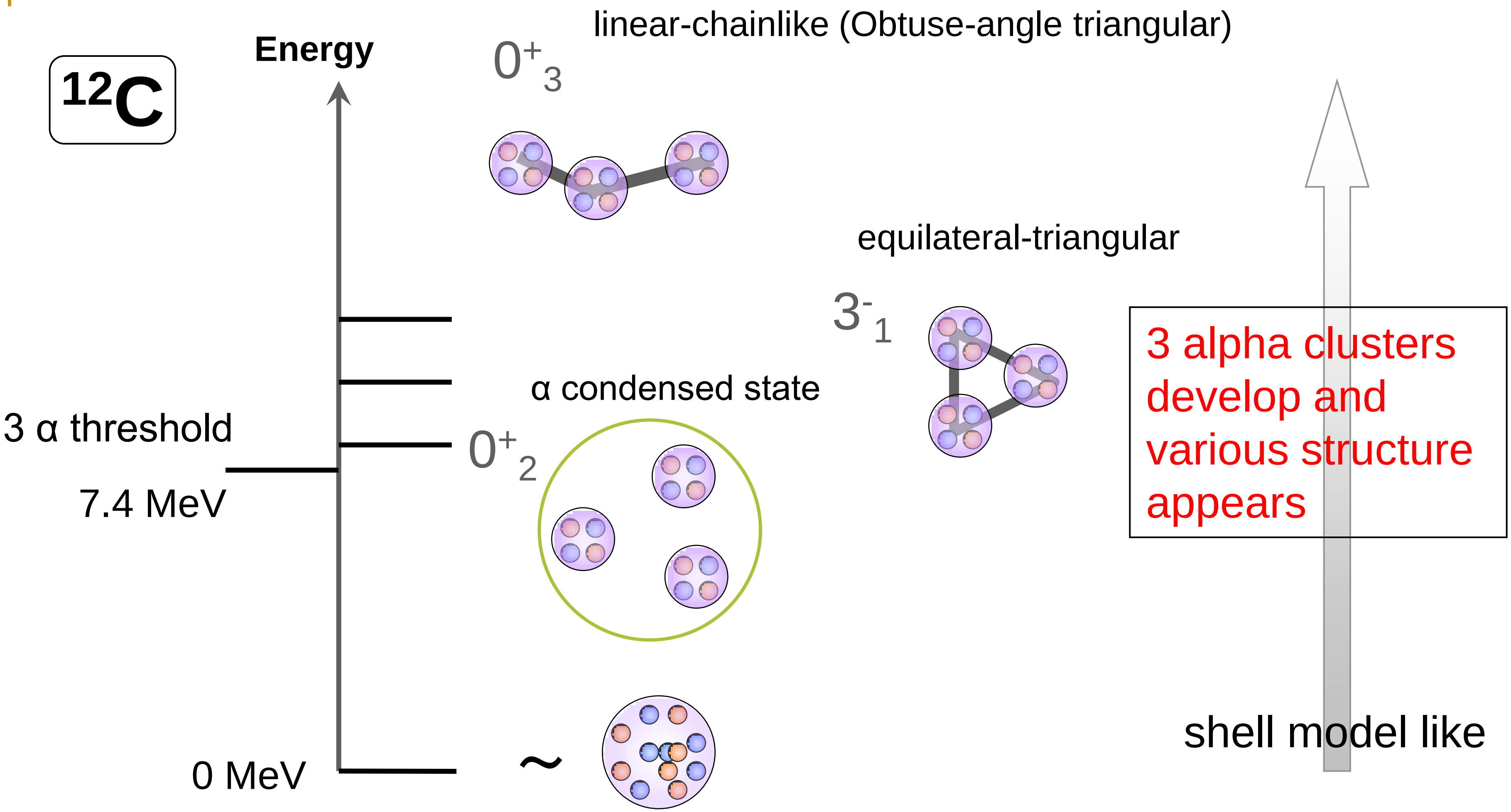
1. Introduction



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)
T. Neff, et al. Nuc. Phys. **A738**, 357 (2004)
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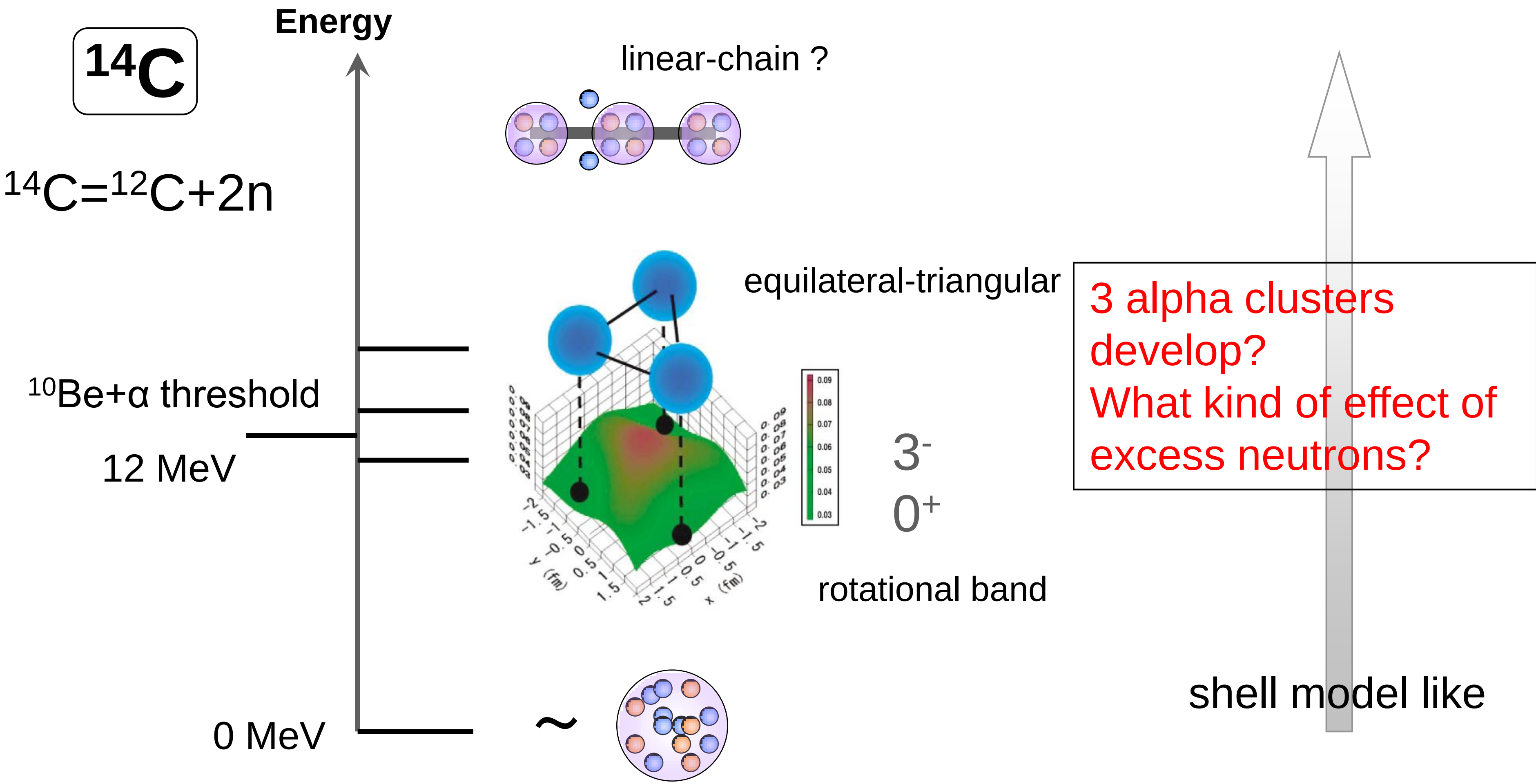
1. Introduction



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

1. Introduction

Aim

・To know what kind of structures appear in ^{14}C

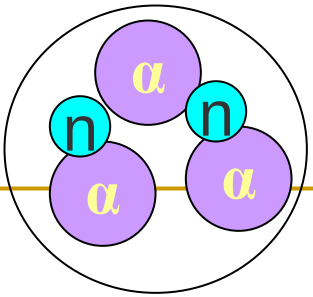
It is expected that various structure appear from an analogy of ^{12}C.

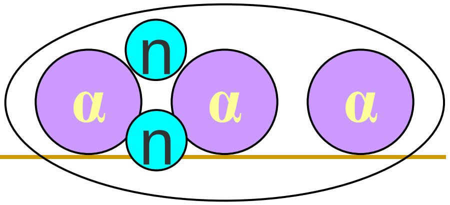
・Do α clusters appear or disappear?
・If α clusters appear, what kind of structure do they have?
Equilateral-triangular, Linear-chain, …
・What kind of effect do excess neutrons give structure?

Methods

β-γ constraint AMD（Antisymmetrized Molecular Dynamics）
Superposition (GCM)

T. Suhara and Y. Kananda-En'yo, Prog. Theor. Phys. 123, 303 (2010).



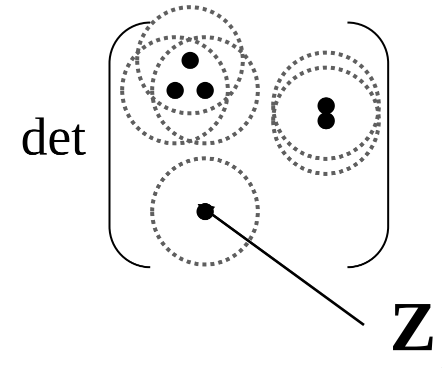


2. Methods (β-γ constraint AMD)

AMD（Antisymmetrized Molecular Dynamics）

a wave function of A-body system

$$\Phi_{\mathrm{AMD}} = \det[\varphi_1, \varphi_2, \cdots, \varphi_A]$$



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

spatial

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

spin and isospin

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

Set of variational parameters

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

- $\mathbf{Z}_i$: center of Gaussian wave packets
- $\boldsymbol{\xi}_i$: spin direction

Parity and angular momentum projections

$$P^{\pm} = \frac{1 \pm P}{2}$$

$$P^{J}_{MK} = \frac{2J+1}{8\pi^2} \int d\Omega D^{J*}_{MK}(\Omega) R(\Omega)$$

We projected AMD wave functions onto parity and angular momentum eigenstates .

In this study, we performed the variation for the parity projected wave function. After the variation, we project the obtained wave function onto the total-angular-momentum eigenstates.

2. Methods (β-γ constraint AMD)

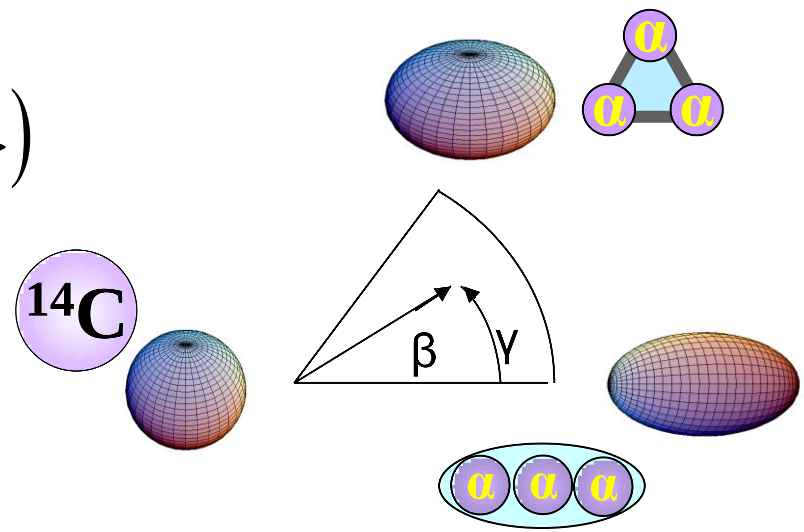
Constraints

The quadrupole deformation (β, γ)

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

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

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



Effective Hamiltonian

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

The central force : The Volkov No.2

$$v_{ij}^{\text{central}} = (v_1 \exp[-(\frac{r_{ij}}{a_1})^2] + v_2 \exp[-(\frac{r_{ij}}{a_2})^2]) X_{ij}$$

$$X_{ij} = W + BP_\sigma - HP_\tau - MP_\sigma P_\tau \quad (W = 0.4, M = 0.6, B = H = 0.125)$$

$$v_1 = -60.65[\text{MeV}], a_1 = 1.80[\text{fm}], v_2 = 61.14[\text{MeV}], a_2 = 1.01[\text{fm}]$$

The LS force : The LS part of the G3RS

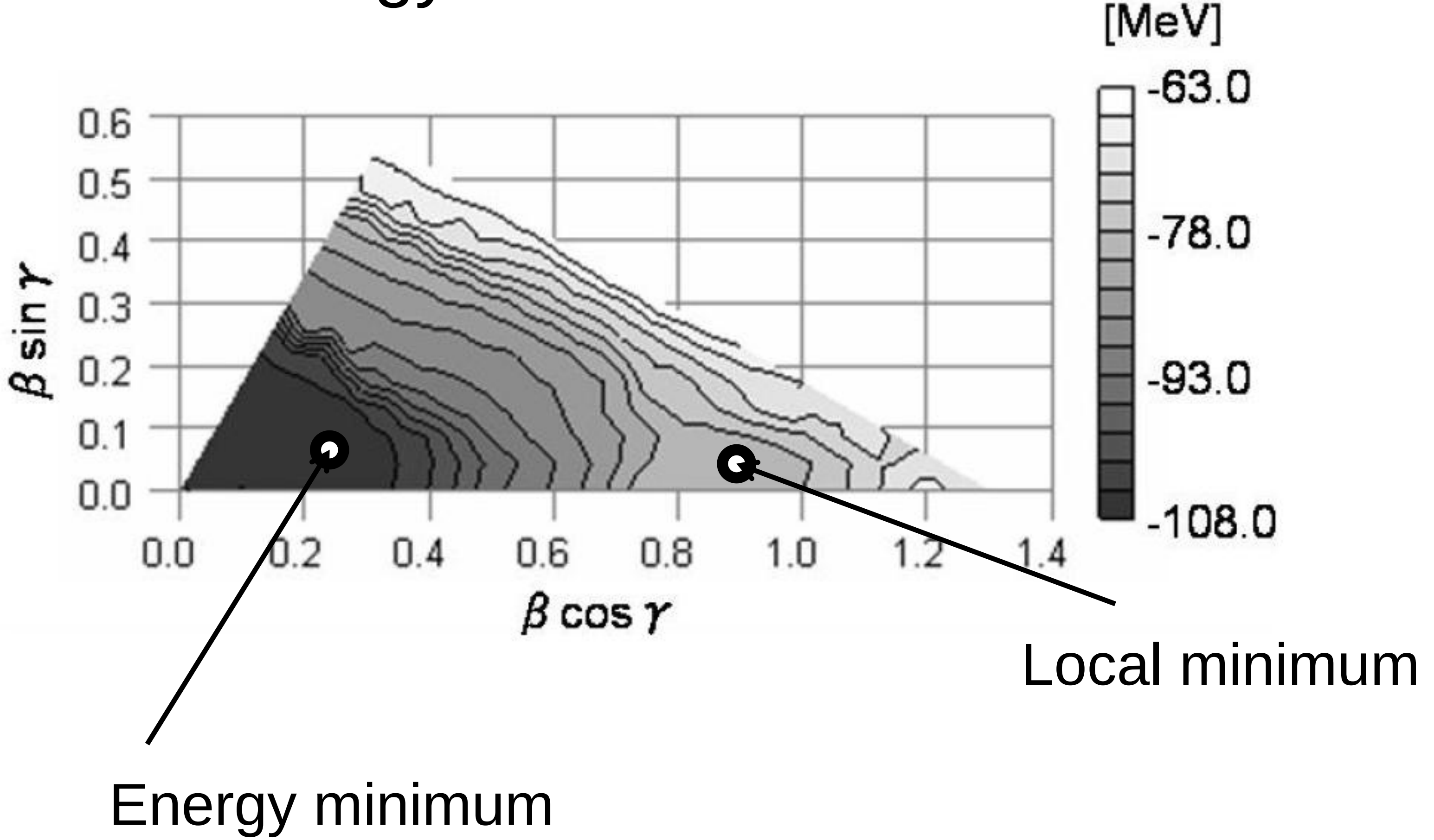
$$v_{ij}^{\text{LS}} = (u_1 \exp[-(\frac{r_{ij}}{a_1})^2] + u_2 \exp[-(\frac{r_{ij}}{a_2})^2]) P(S=1) P(T=1) \mathbf{L} \cdot \mathbf{S}$$

$$P(S=1) = \frac{1+P_\sigma}{2}, P(T=1) = \frac{1+P_\tau}{2}$$

$$u_1 = 1600[\text{MeV}], a_1 = 0.447[\text{fm}], u_2 = -1600[\text{MeV}], a_2 = 0.600[\text{fm}]$$

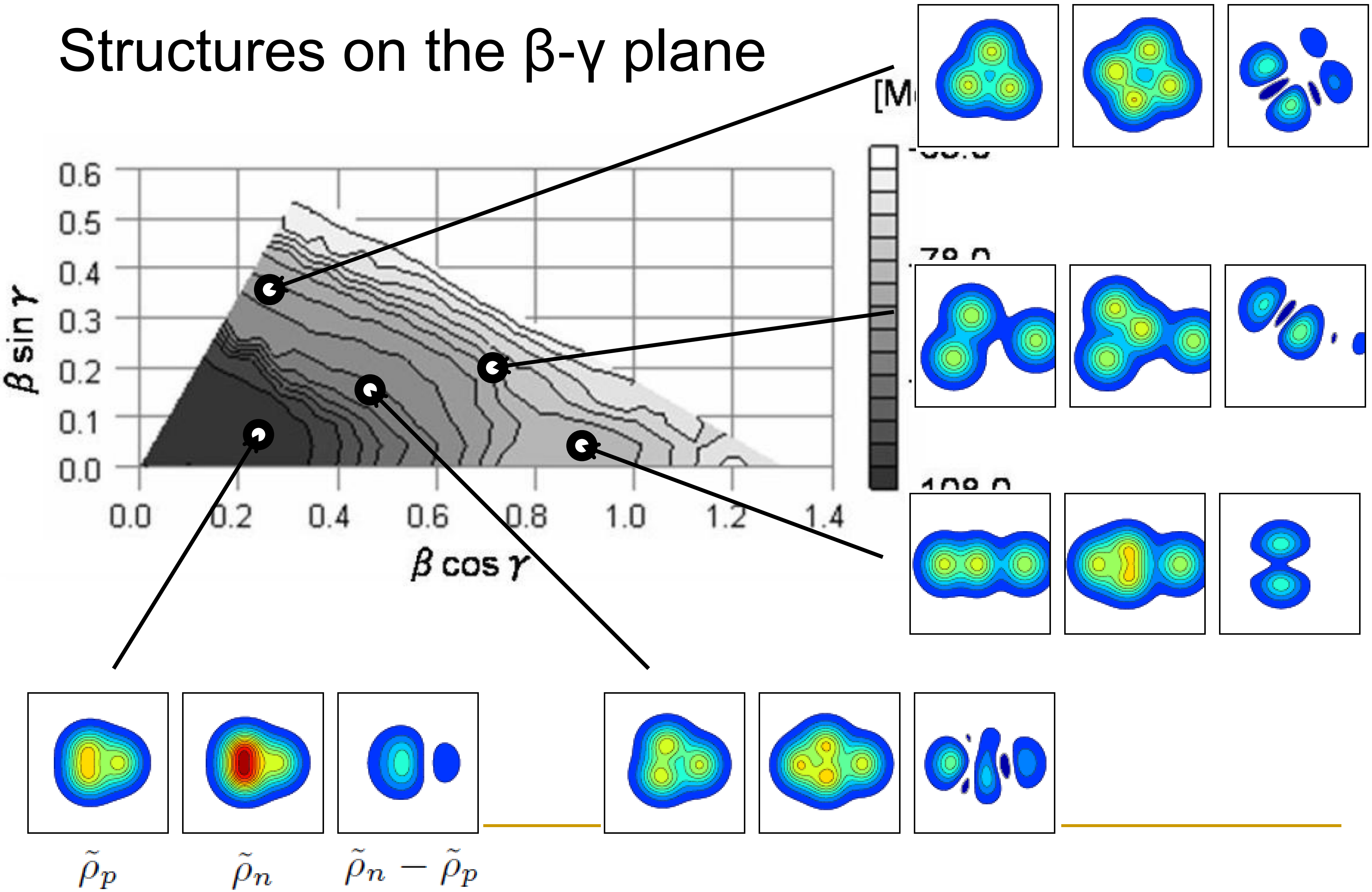
3. Results (+ parity states)

The energy surface for 0^+ states



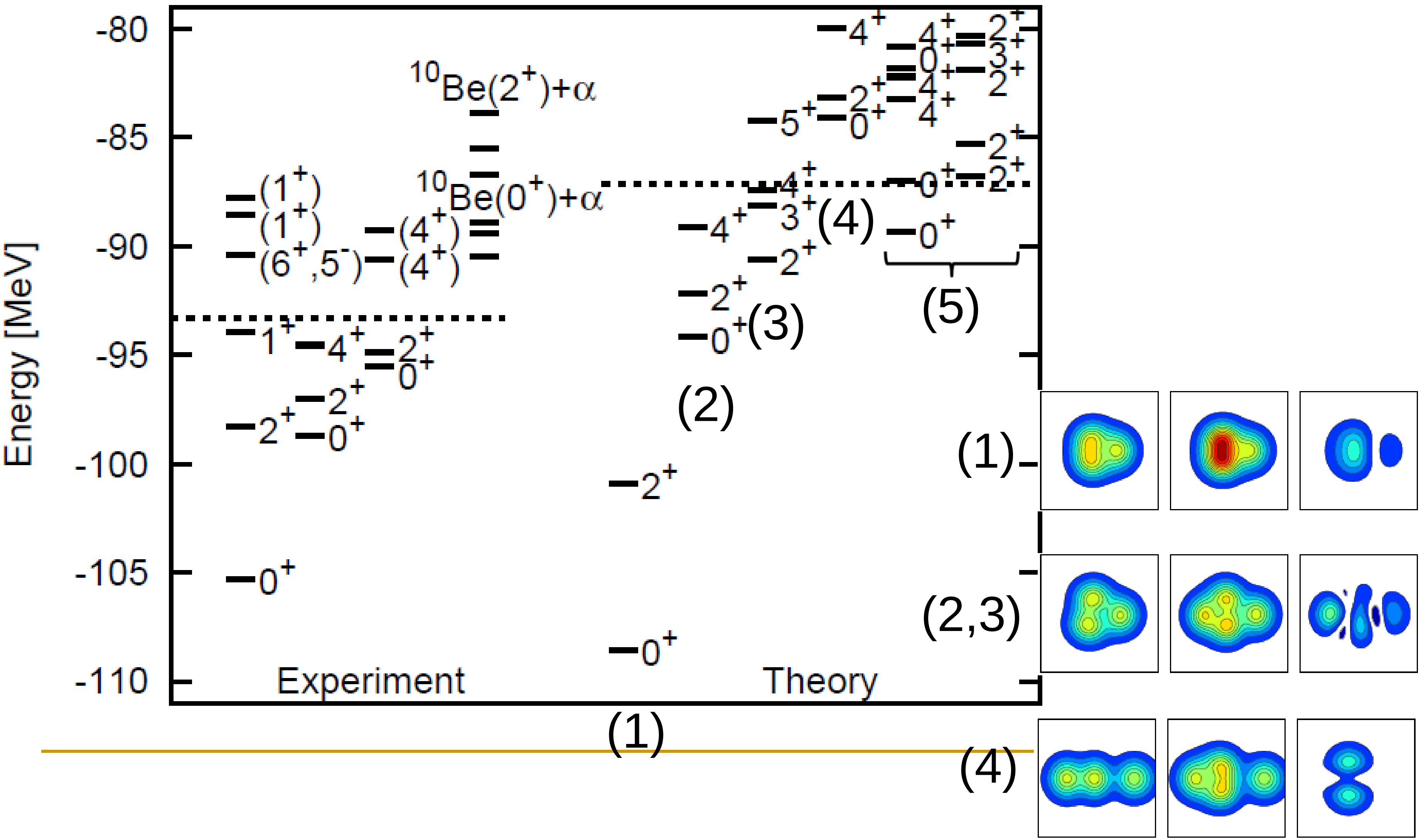
3. Results (+ parity states)

Structures on the β-γ plane



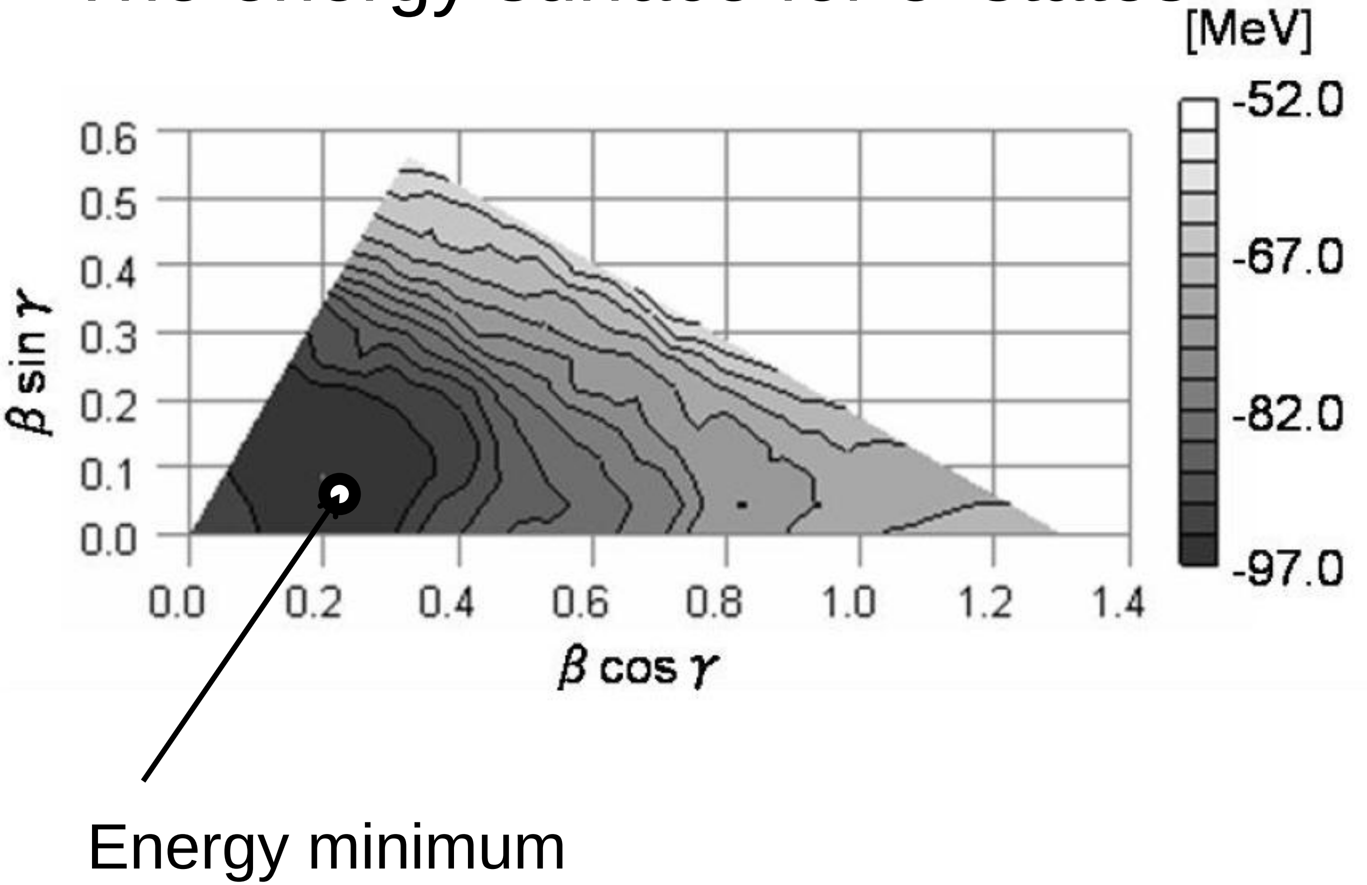
3. Results (+ parity states)

Energy levels



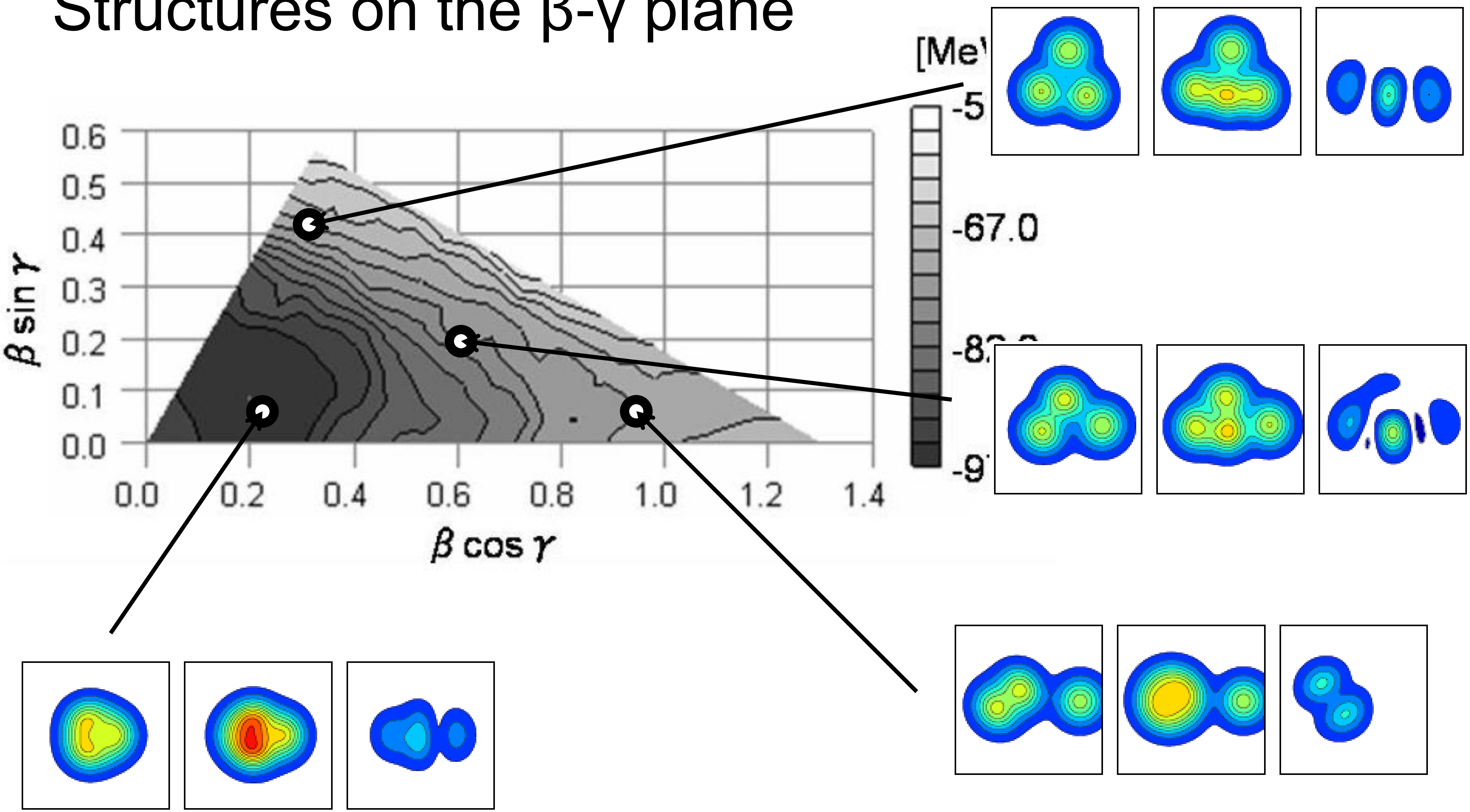
3. Results (- parity states)

The energy surface for 3^- states



3. Results (- parity states)

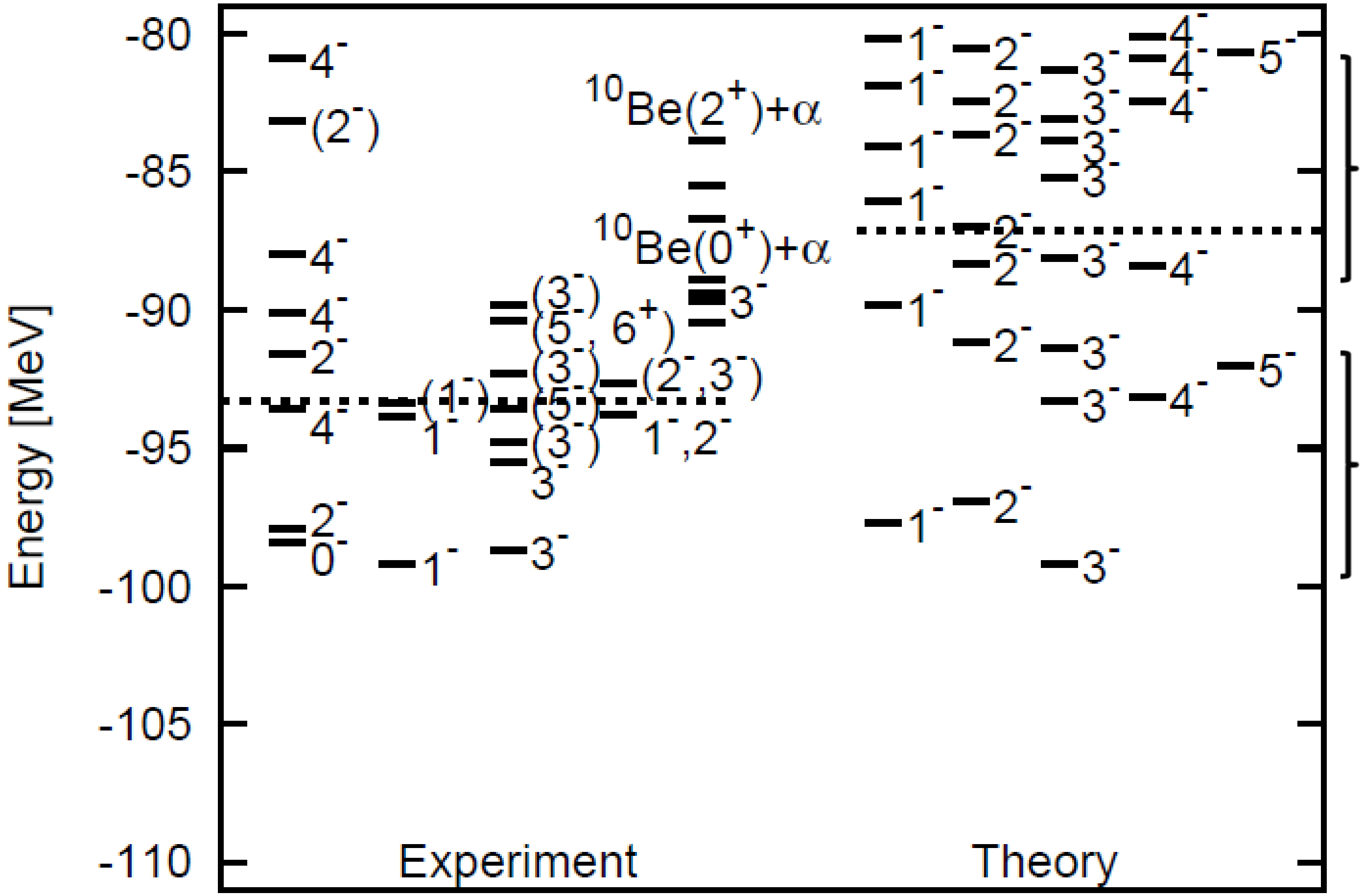
Structures on the β-γ plane

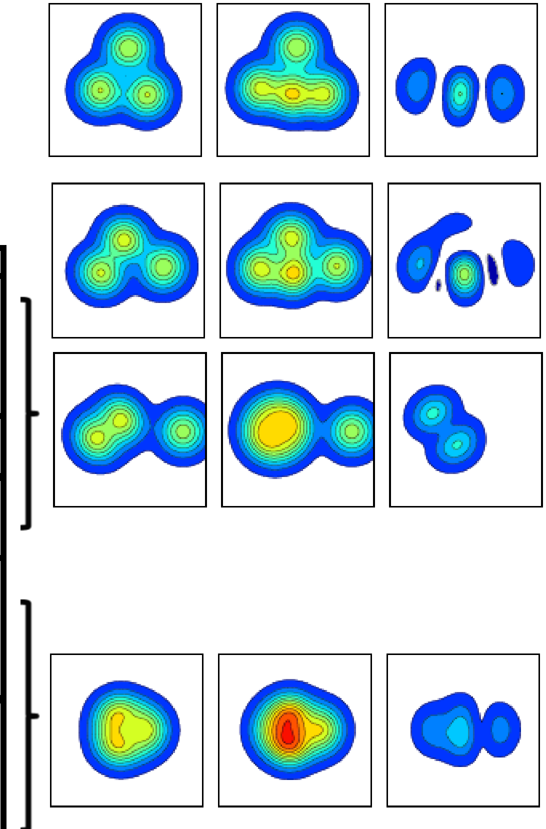


$\tilde{\rho}_p$ $\tilde{\rho}_n$ $\tilde{\rho}_n - \tilde{\rho}_p$

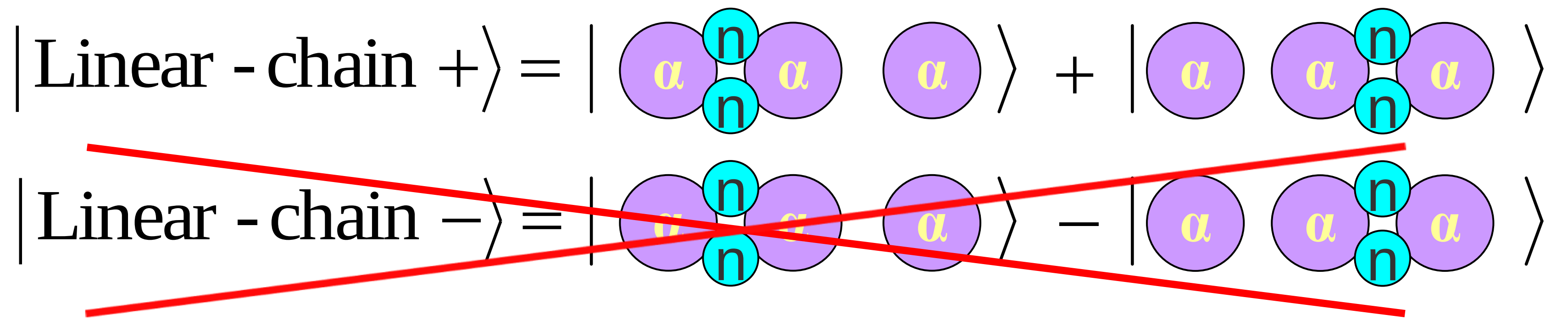
3. Results (- parity states)

Energy levels

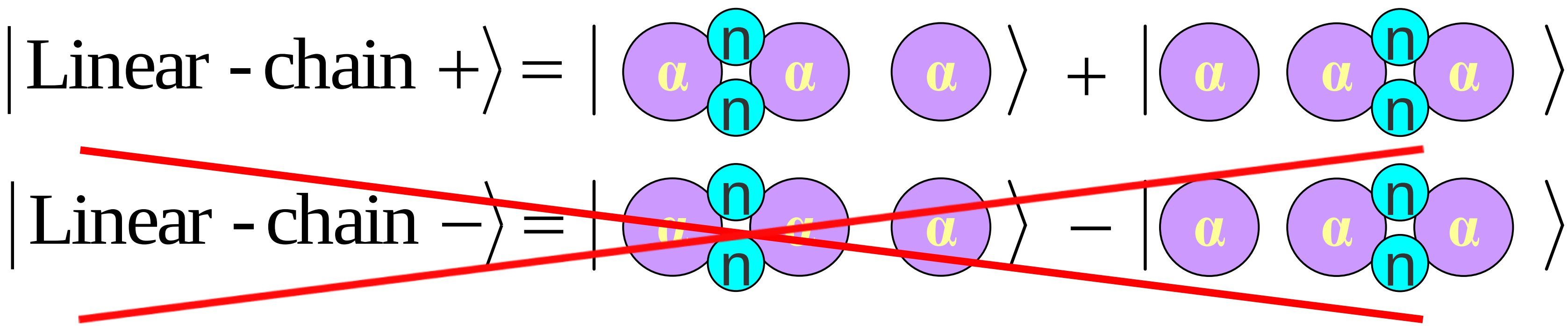




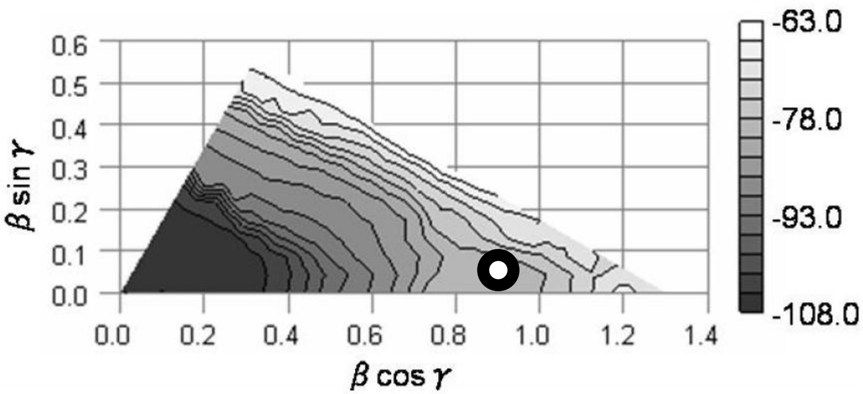
Parity partner



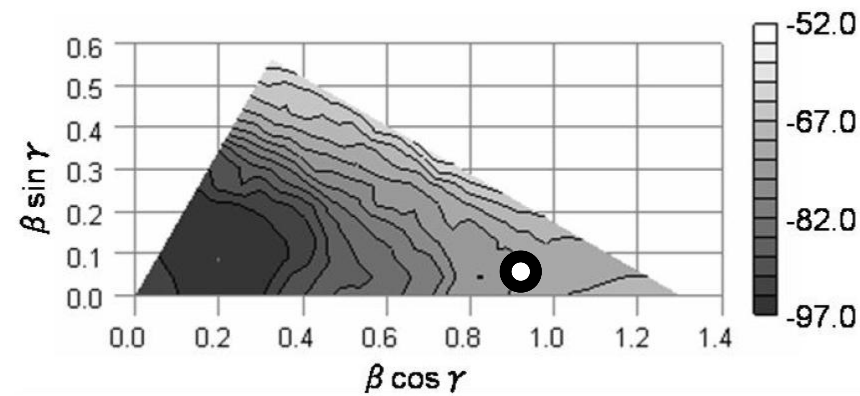
Parity partner

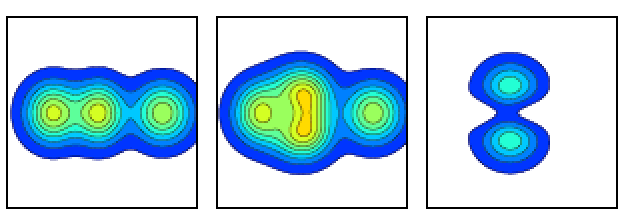


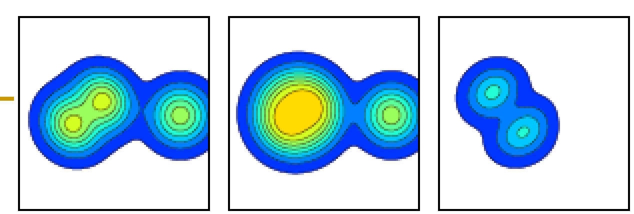
0^+ energy surface



3^- energy surface







5. Summary

We investigated ^{14}C with β-γ constraint AMD+GCM.

・ Various excited states with the developed 3α cluster core structures are suggested in ^{14}C.
・ In the positive-parity states, triaxial deformed and linear-chain structures are found to construct excited bands.
・The linear-chain band has ^{10}Be+α correlation.
・In the negative-parity states, the parity-partner of linear-chain state disappears because ^{10}Be cluster rotates easily.

Future Work

・ Estimating decay widths to $^{10}Be(0^+_1)$+α and $^{10}Be(2^+_1)$+α

Excited states with ^{10}Be+α correlation are the candidates for the states which were observed recently in ^{10}Be+α decays.

・ Further neutron-rich C isotopes