Exotic cluster structures in nuclei

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Collaboration with

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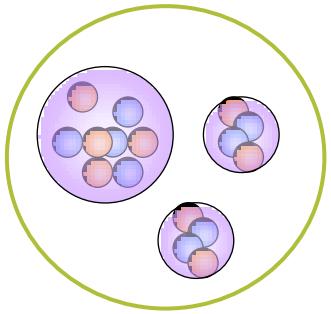
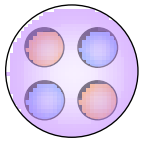
Cluster structure



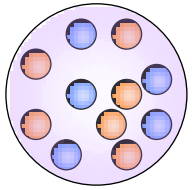
The cluster means a spatially localized subsystem composed of strongly correlated nucleons.

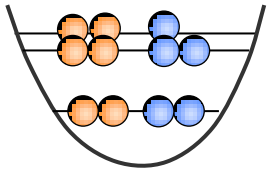


α (^{4}He) cluster

Saturation energy is 8 MeV/nucleon.
Binding energy of α (^{4}He) cluster is 28 MeV (7 MeV/nucleon)

cf. Shell-model structure



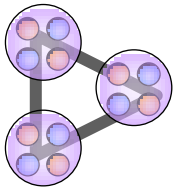


Nucleons make an one-center mean field and move in this field independently.

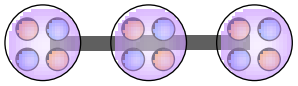
“Exotic” cluster structure

We call a geometric cluster structure a “exotic” structure.

Examples



An equilateral triangular structure of 3 α clusters



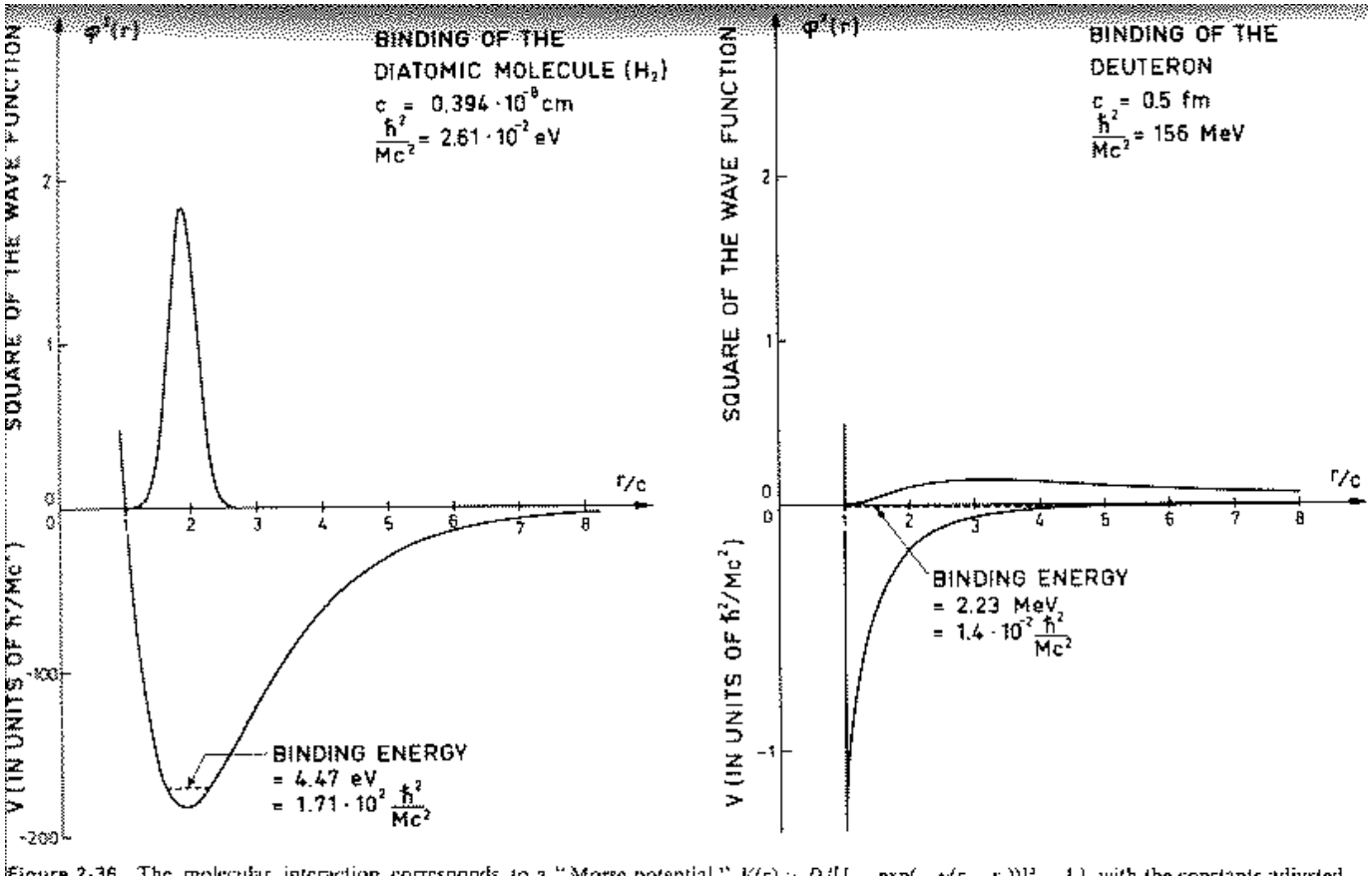
A linear-chain structure of 3 α clusters

and so on.

“Quantum” nuclei

H_2 molecule

Deuteron



Bohr Mottelson,
Nuclear Structure, Vol.1

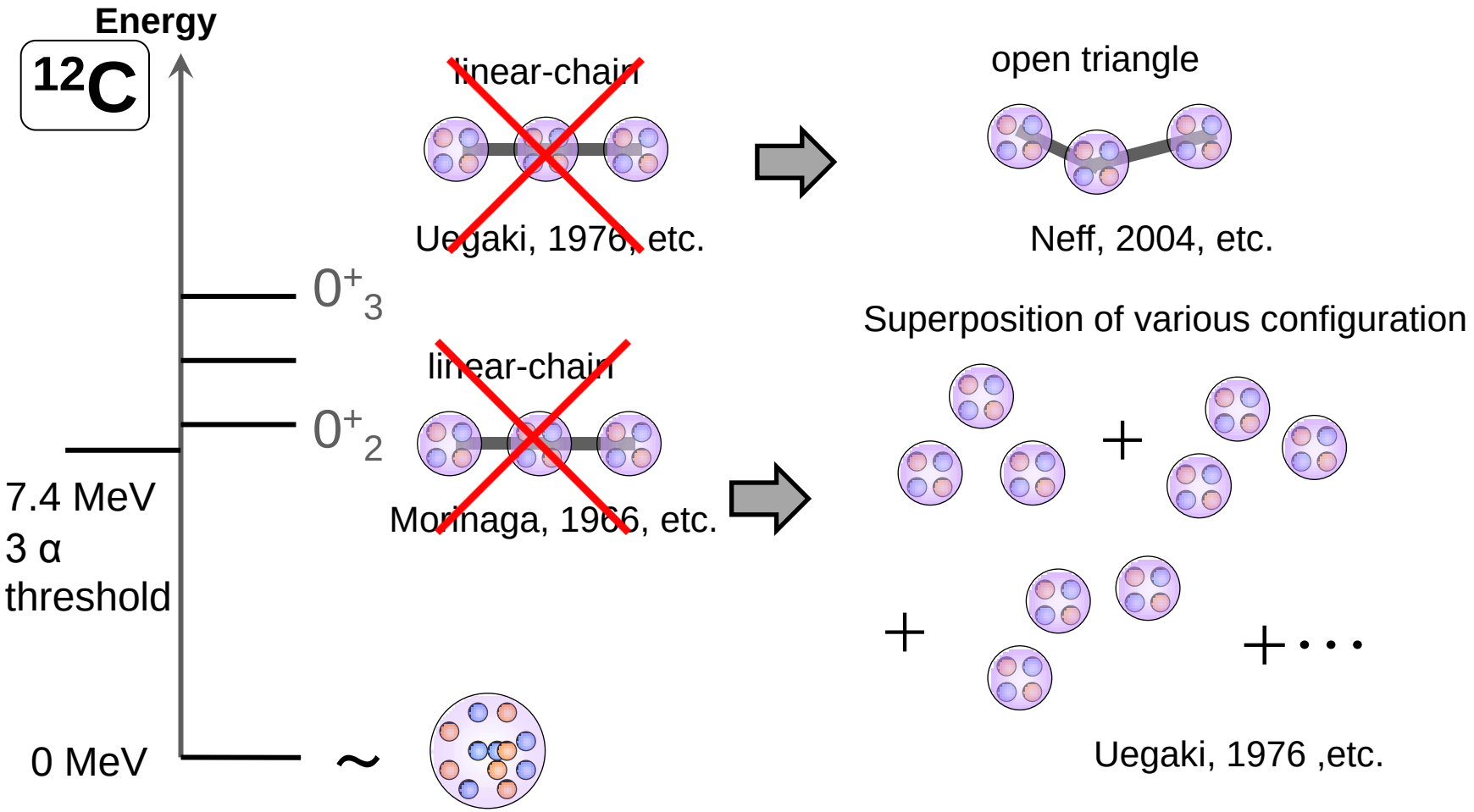
classical

quantum

$\varphi_{H_2} =$ 

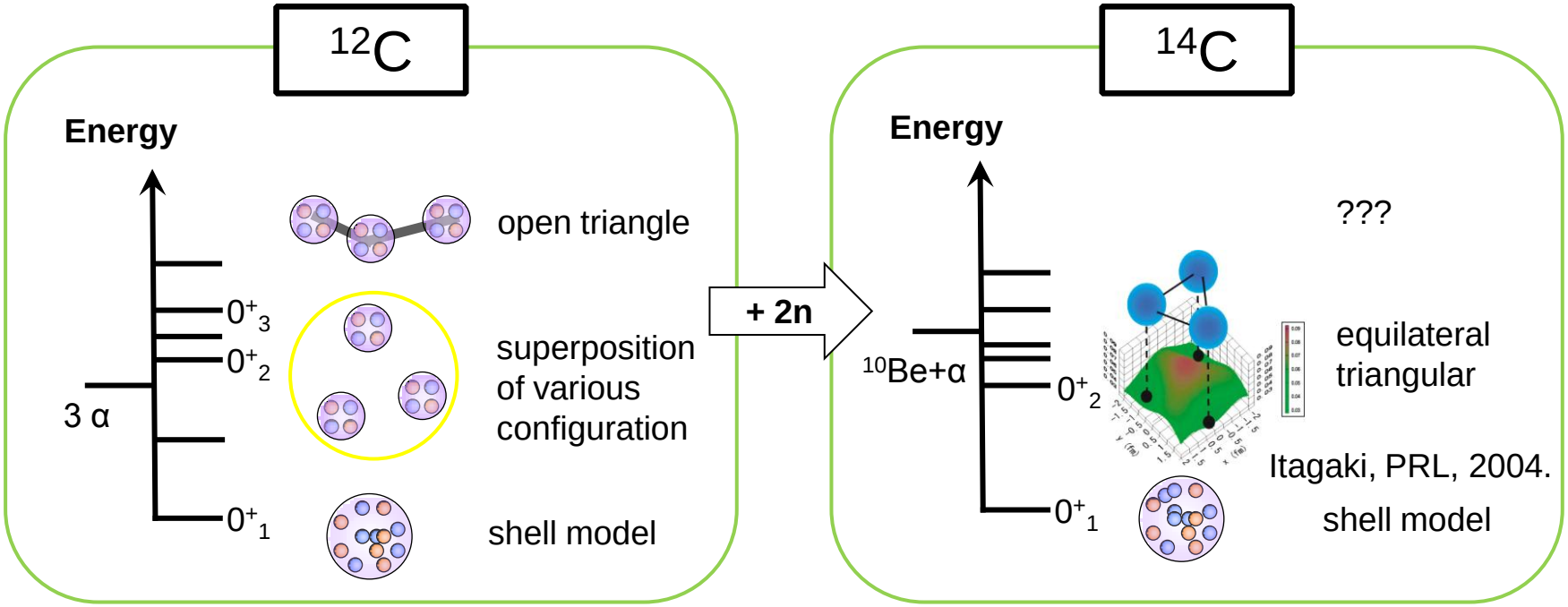
$\varphi_d =$ 

History of a linear-chain structure of 3 α clusters



^{12}C+ excess neutrons

Structure of ^{14}C



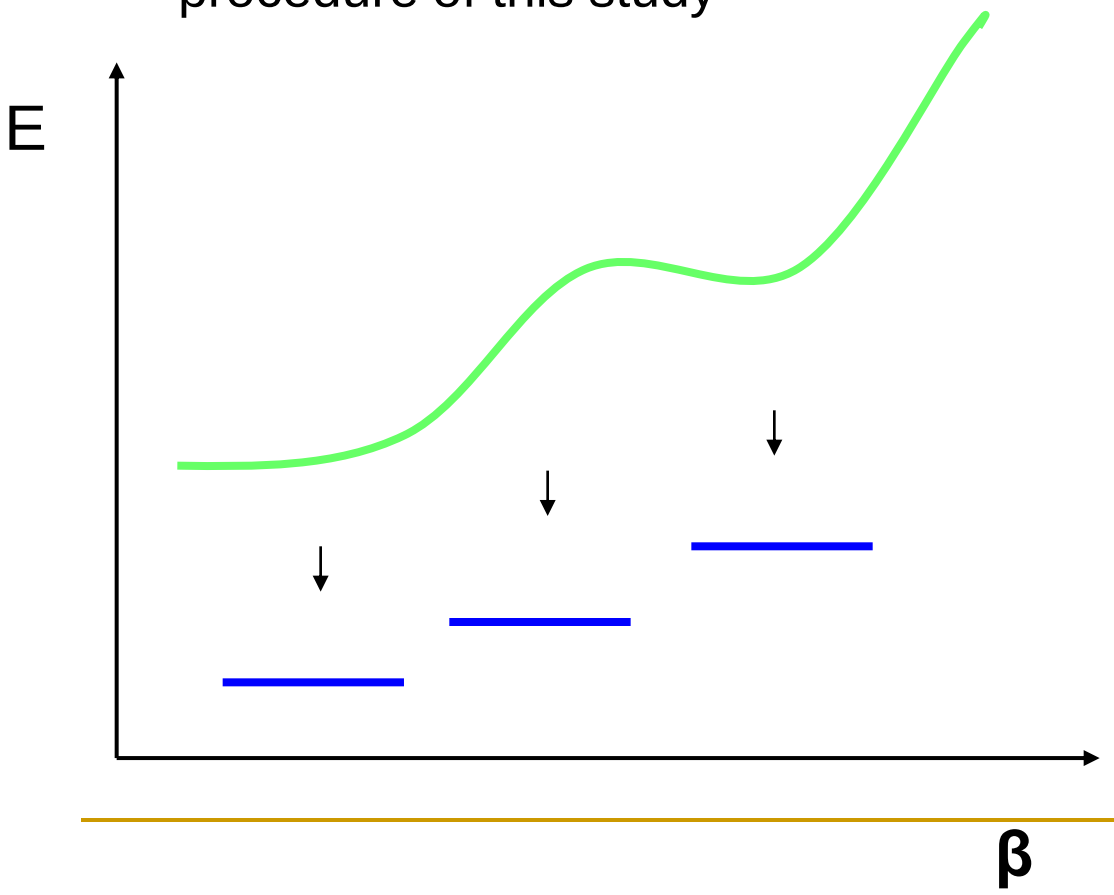
- In ^{14}C, the 0^+_2 state has an exotic structure (equilateral-triangular structure of the 3 α clusters surrounded by two excess neutrons).

- Does a Linear-chain structure appear in ^{14}C ? (rigid or not)

Procedure of our Method

Constrained AMD + Superposition

The schematic figure for the procedure of this study



by constrained AMD, we get $\left|\Phi(\beta)\right\rangle$

using GCM, we get states

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

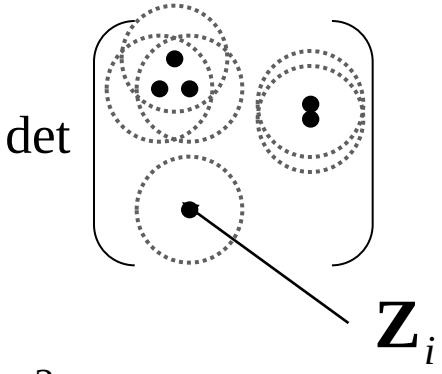
β-γ constraint AMD

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

AMD（Antisymmetrized Molecular Dynamics）

a wave function of A-body system

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



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

spatial

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

spin and isospin

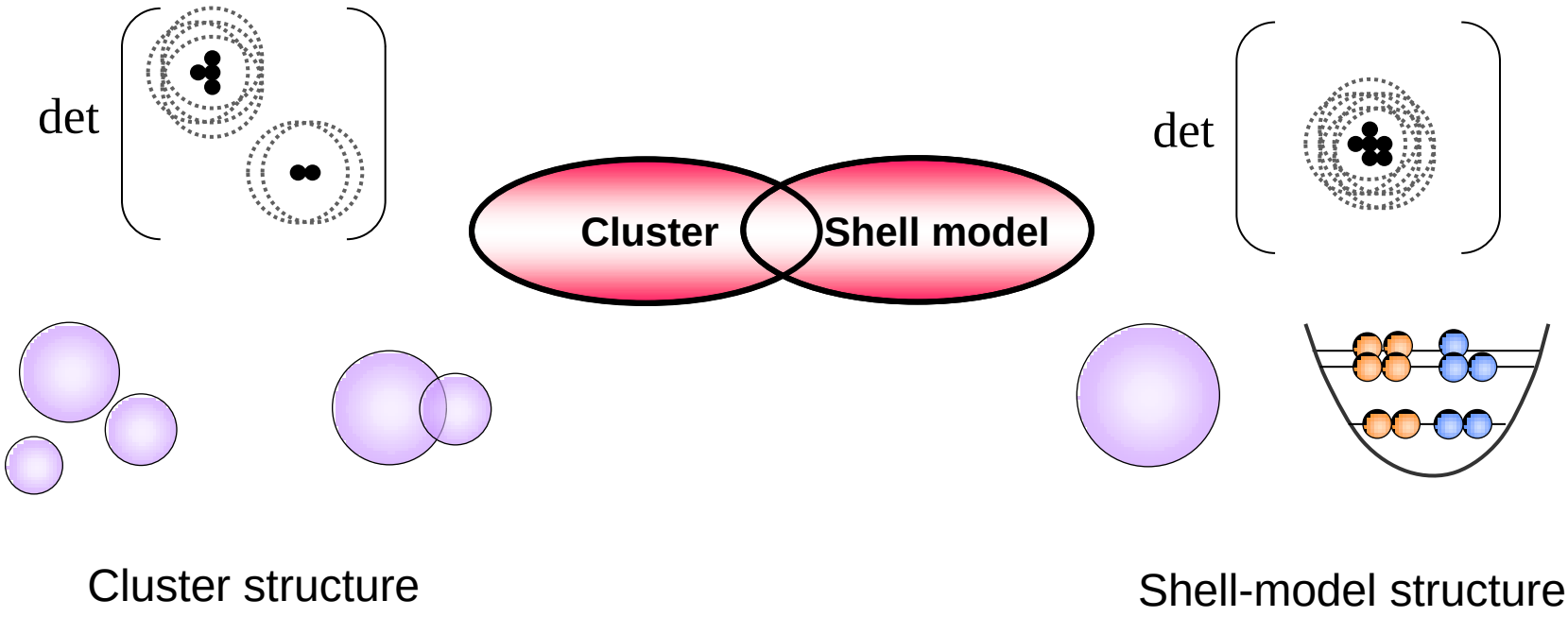
$$\chi(\xi_i) = \begin{pmatrix} \xi_{i\uparrow} \\ \xi_{i\downarrow} \end{pmatrix} \times (\mathrm{p\ or\ n})$$

Set of variational parameters

$$Z = \{\mathbf{Z}_i, \xi_i\}$$

$$\begin{cases} \mathbf{Z}_i : \text{center of Gaussian wave packets} \\ \xi_i : \text{spin direction} \end{cases}$$

Model space of AMD



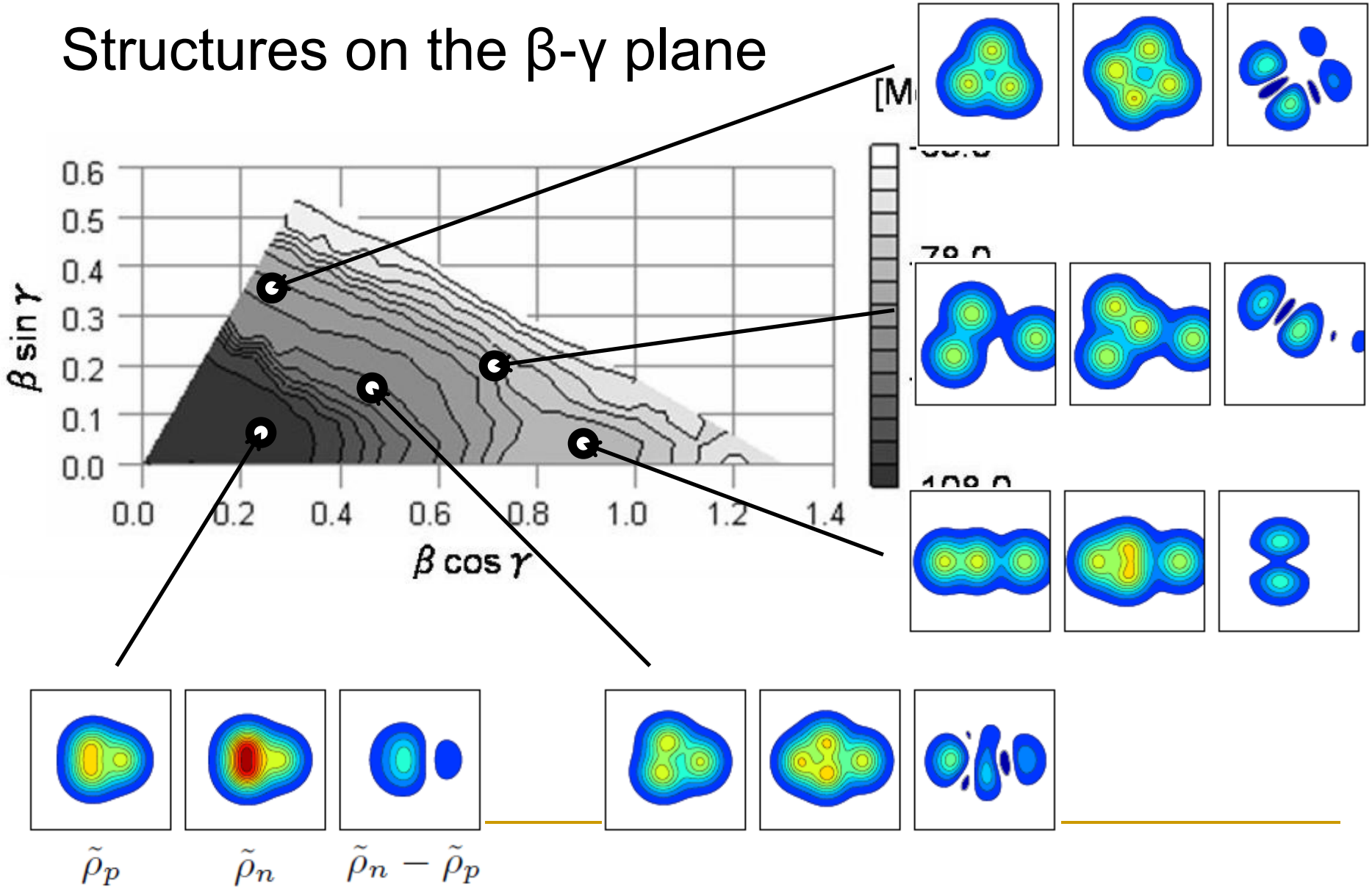
Cluster structure

Shell-model structure

AMD can describe both of cluster structures
and shell-model structures.

Result (+ parity states in ^{14}C)

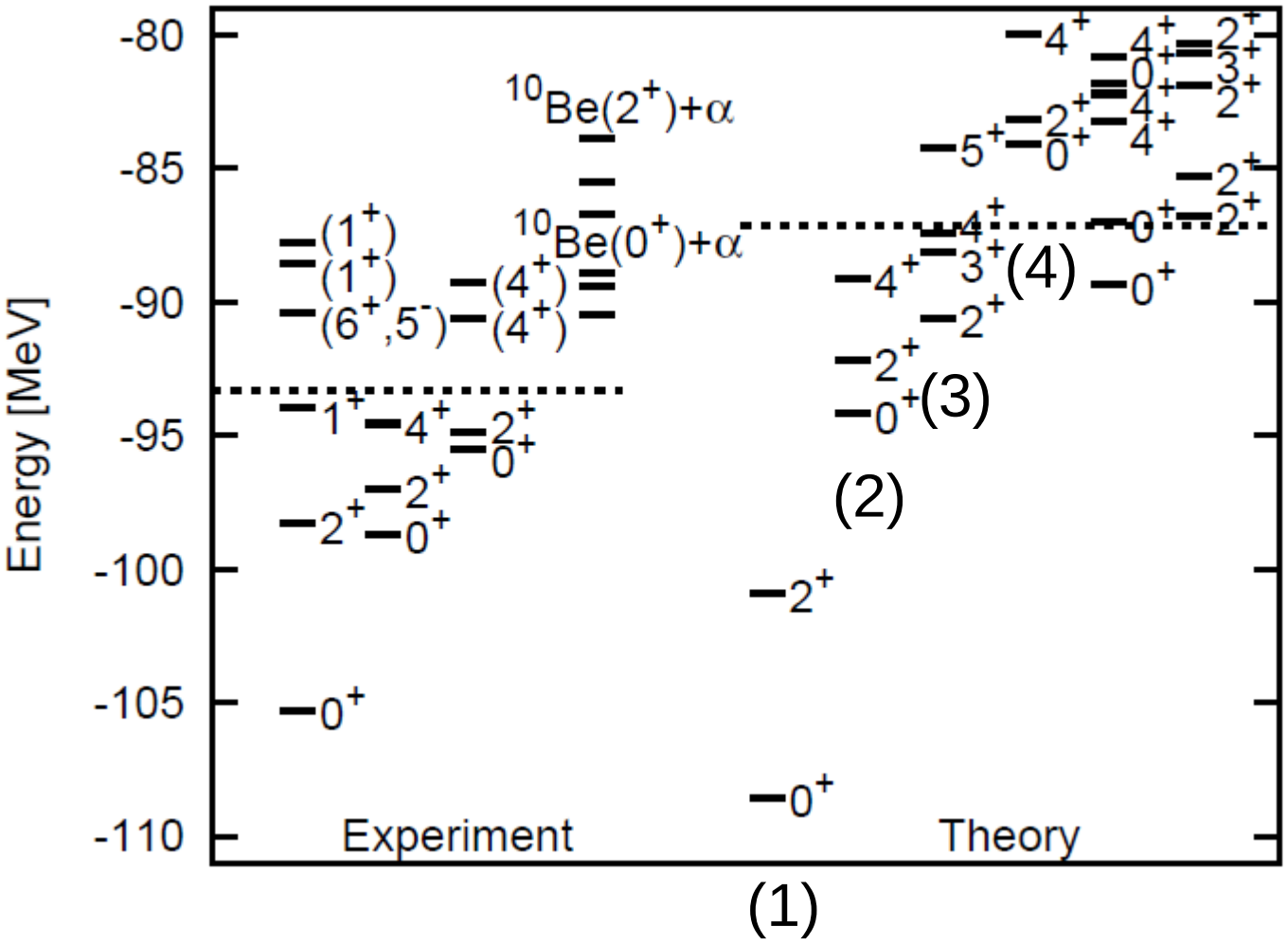
Structures on the β-γ plane



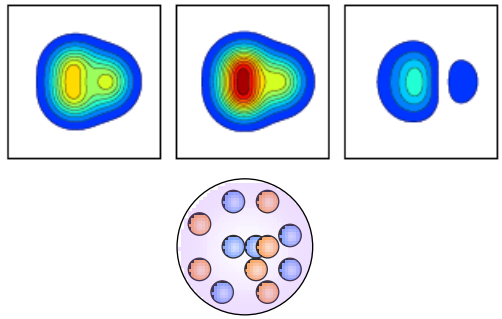
Result (+ parity states in ^{14}C)

T. S. and Y. Kananda-En'yo, Phys. Rev. C 82, 044301 (2010).

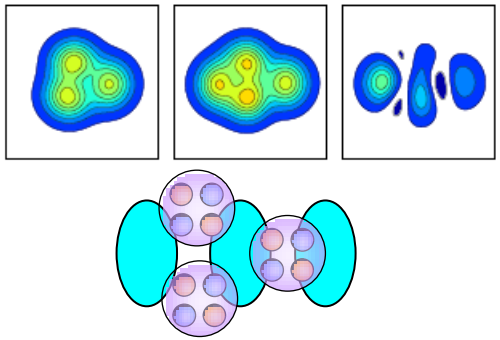
Energy levels



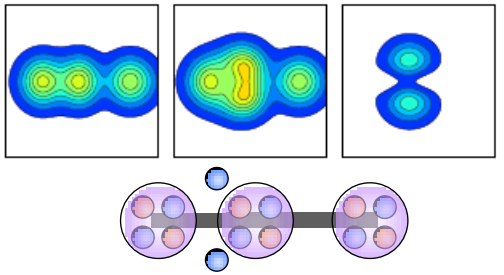
(1) Shell-model



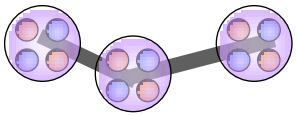
(2,3) Triaxial



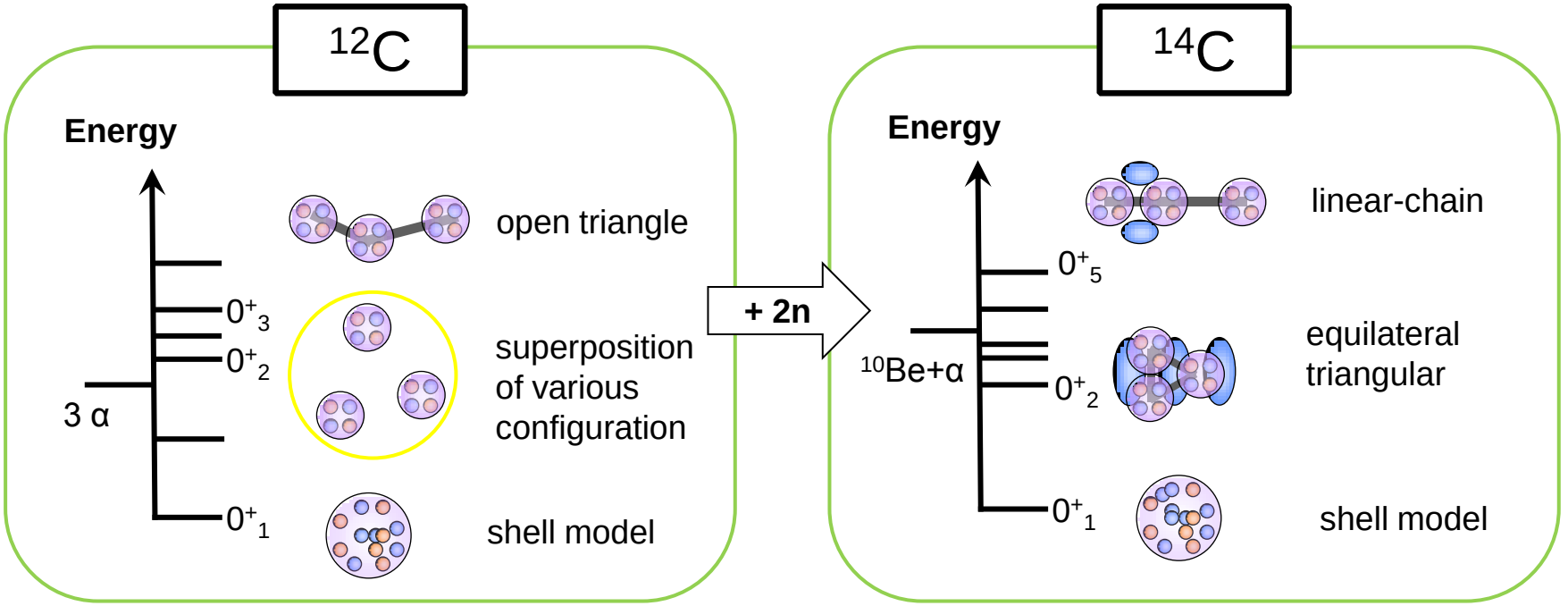
(4) Linear-chain



cf. open triangle structure in ^{12}C



Summary



- In ^{14}C, a linear-chain (exotic) structure appear !
- This linear-chain structure is rigid and constructs a rotational band.