# Unified Studies on structures and reactions in light neutron-rich systems

－Study by cluster model + Eff. NN int. and future extension－

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I. Unified studies on structures and reactions

( Results of cluster model + effective NN interaction )

II. Future studies of  cluster model + realistic NN interactions

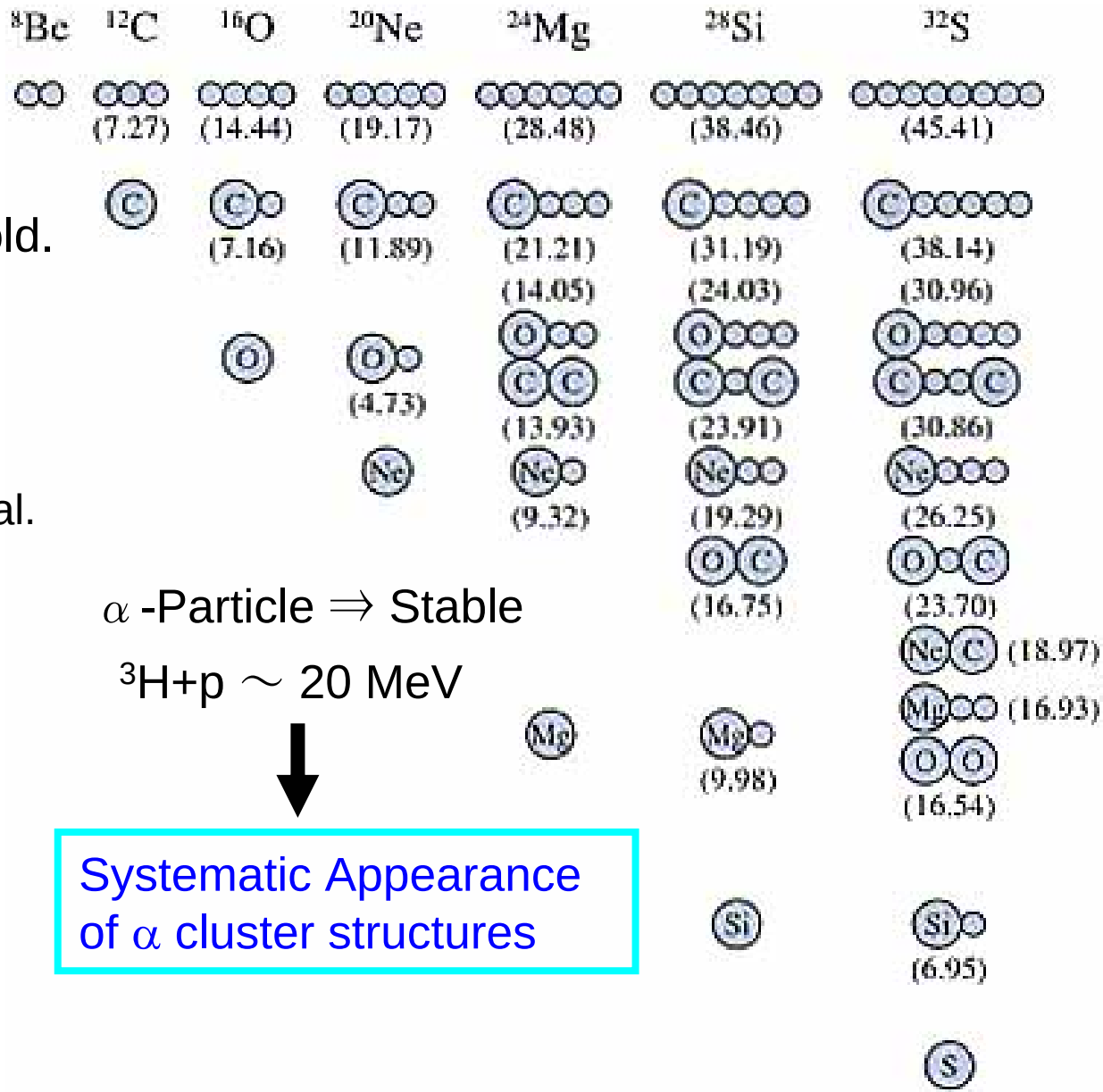
( Application of UCOM and possible perspectives )

# Cluster structures in 4N nuclei

IKEDA Diagram

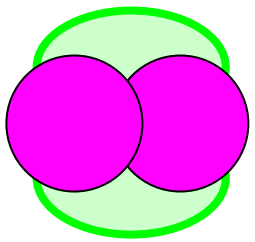
## Ikeda's Threshold rules

Molecular structures will appear close to the respective cluster threshold.

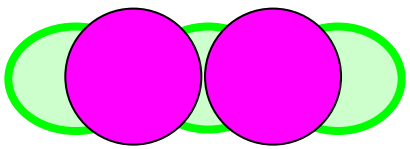



Be isotopes

Molecular Orbital : Itagaki et al.



$\pi^-$



$\sigma^+$

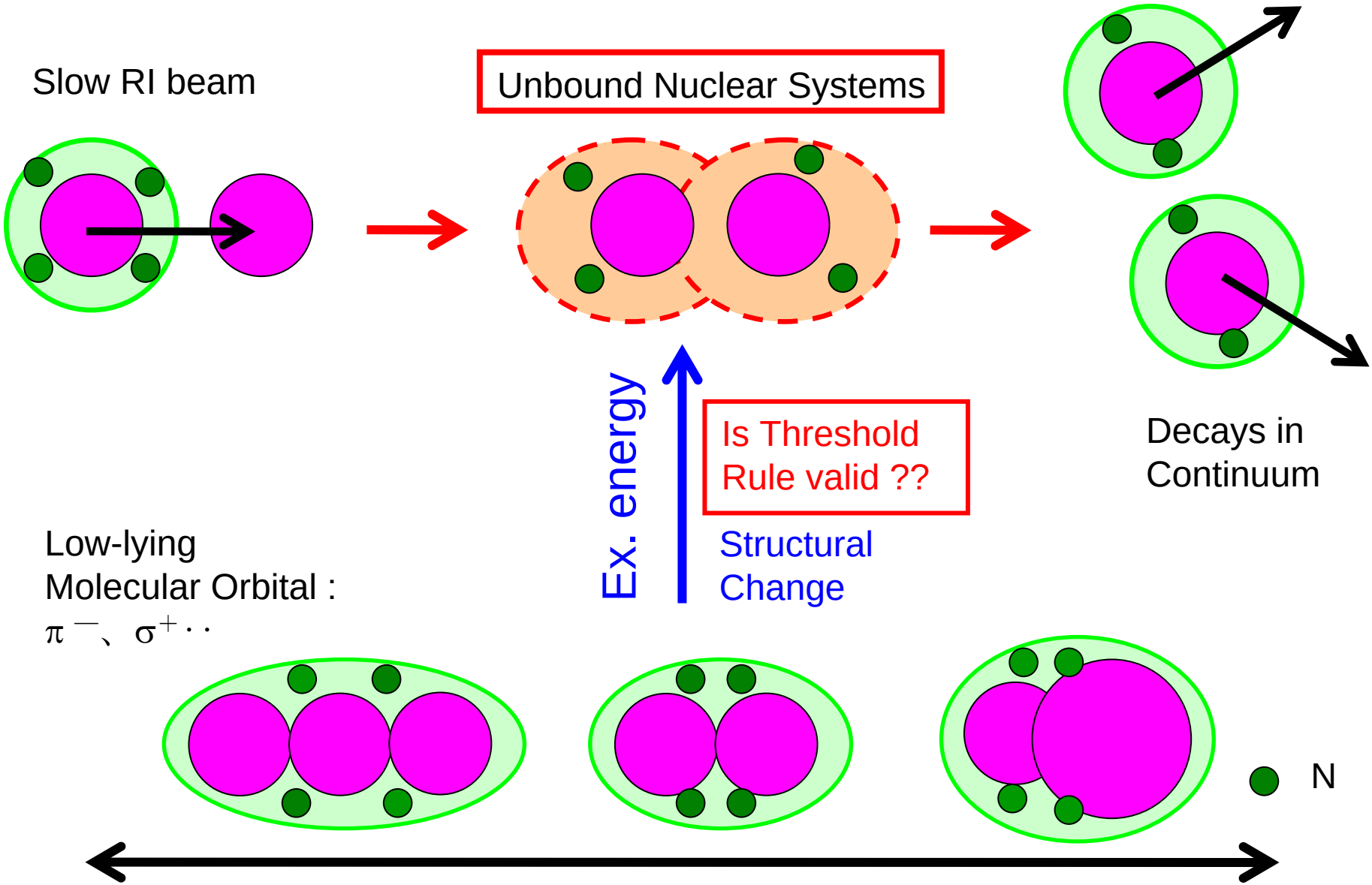
$\alpha$ -Particle $\Rightarrow$ Stable

$^3$H+p $\sim$ 20 MeV

Systematic Appearance of $\alpha$ cluster structures

PRC61,62 (2000)

# Studies on Exotic Nuclear Systems in ($E_x$,N, Z,J) Space



# $^{12}$Be (experiments) (Important system before proceeding systematic studies)

**Low-lying (Breaking of N=8 Magicity)**

**High-lying states (Atomic)**

$^{11}$Be+n: 3.17MeV

E(sd-0p)
～1MeV

2.70 1$^-$

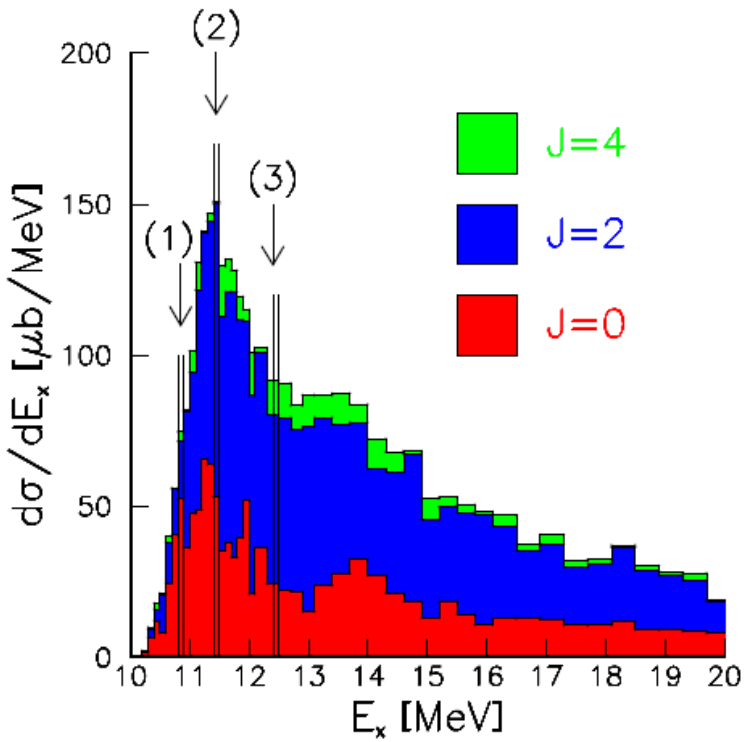
2.24 0$^+$

2.10 2$^+$

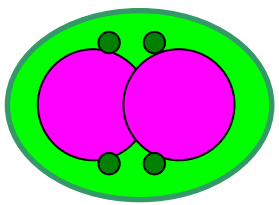
Def. Length～2fm

g.s. 0$^+$

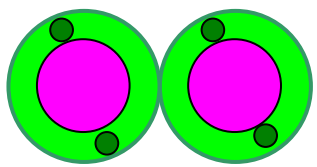
$^{12}$Be+α → ($^6$He+$^6$He)+α : A. Saito et al.




Moleculue



Structural changes



$^6$He + $^6$He (Atomic)

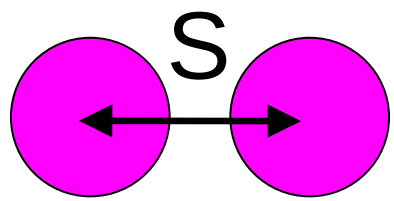
# Generalized Two-center Cluster model

( $^{10}$Be=α+α+4N )

**Basis function**

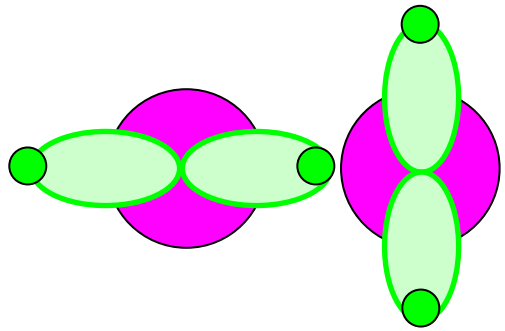
Anti-sym.

$$\Phi^{J\pi}{}_K(\nu,S) = P^{J\pi}{}_K\, A\, \{\, \phi_L(\alpha)\, \phi_R(\alpha)\, \chi(\nu)\, \}_S$$




$\phi(\alpha)$ : $(0s)^4$ in H.O.

$\chi(\nu)$ : 0p 4Neutrons ( L or R, 0p(i), i=x,y,z )



Total W.F. : $\Psi^{J\pi} = \Sigma_S\ \Sigma_\nu\, f(\nu,S)\, \Phi^{J\pi}(\nu,S)$

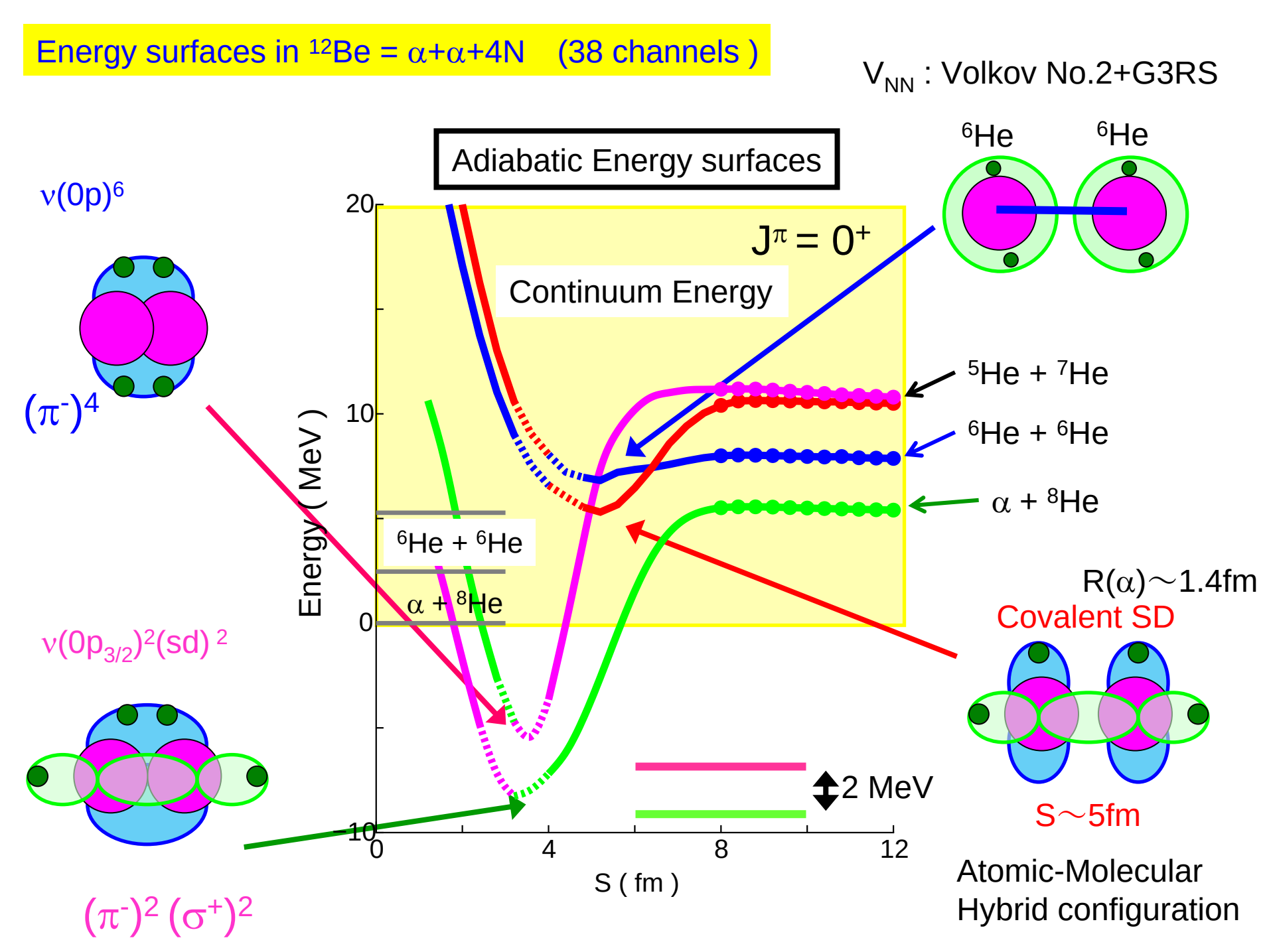
**Eigenvalue equations**

$$< \Phi^{J\pi}{}_K(\nu,S') \mid H - E \mid\ \Psi^{J\pi} > = 0$$ (Full GCM)

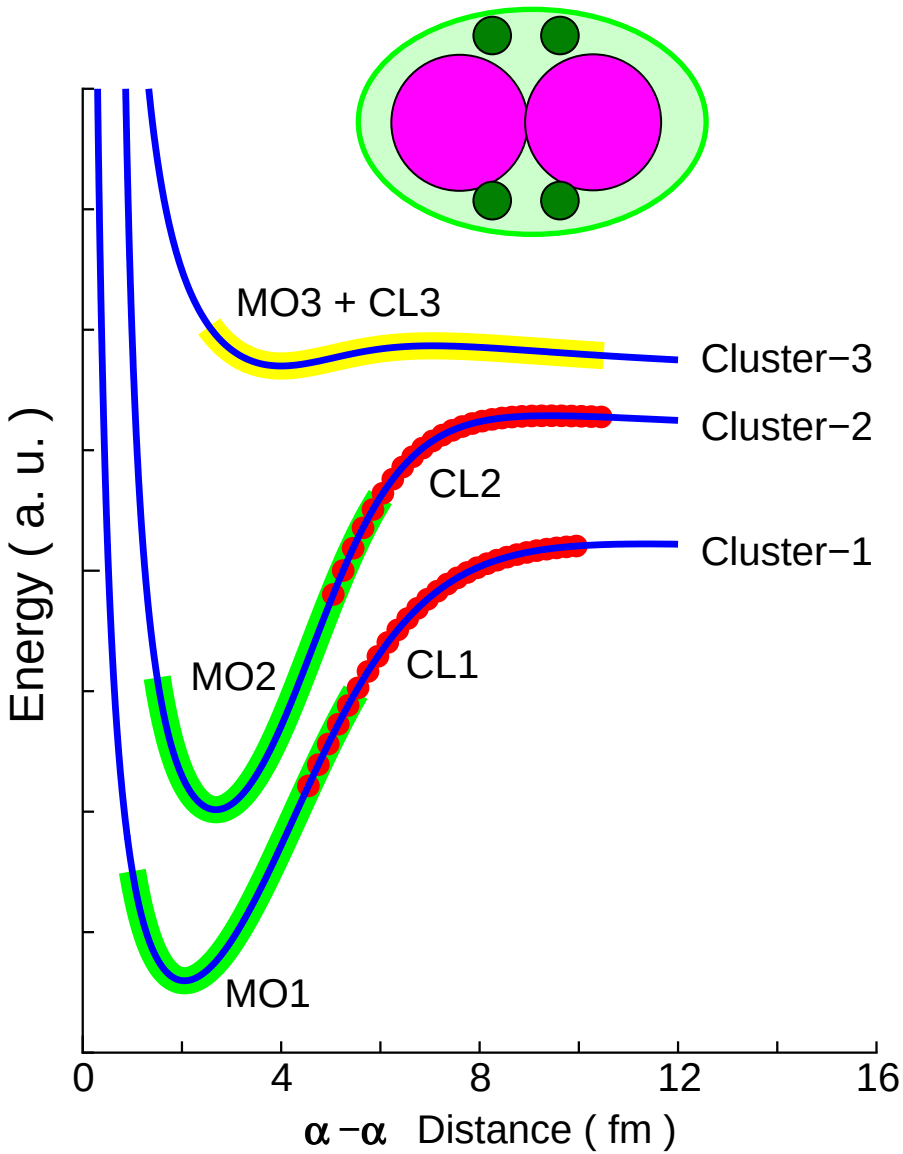
Fixed S → Adiabatic Energy surfaces

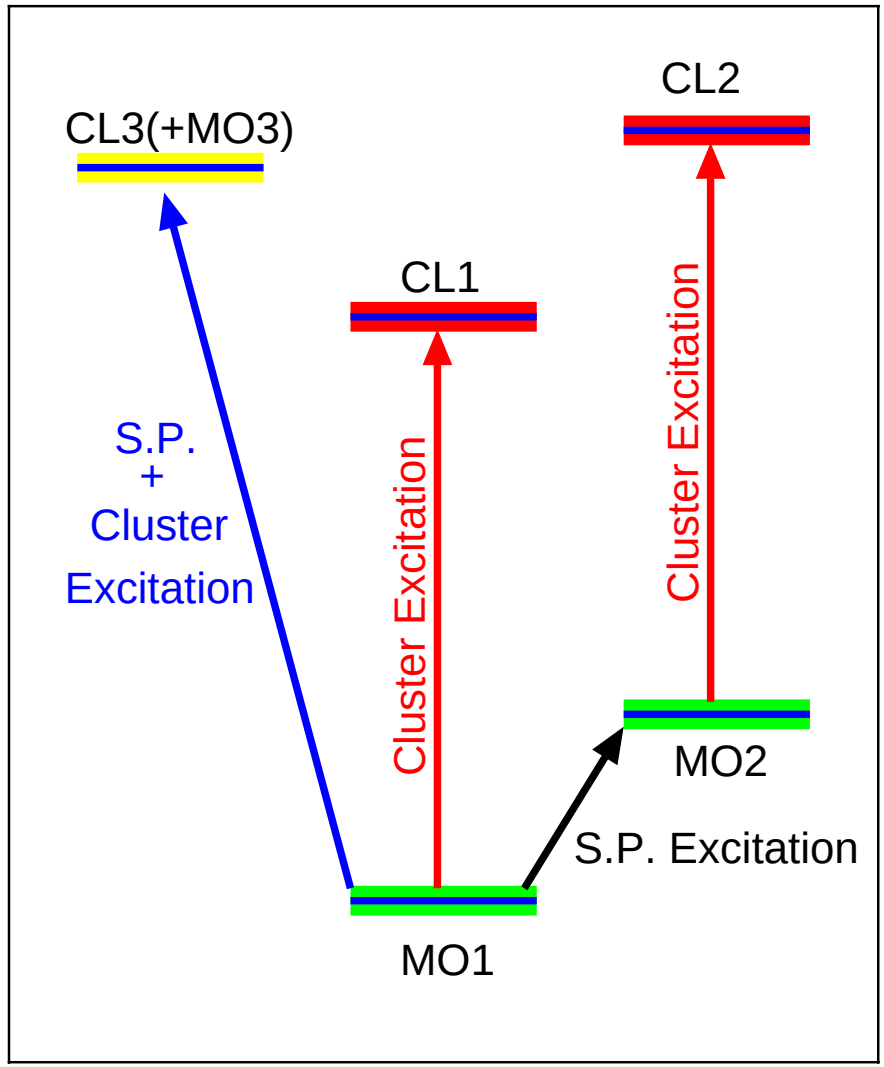
# Energy surfaces in $^{12}$Be = α+α+4N (38 channels )

$V_{NN}$ : Volkov No.2+G3RS



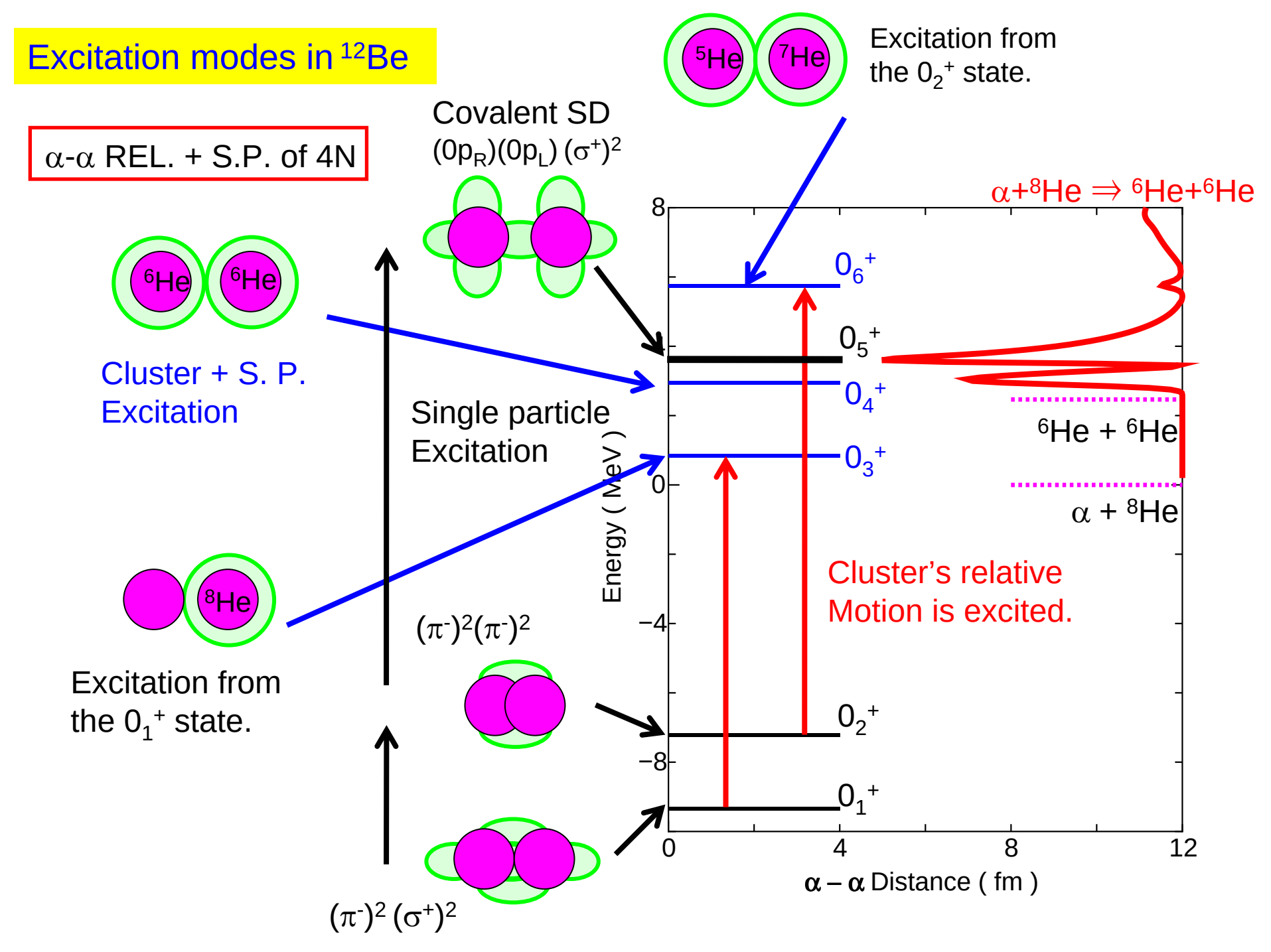
# Schematic picture of excitation modes



# Excitation modes in $^{12}$Be

α-α REL. + S.P. of 4N



## Contents

Unified description of the $\alpha$+$^{8}$He reactions and the exotic structures in $^{12}$Be

- M. I., N. Itagaki, H.Sakurai, K. Ikeda, PRL 100, 182502 (2008).
- M. I., N. Itagaki, PRC78, 011602(R) (2008).
- M. I., N. Itagaki, Phys. Rev. Focus Vol.22, Story4 (2008).

## Results

Unified studies of structures and reactions are open and interesting area.

### New features

1. Exited (resonance) states are characterized in terms of the excitation degree of freedoms included in the ground state. (Val. neutrons or cluster relative motion)
2. The energy spacing of the resonances becomes quite small.
3. The monopole transition is enhanced with a development of the cluster.

### Future studies

1. Extension to other cluster systems : O=$\alpha$+$^{12}$C+XN, Ne=$\alpha$+$^{16}$O+XN
2. Calculation based on realistic nucleon-nucleon interactions

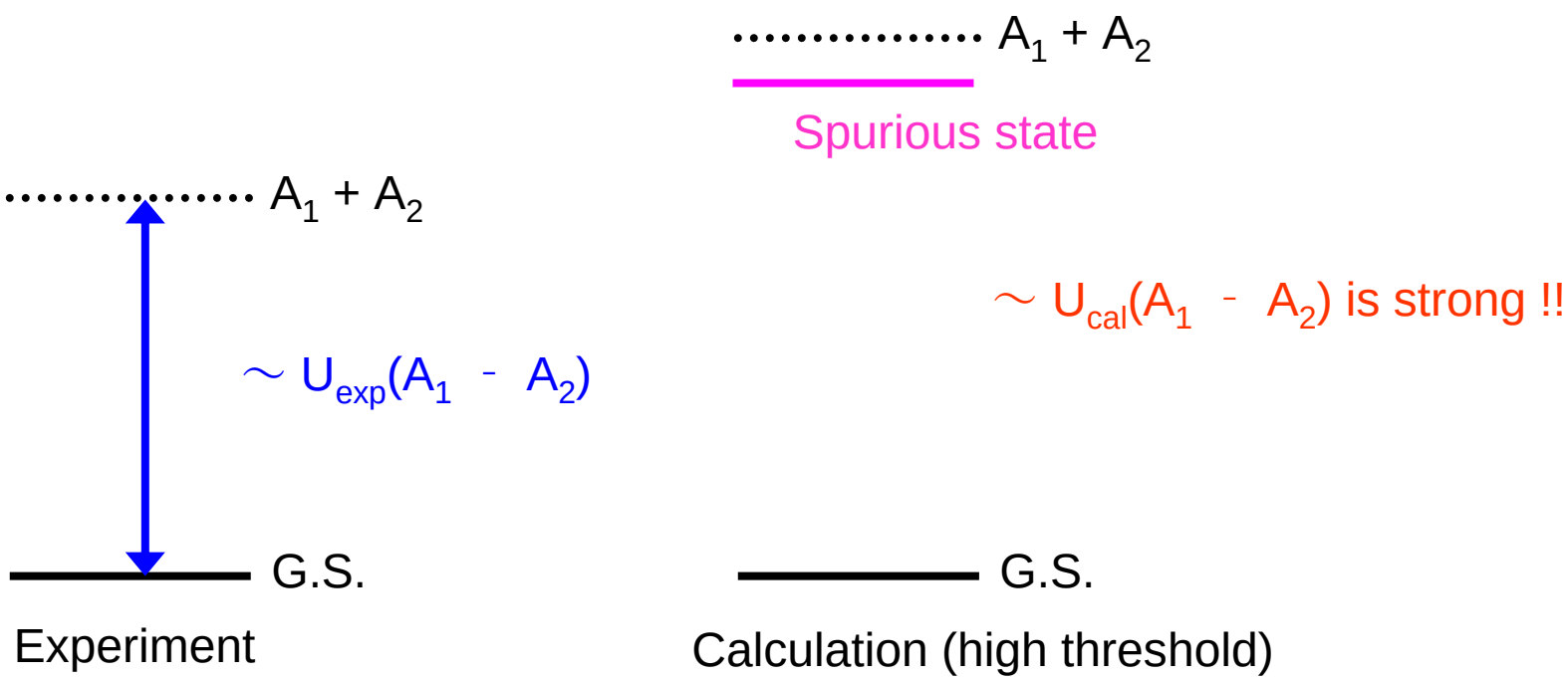
   UCOM is quite useful and easy method for cluster models.

## Important aspects in hadling (effective) NN interactions

In studies on reactions and resonances, it is important to reproduce threshold energies of the relevant cluster configurations.

($A_i$ is underbinding ?)

Threshold Energy : Strength of Cluster-Cluster Interactions (U)




The final result is not so sensitive to effective NN interactions if threshold energies are reasonably reproduced.

## Future study based on realistic NN interaction

To proceed studies based on realistic NN force, we should apply UCOM to microscopic cluster model.

UCOM : quite appropriate for cluster model (Operator form of NN forces).

## Perspective of UCOM in cluster models (Tensor corr.i s recommended by Prof. Roth.)

Radial correlators (without tenstor corr.) may be useful for cluster models.

In realistic cases, 2p-2h tensor coupling are important for reproductions of thresholds, and we had better treat it by the radial correlator.

UCOM (Radial Corr.) + FMD (H. Feldmier et al., NPA632 (98) )

$^{12}$C
- 3α : 7.27 (exp), -22.4 (cal)
- $2^{6}$Li : 28.18 (exp), 32.5 (cal)

$^{20}$Ne
- α+$^{16}$O: 4.73 (exp), 8.4 (cal)
- 2α+$^{12}$C: 11.89 (exp), 10.3 (cal)

$^{16}$O
- α+$^{12}$C: 7.16 (exp), 18.7 (cal)
- 4α : 14.44 (exp), -3.7 (cal)

Calculated thresholds tend to be higher than the experimental values.
⇒ Need improvements !!