Exotic molecular states in the α+^{6,8}He resonant scattering

M. Ito and N. Itagaki

RIKEN Nishina center, RI Physics Laboratory, RIKEN

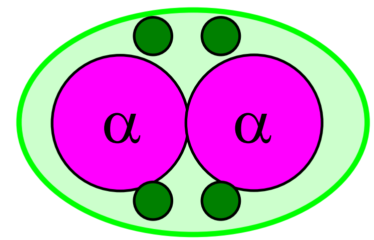
Department of Physics, University of Tokyo

Nuclear clustering in N-rich nuclei

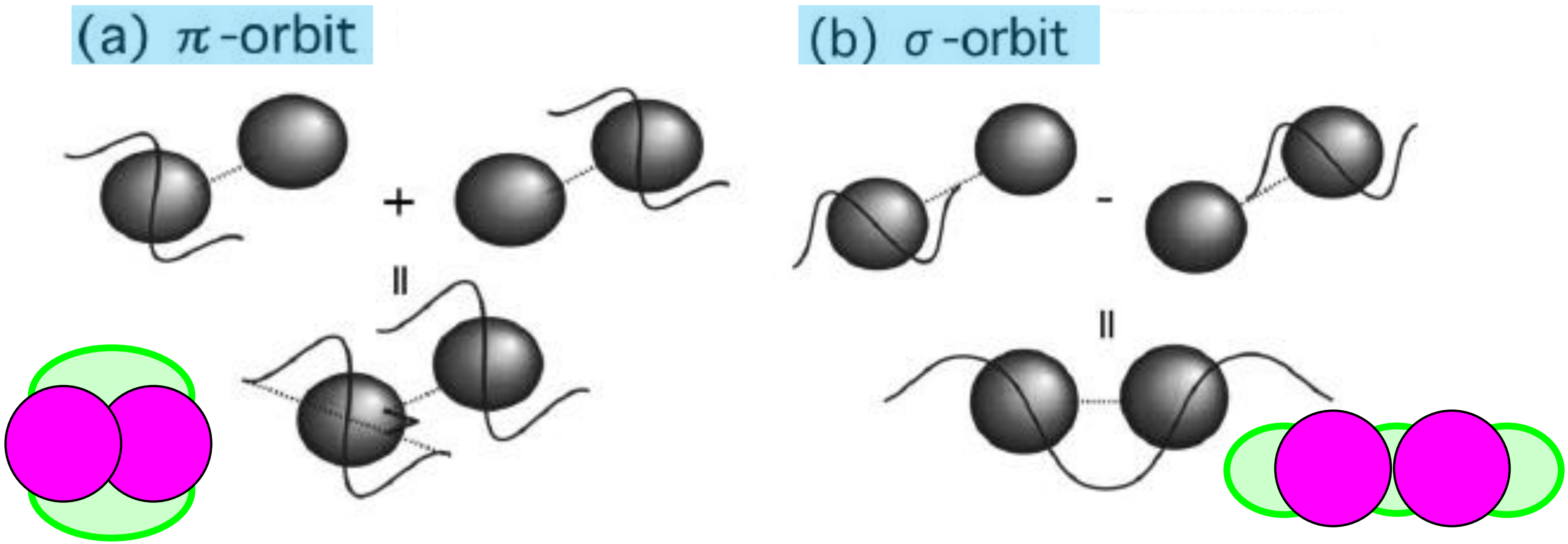
1. α–clustering in stable nuclear systems

$^{8}Be = 2\alpha$、$^{12}C = 3\alpha$、$^{16}O = \alpha + {}^{12}C$、 $^{20}Ne = \alpha + {}^{16}O$

2. Clustering in N-rich systems : Clusters + XN

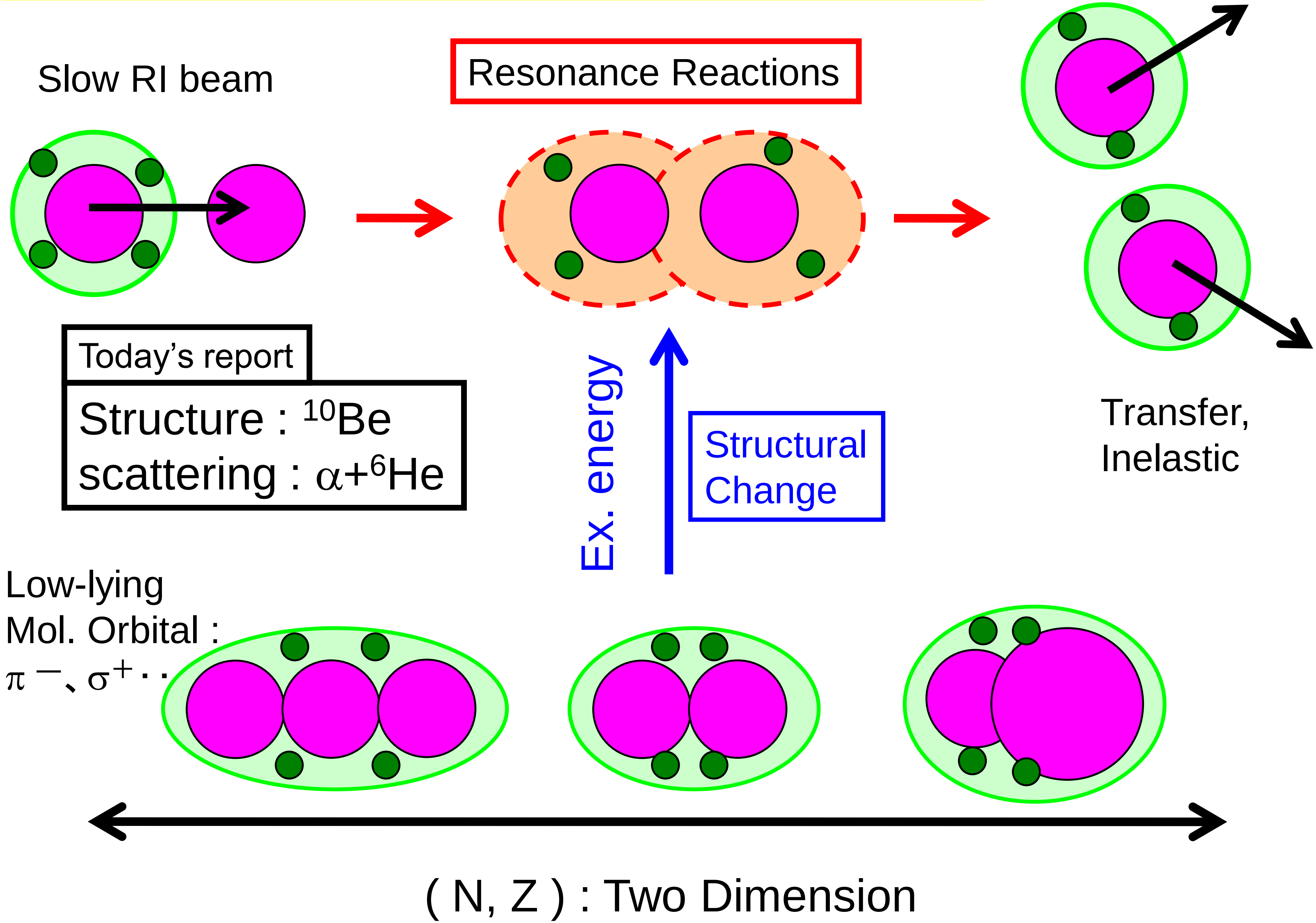


Example : Be isotopes = 2α +XN



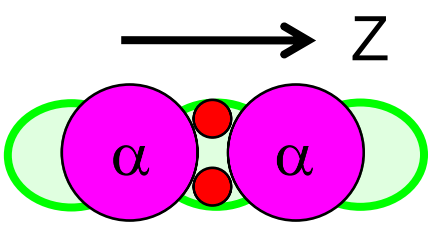
Molecular Orbital model : N. Itagaki et al., PRC61,62 (2000)

Studies on neutron-rich systems in 3-dimensional space



Formulation

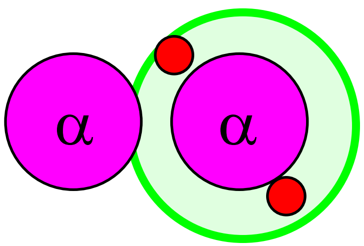
Linear Combination of Atomic Orbital (LCAO)



$$(\sigma^{+})^2 = \left(P_z(L) - P_z(R) \right)^2$$

$$= P_z(L)\cdot P_z(L) + P_z(R)\cdot P_z(R) - 2P_z(L)\cdot P_z(R)$$

$^{6}He + \alpha$ $\qquad$ $\alpha + {}^{6}He$ $\qquad$ $^{5}He + {}^{5}He$



$\alpha + {}^{6}He(0^{+})$

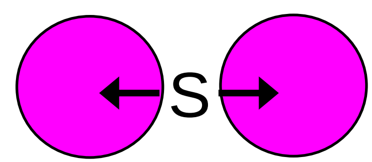
$$= P_x(R)\cdot P_x(R) + P_y(R)\cdot P_y(R) + P_z(R)\cdot P_z(R)$$

Total wave function

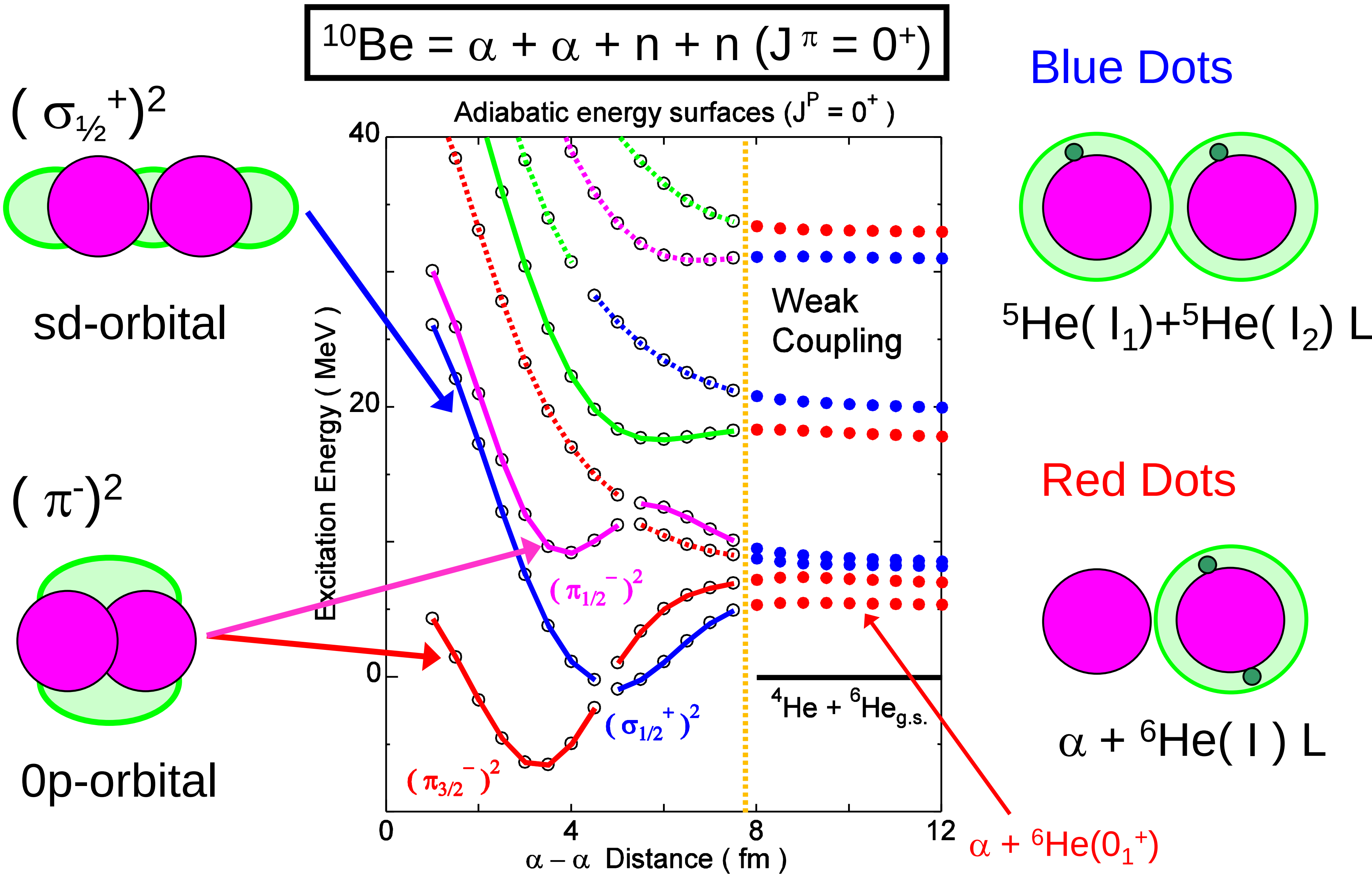
$$\Psi = \sum_{\beta,S} \underline{C(\beta,S)}\, P_m(a)\cdot P_n(b)$$

Variational PRM

(m,n)=x,y,z $\quad$ (a,b) = L,R

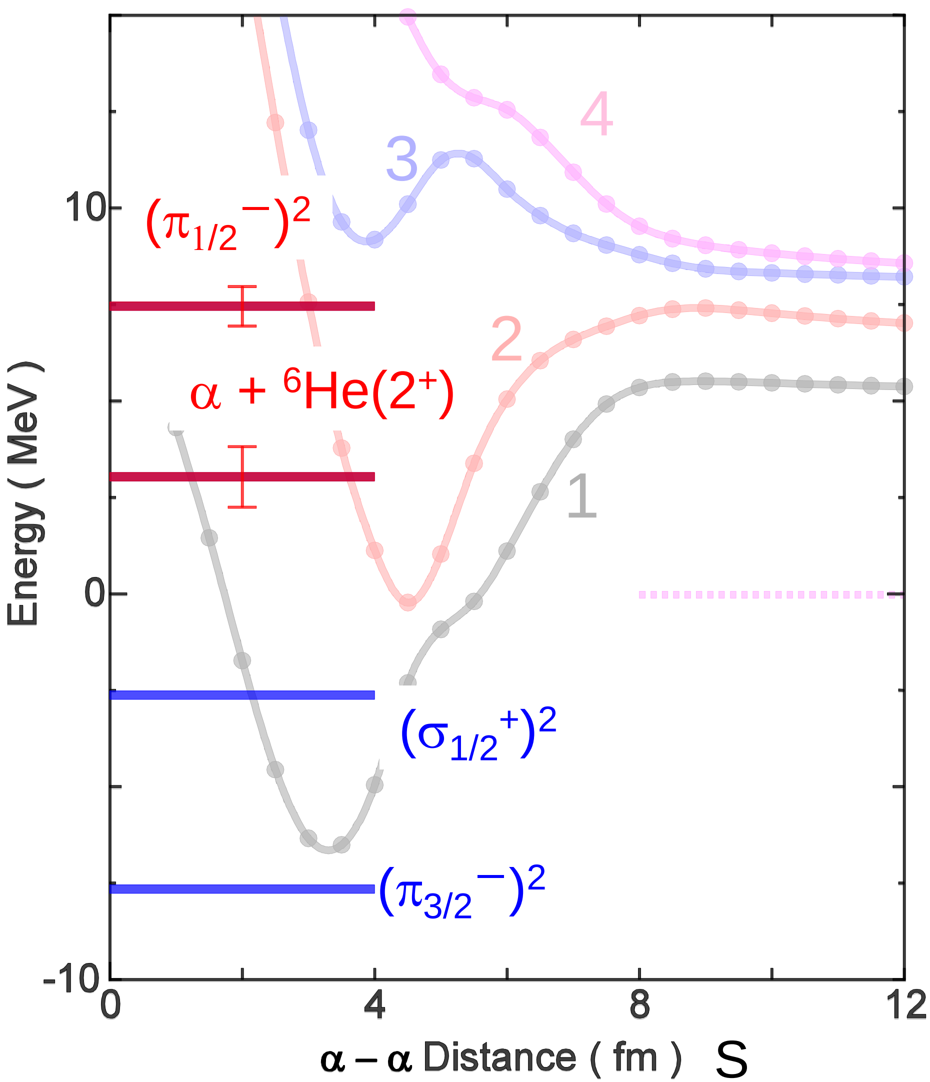


Adiabatic Energy surfaces : NN int. ⇒Volkov No.2 + G3RS



Coupled channels with the adiabatic states

Energy spectra of ^{10}Be



Adiabatic basis

$$\Psi = \sum_{k,S} f(k,S)\,\Phi^{AD}(k,S)$$

$k = 1, 2, 3, 4, \ldots$

$$H = \sum_i t_i + \sum_{i>j} v_{i,j}$$

$$(H - E)\Psi = 0$$

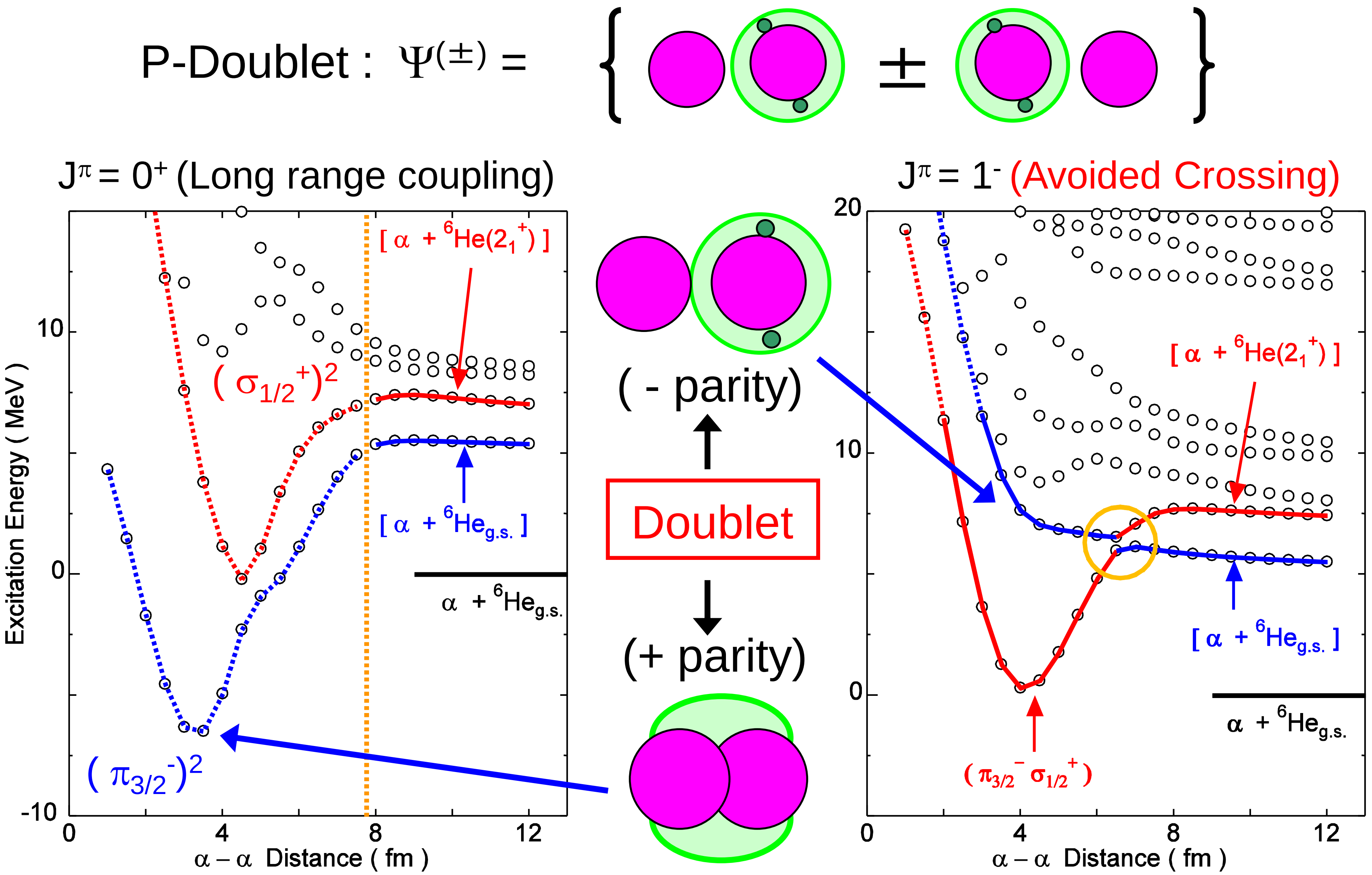
Bound,
Resonant
B.C.

Energy spectra

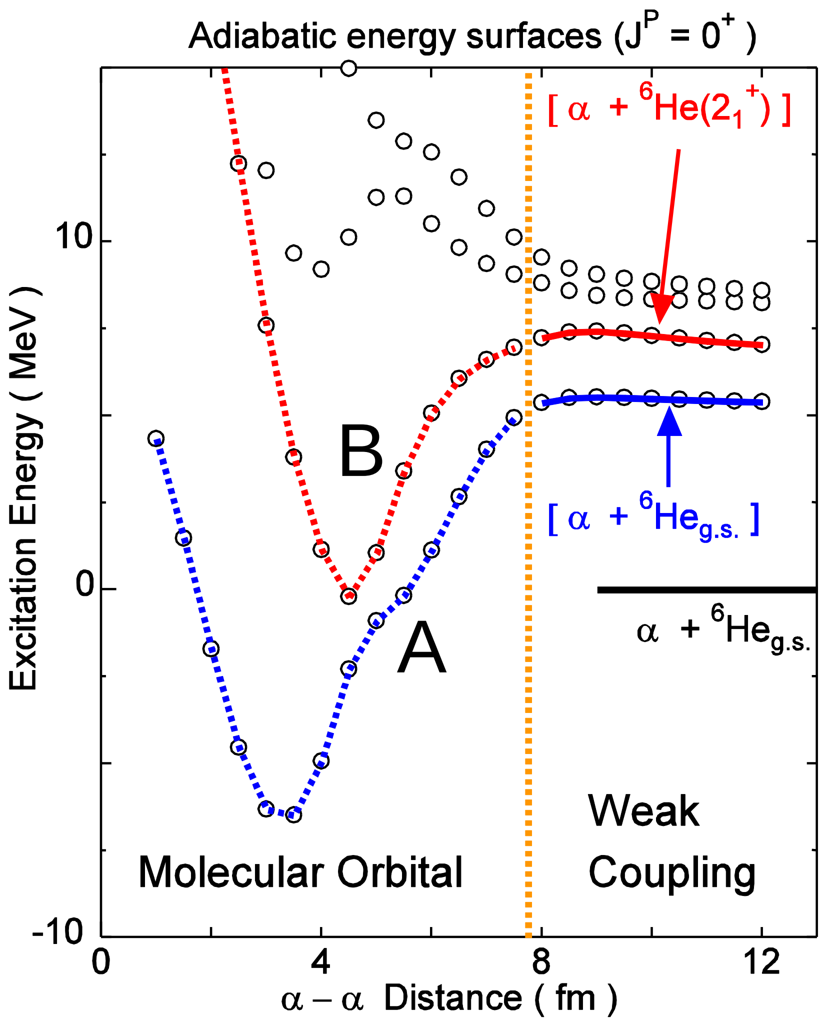
Scattering
B.C.

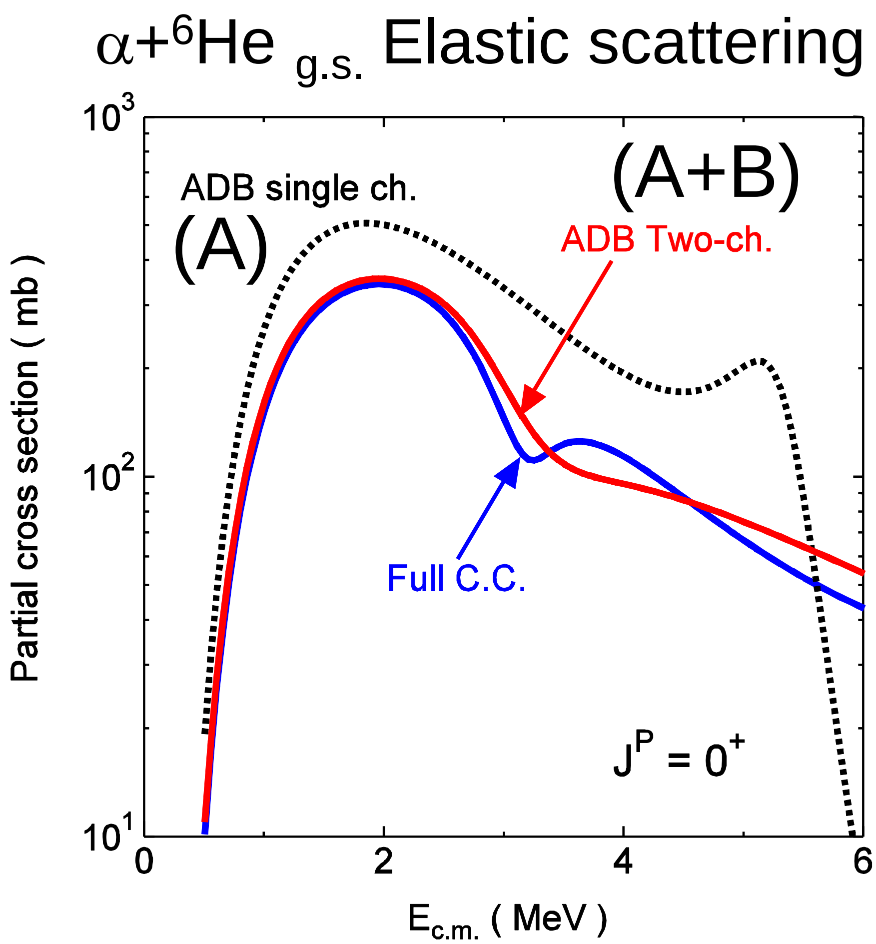
$\alpha + {}^6$He scattering

Parity doublet formation in adiabatic energy surfaces



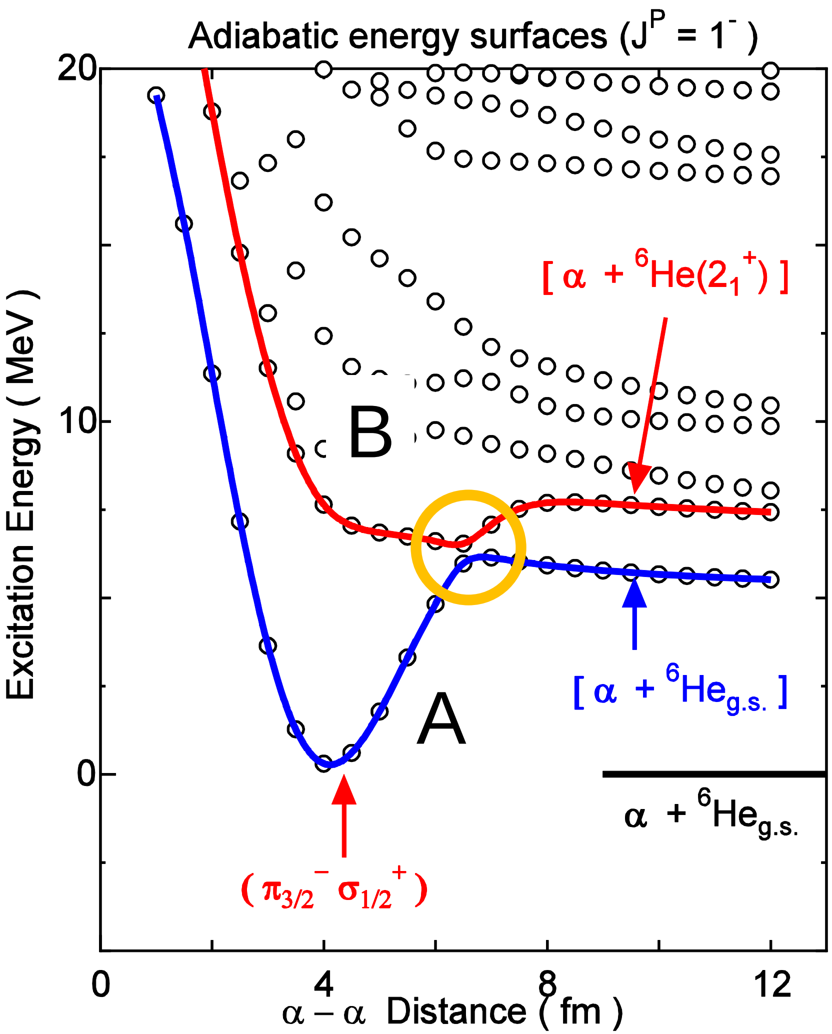
Coupled channels in α+^{6}He elastic scattering (J^{π} =0^{+})

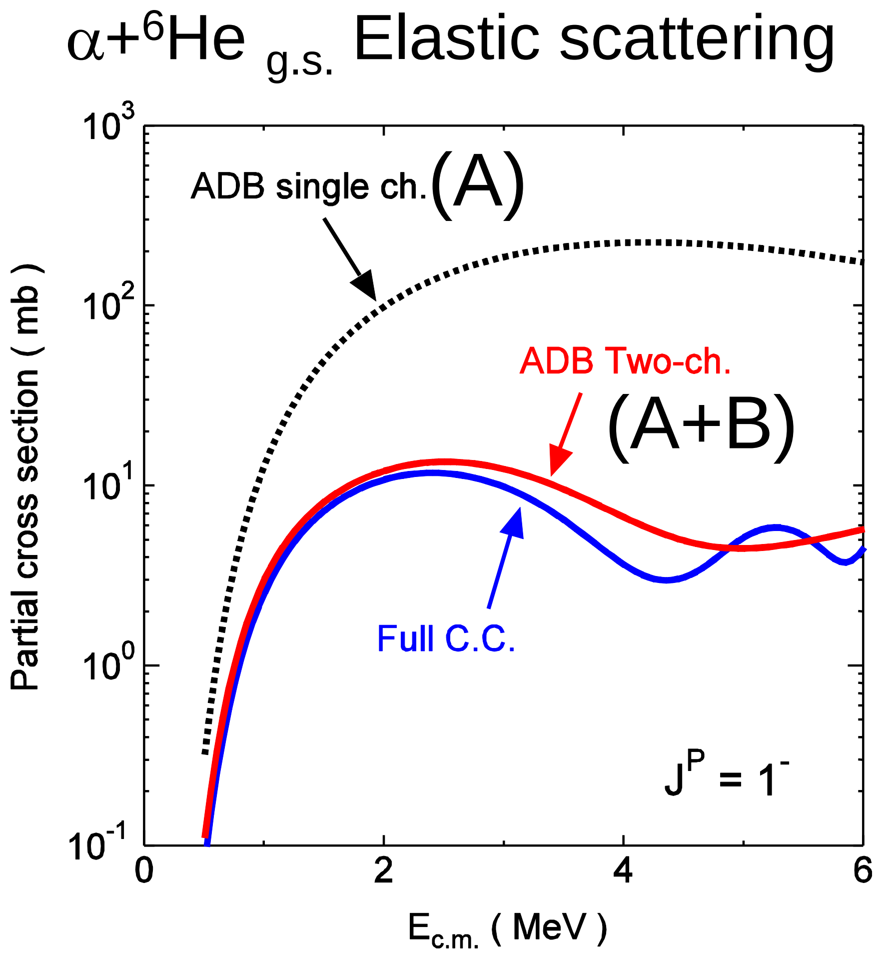




Adiabatic approximation is good.

Coupled channels in $\alpha+^6He$ elastic scattering ($J^\pi = 1^-$)





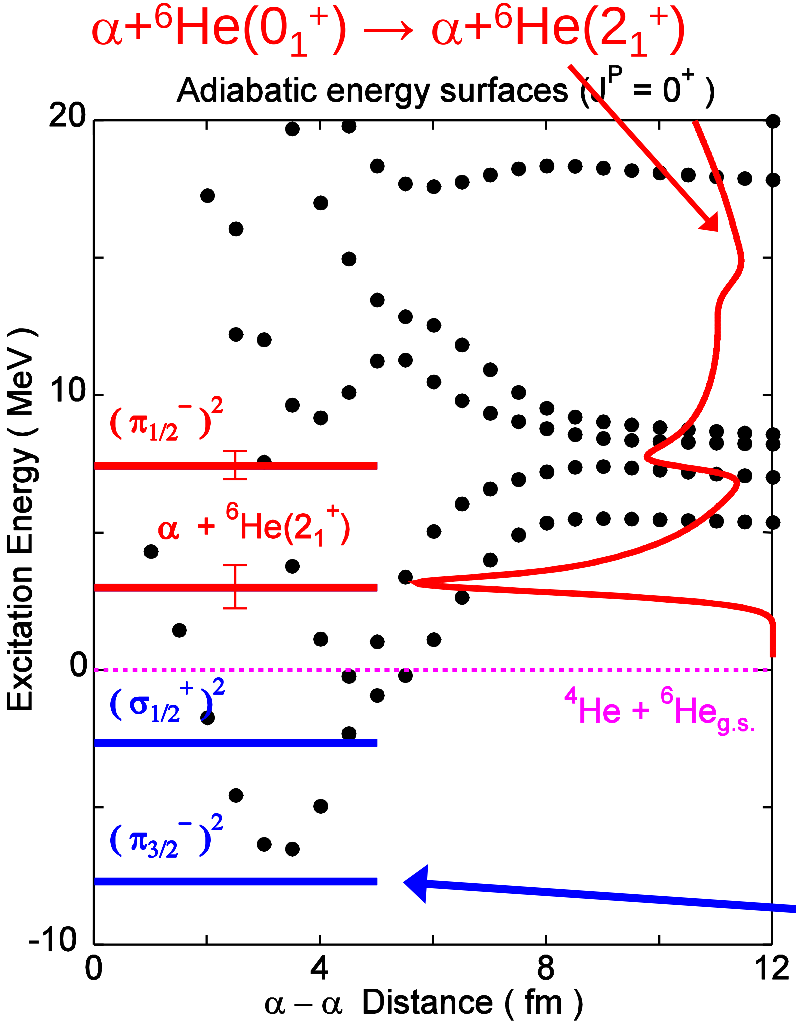
Non-adiabatic transition strongly occurs.

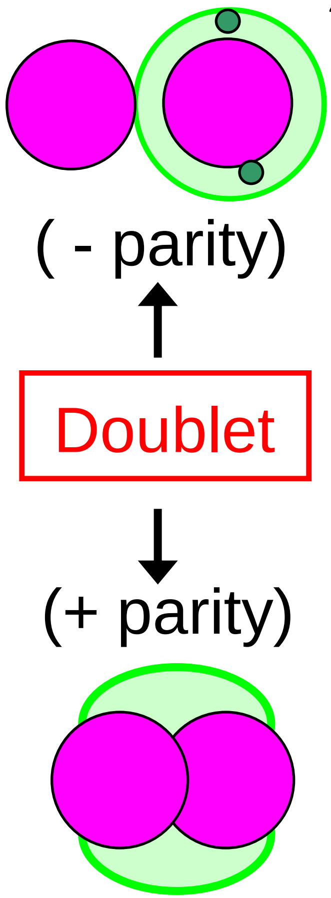
Enhancements in α+^{6}He inelastic scattering

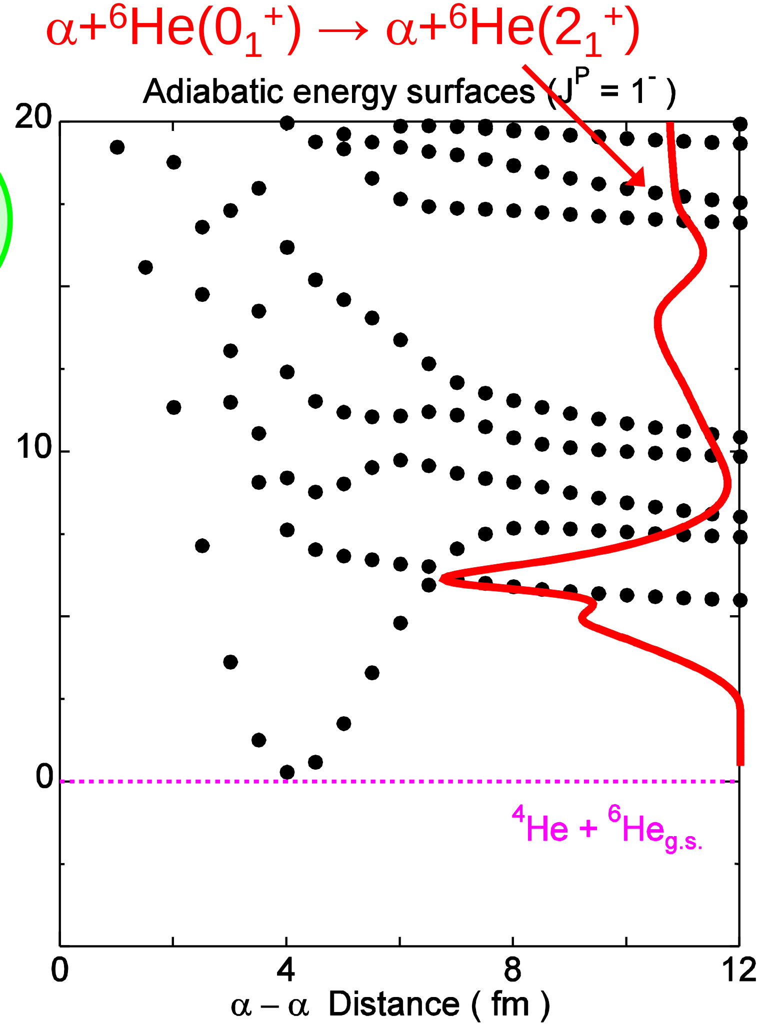
(B. Imanisi et al., Phys. Rep. 155)

$J^\pi = 0^+$ **Resonance Poles**

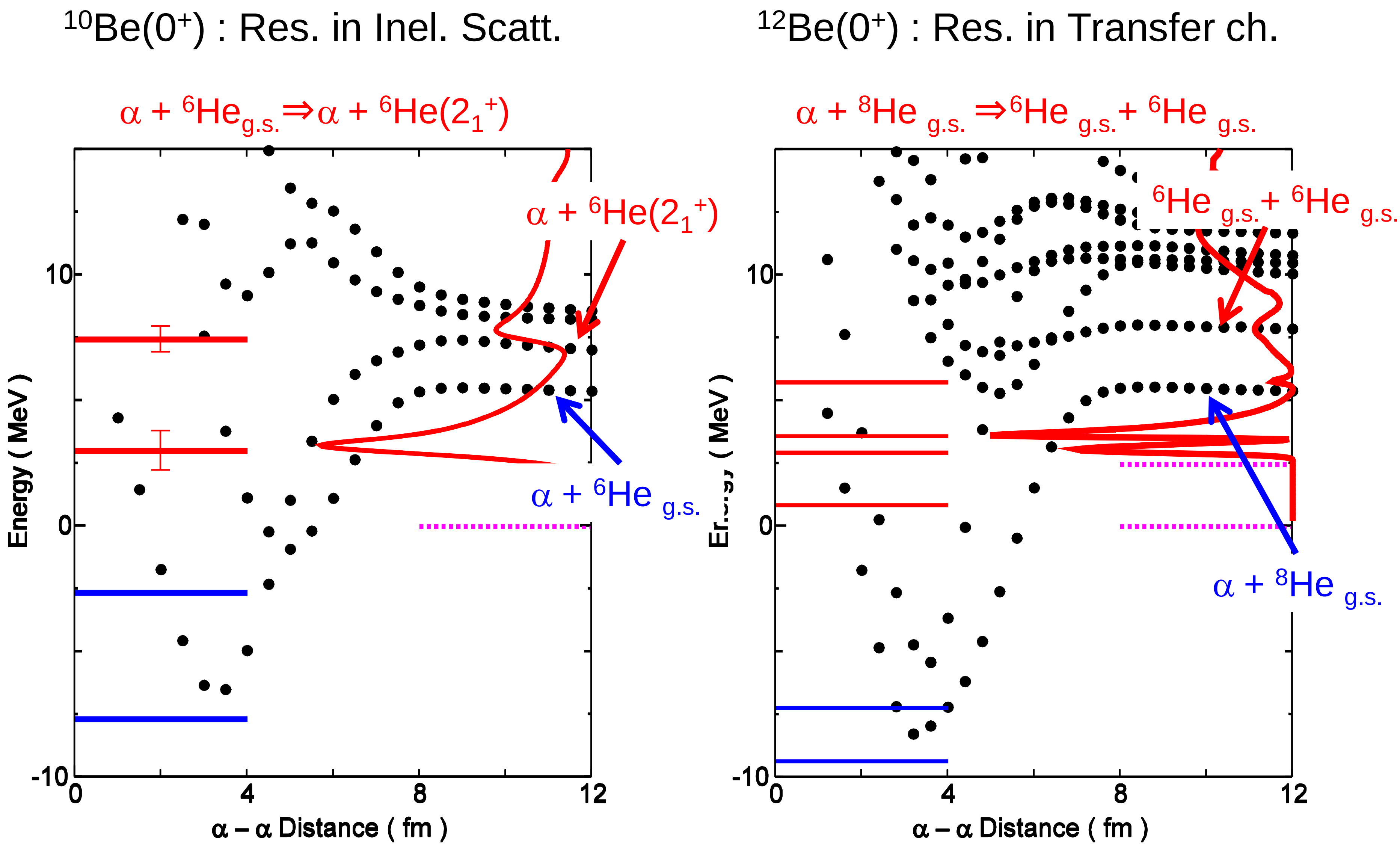
$J^\pi = 1^-$ **L-Z level crossing**







Comparison between α+^{6}He and α+^{8}He scattering



Summary

1. Studies on N-rich systems in (N,Z,E) space is very interesting.
2. Unified description of structures and reaction becomes quite important.
3. We show some enhancements in the α+^{6}He and α+^{8}He scattering.

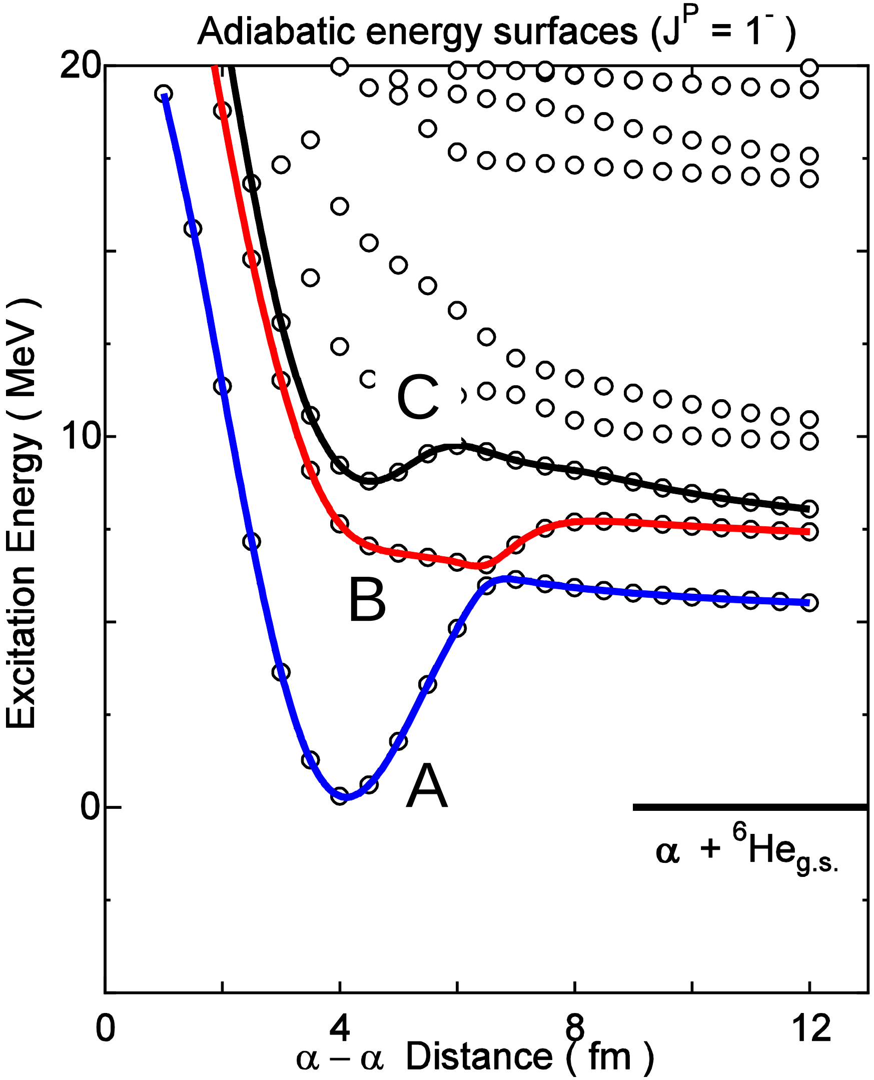
Results of ^{10}Be

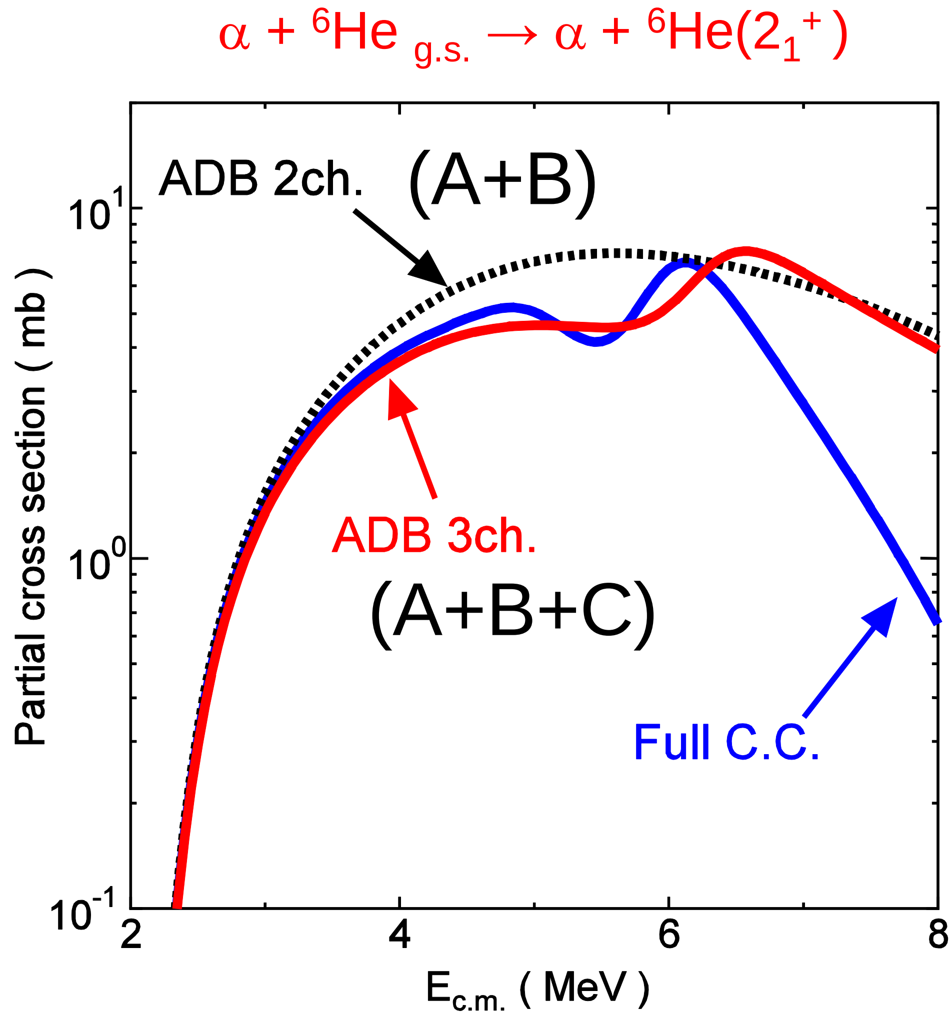
1. Molecular and atomic states coexist in this system.
2. Reaction process is different between the positive parity and the negative one.
3. L-Z transition is predicted in connection to the Parity doublet.

Results of ^{12}Be

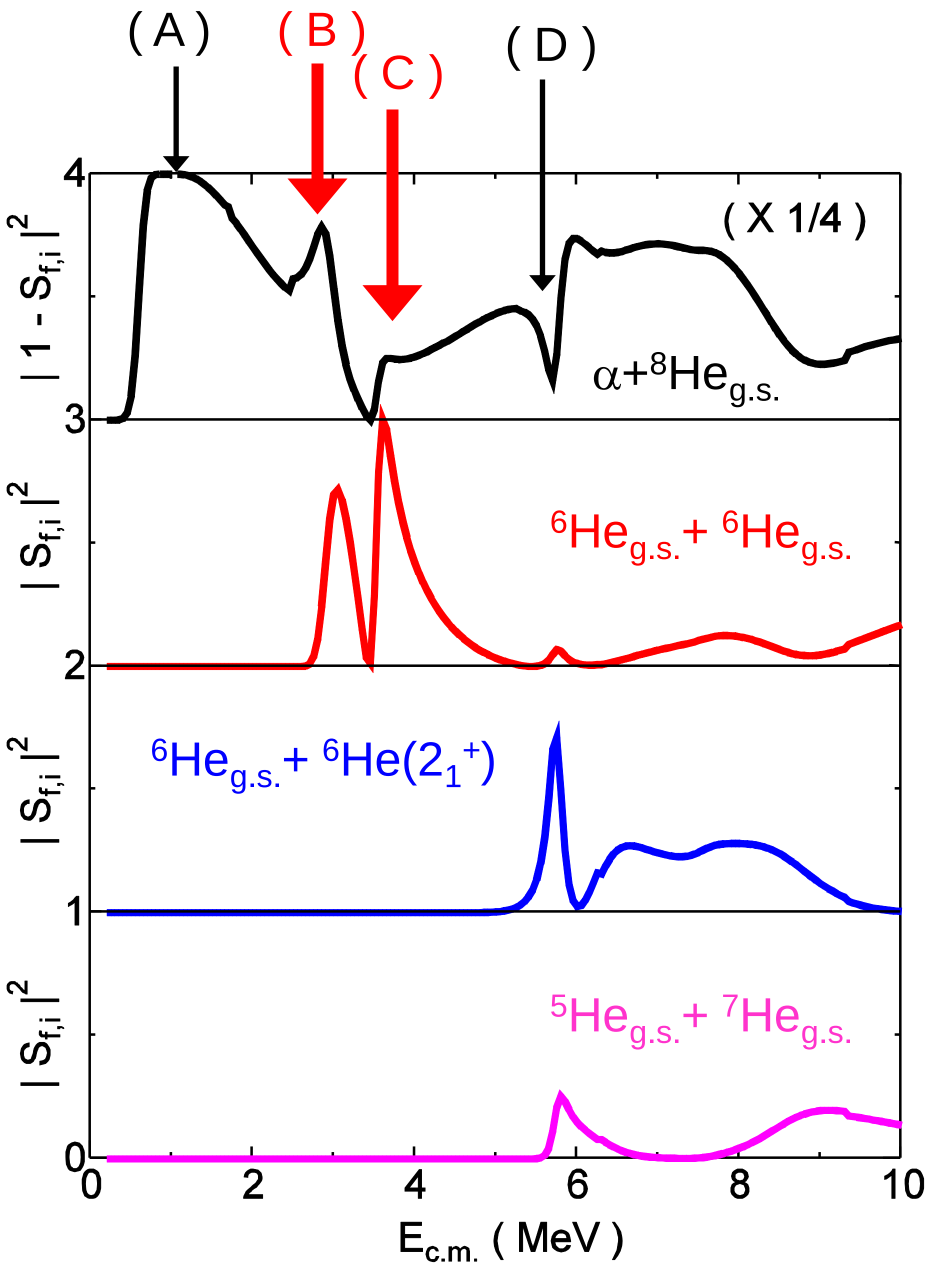
1. Resonances will be observed in two neutron transfers.
2. Exotic structures are excited. (I will report at YITP post symposium.)

Coupled channels with the adiabatic states

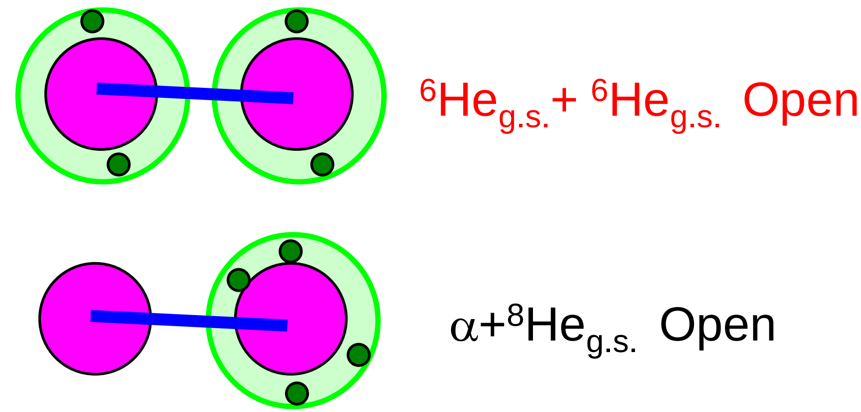




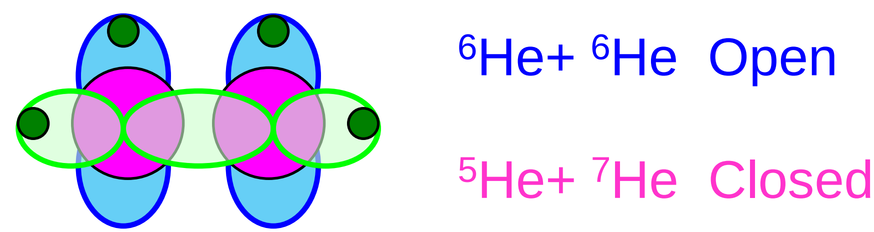
Resonances in $\alpha + {}^8He \Rightarrow {}^xHe + {}^yHe$



(B) Two nucleon transferred state

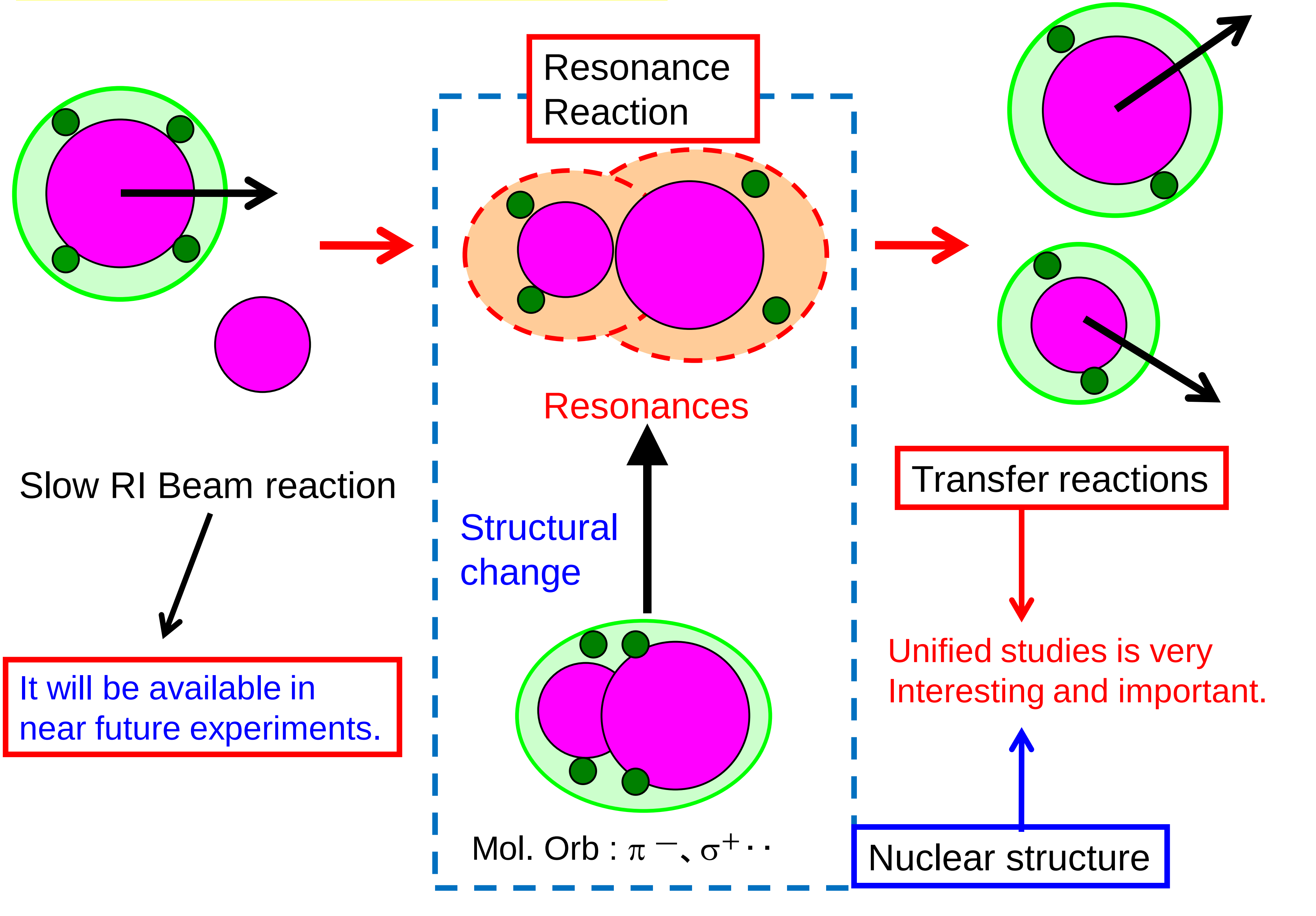


(C) Atom-Molecule hybrid state

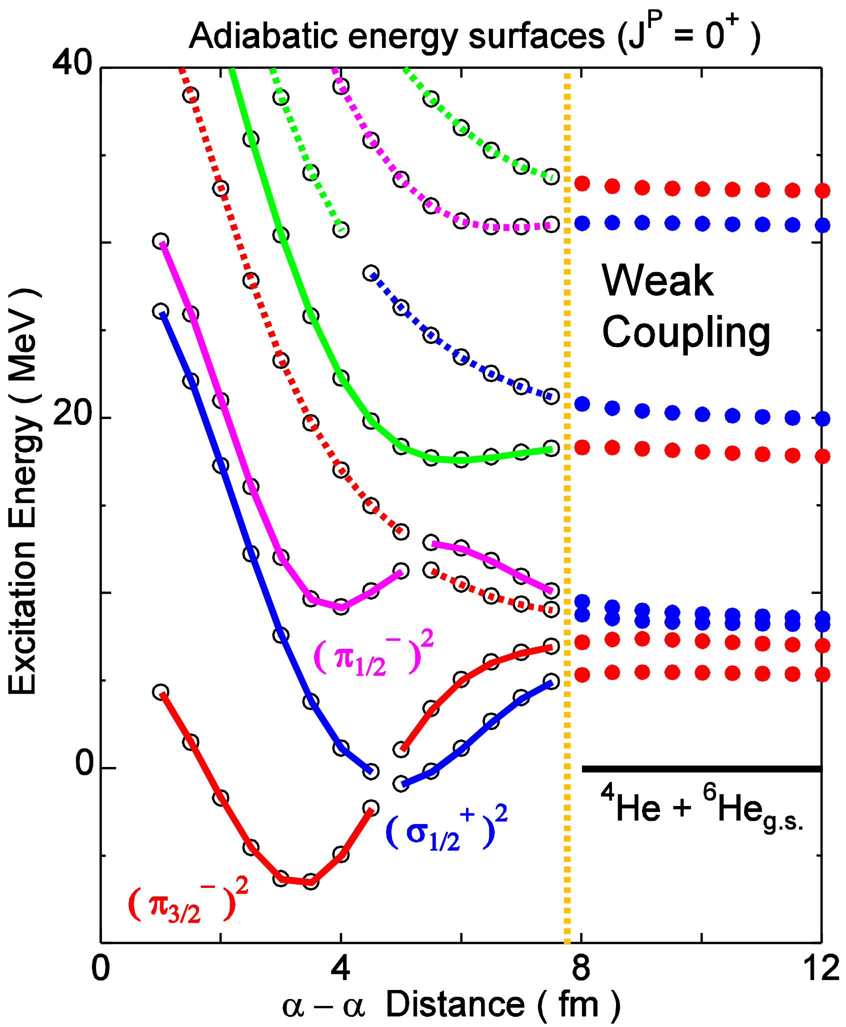


Decay scheme depends on the intrinsic structure

Unified studies in neutron-rich system



Coupled channels with the adiabatic states



$$u^{rel}(\alpha, R, S)\varphi^{in}(\alpha, \xi_\alpha)$$

$$\Phi^{AD}(i,S) = \sum_\beta C_\beta(i)\, u^{rel}(\beta, R_\beta, S)\, \varphi^{in}(\beta, \xi_\beta)$$

$$u^{rel}(\beta, R_\beta, S) \propto \exp\left[-\nu(R_\beta - S)^2\right]$$

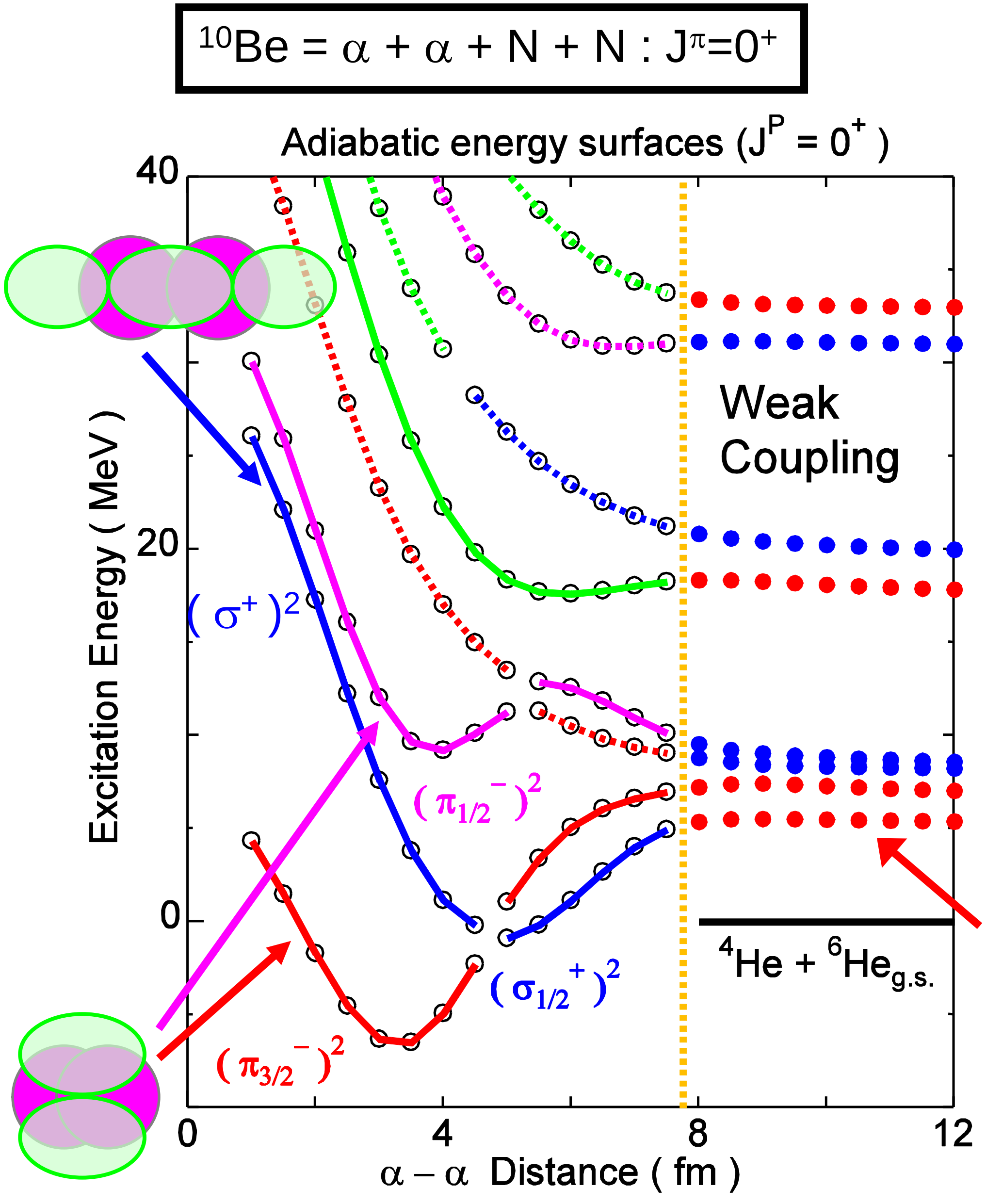
$$u^{rel}(\alpha, R_\alpha, S) \propto \quad \exp\left[-\nu(R_\alpha - S)^2\right] \quad (R \le R_c)$$

$$u_{L\alpha}^{(-)}(R_\alpha) - \varepsilon\, u_{L\alpha}^{(+)}(R_\alpha) \quad (R \ge R_c)$$

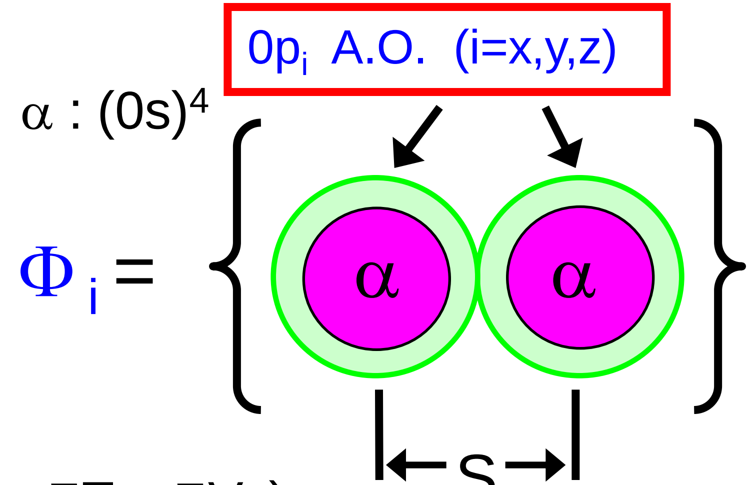
$$\Psi = \sum_{i,S} f(i,S)\, \Phi^{AD}(i,S)$$

$$(H - E)\Psi = 0$$

Generalized Two-center cluster model (GTCM) : PLB588



Basis : Atomic orbital (A.O.)



$(H = \Sigma T_i + \Sigma V_{ij})$

Total wave function

$$\Psi^{J\pi} = P^{J\pi} A \sum C_i \Phi_i$$

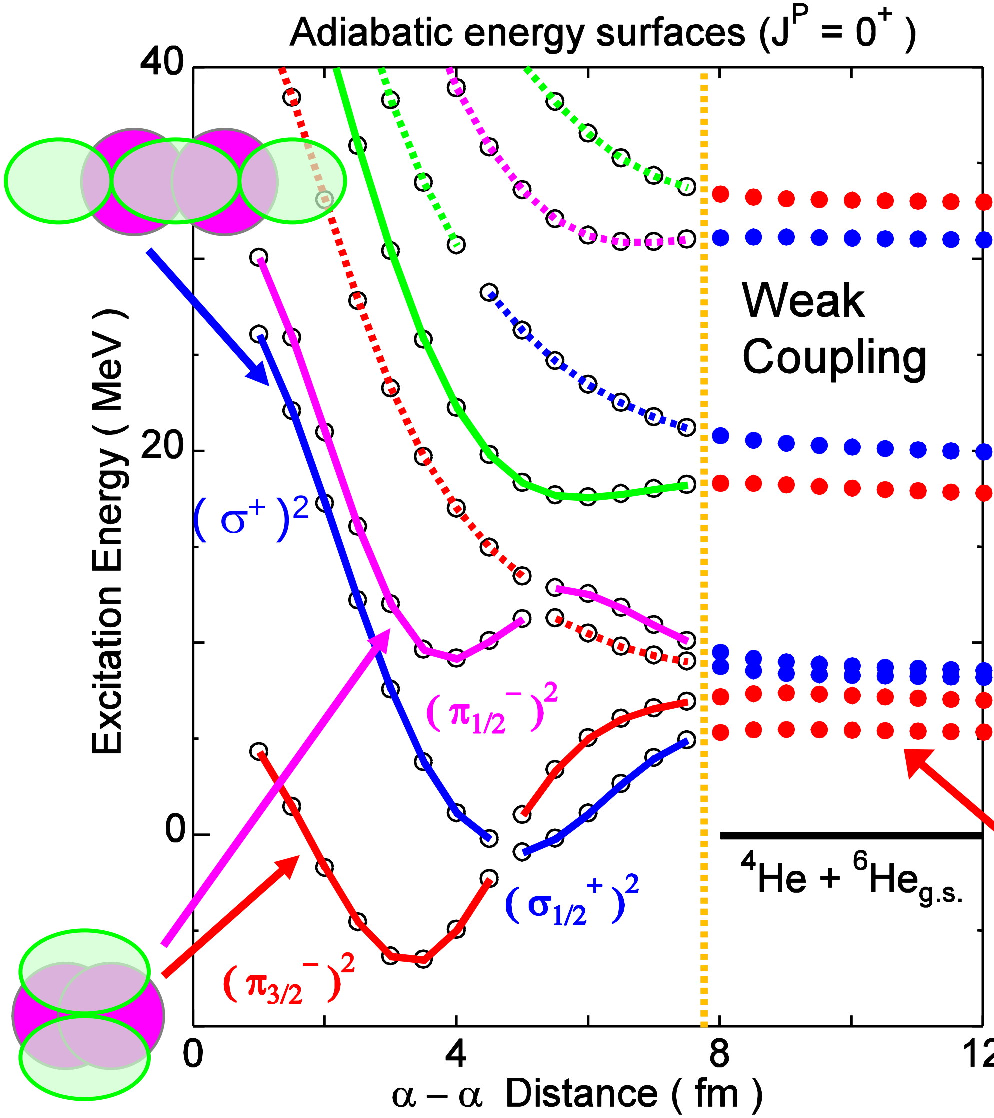
J^{π} Proj. Anti-sym.

●Red Dots : $[\alpha + {}^{6}He (I)] LJ$

●Blue Dots : $[{}^{5}He(I_1) + {}^{5}He (I_2)] LJ$

Generalized Two-center cluster model (GTCM) : PLB588

$^{10}Be = \alpha + \alpha + N + N : J^{\pi}=0^{+}$



$\alpha + {^6He}(0_1^+)$

●Red Dots : $[\alpha + {^6He}(I)]$ LJ

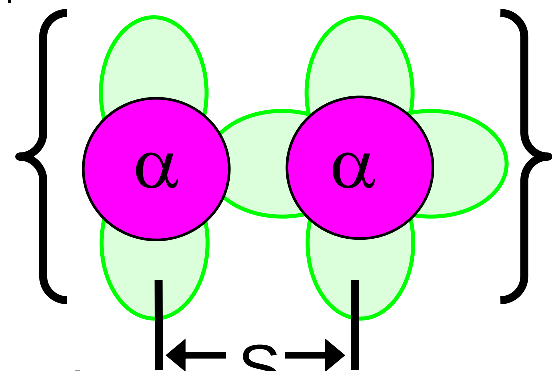
●Blue Dots : $[{^5He}(I_1) + {^5He}(I_2)]$ LJ

Basis : Atomic orbital (A.O.)

$0p_i$ A.O. (i=x,y,z)

$\alpha : (0s)^4$

$\Phi_i =$



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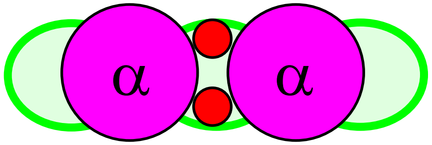
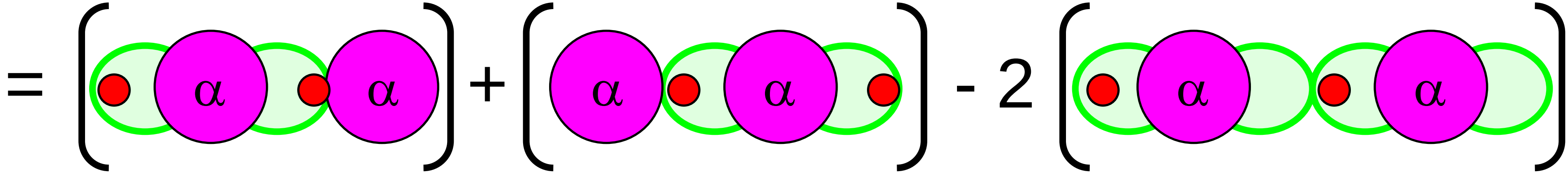
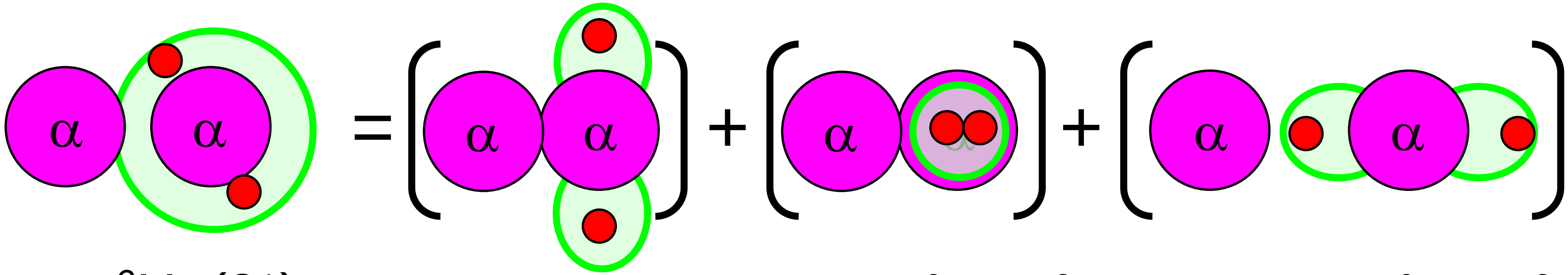


$$(\sigma^{+})^2 = \left(p_z(L) - p_z(R) \right)^2$$



$^{6}He(z)^2 + \alpha$ $\alpha + {}^{6}He(z)^2$ $^{5}He(z) + {}^{5}He(z)$



$\alpha + {}^{6}He(0^{+})$ $\alpha + {}^{6}He(x)^2$ $\alpha + {}^{6}He(y)^2$ $\alpha + {}^{6}He(Z)^2$