Microscopic coupled-channels study of cluster structures in ^{19}Ne

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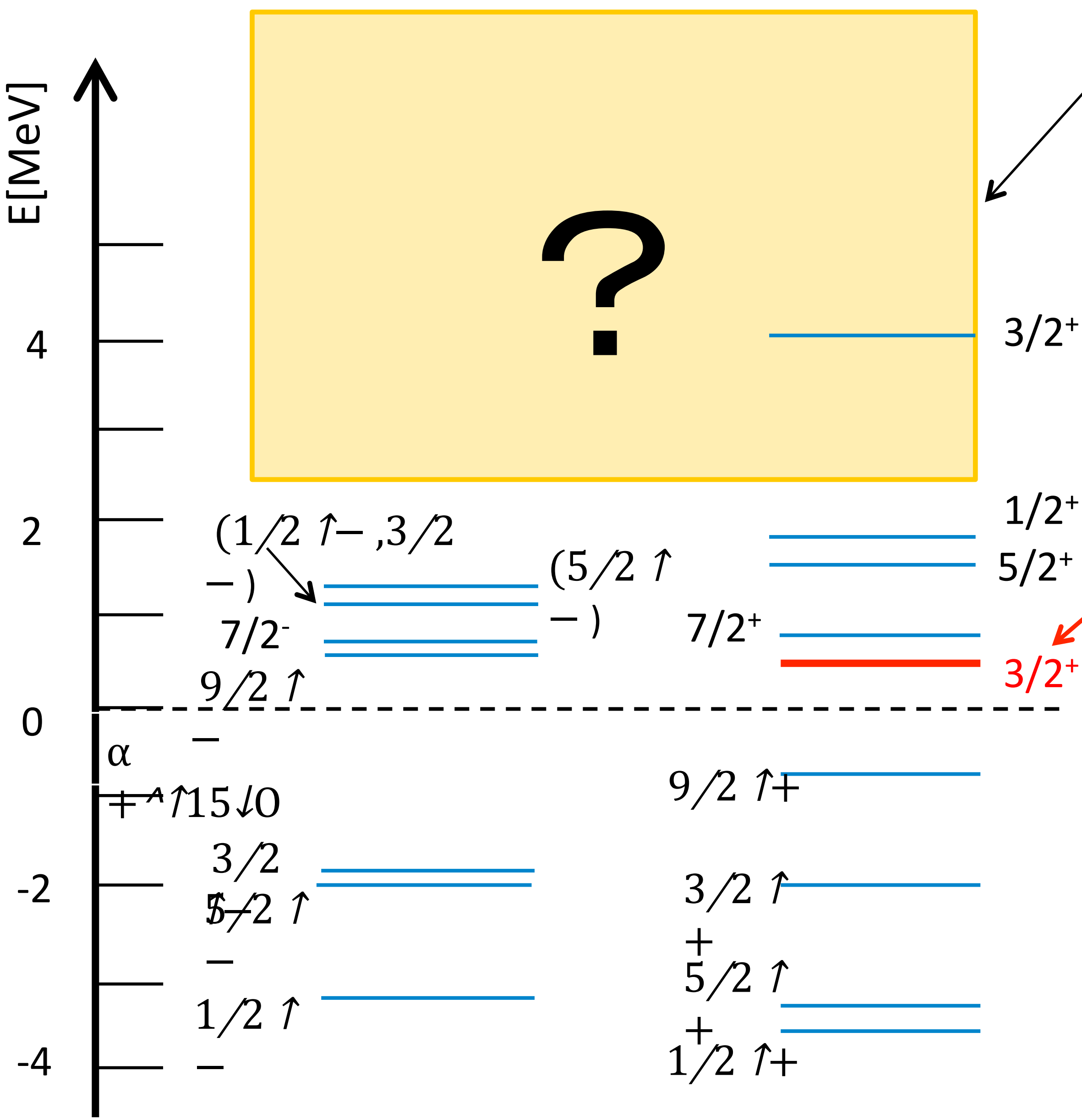
Experimental spectra in ^{19}Ne (TUNL)



Subject 1

Level structure still remains unclear in continuum of ^{19}Ne

EXP. by Korean-Japan and Birmingham-Italy Teams (Resonant α + ^{15}O scattering)

Subject 2

Important for astrophysical phenomena

No theoretical calculations reproduce this level

First Analysis of ^{19}F and ^{19}Ne by the cluster model

B. Buck et al., NPA280 (1977)

Shell model of 3p-0h and 4p-1h (TUNL data base)

Present study

1. Microscopic (^{3}He+^{16}O) + (α+^{15}O) cluster model calculation

① We solve the (α + ^{15}O) + (^{3}He+^{16}O) coupled-channels problem on the basis of microscopic cluster model (GCM).

② Energy levels in continuum region are predicted.

2. Analysis by (^{3}He+^{16}O) + (α+^{15}O) + (^{5}He+^{14}O) (extended model space)

We calculate the energy spectra for the 3/2$^+$ states and investigate the coupling effect of the ^{5}He+^{14}O cluster configuration.

c.f. : ^{19}F = (3H+ ^↿16⇂O) + (^{4}He + ^{15}N) T. Sakuda and F. Nemoto, PTP62 (1979)

Absorbing boundary condition (ABC) is introduced to identify resonant states explicitly.

Ref. R. Otani et al., PRC90, 034316 (2014)

Framework 1: (α+^{15}O) + (^{3}He+^{16}O)

1.Hamiltonian

Coulomb interaction

Spin orbit interaction : G3RS

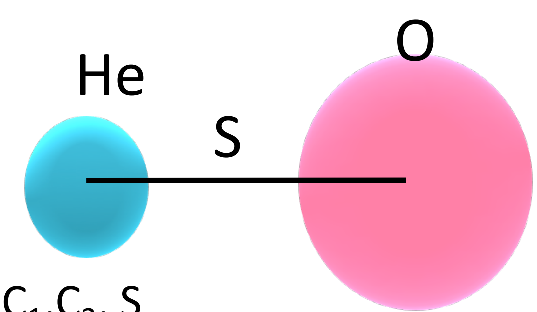
$$H=\sum_{i=1}^{19} t_i+\sum_{i>j}^{19} v_{ij}^{(N)}+\sum_{i>j}^{19} v_{ij}^{(C)}+\sum_{i>j}^{19} v_{ij}^{(LS)}$$

Parameters are tuned to reproduce ^{4}He threshold (Parity dependence is needed)

Central Force : Volkov No.2

2. Generalized two centers cluster model

He,O ⇒ Harmonic Oscillator S.D.



$$\Phi^{J\pi}(S) = P^{J\pi}\mathcal{A}\{C_1|\alpha+{}^{15}\mathrm{O}\rangle+C_2|{}^{3}\mathrm{He}+{}^{16}\mathrm{O}\rangle\}$$

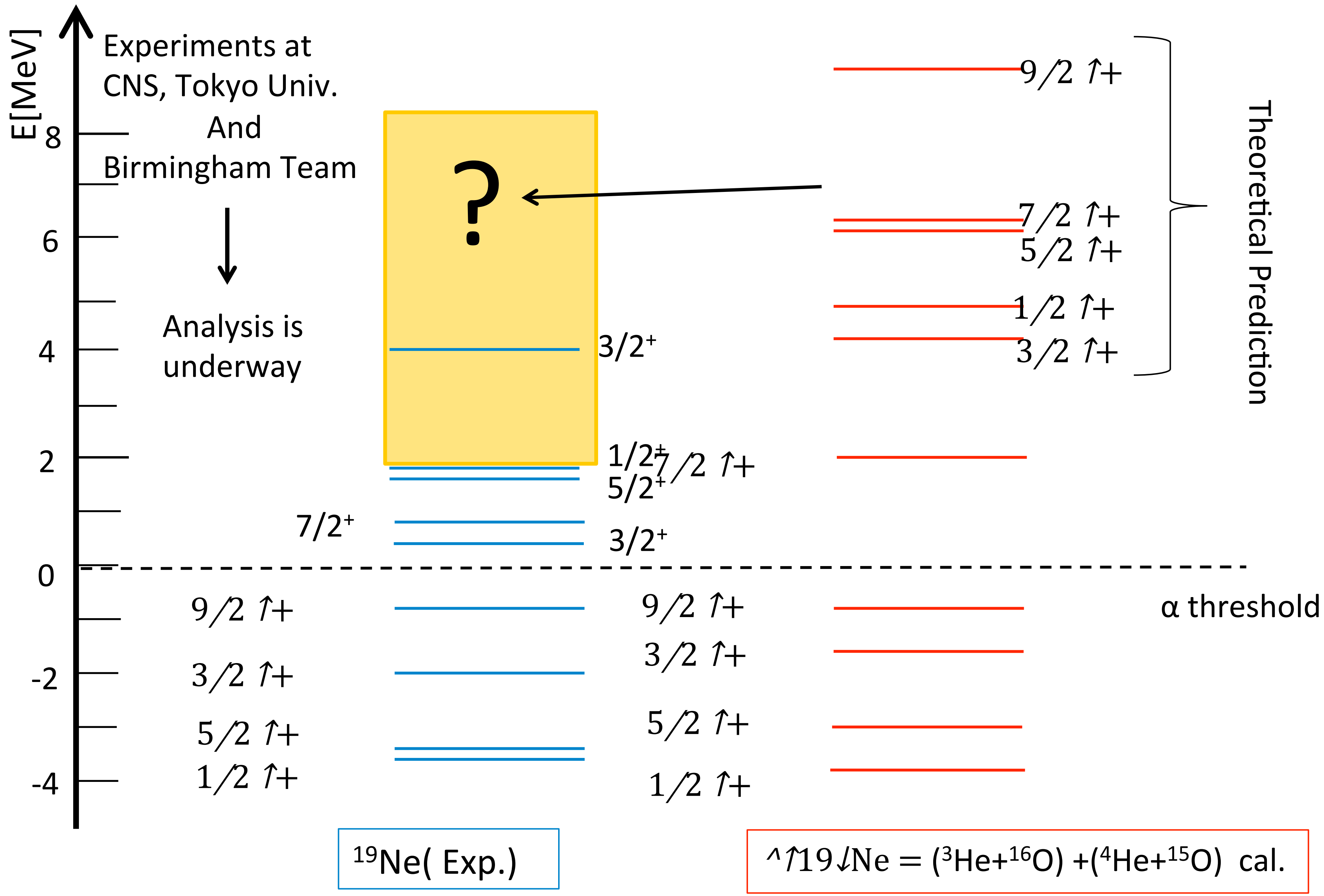
$J\pi$ projection　　Anti-symmertrization　　Variational parameters : C_1,C_2, S

M. Ito and K. Ikeda, ROP77 (2014)

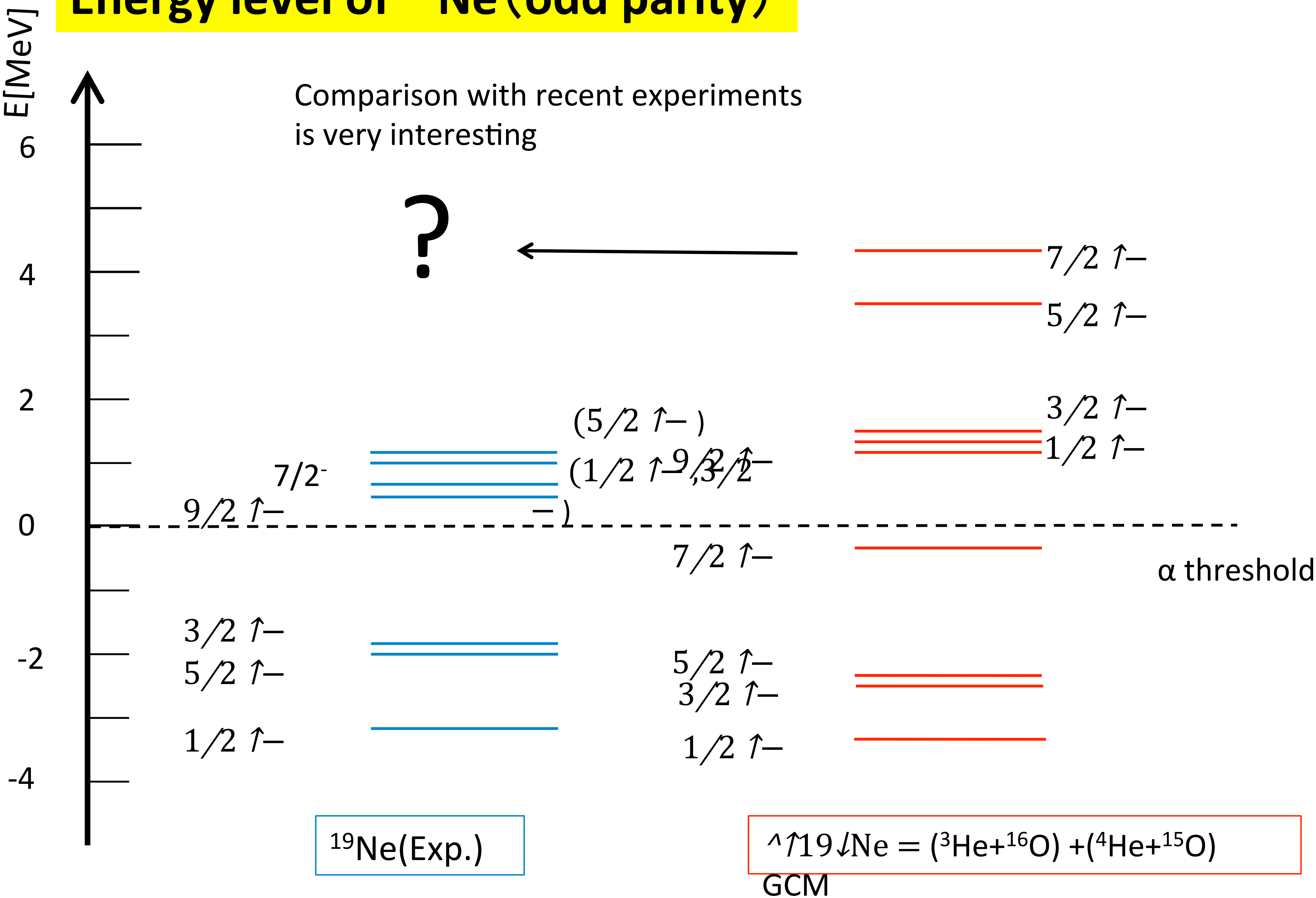
3.Eigenvalue problem

Hill-Wheeler equation : $H\Psi^{J\pi}=E\,\Psi^{J\pi}$ $\qquad \Psi^{J\pi}=\sum_{S} C(S)\Phi^{J\pi}(S)$

^{19}Ne Energy spectra（Even Parity states）



Energy level of ^{19}Ne (odd parity)



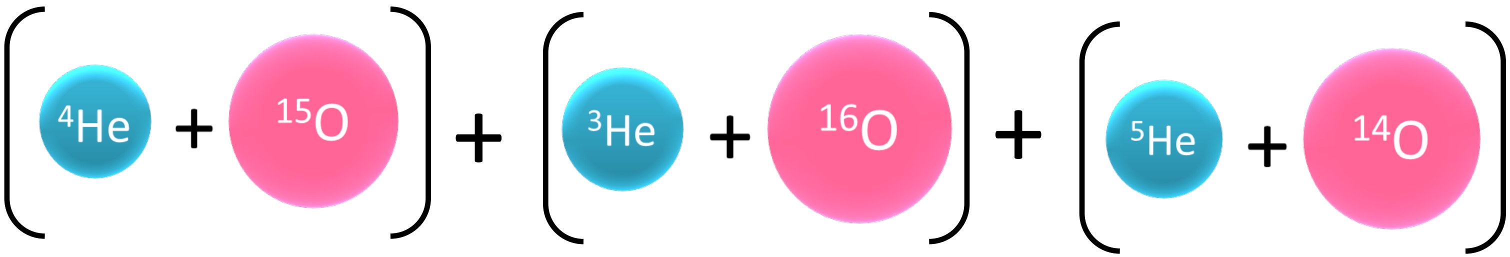
Framework 2: Extended Cal.

5p-2h is expected to be important configuration

Z. Q. Mao et al., PRL74 (1995)

Extension of model space

$\Psi=$



3/2+ level just above the α threshold CANNOT be reproduced (Study of ^{19}F)

New configuration

Large overlap with 5p-2h

Treatment of the separation energies

In theoretical calculations, the energy of ^{19}Ne→ He + O should be reproduced, but.....

^{19}Ne — Separation energy →

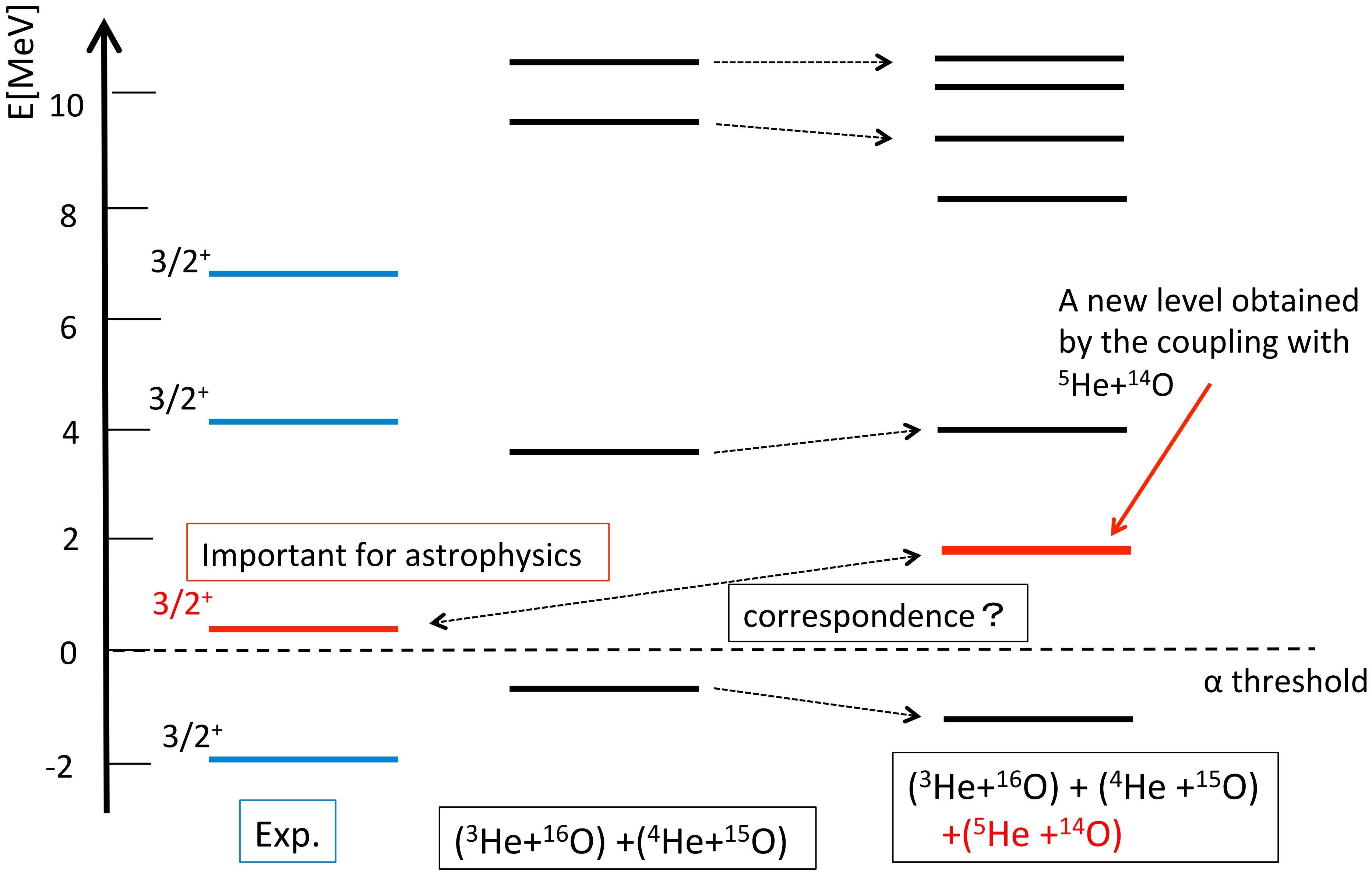
- ^{4}He + ^{15}O ⇒ possible to reproduce
- ^{3}He+^{16}O
- ^{5}He+^{14}O

(^{3}He+^{16}O and ^{5}He+^{14}O:) separation energies are replaced by the experimental value

(Further improvement is needed)

Level Schem in ^{19}Ne(3/2$^+$)

Absorbing boundary condition is applied in identifying the resonant states



Summary

1.We calculate the energy spectra of ^{19}Ne by the microscopic ($\alpha + {}^{15}O$)+($^{3}He + {}^{16}O$) cluster model

2. Theoretical calculation is compared with the experiments

3. The effect of the $^{5}He+{}^{14}O$ conf. is investigated for the 3/2+ states on the basis of ($\alpha + {}^{15}O$) +($^{3}He + {}^{16}O$) + ($^{5}He+{}^{14}O$)

Results

1. Low-lying spectra are reproduced by the microscopic calculation

2. Microscopic calculation predicts the highly exited resonances

3. Our calculation points out the importance of the $^{5}He+{}^{14}O$ configuration for the $3/2^{+}$ state existing around the α threshold

Future subjects

Calculations of width of the 3/2+ resonance and X-sec. for α(15O,ɣ)19Ne are important

Complete calculations should be applied to all of the spin-parity states

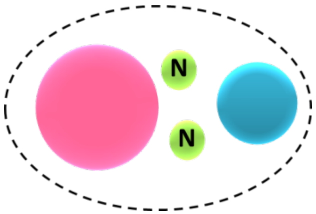
Introduction

1. Cluster structures in neutron-excess systems

α cluster＋valence neutron⇒various structure

$^{16}C = 3\alpha + 4N$, $^{22}Ne = \alpha + {}^{16}O + 2N$, $^{12}Be = 2\alpha + 4N$

N. Itagaki et al., PRC64 (01) M. Kimura, PRC75 (07) M. Ito, RPP77(14)

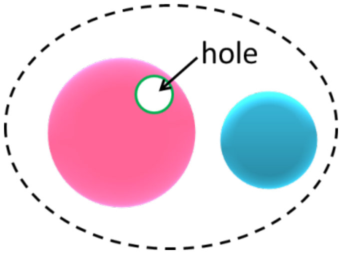


2. Cluster structures with nucleon deficient

Coupling problem of hole＋clusters

$^{11}B = \alpha + \alpha + t$ $^{19}F = \alpha + {}^{15}N$

T. Yamada et al., PRC82 (2010) P. Descouvemont et.al, NPA463 (1987)



Study of the ^{19}F and ^{19}Ne nuclei

Study of ^{19}F has been done by the several theoretical models

$^{19}F= \alpha + {}^{15}N$, $^{3}H + {}^{16}O$ Microscopic cluster model, P. Descouvemont et al., NPA463 (1987)

$^{19}F= \alpha + {}^{15}N$, $^{3}H + {}^{16}O$ Coupled channel OCM, Nemoto et al., PTP62 (1979)

F isotopes Anti-symmetrized molecular dynamics (AMD), M. Kimura et al., PRC83 (2011)

^{19}Ne structure in continuum is still open area! (important in the astrophysical subject)

Parameter

The majorana parameter M should be parity dependent

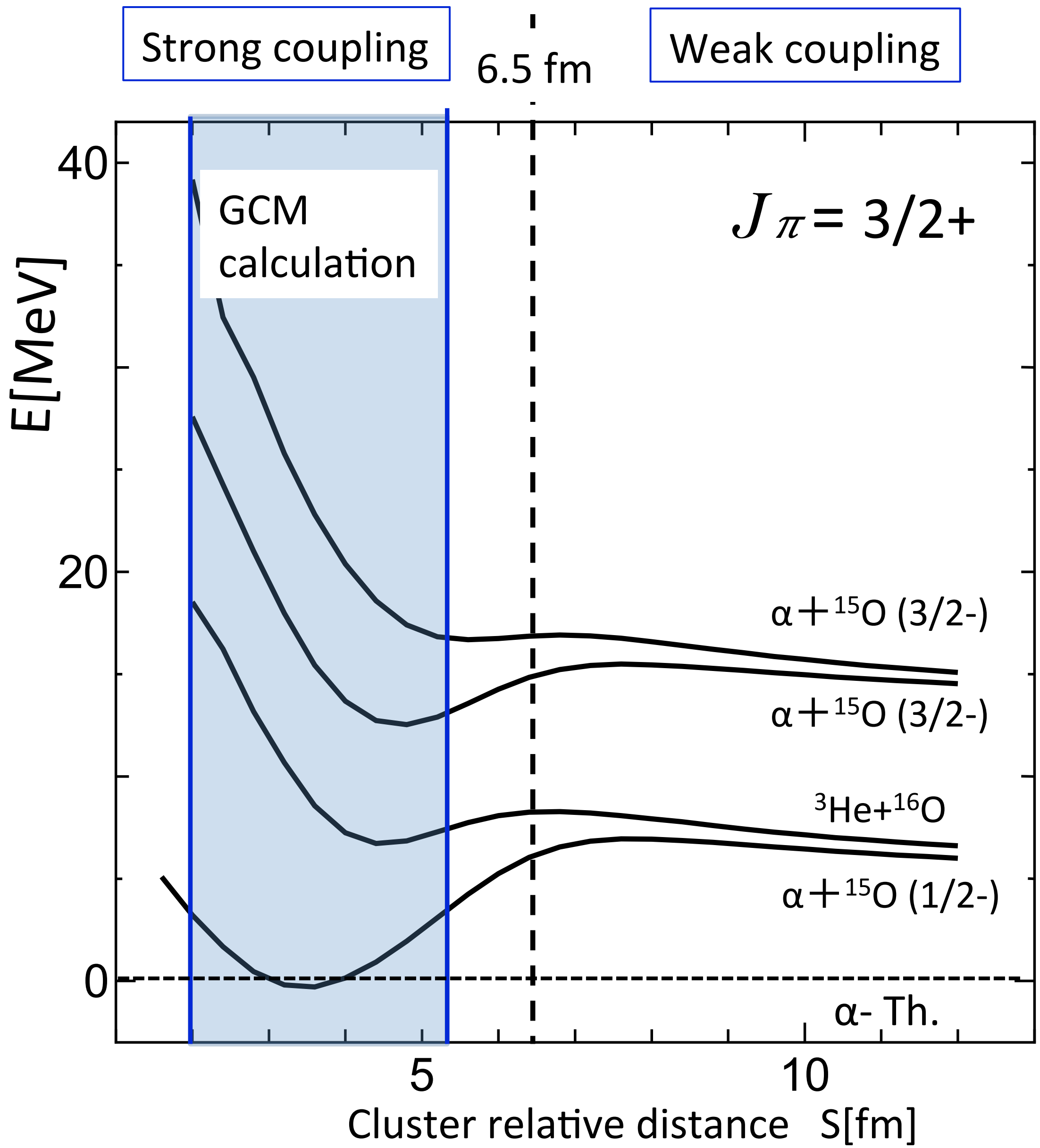
even parity $\Rightarrow$ M=0.638

odd parity $\Rightarrow$ M=0.62

The width parameter b =1.60 fm

Adiabatic energy curve

(α+[15]O)+([3]He+[16]O) calculation



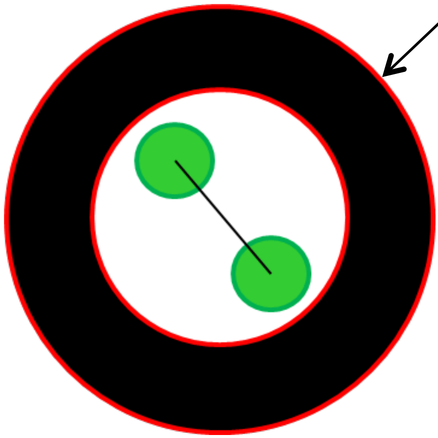
Spatial region of GCM

S = 2.0 ∼ 5.2 fm
ΔS = 0.8 fm

We focus on the energy levels having the strong coupling scheme

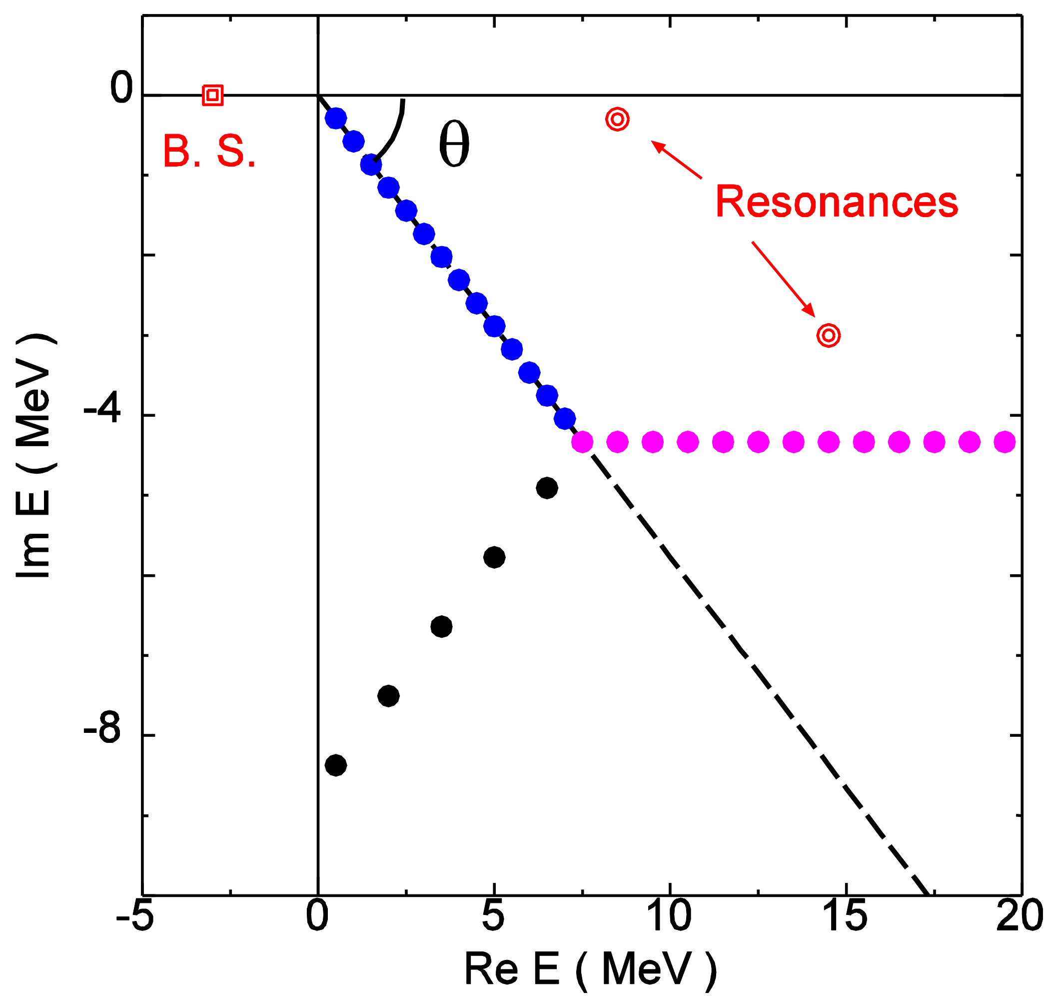
Weak coupling states are excluded

Absorbing boundary condition (ABC)



Negative Imaginary pot. $-i\eta W$

$H \to H - i\eta W$



Shifted Polynomial Absorber

$$W(R) = \theta(R - R_c)(R - R_c)^{\beta}$$

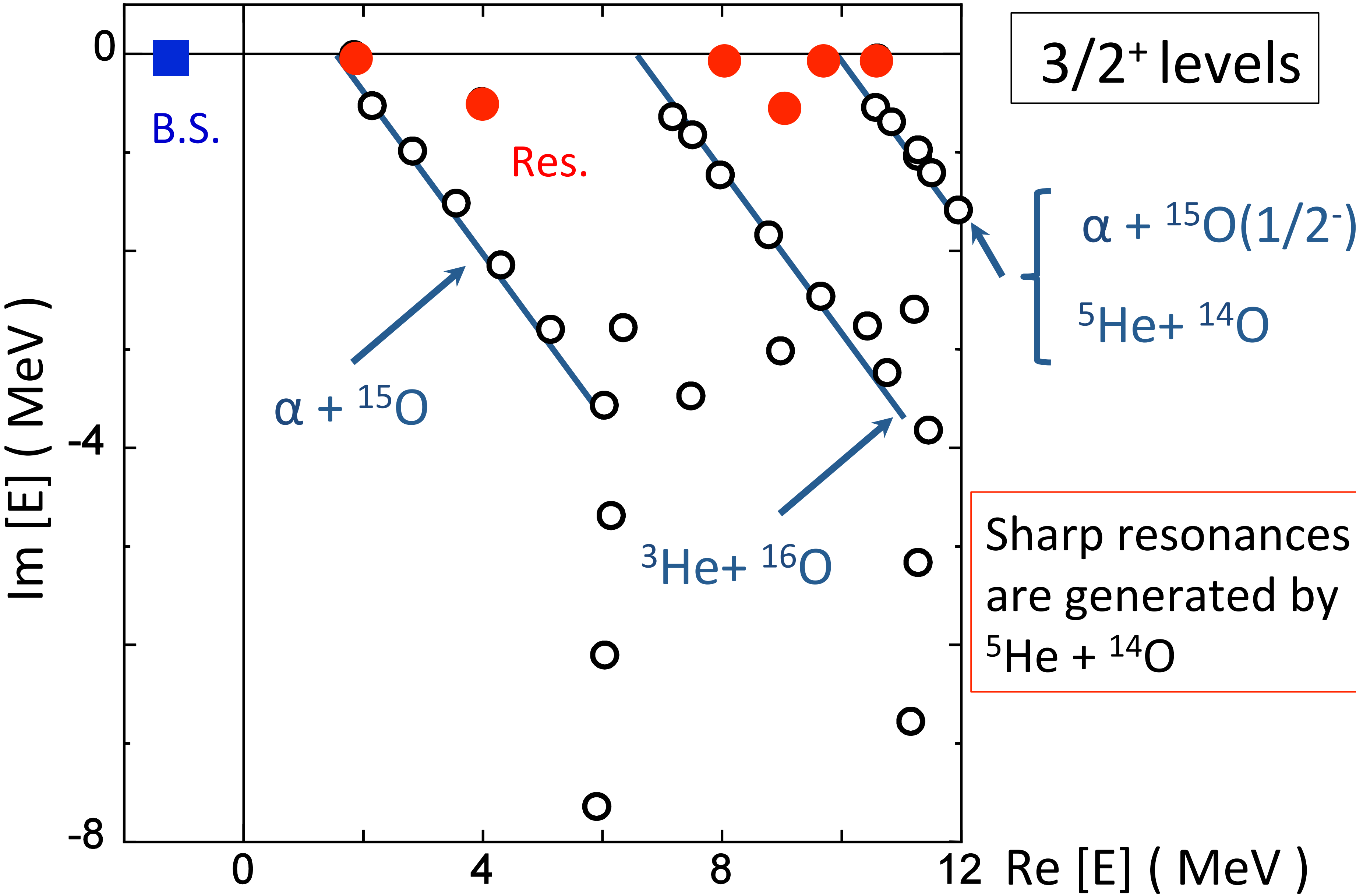
β controls the opening angle

$$\theta = -\pi / (2 + \beta)$$

M. Iwasaki, R. Otani, M. Ito,

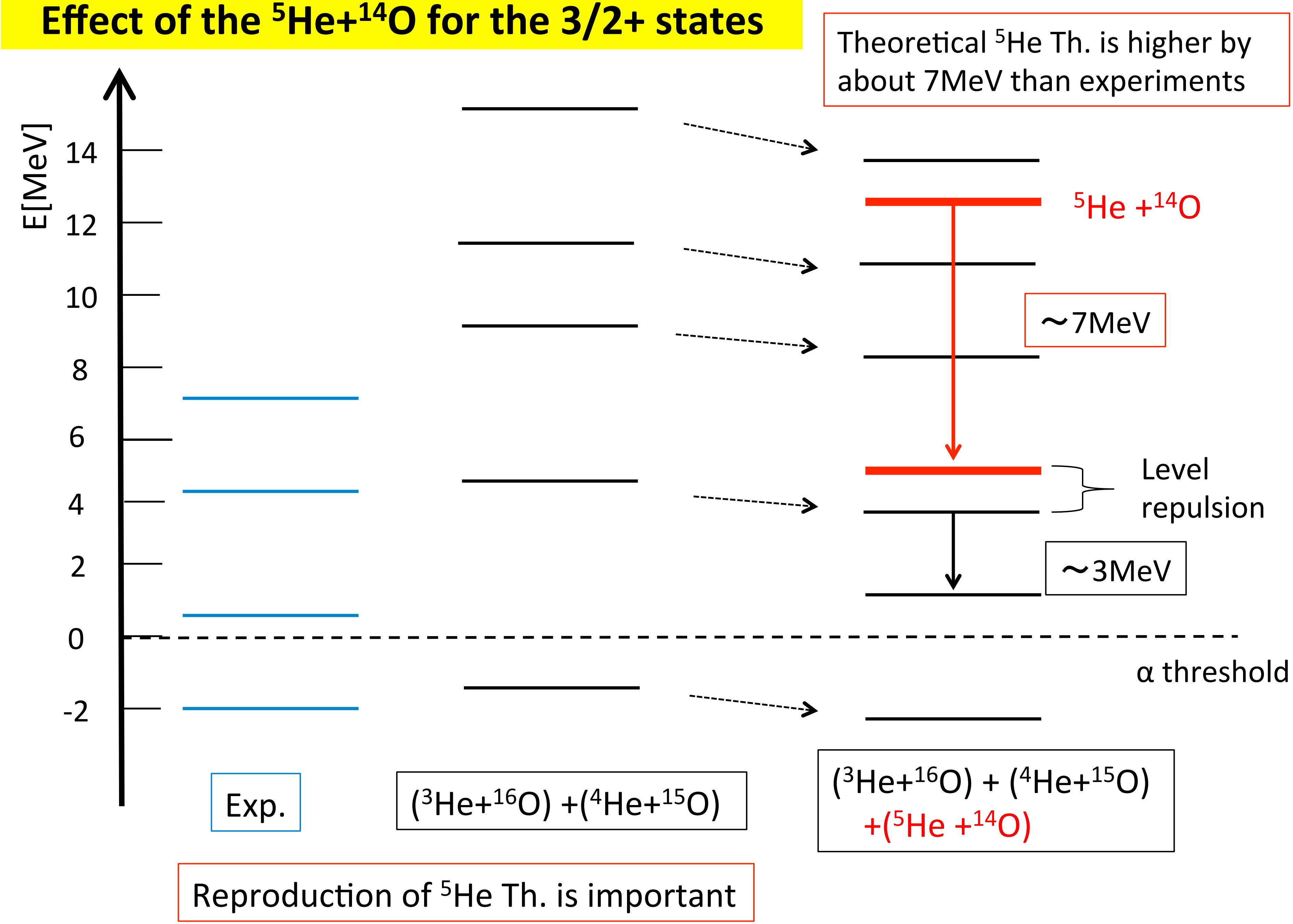
PTP113 (2004), PTEP2014, PTEP2015

Application of ABC to ($^3He+^{16}O$) + ($^4He+^{15}O$) + ($^5He+^{14}O$)

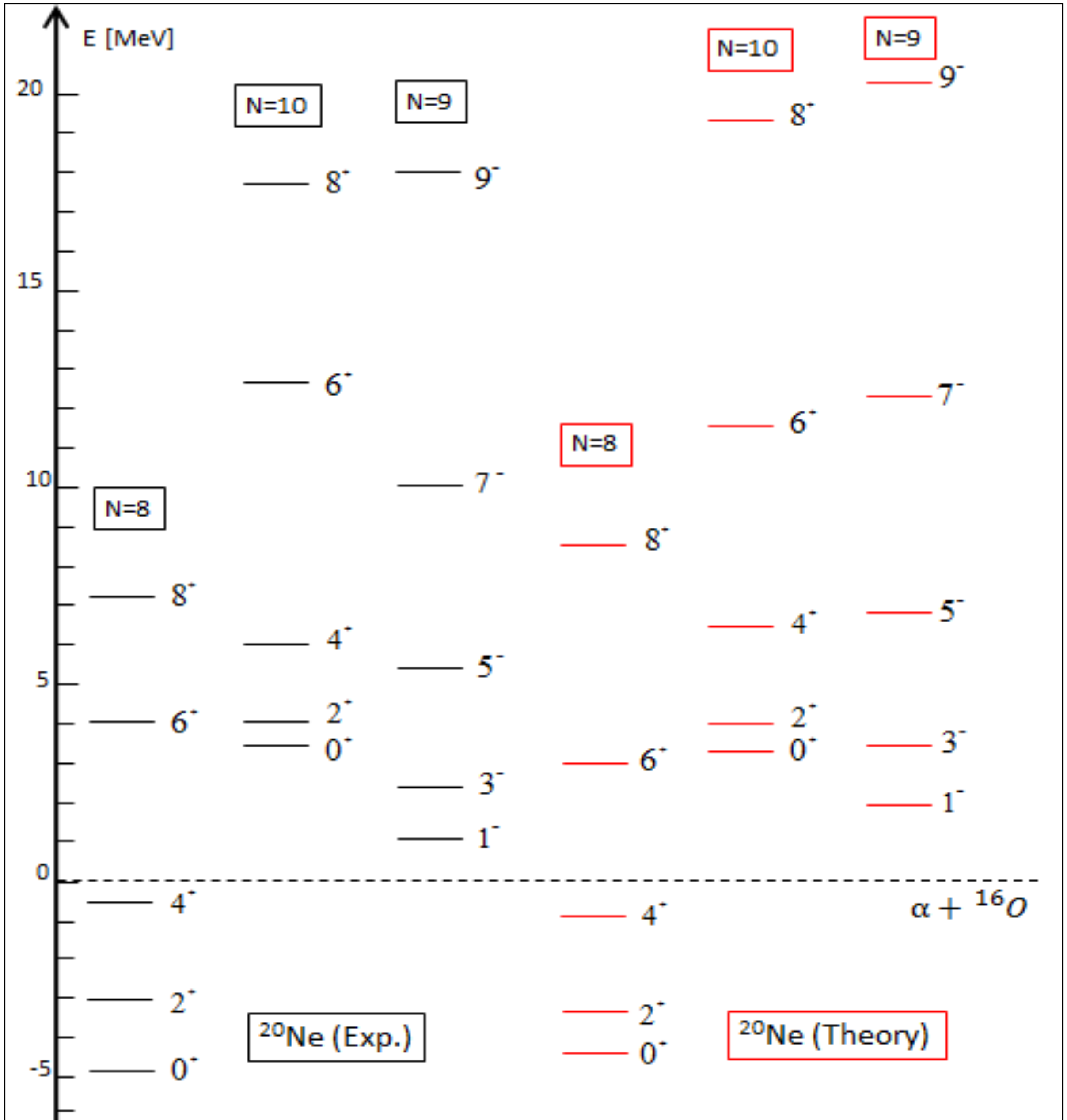


Sharp resonances are generated by $^5He+^{14}O$

Effect of the ^{5}He+^{14}O for the 3/2+ states



Step1: Energy spectra of ^{20}Ne = α+^{16}O



Our calculation nicely reproduces the observed rotational bands

WS parameter

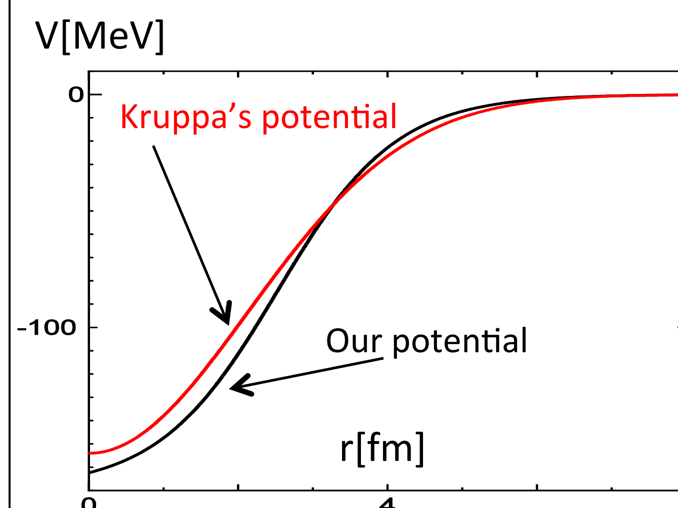
V=−169.21 [MeV]

a=0.796 [fm]

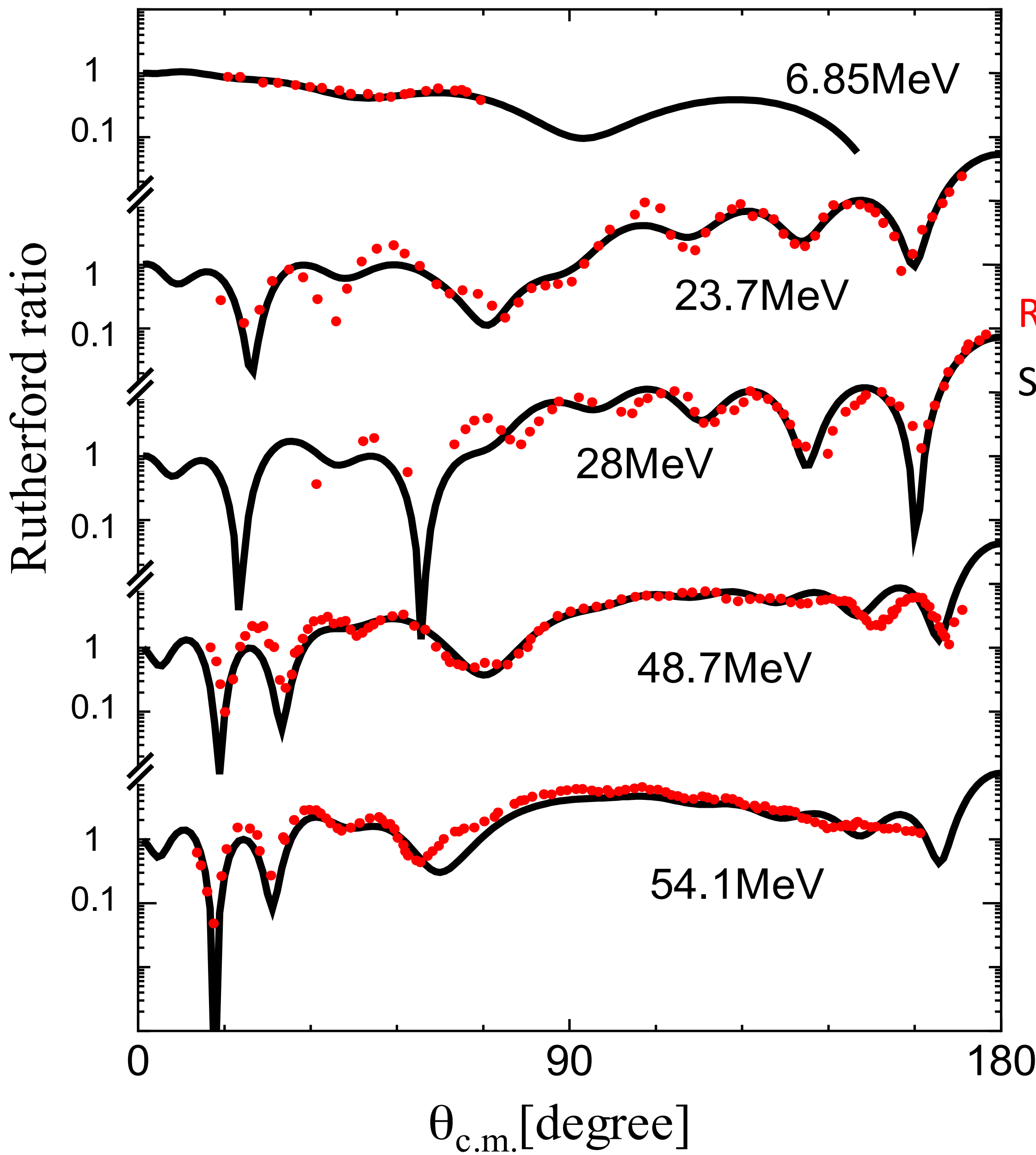
R=2.52 [fm]

The present results are consistent with the α+^{16}O OCM calculation

A. T. Kruppa et al., PTP84 (1990)



Framework 2: potential model



α+^{15}O potential is determined from the calculation of the α +^{15}N elastic scattering

Red dots: the experimental data

Solid curves: the theoretical calculation

WS parameter

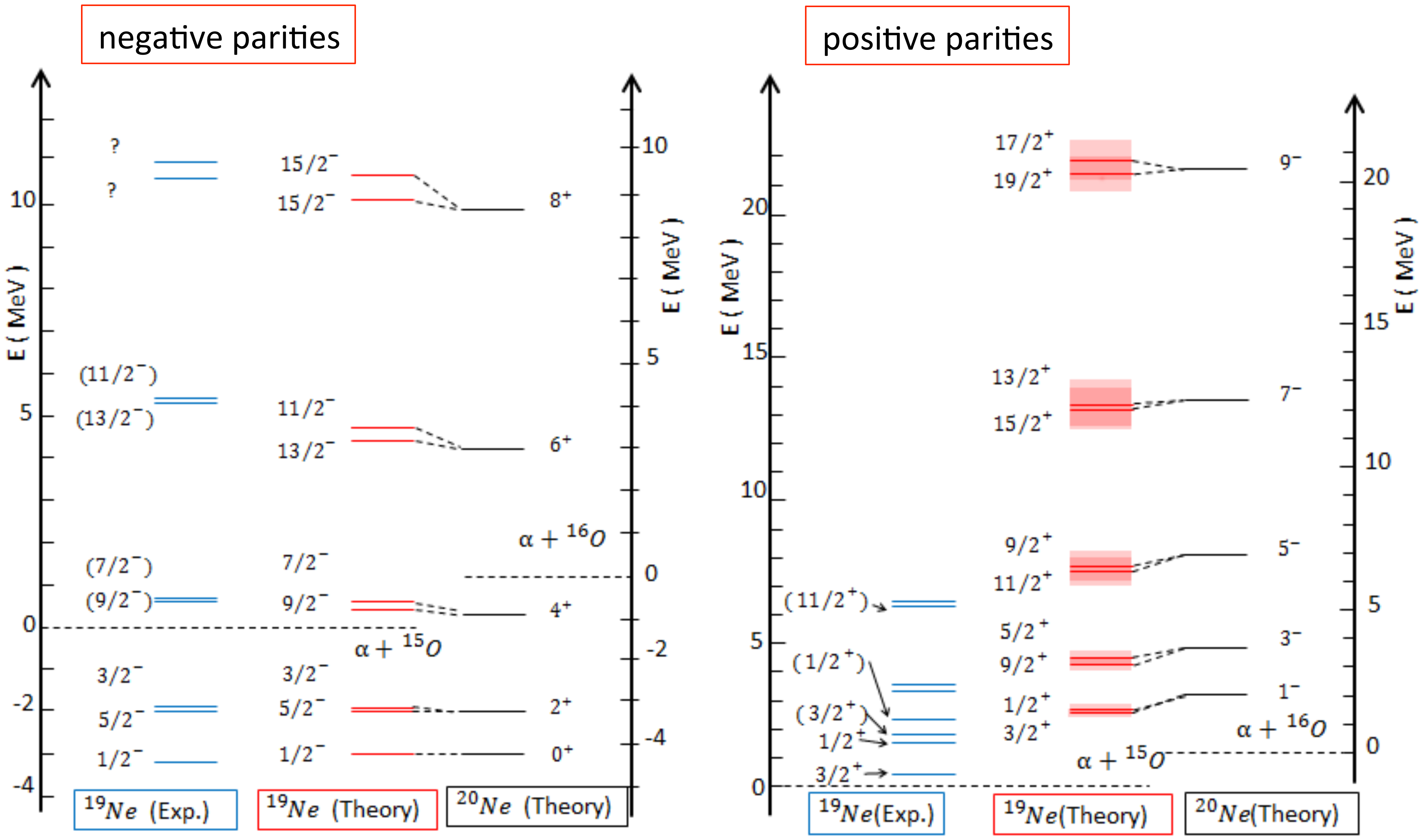
$V = -166.31$ [MeV]

$a = 0.796$ [fm]

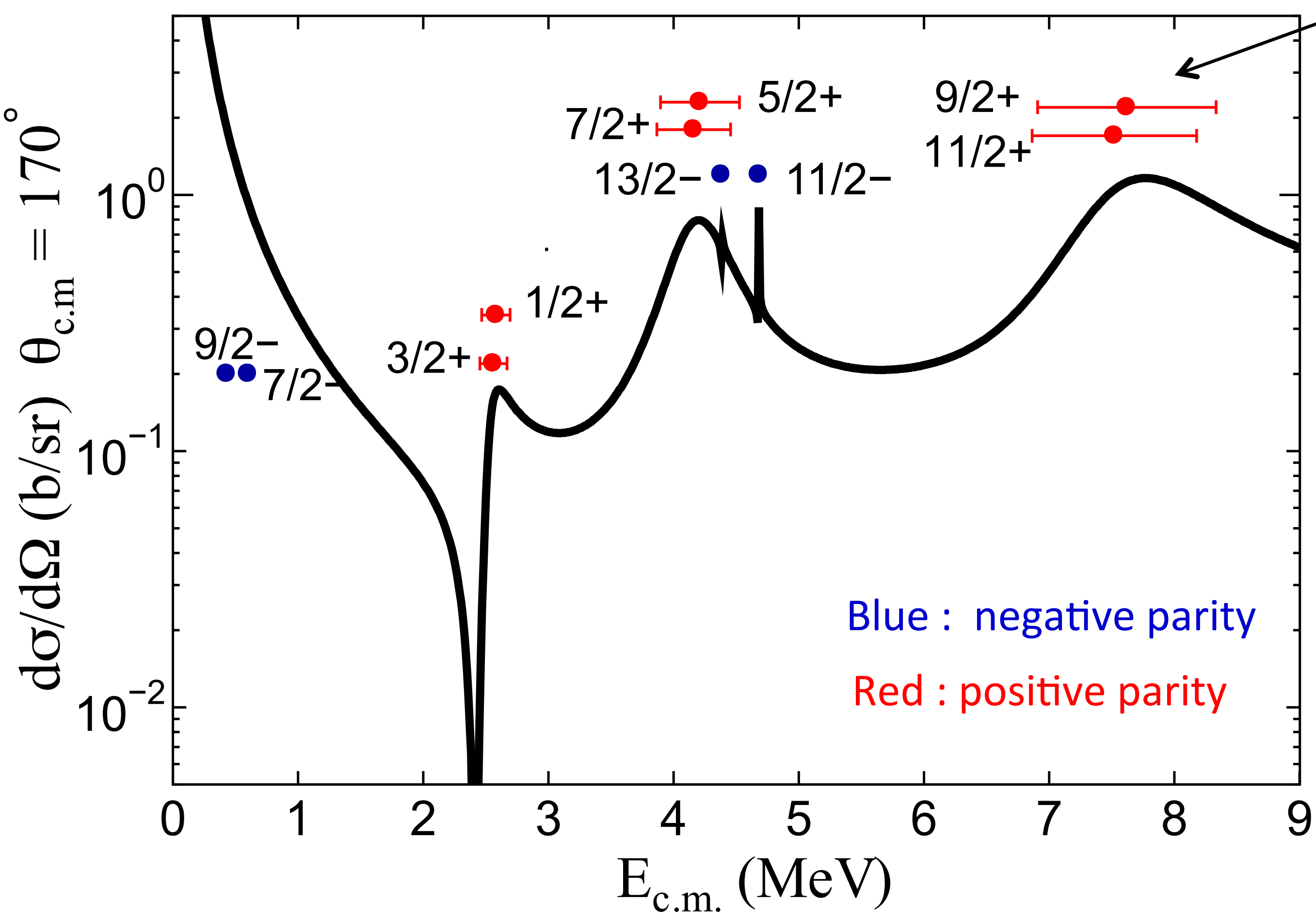
$R = 2.52$ [fm]

Theoretical calculation nicely reproduces the observed angular distribution in the energy range from 6.85MeV to 54.1 MeV

ポテンシャル模型から得られた19Neのエネルギー準位



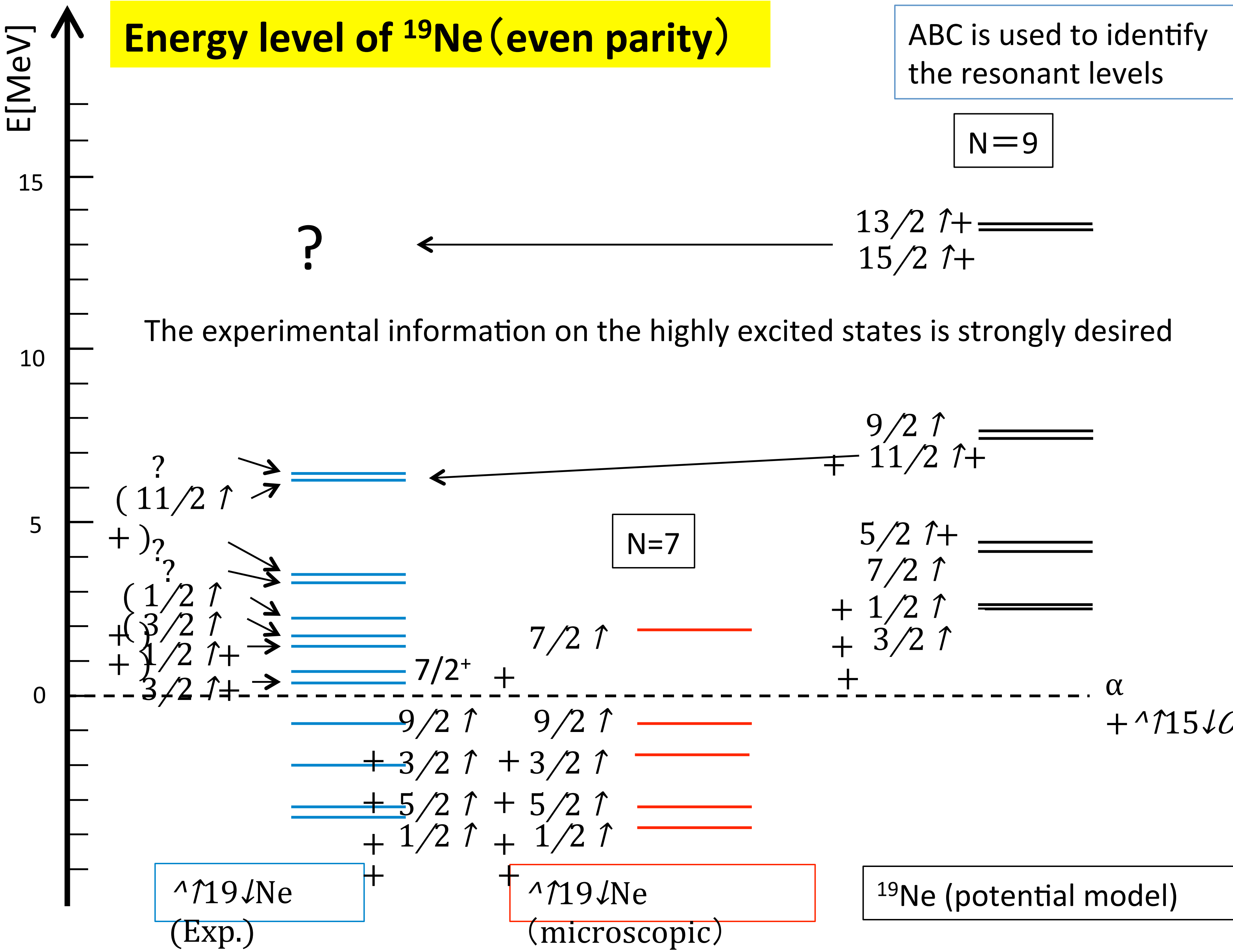
Excitation function of the α+^{15}O scattering



The solid circles and the error bars are the resonant energies and the decay width, respectively

We have obtained the broad peaks of the positive parities, while the sharp peaks appear in the negative parities.

In the experimental energy resolution (ΔE=0.1MeV), there is a possibility that the positive parity resonances may be observed.


Energy level of 19Ne (even parity)
ABC is used to identify the resonant levels
E[MeV]
15
10
5
0
N=9
N=7
?
13/2 ↑+
15/2 ↑+
The experimental information on the highly excited states is strongly desired
9/2 ↑
+ 11/2 ↑+
5/2 ↑+
7/2 ↑
+ 1/2 ↑
+ 3/2 ↑
+
?
(11/2 ↑
+)?
?
(1/2 ↑
(3/2 ↑
+)
+)
1/2 ↑+
3/2 ↑+
7/2+
+
7/2 ↑
α
+ ^↑15↓O
9/2 ↑
+ 3/2 ↑
+ 5/2 ↑
+ 1/2 ↑
+
9/2 ↑
+ 3/2 ↑
+ 5/2 ↑
+ 1/2 ↑
+
^↑19↓Ne (Exp.)
^↑19↓Ne (microscopic)
19Ne (potential model)

Energy level of ^{19}Ne (odd parity)

ABC is used to identify the resonant levels