Shell and cluster correlations in Ne isotopes

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Our theoretical study for Ne isotopes

Interplay between α cluster and valence neutrons.

Investigation of single particle parity, α cluster correlation as a function of # of valence neutrons.

AMD-SSS (Stochastic variational calculation)

Formulation

If the single particle orbit cannot be well described by small number of local Gaussian (Cf. Yukawa Type)

$$\Psi = A\Psi(core)(\underbrace{\phi_1 + \phi_2 + \phi_3 + \cdots}_{\text{}})(\varphi_1 + \varphi_2 + \varphi_3 + \cdots)\cdots$$

↓ large number of local Gauss

$$\Psi = A\Psi(core)(\phi_1\varphi_1 + \phi_3\varphi_3 + \phi_2\varphi_7 + \phi_3\varphi_1 + \cdots)$$

$$\Psi = \sum_i c_i \Psi_i$$

$$\Psi_i = A(\phi_1 \cdots \phi_N)$$

$$\phi_i = \frac{1}{\sqrt{2\pi}^3} \exp(-\nu(r_i - z_i)^2)$$

Effect of LS interaction for single Slater determinant

Single Slater determinant without taking imaginary part

Potential V_{LS} =time odd, G_i => time even

$<G_i \chi | V_{LS} | G_i \chi> = 0$

$$\frac{d\vec{z}_i}{d\tau} = -Im[\frac{\partial E}{\partial \vec{z}_i^*}]i$$

$$\frac{d\vec{z}_i^*}{d\tau} = Im[\frac{\partial E}{\partial \vec{z}_i}]i$$

Cooling of imaginary part of Zi is important.

Phase of wave-packet contributes to LS force.

Only cool imaginary part of local Gauss center.

Effect of LS interaction in case of many Slater determinant(AMD-SSS)

- ^{6}He,^{10}Be
- Reproduction of Energy levels, Halo structure

N. Itagaki et al. / Nuclear Physics A738 (2004) 17–23 21

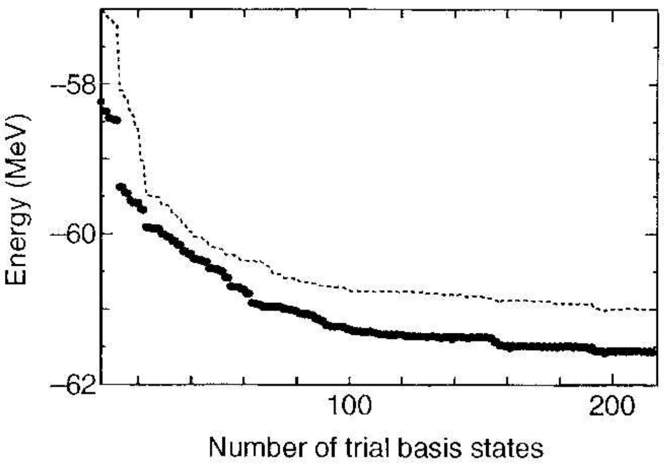


Figure 1. Energy convergence of the ground 0^+ state of ^{10}Be. The model space

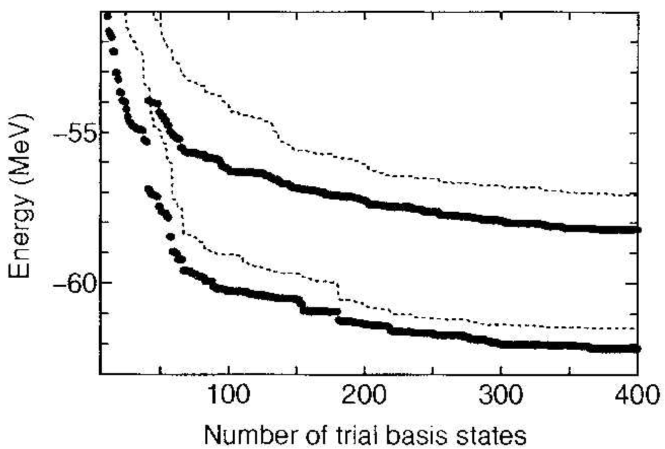


Figure 2. Energy convergence of the two lowest 0^+ states of ^{12}Be. The model space

Hamiltonian

$$\hat{H} = \sum_{i=1}^{A} \hat{t}_i - \hat{T}_{c.m.} + \sum_{i<j}^{A} \hat{v}_{ij}$$

$$V(r) = (W - MP^{\sigma}P^{\tau}) \sum_{i=1}^{2} V_i \exp(-r^2/c_i^2)$$

$$V_{ls} = V_0(e^{-d_1 r^2} - e^{-d_2 r^2}) P(^3O) \vec{L} \cdot \vec{S}$$

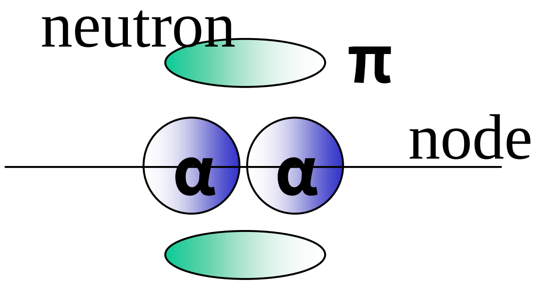
M	c_1[fm^{-2}]	c_2[fm^{-2}]	V_1[MeV]	V_2[MeV]
0.615	1.8	1.01	-60.65	61.14
W	d1[fm^{-2}]	d2[fm^{-2}]	V_0[MeV]	
0.385	5.0	2.778	2000	

semi-realistic Hamiltonian

=> Phase shift of α-α、α-n scattering

[S.Okabe and Y.Abe, PTP49,800(79')]

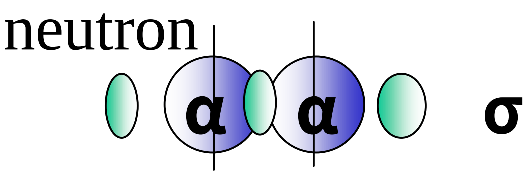
Parity of valence neutron



Example of ^{10}Be =2α+n+n

Parity of core 2α= +1

Parity of valence neutron ＝1、－1



$\pi^1\pi^1 = 1$ $\pi^1\sigma^1 = -1$ $\sigma^1\sigma^1 = 1$

We can calculate parity of valence neutron.

$$\langle P_n \rangle = \sum_i P_i(neutons) - \sum_i P_i(protons)$$

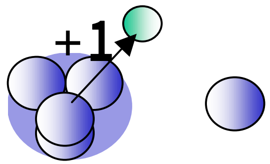
example

$P(\alpha\alpha\pi^2)=P(\alpha)+P(\alpha)+P(\pi)+P(\pi)=+P(\pi)+P(\pi)=-2$

Valence neutron around parity asymmetric nuclei (^{20}Ne)

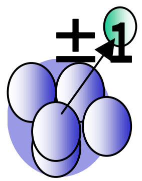
Parity of single particle orbit of valence neutron around ^{20}Ne is not conserved.

Extreme clustering => Pn=0



Deviation of center of mass

Smaller deformation => Pn=±1



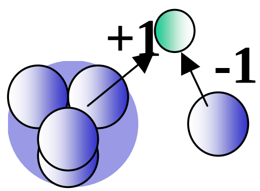
Nilsson model

middle range => Pn= -1 to 1

contributions from each orbit are …

Pn ～ -1 => p-orbit around α cluster

Pn ～ +1 =>sd orbit around ^{16}O



^{21}Ne, parity of valence neutron

energy	parity	<Pn>
-163.16	+	0.953
-162.45	+	0.951
-161.73	+	0.959
-160.87	+	0.948
-159.77	+	0.945
-159.60	+	0.949
-159.09	+	0.918
-158.55	+	0.928
-158.21	+	0.924
-157.20	+	0.024

energy	parity	<Pn>
-153.25	-	0.022
-152.30	-	0.208
-150.68	-	0.096
-150.10	-	0.257
-149.46	-	0.315
-148.91	-	0.368
-148.52	-	0.411
-148.39	-	0.244
-148.07	-	0.343
-147.77	-	0.277

- Positive parity <Pn> close to unity

  almost good parity

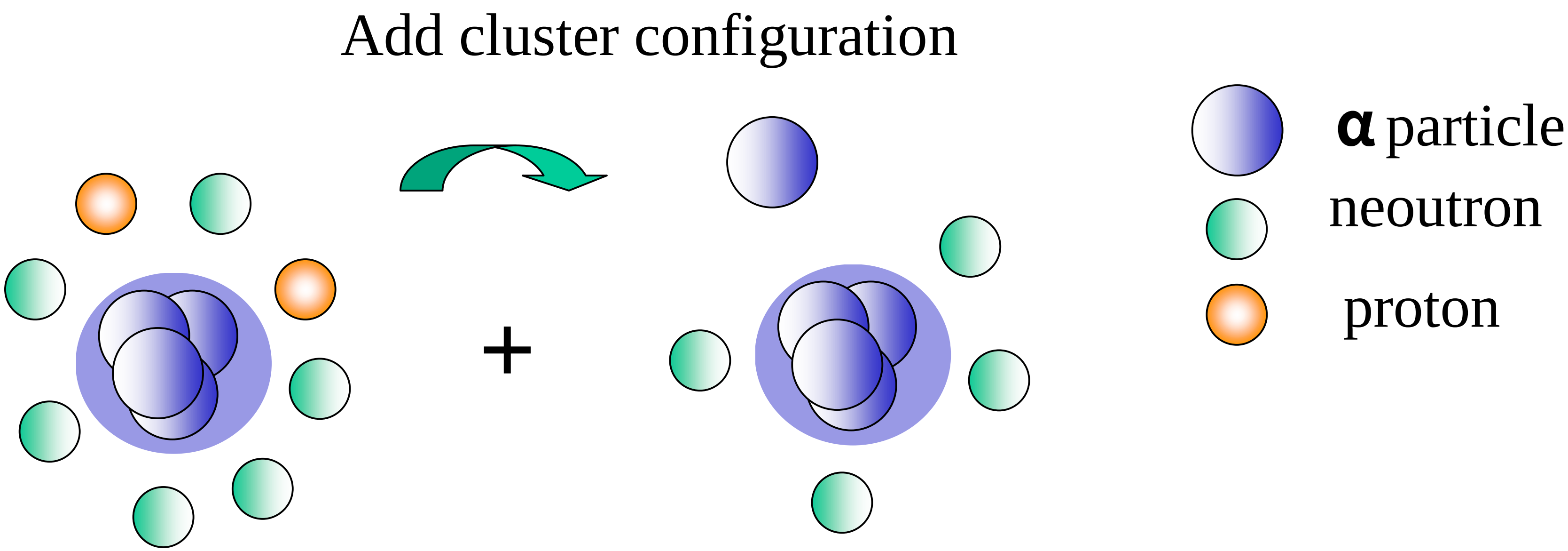
- Negative parity <Pn> not close to 1 or -1

  parity is broken due to α-^{16}O clustering at the core

Study of α correlation

5 **α** +N+N+…, distribute N randomly

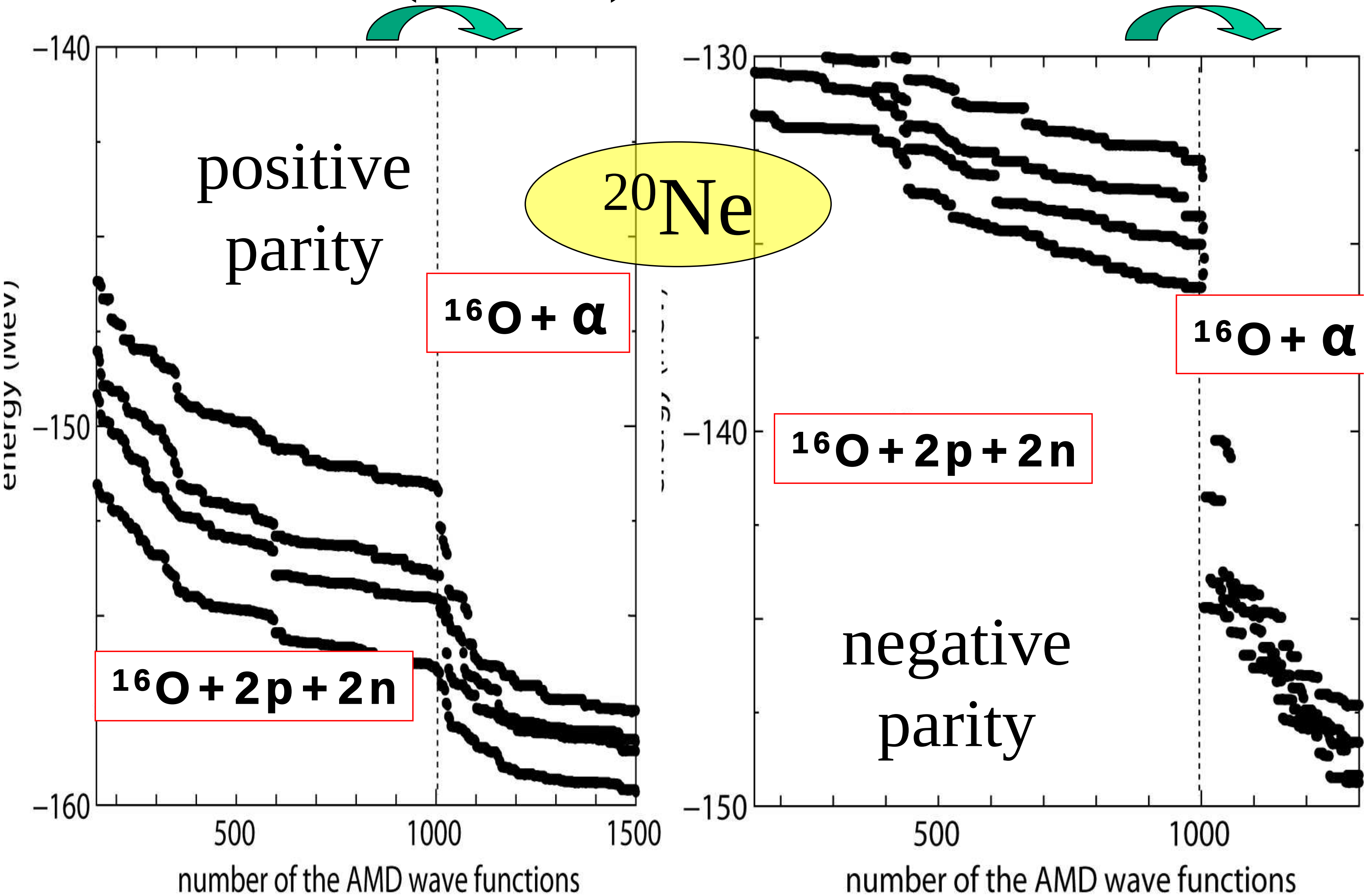
- Shell-model-like configuration
- Cluster-model-like configuration



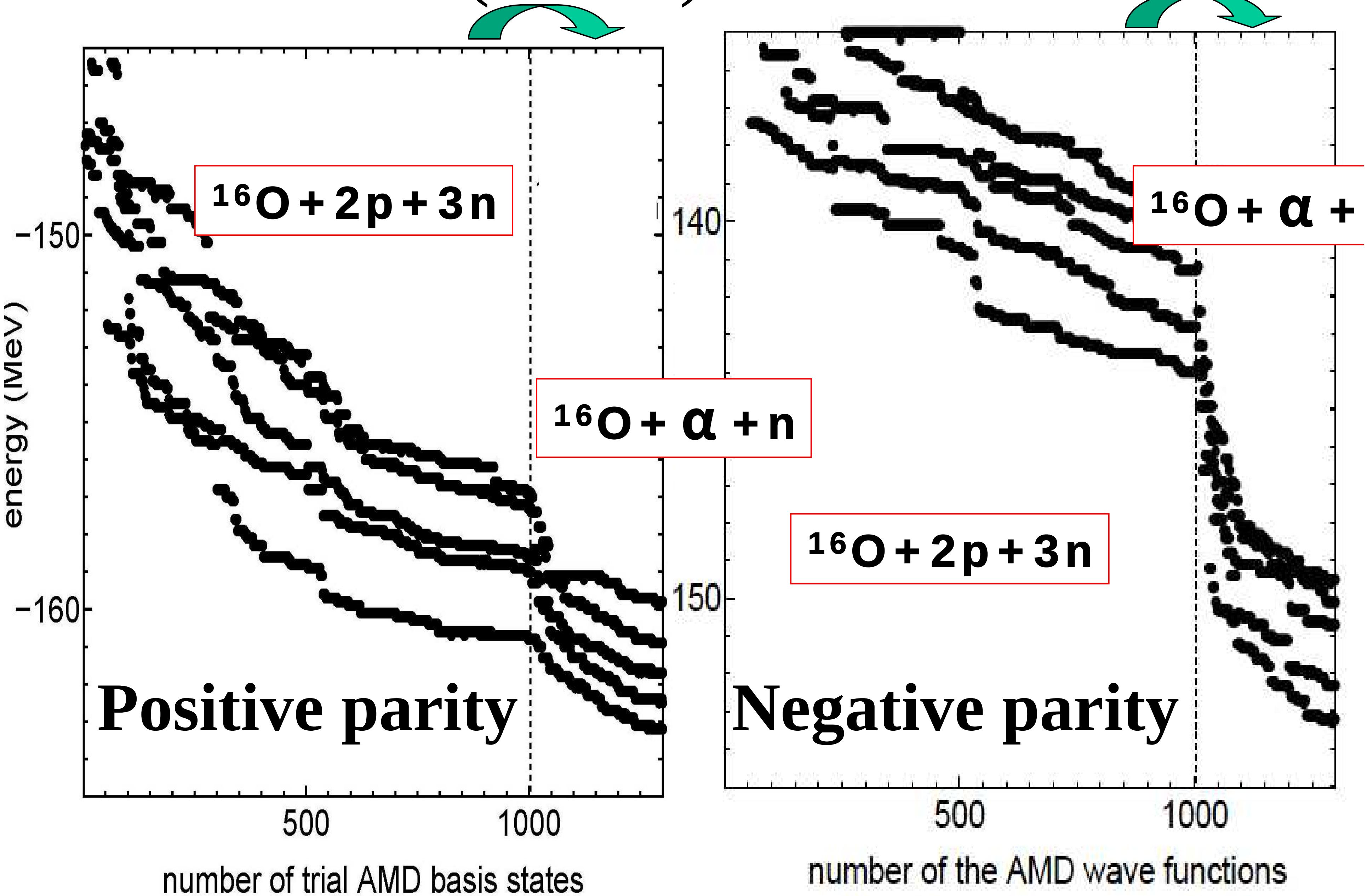
Shell-like configuration

Cluster model configuration

AMD-SSS(GCM) calculation in ^{20}Ne



AMD-SSS(GCM) calculation ^{21}Ne



Sum of parity operator

$$\langle P \rangle = \sum_i P_i(neutons) + \sum_i P_i(protons)$$

We can see what kind of configuration is dominant.
(shell-like or cluster-like configuration)

Estimation of the sum of parity operator
in the case of the lowest shell-like configuration

Positive parity ^{20}Ne ; $(s)^4\,(p)^{12}\,(sd)^4$ Σ Pi = 4-12+4 = - 4

negative parity ^{20}Ne ; $(s)^4\,(p)^{11}\,(sd)^5$ Σ Pi = 4-11+5 = - 2

positive parity states for Ne isotopes

	^{20}Ne	^{22}Ne	^{24}Ne	^{26}Ne	
E(Cal.)	156.5	167.9	183.5	192.9	S
	160.5	173.5	189.0	197.6	+C
E(Exp.)	160.652	177.779	191.845	202.229	
Δ E(S-C)	4.0	5.6	5.5	4.7	
Pn	0.003	1.891	3.875	5.618	S
	0.001	1.925	3.867	5.559	+C
Σ Pi (Cal.)	-3.967	-1.977	-0.882	1.793	S
	-3.902	-2.043	-0.817	1.767	+C
Σ Pi(Shell)	-4	-2	0	2	

S:shell-model-like configuration, +C:add cluster-like configuration

negative parity states for Ne isotopes

	^{20}Ne	^{22}Ne	^{24}Ne	^{26}Ne	
E(Cal.)	138.0	152.4	161.1	175.8	S
	152.4	162.6	171.2	182.1	+C
E(Exp.)	155.685	170.727	(<191)	(<202)	
ΔE(S-C)	14.4	10.2	10.1	6.3	
Pn	-0.046	0.710	1.925	3.804	S
	-0.002	1.395	2.871	3.787	+C
Σ Pi (Cal.)	-3.323	-2.061	-1.889	0.057	S
	-3.209	-2.373	-1.214	-0.073	+C
Σ Pi (Shell)	-2	-2	-2	0	

S:shell-model-like configuration, +C:add cluster-like configuration

Summary

- AMD-SSS (Stochastic variational calculation)
- Valence neutron => single particle parity
- Shell vs Cluster => sum of parity operator
- Effect of α correlation for Ne isotopes
  - Large energy gap(between Shell and Cluster)

  ⬄small shell-like configuration
  - Positive parity states => Shell-like configurations are dominant. (cf Σ Pi or Δ E(S-C))
  - negative parity states=> α - Cluster configurations are still important at large # of valence neutron. (cf Σ Pi)