Ab initio Approach to *s*-Shell Hypernuclei ${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H, ${}^{4}_{\Lambda}$He, and ${}^{5}_{\Lambda}$He with a ΛN-ΣN Interaction

H. Nemura,[1] Y. Akaishi,[1] and Y. Suzuki[2]

[1]*Institute of Particle and Nuclear Studies, KEK, Tsukuba 305-0801, Japan*
[2]*Department of Physics, Niigata University, Niigata 950-2181, Japan*
(Received 8 March 2002; published 17 September 2002)

Variational calculations for *s*-shell hypernuclei are performed by explicitly including Σ degrees of freedom. Four sets of *YN* interactions [SC97d(S), SC97e(S), SC97f(S), and SC89(S)] are used. The bound-state solution of ${}^{5}_{\Lambda}$He is obtained and a large energy expectation value of the tensor ΛN-ΣN transition part is found. The internal energy of the ^{4}He subsystem is strongly affected by the presence of a Λ particle with the strong tensor ΛN-ΣN transition potential.

DOI: 10.1103/PhysRevLett.89.142504 PACS numbers: 21.80.+a, 13.75.Ev, 21.10.Dr, 21.45.+v

Few-body calculations for *s*-shell hypernuclei with mass number $A = 3$–5 are important not only to explore exotic nuclear structure, including the strangeness degrees of freedom, but also to clarify the characteristic features of the hyperon-nucleon (*YN*) interaction. Although several interaction models have been proposed [1–3], the detailed properties (e.g., ${}^{1}S_0$ or ${}^{3}S_1 - {}^{3}D_1$ phase shift, strength of ΛN-ΣN coupling term) of the *YN* interaction are different among the models. The observed separation energies (B_Λ) of light Λ hypernuclei are expected to provide important information on the *YN* interaction, because the relative strength of the spin-dependent term or of the ΛN-ΣN coupling term is affected from system to system.

Recently, few-body studies for $A = 3, 4$ hypernuclei have been conducted using modern *YN* interactions [4–6]. According to these developments, the Nijmegen soft core (NSC) model 97f (or 97e) seems to be compatible with the experimental B_Λ, though the calculated B_Λ for ${}^{4}_{\Lambda}\mathrm{H}^*$ or ${}^{4}_{\Lambda}\mathrm{He}^*$ is actually slightly smaller than the experimental value. These few-body calculations, however, have not yet reached a stage to calculate $B_\Lambda({}^{5}_{\Lambda}\mathrm{He})$.

If one constructs a phenomenological central ΛN potential, which is consistent with the experimental $B_\Lambda({}^{3}_{\Lambda}\mathrm{H})$, $B_\Lambda({}^{4}_{\Lambda}\mathrm{H})$, $B_\Lambda({}^{4}_{\Lambda}\mathrm{He})$, $B_\Lambda({}^{4}_{\Lambda}\mathrm{H}^*)$, and $B_\Lambda({}^{4}_{\Lambda}\mathrm{He}^*)$ values as well as the Λp total cross section, that kind of potential would overestimate the $B_\Lambda({}^{5}_{\Lambda}\mathrm{He})$ value [7,8]. This is known as an anomalously small binding of ${}^{5}_{\Lambda}$He. Though a suppression of the tensor forces [9,10] or of the ΛN-ΣN coupling [11,12] was discussed to be a possible mechanism to resolve the anomaly, the problem still remains an enigma [13] due to the difficulty of performing a complete five-body treatment. Only one attempt was made, using a variational Monte Carlo calculation [14] with the NSC89 *YN* interaction. Though NSC89 well reproduces both the experimental $B_\Lambda({}^{3}_{\Lambda}\mathrm{H})$ [4] and $B_\Lambda({}^{4}_{\Lambda}\mathrm{H})$ [6,14] values as well as the experimental Λp total cross section, a bound-state solution of ${}^{5}_{\Lambda}$He was not found. In view of the aim to pin down a reliable *YN* interaction, a systematic study for *all* *s*-shell hypernuclei is desirable.

The *NN* tensor interaction due to a one-pion-exchange mechanism is the most important ingredient for the binding mechanisms of light nuclei. More than a third, or about one-half, of the interaction energy comes from the tensor force for the ^{4}He [15–17]. Since the pion (or kaon) exchange also induces the ΛN-ΣN transition for the *YN* sector, both the *NN* and ΛN-ΣN tensor interactions may also play important roles for light hypernuclei. If this is the case, the structure of the core nucleus (e.g., ^{4}He) in the hypernucleus (${}^{5}_{\Lambda}$He) would be strongly influenced by the presence of a Λ particle.

The purpose of this Letter is twofold: First is to perform an *ab initio* calculation for ${}^{5}_{\Lambda}$He as well as $A = 3, 4$ hypernuclei explicitly including Σ degrees of freedom. Second is to discuss the structural aspects of ${}^{5}_{\Lambda}$He with an appropriate *YN* interaction which is consistent with all of the *s*-shell hypernuclear data.

The Hamiltonian (H) of a system comprising nucleons and a hyperon (Λ or Σ) is given by 2×2 components as

$$H = \begin{pmatrix} H_\Lambda & V_{\Sigma-\Lambda} \\ V_{\Lambda-\Sigma} & H_\Sigma \end{pmatrix}, \tag{1}$$

where $H_\Lambda (H_\Sigma)$ operates on the Λ (Σ) component and

$$V_{\Lambda-\Sigma} = \sum_{i=1}^{A-1} v_{iY}^{(N\Lambda\text{-}N\Sigma)}. \tag{2}$$

We employ the G3RS potential [18] for the *NN* interaction and the SC97d(S), SC97e(S), SC97f(S), or SC89(S) potential [19] for the *YN* interaction, where all interactions have tensor and spin-orbit components in addition to the central one. We omit small nonstatic correction terms [$(\mathbf{L}\cdot\mathbf{S})^2$ and $\mathbf{L}^2$ terms] in the G3RS *NN* interaction and odd partial-wave components in each interaction in order to focus on the main part of the interaction in the even parity state. The calculated binding energies for light nuclei (^{2}H, ^{3}H, ^{3}He, and ^{4}He) are 2.28, 7.63, 6.98, and 24.57 MeV, respectively. The *YN* interactions have Gaussian form factors whose parameters are set to reproduce the low-energy S matrix of the corresponding original Nijmegen *YN* interactions [20]. These Gaussian form factors help to save significant computer time.

TABLE I. Λ separation energies, given in units of MeV, of $A = 3$–5 Λ hypernuclei for different YN interactions. The scattering lengths, given in units of fm, of $^1S_0(a_s)$ and $^3S_1(a_t)$ states are also listed.

YN	a_s	a_t	$B_\Lambda(^3_\Lambda\mathrm{H})$	$B_\Lambda(^4_\Lambda\mathrm{H})$	$B_\Lambda(^4_\Lambda\mathrm{H}^*)$	$B_\Lambda(^4_\Lambda\mathrm{He})$	$B_\Lambda(^4_\Lambda\mathrm{He}^*)$	$B_\Lambda(^5_\Lambda\mathrm{He})$
SC97d(S)	−1.92	−1.96	0.01	1.67	1.20	1.62	1.17	3.17
SC97e(S)	−2.37	−1.83	0.10	2.06	0.92	2.02	0.90	2.75
SC97f(S)	−2.82	−1.72	0.18	2.16	0.63	2.11	0.62	2.10
SC89(S)	−3.39	−1.38	0.37	2.55	Unbound	2.47	Unbound	0.35
Experiment			0.13 ± 0.05	2.04 ± 0.04	1.00 ± 0.04	2.39 ± 0.03	1.24 ± 0.04	3.12 ± 0.02

The binding energies of various systems are calculated in a complete A-body treatment. The variational trial function must be flexible enough to incorporate both the explicit Σ degrees of freedom and higher orbital angular momenta. The trial function is given by a combination of basis functions:

$$\Psi_{JMTM_T} = \sum_{k=1}^{N} c_k \varphi_k, \quad \text{with } \varphi_k = \mathcal{A}\{G(\boldsymbol{x}; A_k)[\theta_{L_k}(\boldsymbol{x}; u_k, K_k)\chi_{S_k}]_{JM}\eta_{kTM_T}\}. \tag{3}$$

Here, $\mathcal{A}$ is an antisymmetrizer acting on nucleons and χ_{S_k} (η_{kTM_T}) is the spin (isospin) function. η_{kTM_T} has two components: upper (lower) component refers to the Λ (Σ) component. The abbreviation $\boldsymbol{x} = (\boldsymbol{x}_1, \ldots, \boldsymbol{x}_{A-1})$ is a set of relative coordinates. A set of linear variational parameters $(c_1, \ldots, c_N)$ is determined by the Ritz variational principle.

A spatial part of the basis function is constructed by the correlated Gaussian (CG) multiplied by the orbital angular momentum part $\theta_L(\boldsymbol{x})$, expressed by the global vector representation (GVR) [21]. CG is defined by

$$G(\boldsymbol{x}; A_k) = \exp\{-\frac{1}{2}\sum_{i<j}^{A} \alpha_{kij}(\boldsymbol{r}_i - \boldsymbol{r}_j)^2\} = \exp\{-\frac{1}{2}\sum_{i,j=1}^{A-1} (A_k)_{ij}\boldsymbol{x}_i \cdot \boldsymbol{x}_j\}. \tag{4}$$

The $(A-1) \times (A-1)$ symmetric matrix (A_k) is uniquely determined in terms of the interparticle correlation parameter (α_{kij}). The GVR of $\theta_{L_k}(\boldsymbol{x}; u_k, K_k)$ takes the form

$$\theta_{L_k}(\boldsymbol{x}; u_k, K_k) = v_k^{2K_k + L_k} Y_{L_k}(\hat{\boldsymbol{v}}_k), \quad \text{with } \boldsymbol{v}_k = \sum_{i=1}^{A-1} (u_k)_i \boldsymbol{x}_i. \tag{5}$$

The A_k and u_k are sets of nonlinear parameters which characterize the spatial part of the basis function. Allowing the factor $v_k^{2K_k}$ ($K_k \neq 0$) is useful to improve the short-range behavior of the trial function. The value of K_k is assumed to take 0 or 1. The variational parameters are optimized by a stochastic procedure. The above form of the trial function gives accurate solutions. The reader is referred to Refs. [16,21] for details and recent applications. For the spin and isospin parts, all possible configurations are taken into account.

Table I lists the results of the Λ separation energies. The scattering lengths of the $^1S_0(a_s)$ and $^3S_1(a_t)$ states for each YN interaction are also listed in Table I, where the interactions are given in increasing order of $|a_s|$ (and in decreasing order of $|a_t|$). The SC89(S) interaction produces no or very weakly bound state for $^4_\Lambda\mathrm{H}^*$, $^4_\Lambda\mathrm{He}^*$, or $^5_\Lambda\mathrm{He}$. For the SC97d-f(S), the $B_\Lambda(^5_\Lambda\mathrm{He})$ value is about 2–3 MeV. This is a *first ab initio* calculation to produce the bound state of $^5_\Lambda\mathrm{He}$ with explicit Σ degrees of freedom.

The order of the spin doublet structure of the $A = 4$ system is correctly reproduced for all YN interactions; the ground (excited) state has spin parity, $J^\pi = 0^+(1^+)$ for both isodoublet hypernuclei $^4_\Lambda\mathrm{H}$ and $^4_\Lambda\mathrm{He}$. Although the strengths of the $^1S_0$ and $^3S_1$ interactions of the SC97d(S) are almost the same as each other, the energy level of the 0^+ state is clearly lower than that of the 1^+ state. All of the $A = 3$ bound states given in Table I have $J^\pi = \frac{1}{2}^+$, in agreement with experiment. No other bound-state has been obtained for all of the YN interactions. For the SC97e(S), the differences between the calculated and experimental B_Λ values are the smallest among the YN interactions employed in the present study.

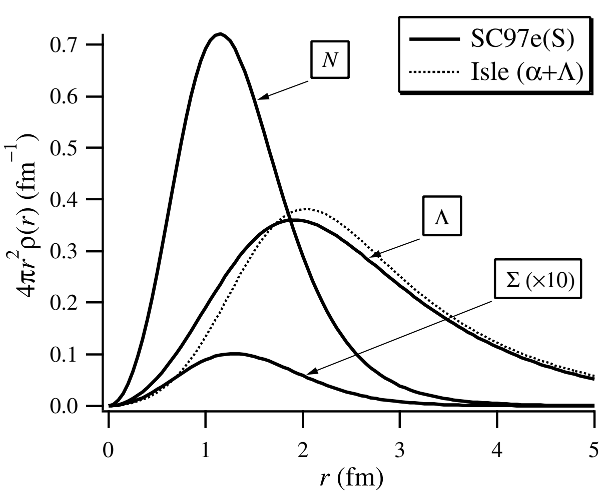

FIG. 1. Density distributions of N, Λ, and Σ for $^5_\Lambda\mathrm{He}$ as a function of r, the distance from the center-of-mass of $^4\mathrm{He}$. The SC97e(S) YN interaction is used. Note that the Σ distribution has been multiplied by a factor of 10 to clarify the behavior. The dotted line is taken from Ref. [22].

TABLE II. Probabilities, given in percentage, of finding a Σ particle in $A = 3$–5 Λ hypernuclei for different YN interactions.

YN	$P_\Sigma({}^3_\Lambda\text{H})$	$P_\Sigma({}^4_\Lambda\text{H})$	$P_\Sigma({}^4_\Lambda\text{H}^*)$	$P_\Sigma({}^4_\Lambda\text{He})$	$P_\Sigma({}^4_\Lambda\text{He}^*)$	$P_\Sigma({}^5_\Lambda\text{He})$
SC97d(S)	0.06	1.27	1.37	1.24	1.35	2.04
SC97e(S)	0.15	1.49	0.98	1.45	0.96	1.55
SC97f(S)	0.23	1.88	1.09	1.83	1.08	1.87
SC89(S)	0.65	3.73	Unbound	3.59	Unbound	1.33

Table II lists the probability, P_Σ (in percentage), of finding a Σ particle in the system. The sizable amount of $P_\Sigma({}^5_\Lambda\text{He})$ is obtained. This implies that the $\Lambda - \Sigma$ coupling plays an important role, even for the ${}^5_\Lambda$He, despite a large excitation energy of the core nucleus, ^{4}He (with the isospin 1), in the Σ component. For the $A = 4$ system, the P_Σ of the 0^+ state are about 1–2%, except for the SC89(S), while the P_Σ of the 1^+ state are nearly equal to or smaller than that of the 0^+ state.

Figure 1 displays the density distributions for ${}^5_\Lambda$He using SC97e(S), and of N, Λ, and Σ from the center-of-mass (c.m.) of ^{4}He. Figure 1 also shows the Λ distribution obtained from the Isle $\Lambda - \alpha$ potential [22]. The experimental pionic decay width of ${}^5_\Lambda$He suggests that the Λ distribution should spread over a rather outer region compared to the distribution of the α, as was discussed in Ref. [22]. The present curve of the Λ distribution is similar to that obtained by the Isle potential. The Σ distribution has a shape similar to the N distribution. The root-mean-square (rms) radii of N, Λ, and Σ from the c.m. of the ^{4}He are 1.5, 2.9, and 1.6 fm, respectively.

Table III lists the energy expectation values of the kinetic and potential energy terms for ${}^5_\Lambda$He. The contributions from the spin-orbit and the Coulomb potentials are not shown in the table, though the calculations include them. Here, T_c is the kinetic energy of the core nucleus (c) subtracted by the c.m. energy of c:

$$T_c = \sum_{i=1}^{A-1} \frac{\boldsymbol{p}_i^2}{2m_N} - \frac{(\sum_{i=1}^{A-1} \boldsymbol{p}_i)^2}{2(A-1)m_N}. \tag{6}$$

The kinetic energy of the relative motion between the Y and the c.m. of c is given by

$$T_{Y-c} = \frac{\boldsymbol{\pi}_{Y-c}^2}{2\mu_Y} + (m_Y - m_\Lambda)c^2, \tag{7}$$

where $\mu_Y = [(A-1)m_N m_Y]/[(A-1)m_N + m_Y]$ is the reduced mass for the $Y + c$ system, and $\boldsymbol{\pi}_{Y-c}$ is the canonical momentum of the relative coordinate between Y and c ($Y = \Lambda, \Sigma$). T_{Y-c} also counts the difference in the rest-mass energy between Λ and Σ. Each potential part $\langle V \rangle$ takes account of a summation over appropriate particle pairs [see Eq. (2), for example]. The energy expectation values of the first three columns in Table III are written as

$$\langle \mathcal{O} \rangle = \langle \Psi_\Lambda | \mathcal{O} | \Psi_\Lambda \rangle + \langle \Psi_\Sigma | \mathcal{O} | \Psi_\Sigma \rangle, \tag{8}$$

where the upper (lower) component of the Ψ_{JMTM_T} is denoted by Ψ_Λ (Ψ_Σ). The first (second) term of each element ($\langle T_c \rangle$, $\langle T_{Y-c} \rangle$, or $\langle V_{NN} \rangle$) in Table III represents the first (second) term of Eq. (8). The energy of the ^{4}He subsystem changes a lot from that of the isolated one,

$$\Delta E_c = (\langle T_c \rangle + \langle V_{NN} \rangle)_{{}^5_\Lambda\text{He}} - (\langle T_c \rangle + \langle V_{NN} \rangle)_{{}^4\text{He}} \approx 4.7 \text{ MeV}. \tag{9}$$

This difference is considerably large despite the fact that the rms radius of N from the c.m. of ^{4}He for the ${}^5_\Lambda$He hardly changes from that for ^{4}He. (Both radii are 1.5 fm.) Most of the change is due to a reduction of the energy expectation value of the tensor NN interaction,

$$[\langle V_{NN}(\text{tensor}) \rangle]_{{}^5_\Lambda\text{He}} - [\langle V_{NN}(\text{tensor}) \rangle]_{{}^4\text{He}} \approx 2.9 \text{ MeV}.$$

On the other hand, the tensor ΛN-ΣN transition part has a surprisingly large energy expectation value (about -20 MeV). This large coupling energy makes ${}^5_\Lambda$He bound in spite of both the energy loss of ΔE_c and the extremely high energy of the Σ component ($\frac{\langle H_\Sigma \rangle}{P_\Sigma} \sim 600$ MeV).

The calculated wave function is divided into orthogonal components according to the total orbital angular momentum (L), the total spin (S), the core nucleus spin (S_c),

TABLE III. Energy expectation values of the kinetic and potential energy terms for ${}^5_\Lambda$He, given in units of MeV. The SC97e(S) YN interaction is used. For each potential part, a summation over appropriate particle pairs is taken into account [see Eq. (2), for example] and two central (${}^1E$ and ${}^3E$) and a tensor (${}^3E$) components are listed separately. The first (second) term of each element $\langle T_c \rangle$, $\langle T_{Y-c} \rangle$, or $\langle V_{NN} \rangle$ represents the first (second) term of Eq. (8) ($\mathcal{O} = T_c, T_{Y-c}$, or V_{NN}). The energy expectation values of $\langle T_c \rangle$ and three $\langle V_{NN} \rangle$ for isolated ^{4}He are 84.86, -33.22, -33.05, and -43.93 MeV, respectively.

$\langle T_c \rangle$	$\langle T_{Y-c} \rangle$	$\langle V_{NN} \rangle$	$\langle V_{N\Lambda} \rangle$	$2\langle V_{\Lambda-\Sigma} \rangle$	$\langle V_{N\Sigma} \rangle$	
83.43 + 2.74	9.11 + 3.88	$-33.14 - 0.35$	-3.97	-0.02	0.07	(Central, ${}^1E$)
		$-32.03 - 0.27$	2.98	-1.02	1.56	(Central, ${}^3E$)
		$-40.91 - 0.12$	-2.24	-19.51	0.87	(Tensor, ${}^3E$)

TABLE IV. Probability, given in percentage, of each component with the total orbital angular momentum (L), total spin (S), core nucleus spin (S_c), and core nucleus isospin (T_c) in the Λ or in the Σ component for ${}^5_\Lambda$He. The SC97e(S) YN interaction is used. The probability in the S or in the D state for ^{4}He is also listed.

	$L=0$		$L=2$		
	$S=\frac{1}{2}$		$S=\frac{3}{2}$		$S=\frac{5}{2}$
	$S_c=0$	$S_c=1$	$S_c=1$	$S_c=2$	$S_c=2$
${}^5_\Lambda$He					
$(T_c=0)\otimes\Lambda$	89.14	0.03	0.19	3.74	5.36
$(T_c=1)\otimes\Sigma$	0.10	0.09	1.34	~0	0.01
^{4}He	89.56		10.44		

and the core nucleus isospin (T_c). Table IV displays the probability of each component for ${}^5_\Lambda$He. The table also lists the probability of the S state or of the D state for ^{4}He. The sizable amount of probability of the Σ component is found in the D state while the sum of D-state probabilities in the Λ component is slightly smaller than that for ^{4}He. Moreover, though the presence of a Λ in ^{4}He with the strong tensor ΛN-ΣN transition potential influences the structure of the D-state component and reduces the energy expectation value of the tensor NN interaction, the large coupling energy $\langle V_{\Lambda-\Sigma}\rangle$ of the tensor part bears the bound state of ${}^5_\Lambda$He instead.

In summary, we have made a systematic study of all s-shell hypernuclei based on *ab initio* calculations using YN interactions with an explicit Σ admixture. The bound-state solution of ${}^5_\Lambda$He was obtained. As Ref. [6] claimed, though there are none of the interaction models to describe very precisely the experimental B_Λ, the five-body calculation convinced us that the anomalous binding problem would be resolved by taking account of the explicit Σ admixture. The B_Λ values, obtained by using SC97e(S), are the closest to the experimental values, among the YN interactions employed in this study. A sizable amount of P_Σ was obtained, even for the ${}^5_\Lambda$He, in spite of the large excitation energy of ^{4}He. The contribution of the energy from the tensor ΛN–ΣN coupling is quite large, and this coupling is considerably important to make ${}^5_\Lambda$He bound. This is a novel finding in contrast with the Brueckner-Hartree-Fock calculation [19]. The present study for ${}^5_\Lambda$He is a first step toward a detailed description of light strange nuclear systems. The core nucleus, ^{4}He, is no longer rigid in interacting with a Λ particle. A similar situation can occur for strangeness $S=-2$ systems. Investigations into the strength of the $\Lambda\Lambda$ interaction based on the experimental data of the binding energy for double Λ hypernuclei (e.g., ${}^{\;\;6}_{\Lambda\Lambda}$He [23]) should take account of the energy reduction of the core nucleus (ΔE_c for ${}^{\;\;6}_{\Lambda\Lambda}$He is expected to be larger than the present ΔE_c for ${}^5_\Lambda$He).

We are thankful to Y. Fujiwara, K. Miyagawa, H. Kamada, K. Varga, and S. Shinmura for useful communications. The calculations of $A=4, 5$ systems were made using the RCNP SX-5 computer and the KEK SR8000 computer.

[1] P. M. M. Maessen, Th. A. Rijken, and J. J. de Swart, Phys. Rev. C **40**, 2226 (1989).
[2] Th. A. Rijken, V. G. J. Stokes, and Y. Yamamoto, Phys. Rev. C **59**, 21 (1999); V. G. J. Stokes and Th. A. Rijken, *ibid.* **59**, 3009 (1999).
[3] Y. Fujiwara, C. Nakamoto, and Y. Suzuki, Phys. Rev. Lett. **76**, 2242 (1996); Phys. Rev. C **54**, 2180 (1996).
[4] K. Miyagawa, H. Kamada, W. Glöckle, and V. Stoks, Phys. Rev. C **51**, 2905 (1995).
[5] E. Hiyama, M. Kamimura, T. Motoba, T. Yamada, and Y. Yamamoto, Phys. Rev. C **65**, 011301 (2001).
[6] A. Nogga, Ph.D. thesis, Ruhr University, Bochum, 2001; A. Nogga, H. Kamada, and W. Glöckle, Phys. Rev. Lett. **88**, 172501 (2002).
[7] R. H. Dalitz, R. C. Herndon, and Y. C. Tang, Nucl. Phys. **B47**, 109 (1972).
[8] H. Nemura, Y. Suzuki, Y. Fujiwara, and C. Nakamoto, Prog. Theor. Phys. **103**, 929 (2000).
[9] H. Bandō and I. Shimodaya, Prog. Theor. Phys. **63**, 1812 (1980).
[10] S. Shinmura, Y. Akaishi, and H. Tanaka, Prog. Theor. Phys. **71**, 546 (1984).
[11] A. R. Bodmer, Phys. Rev. **141**, 1387 (1966).
[12] B. F. Gibson, A. Goldberg, and M. S. Weiss, Phys. Rev. C **6**, 741 (1972).
[13] B. F. Gibson and E. V. Hungerford III, Phys. Rep. **257**, 349 (1995).
[14] J. A. Carlson, in *LAMPF Workshop on* (π, K) *Physics*, edited by B. F. Gibson, W. R. Gibbs, and M. B. Johnson, AIP Conf. Proc. No. 224 (AIP, New York, 1991), p. 198.
[15] Y. Akaishi, in *Cluster Models and Other Topics*, edited by T. T. S. Kuo and E. Osnes (World Scientific, Singapore, 1986), p. 259.
[16] Y. Suzuki and K. Varga, *Stochastic Variational Approach to Quantum-Mechanical Few-Body Problems*, Lecture Notes in Physics (Springer-Verlag, Berlin, 1998), Vol. 54.
[17] Steven C. Pieper *et al.*, Phys. Rev. C **64**, 014001 (2001).
[18] R. Tamagaki, Prog. Theor. Phys. **39**, 91 (1968).
[19] Y. Akaishi, T. Harada, S. Shinmura, and Khin Swe Myint, Phys. Rev. Lett. **84**, 3539 (2000).
[20] S. Shinmura (private communication).
[21] K. Varga and Y. Suzuki, Phys. Rev. C **52**, 2885 (1995); Y. Suzuki, J. Usukura, and K. Varga, J. Phys. B **31**, 31 (1998).
[22] I. Kumagai-Fuse, S. Okabe, and Y. Akaishi, Phys. Lett. B **345**, 386 (1995).
[23] H. Takahashi *et al.*, Phys. Rev. Lett. **87**, 212502 (2001).