What Does the Free Space $\Lambda\Lambda$ Interaction Predict for $\Lambda\Lambda$ Hypernuclei?

C. Albertus, J. E. Amaro, and J. Nieves

Departamento de Física Moderna, Universidad de Granada, E-18071 Granada, Spain

(Received 18 October 2001; published 1 July 2002)

Data on $\Lambda\Lambda$ hypernuclei provide a unique method to learn details about the strangeness $S = -2$ sector of the baryon-baryon interaction. From the free space Bonn-Jülich potentials, determined from data on baryon-baryon scattering in the $S = 0, -1$ channels, we construct an interaction in the $S = -2$ sector to describe the experimentally known $\Lambda\Lambda$ hypernuclei. After including short-range (Jastrow) and RPA correlations, we find masses for these $\Lambda\Lambda$ hypernuclei in a reasonable agreement with data, taking into account theoretical and experimental uncertainties. Thus, we provide a natural extension, at low energies, of the Bonn-Jülich one-boson exchange potentials to the $S = -2$ channel.

DOI: 10.1103/PhysRevLett.89.032501 PACS numbers: 21.80.+a, 13.75.Cs, 13.75.Ev, 21.10.Dr

INTRODUCTION

In past years a considerable amount of work has been done both in the experimental and the theoretical aspects of the physics of single and double Λ hypernuclei [1]. Because of the lack of targets, the data on $\Lambda\Lambda$ hypernuclei provide a unique method to learn details on the strangeness $S = -2$ sector of the baryon-baryon interaction. Ground state energies of three (the production of ${}_{\Lambda\Lambda}^{4}\mathrm{H}$ has been recently reported [2]) $\Lambda\Lambda$ hypernuclei, ${}_{\Lambda\Lambda}^{6}\mathrm{He}$, ${}_{\Lambda\Lambda}^{10}\mathrm{Be}$, and ${}_{\Lambda\Lambda}^{13}\mathrm{B}$, have been measured. The experimental binding energies, $B_{\Lambda\Lambda} = -[M({}_{\Lambda\Lambda}^{A+2}Z) - M({}^{A}Z) - 2m_\Lambda]$, are reported in Table I. Note that the ${}_{\Lambda\Lambda}^{6}\mathrm{He}$ energy has been updated very recently [3] in contradiction to the old one, $B_{\Lambda\Lambda} = 10.9 \pm 0.8$ MeV [7]. The scarce hyperon-nucleon (YN) scattering data have been used by the Nijmegen (NJG), Bonn-Jülich (BJ), and Tübingen groups [1] to determine realistic YN and thus also some pieces of the YY interactions. In Ref. [8] an effective $\Lambda\Lambda$ interaction, with a form inspired in the one-boson exchange (OBE) BJ potentials [9], was fitted to data, and the first attempts to compare it to the free space one were carried out. Similar studies using OBE NJG potentials [10] have been also performed in Ref. [11] and the weak decays of double Λ hypernuclei have been studied in Ref. [12]. Short range correlations (SRC) play an important role in these systems [8], but despite their inclusion the effective $\Lambda\Lambda$ interaction, fitted to the $\Lambda\Lambda$-hypernuclei data, significantly differs from the free space one deduced in Ref. [9] from scattering data. In this Letter we consider the new datum for He and, importantly, the effect of the long range nuclear correlations (RPA) is also incorporated. Starting from the free space BJ interactions, we find a good description of the masses of He, Be, and B $\Lambda\Lambda$ hypernuclei. This has never been achieved before despite the use of different $\Lambda\Lambda$ free space interactions [13]. The BJ set of potentials used here and the new NJG (NSC97e,b [10]) interactions are similar in shape, though the latter ones are shifted around 0.2 fm to larger distances as compared to the BJ potentials. Because of the difficulty of including RPA effects in NJG models, and since both sets of interactions give similar energies in the absence of nuclear effects, in this work we have used BJ-type potentials.

MODEL FOR $\Lambda\Lambda$ HYPERNUCLEI

Variational scheme: Jastrow type correlations.—Following the work of Ref. [8], we model the $\Lambda\Lambda$ hypernuclei by an interacting three-body $\Lambda\Lambda$ + nuclear core system. Thus, we determine the intrinsic wave function, $\mathbf{\Phi}_{\Lambda\Lambda}(\vec{r}_1, \vec{r}_2)$, and the binding energy $B_{\Lambda\Lambda}$, where $\vec{r}_{1,2}$ are the relative coordinates of the hyperons with respect to the nucleus, from the intrinsic Hamiltonian

$$H = h_{\rm sp}(1) + h_{\rm sp}(2) + V_{\Lambda\Lambda}(1,2) - \vec{\nabla}_1 \cdot \vec{\nabla}_2/M_A\,, \quad (1)$$

where $h_{\rm sp}(i) = -\vec{\nabla}_i^2/2\mu_A + \mathcal{V}_{\Lambda A}(|\vec{r}_i|)$, M_A and μ_A are the nuclear core and the Λ-core reduced masses, respectively. The Λ-nuclear core potential, $\mathcal{V}_{\Lambda A}$, is adjusted to reproduce the binding energies, B_Λ (> 0), of the corresponding single-Λ hypernuclei [8], and $V_{\Lambda\Lambda}$ stands for the $\Lambda\Lambda$ interaction in the medium. Because of the presence of the second Λ a dynamical reordering effect in the nuclear core is produced. Both the $\Lambda\Lambda$ free interaction and this reordering of the nuclear core, contribute to $\Delta B_{\Lambda\Lambda} \equiv B_{\Lambda\Lambda} - 2B_\Lambda$. However, the latter effect is suppressed with respect to the former one by at least one power of the nuclear density, which is the natural parameter in all many body quantum theory expansions. We assume the nuclear core dynamical reordering effects to be around 0.5 MeV, as the findings of the α-cluster models of Ref. [14] suggest, for He, Be, and B $\Lambda\Lambda$ hypernuclei, and negligible for medium and heavy ones. This estimate for the size of the theoretical uncertainties is of the order of the experimental errors of $B_{\Lambda\Lambda}$ reported in Table I. Furthermore, the RPA model used below to determine $V_{\Lambda\Lambda}$ accounts for particle-hole (p-h) excitations of the nuclear core and thus it partially includes some nuclear core reordering effects.

In Ref. [8], both Hartree-Fock (HF) and Variational (VAR), where SRC can been included, schemes to solve

 0031-9007/02/89(3)/032501(4)$20.00

TABLE I. Binding energies $B_{\Lambda\Lambda}$ (MeV). Experimental values taken from Refs. [3] (He), [4,5] (Be), and [5,6] (B). We show theoretical results with and without RPA effects and with different treatments of the ϕ-exchange $\Lambda\Lambda$ potential. The used B_Λ values are 3.12, 6.71, 11.37, 18.7, 22.0, and 26.5 MeV.

		Without RPA				With RPA			
			$\Lambda_{\phi\Lambda\Lambda}$ (GeV)				$\Lambda_{\phi\Lambda\Lambda}$ (GeV)		
	$B^{\mathrm{exp}}_{\Lambda\Lambda}$	Without ϕ	1.5	2.0	2.5	Without ϕ	1.5	2.0	2.5
${}^{6}_{\Lambda\Lambda}$He	$7.25^{+0.38}_{-0.31}$	6.15	6.22	6.53	6.84	6.34	6.41	6.83	7.33
${}^{10}_{\Lambda\Lambda}$Be	17.7 ± 0.4	13.1	13.2	13.7	14.2	14.5	14.6	15.5	16.8
${}^{13}_{\Lambda\Lambda}$B	27.5 ± 0.7	22.5	22.6	23.2	23.8	24.2	24.2	25.4	27.0
${}^{42}_{\Lambda\Lambda}$Ca	$\cdots$	37.2	37.3	37.7	38.1	38.3	38.2	39.1	40.1
${}^{92}_{\Lambda\Lambda}$Zr	$\cdots$	44.1	44.2	44.4	44.7	44.6	44.7	45.2	46.0
${}^{210}_{\Lambda\Lambda}$Pb	$\cdots$	53.1	53.1	53.3	53.4	53.4	53.4	53.7	54.1

the Hamiltonian of Eq. (1) were studied. In both cases, the nuclear medium effective $\Lambda\Lambda$ interactions fitted to data were much more attractive than that deduced from the free space YN scattering data. Since the $\Lambda\Lambda$ interactions obtained by σ-ω exchanges behave almost like a hard core at short distances, the VAR energies are around 30%–40% lower than the HF ones (see Fig. 4 and Table 9 of Ref. [8]). Hence, trying to link free space to the effective interaction, $V_{\Lambda\Lambda}$, requires the use of a variational approach where r_{12} correlations (SRC) are naturally considered. We have used a family of ${}^1S_0$ $\Lambda\Lambda$ wave functions of the form $\mathbf{\Phi}_{\mathbf{\Lambda\Lambda}}(\vec{r}_1, \vec{r}_2) = NF(r_{12})\phi_\Lambda(r_1)\phi_\Lambda(r_2)\chi^{S=0}$, with $\chi^{S=0}$ the spin singlet, $\vec{r}_{12} = \vec{r}_1 - \vec{r}_2$, and

$$F(r_{12}) = \left(1 + \frac{a_1}{1 + (\frac{r_{12} - R}{b_1})^2}\right) \prod_{i=2}^{3} (1 - a_i e^{-b_i^2 r_{12}}), \quad (2)$$

where $a_{1,2,3}$, $b_{1,2,3}$, and R are free parameters to be determined by minimizing the energy, N is a normalization factor, and ϕ_Λ is the s-wave Λ function in the single-Λ hypernucleus ${}^{A+1}_{\ \ \Lambda}Z$. This VAR scheme differs appreciably from that used in Ref. [8]. There, $\mathbf{\Phi}_{\mathbf{\Lambda\Lambda}}(\vec{r}_1, \vec{r}_2)$ was expanded in series of Hylleraas type terms whereas here we have adopted a Jastrow-type correlation function. Hylleraas SRC, though suited for atomic physics, are not efficient to deal with almost hard core potentials, as is the case here. Thus, to achieve convergence in Ref. [8] a total of 161 terms (161 unknown parameters) were considered. The ansatz of Eq. (2), which has only seven parameters and thus leads to manageable wave functions, satisfactorily reproduces all VAR results of Ref. [8].

$\Lambda\Lambda$ *interaction in the nuclear medium.*—The potential $V_{\Lambda\Lambda}$ represents an effective interaction which accounts for the dynamics of the $\Lambda\Lambda$ pair in the nuclear medium, but which does not describe their dynamics in the vacuum. This effective interaction is usually approximated by an induced interaction [15] ($V^{\mathrm{ind}}_{\Lambda\Lambda}$) which is constructed in terms of the $\Lambda\Lambda \to \Lambda\Lambda$ ($G_{\Lambda\Lambda}$), $\Lambda N \to \Lambda N$ ($G_{\Lambda N}$), and $NN \to NN$ (G_{NN}) G matrices, as depicted in Fig. 1. The induced interaction, $V^{\mathrm{ind}}_{\Lambda\Lambda}$ combines the dynamics at short distances (accounted by the effective interaction $G_{\Lambda\Lambda}$) and the dynamics at long distances which is taken care of by means of the iteration of p-h excitations (RPA series) through the effective interactions $G_{\Lambda N}$ and G_{NN}. Near threshold ($2m_\Lambda$), the $S = -2$ baryon-baryon interaction might be described in terms of only two coupled channels $\Lambda\Lambda$ and ΞN. For two Λ hyperons bound in a nuclear medium and because of Pauli blocking, it is reasonable to think that the ratio of strengths of the $\Lambda\Lambda \to \Xi N \to \Lambda\Lambda$ and the diagonal $\Lambda\Lambda \to \Lambda\Lambda$ (with no ΞN intermediate states) transitions is suppressed with respect to the free space case. This is explicitly shown for ${}^{6}_{\Lambda\Lambda}$He in Ref. [16], though a recent work [17], using a NJG model, finds increases of the order of 0.4 MeV in the calculated $B_{\Lambda\Lambda}$ values, for He, Be, and B $\Lambda\Lambda$ hypernuclei, due to ΞN components. In any case 0.4 MeV is of the order of the experimental and other theoretical uncertainties discussed above, and we will assume that the data of $\Lambda\Lambda$ hypernuclei would mainly probe the free space, $V^{\mathrm{free}}_{\Lambda\Lambda}$, diagonal $\Lambda\Lambda$ element of the $\Lambda\Lambda - \Xi N$ potential. Hence $G_{\Lambda\Lambda}$ might be roughly approximated by $V^{\mathrm{free}}_{\Lambda\Lambda}$, and the interaction $V_{\Lambda\Lambda}$ can be split into two terms $V_{\Lambda\Lambda} = V^{\mathrm{free}}_{\Lambda\Lambda} + \delta V^{\mathrm{RPA}}_{\Lambda\Lambda}$, where the first one accounts for the first diagram of the right-hand side (rhs) of Fig. 1 and $\delta V^{\mathrm{RPA}}_{\Lambda\Lambda}$ does it for the remaining RPA series depicted in this figure. Let us examine in detail each of the terms.

Free space $\Lambda\Lambda$ interaction: We use the BJ models for vacuum NN [18] and YN interactions [9] to construct the free space diagonal $\Lambda\Lambda$ potential. We consider the exchange between the two Λ hyperons of σ ($I = 0$, $J^P = 0^+$), ω, and ϕ ($I = 0, J^P = 1^-$) mesons. The free space $\Lambda\Lambda$ potential, $V^{\mathrm{free}}_{\Lambda\Lambda}$, in coordinate space (nonlocal) and for the ${}^1S_0$ channel, can be found in Eqs. (24) and (25) of Ref. [8] for σ and ω exchanges, respectively. The

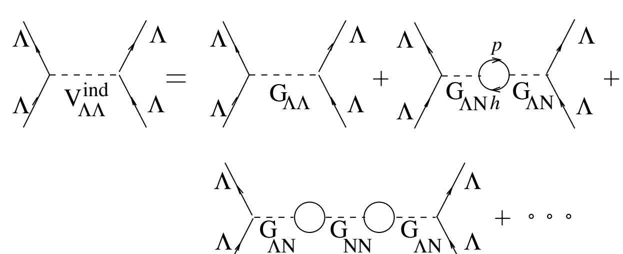

FIG. 1. Diagrammatic definition of $V^{\mathrm{ind}}_{\Lambda\Lambda}$.

ϕ-exchange potential can be obtained from that of the ω exchange by the obvious substitutions of masses and couplings. Besides, monopolar form factors are used [9,18], which leads to extended expressions for the potentials [see Eq. (19) of Ref. [8]]. In the spirit of the BJ models, SU(6) symmetry is used to relate the couplings of the ω and ϕ mesons to the Λ hyperon to those of these mesons to the nucleons. We adopt the so-called "ideal" mixing angle ($\tan\theta_v = 1/\sqrt{2}$) for which the ϕ meson comes out as a pure $s\bar{s}$ state and hence one gets a vanishing ϕNN coupling [18]. This also determines the $\phi\Lambda\Lambda$ couplings in terms of the $\omega\Lambda\Lambda$ ones. Couplings ($g_{\sigma\Lambda\Lambda}, g_{\omega\Lambda\Lambda}, f_{\omega\Lambda\Lambda}$) and momentum cutoffs ($\Lambda_{\sigma\Lambda\Lambda}, \Lambda_{\omega\Lambda\Lambda}$) appearing in the expression of the σ- and ω-exchange $\Lambda\Lambda$ potentials can be found in Table 2 of Ref. [8] which is a recompilation of model $\hat{A}$ of Ref. [9], determined from the study of YN scattering. The ϕ meson couplings are given in Eq. (65) of Ref. [8]. Because the ϕ meson does not couple to nucleons, there exist much more uncertainties on the value of $\Lambda_{\phi\Lambda\Lambda}$. Assuming that this cutoff should be similar to $\Lambda_{\omega\Lambda\Lambda}$ and bigger than the ϕ meson mass, we have studied three values, 1.5, 2, and 2.5 GeV.

RPA contribution to the $\Lambda\Lambda$ interaction: Here, we perform the RPA resummation shown in the rhs (from the second diagram on) of Fig. 1. We will do first in nuclear matter and later in finite nuclei.

(1) Nuclear matter: Let us consider two Λ hyperons inside a noninteracting Fermi gas of nucleons, characterized by a constant density ρ. The series of diagrams we want to sum up correspond to the diagrammatic representation of a Dyson type equation, which modifies the propagation in nuclear matter of the carriers (σ, ω, and ϕ mesons) of the strong interaction between the two Λ's. This modification is due to the interaction of the carriers with the nucleons. Because in our model the ϕ meson does not couple to nucleons, its propagation is not modified in the medium and will be omitted in what follows. The σ-ω propagator in the medium, $\mathcal{D}(Q)$, has been already studied in the context of Fermi liquids in Ref. [19] and it is determined by the Dyson equation

$$\mathcal{D}(Q) = \mathcal{D}^0(Q) + \mathcal{D}^0(Q)\Pi(Q)\mathcal{D}(Q), \tag{3}$$

$$\mathcal{D}^0(Q) = \begin{bmatrix} D^{\omega}_{\mu\nu}(Q) & 0 \\ 0 & D^{\sigma}(Q) \end{bmatrix}, \tag{4}$$

where $\mathcal{D}^0(Q)$ is a 5×5 matrix composed of the free σ and ω propagators, and the Π matrix is the medium irreducible σ-ω self-energy

$$\Pi(Q) = \begin{bmatrix} \Pi^{\mu\nu}(Q) & \Pi^{\mu}(Q) \\ \Pi^{\mu}(Q) & \Pi_s(Q) \end{bmatrix}, \tag{5}$$

where $\Pi_{\mu\nu}$ and Π_s account for excitations over the Fermi sea driven by the ω and σ mesons, respectively, and Π_μ generates mixings of scalar and vector meson propagations in the medium. Obviously, this latter term vanishes in the vacuum. Having in mind the findings of Ref. [8], $V^{\rm free}_{\Lambda\Lambda}$ should give us the bulk of $V_{\Lambda\Lambda}$, we have performed some approximations to evaluate $\Pi(Q)$: (i) We approximate $G_{\Lambda N}$ and G_{NN} in Fig. 1 by the free space diagonal ΛN and NN potentials, which are well described by σ and ω exchanges in the isoscalar $^1S_0$ channel. The $\Lambda\Lambda\sigma$ and $\Lambda\Lambda\omega$ vertices were discussed in the previous subsection, while the $NN\sigma$ and $NN\omega$ Lagrangians can be found in Ref. [18]. The corresponding coupling constants and form factors can be found in Ref. [18] and in Table 3 of Ref. [8]). (ii) We have only considered p-h excitations over the Fermi sea. This corresponds to evaluate the diagrams depicted in Fig. 2 plus the corresponding crossed terms which are not explicitly shown there. (iii) We work in a nonrelativistic Fermi sea and we evaluate the p-h excitations in the static limit.

With all these approximations and taking the four-momentum transferred between the two Λ's, $Q^\mu = (q^0 = 0, 0, 0, q)$, the elements of the $\Pi(0, q)$ matrix read

$$\Pi_{ij}(0, q) = U(0, q; \rho) C^N_i(q) C^N_j(q); \qquad i, j = 1, \ldots, 5, \tag{6}$$

where $C^B(q) \equiv (g_{\omega BB}(q), 0, 0, 0, g_{\sigma BB}(q))$ with

$$g_{\alpha BB}(q) = g_{\alpha BB}\frac{\Lambda^2_{\alpha BB} - m^2_\alpha}{\Lambda^2_{\alpha BB} + q^2}; \qquad \alpha = \sigma, \omega; \qquad B = \Lambda, N. \tag{7}$$

In the Lindhard function, $U(0, q; \rho)$, a finite excitation energy gap is included for particles (see appendix of Ref. [20]). We use gap values between 1 and 3 MeV to account for typical excitation energies in finite nuclei, and we find rather insensitive results. The case of ^{4}He is special and for it we use a gap value of 20 MeV. Using Eq. (6), one can invert the Dyson equation, Eq. (3), and thus one easily gets for the σ-ω propagator in the medium $\mathcal{D}(Q) = (I - \mathcal{D}^0(Q)\Pi(Q))^{-1}\mathcal{D}^0(Q)$. With this propagator, the RPA series of diagrams (from the second one on) of the rhs of Fig. 1 can be evaluated and one gets

$$\delta V^{\rm RPA}_{\Lambda\Lambda}(q, \rho) = \sum_{ij=1}^{5} C^\Lambda_i(q)[\mathcal{D}(Q) - \mathcal{D}^0(Q)]_{ij} C^\Lambda_j(q) = U(0, q; \rho)\frac{(W^\sigma_{\Lambda N} - W^\omega_{\Lambda N})^2}{1 + U(W^\sigma_{NN} - W^\omega_{NN})}, \tag{8}$$

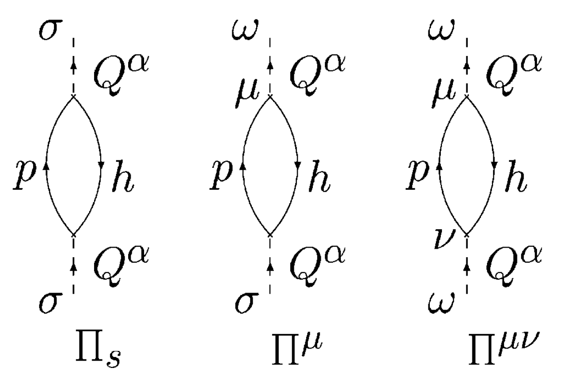

FIG. 2. p-h excitation contributions to Π, Eq. (5).

where $\mathcal{D}^0(Q)$ accounts for the first term of the rhs of Fig. 1, and it has been subtracted to avoid double counting, and finally

$$W^{\alpha}_{BB'} = \frac{g_{\alpha BB}(q) g_{\alpha B'B'}(q)}{q^2 + m_\alpha^2}. \tag{9}$$

In the nonrelativistic limit adopted to evaluate $\delta V^{\rm RPA}_{\Lambda\Lambda}$, and for consistency, we have neglected the spatial and tensor ($f_{\omega\Lambda\Lambda}$) couplings of the ω meson to the Λ.

(2) Finite nuclei: The Fourier transform of Eq. (8) gives the RPA $\Lambda\Lambda$ nuclear matter interaction, $\delta V^{\rm RPA}_{\Lambda\Lambda}(r_{12}, \rho)$, in coordinate space. It depends on the constant density ρ. In a finite nucleus, the carrier of the interaction feels different densities when it is traveling from one hyperon to the other. To take this into account, we average the RPA interaction over all different densities felt by the carriers along their way from the first hyperon to the second one. Assuming meson straight-line trajectories and using the local density approximation, we obtain

$$\delta V^{\rm RPA}_{\Lambda\Lambda}(1,2) = \int_0^1 d\lambda \, \delta V^{\rm RPA}_{\Lambda\Lambda}(r_{12}, \rho(|\vec{r}_2 + \lambda \vec{r}_{12}|)), \tag{10}$$

where ρ is the nucleon center density given in Table 4 of Ref. [8]. Note that $\delta V^{\rm RPA}_{\Lambda\Lambda}(1,2)$ depends on r_{12} and also on the distance of the Λ's to the nuclear core, r_1 and r_2.

RESULTS AND CONCLUDING REMARKS

Using the numerical constants and the Λ nuclear core potentials denoted in Ref. [8] by YNG [21] and by BOY [22] for He and Be, B, Ca, Zr, Pb, respectively, we obtain the results of Table I, where both the effect of the ϕ exchange and that of the RPA correlations can be seen. We have also investigated the dependence of the results on the $\phi\Lambda\Lambda$ couplings (g and f), by varying both couplings by $\pm 10\%$ around their SU(6) values. We find appreciable changes of the energies for the two highest values of $\Lambda_{\phi\Lambda\Lambda}$. These changes become greater for variations of $f_{\phi\Lambda\Lambda}$ than of $g_{\phi\Lambda\Lambda}$, increase with A, and are bigger when RPA effects are considered. For instance, for $\Lambda_{\phi\Lambda\Lambda} = 2.5$ GeV and with RPA the He, Be, and B energies vary in the ranges 7.05–7.83, 16.0–17.7, and 26.0–28.2 MeV, respectively. Finally, in Table II we present details of $F(r_{12})$, Eq. (2). Our conclusions are as follows: (i) It is not possible to describe the experimental masses of the $\Lambda\Lambda$ hypernuclei if RPA effects were not included. (ii) The RPA resummation leads to a new nuclear density or A dependence of the $\Lambda\Lambda$ potential in the medium which notably increases $\Delta B_{\Lambda\Lambda}$ and that provides, taking into account theoretical and experimental uncertainties, a reasonable description of the currently accepted masses of the three measured $\Lambda\Lambda$ hypernuclei (see last column of Table I). This is achieved from a free space OBE BJ potential determined from $S = 0, -1$, baryon-baryon scattering data. Hence, our calculation does not confirm the conclusions of Ref. [13] about the incompatibility of the He, and Be and B data. The binding energies of $^{10}_{\Lambda\Lambda}$Be and $^{13}_{\Lambda\Lambda}$B might change if the single hypernuclei produced in Be and B events were produced in excited states [13]. The modified Be and B masses would then favor a different set of $\Lambda_{\phi\Lambda\Lambda}$ and $\phi\Lambda\Lambda$ couplings [see columns 8–10 in Table I and discussion on SU(6) violations].

TABLE II. Parameters, in Fermi units, of the function $F(r_{12})$ for RPA $\Lambda_{\phi\Lambda\Lambda} = 2.5$ GeV $\Lambda\Lambda$ interaction.

	a_1	b_1	R	a_2	b_2	a_3	b_3
He	6.51	0.81	0.24	0.91	0.94	0.88	0.98
Be	3.33	0.82	0.44	0.77	1.29	0.88	1.16
B	5.39	0.72	0.43	0.81	1.12	0.84	0.99
Ca	1.75	0.71	0.59	0.90	1.47	0.58	1.41
Zr	2.60	0.74	0.51	0.55	1.61	0.91	1.15
Pb	3.75	0.73	0.47	0.85	0.99	0.75	1.51

We warmly thank C. García-Recio for useful discussions. This research was supported by DGES under Contract No. PB98-1367 and by the Junta de Andalucía.

[1] *Proceedings of the International Conference on Hypernuclear and Strange Particle Physics* [Nucl. Phys. **A585** (1995); **A639** (1998); **A691** (2001)].
[2] J. K. Ahn *et al.,* Phys. Rev. Lett. **87**, 132504 (2001).
[3] H. Takahashi *et al.*, Phys. Rev. Lett. **87**, 212502 (2001).
[4] M. Danysz *et al.,* Nucl. Phys. **49**, 121 (1963); R. H. Dalitz *et al.,* Proc. R. Soc. London Sect. A **426**, 1 (1989).
[5] G. B. Franklin, Nucl. Phys. **A585**, 83c (1995).
[6] S. Aoki *et al.,* Prog. Theor. Phys. **85**, 1287 (1991).
[7] D. J. Prowse, Phys. Rev. Lett. **17**, 782 (1966).
[8] J. Caro, C. García-Recio, and J. Nieves, Nucl. Phys. **A646**, 299 (1999).
[9] A. Reuber, K. Holinde, and J. Speth, Nucl. Phys. **A570**, 543 (1994).
[10] Th. A. Rijken, Nucl. Phys. **691**, 322c (2001); V. G. J. Stoks and Th. A. Rijken, Phys. Rev. C **59**, 3009 (1999).
[11] E. Hiyama *et al.*, Prog. Theor. Phys. **97**, 881 (1997).
[12] A. Parreño, A. Ramos, and C. Bennhold, Phys. Rev. C **65**, 015205 (2002); K. Itonaga, T. Ueda, and T. Motoba, Phys. Rev. C **65**, 034617 (2002).
[13] I. N. Filikhin and A. Gal, Phys. Rev. C **65**, 041001 (2002); Nucl. Phys. A (to be published).
[14] A. R. Bodmer, Q. N. Usmani, and J. Carlson, Nucl. Phys. **A422**, 510 (1984).
[15] E. Oset, P. Fernández de Córdoba, L. L. Salcedo, and R. Brockman, Phys. Rep. **188**, 79 (1990).
[16] S. B. Carr, I. R. Afnan, and B. F. Gibson, Nucl. Phys. **A625**, 143 (1997).
[17] T. Yamada and C. Nakamoto, Phys. Rev. C **62**, 034319 (2000).
[18] R. Machleidt, K. Holinde, and Ch. Elster, Phys. Rep. **149**, 1 (1987).
[19] T. Matsui, Nucl. Phys. **A370**, 365 (1981).
[20] E. Oset, D. Strottman, H. Toki, and J. Navarro, Phys. Rev. C **48**, 2395 (1993).
[21] T. Motoba, H. Bando, T. Fukuda, and J. Zofka, Nucl. Phys. **A534**, 597 (1991).
[22] A. Bouyssy, Nucl. Phys. **A381**, 445 (1982).