SUMMARY

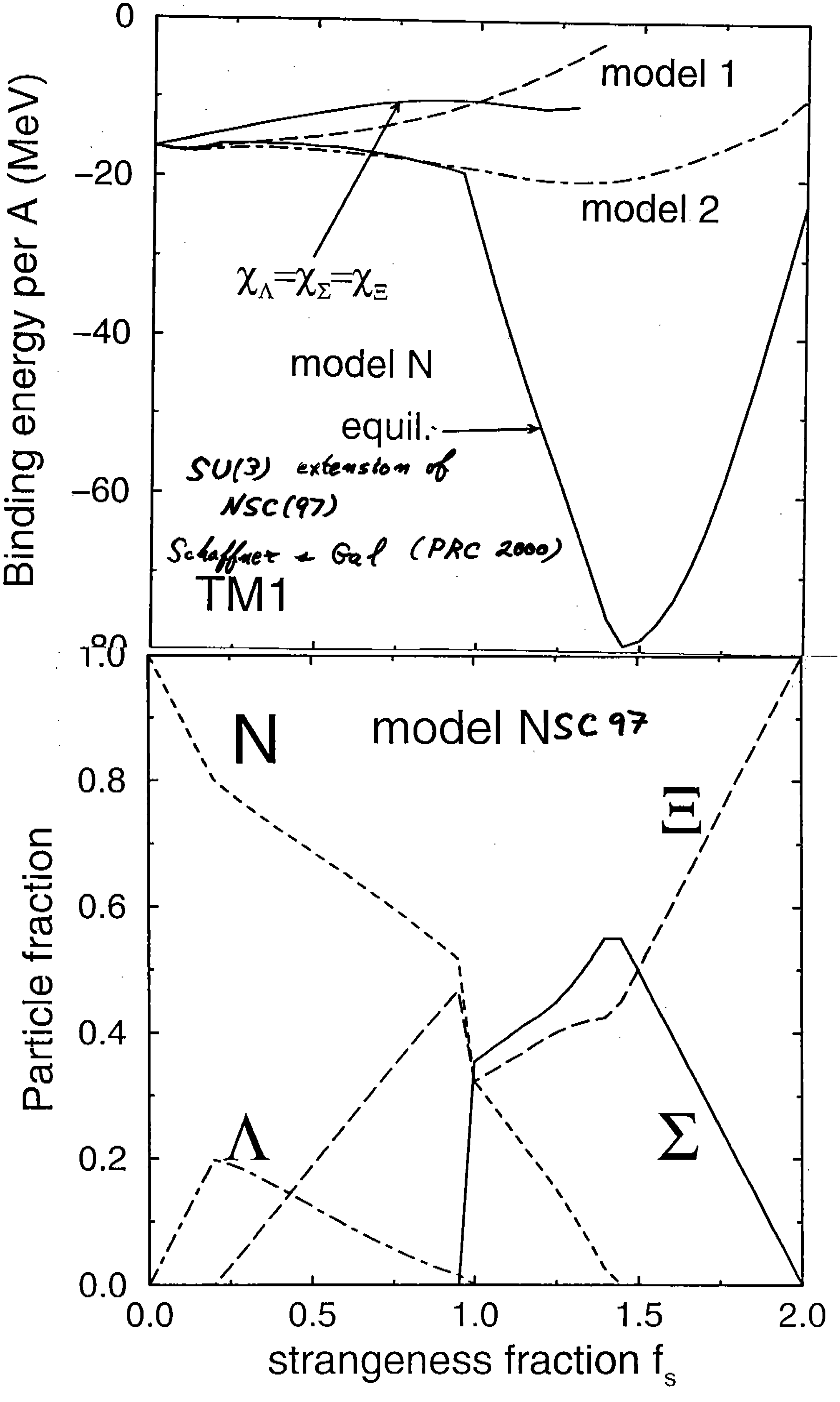
1. 'old' ${}^{10}_{\Lambda\Lambda}\mathrm{Be}$ is inconsistent with ${}^{6}_{\Lambda\Lambda}\mathrm{He}$

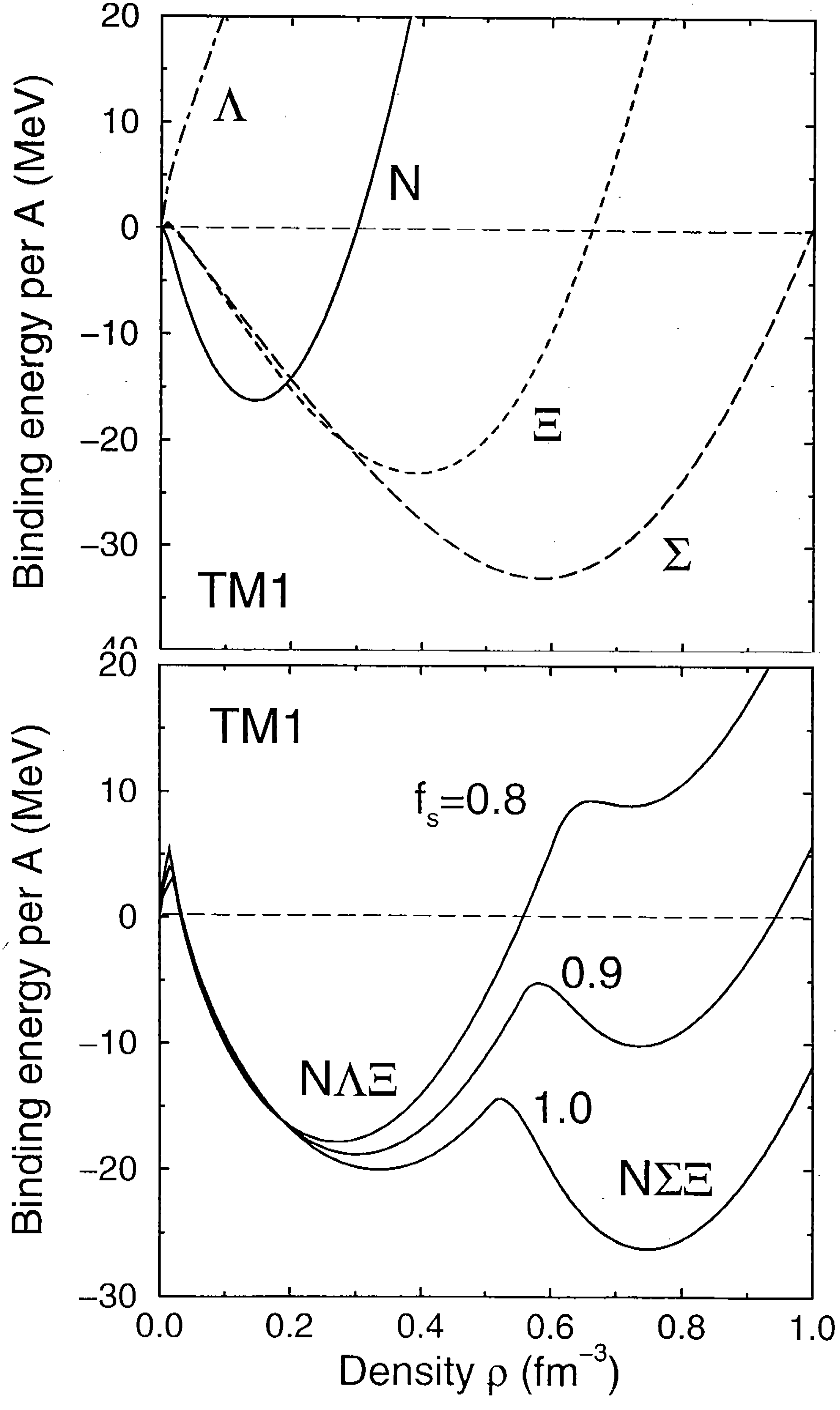
2. 'new' ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ ⇒ NSC97 model; is ${}^{4}_{\Lambda\Lambda}\mathrm{H}$ bound?

3. NSC97 model ⇒ strong hyperon-hyperon forces
   onset of Ξ nuclear stability is ${}^{6}_{\Lambda\Xi}\mathrm{He}$ $(\Lambda\Xi^0\alpha)$

4. strange hadronic matter: phase transition from $N\Lambda\Xi$ phase to $N\Sigma\Xi$ phase

5. more experimentation is needed, extension of both E373 (approved at the AGS for 2004/5) and E906 (also approved recently).
   Will there be any new data before JHF ?


0
−20
−40
−60
−80
Binding energy per A (MeV)
model 1
model 2
$\chi_\Lambda = \chi_\Sigma = \chi_\Xi$
model N
equil.
SU(3) extension of
NSC(97)
Schaffner + Gal (PRC 2000)
TM1
1.0
0.8
0.6
0.4
0.2
0.0
Particle fraction
N
model NSC 97
Ξ
Λ
Σ
0.0
0.5
1.0
1.5
2.0
strangeness fraction f_s



20
10
0
−10
−20
−30
−40
Binding energy per A (MeV)
Λ
N
Ξ
Σ
TM1
20
10
0
−10
−20
−30
Binding energy per A (MeV)
TM1
f_s=0.8
0.9
1.0
NΛΞ
NΣΞ
0.0
0.2
0.4
0.6
0.8
1.0
Density ρ (fm^-3)

Phys. Rev. C 59 (1999) 21

versions a, b, c, d, e, f : fit binding and spin dependence of ${}^{A}_{\Lambda}Z$ hypernuclei

ADP-98-37-T310

${}^{3}_{\Lambda}H$ as $pn\Lambda$ (Glöckle)

Soft-core hyperon-nucleon potentials

Th.A. Rijken
Institute for Theoretical Physics, University of Nijmegen, Nijmegen, The Netherlands

V.G.J. Stoks
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439
and Centre for the Subatomic Structure of Matter, University of Adelaide, SA 5005, Australia

Y. Yamamoto
Physics Section, Tsuru University, Tsuru, Yamanashi 402-0054, Japan
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arXiv:nucl-th/9807082 31 Jul 1998

Abstract

model NSC97

A new Nijmegen soft-core OBE potential model is presented for the low-energy *YN* interactions. Besides the results for the fit to the scattering data, which largely defines the model, we also present some applications to hypernuclear systems using the G-matrix method. The potentials are generated by the exchange of nonets of pseudoscalar, vector, and scalar mesons. As standard in the Nijmegen soft-core models, we also include the $J = 0$ contributions from the tensor f_2, f_2', a_2 and pomeron Regge trajectories, and use Gaussian form factors to guarantee that the potentials have a soft behavior near the origin. An important innovation with respect to the original soft-core potential is the assignment of the cut-off masses for the baryon-baryon-meson (BBM) vertices in accordance with broken $SU(3)_F$, which serves to connect the *NN* and the *YN* channels. As a novel feature, we allow for medium strong breaking of the coupling constants, using the ${}^3P_0$ model with a Gell-Mann–Okubo hypercharge breaking for the BBM coupling. Charge-symmetry breaking in the Λp and Λn channels is included as well. We present six hyperon-nucleon potentials which describe the available *YN* cross section data equally well, but which exhibit some differences on a more detailed level. The differences are constructed such that the models encompass a range of scattering lengths in the ΣN and ΛN channels. In all cases, we obtained $\chi^2/N_{\rm data} \approx 0.55$ for 35 *YN* data. In particular, we were able to fit the precise experimental datum $r_R = 0.468 \pm 0.010$ for the inelastic capture ratio at rest. For the scalar-meson mixing angle we obtained values $\theta_S = 37°$–$40°$, which points to almost ideal mixing angles for the scalar $q\bar{q}$ states. The G-matrix results indicate that the

Extension to YY interactions : Stoks + Rijken PRC 59, 3009 (1999)

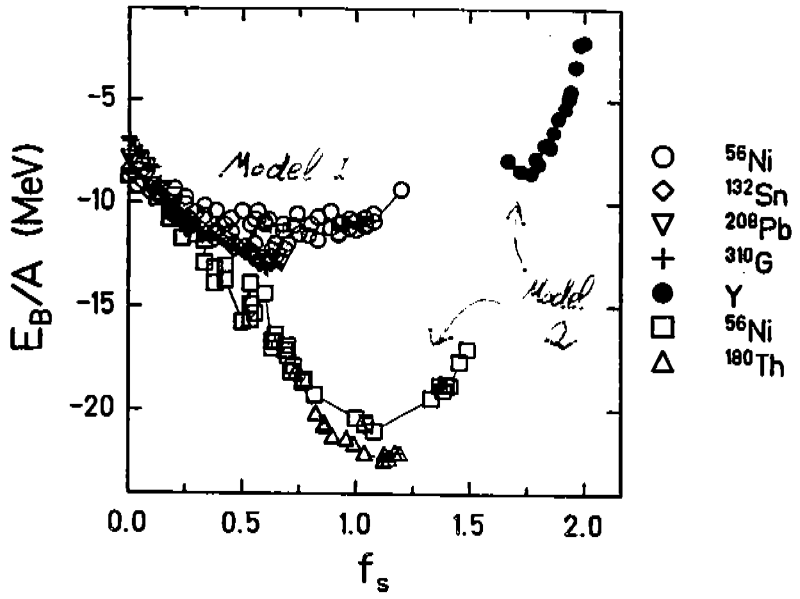


Figure 1: The binding energy of several SHM species vs. the strangeness fraction $f_s = |S|/A$

Schaffner, Dover, Gal, C. Greiner, Stöcker

PRL 71 (1993) 1328 ; Ann. Phys. 235 (1994) 35 .

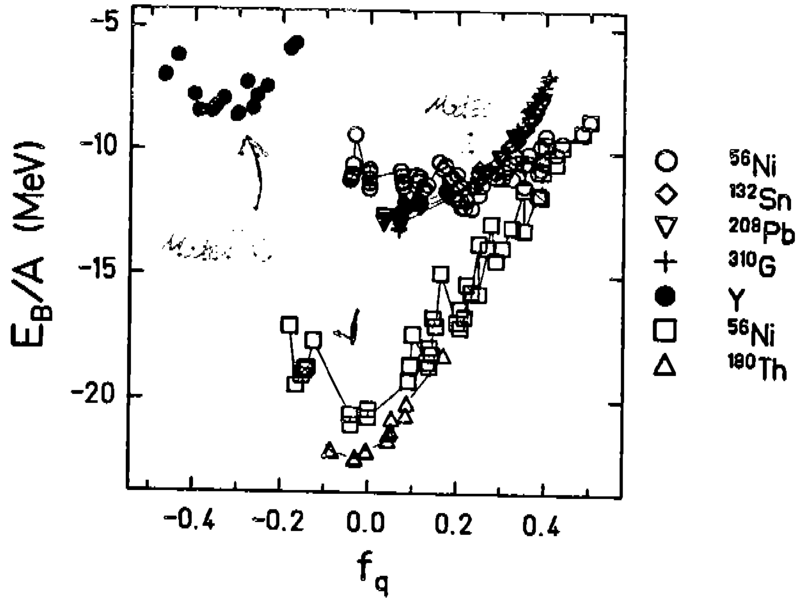
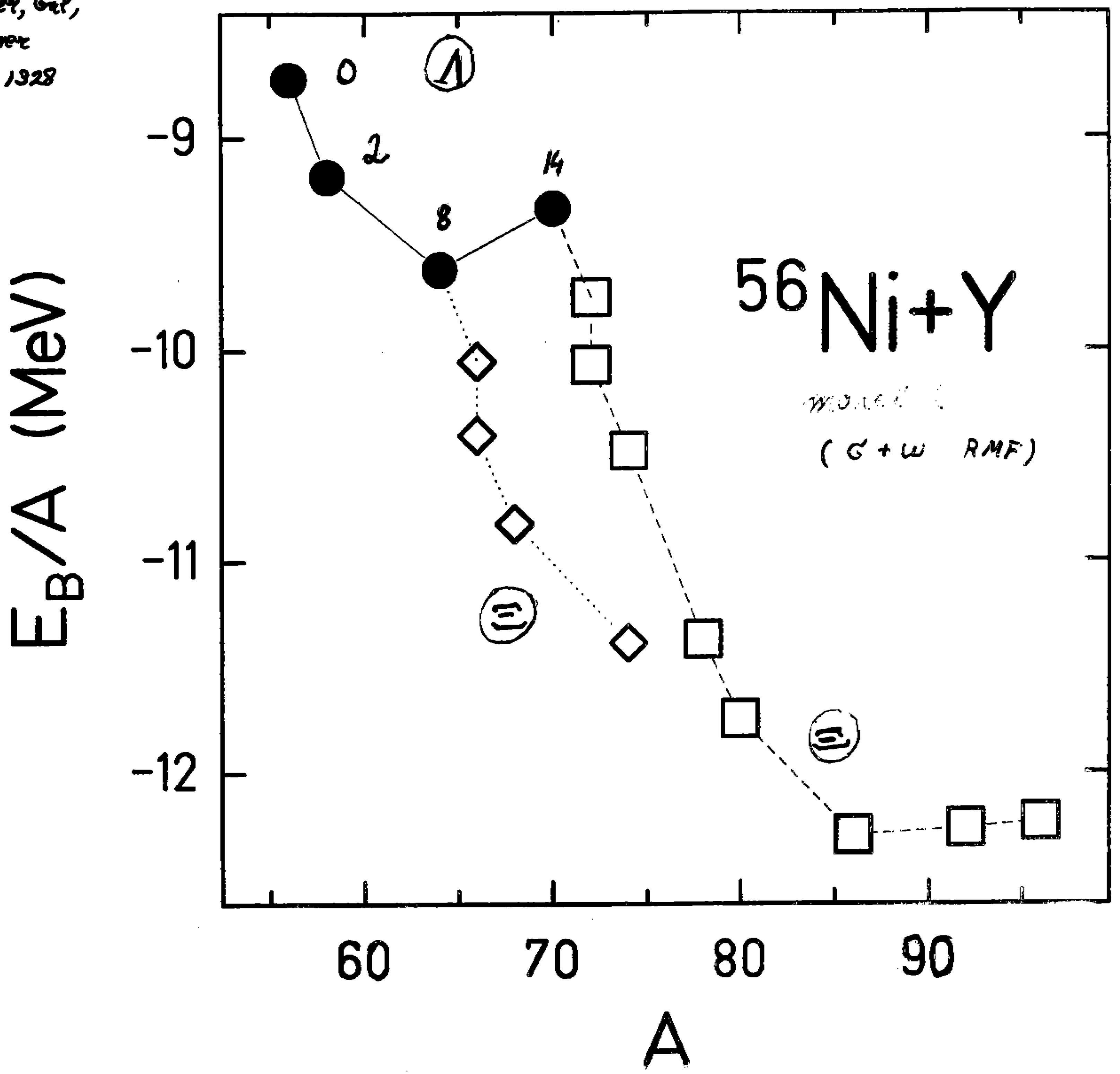


Figure 2: The binding energy of several SHM species vs. the charge fraction $f_q = Z/A$.

Schaffner, Dover, Gal,
Stocker, Greiner
PRL 71 (1993) 1328



3. Multi-Strange Objects -- Λ's and Ξ's

$$\Xi + N \rightarrow \Lambda + \Lambda \quad + \underbrace{(\sim) 25 \text{ MeV}}$$

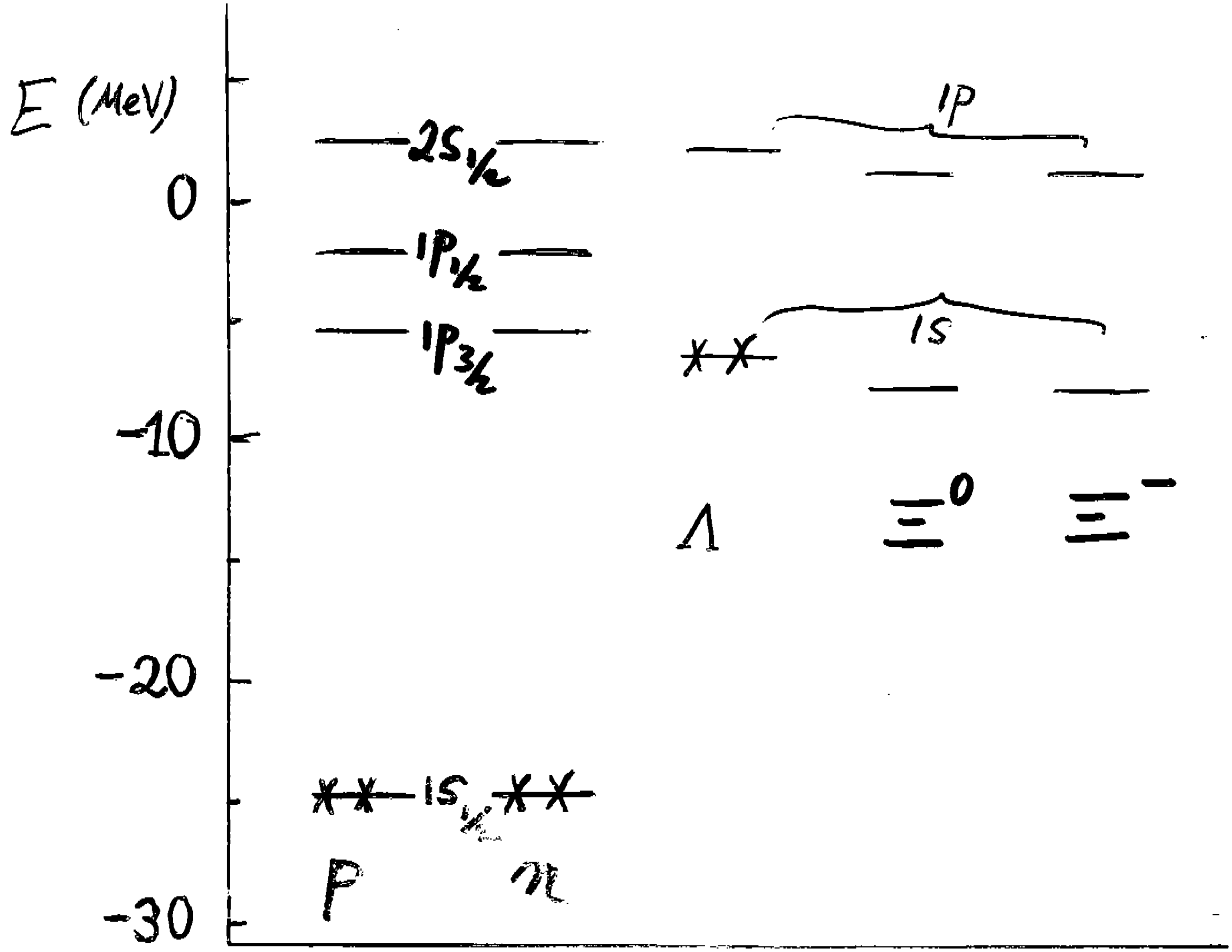
overcome it
by Pauli blocking
of bound Λ's

($\sigma + \omega$ model)

Example: $pp\,nn\,\Lambda\Lambda\,\Xi^0\Xi^0\,\Xi^-\Xi^-$

ג'קת נ'ה

Schaffner et al.
PR C 46, 322 (92)



Faddeev Calculations

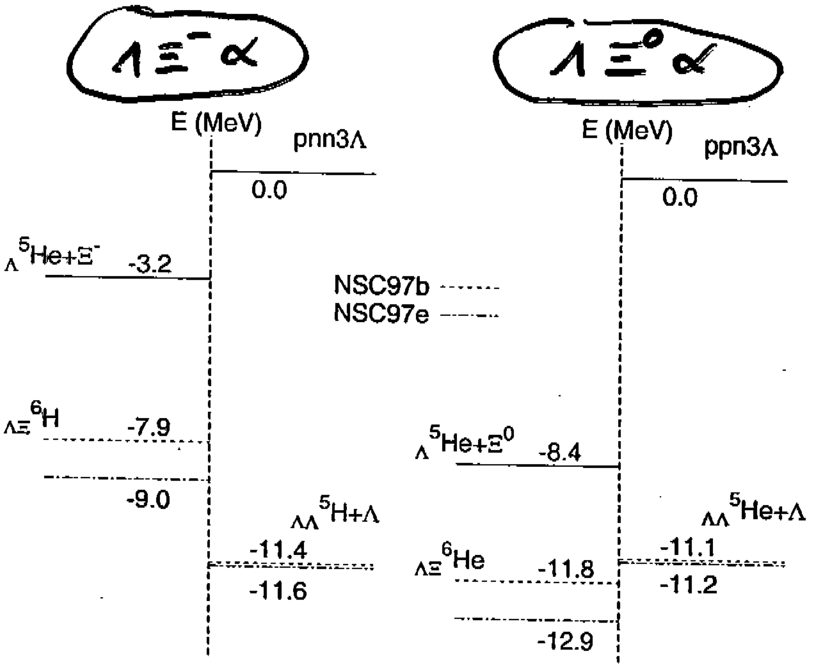
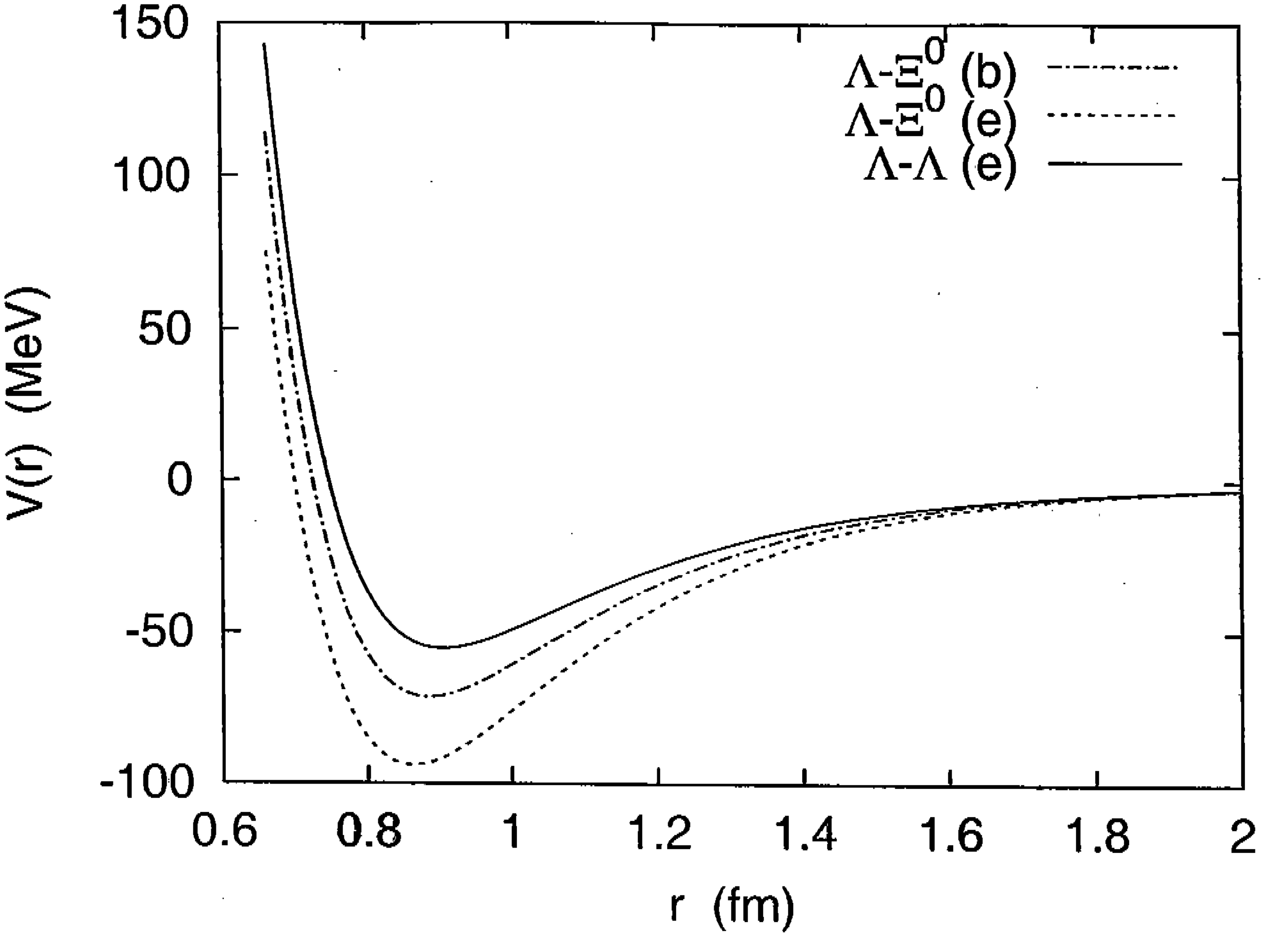


FIGURE 4. Calculated level scheme of $^{6}_{\Lambda\Xi}$H and $^{6}_{\Lambda\Xi}$He hypernuclei.

[18], does not resolve this incompatibility. Adding $^{13}_{\Lambda\Lambda}$B [9] as input does not alleviate it either, since the possibility of unobserved γ deexcitation cannot be dismissed also for this species, while on the theoretical side the analysis of $^{13}_{\Lambda\Lambda}$B in terms of a few-body cluster is more dubious than for the lighter ΛΛ species.

Discarding past history of this emulsion experimentation for ΛΛ hypernuclear events identified as heavier than $^{6}_{\Lambda\Lambda}$He, because of the ambiguities mentioned here, one remains with the very recent report from the KEK E373 experiment [14] which claims to have identified uniquely $^{6}_{\Lambda\Lambda}$He, with $\Delta B_{\Lambda\Lambda} \sim 1$ MeV. No particle-stable excited states are possible for this species or for its Λ hypernuclear core $^{5}_{\Lambda}$He, so this event - if confirmed - should be taken as the most directly relevant constraint on the ΛΛ interaction.

Moreover, $^{6}_{\Lambda\Lambda}$He is also ideally suited for three-body cluster calculations such as the Faddeev equations here solved for the αΛΛ system. Using *s*-wave soft-core ΛΛ potentials that simulate several of the Nijmegen ΛΛ interaction models, we have shown that model NSC97 is the only one capable of coming close to the observed binding, short by about 0.5 MeV of the new value [14]. In fact, we estimate the theoretical uncertainty of our Faddeev calculation for $^{6}_{\Lambda\Lambda}$He as bounded by 0.5 MeV, and such that the precisely calculated binding energy is *larger* by a fraction of this bound than the $\Delta B_{\Lambda\Lambda}$ values shown in Table 4. Taking into account such possible corrections would bring our calculated $\Delta B_{\Lambda\Lambda}$ values to within the error bars of the reported $\Delta B_{\Lambda\Lambda}$ value. There are two possible origins for this theoretical uncertainty, one is the restriction to *s*-waves in the partial-wave expansion of the Faddeev equations, excluding higher ℓ values; the other one is ignoring the off-diagonal $\Lambda\Lambda - \Xi N$ interaction which admixes Ξ components into the $^{6}_{\Lambda\Lambda}$He wavefunction. Both effects have been tested in several previous calculations and found small. For example, a recent work by Yamada and Nakamoto [37] using


150
100
50
0
-50
-100
V(r) (MeV)
0.6
0.8
1
1.2
1.4
1.6
1.8
2
r (fm)
Λ-Ξ⁰ (b)
Λ-Ξ⁰ (e)
Λ-Λ (e)

$S = -3$

${}^{6}_{\Lambda\Xi}\mathrm{He}$ is particle stable ($\Lambda \Xi^0 \alpha$)

${}^{6}_{\Lambda\Xi}\mathrm{H}$ is not particle stable ($\Lambda \Xi^- \alpha$)

($m_{\Xi^-} > m_{\Xi^0}$ by 6.5 MeV)

Lightest $S = -3$ stable bound state ;

requires Ω^- initiated reactions for production

$$\Omega^- + {}^{6}\mathrm{Li} \rightarrow {}^{6}_{\Lambda\Xi}\mathrm{He} + n$$

$$(\ \Xi^- + {}^{6}\mathrm{Li} \rightarrow {}^{6}_{\Lambda\Lambda}\mathrm{He} + n \ )$$

Main assumptions :

1. $\Lambda\Xi$ from model NSC97 which is close to reproducing ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ 'new' $B_{\Lambda\Lambda}$.
2. $\Lambda\alpha$ is fitted to $B_{\Lambda}({}^{5}_{\Lambda}\mathrm{He})$.
3. $\Xi\alpha$ is normalized to $\Xi^- {}^{11}\mathrm{B}$ potential depth as deduced from E885 $K^- + {}^{12}\mathrm{C} \rightarrow K^+ + {}^{12}_{\Xi}\mathrm{Be}$.

Ξ - nucleus interaction is poorly known ;

search for ${}^{A}_{\Xi}Z$ bound states ($\Gamma \lesssim 3$ MeV)
and look for Ξ^- X rays in Ξ^- atoms .

New calculations incorporate

(i) $\Lambda N - \Sigma N$ coupling (evident from $A=4$ Λ hypernuclei)

(ii) $\Lambda\Lambda - \Xi N - \Sigma\Sigma$ coupling

Carr, Afnan, Gibson (1997)

Afnan, Gibson (PRC 2003)

* Myint, Shinmura, Akaishi (EPJ A 2003)

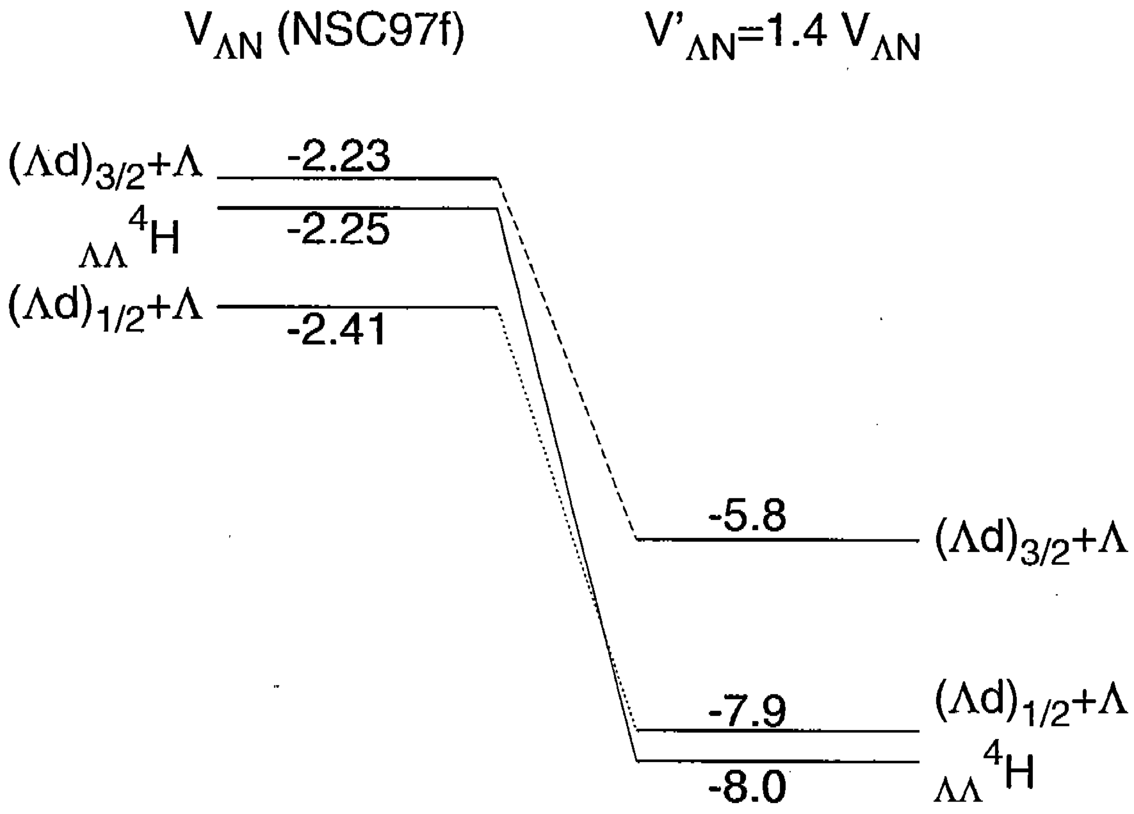
Filikhin, Gal, Suslov (PRC 2003)

Vidaña, Ramos, Polls (2003) $\Sigma\Sigma$ is important!

effects are small, 0.2-0.3 mev, except for *
(about double)

(iii) rearrangement effects in ^{4}He

Kohno, et al (PRC 2003) huge !?
Fujiwara, Akaishi



$\Lambda\Lambda NN$: V_{NN} , $V_{\Lambda\Lambda}$, $4\,V_{\Lambda N}$

ΛN interaction is decisive in this problem

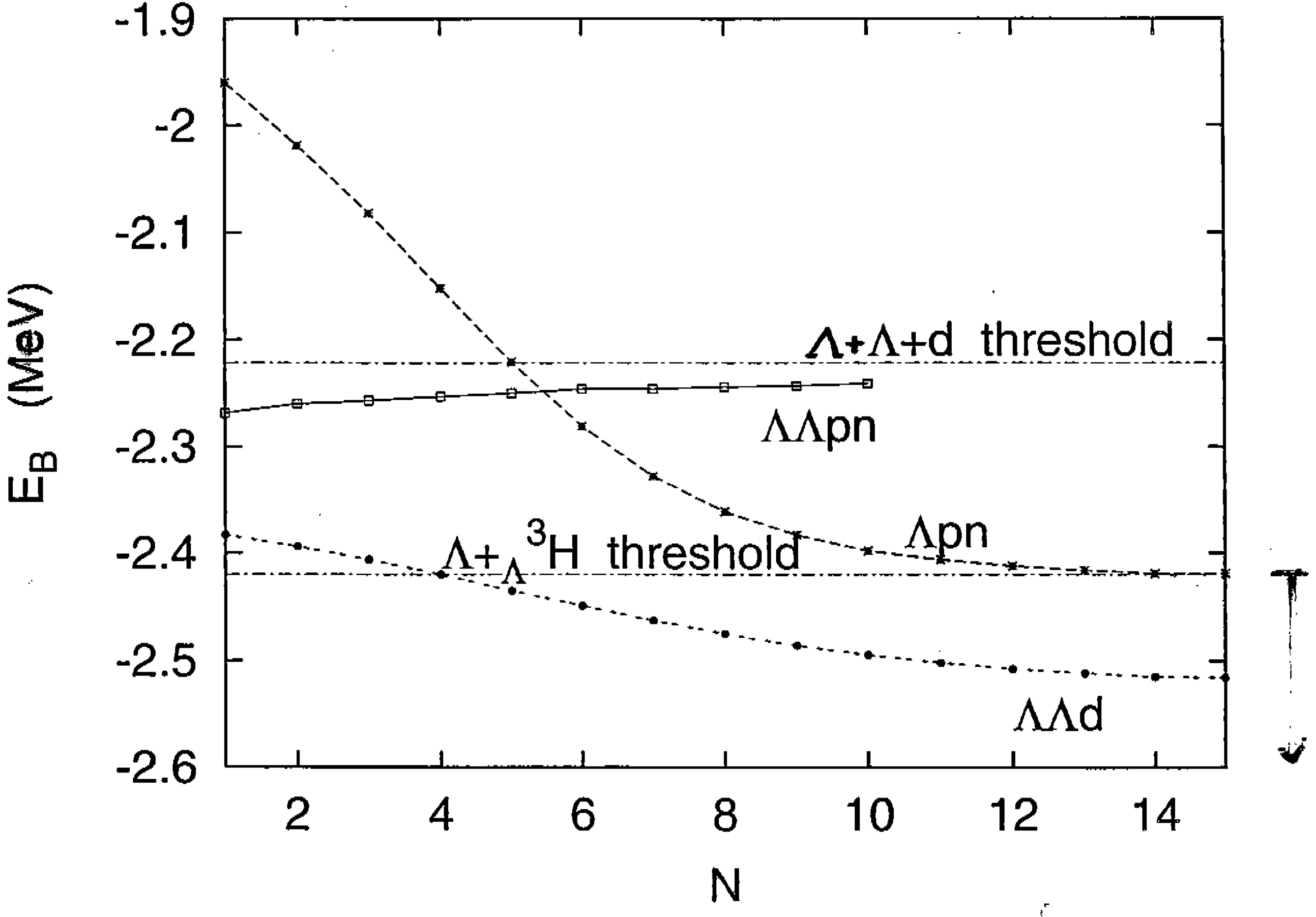
Rearrangement channels: $(\Lambda NN)_{S=1/2} + \Lambda$, $(\Lambda NN)_{3/2} + \Lambda$, $(\Lambda\Lambda N)_{1/2} + N$,

$(\Lambda\Lambda)_0 + (NN)_1$, $(\Lambda N)_0 + (\Lambda N)_1$, $(\Lambda N)_1 + (\Lambda N)_1$

Too many of these channels are effectively repulsive;
4-body calc. allowing p-n structure for d yields less binding than 3-body calc. for $\underbrace{\overbrace{\Lambda\Lambda}}d$.

Normally: 4-body calc. gives more binding than 3-body calc

Filikhin and Gal, PRL 89 (2002)



$^{4}_{\Lambda\Lambda}$H binding !

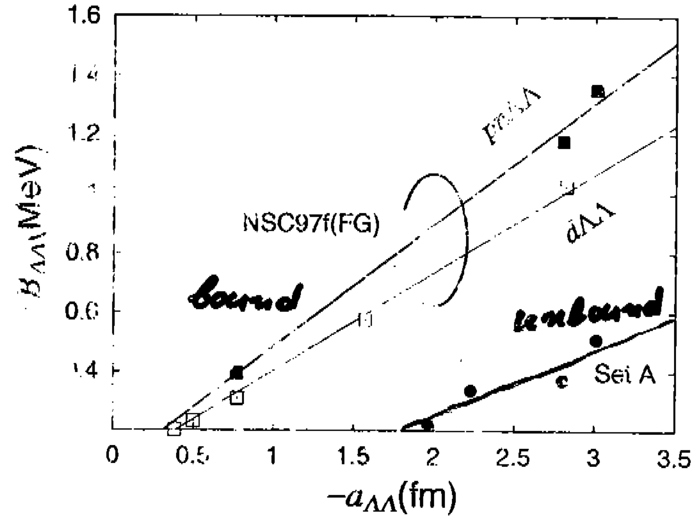
<u>4-body calc.</u>

Increasing $V_{\Lambda\Lambda}$ does not bind $^{4}_{\Lambda\Lambda}$H !

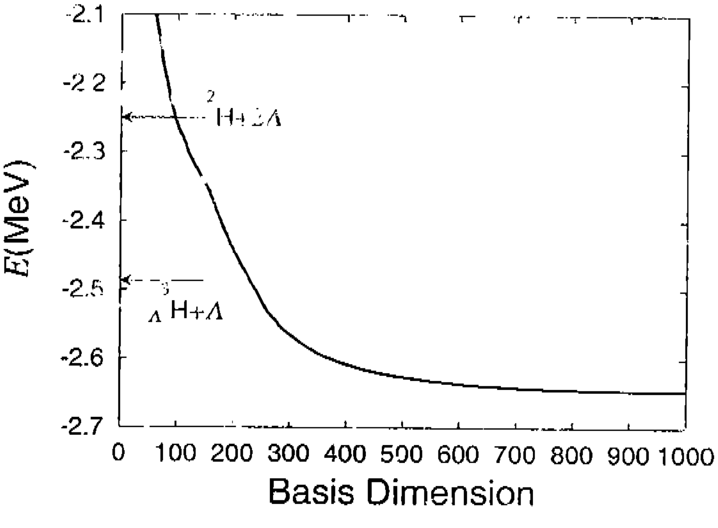
How come Λpn is bound, but ΛΛpn is not ?

Nemura, Akaishi, Myint, PRC $\underset{\sim}{67}$ (2003)

Stochastic variational search for ${}^4_{\Lambda\Lambda}H$



: Calculated $B_{\Lambda\Lambda}({}^4_{\Lambda\Lambda}\mathrm{H})$ as a function of the scatter- ng length, $a_{\Lambda\Lambda}$. The solid squares were obtained using the ·f(FG) ΛN potential and the solid circles by the Set A potential. The open squares are the result of the $d\Lambda\Lambda$ three-body model, taken from Ref. [1]. The straight lines were drawn only for the sake of a guide to the reader.



[illegible] of ${}_{\Lambda\Lambda}$H as a function of the basis mension, K. The interactions are taken from Ref. [1], spin- NSC97f(FG) ΛN, and ΛΛ deduced from the recent perimental $B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}\mathrm{He})$. The converged energy is clearly ver than the ${}^3_\Lambda$H + Λ threshold.

ough the convergence of the energy is rather slow, the

	$\langle T_c\rangle$	$\langle V_{NN}\rangle$	E_c	$\sqrt{\langle r^2_{NN}\rangle}$
^{2}H	18.74	−20.99	−2.25	3.85
${}^3_\Lambda$H*	19.09	−21.20	−2.12	3.7[illegible]
${}^3_\Lambda$H	20 70	−22.30	−1.59	3.54
${}^4_{\Lambda\Lambda}$H($a_{\Lambda\Lambda}=-0.77$fm)	22.28	−23.17	−0.88	3.34
${}^4_{\Lambda\Lambda}$H($a_{\Lambda\Lambda}=-2.8$fm)	24.73	−24.55	0.18	3.08

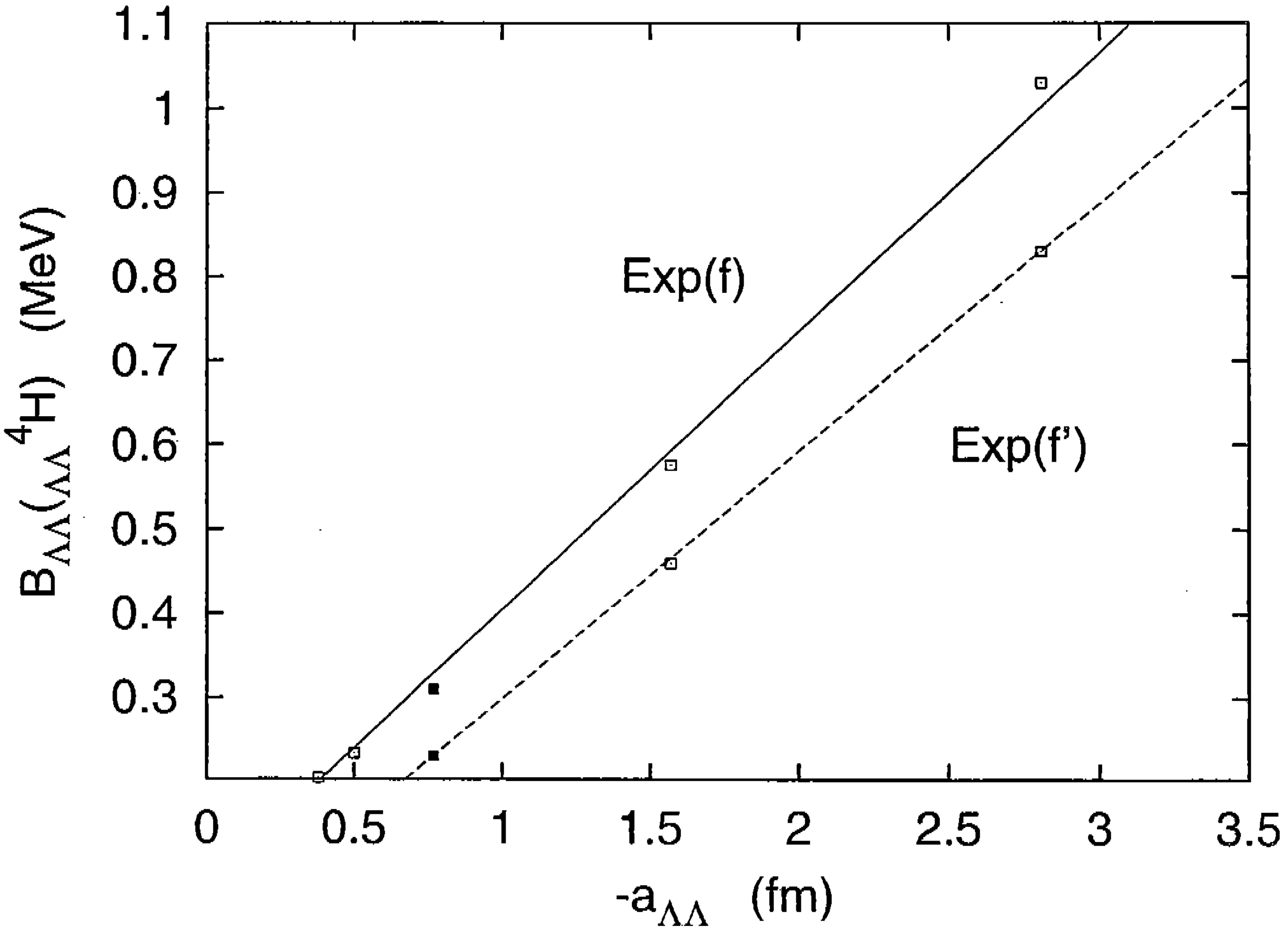
TABLE I: Energy expectation values of kinetic (T_c) tential (V_{NN}) terms, and the sum of these energies (the pn subsystem, in units of MeV. The rms distance a proton and a neutron, or between a nucleon and a Λ listed, in units of fm. The spin-triplet pn and NSC ΛN potentials, taken from Ref. [1], were used.

	$B_\Lambda({}^3_\Lambda\mathrm{H})$	$B_\Lambda({}^4_\Lambda\mathrm{H})$	$B_\Lambda({}^4_\Lambda\mathrm{H}^*)$
NSC97f(FG)	0.24	2.69	1.99
Set A	0.18	2.24	1.14
Experiment	0.13 ± 0.05	2.04 ± 0.04	$1.00\pm0.$

TABLE II: Λ separation energies, given in units of I $A=3,4$ single-Λ hypernuclei. The Minnesota NN p was used.

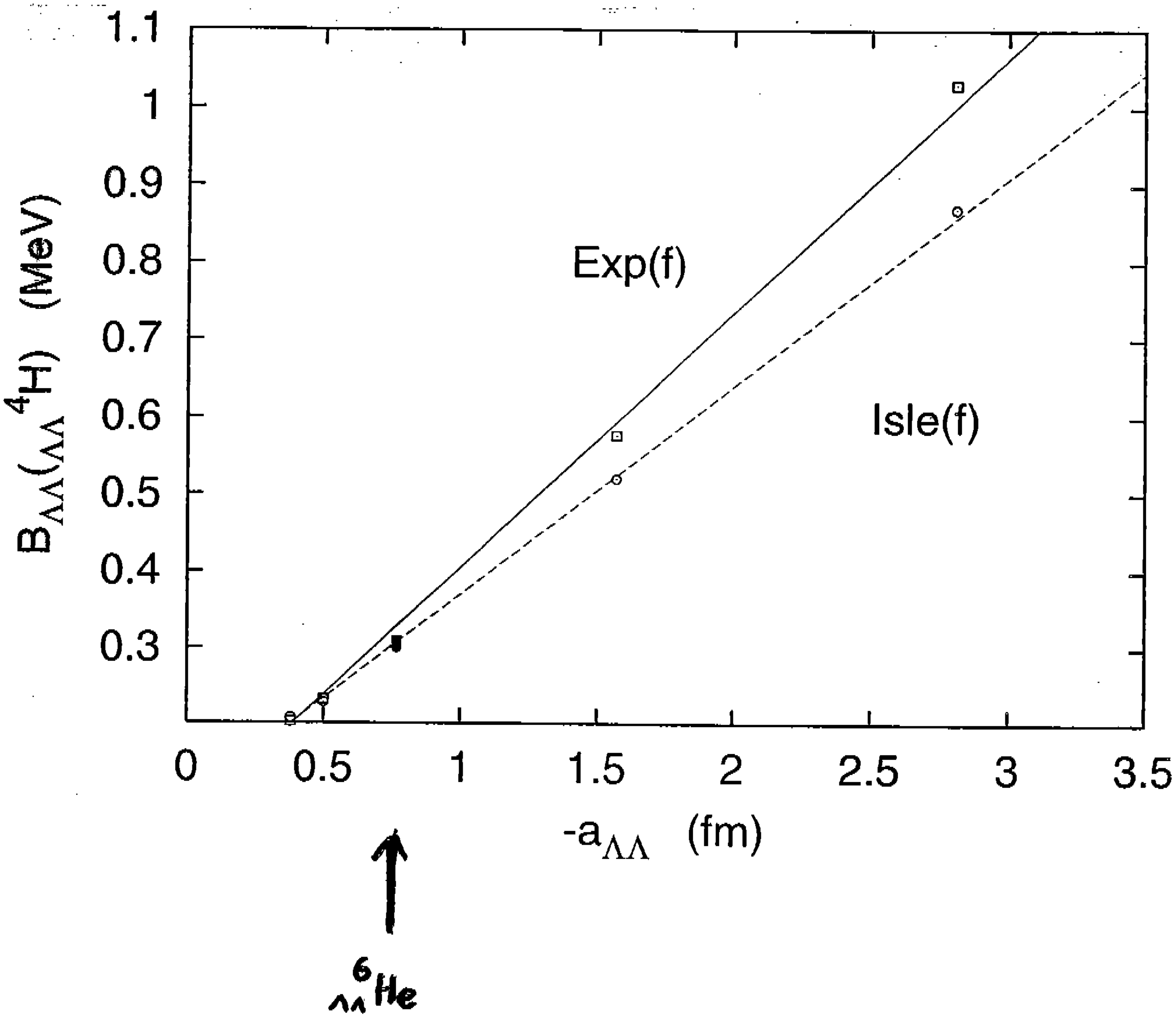
other at the point where $a_{\Lambda\Lambda}=0$ fm. This m a the polarization of the pn subsystem is small, a the $d\Lambda\Lambda$ model is a good approximation if the teraction is very weak. The polarization of the de subsystem grows as the strength of the ΛΛ inte increases. Table I lists the energy expectation val the proton and neutron subsystem in each (hyp cleus, and also the root-mean-square distances b a p and an n, or between a nucleon and a Λ. Her the kinetic energy of the pn subsystem, which is by $T_c=(\boldsymbol{p}_1-\boldsymbol{p}_2)^2/4m_N$. The table shows that fluence of the Λ particle upon the internal struc the pn subsystem becomes large as the Λ particle close to the nucleon. Especially in the case of a st attractive ΛΛ potential, the change in the internal (E_c) or of the rms distance ($\sqrt{\langle r^2_{NN}\rangle}$) is significa

As can be seen in Fig. 2, the $B_{\Lambda\Lambda}$ value is sensi the choice of the ΛN potential. For the purpose dicting whether ${}^4_{\Lambda\Lambda}$H exists as a particle-stable state, the ΛN potential has to be examined ca Table II compares the B_Λ values of $A=3,4$ nuclei. The calculated B_Λ value of the $A=4$ using NSC97f(FG) is larger than that using Set



f : ${}^3_\Lambda H\,(\frac{3}{2}^+)$ slightly bound

f' : 〃 〃 unbound

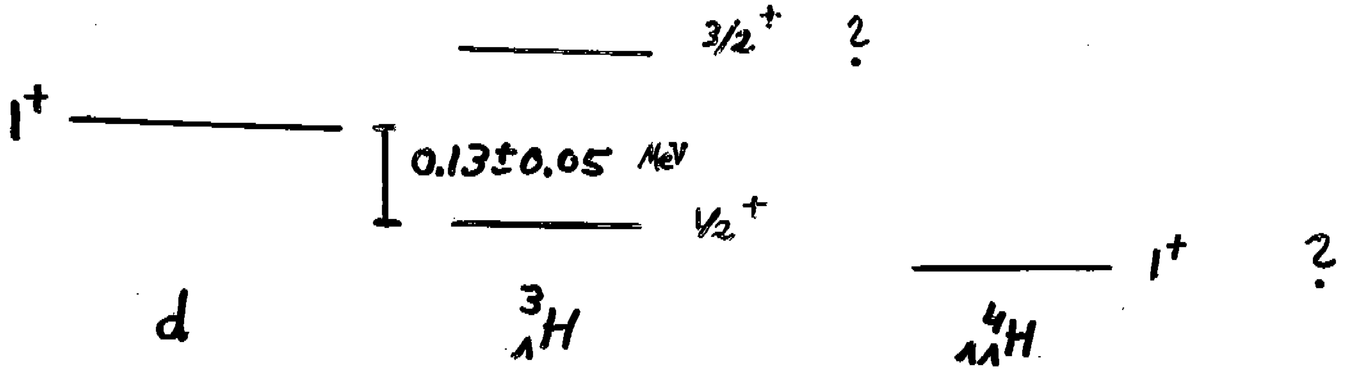


$\Lambda\Lambda d$ model

Λd exponential or Isle potentials fitted to Λpn Faddeev calculations for $J^{\pi} = \frac{1}{2}^{+}$ and $\frac{3}{2}^{+}$

Filikhin + Gal PRL (2002)

${}^{4}_{\Lambda\Lambda}H$: stable or unstable ? ${}^{4}_{\Lambda\Lambda}H \to {}^{3}_{\Lambda}H + \Lambda$?



$$\Delta B_{\Lambda\Lambda}({}^{4}_{\Lambda\Lambda}H) = B_{\Lambda\Lambda}({}^{4}_{\Lambda\Lambda}H) - 2\left(\frac{2}{3}B_{\Lambda}({}^{3}_{\Lambda}H_{exc.}) + \frac{1}{3}B_{\Lambda}({}^{3}_{\Lambda}H_{g.s.})\right)$$

calculation:

(i) ${}^{3}_{\Lambda}H$ binding from Λnp Faddeev, NSC97

	$S=\frac{1}{2}$	$S=\frac{3}{2}$
e	0.069 (0.076)	0.015 (0.015)
f	0.195 (0.203)	0.003 (0.004)

(MeV)

construct Λd potentials to reproduce Λnp scatt. and binding

(ii) ${}^{4}_{\Lambda\Lambda}H$ binding from ΛΛd Faddeev

$V_{\Lambda\Lambda}$:	ESC00	ND	$NSC97_e$	$NSC97_f$	$V_{\Lambda\Lambda}=0$	
e(Λd)		0.74	0.16	0.13	0.092	$B_{\Lambda\Lambda}$
f(Λd)	1.79	0.87	0.23	0.21	unbound	(MeV)

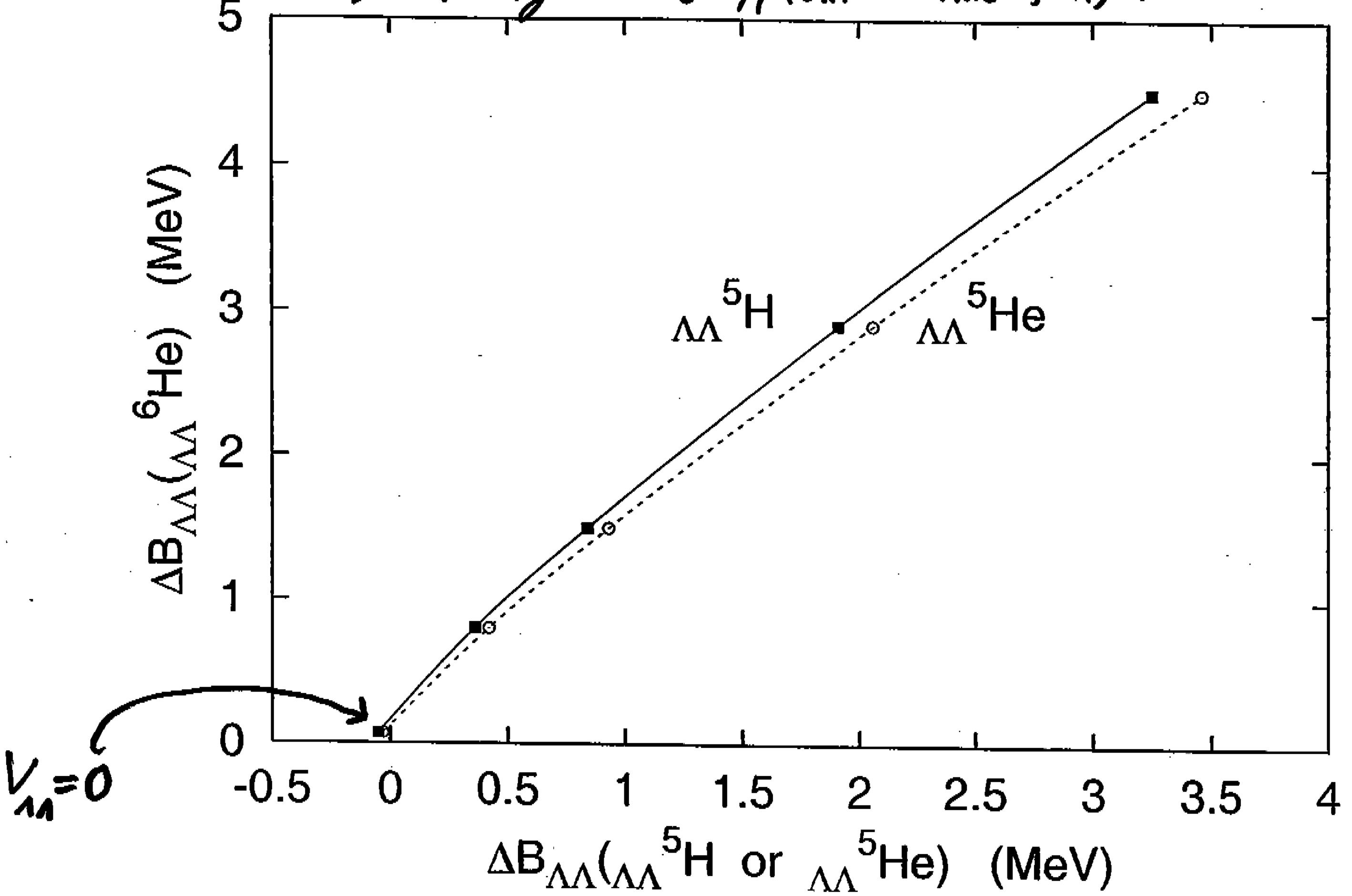
slight stability!

(iii) ${}^{4}_{\Lambda\Lambda}H$ from ΛΛnp Faddeev-Yakubovsky in progress

${}^{6}_{\Lambda\Lambda}He = \Lambda\Lambda\alpha$

Filikhin and Gal, Faddeev calcs. PRC (200 NPA

[removing s-wave approx. – Filikhin, Gal, Suslov PRC (2003)]



${}^{5}_{\Lambda\Lambda}H$: $\Lambda\ \underbrace{\Lambda\ {}^{3}H}_{{}^{4}_{\Lambda}H}$ is reproduced

1^{+} —— 1.1

${}^{5}_{\Lambda\Lambda}He$: $\Lambda\ \underbrace{\Lambda\ {}^{3}He}_{{}^{4}_{\Lambda}He}$ is reproduced

0^{+} —— 0

MeV

${}^{4}_{\Lambda}Z$

$\Delta B_{\Lambda\Lambda} = B_{\Lambda\Lambda} - 2\left(\frac{3}{4} B_{\Lambda}(1^{+}) + \frac{1}{4} B_{\Lambda}(0^{+})\right)$,

yet ${}^{5}_{\Lambda\Lambda}Z$ is stable against ${}^{5}_{\Lambda\Lambda}Z \rightarrow \Lambda + {}^{4}_{\Lambda}Z$

PRL 89 (July 2002)

arXiv:nucl-th/0110046 v3 8 Apr 2002

What Does Free Space ΛΛ Interaction Predict for ΛΛ Hypernuclei?

C. Albertus,[1] J.E. Amaro,[1] and J. Nieves[1]

[1] *Departamento de Física Moderna, Universidad de Granada, E-18071 Granada, Spain*

Data on ΛΛ hypernuclei provide a unique method to learn details on 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 ΛΛ hypernuclei. After including short–range (Jastrow) and RPA correlations, we find masses for these ΛΛ 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 OBE potentials to the $S = -2$ channel.

PACS numbers: 21.80.+a,13.75.Cs, 13.75.Ev,21.10.Dr,21.45+v,21.60.Jz

I. INTRODUCTION

In the 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 ΛΛ 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 ${}^{4}_{\Lambda\Lambda}$H has been recently reported [2]) ΛΛ hypernuclei, ${}^{6}_{\Lambda\Lambda}$He, ${}^{10}_{\Lambda\Lambda}$Be and ${}^{13}_{\Lambda\Lambda}$B, have been measured. The experimental binding energies, $B_{\Lambda\Lambda} = -\left[M\left({}^{A+2}_{\Lambda\Lambda}Z\right) - M\left({}^{A}Z\right) - 2m_\Lambda\right]$, are reported in Table I. Note that the ${}^{6}_{\Lambda\Lambda}$He energy has been updated very recently [3] in contradiction to the old one, $B_{\Lambda\Lambda}=$ 10.9±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 ΛΛ 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 of their inclusion the effective ΛΛ interaction, fitted to the ΛΛ–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 ΛΛ hypernuclei. This has never been achieved before despite the use of different ΛΛ 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. Due to the difficulty of including RPA effects in NJG models and since both sets of interactions give similar energies in absence of nuclear effects, in this work we have used BJ-type potentials.

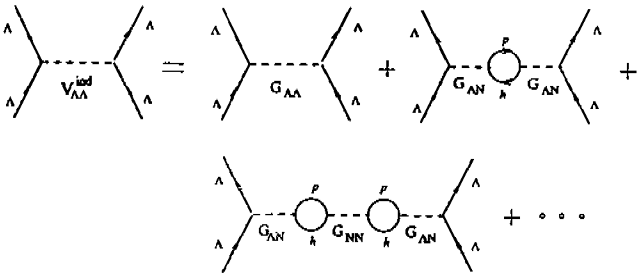


FIG. 1: Diagrammatic definition of $V^{ind}_{\Lambda\Lambda}$.

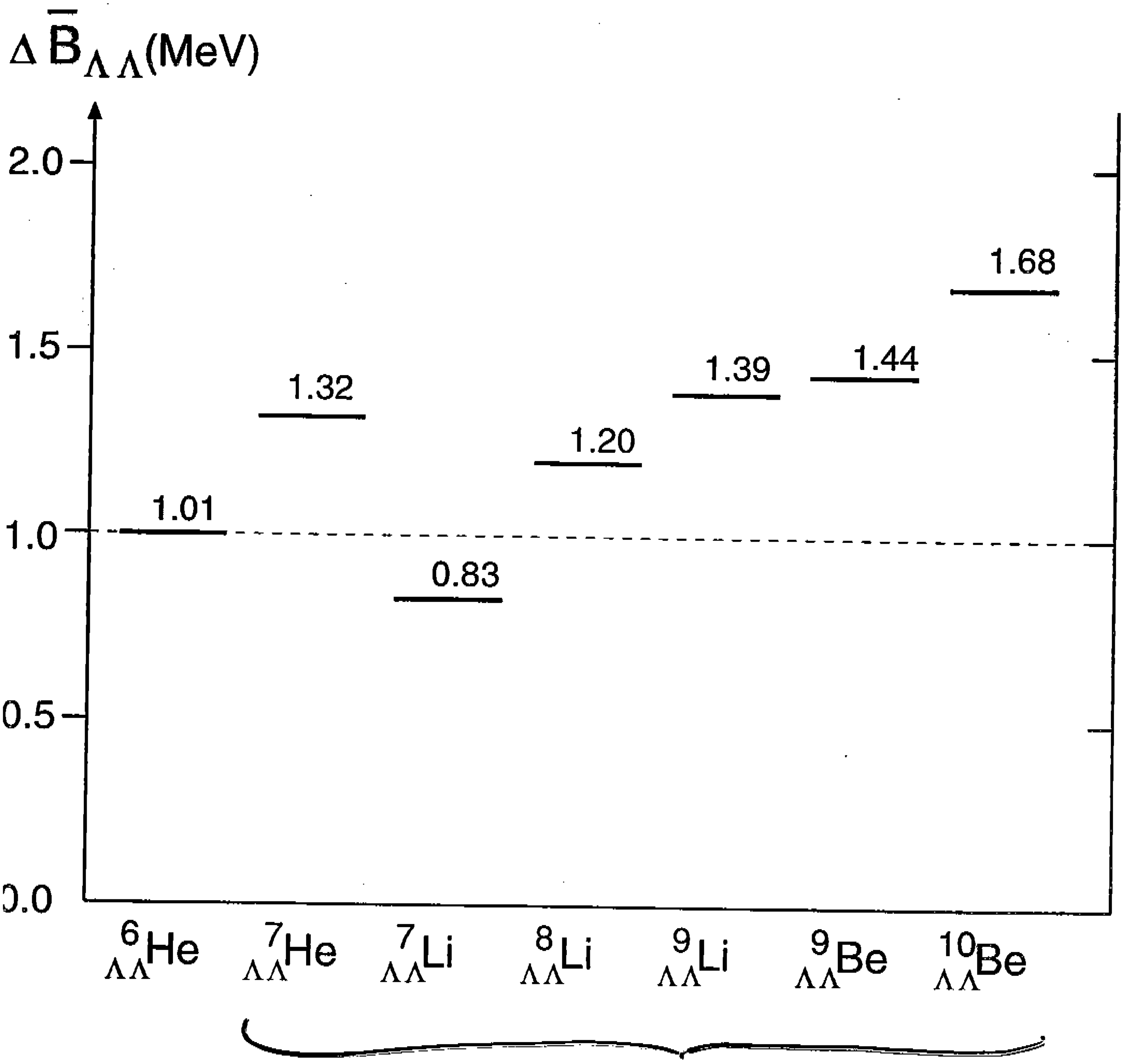
II. MODEL FOR ΛΛ HYPERNUCLEI

A. Variational Scheme: Jastrow type correlations

Following the work of Ref. [8], we model the ΛΛ hypernuclei by an interacting three-body ΛΛ+nuclear core system. Thus, we determine the intrinsic wave–function, $\Phi_{\Lambda\Lambda}(\vec{r_1},\vec{r_2})$, and the binding energy $B_{\Lambda\Lambda}$, where $\vec{r}_{1,2}$ are the relative coordinates of the hyperons respect to the nucleus, from the intrinsic Hamiltonian.

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

where $h_{\rm sp}(i) = -\vec{\nabla}_i^2/2\mu_A + \mathcal{V}_{A\Lambda}(|\vec{r_i}|)$, M_A and μ_A are the nuclear core and the Λ-core reduced masses respectively. The Λ-nuclear core potential, $\mathcal{V}_{A\Lambda}$, is adjusted to reproduce the binding energies, B_Λ (> 0), of the corresponding single–Λ hypernuclei [8], and $V_{\Lambda\Lambda}$ stands for the ΛΛ interaction in the medium. Due to the presence of the second Λ a dynamical re-ordering effect in the nuclear core is produced. Both the ΛΛ free interaction and this re-ordering 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 re-ordering effects



$\alpha\, X\, \Lambda\Lambda$ cluster model

PRC 66, 024007 (2002)

Four-body cluster structure of $A = 7 - 10$ double-Λ hypernuclei

E. Hiyama

Institute of Particle and Nuclear Studies,

High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan

M. Kamimura

Department of Physics, Kyushu University, Fukuoka 812-8581,Japan

T. Motoba

Physics Department, Brookhaven National Laboratory, Upton, New York 11973

*and Laboratory of Physics, Osaka Electro-Comm. University, Neyagawa 572-8530, Japan**

T. Yamada

Laboratory of Physics, Kanto Gakuin University, Yokohama 236-8501, Japan

Y. Yamamoto

Physics Section, Tsuru University, Tsuru, Yamanashi 402-8555, Japan

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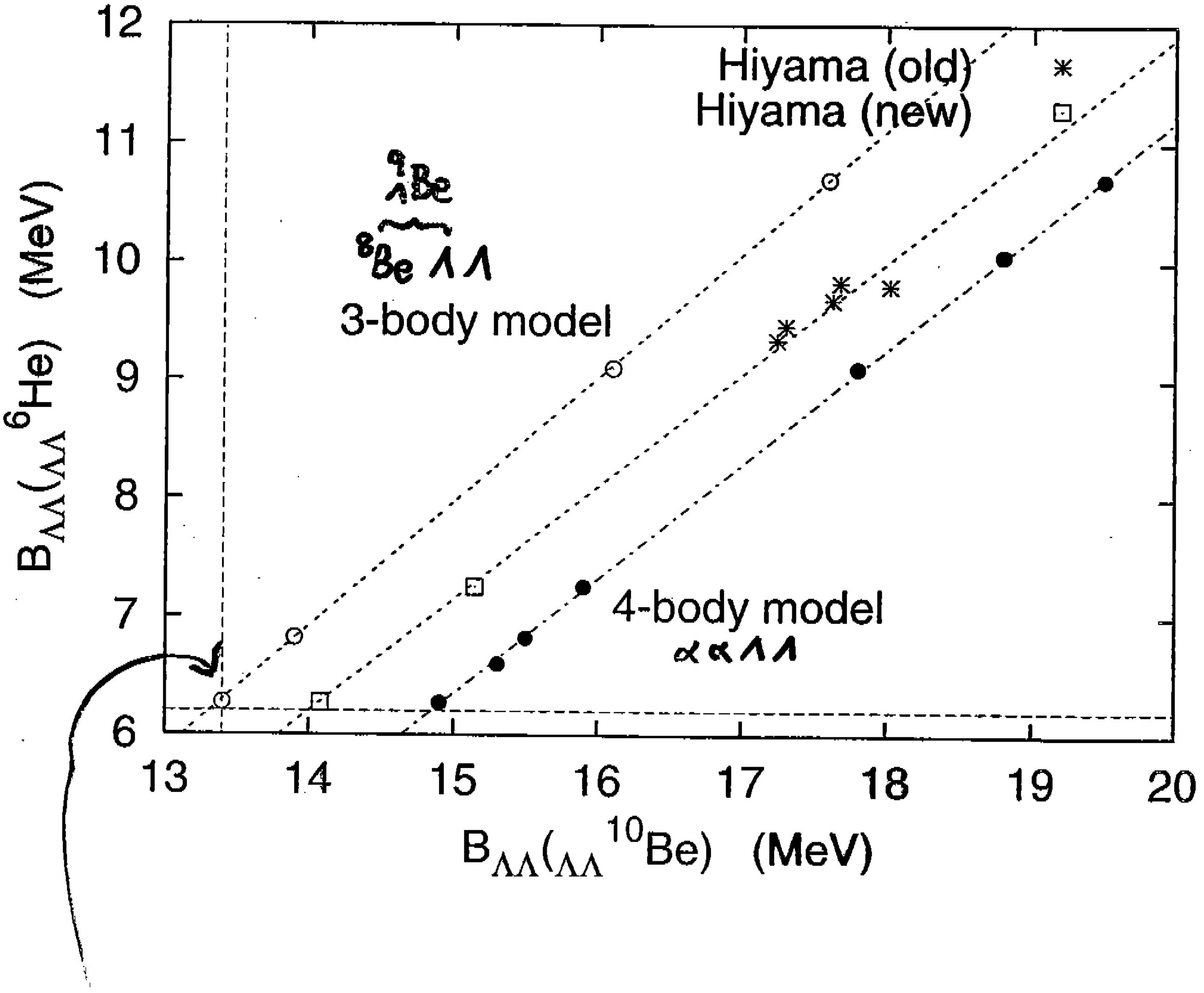
* permanent address

Percentages of rearrangement channels for ${}^{10}_{\Lambda\Lambda}\mathrm{Be}$ as a $\Lambda\Lambda\alpha\alpha$ system

channel	$V_{\Lambda\Lambda}=0$	ND	ESC00
$(\Lambda\alpha\alpha)+\Lambda$ dominated by ${}^{9}_{\Lambda}\mathrm{Be}+\Lambda$	45	37	32
$(\Lambda\Lambda\alpha)+\alpha$ dominated by ${}^{6}_{\Lambda\Lambda}\mathrm{He}+\alpha$	26	38	46
$(\Lambda\alpha)+(\Lambda\alpha)$ dominated by ${}^{5}_{\Lambda}\mathrm{He}+{}^{5}_{\Lambda}\mathrm{He}$	29	25	22
$(\Lambda\Lambda)+(\alpha\alpha)$	$\ll 1$	$\ll 1$	$\ll 1$

more than 50% of ${}^{10}_{\Lambda\Lambda}\mathrm{Be}$ resides in channels not describable by ${}^{8}\mathrm{Be}$ core!



$\Delta B_{\Lambda\Lambda} = 0$

4-body calculation gives $\Delta B_{\Lambda\Lambda} > 0$ for $V_{\Lambda\Lambda} = 0$

2. Calculations

Few Body systems with strong YY interactions

Filikhin + Gal (2001) PRC 65 (2002)
NPA 707 (2002)
PRL 89 (2002)

$\underbrace{a_{YY'}\ ,\ r_{YY'}}_{\text{low-energy scatt. parameters}}$ from OBE models

$$\Downarrow$$

$$V_{\substack{OBE\\ \text{simulated}}} = \sum_{i=1}^{3} \left(v_c^{(i)} + v_\sigma^{(i)}\, \vec{\sigma}_1 \cdot \vec{\sigma}_2 \right) e^{-r^2/\beta_i^2}$$

following YB [illegible] due to Hiyama et al.
PTP [illegible]

ΛΞ : Stoks + Rijken (NSC97, extended)

ΛΛ : Rijken (ESC00), to provide 'strong' ΛΛ binding but also previous potentials (NSC97)

Λα : fitted to ${}^{5}_{\Lambda}He$

Solve Faddeev equations for central interactions

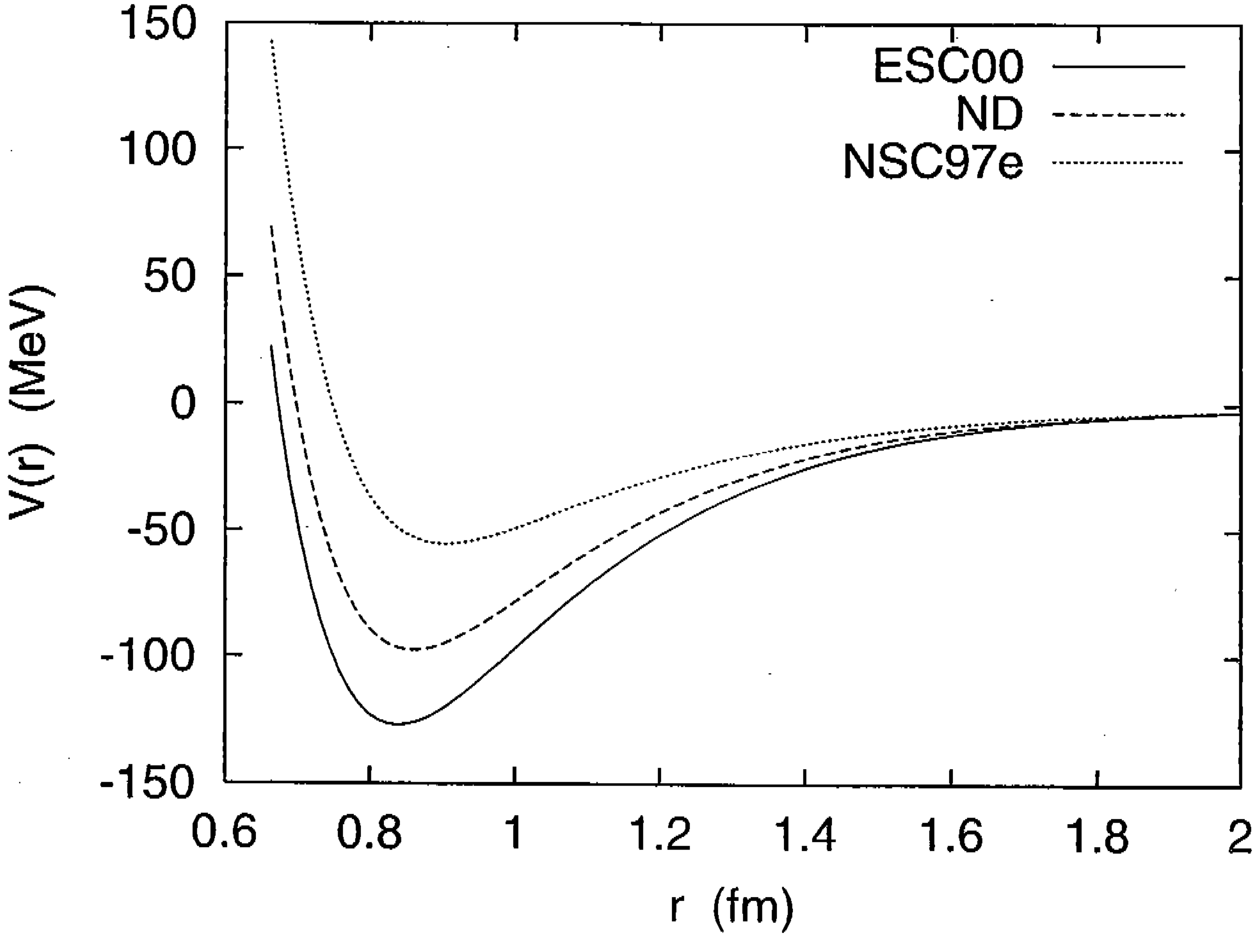
${}^{4}_{\Lambda\Lambda}H$: ΛΛd, ${}^{6}_{\Lambda\Lambda}He$: ΛΛα, ${}^{10}_{\Lambda\Lambda}Be$: ΛΛαα

ΛΛpn
s-wave approximation

Yakubovsky equations

no ΛN–ΣN, ΛΛ–ΞN explicit mixing

Nijmegen $\Lambda\Lambda$ simulated potentials ($^1S_0$)



Nijmegen potential models (one-boson-exchange)

$(\Lambda\Lambda)_{{}^1S_0}$

hard core D (1977) attraction 1 – 5 MeV

F (1979) repulsion

soft core (attractive)

NSC89

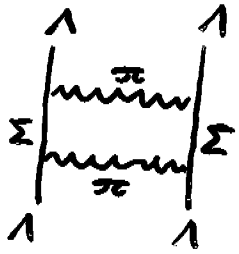
NSC97

Λ-binding ✓ } versions
spin dependence ✓ } e, f $\lesssim 1$ MeV

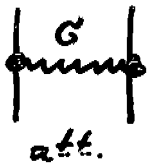
ESC00 ~ 5 MeV

why ΛΛ interaction is expected weak?

1. no one-pion exchange ---- --



2. quark-model motivated couplings



$$\frac{g^2_{\sigma\Lambda\Lambda}}{g^2_{\sigma NN}}, \frac{g^2_{\omega\Lambda\Lambda}}{g^2_{\omega NN}} \sim \left(\frac{2}{3}\right)^2 \quad (\text{non-s quarks})$$

$$\therefore |V_{\Lambda\Lambda}| \lesssim \tfrac{1}{2} |V_{NN}|$$

$$|V_{\Lambda\Lambda}| < |V_{\Lambda N}| < |V_{NN}|$$

but earlier ΛΛ hyp. data indicated $|V_{\Lambda N}| < |V_{\Lambda\Lambda}| \lesssim |V_{NN}|$

A. Gal, Jerusalem

Prague 07/0
TRIUMF 10/01
BNL 10/01
HU 11/01
Prague 01/02
GSI 06/02
EANIC 10/02

MULTI-STRANGENESS IN NUCLEI

1. $\Lambda\Lambda$ hypernuclei – review; and new experiments

AGS E906, Production of ${}^{4}_{\Lambda\Lambda}H$, Ahn et al, PRL **87**, 132504 (09/01)

KEK E373, Observation of ${}^{6}_{\Lambda\Lambda}He$, Takahashi et al., PRL **87** 212502 (11/01)

New calculations: Filikhin + Gal, nucl-th/0110008 0203036 $\downarrow$ 2002
Albertus + Amaro + Nieves, nucl-th/0110046 / 0204059

Hiyama ....

Relevance: existence of H dibaryon? $(uuddss)_{{}^1S_0}$ $\underline{1f}$

2. Few-body calculations: $\Lambda\Lambda d$ $({}^{4}_{\Lambda\Lambda}H)$ $\Lambda\Lambda p n$

$\Lambda\Lambda\alpha$ $({}^{6}_{\Lambda\Lambda}He)$

Test of BB interaction models $\Lambda\Lambda\alpha\alpha$ $({}^{10}_{\Lambda\Lambda}Be)$

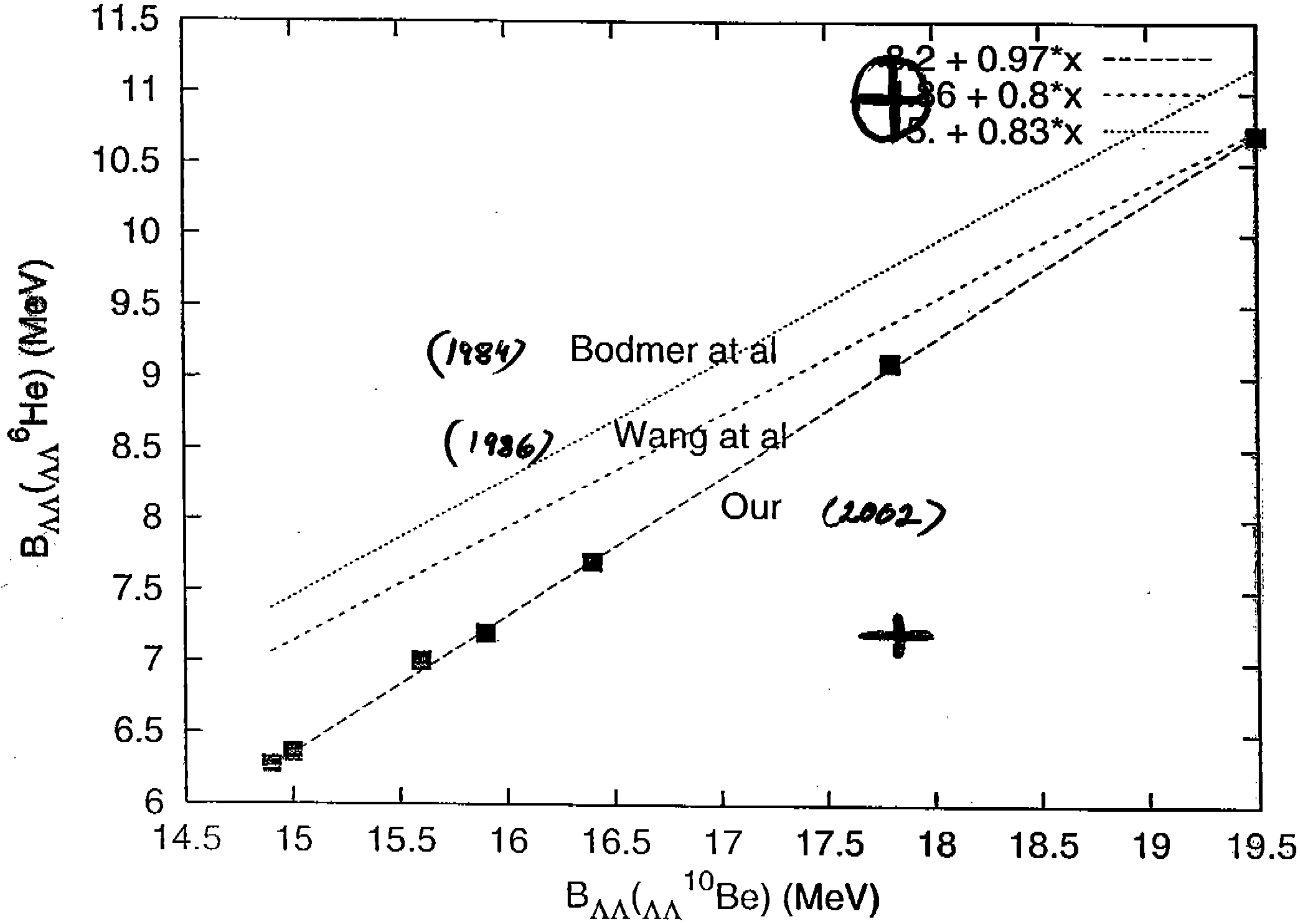
$\Lambda\Xi\alpha$ $({}^{6}_{\Lambda\Xi}He)$: onset of Ξ stability against $\Xi N \to \Lambda\Lambda$

lightest $S=-3$ hypernucleus?

Relevance: hyperon content of neutron stars; hyperstars; transition from hadronic phase to strange quark matter.

3. Strange Hadronic Matter – update: Schaffner + Gal, PRC **62**, 034311 (2000)

N, Λ, Σ, Ξ matter; vs. u, d, s quark matter



- 'old' ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ event (1966)
- 'new' ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ event (2001)

$\Delta B_{\Lambda\Lambda} = \begin{matrix} 4.7 \pm 0.6 \\ 1.0 \pm 0.3 \end{matrix}$ MeV

'Our' = Filikhin and Gal, PRC 65 (2002) 041001
NPA 707 (2002) 491

Review

ΛΛ Hypernuclei

[1998 INT Workshop
by G. Franklin]

Stopped Ξ^- emulsion experiments

- Measure ΛΛ ground state via $\Lambda \to p\pi^-$ decay mode (only possible in light hypernuclei)
- Low K flux requirements
  (but need good K/π ratio)
- 3 reconstructed events identified in 30 years.
- 3 more recently observed ΛΛ hypernucli
  nonmesonic decays
  species and binding not determined
- ΛΛ Hypernuclei exist, $\Delta B_{\Lambda\Lambda}$ probably positive,

but...

extra ΛΛ binding $\langle V_{\Lambda\Lambda} \rangle^{{}^1S_0}$

		#K⁻	stops	$B_{\Lambda\Lambda}$ (MeV)	$\Delta B_{\Lambda\Lambda}$ (MeV)
•	Danysz *et al.* 1963 $\boxed{{}^{10}_{\Lambda\Lambda}\mathrm{Be}} \to {}^{9}_{\Lambda}\mathrm{Be} + p + \pi^-$ $\to \alpha + \alpha + p + \pi^-$	10^5	~2	17.7±0.4	4.3±0.4
• 'old'	Prowse 1966 $\boxed{{}^{6}_{\Lambda\Lambda}\mathrm{He}} \to {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-$ $\to \alpha + p + \pi^-$	10^6	~30	10.9±0.8	4.7 ± 1.0
o	Aoki *et al.* 1990 ${}^{10}_{\Lambda\Lambda}\mathrm{Be} \to {}^{10}_{\Lambda}\mathrm{B} + \pi^-$ $\to {}^3\mathrm{He} + \alpha + p + n + n$	10^9	80	8.5±0.7	−4.9 ± 0.7
	OR: ${}^{14}_{\Lambda\Lambda}\mathrm{C}^* + n \to \boxed{{}^{13}_{\Lambda\Lambda}\mathrm{B}} + p + n$ $\to {}^{13}_{\Lambda}\mathrm{C} + \pi^-$ $\to {}^3\mathrm{He} + \alpha + \alpha + n + n$			27.5±0.7	4.8 ± 0.7

$$\Delta B_{\Lambda\Lambda} \underset{\text{def.}}{=} B_{\Lambda\Lambda} - 2 B_{\Lambda}$$

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Nuclear Physics
Volume 49, November-December 1963, Pages 121-132

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- Abstract

Forty years of ΛΛ hypernucle

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The identification of a double hyperfragment

M. Danysz, K. Garbowska, J. Pniewski, T. Pniewski and J. Zakrzewski

E. R. Fletcher

J. Lemonne, P. Renard[†] and J. Sacton

W. T. Toner[††]

D. O'Sullivan, T. P. Shah and A. Thompson

P. Allen[‡], Sr. M. Heeran and A. Montwill

J. E. Allen, M. J. Beniston[‡‡], D. H. Davis and D. A. Garbutt

V. A. Bull, R. C. Kumar and P. V. March

Institute of Experimental Physics, University of Warsaw and Institute for Nuclear Research, Warsaw, Poland
H. H. Wills Physics Laboratory, University of Bristol, UK
Université Libre de Bruxelles, Belgium
CERN, Geneva, Switzerland
Institute for Advanced Studies, Dublin, Ireland
University College, Dublin, Ireland
University College, London, England
Westfield College, London, England

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Abstract

The detailed analysis is presented of an event which is interpreted as the mesonic cascade decay of a double hyperfragment produced by the capture of a Ξ^- hyperon on a light emulsion nucleus. The most likely interpretations of the double hyperfragment are those in terms of either $_{\Lambda\Lambda}\mathrm{Be}^{10}$ or $_{\Lambda\Lambda}\mathrm{Be}^{11}$.