Few-Body Approaches in Hypernuclei

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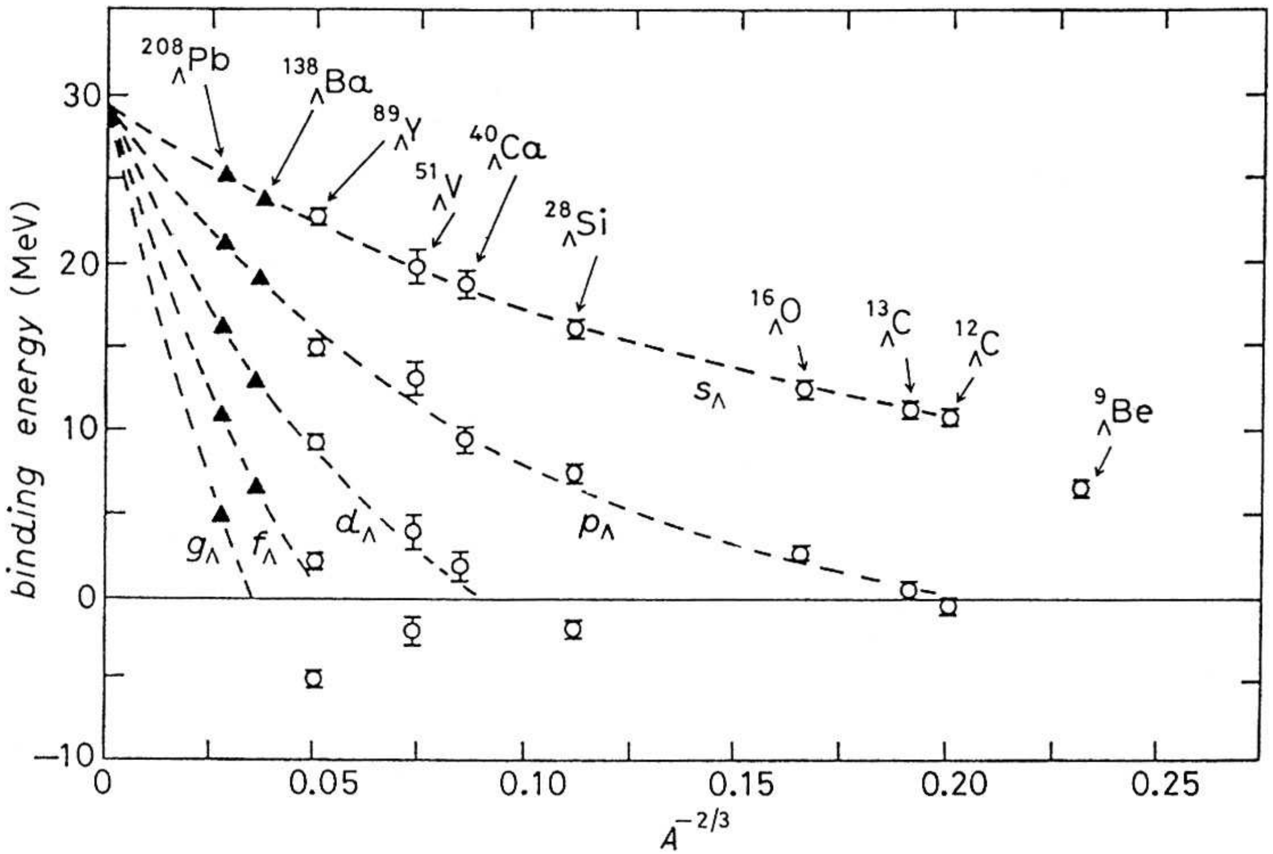
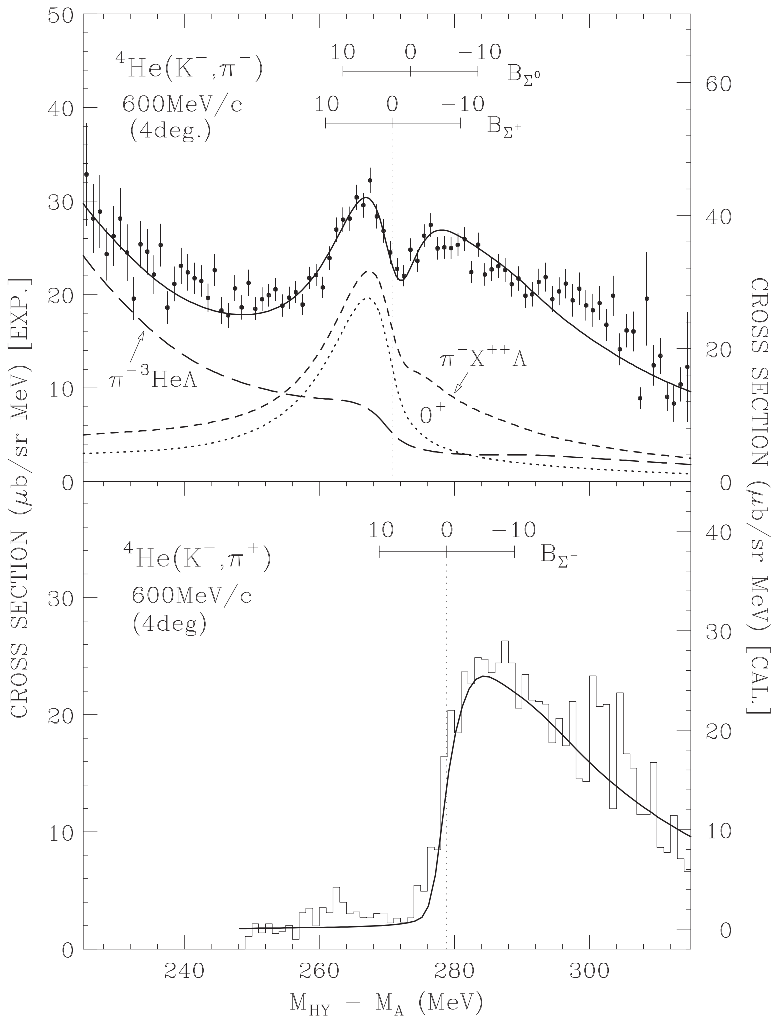
- Updated Nucl. Phys. A **754** (2005) 91c-102c

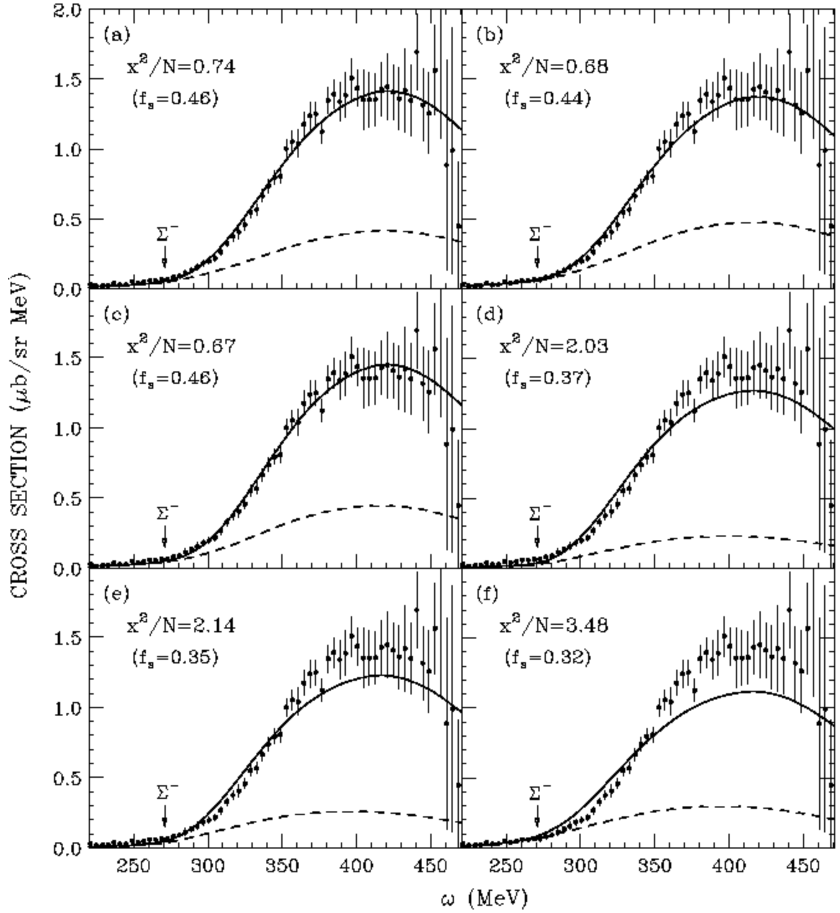
- Λ hyperon is bound by 28 MeV in nuclear matter.
- No ΛN bound state, binding starts with ${}^{3}_{\Lambda}$H;
  a minute binding energy $B_\Lambda({}^{3}_{\Lambda}\mathrm{H}) = 0.13 \pm 0.05$ MeV.
- Σ hyperons are not bound in nuclei except for ${}^{4}_{\Sigma}$He;
  $\Sigma N \to \Lambda N$ releases ~ 80 MeV in free space.
- $\Sigma N - \Lambda N$ coupling is important in certain few-body Λ hypernuclei.



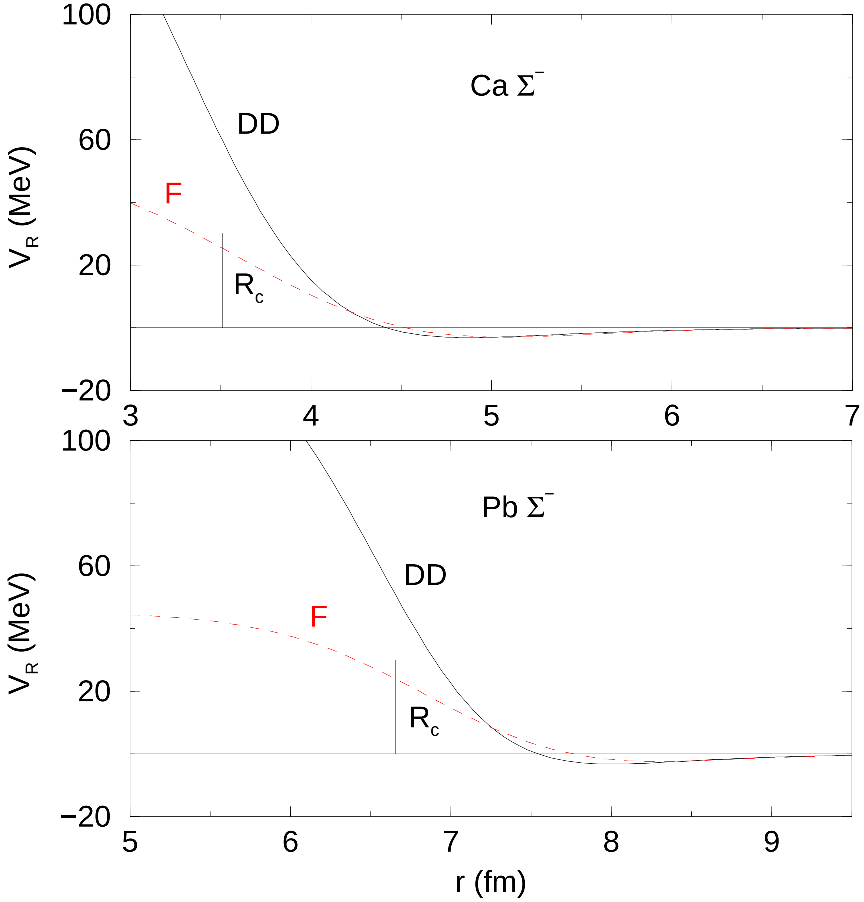
Λ binding energies vs. $A^{-2/3}$. Most B_Λ values are from (π^+, K^+) experiments at KEK. Curves represent calculations using an effective density-dependent Λ-nuclear potential (MDG 1988).



^{4}He$(K^-, \pi^\pm)$ spectra from BNL-E905 and as calculated [Harada, PRL **81** (1998) 5287]: evidence for a quasibound $I = \frac{1}{2}$ $\ {}^4_\Sigma$He.



DWIA calculations by Harada & Hirabayashi, NPA **759** (2005) 143, for the ^{28}Si(π^-, K^+) spectrum from KEK-E438, using six Σ-nucleus potentials, (a)-(c) with inner repulsion, (d)-(f) fully attractive.



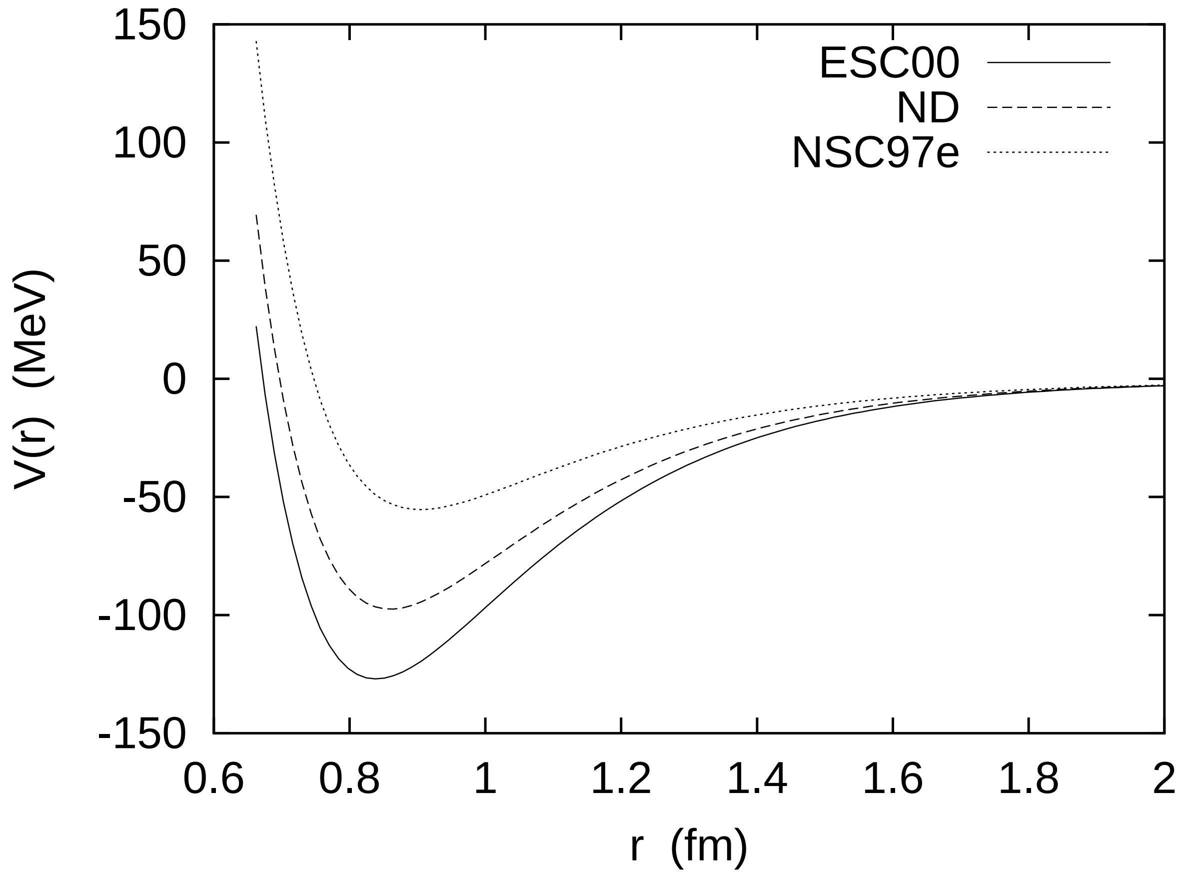
E. Friedman, A. Gal, Phys. Rept. **452** (2007) 89

Σ^- nuclear potentials fitted to Σ^- atomic data.

Inner repulsion established phenomenologically.

- No $\Lambda\Lambda N$, perhaps also no $\Lambda\Lambda NN$ bound state;
  the lightest measured is ${}^{6}_{\Lambda\Lambda}\mathrm{He}$, implying bound ${}^{5}_{\Lambda\Lambda}\mathrm{H} - {}^{5}_{\Lambda\Lambda}\mathrm{He}$.
- Ξ hyperons are perhaps bound by ~ 15 MeV in nuclear matter,
  no measured bound states have been reported that are accepted;
  $\Xi N \longrightarrow \Lambda\Lambda$ releases ~ 25 MeV in free space.
- lightest $S = -3, -4$ bound states? the case for ${}^{7}_{\Lambda\Lambda\Xi}\mathrm{He}$.
- Strange Hadronic Matter $\{p, n, \Lambda, \Xi^0, \Xi^-\}$,
  similarities to strange quark matter.
- Kaon condensation, on earth & in heaven (neutron stars)?

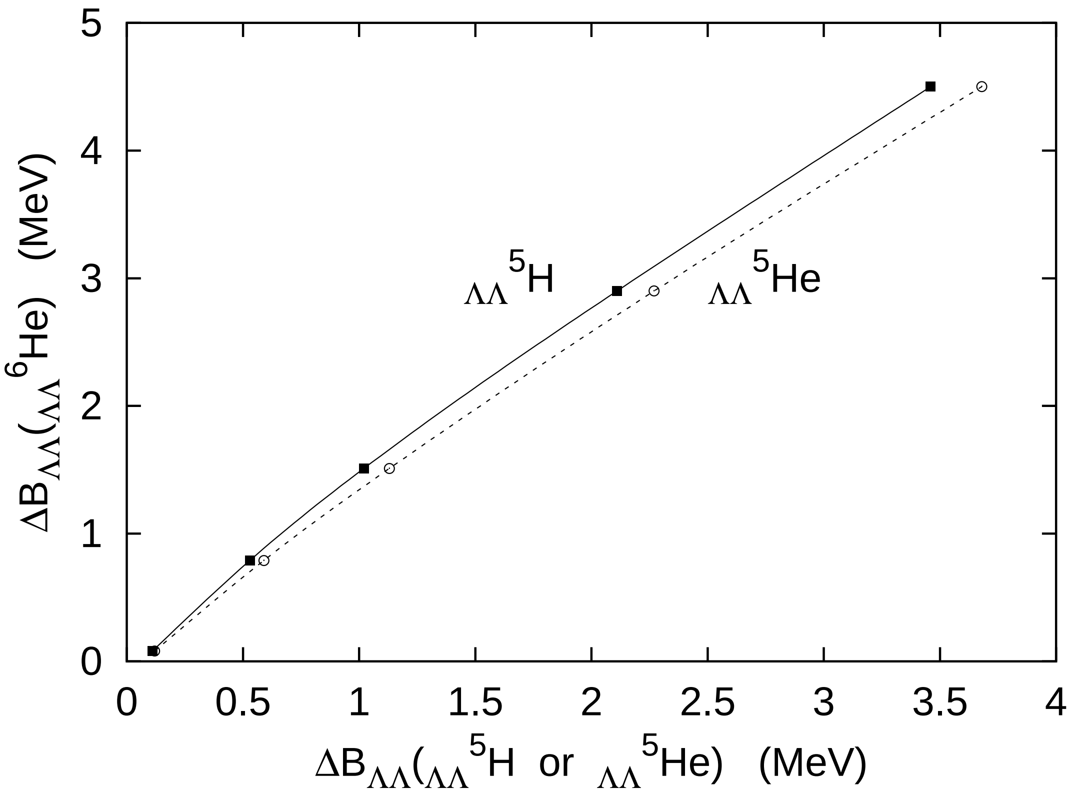
Recent Advances in Strangeness Nuclear Physics
Nucl. Phys. A 804 (2008), Eds. A. Gal, R.S. Hayano



I.N. Filikhin, A. Gal, Nucl. Phys. A **707** (2002) 491.

Nijmegen OBE phase-equivalent soft-core $\Lambda\Lambda$ potentials.

$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) \approx 1$ MeV implies a fairly weak $\Lambda\Lambda$ interaction (NSC97).

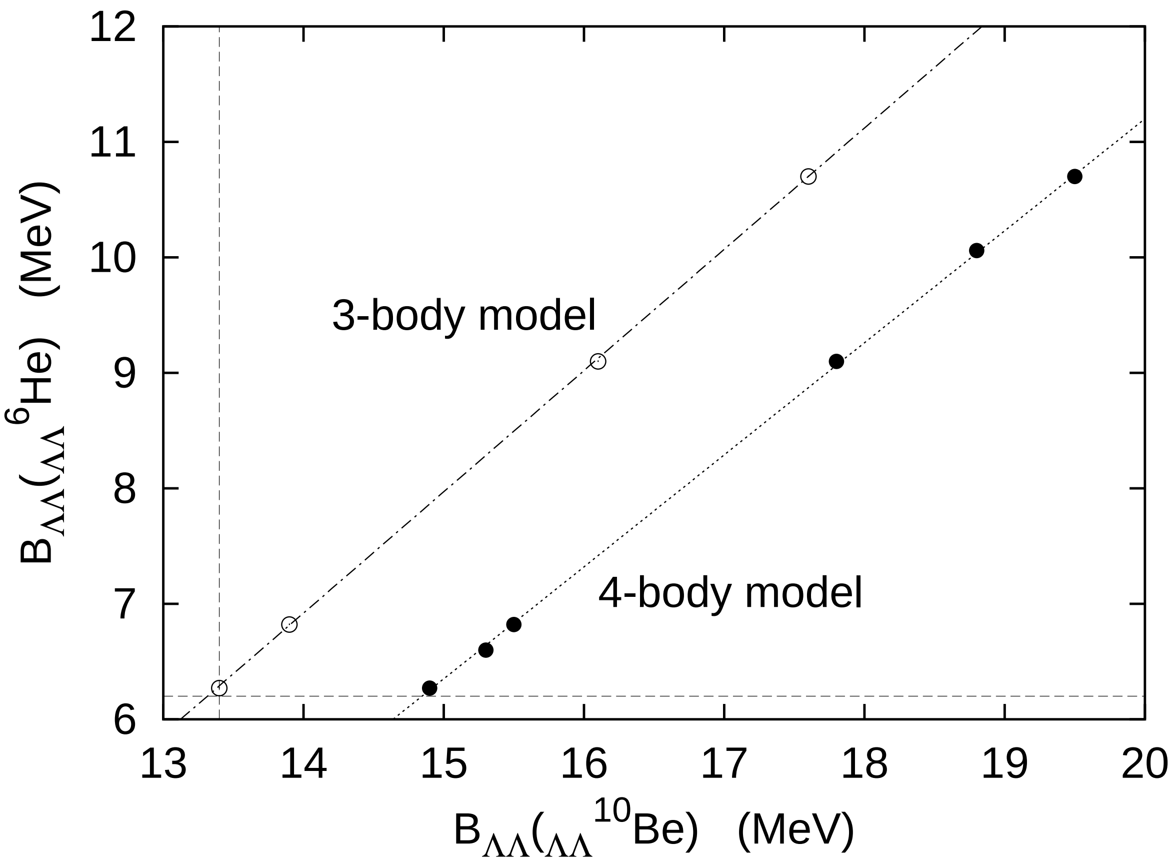


I.N. Filikhin, A. Gal, Nucl. Phys. A **707** (2002) 491.

s-wave Faddeev calculations of $\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He})$ vs. $\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{5}\mathrm{H},\ {}_{\Lambda\Lambda}^{5}\mathrm{He})$.

$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) \equiv \mathrm{B}_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) - 2\mathrm{B}_{\Lambda}({}_{\Lambda}^{5}\mathrm{He})$.

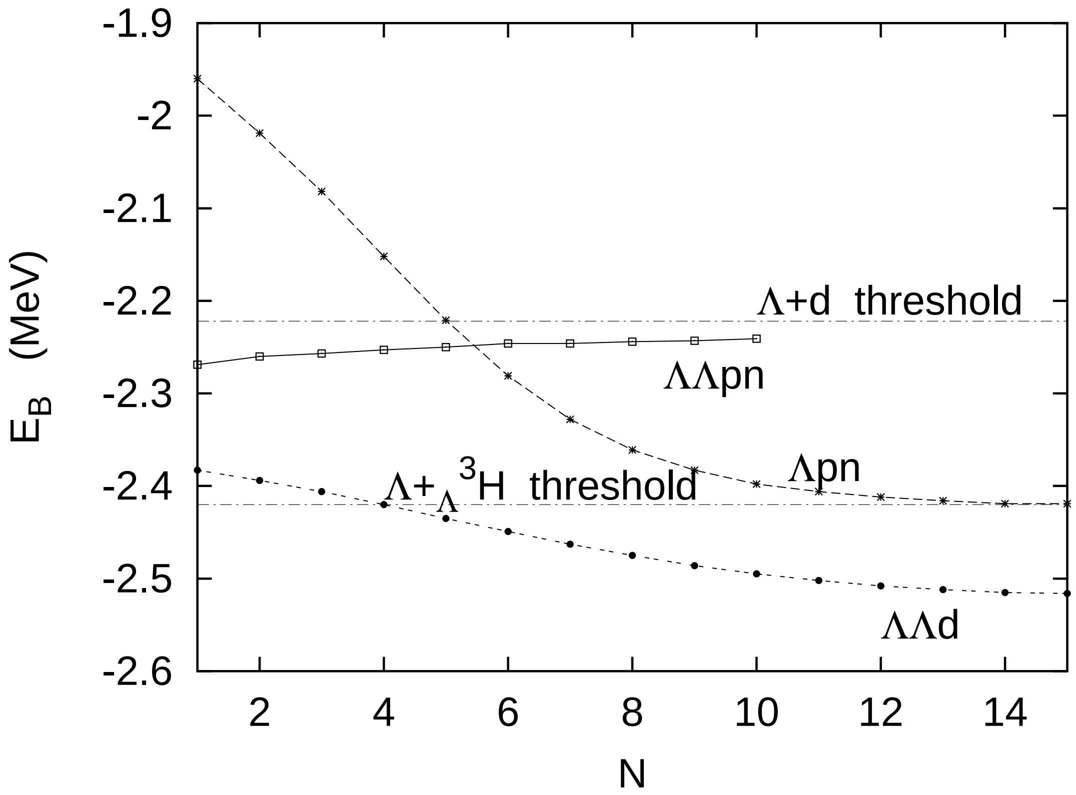
$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) \approx 1$ MeV implies that ${}_{\Lambda\Lambda}^{5}\mathrm{H}$ & ${}_{\Lambda\Lambda}^{5}\mathrm{He}$ are also bound.



I.N. Filikhin, A. Gal, Nucl. Phys. A **707** (2002) 491.

s-wave Faddeev-Yakubovsky calculations for $_{\Lambda\Lambda}^{10}$Be: ^{8}Be$\Lambda\Lambda$ vs. $\alpha\alpha\Lambda\Lambda$.

Four-body model admits $\alpha\Lambda - \alpha\Lambda$ & $\alpha\Lambda\Lambda - \alpha$ correlations.

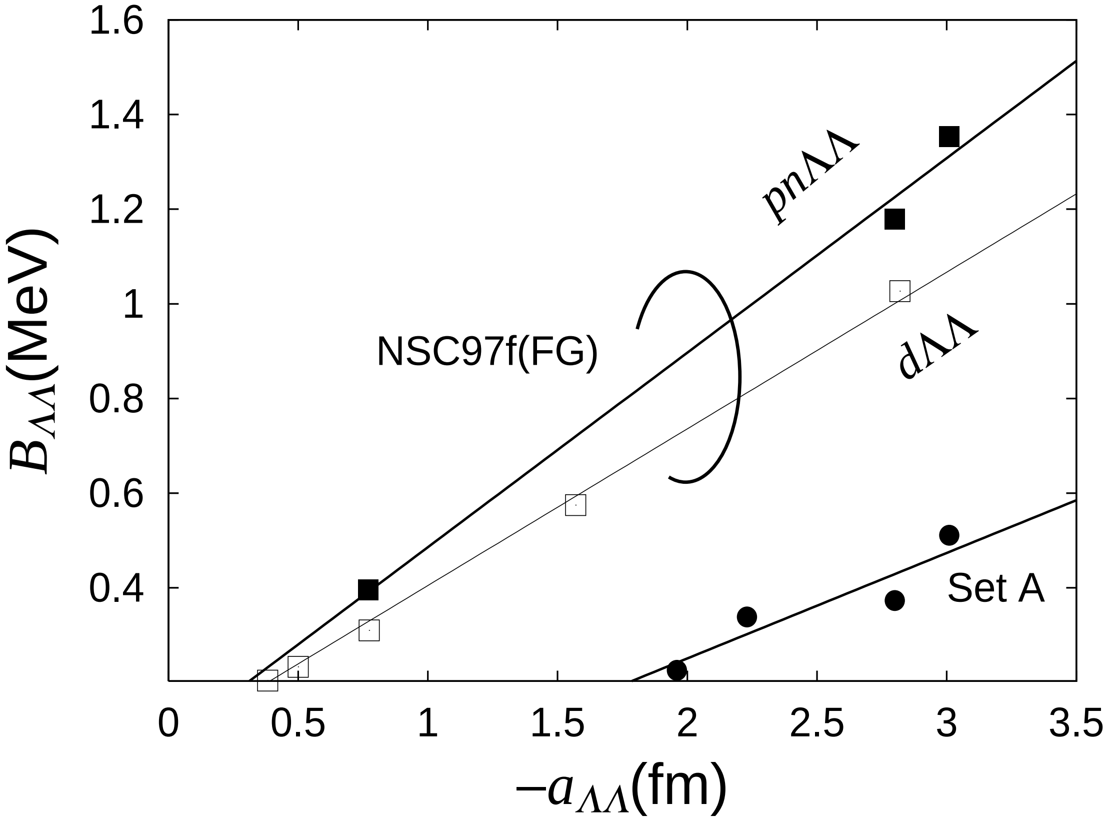


I.N. Filikhin, A. Gal, Phys. Rev. Lett. **89** (2002) 172502.

s-wave Faddeev-Yakubovsky calculations for Λpn, $\Lambda\Lambda d$ and $\Lambda\Lambda pn$.

$\Lambda\Lambda d$: Λd binding implies $\Lambda\Lambda d$ binding.

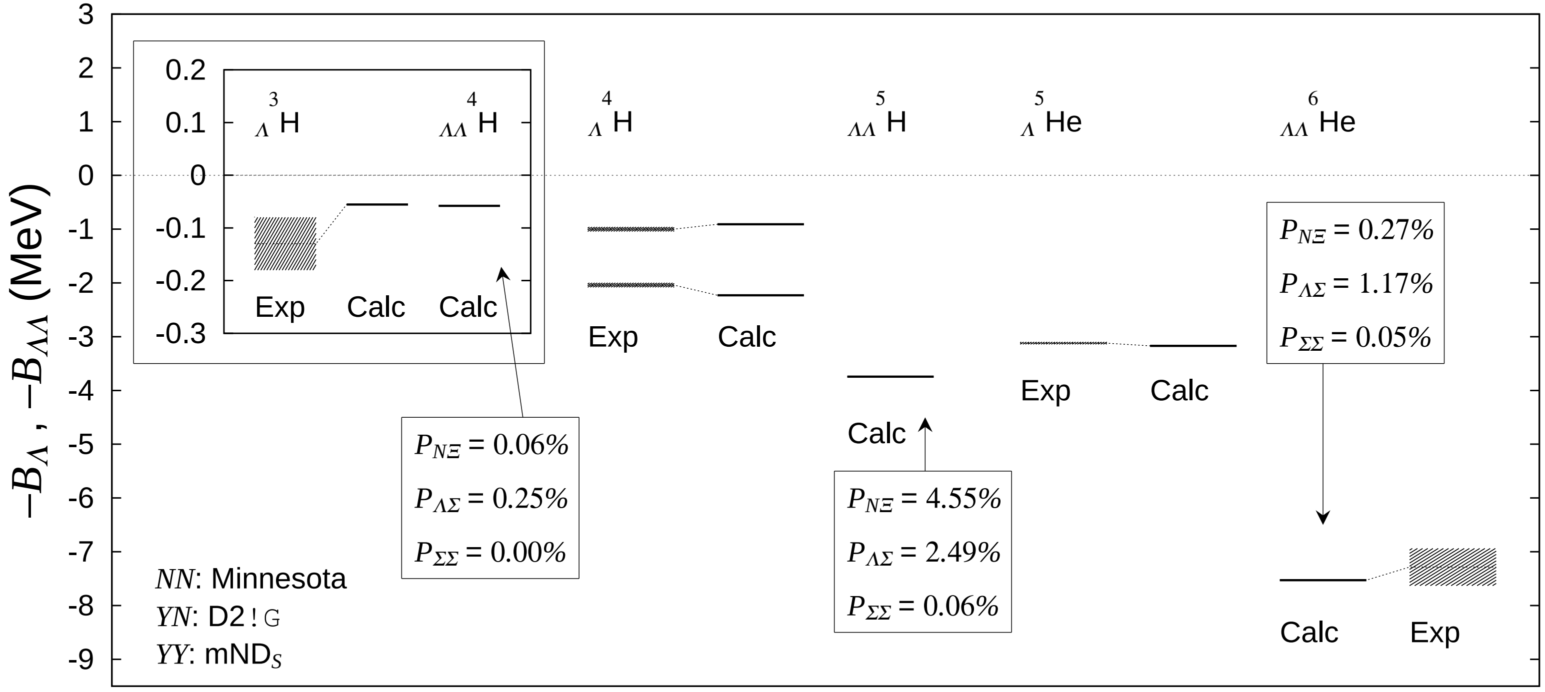
$\Lambda\Lambda pn$: 4 ΛN + 1 $\Lambda\Lambda$ (unbound) pairs vs. 1 pn (bound) pair.



H. Nemura, Y. Akaishi, K.S. Myint, Phys. Rev. C **67** (2003) 051001(R).

$B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{4}\mathrm{H})$ calculated using stochastic variational methods.

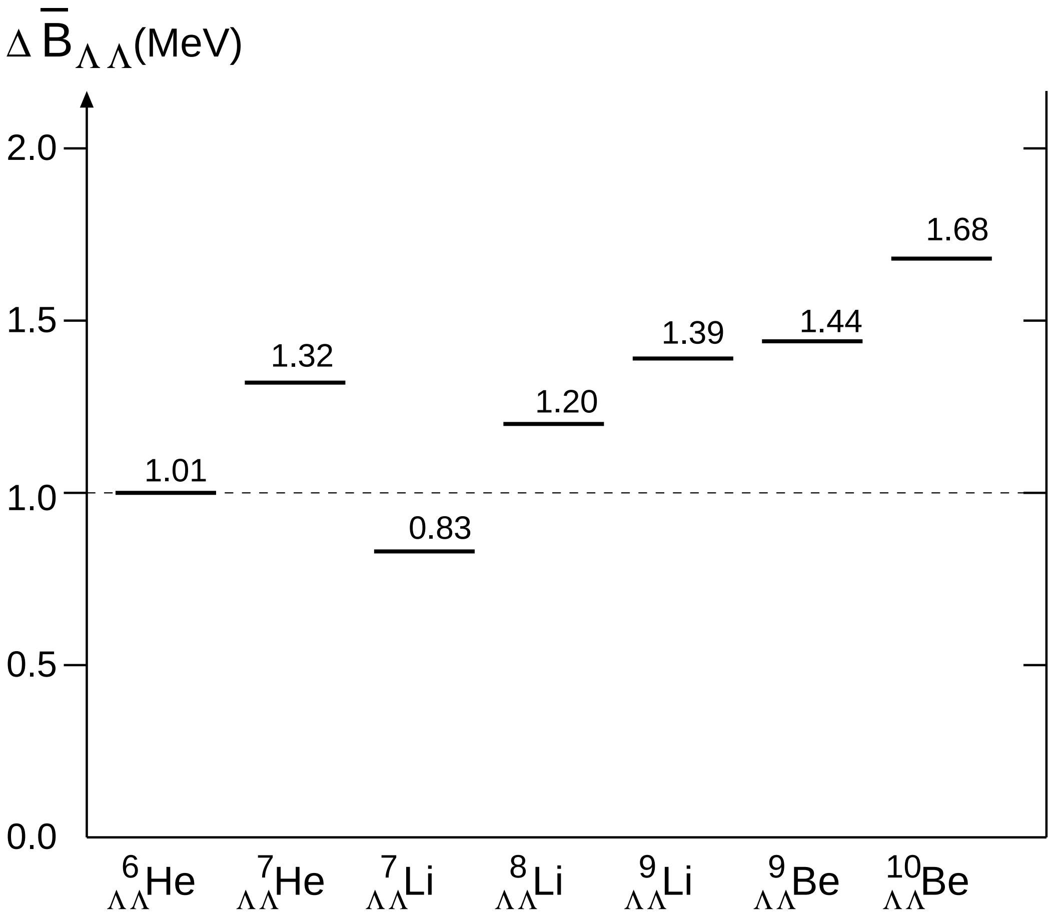
Whether or not ${}_{\Lambda\Lambda}^{4}\mathrm{H}$ is bound is unsettled.



H. Nemura, S. Shinmura, Y. Akaishi, K.S. Myint, PRL **94** (2005) 202502.

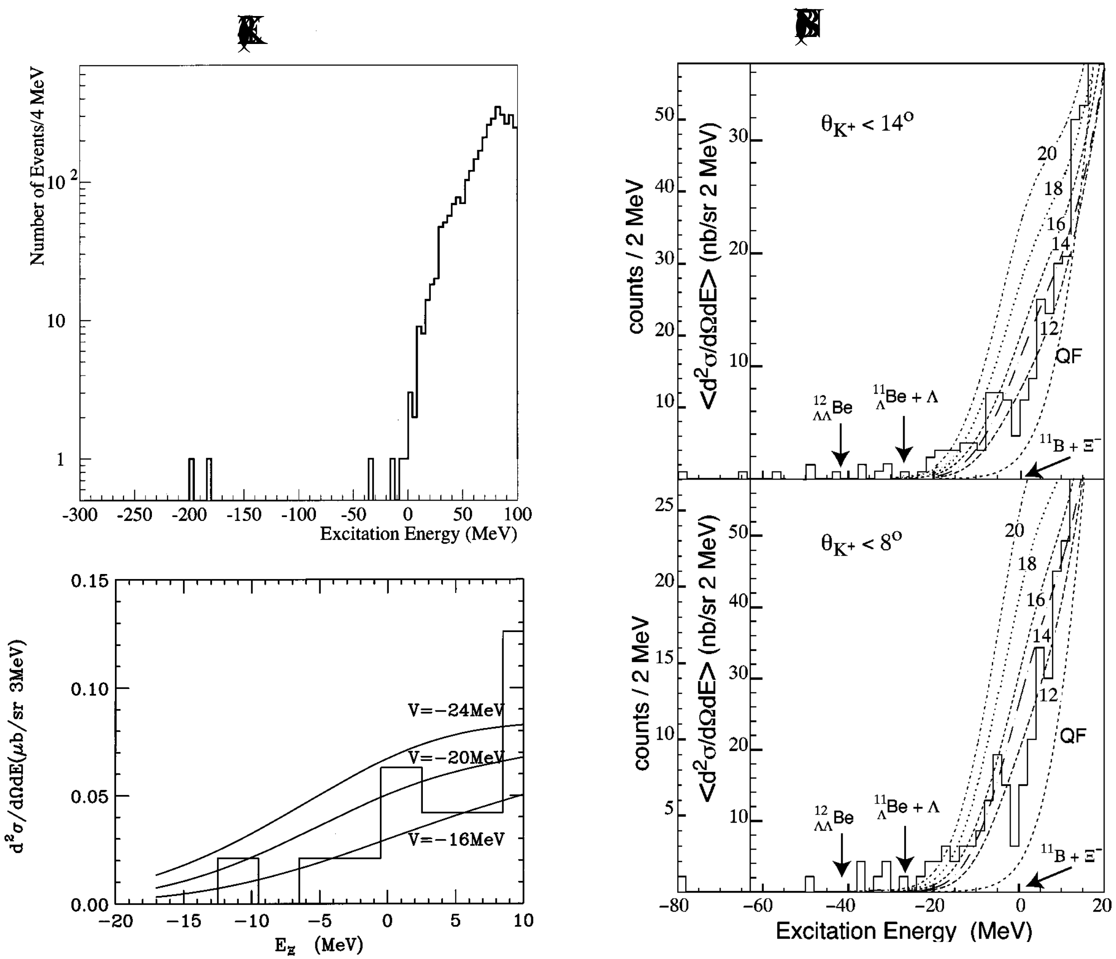
Calculated Λ & $\Lambda\Lambda$ separation energies of s-shell hypernuclei.

$\Lambda N - \Sigma N$ and $\Lambda\Lambda - \Xi N$ mixings are important.

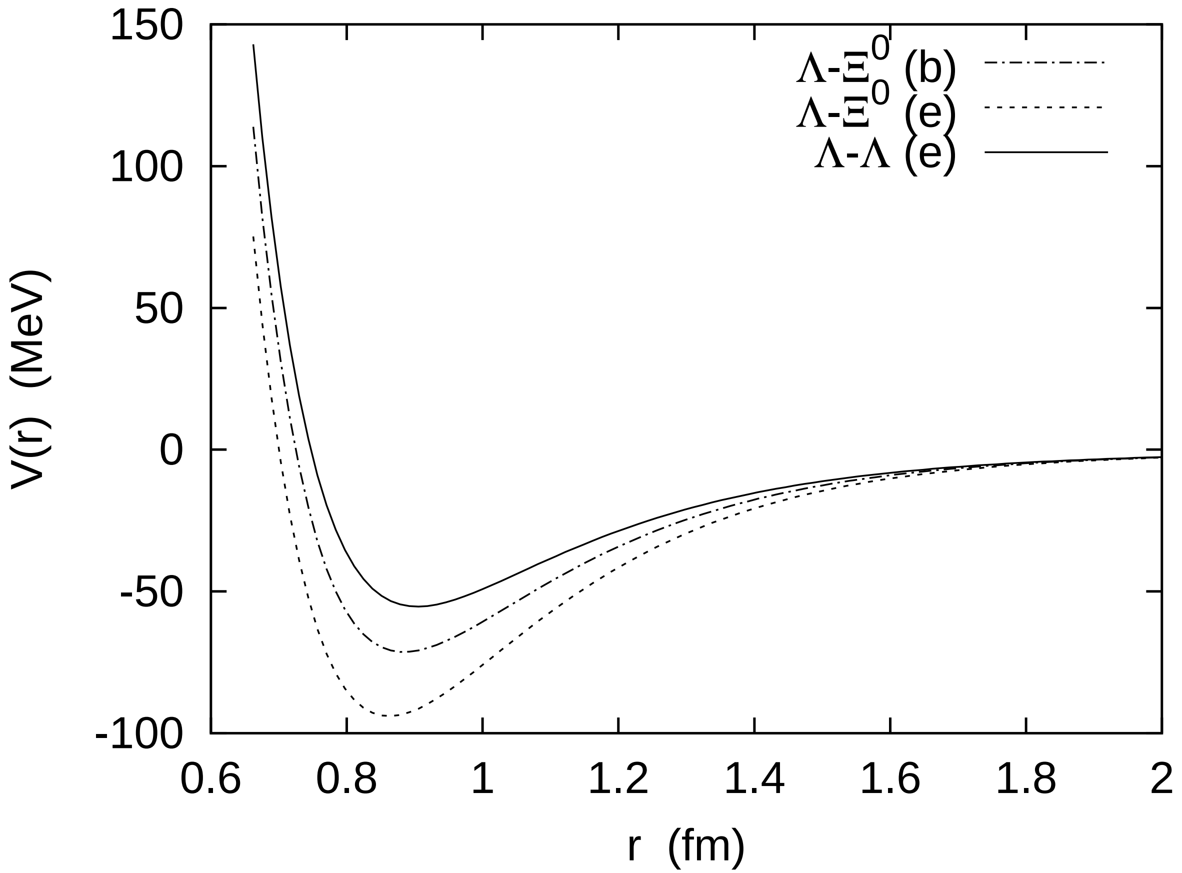


Hiyama, Kamimura, Motoba, Yamada, Yamamoto, NPA **754** (2005) 103c.

Calculated $\Delta B_{\Lambda\Lambda}$ values in 3-body & 4-body cluster models.



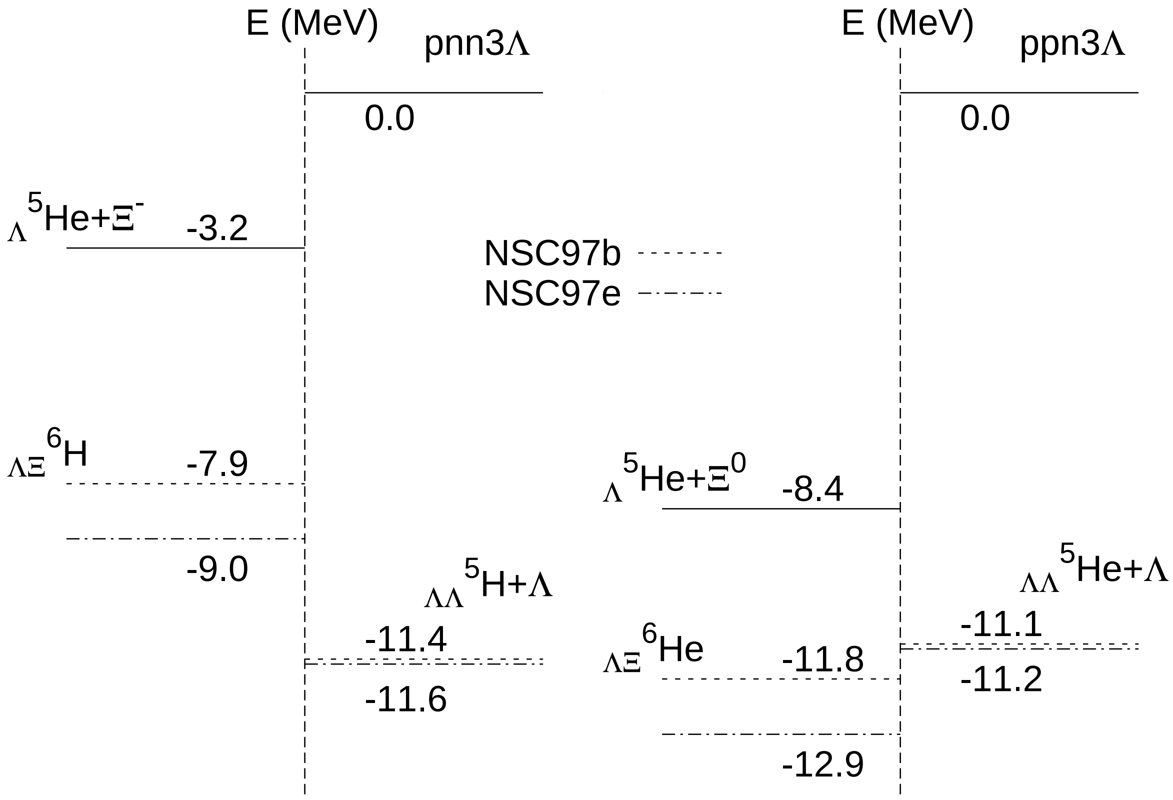
^{12}C(K^-, K^+) missing-mass spectra from KEK-E224 (left), and from BNL-E885 (right), as a function of Ξ^- nuclear potential depth.



I.N. Filikhin, A. Gal, Phys. Rev. C **65** (2002) 041001(R).

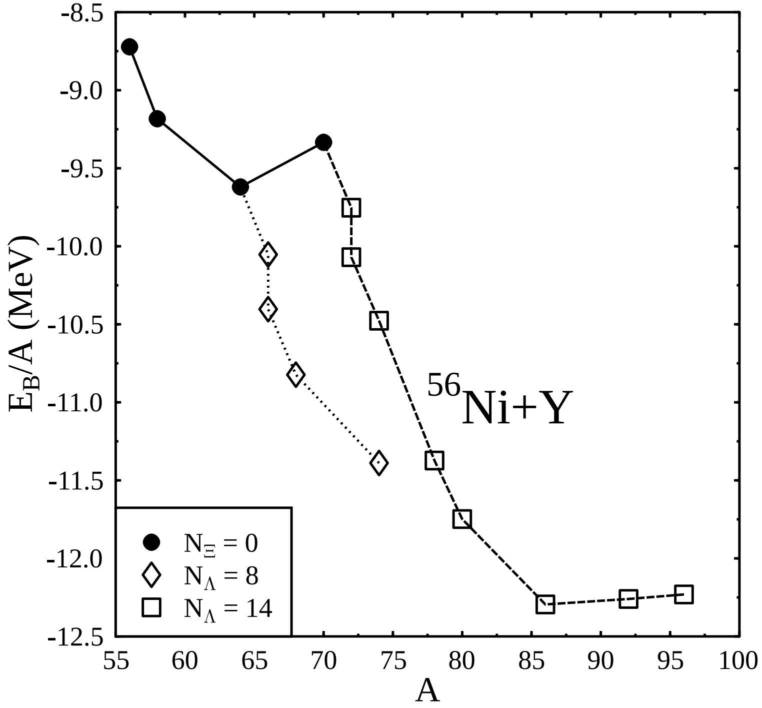
NSC97 phase-equivalent YY potentials.

$\Lambda\Xi$ attraction stronger than $\Lambda\Lambda$.



I.N. Filikhin, A. Gal, Phys. Rev. C **65** (2002) 041001(R).

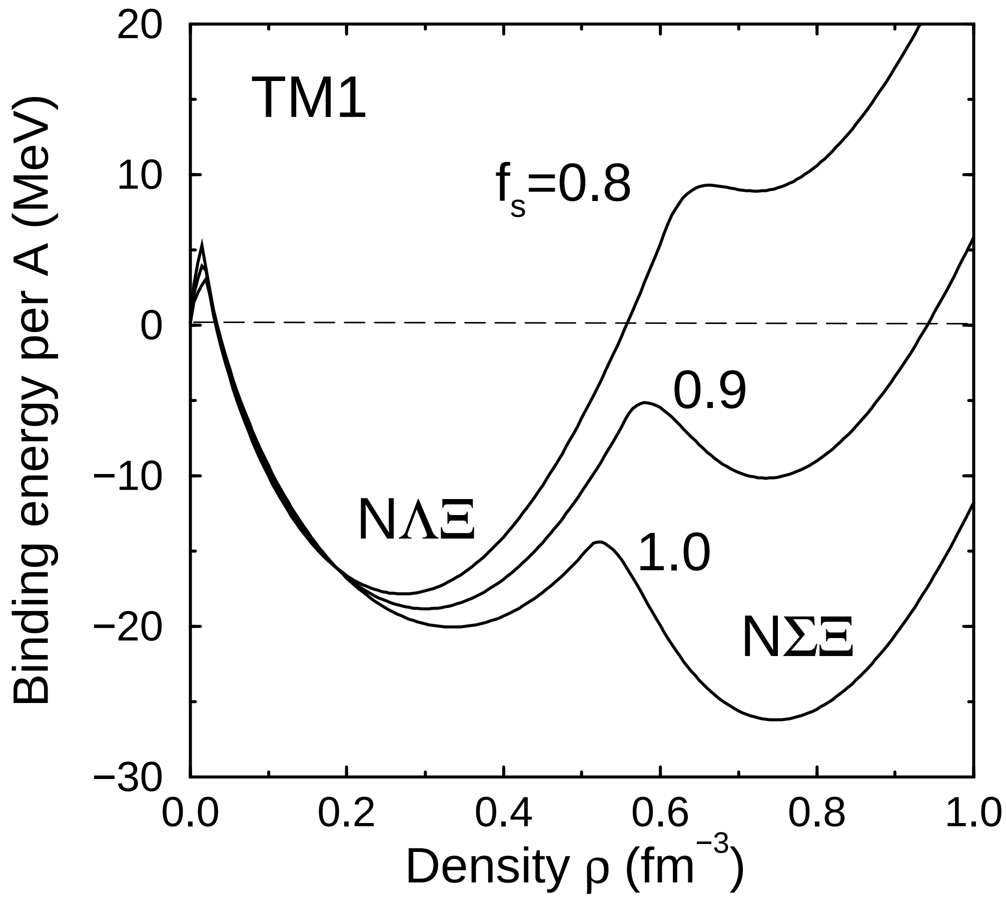
s-wave Faddeev calculations for $_{\Lambda\Xi}^{6}$H and $_{\Lambda\Xi}^{6}$He; marginal binding. Onset of Ξ hyperon stability probably at $_{\Lambda\Lambda\Xi}^{7}$He. Reliable model calculations are warranted (JPG **35** (2008) 135103 is unreliable).



J. Schaffner, C.B. Dover, A. Gal, C. Greiner, H. Stocker, PRL 71 (1993) 1328

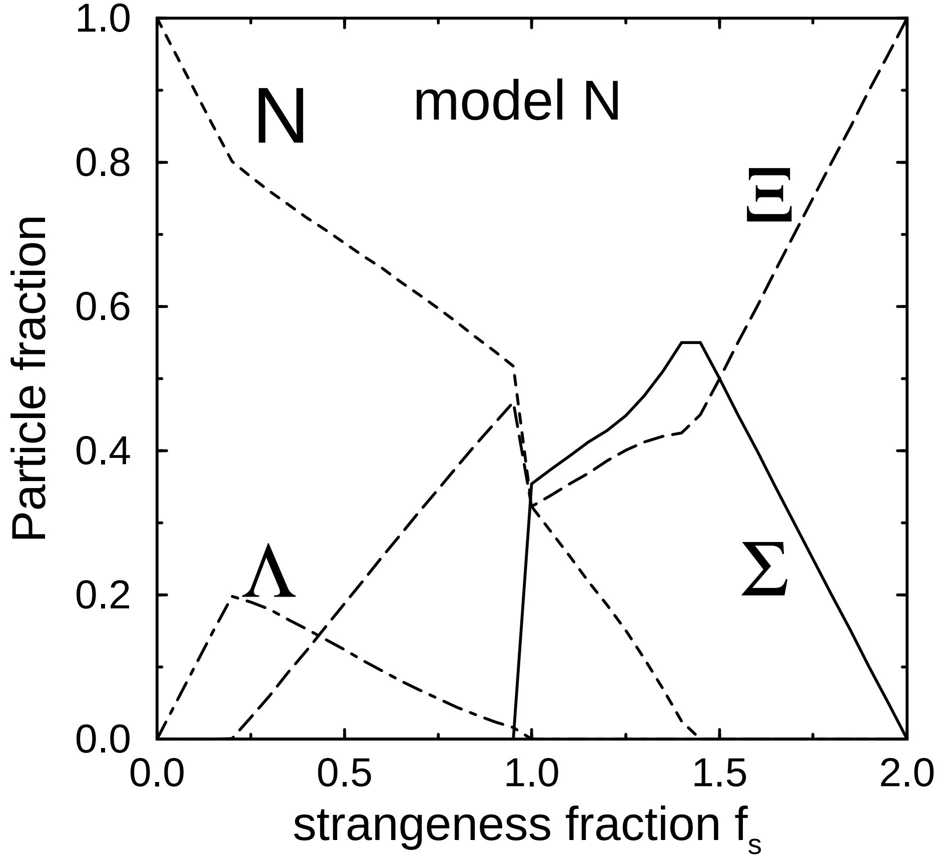
Calculated binding energy of multistrange $^{56}\mathrm{Ni} + \Lambda,\ \Xi$ hyperons.

$\Xi N \rightarrow \Lambda\Lambda$ is Pauli blocked.



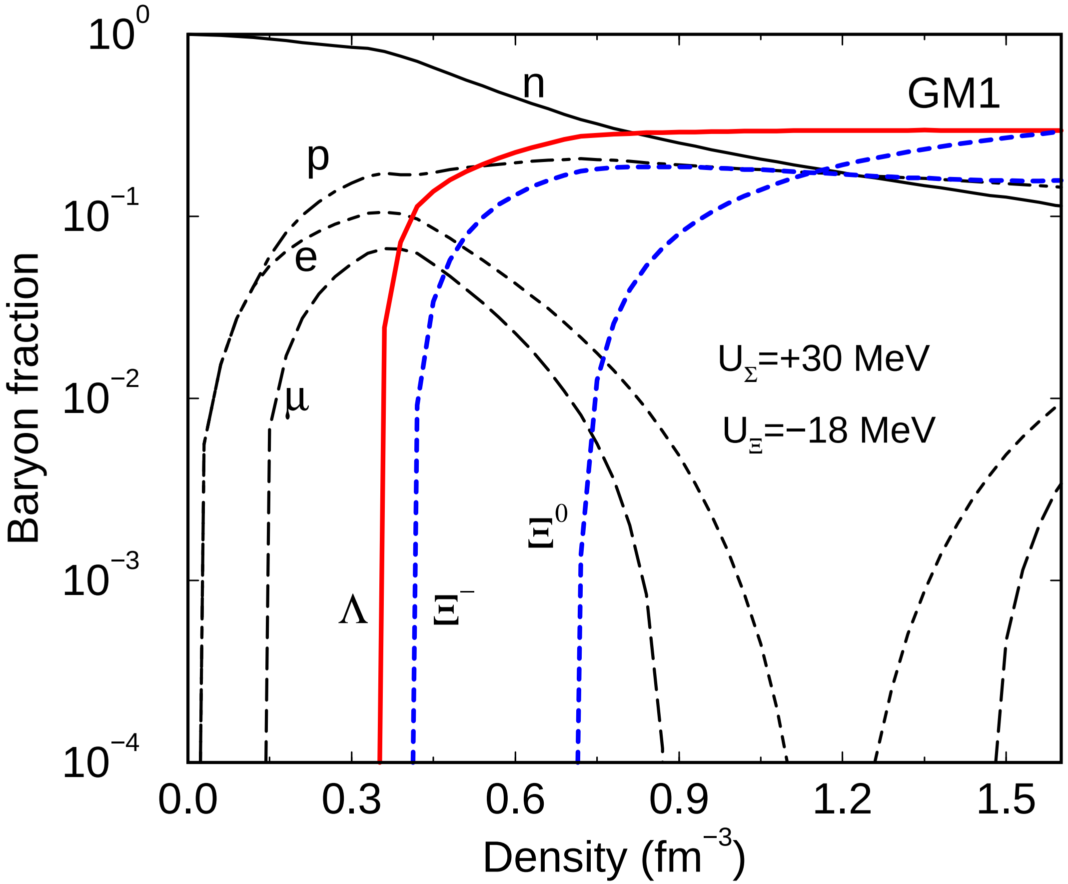
J. Schaffner-Bielich, A. Gal, PRC 62 (2000) 034311

Transition from $N\Lambda\Xi$ to $N\Sigma\Xi$ matter upon increasing the strangeness fraction f_S in NSC97 models with Σ nuclear (outdated) attraction.



J. Schaffner-Bielich, A. Gal, PRC 62 (2000) 034311

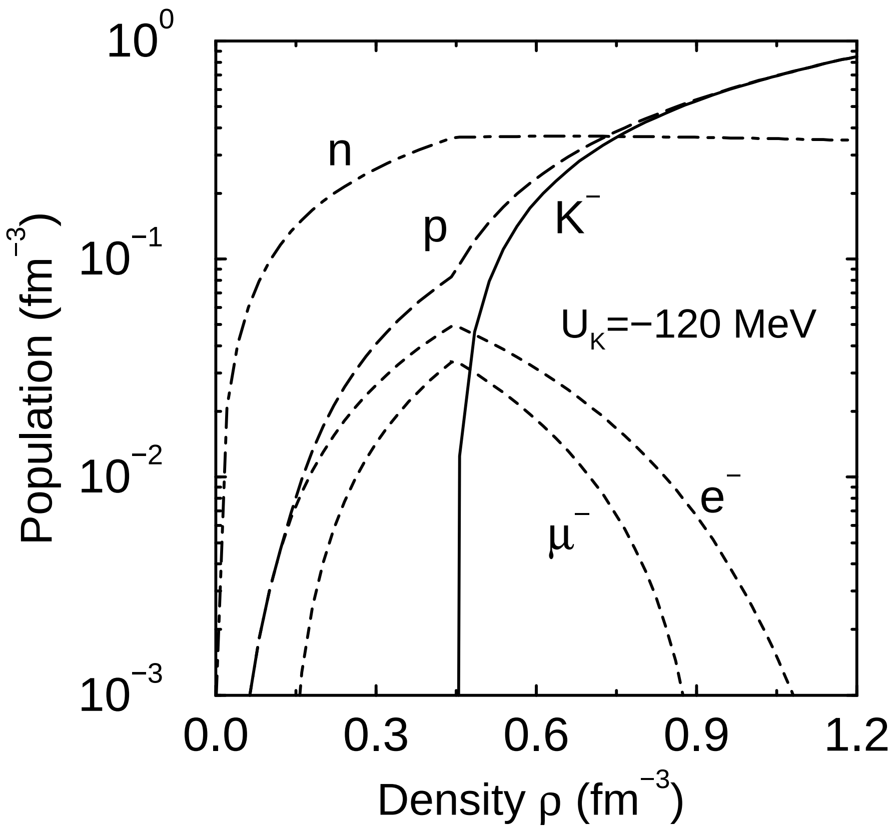
Strange Hadronic Matter composition as a function of f_S in NSC97 models with Σ nuclear (outdated) attraction.



J. Schaffner-Bielich, NPA 804 (2008) 309

RMF calculation of baryon & lepton fractions in neutron star matter.

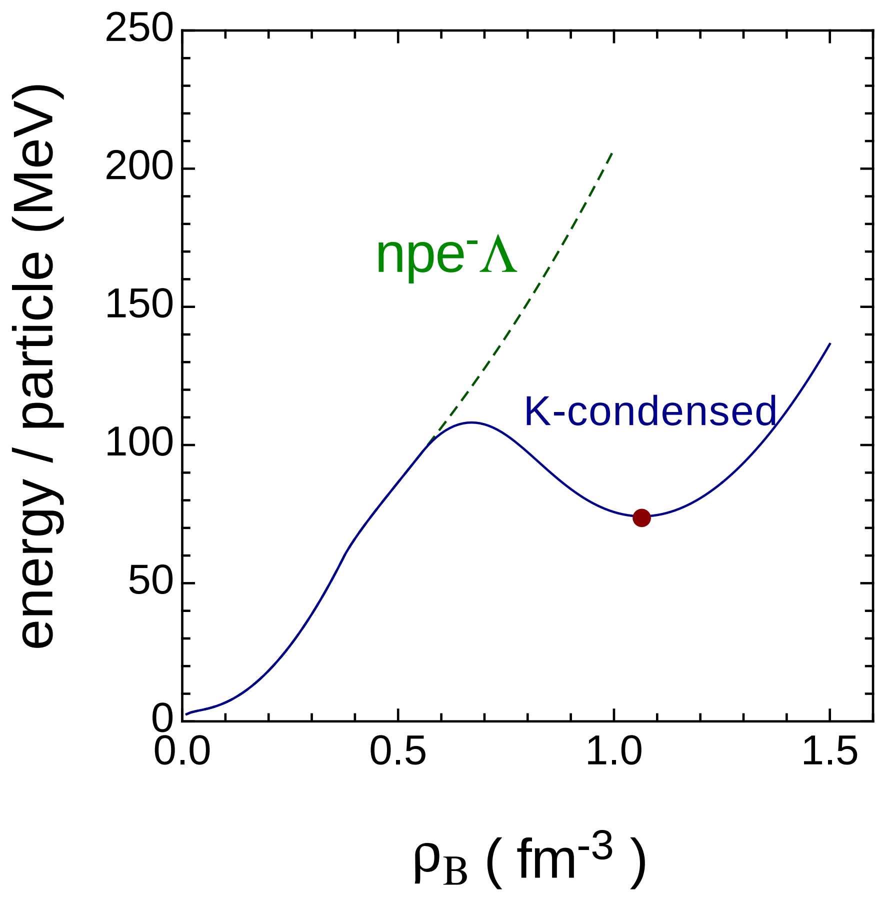
Strangeness acts for densities $\geq 2.5\rho_0$; why not $\Lambda \to p + K^-$?



N.K. Glendenning, J. Schaffner-Bielich, PRC 60 (1999) 025803

Population of nuclear star matter under kaon condensation.

$\ell^- \to K^- + \nu_\ell$: lepton depletion occurs for $\rho \geq 3\rho_0$.



T. Muto, NPA 754 (2005) 350c

Total energy per particle as a function of baryon number density.

Onset of p-wave kaon condensate at $\rho_B \sim 0.55$ fm^{-3}.

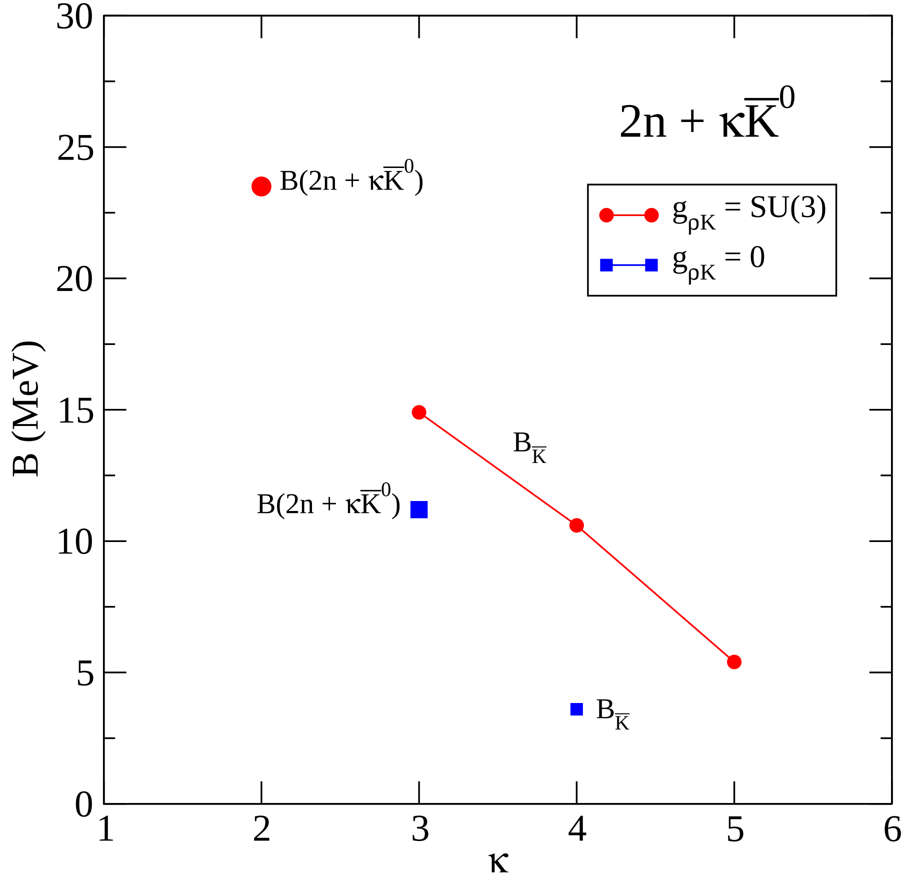
Exotic $\bar{K}$ structures, with unbound nuclear cores

onset of binding: K^-pp and $\overline{K}^0 nn$

Table 1: K^-pp binding energies & widths (in MeV) calculated without $\bar{K}NN \to YN$

	single channel		coupled channels		
	ATMS [1]	AMD [2]	Faddeev [3]	Faddeev [4]	variational [5]
B	48	17–23	50–70	60–95	40–80
Γ	61	40–70	90–110	45–80	40–85

1. T. Yamazaki, Y. Akaishi, PLB **535** (2002) 70
2. A. Doté, T. Hyodo, W. Weise, NPA 804 (2008) 197; arXiv:0806.4917 [nucl-th]
3. N.V. Shevchenko, A. Gal, J. Mareš, PRL **98** (2007) 082301
4. Y. Ikeda, T. Sato, PRC **76** (2007) 035203
5. S. Wycech, A.M. Green, arXiv:0808.3329 [nucl-th] (including p waves)

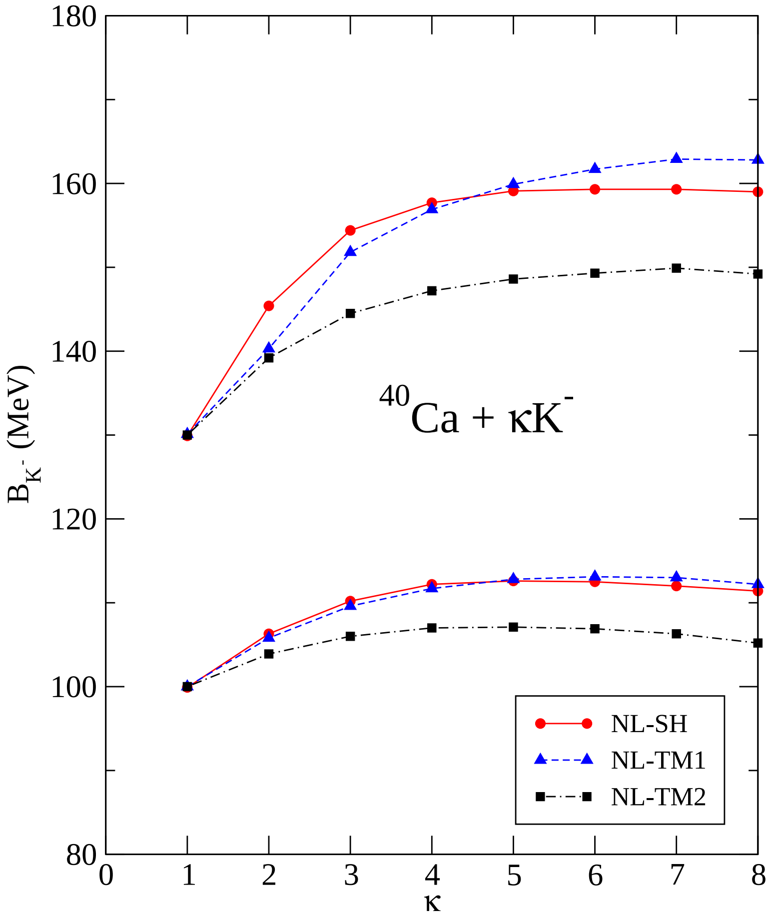


D. Gazda, E. Friedman, A. Gal, J. Mareš, unpublished (2007)

RMF extension of K^-pp calculations

$\bar{K}\bar{K}N$ bound with respect to $\Lambda(1405) + \bar{K}$

Y. Kanada-En'yo, D. Jido, PRC 78 (2008) 025212



D. Gazda, E. Friedman, A. Gal, J. Mareš, PRC 77 (2008) 045206

Saturation of $B_{\bar{K}}$ in ^{40}Ca, far away from $\bar{K}$ condensation.

$B_{\bar{K}}(\kappa \rightarrow \infty) << (m_K + M_N - M_\Lambda) \approx 320$ MeV.