ストレンジ少数系の
精密計算による研究

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Outline –

- Stochastic variational approach to strange nuclear physics PRC67, 051001(R) (2003)
- Fully coupled-channel study of $\Lambda\Lambda$-$N\Xi$-$\Lambda\Sigma$-$\Sigma\Sigma$ for $\Lambda\Lambda$-hypernuclei PRL94, 202502 (2005)
- First-ever 5-body calculation of Ξ-hypernuclei in fully coupled-channel scheme of particle basis
- Tensor ΛN-ΣN correlation in light hypernuclei PRL89, 142504 (2002)
- YN and YY potentials from lattice QCD

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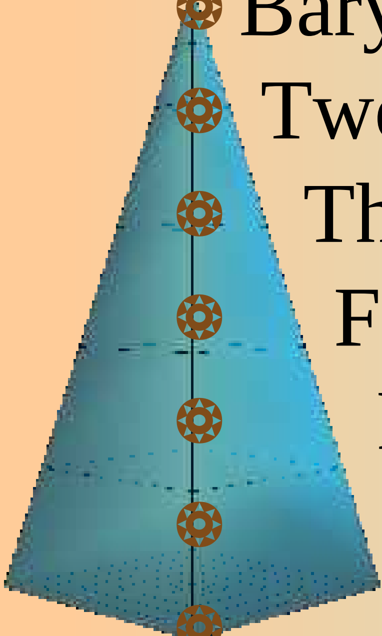
ハイパー核研究の目的

- ストレンジネスを入れることにより、通常核には無い、新しい状態、構造を探る。
- 核力の研究への、新しい視点からのアプローチ
- 斥力芯の存在、スピン依存性の違い、スピン軌道力の違いなど
- 高密度状態におけるストレンジネスの役割

ハイパー核研究における、精密に解くことの重要性

- 精密に解くとは……、
- 入口（ハミルトニアンを与える)
  から、
  出口
  （系のエネルギーや構造を求める)
  までの間に、曖昧さがない。
- 出口で明らかとなった問題点を、入口までさかのぼることができる。

NN and YN potentials

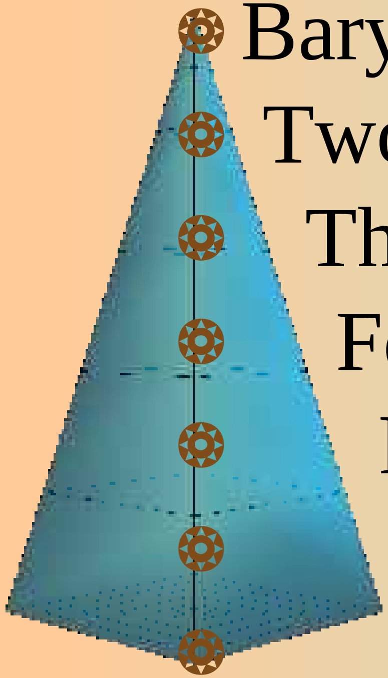


- Baryon-baryon interaction
- Two-body system
- Three-body system
- Four-body system
- Five-body system
- ...
- Many-body systems

Top-down approach

- In the nuclear physics,
  - *NN* potential is given by a modern interaction model, such as Nijmegen model.
    - Few-body calculation is made using the interaction.

NN and YN potentials



- Baryon-baryon interaction
- Two-body system
- Three-body system
- Four-body system
- Five-body system
- ...
- Many-body systems

Top-down and bottom-up approach

- In the hypernuclear physics, phase-shift analysis has not been confirmed yet.
- A phenomenological potential is used, which is phase-equivalent to the modern interaction model (e.g. Nijmegen model), and which reproduces the experimental data of the few-body systems.

ハイパー核研究における、精密に解くことの重要性

- 基本となる相互作用がまだよくわかっていない
- 一度決めた相互作用について、
  少数多体系を解く部分では
  精密に解くことによって、
  余計な曖昧さを排除したい
- 具体例： YN, YY の現在の我々の知識に基づいて、もっとも軽いダブルラムダ核は何か?
- $^{4}_{\Lambda\Lambda}\mathrm{H}$?

Introduction:

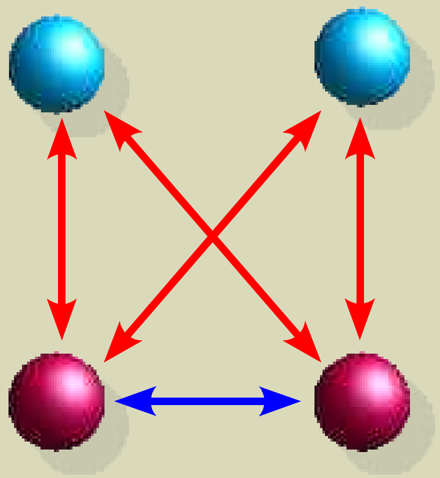
- ${}_{\Lambda\Lambda}{}^{6}$He: A door to the multistrangeness world
  - $\Delta B_{\Lambda\Lambda}$ ~4-5 MeV (Old data) [Prowse, PRL **17**, 782 (1966)]
  - $\Delta B_{\Lambda\Lambda}$ ~1 MeV (Nagara event) [Takahashi *et al*., PRL **87**, 212502 (2001)]
- ${}_{\Lambda\Lambda}{}^{4}$H: Is there a bound state?
  - Earlier theoretical predictions ➜ positive
    - Nakaichi-Maeda and Akaishi, PTP **84**, 1025 (1990).
    - H. N. *et al*., PTP **103**, 929 (2000).
  - BNL-AGS E906 experiment; formation of ${}_{\Lambda\Lambda}{}^{4}$H (?)
    - Ahn *et al*, PRL **87**, 132504 (2001).
  - A theoretical study of weak decay modes from ${}_{\Lambda\Lambda}{}^{4}$H ➜ negative
    - Kumagai-Fuse and Okabe, PRC **66**, 014003 (2002).
  - Faddeev-Yakubovsky search for ${}_{\Lambda\Lambda}{}^{4}$H (based on Nagara datum)
  - Filikhin and Gal, PRL **89**, 172502 (2002). ➜ negative? (but positive on $d\Lambda\Lambda$ model)

Introduction:

- Stochastic variational search for ${}_{\Lambda\Lambda}{}^{4}\mathrm{H}$
  - H.N., Y. Akaishi, and Khin Swe Mynit, PRC**67**, 051001 (2003).
  - The result strongly depends on the choice of ΛN interaction.
- What is the problem on theoretical search for ${}_{\Lambda\Lambda}{}^{4}\mathrm{H}$?
  - Our publicatioin concluded that " *A theoretical search for* ${}_{\Lambda\Lambda}{}^{4}\mathrm{H}$ *is still an open subject*," because the " *${}^{3}S_{1}$ ΛN interaction has to be determined very carefully, since $B_{\Lambda\Lambda}$ is sensitive to the ${}^{3}S_{1}$ channel of the ΛN interaction*."
- How to determine the ${}^{3}S_{1}$ ΛN interaction?

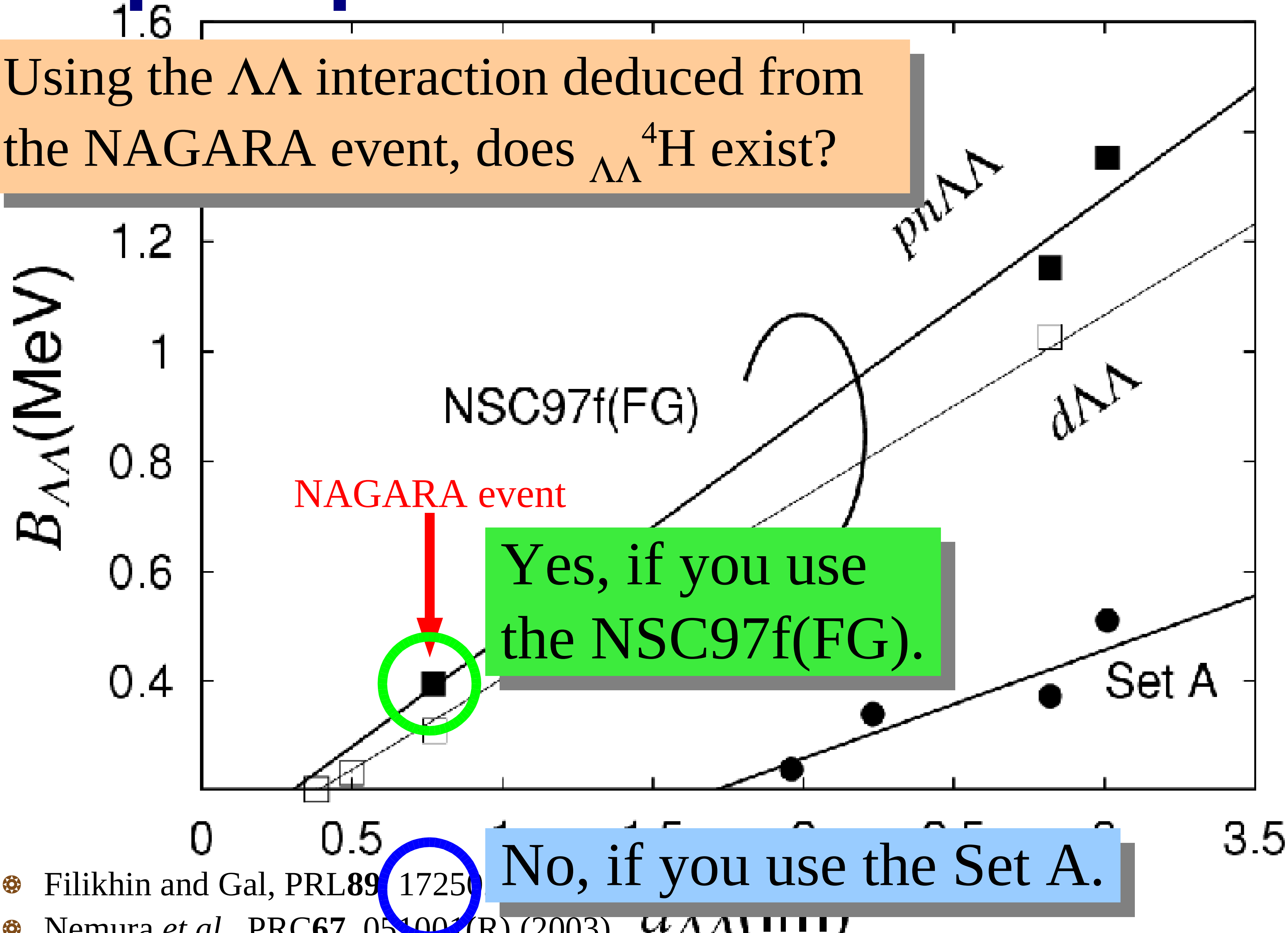
Introduction: S=-2 hypernucleus

- A key issue of S=–2 study: The total binding energies of the S=–2 hypernuclei strongly depend on the strength of the ΛN interaction than the strength of the $\Lambda\Lambda$ interaction.
  - For example, ${}_{\Lambda\Lambda}{}^{4}\mathrm{H} \sim pn\Lambda\Lambda$
  - Number of ΛN pairs: 4
  - Number of $\Lambda\Lambda$ pairs: 1



Spin dependence of ΛN interaction

Using the ΛΛ interaction deduced from the NAGARA event, does $_{\Lambda\Lambda}{}^{4}H$ exist?



Yes, if you use the NSC97f(FG).

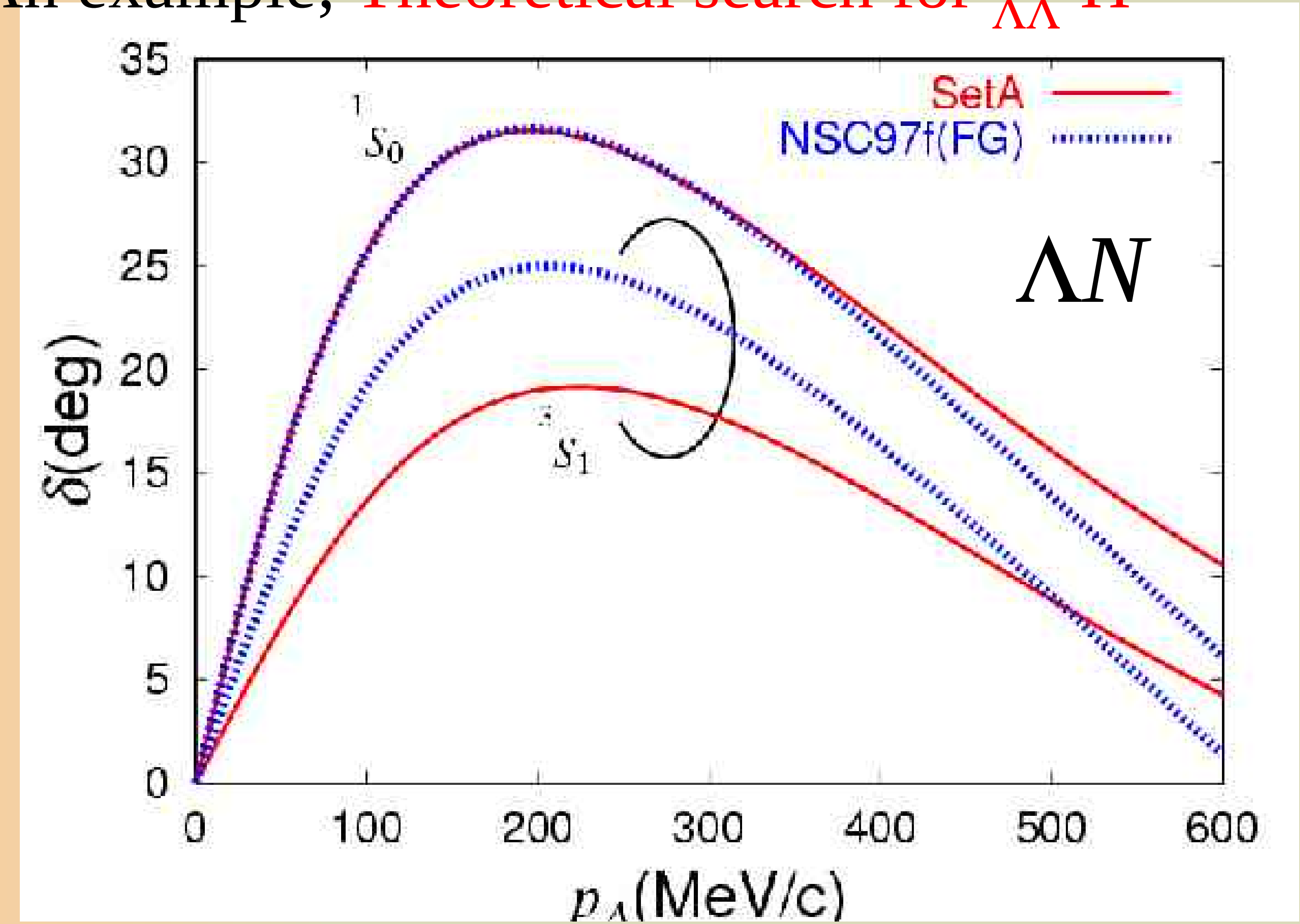
No, if you use the Set A.

- Filikhin and Gal, PRL**89**, 17250…
- Nemura *et al*., PRC**67**, 051001(R) (2003).

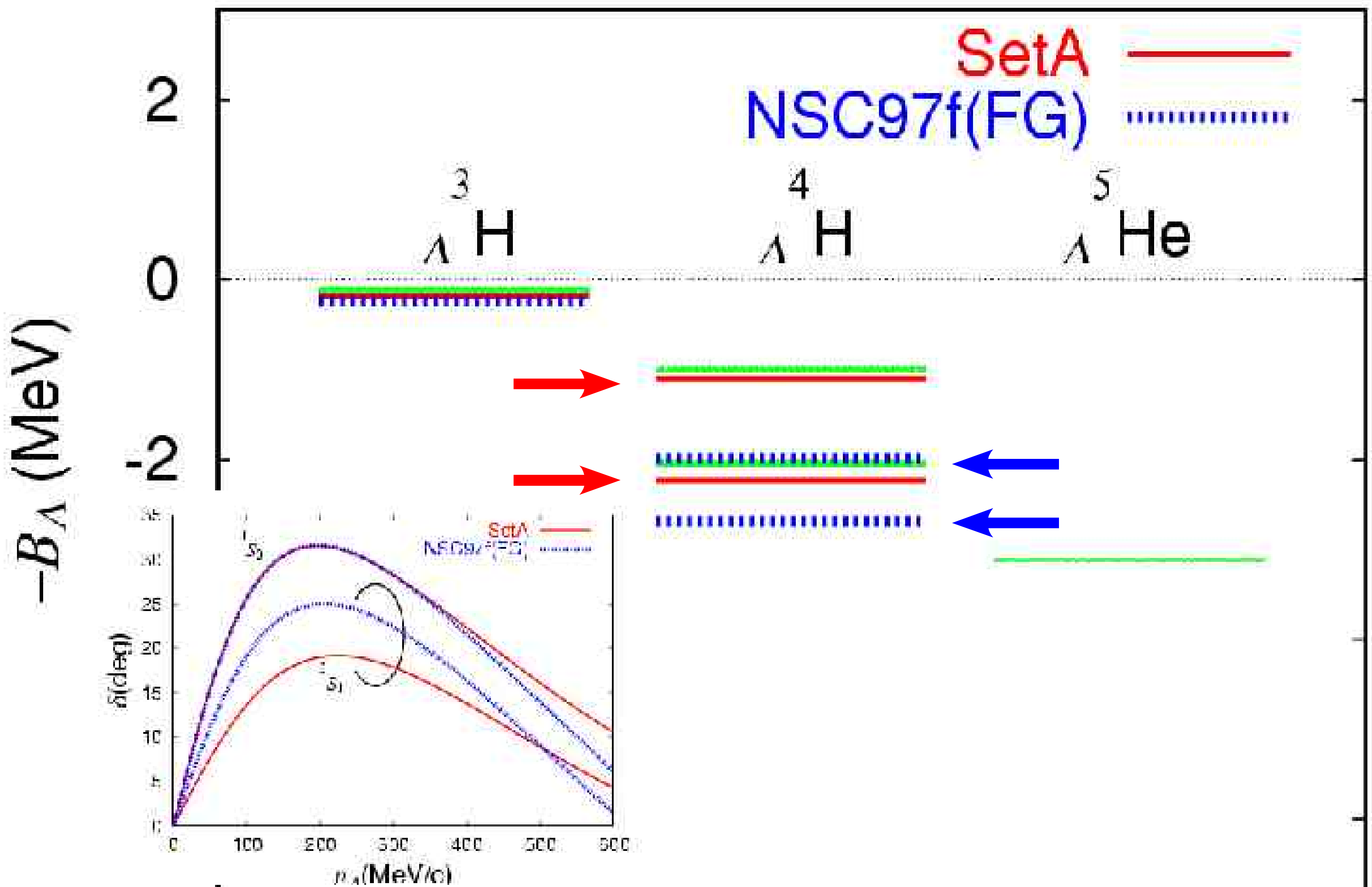
Introduction:

Determination of σ·σ term of the Λ*N* interaction is crucial to study the *S*=–2 systems.

- An example; Theoretical search for ${}_{\Lambda\Lambda}^{4}H$



Spin dependence of ΛN interaction



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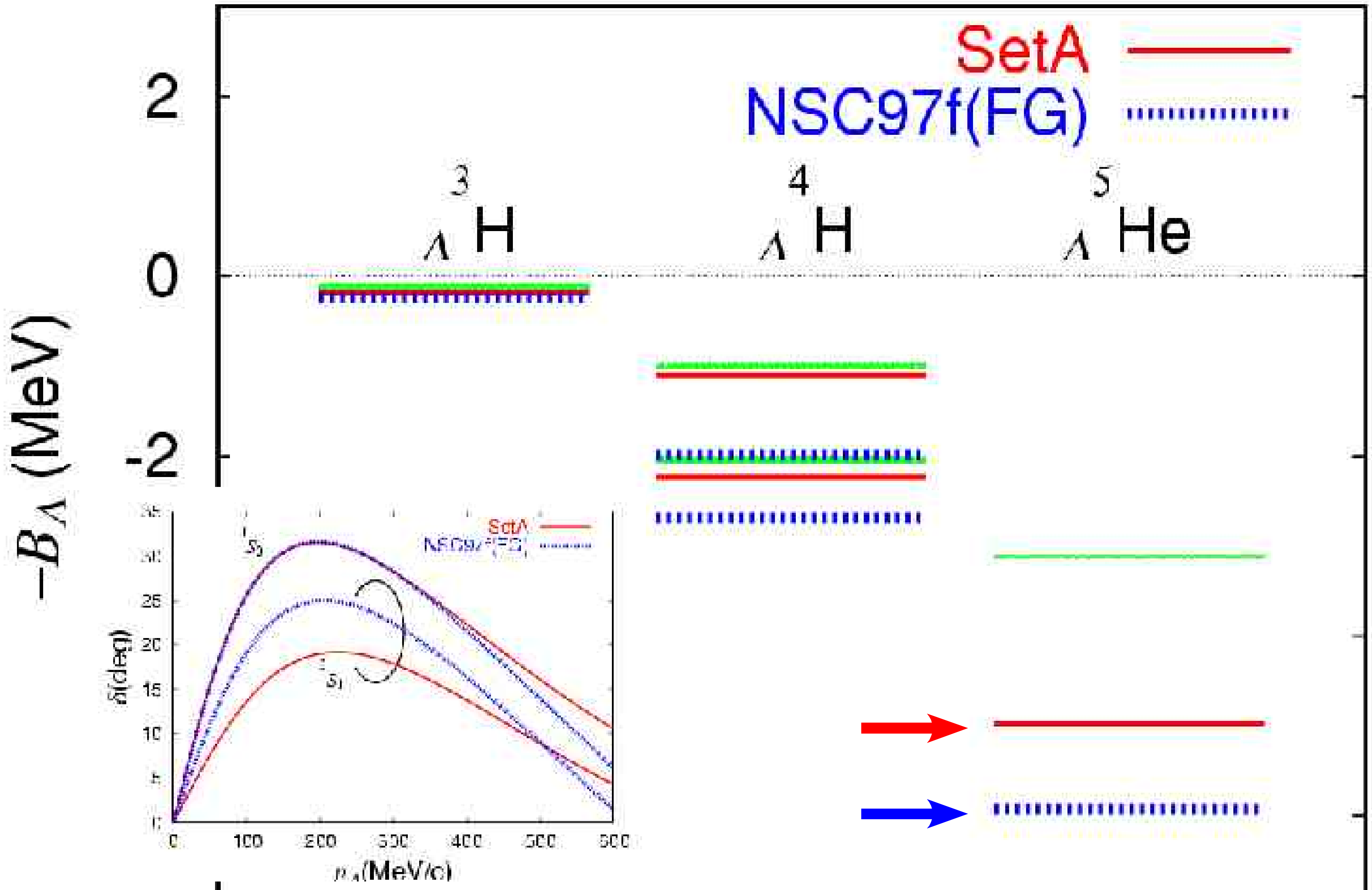
NN:Minnesota

Spin dependence of ΛN interaction



- Filikhin and Gal, PRL**89**, 172502 (2002).
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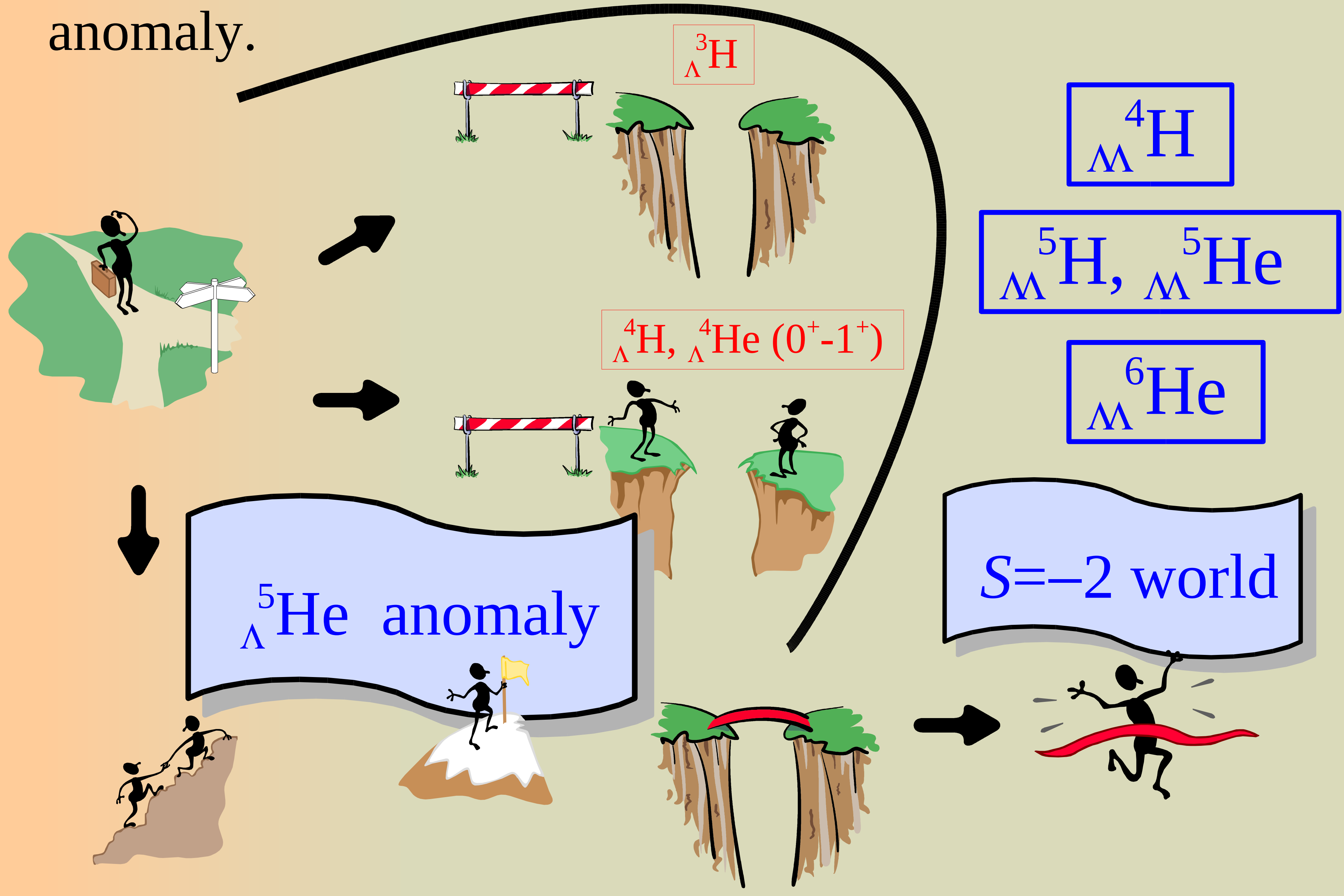
A pass to S=-2 study

- There is no way to S=–2 study on the way avoinding ${}^{5}_{\Lambda}$He anomaly.



Spin dependence of ΛN interaction

- Using the ΛΛ interaction deduced from the NAGARA event, does ${}_{\Lambda\Lambda}^{4}H$ exist?
  - Yes, if you use the NSC97f(FG).
  - No, if you use the Set A.
- The problem is what the Λ*N* interaction we should use.

Introduction:

- How to determine the ${}^3S_1$ ΛN interaction?
  - A detailed analysis concerning Λp scattering has not yet become available.
  - Experimental B_Λ values for ${}^4_\Lambda$H* , ${}^4_\Lambda$He* and ${}^5_\Lambda$He would give useful information for pinning down the ${}^3S_1$ ΛN interaction.
- However, there is a long standing problem on *s*-shell Λ hypernuclei: anomalously small binding of ${}^5_\Lambda$He.
  - Recently, Akaishi *et al*. successfully resolved the anomaly by explicitly taking account of ΛN-ΣN coupling.
    - Akaishi *et al*., PRL **84**, 3539 (2000).

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- YN and YY potentials from lattice QCD

The purpose of this work

- Systematic study for the complete set of *s*-shell Λ hypernuclei with the strangeness $S=-1$ and -2 in a framework of full-coupled channel formulation.
- Theoretical search for ${}^{4}_{\Lambda\Lambda}\mathrm{H}$.
- Fully baryon mixing of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ and ${}^{5}_{\Lambda\Lambda}\mathrm{He}$.

- ${}^{3}_{\Lambda}\mathrm{H}$ $\sim NN\Lambda + NN\Sigma$
- ${}^{4}_{\Lambda}\mathrm{H}$, ${}^{4}_{\Lambda}\mathrm{He}$ $\sim NNN\Lambda + NNN\Sigma$
- ${}^{5}_{\Lambda}\mathrm{He}$ $\sim NNNN\Lambda + NNNN\Sigma$
- ${}^{4}_{\Lambda\Lambda}\mathrm{H}$ $\sim NN\Lambda\Lambda + NN\Lambda\Sigma + NNN\Xi + NN\Sigma\Sigma$
- ${}^{5}_{\Lambda\Lambda}\mathrm{H}$, ${}^{5}_{\Lambda\Lambda}\mathrm{He}$ $\sim NNN\Lambda\Lambda + NNN\Lambda\Sigma + NNNN\Xi + NNN\Sigma\Sigma$
- ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ $\sim NNNN\Lambda\Lambda + NNNN\Lambda\Sigma + NNNNN\Xi + NNNN\Sigma\Sigma$

NN, YN and YY potentials

- *NN* interaction: Minnesota potential
  - The *NN* interaction reproduces the low energy *NN* scattering data, and also reproduces reasonably well both the binding energies and sizes of ^{2}H, ^{3}H, ^{3}He, and ^{4}He.
- *YN* interaction: D2' potential
  - The *YN* interaction reproduces the experimental B_Λ of A=3-5 hypernuclei; Free from the $^{5}_{\Lambda}$He anomaly.
- *YY* interaction: Simulating Nijmegen model (mND$_S$)
  - Fully coupled channel;

hard-core radius

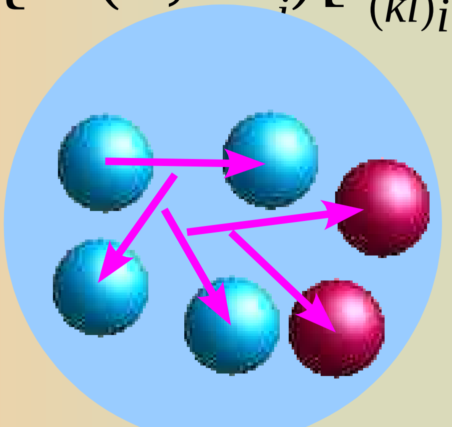
ND: r_c=(0.56, 0.45) fm

	$^{1}S_{0}$	$^{3}S_{1}$
I=0	$\Lambda\Lambda$-$N\Xi$-$\Sigma\Sigma$	$N\Xi$
I=1	$N\Xi$-$\Lambda\Sigma$	$N\Xi$-$\Lambda\Sigma$-$\Sigma\Sigma$

Ab initio calculation with stochastic variational method

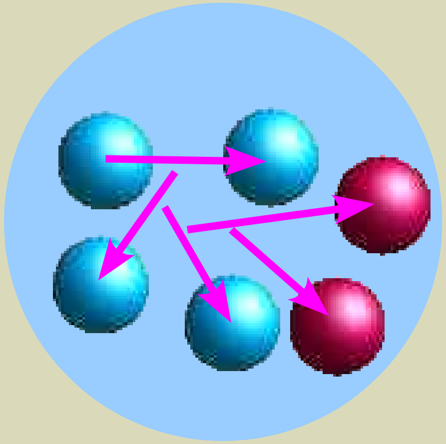
- The variational trial function must be flexible enough to incorporate both
  - Explicit Σ degrees of freedom and
  - Higher orbital angular momenta.
- $\Psi = \sum_i c_i \, \Phi_{JMTM_T}(\boldsymbol{x}; \mathbf{A}_i, u_i)$
- $\Phi_{JMIM_I}(\boldsymbol{x}, \mathbf{A}_i, u_i)$

  $= \mathcal{A}\{G(\boldsymbol{x}; \mathbf{A}_i)[\theta_{(kl)_i}(\boldsymbol{x}; u_i)\times\chi_{S_i}]_{JM}\,\eta_{IM_I}\}$



Complete six-body treatment

Ab initio calculation with stochastic variational method



- Correlated Gaussian

$$G(x;\mathbf{A}_i)=\exp\{-(1/2)\sum_{m<n}\alpha_{i,mn}(\boldsymbol{r}_m-\boldsymbol{r}_n)^2\}$$

$$=\exp\{-(1/2)\sum_{m,n}\mathbf{A}_{i,mn}\boldsymbol{x}_m\cdot\boldsymbol{x}_n\}$$

- Global vector representation

$$\theta_{(kl)_i}(x;u_i)=v_i^{2k+l}Y_{l_i}(\boldsymbol{v}_i),\ \text{with}\ \boldsymbol{v}_i=\sum_m u_{i,m}\boldsymbol{x}_m$$

- Spin function $\chi_{s_i}=[[[\boldsymbol{s}_1\times\boldsymbol{s}_2]_{s_{12}}\times\ldots]_{s_{1234}}\times\boldsymbol{s}_6]_{s_i}$

$$\sim|\uparrow\downarrow\uparrow\downarrow\uparrow\downarrow\rangle+\ldots$$

- Isospin function $\eta_{IM_I}=[[[[N_1\times N_2]_{I_{12}}\times\ldots]_{I_{1234}}\times Y_1]_{I_{12345}}\times Y_2]_{IM_I}$

$$\sim|pnpn\Lambda\Lambda\rangle+\ldots\ \text{or}\ \sim|pnpn\Sigma^0\Lambda\rangle+\ldots$$

Some interesting results

- Benchmark test calculation of a four-nucleon bound state, *Phys. Rev.* C **64**, 044001 (2001).

PHYSICAL REVIEW C, VOLUME 64, 044001

Benchmark test calculation of a four-nucleon bound state

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In the past, several efficient methods have been developed to solve the Schrödinger equation for four-nucleon bound states accurately. These are the Faddeev-Yakubovsky, the coupled rearrangement channel Gaussian basis variational, the stochastic variational, the hyperspherical variational, the Green's function Monte Carlo, the no core shell model, and the effective interaction hyperspherical harmonic methods. In this article we compare the energy eigenvalue results and some wave function properties using the realistic *AV8'* *NN* interaction. The results of all schemes agree very well showing the high accuracy of our present ability to calculate the four-nucleon bound state.

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TABLE I. The expectation values $\langle T \rangle$ and $\langle V \rangle$ of kinetic and potential energies, the binding energies E_b in MeV, and the radius in fm.

Method	$\langle T \rangle$	$\langle V \rangle$	E_b	$\sqrt{\langle r^2 \rangle}$
FY	102.39(5)	128.33(10)	25.94(5)	1.485(3)
CRCGV	102.30	−128.20	−25.90	1.482
SVM	102.35	128.27	25.92	1.486
HH	102.44	−128.34	−25.90(1)	1.483
GFMC	102.3(1.0)	−128.25(1.0)	−25.93(2)	1.490(5)
NCSM	103.35	−129.45	−25.80(20)	1.485
EIHH	100.8(9)	−126.7(9)	−25.944(10)	1.486

very different techniques and the complexity of the nuclear force chosen. Except for NCSM and EIHH, the expectation values of T and V also agree within three digits. The NCSM results are, however, still within 1% and EIHH within 1.5% of the others, but note that the EIHH results for T and V are

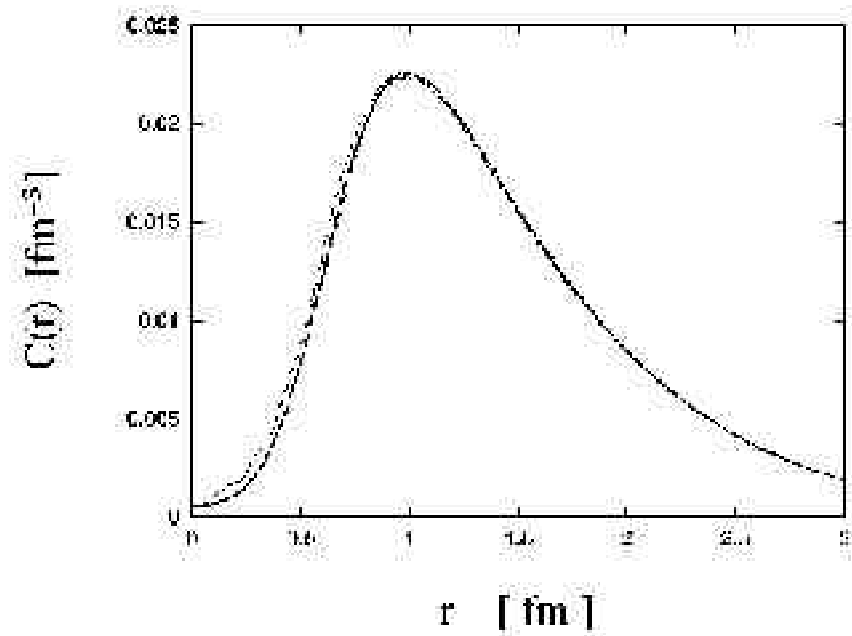
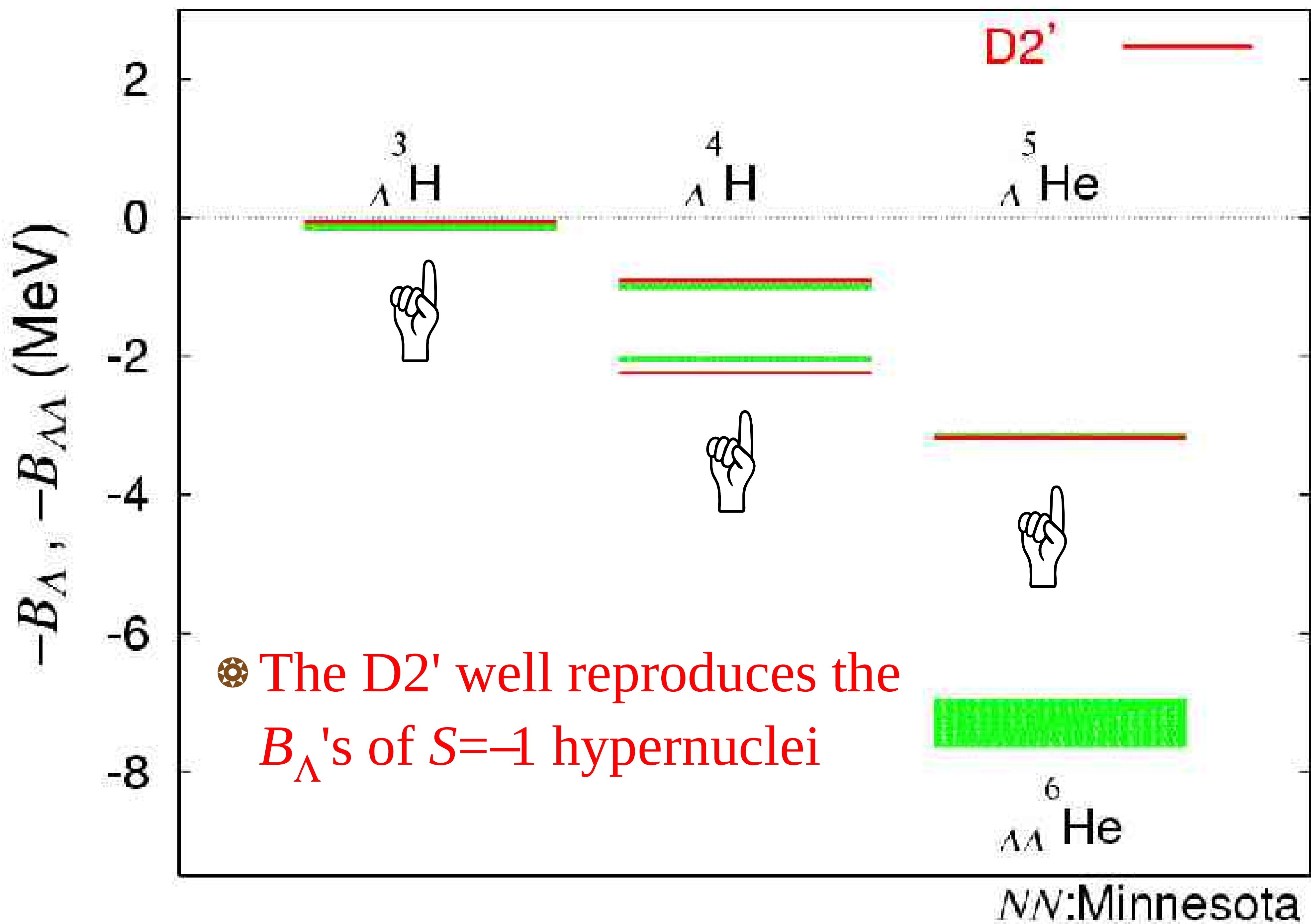


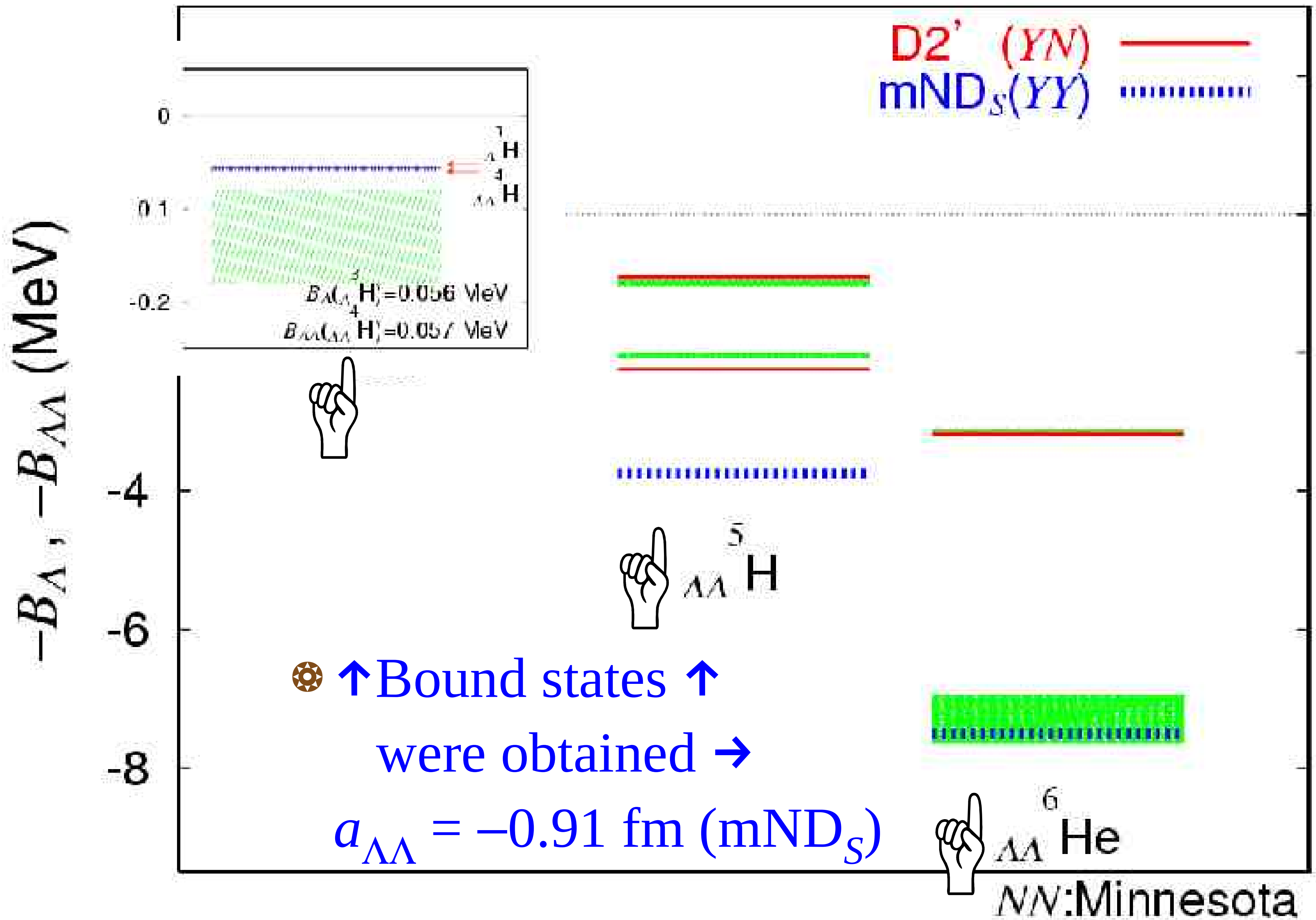
FIG. 1. Correlation functions in the different calculational schemes: EIHH (dashed-dotted curves), FY, CRCGV, SVM, HH, and NCSM (overlapping curves).

Results



- The D2' well reproduces the B_{Λ}'s of S=–1 hypernuclei

Results

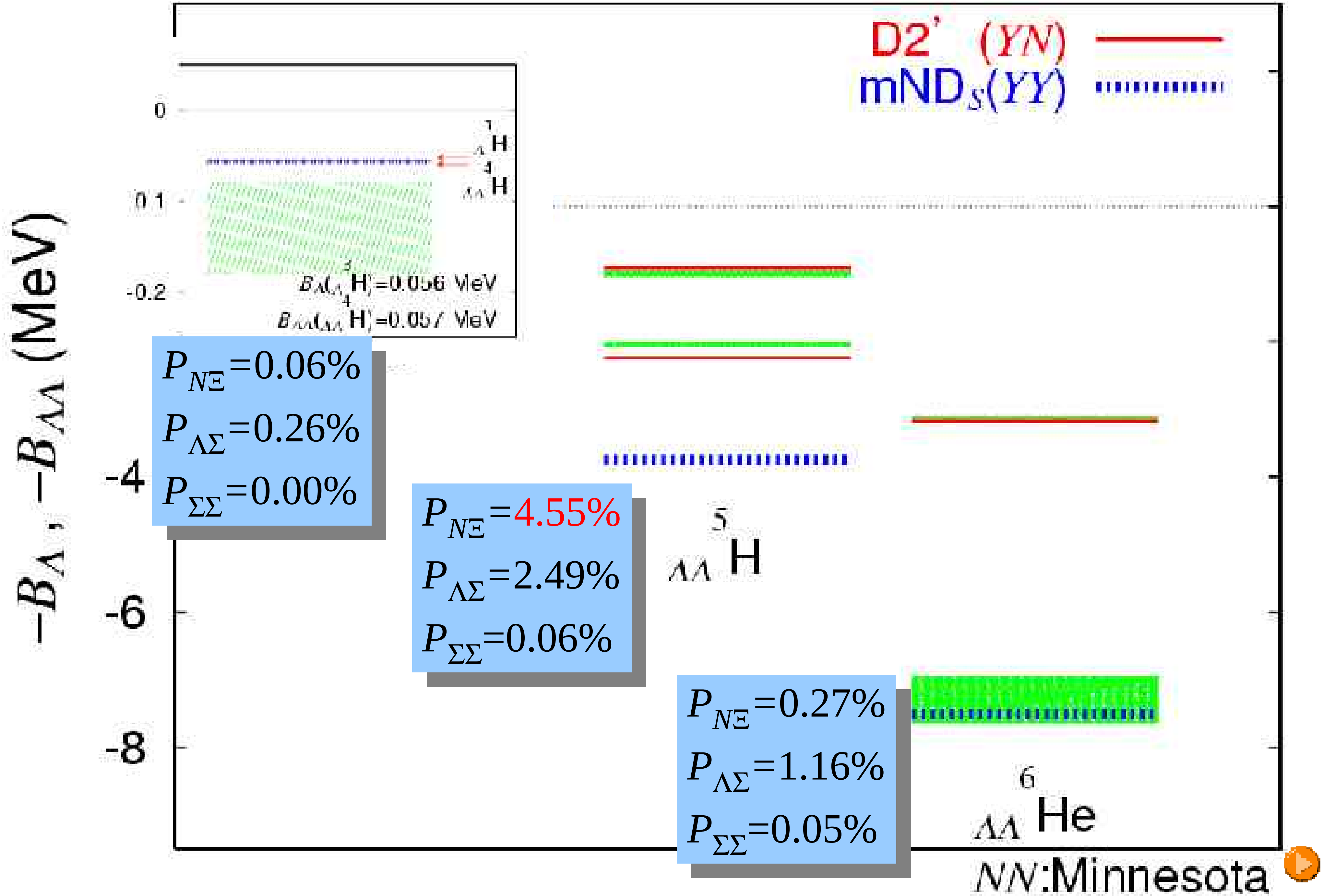


↑Bound states ↑

were obtained →

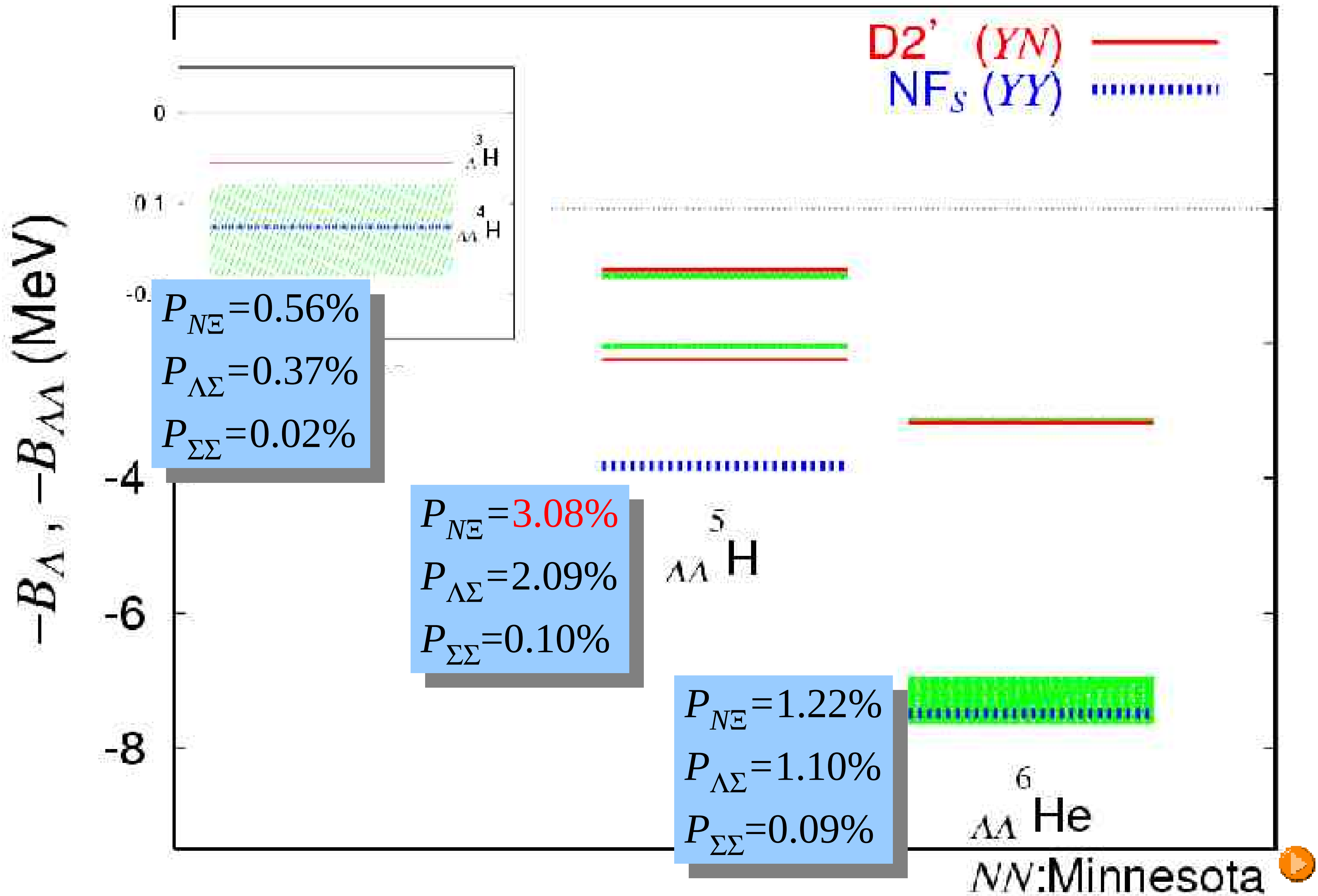
$a_{\Lambda\Lambda} = -0.91$ fm (mND$_S$)

Results



D2' (YN)
mND_S(YY)
$-B_{\Lambda}, -B_{\Lambda\Lambda}$ (MeV)
0
-0.1
-0.2
$^{3}_{\Lambda}$H
$^{4}_{\Lambda\Lambda}$H
$B_{\Lambda}(^{3}_{\Lambda}H)$=0.056 MeV
$B_{\Lambda\Lambda}(^{4}_{\Lambda\Lambda}H)$=0.057 MeV
-4
-6
-8
$P_{N\Xi}$=0.06%
$P_{\Lambda\Sigma}$=0.26%
$P_{\Sigma\Sigma}$=0.00%
$P_{N\Xi}$=4.55%
$P_{\Lambda\Sigma}$=2.49%
$P_{\Sigma\Sigma}$=0.06%
$^{5}_{\Lambda\Lambda}$H
$P_{N\Xi}$=0.27%
$P_{\Lambda\Sigma}$=1.16%
$P_{\Sigma\Sigma}$=0.05%
$^{6}_{\Lambda\Lambda}$He
NN:Minnesota

Results



D2' (YN)
NFs (YY)
$-B_{\Lambda}, -B_{\Lambda\Lambda}$ (MeV)
0
-0.1
-4
-6
-8
$^{3}_{\Lambda\Lambda}$H
$^{4}_{\Lambda\Lambda}$H
$^{5}_{\Lambda\Lambda}$H
$^{6}_{\Lambda\Lambda}$He
NN:Minnesota
$P_{N\Xi}$=0.56%
$P_{\Lambda\Sigma}$=0.37%
$P_{\Sigma\Sigma}$=0.02%
$P_{N\Xi}$=3.08%
$P_{\Lambda\Sigma}$=2.09%
$P_{\Sigma\Sigma}$=0.10%
$P_{N\Xi}$=1.22%
$P_{\Lambda\Sigma}$=1.10%
$P_{\Sigma\Sigma}$=0.09%

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The purpose of this work

- To describe the first-ever 5-body calculation of doubly strange hypernuclei (${}_{\Lambda\Lambda}{}^{5}\mathrm{H}$ -- ${}_{\Xi}{}^{5}\mathrm{H}$ -- ${}_{\Lambda\Sigma}{}^{5}\mathrm{H}$ -- ${}_{\Sigma\Sigma}{}^{5}\mathrm{H}$ and ${}_{\Lambda\Lambda}{}^{5}\mathrm{He}$ -- ${}_{\Xi}{}^{5}\mathrm{He}$ -- ${}_{\Lambda\Sigma}{}^{5}\mathrm{He}$ -- ${}_{\Sigma\Sigma}{}^{5}\mathrm{He}$) in fully coupled channel scheme of particle basis.

- If the Ξ-, ΛΣ-, and ΣΣ-hypernuclear states exist, they must decay via ΛΛ-*N*Ξ-ΛΣ-ΣΣ and Λ*N*-Σ*N* strong interaction.

- How can we calculate the Ξ-, ΛΣ-, and ΣΣ-hypernuclear states?

The strategies to solve the problem

- How can we calculate the Ξ-, $\Lambda\Sigma$-, and $\Sigma\Sigma$-hypernuclear states?
- Let us consider the Ξ-hypernucleus as an example.
  - Single channel calculation of each particle basis, such as $ppnn\Xi^{-}$ or $ppnn\Xi^{0}$:
    - This makes bound state of the Ξ-hypernuclei, if the ΞN potential is so attractive, but not realistic.
  - Fully coupled channel calculation
    - Mixed state among $ppnn\Xi^{-} \leftrightarrow pnn\Lambda\Lambda$

$$\leftrightarrow ppn\Lambda\Sigma^{-}, \ldots$$

$$\leftrightarrow ppn\Sigma^{-}\Sigma^{0}, \ldots$$

Preliminary results

- ${}_{\Lambda\Lambda}{}^{5}H$ -- ${}_{\Xi}{}^{5}H$ -- ${}_{\Lambda\Sigma}{}^{5}H$ -- ${}_{\Sigma\Sigma}{}^{5}H$:
- Single channel calculation of $ppnn\Xi^{-}$:
  - We obtained a bound state with $B_{\Xi} = 0.55$ MeV.

- Fully coupled channel calculation:
  - We found that there are five states below the $^{4}He+\Xi^{-}$ threshold, so far.
  - The lowest is the ground state of ${}_{\Lambda\Lambda}{}^{5}H$.
  - Then, we calculate the probabilities of ΛΛ- and Ξ-channels.

Preliminary results

- ${}_{\Lambda\Lambda}^{5}$He -- ${}_{\Xi}^{5}$He -- ${}_{\Lambda\Sigma}^{5}$He -- ${}_{\Sigma\Sigma}^{5}$He:
- Single channel calculation of $ppnn\Xi^0$:
  - We obtained no bound state, so far.

- Fully coupled channel calculation:
  - We found that there are three states below the ^{4}He+Ξ^0 threshold, so far.
  - The lowest is the ground state of ${}_{\Lambda\Lambda}^{5}$He.
  - Then, we calculate the probabilities of $\Lambda\Lambda$- and Ξ-channels.

Discussions about Ξ-hypernuclei

- The present study uses mND$_s$ *YY* potential, which well reproduces the $\Delta B_{\Lambda\Lambda}$ of the Nagara event, and which is consistent with the recent experimental data of Ξ-nucleus potential.
- The preliminary calculations seem to imply that a Ξ-hypernuclear state exists below the ^{4}He+Ξ^- or ^{4}He+Ξ^0 threshold.
- More precise calculations must be made in the fully coupled channel scheme:
  - Correct energies and widths.
    - ☑Complex scaling method with SVM.

Complex scaling method with SVM

- Asymptotic behavier of wave function:
  - Bound state

$$\Psi_B \sim \frac{e^{-\kappa r e^{i\theta}}}{r e^{i\theta}} \to 0$$

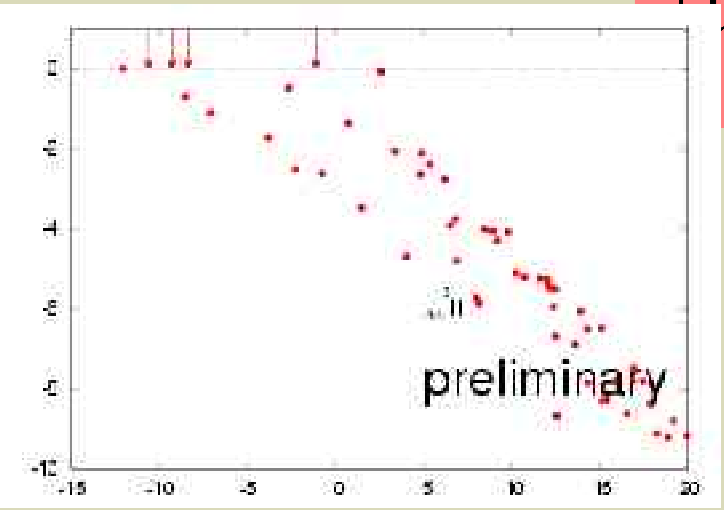
  - Continuum state

$$\Psi_C \sim \frac{e^{-ikr}}{r e^{i\theta}} \to \frac{1}{r}$$

  - Resonance state

$$\Psi_R \sim \frac{e^{-i(k_R - i\gamma) r e^{i\theta}}}{r e^{i\theta}} \to 0$$

$$\left(\tan\theta > \frac{\gamma}{k_R}, \quad |\theta| < \frac{\pi}{2} \right)$$

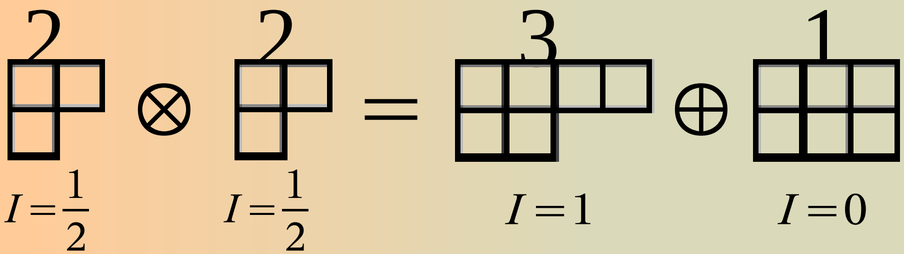


Outline –

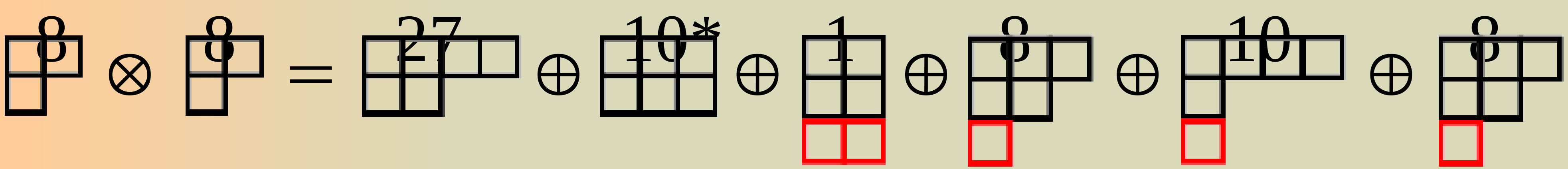
- Stochastic variational approach to strange nuclear physics PRC67, 051001(R) (2003)
- Fully coupled-channel study of ΛΛ-NΞ-ΛΣ-ΣΣ for ΛΛ-hypernuclei PRL94, 202502 (2005)
- First-ever 5-body calculation of Ξ-hypernuclei in fully coupled-channel scheme of particle basis
- Tensor ΛN-ΣN correlation in light hypernuclei PRL89, 142504 (2002)
- YN and YY potentials from lattice QCD

Extension from NN to YN and YY:

- If we take only non-strange sector,
  there are only 2 representations for isospin space.



- On the other hand, if we take account of strange degree of freedom, other representations should be included.



- This means that the *YN* and *YY* interactions cannot be determined from the precise *NN* experimental data even if we assume the flavor SU(3) symmetry.
- Lattice QCD is desirable for the study of the *YN* and *YY*

Recent impressive works of lattice QCD:

- S. Aoki, *et al.*, PRD**71**, 094504 (2005);

  π-π scattering length from the wave function.

- N. Ishii, *et al.*, nucl-th/0611096, PRL in press;

  NN potential from the wave function.

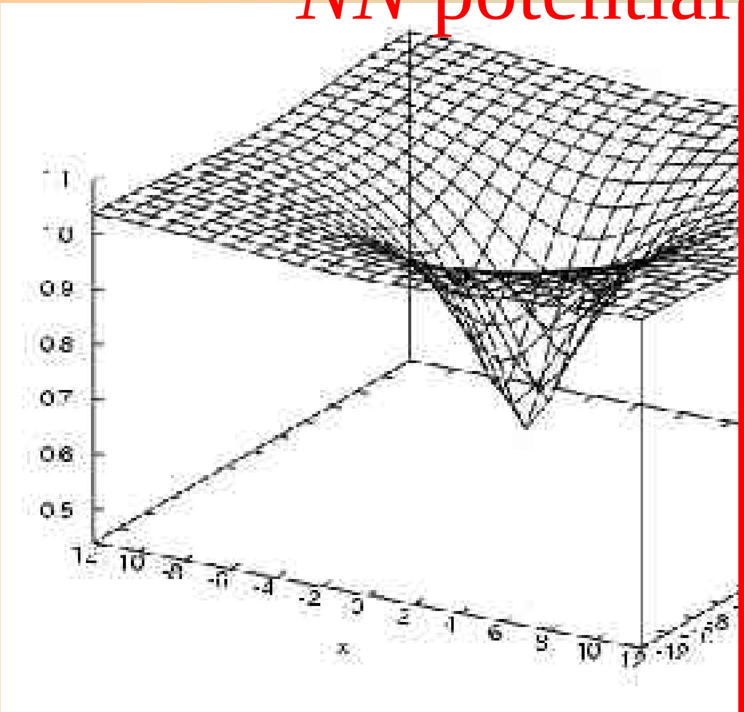
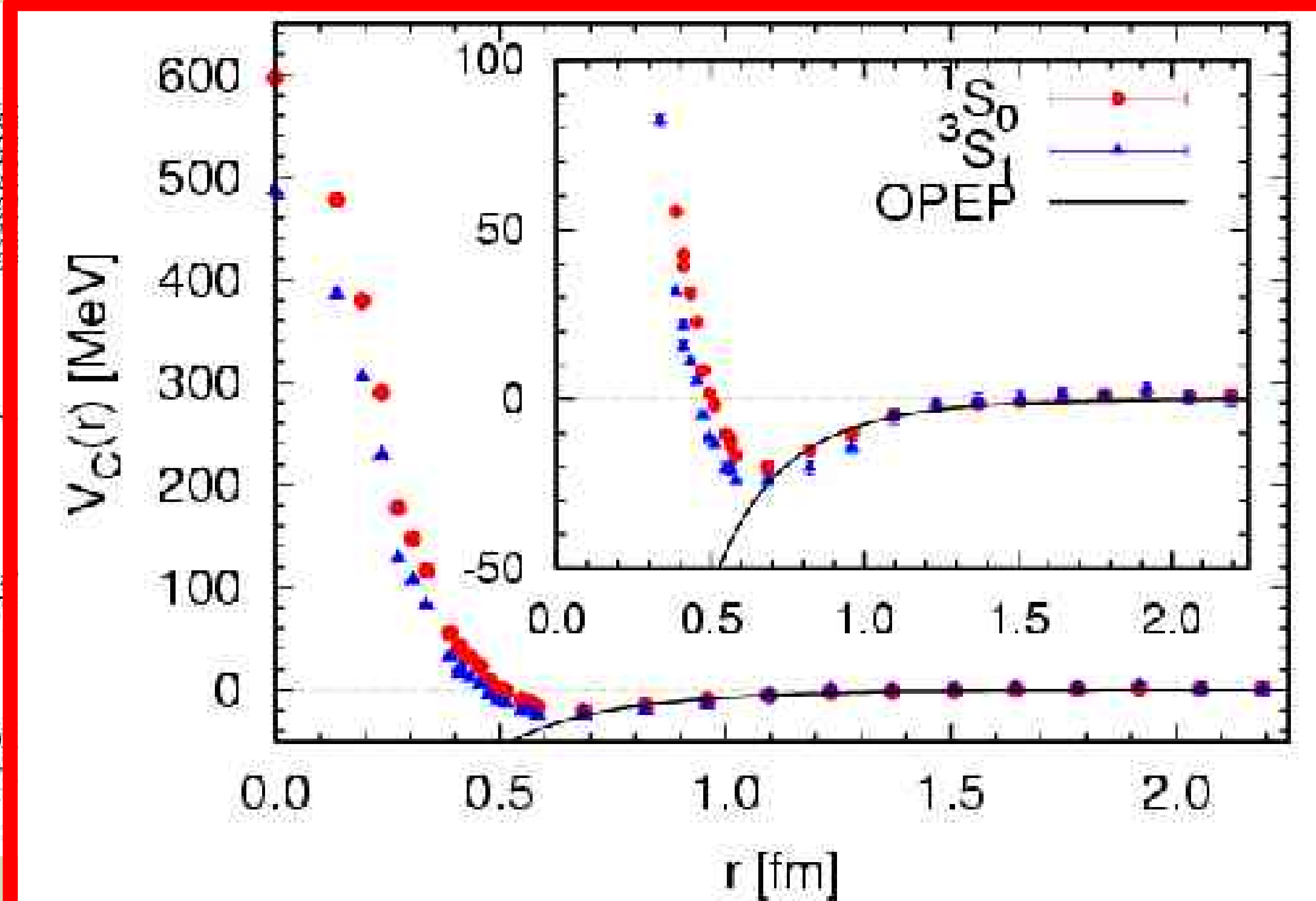


FIG. 1. Two-pion wave function $\phi(\vec{x};k)$ o... $(t,z) = (52,0)$ plane for $m_\pi^2 = 0.273$ GeV^2. T... tor is set at $\vec{x}_0 = (7,5,2)$ $(x_0 = |\vec{x}_0| = 8.832)$.



- This work;

The purpose of this work

- *YN* and *YY* potentials from lattice QCD
  - $N\Lambda$, $N\Sigma$, $\Lambda\Lambda$, $N\Xi$, ...

- $N\Xi$ potential as a first step
  - Main target of the J-PARC DAY-1 experiment
  - Few experimental information, so far

- Focus on the I=1 channel, $^1S_0$, $^3S_1$
  - I=1; $N\Xi$-$\Lambda\Sigma$-$\Sigma\Sigma$: $N\Xi$ is the lowest state.
  - I=0; $\Lambda\Lambda$-$N\Xi$-$\Sigma\Sigma$: $N\Xi$ is not the lowest state.
- I=0 channel will be studied in the future.

A recipe for NΞ potential:

- More accurate explanation, for *NN*, wil be given by Ishii-san.

- Calculate the 4-point *N*Ξ correlator on the lattice,

$$\phi_{N\Xi}(x-y)e^{-E(t-t_0)} \simeq \langle p_\alpha(x,t)\,\Xi^0_\beta(y,t)\,\overline{\Xi^0_{\beta'}}(0,t_0)\,\overline{p_{\alpha'}}(0,t_0)\rangle$$

  - Which has the physical meanings of,
    - Create a *N*Ξ state and making imaginary time evolution, in order to have the lowest state of the *N*Ξ system.
    - Take the amplitude φ(***x***–***y***), which can be understood as a wave function of the non-relativistic quantum mechanics.

- Obtain the effective central potential by assuming that the WF is a solution of effective Schroedinger equation.

$$\left(-\frac{\hbar^2}{2\mu}\nabla^2 + V(r)\right)\phi(r) = E\,\phi(r)$$

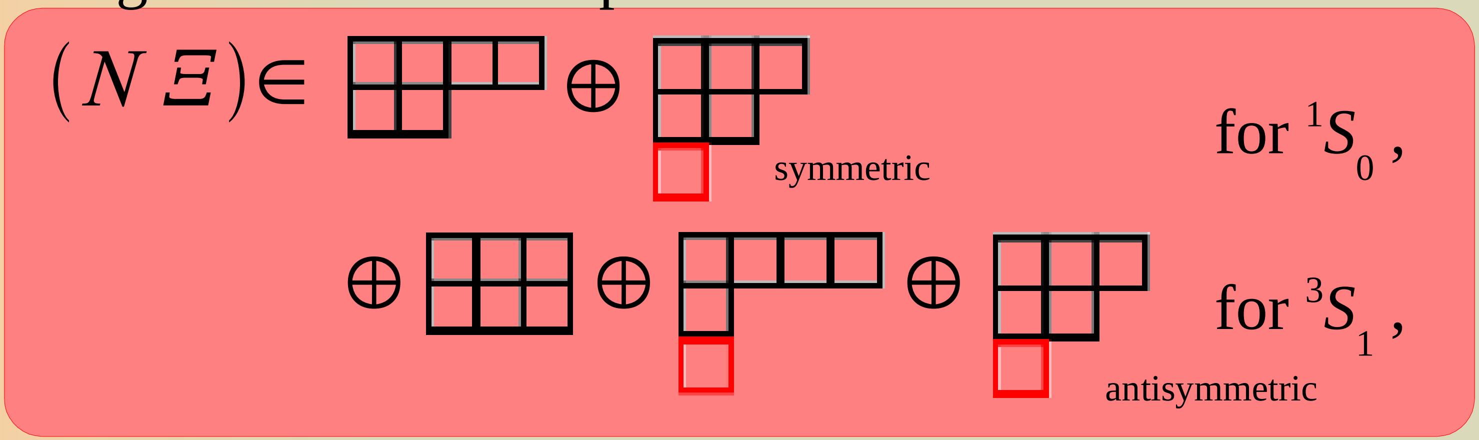
$$V(r) = E + \frac{\hbar^2}{2\mu}\frac{\nabla^2\phi(r)}{\phi(r)}$$

My turn in this work:

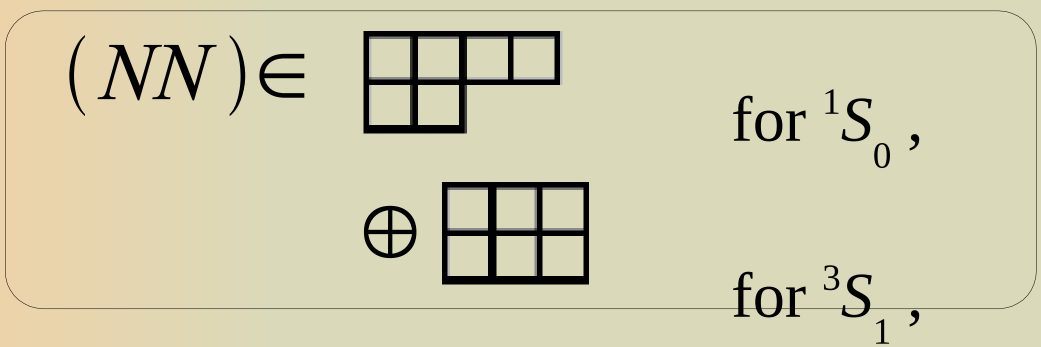
- Calculate the 4-point $N\Xi$ correlator on the lattice,

$$\phi_{N\Xi}(x-y)\,e^{-E(t-t_0)} \simeq \langle p_\alpha(x,t)\,\Xi^0_\beta(y,t)\,\overline{\Xi^0_{\beta'}}(0,t_0)\,\overline{p_{\alpha'}}(0,t_0)\rangle$$

  - This gives the different pattern of the Wick contraction from the *NN*,



cf. ,



- Calculate the 2-point correlators for N and Ξ,

$$\sum_y \langle \Xi^0_\beta(y,t)\,\overline{\Xi^0_{\beta'}}(0,t_0)\rangle \qquad \sum_x \langle p_\alpha(x,t)\,\overline{p_{\alpha'}}(0,t_0)\rangle$$

We need the reduced mass to construct the potential.

$$V(r) = E + \frac{\hbar^2}{2\mu}\frac{\nabla^2\phi(r)}{\phi(r)}$$

Interpolating fields and parameters:

- Interpolating fields:

$$p_{\alpha}(x)=\varepsilon_{abc}(u_a(x)C\gamma_5 d_b(x))u_{c\alpha}(x),$$

$$\Xi^0_{\beta}(y)=\varepsilon_{abc}(u_a(y)C\gamma_5 s_b(y))s_{c\beta}(y),$$

- The lattice calculations were performed by using KEK Blue Gene/L supercomputer.
  - The C++ code reached 1.3GFlops/processor, which is almost a half of the peak value.

1.3TFlops at 512node que

- Volume: $32^3 \times 32$ lattice ($L \sim 4.4$ fm).
- Lattice spacing: $a \sim 0.14$ fm.
- Standard Wilson action:
  - κ_{ud} = 0.1678 for u and d quarks, and
  - κ_s = 0.1665 for s quark.

Meson masses:
$m_{\pi} \sim 0.377(3)$ GeV
$m_{\rho} \sim 0.844(6)$ GeV
$m_{K} \sim 0.463(1)$ GeV
$m_{K^*} \sim 0.868(3)$ GeV

Results —— hadron masses

- Path integrals for the correlators are performed by using 491 gauge configurations, so far:

- Calculated baryon masses (in units of GeV):

m_{p}	m_{Ξ}	m_{Λ}	m_{Σ}
1.210(11)	1.291(5)	1.244(8)	1.271(7)

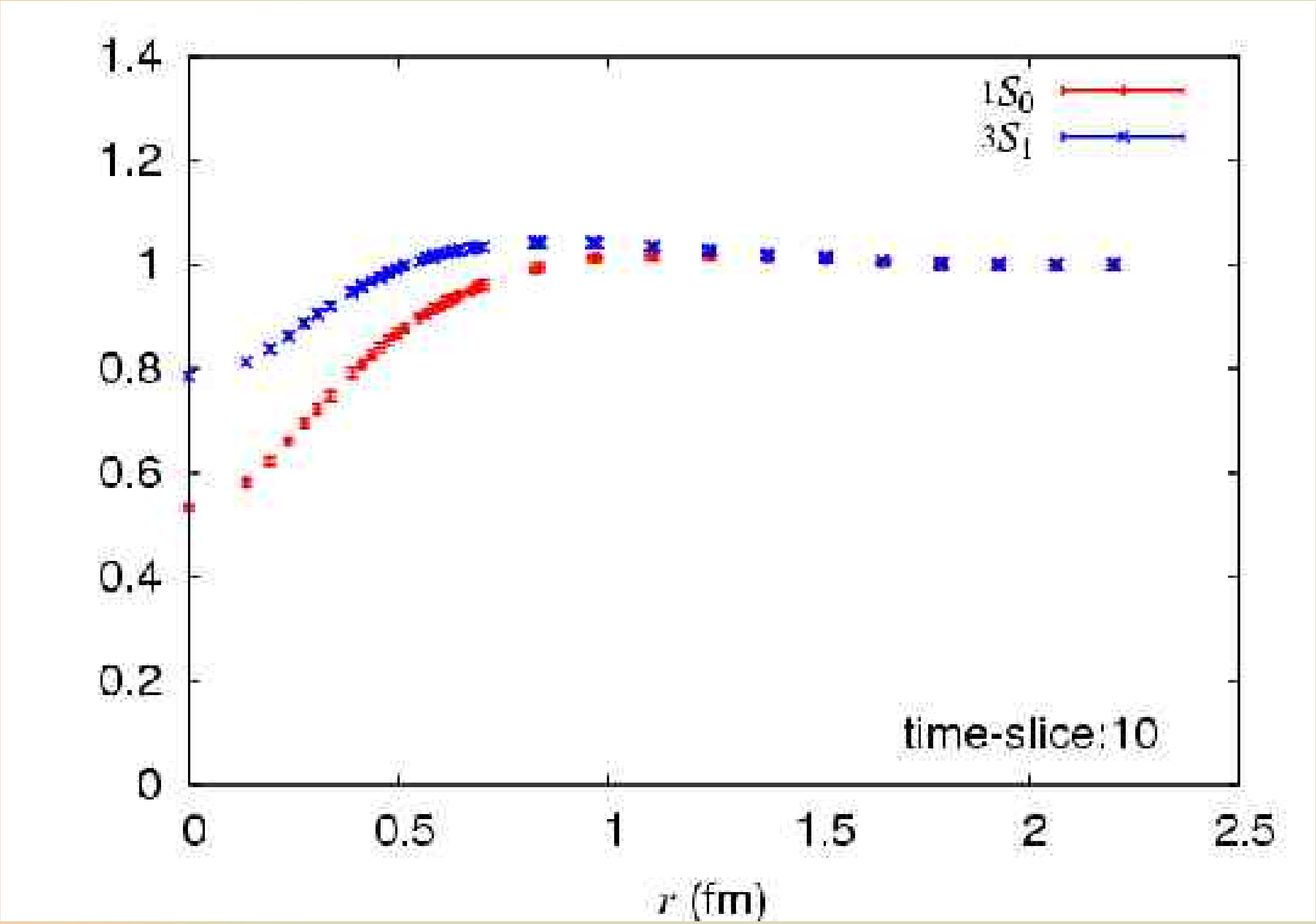
- Interpolating fields for Λ and Σ^{+}:

$$\Lambda_{\alpha}(x)=\frac{1}{\sqrt{3}}\varepsilon_{abc}\left\{(d_a C\gamma_5 s_b)u_{c\alpha}+(s_a C\gamma_5 u_b)d_{c\alpha}-2(u_a C\gamma_5 d_b)s_{c\alpha}\right\}$$

$$\Sigma_{\beta}^{+}(y)=-\varepsilon_{abc}(u_a(y)C\gamma_5 s_b(y))u_{c\beta}(y),$$

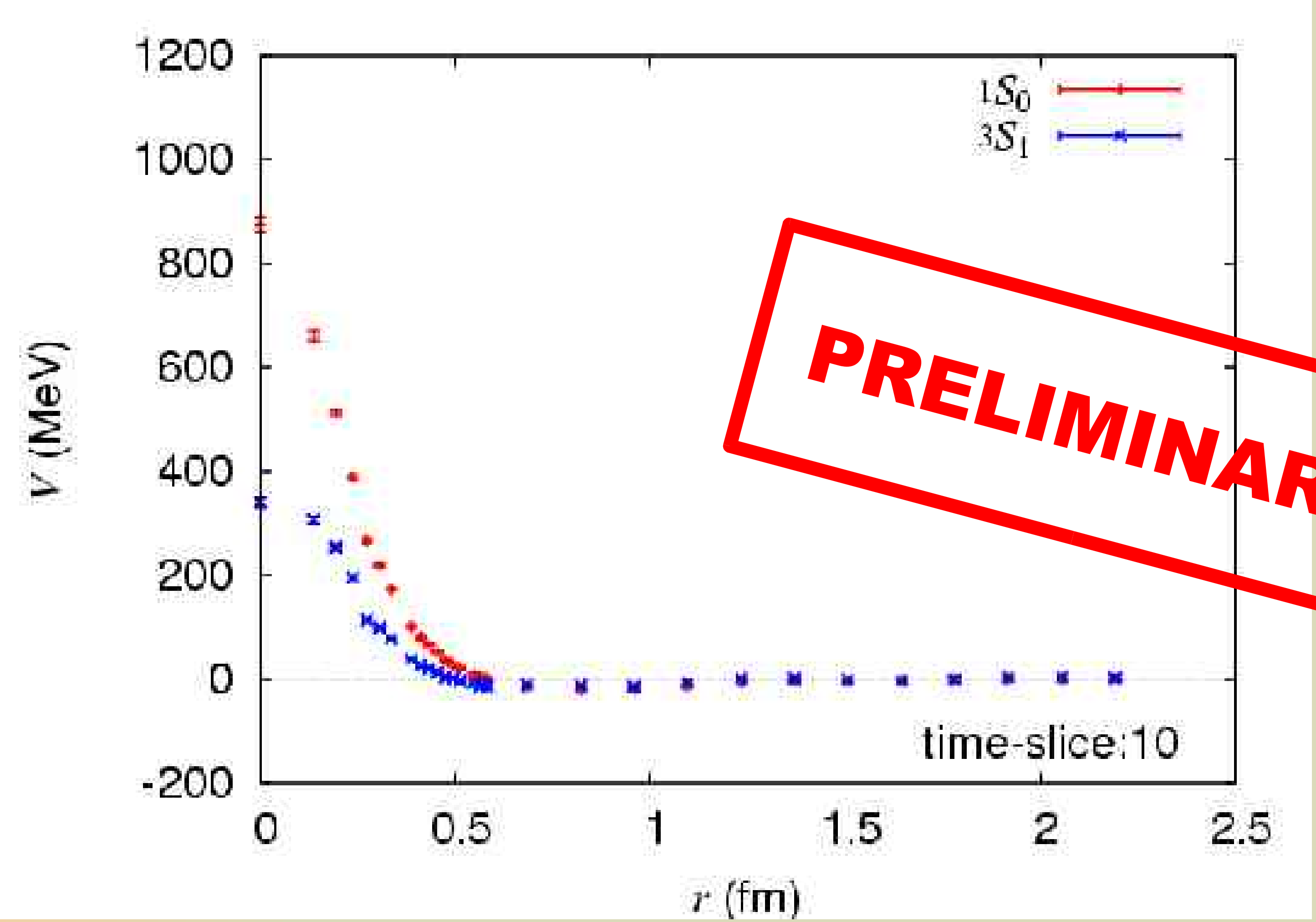
Results —— wave function

- Suggests the repulive core in short range and attractive force in medium range (0.5fm < r < 1fm) for both spin S=0 and 1.



Results —— potential

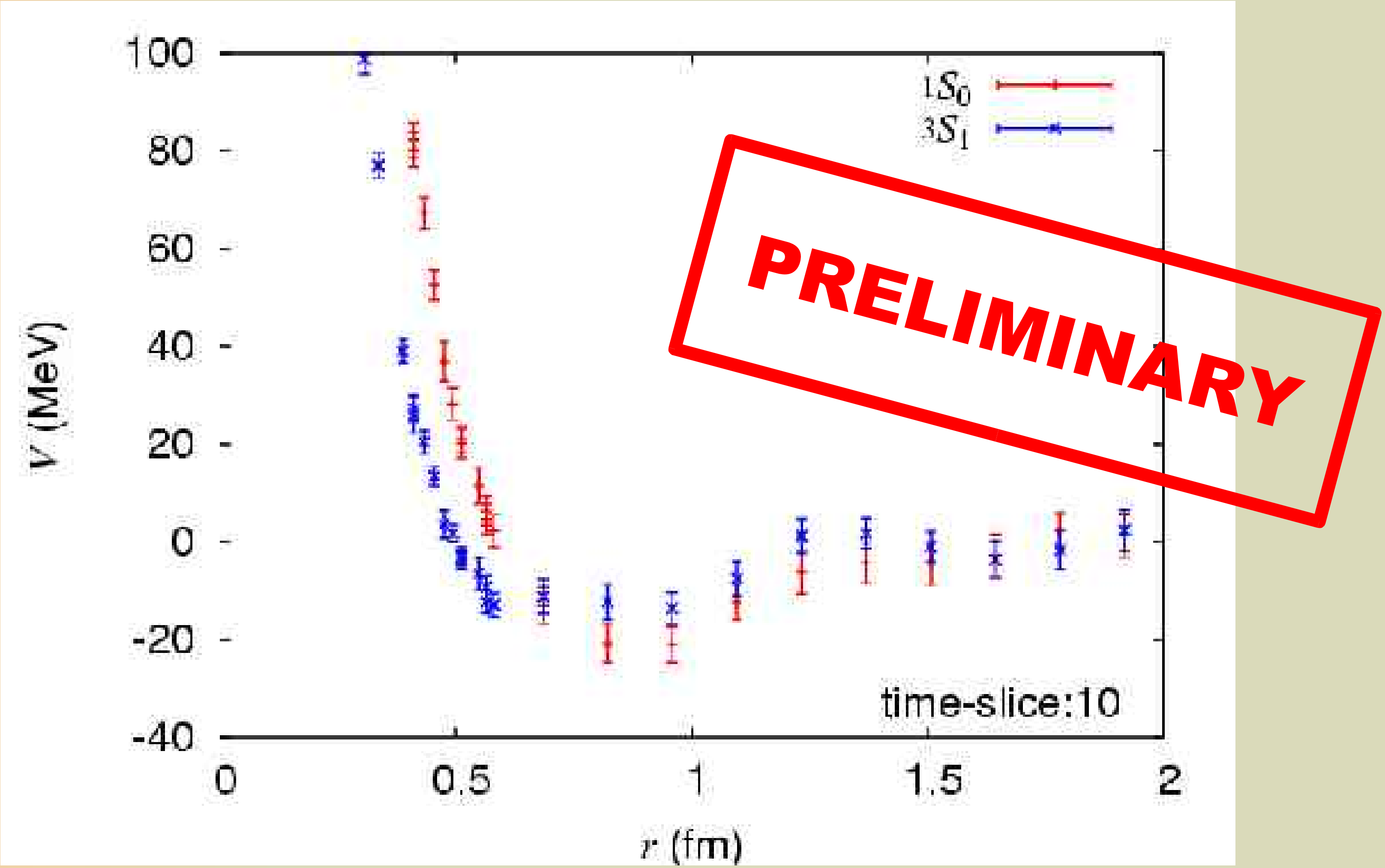
- NΞ potential (I=1), from lattice QCD for the first time.



- Strong repulsive core in spin S=0 channel.
- Strong spin dependence.

Results —— potential

- NΞ potential (I=1), from lattice QCD for the first time.



- Attractive force in medium and long-range region for both spin S=0 and 1.

まとめと今後の課題

- ダブルラムダハイパー核では、
  ΛＮ-ΣＮ結合を考慮することが重要
  特に、テンソル力の役割を考慮した、
  Nagaraイベントの解析
- Ξハイパー核の研究では、
  エネルギー（束縛するか?)、崩壊幅、
  実験の可能性（ターゲットは?)
- 格子ＱＣＤによる、
  ＹＮ、ＹＹポテンシャルの研究
  斥力芯の存在、スピン依存性
- 中性子過剰ハイパー核の可能性
  $^{6}_{\Lambda}H$?