Symposium: Quarks to Universe in Computational Science

(QUCS2012)

Dec. 12–16, 2012

Lambda hypernuclei of He isotope with TOSM + UCOM

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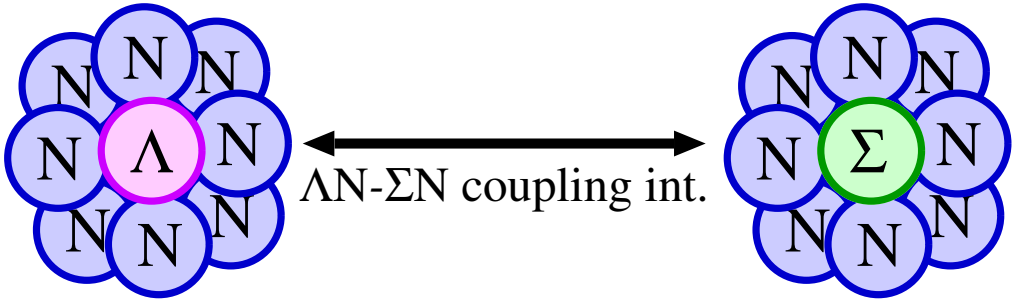
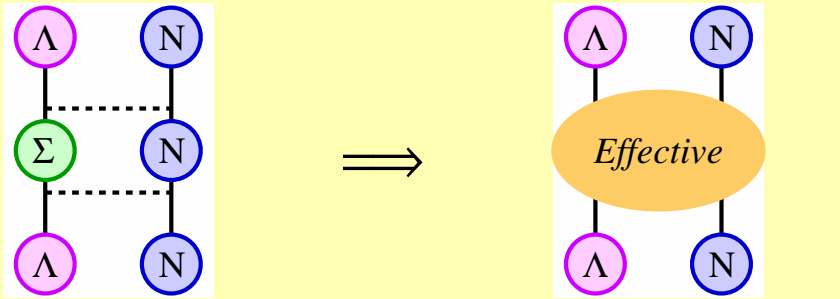
Takayuki MYO (OIT), Emiko HIYAMA (RIKEN)

Hiroshi TOKI (RCNP), Kiyomi IKEDA (RIKEN)

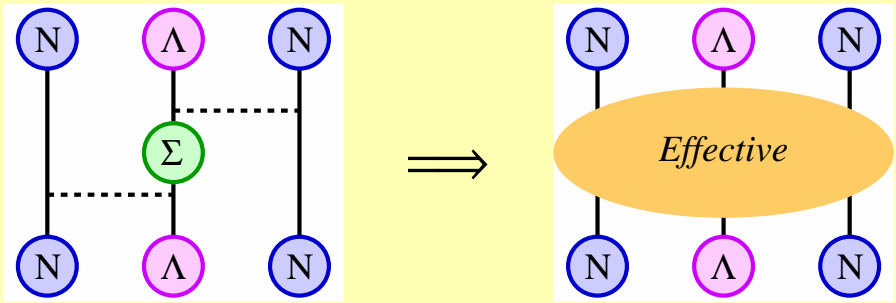
One of the open questions in S=−1 sector of YN interaction

ΛN-ΣN coupling interaction





Effective 2-body ΛN interaction



Effective 3-body ΛNN interaction (Fujita-Miyazawa type)

Strength of the ΛN-ΣN coupling interaction → still unknown

ΛN-ΣN coupling in neutron-rich hypernuclei

Neutron-rich hypernuclei are suited for investigating the ΛN-ΣN coupling

Σ hyperon: Isospin $I = 1$

Neutron-rich nuclei: Large isospin

$\Rightarrow$ **Large Σ-mixing**

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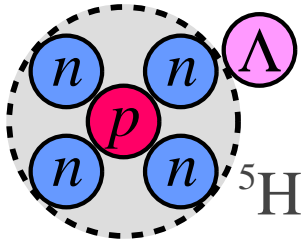
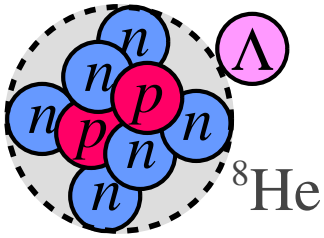
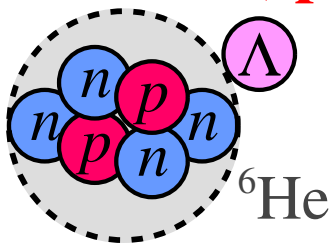
Productions of neutron-rich Λ hypernuclei

- **J-PARC E10 (spokes person: A. Sakaguchi)**

$\rightarrow$ ${}^{6}_{\Lambda}\mathrm{H}$ 

${}^{9}_{\Lambda}\mathrm{He}$ 

- **JLab Hall C E01-011 (spokes person: S.N. Nakamura)**

$\rightarrow$ ${}^{7}_{\Lambda}\mathrm{He}$ 

analysis is in progress

ΛN-ΣN coupling in neutron-rich hypernuclei

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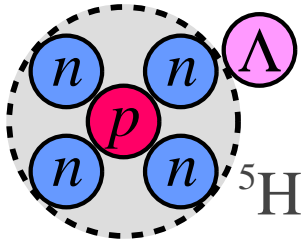
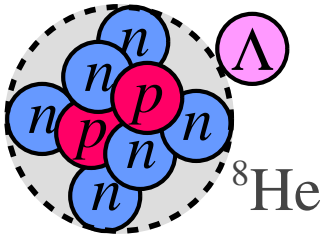
$\rightarrow$ ${}^{6}_{\Lambda}\mathrm{H}$ 

${}^{9}_{\Lambda}\mathrm{He}$ 

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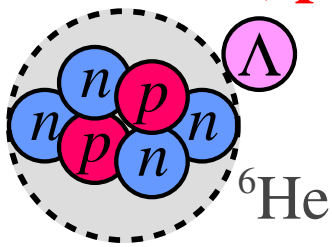
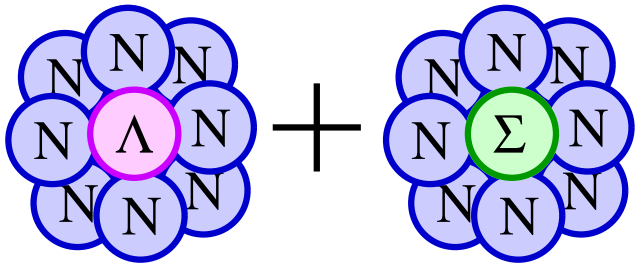
$\rightarrow$ ${}^{7}_{\Lambda}\mathrm{He}$ 

analysis is in progress

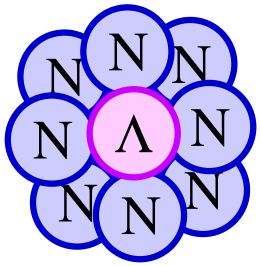
To clarify the structure of neutron-rich Λ hypernuclei

Research plan

ab initio **calculation for neutron-rich hypernuclei with realistic interactions taking into account ΛN-ΣN coupling explicitly**

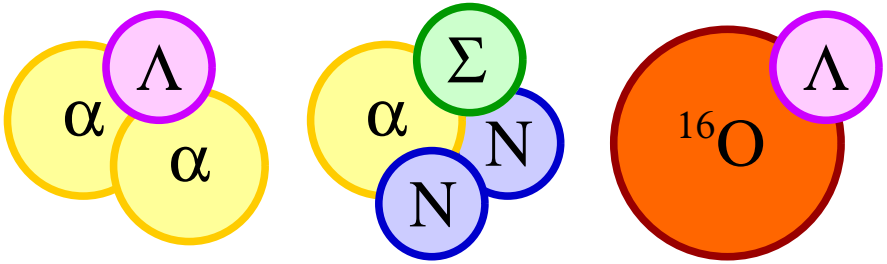


Λ channel + Σ channel
- **great many configulations**
- **difficult and challenging calculation**



only Λ channel (single channel)
- **Few-body calculation**
- **No core shell model**

⋮



assuming α cluster or ^{16}O core
- **Cluster model**
- **Shell model**

⋮

Research plan

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with realistic interactions
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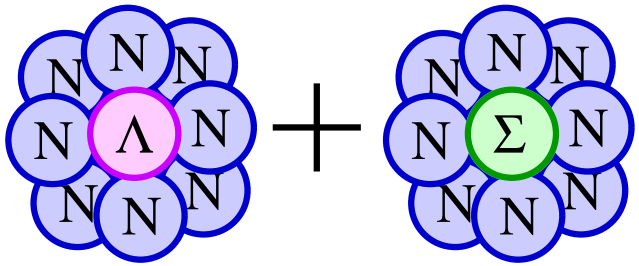

Λ channel + Σ channel
- **great many configulations**
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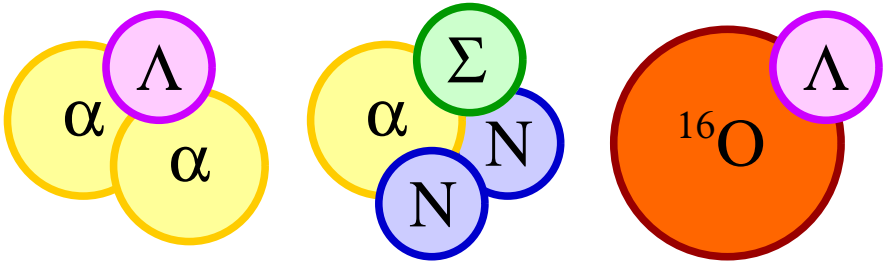
Method: Tensor-Optimized Shell Model (TOSM)

T. Myo *et al.*, Prog. Theor. Phys. 117, 257 (2007).

Suited for a systematic investigation of nuclei with A = 3–10
without assuming an α cluster



Accuracy: a few MeV
- **Cluster model**
- **Shell model**

⋮

Tensor-Optimized Shell Model (TOSM)

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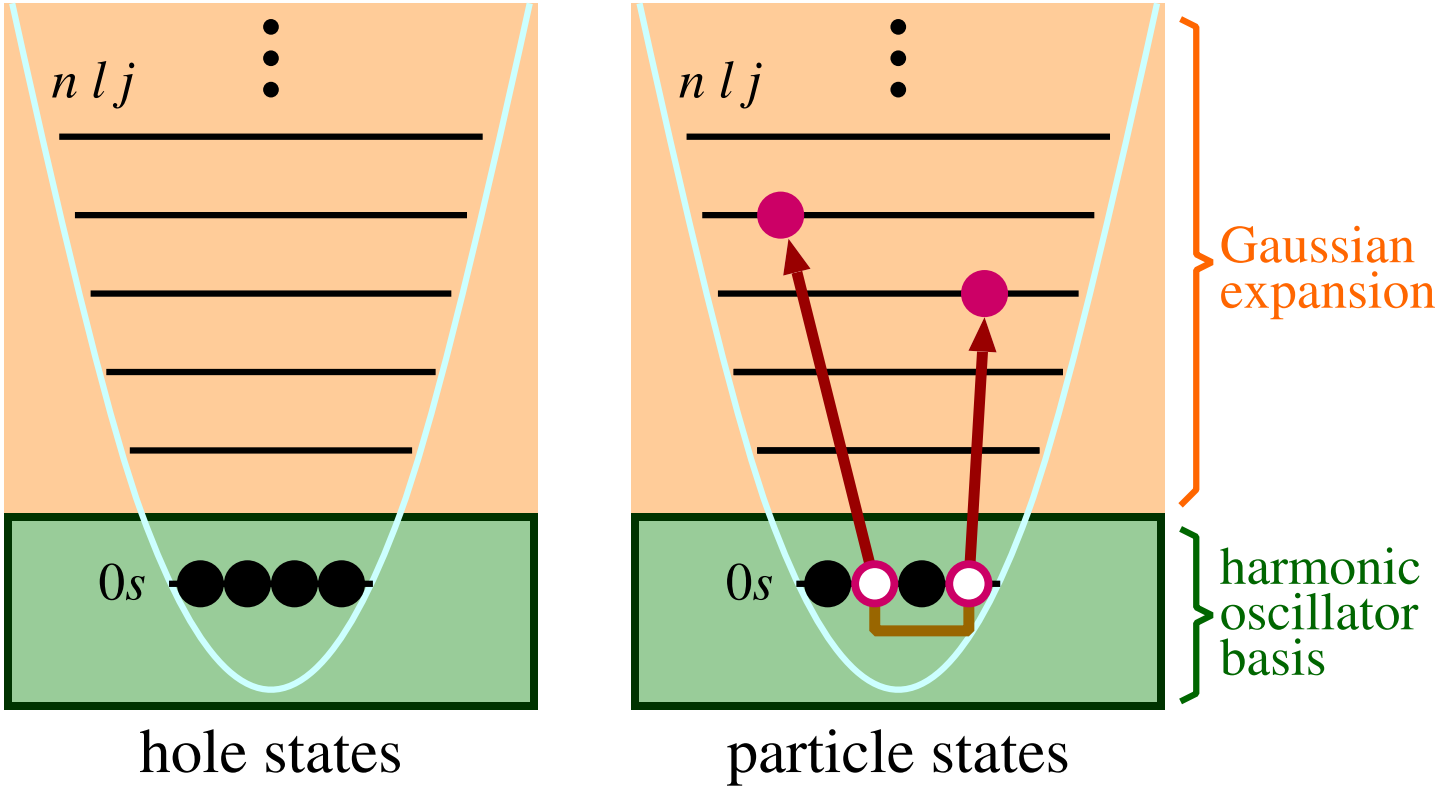
Case of ^{4}He



taking into account high-momentum components described by $1p$-$1h$ and $2p$-$2h$ excitations

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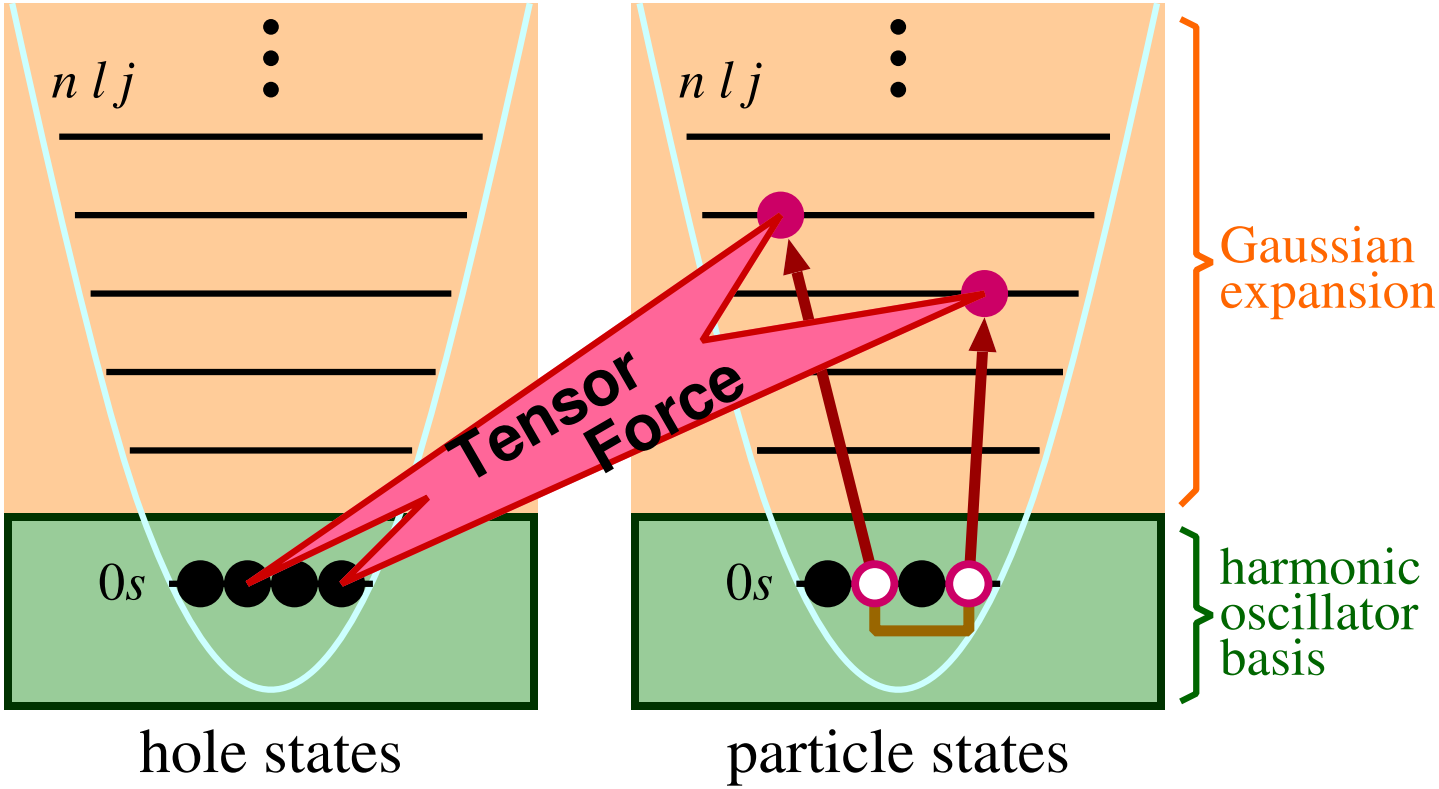

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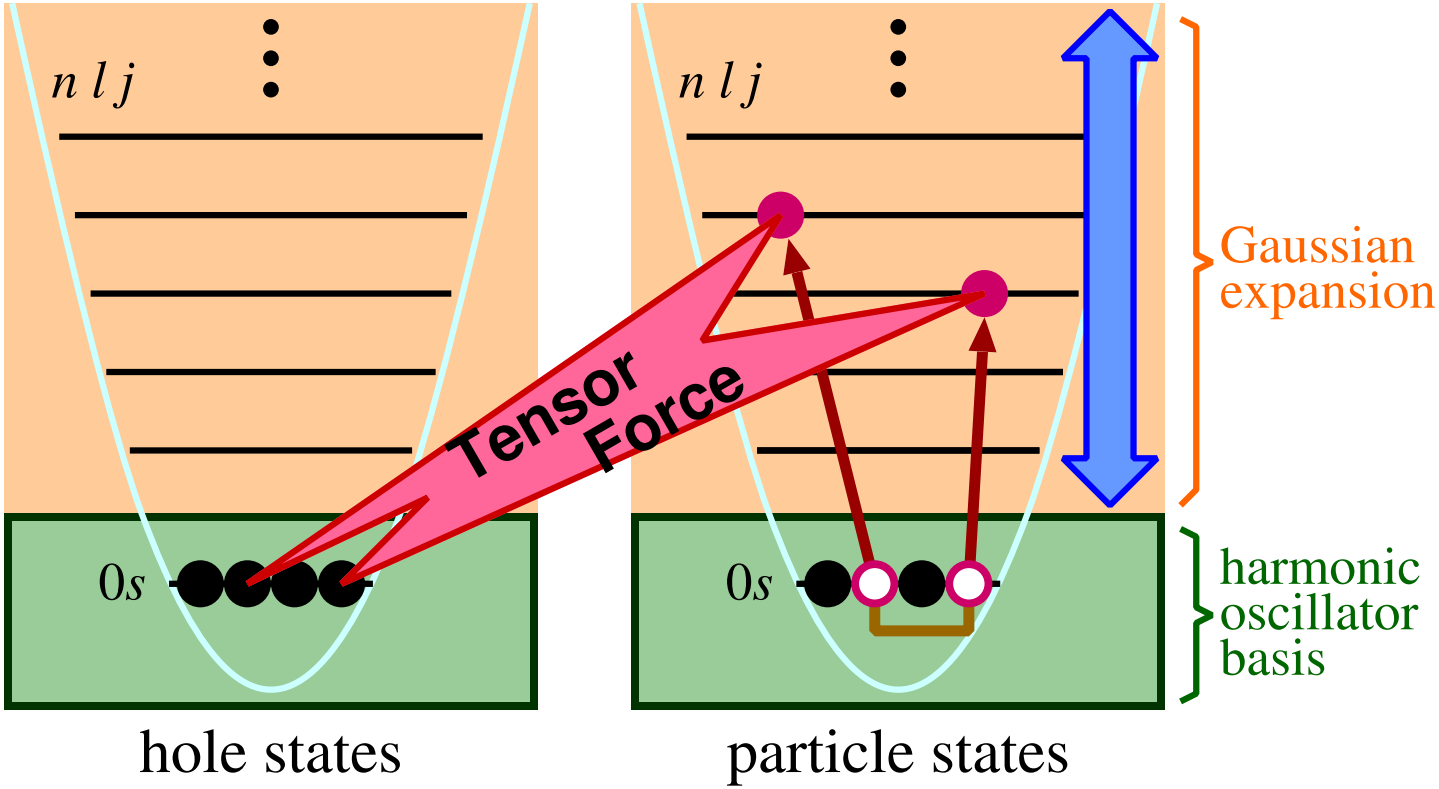

taking into account high-momentum components

described by $1p$-$1h$ and $2p$-$2h$ excitations

- **Model space ← given by maximum number of angular momentum l**
- **Particle states ← described by several Gaussians**

In this talk...

Focus on *s*-shell Λ-hypernuclei

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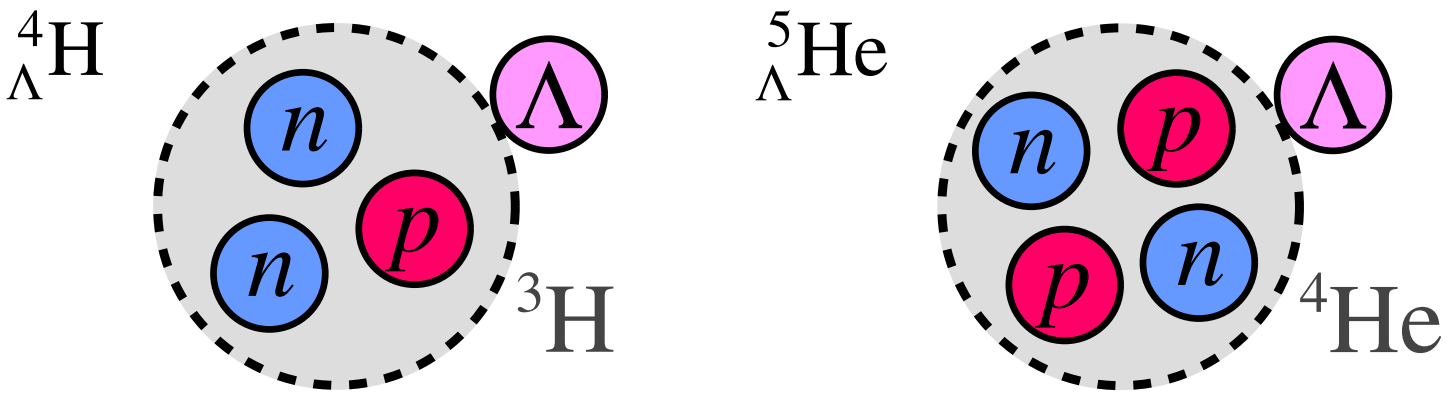
Calculations of energy levels of ${}^{4}_{\Lambda}$H and ${}^{5}_{\Lambda}$He



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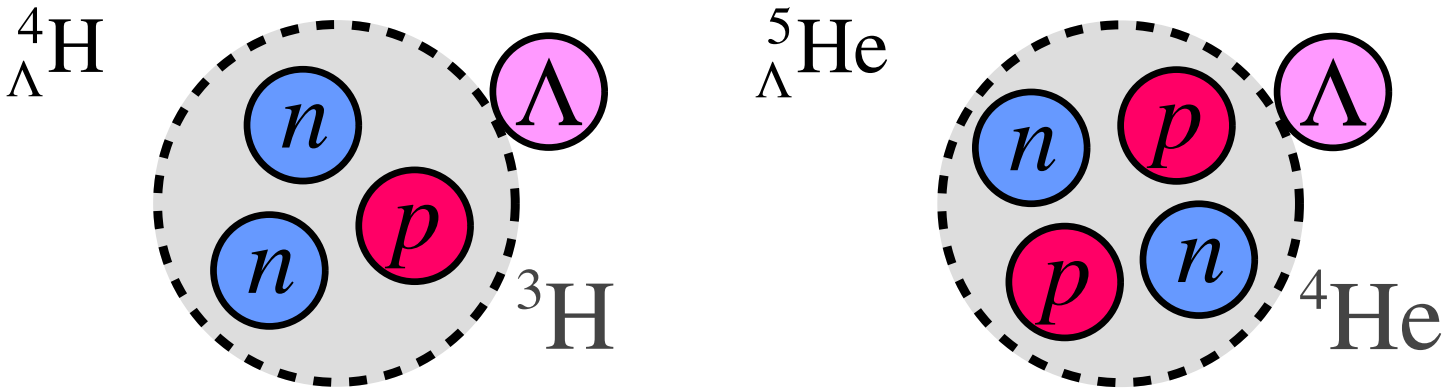

First TOSM calculations of hypernuclei

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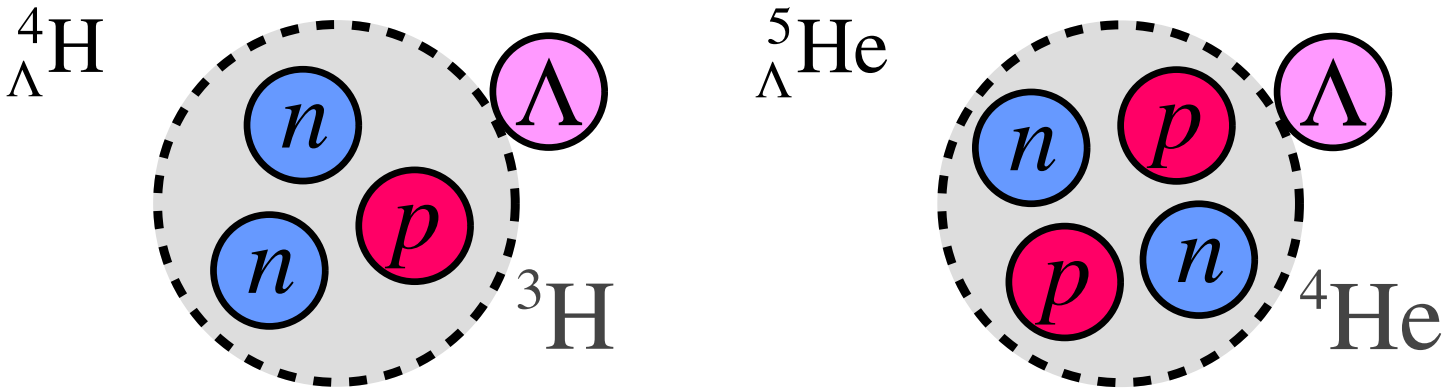

First TOSM calculations of hypernuclei

Comparison with other *ab initio* calculations

checking the accuracy of TOSM for an application to neutron-rich hypernuclei

Application to *s*-shell Λ-hypernuclei

Model space

- **Σ hyperon state in the TOSM wave functions**
- $l_{\max} = 14$ **in the energy variation**

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Model space

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Interactions

- ***NN* interaction**

  AV8' **B.S. Pudliner *et al.*, Phys. Rev. C 56, 1720 (1997).**

- ***YN* interaction (Λ*N*, Σ*N*, Λ*N*-Σ*N* coupling)**

$$V_{YN} = V_0^{YN} + \sigma \cdot \sigma\, V_\sigma^{YN} + \ell \cdot s\, V_{\ell s}^{YN} + S_{12}\, V_{\text{tensor}}^{YN}$$

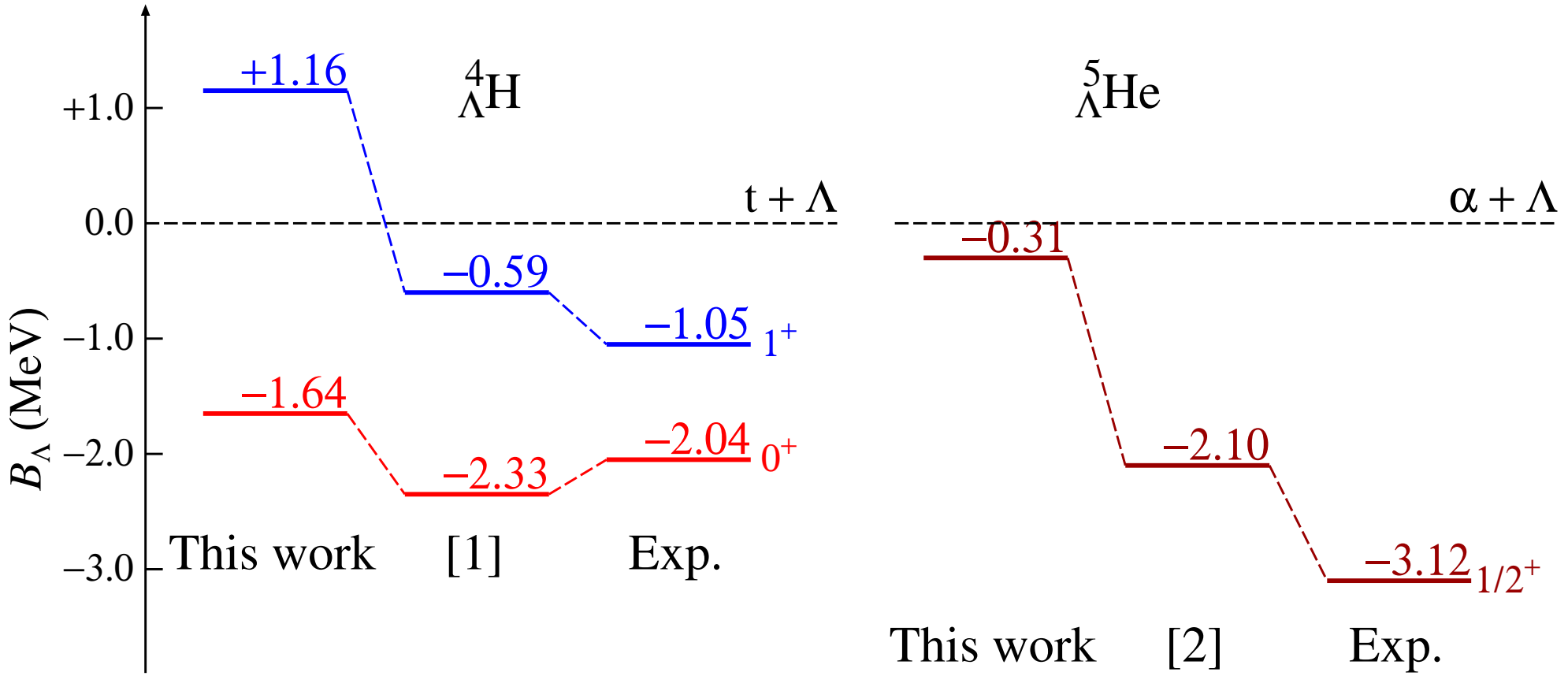
made by S. Shinmura

simulated the scattering phase shifts given by NSC97f

used in few-body calculations

E. Hiyama *et al.*, Phys. Rev. C 65, 011301(R).
H. Nemura *et al.*, Phys. Rev. Lett. 89, 142504 (2002).

Numerical results of energy levels of ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{5}_{\Lambda}\mathrm{He}$



[1] E. Hiyama *et al.*, Phys. Rev. C 65, 011301(R) (2001).
[2] H. Nemura *et al.*, Phys. Rev. Lett. 89, 142504 (2002).
(G3RS potential is used for *NN* interaction in [2].)
R. Tamagaki, Prog. Theor. Phys. 39, 91 (1968).

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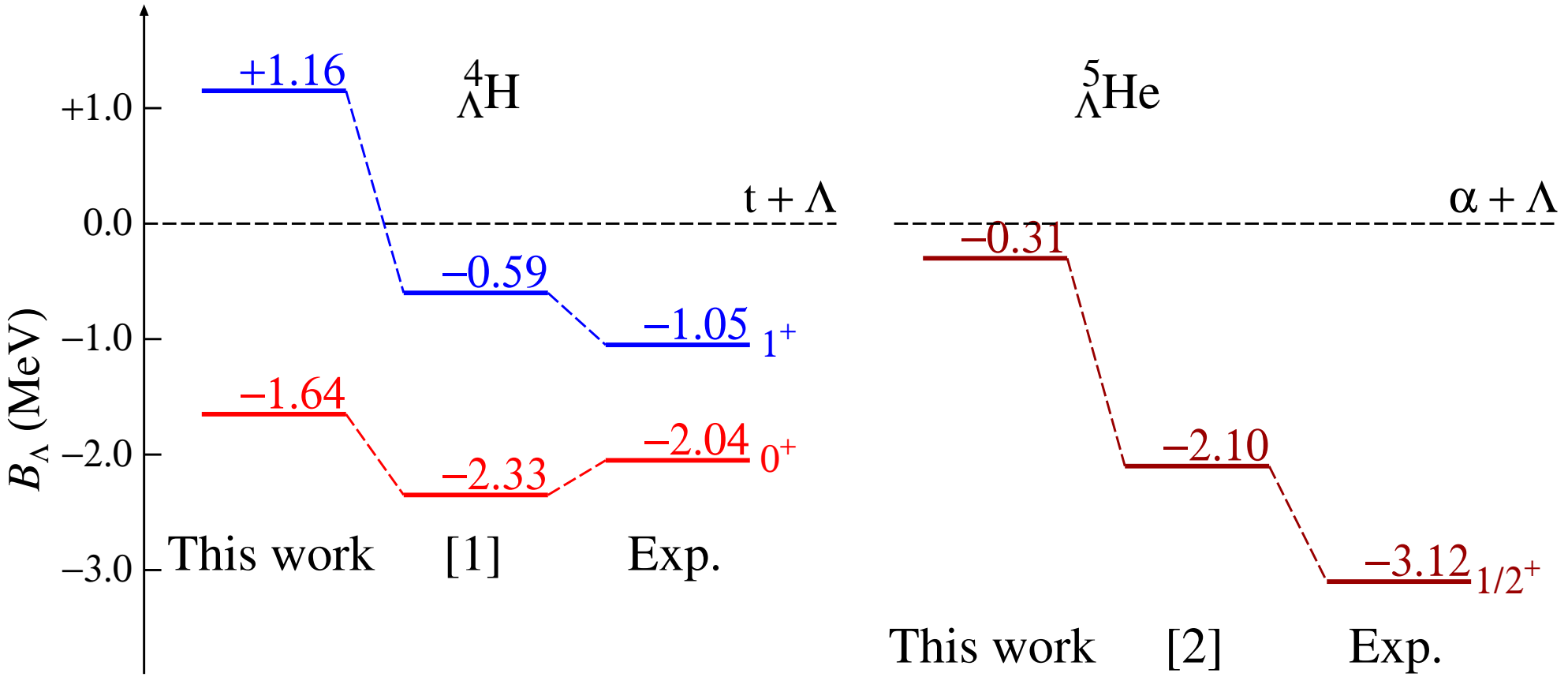
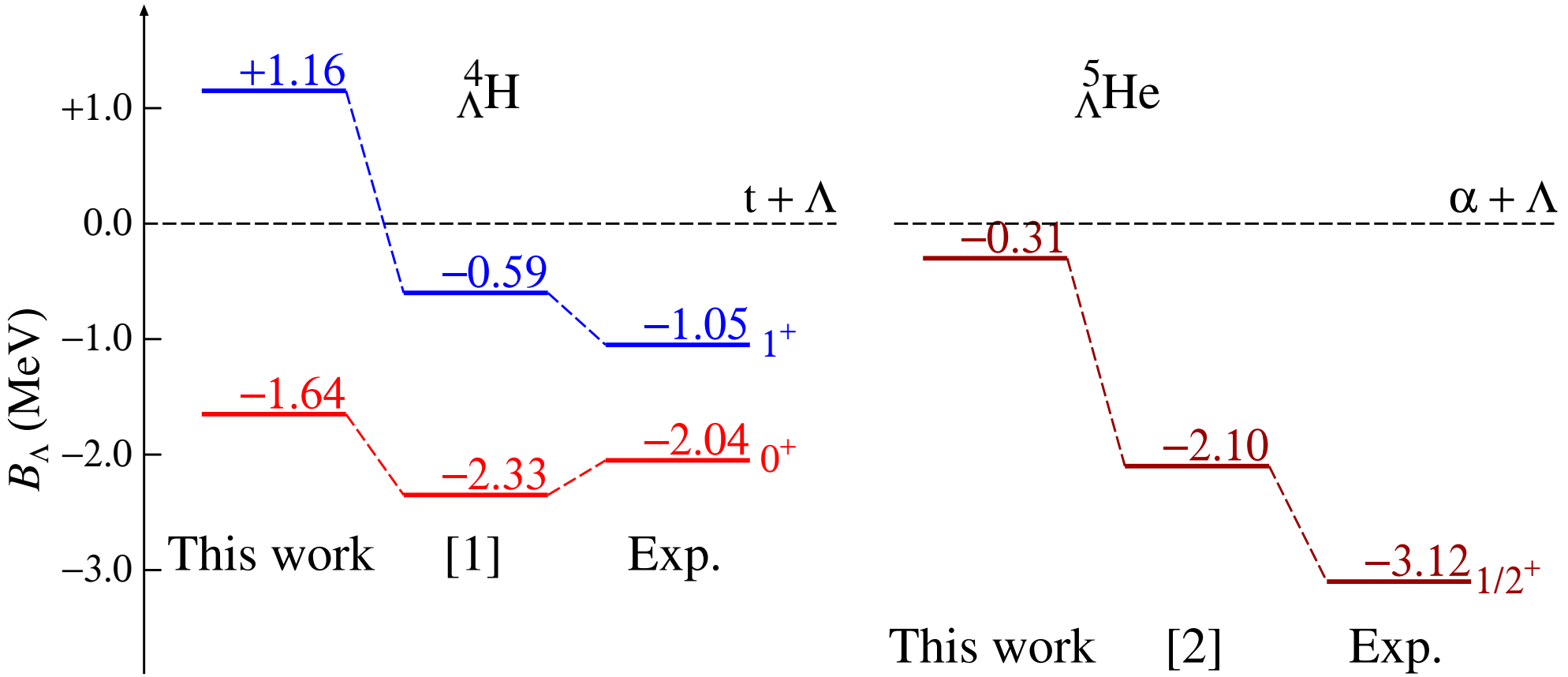


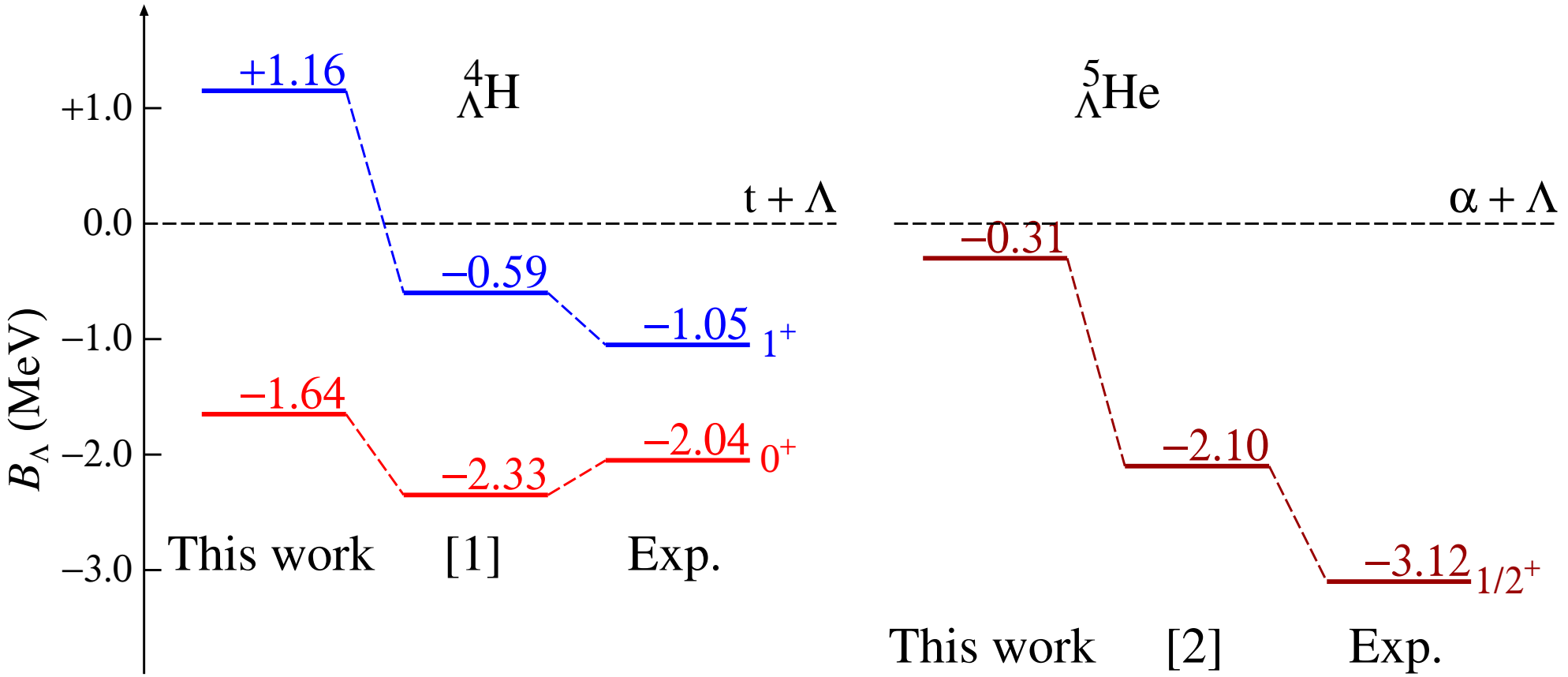
- **not get sufficient binding energies**

Numerical results of energy levels of ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{5}_{\Lambda}\mathrm{He}$



- **not get sufficient binding energies**
- **${}^{4}_{\Lambda}\mathrm{H}$ (1^+) is unbound**

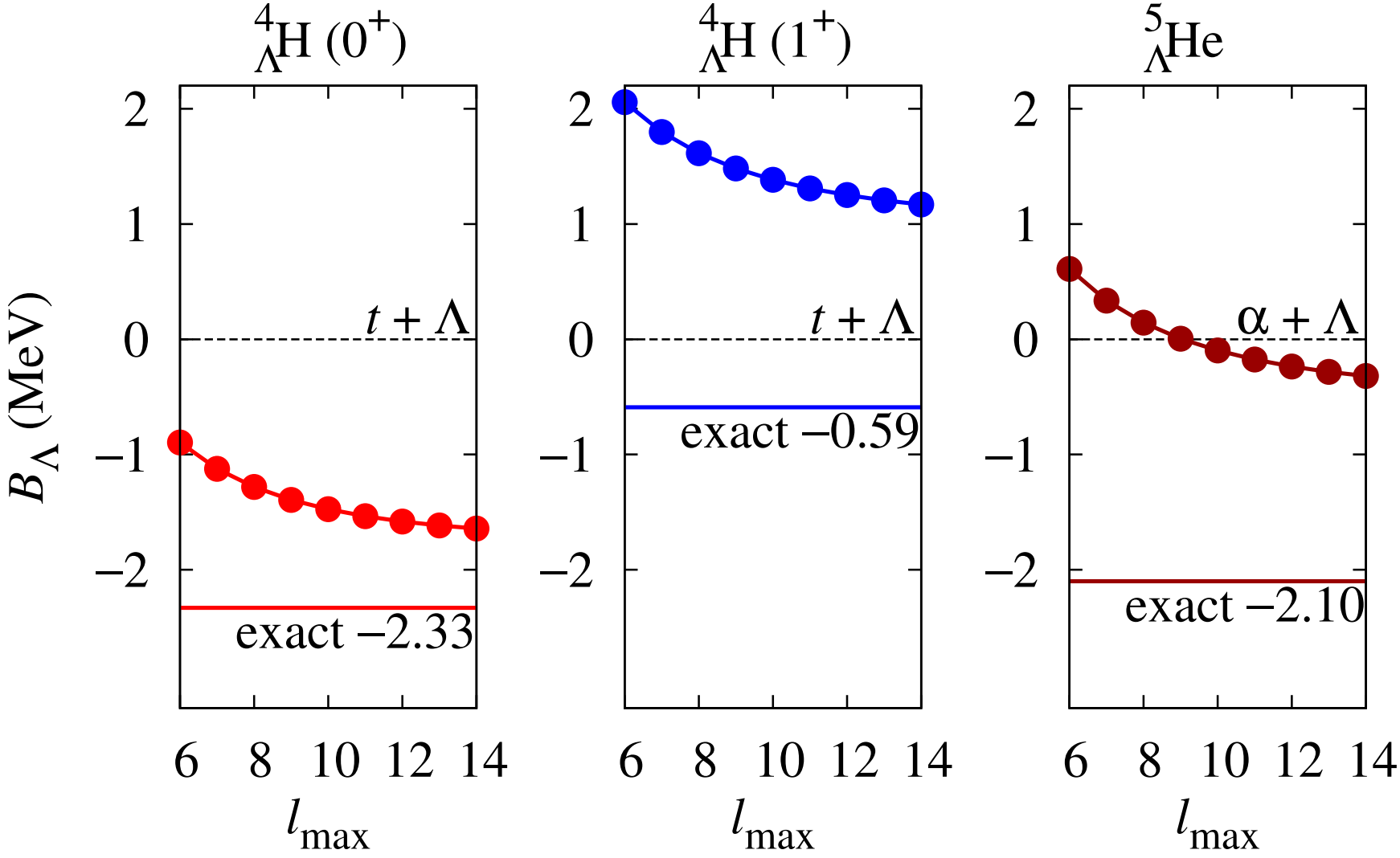
Numerical results of energy levels of ${}^{4}_{\Lambda}$H and ${}^{5}_{\Lambda}$He



- **not get sufficient binding energies**
- **${}^{4}_{\Lambda}$H (1^+) is unbound**

  $\Longrightarrow$ several improvements to get the sufficient binding energies

Convergence of B_Λ



Model space with $L_{\max} = 14$ is not enough to get a sufficient energy convergence.

Role of ΛN-ΣN coupling

Contributions to the binding energies

$\langle V_{YN} \rangle$ in ${}^{4}_{\Lambda}\mathrm{H}; 0^{+}$ (MeV)

	Central	Tensor	*LS*
$N\Lambda$-$N\Lambda$	−5.02	−1.26	−0.23
$N\Lambda$-$N\Sigma$	−3.18	−9.29	0.32
$N\Sigma$-$N\Sigma$	0.62	−2.03	−0.14

$\langle V_{YN} \rangle$ in ${}^{4}_{\Lambda}\mathrm{H}; 1^{+}$ (MeV)

	Central	Tensor	*LS*
$N\Lambda$-$N\Lambda$	−1.47	−0.64	−0.05
$N\Lambda$-$N\Sigma$	−1.33	−9.65	0.13
$N\Sigma$-$N\Sigma$	0.75	−0.23	−0.19

$\langle V_{YN} \rangle$ in ${}^{5}_{\Lambda}\mathrm{He}$ (MeV)

	Central	Tensor	*LS*
$N\Lambda$-$N\Lambda$	−3.08	−0.67	−0.04
$N\Lambda$-$N\Sigma$	−1.39	−11.03	0.12
$N\Sigma$-$N\Sigma$	0.82	0.00	−0.23

The tensor component of the ΛN-ΣN coupling interaction strongly contributes to the binding energy.

These results are qualitative agreement with the few-body calculation by H. Nemura.

H. Nemura *et al.*, Phys. Rev. Lett. 89, 142504 (2002).

Summary

We have calculated the energy spectra of s-shell Λ-hypernuclei, ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{5}_{\Lambda}\mathrm{He}$ by using TOSM which includes the ΛN-ΣN coupling explicitly.

First TOSM calculations of hypernuclei

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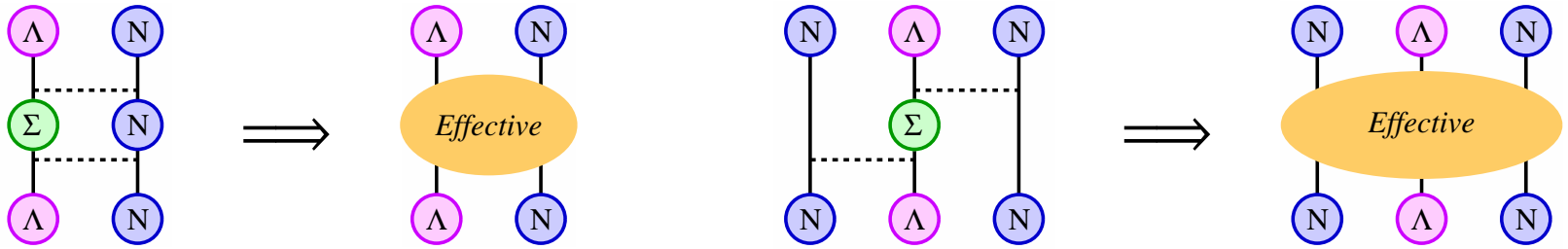
We have calculated the energy spectra of s-shell Λ-hypernuclei, ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{5}_{\Lambda}\mathrm{He}$ by using TOSM which includes the ΛN-ΣN coupling explicitly.

First TOSM calculations of hypernuclei

Future plan

$\Rightarrow$ the TOSM calculation will be improved

- **the results which are close to *ab initio* calculation**
- **quantitative discussion on role of the ΛN-ΣN coupling interaction**



- ***ab initio* like calculations for p-shell hypernuclei**

  $\rightarrow$ prediction of energy levels of ${}_{\Lambda}\mathrm{He}$ isotope up to $A = 9$