素核宇融合による計算基礎物理学の進展
–ミクロとマクロのかけ橋の構築–
2011 年 12 月 3 日 ～ 5 日 於 合歓の郷

テンソル力に適した巨大次元殻模型による中性子過剰ハイパー核の構造研究の進捗状況

(TOSM Calculation of Neutron-Rich Hypernuclei)

Atsushi UMEYA (NIT)

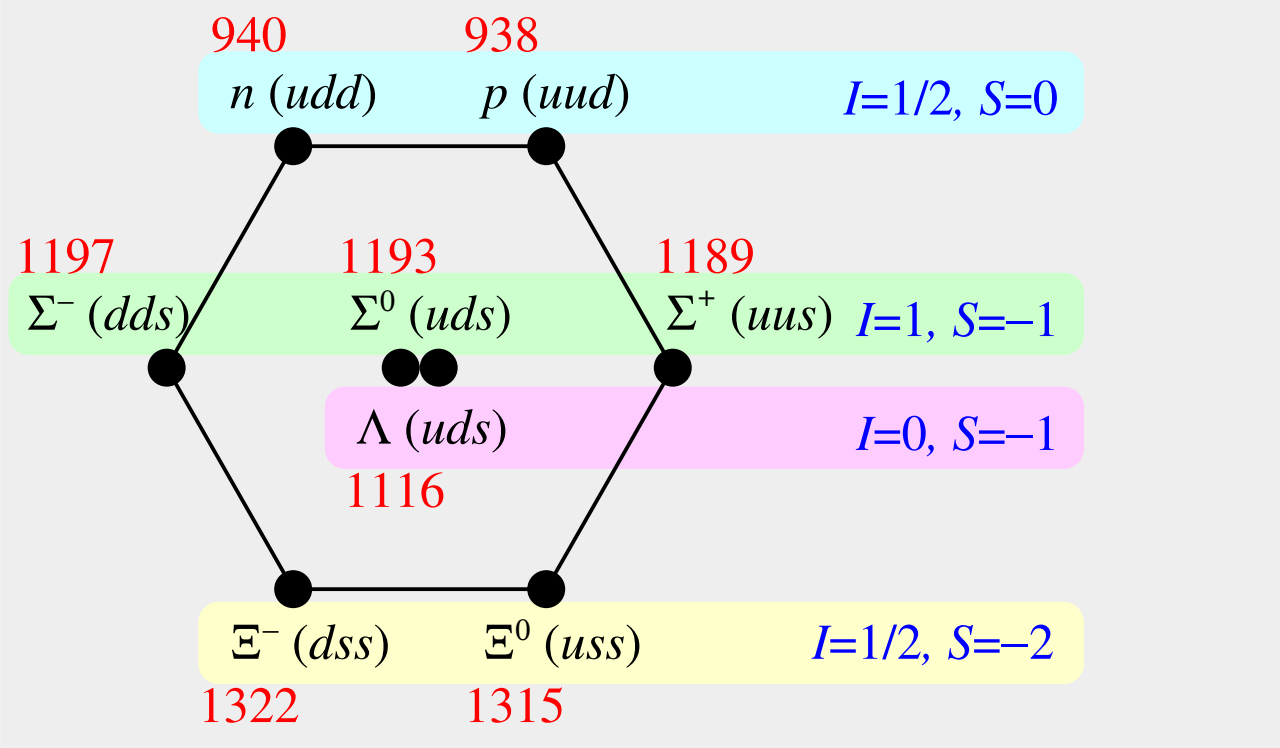
Takayuki MYO (OIT), Emiko HIYAMA (RIKEN)

Hiroshi TOKI (RCNP), Kiyomi IKEDA (RIKEN)

Purpose of hypernuclear study

To get information on baryon-baryon interaction

from the structure of hypernuclei



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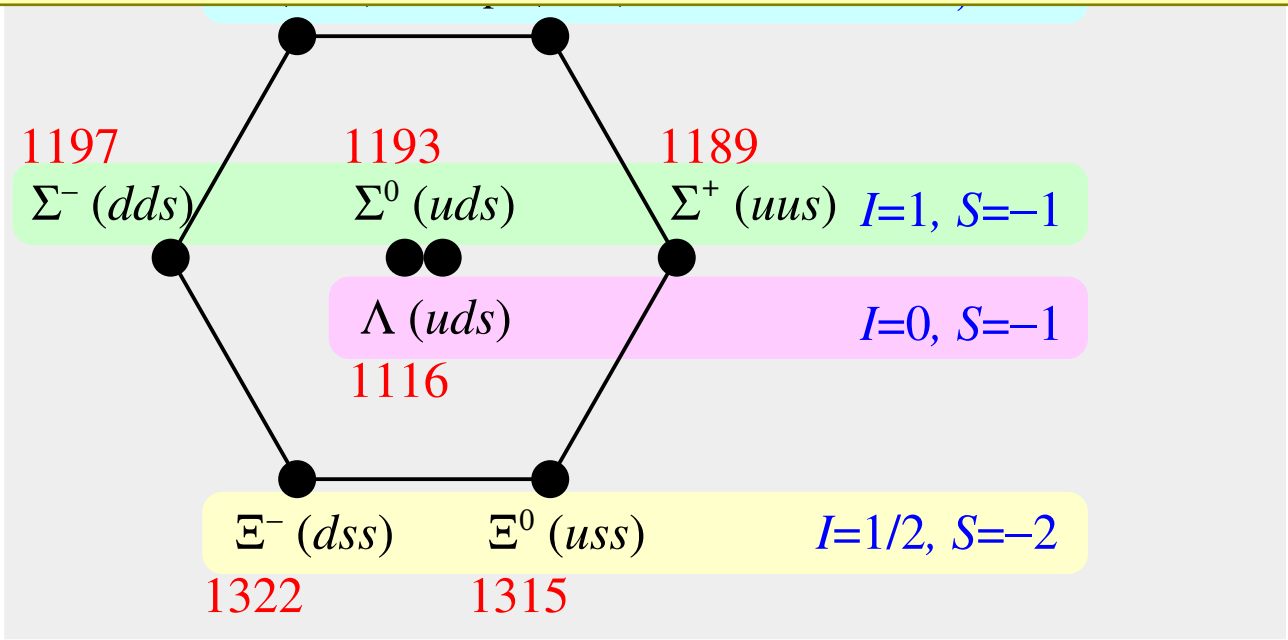
$S = -1$ sector (ΛN int., ΣN int., ΛN-ΣN coupling int.)



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Effective ΛN interaction **Hypernuclear γ-ray data since 1998**

$$V_{\Lambda N}^{\mathrm{eff}} = V_0 + V_{\sigma\sigma}\,\boldsymbol{\sigma}_N\cdot\boldsymbol{\sigma}_\Lambda + V_{\mathrm{SLS}}\,\boldsymbol{\ell}_{\Lambda N}\cdot(\boldsymbol{s}_\Lambda + \boldsymbol{s}_N) + V_{\mathrm{ALS}}\,\boldsymbol{\ell}_{\Lambda N}\cdot(\boldsymbol{s}_\Lambda - \boldsymbol{s}_N) + V_{\mathrm{Tensor}}\,S_{12}$$

- **Millener (p-shell model)** **Nucl. Phys. A 804, 84 (2008).**
- **Hiyama (Few-body)** **Prog. Part. Nucl. Phys. 63, 339 (2009).**

Ξ^- (dss) Ξ^0 (uss) I=1/2, S=–2

1322 1315

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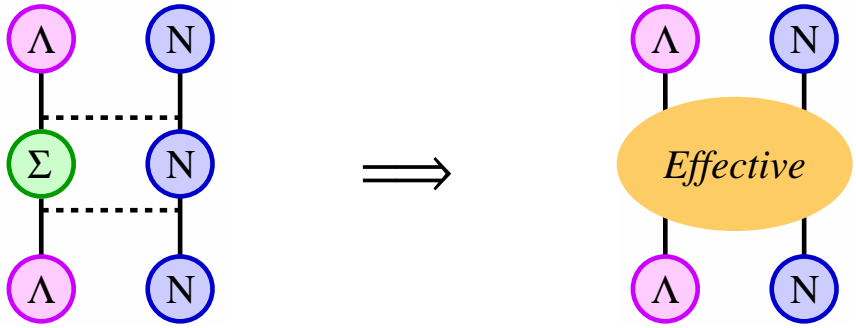
One of the open questions in S=−1 sector of YN interaction

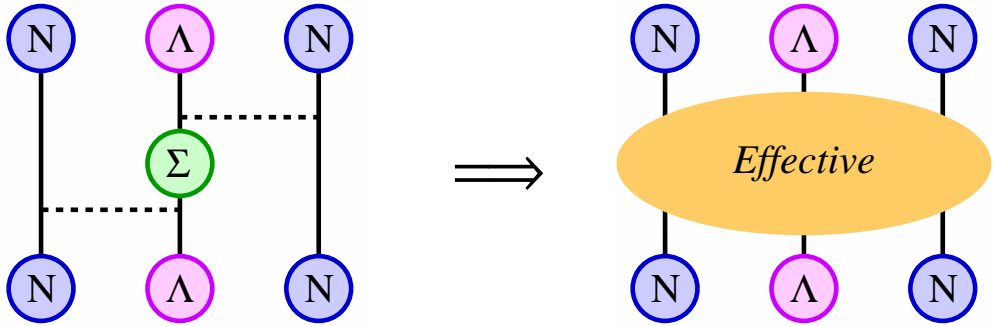
→ ΛN-ΣN coupling interaction

Role of ΛN-ΣN coupling interaction

ΛN-ΣN coupling $\Longrightarrow$ Great contribution to study of neutron star



Effective 2-body ΛN interaction



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

Strength of the ΛN-ΣN coupling interaction → still unknown

Studies for analysis of ΛN-ΣN coupling

s-shell hypernuclei

- Y. Akaishi *et al.*, Phys. Rev. Lett. 84, 3539 (2000).
- E. Hiyama *et al.*, Phys. Rev. C 65, 011341(R) (2001).
- A. Nogga *et al.*, Phys. Rev. Lett. 88, 172501 (2002).
- H. Nemura *et al.*, Phys. Rev. Lett. 89, 142504 (2002).

p-shell hypernuclei (Shell-model study)

- D. Halderson, Phys. Rev. C 77, 034304 (2008).
- D.J. Millener, Nucl. Phys. A 804, 84 (2008).
- A. Umeya, T. Harada, Phys. Rev. C 79, 024315 (2009).
- A. Umeya, T. Harada, Phys. Rev. C 83, 034310 (2011).

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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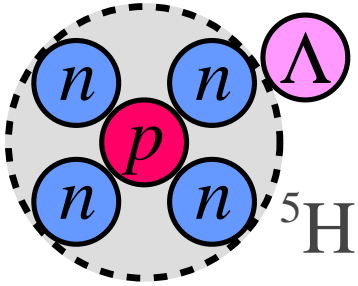
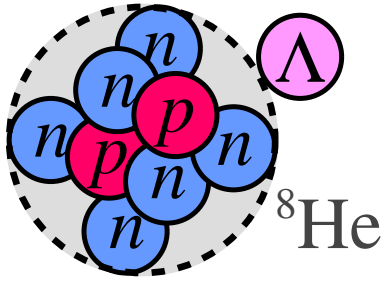
Productions of neutron-rich Λ hypernuclei

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

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

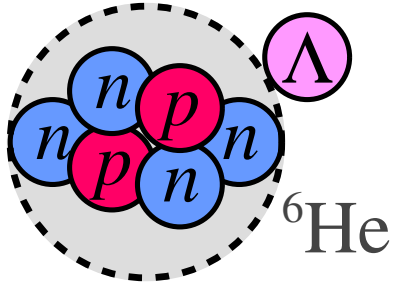


${}^{9}_{\Lambda}\mathrm{He}$



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

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



analysis is in progress

Research plan

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

Nuclei: $^{}_{\Lambda}$He **isotope** $\Rightarrow$ $^{}_{\Lambda}$Li **isotope** $\Rightarrow$ $^{}_{\Lambda}$Be **isotope** $\Rightarrow$ $\cdots$

Method: (1) Tensor-Optimized Shell Model (TOSM)

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

+

Unitary Correlation Operator Method (UCOM)

H. Feldmeier *et al.*, Nucl. Phys. A 632, 61 (1998).

(2) Gaussian Expansion Method (GEM)

E. Hiyama *et al.*, Prog. Part. Nucl. Phys. 51, 223 (2003).

in collaboration with Myo, Hiyama, Toki, and Ikeda

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ab i

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

Nucl

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ab i

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But, insufficient accuracy of about a few MeV
→ extending to about a few hundred keV

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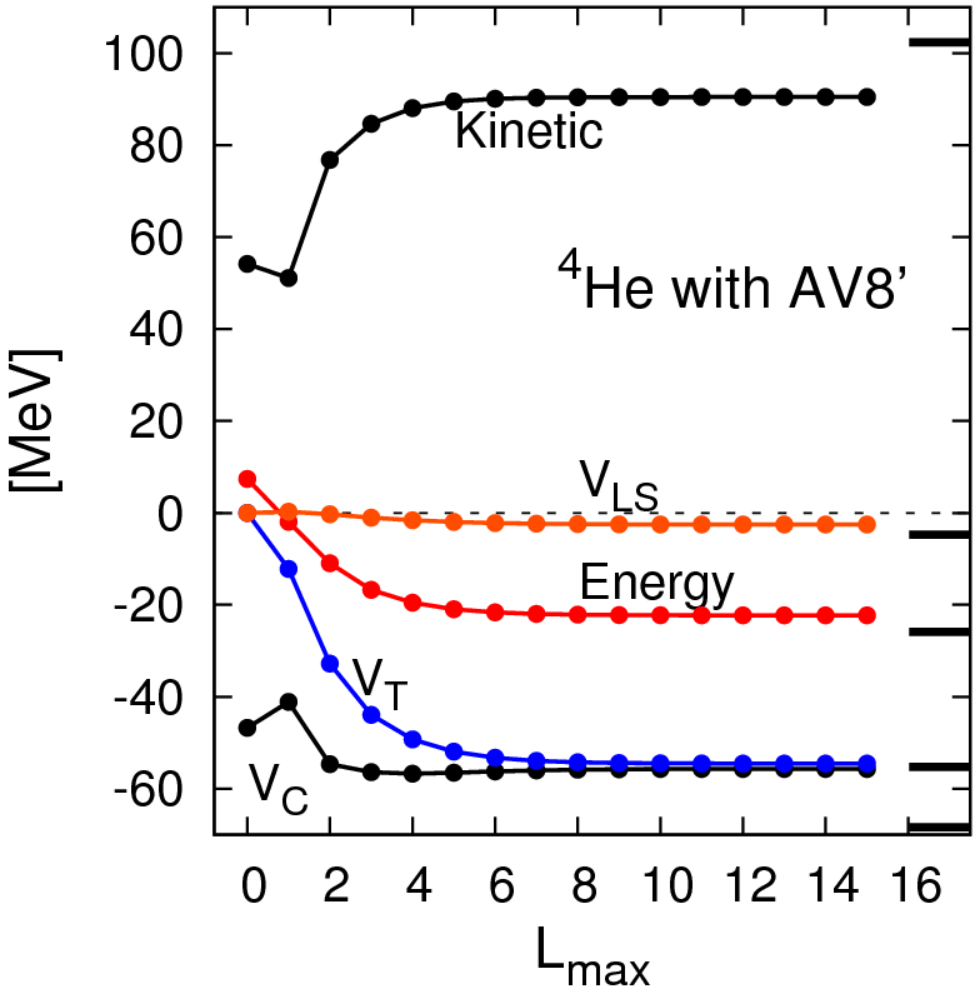
Example of TOSM calculation (^{4}He; 0^+)



← **Exact value**

Benchmark test of *ab initio* calculations

(Kamada *et al.*, Phys. Rev. C 64, 044001 (2001).)

Energy of ^{4}He

TOSM with AV8'

−22.3 MeV

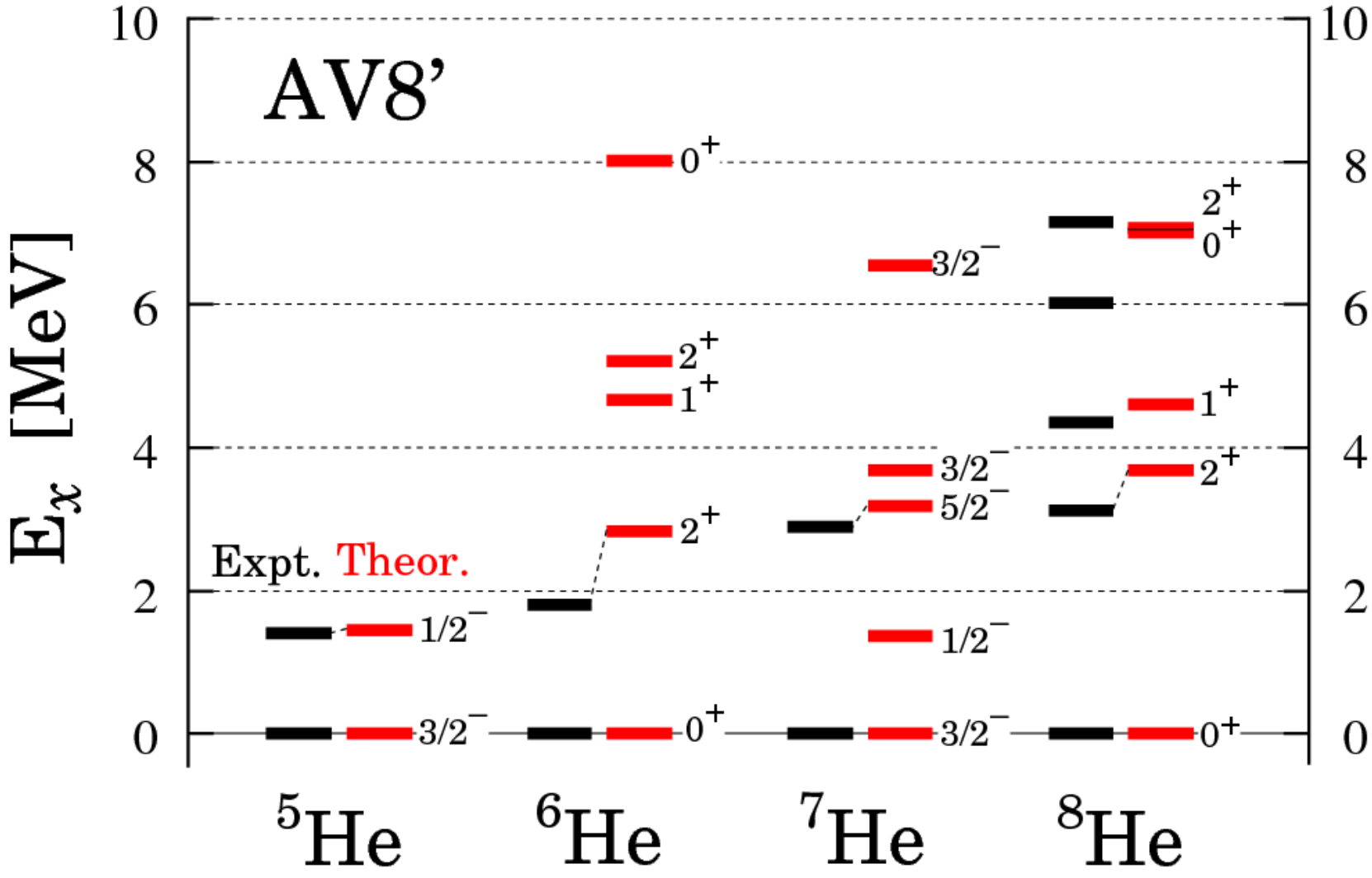
Benchmark test calculation

−25.9 MeV

Energy of ^{4}He in TOSM as a function of the maximum angular momentum

T. Myo *et al.*, Prog. Theor. Phys. 121, 511 (2009).

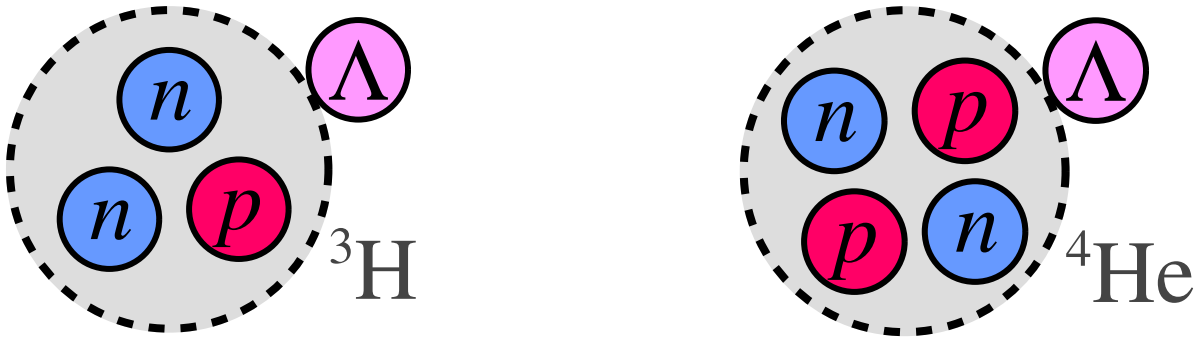
Example of TOSM calculation (Energy spectra of He isotope)



T. Myo, AU, H. Toki, K. Ikeda, Phys. Rev. C 84, 034315 (2011).

In this talk...

- ${}^{4}_{\Lambda}\mathrm{H}$ ${}^{5}_{\Lambda}\mathrm{He}$



- **Contributions of components of *YN* interactions to binding energies of ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{5}_{\Lambda}\mathrm{He}$**

Interactions

- *NN* **interaction**

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

- *YN* **interaction**

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

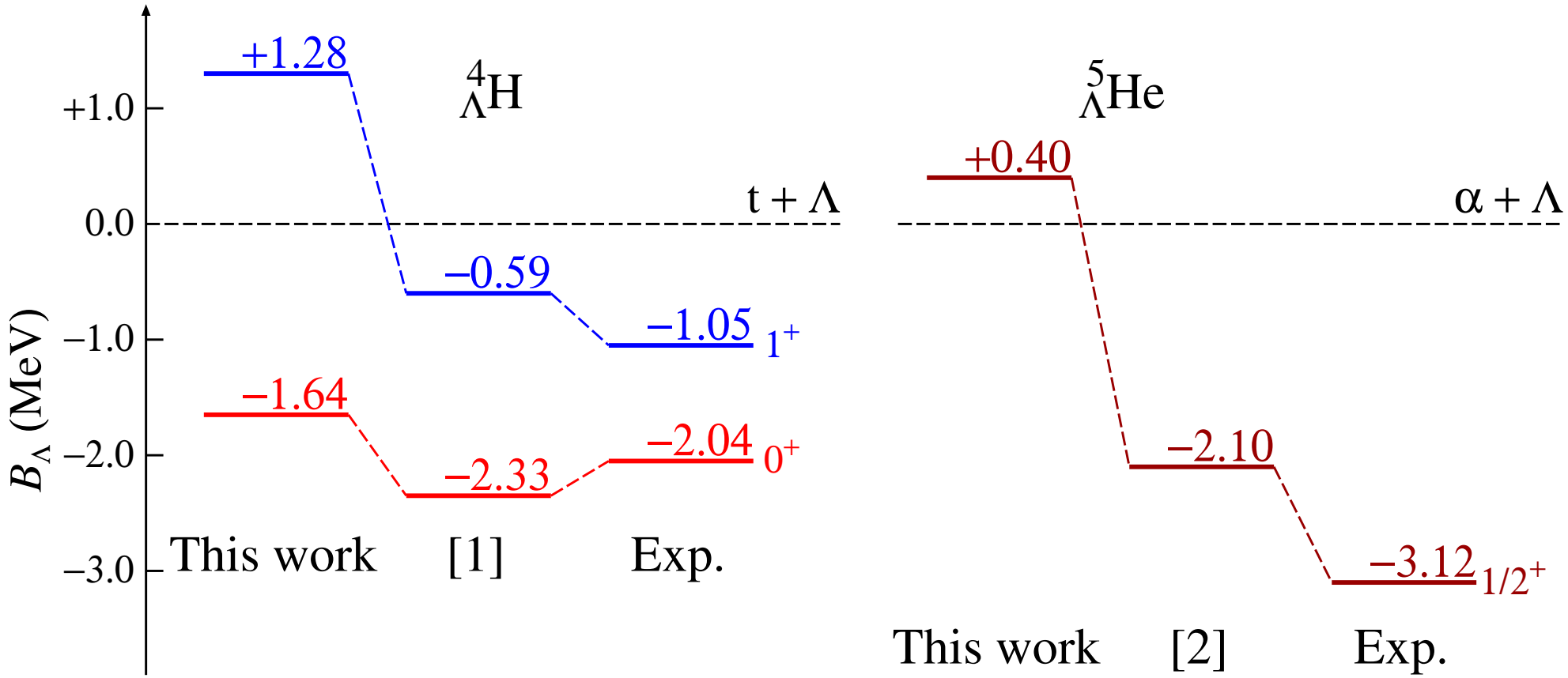
made by S. Shinmura

simulated NSC97f (not original 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).

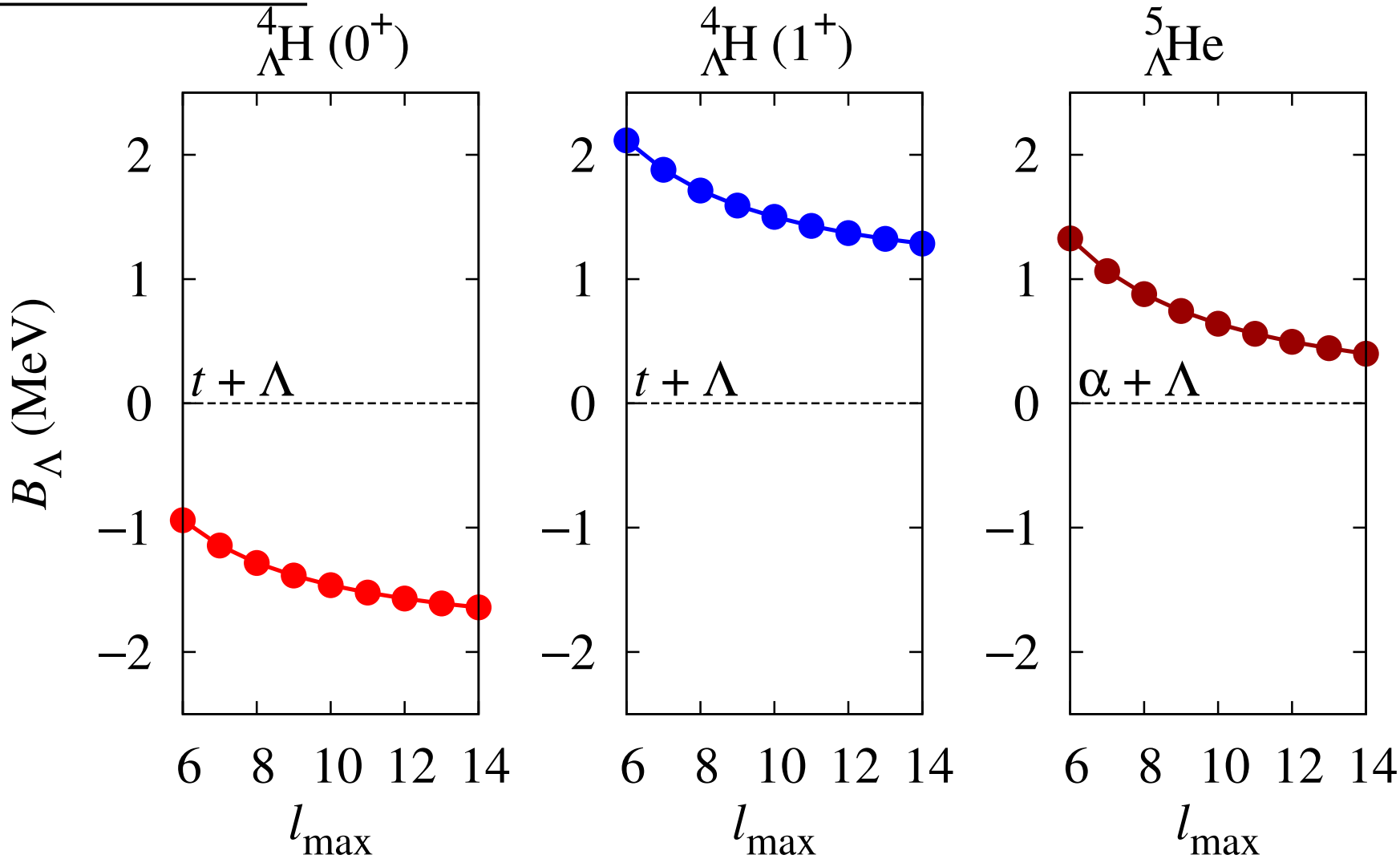
Numerical results of energy levels of ${}^{4}_{\Lambda}\mathrm{H}$, ${}^{5}_{\Lambda}\mathrm{He}$



[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 in [2].)

R. Tamagaki, Prog. Theor. Phys. 39, 91 (1968).

Convergence of B_Λ



insufficient convergence → in progress of calculations with $l_{\max} = 20$

Role of ΛN-ΣN coupling

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

	Central	Tensor	*LS*
*N*Λ-*N*Λ	−5.46	−1.11	−0.16
*N*Λ-*N*Σ	−3.42	−8.75	0.30
*N*Σ-*N*Σ	0.45	−2.04	−0.06

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

	Central	Tensor	*LS*
*N*Λ-*N*Λ	−1.99	−0.60	−0.04
*N*Λ-*N*Σ	−1.38	−9.13	0.13
*N*Σ-*N*Σ	0.64	−0.30	−0.09

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

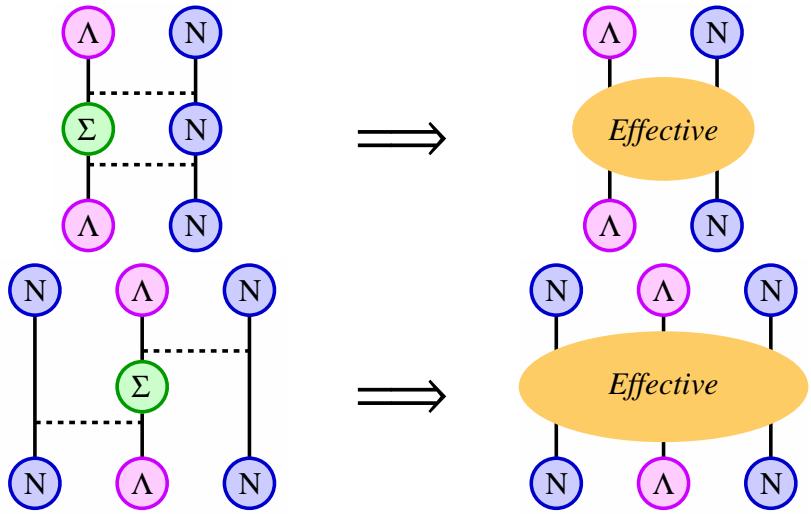
	Central	Tensor	*LS*
*N*Λ-*N*Λ	−3.86	−0.64	−0.03
*N*Λ-*N*Σ	−1.43	−10.52	0.12
*N*Σ-*N*Σ	0.70	−0.08	−0.12

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

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

Future plan

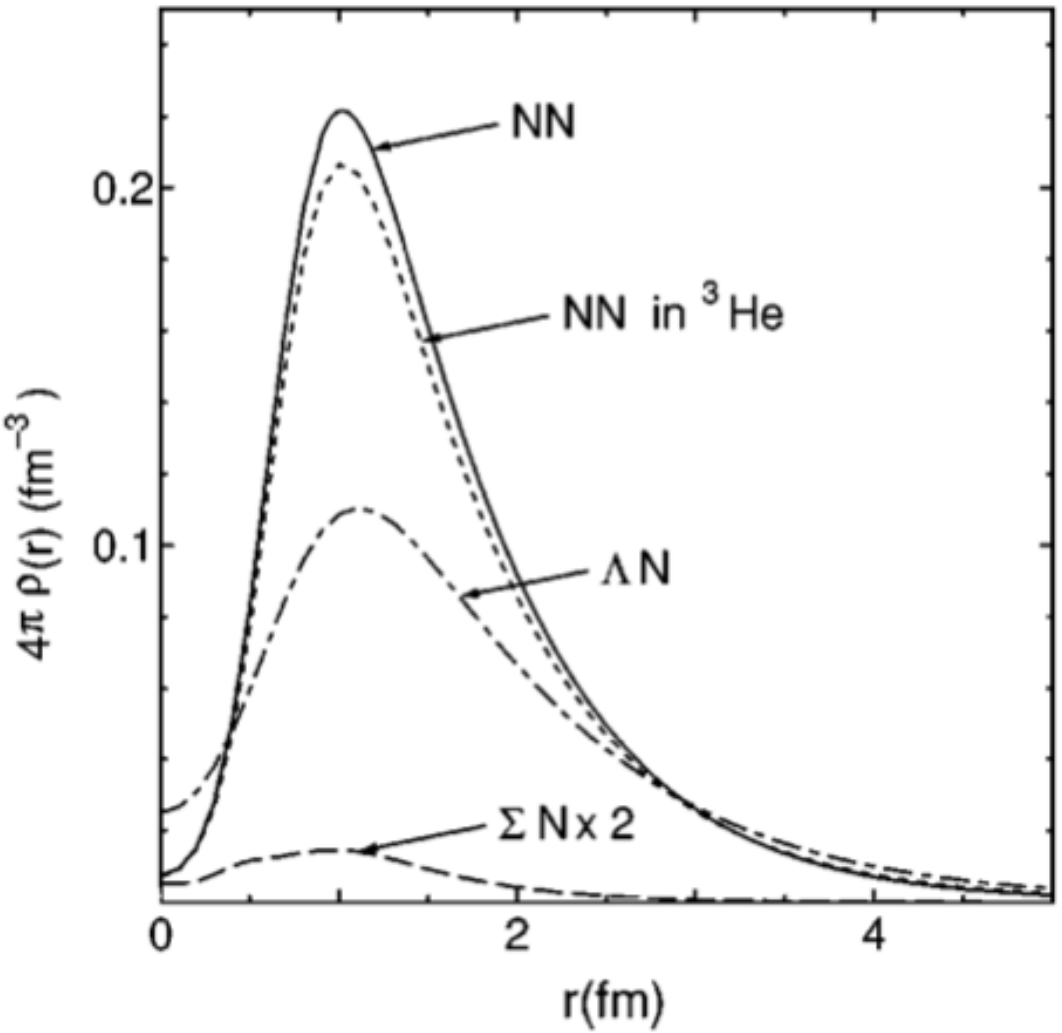
- **to get a sufficient energy convergence of a few hundred keV (in progress of calculations with $l_{\max} = 20$)**
  → We can get the results which are close to *ab initio* calculation.
- **quantitative discussion of role of the ΛN-ΣN coupling interaction**



- ***ab initio* like calculations for p-shell hyper nuclei without supposing an α cluster**
  → prediction of energy levels of $^{\Lambda}$He isotope up to $A = 9$

Backup

Correlation functions in ${}^{4}_{\Lambda}\mathrm{He}$



- **The correlation function of *YN* interaction is different from that of *NN* interaction.**

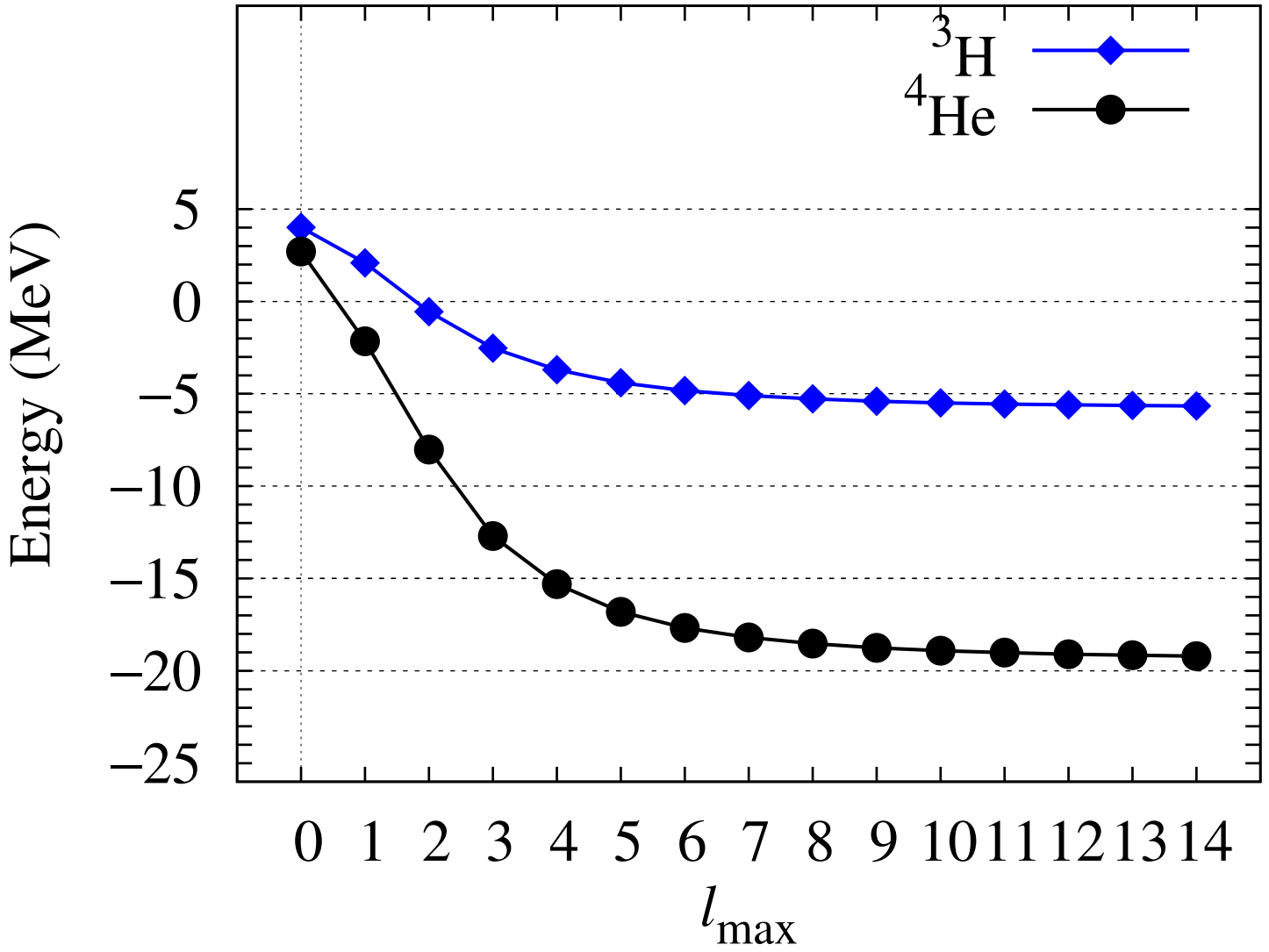
  ⇓

  The UCOM parameters of *YN* int. should be different from those of *NN* int.

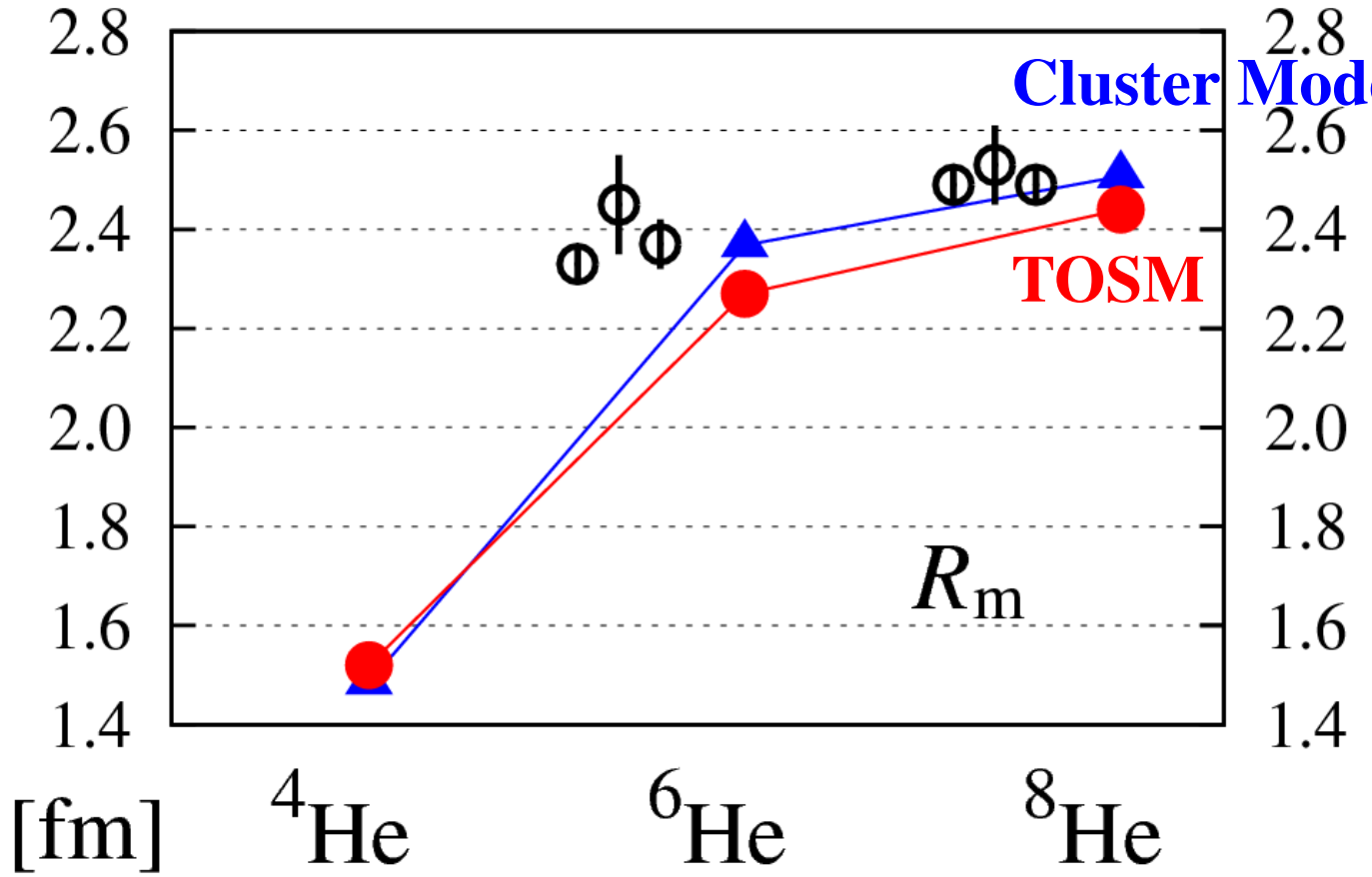
- **In the present calculation, the same UCOM parameters are used for *NN* and *YN* int.**

E. Hiyama *et al.*, Phys. Rev. C 65, 011301(R) (2001).

Energy convergence of ^{3}H and ^{4}He



Matter radius of He isotopes in TOSM



T. Myo, R. Ando, K. Kato, Phys. Lett. B 691, 150 (2010).

T. Myo, AU, H. Toki, K. Ikeda, Phys. Rev. C 84, 034315 (2011).

Exp. data

I. Tanihata *et al.*, Phys. Lett. B 289, 261 (1992). / G.D. Alkhazov *et al.*, Phys. Rev. Lett. 78, 2313 (1997).
O.A. Kiselev *et al.*, Eur. Phys. J. A 25, Suppl. 1, 215 (2005). / P. Mueller *et al.*, Phys. Rev. Lett. 99, 252501 (2007).