Role of tensor force in light nuclei with tensor-optimized shell model

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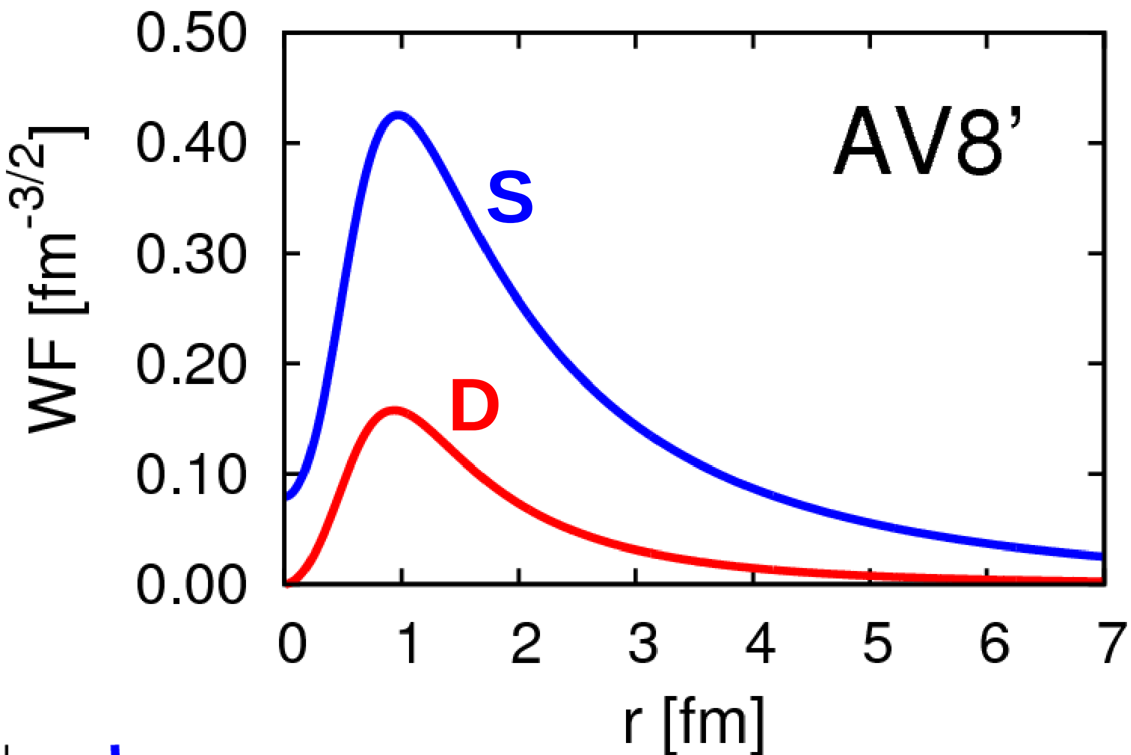
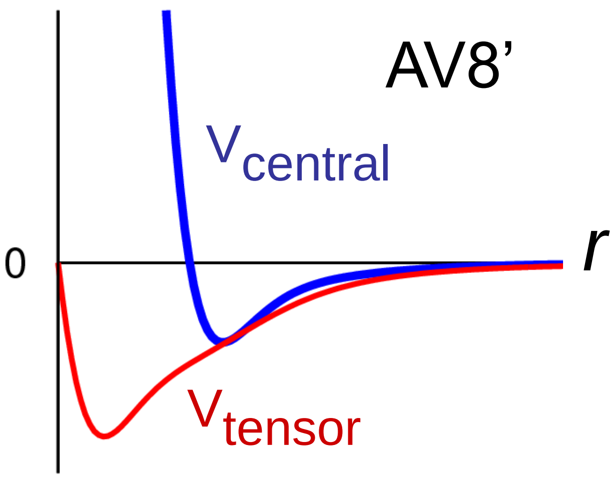
Outline

- **Role of V_{tensor}** in the nuclear structure by describing strong tensor correlation explicitly.
- Tensor Optimized Shell Model (TOSM) to describe tensor correlation.
- Unitary Correlation Operator Method (UCOM) to describe short-range correlation.
- TOSM+UCOM to He & Li isotopes with V_{bare}
- Halo formation in ^{11}Li (application of TOSM)
  - Coexistence of tensor and pairing correlations

Deuteron properties & tensor force



Energy	-2.24 MeV
Kinetic	19.88
Central	-4.46
Tensor	**-16.64**
LS	-1.02
P(L=2)	5.77%
Radius	1.96 fm



$R_m(s)$=2.00 fm

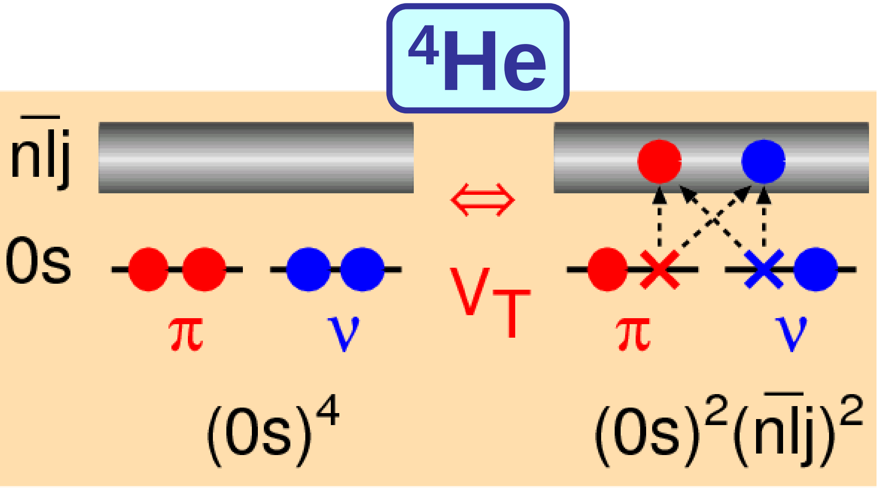
$R_m(d)$=1.22 fm

d-wave is "**spatially compact**" (high momentum)

Tensor-optimized shell model (TOSM)

TM, Sugimoto, Kato, Toki, Ikeda PTP117(2007)257

- Configuration mixing within 2p2h excitations with high-L orbits.
  TM et al., PTP113(2005)
  TM et al., PTP117(2007)



- Length parameters such as b_{0s}, b_{0p}, … are optimized independently, or superposed by many Gaussian bases.
  - Spatial shrinkage of ***D*-wave** as seen in deuteron
    HF by Sugimoto et al,(NPA740) / Akaishi (NPA738)
    RMF by Ogawa et al.(PRC73), AMD by Dote et al.(PTP115)
- Satisfy few-body results with Minnesota central force (^{4,6}He)

Hamiltonian and variational equations in TOSM

$$H = \sum_{i=1}^{A} t_i - T_G + \sum_{i<j}^{A} v_{ij},$$

(0p0h+1p1h+2p2h)

$$\Phi(A) = \sum_k C_k \cdot \psi_k(A)$$

$\psi_k(A)$: shell model type configuration
with mass number A

Particle state : Gaussian expansion for each orbit

$$\varphi_{lj}^{n'}(\mathbf{r}) = \sum_{n=1}^{N} C_{lj,n}^{n'} \cdot \phi_{lj,n}(\mathbf{r}) \qquad \phi_{lj,n}(\mathbf{r}) \propto r^l \exp\left[-\frac{1}{2}\left(\frac{r}{b_{lj,n}}\right)^2\right]\left[Y_l(\hat{\mathbf{r}}), \chi_{1/2}^{\sigma}\right]_j$$

$$\left\langle \varphi_{lj}^{n'} \middle| \varphi_{lj}^{n''} \right\rangle = \delta_{n',n''}$$

Gaussian basis function

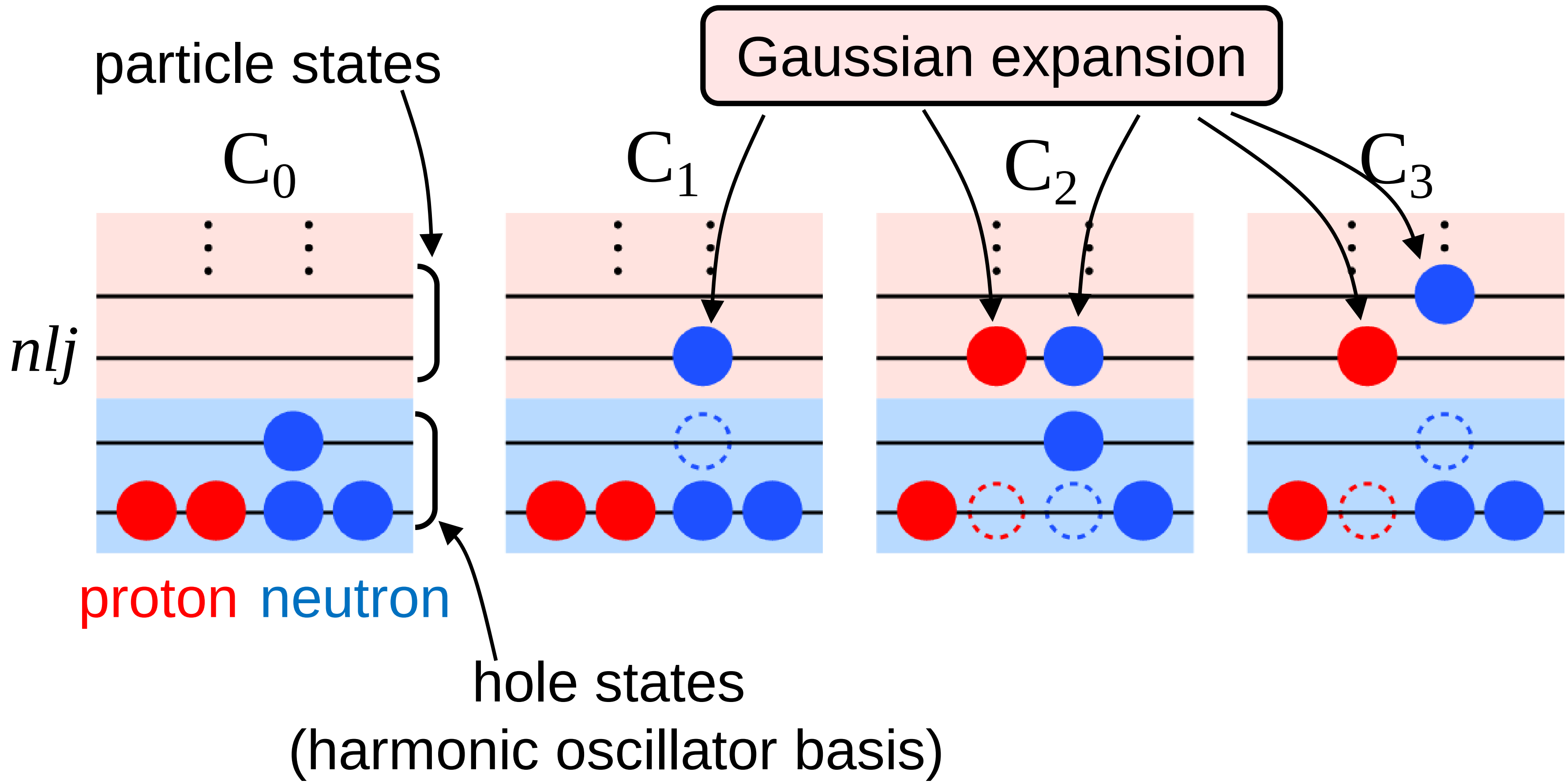
Hiyama, Kino, Kamimura
PPNP51(2003)223

$$\frac{\partial \langle H - E \rangle}{\partial C_k} = 0, \quad \frac{\partial \langle H - E \rangle}{\partial b_{lj,n}} = 0$$

c.m. excitation is excluded
by Lawson's method

TOSM code : *p*-shell region

Configurations in TOSM



Application to Hypernuclei by **A. Umeya**
to investigate ΛN-ΣN coupling

21st Tue.
III-a

Unitary Correlation Operator Method

(short-range part)

$$\Psi_{\mathrm{corr.}} = C \cdot \Phi_{\mathrm{uncorr.}}$$

TOSM

short-range correlator

$$C^{\dagger} = C^{-1} \quad \text{(Unitary trans.)}$$

$$H\Psi = E\Psi \;\to\; C^{\dagger} H C \Phi \equiv \hat{H}\Phi = E\Phi$$

Bare Hamiltonian

Shift operator depending on the relative distance

$$C = \exp(-i\sum_{i<j} g_{ij}), \qquad g_{ij} = \tfrac{1}{2}\left\{ p_r s(r_{ij}) + s(r_{ij}) p_r \right\} \qquad \vec{p} = \vec{p}_r + \vec{p}_{\Omega}$$

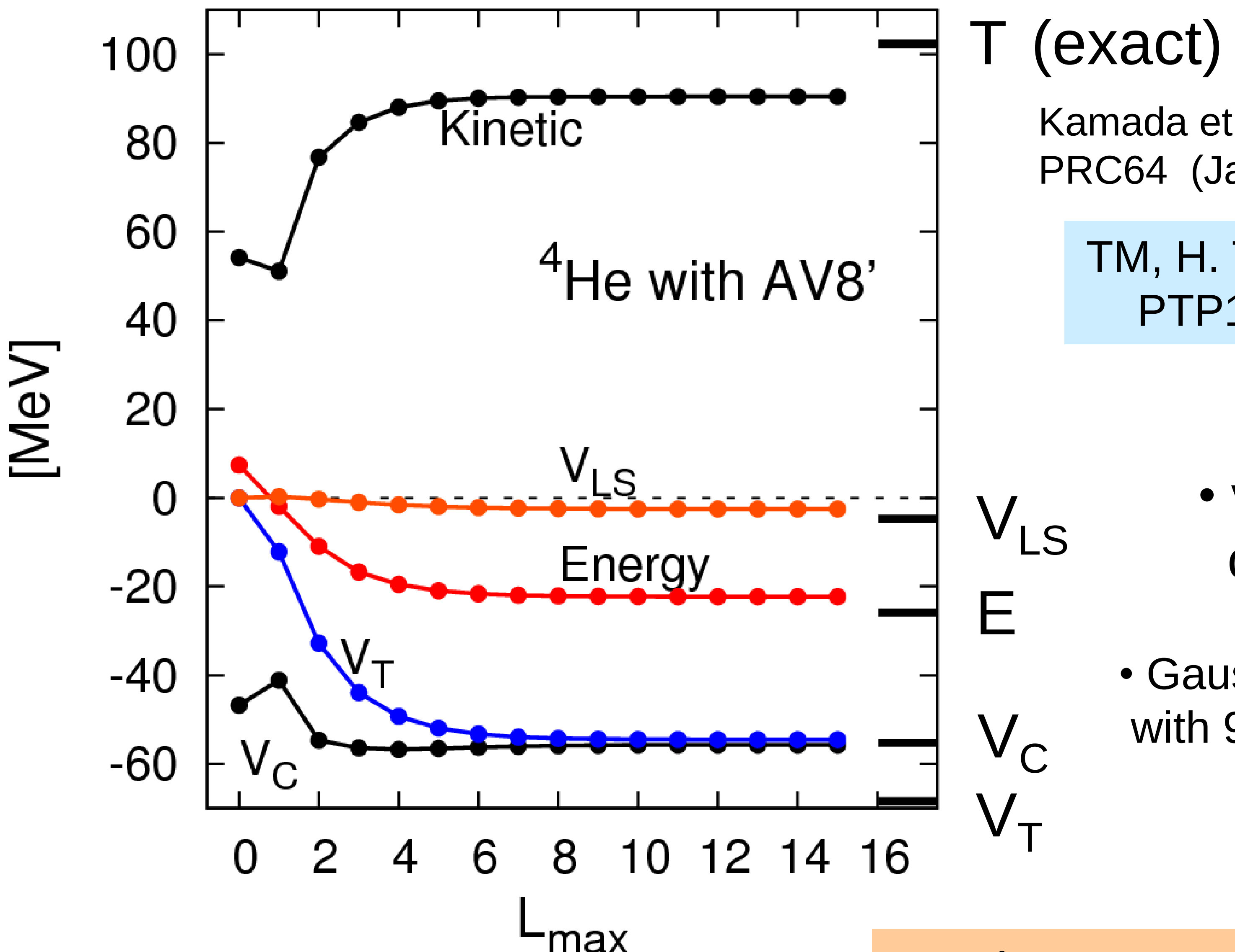
Amount of shift, variationally determined.

$$C^{\dagger} r C \simeq r + s(r) + \tfrac{1}{2} s(r) s'(r) \cdots$$

2-body cluster expansion

H. Feldmeier, T. Neff, R. Roth, J. Schnack, NPA632(1998)61

^{4}He in TOSM + short-range UCOM



Kamada et al.
PRC64 (Jacobi)

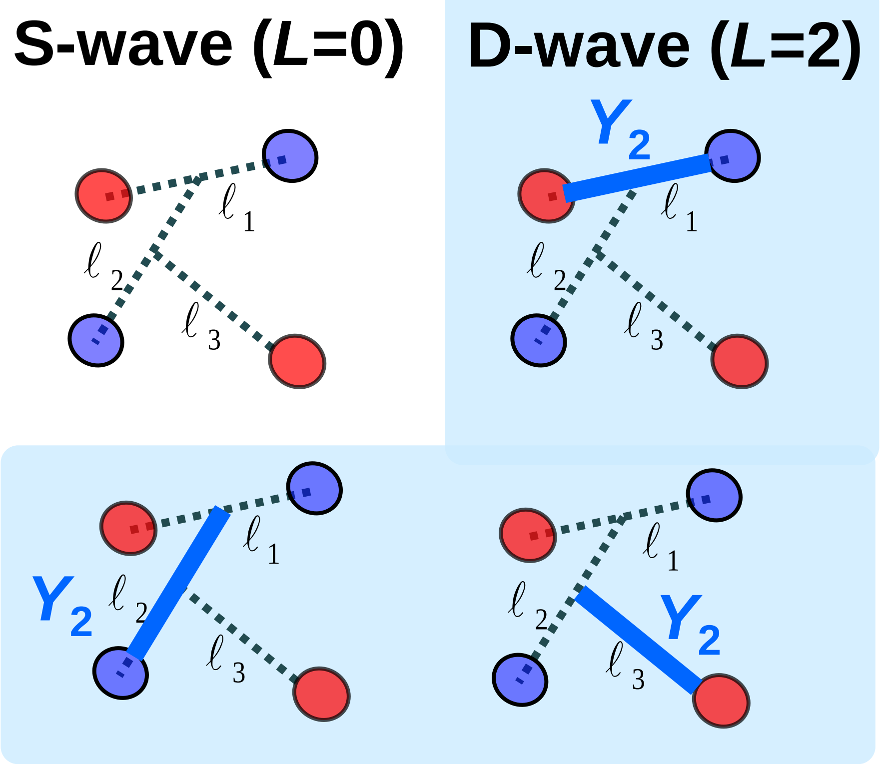
TM, H. Toki, K. Ikeda
PTP121(2009)511

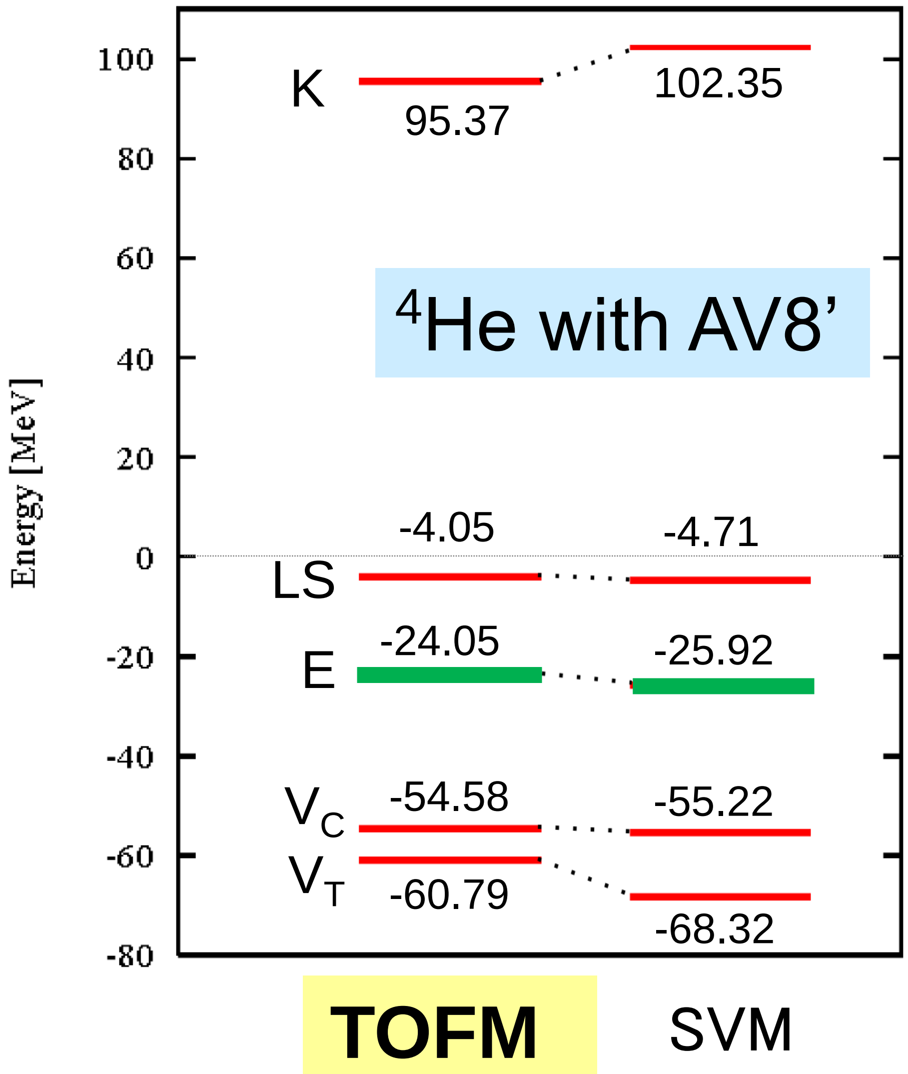
- variational calculation
- Gaussian expansion with 9 Gaussians

good convergence

Tensor Optimized Few-body Model (TOFM)

- Same as TOSM concept
- No use of UCOM
- Correlated Gaussian basis
  + Global vector in SVM





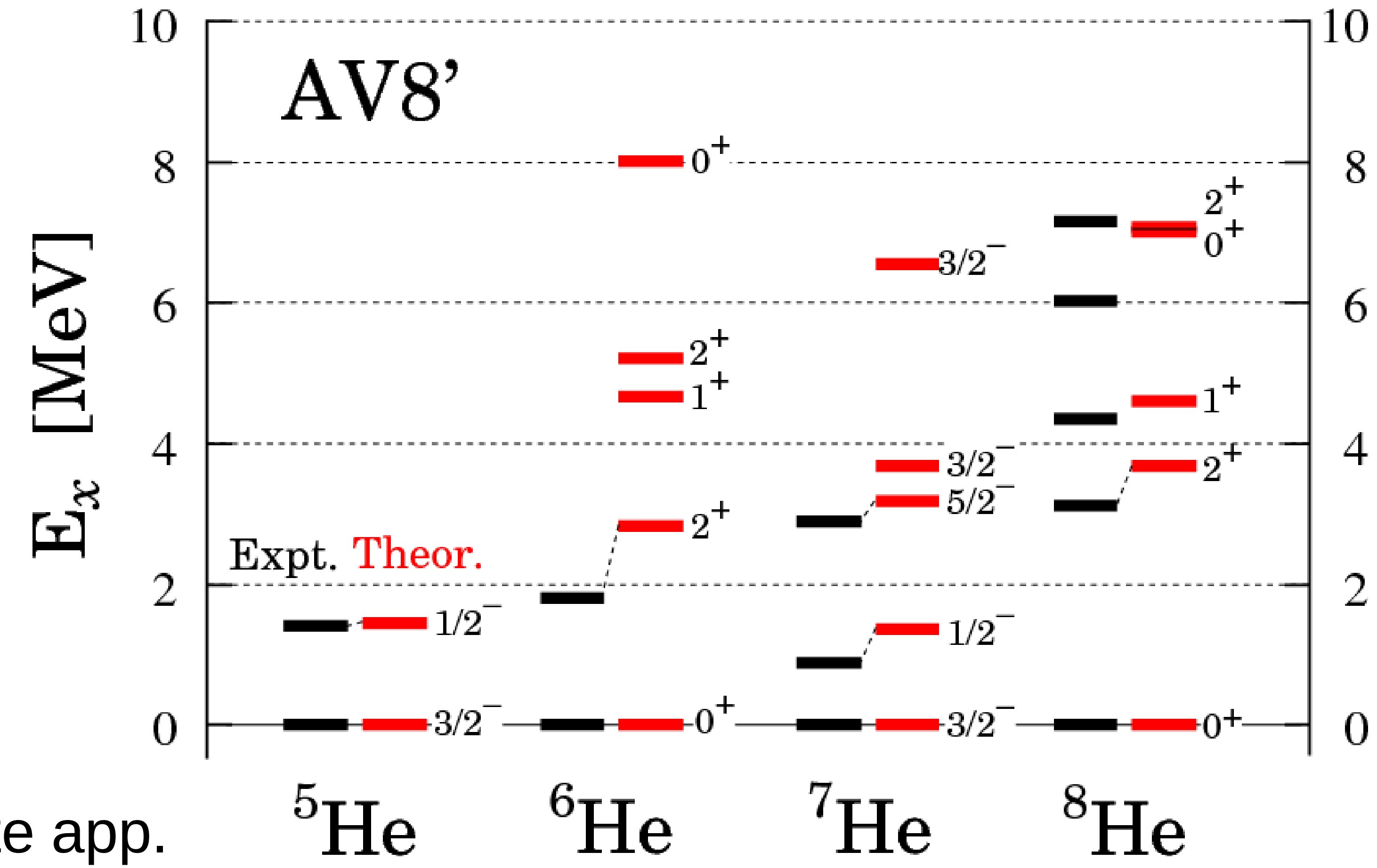
24st Fri. VIII-d

Horii, Toki, Myo, Ikeda PTP127(2012)1010

$^{5-8}$He with TOSM+UCOM

- Excitation energies in MeV

TM, A. Umeya, H. Toki, K. Ikeda
PRC84 (2011) 034315



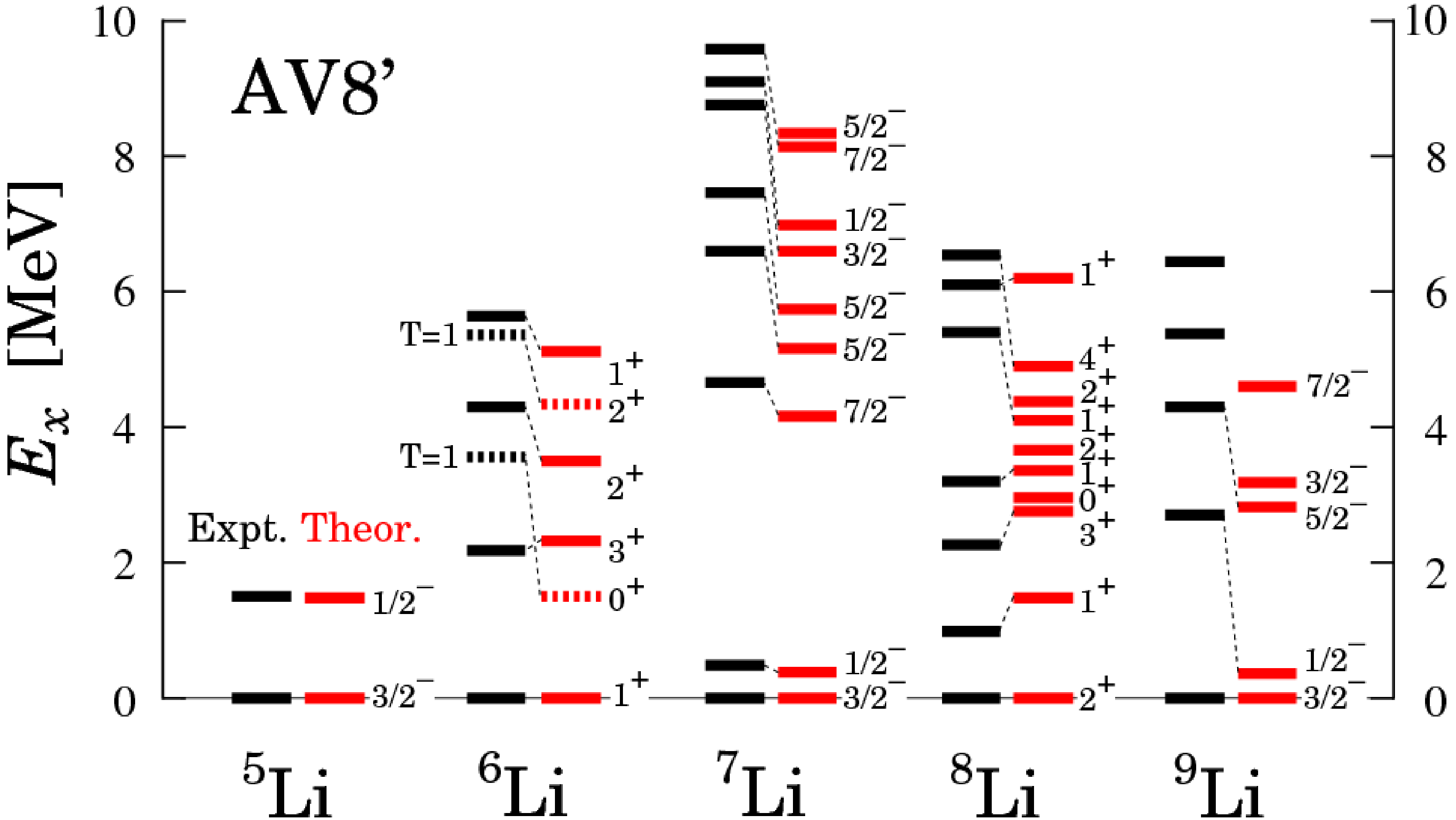
- Bound state app.
- No continuum
- No V_{NNN}

- Excitation energy spectra are reproduced well

$^{5\text{-}9}$Li with TOSM+UCOM

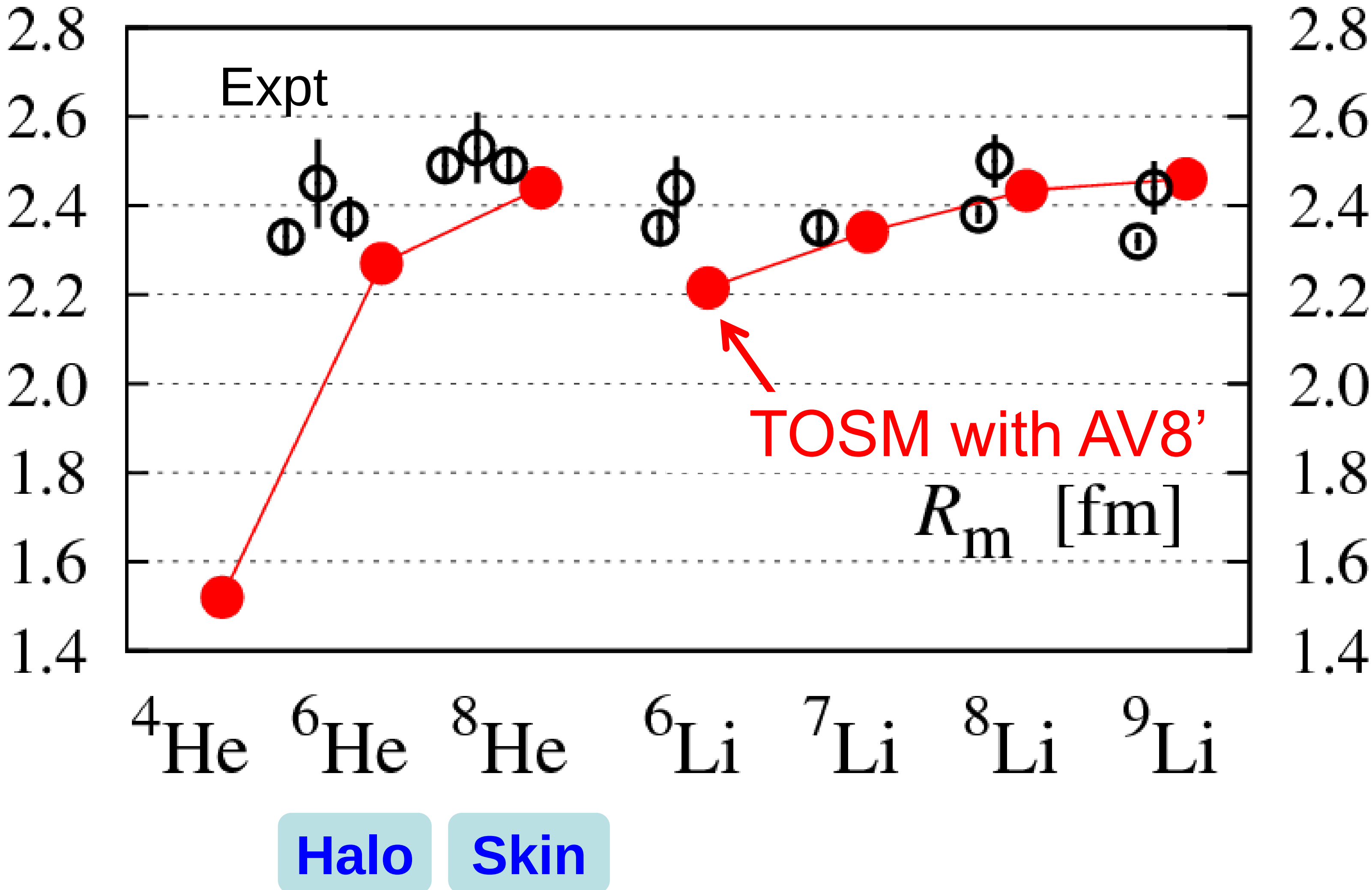
TM, A. Umeya, H. Toki, K. Ikeda
PRC, in press

- Excitation energies in MeV



- Excitation energy spectra are reproduced well

Matter radius of He & Li isotopes



A. Dobrovolsky, NPA 766(2006)1
I. Tanihata et al., PLB289('92)261
G. D. Alkhazov et al., PRL78('97)2313
O. A. Kiselev et al., EPJA 25, Suppl. 1('05)215.
P. Mueller et al., PRL99(2007)252501

Configurations of ^{4}He with AV8'

TM, H. Toki, K. Ikeda
PTP121(2009)511

$(0s_{1/2})^4$	83.0 %
$(0s_{1/2})^{-2}_{JT}(p_{1/2})^2_{JT}$ ***JT*=10**	2.6
JT=01	0.1
$(0s_{1/2})^{-2}_{10}(1s_{1/2})(d_{3/2})_{10}$	2.3
$(0s_{1/2})^{-2}_{10}(p_{3/2})(f_{5/2})_{10}$	1.9
Radius [fm]	1.54

- deuteron correlation with $(J,T)=(1,0)$

Cf. R.Schiavilla et al. (VMC) PRL98(2007)132501
R. Subedi et al. (JLab) Science320(2008)1476
^{12}C(e,e'*pN*)

S.C.Simpson, J.A.Tostevin PRC83(2011)014605
$^{12}\mathrm{C}\rightarrow{}^{10}\mathrm{B}+pn$

- ^{4}He contains $p_{1/2}$ of "***pn*-pair**"
  - Same feature in ^{5}He-^{8}He ground state

Selectivity of the tensor coupling in ^{4}He

0p0h : $(0s)^4_{00}$
$\supset (0s)^2_{10}(0s)^2_{10}$

$\ell_1 = \ell_2 = \ell_3 = \ell_4 = 0$

$s_1 \downarrow \Downarrow \downarrow s_2$ $s_3 \uparrow \Uparrow \uparrow s_4$

$1^+(pn)$ $1^+(pn)$

V_T

2p2h : $(0s)^2_{10}(0p_{1/2})^2_{10}$

$\ell_1 = \ell_2 = 0$

$\ell_3 = 1$
$\ell_4 = 1$
$L=2$

$s_1 \downarrow \Downarrow \downarrow s_2$ $s_3 \downarrow \Downarrow \downarrow s_4$

V_T

2p2h : $(0s)^2_{10}[(1s)(0d_{3/2})]_{10}$

$\ell_1 = \ell_2 = 0$

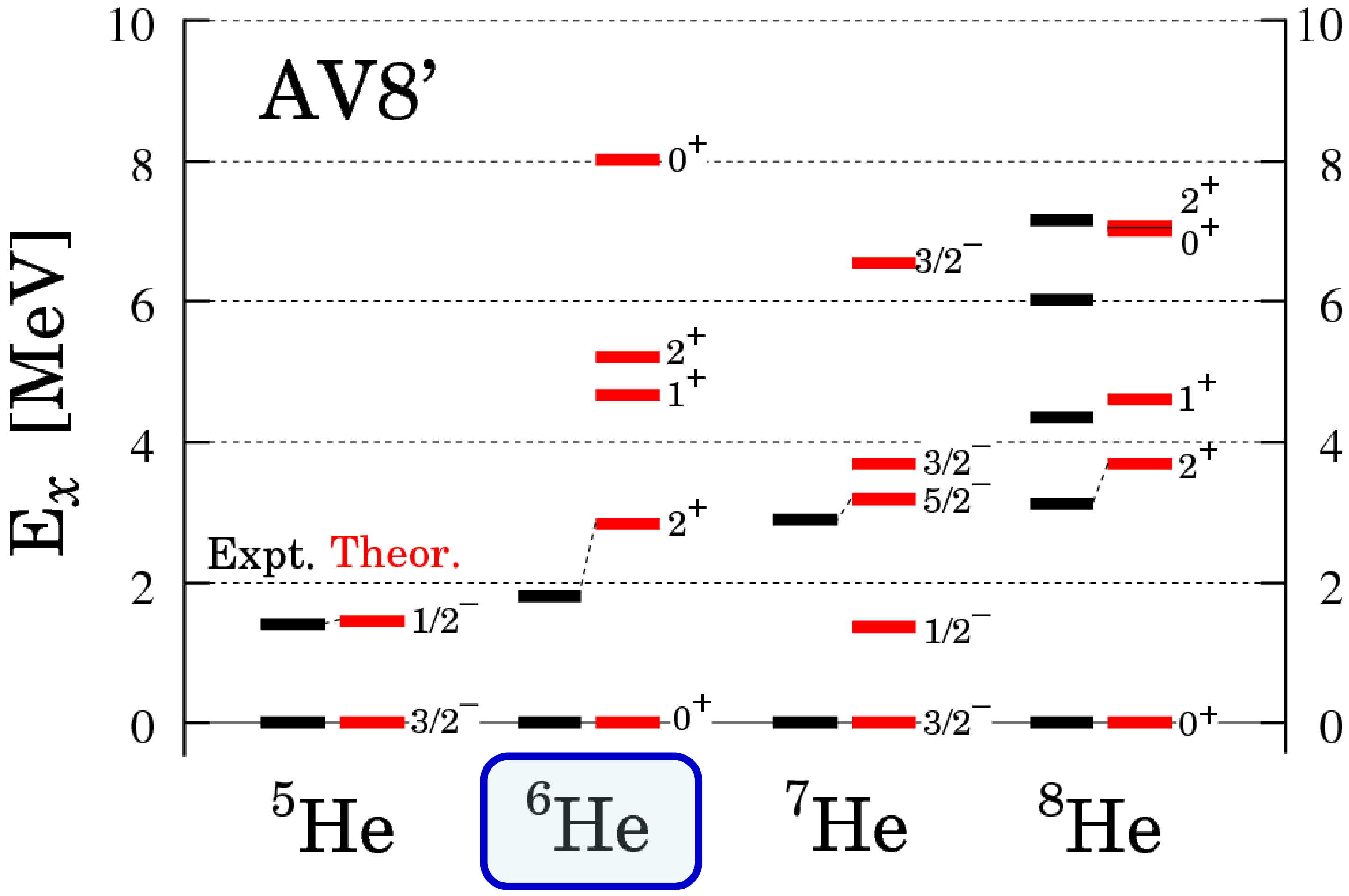
$\ell_3 = 0$
$\ell_4 = 2$
$L=2$

$s_1 \downarrow \Downarrow \downarrow s_2$ $s_3 \downarrow \Downarrow \downarrow s_4$

Selectivity of
tensor operator
$\Delta L=2$, $\Delta S=2$

$^{4-8}$He with TOSM+UCOM

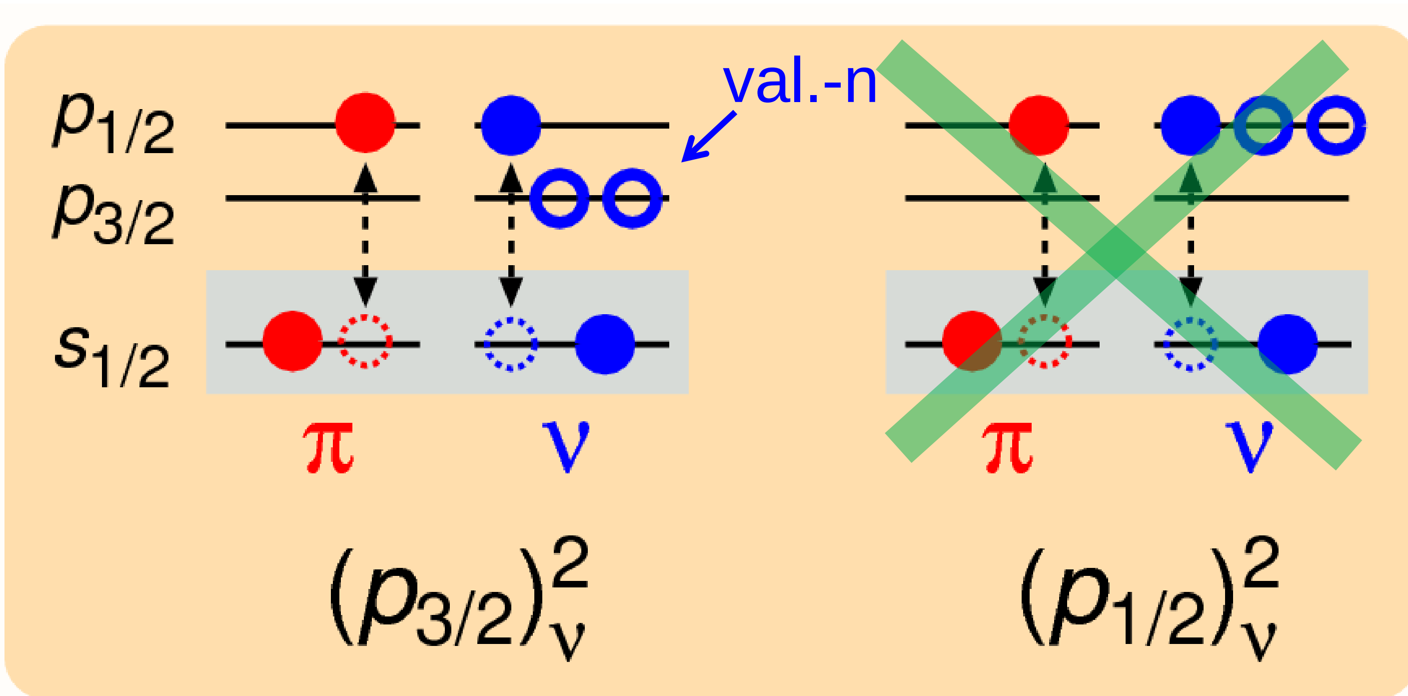
- Excitation energies in MeV



- No V_{NNN}
- No continuum

- Excitation energy spectra are reproduced well

Tensor correlation in ^{6}He



Ground state

halo state (0^+)

Excited state

Tensor correlation is **suppressed** due to Pauli-Blocking

TM, K. Kato, K. Ikeda, J. Phys. G31 (2005) S1681

^{6}He : Hamiltonian component in TOSM

- Difference from ^{4}He in MeV

^{6}He	0^+_1	0^+_2
n^2 config	$(p_{3/2})^2$	$(p_{1/2})^2$

b_{hole}=1.5 fm

$\hbar\omega$=18.4 MeV (hole)

LS splitting energy in ^{6}He

same trend in $^{5\text{-}8}$He

- Terasawa, Arima PTP23 ('60)
- Nagata, Sasakawa, Sawada, Tamagaki, PTP22('59)
- Myo, Kato, Ikeda, PTP113 ('05)

Summary

- **TOSM+UCOM** using V_{bare}.
- Reproduce the excitation energy spectra.
- ^{4}He contains "***pn*-pair of $p_{1/2}$**" than $p_{3/2}$.
- ^{6}He: ***jj*-coupling**
- ^{6}Li : *S*=1 component, ***LS* coupling**, $\alpha+d$.
- $^{7\text{-}9}$Li : ***jj* coupling** with two-kinds of tensor excitations from 0*s* and 0*p* shells.
- Foundation to the analyses of ^{10}Li & ^{11}Li.