Di-neutron相関におけるテンソル力の役割

— Role of the tensor correlation on the halo formation in ^{11}Li —

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Contents

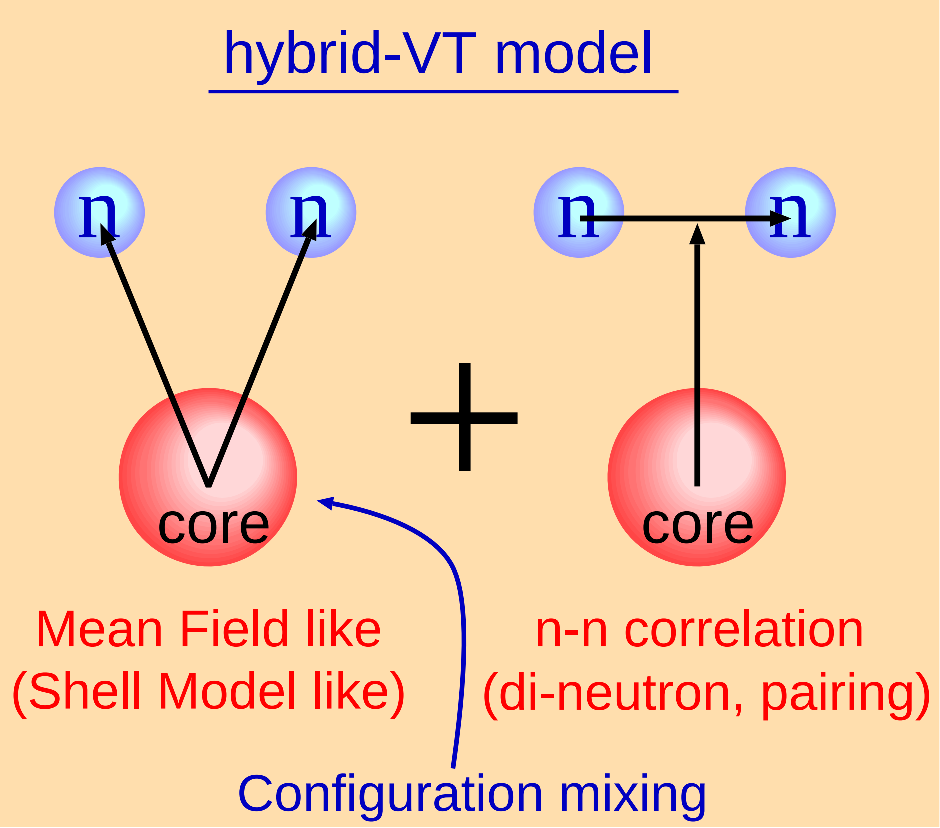
- core+n+n picture of halo nuclei and di-neutron correlation.
- Mechanism of the halo structure and breaking of the magicity in ^{11}Li based on the core+n+n picture.
  1. Naive ^{9}Li+n+n model with a deep s-wave core-n potential.
  2. Coupled ^{9}Li+n+n model with tensor and pairing correlations.
     - Configuration mixing for ^{9}Li.
     - Effects of two correlations on the halo formation.
- Coulomb breakup strengths.

Description of Halo nuclei based on the "core+n+n" model

○ ^{6}He : ^{4}He($(0s)^4$) + n + n.
  – Successful results for G.S., 2^+.
  – many theoretical works.

○ ^{11}Li : ^{9}Li + n + n.
  – Large $(1s)^2$-mixing in G.S.
  – Inversion phenomena in ^{10}Li
  – Problem of soft dipole resonance.
  – Theoretical ambiguity

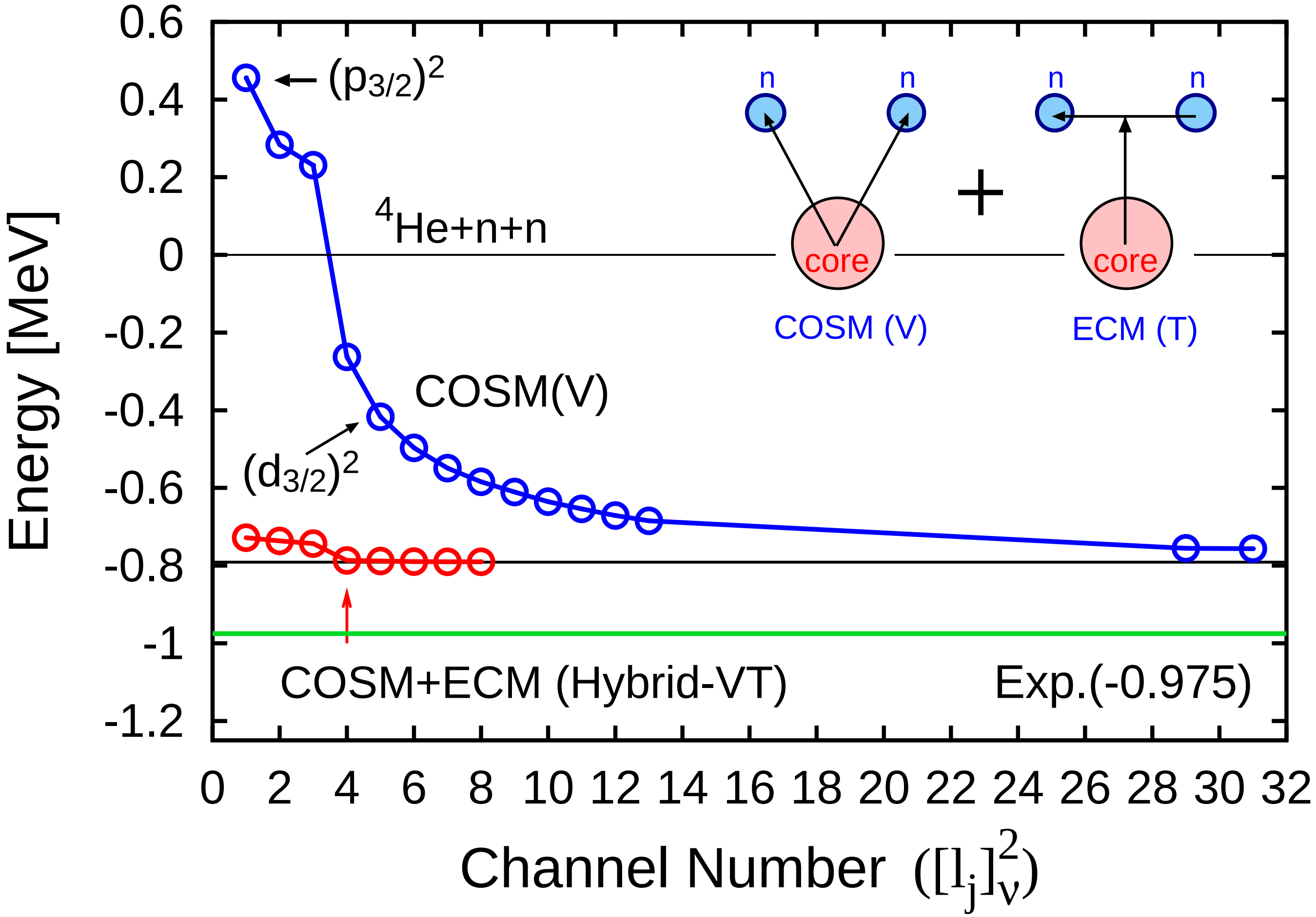
○ Our approach.
  – "core+n+n" picture+correlation



[Ref]:K. Ikeda, NPA538,355c('92)

Application to ^{6}He

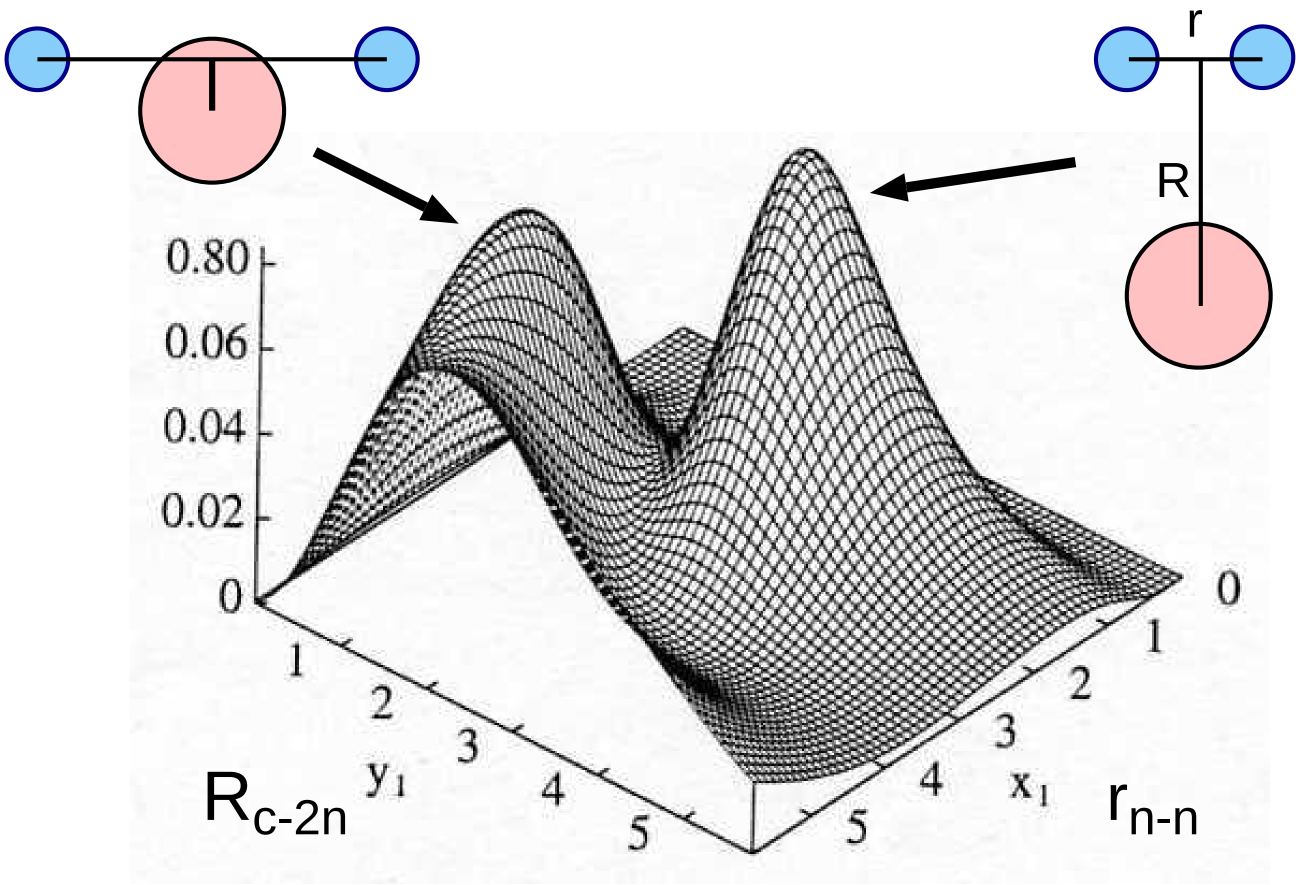
- ^{4}He+n+n with OCM : $\Phi(^6\mathrm{He}) = \mathcal{A}\{\ \Phi(^4\mathrm{He})\ \Phi(\mathrm{nn})\ \}$
- Interaction: ^{4}He-n : KKNN potential, n-n : Minnesota



Pairing correlation
(di-neutron like)
for val-2n is important.

[Ref]: S.Aoyama, S.Mukai, K.Katō, K.Ikeda, PTP93('95)99.

2n Correlation density for ^{6}He G.S.



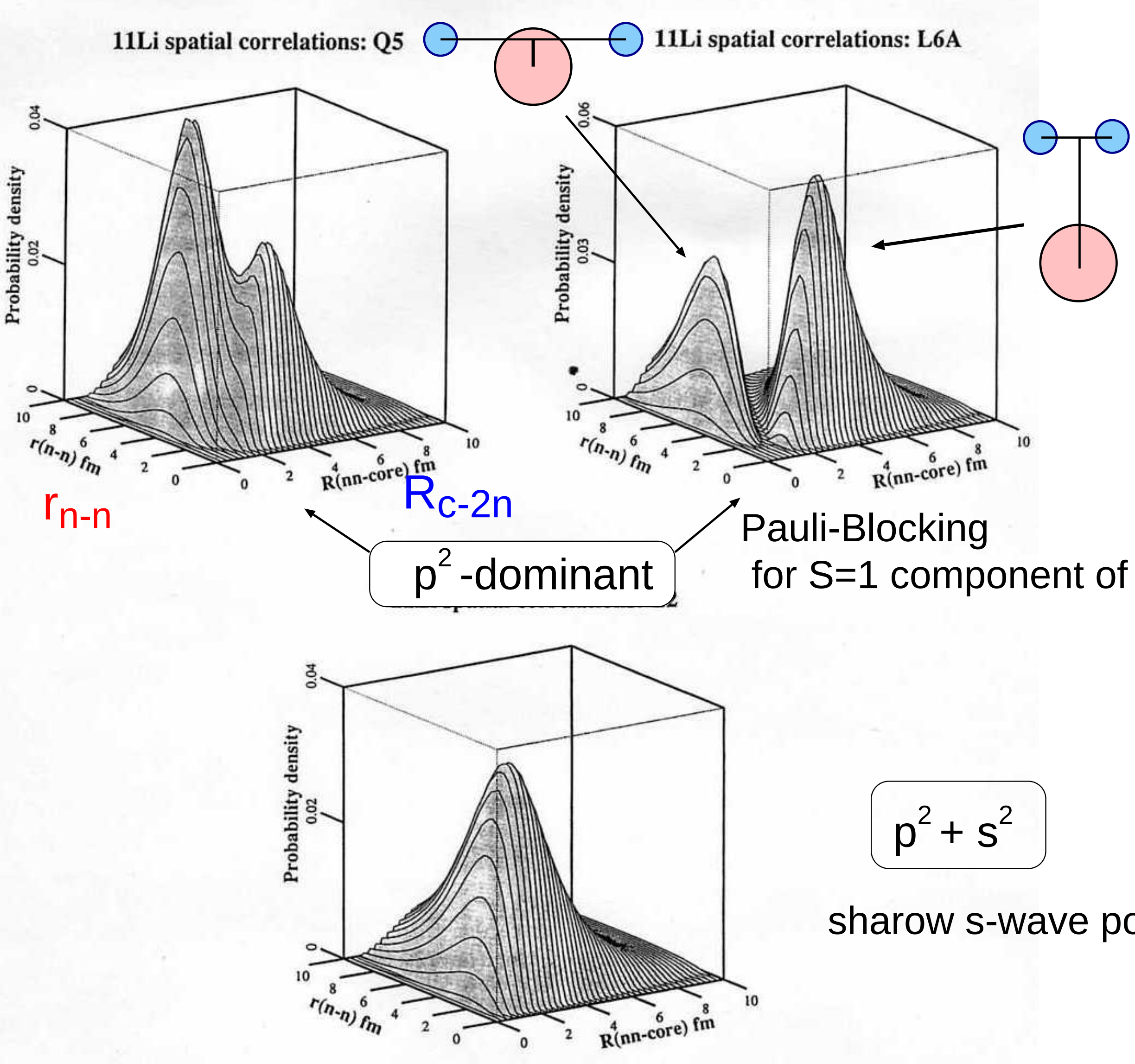
Funada, Kameyama, Sakuragi, NPA575(1994)

Structures of ^{11}Li

- ○ Expt. : S_{2n}=0.31 MeV, R_m=3.12±0.16 / 3.53±0.06 fm (^{9}Li: 2.32 fm).
- ○ Breaking of magic number N=8, halo structure in G.S.
  - – Simon et al.(expt) : $s^2 \sim 50\%$, Mechanism is unclear.
- ○ Virtual s-state in ^{10}Li :
  - – Expt. : Invariant mass spectrum of ^{9}Li-n.
  - – Many theories assume a deep s-wave ^{9}Li(inert)-n potential.
    - ● Thompson-Zhukov(PRC49) / Garrido-Fedorov-Jensen(NPA700).
    - ● Halo structure can be explained in ^{11}Li G.S., and soft dipole resonances appear.
- ○ Excited states: 1.3 MeV (Korsheninnikov,PRL78) / partner of G.S.? (Aoyama)
- ○ Our group performs the extended three-body model analysis with configuration mixing for ^{9}Li (PTP101, PTP108, PLB576, pairing).

2n Correlation density for ^{11}Li G.S. (Zhukov et al.,Phys.Rep.231(1993))

190 M.V. Zhukov et al., The Borromean halo nuclei ^{6}He and ^{11}Li



r_{n-n}

R_{c-2n}

p^2-dominant

Pauli-Blocking
for S=1 component of 2n

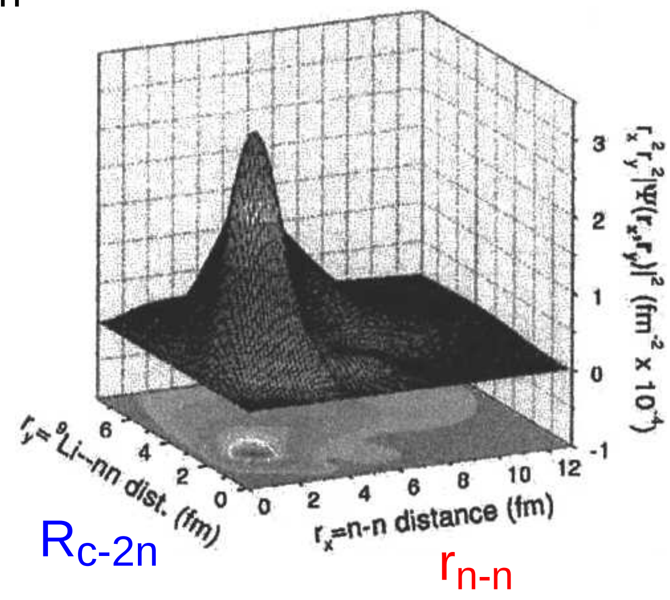
$p^2 + s^2$

sharow s-wave pot.

Fig. 10. Spatial densities of the ^{11}Li ground states calculated by the Faddeev method. The cases are (I) “spin-orbit” case Q10, (II) “pairing” case L6A, and (H) “shallow potential” case Z2.

Nielsen-Garrido-Fedorov-Jensen
Phys. Rep. 347 (2001)

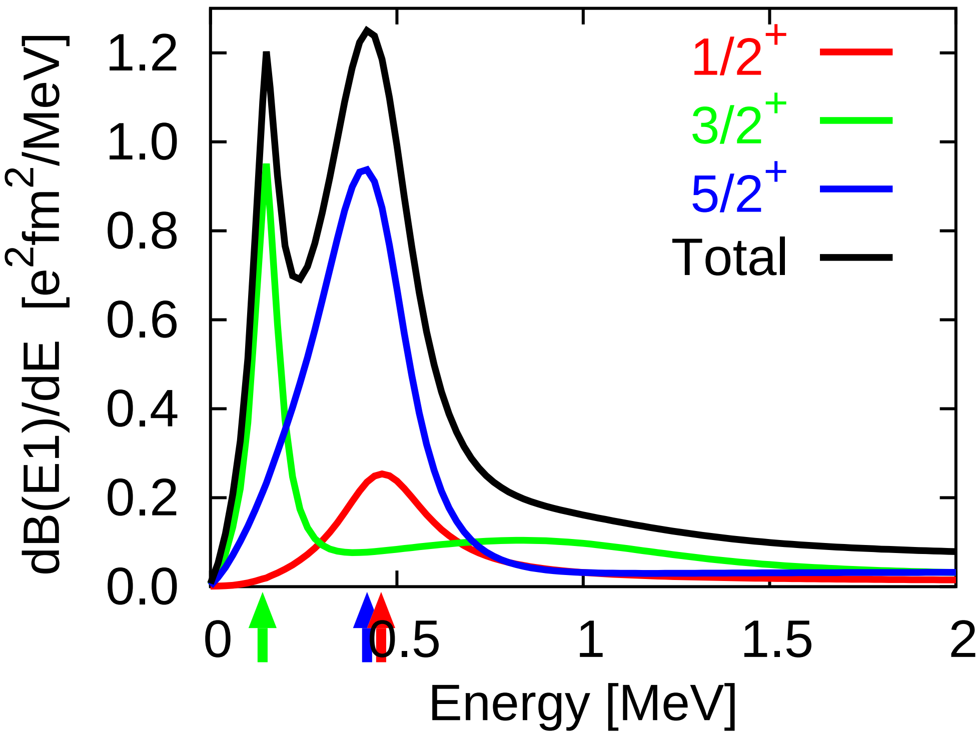
E. Nielsen et al. / Physics Reports 347 (2001) 373–459

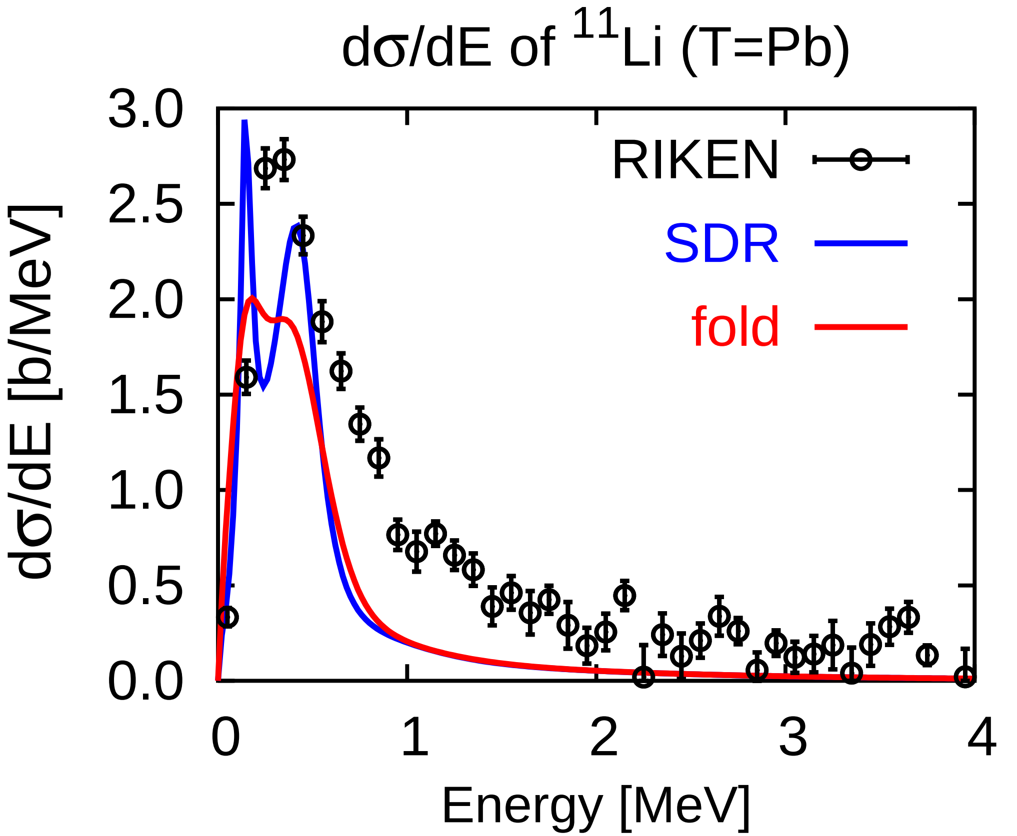


R_{c-2n}

r_{n-n}

B(E1) of ^{11}Li in a naive 3-body model with deep s-wave potential.



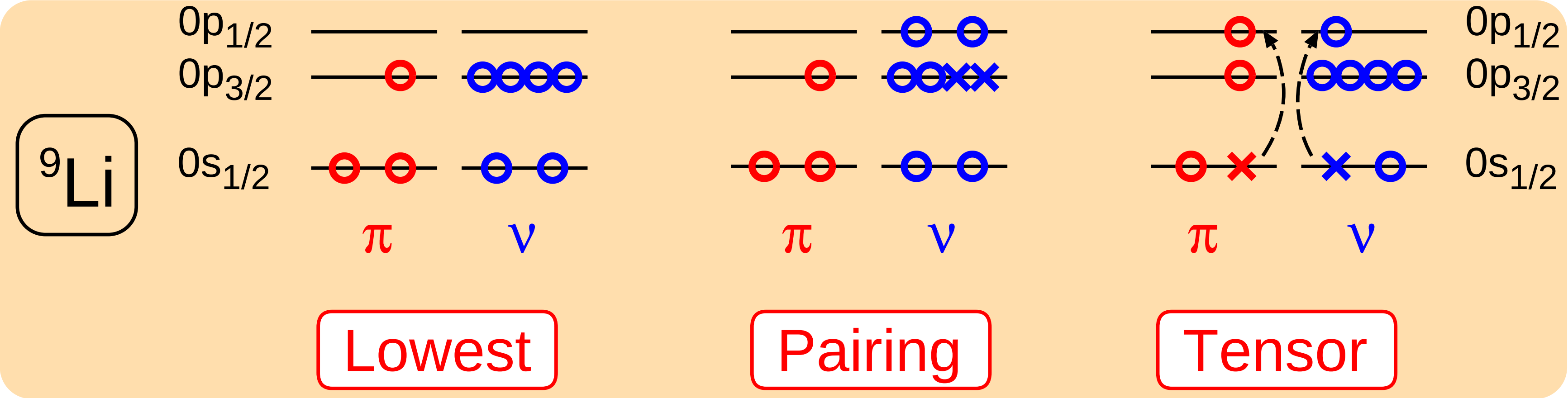


- ○ Strength has two peaks : $3/2^+$ and $\{1/2^+, 5/2^+\}$ due to spin of ^{9}Li ($3/2^-$).
  - $(1s_{1/2}) \otimes (0p_{1/2}) = 0^- \ / \ 1^-$, ^{9}Li : $3/2^-$.
  - $0^- \otimes 3/2^- = 3/2^+$, $1^- \otimes 3/2^- = 1/2^+, 3/2^+, 5/2^+$.

[Ref] T. Suzuki, H. Sagawa, P.F. Bortignon, NPA662(2000)282

Explicit tensor and pairing correlations in ^{9}Li for analysis of ^{11}Li

- We introduce the internal degrees of freedom in ^{9}Li (PTP108, pairing).
- We would like to understand the physical aspects of the tensor force.
- Configuration mixing with H.O. basis function (TM, K.Katō, K. Ikeda, PTP113)
  - $0s + \overline{0p} + \overline{1s0d}$ within 2p2h excitations. (S. Sugimoto et al. for ^{12}C, ^{16}O)
  - Length parameters $\{b_\alpha\}$ are determined independently and variationally. This is useful to represent the high momentum component.



Hamiltonian and variational equations for ^{9}Li

- ○ $H = \sum_{i=1}^{A} t_i - T_G + \sum_{i<j}^{A} v_{ij}, \quad v_{ij} = v_{ij}^{C} + v_{ij}^{T} + v_{ij}^{LS} + v_{ij}^{Clmb}, \qquad \Phi(^9\mathrm{Li}) = \sum_n C_n \phi_n$

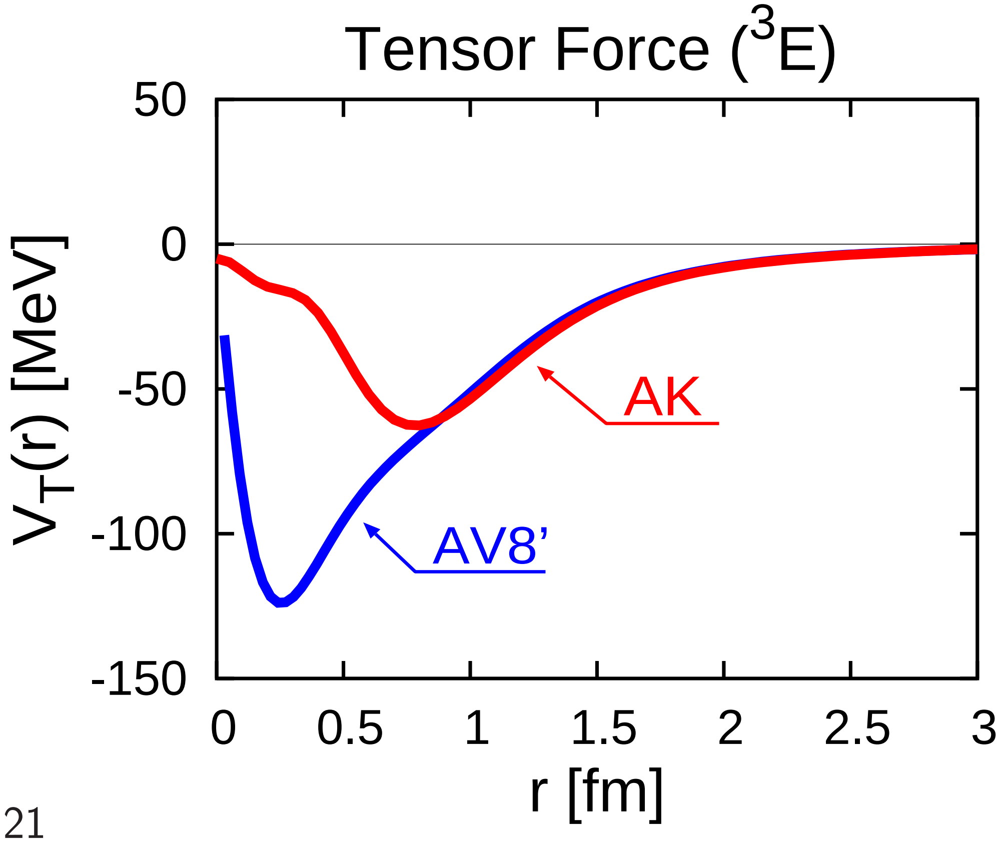
$$\delta \frac{\langle \Phi | H | \Phi \rangle}{\langle \Phi | \Phi \rangle} = 0 \quad \Rightarrow \quad \frac{\partial \langle H - E \rangle}{\partial b_\alpha} = 0\,, \quad \frac{\partial \langle H - E \rangle}{\partial C_n} = 0.$$

- ○ Interaction : Akaishi force (AK) (NPA738)

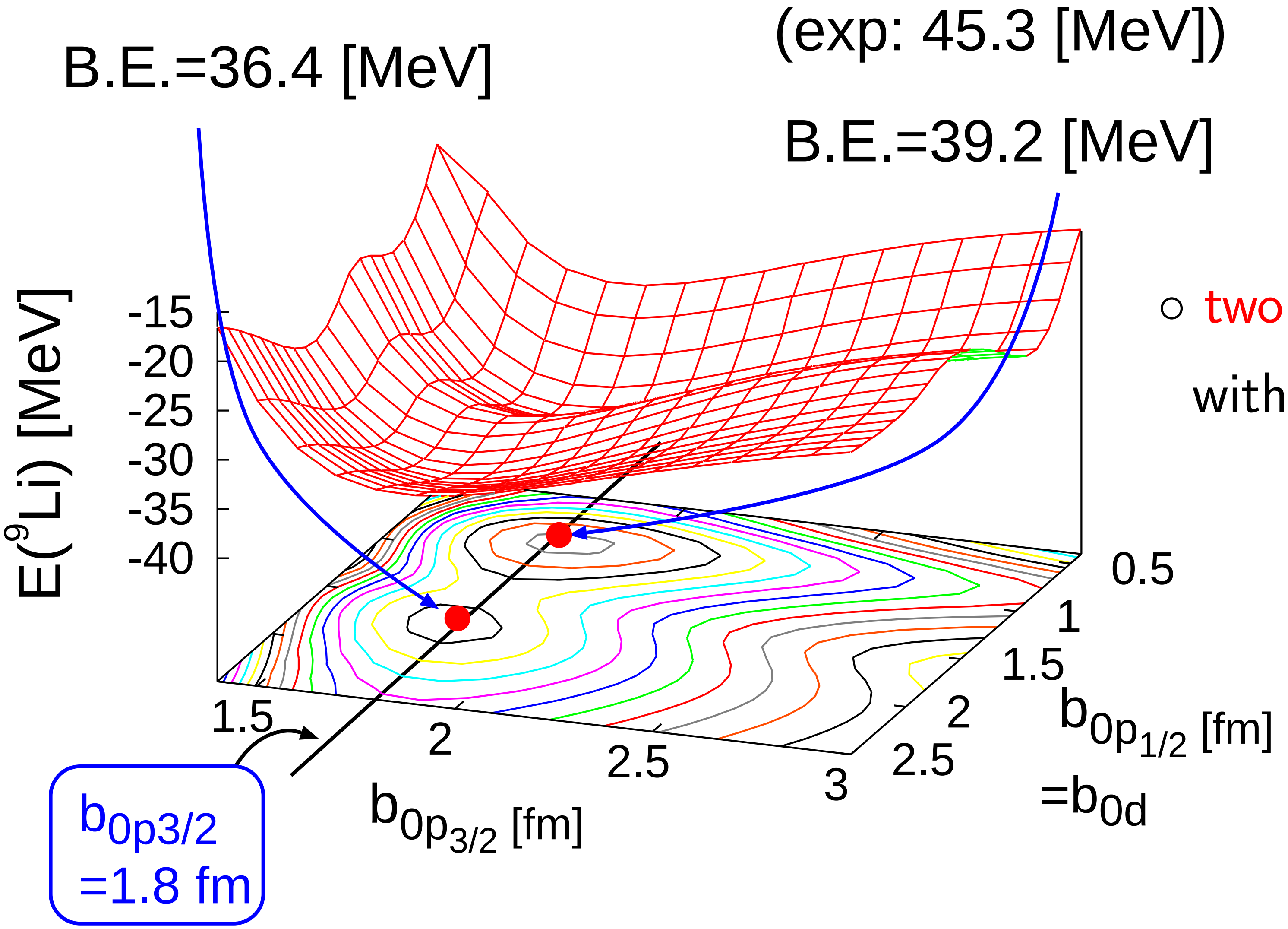
– G-matrix using AV8' with $k_Q = 2.8$ fm^{-1} ($> k_F = 1.4$fm^{-1})

⇒ Long and intermidiate ranges of the tensor force survive.

– Central part : We adjust the intermediate range to fit B.E. and R_m of ^{9}Li.



Energy surface of ^{9}Li for length parameters of HO (b_{0s}= 1.45 [fm])



B.E.=36.4 [MeV]

(exp: 45.3 [MeV])

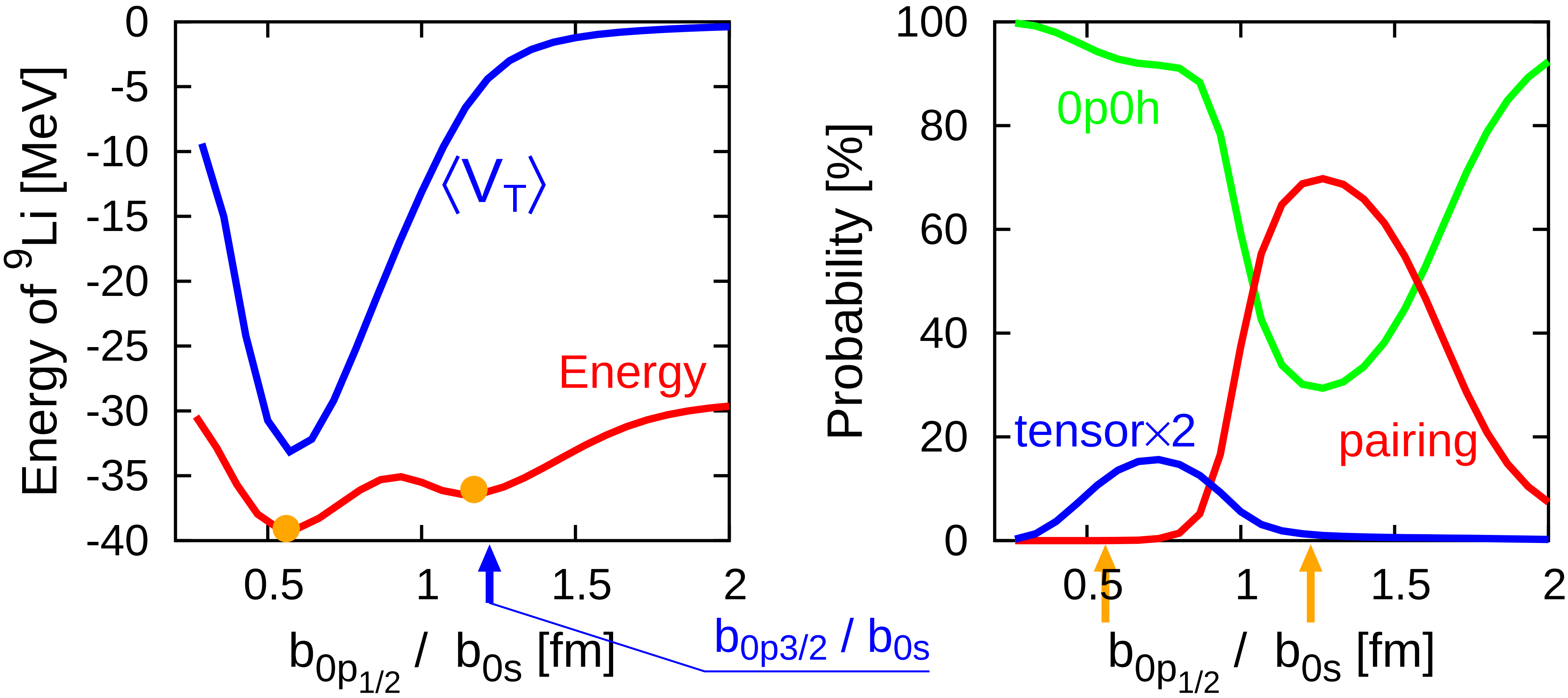
B.E.=39.2 [MeV]

$b_{0p3/2}$
=1.8 fm

○ two minima

with a common $b_{0p3/2}$ value.

Properties of two minima in ^{9}Li



- ○ Tensor correlation (pn) : $(0s)^{-2}_{10}\ (0p_{1/2})^{2}_{10}$, $b_{0p1/2} \sim b_{0s} / 2$.
- ○ Pairing correlation (nn) : $(0p_{3/2})^{-2}_{01}\ (0p_{1/2})^{2}_{01}$, $b_{0p1/2} \sim b_{0p3/2}$.

Superposition of the tensor and pairing correlations in ^{9}Li

Energy [MeV]	-44.3
$\langle V_T \rangle$ [MeV]	-31.9
R_m [fm]	2.30

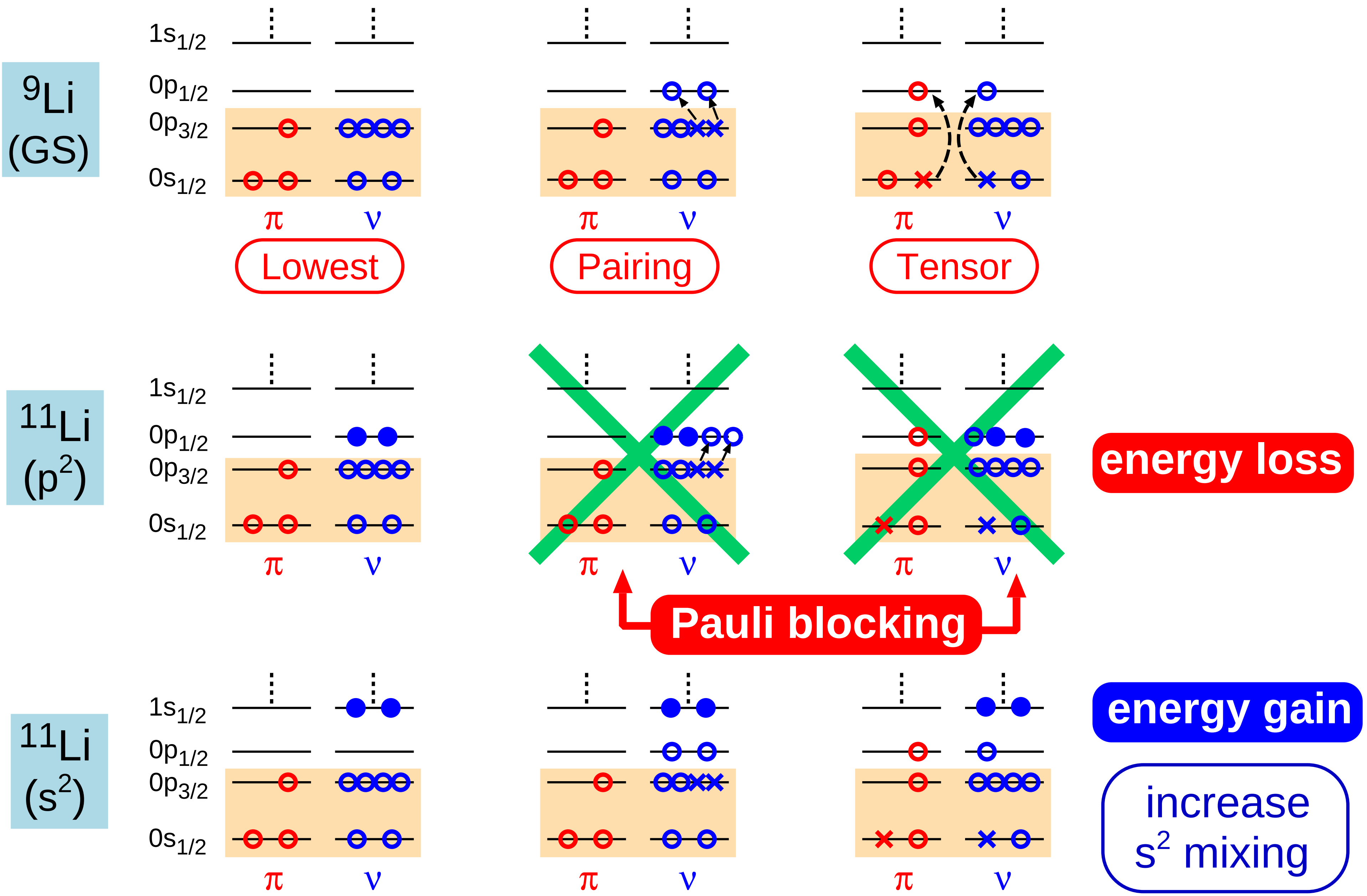
0p0h		78.5 %
$(0p_{3/2})^{-2}_{01}(\overline{0p}_{1/2})^{2}_{01}$		8.8 %
$(0s_{1/2})^{-2}_{JT}(\overline{0p}_{1/2})^{2}_{JT}$	(JT)=(10)	6.8 %
	(JT)=(01)	0.2 %
$(0s_{1/2})^{-2}_{10}[(\overline{1s}_{1/2})(\overline{0d}_{3/2})]_{10}$		1.9 %
$(0s_{1/2})^{-2}_{10}(\overline{0d}_{3/2})^{2}_{10}$		1.2 %

- Tensor correlation:
  - ○ 0^- coupling of $0s_{1/2}-0p_{1/2}$

    ⇒ pion nature of V_T
  - ○ (J,T)=(1,0)

    ⇒ deuteron correlation

Effect of pairing and tensor correlation in ^{11}Li



Lowest

Pairing

Tensor

energy loss

Pauli blocking

energy gain

increase s^2 mixing

Tensor and pairing correlations in ^{11}Li in a coupled ^{9}Li+n+n model

- We prepare ^{9}Li with pairing and tensor correlations.
  - Superposition : 0p0h + pairing(nn) + tensor(pn)

- The system is solved based on the RGM equation
  - $H(^{11}\mathrm{Li}) = H(^{9}\mathrm{Li}) + H_{\mathrm{rel,nn}}, \qquad \Phi(^{11}\mathrm{Li}) = \mathcal{A}\{ \sum_{i=1}^{N} \psi_i(^{9}\mathrm{Li}) \cdot \chi_i(\mathrm{nn}) \}$
  - $\sum_{i=1}^{N} \langle \psi_j(^{9}\mathrm{Li}) \mid H(^{11}\mathrm{Li}) - E \mid \mathcal{A}\{ \psi_i(^{9}\mathrm{Li}) \cdot \chi_i^J(r) \}\rangle = 0, \quad \text{for } j=1,\cdots,N.$

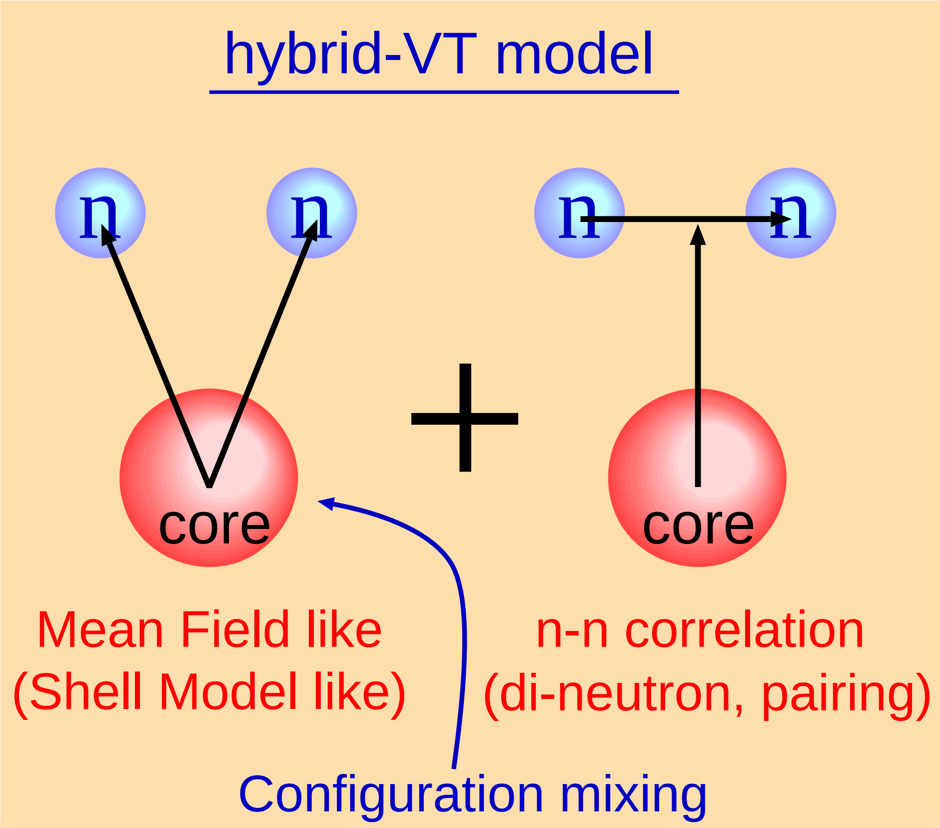
- The Orthogonality Condition Model(OCM) is applied to solve the equations.

$$\sum_{i=1}^{N} [\, h_{ij}(^{9}\mathrm{Li}) + (T_1+T_2+V_{c1}+V_{c2}+V_{12}+ \Lambda_{1,i}+\Lambda_{2,i})\ \delta_{ij} \,]\, \chi_j^J(r) = E\, \chi_i^J(r)$$

$$\Lambda_i = \lambda \cdot \Sigma_{\alpha\in {}^{9}\mathrm{Li}}\, |\phi_\alpha\rangle\langle\phi_\alpha|$$

Hamiltonian for ^{11}Li in the orthogonarity condition mdoel

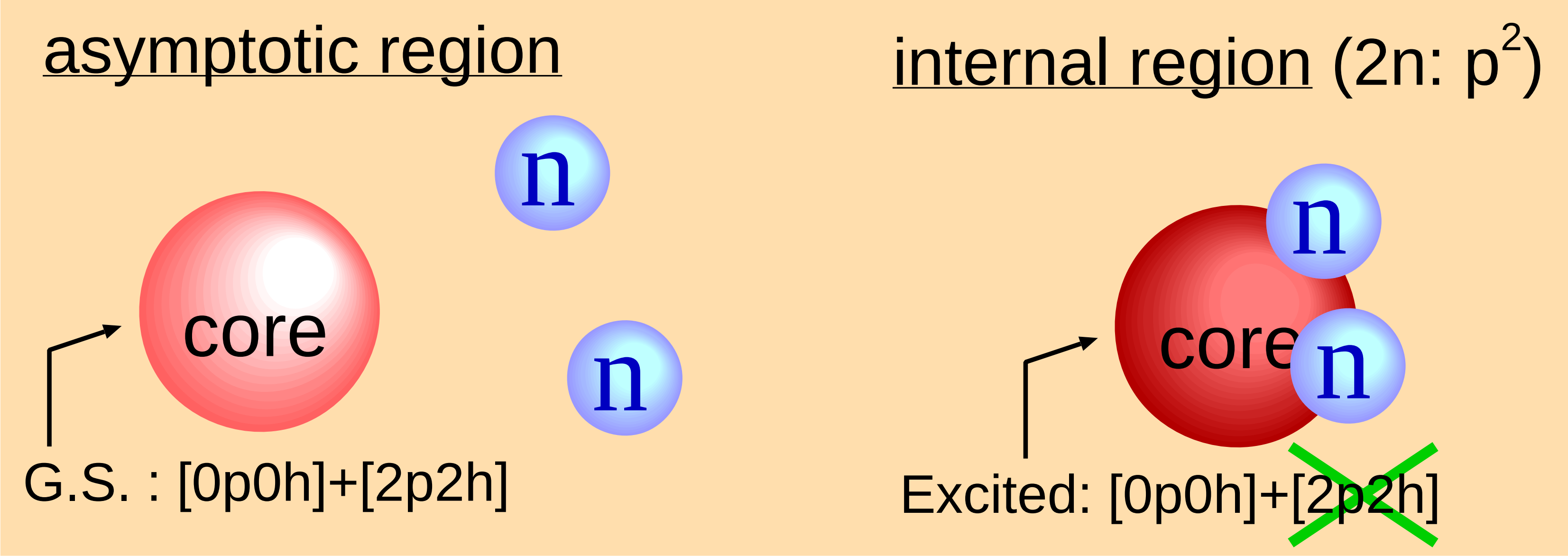
- ○ Folding potential with MHN(G-matrix)
- + Yukawa Tail for ^{9}Li-n ($S_n(^{9}\mathrm{Li})=4$ MeV)
  - – Same strength for s- and p-waves.
  - – Adjust to reproduce $S_{2n}=0.31$ MeV.
- ○ Argonne potential (AV8') for last 2n.



[Ref] TM, S. Aoyama, K.Kato, K.Ikeda, PTP108(2002)

Boundary condition of the coupled ^{9}Li+n+n model

- The ^{9}Li core in ^{11}Li in the asymptotic region is the isolated ^{9}Li fully with the tensor and pairing correlations.



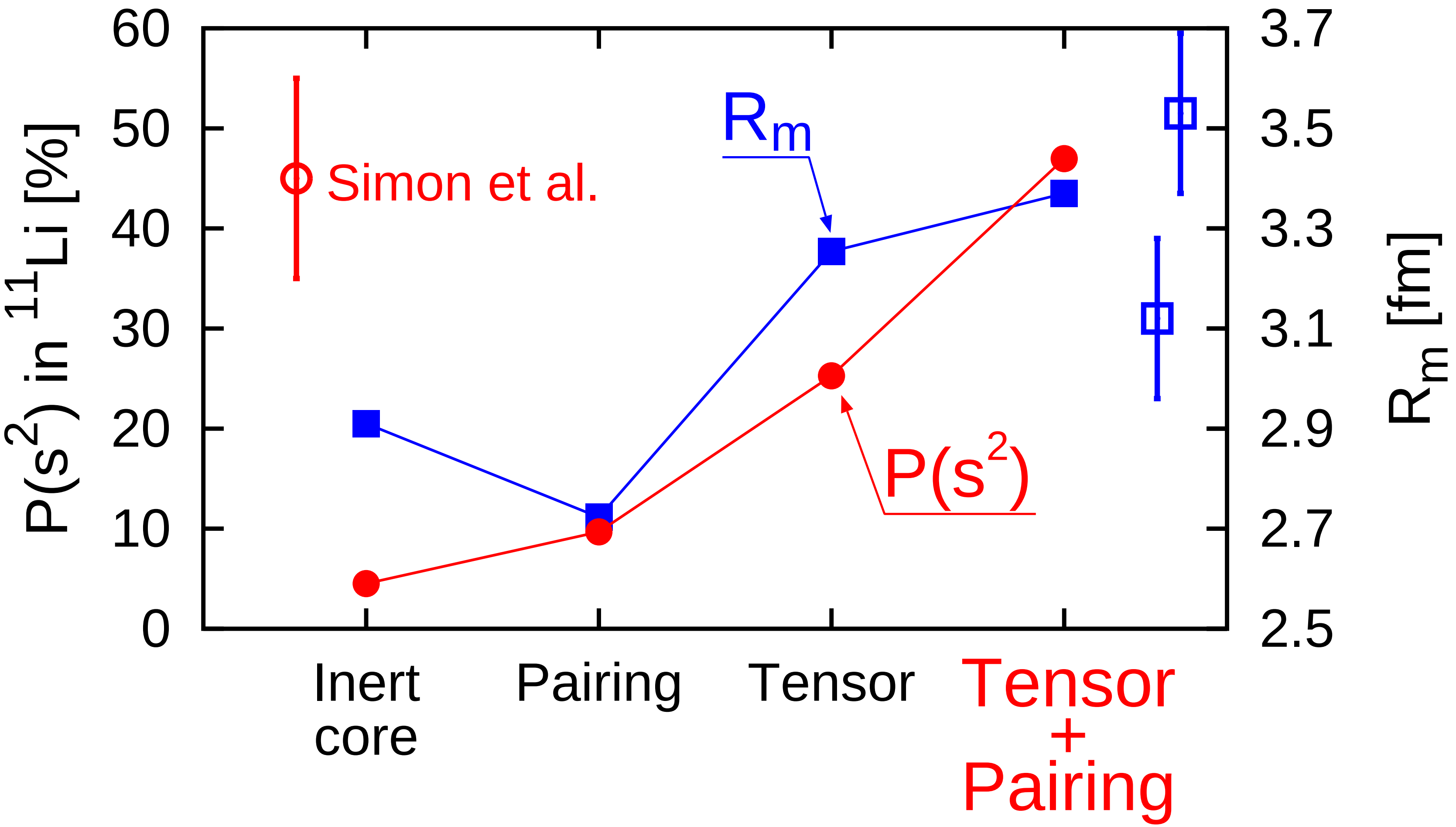
asymptotic region

G.S. : [0p0h]+[2p2h]

internal region (2n: p^2)

Excited: [0p0h]+[~~2p2h~~]

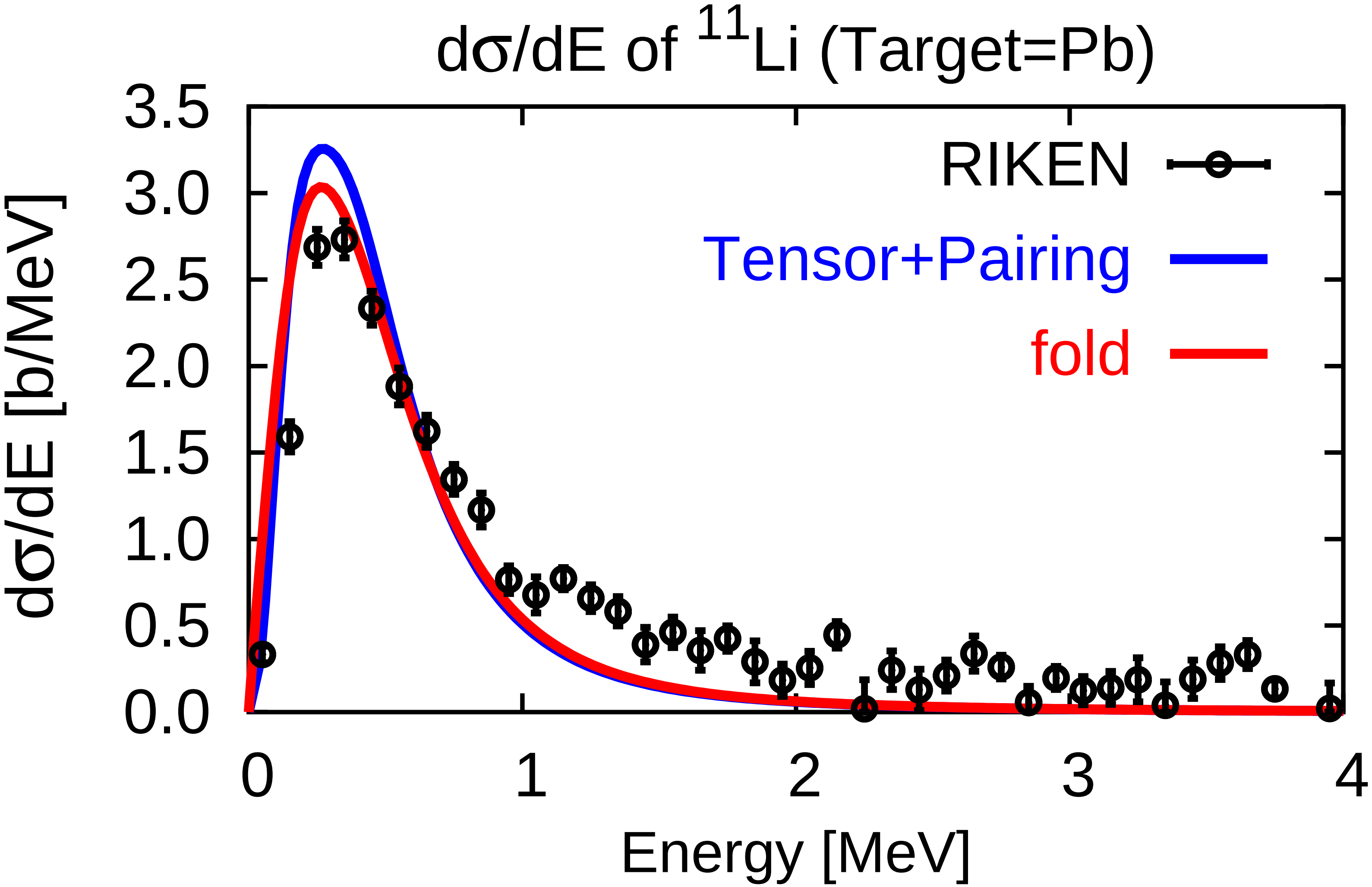
^{11}Li G.S. properties with tensor and pairing correlations



E(s^2)-E(p^2)	2.1	1.4	0.5	–0.1	[MeV]

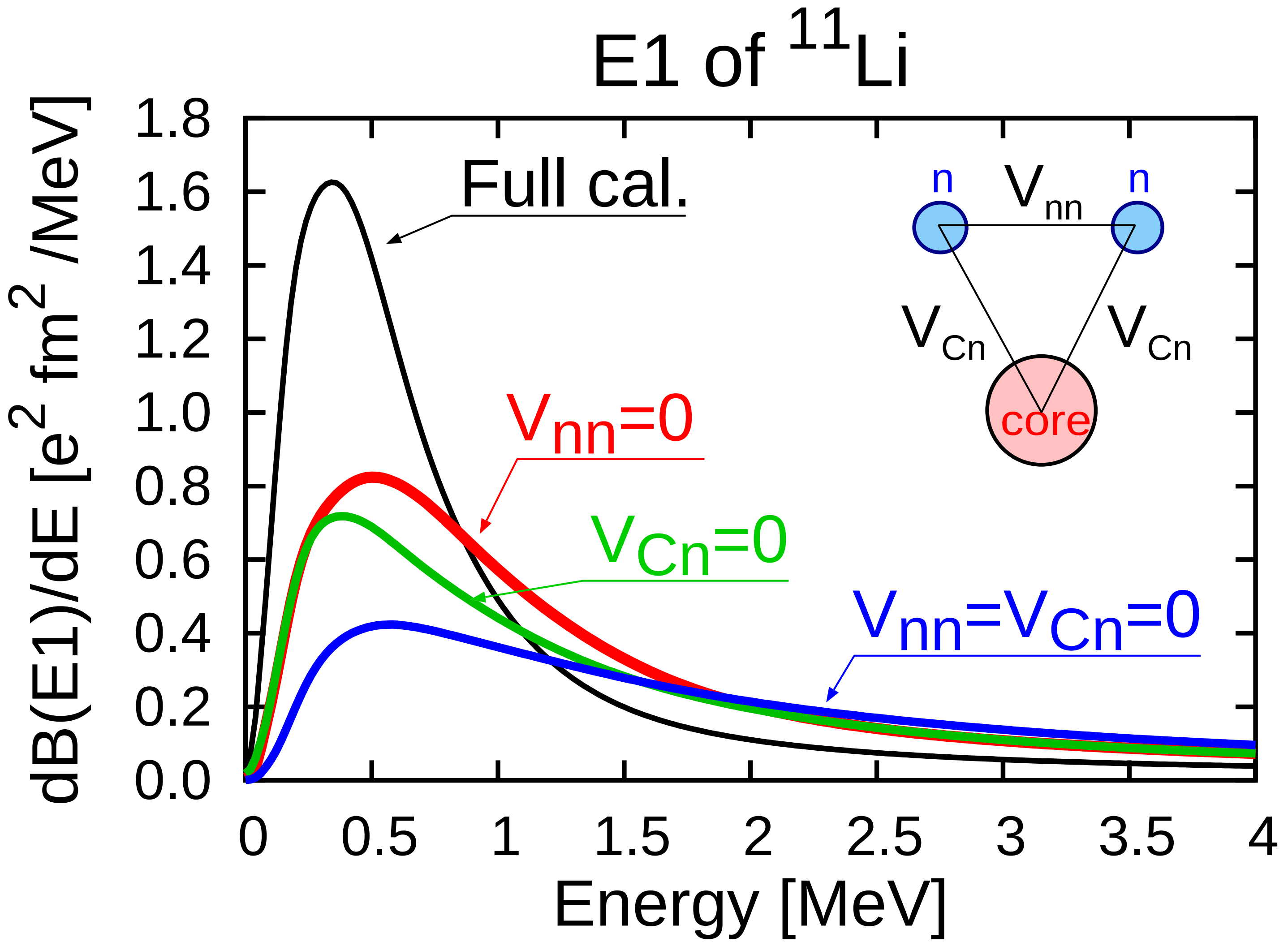
pairing correlation couples $(0p)^2$ with $(1s)^2$ for last 2n

Coulomb breakup strength into ^{9}Li+n+n system



- ○ No three-body resonances.
- ○ Exp. : Nakamura et al., RIKEN Accel.Prog.Rep.38.

Effect of the correlations in the final states of ^{11}Li breakup



Summary

1. We develop the three-body model of halo nuclei
   with tensor and pairing correlations.

2. ^{9}Li : Tensor(pn) and pairing(nn) correlations
   exhibit different 2p2h excitations and spatial properties.

3. ^{11}Li : Tensor suppression leads to the large admixture of $(1s)^2$ in G.S.
   - "Tensor+Pairing" naturally explains 50 % of $(1s)^2$.

4. Coulomb breakup strength depends on the model.
   - Naive three-body model produces three dipole resonances.
   - "Tensor+Pairing" produces no dipole resonances.