Role of the explicit tensor correlation in neutron halo nuclei

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1. Tensor correlation in light nuclei
2. LS splitting in He isotopes (poster, QM-050)
3. Disappearance of shell gap at N=8 in Li isotopes

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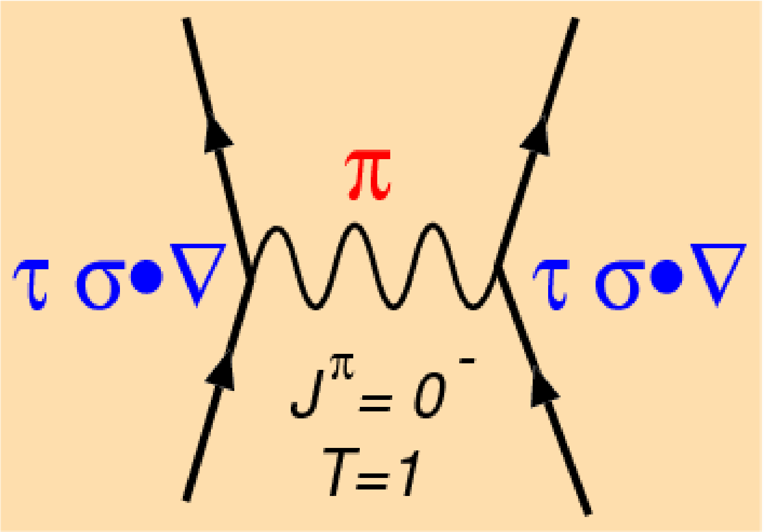
Motivation

- Tensor force (V_{tensor}) plays a significant role in the nuclear structure.
  - In ^{4}He, $\langle V_{tensor} \rangle \sim \langle V_{central} \rangle$
  - $\dfrac{V_\pi}{V_{NN}} \sim 80\%$ (GFMC)

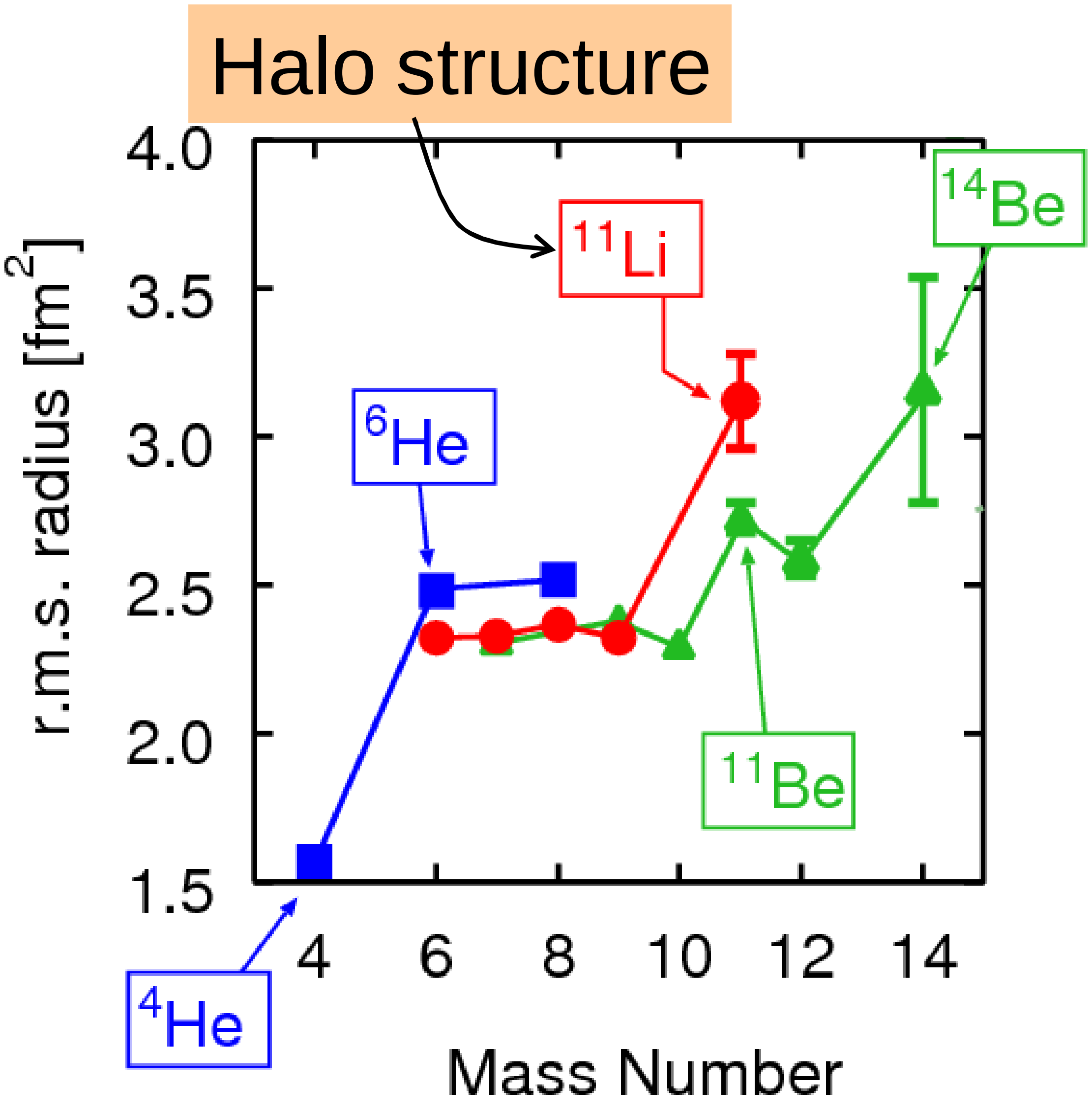


R.B. Wiringa, S.C. Pieper, J. Carlson, V.R. Pandharipande, PRC62(2001)

- We would like to understand the role of V_{tensor} in the nuclear structure by describing tensor correlation explicitly.
  - model wave function (shell model and cluster model).
  - spatial properties, p-h correlation, ...

- Spectroscopy of neutron-rich nuclei : He and Li isotopes

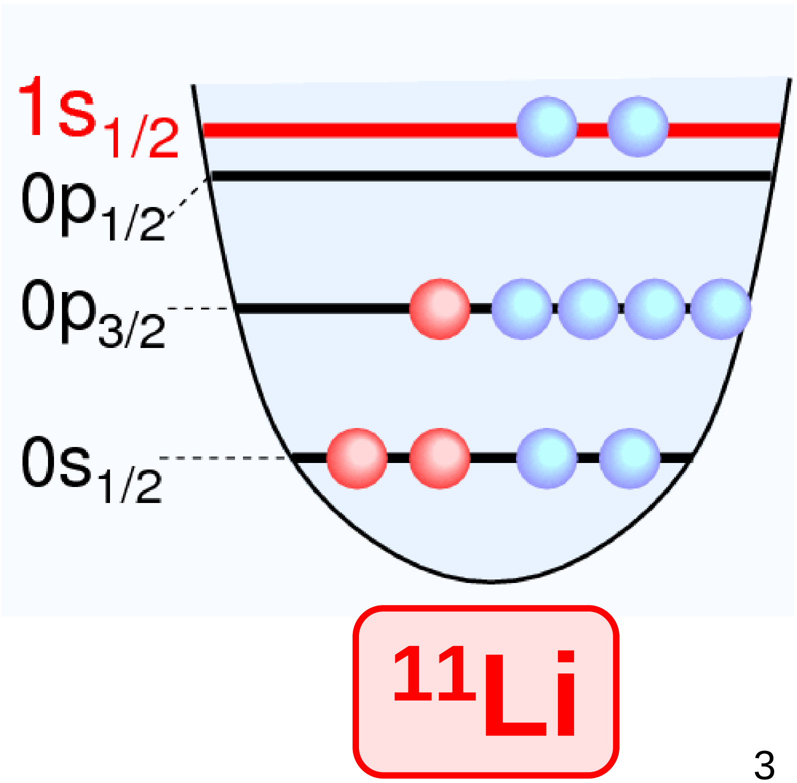
Characteristics of Li-isotopes



I. Tanihata et. al
PLB206(1988)592

- Breaking of magicity N=8
  - $^{10\text{-}11}$Li, $^{11\text{-}12}$Be
  - ^{11}Li … $(1s)^2 \sim 50\%$.

    (Expt by Simon et al.,PRL83)
  - Mechanism is unclear



^{11}Li with coupled ^{9}Li+n+n model

- System is solved based on RGM

$$H(^{11}\mathrm{Li}) = H(^{9}\mathrm{Li}) + H_{nn} \qquad \Phi(^{11}\mathrm{Li}) = \mathcal{A}\left\{\sum_{i=1}^{N} \psi_i(^{9}\mathrm{Li}) \cdot \chi_i(nn)\right\}$$

$$\sum_{i=1}^{N} \left\langle \psi_j(^{9}\mathrm{Li}) \middle| H(^{11}\mathrm{Li}) - E \middle| \mathcal{A}\left\{\psi_i(^{9}\mathrm{Li}) \cdot \chi_i(nn)\right\} \right\rangle = 0$$

$\psi_i(^{9}\mathrm{Li})$: shell model type configuration

- Orthogonality Condition Model (OCM) is applied.

$$\sum_{i=1}^{N} \left[h_{ij}(^{9}\mathrm{Li}) + (T_1 + T_2 + V_{c1} + V_{c2} + V_{12}) \cdot \delta_{ij} \right] \chi_j(nn) = E\chi_i(nn)$$

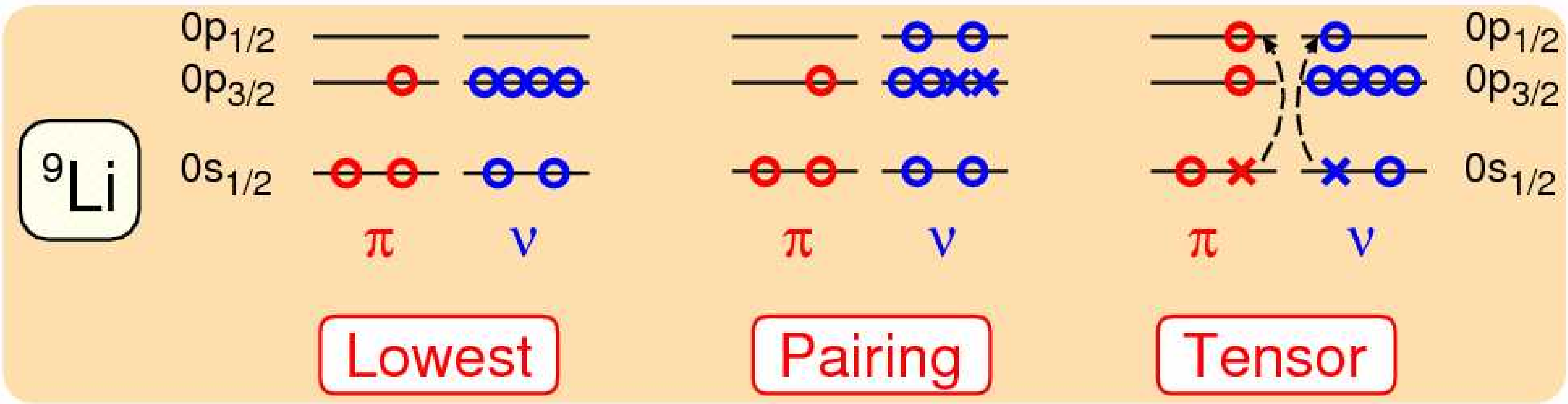
$h_{ij}(^{9}\mathrm{Li}) = \left\langle \psi_i \middle| H(^{9}\mathrm{Li}) \middle| \psi_j \right\rangle$: Hamiltonian for ^{9}Li

$\chi(nn) = \mathcal{A}\{\varphi_1\varphi_2\}$: 2 neutrons with Gaussian expansion method

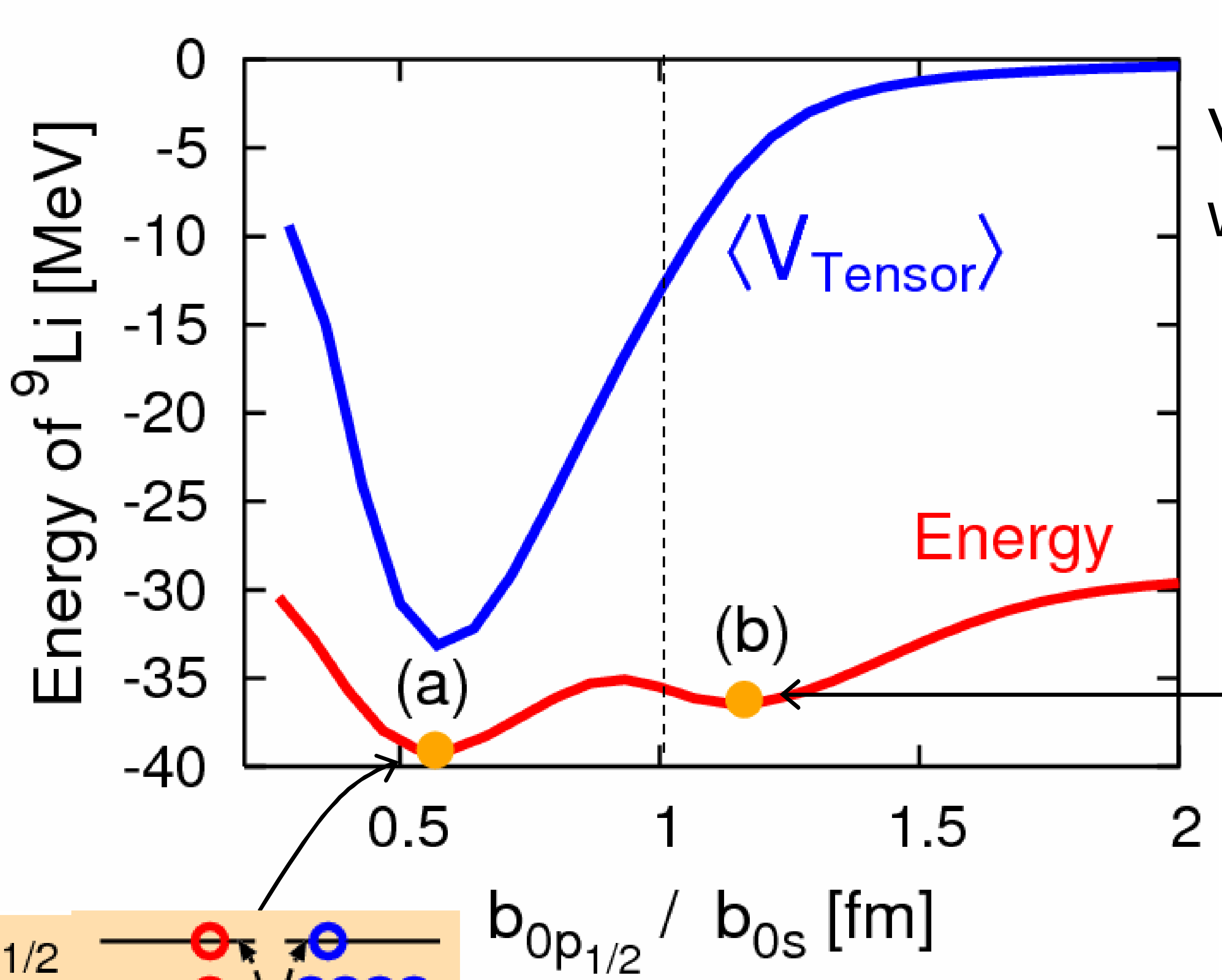
$\langle \varphi_i | \phi_\alpha \rangle = 0,\ \{\phi_\alpha \in {}^{9}\mathrm{Li}\}$: Orthogonality to the Pauli-forbidden states

^{9}Li with tensor and pairing correlations

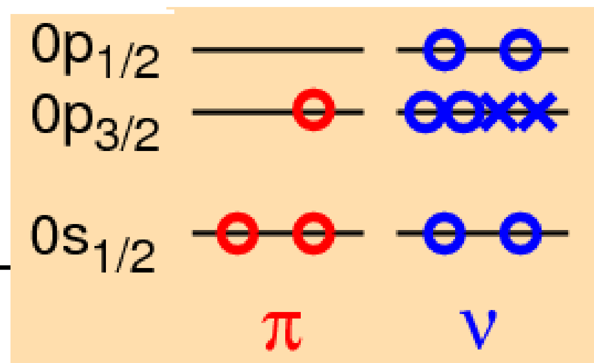
- Tensor-optimized shell model
  TM et al., PTP113(2005), PTP117(2007), Terasawa PTP22(1969).
- 0s+0p+1s0d within 2p2h excitations.
- Length parameters $b_{0s}, b_{0p1/2}, b_{0p3/2}, \ldots$ are determined independently and variationally.
  - Describe high momentum component from V_{tensor}
    cf. CPP-HF by Sugimoto et al.,NPA740 / Akaishi NPA738



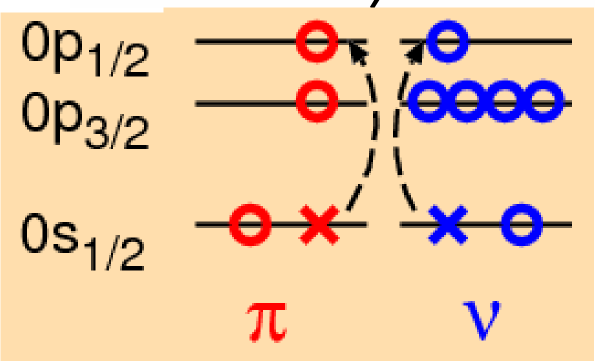
Energy surface for b-parameter in ^9Li



V_{tensor} is optimized with shrunk HO basis

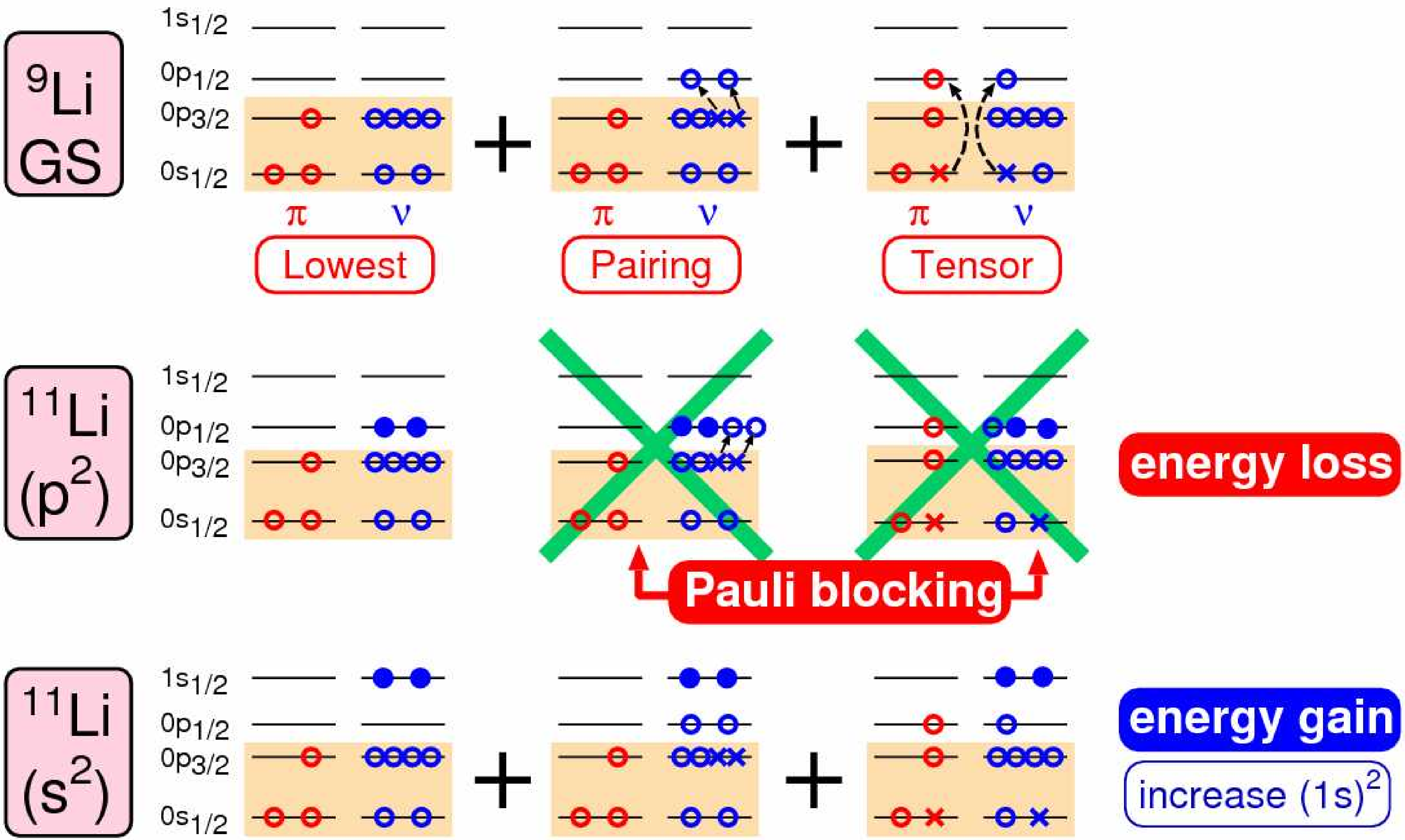


pairing correlation of P-shell



Tensor correlation from the bare V_{tensor}

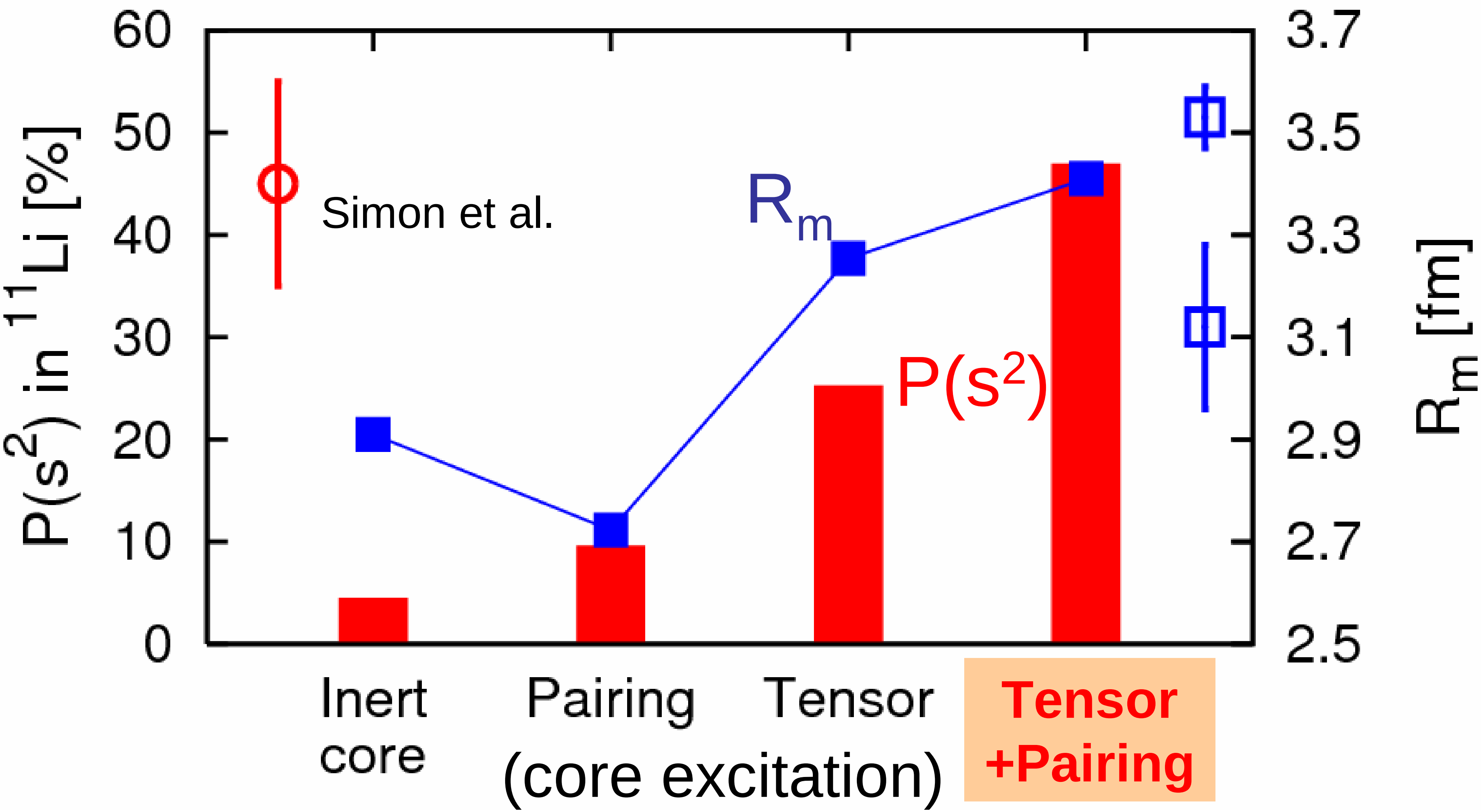
Expected effects of pairing and tensor correlations in ^{11}Li



Pairing-blocking :

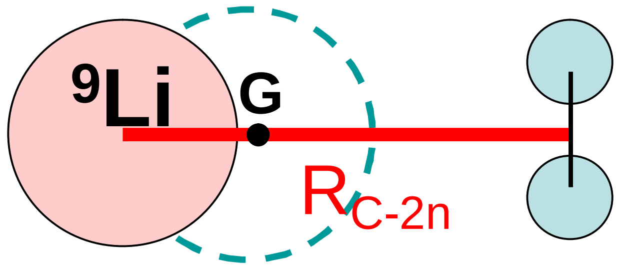
K.Kato,T.Yamada,K.Ikeda,PTP101('99)119, Masui,S.Aoyama,TM,K.Kato,K.Ikeda,NPA673('00)207.
TM,S.Aoyama,K.Kato,K.Ikeda,PTP108('02)133, H.Sagawa,B.A.Brown,H.Esbensen,PLB309('93)1.

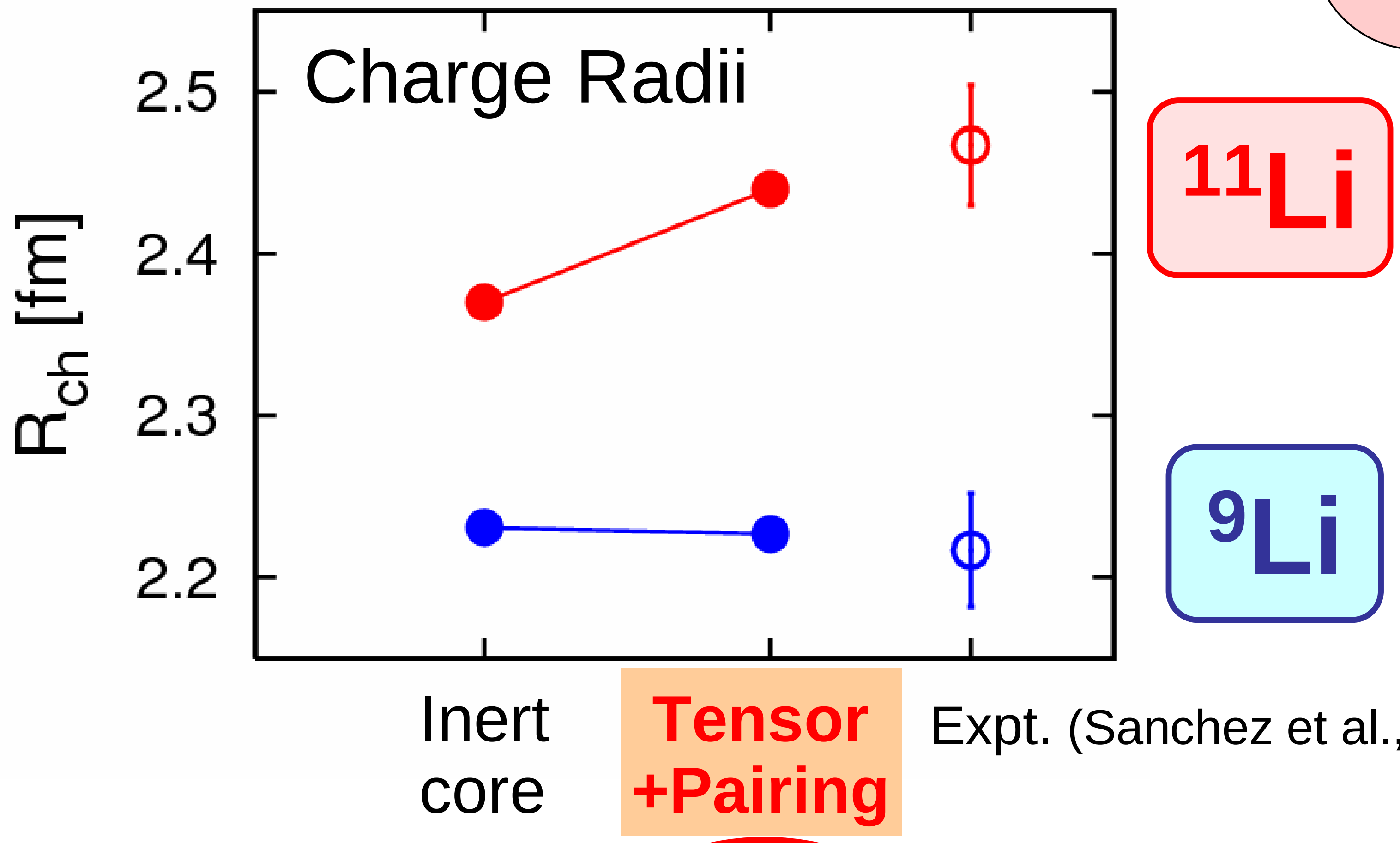
^{11}Li G.S. properties (S_{2n}=0.31 MeV)



Charge Radii of ^{11}Li

$$R^2_{\rm proton}(^{11}\mathrm{Li}) = R^2_{\rm proton}(^{9}\mathrm{Li}) + \left(\frac{2}{11}\right)^2 R^2_{\rm C\text{-}2n}$$

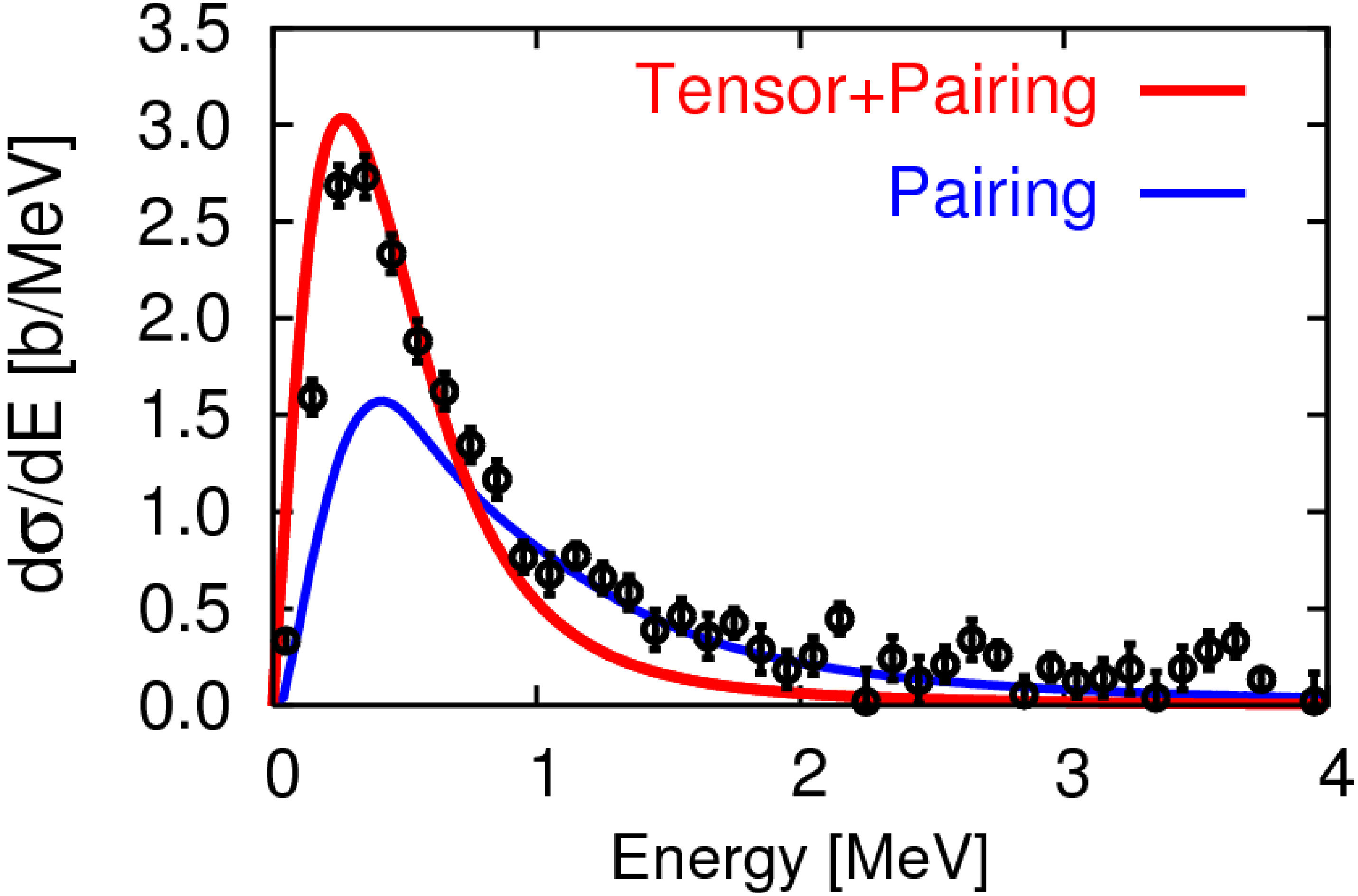




	Inert core	Tensor +Pairing	
R_{C-2n}	4.67	5.69	[fm]
$P(s^2)$	4	47	%

Coulomb breakup strength of ^{11}Li

$$^{11}\mathrm{Li}\,(\mathrm{G.S.}) \rightarrow\ ^{9}\mathrm{Li} + n + n$$



No three-body resonance

E1 strength by using the Green's function method

+Complex scaling method

+Equivalent photon method
(TM et al., PRC63('01))

- Expt: T. Nakamura et al. , PRL96,252502(2006)
- Energy resolution with $\sqrt{E}$ =0.17 MeV.

Virtual s-states in ^{10}Li

- $1s_{1/2}$ virtual state:

$$(0p_{3/2})_\pi (1s_{1/2})_\nu \rightarrow 1^-, 2^-$$

a_s : scattering length of ^{9}Li+n

Expt. M. Thoennessen et al., PRC59 (1999)111.
M. Chartier et al. PLB510(2001)24.
H.B. Jeppesen et al. PLB642(2006)449.

a_s = -10 ~ -25 fm

J^π	Inert core	**Tensor +Pairing**
1^-	+1.4 fm	-5.6 fm
2^-	+0.8 fm	-17.4 fm

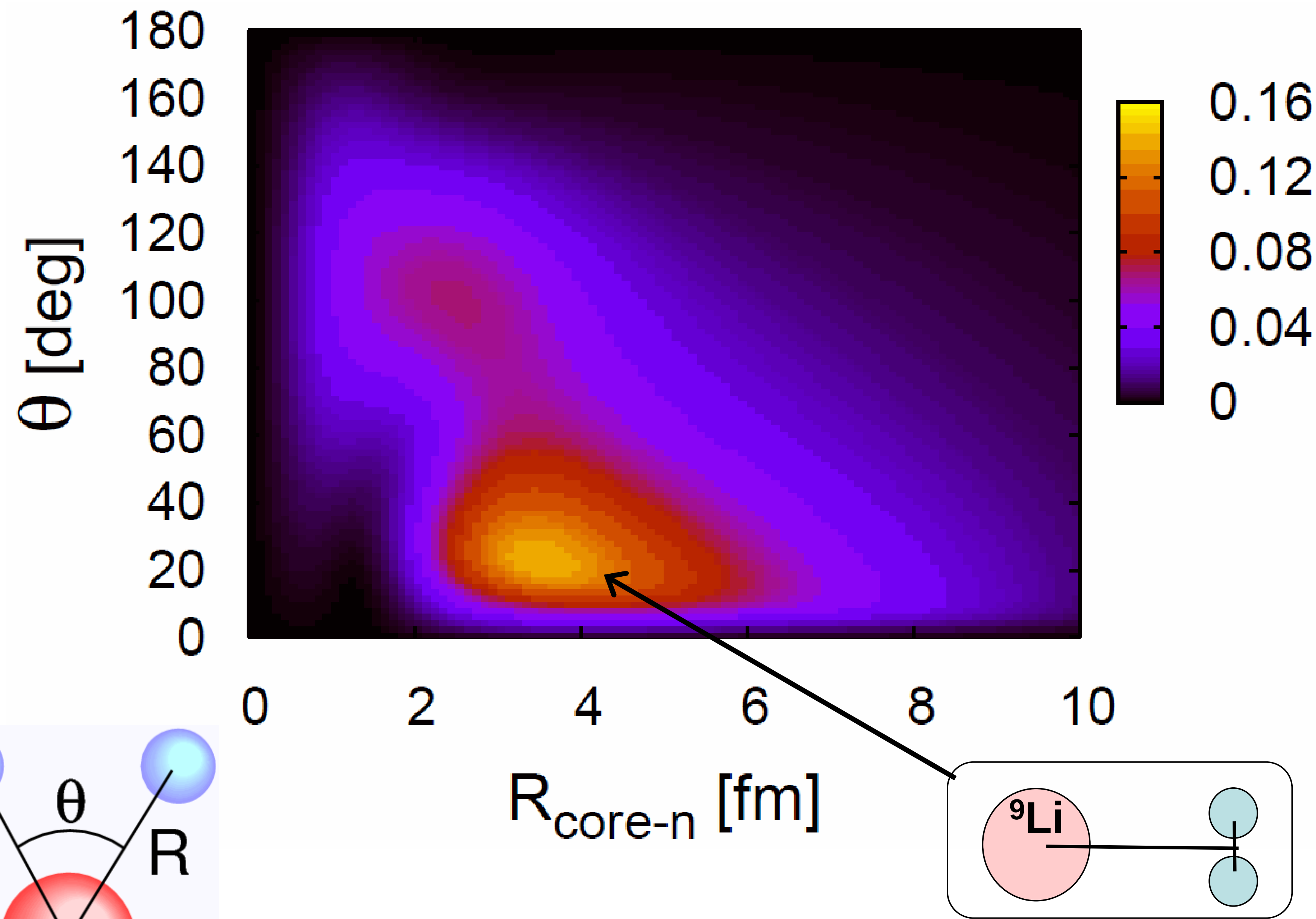
cf. $a_s(nn)$: -18.5 ± 0.5 fm

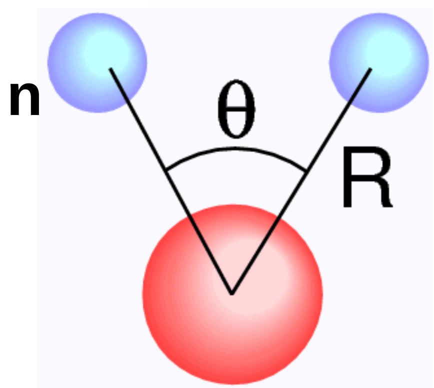
Pauli-blocking naturally describes virtual s-state in ^{10}Li

Summary

- We investigate the explicit tensor correlation in Li-isotopes.
- ^{9}Li with tensor optimization
  - 0^- coupling between $0s_{1/2}$ and $0p_{1/2}$.
  - Deuteron correlation (J=1,T=0) for 2p2h excitations.
- ^{10}Li
  - Pauli-blocking naturally explains the virtual s-states.
- ^{11}Li
  - Pauli-blocking naturally explains breaking of magicity.
  - Charge radii, Coulomb breakup strength, Q-moment.

2n correlation density in ^{11}Li





Di-neutron type config.

H.Esbensen and G.F.Bertsch, NPA542(1992)310

Pion exchange vs. V_{Tensor}

$$3(\vec{\sigma}_1 \cdot \hat{q})(\vec{\sigma}_2 \cdot \hat{q}) \frac{q^2}{m^2+q^2} = (\vec{\sigma}_1 \cdot \vec{\sigma}_2) \frac{q^2}{m^2+q^2} + S_{12} \frac{q^2}{m^2+q^2}$$

$$= (\vec{\sigma}_1 \cdot \vec{\sigma}_2) \left[\frac{m^2+q^2}{m^2+q^2} - \frac{m^2}{m^2+q^2} \right] + S_{12} \frac{q^2}{m^2+q^2}$$

Delta interaction

Yukawa interaction

Involve large momentum

Tensor operator

$$S_{12} = 3(\vec{\sigma}_1 \cdot \hat{q})(\vec{\sigma}_2 \cdot \hat{q}) - (\vec{\sigma}_1 \cdot \vec{\sigma}_2)$$

- V_{tensor} produces the high momentum component.