Strongly Tensor Correlated Hartree-Fock Theory and Delta in Nuclei

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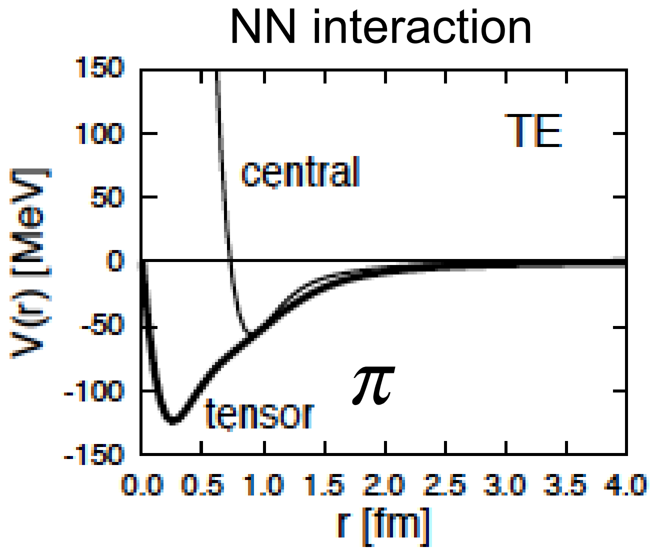
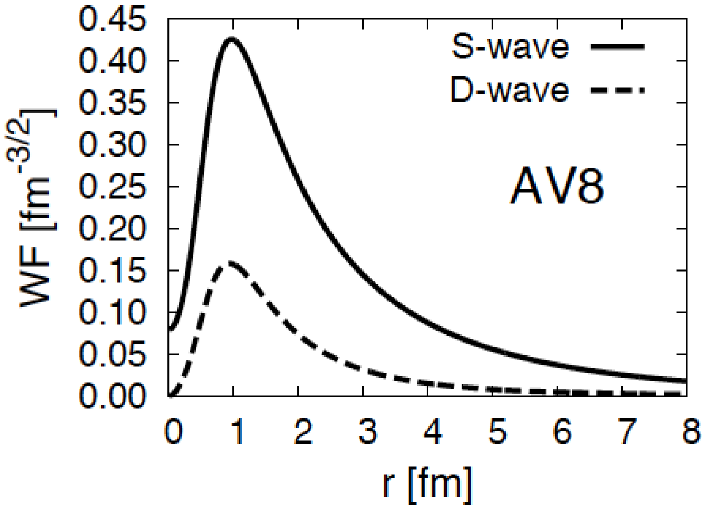
Content

- Importance of tensor force (pion) in light nuclei
- Tensor optimized shell model (TOSM)
  0p0h + 2p2h states
- Strongly tensor correlated Hartree-Fock theory
- Delta for three-body interaction
- Conclusion

The importance of pion (tensor force) is clear in deuteron





$$\Psi = C_S |S\rangle + C_D |D\rangle$$

S=1 and L=0 or 2

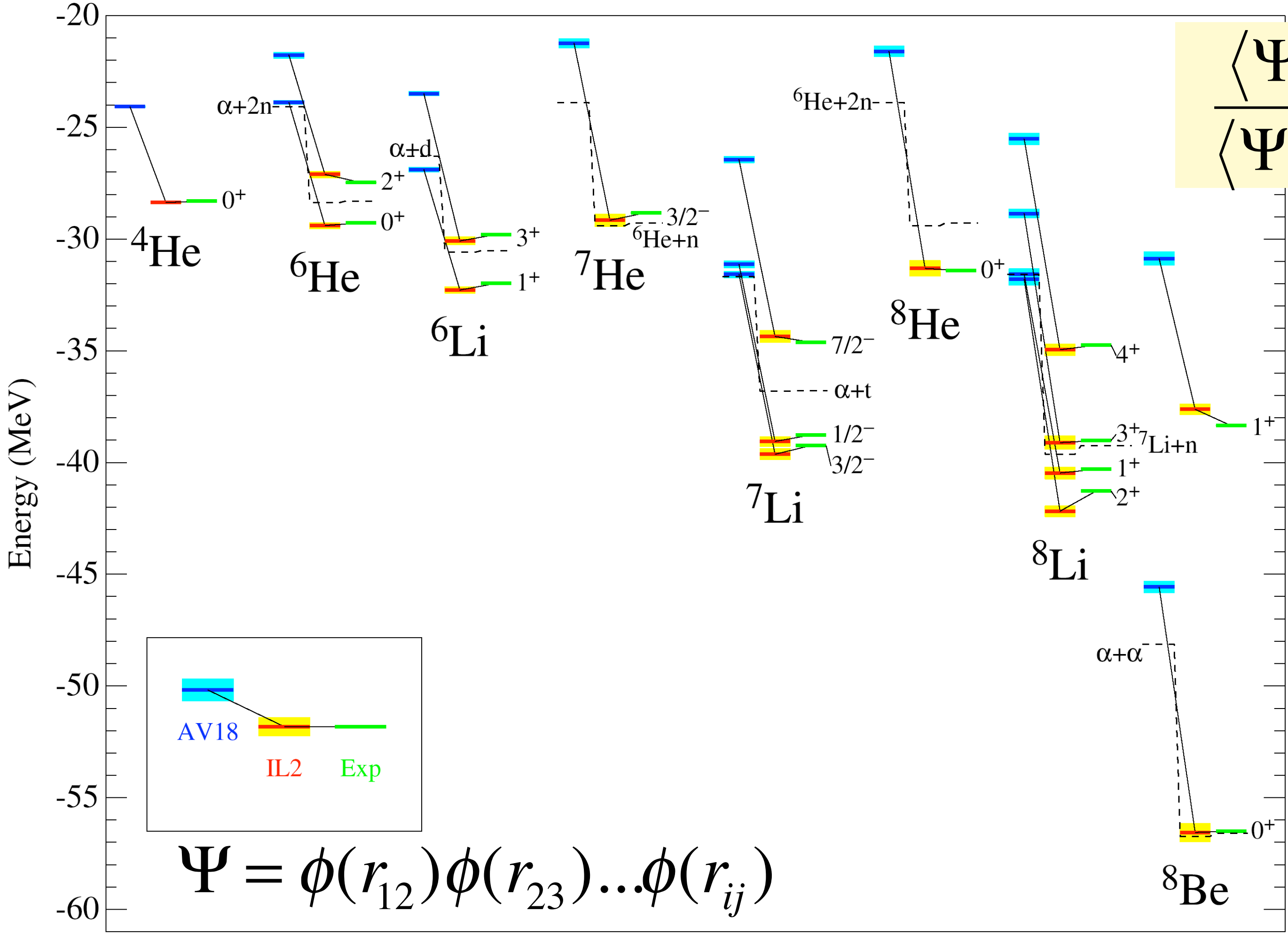
Deuteron (1^+)

Energy	−2.24 [MeV]
Kinetic	19.88
(SS)	11.31
(DD)	8.57
Central	−4.46
(SS)	−3.96
(DD)	−0.50
Tensorc	−16.64
(SD)	−18.93
(DD)	2.29
LS	−1.02
P(*D*)	5.78 [%]
Radius	1.96 [fm]
(SS)	2.00 [fm]
(DD)	1.22 [fm]

Variational calculation of few body system with NN interaction

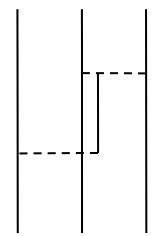
VMC+GFMC

$$\frac{\langle\Psi|V_\pi|\Psi\rangle}{\langle\Psi|V_{NN}|\Psi\rangle} \sim 80\%$$

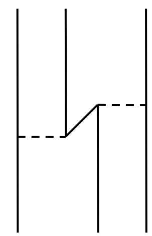


$$\Psi = \phi(r_{12})\phi(r_{23})\ldots\phi(r_{ij})$$

V_{NNN}



Fujita-Miyazawa



Relativistic

C. Pieper and R. B. Wiringa, Annu. Rev. Nucl. Part. Sci.51(2001)

Heavy nuclei (Super model)

Pion is key

Pion is important in nucleus

- 80% of attraction is due to pion
- Tensor interaction is particularly important (50%)

Pion	Tensor	spin-spin

$$\frac{\vec{\sigma}_1 \cdot \vec{q} \vec{\sigma}_2 \cdot \vec{q}}{m_\pi^2 + q^2} = \frac{1}{3} \frac{q^2}{m_\pi^2 + q^2} S_{12}(\hat{q}) + \frac{1}{3} \frac{q^2}{m_\pi^2 + q^2} \vec{\sigma}_1 \cdot \vec{\sigma}_2$$

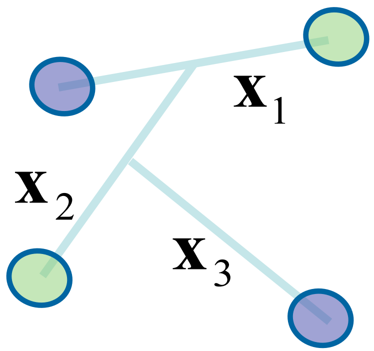
$$= \frac{1}{3} \frac{q^2}{m_\pi^2 + q^2} S_{12}(\hat{q}) + \frac{1}{3} \left(1 - \frac{m_\pi^2}{m_\pi^2 + q^2} \right) \vec{\sigma}_1 \cdot \vec{\sigma}_2$$

high momentum low momentum

$$S_{12}(\hat{q}) = \sqrt{\frac{24\pi}{5}} \left[Y_2(\hat{q}) [\sigma_1 \sigma_2]_2 \right]_0$$

Tensor Optimized Few-body Model (TOFM)

K.Horii H.Toki T.Myo K.Ikeda: PTP (2012)



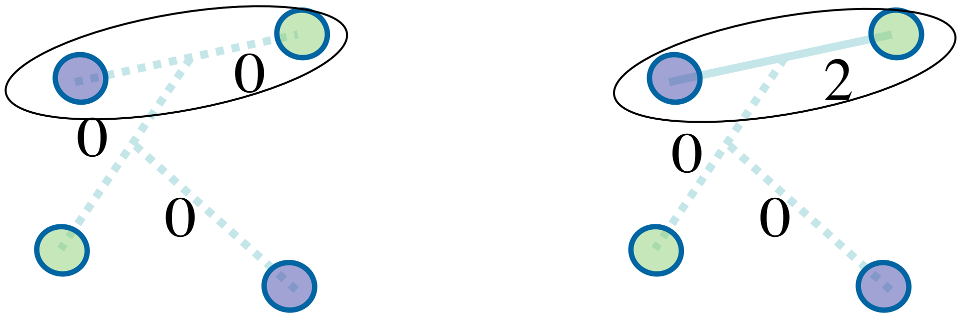
Jacobi coordinate x_1, x_2, x_3

$$|\Psi\rangle = |\Psi\rangle_S + |\Psi\rangle_D \qquad \langle D|S_{12}|S\rangle \neq 0$$

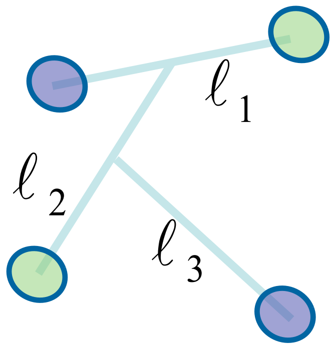
$$|\Psi\rangle_{S,D} = \sum_{i=1}^{k} c_i \psi_i = \sum_{i=1}^{k} c_i \mathcal{A}\left[\psi_L^{space} \chi_S^{spin}\right]_J \chi_T^{isospin}$$

For ^{4}He Total J=0 S-wave(L=0,S=0)
D-wave(L=2,S=2)

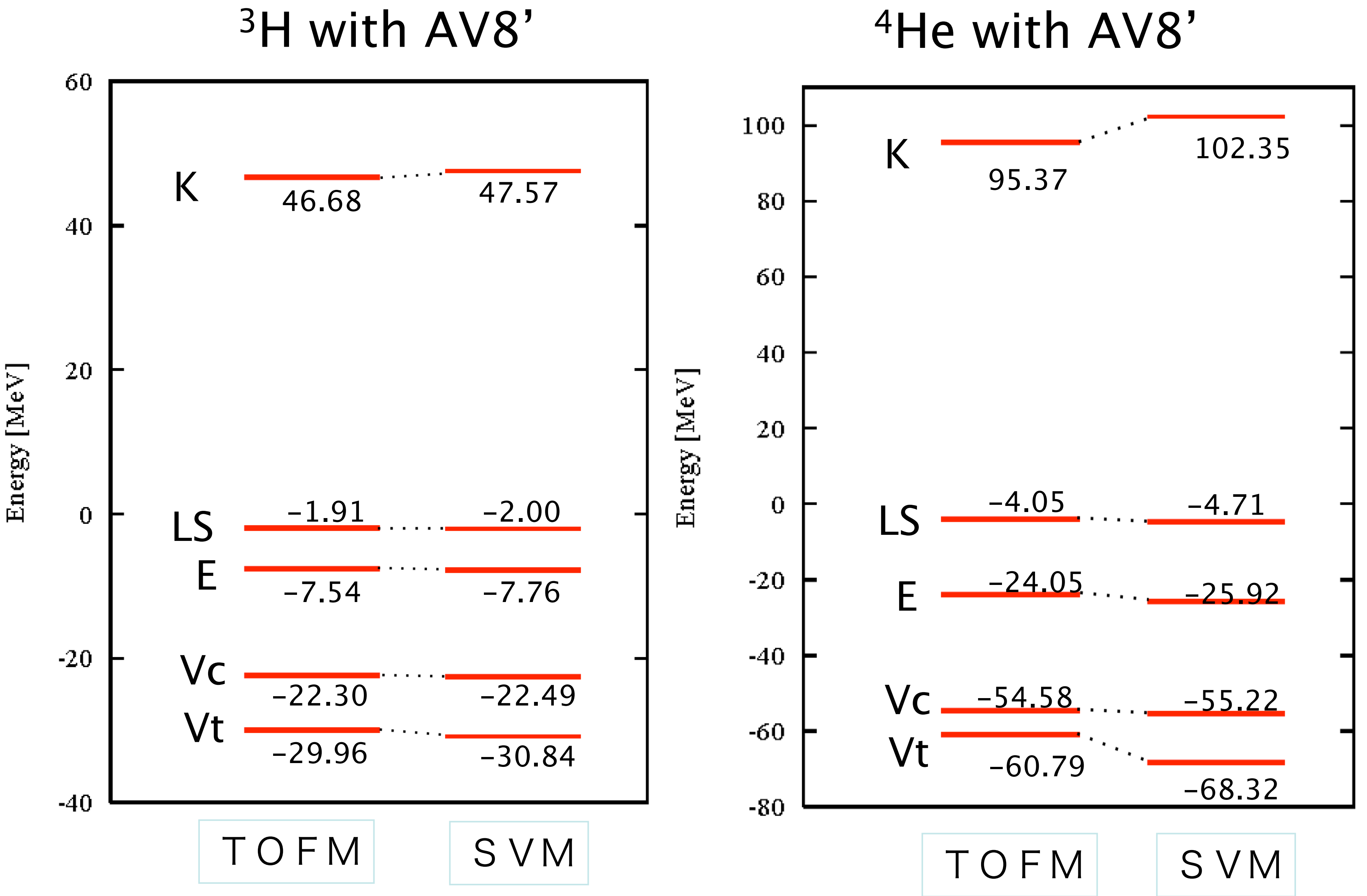
S-wave (L=0) D-wave (L=2)



$$l_1 \neq l_2 \neq l_3 = any$$



Comparison of TOFM with rigorous calculation



Strongly Tensor correlated Hartree-Fock theory

Y.Ogawa H.Toki Annals of Physics (2011)

Super model

$$\langle HF | S_{12} | HF \rangle = 0 \qquad S_{12} = \sqrt{\frac{24\pi}{5}} [Y_2(\hat{r}) \times [\sigma_1 \times \sigma_2]_2]^{(0)}.$$

We cannot treat the tensor interaction in HF space.

$$|\Psi\rangle = C_0 |0\rangle + \sum_{\alpha} C_\alpha |2p - 2h : \alpha\rangle$$

$$\delta \frac{\langle \Psi | H | \Psi \rangle}{\langle \Psi | \Psi \rangle} = 0 \qquad \langle \Psi | \Psi \rangle = |C_0|^2 + \sum_{\alpha} |C_\alpha|^2 = 1$$

Total energy

$$\langle\Psi|H|\Psi\rangle = |C_0|^2\langle 0|H|0\rangle + C_0^*\sum_\alpha C_\alpha\langle 0|H|2p-2h:\alpha\rangle$$
$$+C_0\sum_\alpha C_\alpha^*\langle 2p-2h:\alpha|H|0\rangle + \sum_{\alpha\beta}C_\alpha^* C_\beta\langle\alpha|H|\beta\rangle$$

$$|2p-2h:\alpha\rangle \equiv |\alpha\rangle$$

Variational principle

$$\frac{\partial}{\partial C_\alpha^*}\langle\Psi|H-E|\Psi\rangle = 0$$

$$C_0\langle\alpha|H|0\rangle + \sum_\beta C_\beta\langle\alpha|H|\beta\rangle = EC_\alpha$$

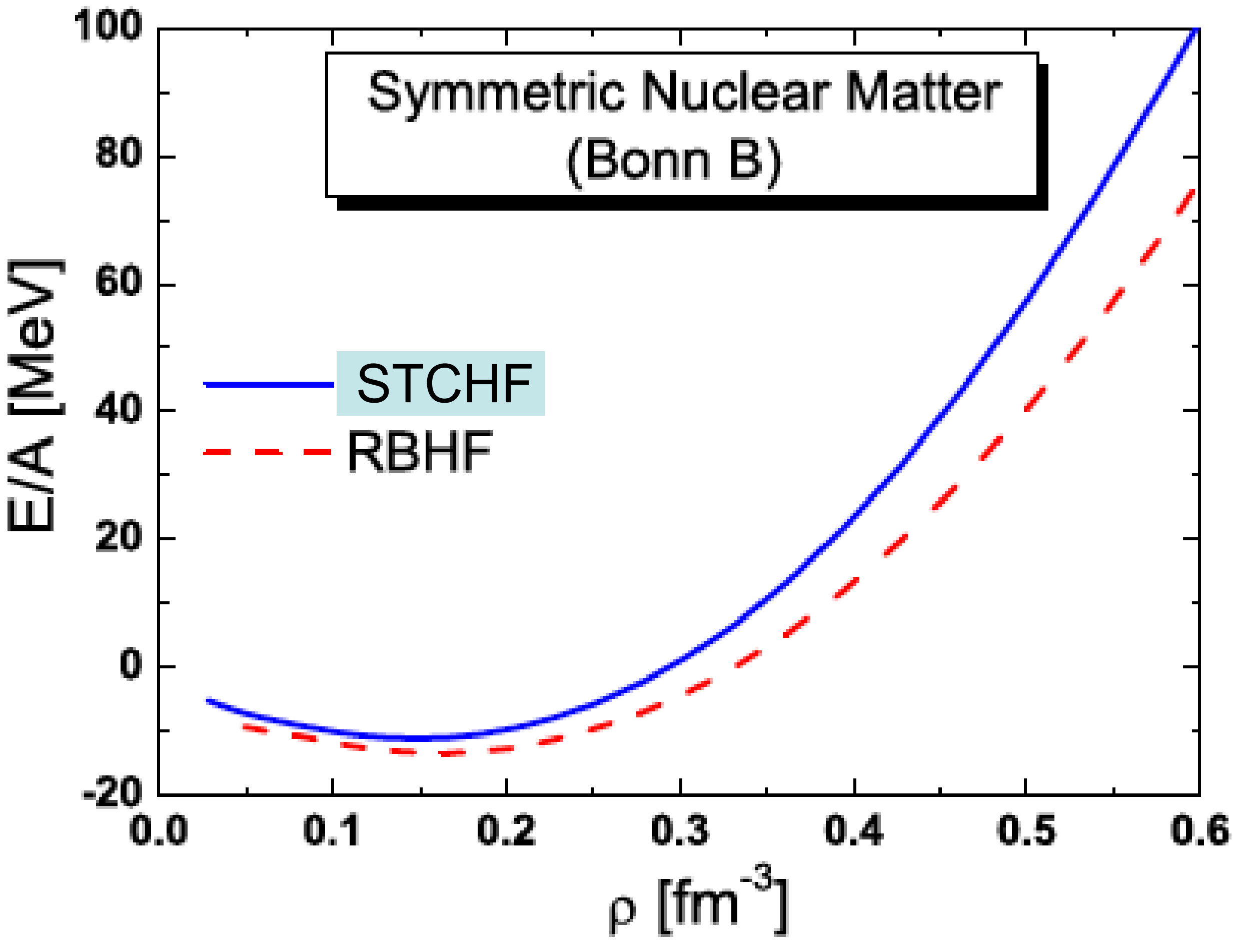
$$\frac{\partial}{\partial\psi_a^*(x)}\left[\langle\Psi|H|\Psi\rangle - \sum_b e_b\psi_b^*(x)\psi_b(x)\right] = 0$$

$$|0\rangle = \prod_a \psi_a(x)$$

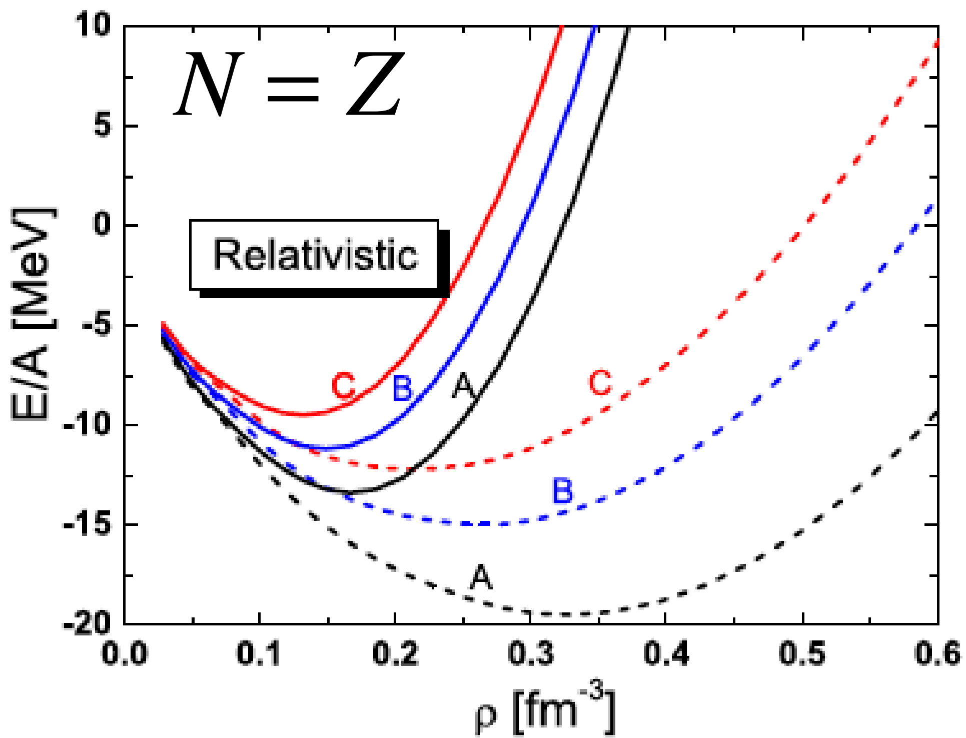
$$|C_0|^2\frac{\partial}{\partial\psi_a^*}\langle 0|H|0\rangle + C_0^*\sum_\alpha C_\alpha\frac{\partial}{\partial\psi_a^*}\langle 0|H|\alpha\rangle + \sum_{\alpha\beta}C_\alpha^* C_\beta\frac{\partial}{\partial\psi_a^*}\langle\alpha|H|\beta\rangle = e_a\psi_a(x)$$

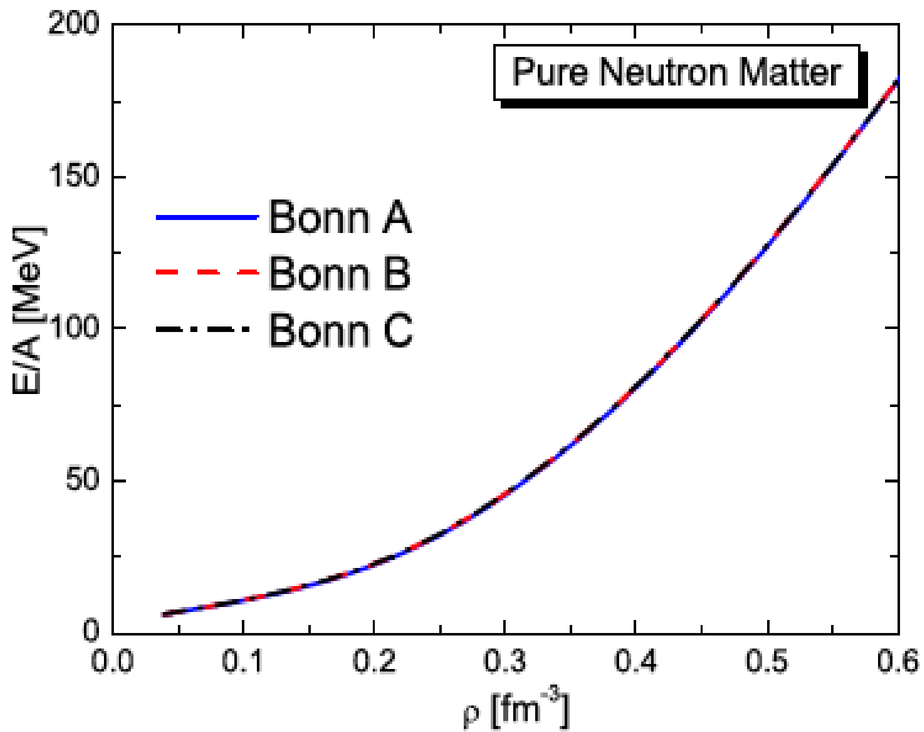
EOS of nuclear matter

Hu Toki Ogawa PTP(2013)



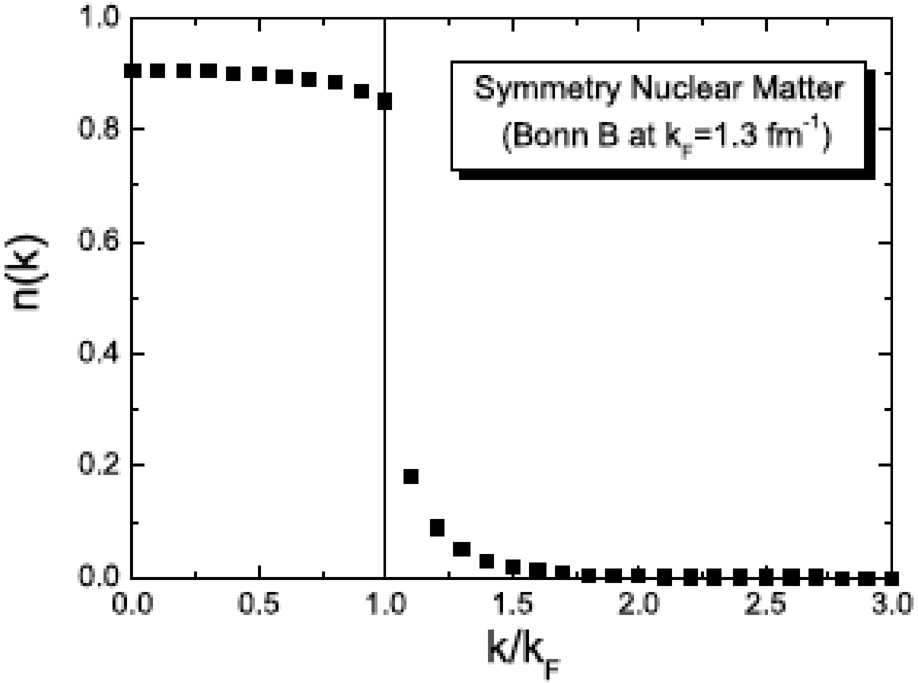
EOS of nuclear matter (N=Z) and (N only)

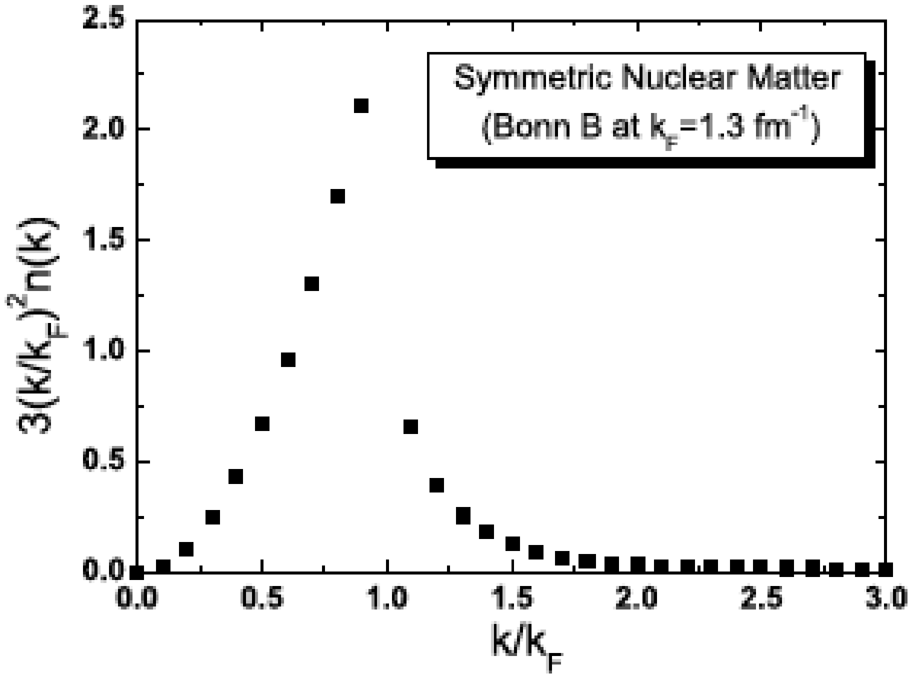




Relativistic effect provides hard EOS at high density
Tensor effect is small in neutron matter

Momentum distribution



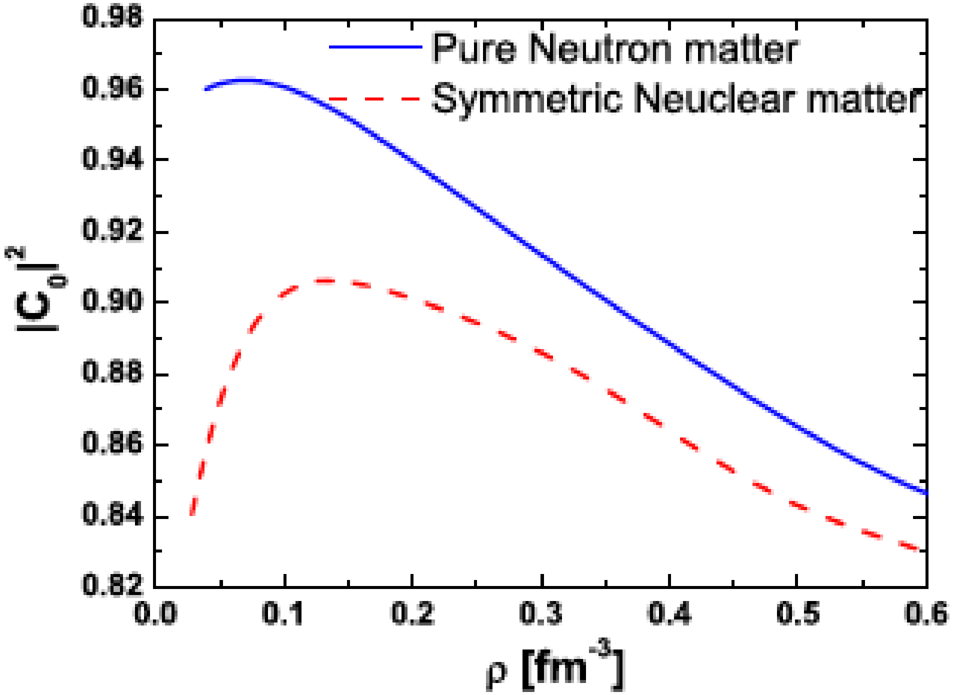


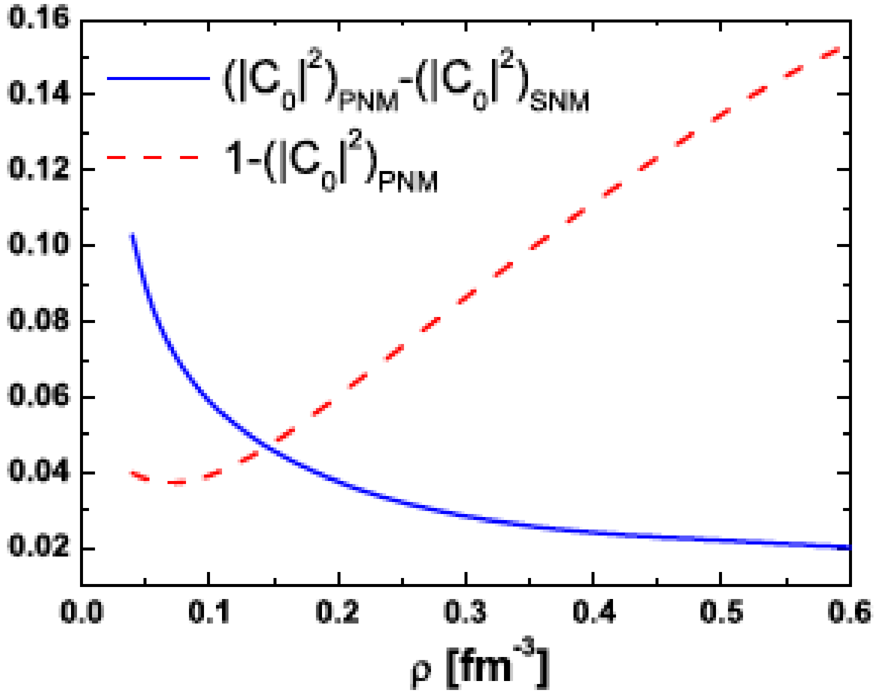
High momentum components

URCA過程

$$n \rightarrow p + e^{-} + \nu$$

Tensor correlation and Short range correlation





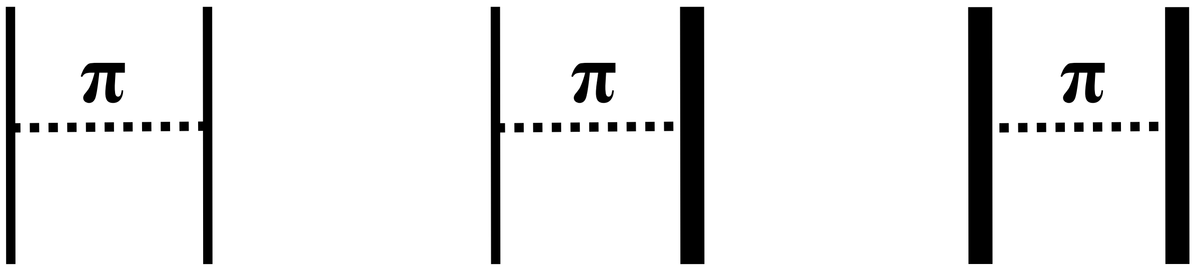
1。Short range correlation increases with density

2。Tensor correlation decreases with density

Delta for three body force

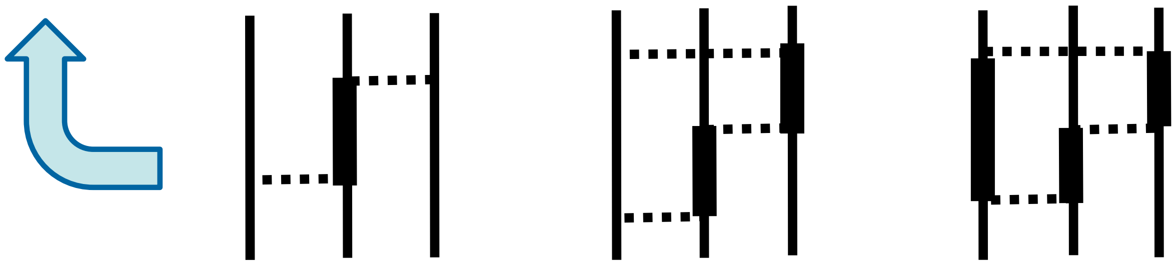
We add the delta degrees of freedom in two-body interaction.

(EX.)



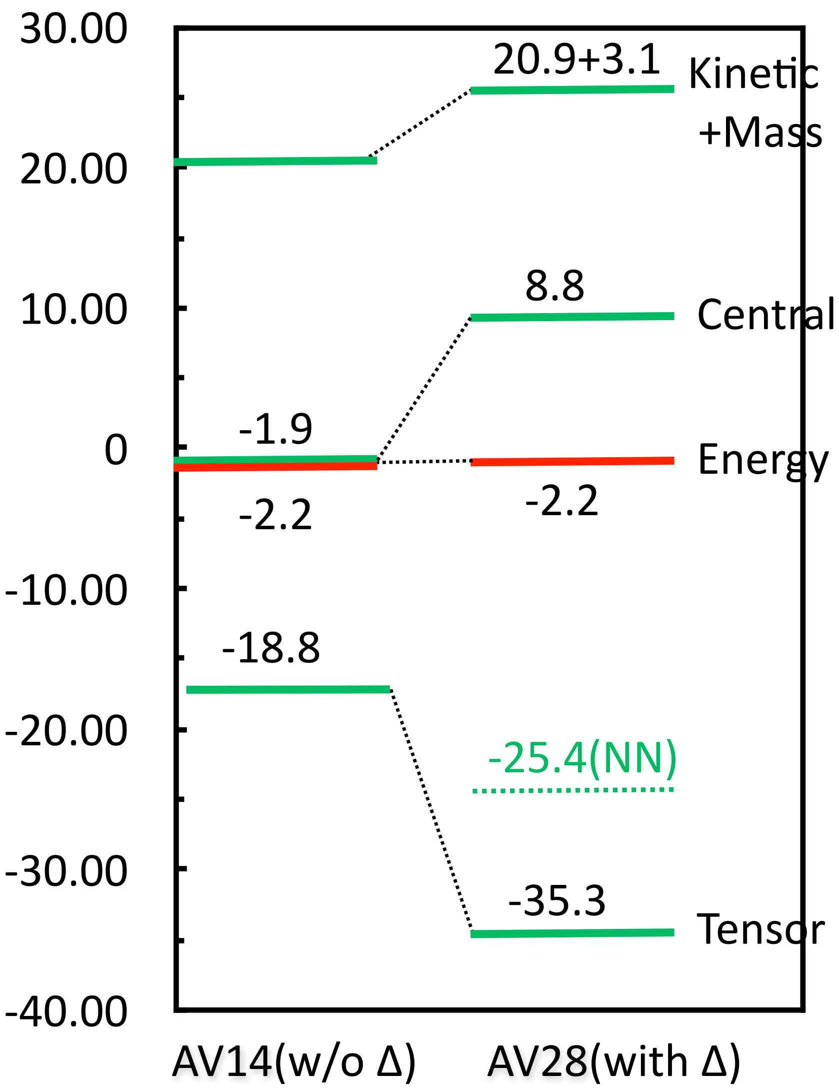
NN channel　　　NΔ channel　　　ΔΔ channel

Many-body forces can be treated by the two-body correlations with delta.



Two-body NN interaction with delta degrees of freedom → AV28 potential

Effect of Δ in deuteron

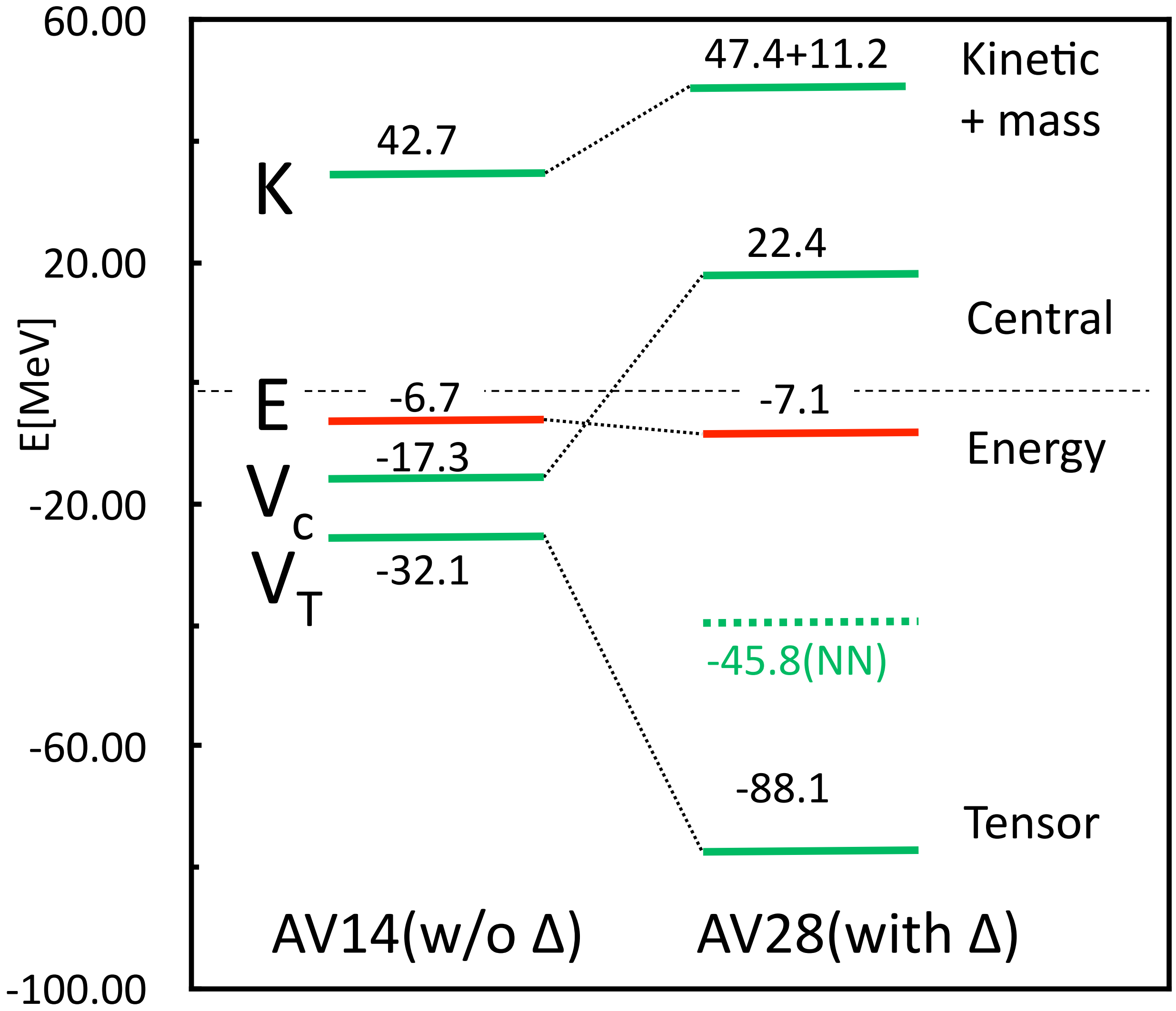


Deuteron 1^+	AV14	AV28
L · S	0.4	0.8
L^2	3.1	3.6
$(L \cdot S)^2$	- 4.0	- 4.1
P_{NN} $[^3S_1]$	93.9	93.3
P_{NN} $[^3D_1]$	6.1	6.2
$P_{\Delta\Delta}$ $[^3S_1]$		0.04
$P_{\Delta\Delta}$ $[^3D_1]$		0.02
$P_{\Delta\Delta}$ $[^7D_1]$		0.42
$P_{\Delta\Delta}$ $[^7G_1]$		0.04

$$\Psi_{NN} = |^3S_1\rangle + |^3D_1\rangle$$
$$\Psi_{\Delta\Delta} = |^3S_1\rangle + |^3D_1\rangle + |^7D_1\rangle + |^7G_1\rangle$$

Result ^3H with AV14 & AV28

^3H $J^{\pi} = 1/2^{+}$



No LS, L^2,LS^2 forces

ΔNN	1.5 [%]
ΔΔN	1.1 [%]

Nuclear Physics with tensor interaction

- We have developed STCHF theory to treat pion
- STCHF theory provides foundation of BHF theory
- Tensor interaction provides the saturation mechanism
- Delta provides three body interaction