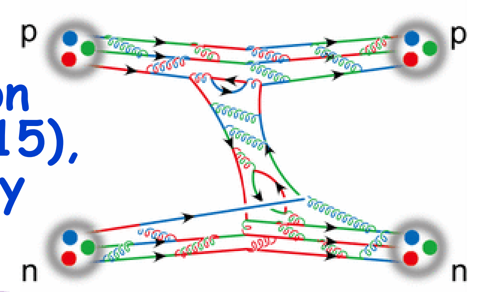
International symposium on "High-resolution Spectroscopy and Tensor interactions" (HST15),
Nov. 16- Nov. 19, 2015, Osaka University
Nakanoshima Center, Osaka, Japan



Tensor effects in nuclear structure from relativistic Brueckner Hartree-Fock theory

Jinniu Hu

School of Physics, Nankai University

The appetizer of Prof. Toki's talk

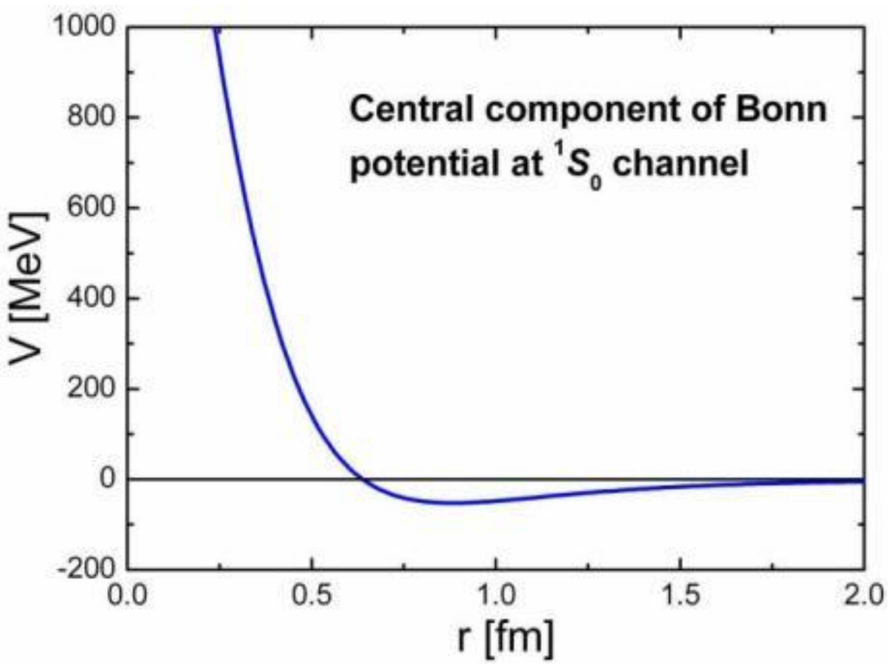
抛砖引玉

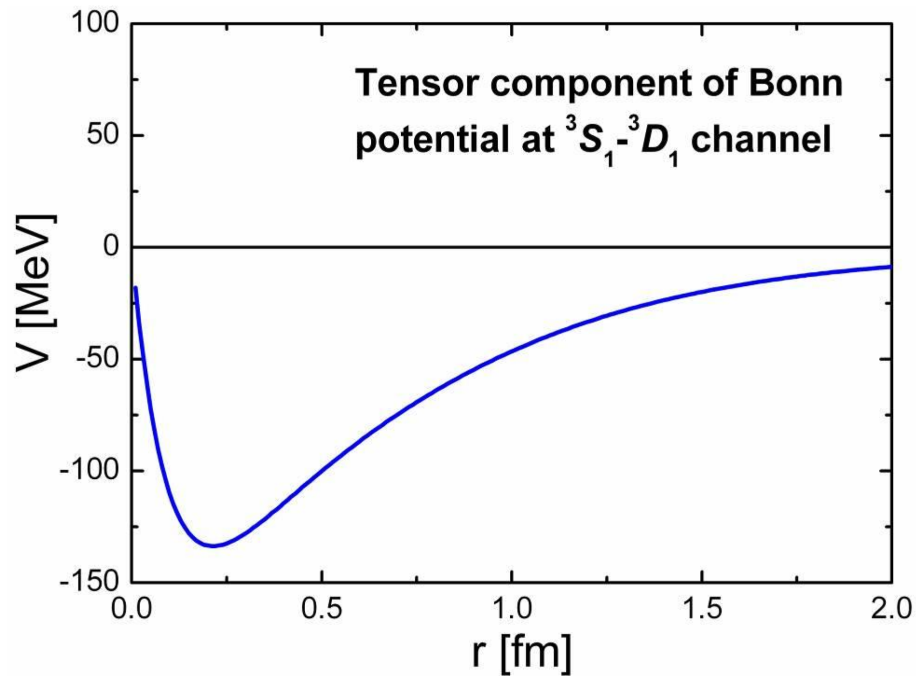
Throw out a minnow to catch a whale

南開大學

□ Tensor effect in nuclear matter

Short range repulsive and tensor force in realistic NN interaction

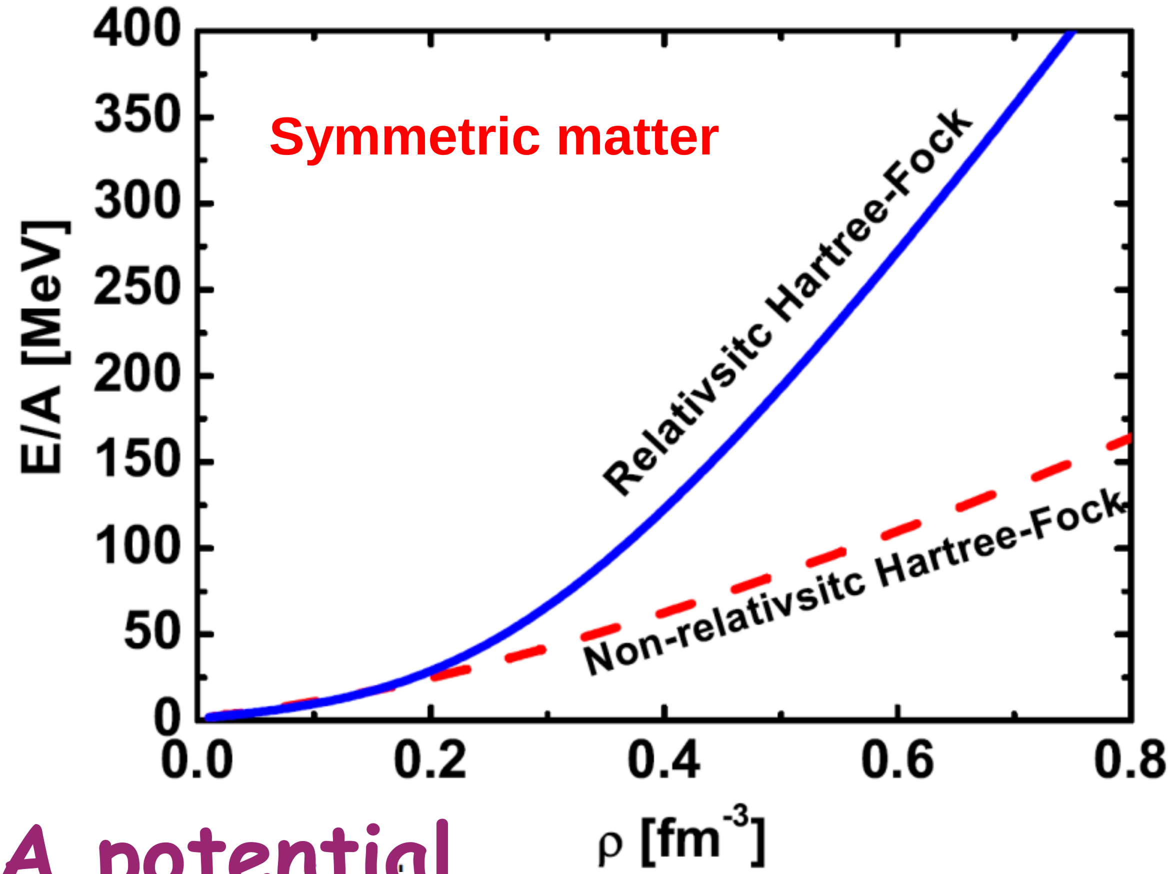




- Strong repulsive force at short range region (isospin-independent)
- Strong tensor force (isospin-dependent)

Machleidt, ANP19(1989)189

Realistic NN interaction for symmetric nuclear matter with mean-field theory

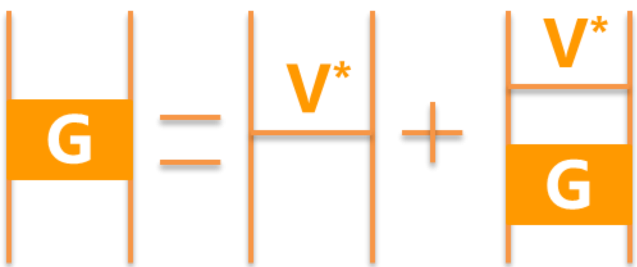


Bonn A potential

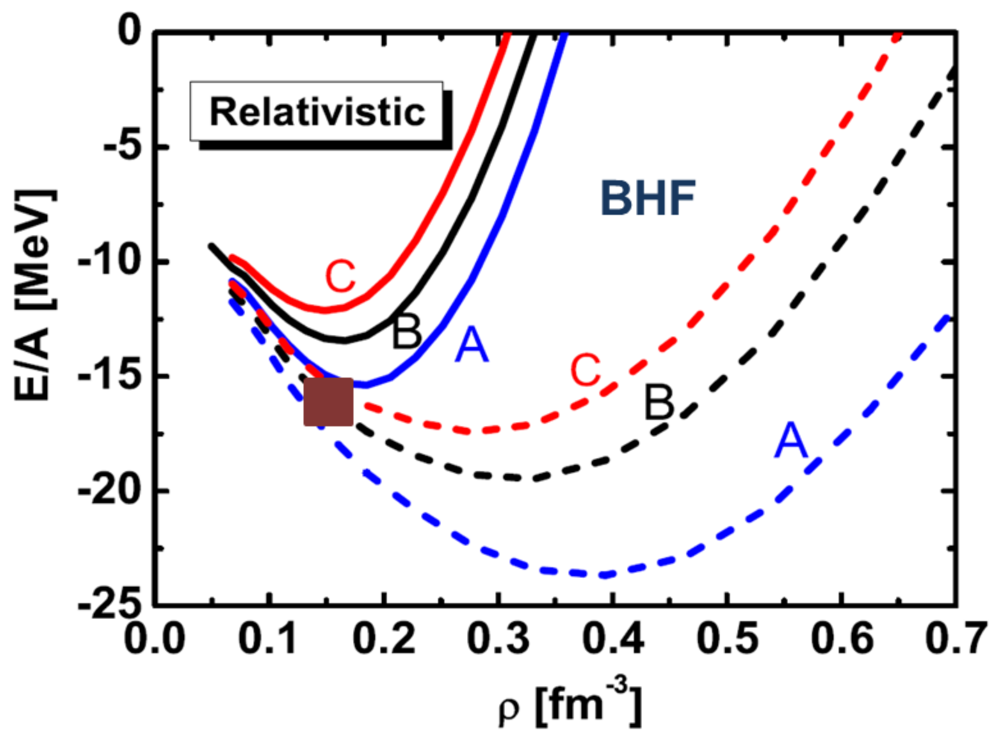
Relativistic Brueckner Hartree-Fock (RBHF) theory

R. Brockmann, and R. Machleidt PRC42(1990)1965

$$G(w) = V^* + V^* \frac{Q}{w - H_0} G(w)$$

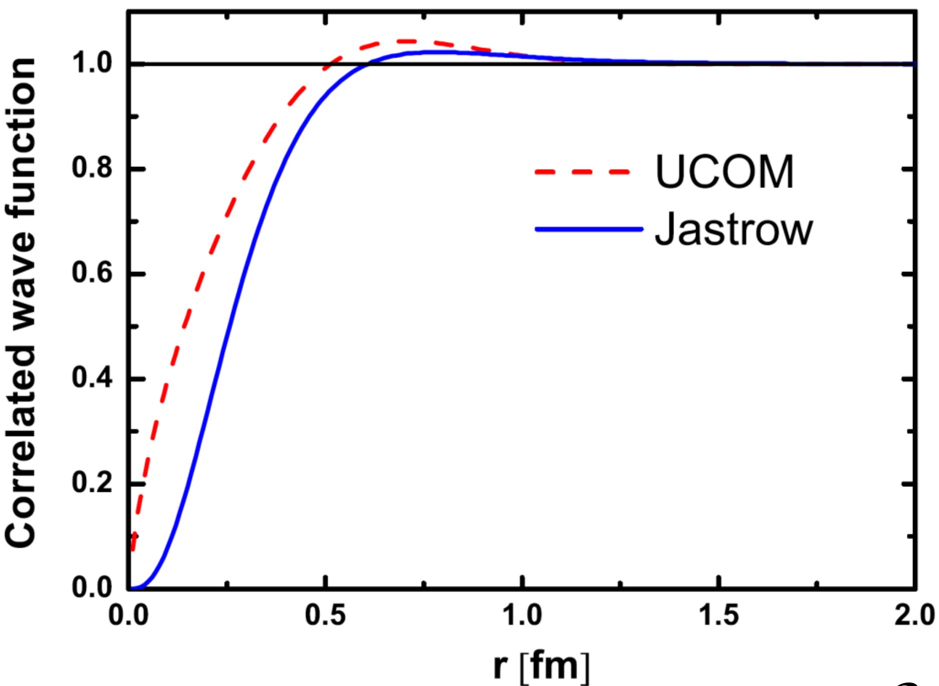


- V* : Realistic interaction
- Q: Pauli Operator

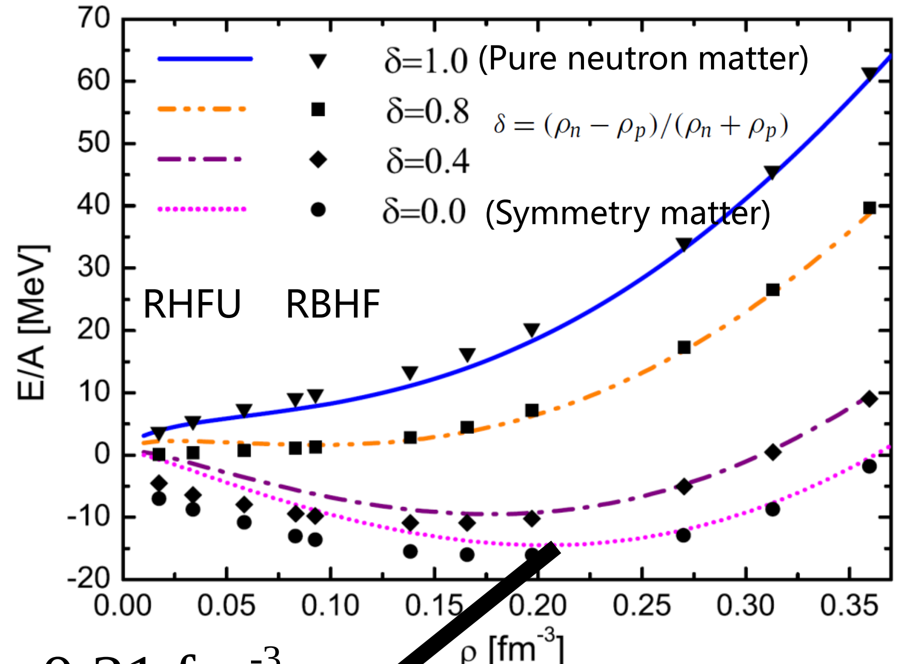


UCOM method in nuclear matter

Correlation function



EOS of asymmetric matter



$$\rho_0 = 0.21\ \mathrm{fm}^{-3}$$

$$E/A = -14.48\ \mathrm{MeV}$$

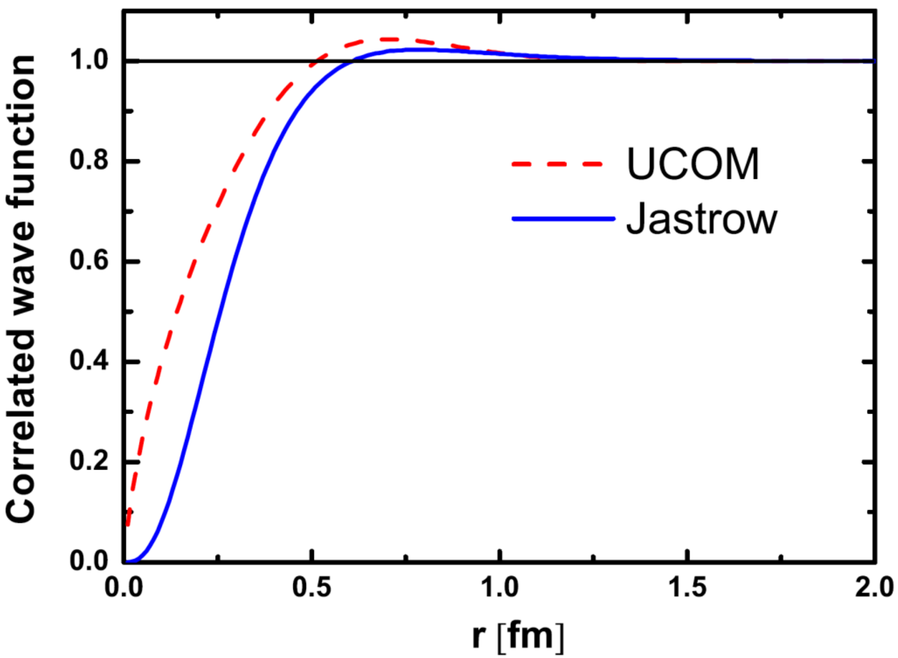
$$K = 249\ \mathrm{MeV}$$

JH, H. Toki, W. Wen and H. Shen, PLB687(2010)271

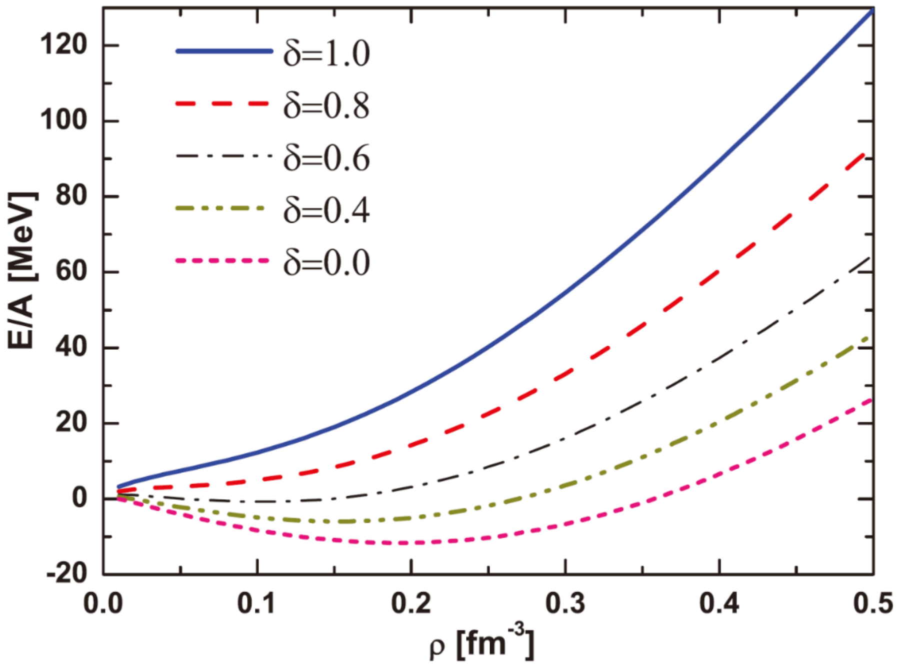
Jastrow correlation in nuclear matter

南開大學

Correlation function



EOS of asymmetric matter

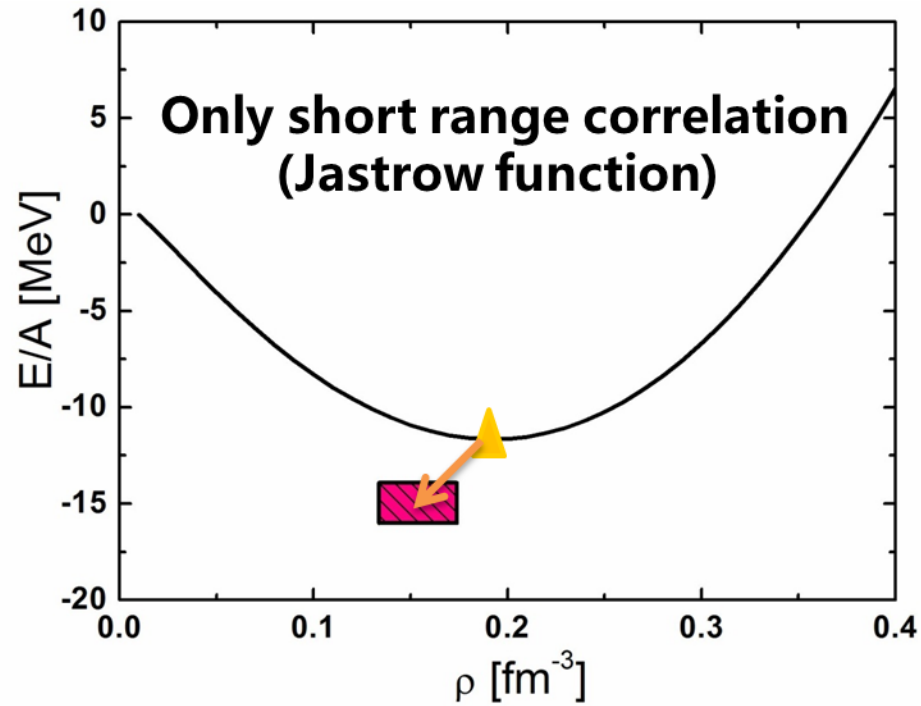


Saturation properties

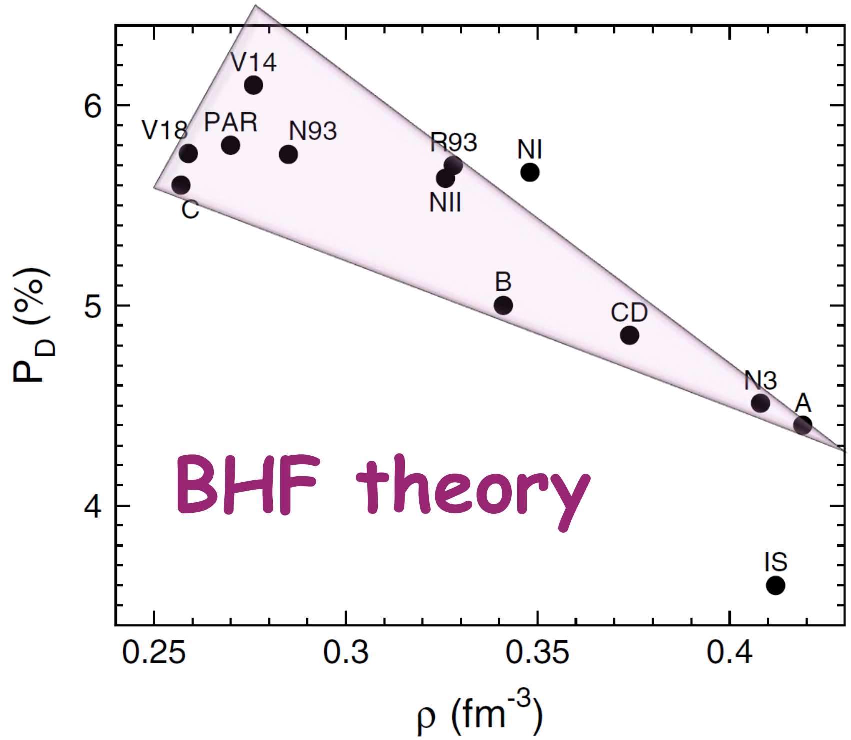
ρ (fm^{-3})	E/A (MeV)	K (MeV)	a_4 (MeV)	T_c/A (MeV)
0.192	−11.66	264	37.88	6.57

JH, H. Toki and H. Shen, JPG38(2011)085105

Tensor force is very important for the saturation properties of symmetric nuclear matter



Coester band



Z. H. Li, et al, PRC74(2006)047304

Tensor force with perturbation theory

Y. Wang, JH, H. Toki and H. Shen, PTP127(2012)739

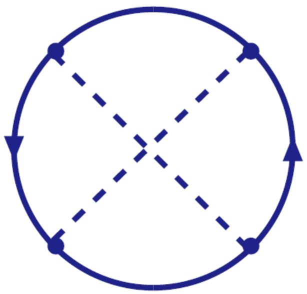
$$H = T + V_S + V_T$$

Direct

$$\frac{\langle V_T \rangle_D}{A} = \frac{1}{2\rho} \sum_{k_1,k_2,q} \frac{\langle k_1 k_2 | V_T | k_1' k_2' \rangle^2}{\epsilon_{k_1} + \epsilon_{k_2} - \epsilon_{k_1+q} - \epsilon_{k_2-q}} \,,$$

$$(|\boldsymbol{k}_1|, |\boldsymbol{k}_2| < k_F; \ |\boldsymbol{k}_1 + \boldsymbol{q}|, |\boldsymbol{k}_2 - \boldsymbol{q}| > k_F)$$

Exchange

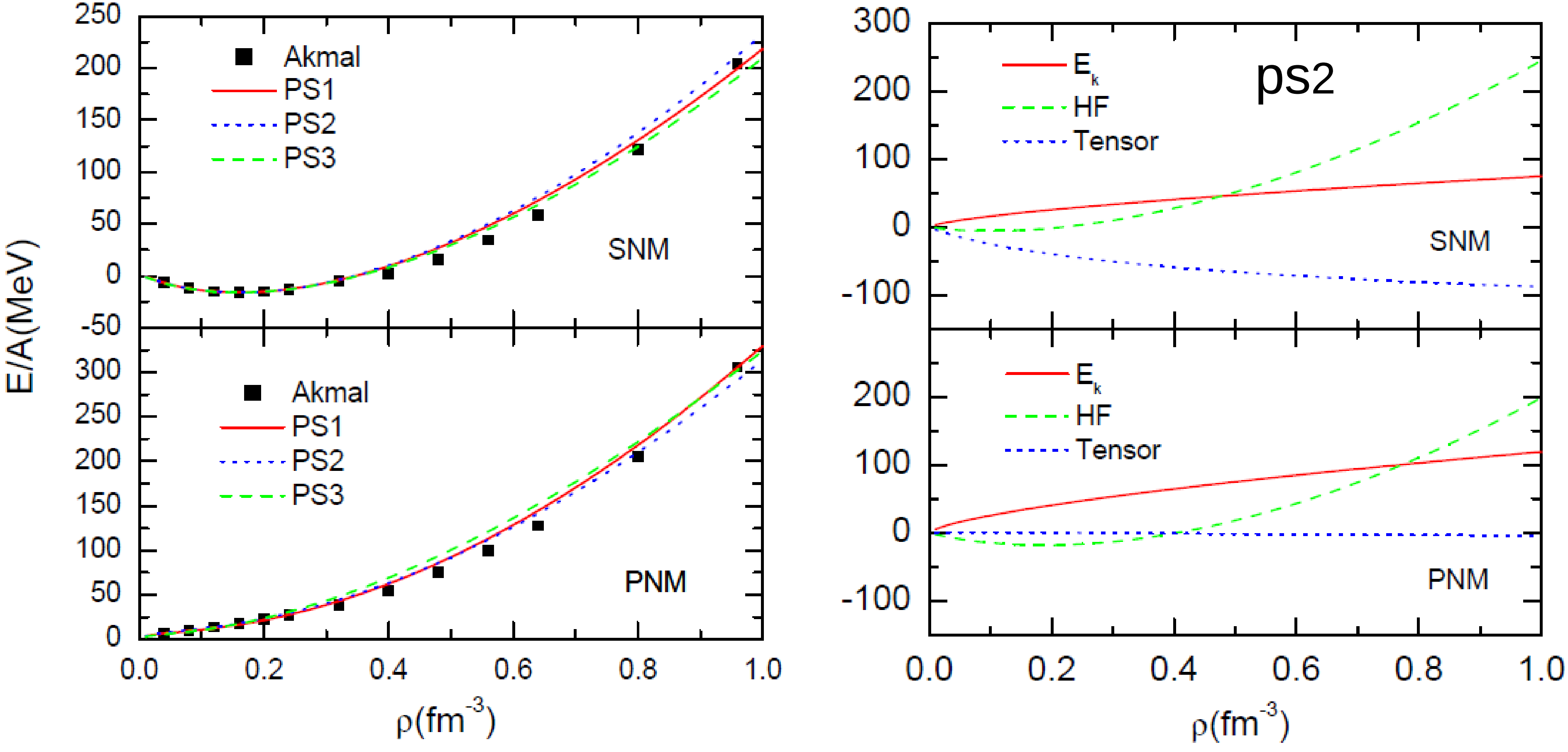


$$\frac{\langle V_T \rangle_E}{A} = -\frac{1}{2\rho} \sum_{k_1,k_2,q} \frac{\langle k_1 k_2 | V_T | k_1' k_2' \rangle \langle k_2' k_1' | V_T' | k_1 k_2 \rangle}{\epsilon_{k_1} + \epsilon_{k_2} - \epsilon_{k_1+q} - \epsilon_{k_2-q}}$$

$$(|\boldsymbol{k}_1|, |\boldsymbol{k}_2| < k_F; \ |\boldsymbol{k}_1 + \boldsymbol{q}|, |\boldsymbol{k}_2 - \boldsymbol{q}| > k_F)$$

Tensor force with perturbation theory

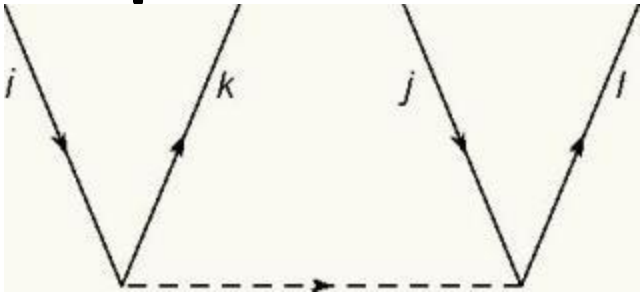
Y. Wang, JH, H. Toki and H. Shen, PTP127(2012)739



Beyond RBHF theory

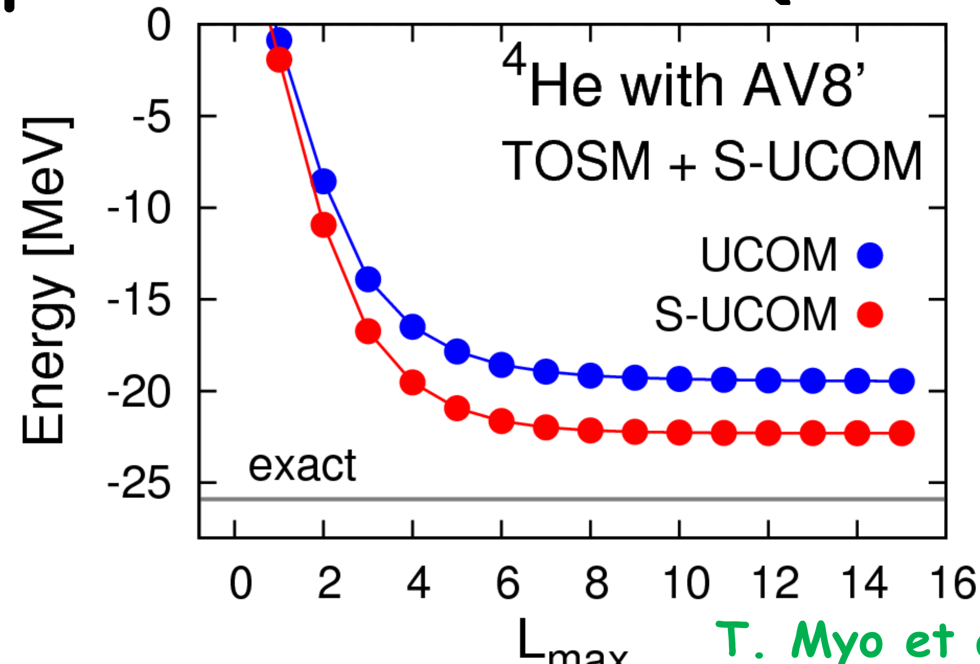
南開大學

Two-particle-two-hole (2p-2h) states



$$< 0 | S_{12} | 2p - 2h > \neq 0$$

Tensor optimized shell model (TOSM)



T. Myo et al. PTP 121(2009)511

Beyond RBHF theory

南開大學

Nucleon wave function

H. Toki, Y. Ogawa and JH, PPNP67(2012)511
JH., H. Toki, and Y. Ogawa, PTEP(2013)103D02

$$|\Psi\rangle = C_0|0\rangle + \sum C_\alpha|\alpha\rangle$$

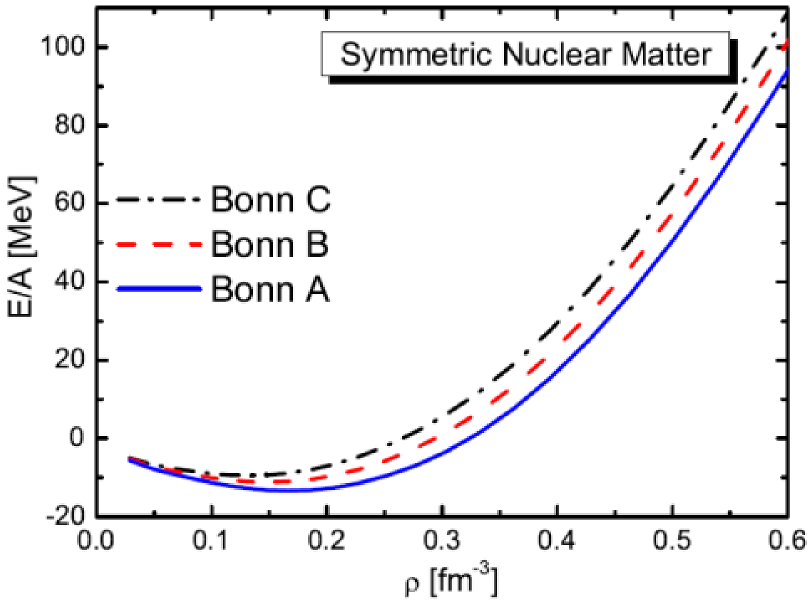
$$|C_0|^2 + \sum_\alpha |C_\alpha|^2 = 1$$

$$\alpha = \{i,j,k,l\} \begin{cases} i,j < F \\ k,l > F \end{cases}$$

Total energy

$$\begin{aligned}\langle\Psi|\mathcal{H}|\Psi\rangle &= |C_0|^2\langle\Psi_0|\mathcal{H}|\Psi_0\rangle + \sum_m C_0^* C_m \langle\Psi_0|\mathcal{H}|2p-2h,m\rangle \\ &+ \sum_n C_0 C_n^* \langle 2p-2h,n|\mathcal{H}|\Psi_0\rangle + \sum_{m,n} C_n^* C_m \langle 2p-2h,n|\mathcal{H}|2p-2h,m\rangle\end{aligned}$$

EOS of symmetric nuclear matter



The difference of A, B, C potentials: tensor components.

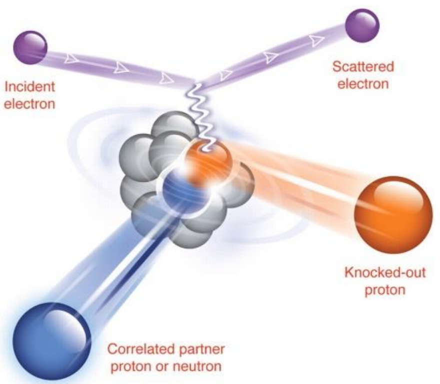
PD: D state probability

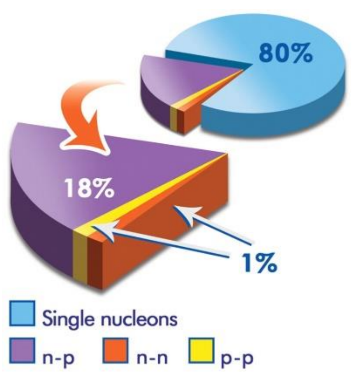
Bonn A: PD smallest
Bonn C: PD biggest

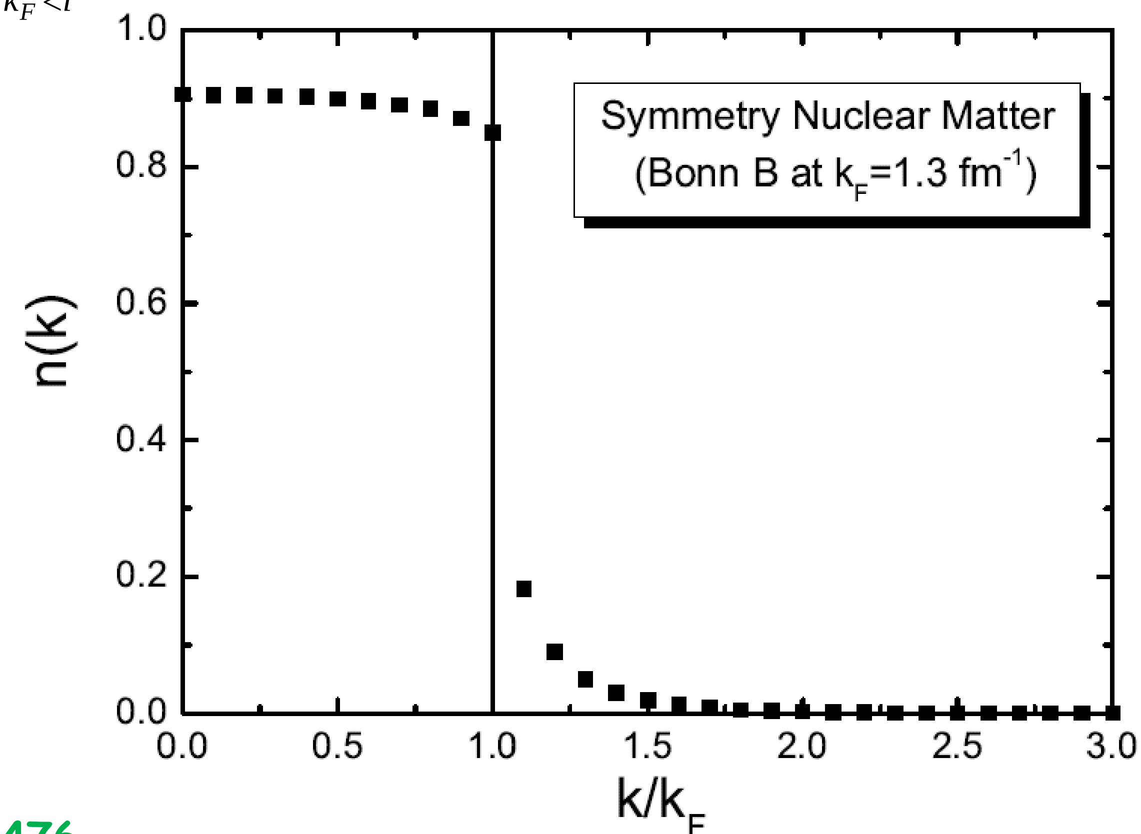
Methods	Potential	ρ [fm^{-3}]	E/A [MeV]	K [MeV]	M_N^*/M_N	$\lvert C_0\rvert^2$
RBHF	Bonn A	0.1814	−15.38	302.9	0.598	1.0
	Bonn B	0.1625	−13.44	240.3	0.621	1.0
	Bonn C	0.1484	−12.12	181.6	0.640	1.0
RHFT	Bonn A	0.1699	−13.62	272.7	0.601	0.911
	Bonn B	0.1484	−11.48	210.5	0.625	0.905
	Bonn C	0.1320	−9.80	163.9	0.648	0.901

Momentum distribution

$$n(k)=\begin{cases}1-\sum\limits_{i<k_F,k_F<p,l}2C_m^*C_m & k<k_F, \quad m=\{i,k,p,l\}\\ \sum\limits_{i,j<k_F,k_F<l}2C_m^*C_m & k>k_F, \quad m=\{i,j,k,l\}\end{cases}$$

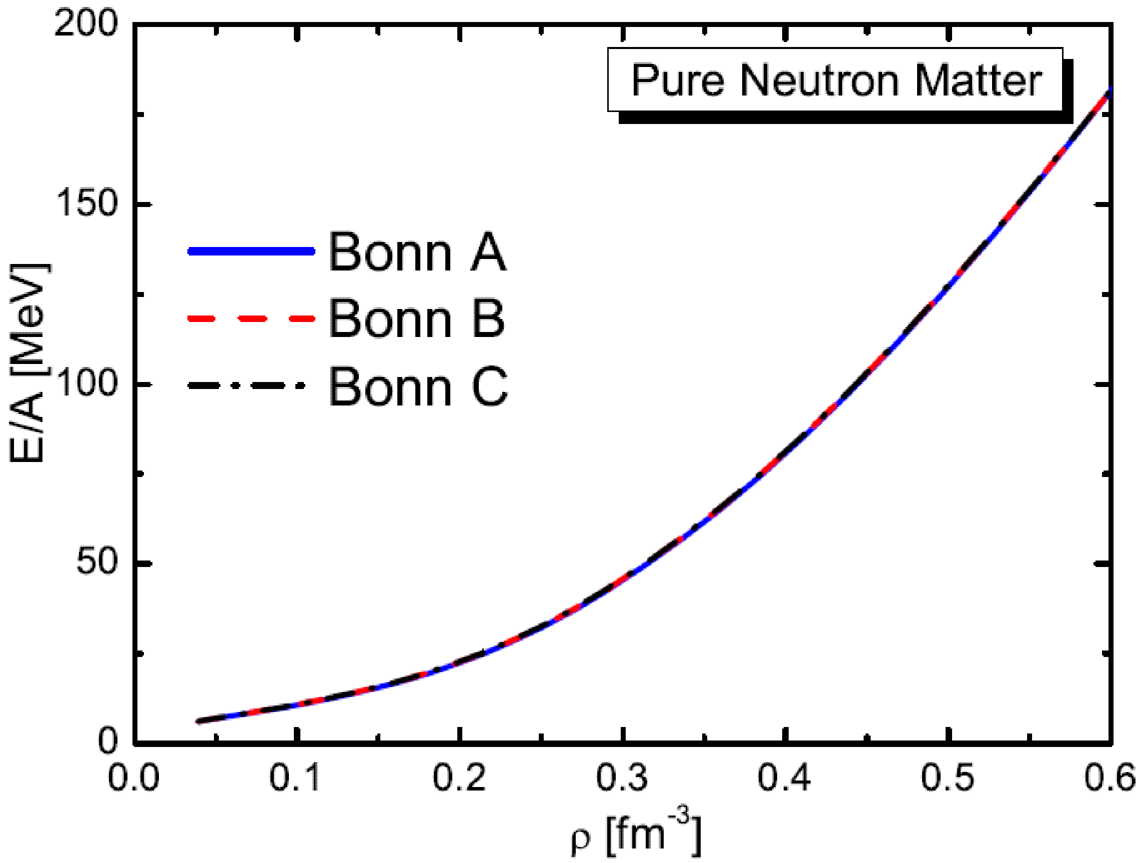






Subedi et al. Science 320(2008)1476

EOS of pure neutron matter



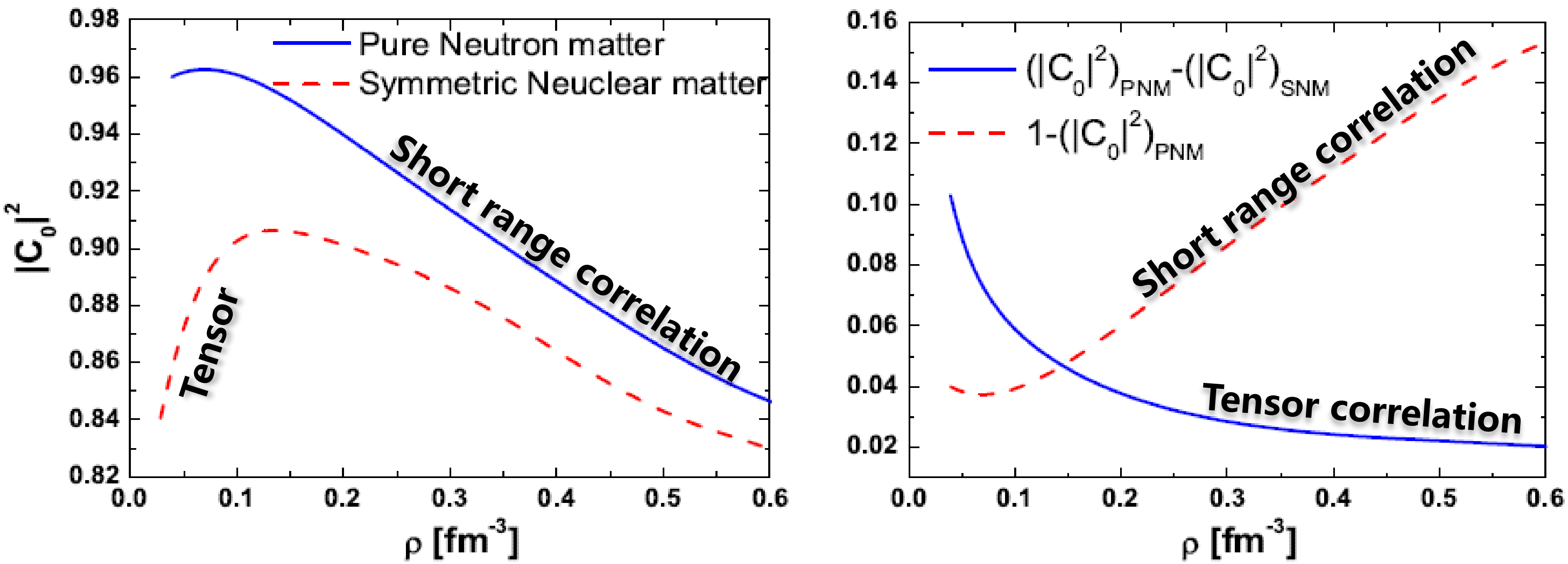
The EOSs of pure neutron matter with different potentials are identical since the tensor effect is very weak in T=1 channel

南開大學

Nucleon wave function

$$|\Psi\rangle = C_0|0\rangle + \sum_\alpha C_\alpha|\alpha\rangle \qquad |C_0|^2 + \sum_\alpha |C_\alpha|^2 = 1$$

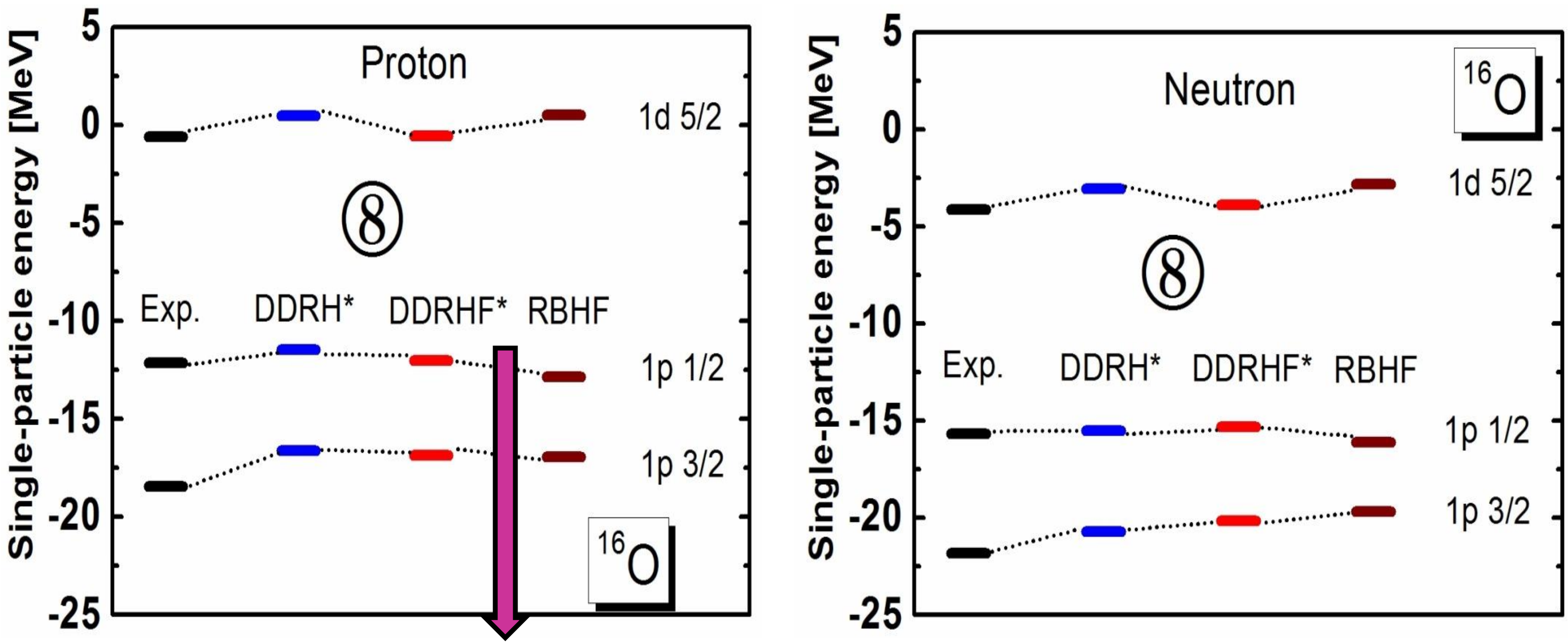
Coefficients



Tensor force determines the location of saturation point

□ Tensor effect in finite nuclei

The single particle levels of ^{16}O in different theories

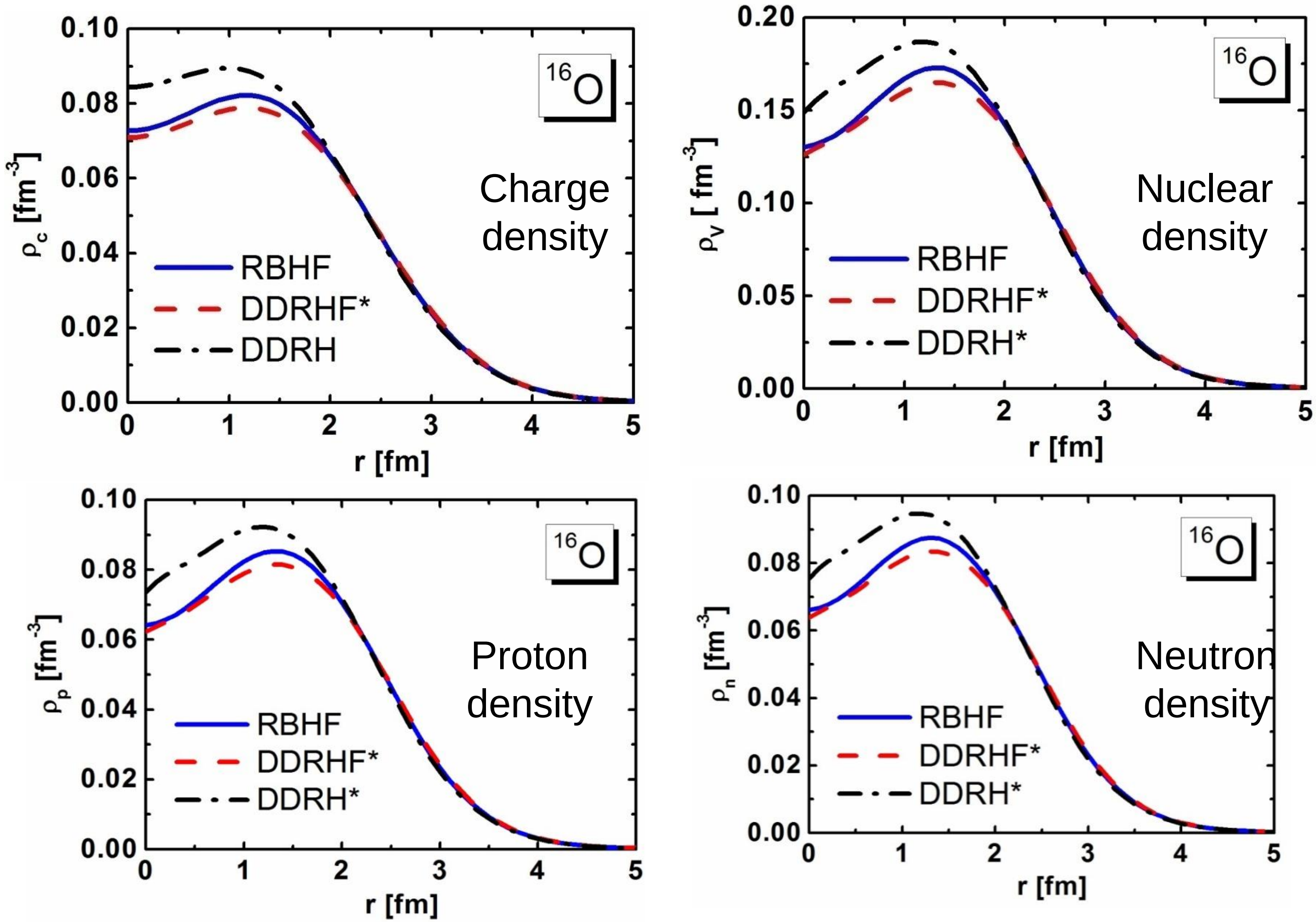


Tensor effect

RBHF theory for finite nuclei

南開大學

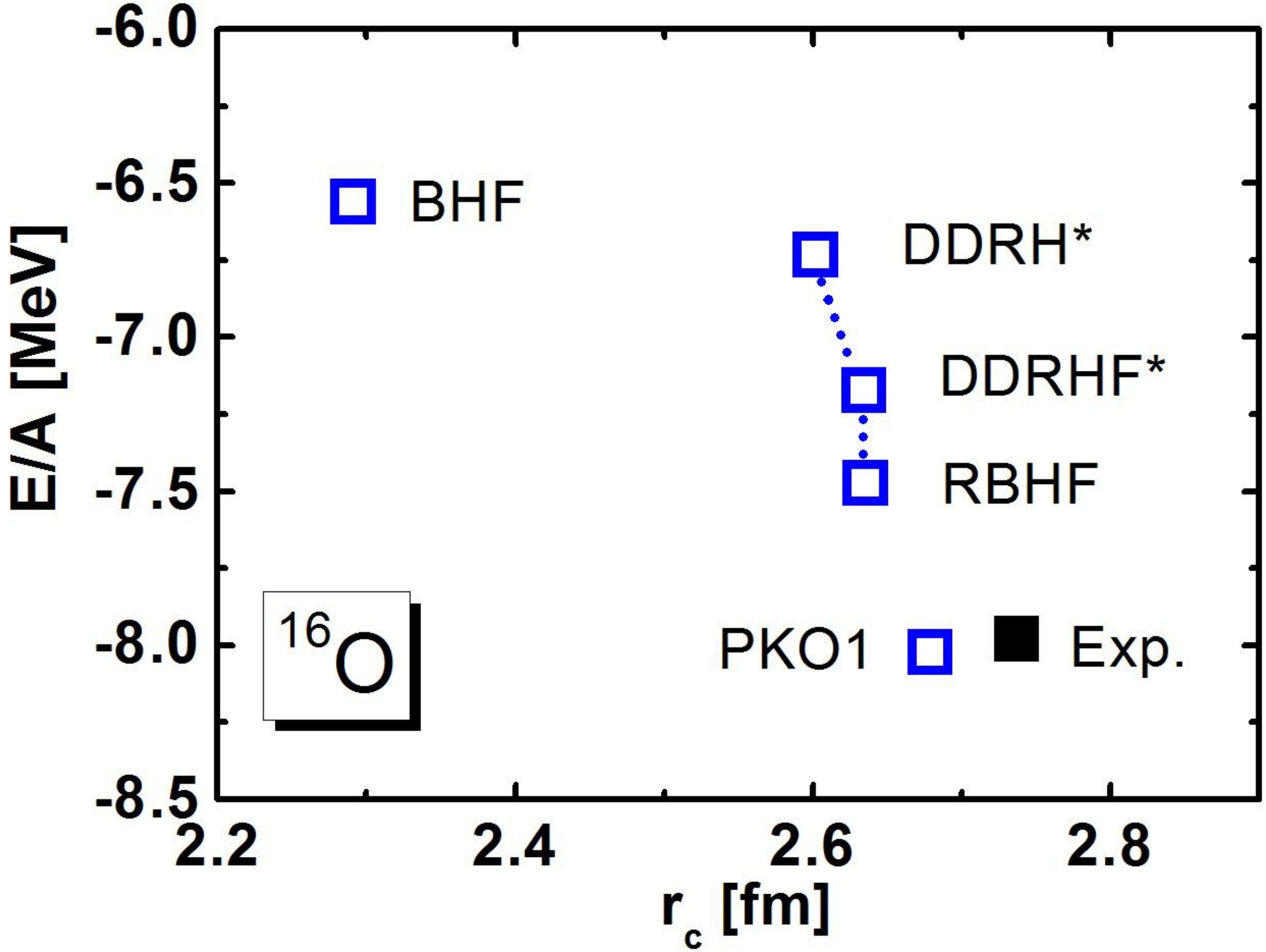
The densities of ^{16}O in different theories



RBHF theory for finite nuclei

南開大學

The relation between binding energy and radii of ^{16}O in different theories



Summary and perspectives

南開大學

- The tensor force is very important at low densities, especially for the saturation properties of symmetric nuclear matter. It becomes very weak in pure neutron matter.
- The tensor force can influence the spin-orbit splitting of finite nuclei and provide attractive contribution on the binding energy.

Perspectives

- The high momentum distribution in finite nuclei
- The quantitative tensor effect in nuclear matter
- ......

Thank you very much for your attention!

Collaborators

- J. Meng
- Y. Ogawa
- P. Ring
- S. Shen
- H. Shen
- H. Toki

Skyrme Hartree-Fock theory

The interaction in Skyrme Hartree-Fock theory **Vautherin PRC1972**

$$V = t_0(1+x_0P_\sigma)\delta(\vec{r}_i-\vec{r}_j)+\frac{1}{2}t_1\delta(\vec{r}_i-\vec{r}_j)(1+x_1P_\sigma)(k^2+k'^2)$$
$$+t_2(1+x_2P_\sigma)\vec{k}'\cdot\delta(\vec{r}_i-\vec{r}_j)\vec{k}+iW_0(\sigma_i+\sigma_j)\cdot\vec{k}'\times\delta(\vec{r}_i-\vec{r}_j)\vec{k}$$
$$+\frac{1}{6}t_3(1+x_3P_\sigma)\delta(\vec{r}_i-\vec{r}_j)\rho^\alpha\left(\frac{\vec{r}_i+\vec{r}_j}{2}\right)$$

The wave function of nucleon

$$\psi(x)=\sum_{p,s,t}e^{-i\vec{p}\cdot\vec{x}}\chi_s\chi_t$$

The symmetric nuclear matter in Skyrme Hatree-Fock theory **Chabanat NPA1997**

$$\frac{E}{A}(\rho)=\frac{3\hbar^2}{10m}\left(\frac{3\pi^2}{2}\right)^{2/3}\rho^{2/3}+\frac{3}{8}t_0\rho+\frac{3}{80}[3t_1+(5+4x_2)t_2]\left(\frac{3\pi^2}{2}\right)^{2/3}\rho^{5/3}+\frac{1}{16}t_3\rho^{\sigma+1}$$

Relativistic mean field theory

Serot ANP1986

The Lagrangian of relativistic mean field theory

$$L = \bar{\psi}_N (i\gamma_\mu \partial^\mu - M_N - g_{\sigma N}\sigma - g_{\omega N}\gamma_\mu \omega^\mu)\psi_N$$
$$+\frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{4}\Omega_{\mu\nu}\Omega^{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu$$

The wave function of a nucleon

$$\psi(x) = \sum_{p,s,t} u(p,s) e^{-i\vec{p}\cdot\vec{x}} \chi_s \chi_t$$

The nuclear matter in relativistic mean field theory

$$E = \frac{4}{(2\pi)^3}\int_0^{k_F} d^3k (k^2 + M^{*2})^{1/2} + \frac{g_\omega^2}{2m_\omega^2}\rho_B^2 + \frac{g_\sigma^2}{2m_\sigma^2}\rho_s^2$$

Effective mass

$$M^* = M_N - g_\sigma \sigma$$

Baryon density

$$\rho_B = \langle \psi^\dagger \psi \rangle$$

Scalar density

$$\rho_S = \langle \bar{\psi}\psi \rangle$$