Dynamic isovector reorientation of deuteron as a probe to nuclear symmetry energy

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2015.6.29-7.2 @ NuSYM15 Krakow, Poland
Outline

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2. Idea
3. Results and discussion
4. Summary
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What? Why? Where?

Every audience here Know!
For constraint of $E_{\text{sym}}$ by HIC, accurate information at low density is helpful to reduce $E_{\text{sym}}$ uncertainty at high density!
Tool: ImQMD model, $E_{sym}$ in ImQMD

\[ \dot{r}_i = \frac{\partial H}{\partial p_i}, \quad \dot{p}_i = -\frac{\partial H}{\partial r_i} \]

\[ H = T + U_{loc} + U_{Coul} \]

\[ U_{loc} = \int V_{loc} dr \]

\[ E_{sym}(\rho) = \frac{C_{s,k}}{2} \left( \frac{\rho}{\rho_0} \right)^{2/3} + \frac{C_{s,p}}{2} \left( \frac{\rho}{\rho_0} \right)^\gamma \]

\[ V_{loc}(\rho) = \frac{\alpha}{2} \frac{\rho^2}{\rho_0} + \frac{\beta}{\gamma+1} \frac{\rho^{\gamma+1}}{\rho_0^\gamma} + \frac{g_{sur}}{2\rho_0} (\nabla \rho)^2 \]

\[ + \frac{g_{sur,iso}}{\rho_0} [\nabla (\rho_n - \rho_p)]^2 + \frac{C_s}{2} \left( \frac{\rho}{\rho_0} \right)^\gamma \rho \delta^2 + g_{\rho\tau} \frac{\rho^{8/3}}{\rho_0^{5/3}}. \]
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θ is larger for proton undergoing stronger symmetry potential!

Angular distribution for elastic scattering nucleon can be an observable for $E_{\text{sym}}$. 
$\Delta \theta = \theta_p - \theta_n$:

- $\gamma = 0.5$, $\gamma = 0.5$, soft
- $\gamma = 1.0$, linear
- $\gamma = 2.0$, stiff

$100 \text{ MeV } p + ^{132}\text{Sn} \ b = 7.5 \text{ fm}$

$\gamma$ = 0.5

$\gamma$ = 1.0

$\gamma$ = 2.0

Li Ou et al. PRC78, 044609 (2008)
\[ \Delta \theta = \theta_p - \theta_n = \begin{cases} 5.5^\circ, & \gamma = 0.5, \text{soft} \\ -6.6^\circ, & \gamma = 1.0, \text{linear} \\ 1.0^\circ, & \gamma = 2.0, \text{stiff} \end{cases} \]

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Deuteron breakup reaction

\[ \vec{p}_p - \vec{p}_n = z \]

\[ F_s \] from isoscale potential, deflexion;
\[ F_{\text{Coul}} \] from Coulomb potential, anticlockwise;
\[ F_{\text{p}v} \] on proton from isovector potential;
\[ F_{\text{n}v} \] on neutron from isovector potential.

Stronger isovector potential implies larger \( \alpha \)!!
Deuteron breakup reaction

\[ \vec{p}_p - \vec{p}_n = z \]

\[ \vec{p}_p - \vec{p}_n = \alpha \]

\[ F_s \text{ from isoscale potential, deflexion; } \]

\[ F_{Coul} \text{ from Coulomb potential, anticlockwise; } \]

\[ F_{pv} \text{ on proton from isovector potential; } \]

\[ F_{nv} \text{ on neutron from isovector potential; } \]

\[ \text{Stronger isovector potential larger } \alpha! \]
Deuteron breakup reaction

\[ \vec{p}_p - \vec{p}_n = z \]

\[ \Delta \vec{p} = \vec{p}_p - \vec{p}_n \]

\[ \vec{v}_p \text{ from isovector potential; clockwise} \]

\[ \vec{v}_n \text{ from isovector potential; clockwise} \]

\[ F_s \text{ from isoscale potential, deflexion;} \]

\[ F_{Coul} \text{ from Coulomb potential, anticlockwise;} \]
Deuteron breakup reaction

\[ \vec{p}_p - \vec{p}_n = \Delta \vec{p}_\alpha \cos \alpha = \vec{p}_p - \vec{p}_n \]

- \( F_s \) from isoscale potential, deflexion;
- \( F_{Coul} \) from Coulomb potential, anticlockwise;
- \( F^p_v \) on proton from isovector potential;
- \( F^n_v \) on neutron from isovector potential;
Deuteron breakup reaction

\[ \vec{p}_p \parallel \vec{p}_n \]

\[ \alpha = \frac{\vec{p}_p - \vec{p}_n}{|\vec{p}_p - \vec{p}_n|} \]

\[ F_s \text{ from isoscale potential, deflexion;} \]

\[ F_{\text{Coul}} \text{ from Coulomb potential, anticlockwise;} \]

\[ F_{\text{p}}^{\text{p}} \text{ on proton from isovector potential;} \]

\[ F_{\text{v}}^{\text{n}} \text{ on neutron from isovector potential;} \]
Deuteron breakup reaction

\[ \mathbf{p}_p \cdot \mathbf{n} = \mathbf{p}_p - \mathbf{p}_n \]

\[ \cos \alpha = \frac{p_z^p - p_z^n}{|\mathbf{p}_p - \mathbf{p}_n|} \]

- \( F_s \): from isoscale potential, deflexion;
- \( F_{\text{Coul}} \): from Coulomb potential, anticlockwise;
- \( F^p_v \): on proton from isovector potential;
- \( F^n_v \): on neutron from isovector potential;
\[ \cos \alpha = \frac{p_z^p - p_z^n}{|\vec{p}^p - \vec{p}^n|} \]

- \( F_s \) from isoscale potential, deflexion;
- \( F_{\text{Coul}} \) from Coulomb potential, anticlockwise;
- \( F_v^p \) on proton from isovector potential;
- \( F_v^n \) on neutron from isovector potential;
Deuteron breakup reaction

Stronger isovector potential
larger $\alpha$!!

$F^p_s$ from isoscale potential, deflexion;

$F^p_C$ from Coulomb potential, anticlockwise;

$F^p_V$ on proton from isovector potential;

$F^n_V$ on neutron from isovector potential;

$\cos \alpha = \frac{p^p_z - p^n_z}{|p^p - p^n|}$
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Isospin effect on reorientation of deuteron

Effect of the symmetry potential is largely smeared by the random initial orientation of the incident deuteron.
Isospin effect on reorientation of deuteron

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\[ d + ^{124}\text{Sn} \]
Isospin effect on reorientation of deuteron

- Effect of the symmetry potential is largely smeared by the random initial orientation of the incident deuteron.
- Effect is more clear with polarized deuteron.
- $\alpha$ distribution is robust against isoscaler part of EOS.
- $\alpha$ distribution is nearly symmetric.
\[ \ln \left[ \frac{d \sigma}{d (\cos \alpha)} \right] = b_0 + b_2 \cos^2 \alpha \]

Quadratic coefficient \( b_2 \) increases significantly with \( \gamma \), can be a sensitive observable to constrain \( E_{\text{sym}} \).
Nucleons from projectile or target can be distinguished by $\theta$-$E_k$ correlation. Two components are evidently separated.
Nucleons from projectile or target can be distinguished by $\theta - E_k$ correlation. Two components are evidently separated.

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With energy cut $E_k \geq 50$ MeV, breakup events caused by collision can be excluded.

Sensitivity represented by the slope of $b_2$ on $E_{\text{sym}}$ is maintained.
$E_{\text{sym}}$ below $0.5 \rho_0$ can be obtained by this method.

More sensitive and clear than HIC observables because the influence of collision can be easily excluded.
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Within ImQMD framework, the reorientation effect of deuteron attributed to isovector interaction in the nuclear field of heavy target nuclei has been investigated for the first time.

The correlation angle of nucleons from breakup polarized deuteron, depends sensitively on the isovector potential but insensitively on the isoscaler potential and the effective mass.

In terms of sensitivity and cleanness, the breakup reactions induced by polarized deuteron beam at about 100 MeV/u provide a more stringent constraint to the symmetry energy at subsaturation densities.
Thank you for your attention!