Polarization effects in deuteron-induced reactions

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Outline

1. Motivation
2. Model
3. Results and discussion
4. Summary
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The energy of per nucleon in a nuclear matter $E(\rho, \delta, T)$. 
What & Why Symmetry Energy

Symmetry Energy

\[ E(\rho, \delta) = E(\rho, 0) + E_{\text{sym}}(\rho)\delta^2 + \mathcal{O}(\delta^4) \]

\[ E_{\text{sym}}(\rho) = E(\rho, \delta = 1) - E(\rho, \delta = 0) \]

Isospin Dependence of Strong Interactions

- Nuclear Masses
  - Neutron Skin Thickness
  - Isovector Giant Dipole Resonances
  - Fission
- Heavy Ion Flows
  - Multi-Fragmentation
  - Nuclei Far from Stability
  - Rare Isotope Beams

Many-Body Theory

Symmetry Energy

(Magnitude and Density Dependence)

- Supernovae
  - Weak Interactions
  - Early Rise of \( L_{\nu e} \)
  - Bounce Dynamics
  - Binding Energy
- Proto-Neutron Stars
  - \( \nu \) Opacities
  - \( \nu \) Emissivities
  - SN r-Process
  - Metastability
- Neutron Stars
  - Observational Properties
- Binary Mergers
  - Decompression/Ejection of Neutron-Star Matter
  - r-Process

- QPO’s
  - Mass
  - Radius
- NS Cooling
  - Temperature
  - \( R_m, z \)
  - Direct Urca
  - Superfluid Gaps
- X-ray Bursters
  - \( R_m, z \)
- Gravity Waves
  - Mass/Radius
  - dR/dM
- Pulsars
  - Masses
  - Spin Rates
  - Moments of Inertia
  - Magnetic Fields
  - Glitches - Crust

There is great uncertainty at super-high and sub-saturation density. Need to be constrained by experiment!
Current constraints on $E_{\text{sym}}(\rho)$

$E_{\text{sym}}(\rho_0) = 32.5 \pm 2.5$ MeV  \quad L = 55 \pm 25$ MeV

$E_{\text{sym}}(\rho) = E_{\text{sym}}(\rho_0) (\rho/\rho_0)^\gamma$ \quad with \quad $\gamma = 0.9 \pm 0.4$
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Method

- proton
- neutron
Method

- From isoscale potential, deflexion;
- From Coulomb potential, anticlockwise;
- On proton from isovector potential;
- On neutron from isovector potential.

Stronger isovector potential larger $\alpha$!!
$F_s$ from isoscale potential, deflexion;
Method

$F_S$ from isoscale potential, deflexion;

$F_{Coul}$ from Coulomb potential, anticlockwise;
Method

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

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

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

\[ F_v^n \text{ on neutron from isovector potential; } \]
Method

$F_S$ 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;

Stronger isovector potential larger $\alpha$!!
\[ \dot{r}_i = \frac{\partial H}{\partial p_i}, \quad \dot{p}_i = -\frac{\partial H}{\partial r_i} \]

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

\[ U_{\text{Coul}} = \frac{1}{2} \int \rho_p(r) \frac{e^2}{|r-r'|} \rho_p(r') dr dr'. \]

\[ T = \sum_i T_i = \sum_i \frac{p_i^2}{2m}, \]

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

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

\[ + \frac{g_{\text{sur,iso}}}{\rho_0} [\nabla (\rho_n - \rho_p)]^2 + \frac{C_s}{2} \left( \frac{\rho}{\rho_0} \right)^{\gamma+1} \delta^2 + g_{\rho\tau} \frac{\rho_0^{8/3}}{\rho_0^{5/3}}. \]
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Isospin effect on polarization

Symmetry potential has effect on polarization angle.

\[
\cos \alpha = \frac{p^p_z - p^n_z}{|\vec{p}^p - \vec{p}^n|}
\]

randomly oriented projectile

100 MeV/u d\(^{124}\)Sn b=7 fm

\(\gamma = 0.5\)

\(\gamma = 2.0\)

\(\gamma = 0.5\)

\(\gamma = 2.0\)

randomly oriented projectile

\(\vec{z}\)
Isospin effect on polarization

Symmetry potential has effect on polarization angle.

Effect is more clear on pre-oriented projectile.
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Effect is more clear on pre-oriented projectile.

Polarization direction is changed more with stronger symmetry potential ($\gamma = 0.5$).
With impact parameter decreases, the isospin effect becomes more and more weak.

- Asymmetry degree becomes smaller and smaller;
- Too strong isoscale potential weakens isospin effect.
Clear density range

- HIC, difficult to exclude collision events and distinguish the density.
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Deuteron breakup reaction, no collision and clear density range.
Clear density range

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- **HIC**, difficult to exclude collision events and distinguish the density.
- Deuteron breakup reaction, no collision and clear density range.
Angle distribution

Stronger isovector potential
larger $\theta_p$! smaller $\theta_n$!
Angle distribution

Strong symmetry potential, peak closes to each other; Difference vanishes for randomly oriented projectile.

100 AMeV d+^{124}Sn @ b=7 fm
Angle distribution

Strong symmetry potential, peak closes to each other; Difference vanishes for randomly oriented projectile.

100 AMeV d+$^{124}$Sn @ b=7 fm

\[ \gamma = 0.5, 2.0 \]

\[ p, n \]

\[ dN/d\theta \]

isoscale potential
Angle distribution

Strong symmetry potential, peak closes to each other; Difference vanishes for randomly oriented projectile.

pre-oriented projectile

randomly oriented projectile

100 AMeV d+^{124}Sn @ b=7 fm

\( \gamma \)

0.5 2.0

p  n

\( dN/d\theta \)

\( 0 \quad 20 \quad 40 \quad 60 \)

\( \theta \)

\( 0 \quad 20 \quad 40 \quad 60 \quad 80 \quad 100 \)

plus
Coulomb potential

isoscale potential
Angle distribution

pre-oriented projectile
100 AMeV d+^{124}Sn @ b=7 fm

\[ \gamma \quad 0.5 \quad 2.0 \]
\[ p \quad \square \quad \blacksquare \]
\[ n \quad \circ \quad \bullet \]

randomly oriented projectile

\[ \text{plus Coulomb potential} \quad \text{plus isovector potential on proton} \]

\[ \text{isoscale potential} \]
Strong symmetry potential, peak closes to each other; Difference vanishes for randomly oriented projectile.
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**Angle distribution**

![Graphs showing angle distribution for pre-oriented and randomly oriented projectiles.]

- **Strong symmetry potential**, peak closes to each other;
- **Difference vanishes for randomly oriented projectile.**
Angle distribution

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- **Difference vanishes for randomly oriented projectile.**
There is also clear (but smaller) isospin effect if pre-oriented direction is reversed. One possible reason is that the sequence of proton and neutron enter the meanfield is reversed.
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Polarization effect of deuteron due to isovector interaction in the nuclear potential of heavy target is investigated within ImQMD framework.

Because of simple and clear reaction mechanism, pre-oriented deuteron-induced reaction provide a very clean probe to detect the density dependence of symmetry energy.
Thanks!