HDice, the Polarized Solid HD Target in the Frozen Spin Mode for Experiments with CLAS

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- and the CLAS Collaboration
Topics

- How the HDice target works
- Target Production
- Performance of HDice target
- \( \gamma + \)HDice results with CLAS
- \( e + \)HDice test results
- Conclusion
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**Polarizing HD: the rotational levels of the solid hydrogens**

At liquid helium temperature and below, only J=1 and 0 states are occupied, for H$_2$ and D$_2$, and only J=0 is populated for HD.

The relative energy spacing of the low-lying nuclear spin, I, and molecular orbital angular momentum, L, levels in H$_2$, HD and D$_2$ system. The symmetries of the nuclear spin wavefunction, c$_S$, are indicated.
Polarizing HD: cross coupling between H and D, POLARIZING

At $J=0$ states, protons and deuterons are decoupled from the lattice.

$\Rightarrow$ long relaxation time or non-polarizable

$\Rightarrow$ help from $J=1$ $H_2$ and $D_2$ through spin-wave is needed for polarizing HD

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Heat generation due to $L=1$ to $L=0$ Conversion

Heat generation ($J=1$ to $J=0$): 2.6mW/mole for $H_2$ and 0.46mW/mole for $D_2$.

$\Rightarrow$ For HDice at $c_1 \sim 0.001$, 0.94μW/target from $H_2$ and 0.17μW/target from $D_2$.

$\Rightarrow$ Heat has to be removed from HD in order to polarize HD target

$H_D\text{dice dilution refrigerator cooling power at 10mK : } 10\mu W$ 😊

The relative energy spacing of the low-lying nuclear spin, $I$, and molecular orbital angular momentum, $L$, levels in $H_2$, HD and $D_2$ system. The symmetries of the nuclear spin wavefunction, $c_S$, are indicated.
Topics

• *How the HDice target works*
• *Target Production*
• *Performance of HDice target*
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Instrumentation: Target Cell

- HDice target cells:
  - 750 × 50μm Al wires
  - pCTFE cell

- Material in the beam path:
  - 77% HD + 17% Al + 6% pCTFE (remove with vertex cuts)
Operation: Target transfer
**Operation: Target transfer**

- **PD**: (Injecting target, NMR-TE)
- **TC**: (Moving target)
- **DF**: (Polarizing target)
- **SD**: (Storing/transporting target)

Temperature and Magnetic Field Conditions:
- **1.6K, 7T**
- **2K, 2T**
- **0.01K, 15T**
- **2K, 0.1T**
Operation: Target transfer

Target transfer between PD and DF
Operation: Target transfer

Target transfer between PD and DF
Operation: Target transfer

Target transfer between PD and DF
Operation: Target transfer

Target transfer between DF and SD
Operation: Target transfer

Target transfer between DF and SD
Operation: G-14 Run at Hall-B

Loading target into IBC and moving IBC inside CLAS
Instrumentation: In-Beam Cryostat

- \( T \): 50mK
- \( B_{//} \): 1.0T
- \( B_{\perp} \): 0.075T
- \( B_{\text{auxiliary}} \): >0.1T
- \( B_{\text{backup}} \): 0.01T

In-Beam Cryostat (IBC)
Topics

- How the HDice target works
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- **Performance of HDice target**
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Target Polarization Calibration for G-14 Run

HD removed from DF after 3 months Aging at high field and low temp

- Frozen-spin NMR compared to thermal equilibrium (TE) calibration

B field sweep

\[ P(H) = 61.3 \pm 1.8\% \]
\[ P(D) = 15.5 \pm 0.6\% \]

Number of sweeps: 1 for polarized signals and (typical) \~250 for TE signals
Polarization Manipulation during G-14 Run

Increasing D polarization by spin transfer:

- Brute force (high B/low T) \( \Rightarrow \) \( P_D \sim 15\% \) \( (\mu_D / \mu_H \sim 1/3) \)
- 1\textsuperscript{st} forbidden adiabatic fast passage (FAFP) to invert state populations

Zeeman levels of HD

- polarize H
- RF transfer \( P(H) \rightarrow P(D) \)
- requires high RF powers and very uniform fields

- alternative: saturate the FAFP transition
  \( \rightarrow \) equalize \{ \( m_H = +1/2; m_D = -1, 0 \) \( \leftrightarrow \) \{ \( m_H = -1/2; m_D = 0, +1 \) \}
Polarization Manipulation with SFP during G-14 Run

\[
P(H)_{\text{init}} \sim 50\%
\Rightarrow \text{SFP} \Rightarrow
\]

\[
P(H)_{\text{final}} = 28 \pm 1\%
\]

\[
P(D)_{\text{init}} \sim 16\%
\Rightarrow \text{SFP} \Rightarrow
\]

\[
P(D)_{\text{final}} = 27 \pm 1\%
\]
The HDice targets were in frozen spin mode during G-14 Run. Relaxation times was longer than one year at B=0.9T and T<100mK.
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Clean empty cell (21a) subtraction from $\gamma \ n \rightarrow \pi \ p$

**Reconstructed Vertex for HDice Target during G-14 Run**

- **Full target cell**
- **Empty cell**
- **HD from full-empty (flux weighted)**

<table>
<thead>
<tr>
<th>zvertex</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25470</td>
<td>-5.185</td>
<td>5.956</td>
</tr>
</tbody>
</table>
On-going Analysis for G-14 Run

identified analysis projects:

\[ \gamma \ n (p) \rightarrow K^\circ \Lambda \ (p) \]
\[ \gamma \ n (p) \rightarrow K^- \Sigma^+ \ (p) \]
\[ \gamma \ n (p) \rightarrow \pi^- p \ (p) \]
\[ \gamma \ n (p) \rightarrow \pi^+ \pi^- n (p) \Leftrightarrow \pi^+ \Delta^- (p), \ \pi^- \Delta^+ (p), \ \rho n (p) \]
\[ \gamma \ n (p) \rightarrow \pi^+ \pi^- \pi^0 \ n (p) \Leftrightarrow \eta \ n (p), \ \omega \ n (p) \]
\[ \gamma \ n (p) \rightarrow \pi^0 \pi^- p \ (p) \]

1st look at data

Beta vs. Momentum
1st look at neutron data from G-14/H Dice (concluded on 05/18/2012)

- $\gamma \tilde{n} (p) \rightarrow \pi^- p (p)$
- E beam-target helicity asymmetry from a few % of the g14 data:

<table>
<thead>
<tr>
<th>$W$</th>
<th>E asymmetry of $\gamma n \rightarrow \pi^- (p)$ at $E_\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1515</td>
<td>$0.7 - 0.8 \text{ GeV}$</td>
</tr>
<tr>
<td>1575</td>
<td>$0.8 - 0.9 \text{ GeV}$</td>
</tr>
<tr>
<td>1630</td>
<td>$0.9 - 1.0 \text{ GeV}$</td>
</tr>
<tr>
<td>1690</td>
<td>$1.0 - 1.1 \text{ GeV}$</td>
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<tr>
<td>1745</td>
<td>$1.1 - 1.2 \text{ GeV}$</td>
</tr>
<tr>
<td>1795</td>
<td>$1.2 - 1.3 \text{ GeV}$</td>
</tr>
</tbody>
</table>

Preliminary - N. Walford, CUA

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SAID extrapolations from proton data
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Electron Beam Tests for $\vec{e} + \vec{H} \perp D$ runs with CLAS12

$D$ is damaged by radiation, $T_1(D) = 0.2 \text{ d.}$

$H$ is not harmed, $T_1(H) > 50 \text{ d.}$

Beam Heating is the main concern for $H.$

$\Rightarrow$ redesign target cell

build faster beam raster

expected $T_1$ range at 1 nA after improvements

$t(\text{HD}) \sim 1 \text{ K}$

$t(\text{HD}) \sim 3 \text{ K}$

$T_1 = \alpha / I_e$

$H$ is not harmed, $T_1(H) > 50 \text{ d.}$
Conclusion

• **HDice target has been successfully installed at CLAS.**

• **Performance of HDice target demonstrated a huge potential for photon experiments.**

• **Comparing with the conventional target, which polarizes 80% of the 20% usable material, the HDice has 20% polarization of 80% target material.**

  *BUT, G-14 TOOK THE DATA AT 10 TIMES FASTER RATE BECAUSE OF LOW BACKGROUND FROM LOW Z.*

• **Electron beam on HD test shown the road of applying transversely polarized HDice target at CLAS12 Era.**