Polarized $^3$He Target Updates

Kai Jin, University of Virginia, on behalf of JLab polarized $^3$He group
Hall A Winter Collaboration Meeting, January 19, 2017

- Introduction to polarized 3He target
- Target upgrade plan
- Progress & Status
- Summary
Polarized 3He Introduction

3He: Effective polarized neutron target

1. Optical pumping:
- Splitting of Alkali atomic state by $B$ field;
- Polarized laser light excite electrons from $5S_{1/2} (M=-1/2) \rightarrow 5P_{1/2} (M=1/2)$;
- Decay from excited state to ground states;
- Alkali atoms can reach $\sim 100\%$ polarization!
Polarized $^3$He Introduction

2. Exchange spin with $^3$He:
- Collision with angular momentum conservation;
- Rb-K mixture Alkali gas (hybrid cell);
- Higher in-beam polarization 55-60%;
3He Target Upgrade

• Stage I:
  - I~30 μA, target L=40 cm, L~2.2X10^{36} cm^{-2}s^{-1}
  - In beam polarization ~60%
  - Glass cell, with convection flow, pumping chamber: 3.5” (optional to 4”)
  - Polarimetry uncertainty ~3%
  - Engineering: Hall A&C compatible
  - Experiments: d2n in Hall C, A1n in Hall C, A1n in Hall A

• Stage II:
  - I~60 μA, target L=60 cm, L~6.6X10^{36} cm^{-2}s^{-1}
  - In beam polarization ~60%
  - Glass cell, with convection flow, metal window, pumping chamber: 4.4”
  - Polarimetry uncertainty ~3%
  - Engineering: shield large field gradient from SBB fringe field
  - Experiments: GEN in Hall A
Mechanical Design

- Raising Helmoholtz coils by 15 cm
- Oven modifications
- Oven support modifications
- Mirror arrangements
- EPR optics design
- Optics change
- Enclosure
- Fitting to Hall C: Pivot modifications
  Access Platform
Oven design finished;
Components of first oven have been manufactured and delivered to JLab;
Assembling in progress, will be tested soon.
Lasers & Optical Fibers

• 7 Raytum lasers (3 upgrade, 4 new):
  ➢ Power **30 W**, wavelength 794.71 nm, width 0.2 ~0.3 nm;
  ➢ Worked with Raytum to improve laser quality.
• 10 new fibers arrived, have been tested.
Testing of Stage I Cell

• not thin window cell:
  - Protovec-I (tested @ Jlab)
  - Protovec-II (tested @ UVA)

• thin window cell:
  - first 2 cells broke
  - New Stage I cell “Savior” being tested @ UVA
    full characterization will be done @ JLab.

• More cells will be made afterwards;
  • GE180 Glass production was discontinued,
    already bought enough for Stage I&II, or more.
### Cell test for Protovec-1

<table>
<thead>
<tr>
<th>AFP loss(single flip)</th>
<th>Pumping chamber(%)</th>
<th>Target chamber(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool without convection</td>
<td>1.18</td>
<td>0.21</td>
</tr>
<tr>
<td>Hot without convection</td>
<td>0.95</td>
<td>0.37</td>
</tr>
<tr>
<td>Hot with convection</td>
<td>1.43</td>
<td>1.44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lifetime</th>
<th>Pumping chamber(hr)</th>
<th>Target chamber(hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool without convection</td>
<td>26.57</td>
<td>23.11</td>
</tr>
<tr>
<td>Hot without convection</td>
<td>13.49</td>
<td>15.97</td>
</tr>
<tr>
<td>Hot with convection</td>
<td>14.56</td>
<td>14.54</td>
</tr>
</tbody>
</table>
Characterization of new cell “Savior”

- Maximum polarization: 64%
- Lifetime: 41 hours

Plots from Sumudu Katugampola @ UVA
Polarimetries of $^3$He target

- **AFP-NMR** (nuclear magnetic resonance):
  - Field sweep (frequency sweep).
  - Calibrated with water NMR or EPR.
- **EPR** (electron paramagnetic resonance): absolute measurement.
- **Pulse NMR**: need to be calibrated against EPR/NMR (new polarimetry at target).
EPR polarimetry

• Principle: use Alkali EPR resonance frequency and the shift in frequency due to small contribution from 3He polarization;
  ➢ polarized $^3$He nuclei generate $B_{^3\text{He}} \sim 0.1$ G
  ➢ Rb’s Zeeman splitting $\nu_{EPR} \propto B = B_H + B_{^3\text{He}}$
  ➢ AFP reverse $^3$He polarization $\Rightarrow \Delta \nu_{EPR} \propto B_{^3\text{He}} \propto P_{^3\text{He}}$

• Measure absolute polarization
• Uncertainty: $\sim 3\%$. 
Pulse NMR

- **PNMR**: metal windows target chamber, can’t send RF field through metal. (end of target chamber).

- **Principle**:
  - Send a pulse at Larmor frequency (81kHz).
  - \(^3\)He spin precesses and tips away from main field.
  - Detect free-induction-decay signal (FID). Measure the transverse component of magnetic moment.

\[
S \sim M_Z \sin(\theta_{\text{tip}}) e^{-t/T^2} \sin(\omega t)
\]
PNMR vs NMR in target chamber

Hot spin down measurement (2 hours). No convection. Pulse NMR measure at target chamber.

✓ Reach 1% uncertainty
PNMR (at transfer tube) vs NMR (at target chamber)

Hot spin down measurement (2 hours). No convection.
Pulse NMR measure at transfer tube.
Metal windows:

• Tests of metal test cells completed;
• Glass to metal seals (“Housekeeper seals”) work very well;
• OFHC copper metal end windows, with gold electroplating on inner surface;
• good spin relaxation properties: relaxation contribution from metal windows < $1/100 \text{ hr}^{-1}$;
• Have not produced an actual window yet;
Summary:

- Two steps upgrade of polarized 3He target system;

- Progress & Status:
  - Stage I: Can be ready in a few months for Hall C experiments
    - Mechanical Design: finished;
    - Laser & Fiber: already have in house enough to start experiment;
    - Cell: made 1 thin window cell, with reasonable performance, production will follow;
    - Polarimetry: PNMR systematic study ongoing; convection cell polarization study;
    - Full characterization of cells;
    - Testing oven, lasers, fibers;
    - EPR $\kappa_0$ study(at W&M, UVA);
  
  - Stage II:
    - Mechanical Design: started: optics platform, shielding structure...
    - Cell: metal window R&D in progress
Thanks!

- **People@JLab:**
  - Supervisor: Jian-ping Chen
  - Graduate student: Nguyen Ton, Kai Jin
  - Engineering/Design: Al Gavalya, Bert Metzeger

- **Collaborators University:**
  - UVa: Gordon Cate’s Group
  - W&M: Todd Averett’s Group
  - **Help from:** Jie Liu, Jin Huang, JLab electronics group ......
  - UVa: Xiaochao Zheng(My Advisor)
Back Up
beam compensation

- Mirror has relative phase shift between S&P wave of laser;
- For longitudinal pumping, mirror which redirect laser to cell is not in polarization preserving configuration;
- Laser circular polarization ~ 70%, not suitable for $^3$He pumping;
- Working on solutions to compensate the beam polarization loss.

transverse pumping, polarization preserving configuration;

longitudinal pumping, not polarization preserving configuration;
## Experiment Requirements

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Spectro</th>
<th>target</th>
<th>Density</th>
<th>Length</th>
<th>Pol.</th>
<th>Current</th>
<th>Lumi</th>
<th>Polarimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>d2n-Hall C</td>
<td>HMS/SHMS</td>
<td>Stage I</td>
<td>proposed</td>
<td>10 amg</td>
<td>60 cm</td>
<td>55%</td>
<td>30 uA</td>
<td>3x10^{36}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>accepted</td>
<td>10 amg</td>
<td>40 cm</td>
<td>55%</td>
<td>15 uA</td>
<td>1x10^{36}</td>
<td>3%</td>
</tr>
<tr>
<td>A1n-Hall C</td>
<td>HMS/SHMS</td>
<td>Stage I</td>
<td>proposed</td>
<td>10 amg</td>
<td>60 cm</td>
<td>60%</td>
<td>60 uA</td>
<td>6x10^{36}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>accepted</td>
<td>10 amg</td>
<td>40 cm</td>
<td>60%</td>
<td>30-40 uA</td>
<td>3x10^{36}</td>
<td>3%</td>
</tr>
<tr>
<td>A1n-Hall A</td>
<td>Big Bite/HRS</td>
<td>Stage I</td>
<td>proposed</td>
<td>10 amg</td>
<td>60 cm</td>
<td>55%</td>
<td>30 uA</td>
<td>3x10^{36}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>accepted</td>
<td>10 amg</td>
<td>40 cm</td>
<td>55%</td>
<td>30 uA</td>
<td>2x10^{36}</td>
<td>3%</td>
</tr>
<tr>
<td>GEN-Hall A</td>
<td>SBS</td>
<td>Stage II</td>
<td>proposed</td>
<td>10 amg</td>
<td>60 cm</td>
<td>60%</td>
<td>60 uA</td>
<td>6x10^{36}</td>
</tr>
<tr>
<td>SIDIS</td>
<td>Big Bite/SBS</td>
<td>Stage II</td>
<td>proposed</td>
<td>10 amg</td>
<td>60 cm</td>
<td>60%</td>
<td>40 uA</td>
<td>4x10^{36}</td>
</tr>
</tbody>
</table>