Polarized $^3$He target update

• Comments on the evolving capabilities
• New developments for the 12 GeV era
• Milestone #1 - choice of target-cell design for SBS $G_E^n$
Polarized $^3$He target requirements: past and future

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Current (µA)</th>
<th>Polarization</th>
<th>Luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAC E142</td>
<td>3.3</td>
<td>33%</td>
<td>$1.5 \times 10^{35}$</td>
</tr>
<tr>
<td>GDH</td>
<td>12.5</td>
<td>35%</td>
<td>$1.0 \times 10^{36}$</td>
</tr>
<tr>
<td>GEn</td>
<td>8</td>
<td>47%</td>
<td>$6.1 \times 10^{35}$</td>
</tr>
<tr>
<td>Transversity</td>
<td>12</td>
<td>55%</td>
<td>$9.0 \times 10^{35}$</td>
</tr>
<tr>
<td>Hall A A In</td>
<td>30</td>
<td>65%</td>
<td>$3.3 \times 10^{36}$</td>
</tr>
<tr>
<td>SBS GEn</td>
<td>60</td>
<td>62%</td>
<td>$6.6 \times 10^{36}$</td>
</tr>
<tr>
<td>Hall C A In</td>
<td>60</td>
<td>60%</td>
<td>$6.6 \times 10^{36}$</td>
</tr>
</tbody>
</table>

Past

Future
Important technology

- High-power diode-laser arrays (SLAC E154/JLab E-94-010 (GDH))
- Careful selection through full-power tests (E-99-117 (A1n))
- Alkali-hybrid spin-exchange optical pumping (GEn)
- Spectrally-narrowed high-power diode-laser arrays (Transversity)
- Convection-driven cells (demonstrated in bench tests)
- Metal end windows (in development)
The performance of polarized $^3$He targets have increased by roughly a factor of 30 since SLAC E142.

The scales of the FOMs shown have been normalized so that they are of equal height for the target used during E142.

**Commercial fiber-coupled high-power diode laser arrays: early JLab**

**Alkali-hybrid SEOP**

**Commercial spectrally narrowed high-power diode laser arrays**
Most recent JLab targets

- Luminosity $\approx 10^{36}\text{cm}^{-2}\text{s}^{-1}$
- Total quantity of gas polarized: $\approx 3$ STP liters in larger cells
- Polarizations $> 70\%$, $> 60\%$ in $15\,\mu\text{A}$ beam, but only $\approx 55\%$ in the target chamber
- Ultimately, during Transversity, the single “transfer tube” became a performance limiting factor

Tuesday, December 9, 2014
New technologies important for the next jump in performance
Convection-based target cells

The convection-style cells have two transfer tubes instead of one.

A small heater on one transfer tube creates a buoyancy force that induces convection.

Measuring the gas speed
A “Zapper coil” is used to produce a depolarized slug of gas. Four NMR pickup coils register the passage of the slug of gas as a function of time.

Dolph, Singh, Averett, Kelleher, Mooney, Nelyubin, Tobias Wojtsekhowski and Cates, PRC vol 84, pg 065201 (2011)
Simulated beam tests suggest that at least 49%, is achievable with 45 \( \mu \) A on a Protovec-style cell.

The above simulated beam test suggests that 60% is achievable with the chosen \( G_E^n \) cell design and 60 \( \mu \) A of beam.
Tests of Protovec-II in 2014 show further progress

Progress on prototype testing since November 2013:

- Having previously studied Protovec-I, we have completed extensive testing on a second Prototype (Protovec-II). Fifty studies were completed over a four month period.
- Intrinsic cell lifetime of 48 hours measured, the longest of any JLab alkali-hybrid cell.
- Polarization of 64% was measured without convection, and 55% with convection speed at approximately 6cm/min.
For high beam currents, we would at least like metal end windows on the target chamber.
We have had a long campaign trying to incorporate metal into cells successfully!
In January 2014, we established acceptable spin-relaxation properties. Compared spin-relaxation of GoldRush with all-glass control cell. Relaxation difference implies the contribution from the metal of around $1/34$ hours. Metal end caps on a Protovec-style cell would contribute less than $1/150$ hours to cell’s intrinsic spin-relaxation rate. For chosen $G_E^n$ design, contribution would be even less.
Technology (finally!) demonstrated for incorporating metal into our targets

Several years of development working closely with Larson Glass (glass-to-metal seals), Epner Technology Inc. (electroplating) and Mike Souza (Princeton glass blower).

- OFHC Glass-to-metal seal provides excellent vacuum/pressure integrity.
- Metal is first mechanically polished.
- Next the metal is electropolished.
- Gold is next electroplated onto the interior surface.
- Finally, the piece is incorporated into a cell.
Tests of cell “GoldenVec” establish reproducibility

- Convection-style cell “GoldenVec” demonstrated fairly similar properties.
- While current performance appears quite adequate for GEn target cells, we believe it is likely that improved performance is possible.
- We hope for continued improvement through better control of the introduction of contaminant gases (not worth worrying about until basic technology is working).
Tests of cell “GoldenVec” AFTER convection

- There appears to be some degradation of the cell during convection.
- This performance, however, is already good enough.
- We believe we can do even better by further limiting contaminants (we’ll see!).

\[ P = p_0 \exp \left( -\frac{t}{T} \right) \]

- \( T = 6.12 \text{hr} \)
- \( R^2 = 0.99946 \)

\( T_1 = 6.1 \text{ hrs} \)

even after extended running of cell with convection
More tests coming!

- Want to improve on gold-coated OFHC copper
- Would prefer gold-coated titanium (this is at an earlier stage).
Polarized $^3$He target milestone #1: Selection of target cell design for $G_{E^n}$

- Convection-based design, now well tested in Protovec-series cells.
- Contains 6 STP liters of $^3$He in 750 cm$^3$ volume cell.
- OFHC copper metal end windows with gold electroplating on inner surface.
- 60 cm target-chamber length will deliver desired luminosity with 60 $\mu$A electron beam.
Additional progress on target-hardware design for Hall A since last review
Fringe fields during $G_{E^n}$

Tosca calculations indicate significant fringe fields in the vicinity of the polarized $^3$He target when using the SBS geometry for the $G_{E^n}$ measurement.
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.

- Uses both symmetry, and the concept that you want to keep your clamp away from the large fields so that it does not suck the flux lines in.
- Single-walled box doesn’t quite cut it.

Developed by Vladimir Nelyubin, a double-walled box provides excellent shielding within limited space.

<table>
<thead>
<tr>
<th></th>
<th>Z</th>
<th>-30</th>
<th>-20</th>
<th>0</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bx</td>
<td></td>
<td>2.2</td>
<td>2.2</td>
<td>2.1</td>
<td>2</td>
<td>1.9</td>
</tr>
<tr>
<td>By</td>
<td></td>
<td>-0.4</td>
<td>-0.36</td>
<td>-0.27</td>
<td>-0.3</td>
<td>-0.26</td>
</tr>
<tr>
<td>Bz</td>
<td></td>
<td>-0.17</td>
<td>-0.08</td>
<td>-0.21</td>
<td>-0.2</td>
<td>-0.28</td>
</tr>
</tbody>
</table>

Tuesday, December 9, 2014
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.

The double-walled box works with the Transversity coils. The double-walled box also accommodates the Helmholtz coils (and most other hardware) used during the Hall A “Transversity” experiments.
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.

The gradients look acceptable for the double-walled box + Transversity coils, for a single-pumping chamber 60 cm cell.

Magnetic field inhomogeneities with the geometry from the previous slide are acceptable for performance requirements of the Ge^n polarized target.
Activity in the JLab target lab testing new target technologies
Highlights of activities in the JLab target lab

The integration of new target technologies into the JLab polarized $^3$He target system is well underway

- New-style convection-based target cell (Protovec-I) has been installed in the JLab target system and is actively being tested.
  - Includes measurements of gas speed through the target chamber.
  - JLab target lab developed new simplified approach for driving convection.
- Pulse-NMR polarimetry system (necessary when we move to metal target-cell windows) is working, and polarimetry systematic studies are ongoing.
- Studies now complete of polarization losses in convection cells when using the NMR technique of Adiabatic Fast Passage (AFP).
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.

Pulse NMR polarimetry at the JLab target lab

- Historically, we have used the NMR technique of AFP for online monitoring of polarization.
- During an AFP scan, ALL spins in the target are flipped twice.
- With metal end windows, huge losses occur wherever there is nearby metal.
- Solution: use pulse NMR, which can be performed on a small part of the target.
Examples of recent data from JLab target lab

Measurement of NMR signal from 1st and 2nd pick-up coils provide measurement of gas speed by observing the passage of a depolarized "slug" of gas.

Successive rapid measurements of AFP signals provide measurements of AFP-related polarization losses with (at left) and without (at right) convection. In all cases, losses are less than 1% per sweep.
Summary

- We are ready to begin production on new target cells based on the Protovec-I and II. The size of the first production targets will depend on which polarized $^3$He experiment is scheduled first.
- We are nearly ready to begin production on cells with metal end windows.
- Ready to begin design and engineering for target hardware on the Hall A pivot for the SBS $G_E^n$ experiment.
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.

- Metal shape will be different, otherwise largely the same as in test cells.
- Gold-coated OFHC copper appears capable of achieving window thickness comparable to or smaller than glass windows.
- Gold-coated titanium may give us a factor of three or more.
- Am I being too conservative?
New 1-inch optics design specifically for $G_E^n$ target

- Existing Hall A polarized $^3$He optics system uses a “five-to-one” combiner, and 2-inch diameter optics (which are expensive).
- We have developed a modular one-inch optics system that can be duplicated for a scalable high-power system.
- This system is ideally suited to the new larger $G_E^n$ target design, which will include:
  - a larger 4-inch diameter pumping chamber, and
  - laser illumination from two directions simultaneously, to limit laser intensity incident on the cell’s glass walls and to achieve more uniform alkali-vapor polarization.
New 1-inch optics design for $G_{E^n}$ target

- Modular design allows optics for multiple lasers to be stacked.
- With a single lens for each set of optics, it is trivial to achieve coverage for the larger four-inch diameter GEn target cell.
- Modular design also makes it easier to split available laser power between the two (front and back) simultaneous pumping directions.
Control cell “Pyrah” for glass- and-metal-cell tests: centered and elevated positions

Cell has pumping chamber centered in Helmholtz coils

Cell is elevated roughly 7cm relative to center of Helmholtz coils

We have noticeable relaxation due to magnetic field inhomogeneities in these glass/metal test cells.

\[ \tau = 20.3 \, \text{hrs} \]

\[ \tau = 26.5 \, \text{hrs} \]
In the QCD DSE approach, it is the diquark that causes such a different behavior for the u and d quarks.