First Results of Laser Stripping of a 10 μs, 1 GeV H⁻ Beam at the SNS Accelerator

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Workshop on High-Intensity, High Brightness and High Power Hadron Beams

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Facility for Rare Isotope Beams
Kellogg Hotel & Conference Center
East Lansing, MI

Plenary Speakers
Richard Baartman (TRIUMF)
Riccardo de Maria (CERN)
Nobuhiisa Fukunishi (RIKEN)
Stuart Henderson (FNAL)
Hideaki Hotchi (J-PARC)
Mats Lindroos (ESS)
Thomas Roser (BNL)
Peter Spiller (GSI)
Jie Wei (MSU)
Hongwei Zhao (IMP)

Michigan State University
Abstract Deadline: 11 August 2014
Early Registration Deadline: 12 September 2014
frb.msu.edu/hb2014

Contact: HB2014@frb.msu.edu
Chairperson: Yoshihide Yamazaki
Status of Preparations for a 10 &micro;s Laser-Assisted H⁻ Beam Stripping Experiment

S. Cousineau, A. Aleksandrov, V.V. Danilov, F. Garcia, T. Gorlov, D. Johnson, Y. Liu, N. Luttrell, A. Menshov, M. Plum, A. Rakhman, A. Shishlo, Y. Takeda, Y. Wang

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IT WORKED!!!
Laser Assisted Stripping Concept

Step 1: Lorentz Stripping
\[ H^- \rightarrow H^0 + e^- \]

Step 2: Laser Excitation
\[ H^0 + \gamma \rightarrow H^{0*} \]

Step 3: Lorentz Stripping
\[ H^{0*} \rightarrow p + e^- \]
Laser Assisted Stripping Concept

\[ H^- \rightarrow 2 \, e^+ + p \]

Step 1: Lorentz Stripping
\[ H^- \rightarrow H^0 + e^- \]

Step 2: Laser Excitation
\[ H^0 + \gamma \rightarrow H^0* \]

Step 3: Lorentz Stripping
\[ H^0* \rightarrow p + e^- \]

2006 Proof of Principal Experiment

Experiment conducted with:
- 10 MW UV laser.
- Diverging laser
- Laser in tunnel

Straightforward scaling to 1 ms requires: \(~600 \, kW\) average UV laser power (way too much!)
**Laser Power Savings Techniques**

- Temporally match laser to ion beam 402.5 MHz structure. 10 μs burst

![Diagram showing temporally matched laser to ion beam structure](image)

- Apply dispersion tailoring to reduce transition frequency spread.

![Diagram showing dispersion tailoring](image)

- Squeeze beam longitudinally and vertically to maximize photon density and overlap: <1 mm vertical beam size, < 35 ps FWHM longitudinal size.

- Enforce $\alpha_x = 0$ at interaction point.
Configuration of 10 μs Experiment

- Experiment is in the transport line to the ring (HEBT)
- Laser is located remotely in Ring Service Building (RSB)

70 m + 9 mirrors in transport.

Concerns:
- Laser power loss
- Pointing stability
Engineering View of Experimental Vessel

- Beam Current Monitor (BCM)
- Wire scanner at interaction point
- Retractable Stripper Magnets
- Interaction Point

Courtesy Menshov

National Laboratory
Installed Experimental Vessel

- Demonstrated 100% conversion $\text{H}^\text{+}$ to $\text{H}^\text{0}$
- No interference with high power operations
Laser At Interaction Point

Laser Temporal Structure

~50 ps

402.5 MHz

Centroid Position

0.2 mm
## Final Measured Laser Parameters at IP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Required (Design)</th>
<th>Delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remote Station Laser Parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macropulse length</td>
<td>10 us</td>
<td>10 us</td>
</tr>
<tr>
<td>Micropulse width</td>
<td>&gt; 30 ps</td>
<td>30 – 50 ps (adjustable)</td>
</tr>
<tr>
<td>Peak Power in RSB</td>
<td>1.5 MW</td>
<td>2.5 MW (at 35 ps)</td>
</tr>
<tr>
<td><strong>In Tunnel Laser Parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission Efficiency</td>
<td>60%</td>
<td>70%</td>
</tr>
<tr>
<td>Maximum Peak Power</td>
<td>1 MW</td>
<td>~2 MW</td>
</tr>
<tr>
<td>Pointing stability at IP</td>
<td>±0.10 mm (H) x ±0.11 mm (V)</td>
<td></td>
</tr>
<tr>
<td>Horizontal divergence at IP</td>
<td>2 mrad</td>
<td>2.6 mrad</td>
</tr>
<tr>
<td>Vertical size at IP</td>
<td>0.8 mm</td>
<td>1.1 mm</td>
</tr>
</tbody>
</table>
Ion Beam Configuration During Experiment

- Ion Beam Configuration:
  - $D = 0$, $D' = -2.7$, as desired

- $\sigma_v = 0.15$ mm
  - Would have preferred $< 0.1$ mm, but good enough.

- $\sigma_l \leq 7.2^\circ$
  - Limited by bunch shape monitor resolution.
Laser-Ion Beam Alignment: Vertical Position

Need to vertically align laser and ion beams:

Complicated by the need to also phase match the laser and ion beam.

Slightly laser and beam frequency to introduce a sweep over all phase:

\[ f_{\text{laser}} = 402.51 \text{ MHz} \]

\[ f_{\text{beam}} = 402.50 \text{ MHz} \]
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Method 1: Steer laser or ion beam, look for beam loss by photo-detachment.

Loss monitor signal from photo-detachment.
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Need to vertically align laser and ion beams:

Complicated by the need to also phase match the laser and ion beam.

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\[ f_{\text{laser}} = 402.51 \text{ MHz} \]

\[ f_{\text{beam}} = 402.50 \text{ MHz} \]

Method 1: Steer laser or ion beam, look for beam loss by photo-detachment.

Method 2: Look for ion and laser beam on interaction point wirescanner.
Laser-Ion Beam Alignment: Phase

- After vertical alignment accomplished, restore laser to 402.5 MHz.

- Sweep laser phase and look for beam loss from photo-detachment.
First Attempt – No Stripping

Final steps:

1. Insert stripping magnets, confirm $H^0$ conversion.

2. Vary laser incoming angle to find tune resonant frequency.
   
   ➔ Only indication of correct angle is stripped beam.

   We saw NOTHING.
First Attempt – No Stripping

Final steps:

1. Insert stripping magnets, confirm H⁰ conversion.
2. Vary laser incoming angle to find tune resonant frequency.
   ➔ Only indication of correct angle is stripped beam.
   We saw NOTHING.

Back to the drawing board…We realized:

- Vessel was designed for 987 MeV, α=37.5°.
  (Due to concerns over SCL performance.)

- 2 years later we had forgotten this -- set the experiment up for 1 GeV, α=39.7°

- Resulted in incorrect resonant excitation frequency for H⁰.
Second Attempt – First Signature

“You have to really use your imagination…” – Mike Plum
Final Results and Estimated Efficiency

March 28, 2016

Stripping efficiency > 90% (exact value pending)

BCM has ~6% noise.
Impact of Laser Jitter

- Due to laser jitter, the stripping efficiency varied pulse by pulse
- This made fine tuning very difficult.
Continuing Work On:

1. Final stripping efficiencies.

1. Parameter sensitivities:
   I. Impact of dispersion tailoring on stripping efficiency
      ➢ Measured for D’=nominal, D’=half, D’=0 (no tailoring)
   II. Efficiency vs. laser power.