Photodetachment of H⁻ at the GBAR Experiment

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Motivation for GBAR Experiment

Our understanding of gravity is incomplete.
• Quantum Field Theory says nothing about gravity
• Dark Energy and Dark Matter linger

Test the Weak Equivalence Principle with antimatter.
• No (meaningful) direct measurement of the interaction of gravity on antimatter exists.
  • Best and only direct result from free fall: $-65g < \bar{g} < 110g$ from ALPHA

Require a stable, neutral particle for freefall.
• Cannot use antineutrons, positronium…
• Next simplest particle: antihydrogen!

Wikipedia

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Excited positronium reacts with slow antiprotons.

- Antihydrogen ions are produced and are directed based on their charge

**Landmark goal:** Cross-section measurement of $\bar{H} + Ps \rightarrow \bar{H}^+ + e^-$.  
- Can use hydrogen as a proxy for antihydrogen: $H + Ps \rightarrow H^- + e^+$
  - To study this process, we must produce $H$ in-line!

Have access to $H^-$ beam from ELENA.

- Photodetach $H^-$ upon entering reaction chamber to form neutral $H$.
- $H$ will also be used for beam alignment.
1: Alignment of Beam into Reaction Chamber

- **Objective:** Align photodetachment beam from laser room into reaction chamber
  - Use low-powered diode lasers as to not blind myself during alignment
  - Then align high-powered beam to low-powered diode.

- Turned out to be much more challenging than initially anticipated…
2: Designing Diagnostics for Laser

- Objective: safely measure transmission of high-powered laser beam into reaction chamber.

Detect transmission and block beam here.

CAD Design
3: Pulsed Laser Trigger Timing

Objective: Time laser pulse so that beam pulse arrives on $\text{H}^-$ ions as they enter the reaction chamber.

- Receive two triggers from beamline: -3s, and -1ms.
  - Need to shape, delay, and (possibly) sum both before triggering laser flashlamp and Q-switch.
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4: Simulation of Photodetachment Process

- Objective: Simulate photodetachment rates of H⁻ via process \( H^- + \gamma \rightarrow H + e^- \).

- Model via differential equation

\[
\frac{\partial n(x, y, z, t)}{\partial t} = -\frac{\partial n}{\partial y} v_H - n\sigma \frac{I(x, y, z, t)}{E_\gamma}
\]

- Number of photodetached \( H^- \) given by

\[
N_{\text{photodetached}} = N - \lim_{t \to \infty} \int n \, dV
\]

- Formal solution via method of characteristics:

\[
N_{\text{photodetached}} = \int N_0(x, y, z) \left( 1 - \exp \int -\sigma \frac{I(x, y + v_H t, z, t)}{E_\gamma} \, dt \right) \, dV
\]
Mathematica Numerics

\[ N_{\text{photodetached}} = \int N_0(x, y, z) \left(1 - \exp \left( -\sigma \frac{I(x, y + v_{H} t, z, t)}{E_{\gamma}} \right) dt \right) dV \]

Can no longer compute \( N_{\text{photodetached}} \) numerically.

But \( I(x, y, z, t) \) is Gaussian, so we can (in principle) compute the innermost integral analytically.

Then we compute the rest numerically.
Simulation Results

Predicted Levels of H– Photodetachment versus Laser Energy

Maximum operating energy

>100x background

>10x background

$N = 5 \cdot 10^6$ H– per pulse

Photodetached H–

- Photodetached H–
- Linear fit $y = 25200x$
- H background levels

Laser Pulse Energy (mJ)