E12–14–009: Ratio of the electric form factor in the mirror nuclei $^3$He and $^3$H

(The $^3$He – $^3$H Charge Radius Difference)

Luke Myers
Hall A Winter Meeting

December 9, 2014
Absolute methods

Elastic electron scattering

\[ \langle r^2 \rangle = 6 \left. \frac{dG_E}{dQ^2} \right|_{Q^2 \to 0} \]
Absolute methods

Elastic electron scattering
\[ \langle r^2 \rangle = 6 \frac{dG_E}{dQ^2} \bigg|_{Q^2 \to 0} \]

Electronic spectroscopy
2S–2P transition

Muonic spectroscopy
\[ e \to \mu \Rightarrow \text{greater precision} \]
Measuring $\langle r^2 \rangle$

- **Absolute methods**
  - Elastic electron scattering
    \[
    \langle r^2 \rangle = 6 \frac{dG_E}{dQ^2} |_{Q^2 \to 0}
    \]
  - Electronic spectroscopy
    - 2S–2P transition
  - Muonic spectroscopy
    \[ e \to \mu \Rightarrow \text{greater precision} \]

- **Relative method**
  - Isotopic shifts
Proton radius extracted from all three methods

\[ ep: \quad 0.879 \pm 0.009 \text{ fm} \]
\[ eH: \quad 0.876 \pm 0.008 \text{ fm} \]
\[ \mu H: \quad 0.84087 \pm 0.00039 \text{ fm} \]

What is going on here?!
Proton radius extracted from all three methods

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\begin{align*}
ep: & \quad 0.879 \pm 0.009 \text{ fm} \\
eH: & \quad 0.876 \pm 0.008 \text{ fm} \\
\muH: & \quad 0.84087 \pm 0.00039 \text{ fm}
\end{align*}
\]

What is going on here?!

Just for laughs...

Deuterium radius

\[
\begin{align*}
eD: & \quad 2.130 \pm 0.010 \text{ fm} \\
\muH + \text{Iso. Shift}: & \quad 2.12771 \pm 0.00022 \text{ fm} \\
\muD (\text{prelim}): & \quad 2.128 \text{ fm}
\end{align*}
\]
Experimentally, large uncertainties & discrepancies
arXiv:1412.2603 – new radii and moments of $^{3,4}\text{He}$
Lightest isotope with excess neutrons (skin?)

<table>
<thead>
<tr>
<th></th>
<th>$\langle r^2 \rangle_{^{3}\text{H}}$</th>
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<tbody>
<tr>
<td>SACLAY</td>
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<tr>
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Why Tritium? Why Now?

Experimentally, large uncertainties & discrepancies

*arXiv:1412.2603 – new radii and moments of $^{3,4}\text{He}$*

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"Because the $^3\text{H}$ (tritium) charge radius currently has large errors, in my opinion the single most valuable measurement to be undertaken for nuclear physics purposes would be the tritium-hydrogen ($^3\text{H}-^1\text{H}$) isotope shift"

J.L. Friar
Why Tritium? Why Now?

**One-time** procurement of $^3\text{H}$ target at JLab
Why Tritium? Why Now?

One-time procurement of $^3$H target at JLab
Precise theoretical calculations of $\langle r^2 \rangle_{^3\text{H}}$, $\langle r^2 \rangle_{^3\text{He}}$

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Why Tritium? Why Now?

**One-time** procurement of $^3\text{H}$ target at JLab

Precise theoretical calculations of $\langle r^2 \rangle _{^3\text{H}}$, $\langle r^2 \rangle _{^3\text{He}}$

$^3\text{H}:^3\text{He}$ connects the hydrogen, helium chains

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Experimental Setup

- Setup ~same as MARATHON and SRC
- Targets: $^3$H, $^3$He as well as $^1$H, $^2$H, empty cell and $^{12}$C
- Beam: 1.1 GeV, 5 $\mu$A for 1.5 days
- Special collimator plate
Collimator Plate
- reduce overall rate
- equalize rate in bins

Holes allow for simultaneous optics
**Kinematics with LHRS**

<table>
<thead>
<tr>
<th>$\theta_{\text{HRS}}$ [deg]</th>
<th>$p_{\text{HRS}}$ [GeV/c]</th>
<th>$Q^2$ [GeV$^2$]</th>
<th>$^{3}\text{H}$ Rate [Hz/bin]</th>
<th>$^{3}\text{He}$ Rate [Hz/bin]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5</td>
<td>1.07</td>
<td>0.049–0.065</td>
<td>210</td>
<td>510</td>
</tr>
<tr>
<td>15.0</td>
<td>1.07</td>
<td>0.072–0.091</td>
<td>60</td>
<td>125</td>
</tr>
</tbody>
</table>

- Only **one** momentum setting
  - Works for $^{3}\text{H}$, $^{3}\text{He}$ as well as $^{1}\text{H}$, $^{2}\text{H}$, $^{12}\text{C}$
  - $^{1}\text{H}$, $^{12}\text{C}$ data for systematics cross check

- Count rates are HUGE!
  - $I_{\text{beam}} \sim 5\mu\text{A}$
  - Even with losses, $10^5$ counts/bin/hr
Non-target Scattering

1) Scattering from windows
   - Dedicated, empty target runs
   - Vertex cuts

2) 1.1 GeV beam halo
   - Heating and scattering concerns
   - If needed, reduce raster size

3) Rescattering from target walls
   - Simulations: small absolute effect, cancellation

4) Rescattering from collimator plate
   - Software cuts, $^{12}$C comparison
## Error Budget

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistics</td>
<td>0.4%</td>
</tr>
<tr>
<td>Charge</td>
<td>&lt;0.5%</td>
</tr>
<tr>
<td><strong>Relative target thickness</strong></td>
<td>1.5–2%</td>
</tr>
<tr>
<td>Deadtime, efficiency, etc</td>
<td>&lt;0.5%</td>
</tr>
<tr>
<td>$G_M$ subtraction</td>
<td>0.4%</td>
</tr>
<tr>
<td>Radiative corrections</td>
<td>0.5%</td>
</tr>
<tr>
<td>Coulomb correction, TPE</td>
<td>0.4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.8–2.2%</td>
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EXPECTED RESULTS
Expected Results

Ratio of $G_E^{(3\text{He})}:G_E^{(3\text{He})}$ to $Q_m^2$

- ±0.6%$_{\text{stat}}$
- Dipole Form Factor
- Monopole Form Factor

Q$^2$ [GeV$^2$]
The Wrap-Up

- 1.5 day experiment
  Single-arm, two angles, single $p$ setting
  $^1\text{H}$, $^2\text{H}$, $^3\text{H}$, $^3\text{He}$, and $^{12}\text{C}$

- 2% measurement of $G_E(^3\text{H}):G_E(^3\text{He})$
  $\langle r^2 \rangle^{^3\text{He}} - \langle r^2 \rangle^{^3\text{H}} \approx (0.20 \pm 0.03) \text{ fm}$
  Reduction in uncertainty by $\sim 3x$

- “[T]his proposal offers an opportunity to perform an interesting measurement, which will provide valuable input to theoretical calculations, and will enable their further progress.” – JLab Theory Advisory Committee

- Best chance to measure the $^3\text{H}$ radius
Thank you!
# Beamtime Allotment

<table>
<thead>
<tr>
<th>Description</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerator scaling to 1.1 GeV</td>
<td>4 hr</td>
</tr>
<tr>
<td>BCM calibration and luminosity scans</td>
<td>2 hr</td>
</tr>
<tr>
<td>Optics and acceptance studies with collimator</td>
<td>4 hr</td>
</tr>
<tr>
<td>Production running at 12.5° (1.5 hrs/target)</td>
<td>9 hr</td>
</tr>
<tr>
<td>Target changes at 12.5°</td>
<td>1 hr</td>
</tr>
<tr>
<td>Move spectrometer from 12.5° to 15.0°</td>
<td>2 hr</td>
</tr>
<tr>
<td>Optics and acceptance studies with collimator</td>
<td>4 hr</td>
</tr>
<tr>
<td>Production running at 15.0° (1.5 hrs/target)</td>
<td>9 hr</td>
</tr>
<tr>
<td>Target changes at 15.0°</td>
<td>1 hr</td>
</tr>
</tbody>
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**Total Beam Time Request**  
1.5 PAC Days
**Target Contribution**

1) Scattering from windows
   - Dedicated, empty target runs
   - Vertex cuts at ±10 cm