Proton Charge Radius Experiment (PRad) at JLab Hall B

CLAS2013
On behalf of the PRad collaboration

Chao Peng
Duke university
11/22/2013
Outline

• Physics motivation

• PRad experiment
  – Experimental apparatus

• Simulations for PRad
  – Target simulation
  – Background study
  – Radiative corrections
  – Radius extraction

• Current status and future plan
Physics motivation

- Protons and neutrons are the primary building blocks of the atomic nucleus. Proton charge radius is a fundamental quantity important to QCD and QED.

- How to experimentally determine the proton charge radius?
  - Electron-proton elastic scattering measurements
  - Hydrogen Lamb shift measurements (electronic or muonic)

- In scattering experiments, at very low $Q^2$, rms charge radius is given by

$$G_E^p(Q^2) = 1 - \frac{Q^2}{6} \langle r^2 \rangle + \frac{Q^4}{120} \langle r^4 \rangle + \ldots.$$  

$$\frac{\langle r^2 \rangle}{6} = - \frac{dG_E^p(Q^2)}{dQ^2} \Bigg|_{Q^2=0}$$
Physics motivation

- The proton charge radius puzzle was raised by the Lamb shift measurement of muonic hydrogen at PSI\(^1, 2\)

- PSI value is the most precise (0.05\%), but 7\(\sigma\) away from CODATA value\(^3\)
  - CODATA value: a compilation of world data from e-p elastic scattering measurements and hydrogen Lamb shift measurements

- Discrepancy is not understood yet. New experiments with different systematics are needed

PRad experiment

- Non-magnetic and calorimetric experiment
- Very low $Q^2$, never reached by electron scatt. experiments, $2 \times 10^{-4} - 2 \times 10^{-2} \text{(GeV/c)}^2$
- Windowless gas-flow target
- e-p cross sections normalized to the well known Møller process

Spokesperson: A. Gasparian
Co-spokesperson: M. Khandaker, H. Gao and D. Dutta
Experimental apparatus

- Windowless gas-flow target
  - Removed the typical background source: target windows
  - Vertical tube as gas-inlet
  - Horizontal tube with the opened end-caps
- Expected target thickness $\sim 10^{18}$ atoms/cm$^2$ at 25 K
- Minimized thickness of the tubes to reduce the background from beam halo
Experimental apparatus

• High resolution hybrid calorimeter (HyCal)
  – Built by the PrimEx collaboration at Jlab
  – PbWO$_4$ crystal + lead glass

• Central part (crystal) resolution
  – $\sigma_E/E = 2.6\%/\sqrt{E}$, $\sigma_{x,y}/E = 2.5\ mm/\sqrt{E}$

• 5 meters away from the target
  – Detection angle up to 4 degree for the central part
Target simulation

- Target density was studied by COMSOL Multiphysics

- Surface pressure of the chambers
  - 1st stage: $6 \times 10^{-4}$ torr
  - 2nd stage: $9 \times 10^{-6}$ torr, satisfies beam line vacuum requirements

- Gas density and target thickness
  - Target thickness at center: $3.42 \times 10^{18}$ H/cm$^2$
Background study

- Full simulation based on Geant4
- The primary background source is the electron-nuclei scattering of beam halo from the target structure
- Minimize the background: Subtraction from the empty target run
Background study

- Need about 20% beam time for the empty target run for the best subtraction

- Statistical uncertainties: 0.06% to 0.50% for 12 angular bins ranged from 0.8 degree to 3.8 degree

- Assuming 1% systematic of the monitored beam charge, it results in a 0.37% systematical uncertainty in the subtraction
Radiative corrections

• Event generators including radiation effects of e-p and e-e scattering were developed

• Go beyond the ultra-relativistic approximation (URA, $m_e^2 \ll Q^2$)

Work by M. Meziane (Duke)
Radiative corrections

- Angular distributions of real photons
  - Most are at very forward angles, < 5 deg

Work by M. Meziane (Duke)
Radius extraction

- We are trying to extend the $Q^2$ coverage for a higher precision
  - Use the lead glass part of the calorimeter, increasing detecting angle from 4 degree to 10 degree
  - Exploring options to have a higher beam energy (e.g. 3.3 GeV beam)

- Assumed 0.6% systematics for measured cross-sections in simulation (dipole fit, $r_p = 0.8768$ fm as the input)

Including lead glass part up to 10 deg

\[ r_p = 0.8773 \pm 0.0050 \text{ fm} \]

Including 3.3 GeV beam up to 4 deg

\[ r_p = 0.8753 \pm 0.0052 \text{ fm} \]
Radius extraction

- The precision of the extracted radius is expected to be sub-percent.
Current status and future plan

Current status

- **Hardware**
  - Major components of target are procured or being procured. Pumps, chiller and cryocooler have already been at Jlab. Orders of 3D positioner and chambers are placed.
  - Design of vacuum box and stands started.
  - Preliminary DAQ system design.

- **Software**
  - Target simulation completed.
  - Full Geant4 simulation with event generators including radiative corrections to both ep and Møller processes is near completion.
  - DAQ software is being developed.

Future plan

- **General**
  - Finalize design/desired schedule/beam requirements.
  - Verify running compatibility with 12 GeV installation and HPS.

- **Hardware**
  - Test HyCal.
  - Final setup of the beamline.

- **Software**
  - More studies with the full simulation code.
  - Complete DAQ software.
Thank you

• The project is supported by U.S. Department of Energy under contract number DE-FG02-03ER41231 and NSF MRI award PHY-1229153

<table>
<thead>
<tr>
<th>PRad Collaboration</th>
<th>JLab experiment E12-11-106</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jefferson Lab</td>
<td>Old Dominion University</td>
</tr>
<tr>
<td>NC A&amp;T State University</td>
<td>University of Kentucky</td>
</tr>
<tr>
<td>Duke University</td>
<td>College of William &amp; Mary</td>
</tr>
<tr>
<td>Idaho State University</td>
<td>Argonne National Lab</td>
</tr>
<tr>
<td>Mississippi State University</td>
<td>Hampton University</td>
</tr>
<tr>
<td>Norfolk State University</td>
<td>University of New Hampshire</td>
</tr>
<tr>
<td>University of North Carolina at Wilmington</td>
<td>Tsinghua University</td>
</tr>
</tbody>
</table>