The New Proton Charge Radius Experiment at JLab

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Outline

1. The Proton Charge Radius Puzzle
2. A New Experiment (PRad)
   - windowless target
   - high resolution calorimeter
   - simultaneous detection of elastic and Moller
3. Preliminary Online Results
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The Proton Charge Radius Puzzle

\(~8\sigma\) discrepancy between muon and electron based measurements

Proton rms charge radius measured using

- **electrons**: \(0.8770 \pm 0.0045\) (CODATA2010 + Zhan et al.)
- **muons**: \(0.8409 \pm 0.0004\)
Are the state of the art QED calculations incomplete?

Are there additional corrections to the muonic Lamb shift due to proton structure (such as proton polarizability $\propto m^4$)?

Are higher moments of the charge distribution accounted for in the extraction of rms charge radius?

Is there an extrapolation problem in electron scattering data?

Has new physics been discovered (violation of Lepton Universality)?
More experiments are needed!

- Redo atomic hydrogen spectroscopy
- Muonic deuterium and helium (PSI)
- Muon-proton scattering (MUSE experiment)
- Electron scattering experiments (PRad) (preferably with completely different systematics)
PRad: a novel electron scattering experiment

- High resolution, Hybrid calorimeter (magnetic spectrometer free)
- Windowless, high density H\textsubscript{2} gas flow target (reduced backgrounds)
- Simultaneous detection of elastic and Moller electrons (control of systematics)
- Vacuum box, one thin window, large area GEM chambers (improved resolution)
- Q\textsuperscript{2} range of 10\textsuperscript{-4} – 6\times10\textsuperscript{-2} GeV\textsuperscript{2} (lower than all previous electron scattering expts.)
The PRad Collaboration

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PRad: First JLab 12 GeV era experiment

Ran with 1.1 and 2.2 GeV beam in Hall-B at JLab

- Experimental goals:
  - fill in the very low $Q^2$ range
  - large $Q^2$ range in a single setting ($\sim 1 \times 10^{-4} - 6 \times 10^{-2}$ GeV$^2$)
  - measure cross section with sub-percent precision
  - sub-percent rms proton charge radius extraction

- High resolution, Hybrid calorimeter (access small scattering angle: $0.7^\circ - 7.0^\circ$)
- Windowless, high density $H_2$ gas flow target (reduced backgrounds)
- Simultaneous detection of elastic and Moller electrons (control of systematics)
- Vacuum box, one thin window, large area GEM chambers (improved resolution)

Bernauer data for lowest spectrometer setting

Mainz low $Q^2$ data set
High resolution calorimeter

Reused PrimEx HyCal

- PbWO$_4$ and Pb-glass calorimeter (118x118 cm$^2$)
- 34x34 matrix of 2.05 x 2.05 cm$^2$ x18 cm PbWO$_4$
- 576 Pb-glass detectors (3.82x3.82 cm$^2$ x45 cm)
- 5.5 m from the target,
- 0.5 sr acceptance

PbWO$_4$ resolution:
\[ \frac{\sigma_E}{E} = 2.6\%/\sqrt{E} \]
\[ \sigma_{xy} = 2.5 \text{ mm}/\sqrt{E} \]

Pb-glass:
2.5 times worse
Large area GEM coordinate detectors

- Two large GEM based X and Y- coordinate detectors with 100 µm position resolution

- Designed and built at University of Virginia (UVa)

- The GEM detectors provided:
  ➢ factor of >20 improvements in coordinate resolutions
  ➢ similar improvements in $Q^2$ resolution
  ➢ unbiased coordinate reconstruction (including HyCal transition region)
  ➢ increase $Q^2$ range by enabling use of Pb-glass part of calorimeter
HyCal and GEMs on the beamline

beam view

downstream view
Windowless cryo-cooled gas flow target

Target cell (8 cm dia x 4 cm long copper)

7.5 µm kapton foil with 2mm hole

Operating parameters:
Areal density: $\sim2\times10^{18}$ H atoms/cm$^2$

cell / chamber/ vacuum tank pressure:
470 mtorr / 2.3 mtorr / 0.3 mtorr
Vacuum chamber with one thin window

two stage, 5 m long vacuum box

1.7 m dia, 2 mm thick Al window
High quality, stable CEBAF electron beam

Electron beam profile at target
(measured with harp scan)

- Typical width: 25 µm
- Position stability: ± 250 µm

Experiment ran during May/June 2016
- With $E_e = 1.1$ GeV beam
  - Collected 4.2 mC on target ($2 \times 10^{18}$ H atoms/cm$^2$)
  - 604 M events with H and
  - 53 M events without H in target
  - 25 M events on 1µm Carbon foil target

- With $E_e = 2.2$ GeV beam
  - Collected 14.3 mC on target ($2 \times 10^{18}$ H atoms/cm$^2$)
  - 756 M events with H and
  - 38 M events without H in target
  - 10.5 M events on 1µm Carbon foil target
Preliminary online results

$ep \rightarrow ep$ event candidate

HyCal calorimeter

GEM detectors
Preliminary online results

\[ ee \rightarrow ee \quad \text{event candidate} \]

HyCal calorimeter

GEM detectors
Preliminary online results

2.2 GeV data

Cluster Energy (MeV) vs Scattering Angle (deg.)

e-p elastic

Møller
**Preliminary online results**

**e-p elastic** (unnormalized and no acceptance corrections)

Counts vs. $Q^2$ $(\text{GeV}^2)$

- $E_0 = 2.2 \text{ GeV}$
- $E_0 = 1.1 \text{ GeV}$

0.3% of data
Summary

- The proton charge radius is a fundamental quantity in Physics
  - Important for precision atomic spectroscopy
  - Precision tests of future lattice QCD calculations
  - “New Physics”

- The proton radius puzzle is still unresolved

- A novel electron scattering experiment (PRad) was recently completed at JLab Hall-B.
  - large statistics, high quality, rich data have been collected;
  - lowest $Q^2$ ($\sim 10^{-4} \text{ GeV}/\text{C}^2$) in ep-scattering experiments was achieved;
  - simultaneous measurement of the Møller and elastic scattering processes was demonstrated to control systematic uncertainties;
  - data in a large $Q^2$ range ($10^{-4}$ - $6 \times 10^{-2}$ GeV$^2$) have been recorded with the same experimental setting, for the first time in ep-scattering experiments.

- Analysis underway, first preliminary results expected soon.

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