Proton Charge Radius Experiment (PRad) at JLab Hall B

CLAS2013

On behalf of the PRad collaboration

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Outline

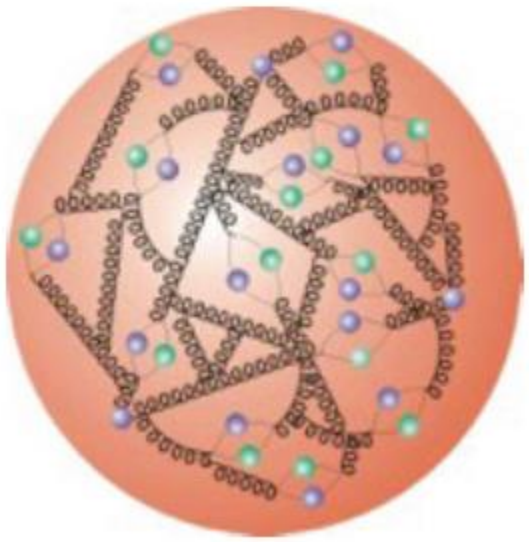
- Physics motivation
- PRad experiment
  - Experimental apparatus
- Simulations for PRad
  - Target simulation
  - Background study
  - Radiative corrections
  - Radius extraction
- Current status and future plan

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

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

$$\frac{\langle r^2 \rangle}{6} = -\left. \frac{dG_E^p(Q^2)}{dQ^2} \right|_{Q^2=0}$$

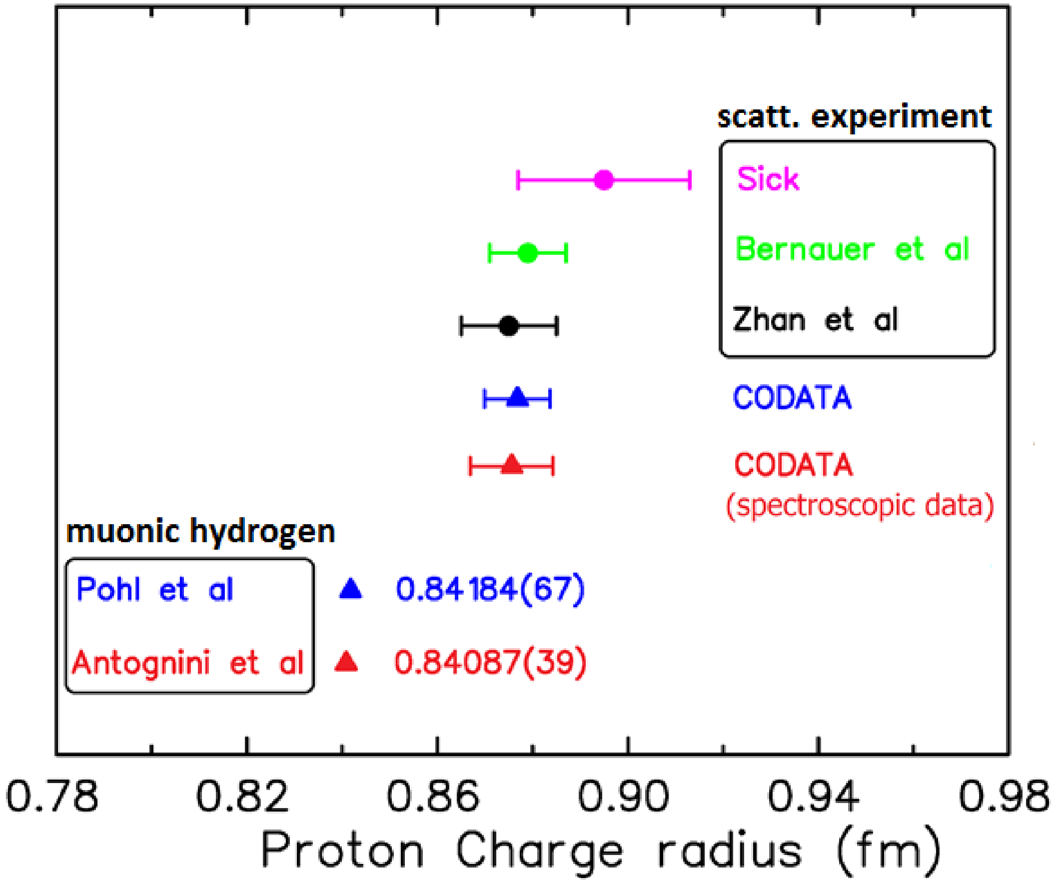


Proton
Bag of quarks and gluons

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 7σ 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

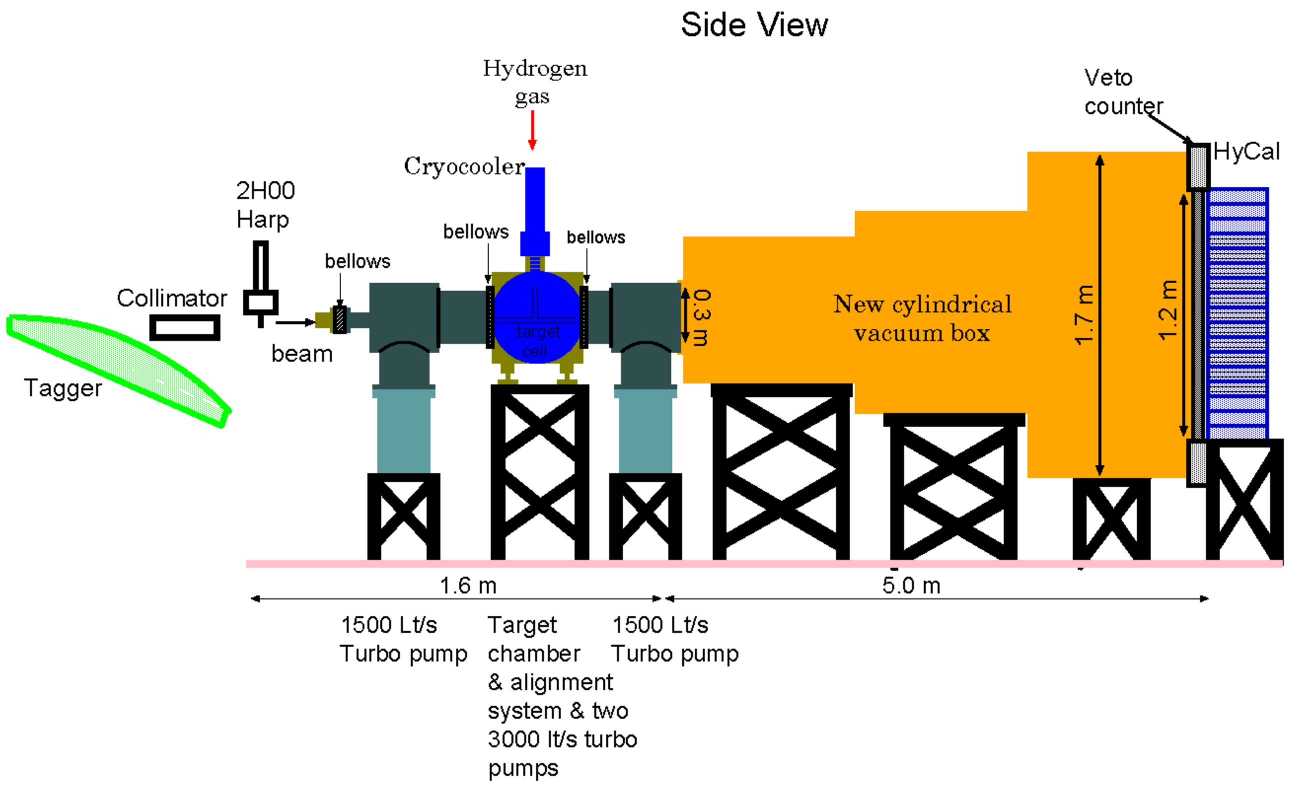
4, 5, 6



1. R. Pohl, A. Antognini, F. Nez, *et al.*, Nature 466, 213 (2010).
2. A. Antognini, F. Nez, K. Schuhmann, *et al.*, Science 339, 417 (2013).
3. P.J. Mohr, B.N. Taylor, and D.B. Newell, Rev. Mod. Phys. 84, 1527 (2012).
4. I. Sick, Phys. Lett. B 576, 62 (2003).
5. J. C. Bernauer *et al.*, Phys. Rev. Lett. 105, 242001 (2010).
6. X. Zhan *et al.*, arXiv 1102:0318v2 [nucl-ex] (2011).

PRad experiment

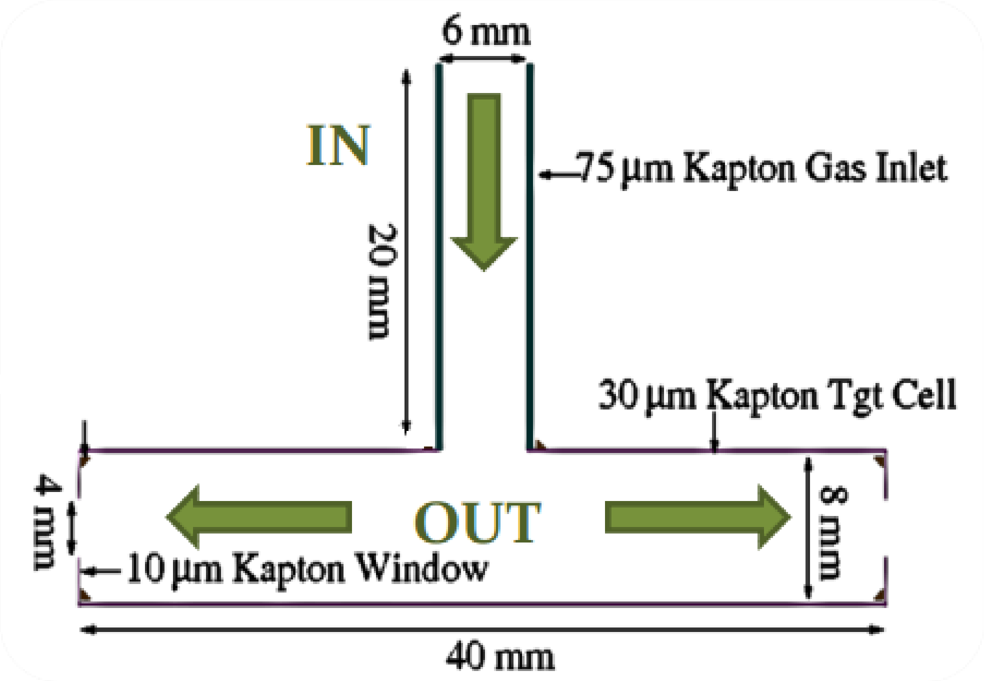
- Non-magnetic and calorimetric experiment
- Very low Q^2, never reached by electron scatt. experiments, $2 \times 10^{-4} - 2 \times 10^{-2}$ $(GeV/c)^2$
- Windowless gas-flow target
- e-p cross sections normalized to the well known Møller process



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

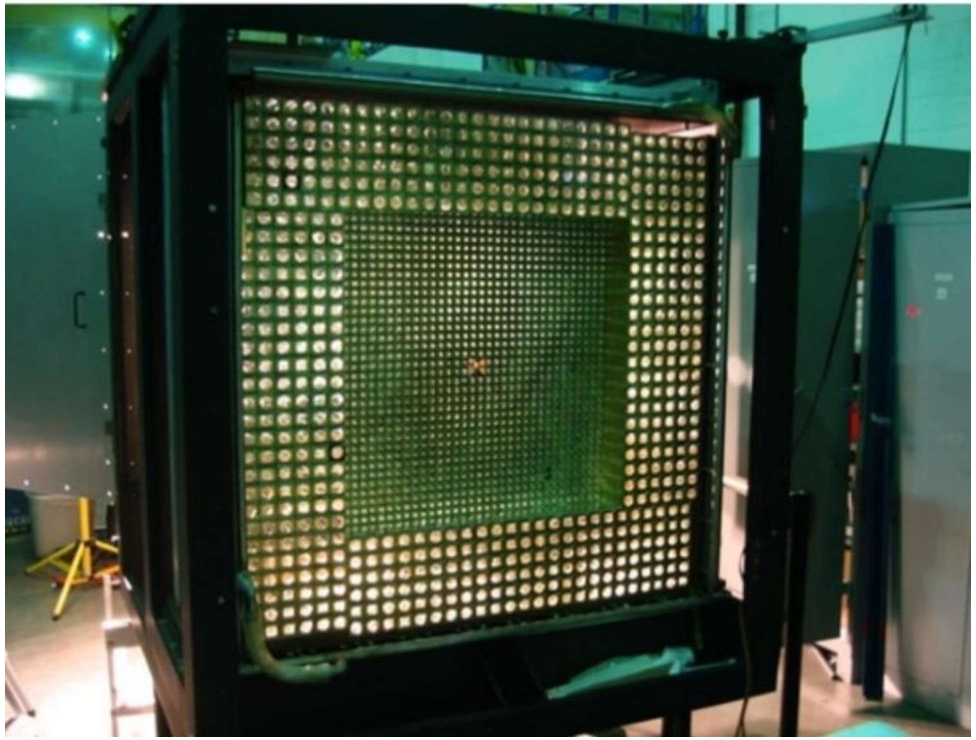
Experimental apparatus

- 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 ~10^{18} atoms/cm^2 at 25 K
- Minimized thickness of the tubes to reduce the background from beam halo



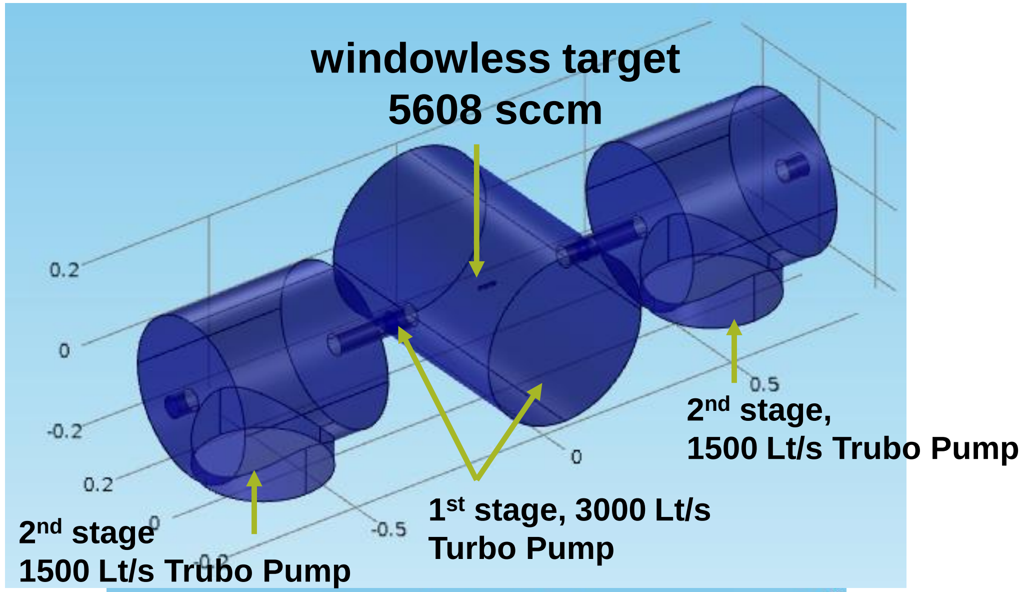
Experimental apparatus

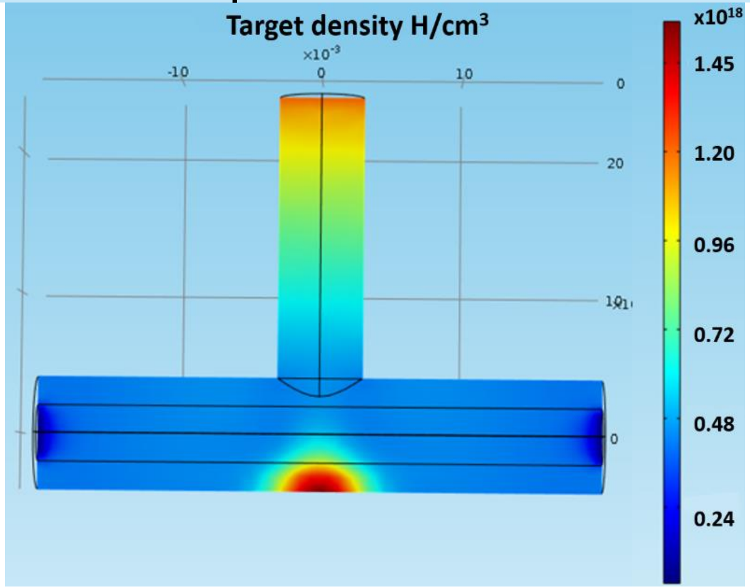
- High resolution hybrid calorimeter (HyCal)
  - Built by the PrimEx collaboration at Jlab
  - $\mathrm{PbWO_4}$ crystal + lead glass
- Central part (crystal) resolution
  - $\sigma_E/E = 2.6\%/\sqrt{E}$, $\sigma_{x,y}/E = 2.5\ mm/\sqrt{E}$
- 5 meters away from the target
  - Detection angle up to 4 degree for the central part



Target simulation

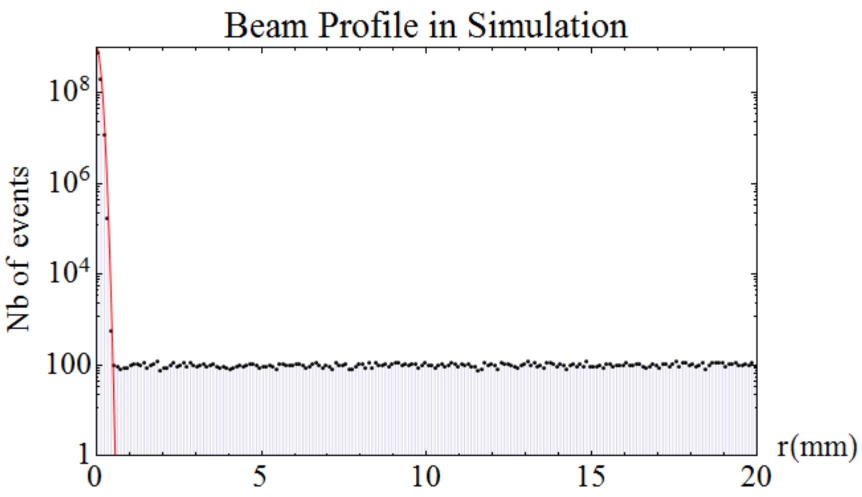
- Target density was studied by COMSOL Multiphysics
- Surface pressure of the chambers
  - 1st stage: 6×10^{-4} torr
  - 2nd stage: 9×10^{-6} torr, satisfies beam line vacuum requirements
- Gas density and target thickness
  - Target thickness at center: 3.42×10^{18} H/cm^2

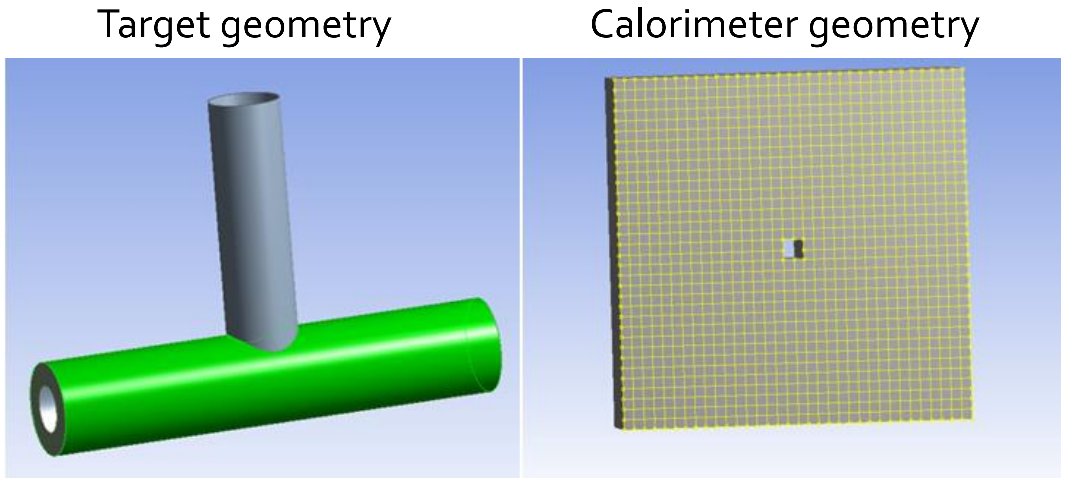


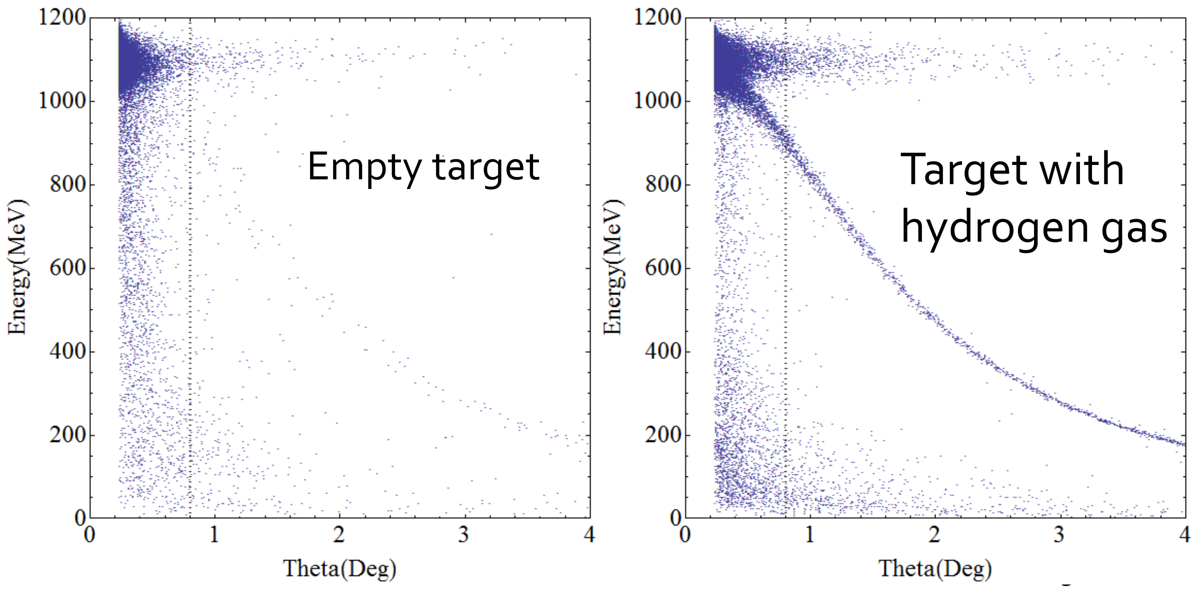


Background study

- 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





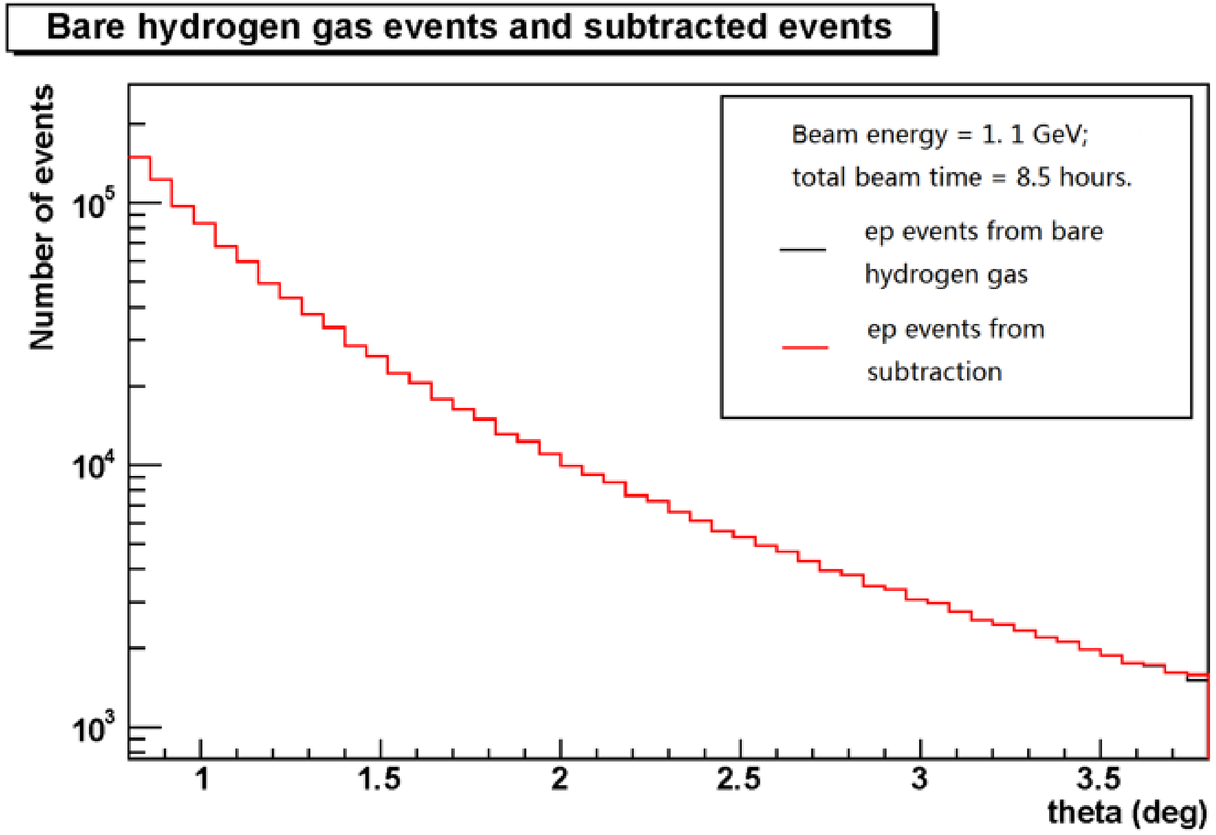


Background study

- 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

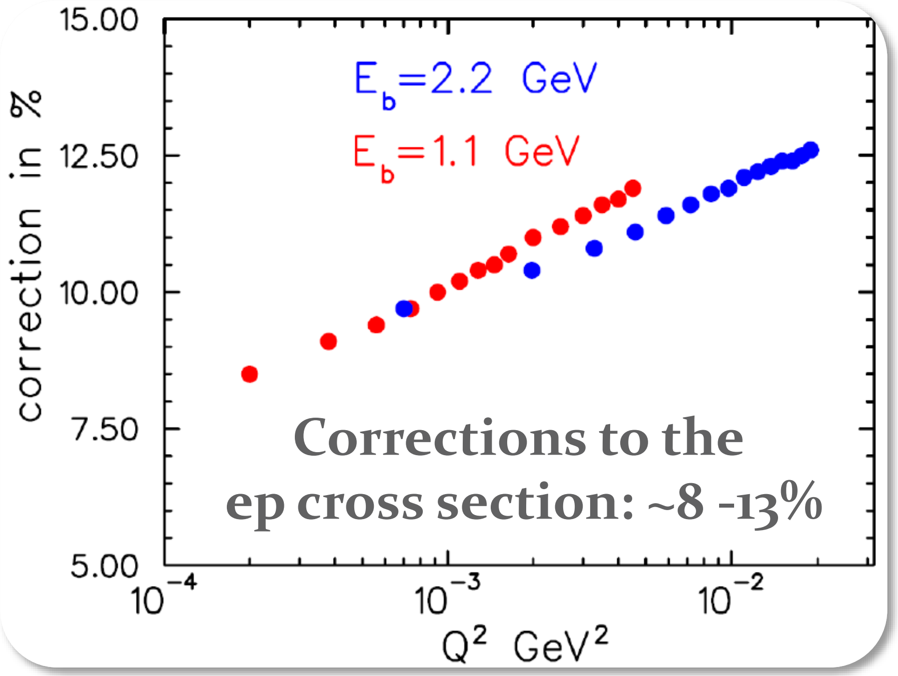
- Assuming 1% systematic of the monitored beam charge, it results in a 0.37% systematical uncertainty in the subtraction

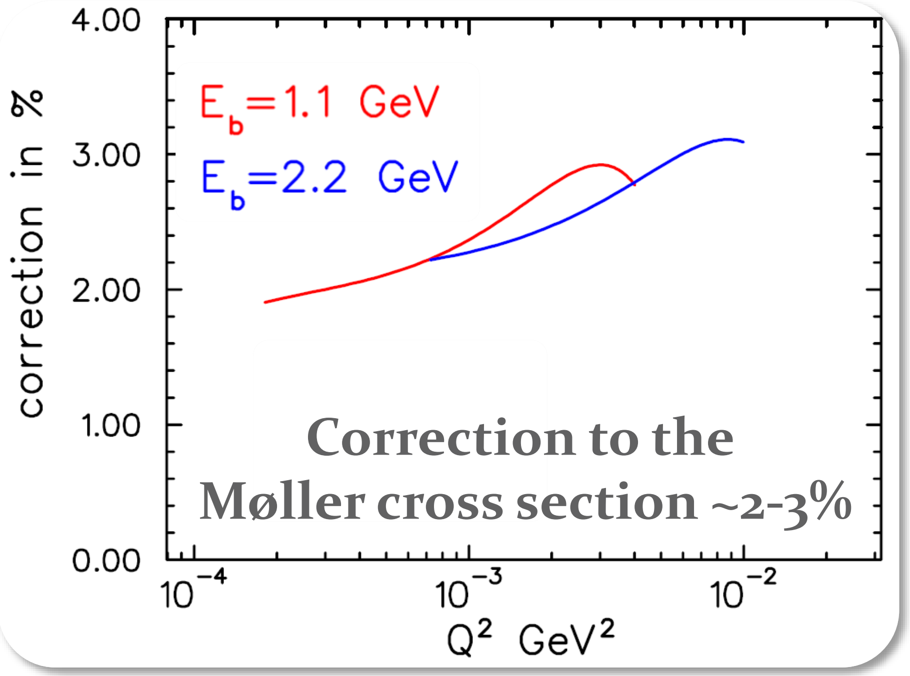


Work by M. Meziane (Duke)

Radiative corrections

- Event generators including radiation effects of e-p and e-e scattering were developed
- Go beyond the ultra-relativistic approximation (URA, $m_e^2 << Q^2$)

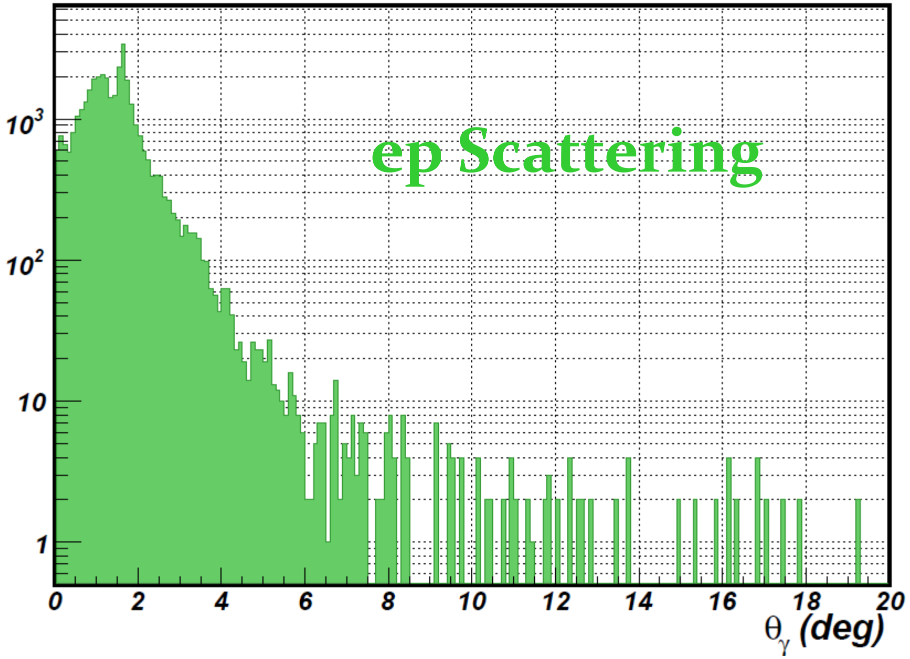


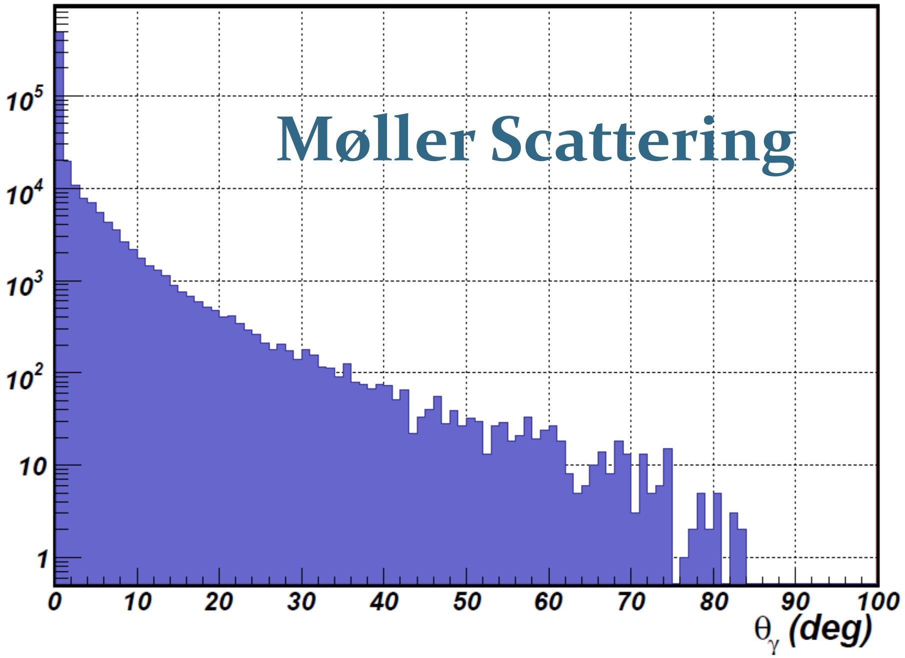


Work by M. Meziane (Duke)

Radiative corrections

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

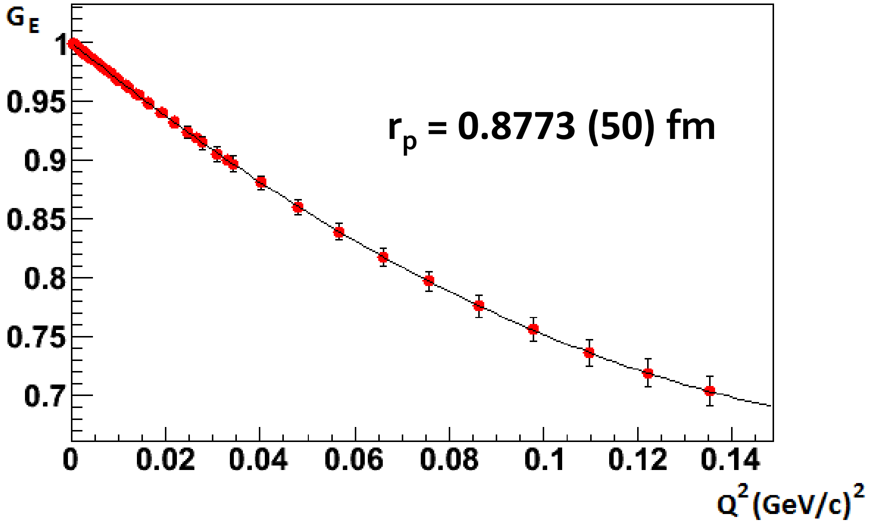




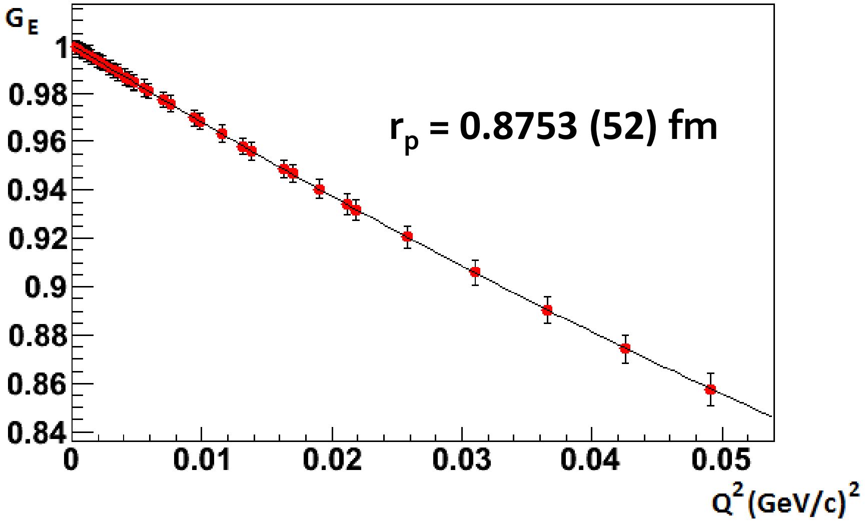
Radius extraction

- 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

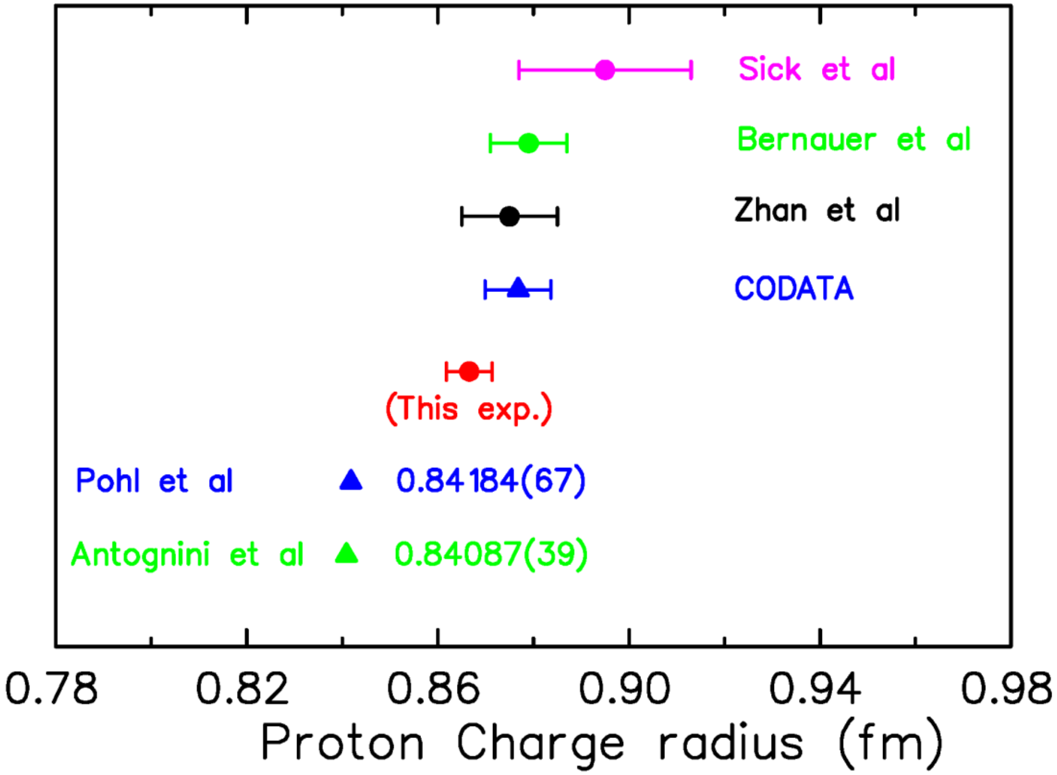


Including 3.3 GeV beam up to 4 deg



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

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PRad Collaboration

JLab experiment E12-11-106

Jefferson Lab
NC A&T State University
Duke University
Idaho State University
Mississippi State University
Norfolk State University
University of North Carolina at Wilmington
Old Dominion University
University of Kentucky
College of William & Mary
Argonne National Lab
Hampton University
University of New Hampshire
Tsinghua University