Proton Charge Radius Experiment (PRad) in Hall B, JLab

Few Body 21

On behalf of the PRad collaboration

Chao Peng

Duke university

05/05/2015

Outline

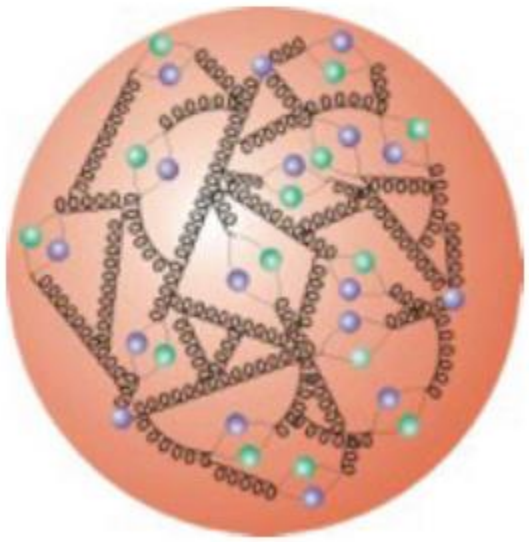
- Physics motivation
- PRad experiment
  - Experimental apparatus
- Simulations for PRad
  - Target simulation
  - Background study
  - Radiative corrections
  - Radius extraction
- Precision Projection

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

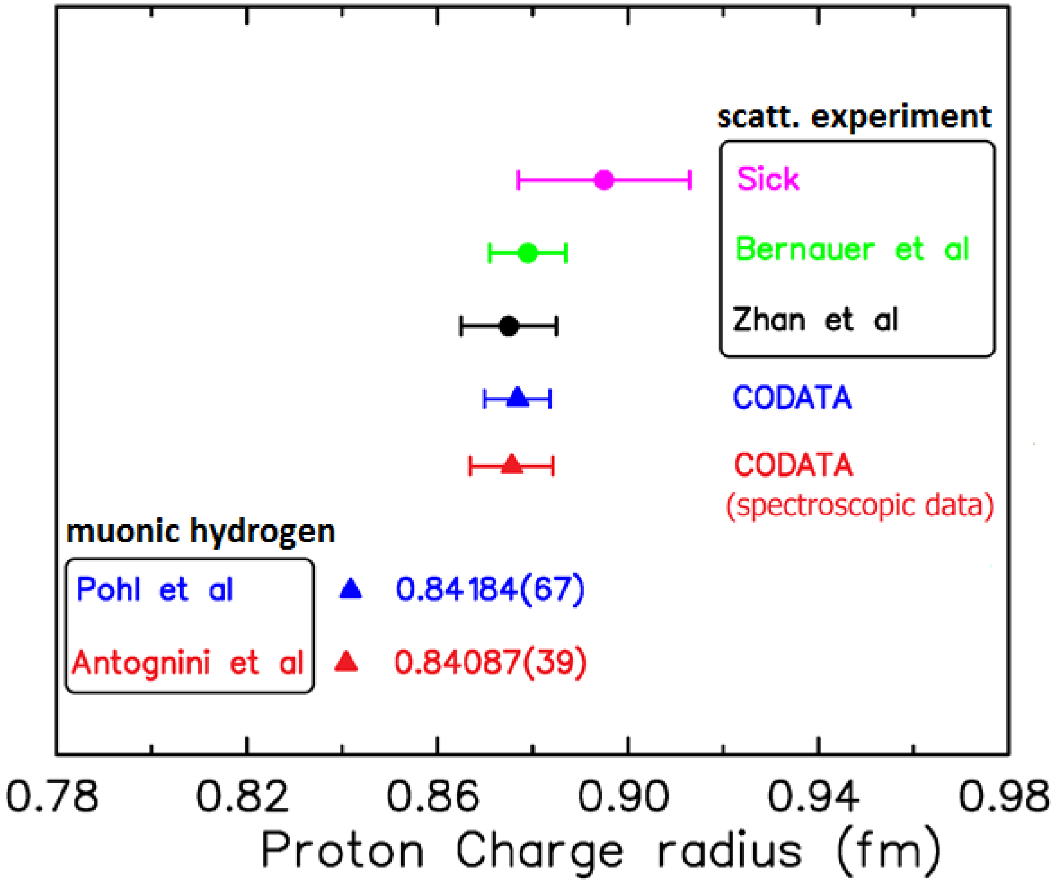
Physics motivation

- 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

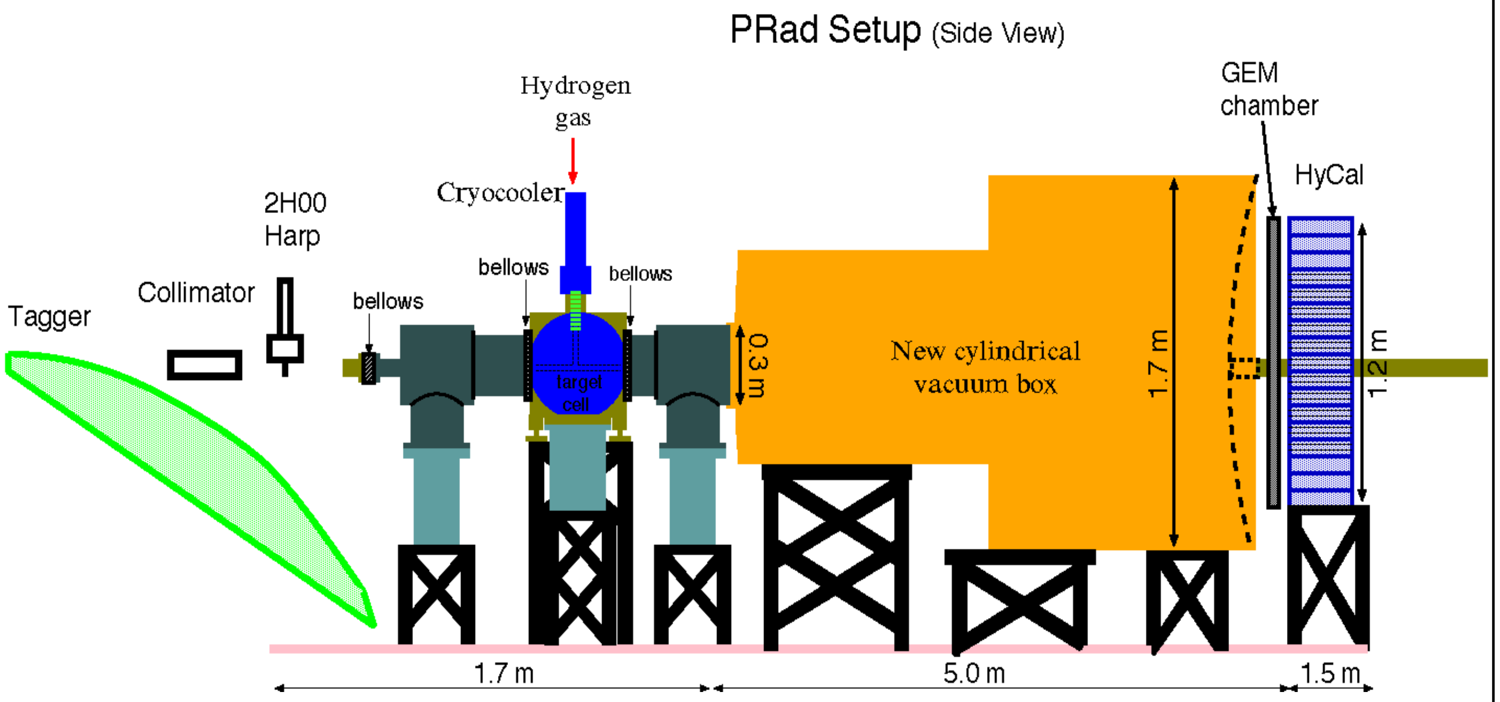
4, 5, 6



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: D. Dutta, H. Gao, A. Gasparian (contact) and M. Khandaker

Experimental apparatus

- Windowless gas-flow target
  - Removed the typical background source from target windows

- Expected target thickness ~10^{18} atoms/cm^2 at 25 K

- Minimized the material for low background from beam halo

Target chamber

Target cell

Experimental apparatus

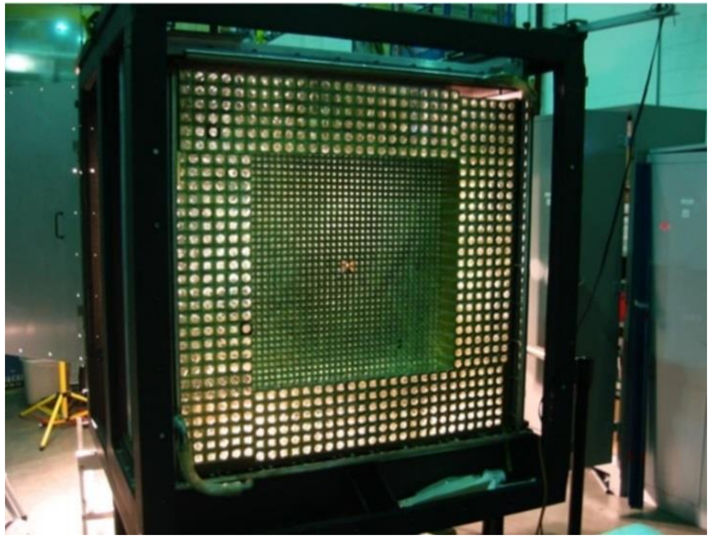
- The vacuum box will be directly connected to the beam pipe
  - It removes the background from other materials on the beamline

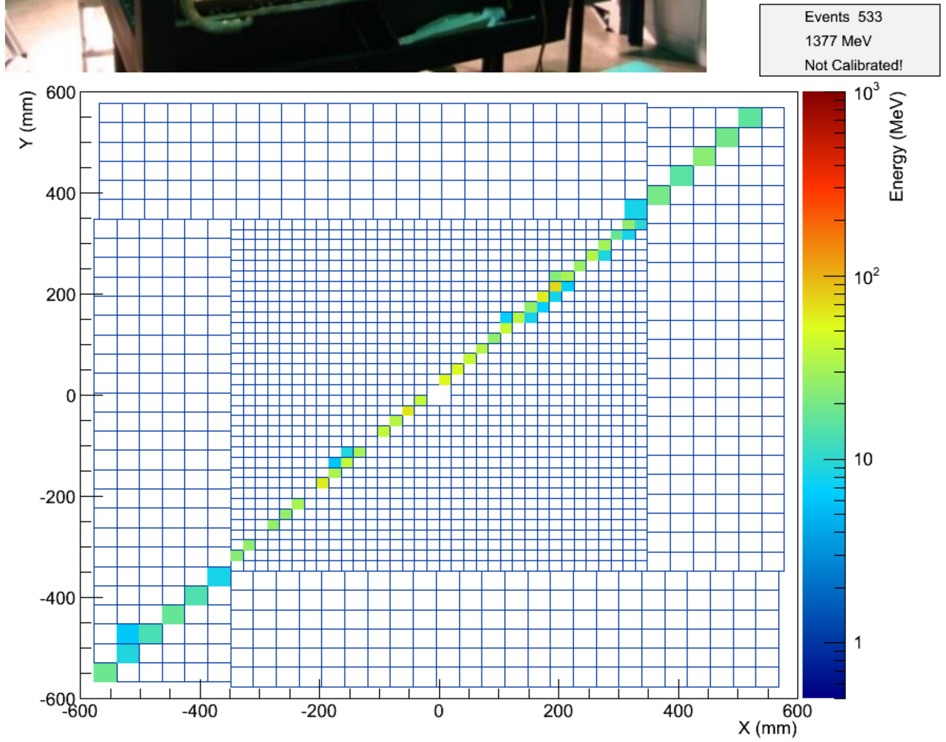
Vacuum box vessel

Think window

Experimental apparatus

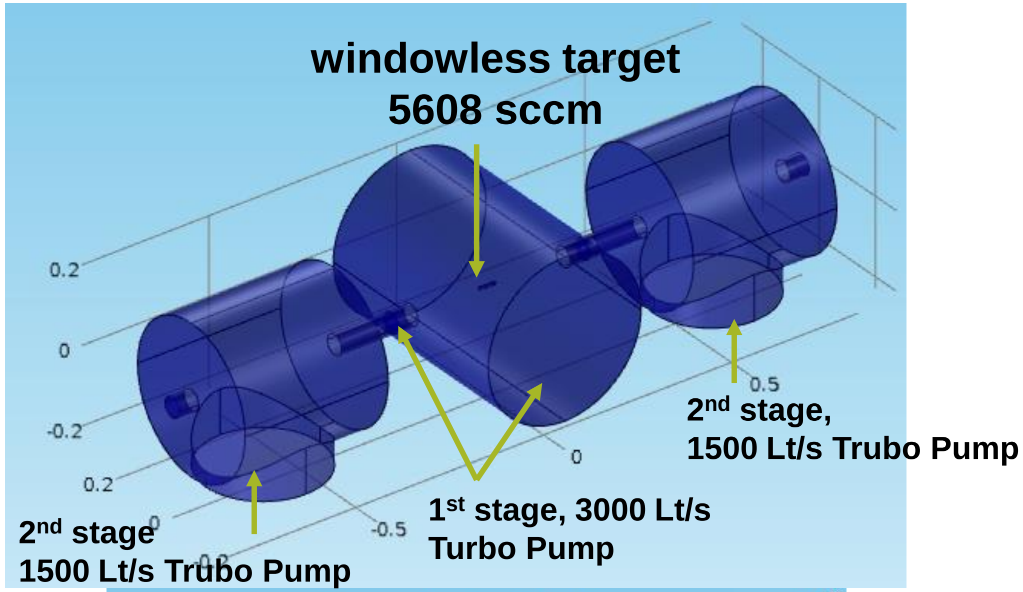
- High resolution hybrid calorimeter (HyCal)
  - Built by the PrimEx collaboration at Jlab
  - $\mathrm{PbWO_4}$ crystal + lead glass
- Central part (crystal) resolution
  - $\sigma_E/E = 2.6\%/\sqrt{E}$, $\sigma_{x,y}/E = 2.5\ mm/\sqrt{E}$
- Gas electron multiplier (GEM)
  - At the upstream of HyCal
  - Improve the position resolution to $0.1\ mm$

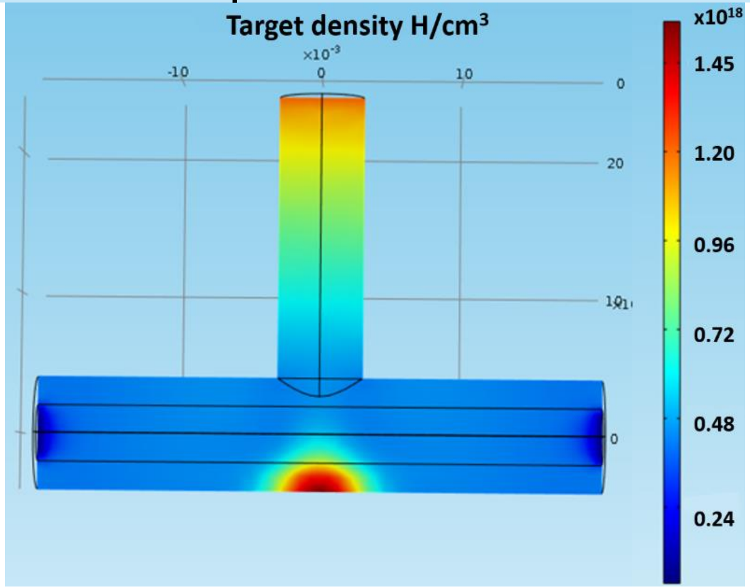




Target simulation

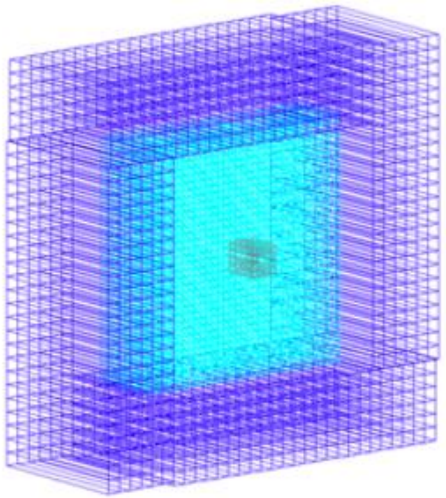
- Target density was studied by COMSOL Multiphysics, and verified by target test
- Surface pressure of the chambers
  - 1^{st} stage: 6×10^{-4} torr
  - 2^{nd} stage: 9×10^{-6} torr, satisfies beam line vacuum requirements
- Gas density and target thickness
  - Target thickness at center: 3.42×10^{18}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



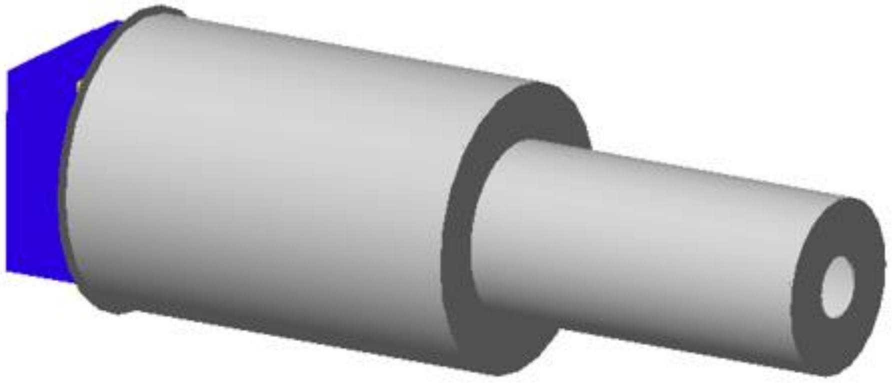


Background study

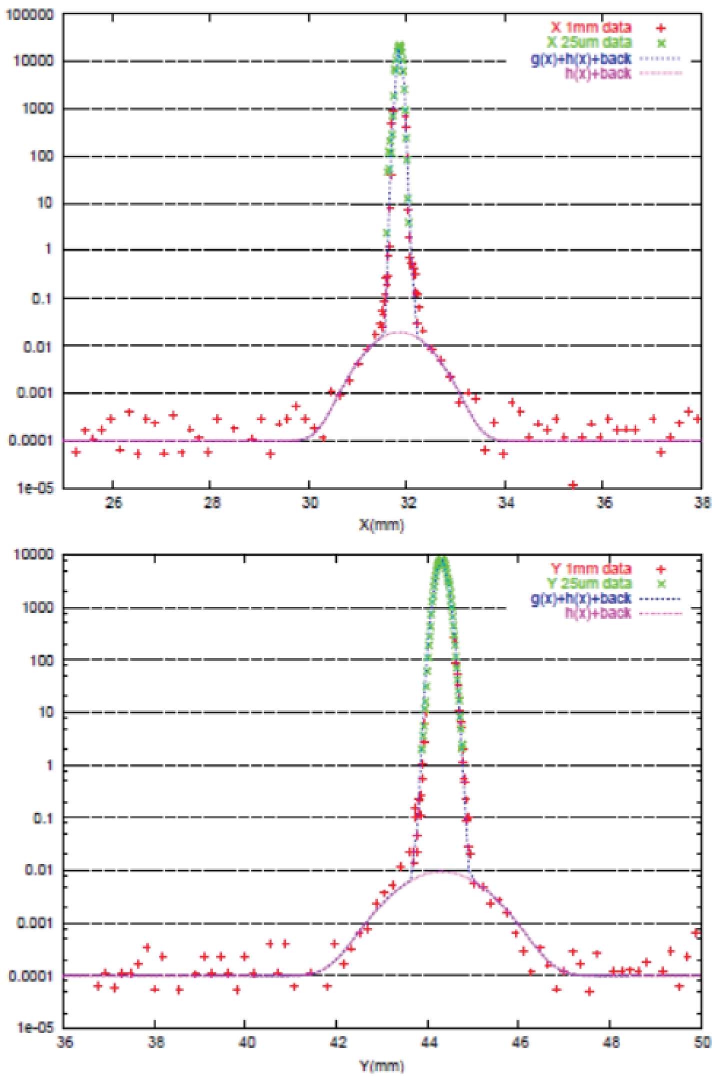
- Full simulation based on Geant4
- The primary background source is the electron-nuclei scattering of beam halo from the target structure
- Minimize the background: Subtraction from the empty target run



HyCal in frame view



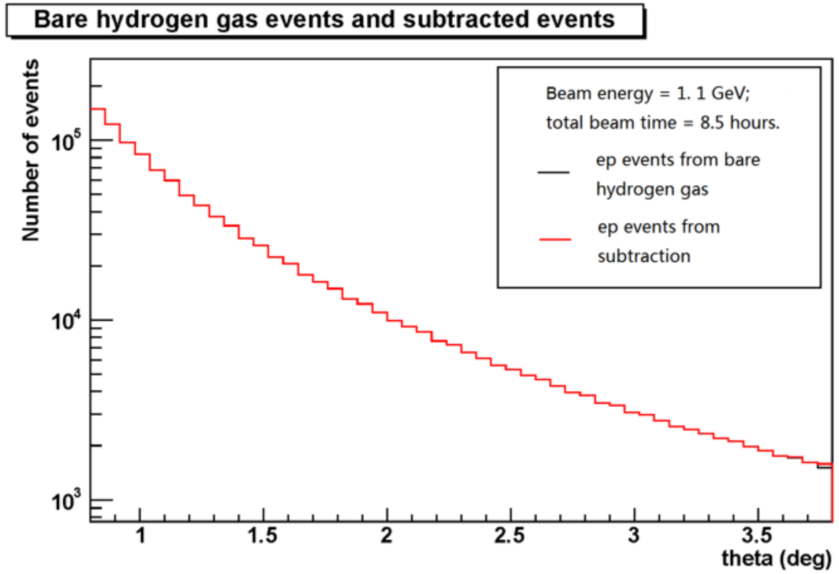
Geometries in the code

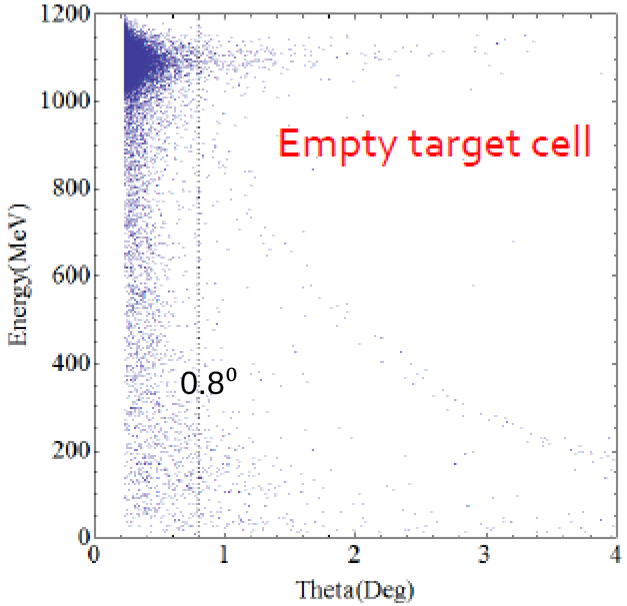


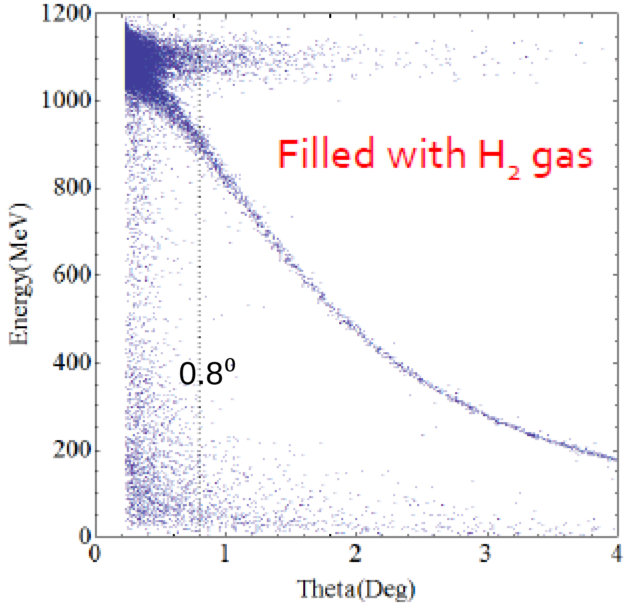
Beam profile for 6 GeV machine
From A. P. Freyberger

Background study

- Empty target run for background subtraction
- Statistical uncertainties < 0.5% according to the simulation
- Systematic uncertainty ~ 0.4% with the assumption of 1% uncertainty on the measured beam charge, (Normalize to Møller process will further improve it)



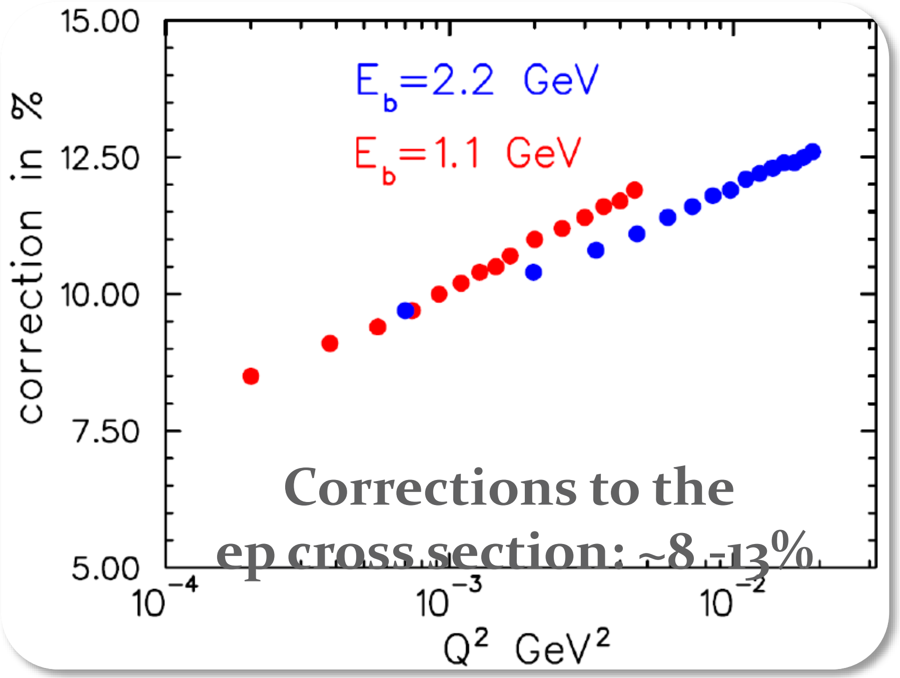


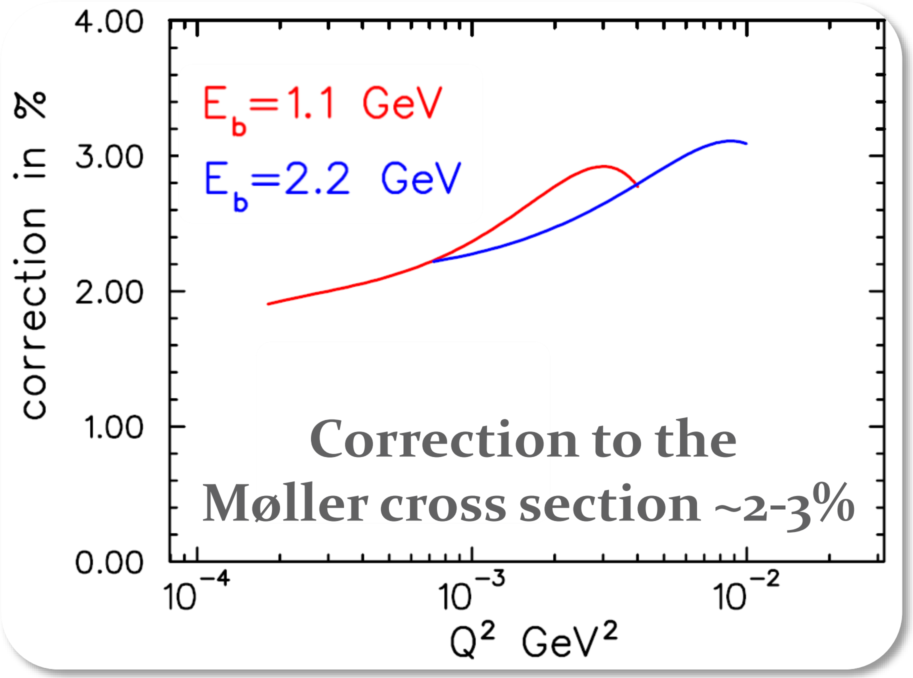


Work by M. Meziane (Duke)

Radiative corrections

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

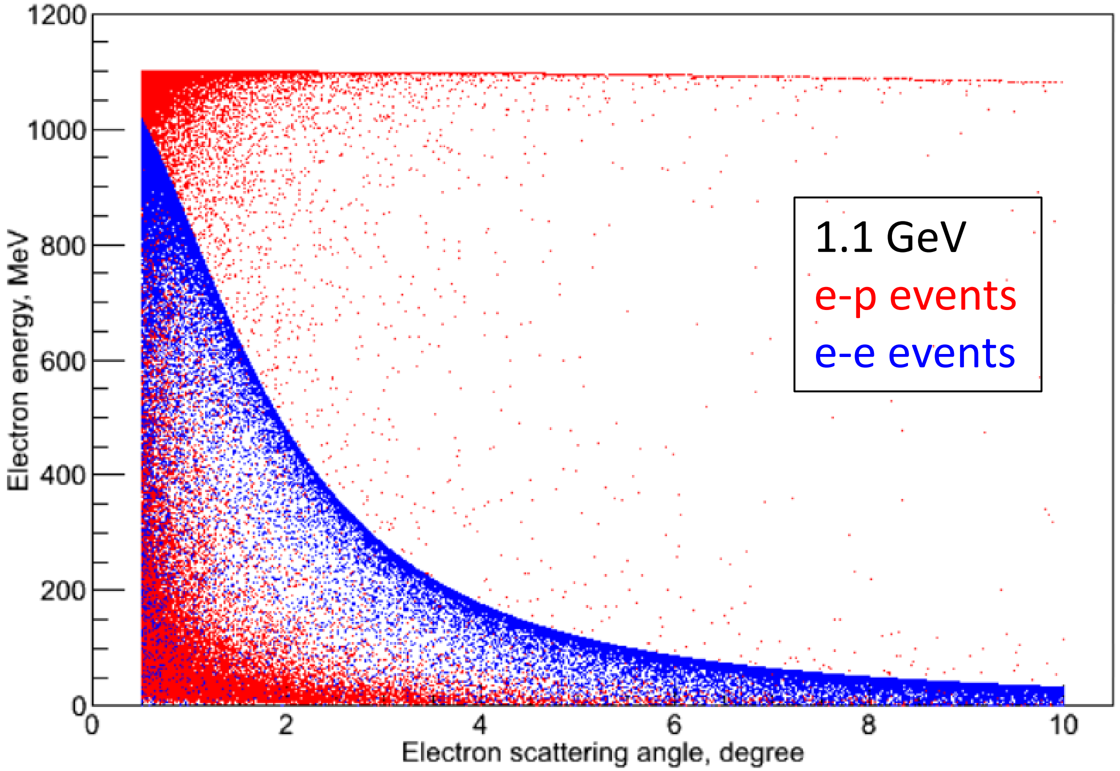




I. Akushevich, H. Gao, A. Ilyichev, and M. Meziane, Eur. Phys. J. A 51, 1 (2015)

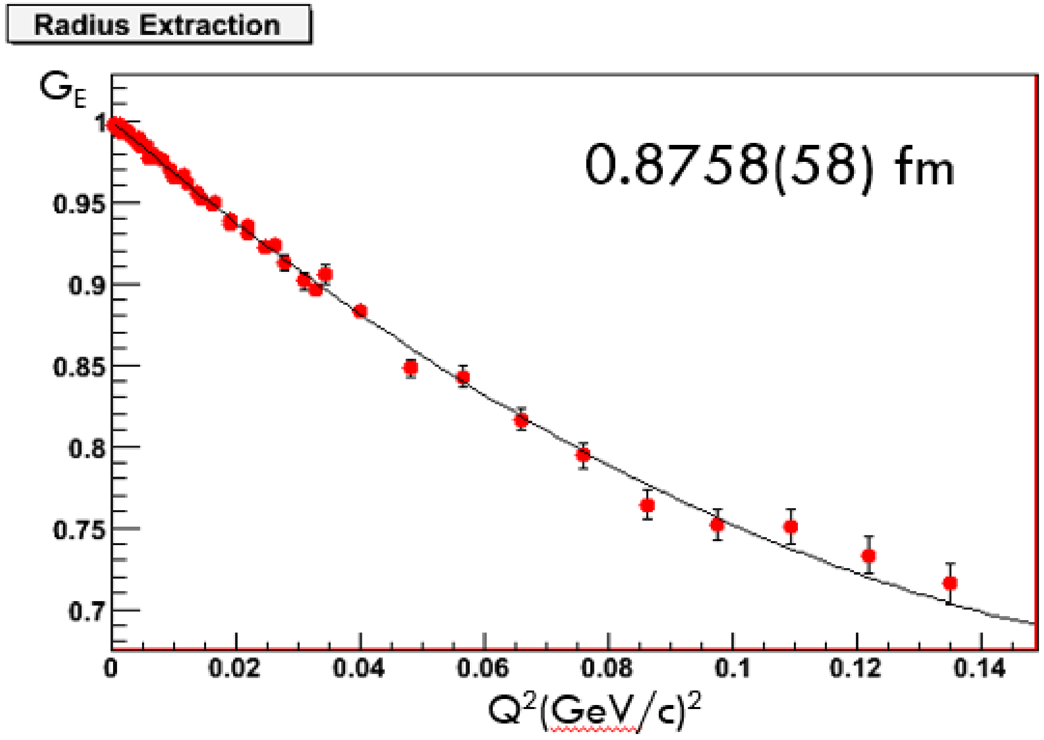
Radiative corrections

- We also use another event generator with RC for cross check
- It is developed by A. Gramolin
  - Lowest order QED radiative corrections
  - First order bremsstrahlung without soft-photon or ultra-relativistic approximations



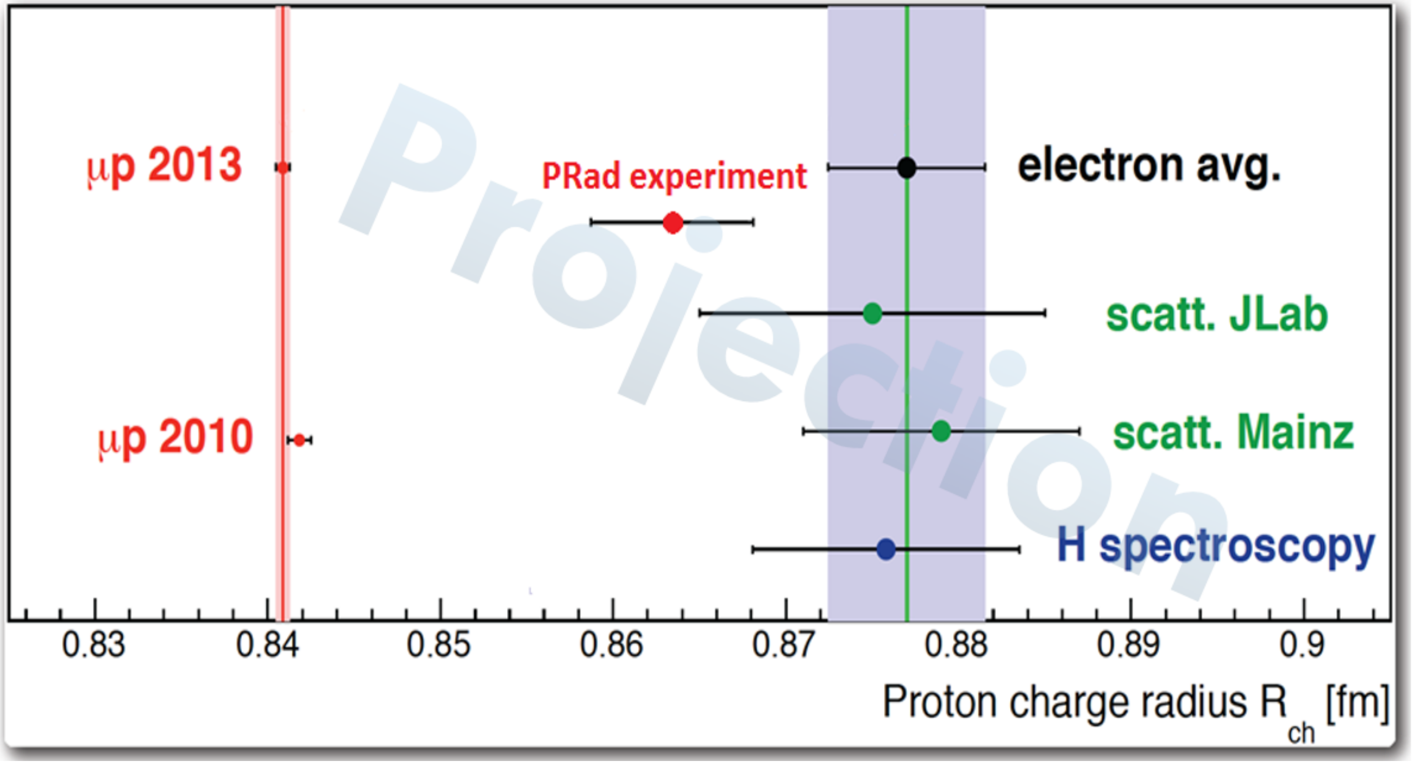
Radius extraction

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



Precision Projection

- The precision of the extracted radius is expected to be sub-percent



Thank you

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

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