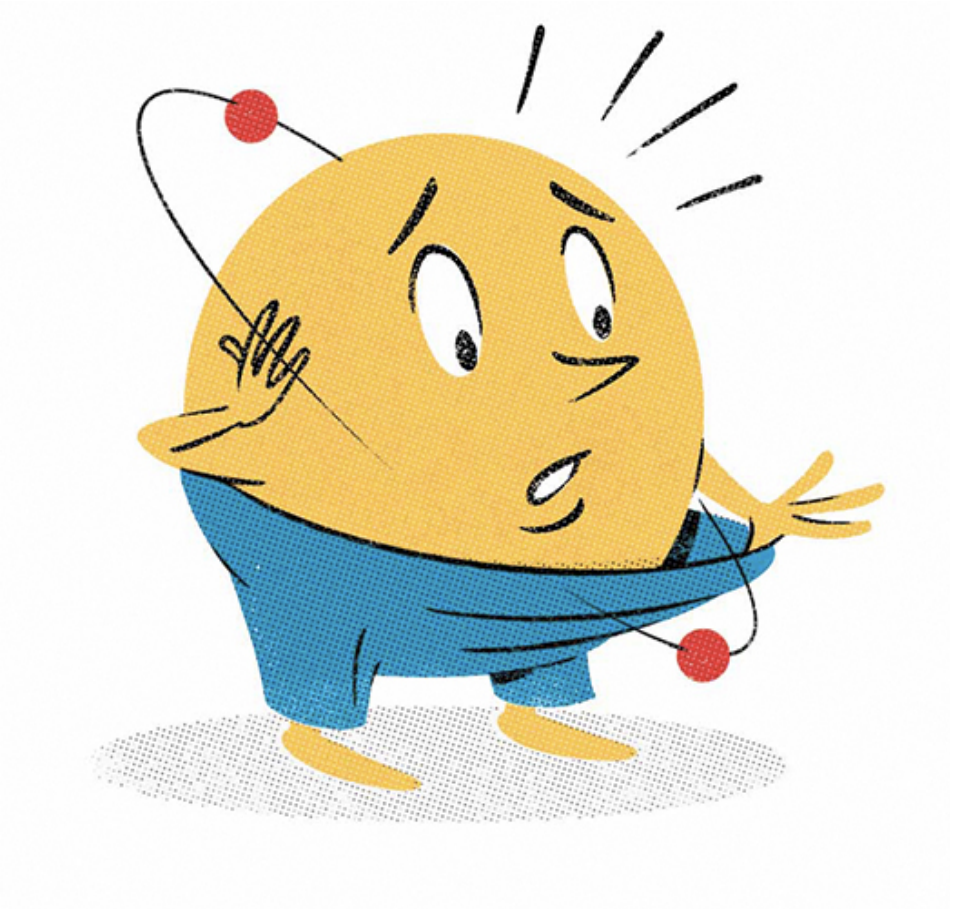
Proton Charge Radius (PRad) Experiment at Jefferson Lab

Weizhi Xiong
Duke University
For the PRad Collaboration
Spokespersons: A. Gasparian, H. Gao, M. Khandaker, D. Dutta

SPIN 2016
Septempter 26th, 2016

Outline

- The proton charge radius puzzle
- PRad experiment at Jefferson Lab
  - Experimental goal and approach
  - PRad apparatus
  - Data acquisition status
- Preliminary online analysis results

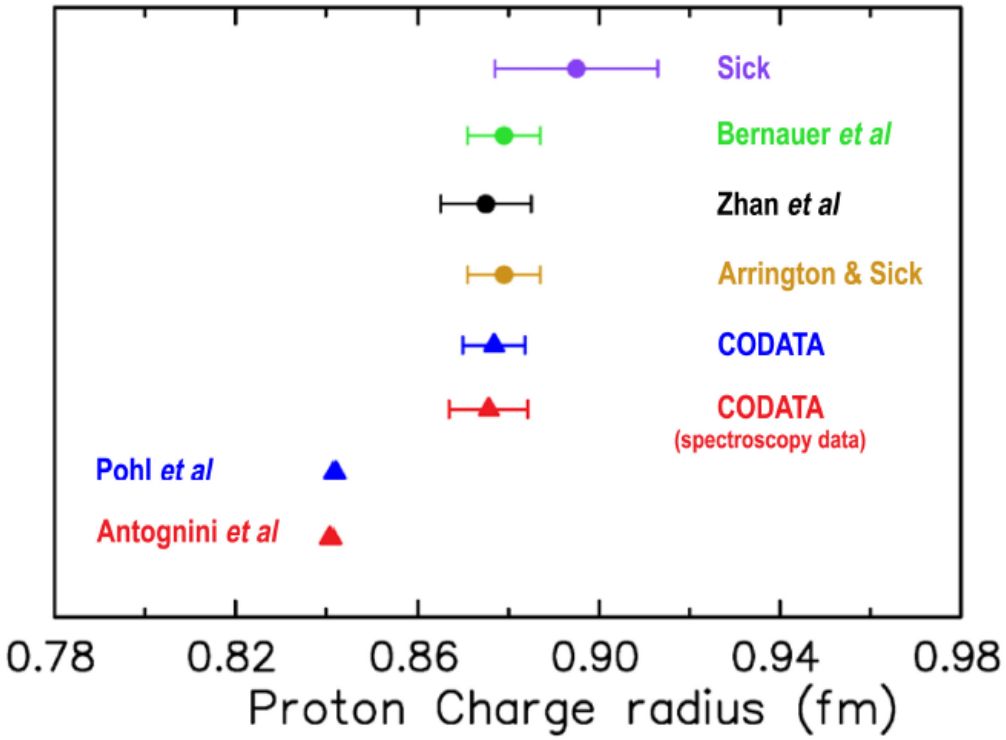


Proton Charge Radius Puzzle

- Electronic measurement (ep elastic + ordinary H spectroscopy) v.s. muonic measurement (muonic H spectroscopy)

- μp Lamb shift measurements by CREMA (2010, 2013)
  - Unprecedented precision, <0.1%
  - 7σ away from CODATA 2012 recommended value

- The discrepancy is not understood yet. New experiment with different systematic is necessary



Proton Charge Radius from ep Elastic Scattering

- Elastic ep scattering, in the limit of Born approximation (one photon exchange):

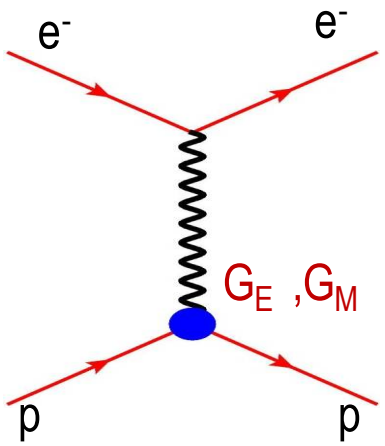
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left(G_E^{p\,2}(Q^2) + \frac{\tau}{\varepsilon} G_M^{p\,2}(Q^2)\right)$$

$$Q^2 = 4EE' \sin^2\frac{\theta}{2} \qquad \tau = \frac{Q^2}{4M_p^2} \qquad \varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$

- Structure-less proton:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} = \frac{\alpha^2\left[1 - \beta^2 \sin^2\frac{\theta}{2}\right]}{4k^2 \sin^4\frac{\theta}{2}}$$

- G_E and G_M were extracted using Rosenbluth separation, or at extremely low Q^2 the G_M can be ignored



Taylor expansion of G_E at low Q^2

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

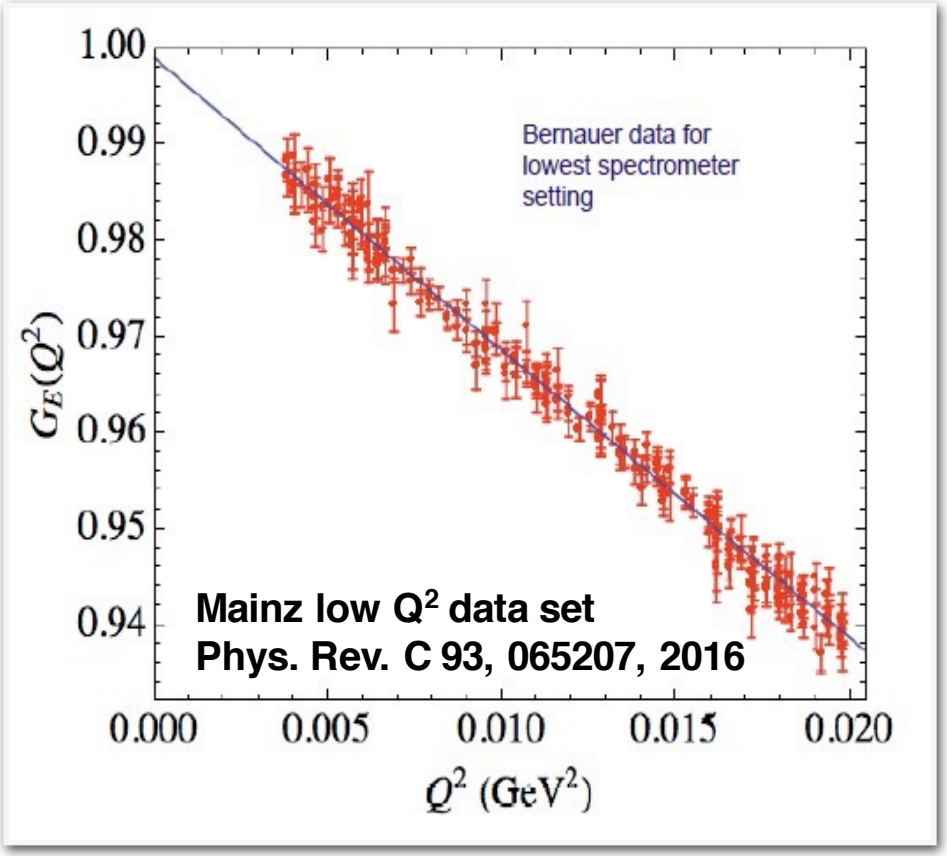
Derivative at low Q^2 limit

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

PRad Experiment Overview

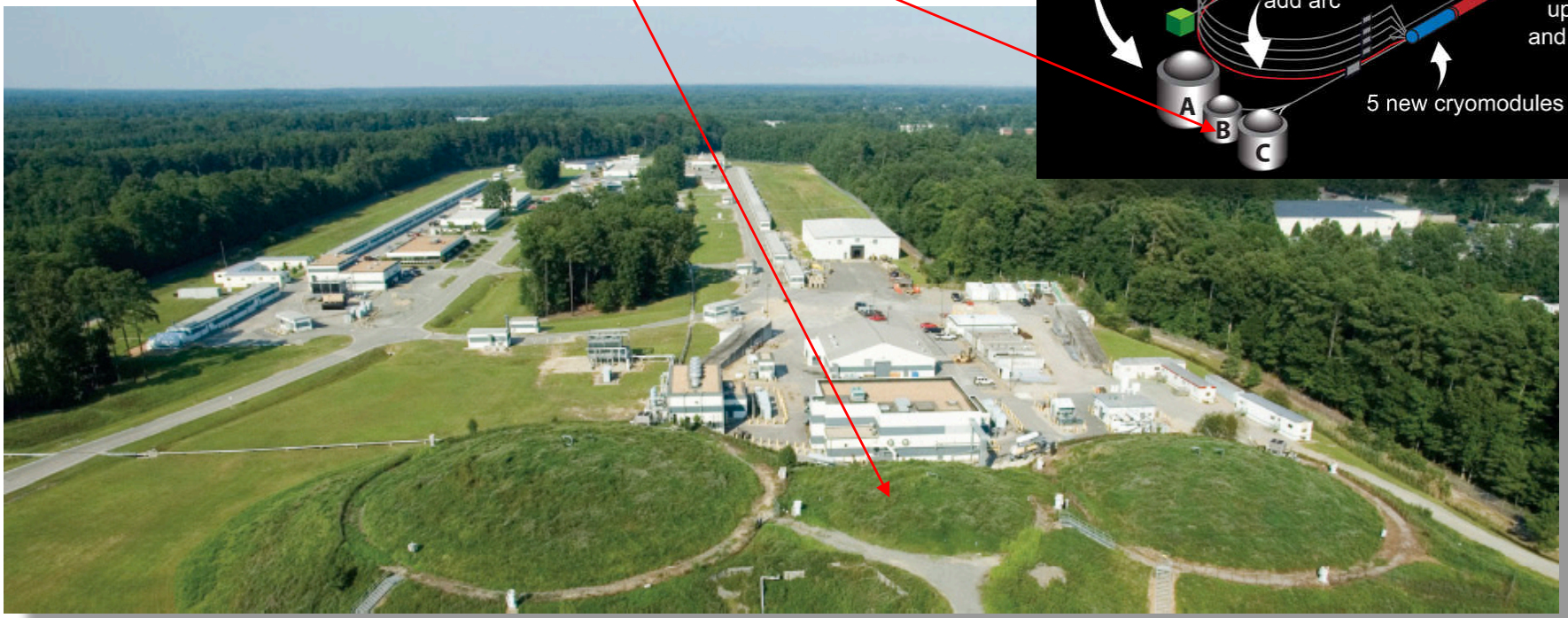
- PRad goal: Measuring proton charge radius using ep elastic scattering

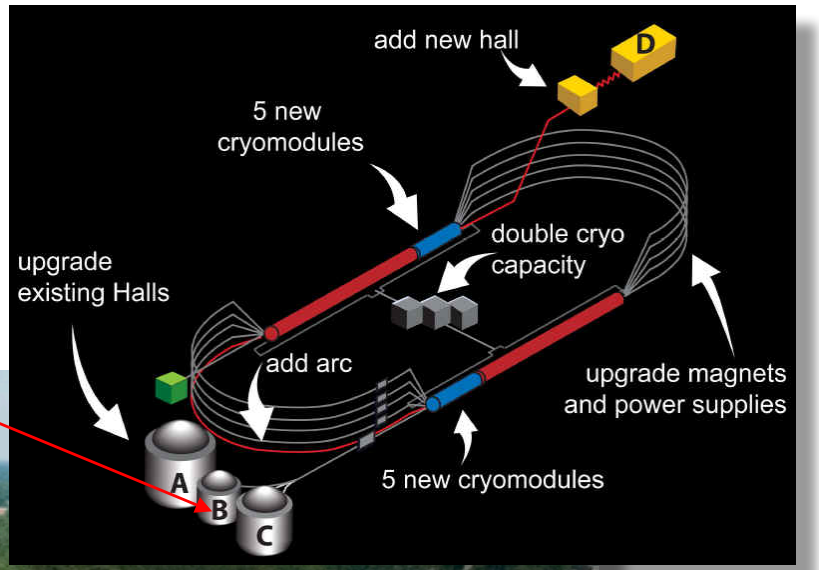
- Unprecedented low Q^2 (~2×10^{-4} GeV^2)
  - Fill in very low Q^2 region
- Large Q^2 range in a single setting
  - ~2×10^{-4} - 6×10^{-2} GeV^2
- Calibrate to the simultaneously measured Møller scattering process
  - best known control of systematics
- Aims to extract cross section and radius to sub-percentage level



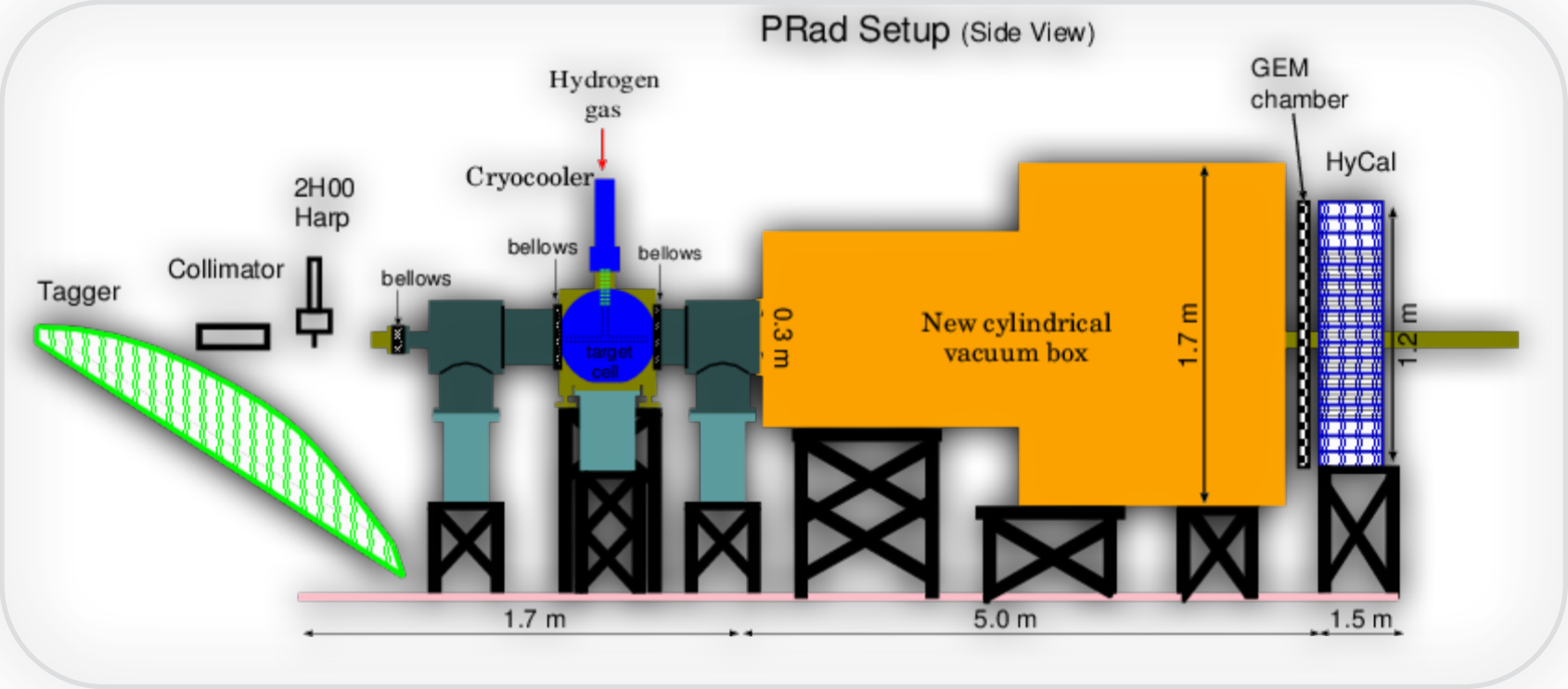
Jefferson Lab CEBAF Accelerator Facility

PRad experiment was performed in Hall B at Jefferson Lab





PRad Experimental Apparatus

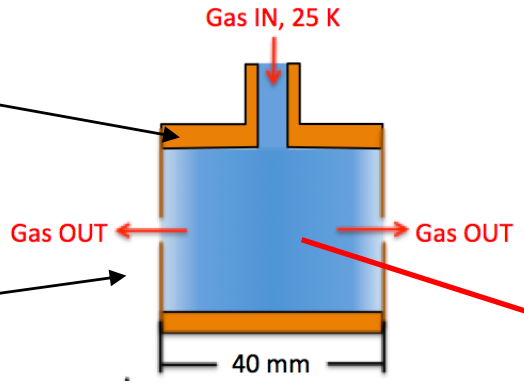


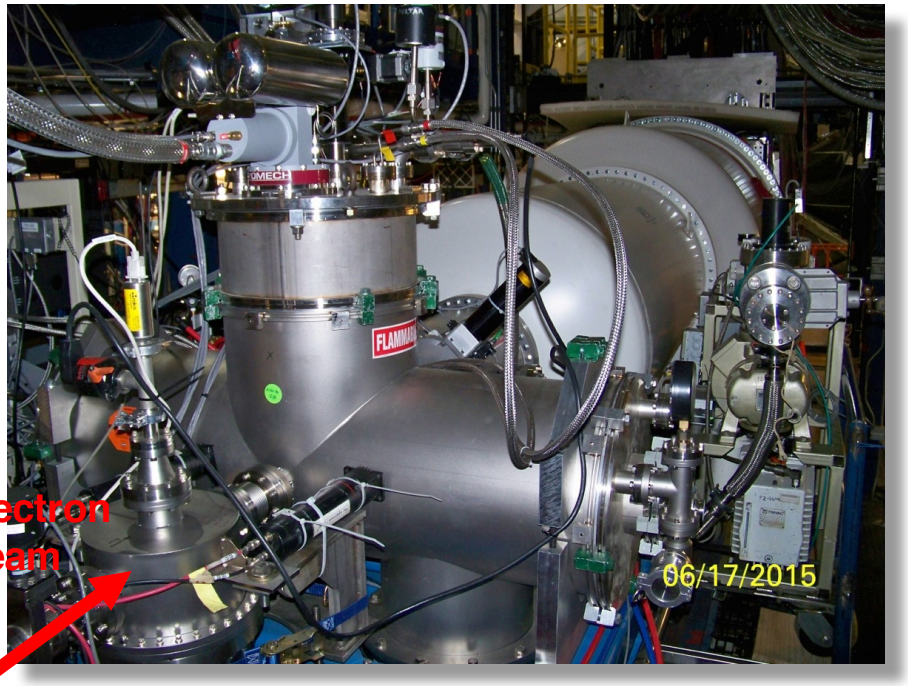
- Windowless, high density H_2 gas flow target (background control)
- Vacuum box, one thin window at downstream
- High resolution and high efficiency, Hybrid calorimeter (HyCal)
- Two Large area Gas Electron Multipliers, improve position resolution

Windowless Gas Target

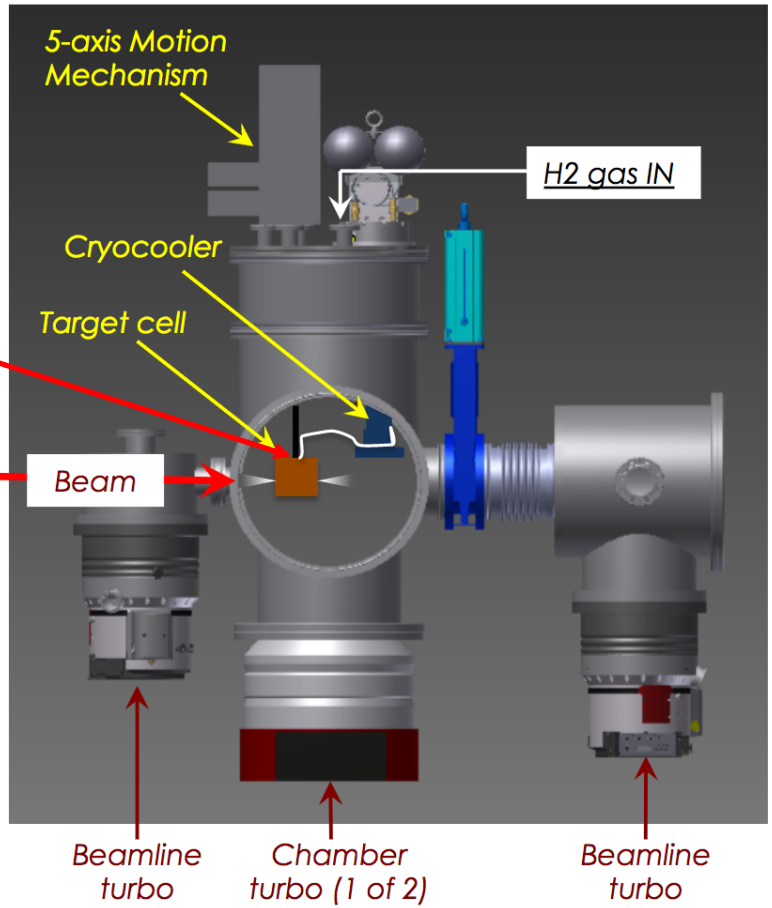
Target cell
(8 cm dia x 4 cm long copper)

7.5 μm kapton foil with 2mm hole





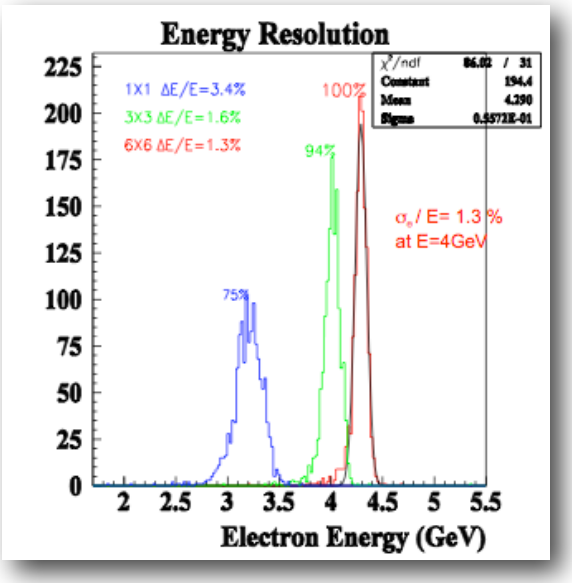
Electron Beam



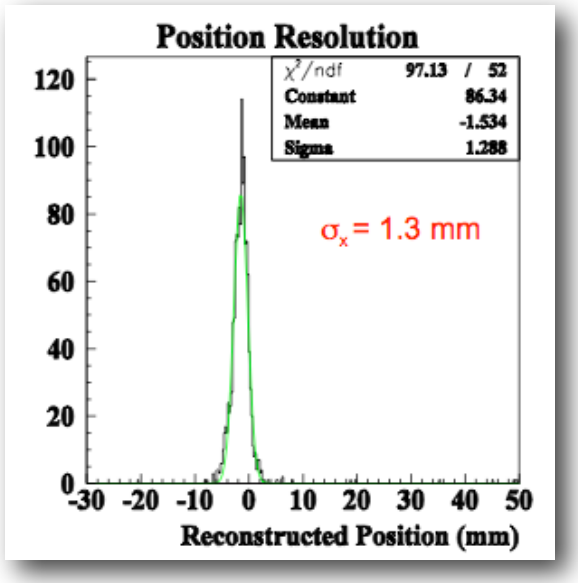
Areal density: ~2 x 10^{18} H atoms / cm^2
Cell / chamber / vacuum tank pressure:
470 mtorr / 2.3 mtorr / 0.3 mtorr

Hybrid Calorimeter (HyCal)

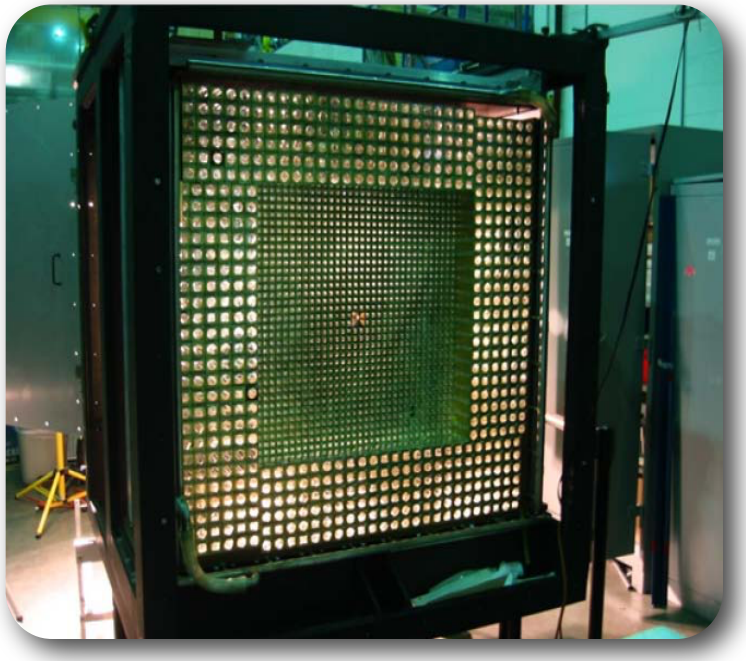
- Used in the PrimEx experiment
- $PbWO_4$ and Pb-glass calorimeter (118x118 cm^2)
- 576 Pb-glass detectors (3.82x3.82 cm^2 x45 cm)
- 5.8 m from the target
- ~0.5 sr acceptance

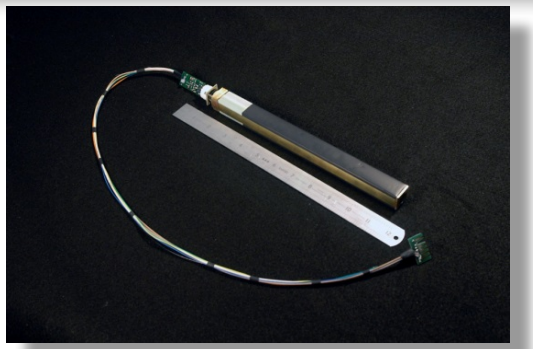


$PbWO_4$ resolution:
$\sigma_E/E = 2.6\%/\sqrt{E}$
$\sigma_{xy} = 2.5\ mm/\sqrt{E}$



Pb-glass:
2.5 times worse

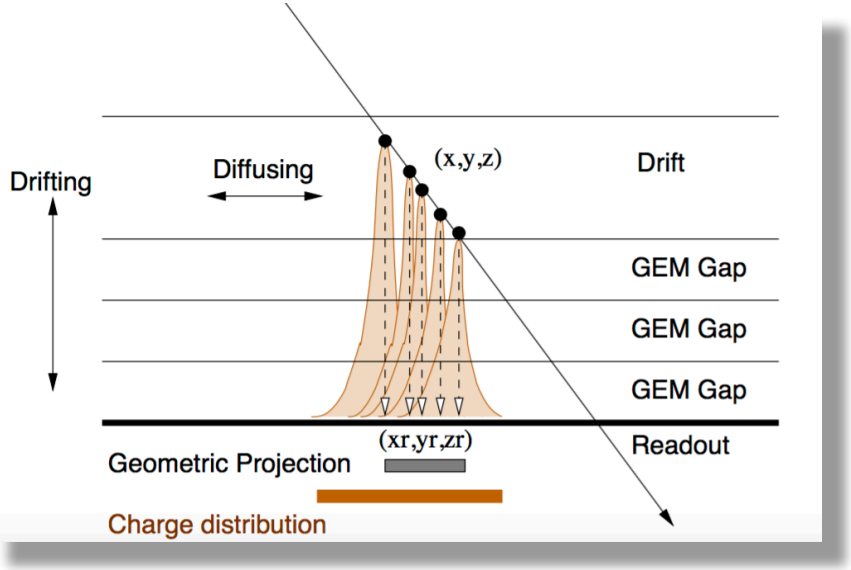


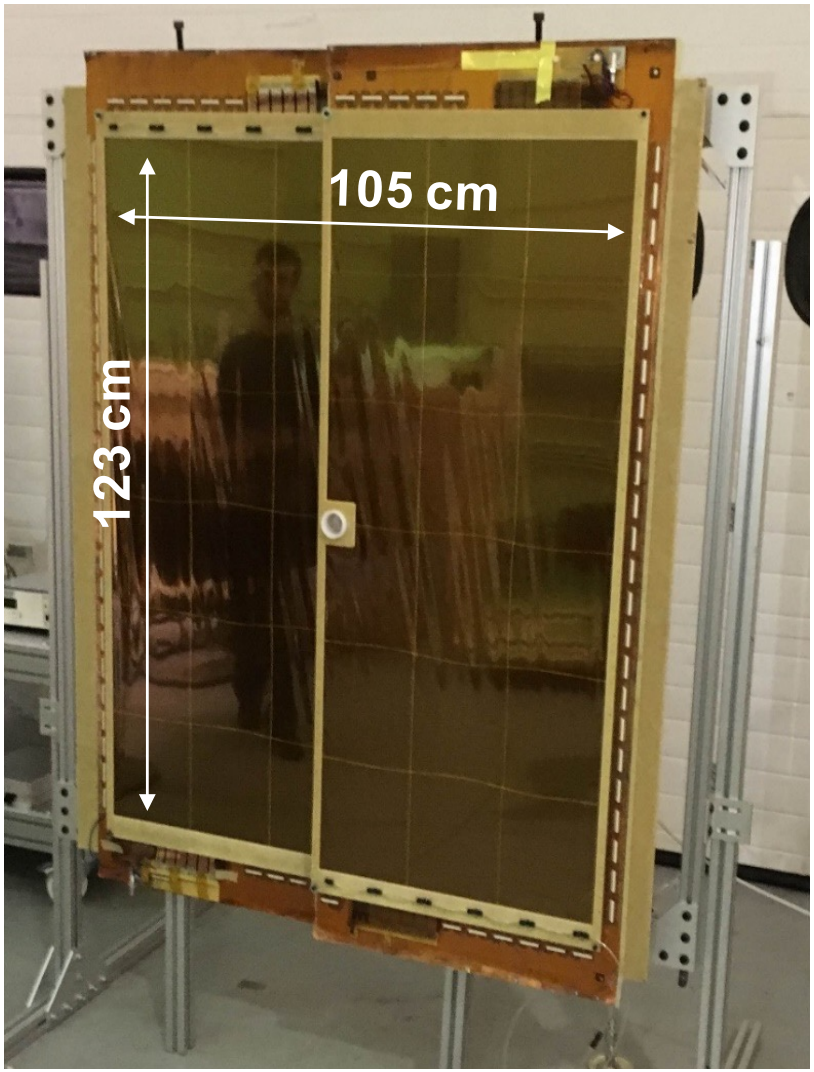


Gas Electron Multipliers (GEM)

- Two large area GEM detectors with 2D Cartesian readout planes
- ~100 μm position resolution

- The GEM detectors can provide:
  - >20 times improvement on position resolution
  - Similar improve for Q^2 resolution





PRad in Jefferson Lab Hall B

Beam-side view

GEMs mounted on HyCal

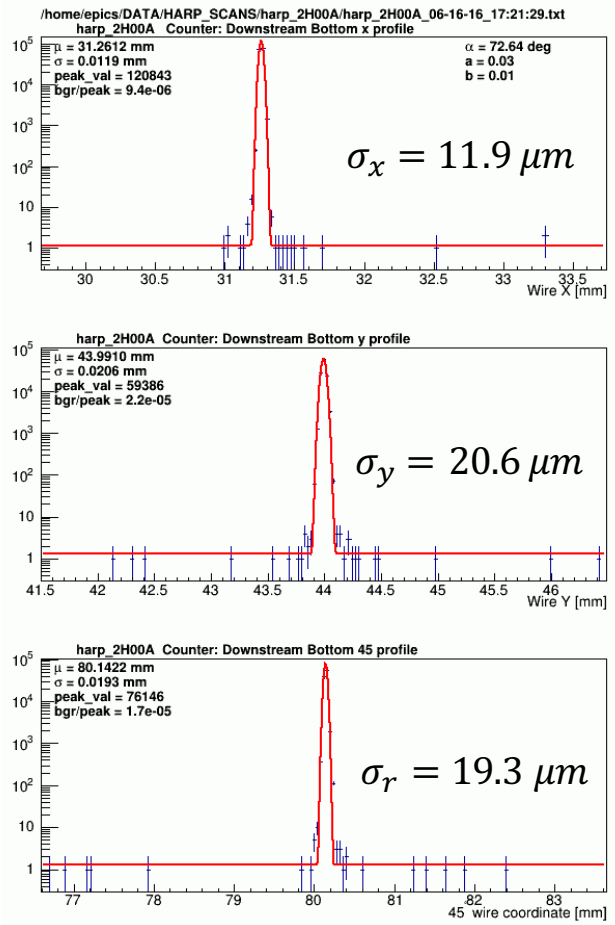
Experimental Data Collected

- Experiment ran in May - June 2016
- Large amount of data taken with high quality and stable electron beam from CEBAF
  - Beam position stability: ~250 μm
  - Beam width: ~ 25 μm

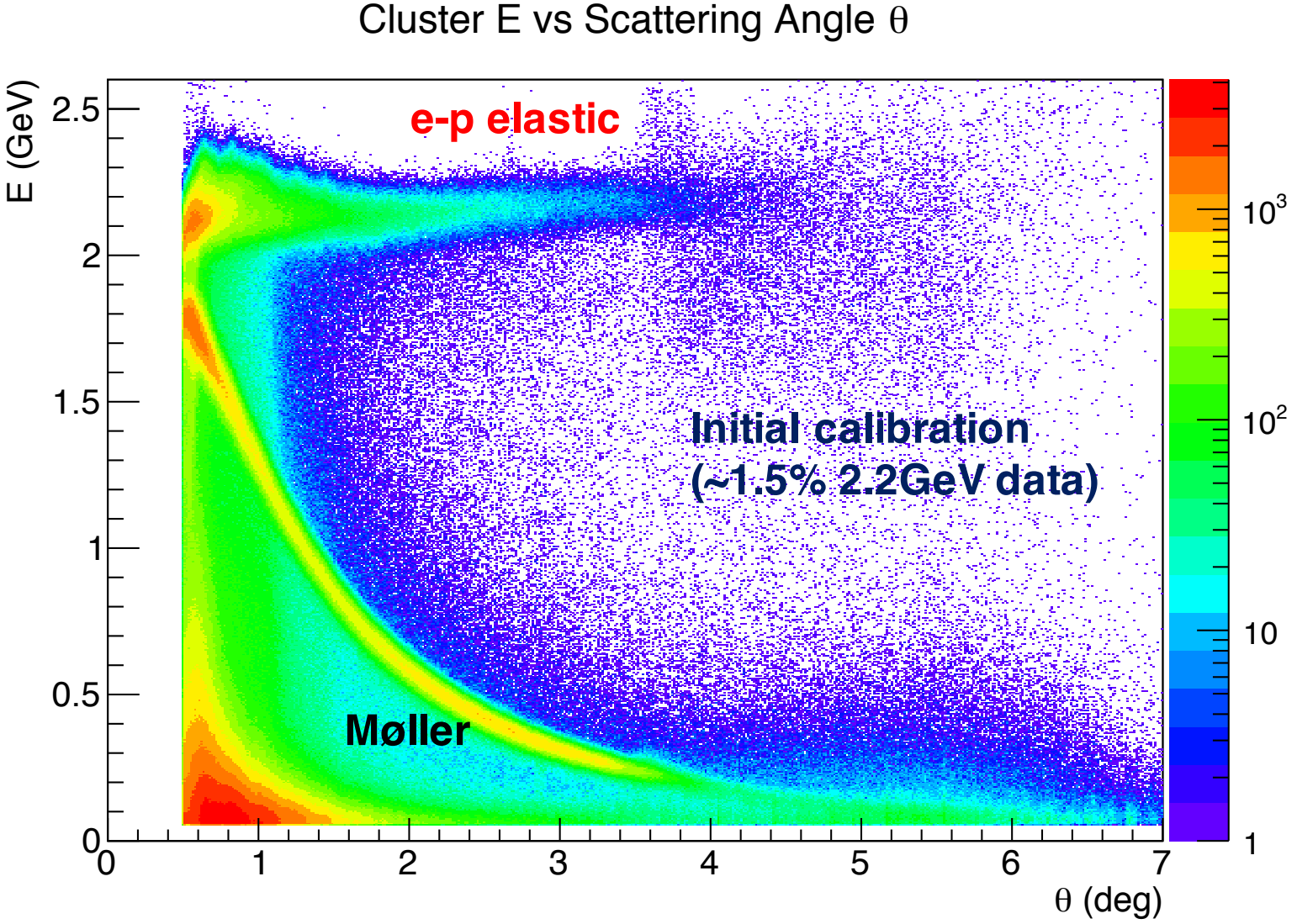
- Data taking with 1.1 GeV beam:
  - 604 M events with H_2 in cell
  - 53 M events without H_2 in cell
  - 25 M events with 1μm carbon foil target
  - Collected 4.2 mC on target (2x10^{18} H atoms/cm^2)

- Data taking with 2.2 GeV beam
  - 756 M events with H_2 in cell
  - 38 M events without H_2 in cell
  - 10.5 M events with 1μm carbon foil target
  - Collected 14.3 mC on target (2x10^{18} H atoms/cm^2)

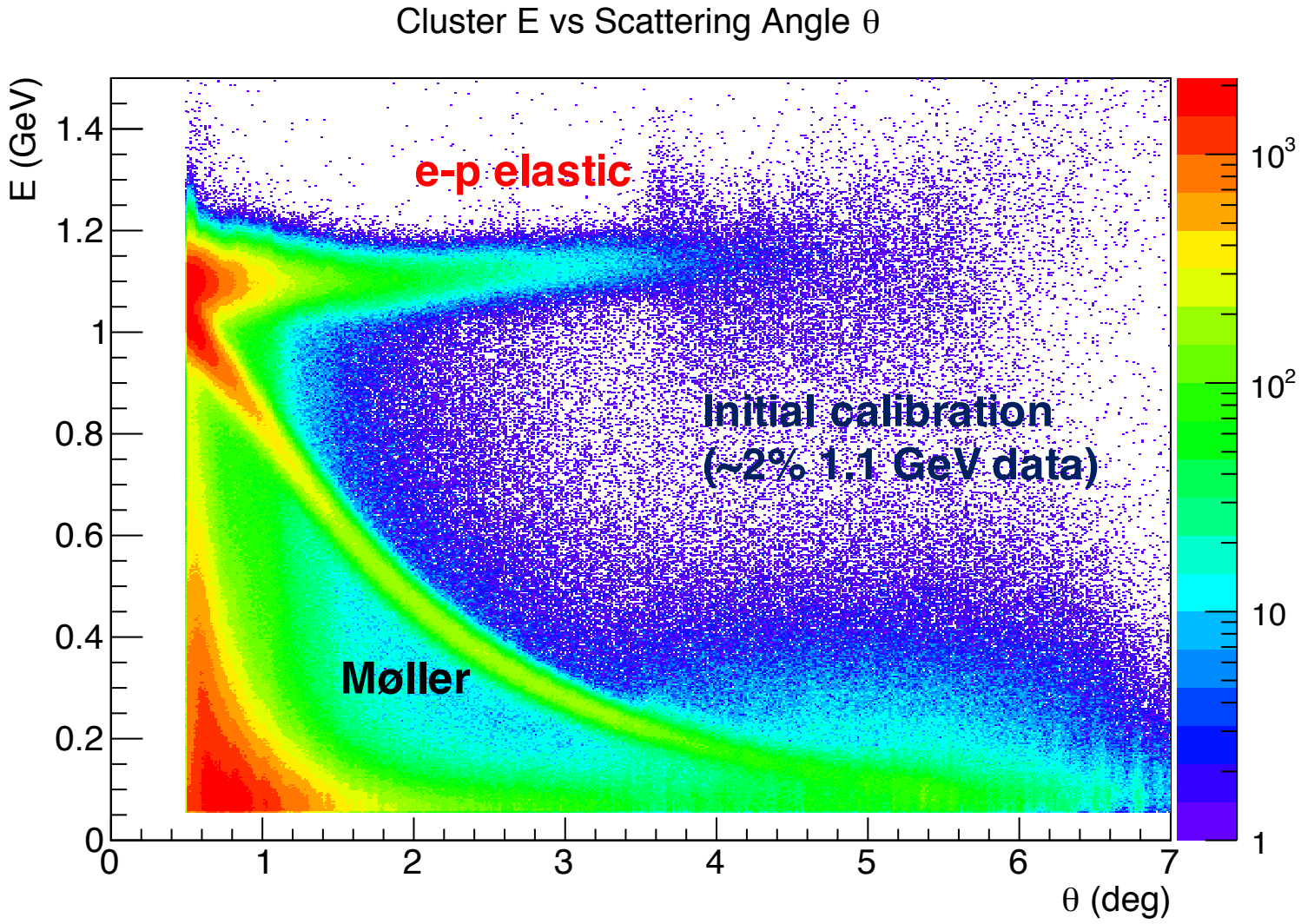
Example electron beam profile at target (measured with harp scan)



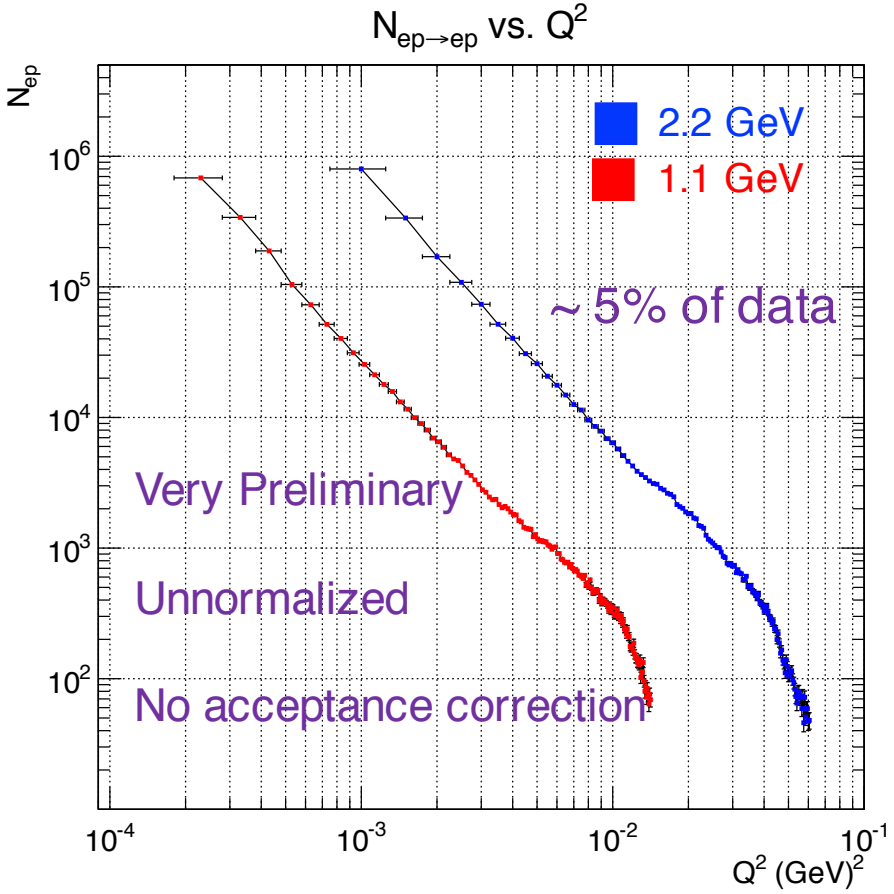
Preliminary Online Analysis Results

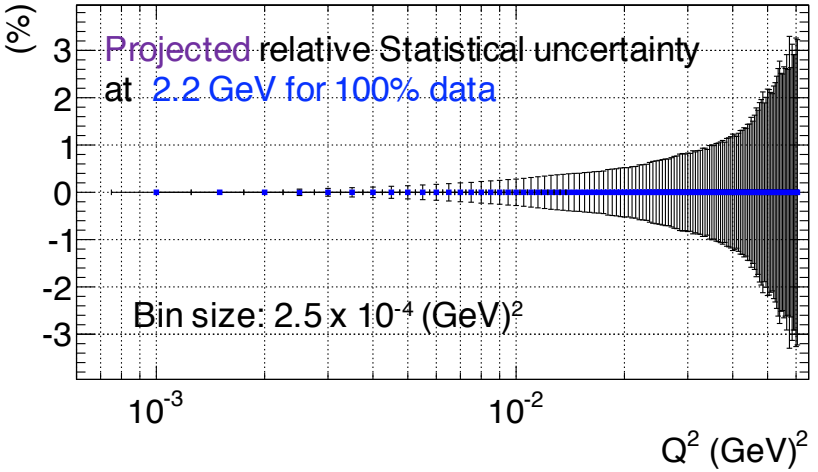


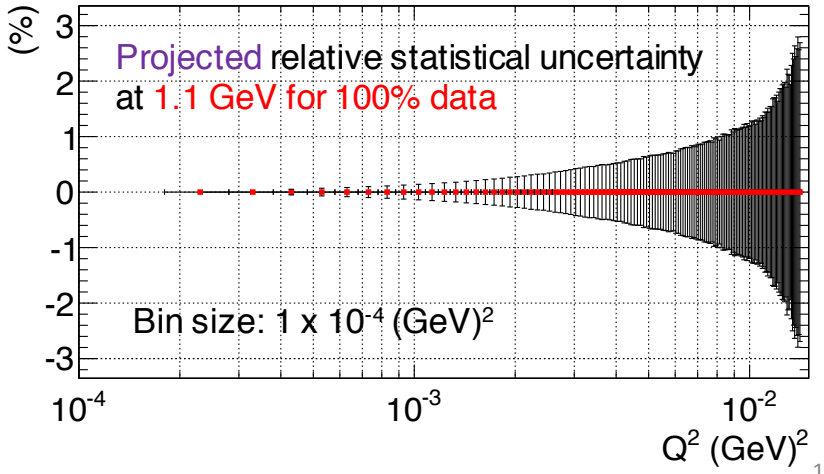
Preliminary Online Analysis Results



Preliminary Online Analysis Results







- Good Q^2 resolution and large statistics at low Q^2 will allow finer binning

The PRad Collaboration

Jefferson Lab,
NC A&T State University,
Duke University,
Idaho State University,
Mississippi State University,
Norfolk State University,
University of Virginia
University of North Carolina at Wilmington,
Old Dominion University,
University of Kentucky,
College of William & Mary,
Argonne National Lab,
Hampton University
Tsinghua University, China
ITEP, Moscow, Russia
Budker Institute of Nuclear Physics, Russia
MIT

Graduate students

Chao Peng (Duke)
Li Ye (MSU)
Weizhi Xiong (Duke)
Xinzhan Bai (UVa)
Abhisek Karki (MSU)

Post-docs

Mehdi Meziane (Duke)
Zhihong Ye (Duke)
Krishna Adhikari (MSU)
Maxime Lavillain (NC A&T)
Rupesh Silwal (MIT)

Summary

- The *Proton Radius Puzzle* is still unsolved after six years

- The PRad experiment is a unique piece to the Puzzle:
  - Lowest Q^2 data set (~2×10^{-4} GeV) has been collected for the first time in ep elastic scattering experiment
  - Data in a large Q^2 range (~2×10^{-4} – 6×10^{-2} GeV^2) has been collected with the same experimental setting
  - Large statistics, high quality, rich data has been collected
  - Systematic uncertainty well under control by simultaneous measurement of ep elastic and Møller processes

- Analysis is ongoing, first preliminary result expected soon

This work was supported by NSF-MRI grant PHY-1229153 and US DOE grant DE-FG02-07ER41528