Data Quality and Analysis Status of PRad Experiment at Jefferson Lab

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For the PRad Collaboration

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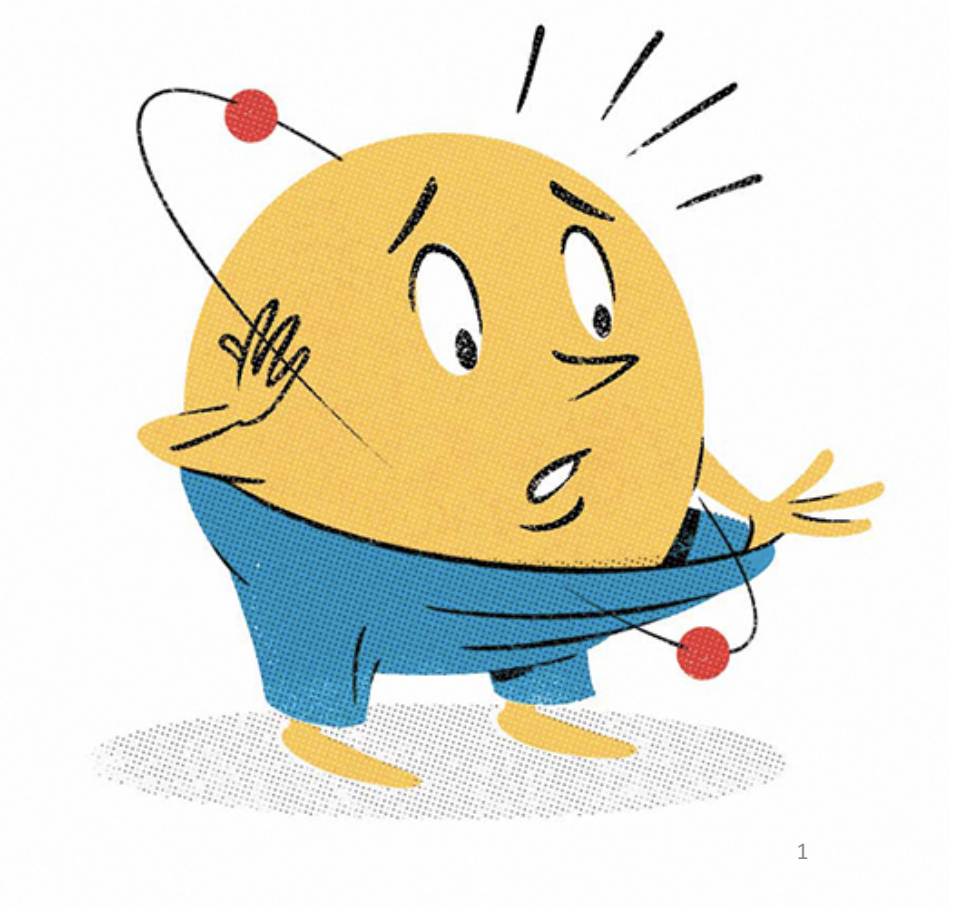
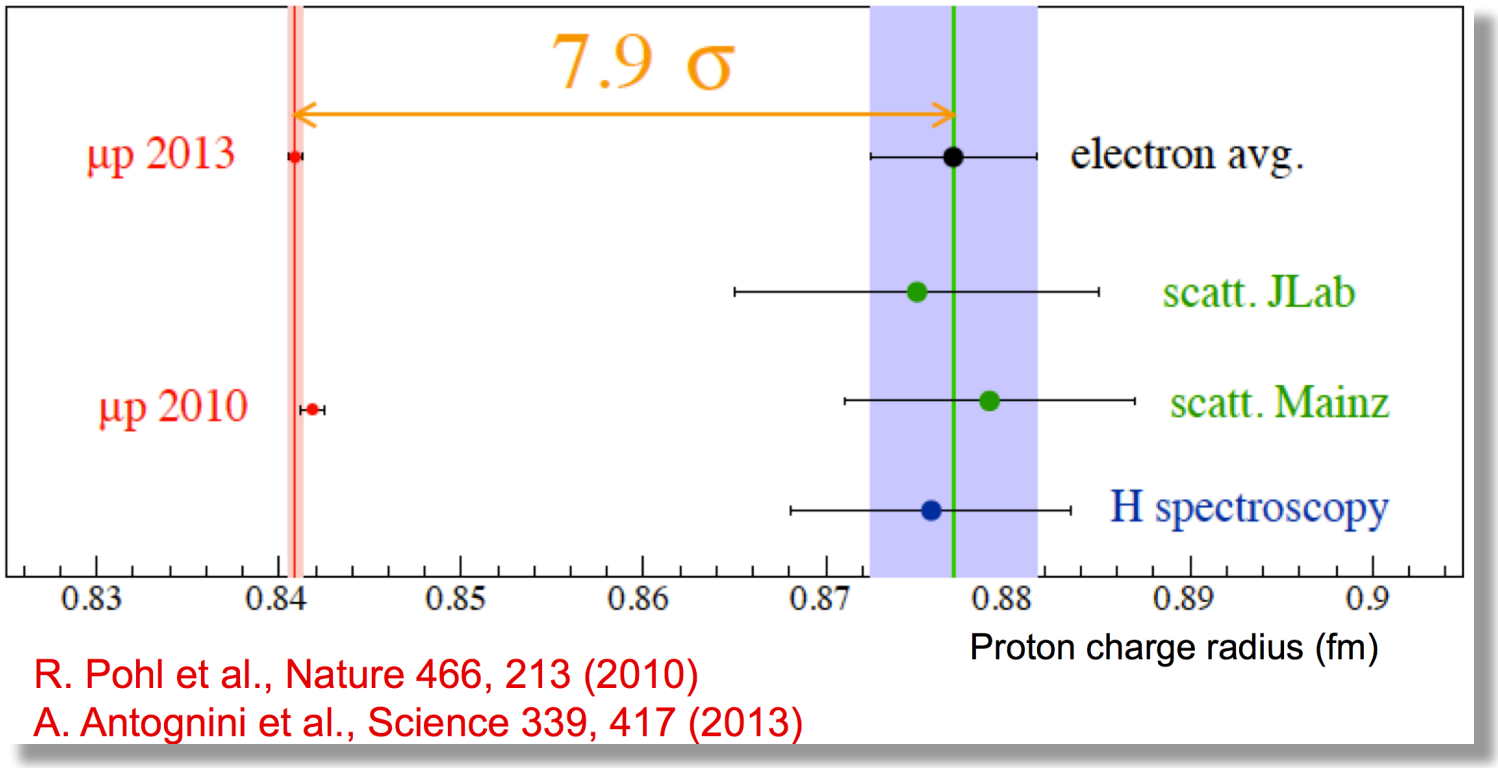
Outline

- Proton charge radius puzzle and PRad experiment
- PRad experimental apparatus
- Data quality and current status
- Summary



Proton Charge Radius Puzzle



R. Pohl et al., Nature 466, 213 (2010)
A. Antognini et al., Science 339, 417 (2013)

- 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%

Proton Charge Radius from ep Elastic Scattering

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

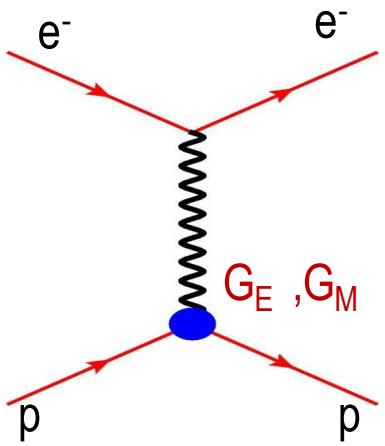
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left(G_E^{p\,2}(Q^2) + \frac{\tau}{\varepsilon} G_M^{p\,2}(Q^2)\right)$$

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

- 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 can be extracted using Rosenbluth separation
- For PRad, cross section dominated by G_E



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

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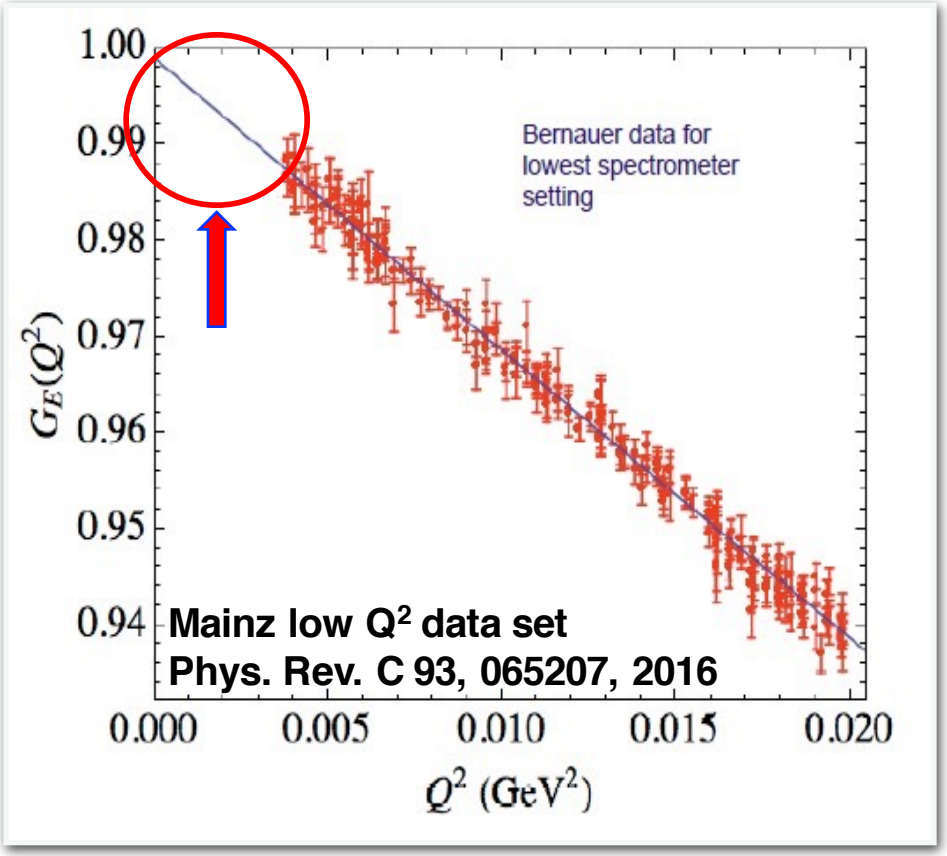
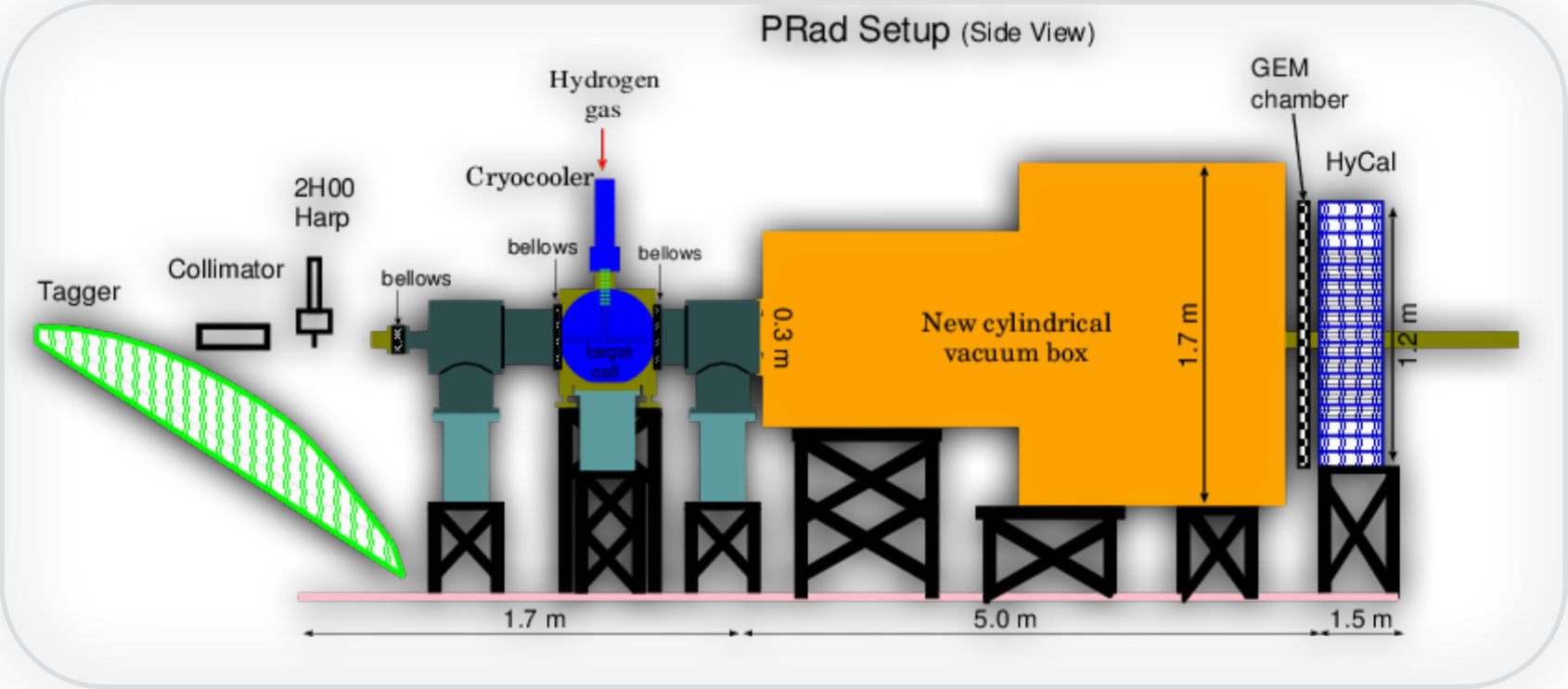
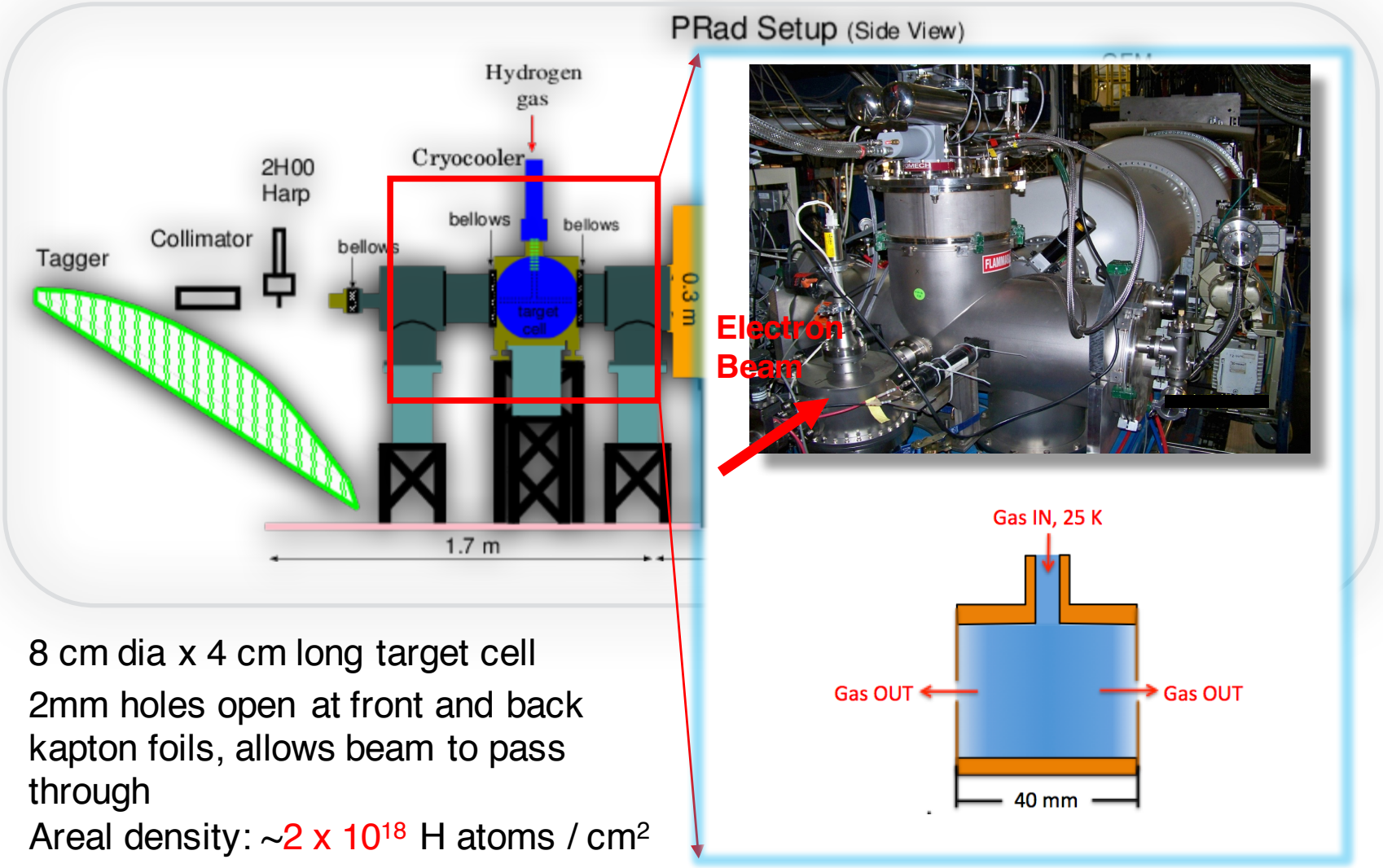


PRad Experimental Apparatus



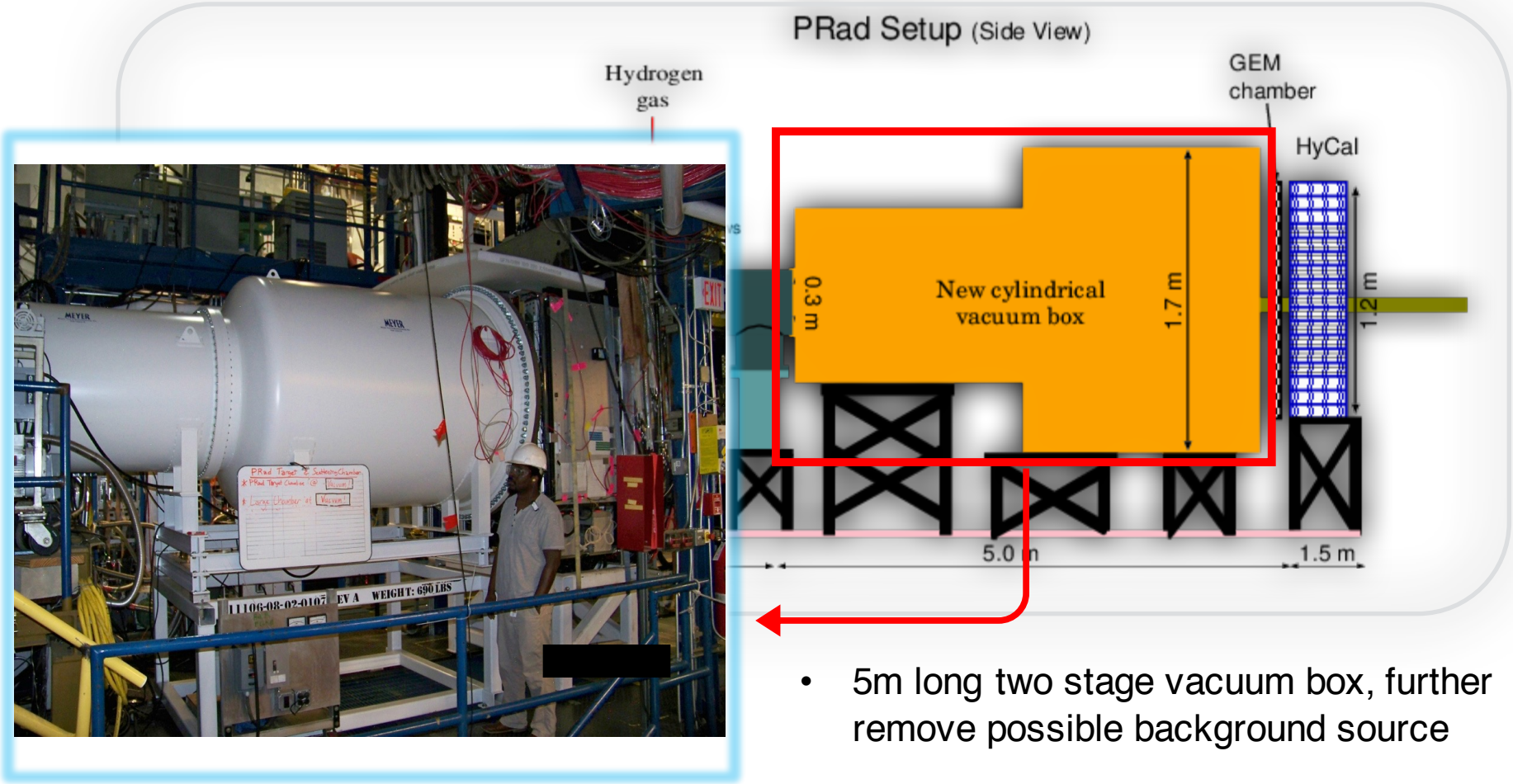
- PRad finished data taking in May and June of 2016 in Hall B at Jefferson Lab, with 1.1 and 2.2 GeV electron beam

PRad Experimental Apparatus



- 8 cm dia x 4 cm long target cell
- 2mm holes open at front and back kapton foils, allows beam to pass through
- Areal density: ~2 x 10^{18} H atoms / cm^2

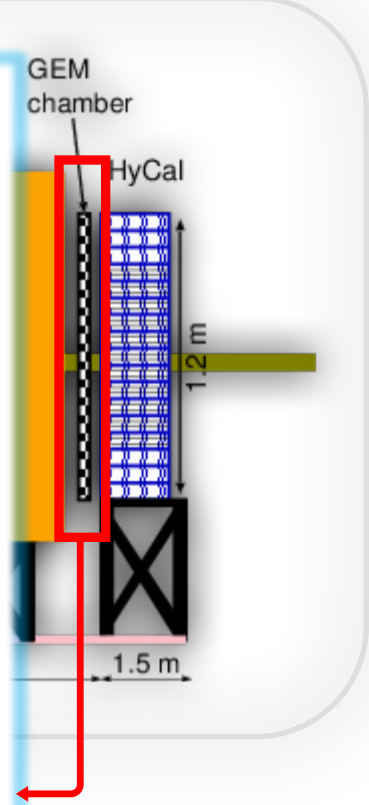
PRad Experimental Apparatus



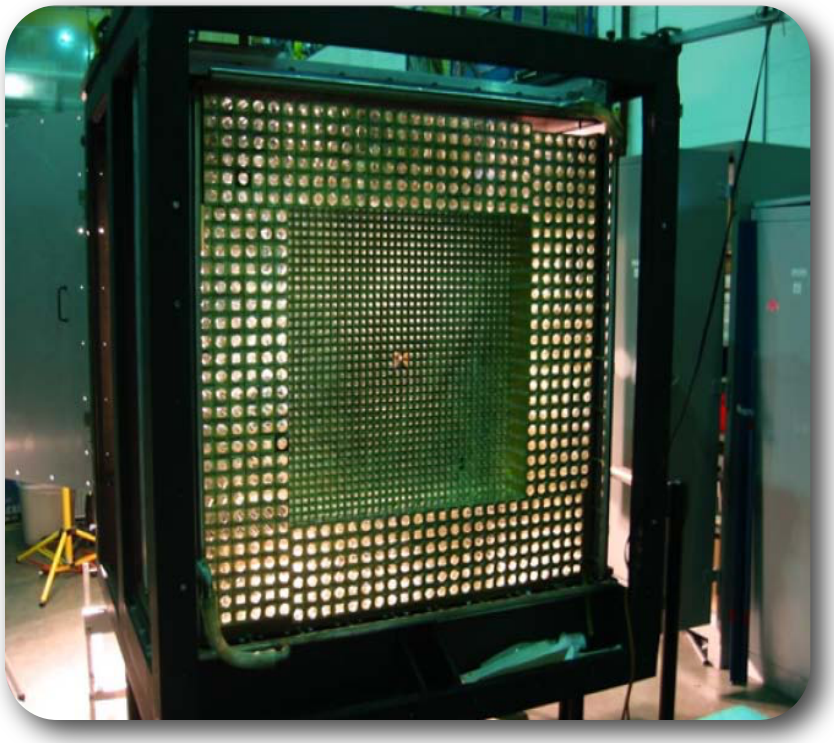
- 5m long two stage vacuum box, further remove possible background source
- vacuum tank pressure: 0.3 mtorr

PRad Experimental Apparatus

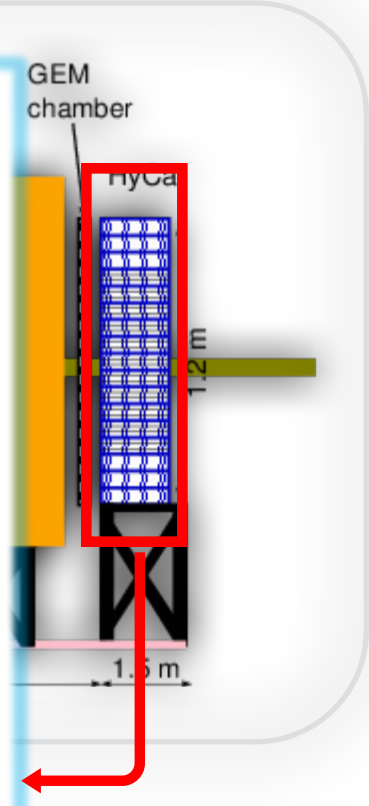
- Two large area GEM detectors
- Small overlap region in the middle
- Excellent position resolution (~72μm)
- Improve position resolution of the setup by > 20 times
- Similar improvement for Q^2 determination at small angle



PRad Experimental Apparatus

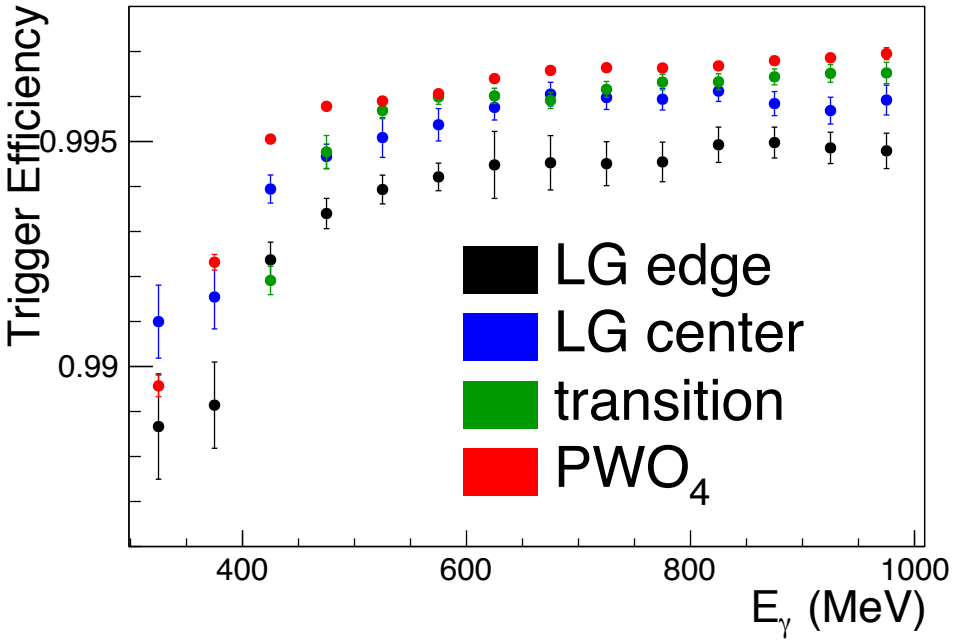


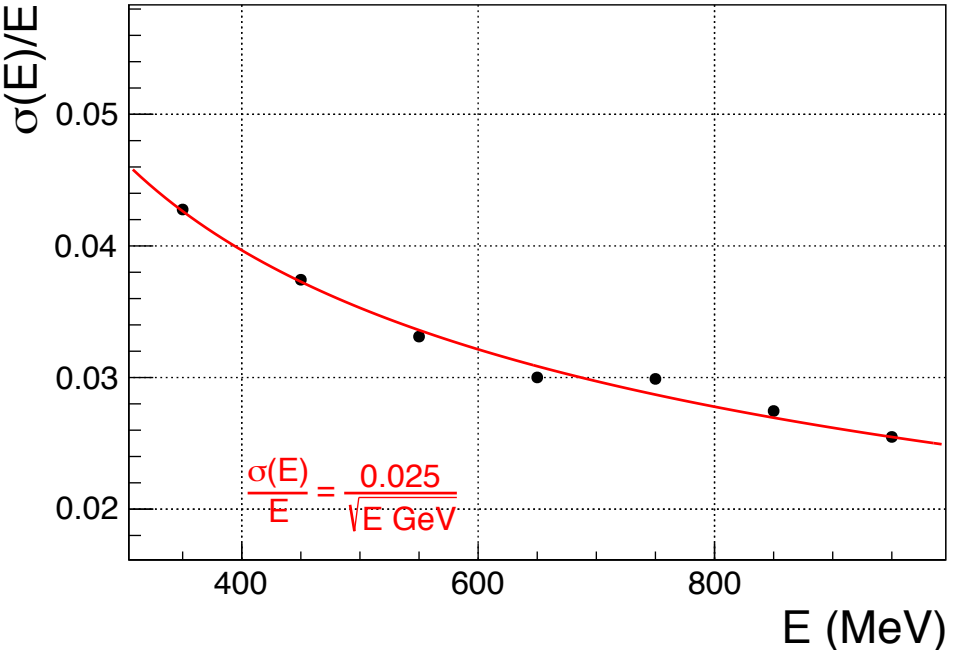
- Hybrid EM calorimeter
  - Inner 1156 PWO_4 modules
  - Outer 576 lead glass modules
- 5.8m from the target
- Polar angle coverage: ~ 0.6˚ to 7.5˚
- Azimuthal angle coverage: 2π
- High resolution and efficiency



HyCal Resolution and Efficiency

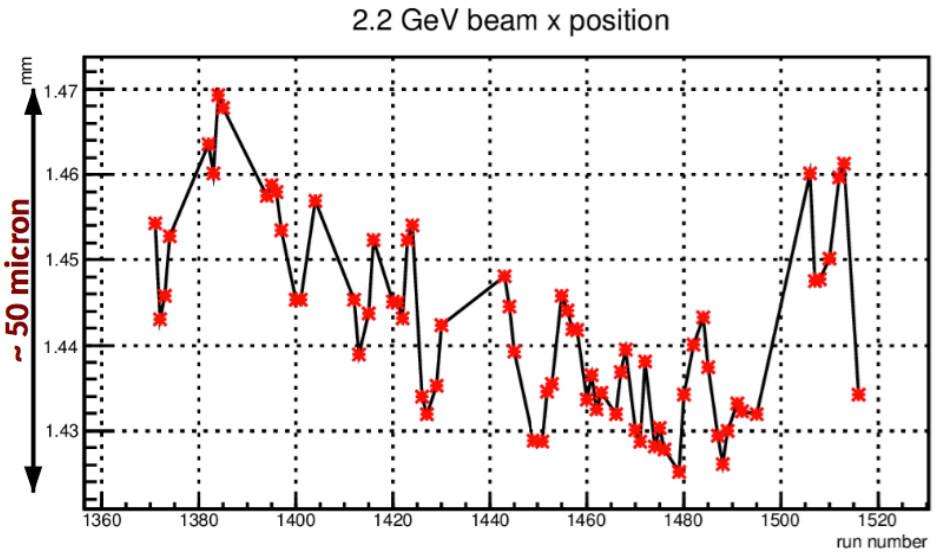
- HyCal energy resolution and trigger efficiency extracted using high energy photon beam from Hall B at Jlab
  - > 99.5% trigger efficiency obtained for $E_\gamma > 500$ MeV, for various parts of HyCal
  - Energy resolution ~2.6% for PWO_4 part, lead glass part able 2.5 time worse

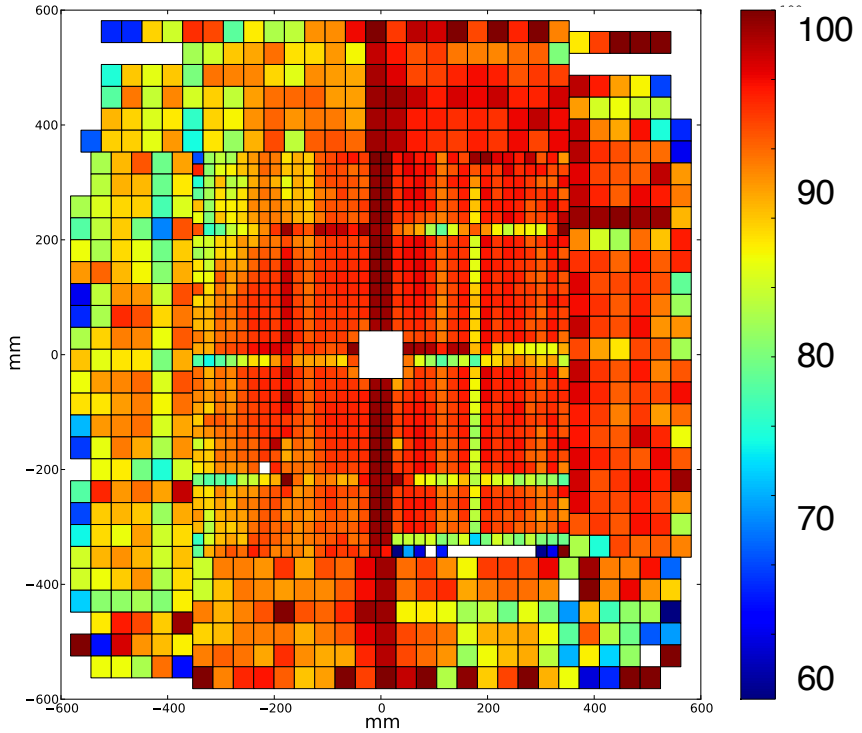




Performance of GEM Detectors

- GEM detection efficiency measured in both photon beam calibration (pair production) and production runs (ep and ee)
- Using overlap region of GEMs to measure position resolution (~72μm)
- Monitoring beam stability production runs



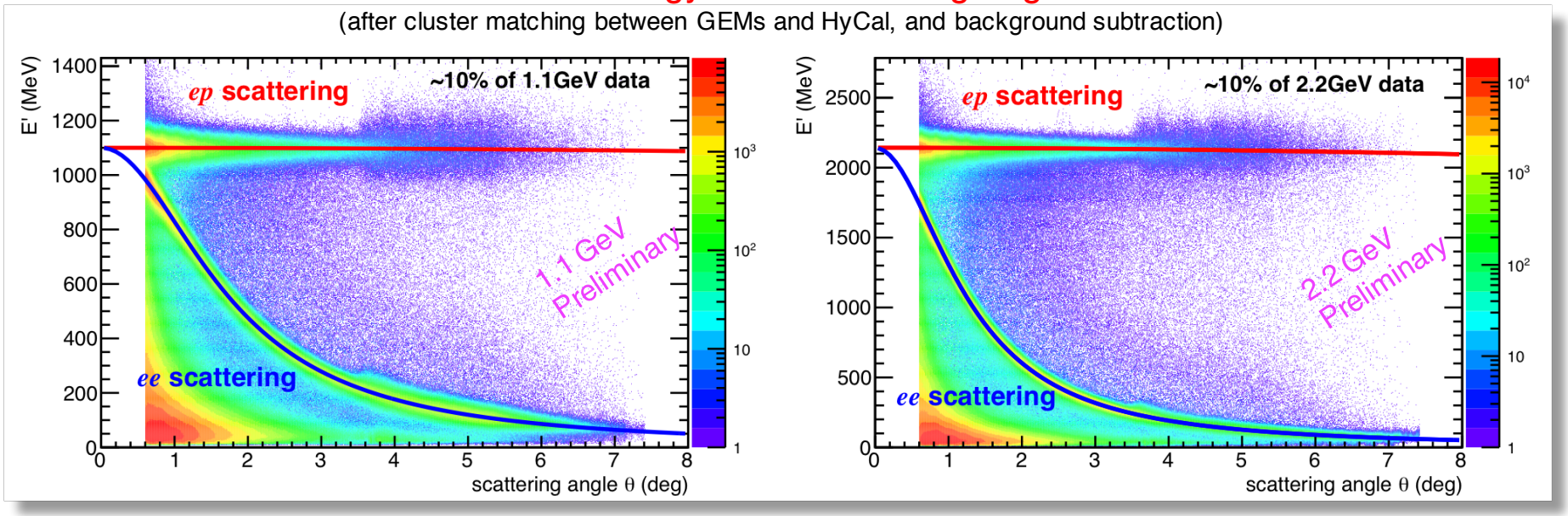


More details see presentation of X. Bai in session E12

PRad Data Analysis Status

Cluster Energy E' vs. Scattering Angle θ

(after cluster matching between GEMs and HyCal, and background subtraction)



- HyCal calibration accomplished with tagged photon beam and majority of physics data
  - Reached expected energy resolution of 2.6% for PWO_4 modules and 6.2% for lead glass
- Obtained preliminary result for HyCal trigger efficiency (>99.5% for $E_\gamma > 500$ MeV)
- Detector alignment accomplished, matching of GEMs and HyCal achieved
- Obtained GEM position resolution (72μm) and preliminary detection efficiency (~92%)
- Analysis for cross section is ongoing

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^2) 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) have 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 on the first preliminary result is ongoing

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