



# Data Quality and Analysis Status of PRad Experiment at Jefferson Lab

Weizhi Xiong

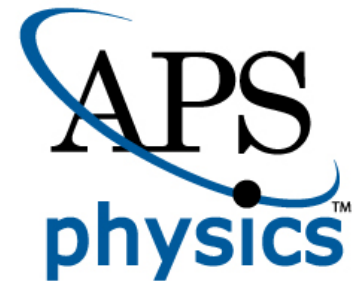
Duke University

For the PRad Collaboration

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

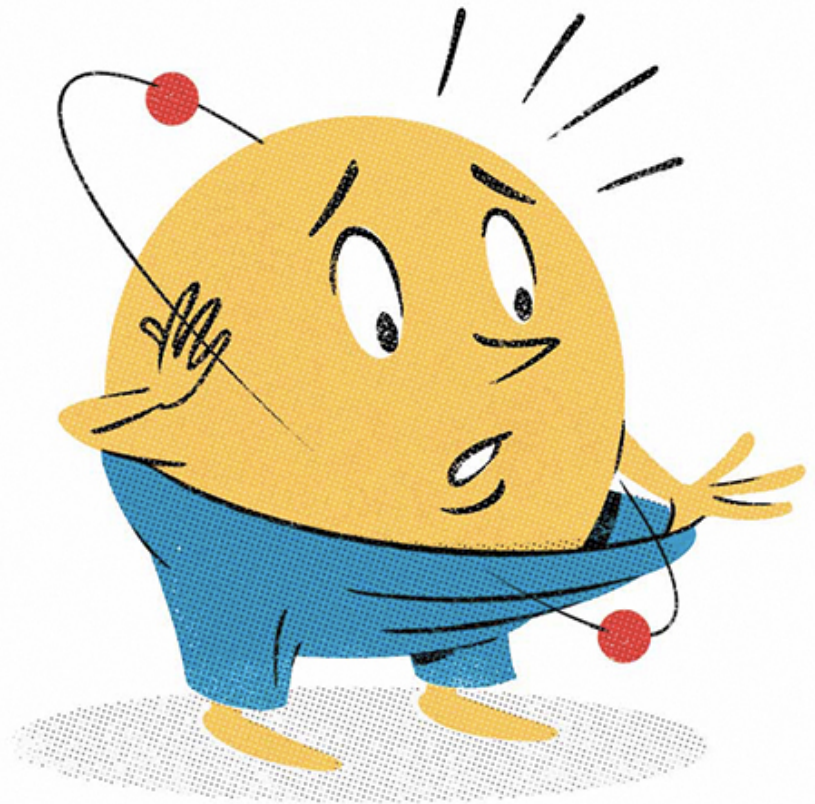
APS April Meeting 2017

January 28<sup>th</sup>, 2017

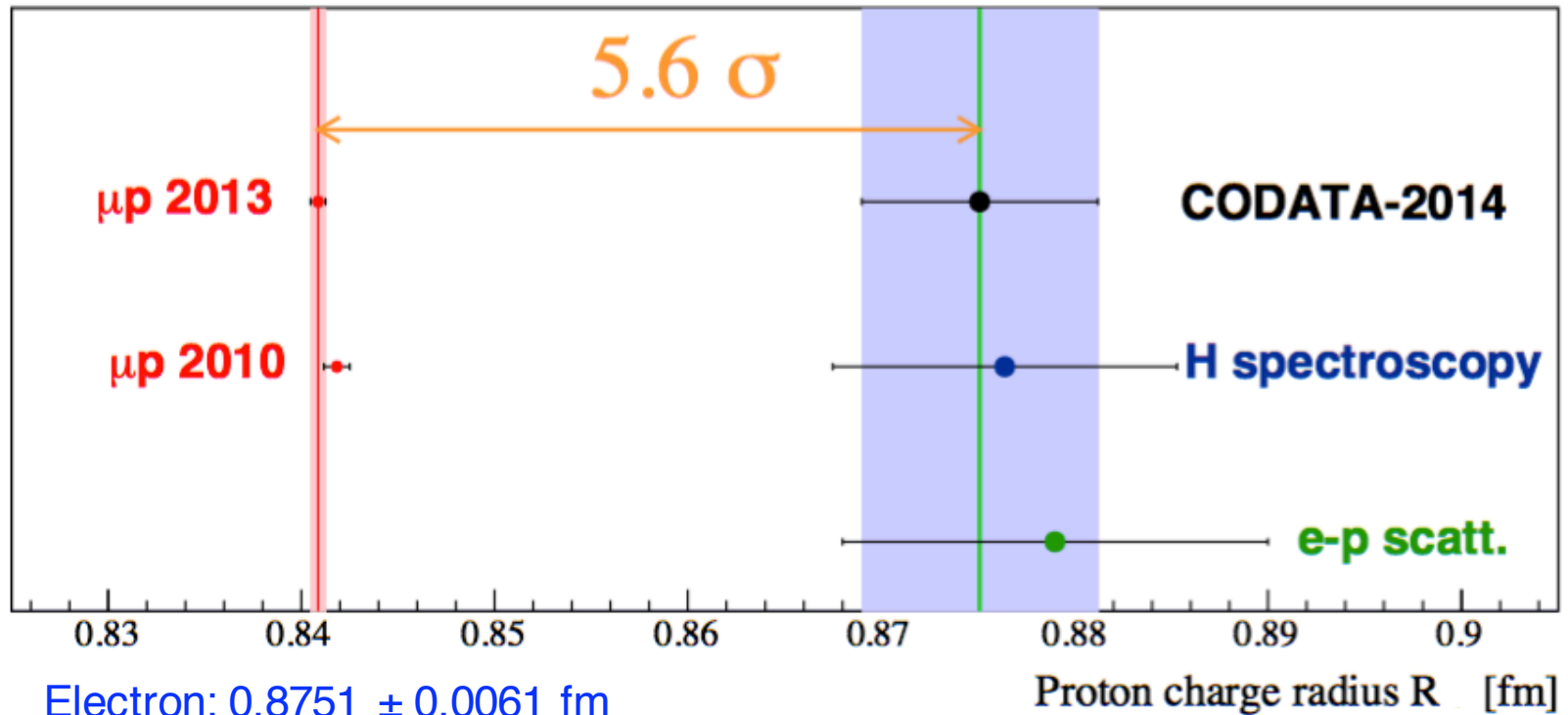


# Outline

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



# Proton Charge Radius Puzzle



- Electronic measurement (ep elastic + ordinary H spectroscopy) v.s. muonic measurement (muonic H spectroscopy)
- $\mu p$  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):

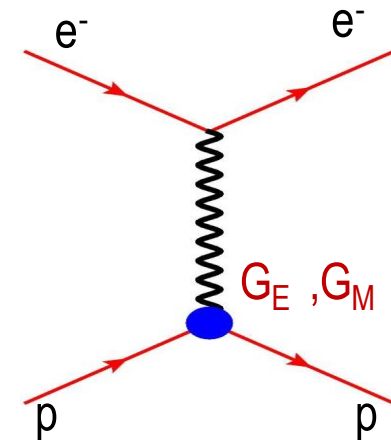
$$\frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_{\text{Mott}} \left( \frac{E'}{E} \right) \frac{1}{1+\tau} \left( G_E^p{}^2(Q^2) + \frac{\tau}{\epsilon} G_M^p{}^2(Q^2) \right)$$

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

- Structure-less proton:

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

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



Taylor expansion of  $G_E$  at low  $Q^2$

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

Derivative at low  $Q^2$  limit

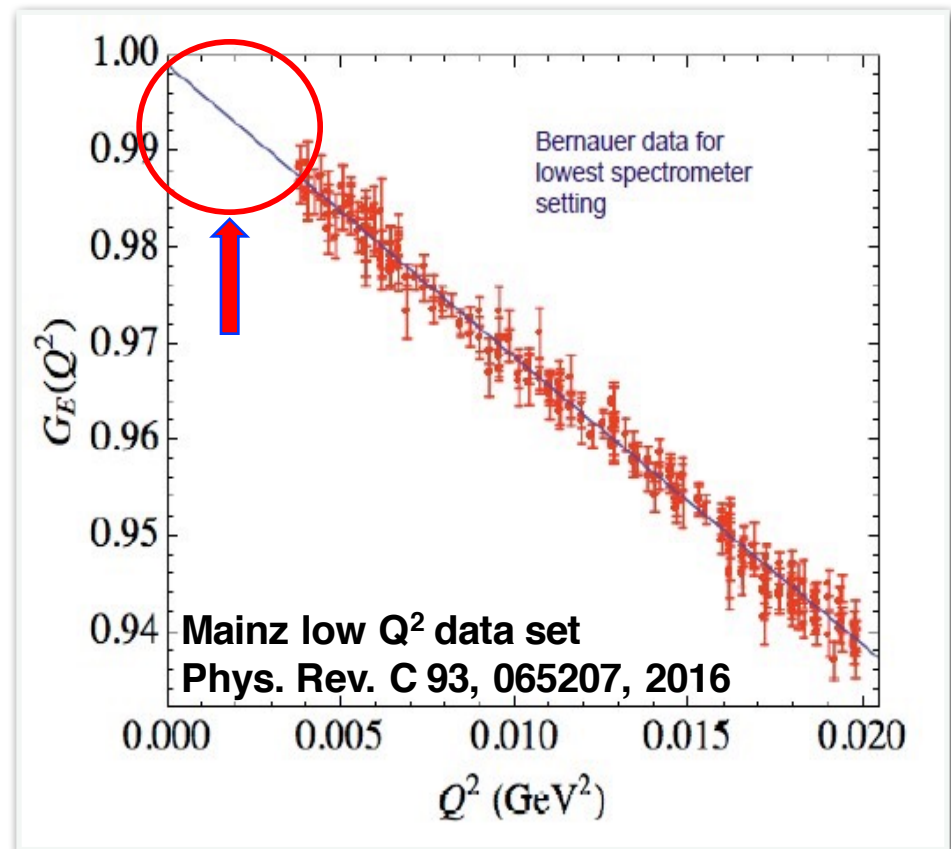
$$\langle r^2 \rangle = -6 \left. \frac{dG_E^p(Q^2)}{dQ^2} \right|_{Q^2=0}$$

# PRad Experiment Overview

- PRad goal: Measuring proton charge radius using ep elastic scattering
- Unprecedented low  $Q^2$  ( $\sim 2 \times 10^{-4} \text{ GeV}^2$ )
  - Fill in very low  $Q^2$  region
- Covers two orders of magnitude in low  $Q^2$ 
  - $\sim 2 \times 10^{-4} - 6 \times 10^{-2} \text{ GeV}^2$
- Calibrate to the simultaneously measured Møller scattering process
  - best known control of systematics
- Aims to extract cross section and radius to **sub-percentage** level

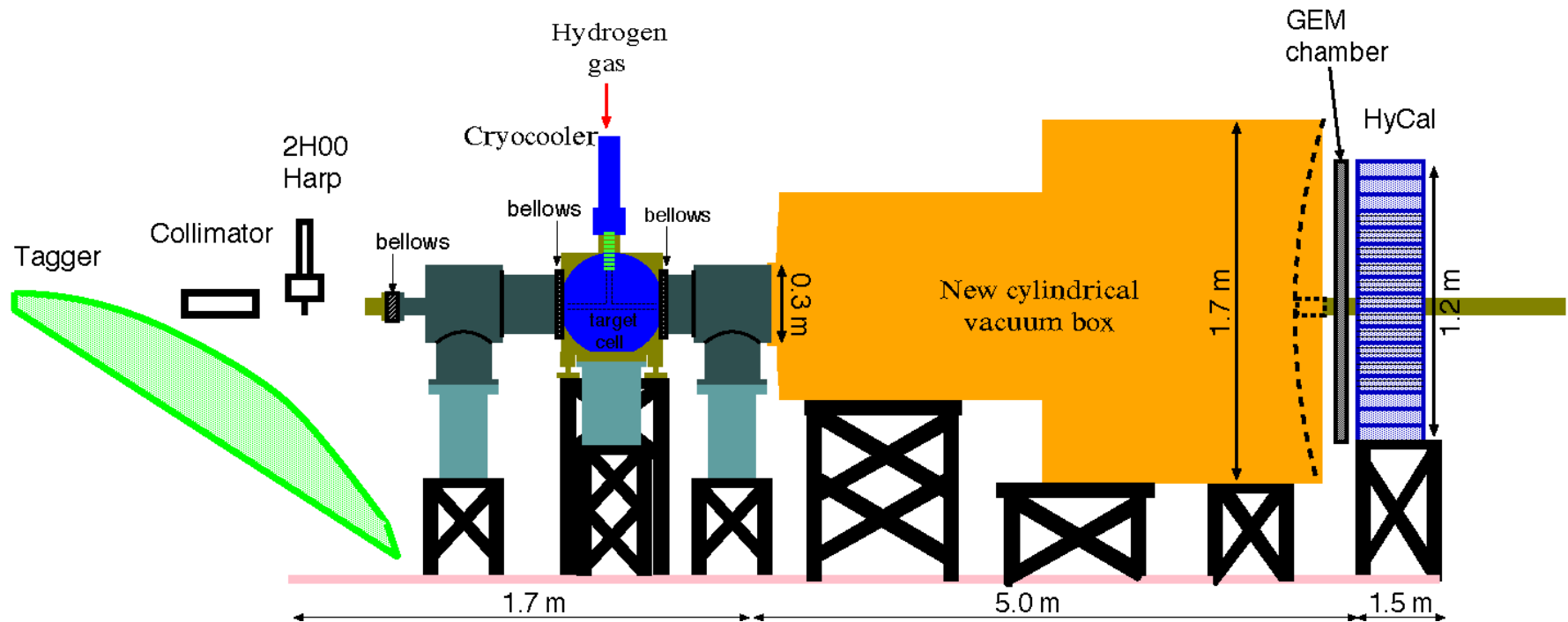
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# PRad Experimental Apparatus

PRad Setup (Side View)

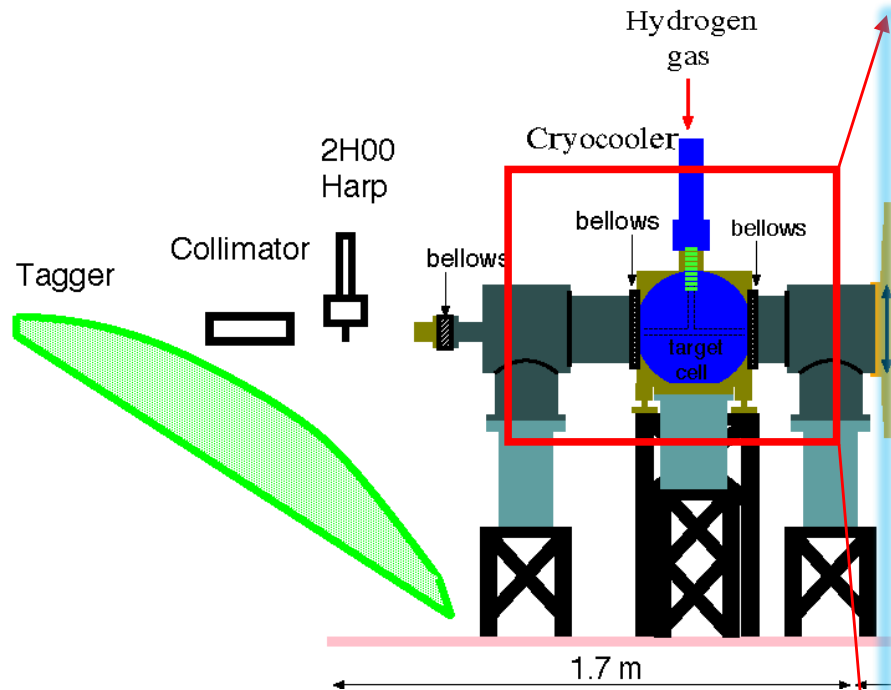


- Data taking in May and June of 2016 in Hall B at Jefferson Lab, with **1.1** and **2.2** GeV electron beams
- Over **1.3** billion events taken with hydrogen target

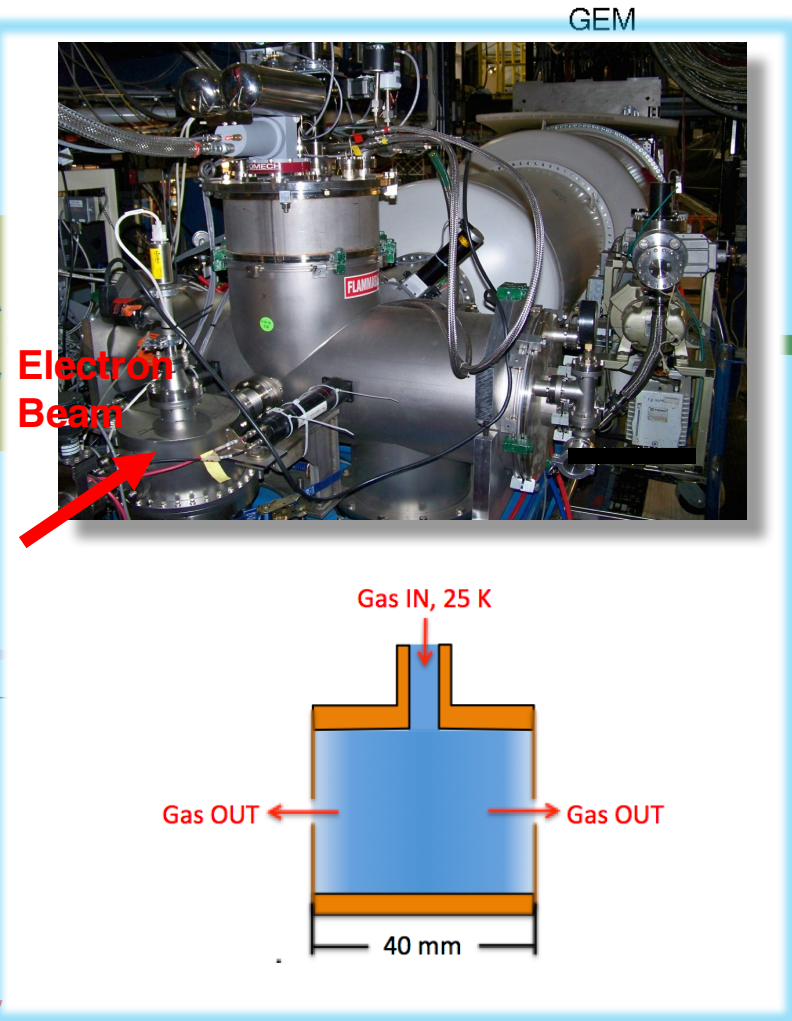


# PRad Experimental Apparatus

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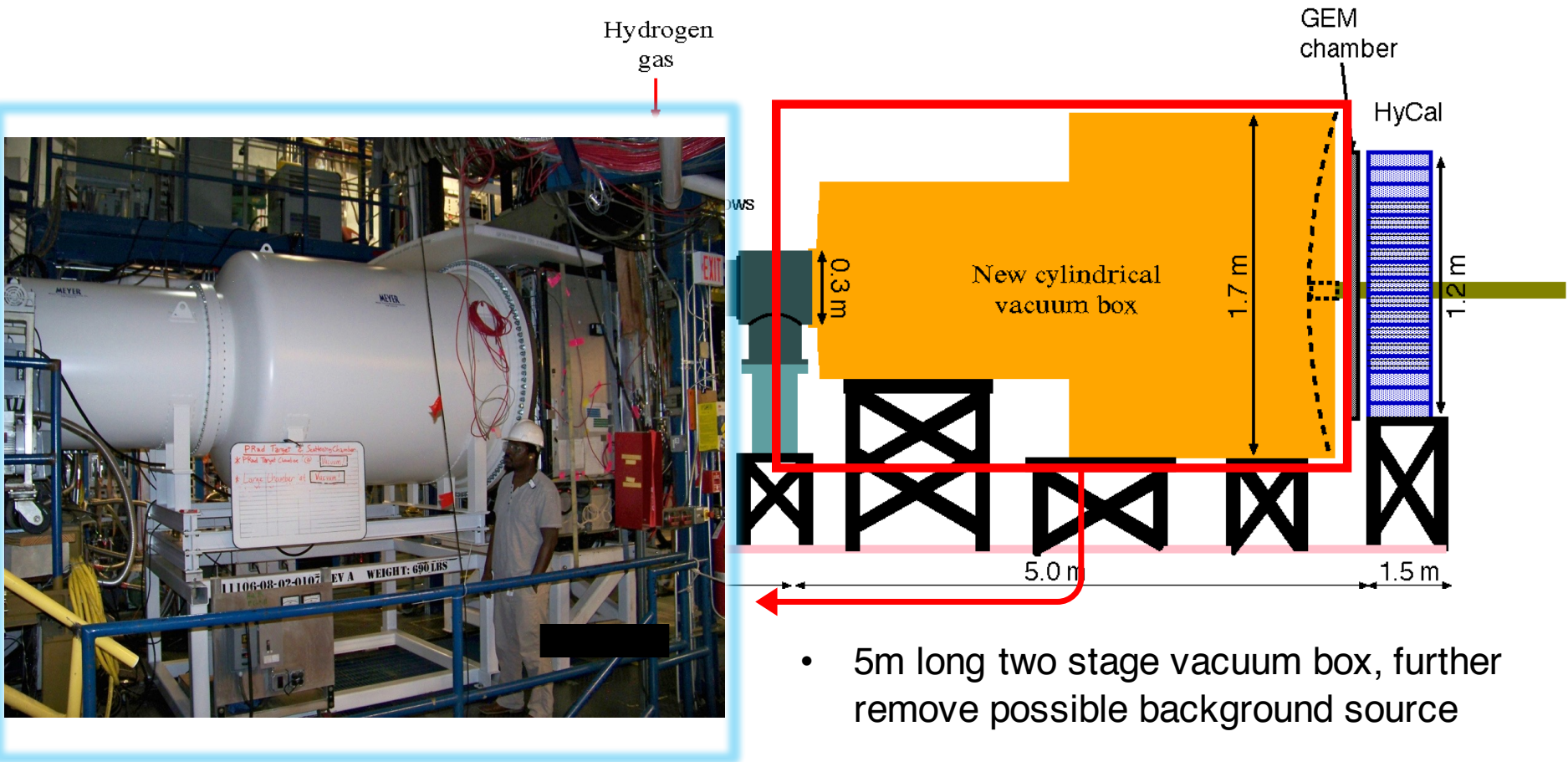
- 8 cm dia x 4 cm long target cell
- 2mm holes open at front and back kapton foils, allows beam to pass through
- Target thickness:  $\sim 2 \times 10^{18}$  H atoms / cm<sup>2</sup>





# PRad Experimental Apparatus

PRad Setup (Side View)



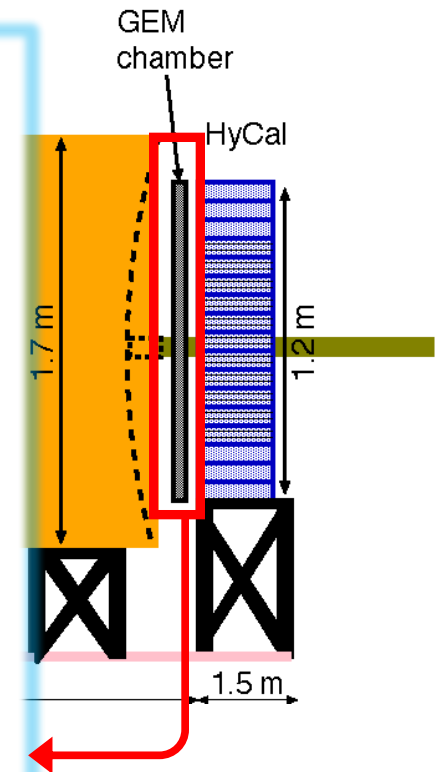
# PRad Experimental Apparatus

PRad Setup (Side View)

Hydrogen



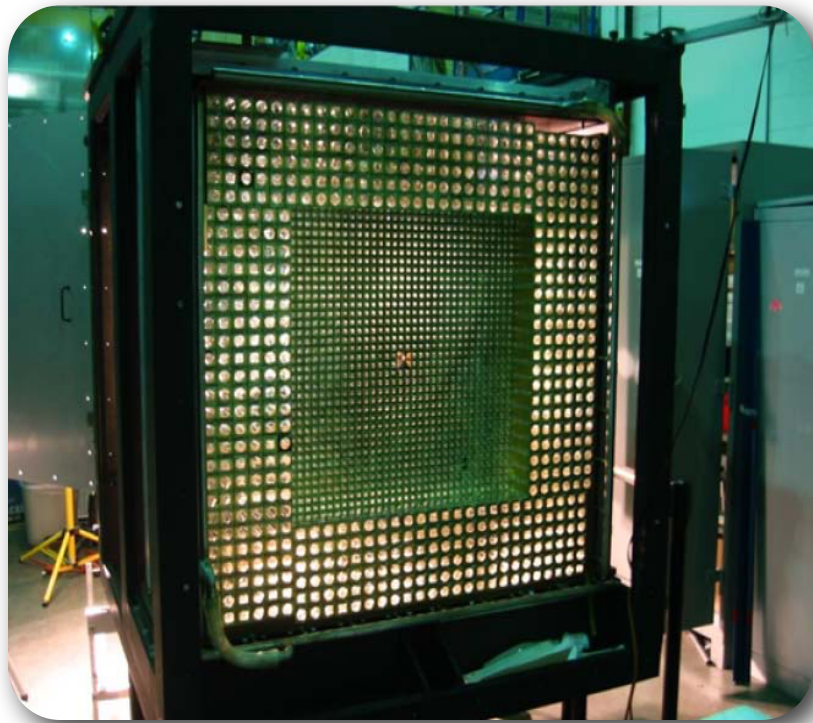
- Two large area GEM detectors
- Small overlap region in the middle
- Excellent position resolution ( $\sim 72\mu\text{m}$ )
- Improve position resolution of the setup by  $> 20$  times
- Similar improvement for  $Q^2$  determination at small angle



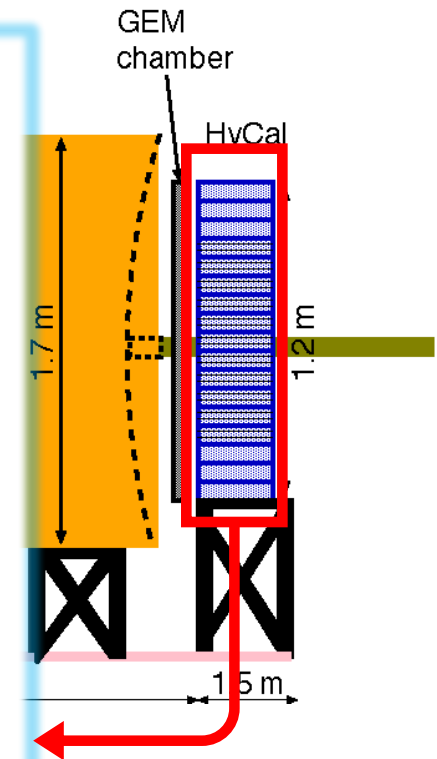
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PRad Setup (Side View)

Hydrogen

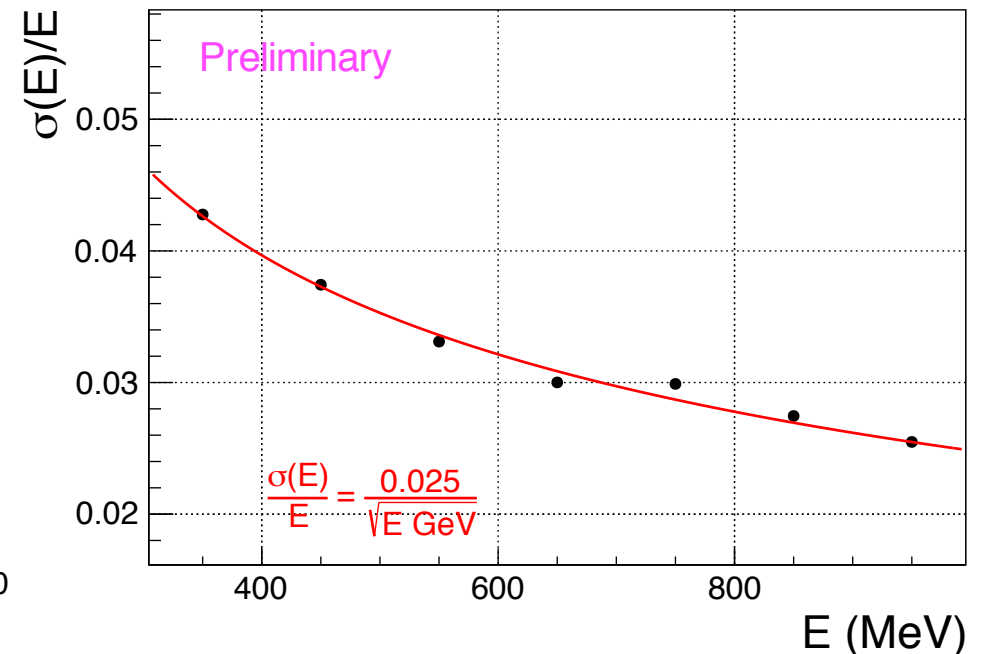
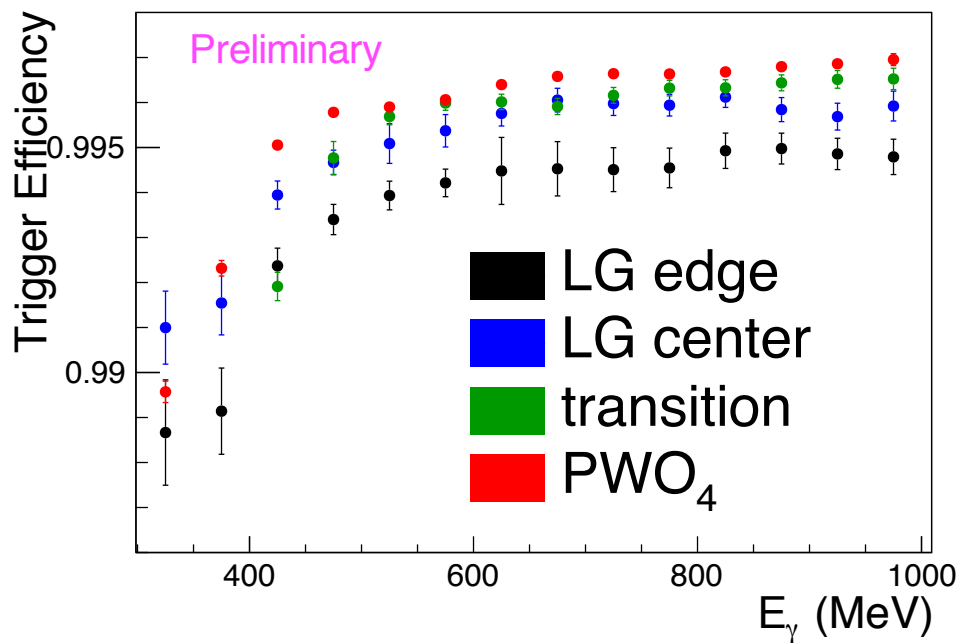


- Hybrid EM calorimeter
  - Inner 1156 PWO<sub>4</sub> modules
  - Outer 576 lead glass modules
- 5.8m from the target
- Polar angle coverage:  
 $\sim 0.6^\circ$  to  $7.5^\circ$
- Azimuthal angle coverage:  $2\pi$
- High resolution and efficiency



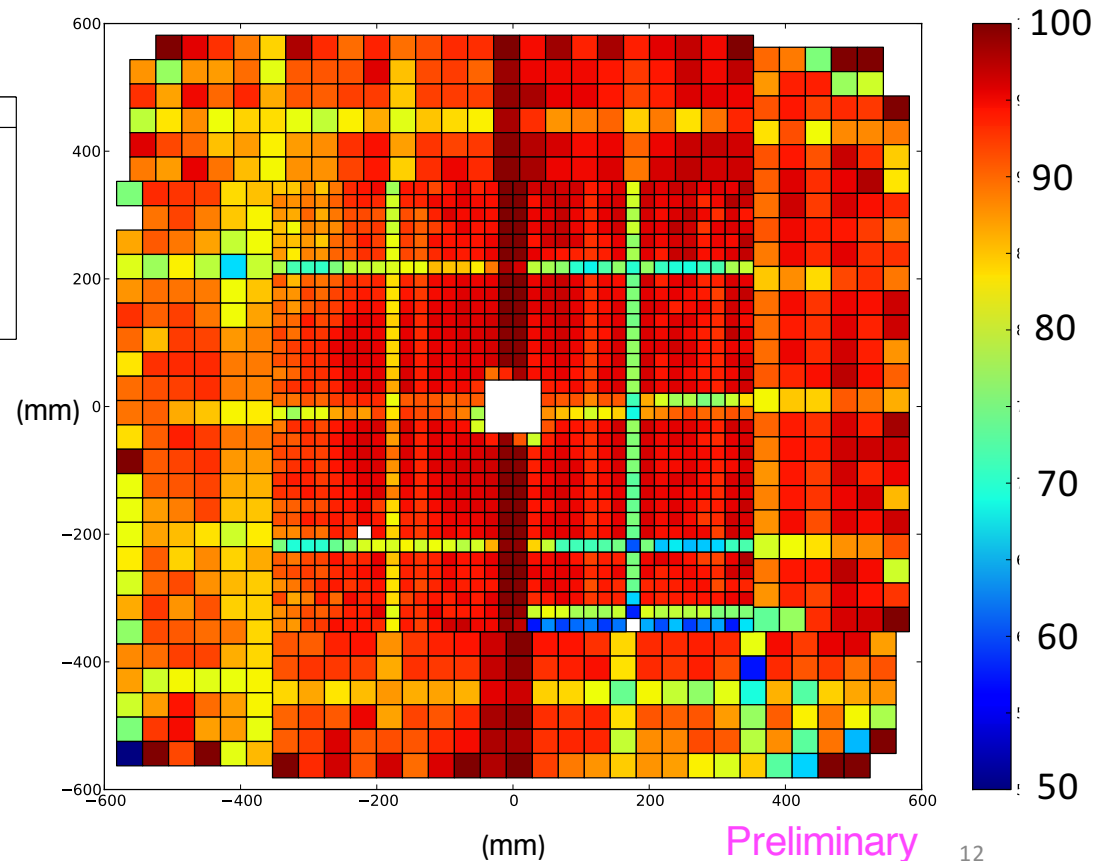
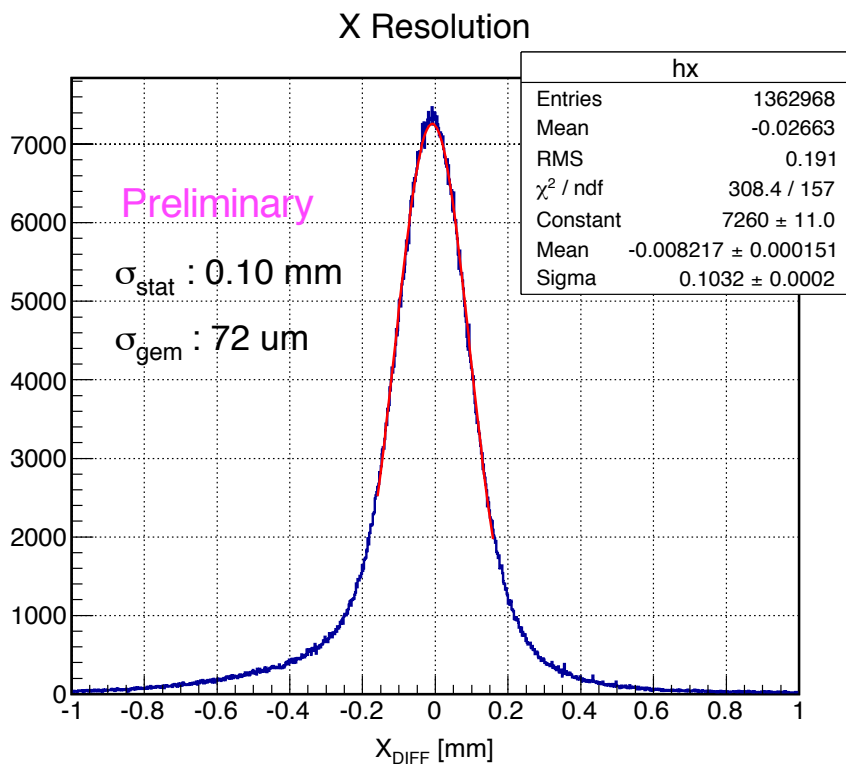
# HyCal Resolution and Efficiency

- 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  $\sim 2.6\%$  for  $\text{PWO}_4$  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 ( $\sim 72\mu\text{m}$ )



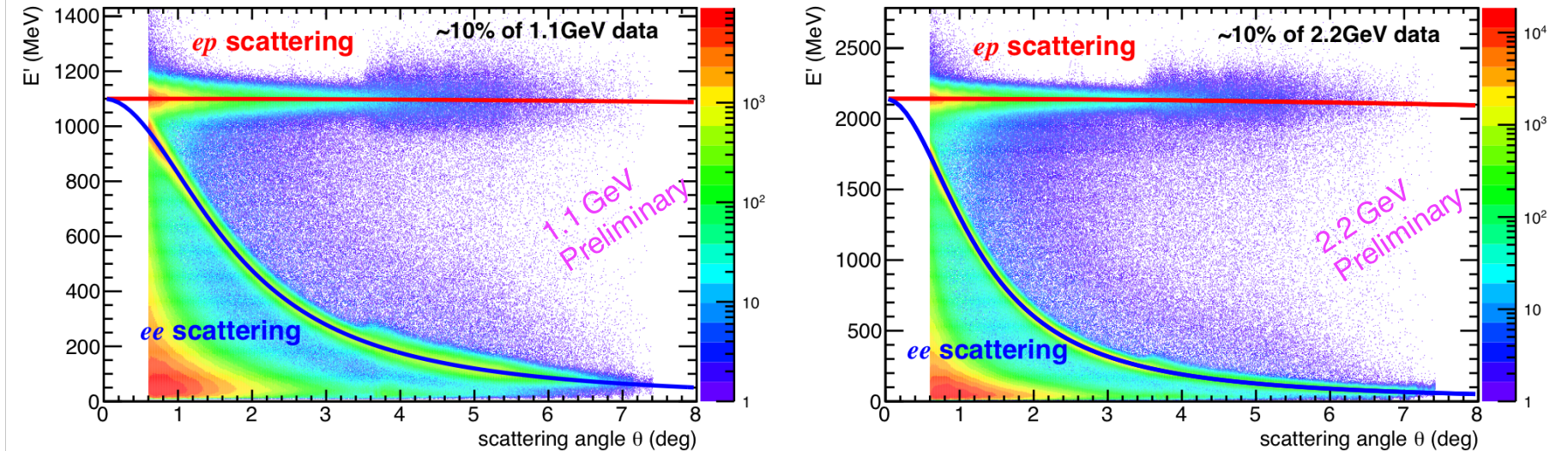
More details see presentation of X. Bai in session E12



# PRad Data Analysis Status

## Cluster Energy $E'$ vs. Scattering Angle $\theta$

(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  $\text{PWO}_4$  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 (**72 $\mu\text{m}$** ) and preliminary detection efficiency ( **$\sim 92\%$** )
- 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 ( $\sim 2 \times 10^{-4} \text{ GeV}^2$ ) has been collected for the first time in ep elastic scattering experiment
  - Data with two orders of magnitude in low  $Q^2$  range ( $\sim 2 \times 10^{-4} - 6 \times 10^{-2} \text{ GeV}^2$ )
  - Large statistics, high quality, rich data have been collected
  - Systematic uncertainties well under control by simultaneous measurement of ep elastic and Møller processes
- Analysis on the cross section is ongoing

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