

## Status of PRad Experiment

Maxime Levillain

North Carolina A&T State University

for the PRad Collaboration

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**PR**oton  
radius

## 1 The Proton Charge Radius

## 2 PRad Setup

## 3 PRad Run

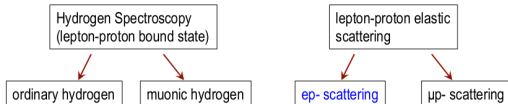
## 4 Data Analysis Status

- GEM Analysis Status
- HyCal Analysis Status

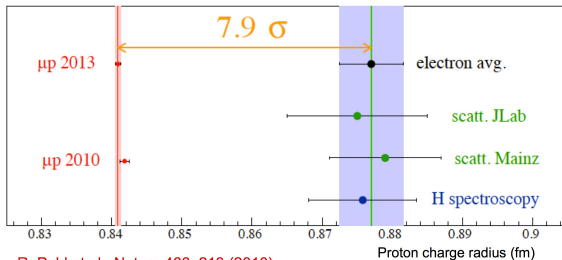
## 5 Summary

# The Proton Charge Radius Puzzle

- ▶ 4 different methods to measure the proton charge radius



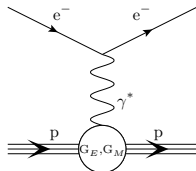
- ▶  $\sim 8\sigma$  discrepancy between muonic hydrogen spectroscopy and atomic hydrogen measurements



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

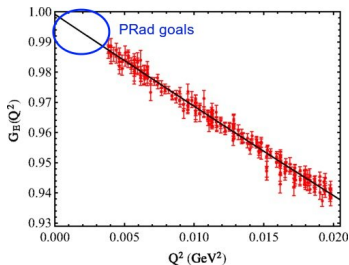
- ▶ Model dependent fitting of  $G_E$  to extract  $r_p$

- ▶ Previous measurements with large systematic uncertainties and small  $Q^2$  limited range
- ▶ Requirements for PRad Experiment:
  - ▶ large  $Q^2$  range
  - ▶ extend to very low  $Q^2$
  - ▶ controlled systematics at sub-percent precision



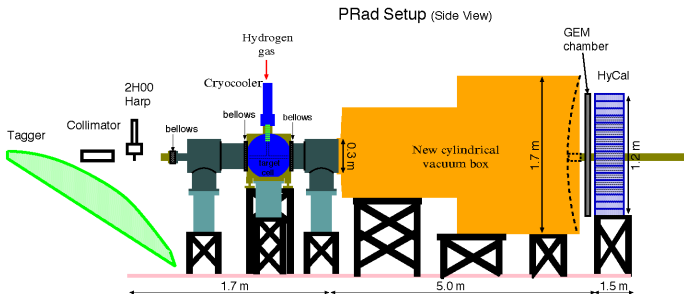
- ▶ Extraction of  $\langle r^2 \rangle = -6 \cdot \left. \frac{dG_E^p}{dQ^2} \right|_{Q^2=0}$  through:

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



Phys. Rev. C 93, 065207

- 2011 - 2012 Initial proposal
- 2012 Approved by JLab PAC39
- 2012 Funding proposal for windowless H<sub>2</sub> gas flow target
- 2012 - 2015 Development, construction of the target
- 2013 Funding proposals for the GEM detectors
- 2013 - 2015 Development, construction of the GEM detectors
- 2015, 2016 Experiment readiness reviews
- January/April 2016 Beam line installation
- May 2016 Beam commissioning
- May 24 - May 31 Detectors calibration
- June 4 - June 15 1.1 GeV data taking
- June 15 - June 22 2.2 GeV data taking

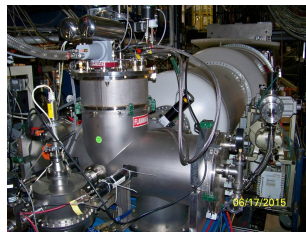
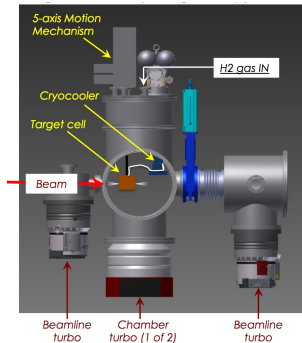


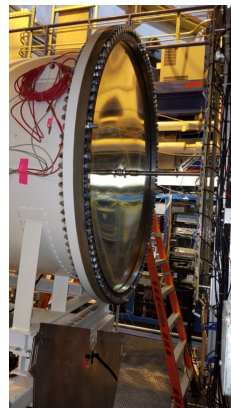
- ▶ Electron beam or tagged photon beam at  $\sim 1$  GeV and  $\sim 2$  GeV
- ▶ Windowless  $H_2$  gas flow target
- ▶ Vacuum box
- ▶ GEM detectors
- ▶ Primex HyCal

# Windowless H<sub>2</sub> Gas Flow Target

- ▶ gas target of cryogenically cooled hydrogen at 19.5 K
- ▶ beam opening: 2 mm, length: 4 cm
- ▶ cell density:  $\sim 2 \cdot 10^{18}$  H atoms/cm<sup>2</sup>
- ▶ pressures:
  - ▶ cell pressure: 471 mTorr
  - ▶ chamber pressure: 2.34 mTorr
  - ▶ vacuum chamber pressure: 0.3 mTorr

Developed and build by JLab target group



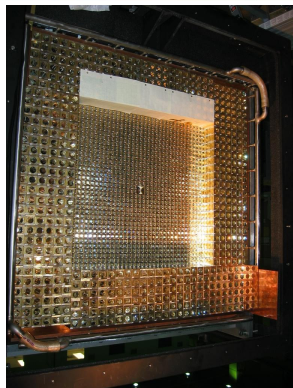


- ▶ 1.7 m diameter, 2 mm aluminum vacuum window
- Limited background

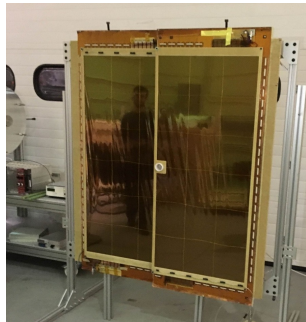


Hybrid detector:

- ▶ Central part:
  - ▶ 34 x 34 matrix of  $\text{PbWO}_4$  detectors
  - ▶ dimension of block:  $2 \times 2 \times 18 \text{ cm}^3$
  - ▶ 2 x 2 blocks removed from the center for beam line to pass through
- ▶ Peripheral part:
  - ▶ 576 lead glass detectors
  - ▶ dimension of block:  $4 \times 4 \times 45 \text{ cm}^3$



- ▶ Two large area GEM detectors: 55 cm x 123 cm
- ▶ Purpose:
  - ▶ improve spatial resolution by a factor 20 to 40  $\rightarrow$  100  $\mu\text{m}$
  - $\rightarrow$  to reduce uncertainties on  $\theta$  and  $Q^2$
- ▶ Central overlap between the 2 planes and central hole for the beam line



Developed and build by UVA

① The Proton Charge Radius

② PRad Setup

③ **PRad Run**

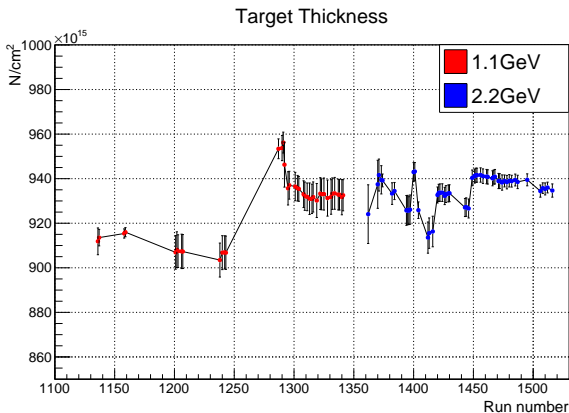
④ Data Analysis Status

- GEM Analysis Status
- HyCal Analysis Status

⑤ Summary

- ▶ Calibration with tagged photon beam
  - ▶ Every calorimeter module moved into the beam
  - ▶ Allows study of resolution, linearity, trigger efficiency
  
- ▶ 1.1 GeV electron beam
  - ▶ 4.2 mC
  - ▶ 604 M events with target
  - ▶ 53 M events with “empty target”
  - ▶ 25 M events with  $^{12}\text{C}$  target for calibration
  
- ▶ 2.2 GeV electron beam
  - ▶ 14.3 mC
  - ▶ 756 M events with target
  - ▶ 38 M events with “empty target”
  - ▶ 10.5 M events with  $^{12}\text{C}$  target for calibration

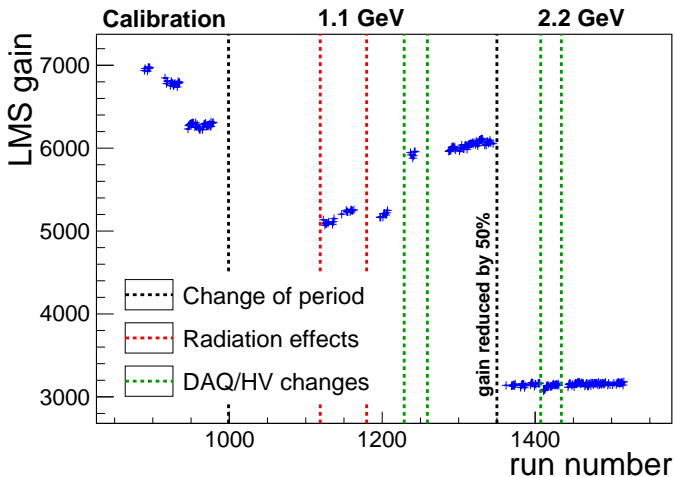
- ▶ Control of target properties (pressure, temperature, position) via EPICS



→ Less than 2% deviation

Weizhi Xiong

- ▶ Control of HyCal gain with its *Light Monitoring System (LMS)*



① The Proton Charge Radius

② PRad Setup

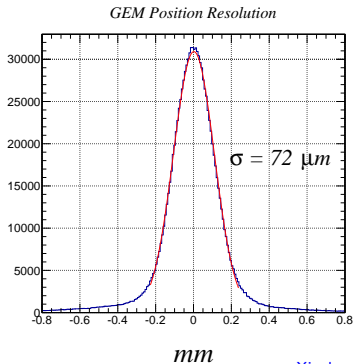
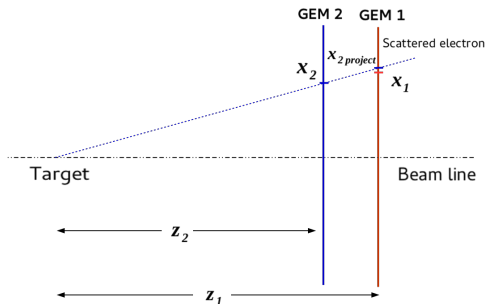
③ PRad Run

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⑤ Summary

- ▶ Extraction of GEM spatial resolution using GEM central overlapping region

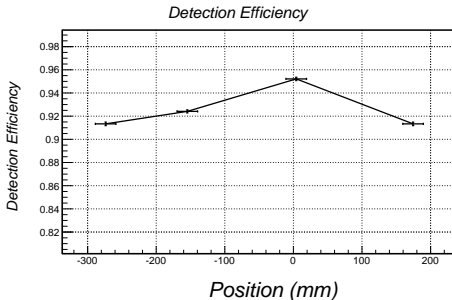


Xinzhan Bai

- ▶ Good spatial resolution achieved



- ▶ Study of efficiency with tagged photon beam
  - ▶ Scintillators added on the beam line before GEM detector
  - ▶ Efficiency calculated using scintillators and HyCal matching



Xinzhan Bai

- ▶ Average detection efficiency of 0.92 with 0.12% of statistical uncertainty
- ▶ GEM are also calibrated using physics runs

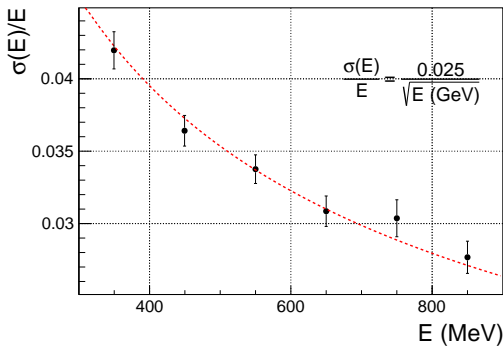
- ▶ Gains controlled by *Light Monitoring System (LMS)*
- ▶ Two different calibrations:
  - ▶ Before data taking:  
Scan with 250-1050 MeV tagged photon beam moved in front of each module  
→ study of resolution, efficiency and non linearity
  - ▶ During physics data taking:  
With Møller and  $ep$  events

- ▶ Iterative method:

$$gain_{module}(n+1) = \frac{gain_{module}(n)}{\langle E_{measured} / E_{expected} \rangle}$$

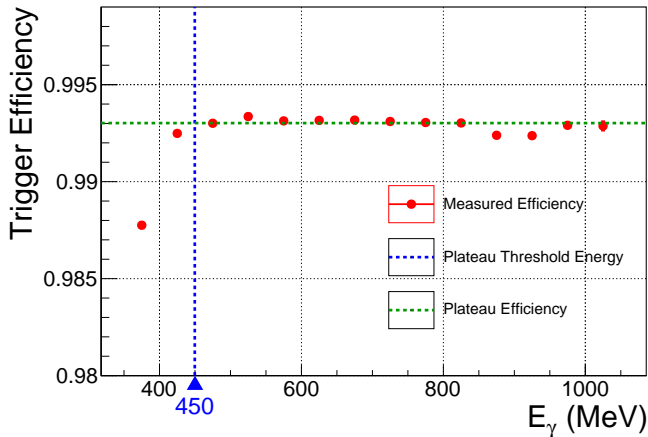
- ▶ Different clustering algorithms used for cross-check

- ▶ Crystal energy resolution with statistical uncertainties and systematic coming from non-uniformity



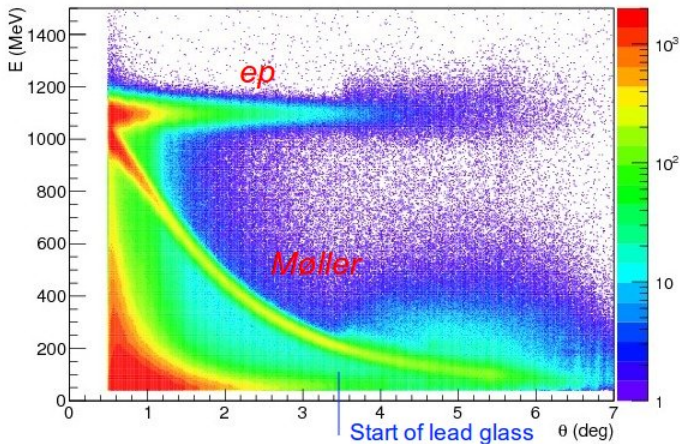
Li Ye, Ilya Larin, Weizhi Xiong, Maxime Levillain

- ▶ Achieved expected energy resolution:
  - ▶ 2.5% at 1 GeV for crystal part
  - ▶ 6.1% at 1 GeV for lead glass part



Maxime Levillain

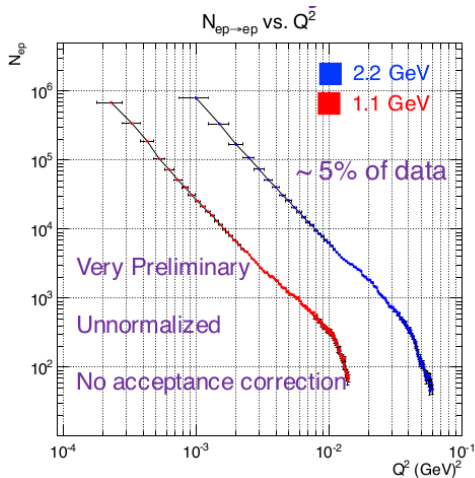
- ▶ Plateau from 450 MeV with an efficiency of 0.994
- ▶ Good uniformity



Weizhi Xiong

- Separation between ep scattering and Møller events possible for  $\theta > 0.7^\circ$

- ▶ No normalization and acceptance correction
- ▶ 1.1 GeV data set:  
 $Q^2 \in [2 \cdot 10^{-4}, 1.3 \cdot 10^{-2}] \text{ GeV}^2$
- ▶ 2.2 GeV data set:  
 $Q^2 \in [8 \cdot 10^{-4}, 6 \cdot 10^{-2}] \text{ GeV}^2$



Weizhi Xiong

- ▶ The PRad experiment was uniquely designed to address the *Proton Radius Puzzle*
- ▶ The experiment was successfully performed in May-June 2016
- ▶ GEM calibration and alignment are finalized
  - spatial resolution of  $72 \mu\text{m}$
  - and detection efficiency of  $0.92 \pm 0.001$
- ▶ HyCal calibration from photon tagged beam finalized
  - good energy resolution and high and uniform efficiency
- ▶ HyCal and GEM calibration with physics events in progress
- ▶ The physics analysis will start soon!

Thanks to JLab, Hall B, Accelerator Division and Target Group

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