U.S. DEPARTMENT OF ENERGY

JSA

Status of PRad Experiment

Maxime Levillain

North Carolina A&T State University

for the PRad Collaboration

November 2, 2016

PRoton PRadius

Outline

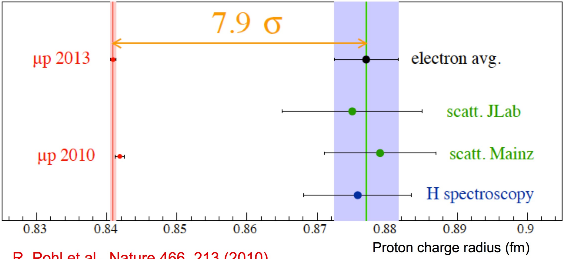
The Proton Charge Radius Puzzle

- 4 different methods to measure the proton charge radius

Hydrogen Spectroscopy (lepton-proton bound state)
- ordinary hydrogen
- muonic hydrogen

lepton-proton elastic scattering
- ep- scattering
- μp- scattering

- $\sim 8\sigma$ 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

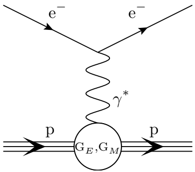
ep Scattering

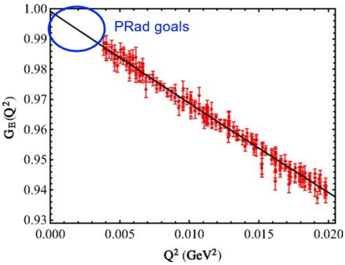
- Previous measurements with large systematic uncertainties and small Q^2 limited range

- Requirements for PRad Experiment:
  - large Q^2 range
  - extend to very low Q^2
  - controlled systematics at sub-percent precision

- Extraction of $< r^2 >= -6 \cdot \frac{dG_E^p}{dQ^2}\Big|_{Q^2=0}$ through:

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



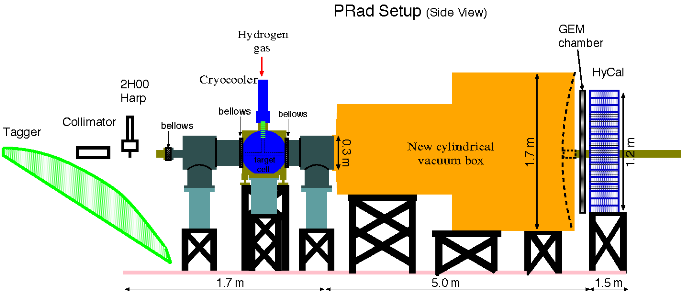


Phys. Rev. C 93, 065207

PRad Timeline

• 2011 - 2012	Initial proposal
• 2012	Approved by JLab PAC39
• 2012	Funding proposal for windowless H_2 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

PRad Setup

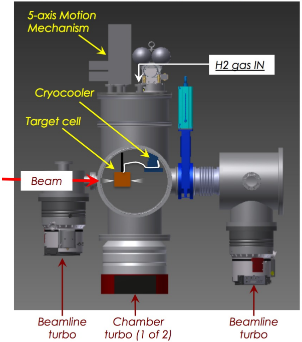


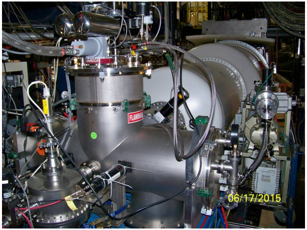
- Electron beam or tagged photon beam at ~ 1 GeV and ~ 2 GeV
- Windowless H_2 gas flow target
- Vacuum box
- GEM detectors
- Primex HyCal

Windowless H_2 Gas Flow Target

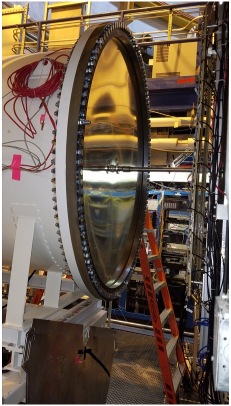
- gas target of cryogenically cooled hydrogen at 19.5 K
- beam opening: 2 mm, length: 4 cm
- cell density: $\sim 2 \cdot 10^{18}$ H atoms/cm^2
- pressures:
  - cell pressure: 471 mTorr
  - chamber pressure: 2.34 mTorr
  - vacuum chamber pressure: 0.3 mTorr

Developed and build by JLab target group



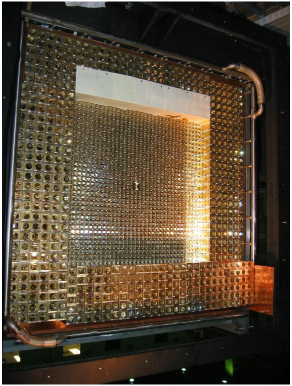


Vacuum Box



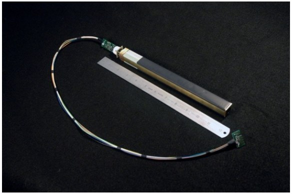
- 1.7 m diameter, 2 mm aluminum vacuum window

$\rightarrow$ Limited background



Hybrid detector:

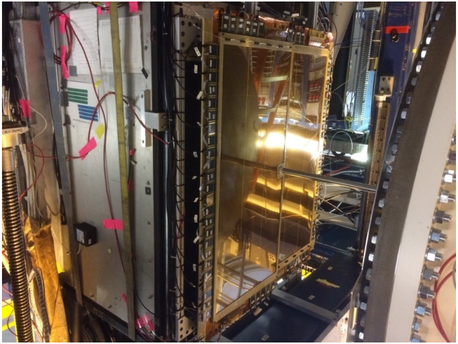
- Central part:
  - 34 x 34 matrix of $PbWO_4$ detectors
  - dimension of block: 2 x 2 x 18 cm^3
  - 2 x 2 blocks removed from the center for beam line to pass through
- Peripheral part:
  - 576 lead glass detectors
  - dimension of block: 4 x 4 x 45 cm^3

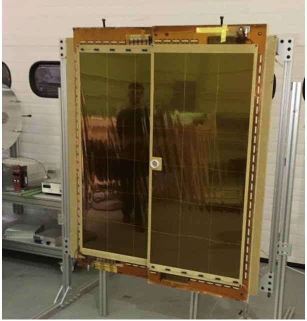


GEM Detectors

- Two large area GEM detectors: 55 cm x 123 cm
- Purpose:
  - improve spatial resolution by a factor 20 to 40 $\rightarrow$ 100 μm

  $\rightarrow$ to reduce uncertainties on θ and Q^2
- Central overlap between the 2 planes and central hole for the beam line





Developed and build by UVA

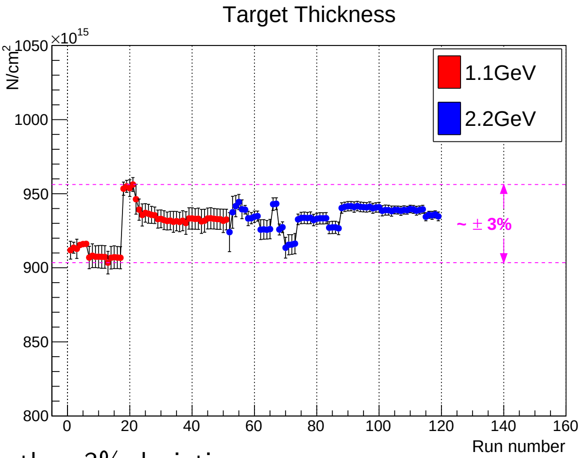
Outline

Data Collected

- 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}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}C target for calibration

Target Stability

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

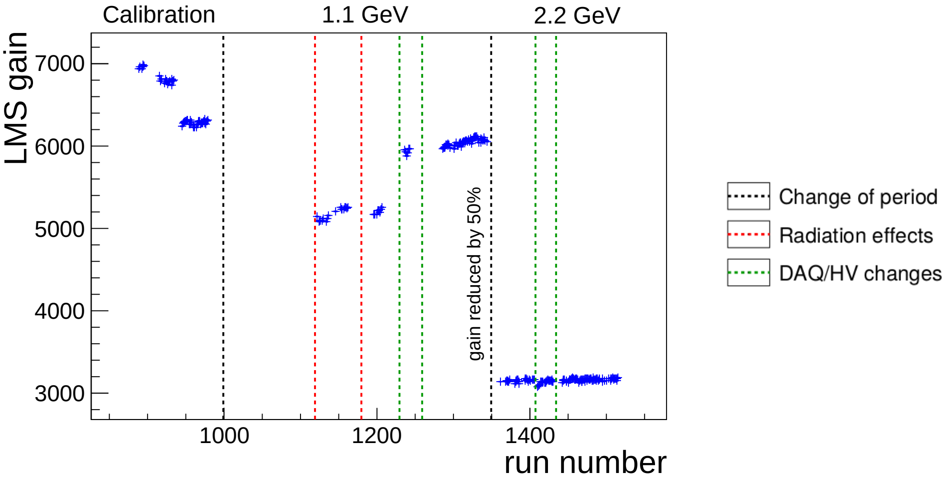


→ Less than 3% deviation

Weizhi Xiong

HyCal Gain Stability

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

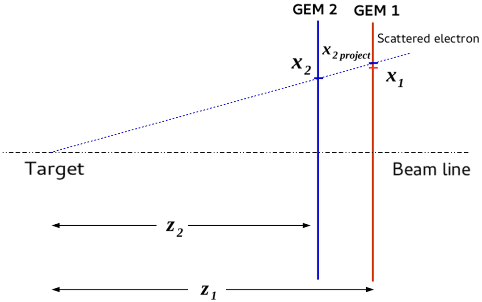


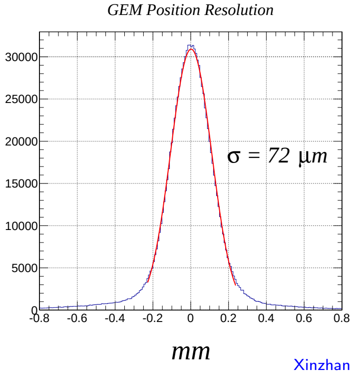
Outline

GEM Spatial Resolution

PRoton Radius

- Extraction of GEM spatial resolution using GEM central overlapping region



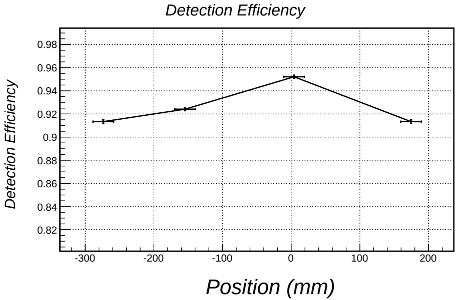


Xinzhan Bai

- Good spatial resolution achieved

GEM Detection Efficiency

- 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

HyCal Energy Calibration

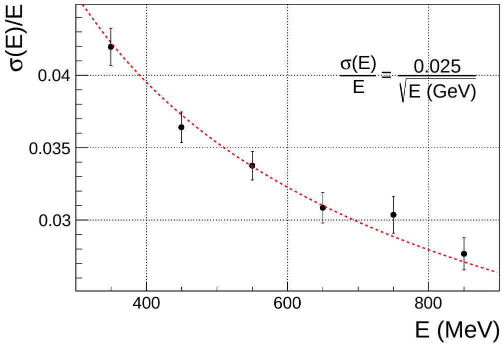
- Gains controlled by *Light Monitoring System (LMS)*
- Two different calibrations:
  - Before data taking:
    Scan with 250-1050 MeV tagged photon beam moved in front of each module
    $\rightarrow$ study of resolution, efficiency and non linearity
  - During physics data taking:
    With Møller and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

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

- Different clustering algorithms used for cross-check

HyCal Resolution

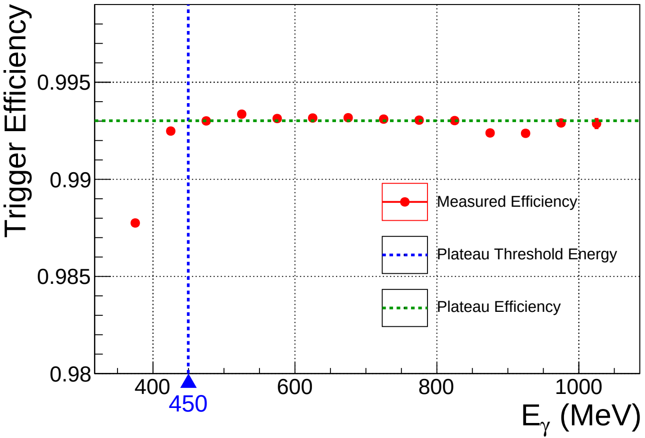
- Crystal energy resolution with statistical uncertainties and systematic coming from non-uniformity



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

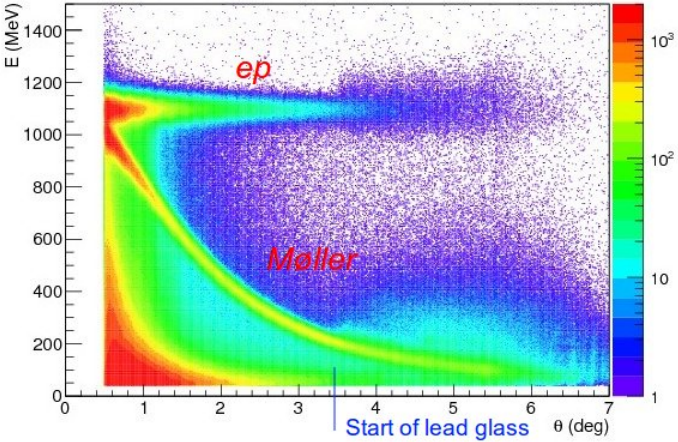
HyCal Trigger Efficiency



Maxime Levillain

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

Phase Space (1.1 GeV)

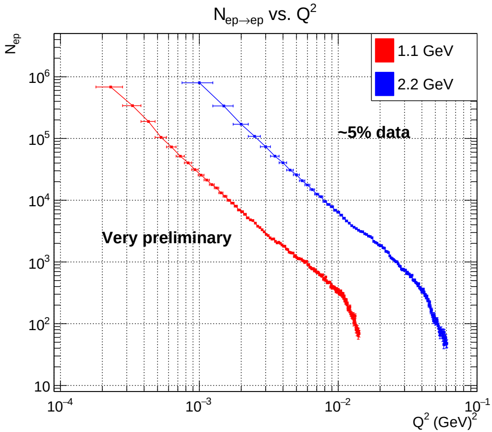


Weizhi Xiong

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

Q^2 Range

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



Weizhi Xiong

Summary

- 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
  $\rightarrow$ spatial resolution of 72 μm
  and detection efficiency of 0.92$\pm$0.001
- HyCal calibration from photon tagged beam finalized
  $\rightarrow$ 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

PRad is supported in part by NSF MRI award PHY-1229153, as well as DOE awards for GEM;
my research work is supported by NSF awards: PHY-1506388 and PHY-0855543