Status of PRad Experiment

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for the PRad Collaboration

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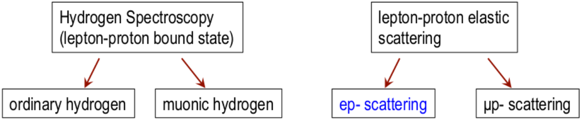
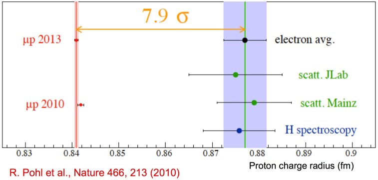
Outline

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

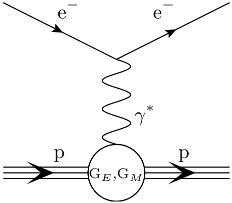


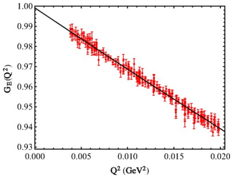
R. Pohl et al., Nature 466, 213 (2010)
A. Antognini et al., Science 339, 417 (2013)

- Controverted methods for fitting G_E and extracting r_p

- Previous measurement with strong systematic uncertainties and limited Q^2 range
- Requirements for PRad Experiment:
  - large Q^2 range
  - 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

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



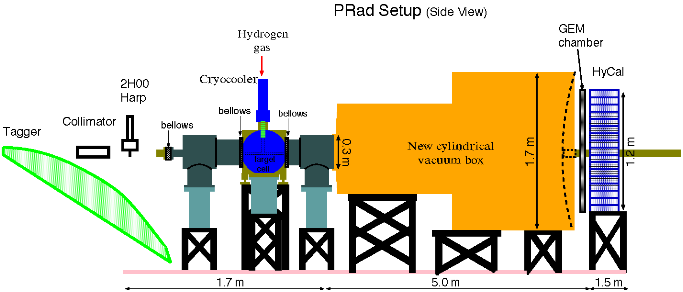


Phys. Rev. C 93, 065207

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

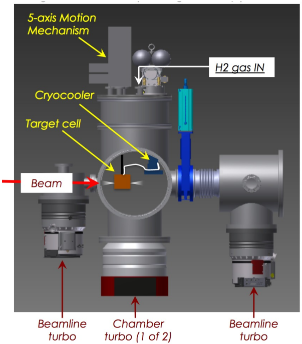


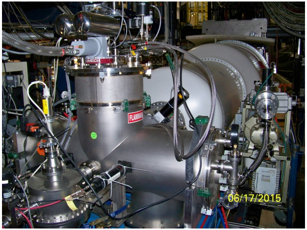
- Electron beam or tagged photon beam at $\sim$ 1GeV or $\sim$ 2GeV

- Windowless H_2 gas flow target
- Vacuum box
- GEM detectors
- Primex HyCal

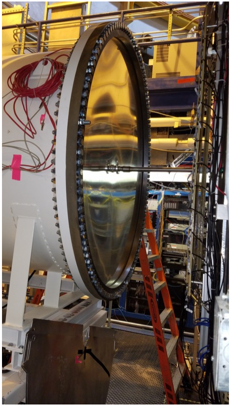
Windowless H_2 Gas Flow Target

- gas target of cryogenically cooled hydrogen
- diameter: 8cm, length: 4cm
- temperature: 19.5 K
- cell density: $\sim 2 \cdot 10^{18}$ H atoms/cm^2
- cell pressure: 471 mtorr
- chamber pressure: 2.34 mtorr





Vacuum Box



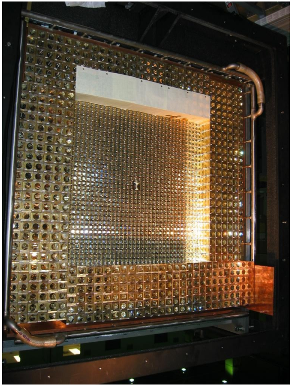
- 1.7 m diameter, 2mm *Al* vacuum window

→ Limited background

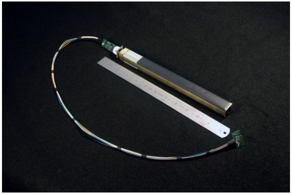
Primex HyCal

Hybrid detector:

- Central part:
  - 34 x 34 matrix of $PbWO_4$ detectors
  - dimension of block: 2.077 x 2.075 x 18 cm^3
  - 2 x 2 blocks removed from the middle

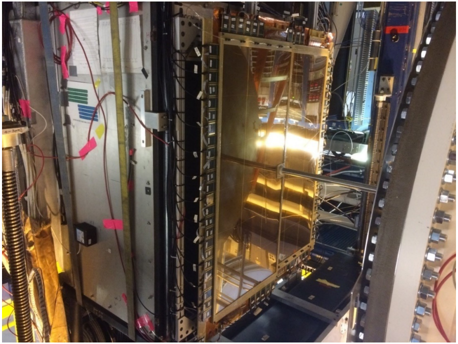


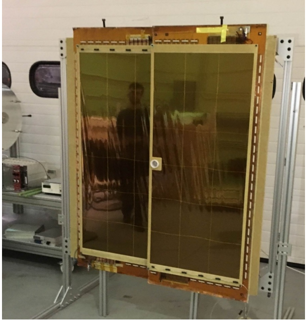
- Peripheral Part:
  - 576 Leadglass detectors
  - dimension of block: 3.815 x 3.815 x 45 cm^3



GEM Detectors

- Two large area GEM detectors: 55cm x 123 cm
- Purpose: improve spatial resolution $\rightarrow$ 100 μm
- Less uncertainties on θ and Q^2





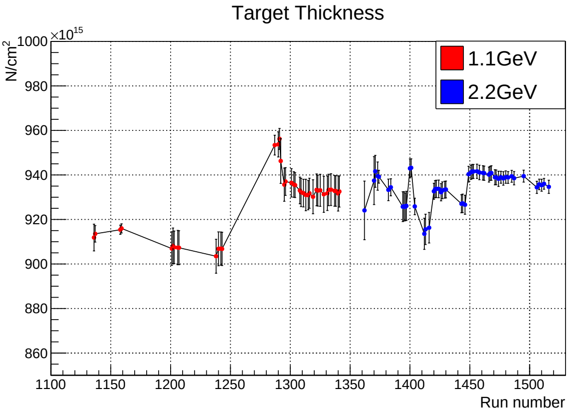
Outline

Data Collected

- Calibration with tagged photon beam
  - Every module moved in front of 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

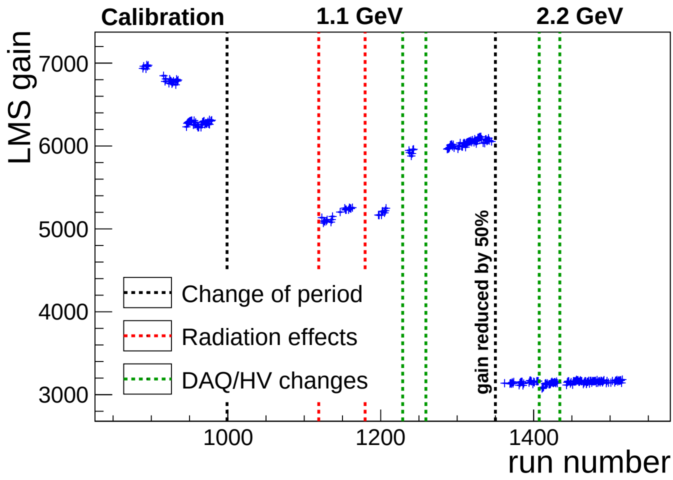


→ Less than 2% deviation

Weizhi Xiong

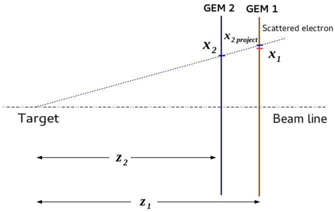
HyCal Stability

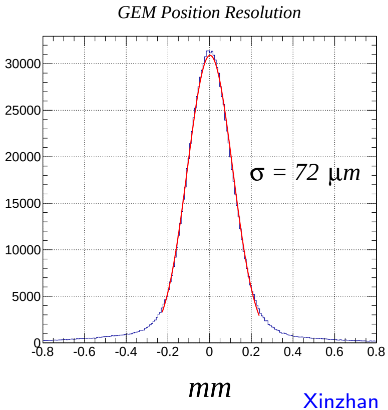
- Control of Calorimeter gain throughout the data taking thanks to the *Light Monitoring System (LMS)*



Outline

- Extraction of GEM resolution using GEM central overlapping region



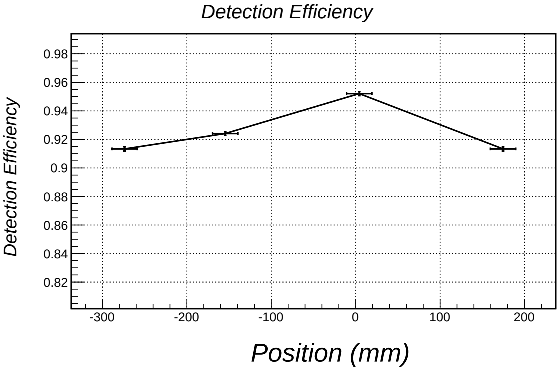


Xinzhan Bai

- Spatial resolution $< 74\mu$m

GEM Detection Efficiency

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



Xinzhan Bai

- Detection efficiency of 0.92

HyCal Calibration Process

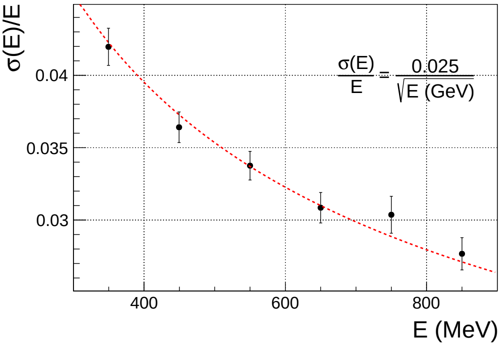
- Gains controlled by *Light Monitoring System (LMS)*
- Two different calibrations:
  - Before data taking:
    Scan with 250-1050 MeV tagged photon beam moved in front of each module
    $\rightarrow$ study of resolution, efficiency and non linearity
  - During physics data taking:
    With Møller and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

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

- Different clustering *Island* algorithms used for cross-check

HyCal Resolution

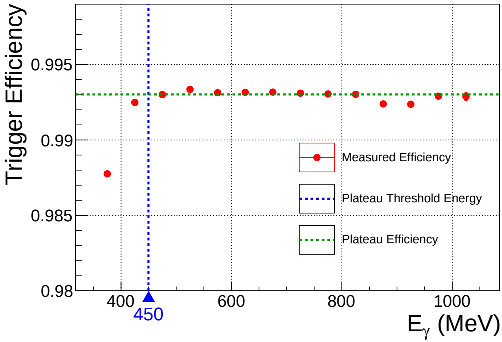
- Crystal energy resolution with statistical uncertainties and systematic coming from non-uniformity



Li Ye, Ilya Larin, Weizhi Xiong, Maxime Levillain

- Achieved expected energy resolution:
  - 2.5% for crystal part
  - 6.1% for leadglass part

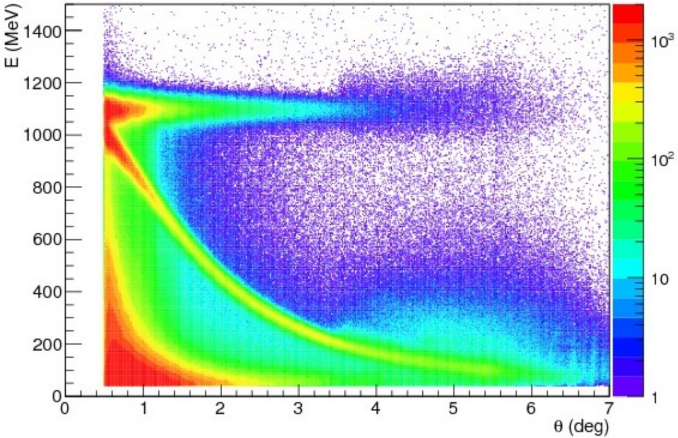
HyCal Trigger Efficiency



Maxime Levillain

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

Phase Space (1.1 GeV)

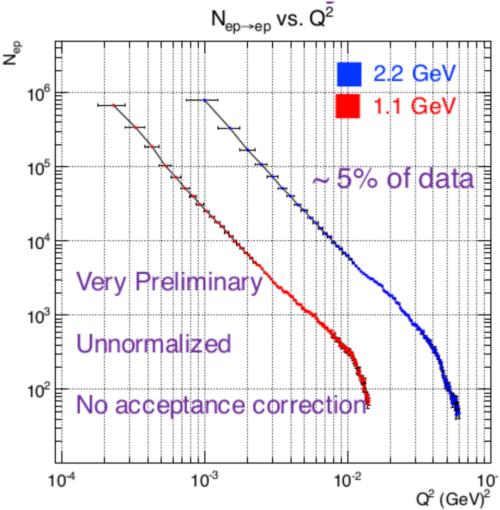


Weizhi Xiong

- Separation between *ep* scattering and Møller phase space for $\theta > 0.5^\circ$

Preliminary Q^2 range

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



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 74μm and detection efficiency of 0.92
- HyCal calibration from photon tagged beam finalized
  $\rightarrow$ good energy resolution and high and uniform efficiency
- HyCal physics calibration on progress
- The physics analysis will start soon!

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