The New Proton Charge Radius Experiment at JLab

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(for the PRad Collaboration)

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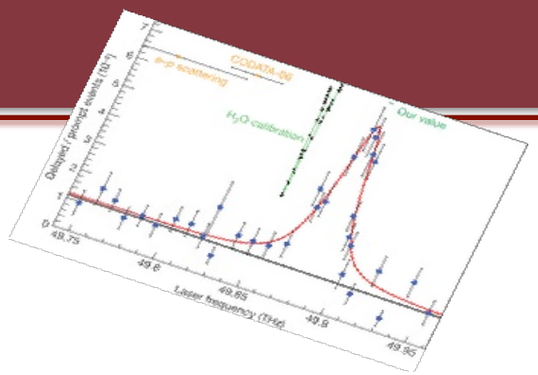
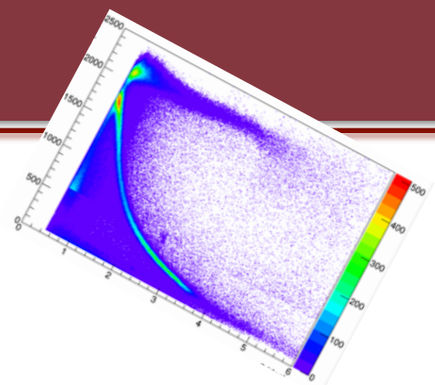
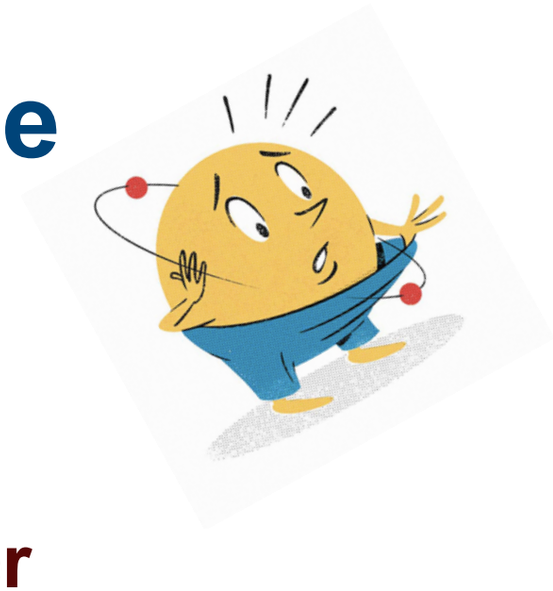
Outline





1. **The Proton Charge Radius Puzzle**
2. **A New Experiment (PRad)**



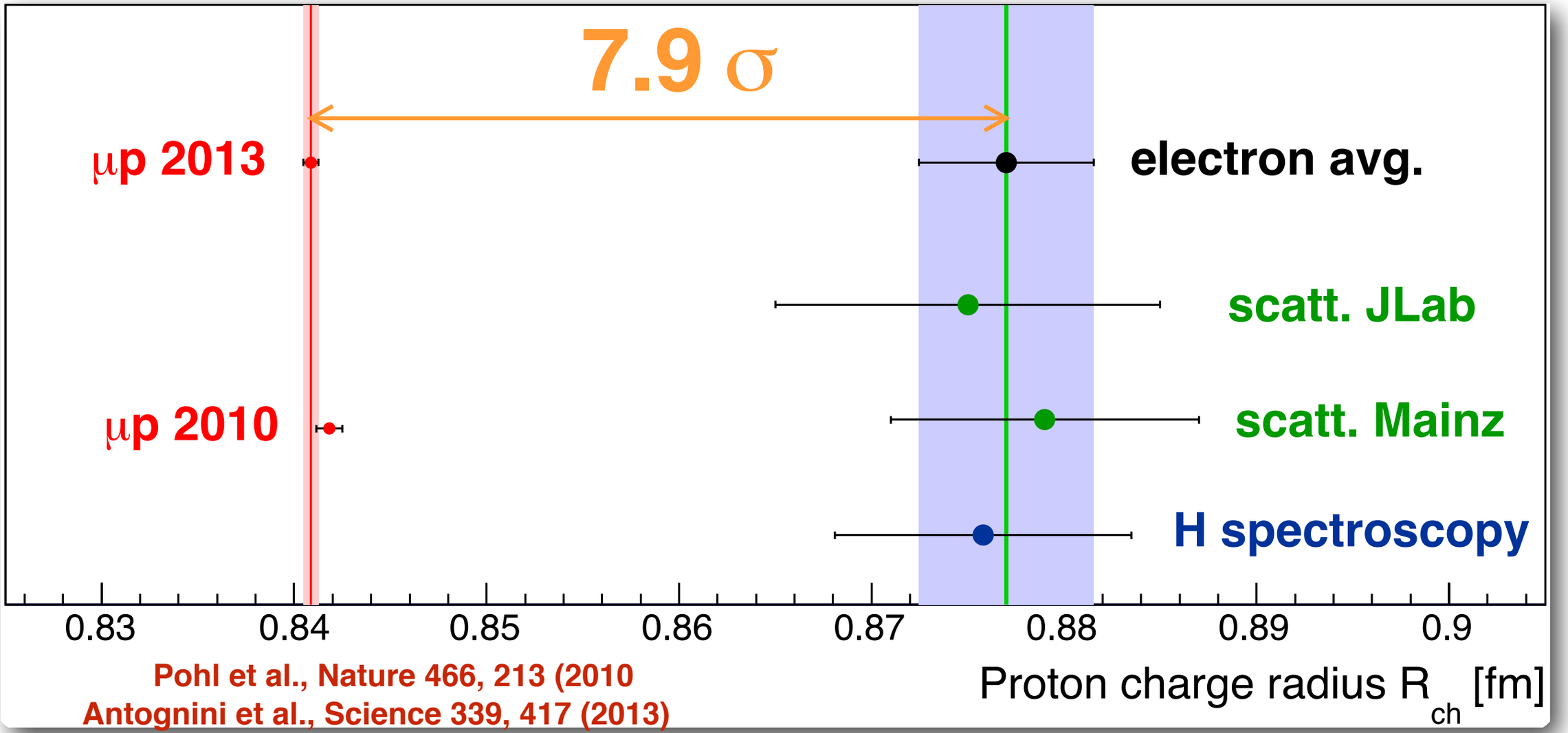
   - **windowless target**
   - **high resolution calorimeter**
   - **simultaneous detection of elastic and Moller**

3. **Preliminary Online Results**
4. **Summary**

PRoton Radius

The Proton Charge Radius Puzzle

~8σ discrepancy between muon and electron based measurements



Proton rms charge radius measured using

electrons: 0.8770 ± 0.0045 (CODATA2010 + Zhan et al.)

muons: 0.8409 ± 0.0004

Numerous possible resolutions explored

★ **Are the state of the art QED calculations incomplete?**

- E. Borie, Phys. Rev. A 71, 032508 (2005)
- U. D. Jentschura, Ann. of Phys. 326, 500 (2011)
- F. Hagelstein, V. Pascalutsa, Phys. Rev. A 91, 040502 (2015)

★ **Are there additional corrections to the muonic Lamb shift due to proton structure (such as proton polarizability $\propto m_l^4$)?**

- C. E. Carlson, V. Nazaryan and K. Griffioen, Phys. Rev. A 83, 042509 (2011)
- R. J. Hill and G. Paz, Phys. Rev. Lett. 107, 160402 (2011)

★ **Are higher moments of the charge distribution accounted for in the extraction of rms charge radius?**

- M. O. Distler, J. C. Bernauer and T. Walcher, Phys. Lett. B 696, 343 (2011)
- A. de Rujula, Phys. Lett. B 693, 555 (2010), and 697, 264 (2011)
- I. Cloet, and G. A. Miller, Phys. Rev. C. 83, 012201(R) (2011)

★ **Is there an extrapolation problem in electron scattering data?**

- D. W. Higinbotham et al., Phys. Rev. C 93, 055207 (2016)
- K. Griffioen, C. Carlson, S. Maddox, Phys. Rev. C 93, 065207 (2016)

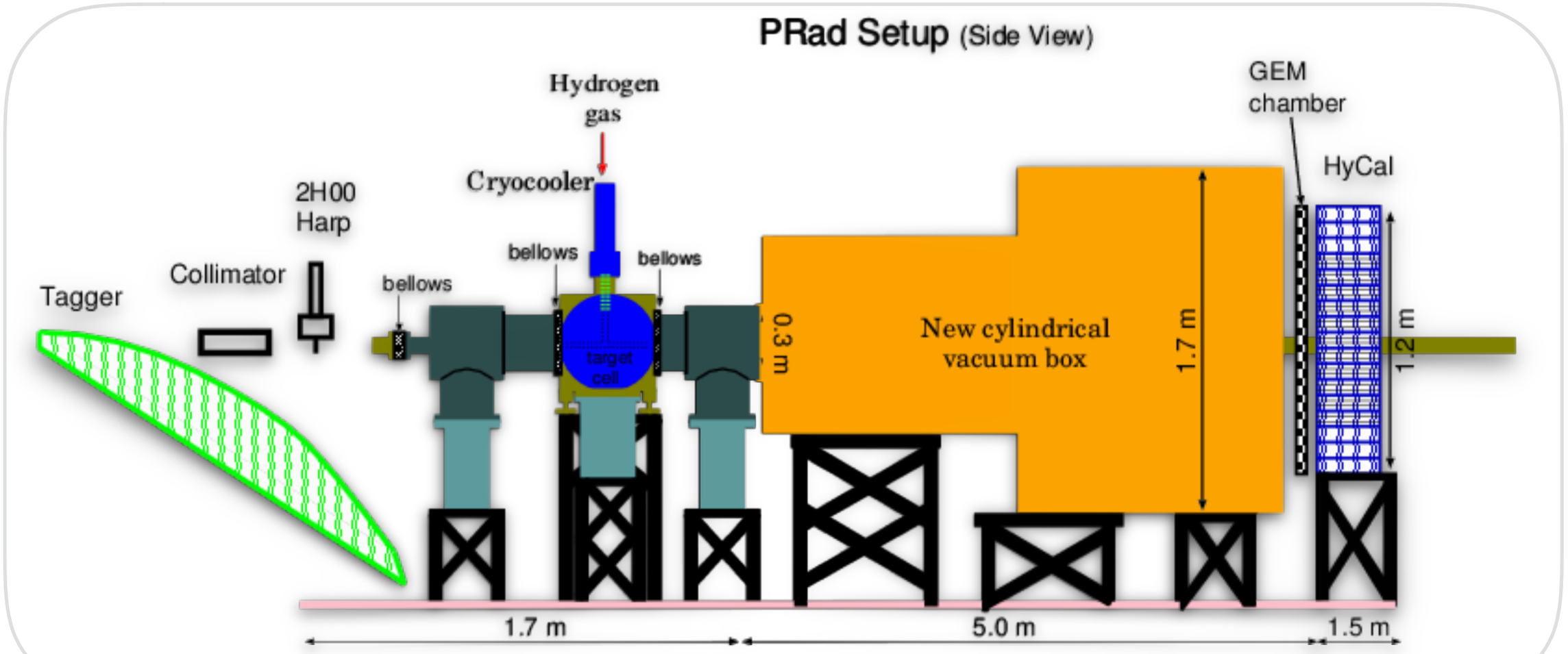
★ **Has new physics been discovered (violation of Lepton Universality)?**

- V. Barger, et al., Phys. Rev. Lett. 106, 153001 (2011)
- B. Batell, D. McKeen, M. Pospelov, Phys. Rev. Lett. 107, 011803 (2011)
- D. Tucker-Smith, I. Yavin, Phys. Rev. D 83, 101702 (2011).

More experiments are needed !

- **Redo atomic hydrogen spectroscopy**
- **Muonic deuterium and helium (PSI)**
- **Muon-proton scattering (MUSE experiment)**
- **Electron scattering experiments (PRad)**
  (preferably with completely different systematics)

PRad: a novel electron scattering experiment



Spokesperson: A. Gasparian,
Co-spokespersons: D. Dutta, H. Gao, M. Khandaker

- **High resolution, Hybrid calorimeter (magnetic spectrometer free)**
- **Windowless, high density H_2 gas flow target (reduced backgrounds)**
- **Simultaneous detection of elastic and Moller electrons (control of systematics)**
- **Vacuum box, one thin window, large area GEM chambers (improved resolution)**
- **Q^2 range of 10^{-4} – 6×10^{-2} GeV^2 (lower than all previous electron scattering expts.)**

The PRad Collaboration

Jefferson Lab,
NC A&T State University,
Duke University,
Idaho State University,
Mississippi State University,
Norfolk State University,
University of Virginia
University of North Carolina at Wilmington,
Old Dominion University,
University of Kentucky,
College of William & Mary,
Argonne National Lab,
Hampton University
Tsinghua University, China
ITEP, Moscow, Russia
Budker Institute of Nuclear Physics, Russia
MIT

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Li Ye (MSU)
Weizhi Xiong (Duke)
Xinzhan Bai (UVa)
Abhisek Karki (MSU)

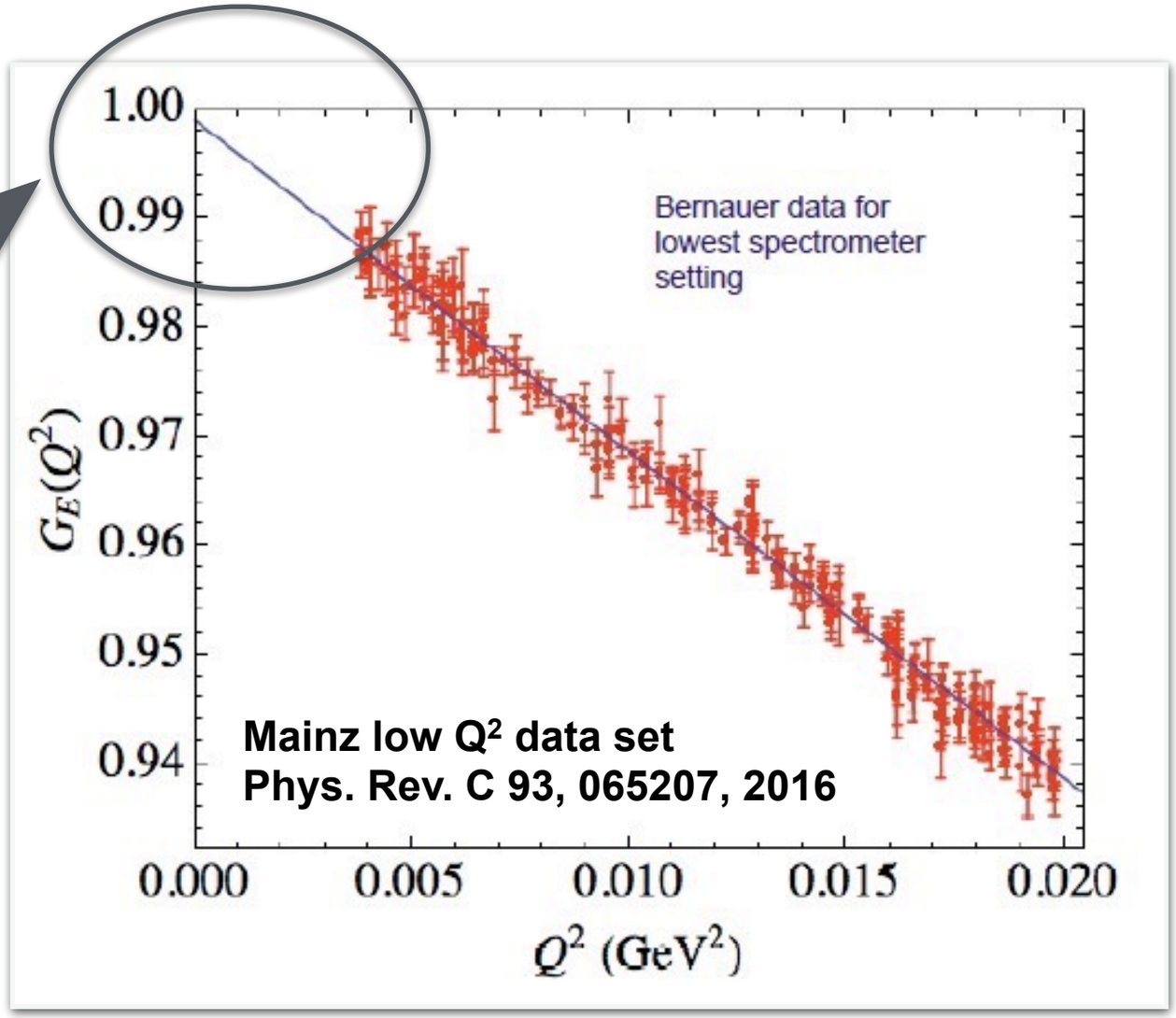
Post-docs

Mehdi Meziane (Duke)
Zhihong Ye (Duke)
Krishna Adhikari (MSU)
Maxime Lavillain (NC A&T)
Rupesh Silwal (MIT)

PRad: First JLab 12 GeV era experiment

Ran with 1.1 and 2.2 GeV beam in Hall-B at JLab

- **Experimental goals:**
  - **fill in the very low Q^2 range**
  - **large Q^2 range in a single setting (~1×10^{-4} - 6×10^{-2} GeV^2)**
  - **measure cross section with sub-percent precision**
  - **sub-percent rms proton charge radius extraction**

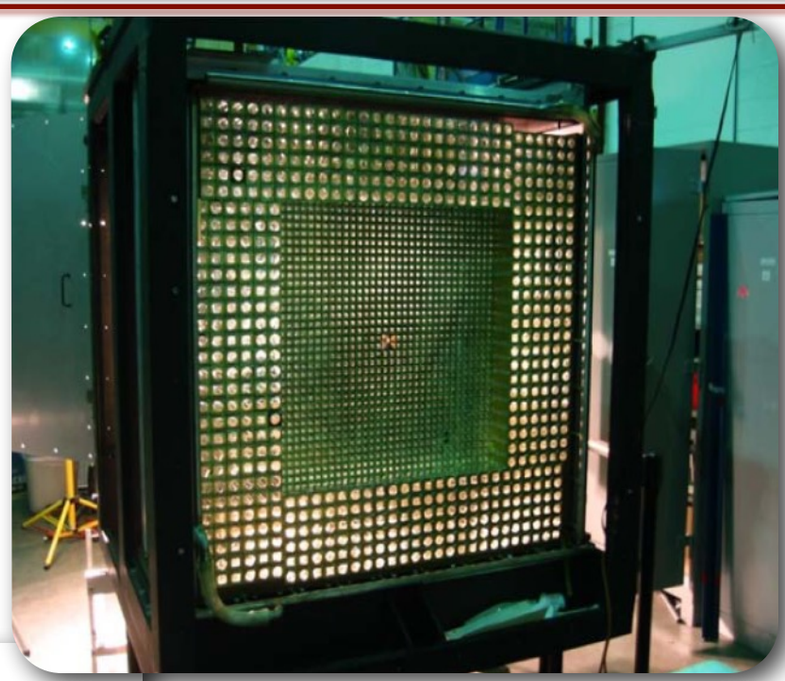


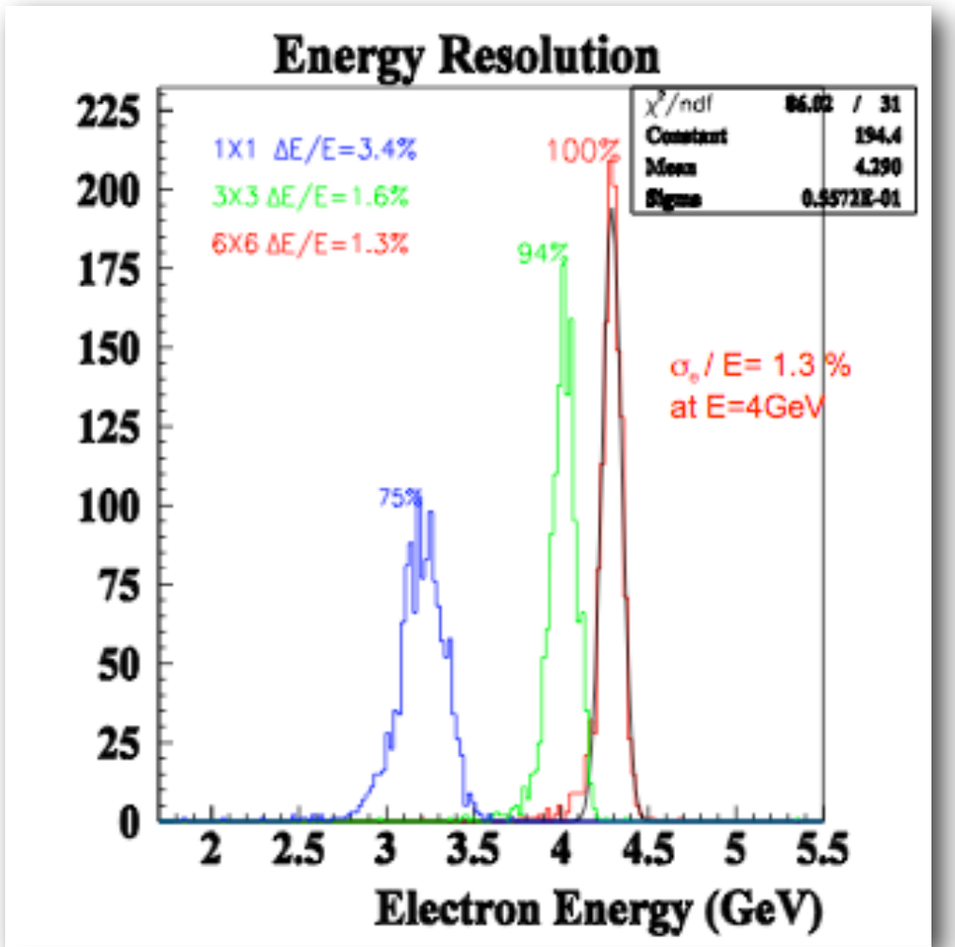
- **High resolution, Hybrid calorimeter (access small scattering angle: 0.7° - 7.0°)**
- **Windowless, high density H_2 gas flow target (reduced backgrounds)**
- **Simultaneous detection of elastic and Moller electrons (control of systematics)**
- **Vacuum box, one thin window, large area GEM chambers (improved resolution)**

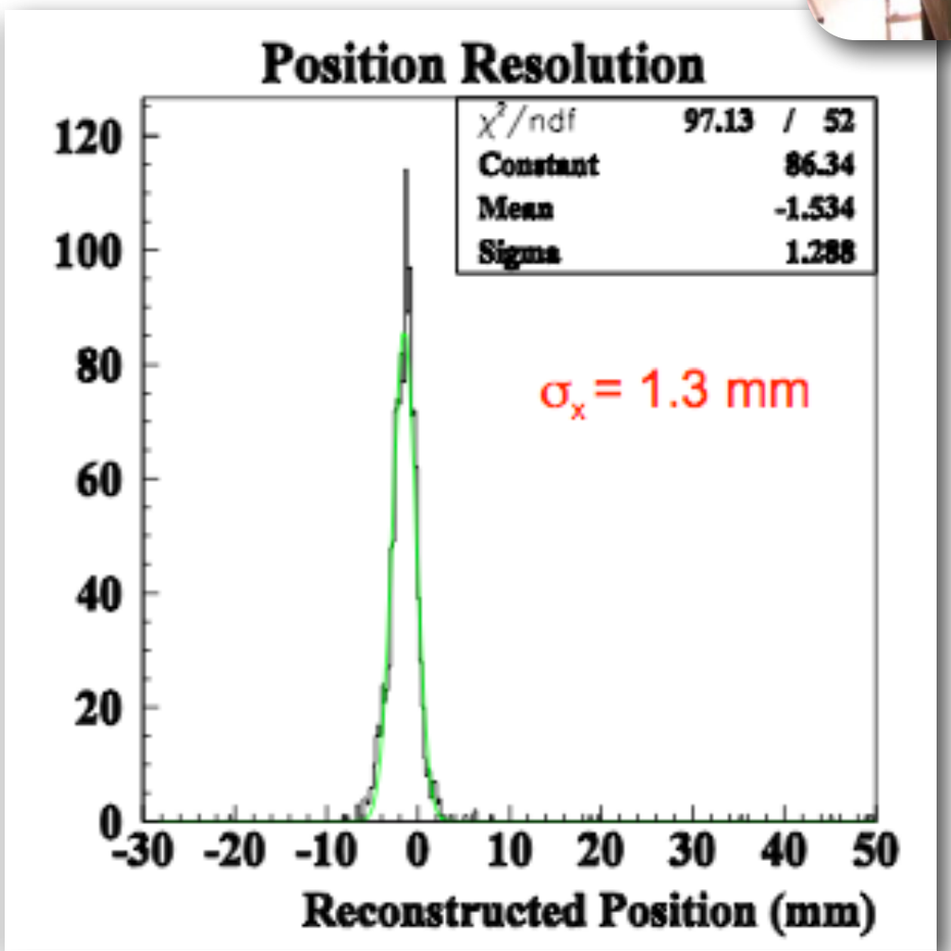
High resolution calorimeter

Reused PrimEx HyCal

- $PbWO_4$ and Pb-glass calorimeter (118x118 cm^2)
- 34x34 matrix of 2.05 x 2.05 cm^2 x18 cm $PbWO_4$
- 576 Pb-glass detectors (3.82x3.82 cm^2 x45 cm)
- 5.5 m from the target,
- 0.5 sr acceptance







$PbWO_4$ resolution:
$\sigma_E/E = 2.6\%/\sqrt{E}$
$\sigma_{xy} = 2.5\ mm/\sqrt{E}$

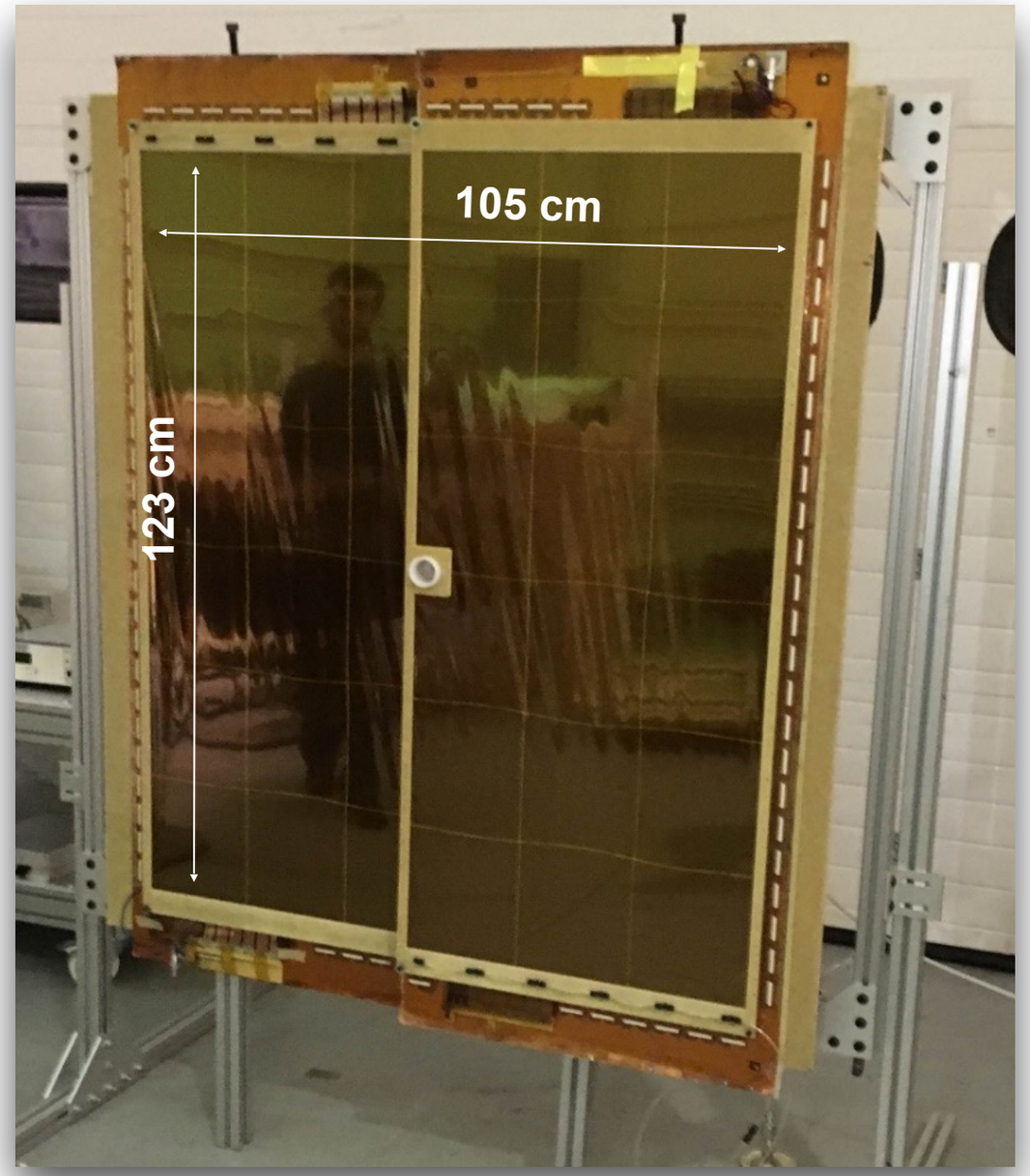
Pb-glass:
2.5 times worse

Large area GEM coordinate detectors

- **Two large GEM based X and Y- coordinate detectors with 100 μm position resolution**

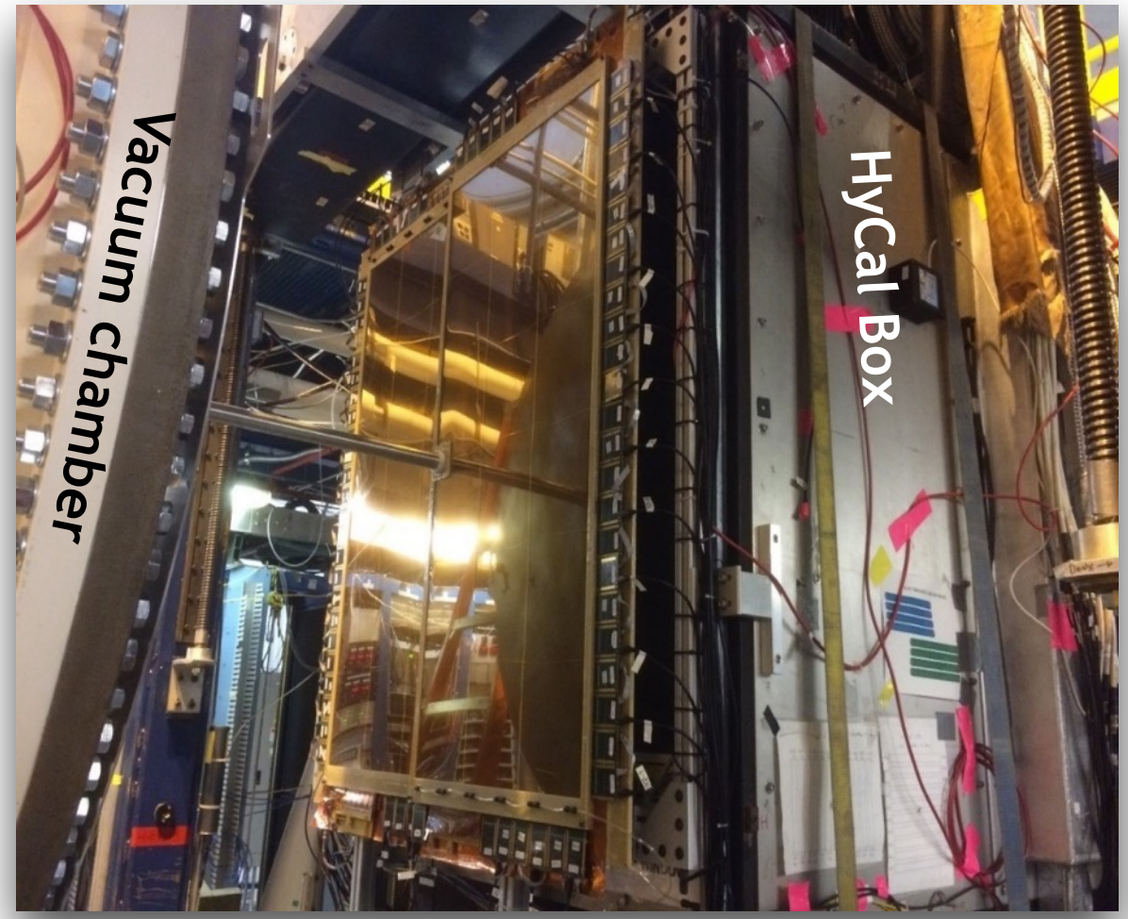
- **The GEM detectors provided:**
  - **factor of >20 improvements in coordinate resolutions**
  - **similar improvements in Q^2 resolution**
  - **unbiased coordinate reconstruction (including HyCal transition region)**
  - **increase Q^2 range by enabling use of Pb-glass part of calorimeter**

- **Designed and built at University of Virginia (UVa)**



HyCal and GEMs on the beamline

beam view

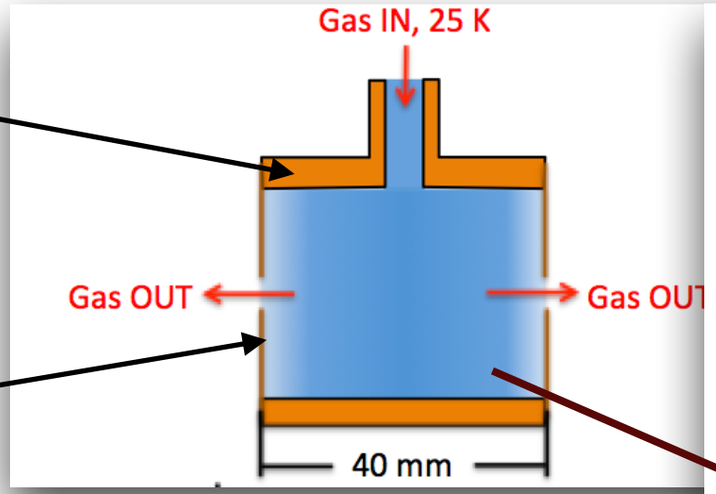


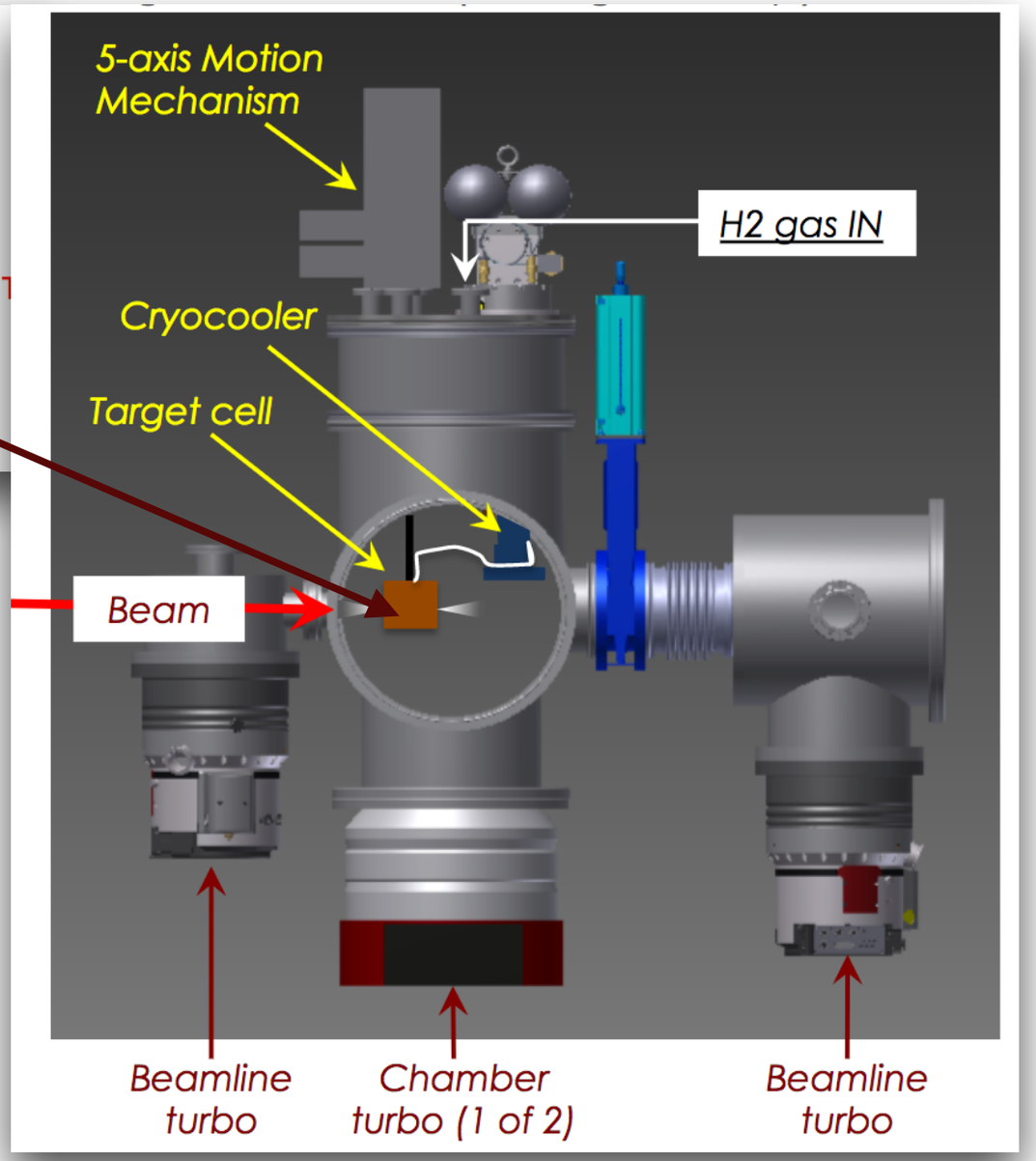
downstream view

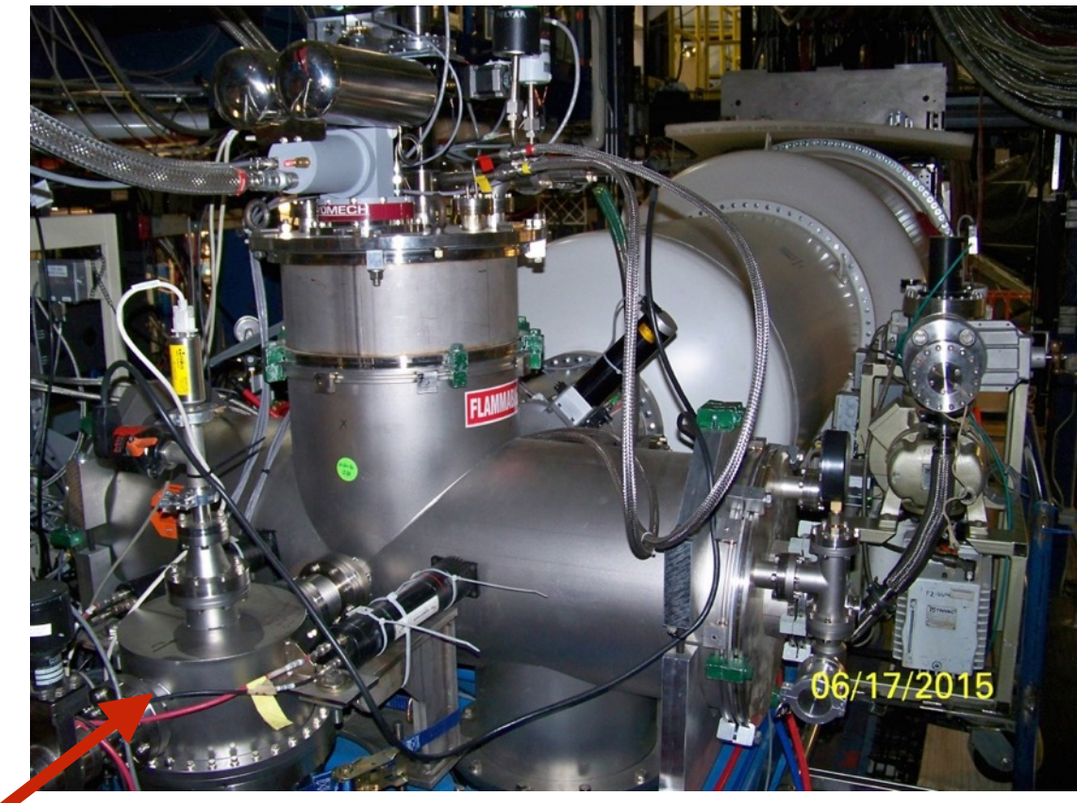
Windowless cryo-cooled gas flow target

Target cell (8 cm dia x 4 cm long copper)

7.5 μm kapton foil with 2mm hole





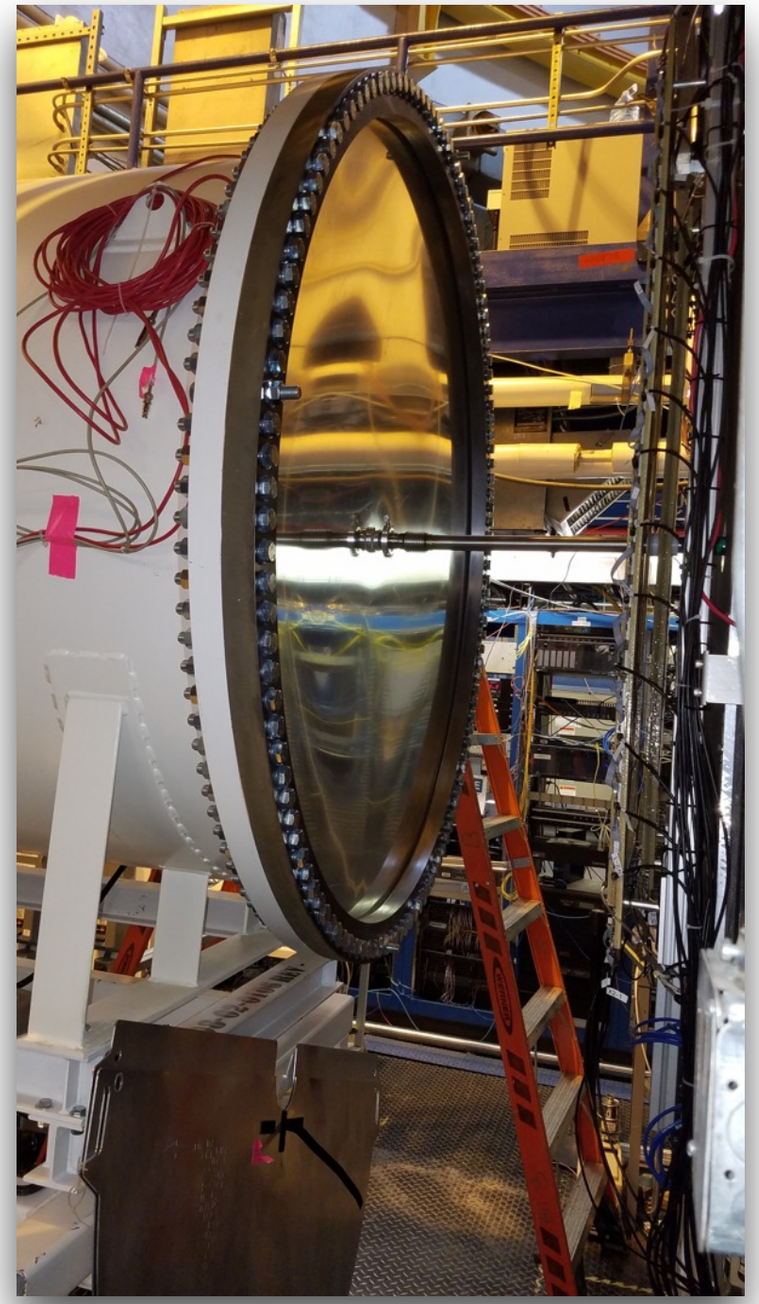


e^- beam

Operating parameters:
Areal density: ~2×10^{18} H atoms/cm^2
cell / chamber/ vacuum tank pressure:
470 mtorr / 2.3 mtorr / 0.3 mtorr

Vacuum chamber with one thin window

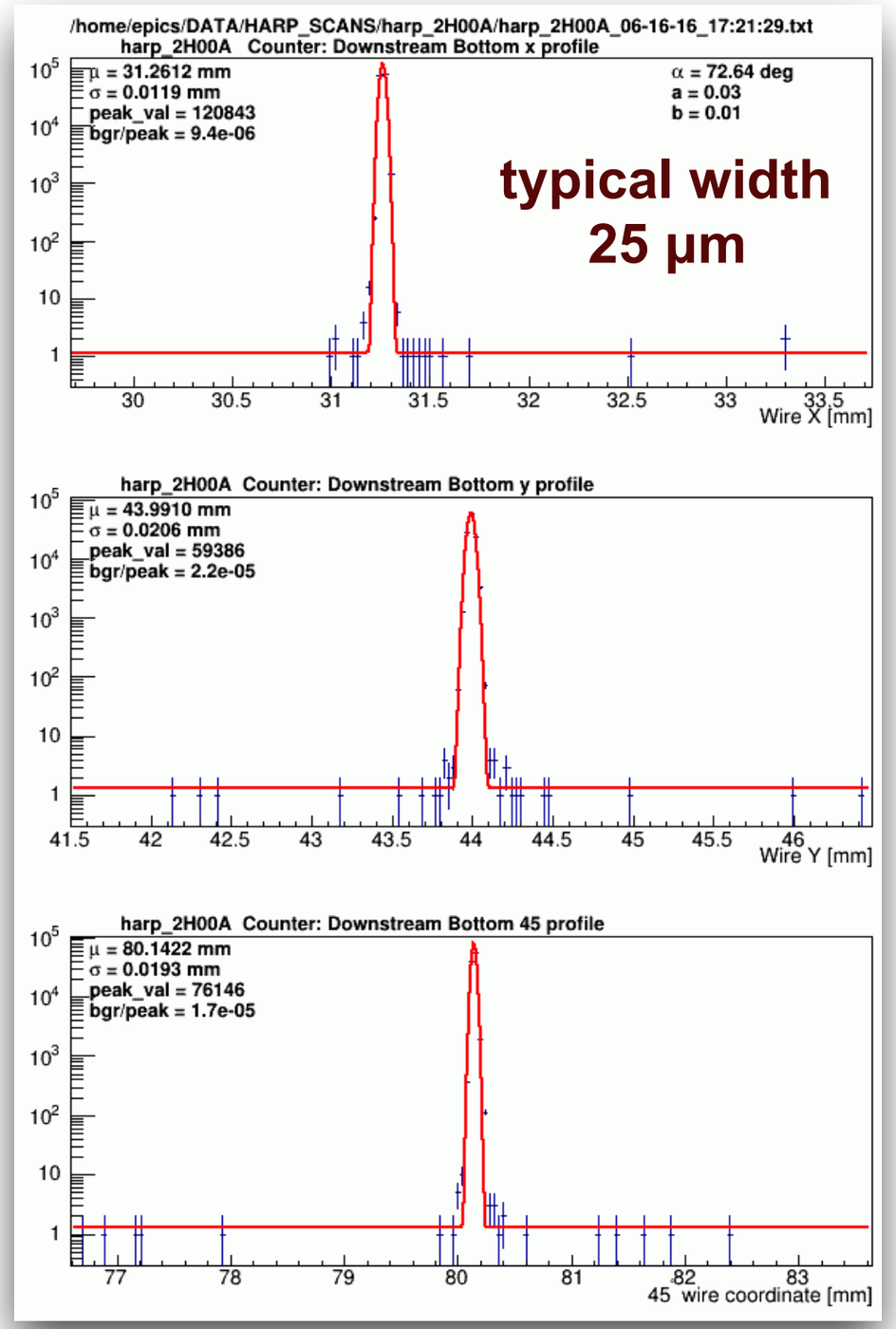
two stage, 5 m long vacuum box



1.7 m dia, 2 mm thick Al window

High quality, stable CEBAF electron beam

electron beam profile at target
(measured with harp scan)



position stability : ± 250 μm

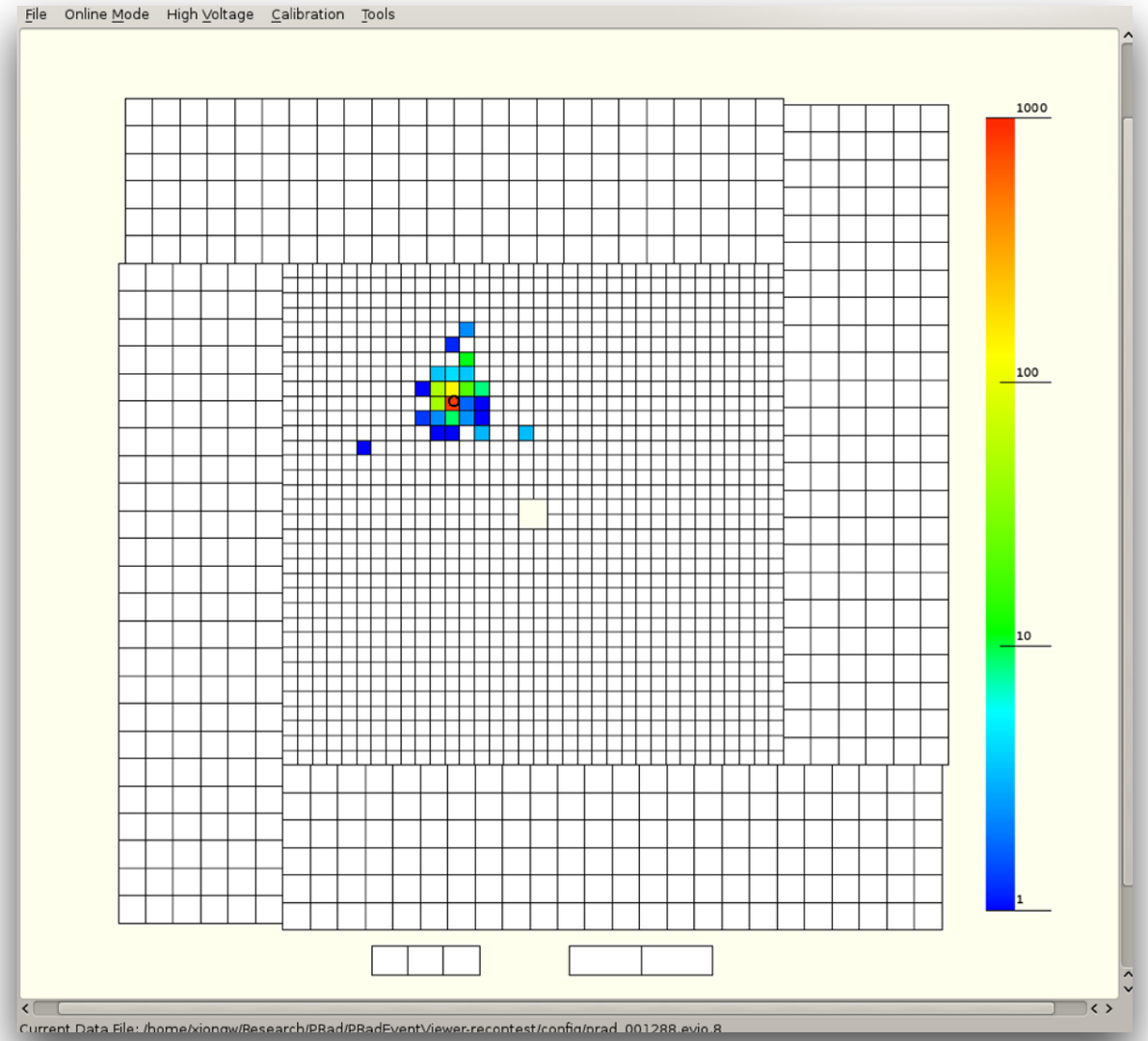
Experiment ran during May/June 2016

With E_e = 1.1 GeV beam
collected 4.2 mC on target (2x10^{18} H atoms/cm^2)
604 M events with H and
53 M events without H in target
25 M events on 1μm Carbon foil target

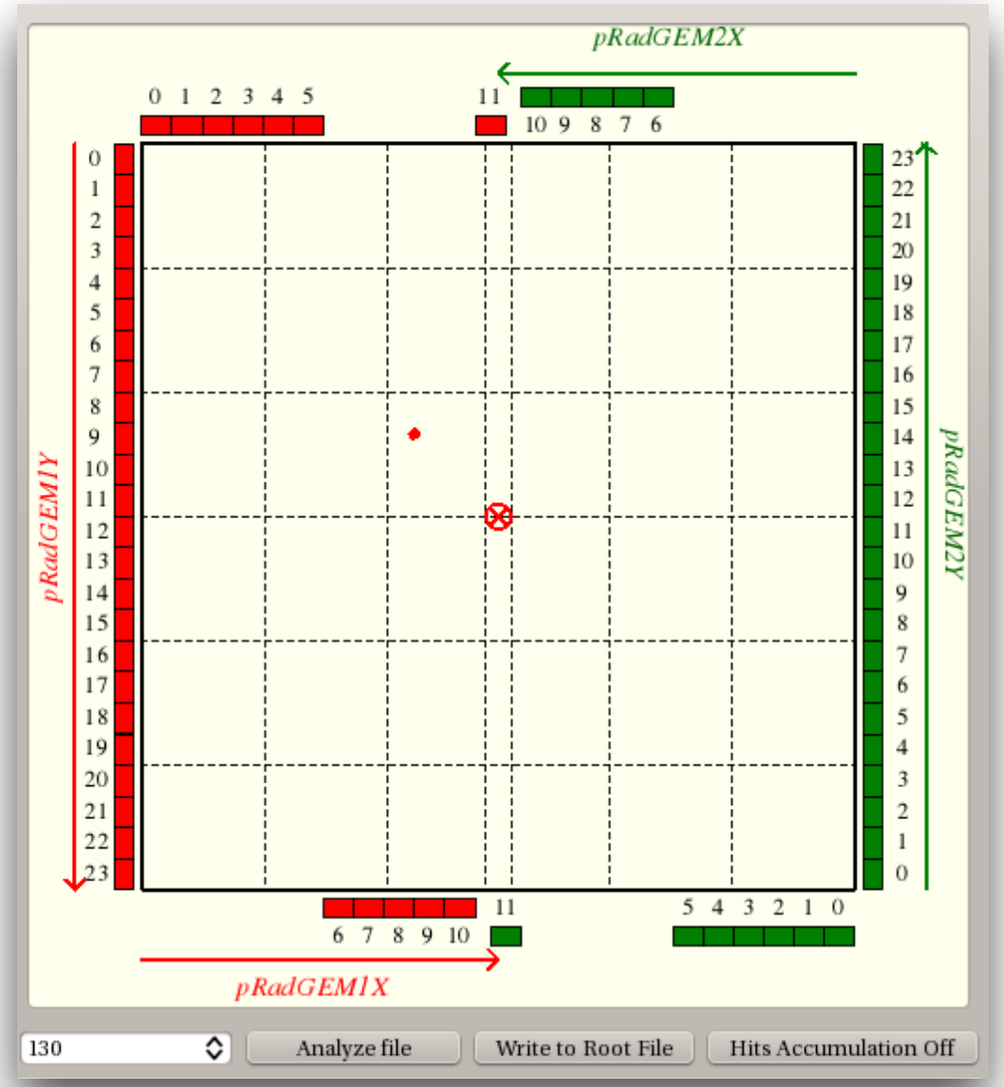
With E_e = 2.2 GeV beam
collected 14.3 mC on target (2x10^{18} H atoms/cm^2)
756 M events with H and
38 M events without H in target
10.5 M events on 1μm Carbon foil target

Preliminary online results

ep → ep event candidate



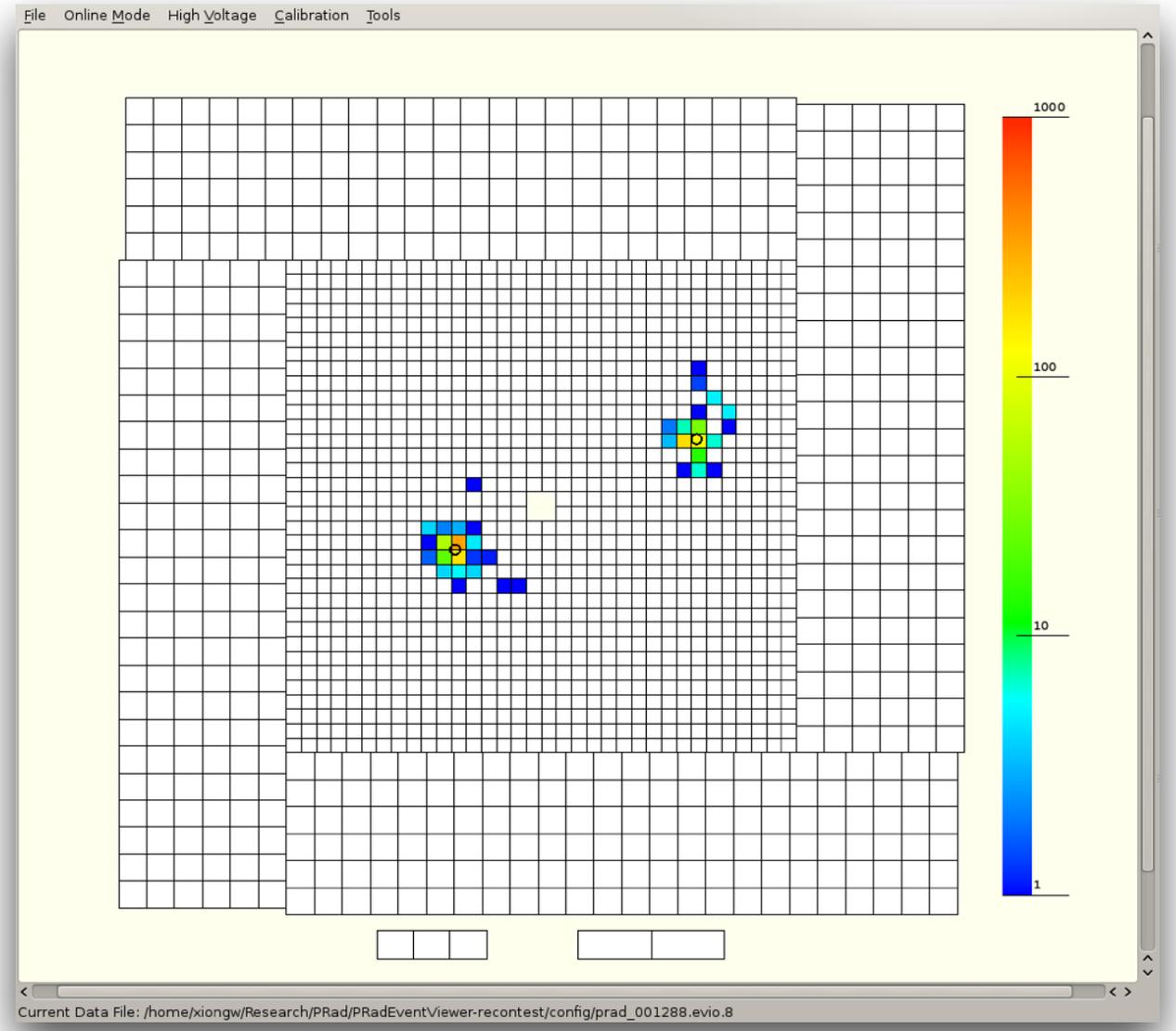
HyCal calorimeter



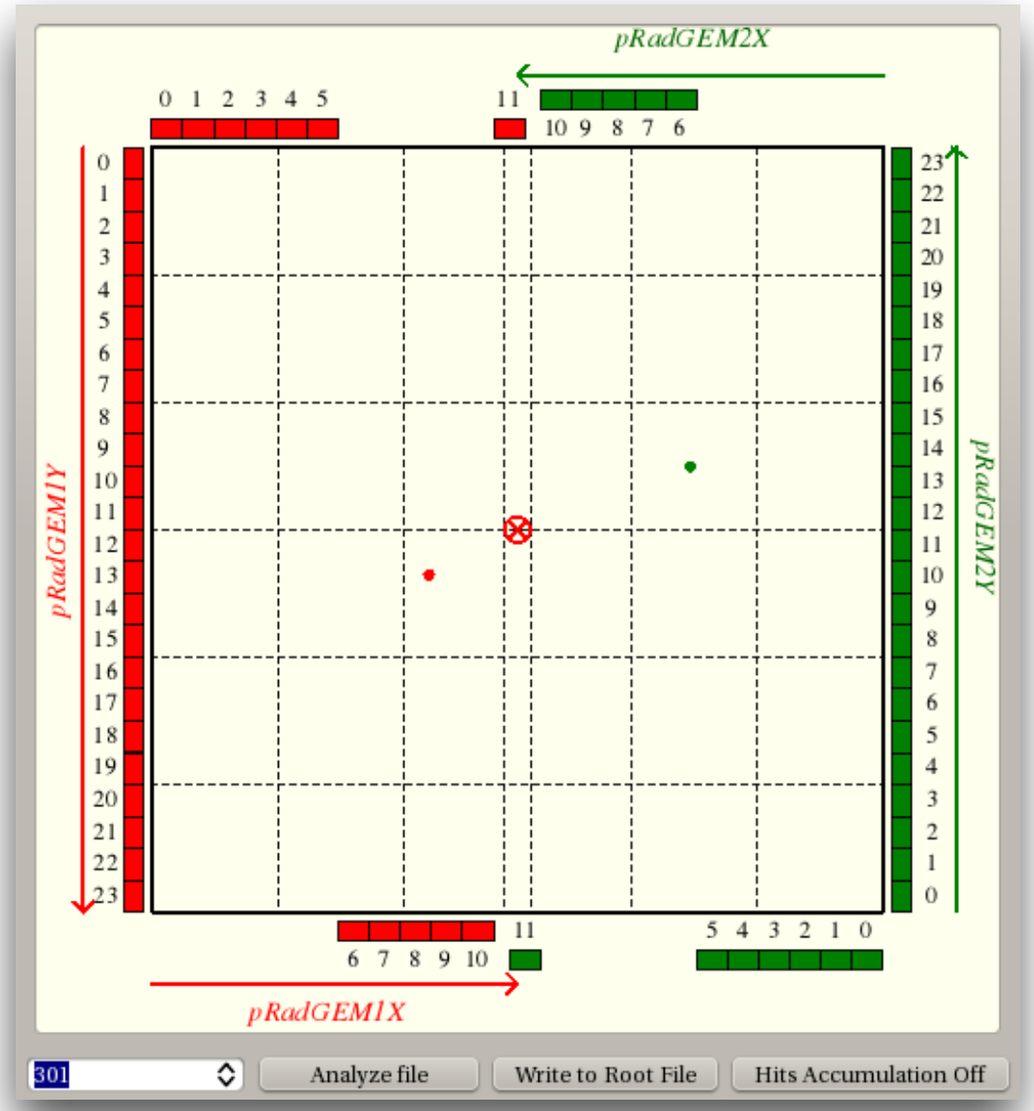
GEM detectors

Preliminary online results

ee → ee event candidate

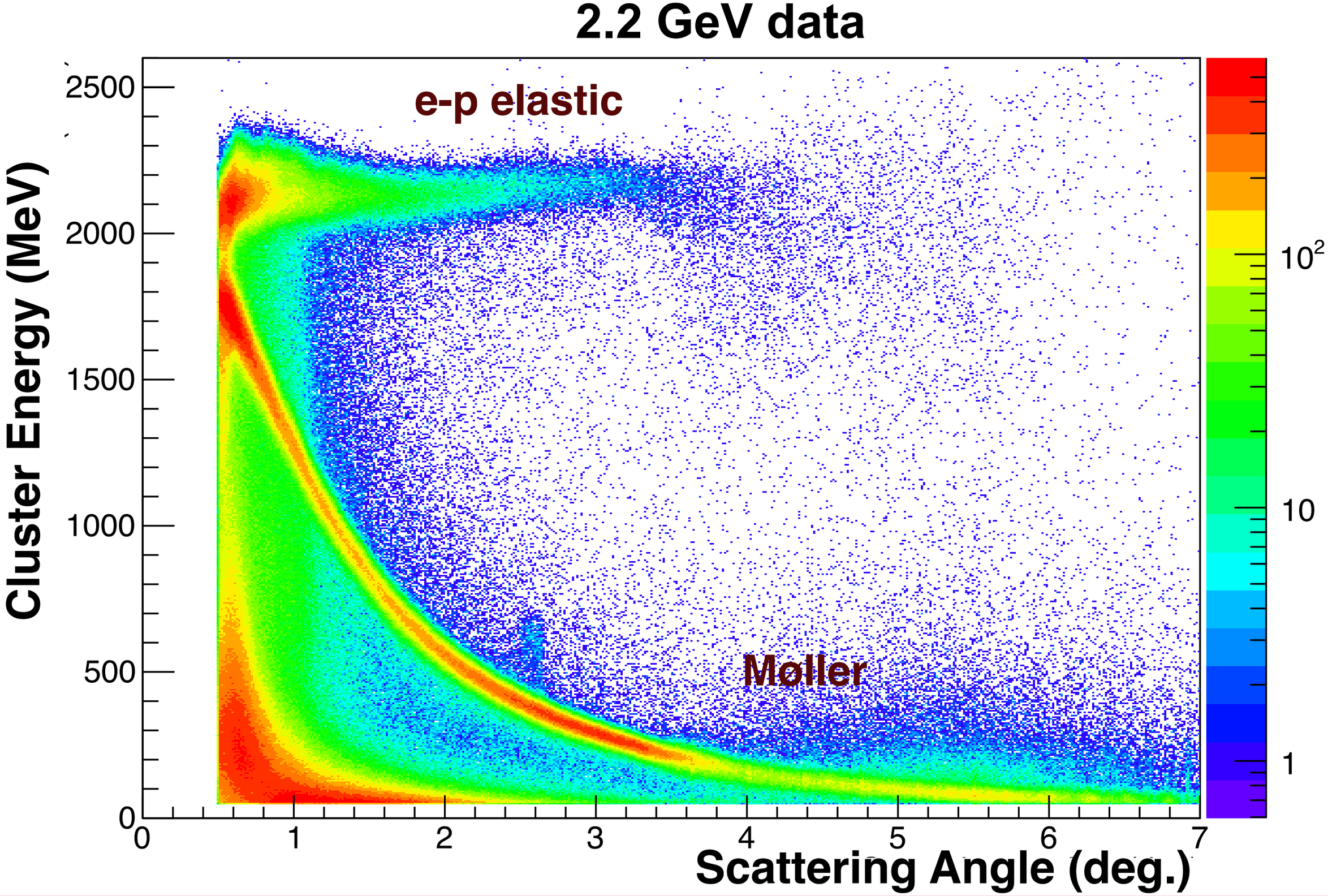


HyCal calorimeter



GEM detectors

Preliminary online results



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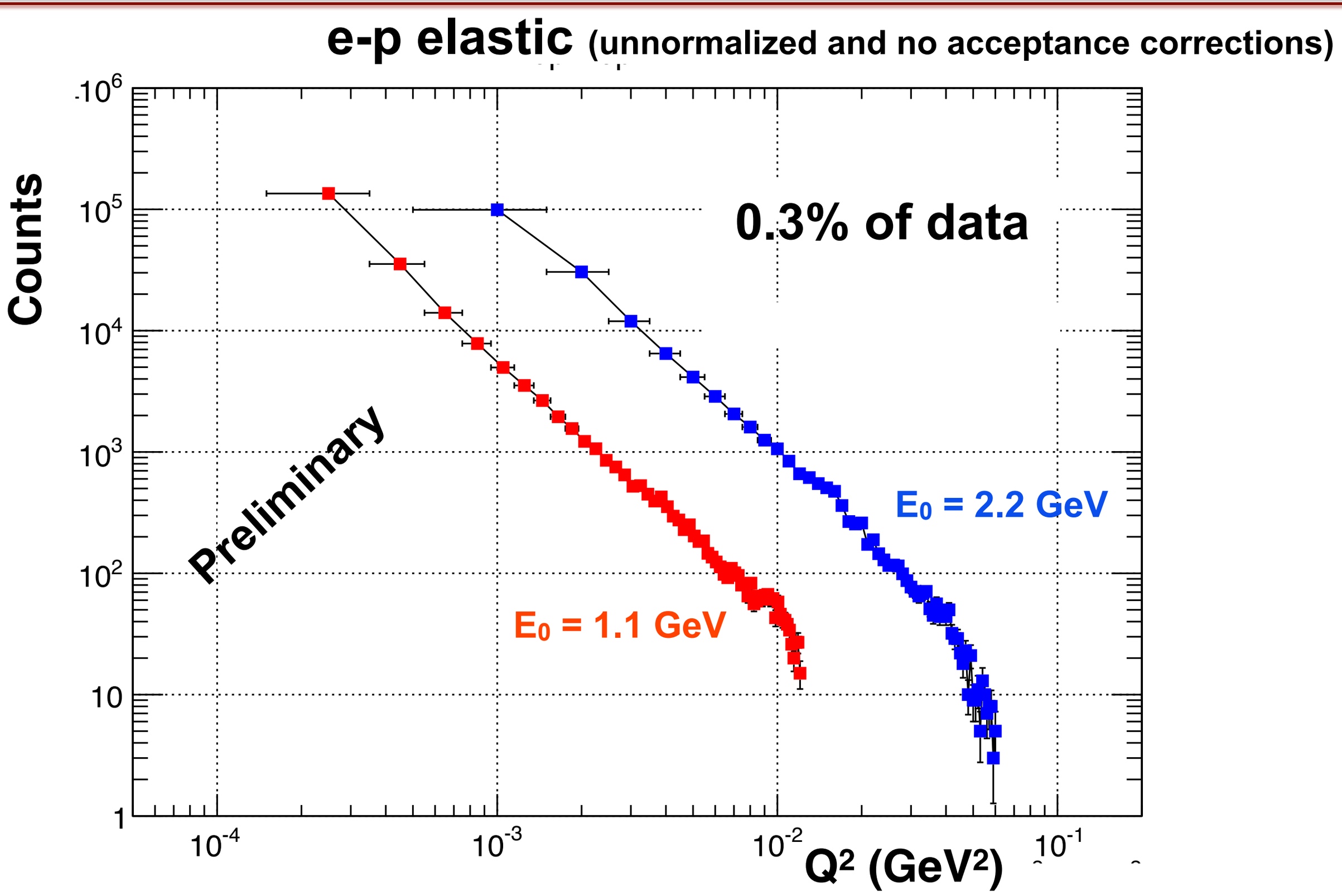

Summary

- **The proton charge radius is a fundamental quantity in Physics**
  - ✓ Important for precision atomic spectroscopy
  - ✓ Precision tests of future lattice QCD calculations
  - ✓ "New Physics"

- **The proton radius puzzle is still unresolved**

- **A novel electron scattering experiment (PRad) was recently completed at JLab Hall-B.**
  - ✓ large statistics, high quality, rich data have been collected;
  - ✓ lowest Q^2 (~10^{-4} GeV/C^2) in ep-scattering experiments was achieved;
  - ✓ simultaneous measurement of the Møller and elastic scattering processes was demonstrated to control systematic uncertainties;
  - ✓ data in a large Q^2 range (10^{-4} - 6x10^{-2} GeV^2) have been recorded with the same experimental settings, for the first time in ep-scattering experiments.

- **Analysis underway, first preliminary results expected soon.**

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