The New Proton Charge Radius Experiment at JLab

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(for the PRad Collaboration)

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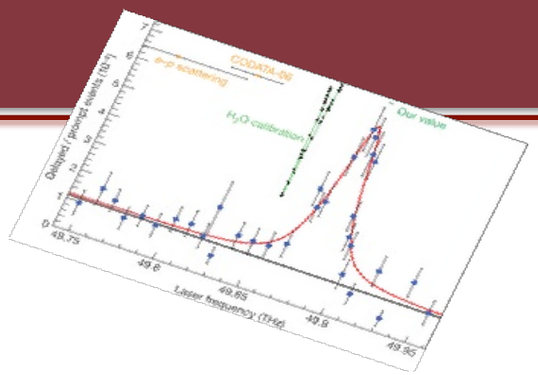
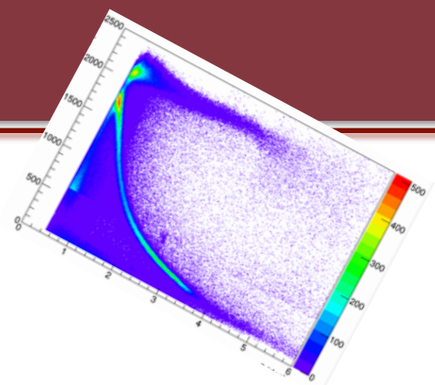
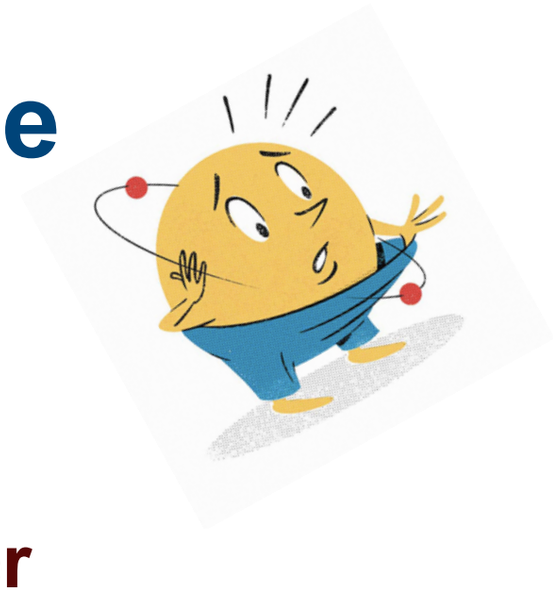
Outline





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



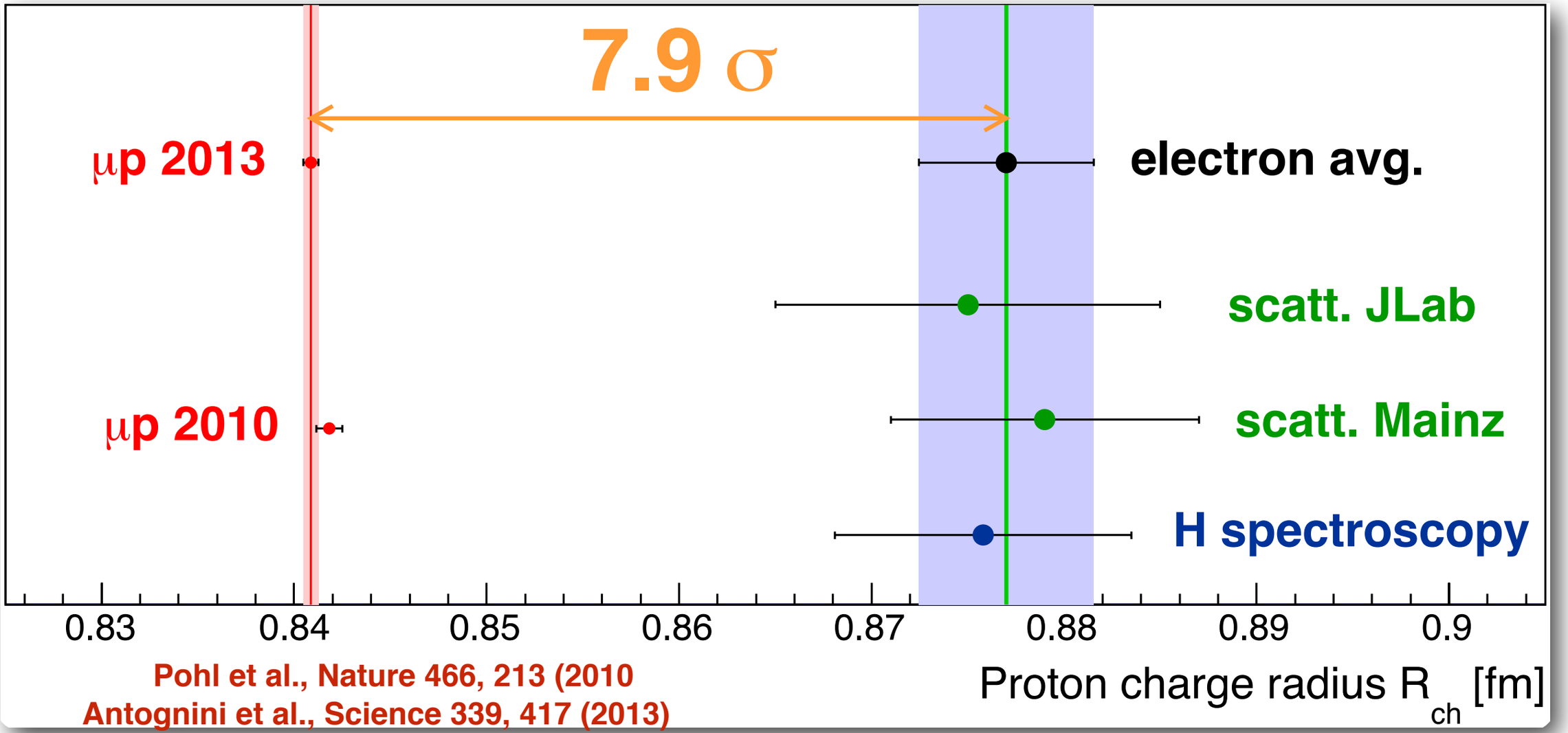
   - **windowless target**
   - **high resolution calorimeter**
   - **simultaneous detection of elastic and Moller**

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 a fitting 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)?**

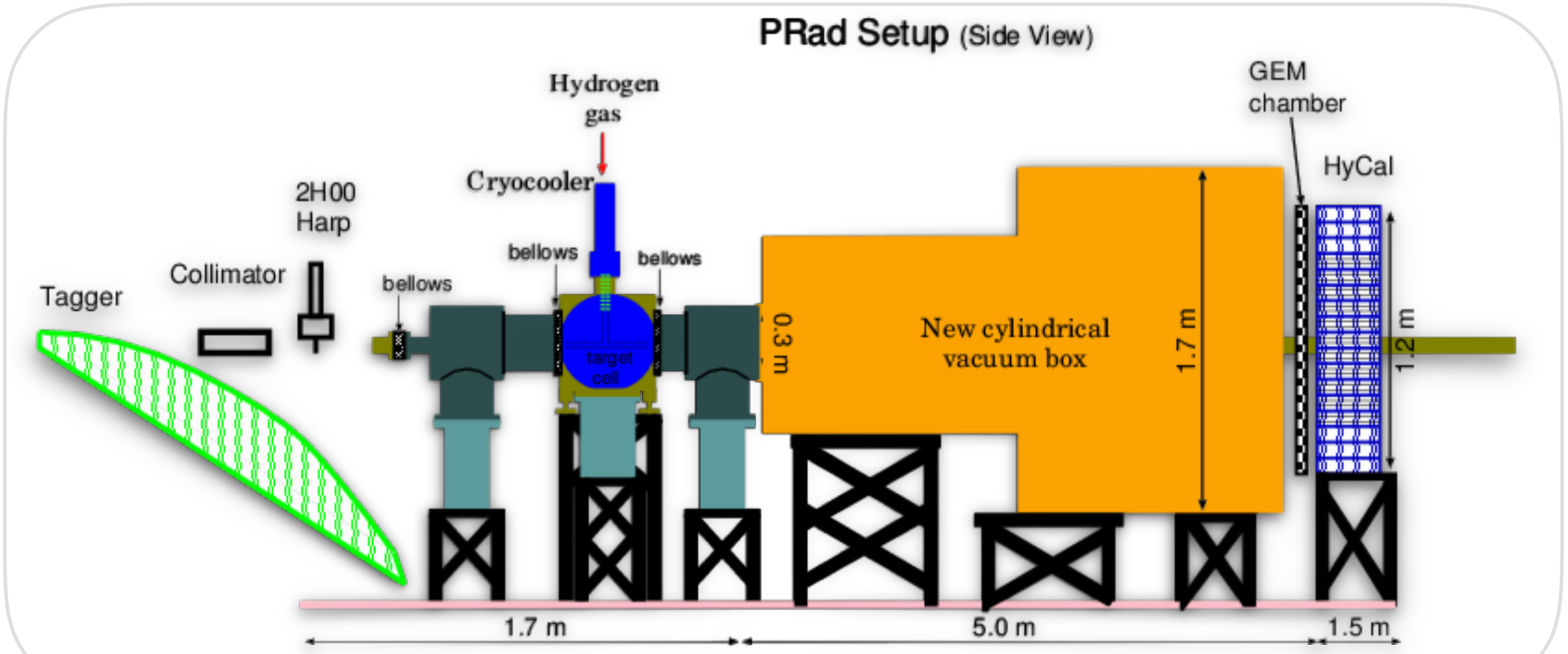
- V. Barger, et al., Phys. Rev. Lett. 106, 153001 (2011)
- B. Batell, D. McKeen, M. Pospelov, Phys. Rev. Lett. 107, 011803 (2011)
- D. Tucker-Smith, I. Yavin, Phys. Rev. D 83, 101702 (2011).

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



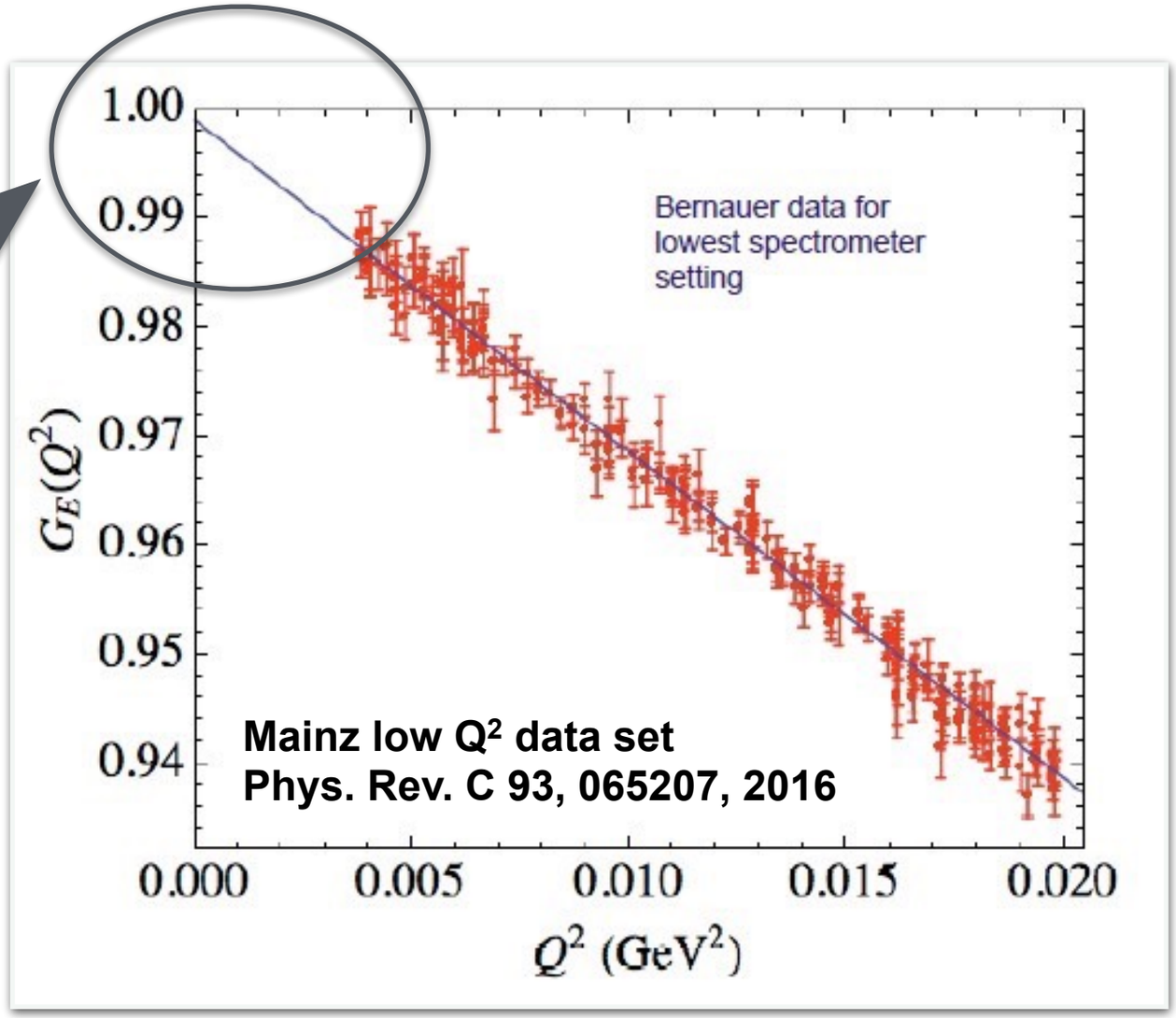
Spokesperson: A. Gasparian,
Co-spokespersons: D. Dutta, H. Gao, M. Khandaker

- **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.)**

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**

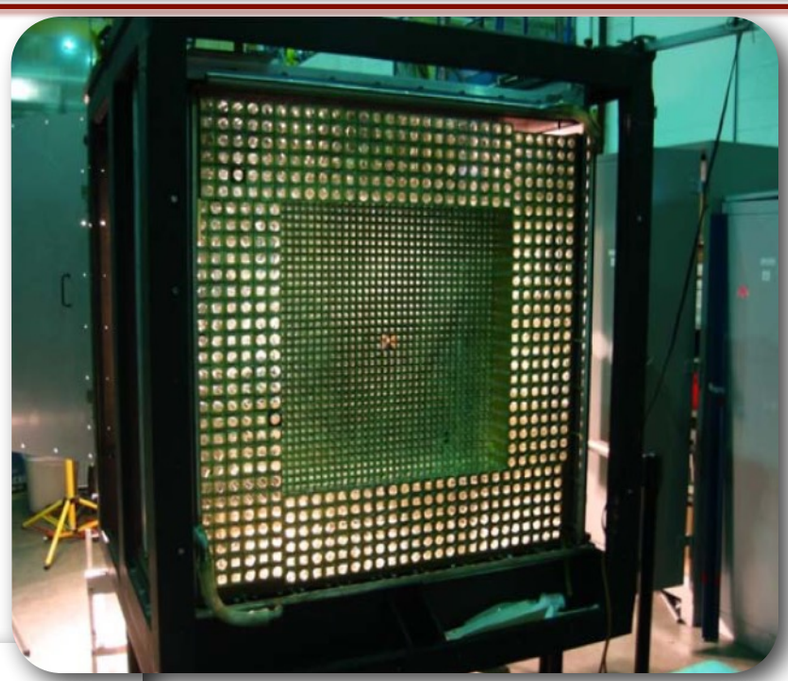


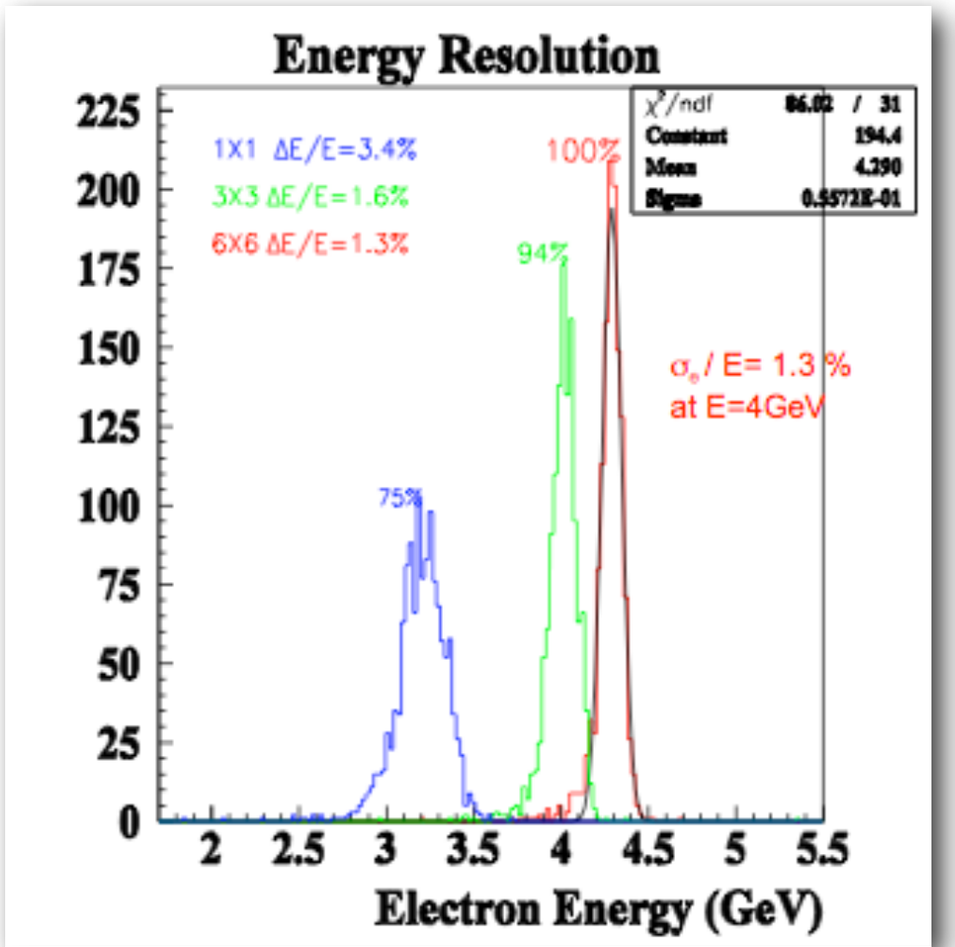
- **High resolution, Hybrid calorimeter (access small scattering angle: 0.7° - 7.0°)**
- **Windowless, high density H_2 gas flow target (Reduced backgrounds)**
- **Simultaneous detection of elastic and Moller electrons (control of systematics)**
- **Vacuum box, one thin window, large area GEM chambers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

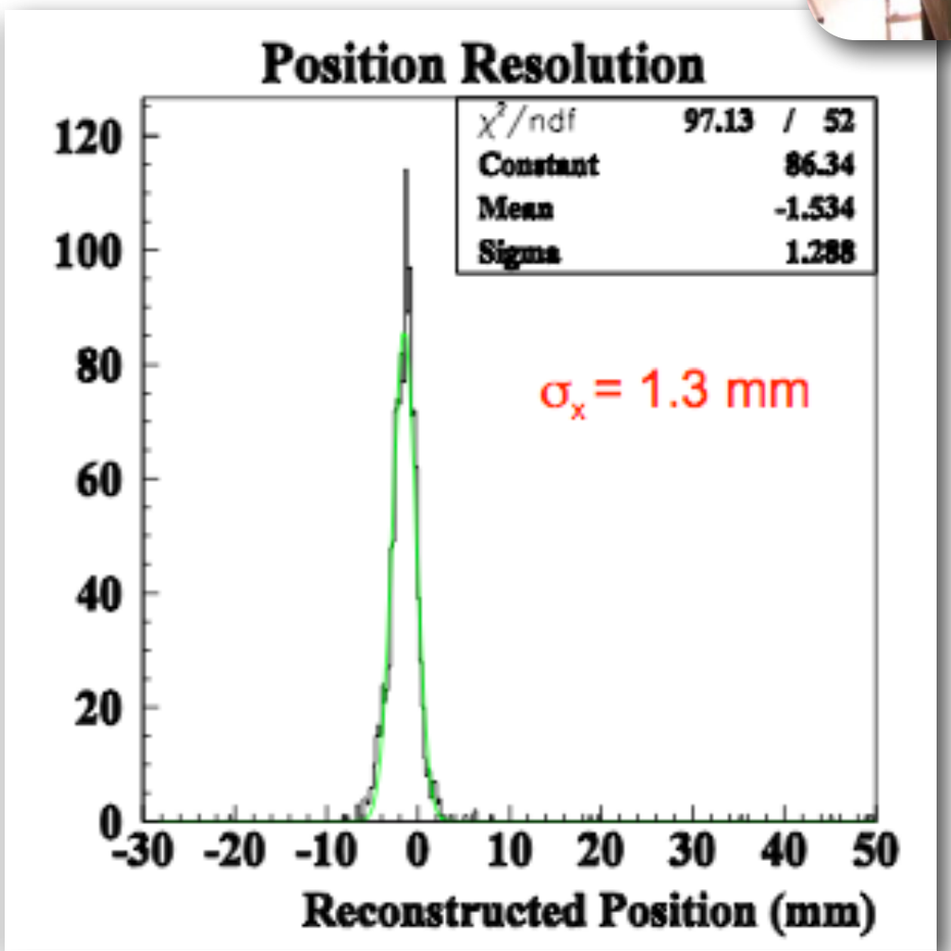
High resolution calorimeter

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

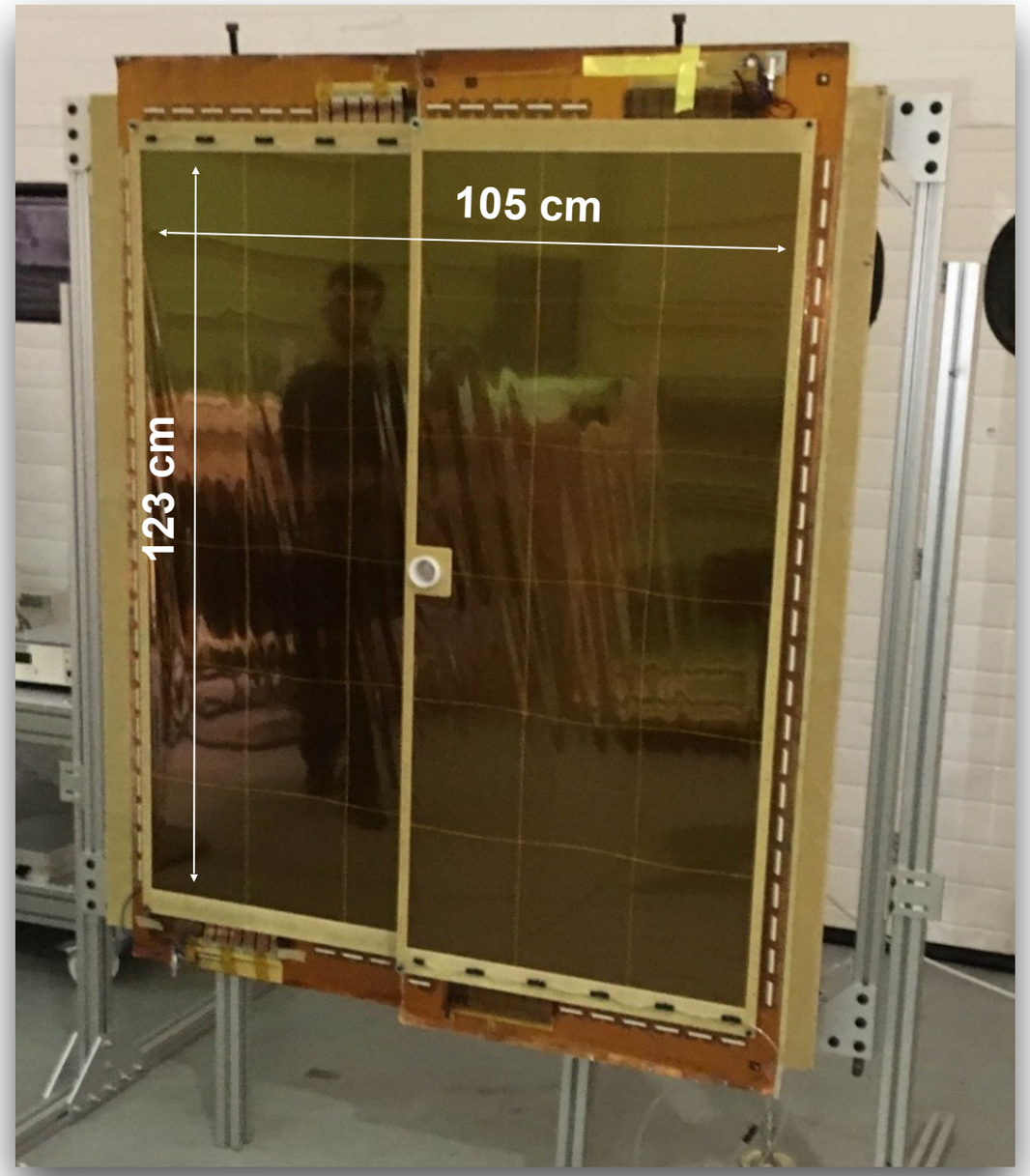
Pb-glass:
2.5 times worse

Large area GEM coordinate detectors

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

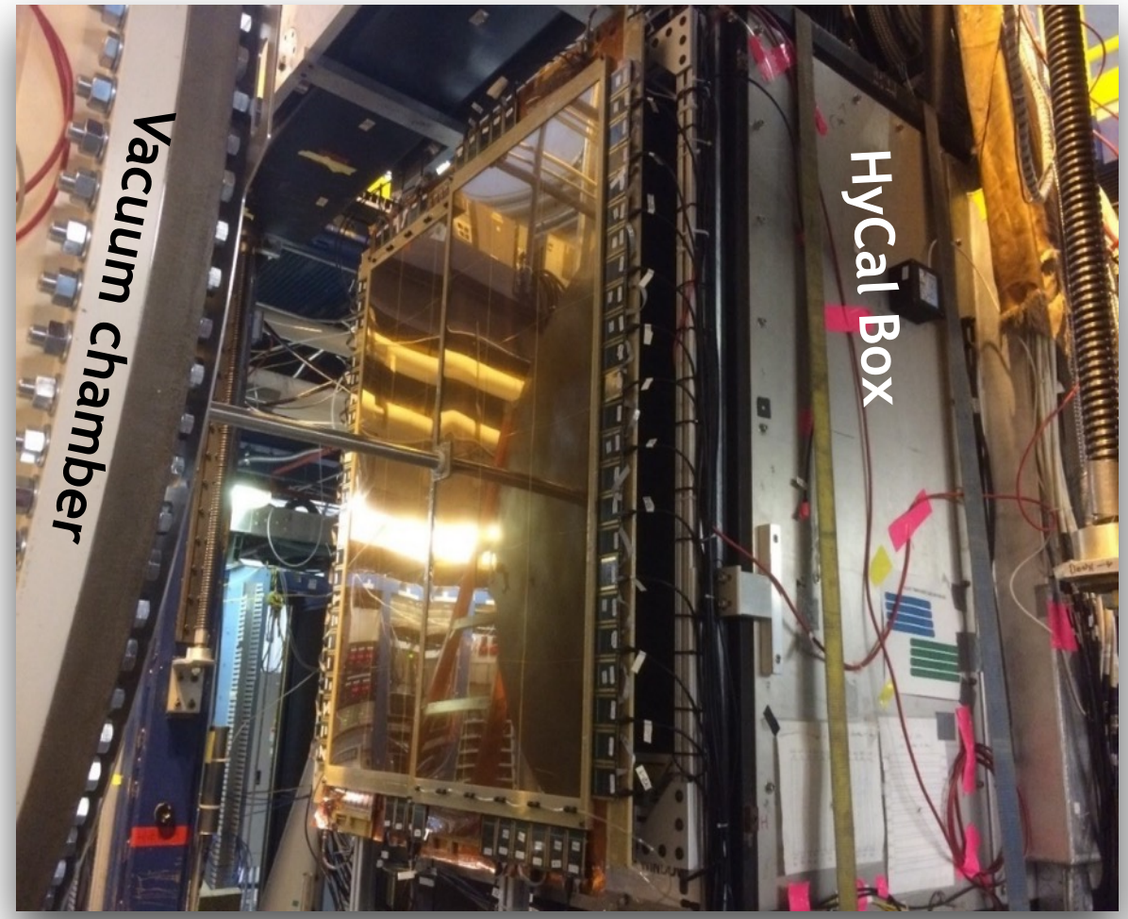
- **The GEM detectors provided:**
  - **factor of >20 improvements in coordinate resolutions**
  - **similar improvements in Q^2 resolution**
  - **unbiased coordinate reconstruction (including HyCal transition region)**
  - **increase Q^2 range by enabling use of Pb-glass part of calorimeter**

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



HyCal and GEMs on the beamline

beam view

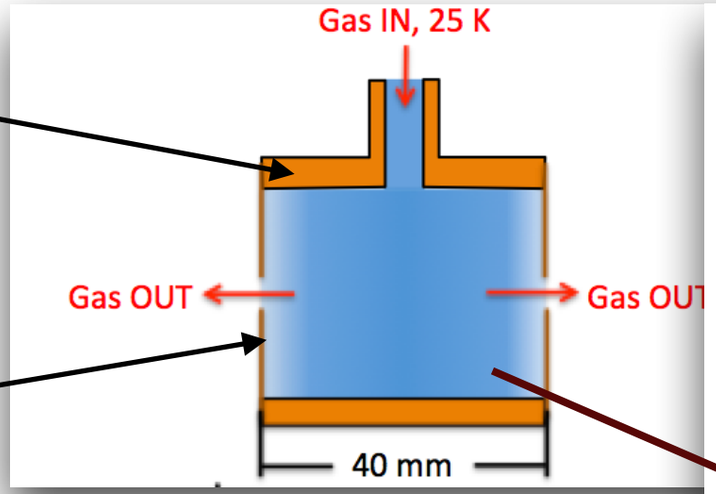


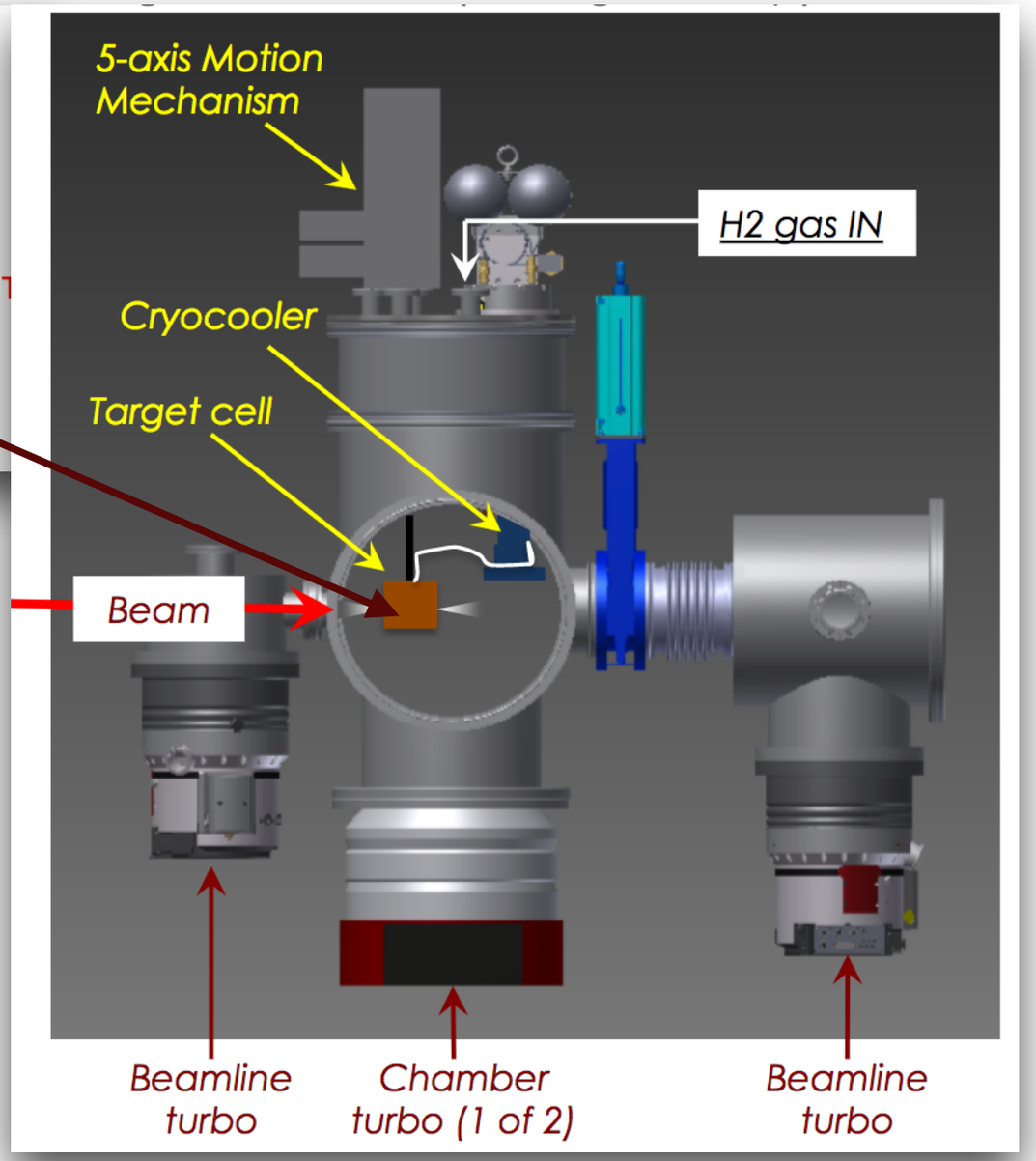
downstream view

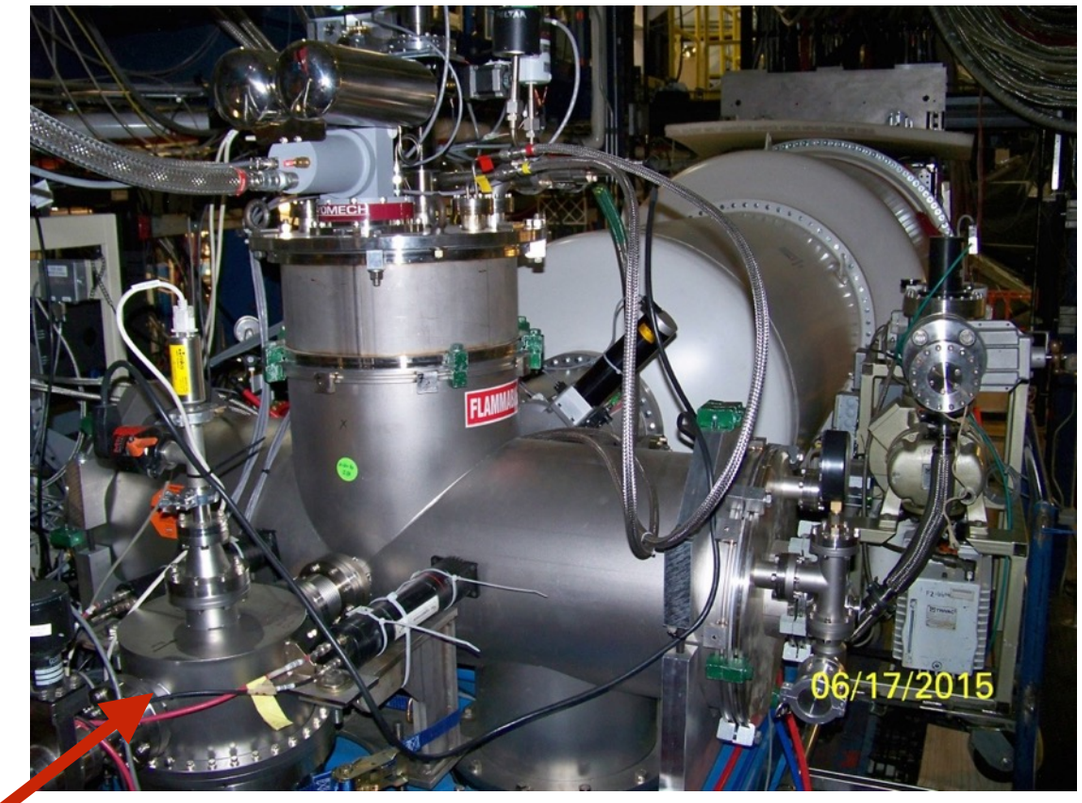
Windowless cryo-cooled gas flow target

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

7.5 μm kapton foil with 2mm hole





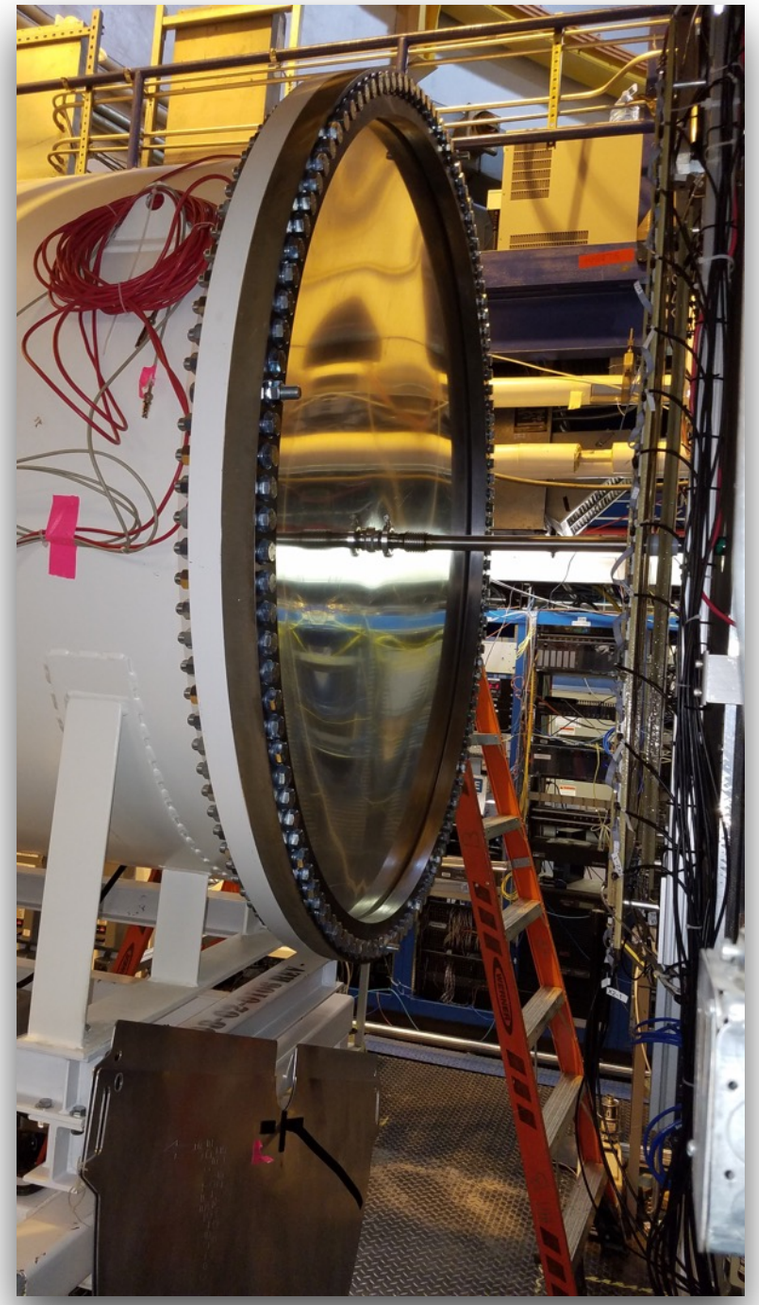


e^- beam

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

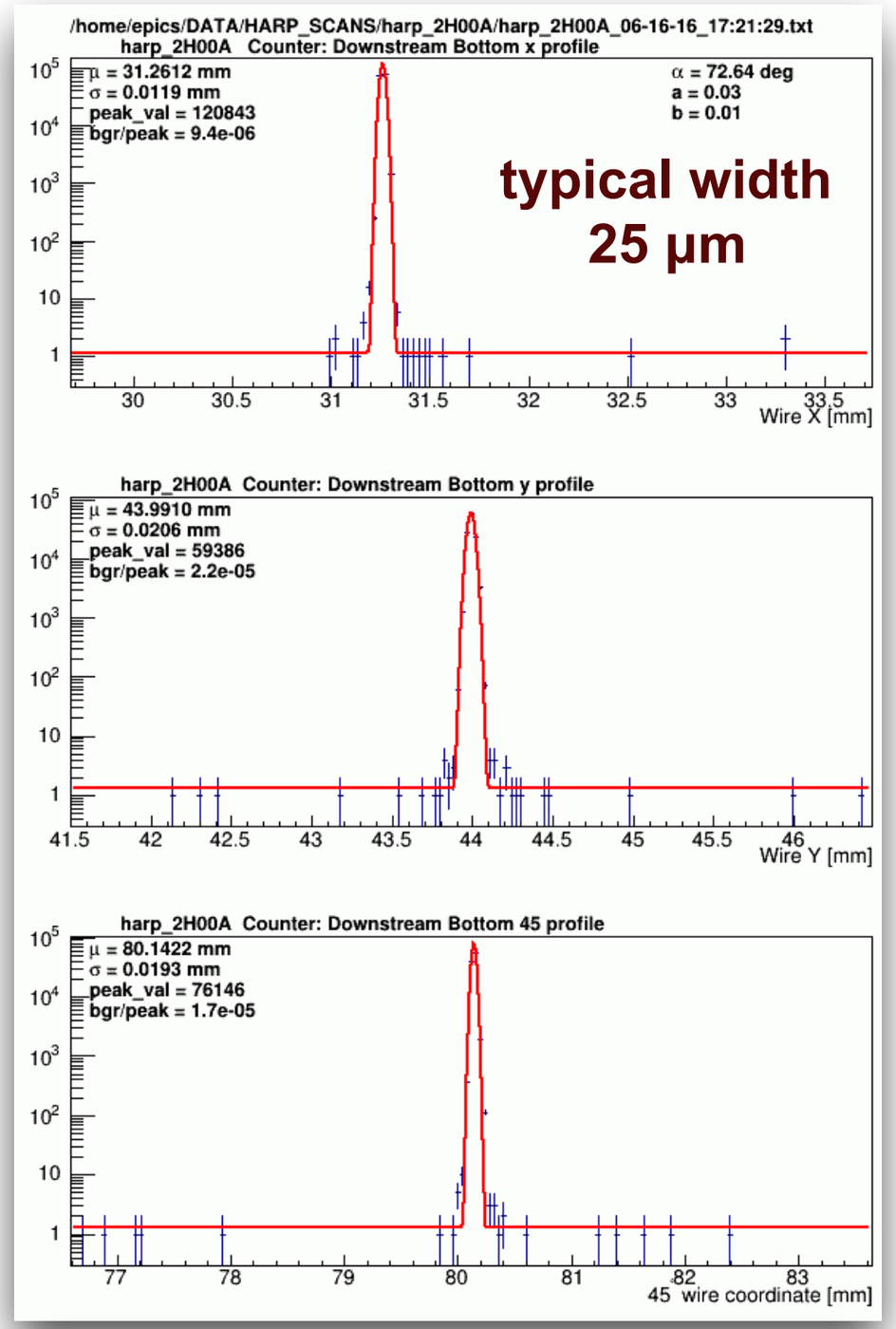
two stage, 5 m long vacuum box



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

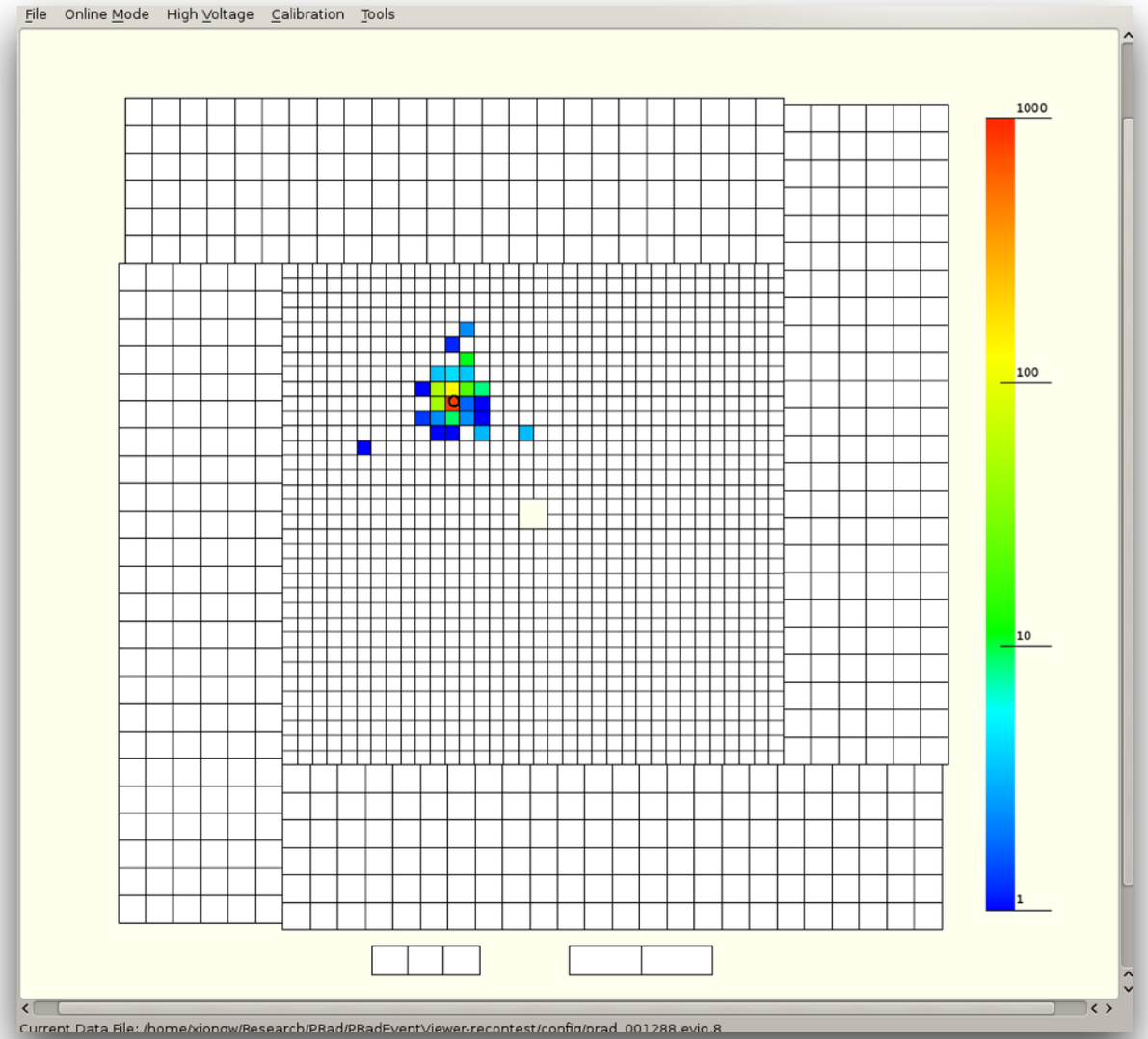
Experiment ran during May/June 2016

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

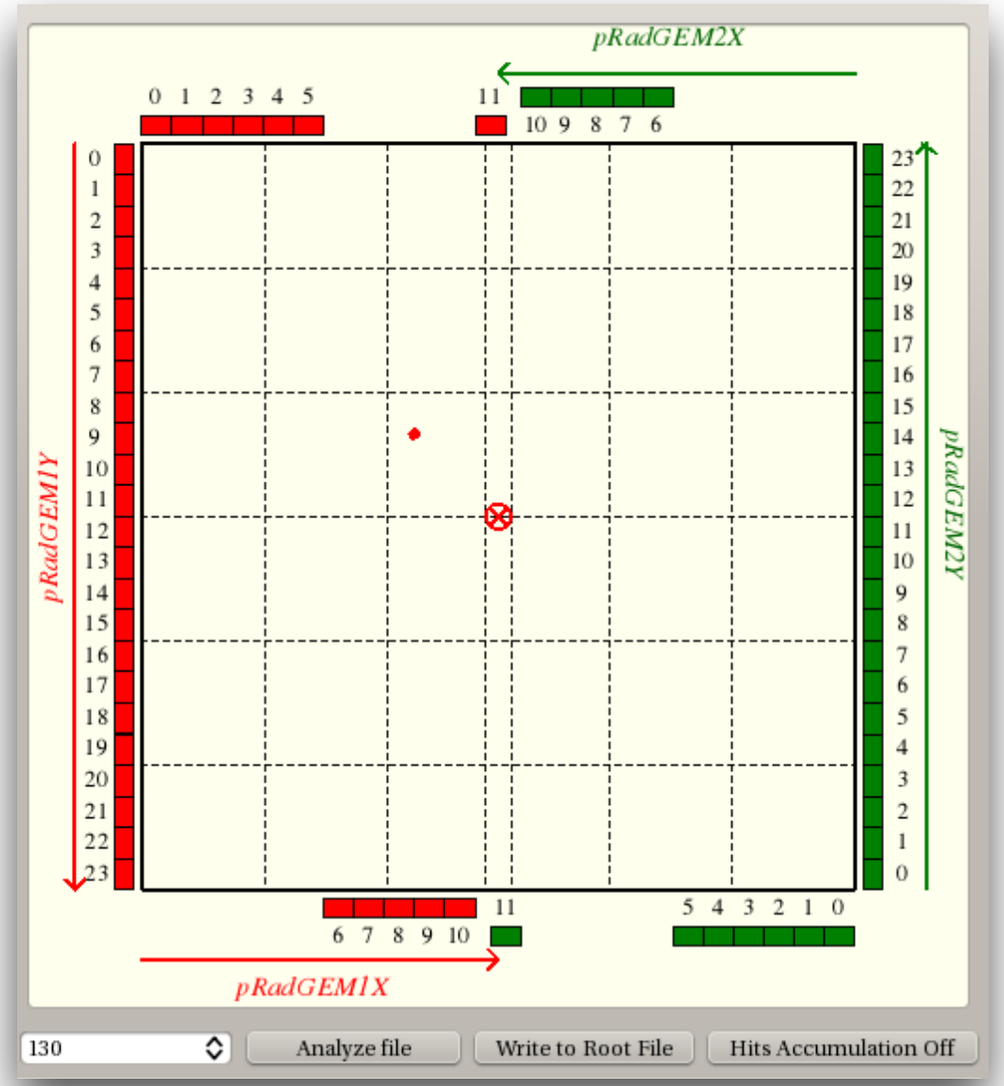
With E_e = 2.2 GeV beam
collected 14.3 mC on target (2x10^{18} H atoms/cm^2)
756 M events with H and
38 M events without H in target
10.5 M events on 1μm Carbon foil target

Preliminary online results

ep → ep event candidate



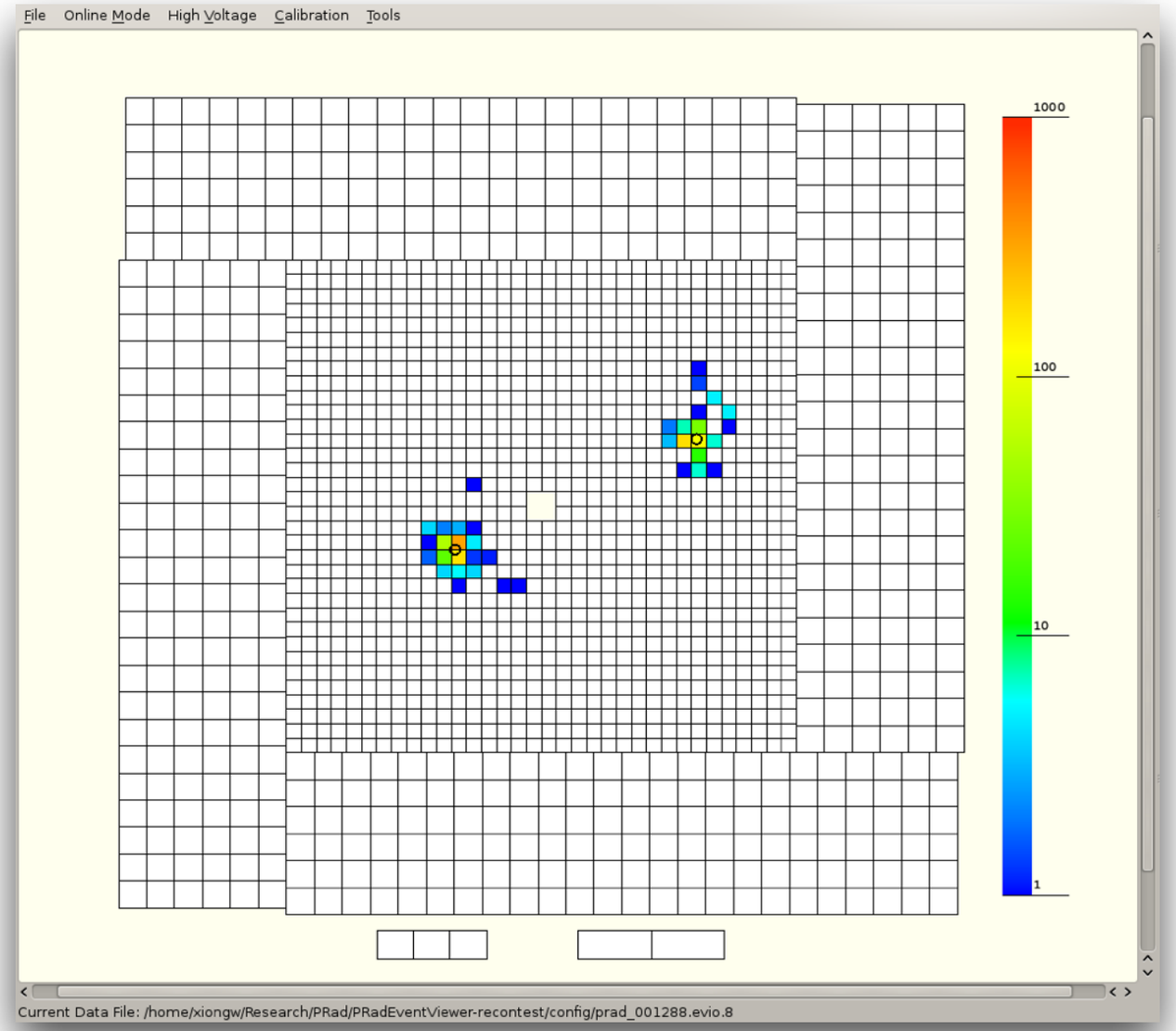
HyCal calorimeter



GEM detectors

Preliminary online results

ee → ee event candidate



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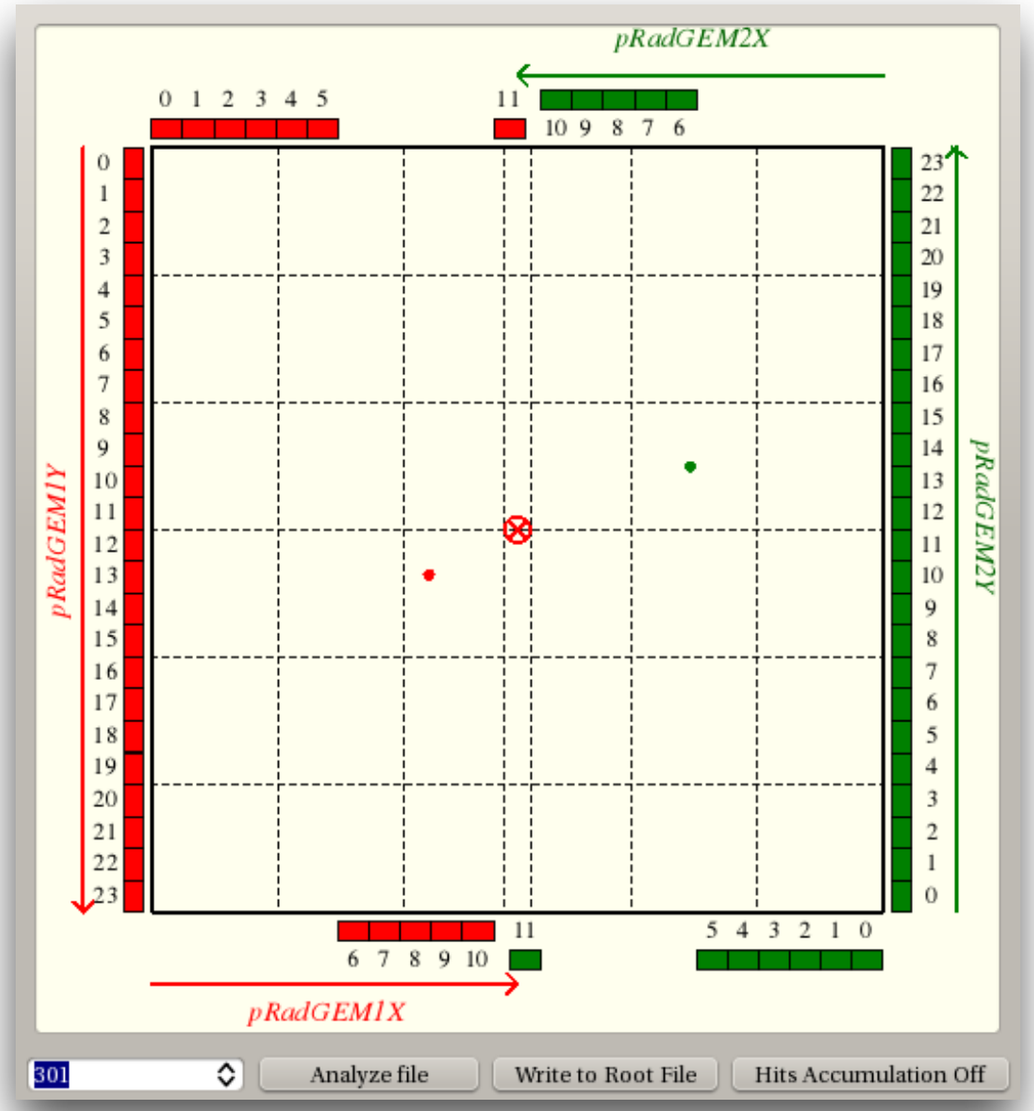
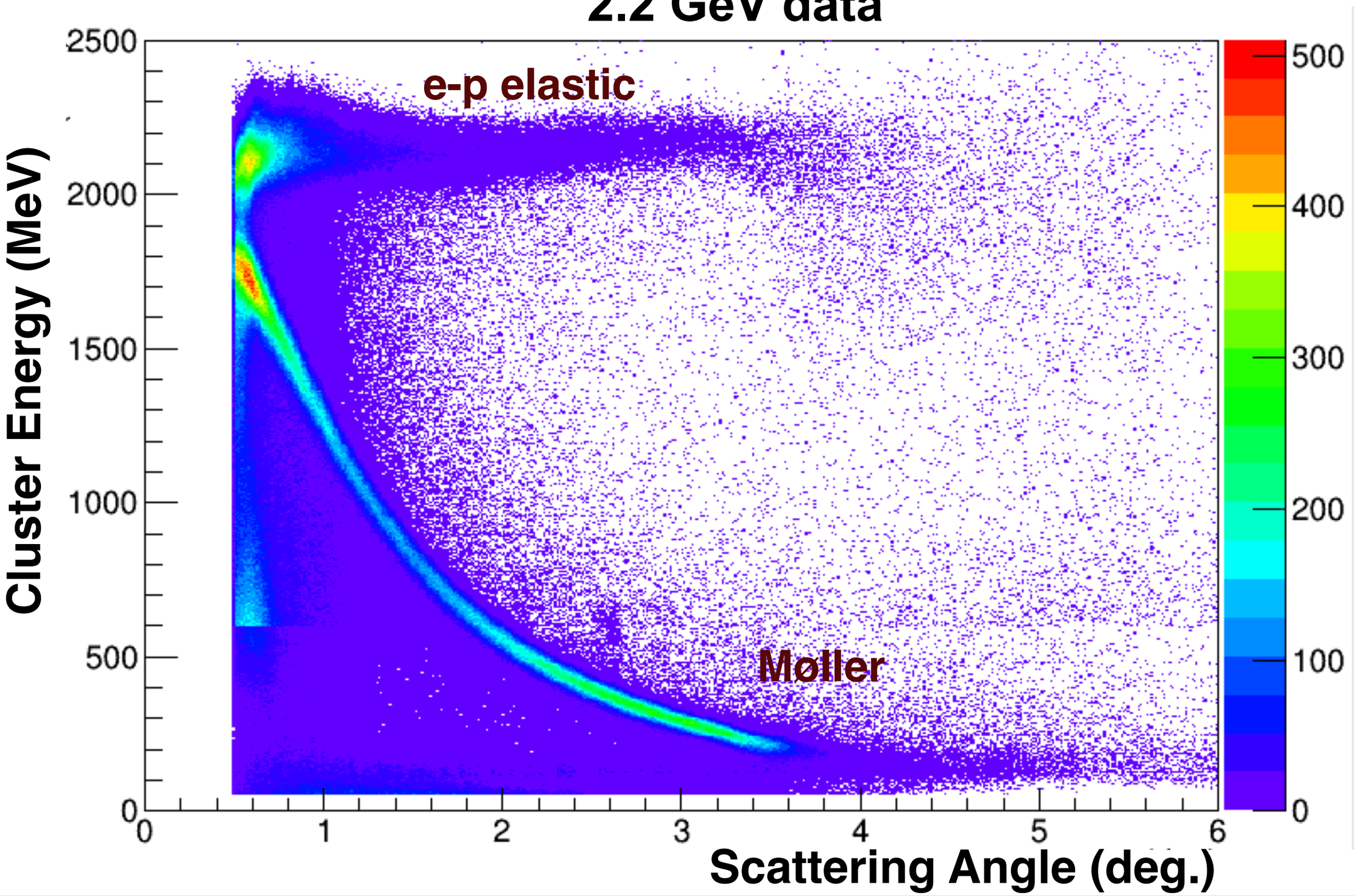


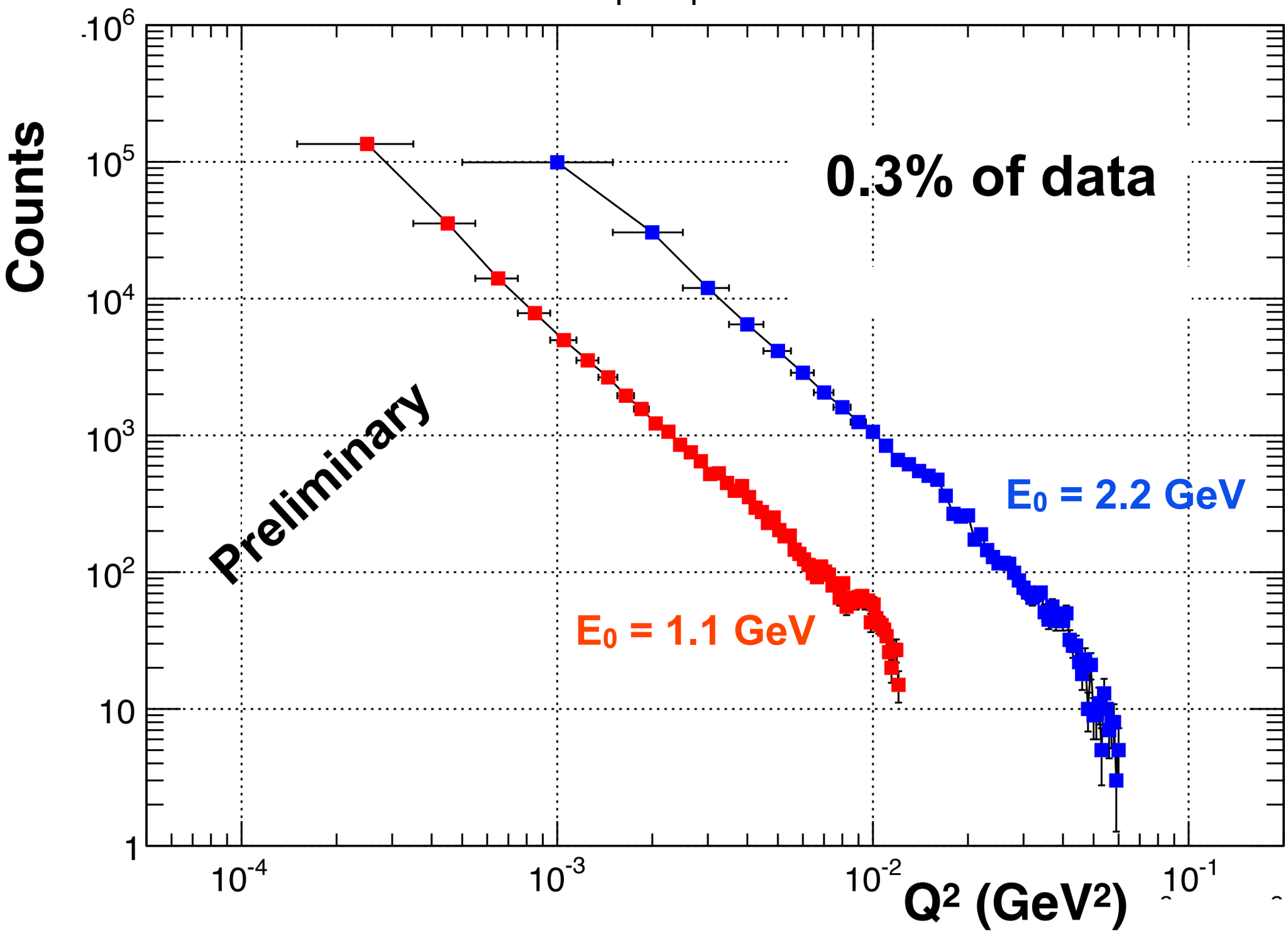
GEM detectors

Preliminary online results



Preliminary online results

e-p elastic yield (unnormalized and no acceptance corrections)



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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The PRad Collaboration

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