Status of PRad Experiment

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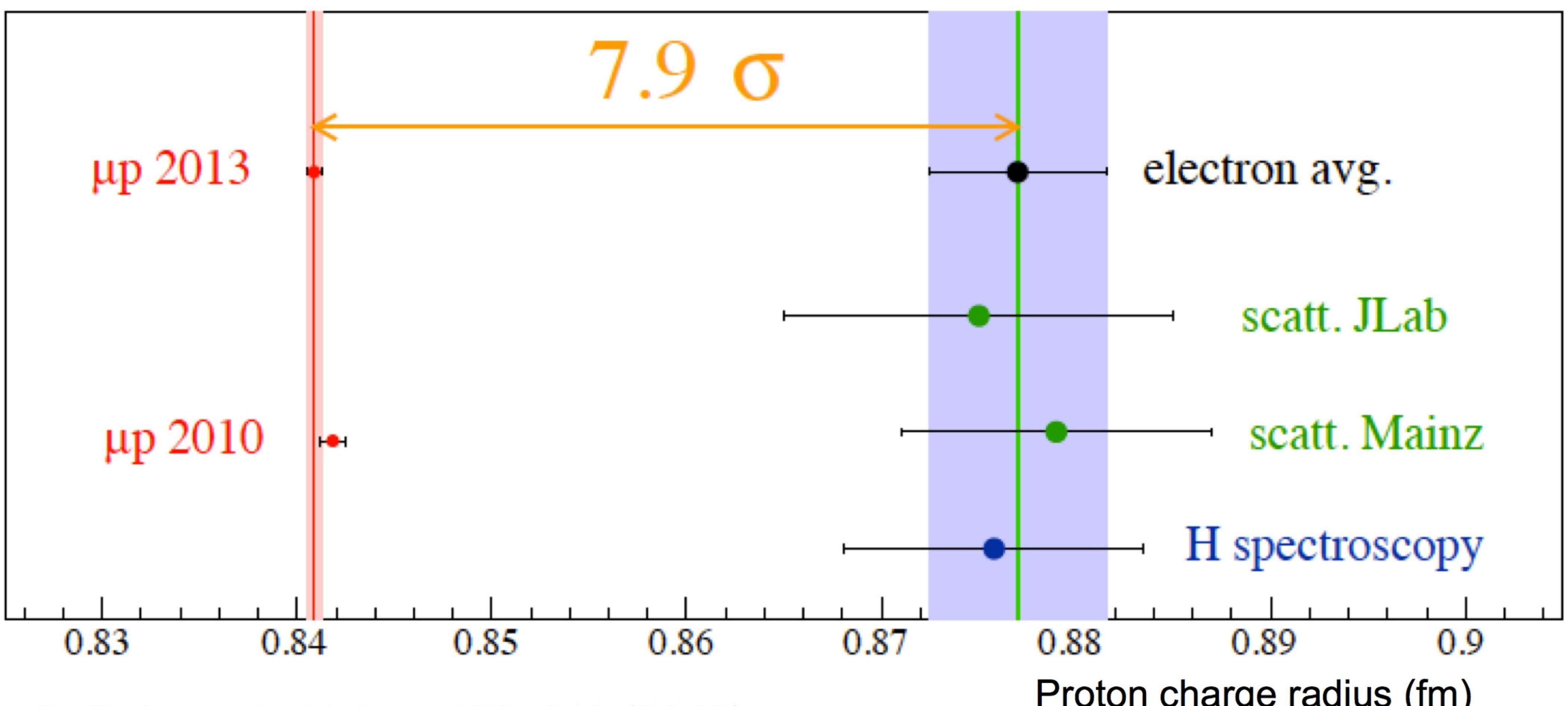
For PRad Collaboration

Outline

- The Proton Charge Radius
- Experiment Setup
- Analysis Status and Preliminary Results

The Proton Charge Radius Puzzle

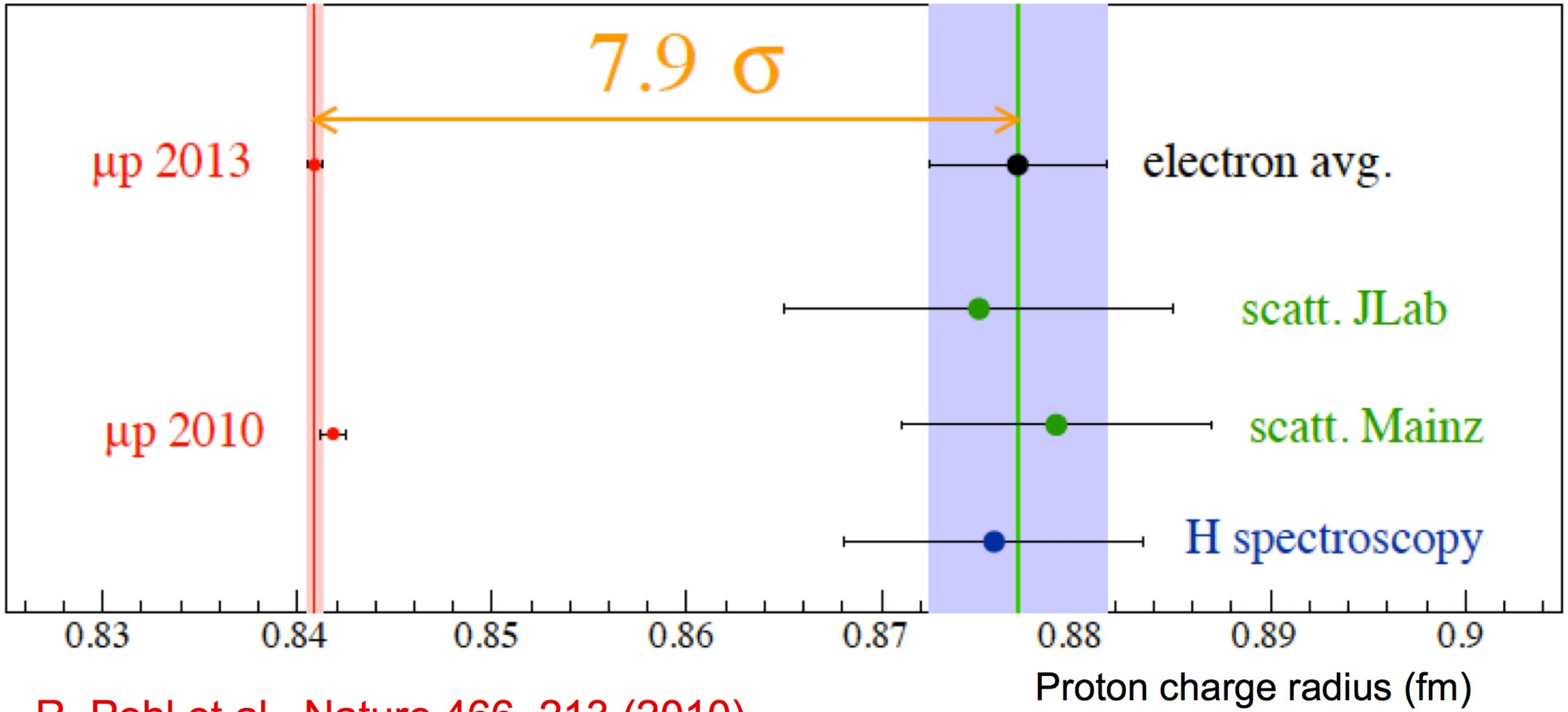
- Proton radius is one of the most fundamental quantities in physics:
  - Critically important for atomic physics in precision spectroscopy of atom
  - Precision test of nuclear/particle models
  - Connects atomic and subatomic physics



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

The Proton Charge Radius Puzzle

- 4 different methods to measure the proton charge radius:
  - Hydrogen spectroscopy (ordinary hydrogen, muonic hydrogen)
  - Lepton-proton elastic scattering (ep, μp)
- The proton charge radius puzzle:
  - ~8σ discrepancy between the new muonic-hydrogen spectroscopy measurements and all previous results



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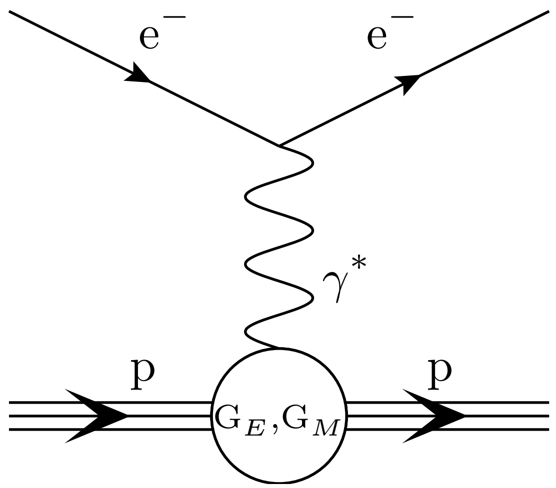
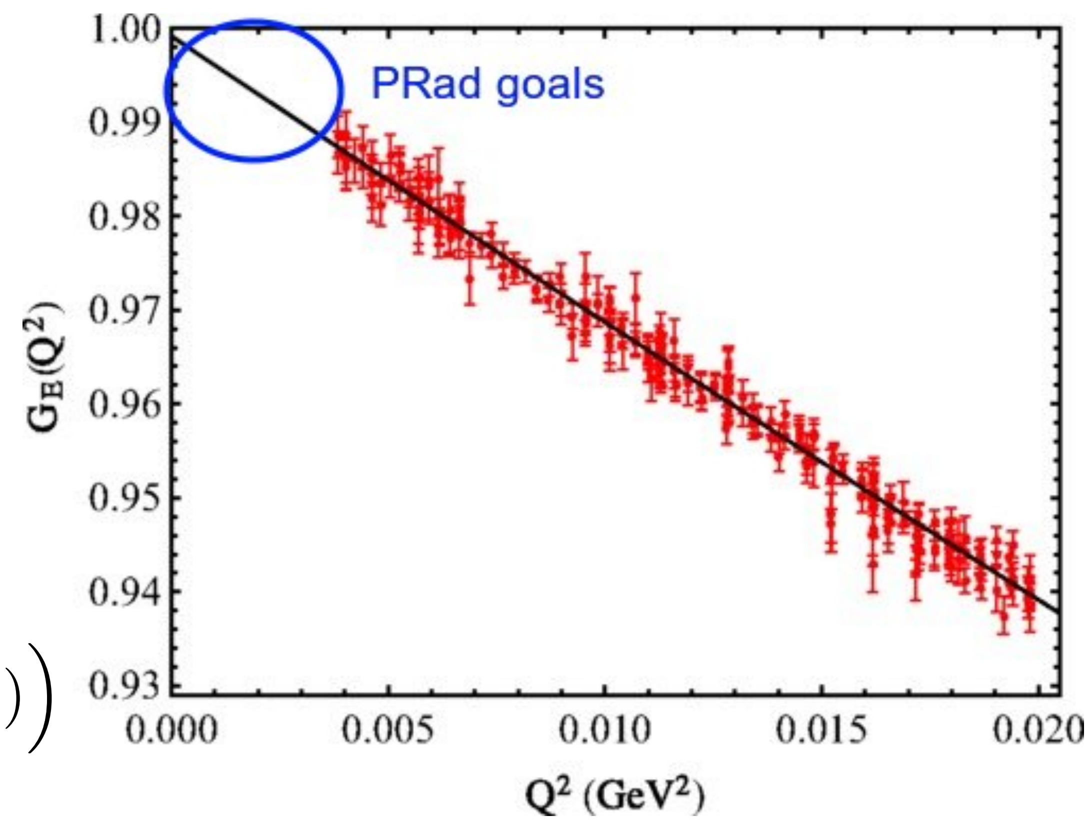
ep Scattering

- Previous measurements have large systematic uncertainties and a limited coverage at small Q2
- Requirements for PRad Experiment:
  - large Q2 range
  - extend to very low Q2
  - controlled systematics at sub-percent precision
- Extraction of $\langle r^2 \rangle = -6 \frac{dG_E^p(Q^2)}{dQ^2}\Big|_{Q^2=0}$





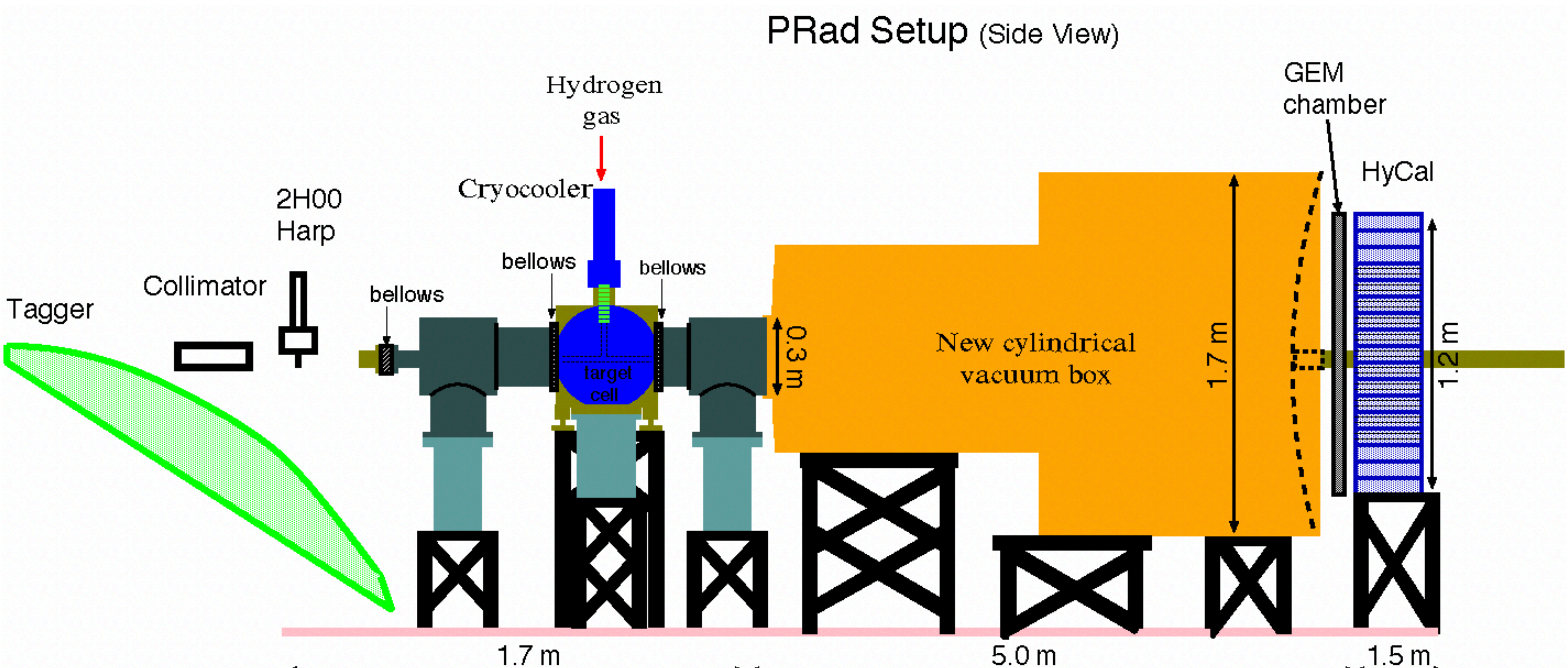
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Mott}} \left(\frac{E'}{E}\right) \frac{1}{1+\tau} \left(G_E^2(Q^2) + \frac{\tau}{\varepsilon} G_M^2(Q^2)\right)$$

PRad Timeline

- 2011 - 2012 Initial proposal
- 2012 Approved by JLab PAC39
- 2012 Funding proposal for windowless H2 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
- Jan - Apr 2016 Beam line installation
- May 2016 Beam commissioning
- May 24 - 31 2016 Detectors calibration
- Jun 4 - 22 2016 Data taking

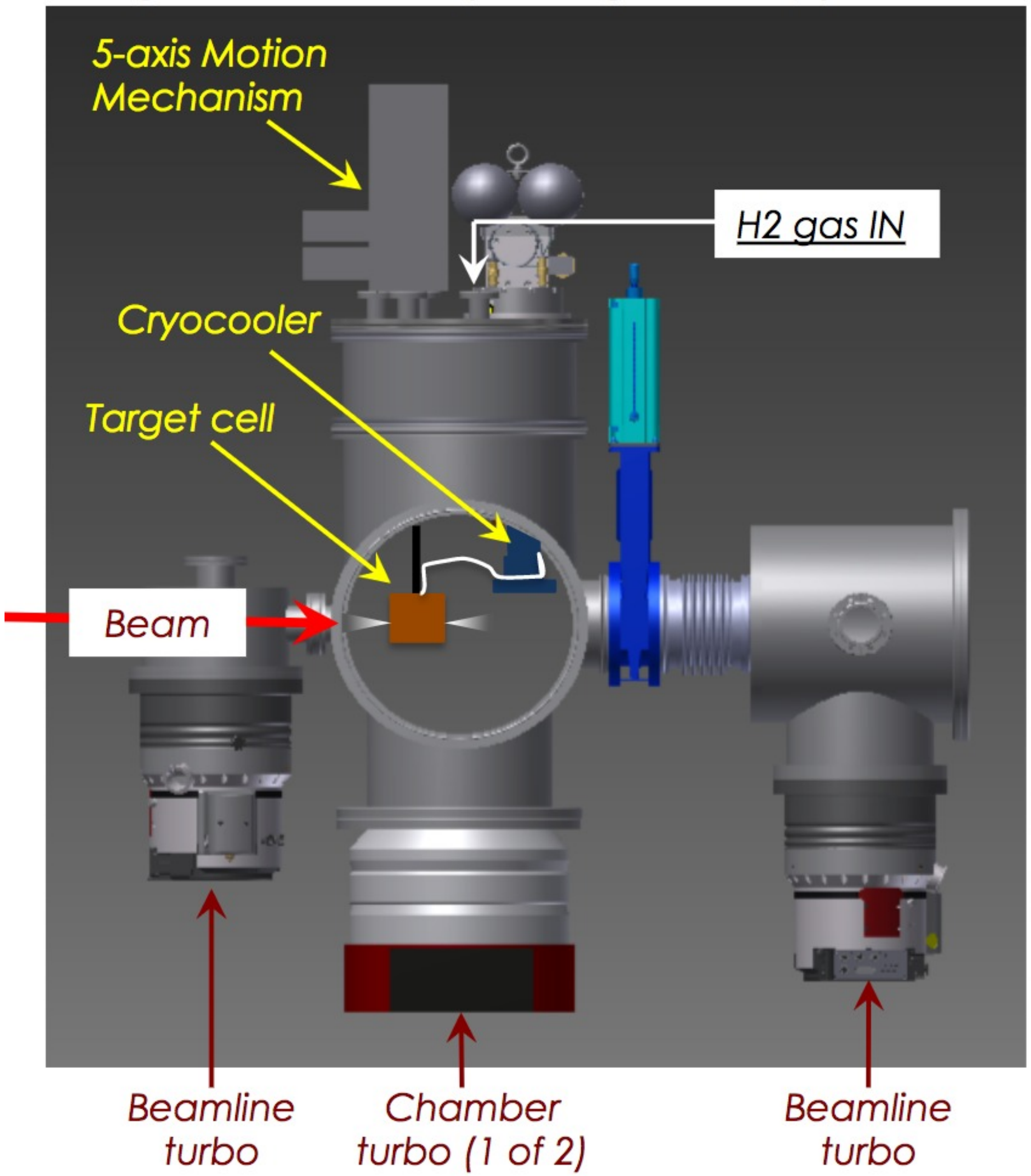
PRad Setup

- Electron beam at 1.1 GeV and 2.2 GeV
- Windowless H2 gas flow target
- Vacuum box
- GEM detectors
- PrimEx HyCal



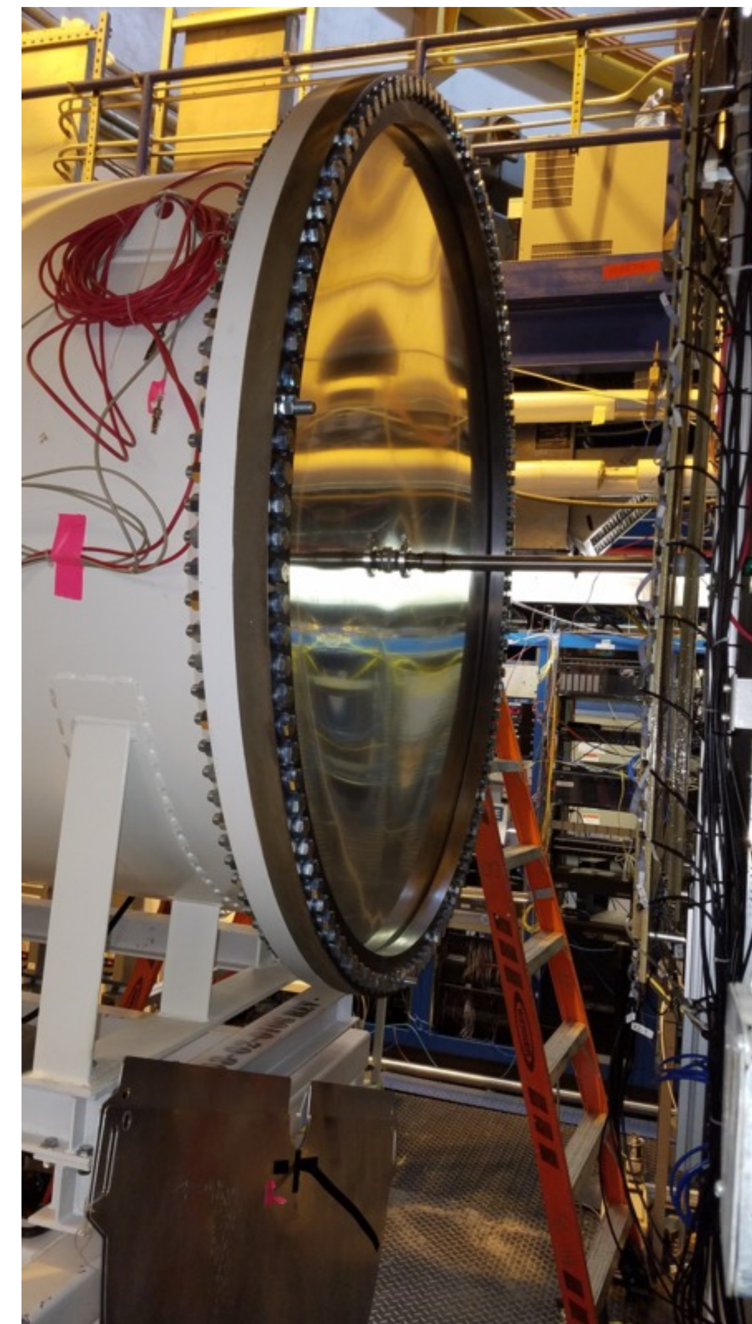
Windowless H2 Gas Flow Target

- A windowless gas target of cryogenically cooled hydrogen:
    - 4 cm long copper target cell
    - 7.5 µm kapton windows with 2 mm beam orifices
    - H2 gas cooled at 19.5 K
    - Target density: ~2×10^{18} H atoms/cm^2
    - Four-axis motion system to position the target cell with 10 µm accuracy
- Pressures:
    - Cell pressure: 471 mTorr
    - Chamber pressure: 2.34 mTorr
    - Vacuum chamber pressure: 0.3 mTorr
- Two additional solid target foils: 1 µm ^{12}C and Al



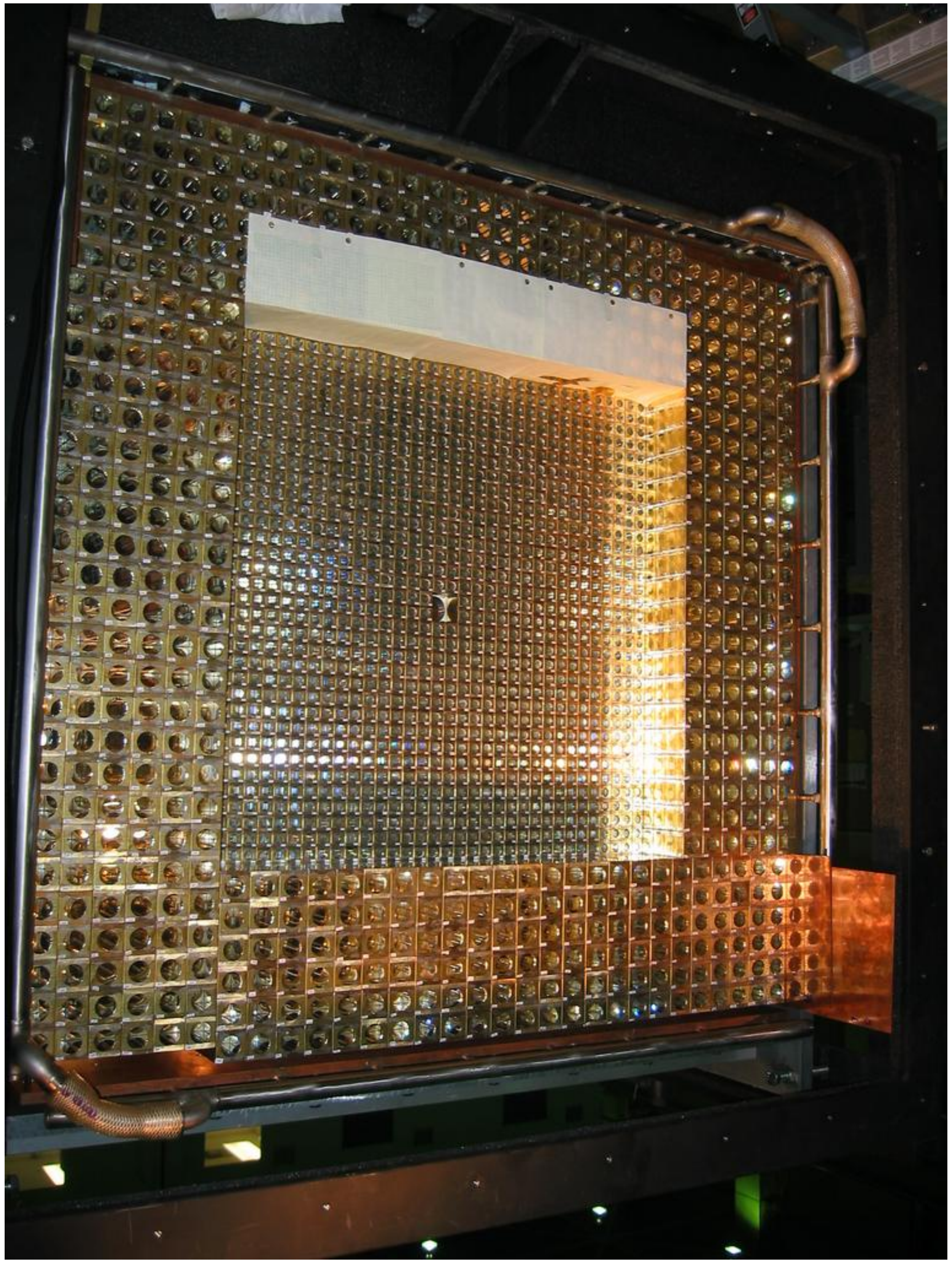
Vacuum Box

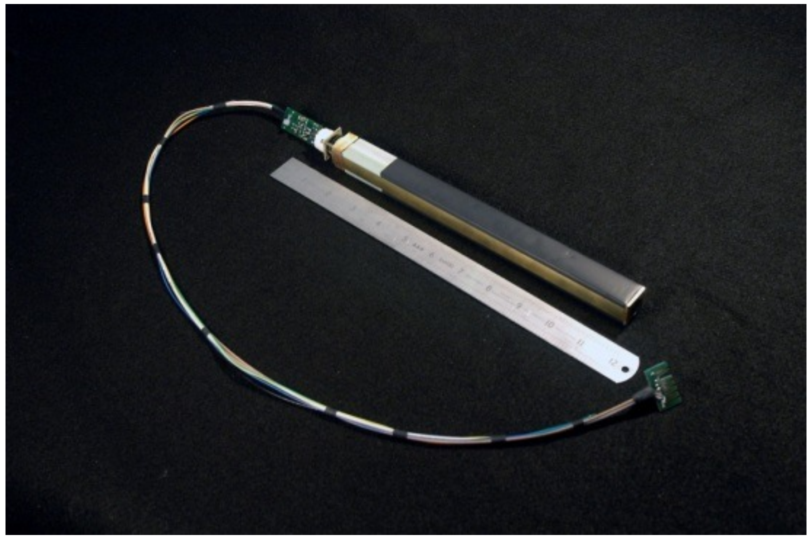
- 1.7 m diameter, 1.6 mm aluminum vacuum window



Electromagnetic Calorimeter (PrimEx HyCal)

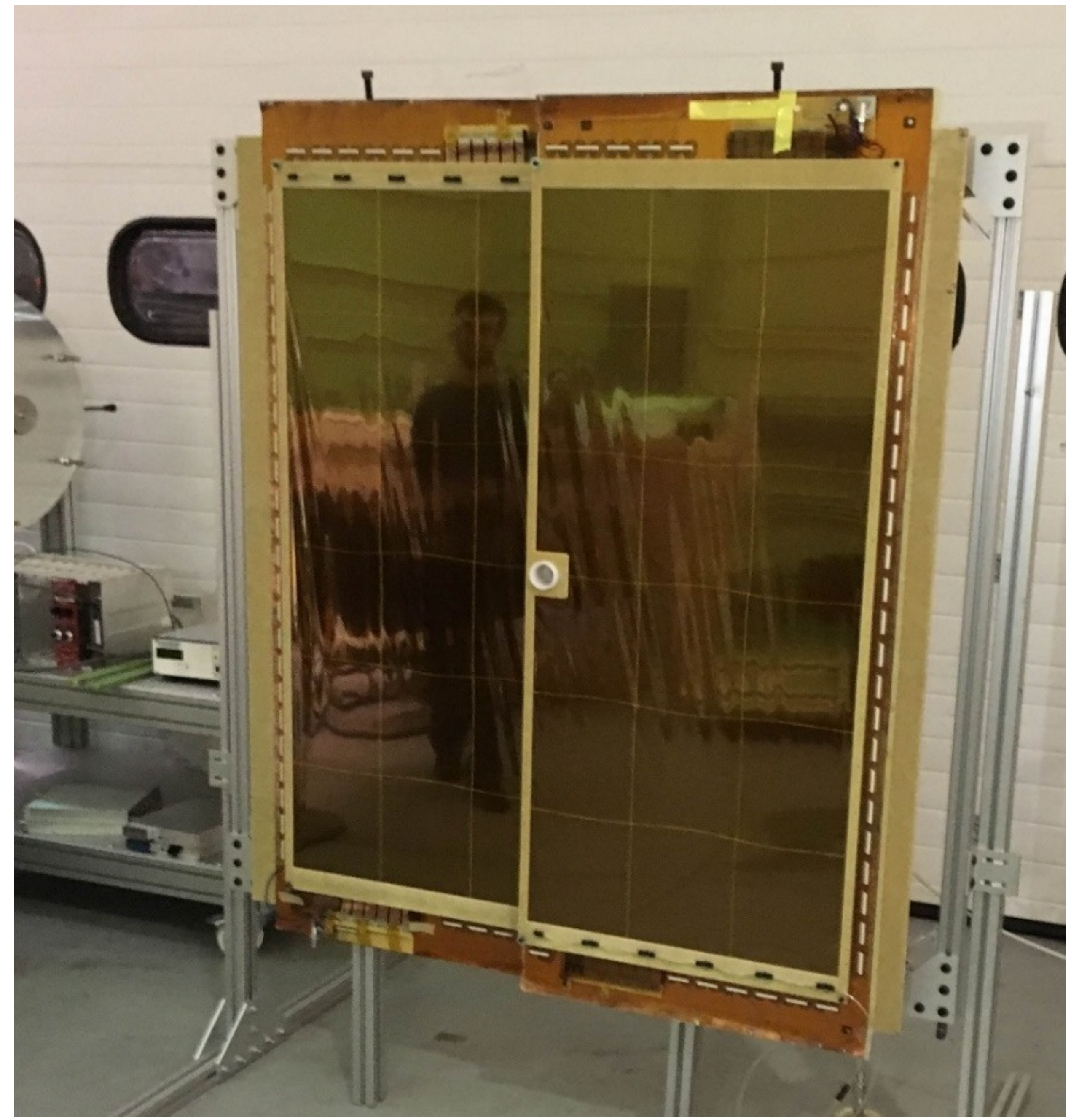
- Combination of $PbWO_4$ and Pb-glass detectors (118 x 118 cm^2)
    - 34 x 34 matrix of 2.05 x 2.05 x 18 cm^3 $PbWO_4$ shower detectors
    - 576 Pb-glass shower detectors (3.82 x 3.82 x 45 cm^3)
    - 2 x 2 $PbWO_4$ modules removed in the middle for beam passage
- 5.8 m from the target
- Successfully used for PrimEx experiments





GEM Detectors

- Two large area GEM detectors (55 cm x 123 cm)
  - Central overlapped between two planes with a hole for the beam passage
- Purpose:
  - Factor of >20 improvements in coordinate resolutions
  - Similar improvements in Q^2 resolution (important)
  - Unbiased coordinate reconstruction
  - Increase Q^2 coverage by including HyCal Pb-glass part
- Designed and built at University of Virginia (UVa)

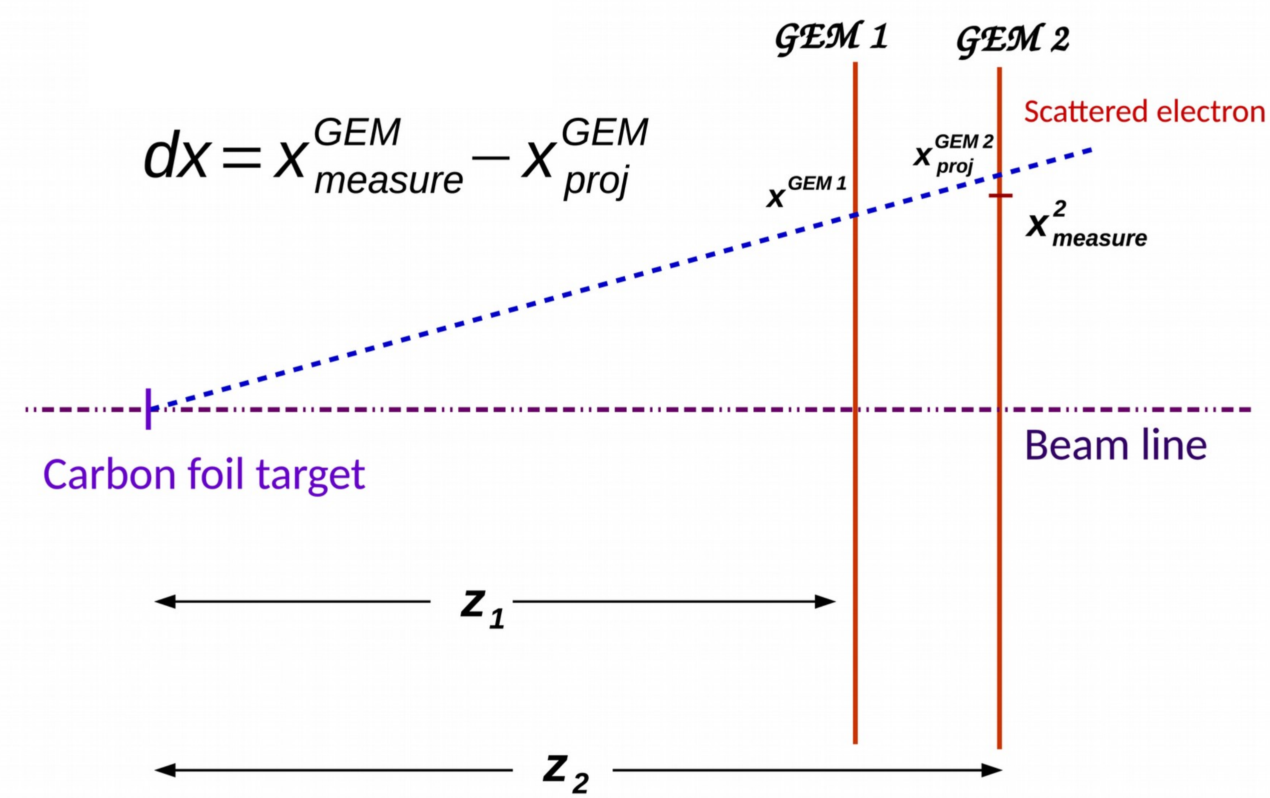


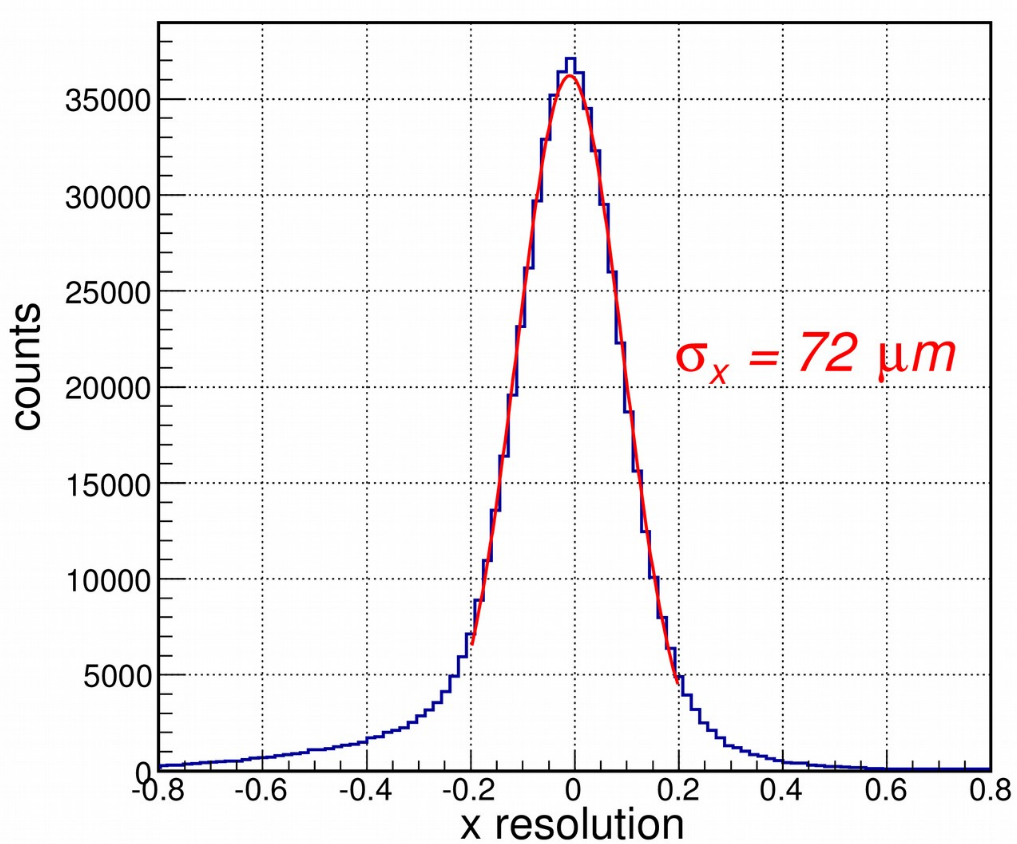
Experiment Data Collected

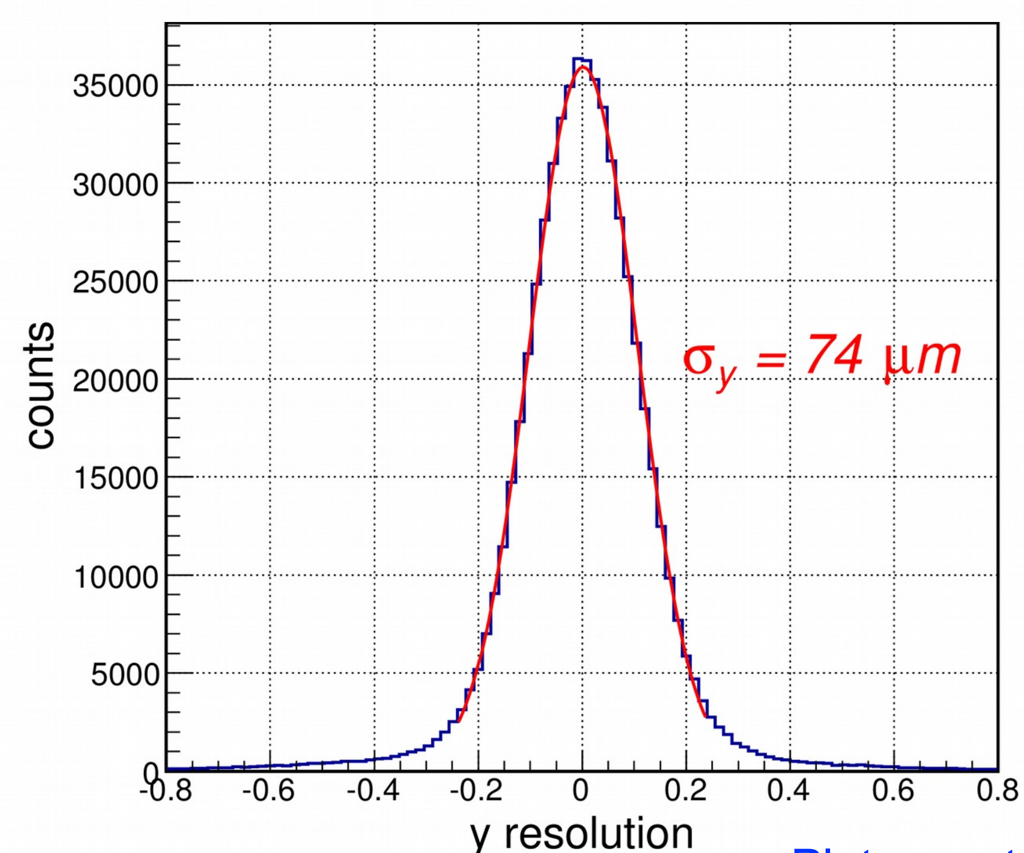
- With 1.1 GeV beam:
  - Collected 4.2 mC
  - 604 M events with H_2 target
  - 53 M events with "empty" target
  - 25 M events with ^{12}C target for calibration
- With 2.2 GeV beam:
  - Collected 14.3 mC
  - 756 M events with H_2 target
  - 38 M events with "empty" target
  - 10.5 M events with ^{12}C target for calibration

GEM Resolution

- Extraction of GEM spatial resolution using GEM central overlapping region
- Good spatial resolution achieved



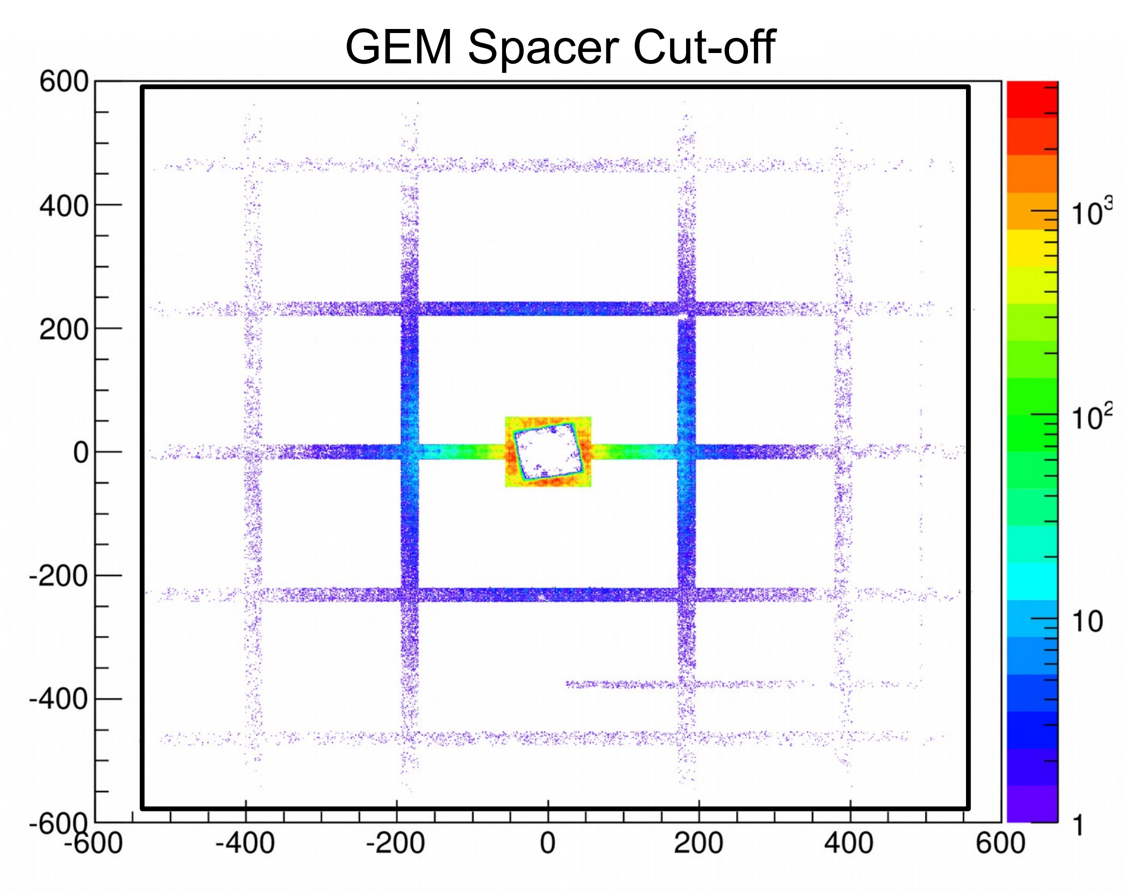


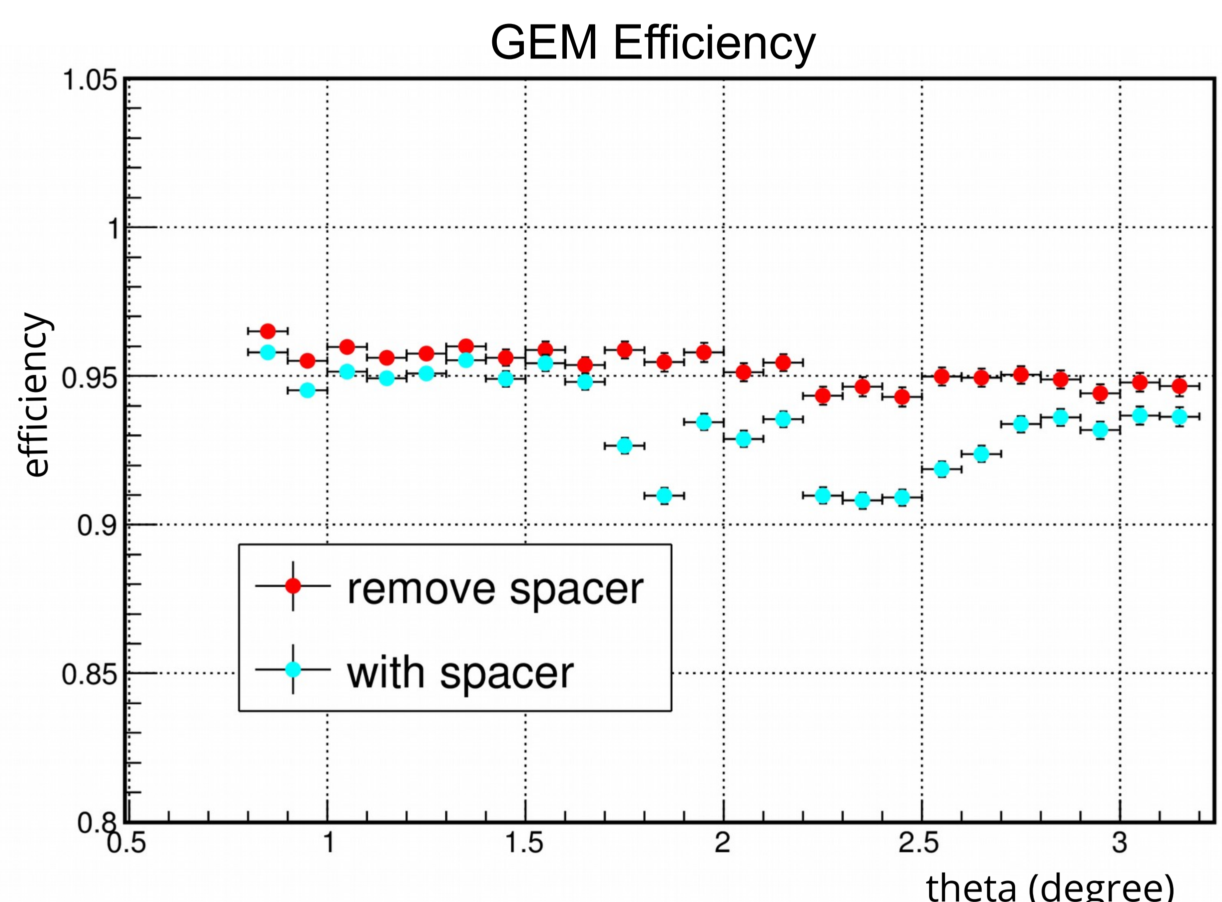


Plots courtesy of X. Bai

GEM Efficiency

- GEM efficiency calibrated using physics runs
  - GEM spacer introduces deficient area
  - Evenly distributed efficiency after spacer correction
- Stable GEM efficiency over time
  - Average efficiency fluctuation: ~0.5% level

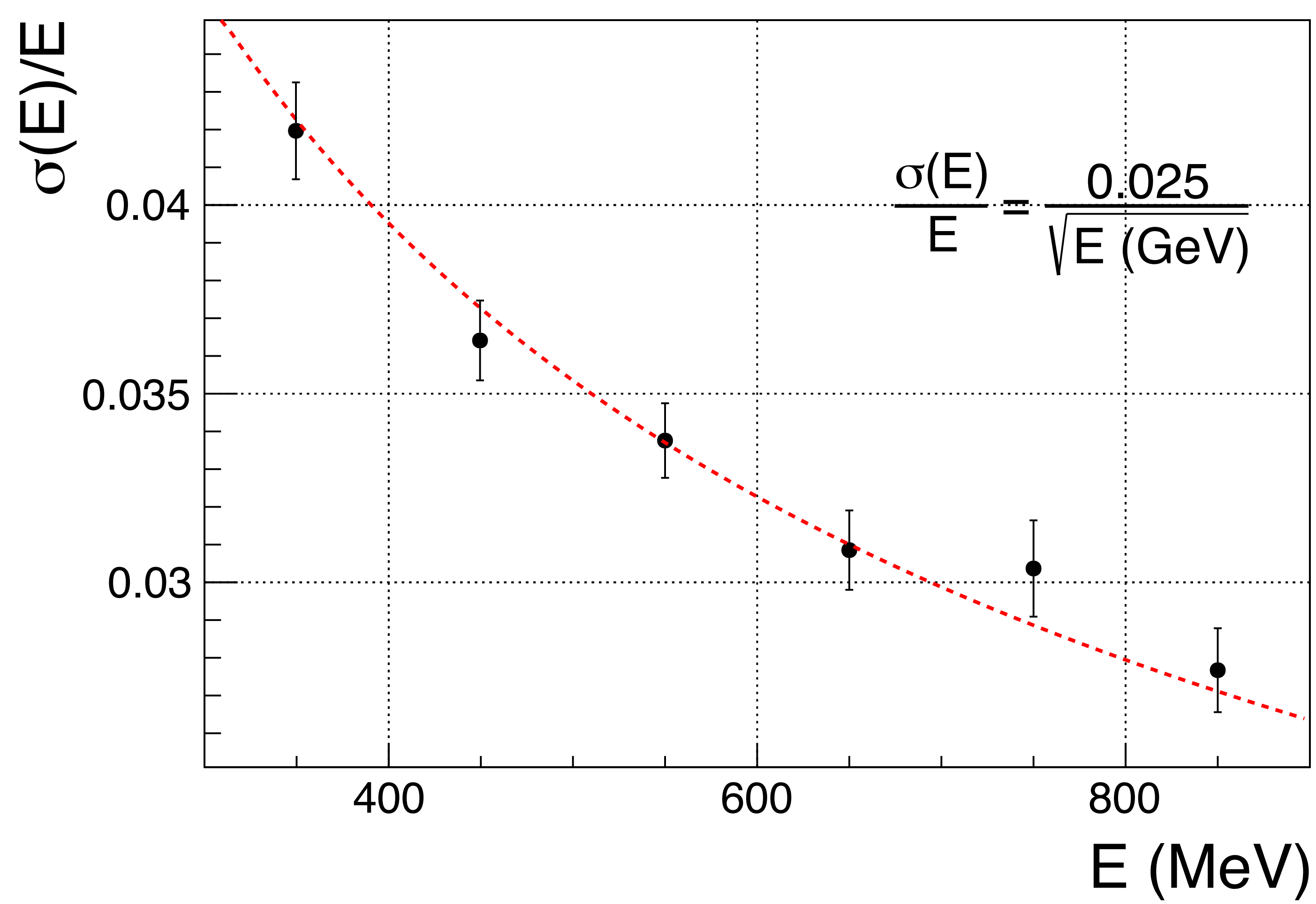




Plots courtesy of X. Bai

HyCal Calibration

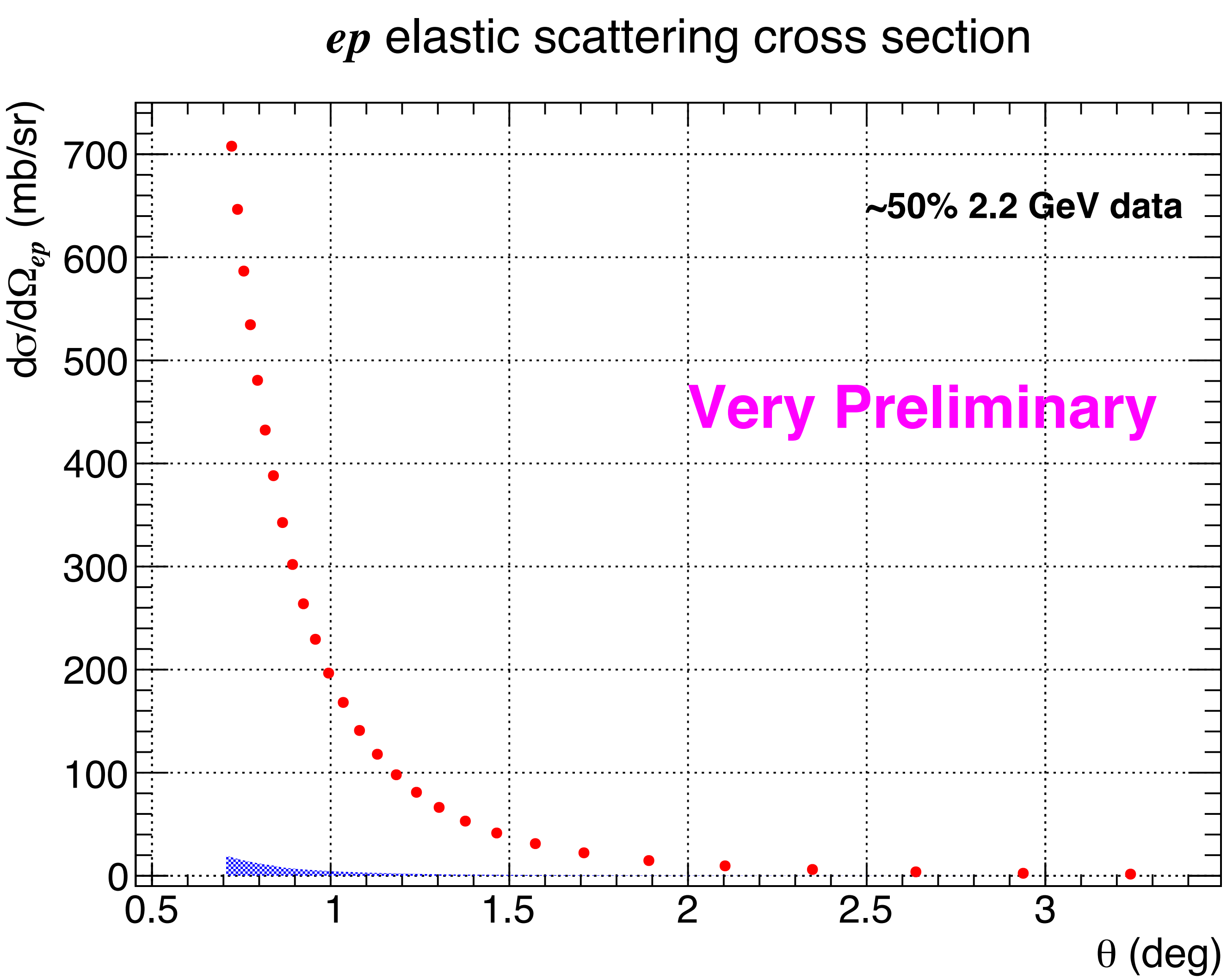
- Gains controlled by Light Monitoring System (LMS)
- Two different calibrations:
    - Before data taking: Scan with 250-1050 MeV tagged photon beam moved in front of each module to study of resolution, efficiency and non linearity
    - During data taking: With Moller and ep events
- Achieved expected energy resolution:
    - 2.5% at 1 GeV for $PbWO_4$ part
    - 6.1% at 1 GeV for Pb-glass part
- Plot shows the energy resolution for PbWO4 part with statistical uncertainties and systematic coming from non-uniformity

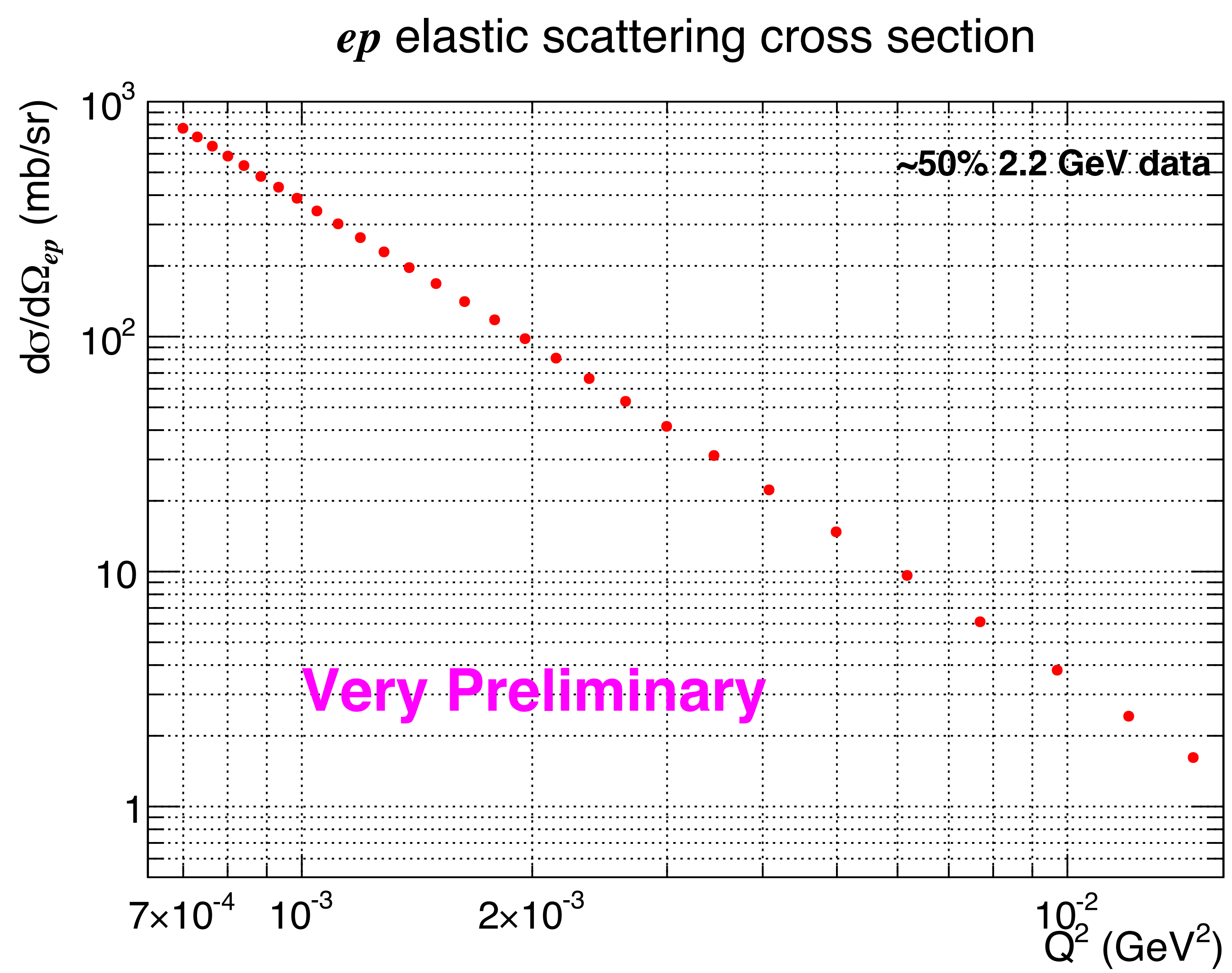


Plots courtesy of M. Levillain

Preliminary Results

- Extracted differential cross section vs scattered angle, for 2.2 GeV incident beam energy (Very Preliminary)
- Statistical errors are ~0.2% per point
- Systematic errors at this stage are estimated to be on 4%(?) level (shown with a dashed area).





Plots courtesy of W. Xiong

Conclusion

- The PRad experiment was uniquely designed to address the "Proton Radius Puzzle"
- Experiment had been successfully performed in May - June, 2016
- About half of the 2.2 GeV beam energy data have been analyzed so far:
    - Very preliminary differential cross sections for the elastic ep scattering have been extracted for the forward angle range from 0.70 to 3.00 deg
- Preliminary fit to extract the proton radius from the 2.2 GeV data set is expected to be done by October this year

Thanks