Calibration of the HyCal calorimeter for the PRad Experiment at JLab[1]

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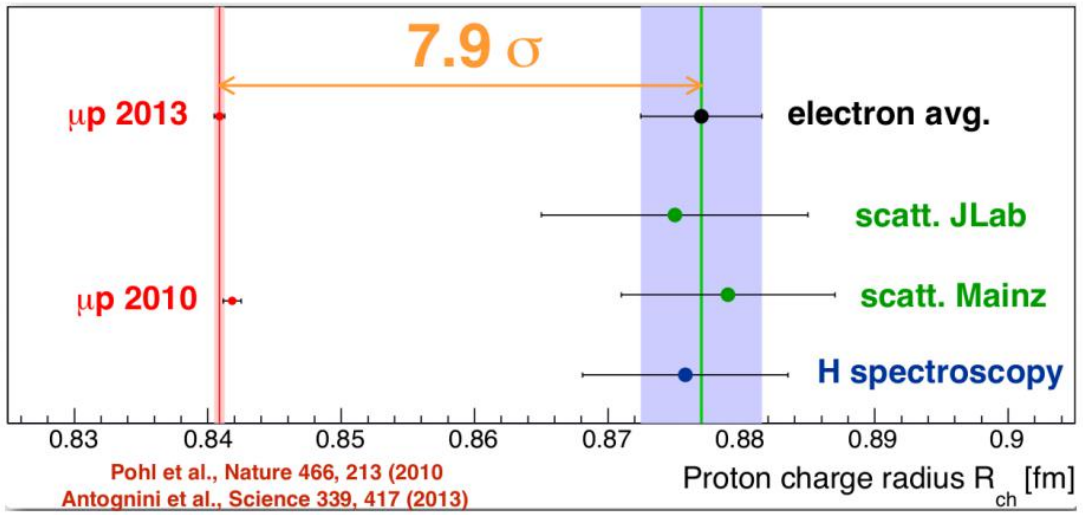
Outline

- ***PRad Physics goals***
- ***Experimental setup***
- ***Calibration Methods***
- ***Trigger Efficiency***
- ***Summary***

The Proton Charge Radius Puzzle

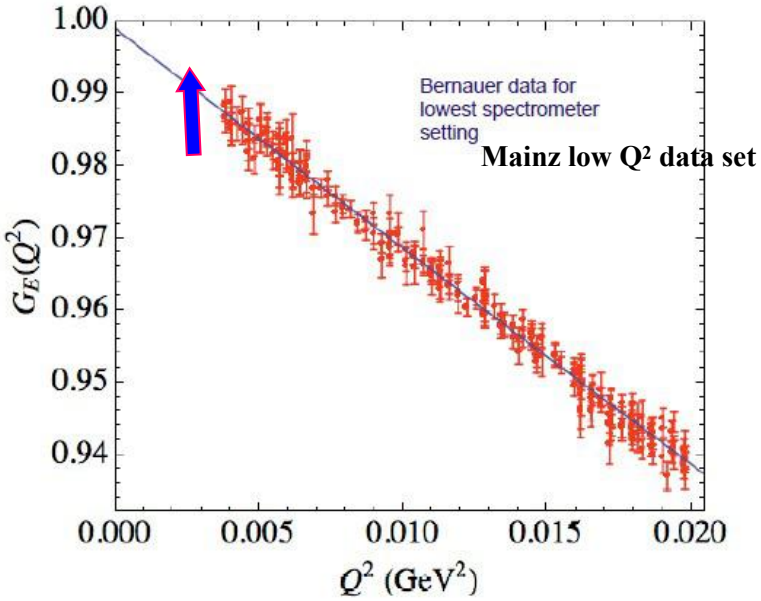
Existing data :
1.electron-proton elastic scattering measurements
2.Lamb shift measurements in atomic hydrogen
3.Lamb shift measurements in muonic hydrogen



- Muonic hydrogen Lamb shift experiment at PSI (2010,2013)
- **r_p = 0.84184(67) fm ➡ Unprecedented less than 0.1% precision**
- **~ 7.9 σ discrepancy from most of previous experimental results and analyses**

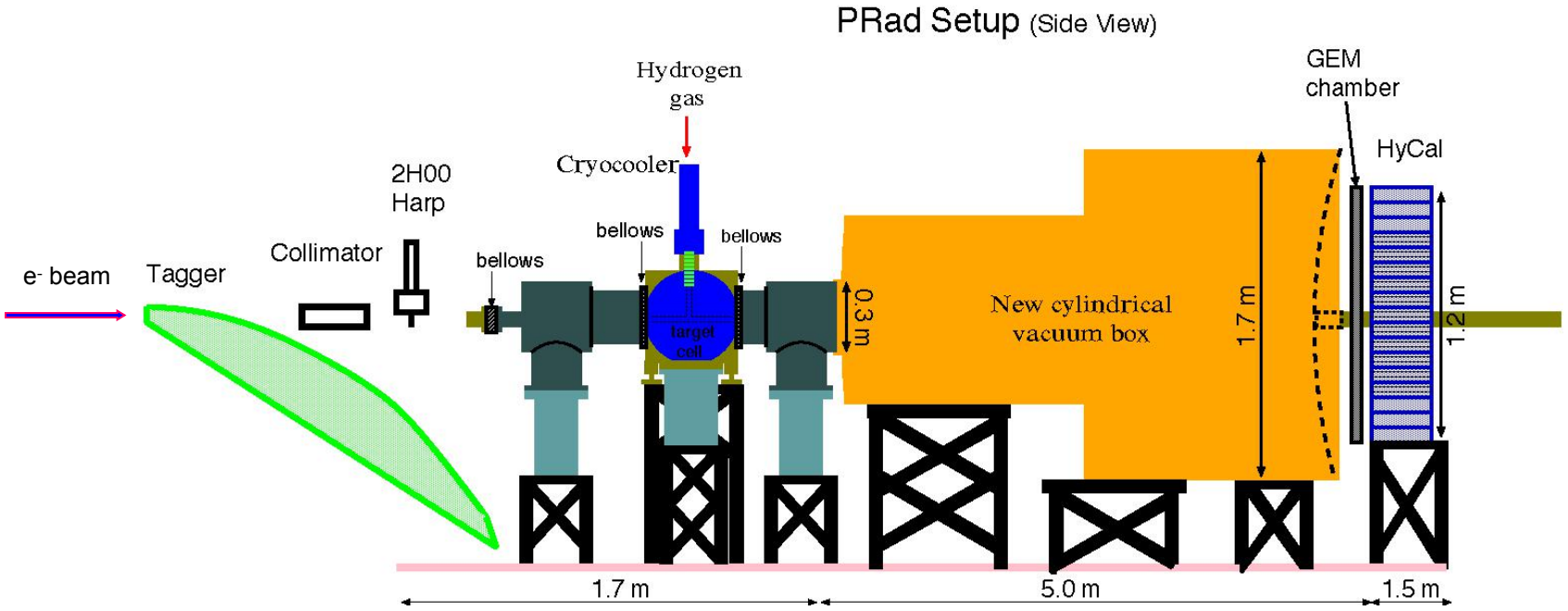
The PRad Experiment (E12-11-106)

- Experimental goals:
  - reach very low Q^2 range (~ 10 times less than the Mainz experiment)
  - reach sub-percent precision in r_p extraction



- Novel Techniques Used:
  1) Non-magnetic-spectrometer method:
     use high resolution high acceptance calorime
     and high position resolution GEM detector
     - reach smaller scattering angles: (Θ = 0.5⁰ – 7.
       (Q^2 = 2x10^{-4} – 6x10^{-2}) GeV/c^2
       essentially, model independent r_p extraction
  2) Simultaneous detection of *ee* → *ee* Moller scattering
     - (best known control of systematics)
  3) Use high density windowless H2 gas flow target:
     - beam background fully under control with high quality CEBAF beam
     - minimize experimental background
- Two beam energies: E_0 = 1.1 GeV and 2.2 GeV to increase Q^2 range: (2x10^{-4} – 6x10^{-2}) GeV/c^2
- Will reach sub-percent precision in r_p extraction

PRad Experimental Setup (schematics)



- High resolution, Hybrid calorimeter (Magnetic Spectrometer Free)
- Windowless, high density H2 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 2×10^{-4} – 6×10^{-2} GeV^2 (lower than all previous electron scattering expts.)

Windowless H_2 Gas Flow Target

- Target chamber is differentially pumped with four high speed turbos.
- Kapton orifices up- and downstream from the cell reduce the beam line vacuum.
- A four-axis motion mechanism positions the target cell, with approximately ±10 μm accuracy.

Target specs:

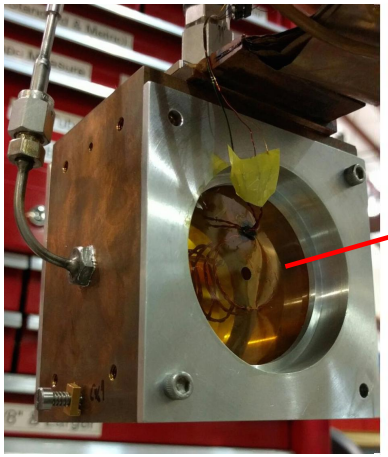
Cell: 30 μm thick Kapton, length 4 cm

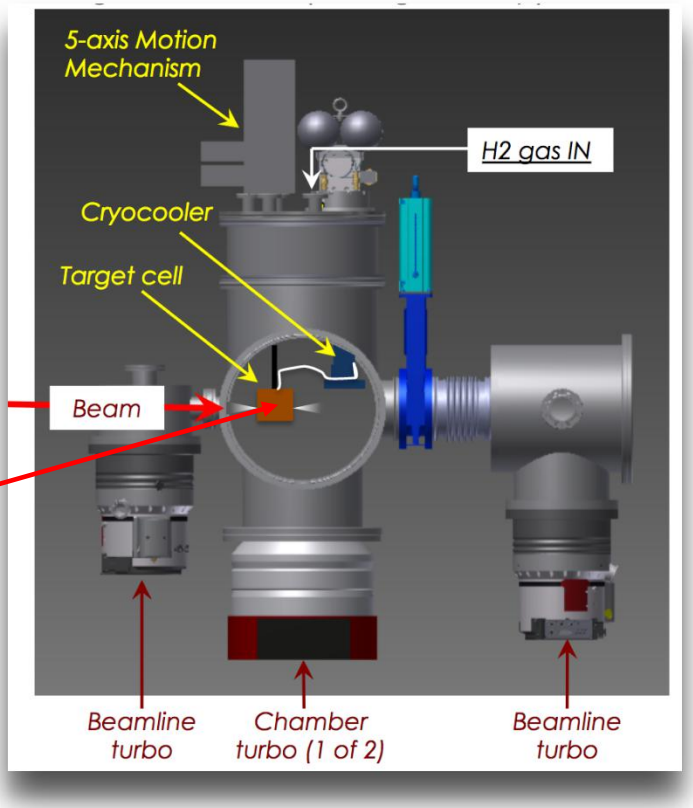
- ✓ diameter 8 cm with 2 mm diameter holes for the beam to pass through
- ✓ Cell pressure 0.5 torr

Target: H_2 input gas temp. 19.5 K

- ✓ thickness 2×10^{18} **(atoms)** / cm^2
- ✓ density 2.75×10^{17} **(molecules)** / cm^3
- ✓ Cell / chamber / vacuum tank pressure:

470 mtorr / 2.3 mtorr / 0.3 mtorr





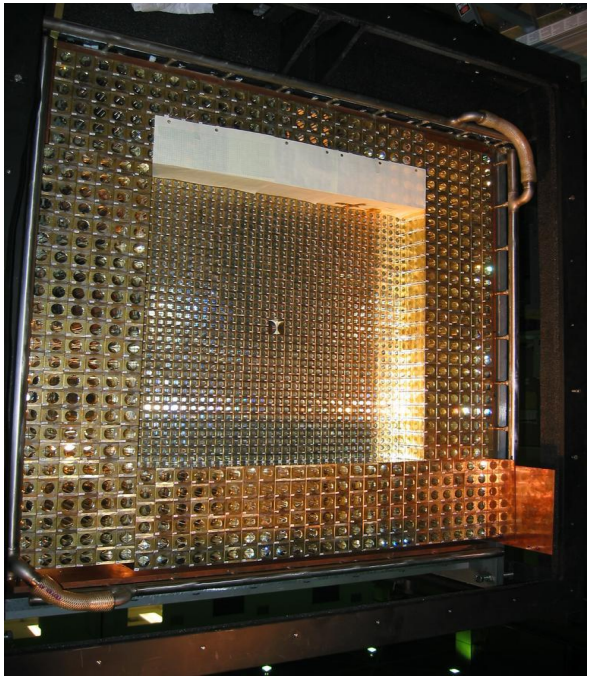
Funded by a NSF MRI grant

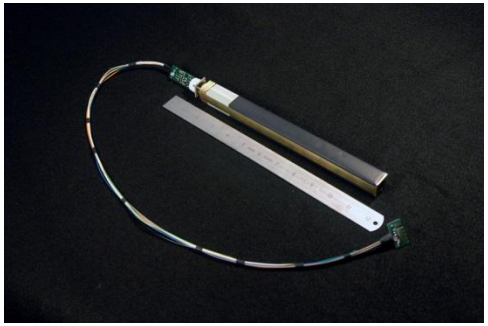
Electromagnetic Calorimeter (PrimEx HyCal)

- Combination of $PbWO_4$ and Pb-glass detectors (118x118 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 (3.82x3.82x45.0 cm^3)
- 2 x 2 $PbWO_4$ modules removed in middle for beam passage
- 5.5 m from H_2 target (~0.5 sr acceptance)

- Moved back to Hall B in June, 2014:

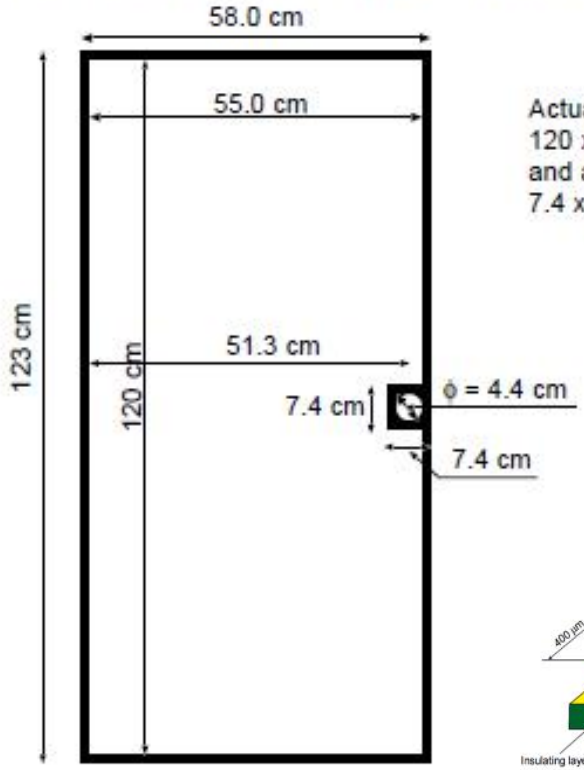
  Cabling system with infrastructure reassembled
  - Trigger, analog and HV electronics are reinstalled
  - Cooling system is operational
  - LMS checked and repaired
  - All individual detectors checked and repaired
  - DAQ is operational (HyCal readout part)
  - Transporter is reinstalled/repaired and operational





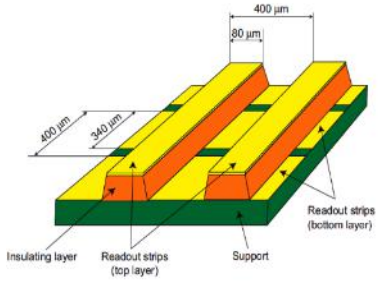
PRad GEMs: Design & Specifications

Desired Sensitive area: 116.4 x 116.4 cm^2
central hole: diameter 4.4 cm, including the frame max allowed
maximum allowable non-sensitive region 7.8 x 7.8 cm^2

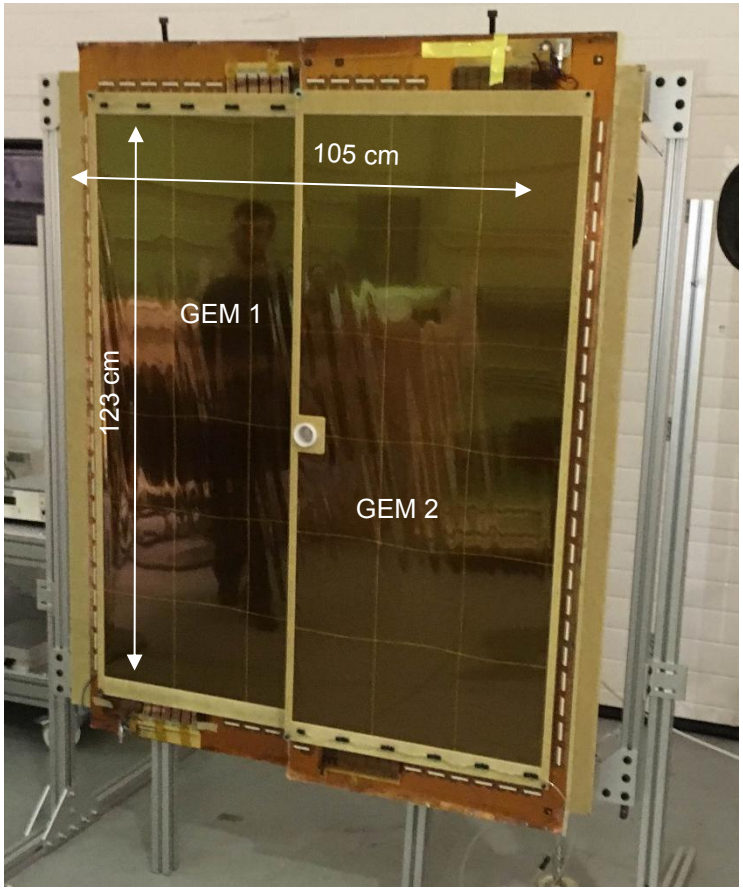


Actual sensitive area:
120 x 102.6 cm^2
and actual non-sensitive area:
7.4 x 7.4 cm^2

2D strips readout
spatial resolution < 70 μm



Two modules mounted on the holding frame in PRad GEM configuration before the cosmic run in EEL (March 2016)



- Largest GEM detector ever built in the world
  - Each module(123 cm x 55 cm) is twice the size of SBS Back Tracker GEMs
  - The two modules overlap in the central part for the alignment of the beam pipe hole
- COMPASS-like strip readout (1.3 m long strips in the vertical direction ⇨ capacitance noise still OK)

PRad in Jefferson Lab Hall B

Beam-side view

GEMs mounted on HyCal

Calorimeter Calibration Method

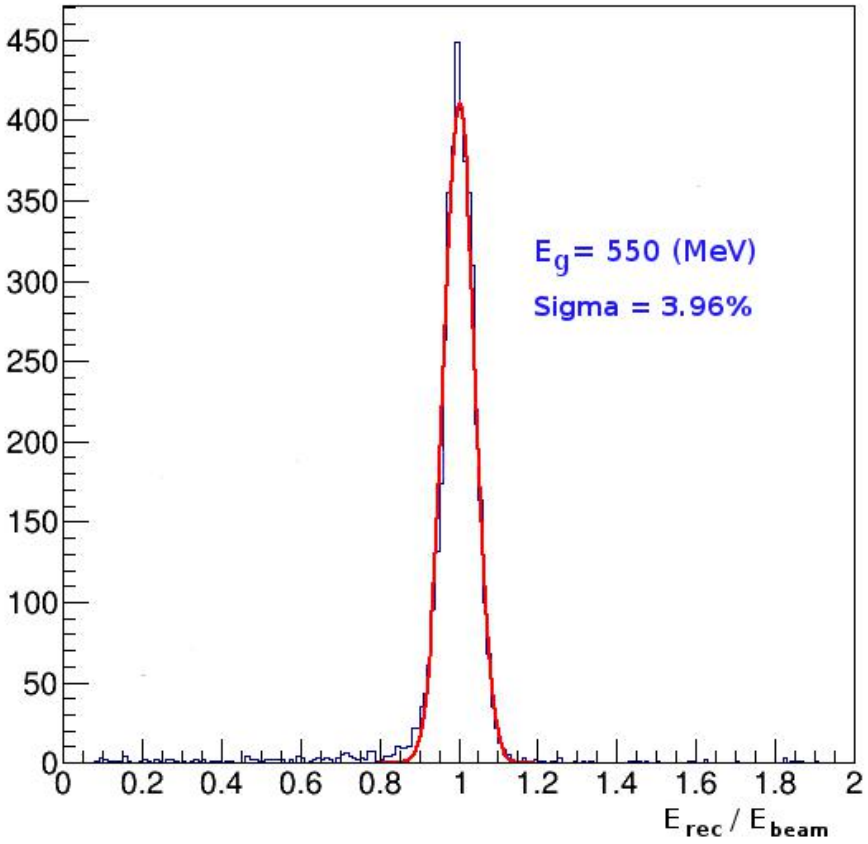
- Gains controlled by Light Monitoring System (LMS)
- Two different calibrations:
  - Before data taking: Scan with 250~1050 MeV tagged photon beam moved in front of each module

    → study of resolution, efficiency and non-linearity
  - During physics data taking:

    With Moller and ep events
- Iterative method:

  $\mathbf{gain}_{module}(n+1) = \mathbf{gain}_{module}(n)/\langle \mathbf{E}_{measured}/\ \mathbf{E}_{expected} \rangle$
- Different clustering Island algorithms used for cross check

Calorimeter Calibration Method

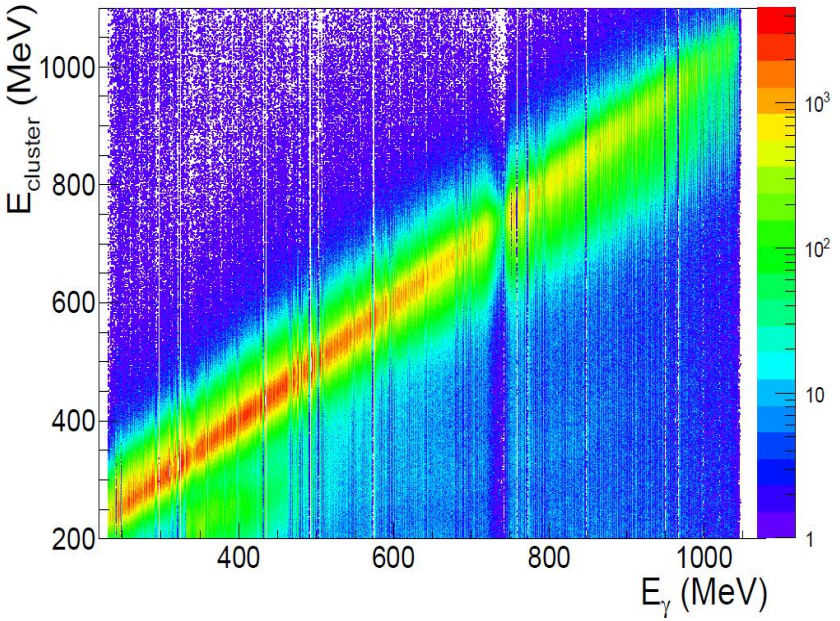


Example of module W222

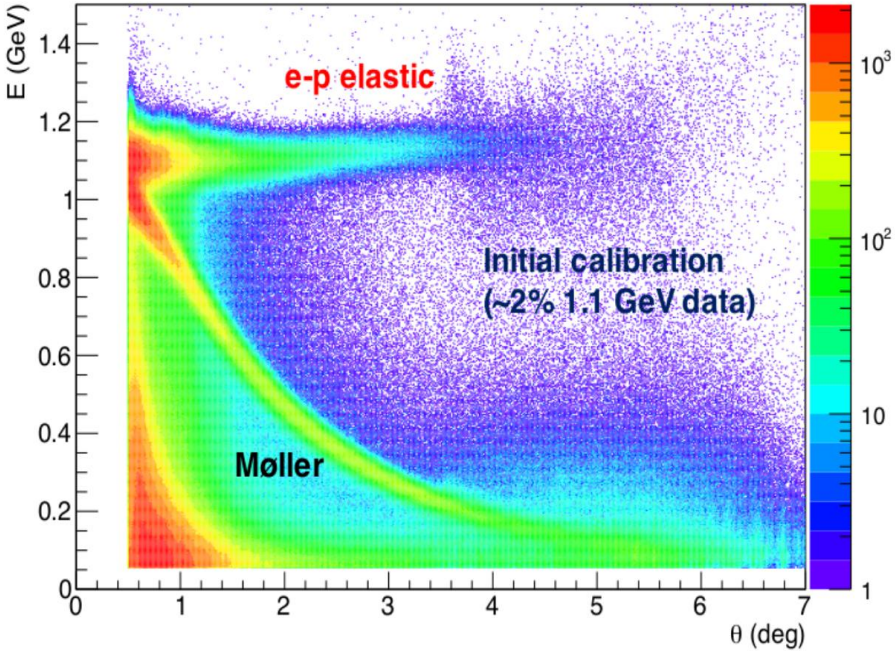
ratio = reconstruct energy / beam energy

Calorimeter Calibration

Calibration with tagged photon beam

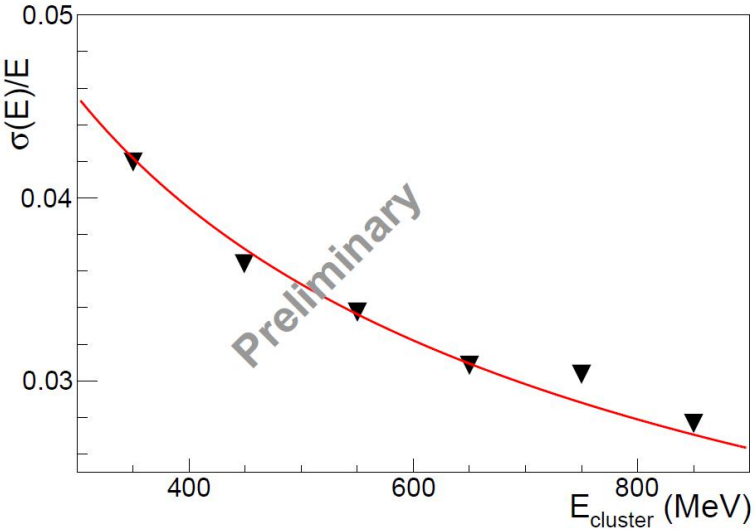


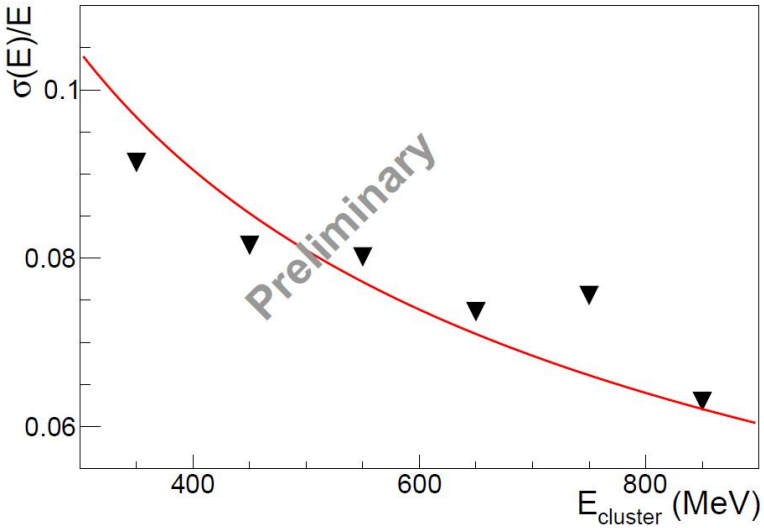
Physics Calibration



Calorimeter Calibration

$$\frac{\sigma(E)}{E} = \frac{r}{\sqrt{E(GeV)}}$$





PbWO4

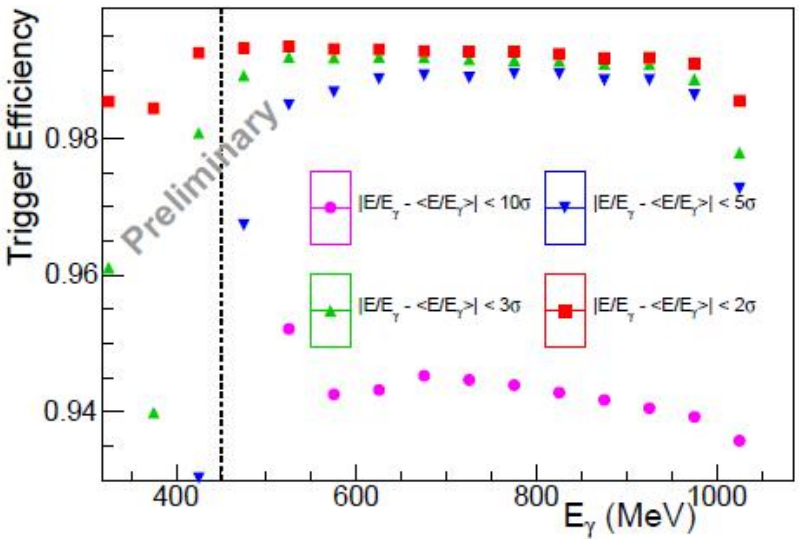
resolution at 1 GeV: 2.5%

Lead Glass

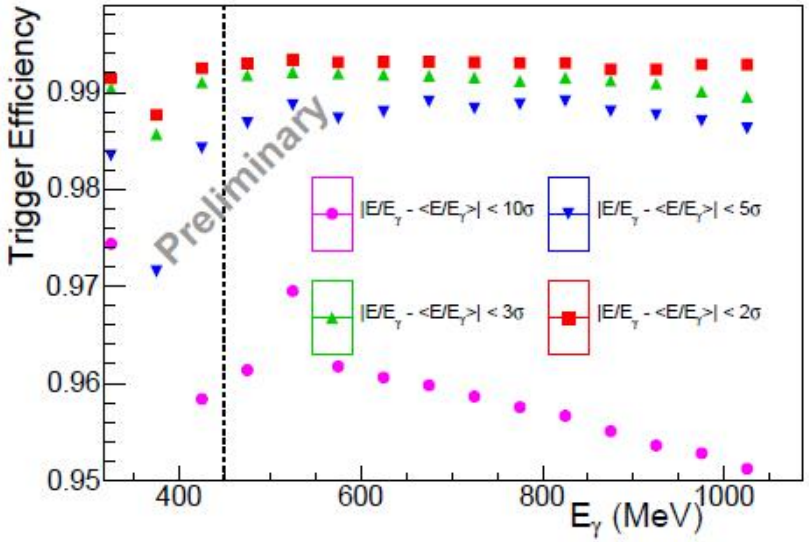
resolution at 1 GeV: 6.1%

Trigger Efficiency

- Three triggers: 1.LeadGlassSum, 2.TotalSum, 3.Tagger
- Plateau from 450 MeV with 0.994 efficiency
- Good uniformity



PbWO4



Lead Glass

Summary

- ✓ The Proton Radius Puzzle is still unsolved
- ✓ The PRad experiment was uniquely designed to address the Proton Radius Puzzle
- ✓ HyCal calibration and alignment are finalized
  → good energy resolution , high and uniform efficiency
- ✓ The physics analysis will start soon!