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

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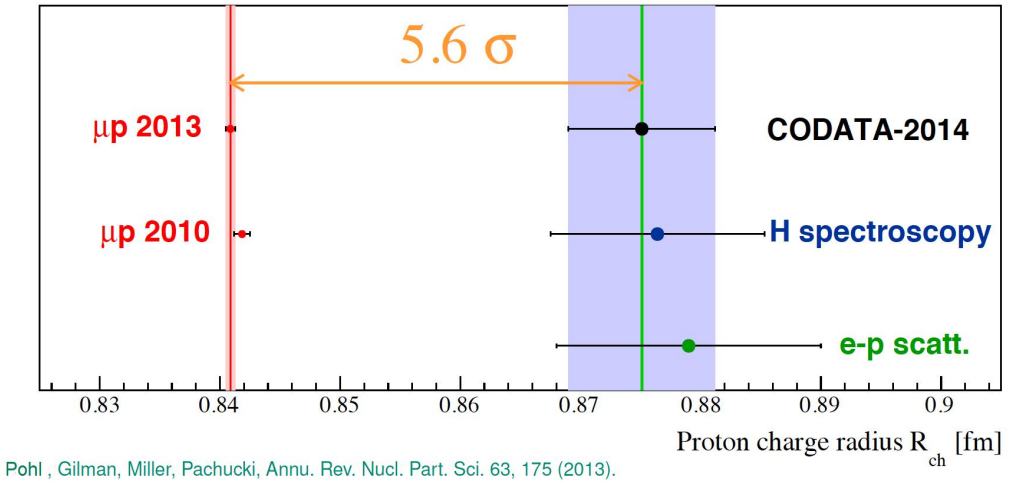
Outline

- ***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

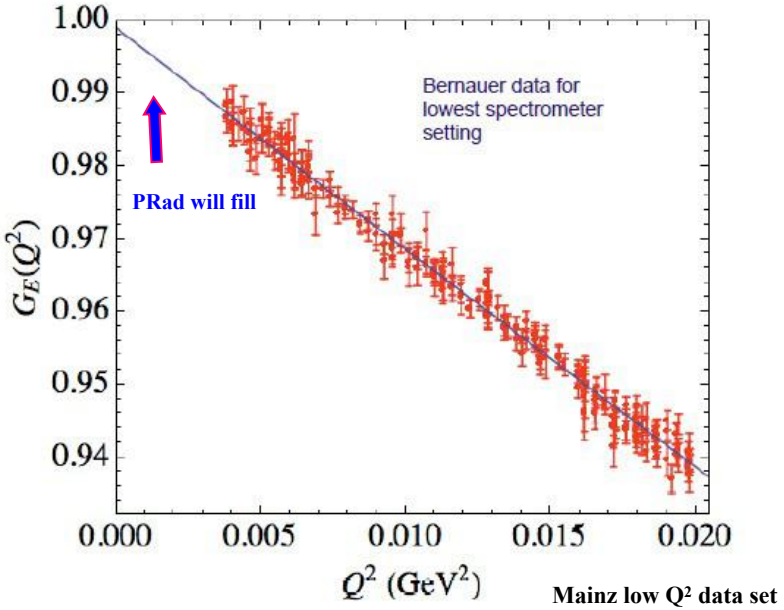


Pohl , Gilman, Miller, Pachucki, Annu. Rev. Nucl. Part. Sci. 63, 175 (2013).

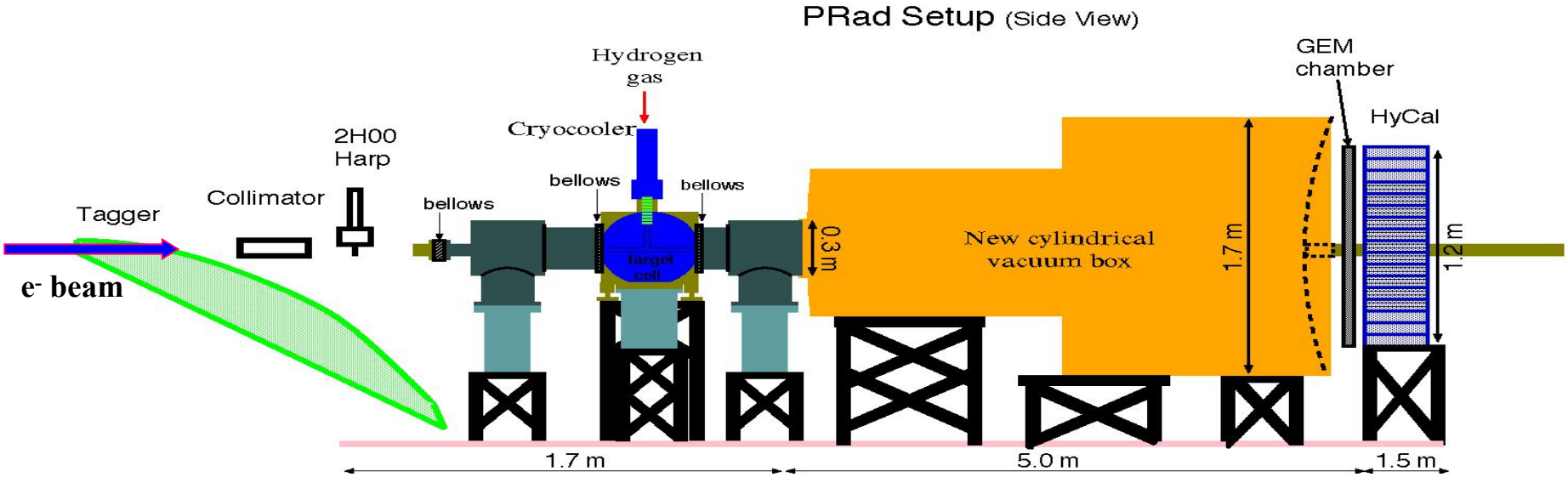
- Muonic hydrogen Lamb shift experiment at PSI (2010,2013)
- **r_p = 0.84184(67) fm ➡ Unprecedented less than 0.1% precision**
- **~ 5.6 σ discrepancy from most of previous experimental results and analyses**

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 calorimeter and high position resolution GEM detector
    - reach smaller scattering angles: ($\Theta = 0.6^0 - 7.5^0$)
      ($Q^2 = 2\times10^{-4} - 6\times10^{-2}$) GeV^2/c^2
      essentially, model independent r_p extraction
  - ② Simultaneous detection of $ee \rightarrow ee$ Moller scattering (best known control of systematics)
  - ③ Use high density windowless H_2 gas flow target:
    - beam background fully under control with high quality CEBAF beam
    - minimize experimental background



PRad Experimental Setup (schematics)



- 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)

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:

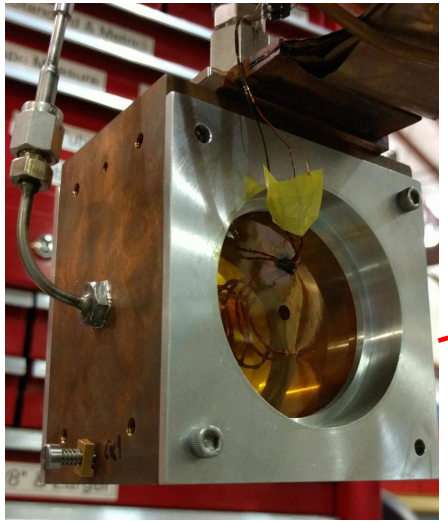
Cell: 30 μm thick Kapton, length 4 cm

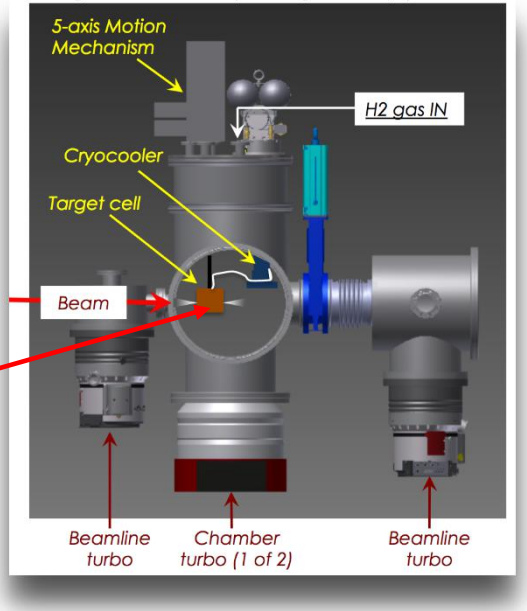
- ✓ diameter 8 cm with 2 mm diameter holes for the beam to pass through
- ✓ Cell pressure 0.5 Torr

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

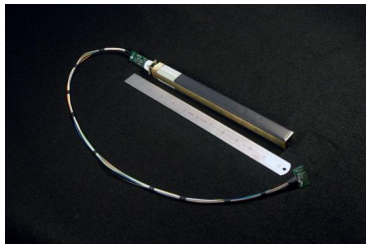
Funded by a NSF MRI grant

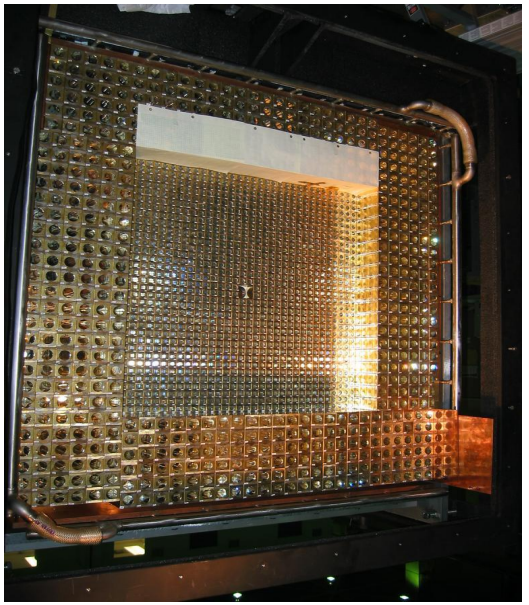




Electromagnetic Calorimeter (PrimEx HyCal)

- Combination of $PbWO_4$ and Pb-glass detectors (118×118 cm^2)
- 34×34 matrix of $2.05 \times 2.05 \times 18$ cm^3 $PbWO_4$ shower detectors
- 576 Pb-glass shower detectors ($3.82 \times 3.82 \times 45.0$ cm^3)
- 2×2 $PbWO_4$ modules removed in middle for beam passage
- 5.8 m from H_2 target (~0.5 sr acceptance)

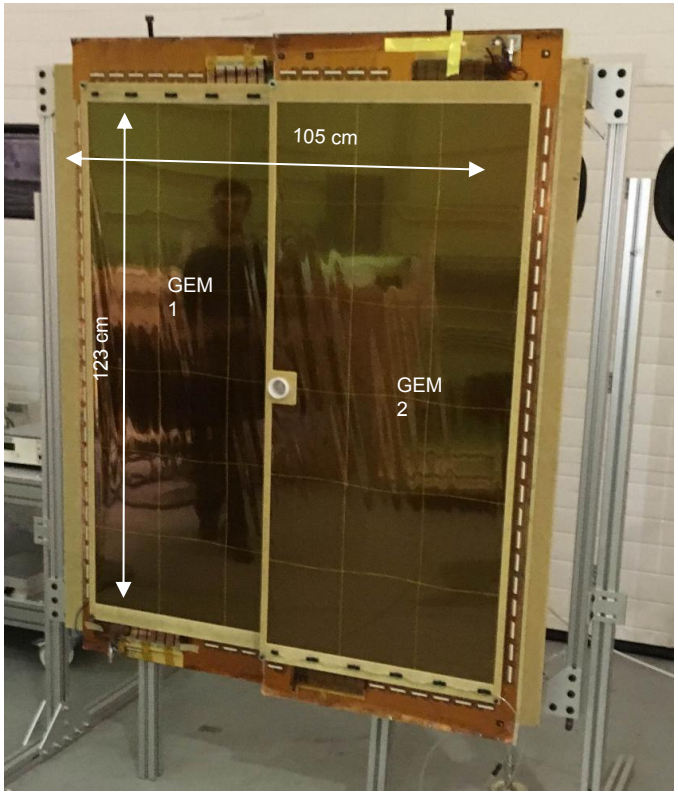




PRad GEMs: Design & Specifications

- 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)
  - ✓ 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)

More details at Xinzhan Bai's talk in the same session



PRad in Hall B Jefferson Lab

Beam-side view

GEMs mounted on HyCal

Calorimeter Calibration Method

- Gains of every detector module controlled by Light Monitoring System (LMS)
- Two different calibration modes:
  - Before physics data collection: Scan with 250~1050 MeV tagged photon beam incident on each module

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

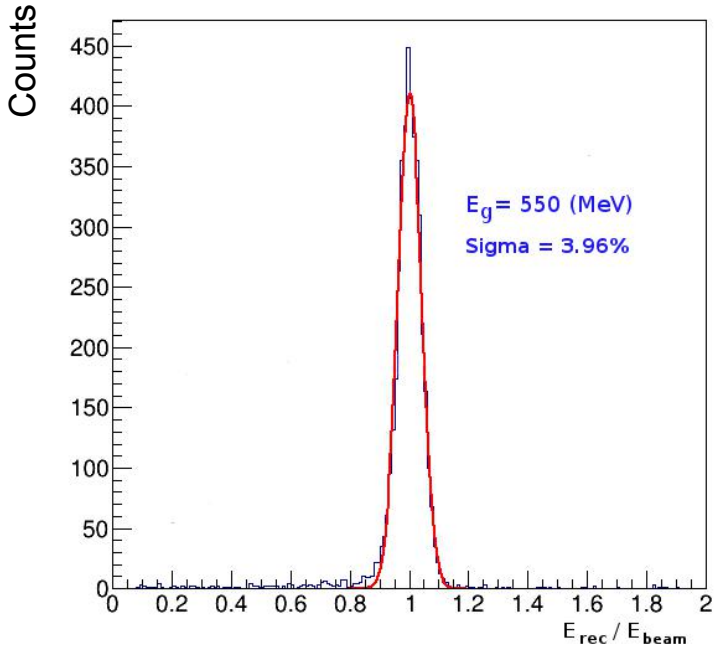
    With Moller and ep elastic events

- Two different clustering algorithms used for cross check
- Iterative method:

$$\mathbf{gain}_{module}(n+1) = \mathbf{gain}_{module}(n)/\langle \mathbf{E}_{measured}/\ \mathbf{E}_{expected} \rangle$$

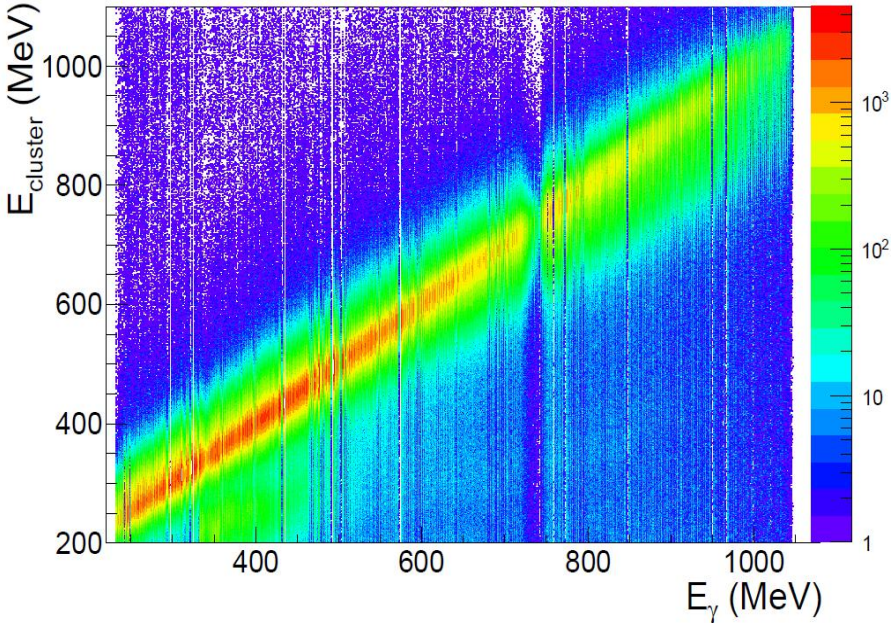
Calorimeter Calibration Example

Example for PbWO4 module W222

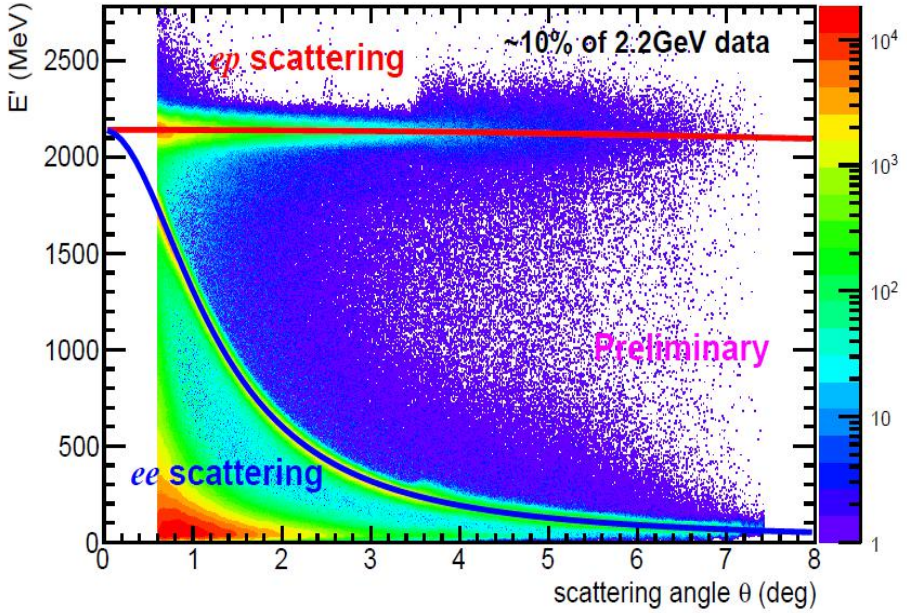


reconstructed energy / beam energy

Events Reconstruction

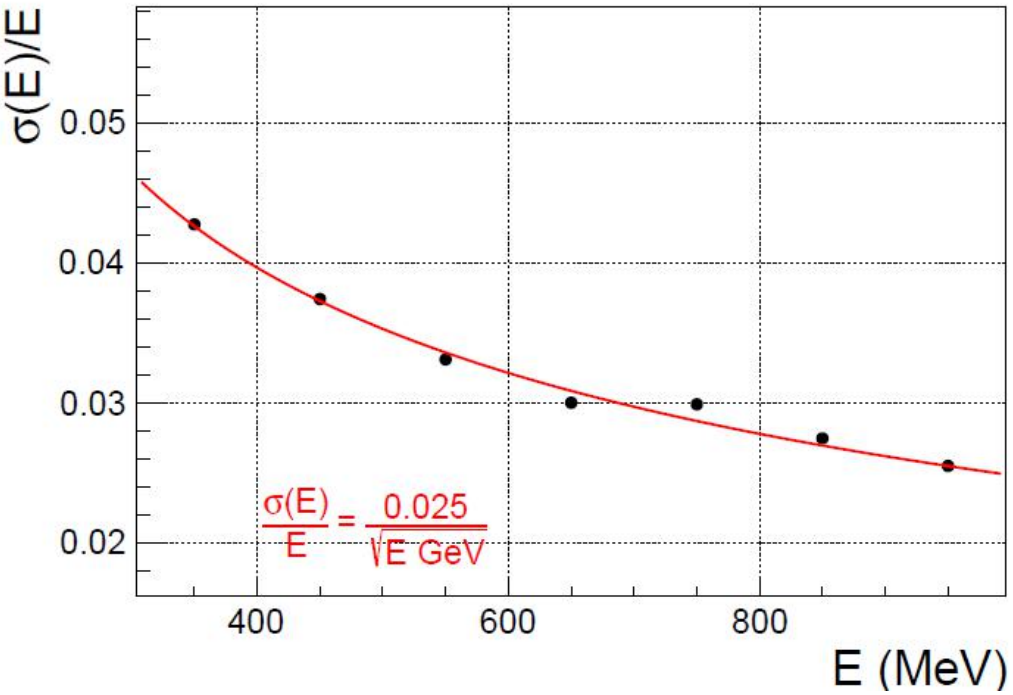


reconstructed calibration events



reconstructed physics events

Preliminary Energy Resolution



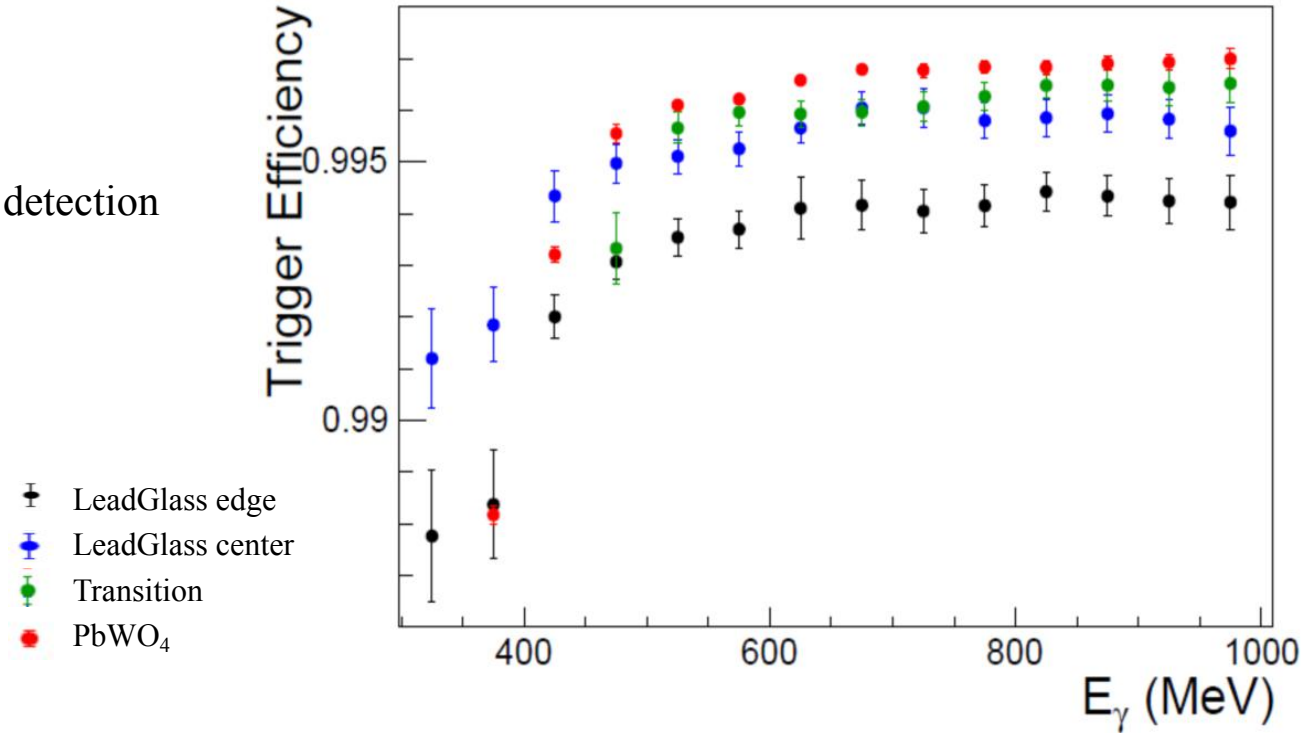
PbWO4 resolution at 1 GeV: 2.5%

Trigger Efficiency

Three triggers:

① LeadGlassSum
② TotalSum
③ Tagger

- Above 450 MeV with detection efficiency 0.994
- Good uniformity



Summary

- ✓ The Proton Radius Puzzle is still unsolved
- ✓ The PRad experiment was uniquely designed to address the Puzzle
- ✓ The experiment succefully ran in May 2016
- ✓ HyCal calibration and alignment are finalized
  → good energy resolution , high and uniform efficiency
- ✓ The physics analysis is in progress!