Monte Carlo Simulation of the PRad Experiment at JLab[1]

Li Ye
Mississippi State University
for the PRad collaboration

[1].This work is supported in part by NSF MRI award PHY-1229153, the U.S. Department of Energy under Contacts No. DE-FG02-07ER41528, Thomas Jefferson National Laboratory, Mississippi State University and PRad collaboration

Outline

- ***PRad Physics goals***
- ***Experimental setup***
- ***Monte-Carlo Simulation***
  - ***GEANT4 geometry and beam profile***
  - ***Background study and subtraction***
- ***Summary***

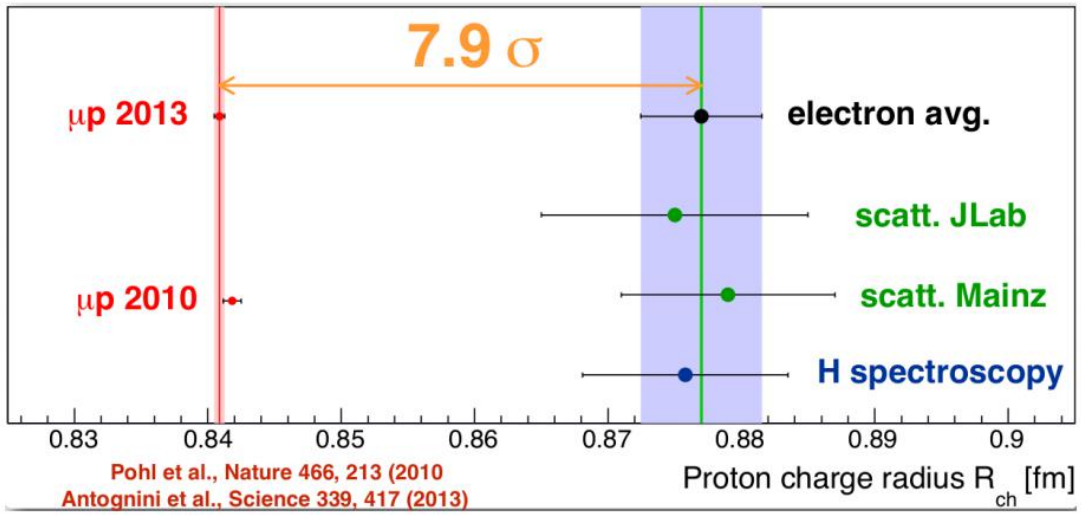
The Proton Charge Radius Puzzle

Existing data :

1.electron-proton elastic scattering measurements

2.Lamb shift measurements in atomic hydrogen

3.Lamb shift measurements in muonic hydrogen

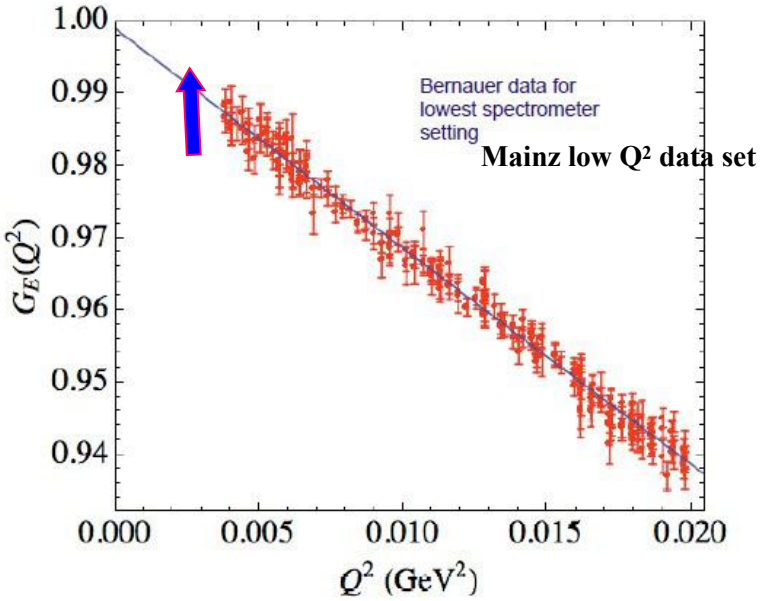


- Muonic hydrogen Lamb shift experiment at PSI (2010,2013)
- r_p = 0.84184(67) fm ➡ Unprecedented less than 0.1% precision
- ~ 7.9 σ discrepancy from most of previous experimental results and analyses

The PRad Experiment (E12-11-106)

The experiment completed data taking during May-June 2016

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

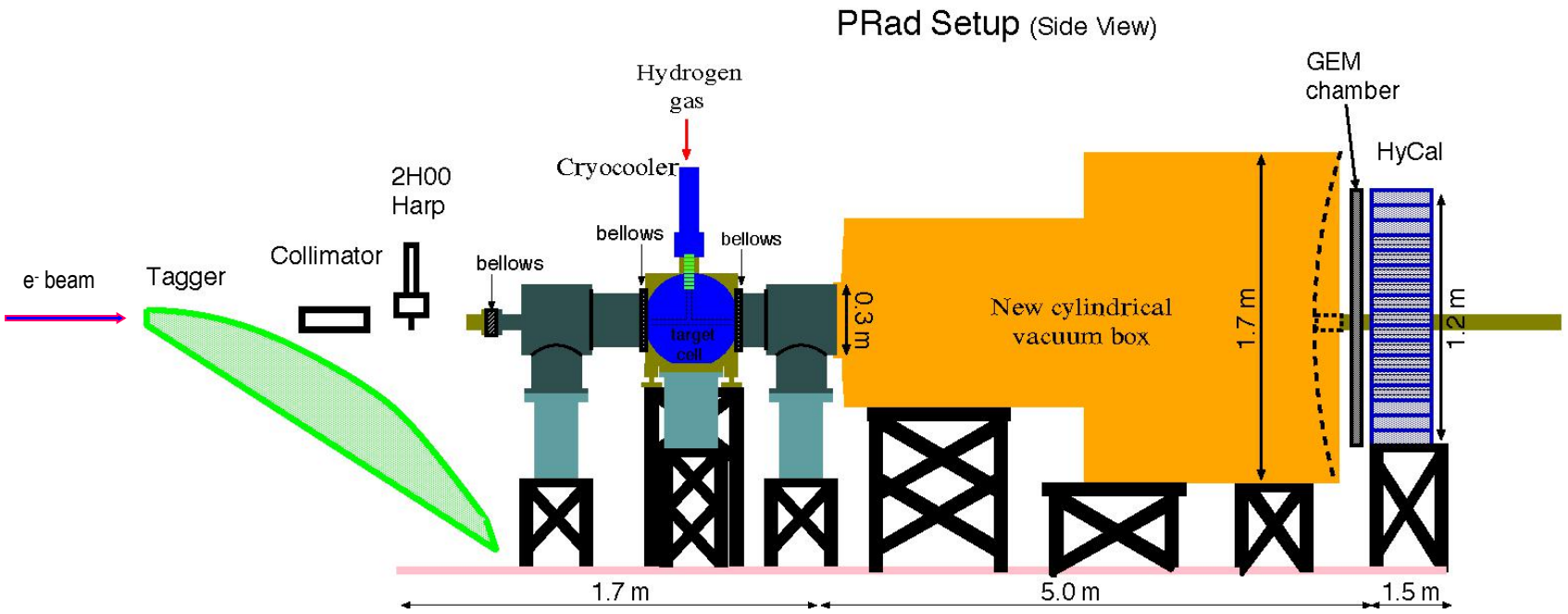


- Novel Techniques Used:
  1) Non-magnetic-spectrometer method:
     use high resolution high acceptance calorimeter and high position resolution GEM detector
     - reach smaller scattering angles: (Θ = 0.5^0 – 7.5^0)
       (Q^2 = 2×10^{-4} – 6×10^{-2}) GeV/c^2
       essentially, model independent 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: (2×10^{-4} – 6×10^{-2}) GeV/c^2
- Will reach sub-percent precision in r_p extraction

PRad Experimental Setup (schematics)

More details at WeiZhi Xiong's talk in the same section



- 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.)

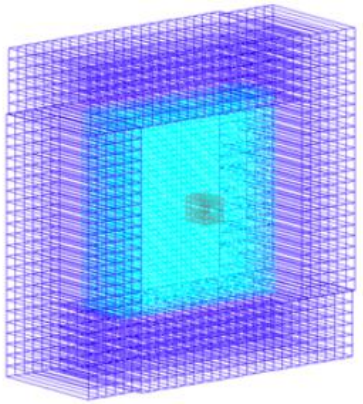
Monte-Carlo Simulation

- A thorough simulation of the experiment to identify possible sources of background is important to achieve sub-percent precision in the cross section measurement and proton radius extraction.

- A simulation code for the target and the calorimeter was developed based on GEANT4

- Event generators with radiative corrections of e-p and e-e scattering were also developed.

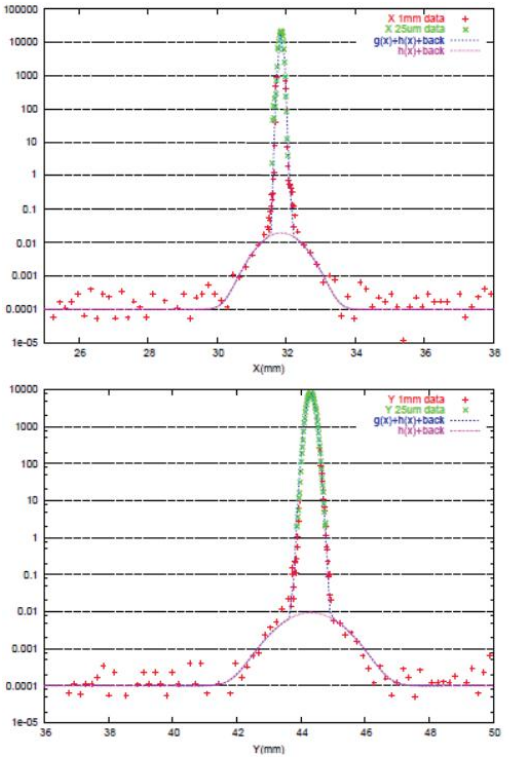
GEANT4 geometry and beam profile



- ***Target, made of Kapton***
  - Cylindricaltube open at both ends and a gas inlet neck

- ***Calorimeter, central part of HyCaL***
  - 34×34 $PbWO_4$ crystal modules with four removed at the center
  - Dimension of each module: 2.05×2.05×18cm^3
  - Energy resolution 2.6%/√E, position resolution 2.5mm/√E

- ***Electron beam, 15days of beam time***
  - 1.1 GeV, 2.2 GeV or higher energy
  - A uniform halo of 10^{-7} relative to the peak was included.



GEANT4 Simulation Geometry

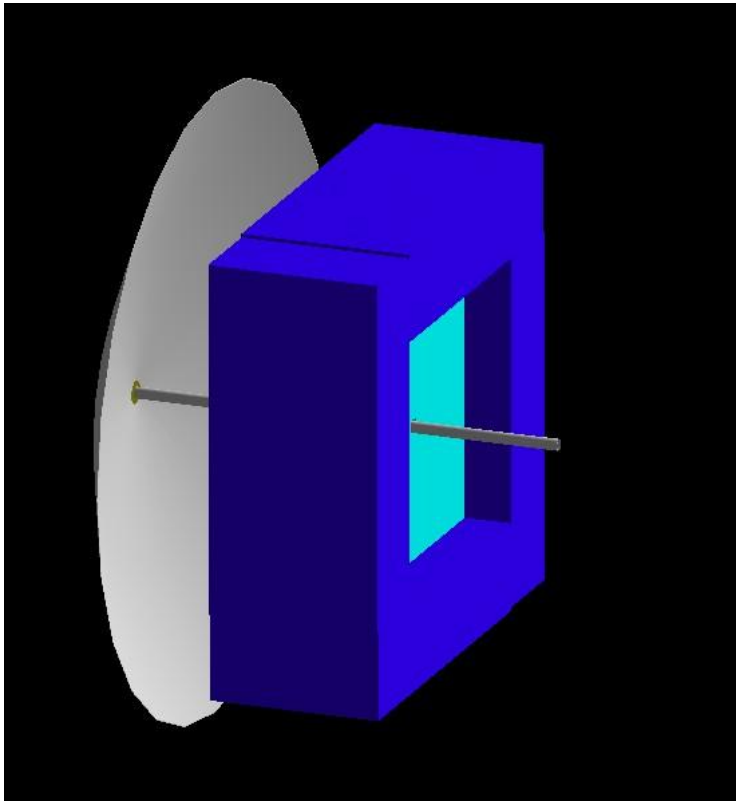
Flange(window Coupling) :
material Al, outer diameter 2.3" , inner diameter 1.3",

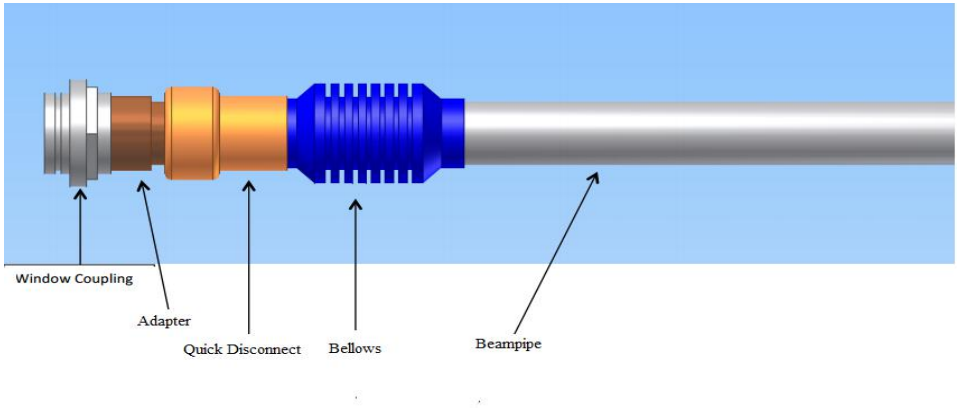
Adapter:
material Fe, outer diameter 1.62" , inner diameter 1.245",

Quick Disconnect big:
material Fe, outer diameter 2" , inner diameter 1.39",

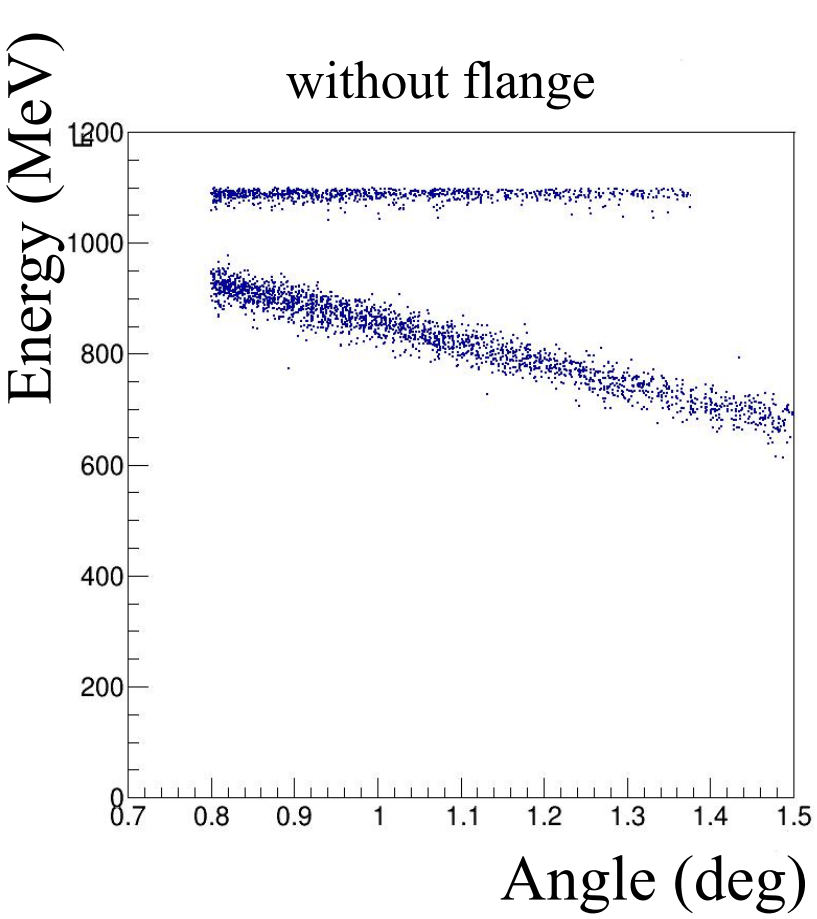
Quick Disconnect small:
material Fe, outer diameter 1.62" , inner diameter 1.39",

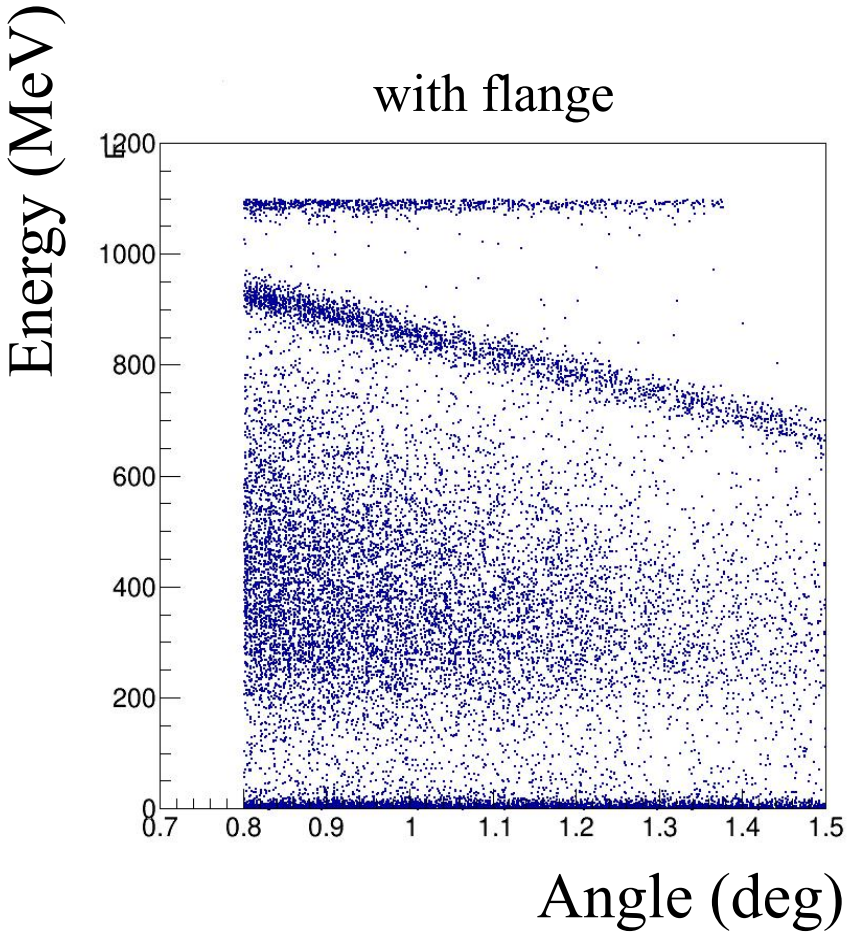
Beam Pipe:
material Fe, outer diameter 1.375", inner diameter1.245",
note: the beam pipe is all the way connect to the Adapter
in the simulation



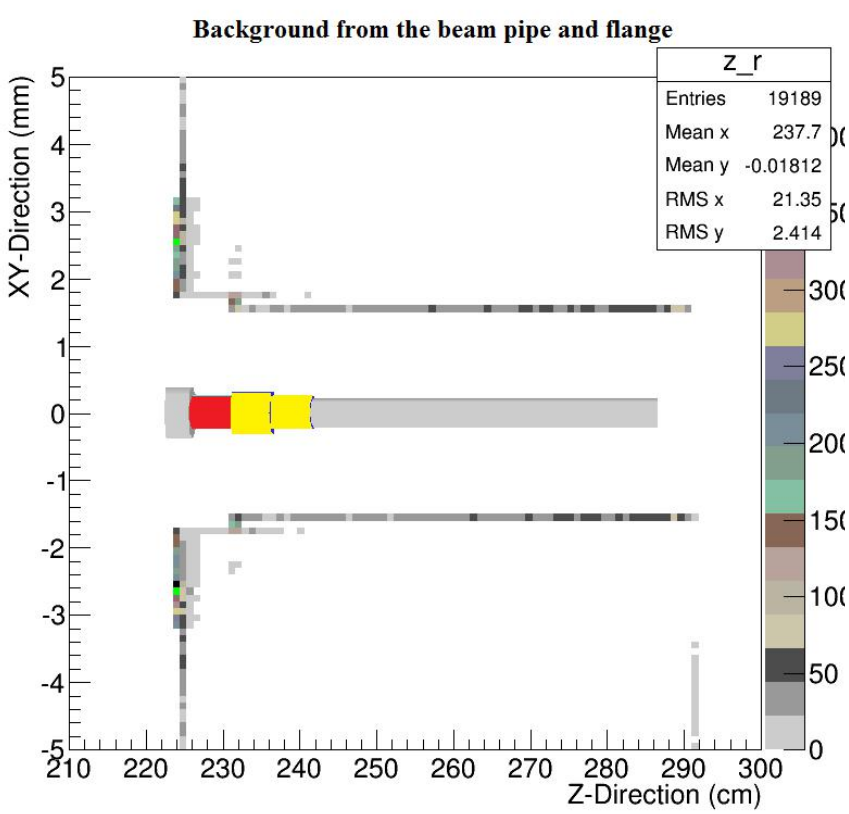


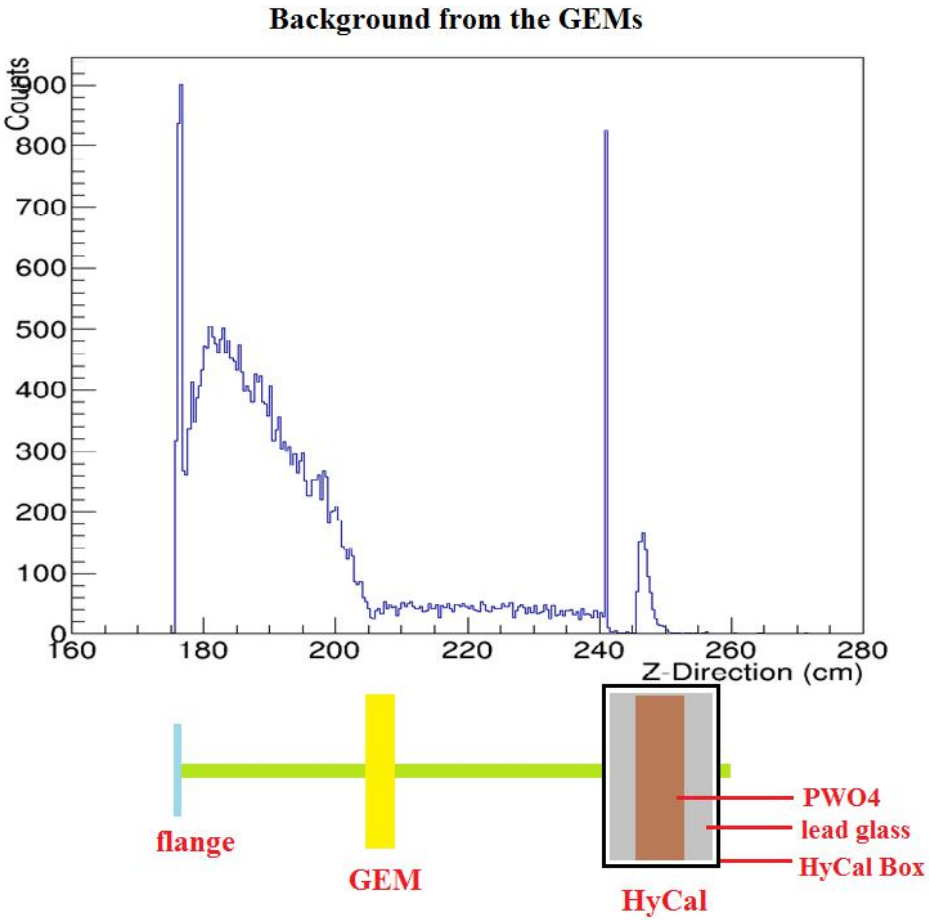
Background from Beam Flange



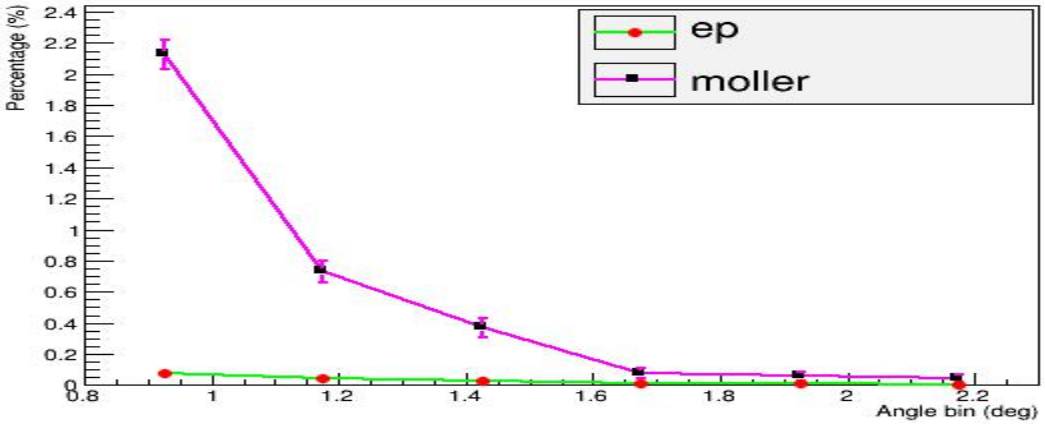


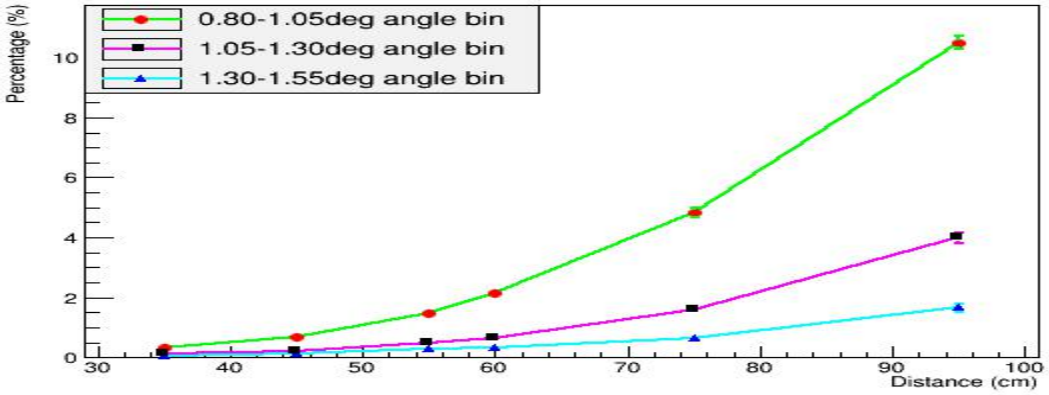
Background from Beamline and Flange





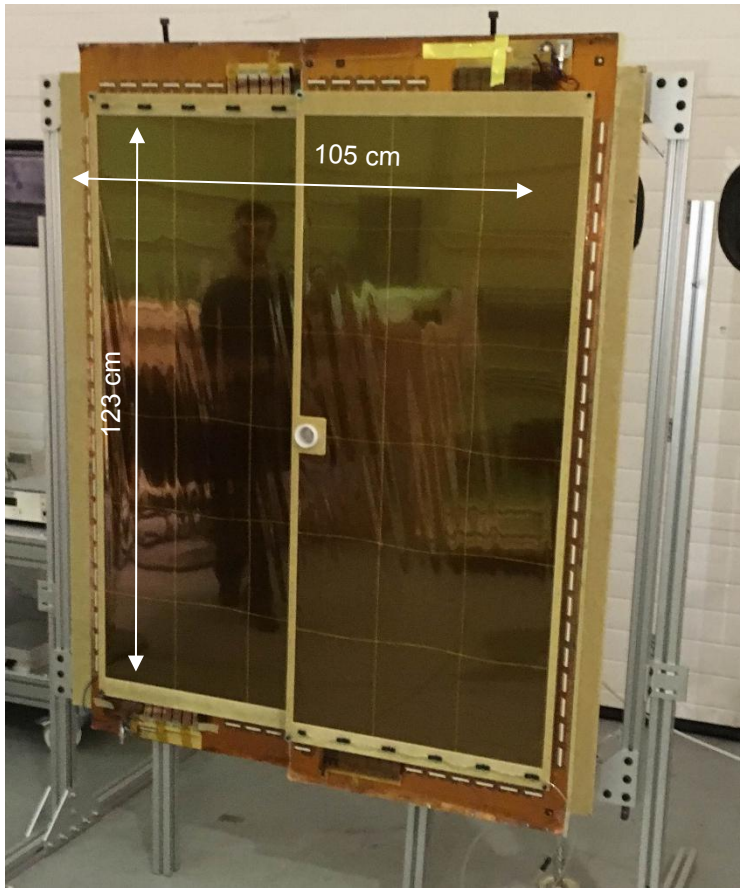
Backgrounds From the Beamline Flange

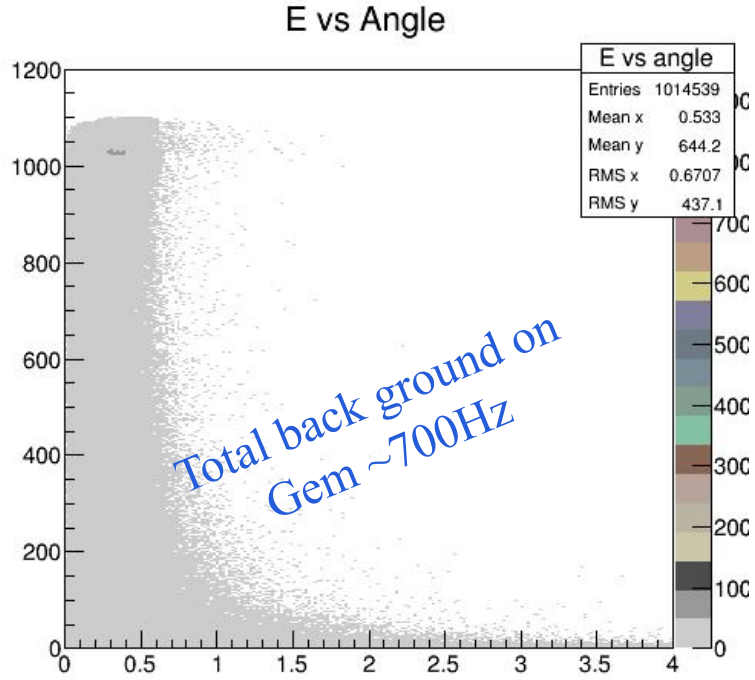




- Background from re-scattered Moller events concentrated in first angle bin, around ~2.1% of data.
- Background events as a function of distance from flange to HyCal $PbWO_4$ surface.
- Total backgrounds on HyCal ~120Hz

Background from GEMs





Total background in experiment: (HyCal trigger)
~200Hz @ 1.1GeV no target
~350Hz @ 1.1GeV empty target cell and chamber
~550Hz @ 2.2GeV empty target cell and chamber
higher than simulation due to residual gas from upstream beamline

Material: G10, Kapton foils, copper, Ar, CO2 ~~0.5% radiation length
G10 Frame : 1.5cm ~~7.5% radiation length
Distance from Hycal surface : 30cm

Summary

- A larger Q^2 coverage is helpful to the radius extraction in this experiment, the expected uncertainty of the extracted radius is less than 1%.
- A comprehensive Geant4 simulation of the PRad experiment was developed and radiative corrections for both elastic and Moller scattering were included in the simulation.
- Background simulation study helped to make better design of vacuum box window, connection flange and pipe.
- The primary background source is from the residual gas and beamline; Empty target subtraction will help reduce the background.