Simulation for PRad Experiment at JLab[1]

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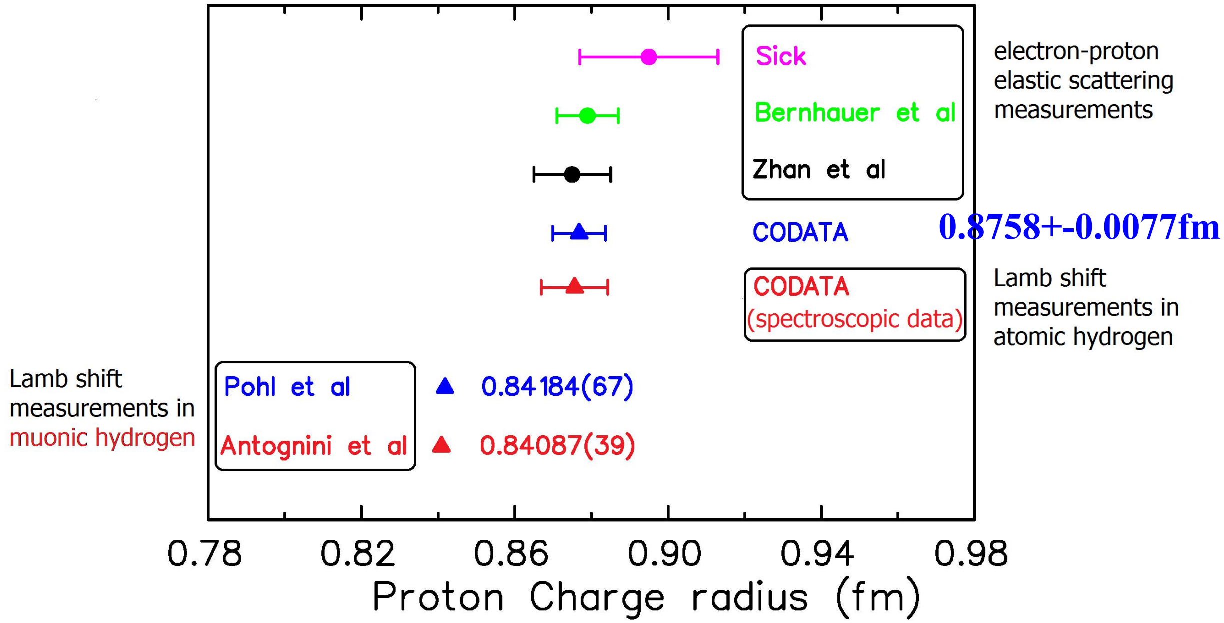
Outline

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

- ***Summary***

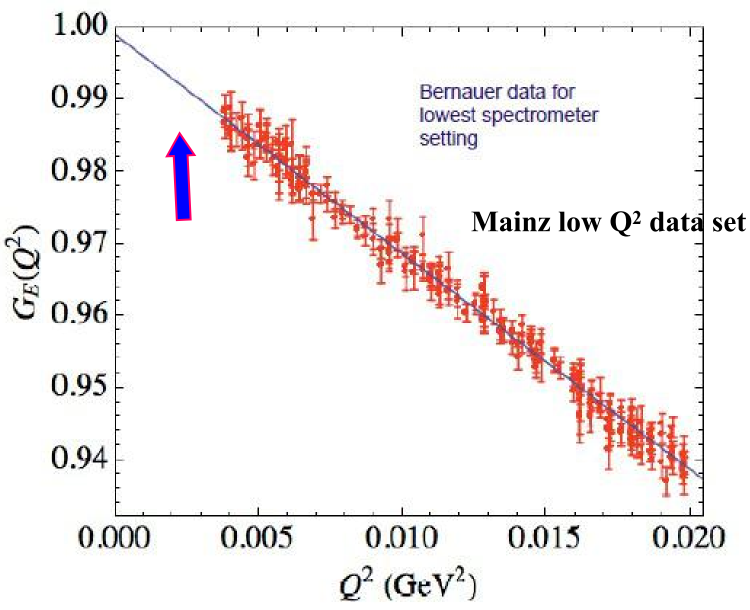
The Proton Charge Radius Puzzle

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 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
- Suggested solutions:
  1) Non-magnetic-spectrometer method:
     use high resolution high acceptance calorimeter and high position resolution GEM detector
     - reach smaller scattering angles: ($\Theta = 0.8^0 - 7.0^0$)
       ($Q^2 = 2x10^{-4} - 1x10^{-1}$) 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: ($2x10^{-4} - 1x10^{-1}$) GeV/c^2
- Will reach sub-percent precision in r_p extraction
- Approved by PAC39 (June, 2012) with high "A" scientific rating

PRad Experimental Setup (schematics)

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

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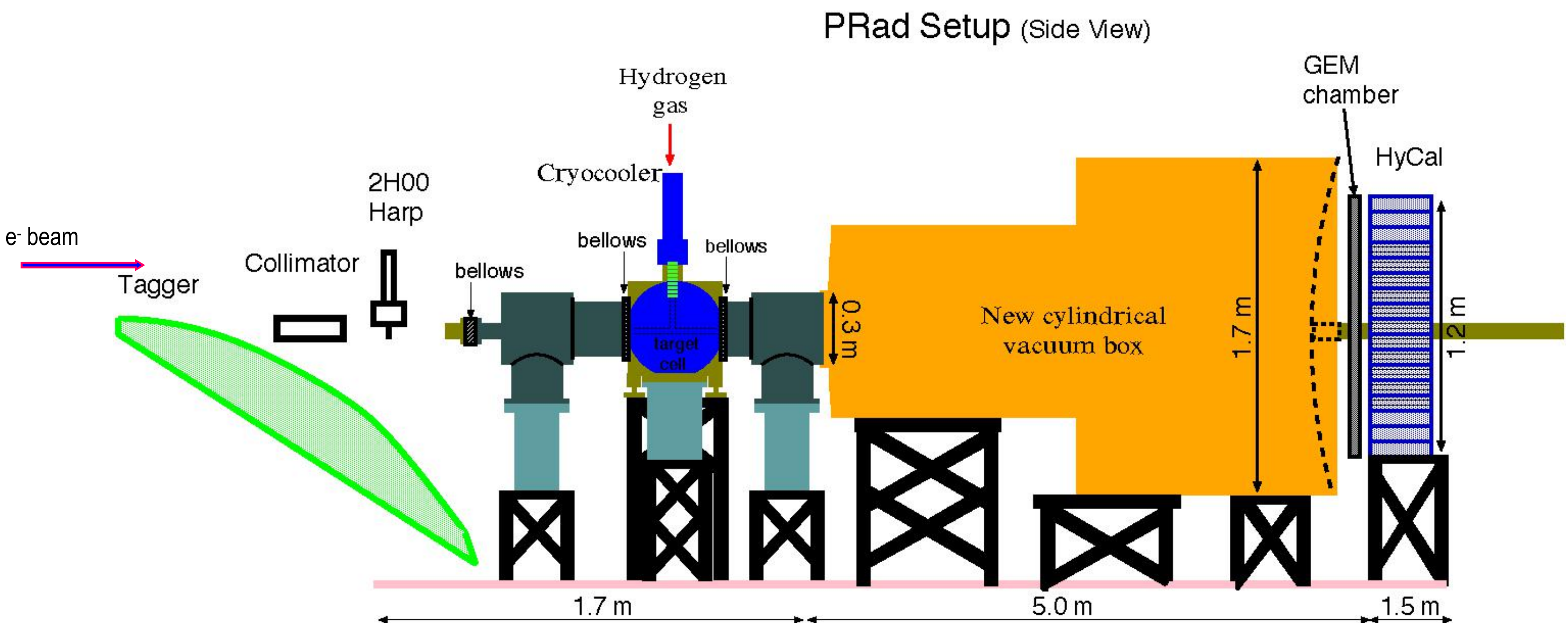
- Main detectors and elements:
  - windowless H_2 gas flow target
  - PrimEx HyCal calorimeter
  - vacuum box with one thin window at HyCal end
  - X,Y – GEM detector in front of HyCal
- Beam line equipment:
  - standard beam line elements (0.1 – 10 nA)
  - photon tagger for HyCal calibration
  - collimator box (6.4 mm collimator for photon beam, 12.7 mm for e^- beam halo "clean-up")
  - Harp 2H00
  - pipe connecting Vacuum Window through HyCal

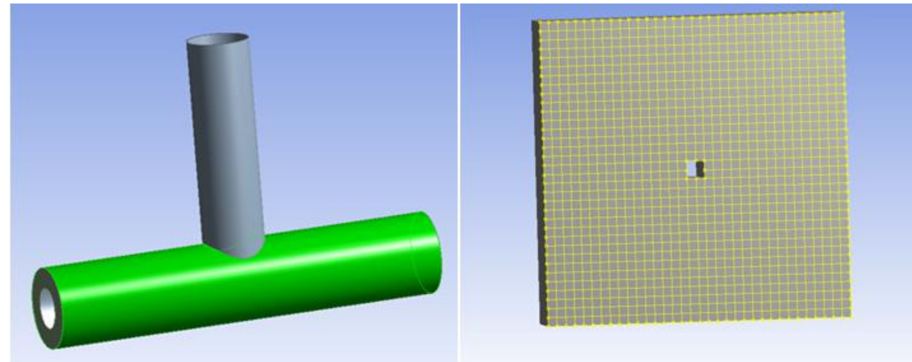


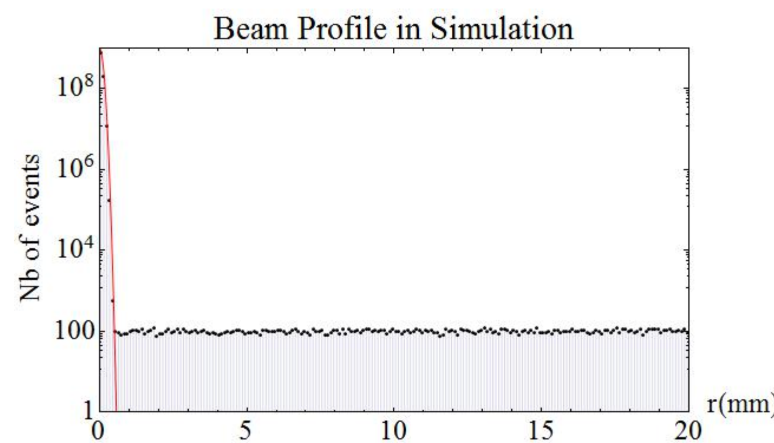
Monte-Carlo Simulation

- A thorough simulation study about the possible background sources is important to achieve a sub-percent precision
- The 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
  - Cylindrical tube 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: 2.05×2.05×18 cm^3
  - energy resolution $2.6\%/\sqrt{E}$, position resolution $2.5\,mm/\sqrt{E}$
- Electron beam, 15 days of beam time
  - 1.1 GeV, 2.2 GeV or higher energy
  - A uniform halo with a peak ratio of 10^{-7} to the beam





GEANT4 geometry and beam profile

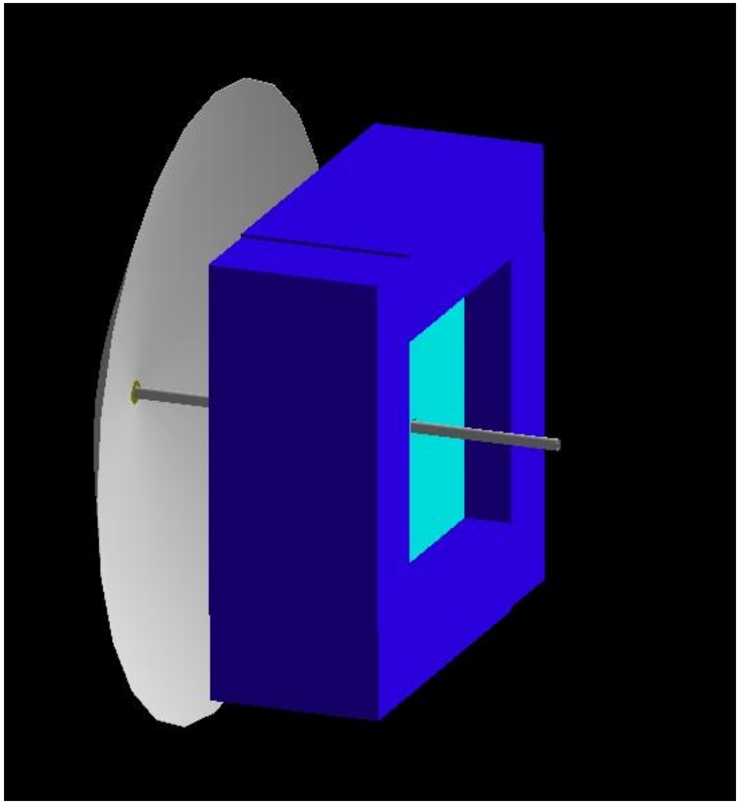
Simulation geometry update :
Flange(winoow Coupling) :
material Al, outer diameter 2.3" , inner diameter 1.3",

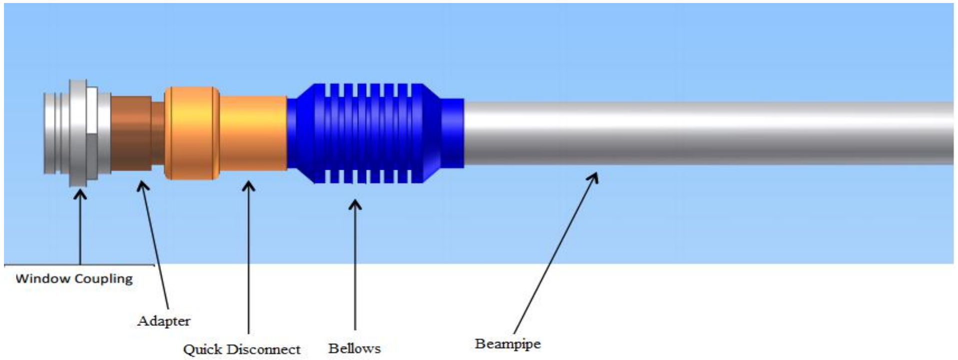
Adapter:
material Fe, outer diameter 1.62" , inner diameter 1.245",

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

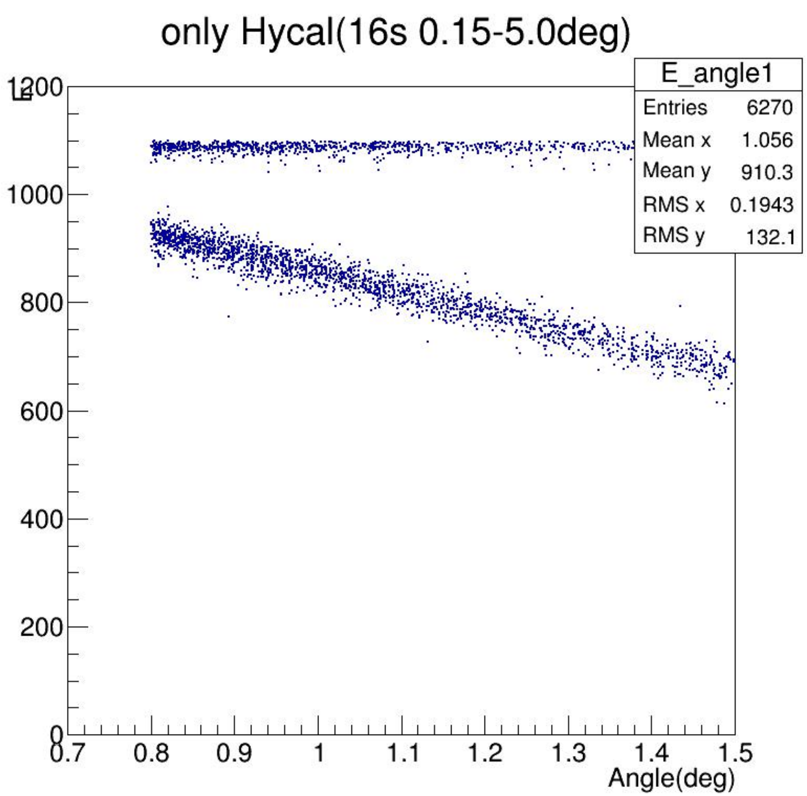
Quick Disconnect small:
material Fe, outer diameter 1.62" , inner diameter 1.39",

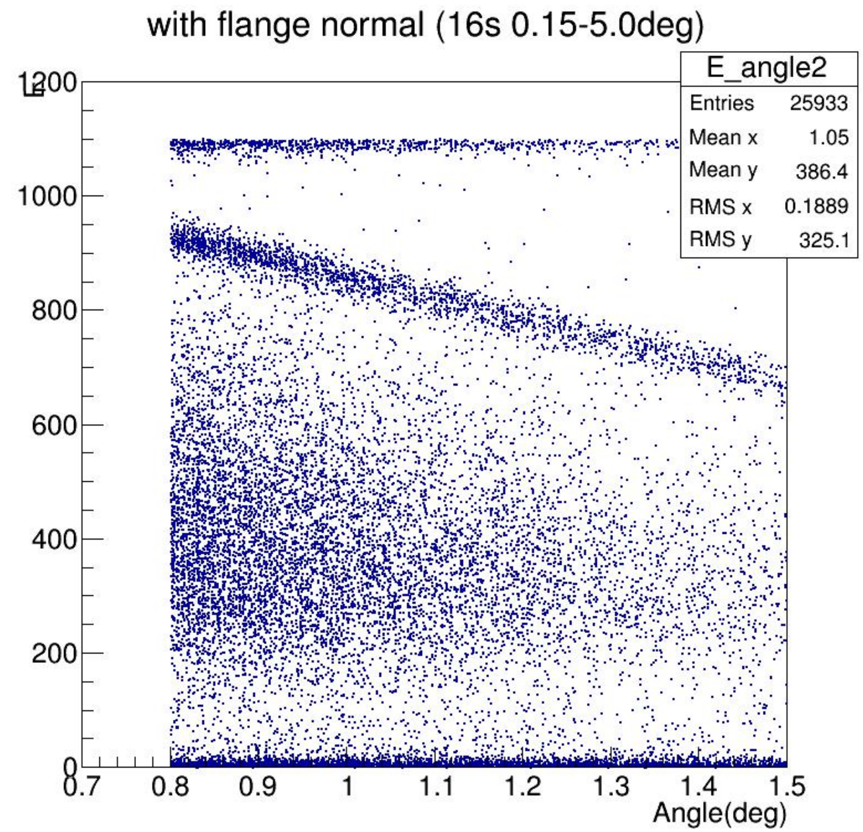
Beam Pipe:
material Fe, outer diameter 1.375", inner diameter1.245",
note: the beam pipe is all the way connect to the Adapter in the simulation



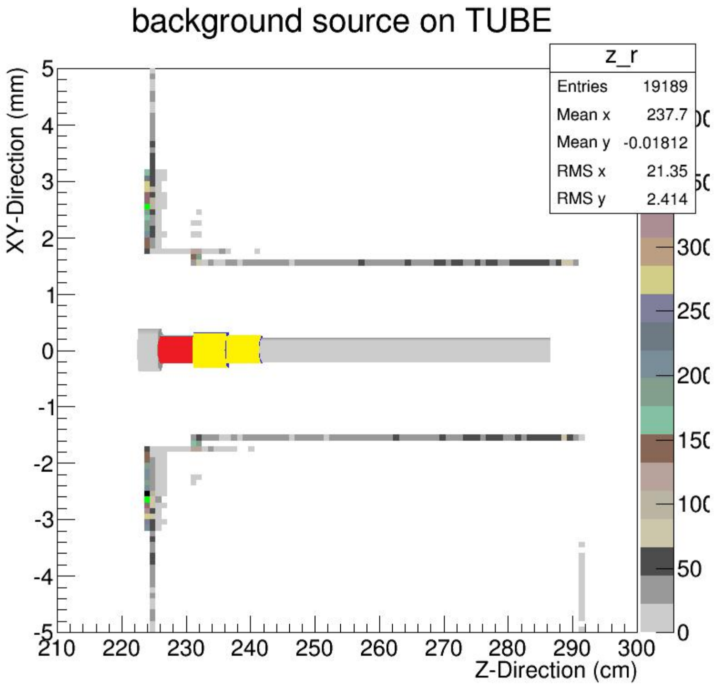


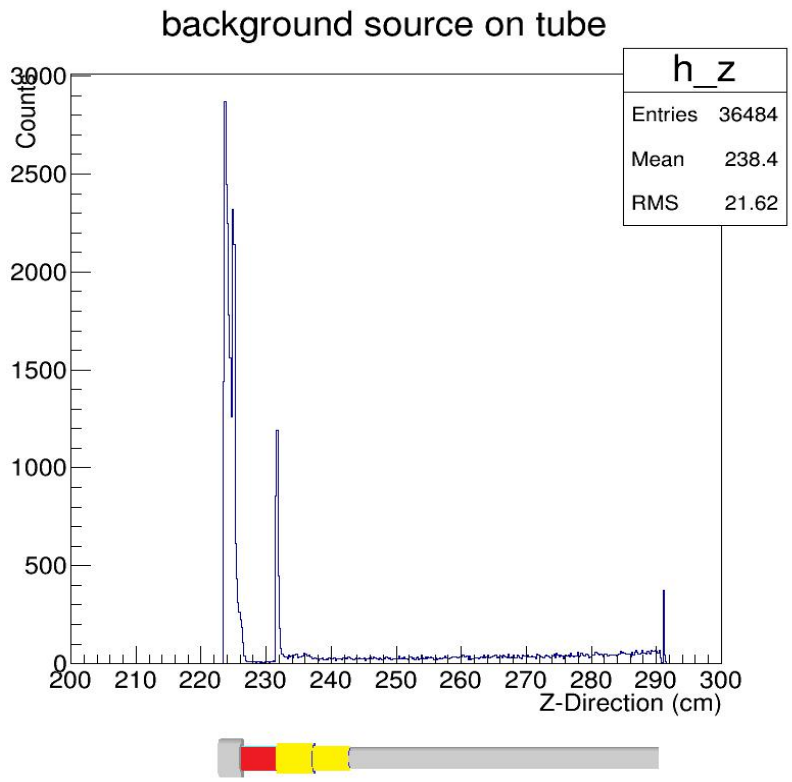
Back ground on flange



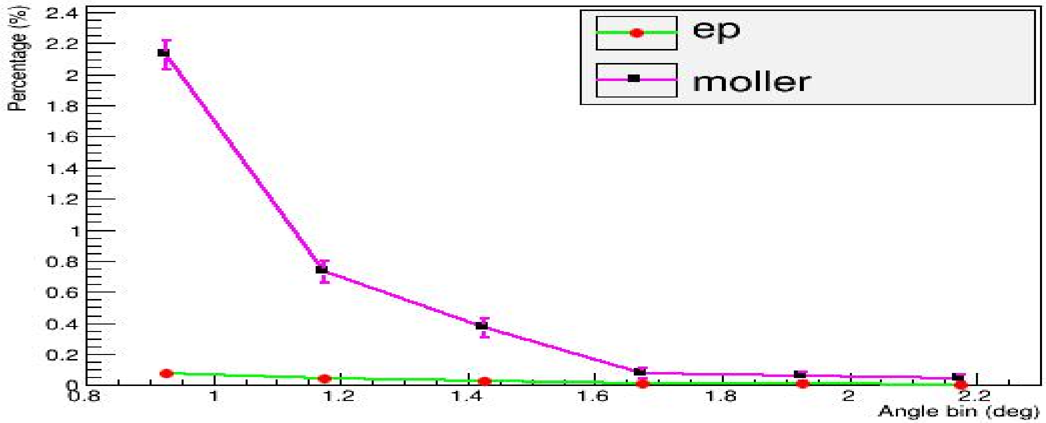


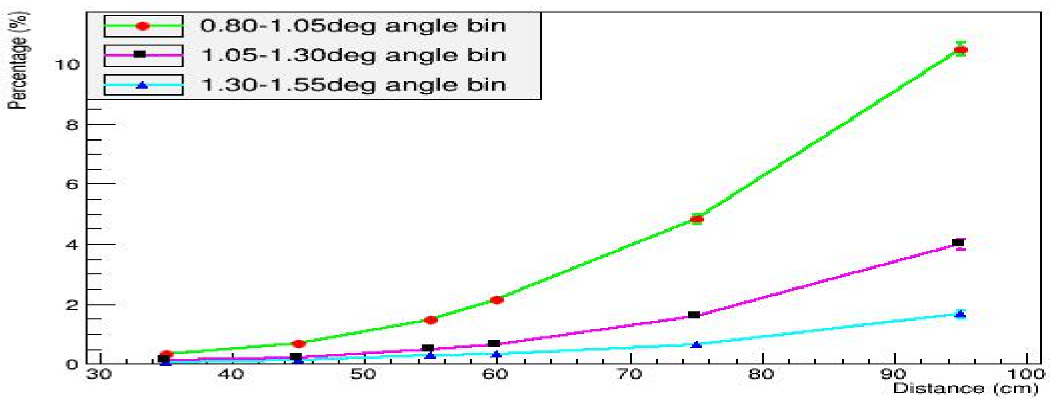
Back ground on flange





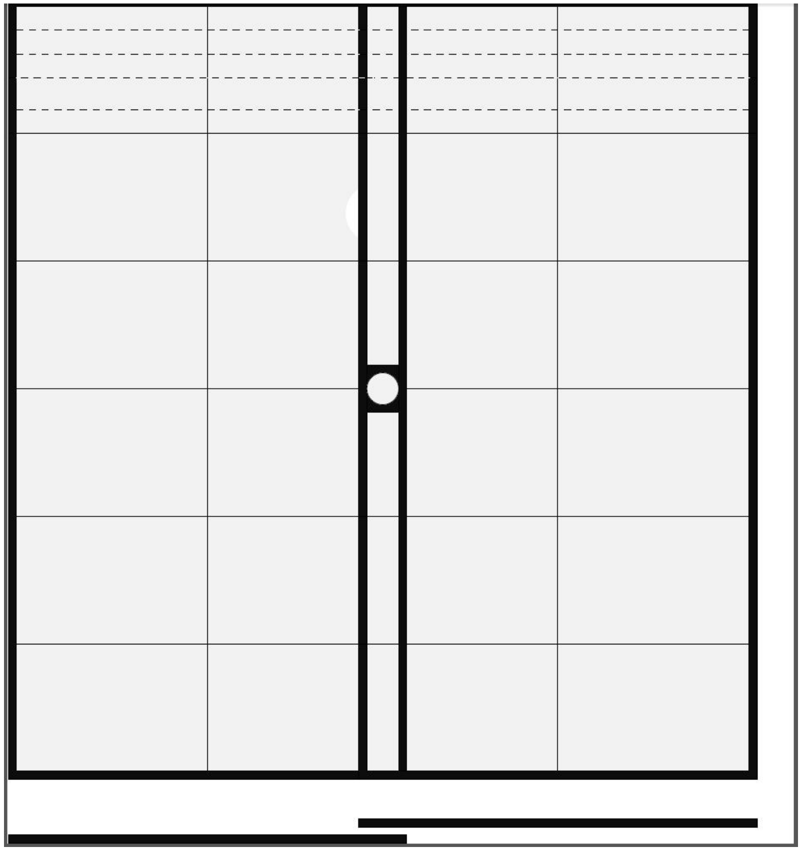
Back ground on flange

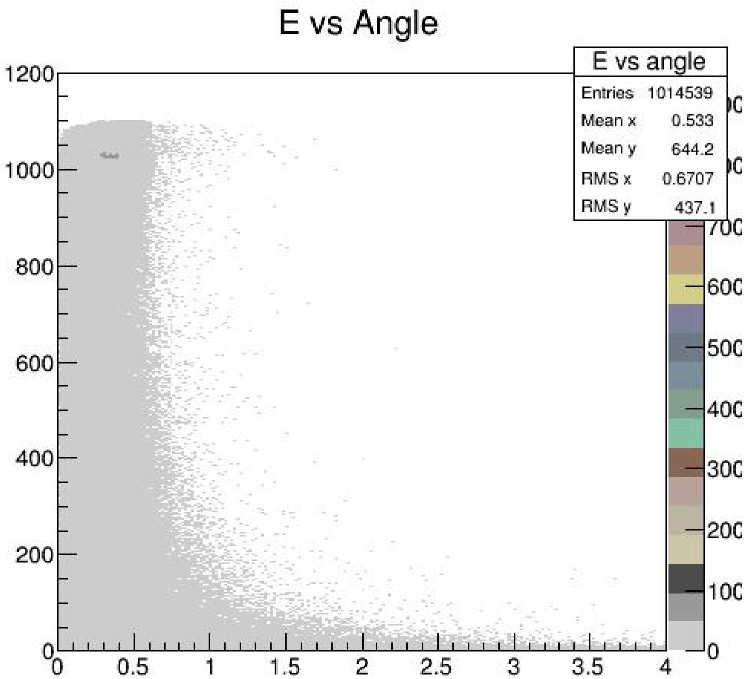




- Re-scattered Moller events ground appears at first angle bin of moller region around 2.1% of data
- Background of different distance from flange to HyCal PbWO4 surface
- Total background on HyCal ~120Hz

Back ground on GEMs





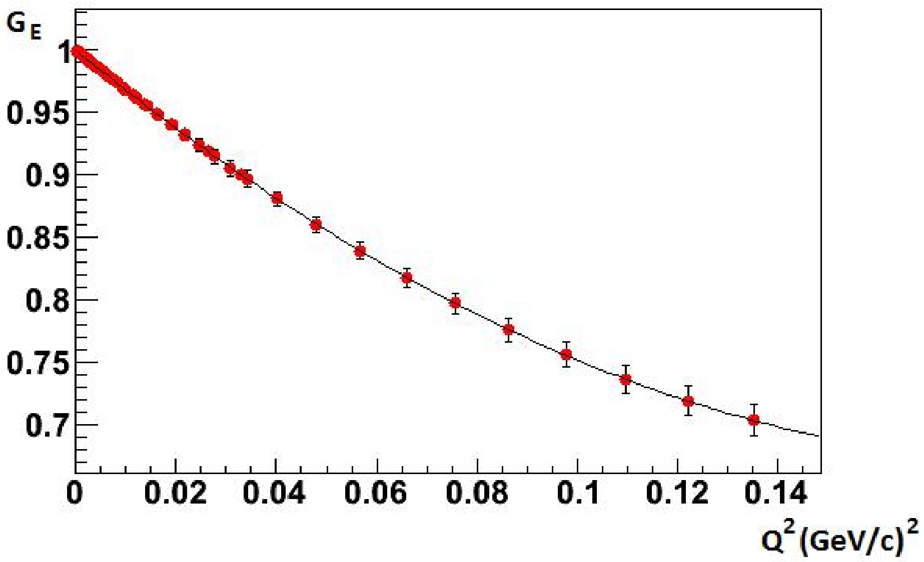
Total back ground on Gem ~700Hz

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

Radius extraction

- To obtain a higher precision in extraction. We are trying to extend the Q^2 coverage in two ways
  - Use the lead glass part of the calorimeter, increasing detecting angle from 4 degree to 10 degree
  - Exploring options to have a higher beam energy (e.g. 2.2 GeV beam)

- Assumed 0.6% systematics for measured cross-sections, extracted radius has a sub-percent precision (dipole fit, r_p = 0.8768 fm as the input)



Summary

- The primary background source is from the beam halo, empty target subtraction will help reduce the background.
- 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%.
- Radiative corrections are implemented in the simulation.
- Background simulation study helped to make better design of vacuum box window, connection flange and pipe.

PRoton Radius