GEM Detectors for Proton Charge Radius (pRad) Experiment

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for PRad Collaboration

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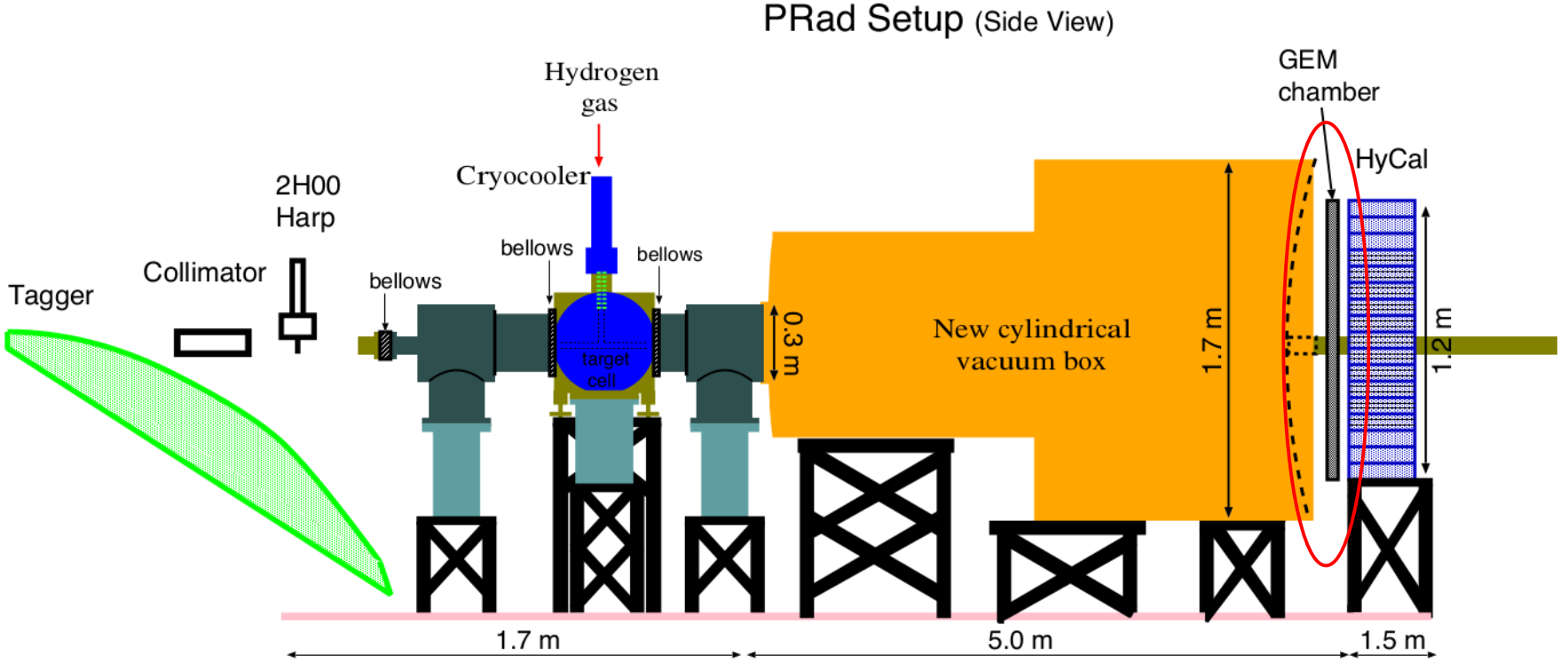
PRad Experimental Setup

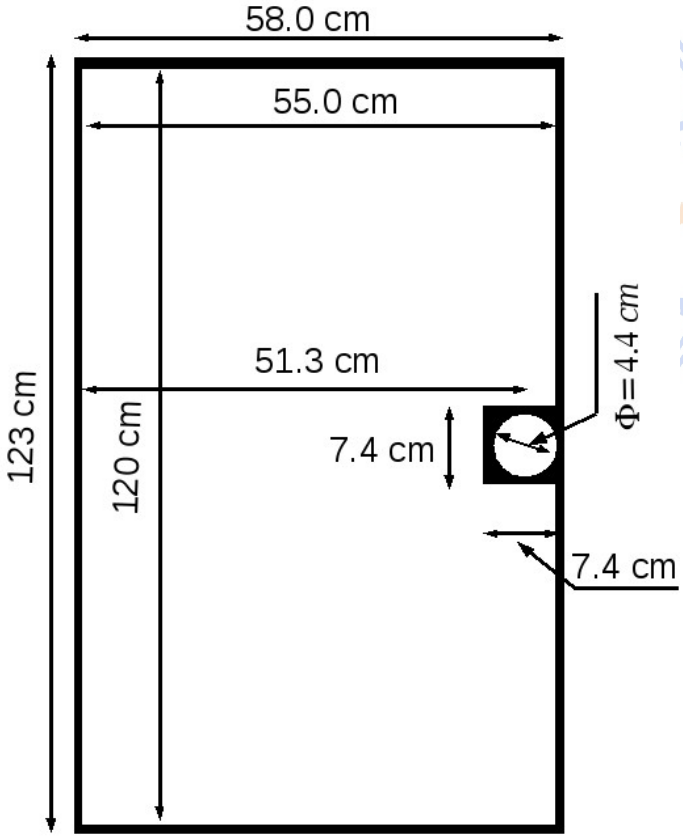


PRad Detector Setup

- PRad Experiment designed to measure proton charge radius with sub-percent precision, to solve the Proton Radius Puzzle.
- Using GEM detector improves position resolution by a factor of 20 – 40.
- The combination of HyCal and GEM delivers powerful performance.

PRad GEM Design

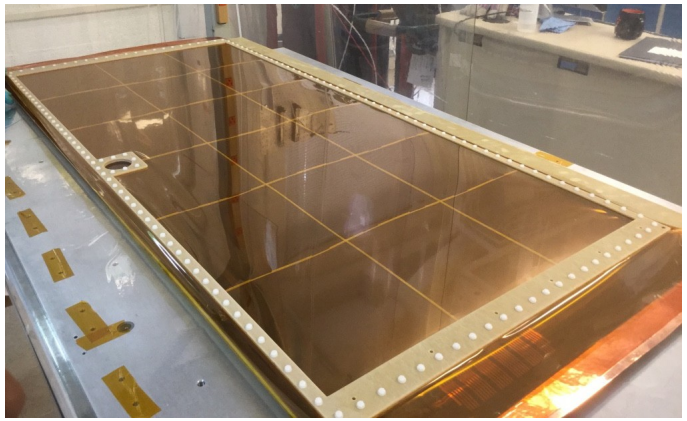
- Desired Sensitive Area: 116.4 x 116.4 cm^2
- Central Hole: diameter 4.4cm, including the frame max allowed
- Maximum allowable non-sensitive regioin 7.8 x 7.8 cm^2



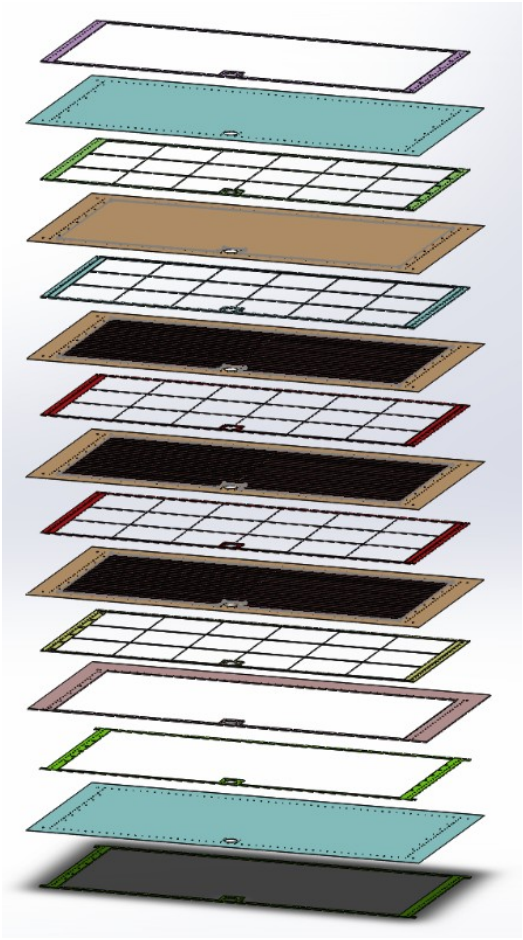
The World's Largest GEM Chambers

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

PRad GEM Detector



Triple GEM Detector

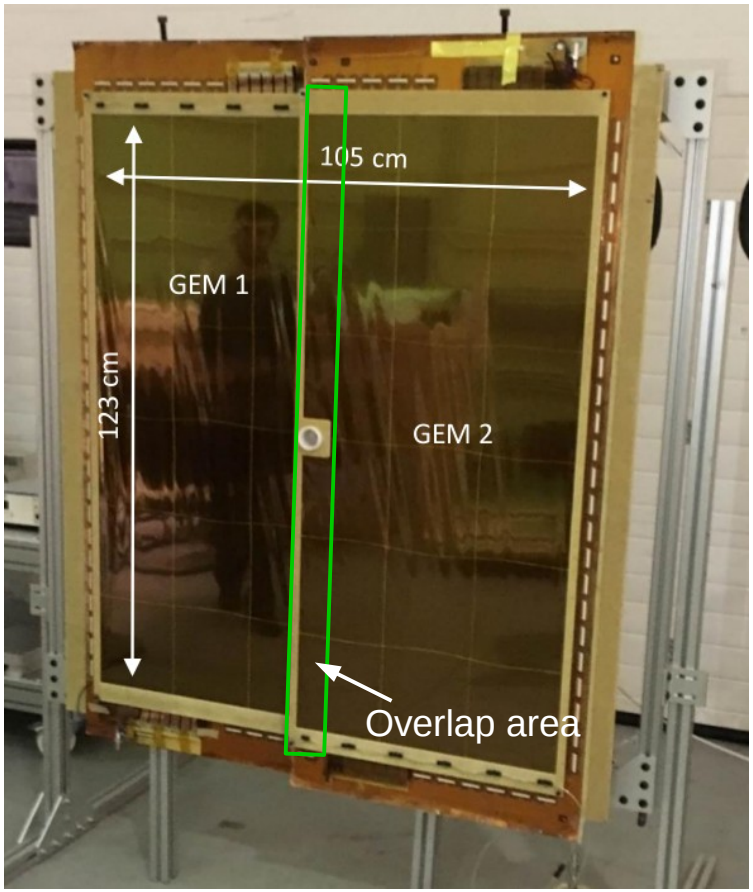


Challenges encountered:

- Large area, difficult to keep the space between each gem foil to be 2mm.
- Longer Strips, higher noise level.
- Biggest foil ever made.

PRad GEM Construction

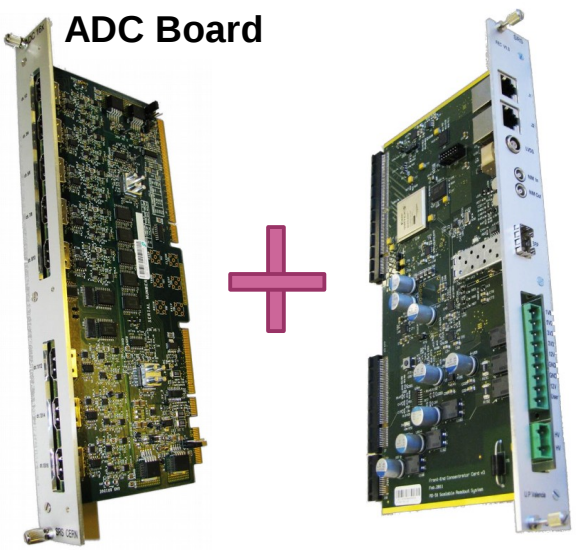
- Design and Constructed at UVa in 2015.
- Installed in Hall B beam line at JLab in 2016.



Two chambers, Overlap in the central part.
With a Central opening hole for beam.

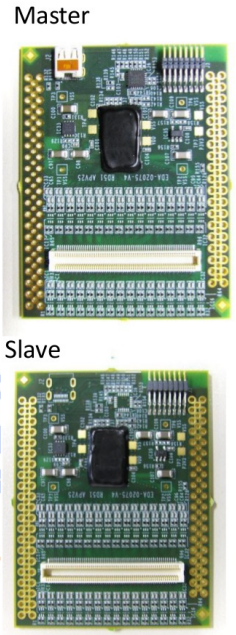
Chamber mounted on HyCal in Hall B

PRad GEM DAQ



GEM

Panasonic Connector



HDMI Connection

Data Flow

- Normal Event Rate: ~ 4kHz
- 2 SRUs
- 2 GEM Chambers
- 8 FEC + ADC's
- 72 APVs (a total of 9216 channels)
- 3 Time Sample
- Normal Data Transfer Rate per ROC: 150~250MB/s

- DAQ Software: Hall B CODA.
- Electronics: APV25 based Scalable Readout System (SRS).

SRS Crate

SRU

TCP/UDP CAT6

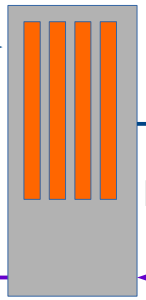
GEM ROC

Infiniband

10Gbps Fibre

TIpcie

Trigger



Trigger

Logic & Translator

Busy Signal

Trigger From Master TI

Cluster Reconstruction

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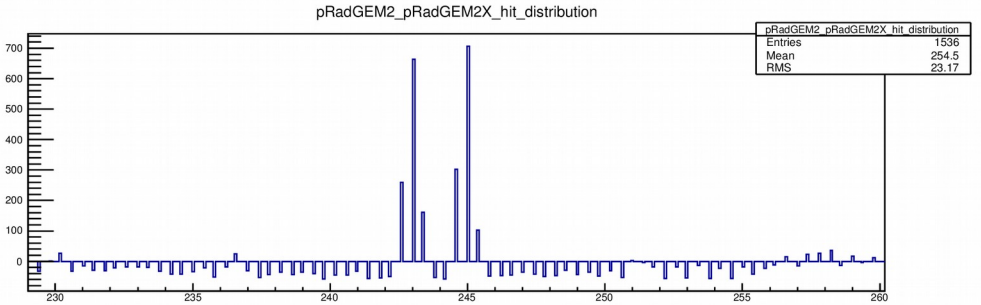
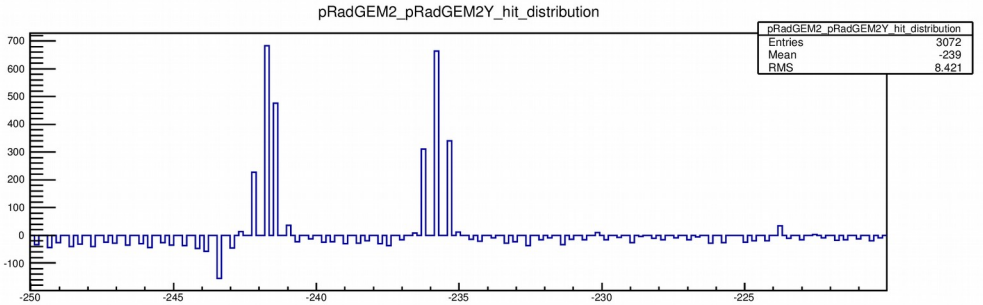
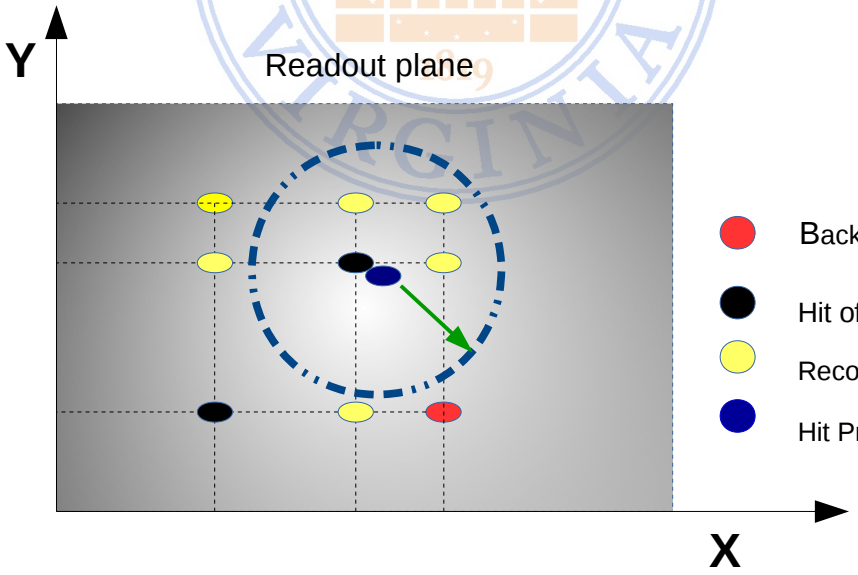
One typical event from GEM Detector

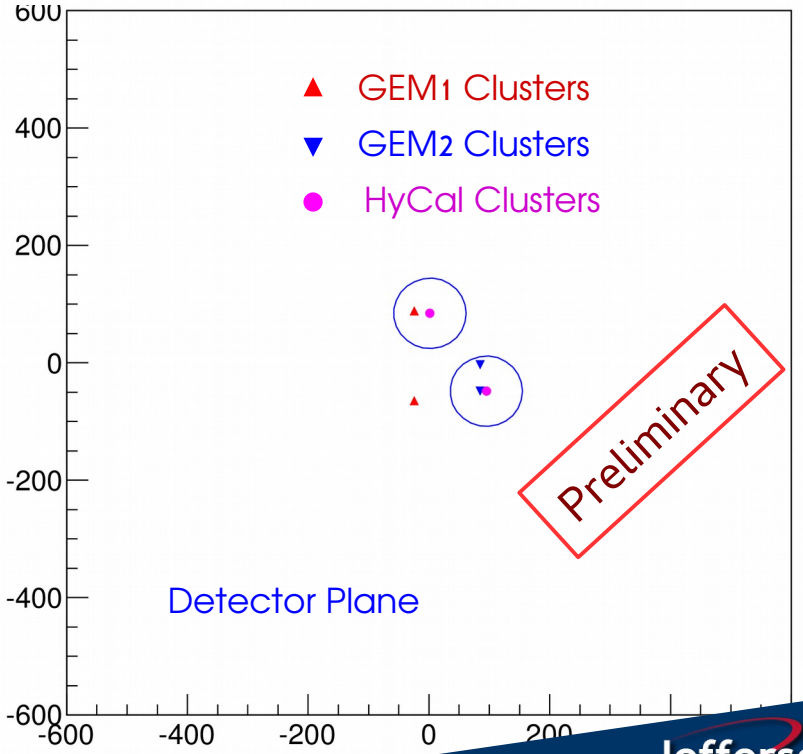
- Mostly Relativistic Electrons.
- Minimum Ionization Particles (MIP).
- Only one layer of GEM detectors, no tracking.
- No timing information.
- Challenge to match X-Y clusters.
- An experiment-dependent clustering method.







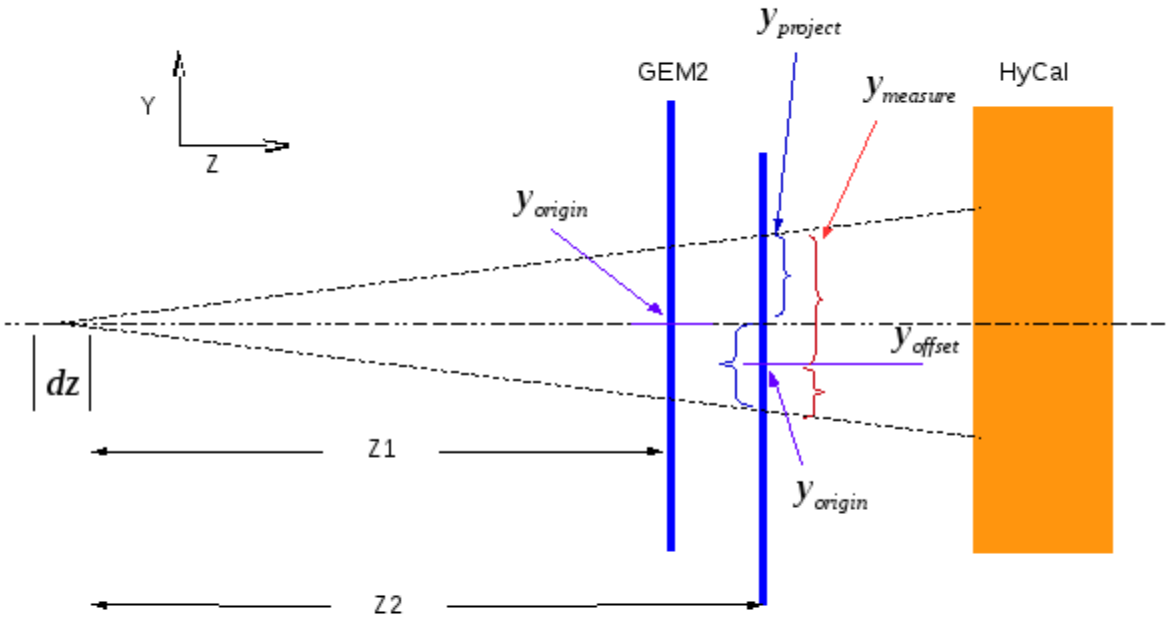
Use HyCal Information to Filter GEM Clusters

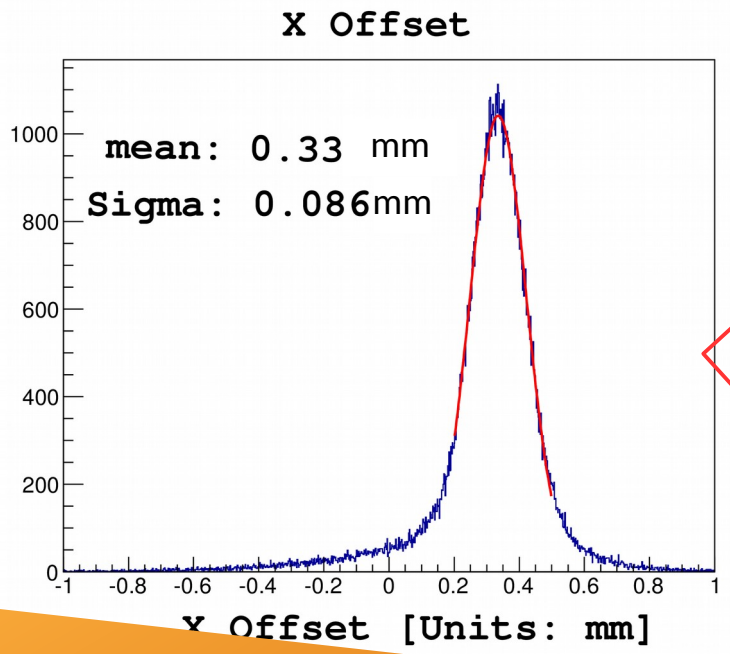


Detector Alignment

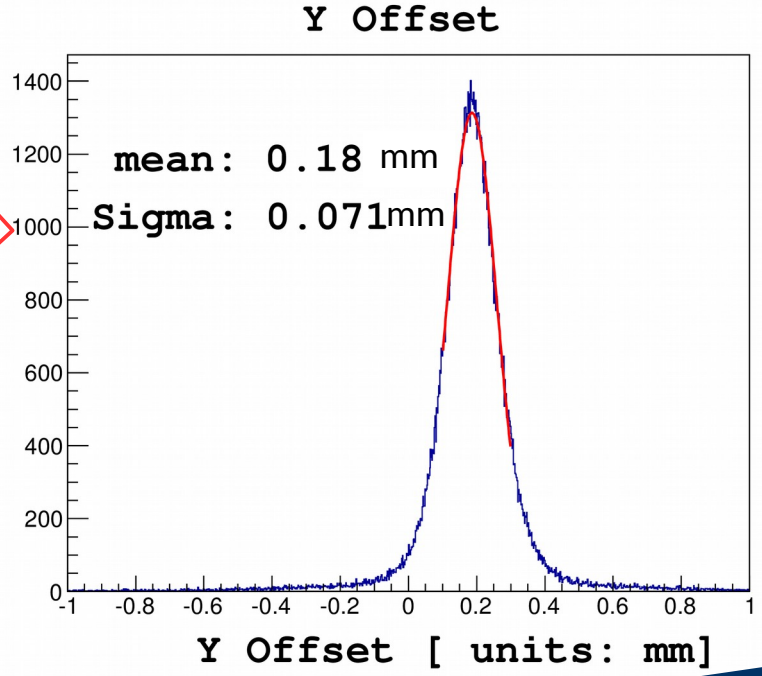
X-Y Offset:

- Using overlapping area events.
- Project GEM1 Coordinates to GEM2.
- Take the difference of projected value and measured value.



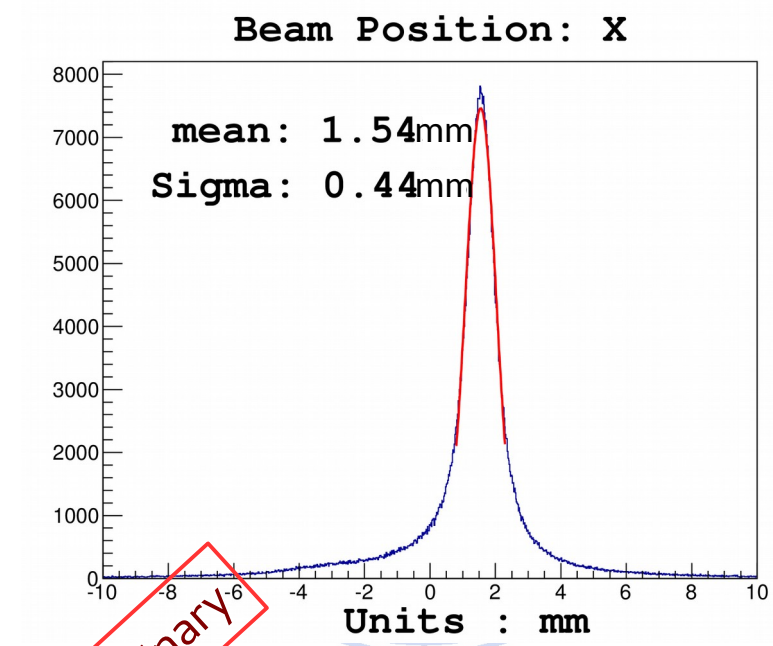


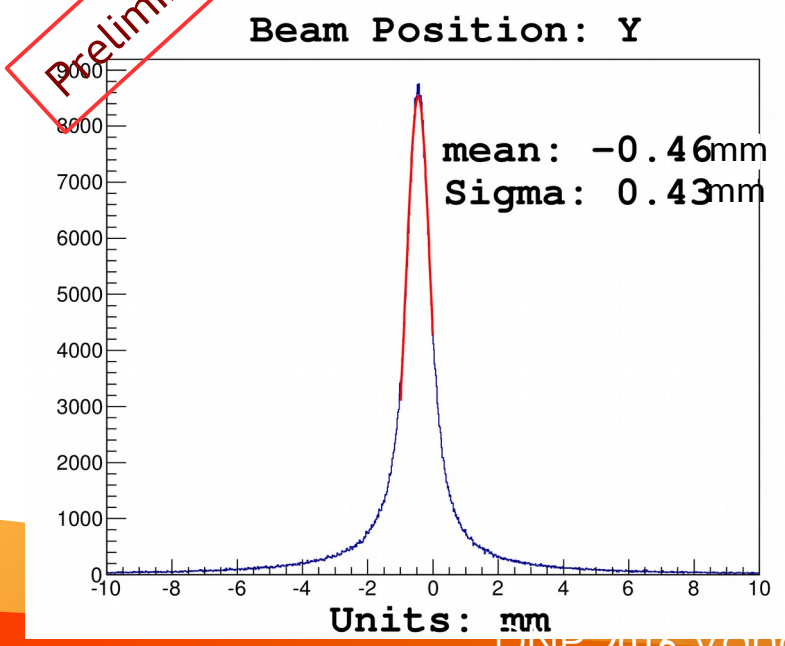
Preliminary



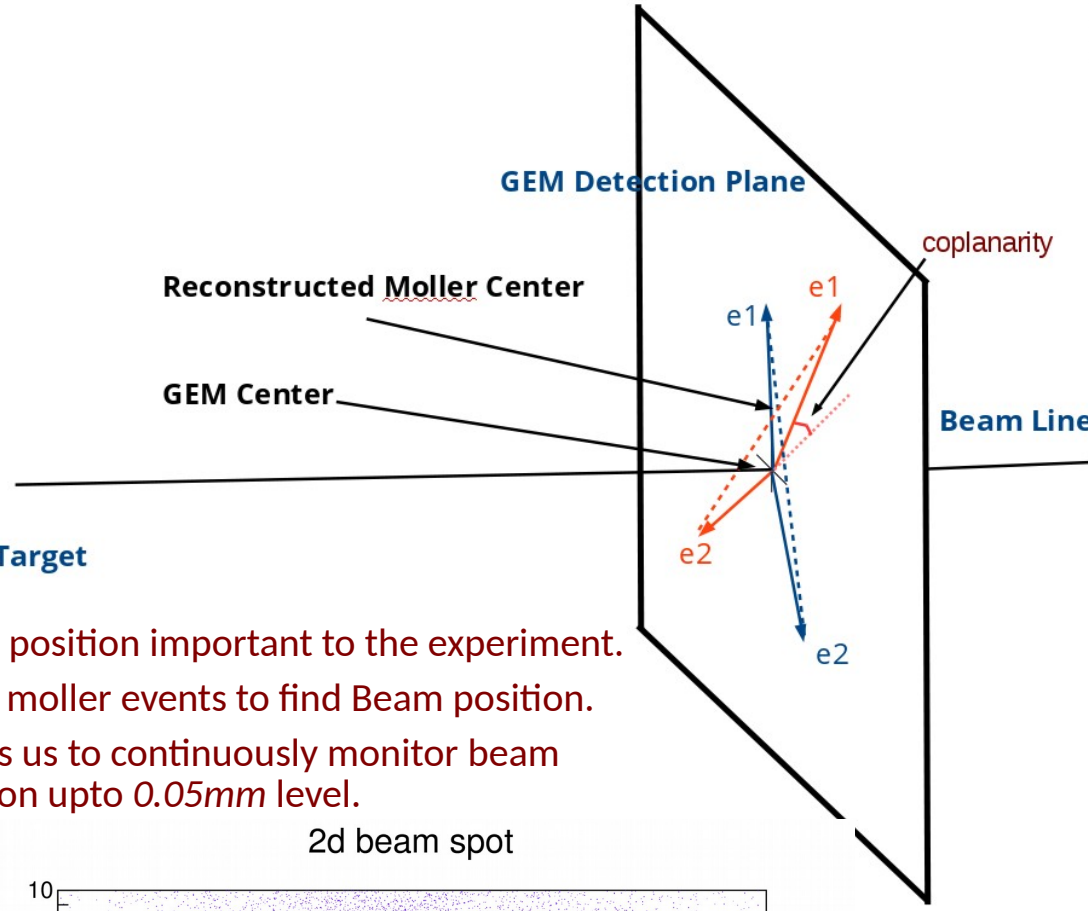
Detector Alignment

Reconstructed Beam Spot:

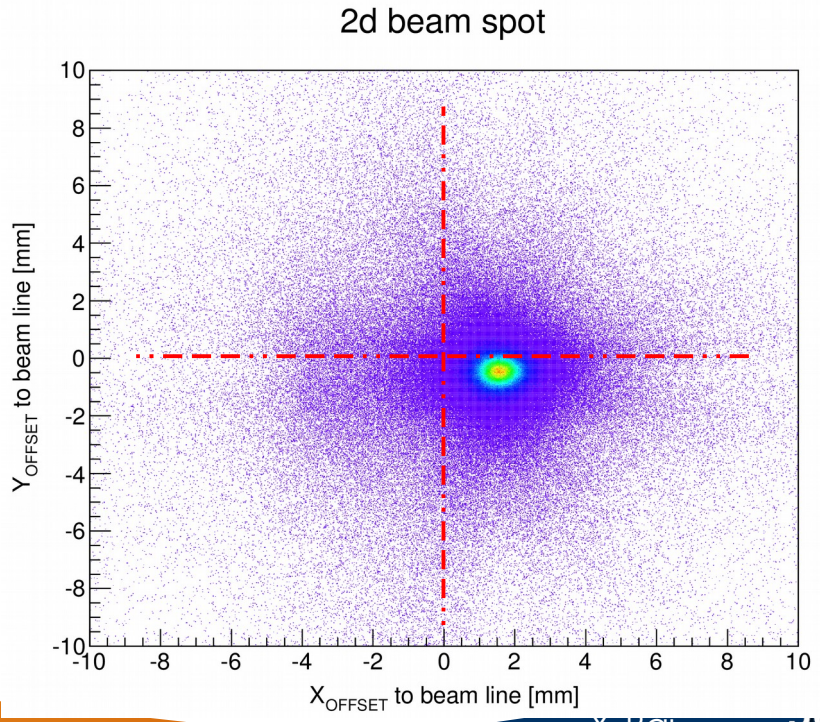




preliminary



- Beam position important to the experiment.
- Using moller events to find Beam position.
- Allows us to continuously monitor beam position upto *0.05mm* level.



Resolution

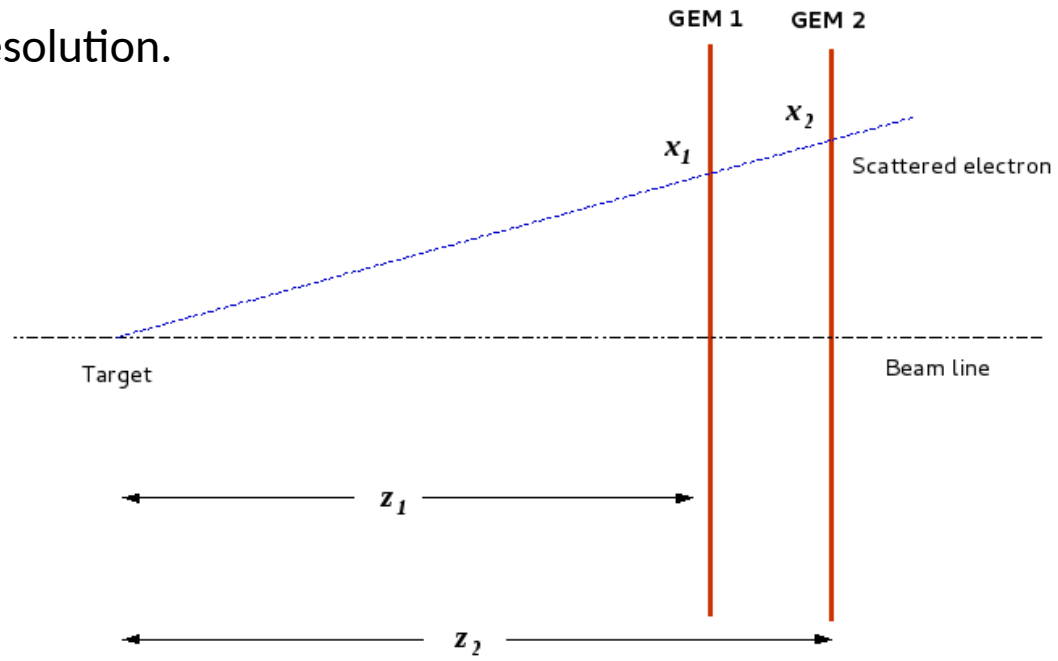
Using overlapping area e-p events to check resolution.

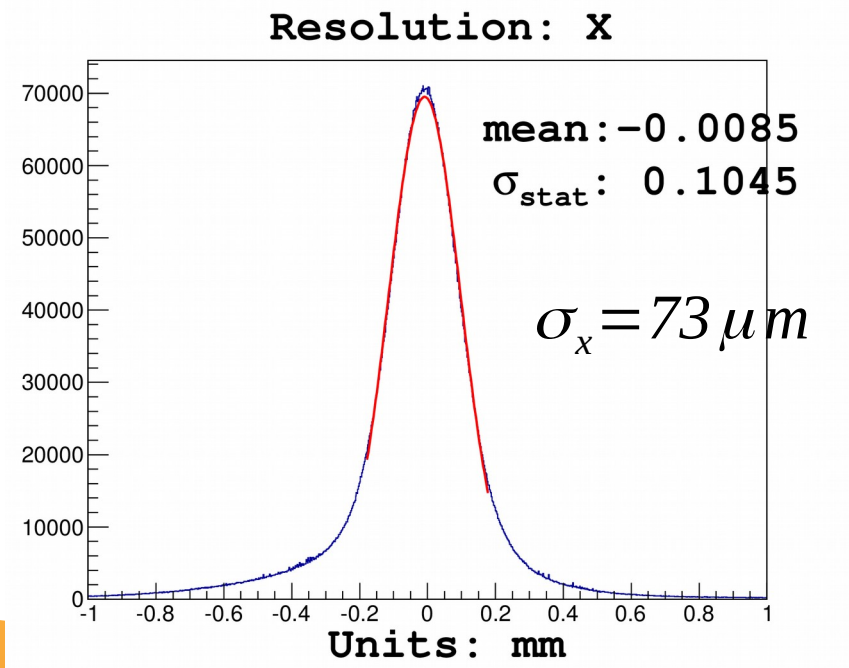
Procedures to Check Spatial Resolution:

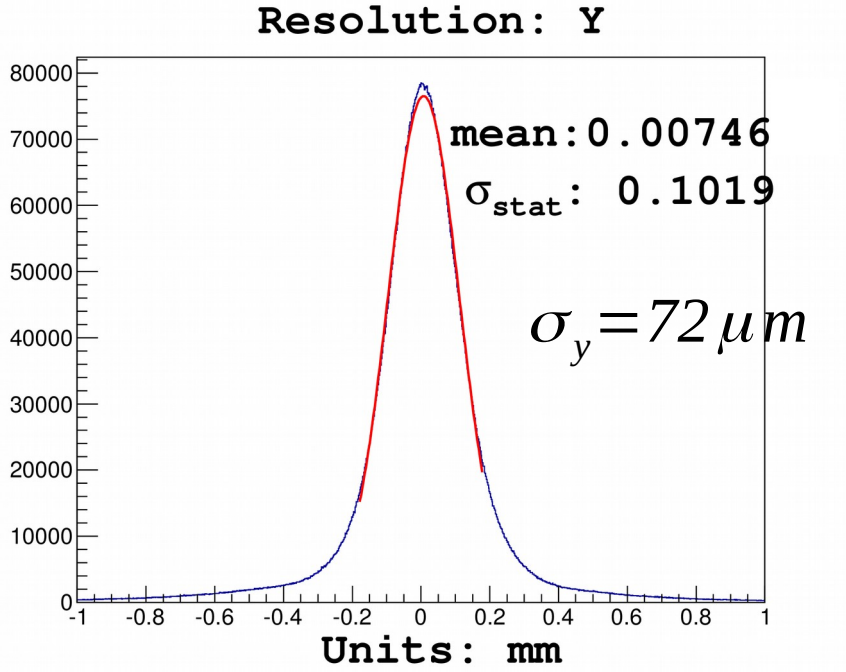
- Correct offsets.
- Project GEM1 coordinates to GEM2.
- Find statistical width.
- Assume two chambers have the same resolution:

$$\sqrt{\sigma_{gem\,1}^2+\sigma_{gem\,2}^2}=\sigma_{stat}$$

$$\sigma_{gem}=\sigma_{stat}/\sqrt{2}$$







Efficiency From Production Data

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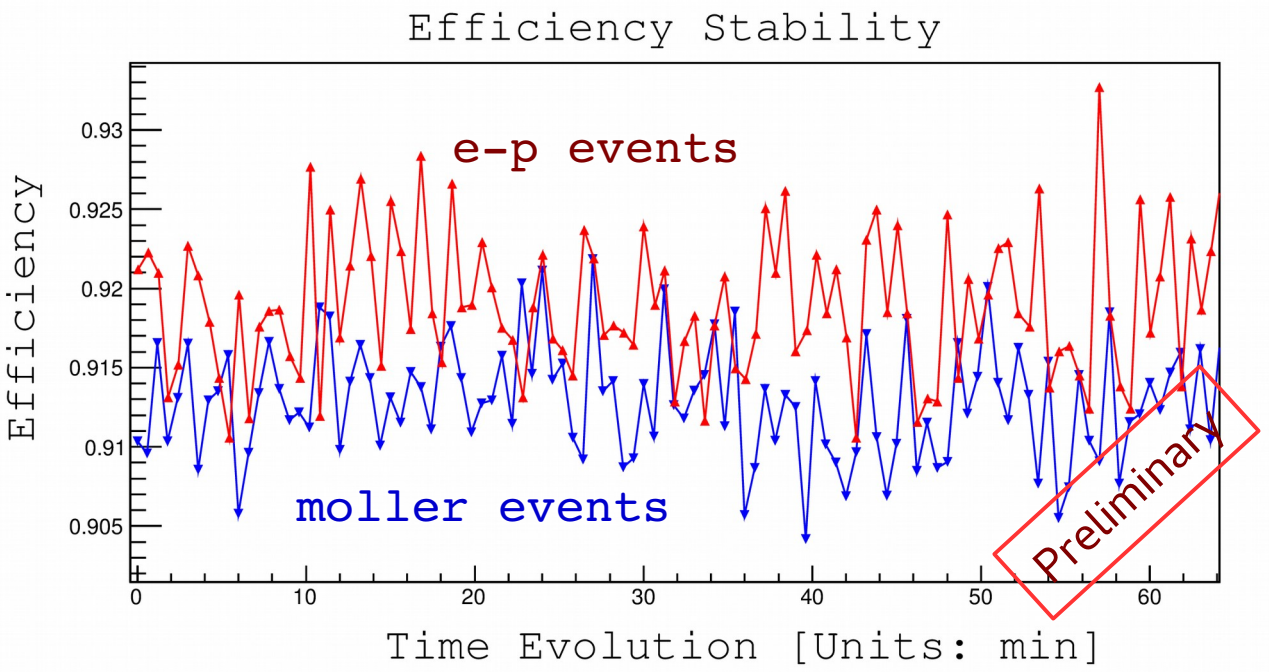
Efficiency from e-p events:

1), Select e-p events from HyCal.
2), Match gem Clusters.
3), # GEM cluster / # HyCal cluster.

Efficiency from Moller events:

1), Select moller events from HyCal.
2), Match gem Clusters.
3), # GEM cluster / # HyCal cluster.



Efficiency Preliminary Results:

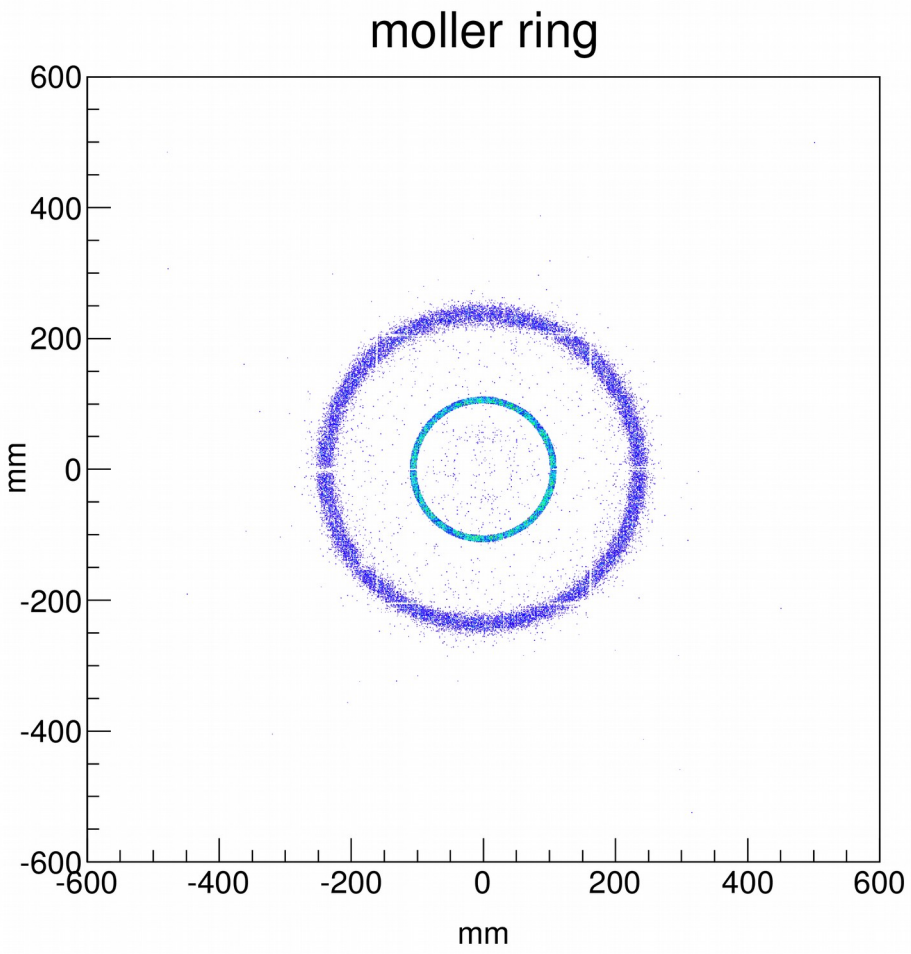
E-p: 92.0% +/- 0.03%
Moller: 91.4% +/- 0.03%

Moller events covering a larger detection area, includes more dead area. Has slightly lower efficiency.

Dead Area Not yet Excluded, Efficiency can be higher.

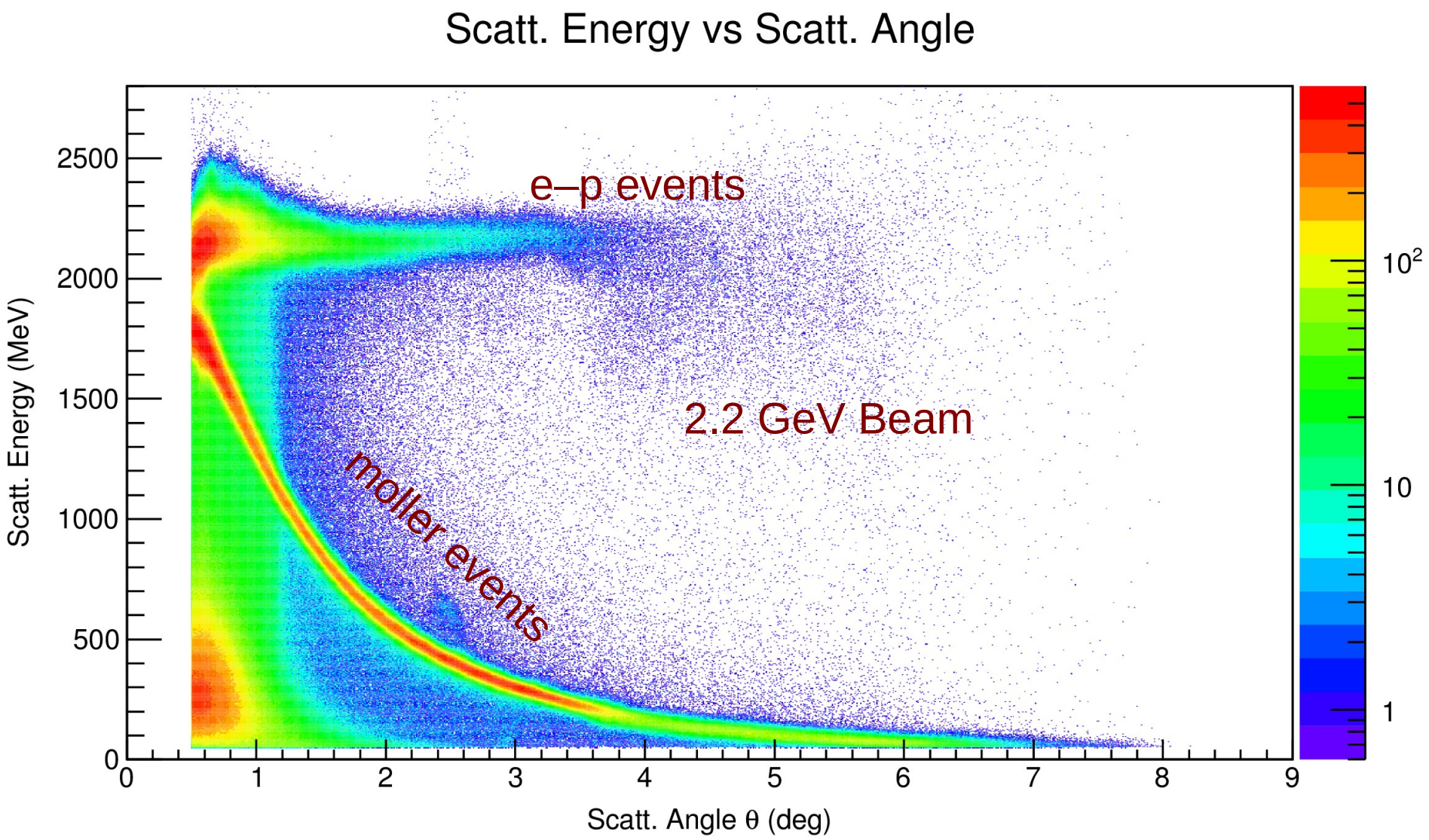
Performance

- Use two-cluster Events (Moller Events).
- Inner scattering angle cut: 1.0deg ~ 1.1 deg



Moller Ring From GEMs

Performance



Summary

- Two new large GEM detectors built for PRad Experiment to improve space resolution.
- Detector performed well, delivered designed requirements
  - a), High Position Resolution achieved.
  - b), very stable, and uniformly distributed efficiency.
- World's largest GEM detectors.
- Data Analysis in Progress .....

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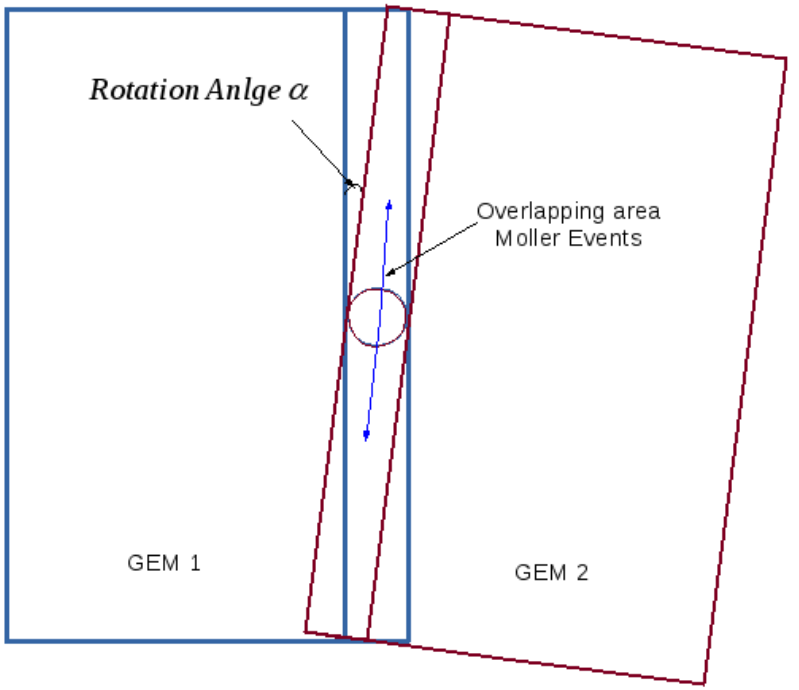
Backup Slides

Detector Alignment

Two Offsets:

1), Relative Rotation Between Two GEM chambers.

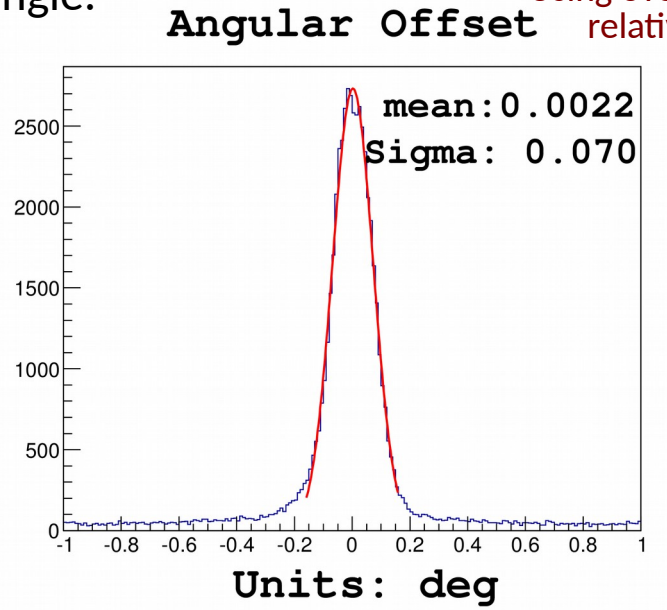
2), X-Y Offsets Between Two Chambers.



Angular Offset:

- Select moller events in the overlapping area.
- Connect the two electrons.
- On each chamber find the angle between the electron line and GEM axis.
- Get difference for rotation angle.

Using overlapping area moller events to find relative rotation between two gems.

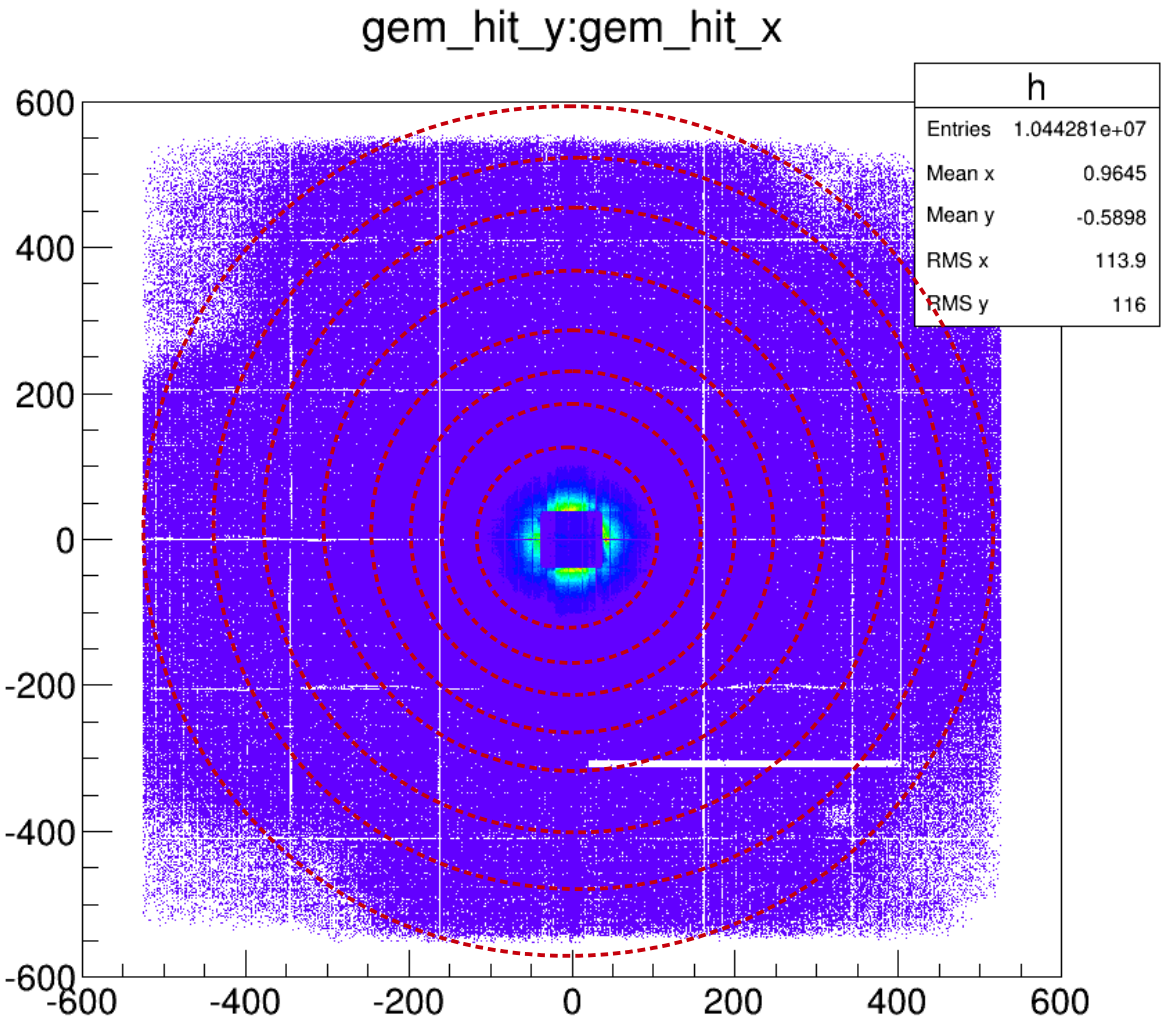


Value: ~ 0.0022 deg.
negligible

Efficiency

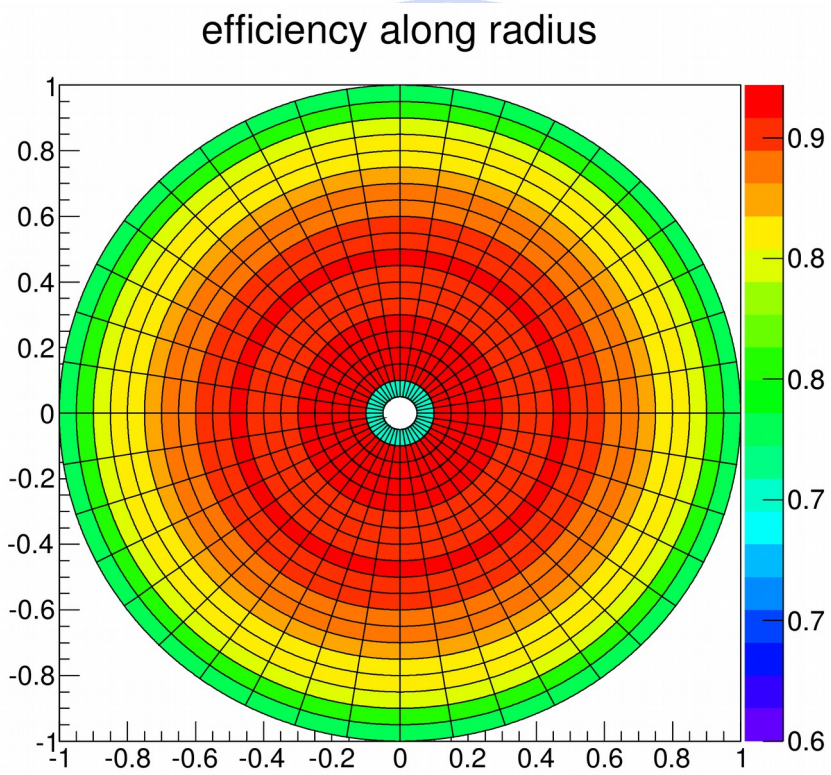
Using preliminary e-p + Moller events. Efficiency relative to hycal. Clusters Filtered by HyCal.

- Divide GEM Plane into 20 rings. (ring radius difference: 30mm).
- Estimate Efficiency for each ring.

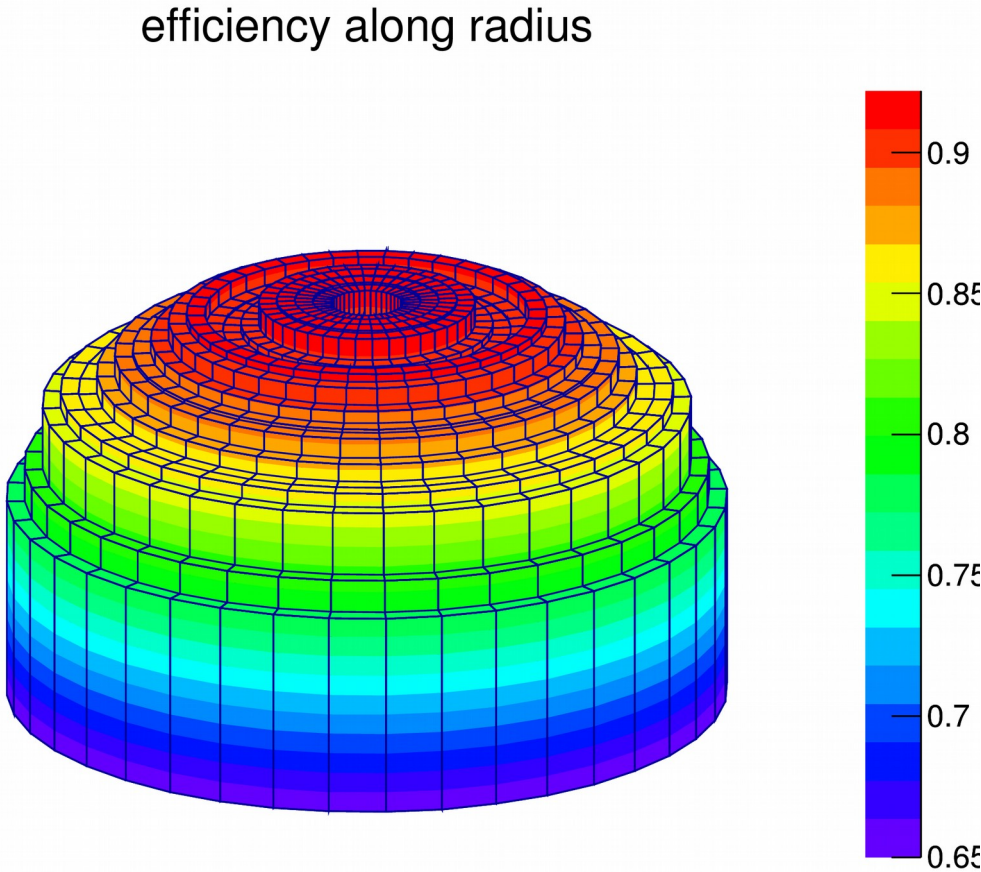


A Qualitative plot showing Efficiency Along Radius

Using preliminary e-p + Moller events. Efficiency relative to hycal. Clusters Filtered by HyCal.



Units R/600mm



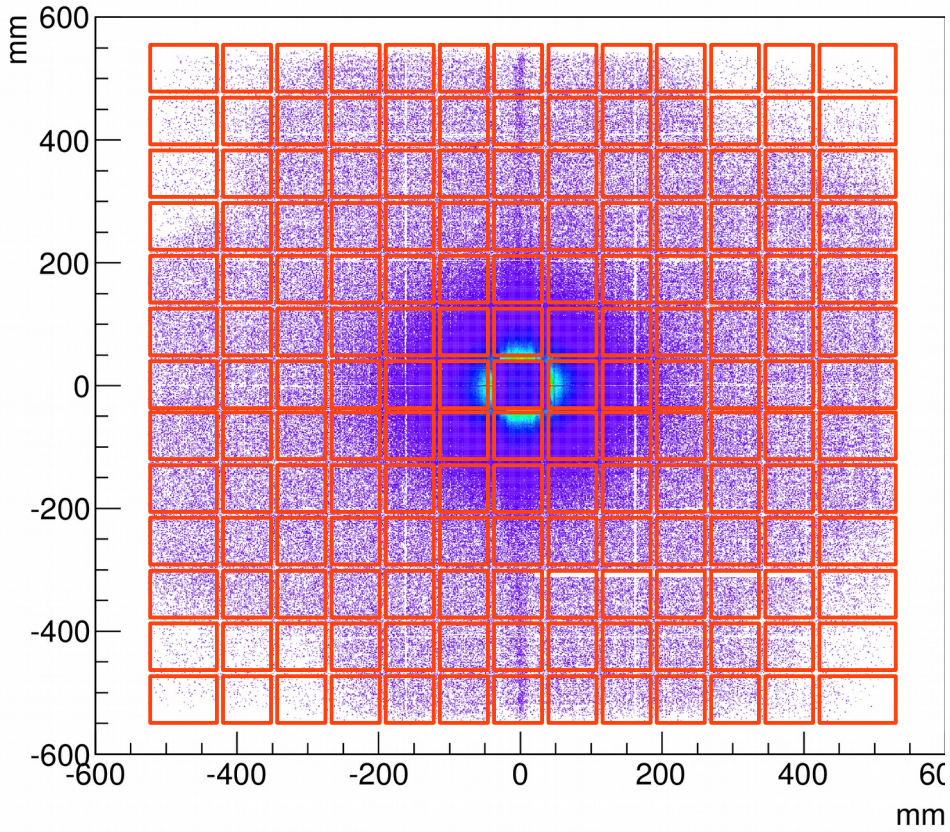
Dead Area Not yet Excluded

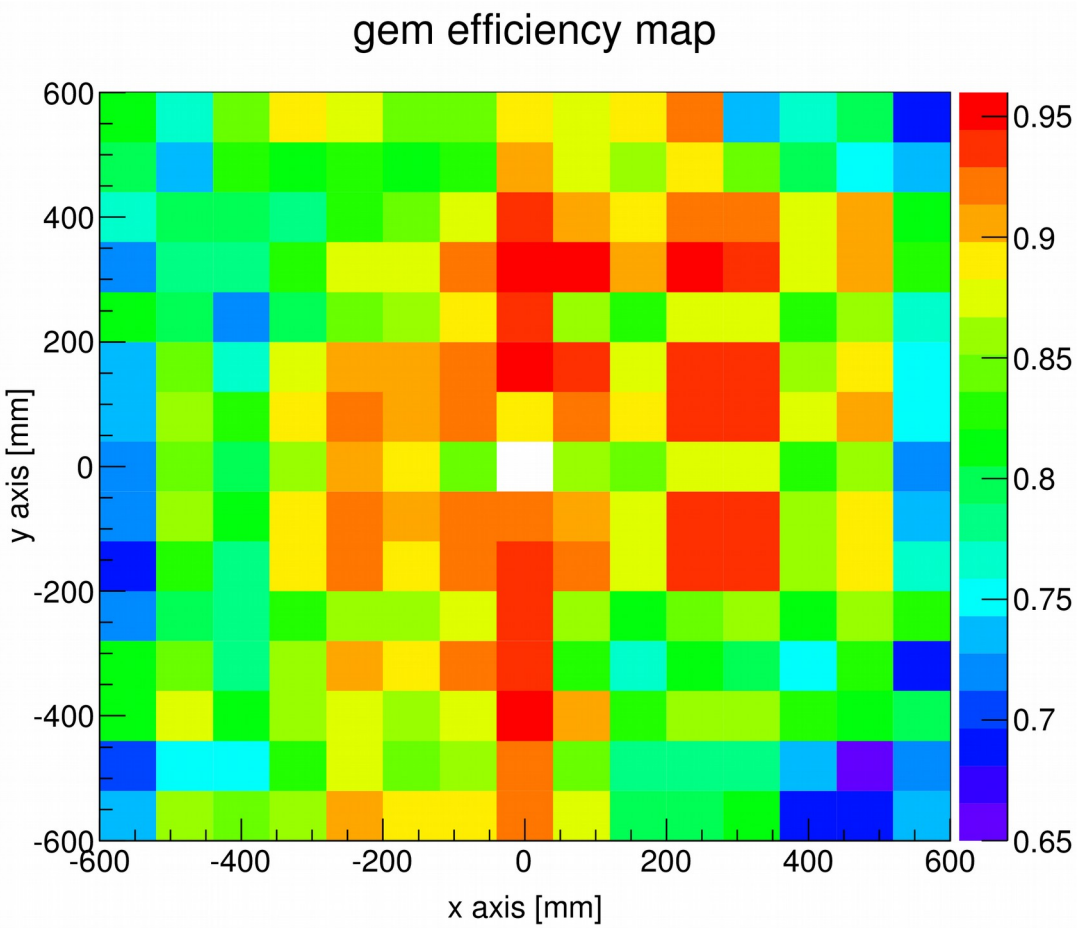
Efficiency by Sectors

Using preliminary e-p + Moller events. Efficiency relative to hycal. Clusters Filtered by HyCal.

- Divide GEM Plane into 225 sectors (sector size: 72mm by 72mm).
- Estimate Efficiency for each sector.

A Qualitative Plot showing efficiency by sectors.





Dead Area Not yet Excluded