Performance of a Large-Area GEM Detector Prototype for the Upgrade of the CMS Muon Endcap System

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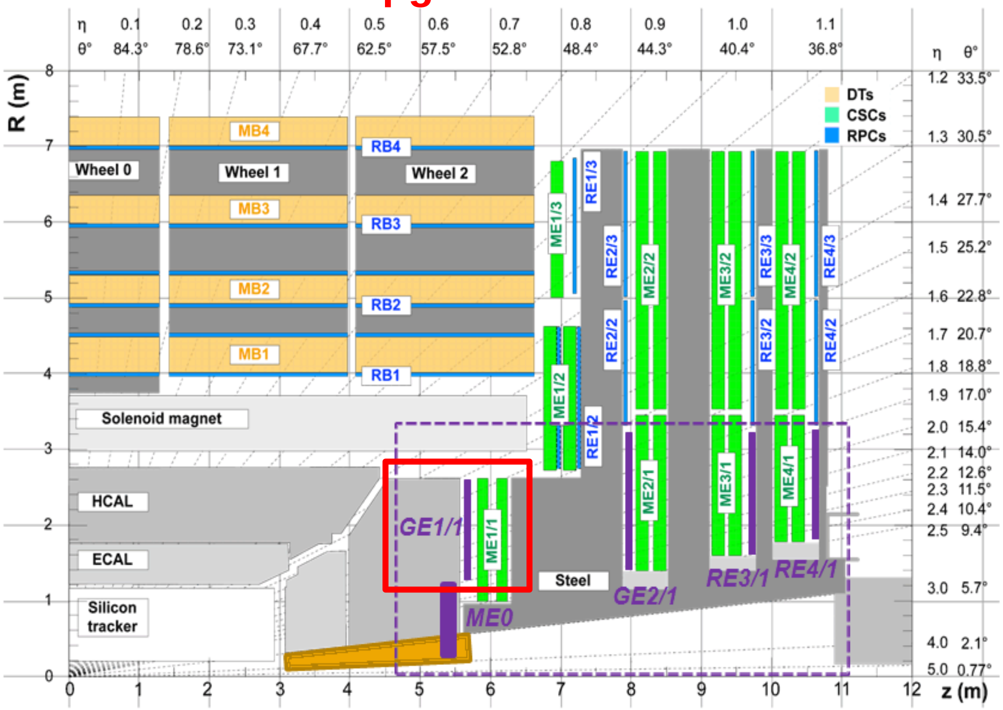
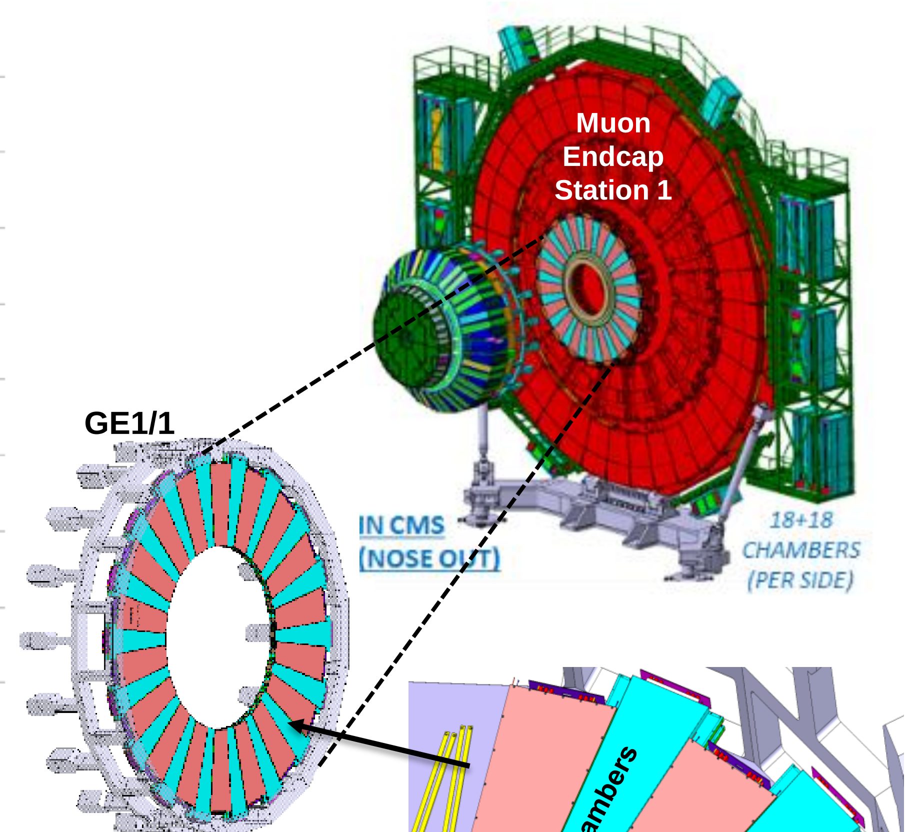
Outline

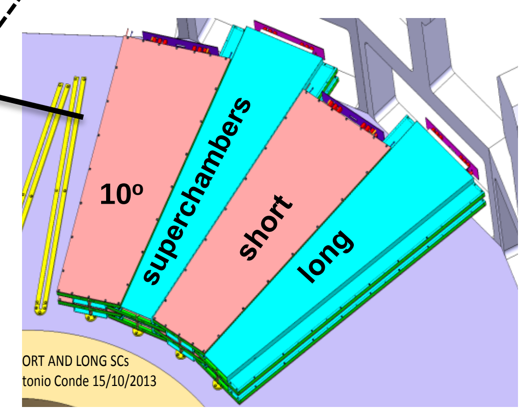
- GEMs for Future CMS Muon Endcap Upgrade
- Construction of GE1/1 Prototype Large-Area GEM Detector
- FNAL Test Beam Oct 2013: Setup and Measurements
- Detector Performance in FNAL Test Beam
  - Uniformity, Strip Multiplicity, Efficiency
- Tracking Results
  - Correlation of GE 1/1 Detector with Trackers, Resolution
- Correction for Non-Linear Strip Response
- Efficiency and Resolution for Emulated VFAT Binary Hit Input using APV Analog Readout
- Summary and Future Plans

GEMs for Future CMS Muon Endcap Upgrade

CMS Upgrade for LS2



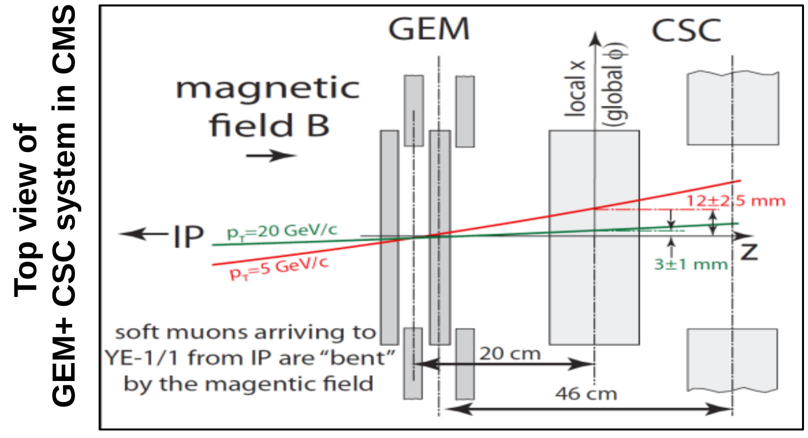


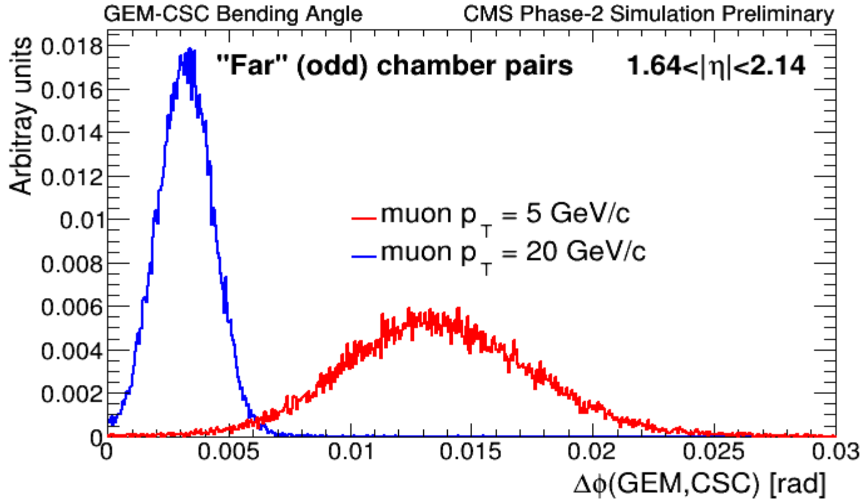


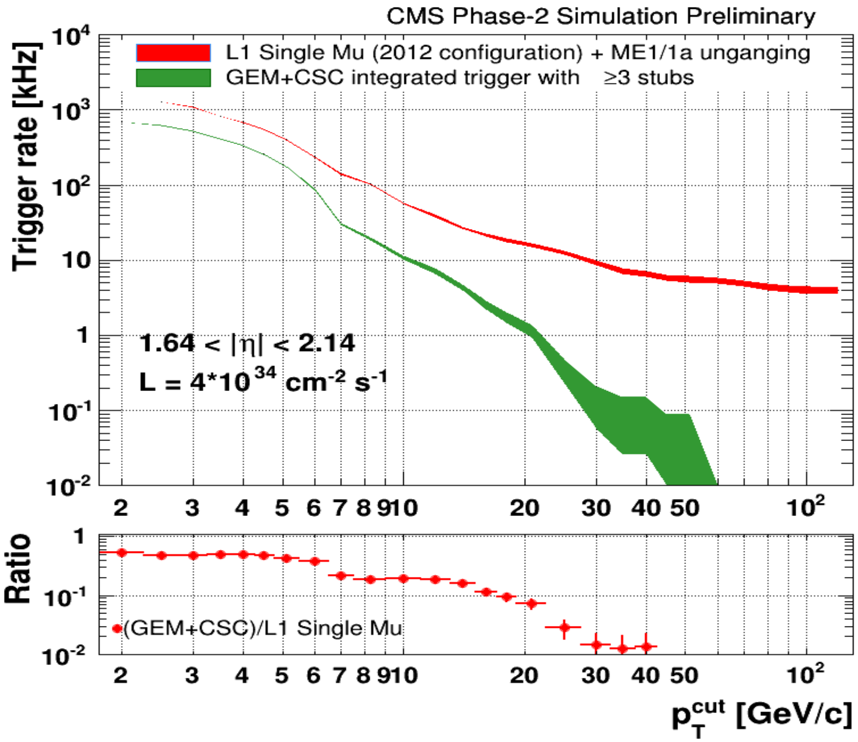
- During Long shut down 2 (LS-2)
  - Introducing GE1/1 in high-η region $1.5<|\eta|<2.2$
  - 10^0 superchambers (trapezoidal triple-GEM detectors) with long ($1.5<|\eta|<2.2$) and short ($1.6<|\eta|<2.2$) version
  - 36 superchambers in each endcap

(Refer to Patrizia Barria's talk (N44-4) for an overview of the CMS muon endcap upgrade)

GEMs for Future CMS Muon Endcap Upgrade
Why GEMs?



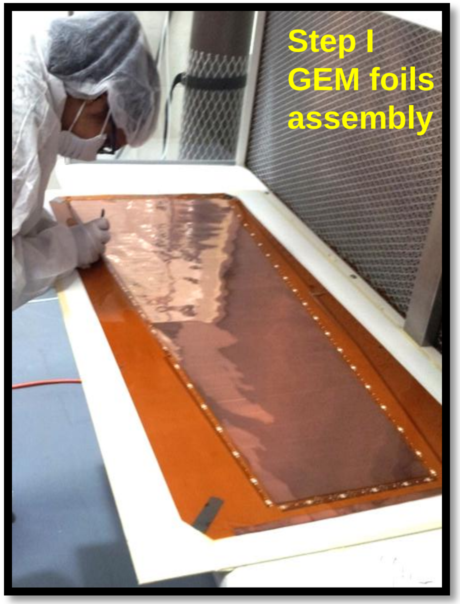


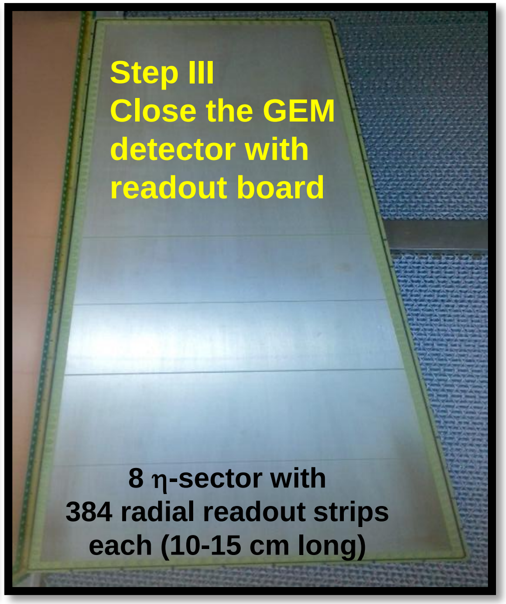


- High gain (~10^4)
- Sustains a high rate (~MHz/cm^2)
- Precise tracking and time resolution (~ns)
- High spatial resolution
- CSC + GEM -> accurate measurement of muon bending angle
- Discriminate lower p_T muon from higher p_T
- Helps to lower global muon trigger rate

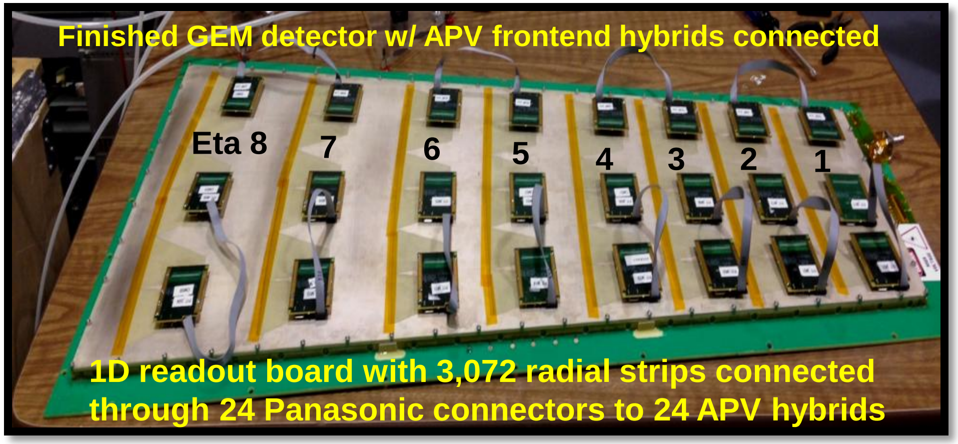
Construction of a Large-Area GEM Detector GE1/1 Prototype III at Florida Tech

Total assembly time 3 Hrs 40 mins with 2 people

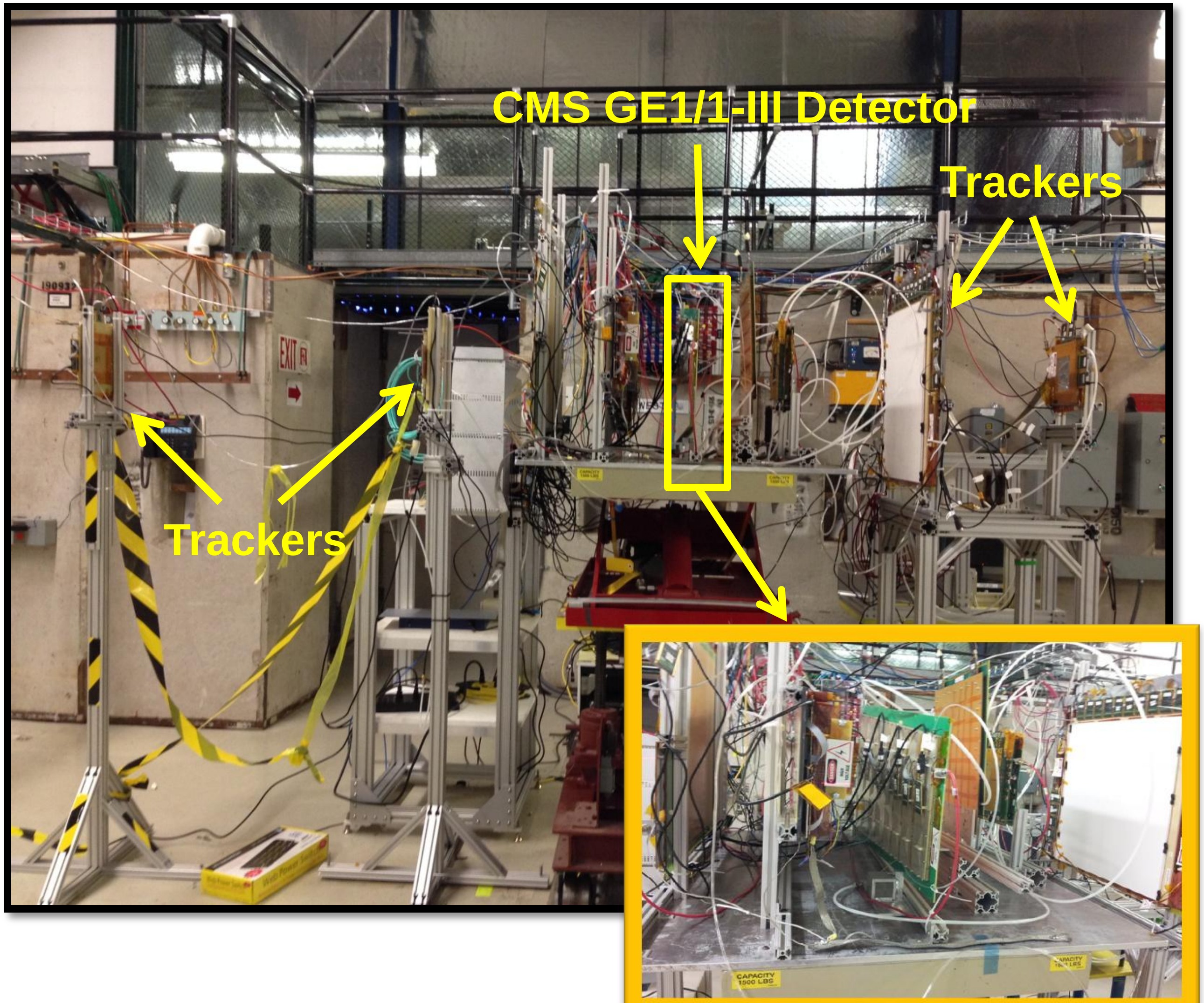




- **Internal gap configuration of the detector: 3/1/2/1mm**
- **GEM foils produced by single-mask etching technique at CERN**
- **Active area: approximately 99 × (28 - 45) cm^2**



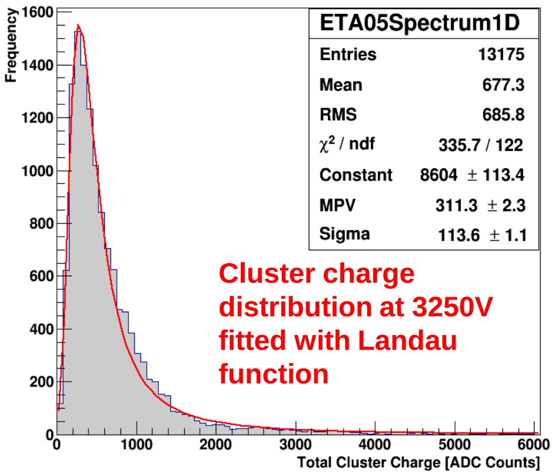
FNAL Test Beam Oct 2013
Setup and Measurements



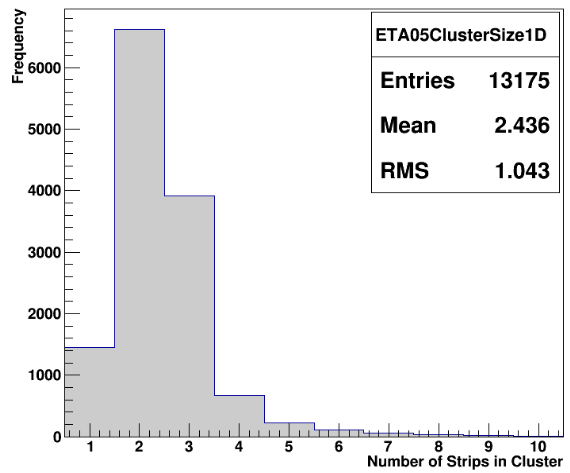
- Gas mixture used in all detectors: Ar/CO_2 70:30
- Beam Energies:
  1. Mixed hadrons: 32 GeV
  2. Proton: 120 GeV
- Three 10 cm × 10 cm & one 50 cm × 50 cm GEM trackers with 2D readout area @ 4200V
- DAQ with RD51 SRS
- GE1/1-III detector tests:
  1. High voltage scan from 2900V to 3350V
  2. Position scan at 3250V in 3 positions:
     Upper row APV
     Middle row APV
     Lower row APV

Basic Performance Characteristics of Detector from FNAL Test Beam Data

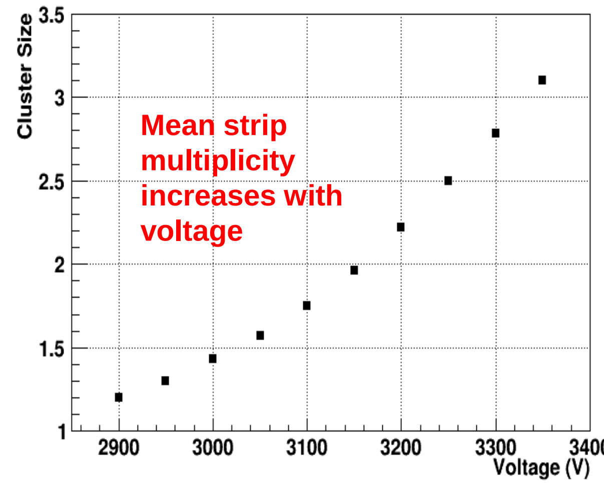
Cluster Charge Distribution



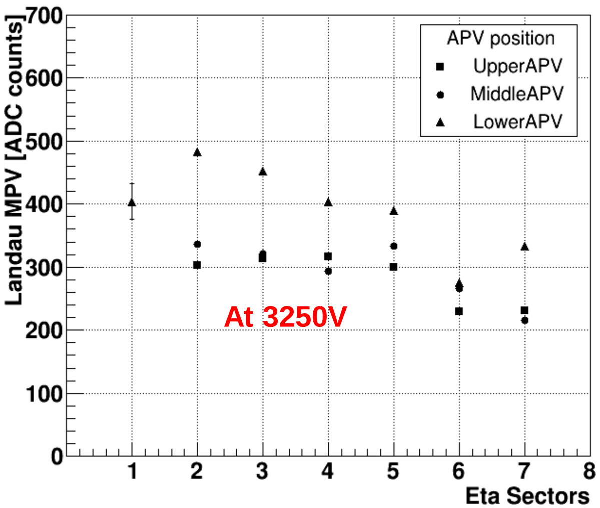
Cluster Size at 3250V



Cluster Size vs. High Voltage

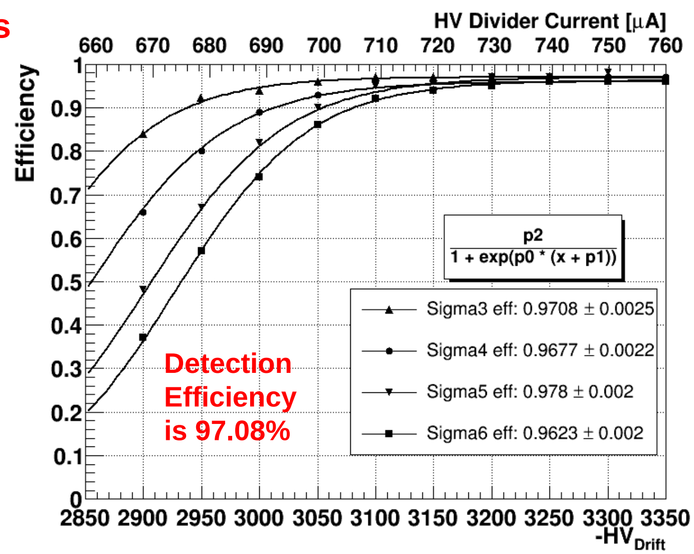


Charge Uniformity



- Average **strip multiplicity** at operating voltage is **2.4 strips**
- At 3250V, most probable values for all 3 APV position are used to determine the charge uniformity across the detector
- **Detection efficiency** measured with this detector is **97.08%** (with 5-sigma cut on pedestal width).

Detection Efficiency with Different Cuts on Pedestal Widths

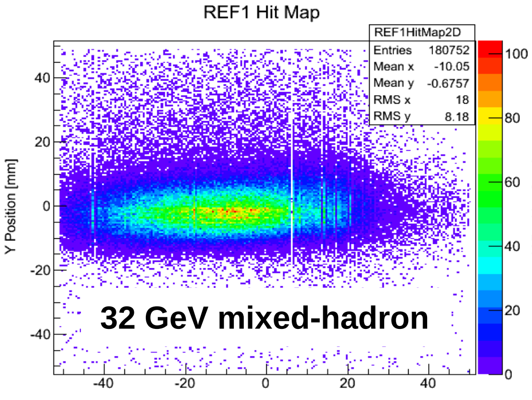


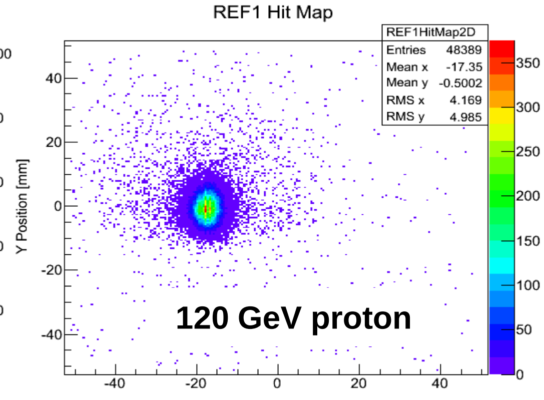
Tracking Results

Reference Tracker and Correlations with CMS GE1/1 Detector

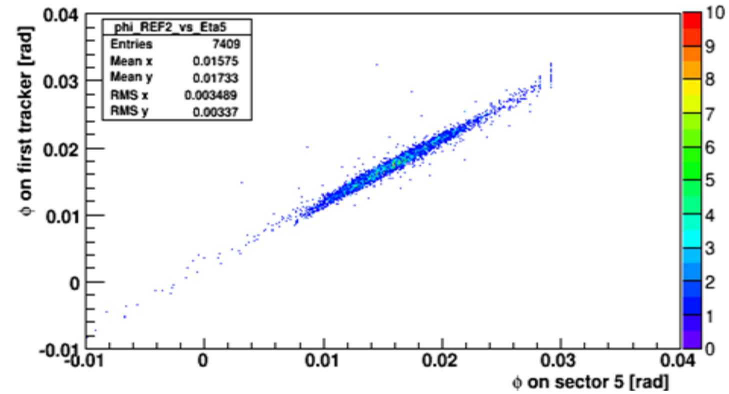
Florida Tech

Beam profiles with first tracker

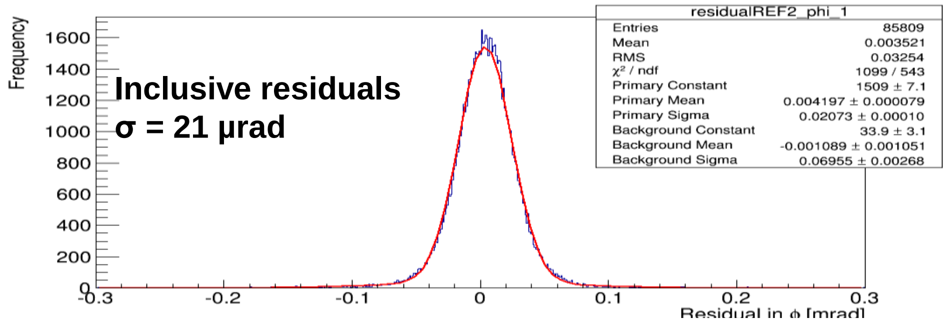


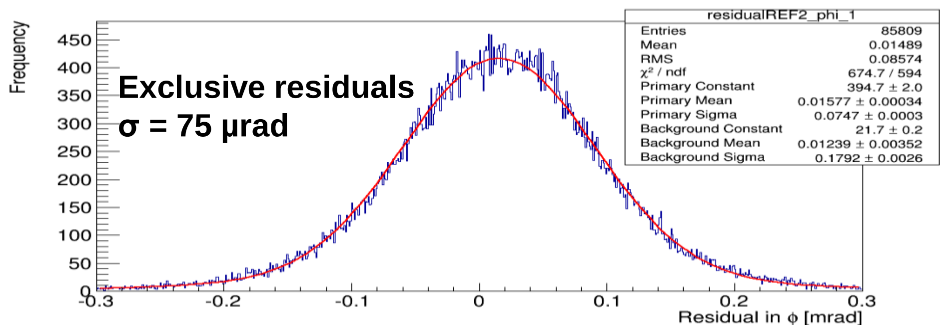


Correlation of GE1/1 detector hits with hits in first tracker detector:

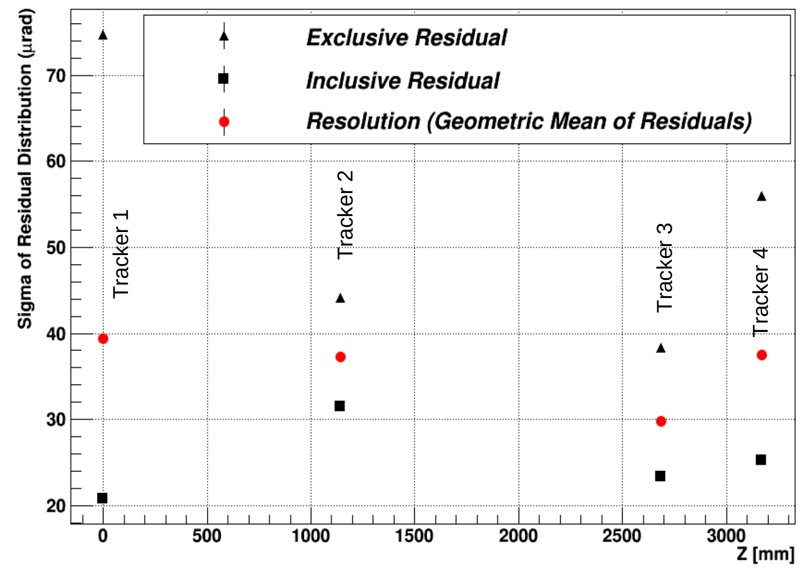


Residuals of Tracker 1 in φ





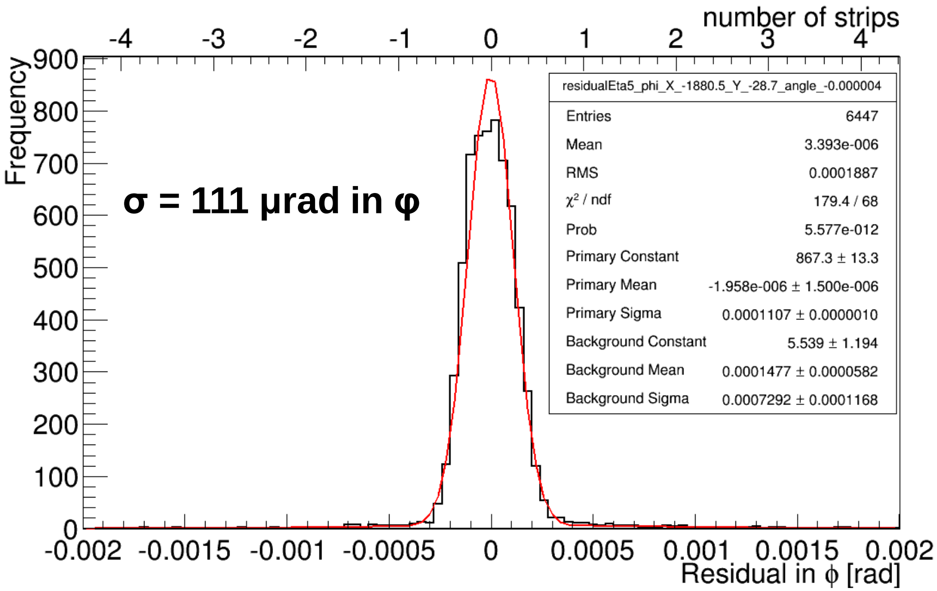
Reference detector resolutions in φ



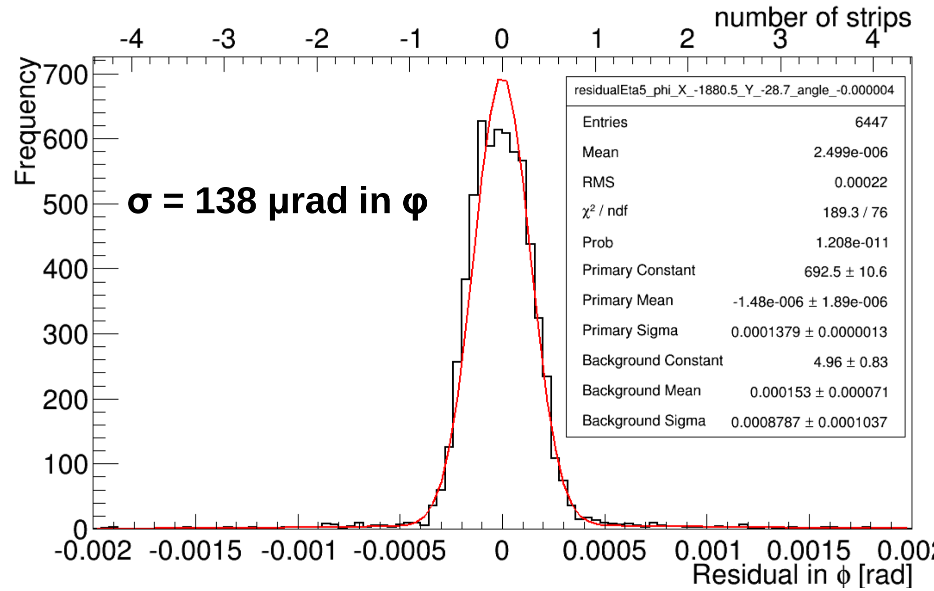
Tracking Results

Resolutions for CMS GEM Detector in Eta Sector 5

Inclusive Residual



Exclusive Residual



The resolution of the GE1/1 detector is obtained from the geometric mean

$$\sigma = \sqrt{\sigma_{inc} \times \sigma_{exc}}$$

of the inclusive and exclusive residual widths.

Resolution of the detector: σ_{analog} = 124 μrad (27% of strip pitch)

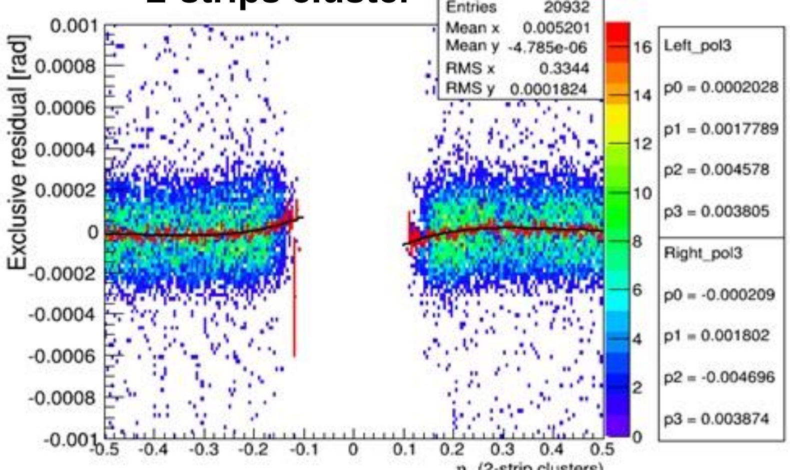
(corresponds to σ = 233 μm in azimuthal direction)

Non-Linear Strip Response Correction

- **The resolution of the same detector with a zigzag-strip readout board can be improved by ~30% (Refer to Aiwu Zhang's poster N05-12)**
- **Hence, we implemented the same correction to find the corresponding improvement in the resolution of the standard GE1/1 detector discuss here**
- **Strip cluster position is reconstructed via cluster barycenter (centroid): $S_b = \sum_{i=1}^{n} \frac{q_i s_i}{q_{total}}$, where q_i is charge of the i^th strip, s_i is strip number, and q_{total} is total cluster charge**
- **For cluster size N > 1, we define $\eta_N = s_b - s_{max}$, where s_{max} is the strip with maximum charge value. Then we plot exclusive residuals against η_N for N = 2 and N = 3**
- **Corrected resolution is obtained by subtracting the exclusive residual means as function of η_N from the original residuals**

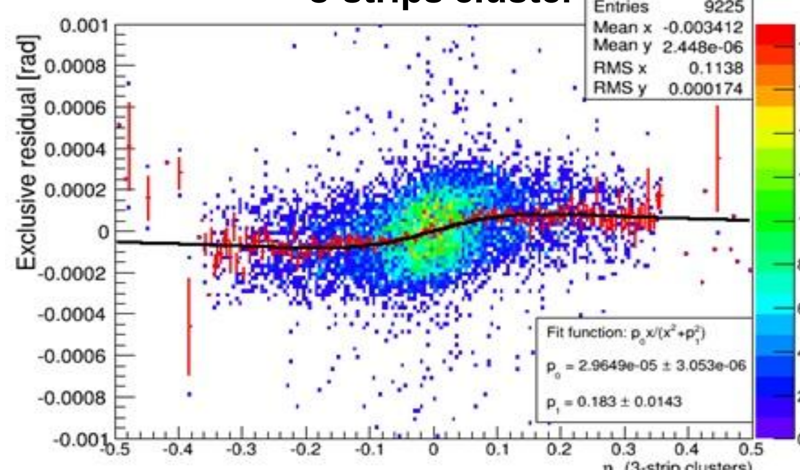
Scatter Plots of Exclusive Residual vs. η_N using combined HV scan data

2-strips cluster



η_2 fitted with 10-degree polynomial function

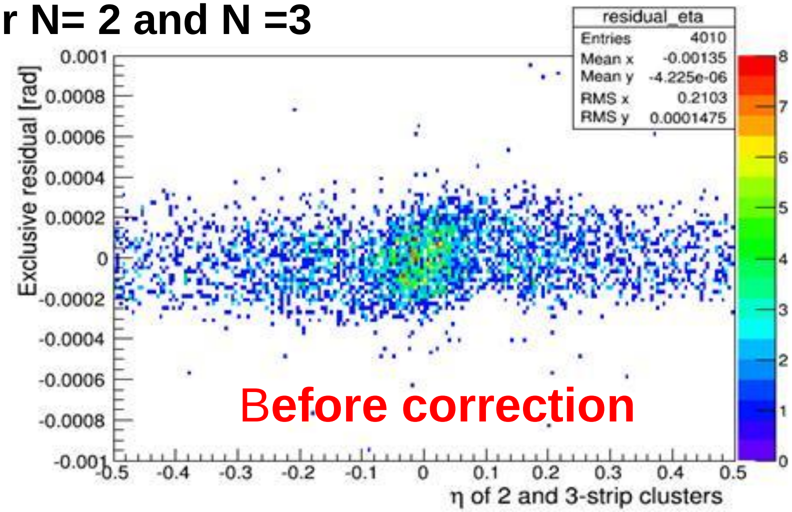
3-strips cluster

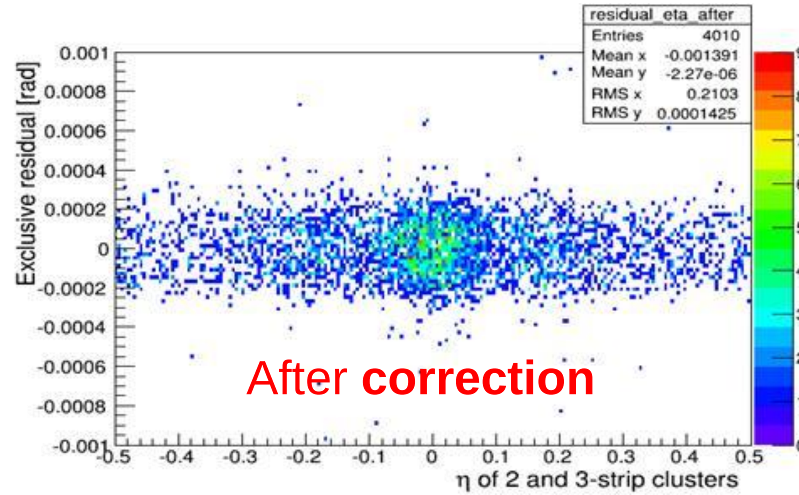


η_3 fitted with serpentine function

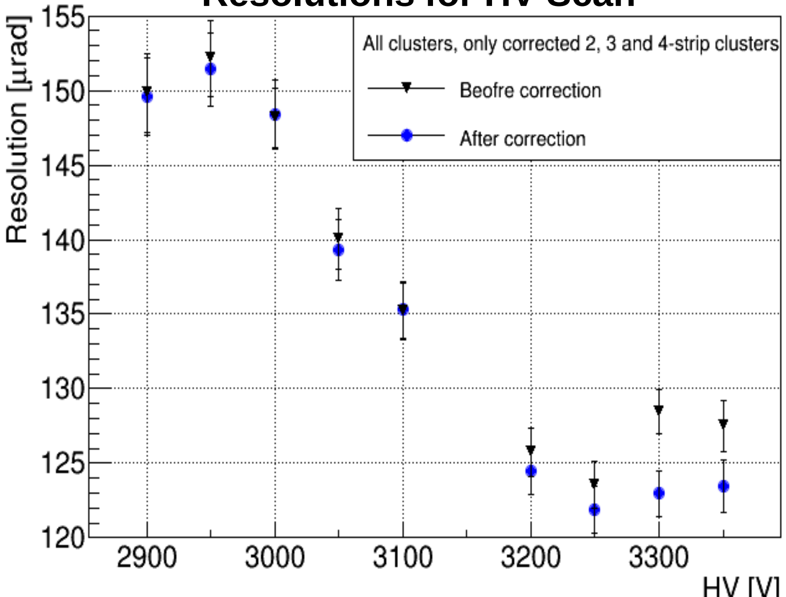
Non-Linear Strip Response Correction

For N= 2 and N =3

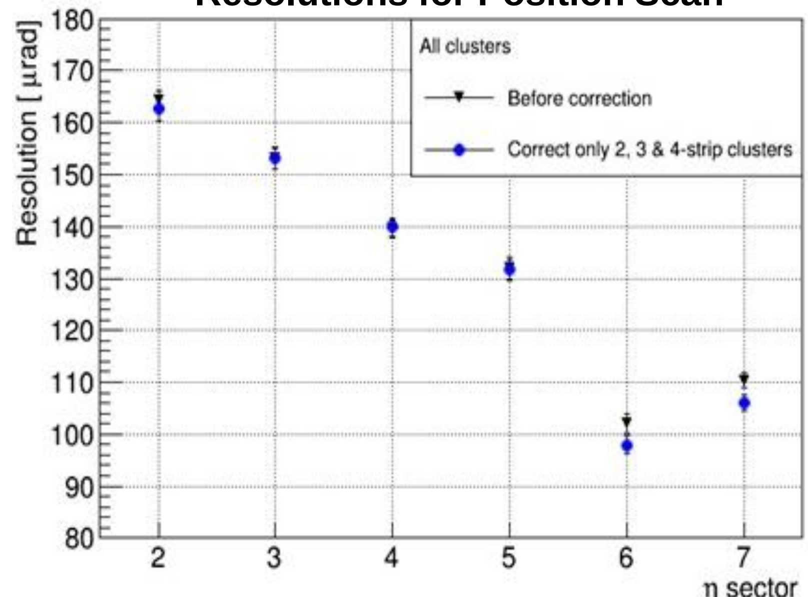




Resolutions for HV Scan



Resolutions for Position Scan



Overall resolution is improved by ≤ 8% after correcting the non-linear strip response

Emulated VFAT Binary Readout Results Using APV Analog Readout

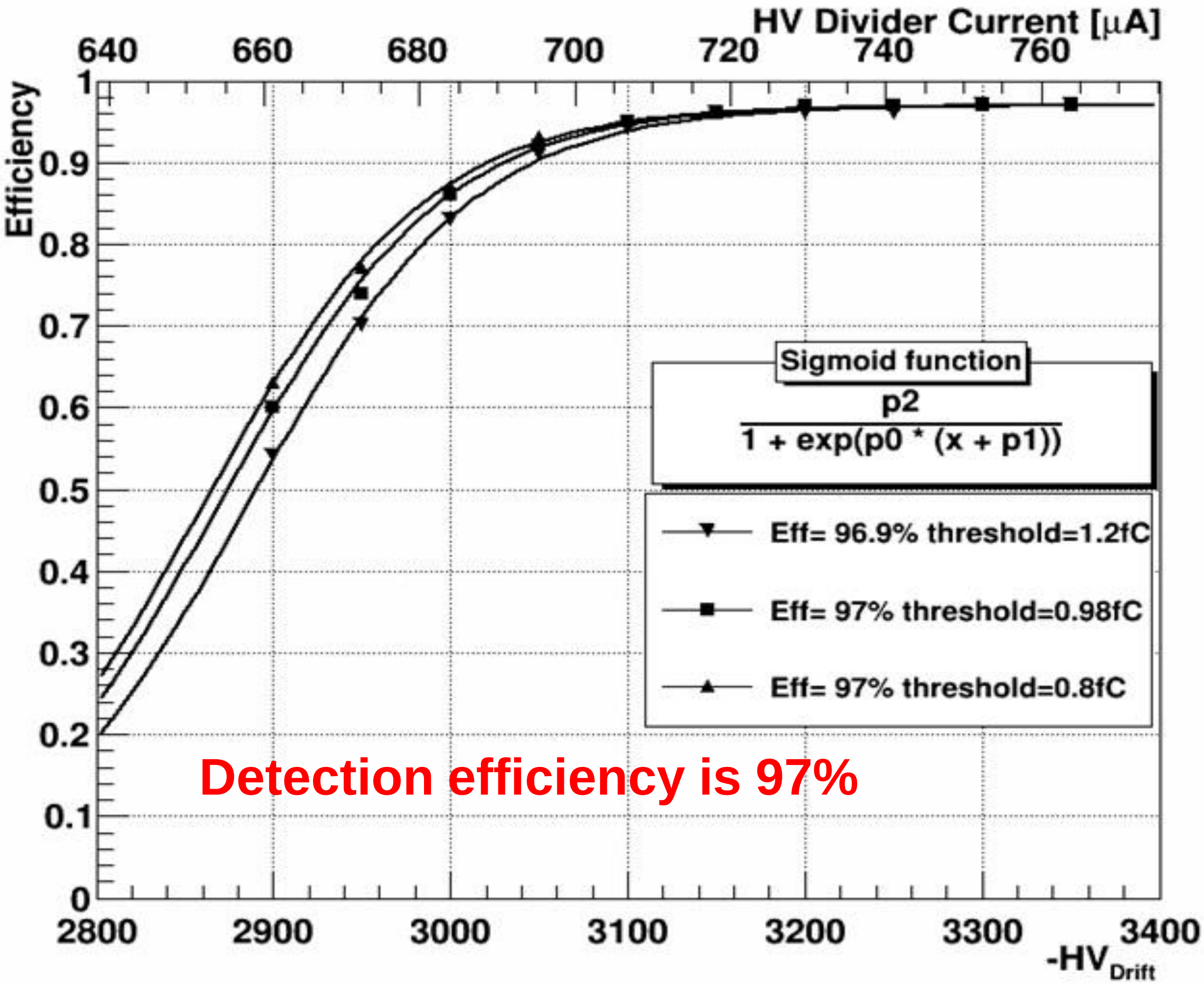
- **CMS upgrade electronics proposes VFAT3 that collects data using binary output**
- **VFAT threshold reconstructed using following conversions**

  1 ADC count = 0.03172 fC

  and

  1 VFAT unit = 0.08 fC
- **Efficiency is plotted for three threshold values 10 VFAT, 12 VFAT, and 15 VFAT units**

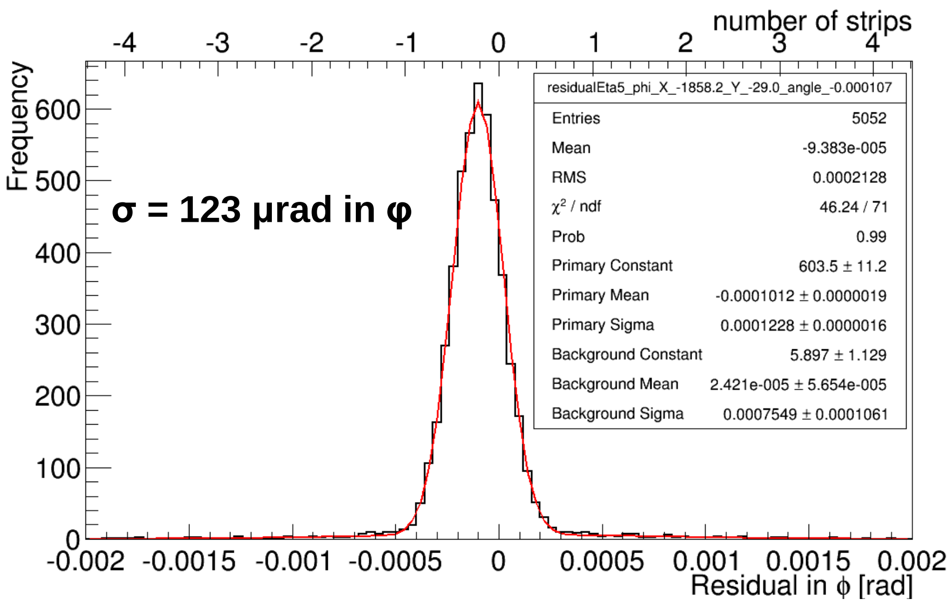
Detection efficiency using different VFAT thresholds



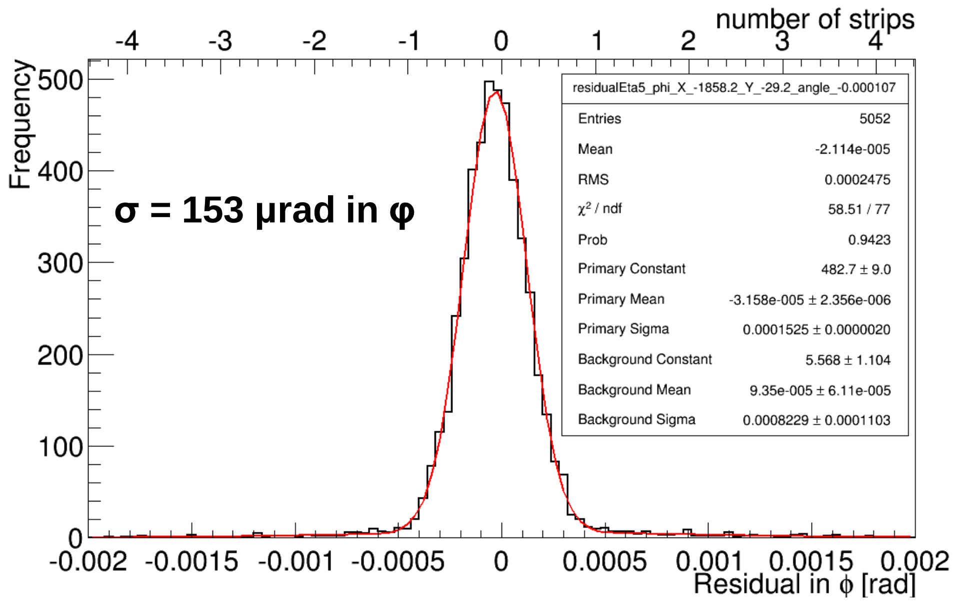
Emulated VFAT Binary Readout Results Using APV Analog Readout

Resolutions for CMS GEM Detector in Eta Sector 5

Inclusive Residual



Exclusive Residual



The resolution of the GE1/1 detector is again obtained using geometric mean of inclusive and exclusive residuals

Resolution of the detector σ_{binary} = 137 μrad

(corresponds to σ = 255 μm in azimuthal direction)

To be compared with expected resolution using strip pitch: pitch/$\sqrt{12}$ = 131 μrad

Summary

- The beam test at FNAL was successful as the performance of the GE1/1 prototype-III large-area detector meets the expectation for the CMS upgrade.
- Detection **efficiency** of the detector is **97%** for both **pulse height readout** and **emulated VFAT binary readout** in eta sector 5.
- We observed non-uniformity in all three APV positions due to slight bending of drift and readout boards. This is being improved in new GE1/1 prototype detectors developed this year.
- The spatial resolution improves with high voltage and gives the best value of **124 μrad** using full pulse height readout, when the detector is operated at efficiency plateau.
- Resolution of GE1/1 detector is **improved by ≤ 8%** after correcting the non-linear strip response.
- Resolution using emulated VFAT binary method is **137 μrad,** which is consistent with **pitch/$\sqrt{12}$ = 131 μrad**

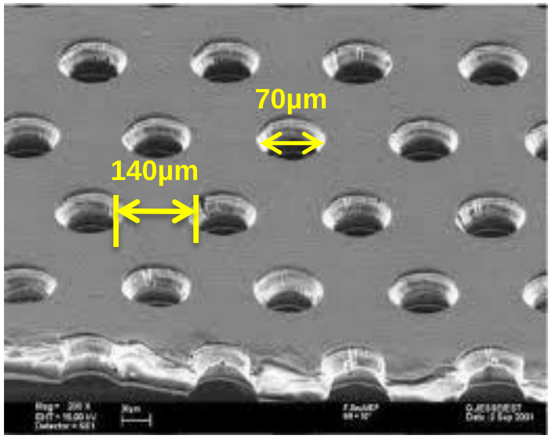
Thank You!

Backup Slides

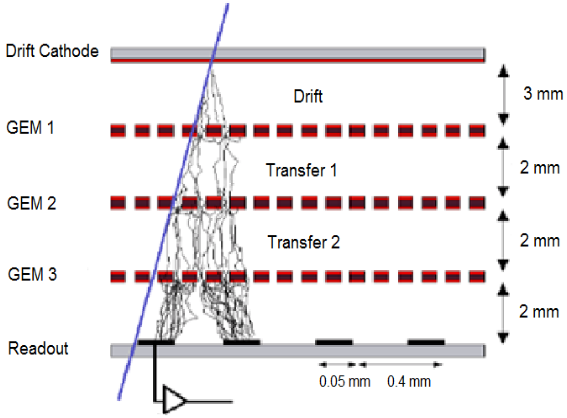
Gas Electron Multiplier Detector

- Micro Pattern Gas Detector (MPGD)
- GEM foil is a kapton foil coated with copper on both sides that has an array of holes (typically 140µm pitch)
- High voltage is applied across foils, which creates avalanche of electrons through holes
- Provides good efficiency and spatial resolution
- Typical gas gain of 10^4 with gas mixture of Ar/CO_2

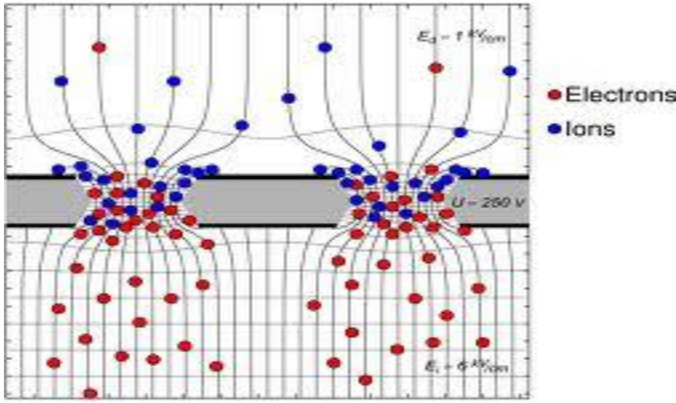
Triple GEM configuration:
Most popular and reliable



Source: http://gdd.web.cern.ch/GDD/



Murtas, F.: "Development of a gaseous detector based on Gas Electron Multiplier (GEM) Technology



Source: http://www.flc.desy.de/tpc/basicsgem.php

Efficiency Measurement

- Studied the hit distribution, charge distribution and cluster size for HV scan and Position scan
- Evaluates the efficiency from cluster multiplicity(CM)

$$Efficiency = \frac{N1}{(N - N2)}$$

Where, N1: No. of events with CM≥1 for given sector

N: Total no. of events

N2: sum of the no. of events with CM≥1 for other sectors

Tracking

- **Tracking is done in three steps**:
- **Step I - <u>Alignment</u>**: By iterating the shift parameters in X and Y, we center all detector residuals on zero and then with respect to the first reference tracker, we rotate the remaining three trackers until the residual widths are minimized
- **Step II - <u>Conversion from (x,y) to (r,φ) coordinate system</u>:** Since we are dealing with radial readout strips in the GE1/1, it is more appropriate to use (r,φ) coordinates for tracking.

$$r = \sqrt{x^2 + y^2} \qquad \varphi = \mathrm{atan}(y/x)$$

- **Step III - <u>Calculate final residuals (inclusive and exclusive)</u>**

We measure both exclusive and inclusive residuals for GE1/1 detector and then calculated the resolution (Geometric mean of inclusive and exclusive residual) $\sigma = \sqrt{\sigma_{inc} \times \sigma_{exc}}$ (**Ref: R.K. Carnegie et al., "Resolution studies of cosmic-ray tracks in a TPC with GEM readout," Nucl. Instrum. Meth. A, 535(2005), p. 372-383.**)