Study of a Large-Area GEM Detector Read Out with Radial Zigzag Strips for Forward Tracking in Experiments at a Future Electron-Ion Collider

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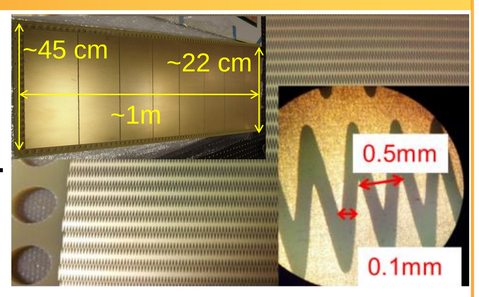
Introduction

The RD6-FLYSUB consortium is performing R&D on tracking and particle ID with GEM detectors for a future Electron-Ion Collider (EIC). A 1m-long trapezoidal triple-GEM detector read out by 1,024 radial zigzag strips in eight η-sectors is an option under study for tracking in the forward region. The zigzag structure allows a threefold reduction in the required number of strips and electronic channels over a conventional straight-strip readout while preserving good spatial resolution. The geometry of this zigzag structure is briefly discussed. We report results from a beam test of this prototype with 20-120 GeV hadrons at the Fermilab Test Beam Facility (FTBF). The readout design shows a typical cross-talk of not more than 6%. Spatial resolution and efficiency are studied as a function of high voltage and for different positions on the detector. The measured charged-particle detection efficiency of this detector on plateau exceeds 98%. With hit positions based on the barycenters of zigzag-strip clusters, the overall measured spatial resolution of the detector is ~240 μrad given a 1.37 mrad azimuthal pitch of the radial zigzag strips. The non-linearity of the zigzag-strip response is corrected using track information which improves the resolution to ~170 μrad, or 12% of the strip pitch.

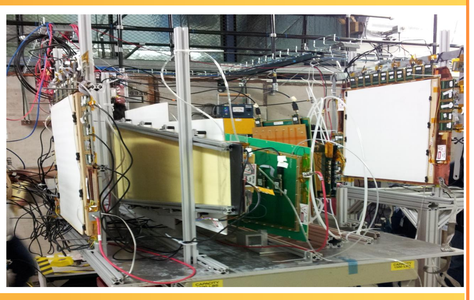
1. Zigzag Readout Strips & GEM detector

- The zigzag readout board is divided into eight η-sectors; each sector has a length of ~12 cm and comprises 128 zigzag strips; zigzag strips run in radial direction and measure polar coordinates (φ).
- The opening angle of the board is 10°; the angular pitch between zigzag strips is ~1.37 mrad.
- Distance between two neighboring tips is 0.1 mm; distance between two tips in one strip is 0.5 mm.
- GEM foils and drift frame are from a CMS-GEM prototype (GE1/1-III) for the CMS muon upgrade; gas gaps in the 3-GEM detector are 3/1/2/1 mm.
- **Only 8 APVs are needed to fully read out the detector, 2/3 of electronics are saved** compared with 24 APVs in the CMS project w/ straight strips.



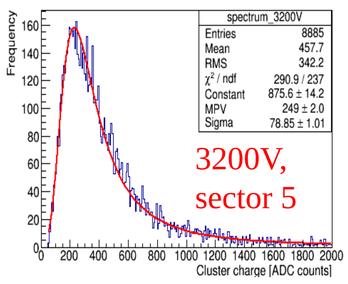
2. Setup in the Beam at Fermilab TBF

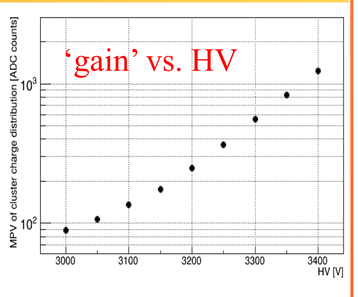
- The zigzag GEM detector was tested at FTBF in a tracking system. Four standard GEM detectors worked as trackers (two in front and two in back).
- All detectors were operated with Ar/CO_2 70:30.
- Most of the data for the zigzag GEM were taken with 32 GeV/c mixed hadrons (p, π, and K).



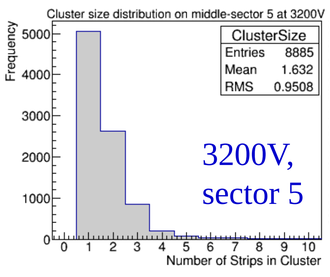
3. Basic Performances of the Zigzag GEM

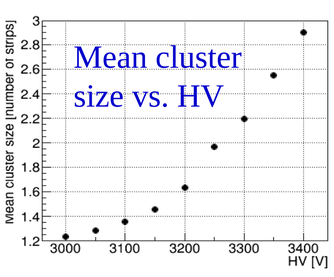
- Cluster charge distribution fits well to a Landau function. A typical exp. 'gain' curve is obtained with the HV scan on the middle of sector 5.



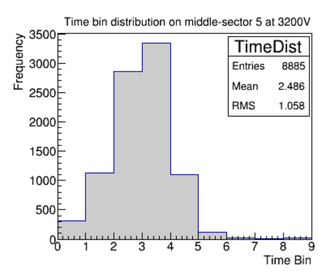


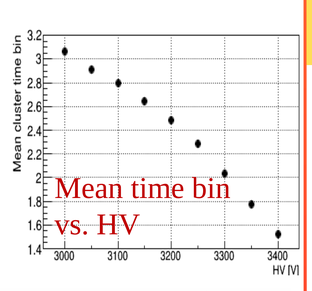
- Mean cluster size (number of strips in a cluster) is approximately an exponential function of HV. Mean cluster size at the highest voltage is less than 3 strips.



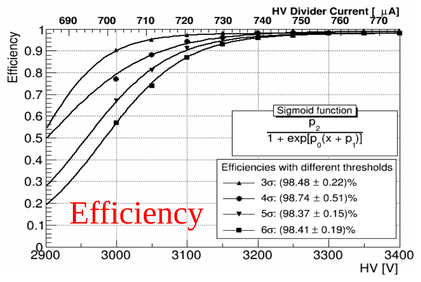


- Time bin where the maximum signal appears in APV time window. At higher HV, the time bin is smaller because the signal pulse peaks earlier.

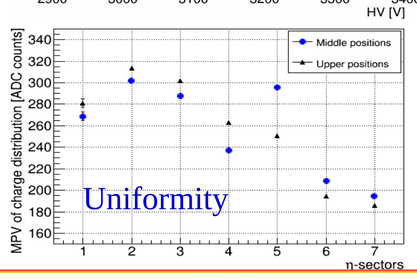




- Detection efficiency of the zigzag GEM is measured to be (98.4 ± 0.2) % with a 5σ threshold cut, where σ is the width of the pedestal distributions. Different thresholds are compared and consistent efficiencies are observed. Efficiency plateau width is about 250V.



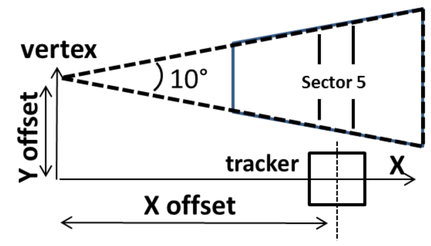
- The zigzag GEM was scanned at two points in each of sector 1 - 7 at 3200V. The response in cluster charge **varies by about 25%** at different positions. This non-uniformity is most likely caused by slight bending of the drift board after foils are stretched.

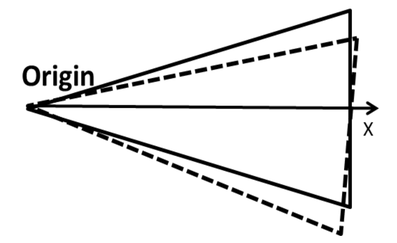


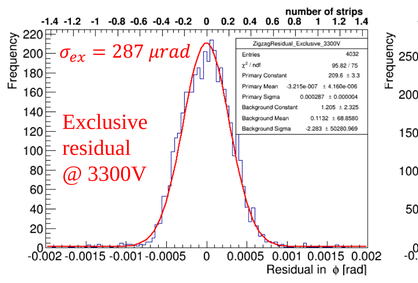
4. Spatial Resolutions with Centroid Method

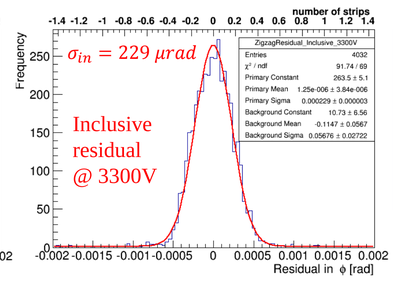
- Since the zigzag strips measure ϕ coordinate, we study the spatial resolution in polar coordinates. Cluster positions are reconstructed with the barycentric method, i.e. by finding the centroid. First we align the trackers in Cartesian coordinates, then we pick the vertex of the trapezoid as the origin and find (X_{offset}, Y_{offset}) pairs for the trackers; we also correct for rotations of the trackers relative to each other and of the zigzag GEM relative to the trackers.
- After alignment, we measure both exclusive and inclusive residuals for the zigzag GEM and get exclusive (σ_{ex}) and inclusive (σ_{in}) resolutions; then the detector resolution σ is calculated from the geometric mean of the residuals:

$$\sigma = \sqrt{\sigma_{ex} \times \sigma_{in}}.$$



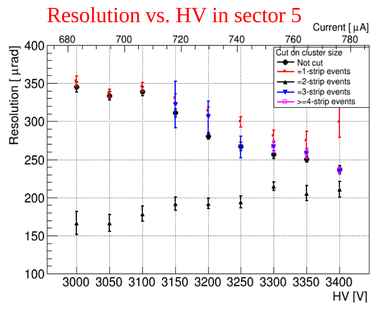






- At 3300V, in central sector 5, $\sigma_{ex} = 287\ \mu rad, \sigma_{in} = 229\ \mu rad$, so the uncorr. resolution is:
- $\sigma = \sqrt{287 \times 229} = 256\ \mu rad.$

Resolution vs. HV in sector 5



Resolutions at different positions

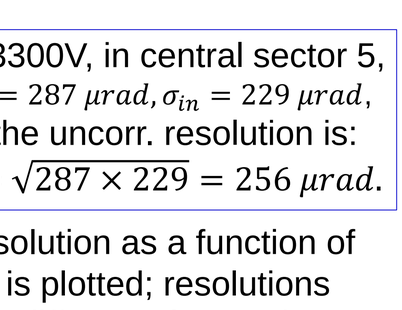
- Resolution as a function of HV is plotted; resolutions with different cluster sizes are also compared. On the efficiency plateau, resolution is ~240 μrad.
- Resolution at different positions are measured to be around 260 μrad.

5. Correction of Non-linear Strip Response and Resulting Resolution Improvement

- The zigzag strips have non-linear response to signal collection due to their special structure, which biases the cluster centroids away from their true positions.

Residuals vs. η_2

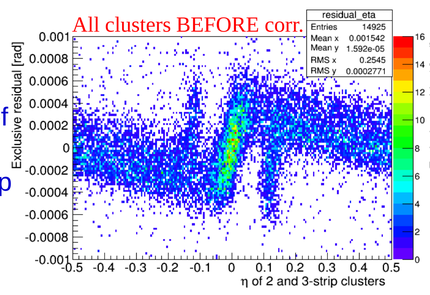
Residuals vs. η_3



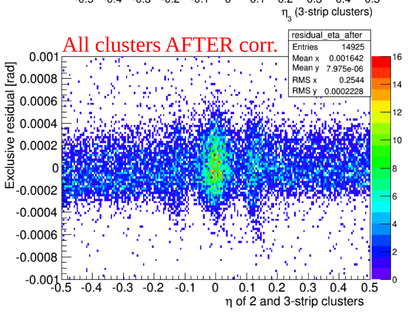
- **Correction method:**

(1) Define $\eta \equiv s_g - s_{max}$, where $s_g = \sum_{i=0}^{n} s_i q_i / \sum_{i=0}^{n} q_i$ is the centroid of a strip cluster with size n; s_i, q_i are strip number and charge for the i[th] strip in the strip cluster, respectively; s_{max} is the strip number on which the max. charge is collected.

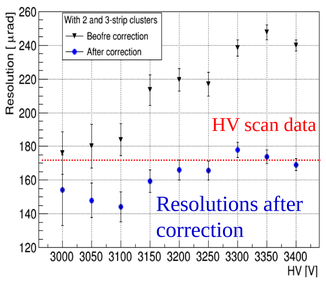
All clusters BEFORE corr.

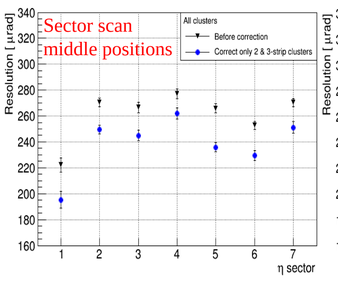


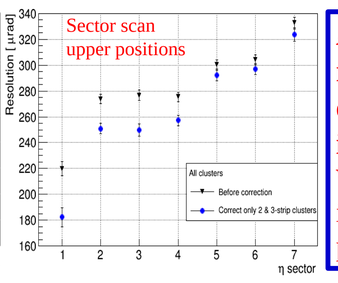
All clusters AFTER corr.



(2) Using tracks, exclusive residuals are plotted vs. η and fitted. **Narrower residuals** can then be obtained by subtracting η-dependent offsets given by the 2-strip and 3-strip fit functions from the original residuals.



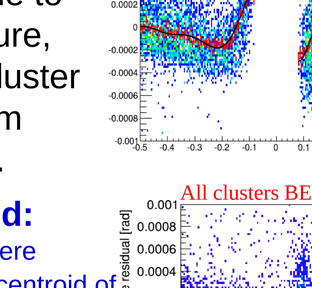


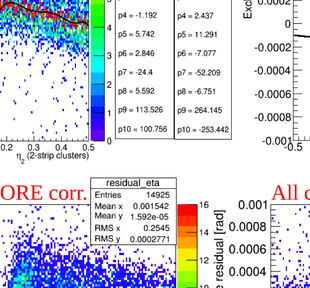


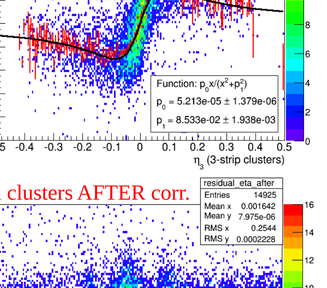
After corrections, the resolution on the efficiency plateau is improved to 170 μrad. We observed resolution improvements for all positions on the chamber.

6. Crosstalk among Zigzag Strips

The zigzag strips #63 and #127 were grounded by mistake when the PCB was manufactured, which allows us to check the crosstalk between the strips experimentally. From pedestal widths, we estimate the mean cross talk on the 'victim' strips to be about 5-6%.







7. Conclusion & Outlook

- The GEM detector with zigzag strip performed quite well in the beam test.
- The efficiency is high; the response uniformity can be improved further.
- The **angular resolution** of the detector reaches **170 μrad** (170 μm at r = 1 m), or **8% of the strip pitch**. Multiple scattering (for ~14% X_0) is not yet included in the analysis; we expect even better resolution after this effect is subtracted.
- **In conclusion, a GEM with zigzag strip readout is a viable and cost-effective option for forward tracking in an experiment at a future EIC.**

RD6-FLYSUB is a collaboration of researchers from BNL, Florida Institute of Technology, Lawrence Livermore National Lab., Stony Brook U., U. of Virginia, Weizmann Institute of Science and Yale U. formed to carry out R&D for tracking and particle identification for detectors for a future Electron-Ion Collider (EIC). We would like to acknowledge BNL for the support of this work (under the EIC-RD6 task force) and the staff of the FNAL test beam facility for all their help.