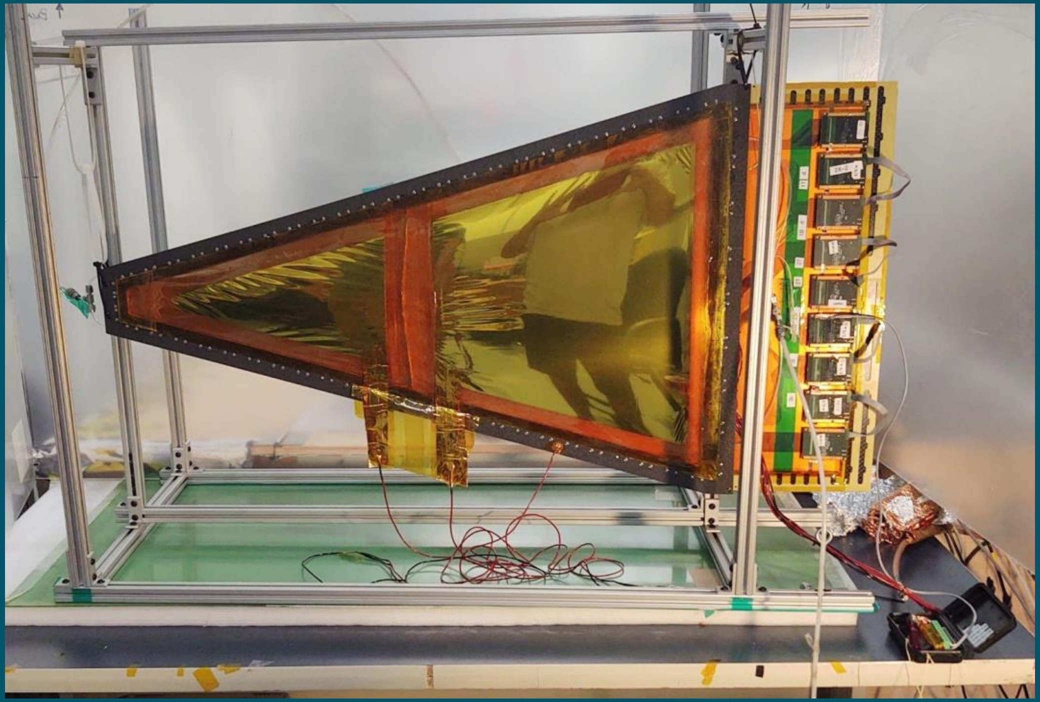

Construction and Performance of a Large Area GEM Detector with Low Mass and Zigzag-strip Readout for the EIC

<u>Merrick Lavinsky,</u> Jared Hadley, Aiwu Zhang*, and Marcus Hohlmann

Florida Institute of Technology

** now at Leidos, Inc.*

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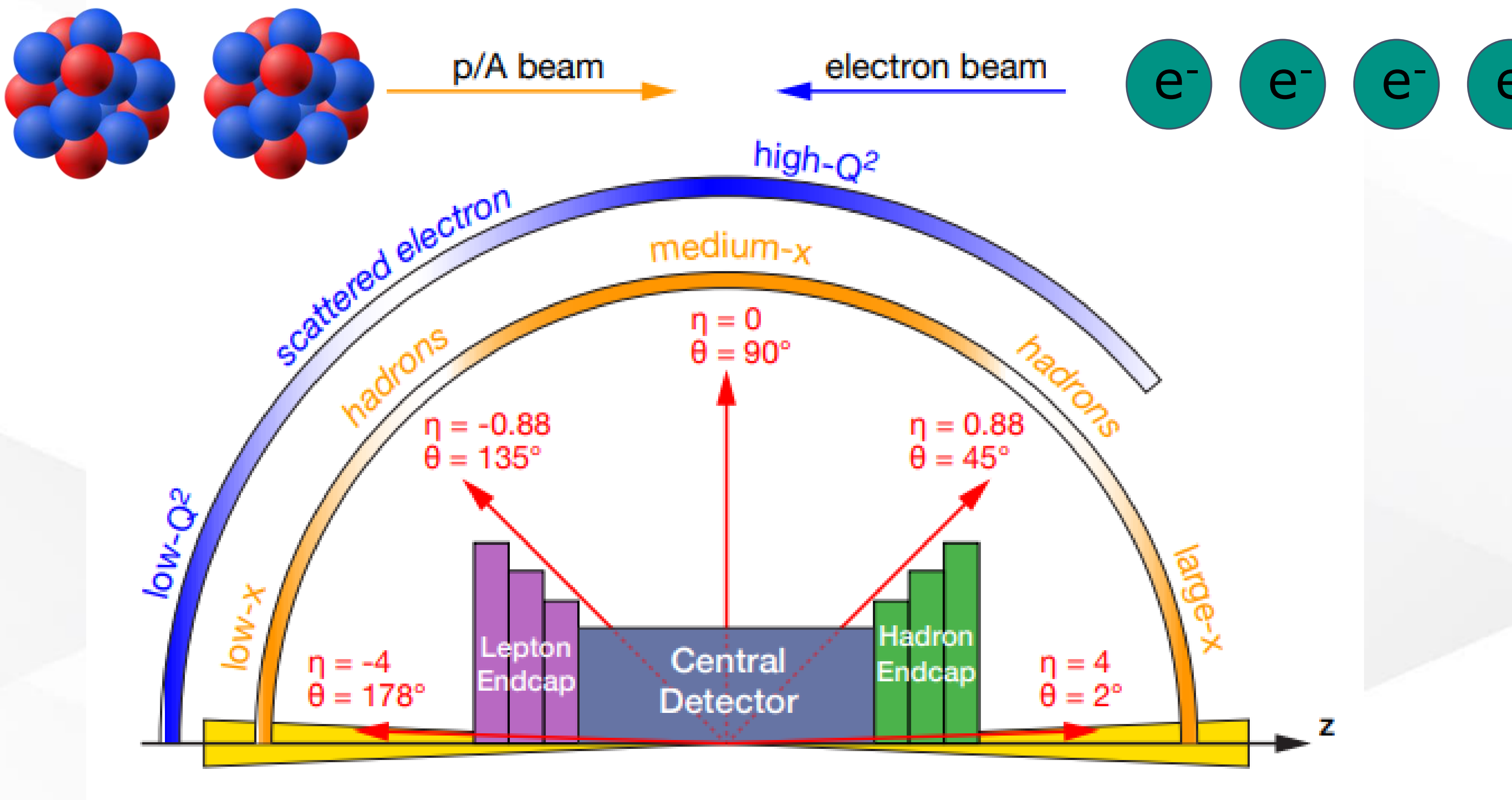
The Future Electron Ion Collider

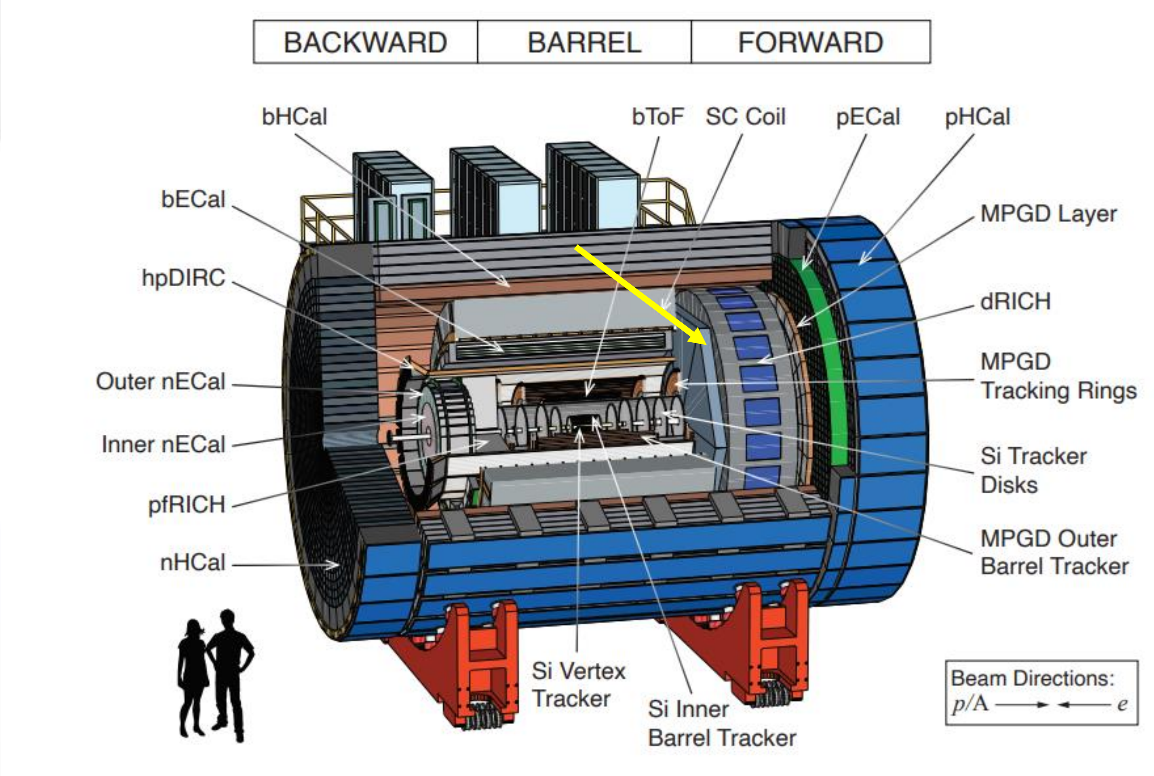
- Proposed to be built at BNL in NY using infrastructure from RHIC
- Collide electron beam with variety of heavy ion beams
  - U, Pb, Protons, etc..
- Break the QCD barrier!
  - quark-gluon position and spin distribution within the nucleus
  - Understand how the nuclear force/properties of nuclear matter emerge from quark-gluon interactions

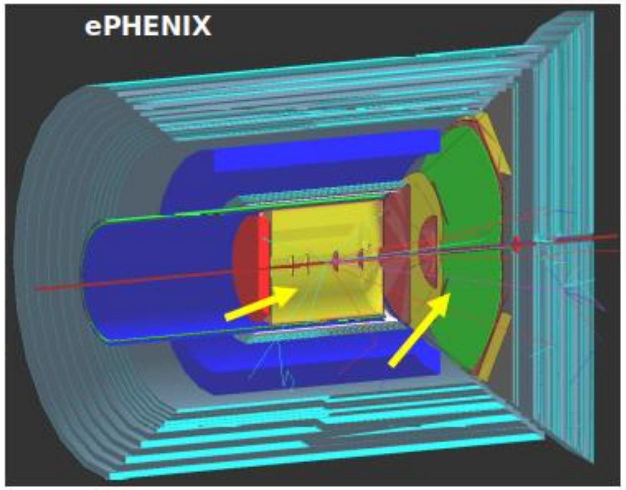


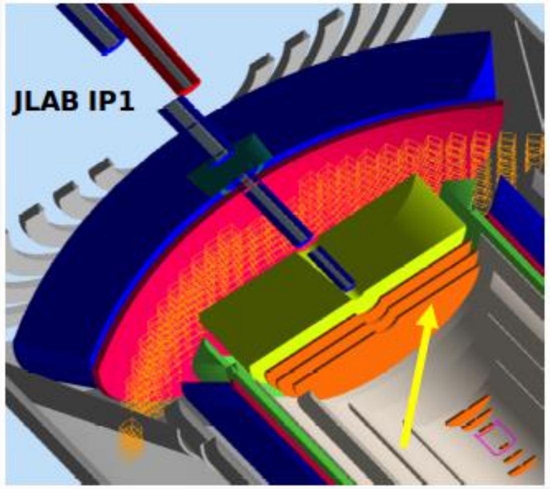
"Understand the GLUE that binds us all"

GEM Detector Presence at the EIC

So far, all proposed EIC detector designs exhibit the use of large planar GEM detectors for tracking in the forward or backward regions.







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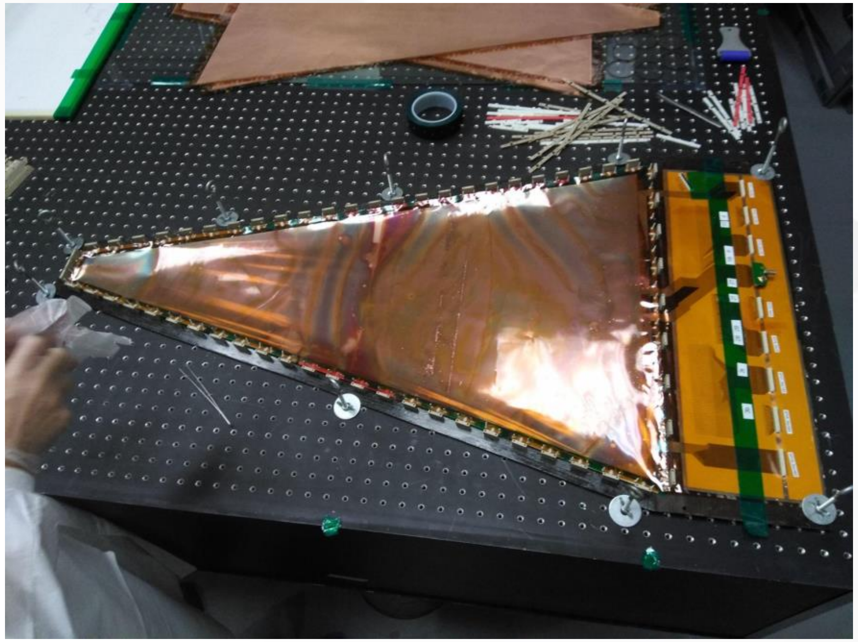
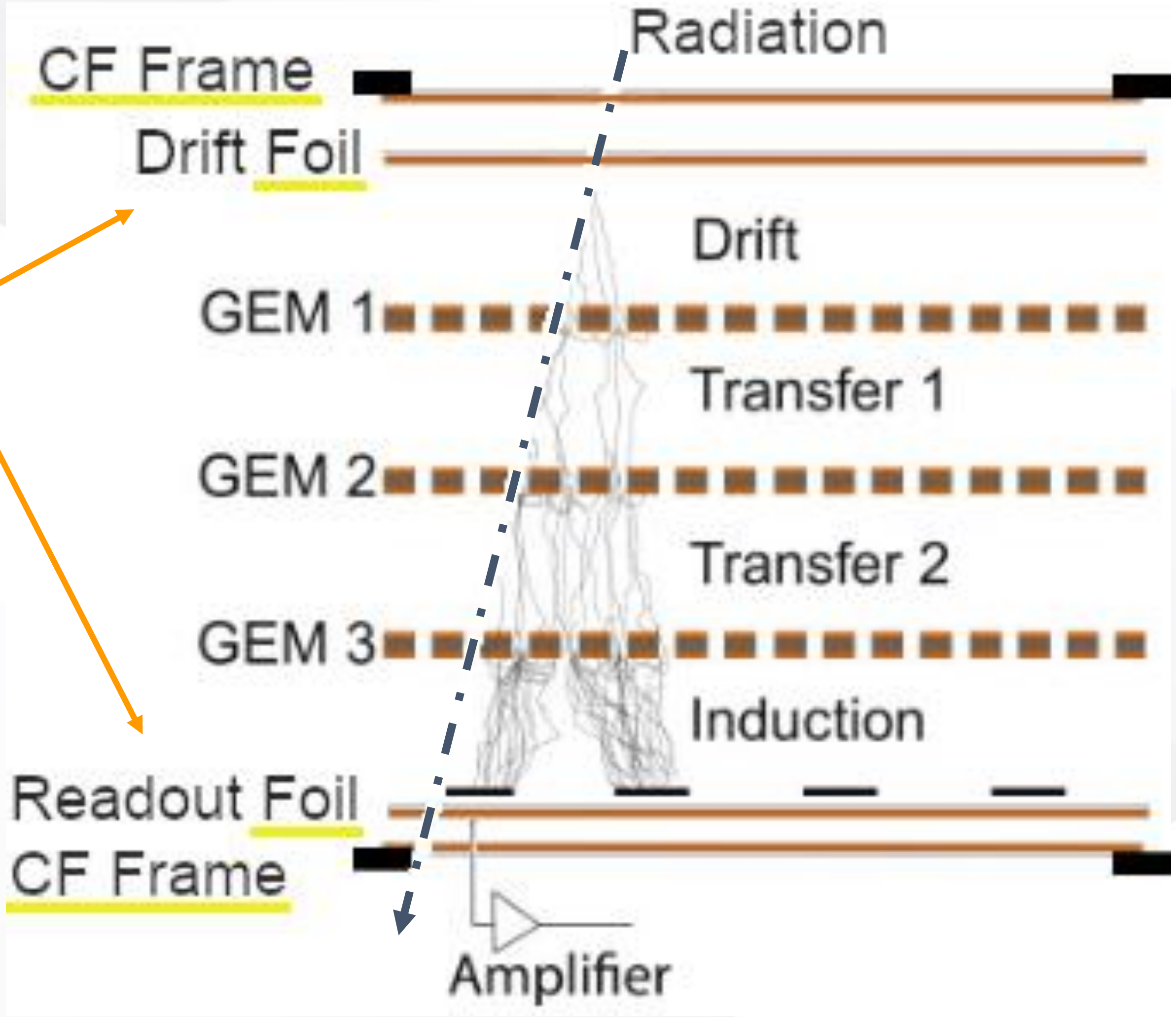
What Advantages Does Our Design Have?

- Ideal EIC tracking detectors have low scattering material to optimize tracking
- Drift and readout PCB’s replaced with foils
  - Radiation length reduced from 4% to 0.59% (6.7 times less!)



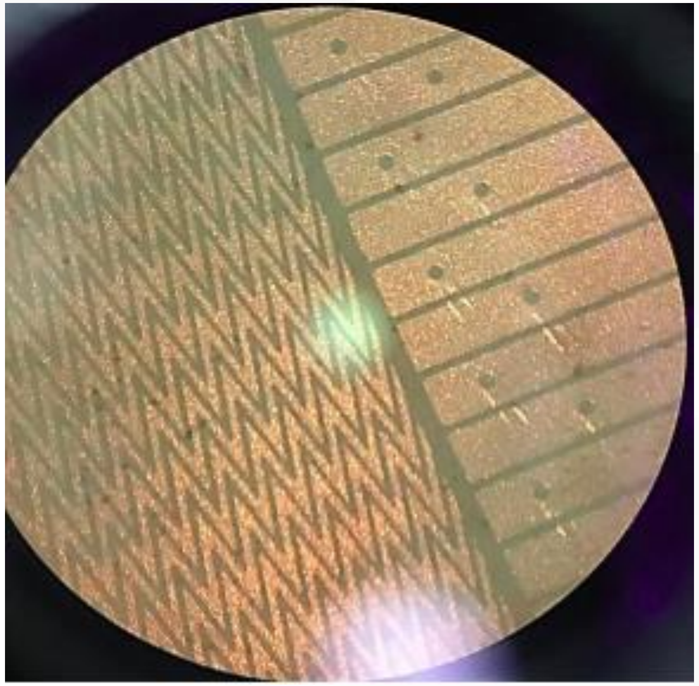
Modified GEM readout foil



GEM stack diagram with modified parts underlined in yellow

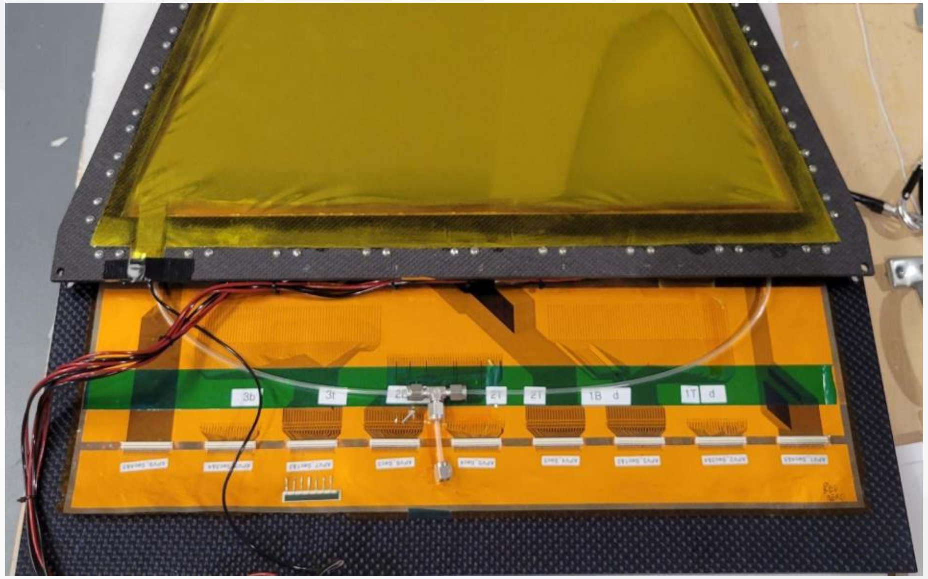
What Advantages Does Our Design Have?

- The spatial resolution of a tracker can be optimized with strip geometry
- This readout uses small and large zigzag readout strips
  - Better spatial resolution than normal straight strips due to strip overlap
  - 66% less channels for the readout!



Left: Microscopic view of the zigzag strips of sector 2 (left) next to the straight strips in sector 1 (right) [3]

Right: Modified GEM stack only needs 9 readout cards



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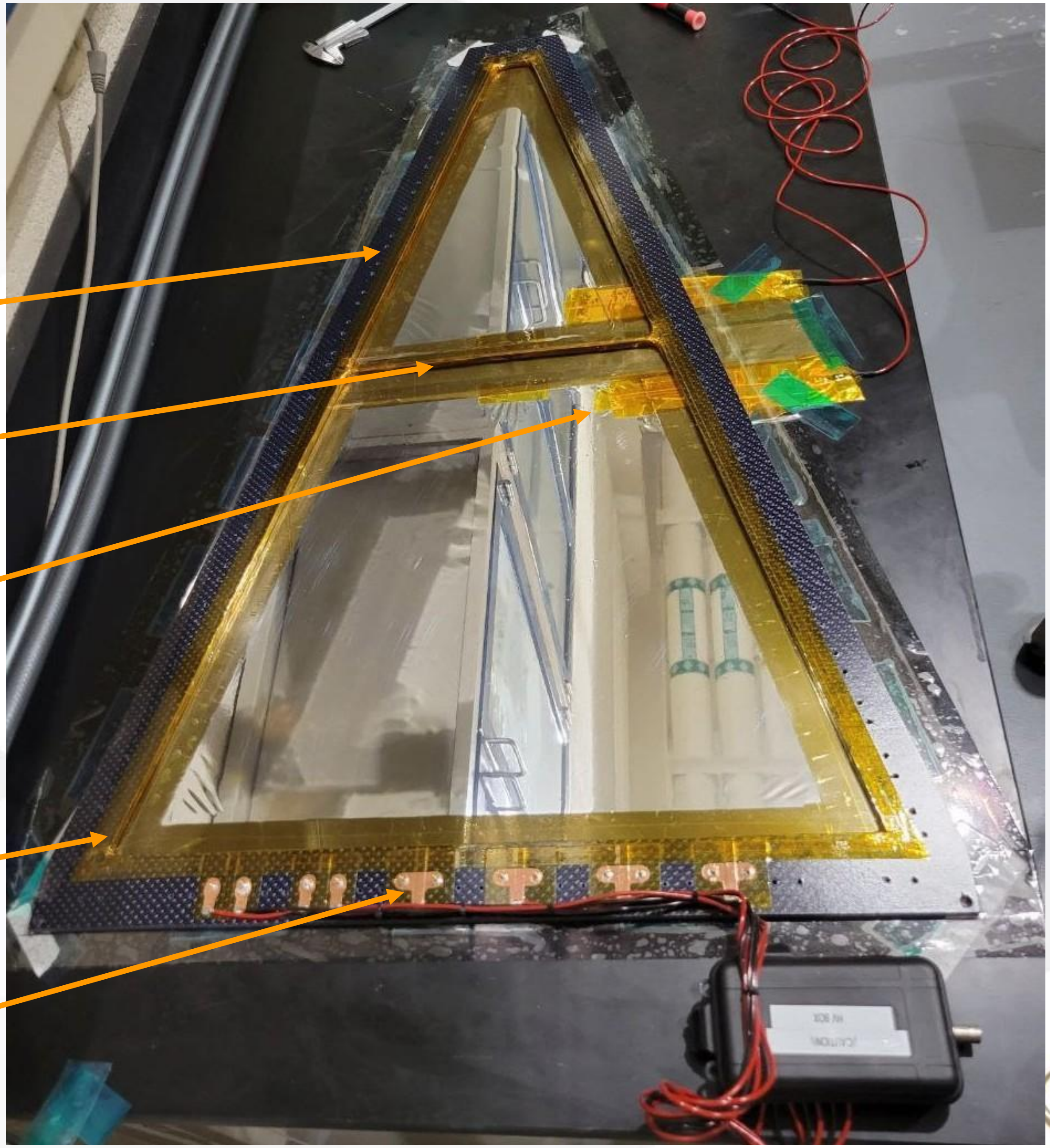
Design of External Frames

GEM foils need a working gas to operate

- $70\%Ar : 30\%CO_2$

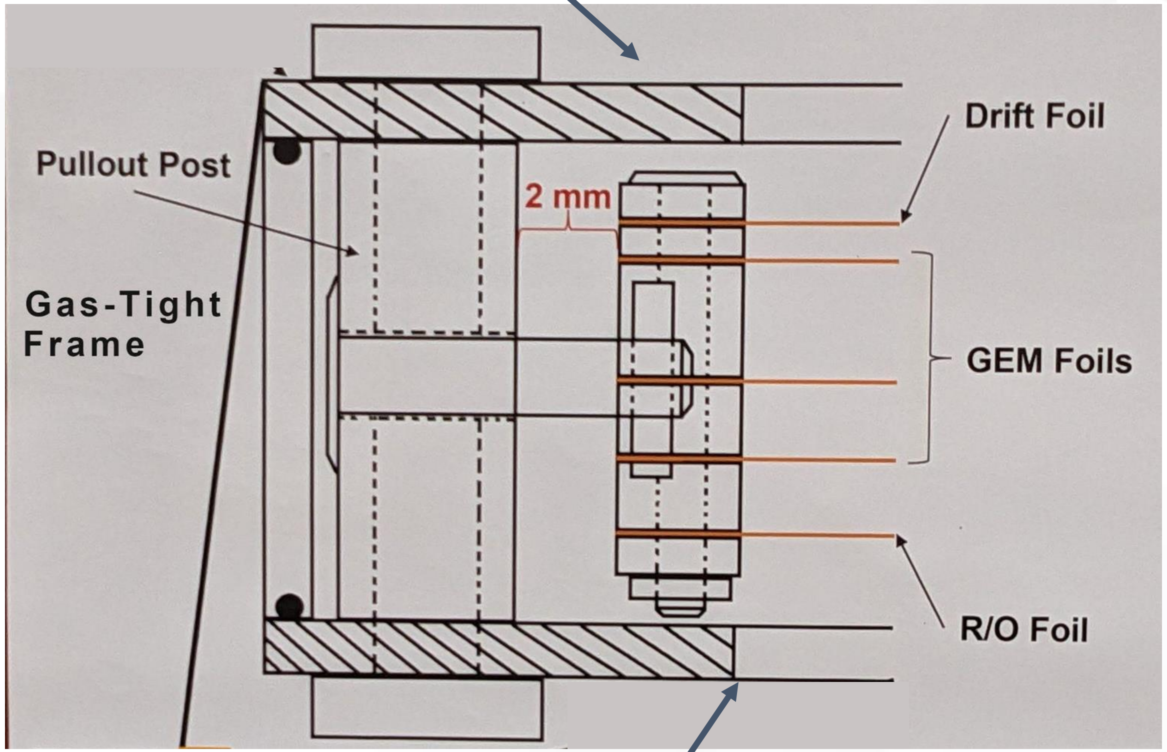
- Carbon fiber (CF) frame with Al-Kapton windows
- Narrow rib in frame to fortify window and frame
- Voltage applied to Al side of drift window to counteract electrostatic force of drift foil
- Al removed in top frame window edges to insulate from CF Frame
- Electrical HV connections to GEM foils



How this GEM Detector was Assembled

- Drift/GEMs/Readout spacing of 3/2/2/2 mm

Top CF Frame

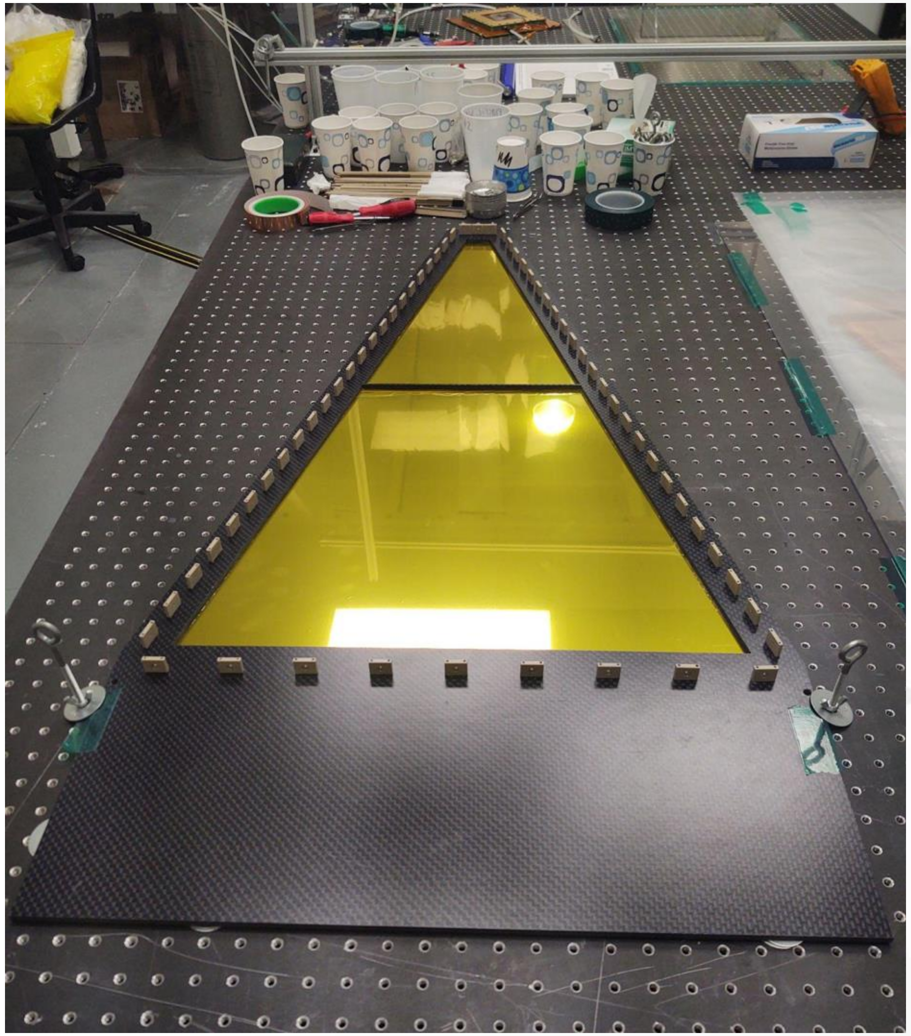


Bottom CF Frame

Side view of modified GEM detector

How this GEM Detector was Assembled

- Drift/GEMs/Readout spacing of 3/2/2/2 mm
- Pullout posts attached to bottom CF frame



Bottom CF frame with pullout posts attached

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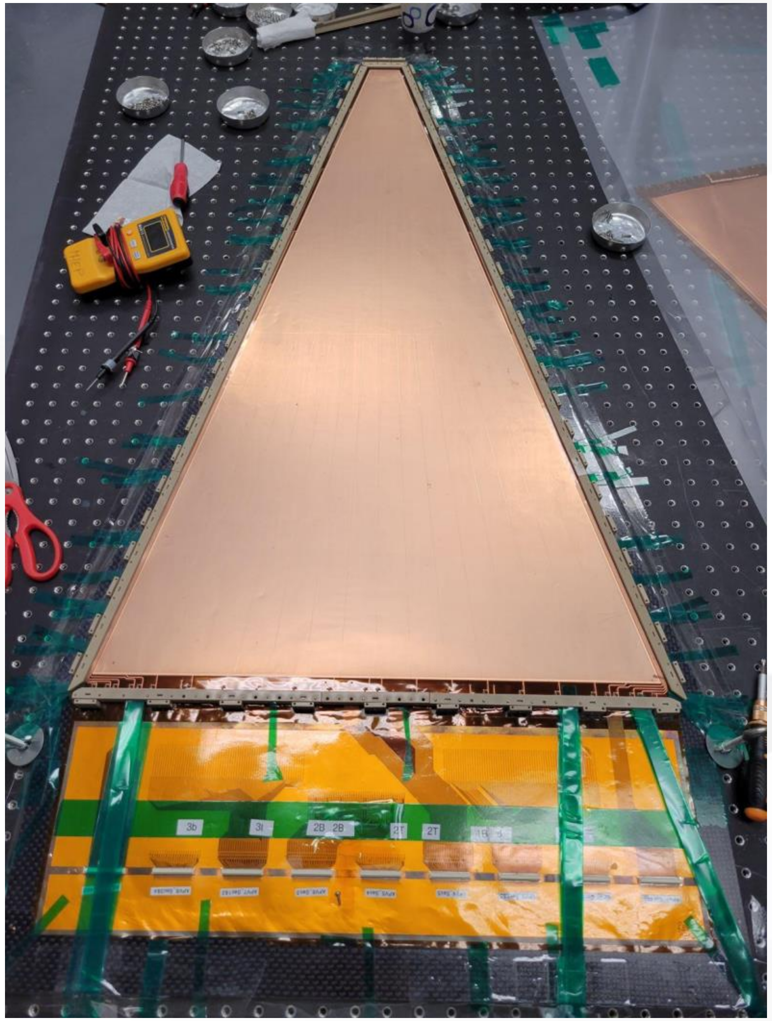
How this GEM Detector was Assembled



Modified GEM stack in the assembly process

- Drift/GEMs/Readout spacing of 3/2/2/2 mm
- Pullout posts attached to bottom CF frame
- GEM stack is assembled as follows:
  a. Foil placed on stack and stretched with tape
  b. Spacer added
  c. Foil tested for shorts
- Tighten GEM stack screws and cut tape
- Pullouts tighten entire stack

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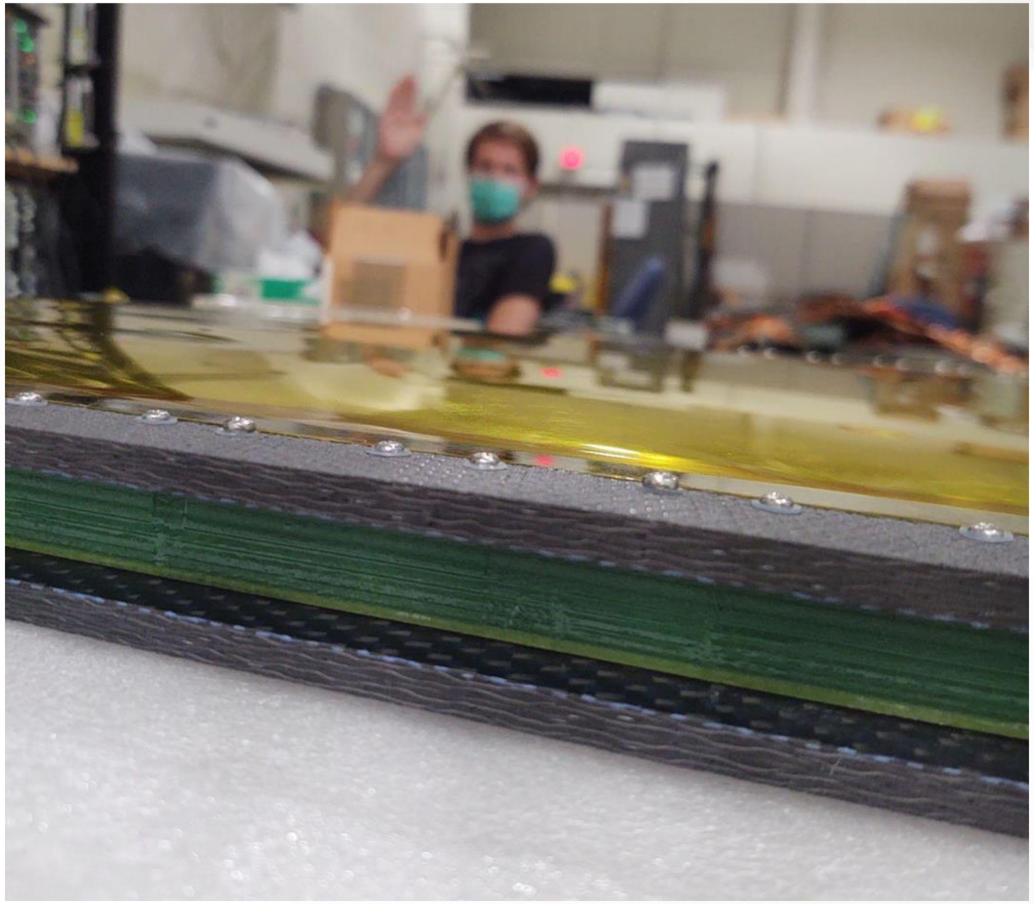
How this GEM Detector was Assembled

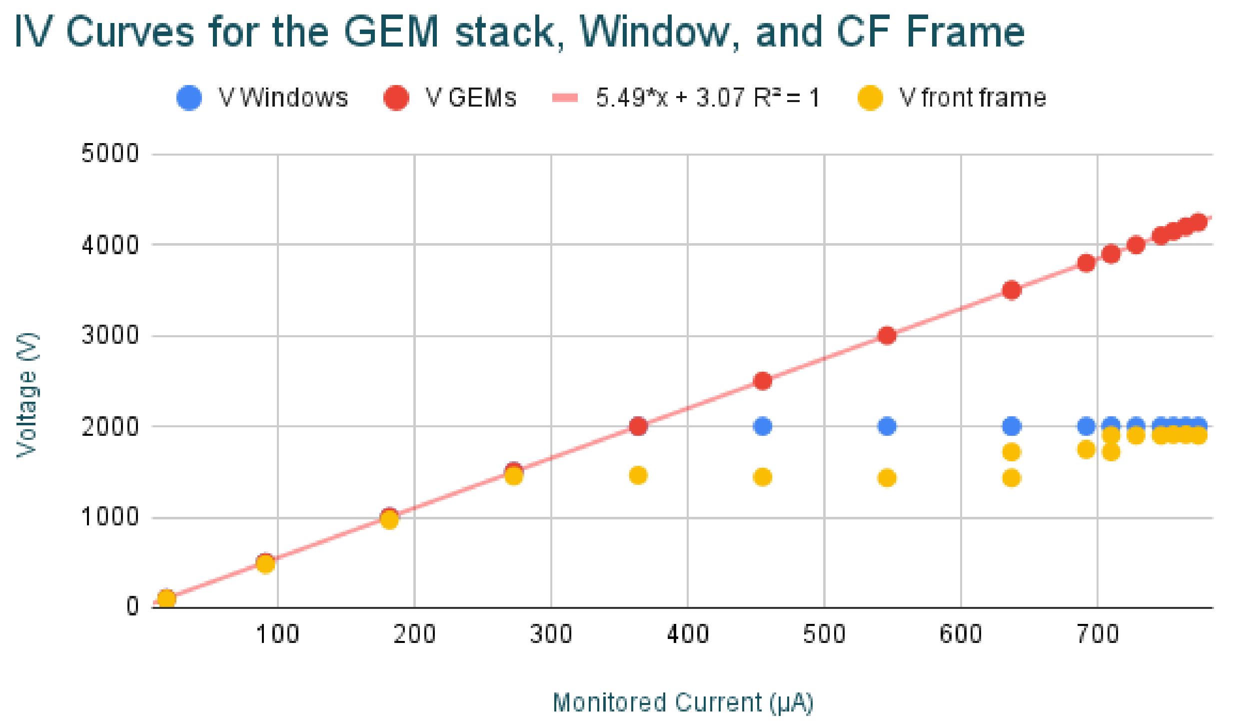


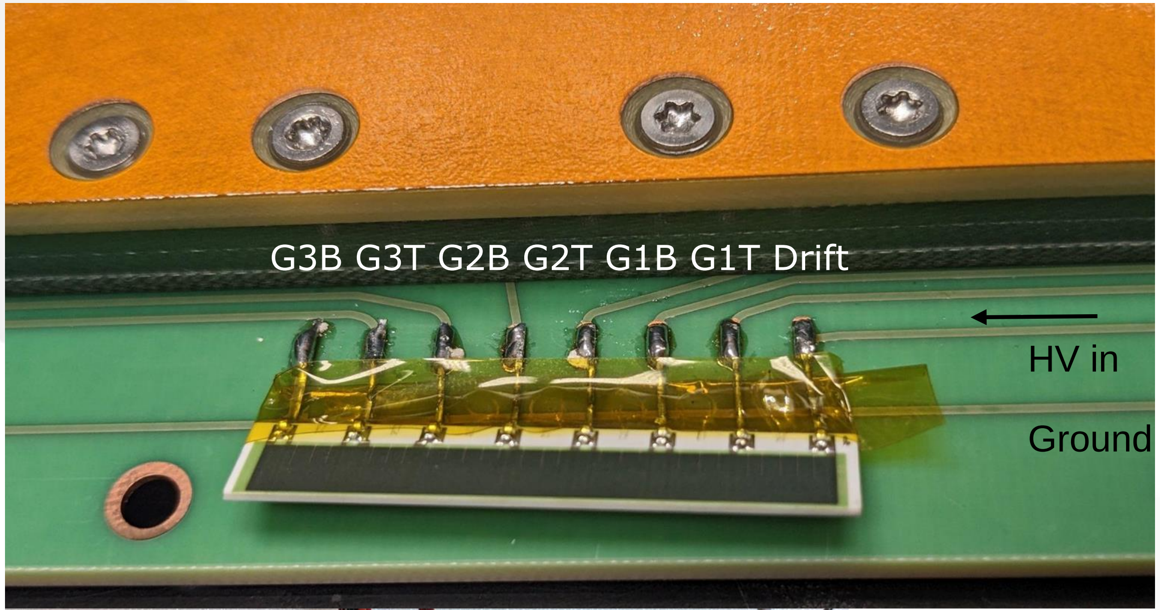
Modified GEM stack in the assembly process

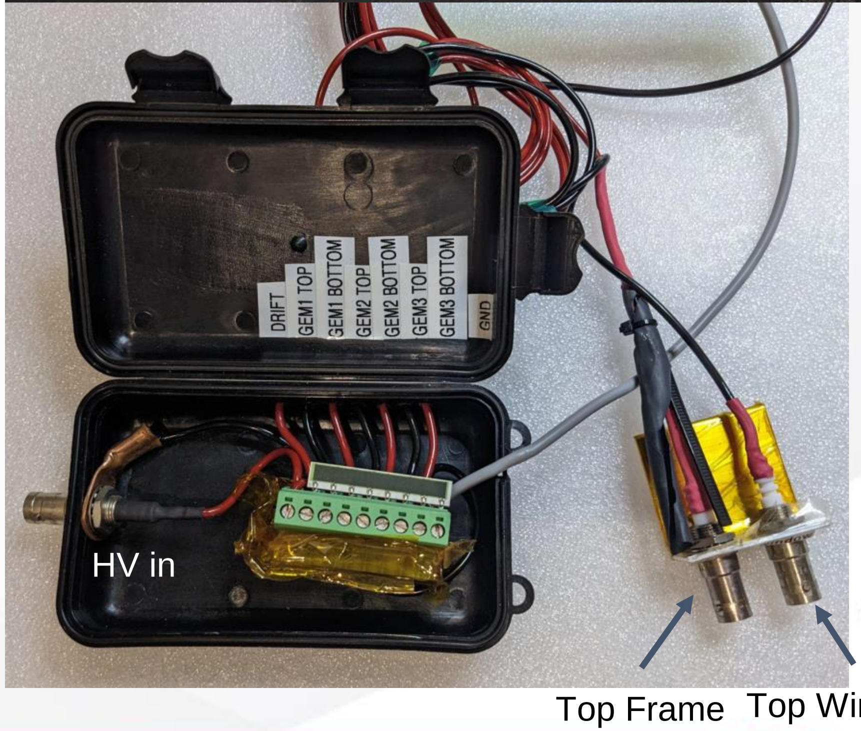
- Drift/GEMs/Readout spacing of 3/2/2/2 mm
- Pullout posts attached to bottom CF frame
- GEM stack is assembled as follows:
  a. Foil placed on stack and stretched with tape
  b. Spacer added
  c. Foil tested for shorts
- Tighten GEM stack screws and cut tape
- Pullouts tighten entire stack
- Add gas tight frame (green), attach top CF frame
- Modified GEM is now complete

Quality Control Testing

- Power is distributed to GEM foils via HV divider
  - Ensure the HV divider is behaving in a linear, ohmic manner
- HV is induced on conductive CF frame !
  - Need to power window with HV to suppress discharges







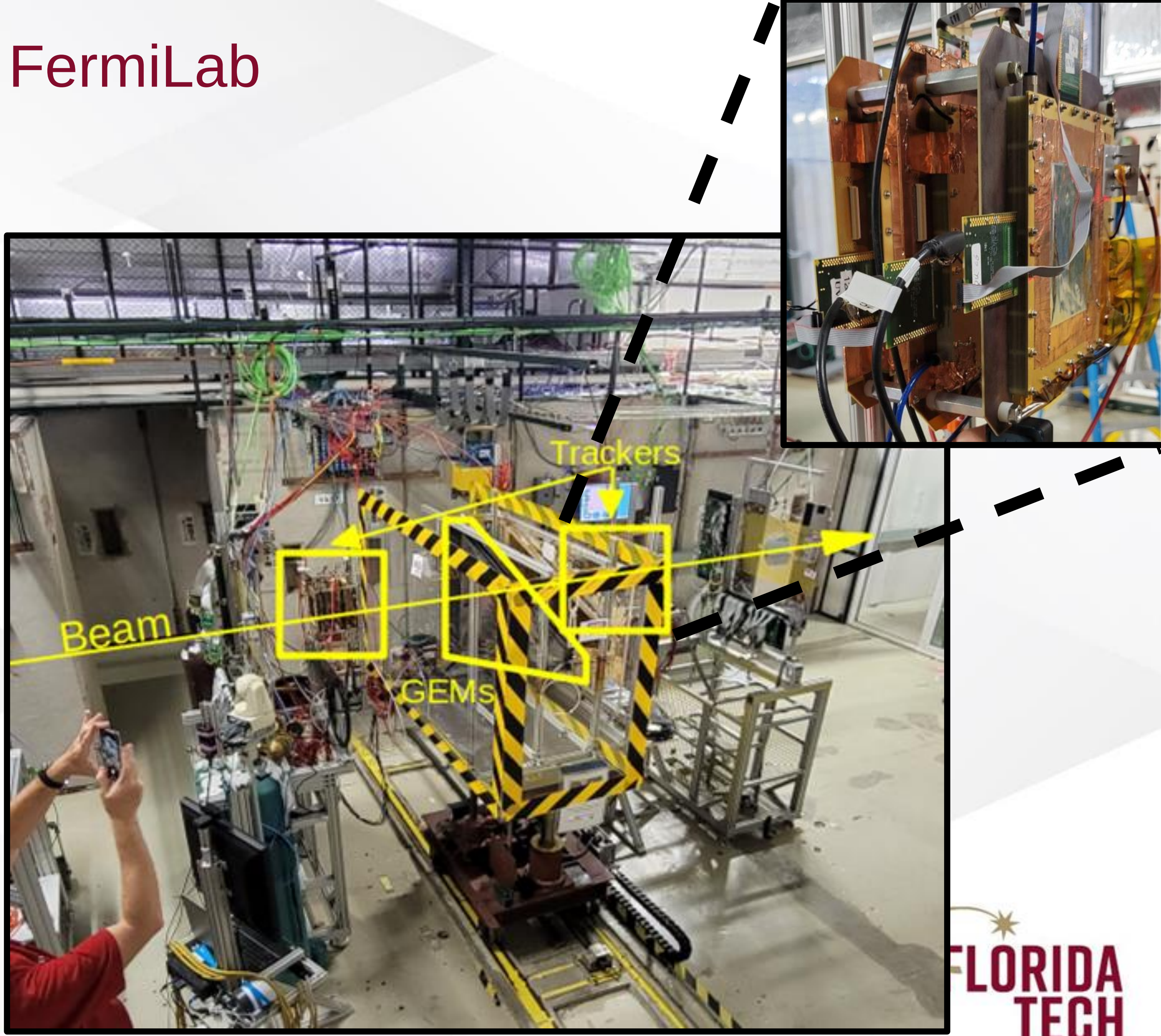
Top: HV divider on M5 GEM detector

Left: HV divider with power to top window and top frame for modified GEM

Beam Test Detector Setup at FermiLab

- FNAL Test Beam Facility (FTBF)
  - 120 GeV Protons (10s pulse / Minute)
- Install detector in beam, between 2 sets of calibrated GEM trackers

FermiLab National Laboratory



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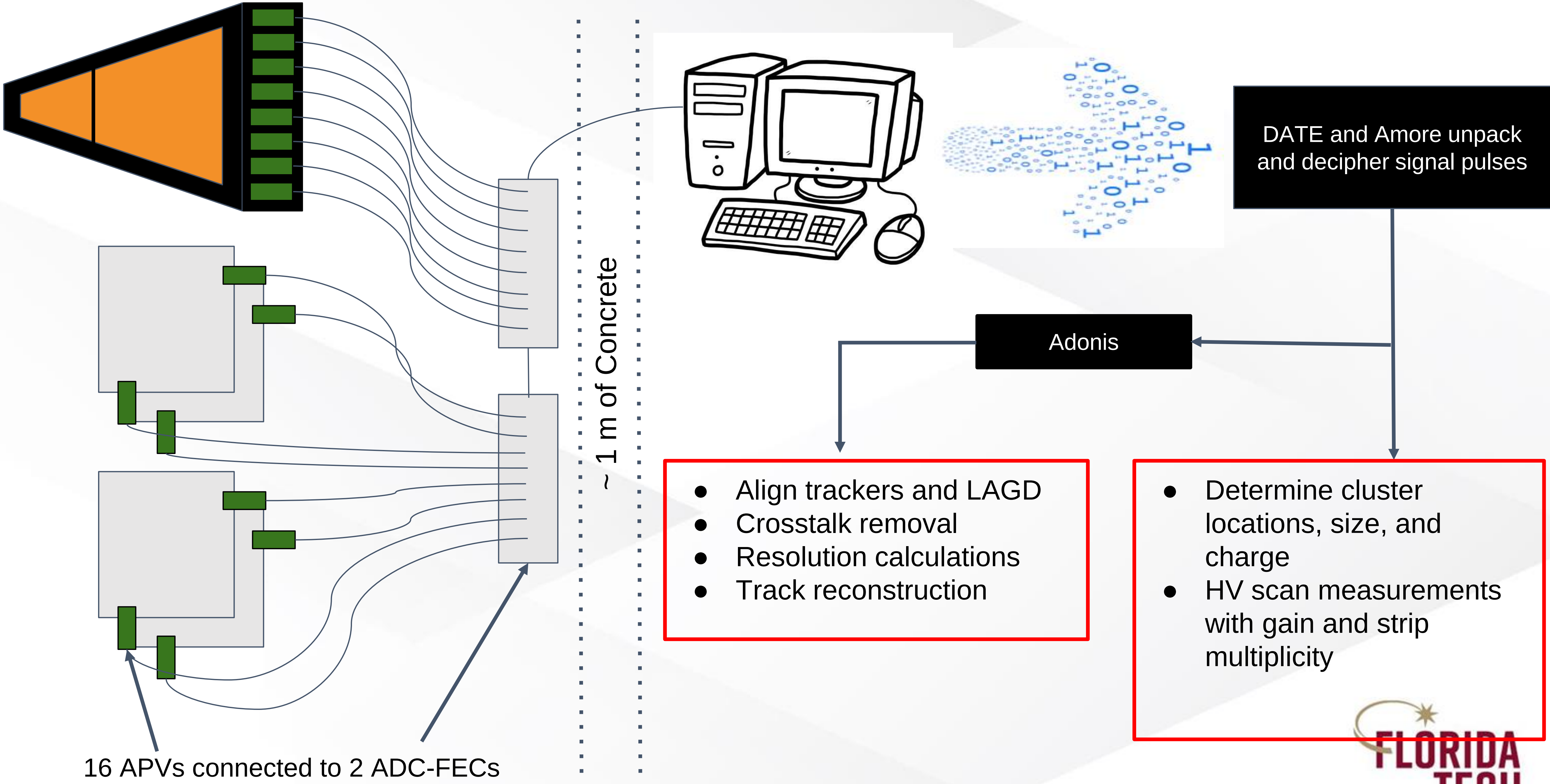
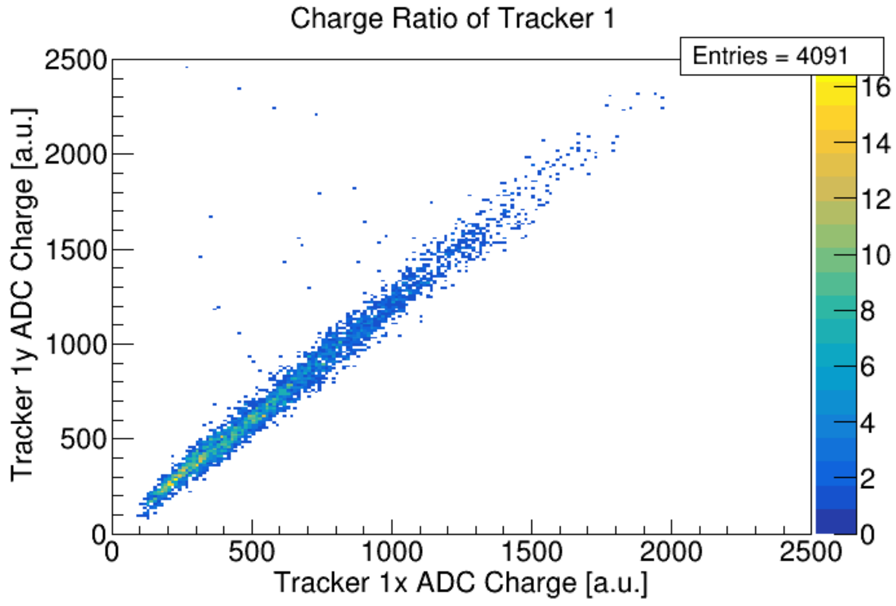
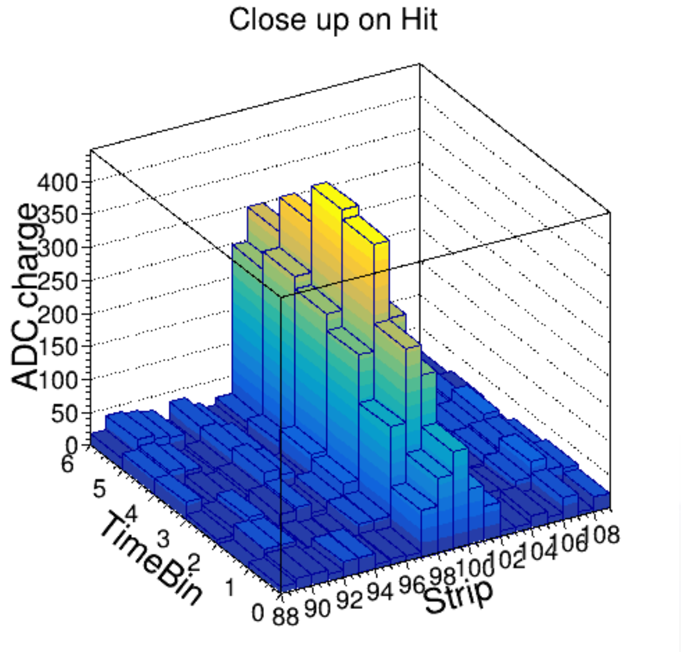
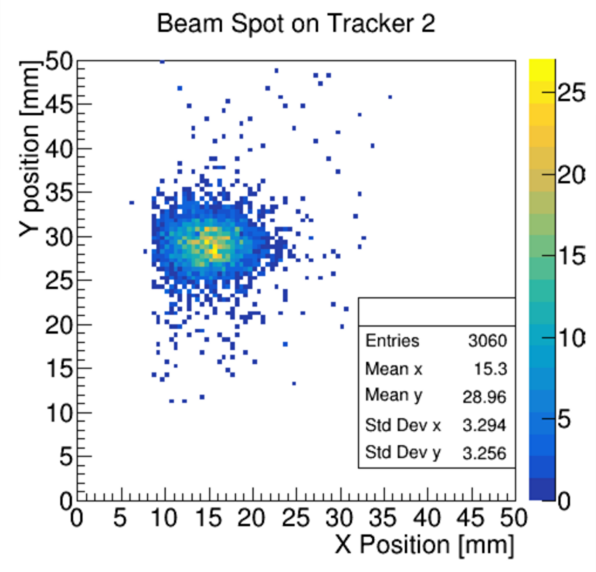

~ 1 m of Concrete
DATE and Amore unpack and decipher signal pulses
Adonis
Align trackers and LAGD
Crosstalk removal
Resolution calculations
Track reconstruction
Determine cluster locations, size, and charge
HV scan measurements with gain and strip multiplicity
16 APVs connected to 2 ADC-FECs

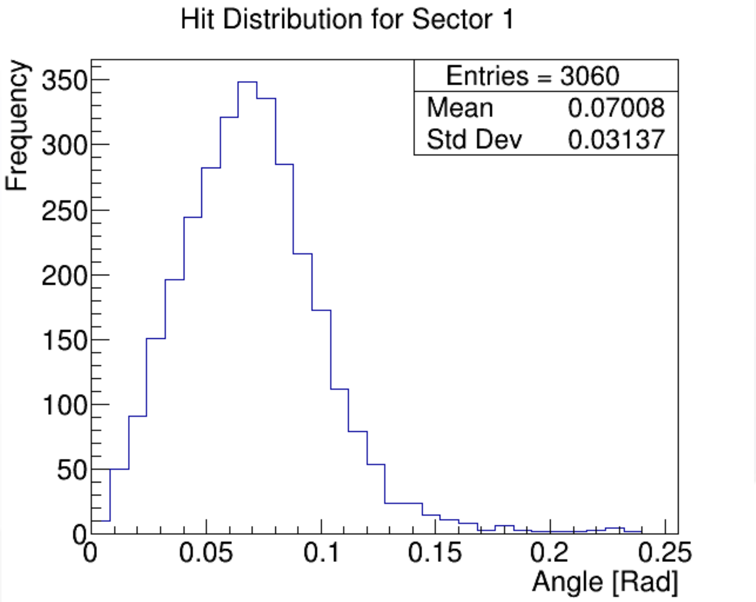
Tracker Hit Characteristics

- Charge Ratio of X and Y hits on trackers
- Strip Multiplicity of hits
- Beam Spots



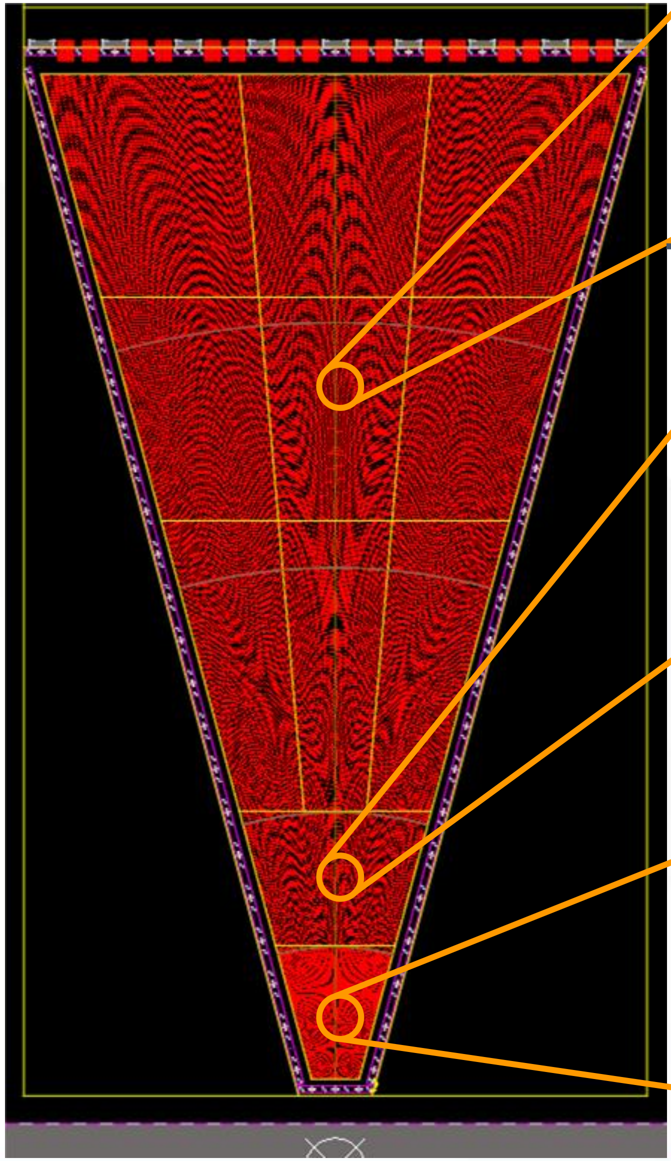




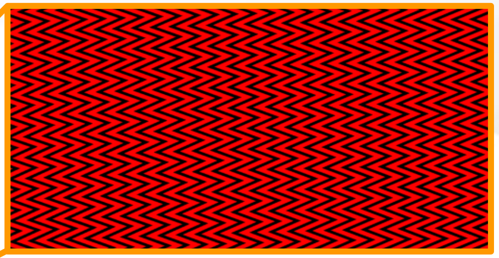


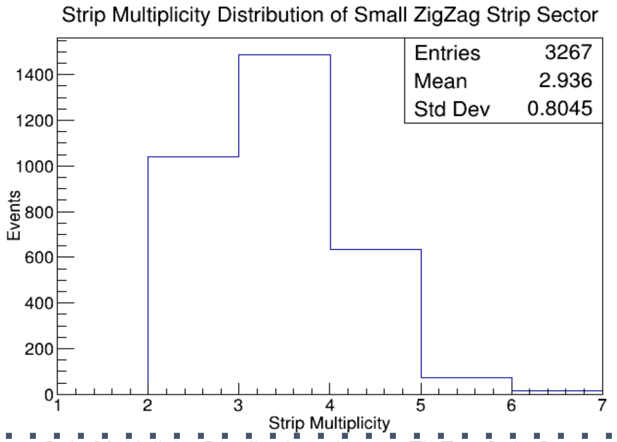
Beam Spot in Trackers 1 and 2 as well as Angular Distribution in LAGD

Strip Multiplicity Results in Different Strip Geometries

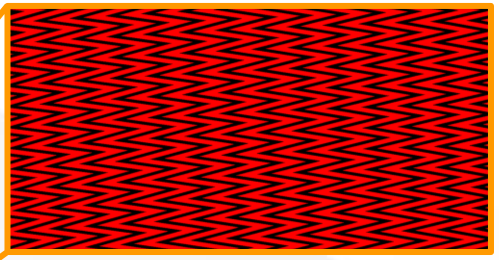


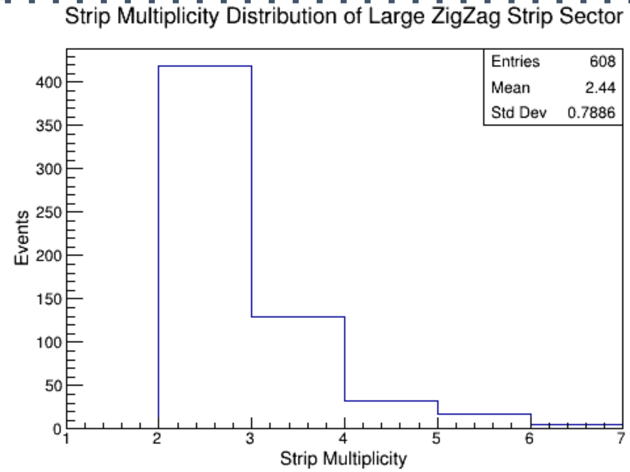
Strip Pitch: 1.37 320 < R < 985 mm



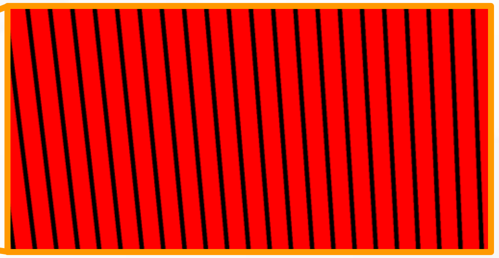


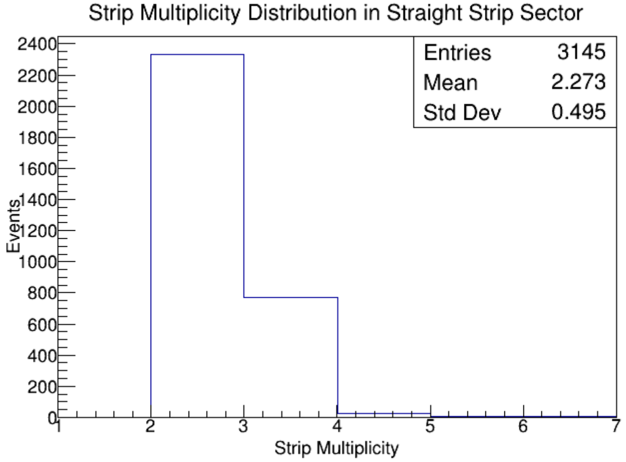
Strip Pitch: 4.14 mRad 200 < R < 320 mm





Strip Pitch: 4.14 mRad 80 < R < 200 mm





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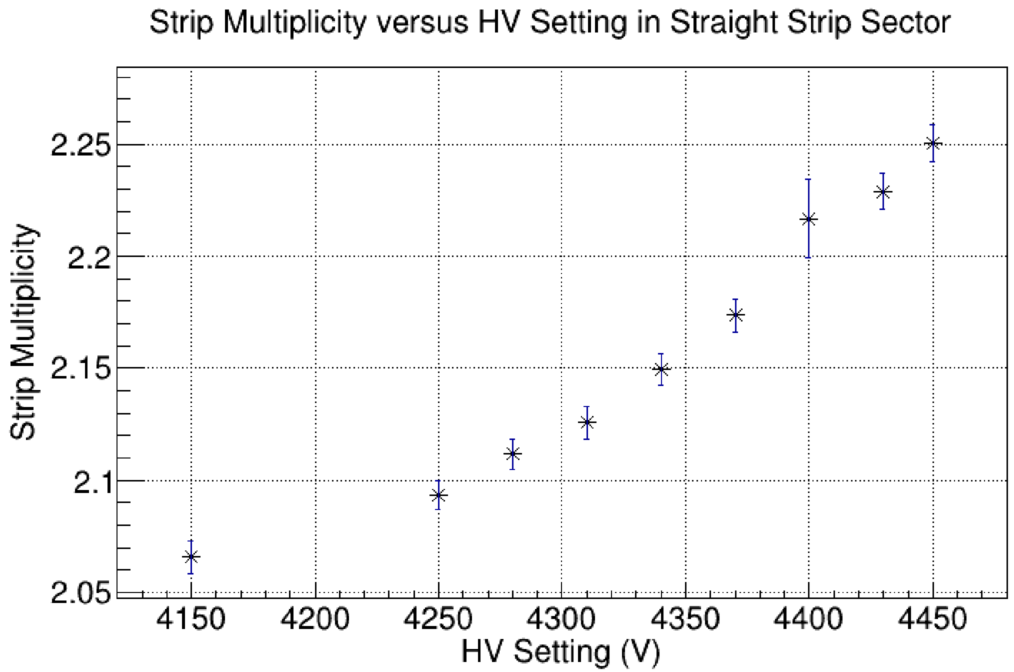
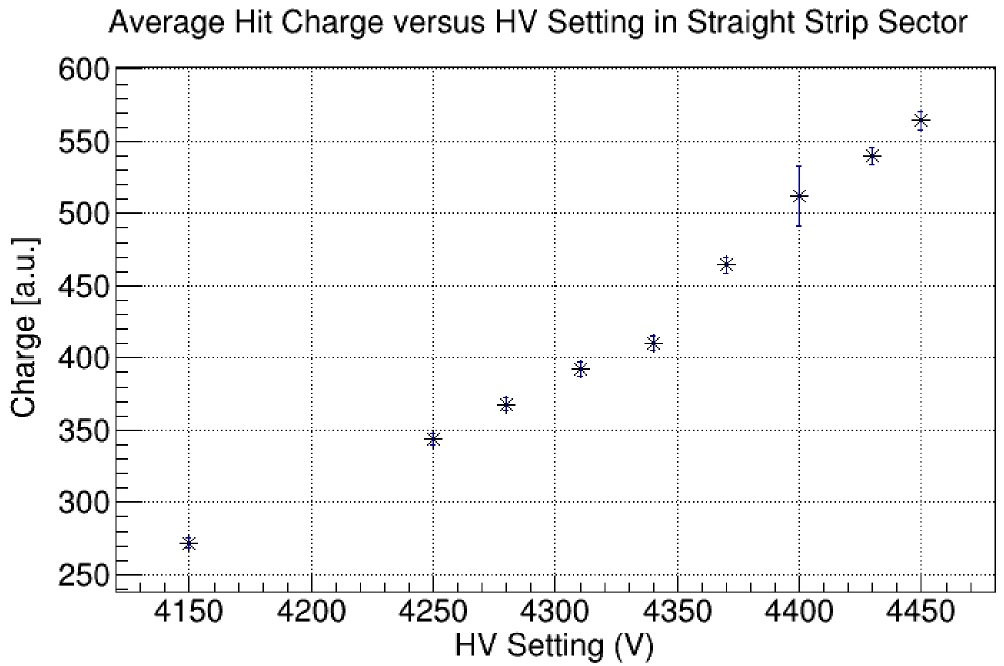
mlavinsky2016@my.fit.edu

High Voltage Scan Results - Large Detector



at R ≈ 103 mm



Increased voltage supplied to the GEM detector leads to increased gain, which leads to more electrons being produced.

1. Wider signal pulses
2. More charge induced on the readout

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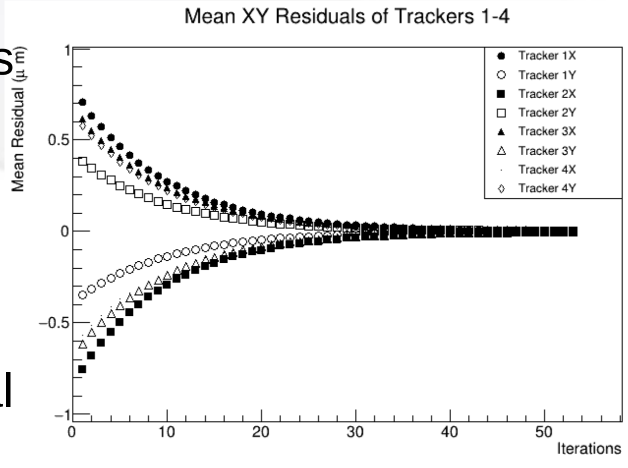
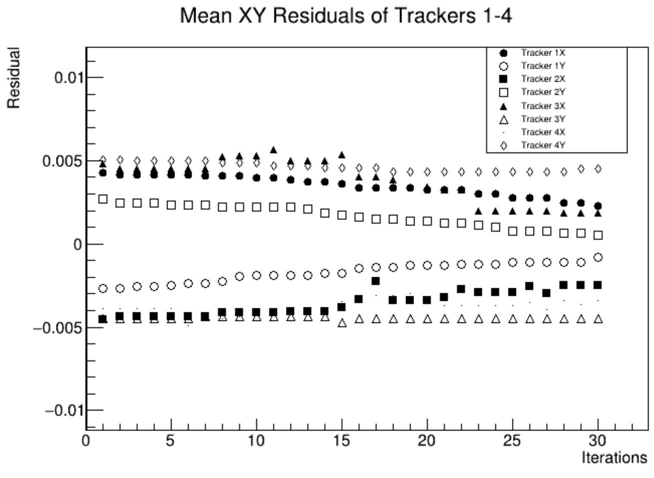
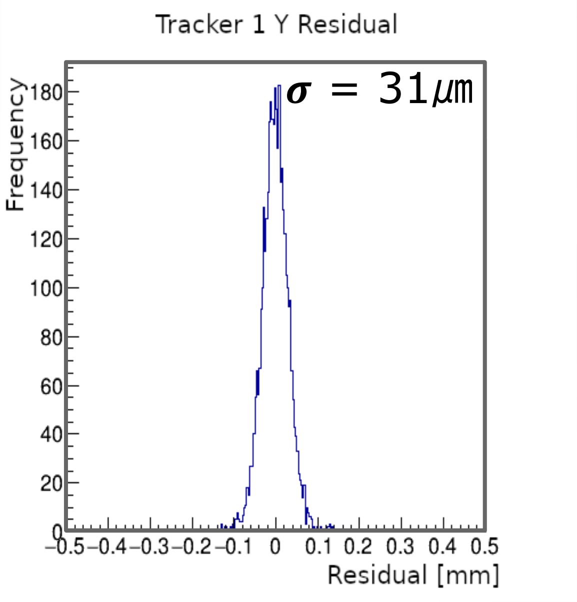
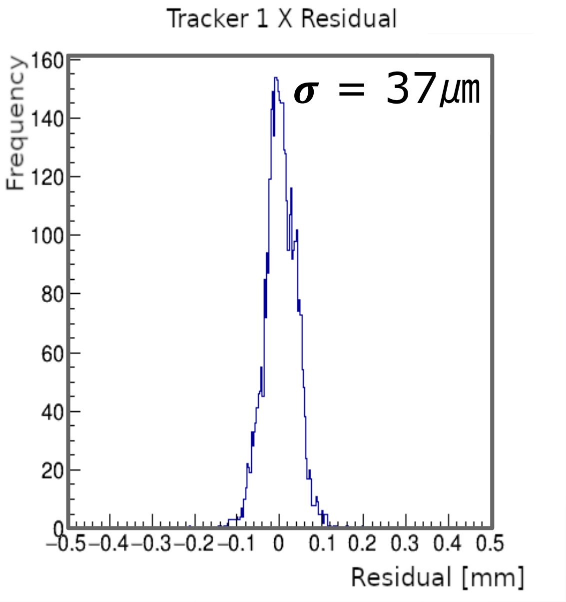
Alignment of the Tracker GEMs

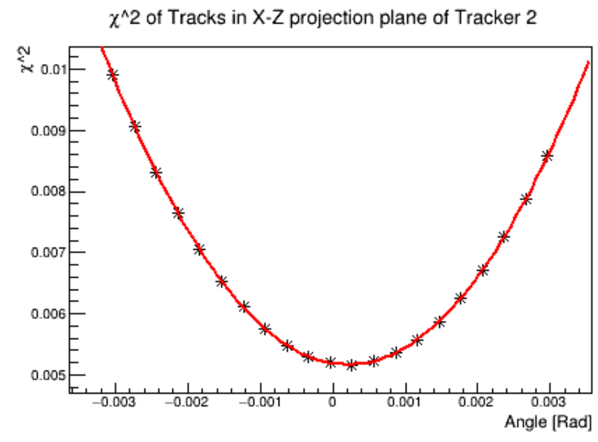
- Need trackers aligned to accurately reconstruct tracks
- 3 main alignment steps
  - Shift in X and Y
  - Shift and rotate at the same time
  - Individually rotate each tracker
- Each iteration shifts trackers by 10% of mean residual
- Trackers mean residuals aligned to within ≈35 μm

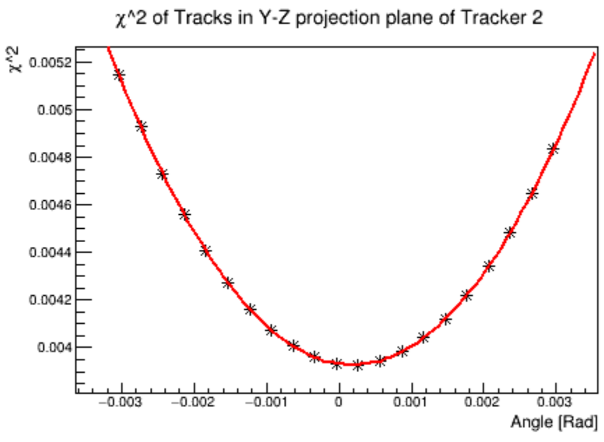












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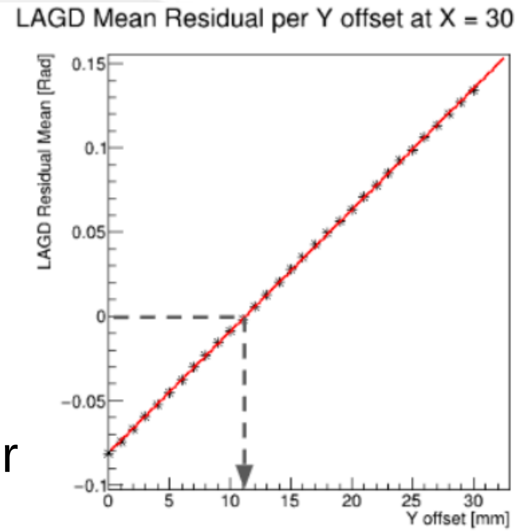
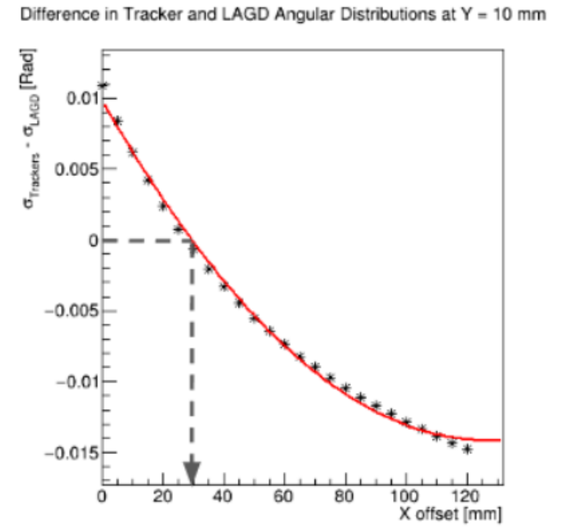
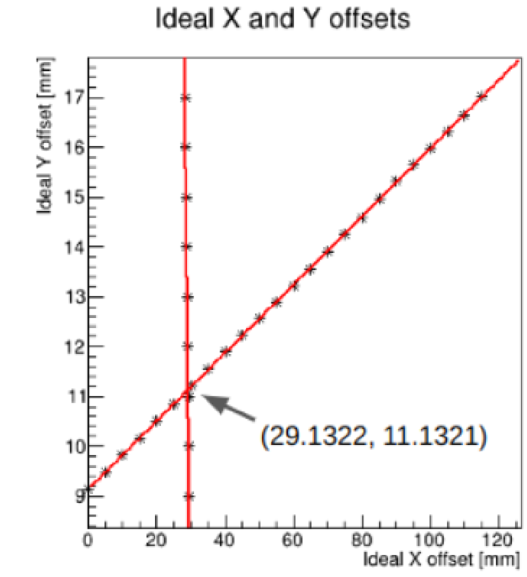
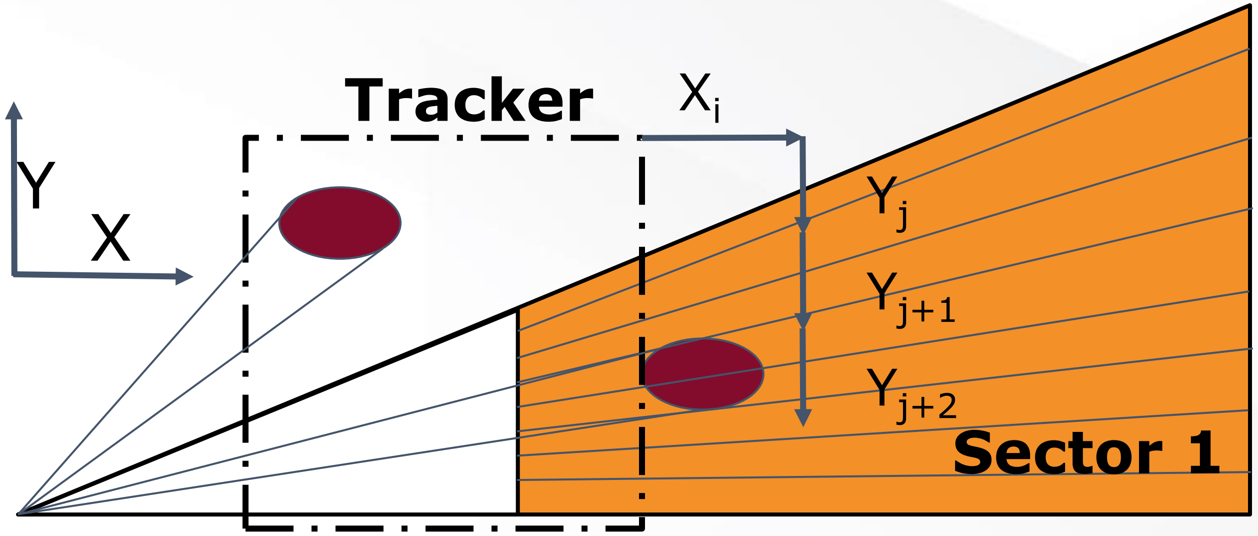
Aligning the Trackers with the LAGD

- Need to determine X,Y offsets to align trackers with the active sector on the LAGD
- LAGD only measures azimuthal angle
- Covert tracker XY coordinates to polar coordinates
- The tracker beam spot is shifted throughout the active sector and tracks are reconstructed
  - Ideal Y offset minimizes LAGD residual mean
  - Ideal X offset minimizes LAGD residual standard deviation









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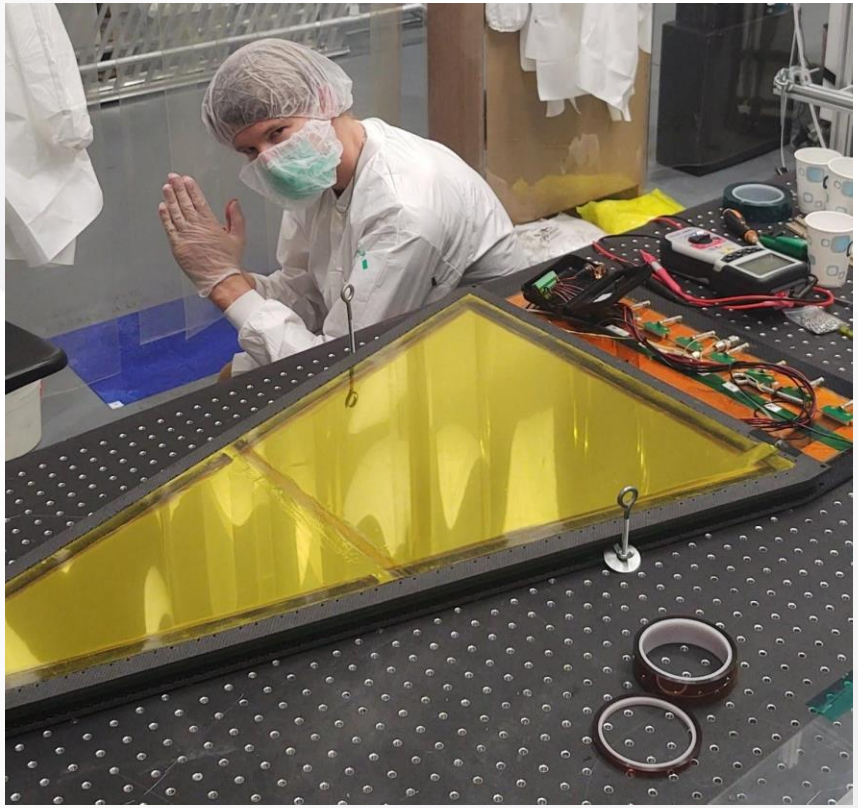
Conclusions and Future Outlook

- Designed, assembled, and successfully took data with a low-mass, large-area GEM detector!
- Hit characterization, HV scans, and tracker alignment completed
- In progress:
  - Resolution studies of different strip regions
  - Mitigate leakage current to outer frame
  - gain curves



Jared kneeling beside modified GEM after first successful complete assembly

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Questions?

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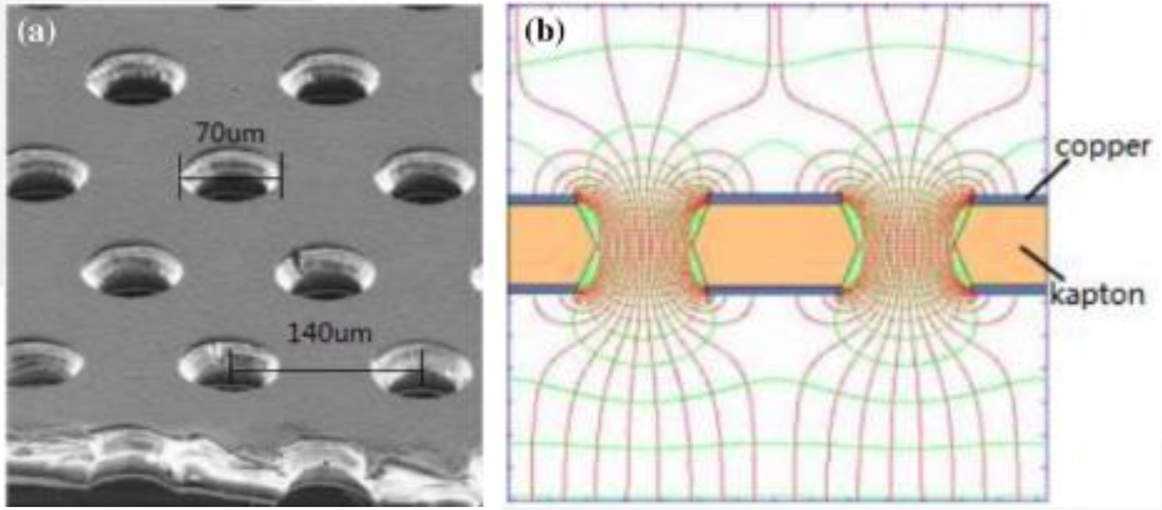
References

1. https://wiki.bnl.gov/EPIC/index.php?curid=154
2. https://wiki.bnl.gov/EPIC/index.php?curid=11
3. https://arxiv.org/pdf/1711.05333.pdf
4. https://cms.cern/content/homeland-security
5. https://link.springer.com/article/10.1007/s41605-020-00166-0
6. Sauli, F. (2020). Micro-Patterned Gaseous Detectors.
7. https://www.flickr.com/photos/brookhavenlab/albums/72157714316624996
8. https://atlas.cern/updates/news/scientific-potential-high-luminosity-lhc

Backup Slides

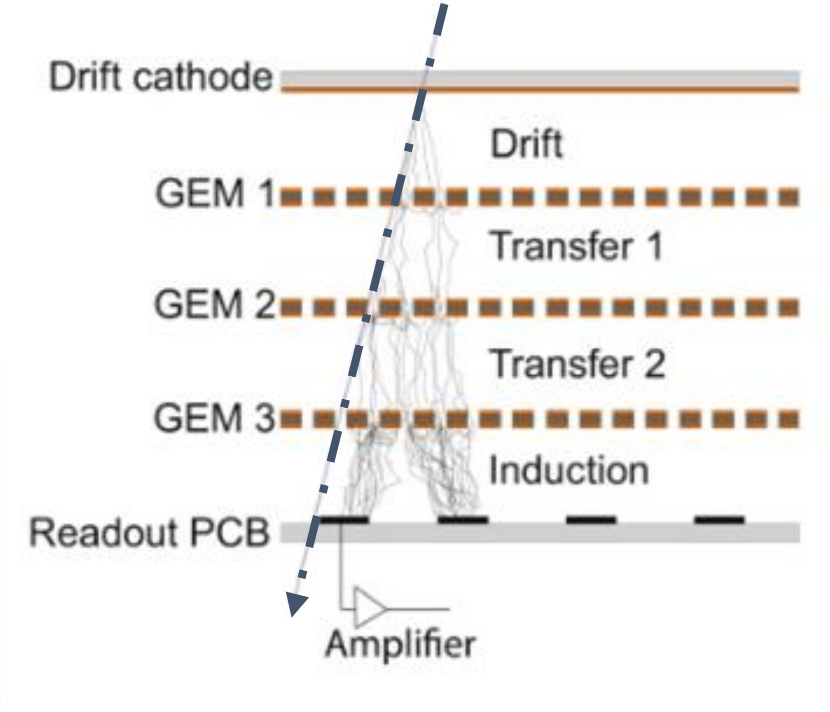
How GEM Detectors Work

Gas Electron Multiplier foils amplify the signal within gaseous radiation detectors



Left: Close up of GEM foil [5]. Right: Electric field pinching in GEM foil pores [5]

1. Radiation particle enters detector
2. Ionizes gas, releasing electrons
3. Electrons forced towards readout and through GEM foils via electric fields
4. Readout signal induced on strips by electron showers



Left: Side view of radiation particle interacting with a GEM detector [4]

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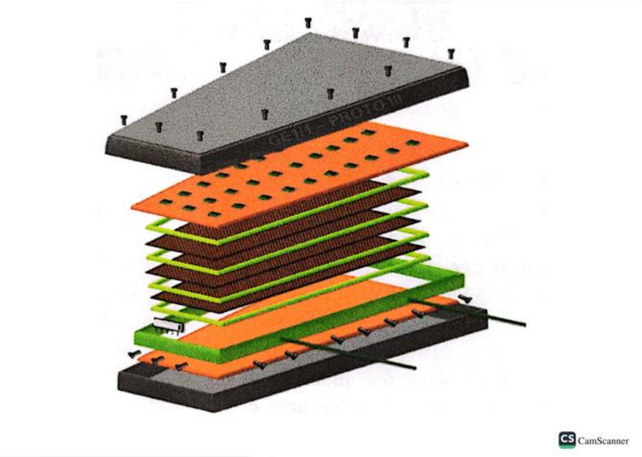
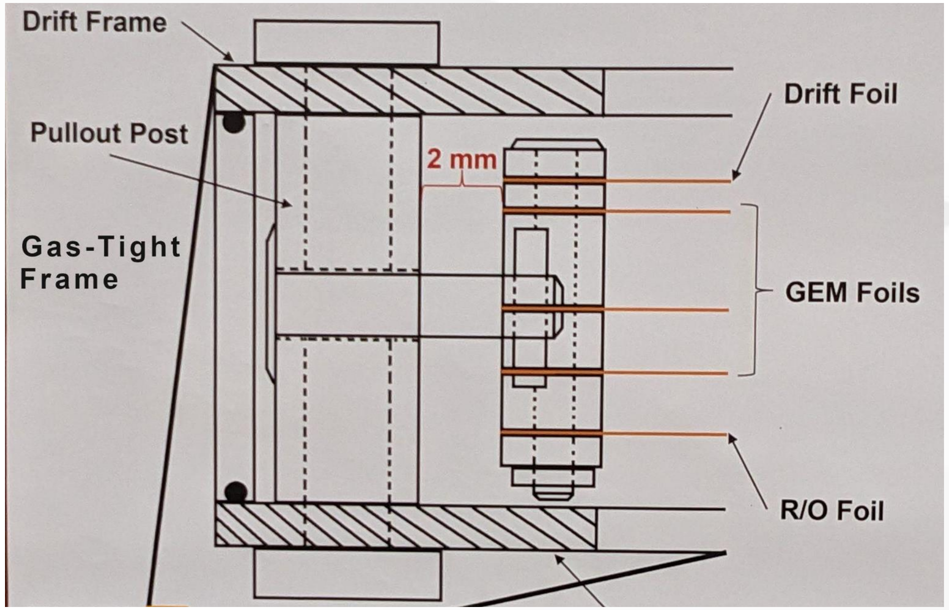
How this GEM Detector was Assembled



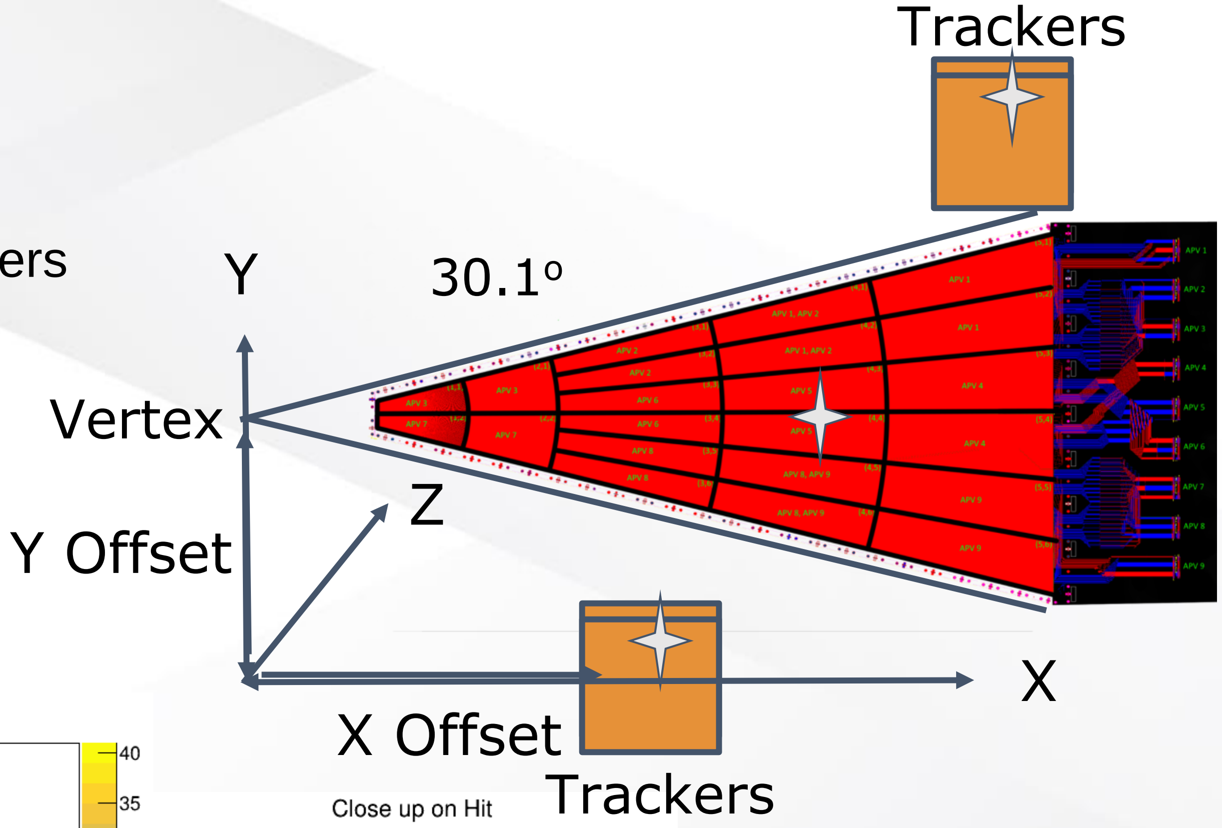


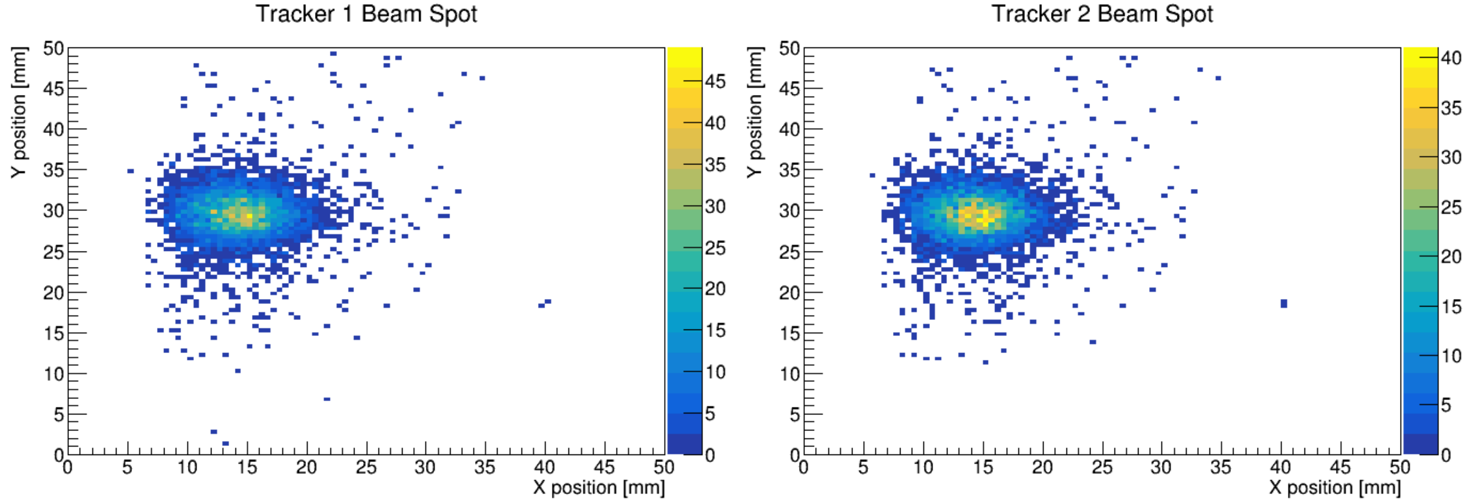
Exploded View [6] and Side Profile [] of assembled GEM stack

- Foils tested for Shorts
- GEM stack is assembled:
  - Foil placed on stack and stretched with tape
  - Spacer added
  - Foil tested for shorts
  - Repeat for all foils
- Tighten stack screws and cut tape
- GEM stack placed in bottom frame and connected to pullouts for last stretch
  - Planarity is Important for Uniform Gain
- Electrically test and add gas tight frame to seal top and bottom frames
- Screw on top frame and assembly is finished!

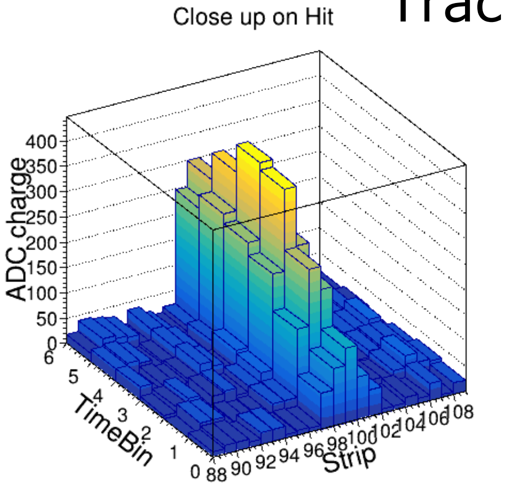
How Adonis Analyzes the Data

- Use decoded signals from strips in GEMs and trackers
- Determine strip multiplicity and cluster charge
- Reconstruct particle track
    - Z positions were measured at FTBF
- Align trackers and GEMs (X,Y and rotational)
- Calculate reconstruction level data



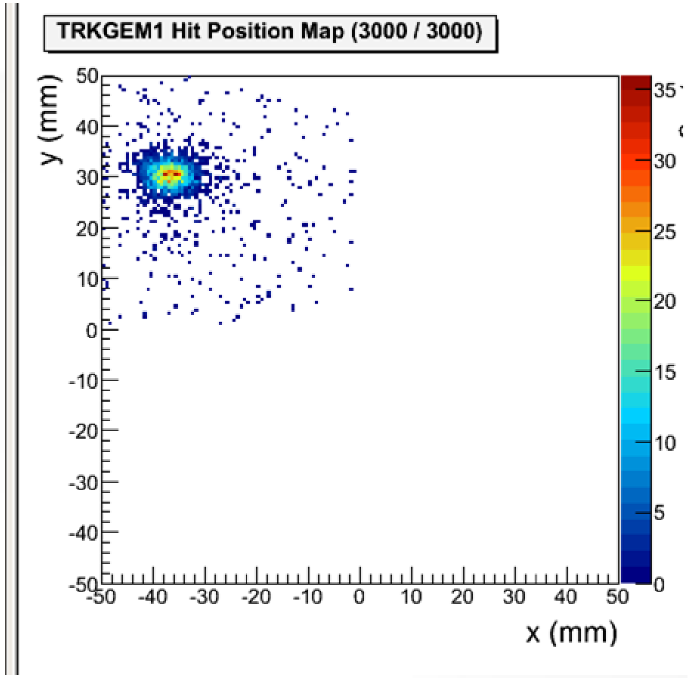


Beam Spot in Trackers 1 and 2

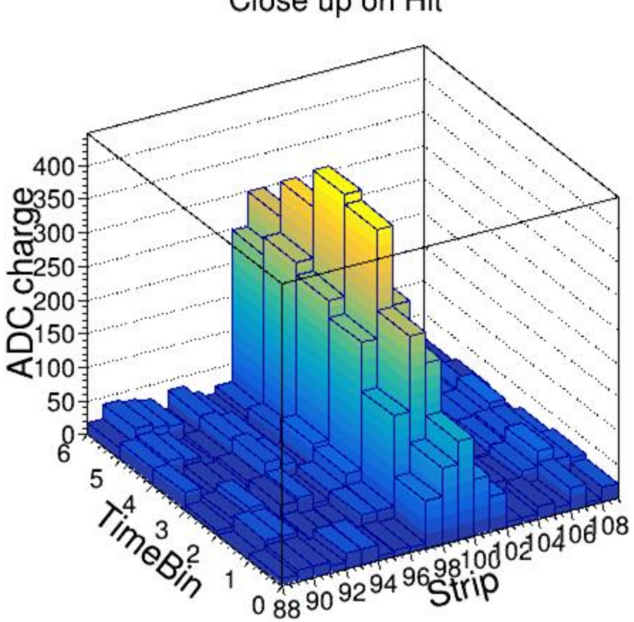


Example Hit with Strip Multiplicity of 4

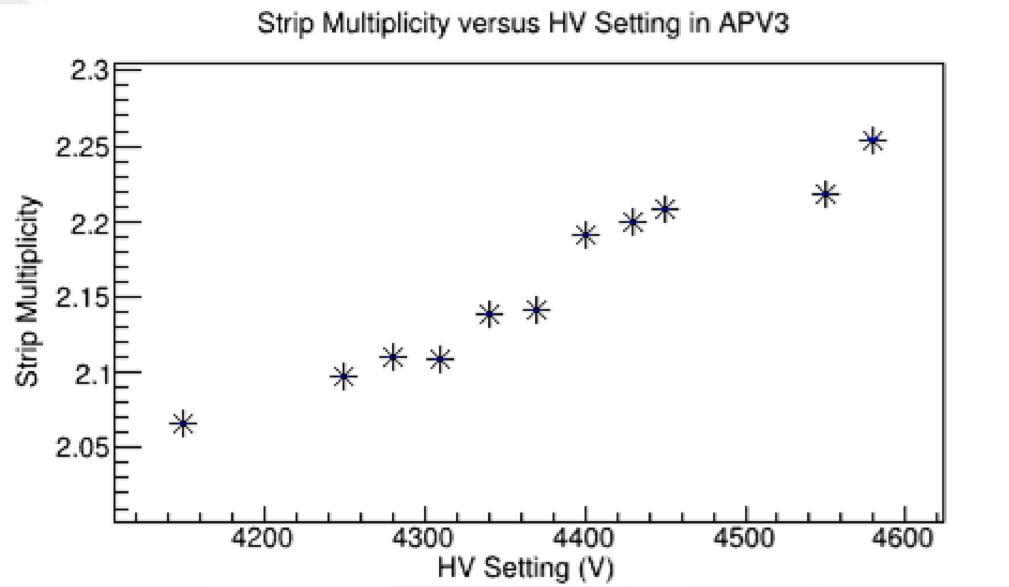
Data from FTBF!



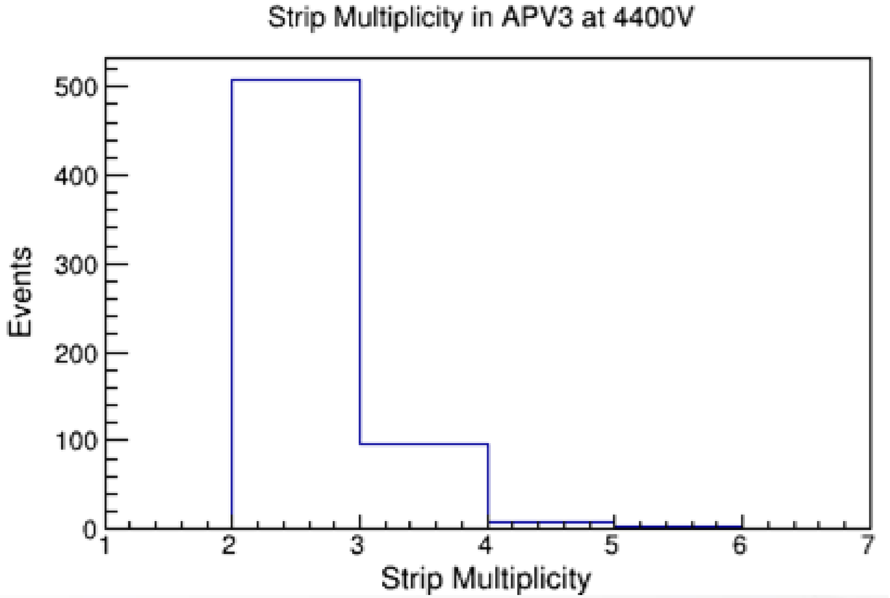
Hitmap of beam in Tracker 1

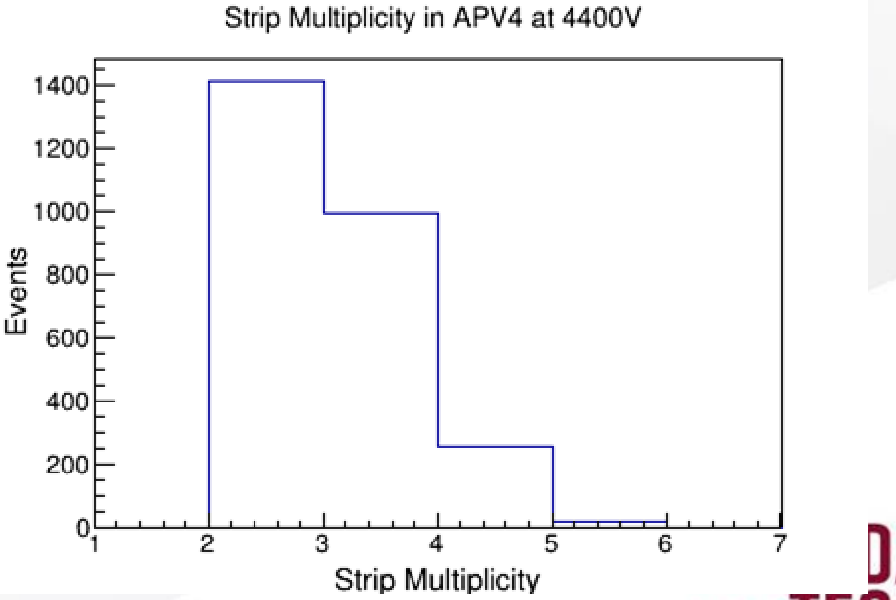


Example Hit with Strip Multiplicity of 4



Strip Multiplicity over a range of HV settings in APV3





Comparison of Strip Multiplicities from Straight and ZigZag strips