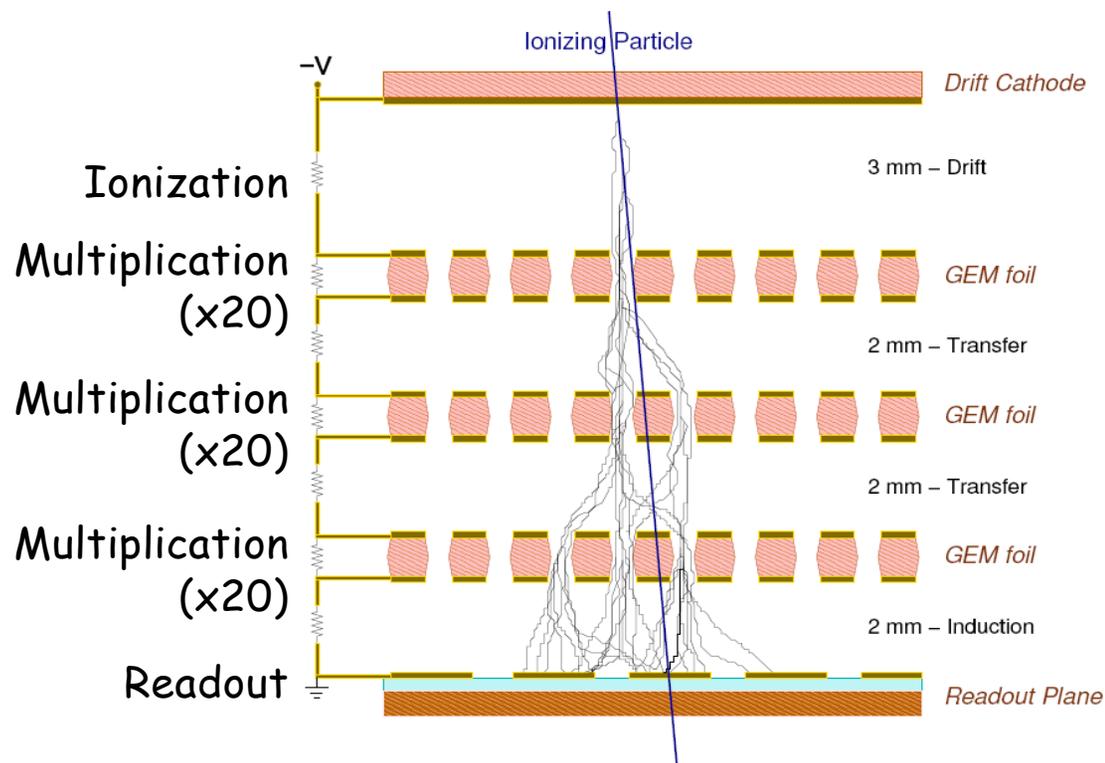


GEMs for future SBS

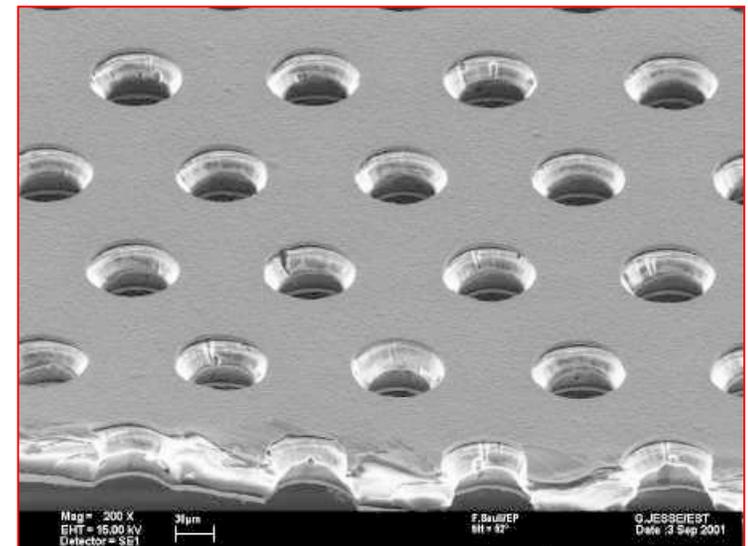
Nilanga Liyanage

Why did we have to use GEMs for SBS ?

- SBS concept called for high rate trackers with good position resolution.
- GEMs: cost effective for high resolution tracking under high rates over large areas.
 - Rate capabilities higher than many MHz/cm²
 - High position resolution (< 75 μ m)
 - Ability to cover very large areas (10s – 100s of m²) at modest cost.
 - Low thickness (\sim 0.5% radiation length)
- Used for many experiments around the world: COMPASS, CMS upgrade, ALICE TPC, pRad etc.



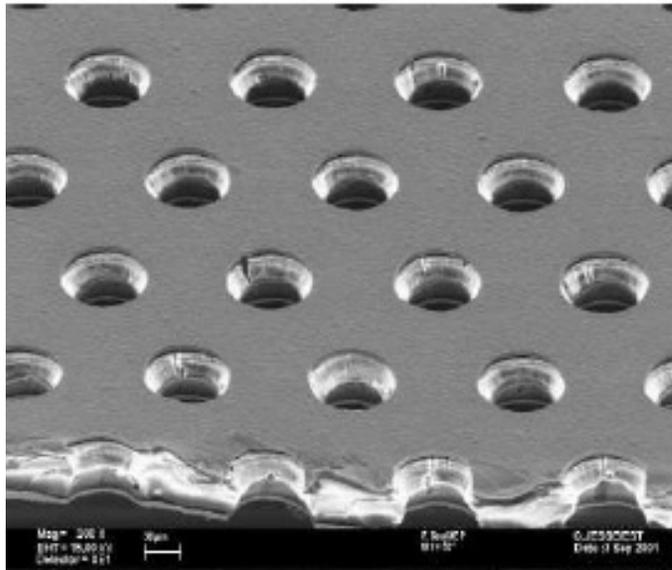
GEM foil: 50 μ m Kapton + few μ m copper on both sides with 70 μ m holes, 140 μ m pitch



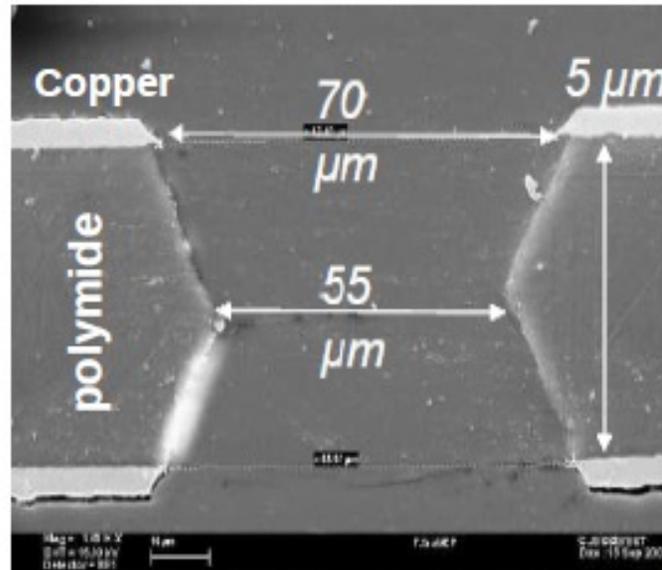
GEM foil: Electron amplification device

- Thin, metal-clad polymer foil chemically perforated by a high density of holes, typically $100/\text{mm}^2$
- Voltage of ~ 350 V across the Cu electrode creates a strong field in the hole leading to amplification
- The ionization pattern is preserved by design with the electric field focusing the charges inside the holes

GEM foil



GEM hole parameters



E Field pattern

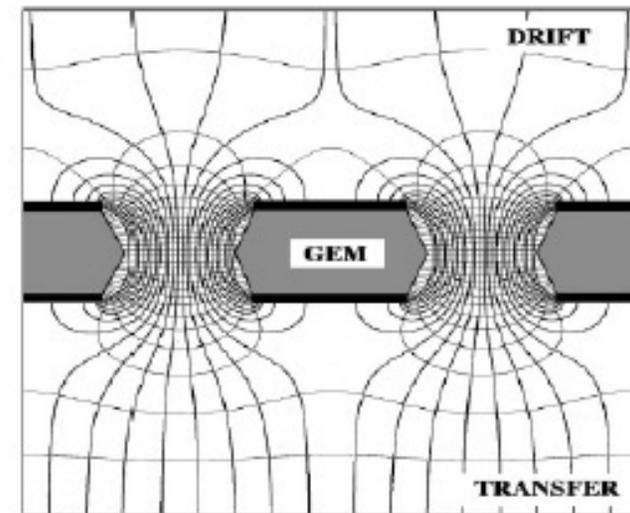


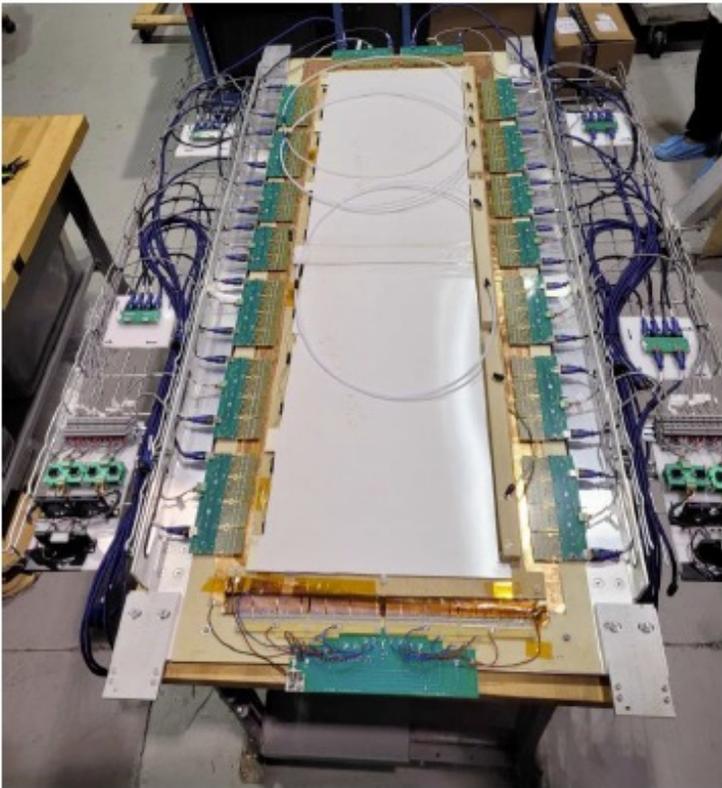
Figure 54 Electric field and equipotentials lines in the gas electron multiplier.

UNIQUE FEATURE

Charge amplification is decoupled from the charge collection \Rightarrow Multi-stage amplification

SBS GEM trackers: gaining GEM operation experience under conditions exceeding SoLID requirements

- 50 cm x 60 cm GEM modules for SBS rear tracker
- 150 cm x 40 cm large GEM modules for SBS front tracker: 6 modules



UV (shown)
40 x 150 sq.cm
Single module



XY (shown)
60 x 200 sq.cm
4 modules

UVa GEM project co-PI
Dr. Huong Nguyen and
her team built the UV
and XW GEMs in record
time and in the middle
of the pandemic.

All 6 of these GEMs
have performed
exceptionally well in
beam, exposed to the
highest rates.

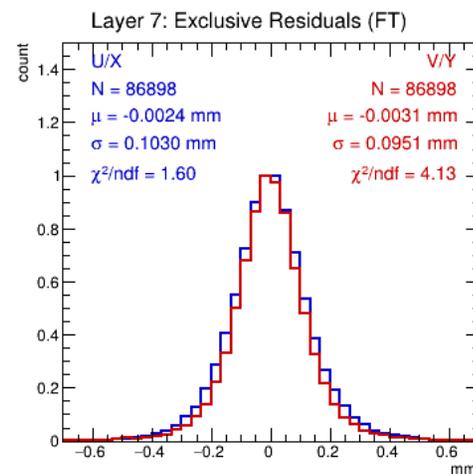
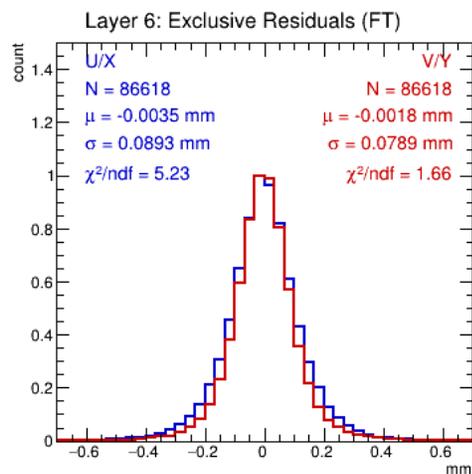
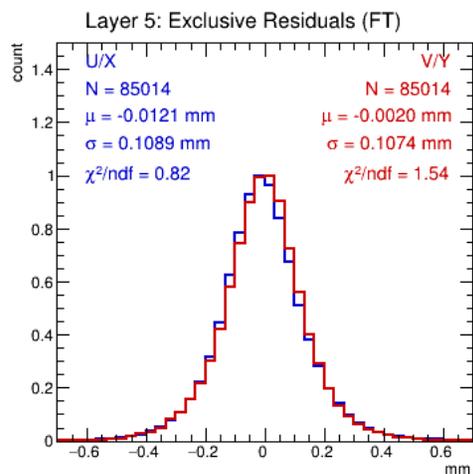
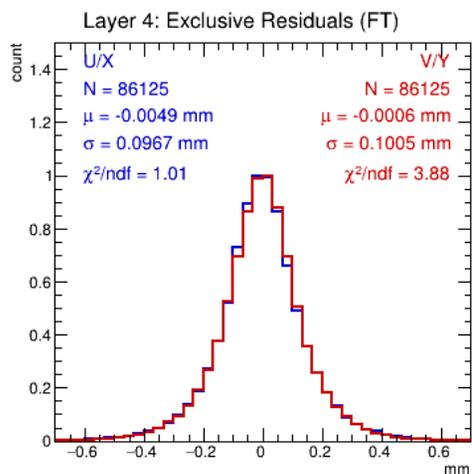
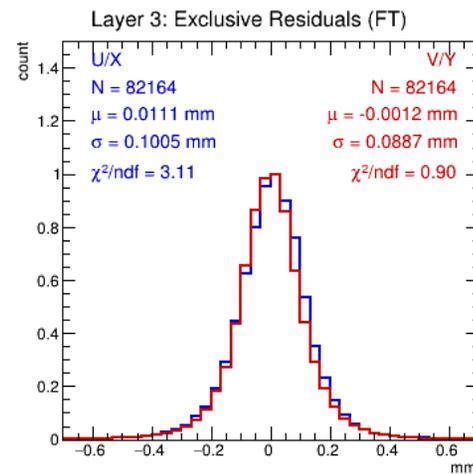
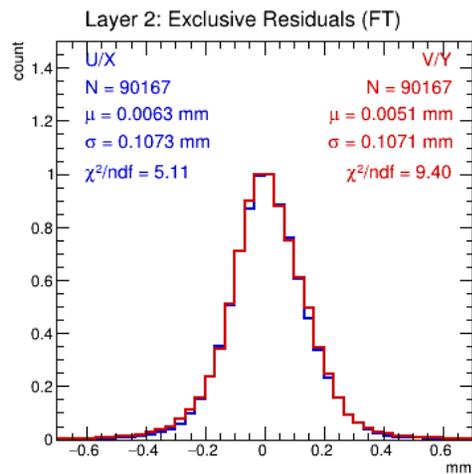
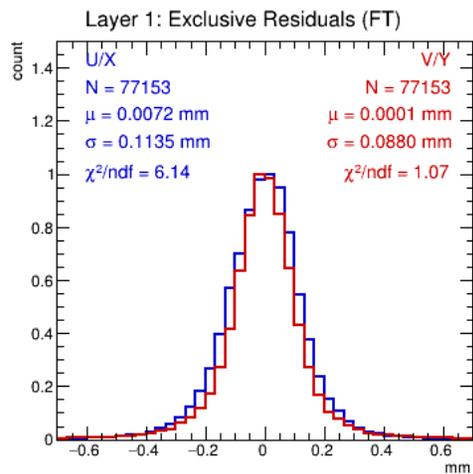
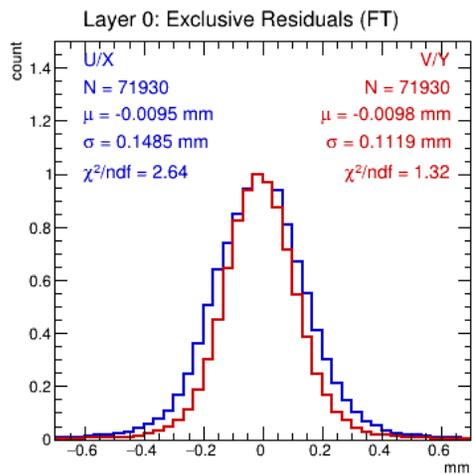
These are the largest
area GEMs in the world.

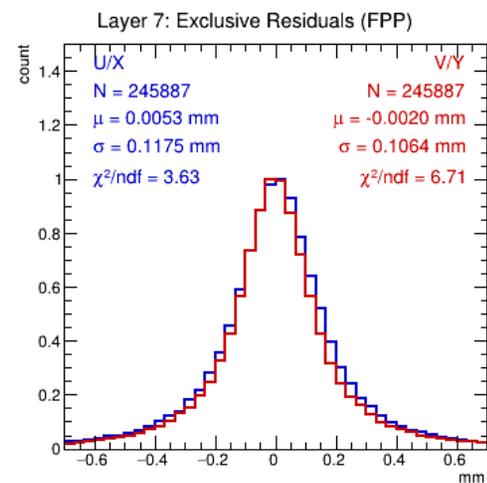
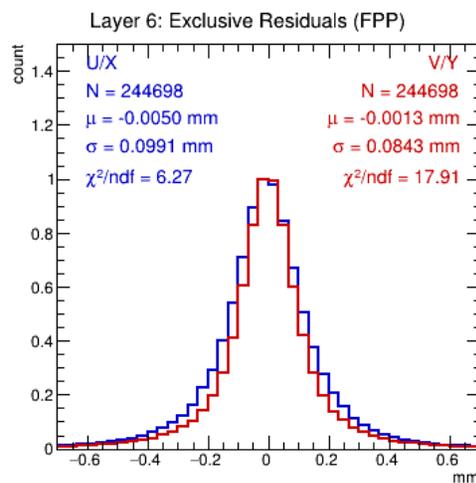
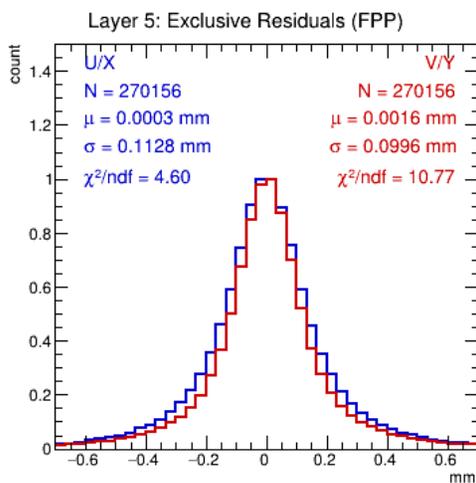
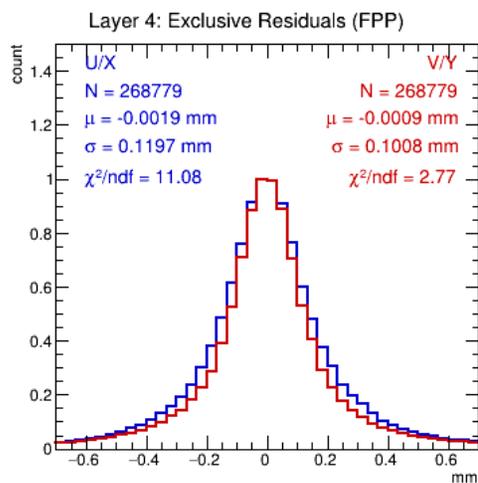
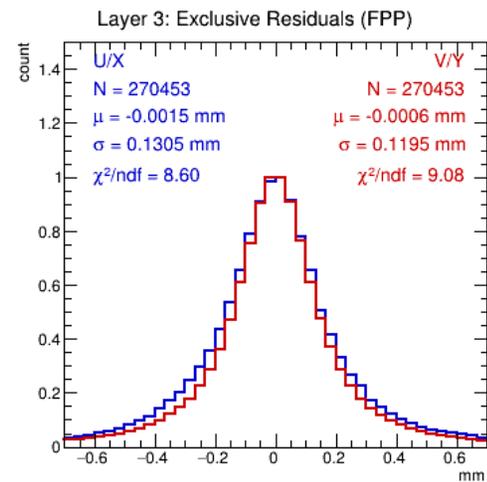
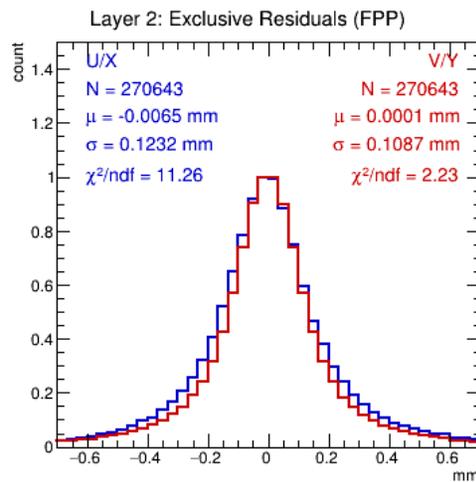
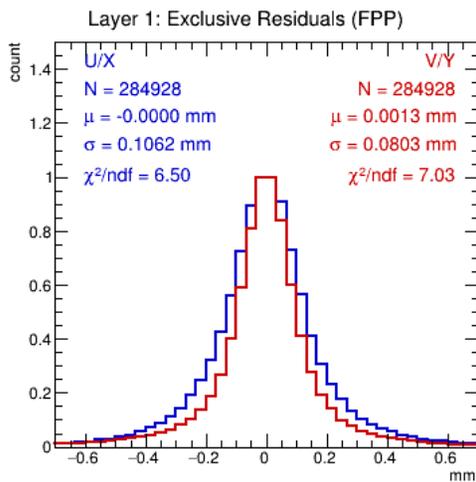
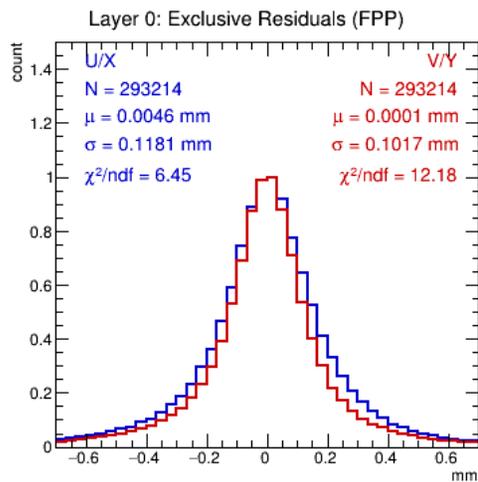
We asked a lot from SBS GEMs

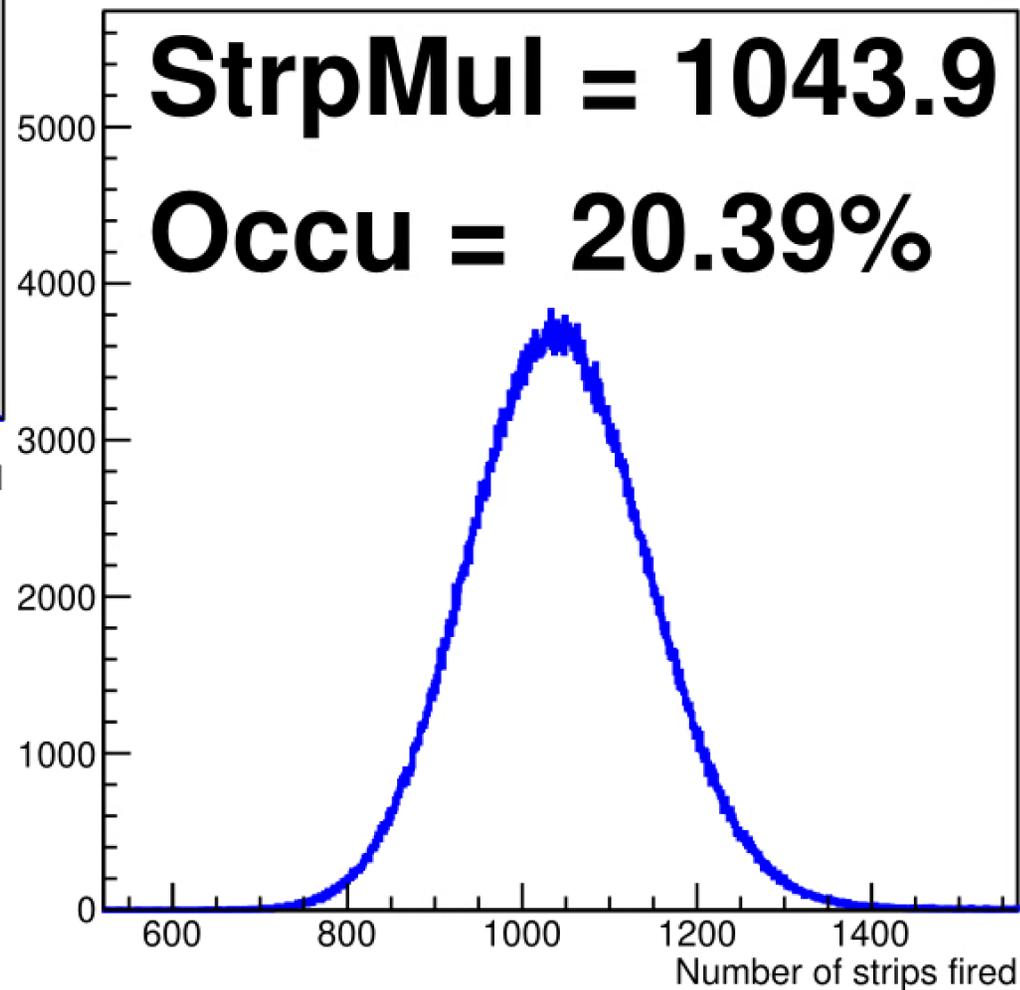
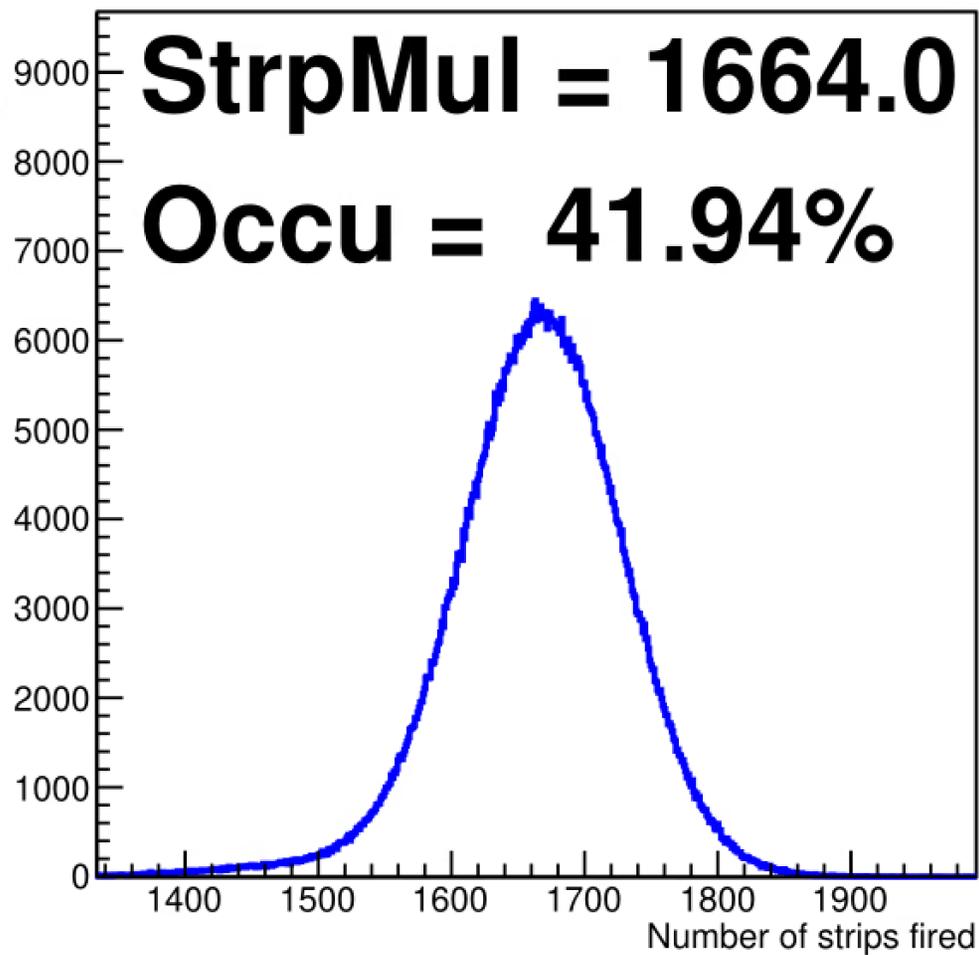
- Very high particle rates : few hundred kHz per cm², ~ an order of magnitude higher than any previous experiment.
- But GEM detectors can handle up to 100 MHz/cm² or more. So what is the problem ?
- Yes, but that assumes a pixelized readout, or a readout with short strips. Such a readout requiring ten times the readout channels would have cost much more (~ \$ 5 M more)
- Our limitation was the ~ 50 cm long readout strips we had to use; all we could afford.
- This caused very high occupancy rates: up to about 40%: an order of magnitude higher than any previous experiment.
-

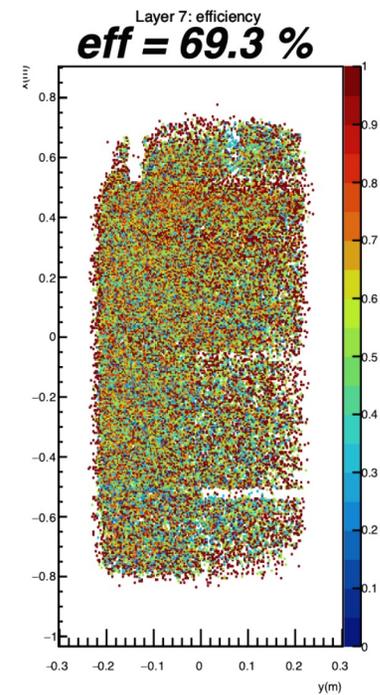
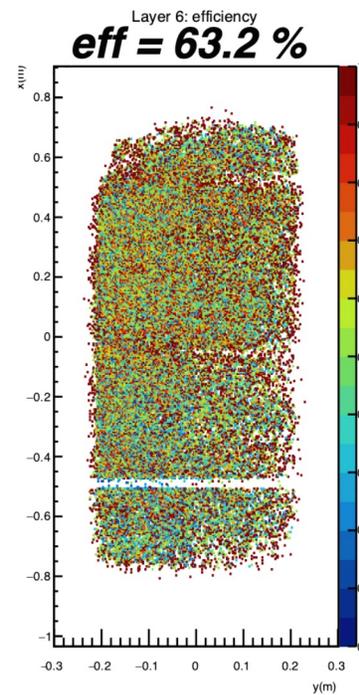
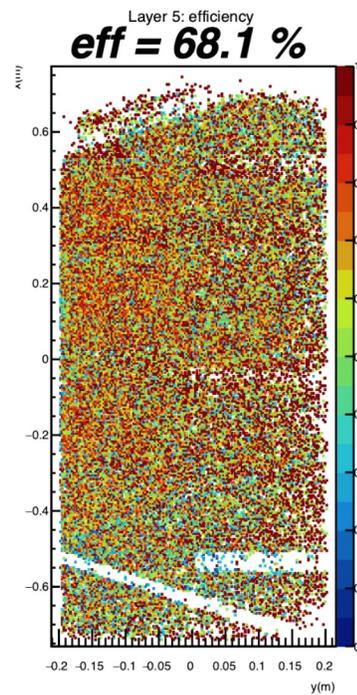
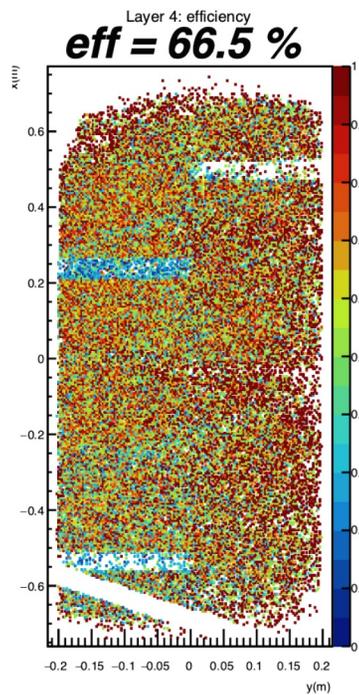
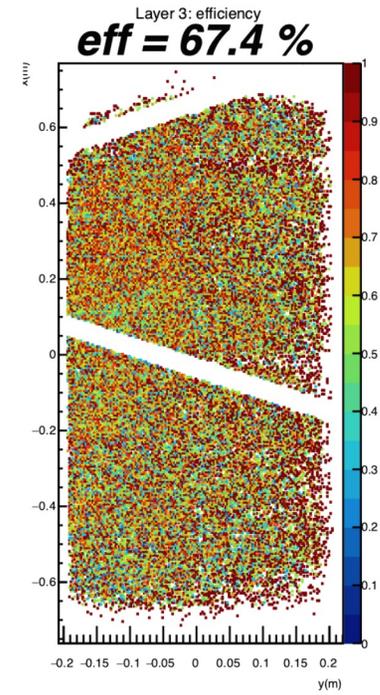
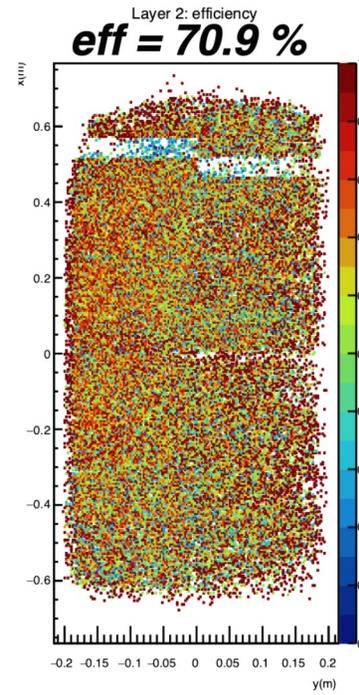
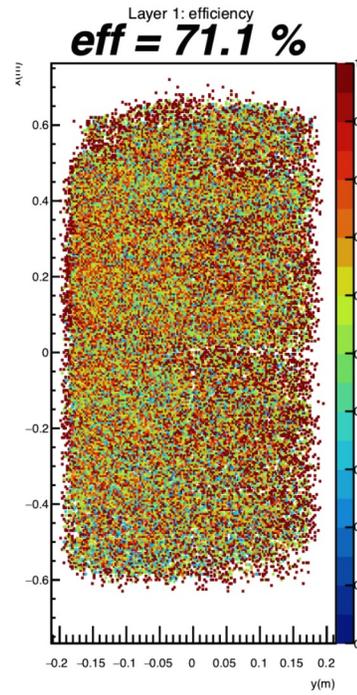
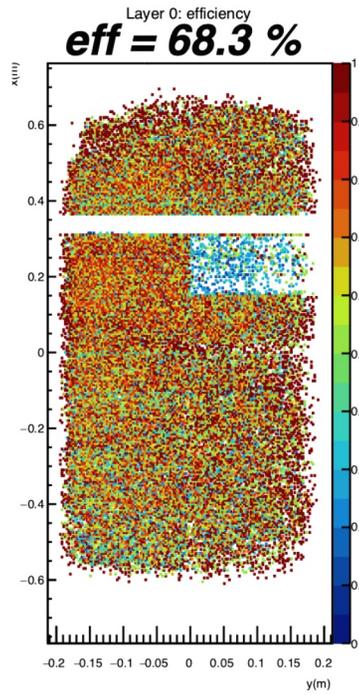
We asked a lot from SBS GEMs

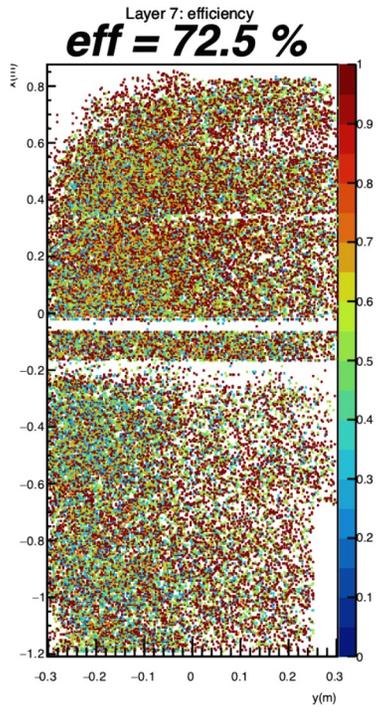
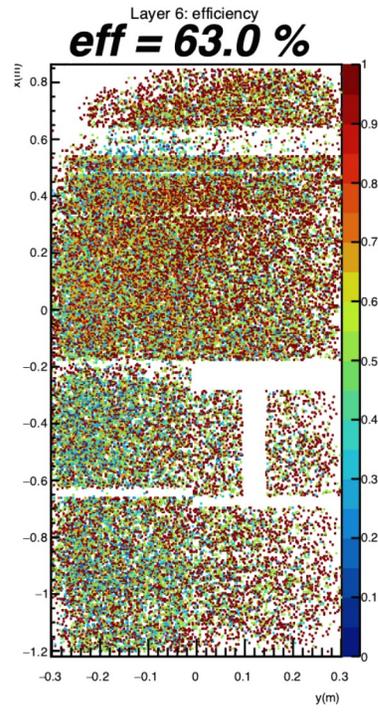
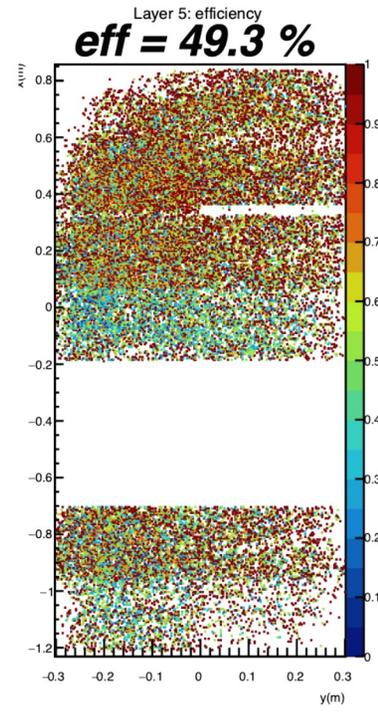
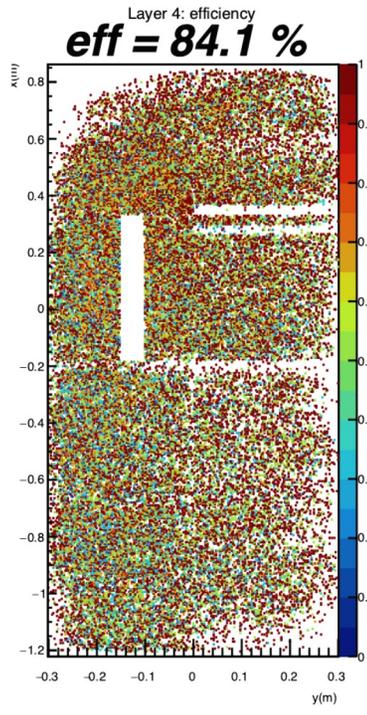
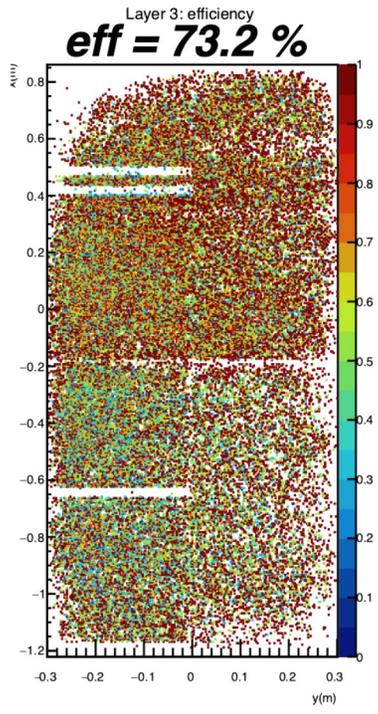
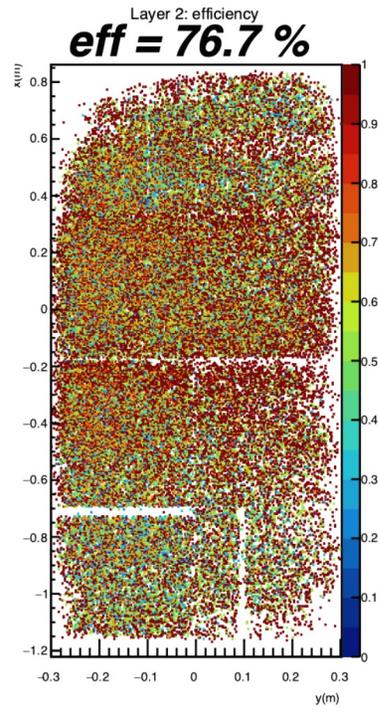
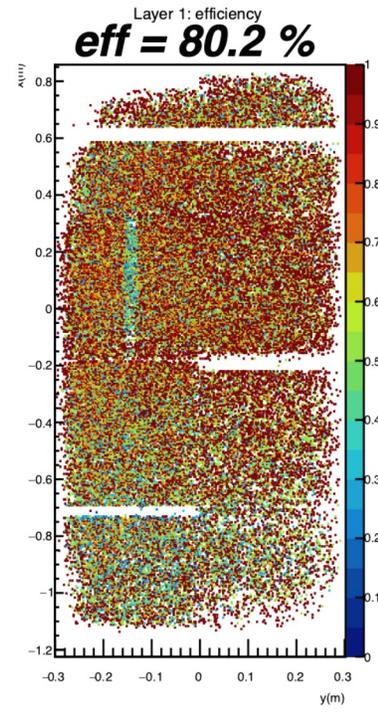
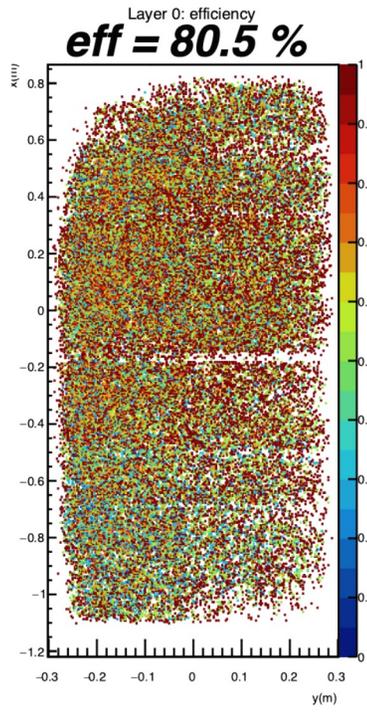
- Even worse: most of our background hits were not MIPs; they were highly ionizing electrons converted from low energy photons. these electrons deposits about an order of magnitude more energy into the GEM than a MIP.
- Signal hits much smaller than the back-ground hits
- the amount of charge deposited in the detector was about two orders of magnitude higher than in previous experiments
 - Very high leakage currents leading to issues with the voltage dividers: needed individual channel power supplies to remedy.
 - Under high rate exposure, high level of charge input into the readout channels caused the signal baseline to sag below the dynamic range of the readout. As a result signals would drop out of range leading to signal loss. This effect eventually limited the maximum luminosity to run at.











SBS GEM trackers: Overall Performance

- Both front- and back- SBS GEM trackers worked well under harsh conditions and high rates during GEp-V experiment.
- The six $150 \times 40 \text{ cm}^2$ front tracker GEMs closest to the target were the ones designed and built after 2020. These detectors showed excellent, stable performance with very few high voltage trips during the entire experiment, despite being exposed to the the highest rates in the detector stack.
- Of the forty $50 \times 60 \text{ cm}^2$ GEM modules built during the original production, two modules experienced frequent discharges at the regular operating high voltage, leading to DAQ crashes. To avoid DAQ dead time, these two modules were operated at a lower high voltage, resulting in reduced efficiency. The other 38 GEMs of this set worked well.
- The GEM electrodes are separated into sectors. Severe electrical discharges cause shorted GEM sectors leading to dead areas. Out of over 4500 sectors in the set of GEMs, only 20 developed shorts during the experiment

SBS GEM trackers: Readout electronics

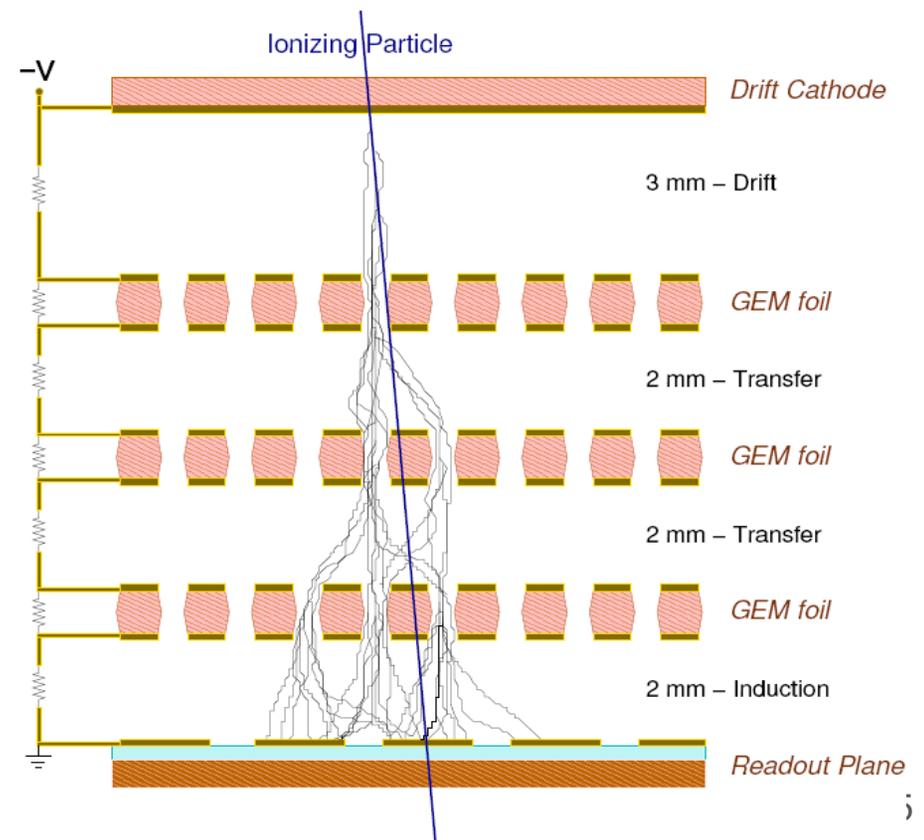
- Several sets of frontend cards malfunctioned during the experiment leading to some dead areas in GEM layers.
- A set of 12 frontend cards reading an entire back tracker GEM module malfunctioned; it was not possible to replace these due to space constraints of the tracker. As a result, that GEM module remained off during the experiment.

SBS GEM trackers: Important conclusions about long term running under very high exposure conditions

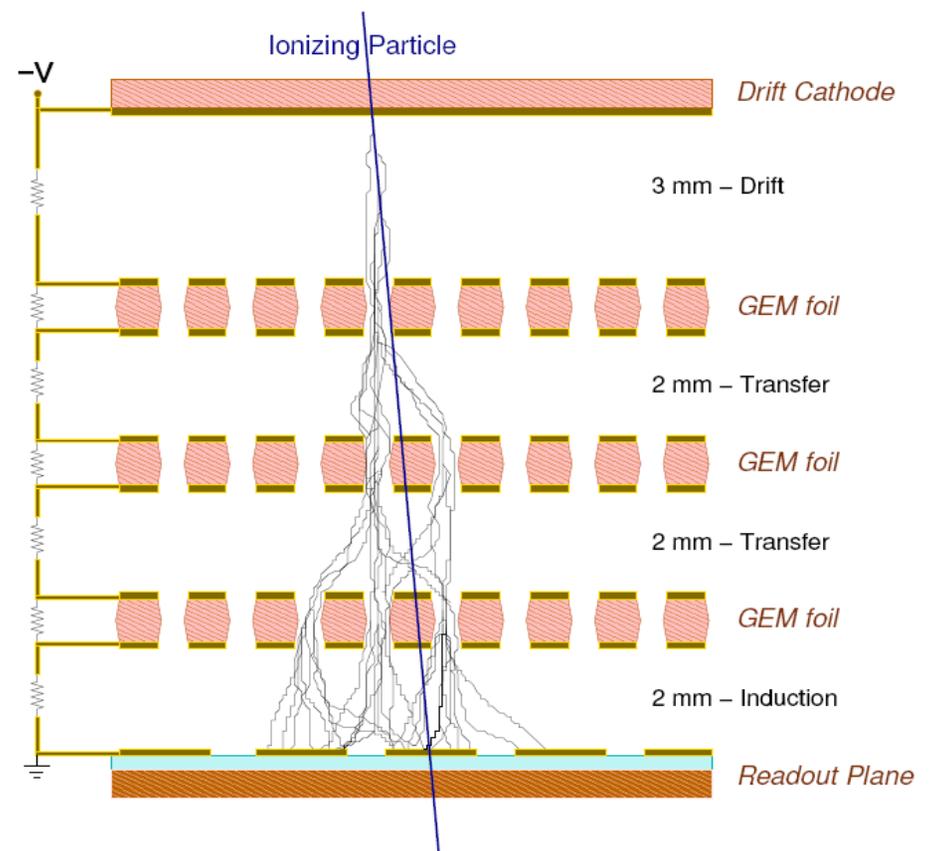
- The GEM tracker layers have been working very well:
 - stable operation: some occasional HV trips, manageable.
 - Robust under harsh conditions. Only 4 out of the ~ 60 detectors in beam had to be swapped out due to suspected short in a couple of sectors (out of 30 in the detector).
 - No radiation damage observed
 - No detector aging effects observed
 - Noise levels sufficiently low
 - Good gain: signals well above noise
 - Very good resolution: ~ 80-100 μm

GEM trackers for future high luminosity experiments

- SBS: direct line of sight to target : we are showered by photons.
 - The biggest background we had was low energy photons converting to electrons.
 - Many of these photons are in the 1 keV – 100 keV range.
 - The conversion depends strongly on Z of the material in the path.
-
- Explore the possibility of changes to minimize the photo-conversion:
 - Replace the 5-micron Cu cathode with a 0.1 micron Aluminum cathode.
 - Switch cathode foil material from 50 micron Kapton to 6 micron Mylar.
 - Change the detector work gas from Argonne to Helium

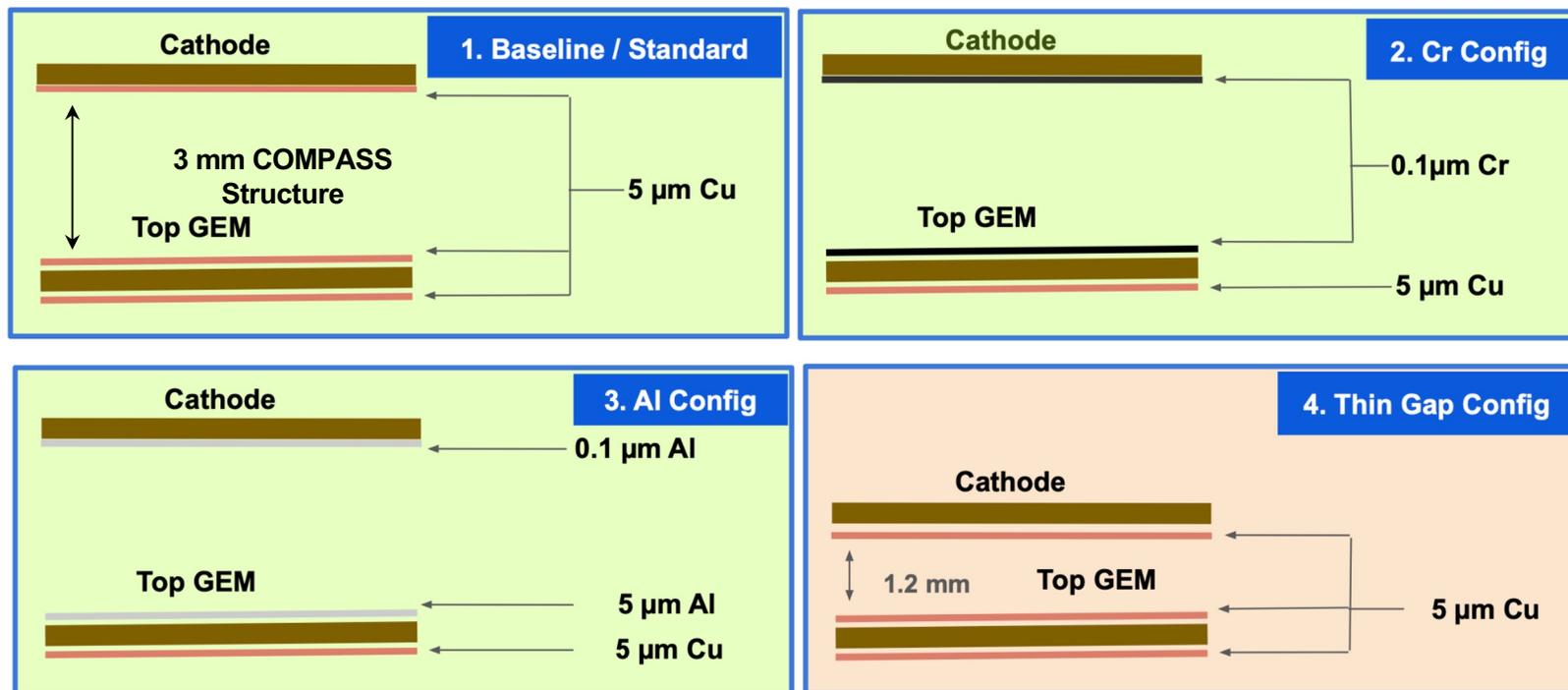


- Explore the possibility of changes to minimize the photo-conversion:
 - Move the metalized part of Cathode to the top; some of the electrons created in the metalized part absorbed in the foil.
 - Reduce the copper thickness of the top side of top GEM.
 - Replace the honeycomb entrance window with a thin Mylar window.
- Increase the thickness of the drift gap from 3 mm to 1 cm or more
 - Increases the signal strength
 - More strips in a cluster; better for suppressing noise hits
 - Some of the photo converted electrons absorbed in the thick drift gap.



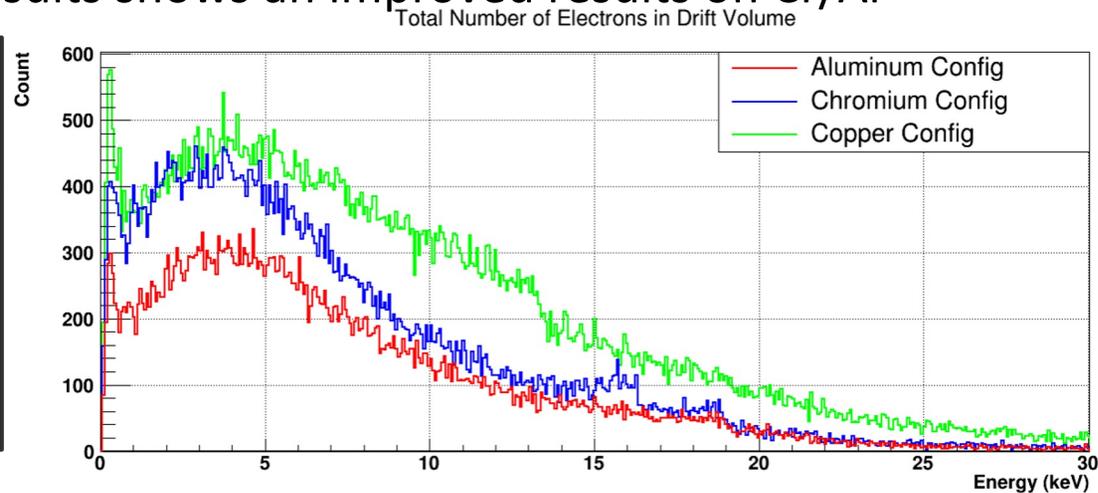
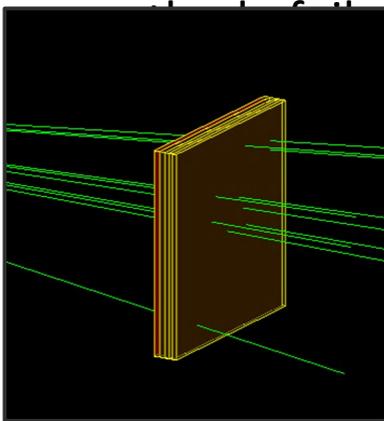
Geant4 Simulation on Optimizing GEM Foil/Detector Structure

- ❑ Effort to reduce the photon conversion rate on GEM detectors
- ❑ Simulation on different GEM foil/detector structure



Geant4 Simulation on Optimizing GEM Foil/Detector Structure

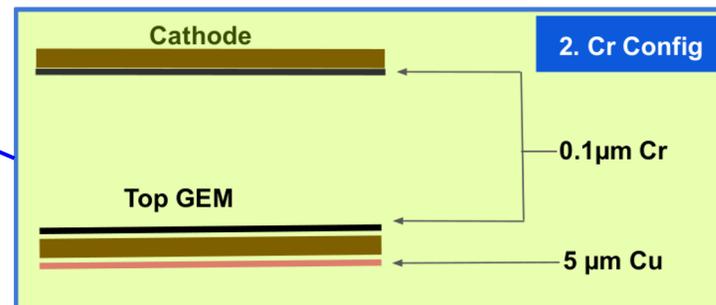
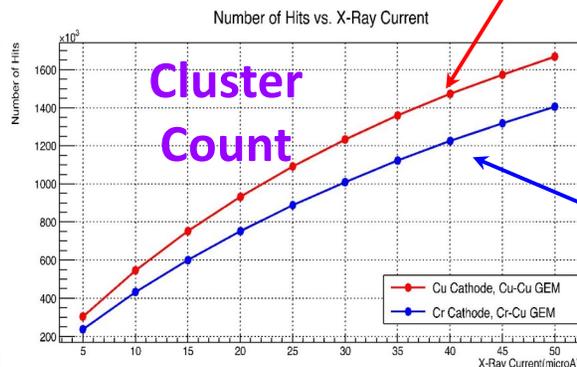
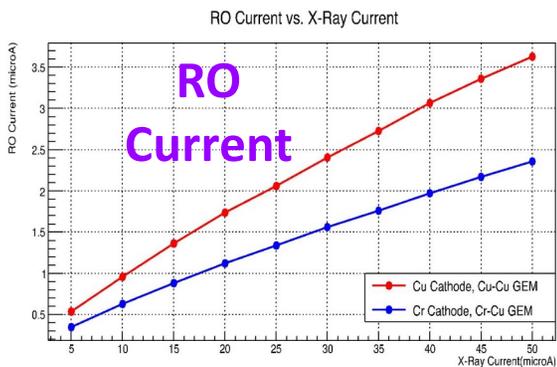
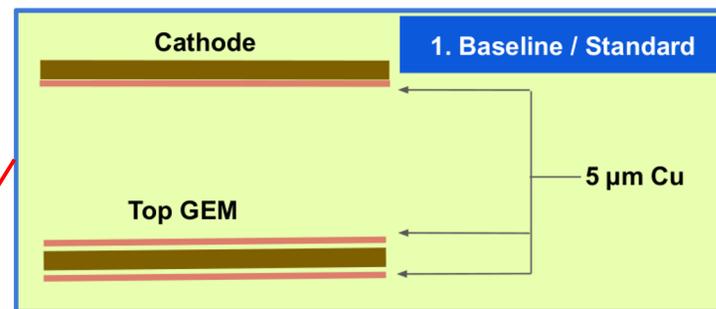
- ❑ Prototypes of different configurations completed
- ❑ Under test using x-ray
- ❑ Similar setup in Geant4
- ❑ Simulation results shows an improved results on Cr/Al



UVA x-ray

Geant4 Simulation on Optimizing GEM Foil/Detector Structure

- ❑ Photon conversion – cathode foil, drift region (thin-gap)
- ❑ Experimental measurements
 - ❑ Current from readout board
 - ❑ cluster count under a fixed amount of time
- ❑ Significant photon-converted cluster count reduction: **16%** for **Cr GEM detectors**



What else can we do to reduce the occupancy and charge input to electronic channels ?

- Segment the strips:
 - reduces the occupancy
 - reduces the charge into electronics.
 - For example 10 cm strip segments in the highest occupancy areas would have allowed us to run at full luminosity easily .
 - Cost of electronic would have gone up from \$ 750 k to ~ \$ 2.5 M (2016 \$)

• APV25 turned out to be a fantastic chip: radiation hard , good enough for what we wanted to do and really cheap.

• If we are to do this again, make a new batch of APV25 chips with some minor changes

