Update on Avalanche Simulations in a Triple GEM

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OUTLINE

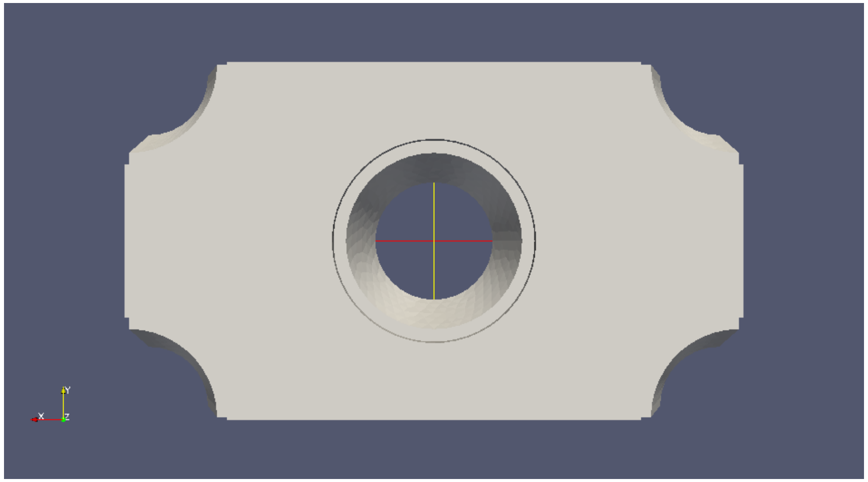
Some updates on the work we presented at the RD51 Mini-week, 10-13 February 2020, with regards to the following points -

- Improved field maps
- Simulating more number of events, 320 as compared to 32.
- Understanding the charge distribution in holes of lower layers in a triple GEM structure primarily due to **diffusion**, starting from a single primary electron in the drift gap, which leads to higher gains attainable with multi-GEM structures.

We have also done some preliminary studies on the ion backflow in a triple GEM structures, and some of those results have been presented.

Simulation Parameters and Field Maps

Triple GEM structure designed and meshed in *GMSH*.
Fields+Potentials solved in *Elmer* – entirely open source!



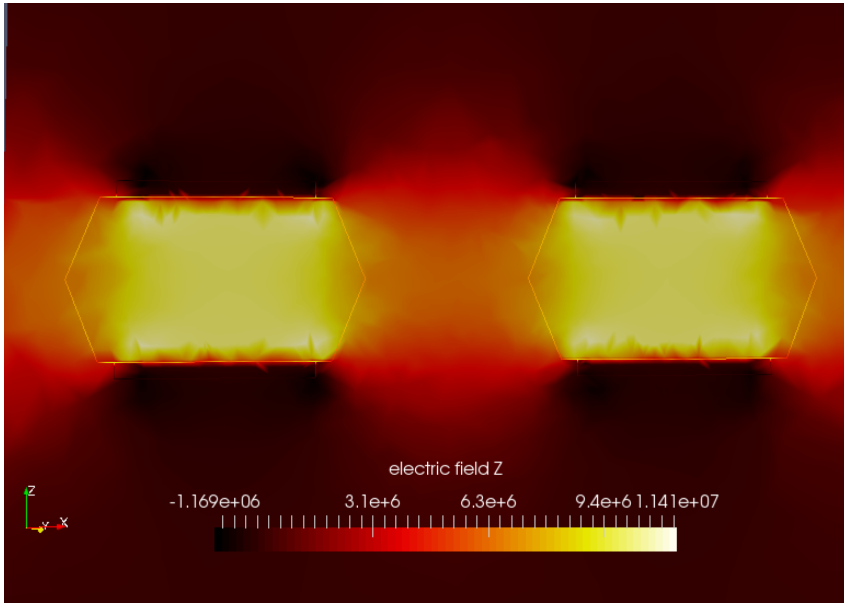
Unit Cell used in the simulation – it has simple periodicity along X and Y axes.

Gap configuration in triple GEM is 3-2-2-2 mm.

Pitch: 140um
Outer hole diameter: 70um
Inner Hole diameter: 50um
Copper coatings: 5um

Better colour scheme from last time for improved understanding.

This is the electric field magnitude in Z direction only.



Electric field magnitude is very high in the hole region, drops drastically just outside.
Otherwise, avalanche would not happen.
As expected, no electric field in copper – its a metal!

Simulation Methodology

(Same as last time)

Parameters:

a) Drift Field: 1kV/cm

b)Transfer Fields: 2.5kV/cm

c) Induction Field: 2.5kV/cm

$$\Delta V_{GEM} = 500\text{ V}$$

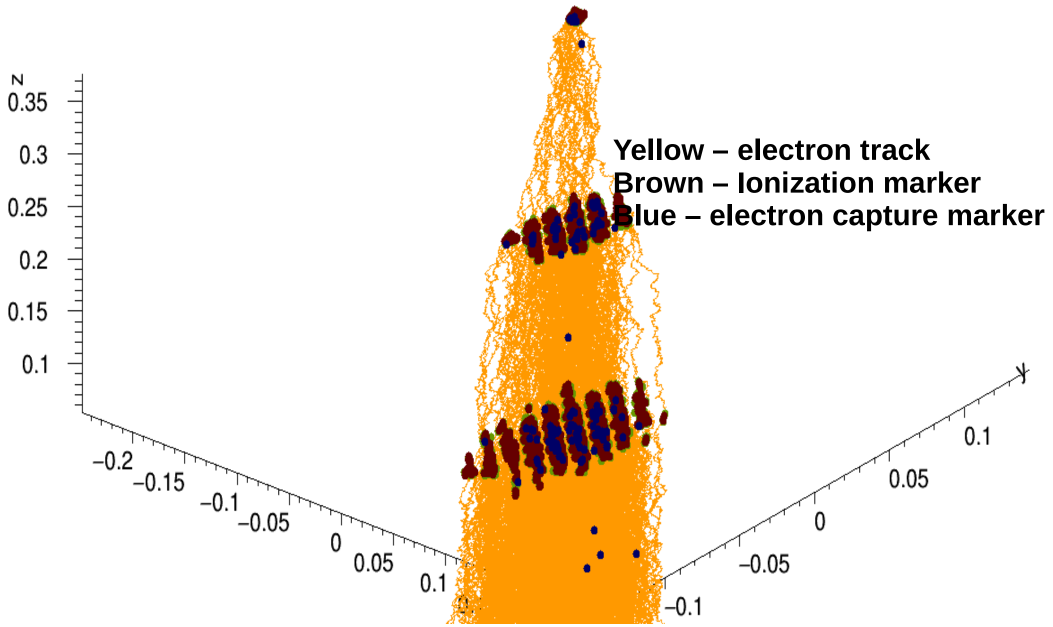
Methodology

1. Single primary electron generated **70um** above GEM hole of top foil - initial velocity vector, and energy were randomized. This was at **150um** earlier – reason for this decrease, to prevent *diffusion into more than one hole* from drift gap to top GEM.

2. Avalanche size limit for triple GEM simulation enforced. Otherwise, very expensive in computational terms.

3. Collision step size – set to 100.

4. Garfield++ allows for microscopic tracking – using class **AvalancheMicroscopic()**



Yellow – electron track
Brown – Ionization marker
Blue – electron capture marker

Figure: 3D view – Avalanche in triple GEM

Results from simulation using single primary electron

Total of 320 such events simulated! (using MPI)
(32 earlier)

ΔV_{GEM} was kept at 500 V

Other parameters are stated earlier!

Electron generation histograms layer-wise (1-D view)

Uniform 10um bins

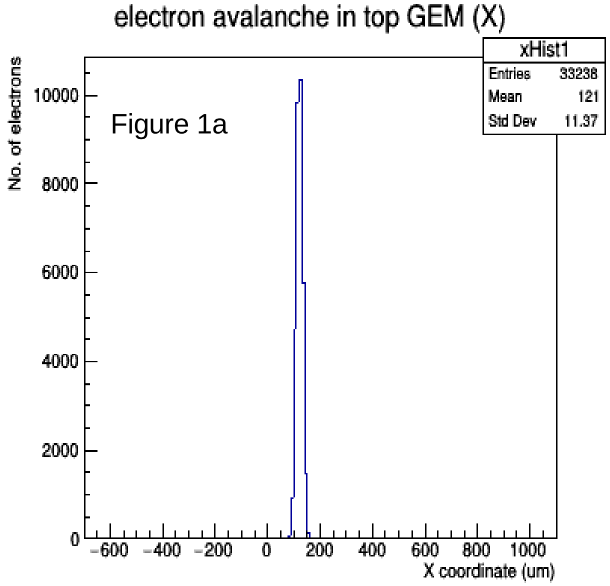


Figure 1a

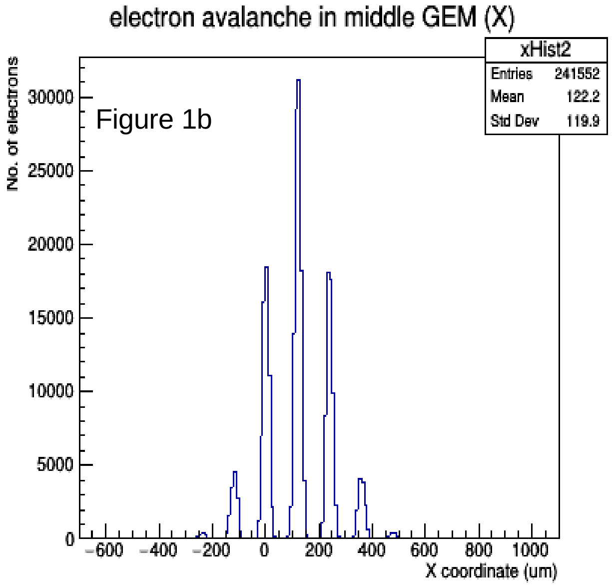


Figure 1b

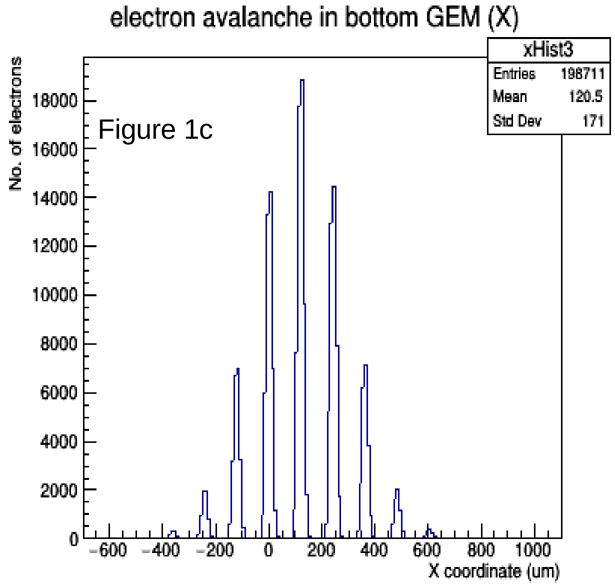


Figure 1c

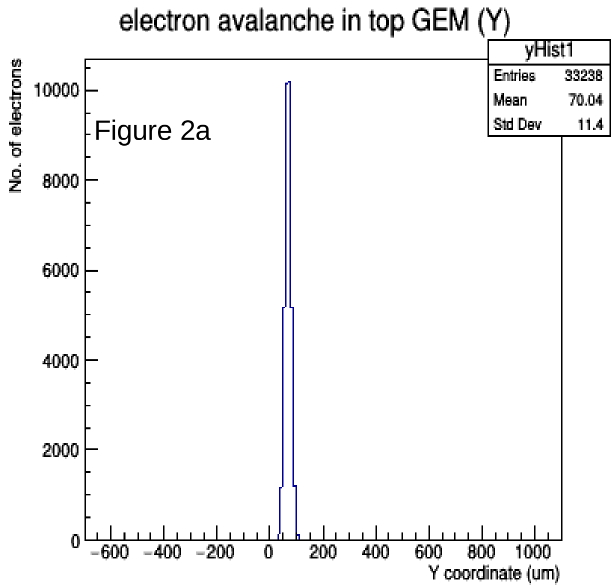


Figure 2a

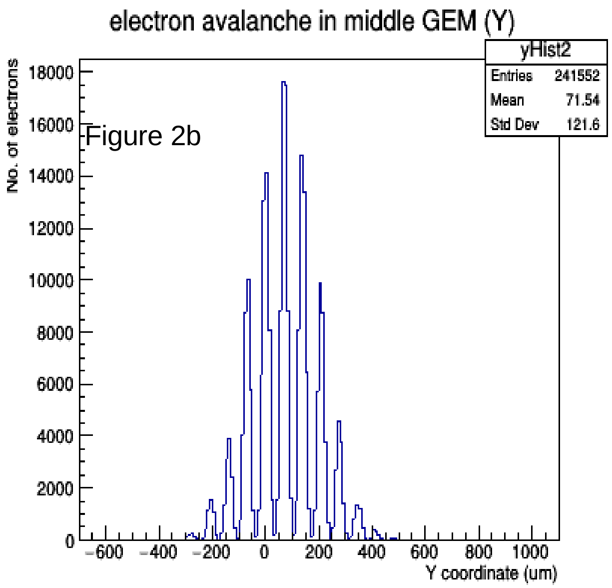


Figure 2b

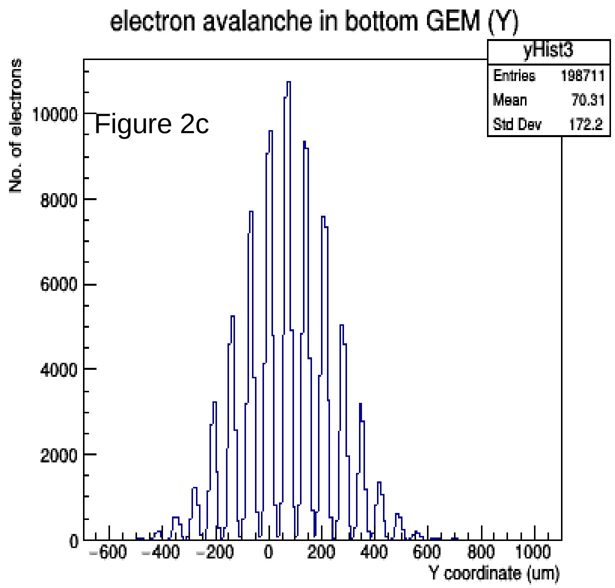


Figure 2c

Electron generation color maps layer-wise (2-D view)

Uniform 10um bins

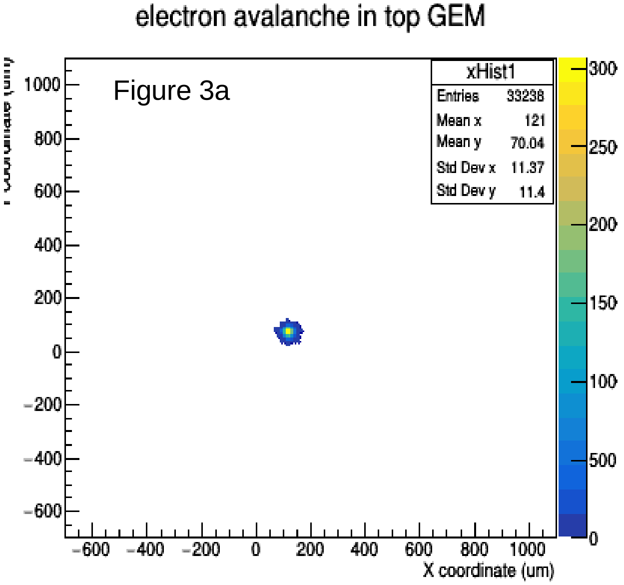


Figure 3a

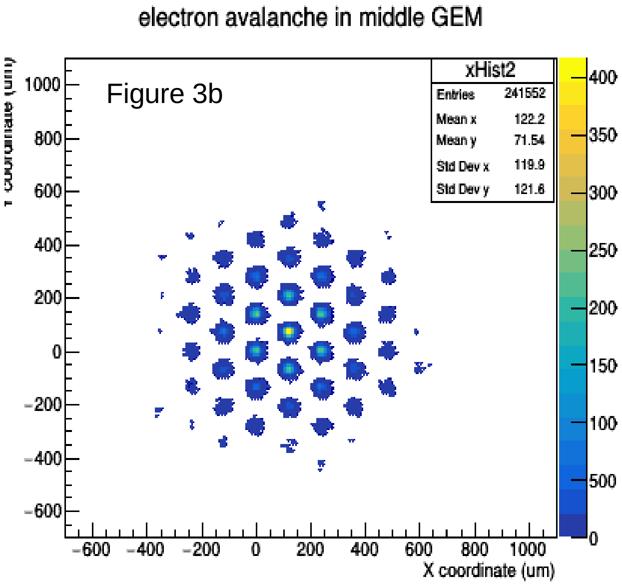
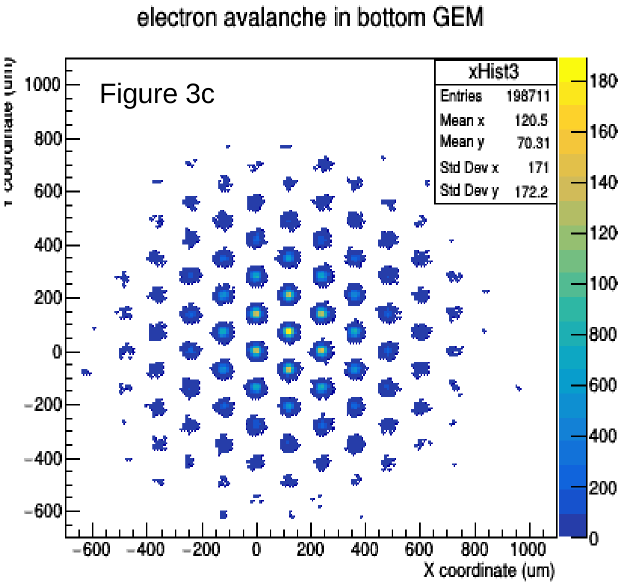


Figure 3b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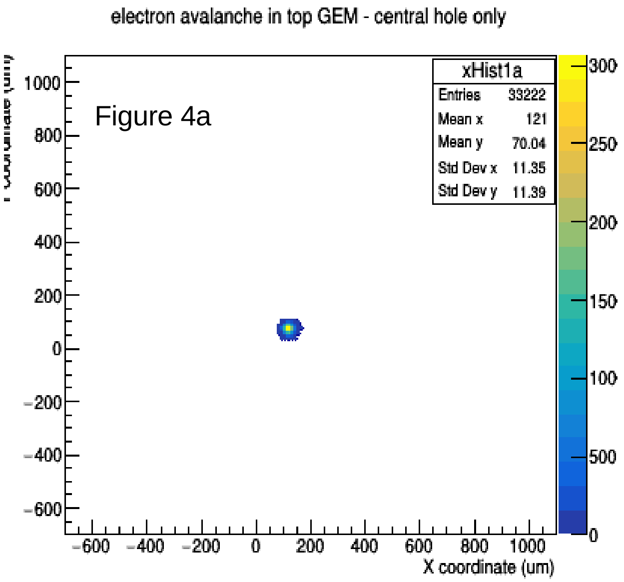


Figure 4a

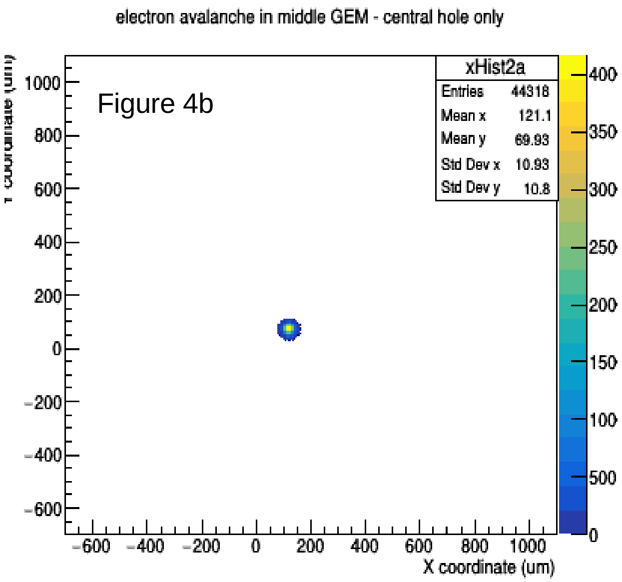


Figure 4b

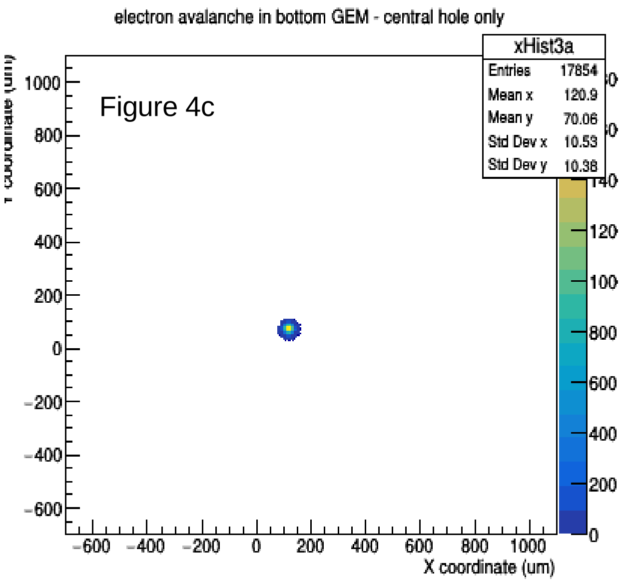


Figure 4c

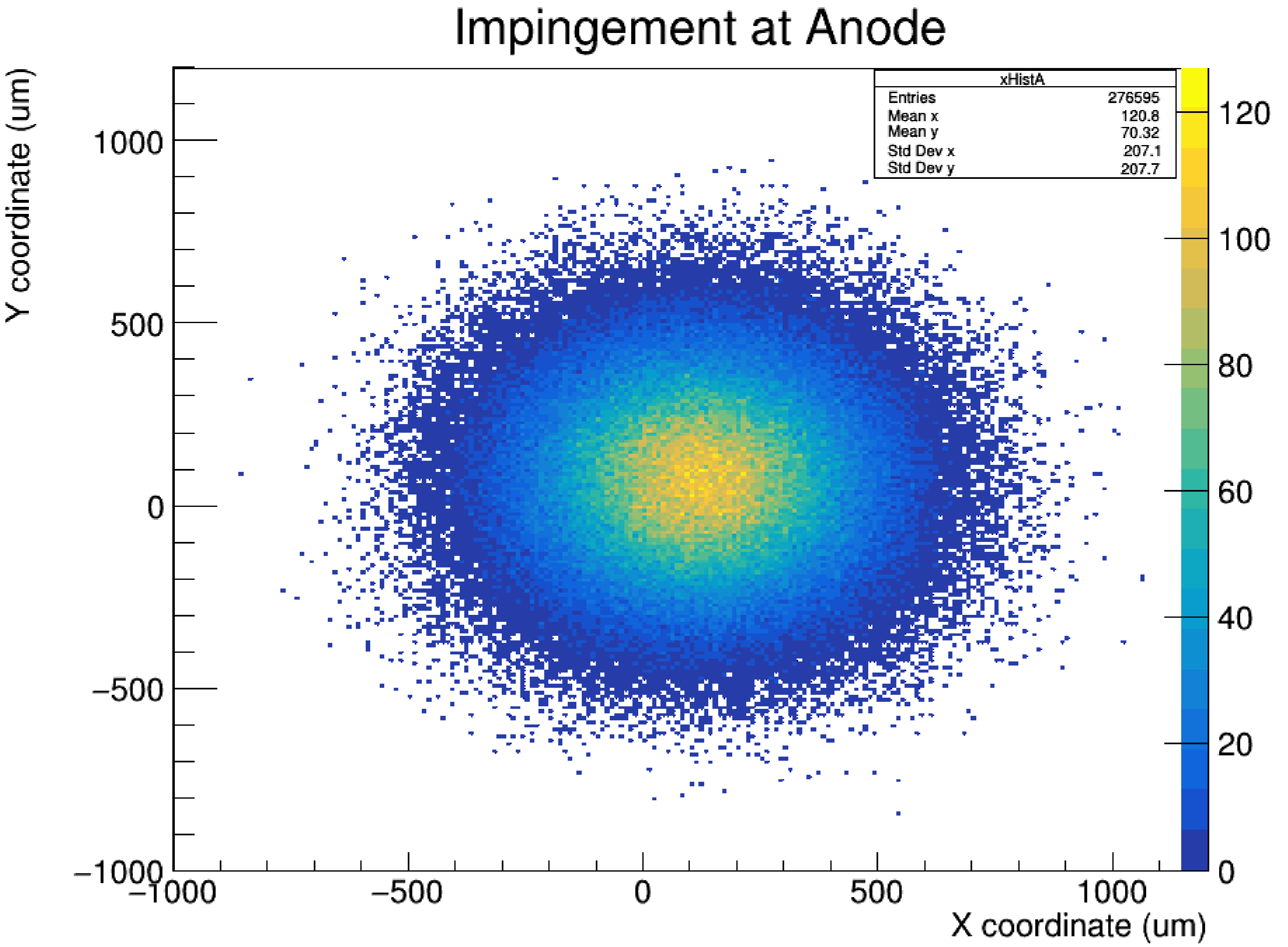


Fig 5: 2D Colour Map

Observations

1. The electron release distance above top GEM was decreased to 70um from the earlier 150um – hence no transverse diffusion in drift gap, observe the absence of smaller peaks in Figures 1a & 2a, which were there earlier.

2. Spatial Distribution at the anode is Gaussian.

$$\boldsymbol{\sigma_x = 207.1\text{um}, \sigma_y = 207.7\text{um}}$$

$\sigma_x = 214$um, $\sigma_y = 209.5$um earlier with 32 events only - the difference has **gone down**

3. The avalanche size in middle GEM is actually larger than that in bottom GEM – transparency is low as reflected in the numbers at the anode.

What do we conclude from this?

1. The higher gains attainable with multi-GEM stacks can be because of the charge distribution over the holes, primarily due to diffusion. A good numerical estimate of this (based on *feedback we received from Dr F. Sauli* at the miniweek) can be seen by the ratio of total avalanche size to central hole avalanche size, which is -

- 1 for top GEM (since single primary is released directly above it).
- 5.45 for middle GEM
- 11.13 for bottom GEM

2. The σ value at each layer gives us a measure of diffusion in transfer and induction gaps (which have field magnitude of 2.5 kV/cm) -

- ~120.5um in middle GEM
- ~171.6um in top GEM
- ~207um at anode.

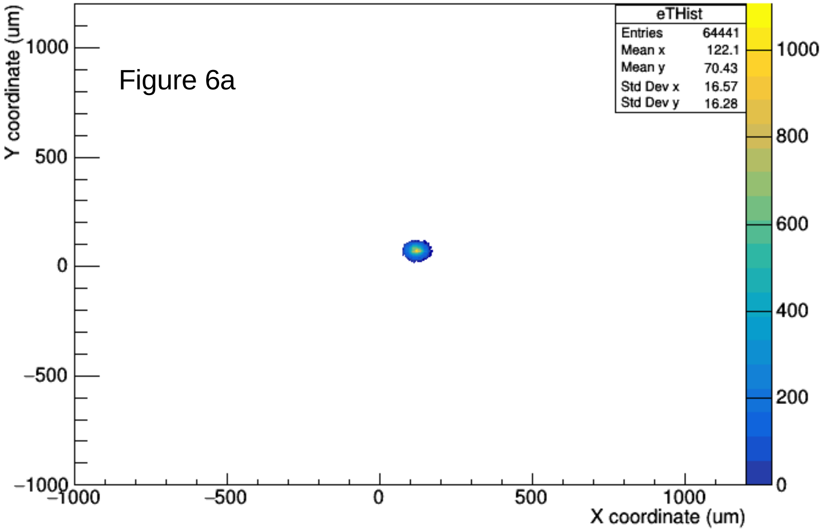
3. The avalanche, initiated by a single electron in drift gap, spreads into ~3 holes on either side in the mid Gem, and ~5 holes on either side at the bottom GEM.

Ion back-flow studies : preliminary results

Total 250 events simulated!

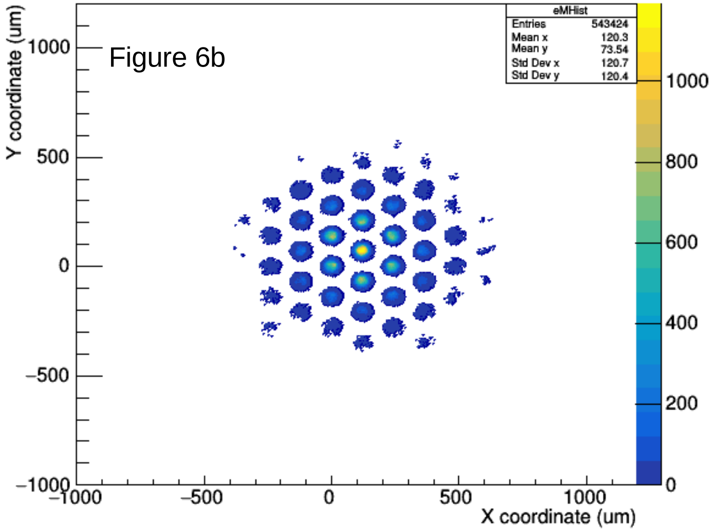
All other parameters the same as earlier.

Electron shower histograms



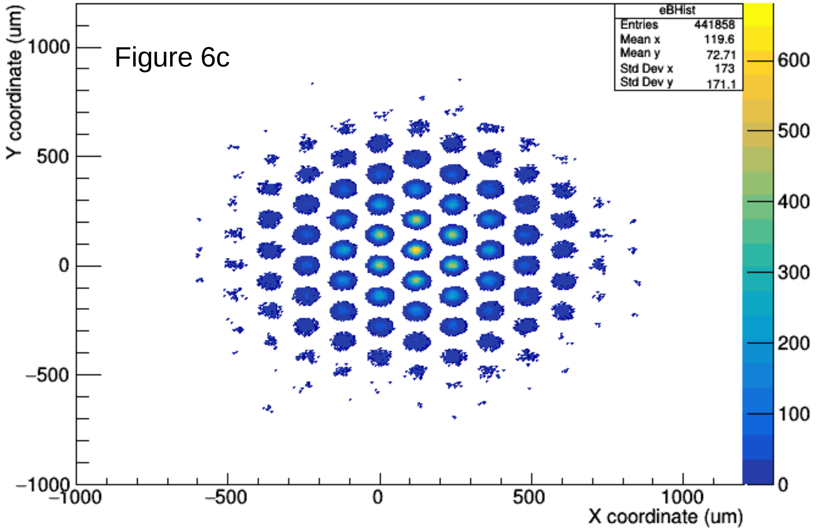
Electron generation - top GEM

Figure 6a



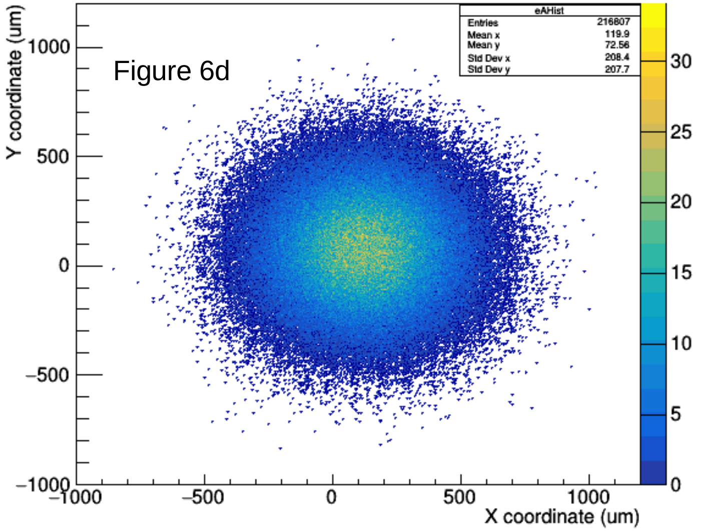
Electron generation - mid GEM

Figure 6b



Electron generation - bottom GEM

Figure 6c



Electron impingement at anode

Figure 6d

Ion deposition in the layers – 2D color maps

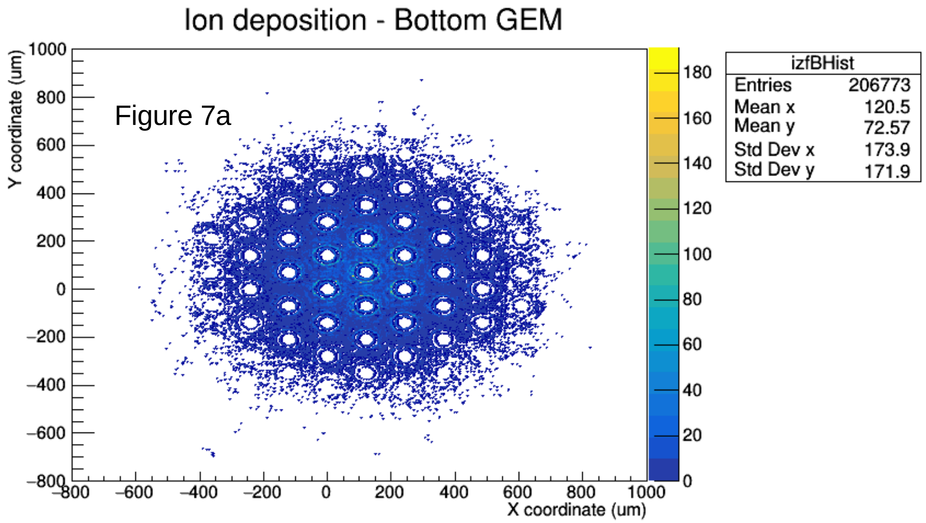


Figure 7a

Ion deposition - Bottom GEM

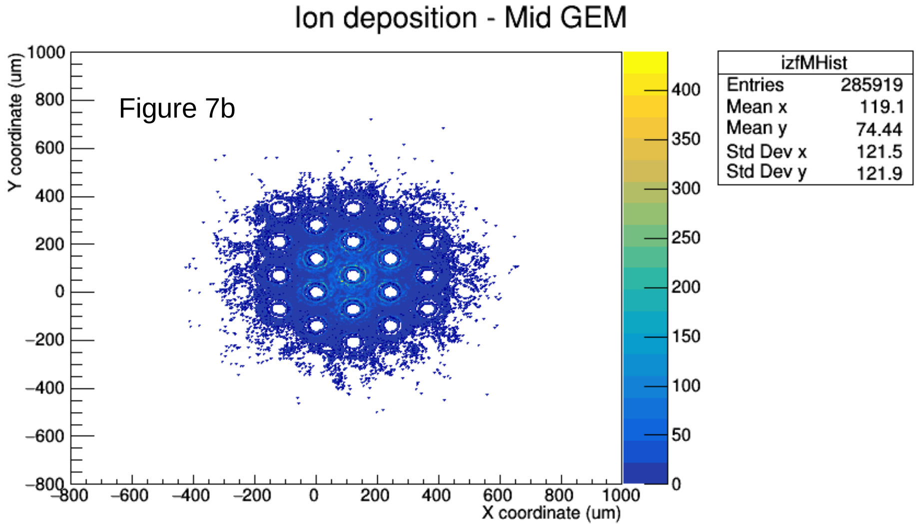


Figure 7b

Ion deposition - Mid GEM

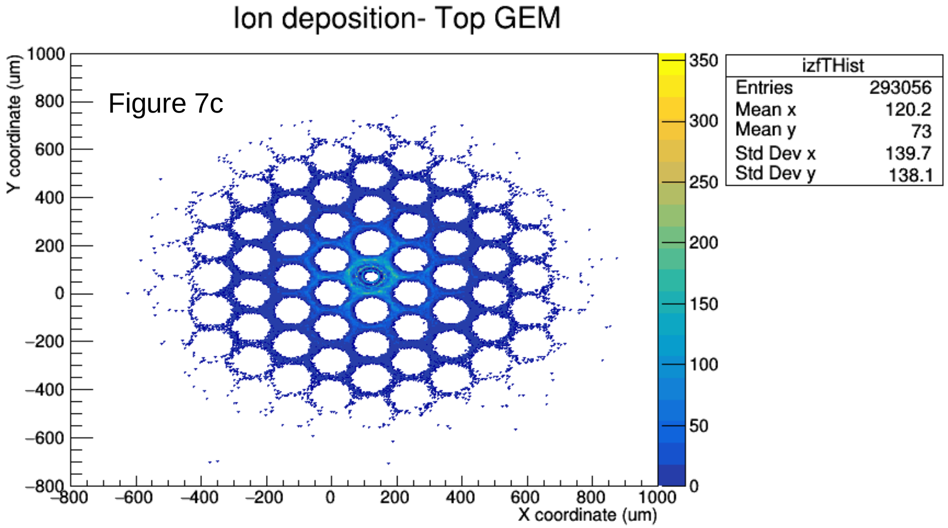


Figure 7c

Ion deposition- Top GEM

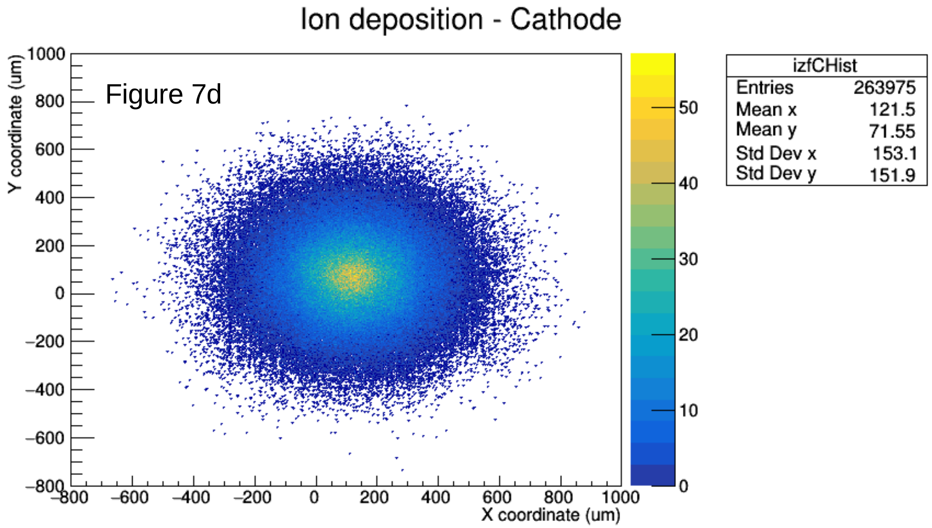


Figure 7d

Ion deposition - Cathode

Ion deposition in the layers – Z Histograms

Figure 8a

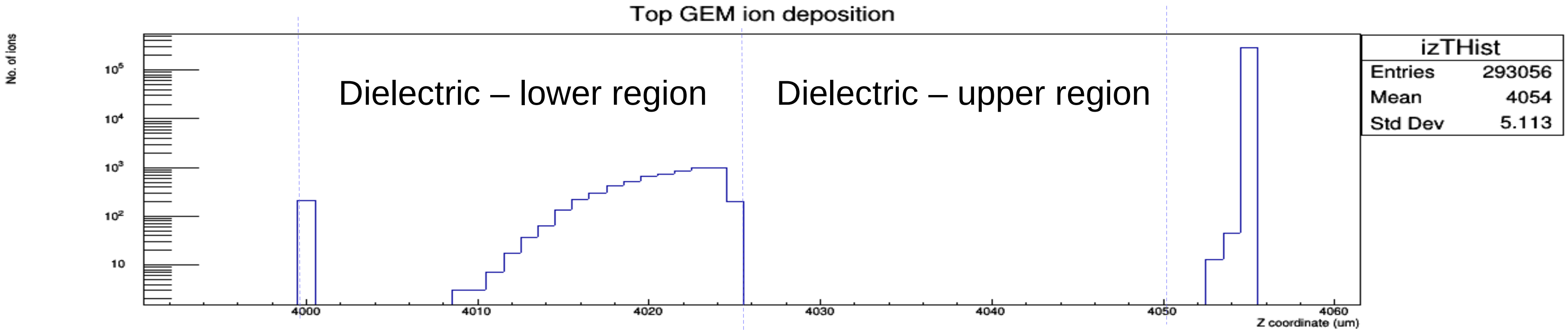
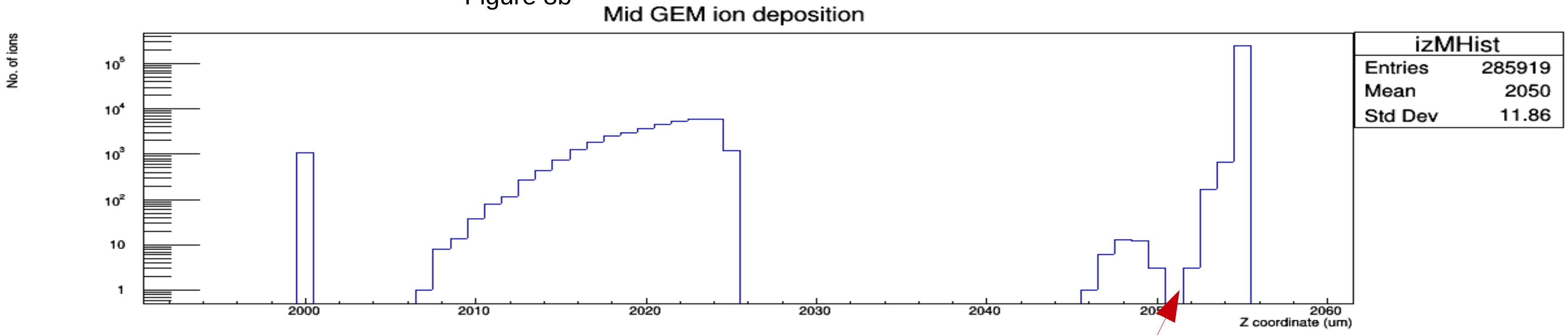
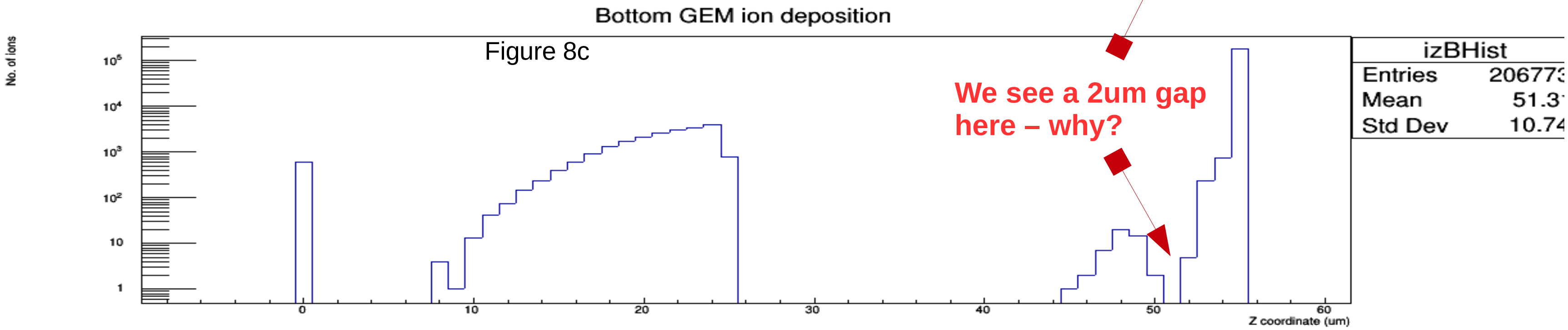


Figure 8b



Y axis scale is logarithmic!

Figure 8c



We see a 2um gap here – why?

Uniform 1um bins

Some observations and calculations

1. Electron diffusion is dominant over the ion diffusion, which is apparent from the values of σ_{ion} at the bottom (~**170um**) and mid (~**120um**) GEM layers, which is very close to $\sigma_{electron}$. At the top GEM, σ_{ion}~ **140um**, which can be entirely attributed to the diffusion of the ions flowing back from bottom and mid GEMs.

Note that - $\sigma_{ion,bottom} > \sigma_{ion,cathode} > \sigma_{ion,top} > \sigma_{ion,mid}$

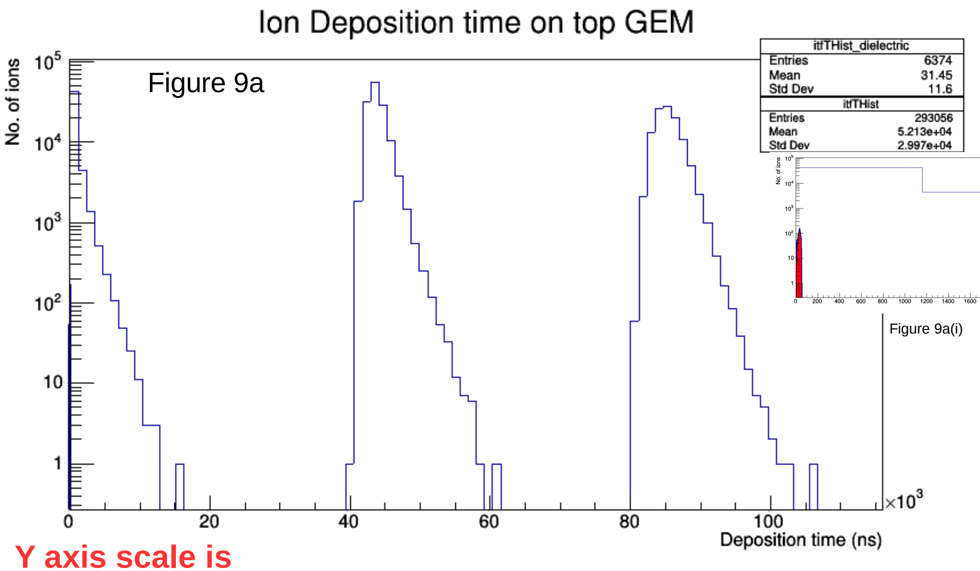
2. At the cathode, σ_{ion} ~ **152.5um**, which is less than the corresponding value at the anode for the electrons. As expected, ion diffusion is less.

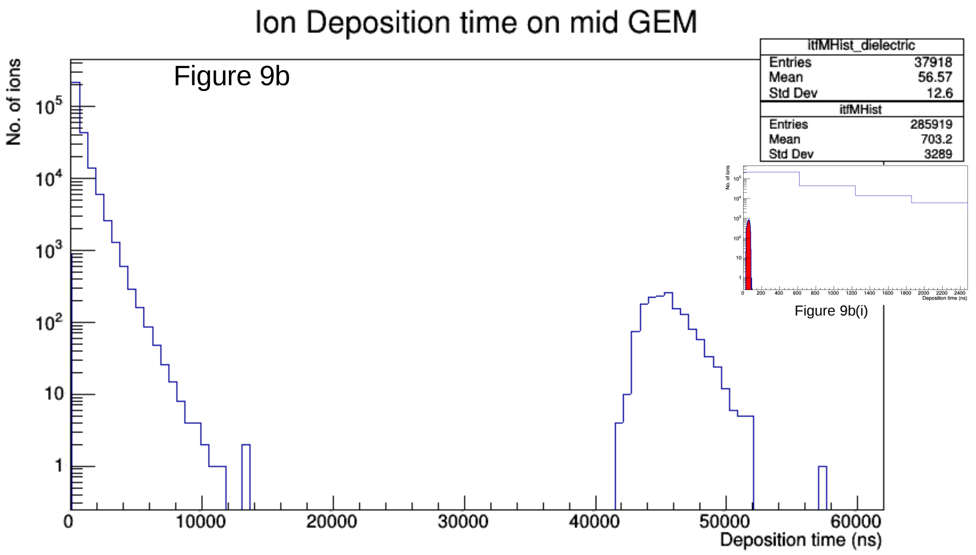
3. Ions absorbed in the dielectric contribute to charging up. Out of all avalanche electrons generated per layer, the percentage absorbed in dielectric is approximately -

- Bottom layer ~10.3%
- Mid layer ~13%
- Top layer ~ 10%

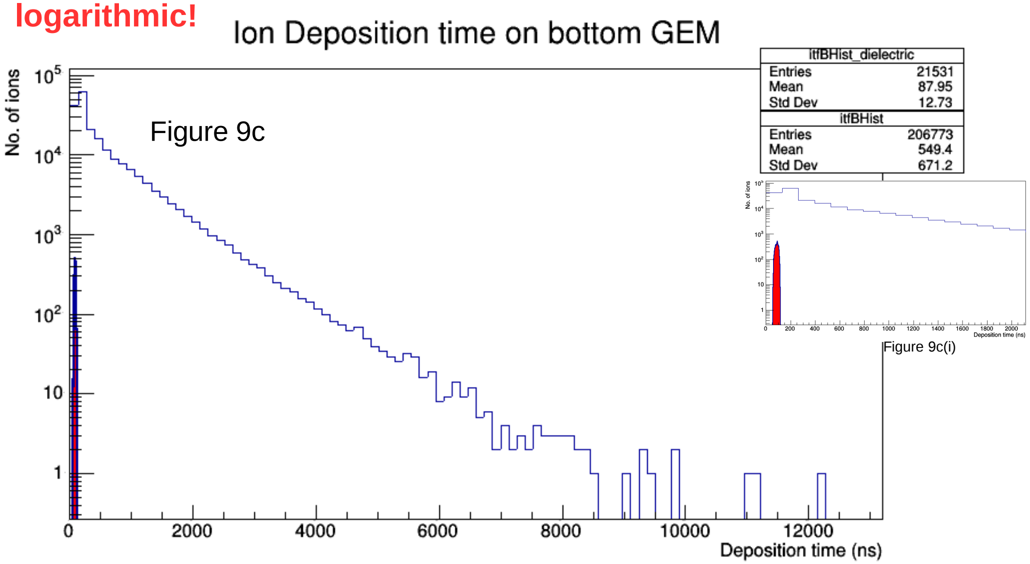
4. Ions flowing backward from the lower layers to the upper layer(s) were observed to be entirely absorbed in the copper coatings only. All deposition in the dielectric was observed to be from the ions in the **same** layer.

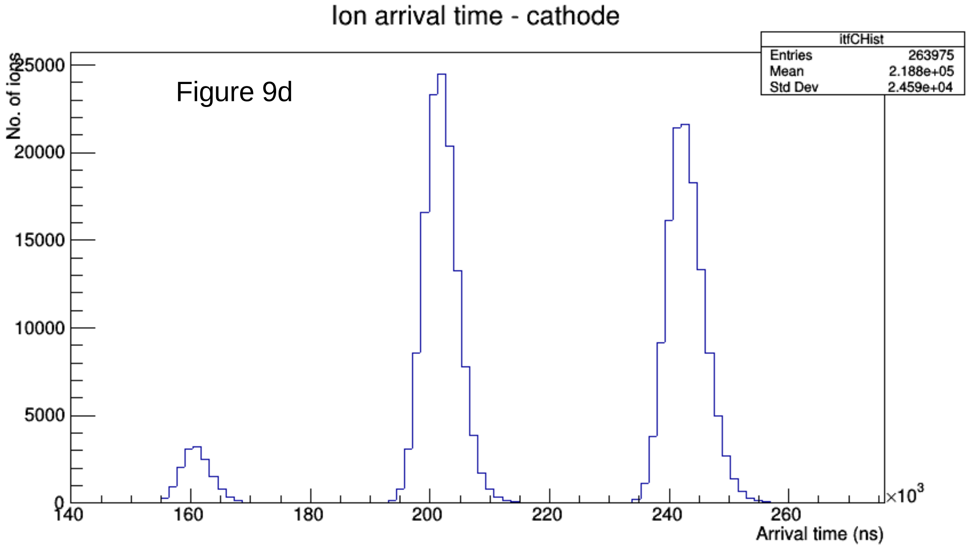
Time Histograms – Ions





Y axis scale is logarithmic!





Inset: The charge deposition on the exposed dielectric

Some more observations

1. The ion drift time between layers is typically on the <u>microsecond</u> order, but the charge deposition on the exposed dielectric takes place on the <u>nanosecond</u> scale – as the inset histograms suggest.

2. The typical transparency numbers for ions are ~53% for bottom layer and ~48% for mid layer.

3. For ions flowing back from the bottom GEM, the mid GEM layer stopped **only ~0.6%** (ref: Fig 9b) and the top GEM layer, ~21%. The remaining ions were observed to drift till the cathode.

4. However, for ions flowing back from the mid GEM, the **top GEM layer stopped ~54%.** The balance ~46% of these ions ended up on the cathode.

Outlook

1. Simulate realistic muon track events and study the ion properties.

2. Carry out further analysis on the ion diffusion and backflow part – particularly the effect of varying pitch and differing hole alignment layer-wise.

3. Make a movie to show the ion backflow in a triple GEM structure and study its time development, similar to the electron avalanche movie we already presented at the Miniweek held in February.

Useful links -

1. **Simulation of Triple GEM with animations – RD51 Miniweek, 10-13 February 2020**
2. **Movies of avalanches in a triple GEM – Garfield++ examples**

Suggestions/comments/queries are always welcome! Feel free to contact any of us -

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Thank You!