GEM tracking performance with GMn backgrounds

August 11, 2019

The GEM tracking performance is evaluated with digitized data from Geant4 simulation of full GMn experiment setup. This GEM tracking test is done in a way as realistic as possible where electronic noise, realistic GEM hit cluster profiles, APV-25 cross talk and timing uncertainty are all taken into account. The random background rate in GEM from the Geant4 simulation is around 100 kHz/cm^2 as shown in Figure 1. Elastic events are generated with an elastic generator and mixed with random background hits from a beam on target simulation. The amount of background to mix with each elastic event is determined by matching the random background rate as shown in Figure 1. This simulation result is then converted to simulated raw data files by a digitization library which simulates the signal generation in GEM and adds in all realistic effects. Lastly GEM tracking is applied on the simulated raw data files and evaluated by comparing to MC information.

1 Digitization

The digitization procedure takes in the simulated results and mixes in all realistic effects to make the output raw data file as similar as possible to real data. The following are the major parts built based on experience with real data from cosmic tests, a Hall A beam test, and X-ray testing.

- **Ionization**: Using the hit position, deposited energy, and range of hits from the simulation, electron-ion pairs are generated in a GEM drift region. The electron-ion pairs are distributed randomly within the are the hit covers within the GEM drift region. The number of

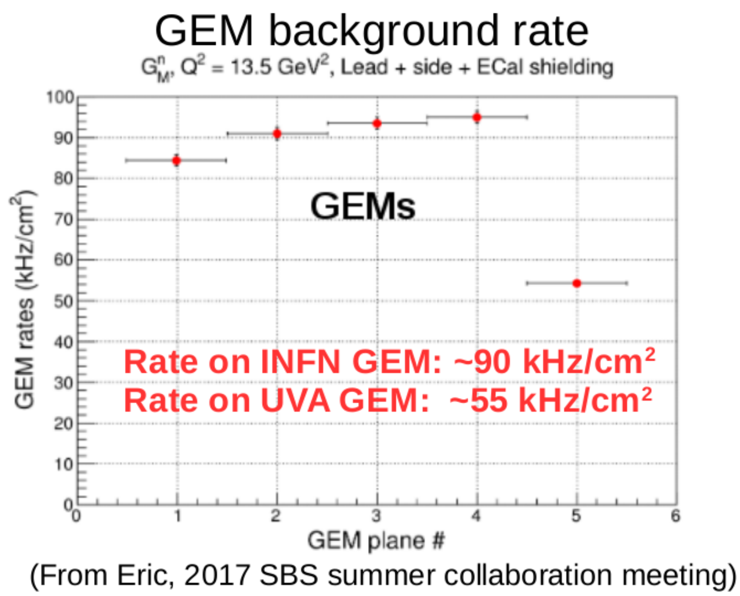

Figure 1: Random background rate in GEM layers in GMn experiment.

electron-ion pairs is proportional to the energy deposition of the hit. Thus for a hit resulting from a photoelectric interaction from a soft photon, the cluster amplitude and size will be much larger than a hit from a MIP-like particle.

- **Amplification and Drift**: The electron signals is are then amplified while drifting through GEM foils and propagate to the readout plane. Diffusion is also taken into account. The ADC gain is tuned such that the MIP-like elastic electrons in the GMn simulation shares similar hit cluster profile as cosmic hits seen in real cosmics testing (Figure 2).

- **Electronic noise**: Pedestal noise of the same level as real data are added into both fired and non-fired channels. Common mode, which describes the group baseline level of 128 channels on an APV card, is not set explicitly in the digitization. However, it is also effectively being taken into account just like in real data because the analysis code always tries to figure out the true common mode instead of assuming a zero baseline.

- **Cross talk**: In the MPD-APV readout system, a strong hit in a channel always introduces a small detectable image signal in adjacent channels. This effect, often referred as "cross talk", is seen and measured in the PRad experiment. In the digitization process, the ratio of the cross talk signal to the original signal has an average of 0.1 and an RMS of 0.3. A cross talk signal is added to corresponding channels for every primary signal.
- **Signal jitter in time**: Signal from the MPD-APV readout system have a random jitter with maximum of 25 ns due to the non-synchronization between the APV clock and the MPD clock. Although this time jitter will be measured and corrected in real data runs, there is still an additional timing residual due to this effect. This additional time uncertainty is also added to the intrinsic time uncertainty of GEM signals in the digitization procedure.

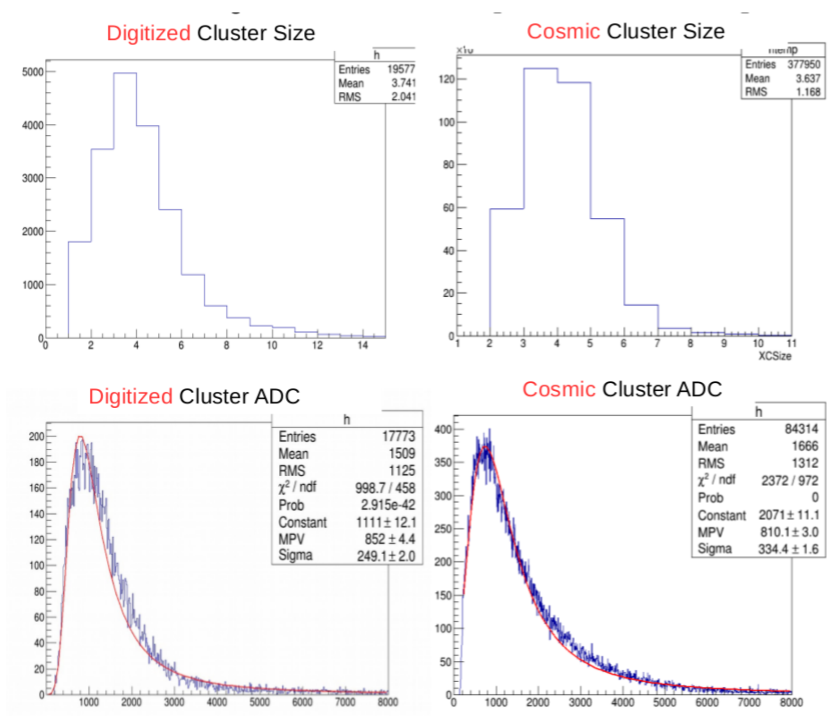

Figure 2: Cluster size and amplitude of digitized elastic electron hits and real cosmic hits.

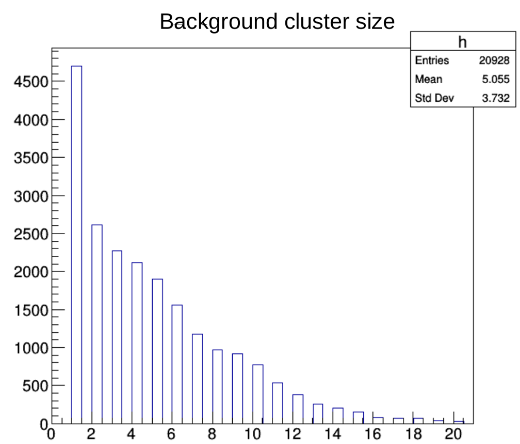

Figure 3: Cluster size of background hits after digitization. As can be seen in the plot, most of the background hits have a large cluster size.

2 Tracking performance

The main challenge of GMn tracking lies in handling the high level of random background. The background hits decrease the elastic electron detection efficiency and thus negatively impact tracking efficiency when they overlap and cover an elastic electron hit. This is mostly handled during the clustering step of the GEM analysis. The background hits also need to be rejected and only the tracks from elastic electrons should remain to allow accurate reconstruction of target vertex variables. Several techniques are used in the clustering and track reconstruction stages to reject these random background hits. The two major analysis stages are discussed briefly below.

2.1 Clustering and preserving primary hit

At the level of the expected GMn background, the raw average occupancy in the GEM is about 25%. At this occupancy, 60% of the elastic electron hits overlap in time with random background hits to as shown in Figure 4. Sometime the primary signal is completely covered by a large background hit and is lost. To minimize this effect and minimize the drop in elastic electron detection efficiency, the timing information of strips are examined along with the position information to help isolate an elastic electron cluster from random background clusters. First, clusters are split into two sub clusters when a peak-valley-peak pattern is spotted in the cluster. Second, only strips with similar timing information are allowed to form a cluster. After the clustering step, 85% of original primary hits are reconstructed and remain sufficiently "accurate" to form good tracks (that is, with a residual within 500 μm). The clustering stage also applies a timing cut to remove uncorrelated random background hits based on the timing correlation of a primary hit and the event trigger. Along with the primary hit, there are on average 50 hits that are indistinguishable from the signal hit. Figure 5 shows the distribution of the number of indistinguishable background clusters per event per plane at this stage of the analysis.

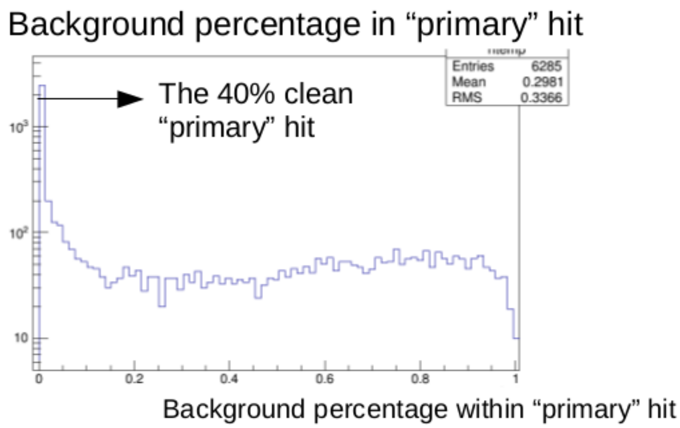

Figure 4: Example of pedestal results.

2.2 Tracking and rejecting random background hits

2.2.1 Calorimeter Cut

A primary track is formed by high energy electrons which deposit energy in the calorimeter, while a ghost track is from random background hits and does not have a corresponding calorimeter hit. The analysis requires a track's projection point to the calorimeter plane to be < 10 times the calorimeter position resolution away from its closest calorimeter hit for it to be considered as a good track. The position resolution of the calorimeter, and the residual of primary hits' projected point in the calorimeter plane are shown in Figure 6.

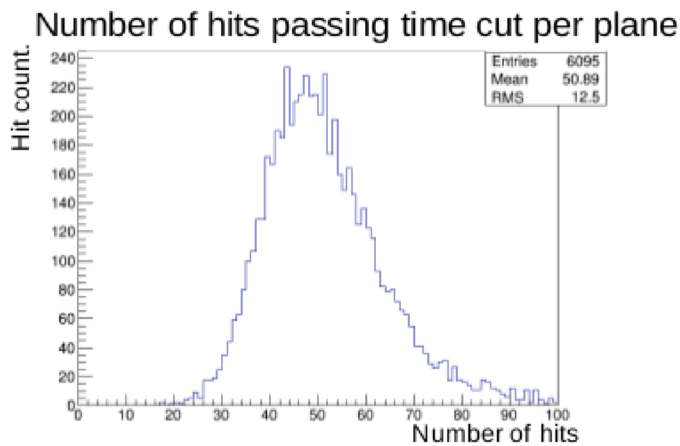

Figure 5: Number of background clusters indistinguishable from primary hit per plane.

2.2.2 Elastic kinematics cut

For an elastic track, there is a strong correlation between the slope and interception of the track. This is used to reject false tracks from random background hits and inelastic tracks. The correlation and the actual cut applied on candidate tracks is shown in Figure 7.

2.2.3 Matching hit information between two tracking planes

The horizontal and vertical tracking planes are treated separately in the above analysis. Additional cuts are applied to reject backgrounds when forming a 3-D track from 2-D tracks. These cuts mainly uses the hit information on different tracking layers of a track to match with track in the other tracking plane.

- **Module ID** GEM layers consist either three or four individual GEM modules in the GMn experiment. Each hit within a track has its associated module ID indicating which module the hit comes from. This module ID is required to match for two tracks to be eligible to form a 3D track.

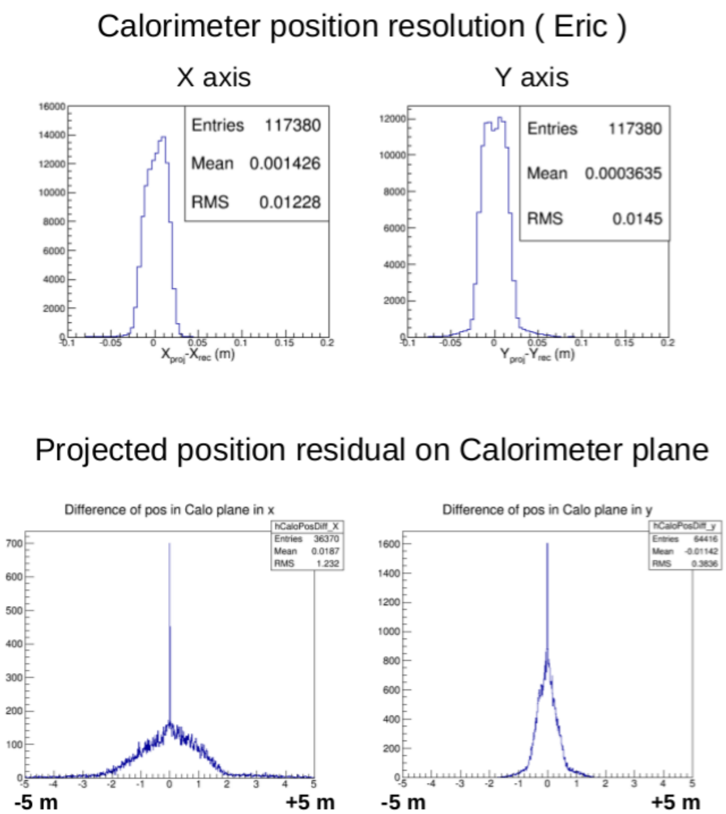

Figure 6: Calorimeter resolution and residual of primary hits' projected point in the calorimeter plane.

- **Hit amplitude** On the same GEM layer, hits are required to have similar amplitudes for two tracks to match.
- **Timing** On the same GEM layer, hits are required to have similar timing for two tracks to match. (This is turned off in the current GMn analysis. This is because: firstly the primary hits timing is distorted by background hits thus tight cuts affects efficiency, secondly backgrounds are already well rejected without this cut).

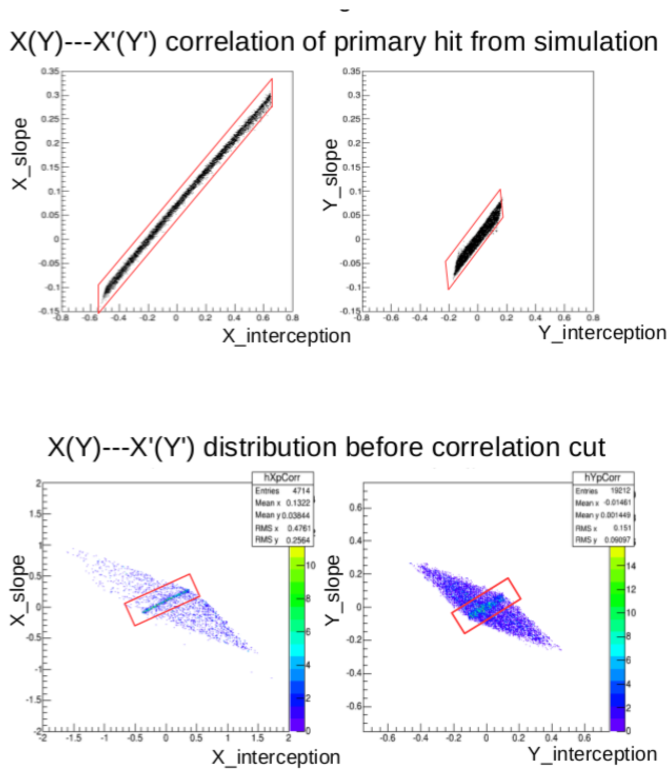

Figure 7: The top plot shows the correlation between slope and interception of a elastic track and the bottom plot shows the cut applied to reconstructed candidate tracks

2.3 Number of track candidates

The number of candidate tracks throughout the analysis is shown in Figure 8.

2.4 Tracking efficiency and accuracy

Target vertex variables are reconstructed for every remaining track after the cuts described above. A final cut requiring the Z-vertex falling within the target length is applied. The tracking efficiency is estimated by calculating the ratio of the final number of events that have at least one remaining track candidate to the total number of events. This efficiency, along with a GEM occupancy which is estimated by the percentage of fired strips, is evaluated

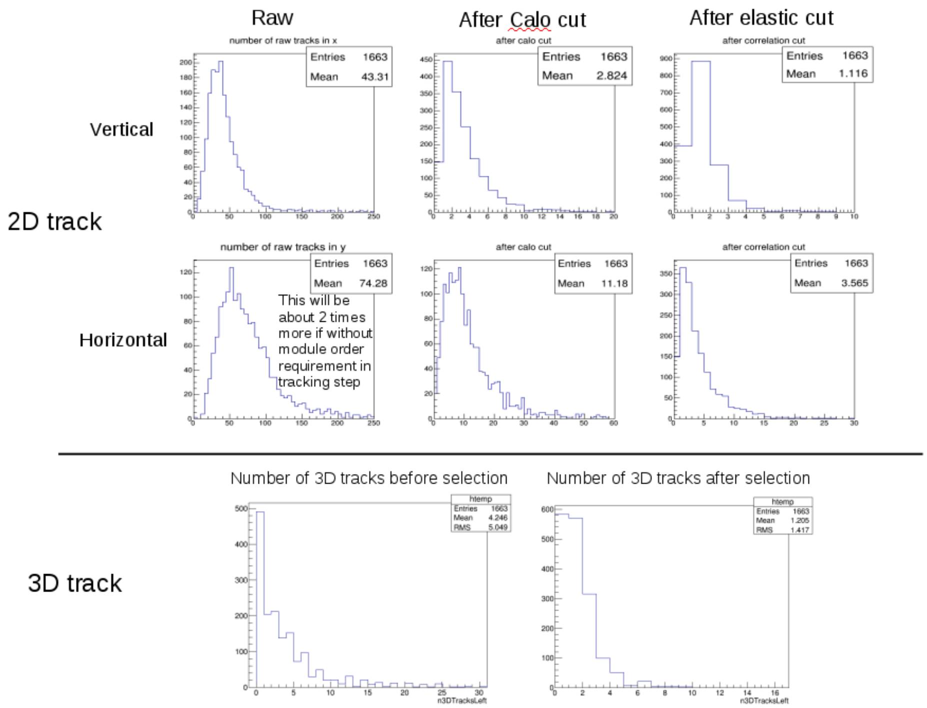

Figure 8: Occupancy level and tracking efficiency at different background levels.

for different background intensity levels and shown in Figure 9. When more than one remaining track candidates survives, the one with the smallest chi-squared value is selected. The accuracy of this final selected track at the full GMn background levels is evaluated by comparing the target vertex variables reconstructed from this track to the MC information of the analyzed event and shown in Figure 10.

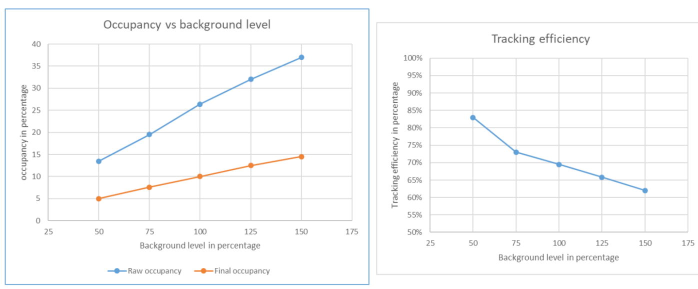

Figure 9: Occupancy level and tracking efficiency *vs.* background level. The GMn background estimated by simulation is denoted 100%. The raw occupancy includes all background hits within the readout window. The final occupancy excludes hits rejected at the hit reconstruction stage using timing information, and gives sense of background level that needs to be handled at the track reconstruction stage.

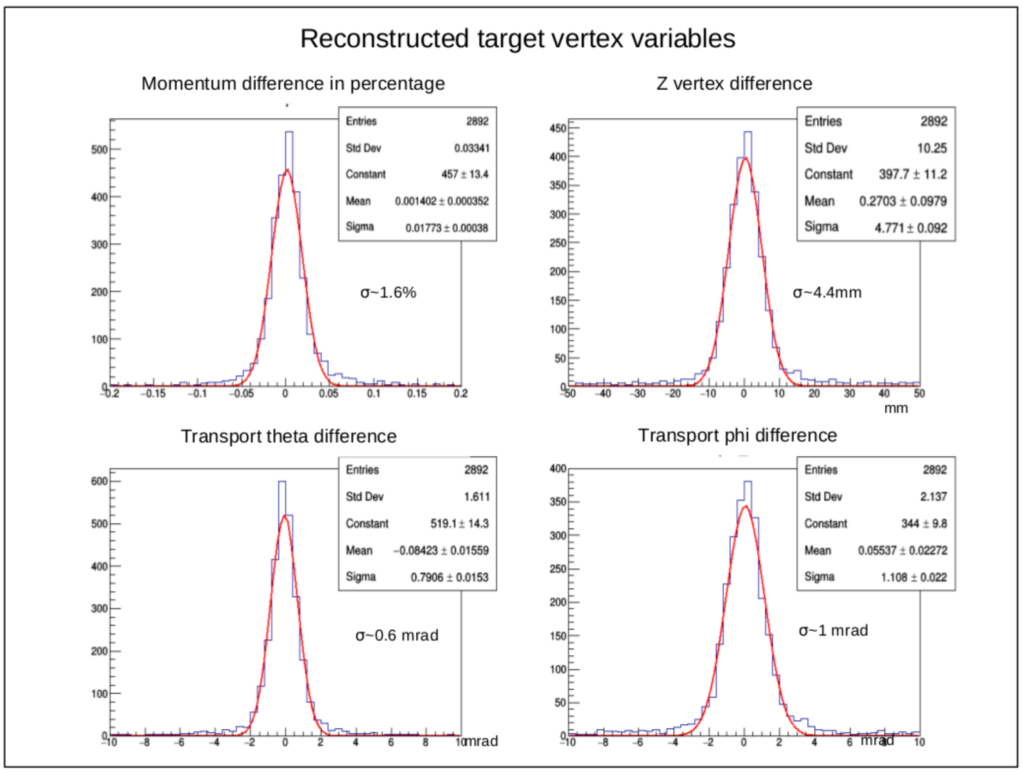

Figure 10: Accuracy of reconstructed target vertex variables at 100% estimated background level in the GMn experiment.