PROCEEDINGS OF SCIENCE

Simulation of the ATLAS New Small Wheel Trigger

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The instantaneous luminosity of the LHC will increase up to a factor of seven with respect to the original design value to explore physics at higher energy scale. The inner station of the ATLAS muon end-cap system (Small Wheel) will be replaced by the New Small Wheel (NSW) to benefit from the high luminosity. The NSW will provide precise track-segment information to the Level-1 trigger system in order to suppress the trigger rate from fake muon tracks. This article summarizes the NSW trigger decision system and track-segment finding algorithm implemented in the trigger processor, and discusses results of performance studies on the trigger system. The results demonstrate that the NSW trigger system is capable of working with good performance satisfying the requirements.

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1. LHC Upgrade and New Small Wheel Trigger

The instantaneous luminosity of the LHC will increase up to 3×10^{34} $cm^{-2}s^{-1}$ in 2021 (Run3) and 7×10^{34} $cm^{-2}s^{-1}$ in 2026 (HL-LHC) by undergoing an extensive upgrade program. In order to benefit from the high luminosity, the inner station of the ATLAS muon end-cap system (Small Wheel) [1] will need to be replaced by the New Small Wheel (NSW) [2] (Figure 1 (Left)) during the long shutdown in 2019-2020 to solve two problems; the degradation of the muon reconstruction efficiency due to the efficiency drop of the precision tracker at high background hit conditions and the increase of the fake muon triggers proportional to the luminosity. The NSW consists of Micromegas (MM) and small-strip Thin Gap Chambers (sTGC), and is composed by tracking and trigger detectors, providing precise track-segment information to the muon Level-1 trigger system in order to reduce fake triggers arising from particles that are not originating from the Interaction Point (IP). Both systems find track-segments independently and provide for each track its position (η, ϕ) on the detector as well as the angle deviation $\Delta\theta$ of the segment with respect to the direction from the IP. Finally, a coincidence in (η, ϕ) between the NSW and the outer muon system (Big Wheel-TGC) is required to suppress the fake triggers.

A detailed study of the final design and validation of the read out electronics for the NSW trigger system has been performed. A NSW simulation has been developed to model the actual response of the detector and its fast electronics, and has been used to get a deep understanding of the trigger algorithm and its performance at the high background hit rate expected during the next phases of operation of ATLAS at the LHC. In this article, the NSW MM trigger system is described in Section 2, and the results of the performance study are discussed in Section 3.

2. NSW MicroMegas Trigger System

The NSW MM detector has very fine read out strips of 0.45 mm pitch, and comprises 8 layers; 4 layers of η strips (X plane) and 4 layers of small angle stereo strips (U and V planes) for ϕ-coordinate [2]. Since the total number of channels is more than two millions, it is hard to process

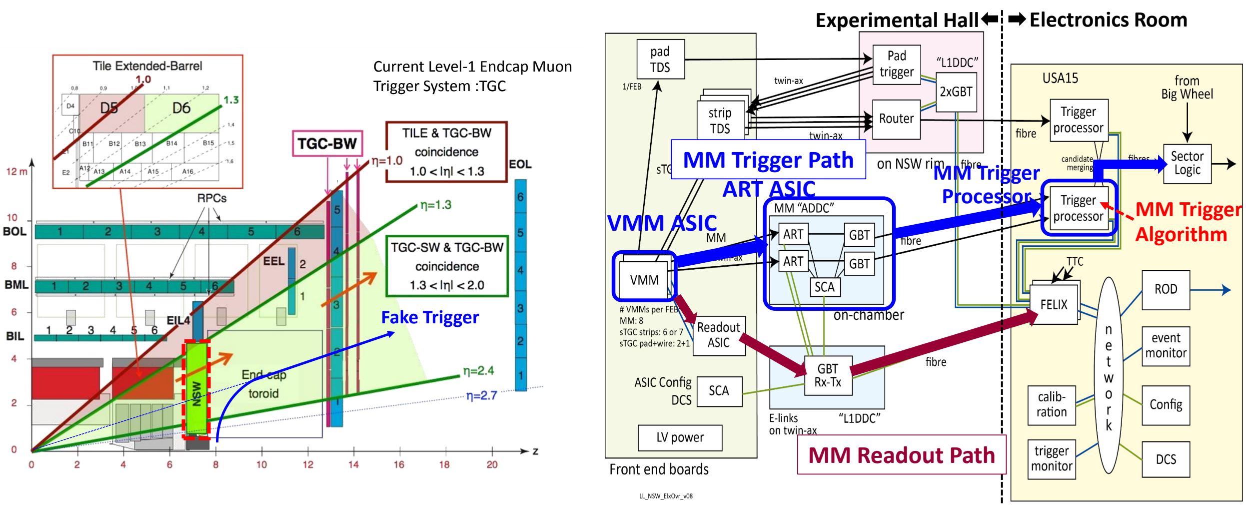

Figure 1: (Left): The ATLAS Muon Spectrometer with the NSW. The current end-cap muon trigger relies on BW-TGC signals, which have a lot of fake triggers. The NSW trigger system will contribute to suppress the fake triggers. (Right): NSW Electronics and DAQ data flow scheme.

all the channels in the Level-1 trigger latency [3]. A data suppression is essential to use the MM signals in order to form the Level-1 trigger accept signal.

Figure 1 (Right) is a schematic view of the NSW Electronics and DAQ data flow scheme. The MM strip signal is sent to the 64-ch VMM ASIC [4], which outputs the address of the strip with first threshold crossing signal within the 64 channels. No charge information is used for the trigger read out, but the small strip pitch makes a good position resolution possible still. This scheme significantly suppresses the data size to be processed. An ART ASIC collects the data from 32 VMMs within 25 ns, and sends the signals with the bunch crossing identification to the MM trigger processor. The MM trigger processor finds track-segments and calculates the track parameters. The algorithm implemented in the trigger processor FPGA is described below [5].

1. The incoming strip addresses are converted to the global strip position, and the slope value is calculated using a look-up-table, where the slope value is defined as the ratio of the radial distance of the hit from the beam and the z-coordinate of the relevant detector plane.
2. Multi-plane hit coincidence between the 8 layers is performed to find a track-segment pointing to the IP. The coincidence independently requires a minimum number of X and UV planes to have a hit in a given slope-road, for instance, 3X3UV ($\geq$3 hits in X, $\geq$3 hits in U+V planes).
3. The two dimensional positions (η, ϕ) and $\Delta\theta$ for the track-segment are calculated.

The η, ϕ and $\Delta\theta$ are sent to the Sector Logic boards and combined with the BW-TGC signal to determine the muon p_{T} and to generate the Level-1 trigger accept signal.

3. Performance of the MicroMegas Trigger System

3.1 Track-segment Finding Efficiency

Figure 2 (Left) shows track-segment finding efficiencies as a function of the mean number of interactions per bunch crossing ($<\mu>$). The hit rate condition at $<\mu>$=80 (160) corresponds to that of the LHC Run3 (HL-LHC) approximately. The efficiency of the 4X4UV coincidence decreases in particular at high $<\mu>$, while the 3X3UV and 2X2UV coincidences maintain good efficiencies. The inefficiency at $<\mu>$=80 and 160 with respect to that at $<\mu>$=0 is due to the front-end electronics deadtime and hits from the pileup events, and is about 1% at the 3X3UV coincidence.

Figure 2 (Middle) shows track-segment finding efficiencies for various coincidences and $<\mu>$ values as a function of η. The coverage of the NSW trigger in η is up to 2.4. At $<\mu>$=80 and 160, a few % efficiency drop is observed at high η region, where the background hit rate is the highest.

3.2 Track-segment Rate

Figure 2 (Right) summarizes the average numbers of reconstructed track-segments per trigger sector per bunch crossing for various coincidences. This is an important number because the number of track-segments that can be sent to the Sector Logic is limited to at most 8 per bunch crossing due to the bandwidth (two optical fibres of 6.4 Gbps). The 3X3UV coincidence has less than one track-segment even at $<\mu>$=160, while the 2X2UV coincidence has about 2.5 track-segments per bunch crossing mainly due to background hits. In case of the 2X2UV coincidence, a fraction of events above 8 track-segments is a few %, which is not negligible. On the other hand, the 3X3UV coincidence has a negligible fraction. Therefore, the 3X3UV coincidence can be the best option in terms of the track-segment finding efficiency and track-segment rate.

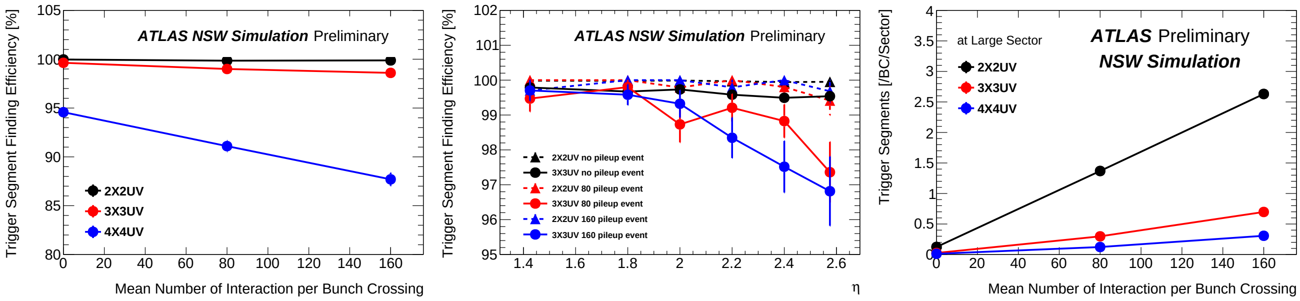

Figure 2: (Left): Track-segment finding efficiencies for various hit coincidences as a function of the mean number of interactions per bunch crossing (<μ>). (Middle): Track-segment finding efficiencies for various coincidences and <μ> as a function of η. The coverage of the NSW trigger ends up to $\eta = 2.4$. (Right): The average numbers of track-segments per trigger sector per bunch crossing for various hit coincidences.

3.3 Resolutions of Track-segment Parameters

Figure 3 shows residual distributions of measured η, ϕ and $\Delta\theta$ with respect to truth values, obtained by a tracking of truth hits, with the 3X3UV hit coincidence at <μ>=160. Resolutions obtained from the distributions are 4.7×10^{-5} for η, 1.9 mrad for ϕ and 1.1 mrad for $\Delta\theta$ measurements, which are better than the requirements of 5×10^{-3} and 20 mrad for η and ϕ measurements, respectively, and is comparable to the requirement of 1.0 mrad for $\Delta\theta$ measurement.

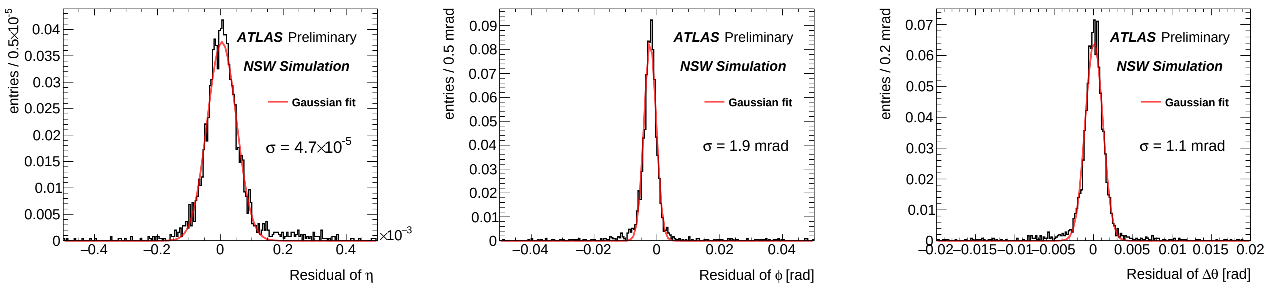

Figure 3: Residual distributions of measured η (left), ϕ (middle) and $\Delta\theta$ (right) with respect to truth values for track-segments, with the 3X3UV coincidence at <μ>=160.

4. Conclusion

The NSW trigger system is necessary for the ATLAS experiment at the expected high luminosity performance of the LHC. The NSW MM trigger simulation has been developed to model the actual response of the detector and its electronics, and used to get a deep understanding of the trigger logic and the performance. The track finding efficiency is higher than 98%, and the track rate is much smaller than 8, as well as the good resolutions of η (4.7×10^{-5}), ϕ (1.9 mrad) and $\Delta\theta$ (1.1 mrad) measurements, at the highest value of pile-up conditions. The results of the performance studies demonstrate that the MM trigger system is capable of working with good performance satisfying the requirements.

References

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