Simulation of the ATLAS New Small Wheel (NSW) System

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Abstract. New Small Wheel (NSW) is a major detector upgrade project of the ATLAS muon spectrometer for the LHC luminosity upgrade. NSW comprises sTGC and Micromegas as muon tracking detectors of high rate capability, and front- and back-end electronics for upgrading the muon level-1 trigger. Detailed simulation of the detectors and the electronics has been developed and used for the study of expected performance. An overview of the NSW system and some results of the trigger performance with the Micromegas are presented.

Keywords: ATLAS, Muon, New Small Wheel (NSW).

1 Introduction

Upgrades of the Large Hadron Collider (LHC) [1] will take place in several phases. After the second long shutdown (LS2) in 2019-20, the LHC instantaneous luminosity will increase up to $3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, which is three times the design luminosity, and 7.5×10^{34} after the LS3 in 2024-26. At these high luminosities, two problems arise in the ATLAS [2] end-cap region of the muon spectrometer: degradation of muon reconstruction efficiency due to an efficiency drop of the precision tracker in the inner-most muon station (the Small Wheel) at high background conditions, and an increase of fake level-1 muon triggers proportional to the luminosity to an unacceptable rate.

In order to solve these two problems, the Small Wheel will be replaced by a new detector, the New Small Wheel (NSW) [3]. NSW is equipped with tracking detectors of high rate capability (20 kHz/cm^2), and a function of generating real-time trigger segments for the use in the level-1 trigger to suppress the fake triggers.

2 Fake trigger suppression with New Small Wheels

Current level-1 muon trigger in the end-cap is generated using the trigger segment in the Big Wheels (BW). Transverse momentum (p_T) of a muon is determined based on the pointing angle of the segment reflecting the bending in the toroidal magnetic field in front of BW (Fig. 1(a)).

Fake Level-1 muon triggers are mainly caused by particles produced in the material before BW. Such fake triggers can be rejected by requiring the presence of a NSW

segment in space-time coincidence with the BW segment, reducing the rate of end-cap level-1 to about 1/3 [3]. In the NSW trigger processor, trigger segments are reconstructed and a set of parameters, the position of the segment in (θ, ϕ) and the IP pointing angle $\Delta\theta$, are generated (Fig. 1(b)). These information are combined with the BW segment in the Sector logic to produce muon Level-1 signals.

Fig. 1 (a) A z-y view of 1/4 of the ATLAS detector. (b) Trigger scheme with NSW.

3 New Small Wheel Detectors and Electronics

NSW comprises eight small-strip Thin Gap Chamber (sTGC) and eight Micromegas (MM) detector planes, consisting in total of 16 detector planes (Fig. 2(a), 2(b)). The sTGC-MM technology combination represents a highly redundant detector system for triggering and precision tracking. This document focuses on the MM trigger system.

Micromegas comprises a drift electrode, a drift gas gap of 5 mm thickness, a thin metallic mesh at 128 μm distance from resistive anode strips, creating the amplification region as shown in Fig. 2(c). Fast evacuation of the positive ions in 100ns in the thin amplification gap enables MM to operate at very high particle fluxes. The MM strips have a 450 μm strip pitch. The MM system has 2.1 million readout channels.

Signals from the readout strips are processed by custom made VMM ASICs. A VMM chip has 64 input channels. Each channel contains an amplifier-shaper-discriminator (ASD), and TDC and ADC circuits. It also contains a function of providing, for each LHC clock, the channel number in the VMM chip of the first arriving hit, the Address-Real-Time (ART) signal. ART is used to derive the position of muons at the MM readout board to be used for generating the MM trigger information in the trigger processor.

Fig. 2 (a) Overview of NSW. (b) A sector of NSW. (c) MM structure. Drift and avalanche multiplication of ionized electrons are depicted.

60 **4 Simulation of Micromegas Trigger System**

61 GEANT4 is used to model the detector materials and geometry as well as the interac-
 62 tion of particles in the detector. The simulation of the MM signals proceeds as fol-
 63 lows. Energy deposits in the sensitive gas volume is used to simulate ionization elec-
 64 tron clusters along the particle tracks. Drift of electrons to the mesh is calculated tak-
 65 ing into account the drift velocity, transverse and longitudinal diffusion, and Lorentz
 66 angle using parametrization of GARFIELD calculations. Gas multiplication is mod-
 67 elled according to the Polya distribution.

68 Pulse shape of amplifier output is modelled according to the characteristics of the
 69 amplifier-shaper circuit of the VMM chip. It is then compared to the discriminator
 70 threshold to generate hit signals. For each group of 64 channels in a VMM chip, the
 71 strip with first arriving hit is identified and the ART signal is generated. Dead time of
 72 each input channel after hit signals (300 ns) and of the ART logic after generation of
 73 an ART signal (40 ns) is implemented. ART signals from VMM chips are then col-
 74 lected and passed to the trigger processor, where the MM trigger algorithm is per-
 75 formed.

76 **5 Micromegas Trigger Performance Study**

77 Performance of the MM trigger is studied using simulated single muon events. In
 78 order to see the effects of pile-up, inelastic pp interactions are also simulated and
 79 added to the single muon event in the same bunch crossing (BC) and several BCs
 80 before and after the muon event. The mean number of pp interaction per BC consid-
 81 ered here are 80 and 160, corresponding to the peak luminosity during Run-3 and HL-
 82 LHC [4].

83 **5.1 Segment Finding Efficiency and Trigger Link Occupancy**

84 Fig. 3(a) shows the timing distribution of the ART signal. In order to collect signals
 85 with high efficiency, a time window of 50 ns (two LHC BCs) or more is needed. In
 86 the following, ART signals are collected within 50 ns time window. The MM detector
 87 has 8 layers. 4 of them have strips parallel to ϕ direction (X) and the other 4 layers
 88 have strips tilted by $+1.5^\circ$ (U) or -1.5° (V). Fig. 3(b) and (c) show the efficiency of
 89 finding trigger segments for different requirements on the number of hit strips (out of
 90 4 X hits and 4 UV hits) found within a common slope (R/Z) road. The trigger segment
 91 finding efficiency decreases at large number of pile-up events due to VMM dead
 92 time. However, there is no significant impact for 3X3UV and 2X2UV coincidence
 93 threshold. Even at the highest η where the background hit rate is the highest, the inef-
 94 ficiency is at most 3 %.

95 Due to bandwidth limitation of data transmission, the NSW trigger electronics can
 96 send out at most 8 trigger segments per BC per sector to downstream. The number of
 97 tracks due to background particles and fake tracks is less than one with the threshold
 98 of 3X3UV and 4X4UV as shown in Fig. 3(d).
 99

Fig. 3 (a) Timing distribution of ART output. (b) Trigger segment finding efficiency as a function of the number of pileup events. (c) Trigger segment finding efficiency as a function of η . (d) Average rate of trigger segments per crossing per sector as a function of the number of pileup events.

5.2 Resolution

Resolution of the segment parameters for the 160 pile-up condition is 1.1 mrad for $\Delta\theta$, 4.7×10^{-5} for η and 1.9 mrad for ϕ . For all the 3 parameters, the resolution meets the requirement.

6 Conclusion

The MM trigger performance is studied using a detailed simulation of single muons plus high pile up background. Trigger segment finding efficiency is found to be higher than 97% even in the highest hit rate conditions. The segment resolution meets the requirement and trigger link occupancy is low. The study shows the MM trigger maintains its performance in the highest background rate condition for the future LHC operation.

References

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