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The New Small Wheel Trigger for the ATLAS experiment

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Abstract

The ATLAS New Small Wheel (NSW) Muon spectrometer upgrade, completed in 2022, was the largest Phase I detector upgrade among LHC experiments. The NSW enhances triggering in the endcap region ($1.3 < |\eta| < 2.4$) by confirming muons from the Interaction Point (IP) and rejecting fake contributions. It also improves muon tracking with 2.5 million high-resolution channels across 16 layers. The NSW Trigger, based on small-strip Thin Gap Chambers (sTGC) and Micromegas (MM) technologies, provides Level-1 triggers at every Bunch Crossing (BC) with a fixed low latency (44 BC). Integrated into ATLAS in 2023, the NSW Trigger significantly reduces fake rates and overall readout deadtime. The custom electronics of the NSW Trigger system efficiently collect, process, and trigger on IP muons, focusing on the fully operational sTGC pad-only path based on the Pad Trigger (PT) and Trigger Processor (TP) FPGA based boards. Performance studies using 13.6 TeV pp collisions are presented, demonstrating NSW's readiness for the High Luminocity LHC (HL-LHC) era and outlining Phase II upgrade perspectives.

Keywords: ATLAS, Muon Spectrometer, New Small Wheel, NSW, TDAQ, Electronics, Run 3

1. Upgrade of the muon spectrometer: New Small Wheel

The ATLAS [1] NSW Muon spectrometer upgrade was completed in 2022 and constituted the largest detector upgrade in Phase I among the LHC experiments The innermost station of the muon endcap spectrometer was replaced by two detector technologies, the MM and the sTGC [2].

The performance of the muon tracking chambers in the end-cap region of the ATLAS detector degrades with increased cavern background rates, particularly at high luminosity and energy conditions. This results in substantial degradation of tracking performance in the inner end-cap station (Small Wheels), affecting the efficiency and resolution which is crucial for muon momentum measurements. Additionally, the Level-1 muon trigger in the end-cap region suffers from a high rate of background, primarily caused by low-energy particles generating fake triggers. Consequently, approximately 90% of the muon triggers in the end-caps are fake, leading to a trigger rate that is 8-9 times higher than in the barrel region. This degradation poses significant challenges for the overall performance of the ATLAS detector.

The installation of the New Small Wheel (NSW), completed in 2022, addresses these issues with its advanced triggering and tracking capabilities. The fake trigger rate will be significantly reduced by introducing a track coincidence between the NSW and the Big Wheel (BW), and by rejecting segments that do not point to the IP through a cut in the $\Delta\theta$ angle (θ: the angle of the segment with respect to an 'infinite momentum track').

2. NSW trigger in Run 3

At the beginning of 2023 it was decided that NSW trigger should contribute to the ATLAS trigger decision, since according to studies, the higher pile-up and the increased luminosity will lead to an increase in the Level-1 trigger and to a deadtime at the level of 5%. It was then suggested that the inclusion of a part of NSW trigger could reduce the Level-1 rate by 8 kHz [3].

The NSW TDAQ system can be seen in Figure 1. From this complicated trigger path a smaller part was selected to participate in the Level-1 muon trigger decision. The *pad-only path*, as it was named, included the data coming from the pads of the eight layers of the sTGC detector which then enter the PT board. The PT is based on an FPGA and its logic decides

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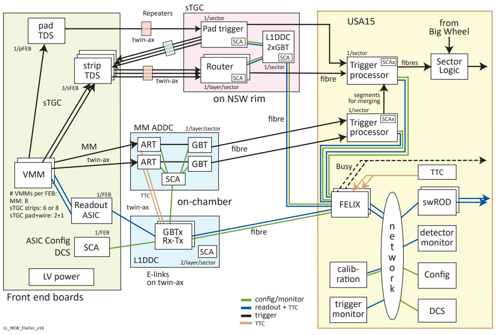

Figure 1: Schematic of NSW TDAQ electronics system [4].

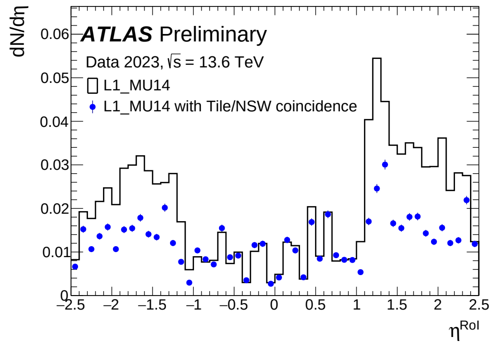

Figure 2: The pseudorapidity (η) distribution of the Level-1 Region-of-Interests (RoIs), which fulfill the primary Level-1 muon trigger before and after the deployment of the Tile ($1 < |\eta| < 1.3$) and NSW ($1.3 < |\eta| < 2.4$) coincidences in the Level-1 trigger decisions in 2023 Run 3 data [5].

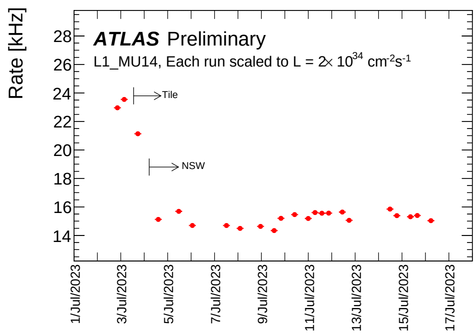

Figure 3: The trigger rate of the primary Level-1 muon trigger, scaled to the instantaneous luminosity of $2 \times 10^{34} cm^{-2} s^{-1}$, as a function of time in 2023 Run 3 data [5].

whether there is a coincidence in three-out-of-four and two-out-of-four layers, from a predefined look-up-table (LUT). In the end the trigger decision from the PT board is forwarded to the TP board, which forms the final trigger segment and forwards it to the Sector Logic (SL). Subsequently, SL checks the coincidence between NSW and BW within a predefined (η, ϕ) window.

The PT and TP trigger logic were modified to facilitate the inclusion of the NSW in the Level-1 muon trigger decision. Changes included duplicating pad hits in subsequent BCs to prevent missed triggers due to timing issues, and additional trigger segment duplication in the TP complemented with a duplicate removal system. The PT LUT was updated with new patterns and configurable trigger coincidence criteria. Busy logic for PT and TP was implemented but not yet used. The PT also gained mask_to_1 and mask_to_0 capabilities to address high voltage issues, unresponsive front-end boards, and noisy or inactive detector pads. Finally, NSW ensures fixed latency to the SL.

3. Results

This effort culminated in the inclusion of 75% of NSW sectors in the Level-1 muon trigger decision by the summer of 2023, as illustrated in Figure 2 and Figure 3. These figures utilize data from multiple Run 3 *pp* collision runs, with a transverse momentum threshold of 14 GeV (L1_MU14) , incorporating Tile and NSW pad-only coincidences in the SL.

In Figure 2, the pseudorapidity (η) distribution is shown before (white histogram) and after (blue points) the deployment of Tile/NSW coincidences. The white histogram is scaled to 1, and the blue dots are normalized relative to this, based on the integrated luminosity. In this figure the rejection of fake triggers after the inclusion of NSW can be seen. The rate reduction due to NSW at $L = 2 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ was 6 kHz, as depicted in Figure 3, which shows the trigger rate reduction over time in 2023. The observed variations result from on-the-fly adjustments made to address issues in the NSW detector.

4. Summary

The inclusion of the NSW pad-only trigger in the Level-1 muon trigger decision demonstrated that even a partial implementation of the NSW trigger can contribute to reducing the trigger rate, allowing ATLAS to maintain high performance and successful data collection during Run 3.

The full NSW trigger path, which includes the sTGC strips and MM paths, will further support this goal as ATLAS moves toward Phase II upgrades and the HL-LHC. Additionally, a new TP with integrated MM and sTGC capabilities will be developed for Phase II, capable of handling a readout rate of 1 MHz, compared to the current 100 kHz.

References

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