Enhancing the ATLAS Level-1 Endcap Muon Trigger with New Small Wheel Integration in Run 3

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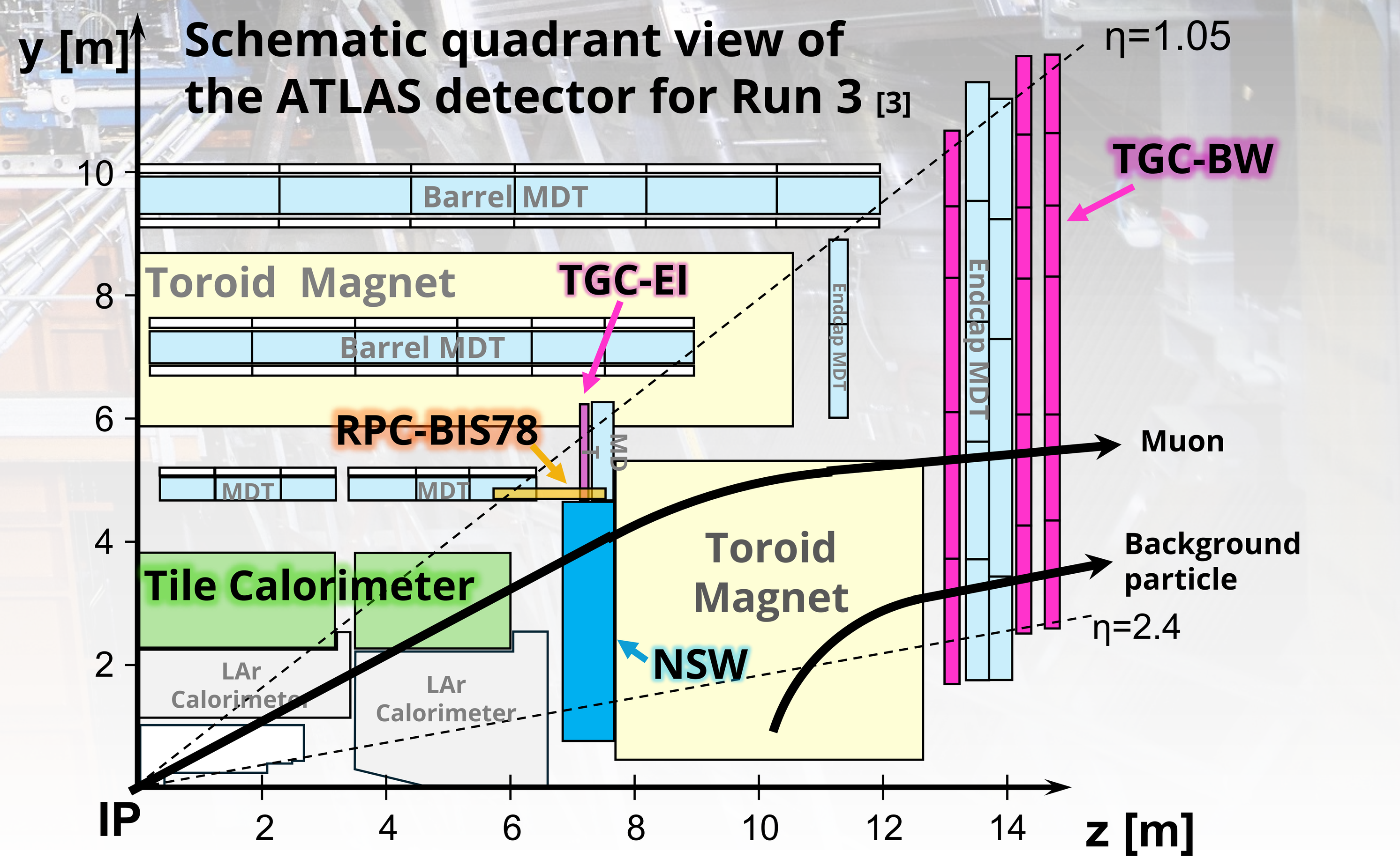
Abstract The Level-1 muon endcap trigger in the ATLAS experiment utilises signals from the Thin Gap Chambers (TGCs) located in the outer muon stations. A significant challenge for this system has been the high background rate caused by particles not originating at the interaction point, which increased the Level-1 trigger rate. To address this issue, the New Small Wheel (NSW) detectors, installed at the inner muon stations during Long Shutdown 2, were integrated into the Level-1 endcap muon trigger system for Run3 operations. In 2024, the full integration of the NSW sectors into the Level-1 trigger decision was successfully completed. By cross-checking the consistency between muon candidates identified by TGC signals and those by the NSW, the system achieved a significant improvement in the discrimination between muons and background particles. This advancement reduced the Level-1 trigger rate by approximately 15 kHz, effectively decreasing the load on the Trigger and DAQ systems and substantially enhancing the data-taking efficiency of the ATLAS experiment.

ATLAS Level-1 Endcap Muon Trigger

The Level-1 endcap muon trigger in the ATLAS experiment uses **Big Wheel (BW) Thin Gap Chambers (TGCs)**. It reconstructs straight muon tracks via multi-layer TGC coincidences and selects high-momentum muons based on the position deviation from the infinite-momentum line. This, however, suffers from high background rates due to non-interaction-point (IP) particles.

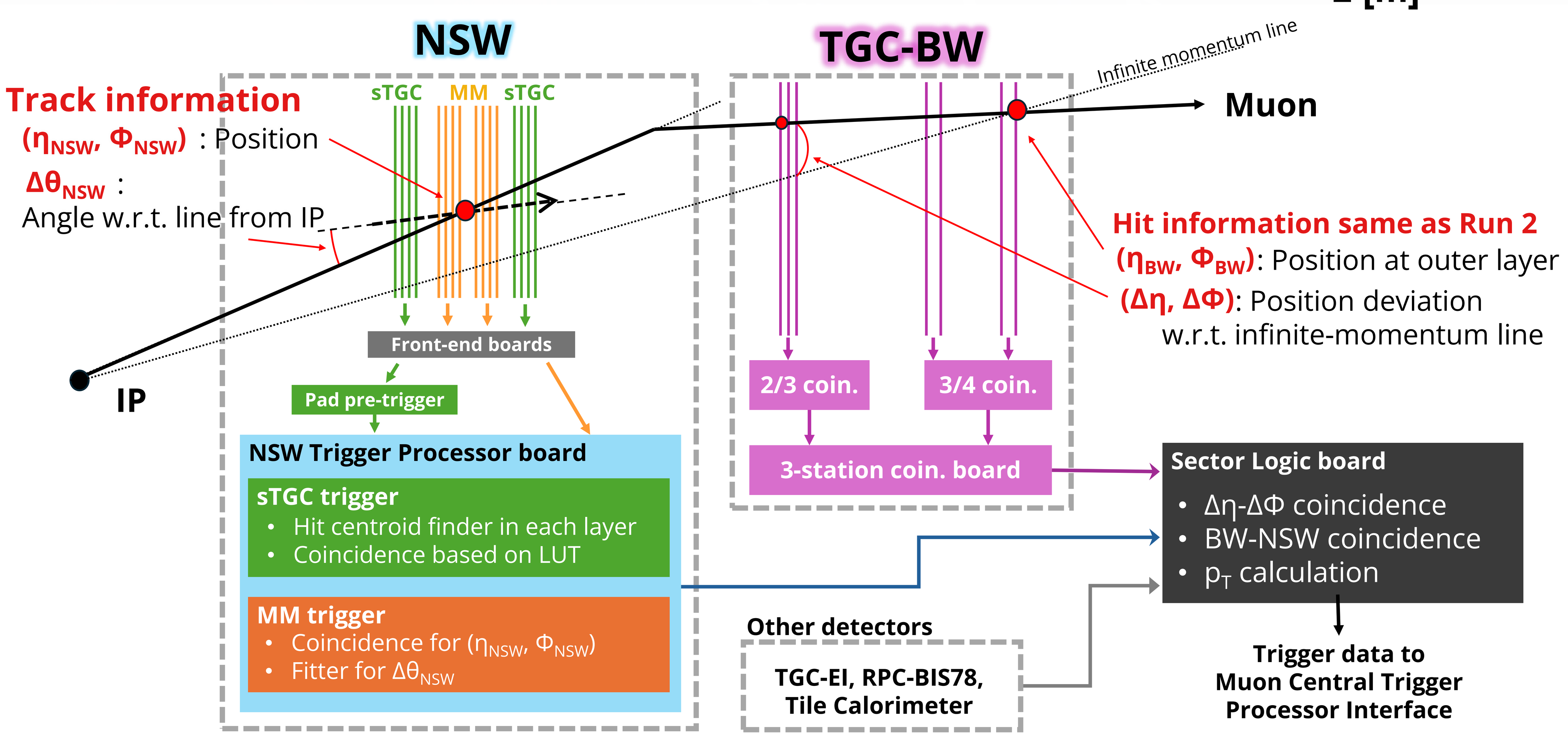
To address this, track coincidence with the newly introduced **New Small Wheel (NSW)** detector inside the magnetic field is used [1].



Trigger Algorithm for BW-NSW Coincidence

NSW consists of two gas detector technologies: **small-strip TGC (sTGC)** and **Micro Megas (MM)**. Compared to the old Small Wheel, the NSW provides **increased η coverage** ($|\eta| < 1.8 \rightarrow 2.4$) and **improved position resolution**. Tracks in the NSW are independently reconstructed by layer coincidences in both sTGC and MM. The position/angle information is sent to the **Sector Logic board**.

In the **Sector Logic**, the R/Φ position and transverse momentum (p_T) are first determined from TGC-BW hit information. Next, coincidence with NSW track information is used to suppress fake candidates. The coincidence is implemented by referencing a precomputed Look-Up Table stored in the FPGA.

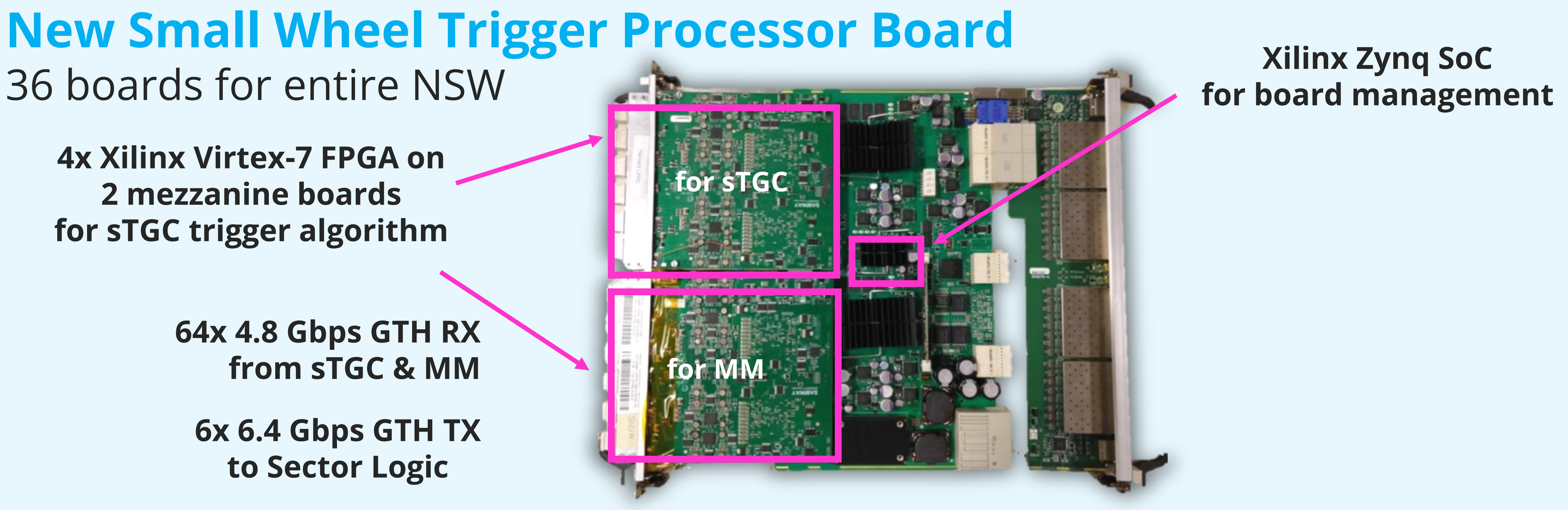


New Trigger Processors for Run 3

New NSW Trigger Processor Boards and Sector Logic Boards were designed with larger resource FPGA and numerous optical transceivers.

New Small Wheel Trigger Processor Board

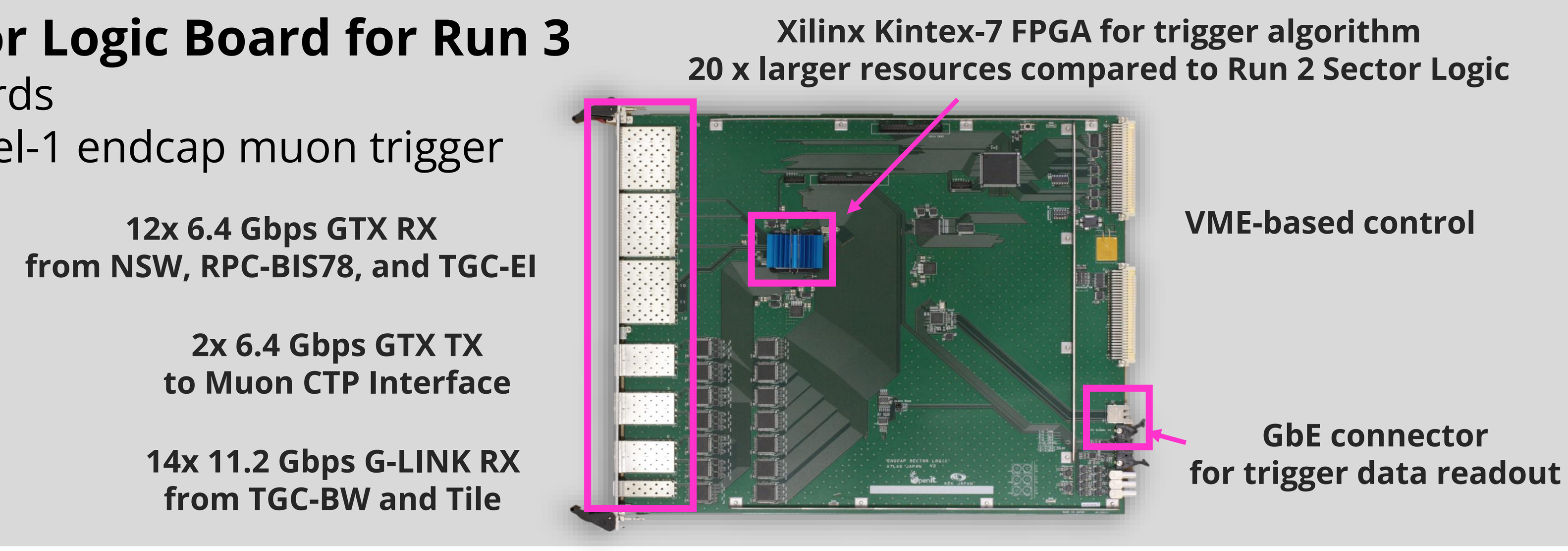
36 boards for entire NSW



Sector Logic Board for Run 3

72 boards

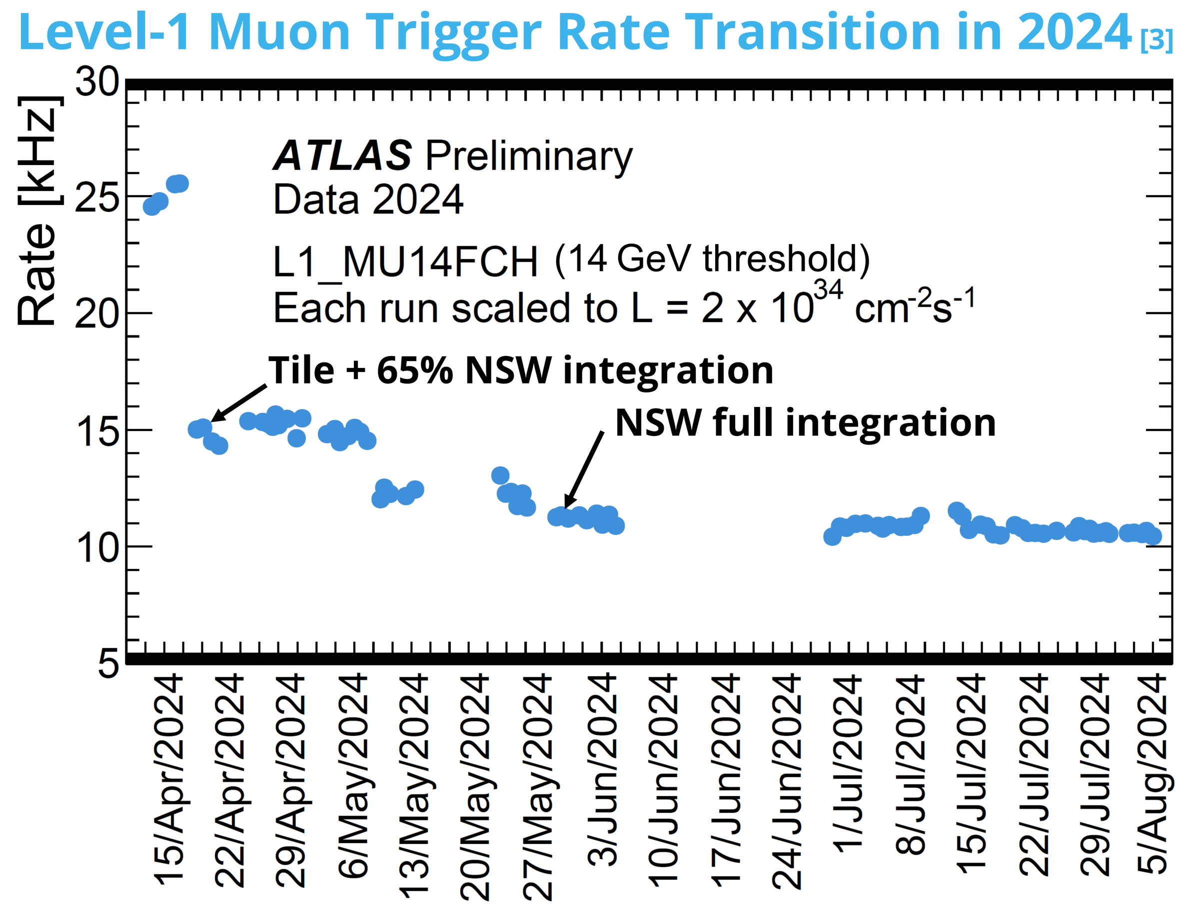
for Level-1 endcap muon trigger



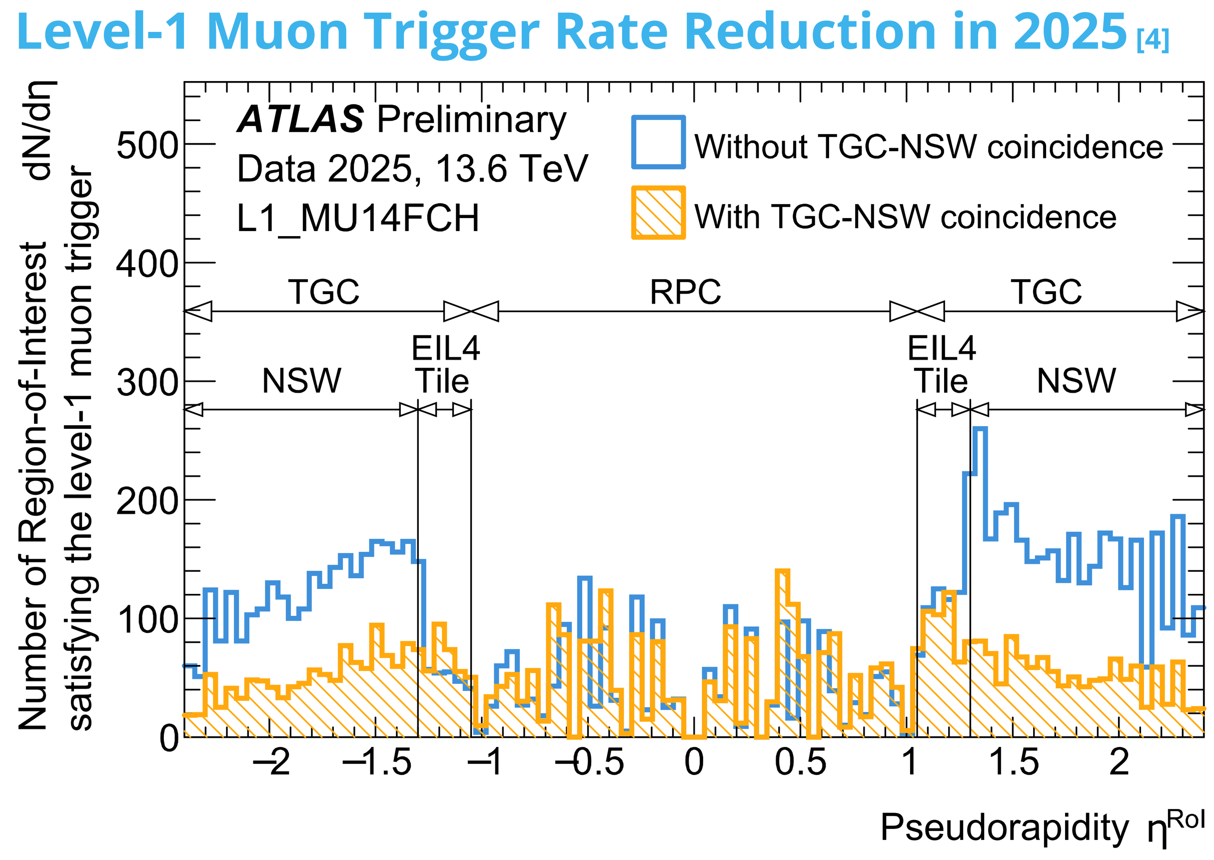
Level-1 Endcap Muon Trigger Performance for NSW Integration

The NSW coincidence was partially introduced in 2023 and **fully integrated across all NSW sectors in 2024**. In addition, the inclusion of coincidences with TGC-EI and the Tile Calorimeter enabled full-coverage coincidence for the entire TGC system. In 2025, the inefficiency introduced by the inner-coincidence requirement was reduced to about 2% through optimization. This upgrade halved the Level-1 muon trigger rate, **25 kHz → 11 kHz @ 2×10^{34} cm^{-2}s^{-1}**, contributing to improved data-taking efficiency for ATLAS.

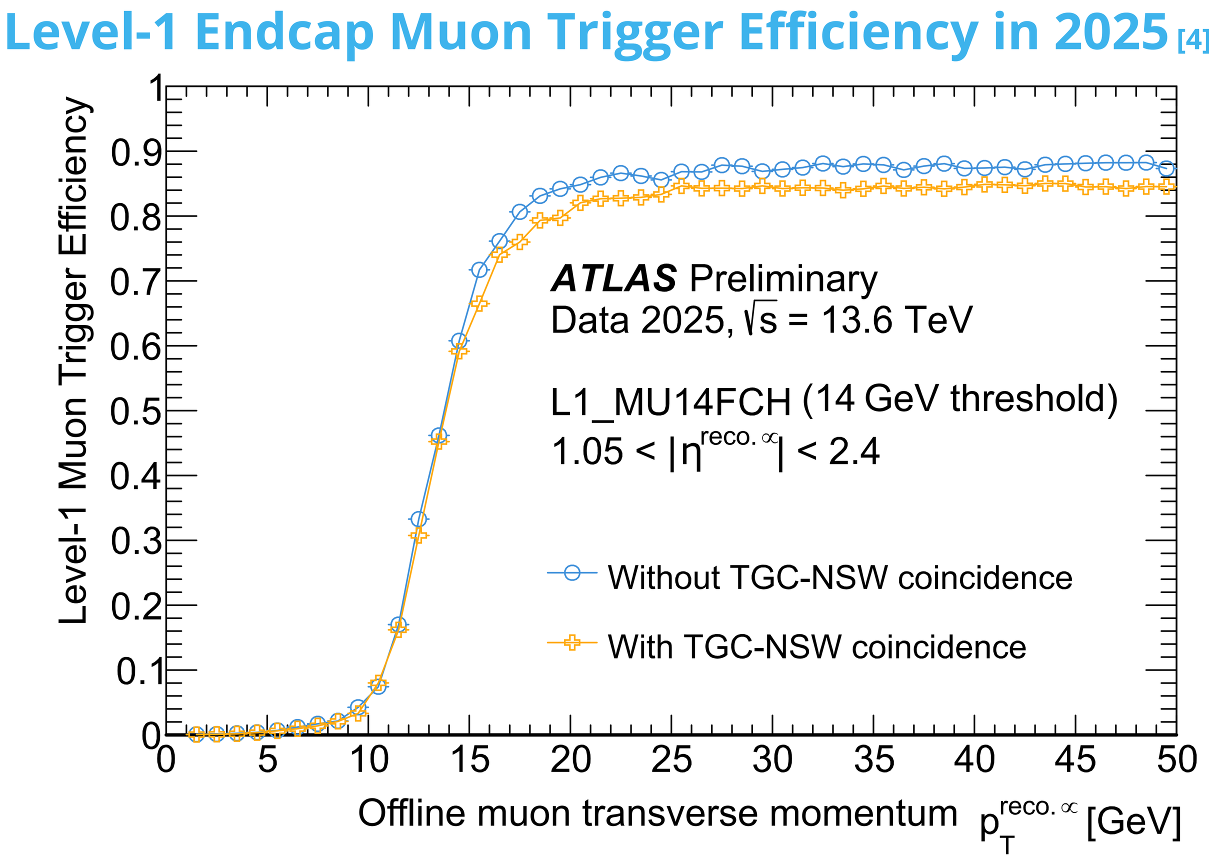
Level-1 Muon Trigger Rate Transition in 2024 [3]



Level-1 Muon Trigger Rate Reduction in 2025 [4]



Level-1 Endcap Muon Trigger Efficiency in 2025 [4]



[1] ATLAS Collaboration, *Technical Design Report for the Phase-I Upgrade of the ATLAS TDAQ System*, CERN-LHCC-2013-018, ATLAS-TDR-023 (2013).
[2] ATLAS Collaboration, *The ATLAS experiment at the CERN Large Hadron Collider: a description of the detector configuration for Run 3*, JINST 19 P05063 (2024).
[3] ATLAS Collaboration, *Performance of the Tile and NSW inner-coincidence for the L1Muon Endcap trigger*, L1Muon Trigger Public Results PLOT-TDAQ-2024-08, August 2024.
[4] ATLAS Collaboration, *Performance of the Tile and NSW inner-coincidence for the L1Muon Endcap trigger*, L1Muon Trigger Public Results PLOT-TDAQ-2025-02, August 2025.