ATLAS Level-0 Endcap Muon Trigger for HL-LHC

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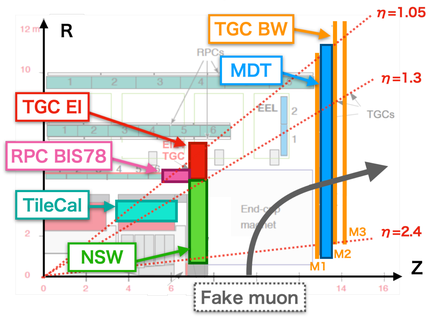
Abstract : High Luminosity LHC (HL-LHC) is an upgrade of LHC to achieve higher luminosities, thereby enabling experiments to reach better physics sensitivity. Operation of HL-LHC is scheduled to start in 2027 with an instantaneous luminosity of 7.5 x 10^{34} cm^{-2} s^{-1} . In order to cope with the luminosity at HL-LHC, the trigger and readout systems need to be upgraded. The design for the Level-0 endcap muon trigger of the ATLAS experiment at HL-LHC and the status of the development are presented.

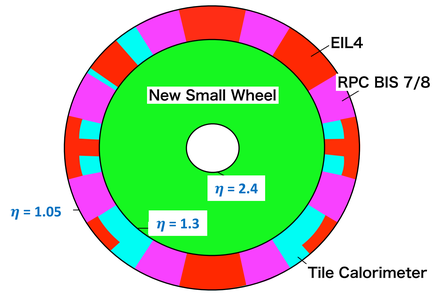
Level-0 endcap muon trigger for HL-LHC

- **Main detector of endcap muon trigger**
  - ➢ Thin Gap Chamber on the Big Wheel (TGC BW)
    - ❖ Multi-wire proportional chamber
    - ❖ Two-dimensional position measurement using signals from wires and strips orthogonal to the wires
    - ❖ Consists of three stations. Stations M1, M2 and M3 have three, two and two layers respectively
- **Original trigger scheme**
  - ➢ Simple coincidence logic in on-detector boards
  - ➢ Transverse momentum (p_T) is evaluated by look-up tables in trigger logic boards (Sector Logic : SL)
  - ➢ Triggers by the *fake muons suppressed by combining signals from various subdetectors (Inner Coincidence)
    - ❖ TGC in the Endcap Inner station (TGC EI)
    - ❖ Resistive Plate Chambers in the barrel inner station (RPC BIS78)
    - ❖ Tile hadronic calorimeter (TileCal)
    - ❖ New Small Wheel (NSW)

*low-momentum charged particles emerging from large amounts of dense material such as the toroid coils and shields

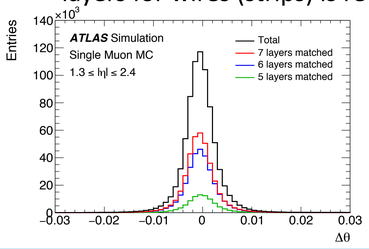
- **New Level-0 endcap muon trigger for HL-LHC**
  - ➢ Track reconstruction using full-granular information will be enabled by transferring all hit information to SL
  - ➢ Improved p_T resolution by implementing complex coincidence logic for Inner Coincidence
  - ➢ Monitored Drift Tube (MDT) is used to improve the p_T resolution at the Level-0 muon trigger
- Main functions of SL are implemented on the Virtex UltraScale(+) FPGA provided by Xilinx





TGC track segment reconstruction

- Tracks are reconstructed in TGC with a "**pattern matching**" algorithm
  - ➢ Comparing the TGC hits with predefined hit lists for high-p_T muons
  - ➢ Each predefined hit pattern has angle and position information
- Requirement for hits
  - ➢ Run-2 : At least two (one) hits in the inner three (two) layers and at least three hits in the outer four layers for wires (strips)
  - ➢ HL-LHC : A looser coincidence with at least five (four) hits in seven (six) layers for wires (strips) is required to improve the efficiency

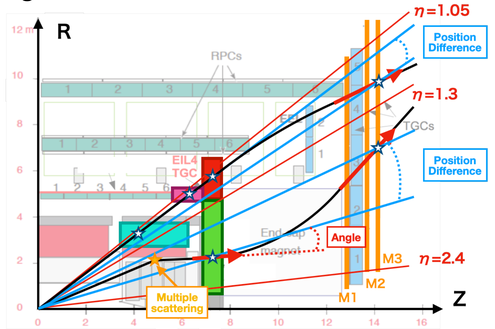


Track segment angular resolution

- ➢ Distributions of the difference of the polar angle (Δθ) between the TGC track segment and the track segment reconstructed by the ATLAS full offline analysis.
- ➢ Track segments are reconstructed with an average angular resolution of **4 mrad**.

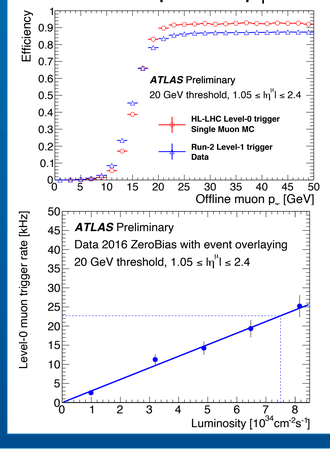
Trigger scheme using inner detectors

- p_T is determined from
  - ➢ 1.05 < |η| < 1.3 : Position difference between TGC BW track segments and hits in the TGC EI, RPC BIS78 and TileCal.
  - ➢ 1.3 < |η| < 2.4 : Position difference between the TGC BW track segments and the tracks reconstructed in NSW.



Improvement of trigger performance

- Trigger performance of the Level-0 endcap muon trigger (not including the more precise p_T measurement in MDT) was evaluated.



Efficiency

Compared to the Run-2 trigger

- ➢ **Higher efficiency (~ 4%)** in the plateau region due to the looser coincidence.
- ➢ **Better rejection** for low p_T muons thanks to the good angular resolution.

Trigger rate

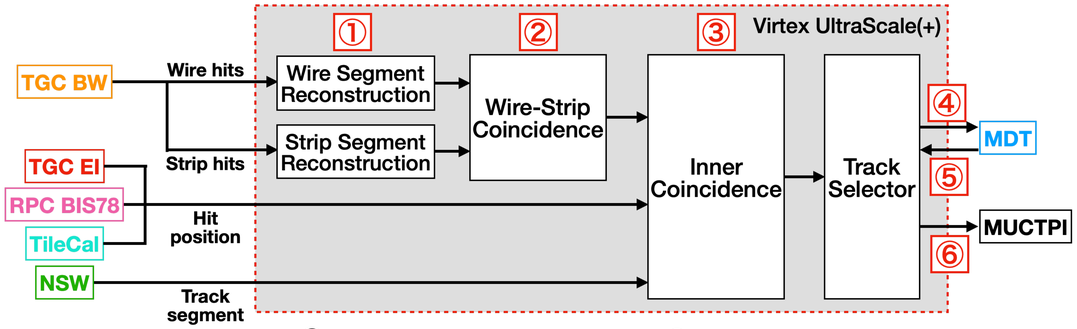
- ➢ Rate for 20 GeV threshold is about **23 kHz.** (constitutes only about 2.3% of the assumed total Level-0 trigger rate of 1 MHz)
- ➢ Further rate reduction by ~50% in the next step with MDT is expected.

Firmware design

① Reconstruct track segments using wire (strip) hits from the TGC BW

② Evaluate p_T by combining wire and strip track segments

③ Combine track segments with information from inner detectors to evaluate p_T with higher precision



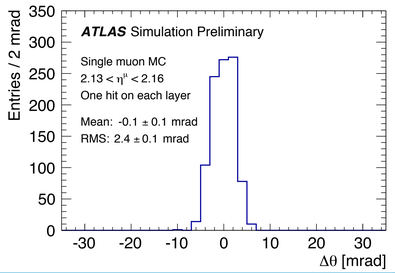
④ Send three muon candidates with the highest-p_T to the MDT

⑤ Receive muon candidates with updated p_T from the MDT

⑥ Transfer the muon candidates to the Muon to Central Trigger Processor Interface (MUCTPI)

Initial test of TGC segment reconstruction on hardware

- Test firmware of TGC pattern matching algorithm for a specific unit is implemented in an FPGA with an evaluation board VCU118.



Performance

- ➢ Test vectors of TGC hits are obtained from Monte-Carlo (MC) sample and used as the FPGA inputs.
- ➢ The angular resolution estimated from the offline analysis is reproduced in the test.

- Development of full chain firmware for limited coverage is in progress
  - ➢ Trigger performance will be evaluated by injecting test vectors made from MC samples this summer.

References :

[1] The ATLAS Collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS TDAQ system, CERN-LHCC-2017-020.

[2] The ATLAS Collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer, CERN-LHCC-2017-017.

[3] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L0MuonTriggerPublicReults