ATLAS Level–1 Endcap Muon Trigger for Run 3

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Jul. 12 2019
Introduction and Run 2 status

✓ Overview of the ATLAS L1 endcap muon trigger:

- Hardware trigger by Thin Gap Chambers (TGC) for $1.05 < |\eta| < 2.4$.
  - New coincidences using TGC inner stations (TGC–EIFI) and Tile calorimeter were introduced in Run2.
- Muon $p_T$ measurement using pre-defined Look Up Tables (LUT).

✓ Run 2 performances:

- Primary single muon trigger with a 20 GeV $p_T$ threshold (L1_MU20).
  - ~17kHz@L=2x10^{34}cm^{-2}s^{-1} (2018 data)
- ~90% plateau trigger efficiencies with a stable operation.
Main motivation of upgrade program for Run 3:

- Reject “fake” triggers, ~50% of the trigger candidates is fake due to slow particles emanating from the endcap toroid or shielding.
- Reduce low-\(p_T\) muon contamination below the threshold.

Improvements of the L1 muon trigger are important for various physics analyses. (the total budget of L1 rate is 100 kHz)

This presentation focuses on:

- Development of the new trigger processor board (Sector Logic) and its trigger algorithms.
- Trigger rate estimation.
Upgrade overview for Run 3

✓ New muon detectors will be installed into the inner regions:

- Small Wheel (TGC, MDT, CSC) will be replaced with New Small Wheel (sTGC, MM)
  - sTGC: small–strip TGC detector, MM: Micromegas detector
  → better coverage for the TGC–BW and Small Wheel coincidence ($|\eta| < 2.0 \rightarrow |\eta| < 2.4$)
  → precision measurement of muon track segments

- New RPC detectors (RPC–BIS78) will be added to the edge of the barrel muon trigger system

New coincidences between TGC–BW and NSW/RPC–BIS78 will be introduced to reject the fake triggers and improve the $p_T$ resolution.

→ New electronics have been developed to handle the new information and make coincidences.
L1 endcap muon trigger schema for Run 3

**NSW**
- sTGC1
- MM1
- MM2
- sTGC2

**TGC-BW**
- BW1
- BW2
- BW3

Interaction point

Track information ($\Delta \theta$, $\eta_{NSW}$, $\phi_{NSW}$)

**Front end board**
- sTGC trigger processor
- MM trigger processor

**Vector information**

**Hit information** ($\eta_{BW}$, $\phi_{BW}$, $\Delta R$, $\Delta \phi$) Same as Run2 system

**New Sector Logic**
- $\Delta R$–$\Delta \phi$ coincidence
- BW–NSW coincidence
- $p_T$ calculation, etc

**Other detectors**
- Tile Calorimeter, TGC-EI, RPC-BIS78

**Trigger data to central trigger processor (MuCTPi)**
New Sector Logic board design

- 12x [*]GTX inputs for NSW, RPC-BIS78, [(**) Tile and TGC-EI (12 x 6.4Gbps = 76.8Gbps)
- 2x GTX outputs for MuCTPi
- Main FPGA for trigger algorithms
- x20 times larger resources compared to Run2 FPGA
- 14x G-Link inputs for legacy TGC-BW (14 x 0.8Gbps = 11.2Gbps)
- GbE connector for trigger data readout
- x72 Sector Logic boards for the whole L1 endcap muon trigger system
- The new Sector Logic boards have been produced and installed to the ATLAS counting room, commissioning is ongoing.

[*] GTX: multi-gigabit transceivers for Xilinx Kintex-7 FPGAs
[(**)] Tile and TGC-EI(FI) signals will be converted to GTX by dedicated electronics
Idea of BW and NSW coincidence

✓ There are several baseline ideas for TGC–BW and NSW coincidence.
  ‣ Use the position and angle correlations between TGC–BW and NSW.
    - $(\eta_{BW}, \phi_{BW})$ and $(\eta_{NSW}, \phi_{NSW})$
    - $\Delta \theta$ and $(\eta_{BW} - \eta_{NSW})$
  ‣ LUT is defined based on hit and angle patterns of simulations.

$p_T = 20$ GeV

$p_T = 40$ GeV

$p_T$ resolution will improve thanks to the fine NSW granularity.

Position resolution: $\eta_{NSW}=0.005, \phi_{NSW}=0.01$

Angle resolution: $\Delta \theta=0.001$ rad

are assumed in this study.
Performance of BW and NSW coincidence

✓ Low $p_T$ candidates are rejected effectively by the coincidence.
  - Only a few percent efficiency loss is expected because of the NSW track reconstruction efficiency.
  - For L1_MU20, 50% reduction at 10 GeV and 85% reduction at 5 GeV.

![Graph showing relative efficiency vs. offline $p_T^{\text{muon}}$]

- Link to L1 Muon Trigger Public Results

![Graph showing L1_MU20 candidate distribution vs. offline $p_T^{\text{muon}}$]

- ATLAS Preliminary
  - Phase I upgrade study
  - Data $\sqrt{s} = 13$ TeV, 25 ns
  - $|\eta^{\text{RoI}}| < 2.4$
Muon charge identification at L1 trigger

✓ L1 muon endcap trigger has a capability of identifying muon charges.
  ▸ Several applications in the L1 trigger benefit by the charge information.
    - E.g. Topological triggers for low $p_T$ muons, such as di-muons with opposite charges for $Y(nS)$ decays.
    - Crucial use case for the flavor physics.
  ▸ Dedicated LUTs can be implemented thanks to new FPGA resources.

✓ Accuracy of the muon charge identification at the L1 muon endcap trigger is estimated using simulations.
  ▸ The accuracy is very high for low $p_T$ muons, >98% accuracy up to $p_T=30\text{GeV}$
    (The charge information is not important for high $p_T$ single muon triggers)
Trigger rate estimation

- Expected reductions of the trigger rate by introducing the new coincidences are estimated using Run 2 real data.
  - MDT track segments in the current system are used as NSW and RPC–BIS78 tracks.
  - >90% of fake triggers are rejected by the new coincidences!!
  - Low $p_T$ candidates are reduced thanks to the fine granularity of NSW.

\[ \int \mathcal{L} \, dt = 2.9 \text{ fb}^{-1} \]

\[ \eta \]

\[ \text{Data 2017, } \mathcal{L} = 13 \text{ TeV} \]

\[ \text{rejected by Tile coincidence} \]

\[ \text{rejected by RPC BIS 7/8 coincidence (estimation)} \]

\[ \text{rejected by NSW coincidence (estimation)} \]

\[ \text{expected distribution in Run 3} \]

- Offline reconstructed muons

\[ 20 \text{ GeV} \geq T_{\text{offline}} \]

\[ \text{ATLAS Preliminary} \]

- Reduction of low $p_T$ candidates

\[ \rightarrow \sim 45\% \text{ rate reduction is expected for the L1\_MU20 trigger.} \]
Summary

✓ The upgrade of the ATLAS L1 endcap muon trigger is required to cope with the high event rate in Run 3.
  ‣ New muon detectors (NSW and RPC–BIS78) will be installed to improve the detector coverage and resolutions.
    → New electronics need to be developed to handle the data.

✓ The new Sector Logic boards have been produced.
  ‣ Installation completed, and commissioning is underway.
  ‣ Baseline ideas of trigger algorithms, such as TGC–BW and NSW coincidence, are tested using simulations, and show good performances.
    - e.g: >90% of fake triggers will be rejected by the TGC–BW and NSW coincidence.

✓ L1_MU20 trigger rate for Run 3 is estimated using real data.
  ‣ ~45% rate reduction is expected compared to Run 2.
The readout system for trigger data is re-designed.

- Custom electronics → commercial PCs and network switches.
- Software-based data acquisition system (SROD).

- Sector Logic
  - L1 buffer
  - Zero suppress
  - ~2000 bits/event/board

- 10 GbE Switch
  - N-to-1 connection

- SROD(PC)
  - Event Building
  - Busy signal

- ATLAS ReadOut system

✓ The SROD shows a good processing speed.
  - Maximum L1 trigger rate is 100kHz.

[*] SiTCP

[**] Ref.


[**] L1 Muon Hardware Public Results
Trigger rate and physics impact

**Requirement for Run3 (~15kHz)**

**Graph and Data**

- **ATLAS-TDR-023**
  - Plot: Muon level-1 trigger rate vs. $p_T$ threshold [GeV]
  - Conditions: $\sqrt{s} = 14$ TeV, $L=3 \times 10^{34}$ cm$^2$s$^{-1}$
  - Lines and markers:
    - Black circles: Extrapolation with 2012-run setting
    - Blue squares: Extrapolation with Pre-phase1
    - Red triangles: Extrapolation with Pre-phase1 + NSW

- **ATLAS-TDR-020**
  - Plot: $p_T$ distribution of $W\rightarrow \mu \nu b\bar{b}$
  - Data points:
    - Line: No cut
    - Red dashed line: $p_T > 20$ GeV (Eff = 93%)
    - Green dotted line: $p_T > 40$ GeV (Eff = 61%)

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**Graph Details**

- X-axis: $p_T$ threshold [GeV]
- Y-axis: Muon level-1 trigger rate [Hz]
- Events distribution: Histogram showing $p_T$ values for $W\rightarrow \mu \nu b\bar{b}$ events.

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**Notes**

- **ATLAS Simulation**
- requirement for Run3 (~15kHz).
Coverage of inner detectors

Map of covered region by each detector