Commissioning of the ATLAS Muon High Level Trigger with beam collisions at the LHC

Takayuki Kanno on behalf of the ATLAS Collaboration
Tokyo Institute of Technology, 2-12-1 O-okayama, 152-8551, Japan
E-mail: kanno@hep.phys.titech.ac.jp

Abstract. The performance of the ATLAS muon trigger has been evaluated using data from proton-proton collisions at $\sqrt{s} = 7$ TeV with a total integrated luminosity of approximately $94$ nb$^{-1}$. This paper shows the results of the study for individual algorithms composing the muon trigger, with respect to efficiency, resolution and rate.

1. Introduction
The purpose of the ATLAS experiment is to study physics in proton-proton (and heavy ion) collisions at CERN’s Large Hadron Collider (LHC), including verification of the Standard Model and observation of possible new physics [1].

To investigate these physics processes, muons will be one of the important probes. The ATLAS detector has a subsystem called Muon Spectrometer (MS), dedicated to muon measurements. It is possible to reconstruct muons in stand-alone mode using MS, as well as in combined mode with additional Inner Detector (ID) track information to refine track parameters. Also the muon trigger is installed in ATLAS Trigger/DAQ system to collect muons with high efficiency from 40 MHz proton-proton collisions provided by the LHC.

The ATLAS experiment has started data taking from proton-proton collisions at $\sqrt{s} = 7$ TeV at the end of March 2010. The plan of the experiment for the run period 2010/2011 is to collect physics data corresponding to an integrated luminosity of about 1 fb$^{-1}$ at luminosities of $10^{32}$ cm$^{-2}$s$^{-1}$ or above. The commissioning of the muon trigger has been an important issue in the early period of the run for future stable data taking. This paper describes the results of muon trigger performance studies using data obtained from proton-proton collisions by July 2010.

2. The ATLAS muon trigger
The ATLAS trigger system consists of 3 stages [2], namely Level 1 (L1), Level 2 (L2) and Event Filter (EF). L1 is made up from custom hardware providing a fast decision. L2 and EF are based fully on software to do more precise reconstruction for tighter trigger selection. L2 and EF are collectively called High Level Trigger (HLT). Several muon trigger algorithms are located in each stage to form a chain structure, i.e. a muon algorithm runs reconstruction around muon candidates identified by the muon algorithm of the previous stage.

At L1, the muon trigger uses Resistive Plate Chambers (RPC) in the barrel ($|\eta| < 1.05$) and Thin Gap Chambers (TGC) in the endcap ($|\eta| > 1.05$). Both TGC and RPC have several layers.
to form coincidence for muon detection, and the toroidal magnetic field induces curvature of the muon track, which is measured for transverse momentum determination.

At HLT, additional components called Monitored Drift Tubes (MDT) are used for precise transverse momentum measurement. The L2 muon trigger consists of rather simpler and faster algorithms than EF to save processing time, while the EF muon trigger can make use of offline algorithms for detailed muon reconstruction. Both L2 and EF muon triggers have a stand-alone mode and a combined mode. The EF muon trigger has two algorithms for the combined mode: “outside-in” and “inside-out”. The “outside-in” algorithm uses a stand-alone track, back-extrapolates it to the ID and combines it with the ID track. On the other hand, the “inside-out” algorithm doesn’t use a stand-alone track. It starts from the ID track, extrapolates it to the MS and finds hits in the MS to build a muon track.

3. Data Sample
The data used for this study were taken from proton-proton collisions at $\sqrt{s} = 7$ TeV between April and July 2010, which corresponds to an integrated luminosity of approximately 94 nb$^{-1}$. The data are required to have been taken in the time period when the detectors were operating well. Note that for the L1 study, a partial data-set is used which corresponds to an integrated luminosity of approximately 9.5 nb$^{-1}$.

Different trigger requirements must be made between samples for the L1 and the HLT study to do unbiased analysis. The sample for the L1 study has been collected using L1 minimum bias trigger with EF muon “fullscan” trigger. The term “fullscan” means special configuration of the EF muon trigger in which a full geometrical search is done, i.e. it is compatible with offline muon reconstruction. The sample for the HLT study has been collected using the L1 muon trigger. Note that the HLT was running online but not rejecting the events during this period.

The events are required to have a reconstructed vertex which has at least 3 associated tracks and $|z_{\text{vertex}}| < 150$ mm. This is to reject non-collision-originated events e.g. cosmic ray induced events.

Offline combined muon reconstruction is used as a reference for the trigger performance study. These reference muons are required to pass the following selection:

- $p > 4$ GeV
- $p_T > 2$ GeV
- Number of silicon tracker hits > 5
- Number of pixel hits > 0
- $\chi^2_{\text{match}} < 50$

where $p$ and $p_T$ refer to momentum and transverse momentum, respectively, and $\chi^2_{\text{match}}$ refers to the chi-square estimator for the matching between the MS and ID measurements using track parameters and the full covariance matrix.

Offline combined muons have two results for the $p_T$ measurement, one from the stand-alone algorithm and another from the combined algorithm. These two values can be significantly different in case the reconstructed objects are actually the in-flight decay of light mesons to muons, especially at the low $p_T$ region. To minimize the effect of this, the offline stand-alone algorithm $p_T$ (denoted “SA $p_T$”) is used when the stand-alone muon trigger algorithm is evaluated, and the offline combined algorithm $p_T$ (denoted “CB $p_T$”) is used when the combined muon trigger algorithm is evaluated.

---

1 The data-set is restricted to runs taken from April 2010 because the RPC L1 trigger configuration has been updated in April 2010.
4. Muon Trigger Performance

One of the aims of the muon trigger is to keep high efficiency. To extract the performance of the trigger algorithms for muons, the efficiency with respect to muons reconstructed offline is measured for each trigger algorithm. For the HLT algorithms, the residual of $p_T$ between trigger and offline algorithm is used to evaluate the $p_T$ measurement of the trigger algorithm. The reduction of the background rate is another aim of the muon trigger. The trigger rates measured on data are investigated.

4.1. Efficiency with respect to muons reconstructed offline

Figure 1 shows the L1 trigger efficiency as a function of offline SA $p_T$. The efficiency is defined with respect to the muons reconstructed offline. A matching criterion of $\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2} < 0.5$ between offline and L1 muon is applied to judge whether a muon has been triggered at L1. The investigations are done separately for PRC and TGC by adding a cut on offline muon $\eta$. 

Figure 1. L1 muon trigger efficiency with respect to muons reconstructed offline.

Figure 2. L2 muon trigger efficiency with respect to muons reconstructed offline.

Figure 3. EF muon trigger efficiency with respect to muons reconstructed offline.
$|\eta| < 1.05$ is required for the RPC study and $1.05 < |\eta| < 2.4$ is required for the TGC study. The plateau efficiency is obtained from each of the turn-on curves for RPC ($\sim 70\%$) and TGC ($\sim 90\%$). Note that the RPC efficiency is lower than that of the TGC due to geometrical acceptance.

Figures 2 and 3 show the HLT efficiency with respect to muons reconstructed offline as a function of offline SA or CB $p_T$. The efficiency is defined relative to the previous trigger stage, and appropriate offline $p_T$ is chosen as explained in section 3, i.e. the efficiency is defined for:

- L2 stand-alone as relative to L1, as a function of offline SA $p_T$
- L2 combined as relative to L2 stand-alone, as a function of offline CB $p_T$
- EF stand-alone as relative to L2 stand-alone, as a function of offline SA $p_T$
- EF combined as relative to L2 combined, as a function of offline CB $p_T$

Each of the HLT algorithms shows good performance, i.e. high plateau efficiency and sharp turn-on curve. A comparison is done to MC simulation. Good agreement between data and MC simulation is found.

4.2. The residual of $p_T$ with respect to offline muon

The residual of $p_T$ with respect to offline muon is defined as

$$
\Delta p_T = \frac{1}{p_T^{\text{off}}} - \frac{1}{p_T^{\text{rig}}} - \frac{1}{p_T^{\text{off}}}
$$

(a) Mean

(b) Sigma

**Figure 4.** Result of Gaussian fitting on residual distribution of the L2 stand-alone algorithm.

(a) Mean

(b) Sigma

**Figure 5.** Result of Gaussian fitting on residual distribution of the L2 combined algorithm.
where $p_{T}^{\text{off}}$ and $p_{T}^{\text{trig}}$ refer to the $p_T$ measured by offline and trigger algorithm, respectively. The residual is related to the resolution of the trigger algorithm, thus is useful information to evaluate the performance of the trigger algorithms.

Figures 4, 5 and 6 show the result of Gaussian fitting performed on the residual distributions for each of the HLT algorithms. Slightly worse resolution is observed in data than in MC simulation for each of the algorithms, the reason of which is under investigation.

### 4.3. Trigger rate

The trigger must keep sufficient efficiency for physics events of concern, while the trigger rate has to stay within the limit of DAQ system. Thus it is important to understand the trigger rate.

Fitting is performed on the trigger rate with the equation:

$$r = c_1 L + c_0 N_{BC} \quad (2)$$

where $L$ indicates instantaneous luminosity and $N_{BC}$ indicates the number of bunch crossings open to the trigger. The first term of the equation corresponds to the collision component whose rate depends on $L$. The second term is the accidental component e.g. cosmic ray induced events. Note that the muon trigger is opened in coincidence with the crossing of filled bunches. Figure 7 shows the measured rate as a function of instantaneous luminosity, together with the fit results. Detail of the fit result for each muon trigger is summarized in Ref. [3]. For each of the algorithms, the fitting result is found to describes the data well.

Figure 8 shows the HLT rate relative to L1 for each of the trigger algorithms and $p_{T}$ thresholds. The figure shows additional rejection power of HLT with respect to L1. The combined algorithms have more rejection power than the stand-alone algorithm due to better $p_T$ resolution.

### 5. Conclusion

Commissioning of the ATLAS muon trigger has been done with approximately 94 nb$^{-1}$ of beam collision data. Evaluation is done with respect to efficiency, resolution and rate, and results indicate good performance for each of the muon trigger algorithms used. These studies will be continued to further improve the performance of the muon trigger.

### Acknowledgments

I would like to thank the Tokyo Institute of Technology Global Center of Excellence program “Nanoscience and Quantum Physics” for financial support.
Figure 7. Trigger rate as a function of instantaneous luminosity for each muon trigger. Different colors correspond to different $p_T$ thresholds. Points are measured rates and lines are fit results. The steps are due to the change of $N_{BC}$.

Figure 8. HLT rate relative to L1 for each of trigger algorithms and $p_T$ threshold.

References
[1] ATLAS Collaboration, *Expected Performance of the ATLAS Experiment - Detector, Trigger, and Physics*, CERN-OPEN-2008-020, 2009.
[2] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, Journal of Instrumentation, vol. 3, p. S08003, 2008.
[3] ATLAS Collaboration, *Performance of the ATLAS Muon Trigger in p-p collisions at $\sqrt{s} = 7$ TeV*, ATLAS-CONF-2010-095.