ATL-MUON-PROC-2009-008
19 October 2009

ATLAS MUON SPECTROMETER
– Status and Performance –

Yuta TAKAHASHI

Graduate School of Science, NAGOYA University, Furo-cho, Japan

On behalf of the ATLAS Muon Collaboration

Muons are a promising probe for new physics. In order to efficiently detect muons and measure their properties with high precision, the ATLAS detector has a Muon Spectrometer composed of toroidal magnets, a precision tracker ($|\eta|<2.7$) and trigger chambers ($|\eta|<2.4$). The target performance is to trigger muons with $P_T>6$ GeV from 40 MHz proton-proton collisions, and to measure their momentum with an accuracy of 2–3% for $P_T<100$ GeV, and under 10% up to $P_T = 1$ TeV. Since the completion of the detector installation in August, 2008, 400 M cosmic ray events and 8 k single proton beam events have been collected. We report on the detector performance and show that we are very close to the design performance before the start of LHC collision data-taking.

1. Introduction

The main purpose of the ATLAS experiment is to search for the Higgs boson and to explore new physics beyond the Standard Model. The muons from Higgs decays such as $H \rightarrow ZZ^* \rightarrow ll\mu\mu$ and new vector boson decays such as $Z^{'} \rightarrow \mu\mu$ are some of the most important signatures for this purpose. For the efficient detection of muons, the ATLAS muon spectrometer (Fig. 1) has two kinds of trigger chambers: RPC (Resistive Plate Chamber) and TGC (Thin Gap Chamber), and two kinds of precision tracking chambers: MDT (Monitored Drift Tube) and CSC (Cathode Strip Chamber). The RPCs and TGCs, covering $|\eta|<1.1$ and $1.1<|\eta|<2.4$ respectively, are dedicated to the fast muon trigger, which makes trigger decisions of the events with muons of $P_T>6$ GeV from 40 MHz (25 ns interval) proton-proton collisions. The MDTs and CSCs, covering $|\eta|<2.7$ and $2.0<|\eta|<2.7$ respectively, are dedicated to the precise P_T measurement with an accuracy of 2–3% for $P_T<100$ GeV and 10% at $P_T = 1$ TeV. The P_T of the muon tracks can be measured by the magnetic deflection by the toroidal magnets (2–6 T·m).

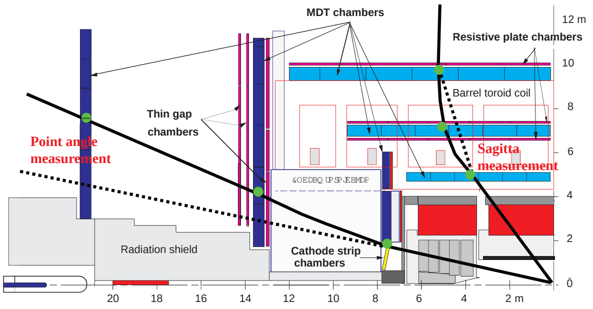

Fig. 1. Schematic cut-away view of the ATLAS Muon Spectrometer. There are two kinds of trigger chambers (TGC and RPC) dedicated to the first trigger, and two kinds of precision tracker (MDT and CSC) dedicated to the precise P_T measurement.

Since the completion of the assembly of the Muon Spectrometer in August 2008, combined data taking of the ATLAS detector with cosmic ray muons and the single proton beam has been taking place. Table 1 summarizes the current fraction of active channels, number of channels, and the fraction foreseen at the start of LHC beam in December, 2009.

Table 1. Fractions of active channels (October, 2009) with their number of channels, and fractions foreseen at the start of LHC beam.

detector	active channels (%)	number of channels	active channels foreseen at December, 2009
RPC	97.0%	359k	99.5%
TGC	99.6%	320k	99.6%
MDT	99.7%	341k	99.7%
CSC	98.4%	31k	98.4%

The following article presents in-situ analyses results of the performance of trigger selectivity and momentum resolution obtained with 400 M cosmic ray events and 8 k single proton beam events.

2. Detector Performance

2.1. *Trigger Selectivity*

The TGCs and RPCs measure the transverse momentum within 2.5 μs using the coincidence logic of on-detector ASICs and FPGAs. By comparing the angular difference between an infinite-momentum track and the one measured ($\Delta\theta$), the trigger is satisfied with typical P_T thresholds of 6, 8, 10, 15, 20, and 40 GeV. For cosmic ray muons, the TGCs adopted three types of special trigger conditions according to the tightness of IP-pointing, while RPCs adopted 4 types. The total TGCs trigger rate is 20 Hz, and of RPCs is 500 Hz. The current detection efficiency is 94% (ideally 94%) for TGCs and 94% (ideally 97%) for RPCs. Fig. 2(a), (b) shows the R-Z view of the muon trajectories triggered by TGCs and their $\Delta\theta$ distributions.

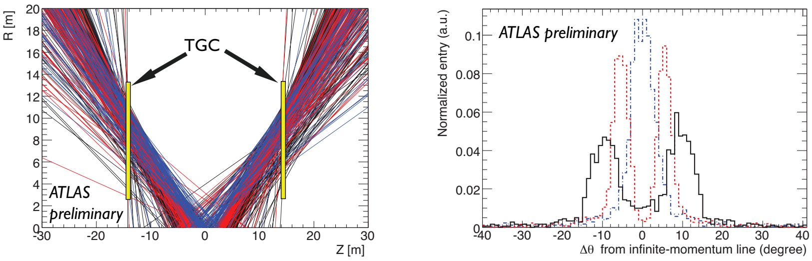

Fig. 2. (a) Muon trajectories triggered by TGC, (b)$\Delta\theta$ distributions. Loose (solid), medium (dashed), and tight (dot-dashed) trigger conditions are shown. As the trigger conditions are changed, the tightness of IP-pointing also becomes sharper.

Moving in step with the single-beam circulation, we succeeded in emulating the TGC trigger timing. The time jitter due to the time-of-flight, and the propagation via a variety of the signal cables can be controlled within a few ns by more than 20,000 parameters in the delay circuits. Including the time jitter due to the detector response (the typical time jitter of the TGC is 20 ns and of the RPC is a few ns), the total time jitter is within 25 ns. Thus, the trigger decision is issued with fixed latency tuned to the 40 MHz clock phase. As shown in Fig. 3, the TGC trigger timing with respect to the timing of the proton beam passing through the ATLAS detector has been evaluated using the beam pick-up electrodes, located 175 m upstream of the ATLAS detector that monitors the timing of the proton beam circulations. The two sharp peaks correspond to the timing from both endcaps, while their distance (100 ns) is due to the time of flight (30 m) between them. The TGC trigger timing was confirmed to be under control for beam collisions.

2.2. *Momentum Resolution*

To achieve the desired momentum resolution, the MDTs aim to reconstruct the muon tracks with a position resolution better than 80 μm per chamber.

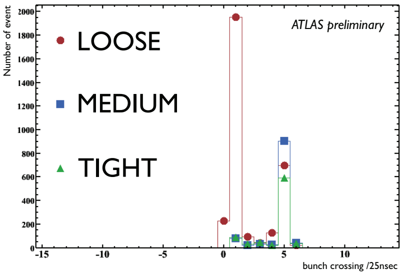

Fig. 3. TGC trigger timing with respect to the beam pick-up signal. Two peaks show the trigger signal from both endcaps; their separation (100 ns) shows their time-of-flight.

For this purpose, there are 12,000 optical sensors continuously monitoring chamber deformations and relative positions. With the additional inclusion of track-based alignment, positioning accuracy of 30 μm is expected. Fig. 4(a), (b) shows residual distributions before and after alignment corrections for the barrel and the endcap region, respectively. The mean value of each distribution indicates the current achievement of the alignment, while the width of order $O(1\ \mathrm{mm})$ is mainly determined by the multiple scattering. With present statistics and granularity, the alignment accuracy is around 40 μm for the endcap and 50–1000 μm for the barrel depending on their chamber size.

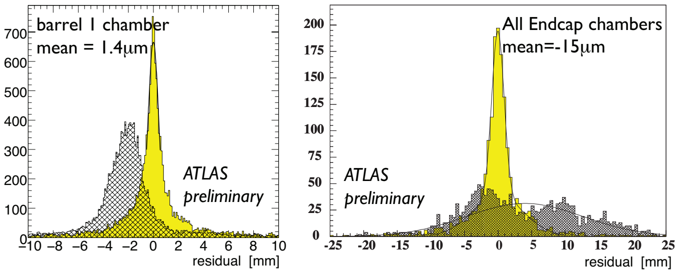

Fig. 4. Residual distribution for the (a) barrel ($|\eta|$<1.1) and the (b) endcap ($|\eta|$>1.1) region before (shaded) and after (yellow) the optical alignment. For the barrel, specific one chamber is shown, while for the endcap whole chambers are included.

Finally, momentum resolution has been evaluated. The P_T resolution is described by three terms as a function of P_T, $p_0 P_T + p_1 + p_2 P_T^{-1}$. Each parameter corresponds to the errors due to the intrinsic resolution, multiple scattering, and the energy loss, respectively. As shown in Fig. 5, the data (black) with cosmic ray muons follows this model well, though the high-P_T region does not follow the ideal line (red). A week of data taking at $\mathcal{L} = 10^{31}$ cm^{-2}s^{-1} with charged particles from collisions will provide us with alignment constants better than 30 μm, allowing for better agreement.

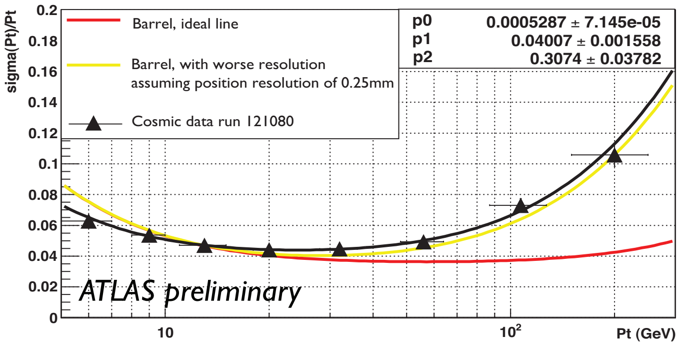

Fig. 5. The P_T resolution vs P_T with its ideal line (red) and the data line (black). The data is well characterized by intrinsic resolution, multiple scattering, and energy loss.

3. Summary

The ATLAS Muon Spectrometer is almost fully operational, the fraction of active channels has surpassed 97% and will be improved to 99.5% before first LHC collision. Using 400 M events of cosmic ray muons and single-beam events, most of the essential features of detector performance, such as the IP-pointing functionality, trigger timing ($\sim$25 ns) and P_T resolution, have been well characterized. Although the P_T resolution at high-P_T needs to be understood with collision data, a week of data taking at $\mathcal{L} = 10^{31}$ cm^{-2}s^{-1} will provide alignment and calibration constants with sufficient accuracy to lead to ideal performance. The Muon Spectrometer is in excellent shape to provide high quality muons for physics analysis at the LHC startup.

References

1. ATLAS Muon Spectrometer TDR, CERN/LHCC/97-22 CERN (1997).
2. The ATLAS beam pick-up based timing system, arXiv:0905.3648 (2009).
3. The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 S08001 (2008).