Performance of muon identification and reconstruction in ATLAS

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2010-01/196

Muon final states provide clean signatures for many physics processes at the LHC. The performance of the ATLAS muon reconstruction and identification was studied with up to 0.6 nb^{-1} of LHC pp collision data at $\sqrt{s} = 7$ TeV collected with a minimum bias trigger. Measured detector efficiencies, hit multiplicities, muon isolation, and residual distributions of reconstructed muon tracks are well reproduced by the Monte-Carlo simulation.

1 Data and simulation samples and event selection

The performance of the muon reconstruction was studied [1] using up to 0.6 nb^{-1} of integrated luminosity recorded by the ATLAS detector at a center-of-mass energy of 7 TeV. Stable beam operation as well as proper functioning of all the subdetectors was required in the event selection. In addition, to reduce the background from cosmic events, at least three tracks in the inner detector with at least one pixel hit and six SCT hits were required. For triggering the Minimum Bias Trigger Scintillator (MBTS) was used [2]. Compared to the dedicated muon triggers, the MBTS allows an unbiased study of the muon performance without a momentum cutoff.

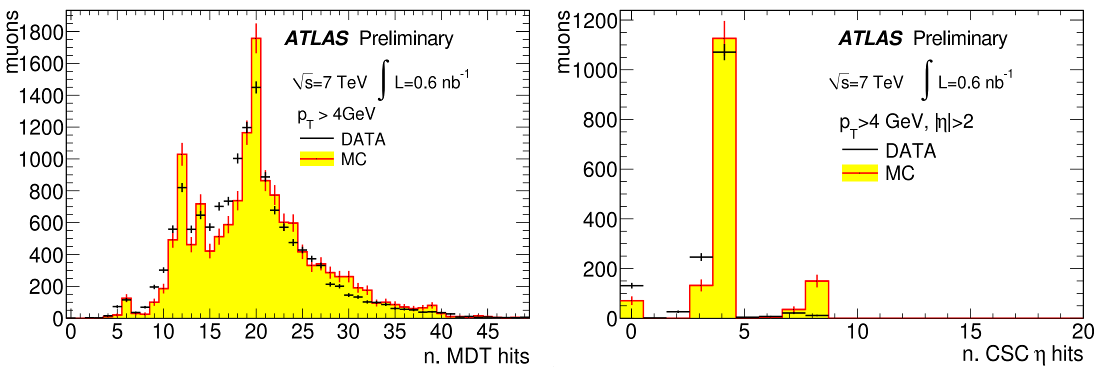

Figure 1: Comparison of the measured distributions of the number of MDT hits (left plot) and CSC hits in the bending plane (right plot) on the combined muon tracks with the Monte-Carlo predictions.

Several different types of reconstructed muon objects are available in ATLAS: *stand-alone* *muons*, *combined muons*, *segment tagged muons*, *calorimeter tagged muons*. The highest quality category of muons are combined muons, i.e. muons that are formed by combining an inner detector track with a muon spectrometer track. Unless stated otherwise, we will only consider combined muons in this article, as these have a very low contamination from cosmic ray events.

2 Validation of the muon Monte-Carlo simulation

The predictions of the muon Monte-Carlo simulation are validated first by studying elementary distributions, like the number of hits per reconstructed track and the distribution of the reconstructed track parameters. The tracking performance of the inner detector is well described by the Monte-Carlo simulation, more details can be found in Ref. [3]. The distributions of the number of MDT and CSC hits, which measure the position of the track in the bending plane in the muon spectrometer, are shown in Fig. 1. Reasonable agreement between the data and simulation is observed, the relative lack of tracks with eight CSC hits (in the overlaps between adjacent CSC chambers) in the data is expected to be solved with updated alignment constants. Larger discrepancies were observed for the distributions of the number of muon trigger hits per track, due to known inefficiencies of the trigger chambers that were not simulated.

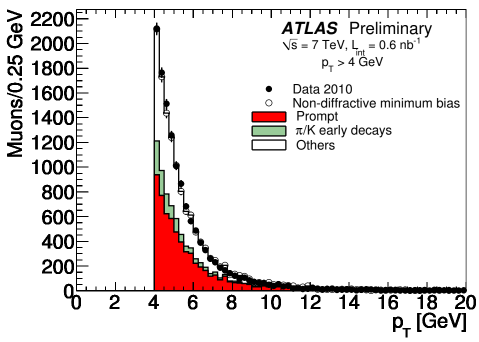

Figure 2: p_T spectrum of the reconstructed combined muons.

The distributions of the reconstructed track parameters were also studied, as shown in Fig. 2 where the p_T spectrum is shown for the data and the simulation. According to the simulation, the spectrum is dominated by light meson decays at low p_T, while the contribution from prompt muons becomes more important at high momentum.

3 Validation of muon energy deposits in the calorimeters

Muons inside jets tend to be produced by hadron decays, therefore a powerful tool for selecting prompt muons is the requirement that the muon is isolated. The isolation can be performed in two ways: by cutting on the energy deposited in a cone around the muon (subtracting the energy deposited by the muon itself), or by cutting on the sum of the transverse momenta of the tracks in a cone around the muon. The size of the cone is typically $0.2 \leq \Delta R \leq 0.4$ ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$). In Fig. 3 the distribution of the track isolation is shown for the data and the simulation, with a cone of size $\Delta R = 0.3$. As before reasonable agreement between the measured and simulated distributions is achieved.

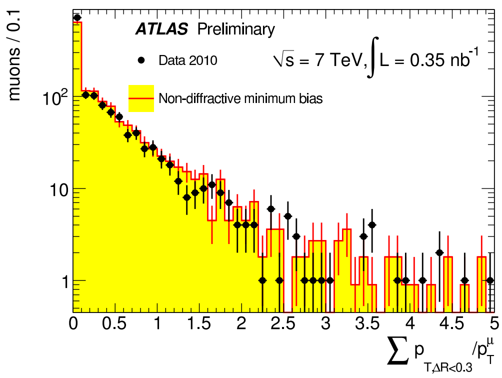

Figure 3: Measured sum of the transverse momenta of tracks around a combined muon in a cone of $\Delta R < 0.3$.

One can conclude that the ATLAS Monte-Carlo simulation can be used to optimize muon isolation criteria.

4 Measurement of relative efficiency and momentum resolution

Investigation of the relative efficiencies of the muon reconstruction algorithms provides a study of the predictive power of the Monte-Carlo simulation at a higher level of complexity. For instance, the efficiency of the combined muon reconstruction algorithm can be measured for muons that are reconstructed in the inner detector and that are both segment tagged and calorimeter tagged (tagged muons). This latter category of muons is used because it has a high purity and a high efficiency (90% according to MC). Fig. 4 shows the efficiency of reconstructed combined muons measured with respect to tagged muons for collision data and for Monte-Carlo simulation. The combined muon reconstruction efficiency in simulation, measured using only muons identified in the simulation as true muons, is also shown in the figure (as the star-shaped symbols labeled as MC truth). The relative efficiency for data is on average a few percent lower than predicted by simulation, indicating either a lower purity of the tagged muon sample in data than in simulation or a lower efficiency of combined muon reconstruction in data than simulation. The relative efficiency predicted for simulation is also a bit lower than the efficiency of combined muon reconstruction in simulation, due to some contamination of the tagged muon sample by inner detector tracks that are mistagged as muons.

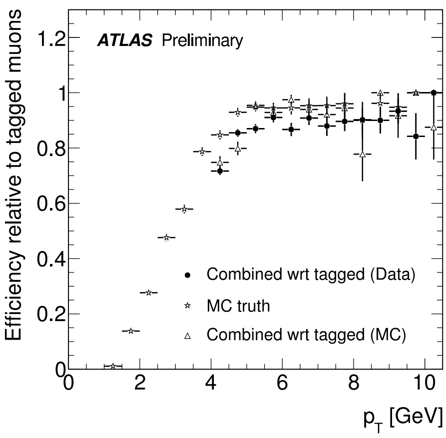

Figure 4: Efficiency of the combined reconstruction relative to the segment and calorimeter tagged muons.

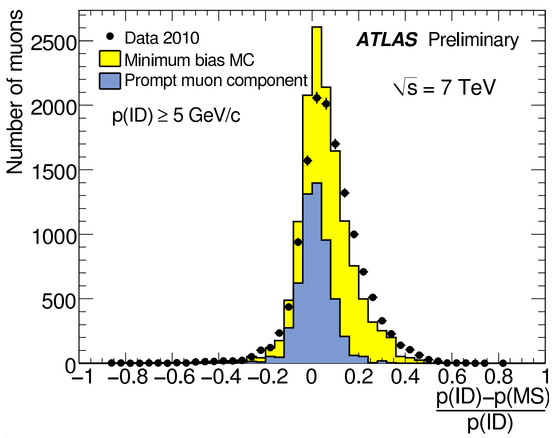

Figure 5: Relative difference between the inner detector and stand-alone muon momentum.

The inner detector momentum resolution for muons with 6 GeV $< p_T <$ 20 GeV is dominated by multiple scattering. A fractional momentum resolution of $\lesssim$ 2% is reached in the barrel region which increases to about 5% in the forward end-cap region [4][5]. The stand-alone muon momentum resolution is dominated by energy loss fluctuations for $p_T \lesssim$ 10 GeV and by multiple scattering above 10 GeV. A fractional stand-alone momentum resolution of $\gtrsim$ 5%

is expected for muons with $p_T \lesssim 10$ GeV [4]. The distribution of the difference of the muon momentum measured in the inner detector and the stand-alone muon momentum therefore provides an estimate of the stand-alone muon momentum resolution. Fig. 5 shows the distribution of this difference divided by the momentum measured in the inner detector. The distribution has a narrow core and a tail to positive values. The shape of the distribution is similar in the Monte-Carlo simulation. According to the Monte-Carlo simulation, the tail of the distribution to positive values is caused by muons from pion and kaon decays-in-flight. There is a larger tail in the measured than in the simulated distribution, the origin of which was found to be remaining misalignments in one of the endcaps of the inner detector, which has already been improved at the time of writing.

5 Conclusions

The first half inverse nb of pp collision minimum bias data at $\sqrt{s} = 7$ TeV has been used to validate the muon Monte-Carlo simulation. The measured relative efficiencies of the muon reconstruction algorithms are well predicted by the Monte-Carlo simulation. The same level of agreement between simulation and experimental measurement is observed in the energy deposition in the calorimeters for isolated and non-isolated muons. The ATLAS muon Monte-Carlo simulation has shown to be a reliable tool for muon performance studies.

References

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