Alignment of the ATLAS Muon Spectrometer with Tracks

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Abstract

The muon spectrometer of the ATLAS experiment at the Large Hadron Collider is designed to measure the muon momenta of up to 1 TeV/c with a resolution of better than 10% in a toroidal magnetic field of superconducting air-core magnets. The muon track sagitta is measured in three layers of pressurized drift-tube chambers. The precision muon chambers have to be aligned with an accuracy of better then 30 micron in the track bending plane. An optical alignment system monitors movements of the muon chambers with a precision of few microns. In order to determine the chamber positions in the spectrometer, the initial chamber positions have to be measured with 30 micron accuracy using straight muon tracks from proton-proton collisions in a dedicated run of the ATLAS detector with the toroid magnets turned off. A least-square algorithm has been developed which determines the misalignment parameters of a complete azimuthal sector of the barrel part of the muon spectrometer. It has been tested with straight cosmic muon tracks during the commissioning of the ATLAS experiment. Simulations show that the required alignment accuracy is reached with 100000 muons per sector originating from the interaction point with transverse momentum greater than 10 GeV. About half of the barrel chambers have already been aligned with 30 micron accuracy using cosmic muons.

The design goal for the ATLAS muon spectrometer is to measure the momentum of a 1 TeV muon with a resolution of better than 10 % [1]. According to this requirement track sagitta of 500 μm must be measured with an accuracy of better than 50 μm. The two major contributions to the sagitta measurement at 1 TeV are 40 μm from the drift tube resolution and 30 μm from the precision of the relative positioning of the muon chambers provided by the alignment system.

The displacements and rotations of the muon chambers are monitored by the optical alignment system [2]. Nevertheless, there are several alignment tasks which can be carried out only by using reconstructed muon tracks. These tasks constitute so called *track based alignment* of the muon spectrometer. The most important part of the track based alignment is to provide the optical alignment system with the initial reference geometry. Simulations show that the optical alignment system alone can not achieve the required final resolution for the barrel part of the muon spectrometer and initial calibration with straight tracks is required. A special run of ATLAS detector with the toroidal magnetic field switched off is planned during the initial satage of LHC operation to perform the alignment with straight tracks. Once the optical alignment system is provided with the starting reference geometry it will trace all relative chamber displacements with the required accuracy when the magnetic field will be switched on.

To align the barrel part of the muon spectrometer with straight tracks an alignment algorithm has been developed [3]. The alignment procedure is based upon the *Linear Least Squares Fits with a Large Number of Parameters* (MILLEPEDE) method [4]. This algorithm performs χ^2 minimization in alignment and track parameters simultaneously. As a result all correlations between alignment and track parameters are taken into account and the alignment algorithm becomes unbiased. Monte Carlo simulations show that about 100 000 of 20 GeV straight muon tracks is enough to align each sector of the muon spectrometer to the final 30 μm precision (Figure 1). The sectors where toroid magnet coils are located (*small sectors*) require approximately five times larger statistics than *large sectors* because of the muon multiple scattering.

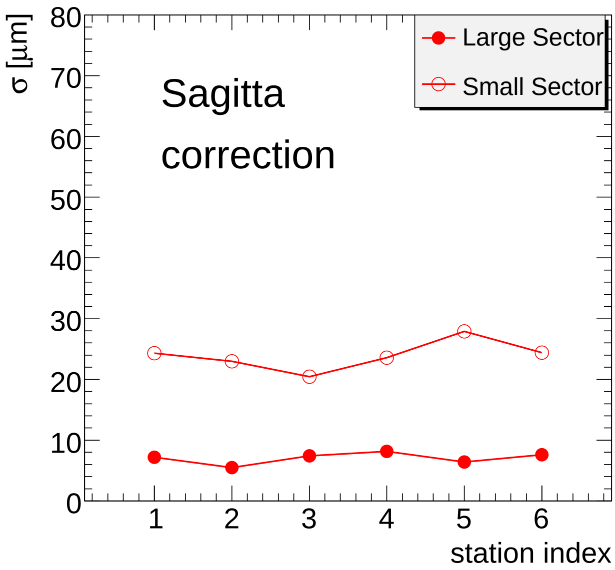

Figure 1: Statistical uncertainty on sagitta measurement provided by the alignment with 20 GeV straight muon tracks. Station index 1 corresponds to $\eta \approx 0$. Station index 6 corresponds to $\eta \approx 1$.

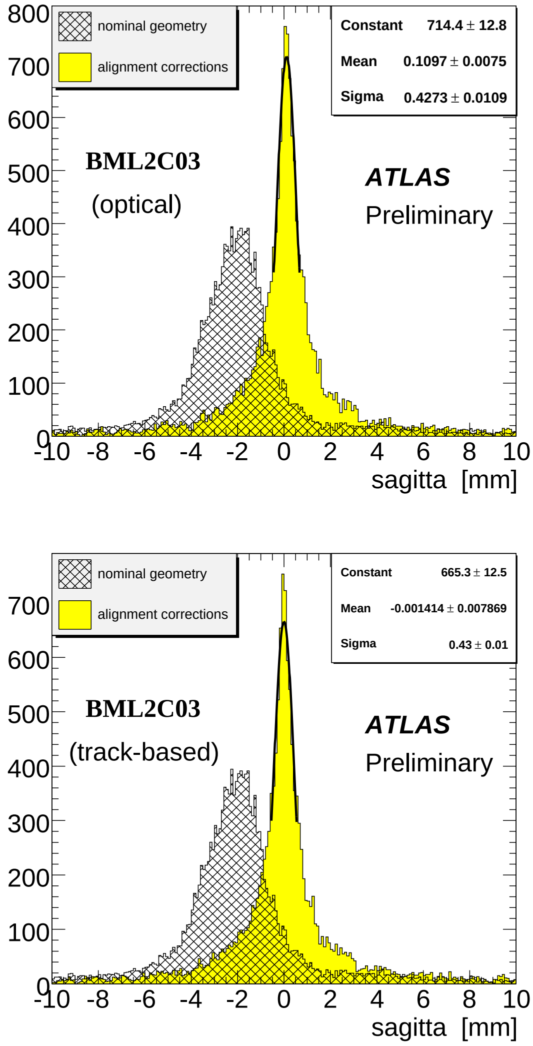

Figure 2: Sagitta of the straight cosmic muon tracks measured in the one of the large barrel middle chambers of the muon spectrometer. First plot is produced with the optical corrections applied. Second plot is produced with the track based corrections applied.

The performance of the alignment algorithm has been tested with straight cosmic muons collected during the commissioning period. An independent set of alignment corrections has been produced using 2008 cosmic data in addition to the corrections provided by the optical alignment system. The number of events used for the alignment with straight tracks corresponds to about 300 000 cosmic muons per barrel sector. The statistical uncertainty of the alignment on sagitta measurement was estimated to be 30 μm for the large barrel sectors.

Cosmic data have been reprocessed twice, the first time using optical alignment corrections and the second time using track-based corrections. Both geometries have been tested by checking track sagitta of straight cosmic muons crossing all three layers of chambers (inner, middle and outer). Inner and outer chamber hits on track have been fitted by a straight line while the middle chamber hit residuals have been plotted on a histogram. In a good approximation the mean value of the hit residuals in the middle chamber corresponds to the track sagitta. For straight tracks this sagitta should be equal to zero.

The results of this cross-check for the one of the large barrel middle chambers of the muon spectrometer are shown in the Figure 2. The top plot corresponds to the geometry produced with the optical alignment corrections. The bottom plot corresponds to the geometry produced with the track-based alignment corrections taken into account. Sagitta distributions are shown in comparison with the distribution produced with the nominal geometry. The distribution produced with the optical corrections is almost identical in shape with the one produced with the track-based corrections but is shifted by 100 μm with respect to zero. The width of the sagitta distributions produced with the corrected geometries is dominated by the muon multiple scattering inside the muon spectrometer. The mean values of the sagitta distributions are at the level of 200 μm for the large barrel sectors if to use the geometry corrected by the optical alignment system. If to use the geometry corrected by the track based alignment, the sagitta is reduced to the level of 30 μm for the most part of these chambers. Small sectors require several times larger amount of tracks to reach this level of accuracy.

Presented results show that with the aid of the track based alignment the performance of the optical alignment system can be improved to the required level of accuracy for the most part of the barrel chambers of the muon spectrometer already using cosmic muons.

References

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