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Calibration of the ATLAS Muon Chambers

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The high-pressure drift tube chambers for the muon spectrometer of the ATLAS detector at the LHC have to provide a track position resolution of 40 μm. The chambers consist of two triple or quadruple layers of drift tubes of 30 mm diameter with a average spatial resolution of 80 μm. The precise knowledge of the space-to-drift-time relation $r(t)$ to better than 20 μm is mandatory. It has to be recalibrated every few hours during ATLAS data taking using muon tracks from a dedicated data stream. The data of the stream will be processed at three calibration centres such that a new drift chamber calibration will be provided within a few hours after data taking. We shall present the drift-chamber calibration concepts, the key features of the calibration algorithms, and the results of the calibration of cosmic muon data recorded by the ATLAS detector.

Keywords: ATLAS; muon spectrometer; drift tube; calibration

1. Introduction

The muon spectrometer of the ATLAS experiment at the Large Hadron Collider (LHC) is designed to detect muons with high precision and high efficiency up to the TeV range. It uses drift tube chambers operated in a toroidal magnetic field of about 0.4 T for the measurement of muon trajectories. The drift tubes of the ATLAS muon chambers[1] have a diameter of 3 cm, a wire with a diameter of 50 μm, and are filled with an Ar/CO_2-mixture (93/7) at a constant pressure of 3 bar. With a high voltage of 3080 V, a gas gain of $2 \cdot 10^4$ is reached. The tubes are arranged in two multi-layers of 3 or 4 tube-layers glued on either side of a support frame. The drift tube chambers have a surface of 0.5 to 11 m^2. The Ar/CO_2 gas mixture was chosen because it causes no ageing of the tubes in a high radiation environment, but its drift properties are highly dependent on environmental conditions like temperature, magnetic field, and irradiation.

Therefore, a continuous calibration has to be performed.

1.1. *Calibration Tasks*

The calibration of the muon drift-tube chambers is performed in several steps. In the first step the drift-time measurements of the tubes are synchronized. An offset for the drift time (t_0) is obtained by fitting the leading edge of the drift time spectrum with a Fermi-function. It is subsequently subtracted from the measured drift time to compensate for signal propagation times in cables and electronics.

The space drift-time relation $r(t)$ is derived from the data. An initial space drift-time relation of 200 μm accuracy is obtained by integrating the drift-time spectrum. The accuracy of the initial relation is sufficient for track segment fits in the chamber. The difference between the distance of the segment to the wire and the drift radius is used to calculate an improved r-t relation. This is repeated iteratively.[2] For the spectrometry of muons in the TeV-range, the r-t precision is one of the limiting factors for the resolution.[3] A r-t precision of 20 μm is required to reach 10% relative transverse momentum resolution at $p_T = 1$ TeV/c. The production rate of high-p_T muons is low. So in the first pp collisions in the LHC expected end of 2009, which will be at a reduced center of mass energy of 7 TeV and a reduced Luminosity between 10^{29} cm^{-2} s^{-1} and 10^{31} cm^{-2} s^{-1}, mainly muons with $p_T < 100$ GeV/c will be examined. In this energy range, the muon momentum resolution is dominated by multiple scattering. Therefore, in this phase an r-t precision of 100 μm is sufficient.

The spatial resolution of the drift tube is determined from the width of the track segment residuals in the chamber.[4]

In in order to have enough statistics for the calibration, one r-t relation per chamber is determined. The dependence of the r-t relation on environmental conditions which are non-uniform across a chamber are corrected by functions derived from theory and simulations: r-t corrections depending on the local magnetic field[5] and the local temperature are applied to the drift time.

1.2. *Infrastructure*

The level 2 and 3 event-filter discards 90 % of the muon tracks, most of them being still suitable for calibration. Therefore, a special calibration stream was introduced, that is derived from the muon-tracks used in the level 2 trigger. Tracks with a rate of up to 1 kHz are sampled, and sent to the calibration centres in Ann Arbor (University of Michigan), Munich (Ludwig-Maximilians-Universität, Max-Plank-Institut) and Rome (INFN Roma/ INFN Roma Tre), where the calibration is performed.[6]

1.3. *Calibration during Commissioning of the ATLAS Detector with Cosmics*

For the runs that were taken during the commissioning of the ATLAS detector with cosmic muons, calibration constants for the muon chambers were regularly produced. The calibration was used in muon reconstruction. The commissioning data also allowed detailed tests of the calibration model.

1.4. *Performance*

To study the precision of the t0-fit, a spectrum with 10 million cosmic hits was filled. This spectrum was used as a probability density distribution, to create random drift times. In order to test the precision of the fit as a function of the number of hits in the fitted spectrum, drift-time spectra with statistics between 1000 to 100000 hits were filled with these hits. For each statistics point 20000 drift time spectra were generated. In Figure 1(a), the mean deviation and the width of the distribution of the t_0 fitted to these spectra is plotted versus the fit statistics. With more than 10000 hits per spectrum, both the mean deviation as well as the width of the distribution is well inside the 0.5 ns limit.

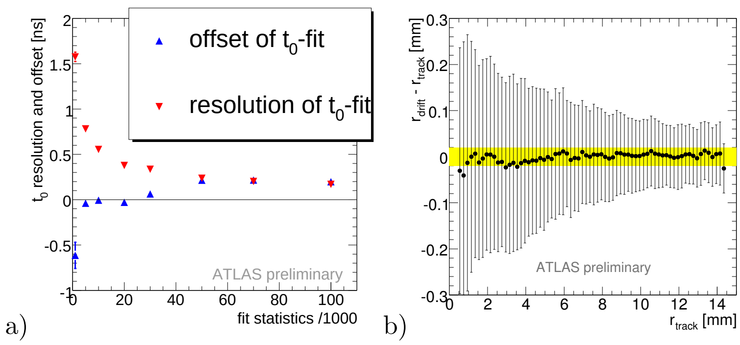

Fig. 1. (a) The precision and systematic offset of the t0-fit vs. the number of hits in the fitted spectrum. (b) Width and mean value of the residual distribution vs. the radius.

The quality of the r-t relation is checked using the track segment residual distribution. The mean value and the width of the residuals are shown in Figure 1(b). The mean value is inside the required 20 μm. The width matches the expectation from the single tube radius of the order of 100 μm.

The magnetic field correction to the r-t relation was checked by applying an r-t relation determined on data with no magnetic field to data with magnetic field. A clear slope in the residual distribution can be seen, when the magnetic field correction is not applied, while it is flat, when the correction is applied, and the rt-precision is inside the 20 μm range (Figure 2).

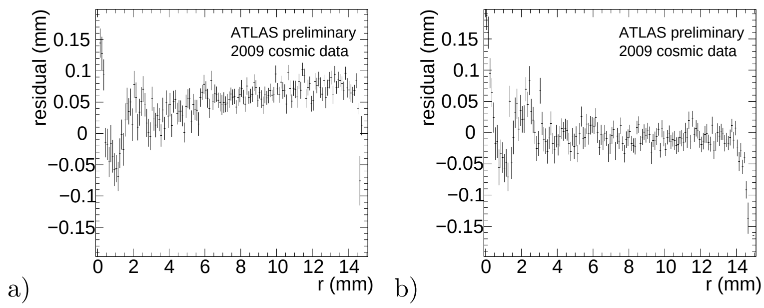

Fig. 2. Residual distributions obtained, when a r-t relation fitted without magnetic field is applied to data with magnetic field, without (a) and with (b) magnetic field correction applied. These are the data from one chamber.

2. Calibration with First *pp* Collision Data

For end of 2009, the centre-of-mass energy for the *pp* collisions at the LHC will be between 6 and 7 TeV. The peak luminosity will be ramped up from 10^{29} cm^{-2}s^{-1} to 10^{31} cm^{-2}s^{-1}. This reduces the number of muons available for calibration.

The statistics of about one million muon tracks per chamber required for a synchronization of the drift-time measurements of the individual drift tubes with 1 ns accuracy will not be available at the start of the LHC operation, even when accumulating data over several weeks. The drift-time measurements of the tubes within a chamber will be synchronized with huge statistics of cosmic muons to be acquired end of October. The synchronization of the drift time measurements of the muon chambers for *pp* collisions requires one order of magnitude fewer muon tracks and can be done with the required precision within a week of LHC operation at $L = 10^{29}$ cm^{-2}s^{-1}.

The calibration of r-t relations requires $\sim$10000 segments per chamber. A daily r-t calibration will be impossible at the initial LHC luminosity. To have a fast monitor of the drift-gas properties, a package of two drift tube chambers are installed in the surface gas building. They sample gas from the input and the return gas line of the muon spectrometer. A scintillator triggers on cosmic muons with a rate of 20 Hz, which allows to fit 2 r-t relations per hour. The r-t relation is created at a fixed temperature of 20^0C and $B = 0$. In the initial phase, when no rt-relation form the calibration will be available, this rt-relation will be applied adapting it according to the temperature and the magnetic field. The precision of this is 100 μm.[7]

3. Conclusion

The data from the commissioning of the Muon Spectrometer with cosmic muons was successfully used to validate the performance of the calibration procedure. Calibration for these runs ware regularly produced.

In the start-up phase of the LHC, a calibration with a precision of 100 μm will be generated, which is sufficient for the studies done with these data. This precision will improve to 20 μm at the end of the first LHC-run.

References

1. ATLAS Collaboration, *J. Instrum.* **3**, p. 08003 (2008).
2. M. Deile et al., An efficient method to determine the space-to-drift-time relationship of the atlas monitored drift tube chambers, in *Nuclear Science Symposium and Medical Imaging Conference 685-688 (vol.1)*, (Honolulu, HI, USA, 2007).
3. The ATLAS Collaboration, Expected performance of the atlas experiment - detector, trigger and physics, arxiv:0901.0512v4 [hep-ex] cern-open-2008-020 (2008).
4. S. Horvat et al., *Determination of the Spatial Drift-Tube Resolution using Muon Tracks*, ATLAS Note ATL-MUON-PUB-2006-008, CERN (CERN, Geneva, 2008).
5. S. Horvat et al., *IEEE Trans. Nucl. Sci. 53 (2006) 562-6* (2006).
6. P. Bagnaia et al., *Calibration model for the MDT chambers of the ATLAS Muon Spectrometer*, ATLAS Note ATL-MUON-PUB-2008-004, CERN (CERN, Geneva, 2008).
7. D. Levin et al., *Nuclear instruments and methods in physics research. Section A* **588**, 347 (2008).