Precision of the ATLAS muon spectrometer
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Chapter 6  Conclusions

Now all has been heard; here is the conclusion of the matter:
Fear God and keep his commandments,
for this is the whole duty of man.
Ecclesiastes 12:13

The first three of the following contributions to the precision of the muon momentum measurement of the ATLAS muon spectrometer have been studied in this thesis:

1. Mechanical precision of an assembled muon precision chamber;
2. Single muon drift tube resolution including its calibration;
3. Relative alignment of the muon precision chambers in the spectrometer;
4. Multiple scattering in the material of the muon spectrometer, both in the magnet elements and in the muon chambers;
5. Measurement precision of the magnetic field;

The requirements on the first three contributions are mainly driven by the target momentum resolution of 10% for muons with very high momentum (1 TeV/c):

1. 20 µm r.m.s. on the drift tube wire positions in an assembled chamber, when tested against a fixed regular grid;
2. 80 µm resolution of a single drift tube (including the calibration and averaged over the tube radius);
3. 30 µm uncertainty on the muon track sagitta due to chamber misalignments;

and lead to a total uncertainty of the measured track sagitta of 50 µm. The first requirement is actually absorbed in the calibration mentioned in the second requirement.

The reason for the first requirement is a practical one: with only a few input parameters describing the wire grid, all wire positions can be calculated. Otherwise all wire positions of all assembled chambers must be measured, and stored. In the chosen solution only the wire positions of a sample of the chambers (about one in eight) are measured at CERN by the X-ray tomograph for quality control. It has been shown in this thesis that a sample of BOL chambers (constructed at NIKHEF) have a mechanical precision of 15 µm, which is well within the requirement.

The single tube resolution, including the calibration, has been tested using cosmic muons. The detector operating point as foreseen for ATLAS was used, except for the used gas gain, which was
3.5 times higher. The space-time relation of the drift tube is determined in an auto-calibration procedure, with an average left-over systematic deviation of less than 3 μm. The larger systematic deviations near the wire (up to 70 μm) need some more attention, although it is still significantly smaller than the local resolution. The single drift tube resolution is estimated by calculating a scaling factor that is applied to the width of the residual distribution of the track fit, where the hit concernend is left out of the track fit. This method uses only the data of the detector itself, and works very well, which is evinced by the flat distribution of the confidence level of the track fit. A resolution of 82 μm, averaged over the tube radius, has been achieved (after corrections for multiple scattering). This includes errors from the calibration procedure and errors due to the limited precision of the wire positions and is therefore the relevant resolution. It is close to the target resolution. The detection efficiency of the tubes is excellent (99.984%), and the hit-on-track inefficiency (5%) is dominated by δ-electrons ejected by the muons. Significant systematic tube-to-tube variations in the operation point have been observed, which are related to the (partly serial) gas distribution system, and need further investigation.

The relevant parameter that summarises requirements 1 and 2 is the precision of an individual track segment in one muon chamber, or more precisely, the precision of the combination of three segments in the muon track sagitta. This target precision on the sagitta due to the track segment precision is 40 μm, which is shown in this thesis to have been achieved: 34 μm (although for yet another operating point of the drift tubes).

It has also been demonstrated in this thesis that the alignment systems are capable of monitoring changes in the geometry with a precision of 11 μm on the muon track sagitta. This achievement has one caveat: it was a relative test. It is yet to be demonstrated that the alignment system can provide the absolute corrections using pre-calibrated Rasnik systems. This is the main goal of the H8 set-up at CERN (summer 2002), where the DATCHA experiment is repeated using a 20 GeV muon beam and final ATLAS muon precision chambers. First results are expected at the end of 2002. The H8 data could possibly also be used to test the feasibility of the in-situ calibration of the alignment systems using straight muon tracks.

The twin-tube concept, where two drift tubes are interconnected at the high-voltage end to provide an effective read-out on both sides of the tubes, has been shown to provide an adequate second coordinate measurement. It thereby transforms the two-dimensional drift tube chambers into a real three-dimensional tracker system. The twin-tube concept is not the ATLAS baseline, but it may actually be implemented in the outer stations of the muon spectrometer.

Concerning the search for the Standard Model Higgs boson in the $H \rightarrow Z^0Z^0 \rightarrow \mu^+\mu^-\mu^+\mu^-$ channel, the requirements that were inspired by 1 TeV muons seem overdone if indeed the Higgs mass falls in the mass region expected from the LEP experiments (< 200 GeV). In this mass region, the momentum resolution of the four muons, as measured by the muon spectrometer, is dominated by multiple scattering in the spectrometer itself, and by energy loss fluctuations in the calorimeters. The requirement on the alignment precision could, from this point of view, easily be relaxed to 100 μm without any significant loss in momentum resolution. This is reassuring, since the absolute calibration of the alignment systems in the ATLAS muon spectrometer is yet to be demonstrated.