Precision of the ATLAS muon spectrometer
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Appendix B  Twin tubes

Chapter 4 explained in detail the different steps required to extract a drift distance from a measured drift time in an MDT. The correction for the delay due to the signal propagation along the tube turns out to be one of the larger corrections, notably for the 5 m long MDTs in the BOL chambers. This correction can only be made once the location along the wire, at which the muon passed through the MDT, is known. In the baseline design of the ATLAS muon spectrometer this so-called second coordinate must be extracted from the trigger chamber data. To achieve this, the trigger chambers (RPCs) of the muon spectrometer include strip planes segmented in the non-bending plane. With this configuration, only MDT hits that can be matched to trigger chamber hits can be corrected for propagation delay. This appendix describes an economic proposal to use the MDTs themselves to make the propagation delay correction to the required precision.

B.1  Concept

The 'twin tube' principle is shown schematically in figure B-1. Pairs of tubes are interconnected at the high-voltage (HV) end via an impedance matched HV-jumper. This way the MDTs are effectively read-out on both ends\(^1\). The main drawback of this scheme is the doubling of the occupancy in the MDTs. Some examples of measured raw muon signals on twin tubes were given in figure 4-4. The MDT through which the muon passes records a drift time \(t_1\) as usual. Its twin partner records a delayed drift time \(t_2\), where the delay depends on the location \(x\) along the wire where the muon passes the MDT (\(x = -\frac{L}{2}\) at the read-out end and \(x = +\frac{L}{2}\) at the HV end with \(L\) the total length of the MDT). The HV-jumper has a built-in delay of \(\Delta_0 = 12\) ns to minimise confusion for muons passing near the HV end of an MDT. The drift time \(t_{\text{drift}}\) of the ionisation in the MDT gas is related to these quantities, the \(t_0\)'s of these two MDTs and the time-of-flight delay \(\Delta t_{\text{ToF}}\) via:

\[
\Delta t_{\text{drift}} = \Delta_0 + t_{\text{drift}}(x) - t_1 - t_2
\]

\(\Delta t_{\text{drift}}\) and \(t_{\text{drift}}(x)\) can be calculated from the measured \(t_0\)'s and the known distance \(L\) between the MDTs.

\(\Delta t_{\text{drift}}\) is then used to correct the measured drift times to the position along the wire where the muon passed the MDT. The correction is applied by subtracting \(\Delta t_{\text{drift}}\) from the measured drift time. This results in a correction for the delay due to signal propagation along the tube, which is one of the larger corrections.

\(1.\) Of course an even better performance can be achieved by reading out the MDTs on both ends. However, this does not qualify as an economic solution (doubles the number of read-out channels).
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\[
t_1 = t_{\text{drift}} + t_{0,1} + \frac{1}{2}L + x + \frac{L + x}{v} + \Delta t_{\text{ToF}}
\]

\[
t_2 = t_{\text{drift}} + t_{0,2} + \frac{3}{2}L - x + \frac{L - x}{v} + \Delta t_{\text{ToF}} + \Delta t_{0}
\]

Solving for \( t_{\text{drift}} \) yields:

\[
t_{\text{drift}} = \frac{(t_1 - t_{0,1}) + (t_2 - t_{0,2})}{2} - \left(\frac{L}{v} + \frac{\Delta t_{0}}{2}\right) - \Delta t_{\text{ToF}}.
\]

In these expressions \( v \) stands for the signal propagation speed along the MDT wire. Note that \( t_{\text{drift}} \) does not depend on \( x \), nor on \( v \) (except for a constant offset), but only on the two measured times and a set of pre-calibrated constants! The time-of-flight correction is calculated as for ordinary tubes, except that the \( x \)-coordinate is calculated from the difference of the measured times:

\[
x = \frac{L}{2} - (\Delta t - \Delta t_{0}) \frac{v}{2} \quad \text{with} \quad \Delta t \equiv (t_2 - t_{0,2}) - (t_1 - t_{0,1}),
\]

where the signal propagation speed \( v \) can be extracted from figure 4-7.

In the implementation, the MDTs are twinned (for chambers with three layers per multilayer) as shown in figure B-2. This layout excludes that both twin partners are directly hit by the same traversing muon, and it is compatible with the segmentation of the on-chamber high-voltage distribution boards. Secondaries, e.g. from an accompanying electromagnetic shower, can still lead to undesirable correlated hits in both twin partners.

The jumpers, mounted on the high-voltage distribution board, are shown in figure B-3. A single jumper is realised using a four layer printed circuit board. Its impedance is 330 \( \Omega \) and the measured delay is 11.3 ns. For large quantities, the cost of the HV-jumper is about equal to the cost of the HV capacitors and termination resistors it replaces.

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**Figure B-2** Twin tube connections on one high-voltage board for a chamber with three layers per multilayer.

**Figure B-3** Photograph of a high voltage distribution board with 12 twin tube HV-jumpers mounted.
B.2 Results

The twin tube concept has been studied and used in the test stands described in chapters 4 and 5 of this thesis. Its performance is best illustrated using the results of the DATCHA setup, where a special assembly of 16 MDT tubes equipped with HV-jumpers was mounted diagonally across the MDT tower as visible on the photograph in figure 5-1. Because of this large angle, the second coordinate measuring capabilities of the twin tubes can be evaluated using either the measurements of the RPCs or the measurements of the MDT chambers.

A typical twin tube event recorded at the NIKHEF cosmic ray test stand (see chapter 4) is shown in figure B-4. The hit-pair efficiency was measured to be 98%. The resolution on the time difference was determined by comparing the expected time difference obtained from the x-coordinate of the RPCs to the measured time difference. The distribution of the residuals is shown in figure B-5. The width of this distribution is 0.8 ns, which agrees with the expected resolution of the TDCs (1 ns bins) used in the DATCHA setup. Using an inverse propagation speed of 3.8 ns/m (see figure 4-7), this corresponds to a resolution of the second coordinate measurement of about 10 cm. For ATLAS, where the TDCs have 0.78 ns bins, this x-resolution is expected to be about 8.0 cm per tube, which is more than adequate for the time-of-flight correction. With typically six hits on a track segment, the track segment second coordinate is expected to be determined with a precision of about 3 cm in ATLAS using the twin tubes only.

Figure B-4 Typical twin tube event at the NIKHEF cosmic ray test stand showing the original hits (solid circles) and the twin partner hits (open circles).

Figure B-5 Residual distribution of the measured twin tube time difference.
B.3 Conclusion

The twin tube concept offers an adequate determination of the second coordinate for the propagation delay and time-of-flight corrections, without the need for the RPCs. This simplifies the pattern recognition and subsequent track fitting software for the ATLAS muon spectrometer. The role of the RPCs still remains essential for the triggering and the global timing reference. The count rates expected in notably the outer layers of the ATLAS muon spectrometer do not exclude the implementation of the twin tube concept.