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Twin-tubes: 3D tracking based on the ATLAS muon drift tubes

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Abstract

The Monitored Drift Tubes (MDTs) of the ATLAS Muon Spectrometer have been paired to form so-called twin-tubes to measure the coordinate which runs along the wire direction. This modification endows the MDTs with full 3D track reconstruction using specially designed electronic boards. The performance of the twin-tubes has been measured for an equipped MDT chamber at the ATLAS Muon Cosmic Ray Test Stand at NIKHEF. The efficiency of a twin-tube has been determined to be 99.8%, and the measured resolution 17 cm per hit. By equipping one multilayer consisting of three layers and combining the measurements a resolution of 10 cm has been obtained.

Keywords: Monitored drift tube; Twin-tube; ATLAS; Muon chamber

1. Introduction

ATLAS is one of the two general-purpose detectors at the Large Hadron Collider at CERN and is scheduled to start data taking in 2007. Its Muon Spectrometer [1] measures the deflection of the muons in the magnetic field with high precision in the bending direction with Monitored Drift Tube (MDT) chambers [2]. A single MDT consists of a 400 μm thick aluminum tube with a diameter of 30 mm, which holds a 50 μm diameter goldplated tungsten wire at its centre. The tube serves as the cathode and is filled with the drift-gas Ar/CO_2. The central wire is the anode of the drift tube. A chamber consists of two multilayers (with each three or four layers of tubes) separated by a spacer frame. High-Voltage (HV) is applied to the wires on one end of the tubes and the signals are collected at the other ends: the Read-Out (RO) side.

A muon traversing the MDT at a certain distance of the wire ionises the gas. The electrons drift to the anode wire and after gas amplification a signal is generated that propagates to both ends of the wire. At the RO side, the on-chamber electronics shape the signal and when it passes the (adjustable) threshold, measure the arrival time by a Time-to-Digital Converter (TDC). The distance of the muon's trajectory with respect to the wire is accurately determined from the measured time using a space-time relation.

The time (t_{TDC}) is measured in bins of 0.78 ns with respect to the time of the proton-proton collision, and has several contributions: the drift time (t_{drift}), the propagation delay (t_{prop}) of the signal along the anode wire, the time-of-flight (t_{ToF}) from the interaction point to the the impact point, and delays due to cables and electronics (t_0). The propagation delay is proportional to the distance x from the impact point to the Read-Out end of the tube: $t_{\mathrm{prop}} = x/v$, where v is the effective signal propagation speed (see Fig. 1). The drift time is then given by

$$t_{\mathrm{drift}} = t_{\mathrm{TDC}} - t_0 - t_{\mathrm{ToF}} - \frac{x}{v}. \qquad (1)$$

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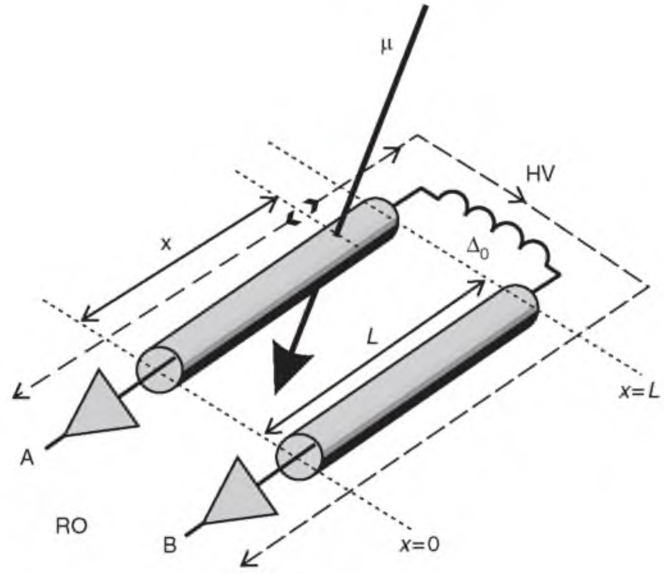

Fig. 1. Schematic view of a twin-tube, consisting of two MDTs. A muon and the coordinate system are indicated. The dashed arrows indicate the propagation of the signals. The chamber is read out at A and B.

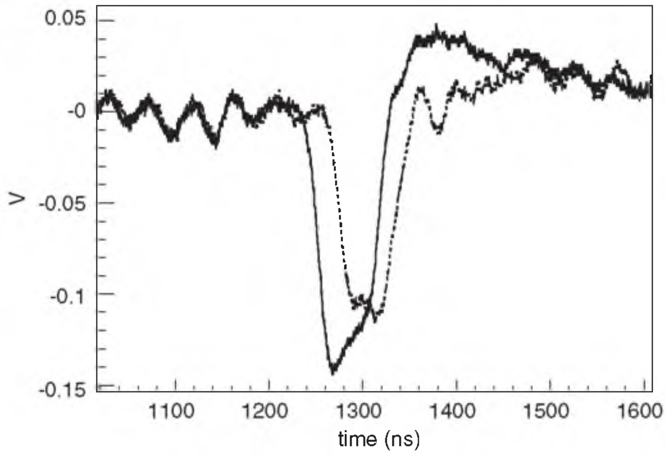

Fig. 2. Example of measured twin-tube pre-amplifier output signals. The continuous line represents the prompt signal and the dashed line the delayed twin-partner signal.

The correction for the delay due to the signal propagation along the wire turns out to be one of the larger corrections, notably for the 5 m long MDTs in the Barrel Outer Large (BOL) chambers. This correction can only be made once the location along the wire at which the muon passes through the MDT, is known. In the baseline design of the ATLAS Muon Spectrometer this so-called second coordinate is extracted from the trigger chamber data. To achieve this, the trigger chambers (Resistive Plate Chambers (RPC) in the ATLAS barrel region) of the Muon Spectrometer include strip planes segmented in the non-bending plane with 30 mm wide strips.

The second coordinate can also be measured by pairing two MDTs at the HV side forming a so-called twin-tube. This modification endows the MDTs with full 3D track reconstruction using specially designed electronics boards. In Section 2 the twin-tube principle is outlined, and in Section 3 its technical implementation is shown. In Section 4 the method of calibration and the achieved performance are presented. The last section summarises the results.

2. Twin-tube principle

Using a twin-tube, i.e. a pair of MDTs, the second coordinate can be determined from the two registered times. This principle is shown schematically in Fig. 1. A pair of tubes is interconnected at the HV end via an impedance-matched delay line. The prompt muon signal generated in tube A, propagates to the Read-Out end of tubes A and B. In Fig. 2 the measured raw muon signals on a twin-tube pair are shown. The muon traverses tube A and it records a drift time $t^{\rm A}_{\rm TDC}$ as usual. Its twin-partner (tube B) records a drift time $t^{\rm B}_{\rm TDC}$ with an extra delay of $\Delta_0 \simeq 5\,{\rm ns}$ (in our implementation). The built-in delay is needed to distinguish prompt and twin-partner signals for muons passing near the HV end of a MDT. The measured times in the two MDTs are related to the drift time $t_{\rm drift}$, the t_0's and the time-of-flight delay via:

$$t^{\rm A}_{\rm TDC} = t_{\rm drift} + t^{\rm A}_0 + \frac{x}{v_{\rm A}} + t_{\rm ToF}, \tag{2}$$

$$t^{\rm B}_{\rm TDC} = t_{\rm drift} + t^{\rm B}_0 + \frac{L-x}{v_{\rm A}} + \frac{L}{v_{\rm B}} + t_{\rm ToF} + \Delta_0 + \Delta t^B, \tag{3}$$

where L is the chamber length and x the coordinate along the wire.

In case the amplitude of the signal is infinite and there is no damping, the velocities $v_{\rm A}$ and $v_{\rm B}$ are equal to the speed of light and Δt^B is zero.

A model was developed assuming signal propagation with the speed of light. The time slewing caused by the exponential damping of the signal and the different gains of the amplifiers were added as time corrections. The time shift induced by reflections at the HV side was also added. The data can be adequately described in terms of these parameters. The electronics gain of the amplifier was found to vary by 12%, consistent with the electronics specifications. The timeshift induced by reflections was about 0.7 ns.

If this model is linearised it can be written as Eqs. (2) and (3). The speed of light has to be replaced by two effective propagation speeds $v_{\rm A}$ and $v_{\rm B}$ and one needs to add a constant Δt^B to the time delay. The data will be calibrated using these linear expressions. This will be discussed in Section 4. Defining the corrected time difference Δt as:

$$\Delta t = (t^{\rm B}_{\rm TDC} - t^{\rm B}_0) - (t^{\rm A}_{\rm TDC} - t^{\rm A}_0), \tag{4}$$

and solving for the second coordinate x yields:

$$x = \frac{v_{\rm A}}{2}\left(-\Delta t + \Delta_0 + \Delta t^B + \frac{L}{v_{\rm A}} + \frac{L}{v_{\rm B}}\right). \tag{5}$$

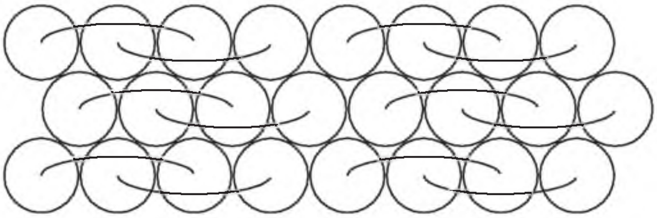

Fig. 3. Twin-tube connections on one High-Voltage board for a chamber with three layers per multilayer.

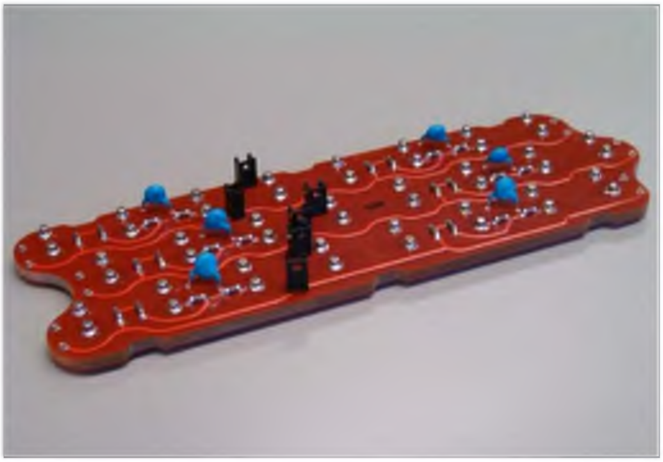

Fig. 4. Photograph of a twin-tube High voltage distribution board with 12 integrated delay lines.

The x-coordinate is linear in the corrected time difference. For deciding which tube was traversed by the muon it is sufficient to require that Δt is positive.

3. Twin-tube implementation

In the implementation for a chamber consisting of two times three layers, the MDTs are paired as shown in Fig. 3. This layout excludes that both twin-partners are directly hit by the same traversing muon. It is compatible with the segmentation (three layers of eight tubes) of the baseline on-chamber HV distribution boards. The twin-tube HV distribution board is shown in Fig. 4. The delay lines are integrated in the six layer printed circuit board. The delay is realised by a series of LCs, its impedance is 330 Ω and the delay is 5 ns.

4. Twin-tube calibration and performance

Per twin-tube pair six calibration constants have to be determined: two t_0's, two propagation speeds v_A and v_B and two times $\Delta^A = \Delta_0 + \Delta t^A$ and $\Delta^B = \Delta_0 + \Delta t^B$. The t_0's and propagation speeds are also needed for standard MDTs. Thus two extra calibration constant are needed per twin-tube pair.

To test and calibrate the twin-tubes, one multilayer of a BOL chamber was fully equipped with twin-tube HV boards. The data were taken at the NIKHEF ATLAS Muon Cosmic Ray Test Stand shown in Fig. 5 and read out with the standard ATLAS electronics.

The Cosmic Ray Stand consists of five BOL chambers. The trigger is provided by a coincidence of scintillators located below the chambers. Cosmic muons have to penetrate 50 cm of iron in between the scintillators. The scintillators were placed at x values around 700, 2500 and 4300 mm and have a resolution of about 40 mm. The coordinate system is shown in Fig. 1. The chambers were

Fig. 5. Photograph of the ATLAS Muon Cosmic Ray Test Stand at NIKHEF.

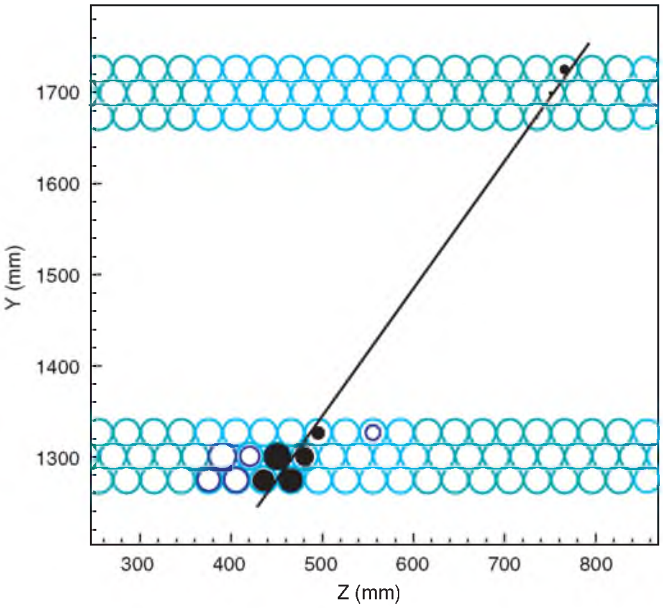

Fig. 6. Typical twin-tube event at the Cosmic Ray Test Stand showing the original hits (solid circles) and the twin-partner hits (open circles).

operated at 3300 V with a gas mixture of Ar/CO$_2$.Track segments were reconstructed per chamber requiring at least 2 hits per multilayer. A display of an event recorded at the Cosmic Ray Test Stand with twin-tube information is shown in Fig. 6.

The t_0's of the drift tubes are determined by fitting a step-like function to the lower part of the TDC spectrum. The propagation speeds and the time delay Δ_0 are determined by a fit to the distribution of x as a function of Δt.

Fig. 7 shows the x-coordinate—measured by the scintillators—as a function of the Δt for one pair of twin-tubes. The slopes of the straight line fits to the data give v_{A} and v_{B}, respectively. The off-sets are related to Δ^A and Δ^B. The data can be described within the experimental uncertainties by the linearised equation (4).

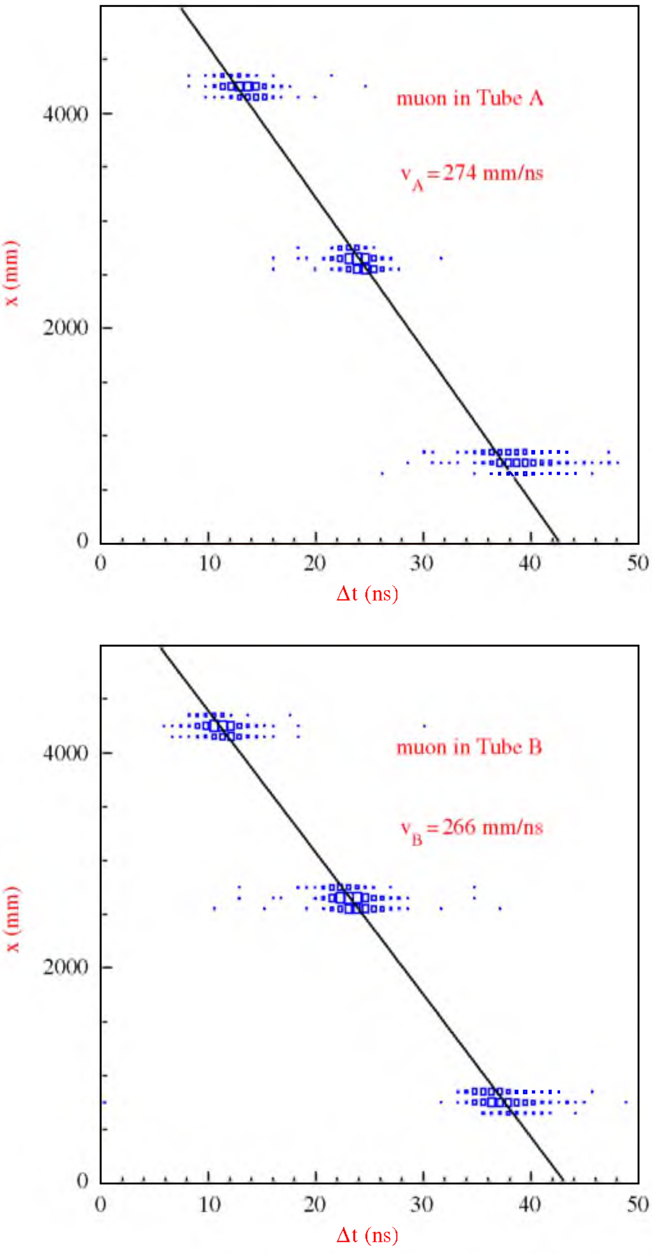

Fig. 7. The x-coordinate along the anode wire vs the measured time difference Δt of a twin-tube pair. The straight lines show the fit results.

From the data the efficiency was determined to be 99.8%. This means that if we have a registered TDC value in a tube, the probability to find no signal in its twin-partner is 0.2%.

The resolution on the x-coordinate for a single twin-tube measurement was determined by comparing the x-coordinate measured by the scintillators to the twin-tube x-coordinate. The twin-tube x-coordinate was obtained using Eq. (5) with the measured Δt, the fitted propagation speeds and time delay as inputs. The distribution of the residuals is shown in Fig. 8. The width of this distribution is 17 cm. The non Gaussian tails are due to slewing. The time resolution on Δt corresponds to 1.3 ns. It was verified that the combination of three measurements in one multilayer gives—as expected—a resolution of 10 cm.

Changing a MDT tube into a twin-tube has a small impact on the resolution of the precision coordinate. The resolution of a twin-tube is slightly worse—by about 5%—than that of a standard MDT.

The occupancy will be doubled by the introduction of twin-tubes. They can e.g. be installed in the outer layers of the ATLAS muon spectrometer where the occupancy is low. Twin-tubes would complement the ATLAS trigger chamber measurements and help in the 3D pattern recognition.

5. Conclusion

The Monitored Drift Tubes of the ATLAS spectrometer have been paired to form twin-tubes to measure the second

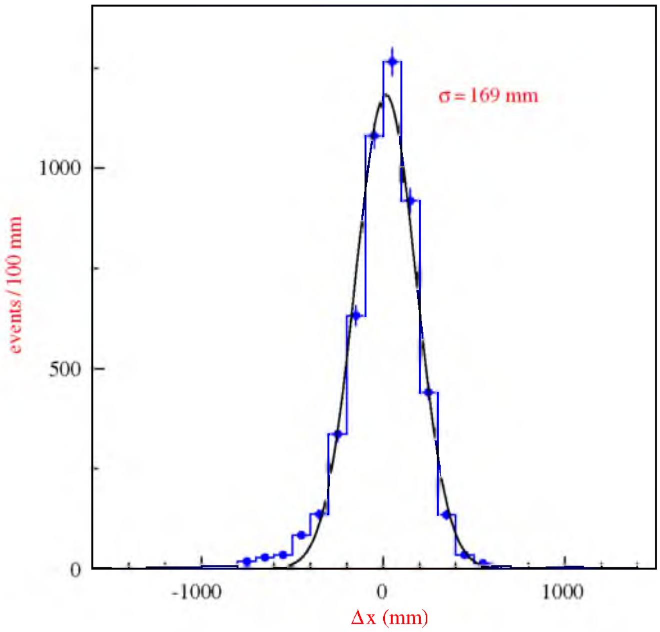

Fig. 8. Residual distribution of the measured twin-tube x-coordinate (mm). The solid line shows the Gaussian fit result with a width of 17 cm.

coordinate along the wire direction. Using this coordinate, full 3D standalone tracking can be done with the MDTs. The twin-tube HV distribution boards have been designed and implemented and the performance of the twin-tubes is measured at the ATLAS Muon Cosmic Ray Test Stand at NIKHEF. The efficiency of a twin-tube has been determined to be 99.8%, and the measured resolution 17 cm per hit. By equipping one multilayer of three layers and combining the measurements a resolution of 10 cm has been obtained.

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