

# Resolution and Efficiency of the ATLAS Muon Drift-Tube Chambers at High Background Rates

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## Abstract

The resolution and efficiency of a precision drift-tube chamber for the ATLAS muon spectrometer with final read-out electronics was tested at the Gamma Irradiation Facility at CERN in a 100 GeV muon beam and at photon irradiation rates of up to 990 Hz/cm<sup>2</sup> which corresponds to twice the highest background rate expected in ATLAS. A silicon strip detector telescope was used as external reference in the beam. The pulse-height measurement of the read-out electronics was used to perform time-slewing corrections which lead to an improvement of the average drift-tube resolution from 104  $\mu\text{m}$  to 82  $\mu\text{m}$  without irradiation and from 128  $\mu\text{m}$  to 108  $\mu\text{m}$  at the maximum expected rate. The measured drift-tube efficiency agrees with the expectation from the dead time of the read-out electronics up to the maximum expected rate.

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## 1 Introduction

The muon spectrometer of the ATLAS detector at the Large Hadron Collider (LHC) is designed for the measurement of muon momenta with an accuracy of 3% over a wide energy range reaching 10% resolution at 1 TeV. The muon trajectories in the 0.4 T field of a superconducting air-core toroid magnet are

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measured in three stations of precision drift chambers chambers, the monitored drift-tube (MDT) chambers.

The MDT chambers consist of two triple or quadruple layers of aluminium drift tubes of 0.4 mm wall thickness and 29.170 mm inner diameter with a 50  $\mu\text{m}$  diameter gold-plated tungsten-rhenium wire at the center. The tubes are filled with Ar:CO<sub>2</sub> (93:7) gas mixture at a pressure of 3 bar. Operated at a gas gain of  $2 \cdot 10^4$ , the drift tubes must provide a spatial resolution of better than 100  $\mu\text{m}$  in order to reach the required chamber position resolution of better than 40  $\mu\text{m}$  [1] with a sense wire positioning accuracy of 20  $\mu\text{m}$  which has been achieved in the chamber serial production [3].

The operating conditions of the ATLAS muon chambers at the LHC are characterized by unprecedentedly high neutron and  $\gamma$  backgrounds (see Figure 1). The chambers will experience background count rates ranging from 40 Hz/cm<sup>2</sup> to 500 Hz/cm<sup>2</sup> including a safety factor of 5 [1] corresponding to count rates per tube between 45 and 300 kHz for tube lengths of 1.7 – 5.8 m.

In summer 2003, one of the largest MDT chambers constructed for the ATLAS muon spectrometer containing 432 drift tubes of 3.8 m length [3] has been tested at the Gamma Irradiation Facility [2] at CERN with a 740 GBq <sup>137</sup>Cs source in a 100 GeV muon beam. The chamber was equipped with the final read-out electronics for ATLAS which measures both the drift time and the pulse height of ionizing particle tracks. The chamber was operated at photon count rates of up to 990 Hz/cm<sup>2</sup>. A silicon strip detector telescope (see Figure 2) was used as external reference to determine the space-to-drift time relationship and the spatial resolution and efficiency of the drift tubes.

## 2 Spatial Resolution Measurement

The discriminator threshold of the read-out electronics was optimized to a value of 4.6 times the thermal noise fluctuations corresponding to the 25<sup>th</sup> primary ionization electron. By extrapolating the muon trajectory measured by the silicon strip detector telescope with 10  $\mu\text{m}$  accuracy to the nearest triple layer of the chamber at a distance of 58 cm, the muon impact radius  $r_{true}$  in the drift tubes of this layer is determined with a precision of 20  $\mu\text{m}$ . With this information, the space-to-drift time relationship and the spatial resolution of the drift tubes as a function of the impact radius is determined depending on the  $\gamma$  irradiation rate (see Figure 3a).

The measured drift radii show a systematic deviation from the impact radii determined with the silicon detector telescope which increases with decreasing pulse height measured by the read-out electronics. The deviation is interpreted

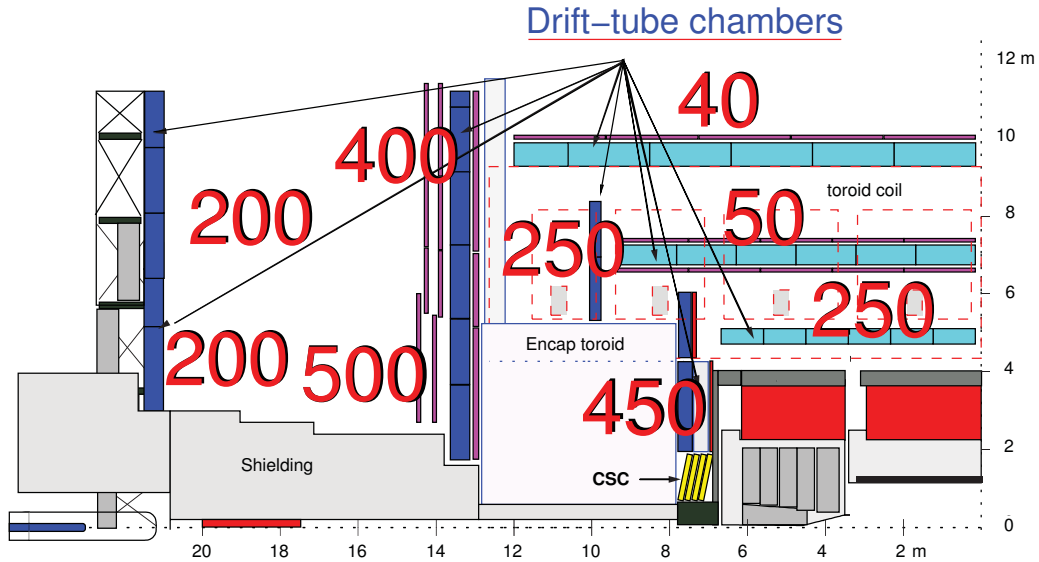


Fig. 1. Expected background count rates in  $\text{Hz}/\text{cm}^2$  (including a safety factor of 5) in the MDT chambers in different regions of the ATLAS muon spectrometer. The cross section of one quadrant of the ATLAS detector containing the LHC proton beam line is shown.

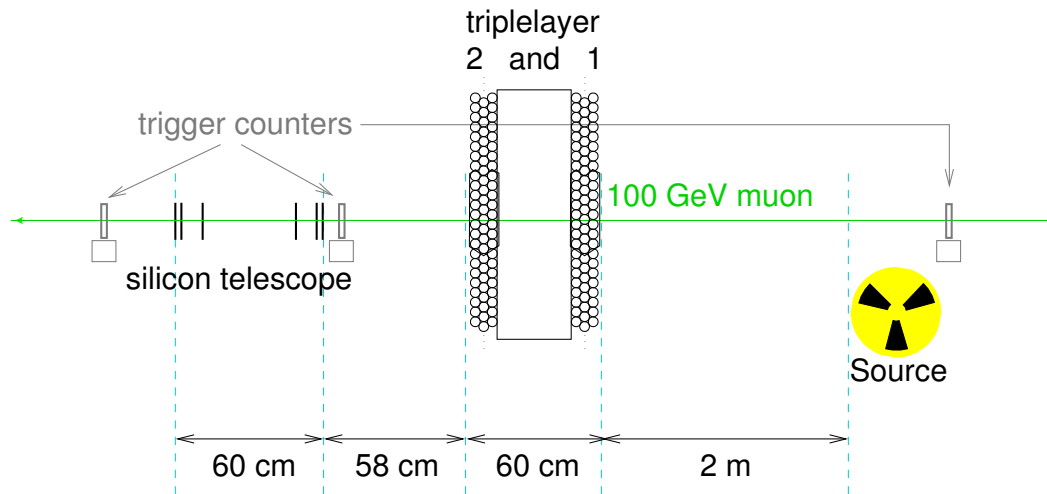


Fig. 2. Top view of the experimental set-up at the Gamma Irradiation Facility at CERN with a MDT chamber consisting of two triple layers of drift tubes and a silicon strip detector telescope in a 100 GeV muon beam.

as a time-slewing effect of the read-out electronics. By parametrizing the observed correlation as a function of pulse-height and impact radius, an average time-slewing correction function is determined. The time-slewing corrections

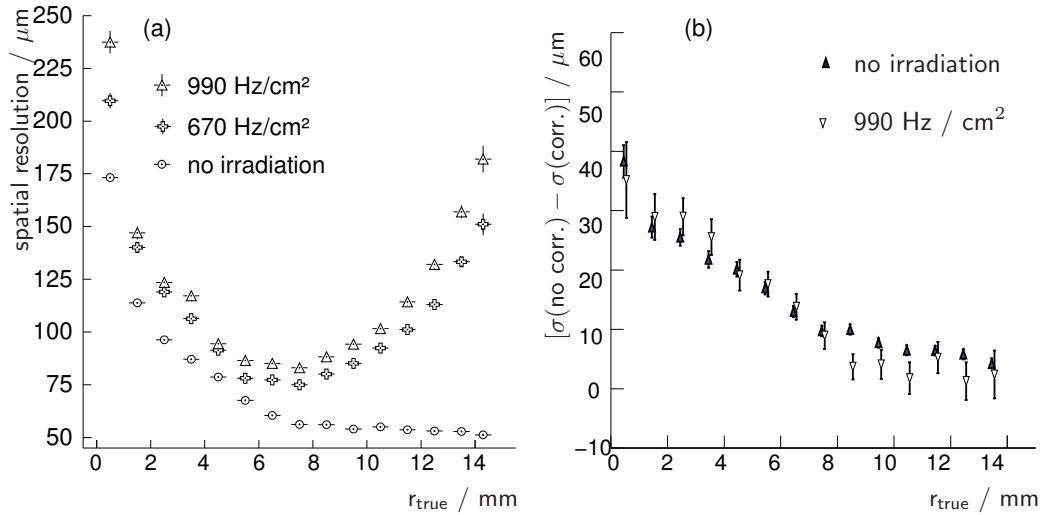


Fig. 3. a) The spatial resolution of the drift tubes as a function of the impact radius  $r_{\text{true}}$  of the muon determined by the silicon detector telescope at different photon count rates after time-slewing corrections. b) Improvement of the average drift-tube resolution due to time-slewing corrections using the pulse-height measurement of the read-out electronics. The improvement increases at smaller impact radii and is independent of the irradiation rate.

lead to a significant improvement of the drift-tube resolution of up to  $40 \mu\text{m}$  at small radii independent of the irradiation rate (see Figure 3b).

The Ar:CO<sub>2</sub> gas mixture shows a strong dependence of the drift velocity on the electric field. Therefore, fluctuations in the space charge density created in the tubes by the  $\gamma$  irradiation cause an uncertainty in the space-to-drift time relationship. This effect [4],[5] leads to a degradation of the spatial resolution with increasing irradiation rates (see Figure 3a). The degradation increases rapidly for large impact radii. The average drift tube resolution as a function of the photon count rate is shown in Figure 4a with and without time-slewing corrections. The resolution degrades linearly with increasing count rate.

Without irradiation, the average drift-tube resolution is  $104 \mu\text{m}$  without and  $82 \mu\text{m}$  with time-slewing corrections. For the maximum expected background count rate in ATLAS,  $500 \text{ Hz/cm}^2$ , the time-slewing corrections improve the resolution from  $128 \mu\text{m}$  to  $108 \mu\text{m}$ .

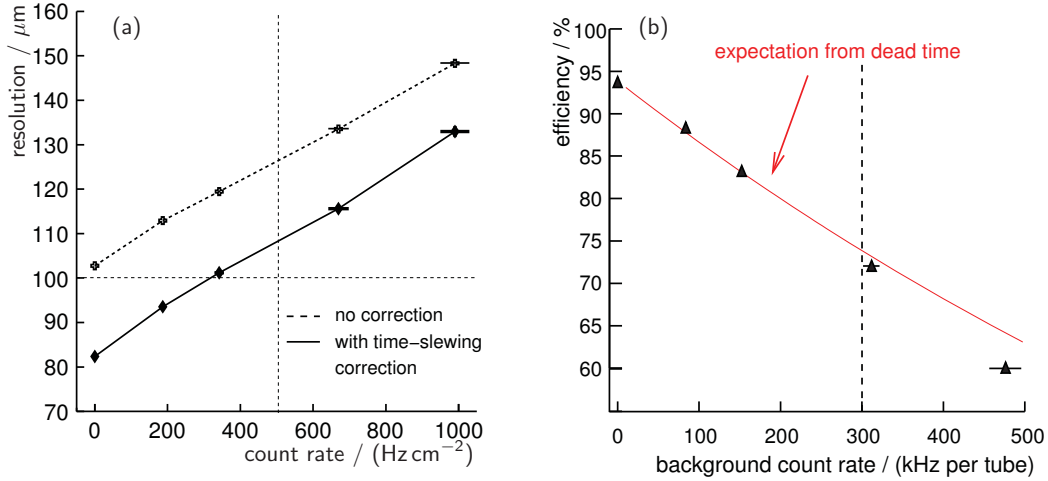


Fig. 4. a) The average spatial resolution of the drift tubes with and without time-slewing corrections and b) the drift-tube efficiency for 790 ns dead time as a function of the photon count rate.

### 3 Drift-Tube Efficiency

Because of the fixed dead time (790 ns in the test beam measurements) built into the read-out electronics, muon hits in the drift tubes can be masked by earlier hits of  $\delta$ -rays and from the background radiation. Hence, a reduction of the drift tube efficiency by 6% due to  $\delta$ -rays is expected even without irradiation and a further decrease of efficiency with increasing irradiation rate.

The probability of finding a hit with drift radius compatible with the muon impact radius determined by the silicon detector telescope within three times the spatial resolution is shown in Figure 4b. Up to the highest anticipated count rate per tube in ATLAS of 300 kHz, the measured efficiency follows the expectation based on a simple model of the read-out electronics with 790 ns dead time without taking into account details of the pulse shape. The muon hit efficiency drops from 94% without photon irradiation to 72% at 300 kHz background count rate per tube. Due to the redundant track-point measurements in the 6 to 8 tube layers of a MDT chamber, the measured drift-tube efficiency allows for an efficient reconstruction of muon trajectories in the ATLAS muon spectrometer up to the highest expected background rates.

## 4 Conclusions

A full-scale monitored drift-tube chamber from the serial production for the ATLAS muon spectrometer equipped with final read-out electronics has been tested in a muon beam at  $\gamma$  irradiation rates of up to twice the maximum background rate expected during operation at the LHC. Even at the highest anticipated background rate of 500 Hz/cm<sup>2</sup> which leads to a deterioration of the drift tube resolution by 25  $\mu$ m, a spatial resolution of close to 100  $\mu$ m is achieved as required by applying time-slewing corrections. The measured drift tube efficiency as a function of the photon count rate follows the expectation from the built-in dead time of the read-out electronics.

## References

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