Eur Phys J C **33**, s01, s996–s998 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2004-03-1793-6

EPJ C direct
electronic only

Precision drift chambers for the ATLAS muon spectrometer

Susanne Mohrdieck-Möck, for the ATLAS Muon Collaboration

Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

Received: 31 October 2003 / Accepted: 10 March 2004 /

Abstract. Precision drift tube chambers for the ATLAS muon spectrometer with a sense wire positioning accuracy of 20 μm are under construction at 13 production sites in 7 countries. 58% of in total 1194 chambers have been assembled so far. Measurements during the production demonstrate, that the required wire positioning accuracy is achieved. Tests under LHC background conditions show, that even at the highest expected irradiation rates the required chamber resolution of 50 μm is maintained and the track reconstruction efficiency is not significantly deteriorated.

PACS. 29.40Gx tracking and position sensitive detectors – 29.40Gs gas filled counters: ionization chambers, proportional and avalanche counters – 14.60Ef muons

1 Introduction

The ATLAS detector at the Large Hadron Collider (LHC) is designed as a multi-purpose detector to search for the Higgs particle and for new physics. An important part of the detector is the muon spectrometer [1] which will measure muon momenta with an accuracy of 3 to 10% in the range of 10 to 1000 GeV. The muon spectrometer has a toroidal magnetic field ($< \mathrm{B} > = 0.4\,\mathrm{T}$) to permit a high p_t-resolution independent of the polar angle over a range of 8° to 172°. To minimise multiple scattering superconducting air-core magnets are used. The size of the muon spectrometer and with it the size of the whole ATLAS detector (45 m length and 25 m diameter) is determined by the large lever arm needed for the high *stand-alone* resolution of the spectrometer. The track sagitta for a muon of 1 TeV momentum is only 500 μm. To achieve the desired resolution of 10% at 1 TeV a muon chamber resolution of 50 μm is needed [1].

The muon trajectory is detected in three detector stations arranged in cylindrical layers in the central barrel region and in wheel shaped planes in the forward and backward end-caps. The high resolution tracking is performed by Monitored Drift Tube (MDT) chambers, except for a small region in the inner innermost end-cap stations where the background irradiation is highest and Cathode Strip Chambers (CSC) are used. The fast trigger signals from the ATLAS muon spectrometer are provided by Resistive Plate Chambers (RPC) in the barrel region and Thin Gap Chambers (TGC) in the end-caps. These chambers measure also the second track coordinate along the drift tubes of the MDT chambers.

In the following the Monitored Drift Tube chambers and their performance is presented.

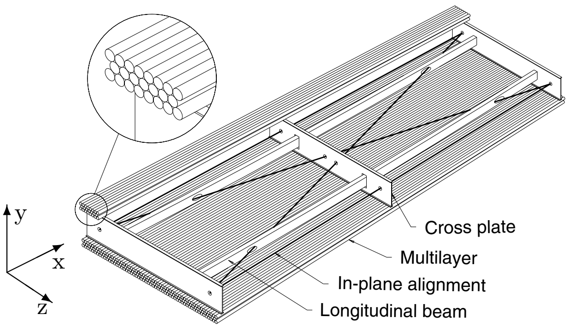

Fig. 1. Schematical picture of a barrel MDT chamber

2 Precision muon chambers

The Monitored Drift Tube chambers consist of six (in the inner detector stations of eight) drift tube layers organised in two multilayers of three (four) tube layers separated by a space frame (see Fig. 1). Incorporated in the chamber support structure is an optical measuring system consisting of four RASNIK sensors to monitor chamber deformations during the production and the operation of ATLAS. The MDT chambers have a width of 1 to 2 m and vary in length between 1 and 6 m. They are built of up to 432 drift tubes. The aluminium drift tubes have an outer diameter of 30 mm, a wall thickness of 0.4 mm and contain a gold-plated W-Re sense wire which is precisely centered in special endplugs.

The tubes are produced with an automated wiring machine and extensively tested before assembly for wire positions, high voltage stability, gas thightness and wire tension. The wires are centered within the tube with a deviation of 7 μm, as measured with X-rays. The total rejection rate is of the order of 2.6%.

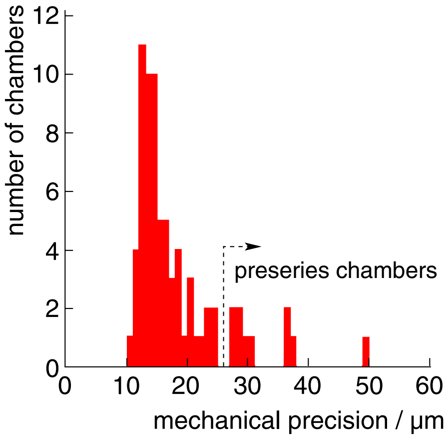

Fig. 2. Wire positioning accuracy of 74 X-rayed MDT chambers as determined by the X-ray scanning device

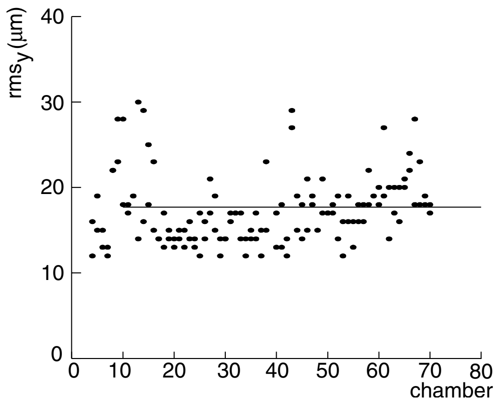

Fig. 3. `Rms` values of the residuals of the measured vertical (y) wire positions with respect to the nominal positions as a function of the chamber number for one production site [4]. The average `rms` value is indicated by the *horizontal line*

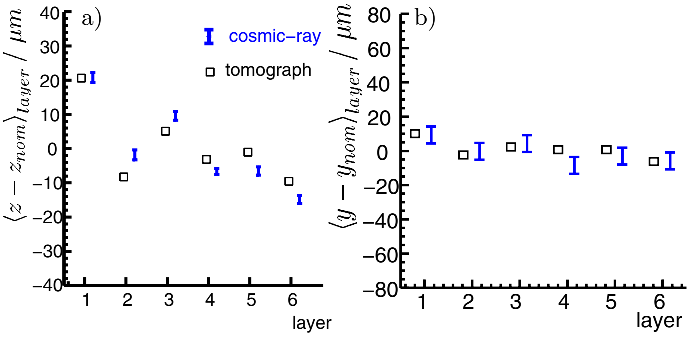

Fig. 4. Deviations of the **a** horizontal (z) and **b** vertical (y) tube layer positions from the nominal values. The results of the cosmic ray measurements are compared to the X-ray results [5]

The MDT chambers are operated with a gas mixture of Ar:CO_2 (93:7) at 3 bar pressure and at a gas gain of $2 \cdot 10^4$. The gas and operation parameters are chosen to restrict the drift time to $\sim$ 700 ns, to reduce occupancy and to prevent aging while keeping sufficient primary ionization.

The required chamber resolution of 50 μm corresponds to a single-tube resolution of about 100 μm with a wire positioning accuracy within the chamber of 20 μm.

For ATLAS the MDT chambers are produced at 13 sites in 7 countries. In July 2003, 58% of in total 1194 chambers were assembled; the production will be completed end of 2005.

3 Monitoring of the chamber precision

The MDT chambers are assembled layer by layer using a precision table with precise combs on which the drift tubes are positioned within a layer in the horizontal direction (z direction in Fig. 1) [1,2]. The tube layers are glued successively to the spacer frame. The relative vertical positioning of the tube layers (y direction in Fig. 1) is achieved by precisely positioning the spacer frame with respect to the combs on the assembly table.

The wire positioning accuracy of the chambers is measured with several methods during the production.

The first method uses an X-ray scanning device [3] developed at CERN. The chambers are scanned by two stereo X-ray beams moving transversely to the signal wires with a precise stepping motor. The wire positions are determined from the positions of the shadows in the transmitted intensity profile as a function of the X-ray beam position. The measurement accuracy is 3 μm. About 10% of all chambers will be tested with this method. The mechanical precision of 74 chambers scanned so far is shown in Fig. 2. The average measured wire positioning accuracy of 15 μm is well within the required accuracy of 20 μm.

Since only a fraction of the MDT chambers can be measured with the X-ray scanning device, the geometrical chamber parameters like distances between the tube layer and the multilayers are monitored for *all* chambers during the production with optical sensors. Combining the optical measurements with mechanical measurements of the tube positions in the tube layers and with the measured wire positions in the individual tubes, the wire positions in the chamber can be determined [4].

In Fig. 3 the `rms` values of the deviations of the reconstructed vertical wire positions from the nominal positions are shown for one chamber production site as an example [4]. The average `rms` value is 18 μm. Comparing this value with the average wire positioning accuracy of the X-ray scanning device, the monitoring precision in the vertical wire position is estimated to be 10 μm. The monitoring is incomplete for the horizontal direction. In the horizontal direction only the wire position within each tube and the relative tube layer positions are measured while the positions of the individual tubes in this direction are not monitored.

The functionality of all tubes and electronics channels in each chamber are tested in cosmic ray test stands at the production sites. By placing the test chamber in between two reference chambers which have been measured with the X-ray scanning device, the wire positions and geometrical parameters of the chamber can be determined in addition [5]. The accuracy of the reconstruction of the wire

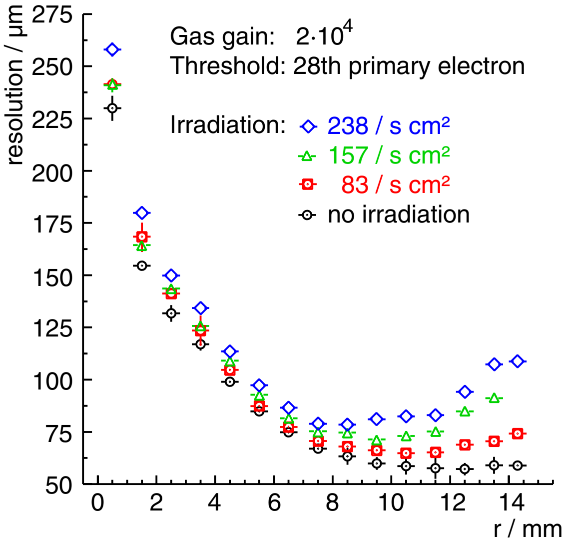

Fig. 5. Single-tube resolution as a function of the drift radius r for different irradiation rates

positions with cosmic rays is 25 μm in vertical and 9 μm in the horizontal direction as determined from the comparison to the X-ray measurement. Based on the measured wire positions, the geometrical chamber parameters can be determined with high accuracy. The individual layer positions are measured with a precision of 2 μm in z and of 4 μm in y (see Fig. 4).

4 Performance under LHC conditions

At the LHC, the ATLAS muon spectrometer will be operated under unprecedentedly high neutron and photon background. The background rates experienced by the MDT chambers range from 8 Hz/cm^2 in the outer barrel station to 100 Hz/cm^2 in the inner part of the middle end-cap station [1].

The performance of the MDT chambers under these conditions has been tested with a 3.8 m long six-layer chamber in a 100 GeV muon beam at the γ-ray irradiation facility at CERN [6]. The irratiation is provided by a 740 GBq Cs-137 source and the rate can be adjusted with filters in front of the source. A beam telescope consisting of four silicon strip detectors was used as an external reference.

Figure 5 shows the single-tube resolution as a function of the drift radius for different irradiation rates for a discriminator threshold at the 28th primary ionization electron. At low background rates an average resolution of 104 μm is measured. It is degraded by 8% at the highest background rates of 100 Hz/cm^2 expected in ATLAS and by 20% at 238 Hz/cm^2. A chamber resolution of 50 μm is maintained even at the maximum rate. The degradation of the resolution due to the background irradiation is caused by space charge fluctuations which lead to variations of the *rt*-relation, dominantly at large drift radii. Recent studies [7] show that the single-tube resolution can be improved to 82 μm at low background rates and 88 μm at 100 Hz/cm^2 by optimising the descriminator threshold and applying time slewing corrections.

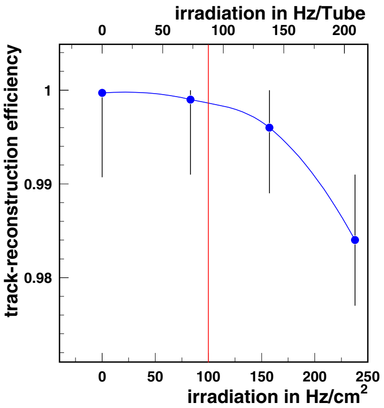

Fig. 6. Track reconstruction efficiency (at least three out of six hits) for a MDT chamber with six tube layers. The highest expected ATLAS rate of 100 Hz/cm^2 correspond for 3.8 m long tubes to a rate of 88 Hz/tube

The track reconstruction efficiency as a function of the background rate is determined by using the silicon beam telescope and presented in Fig. 6. At the highest expected irradiation rate the efficiency for finding three out of six possible hits on the track is $(99.87\,^{+0.13}_{-0.8})\%$.

5 Conclusions

The construction of the precision drift tube (MDT) chambers for the ATLAS muon spectrometer is well advanced and will be finished end of 2005. The chambers fulfill the requirements on the positioning accuracy of the sense wires as verified by several measurements during the production. A large MDT chamber has been tested under LHC background conditions. The measurements show that the required chamber resolution of 50 μm is reached and that the track reconstruction efficiency is not significantly deteriorated even at highest expected irradiation rates.

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