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The First Precision Drift Tube Chambers for the ATLAS Muon Spectrometer ⋆

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Abstract

The muon spectrometer of the ATLAS detector for the Large Hadron Collider is designed to provide a muon transverse momentum resolution of $2-10\%$ for momenta between 6 GeV and 1 TeV over a pseudo-rapidity range of $|\eta| \leq 2.7$. This required the development of precision drift chambers with a track position resolution of 40 μm, the Monitored Drift Tube (MDT) chambers. We report about the construction of the three main types of MDT chambers for ATLAS, test results and the first production experience.

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The Monitored Drift Tube (MDT) chambers for the ATLAS muon spectrometer [1] consist of 3 or 4 layers of precision aluminum drift tubes with 29.970 ± 0.015 mm outer diameter and 400 μm wall thickness on either side of a space frame consisting of two longitudinal beams and three cross plates (see Fig. 1). Optical measurement systems integrated in the space frame monitor the planarity of the chamber. The drift tubes are operated at a gas pressure of 3 bar to provide a single-tube position resolution of at least 80 μm with an Ar:CO_2 (93:7) gas mixture at the low gas gain of 2×10^4 required to prevent ageing of the drift tubes at the high background rates at the LHC. The sense wires of the drift tubes have to be positioned in the chamber with an accuracy of 20 μm (rms).

In total 1200 MDT chambers containing 400000 drift tubes of 0.9–6.2 m length and covering a total active area of 5500 m^2 have to be constructed for the ATLAS muon spectrometer at 13 production sites over a period of 4 years. We report about the construction of the three main types of MDT chambers in the ATLAS detector at the sites where the serial production has already started.

In Munich, 88 rectangular 6-layer chambers of up to 2.16 m width with in total 36000 drift tubes of 3.8 m length (see Fig. 1) are being built for installation at the outer circumference of the barrel part of the muon spectrometer (type 'BOS'). The drift tubes for these chambers are assembled and tested in a common facility at the Joint Institute for Nuclear Research in Dubna, Russia. For the innermost layer of the barrel spectrometer with the highest background rate, 128 rectangular 8-layer chambers of about 1 m width with in total 30000 drift tubes of 1.7 m length (type 'BIS') are under construction in Thessaloniki in collaboration with groups at the University and the National Technical University of Athens where the drift tubes are assembled and tested. At the University of Michigan, 80 trapezoidal 6-layer chambers with in total 38000 drift tubes of varying lengths of up to 5.8 m have to be built for the endcap part of the muon spectrometer.

The construction of a MDT chamber proceeds in two major steps, the fabrication of the drift tubes and the precise assembly of the tubes in the chamber. In order to position the sense wires at the drift tube ends with the required accuracy of 10 μm (rms) an endplug with precisely machined reference surfaces has been developed (see Fig. 2). The wire is located in a spiral hole, concentric with an outer aluminum reference ring, enabling automated wire insertion. The insulating plastic (Noryl) body of the endplug is injection moulded in a carefully optimized process in order to prevent the development of cracks and gas leaks over time. After drift tube assembly, the wire positioning accuracy was measured to be 7 μm (rms) using stereo X-ray or electronic pickup methods. The drift tubes have to pass stringent quality control tests including measurements of the wire position, gas leak rate, wire tension and high voltage leakage current. The drift tube rejection rate at the start of the serial production is below 2%.

For the assembly of a MDT chamber, the drift tubes for each layer are positioned on precision aluminum combs on a flat granite table in a temperature and humidity-controlled clean room (see Figs. 3 and 4). The positioning accuracy of the aluminum reference rings of the endplugs is better than 5 μm (rms) as verified by regular measurements of the endplug heights on the combs with a mechanical feeler gauge during assembly (see Fig. 5).

In the case of the BOS MDT chambers, the tube layers are then glued successively to both sides of the space frame which for this purpose is positioned with respect to the combs on precision towers at the ends of each cross plate with an accuracy of ± 5 μm in horizontal and in vertical direction (see Fig. 3). The gravitational deformations of the cross plates during assembly of up to 100 μm are compensated by 8 computer-controlled pneumatic pistons acting on the longitudinal beams. During glue curing, the tubes are held on the combs by vacuum suction.

For space reasons, the two quadruple layers of the BIS MDT chambers are separated by an only 6 mm wide gap while the space frames of the endcap MDT chambers are designed for vertical installation of the chambers and show much larger gravitational deformations during assembly than in the case of the barrel chambers. In these cases, the tube layers are temporarily attached to a stiff auxiliary frame for glueing them to each other (see Fig. 4). The space frame is inserted between the two triple-layers of the endcap chambers in a final assembly step (see Fig. 4).

The wire positions in the first BIS and the first BOS chamber have been measured at CERN in summer 2000 by scanning them perpendicular to the wires with stereo X-ray sources [2]. The wire positioning accuracy was found to be 11 μm (rms) for the BIS chamber and 14 μm (rms) for the BOS chamber (see Fig. 6) which is well within the required 20 μm (rms). Similar results have been obtained in the meantime for the first chambers of several other production sites as well. With allowed variations in the wire tension and therefore in the wire sag of only 2% (rms), the wire positions in between the chamber ends are determined even more precisely.

In the barrel chambers, the gravitational sag of the tube layers is adjusted by screws between the longitudinal beams and the middle cross plate such that it matches the sag of the wires for each chamber orientation. For most of the vertically installed endcap chambers, the tube curvature would have to be built in during glueing of the tube layers. With the aim to avoid this complication, detailed studies are in progress to determine the effect of wire displacement from the drift tube center by up to 480 μm for the longest tubes on the operation and resolution of the endcap chambers. Simulations show only minor degradation of the average momentum resolution of the endcap muon spectrometer.

The first demonstration that the required mechanical precision can be achieved with methods suitable for serial production was performed with the construction of a full-scale BOS prototype chamber at the Max-Planck-Institut [3] and with the subsequent X-ray measurement at CERN in 1998 [2]. The chamber resolution under the nominal operating conditions was demonstrated with the prototype chamber in a 300 GeV muon beam at CERN in 1999. Using a silicon strip detector beam telescope as external reference, the space to drift-time relationship and the position resolution as a function of the drift distance were determined for individual drift tubes. The average single-tube resolution at the modest interaction rates in the test beam is 70 μm (rms). Applying this r-t-relationship to all drift tubes in the 1×1 m^2 wide trigger area, the relative wire positions in the chamber plane could be determined using tracking information in each of the triple layers. This measurement and the X-ray measurement of the wire coordinates agree within 10 μm (rms).

At almost all of the 13 construction sites the first MDT chamber has been assembled. The serial production of chambers for ATLAS has started in Munich (3 chambers completed), in Thessaloniki (10 chambers completed) and at the University of Michigan (7 chambers completed) together with the two other production sites in the United States. The optimization of the serial production is now in progress. In order to be ready for installation in the ATLAS detector in 2004 an MDT chamber has to be completed and tested within less than 2 weeks at most of the production sites.

Acknowledgements

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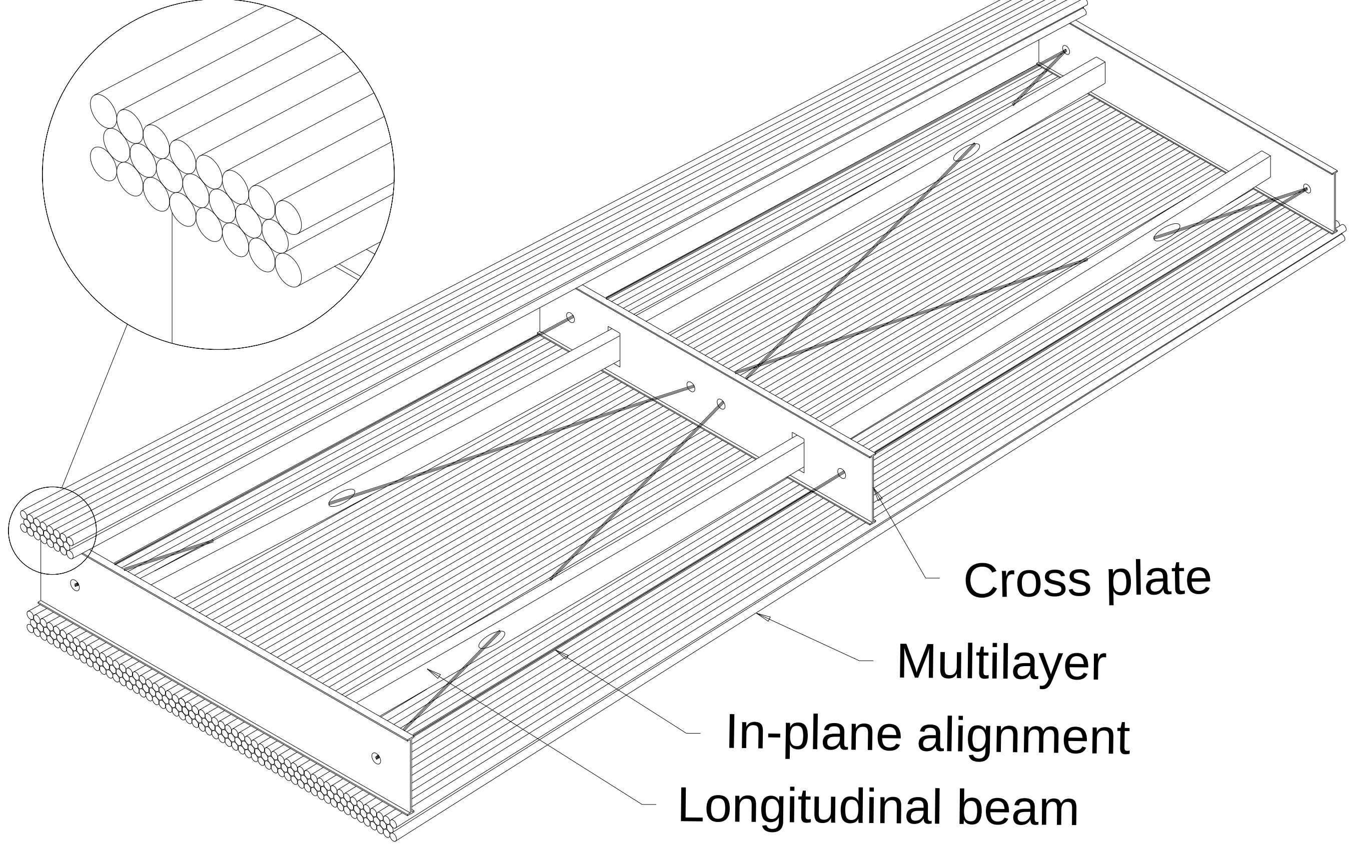

Fig. 1. MDT chamber for the ATLAS muon spectrometer.

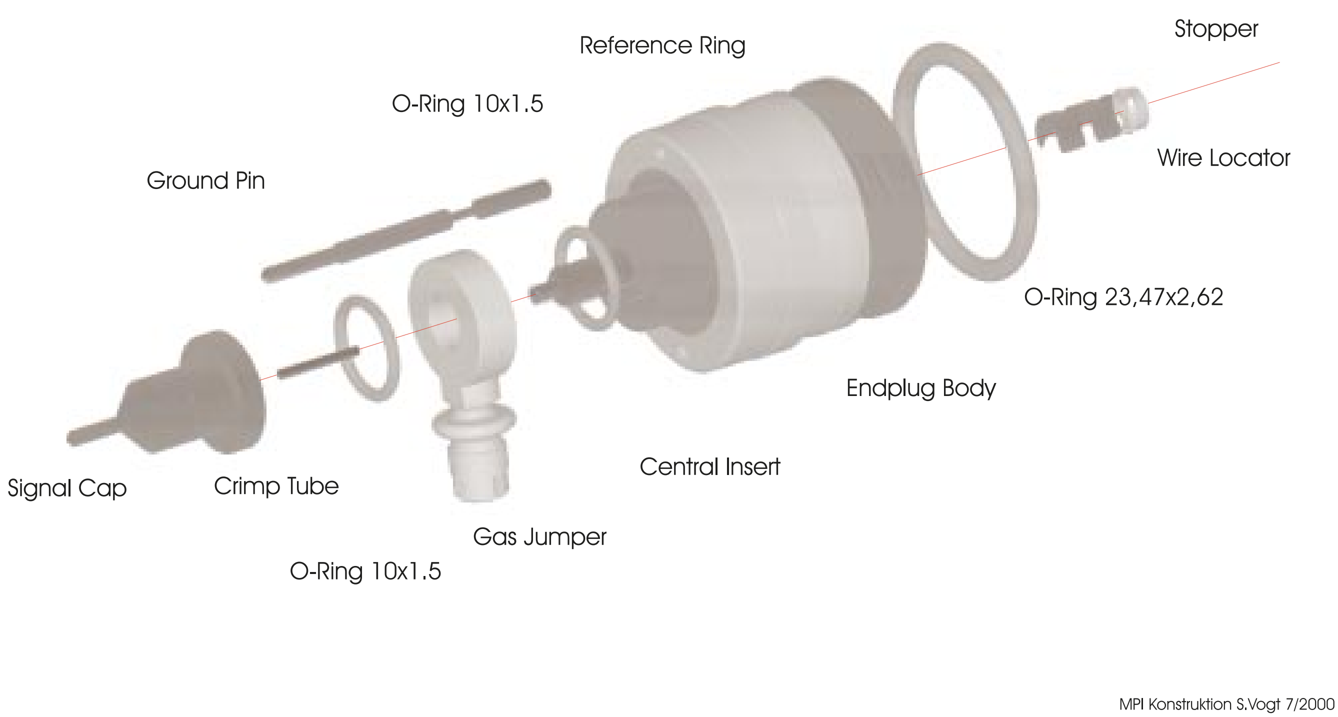

Fig. 2. Exploded view of the endplug for the MDT drift tubes providing precise wire positioning.

Fig. 3. Assembly facility for BOS MDT chambers with the first chamber under construction.

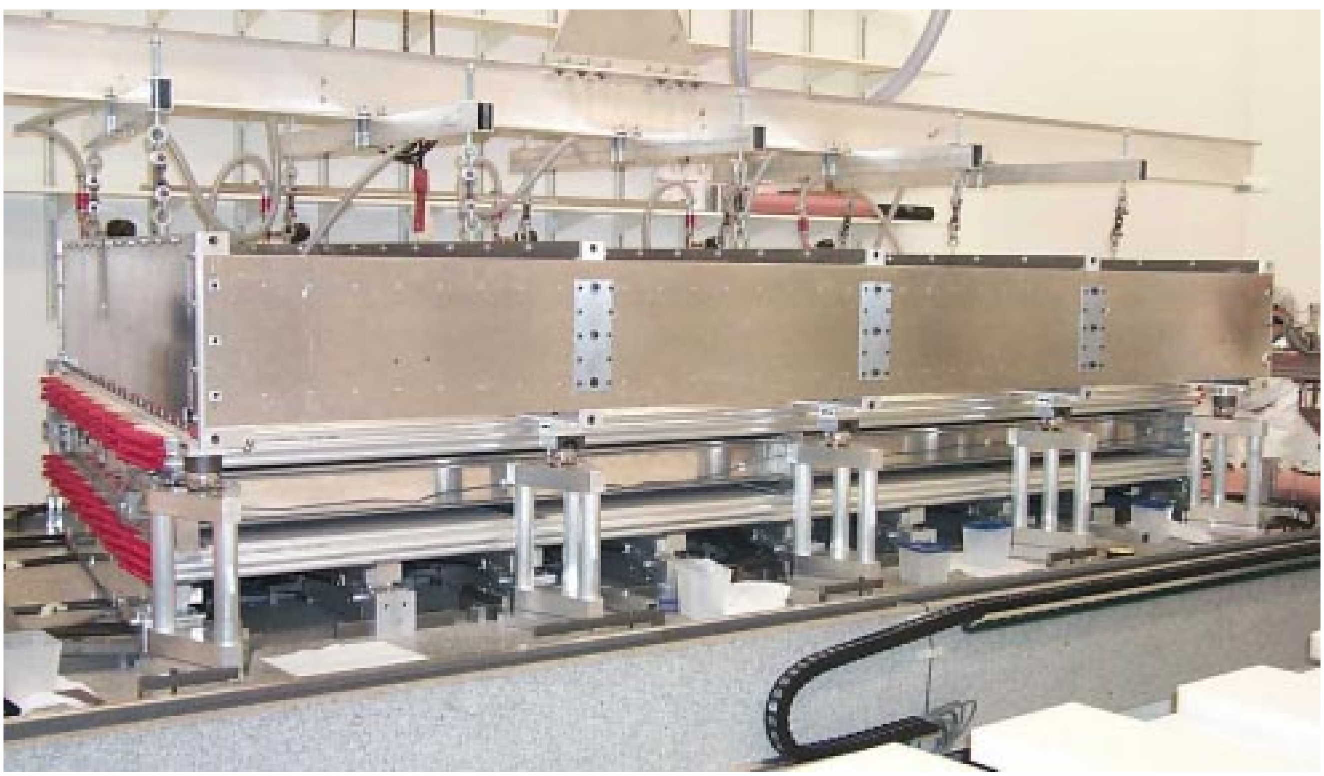

Fig. 4. Assembly table for endcap MDT chambers with the stiff auxiliary frame.

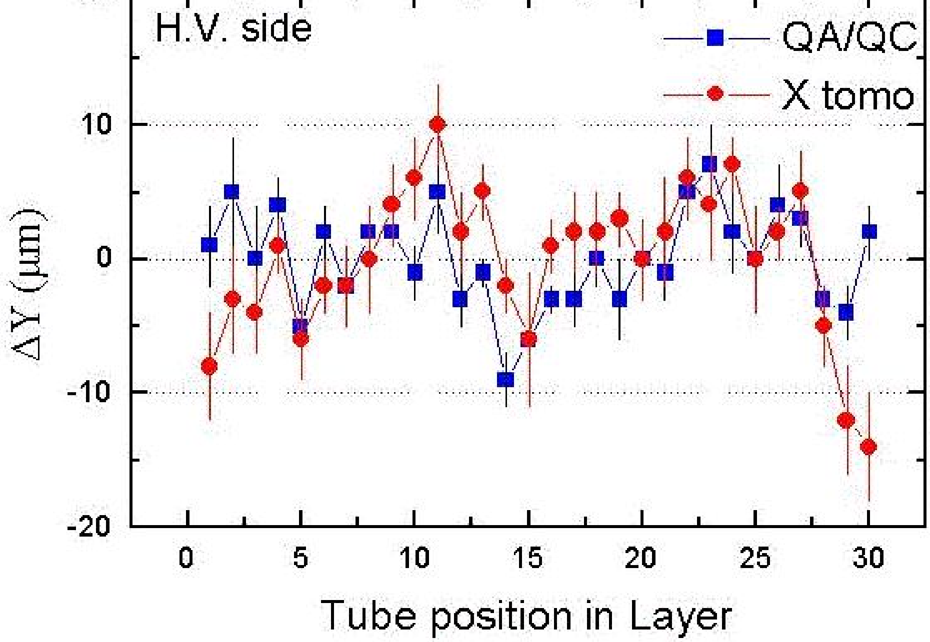

Fig. 5. Correlation between the endplug height measurements during assembly of a BIS MDT chamber (QA/QC) and the vertical wire coordinate (y) measured with X-rays (X-tomo) after averaging over the 8 layers.

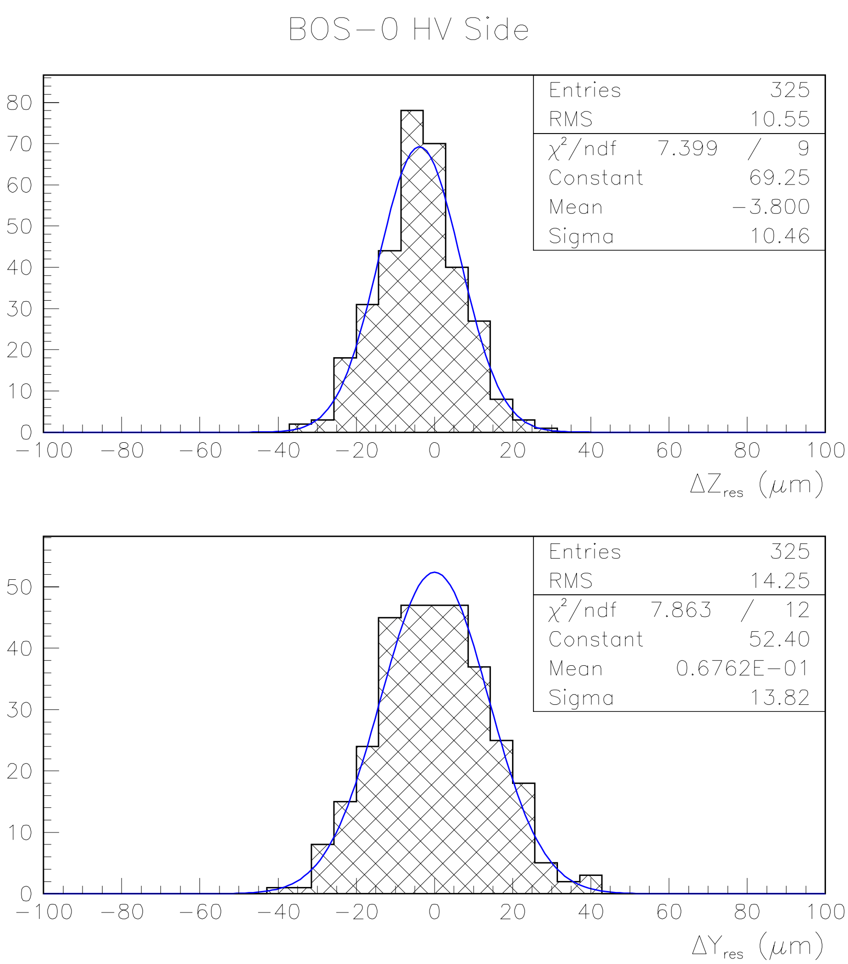

Fig. 6. Residuals of the wire coordinates measured with X-rays with respect to the ideal wire grid for the high-voltage end of the first BOS MDT chamber (z: parallel, y: perpendicular to the tube layers).