Construction and Performance of the Precision Tracking Chambers for the ATLAS Muon Spectrometer Upgrade for High-Luminosity LHC

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Abstract

For the operation at HL-LHC, the MDT chambers of the inner barrel layer (BIS) of the ATLAS muon spectrometer will be replaced by small-diameter Muon Drift Tube (sMDT) chambers which will be integrated with triplets of thin-gap RPC chambers in order to improve the acceptance and robustness of the barrel muon trigger system. The sMDT chambers have half the drift tube diameter of the MDT chambers and about one order of magnitude higher background rate capability. The construction of the 96 new sMDT chambers was performed between January 2021 and September 2023 at two production sites at a continuous rate of one chamber every two weeks. The sense wire positioning accuracy guaranteed by precision assembly jigs was measured to be around 5 μm over the whole construction period. Stringent performance tests had to be passed during the production which have been successfully repeated after delivery of the chambers to CERN. The chambers have been tested with the new MDT front-end ASICs developed for operation at HL-LHC which improve the spatial resolution of the drift tubes by 10 % compared to readout with the legacy electronics.

Keywords: Muon chambers, ATLAS detector, small-diameter MDT chambers

1. Introduction

During the third long shutdown of the LHC between 2026–2029, 96 new precision muon tracking detectors in combination with new trigger chambers will be installed on the toroid magnet coils in the barrel inner layer (BIS) of the ATLAS muon spectrometer [1]. These new detector components are an integral part of the ATLAS upgrade for the conditions of the High-Luminosity (HL) LHC where luminosities five times higher than during the current run are expected. The goal is to improve the trigger acceptance, efficiency and selectivity at these extreme collision rates. The precision tracking chambers were constructed between January 2021 and September 2023 at two production sites, the MPI in Munich and MSU/UM in Michigan.

The new small-diameter muon drift tube (sMDT) precision tracking chambers consist of drift tubes with a diameter 15 mm which is half of the tube diameter of the MDT chambers that they are replacing. This leads to multiple advantages [2]. Firstly, additional space is available to accommodate Resistive Plate (RPC) trigger chambers also in the BIS region. Secondly, a smaller diameter causes lower maximum drift times and less tube cross-section exposed to background radiation which in total reduces the occupancy by a factor of 8. Another remarkable advantage of the sMDT drift tubes is the endplug design. The endplugs contain a brass insert (surrounded by an insulator) holding a spiral wire locator (see figure 1). This ensures the wire position is known relative to an external reference surface with a precision of 1 μm.

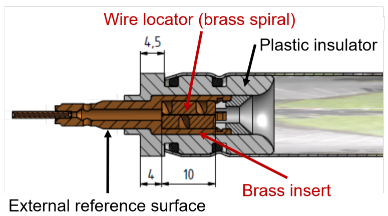

Figure 1: Endplug design of sMDT drift tubes.

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2. Chamber Construction

Aluminium assembly combs with precise boreholes and a horizontal layer structure are used to position the reference surfaces of the drift tube endplugs on both sides of the chamber and consequently define the positions of the sense wires. The positions of the boreholes were measured with a coordinate measuring machine (CMM) and fitted to an ideal grid. The accuracy of the position of the boreholes was determined to be 3 μm for the high-voltage (HV) and 4 μm for the readout (RO) side comb.

8 layers of drift tubes are glued layer by layer using an automated glue dispenser within 7 work days. Another 2 days is spent gluing and testing the support structures and alignment platforms. The platforms are an essential part of the optical alignment system connecting the precision chambers to other sectors of the ATLAS detector. After completion of all mechanical quality assurance tests (see section 3.1), the gas system is installed and tested, usually during one week. Finally, the electronics are installed and the chambers are certified by measuring cosmic muons (see section 3.2).

3. Quality Control

Any measurements done to assure the quality of the sMDT chambers during construction were recorded in a dedicated database with web-frontend, common to both production sites.

3.1. Wire Positioning

The CMM is used to measure the vertical (y) and horizontal (z) position of every drift tube on both sides of the chamber. The wire radial position is then defined as $r = \sqrt{y^2 + z^2}$. By comparing the measured wire positions to an ideal wire grid fitted to the chamber parameters, a residual in r can be derived. For a whole chamber, the residuals of its single drift tubes are distributed according to a gaussian distribution. The standard deviation of this residual distribution is used as a measure of the wire positioning accuracy (see figure 3). The measured production average is 4.8 μm (5.5 μm) on the HV (RO) side. This is significantly better than the required ATLAS precision of 20 μm. It matches almost the assembly comb borehole precision, proving the reliability of the sMDT endplug design.

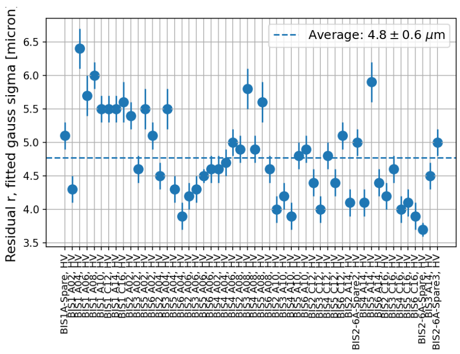

Figure 2: Wire positioning accuracy on the HV side over the course of the whole production campaign at MPI.

3.2. Chamber Performance

The spatial resolution of the drift tubes of a chamber is determined by measuring for cosmic muons over a time period of 24 h at a threshold corresponding to 31 primary ionising electrons (p.e.). The resolution is measured by comparing the drift radii of single drift tube measurements to the expected drift radii from the reconstructed track associated with the same hit. Corrections considering the multiple coulomb scattering of low energy cosmic muons are applied. These dominate the uncertainty (10 μm) on the measured resolution. The single tube resolution for all tested chambers is shown in figure 3. An average single tube resolution over all chambers of 0.119 ± 0.002 mm without time walk corrections is determined. These results were reproduced after shipping the chambers to CERN and repeating the measurements. Performance tests at the production site in Michigan and testbeam measurements with high-energetic muon beams were performed with time walk corrections applied. As can be seen in figure 4 and from the testbeam results in figure 3, the spatial resolution can be improved by over ≈ 0.2 mm with the corrections taken into account. The testbeam results in particular give a precise estimate as multiple scattering uncertainties can be neglected.

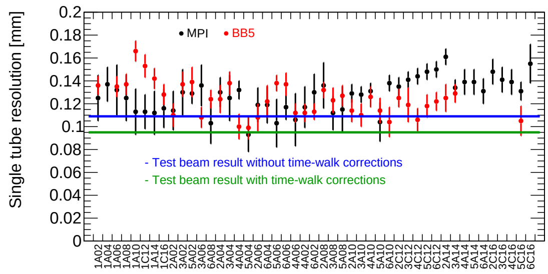

Figure 3: Single tube resolution as a measure of the sMDT chamber performance. Results achieved at the MPI were reproduced at CERN hall BB5.

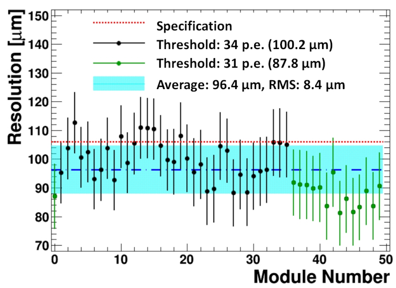

Figure 4: Single tube resolution as a measure of the sMDT chamber performance. Results from the UM production site, time walk corrections are applied.

References

[1] ATLAS Collaboration, ATLAS Muon Spectrometer Phase-II Upgrade: Technical Design Report, 2017. URL: `https://cds.cern.ch/record/2285580`.

[2] H. Kroha, R. Fakhrutdinov, A. Kozhin, New High-Precision Drift-Tube Detectors for the ATLAS Muon Spectrometer, Journal of Instr. 12 (2017) C06007.