Upgrades of the ATLAS Muon Spectrometer with New Small-Diameter Drift Tube Chambers


Max-Planck-Institute for Physics, Munich, Germany
Institute for High Energy Physics, Protvino, Russia

Abstract
Small diameter muon drift-tube (sMDT) chambers with 15 mm tube diameter provide excellent spatial resolution like the MDT chambers with 30 mm tube diameter used in the ATLAS muon spectrometer so far, but can be operated at ten times higher background rates and allow for the instrumentation of regions where MDT chambers do not fit in. In April 2014 two BME and in January 2016 another 12 BMG sMDT chambers have been installed in the middle layer of the barrel muon detector and are operational since then in order to increase the acceptance for precision muon momentum measurement using three chamber layers. An unprecedentedly high sense wire positioning accuracy of 5 \( \mu \)m (rms) has been achieved. In the next long LHC shutdown 2019-2020, 16 BIS 78 sMDT chambers will be installed in the barrel inner layer in the transition region to inner endcap layer to make room for the installation of new RPC muon trigger chambers in order to reduce the accidental trigger rate in this region as required for operation at HL-LHC. This is a pilot project for the complete replacement of the MDT chambers in the small sectors of the barrel inner layer by integrated sMDT-RPC detectors (BIS 1-6) in the ATLAS upgrade for HL-LHC.

Keywords: Muon precision tracking, ATLAS detector, drift-tube detectors, MDT chambers, sMDT chambers

PACS: 29.40.Cs, 29.40.Gx

Figure 1: Overview of the sMDT chambers in the ATLAS muon spectrometer.

1. The sMDT Chambers in ATLAS

An overview of the small-diameter drift tube (sMDT) chambers contructed for the ATLAS muon spectrometer is given in Figure 1. The first sMDT chambers [1] have been installed in April 2014 in the barrel middle layer in the access shafts to the calorimeters at the bottom of the detector (BME chambers), followed in January 2016 by the installation of 12 BMG sMDT chambers in gaps inside the detector feet in the bottom sectors of the barrel middle layer. Both the BME and the BMG chambers improve the muon momentum resolution by a factor of two by allowing for three-point track curvature measurement within their geometrical acceptance. Currently 16 BIS 78 sMDT chambers are under construction for installation at the ends of the toroid coils in small sectors of the barrel inner layer in the long LHC shutdown 2019-2020. The chambers will replace the present BIS 7 and BIS 8 MDT chambers to make space for new thin-gap RPC trigger chambers which will significantly reduce the accidental muon trigger rate in the transition region 1.0 < |\( \eta \) | < 1.3 between barrel and endcap at HL-LHC. In the ATLAS high-luminosity upgrade 2025-2026, the remaining MDT chambers in the small sectors of the barrel inner layer (BIS 1-6) will be replaced by integrated sMDT-RPC chambers of the same type as the new BIS 78 chambers in order to improve the muon trigger coverage and efficiency in the barrel at the High-Luminosity LHC (HL-LHC) [2].

2. sMDT Chamber Design and Construction

Small-diameter muon drift tube (sMDT) chambers with a tube diameter of 15 mm, i.e. half the diameter of the MDT tubes, have been developed to cope with the higher background irradiation rates at High-Luminosity LHC (HL-LHC) and future hadron colliders and to fit into the small available spaces available for the upgrades of the ATLAS muon spectrometer.
Design and assembly procedures optimized for mass production.
- Simple, low-cost drift tube design ensuring high reliability.
- Industry-standard aluminum tubes (0.4 mm wall thickness).
- Sense wire position defined by metal insert alone with high accuracy.
- Injection molded endplug and modular gas connector materials selected to prevent outgassing and cracking.
- No aging observed up to 9 C/cm charge accumulated on the wire (MDT requirement: 0.6 C/cm).

They have an order of magnitude higher rate capability than the MDT chambers [1].

At the same time, the drift tube design and the chamber assembly methods have been optimised for mass production leading to significant savings in cost, construction time and manpower compared to the ATLAS MDT chambers while providing even higher sense wire positioning accuracy. A record sense wire positioning accuracy of better than 5 μm (rms) has been achieved for the BMG chambers with about 350 drift tubes of 1.12 m length [1]. The wire positioning accuracy of the large BIS 78 chambers with up to 744 drift tubes of 1.66 m length is better than 10 μm (rms). The required positioning accuracy is 20 μm. The wire positions at the tube ends are measured with few micron precision with a coordinate measuring machine (CMM) for the BMG chambers (see Figure 2) and with a feeler gauge on a flat granite table for the BIS 78 chambers. The chambers carry several optical monitoring systems for deformation measurements and global alignment which are mounted with high accuracy with respect to the wires during chamber assembly and are measured with 10 μm precision with the CMM or with feeler gauges, respectively.

The complex chamber shapes required for the ATLAS upgrades can only be realised with the specific sMDT drift tube design and assembly procedure (see Figures 3 and 4). Standard aluminium tubes with 0.4 mm wall thickness are used. The sMDT chambers are operated with the same Ar:CO₂ (93:7) gas mixture at 3 bar and the same gas gain of 20000 as the MDT chambers. Assembled BIS 78 sMDT chambers are shown in Figure 5. Dedicated stacked readout electronics boards have been developed for the sMDT chambers which carry the same ASD and TDC chips as the MDT chambers (see Figure 6).

References