Construction and testing of the sMDT system for the HL-LHC ATLAS muon detector upgrade

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Abstract

The ATLAS HL-LHC upgrade includes an upgrade to the Muon Spectrometer in which the Monitored Drift Tube (MDT) chambers in the barrel inner small-sectors are replaced with new small-diameter MDT (sMDT) chambers. The sMDT chambers will make space for a new triple-layer of Resistive Plate Chambers (RPCs) to improve the Level-1 muon triggering. There are 96 new sMDT chambers for this upgrade which are under construction at the Max Planck Institute Munich (MPI) and the University of Michigan. This document reports the construction and testing of the sMDT chambers at both production sites. Through stringent measurements on mechanical precision, noise rate, efficiency, and tracking resolution, all chambers produced so far satisfy the precision and performance requirements.

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1. Introduction

The University of Michigan and the Max Planck Institute Munich (MPI) are constructing sMDT chambers as part of the ATLAS [1] Muon Spectrometer [2] High-luminosity LHC (HL-LHC) upgrade [3, 4]. The chambers were designed by MPI [5]. Each chamber has 8 layers and either 70 tubes (type 1) or 58 tubes (types 2-6) per layer. The 8 layers are assembled into two "multilayers" of 4 layers each, with a spacer-frame in between the two multilayers. Inside the spacer-frame is an in-plane alignment optical system to measure chamber deformation in real time. A total of 96 chambers (48 at each construction site) with a total of 46,080 drift tubes must be constructed for the HL-LHC upgrade. Results shown in this paper are based on 60 sMDT chambers built so far at both sites.

2. Drift tube construction and testing

Table 1: Specifications of the sMDT drift tubes [5].

Parameter	Value
Outer diameter	7.5 mm
Inner diameter	7.1 mm
Tube length	1.6245 m
W-Rh wires diameter	50 μm
Wire potential	2730 V
Gas mixture	93:7 (Ar:CO_2)
Gas pressure (absolute)	3 bar

Drift tubes are constructed at MPI and at Michigan State University. Table 1 summarizes the properties of the drift tubes for sMDT detectors. The tube is made of aluminum and the wire is a gold-plated tungsten-rhenium alloy. A more complete discussion of the sMDT design can be found in Ref. [5]. Each drift tube is tested for wire tension ($335\text{g} < T < 370\text{g}$), gas leaks (rate $< 10^{-5}\ mbar \times l/s$), and dark current (< 2nA / tube). The average failure rate of tube tests is less than 3%. Each tube is tested twice with a minimum of two weeks apart to ensure that the wire tension is not slipping over time. The final measured wire tension is 357±6g on average.

3. Chamber construction and mechanical precision

Chamber construction is performed on a granite table precision surface. The horizontal wire pitch, 15.1 mm, is well constrained by the jigging with an accuracy of 5 microns. The nominal tube-layer spacing is 13.077 mm; however, the height of each layer, and of individual tubes within that layer, can vary slightly. Each tube height is measured on granite after the chamber construction. The mechanical precision better than 15 μm RMS of the target is achieved for all the chambers produced at both MPI and Michigan construction sites. For RMS y-pitch measurements from 60 sMDT chambers, see Figure 1.

4. Noise rate testing

For each chamber we perform a noise rate test to characterize the detector performance. The noise rate is calculated with threshold voltage settings between 19 and 39 mV, with both the high-voltage (HV) on and off. All noise rate measurements use a random 10 kHz software trigger. For results with the nominal 39 mV threshold, see Figure 2. Only one chamber exceeds the design specification of 500 Hz/tube (Michigan chamber 4), but this is simply due to high noise on a single tube.

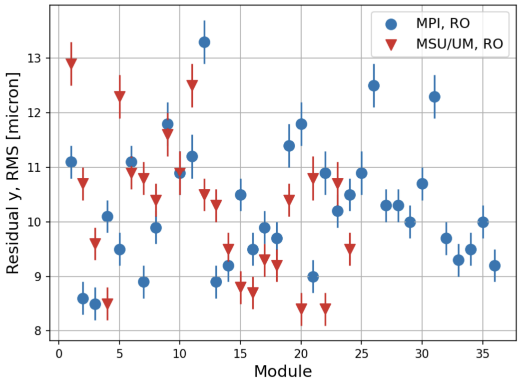

Figure 1: RMS layer spacing residuals for 60 sMDT chambers. The x axis is the sector and number of the chamber, with more recently constructed chambers on the right. All chambers are constructed with precision better than 15 µm RMS for the y spacing of the layers.

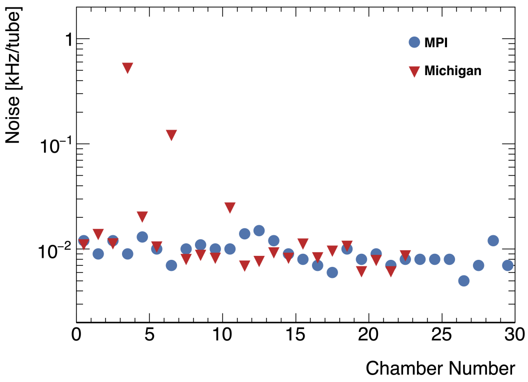

Figure 2: Noise results for 53 chambers constructed at MPI and Michigan using the nominal threshold (39 mV). The x axis is the chamber number, with more recently constructed chambers to the right. A single chamber at Michigan is above the target noise threshold (500 Hz/tube), but this is driven by a single tube with extremely high noise.

5. Cosmic-ray tests

Each chamber is tested for resolution and efficiency using a data sample collected on cosmic-rays. A full discussion of the procedure can be found in Ref. [6]. In this note we will summarize new results collected.

The observed (expected) median single-hit spatial resolution is 102.9±8.1 (106) µm, from 19 chambers tested at the University of Michigan. The observed sMDT resolution as a function of radial hit position agrees with the ATLAS Run 2 MDT result [7], as expected. The results for resolution include a correction for multiple Coulomb scattering of cosmic-rays [6], estimated in Geant4 [8].

The efficiency of each tube is calculated from the cosmic-ray test. The efficiency is defined to be the fraction of a time that a tube has a hit, given that a track was reconstructed to be within the inner radius of that tube (7.1 mm or less from the wire). Note that this definition of efficiency leaves out any geometric acceptance, and while a tube is on average about 99% efficient within its gas volume, some cosmic-rays will pass between the fiducial volumes of neighboring tubes.

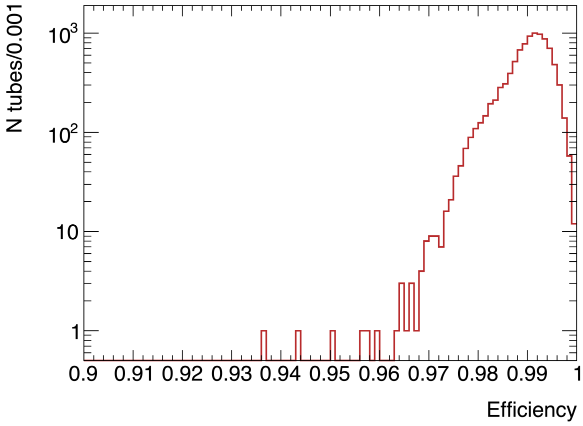

Figure 3: Efficiency of 19 sMDT chambers (9584 tubes) from the University of Michigan production site. 7 tubes have a wire removed for various problems from early production, including wires slipping due to poor tension. These tubes have an efficiency of 0 and are the only tubes not shown on this plot.

In Figure 3 we report the efficiency results for 9584 tubes installed in 19 chambers from the Michigan production site. 7 tubes have wires removed for various defects, including wire slippage, which was a problem in early production of chambers but has been resolved. The observed mean and mode tube efficiencies are both above 99%.

6. Conclusions

The HL-LHC upgrade of the ATLAS Muon Spectrometer requires the construction of 96 precision sMDT chambers containing 46,080 drift tubes. Quality control tests including tension, dark current, gas leak for individual tubes and mechanical precision, noise, efficiency, and tracking resolution for whole chambers demonstrate that the chambers built so far for the upgrade are within the specifications.

References

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