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# Design and Construction of Integrated Small-Diameter Drift Tube and Thin-Gap Resistive Plate Chambers for the Phase-1 Upgrade of the ATLAS Muon Spectrometer

H. Kroha on behalf of the ATLAS collaboration[a,*]

[a] *Max-Planck-Institute for Physics, Munich, Germany*

**Abstract**

In the long shutdown for the Phase-1 upgrade of the Large Hadron Collider (LHC) in 2019-2020, 16 new integrated muon tracking and trigger chambers will be installed at the ends of the toroid magnet coils in the small azimuthal sectors of the inner barrel layer (BIS) of the ATLAS muon spectrometer in order to improve the trigger selectivity and fake trigger suppression in the transition region $1.0 < |\eta| < 1.3$ between the barrel part and the endcaps. The new muon detectors consist of a small-diameter muon drift tube (sMDT) precision tracking chamber with 15 mm tube diameter and a pair of thin-gap RPC chambers with 1 mm gas gap width. The new integrated chamber modules (labelled BIS 78) are currently under construction and will replace the present BIS 7 and 8 MDT tracking chambers with 30 mm diameter drift tubes. The project is the pilot phase for the complete replacement of the small barrel inner layer MDT chambers with the new integrated tracking and trigger detectors in the ATLAS Phase-2 upgrade in 2024-2026 in order to increase the barrel first-level muon trigger coverage and efficiency at the high luminosities at HL-LHC. The sMDT chambers have been chosen to make room for the new trigger chambers and because of their eight times higher rate capability than MDT chambers. The new thin-gap RPC chambers have about 15 times lower avalanche charges and correspondingly increased lifetime and rate capability at HL-LHC and will be operated in coincidence with the endcap trigger chambers. They consist of a triplet of gas gaps which has to be very thin as well and which is supported by a light-weight aluminum structure which is interleaved with the sMDT chamber supports.

*Keywords:* Muon chambers, ATLAS detector, small-diameter MDT chambers, thin-gap RPC chambers
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## 1. Chamber Layout and Design

In the 2019-2020 shutdown of the LHC, 16 new integrated muon tracking and trigger chambers will be installed at the ends of the toroid magnet coils in the small sectors of the barrel inner layer (BIS) of the ATLAS muon spectrometer. This upgrade will significantly improve the trigger selectivity and fake trigger suppression in the transition region $1.0 < |\eta| < 1.3$ between the barrel and endcaps (see Fig. 1).

The new BIS 78 chambers have to fit into a very confined space between the barrel toroid magnet of the ATLAS muon spectrometer and the calorimeter and overlap with the inner wheels of the endcap muon spectrometer. Therefore, the thickness of the chambers and also the lateral dimensions and services are tightly constrained. In order to make space for the new triplet RPC trigger chambers, which must not exceed 60 mm thickness for the BIS 7 and 50 mm for the BIS 8 part including the support frames, the present BIS 7 and 8 MDT chambers with 30 mm diameter drift tubes will be replaced by single small-diameter muon drift tube (sMDT) chambers [1] with 15 mm tube diameter which have been developed for this purpose. Another advantage of the sMDT chambers is their 8 times higher rate capability compared to the MDT chambers. MDT and sMDT chambers are operated with Ar:$CO_2$ (93:7) gas at 3 bar. The integrated chambers (see Figure 2) have a height of 249 mm including the rail supports. Because of the overlap with the inner endcap wheels, The sMDT chambers have complex shapes, which vary between the azimuthal barrel sectors, because of the overlap with the inner endcap wheels. These mechanically complex chambers can only be assembled with

*Corresponding author
*Email address:* kroha@mppmu.mpg.de (H. Kroha on behalf of the ATLAS collaboration)

the required high sense wire positioning accuracy of better than 20 $\mu$m by using the assembly method newly developed for the sMDT chambers. The BIS 78 chambers contain either 648 or 744 drift tubes.

The new trigger detectors, also used for the Phase-2 upgrade, are thin-gap RPC chambers with 1 mm gas gap compared to the 2 mm of the existing ATLAS RPC chambers and with high-pressure phenolic laminate (HPL) electrodes of only 1.2 mm thickness [2]. With the smaller gas gap thickness and new highly sensitive preamplifiers, the operating voltage can be reduced from 9.6 to 5.8 kV and the avalanche charge decreased by a factor of about 15 increasing the lifetime proportionally. by the same factor, allowing for more than 10 years of operation at HL-LHC using the same gas as the current RPCs. The rate capability reaches 10 kHz/cm$^2$. The highest background rates expected in the BIS layer at HL-LHC are 600 Hz/cm$^2$. The BIS 78 trigger chambers consist of a triplet of gas gaps. Like the present ATLAS RPC chambers, they are operated with a $C_2H_2F_4$:i-$C_4H_10$:$SF_6$ (94.7:5:0.3) gas mixture. Readout panels with orthogonal strip electrodes for $\eta$ and $\phi$ coordinate measurement are attached to opposite sides of each gas gap. Each readout panel consists of a PCB with copper strips pointing towards the gas gap and a PCB with continuous copper ground plane serving as part of the Faraday cage on the other side of a 3 mm thick dielectric layer with refractive index n ≈ 1.2. A gas gap with its two readout panels has a thickness of 11.7 ± 0.7 mm. Three such singlets are stacked inside an light-weight aluminum support frame of 60 mm height. The detector components are held together by 2 mm thick prebent aluminum sheets which keep the detector deformations within the 60 mm envelope and distribute the forces uniformly. The total weight of the RPC triplet is about 50 kg.

## 2. Chamber Construction and Test

Four of the 16 BIS 78 sMDT chambers have already been assembled (see Figure 3). They carry optical sensors for monitoring of deformations and for global alignment in the barrel on the rail support side oriented towards the toroid coils and new optical alignment systems connecting them to the endcap wheels on the opposite surface pointing to the RPC. The sensor mounting platforms are glued to the outer tube layers on the assembly jig with typically 100 $\mu$m precision with respect to the sense wires. Afterwards, the platform positions are measured with 10 $\mu$m precision with feeler gauges. The wire grid at both chamber ends is measured with feeler gauges on a flat granite table determining also gravitational sag and torsion around the tube axis. The mechanical wire position measurement makes use of precisely machined reference surfaces on the metal inserts of the injection molded plastic endplugs of the drift tubes which also hold the wires [1]. A three-dimensional measurement of the endplugs of the first BIS 78 chamber has been performed with a large coordinate measuring machine based on the same principle. The measurement showed an overall wire positioning accuracy of 12 $\mu$m (rms). The design of the RPC support frame is completed and the assembly of the RPC chambers will start in October 2018. An integration test of the sMDT and RPC prototype chambers on their independent but interleaved rail support structures (see Figure 3) demonstrated that the chambers do not interfere even with maximum mechanical deformations in the horizontal and reversed orientations.

## References


[1] H. Kroha, et al., Construction and Test of New Precision Drift Tube Chambers for the ATLAS Muon Spectrometer, Nucl. Instr. and Meth. A 845 (2017) 244.

[2] The ATLAS collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer, CERN-LHCC-2017-017, December 2017.


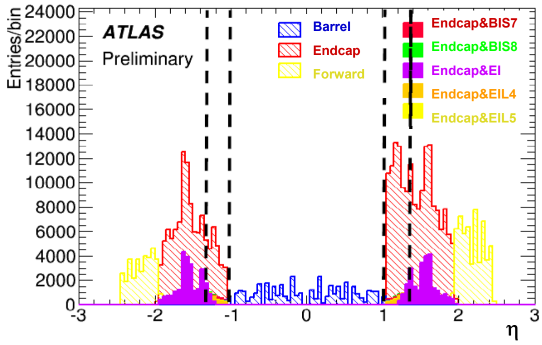


Figure 1: ATLAS Level-1 muon trigger rate at 20 GeV nominal $p_T$ threshold as a function of $\eta$ in LHC Run-2 (hatched histograms). The accidental trigger rate in the transition region $1.0 < |\eta| < 1.3$ (dashed black lines) can be strongly reduced to the level of the barrel trigger rate by including the new BIS 78 RPC trigger chambers together with the standard endcap TGC trigger chambers in the middle endcap layer (EM). This combination leads to very small fake trigger rates in this region indicated by the red and green full histograms. The purple and yellow full histograms show the rate reduction which can be achieved by adding TGC trigger chambers in the inner endcap layer EI.

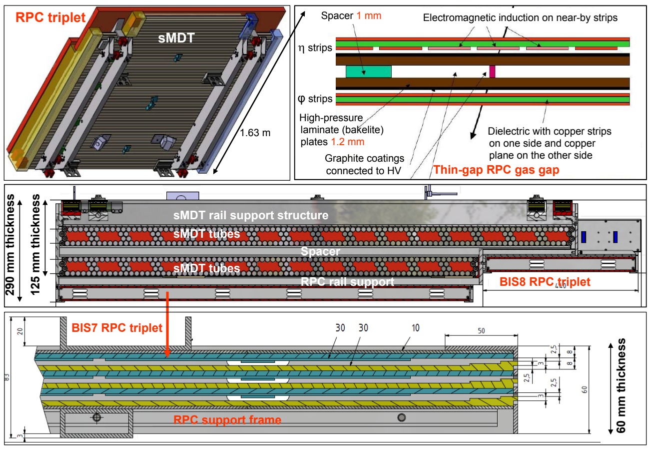


Figure 2: Design of the integrated BIS 78 sMDT and triple thin-gap RPC chambers (see text).

Figure 3: Assembly of a BIS 78 sMDT chamber (bottom) with a prototype triplet RPC chamber in its aluminum space frame (top) on the interleaved rail support structures.