Commissioning and installation of the new small-diameter Monitored Drift Tube detectors for the phase-1 upgrade of the ATLAS muon spectrometer

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TIPP 2021
International Conference on Technology and Instrumentation in Particle Physics, 24-29 May 2021
Talk Overview

Introduction
- ATLAS Muon Spectrometer Upgrades
- New BIS-78 sMDT Detector for the ATLAS Muon System
- Overview of the Surface Commissioning Protocol

BIS-78 sMDT surface commissioning @CERN
- Gas Leak Test
- Connectivity and Noise Rate Test
- Cosmic-Ray Test

BIS-78 sMDT and RPC detectors integration
- Integration Procedure
- Interference Noise Test
- Final Mechanics & Services Installation

Installation & commissioning @ATLAS Cavern
- Sector Preparation
- Installation
- Commissioning
1. Improvement of the barrel muon trigger detector efficiency
   - new triple-Resistive Plate Chamber (t-RPC) -> 276
     - to close acceptance gaps due to magnet ribs
     - to compensate for efficiency loss of the existing RPC trigger
   - new small Monitored Drift Tubes chambers (sMDT) -> 96
     - to make space for the new RPCs
     - to increase the background rate capability of the MDTs

2. Improvement of the first-level muon trigger selectivity
   by including the (s)MDT chambers in the trigger to achieve the highest possible muon momentum resolution at the trigger level.

In 2019/21 (Long shutdown-2) the BIS-78 Phase-1 Upgrade project will realize as a pilot for Phase-2:

16 sMDT and 32 thin RPC chambers will be installed in the barrel-endcap transition region at $1.0 < |\eta| < 1.3$ as a replacement for the old MDT layers.

In total: $\sim 11000$ drift tubes!
BIS-78 sMDT Detector for ATLAS Muon Spectrometer Phase-I Upgrade

**BIS-78 project in Phase-1/Run-3 March 2022**

12 different sMDT detector types

*Note: different name's color = different chamber's design*

BIS-78 station in the ATLAS Muon System
**BIS-78 Muon Station Layout**

- **Two thin RPC detectors:**
  - BIS7 RPC triplet
  - BIS8 RPC triplet

- **One BIS-78 sMDT detector**

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**3D model of the BIS-78 Muon station**

- Axial/Praxial, CCC Alignment systems
- B-field sensors
- In-plane Alignment system
- High Voltage side
- Overall thickness 330.9 mm
- RPC 7 envelope
- sMDT rail supports
- sMDT envelope

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**BIS-78 RPC triplet cross section**

- 1mm gas gap
- 1mm gas gap
- Multilayer 1
- Multilayer 2

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**BIS-78 sMDT (tube Ø 15 mm) cross section**

- Multilayer 2
- Multilayer 3

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*Elena Voevodina*
The sMDT Technology has been developed since 2008 in order to cope with the expected high background rates at the HL-LHC.

**New small Drift Tube Chamber Technology**

**sMDT baseline parameters**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Current MDT</th>
<th>New sMDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube Diameter</td>
<td>30 mm</td>
<td>15 mm</td>
</tr>
<tr>
<td>Number of tube layers</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Operating Gas Mixture</td>
<td>Ar: CO₂ (93:7)</td>
<td>Ar: CO₂ (93:7)</td>
</tr>
<tr>
<td>Operating Pressure</td>
<td>3 bar</td>
<td>3 bar</td>
</tr>
<tr>
<td>Operating HV working point</td>
<td>3070 V</td>
<td>2730 V</td>
</tr>
<tr>
<td>Gas gain</td>
<td>2 × 10⁴</td>
<td>2 × 10⁴</td>
</tr>
<tr>
<td>Max. Drift time</td>
<td>~ 720 ns</td>
<td>~ 175 ns</td>
</tr>
<tr>
<td>Average tube spatial resolution*</td>
<td>83 ± 2 μm</td>
<td>106 ± 2 μm</td>
</tr>
</tbody>
</table>

* Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer, CERN-LHCC-2017-017; ATLAS-TDR-026

**Main Advantages of the 15 mm Ø sMDT detector:**

- 10 times high rate capability with respect to the current MDT detectors, i.e. 8 times lower background detector occupancy
- 4 times lower electronics dead time (= max. drift time)
- 2 times more tube layers within the same detector volume allowing for additional increase in the muon tracking efficiency
- No aging effects after foreseen integrated luminosity of HL-LHC (even up to 9 C/cm)
BIS-78 sMDT + RPC assembly and test protocol

- Semi-automated drift tube assembly in a clean room
- sMDT chamber assembly using automated glueing machine
- sMDT chamber assembly in temperature controlled clean room
- 16 sMDT chambers assembled/tested in MPI
- 32 RPC produced/tested at CERN
- sMDT final validation test performed at CERN
BIS-78 sMDT + RPC Validation Tests Protocol @CERN

sMDT QA/QC

❖ Visual Inspection
❖ Preparation phase for QC
❖ Leak Rate Test
❖ Connectivity & Noise Rate Test
❖ Cosmic Ray Test

RPC BIS-78 QA/QC

❖ Visual Inspection
❖ Detector Components Validation:
  • Gas gap tightness
  • V/A characteristic
  • Gap conditioning & stability tests @GIF++
  • FE Board Test, etc ...
❖ Singlet/Triplet Assembly
❖ Singlet/Triplet Cosmic Ray test

sMDT + RPC BIS-78 Integration

❖ Final Mechanics & Services Installation
❖ Connectivity & Interference Noise Test
❖ Final Certification Tests

Final BIS-78 Detector Module Installation @P1
8 “A-side” sMDT detectors have been shipped from MPI-Munich to CERN in 2019

8 “C-side” sMDT modules have been delivered from the MPI-Munich in 2020 when the storage and test spaces at CERN were available

Assembled sMDT detectors arrived from MPI (Munich) to BB5 facility (CERN, Geneva)
Gas Leak Rate Measurement

- Detector is pressurized at 3 bar in Ar: CO₂ (93: 7)
- Pressure measurement \( p(t) \) with accuracy 0.3 mbar
- Temperature measurement \( T(t) \) with accuracy 0.1 K.
  (12 on-chamber sensors)
- Duration: > 24 hours

\[
\Delta p = \left[ \frac{p_f}{T_f} - \frac{p_i}{T_i} \right] \cdot \frac{V}{(t_f - t_i) \cdot N_{plugs}}
\]

\( T_{ref} = 293.15 \text{ K} \) — reference temperature
\( p_i, p_f, T_i, T_f \) — initial, final pressures and temperatures
\( V, N_{plugs} \) — volume under test and number of the tube end plugs

\( \delta(\Delta p) = 1.6 – 2 \text{ mbar} \)

\( T \text{ typical gas leak rate} \)
\( 2.95 \times 10^{-6} \text{ bar} \times L \times s^{-1} \text{ at the} \)
Criteria \( 6.24 \times 10^{-6} \text{ bar} \times L \times s^{-1} \)

\( \Delta p \leq 2n_{\text{tubes}} \times 10^{-8} \text{ bar} \times \text{Liters} \times s^{-1} \)

\( \text{ATLAS acceptance criteria:} \)
Drift tube positioning in precision jigs

Connectivity & Electronics Noise Test

Measurement of the accidental hit rate in each tube with and without high voltage

sMDT setup @CERN BB5: \( WP = 2730\, \text{V}, \, P = 3\, \text{bar} \) in \( \text{Ar}:\text{CO}_2 \) (93: 7)

\[
\text{Noise Rate Test Summary:}
\]

\( \text{Noise Rate (HV OFF)} = (63.5 \pm 6.2) \, \text{Hz/tube} \)

\( \text{Noise Rate (HV ON)} = (102.8 \pm 9.7) \, \text{Hz/tube} \)

Number of disconnected tubes: 20/10944

\( \text{ATLAS requirement} \rightarrow \text{Noise}^{\text{ON}}_{t} < 1 \, \text{kHz} \)

\( \sqrt{\text{Noise}}^{\text{ON}} < 0.15 \, \text{kHz} \rightarrow \text{sMDT + FE elect. is a low noise system!} \)
**Cosmic Ray Test**

**Tube spatial resolution**

\[ y(z) = m \cdot z + b \]

- Select nearly vertical muon tracks
  - For perfectly vertical tracks:
    \[ \sigma(r_1) = 2^{-0.5} \cdot \sigma(r_2 - r_1) \]
  - For tracks with inclination \(|m| < 0.01|\)
    \[ \sigma(r_{1/2}) = \sigma \left( \frac{r_2 - r_1}{\sqrt{2}} \right) + \frac{m \cdot (z_2 - z_1)}{\sqrt{2} \cdot (1 + m^2)} \]

**Tube muon detection efficiency**

- Reconstruction of muon tracks leaving out one layer after the other.
- Measurement reproduces known dependence of the efficiency on the distance of the muon track from anode wire.

**Resolution via double Gaussian fit**

![Resolution](image)

**Dependence of the detection efficiency on the drift radius.**

**Single tube muon detection efficiency**

![Efficiency](image)
sMDT + RPC Integration

The integrated mechanical design of the two chambers with small tolerances are required.

Rotation
Integration
Move into the test stand

The mechanical adjustment accuracy is about 0.5 mm, fulfilling the requirements on the chamber alignment in the detector.

8 “A-side” sMDT chambers have been successfully integrated with RPCs!

Elena Voevodina
BIS-78 sMDT Interference Test

BIS-78 A04 - Interference Study @BB5

BIS-78 A04 - Interference Test Result

→ average noise rate for sMDT A04 with **RPC system OFF** is \((0.17 \pm 0.03) \text{ kHz/tube}\)

→ average noise rate for sMDT A04 with **RPC system ON** is \((0.43 \pm 0.03) \text{ kHz/tube}\)

*Detailed study shown that the effect of the RPC detector + its electronics is negligible to sMDT system (chamber + its electronics at the operating threshold) in the term of noise!*

“All 8 “A-side” sMDT chambers have passed test!”
17th of September 2020 the first BIS78 Detector Module has been successfully installed to the A04 sector of the ATLAS Muon spectrometer.

**Installation Sequence:**

- Insertion into the installation frame
- Lowering into the ATLAS Cavern, change of cranes
- Docking of the installation frame to the ATLAS Muon Spectrometer rail system
- Installation of the muon station with two winches
- Final positioning and fixation of support frame on rails

*Insertion into the frame*
Installation (video)

Insertion into the installation frame

Lowering into the ATLAS Cavern

Docking to the ATLAS Muon System rail system

Installation of the station with two winches
The new sMDT subsystem has been successfully implemented/integrated in the ATLAS operational system.

Alignment connected and checked -> chamber in expected positions;
Gas line connected, flushed and @3 bar;
2 of each CSMs, CSM-motherboards and MDMs installed and checked;
Service cables (mezzanine, HV, B-/T-sensors and grounding) connected;
LV and fibers checked to ensure right mapping;
B-/T-sensor and front-ends V-/T-sensor readout checked;
LV and HV applied and all currents in expected range.

The new sMDT BIS7A sub-system has already recorded cosmic data during the M5 ATLAS combined run!

Stable long DAQ without any mezzanine
Conclusions

**BIS78 sMDT production and commissioning:**
- Successful and on-time production of both A/C-side BIS-78 sMDT detectors (~11,000 drift tubes => 16 detectors) from 2017 to 2019.
- 16/16 chambers have been fully assembled and validated at MPI.
- In 2019/2020, the 16 A/C-side BIS-78 sMDT chambers have been shipped to CERN BB5 facility.
- Each detectors have been fully validated @CERN BB5 facility.
- 8 “A-side” sMDT detectors have been integrated with two new trigger RPC chambers.

**new Muon module installation and commissioning:**
- 8/16 BIS-78 Muon stations successfully installed in ATLAS from Sept. 2020 to Jan. 2021
- 8 sMDT BIS7A have been commissioned!
- 8 sMDT chambers had been integrated into ATLAS DAQ.
- Stable DAQ after long time debug and tests was obtained.
- 1st recorded dataset with all sMDT BIS7A data from ATLAS combined run in M5 has been completed.
- The analysis of data is ongoing!