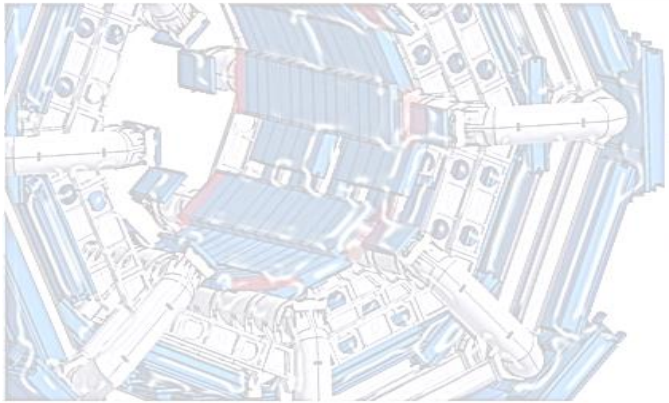
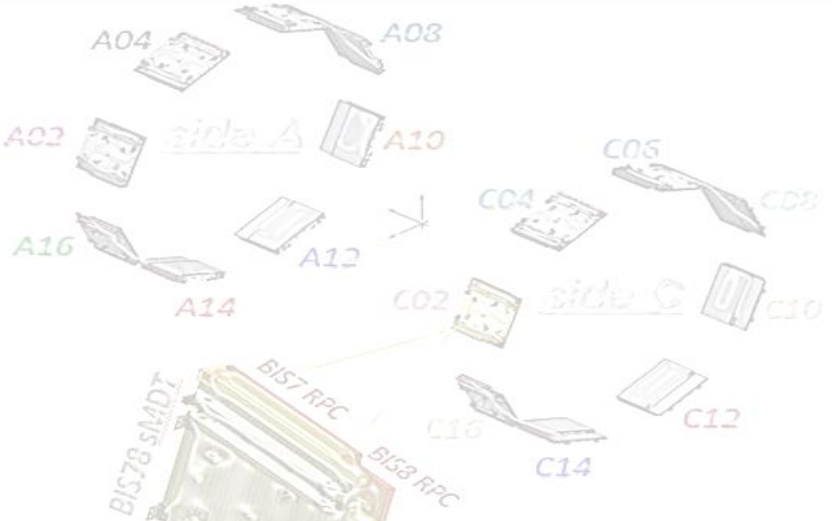




Commissioning and installation of the new small-diameter Monitored Drift Tube detectors for the phase-1 upgrade of the ATLAS muon spectrometer

Elena VOEVODINA

on behalf of ATLAS Muon Collaboration

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

TIPP 2021

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

MAX-PLANCK-GESELLSCHAFT

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 commssioning @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

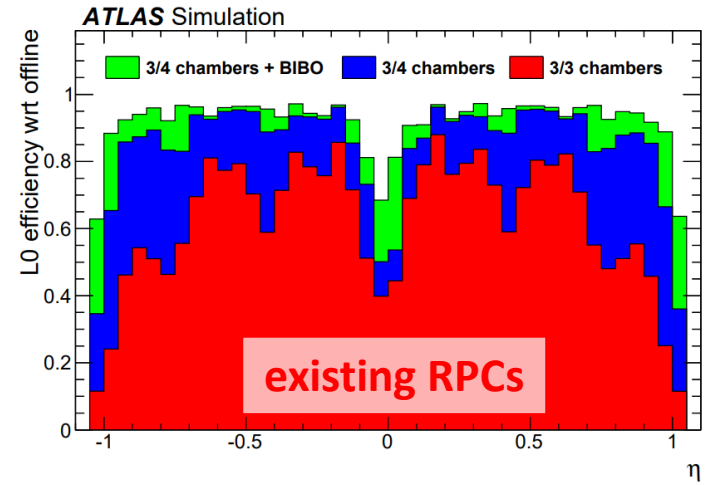
- ***Sector Preparation***
- ***Installation***
- ***Commissioning***

ATLAS Muon Spectrometer Upgrades for the Barrel Inner region

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 backgr. rate capability of the MDTs

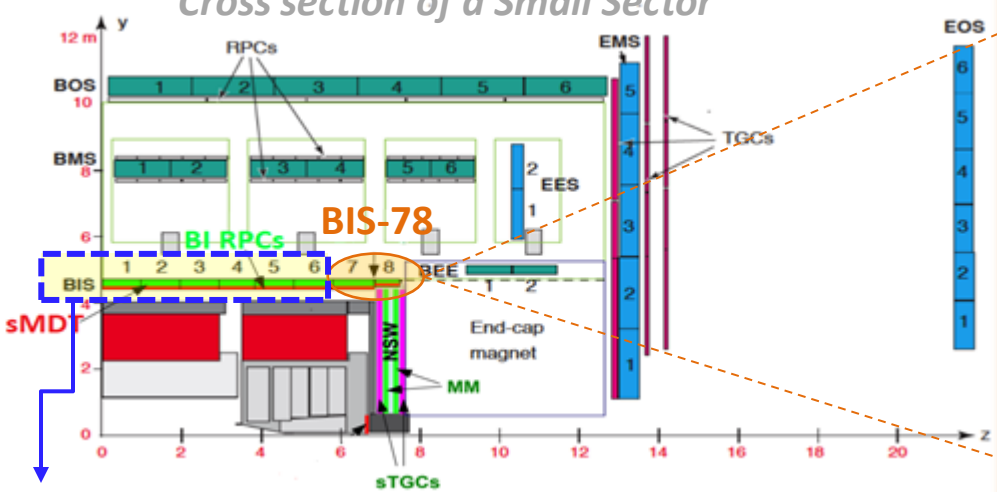
Barrel muon trigger coverage



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.

Cross section of a Small Sector



BI 1-6 = Barrel Inner Upgrade Project of Phase-2

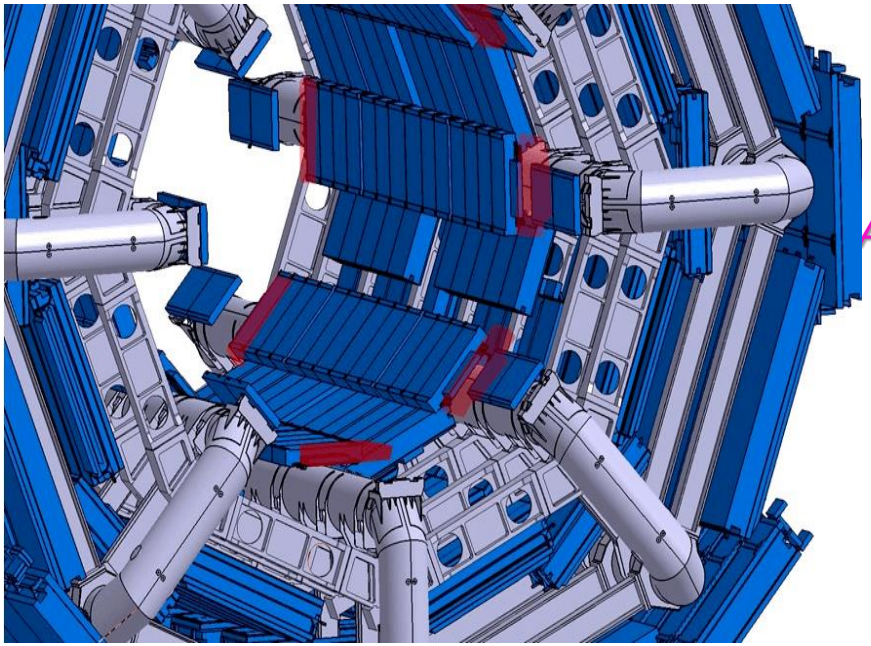
In 2019/21 (Long shutdown-2) the BIS-78 Phase-1 Upgrade project will realize as a pilot for Phase-2:

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.

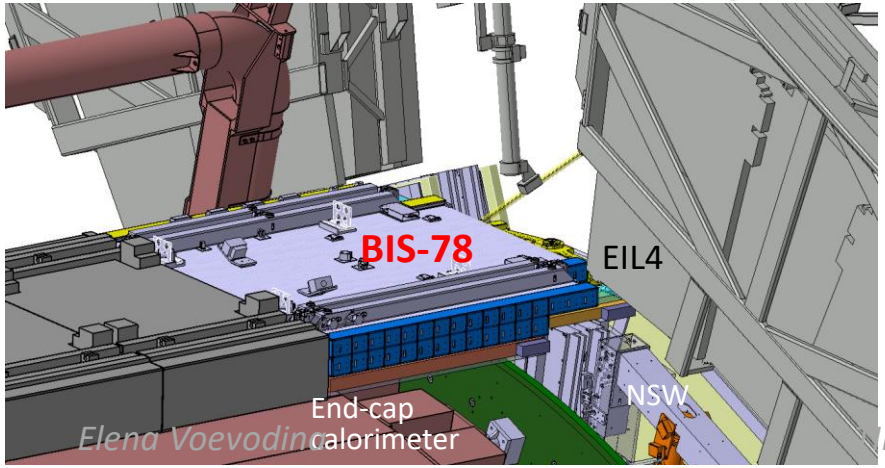
In total: ~ 11000 drift tubes!

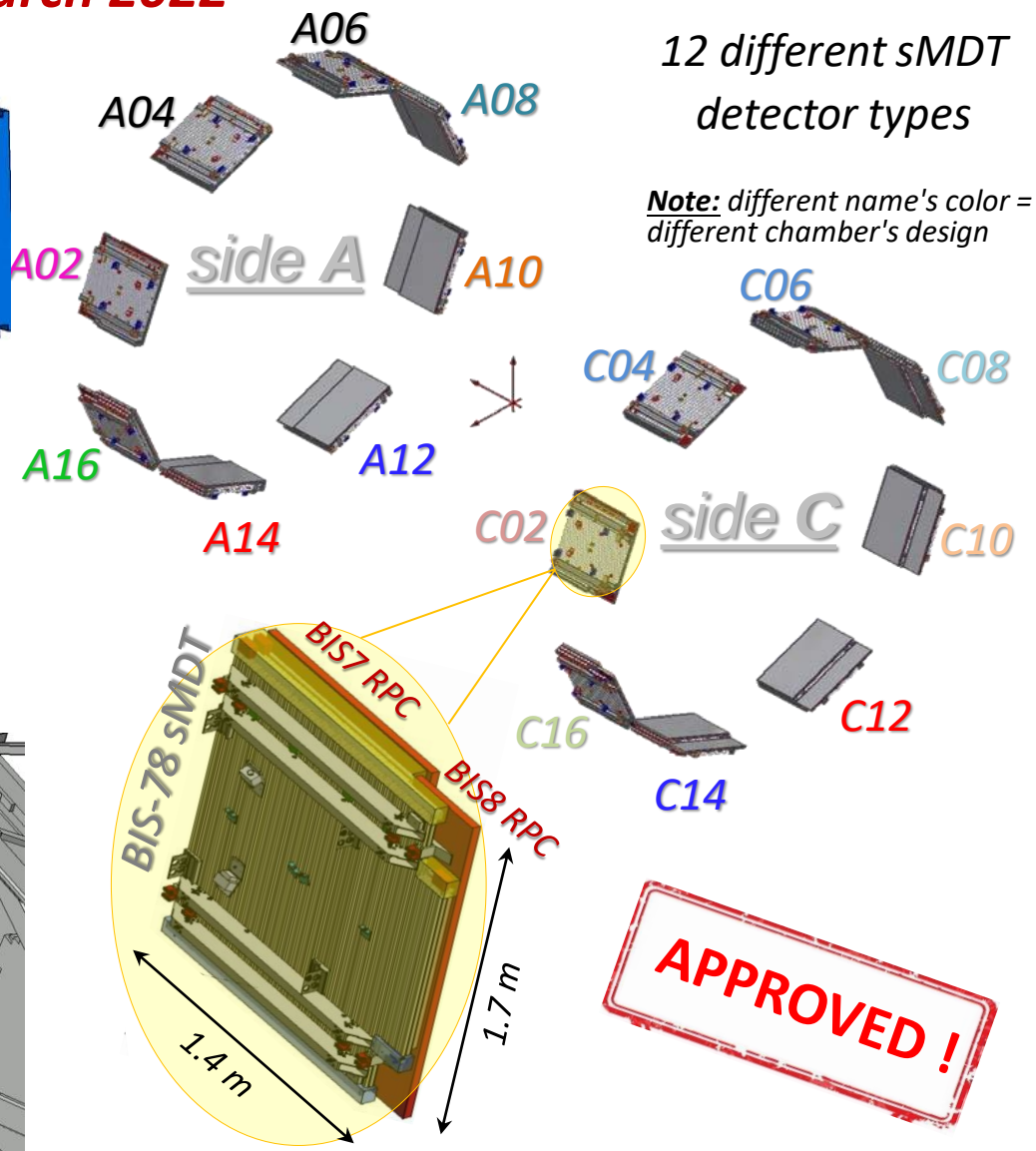
BIS-78 sMDT Detector for ATLAS Muon Spectrometer Phase-I Upgrade

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



BIS-78 station in the ATLAS Muon System





12 different sMDT detector types

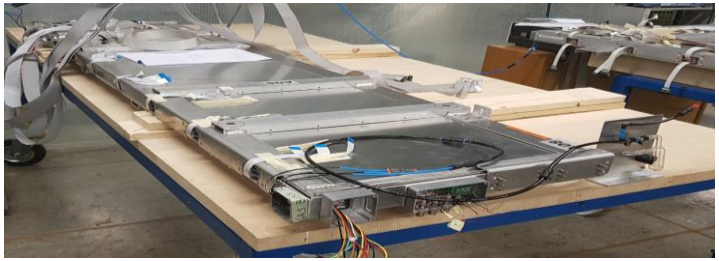
Note: *different name's color = different chamber's design*

APPROVED !

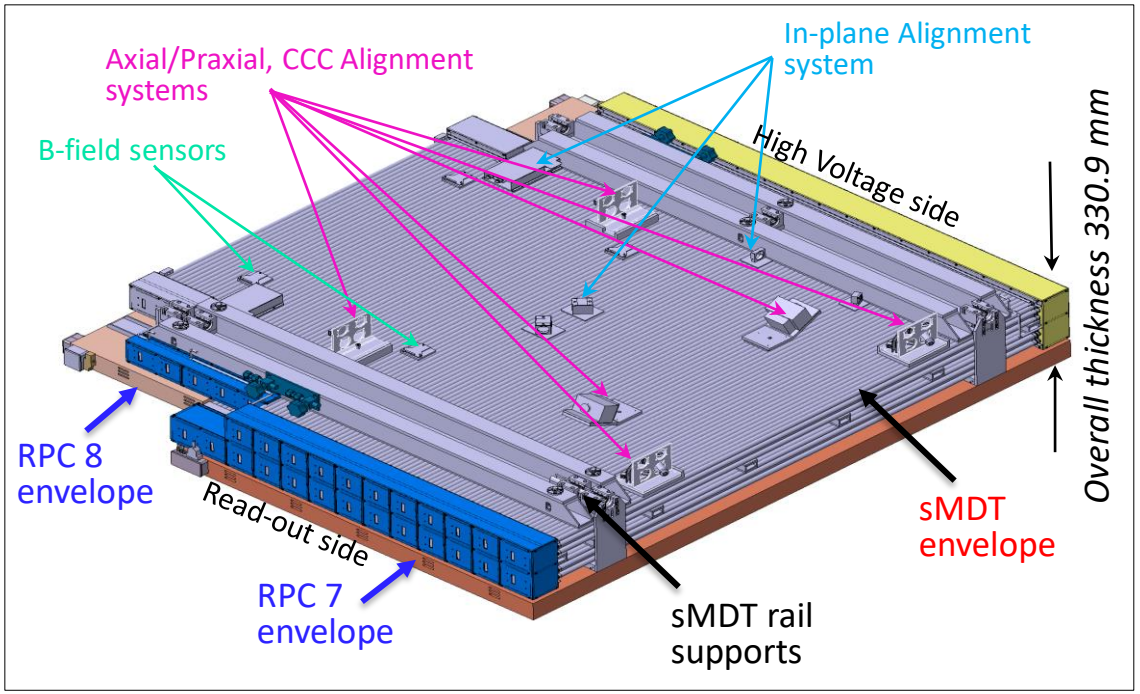
BIS-78 Muon Station Layout

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

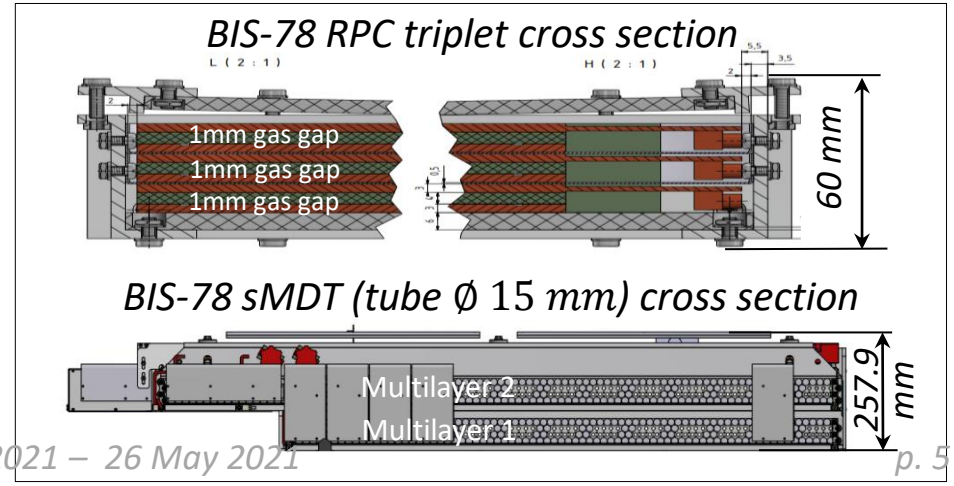
  - BIS8 RPC triplet



3D model of the BIS-78 Muon station

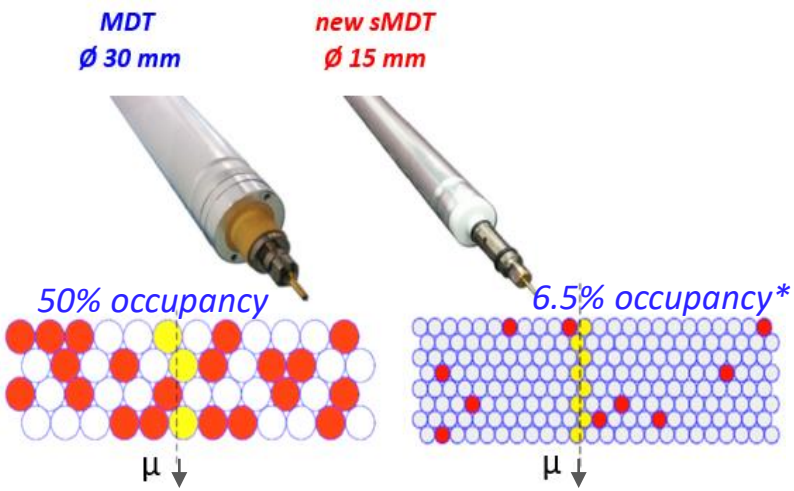


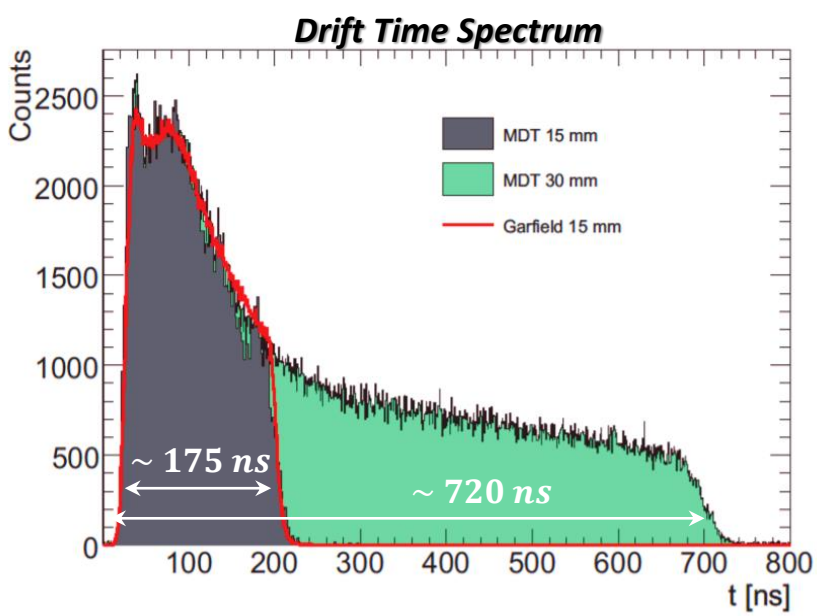
- **One BIS-78 sMDT detector**



New small Drift Tube Chamber Technology

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





sMDT baseline parameters

Properties	Current MDT	New sMDT
Tube Diameter	$30\ mm$	*15 mm*
Number of tube layers	4	*8*
Operating Gas Mixture	$Ar: CO_2$ (93:7)	$Ar: CO_2$ (93:7)
Operating Pressure	$3\ bar$	$3\ bar$
Operating HV working point	*3070 V*	*2730 V*
Gas gain	2×10^4	2×10^4
Max. Drift time	$\sim 720\ ns$	$\sim 175\ ns$
*Average tube spatial resolution**	*83 ± 2 μm*	$106 \pm 2\ \mu m$

** 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

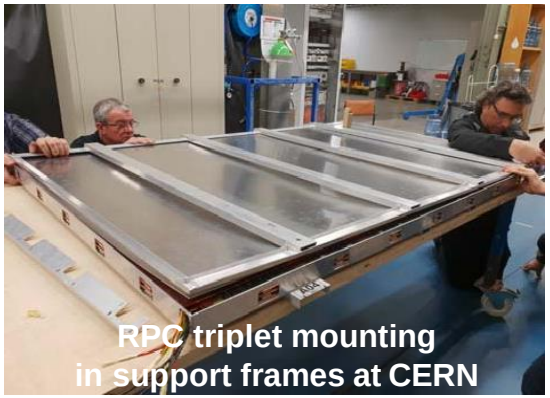

Semi-automated drift tube assembly in a clean room


sMDT chamber assembly using automated glueing machine


sMDT chamber assembly in temperature controlled clean room


sMDT chamber construction stages


RPC assembly and test at CERN


RPC triplet mounting in support frames at CERN


sMDT and RPC integration


Common sMDT + RPC commissioning

- **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

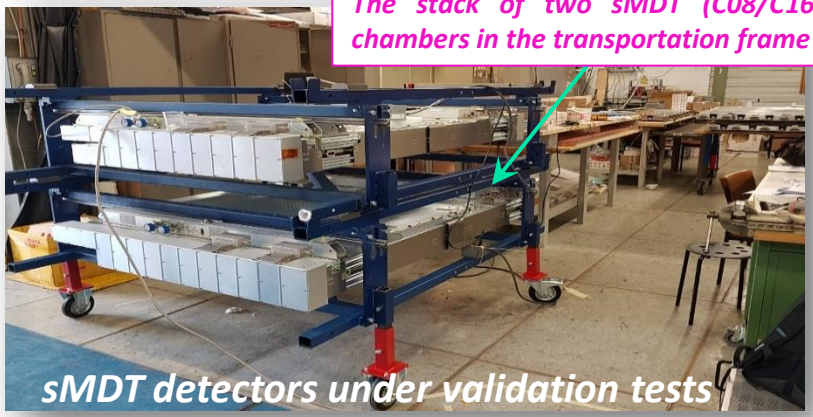
Final BIS-78 Detector Module Installation @P1

16 BIS-78 sMDT @CERN BB5 facility

- ☑ ***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)

Short-term sMDT storage @CERN BB5



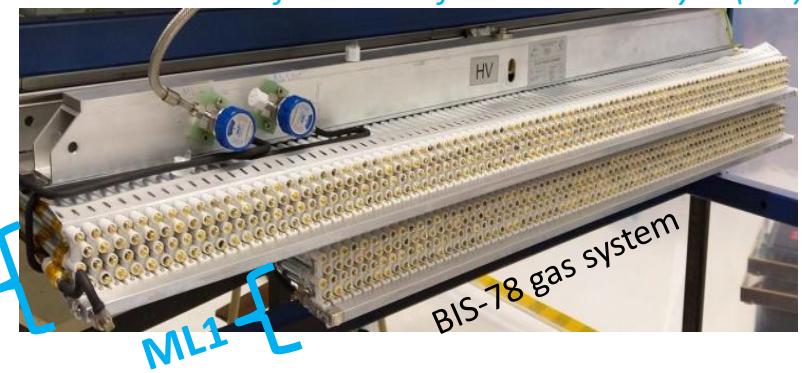
The stack of two sMDT (C08/C16) chambers in the transportation frame

sMDT detectors under validation tests

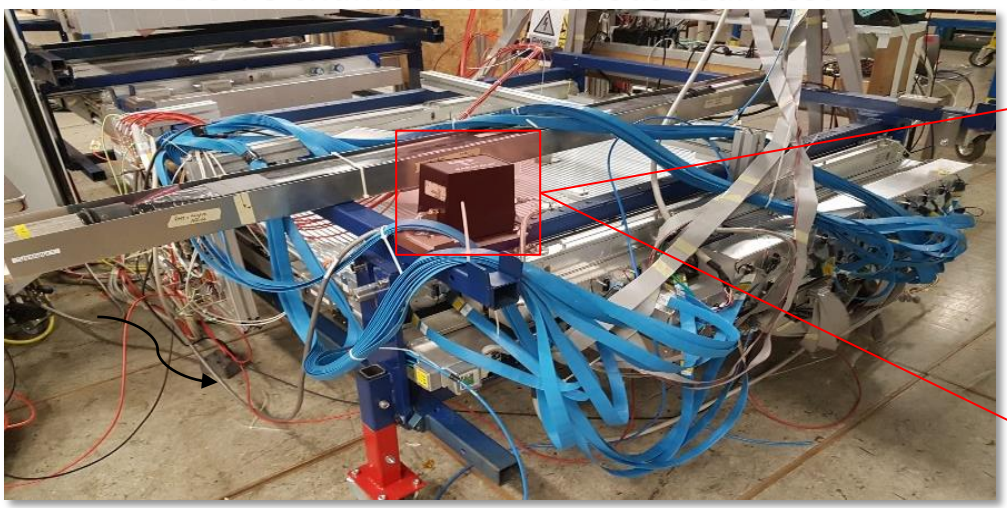
Gas Leak Rate Measurement

- **Detector is pressurized at** ***3 bar*** **in** $Ar: CO_2\ (93:7)$
- **Pressure measurement** $p(t)$ **with accuracy** ***0.3 mbar***
- **Temperature measurement** $T(t)$ **with accuracy** ***0.1 K.*** (12 on-chamber sensors)
- **Duration:** $> 24\ hours$

Determination of Gas Leak for each Multilayer (ML)



BIS-78 chamber is under Gas Leak Test



MKS Instruments
390HA-00001SP12

Accuracy:
0.3 mbar at 3000 mbar

- **Gas Leak estimation:** $$\Delta p = [\, p_f \cdot \frac{T_{ref}}{T_f} - p_i \cdot \frac{T_{ref}}{T_i} \,] \cdot \frac{V}{(t_f - t_i) \cdot N_{plugs}}$$

$T_{ref} = 293.15\ K - reference\ temperature$
$p_i, p_t; T_i, T_t - initial, final\ pressures\ and\ temperatures$
$V,\ N_{plugs} - volume\ under\ test\ and\ number\ of\ the\ tube\ end\ plugs$

$$\delta(\Delta p) = 1.6\ - 2\ mbar$$

☑ **TEST PASSED!**

Typical gas leak rate
$2.95 \times 10^{-6} bar \times L \times s^{-1}$ at the Criteria $6.24 \times 10^{-6} bar \times L \times s^{-1}$

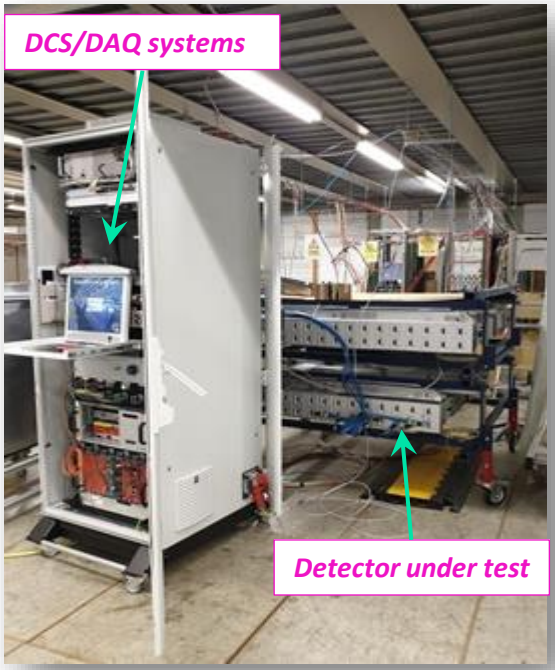
→ ***ATLAS acceptance criteria:*** $\Delta p \leq 2 n_{tubes} \times 10^{-8}\ bar \times Liters \times s^{-1}$

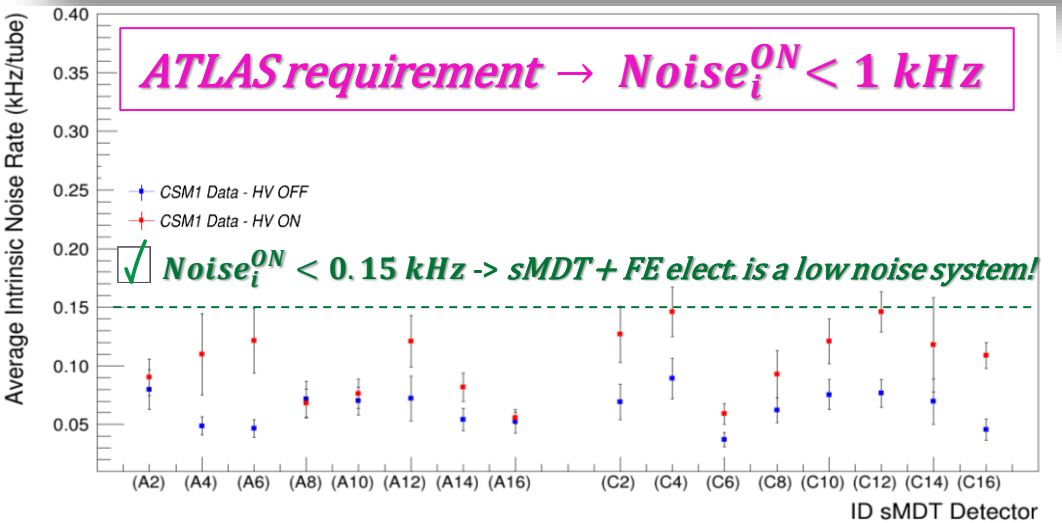
Connectivity & Electronics Noise Test

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

sMDT setup @CERN BB5: WP = 2730V, P = 3 bar in $Ar:CO_2$ (93:7)

Movable service rack





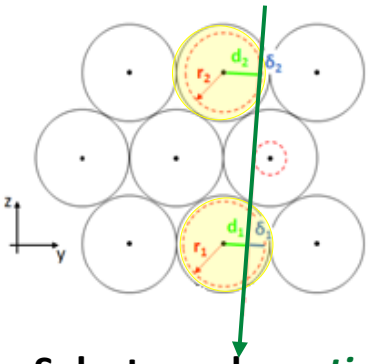
Noise Rate Test Summary:

→ ***"A/C-side" sMDT chambers***

Noise Rate (HV OFF) = (63.5 ± 6.2) *Hz/tube*
Noise Rate (HV ON) = (102.8 ± 9.7) *Hz/tube*
Number of disconnected tubes: 20/10944

Cosmic Ray Test

Tube spatial resolution



$$y(z) = m \cdot z + b$$

r_k – *measured drift radii*
d_k – *distance of the reconstr. track to the k wire*
δ_k – *resulting residuals*

- **Select nearly *vertical muon tracks***

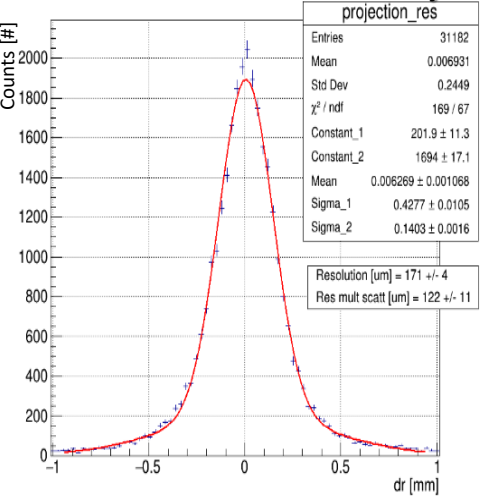
→ **For perfectly vertical tracks:**

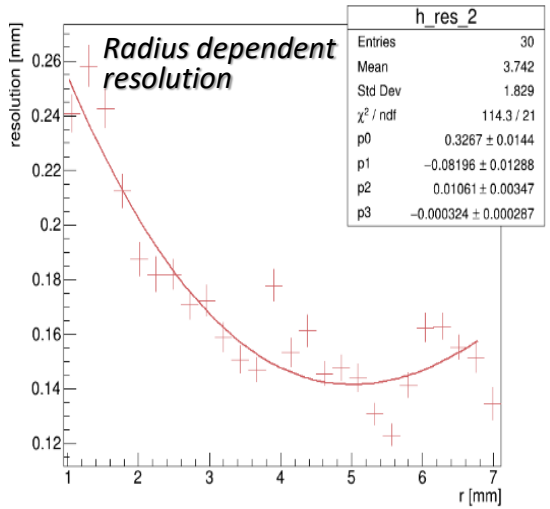
$$\sigma(r_1) = 2^{-0.5} \cdot \sigma(r_2 - r_1)$$

- **For tracks with inclination $|m| < 0.01$:**

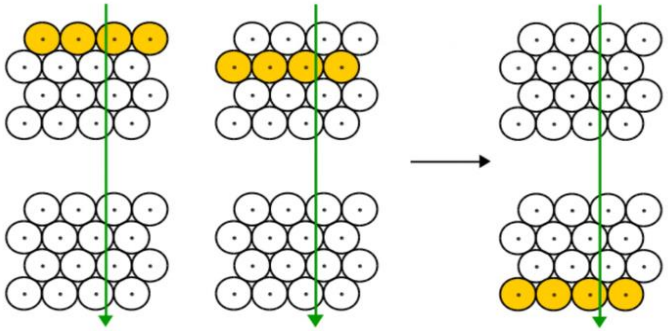
$$\sigma(r_{1/2}) = \sigma\left(\frac{r_2 - r_1}{\sqrt{2}} \mp \frac{m \cdot (z_2 - z_1)}{\sqrt{2 \cdot (1 + m^2)}}\right)$$

Resolution via double Gaussian fit

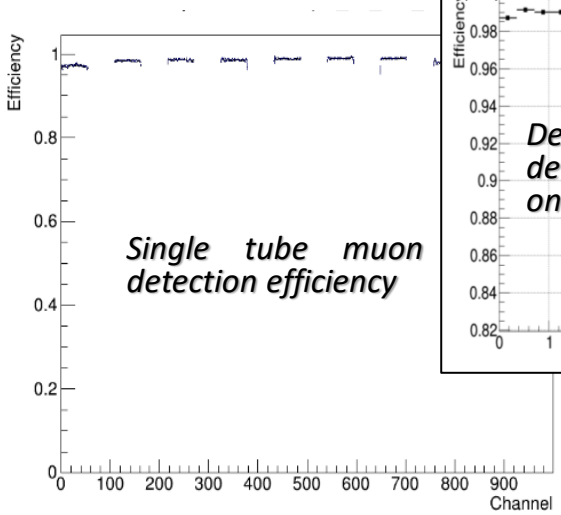


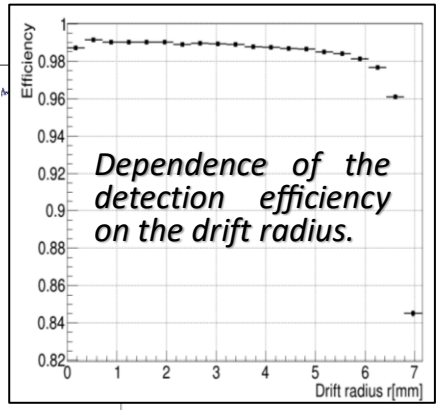


Tube muon detection efficiency



- **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.**

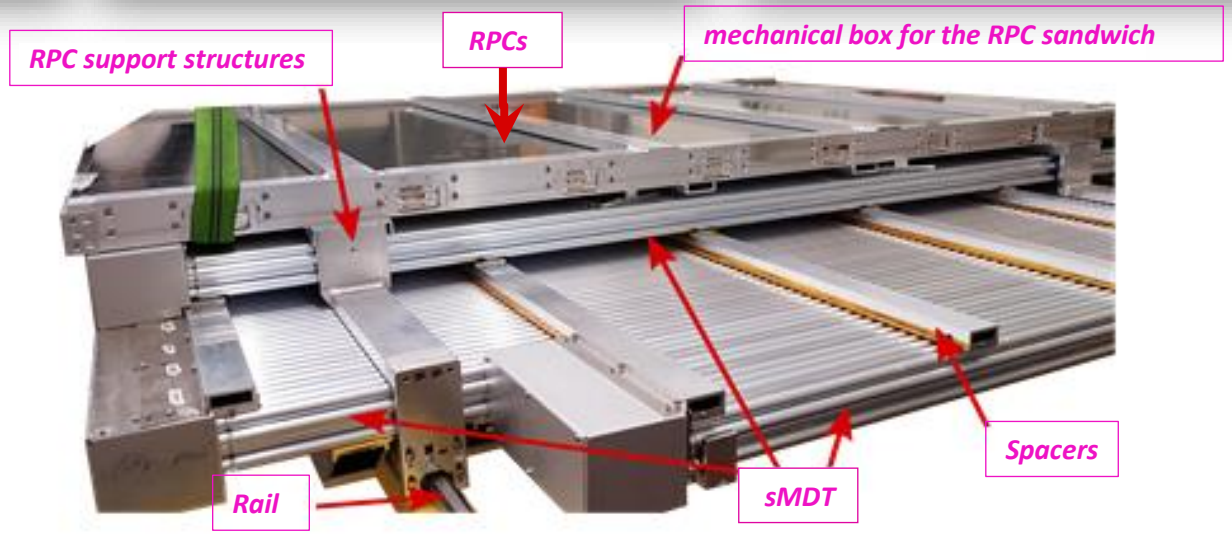




sMDT + RPC Integration

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

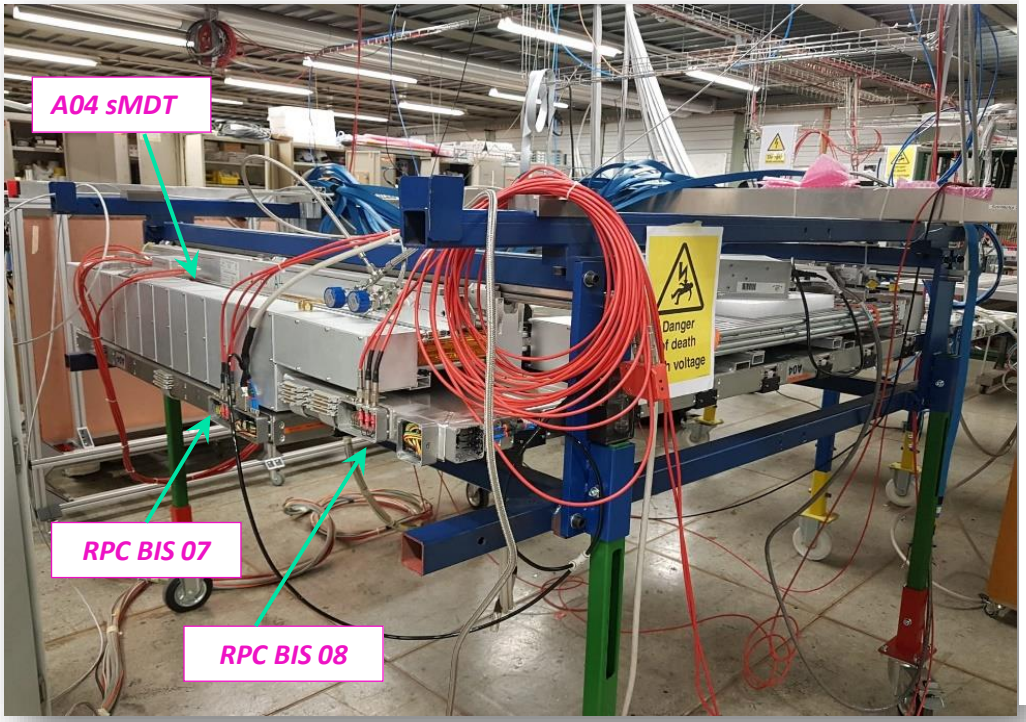
The mechanical adjustment accuracy is about 0.5 mm, fulfilling the requirements on the chamber alignment in the detector.



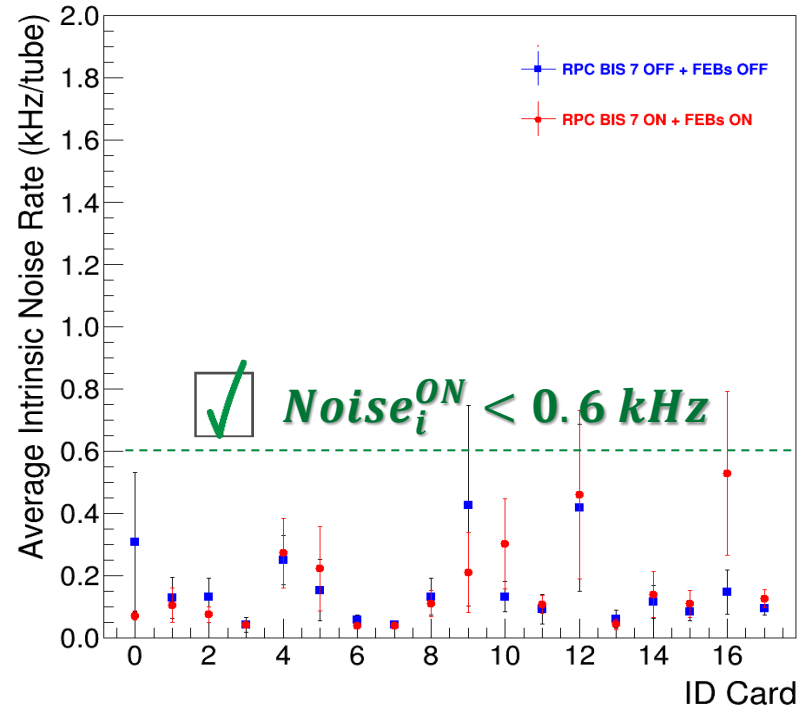
8 "A-side" sMDT chambers have been successfully integrated with RPCs!

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 ± 0.03) kHz/tube**

→ **average noise rate for sMDT A04 with RPC system ON is (0.43 ± 0.03) 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!**

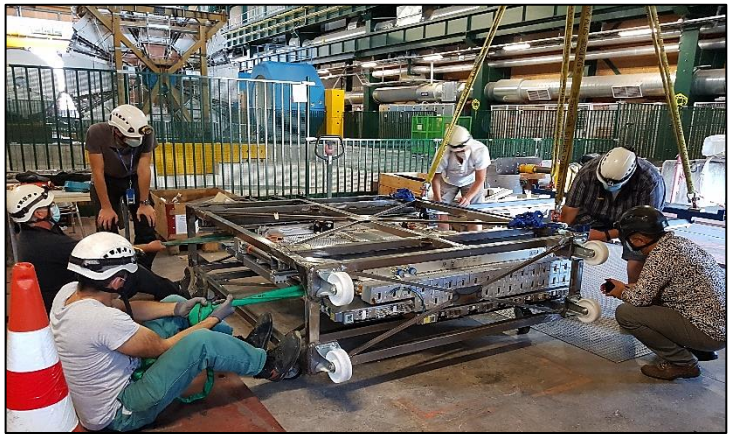
Installation

17th of September 2020 the first BIS78 Detector Module has been successfully installed to the A04 sector of the ATLAS Muon spectrometer.

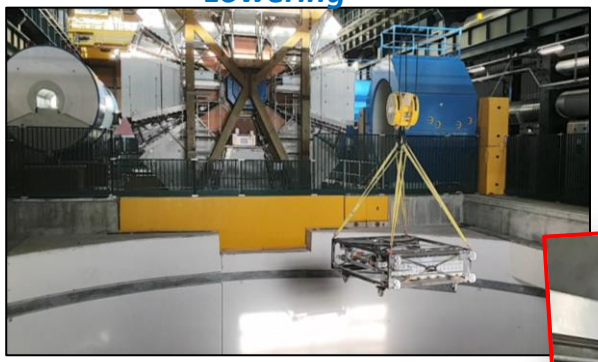
Installation Sequence:

- **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**

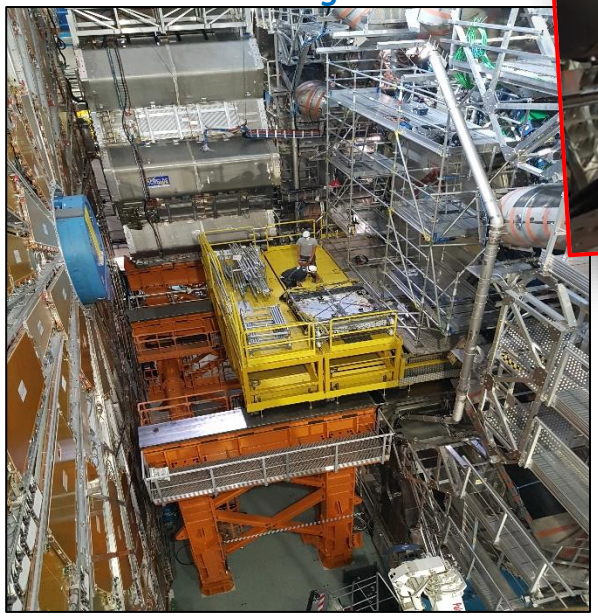
Insertion into the frame



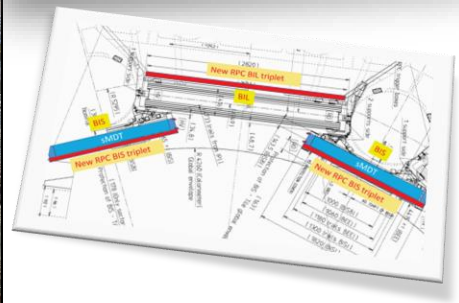
Lowering



Docking



Installation

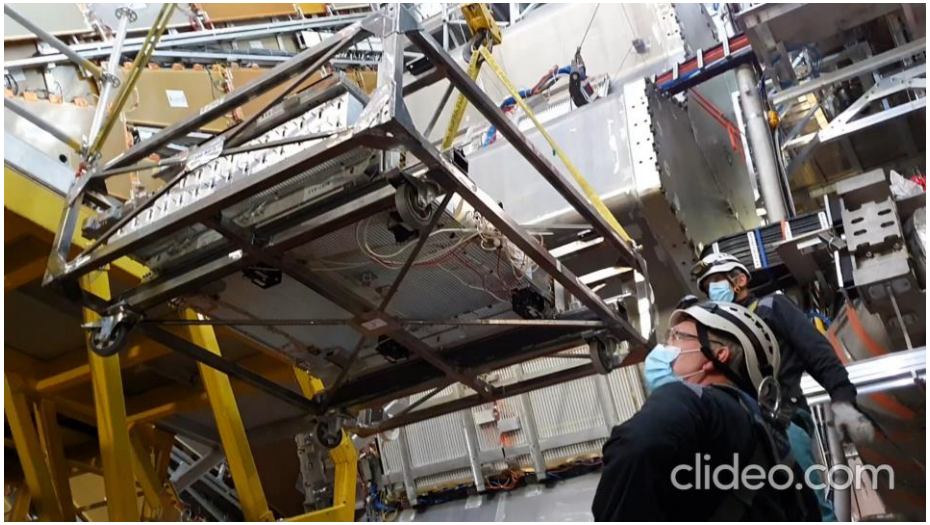


Installation (video)

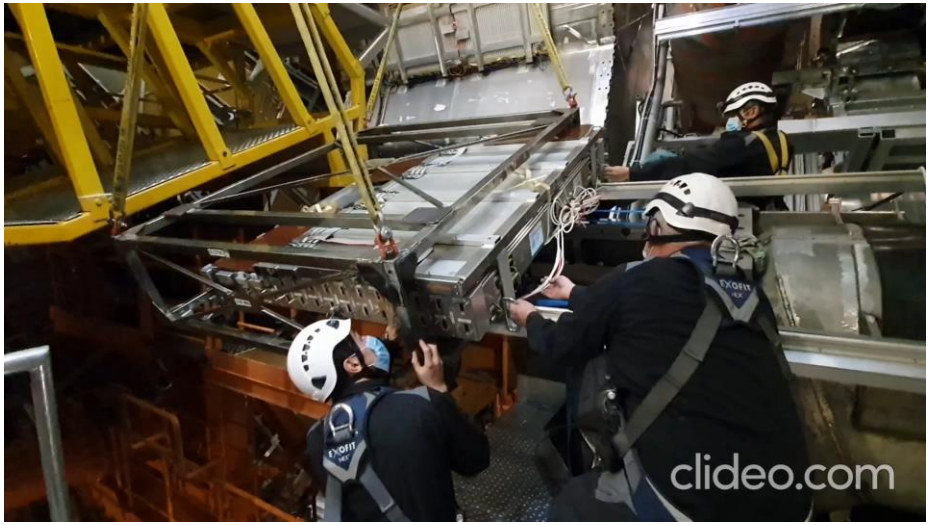
Insertion into the installation frame

Lowering into the ATLAS Cavern

Docking to the ATLAS Muon System rail system



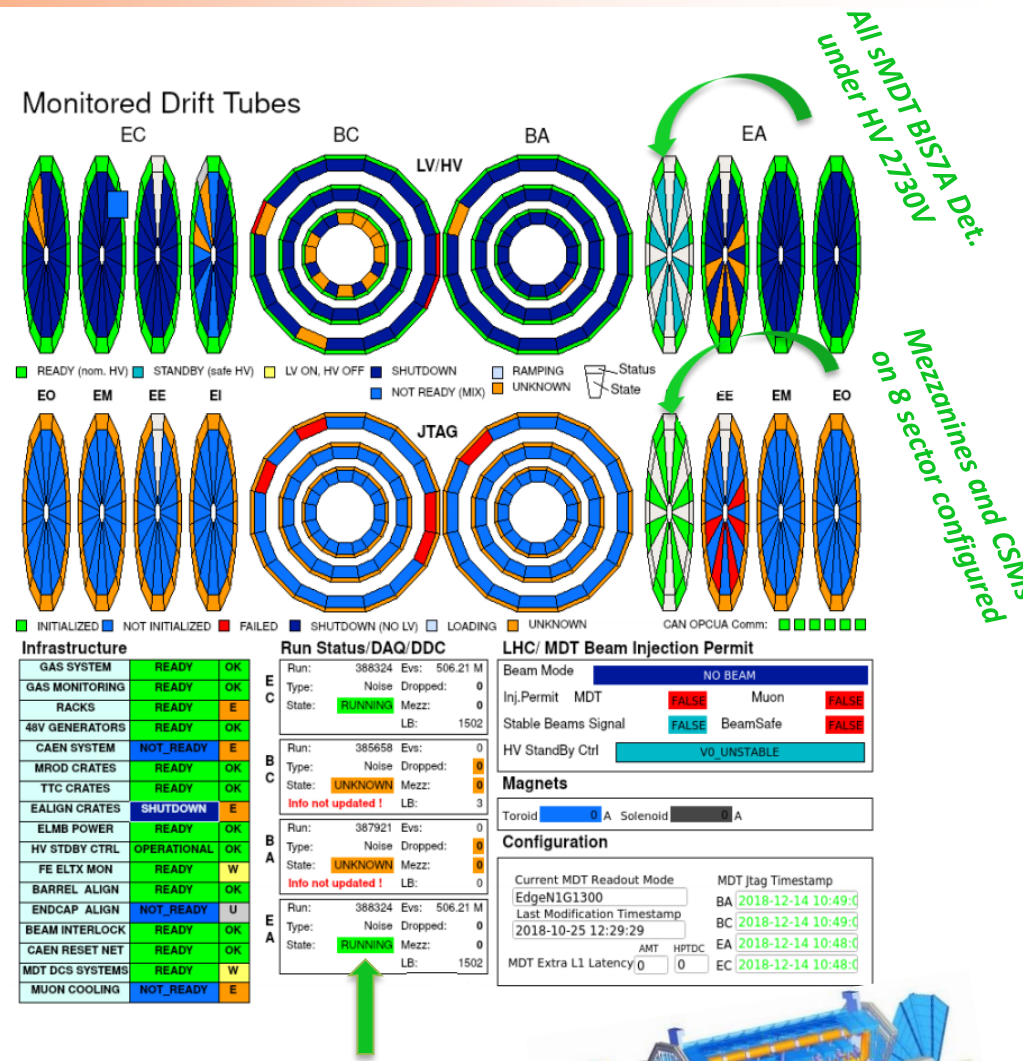
Installation of the station with two winches



BIS-78 sMDT Detector Commissioning

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.



All sMDT BIS7A Det. under HV 2730V

Mezzanines and CSMs on 8 sector configured

Stable long DAQ without any mezzanine

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

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!**