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

The sMDT muon detector

- The small-diameter monitored drift tube (sMDT) muon detector is being built at the production sites of MPI and Michigan to upgrade the ATLAS muon spectrometer for the HL-LHC [1,2,3].
- The expected single-hit spatial resolution of sMDT detectors is 106 μm [3].
- Each detector has 8 layers of tubes separated by a spacer frame between layers 4 and 5.
- 55 of 96 chambers constructed for a total of 46080 tubes to be delivered by end of 2023.

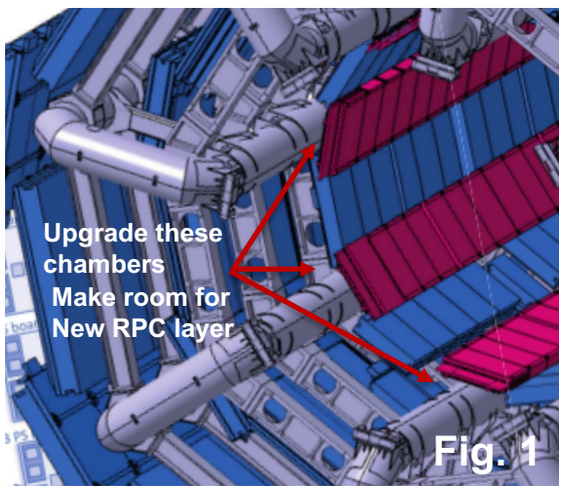

Fig. 1

Fig. 2

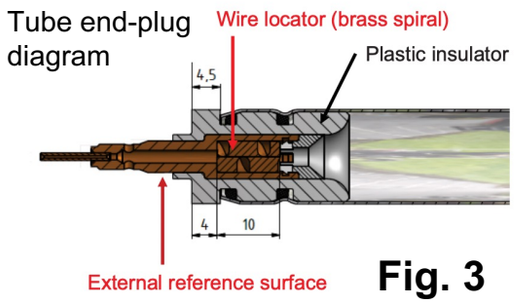

Fig. 3

Drift tube construction

- Drift tubes tested for wire tension, length, gas leaks, dark current. Tension tested twice, 2 weeks apart.
- Fig. 4: histogram of wire tension test results. Minimum wire tension is 325 g.

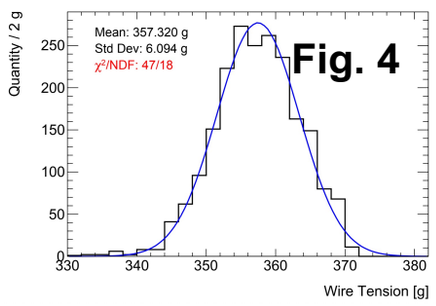

Fig. 4

Parameter	Value	Parameter	Value
Outer diameter	15 mm	Wire thickness	50 μm
Wall thickness	0.4 mm	Wire potential	2730 V
Tube length	1.6245 m	Gas mixture	Ar:CO_2 (93:7)
Wire composition	W-Rh, Au plated	Gas pressure	3 bar (abs.)

Mechanical precision and alignment

- Fig. 5: at Michigan wire position is measured on granite table using reference surface with a height gauge. At MPI an automated coordinate measurement machine is used.
- Fig. 6: wire position accuracy measured better than **10 μm** rms.
- Platforms for alignment and magnetic field sensors are mounted on the chamber. Platform positions are within **±200 μm** and measured with 10 μm precision. Alignment sensors establish the chamber position relative to other ATLAS chambers.
- The spacer frame contains an in-plane alignment system to measure chamber deformation. The alignment system measures along 4 optical paths: 2 parallel to the tubes and 2 diagonal across the chamber.
- Fig. 7: deformation is limited to **120 μm** as the chamber is rotated through 360°.
- Fig. 8: gas distribution manifolds are installed. Chambers are leak tested to verify the total leak rate is **less than 0.3 mbar/h** at 3 bar.

Fig. 5

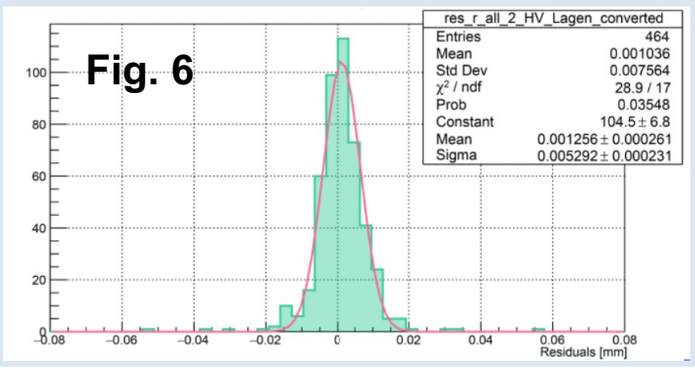

Fig. 6

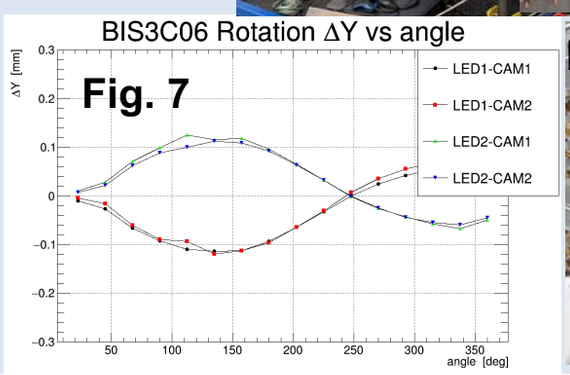

Fig. 7


Fig. 8

Data acquisition

- Fig. 9: trigger setup [6].
- Fig. 10: read-out ASIC digitizer electronics mounted on a chamber.
- Fig 11: drift time spectrum for one tube from cosmic-ray test. **Maximum drift time ≅200 ns**. A time slew correction is applied. Leading (falling edges) fit with Fermi-Dirac (exponential x Fermi-Dirac) [6].
- Fig 12: Wilkinson ADC spectrum for one tube, fit with skew normal [6].

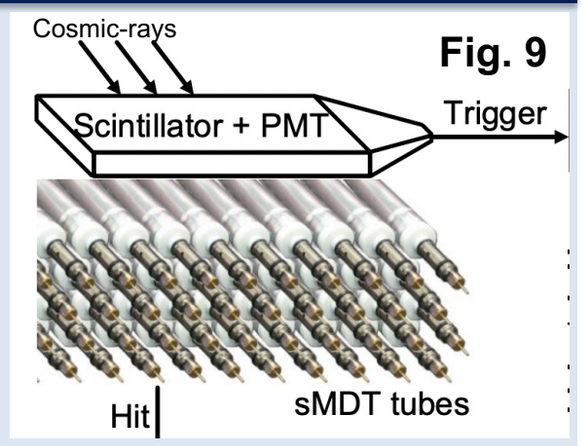

Fig. 9


Fig. 10

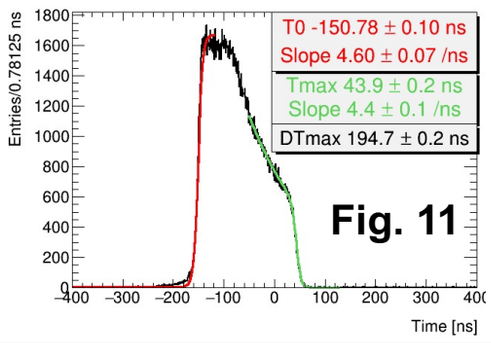

Fig. 11

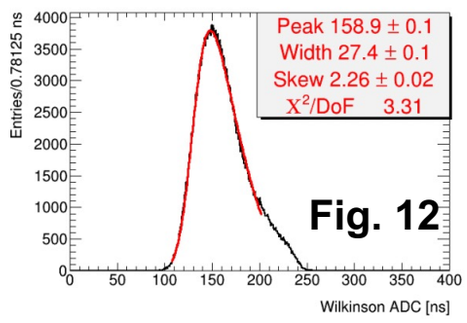

Fig. 12

Cosmic-ray tracking

- A time-to-space r(t) function is derived in situ [4,6].
- Fig. 13: tracks are parameterized as 2D straight lines in the plane perpendicular to the wires. Blue circles are reconstructed drift radii. Grey and white circles show tubes connected to different front-end boards.
- Fig 14: Geant4 [7] simulation is used to estimate the multiple Coulomb scattering correction. Correction to residual distribution is applied using a deconvolution [6].

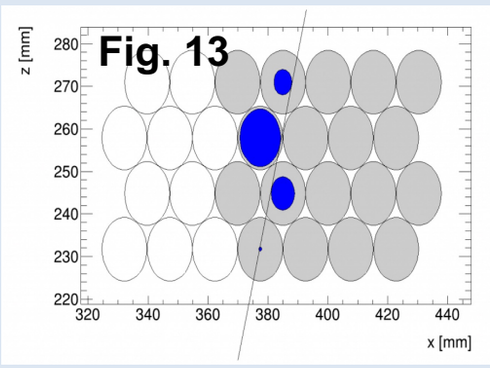

Fig. 13

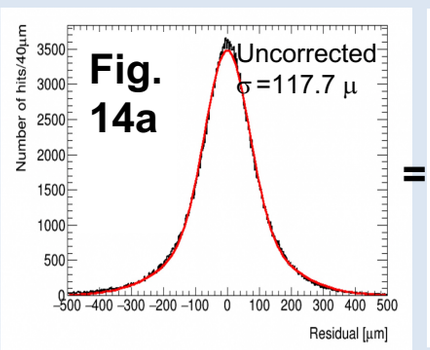

Fig. 14a

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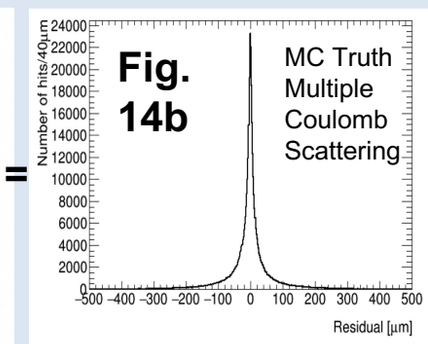

Fig. 14b

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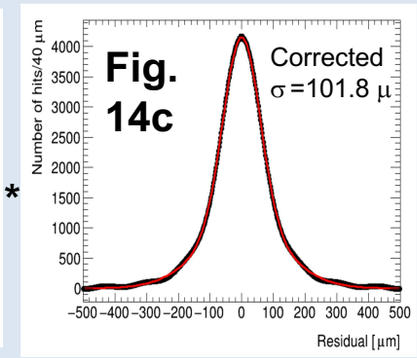

Fig. 14c

Chamber test results

- Fig. 15: Average tube noise measured at University of Michigan site.
- Fig. 16: average tube noise measured at MPI Munich site.
- Fig. 17: Tubes on average **99% efficient**. Each layer is 94.6% efficient due to geometric acceptance from tube walls. 6896 tubes (15 chambers) from University of Michigan shown.
- 24 of 28176 tubes had wire removed for various issues (wire slipped, wire snapped).
- Fig. 18: The observed (expected) **median single-hit resolution is 102.9±8.1 μm** (106 μm) [3]. (Fig. 15c shows one chamber). Results for 19 chambers produced at University of Michigan shown. MPI results are consistent.
- Fig 19: sMDT resolution as a function of drift radius is consistent with the ATLAS Run 2 MDT result [5].

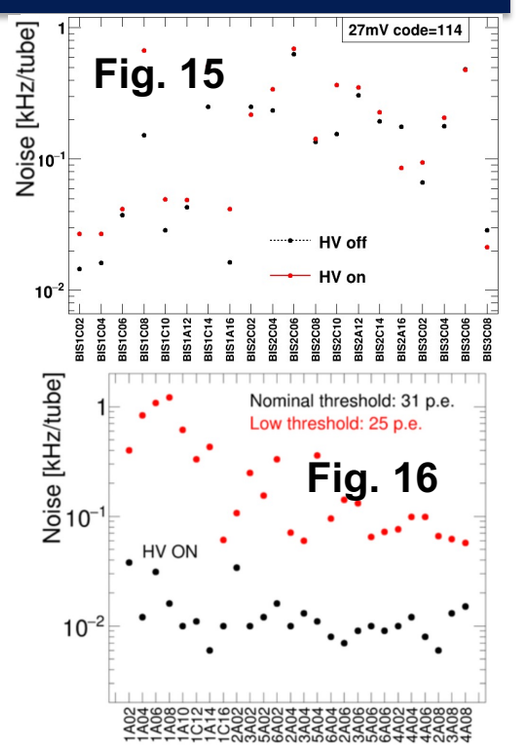

Fig. 15

Fig. 16

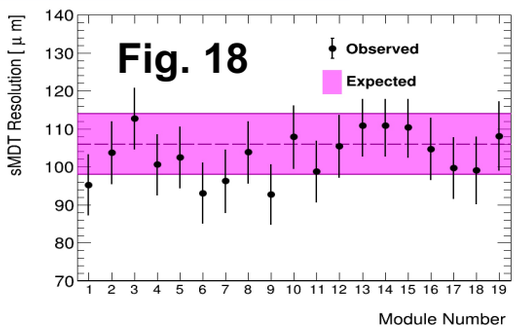

Fig. 18

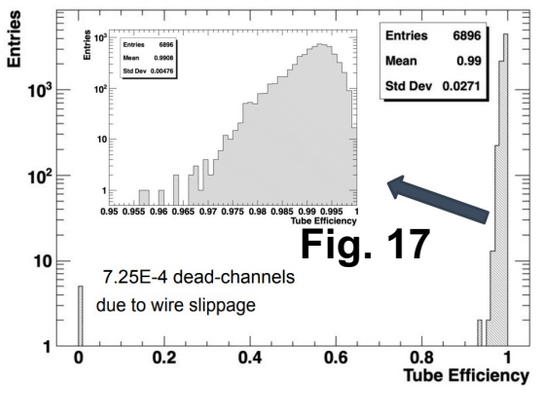

Fig. 17

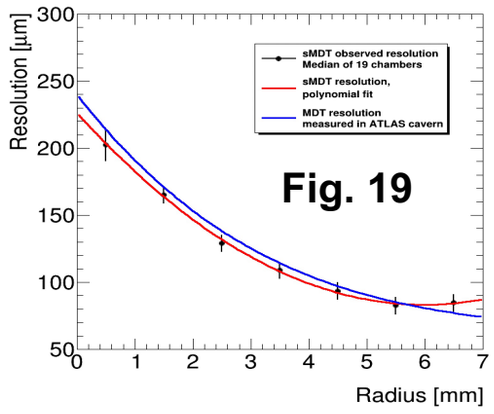

Fig. 19

References

[1] ATLAS collaboration, JINST 3 (2008) S08003
[2] ATLAS collaboration, ATLAS-TDR-026 (2017).
[3] H. Kroha, R. Fakhrutdinov and A. Kozhin, JINST 12 (2017) 12
[4] O. Kortner, H. Kroha, J. von Loeben, ATL-COM-MUON-2011-03
[5] ATLAS collaboration, JINST 14 (2019) P09011
[6] K. Nelson, Y. Guo, D. Amidei, E. Diehl, arXiv:2105.09263
[7] The Geant4 collaboration, Nucl. Inst. Meth. A. 506 (2003) 3 p. 250-303

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