New High-Precision Drift Tube Detectors for the ATLAS Muon Spectrometer

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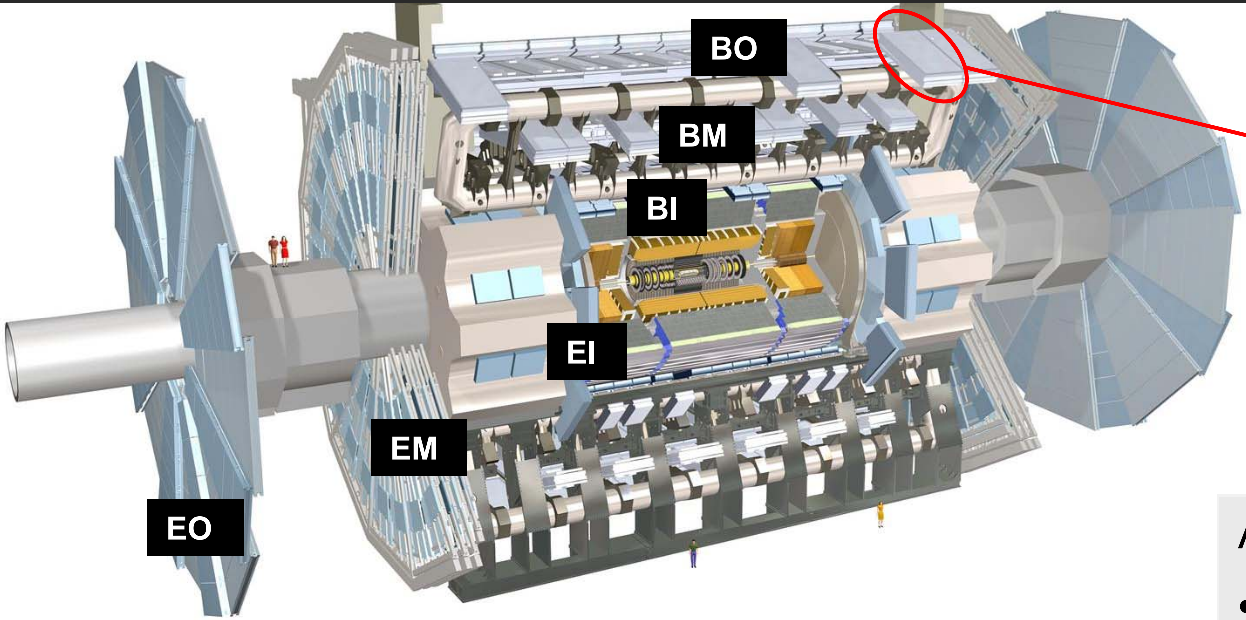
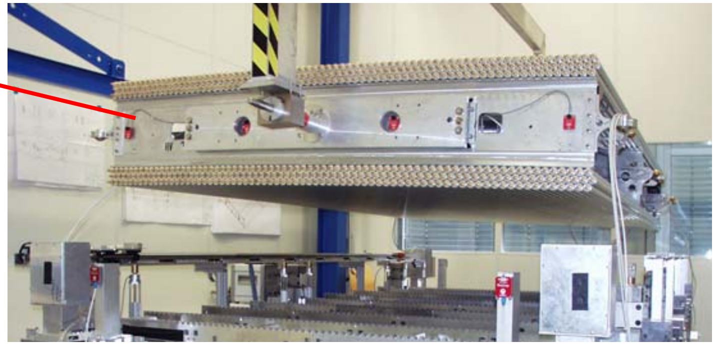
ATLAS Muon Spectrometer





1200 Monitored Drift Tube (MDT) chambers with 400k tubes

Mechanically robust, reliable and cost effective detectors for large-area precision muon tracking.

Optical alignment monitoring system with 30 μm track sagitta accuracy.

Combined with RPCs (barrel) and TGCs (endcaps) for triggering and coordinate measurement along tubes.

Unprecedentedly high neutron and gamma background in the ATLAS muon spectrometer with air-core toroid magnet system.

MDT rate capability up to 500 Hz/cm^2 and 30% occupancy (in forward region at the LHC design luminosity).

ATLAS MDT chambers:

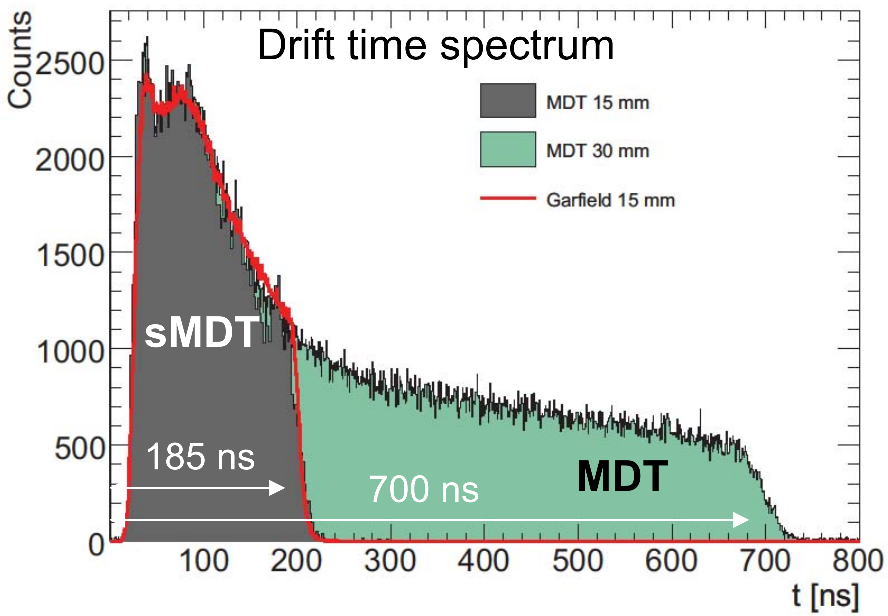
- 30 mm diameter aluminum drift tubes with 0.4 mm wall thickness
- 6 – 8 layers of drift tubes
- Ar:CO_2 (93:7) gas mixture at 3 bar and gas gain $2 \cdot 10^4$ to prevent aging
- Drift tube spatial resolution 80 μm
- Sense wire positioning accuracy 20 μm
- Chamber resolution 35 μm

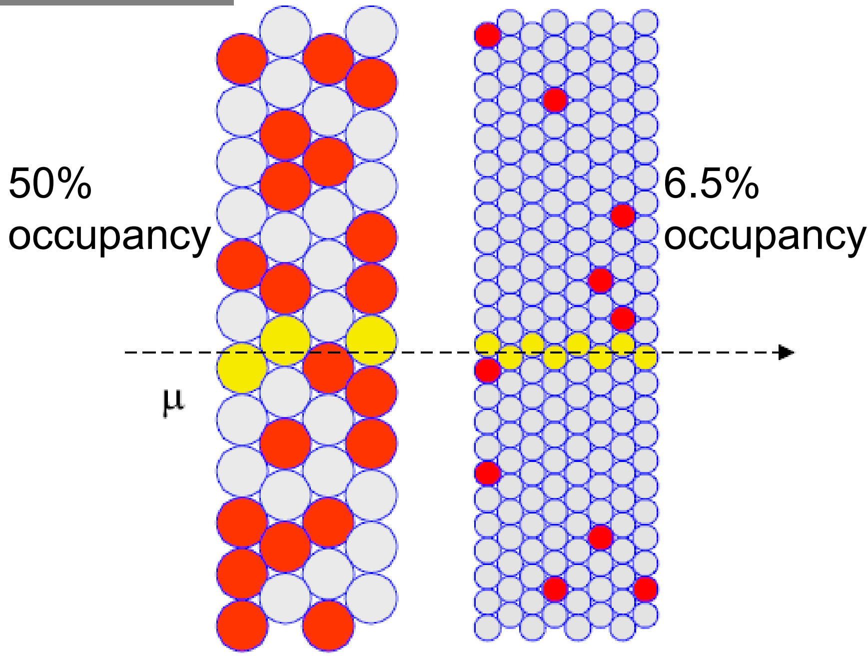
→ About 10 x higher background rates are expected at HL-LHC !

Small-Diameter Drift Tubes (sMDT) for High Rates

Reduction of drift tube diameter from 30 mm (MDT) to 15 mm (sMDT) at otherwise unchanged operating conditions allows for

- 8 x lower background occupancy (4 x shorter maximum drift time, 2 x smaller tube cross section) and
- 4 x reduction of the electronics deadtime (≈ max.drift time to avoid afterpulses) and thus of the masking of muon hits by preceeding background hits,
- 2 x as many tube layers or space for other (trigger) chambers within the same available detector volume, important for ATLAS upgrade



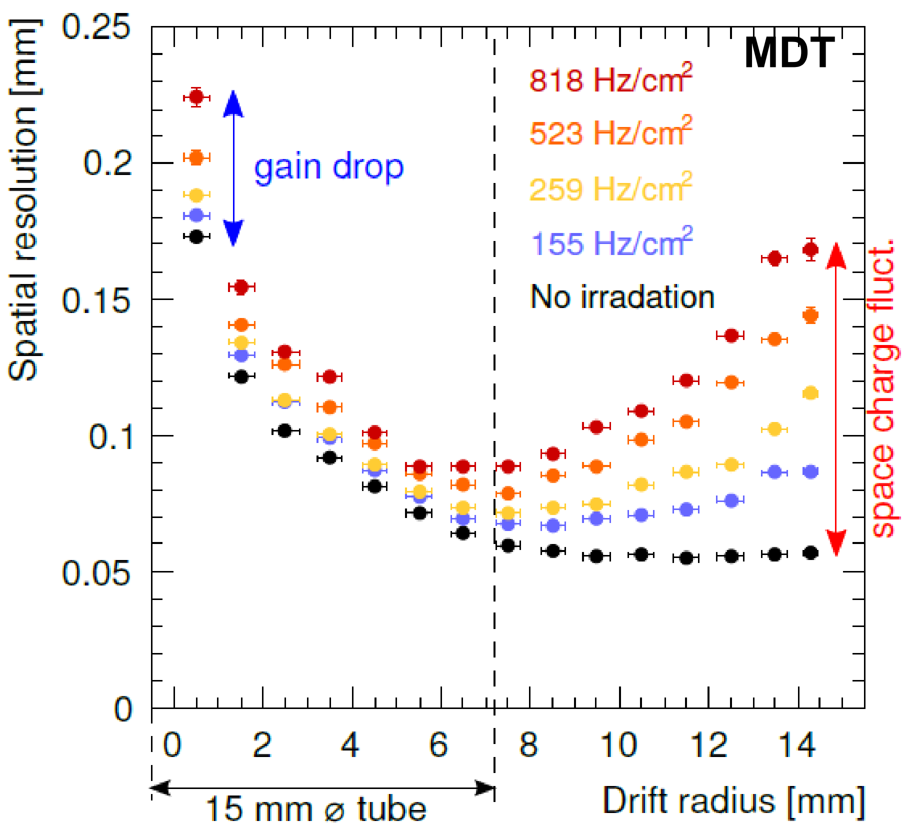


Space Charge Effects

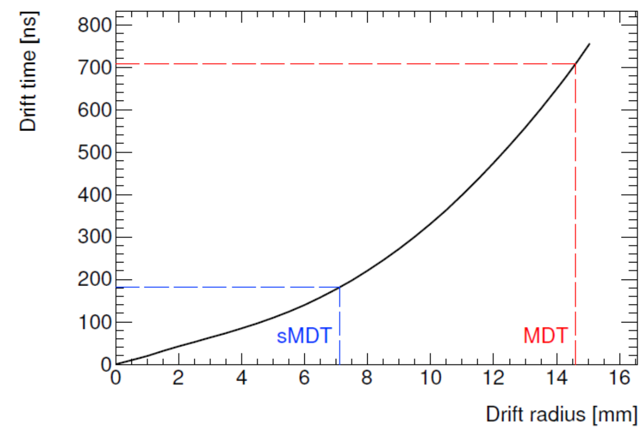
Why 15 mm tube diameter?

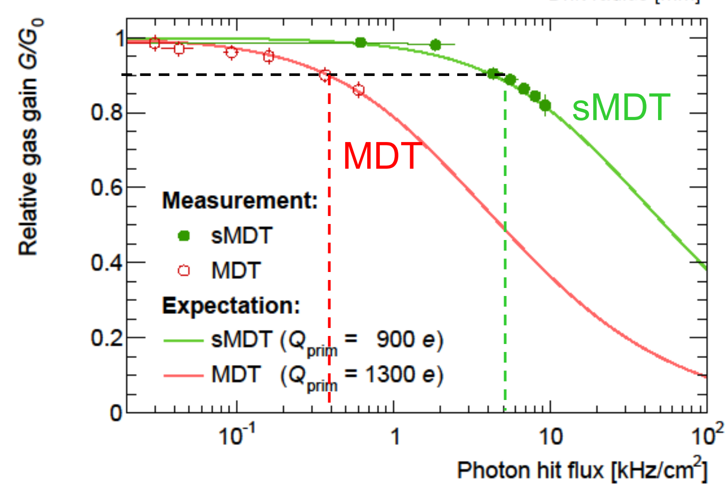
Space charge effects due to background radiation are strongly reduced in sMDT tubes:

- Effect of space charge fluctuations eliminated for r < 7.5 mm due to almost linear r-t relation.
- Gain loss suppressed proportional to r^3 and less primary ionization.



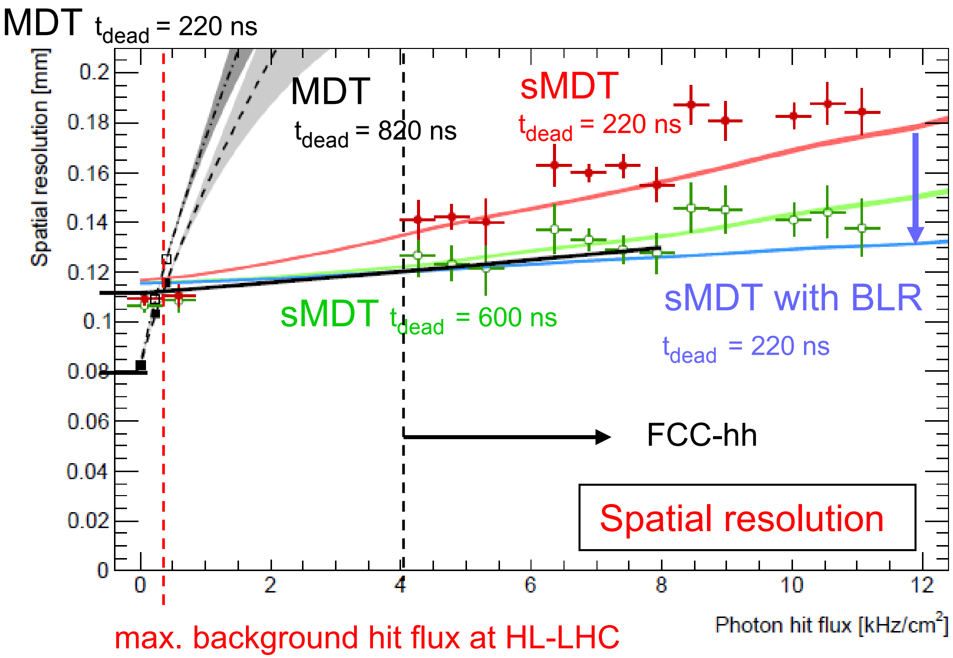
Measurements performed at the CERN Gamma Irradiation Facility

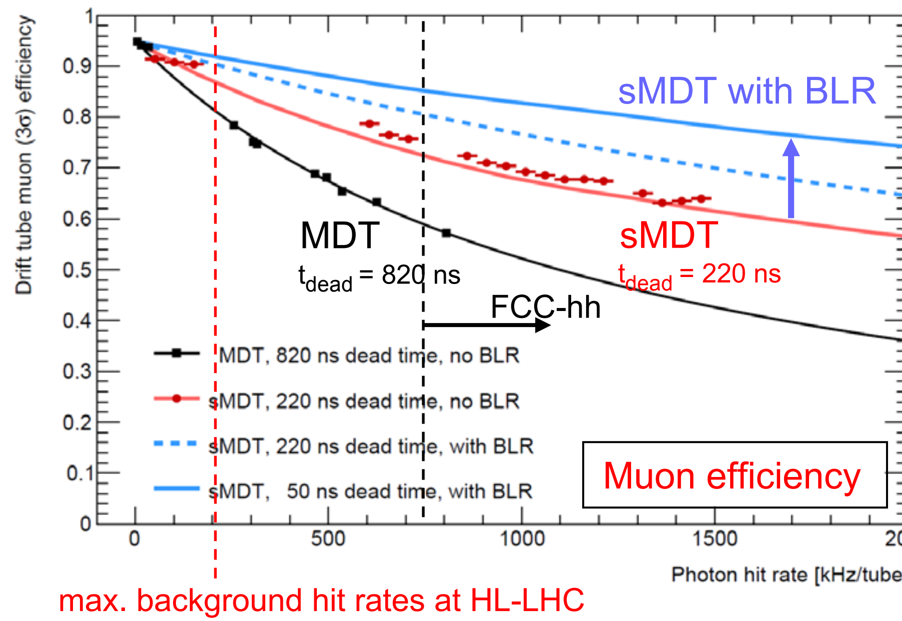




Rate Capability of sMDT Chambers

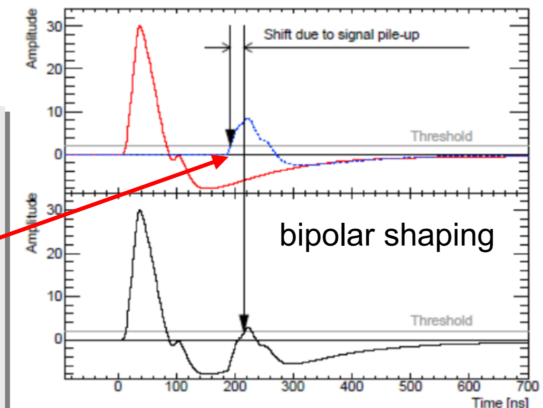
Measurements at the CERN Gamma Irradiation Facility (GIF) with 0.5 TBq ^{137}Cs source and cosmic muons using standard MDT readout electronics (bipolar shaping, 220 ns min., 820 ns max. adjustable deadtime):



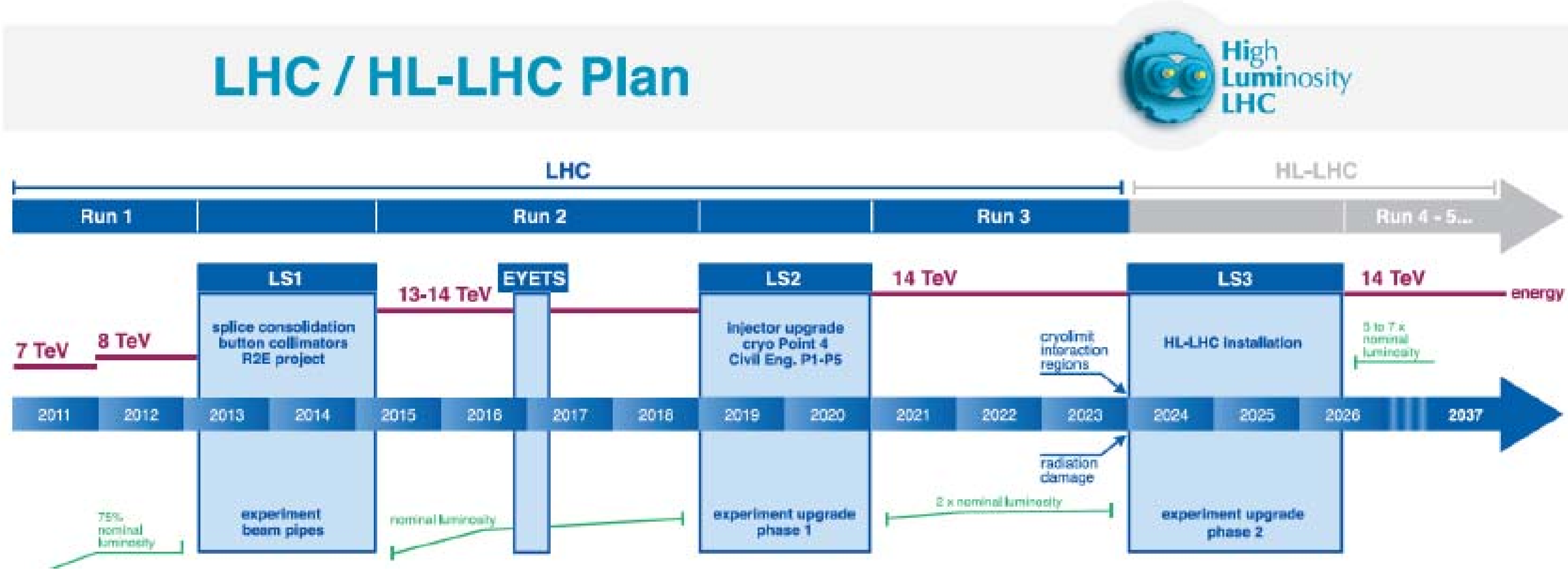


Curves: predictions from full simulation of drift tube and electronics response

- Rate capability of sMDT tubes exceeds the one of MDTs by an order of magnitude.
- By far sufficient for the highest background regions in ATLAS at HL-LHC.
- sMDT high-rate performance limited by signal pile-up effects of the readout electronics.
- Signal pile-up effects can be suppressed for future applications by employing additional fast active baseline restoration (BLR) under development at MPI Munich



ATLAS Muon Chamber Upgrades



2014 (LS1):
2 sMDT + RPC chambers
to improve acceptance and momentum resolution (by factor 2 – 4 at 1 TeV) in the bottom barrel sector.
Pilot project for phase 1.
In operation since Run 2.

Jan.– Mar. 2017:
12 sMDT chambers
to improve the momentum resolution (by factor of 2 at 1 TeV) in the regions of the detector feet.

4500 drift tubes.

2019/20 (LS2):
16 sMDT + 32 RPC chambers
to improve the trigger selectivity and the rate capability in the barrel inner layer.
Pilot project for phase 2 upgrade.

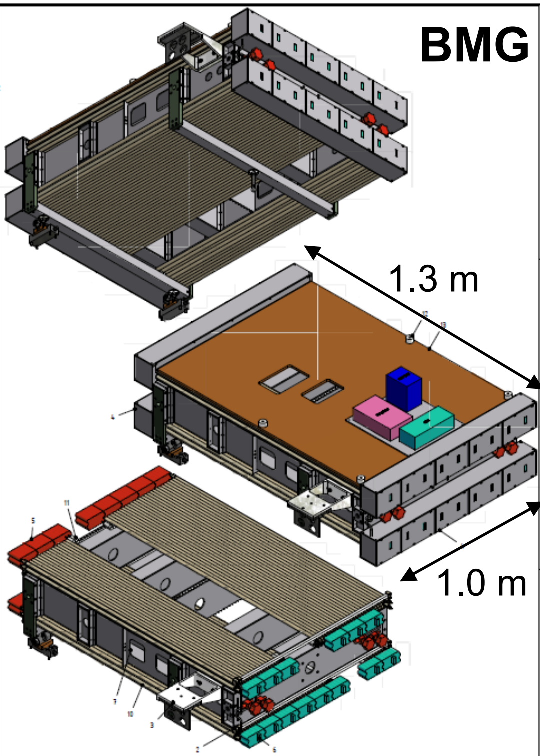
9600 drift tubes.

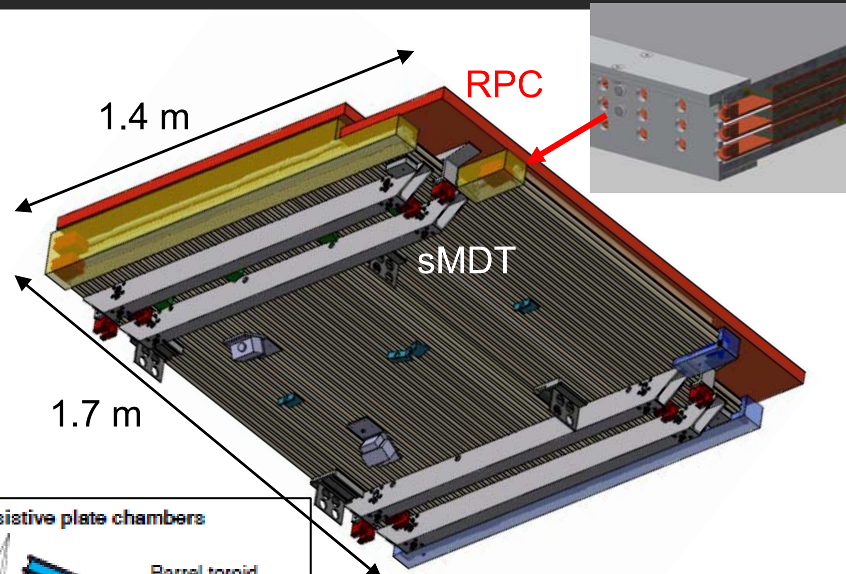
2024-26 (LS3):
96 sMDT + 276 RPC chambers
for the barrel inner layer to increase the robustness of the barrel muon trigger system.

48000 drift tubes.

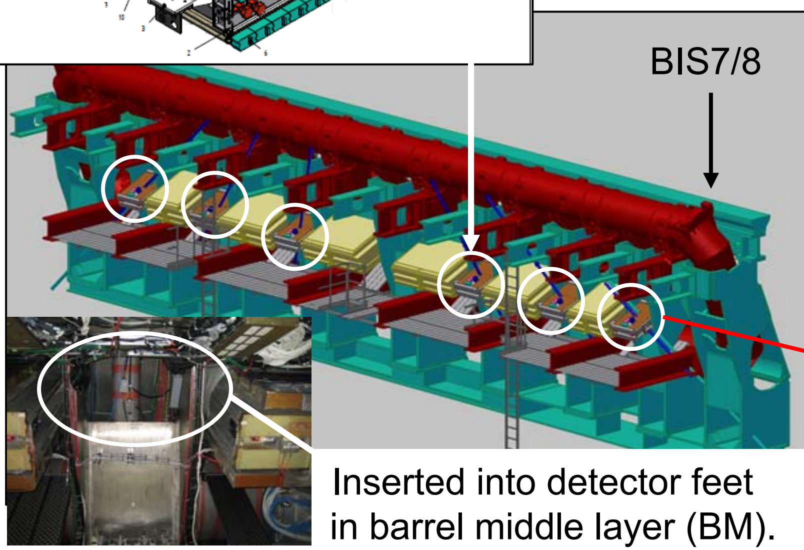
Collaboration between MPI Munich and IHEP Protvino

sMDT Chambers for ATLAS

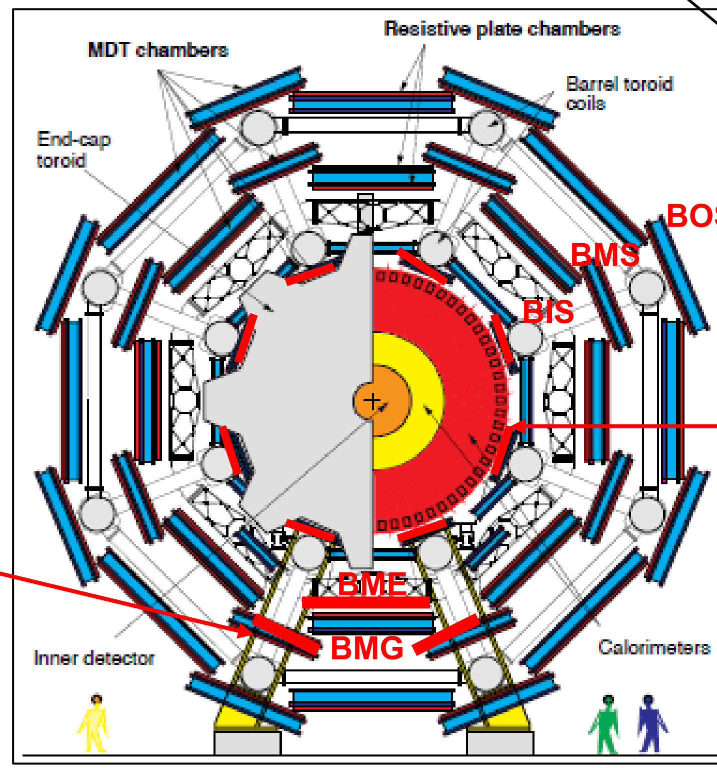


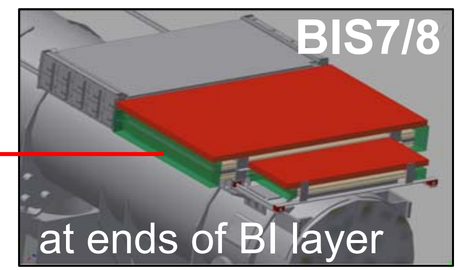


Thin modules of sMDT and triple thin-gap RPC for barrel inner layer (BI).



Inserted into detector feet in barrel middle layer (BM).

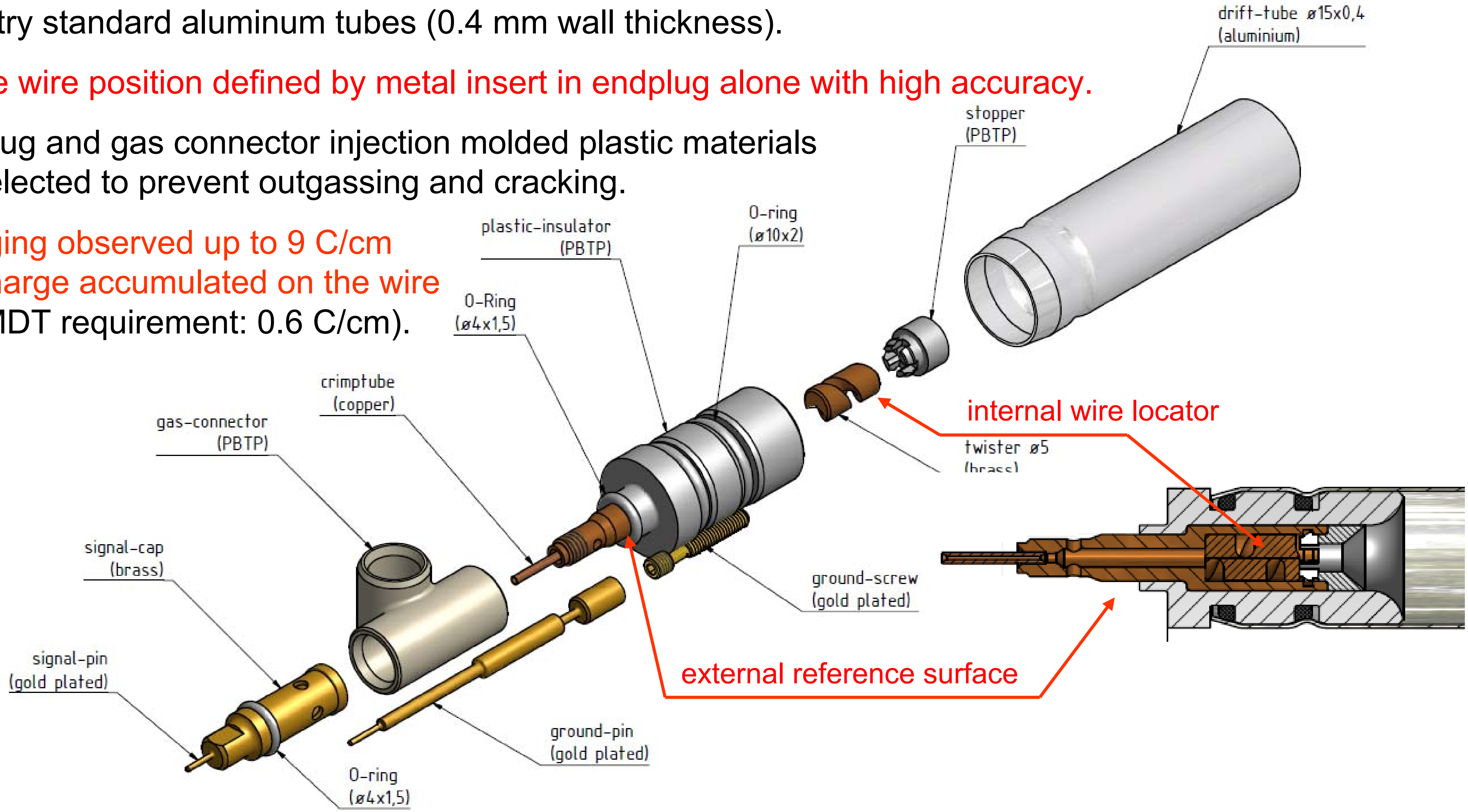




Design for replacement of **complete BIS layer** for HL-LHC (Phase-2) is very simular to BIS7/8.

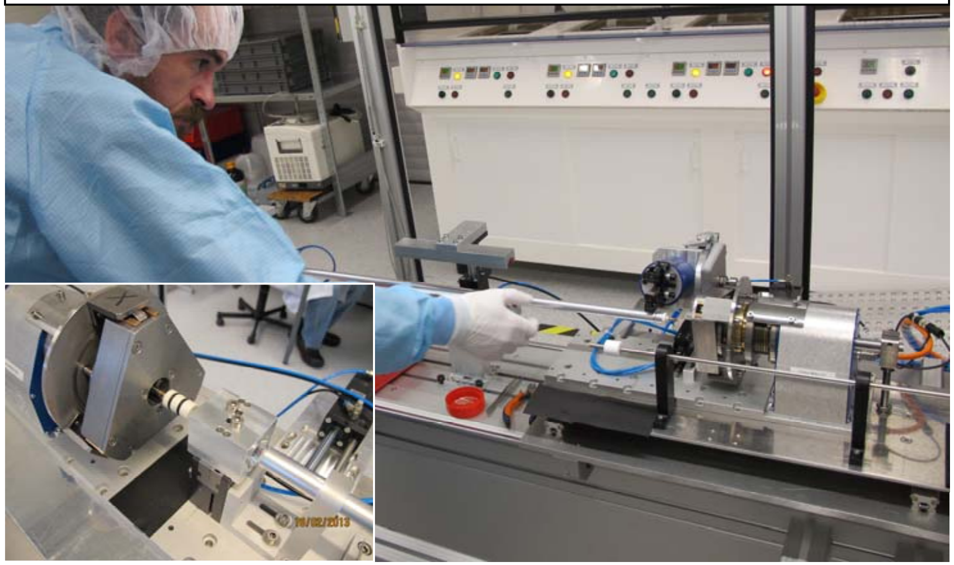
sMDT Drift Tube Design

- Design and assembly procedures optimized for mass production.
- Simple, low-cost drift tube design ensuring high reliability.
- Industry standard aluminum tubes (0.4 mm wall thickness).
- Sense wire position defined by metal insert in endplug alone with high accuracy.
- Endplug and gas connector injection molded plastic materials selected to prevent outgassing and cracking.
- No aging observed up to 9 C/cm charge accumulated on the wire (MDT requirement: 0.6 C/cm).



Semi-Automated Drift Tube Assembly

Endplug sealing and wire insertion with air-flow



Wire tensioning and crimping + tension measurement

HV and Helium leak test at 3 bar

Technicians from IHEP Protvino in temperature controlled clean rooms, class 1000, at the Max-Planck-Institute in Munich: 5000 BMG tubes.

Typically 50 tubes per day, up to 100 per day possible.

Stringent requirements:

- Wire tension 350 ± 15 g $\rightarrow$ wire sag ± 10 µm
- Leakage current under HV < 2 nA/m
- Gas leak rate at 3 bar < 10^{-8} bar l/s

Total failure rate < 4%.

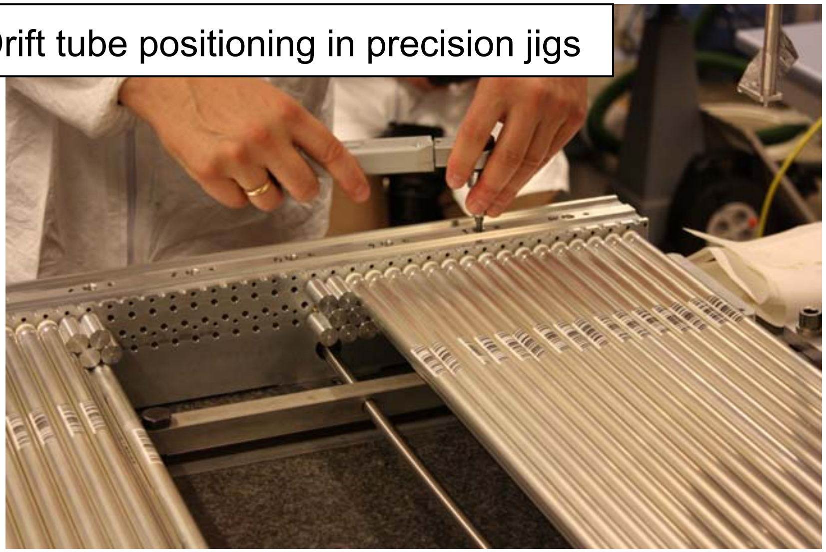
BMG Spacer Frame and Supports

Stiff and mechanically very precise aluminum spacer frame for BMG chambers constructed at IHEP Protvino

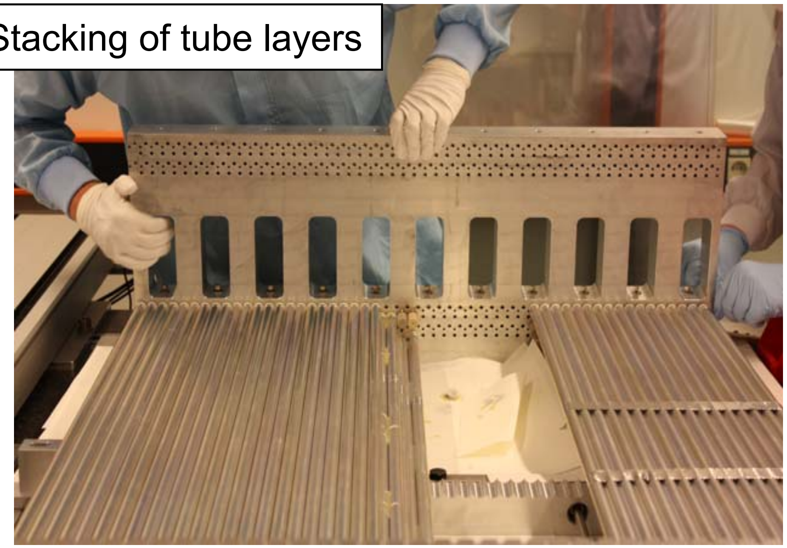
BMG Chamber Assembly

Designed for mass production of chambers with large numbers of tube layers:

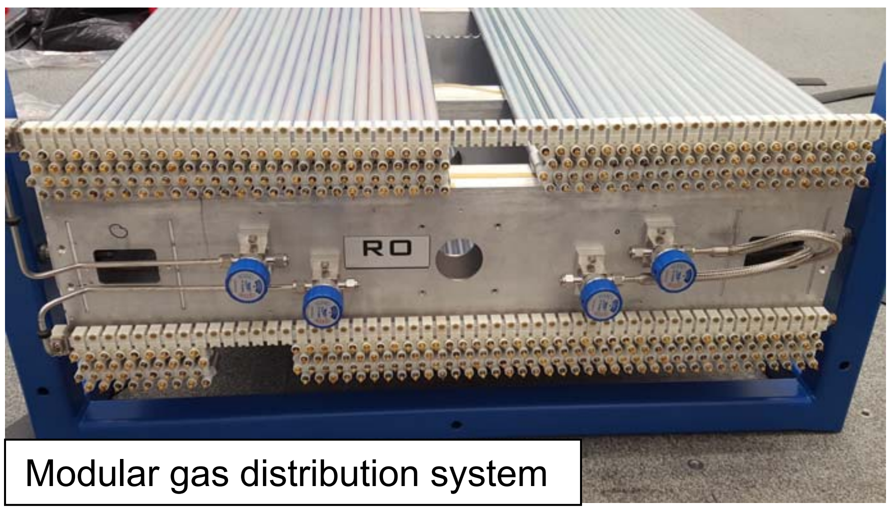
Assembly of sMDT within one working day, independent of the number of layers (MDTs: 1 layer per day).



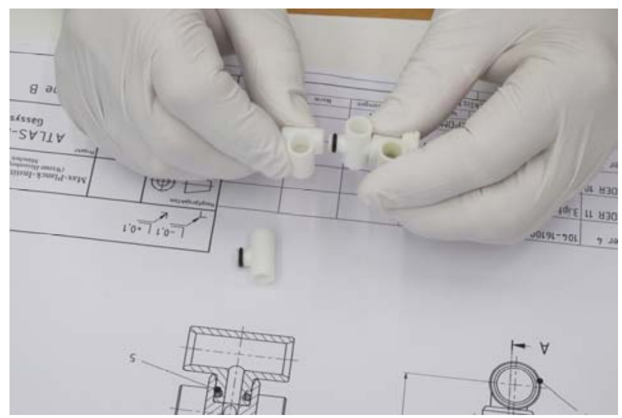
Drift tube positioning in precision jigs



Stacking of tube layers

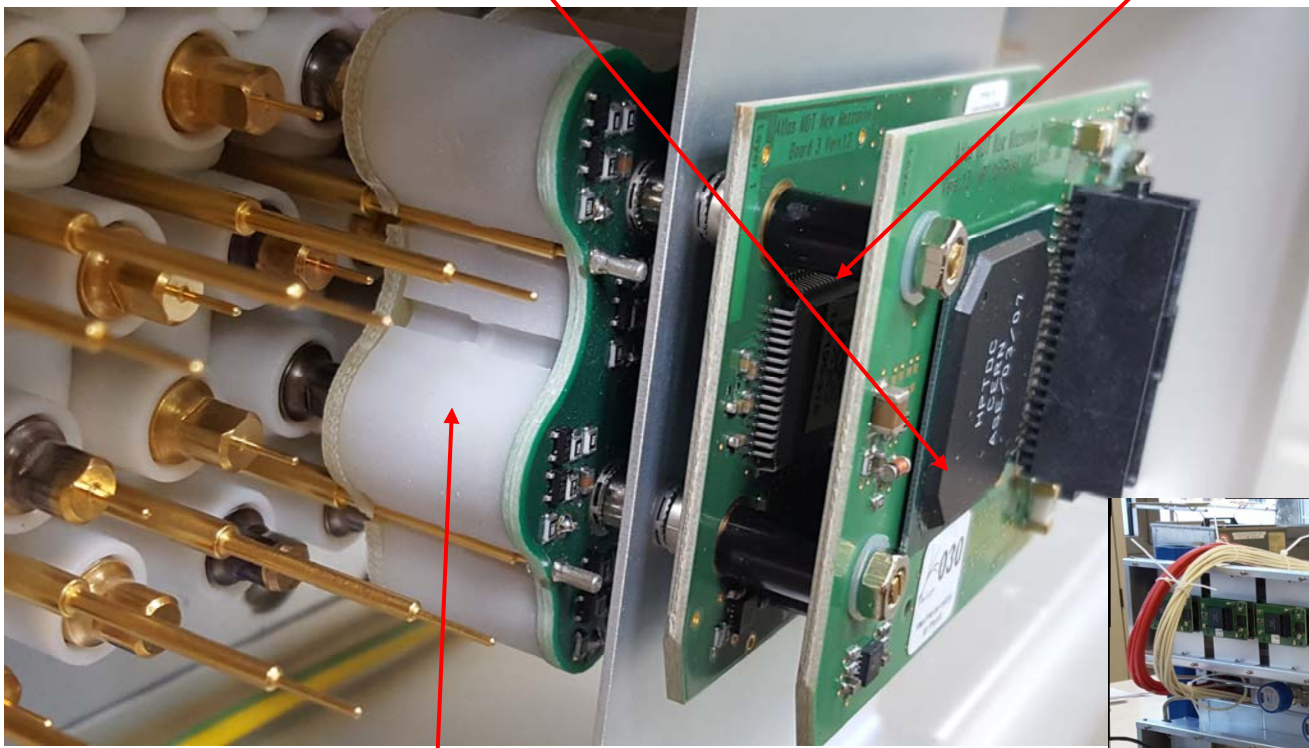


Modular gas distribution system

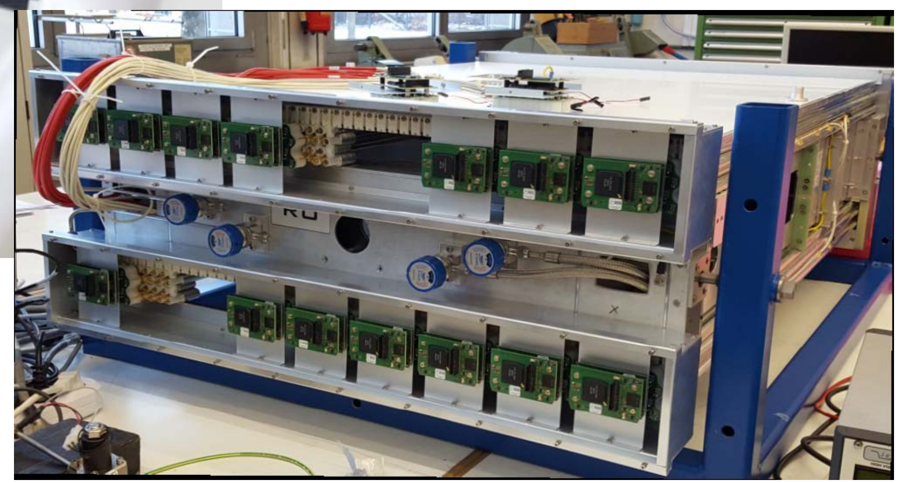


Developed at MPI Munich: 4 x higher channel density than for MDTs.

Three existing 8-channel amplifier-shaper-discriminator (ASD) chips combined with new TDC chip (CERN HPTDC for BMG and BIS7/8).

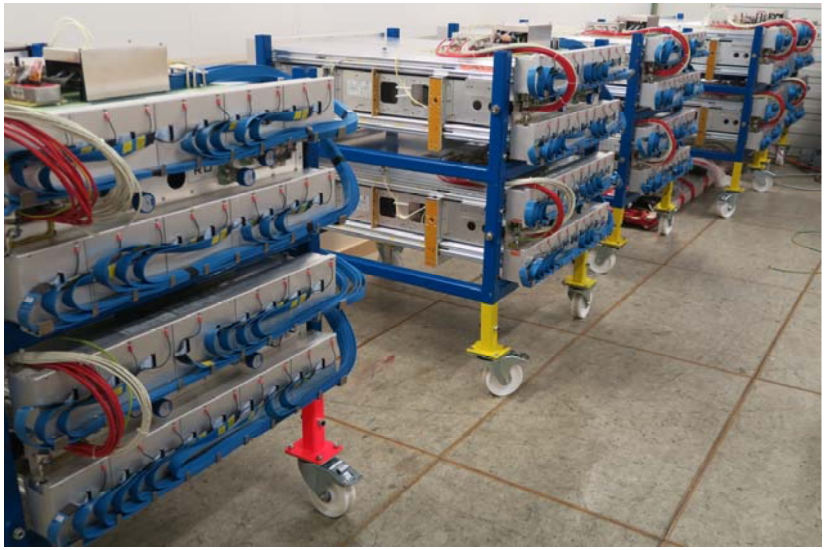


New ASD and TDC chips under development for Phase-2 Upgrade.

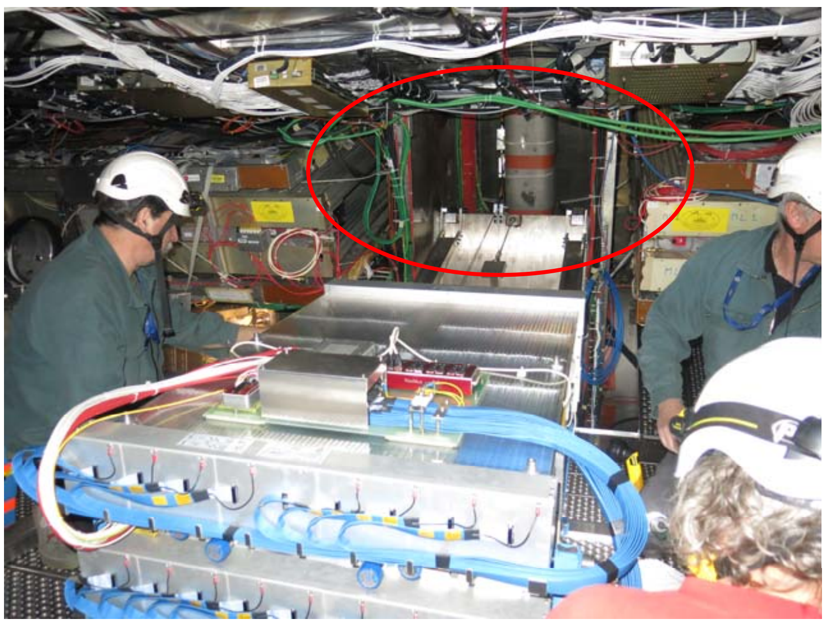


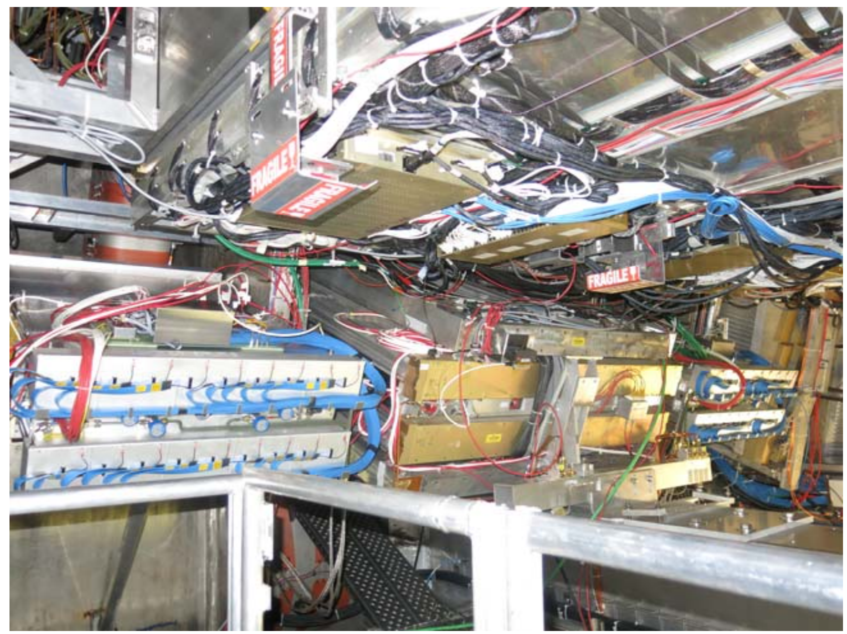
Encapsulated coupling capacitors for op. at 2730 V

BMG sMDT Chamber Installation in ATLAS in January 2017

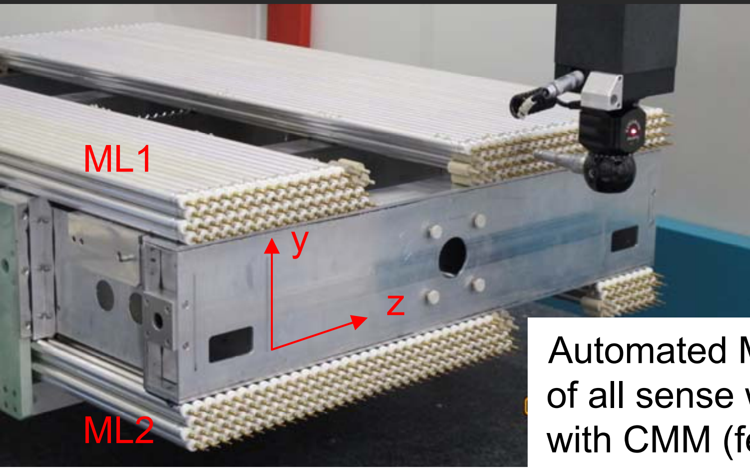


12 BMG chambers inserted into the detector feet in the barrel middle layer.
Only sMDT chambers fit into the small available space.

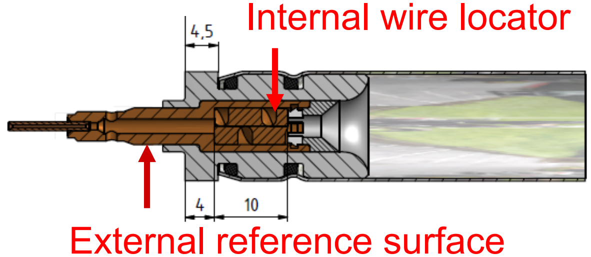


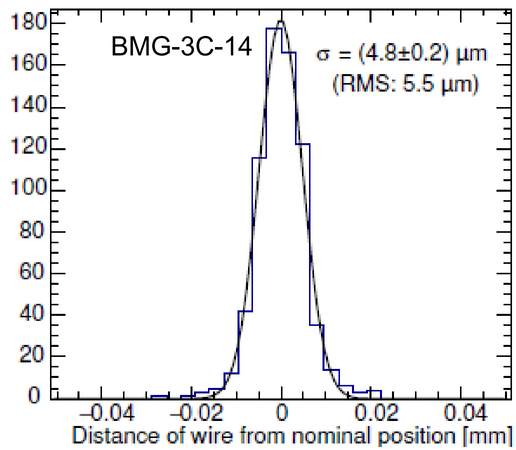


Wire Positioning Accuracy in BMG chambers



Automated Measurement of all sense wire positions with CMM (feeler gauge).





Record wire pos. precision

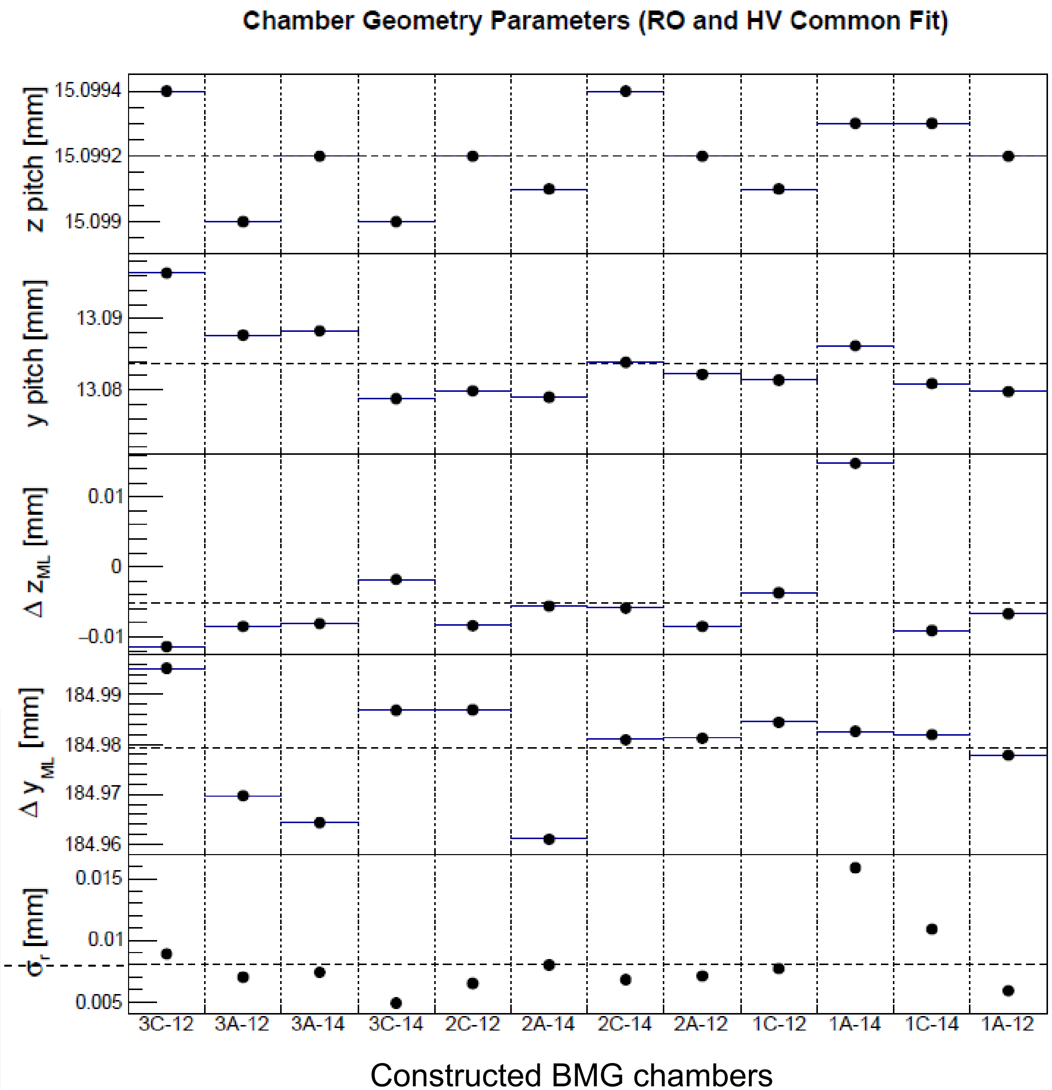
5 µm (rms).

Average of 12 BMG:

8 µm (rms).

Requirement (as MDTs):

20 µm (rms).



Dashed lines: nominal parameters

Conclusions

- Small-diameter drift-tube (sMDT) chambers are very well suited for upgrades of the ATLAS detector with respect to space constraints and rate capability at HL-LHC.

  They will be used for the Phase 2 ATLAS muon tracking detector upgrades.

  First chambers of this type have been installed in ATLAS in the 2013 and the 2016/17 LHC shutdowns.

  The construction of the next 16 chambers for installation in the 2019/18 shutdown has started.
- They inherit the high reliability of the ATLAS MDT chambers and exceed their mechanical precision.
- The rate capability reaches far beyond the HL-LHC requirements.
- sMDT chambers therefore are also ideal, cost-effective precision muon tracking detectors for future high-energy and high-luminosity hadron colliders like FCC-hh.
- The drift tubes and the assembly procedure have been designed for large-scale chamber production.