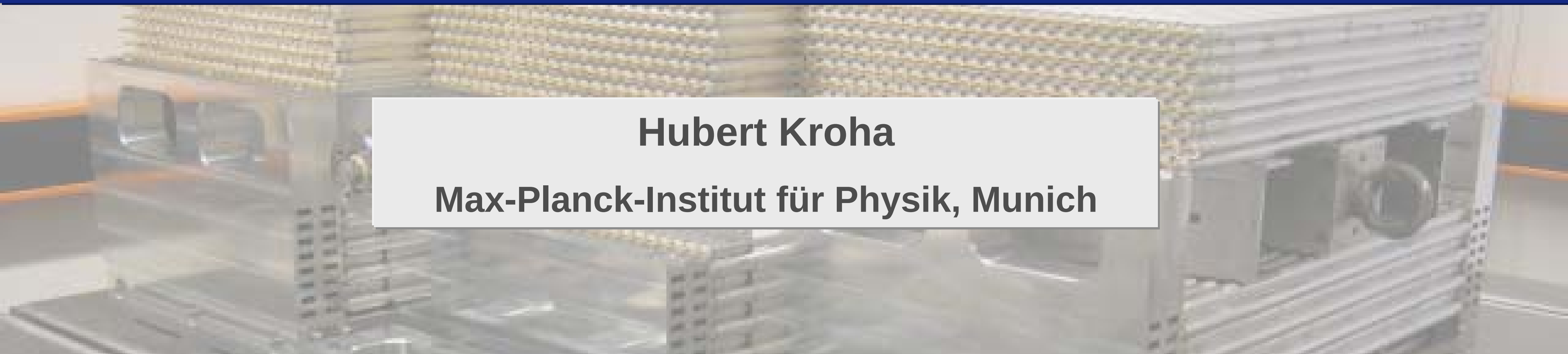
Construction and Test of New Precision Drift Tube Chambers for the ATLAS Muon Spectrometer



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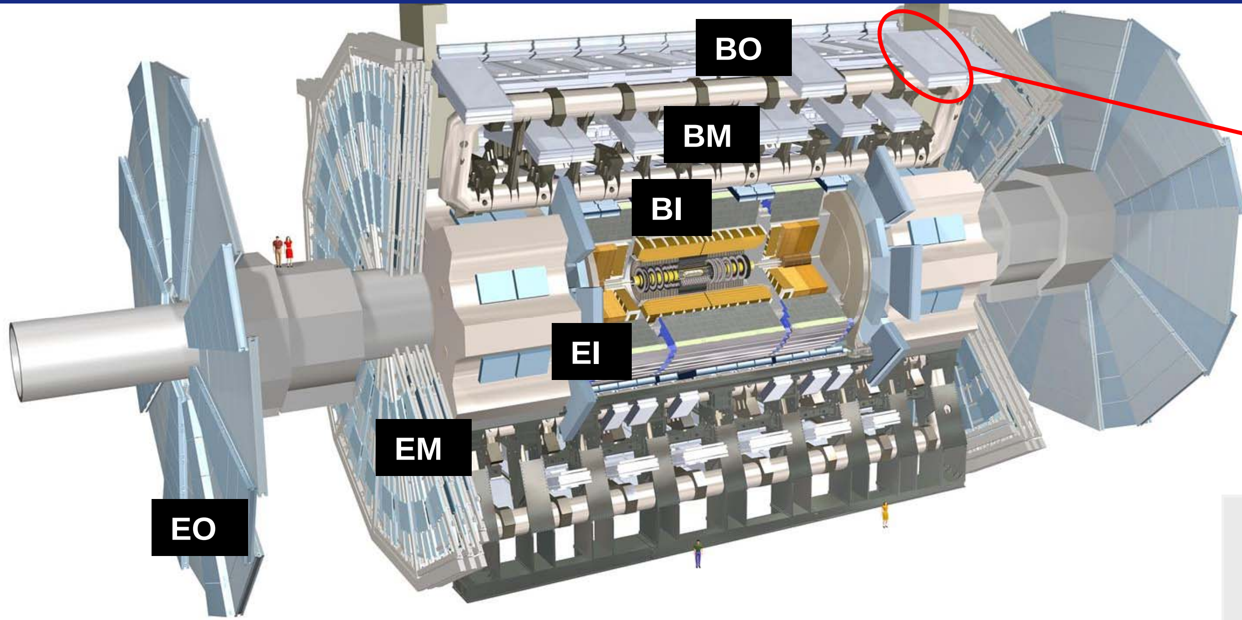
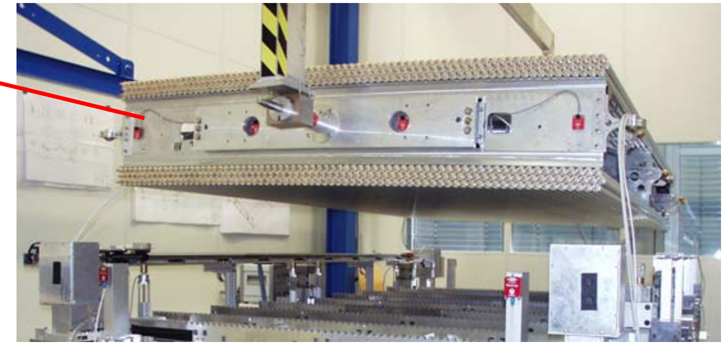
ATLAS Muon Spectrometer





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/cm² 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 $2\cdot10^4$ to prevent aging
- Drift tube spatial resolution 80 μm
- Sense wire positioning accuracy 20 μm
- Chamber resolution 35 μm

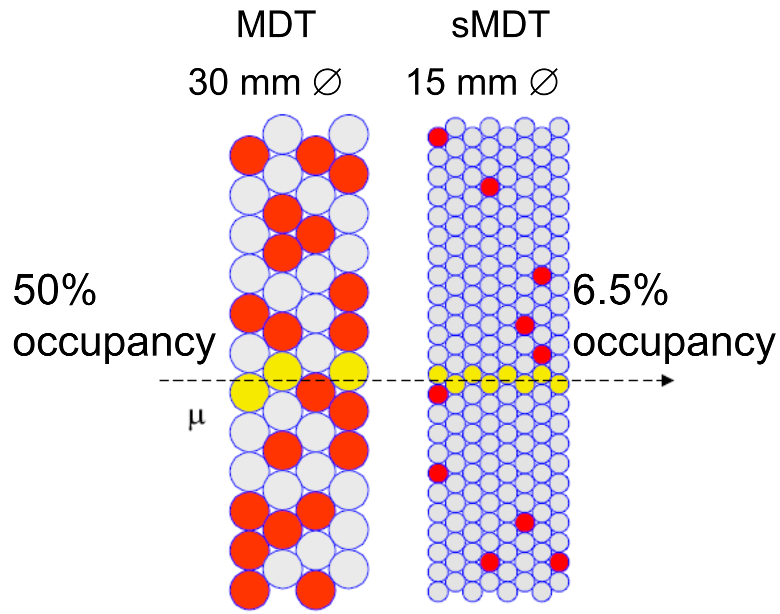
About 10 x higher background rates are expected at HL-LHC !

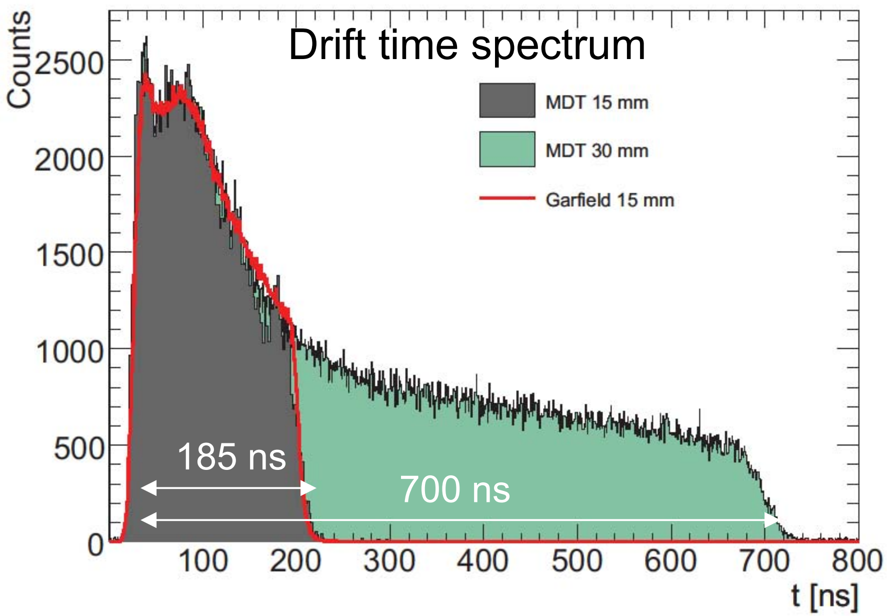
Small Diameter Drift Tubes (sMDT) for High Rates

By reducing the drift tube diameter
from 30 mm (MDT) to 15 mm (sMDT)
at otherwise the unchanged operating conditions and while keeping all advantages of the MDTs as well as their services:

- 8 x lower background occupancy
(4 x shorter maximum drift time, 2 x smaller tube cross section).

- Electronics deadtime (≈ max.drift time because of afterpulses) can be reduced by a factor of 4, thus the masking of muon hits by preceeding background hits.





- Also, space for twice as many tube layers within the same available detector volume,

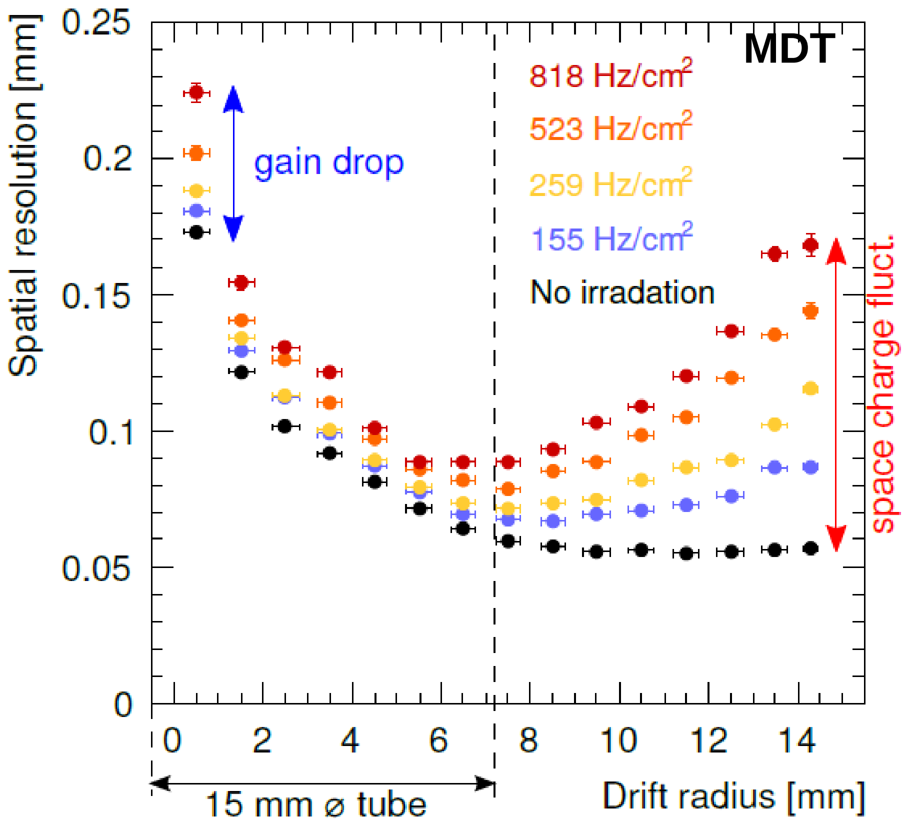
allowing for additional increase in muon tracking efficiency and resolution.

Space Charge Effects

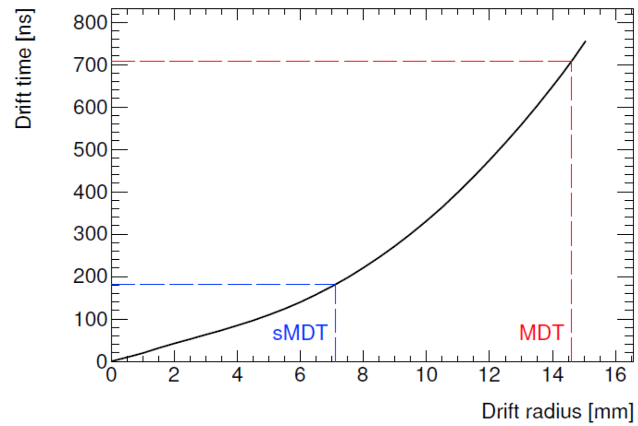
Why 15 mm tube diameter?

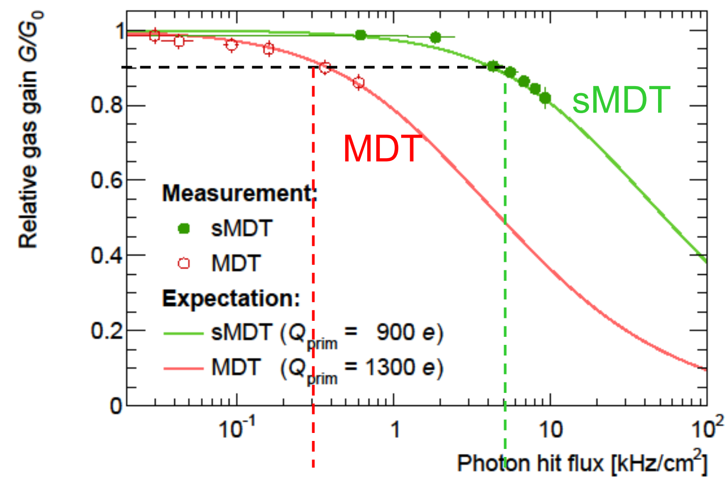
Space charge effects due to background radiation are strongly reduced in sMDT tubes:

- 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

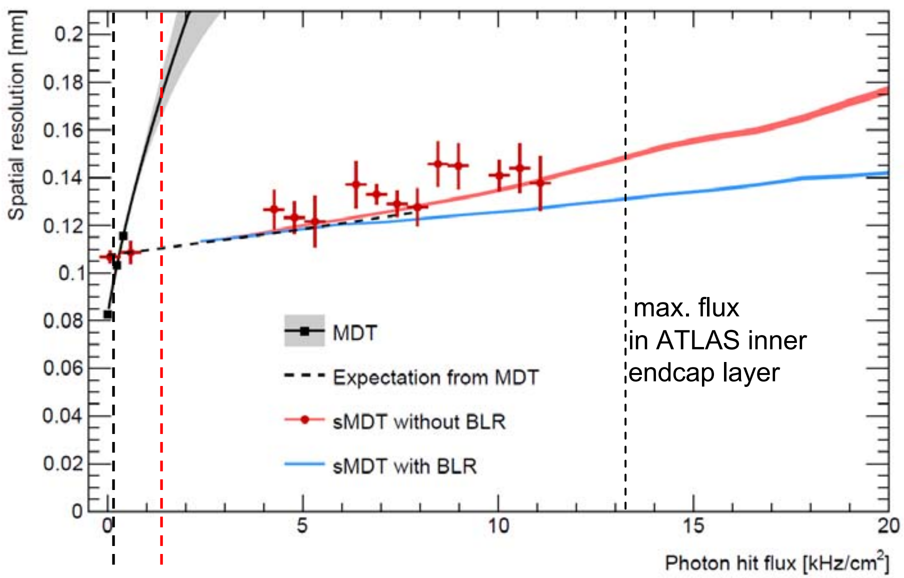




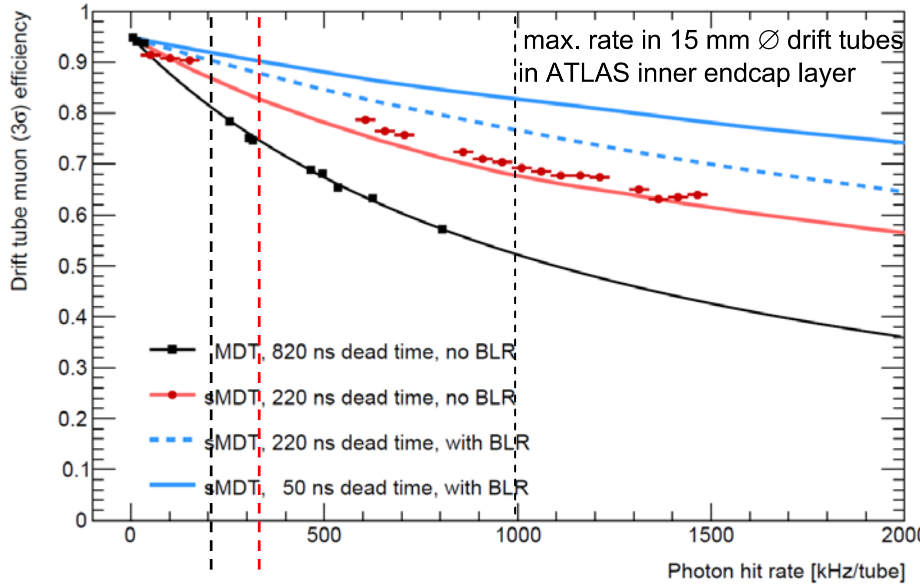
Max. rates at HL-LHC in **MDT** **sMDT**

Rate Capability of sMDT Drift Tubes

Measurements at the CERN Gamma Irradiation Facility with standard MDT readout electronics, compared to detailed simulations of drift tube and electronics response (bipolar shaping, 220 ns mininium deadtime):

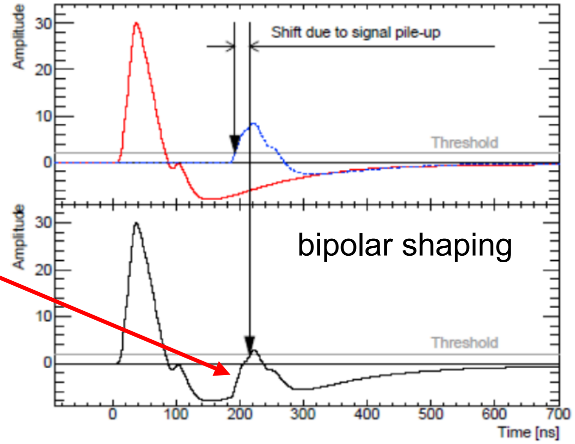


ATLAS **MDT** **sMDT** max. background flux at HL-LHC (barrel region)

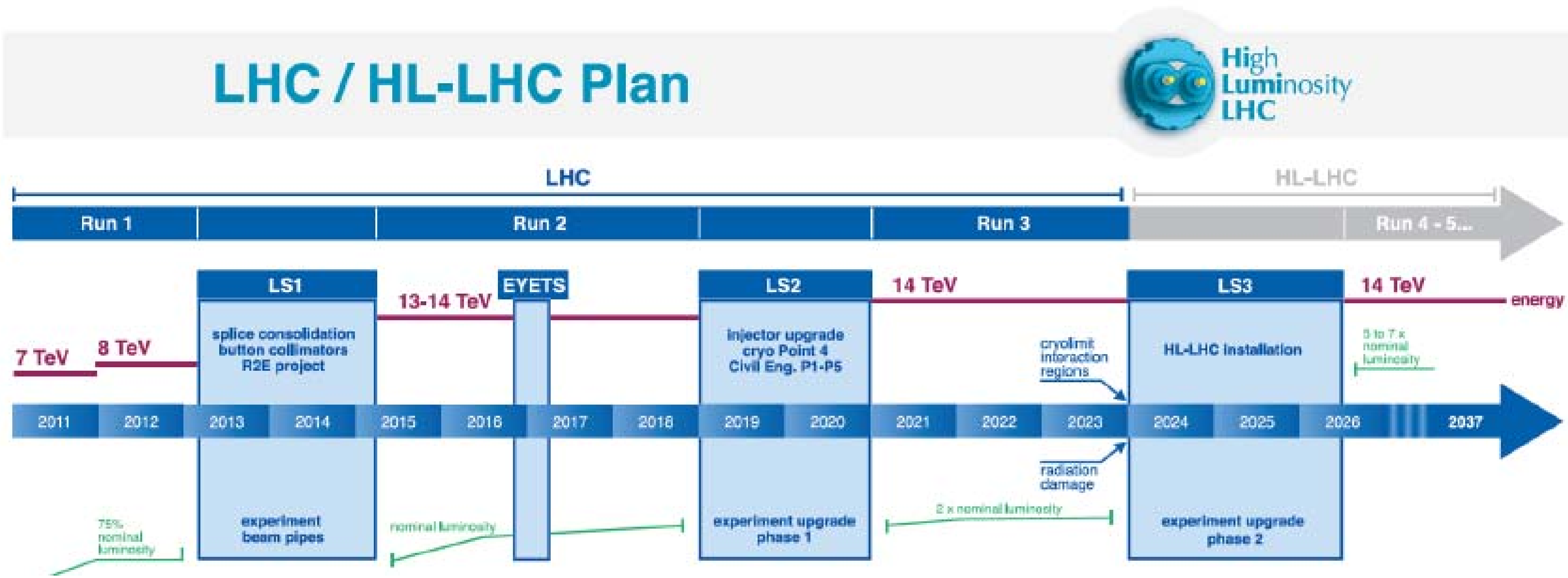


ATLAS **MDT** **sMDT** max. rates in ATLAS at HL-LHC

- Rate capability of sMDT tubes exceeds the one of MDTs by one order of magnitude.
- Sufficient for the highest background regions in ATLAS at HL-LHC as well as for most of the muon detector coverage at future hadron colliders.
- sMDT high-rate performance limited by readout electronics: signal pile-up effects
- Signal pile-up effects can be suppressed for future applications by employing additional fast active baseline restoration (BLR) → see Poster # 30 (P.Gadow)



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 upgrade.
In operation since Run 2.

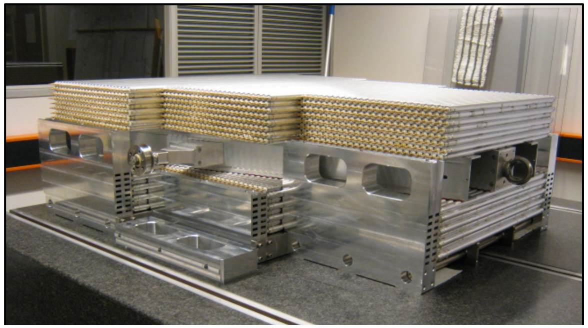
Jan.– Mar. 2017:
12 sMDT chambers
to improve the momentum resolution (by factor of 2 at 1 TeV) in the regions of the detector feet.

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

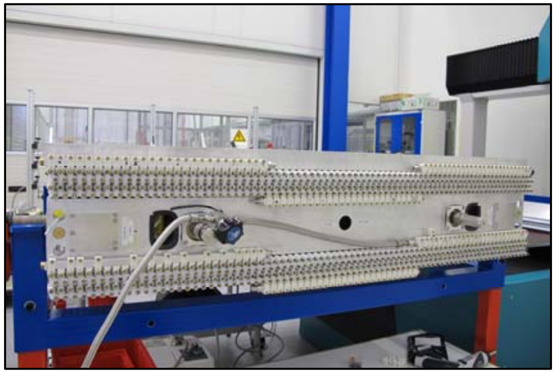
2024-26 (LS3):
96 sMDT + RPC chambers
for the barrel inner layer to increase the robustness of the barrel muon trigger system.

MDT and sMDT chambers included in the L0 muon trigger
to increase the trigger momentum resolution and selectivity.

sMDT Chambers for ATLAS

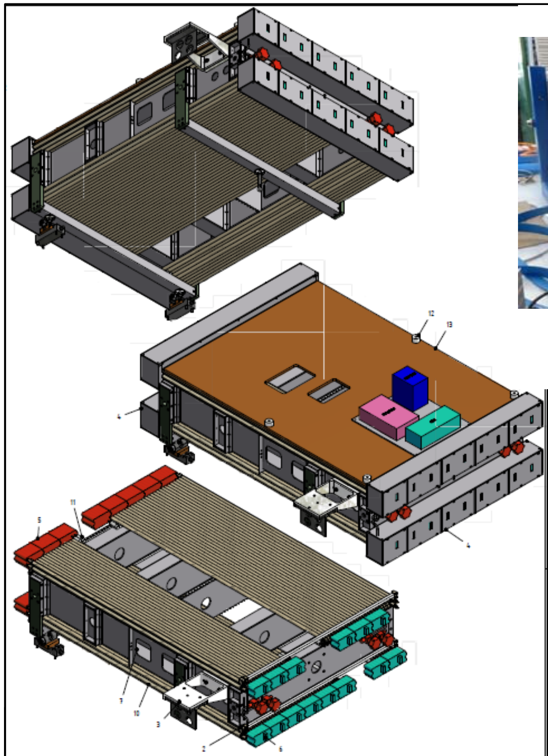


Construction of 16-layer trapezoidal prototype chamber for the inner endcap layer in 2010

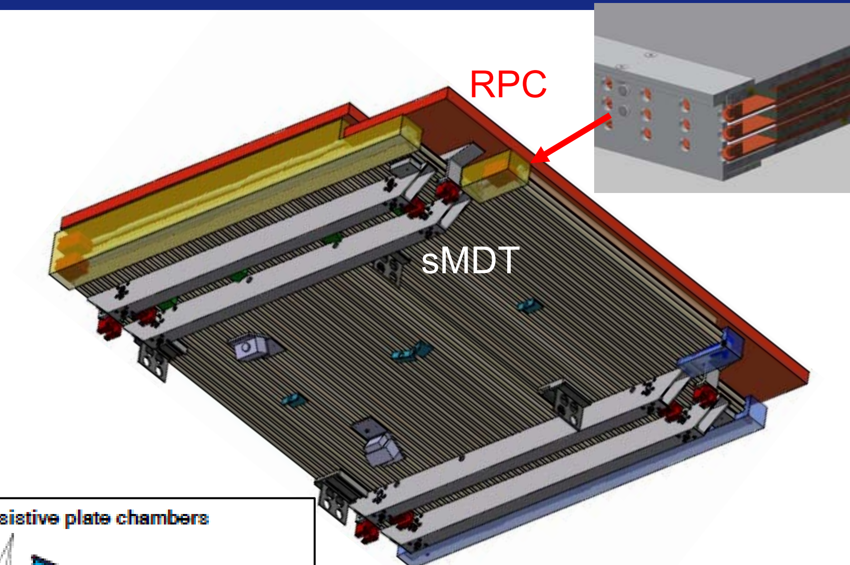


Installation of two 8-layer chambers in the bottom barrel sector in 2014

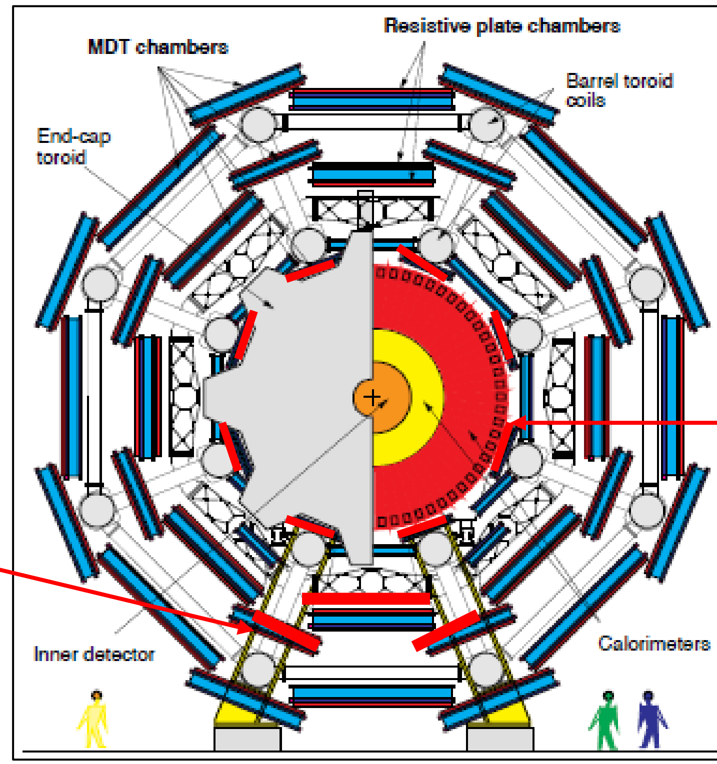
sMDT Chambers for ATLAS

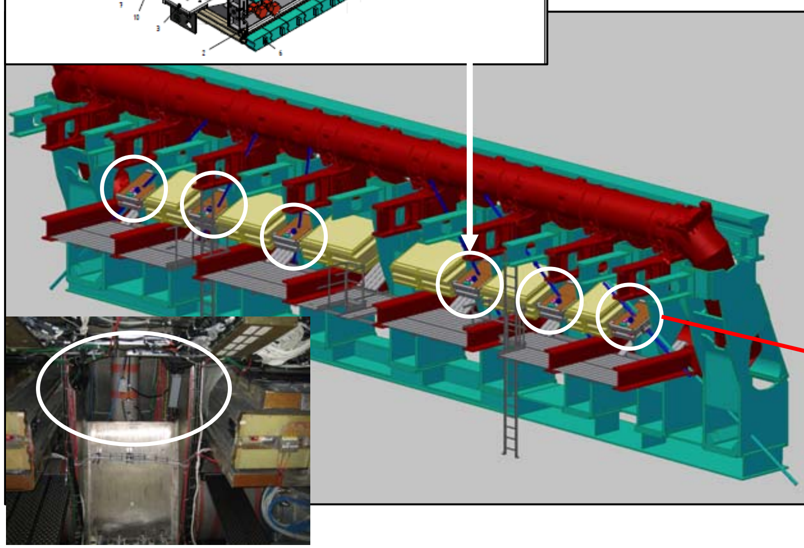


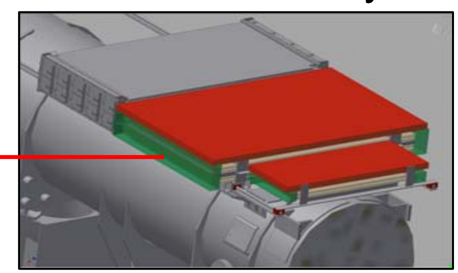
Under construction 2015/16 for the feet regions



Integrated design of sMDT and triple thin-gap RPC for barrel inner layer

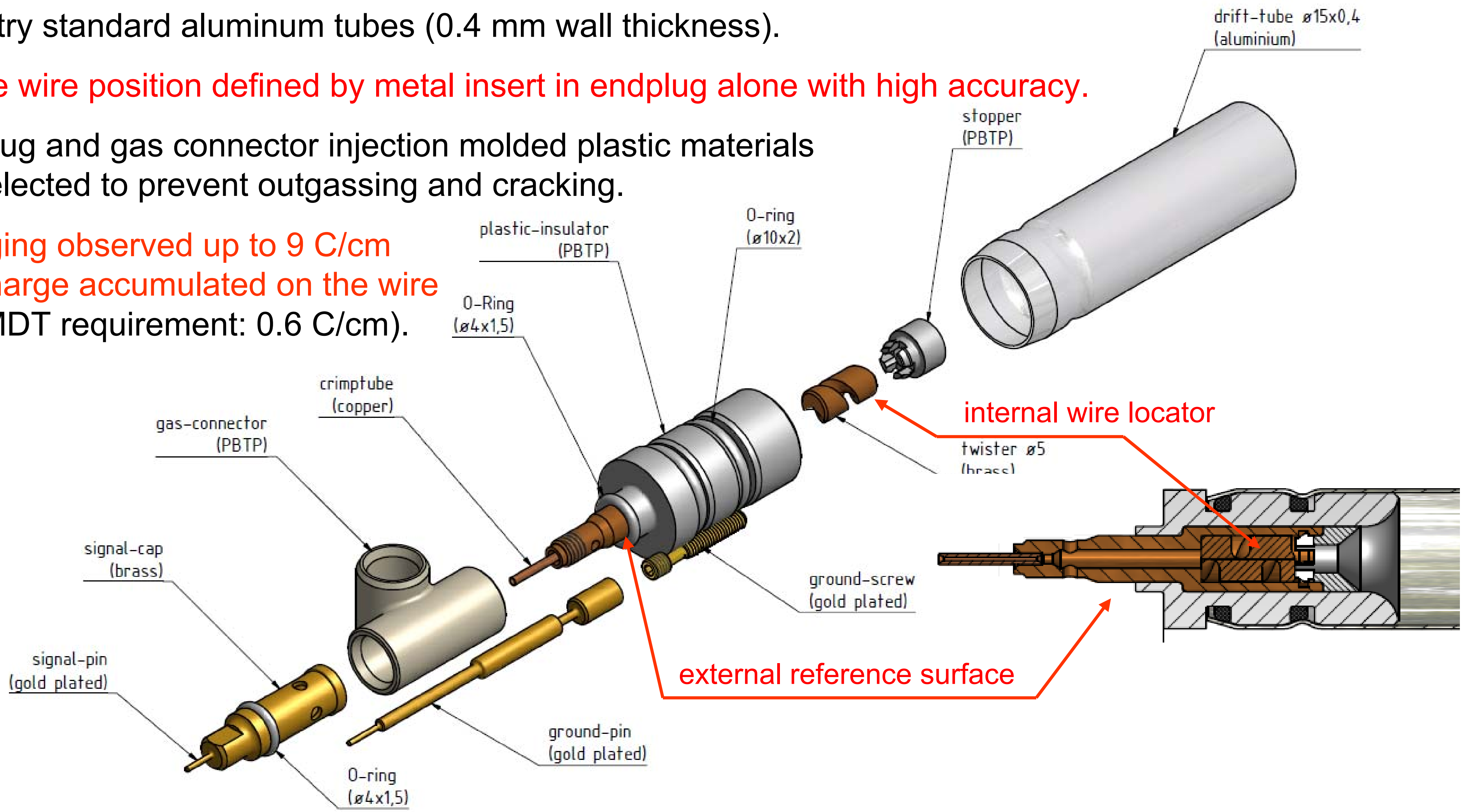




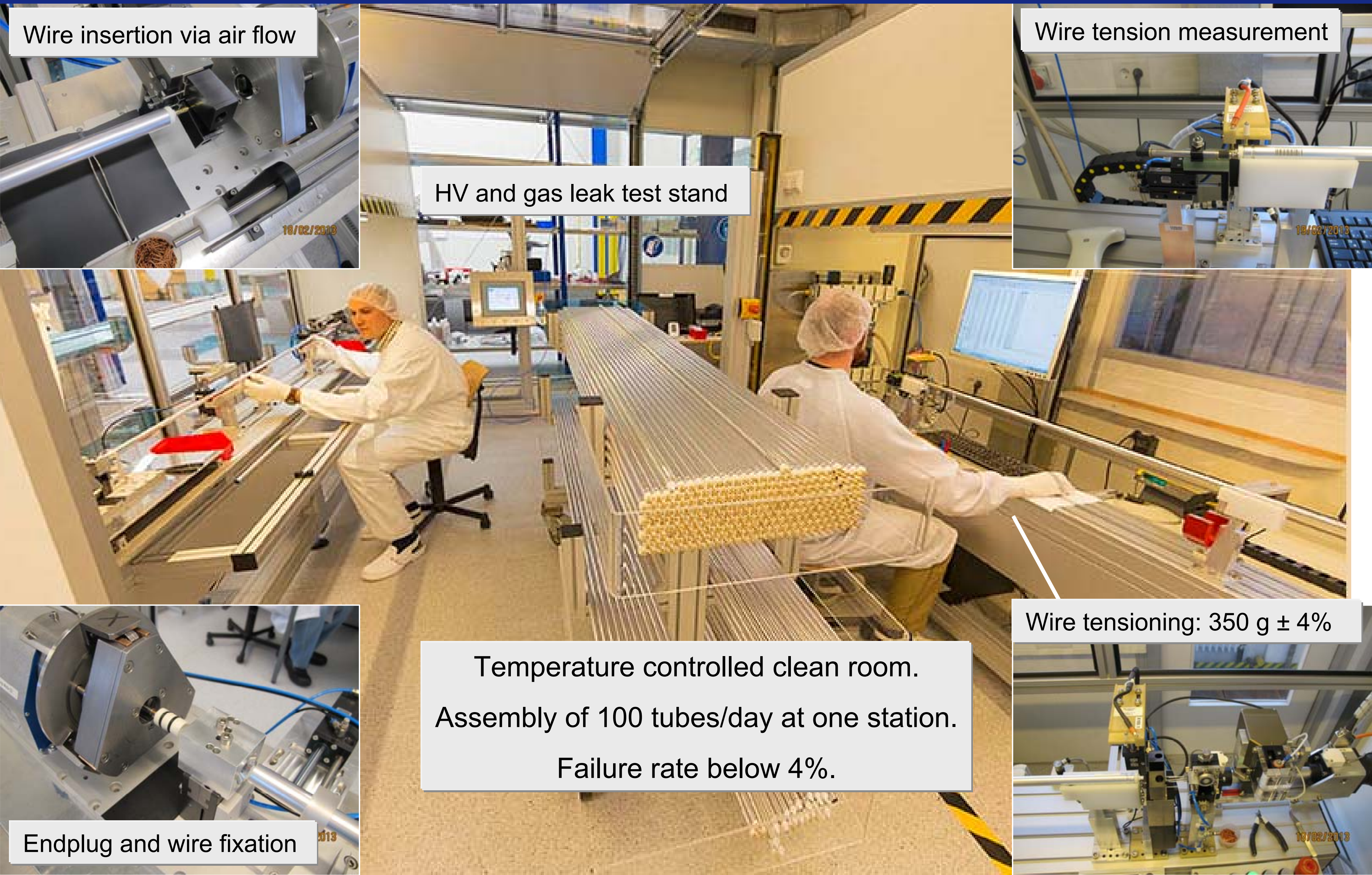


sMDT Design and Construction

- 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).

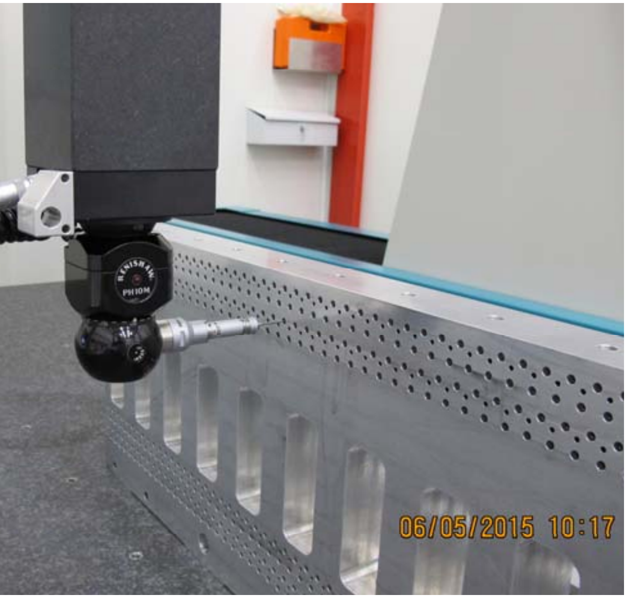


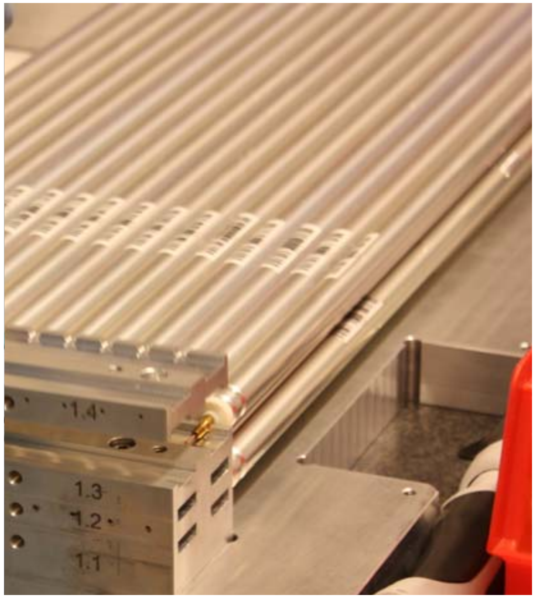
Semi-Automated Drift Tube Assembly and Test

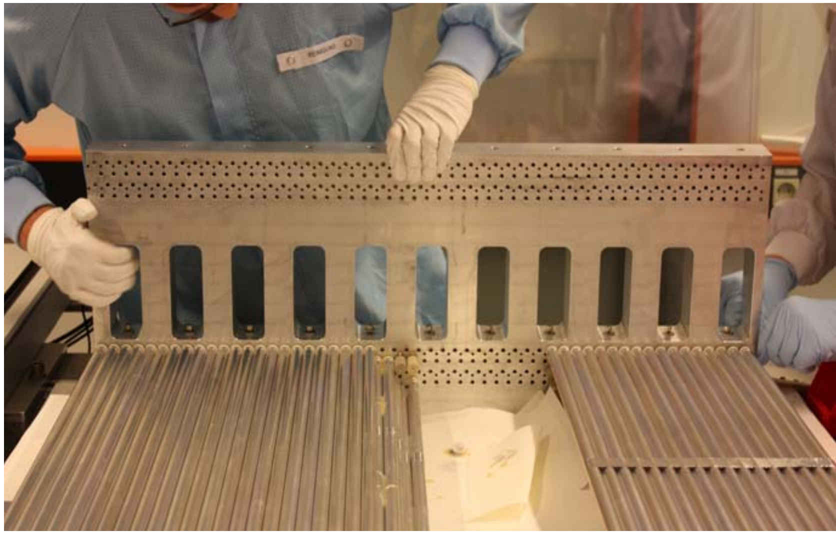


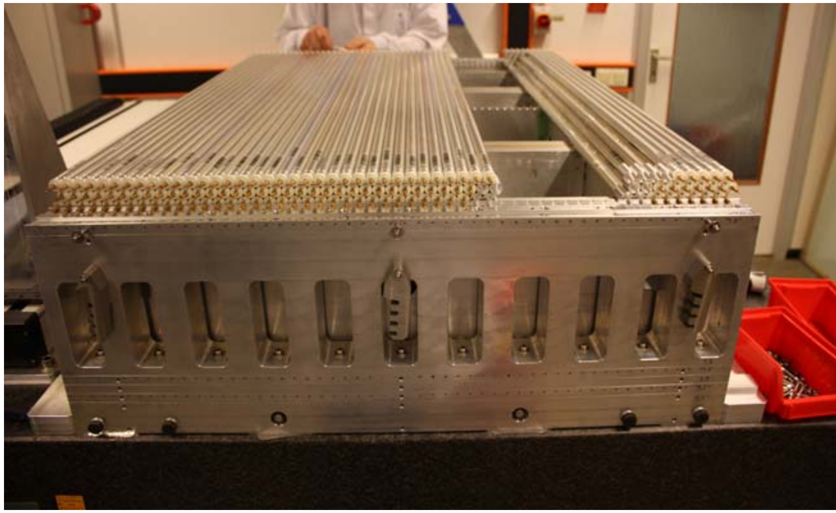
sMDT Chamber Assembly

Design for mass production of sMDT chambers with large numbers of tube layers:
Assembly within one working day independent of the number of layers (MDTs: only one tube layer per day).

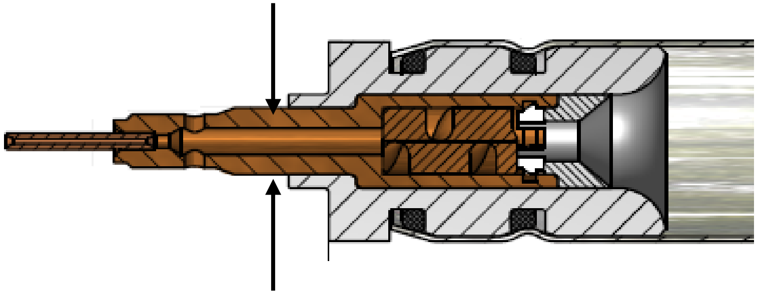








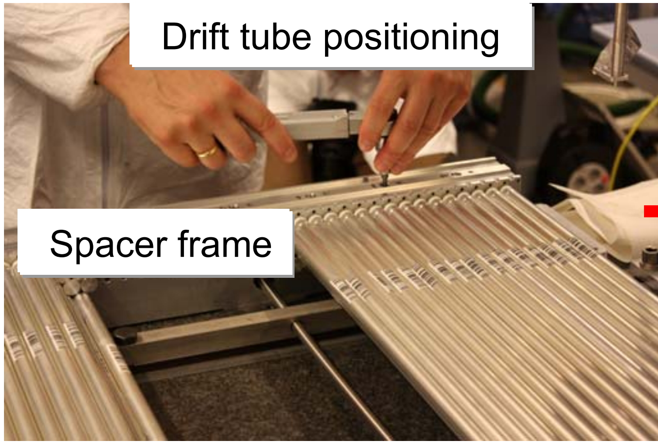
Precision machined jigs with 2D hole grid for endplug insertion for the whole chamber



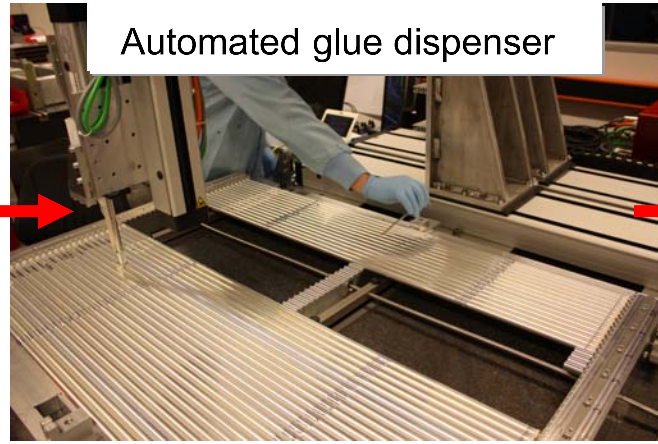
Ongoing sMDT Chamber Construction

Drift tube positioning

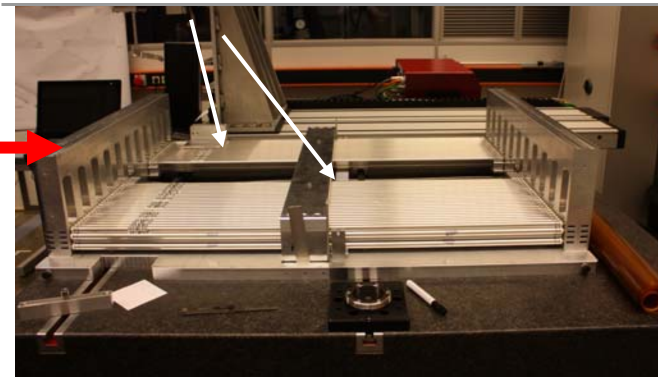
Spacer frame

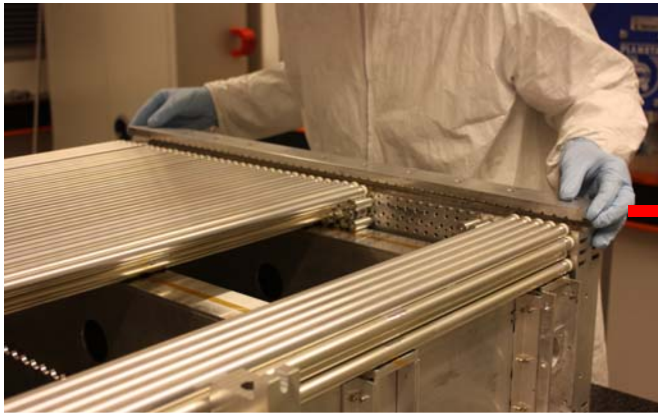


Automated glue dispenser



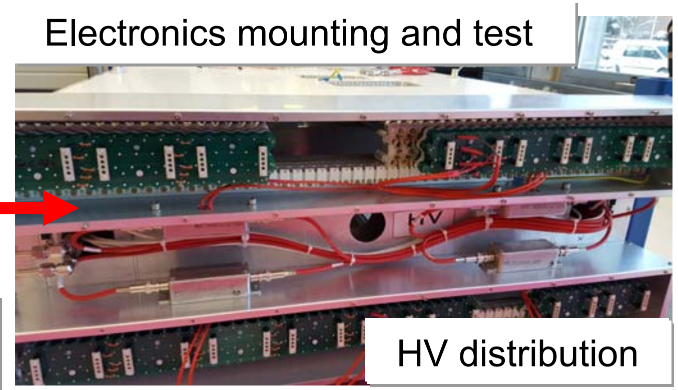
Alignment sensor mounting rel. to wires



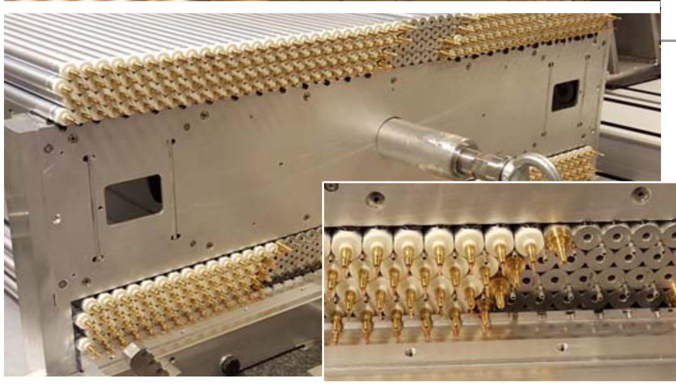


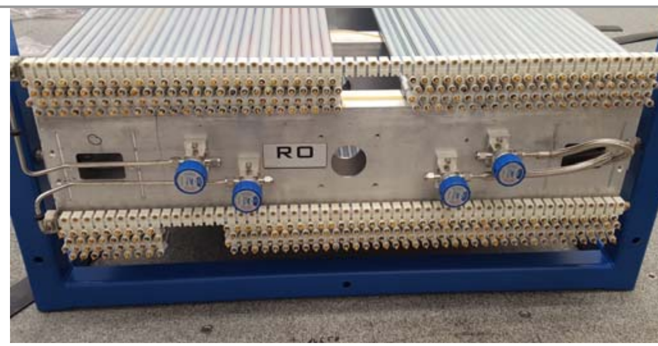
Mounting of gas connections: very tight leak rate requirement of < 0.2 mbar/h achieved

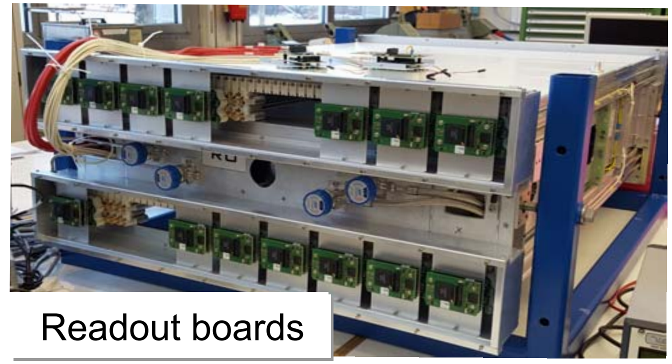
Electronics mounting and test



HV distribution







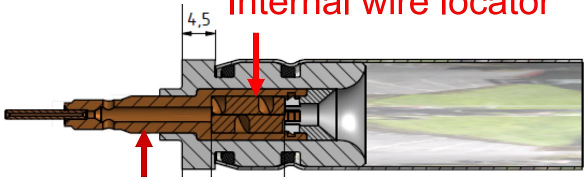
Readout boards

Wire Position Measurement in sMDT Chambers

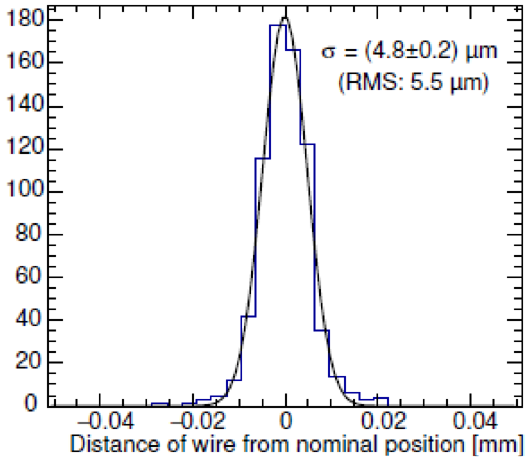
- Measurement of individual wire positions with with 3D coordinate measuring machine.
- Wire positioning accuracy of better than 5 μm,

  at the limit of the measuring accuracy and

  at the limit of the precision of the jigging.



	Measured geometry (equal on both ends)	Nominal geometry
Horizontal pitch [mm]	15.0992 ± 0.00001	15.0990
Vertical pitch [mm]	13.079 ± 0.0001	13.079
Spacer height [mm]	184.990 ± 0.0005	184.990

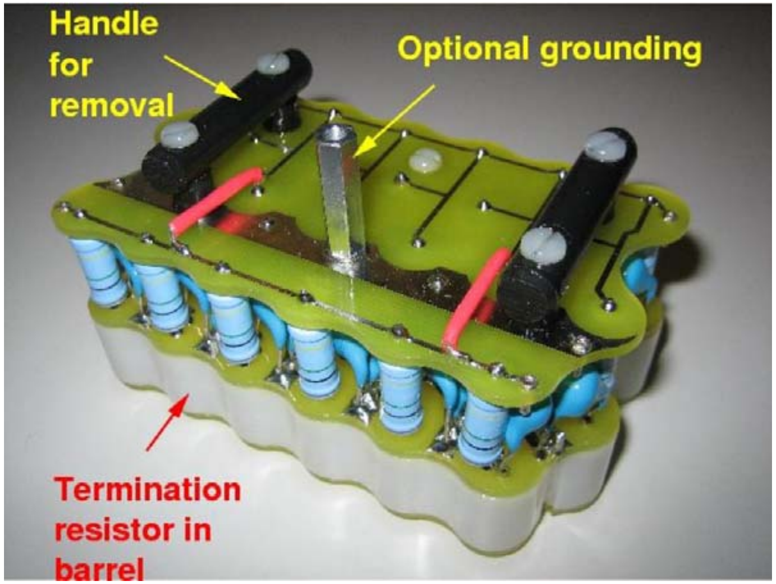


- Precise 3D position measurement of the alignment sensor mounting platforms with respect to the wires.

Essential for absolute optical alignment monitoring with accuracy on the order of the chamber resolution.

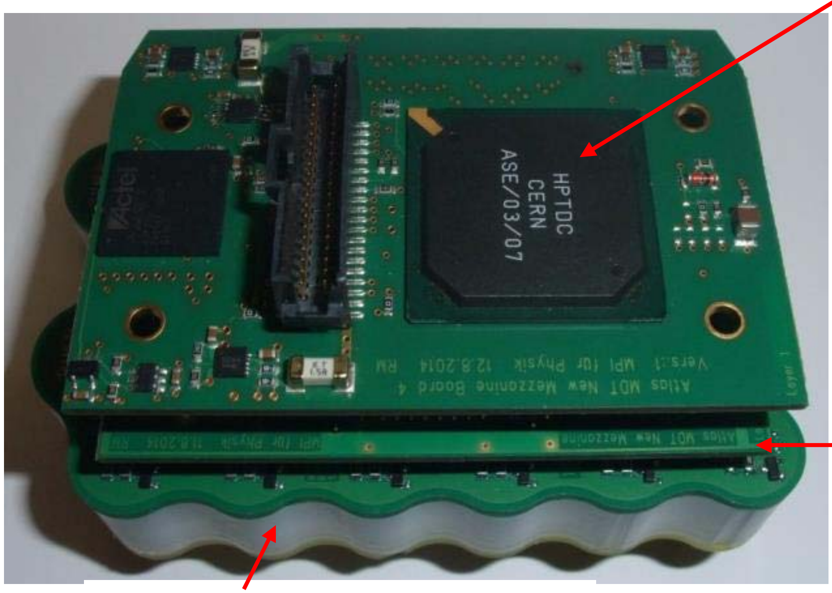
sMDT Readout Electronics

High-voltage distribution boards (24 channels)



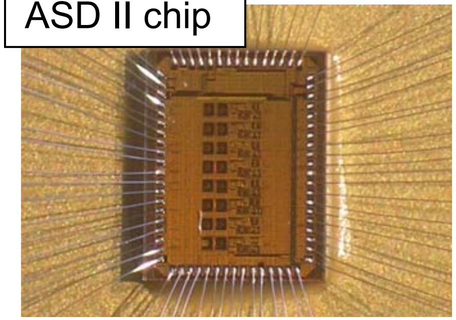
Signal distribution and readout boards (24 channels)

with three 8-channel amplifier-shaper-discriminator (ASD) chips from MDT production and one TDC chip (CERN HPTDC)



Coupling capacitor in barrel

ASD II chip



New ASD and TDC chips in 130 nm CMOS technology are under development both for ATLAS MDT and new sMDT chambers at HL-LHC.

New TDCs with fast readout for (s)MDT-based Level-0 muon trigger for HL-LHC with high momentum resolution and selectivity.

Conclusions

- New Drift tube detectors for high precision muon tracking under high background rates at HL-LHC and future high-energy hadron colliders have been developed: sMDT chambers.
- Cost-effective solution for large-area high-precision muon tracking at high counting rates.
- Tests at the CERN Gamma Irradiation Facility demonstrated the expected 10 times higher rate capability compared to the ATLAS MDT chambers, sufficient for HL-LHC. Further improvement possible with optimised readout electronics for high rates.
- Design of drift tubes and assembly methods optimised for mass production. Simple enough to be transferred to industry.
- Highest mechanical precision over large volumes at the limit of the measuring accuracy: better than 5 μm sense wire positioning accuracy (MDTs: 20 μm).
- Two chambers already in operation in ATLAS. More chambers under construction for installation in the LHC winter shutdown 2016/17. Design of integrated sMDT + thin-gap RPC for ATLAS phase 1 and 2 upgrades. New readout electronics development for implementation of (s)MDT-based Level-0 muon trigger.