sMDT Muon Tracking Chambers for FCC-hh Detectors

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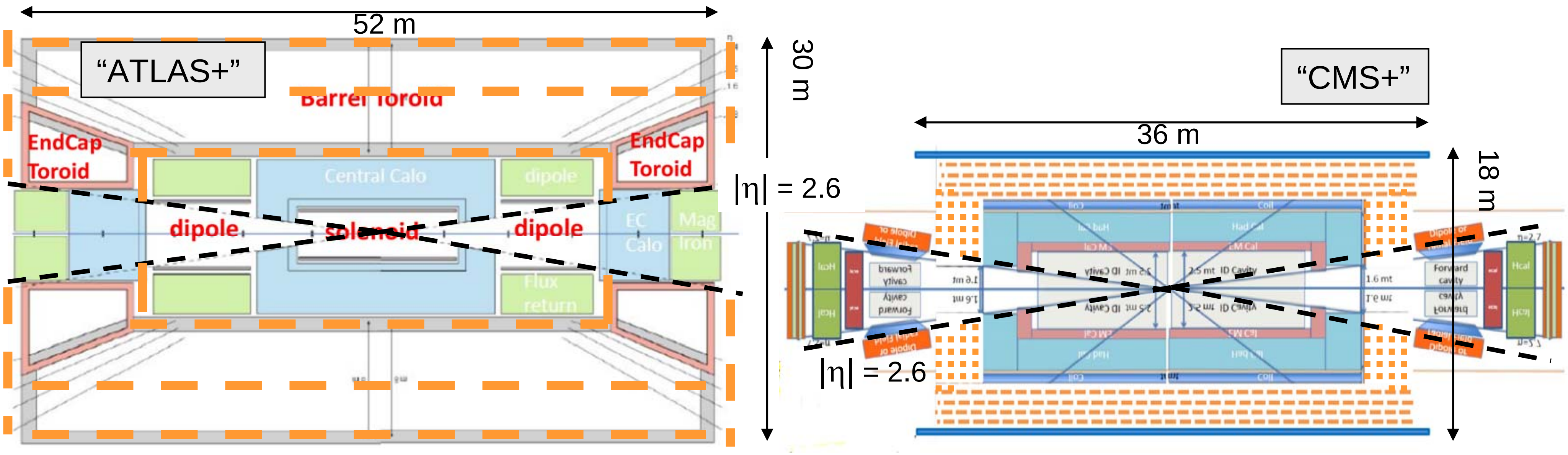
Requirements

- The muon spectrometers of the FCC-hh detectors under discussion with air-core (toroid or twin-solenoid) magnet systems require efficient muon tracking with very high spatial resolution (30-40 μm) and precise optical alignment monitoring over large areas at high background rates.
- The Monitored Drift Tube (MDT) chambers of the ATLAS muon spectrometer have proven that they provide very reliable, high-precision tracking up to neutron and γ fluxes of 500 Hz/cm^2 over an area of 5000 m^2 (1200 chambers with 400000 drift tubes).
- Similar muon detector areas in the FCC-hh detectors.
- Large variation of track incidence angles from 90 to 45°.



Requirements

- ATLAS MDT chambers are exposed to high beam induced irradiation rates of neutrons and γ rays. Expected occupancies at HL-LHC exceed 30% mainly in the inner endcap layer (to be replaced).

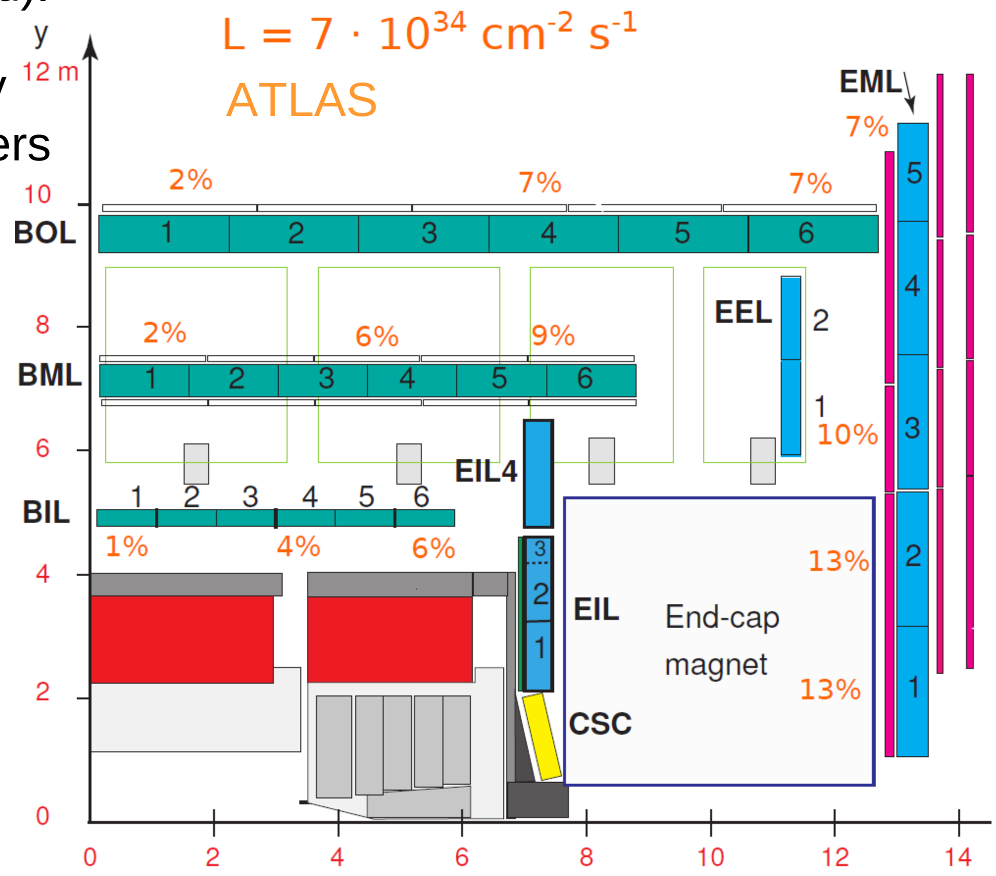
- MDT chambers provide high tracking efficiency up to occupancies of ~30% with 2 x 4 tube layers independent of the track incidence angle.

  M. Deile at al., Nucl.Instr.& Meth. A518 (2004) 65.

  O.Kortner et al., Nucl.Instr.& Meth. A581 (2007) 545

- For maximum FCC-hh luminosity of 3×10^{35} cm^{-2} s^{-1} about 4 x higher background rates are expected in the muon spectrometer compared to ATLAS at HL-LHC with similar η dependence:

  Typically 80 - 250 Hz/cm^2, except for the inner endcap layer with 0.6 - 40 kHz/cm^2.



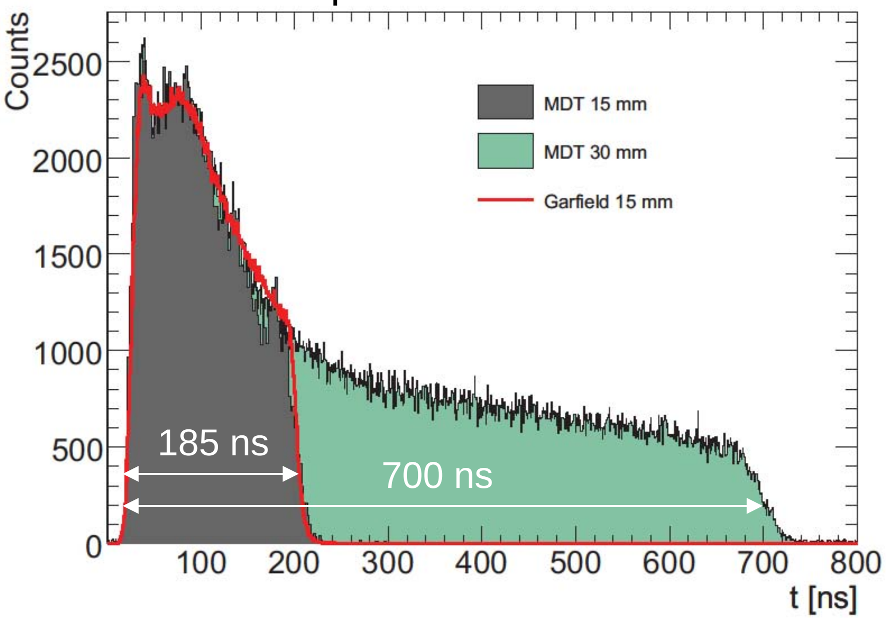
Small-Diameter Drift Tubes (sMDT) for Very High Counting Rates

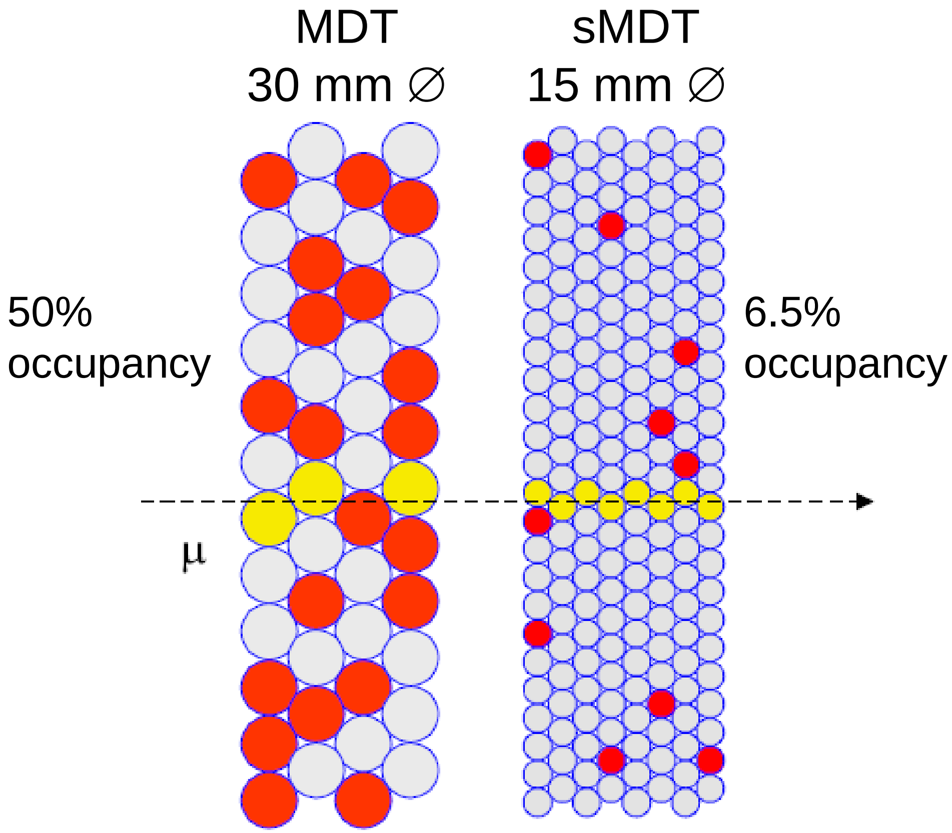
8 x lower occupancy
(4 x shorter max. drift time, 2 x smaller cross section)

by reducing the drift tube diameter
from 30 mm (MDT) to 15 mm (sMDT)
at otherwise the same operating conditions:

Aluminum drift tubes with 0.4 mm wall thickness,
50 μm diameter sense wire, Ar:CO_2 (93:7) gas at 3 bar,
gas gain of 20000 (no aging).

Drift time spectra



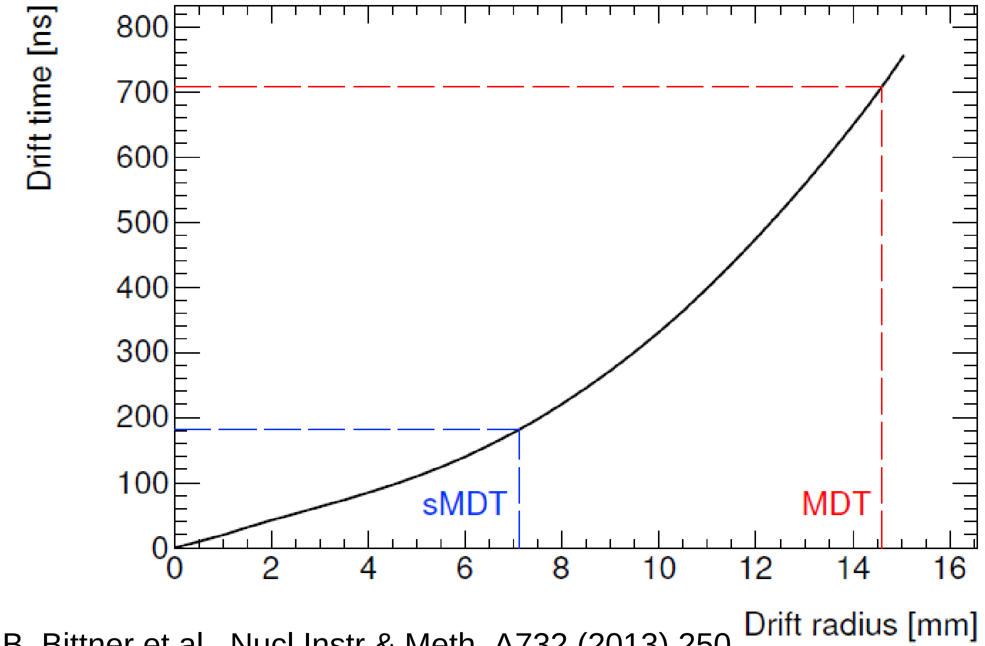


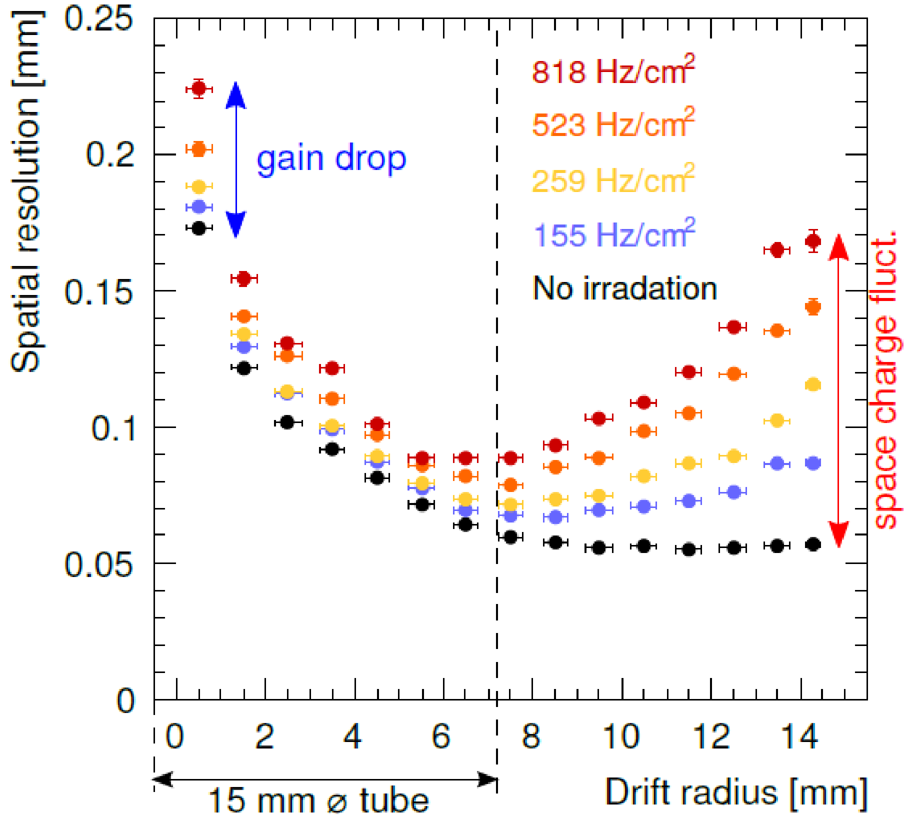
Space Charge Effects

Space charge effects due to background radiation are strongly suppressed in sMDT tubes.

Why 15 mm tube diameter?

- linear r-t relationship, effect of radiation induced space charge fluctutions eliminated
- gain loss suppressed proportional to r^3
- mechanically robust like MDTs



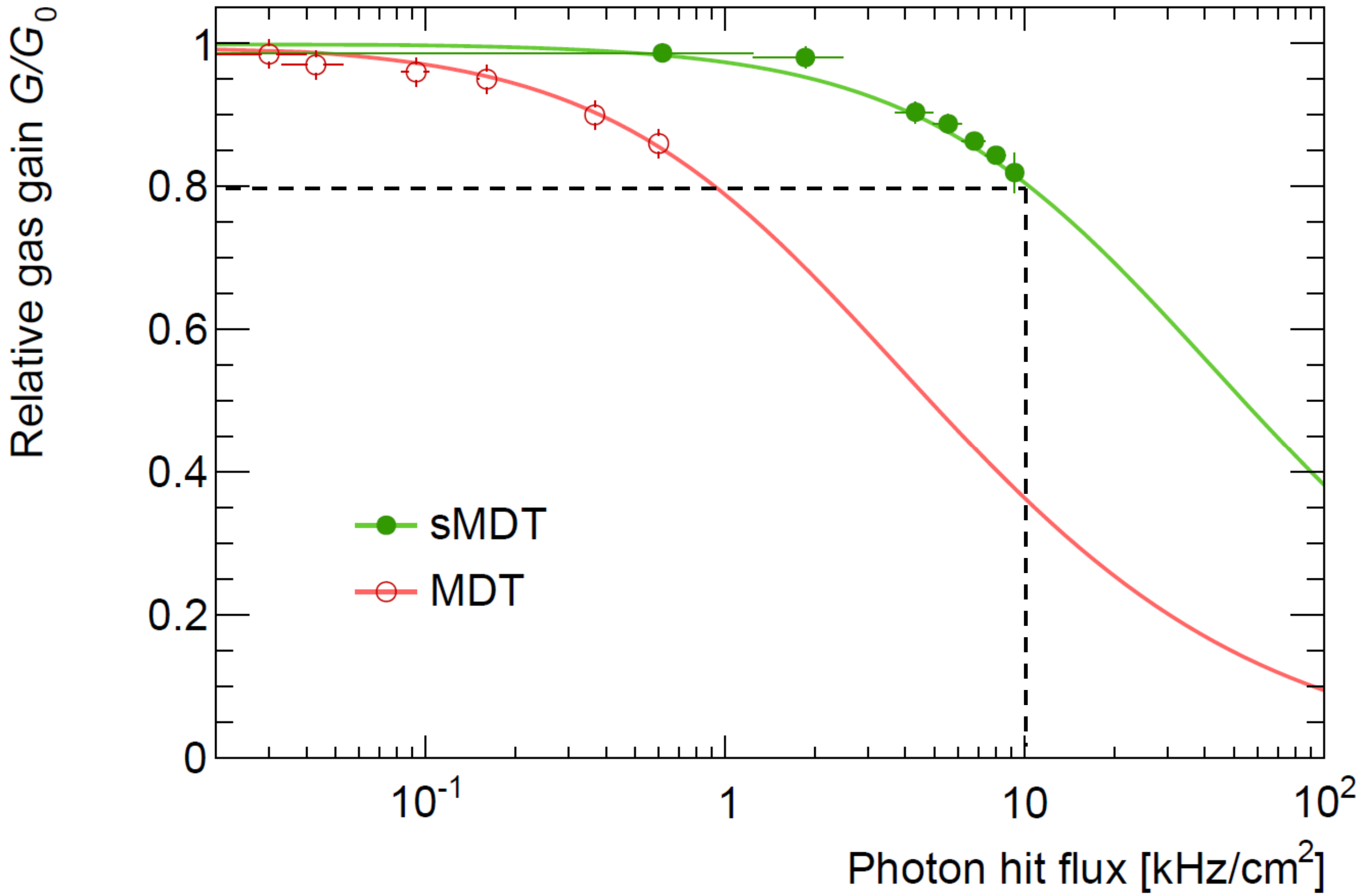


B. Bittner et al., Nucl.Instr.& Meth. A732 (2013) 250

Ph. Schwegler et al., Proc. IEEE NSS 2014

Space Charge Effects

sMDT tubes show only 20% gain loss at 10 kHz/cm^2 γ hit rate



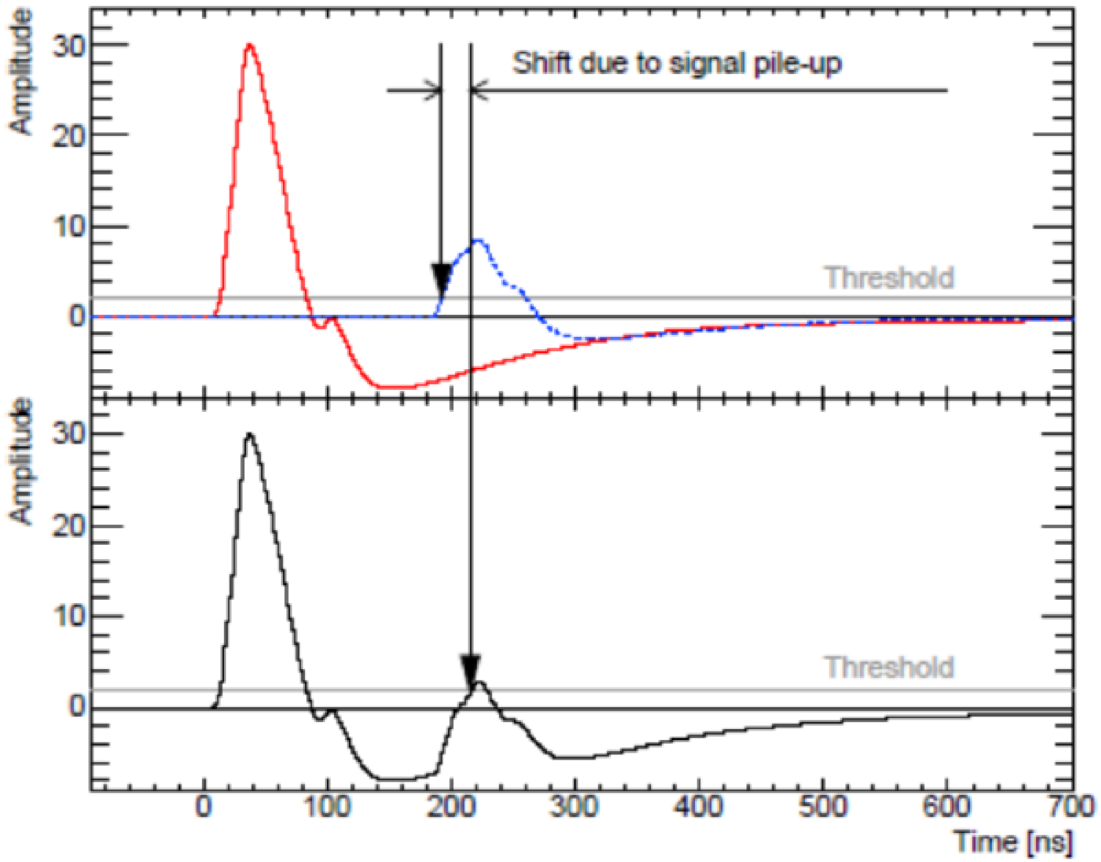
Measurements at the CERN Gamma Irradiation Facility GIF, compared to simulation of drift tube and electronics response. Current MDT RO electronics has 220 ns minimum deadtime and no BLR.

B. Bittner et al., Nucl.Instr.& Meth. A732 (2013) 250
Ph. Schwegler et al., Proc. IEEE NSS 2014

Signal Pile-Up Effects

sMDT performance limited at high rates by signal pile-up effects of the readout electronics using bipolar shaping.

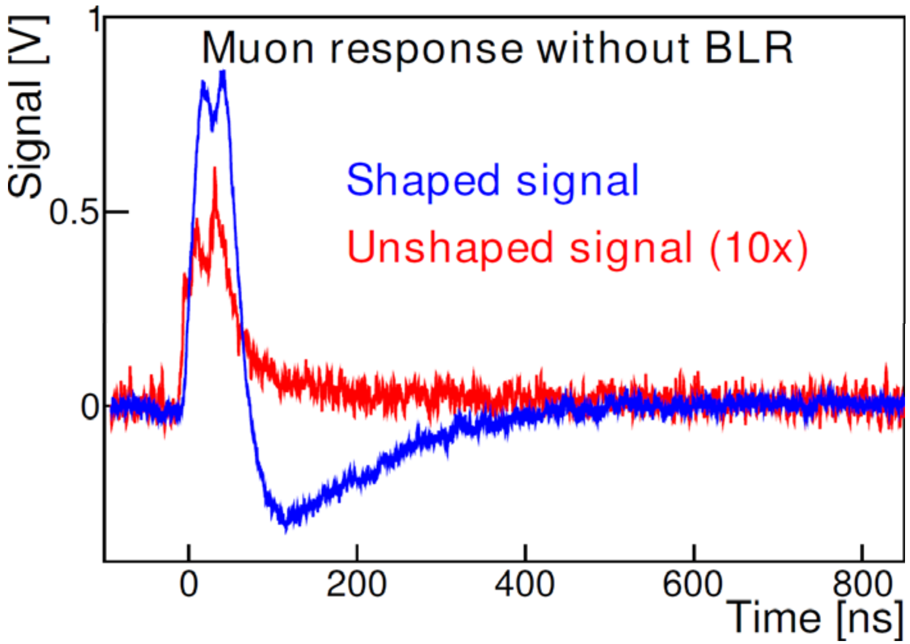
Deterioration of the efficiency and spatial resolution of muon pulses succeeding a background hit:

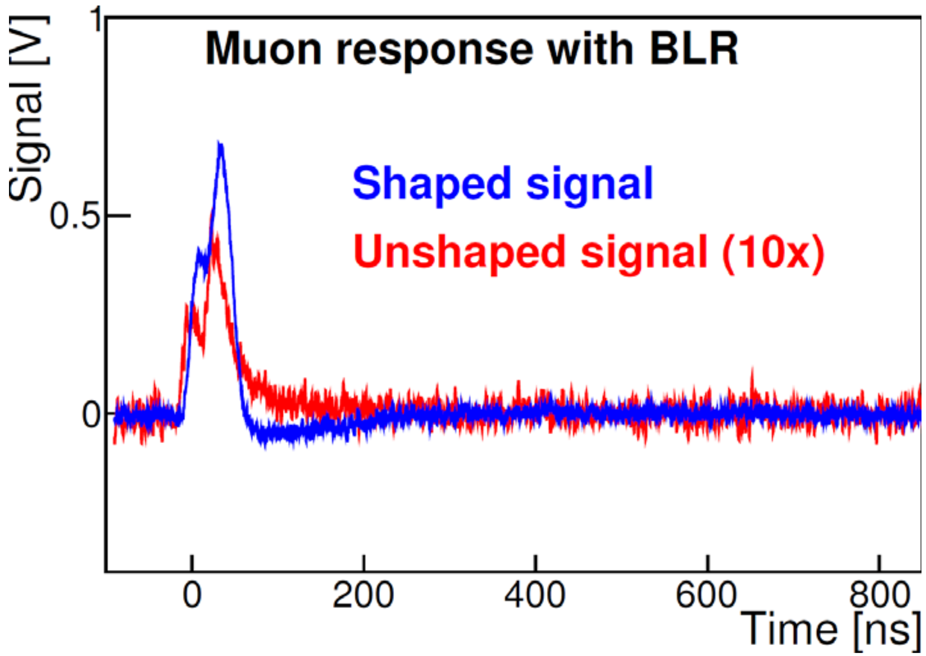


Baseline Restoration

Fast baseline restoration desirable for sMDT readout at very high counting rates to prevent signal pile-up effects (see below), while only small improvement for MDTs (not realised in current MDT RO electronics).

Signal pulses with standard MDT readout electronics with bipolar shaping with and without additional active baseline restoration (BLR) circuit:



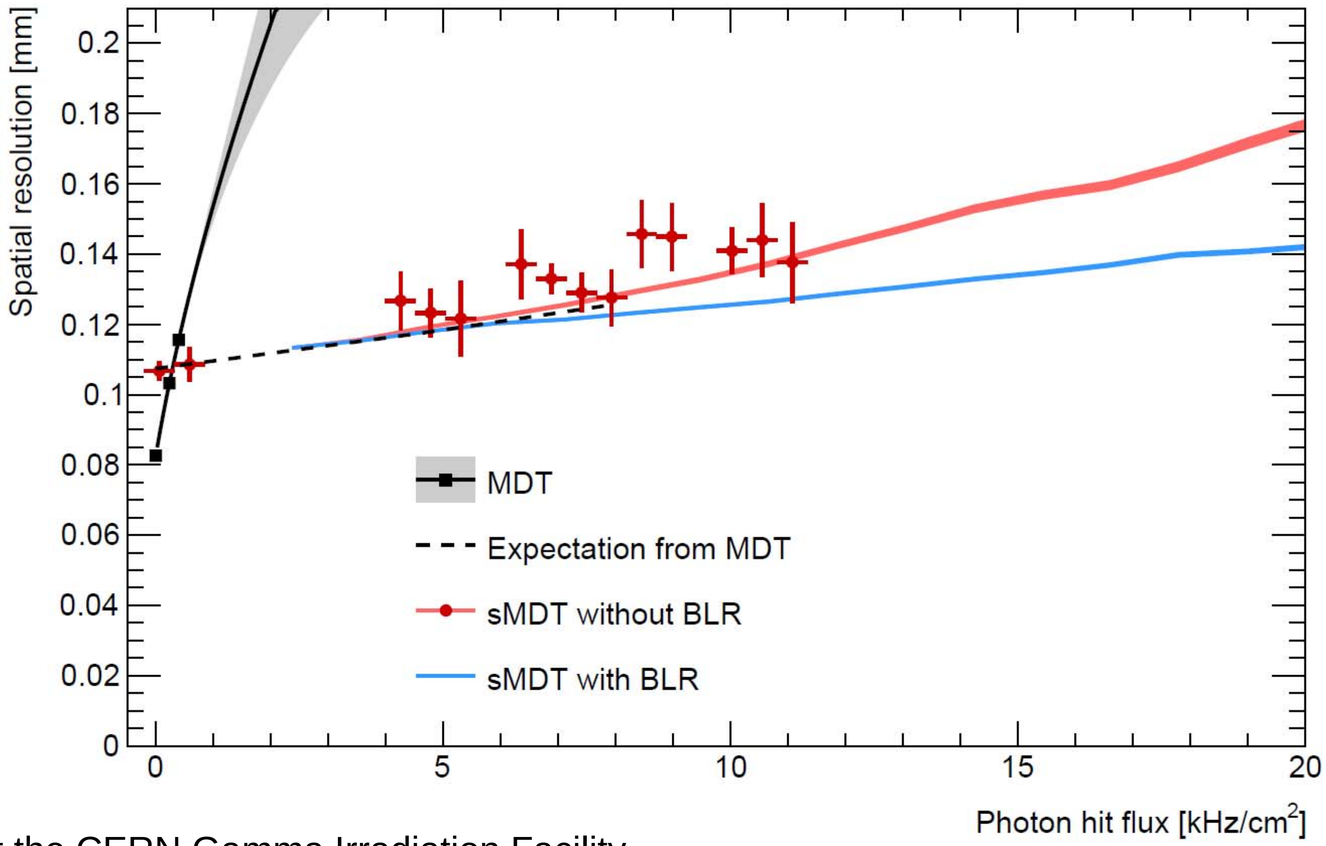


The BLR method has been successfully applied in the ATLAS Transition Radiation Tracker (TRT).

sMDT Single-Tube Resolution

sMDT resolution limited at high counting rates by signal pile-up effects of the electronics, in contrast to MDTs where space charge effects dominate

- suppression of signal pile-up effects with fast baseline restoration (BLR)



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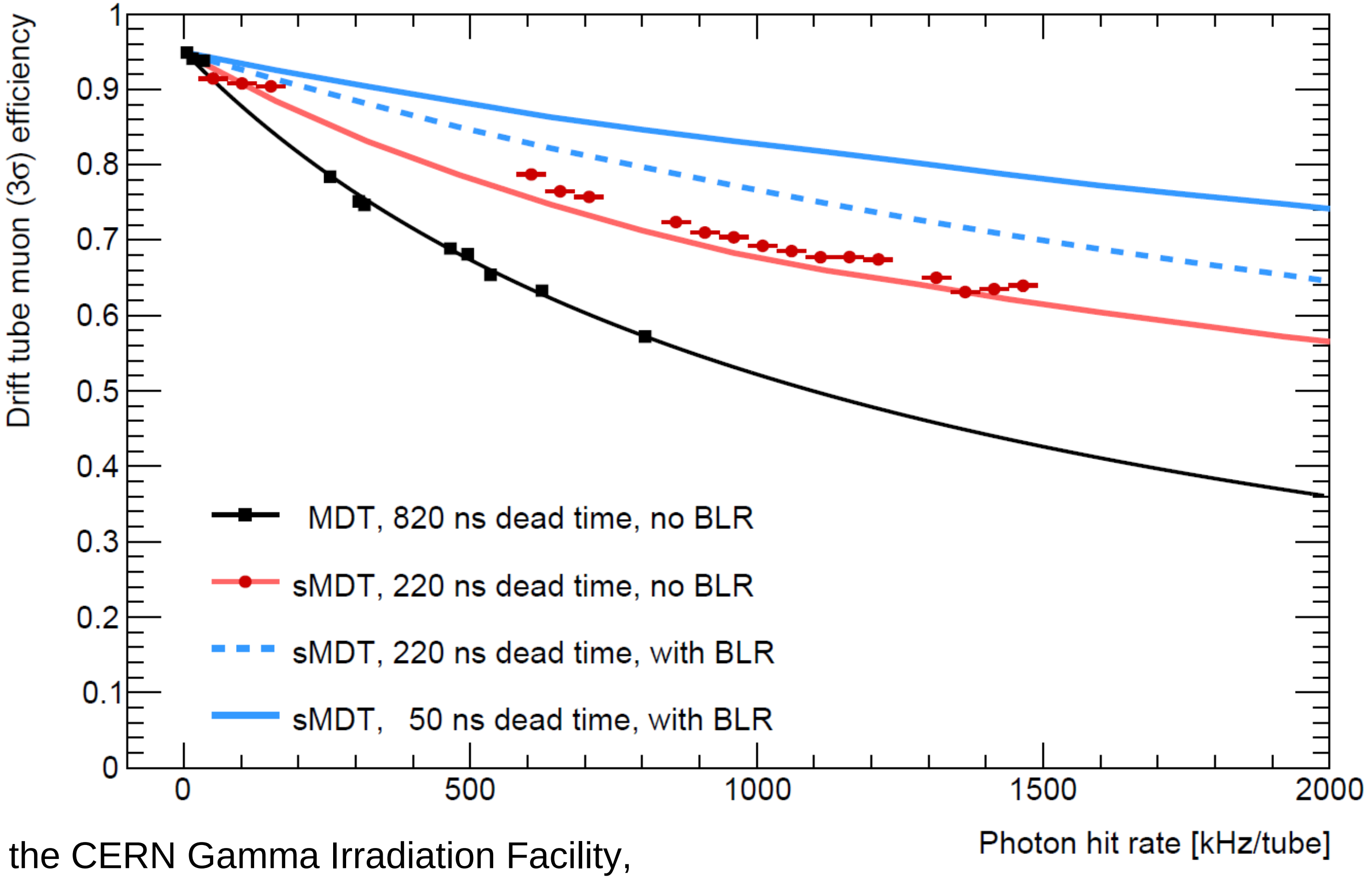
Ph. Schwegler et al., Proc. IEEE NSS 2014

sMDT Single-Tube Muon Efficiency

Muon efficiency of sMDT drift tubes at high counting rates limited by readout electronics:

- use of minimum electronics deadtime (shorter max. drift time, no afterpulsing)
- suppression of signal pile-up effects (fast baseline restoration, BLR)



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Requirements

Extension of the proven cost effective and robust MDT technology to high background rates.

Occupancies of MDT (30 mm ∅) and sMDT (15 mm ∅) tubes at maximum FCC luminosity in the ATLAS geometry (with ATLAS operating parameters and tube lengths):

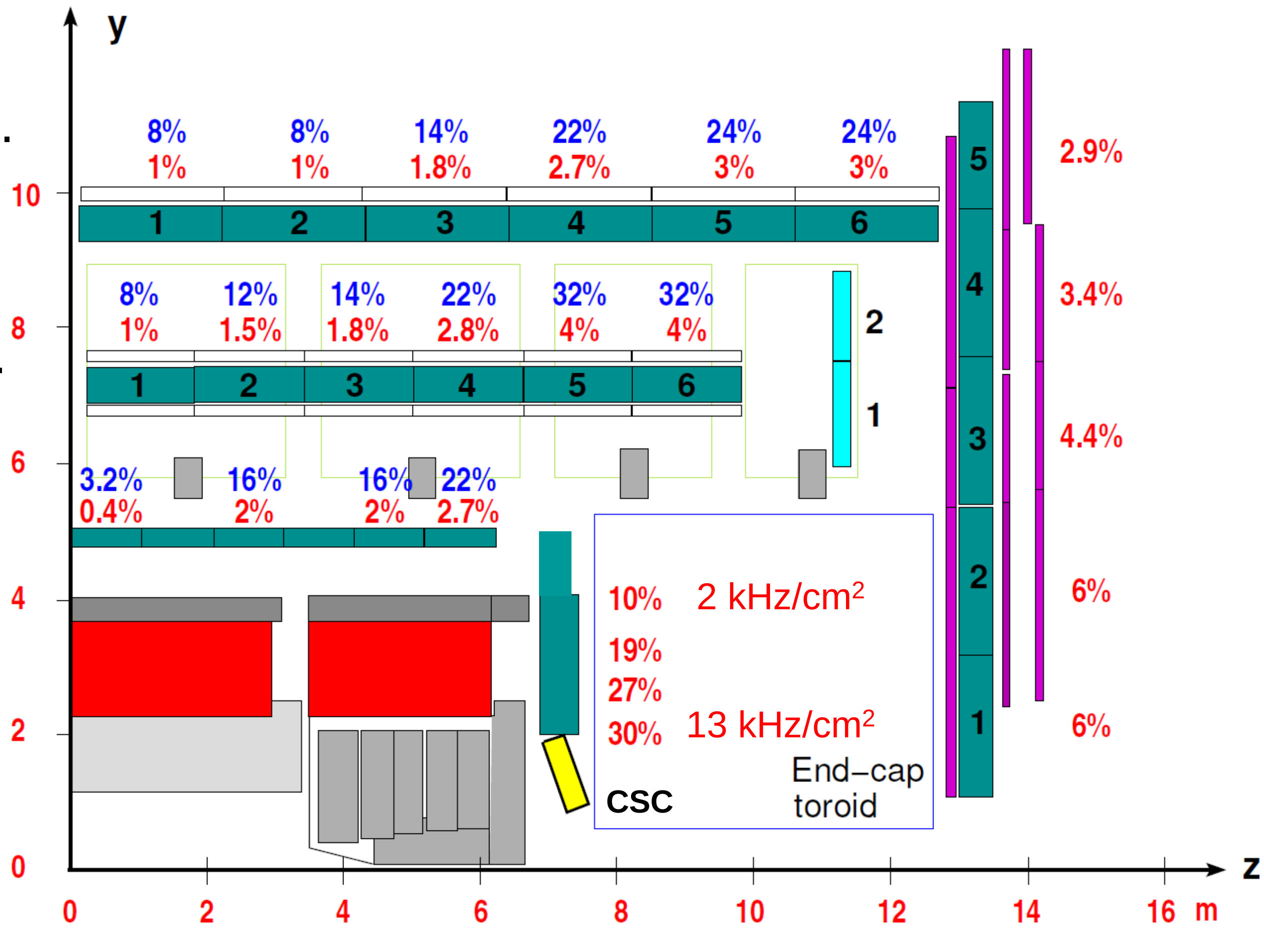
Max. sMDT occupancy at FCC is half the MDT occupancy at HL-LHC.

FCC detectors not limited to ATLAS operating parameters and geometry.

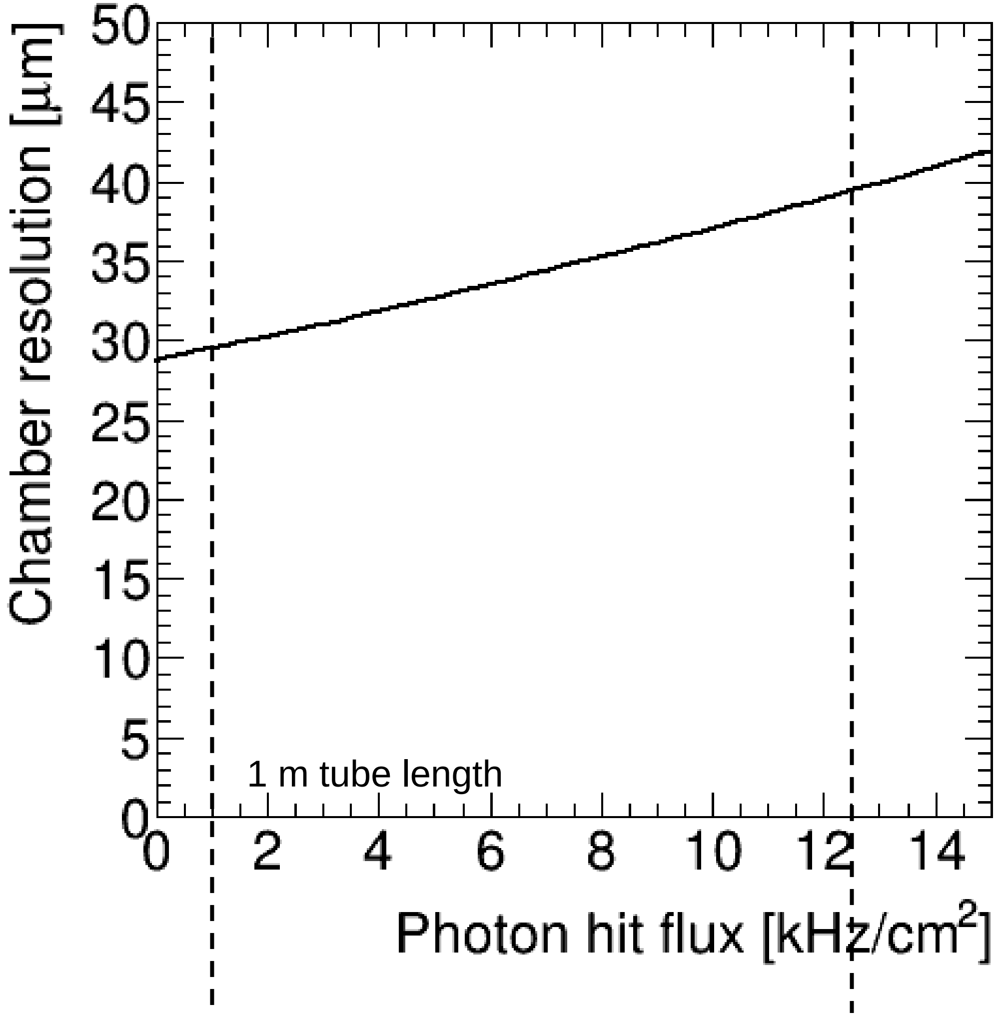
Further optimization of

- tube diameter and length dep. on η
- gas parameters
- readout electronics (in progress)

to extend η range to |η| ≈ 2.7.



sMDT Chamber Resolution



Expected spatial resolution of 2 x 8 layer sMDT chambers

(for Ar:CO_2 (93:7) at 3 bar, gas gain 20000 and anode wire positioning accuracy 20 μm, the present MDT parameters),

corresponding to a muon track reconstruction efficiency of 100%,

based on the measured single-tube resolution and efficiency.

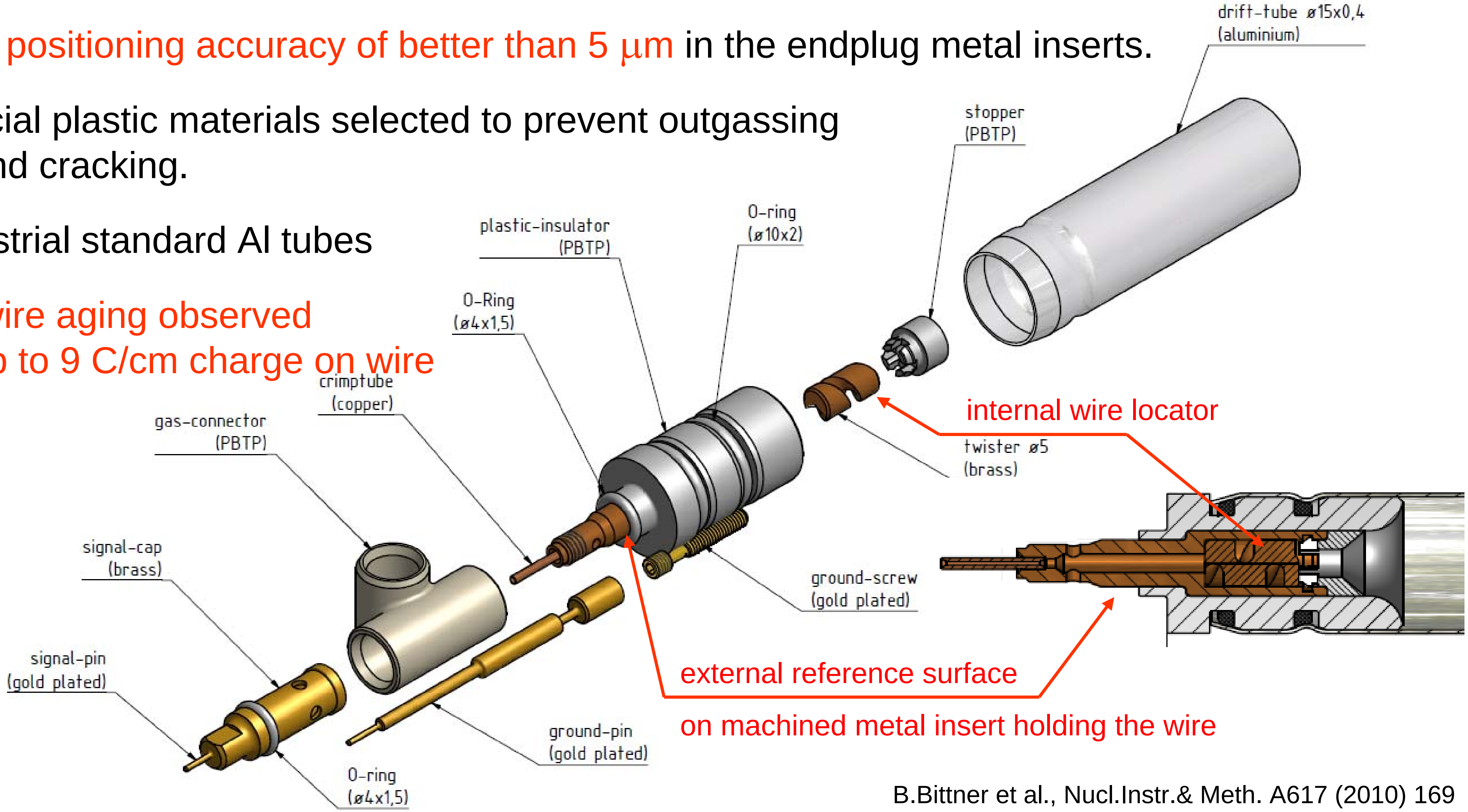
The spatial resolution is completely independent of the track incidence angle due to the circular geometry.

Maximum rate over almost the whole muon detector

Maximum rate reached in sMDTs only in inner endcap layer

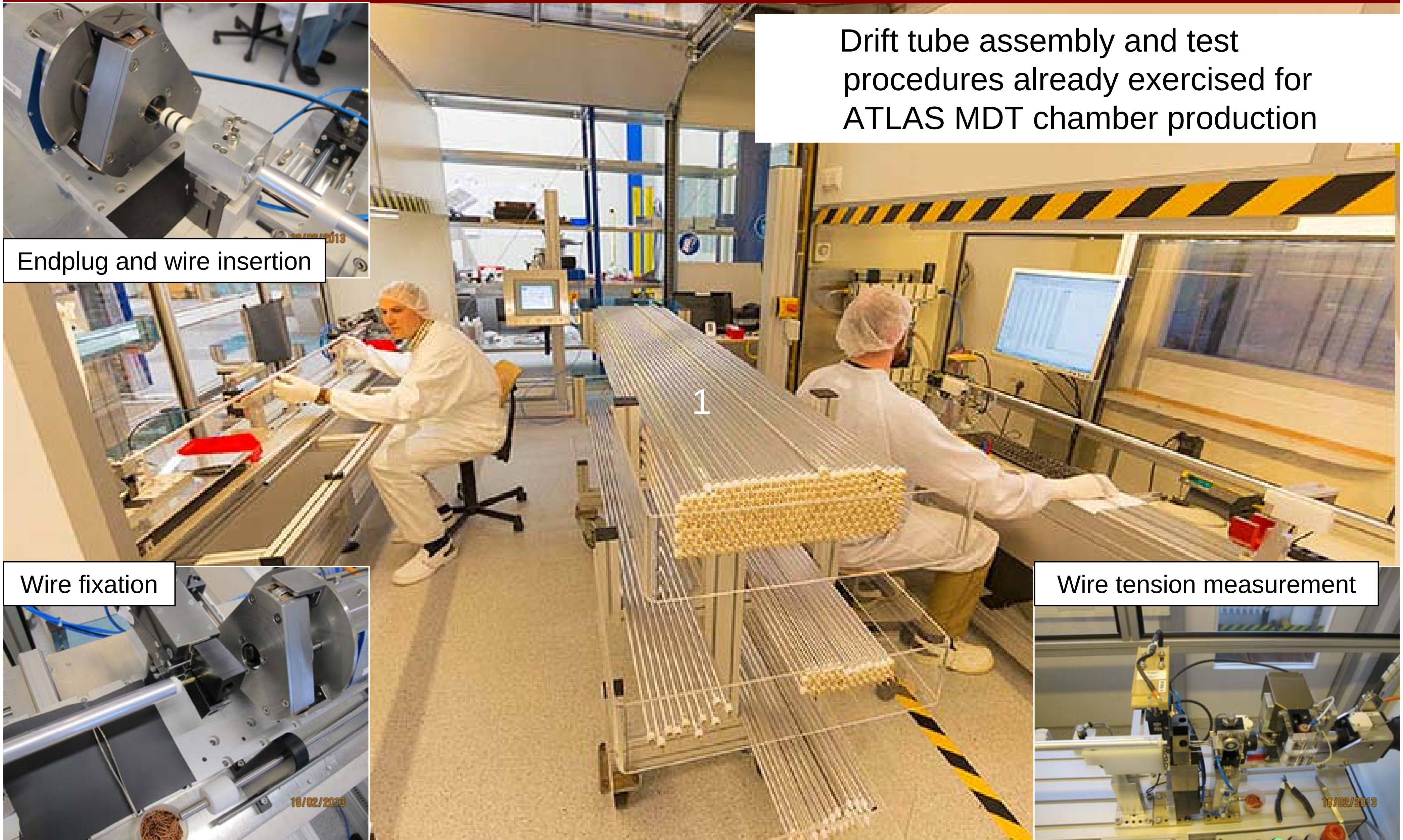
sMDT Design and Construction

- sMDT chamber design and assembly procedures optimized for mass production.
- Simple and cheap drift tube design with high reliability.
- Wire positioning accuracy of better than 5 μm in the endplug metal inserts.
- Special plastic materials selected to prevent outgassing and cracking.
- Industrial standard Al tubes
- No wire aging observed up to 9 C/cm charge on wire



B.Bittner et al., Nucl.Instr.& Meth. A617 (2010) 169
H. Kroha et al., Nucl.Instr.& Meth. A718 (2013) 427

Automated Drift Tube Production and Test



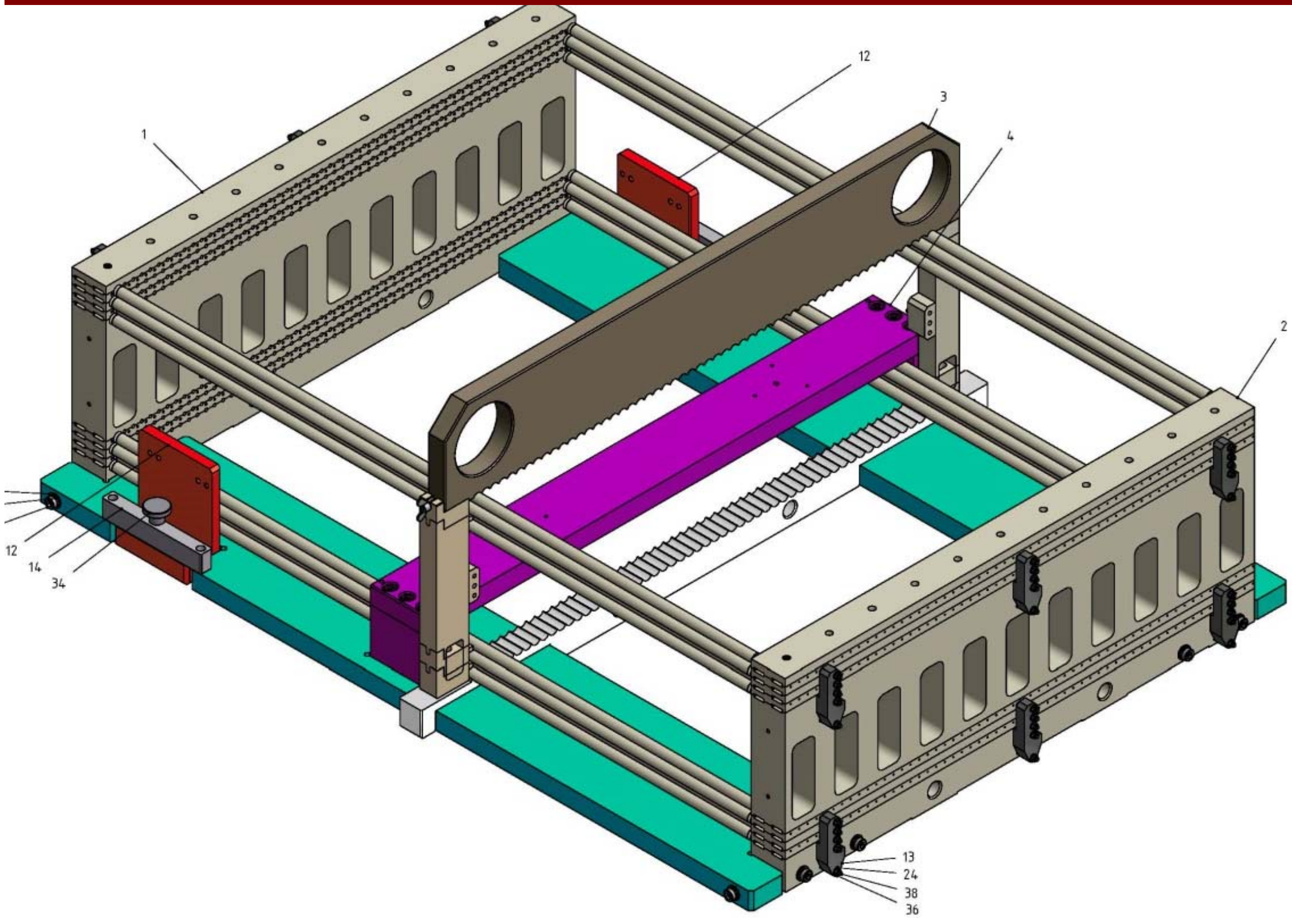
Drift tube assembly and test procedures already exercised for ATLAS MDT chamber production

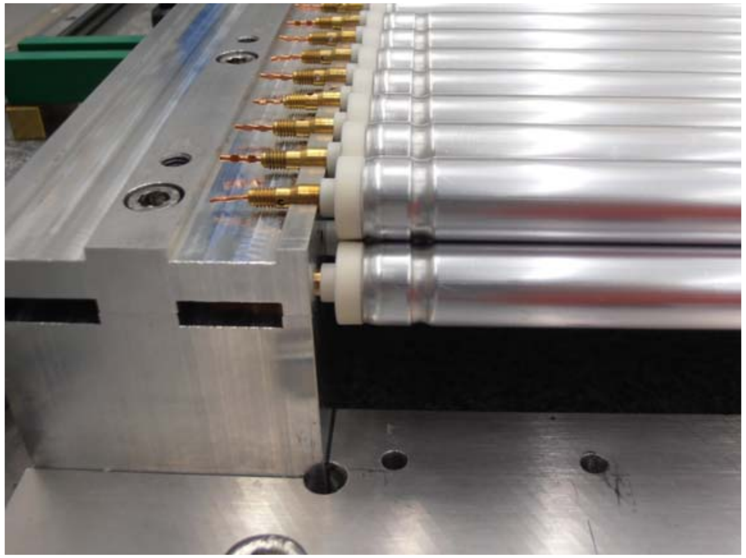
Endplug and wire insertion

Wire fixation

Wire tension measurement

sMDT Chamber Construction

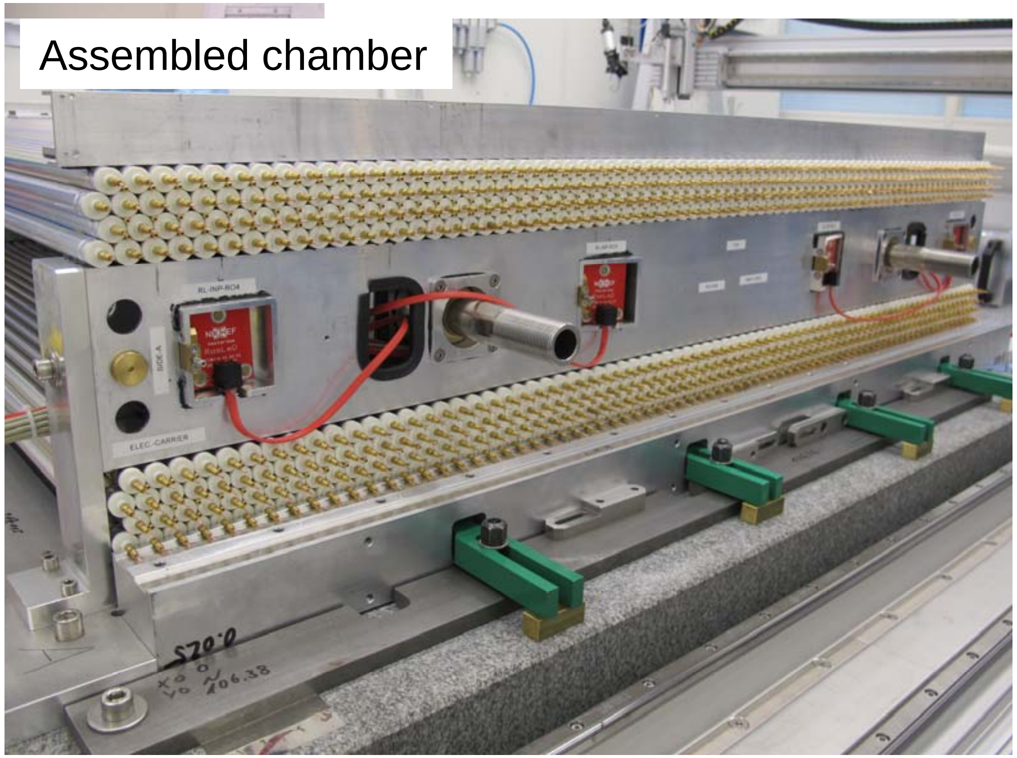


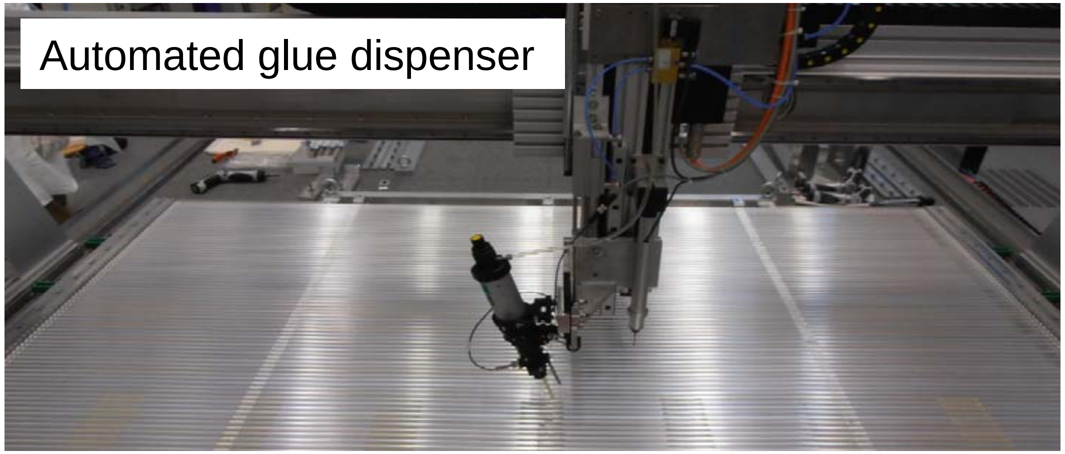


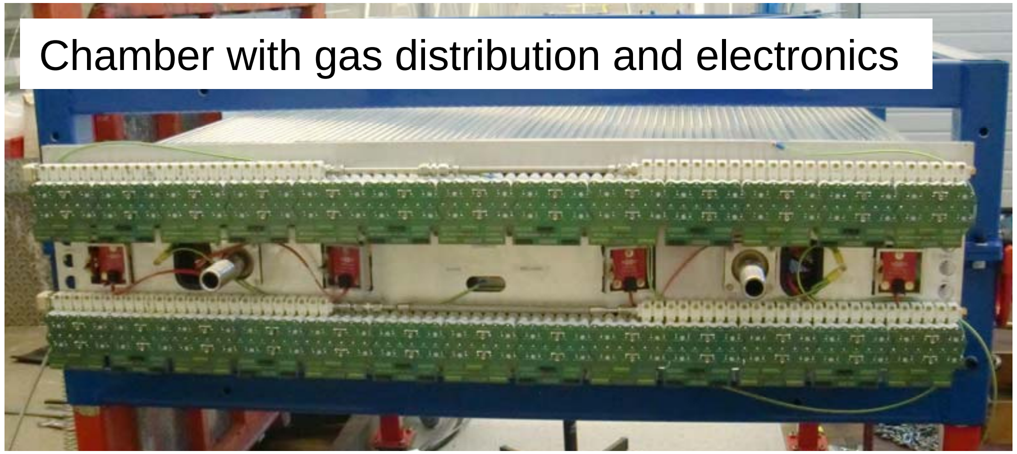
- Tubes stacked in 2D matrix at each end using the reference surfaces of the endplugs to position the sense wires with 10 μm accuracy.
- Precise positioning of alignment sensor mounts w.r.t. wires during chamber assembly.
- Precision assembly of a chamber within 1 working day (ATLAS MDT: 7 days/chamber).

sMDT Chamber Construction for ATLAS Upgrades


Drift tube stacking


Assembled chamber


Automated glue dispenser


Chamber with gas distribution and electronics

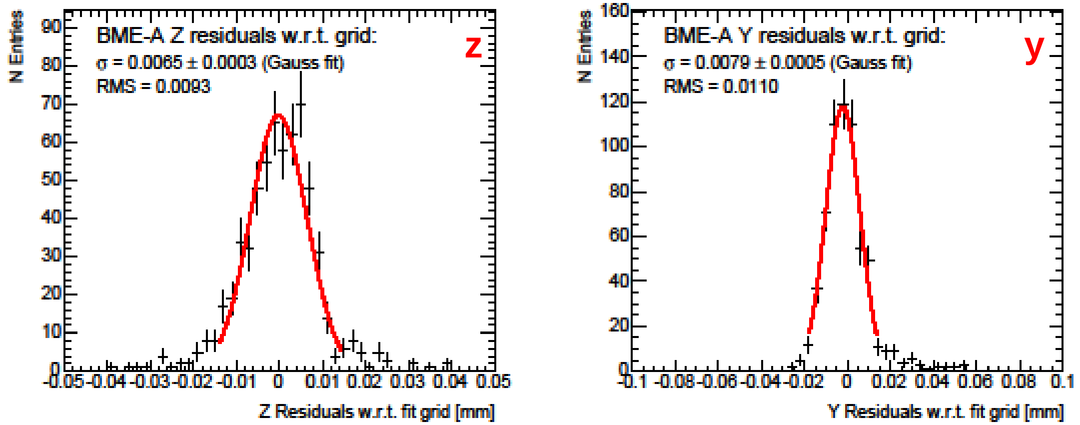
sMDT Chambers for ATLAS Upgrades

- 40 new chambers under construction chambers for Phase I upgrade. Two chambers are already installed.
- 140 new chambers planned for Phase II upgrade.

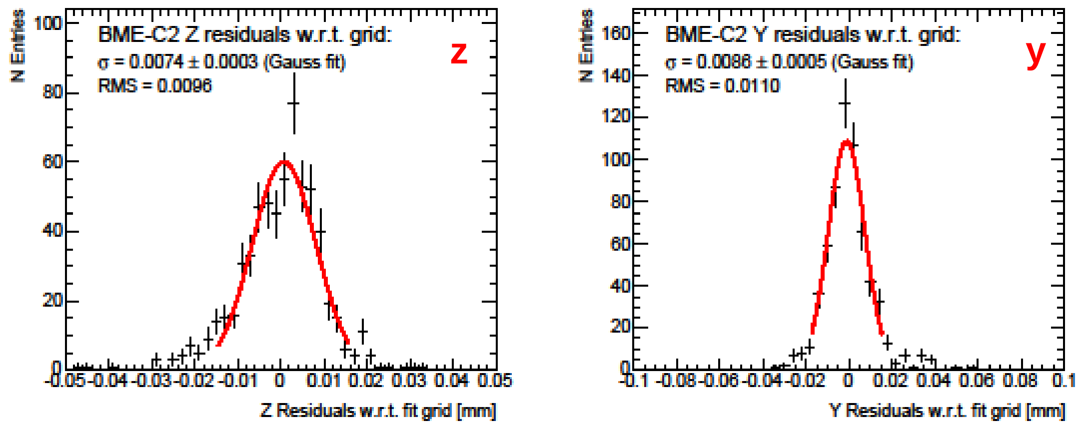
Chamber Precision

Wire and alignment sensor positions directly measured on a 3D coordinate measuring machine.

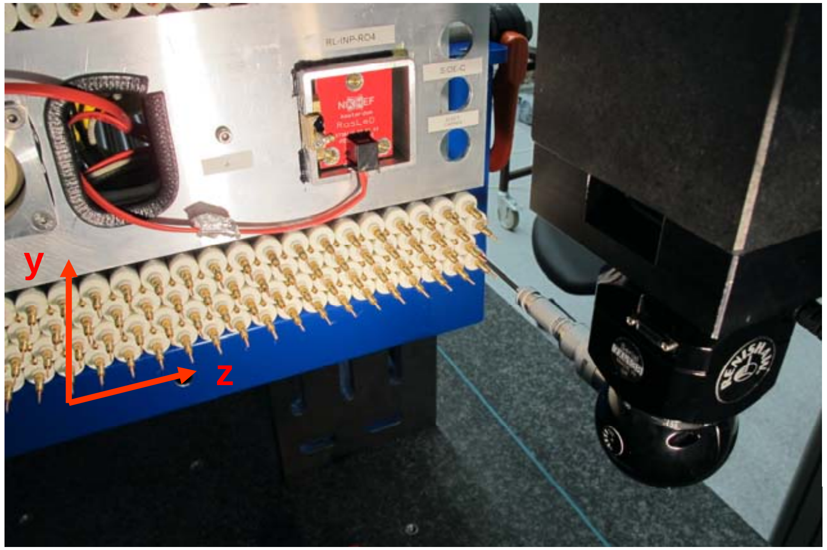
Wire positioning accuracy better than 10 μm (only 20 μm required, most precise chambers so far).

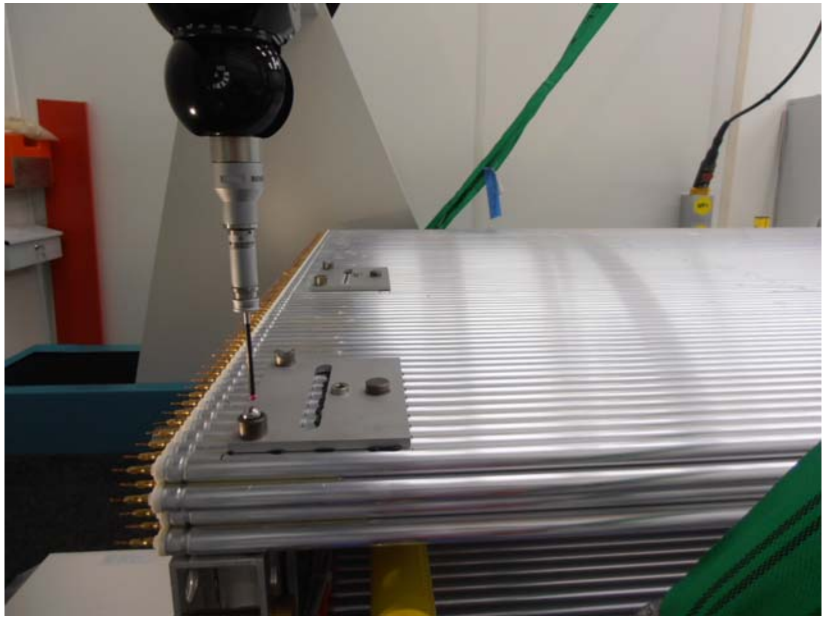


Chamber A, 1 x 2 m, 2 x 4 Lagen



Chamber B, 1 x 2 m, 2 x 4 Lagen





Conclusions

- sMDT chambers are a well suited for high-accuracy muon tracking at high background levels as required for the FCC.
- The inherent accuracy of the drift tube chambers allows for the coverage of large detector areas in a cost effective way, as only moderate granularity of tubes and electronics is required.
- sMDT chambers require about an order of magnitude less electronics channels per detector area than other detector technologies with comparable spatial resolution resulting in important cost saving.
- The high reliability of the drift-tube chambers has been proven in ATLAS.
- Their performance at high background rates is well understood.
- No aging observed up to 15 times the ATLAS requirement w.r.t. charge accumulation on wire.
- The drift tube technology by design allows for accurate positioning of the alignment sensors with respect to the sense wires (and for even more precise measurement of their positions) which is an essential requirement for achieving high track and momentum resolution at high energies.