Precision Muon Tracking Detectors for FCC-hh

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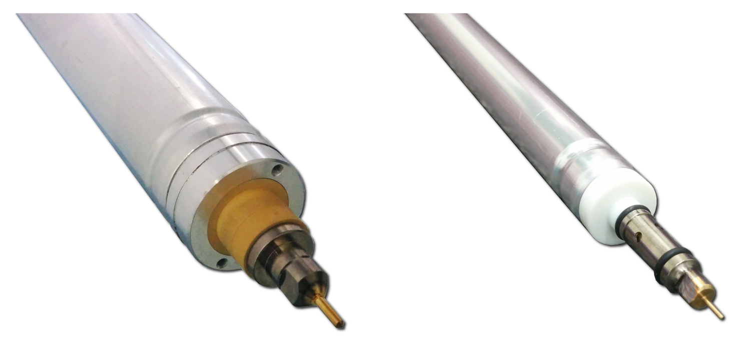
27 July 2016

Abstract

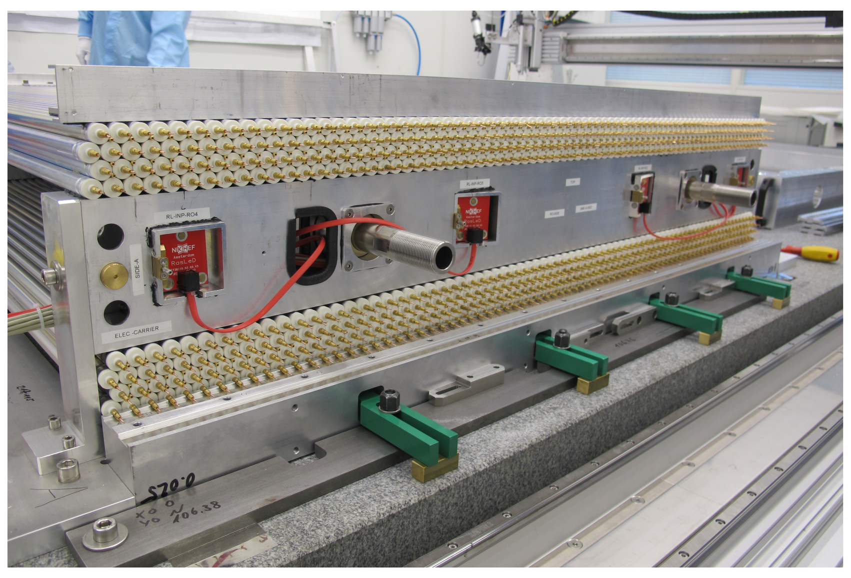
The ATLAS Muon Drift-Tube (MDT) chambers provide precision muon tracking with high reliability over large areas. At the LHC, the chambers are exposed to unprecedentedly high background rates of photons and neutrons. Still higher background rates are expected at future hadron colliders, HL-LHC and FCC-hh. Drift-tube detectors with smaller tube diameter of 15 instead of 30 mm (sMDT chambers) have been developed for operation under such conditions. Tests at the Gamma Irradiation Facility at CERN showed an improvement of the rate capability by an order of magnitude due to strong suppression of space charge effects. Further improvement can be achieved with new readout electronics optimised for high counting rates which is under development. The chamber design and assembly methods have been optimized for large-scale production reducing considerably the construction time and cost. The production of 12 new sMDT chambers for the upgrade the ATLAS muon spectrometer in the LHC winter shutdown 2016/17 has just been completed. An unprecedentedly high sense wire positioning accuracy of better than 5 micron has been achieved.

Muon Drift Tube Chambers



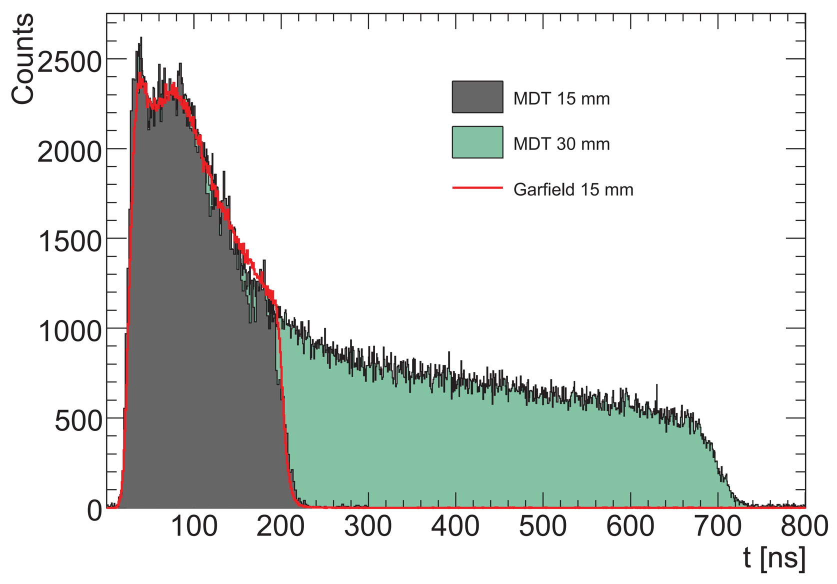
⌀30 mm MDT ⌀15 mm sMDT

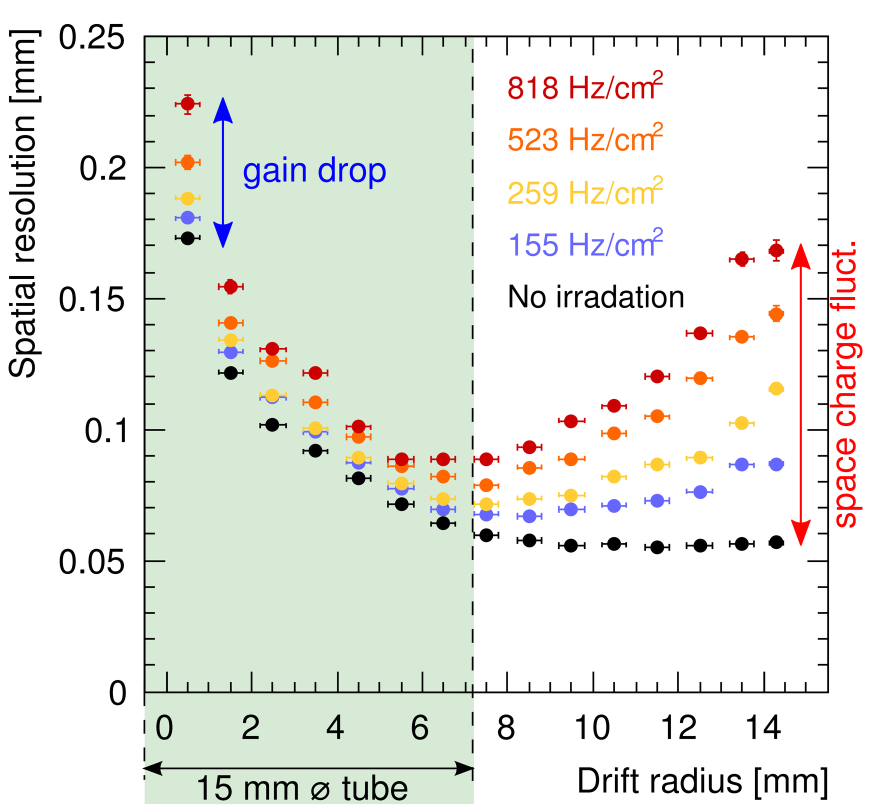
Assembled sMDT chamber for ATLAS

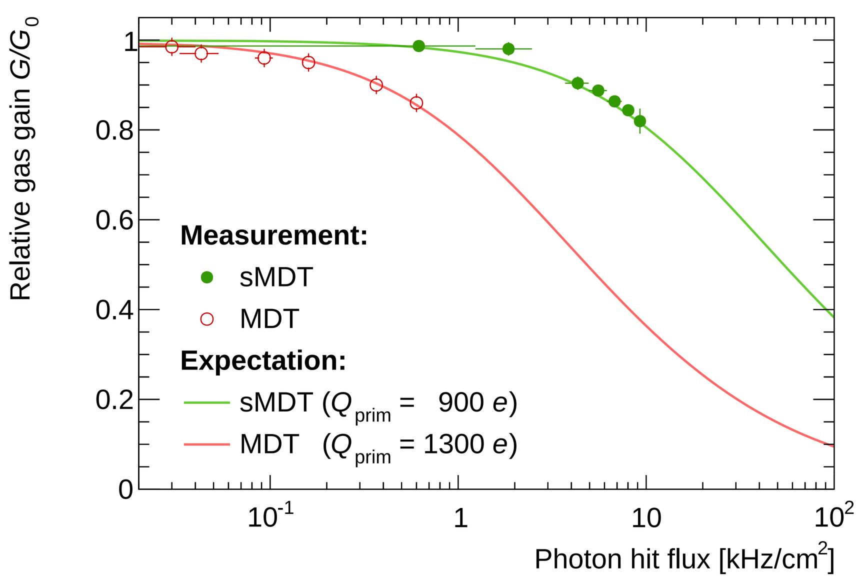


Monitored Drift Tube chambers, MDT: Precision tracking detectors in the ATLAS Muon Spectrometer with 30 mm diameter aluminum drift tubes operated with $Ar:CO_2$ (93:7) gas at 3 bar and a gas gain of 20000.

Small-Diameter MDT chambers, sMDT: Precision muon drift-tube detectors with 15 mm tube diameter and **10 times higher rate capability** compared to MDTs for ATLAS upgrades and for future hadron colliders.

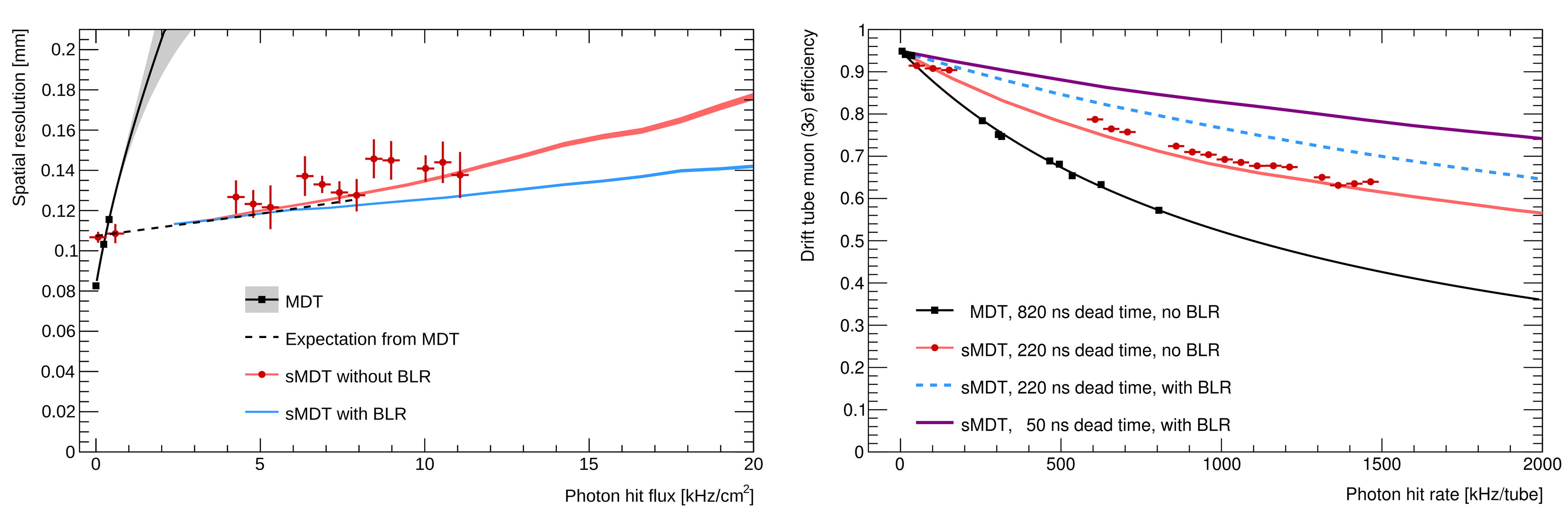






- The high neutron and γ background radiation at hadron colliders creates space charge of slowly drifting ions in the muon drift tubes and masks muon hits causing muon efficiency reduction which increases with the electronics dead time.
- Space charge fluctuations deteriorate the drift tube spatial resolution only for drift distances larger than the sMDT tube radius.
- Gas gain loss due to the shielding of the wire potential by the space charge increases with the tube be walls, and therefore is strongly suppressed in sMDT tubes.
- The 4 times shorter maximum drift time of sMDTs (185 ns) compared to MDTs (700 ns) at the same operating conditions and the 2 times smaller tube cross section lead to 8 times lower background occupancy.
- Reduction of the electronics dead time leads to a significant improvement of the muon detection efficiency at high counting rates. For full exploitation new readout electronics with suppression of signal pile-up effects is under development.

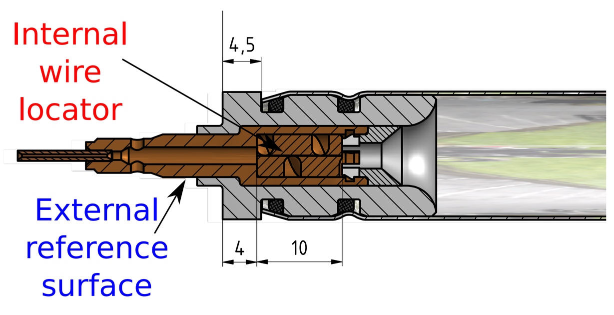
sMDT High-Rate Performance at CERN Gamma Irradiation Facility



Active baseline restoration (BLR) suppresses the observed signal pile-up effects promising further improvement of spatial resolution and muon efficiency (hit within $3\sigma_{resol}$ of the extapolated muon track) at high counting rates.

sMDT Chamber Design

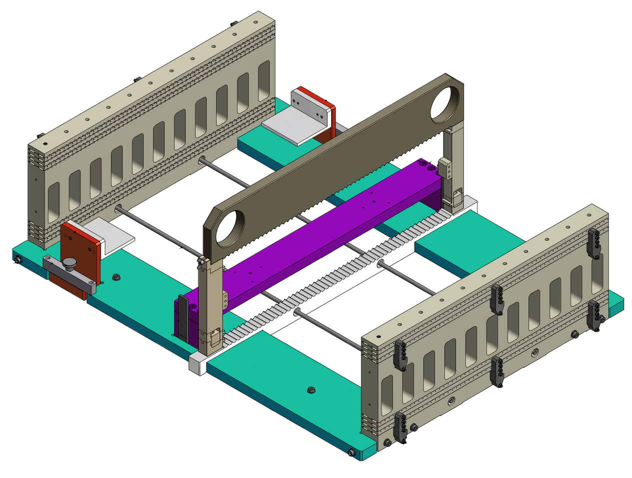
- sMDT chamber design and assembly optimized for mass production and speed independent of number of tube layers per chamber.
- Simple, low-cost drift tube design reliability and mechanical precision.
- Standard industrial aluminum tubes with 0.4 mm wall thickness.
- Plastic endplug materials selected to prevent outgassing and cracking.
- No wire aging observed up to 9 $\frac{C}{cm}$ charge on the wire (15 times current ATLAS requirement).



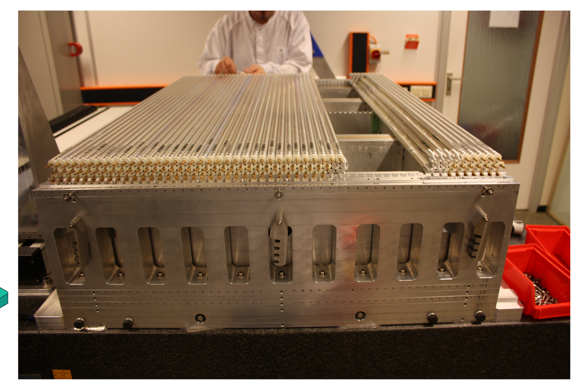
Cross section of an sMDT endplug

sMDT Chamber Assembly

- Semi-automated drift-tube production and chamber assembly in an air-conditioned clean room.
- Automated measurement of wire tension, gas leak rate and leakage current at nominal operating voltage (2730 V).



sMDT wire positioning by insertion of endplug reference surfaces into precisely machined jigs



sMDT chamber assembly

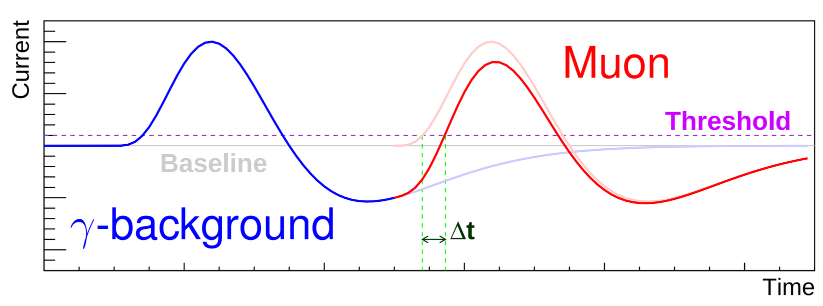
- Assembly of a chamber within one working day.
- Measurement of wire positions with coordinate measuring machine with few μm accuracy.
- **Sense wire positioning accuracy of better than 5 μm.**

Limitation of Standard MDT Read-Out Electronics at High Rates

- Bipolar shaping used to guarantee baseline stability at high rates.
- Disadvantage: long undershoot following the shaped signal pulse.

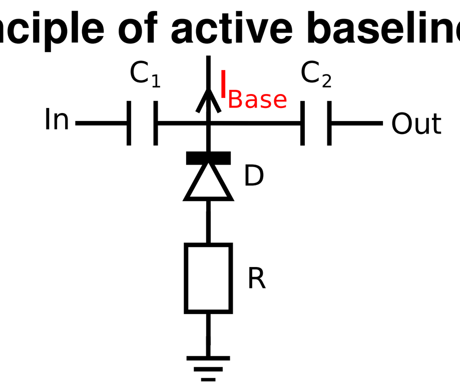
$\Rightarrow$ For desired operation at short dead time: amplitude of secondary muon pulses effectlively reduced and jitter of discriminator threshold crossing time increased.

Signal pile-up at high hit rates



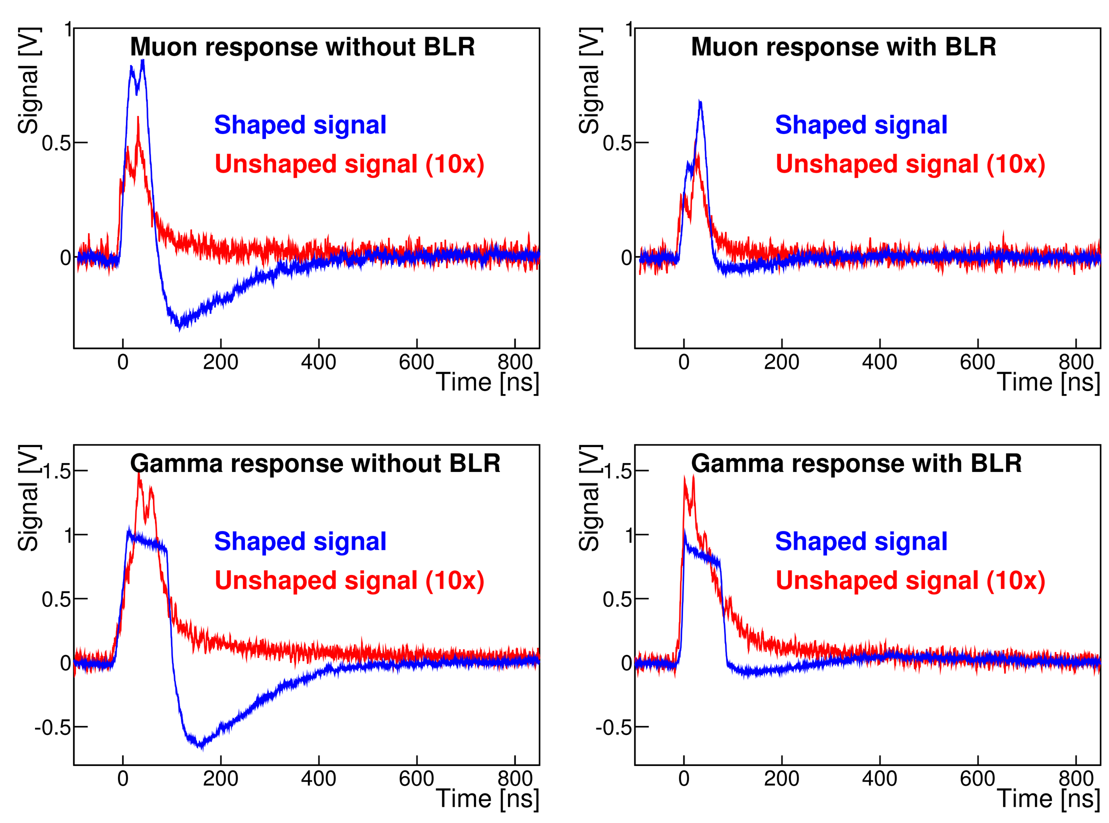
Signal Shaping With Active Baseline Restoration

Principle of active baseline restoration



- Diode conducting at $I_{Base} \neq 0$ working point.
- Diode non-conducting for positive signal polarity. $\Rightarrow$ signal stays unchanged.
- Diode conducting for negative polarity (undershoot) restoring baseline by draining current to ground.

Effect of Active Baseline Restoration



- Muon and γ background signals recorded before and after standard MDT bipolar shaping, the latter with and without turning on additional active baseline restoration (BLR) on a prototype circuit board.
- The BLR function clearly suppresses the bipolar undershoot. Promising option for operation of sMDT chambers at very high background counting rates.

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