Precision Muon Tracking Detectors and Readout Electronics for Operation at Very High Background Rates at Future Colliders

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Abstract

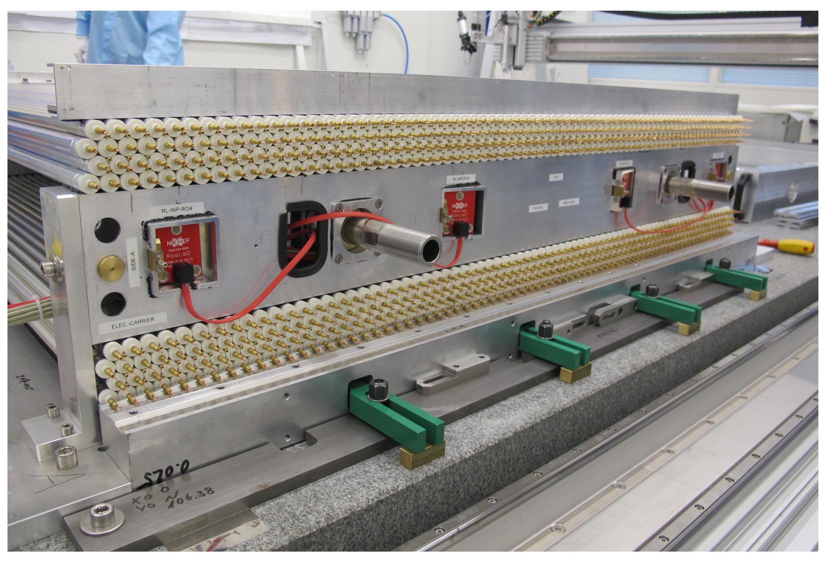
The experience of the ATLAS muon spectrometer shows that drift-tube chambers provide highly reliable precision muon tracking over large areas. The ATLAS muon chambers are exposed to unprecedentedly high background of photons and neutrons induced by the proton collisions. Still higher background rates are expected at future high-energy and high-luminosity colliders beyond HL-LHC. Drift-tube detectors with 15 mm tube diameter (30 mm in ATLAS) and improved readout electronics optimized for high rate operation have been developed for such conditions. Several full-scale chambers have been constructed with unprecedentedly high sense wire positioning accuracy of better than 10 micron. The chamber design and assembly methods have been optimized for large-scale production, reducing considerably cost and construction time while maintaining the high mechanical accuracy and reliability. Tests at the Gamma Irradiation Facility at CERN showed that the rate capability of sMDT chamber is improved by more than an order of magnitude compared to the ATLAS chambers as space charge effects are strongly suppressed and operation with minimal electronics dead time becomes possible. In order to further increase the high rate performance, the read-out electronics has been improved.

MDT and sMDT Chambers

⌀30 mm MDT

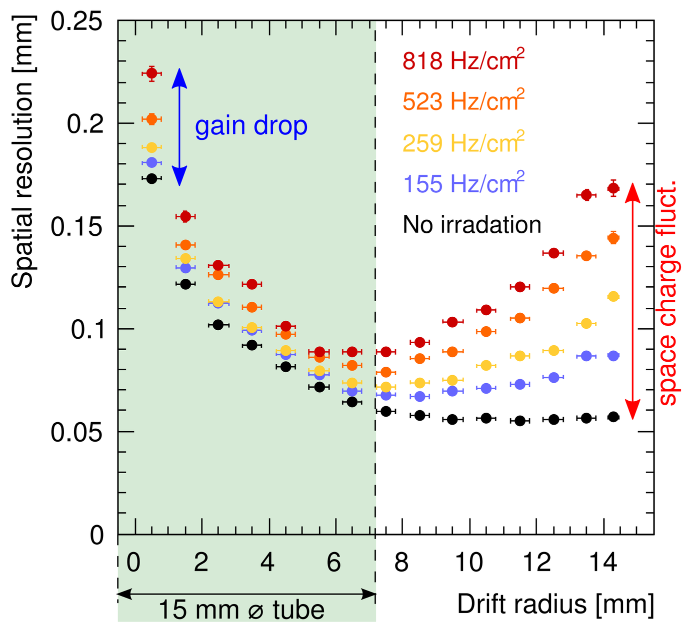
⌀15 mm sMDT

Assembled sMDT chamber



MDT chambers: drift tube detectors with 30 mm tube diameter accounting for the majority of precision tracking chambers in the ATLAS Muon Spectrometer

sMDT chambers: newly developed drift tube detectors with 15 mm tube diameter

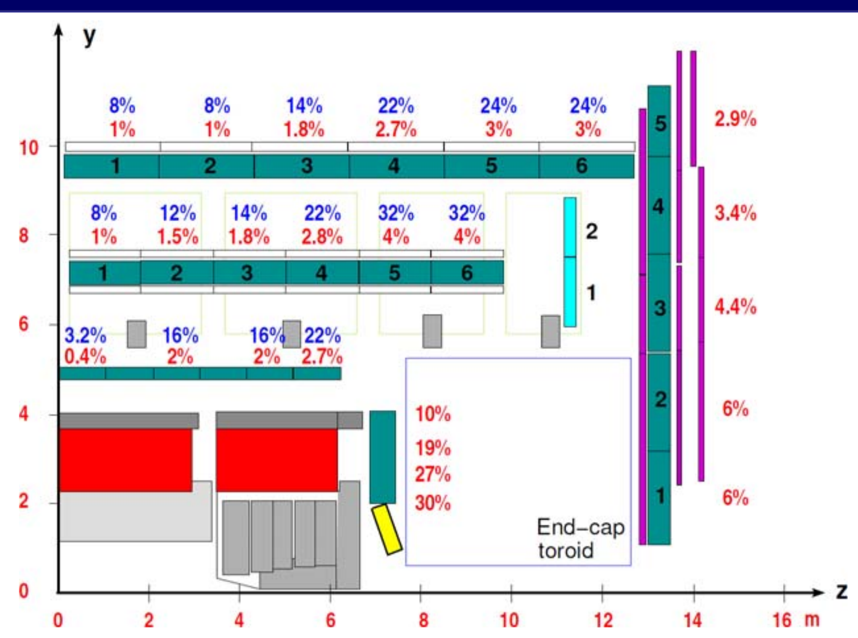


- Each particle hit causes space charge consisting of the slowly outwards drifting ions created in the charge multiplication in the vicinity of the wire
- Space charge effects due to the altered electric field leading to a decrease of the gas amplification: $\sim R^3$ for γ and $\sim R^4$ for charged particles

$\Rightarrow$ Rate capability in terms of gain drop by almost an order of magnitude higher for sMDT compared to MDT tubes [1]

Space charge effects are strongly mitigated in sMDT chambers and do no longer limit the performance

Occupancies at Maximum FCC Luminosity (ATLAS Geometry)

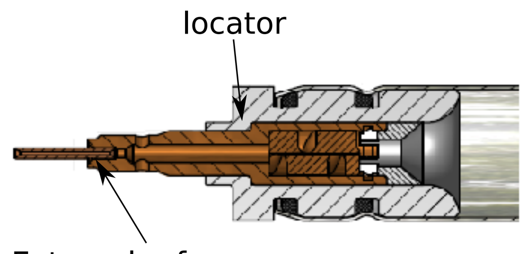


- Maximum sMDT occupancy at FCC is half the MDT occupancy at HL-LHC
- FCC detectors are not limited to ATLAS operating parameters and geometry

Further optimization of
  - Tube length depending on η
  - Drift gas parameters
  - **Read-out electronics**

sMDT Design

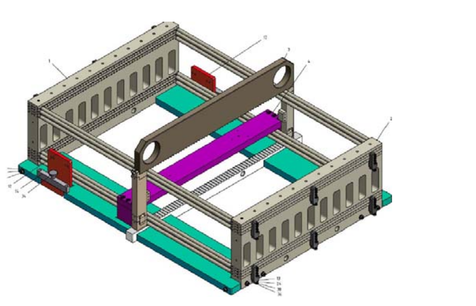
- sMDT chamber design and assembly procedures optimized for mass production
- Simple and cheap drift tube design with high reliability
- Special plastic materials selected to prevent outgassing and cracking
- Industrial standard Al tubes
- Wire positioning accuracy better than 10 μm



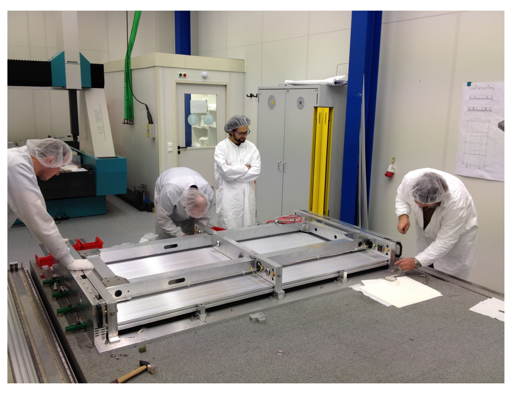
Schematic of an sMDT end-plug

sMDT Chamber Construction

- Semi-automated drift-tube production and chamber assembly take place in a air-conditioned clean room
- Automated testing of tube leakage rate, leakage current and wire tension



Tube positioning using precisely machined jigs



Chamber assembly in a clean room

- 2 sMDT chambers already installed in the ATLAS detector
- Additional 12 (16) sMDT chambers under construction until 2016 (2018)

Limitation of Present sMDT Read-Out Electronics

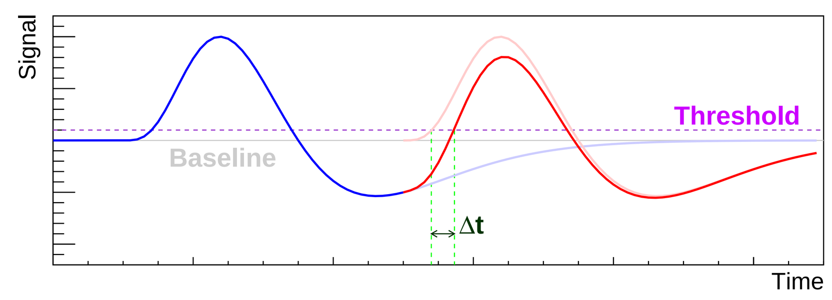
- Bipolar shaping used to guarantee baseline stability at high rates
- Disadvantage: long overshoot at the end of each signal

$\Rightarrow$ Effectively higher threshold and increased dead time for subsequent hits

- Want to operate with short dead time to maintain high efficiency at high rates

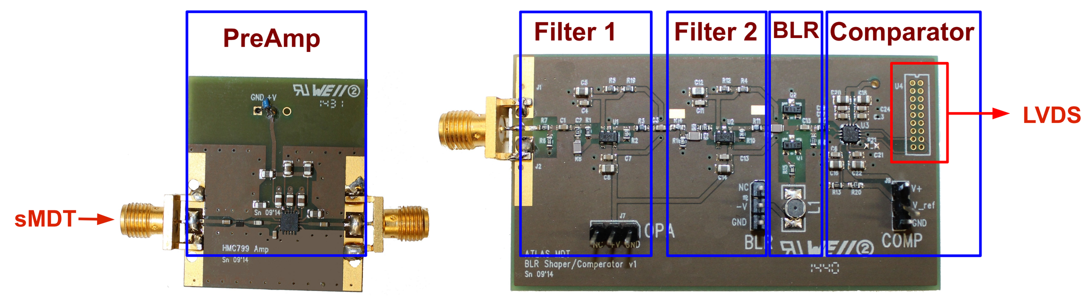
$\Rightarrow$ strong influence of undershoot

Signal Pile-Up of Closely Spaced Hits



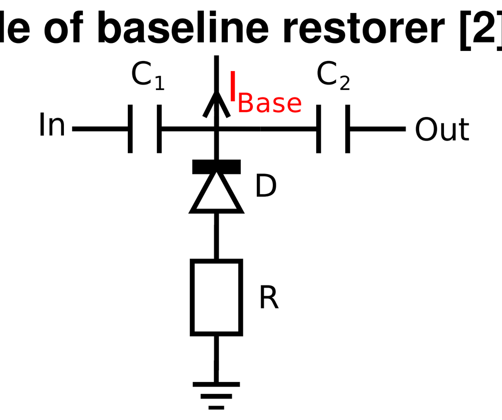
Solution: Shaping Circuit With Baseline Restoration

- High bandwidth (700 MHz) transimpedance amplifier (PreAmp)
- Discrete bipolar shaping circuit (2 filter stages) with baseline restoration (BLR)



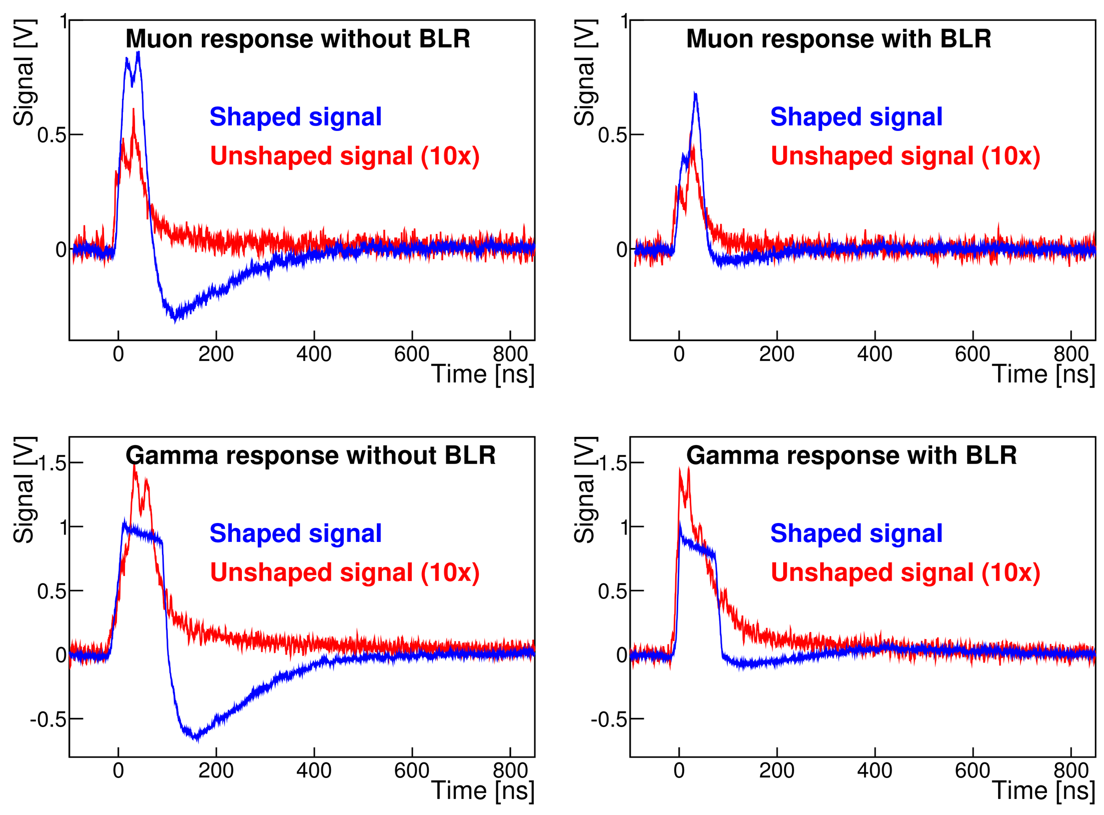
Photograph of preamplifier (PreAmp) and shaping circuit (Filter 1-2, BLR) with comparator

Principle of baseline restorer [2]



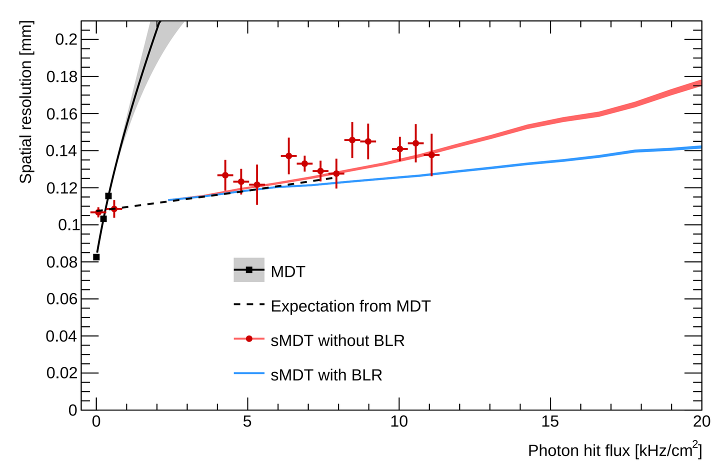
- Diode slightly conducting at working point (I_{Base})
- Diode is non-conducting for positive (desired signal) polarity $\Rightarrow$ signal stays unchanged
- Diode is conducting for negative (undesired signal) polarity $\Rightarrow$ signal is pulled to baseline

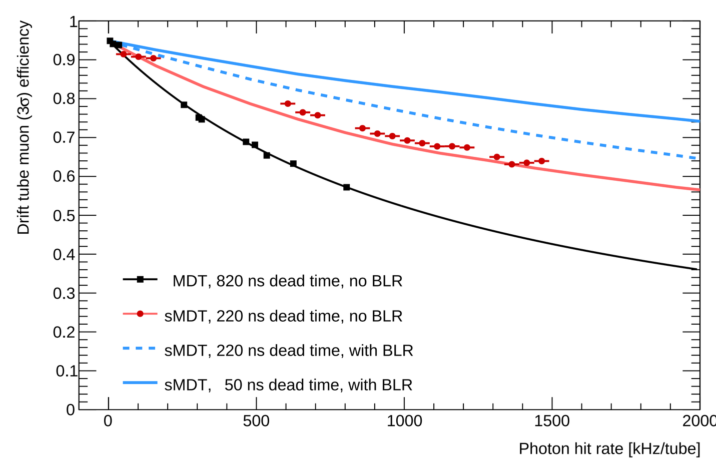
Application of Baseline Restoration on sMDT Muon and Gamma Pulses



- Due to the discrete circuit, the amplified signal before and after the signal shaping can be measured in parallel
- Baseline restoration leads to a clear suppression of the bipolar undershoot
- The diode used in the baseline restorer causes a slightly smaller pulse amplitude compared to shaping without baseline restoration

sMDT Performance Test at the CERN Gamma Irradiation Facility





- Measurements show huge improvement in terms of rate capability for sMDT compared to MDT drift tubes in both spatial resolution and muon efficiency
- Baseline restoration suppresses the pile-up effects and, therefore, avoids resolution and efficiency degradation at high counting rates

Bibliography

[1] B. Bittner et al., *Performance of Drift-Tube Detectors at High Counting Rates for High-Luminosity LHC Upgrades*, Nucl. Instr. and Meth. A732 (2013) 250-254.

[2] L. B. Robinson, *Reduction of Baseline Shift in Pulse-Amplitude Measurements*, Rev. Sci. Instrum. 32 (1961) 1057.

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