Optimisation of the Front-End Electronics of Drift Tube Chambers for High-Rate Operation

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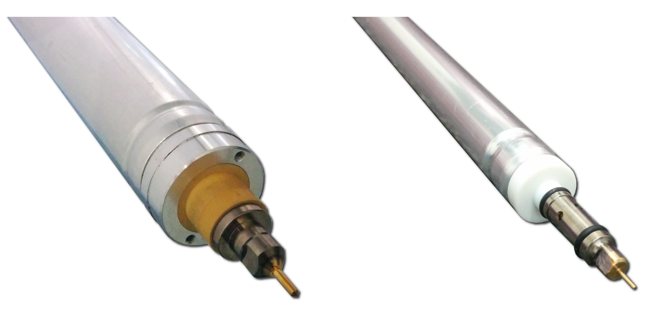
Abstract

The Monitored Drift Tube (MDT) chambers of the ATLAS experiment provide muon track reconstruction with a spatial resolution of about 35 µm and efficiency of almost 100% up to the maximum expected background rates at nominal LHC luminosity. For much higher background rates, as they are anticipated for LHC luminosity upgrades (HL-LHC), sMDT chambers with 15 mm tube diameter, which is half the diameter of the MDT chambers, have been developed. Compared to MDT chambers, they suffer much less from space charge caused by background hits and provide more redundancy due to the higher packing density of the drift tubes. In the existing MDT front-end electronics, bipolar shaping is used to eliminate the long signal tail caused by the slowly drifting ions and to guarantee baseline stability at high rates. The undershoot of the bipolar shaping causes, however, signal pile-up of closely spaced pulses. The impact of signal pile-up is equivalent to a higher discriminator threshold for the subsequent pulse and implies additional time slewing and degradation of the detection efficiency. A technical solution is provided by active baseline restoration.

MDT and sMDT Chambers

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

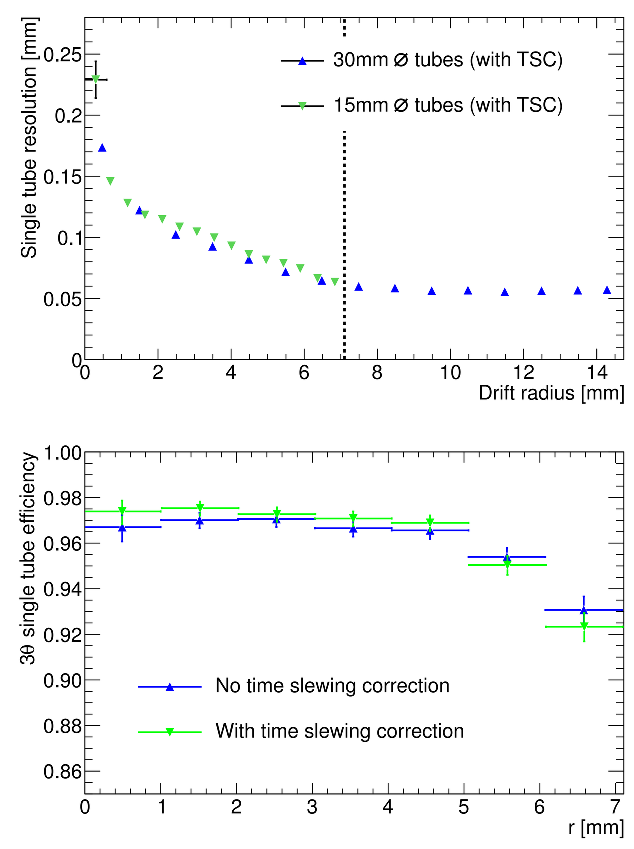


⌀30 mm MDT ⌀15 mm sMDT

Advantages of smaller tube diameter:

- much higher rate capability (see below)
- more compact chamber geometry
- more robust pattern recognition

Performance in the Absence of Radiation Background

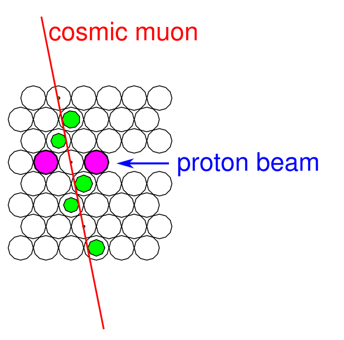


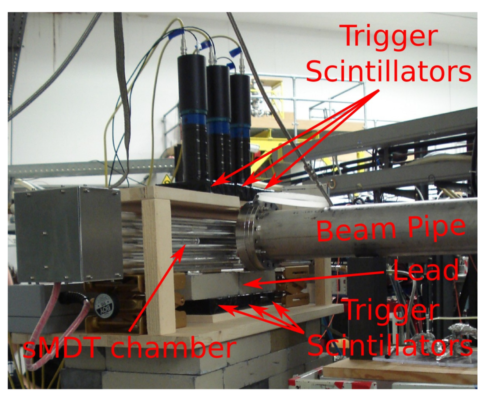
- average single tube resolution: (108 ± 2) µm (128 ± 2 µm without time slewing corrections).
- average 3σ single tube efficiency: 94%.

Measurement under Proton Irradiation (with LMU Munich)

Tandem accelerator at the MLL in Garching

- 20 MeV protons
- flux up to 100 kHz/cm^2





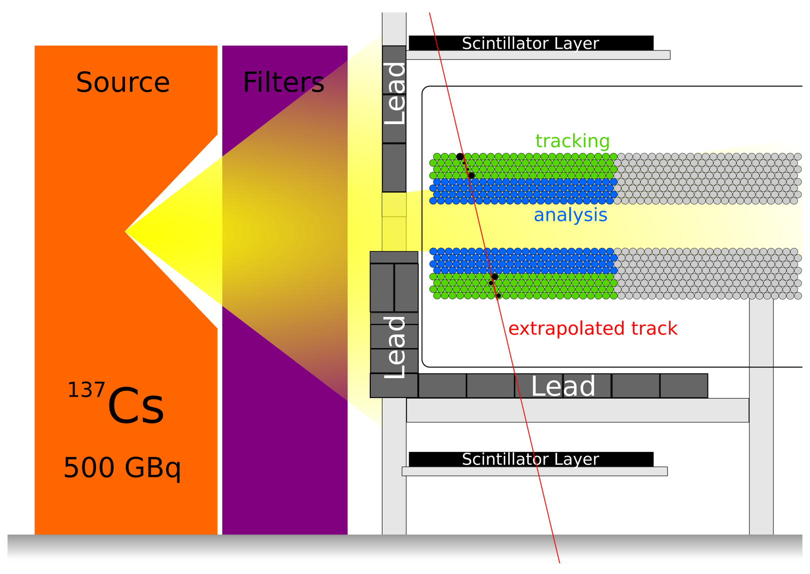
Using a custom sMDT chamber to maximise cosmic muon acceptance:

- Reconstruct cosmic muon tracks in upper and lower tube layers.
- Calculate off-track residuals in irradiated tube layer.
- Monitor proton rate and current drawn by the irradiated tubes for gas gain measurement.

Measurement under Gamma Irradiation

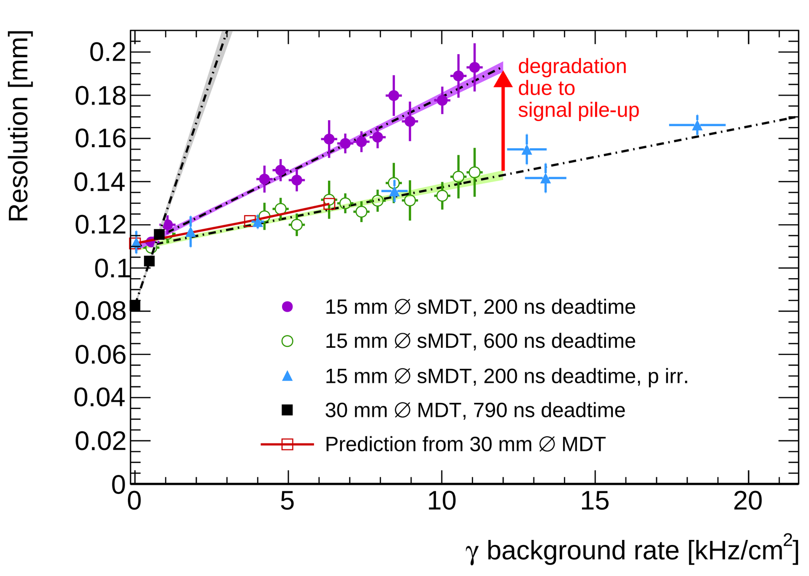
CERN Gamma Irradiation Facility (GIF)

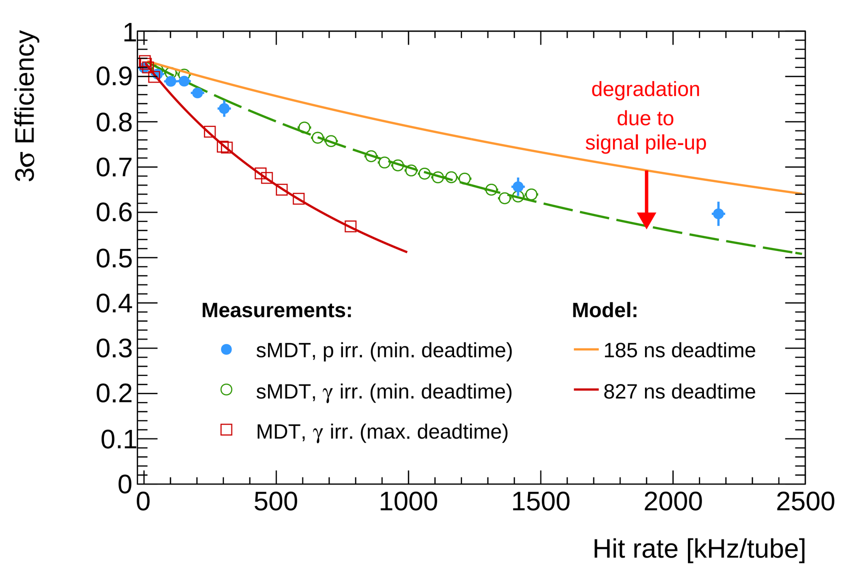
- 500 GBq ^{137}Cs source
- flux up to 10 kHz/cm^2



- Central tube layers of the chamber irradiated, outer (shielded) layers used for tracking of cosmic muons.
- Use track reconstructed in shielded part of the chamber to determine off-track residuals in irradiated tubes.

Measurement Results





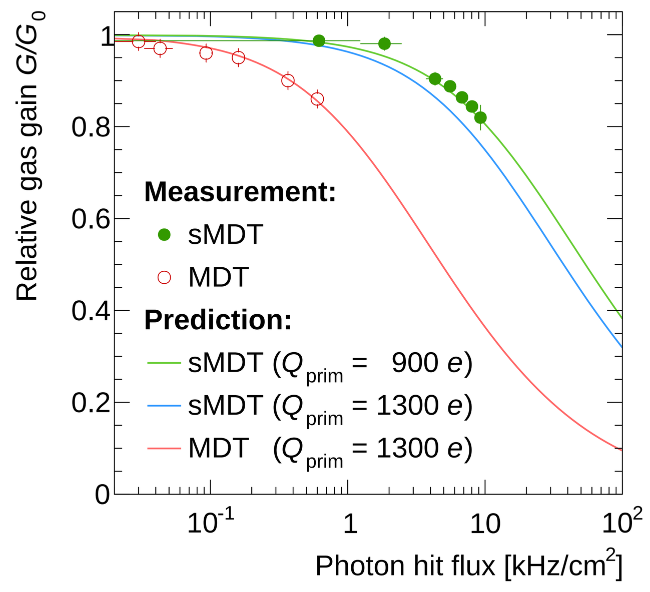
3σ efficiency: probability to detect a hit with a precision of better than 3 times the drift tube spatial resolution σ.

Gain Drop due to Space Charge Induced by Radiation

- Each particle hit causes space charge consisting of the slowly outwards drifting ions created in the charge multiplication in the vicinity of the wire.
- The space charge alters the electric field $E(r)$ resulting in a decrease of the gas amplification

$$G = \left[\frac{E_{\text{wire}}}{3E_{\text{min}}}\right]^{\frac{r_{\text{wire}}E_{\text{wire}}\ln 2}{\Delta V}},$$

where E_{wire} is the electric field at the wire surface, which depends on the space charge and hence on radiation level.

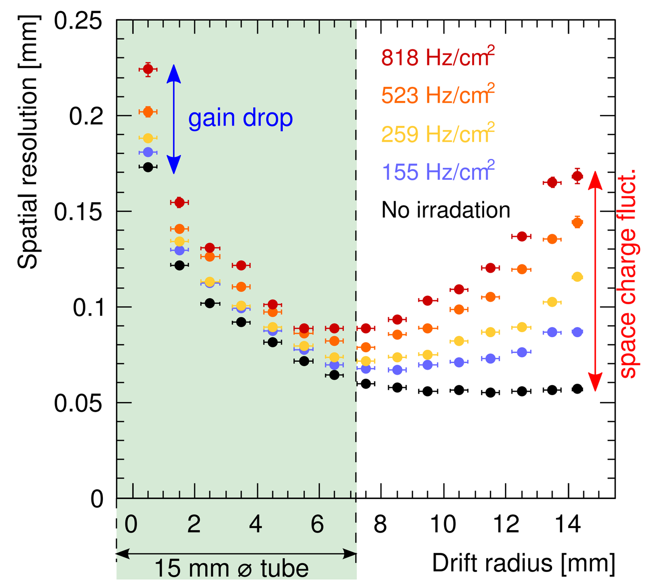


Rate capability in terms of gain drop approximately 8 times higher for sMDT's compared to MDT's.

Space Charge Fluctuations

- The space–drift time relationship $r(t)$ depends on the electric field $E(r)$
- $E(r)$ is modified by radiation induced space charge
- Space charge fluctuations ⇒ $E(r)$ fluctuations ⇒ $r(t)$ fluctuations

Effect is large when r(t) is non-linear, which is the case for r > 6 mm with the Ar/CO_2 gas used ⇒ sMDT's (r_{max} = 7.1 mm) hardly affected

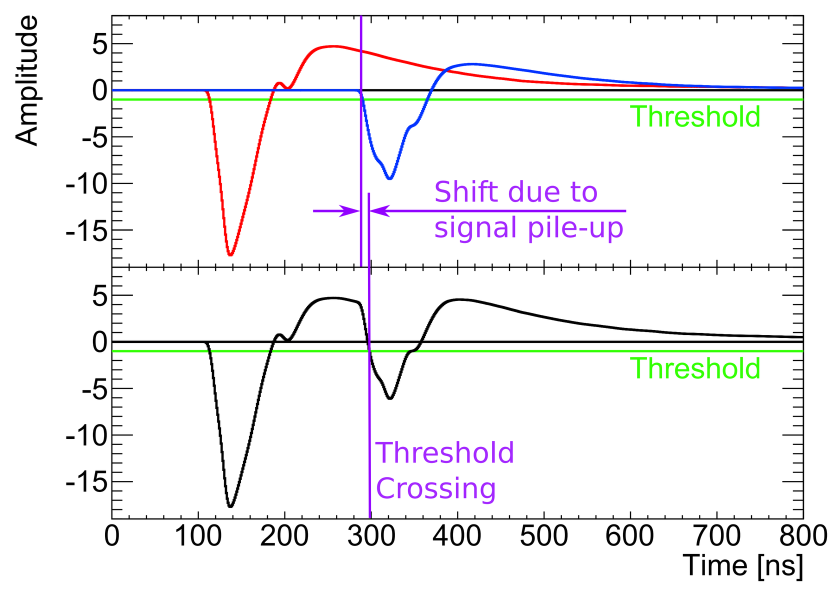


Signal Pile-Up of Closely Spaced Hits

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

⇒ Effectively higher threshold and increased dead time for subsequent hits

- Want to operate with short dead time to maintain high efficiency at high rates ⇒ strong influence of undershoot.

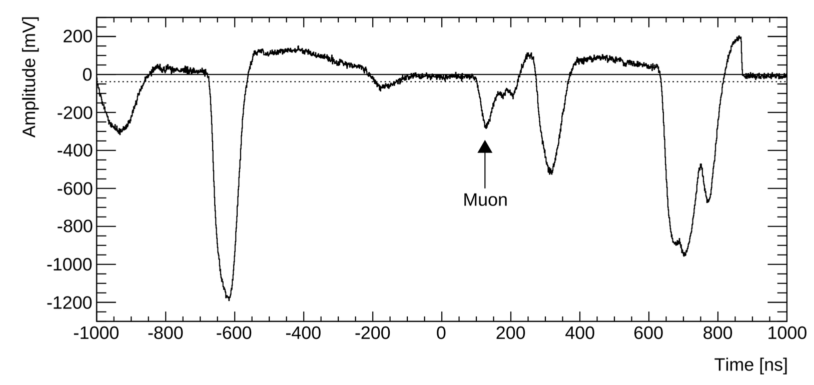


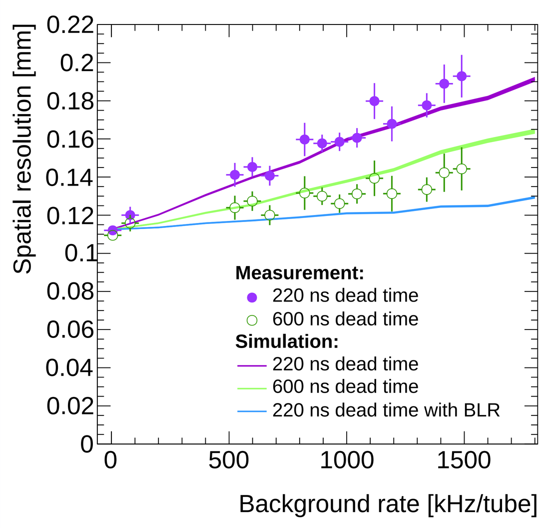
Cure: Active baseline restoration (BLR), as used e.g. in the ATLAS Transition Radiation Tracker strongly suppresses the undershoot also for sMDT's.

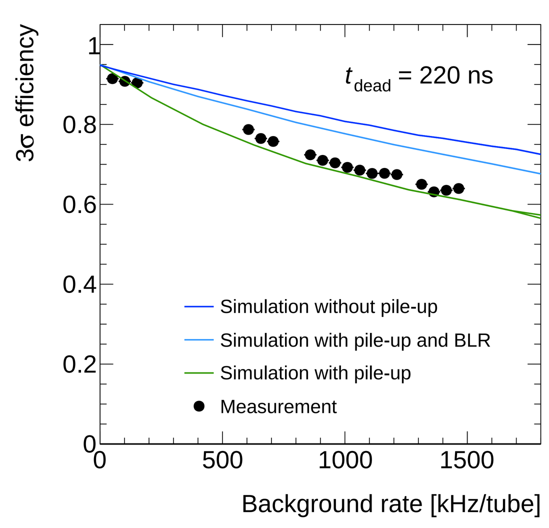
ASDBLR chip: [T. Akesson et al., Nucl. Inst. Meth. A, 449 (2000) 446]

Simulation of Signal Pile-Up Effect

- Simulation of signal pile-up using recorded and/or simulated single signals superimposed corresponding to specific rates



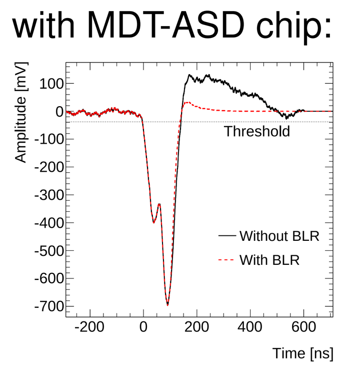




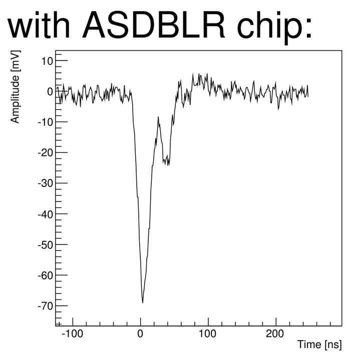
- Simulation without BLR describe well the measurements
- Simulation with baseline restoration predicts substantial improvement

Baseline restoration (BLR) in simulation: exponential attenuation of the undershoot with a time constant of 50 ns in signals recorded with the ASD chip (no baseline restoration) in order to mimic the behaviour of the active baseline restoration (see snapshots on the right, for comparison a pulse recorded with the ASDBLR chip is shown).

with MDT-ASD chip:



with ASDBLR chip:



Conclusions

- MDT chambers suffer at high rates from
  - gain drop,
  - space charge fluctuations,
  - high occupancy.
- sMDT chambers have a much higher rate capability (approximately factor 8).
- Predominant performance loss of sMDT's is due to signal pile-up for hits at short time intervals.
- Further improvement possible with new front-end electronics employing active baseline restoration (BLR).

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