A new Highly Selective First Level ATLAS Muon Trigger With MDT Chamber Data for HL-LHC

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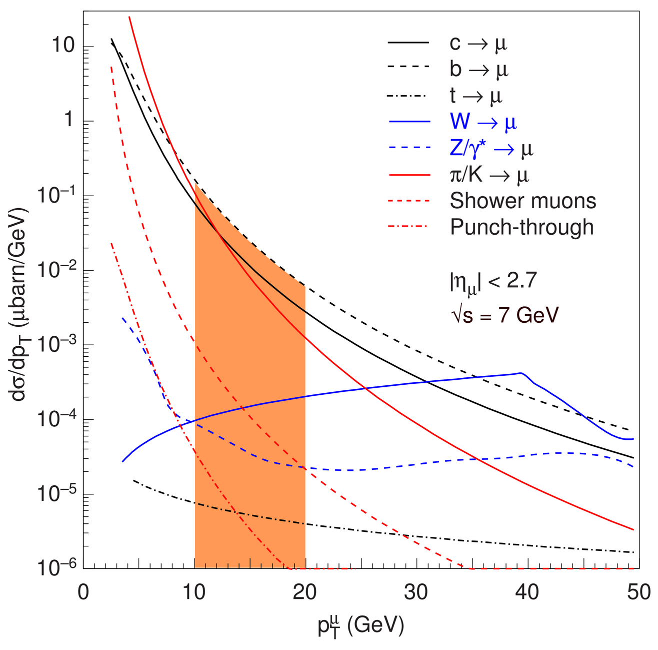
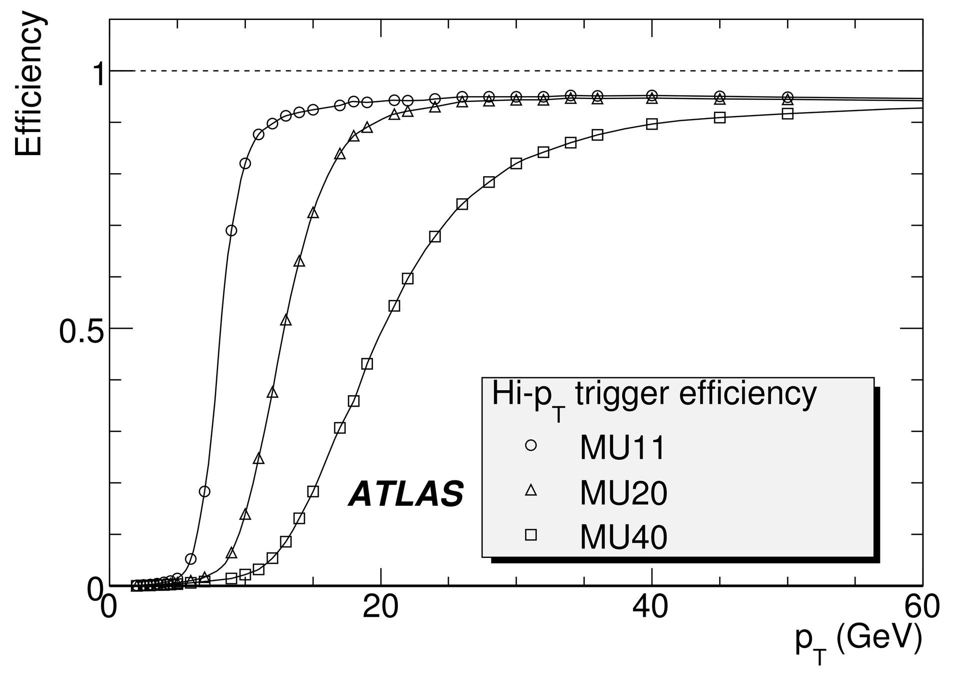
Abstract

Highly selective first level triggers are essential for the physics programme of the ATLAS experiment at the HL-LHC where the instantaneous luminosity will exceed the LHC's instantaneous luminosity by almost an order of magnitude. The ATLAS first level muon trigger rate is dominated by low momentum sub-trigger threshold muons due to the poor momentum resolution at trigger level caused by the moderate spatial resolution of the resistive plate and thin gap trigger chambers. This limitation can be overcome by including the data of the precision muon drift tube chambers in the first level trigger decision. This requires the implementation of a fast MDT read-out chain and a fast MDT track reconstruction. A hardware demonstrator of the fast read-out chain was successfully tested under HL-LHC operating conditions at CERN's Gamma Irradiation Facility. It could be shown that the data provided by the demonstrator can be processed with a fast track reconstruction algorithm on an ARM CPU within the 6 microseconds latency of the first level ATLAS trigger anticipated for the HL-LHC.

Motivation

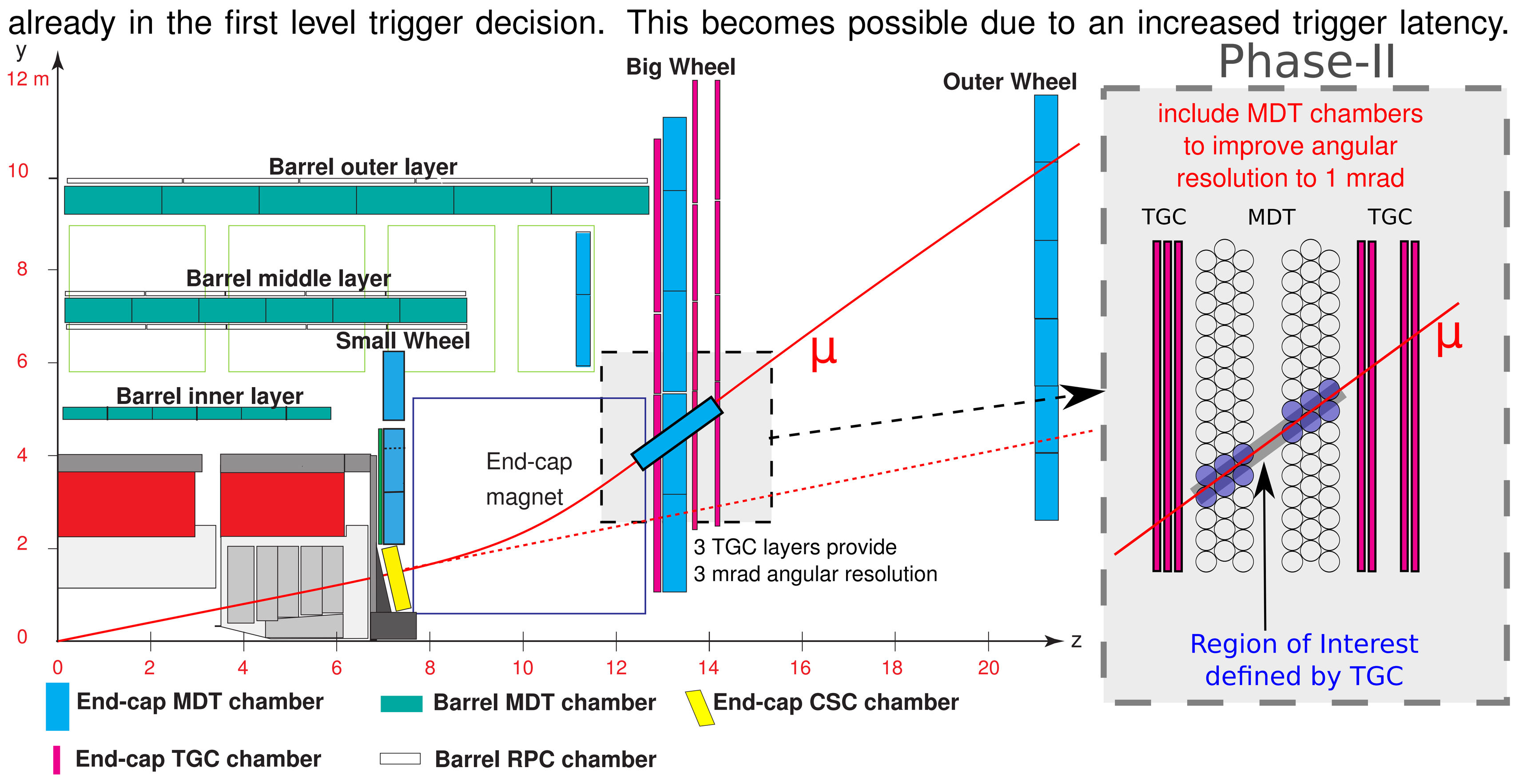
The large rate of low energy muons and the poor momentum resolution of the existing muon trigger system will lead to very high trigger rates for the low momentum trigger [1, 2].





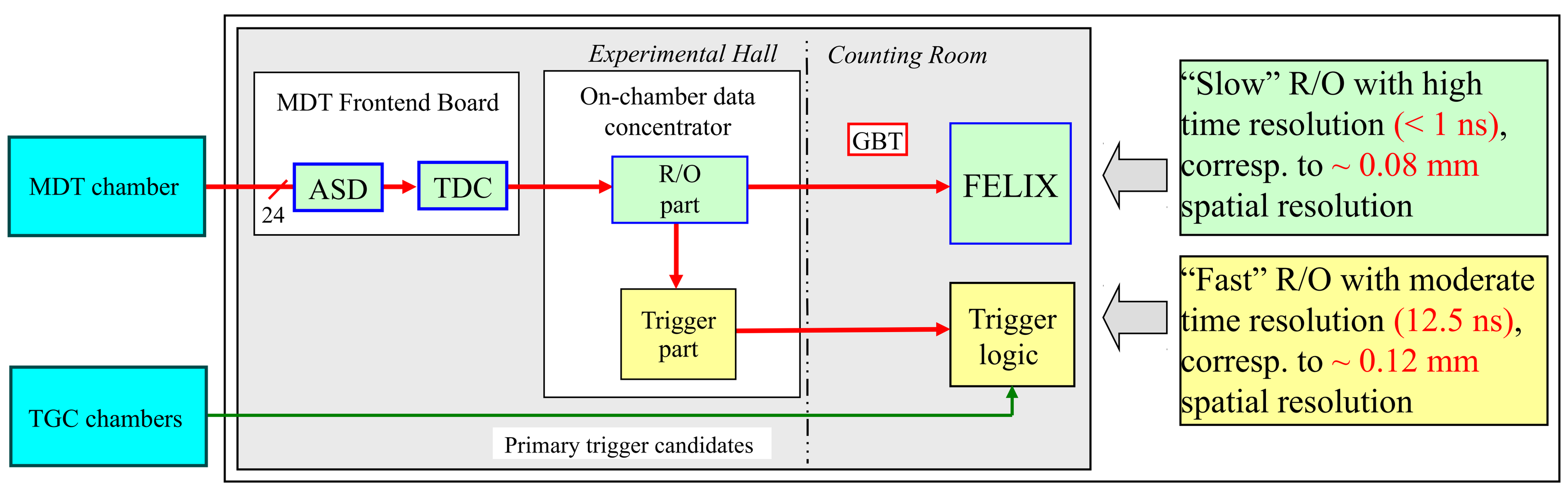
Including the MDT Chambers in the Level-1 Trigger

The momentum resolution of the existing muon trigger system is defined by the spatial/angular resolution of the trigger chambers. At the High-Luminosity LHC it will become possible to use in addition information of the precision tracking chambers, the Monitored Drift Tube (MDT) chambers, already in the first level trigger decision. This becomes possible due to an increased trigger latency.



Technical Implementation

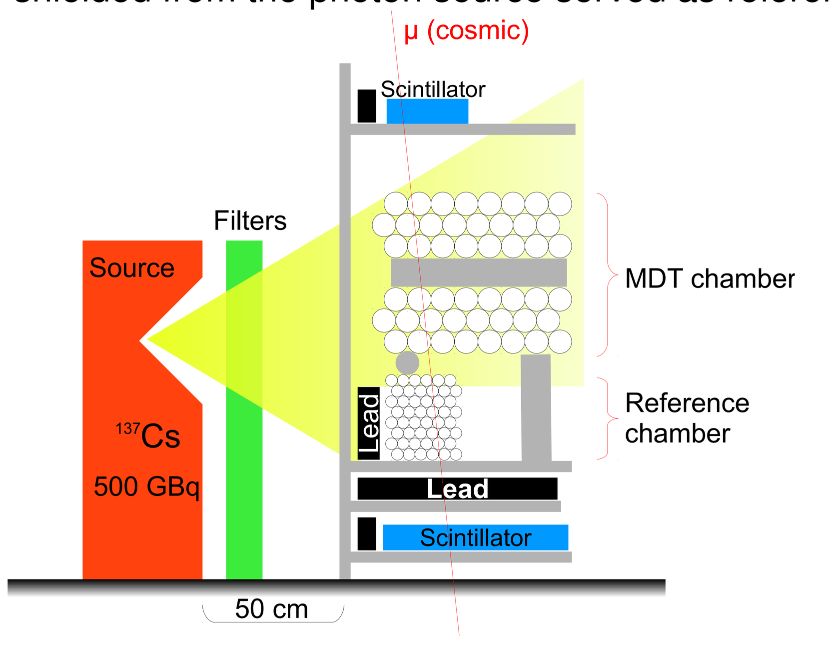
An additional fast read-out chain with reduced time resolution is needed in the MDT front-end electronics.

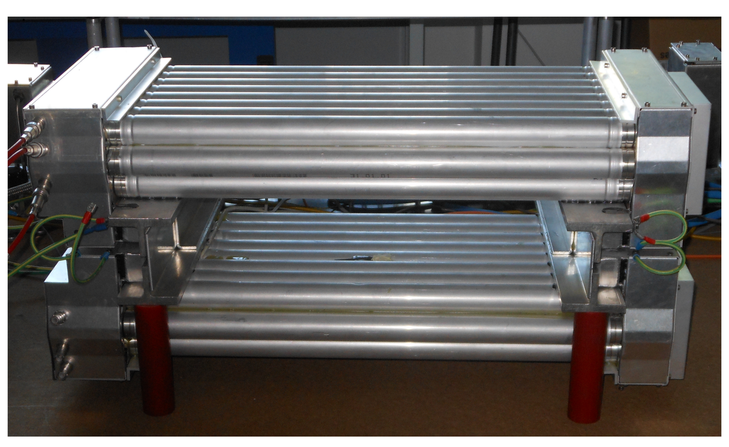


ASD: Amplifier Shaper Discriminator → Analog read-out chip
TDC: Time to Digital Converter → Drift time measurement
GBT: Gigabit Transceiver → Optical link
FELIX: Front-End Link Interface eXchange → Interface to data processing

Demonstrator Setup Used for Cosmic Muon Track Reconstruction in the CERN Gamma Irradiation Facility (GIF)

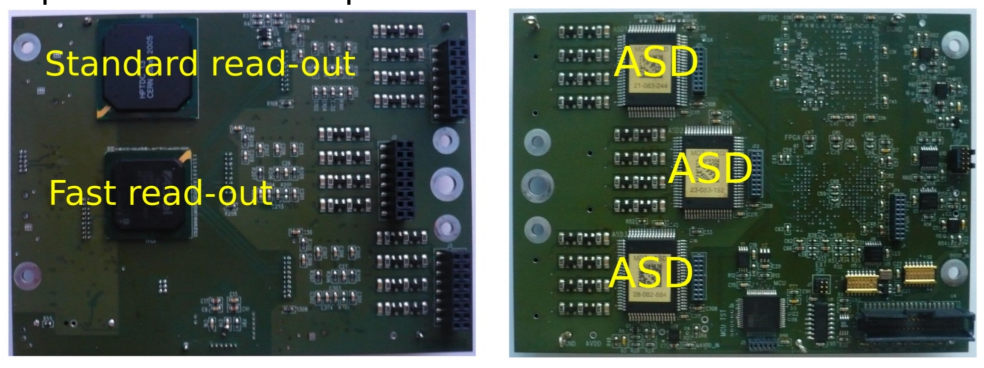
An MDT chamber (photograph) equipped with new front-end electronics including the additional fast read-out chain was used for track reconstruction of cosmic muons under photon irradiation in the CERN Gamma Irradiation Facility (GIF). An sMDT chamber with half the tube diameter mounted below and shielded from the photon source served as reference tracker.





New Front-End with Fast Read-Out Chain

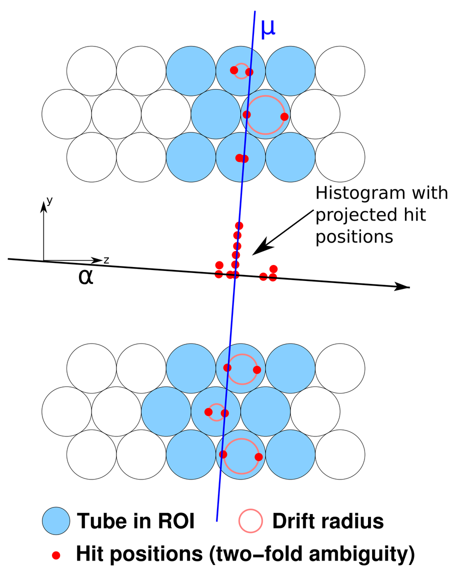
New front-end electronics which include the fast read-out chain were designed for the demonstrator. The fast read-out is implemented in an FPGA and operates with the 40 MHz LHC clock corresponding to a time resolution of 25 ns compared to 0.78 ns of the standard read-out. In the next version, the time resolution of the fast read-out will be improved to 12.5 ns, which brings a substantial improvement in the spatial resolution as can be seen below.



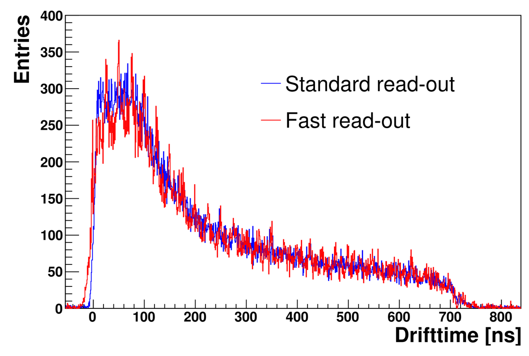
Back side Front side

Fast Track Finding Algorithm

Histogram based pattern recognition. The algorithm projects the approximate hit positions in the direction perpendicular to the expected track.



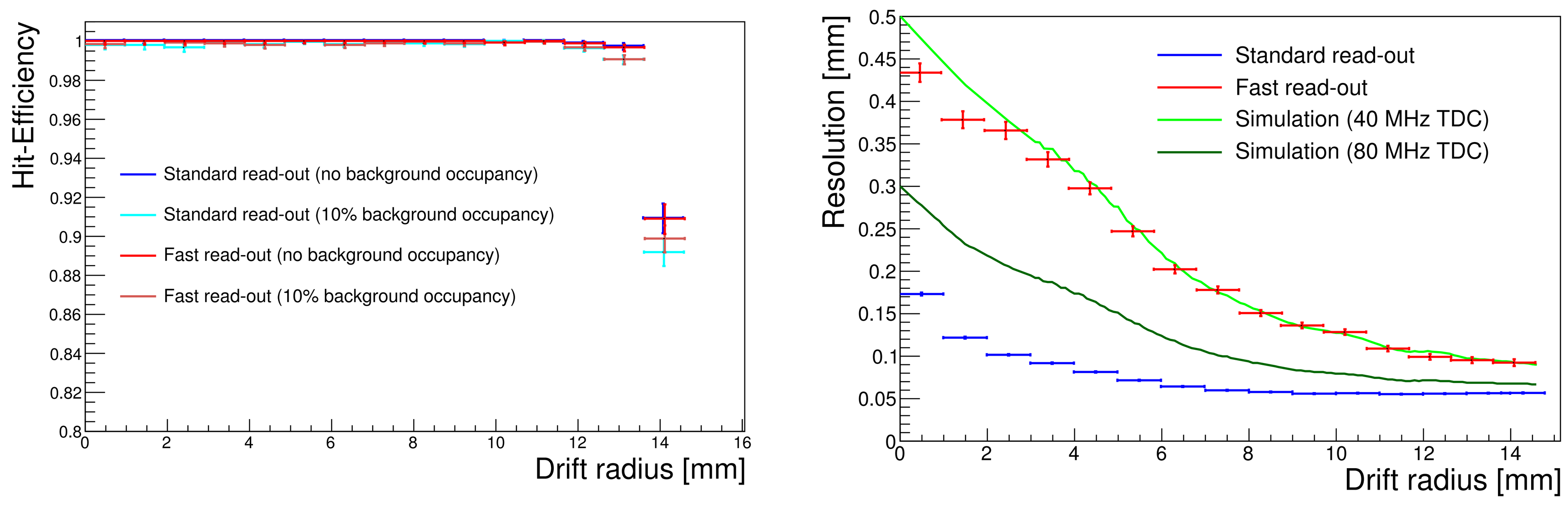
Drift Time Spectra with Fast and Standard Read-Out



- Good agreement in shape.
- Rising edge with fast read-out slightly wider due to the limited resolution.
- No discrete 25 ns time steps visible in fast read-out because measurement was performed with cosmic ray muons which are not correlated to the fixed 40 MHz clock.

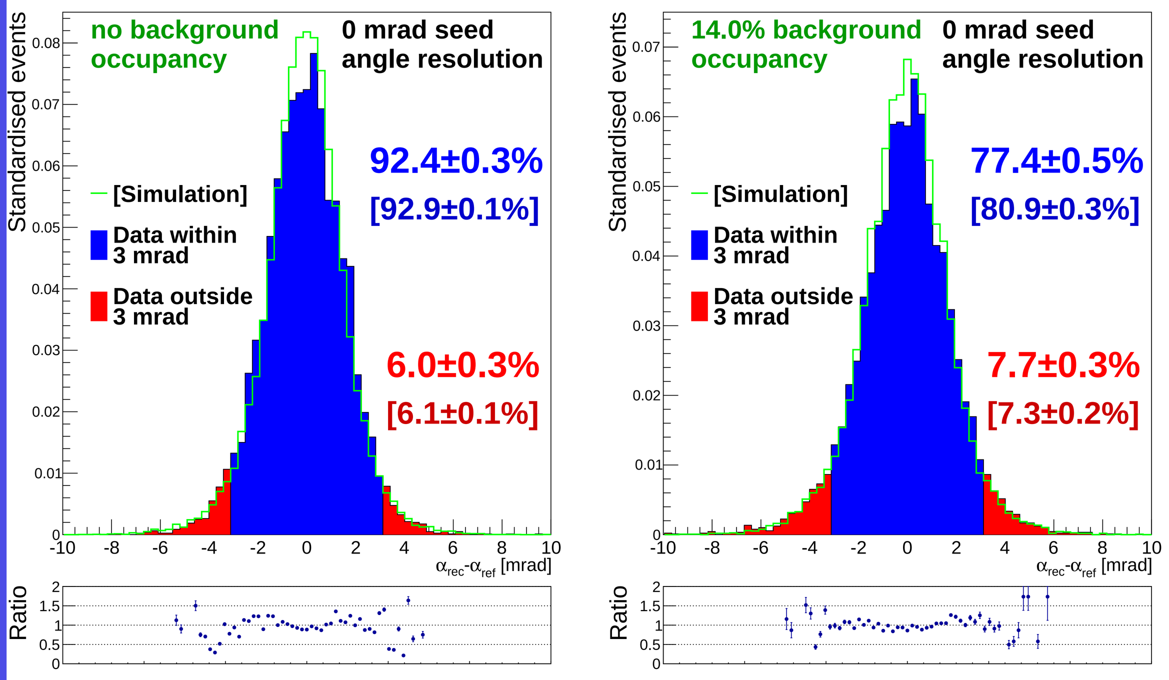
Performance of the Fast Read-Out Chain

Comparison of the efficiency and spatial resolution between the fast read-out with 40/80 MHz TDC and the standard read-out [3]:



The spatial resolution of the fast MDT read-out in the sub-millimeter range is to be compared to the spatial resolution of the trigger chambers which is on the order of few cm. This is sufficient to achieve the desired improvement in the momentum resolution.

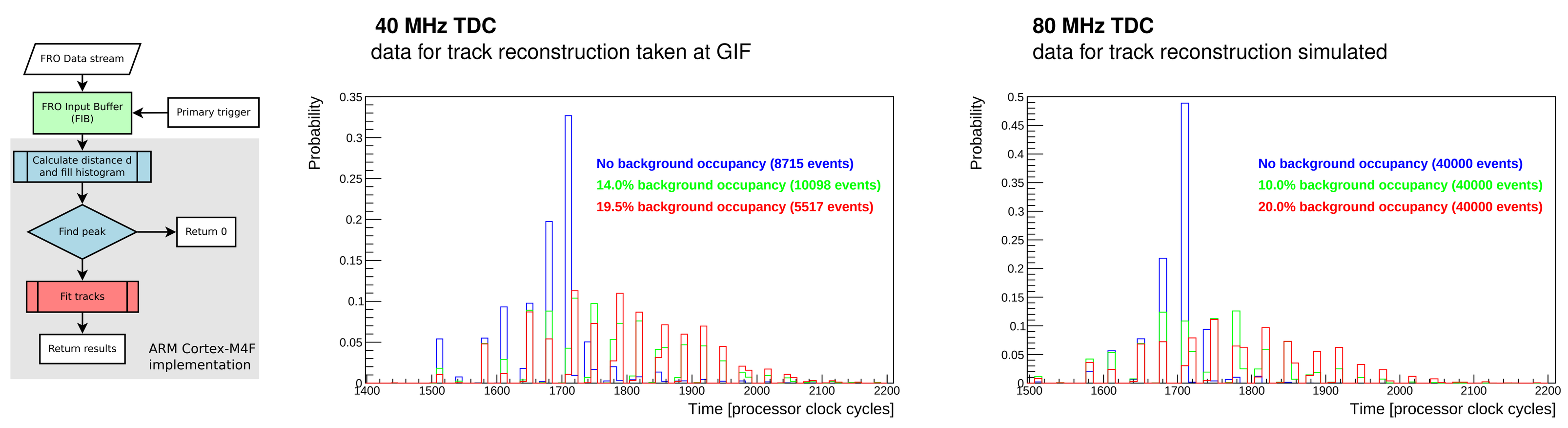
Performance Study of the Fast Tracking Algorithm with Cosmic Ray Muon Tracks



- Quality of reconstructed tracks defined by the deviation of the reconstructed slope (α_{rec}) from the true one (α_{ref})
- Efficiency: Successfully fitted tracks (fast tracking algorithm)
- Simulation with Geant4 (numbers in brackets)
- Poor efficiency for high background occupancy due to preliminary long dead time (1500 ns) of the fast read-out chain (200 ns dead time due to hit buffering already implemented in the newest demonstrator setup version)

Latency Estimation for the Fast Tracking Algorithm

The fast track reconstruction algorithm has been implemented in ARM Cortex-M4F (200 MHz) assembler (processing time simulation with Keil μVision).



- Required processing time increases with the amount of cavern background.
- Required processing time <2200 clock cycles (11 μs; ~6μs for ARM Cortex A9).

Bibliography

[1] ATLAS Collaboration, *ATLAS muon spectrometer: Technical Design Report*, CERN/LHCC/97-22, May 1997.

[2] http://twiki.cern.ch/twiki/bin/view/AtlasPublic/MuonTriggerPlots

[3] S. Nowak (ATLAS Muon Collaboration), *A Muon Trigger with high pT-resolution for Phase-II of the LHC Upgrade, based on the ATLAS Muon Drift Tube Chambers*, Proceedings of Technology and Instrumentation in Particle Physics 2014 Conference, PoS (TIPP2014) 205.

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