Test of a demonstrator of an MDT-based first level muon trigger for HL-LHC under realistic operating conditions

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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 limited momentum 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.
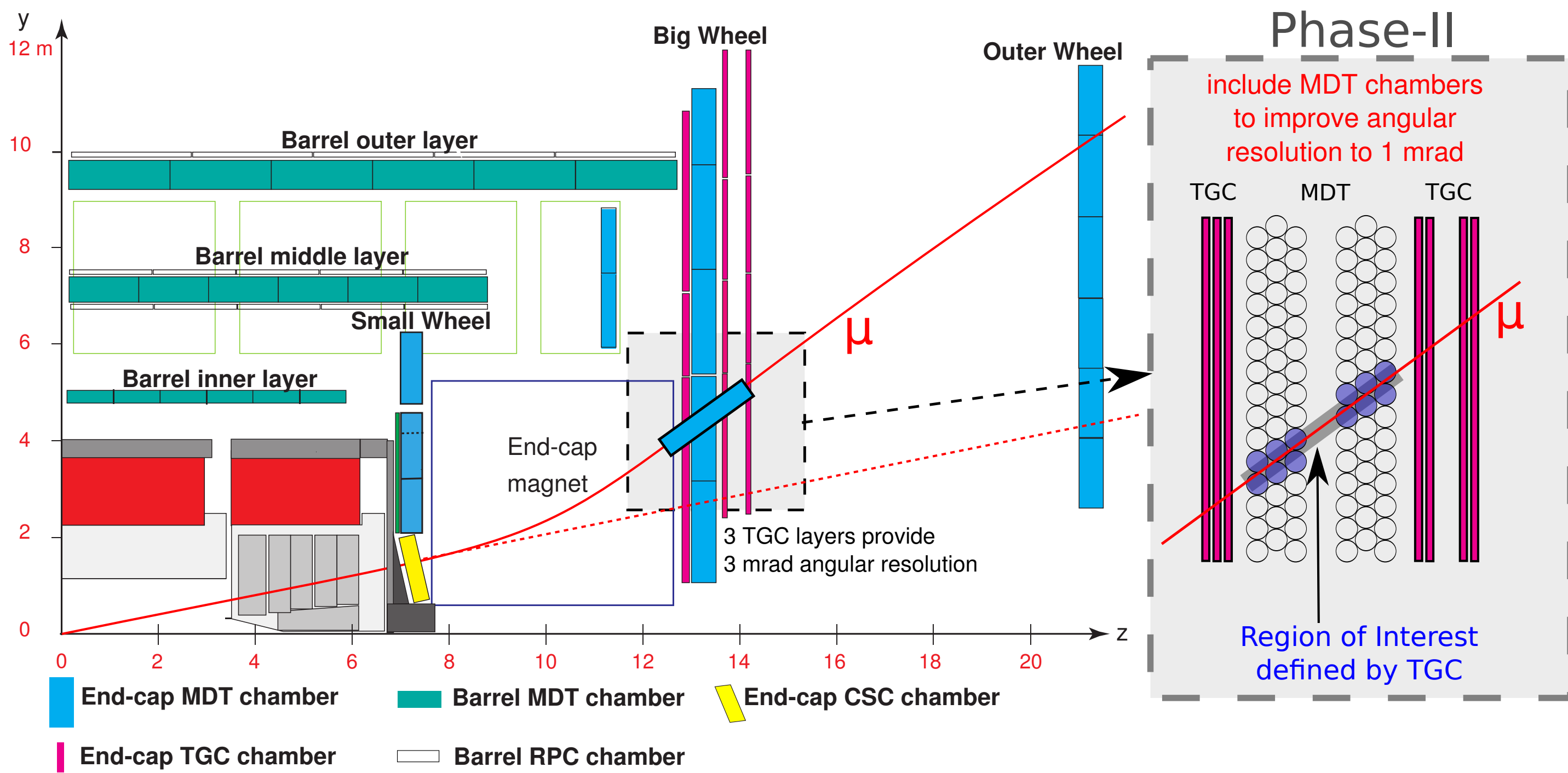
Motivation

The large rate of low energy muons and the limited momentum resolution of the existing muon trigger system will lead to very high trigger rates for the low momentum trigger [1]. An MDT-based first level muon trigger allows for substantial improvements in this region [2].
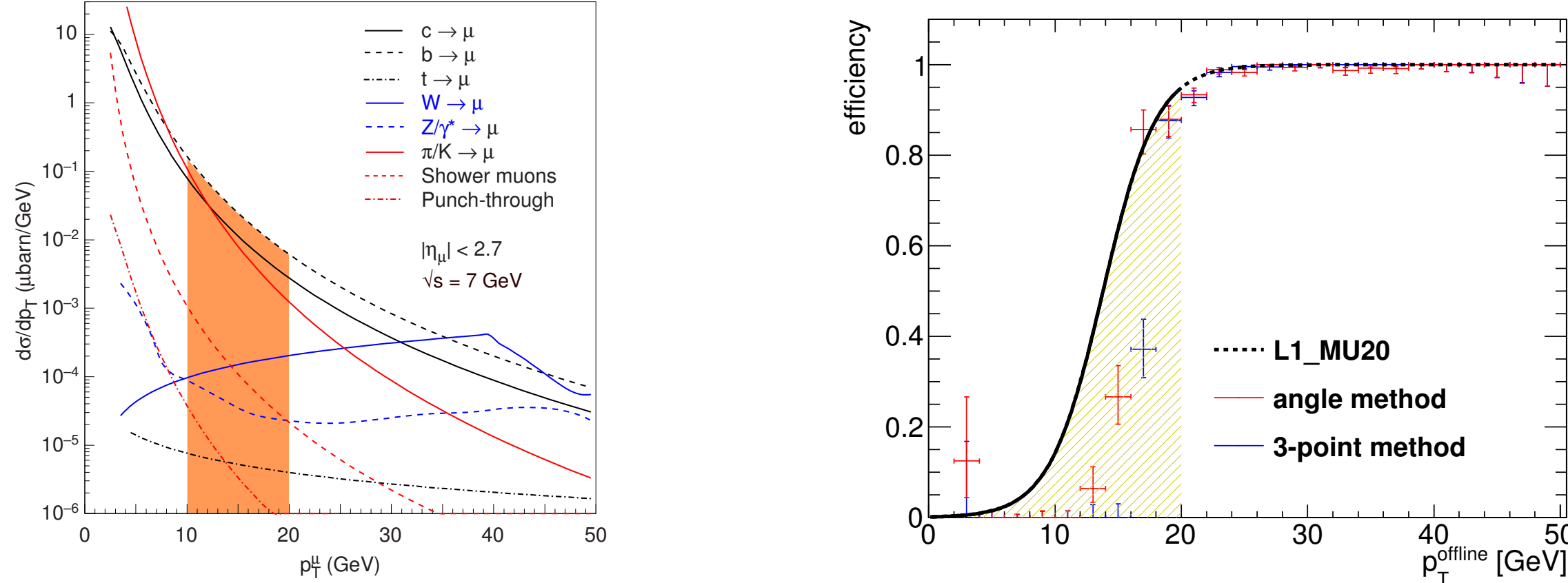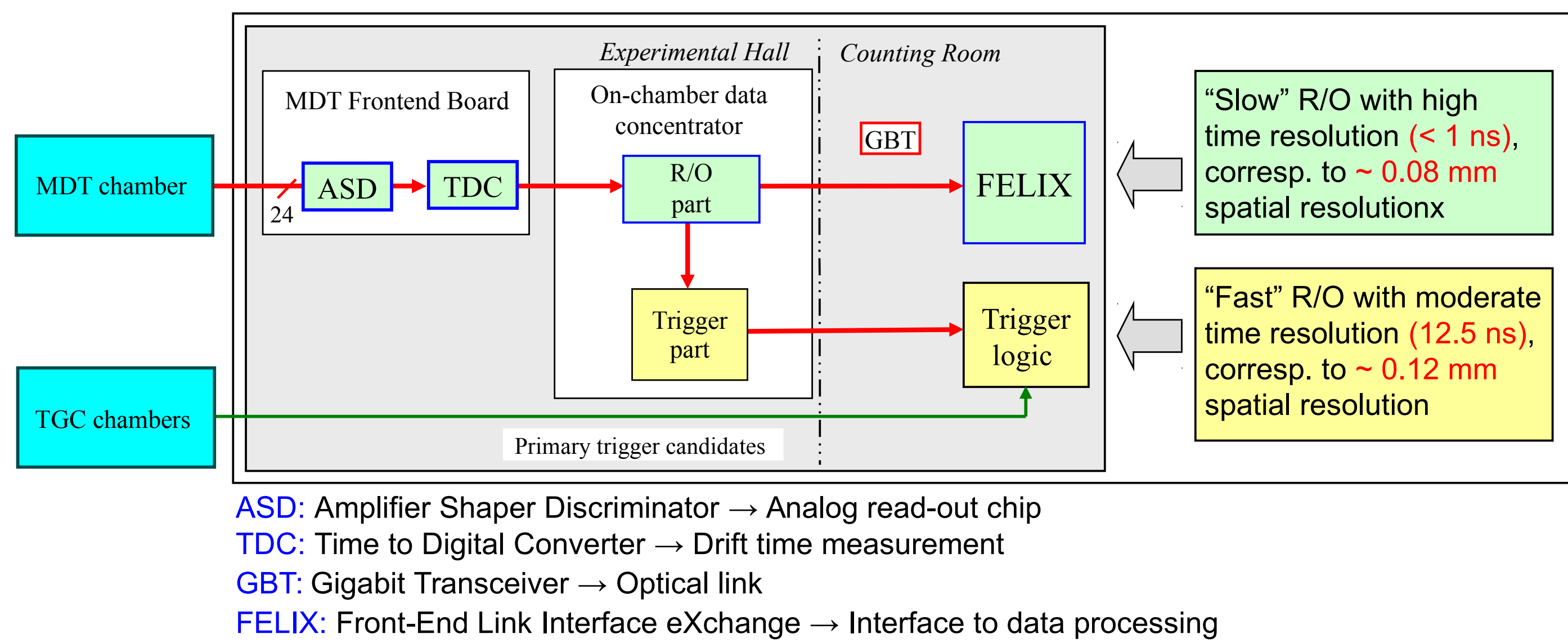
Including the MDT Chambers in the Level-1 Trigger

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.

include MDT chambers to improve angular resolution to 1 mrad

3 TGC layers provide 3 mrad angular resolution

Region of Interest defined by TGC

End-cap MDT chamber   Barrel MDT chamber   End-cap CSC chamber
End-cap TGC chamber   Barrel RPC chamber

Technical Implementation

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

"Slow" R/O with high time resolution (< 1 ns), corresp. to ~ 0.08 mm spatial resolutionx

"Fast" R/O with moderate time resolution (12.5 ns), corresp. to ~ 0.12 mm spatial resolution

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

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.

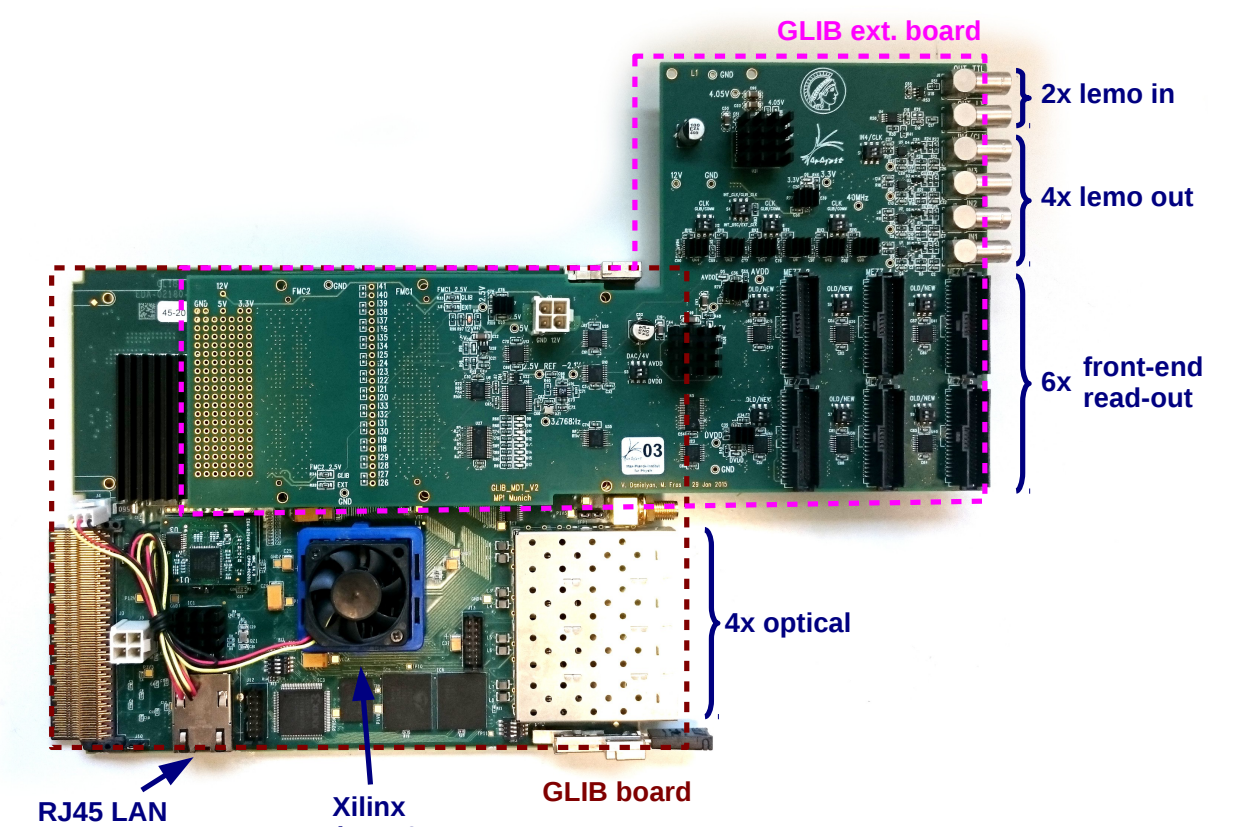Standard read-out
Fast read-out
Back side   Front side
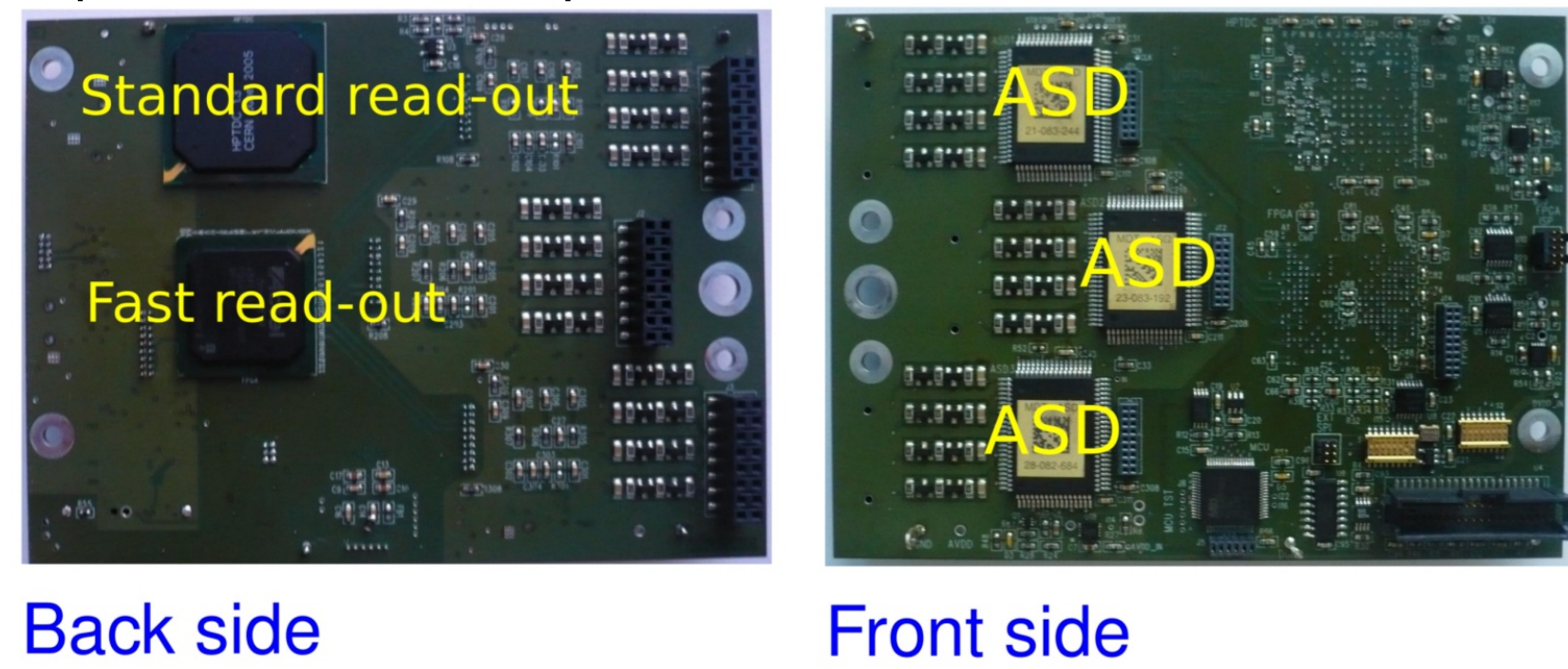
Fast Track Finding Algorithm

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

Histogram with projected hit positions

Tube in ROI   Drift radius
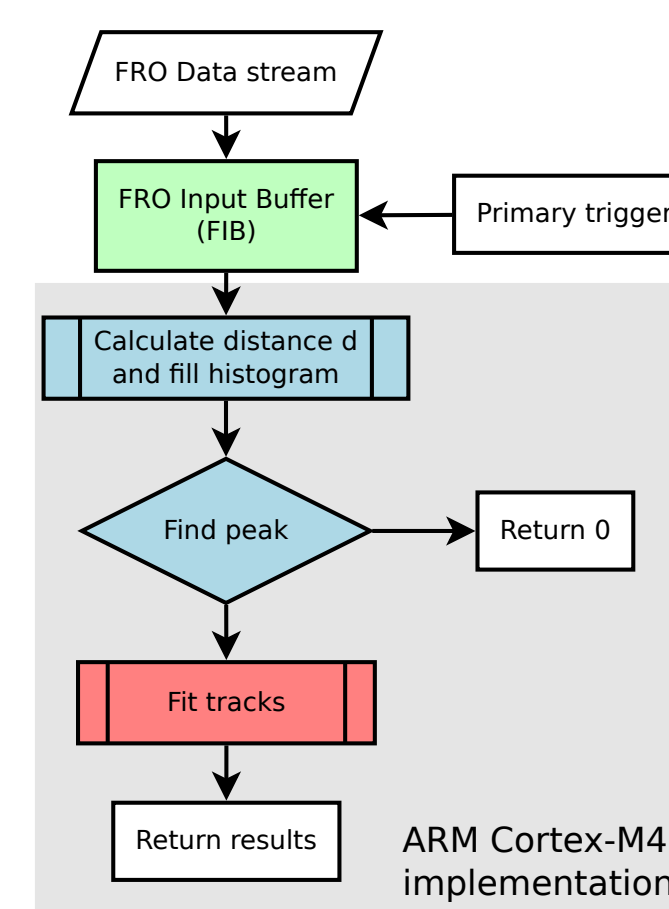Hit positions (two-fold ambiguity)
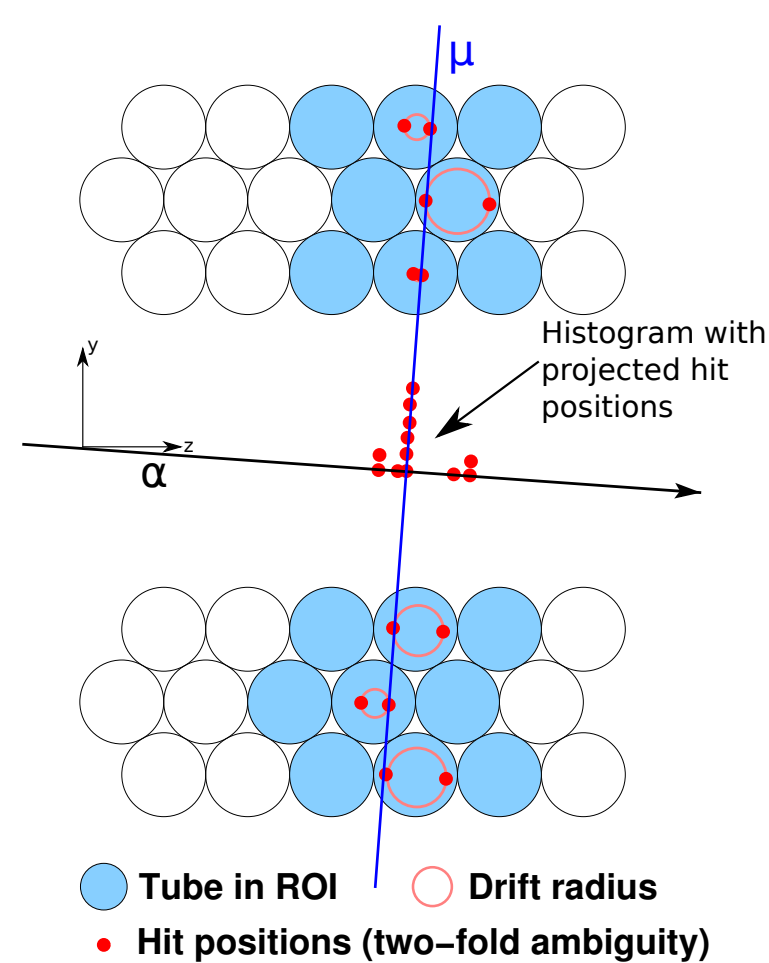
New Data Read-out with the GLIB Extension Board

A Gigabit Link Interface Board (GLIB) serves as basis for the data acquisition. It uses a Virtex-6 FPGA and provides four SFP+ transceiver modules as well as an ethernet connection to a PC for the data transmission. The GLIB extension board was built for the demonstrator as an interface card for up to 6 new front-end electronics boards. It also provides the trigger input and synchronisation of serveral GLIB boards in parallel.

GLIB ext. board   2x lemo in   4x lemo out   6x front-end read-out   4x optical
RJ45 LAN   Xilinx Virtex-6   GLIB board

Latency Estimation for the Fast Tracking Algorithm

The fast track reconstruction algorithm has been implemented in ARM Cortex-M4F (200 MHz) assembler. Keil μVision was used to simulate the processing time. [4]
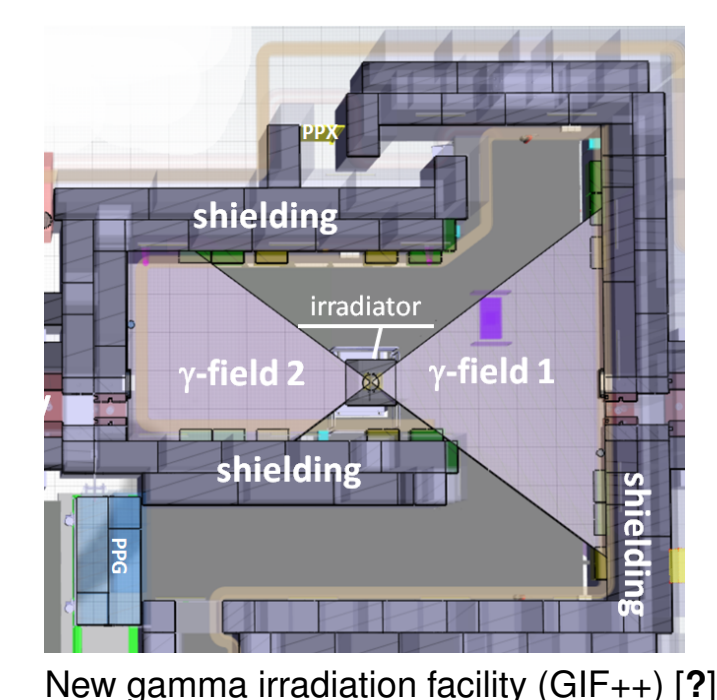
FRO Data stream
FRO Input Buffer (FIB)   Primary trigger
Calculate distance d and fill histogram
Find peak → Return 0
Fit tracks
Return results
ARM Cortex-M4F implementation

40 MHz TDC
data for track reconstruction taken at GIF

No background occupancy (8715 events)
14.0% background occupancy (10098 events)
19.5% background occupancy (5517 events)

80 MHz TDC
data for track reconstruction simulated

No background occupancy (40000 events)
10.0% background occupancy (40000 events)
20.0% background occupancy (40000 events)

- ▶ Required processing time increases with the amount of cavern background.
- ▶ Required processing time <2200 clock cycles (11 μs)
- ▶ Expected processing time for ARM Cortex A9 $\sim 6\mu$s.
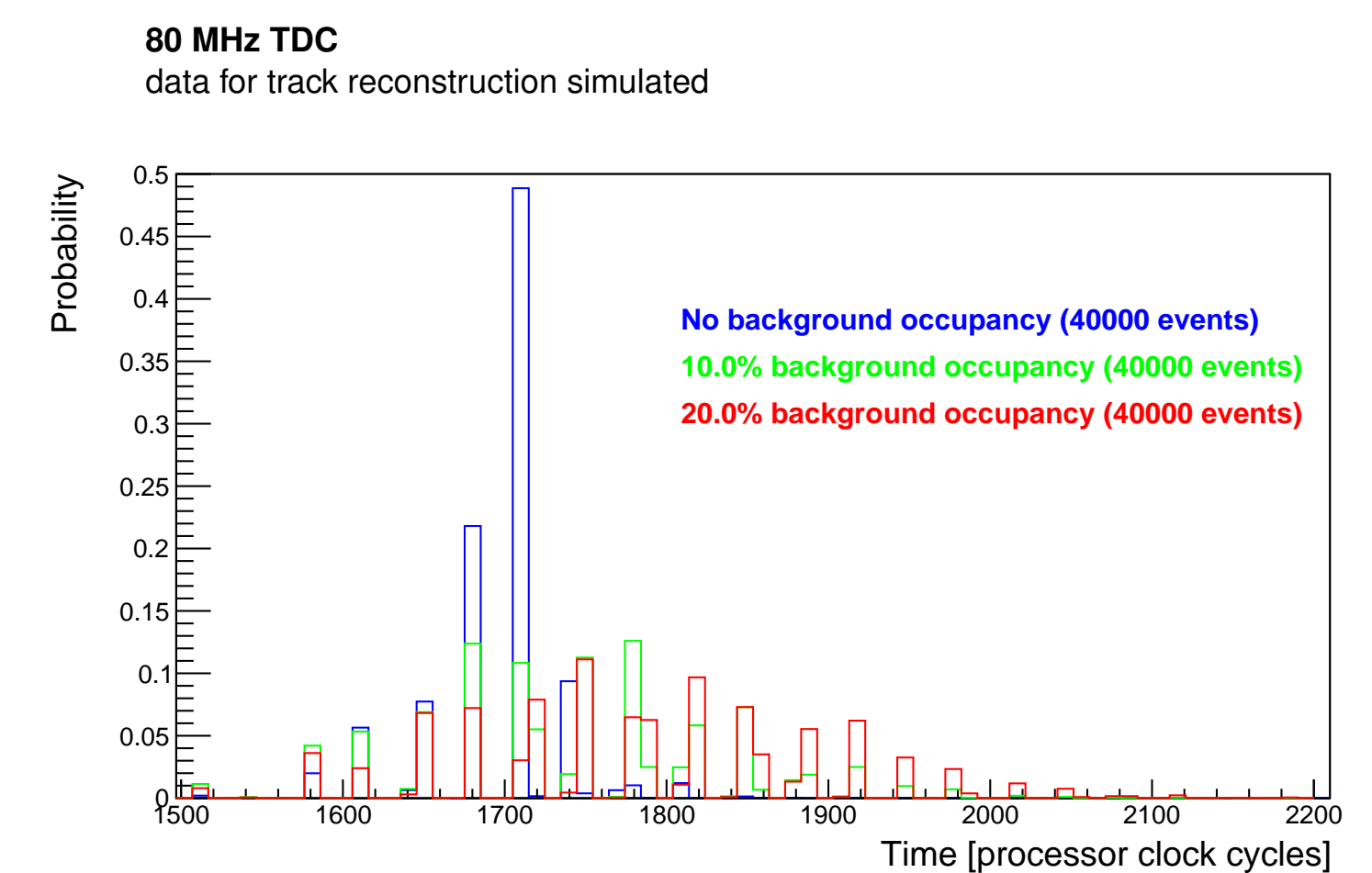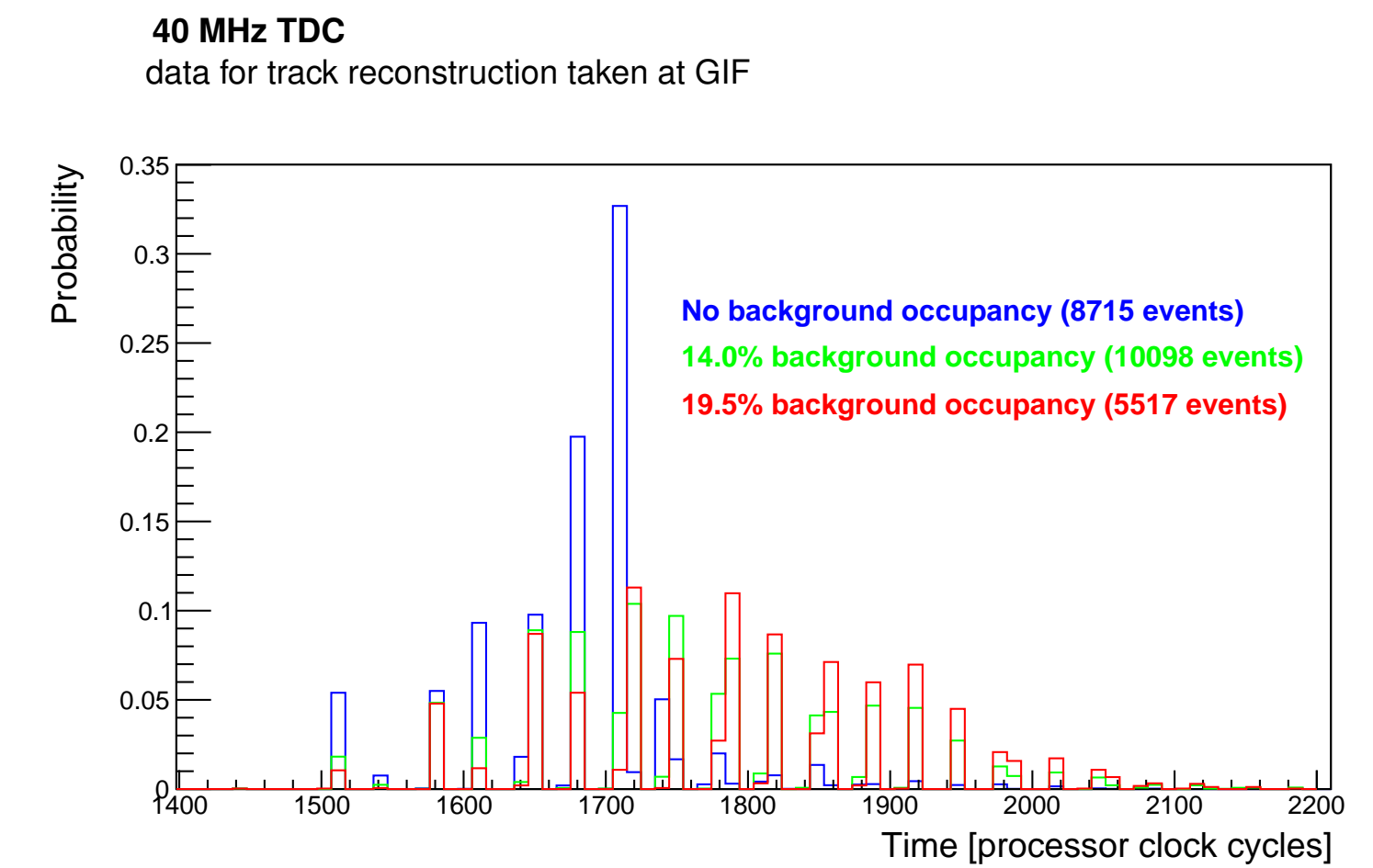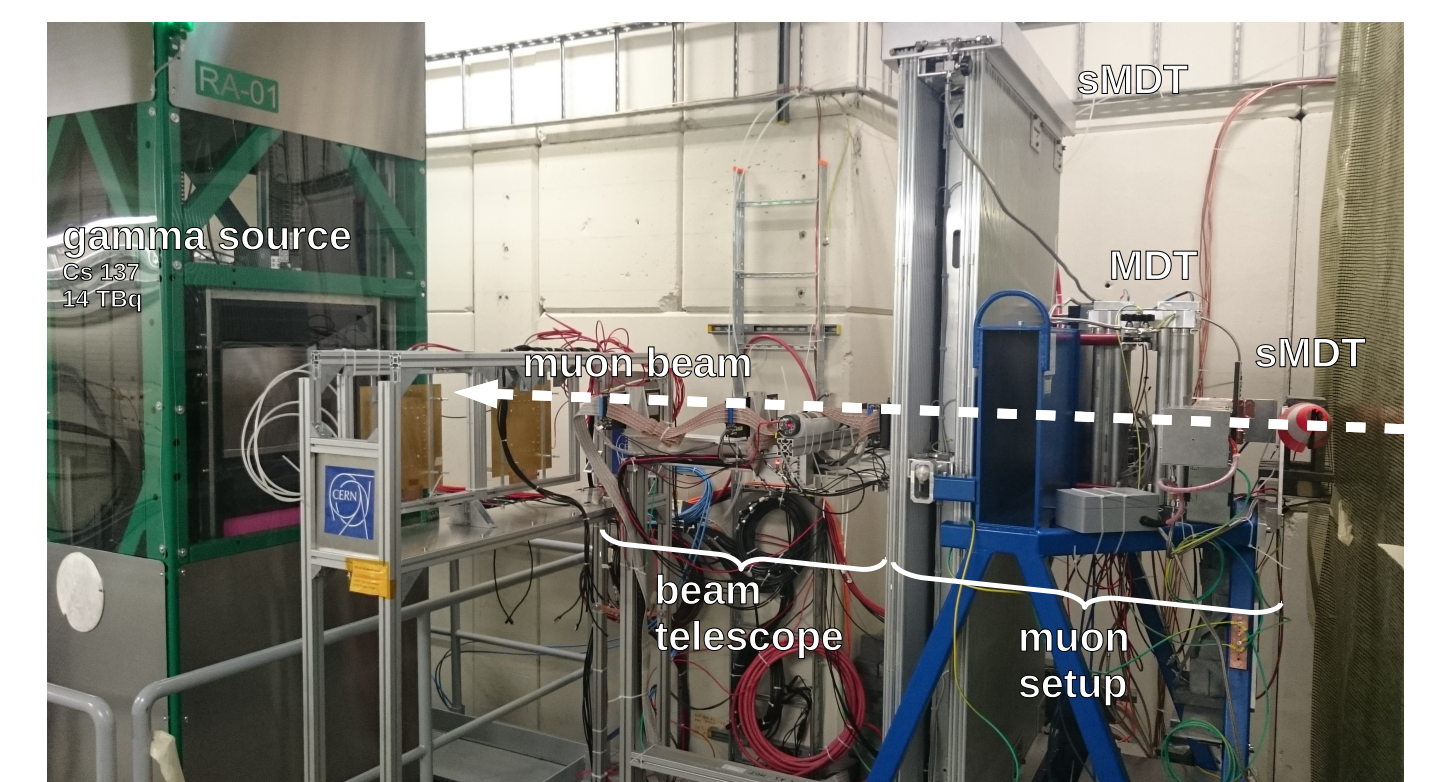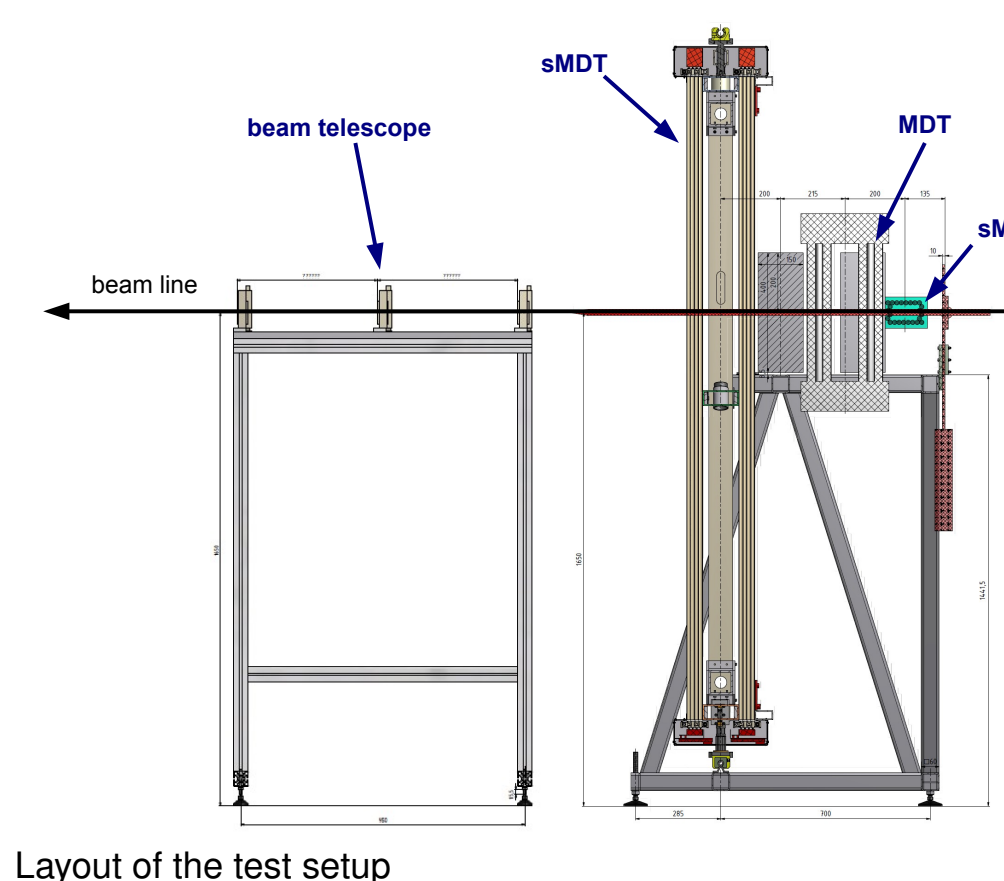
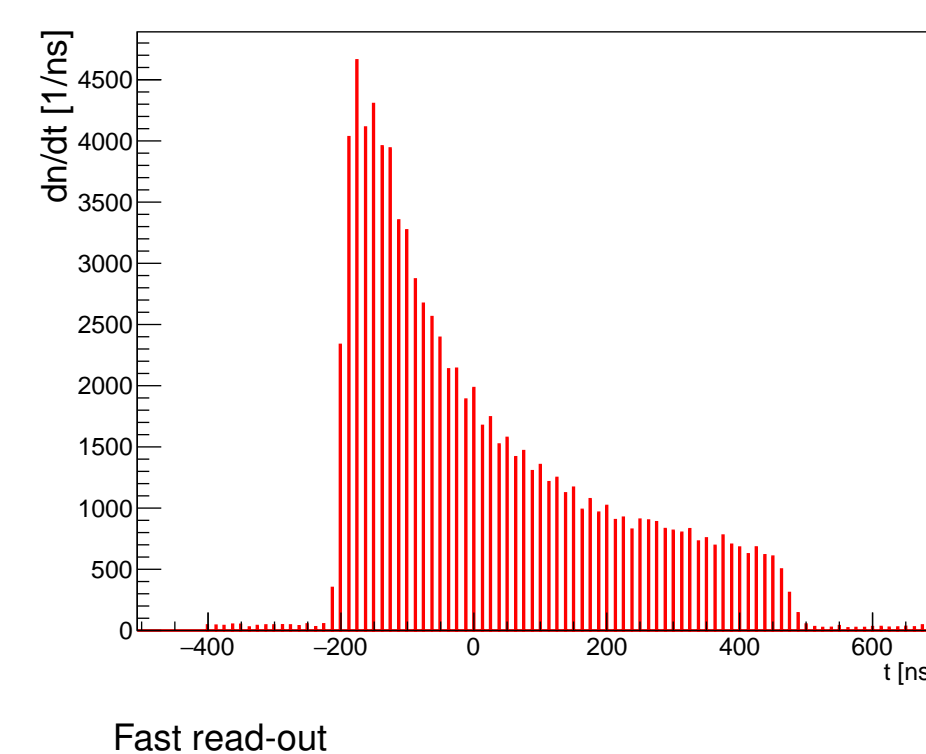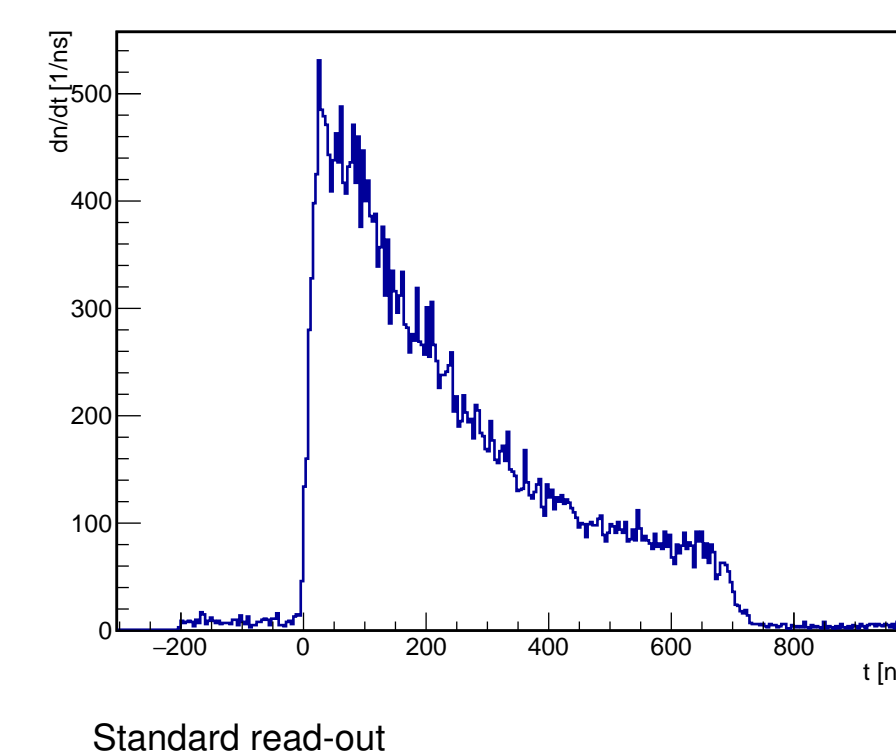## Demonstrator Setup in the new Gamma Irradiation Facility (GIF++) at CERN

A setup of 3 (s)MDT chambers equipped with new front-end electronics including the additional fast read-out chain was used for track reconstruction of muons under photon irradiation in the new CERN Gamma Irradiation Facility (GIF++). The GIF++ provides photons at 662 keV and fluxes up to $10^6 \, s^{-1} cm^{-1}$ from a ^{137}Cs source to simulate HL-LHC operating conditions, as well as a muon beam from SPS/H4 beam line. A silicon strip beam telescope served as reference for the track reconstruction.

shielding   irradiator   γ-field 2   γ-field 1   shielding
New gamma irradiation facility (GIF++) [?].

beam telescope   sMDT   MDT   sMDT   beam line
gamma source   muon beam   beam telescope   muon setup
Layout of the test setup   Setup inside the GIF++ facility

Drift Time Spectra with Fast and Standard Read-Out

Standard read-out   Fast read-out

Data from August '15 measurement period:
- ▶ Good agreement in shape between standard and fast read-out.
- ▶ Rising edge with fast read-out slightly wider due to the limited resolution.

Bibliography

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

[2] ATLAS Collaboration, *ATLAS Phase-II Upgrade Scoping Document*, CERN, Sept 2015

[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.

[4] S. Nowak (ATLAS Muon Collaboration), *A new Highly Selective First Level ATLAS Muon Trigger With MDT Chamber Data for HL-LHC*, Proceedings of 13th Pisa Meeting on Advanced Detectors, 2015, *to be bublished*.