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Corresponding Author: Dr. Oliver Kortner, PD Dr.

Corresponding Author's Institution: Max-Planck-Institut für Physik

First Author: Oliver Kortner, PD Dr.

Order of Authors: Oliver Kortner, PD Dr.; Sergey Abovyan; Davide Cieri; Varuzhan Danielyan; Markus Fräs; Philipp Gadow; Sandra Kortner; Hubert Kroha; Felix Müller; Sebastian Nowak; Robert Richter; Korbinian Schmidt-Sommerfeld

Abstract: Single muon triggers are crucial for the physics programmes as hadron collider experiments. To be sensitive to electroweak processes, single muon triggers with transverse momentum thresholds down to 20 GeV and dimuon triggers with even lower thresholds are required. In order to keep the rates of these triggers at an acceptable level these triggers have to be highly selective, i.e. they must have small accidental trigger rates and sharp trigger turn-on curves. The muon systems of the LHC experiments and experiments at future colliders like FCC-hh will use two muon chamber systems for the muon trigger, fast trigger chambers like RPCs with coarse spatial resolution and much slower precision chambers like drift-tube chambers with high spatial resolution. The data of the trigger chambers are used to identify the bunch crossing in which the muon was created and for a rough momentum measurement while the precise measurements of the muon trajectory by the precision chambers are ideal for an accurate muon momentum measurement. A concept for the muon trigger of the baseline detector for the FCC-hh which exploits the precision measurements of drift-tube chambers is presented including the description and the test of a compact muon track reconstruction algorithm.

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First-Level Muon Track Trigger for Future Hadron Collider Experiments

List of authors

S. Abovyan, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

D. Cieri, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

V. Danielyan, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 Münche

M. Fras, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

Ph. Gadow, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

O. Kortner, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

S. Kortner, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

H. Kroha, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

F. Müller, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

S. Nowak, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

R. Richter, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

K. Schmidt-Sommerfeld, Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München

Problem statement

Proposal for a highly selective muon trigger for future hadron collider experiments.

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First-Level Muon Track Trigger for Future Hadron Collider Experiments

S. Abovyan, D. Cieri, V. Danielyan, M. Fras, Ph. Gadow, O. Kortner, S. Kortner, H. Kroha, F. Mller, S. Nowak, R. Richter, K. Schmidt-Sommerfeld^a

^aMax-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

Abstract

Single muon triggers are crucial for the physics programmes as hadron collider experiments. To be sensitive to electroweak processes, single muon triggers with transverse momentum thresholds down to 20 GeV and dimuon triggers with even lower thresholds are required. In order to keep the rates of these triggers at an acceptable level these triggers have to be highly selective, i.e. they must have small accidental trigger rates and sharp trigger turn-on curves. The muon systems of the LHC experiments and experiments at future colliders like FCC-hh will use two muon chamber systems for the muon trigger, fast trigger chambers like RPCs with coarse spatial resolution and much slower precision chambers like drift-tube chambers with high spatial resolution. The data of the trigger chambers are used to identify the bunch crossing in which the muon was created and for a rough momentum measurement while the precise measurements of the muon trajectory by the precision chambers are ideal for an accurate muon momentum measurement. A concept for the muon trigger of the baseline detector for the FCC-hh which exploits the precision measurements of drift-tube chambers is presented including the description and the test of a compact muon track reconstruction algorithm.

Keywords: muon system, FCC, drift-tube chambers, MDT, trigger

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1. Introduction

In order to study the Higgs sector of the Standard Model of the electroweak interaction with high precision and to search for physics beyond the standard model new collider experiments are needed. In 2026 the High-Luminosity LHC will go into operation and provide 3 ab^{-1} of pp collision data at 14 TeV centre-of-mass energy. To push the energy frontier to higher values two future collider projects are currently discussed: the High-Energy LHC with 28 TeV centre-of-mass energy and the Future Circular Collider (FCC) with 100 TeV centre-of-mass energy.

Single muon triggers will be crucial for the physics programmes of the corresponding experiments. To be sensitive to electroweak processes, single muon triggers with transverse momentum thresholds down to 20 GeV and dimuon triggers with even lower thresholds are required. In order to keep the rates of these triggers at an acceptable level these triggers have to be highly selective, i.e. they must have small accidental trigger rates and sharp trigger turn-on curves.

This can be achieved by combining fast trigger chambers with coarse spatial resolution with slower drift-tube chambers

providing a high spatial resolution. The proposed muon system for a detector at the FCC will use a monolithic drift-tube chamber in combination with a doublet of thin-gap RPCs as depicted in Figure 1. In the muon trigger of this detector one has to use the angle between the straight-line interconnection of the muon position in the muon system and the direction of flight in the muon system as stand-alone measurement of the muon momentum. The angle has to be measured with an accuracy of $< 1 \text{ mrad}$ at trigger level which is achievable with the drift-tube chamber data.

2. A compact muon finder for fast muon track reconstruction at the first trigger level

However, this requires a fast track reconstruction algorithm. We are proposing the following compact muon finder algorithm.

A typical hit configuration in the presence of muon is illustrated in Figure 2. In the first step of the algorithm the RPC data are used to define a region of interest (ROI) and to determine the time of the pp collision (BCID) in which the muon was generated. The MDT pattern recognition is performed in the second

Figure 1: Schematic drawing of the conceptual design of the muon system at the FCC. A muon drift-tube (MDT) chamber is used for a precise direction measurement, RPCs for precise timing.

step. Only tubes in the ROI are considered. The times of the hits in these tubes are converted into drift times and drift radii using the BCID from the RPC system. The RPC hits are also used to compute a seed $\tilde{m}$ for the slope of the muon track. This makes it possible to solve the relationship r for the distance of a straight line $y = \tilde{m}z + b$ from an anode wire at (w_y, w_z) for the intercept b :

$$r = \frac{|\tilde{m}w_z + b - w_y|}{\sqrt{1 + \tilde{m}^2}}$$

$$\Rightarrow b_{\pm} = \pm \sqrt{1 + \tilde{m}^2} \cdot (\tilde{m}w_z - w_y).$$

With these equations one can compute values for $b_{\pm}$ for each hit and fill them into two histograms, one for each multilayer. The histograms will have maxima at the correct values of the intercept b .

In the third step one determines the precise values of the slope and intercept of the track by fitting a straight line to the MDT hits belonging to the maxima. The precise track angle is finally converted into a muon momentum.

All combinations of maxima are considered. Ambiguities are resolved by selecting the track with the smallest χ^2 value.

3. Hardware implementation and test of the compact muon finder

The compact muon finder algorithm was implemented in C++ and VHDL. The implementations were tested with simulated and muon test-beam data. The firmware implementation was validated against the C++ version on a Zynq SoC 7045 FPGA on a Xilinx evaluation board. The algorithm finds tracks with more than 99% efficiency. 100% agreement between the resolution of the firmware implementation and the C++ code was found. 40 μm intercept resolution is obtained (see Figure 3) as expected from the average spatial single-tube resolution.

The implementation of the compact muon finder makes very limited use of FPGA resources. 3 compact muon finder could be implemented on the FPGA. The present firmware version

Muon track in an MDT chamber

Figure 2: Schematic drawing of the hit configuration in the muon chamber system of the proposed muon system for the FCC.

Figure 3: Distribution of the intercepts of muon tracks reconstructed with the compact muon finder from the true values of the intercepts.

used 70,000 look-up tables, 52,000 flip flops, 12 BRAMs, and 770 DSPs. The latency of the algorithm is low, 250 ns at a clock frequency of 240 MHz.

4. Summary

Experiments at future hadron colliders need highly selective muon triggers. These can be accomplished by using the data of fast trigger chamber for timing and the data of precision muon drift-tube chambers for a precision track measurement. A fully efficient, but FPGA resource saving algorithm has been developed and tested successfully on a Zynq evaluation board.