The Compact Muon Solenoid Experiment

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Simulation studies on the muon triggering capability of the ME0 GEM station in the CMS experiment

Martina Ressegotti on behalf of the CMS Muon Group

Abstract

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I. INTRODUCTION

A. The CMS muon system

THE CMS muon system [1] (Fig. 1) is currently composed of three different detector technologies in distinct regions of pseudorapidity (η): Drift Tubes (DTs) up to $|\eta| < 1.2$, Cathode Strip Chamber (CSCs) up to $|\eta| < 2.4$, Resistive Plate Chambers (RPCs) up to $|\eta| < 1.6$ (coverage with 4 detector layers). In this configuration the muon system is not instrumented at $|\eta| > 2.4$. In addition, fewer muon detector layers are present in the forward region ($|\eta| > 1.6$), where the highest background rate is present.

B. The GEM upgrade

After 2025 the High Luminosity phase of the Large Hadron Collider (HL-LHC) will start. Due to the high particle rates during the HL-LHC the current muon system configuration will not allow maintaining an acceptable Level-1 (L1) trigger rate without increasing the thresholds on the muon transverse momentum p_T , especially in the forward region. At $|\eta| < 2.0$ no higher p_T thresholds will be necessary thanks to the introduction of the track trigger [2]. However, a good standalone muon trigger is required for high quality matching of the tracker and the muon system information. As a large number of measured hits along a particle's trajectory helps to reconstruct it unambiguously and efficiently, the installation of three new stations (GE1/1, GE2/1, ME0) based on Gas Electron Multiplier (GEM) [3] technology is foreseen in the

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Fig. 1. Cross-sectional view of one quarter of CMS detector. Both the current and the future stations are shown in the muon system. In particular, the GEM-based stations GE1/1, GE2/1, ME0 are displayed.

forward region of the muon endcap [4]. Their main goal is to allow to maintain or to improve the trigger performance in this challenging region. In addition, they also aim to mitigate aging effects of the Cathode Strip Chambers system, on which currently the forward trigger only relies for $|\eta| > 1.6$, that might otherwise cause large efficiency losses.

II. THE ME0 STATION

The ME0 station is a six-layered triple-GEM based muon detector to be installed in the CMS experiment in 2024 in the $2.0 < |\eta| < 2.8$ region of the muon system (Fig. 1), when the endcap calorimeter will be replaced with the High Granularity Calorimeter (HGCAL).

The ME0 station stands out from the other GEM stations, as part of its η coverage will overlap with the existing muon system (up to $|\eta| < 2.4$) contributing to provide redundancy similarly to the GE1/1 and GE2/1 stations, and part of it will extend beyond the existing muon system increasing its acceptance. So in the region $|\eta| < 2.4$ it shares the same goals of the other GEM stations: adding redundancy to the existing muon system, sustaining triggering at current trigger thresholds and improving high- η muons tagging. On the other hand, its most interesting feature is that it offers a significant increase of the muon acceptance beyond $|\eta| > 2.4$, with possible impact on the discovery potential of several physics channels with final state muons in the forward region.

Different trigger strategies are under development for the region $2.0 < |\eta| < 2.4$ and the extended muon coverage $2.4 < |\eta| < 2.8$.

Fig. 2. L1 Muon trigger rate as a function of the p_T threshold for the prompt muon trigger algorithm in the region $2.1 < |\eta| < 2.4$. Trigger rates with and without the ME0, GE11, GE21 stations are shown for comparison [6].

Fig. 3. L1 Muon trigger efficiency for the prompt muon trigger algorithm and a trigger threshold of 15 GeV as a function of the true muon p_T in the region $2.1 < |\eta| < 2.4$. Efficiencies with and without the ME0, GE11, GE21 stations are shown for comparison [6].

III. TRIGGERING IN $2.0 < |\eta| < 2.4$

In the region $2.0 < |\eta| < 2.4$ the muon system is also instrumented with CSC detectors. The segment built in the ME0 station will be sent to the Endcap Muon Track Finder (EMTF) [5] and the muon p_T estimation will be performed in conjunction with the existing ME1/1 CSC muon detectors. The ME0 station contributes to sustain trigger rates at current thresholds and to improve muon reconstruction. Fig. 2 and 3 show the impact of the new GEM stations on the L1 trigger performance in this region. In particular, a clear reduction of the L1 trigger rate is achieved, up to one order of magnitude at the highest considered p_T thresholds, as well as an improvement of the L1 trigger efficiency over a wide range of muon p_T .

IV. TRIGGERING AT $2.4 < |\eta| < 2.8$

An important feature of the ME0 station is that the part at $|\eta| > 2.4$ would extend the muon system's pseudorapidity coverage by 17%, allowing for more events with final very forward muons to become accessible. Some examples are the decay of the Higgs boson into four muons $H \rightarrow ZZ^* \rightarrow 4\mu$,

Fig. 4. Bending angle $\Delta\phi$ distributions measured in the ME0 station for muons with different transverse momentum p_T and for background particles that cross at least four ME0 layers [6]. The first and last bins contain underflow and overflow events.

a golden channel for the complete reconstruction of the Higgs boson with low background, the double parton scattering resulting in two W bosons with the same charge that decay into $W \rightarrow \mu\nu$, or the decay of the tau lepton decaying into $\tau \rightarrow 3\mu$ (from exotic models), and others.

In the newly instrumented region at $|\eta| > 2.4$, six layers of triple GEM detectors are expected to provide sufficient information to efficiently identify muon segments among background hits. Differently to the design of the L1 trigger in the redundant region, which is in an advanced state, the inclusion into the L1 trigger of the information coming from the ME0 station at $|\eta| > 2.4$ is still under development. A potential candidate is the use of muon segments reconstructed in the ME0 station only to reconstruct the local direction of crossing particles. The segment's bending angle can be used to apply selections on the muon transverse momentum. Some examples of bending angles measured for signal muons and pile up particles are shown in Fig. 4. An L1 standalone ME0 based trigger is not feasible due to the high rate of track segments in this very forward region caused by background muons. Background muons are reconstructed muons not associated with a true prompt muon, for example coming from a b-quark decay or a π/K decay-in-flight. Hence the strategy under study here is to use segments as part of multi-object topological triggers dedicated to specific physics analyses, already at the L1 trigger level.

A. Triggering the $\tau \rightarrow 3\mu$ decay

The $\tau \rightarrow 3\mu$ decay is of utmost interest because it is one of the cleanest Lepton Flavour Violation decay channels, whose observation would give an important indication of new physics beyond the Standard Model (SM). In the SM the decay has a negligibly small branching fraction ($\mathcal{B} \sim 10^{-40}$) to be observed effectively, but several exotic models predict branching fractions up to 10^{-8} that could be within experimental reach. The worldwide strictest limit is currently $\mathcal{B}(\tau \rightarrow 3\mu) < 2.1 \cdot 10^{-8}$, set by the Belle experiment [7].

Tau leptons usually come from B/D meson decays, with very low momenta and boosted in the very forward direction.

Fig. 5. Pseudorapidity distribution of the most forward muon in reconstructed $\tau \rightarrow 3\mu$ events. The shaded area corresponds to the pseudorapidity range covered by the ME0 station only [6].

Hence muons from the tau lepton decay are also in the forward region. With its current acceptance the CMS experiment can collect only about 1.3% of the signal events. Fig. 5 shows that a large fraction of reconstructed events has the most forward muon within the acceptance of the ME0 station, indicating that the extension of the muon system up to $|\eta| \sim 3$ by the ME0 station would provide an important enhancement of the acceptance to this decay. In addition, about 10^{15} tau leptons will be produced over the lifetime of HL-LHC, begging for a $\tau \rightarrow 3\mu$ decay search. It is then of interest to study and enhance the reconstruction capabilities of this channel of the upgraded muon system.

Muons from the tau lepton decay are very soft with transverse momenta of few GeV, and quite collimated. A multi-object topological trigger design with low p_T thresholds, looking for up to three segments reconstructed in the ME0 station, is under development. A possibility to add information from other subdetectors is also considered in order to improve the trigger performance.

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