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A proposed Drift Tubes-seeded muon track trigger for the CMS experiment at the High Luminosity-LHC

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ABSTRACT

The LHC program at 13 and 14 TeV, after the observation of the candidate SM Higgs boson, will help clarify future subjects of study and shape the needed tools. Any upgrade of the LHC experiments for unprecedented luminosities, such as the High Luminosity-LHC ones, must then maintain the acceptance on electroweak processes that can lead to a detailed study of the properties of the candidate Higgs boson. The acceptance of the key lepton, photon and hadron triggers should be kept such that the overall physics acceptance, in particular for low-mass scale processes, can be the same as the one the experiments featured in 2012. In such a scenario, a new approach to early trigger implementation is needed. One of the major steps will be the inclusion of high-granularity tracking sub-detectors, such as the CMS Silicon Tracker, in taking the early trigger decision. This contribution can be crucial in several tasks, including the confirmation of triggers in other subsystems, and the improvement of the on-line momentum measurement resolution. A muon track-trigger for the CMS experiment at the High Luminosity-LHC is presented. A back-extrapolation of Drift Tubes trigger primitives is proposed to match tracks found at Level 1 with muon candidates. The main figures-of-merit are presented, featuring sharp thresholds and less contamination from lower momentum muons, and an expected rate reduction of a factor of 5–10 at typical thresholds with respect to the muon trigger configuration used in 2012.

1. Introduction

A new approach to early trigger implementation is needed at the High Luminosity-LHC (HL-LHC), foreseeing unprecedentedly high luminosities, leveled up to $\approx 5\times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ with an expected average number of 140 superimposed collisions (pile-up) at 40 MHz bunch crossing rate. The current resolution of the on-line muon momentum measurement would not provide enough discrimination power to keep the Level 1 acceptance rate low together with a high selection efficiency at the electroweak scale. A combined Drift Tubes (DT)-silicon tracker muon trigger for the CMS experiment [1] at the HL-LHC is proposed. The proposed algorithm relies on the back-extrapolation of DT trigger primitives to be matched with tracks found by the Level 1 track trigger, i.e. Level 1 Tracks. Such Level 1 track finding will be possible using a novel tracker specifically designed for online track finding [2,3]. Given the better momentum resolution of the CMS silicon tracker, the crucial role of the muon trigger will be to provide good spatial information to enhance the association with Level 1 Tracks, rather than a standalone momentum measurement. The study presented herein is based on the Run 1 Trigger Primitives [4], assuming analogous performance of local muon trigger at the HL-LHC.

2. Summary of the algorithm

The algorithm sequence aims at improving the resolution of local DT trigger primitives by associating them to Level 1 Tracks in a unique and non-ambiguous way. This association relies on a precise back-extrapolation of the Level 1 DT primitives and a definition of fiducial regions in the tracker.

DT seed from local trigger primitives: The DT system is composed of DT chambers arranged in a barrel layout, defining radial stations, azimuthal sectors and longitudinal wheels [1]. Local DT Trigger

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Primitives, i.e. local track segments in chamber super-layers, provide position in polar coordinates ϕ and θ, as well as local bending angle ϕ_B, and can be used to seed a muon track-trigger. Only the first two stations MB1 and MB2 in each wheel are used, as MB3 cannot measure ϕ_B and MB4 does not provide a good resolution. A high (low) quality code is assigned to seeds built from correlated (uncorrelated) track segments in chamber super-layers.

Fiducial regions for matching: A set of fiducial regions in the tracker is built as a function of ϕ_B, for each wheel, station and quality. A fiducial region is centered on the average distance between seed position and L1 Track direction at vertex, and its size is a multiple of the width of residuals distribution. A full parameterization of the DT seed p_T, of the extrapolated (expected) L1 Track direction and fiducial region size is implemented with a 12-bits integer resolution (9 bits for ϕ_B).

DT seed extrapolation and matching: The DT seed is back-extrapolated to the beam line according to the measured value of ϕ_B and matched in ϕ and θ with p_T-compatible L1 Tracks inside the fiducial region. The fiducial region is 3σ wide and the p_T-compatibility is defined as 3σ in ϕ_B.

p_T assignment and ambiguities: The matched L1 Track p_T is assigned to the candidate muon track-trigger. Ambiguities and multiple triggers are reduced in three steps. Position and p_T of multiple seeds are compared before back-extrapolation and, if compatible, only highest quality seed is retained. No more than one L1 Track is associated to each seed: the closest to the extrapolated direction, among p_T-compatible ones in fiducial volume is retained. Finally, after association, if the same L1 Track is selected by more than one seed, only the candidate with highest quality seed is retained.

3. Expected performance

The proposed algorithm (DT-seeded L1Tk, [5]) is compared to the Run 1 muon trigger (GMT 2012, [6]) and to a proposed inside-out matching of L1 Tracks to comprehensive muon triggers (L1Tk-to-GMT, [7,3]): all the candidates for comparison are restricted to the barrel, i.e. must be built from a regional barrel candidate (either DT or Resistive Plate Chambers) or a forward candidate incorporating a track segment in MB1. Both the proposed triggers for the HL-LHC improve momentum assignment using the silicon

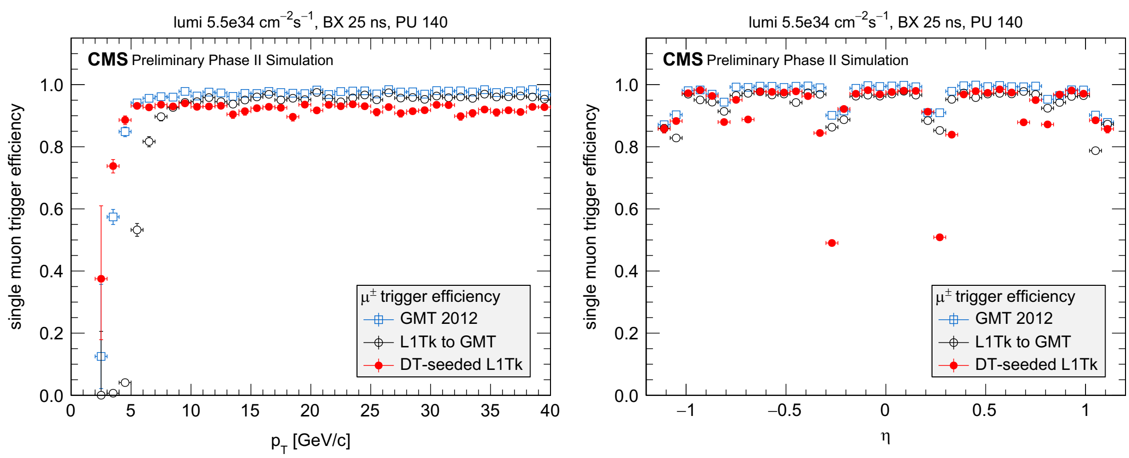

Fig. 1. Trigger efficiency for muons ionizing the gas mixture in the DT chambers, as a function of generated muon p_T (left) and η (right). Generated muons with flat p_T distribution in the 2–160 GeV/c range are superimposed to minimum-bias background at the average pile-up of 140 with 25 ns bunch separation. The performance of the DT-seeded algorithm (red) is compared to those of the Run 1 Global Muon Trigger (blue) and inside-out muon track trigger (black), only for candidates built from signals collected in the barrel. The track preselection of the inside-out muon track trigger can still be tuned up to improve the efficiency at low p_T. Gaps in η are due to the geometry of the DT system: they are more significant for the DT-seeded algorithm as it does not make use of all four stations and seeding does not combine different wheels. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

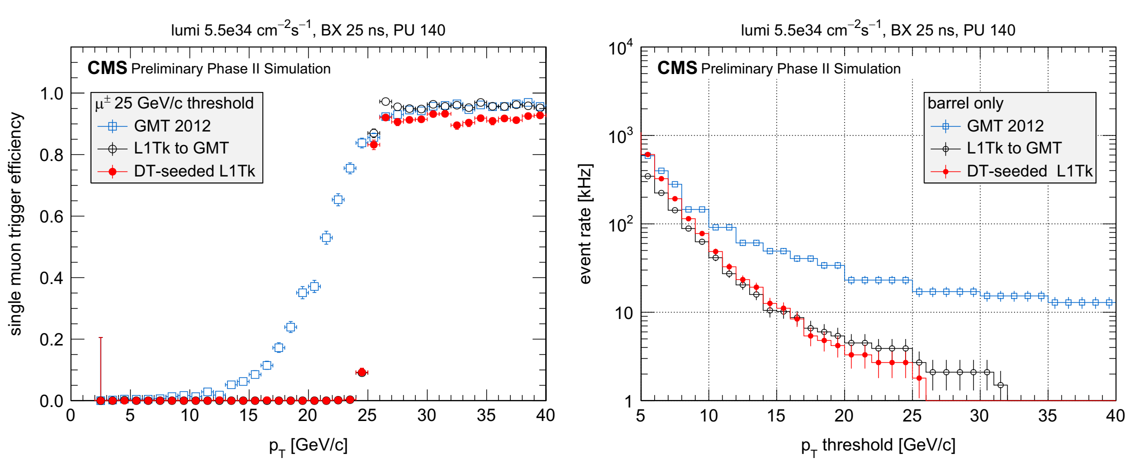

Fig. 2. Efficiency of a single muon trigger with p_T threshold at 25 GeV/c for muons ionizing the gas mixture in the DT chambers, as a function of generated muon p_T (left) and expected background rate as a function of the threshold for single muon trigger, at the average pile-up of 140, with 25 ns bunch separation and 0.75 fill factor (right). Generated muons with flat p_T distribution in the 2–160 GeV/c range are superimposed to minimum-bias background at the average pile-up of 140 with 25 ns bunch separation. The performance of the DT-seeded algorithm (red) is compared to those of the Run 1 Global Muon Trigger (blue) and inside-out muon track trigger (black), only for candidates built from signals collected in the barrel. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

tracker with full resolution, while the Run 1 configuration relies on the standalone muon system providing binned p_T. A comparison of the trigger efficiencies, of the effects of a typical threshold and of the expected rates is presented in Figs. 1 and 2.

4. Concluding remarks

The proposed DT-seeded muon track-trigger features specific benefits. First, seeding in the DT acts as a two-fold filter: there is no need of a minimum p_T threshold as low-p_T muons do not reach the DT system, and only few tracks need to be extrapolated as calorimeters and iron yoke stops electrons and hadrons. Then, the seed extrapolation can be parallel to the L1 Track finding and, thanks to the latency for the DT-seeding expected to be shorter than the one for L1 Tracks, the L1 Tracks can be matched as soon as found.

Given the much better resolution of a silicon tracker specifically designed for L1 Track finding, the crucial role of future muon triggers will be to provide good spatial information to enhance the association with L1 Tracks, rather than measuring their momentum with accuracy. The proposed DT-seeded muon track trigger features sharp threshold, allowing for a reduced contamination from low-momentum muons and for an expected rate reduction of a factor 5–10 at typical thresholds with respect to the muon trigger configuration used in 2012.

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