PROCEEDINGS OF SCIENCE

A muon tracking algorithm for the L1 trigger in the CMS barrel muon chambers during the High Luminosity-LHC

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The electronics of the CMS drift tubes chambers will need to be replaced for the High Luminosity LHC operation due to the increase in occupancy and trigger rates in the detector, which cannot be sustained by the present system. A new backend system will be in charge of building the trigger primitives of each chamber, aiming at space and time resolutions comparable to the ones that the High Level Trigger can obtain nowadays and improving the resilience to potential aging situations. An algorithm for the trigger primitive generation that aims to run in this new backend system has been developed and its performance has been validated through a software emulation approach. The results show close to perfect reconstruction efficiency, and angular and time resolutions at the per cent of miliradian and nanosecond.

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1. Introduction

The High Luminosity LHC (HL-LHC) will introduce new challenging running conditions for the CMS detector. The high pile up environment of the HL-LHC will lead to an increase in most subdetector's occupancy, which would lead to level-1 trigger (L1T) rates surpassing current hardware limitations. At the same time, the higher radiation environment introduces the additional challenge of dealing with detector aging scenarios. The Phase II upgrade of the CMS L1T has been carefully designed to tackle these problems with the replacement of part of the detector's electronics. Simultaneously, improved reconstruction algorithms have been designed to profit from the increased computational power of the new system and provide resilience against this issues.

The barrel muon chambers of the CMS detector are divided into five separate wheels (Wh) along the z axis. Each of these wheels is further subdivided into a varying number of sectors (S) around the ϕ axis and four different stations (MB) along the r axis. At each station, a system composed of eight to twelve layers of drift tube cells (DT) plus one or two resistive plate chambers (RPC) are included. The layers of drift tubes are stacked into sets of four called superlayers (SL) and target measurements along the longitudinal ($r - \theta$ SLs) or bending ($r - \phi$ SLs) plane. We introduce a L1T algorithm which focuses on the reconstruction of muons at the station level, combining the information from both all the DT SLs and the RPCs to provide measurements of the passing particle's track. The resulting measurements, trigger primitives, are later used as an input to track finding algorithms that aim to combine them across the whole muon chambers to provide precise estimations of the particle's kinematics by reconstructing its whole trajectory. As a consequence, obtaining the best spatial and temporal resolution in the trigger primitive measurements is a key factor in the performance of the CMS L1T system.

2. The analytic approach

The analytical method approach (AM) has been developed in the framework of the CMS L1 TDR [1] and aims to locally reconstruct muons inside the muon barrel chambers by using analytically derived best fit formulae.

As multiple muons might pass simultaneously across the same station, and each one can produce energy depositions (hits) in multiple drift tube cells across layers, a first preselection must be performed to select sets of hits that are likely to come from the same muon. This first step, called *grouping*, aims to provide this sets for each of the DT SLs independently. The innermost DT layer in each SL is scanned thoroughly and, if a hit is detected in a given cell inside it, cones of 10 cells distributed across nearby layers are examined looking for all possible hit combinations consistent with a straight line passing through the SL. The candidate sets of hits are forwarded to the next step.

A second step called **fitting** is performed to extract the muon parameters for each of the previous candidates. First, the bunch crossing associated to the candidate is obtained from the mean measurement of the timings. Analytical formulas derived from χ^2 minimization are applied to obtain measurements of the angular position (ϕ, θ) and slope (ϕ_b, θ_b) of the candidate track inside the station. These candidates and their measurements are called *uncorrelated* DT primitives.

If any candidates are found in both $r - \phi$ SLs, a *correlation* step is performed to combine candidates likely to come from the same original muon. If two candidates are found within a time window of 25 ns, track parameters are recalculated using the joint set of hits. This new combined candidates are called *correlated* DT primitives and are the final result of the algorithm. To maximize efficiency, if no match is found for an uncorrelated DT primitive, then it is provided as well.

Last, if any RPC cluster is found within a window of 75 ns of either DT primitive, a combination of the two is attempted based on the compatibility of azimuthal angle measurements. Consistent combinations profit from both the spatial resolution of the DTs with the updated timing information obtained from the RPCs and are provided as a final output of the algorithm called *superprimitives*.

3. Algorithm performance

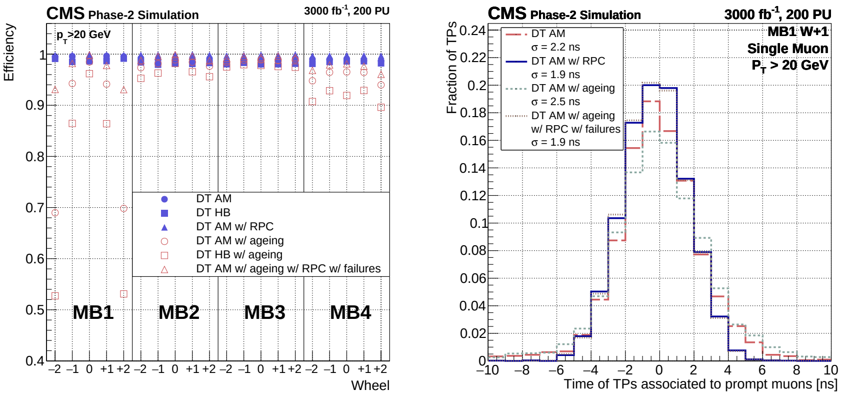

Figure 1: (Left) Trigger primitive efficiency with respect to segments for the different DT trigger primitive reconstruction algorithms and detector conditions, split by wheel and station. (Right) Timing resolution for the configurations of the AM algorithm measured in muons generated inside the innermost station of Wh+1.

The performance of the AM algorithm has been studied in Monte Carlo samples simulating several possible running conditions of the HL-LHC. The algorithm response is observed to be stable for different pile up ranges ranging from 0 to 300 average pileup interactions. The effect of aging in the DT subsystem or failures in the RPCs is also considered in the simulation for pessimistic conditions corresponding to an accumulated dose equivalent to a 3000 fb^{-1} luminosity up to a safety factor of 2 [2]. In the following results, the AM algorithm is compared with a histogram based (HB) algorithm based on the Compact Hough Transform [3, 4] and developed as a possible alternative. Hardware based studies have been performed in the context of the L1T TDR and have been found to be consistent with the Monte Carlo results.

The algorithm efficiency can be observed in Figure 1 (left). The measured efficiency in ideal non-aged detector conditions is very high (> 99%) for all considered cases. The effect of detector degradation is mostly observed in the innermost and outermost station, where the inclusion of the RPC information is able to increase the worst case scenario of 70% efficiency up to overall values over the 92%. The resolution of the algorithm in terms of timing is shown in Figure 1 (right). The effect of including the RPC clusters leads to a 15% improvement in this case, leading to precisions under 2 ns.

Finally, the spatial measurements' resolution is shown in Figure 2. The ϕ measurements (left) improve as muons go towards outside the detector, providing a precision between 0.04 and 0.02

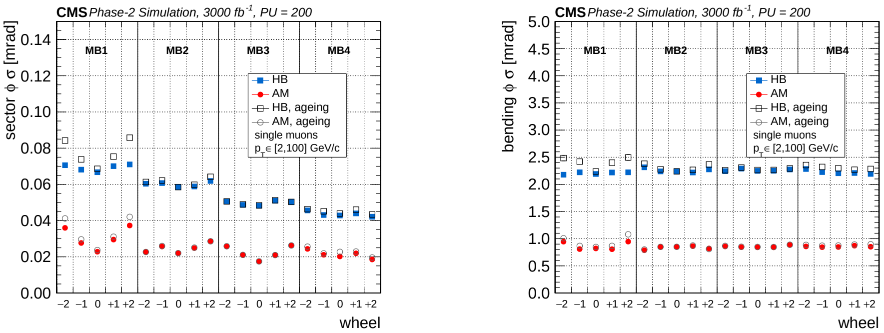

Figure 2: Resolution of the different DT trigger primitive reconstruction algorithms in different detector conditions for the ϕ (left) and ϕ_b (right) measurements split by wheel and station. Due to the little spatial resolution provided by the RPC subdetector, the AM DT+RPC algorithm is not shown in the figures.

mrad. The ϕ_b measurement (right) is quite consistent for all stations, with to measurements of under 1 mrad that are scarcely affected by detector aging effects.

4. Possible future improvements

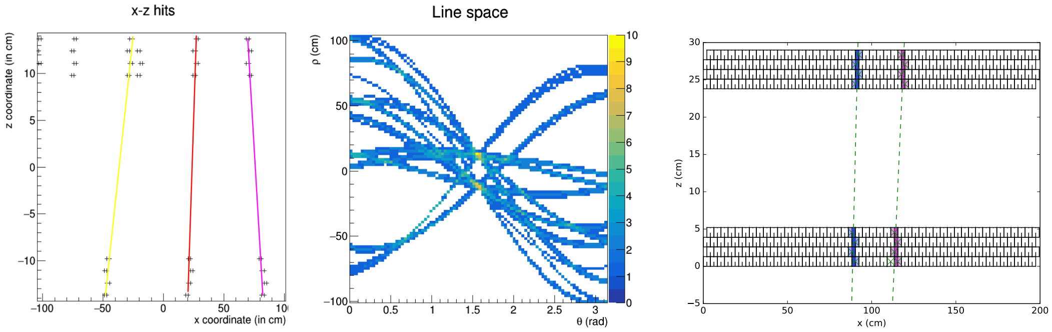

Figure 3: Examples of the joint grouping plus correlation step. (Left) Using the Hough transform approach, with hits represented as black crosses and group candidates as straight lines in the point space. (Middle) In the line space, after the Hough transform from the line space. (Right) Using the naïve Bayes classifier with hits represented with green crosses and groups as colored sets of cells matching patterns in green.

Extensions to the current algorithm that might improve its latency and overall performance are considered into study. A proposal has been made to employ pattern recognition techniques based on a naïve Bayes classifier to do correlated hit grouping is being studied. The algorithm is based on the comparison with several pregenerated hit patterns that are seeded and loaded by the first two hits arriving into the detector to reduce the combinatorics of the current grouping step. A final alternative approach, based on the Hough transform formalism, transforms geometrically detector hits into lines in the auxiliar (Hough) space, in which the best fit trajectory would correspond to the point in line space where most lines intersect. Thus, the problem of *grouping* is reduced a a maxima search in 2D space. Both approaches directly apply the fitting over the already correlated groups, reducing the algorithm's latency as a consequence.

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