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The use of the tracker in the CMS trigger

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Abstract

The CMS trigger stands for the daunting task of selecting rare signal processes amidst the 40 million bunch crossings per second of the LHC. While information from the tracker is not available in the first hardware trigger level, reconstructed tracks play a crucial role in the subsequent High Level Trigger (HLT). In this contribution an overview of the online selection algorithms that have been developed within the collaboration is given. Then, an outlook toward the even more challenging situation in the luminosity upgrade of the LHC (known as super-LHC). Two proposals to employ the tracker information in the first level selection are briefly outlined.

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Keywords: High level trigger; CMS; Tracker

1. Introduction

The Large Hadron Collider at CERN is designed to explore the energy frontier. The machine is designed to deliver proton–proton collisions with a beam energy of 14 TeV and a luminosity of $2 \times 10^{33}\,cm^{-2}\,s^{-1}$ in the initial phase growing to the design value of $1 \times 10^{34}\,cm^{-2}\,s^{-1}$. The online selection of rare signal events among the overwhelming background production is an unprecedented challenge.

The CMS detector has a large all-silicon tracker in a 4 T solenoidal field for precise measurement of the transverse momentum of charged particles. Close to the interaction point a pixel detector consisting of three pixel barrel layers at radii of 4,7 and 10 cm and two pixel disks in each end-cap provides precise 2-dimensional space points. The central silicon strip tracker consists of four Tracker Inner Barrel cylinders up to a radius of 55 cm, and six Tracker Outer Barrel cylindrical layers out to $R = 110$ cm. Hermetic coverage up to a pseudo-rapidity of 2.5 is ensured by three Tracker Inner Disks and nine Tracker End Cap disks on each side. The tracker information is complemented by an Electromagnetic and Hadronic calorimeter and an outer tracking system for muons.

The CMS trigger in Fig. 1 consists of two distinct levels. The first stage known as first level trigger or L1 is entirely implemented in custom hardware. It performs a rapid (latency of the order of 3 μs) decision on the basis of information from the calorimeters and muon chambers reducing the event rate to the level of 100 kHz. Throughout

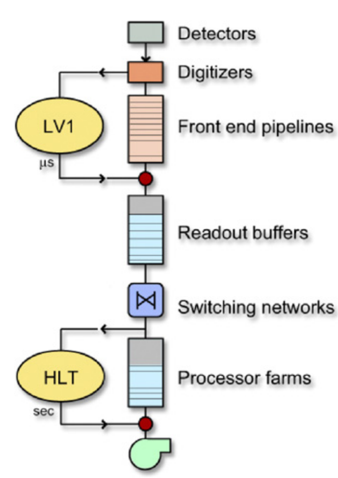

Fig. 1. Schematic representation of the CMS trigger architecture.

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the L1 latency the tracker information is buffered on the Front End electronics. On receipt of a L1 trigger signal the (sparsified) analog data from 60 million pixels and from over eight million SST channels is shipped to the Front End Drivers and digitized.

In the High Level Trigger (HLT) the 100 kHz L1 rate is reduced to the 100–150 Hz that is written to persistent storage. The HLT has access to the complete event information including that from the tracker. The HLT reconstruction and selection algorithms are implemented in software and run on a large filter PC-farm. This provides a flexible environment in which the HLT can benefit from algorithms of arbitrary complexity. Importantly, there are no separate trigger levels within the HLT. Several trigger streams corresponding to different HLT objects are scheduled to run independently.

In this contribution, an overview is given of the role of the CMS tracker in several important algorithms of the HLT selection. In Section 2 the track reconstruction algorithms developed for use in the HLT are introduced. The reconstruction and selection steps for the most important trigger objects are outlined in Section 3. In Section 4 the expected trigger performance is briefly discussed. This contribution concludes with an outlook toward the luminosity upgrade of the LHC. In Section 5 two proposals for including tracker information in the first level are introduced.

A very detailed description of the CMS trigger strategy and expected performance can be found in the collaboration's trigger and data acquisition Technical Design Report [1]. More recent information is found in Refs. [2,3].

A lively discussion concerning the R&D for SLHC is found in the minutes of the CMS SLHC workshops [4].

2. Online track reconstruction

In the CMS HLT environment, algorithms of arbitrary complexity can in principle be implemented. The most severe constraint is posed by the available CPU time. Two algorithms are employed to reconstruct high-quality tracks at a minimum computing load [5,6].

An important speed-up is achieved by performing track reconstruction in regions-of-interest identified by the previous trigger level. In this case only a sub-set of the event data is accessed. Thus, the combinatorial Kalman Filter track finder (or CKF, the default CMS offline algorithm) can be used in the later stages of the HLT. Several parameters of the algorithm are tuned for the online application. Where for offline applications an infinitesimal increase in efficiency is often preferred over a gain in execution speed, in the HLT the balance may be quite different.

The quality of regionally reconstructed tracks is quite comparable to those reconstructed offline in terms of parameter resolution and efficiency and fake rate. These tracks play a central role in the latest stage of most HLT algorithms, where ultimate precision is needed.

The degradation of the tracking and vertexing performance due to misalignment of the tracker elements has been studied in Ref. [7]. For the first data up to few $100\,\mathrm{pb}^{-1}$ of accumulated luminosity, the tracker alignment is assumed to be known with very limited precision from engineering specifications, survey results and the laser alignment system. The relatively small pixel detector is expected to be aligned with tracks to a precision of $10\,\mu\mathrm{m}$. At this early stage the track parameter resolution is significantly degraded with respect to perfect alignment and the tracker contribution to the HLT is likely to be compromised. After a few fb^{-1} a complete track-based alignment down to the sensor level should be available resulting in an overall alignment uncertainty of the Strip tracker of $\sim 20\,\mu\mathrm{m}$. While a dedicated analysis on the impact on the trigger efficiency is still lacking, the effect is expected to be minor.

The pixel-only track reconstruction algorithms provides tracks based on a simplified track fit of all triplets of hits in the pixel detector [8] that are compatible with a minimum transverse momentum and with the beam spot. Pixel-only reconstruction is an order of magnitude faster than the offline algorithm. Global reconstruction of all tracks with transverse momentum greater than $1\,\mathrm{GeV}/c$ is well within the HLT budget[2] Moreover, sharing of the load of the pixel-only reconstruction between several trigger streams leads to a significant gain.

The simplified pattern recognition relies on three hits out of three pixel layers, thus posing a severe requirement on the single layer efficiency. The fake rate is rather well controlled by the three-out-of-three requirement (to the level of 10%) and can be further improved by requiring compatibility with the primary vertex. The small lever arm of the three measurements leads to a much reduced track parameter resolution in the transverse plane (p_T, d_0). Finally, sufficiently accurate error estimates are achieved for pixel-only reconstruction [9].

Pixel-only tracks—although of limited quality—are crucial to provide fast rejection of background events in the earlier stages of the HLT.

3. HLT algorithms

In this section the online reconstruction of the most important final state objects is outlined. The emphasis is on those algorithms where the tracker plays a crucial role.

Many of the trigger streams rely on the two track reconstruction algorithms outlined in the previous section. This does not imply, however, that the streams share reconstruction steps. Where trigger streams have considerable overlap (for example for the pixel-only reconstruction), the framework allows to schedule the algorithms

[2]Timing measurements are found in Refs. [1,9]. Note that these only include the pure algorithmic CPU requirement. Loading and unpacking times of the detector data, cluster reconstruction and framework overhead are to be evaluated separately.