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A Level 1 Tracking Trigger for the CMS Experiment

Nicola Pozzobon for the CMS Collaboration

Abstract

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A Level 1 Tracking Trigger for the CMS Experiment

Nicola Pozzobon (on behalf of the CMS Collaboration)

*Dipartimento di Fisica “G. Galilei”, Università degli Studi di Padova,
and Istituto Nazionale di Fisica Nucleare, Sezione di Padova
Padova, 35131, ITALY*

** E-mail: nicola.pozzobon@pd.infn.it*

The LHC machine is planned to be upgraded in the next decade in order to deliver a luminosity about 5 to 10 times larger than the design one of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$. In this scenario, a novel tracking system for the CMS experiment is required to be conceived and built. The main requirements on the CMS tracker are presented. Particular emphasis will be given to the challenging capability of the tracker to provide useful information for the Level 1 hardware trigger, complementary to the muon system and calorimeter ones. Different approaches based on pattern hit correlation within closely placed sensors are currently under evaluation, making use of either strips or macro-pixels. A proposal to optimize the data flow at the front-end ASIC and develop a tracking algorithm to provide tracks at Level 1 will be presented.

Keywords: ICATPP 2011; Proceedings; LHC; CMS; Tracker; Upgrade; Level 1 Trigger.

1. Introduction

A luminosity upgrade of the CERN Large Hadron Collider¹ is expected to take place in two phases.^{2,3} The typical collider luminosity will then range from $\mathcal{L} \simeq 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ to $10^{35} \text{ cm}^{-2}\text{s}^{-1}$, instead of the design one of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$. The current CMS tracker⁴ was not designed to operate in such an environment: radiation damage and data losses will necessitate the replacement of the Pixel Detector in about 5 years, while novel trigger strategies will be needed when the event rate starts exceeding the scale of GHz. As an example, the maximum allowed Level 1 (L1) muon trigger bandwidth, for nominal LHC conditions, is 12.5 kHz, a rate that can be kept under control at $\mathcal{L} \simeq 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ using full Muon System information but which will become much larger at $\mathcal{L} \simeq 10^{35} \text{ cm}^{-2}\text{s}^{-1}$, requiring also the use of information from the tracker to overcome this limitation. Without upgrading the L1 trigger, the 12.5 kHz rate will be obtained imposing muon

p_T thresholds at values larger than 60 GeV/ c , which will eventually reject all the interesting events.

The main goals of the L1 tracking trigger are the reduction of the overall data rate and the completion of muon and calorimeter L1 triggers to identify relevant trigger objects such as leptons. The first one can be achieved building L1 trigger primitives, independent on the tracker layout, rejecting hits from low p_T tracks, while the accomplishment of the second one will need dedicated online tracking and vertexing algorithms.

2. On-Detector Data Rate Reduction

One promising strategy to reject hits from low p_T tracks relies on pattern hit correlation in closely placed sensors.⁵ Simulations of pp collisions at $\sqrt{s} = 14$ TeV show that the 95% of tracks leaving hits in silicon sensors at radius $R \simeq 30 - 50$ cm from the beam have $p_T < 2$ GeV/ c . The lateral displacement of hits from a $p_T = 2$ GeV/ c track in sensors at $R \simeq 50$ cm separated by $\Delta R \simeq 1$ mm is about 100-150 μm , corresponding to the typical pitch of current pixels and strips of the CMS tracking system. Silicon tracker modules capable of performing the necessary hit correlation to identify low p_T tracks based on this concept, called “stacked modules” or “ p_T -modules”, are currently being designed.

Two experimental proofs-of-principle took place in 2010. Spare strip modules of the current CMS tracker were bonded together 2 mm apart from each other and used to record the passage of cosmic rays. The angle of incidence of tracks could then be clearly correlated to the separation between measured clusters up to 20° , an angle analogous to the one of $p_T = 2$ GeV/ c tracks at $R \simeq 108$ cm in a 4 T magnetic field. Another interesting proof of this concept came from pp collision data at $\sqrt{s} = 7$ TeV. An offline analysis of hits in stereo double-sided strip modules at $R \simeq 70$ cm showed that a cut on lateral displacement between clusters could be translated in a p_T threshold of few GeV/ c with a clear turn-on curve, as shown in Fig. 1.⁶

The L1 tracking trigger primitives built by p_T -modules are called *track stubs*. This functionality is being studied both in terms of design of the chip logic (FNAL proposal) and simulations within the framework of CMS analysis software (CMSSW). One of the major proposals within CMS makes use of well-established designs already used in advanced computing electronics. The main requirements for the pipelines used for data transfer are the capability to sustain input data every 25 ns and to be asynchronous in order to avoid the use of additional clocks. A submission of a test chip through MOSIS is expected for spring 2012.⁷

Simple clustering algorithms are needed to reduce the number of combinatory hit pairs to be matched in order to build stubs. To have them implemented in fast boolean logic, all the strips or pixels over threshold count as a logic “1”. The simplest of these algorithms compares the signals from adjacent strips or pixels in the plane transverse to the beam line, requiring that no more than three consecutive positive signals are found between two cells with null content. Other algorithms under preliminary study may be eligible for ~ 1 mm long pixels and try to include in the cluster also signals from adjacent rows in the sensor.

The production of track stubs, according to the FNAL proposal, is based on the comparison between position of clusters in sensors with different length: the outer sensor has longer pixels or strips which are used to give the actual p_T discrimination while the shorter ones in the inner sensor are used to locate the stubs in the direction of the beam. The size of search windows are defined by look-up tables (LUT's) depending mainly on the distance from the beam line. LUT-based algorithms, even if easy to implement, are not currently being used within CMSSW in favor of procedures based on p_T threshold and backprojection to the luminous region, until the final tracker layout is chosen and LUT's can be optimized.⁸

Fig. 1. Proof-of-principle of low p_T track rejection with stacked sensors. The correlation between lateral separation of Si strip clusters in the two sides of the second layer of the current CMS Tracker Outer Barrel, and track p_T , is shown on the left. The efficiency in selecting tracks as a function of track p_T is shown on the right for lateral separations smaller than 1.5 mm.⁶

3. Off-Detector Online Tracking and Vertexing

The track stubs are the actual L1 tracking trigger primitives which can be combined in a projective geometry to produce objects that can be used

Fig. 2. A 15 degree home sector and the two neighboring sectors used to define the search algorithm to match stubs to existing seed tracklets in the innermost double stack of a tracker layout in the long barrel style. By using both p_T and position in the innermost layer, one can sort the tracklets according to their position in the outermost one. Distances are expressed in mm.

in lepton triggers to improve muon system or calorimeter resolutions or to isolate trigger objects from the same detectors. The concept tracker layout used to study this aspect is the so called “long barrel”, which consists of the Phase 1 Pixel Detector and of an Outer Tracker composed of 6 barrel-like layers of p_T modules. Barrels of stacks are mounted on ladders featuring a lever arm between stacks of ~ 4 cm and arranged in a hermetic fashion so that data flow to combine stubs together into consecutive stacks is maintained within each ladder, allowing also for redundancy in overlap regions. If the stub production corresponds to the current local trigger, the matching of pairs of stubs together within a ladder into *tracklets* is analogous to the regional trigger while the full tracking at L1 corresponds to the global trigger idea. There are also other layouts under evaluation and a variety of tools are being developed to help in the decision of the final design.

Tracking algorithms at L1 for the long barrel tracker are currently being studied both in the context of the FNAL proposal and CMSSW. In both cases, stubs are used as inputs for track finders and tracklets seed the search. To guarantee a parallel approach, the FNAL proposal requires that the tracker is divided into 15° sectors so that the bending radius of a track spanning also an adjacent sector (maximizing the search window) corresponds to $p_T \simeq 2.4$ GeV/c, which then becomes a sort of “intrinsic” threshold within the tracking algorithm, as shown in Fig. 2. Straight line approximation of tracklet projection is used to program a cluster of about 20 FPGA’s per sector which actually will compose the hardware of the online tracking. On the CMSSW simulations side, the collaboration is

currently facing some of the relevant problems in the development of L1 tracking trigger tools, such as optimizing the tracklet builder, defining the seed propagation and the matching windows, handling and removing duplicate tracks, defining the required vertex resolution, assigning momentum information to a track minimizing the number of encoding bits.⁹ Moreover, once these simulation tools are realistic in their implementation, an accurate evaluation of fake rates will be needed in order to rely on the candidate physical objects which the L1 trigger will output.

4. Summary

The effort in developing a L1 tracking trigger for the CMS experiment at the LHC Phase 2 luminosities is dealing with many challenging aspects of the final task to be accomplished. The rejection of low p_T tracks by means of pattern hit correlation in closely placed sensors has already undergone proof-of-principle also with collision data. Different options for the trigger modules and the front-end electronics are being designed for test and evaluation. Also the design of an online tracking algorithm to be implemented in FPGA's and coping with a 40 MHz bunch crossing is in progress and based on sound ideas which can be realized with commercial electronics. Different ongoing studies aim at the definition of physical objects to trigger on, and eventually this will be of major interest for the L1 tracking trigger because of its impact on CMS scientific production.

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