PROCEEDINGS OF SCIENCE

The CMS Track Trigger Upgrade for SLHC

Anders Ryd[*] [†]
Cornell University, Newman Laboratory, Ithaca NY 14853, USA
E-mail: Anders.Ryd@cornell.edu

For a luminosity upgrade of the LHC to an instantaneous luminosity of 10^{35} cm^{-2}s^{-1} there are several issues that needs to be addressed with the CMS detector. Amongst these are 1) the current tracker has to be replaced as it can not cope with the occupancies and will have to be more radiation hard in order to survive in the harsh radiation environment and 2) the current trigger will not be efficient for the physics goals while keeping the rate below 100 kHz, which is the DAQ limit. To address both of these points CMS is considering a tracker replacement which adds trigger capabilities to the tracker. This talk discusses some ideas that are being pursued for the addition of tracking information to the L1 trigger. The basic idea is to use p_T discrimination to reduce the data volume that is required to be read out from the tracking detector in order to provide track trigger primitives in L1.

18th International Workshop on Vertex detectors
September 13–18, 2009
Putten, The Netherlands

[*]Speaker.
[†]On behalf of the CMS Track Trigger Task Force

PoS(VERTEX 2009)040

1. Introduction

The current Compact Muon Solenoid (CMS) experiment has been designed to meet the challenges of data taking with an instantaneous luminosity up to 10^{34} cm^{-2}s^{-1} [1]. One of the key features of the detector is the all silicon tracking system consisting of the inner pixel detector with three barrel layers and two forward discs on each side followed radially outward by the main tracker which provides a precise momentum measurement using the 3.8 T magnetic field provided by the CMS solenoid [2]. The trackers are not contributing to the Level 1, hardware, trigger decision. The Level 1 trigger decisions are based on information from the calorimeters, electromagnetic plus hadronic calorimeters, and the muon system. The readout of the detector is limited to 100 kHz and without substantial changes to the front ends this limit can not be increased. The trigger in CMS is a fixed latency trigger with a $\sim$3.2 μs latency.

With the proposed upgrades to the LHC with luminosities as much as an order of magnitude higher, and the constraints from the CMS readout, the current trigger needs to be enhanced to handle the data rate. To illustrate the issues I will consider two examples. First, the muon rate as a function of the p_T threshold with the current trigger at a luminosity of 10^{34} cm^{-2}s^{-1} plateaus at a rate of about 2 kHz largely independent of the threshold for the L1 trigger. The problem is that the momentum measurement in the L1 muon trigger is poor and soft muons are often reconstructed with a higher momentum. At a luminosity ten times higher than the design luminosity for the LHC this rate becomes unmanagable in the L1 trigger. Similarly, for the electromagnetic calorimeter the rate of electron and photon candidates will increase by at least a factor of ten as the luminosity increases and also as isolation becomes a less powerful discriminator at the higher occupancies. The rates for these triggers can be controlled by increasing the thresholds, but it is highly desirable to improve the trigger in order to keep the thresholds at the same level as is expect for running at 10^{34} cm^{-2}s^{-1}.

The phase 2 upgrade for the super LHC (sLHC) is within CMS defined as the replacement of the main tracker. This allow us to remove several constraints that we have now. First, it allows us to add readout of tracking information to be used in the Level 1 trigger decision. The main challenge here is how to reduce the data volume to allow reading out this data for each beam crossing at 40 MHz. One of the main ideas here is to use stacked modules that provide a discrimination on the transverse momentum of the track that generated the hits. This is discussed in some detail in these proceedings. It will also allow us to increase the front end buffers to allow in increase in the latency of the trigger decision as the trackers are currently limiting this. It is envisioned that we would go to a latency of 6.4 μs after upgrading the tracker.

One of the most carefully studied ideas for the upgrade is to use a tracker with stacked layers, which provide p_T discrimination for L1 trigger primitive generation [3]. The information from the tracker would be combined with the muon and calorimeter information in the L1 trigger in order to improve the muon momentum estimate and provide electron identification and possibly also tracker isolation. This talk presents the current status of these studies and discuss work that is planned to prototype modules that can provide the required p_T discrimination.

2. Transverse momentum discrimination

One of the challenges with using information from the trackers in the L1 trigger is the read-out of the large volume of tracker data. The most promising idea for how to reduce the data in the tracker is to reject in the front end hits generated by soft tracks. This can be done by using the bending in the magnetic field. By placing two sensors separated by about 1 mm radially, as illustrated in Fig. 1, one can reject hits from low p_T tracks by requiring a coincidence in the inner and outer sensors consistent with a stiff track. This arrangement of two closely spaced sensors is referred to as a stack, or stacked module. In addition to using two closely placed sensors, the idea of using one thicker sensor is also being studied. In this approach high p_T tracks will leave hits in smaller clusters while soft particles will create larger clusters.

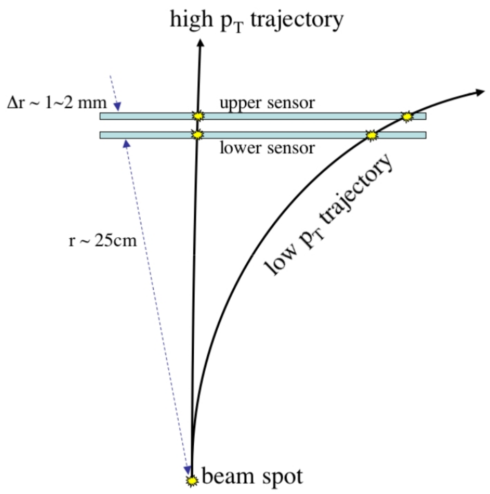

Figure 1: The idea for the stacked modules is illustrade here. Low p_T particles bend in the magnetic field and produce hits in the two sensors that are not consistent with a high p_T track from the interaction point.

3. Simulation Studies

In order to simulate the performance of stacked modules CMS is considering a few possible geometries for the upgraded tracker. One of these, the so called 'Long Barrel' geometry, consists of 10 layers of stacked modules. These layers are grouped as 5 double stacks, where within the double stack a separation of about 4 cm between the stacks is used. This geometry is shown in Fig. 2. In addition to the long barrel geometry the 'Hybrid' geometry which has two stacked layers at radii of about 25 and 35 cm and radially outward a tracker similar to the current CMS detector with barrel modules in the center and disks in the forward region. For the purpose of this presentation results based on the inner layers of the long barrel geometry will be presented. In the long barrel geometry we have used pixels that are 100 μm by 1 mm and a sensor thickness of 200 μm.

The results presented here are based on the CMS fast simulation. The fast simulation in CMS implements a simplified geometry and description of interactions. In particular the material in the tracker is modeled as thin concentric cylinders at the approximate radii of the layers and delta ray production is not included.

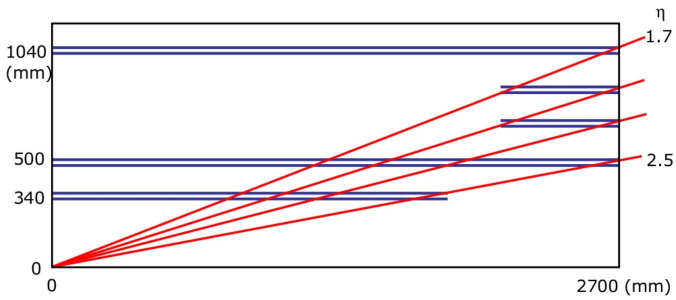

Figure 2: The layout of the the long barrel detector concept. There are ten layers of double stacks. A nominal separation of 1 mm between the modules in the stack has been used, and a separation of 4 cm between the stacks in the double stacks. Two of the double stacks cover only the forward region. This ensures that we have three double stack coverage over most of the η range.

By default in these simulations we have used a stack separation of 1 mm and a stub threshold of 2 GeV. In Fig. 3 the efficiency for finding a stub as a function of p_T is shown for muons for a stack placed at a radius of 35 cm. The plot shows that a fairly sharp turn-on is achieved for a 2 GeV threshold. Sensor separations from 0.5 mm to 3 mm were studied, and it can be seen from the figure that the smaller sensor separation gives a softer turn on curve. The asymptotic efficiency for high momentum tracks reaches an efficiency of about 97% where the loss of efficiency is dominated by the gaps in z between modules. The rate of hits and stubs, as a function of the z position of the module is shown in Fig. 4. This simulation assumes 400 pp interaction per beam crossing. The 2 GeV stub threshold reduces the rate by about a factor of 30 in this simulation.

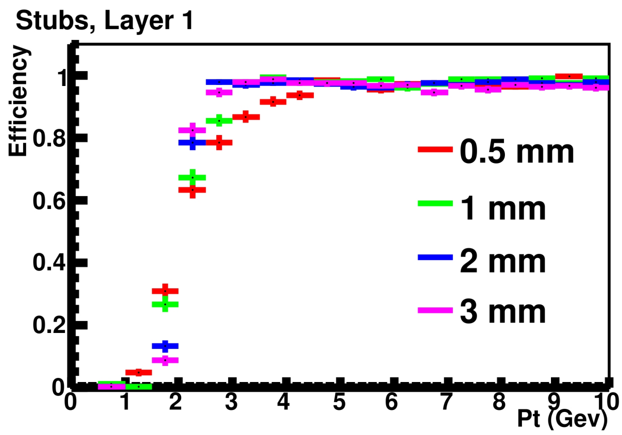

Figure 3: The stub finding efficiency as function of p_T for different stack separations.

3.1 Electron triggering

In order to study how the track trigger primitives, stubs, can be used to improve the L1 trigger performance a simple algorithm used in the high level trigger (HLT) has been ported to use the

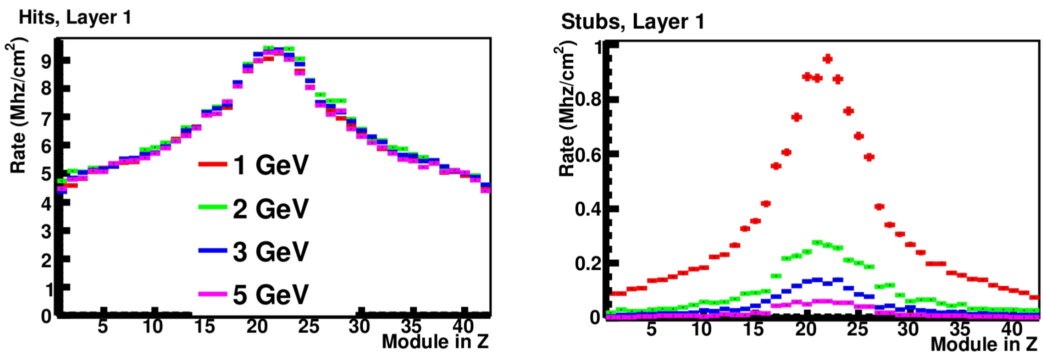

Figure 4: The hit and stub finding rate for different thresholds for a module at a radius of 35 cm.

L1 stubs instead of cluster in the current strip tracker. In this algorithm we start with the electron candidates from the L1 calorimeter trigger. We use the η, ϕ, and transverse energy in order to open a search road in the tracker. We use the transverse energy to determine the curvature of the track and we use an uncertainty in ϕ of about 0.1 radians due to the poor L1 calorimeter position resolution. In r–z we require that the stub and the calorimeter position is consistent with a track originating within $\pm$20 cm of the nominal interaction point in z. In a second pass the stubs found in these roads are required to satisfy tighter constraints. In particular, in r–ϕ the two stub positions, when combined with a constraint that the track comes from the interaction point, are required to have a curvature consistent with the measured transverse energy in the calorimeter.

These studies are still in their early stages and the results we have are preliminary. They do however indicate that for the electron identification significant improvements in the trigger rate can be obtained using tracking information. In Fig. 5 the efficiencies and rate reductions for the tested algorithm is shown. A rejection factor of about 10 is obtained for electrons over 15 GeV. The efficiency for this selection is close to 90% in the central region of the detector. For large $|\eta|$ the efficiency drops significantly. This drop in efficiency is due to increases in material for forward going particles. In addition to the material effect, the cuts used to select the electrons are not optimized for the forward region.

Similar studies are underway for muons. If the correct hits are assigned to the muon candidate the tracking information from just a few layers provide a sufficiently precise momentum measurement to significantly reduce the rate of low momentum muons that are mismeasured in the L1 muon trigger.

In addition to the electron and muon studies CMS is considering tau identification. Here the main tool is track based isolation. This is a more challenging task as we have to find tracks near the tau jet candidate that are consistent with originating from the same primary interaction point. If such tracks are found in the 'isolation' cone around the tau candidate the candidate will be rejected. These studies are underway and results will be reported in the future.

4. Module R&D

In addition to the simulation studies described above CMS has started R&D programs to de-

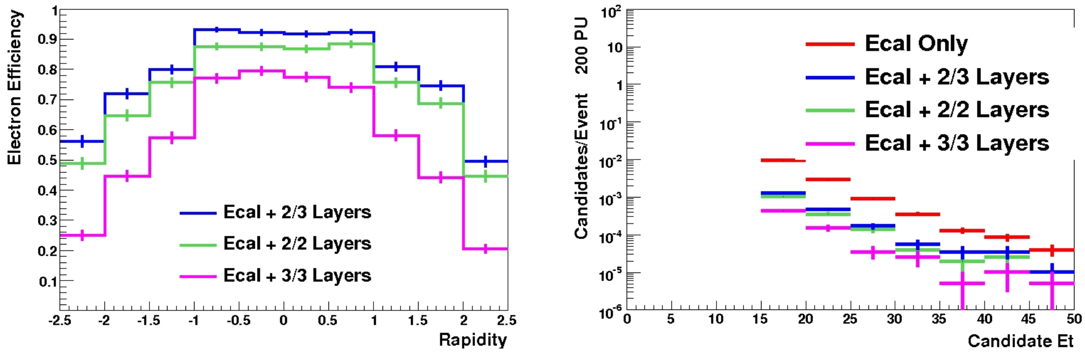

Figure 5: Electron trigger performance for different number of stacked layers used in the algorithm. The efficiency for identifying an electron is shown as a function of η on the left. The background rate from minbias events is shown as function of electron candidate transverse energy, E_t, on the the right.

velop modules that can provide the trigger primitives. There are two main ideas for stacked modules that are being pursued. The first is the so called 'p_T' modules [4]. In these modules conventional technology used in the current silicon detectors are used to bring the signals from the sensors to the edges of the module. Here the signals from the two sensors are combined to form the stubs. This is illustrated in Fig. 6. In the alternative approach, 'vertically integrated', modules use 3D integration [5]. This is illustrated in Fig. 7. Here the signals from one sensor is transferred vertically down through an interconnection layer, the interposer, which provide a separation of about 1 mm between the two sensors. The readout is integrated in this assembly.

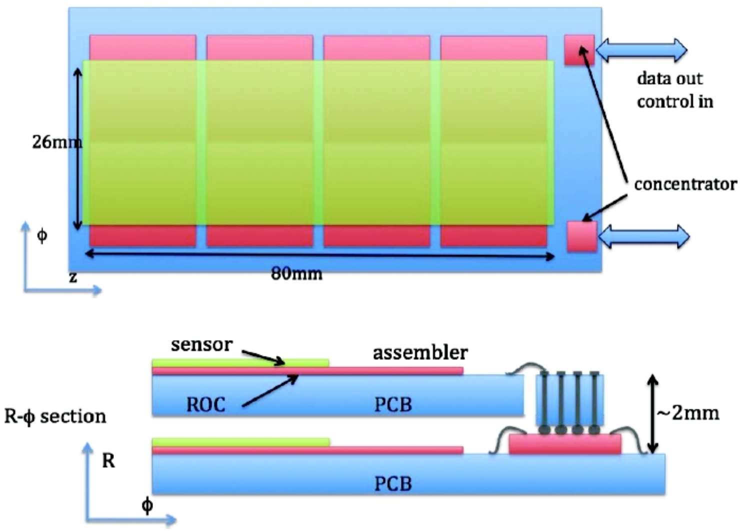

Figure 6: The concept for the 'p_T' module. The signals from the sensors are brought to the edge of the module where they are correlated to form the stubs.

One of the challenges with these modules, in either of the approaches described above, is the power consumption. Table 1 summarizes the power consumption in the front ends using 130 nm

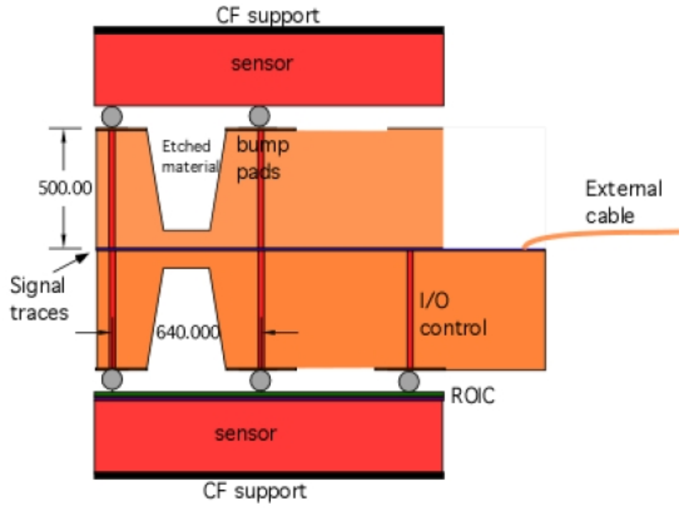

Figure 7: The concept of a 'vertically integrated' module. Two sensors, at the top and bottom, are separated by about 1 mm using the interposer that brings the signals from the top sensor to the bottom sensor.

Table 1: Power consumption estimates for the 'p_T' module concept per pixel for the front end power.

	P [μW]/pixel	Functions
Front end	25	amplifier, discriminator local logic, cf ATLAS 130 nm
Control, PLL	10	1 PLL/ROC 5 mW, x2
Digital logic	8	comparison logic and transfer to edge: 1mW/column
Data transfer	2.5	few cm across module
Data transfer	10	transport to remote GBT
Concentrator	5	buffer to and from GBT: 2 ASICs 20 mW
Full readout	20	following L1 trigger, extrapolate from CMS pixel
Sub-total	80	
Total with DC-DC	106	75% efficiency for DC-DC conversion

feature sizes [4]. Assuming a 100 μm $\times$ 2.5 mm pixel size and two layers at radii of 25 and 35 cm respectively we estimate the number of links and power as summarized in Table 2. Assuming a 50% link bandwidth utilization for a 2 W optical link [6] operating at 3.6 GHz we estimate a power consumption of over 28 kW in these two layers[1]. This is comparable to the current CMS strip detector. Keeping in mind that in order to not degrade the tracking performance we would ideally want to reduce the material in the upgraded tracker with respect to what is in the current CMS strip tracker it is clear that this is a major engineering challenge. A significant R&D program is underway to understand how to power and cool the upgraded tracker. CMS has picked DC-

[1] The estimate of 2 W per GBT link is likely very conservative.

Table 2: Power consumption estimates for a two layer layout. Number in parenthesis corresponds to assuming a 50% average utilization of the optical links, i.e. it assumes that you need twice as many links as you would need assuming a 100% utilization.

R [cm]	L [m]	A [m^2]	N_{chan}	N_{module}	N_{links}	P [kW]
25	3.0	9.6	38.5M	4700	1440 (2880)	6.7 (9.6)
35	4.2	18.7	75M	9200	2810 (5620)	13.1 (18.7)

DC converters on the detector as the baseline for power distribution and R&D on CO_2 cooling is underway.

5. Conclusions

CMS has an active program for studying L1 track triggering. Ideas for stacked modules are being actively simulated and initial results are encouraging for muon and electron selection. More work is needed before these conclusions are solid and the studies also need to be expanded to cover isolation for tau selection. In addition to the simulation studies, R&D projects are now getting underway to explore the technologies needed to build these modules. Major engineering challenges exists for the design and operation of this upgrade, but work is underway to address many of these challenges.

6. Acknowledgments

This work was supported by the US National Sicience Foundation grants PHY-0757894 and CAREER Award PHY-0846388, and the Alfred P. Sloan Foundation. I also wish to thank all my CMS collaborators who has contributed to this project and the organizers of the VERTEX 2009 conference.

References

[1] R. Adolphi *et al.* [CMS Collaboration], JINST **3** (2008) S08004.

[2] The CMS Collaboration, *CMS Tracker Technical Design Report*, CERN/LHCC 98-6 (1998) and Addendum CERN/LHCC 2000-016 (200).

[3] J. Jones, G. Hall, C. Foundas, and A. Rose, *A Pixel Detector for Level-1 Triggering at SLHC*, arXiv:physics/05102289. CERN REport CERN-2005-011 (2005) 130-134.

[4] G. Hall, *Design of a trigger module for the CMS Tracker at SLHC*, presented at TWEPP 2009, `http://indico.cern.ch/conferenceDisplay.py?confId=49682`.

[5] R. Lipton, *Application of Vertically Integrated Electronics and Sensors (3D) to Track Triggers*, presented at ACES 2009, `http://indico.cern.ch/conferenceDisplay.py?confId=47853`.

[6] `https://espace.cern.ch/GBT-Projet/default.aspx`.