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THE LEVEL-1 CALORIMETER TRIGGER FOR THE CMS DETECTOR[*][†]

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Abstract

We present results from simulation studies and implementation ideas for the level-1 calorimeter trigger for the CMS detector at the LHC collider. QCD background trigger rates and signal efficiencies for electron and photon triggers using several simple level-1 algorithms are discussed. Jet trigger rates and efficiencies are studied for various calorimeter tower sums. Some of the technical challenges in implementing these simple trigger algorithms in a high rate environment are also explored. Design of an high speed adder ASIC is briefly discussed.

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INTRODUCTION

The CMS detector[1] is designed to study high p_T physics in 14-15 TeV center of mass proton-proton collisions at the LHC. In order to extend the mass range for Higgs searches and study the TeV scale the LHC is designed to operate at the luminosity of 10^{34} cm^{-2} s^{-1}. The physics program includes the study of electroweak symmetry breaking, studies of the top quark, searches for new heavy gauge bosons, probing quark and lepton substructure, looking for supersymmetry and exploring for other new phenomena. Most of these physics topics are best studied in the events with high p_T leptons or photons because the profusely produced QCD events obscure hadronic channels.

Triggering is one of the extraordinary challenges facing detector designers at the high luminosity LHC collider. For the nominal LHC design luminosity of 10^{34} cm^{-2} s^{-1}, an average of 25 events occur at the beam crossing frequency of 25 nsec. This input rate of 10^9 interactions every second must be reduced by a factor of at least 10^4 to 100 KHz, the maximum rate that can be analyzed by subsequent processing in an on-line computer farm. This must be done for all channels without dead time. CMS has chosen to reduce this rate in two steps. The first level stores all data for 3 μs, after which no more than a 100 KHz rate of the stored events is accessible by the on-line processor farm. The farm processors first analyze a subset of the event data using fast algorithms operating as a “virtual level-2”, to further filter events. A hierarchy of such filters screen the events before saving data to disk at 100 Hz.

We have explored the trigger issues extensively for the SDC detector which was to have been built at the SSC [2, 3]. The physics interest and the background challange is similar for the CMS experiment at the LHC. We therefore build upon the trigger work on the SDC experiment that has direct application in CMS. However, the choice of the trigger algorithms, and, therefore, the trigger hardware realization, depend on the detector geometry and performance. Additionally, the greater pileup expected at the LHC, and, the lack of a physical level-2 trigger, are likely to place more stringent requirements on the trigger.

TRIGGER SIMULATION

As a first step in this effort we have reworked our SDC fast simulation program to describe the CMS detector geometry and materials. The response of the calorimeter is calculated in this program using standard shower parameterizations available in literature. Before trigger simulation the detector response to hard scattering events and a suitable number of Poisson distributed minimum bias events at the desired luminosity were added. For the purpose of EM trigger simulation, calorimeter transverse energy deposits, in each $0.1\eta \times 0.1\phi$ trigger tower region, were summed and converted to an 8-bit linear scale, with a resolution of 0.5 GeV, to simulate the dynamic range limitation.

The trigger response was then simulated for each event using various level-1 algorithms, including several we have devised and algorithms from other sources such as RD-27[4]. Most algorithms considered all possible two EM trigger tower pairs to cut on the summed EM transverse energy. Our SDC-style EM trigger algorithm involves two separate cuts on the longitudinal and transverse isolation of the EM energy deposit. The first cut requires a hit tower HAD to EM energy ratio, $H/E < 0.05$. The second cut requires transverse isolation, i.e. a cut on sum of HAD

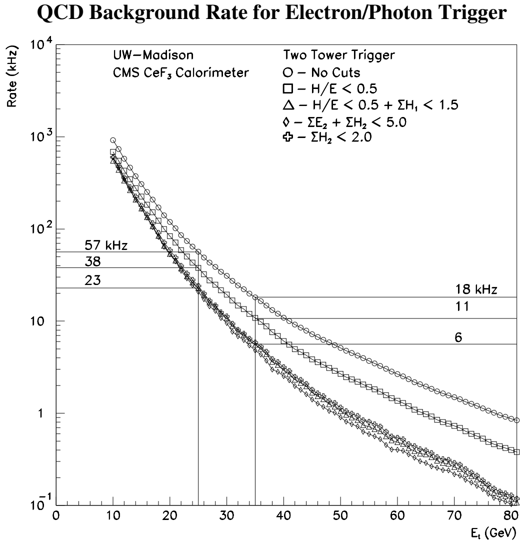

Figure 1: Single electromagnetic cluster trigger background rate for CMS is plotted versus the two tower sum transverse energy deposited with various cuts. The circular points are without any cuts, the square points and the triangular points are for our algorithm, the diamond and plus shaped points are for the RD-27 algorithm.

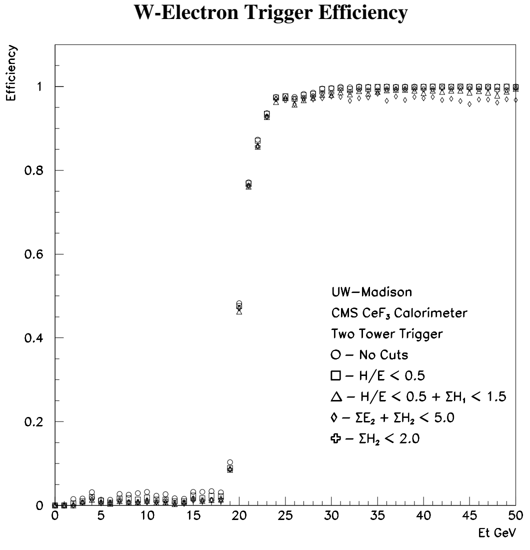

Figure 2: Efficiency of triggering on electrons from W decay events for CMS is plotted versus p_T of the electron for various algorithms with labeling as defined in the Figure 1.

transverse energies in the nearest eight towers surrounding the hit tower, $H_1 < 1.5$ GeV. In order to reduce the number of bits of information exchanged between electronics cards we limit the dynamic range of neighboring tower HAD information to 3 bits. Overflows of both the 8 bit scale for EM and central HAD towers, and 3 bit scale for neighboring HAD towers are treated as maxima. The RD-27 algorithm [4] involves only one cut on the sum energy of the 12 border EM towers and 16 HAD towers in the $0.4\eta \times 0.4\phi$ region, i.e, $\Sigma E_2 + \Sigma H_2 < 5$ GeV.

We have studied the expected trigger rates for various algorithms from the QCD background, and the efficiencies for several high p_t physics processes. We have found that the electromagnetic trigger algorithm proposed for the SDC detector works satisfactorily for the CMS trigger. We find that the transverse isolation criterion which provided marginal improvement for the SDC is essesential to trigger on interesting physics at the LHC. We have also compared our SDC style algorithm to the one proposed by CERN RD-27 group [4] for Atlas trigger. The rates from QCD two jet production background are shown for various algorithms in Figure 1. The efficiencies of the electron trigger for these algorithms obtained using W decay events including the minimum bias background is shown in Figure 2. We find that our SDC algorithm performs similarly to the RD-27 algorithm. There are two interesting features in our SDC algorithm. Firstly, our proposed algorithm requires smaller amount of data than the RD-27 algorithm.. Secondly, our algorithm allows for a non-isolated electron trigger for the initial low luminosity running at the LHC when one might be interested in studying B physics which requires a non-isolated electron trigger.

We have studied jet trigger rates (see Fig-

Jet Rates for various tower sum regions

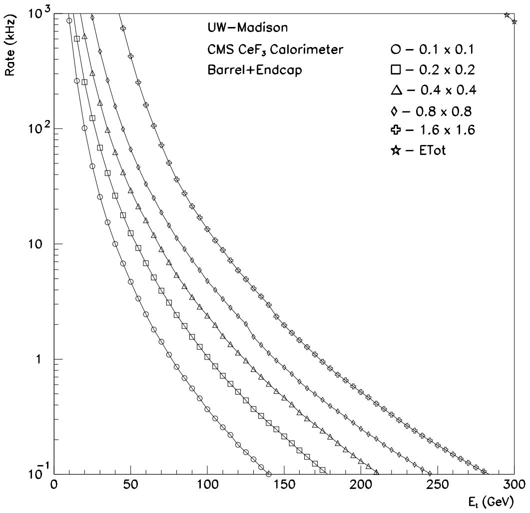

Figure 3: Jet trigger rates using various tower region sums are plotted versus the E_t deposited in the calorimeter region. The rate includes only barrel and endcap calorimeters, i.e. $|\eta| < 2.6$.

Jet Trigger Efficiency

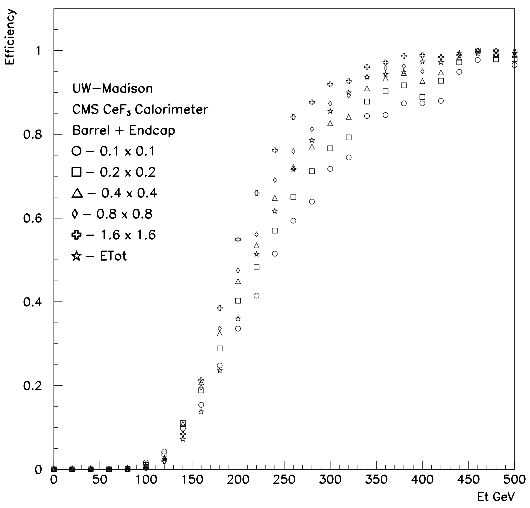

Figure 4: Efficiency of jet trigger for various tower region sums is plotted versus the jet p_T.

ure 3) and efficiencies (see Figure 4) and found that transverse energy sums in $0.8\eta \times 0.8\phi$ regions provide sufficient performance. We have also studied efficiencies for various high E_t physics signals as a function of chosen thresholds for single and double EM triggers. Although the efficiency for very high E_t physics processes resulting in two or more electrons/photons is very good, efficiency for top and W triggers is somewhat low for the nominal rates/thresholds proposed for CMS (see Table 1).

CMS TRIGGER DESIGN

The CMS Level 1 Calorimeter trigger data is received from the front end electronics on optical fibers in digital form, either on an 8-bit nonlinear scale that is decoded with memory lookups or on a 10-bit linear scale. The fiber receiver converts the serial optical data to parallel data on copper. It synchronizes the incoming data to the trigger system 25 nsec clock and aligns it to the correct crossing number. The fiber receiver does error detection, using error codes transmitted with the data, and logs the errors for subsequent readout.

After reception and synchronization, the calorimeter trigger data is fed to two circuits. The first uses memory lookup tables to convert the energies into E_t, E_x, and E_y and then injects these quantities into a summation network, based on a high speed GaAs Adder ASIC [5], and computes sums of energies on groups of towers for jet triggers and over the entire calorimeter for the global E_t and missing P_t triggers. The second circuit performs our isolation algorithm, described earlier, to identify electrons and photons. The results of both circuits are compiled by subsequent logic into lists of jets and electrons passing various thresholds and other conditions, as well as the global energy sums. These are forwarded to the global level 1 trigger.

We are presently in the process of completing the adder ASIC design (see Figure 5) and producing a test GaAs integrated circuit. We will build a VME board to test this ASIC at speeds up to 160 MHz.

We plan to cycle the CMS calorimeter trigger system at four times the LHC speed, i.e. 160 MHz, in order to attain a compact size at an affordable cost. System engineering issues to realize such a design are being studied.

References

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Singles Threshold GeV	Doubles Threshold GeV	Background Rate kHz	Higgs trigger Efficiency %	Top trigger Efficiency %	W trigger Efficiency %
20	10	54.5	99	85	79
25	12.5	23.0	97	79	67
30	15	10.8	95	71	52
35	17.5	5.6	92	63	33
40	20	2.9	87	57	16
45	22.5	1.7	82	49	7
50	25	1.1	74	43	4

Table 1: CMS calorimeter trigger efficiency for Higgs decays to two photons, top decays to electron, and W decays to electron processes are shown for our algorithm as a function of trigger threshold with corresponding rates from QCD background.

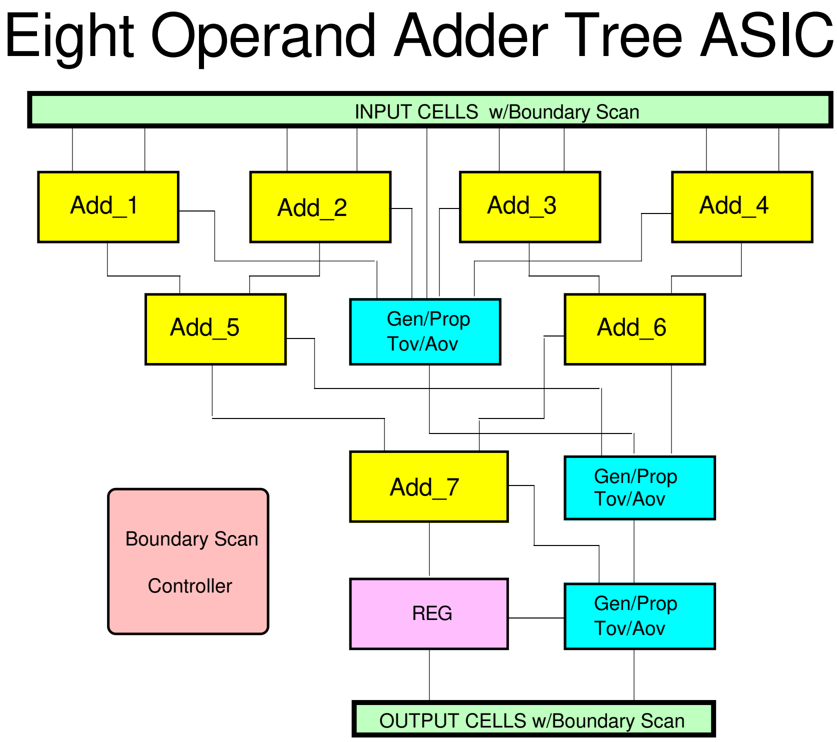

Figure 5: Adder ASIC design block diagram.