CMS REGIONAL CALORIMETER TRIGGER JET LOGIC

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Abstract

The CMS regional calorimeter trigger system detects signatures of electrons/photons, taus, jets, and missing and total transverse energy in a deadtimeless pipelined architecture. This system contains 20 crates of custom-built electronics. Recent changes to the Calorimeter Trigger have been made to improve the efficiency and purity of jet and τ triggers. The revised algorithms, their implementation in hardware, and their performance on physics signals and backgrounds are discussed.

1. CMS CALORIMETER L1 TRIGGER

The CMS level 1 trigger decision is based in part upon local information from the level 1 calorimeter trigger about the presence of physics objects such as photons, electrons, and jets, as well as global sums of E_T and missing E_T (to find neutrinos) [1].

For most of the CMS ECAL, a 5 x 5 array of PbWO4 crystals is mapped into trigger towers. In the rest of the ECAL there is somewhat lower granularity of crystals within a trigger tower. There is a 1:1 correspondence between the HCAL and ECAL trigger towers. The trigger tower size is equivalent to the HCAL physical towers, .087 x .087 in η x ϕ. The ϕ size remains constant in Δϕ and the η size remains constant in Δη out to an η of 2.1, beyond which the η size increases.

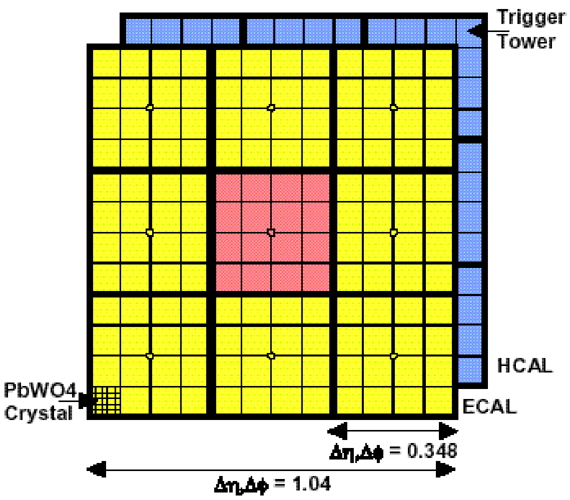

Figure 1. Calorimeter Trigger Jet Algorithm

The jet trigger algorithm shown in Figure 1 uses the transverse energy sums (ECAL + HCAL) computed in calorimeter regions (4x4 trigger towers). Jets and τs are characterized by the transverse energy E_T in 3x3 calorimeter regions (12x12 trigger towers). For each calorimeter region a τ-veto bit is set if there are more than two active ECAL or HCAL towers in the 4x4 region. A jet is defined as 'tau-like' if none of the 9 calorimeter region τ-veto bits are set.

2. CALORIMETER TRIGGER HARDWARE

The calorimeter level 1 trigger system, shown in Figure 2, receives digital trigger sums from the front-end electronics system, which transmits energy on an eight bit compressed scale. The data for two trigger towers is sent on a single link with eight bits apiece, accompanied by five bits of error detection code and a "fine- grain" bit for each trigger tower characterizing the energies summed into it, i.e. isolated energy for the ECAL or an energy deposit consistent with a minimum ionizing particle for the HCAL.

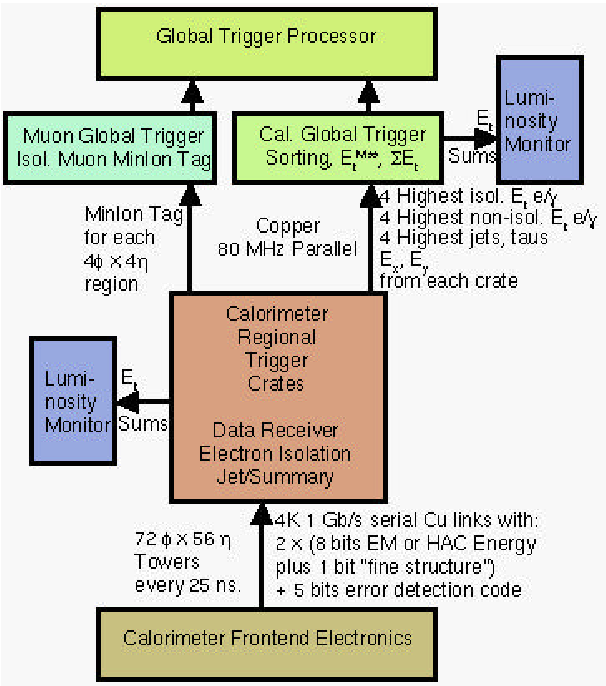

Figure 2. Overview of Level 1 Calorimeter Trigger

The calorimeter regional crate system uses 20 regional processor crates covering the full detector. Eighteen crates are dedicated to the barrel and two endcaps. These crates cover the region $|\eta|<3$. One special crate covers both HF Calorimeters that extend missing E_T and jet finding coverage to $|\eta|<5$. The remaining crate (Cluster crate) collects regional information from these 19 trigger crates and clusters their regions to find jets and taus. It also continues the summation tree to provide sums of E_T in various ϕ regions.

The Cluster crate sends its 9x4 highest energy central and forward jets and tau candidates along with information about their location and sum E_T for the 18 ϕ regions it covers. The global calorimeter trigger then forms E_x and E_y using look-up tables and sums the energies, separately sorts the electrons, jets and taus, and sends the top four calorimeter-wide candidates, as well as the total calorimeter missing and sum E_T to the CMS global trigger.

Eighteen crates of the Calorimeter Regional Trigger use three custom board designs that are dedicated to receiving and processing data from the barrel and endcap calorimeters. In these crates there are seven rear mounted Receiver cards, seven front-mounted Electron Isolation cards, and one front-mounted Jet Summary card for a total of 15 processor cards per crate. These cards and an additional clock and control card are plugged into custom "backplane" which provides 160 MHz point-to-point links between the cards. A VME bus is also provided to these cards using high-density connectors in the top 3U section of the backplane. In addition there are two slots with standard VME backplane connectors for crate processor and monitoring cards.

The 19th crate covering the forward calorimeter houses special cards that use portions of circuitry of the Receiver and Jet Summary cards to drive the signals out for forming jets and E_T sums. The 20th cluster crate is similar to the 18 barrel and endcap crates but uses a different backplane and a set of cluster processor cards that implement the jet and tau finding algorithms and E_T sums. These cards and backplane are based on the same technology used in the other crates.

The regional calorimeter trigger crate, shown schematically in Figure 3, has a height of 9U and a depth approximately of 700 mm [2]. The front section of the crate is designed to accommodate 280-mm deep cards, leaving the major portion of the volume for 400 mm deep rear mounted cards

The Receiver Card synchronizes the input data and passes it through look-up tables to separately linearize the energies into the number of bits needed for electron identification and energy triggers. Data in parallel form is shared with the neighboring crates at 80 MHz. The entire system operates in lock step after this stage at 160 MHz. The energies are then summed in 4 x 4 trigger tower regions.

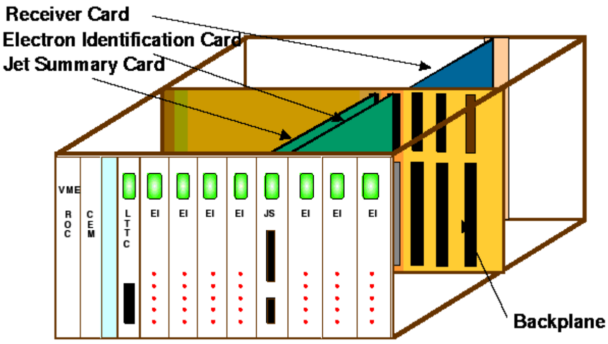

Figure 3. Schematic view of a typical Calorimeter Level 1 Regional crate.

The data for the electron identification logic, which includes both that received on the serial cables and that received on inter-crate cables, are transferred to the Electron Identification cards plugged into the front side of the backplane. The 4 x 4 sums are transferred to the Jet/Summary card plugged into the center of backplane on the front-side of the crate.

The Electron Isolation card implements its algorithm in the Isolation ASIC [3]. The candidate electrons are ranked and top candidates are passed to the Jet/Summary card. The Jet/Summary card sorts the isolated and non-isolated electron candidates and jet candidates in the crate to output the top four candidates of each kind on a cable to the global trigger. It also transmits 4x4 E_T sums to the cluster crate, which calculates jets, taus, and 18 E_T sums in phi, which are also transmitted to the GCT. The GCT sorts objects and sums energies to obtain the final output of the calorimeter trigger which is used by the Global Trigger together with the muon trigger data to provide the final trigger decision.

3. JET AND τ TRIGGER DESIGN

The jet trigger uses the transverse energy sums (ECAL + HCAL) computed in calorimeter regions (4x4 trigger towers), except in the HF region where it is the trigger tower itself. The input tower E_T is coded in an 8 bit linear scale with programmable resolution. Values exceeding the dynamic range are set to the maximum. The subsequent summation tree extends to a 10 bit linear scale with overflow detection. Simulation studies showed that a scale of 10 bits with LSB=1 GeV gives adequate jet trigger performance.

The jets and τs are characterized by the transverse energy E_T in 3x3 calorimeter regions using a sliding window technique that spans the complete (η,ϕ) coverage of the CMS calorimeters seamlessly. The summation spans 12x12 trigger towers in the barrel and endcap or 3x3 larger HF towers in the HF. The ϕ size of the jet window is the same everywhere. The η binning gets somewhat larger at high η due to the size of calorimeter and trigger tower segmentation. The jet trigger central region E_T is required to be higher than the eight neighbor region E_T values.The jets are labeled by (η,ϕ) indexes of the central calorimeter region.

For each calorimeter region a τ-veto bit is set ON if there are more than two active ECAL or HCAL towers in the 4x4 region. This assignment of a τ-veto bit is performed by the input memory lookup tables on the Receiver Card that assign the E_T values to the appropriate scales for downstream processing. Spare bits in these memories are used as threshold E_Ts to determine the number of active towers. These towers are counted by the downstream logic to determine τ-like energy deposits. A jet is defined as "τ-like" if none of the 9-calorimeter region τ-veto bits are ON.

The Jet/Summary card receives 4x4 trigger tower 10-bit 4x4 E_T sums, 1 overflow bit and active trigger tower counts from all Receiver cards in the crate, including all of the 14 regions 4x4 served by the crate. These data are multiplexed for transmission at 80 MHz to the Cluster crate for finding jets and τ candidates.

The Jet/Summary card processes the 2-bit ECAL and HCAL activity counts for each of the 14 regions covered by the crate. If the trigger tower activity counts from ECAL or HCAL are greater than two, the 4x4 region τ veto bit is set ON. There is enough room on the card to implement this algorithm in discrete logic components. The logic is used at least twice per crossing to determine τ veto bits for all 14 regions handled by this card.

The eighteen regional trigger crates and the single HF crate send 4x4 trigger tower E_T sums to a single Cluster crate where 12x12 overlapping E_T sums are calculated to form jet and τ candidates. As shown in Figure 4, the Cluster crate consists of 9 Cluster Processor cards each receiving data from two regional crates and one HF crate on six 34-pair cables. The data from two regional crates, covering |η|<3 and a 40° bin in ϕ and consisting of 10 bits of E_T and 1 τ veto bit per 4x4 region, are received on 80 MHz parallel differential ECL links by each Cluster Processor card.

The same technology is used to receive data from HF crate covering -5<η<-3 and 3<η<5. In order to seamlessly cover the η–ϕ plane these data are exchanged on a custom point-to-point backplane similar to the backplane of regional trigger crates. Adder ASICs [3] are used to make E_T sums of 3x3 trigger tower regions centered around each trigger tower region. The central 4x4 region E_T is required to be greater than the neighbors to the right and bottom, and to be greater than or equal to the neighbors on the left and top. Each Cluster Processor card produces 36 such 12x12 E_T sums. These candidates are divided into central and forward jets. The central 28 sums are classified as τ candidates if they are not vetoed by any of the nine 4x4 regions contained in it. The remaining candidates are classified as central jets.

The central and forward jet, and the τ candidate E_T sums are compressed using a look-up table with a 6-bit rank and are also associated with 5 bits defining their position on each Cluster Processor card. These candidates are separately sorted based on their rank while keeping track of their position bits to find the top four candidates of each category. Sort ASICs [3] are used for this operation. The top four candidates of each type, from each Cluster Processor card, are staged to the Cluster Output card for sending to the Global Calorimeter trigger. The Global Calorimeter trigger system continues the sort tree to obtain top four candidates over the entire η–ϕ plane. Additionally, it also tests these candidates against thresholds to count the numbers of jets above programmable thresholds in various η regions to provide triggers for events with more than four jets.

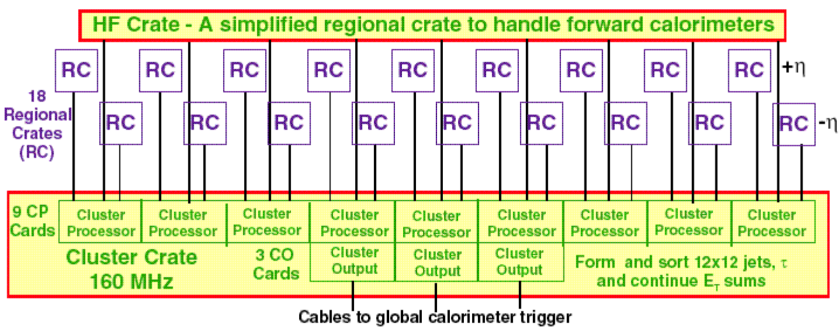

Figure 4. Calorimeter Regional Trigger Cluster Crate Organization

The four highest energy central and forward jets, and central τs in the calorimeter are selected. This choice of the four highest energy central and forward jets and of the four highest energy τs provides enough flexibility for the definition of combined triggers.

In addition, counters of the number of jets above programmable thresholds in various η regions are provided to give the possibility of triggering on events with a large number of low energy jets. Jets in the forward and backward HF calorimeters are sorted and counted separately. This separation is a safety measure to prevent the more background-susceptible high-η region from masking central jets. Although the central and forward jets are sorted and tracked separately through the trigger system, the global trigger can use them seamlessly as the same algorithm and resolutions are used for the entire η–φ plane.

Another possibility of performing the sliding window jet cluster algorithm is to use the Global Calorimeter Trigger hardware [4]. In this option, the GCT receives 14 subregion energies from the Jet/Summary Card in each RCT barrel / endcap crate, along with the τ feature bits. The subregion energy data from the HF is also input. A clustering algorithm based on a 3 x 3-subregion sliding window is employed to find jets over the full range. The jets found by this procedure are then sorted as in the baseline design in three streams: central jets, forward jets and τ-jets.

In either realization, single, double, triple and quad jet (τ) triggers are possible. The single jet (τ) trigger is defined by the transverse energy threshold, the (η,φ) region of validity and eventually by a prescaling factor. Prescaling will be used for low energy jet (τ) triggers, which are necessary for efficiency measurements.

The multi jet (τ) triggers are defined by the number of jets (τs) and their transverse energy thresholds, by a minimum separation in (η,φ), as well as by a prescaling factor. The global trigger accepts the definition, in parallel, of different multi jet (τ) triggers conditions.

4. JET AND t -TRIGGER PERFORMANCE

The jet trigger efficiency turn-on versus the generator level jet p_T for the location matched jets is shown in Figure 5 for single, double, triple and quadruple jet events. The plots are made from a full GEANT-based detailed simulation of the CMS detector and trigger logic. The jet trigger integrated rate is plotted versus the corrected L1 jet E_T for single, double, triple and quadruple jet events in Figure 6. For the multi-jet triggers all the trigger jets are required to be anywhere in $|\eta|<5$ and to be above the jet E_T cutoff. The 1,2,3, and 4-jet trigger rates are 0.4, 0.4, 0.7, and 0.2 kHz for thresholds of 285, 225, 125, and 105 GeV respectively.

The simulated background rates for low ($10^{33}cm^{-2}s^{-1}$) and high ($10^{34}cm^{-2}s^{-1}$) luminosities after the τ veto are compared to jet rates in Figure 7 and Figure 8. The jet trigger efficiency at high luminosity is plotted versus generator level jet p_T for single, double, triple and quadruple jet E_T cutoffs. Providing a dedicated trigger stream for τ-jets is useful because efficiencies can be measured with better understanding of systematics. The E_T cuts used in this simulation for single and double τ triggers respectively are 150, 80 GeV for high luminosity and 80, 60 GeV for low luminosity. A 95% trigger efficiency is reached for single (double) τ-jets at energies of 95 GeV and 180 GeV (75 and 110 GeV) at low and high luminosity, respectively. The resulting efficiencies for a 200 GeV higgs double τ decay are 96% and 73% at low and high luminosity, respectively.

5. CONCLUSIONS

The CMS level-1 regional calorimeter trigger design has been upgraded to improve performance on jet and τ triggers. Simulation results show that it will be able to control the trigger rate while retaining interesting high E_T jet and τ physics events with high efficiency.

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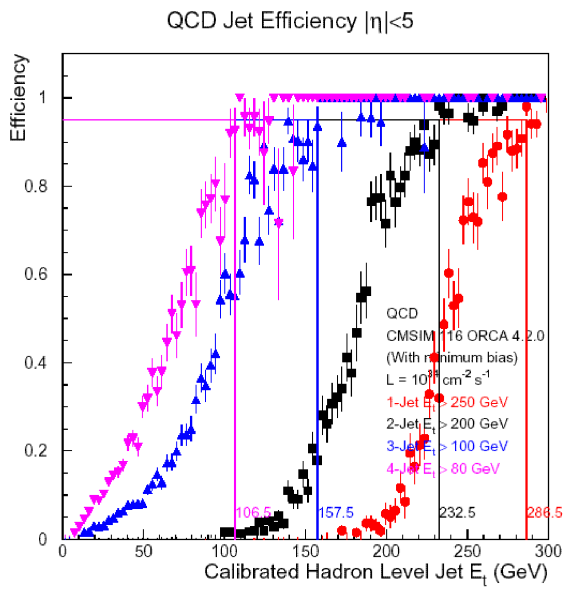

Figure 5. Jet trigger efficiencies for single, double, triple and quadruple jet triggers.

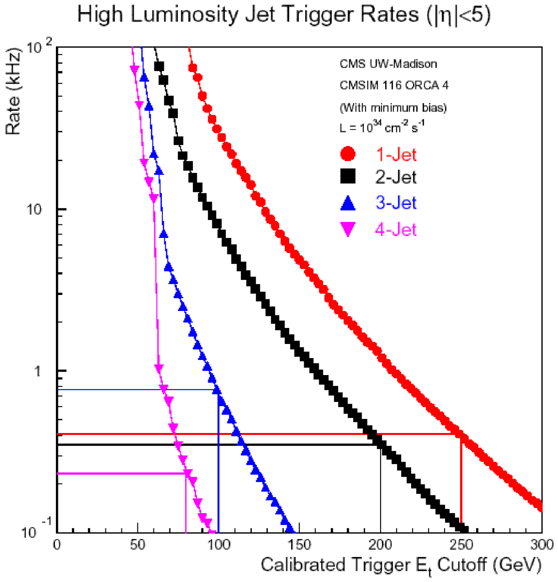

Figure 6. Jet trigger rates for single, double, triple and quadruple jet triggers.

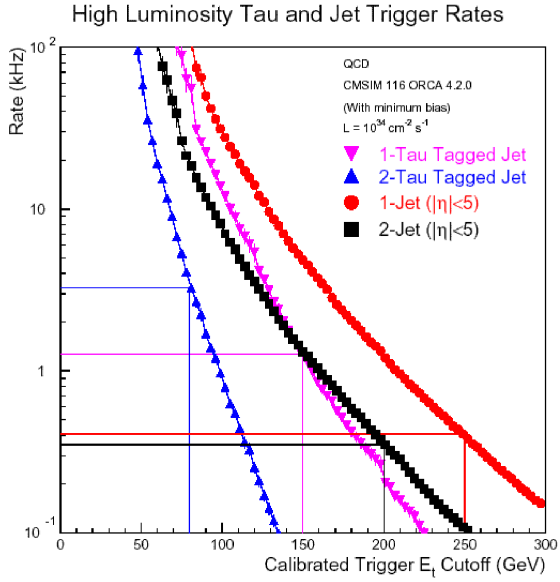

Figure 8. High Luminosity Single and double jet and tau trigger rates.

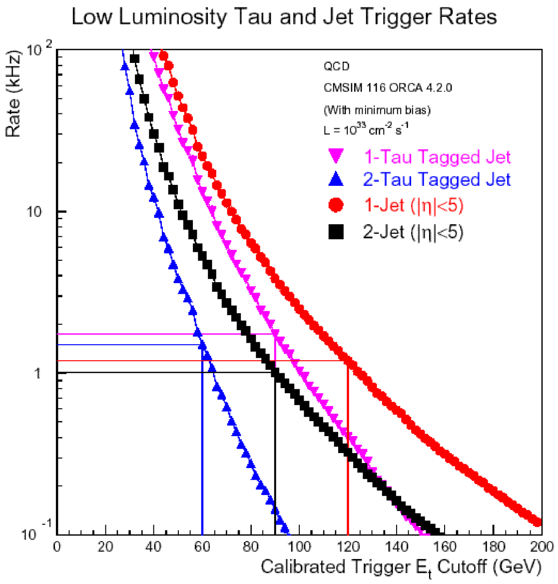

Figure 7. Low Luminosity single and double jet and tau trigger rates.

6. REFERENCES

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