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CMS Calorimeter Trigger

Preliminary specifications of the baseline trigger algorithms

CMS Calorimeter Trigger Group

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ABSTRACT

This document contains the specifications of the CMS baseline calorimeter trigger algorithms. Detailed information on the physics performance of the algorithms can be found in the technical notes listed at the end of the document.

The present specifications provide the basis for further simulation studies with the aim of refining its details. It also provide the basis for the design studies, prototype developments and beam tests to be carried out in 1996-98.

These specifications are preliminary and may be modified as a result of the foreseen tests and technical developments.

Final draft

Subject to approval by ECAL, HCAL and Physics groups

1. Introduction

The CMS calorimeter trigger system should be capable of selecting electrons, photons and jets over a large rapidity range with high efficiency. Triggering on events with large missing E_t is also required. The need for a trigger on τ-jets is presently being investigated. A summary of the physics and rate requirements on the level 1 calorimeter trigger is given in §1.1 and §1.2.

Several simulation studies were performed since the Technical Proposal aiming at a better understanding and refinement of the calorimeter trigger algorithms. Detailed GEANT simulations complemented the studies done before with fast shower parametrizations, and provide today a more accurate estimation of the trigger algorithms performance. A description of these studies can be found in the technical notes listed at the end of the document.

In the following sections, we present the specifications of the calorimeter trigger algorithms that performed the best in fulfilling the requirements. These specifications are not final, in the sense that they can change as a result of the design studies, prototype developments and beam tests to be carried out in the next two or three years. In some cases, complementary simulation work in needed in order to achieve a more precise specification. For each specification we provide its definition, justification and status.

1.1. Physics requirements

The physics requirements for the CMS calorimeter trigger, as defined in the CMS Technical Proposal [1] are summarized in the following:

1) At high luminosity ($L=10^{34}cm^{-2}s^{-1}$), the single electron/photon trigger is required to be fully efficient (>95%) in the pseudorapidity range $|\eta|<2.5$ for isolated electrons and photons above E_t>40 GeV. The dielectron/diphoton trigger is required to be fully efficient for E_t>20 GeV for each particle in the same rapidity range.

Recommendation: The trigger group recommends to change the threshold requirements on the single and double electron/photon trigger to 35 and 15 GeV, respectively, in order to achieve the efficiencies mentioned above [5,14].

Justification: A large fraction of the physics channels expected at the LHC involve electrons and photons in the final state. The threshold on the isolated single electron momentum was chosen so to guarantee a trigger efficiency for identifying W decay electrons above 50% (integrated over all electron momenta). The threshold on the dielectron/diphoton momenta was chosen in order to guarantee an efficiency above 95% for the Higgs (80 GeV mass) decay to two photons.

Given the efficiency turn-on curves expected at level 1, the trigger thresholds must be significantly lower than the particle momenta, of the order of 25 and 10 GeV respectively for the single and double electron/photon triggers [2,4].

2)Single and multiple jet triggers at various thresholds are also required, having a well known efficiency in order to allow reconstruction of the jet spectrum.

Justification: Jet triggers are required in order to reconstruct jet spectra that overlap with data attainable at lower energy colliders. Jet triggers were shown to bring significant contributions to the overall trigger efficiency for top events and for SUSY physics [14]. Jet triggers will be important in the search for quark substructure at very high E_t and ressonances decaying into jets , as well as checking QCD.

3) At high luminosity ($L=10^{34}cm^{-2}s^{-1}$), the missing transverse energy trigger is required to be fully efficient for missing E_t above 250 GeV and to be above 80% efficient for missing E_t larger than 150 GeV.

Justification: The missing E_t trigger is an important component in the search for SUSY events. In particular, the search for squarks and gluinos requires the identification of events with E_t above 150 GeV [1]. The required performance is achieved when a level 1 threshold of the order of 80 GeV is chosen [8].

In addition, the following physics requirements, requested by the Physics Group, are now under consideration:

4) At low luminosity ($L=10^{33}cm^{-2}s^{-1}$), the system is required to trigger on single and double electrons from b-decays, in the pseudorapidity range $|\eta|<1.6$, with momenta above 10 and 5 GeV, respectively, with an efficiency above 50%.

Justification: The low P_t electron trigger is complementary to the muon trigger in the b physics studies. Detailed simulations [11] showed than an efficiency above 50% for electrons with E_t>10 GeV is achievable at the level 1 trigger, keeping the rate requirements (see §1.2). The possibility of triggering on dielectrons with E_t>5 GeV from events $b\bar{b}\rightarrow e+J/\psi+X$ is being investigated.

5) The system is required to select hadronic τ-jets in the pseudorapidity range $|\eta|<2.0$ and originating a jet with $E_t>40$ GeV, with an efficiency above 50%; the τ-jets are used to define a double τ-jet trigger, as well as combined triggers with an electron or a muon.

Justification: The tau-jet triggers should allow to improve the efficiency of the trigger system to the neutral SUSY Higgs decays into tau pairs, as well as to the charged SUSY Higgs decaying in tau-neutrino [14]. Simulation studies [12] indicate that a relative simple and low cost extension of the jet trigger is able to select tau-jets with an efficiency above 50%.

1.2. Rate requirements

The CMS calorimeter trigger should fulfill the following rate requirement:

1)The background rate should not exceed approximately 15 kHz.

Justification: The uncertainties in estimates of cross-sections at high energies and limited knowledge of branching ratios impose a large error on the estimated trigger rates. Uncertainties in the simulation itself and in the final detector design also contribute to the error in the trigger rates. Therefore, we provide for a safety margin of a factor three from the design 100 kHz maximum level 1 output rate to 30 kHz, in designing algorithms for level 1 triggers. Furthermore, this 30 kHz bandwidth of level 1 output has to be shared amongst both muon and calorimeter triggers. In order to meet this requirement some triggers (e.g. the low threshold jet trigger) will be prescaled.

2. Geometry and definitions

2.1. Trigger cell

The basic calorimeter *trigger cell* has dimensions $\Delta\eta.\Delta\phi$=0.087x0.087 up to η=2.27, and $\Delta\eta.\Delta\phi$=0.174x0.087 in the interval 2.27<η<2.62. Each trigger cell in the barrel and in the endcaps corresponds to the size of an HCAL tower. In the barrel ECAL, the trigger cell is formed by 6x6 crystals. In the ECAL endcap, a variable number of crystals forms the trigger cells, depending on the final endcap design. In all cases, there is an exact match between the boundaries of ECAL and HCAL trigger cells.

Justification: The trigger cell dimension results from a compromise between the number of trigger channels, which must be as small as possible, and the jet background rate, which increases with the cell size. The ECAL and HCAL trigger cells match to each other and to the muon trigger segmentation in order to allow an efficient and easy implementation of the trigger algorithms.

Status: Accepted

2.2. Strips

The ECAL trigger cells are divided in *strips.* In the barrel ECAL, each trigger cell has 6 strips (one crystal in η and six crystals in ϕ). In the endcap, the number of strips per cell and the number of crystals per strip are variable, depending on the final endcap design. The strip E_t is provided by the ECAL front-end electronics.

Justification: The strip information allows the computation of the fine grain primitives (see §3.3). The strips are along the bending plane so that the efficiency of the fine grain criteria to electrons with bremstrhalung and to converted photons is as close as possible to 100% [15].

Status: Accepted in principle, under technical study.

2.3. VFCAL trigger segmentation

In the VFCAL, a possible segmentation, still subject to optimization, is the following: $\Delta\eta.\Delta\phi$=0.35x0.35 for 2.6<η<4.0 and $\Delta\eta.\Delta\phi$=1.0x0.7 for 4.0<η<5.0.

Justification: The optimal size depends on the size of hadronic showers in the VFCAL and its physical segmentation.

Status: Under physics performance study.

2.4. Calorimeter regions

The trigger cells are organized in *calorimeter regions,* each one formed by 4x4 trigger cells. The eta-phi indexes of the calorimeter regions indentify the location of level 1 trigger objects.

Justification: The calorimeter region matches the typical jet size and form the basis of the jet trigger. Calorimeter regions are also chosen so that geometric factors can multiply the E_t in each region to form E_x and E_y without significant loss in missing energy resolution.

Status: Accepted.

3. Trigger primitives

3.1. Calorimeter cell thresholds

Previous to the computation of the trigger primitives, programmable thresholds are applied to ECAL cells before crystals are summed into strips, on the strips before they are summed and on the total 6x6 energy. The thresholds are applied to HCAL on a tower by tower basis.

Justification: Thresholding reduces the sensitivity of the isolation algorithms to noise and pileup, maintaining an high efficiency to electrons and photons. Typically, the threshold is set to $3\sigma^{noise}$.

Status: Accepted in general; thresholds on crystal energies under study.

3.2. E_t sums

The following trigger primitive is computed for every ECAL and HCAL trigger cell:

- Et sum in trigger cell, coded in a 8 bit compressed nonlinear scale that is programmable.

Justification: The E_t sums are coded in a 8 bit compressed nonlinear scale in order to minimize the trigger data flux from the detector. As an example, the scale can be programmed to have a dynamic range of 230 GeV, with resolution of 0.1, 0.5, 1.0 and 2.0 GeV respectively in the E_t regions defined by the boundaries 6.3, 38.3 and 102.3 GeV.

Status: Accepted.

3.3. Fine grain local isolation

The following trigger primitive is computed for every ECAL trigger cell:

- Fine grain local isolation bit (LI bit)

The fine grain local isolation bit is computed from the strips by the following peak-finding algorithm:

- select the maximum E_t sum of two adjacent strips;
- compute R, the ratio between the maximum sum of two strips and the total E_t sum;
- compare R with low and high programmable thresholds to get the LIL and LIH bits;
- the final LI bit depends on the cell E_t range:

$$\begin{array}{ll} \text{if } E_t < E_1 & : LI=0 \\ \text{if } E_1 < E_t < E_2 & : LI=LIH \\ \text{if } E_t > E_2 & : LI=LIL \end{array}$$

where E_1 and E_2 are programmable thresholds.

Justification : The fine grain primitives provide for every trigger cell an information that reflects the lateral extension of the e.m. shower. Electrons and photons (converted and non-converted), in the presence of noise and high luminosity pileup, have R>0.90 (low threshold) in 98% of the cases [15]. The same criteria rejects the fraction of jets where two or more hadrons interact inside one trigger cell.

The high threshold (typically 0.95) is used in the definition of a low P_t beauty electron trigger which requires a moderate efficiency and a high rejection power [11].

Below the threshold E_1 (typically 3 GeV) the LI bit is set to zero to protect the fine grain algorithm against noise (see §4.3.2) .

Status: Accepted in principle, under technical study.

3.4. MIP information

The following trigger primitive is computed for every HCAL trigger cell:

- MIP bit : energy compatible with mip energy deposit

Justification: The mip information can be used in the isolated muon trigger (see §8.) or in a standalone HCAL test trigger.

Status: Under discussion.

4. Electron/photon triggers

4.1. General

The electron/photon trigger uses a 3x3 trigger cell sliding window processing [3,10]. The electron/photon identification is based:

- on the recognition of a large energy deposit in one or two adjacent ECAL trigger cells;
- on the lateral shower profile (fine grain structure in central ECAL cell) ;
- on the longitudinal shower profile (H/E in central trigger cell);
- when isolated electron/photons are requested, on the e.m. isolation energy (energy in Ecal cells surrounding the central cell);
- when isolated electron/photons are requested, on the hadronic isolation energy (energy in Hcal cells surrounding the central cell);

Justification: A large safety margin in the rates is required for the CMS triggers given the various uncertainties that affect the trigger rates estimations. The implementation of longitudinal and lateral shower profile, as well as, e.m. and hadronic isolation programmable criteria provides safety and flexibility for the calorimeter electron/photon trigger.

The use of the energy threshold together with shower profile criteria alone allows to trigger on low p_t electrons from b-decays.

Status: Accepted in general, versions under study.

4.2. *Input data*

The cell E_t at the input of the window processing is coded in a 8 bits linear scale with programmable resolution. A smaller number of bits can be used for the isolation cells. Values exceeding the dynamic range are set to the maximum.

Justification: The limitation in the number of bits is intended to simplify the hardware implementation. Simulation studies showed that a scale of 8 bits with LSB=500 MeV gives adequate trigger performance [4].

Status: Accepted

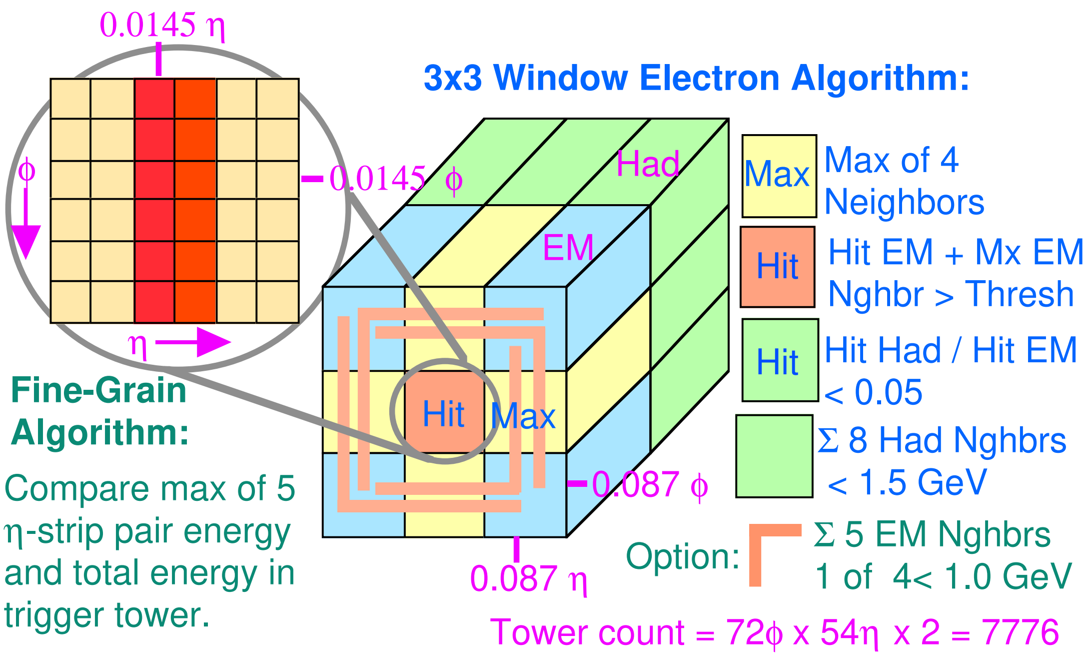

Figure 1. Scheme of the CMS electron/photon trigger.

4.3. *Cluster variables*

4.3.1. Cluster e.m. transverse energy

The electron/photon transverse energy (ETe) is given by the sum of the central cell ('hit cell') with the maximum of the four orthogonal neighbor cells ('max cell'); it is coded in a 8 bits linear scale.

Justification: The sum of neighbor cells is needed to achieve a sharp efficiency threshold curve [4].

Status: Accepted.

4.3.2. Lateral cluster shape

The lateral cluster shape is given by the 'hit cell' local isolation bit (see §3.3).

Justification: Requesting the local isolation bit provides additional background rejection without affecting the isolated electron/photon efficiency. Electrons from b-decays are 80% efficient with respect to the LI criteria [9, 11,15].

Status: Accepted in general; versions under study.

4.3.3. Longitudinal hadronic veto

The longitudinal hadronic veto is given by the ratio of the hadronic and e.m. 'hit cells'; the H/E bit is set to one if the ratio is less than the H/E threshold. The threshold on H/E is energy dependent.

Justification: Requesting the H/E bit provides additional background rejection without affecting the isolated electron/photon efficiency. Electrons from b-decays are 90% efficient with respect to the H/E criteria. The typical H/E threshold is 0.05 and it can be optimized for the beauty electron trigger [4,11].

Status: Accepted.

4.3.4. EM isolation

The EM isolation is given by the smallest of the four sums of 5 (or 7) e.m. cells around the 'hit cell'; the EMI bit is set to one if this energy is less than the EMI e/γ threshold.

Justification: Requesting the EMI bit provides additional background rejection without affecting the isolated electron/photon efficiency. The typical EMI e/γ threshold is 2 GeV [4, 15].

Status: Accepted in general; versions under study.

4.3.5. HAD isolation

The HAD isolation is given by the sum of the eight hadronic cells surrounding the 'hit cell'; the HDI bit is set to one if this energy is less than the HDI e/γ threshold.

Justification: Requesting the HDI bit provides additional background rejection without affecting the isolated electron/photon efficiency. The typical HDI e/γ threshold is 1.5 GeV [4,15].

Status: Accepted.

4.4. EM cluster definition

Each EM cluster is characterized by the variables ETe, LI, E/H, EMI and HDI, as well as by the η-ϕ indexes of the corresponding the calorimeter region where the 'hit cell' is located. Each cluster should be assigned a fully programmable rank based on these variables.

The four highest ranking e.m. clusters should be selected to forward to the global trigger.

Justification: The programmability of the rank determination allows the design of suitable triggers depending upon the luminosity and the physics interest at time of running. For instance, for high luminosity running the emphasis can be on "isolation", and, for low luminosity running the emphasis can be redirected to "shower profile" variables. The selection of the four highest rank clusters provides enough flexibility for the definition of combined triggers.

Status: Accepted.

4.5. Single electron/photon triggers

In general terms, single electron/photon trigger is defined by the highest ranking electron/photon cluster (as specified in §4.4), an η-ϕ acceptance region and a prescaling factor.

The global trigger accepts the definition, in parallel, of different single electron/photon triggers conditions.

Justification: Various single electron/photon triggers conditions will be needed in parallel to match the different physics requirements, as well as for calibration and trigger efficiency measurements.

Status: Accepted.

4.6. Multi electron/photon triggers

In general terms, the multi electron/photon triggers are defined by n≤3 highest ranking electron/photon clusters (as specified in §4.4), 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 electron/photon triggers conditions.

Justification: Various multi electron/photon triggers conditions will be needed in parallel to match the different physics requirements, as well as for calibration and trigger efficiency measurements.

Status: Accepted in general; requirement of minimum η-ϕ separation is under study.

5. Jet triggers

5.1. General

The jet trigger uses the transverse energy sums (e.m.+had) computed in calorimeter regions (4x4 trigger cells). The input cell E_t is coded in a 10 bits linear scale with programmable resolution. Values exceeding the dynamic range are set to the maximum.

Justification: Regions of 4x4 trigger cells matches the typical jet size. Simulation studies showed that a scale of 10 bits with LSB=1 GeV gives adequate jet trigger performance [4].

Status: Accepted.

5.2. Jet transverse energy

Version 1:

The jet transverse energy (ETj) is given by the transverse energy in a calorimeter region.

Version 2:

The jet transverse energy (ETj) is given by the transverse energy sum in 2x2 calorimeter regions. Windows overlapping by one calorimeter region are taken into account.

Justification: The version 2 gives a jet trigger with higher rate but better efficiency threshold curve.

Status: Accepted in general; versions under study.

5.3. Jet definition

The jets are characterized by ETj and by the η-ϕ indexes of the calorimeter region. The four highest rank jets in the calorimeter are selected. The cluster rank is given by the jet transverse energy. Jets occuring in a calorimeter region where an electron or tau is identified are not considered.

Justification: The selection of the four highest rank jets provides enough flexibility for the definition of combined triggers.

Status: Accepted.

5.4. Single jet triggers

The single jet triggers are defined by a threshold value and a η-ϕ acceptance region, as well as by a prescaling factor. The global trigger accepts the definition, in parallel, of different single jet triggers conditions.

Justification: Low threshold jet triggers need to be prescaled in order to meet the rate requirements.

Status: Accepted.

5.5. Multi jet triggers

The multi jet triggers are defined by $n \leq 3$ jets (as specified in §5.3), by a minimum separation en η-ϕ, as well as by a prescaling factor. Jets must be separated by at least one calorimeter region. The global trigger accepts the definition, in parallel, of different multi jet triggers conditions.

Justification: Multijet triggers with different thresholds in each leg are required to trigger on SUSY events.

Status: Accepted in general; requirement of minimum η-ϕ separation is under study.

6. E_t triggers

6.1. General

The E_t triggers use the transverse energy sums (e.m.+had) computed in calorimeter regions (4x4 trigger cells), as specified in §5.1. E_x and E_y are computed from E_t using the coordinates of the calorimeter region center.

Justification: The missing E_t computed from the energy in calorimeter regions has good enough resolution for trigger purposes [8].

Status: Accepted.

6.2 Missing Et triggers

The missing Et is computed from the sums of the calorimeter regions E_x and E_y. The sum extends up to η=5 (end of VFCAL).

The missing Et triggers are defined by a threshold value and by a prescaling factor. The global trigger accepts the definition, in parallel, of different missing Et triggers conditions.

Justification: The missing E_t trigger rates vary with the rapidity coverage [8].

The missing energy trigger is implemented with a number of thresholds. Some of these thresholds are used in combination with other triggers. Other thresholds are used with a prescale and one threshold is used for a standalone trigger.

The missing Et trigger can be used in combination with other triggers, namely jet triggers, in the search for SUSY events.

Status: Accepted.

6.3. *Total Et trigger*

The total Et is given by the sum of the calorimeter regions E_t. The sum extends up to η=5 (end of VFCAL).

The total Et triggers are defined by a threshold value and by a prescaling factor. The global trigger accepts the definition, in parallel, of different total Et triggers conditions.

Justification: The total energy trigger is implemented with a number of thresholds which are used both for physics analysis and for input to the luminosity monitor. Some of these thresholds are used in combination with other triggers. Other thresholds are used with a prescale and one threshold is used for a standalone trigger. The lower threshold Et trigger also provides a good diagnostic for the calorimeter and its trigger.

Status: Accepted.

7. Tau triggers

7.1. *General*

The system selects hadronic decays of the τ lepton. It is basically a jet trigger complemented with criteria to select narrow jets and localized energy deposits. Tau-jets are used in the definition of a double tau-jet trigger, as well as in the definition of combined triggers with electrons or muons.

Justification: The purpose of the tau trigger is to enhance the efficiency of the trigger system to detect taus [14]. The definition of the tau trigger as an extension of the jet trigger is intended to simplify the hardware implementation [12].

Status: Under physics performance study.

7.2. *Tau jet variables*

Version 1:

The τ-trigger uses the following information:

- *τ-jet transverse energy (ETτ):* transverse energy (e.m.+had.) in a 4x4 region, as computed for the jet triggers (see §5.)
- *Narrow jet:* ratio between the 4x4 and the surrounding 12x12 window transverse energy; the NJ bit is set if the ratio is larger than the NJ threshold (typically 0.8).
- *Single pion cluster:* the CLU bit is set to one if the ratio between the highest trigger cell (em.+had) in the 4x4 region and the total energy in that region is larger than a threshold (typically 0.4).

Version 2:

The τ-trigger uses the following information:

- *τ-jet transverse energy* (ETτ)*:* transverse energy (e.m.+had.) in a 4x4 region, as computed for the jet triggers (see §5.)
- *Narrow jet:* ratio between the 4x4 and the surrounding 12x12 window transverse energy; the NJ bit is set if the ratio is larger than the NJ threshold (typically 0.8).
- *τ e.m. cluster:* the CLU bit is set to one if there is one and only one cluster (as defined in e/γ trigger) in the 4x4 window with :
    - Et larger than the TEM Et threshold (typically 10 GeV);
    - e.m. isolation transverse energy smaller than the EMI τ threshold (typically 4 GeV)
    - H/E or HDI e/γ bits equal to zero.

Justification: The first version complements the narrow jet criteria with the identification of an isolated charged pion cluster. The second version relies as complementary criteria on the presence of a single e.m. cluster backed with hadronic energy [12].

Status: Under physics performance study.

7.3. *Tau jet definition*

Each τ-jet is characterized by the variables ETτ, NJ and CLU, as well as by the η-ϕ indexes of the corresponding 'calorimeter region'.

The four highest rank τ-jets in the calorimeter are selected. The cluster rank is defined by the expected trigger rate for that τ-jet. The lowest the rate the highest the rank. Tau-jets occurring in a calorimeter region where an electron is identified are not considered.

Justification: The selection of the four highest rank τ-jets provides enough flexibility for the definition of combined triggers.

Status: Under physics performance study.

8. Quiet and MIP bits

8.1. General

For each calorimeter region (4x4 trigger cells) a quiet and a MIP bit are computed.

Justification: These information is used in the isolated muon trigger or in a standalone HCAL test trigger [3].

Status: Accepted

8.2. Quiet bit definition

The quiet bit is set when the E_t in a calorimeter region is below a threshold.

Status: Accepted

8.3. MIP bit definition

The MIP bit is given by the OR of the MIP trigger primitive bits in a 4x4 region, vetoed by a cut on the E_t in the 4x4 region.

Status: Under study.

9. Calorimeter trigger output

The calorimeter trigger produces for every beam crossing the following output bits :

Objects		Rank	Pattern bits	Eta-phi index	Total
Electron	(4)	8	-	4+5	68
Jet	(4)	8	-	4+5	68
Tau-jet	(4)	8	-	4+5	68
Et triggers	(2)	12	-	-	24
Quiet bits		-	16x18	-	288
MIP bits		-	16x18	-	288

Status: Under discussion.

10. Luminosity monitor

10.1. General

The calorimeter trigger system provides information on the relative luminosity.

Justification: The activity in the calorimeter cells reflects the machine luminosity.

Status: Accepted.

10.2. Luminosity variables

The system provides four thresholds on the energy in each trigger tower region (for this purpose, assumed to be 8x8). The information provided by the calorimeter consists of:

1) Every 0.1 sec:
   - total number of 8x8 trigger tower regions with energies above each of four individually programmable thresholds.
   - time interval (in crossings) over which the statistics were accumulated.

2) Every 5 minutes:
   - number of times each of the crossings in one accelerator cycle has a trigger tower region over a threshold independently programmable from the four listed above. If a particular crossing has n regions that exceed this threshold each time it occurs, then the sum for this crossing is incremented by n;
   - number of times each trigger tower region exceeded the single threshold listed above;
   - time interval (in accelerator cycles) over which the statistics were accumulated.

Status: Under discussion.

CMS Calorimeter Trigger Technical Notes

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