A Calorimeter-Based Level-One Electromagnetic Cluster Trigger for LHC

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Abstract

Level-one triggering at LHC will be very challenging. We have studied the problem of recognition of electromagnetic clusters and have developed an algorithm based on the transverse energy distribution in an electromagnetic calorimeter. This receives 8-bit digitised energies from a 4 X 4 window in the calorimeter. Two cluster thresholds and two isolation thesholds are provided, all of which are programmable. The algorithm has been been implemented as a gate array in 0.8 μm CMOS technology, and is performed using pipelined processing at 67 MHz. The gate array has been tested at full speed, and is being incorporated into a small prototype trigger processor to be tested with beam in conjunction with prototype calorimeters.

INTRODUCTION

At the LHC design luminosity of 1.7×10^{34} $cm^{-2}s^{-1}$ the proton-proton interaction rate will be approximately 1.5×10^9 Hz. If the beam bunches cross every 15 ns this is equivalent to 20 interactions per crossing. Most of these interactions will contain no interesting physics. The function of the trigger is to select the small fraction in which a hard process may have occurred. Signatures for such processes are the production of high p_T leptons, partons or gammas and therefore triggers must recognise these particles in the detectors of the experiment. Selection of potentially interesting interactions is made in several steps or levels, as shown in fig. 1. At level one every interaction is examined and a rejection factor of between 10^4 and 10^5 is required to reduce the input rate into level two to a value where microprocessors can be used. This reduction must be achieved with no deadtime and requires a hard-wired processor operating in a pipelined mode at a clock frequency of 67 MHz. In this paper we describe such a processor, designed to recognise electromagnetic energy clusters in a calorimeter. The dominant background to such triggers comes from jets. The effectiveness of a cluster trigger is measured not only by the efficiency with which it detects real clusters but also by how well it can reject false triggers from jets.

TRIGGER ALGORITHMS

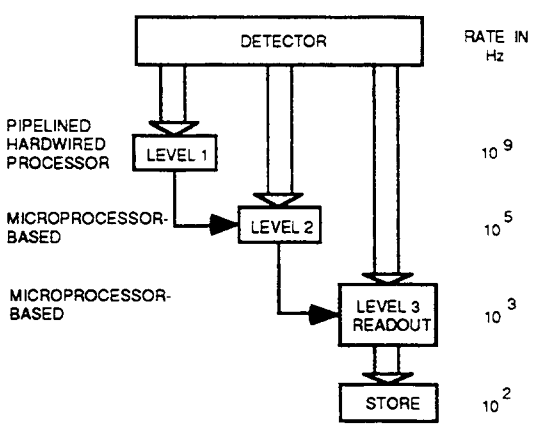

Fig. 1 Conceptual trigger system for a LHC experiment

The effectiveness of various trigger algorithms has been tested using Monte Carlo data simulating p-p collisions at 16 TeV [1]. Results of such a study are shown in fig. 2. Various rates are given as a function of transverse energy, (E_T), threshold. Curve (a) gives the rate of events containing a QCD jet anywhere in phase space having a transverse energy greater than the threshold indicated. Curve (d) gives the rate of events containing a π^0 in the pseudorapidity range $|\eta| < 2.5$ having a transverse energy greater than the threshold indicated. For an electromagnetic cluster trigger, this curve represents the minimum rate realistically achievable at level one. This is a guide to the limit to which one should attempt to reduce the false electromagnetic trigger rate from jets. The other three curves represent the results of applying specific algorithms to the distribution in the calorimeter. These are described below.

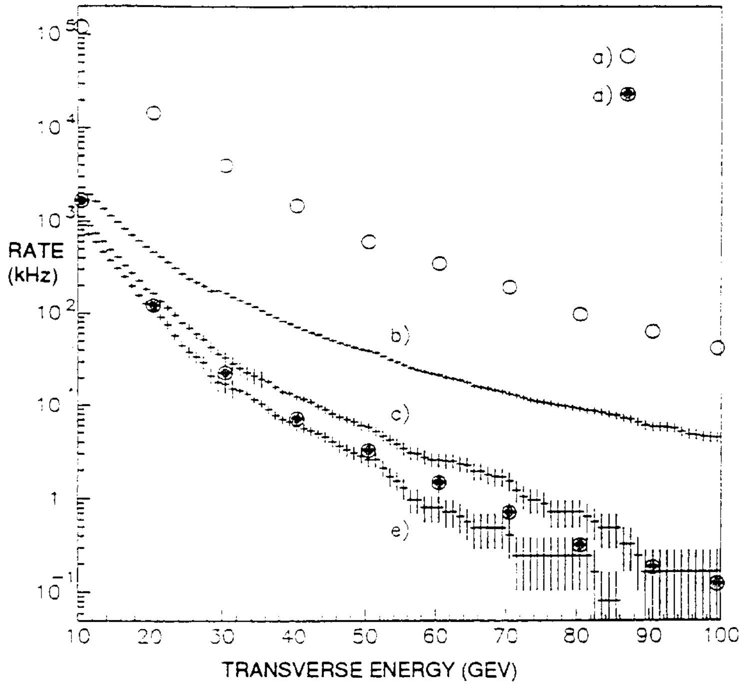

Fig. 2 Various rates as a function of transverse energy threshold for an LHC luminosity of 1.7 x 10^{34} $cm^{-2}s^{-1}$

The inputs to the trigger algorithm are the transverse energies contained in calorimeter trigger cells each covering an area 0.1 X 0.1 in $\eta - \phi$ space, where η is pseudorapidity and ϕ is the azimuthal angle around the beam. A 4 X 4 array of both electromagnetic and hadronic cells is shown in fig. 3. For the simulations the electromagnetic part consists of 29 radiation lengths and the hadronic part 8 interaction lengths. The reference cell for this particular block of electromagnetic calorimetry is labelled (2.2). The distribution of transverse energy in this volume of the calorimeter is examined by the algorithm to determine if there is an electromagnetic energy cluster spanning the reference cell. The process is duplicated, using each electromagnetic trigger cell in the calorimeter as the reference cell, over the pseudorapidity range $|\eta| < 2.5$. The algorithm calculates the sum of the transverse energies in the reference cell and the one above it (2.2+3.2), and in the reference cell and the one to its right (2.2+2.3). The event rate where the larger value of E_T is above threshold is plotted as curve (b) in fig. 2. Addition of adjacent trigger cells is important to provide sharp E_T thresholds, especially for large values of η. Rejection of hadronic jets is improved by requiring that the electromagnetic energy cluster is isolated. Thus the algorithm also calculates the sum of the transverse energies in the surrounding cells and requires this sum to be below a certain threshold. For curve (c) in fig. 2 the ring of electromagnetic cells surrounding the reference cell (as shown in fig. 3) provides the isolation energy sum, and the threshold is 3 GeV transverse energy. For curve (e) this ring of electromagnetic cells and the sum of all 16 hadronic cells are used, and the threshold is 5 GeV transverse energy. In both cases the electron detection efficiency is greater than 95%.

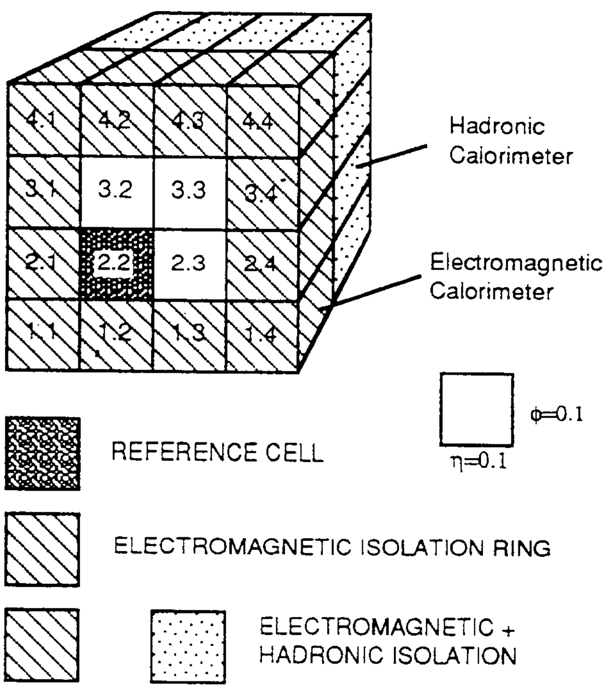

Fig. 3 Block of calorimetry used to study the jet rejection and electromagnetic cluster acceptance algorithm.

The granularity of 0.1 x 0.1 in $\eta - \phi$ space represents a compromise between jet-rejection power and complexity. This granularity with isolation brings the trigger rate down to a level similar to that of the π^0 rate. It is interesting that the full isolation requirement does produce a trigger rate lower than that of the π^0s, and this is because the π^0s are themselves part of jets.

The Implementation of the Algorithm

An ASIC using a gate array in 0.8 μm CMOS has been designed and manufactured to perform the algorithm corresponding to the results shown in curve (c) of fig. 2 [2]. This algorithm was chosen in preference to that corresponding to curve (e) (which requires hadronic information as well) to simplify the prototype ASIC design. The ASIC operates in a pipelined manner with 15 ns between pipeline steps. The ASIC takes in the 16 digitised 8-bit pulse heights from a block of electromagnetic calorimetry. The steps in the pipeline are indicated in fig. 4. It is possible to apply two separate thresholds to the electromagnetic cluster and two separate thresholds to the ring of isolation cells. The ASIC outputs two hit-bits corresponding to the two thresholds, and also the 12-bit sum of the total tranverse energy in all 16 cells. From fig. 4 it can be seen that the latency of the ASIC is 7 clock cycles, ie 105 ns. The ASIC was manufactured by Fujitsu and has been tested up to the full LHC frequency of 67 MHz.

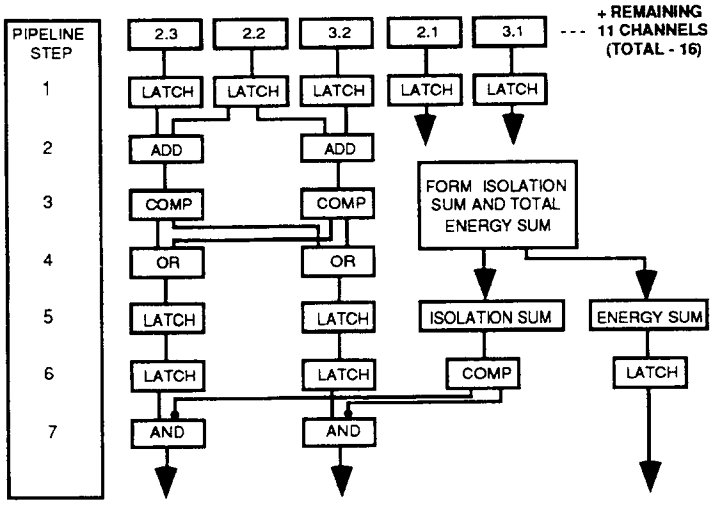

Fig. 4 Pipelined steps performed by the cluster finding ASIC using the electromagnetic trigger cells indicated in fig. 3.

A Prototype Trigger Processor

We are at present assembling a prototype processor which is designed to handle completely a 3 X 3 array of electromagnetic trigger reference cells. The nine cluster-finding ASICs are mounted on one cluster-finding module into which are brought the digitised pulse heights from a 6 X 6 array of electromagnetic trigger cells. The configuration of trigger cells is shown in

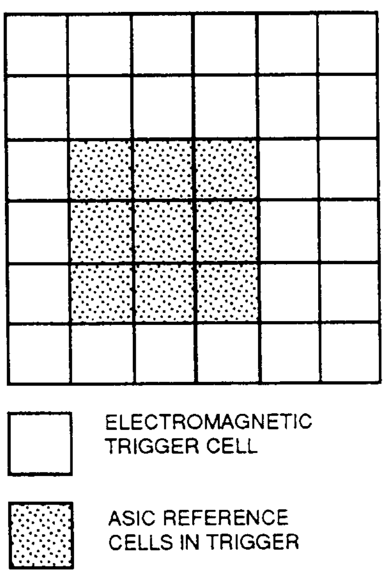

Fig. 5 Configuration of trigger cells processed by a cluster-finding module.

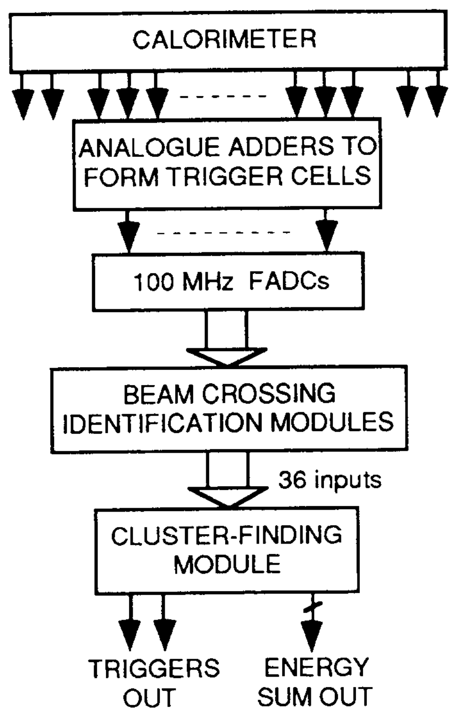

Fig. 6 Components of the prototype trigger processor.

fig. 5. The cluster-finding module is equipped with fast memory on its input and output, to allow it to be tested in an off-line mode. The components of the prototype processor are shown in fig. 6. The crossing identification module will be crucial for the level one trigger at LHC, since the calorimeter pulses will probably be longer than one bunch crossing period. The level one processor must know on a crossing-by-crossing basis which 8-bit words to include in performing the algorithm. The function of the beam-crossing identification module is to compute the peak calorimeter signal and identify the beam crossing responsible for it. Digitisations corresponding to all other crossings will be suppressed. This module has not yet been designed. Its role in beam tests is not crucial, as the activity in any one trigger cell will be low. The other components indicated in fig. 6 are being built. We intend installing the processor on the Accordion calorimeter barrel prototype [3] for beam tests at CERN.

PROGRESS TOWARDS A FULL TRIGGER PROCESSOR DESIGN

This work is now part of the RD27 project to study all aspects of level-one triggering [4]. For the calorimeter trigger the most serious problem is the large number of interconnections between trigger cells required to implement the cluster-finding algorithm we have described. The modularity of the present cluster-finding module results in each calorimeter signal being fanned-out to 4 modules. The module takes in (36 X 8) bits of signal information which is easily achieved using present connector technology. The problem is that this modularity requires about 400 modules to cover the region $\eta < 3.0$ and in a crate-based system results in a very complex inter-crate connection matrix.

We are therefore investigating the implications of increasing the trigger channel density on a single module, which would reduce the number of modules and the number of crates required for the complete processor. A design study is under way of a larger ASIC which would fully process a 2 X 2 array of electromagnetic trigger cells, by taking in a 5 X 5 array of electromagnetic cells and the matching 5 X 5 hadronic cell array. In order to minimise the ASIC I/O requirements, several techniques to reduce the data bandwidth are being studied. These include time-multiplexing the inputs at 134 MHz, and dynamic allocation of tagged above-threshold data to a limited number of transmission paths. Asynchronous systems incorporating zero suppression and data compression are also under consideration. The effects on the various physics processes of implementing these techniques in the trigger processor are being investigated by simulation. The results of these studies so far indicate that an ASIC based on a 100 K gate array in 0.8 μm CMOS, with 179 pins might provide a solution to the problem.

Using such techniques, eight ASICs could be assembled on a 9U cluster-finding module, of which about 120 would then be required to fully process the entire calorimeter. It is currently estimated that only ten crates would be sufficient to accommodate all the necessary processing hardware.

Acknowledgements

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