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The DØ Calorimeter Trigger

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ABSTRACT

The DØ calorimeter trigger system consists of many levels to make physics motivated trigger decisions. The Level-1 trigger uses hardware techniques to reduce the trigger rate from ~100kHz to 200Hz. It forms sums of electromagnetic and hadronic energy, globally and in towers, along with finding the missing transverse energy. A minimum energy is set on these energy sums to pass the event. The Level-2 trigger is a set of software filters, operating in a parallel-processing microvax farm which further reduces the trigger rate to a few Hertz. These filters will reject events which lack electron candidates, jet candidates, or missing transverse energy in the event. The performance of these triggers during the early running of the DØ detector will also be discussed.

The DØ detector[1] at Fermilab's Tevatron collider is a 4π hermetic detector. The $p\bar{p}$ collision rate at a luminosity of 5×10^{30} $cm^{-2}sec^{-1}$ is ~100kHz. A rate of only 2Hz can be written to tape; therefore, the trigger needs to be able to select the interesting physics events. The DØ trigger reduces the event rate at many levels: Level-0, Level-1, Level-1.5 and Level-2. A general description of the trigger and data acquisition system will be given along with a more detailed description of the calorimeter trigger.

1. The Level-1 Trigger

The Level-1 trigger[2] uses inputs from the following detector elements in order to reduce the event rate from ~100kHz to 200Hz. The Level-0 detector consists of scintillator counters mounted on the end calorimeters. It determines the number of interactions in an event, determines the vertex position, rejects beam-gas events and provides a luminosity measurement. The Level-0 fills a lookup table with the vertex correction information which is later used by the Level-1. The muon detector supplies information to the Level-1 trigger on the number of muon tracks in an event and also the momentum of the muons. The calorimeter detector supplies information on the clusters of energy in an event (jet).

The trigger controls the readout of the detector. Figure-1 shows a block diagram of the trigger system. The trigger decision must be made within the beam

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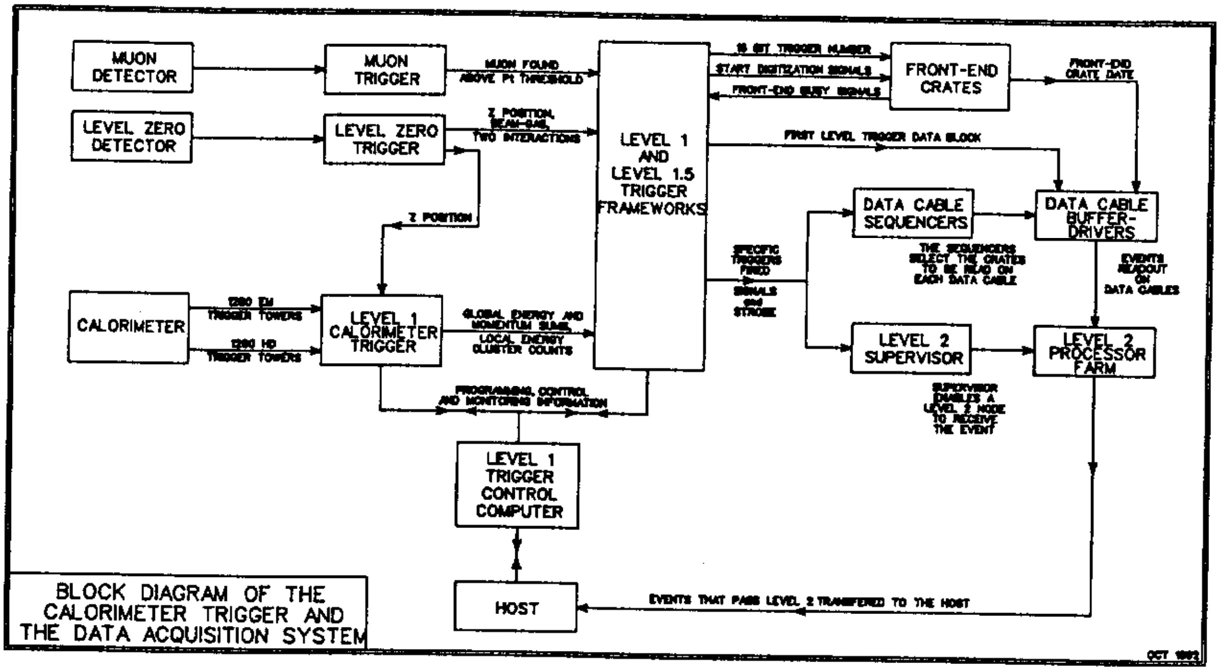

Figure 1: The DØ trigger and data acquisition system.

crossing time at the Tevatron of 3.5μsec. At 2.3μsec after beam crossing, all of the trigger variables (see Table-1) must be stable and the values are then sampled. Up to 256 of these inputs are combined to form up to 32 different triggers. A better determination of the momentum of a muon track can be made by the Level-1.5 trigger than the Level-1 trigger. Level-1.5 is able to reject a trigger within 28μsec of beam crossing. All the thresholds and multiplicity cuts are programable for all Level-1 triggers by downloading them to the Trigger Control Computer. The outputs from the trigger variables are stored in the Level-1 trigger block in a fixed format in order to give the Level-2 system quick access to the information.

Table-1
Trigger Variables

Level-0 Vertex Characteristics		
$p_{T\mu}$	$>$	threshold
Muon multiplicity cuts		
E_T^{EM}(tower)	$>$	threshold
E_T^{EM+HAD}(tower)	$>$	threshold
E_T(total)	$>$	threshold
$\not{E}_T$ (total)	$>$	threshold
EM jet multiplicity cuts		
Hadronic jet multiplicity cuts		

2. The Calorimeter Trigger

The calorimeter trigger[3] variables allow many different sets of thresholds defined at any given time. A given set of thresholds can have different values for each eta and phi region. This allows for a very flexible calorimeter trigger. The calorimeter trigger divides itself into two parts: global triggers and cluster triggers. The global triggers are overall transverse energy sums, $E_T = \sum E_T^{EM}(i) + E_T^{HAD}(i)$ and missing transverse energy sums, $\not{E}_T = \sqrt{E_x^2 + E_y^2}$, where $E_x = \sum E_T^{EM}(i)cos\phi + \sum E_T^{HAD}(i)cos\phi$, and $E_y = \sum E_T^{EM}(i)sin\phi + \sum E_T^{HAD}(i)sin\phi$, where the sum is over all trigger towers (described below). Table-2 shows examples of the calorimeter triggers presently being used.

Table-2

Level-1 Triggers (at Luminosity = 2 x 10^{30})

Triggers	Trigger Rate (before prescale)	Prescale Value
$E_T > 150$ GeV	0.6	100
$\not{E}_T > 30$ GeV + 1 Jet > 3 GeV	0.2	1
$\not{E}_T > 20$ GeV + 1 Jet > 7 GeV	3.8	1
$\not{E}_T > 15$ GeV + 1 e^- > 10 GeV	2.2	1
1 jet > 3 GeV	280	200
1 jet > 7 Gev ($-2 > \eta > 2$)	4	10
2 jets > 7 Gev ($-2 > \eta > 2$)	1	1
1 jet > 7 GeV	16	50
2 jets > 7 GeV	1	3
3 jets > 7 GeV	<0.01	1
4 jets > 5 GeV	2.8	1
1 e^- > 2.5 GeV	1450	10000
1 e^- > 7 GeV	27	200
1 e^- > 14 GeV	4	1
2 e^- > 2.5 GeV	160	500
2 e^- > 7 GeV	3	1
1 e^- > 10 GeV, 2 jets > 5 GeV	5	1

The calorimeter trigger forms trigger towers by adding together calorimeter cells in eta, phi, and depth to form semi-projective towers. The calorimeter is segmented in eta and phi such that $\Delta\eta$ x $\Delta\phi$ = 0.1 x 0.1, with eight to nine readout depths (in electromagnetic, fine and coarse hadronic sections, massless gaps, and inter-cryostat detector). The eta coverage ranges from $-4 < \eta < 4$, for a total of

47,808 channels in the calorimeter. The trigger segmentation is then $\Delta\eta$ x $\Delta\phi = 0.2$ x 0.2, with only two depths (electromagnetic and fine hadronic sections only), and the same eta coverage. The sums are all done in analog at the base-line subtractors (BLS) combining approximately 28–44 calorimeter cells to form one trigger tower channel. This gives 1280 electromagnetic trigger towers and 1280 hadronic trigger towers. At present the trigger is only instrumented from $-3.2< \eta <3.2$, or 1024 electromagnetic and hadronic trigger towers. Corrections for compensation of the varying capacitance and inductance of individual calorimeter cells are made in forming the trigger towers at the BLS level. This is done in the electronics placed near the detector.

The energy of each trigger tower is then converted to transverse energy at outside the shielding wall. The actual beam crossing position, rather than the nominal position, can be used in the E_T calculation. At present the actual crossing position is not being used. Corrections for the differences in cable lengths and signal timing are made. The signal is then digitized with 8-bit flash ADC's, with full scale of 64GeV E_T.

In order to calibrate the calorimeter trigger, the energy deposited in each trigger tower as found by the trigger electronics is compared to the energy deposited in each calorimeter cell as determined through the precision readout. The calibration is found by fitting each trigger tower, $E_T^{Trigger}(i) = m(\eta)E_T^{CAL}(i) + b(\eta)$, where $E_T^{Trigger}(i)$ is the transverse energy of trigger tower i as measured through the trigger electronics and $E_T^{CAL}(i)$ is the sum of the transverse energy of the calorimeter cells forming that trigger tower. The slope and intercept are found separately for each trigger tower, electromagnetic and hadronic. The electromagnetic section is found to have a slope of 1.1 and an intercept of 0.08, both independent of eta. The hadronic section has a slope of approximately 1.2 and an intercept of 0.06. The hadronic slope is not constant with eta, but dips in the intercryostat region. The center region and end regions differ by approximately 15%. It is possible to set the thresholds differently for each eta region, in order to account for this variation in the trigger energy as a function of eta. Modifying the trigger resistors in order to ensure a more uniform calibration is under consideration.

3. The Level-2 Trigger

The Level-2 trigger[4] uses inputs from the Level-1 trigger in order to further reduce the trigger rate from 200Hz to 2Hz. Unlike Level-1, Level-2 is a software based event filter, placing more stringent cuts on the data than Level-1. The filters run on a microvax farm containing 50 VS4000-60 processors running in parallel. At present there are only 32 processors.

The data are read out, see Figure-1, from 80 front-end crates digitized in parallel. The crates are grouped into seven readout sections plus the trigger readout. The crate readout is controlled by the Sequencer microvax. The Supervisor microvax directs the events to a single multiport memory associated with an individual node in the Level-2 farm, at a rate of 40 Mbytes/sec. The entire event is built in a Level-2 node in standard DØ ZEBRA format[†]. The events are then processed by the filters, and the ones that pass are sent to the host computer at a rate of 1 Mbyte/sec (which will increase to 2 Mbytes/sec in the future). The typical event size is 400 kbytes, with events as large as 2 Mbytes at high E_T.

Once an event is built in a node, then the filters can start working on it. Each event is analyzed by all filters that are required depending upon the Level-1 trigger bit passed. All filters are written in FORTRAN. The filter system is very flexible. A maximum of 128 separate filters can be defined. The parameters and thresholds of these filters are easily modifiable and downloaded to the respective filter, at each begin run.

4. The Calorimeter Filters

There are two basic types of calorimeter filters corresponding to the Level-1 global triggers and cluster triggers. The global triggers use information from Level-1 in order to obtain the candidate event for the Level-2 filter to process. These filters unpack all of the calorimeter data in the event, which makes them inherently slower than the cluster triggers. The two filters of this type are scalar E_T, $E_T = \sum_{allcells} E_T >$ Threshold and missing E_T, $\not{E}_T = \sqrt{E_x^2 + E_y^2} >$ Threshold. The $\not{E}_T$ filter contains a significance cut, $S = \not{E}_T \ / \ \not{\sigma}_T$, where $\not{\sigma}_T$ is the missing transverse energy resolution, to reduce the QCD background. A cut to remove isolated *hot cells* in the calorimeter is presently under consideration.

The cluster triggers use the Level-1 calorimeter information to obtain the electron or jet candidates, then only unpack the calorimeter data in the region of the trigger. This greatly increases the speed of these triggers over the global triggers.

The algorithm for the electron filter is based on shape and energy cuts. The shape cuts look at the longitudinal and transverse shape of the electron candidate jet requiring that most of the energy is deposited in the third layer of the electromagnetic modules (shower maximum). The electron candidate jet must also match to a track in the central detector, to reject π^0's. The electrons are also required to be isolated.

Hadronic jets are defined in Level-2 by using a cone algorithm. The Level-1 trigger towers are used as a seed for the jet filter. Most jets are larger than a single trigger tower; the jet algorithm adds together all the trigger towers within the cone. A cut is also made on the electromagnetic fraction of the jet. All events with jets above a given threshold are kept. A summary of the Level-2 filter statistics is given in Table-3.

5. Conclusion

The commissioning of the DØ calorimeter trigger is well underway. The trigger works as expected. The Level-2 filters have good efficiency and good rejection factors. The commissioning phase of the triggers is still continuing. The Level-1 calorimeter

[†]Data management program developed at CERN.

trigger will be extended to eta of four, in the near future. The vertex corrections will be added to both Level-1 and Level-2. Electron tracking will be improved in Level-2. Energy from the inter-cyrostat region will be included in the Level-2 filter's energy calculation. The Level-2 farm will be extended from 32 to 50 microvaxes and the high speed link to the host will be installed. The future for the DØ trigger looks very promising.

Table-3
Level-2 Filter Statistics

	Electron	Jet	$\not{E}_T$	E_T
Efficiency	$> 90\%$	60 – 100%	95%	
Rejection	4 - 16 slope - isolation cuts	10 – 100 depending upon E_T	3 – 10	15
Timing (Level-2)	5ms 40ms with tracking	30ms per jet	50 – 100ms	50 – 100ms

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