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The DØ Level 1.5 Calorimeter Trigger

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ABSTRACT

We describe the design and preliminary performance of the D0 Level 1.5 Calorimeter Trigger.

1. Introduction

The D0 experiment[1] relies on both hardware and software triggers to reduce the $\sim 3 \times 10^5$Hz Tevatron rate to a few Hz of interactions suitable for offline analysis. The hardware trigger is controlled by the Level 1 Framework, which combines triggering information from fast Level 1 subdetector triggers to decide, in the time between beam crossings (3.5μs), whether or not an event is digitized. The software trigger (Level 2) then selects events to be recorded for offline analysis. Level 1.5 is an intermediate hardware trigger used to confirm a subset of the fast Level 1 decisions, but operates on a slower time scale ($10 - 200\mu$s). During Level 1.5 cycles, all Level 1 activity is stalled, resulting in experimental deadtime. Thus Level 1.5 is only used when needed to confirm or reject an event. The Level 1.5 Trigger is presently activated only for a subset of muon triggers, and has been shown to provide a reasonable tradeoff between event quality and experimental livetime, achieving typical rejection factors of $\sim 10-20$ in exchange for deadtime which is typically less than one percent. In this paper, we present the recent addition of a calorimeter trigger, based on Digital Signal Processors (DSP), to Level 1.5.

2. Motivation

The Level 1 Calorimeter trigger provides information based on individual $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ trigger towers. This segmentation presents a triggering problem for electrons, photons and jets. Since these objects often spread their energy over more than one trigger tower, a single tower energy measurement often corresponds to only a fraction of the deposited energy. Consequently, tower energy thresholds must be

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set low enough to maintain adequate triggering efficiency. This in turn leads to high backgrounds and places a strain on bandwidth available at Level 2.

To alleviate this problem, the new D0 Level 1.5 Calorimeter Trigger seeks to use local clustering algorithms on Level 1 trigger tower data. The performance goal is to achieve a high background rejection factor (≥ 2) for electromagnetic triggers, while keeping efficiency $> 90\%$. An additional goal is that deadtime not exceed 10% for input rates of up to 1000 Hz. This in turn requires that processing times not average more than 100μs.

3. Algorithm

Studies using data from the 1992-1993 run showed that the rejection and efficiency goals could be met by applying clustering algorithms, in conjunction with threshold and isolation cuts, on Level 1 Calorimeter data. This data is comprised of electromagnetic (EM) and hadronic (EM+HAD) transverse energy (E_T) measurements from individual trigger towers measuring $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$. The algorithm currently implemented looks for isolated electrons. It first applies a threshold to an EM E_T sum of a single "seed" tower, plus its highest EM E_T neighbor (we denote this sum with the notation $(2 \times 1)_{EM}$, but note that towers may be adjacent in either η or ϕ). It also calculates a $3\eta \times 3\phi$ EM+HAD tower sum around the seed tower and applies a cut on the isolation estimator $(2 \times 1)_{EM}/(3 \times 3)_{EM+HAD}$. The Level 1 EM triggers which require Level 1.5 confirmation correspond in this case to single Level 1 EM towers over threshold, and presently coincide with the seeds used in the clustering algorithm.

4. Level 1.5 Calorimeter Hardware

The hardware of Level 1.5 Calorimeter Trigger can be roughly divided into two parts. One part is a custom-built interface to the Level 1 Calorimeter Trigger Front End (CTFE) electronics, which supply the necessary input data. The other part is the actual trigger machinery, consisting of a VME crate containing commercial DSP boards in addition to several VME components which *(i)* control the operation and readout of the DSP, *(ii)* provide the necessary interface with other triggers, and *(iii)* mediate the readout of Level 1.5 data to Level 2.

4.1. Interface to Level 1 Calorimeter Trigger Data

Ten racks of Level 1 Calorimeter Trigger electronics supply the trigger tower data needed by the Level 1.5 Calorimeter Trigger. Each of these 10 racks holds 32 Tier 1 CTFE cards, which process calorimeter data into quantities suitable for triggering, including the EM and EM+HAD E_T signals needed for the Level 1.5 Calorimeter Trigger. Each CTFE card processes the data of four towers which are adjacent in η and correspond to the same ϕ index. Thus, each rack corresponds to 128 trigger towers, effectively covering a $\Delta\eta \times \Delta\phi = 0.8 \times 2\pi$ region in the calorimeter. In designing the Level 1.5 Calorimeter trigger, the choice was made to import these data using ten cables, or one cable for each Level 1 Calorimeter Trigger rack.

The 32 CTFE cards in a given rack are read out in groups of four by a total of eight custom-built cards, called Energy Readout Paddle Boards (ERPB), which fit onto the same backplane used by the CTFE cards. An ERPB first truncates the 9 bit EM and EM+HAD E_T signals to 8 bits and places them into separate, unit length buffers. These buffers, which reside in on-board Logic Cell Arrays, may be reconfigured to accommodate up to sixteen 8 bit words each, if needed. When notified of a Level 1 Trigger needing Level 1.5 confirmation, an ERPB moves its signals to a transfer register, which then drives them onto a 16 bit data bus. A sequencer (Distributor Card) located at the top of the rack distributes control signals to all the ERPB's and makes sure that loading of the data bus occurs sequentially by tower and at 100 ns intervals. The Distributor Card also converts the (CMOS) signals into ECL signals before driving them, along with a strobe, over a $\sim$ 10m cable to a receiver card located near the Level 1.5 VME crate. Data from each of the 10 CTFE racks are transmitted independently to the Level 1.5 VME crate. The time needed to transport all of the tower data to the Level 1.5 Calorimeter VME crate is therefore $128 \times 0.1\mu s = 12.8\mu s$.

4.2. Level 1.5 Calorimeter Trigger

At the receiver card, the tower data are translated to TTL levels and fanned out to three Ariel Hydra-II VME boards, each containing four Texas Instruments TMS320C40 DSP chips. Each DSP has six buffered communication ports capable of bi-directional data transfer at 20 Mb/s. The I/O cycles needed to move this data are provided by a six-channel Direct Memory Access (DMA) coprocessor which operates independently of the DSP's 20 MHz, 32-bit CPU. Four communication ports on each DSP are available for data transfer from outside the board. The remaining two ports are used to connect to neighboring on-board DSP. Executable code and software parameters are accessible to the DSP chips through shared on-board memory which is visible from the VME bus.

Eleven of the DSP chips are reserved for local processing of trigger objects. The signals from two CTFE racks are routed to each local DSP through its four available communication ports. This gives each DSP data corresponding to 8 consecutive η indices and thus provides sufficient overlap for clusters involving up to 5 consecutive towers in η. The special cases that occur at the forward ends of the calorimeter coverage, where only one rack of data is available to a DSP, are handled by having these DSP's hold zero energy response values for the four eta indices out past the actually calorimeter coverage. This eliminates needing to handle any end effects in the DSP algorithm software. The twelfth (Global) DSP is reserved for global processing of results returned by the Local DSP's. Two of the Global DSP's six communication ports connect to neighboring on-board DSP's, and two of the remaining ports provide data paths from the other two Hydra-II boards. The Global DSP makes the results of its analysis available to a 68020-based (68k) VME CPU board which in turn makes them available to the Level 1.5 Framework.

The 68k VME CPU board initiates, monitors and resets all DSP's for each event that is processed. It also interfaces the Level 1.5 Calorimeter Trigger with the Level 1 and Level 1.5 Frameworks and orchestrates the readout of the VME crate to Level 2. The 68k is assisted by some fast peripheral electronics needed for control functions requiring extra speed.

The Trigger Control Computer (TCC), which controls and monitors the Level 1 and 1.5 Frameworks and the Level 1 Calorimeter Trigger, also configures the Level 1.5 Calorimeter Trigger. In particular, the TCC is used to download executable code and parameters to all DSP's and the 68k.

5. Level 1.5 Calorimeter Software

The software needed to operate the DSP's is organized in such a way that the algorithm, or Tool, used to confirm candidates is embedded in a more general program, called a Frame, which is written to support calls to multiple tools. The Local DSP Frame Code is responsible for *(i)* finding candidates (seed towers) in new data, *(ii)* calling the Local Tool code, and *(iii)* sending a list of up to eight confirmed objects to the Global DSP. The Global Frame Code receives the confirmed-object lists, and applies the Global Tool, which performs a global analysis and makes the answer available to the 68k processor. Currently there is only one Tool implemented. The Local Tool uses the algorithm of Section 3; the associated Global Tool counts the confirmed objects and compares the result to a threshold.

An offline simulation program is used to check the DSP analysis and estimate efficiency and rejection factors. This simulation program is fully integrated into the Level 1 and Level 2 simulation programs, and uses the same configuration files that drive the actual trigger.

6. Current Status

The D0 Level 1.5 Calorimeter Trigger is now fully installed and functional. Special runs using low statistics have so far verified that the trigger works as expected. Preliminary measurements of the processing time average 30% higher than the design specification. If necessary, however, simple changes to the DSP algorithms can bring processing times down to the design specification of $100\mu s$, at the expense of a minor loss in flexibility. Potential bottlenecks in the hardware are also being studied.

Currently underway is a special high-statistics test run which will scan several thresholds and provide enough data to fully characterize the new trigger, including accurate measurements of triggering efficiency, rejection and deadtime.

7. Conclusions

The D0 Level 1.5 Calorimeter Trigger has been fully installed and tests are nearing completion. Full activation of the trigger is anticipated soon, and its first implementation is expected to improve the quality of electron triggers significantly. Use of programmable DSP's allows future implementations of more sophisticated algorithms involving electrons, di-electrons, jets, or combinations of multiple trigger objects. As the number of new triggering strategies grows, Level 1.5 Calorimeter crates can be duplicated and operated in parallel, each using the same interface to Level 1 Calorimeter Trigger data.

References

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