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Level-2 Calorimeter Trigger Upgrade at CDF

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***Abstract* - The CDF Run II Level-2 calorimeter trigger is implemented in hardware and is based on a simple algorithm used in Run I. This system has worked well for Run II at low luminosity. However, as the Tevatron instantaneous luminosity increases, the limitation due to the simple algorithm starts to become clear. In this paper, we will present an upgrade path to the Level-2 calorimeter trigger system at CDF. This upgrade approach is based on the Pulsar board, a general purpose VME board developed at CDF and used for upgrading both the Level-2 tracking and the Level-2 global decision crate. This paper will describe the design, hardware and software implementation, as well as the advantages of this approach over the existing system.**

I. Overview of CDF Trigger System

The goal of the trigger is to retain the most interesting events for physics analysis according with the bandwidth limitation of the CDF data acquisition system.

CDF RunII trigger is a three level trigger system [ref 1], as shown in Fig. 1. At Level-1 (L1), muon, track and calorimeter information is processed to produce the L1 decision. When an event is accepted at Level-1, all data is moved to one of four DAQ buffers in the front end electronics for all subsystems, and at the same time, subsets of detector information are sent to the Level-2 (L2) system where some limited event reconstruction is performed and a L2 decision is made. Upon a L2 accept, the full detector information is readout and sent to L3 processor farm for further processing. Only events accepted at L3 will be sent to mass storage. L1 is a synchronous 40 stage pipeline and is based on custom-designed hardware, L2 is asynchronous and is based on a combination of custom hardware and commodity processor, and Level-3 consists of a processor farm. Each trigger stage has to reject a sufficient fraction of the events to allow processing at the next stage with minimal dead time. For the L2 trigger, this means that the processing speed should be within ~20us. In addition to being fast the L2 trigger needs to provide rejection that is robust against growing instantaneous luminosity.

To prepare for high luminosity running of the Tevatron (2.4×10^{32} s^{-1} cm^{-2} already achieved while in the near future the peak is expected to be as high as 3.0×10^{32} s^{-1} cm^{-2}), many subsystems in the CDF trigger system have already been upgraded in the past few years (shown in pink in Figure 1). The L1 Track Trigger (XFT) is being upgraded to improve its trigger purity. The L2 SVT and Global decision subsystems have been upgraded to improve the processing speed. Both the Event Builder and L3 processor farm have been upgraded to increase the bandwidth downstream of L2.

In this paper we describe an upgrade path for the L2 Calorimeter (L2CAL) subsystem that aims to significantly improve its trigger rejection power at high luminosity and also, improve its capability and flexibility in order to increase its trigger efficiency for important high Pt physics processes.

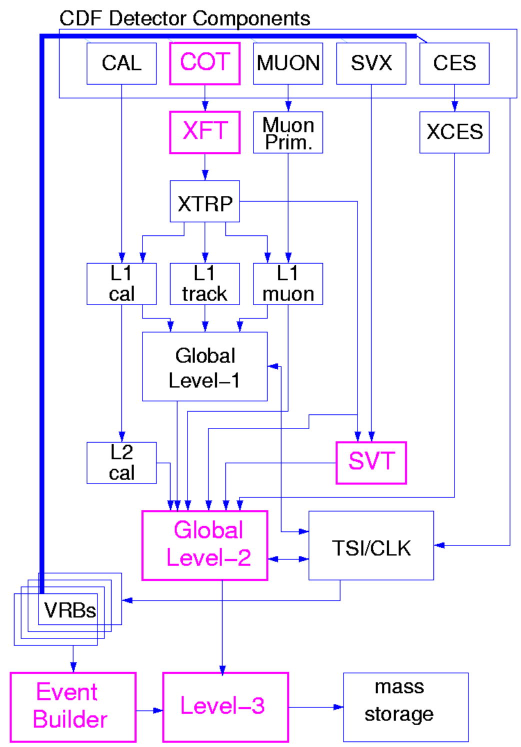

Figure 1: CDF RunII Trigger System. Boxes in pink are subsystems already upgraded in the past few years to prepare for the expected high luminosity. L2 Calorimeter (L2 CAL) and Global Level 2 are the subsystems involved in the upgrade stage described in this paper.

II. CDF Calorimeter Trigger

The goal of calorimeter trigger (both at L1 and L2) is to trigger on electrons, photons, jets, total event transverse energy (SumET) as well as missing transverse energy (MET). For CDF Run II, all calorimeter tower energy information, including both Electromagnetic (EM) energy and Hadronic (HAD) energy, is digitized every 132 ns and the physical towers are summed into trigger towers, weighted by sin to yield transverse energy. This results in a representation of the entire detector as a 24×24 map in the η-ϕ plane. The trigger tower energy information is then sent to both L1 and L2 calorimeter trigger systems with 10-bit energy resolution, using a least significant count of 125 MeV resulting in a full scale Et of 128 GeV. The Level 1 calorimeter (L1CAL) subsystem only uses 8 of the 10 available bits for each trigger tower for L1 processing, with the least significant and most significant bits dropped, giving a least count of 250 MeV and a full scale of 64 GeV.

As examples, electron and photon triggers are formed at L1CAL by simply applying energy thresholds to the EM energy of a single trigger tower while "jet" triggers are formed using the total EM+HAD of a single trigger tower. For electrons, tracks from the Level-1 track trigger (XFT) can be matched to the trigger towers while HAD energy can be used for rejection. L1CAL also calculates global transverse energy per event, total transverse energy (SumET) and missing transverse energy (MET), using the lower resolution 8-bit EM+HAD energy information. The L2CAL subsystem receives the full 10-bit trigger tower energy information. However, the existing hardware-based L2CAL system does not re-calculate the event SumET and MET using the full resolution energy information available, rather, it still uses the SumET and MET information directly from L1CAL. This design feature limits its trigger selection capability for triggers requiring either SumET or MET. The main task of the existing L2CAL is to find clusters using the transverse energy (Et) of trigger towers. The cluster finding algorithm is based on a simple algorithm used for Run I, and is implemented in hardware. The L2CAL hardware forms clusters by combining contiguous trigger towers that have non-trivial energy. Each cluster starts with a tower above a "seed"

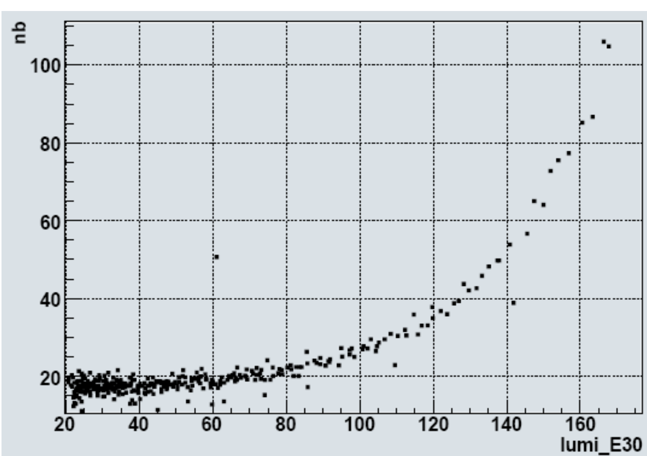

Figure 2: Rate of the jet trigger selection requiring jets above 40 GeV as a function of the instant luminosity ($10^{30}cm^{-2}sec^{-1}$).

threshold (typically a few GeV) and all towers above a second lower "shoulder" threshold that form a contiguous region with the seed tower (or each other) are added to the cluster. The size of each cluster expands until no more shoulder towers adjacent to the cluster are found. The position of the cluster is taken as the seed tower position. The existing L2CAL trigger system has worked well at lower luminosity for Run II. As the instantaneous luminosity increase the calorimeter tower occupancy increases due to pile up events. At high instantaneous luminosity (higher occupancy) clusters start to merge leading to clusters with artificially high number of towers which give rise to fake high Et clusters. These miss identified high Et clusters pass the jet trigger thresholds and cause rapid and unsustainable growth as a function of instantaneous luminosity in jet trigger rates and cross sections at L2 (see Fig 2 & 4).

III. L2 Calorimeter Trigger Upgrade

The basic idea of the upgrade is to provide the full 10 bit resolution trigger tower energy information directly to the Level-2 decision CPU where we can run a new cluster finding algorithm and recalculate the global quantities such as MET and SumET. To do that we need to develop a new hardware path connecting the L1CAL directly to the L2 decision CPU (see Figure 3). This new hardware path is based on the Pulsar board [2], a general purpose VME board developed at CDF and used for upgrading both the Level-2 global decision crate [3] and the Level-2 silicon vertex tracking (SVT) subsystem [4]. In the upgraded L2CAL system the full 10-bit trigger tower information is sent to Pulsars which receive, merge and serialize the tower data so it can be sent to the L2 decision PC where the clustering will take place. The details of the clustering are discussed later.

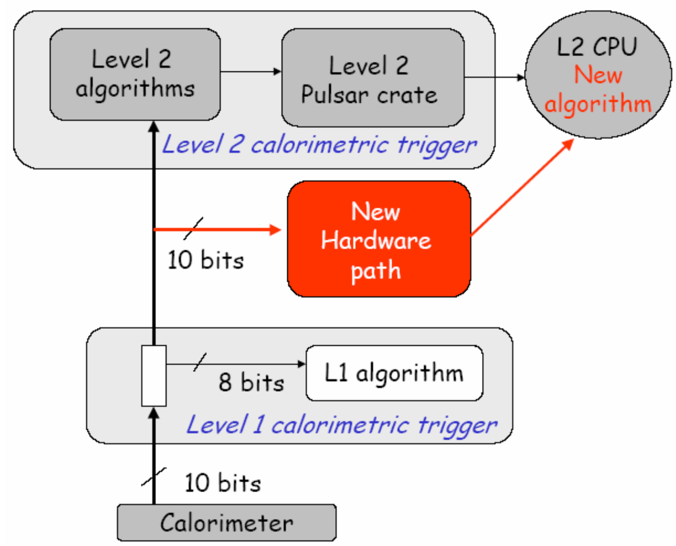

Figure 3: Hardware configuration for the L2 Trigger upgrade. The red path is the new hardware path that makes available the full 10 bit resolution trigger towers to the L2 decision CPU.

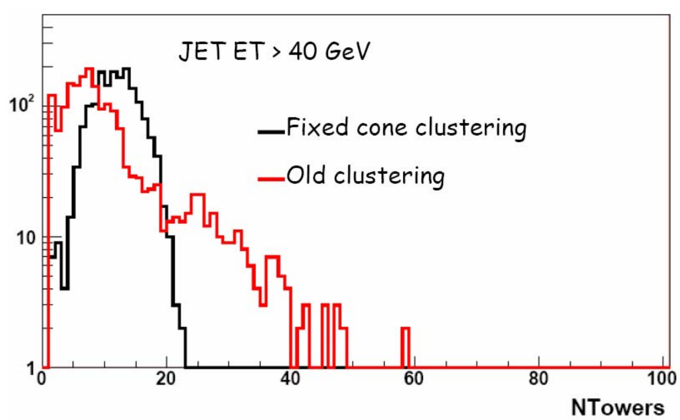

Figure 4: The number of towers in the online reconstructed jets by the old clustering (red line) and the proposed algorithm (black line) for jets above 40

GeV. The seed and shoulder thresholds are respectively set to 3 and 1 GeV. The bump above 20 towers, in the red curve, shows that the frequency of these strange jets is quite large. The figure shows also that the fixed-cone algorithm fixes this problem.

IV. Hardware Configuration

The basic idea of Pulsar is to use a motherboard with powerful Altera FPGAs and RAMs to interface any user data with any industrial standard link (for example, CERN S-LINK or Gigabit Ethernet) through the use of custom mezzanine cards. The key devices on the Pulsar board are three FPGAs (APEX 20K400BC-652-1XV [5]): two DataIO FPGAs and one Control FPGA. Each DataIO FPGA is connected to the Control FPGA. Both DataIO FPGAs provide interfaces to two mezzanine cards each and the connections are bidirectional.

In the current system one L2CAL Pulsar board receives four Low Voltage Differential Signal (LVDS) input cables from the L1CAL system, corresponding to energy information (both HAD and EM) from 8 trigger towers at the CDF clock frequency (132 ns period). In the new system, one new LVDS mezzanine card receives the same amount of input data as a L1CAL board is currently receiving. With 4 mezzanines per Pulsar board 18 Pulsar boards are required to receive all the input data. Then the 3 FPGAs in each Pulsar processes, merges and converts the data into SLINK format. A second set of SLINK Merger Pulsars (already used in the previous L2 upgrade) receive and merge the 18 SLINK data streams into 4 SLINK data streams for input to the L2 CPU. A highly integrated PCI interface, FILAR (Four Input Links Atlas Readout) move data from the SLINK channel to a 32-bit PCI bus running at 66 MHz.

Unlike other L2 trigger paths, the data for the new system will be available before the L1 decision is made. From the L1 decision arrival to the completion of the L2 clustering there ~20us available. The main hardware contribution to the latency timing is due to the SLINK transfer (32-bit at the frequency of 40 Mhz) because the Pulsar can work up to 100 Mhz frequency and the firmware is very simple at each stage of the pulsar cluster. We expect that the latency due to the data transfer will be on average ~10-14 us.

Figure 7 shows a simplified top view of the mezzanine card. 4 logical blocks receive the input data from 4 80-pin Honda connectors. Each connector receives 40 LVDS signals at the CDF clock frequency. Each input block includes 10 LVDS/TTL receiver chips. An Altera Apex device (EP20K160E) controls the flux of data from the Mezzanines to the DataIO Pulsar. The FPGA receives the TTL signals, and simply stores them into four registers at the CDF clock frequency and multiplexes them on a single output sent to the motherboard at a frequency 4 times faster (4xCDF clock). A multiplexer selects among the four sets of data to be sent to the Pulsar at the frequency of 4xCDF clock frequency.

V. Algorithms

In this section we describe the software and clustering algorithms.

The algorithms are executed on the L2 decision PC which has 2 dual core AMD Opteron processors. The Level-2 code framework in which the clustering algorithms run has a threaded structure and the algorithm thread is tied to a specific CPU using Non Uniform Memory Allocation (NUMA). This prevents interrupts affecting the algorithm execution times.

The new algorithms are for MET and jets. In addition to MET and jets we have a fast software emulation of the current hardware based electron/photon clustering. In principle the proposed clustering and MET calculation could be done separately. However, it is natural to merge the MET calculation with the clustering algorithms since the inclusion is straightforward and has negligible impact on the overall algorithm timing. The inputs for the jet algorithm are all the non-zero energy towers. For each trigger tower, HAD and EM energy information are provided. The algorithm performs the following tasks: (1) Sum EM and HAD energy for each tower, selecting the seeds and shoulders according to the corresponding thresholds. (2) MET calculation: this operation can be done while looping over all the input towers for the previous item. (3) Sort the seed list (for jets) in decreasing Et. (4) Cluster generation, beginning with the first seed: sum the Et of all the towers above the shoulder threshold in a fixed cone centered on the seed tower. The shoulder towers around the seed are directly addressed by using a look-up table (to speed up the algorithm). Mark all towers used in the current cluster as “used” and then move to the next seed tower in the list that is not marked as “used” and repeat. When the seed tower list is exhausted, return a list of the clusters. (5). In addition to the MET and jet clustering there are 2 additional clustering passes for electrons and photons. The first is a low Et electron/photon pass which consists of all single trigger towers that have EM energy that is greater than 2 GeV and satisfy HAD/EM less than 0.125. The second electromagnetic pass is the high Et electron/photon pass, this looks for towers that have EM energy > 8 GeV (designates them as seeds) then forms a cluster using towers that satisfy : (seed)±1 in the central rapidity region, and, (seed)±1 and (seed)±1 in the forward rapidity region. Isolation is also calculated for all high Et electron clusters.

VI. Commissioning Strategy

In order to minimize the impact on the operation of the CDF experiment during the commissioning phase, we will make a copy of the LVDS input signals available to the new system, while the original system continues to drive the data acquisition. In order to do that, we use the LVDS “multi-drop” property. The standard and suggested LVDS multi-drop configuration consists of one transmitter (L1CAL boards) and multiple receivers (current and new L2CAL boards). The driver is restricted to be located at one end of the cable and only the other end is terminated. In this standard configuration the signal splitting is done replacing the L1CAL-L2CAL connecting LVDS cable with a longer one having a drop (without termination) on the new LVDS mezzanine receiver.

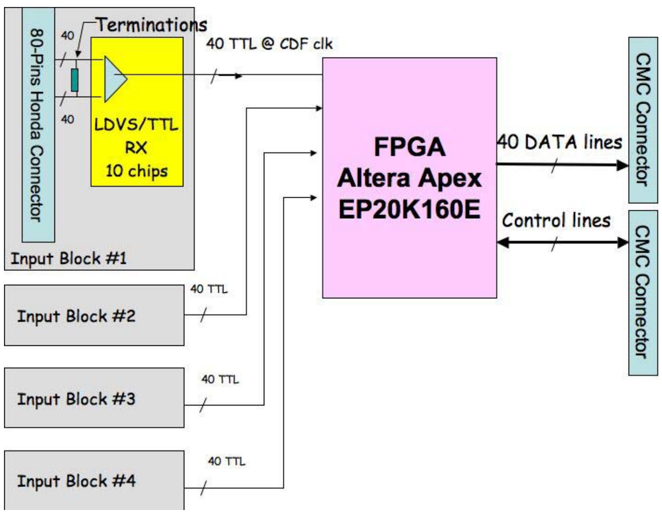

Figure 7: Simplified top diagram of the mezzanine card.

A non-standard multi-drop configuration, instead, consists of one transmitter (L1CAL boards) and double receivers (current L2CAL and new L2CAL), both of them with terminations. Recent measures demonstrate that even using double termination, the voltage level of the differential signal is acceptable and the reflections do not affect the TTL signal. The advantages of this non-standard configuration are multiple: first we don't affect the timing signals arrival for the actual L2CAL during commissioning, because we can maintain the same cable length, second, at the end, we only have to disconnect the previous path without redressing cables. We will run in this configuration with beam for an extended period of time, monitoring that the L1CAL-L2CAL connection doesn't introduce errors in the running system and signals received by the new L2CAL are consistent with the current system.

VII. Summary

The L2CAL upgrade at CDF will improve jet and MET quantities at Level-2. These improvements will allow rate reduction in jet and MET based trigger via better signal/background discrimination. In addition to the rate reduction the upgrade provides more flexibility at trigger level so improvements and more sophisticated trigger algorithms can be implemented in the future. This is a big step forward to improve the CDF triggering capability at Level-2.

VIII. Acknowledgments

We thank Altera for providing free FPGAs.

IX. References

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