Level-3 Calorimetric Resolution available for the Level-1 and Level-2 CDF Triggers

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Abstract

As the Tevatron luminosity increases sophisticated selections are required to be efficient in selecting rare events among a very huge background. To cope with this problem, CDF has pushed the Level 3 calorimeter algorithm resolutions up to Level 2 and, when possible, even at Level 1, increasing efficiency and, at the same time, keeping under control the rates. This strategy increases the purity of the Level 2 and Level 1 samples and produces free-bandwidth that allows to reduce the thesholds. The global effect is an increase of the trigger purity and efficiency, most notably for physics triggers searching for Higgs and new physics. The Level 2 upgrade improves the cluster finder algorithm and the resolution of the Missing Transverse Energy (MET) calculations. The improved MET resolution will be soon available also at Level 1. We describe the CDF Level 2, Level 1 calorimeter upgrades, the architecture and the trigger performances. The Level 2 upgraded system is running as the official one since August 2007, the Level 1 is under commissioning.

I. Overview of the CDF Calorimeter Trigger

The CDF trigger [1] for Run II is a three level system. The goal of each stage in the trigger is to reject a sufficient fraction of the events to allow processing at the next stage with acceptable dead time. The Level 1 and Level 2 triggers use custom-designed hardware to find physics objects in a subset of the event information. The Level 1 is a deadtimeless synchronous pipelined system which form a trigger decision in $5.5\ \mu s$. The Level 1 decision is taken on the basis of a limited reconstruction of the muon, track and calorimeter information. When an event is accepted by the Level 1 trigger, all data are moved to one of four Level 2 data buffers in the front end electronics for all subsystems. At the same time, subsets of detector information are sent to the Level 2 trigger system where some limited event reconstruction is performed and a Level 2 decision is made inside a dedicated PC. Level 2 decision PC has at its disposal all trigger objects used in Level 1, such as tracks from the eXtremely Fast Track trigger (XFT/XTRP), muon primitives and global energy information, as well as the complete Level 1 trigger decision information. Upon a Level 2 accept, the full detector is readout and data are sent to the Level 3. The Level 3 trigger uses the full detector information for complete event reconstruction in a farm of x86 PCs. Only the events accepted at L3 will be sent to mass storage. The goal of the calorimeter trigger (both at Level 1 and Level 2) is to trigger on electrons, photons, jets, total transverse energy (SumET) as well as missing transverse energy (MET).

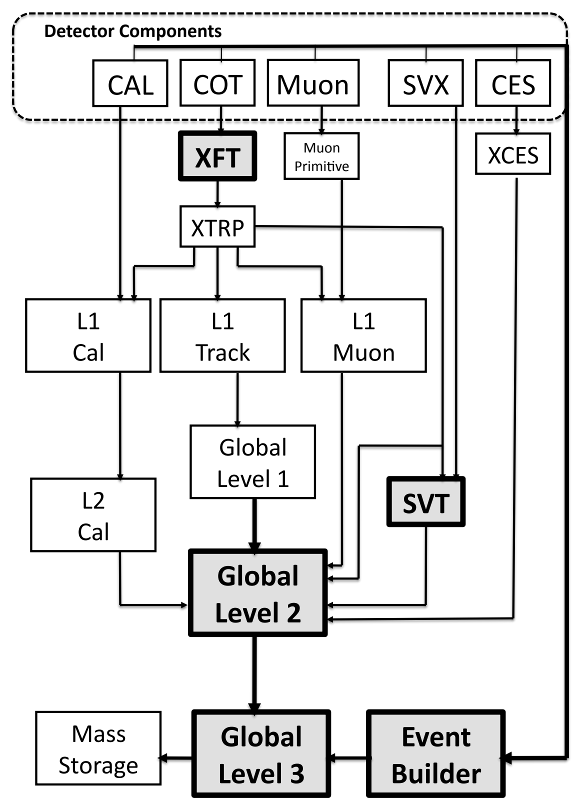

Figure 1: CDF Run II Trigger System. Boxes in gray are subsystems upgraded in the past few years to prepare for the expected high luminosity of the Tevatron. L2 and L1 Calorimeter (L2 CAL) and Global Level 2 and 1 are the subsystems involved in the upgrade stages described in this paper.

In the following we use a coordinate system defined by the polar angle θ , measured from the proton direction, the azimuthal angle ϕ, measured from the Tevatron plane. The pseudo-rapidity is defined as $\eta = \ln(\tan(\theta/2))$. 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 $\sin(\theta)$ to yield transverse energy. A trigger tower covers 15 degree in azimuth ϕ and approximately 0.2 in pseudo-rapidity η. This results in a representation of the entire detector as a 24×24 map in the $\eta - \phi$ 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 and resulting in a full scale of 128 GeV. The Level 1 calorimeter (L1CAL) subsystem only uses 8 of the 10 available bits for each trigger tower, with the two least significant bits dropped, giving a least count of 500 MeV and a full scale of 128 GeV. As an example, electron and photon primitives are formed at L1CAL by simply applying energy thresholds to the EM energy of a single trigger tower while jet primitives 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. The current L1CAL also calculates global SumET and MET, using the lower resolution 8-bit EM+HAD energy information.

The main task of the existing L2CAL was to find clusters using the transverse energy (E_T) of trigger towers. The cluster finding algorithm was based on a simple algorithm used for Run I, and was implemented in dedicated hardware. In this simple algorithm, the L2CAL hardware forms clusters by simply combining contiguous regions of trigger towers with non-trivial energy. Each cluster starts with a tower above a "seed" threshold (typically a few GeV) and all towers above a second lower "shoulder" threshold that form a contiguous region with the seed tower are added to the cluster. The size of each cluster expands until no more shoulder towers adjacent to the cluster are found. Because of this, large "fake clusters" are likely to be formed as the occupancy of the detector increases because towers which are unrelated to any jet activity have their E_T boosted above clustering thresholds. One example of such kind of "fake cluster" is when towers above shoulder threshold between true jets link multiple jets together into a single large cluster (cluster merging). This would reduce the efficiency, and increase the rate, for triggers requiring multiple jets at Level 2 at higher luminosity, such as some important triggers for Higgs and top physics.

One more limitation of the existing hardware-based L2CAL system is that it does not re-calculate SumET and MET using the full 10-bit resolution energy information available, instead it uses the SumET and MET information directly from current L1CAL, which is based on 8-bit resolution. This design feature limits its trigger selection capability, or rejection power, for triggers with global transverse energy requirements.

The existing L2CAL trigger system has worked reasonably well at lower luminosity for Run II, however, as the occupancy in the calorimeter increases with luminosity, the simple hardware-based L2CAL system starts to lose its rejection power. As an example, figure 2 shows the Level 2 JET40 (Jet above 40 GeV threshold) trigger cross section growth with increasing luminosity.

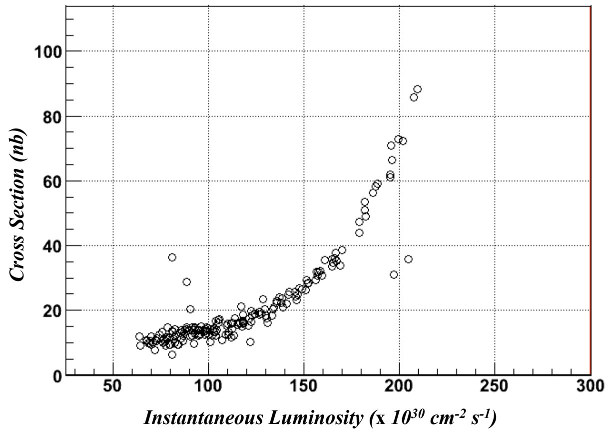

Figure 2: Cross Section of the jet trigger selection requiring jets above 40 GeV as a function of the Instantaneous Luminosity before L2CAL upgrade.

II. The Calorimeter Trigger Upgrade

The basic idea of Calorimeter upgrade is to provide the full 10 bit resolution trigger tower energy information directly to the Level 2 decision CPU where a cluster finding algorithm can reconstruct jets and recalculate MET and SumET and to recalculate the MET at the full resolution for the Level 1 Global Decision.

At hardware level, the full resolution (10-bit) calorimeter trigger tower data are received, preprocessed and merged by a set of Pulsar boards [2] before being sent to the Level 2 decision CPU where more sophisticated algorithms can be implemented. Since the actual cluster-finding is done inside the CPU, it is more flexible and more robust against increasing luminosity or higher occupancy in the calorimeter. With this approach, jet reconstruction using a cone algorithm which is currently being done at Level 3 can be moved to Level 2, albeit clustering trigger towers (instead of physical towers) and using only a single iteration in order to save processing time.

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) Sums 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) Sorts the seed list (for jets) by decreasing E_T. (4) Generates clusters, beginning with the first seed: sums the E_T 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 using a look-up table in order to speed up the algorithm. All towers used in the current cluster are identified as "used". The algorithm then moves to the next seed tower in the list that is not identified as "used" and iterates. When the seed tower list is exhausted, a list of all the clusters that have been found is returned. At the same time the MET and SumET calculated exploiting the full 10 bits resolution of the trigger tower energy information.

The same Pulsar-based hardware can be used to calculate the full resolution MET information for L1.

A. Hardware Architecture

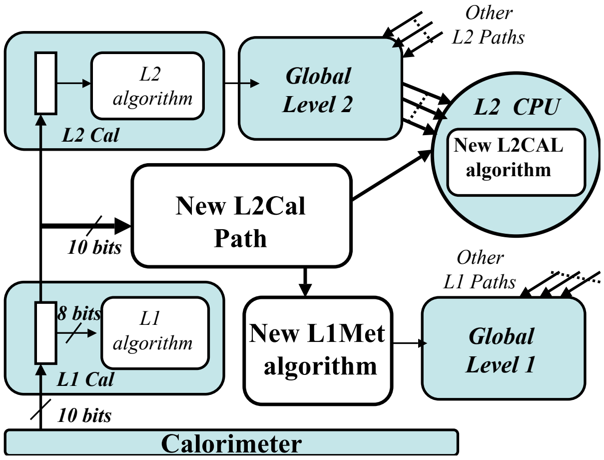

Figure 3: Hardware configuration for the Calorimeter Trigger upgrade: both L1 and L2. The new L2 hardware path makes available the full 10 bits resolution trigger towers to the L2 decision CPU and to a new L1CAL hardware part calculating the MET at the full resolution.

At hardware level, the basic idea of the L2CAL upgrade is to use Pulsar [2] boards to receive the raw (full 10-bit resolution) trigger tower energy information from L1CAL, merge and convert the data into SLINK format, then deliver the SLINK package to the Level 2 decision PC using FILAR(Four Input Links Atlas Readout) [5]. This is very similar to what has been done to all the other Level 2 trigger data paths for the Level 2 Global Decision upgrade [3].

The description of the Pulsar Board can be found in [2] and [3]. The design philosophy of the Pulsar board was to use one kind of general purpose motherboard, with powerful FPGAs and SRAMs, and to interface any custom data link with an industry standard link through the use of mezzanine cards. The key devices on the Pulsar board are three FPGAs (APEX 20K400BC-652-1XV [6]): two DataIO FPGAs and one Control FPGA. Both DataIO FPGAs are connected to the Control FPGA. Each DataIO FPGA interfaces with two mezzanine cards and the connections are bidirectional. Pulsar has a user defined interface to the P3 connector, and is used here for Control FPGA to send SLINK data package to the SLINK mezzanine card on a transition module on the back of the VME crate.

For the existing L2CAL system, since the clustering is done in hardware (designed in mid 90's), the system is quite complicated. The entire system consists of eighty-six 9U VME boards (five different types) with six VME crates using custom P3 backplane. The upgraded L2CAL system only consists of eighteen identical Pulsars as data receivers, and a few existing Pulsar SLINK merger boards from the Level 2 Global Decision upgrade [3]. In order to receive the trigger tower energy LVDS signals from the L1CAL, a new Pulsar mezzanine card is designed for the data receiver Pulsars. Figure 4 shows how the mezzanines are mounted on Pulsar. Since the clustering algorithm will now be done in the Level 2 decision CPU, the Pulsar-based L2CAL system is much simpler and more uniform at the hardware and firmware level.

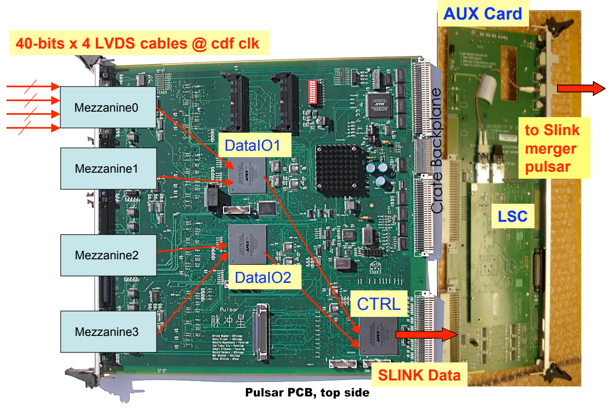

Figure 4: L2CAL mezzanine cards with Pulsar: this shows how four L2CAL mezzanine cards are mounted on the Pulsar board. Also shown on the right is the transition (or AUX) card in the back of the crate with the SLINK LSC mezzanine card. Note that the pictures for Pulsar and AUX card have different scale.

Figure 5 shows the actual mezzanine card. Four logical input blocks receive the input data from four 80-pin Honda connectors. Each connector receives 40 Low Voltage Differential Signal (LVDS) signals running at the CDF clock frequency (132 ns). Each input block includes 10 LVDS/TTL receiver chips. An Altera Apex device ($EP20K160E$) controls the data flow from the Mezzanine card to the DataIO FPGA on Pulsar. The FPGA receives the four sets of TTL signals, and simply stores them on four registers at the CDF clock frequency and then send them to the Pulsar motherboard at a frequency four times faster ($4\times$CDF clock frequency).

In the existing system one L2CAL board receives four LVDS input cables from the L1CAL system, corresponding to energy information (both HAD and EM) from eight trigger towers. In the new system, one new LVDS mezzanine card receives the same amount of input data as one L2CAL board in the existing system. With four mezzanine cards per Pulsar board, eighteen Pulsar boards are required to receive all the input data. A second set of SLINK Merger Pulsars receives and merges the eighteen SLINK channels into four and then deliver the data to the Level 2 decision PC using FILAR [5]. The same set of eighteen LVDS receiver boards can be used to improve the MET resolution at L1: they sent immediately the trigger tower energy information to an additional, but identical to the previous ones, LVDS Pulsar board which calculates MET and makes the L1 trigger calorimeter decision within the L1 timing contraints($5.5\mu s$). The LVDS pulsar boards will start to elaborate the L2 information when they will receive back the global L1 decision (3).

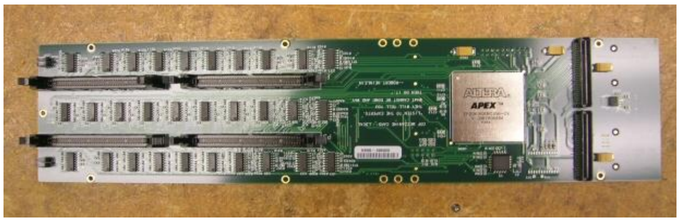

Figure 5: The actual L2CAL LVDS mezzanine card.

III. PERFORMANCES

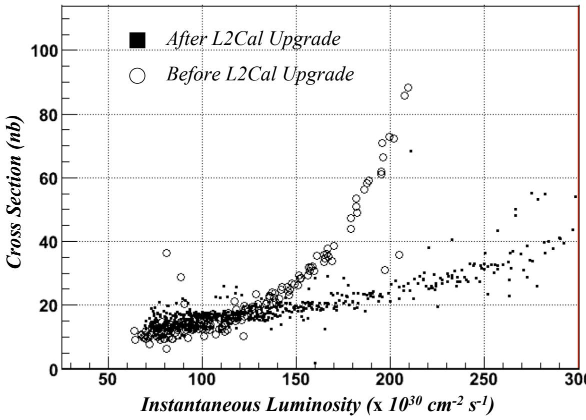

Figure 7: Cross Section of the jet trigger selection requiring jets above 40 GeV as a function of the Instantaneous Luminosity: upgraded L2CAL vs existing L2CAL

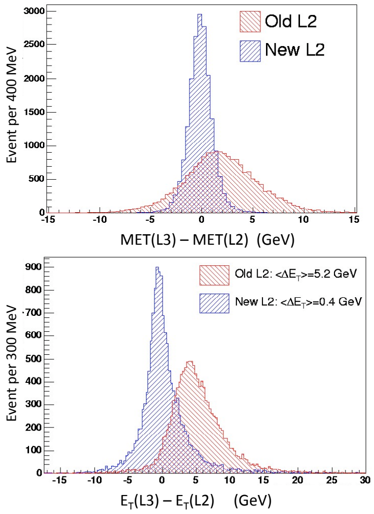

Figure 6: Difference between L2 and L3 MET (top) and jet transverse energy (bottom) for existing and upgraded L2CAL. The average luminosity is $180 \times 10^{30} cm^{-2} s^{-1}$.

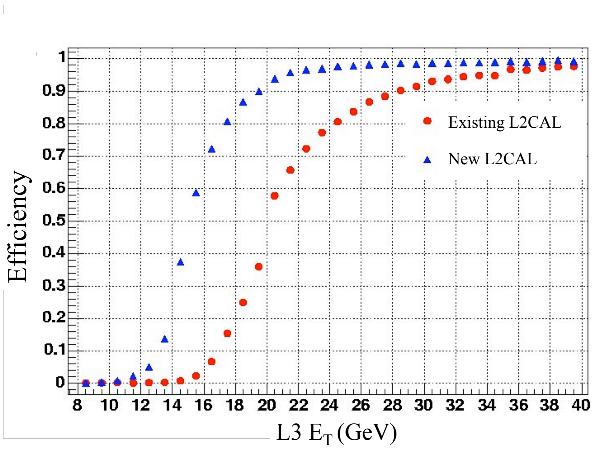

Figure 8: Efficiency verse E_T for Level 2 Jet trigger with 15 GeV threshold, existing L2CAL system and new L2CAL.

The Pulsar-based L2CAL upgrade has improved both jet and MET measurements at Level 2; at Level 1 will improve the Met measurement. Figure 6 shows the difference between the Level 2 and Level 3 in MET (Missing ET) and Jet transverse energy, for the existing system as well as for the upgraded system, with data taking at an average luminosity of $180 \times 10^{30} cm^{-2} s^{-1}$. The same MET difference has been measured between the future L1 Cal system and L3. These improvements allow a significant rate reduction as well as efficiency improvement in jet and MET based triggers both at Level 1 and Level 2. As example, Figure 7 shows the Level 2 JET40 trigger cross section growth with luminosity before and after the upgrade. Figure 8 shows the trigger efficiency curve for the Level 2 JET15 (Jet with E_T above 15 GeV) trigger, for the upgrade L2CAL system and the existing system.

IV. CONCLUSIONS

We have presented the design, the hardware and software implementation and the performance of the Pulsar-based new L2CAL system for CDF experiment. The new L2CAL system makes the full resolution calorimeter trigger tower information directly available to the Level 2 decision CPU. The upgraded system allows more sophisticated algorithms to be implemented in software and both Level 2 jets and MET are made nearly equivalent to offline quality, thus significantly improving the performance and flexibility of the jet and MET related triggers. This is a big step forward to improve the CDF triggering capability at Level 2, to have enough flexibility to deal with potential new challenges at the highest luminosities, and to improve CDF new physics reach sensitivities beyond baseline. We've also presented the under commissioning L1CAL upgrade, easily obtained exploiting the flexibility of the same pulsar boards used for the L2CAL. We foresee many opportunities for additional improvements in trigger purity and efficiency, most notably for physics triggers searching for Higgs and new physics.

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