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The CDF Level 2 calorimetric trigger upgrade

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Abstract

The CDF II calorimeter trigger has been recently upgraded to cope with the higher detector occupancy deriving from the increased Tevatron instantaneous luminosity ($\sim 2.8\times10^{32}$ cm^{-2}s^{-1}). While the original system was implemented in custom hardware and provided a limited-quality jet clustering, performed using a reduced resolution measurement of the transverse energy in the calorimeter trigger towers, the upgraded system provides offline-quality reconstruction of the full resolution calorimeter information (jet clustering, missing E_T and total E_T measurements) to the Level 2 trigger. This allows to improve the CDF II trigger selections and to keep under control the trigger rate dependence on instantaneous luminosity. In particular, simulation studies show that the CDF II potential for an Higgs discovery has been significantly increased. The upgraded calorimeter trigger uses the general purpose VME board Pulsar, developed at CDF II and already widely used to upgrade the Level-2 tracking and Level-2 global decision systems. A battery of Pulsars is used to merge the data from the calorimeter into one single datastream sent to one CPU, where software-implemented algorithms perform offline-like clustering. A review of the design, of the hardware and software implementation, as well as the performance of the upgraded system are presented.

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1 The original CDF II calorimeter trigger

CDF II uses a three-level system to reduce the 1.7 MHz bunch crossing rate to ∼150 Hz written on tape [1]. The Level 1 is a deadtimeless 7.6 MHz synchronous pipeline with 42 cells, which allows 5.5 μs to form a trigger decision. The maximum sustainable Level 1 output rate is ∼30 kHz. The Level 1 decision is taken on the basis of a limited reconstruction of the muon, track and calorimeter information. The Level 2 is an asynchronous pipeline with an average latency of 20 μs. The Level 2 processors perform track reconstruction in the silicon vertex detector and jet reconstruction in the calorimeters. The global Level 2 decision is taken by a dedicated CPU. While the events accepted by Level 1 are being processed by Level 2 processors, they are also stored on one of the four Level 2 buffers, waiting for Level 2 trigger decision. Each buffer is emptied when the Level 2 decision for the corresponding event has been asserted: if the event has been accepted, the buffer is read out, else it is simply cleared. If the Level 2 trigger decision takes too much time and the four buffers are all filled, the Level 1 accept is inhibited. This is a source of deadtime for the CDF II trigger. The maximum Level 2 output rate is ∼700 Hz. The Level 3 trigger is made of a CPU farm and has a maximum output rate of ∼150 Hz. The calorimeter trigger was designed to select events on the basis of the presence of electrons, photons and jets and on the total E_T and missing E_T. The calorimeter trigger towers have a width $\Delta\eta$=0.2 and $\Delta\phi$=15°, and the entire calorimeter can thus be represented by a 24×24 trigger tower map. The trigger tower energy data is sent to both the Level 1 and Level 2 trigger with a 10-bit energy resolution, with a least significant count of 125 MeV and a resulting full scale of 128 GeV. To reduce the complexity and the processing time, the Level 1 trigger uses only a 8-bit trigger tower energy information, by dropping the least significant bit and the most significant bit. Level 1 does not perform any clustering, and it simply select events on the number of trigger towers above programmable transverse energy thresholds or on the values of the computed total E_T and missing E_T. The Level 2 trigger uses the values of the total E_T and missing E_T computed at low resolution by Level 1 and it has the main task to perform jet and electron clustering. This is done with a hardware-implemented algorithm which combines contiguous energetic trigger towers. Each cluster starts from a "seed" tower, which shows a total E_T typically above a few GeV, and includes all the contiguous lower energy towers. The cluster size expands until no more energetic adjacent towers are found. The cluster position is defined as the seed tower position. While this strategy worked well at the low instantaneous luminosity of the initial phase of Run II, it encountered severe problems as the Tevatron luminosity increased above $\sim 1.5 \times 10^{32}$ cm^{-2}s^{-1} and the effect of the multiple

interactions significantly increased the detector occupancy and the presence of many energetic towers around the seed towers. As a consequence of the larger detector occupancy, large numbers of energetic towers could be erroneously clustered around a seed, into a single misidentified jet, yielding an increase of the Level 2 rate for single-jet triggers and a significant efficiency loss for the multi-jet triggers due to the erroneous merging of separate lower energy jets into a smaller number of more energetic jets.

2 The upgraded calorimeter trigger

The upgrade consists mainly of a new hardware path which delivers the full 10-bit resolution trigger tower data to the Level 2 decision CPU, where offline-like clustering algorithms reconstruct jets and electrons and recompute the total E_T and missing E_T [2]. The new hardware path uses a battery of Pulsar boards, a general purpose VME board widely used in many CDF II trigger subsystems [3]. A first layer of 18 Pulsar boards is used to receive the 288 LVDS cables carrying the electromagnetic (10 bit) and hadronic tower energy (10 bit) from the calorimeter. Each Pulsar merges 16 input data streams and outputs the resulting data stream into S-LINK format. A second layer of Pulsars merges the 18 S-LINK data streams into one data stream input to the Level 2 CPU, where all the data from all the trigger towers are simultaneosly available at full resolution for further processing. The latency due to the data transfer is on average $\sim$10 μs and is mainly due to the S-LINK transfer. The new jet clustering uses a fixed-cone algorithm. The towers with a total E_T above a programmable threshold are taken as seeds and the jet energy is computed as the sum of all the towers belonging to the cone centered on the seed tower and with a fixed radius in the η-ϕ space. The jet axis is computed using a weighted mean algorithm, where the total E_T of each trigger tower is taken as weight. Also the electron/photon clustering algorithms, previously implemented in hardware in the old system, are now emulated in the Level 2 CPU. The event total E_T and missing E_T are recomputed with 10-bit resolution by the Level 2 CPU, which significantly improves the trigger selections performance. The latency due to the jet clustering and electron/photon clustering algorithms is $\sim$10 μs and is well within Level 2 time budget. Fig. 1 shows the comparison between the old and the new systems of the resolution on the measurement of the event missing E_T and of the resolution on the jet transverse energy measurement. The increased resolution provides trigger efficiency curves with a significantly sharper turn-on, important to improve the quality of the trigger selections. The simultaneous availability to the Level 2 CPU of the calorimeter information, of the drift chamber tracks reconstructed in three dimensions by the eXtremely Fast Tracker, and of the silicon vertex tracks reconstructed by the Silicon Vertex Trigger, allows to design much more powerful Level 2 trigger

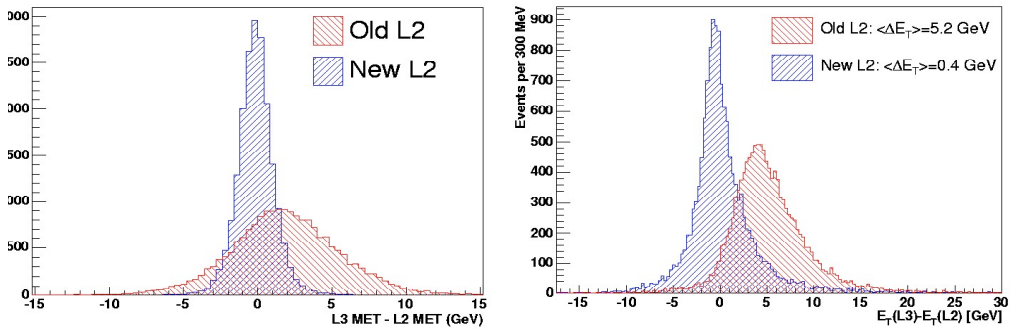

Fig. 1. Left plot. Resolution on the measurement of the missing E_T for the old system (red plot) and the new system (blue plot). Right plot. Resolution on the measurement of the jet energy for the old system (red plot) and the new system (blue plot).

selections which significantly increase CDF II physics reach in many crucial areas, as the Higgs boson search.

3 Conclusions

In this paper we reviewed the upgrade of the CDF II calorimetric trigger, fully commissioned in summer 2007. The upgraded system improves the performance of the Level 2 jet clustering and the measurement of the total E_T and missing E_T. This allows a significant total rate reduction and efficiency increase of many triggers designed to select important high transverse momentum physics processes, and to reduce the dependence of the system performance on the Tevatron instantaneous luminosity.

References

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[2] A. Bhatty *et al.*, "Level 2 Calorimeter Trigger Upgrade at CDF", FERMILAB-CONF-07-165-E.

[3] Pulsar project web page can be found in: http://hep.uchicago.edu/∼thliu/projects/Pulsar.