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CDF trigger final balance: Offline resolution at low level selections to fight against Tevatron increasing luminosity

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ABSTRACT

The CDF detector at Tevatron collider is at present the most long-lasting high energy physics experiment. Since its first data taking in 1992 it has produced many results of primary importance, such as the discovery of top quark and, more recently, the observations of Bs oscillations and single-top production. None of them would have been possible without a fast and efficient trigger system. Based on a three level architecture, the CDF trigger takes decisions on simple calorimetric and tracking objects and assures both high efficiency on signal events and low dead time. It reduces the data flow rate from 2.53 MHz, the collision rate, to 150 Hz, the current limit on tape writing and is flexible enough to be easily adapted to the continuously growing instantaneous luminosity. In the last years the Tevatron instantaneous luminosity has rapidly increased and is now reaching $4\times10^{32}\,cm^{-2}\,s^{-1}$. The CDF trigger system has been widely upgraded to cope with increasing trigger rates. The upgrade result is online reconstruction of missing transverse energy, jets and tracks with a quality comparable to the offline one. Jet energy and direction can be precisely determined and tracks can be subjected to 3-D reconstruction with good resolution. These upgrades reduce high trigger rates to acceptable levels and have provided invaluable tools to increase the purity of the collected samples. They also represent a helpful experience for LHC experiments where background rates will be much more demanding.

1. Introduction

Experiments at hadronic colliders look for very rare events. As an example, at Tevatron accelerator, where p and $\overline{p}$ beams are made colliding at the center-of-mass energy of 1.96 GeV, the cross-section for Higgs boson production is ~1 fb, 10^{10} times lower than $p\overline{p}$ inelastic cross-section (~60 mb). To increase the probability to produce interesting physics events the instantaneous luminosity of the accelerator has to be maximized. The drawback is an increase in the number of multiple interactions per beam crossing with high occupancy of the detectors and an exponential increase in trigger rates. Tighter selections at trigger level can free trigger bandwidth but also decrease the acceptance for signal events. Rate reduction has to be coupled with the ability to simultaneously perform a first selection of the most interesting events.

Since the beginning of Tevatron Run II in 2001, CDF trigger system has undergone many upgrades in order to cope with Tevatron improving performances. Currently the average peak instantaneous luminosity is greater than $3.0\times10^{32}\,cm^{-2}\,s^{-1}$ with ~10 multiple interactions per beam crossing. Both the online tracking system and the calorimetric trigger have been recently upgraded [1]. The new system keeps trigger rates under control and provides new tools to be used to design innovative trigger algorithms to increase the acceptance for signal events.

The upgrades are based on the Pulsar board [2], a general purpose VME board developed at CDF and widely used to upgrade the trigger system [3,4], thanks to its modularity and flexibility.

In the following, we will first review the CDF detector and its trigger system. We will then illustrate the recent upgrades emphasizing their impact on the physics potential of the experiment.

2. CDF detector

CDF is a general-purpose, azimuthally and forward–backward symmetric detector located at the Tevatron $p\overline{p}$ collider at Fermilab. It consists of a charged-particle tracking system immersed in a 1.4 T magnetic field followed by calorimeters which are surrounded by muon detectors. A detailed description can be found elsewhere [5]. Charged particle trajectories are detected by a 8-layers silicon microstrip detector and a drift chamber which provide $|\eta|$ coverage up to 2.0 and 1.0 respectively. The drift chamber consists of cells divided into eight super-layers, each containing 12 layers of sense wires. The odd superlayers have wires parallel to the beam axis (*axial* layers) while the even ones

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have wires tilted by 2° (*stereo* layers) in order to provide stereo information. The calorimeters are used to measure electromagnetic showers and jets from quark fragmentation and consist of projective towers with electromagnetic and hadronic sections covering the region up to $|\eta| < 3.6$. Surrounding the calorimeters are layers of steel instrumented with planar drift chambers and scintillators used for muons identification up to $|\eta| < 1.5$.

The CDF coordinate system uses θ and ϕ as the polar and azimuthal angles respectively, defined with respect to the proton beam axis direction, z. The pseudo-rapidity η is defined as $\eta \equiv -\ln[\tan(\theta/2)]$. The transverse momentum of a particle is $p_T = p\sin\theta$ and the transverse energy is defined as $E_T = E\sin\theta$.

2.1. CDF trigger system

The CDF trigger system has a three level architecture designed to reduce the event rate from 2.53 MHz, the bunch crossing rate, to approximately 150 Hz to be written on tape. At Level-1 (L1) raw muons, tracks and calorimeter information are processed to produce a L1 decision. L1 is a synchronous 40 pipeline based on custom-designed hardware which can provide a trigger decision in 5.5 μs with a rate typically below 30 kHz. When an event is accepted at L1, subsets of detector information are sent to the Level-2 (L2) system, where some limited event reconstruction is performed and a decision is taken. The L2 is an asynchronous pipeline and it is based on a combination of custom-designed hardware and commodity processors. Its average latency is 20 μs and its maximum output rate is 1 kHz. Upon L2 accept, the full detector data is readout and sent to Level-3 (L3) processors farm for further processing. Events accepted at L3 are sent to mass storage.

3. Online tracking processors upgrades

Tracks are reconstructed at trigger level by the eXtremely Fast Tracker (XFT) at L1 and by the Silicon Vertex Trigger (SVT) at L2. Many of the most important CDF physics results would have not been possible without the ability to online select tracks. SVT, for example, allowed to trigger on displaced tracks increasing by several orders of magnitude the efficiency for the hadronic B decay modes. Moreover, high p_T lepton triggers are widely used for Higgs boson searches both in the low and high mass region. Recently CDF, in conjunction with D0 experiment, has excluded the Standard Model Higgs boson at 95% C.L. in the mass interval 160–170 GeV [6].

3.1. XFT upgrade

XFT [7,8] has been developed to reconstruct tracks in the plane of the drift chamber transverse to the beam axis in time for L1 decision. Track identification is performed searching and combining track segments in the four axial superlayers of the drift chamber. XFT measures transverse momentum p_T and azimuthal angle ϕ of all the tracks with $p_T > 1.5$ GeV/c with an efficiency greater than 96% and a resolution $\sigma_{p_T}/p_T^2 \sim 2\%$ (GeV^{-1}) and $\sigma_\phi \sim 6$ mrad.

In the upgraded system track segments are also found in the outer stereo layers of the chamber. This feature allows to reject at L1 fake axial tracks by requiring the association with *stereo* segments. Stereo segments are also sent to L2 and matched to the axial tracks for 3D-track reconstruction which provides a good resolution on $\cot\theta$ ($\sigma_{\cot\theta} =$ 0.11) and z ($\sigma_z = 11$ cm). At L2, tracks can be matched to muon detectors or calorimeters for a better fake track rejection.

In Fig. 1 we show the effect of L1 and L2 upgrades on the cross-section of a trigger requiring a central muon with $p_T > 15$ GeV. The track is first stereo confirmed at L1 and then matched to the muon chambers at L2 with an overall reduction factor of about 10 at high luminosity.

3.2. SVT upgrade

SVT [9,10] is a L2 trigger processor dedicated to the reconstruction of charged particle trajectories in the plane transverse to the beam line. SVT combines hits from silicon detectors with tracks reconstructed by XFT. The association is performed by an *associative memory*, a massive parallel mechanism based on the search of low resolution tracks (*roads*) as coincidences between hits in silicon detectors and XFT tracks. When such an association is found, a track fitter (TF) performs quality cuts and estimates track parameters using the full available spatial resolution in a linearized fit. Overall SVT tracking efficiency is about 80%. SVT provides precise measurement of track impact parameter (d_0), curvature and azimuthal angle. Impact parameter is measured with a resolution of 35 μm for 2 GeV/c tracks, which is comparable to the resolution obtained for offline reconstruction.

The GigaFitter (GF) [11] is a next generation track fitter designed as a possible upgrade for SVT system, in order to enhance its performances in a very high luminosity environment. The GF is based on a modern Xilinx Virtex-5 FPGA chip, rich of powerful DSP arrays and features high speed, modularity, flexibility and reduced size with respect to the current system. It can store a larger number of possible roads thanks to a greater available memory. This will allow an extension of SVT acceptance on track p_T down to 1.5 GeV/c instead of 2 GeV/c, with a significant improvement in the b-tagging capability. The SVT acceptance on impact parameter can also be increased: currently SVT reconstructs only tracks with impact parameter smaller than 1.5 mm but the upgraded system could be sensitive for impact parameter up to 2–3 mm, improving the lifetime measurements.

4. Calorimetric trigger upgrade

The L1 and L2 CALorimeter triggers (L1CAL and L2CAL) make selections on electrons, photons, jets, total event transverse

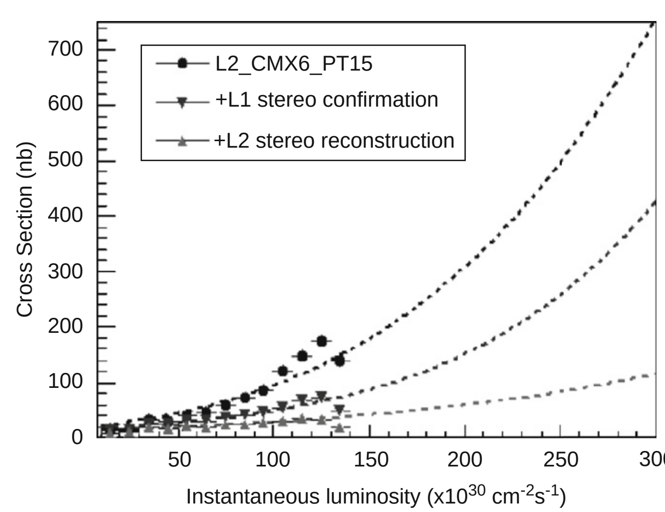

Fig. 1. L2 cross-section as a function of the instantaneous luminosity for a trigger requiring a central muon with $p_T > 15$ GeV. The cross-section is represented before any upgrade, after the L1 stereo upgrade and after the L2 stereo reconstruction upgrade.