THE DØ CENTRAL TRACKER TRIGGER

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The goals of high energy physicists for the next decade require new designs for the online systems of collider experiments. We describe the new DØ Central Tracker Trigger (CTT) System, which makes heavy use of field programmable gate arrays (FPGA) and digital signal processors (DSP) to allow the system to cope with the greatly increased data rate anticipated at the Fermilab Tevatron. We describe briefly how the CTT system meets the physics goals of the collaboration.

1 Introduction

The upgraded Fermilab Tevatron $p\bar{p}$ Collider, which operates at a center of mass energy of 1.96 TeV, will reach an instantaneous peak luminosity of 10^{32} cm^{-2} s^{-1} and eventually of 5×10^{32} cm^{-2} s^{-1}. The bunch crossing time is 396 ns, and later will be reduced to 132 ns.

The quest for new physics has required an upgrade of the DØ detector: the upgrade includes a better Muon Trigger, new electronics for the Calorimeter and data acquisition system, and a new Central Tracker (Fig. 1), comprised of a Silicon Microstrip Tracker (SMT), a Central and Forward Fiber Tracker (CFT), a Central and Forward Preshower (CPS and FPS) and a Central Solenoid. The upgraded detector allows the measurement of charged particles momenta, improved tracking resolution, identification of secondary vertexes and enhanced identification of electrons and photons. The main characteristics of the upgraded DØ are summarized in Table 1.

The improved momentum resolution and the tagging of long lived particles (through secondary vertex and impact parameter measurements) will allow for an enriched sample of events with b quarks in the final state.

In order to record such events with high efficiency a powerful trigger system is required. The larger background to signal ratios need a trigger with higher processing and rejection power. The reduced beam crossing time means that processing must happen faster (algorithms must be run in parallel processors) and with reduced dead times (pipelining must be used). The large scale and systematic use of Field Programmable Gate Arrays (FPGAs), Digital Signal Processors (DSPs) and Alpha Processors has allowed the DØ collaboration to fulfill all these requirements.

Table 1. Characteristics and performance of the DØ detector

Characteristics	Performance
momentum resolution	$\Delta P_t/{P_t}^2 = 0.002$
vertex reconstruction	
primary	$\sigma = 15 - 30\mu m$
secondary	$\sigma = 35\mu m\ (r,\phi)$
	$\sigma = 80\mu m\ (r,z)$
minimum P_t for muons	$\lvert\eta\rvert < 2\ (P_t > 1.5 Gev/c)$
minimum P_t for electrons	$\lvert\eta\rvert < 2.5\ (P_t > 1 Gev/c)$

2 The DØ Trigger

The DØ trigger system (Ref. 1), as shown in the block diagram of Fig. 1, is a multilayer hardware structure composed of three levels called Level 1, Level 2 and Level 3.

The input rate to L1 from the detector front ends is 8 MHz. Since the events can be written to tape at a rate of 20-50 Hz, this implies that a rejection factor of 4×10^5 must be obtained by DØ in Run II. The trigger systems of DØ share the same architecture. The Level 1 Trigger (L1) in Fig. 1 includes information from the Calorimeter and Muon System, the Central Fiber Tracker (CFT) and the Central and Forward PreShower (CPS and FPS). The last three systems provide information to the L1 Central Tracker Trigger (L1CTT). In the L1CTT special boards provide the interface to the Level 2 Silicon Track Trigger preprocessor (L2STT).

The DØ Level 2 Trigger (L2) shown in Fig. 1 is comprised of two stages: an array of preprocessors that format and sort L1 data, and a Global preprocessor that correlates information across the whole detector. The input rate from L1 to L2 is 10 KHz, the output rate to L3 is 1 KHz. L2 uses Alpha processors (Ref. 2): one Alpha controls all data paths (L1, L2, L3) to a trigger control computer, and the others process data. Among the preprocessors, the L2PS, L2CFT and L2STT constitute the L2 Central Tracker Trigger. The L2CFT receives tracks from L1CFT, sorts them by P_t and truncates their number before sending them to L2 Global. The L2STT processes the Silicon Microstrip Tracker data and improves tracking resolution by merging the information from the CFT and the SMT. Tracks are sorted by impact parameter, and optionally vertex information is provided by the L2STT processor.

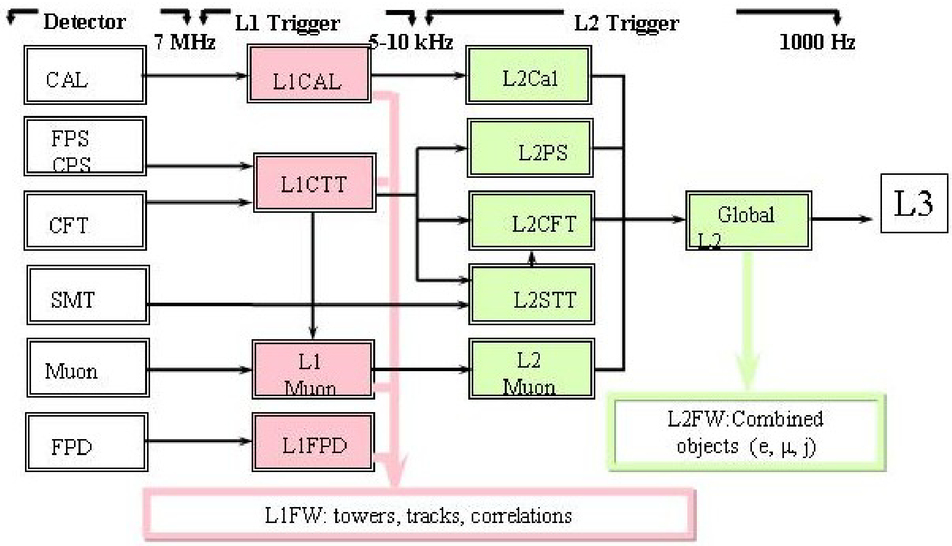

Figure 1. The D0 Trigger System.

3 The Fiber Tracker, PreShower and L1 Central Tracker Trigger

The L1 Central Tracker Trigger (Ref. 3) uses the information from two detectors: the CFT and the PS (see Fig. 2).

The Central Fiber Tracker detector (CFT) contains 16,000 channels of electronics, connected to scintillation fibers, 2 degrees pitch, mounted on eight cylinders ($20 < r < 50$ cm) of alternating axial and stereo doublets. The CFT provides tracking in the central region. Its position resolution is about $400 \mu m$. The PreShower detectors, Central and Forward (CPS and FPS), contain 16,000 channels, where signals are generated in triangular scintillator strips. The position resolution is about $800 \mu m$.

Hits from the CFT are used in L1CTT to form tracks or preshower clusters; the number of tracks/clusters is counted and several categories are made before the tracks/clusters are pipelined for output to L2. Heavy use is made of FPGAs to implement the algorithms, as well as to perform interface and framework tasks. FPGAs (XVC600 and XCV400) are used to find tracks in 4 P_t bins. In the lowest bin there are about 8,000 track equations, stored

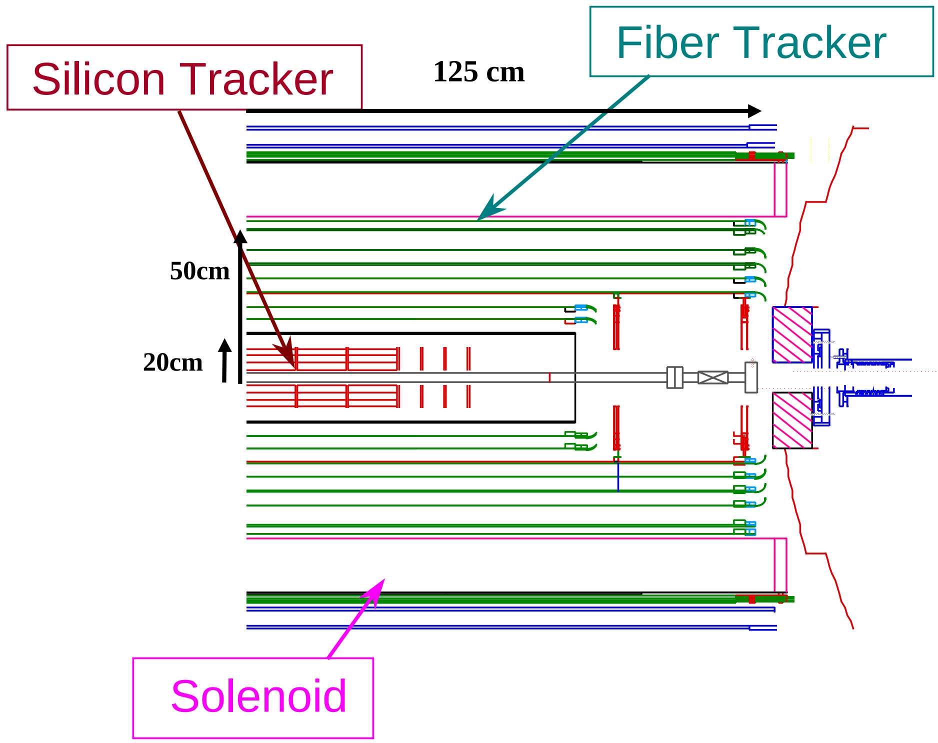

Figure 2. The Central Tracker System of DØ:

as Look Up Tables. Another FPGA (XCV300) does track/cluster matching (Ref. 2).

4 The Silicon Tracker and the L2 Central Tracker Trigger

One essential component of the Central Tracker Trigger of DØ is the Silicon Tracker Trigger (L2STT) (Ref. 4), that receives the information from the Silicon Microstrip Tracker detector (SMT) (Fig. 2). The SMT consists of 800,000 channels, half of which are used by the trigger. The SMT is composed of six cylindrical sections where rectangular detectors are arranged in four concentric layers. All the axial strips have a pitch of 50μm , and the stereo strips, at 2 or 90 degree angle wrt to the axial direction (direction parallel to the beam), have $60-150\mu$ m pitch. The hit resolution is 15μ m, and the impact parameter resolution obtained from offline reconstruction is about 18μ m. The secondary vertex resolution is 35μ m (in $r-\phi$), and 80μ m (in $r-z$).

In contrast to the other L2 preprocessors, the L2STT hardware is based on custom designed VME boards. The L2STT system contains six VME crates. In each crate there is one Fiber Road Card (FRC), nine Silicon Trigger Cards (STC) , and two Track Fitting Cards (TFC). Each STT crate receives the information from one SMT sector, 60 degrees in azimuth. Each FRC contains three Altera FPGAs (FLEX10K) where the tracks are received from the L1CFT, formatted, buffered and transmitted to L2 and L3. Each STC card receives SMT hits via a VBD (VME Buffer Driver) Transition Module, and L1CFT tracks via the FRC. A set of FPGAs performs cluster calculations from the SMT hits; the bad hits are rejected after gain correction and calibration. Downloaded Look Up Tables allow for rapid calculations. Another set of FPGAs in each STC receives the L1 tracks and associates clusters to a CFT track. The STC data are forwarded to TFC track cards, each of which uses eight Digital Signal Processors (DSPs) TI-TMS20C6203 for fitting, and three Altera FLEX10K100 FPGAs for the control logic on the board (Ref. 5).

5 Physics Potential of the Central Tracker Trigger

The expected performance for the CTT is based on detailed simulation studies (Ref. 4). Typically, for a 10 GeV track, the P_t resolution is 18% (if one CFT layer is used in the tracking), 9% if eight CFT layers are used in the tracking, and 6% if the SMT is used for tracking also.

The tracking efficiency in L2STT reaches about 85%. P_t measurements, as well as impact parameter measurements, will be used at reconstruction level for analysis in many physics channels. At the trigger level (L2STT), cuts on P_t and use of trigger objects that include the impact parameter will increase the ratio signal/background making the rate of interesting events compatible with the band width in L2, without a significant reduction in efficiency. The inclusion of the STT in the L2CTT improves the P_t resolution by a factor 2-3. The improved P_t resolution can be used in an Et/Pt cut for electrons at L2. For electrons of $Pt = 5$ GeV the better resolution allows a background rejection improvement of a factor 4, and at $P_t = 20$ GeV, of a factor 2.

The physics channels that will benefit the most from this improvement include:

Top production. Ratio signal/background (s/b) improves by a factor 2 to 7.

Higgs associated production. Ratio s/b improves by a factor 7.

Z boson electroweak production. Ratio s/b improves by a factor 10.

B physics . Though at least one lepton is still required at L1, an increased s/b of a factor 3 is obtained at L2.

References

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