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The Level 1 Central Tracking Trigger for the D∅ Upgrade

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Abstract

The D∅ level 1 tracking trigger uses data from the scintillating fiber tracker, the central and forward preshower detectors, the muon system and the calorimeter. Tracks are found in the scintillating fiber tracker with transverse momentum greater than 1.5 GeV/c. The tracks are then sent to the central preshower detector for electron tagging and to the muon system for muon tagging. Preshower clusters are also used for identifying photon candidates. These multi detector triggers are then sent to the level 1 Trigger Framework where they are further combined with the calorimeter to create the final level 1 trigger. This paper presents an overview of the level 1 trigger system with emphasis on the use of large programmable logic devices (PLD's) in an extensible system architecture that allows complex, multi detector triggers.

I. Introduction

For the Collider Run II at Fermilab, there are three levels of trigger hierarchy in D∅. Level 1 (L1) consists of custom hardware based triggers which search for patterns consistent with muons, electrons and jets. Level 2 (L2) uses DEC Alpha processors and DSP's (Digital Signal Processors) to combine L1 objects and additional hit information into muons, electrons and jets. Level 3 (L3) is a computer farm which uses offline algorithms for particle identification. The maximum trigger rates for events passing L1, L2 and L3 are about 10kHz, 1kHz and 10 Hz respectively.

The upgraded L1 trigger system in the D∅ detector is composed of the calorimeter, the muon system, the central fiber tracker (CFT) and the central and forward preshower detectors (PS). Both the CFT and PS make use of scintillating fibers and are completely new additions to the D∅ detector.

The goal for the L1 tracking trigger is to provide triggers for all charged particles with transverse momenta as low as 1.5 GeV at the highest possible efficiency. The beam-crossing rate is about 7.6 MHz and the L1 trigger is designed to accept a new event every 132 ns. The L1 trigger system has to accommodate a peak luminosity of $2\times10^{32}/cm^2/s$ such that each beam crossing may give rise to more than a hundred charged tracks. Since the L1 muon trigger needs to have CFT tracks as seeds, a list of track information must be passed to the L1 muon trigger system within about 800 ns after the beam crossing. A global L1 trigger decision needs to reach the trigger manager within 4.2 μs after beam crossing. Sufficient buffering is employed so that the L1 trigger system has less than 5% deadtime.

II. CFT and PS Triggering

A. The CFT and PS Front End Board

The CFT is made up of scintillating fibers and the PS is made up of scintillating strips with wavelength-shifting fiber readout. Their front end electronics systems are the same. The detailed description of the upgraded D∅ detector can be found in [1] and only a brief description is given below.

The CFT consists of 32 concentric barrel-shaped layers of scintillating fibers that are arranged in 16 "doublet" layers. Half of the doublet layers have fibers parallel to the z-axis (called axial layers) and the other half are at an angle (stereo layers). Only the 8 axial doublet layers are used in the CFT trigger. The fiber diameter is 835 μm. The radii of the CFT layers range from about 20 cm to 52 cm and it offers full coverage down to about 22° in polar angle. A 2 Tesla solenoid magnet around the CFT provides the field which bends the charged tracks in the radial plane of the CFT.

The central preshower (CPS) is placed in the gap between the solenoid coil and the central calorimeter at a radius of 72 cm. It covers the region down to about 30°. There is a lead absorber placed in front of the CPS to facilitate early showering of electrons for precise position measurements. The CPS consists of 1 axial layer and 2 stereo layers of scintillating strips. The strips have triangular shapes. The size of the triangular base is about 7 mm and the height is about 5 mm.

The CFT and CPS are divided equally into 80 sectors or wedges in the rϕ plane and each sector subtends 4.5°. In each sector, there are 480 fibers in the CFT and 16 strips in the CPS on the axial layers.

At the lowest P_T threshold envisioned (1.5 GeV), all tracks which cross the outermost CFT layer (H layer) of a 4.5° sector are either completely contained in the sector, or partly in the sector and partly in an adjacent sector. To form a seamless trigger for all tracks which intercept the H layer, hit information from the two neighbor sectors are imported.

Photons from the scintillating fibers are converted to electrical signals by the Visible Light Photon Counters (VLPC) [2]. The expected average signal level from the VLPC is about 30,000 electrons per photoelectron. The number of photoelectrons in a single fiber for a single track is between 10 and 40. These signals need to be discriminated for the L1 trigger and digitized for the L3 trigger and offline reconstruction. The discrimination is done by a custom chip, called the SIFT (**ScI**ntillating **F**iber **T**rigger), and the digitization is done by the SVX IIe chip. [3] The SVX chip is identical to the ones used in the D∅ silicon vertex detectors. The SIFT chip sits in front of the SVX chip and has a 70 ns integration window and a selectable discriminator module which can accept up to 72 input fibers. Eight of these modules are mounted on an Analog Front End (AFE) board which is mounted on the cassettes that hold the VLPC's. The discriminator outputs are latched on the AFE and then sent via the standard Low Voltage Differential Signaling (LVDS) channel links to a separate digital board.

Digitized signals are sent from the AFE boards to the L3 trigger system via a fairly standard VME readout system. The discriminated signals, which only indicate whether the corresponding scintillating fibers are hit (1) or not (0), are sent to the digital boards for the home sector and to each of the digital boards for the two neighbor sectors.

Each digital board has a number of PLD's responsible for finding tracks from the individual scintillating fiber hits. Each PLD receives fiber signals from hundreds of fibers in the home sector as well as from its neighbor sectors. A set of predefined candidate trajectories for different P_T ranges are downloaded into each PLD. Each PLD executes the pattern recognition algorithm to find track candidates and reports the number of track candidates found and the coded position and momentum indices for the first six tracks in each of four P_T threshold bins.

PLD's are used in the CFT and PS trigger logic so that one can quite flexibly program (or reprogram) the trigger logic in these devices when they are in place on the detector. Standard VHDL (VHSIC Hardware Description Language) code is used for this task and a trigger test board applying the baseline tracking algorithm has been fabricated and tested. [4]

B. Track Finding in the CFT

Each of the 8 doublet layers in the CFT is made up of two single layers. One of the layers is staggered by half a fiber spacing relative to the other so that there are no gaps. In principle, all tracks pass through a fiber in the inner, the outer or both layers. A doublet bin is a logical combination of inner and outer fibers and it is formed in such a way that the doublet bins do not overlap and each of them is one fiber wide.

The goal of the track finder is to achieve the highest efficiency for finding the real tracks while maintaining the largest possible rejection factor against fake tracks. For the configuration of the CFT, the greatest rejection is achieved in the trigger if a hit is required on all of the eight layers of the tracker and the trajectory width at each layer is one fiber pitch wide, about 1mm. Wider roads result in too many extra fake tracks. Narrower roads may lose real tracks due to multiple scattering and other radiation effects.

The baseline design therefore requires a hit in each of the 8 layers and the 8 doublet hits (bins) are then combined to form a track. A trigger requiring 8 hits out of 8 layers can be used because the efficiency for each doublet layer is over 99.5%. Nevertheless, the scintillating fiber efficiency may deteriorate during the experiment run due to aging and radiation damage, especially if we see high luminosity for much of the run. If it becomes necessary, we may require only 7 hits out of 8 layers for tracks in the highest P_T range. There would be too many candidate trajectories to deal with if we also allowed 7 out of 8 for tracks with lower P_T.

Monte Carlo simulations of the upgraded DØ detector have been used to investigate the outcome of different methods. The Monte Carlo simulation shows that we can limit ourselves to allowing only 2 tracks per doublet bin in the anchor layer (H layer) and only 6 tracks in each of the 4 P_T thresholds (i.e. 24 tracks) in each sector virtually without losing any track efficiency.

The allowed trajectory patterns (logical equations) in the CFT are generated analytically and the total number of equations for 8 out of 8 possible doublet layer hits in the CFT is about 16000. After the experiment starts to run, we will be able to survey the CFT with the particle beam to obtain the actual fiber positions. From that, we can generate and find a more realistic set of track equations. Although we have assumed all tracks pass through the origin, the tracking efficiency for particles originated from points within 1 mm from the origin is still very good.

The eight doublet layers of CFT are named as A, B, … H, from the innermost to the outermost. An example of an equation looks like the following:

$$\begin{aligned} \mathrm{T1013172227323945} = {} & \mathrm{A[10]\ AND\ B[13]\ AND\ C[17]} \\ & \mathrm{AND\ D[22]\ AND\ E[27]\ AND\ F[32]} \\ & \mathrm{AND\ G[39]\ AND\ H[45];} \end{aligned} \quad (1)$$

where the indices (10, 13, …,45) are the doublet bin numbers. Only when all the 8 fibers are hit will an equation become a candidate track.

In the next step, the group of equations that share the same anchor layer (H layer in our baseline design) doublet bin, '45' in this case and belong to a chosen range of P_T (called 'pt15' in this example) are then logically OR'ed together:

$$\mathrm{Trig\_pt15h45} = \mathrm{T1013172227323945\ OR\ \ T\ldots45\ \ OR\ \ ...} \quad (2)$$

Since the equations for a range of P_T are grouped together, each of these P_T groups is assigned a particular bit. The number of P_T groups in our baseline design is 20. As a result, the output from this stage is a matrix of pins which is 44 ϕ bin rows (since there are 44 fibers in the H layer of the CFT), by 40 P_T bin columns (including the two possible signs). Each pin in this matrix will be TRUE (1) if a track is found or FALSE (0) if no track is found.

Each set of equations is put into a set of PLD's which have all the fiber inputs needed by the equations for that particular set. In this way, each set of PLD's can accommodate track equations in the entire range of P_T. The input signals are multiplexed in 6 time slices in the digital boards.

The track pattern recognition stage (in the above section) outputs a matrix of pins in each set of the PLD's. The ϕ array is searched in decreasing P_T order looking for any pins that are TRUE. As each TRUE pin is found, both the ϕ bin address and P_T bin address are loaded into a register. This is basically a serial problem that must be solved in parallel hardware.

This serialization procedure in each PLD is done in a mixed parallel/serial mode to reduce the latency for the process to its minimum as far as the resource allows us. For each ϕ bin, several P_T bins are input into a priority encoder which outputs the indices of the highest P_T and the lowest P_T bins that are TRUE. At the end, the lists of ϕ and P_T addresses are concatenated in a binary tree structure down to a list of 6 and put into an output buffer. We allow up to 6 tracks in each of the 4 P_T thresholds in each CFT sector. This virutually loses no efficiency in track finding because the expected average number of track candidates per sector in a physics event is far below 1.

C. Clustering in the PS

At L1, the clustering scheme for the CPS is relatively simple. Strips in the CPS are scanned to locate those that have valid signal hits. Consecutive strips in the axial layer in the home or neighbor sectors that are hit are grouped into "clusters" with a width attached. From Monte Carlo studies, we understand that it is sufficient to allow a maximum width of 8 strips in each cluster. This algorithm is very simple because there is only one axial layer to deal with for L1 in the CPS. The logic resources taken here are also very small compared to the CFT track finding logic. Stereo layers of the CPS are not used for L1 triggering.

One special feature for the PS triggering is that, the VLPC signal from each PS strip is passively split into two and each is input to a SIFT channel with separate thresholds. Different signal gains are also set in the SVX chip. Different thresholds allow calibration for the PS at different energies and different gains provide us with sensitivity to physics channels at both low and high P_T. The PS clustering process is done in parallel with the CFT track finding in the same PLD.

D. Matching between the CFT and CPS

The matching between CFT and PS is done in a separate PLD. The logic there compares the clusters in the CPS to the CFT track information to form a track match. Matches of the CFT trigger tracks and PS clusters are thought to be "electron-like". The existence of only PS clusters without CFT trigger tracks nearby are deemed to be "photon-like". This helps identifying electron tracks and provides a powerful rejection over the background events such as pions.

The logic also determines if the tracks in each sector should be tagged as isolated. A track is isolated if it is the only track in the home sector and the two neighbor sectors (in all ranges of P_T). Isolated electrons are useful signals for taus and other exotic particles.

III. THE MUON AND CFT

The muon detector system in the upgraded D∅ includes various kinds of scintillator counters and drift tubes. Scintillator hits are used with CFT trigger tracks to make trigger decisions. The ϕ segmentation of these scintillator counters is approximately 4.5° which is designed to match the CFT trigger sector.

The trigger logic on all muon trigger cards is implemented in the PLD's of Altera's FLEX 10K series. The PLD logic is stored in non-volatile RAM on each card for easy reprogramming after power cycling. Information from the CFT digital boards is sent to the muon front end cards over coaxial cable using the AMCC Gbit/s serial link chipset [5]. Up to 6 CFT trigger tracks from each sector are sent on cables to the muon trigger cards. Tracks from different cables are processed in parallel. Trigger decisions involving tracks from a given cable must be made within 18.8 ns so that following tracks can be processed in turn.

In one of the PLD's on the muon trigger card, a memory lookup table is implemented to unpack the bit patterns of each CFT track from the cables to obtain its approximate position, P_T and the sign of bending in the ϕ plane. Depending on which P_T threshold it exceeds, this CFT track information is sent to the trigger logic PLD's with the desired P_T threshold. At the same time, scintillator hit information is also demultiplexed and sent to the same PLD's. Combinatorial logic is used in the PLD's with different P_T threshold to find trigger correlations between the CFT tracks and the scintillator hits which match a pre-defined set of valid trigger conditions. Every matched trigger condition would give rise to a muon candidate in the relevant momentum threshold, whereas the absence of any match would eliminate the possibility of a muon trigger. The requirement of the coincidence between the CFT and the muon detector reduces the cosmic muon background.

IV. TRIGGER FRAMEWORK

The detectors involved for the L1 trigger at D∅ include the CFT, PS, muon and the calorimeter. There are trigger manager boards for CFT/PS, muon and the calorimeter, each making its own trigger decisions. All the necessary L1 trigger information from these trigger managers is sent to the L1 Trigger Framework. Due to relatively long sampling time needed in the calorimeter operation, the calorimeter trigger information can be compared against other trigger components only at this very last stage of the L1 trigger system. Figure 1 illustrates the relationship between the individual components and the Trigger Framework. Moreover, the beam crossing number and other diagnostic information is also sent to the L1 Trigger Framework for debugging and monitoring purposes. The final L1 decision in the Trigger Framework is made within 4.2 μs after the beam crossing.

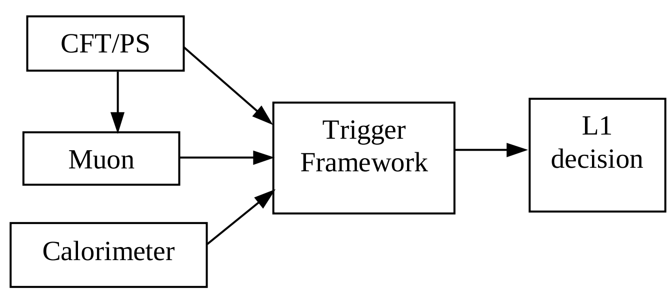

Figure 1: The L1 trigger decision made at Trigger Framework involves the individual trigger components of the CFT, PS, muon and calorimeter.

The trigger logic in the Trigger Framework is also done within some PLD's. There, the calorimeter shower information in each of the four calorimeter quadrants is compared with the track and cluster information from the CFT and PS to look for signal coincidence. The coincidence of a CFT track, a PS cluster and a calorimeter shower would construct an electron trigger, whereas the absence of any coincidence would become a veto. The usage of the calorimeter alone in the electron triggering actually provides the largest rejection against various backgrounds and noises. Nevertheless, the coincidence between the CFT, PS and calorimeter provides an additional factor of 2 in rejection against the backgrounds with high efficiency.

Trigger information is presented in the form of AND/OR trigger terms to the Trigger Framework. Each trigger term represents a trigger signal or a combination of signals in the CFT, the PS, the muon scintillator counters or the calorimeter satisfying some P_T thresholds and topology rules. There are 128 trigger bits allowed in the Trigger Framework. Each trigger bit corresponds to a combination of trigger terms available in the Trigger Framework and caters for a specific physics channel. A L1 trigger is fired when at least one of these bits is true (1). The usage of the PLD's provides us the flexibility to vary the combinatorial trigger logic inside the Trigger Framework. This in turn allows us to vary physics triggers during the collider run.

Most of the front end electronics involved in the L1 trigger system also act as data readout for the L2 and L3 trigger systems as well as the offline system. Some more precise information that is not used at L1 is pipelined during the L1 decision-making time for later readout to the higher level trigger and offline systems. For example, in the CFT, up to 24 tracks in each sector are pipelined in the digital board. After leaving the digital boards, all available CFT tracks in the whole detector are selected and combined into 6 global lists of up to 48 tracks each. These become the track seeds for the L2 trigger when there is a L1 pass. Clusters in the PS with or without associated CFT tracks are also sent to the L2 trigger from the digital boards. Unlike the L1 CFT and PS triggers which only count the number of trigger objects, the position and P_T of each individual CFT track and the position of the PS cluster with its width are sent to and used at L2 and L3. This additional information allows more sophisticated algorithms to be used at L2 and L3.

V. Summary

A fast deadtime-less L1 trigger system has been developed for the D∅ central tracking system. The CFT and PS trigger system consists of Visible Light Photon Counters, sophisticated digitization and discrimination electronics plus fast pipelined trigger logic which is based upon the use of large PLD's. The overall L1 trigger system has heavily made use of the PLD's which provide us with flexibility to make necessary adjustment for the trigger system during the actual run. A major enhancement for the L1 trigger system at D∅ in Run II is that trigger terms from multi detector triggers at L1 are used in the Trigger Framework to make the final L1 decision.

VI. References

[1] Information on the upgrade D∅ detector can be found on the World Wide Web at:

http://www-d0.fnal.gov/hardware/upgrade/upgrade.html.

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[2] M. Adams et al. (D∅ Collaboration), "A Detailed Study of Plastic Scintillating Strips with Axial Wavelength Shifting Fiber and VLPC Readout", Nucl. Instrum and Meth., A366, pp.263-277, 1995.

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