First Results From the Central Tracking Trigger of the DØ Experiment

Yurii Maravin, John Anderson, Robert Angstadt, Levan Babukhadia, Mrinmoy Bhattacharjee, Gerald Blazey, Fred Borcherding, Brian Connolly, Michael Cooke, Satish Desai, David Evans, Paul Grannis, Stefan Grünendahl, Carsten Hensel, Yuan Hu, Vivek Jain, Marvin Johnson, Stephan Linn, Juan Lizarazo, Manuel Martin, Yildirim Mutaf, Carsten Nöding, Jamieson Olsen, Ricardo Ramirez-Gomez, Stefano Rapisarda, Kyle Stevenson, Makoto Tomoto, Brigitte Vachon, Thei Wijnen, Neal Wilcer, Graham Wilson, Qichun Xu, and Kin Yip

***Abstract*—An overview of the DØ Central Track Trigger (CTT) for the Tevatron Run 2 program is presented. This newly commissioned system uses information from the DØ Central Fiber Tracker and Preshower Detectors to generate trigger information for the first level of the three-tiered DØ Trigger. The system delivers tracking detector trigger decisions every 132 ns, based on input data flowing at a rate of 475 Gbit per second. Initial results indicate excellent performance of the CTT. First studies of efficiency and trigger performance of the CTT are presented.**

***Index Terms*—Data acquisition, field programmable gate arrays (FPGAs), parallel scintillation detectors, triggering.**

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Y. Maravin, J. Anderson, R. Angstadt, F. Borcherding, S. Grünendahl, M. Johnson, J. Olsen, S. Rapisarda, M. Tomoto, B. Vachon, and N. Wilcer are with Fermi National Accelerator Laboratory, Batavia, IL 60510 USA (e-mail: maravin@fnal.gov).

L. Babukhadia, M. Bhattacharjee, S. Desai, P. Grannis, Y. Hu, and Y. Mutaf are with the State University of New York, Stony Brook, NY 11794 USA.

G. Blazey and M. Martin are with NICADD/NIU, Northern Illinois University, DeKalb, IL 60115 USA.

B. Connolly and S. Linn are with the Physics Department, Florida State University, Tallahassee, FL 32306 USA.

M. Cooke is with TW Bonner Nuclear Lab, Rice University, Houston, TX 77251 USA.

D. Evans is with the Department of Physics, Lancaster University, Lancaster, U.K.

C. Hensel and G. Wilson are with the Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045 USA.

V. Jain and K. Yip are with the Collider-Accelerator Department, Brookhaven National Laboratory, Upton, NY 11973 USA.

J. Lizarazo and R. Ramirez-Gomez are with the Departamento de Fisica, Universidad De Los Andes, Apartado Aereo 4976, Bogota, Colombia.

C. Nöding is with Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.

K. Stevenson is with Indiana University, Bloomington, IN 47405 USA.

T. Wijnen is with the University of Nijmegen, 6525 ED Nijmegen, The Netherlands.

Q. Xu is with the Department of Physics, University of Michigan, Ann Arbor, MI 48109 USA.

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I. Introduction

DØ [1], [2] is a general-purpose detector situated at the world's highest energy proton-antiproton collider, the Tevatron at Fermi National Accelerator Laboratory, Batavia, IL. The accelerator produces beams of protons and antiprotons at an energy of 1 TeV. Particle bunches are collided head-on in the center of the detector every 396 ns. Interactions between protons and antiprotons result in the production of many secondary particles. The role of the DØ detector is to measure properties of these particles such as their transverse momentum, energy, etc. During operation, only 50 out of the 2.7 million collision events produced every second at the Tevatron can be stored for offline analysis. The decision of whether an event is saved for further analysis is made by the three-tiered (L1, L2, and L3) DØ Trigger system [3].

L1 is a purely hardware-based trigger. It uses a part of the collision data collected by the DØ detector to form a decision for each collision, which is reported to the DØ Trigger framework. The L1 trigger is does not cause any downtime for collision event rates up to 7.5 MHz. Predefined L1 requirements select as many as 2000 events every second for further processing by the other two trigger tiers.

One of the major parts of the DØ Trigger is the Central Track Trigger (CTT). The CTT selects collisions that contain charged tracks with interesting characteristics such as transverse momentum above a given threshold, or charged tracks that are likely to be electrons, etc. In the following section, we provide a brief description of the CTT; a detailed description can be found elsewhere [4]–[9].

II. The Charged Track Trigger at DØ

There are five independent tracking detectors in DØ [10]–[13]. In this paper, we discuss first results for L1 CTT Triggers based on information from two detectors: the Central Fiber Tracker (CFT) and the Central Preshower System (CPS). The CFT consists of 77 000 scintillating fibers arranged in eight concentric cylinders aligned parallel to the beam line. The innermost cylinder is placed 20 cm from the beam line, while the outermost layer is at 50 cm. The CFT provides coverage down to 22° from the beam line. Outside the outermost CFT layer is the superconducting coil that generates a 2-Tesla

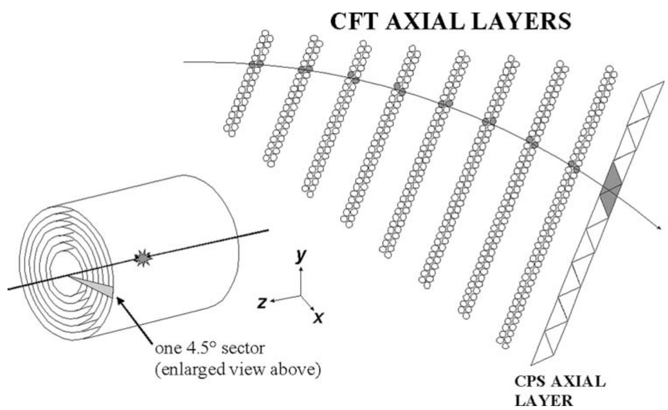

Fig. 1. Hit information from the CFT and CPS detectors is reorganized from cylindrical to azimuth geometry forming 80 equal wedges or trigger sectors of 4.5° each. A hypothetical track is drawn on the eight CFT axial "doublet" layers and one CPS axial layer. The hit pattern is fit to a curved line (shown with an arrow) to reconstruct the charged particle trajectory. The magnetic field generated by the DØ solenoid (not shown) bends the trajectory; thus, enabling the measurement of the transverse momentum of the charged particle.

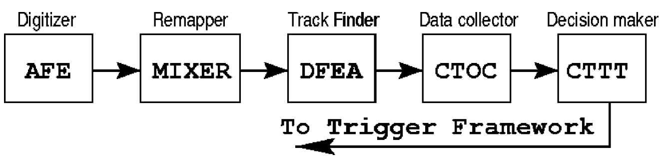

Fig. 2. The L1 CTT block diagram. The data from the visible light photon counters are digitized by the AFEs. The data are further reorganized by MIXER boards and sent to the track-finding digital front-end boards (DFEAs). These boards analyze hit patterns in the CFT and CPS detectors, find tracks, and report information to both the L1 Muon Trigger system and to collector DFE boards (CTOC). Finally, information from the collector DFE boards is reported to the decision-making DFE board (CTTT). It provides information to the DØ Trigger Framework that either accepts or rejects the event.

solenoidal magnetic field. The CPS is constructed of three cylindrical layers of triangular plastic scintillators immediately outside the solenoid (radius 70 cm). One of these layers (axial) is parallel to the beam line, and the other two (stereo) are at an angle of 23° to the beam line. The CPS provides additional means of identifying electrons and photons with coverage down to 29° from the beam axis.

Scintillating fibers emit light as a charged particle passes through them. The light is piped through individual waveguide fibers to visible light photon counters [13] for amplification and conversion to analog output. The analog signal is digitized by the analog front-end board (AFE). If the light intensity is above a predefined threshold, the fiber is identified as "hit." A charged particle produces a pattern of hits in the CFT. If a charged particle is an electron, it will also produce a hit in the CPS (see Fig. 1).

Charged particles curve in the magnetic field of the DØ detector. The curvature is inversely proportional to the transverse momentum $\mathrm{p_T}$ of a particle. Therefore, it is possible both to detect charged tracks and to estimate their respective transverse momentum by detecting and analyzing hit patterns provided by the CFT and CPS. This pattern recognition is done in the first stage L1 CTT (see Fig. 2) by the digital front-end boards (DFE).

There are 80 DFE boards that simultaneously analyze hit information from the 80 axial sectors of the CFT/CPS detectors [14], [15]. Each of these boards is programmed with 16 000

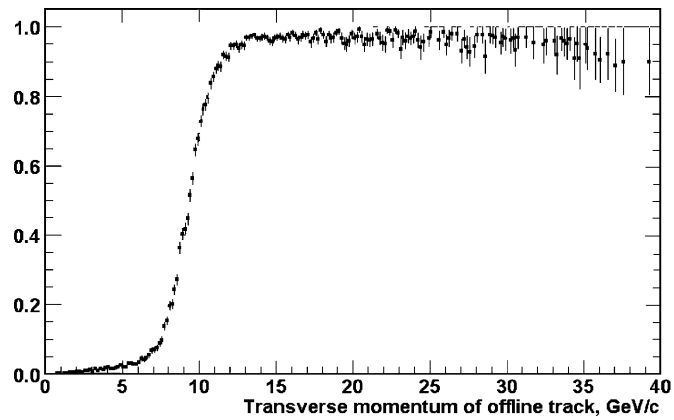

Fig. 3. Single high-$\mathrm{p_T}$ L1 CTT track efficiency as a function of transverse momentum.

Boolean equations that identify patterns of hits that most likely are caused by a charged particle produced in the event. DFE boards are able to detect charged tracks with transverse momentum above 1.5 GeV/c. The boards also classify tracks by their transverse momentum in four ranges 1.5–3, 3–5, 5–10, and above 10 GeV/c.

The resulting list of tracks and their respective transverse momentum is sent to the L1 Muon Trigger system. This permits, in a separate system, to trigger on events that are likely to contain muons.

Information reported by the DFE boards is collected and summarized by the Octant (CTOC) boards. The results are provided to the decision-making CTTT board. The board identifies the number of tracks in the event for each of the four $\mathrm{p_T}$ ranges and provides this and other information—e.g., whether a coincident CPS hit has been found and whether a track is isolated or not—in the form of so-called and/or terms to the DØ Trigger framework.

The first and/or terms of the DØ L1 CTT system were commissioned in February 2003. The CTT is now integrated into the DØ Trigger. In the following sections, we present first results on the L1 CTT efficiency.

III. The L1 CTT Performance

A. Comparison of Offline Data and L1 CTT

One of the ways to measure the L1 CTT performance is to compare the frequency at which L1 CTT finds tracks with the frequency at which the tracks are reconstructed offline with the standard DØ reconstruction software [14]. We perform this study on a data sample that is unbiased with respect to charged-track triggers.

To reject fake offline tracks we require them to pass standard quality criteria: each track must have all 16 (eight axial and eight stereo) hits in the CFT; the χ^2 of the track fit must be less than 10; and, finally, a track's distance of closest approach to the beam pipe must be less than 2 cm. Offline tracks that pass these selection requirements are referred to as 'good' offline tracks.

To analyze the performance of the L1 CTT we plot in Fig. 3 the high-$\mathrm{p_T}$ $(\mathrm{p_T} > 10\ \mathrm{GeV/c})$ CTT trigger turn-on curve as a function of the momentum of good offline tracks. A track is counted as found only if it is matched in azimuth angle by any

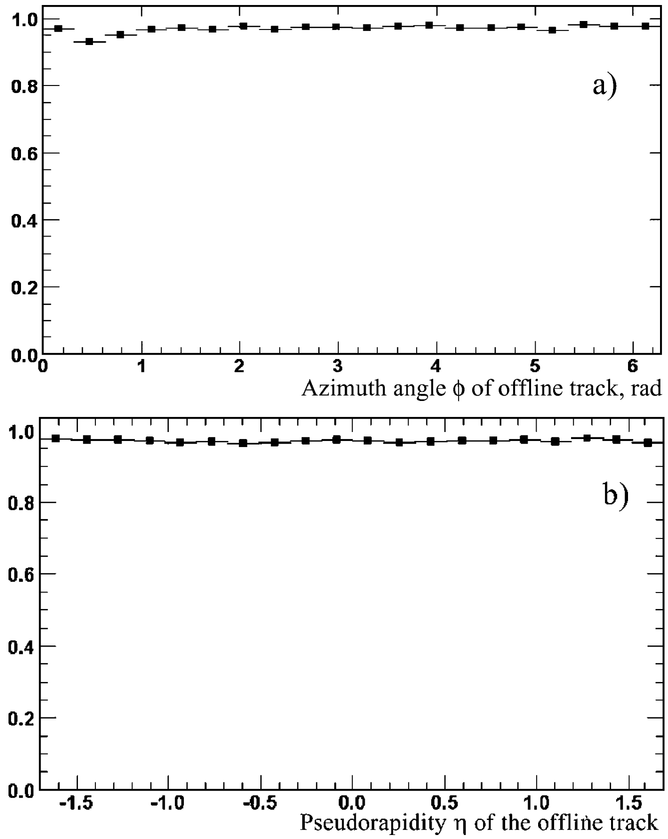

Fig. 4. Single high-p_T L1 CTT track efficiency as a function of (a) azimuth angle ϕ and (b) pseudorapidity η for offline tracks with transverse momentum exceeding 14 GeV/c.

L1 CTT track in the event. We measure the probability of L1 CTT to find tracks that are matched to offline good tracks in azimuth angle ϕ in recent data to be 97.3 $\pm$ 0.1%. The probability is flat in both azimuth angle ϕ and pseudorapidity η, defined as $\eta = \ln(\tan(\theta/2))$, where θ is a polar angle relative to the beam line (Fig. 4).

B. Study of the L1 CTT Performance Using a Sample of $\mathrm{Z} \rightarrow \mathrm{ee}$ *Candidate Events*

A disadvantage of comparing L1 CTT tracks and offline tracks is that even after applying stringent selection criteria on offline tracks, a fraction of them are misreconstructed. One way around this is to use charged leptons with high transverse momentum from well-understood physics processes such as decays of Z bosons into two electrons or two muons. The transverse momentum of the Z daughter leptons is well above 10 GeV/c; therefore, we are able to measure the performance of high-p_T L1 CTT trigger information.

We select good $\mathrm{Z} \rightarrow \mathrm{ee}$ candidate events from the DØ data taken after the CTT was commissioned. We use standard DØ selection criteria that are completely independent of the DØ tracking system. To estimate the efficiency ε of a given L1 CTT requirement, we estimate the number of Z events in the sample before (N_0) and after (N_1) the requirement is imposed. The efficiency is equal to

$$\varepsilon = \frac{N_1}{N_0}. \quad (1)$$

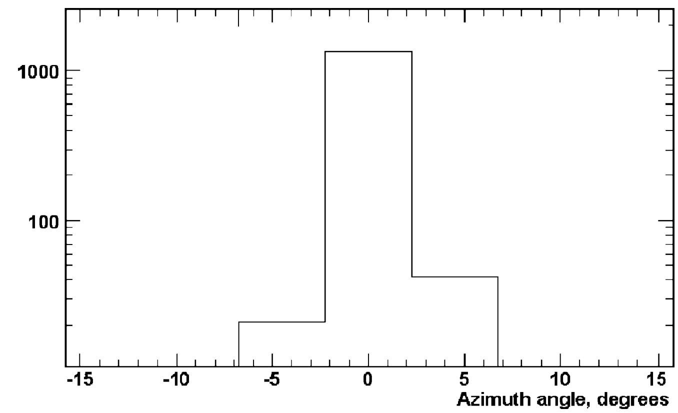

Fig. 5. Distance in azimuth angle between an offline electron from the Z decay and the L1 CTT high-p_T track. The width of each bin corresponds to quantization angle in L1 CTT (4.5 degrees).

To estimate the number of Z events in the sample, we fit the invariant mass distribution to the sum of a gaussian function for the Z peak and an exponential for the background.

The efficiency of finding at least one high-p_T L1 CTT track for an event in the $\mathrm{Z} \rightarrow \mathrm{ee}$ sample is measured to be 98.3 $\pm$ 0.1%. The efficiency of finding at least two high-p_T L1 CTT tracks in the same event is 89.1 $\pm$ 1.5%. The L1 CTT identifies a high-p_T track that is axially matched to an offline track with efficiency of 90.3 $\pm$ 2.0%. The distance in azimuth angle between an offline electron and the nearest high-p_T L1 CTT track is illustrated in Fig. 5.

C. Study of the L1 CTT Performance Using a Sample of $\mathrm{Z} \rightarrow \mu\mu$ *Candidate Events*

We select good $\mathrm{Z} \rightarrow \mu\mu$ candidate events from recent DØ data taken July through September 2003. The standard DØ selection criteria are utilized in the data selection. To reduce background from multijet events, we require two good offline CFT tracks to be matched with muon candidates. Using the same method as employed in the $\mathrm{Z} \rightarrow \mathrm{ee}$ analysis we measure the efficiency of the L1 CTT to find at least one high-p_T track in an event from the $\mathrm{Z} \rightarrow \mu\mu$ sample to be 99.8 $\pm$ 0.1%. The efficiency of L1 CTT to find at least two high-p_T offline tracks in the same event is 91.6 $\pm$ 0.7%. The efficiency of the L1 CTT to find a high-p_T track axially matched to a muon is 92.4 $\pm$ 1.0%.

D. Physics Data Taken With the CTT Trigger

The ability of the CTT to detect charged tracks with p_T as low as 1.5 GeV/c at L1 provides a unique opportunity to trigger on physics processes that are otherwise very hard or impossible to identify at L1, such as $\mathrm{J}/\Psi \rightarrow \mathrm{ee}$ decays. To select events from these processes, a dedicated trigger that uses both the L1 CTT and DØ Calorimeter information was designed. After only a week of running with this trigger, the DØ detector collected about 610 $\mathrm{J}/\Psi \rightarrow \mathrm{ee}$ events in 7.6 pb^{-1} of integrated luminosity, more than during the whole preceeding Run 2 period corresponding to a data sample at least 10 times as big (see Fig. 6).

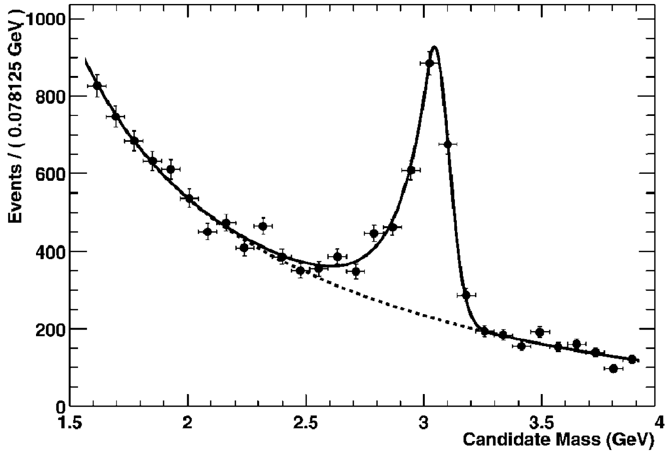

Fig. 6. Invariant mass of the dielectron system in the events collected by the dedicated L1 CTT/L1 CAL trigger.

IV. CONCLUSION

The DØ CTT commissioning is progressing on schedule. DØ began use of L1 CTT information to trigger on tracks in June 2003. First studies of the data indicate excellent performance of the system. The DØ CTT group is currently working both to increase the efficiency of the L1CTT and to commission triggering on forward tracks utilizing the Forward Preshower Detector.

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