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THE LEVEL 0 TRIGGER FOR THE DØ DETECTOR*

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Abstract

The DØ detector [1] has completed its first data taking run at the Fermi National Accelerator Laboratory's $\bar{p}$-p Tevatron collider. The Level 0 trigger system is the DØ experiment's first trigger level used to identify colliding beam crossings containing interactions. It consists of two hodoscopes of scintillation tiles located just outside the DØ central tracking region. The Level 0 trigger provides a fast measurement of the interaction position along the beam axis for use in early trigger decisions. A slower, more accurate position of the interaction and an indication of the occurrence of multiple interactions are available for subsequent trigger decisions. In addition, the Level 0 trigger is used as a luminosity monitor for DØ . Results on the performance of the Level 0 trigger are presented.

I. INTRODUCTION

The Level 0 trigger is a fast triggering device for the DØ detector. With a beam crossing occurring every $3.5\mu s$, the Level 0 trigger indicates which beam crossings contain non-diffractive inelastic collisions and monitors the instantaneous luminosity. The Level 0 detector comprises two hodoscope scintillator arrays located on the inside faces of the DØ Detector's two end-cap calorimeters, $140cm$ from the center of the detector. Each array partially covers a region in pseudorapidity of $1.9 < |\eta| < 4.3$, with nearly complete coverage over $2.2 < |\eta| < 3.9$. The pseudorapidity coverage is set by the requirement that a coincidence of both Level 0 arrays be $\geq 99\%$ efficient in detecting non-diffractive inelastic collisions.

The large spread in the Tevatron vertex distribution at the DØ detector ($\sigma = 30cm$) introduces large errors in the transverse energy (E_t) values calculated by the DØ trigger. The Level 0 trigger provides information on the primary interaction vertex location along the beam direction by timing particles in the beam jets. The difference in the arrival times for particles in the opposing beam jets is used to determine the vertex position according to:

$$z_v \approx \frac{c(t_- - t_+)}{2} \qquad (1)$$

where t_- is the north array arrival time and t_+ is the south array arrival time. The vertex position from the Level 0 trigger is used to correct the E_t values used in subsequent trigger decisions. The spread in particle times is used as an indication of multiple interactions.

We present the results of the investigation into the performance of the Level 0 trigger throughout the run over the full range of luminosities achieved by the Tevatron during the 1992-1993 collider run.

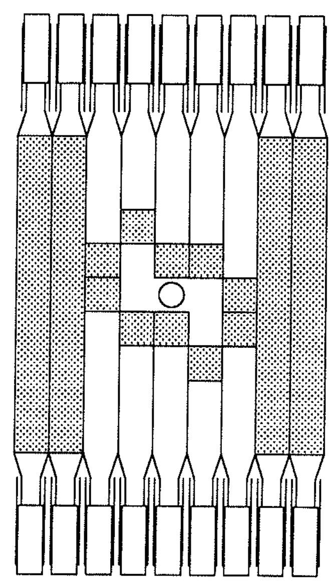

Figure 1: A single layer of one Level 0 array. The shaded regions are scintillator. The PMTs are shown at top and bottom with light guides connecting the scintillator to the PMTs.

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II. Level 0 Detector

The Level 0 detector is composed of a north array ($-z$) and a south array($+z$). Each array is comprised of two layers of $1.6cm$ thick scintillator [2] with $7cm$ square 'short' tiles occupying a 5x5 inner checkerboard and $7cm$ by $65cm$ rectangular 'long' tiles around the perimeter. Each scintillator tile was glued [3] to a light guide [4] which was glued to a photomultiplier tube [5]. Short tiles have a single PMT connected via light guide whereas long tiles have a PMT connected to each end. See Figure 1. Two such layers are positioned at right angles to each other so that the scintillator tiles are not overlapping except in the corners. See Figure 2.

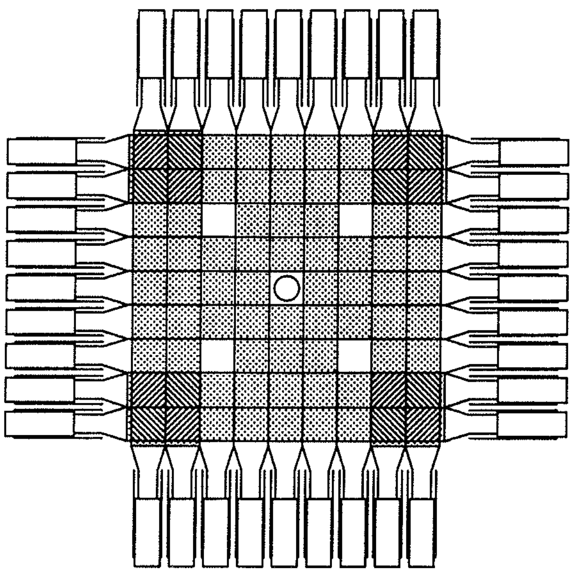

Figure 2: The two overlapped layers of one Level 0 array. The shaded regions are scintillator.

III. Level 0 Electronics

Signals from the photomultipliers are processed on a channel by channel basis in electronics located on the detector platform. A block diagram of the Level 0 electronics is shown in Figure 3.

Each pulse is amplified [6] with one output sent to an analog sum [7] and a second output sent to a charge(Q) and Time to Amplitude Converter (QTAC). Analog sums of the four tiles closest to the beam pipe (sum 4), the 20 short tiles (sum 20), and all 36 channels (sum 36) are accumulated for each end. The sum 20 from each end is passed into a constant fraction discriminator (CFD) [8]. The CFD outputs a start pulse using the sum 20 from the $-z$ array and a delayed stop pulse using the sum 20 by the $+z$ array. A GaAs-based digital TDC [9] determines the time difference to make a fast measurement of the vertex position for Level 1 [10] trigger E_t corrections. A cut on the absolute value of the vertex at $|z_f| < 97cm$ from the center

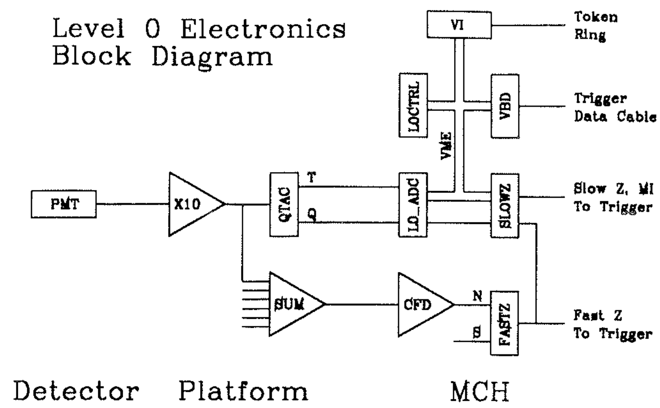

Figure 3: Level 0 Electronics block diagram. A constant fraction discriminator (CFD) converts the array analog sums to start and stop timing pulses. L0CTRL controller controls and coordinates data readout of the L0 trigger hardware. VME Buffer Driver (VBD) accumulates the L0 trigger data for an event to send it into the event stream. The downloading and monitoring of the Level 0 electronics occurs via the Vertical Interconnect (VI). The QTAC, L0_ADC, and L0_VTX (SLOWZ) are described in the text.

of DØ eliminates beam-gas and beam-halo interactions. The fast vertex position is available to the Level 1 trigger within $800ns$ of the beam crossing in the form of a 5-bit two's complement vertex position whose least significant bit (LSB) bin width is $6.25cm$.

The QTACs have eight channels of time to analog conversion and charge integration circuits. For each channel, a time storage capacitor is held at constant voltage until the PMT signal crosses a threshold voltage. This starts current flowing out of the capacitor until an external stop signal halts the flow leaving a final voltage level. Similarly, a charge capacitor is set to ground and accumulates the PMT signal charge during a gated time period. The analog signals from the QTACs are sent from the platform to the Movable Counting House [1] where they are digitized in the L0_ADC boards by 10 bit ADCs [11]. The digitized time has a LSB bin width of $32ps$; the digitized charge has a LSB bin width of $\approx 1pC$. The L0_ADCs convert these quantities into a corrected time, t_c, using Eq. 2:

$$t_c = c_0 + c_1 t + \frac{c_2}{\sqrt{q - q_0}} \qquad (2)$$

where c_0 is the zero time displacement, c_1 is the slope correction, c_2 is the charge-slewing correction, t is the digitized time, q is the digitized charge, and q_0 is the charge pedestal. The corrected times are calculated using lookup tables downloaded into the L0_ADCs via the Vertical Interconnect (VI) [12]. Corrected times have a LSB bin width of $50ps$ and are zeroed if they do not fall within a valid time window. The corrected times for the two PMT signals of each long tile are averaged. Each ADC board calculates the number of valid corrected times, a sum of the times, a sum of the squares of the times, the minimum time, and the maximum time. Each L0_ADC adds its quantities into the values of the previous L0_ADC until the last one which passes the result on to the vertex board (L0_VTX) associated with its channels. Statistical quantities for short and long tiles are separately passed to the L0_VTX boards.

Each L0_VTX board calculates the average arrival time for particles hitting each scintillator array. First, if the number of short tiles with valid time hits exceeds 3 then only the short tiles are used. If there are insufficient short tile hits, then the long tile hits are also used. If at least 5 tiles have hits then a further check is made. If the earliest and latest time differ by greater than $600ps$ then both are thrown out. This reduces the effect of the long tails in the hit time distributions. The remaining times are then used in the calculation of a mean and standard deviation for the array. The difference of the two mean times is used to obtain the vertex position using Eq. 1. The standard deviations from both ends are added in quadrature to obtain a total deviation (σ_{tot}) which is used to set the multiple interaction flag.

In any beam crossing, more than one interaction can occur with the probability of a multiple interaction increasing with luminosity. The Tevatron beam bunches are of finite size so that there is a spread in the time and position of each interaction with respect to the nominal crossing time and center of the DØ detector. Thus, beam crossings with multiple interactions will have an increased spread in arrival times at the Level 0 arrays. The vertex board has four flag values (1-4) that it can use to indicate a single or multiple interaction likelihood. The four flags are 'most likely single' (flag=1, $\sigma_{tot} < 0.4ns$), 'likely single' (flag=2, $\sigma_{tot} < 0.6ns$), 'likely multiple' (flag=3, $\sigma_{tot} > 0.6ns$), or 'most likely multiple' (flag=4, $\sigma_{tot} > 1.0ns$) interaction. Note that the vertex position is no longer accurately measured for multiple interactions. This process is somewhat slower than the fast sums and arrives at the DØ trigger within $2.1\mu s$.

The digitized times and charges, the corrected times, the vertex and multiple interaction information are stored for the triggered beam crossing and the five previous beam crossings. These data are double-buffered with readout into the VME Buffer Driver (VBD) [13] coordinated by the L0_CTRL controller board. The VBD provides a standard interface to the DØ data acquisition system [14].

IV. CALIBRATION

Calibration of the Level 0 was achieved using beam data taken during the run every three to four weeks or after a change to the hardware. Runs were selected with relatively low luminosity to reduce multiple interactions. Cuts were made to select single interactions based on DØ central tracking information. The ADC pedestals were obtained for each channel and a fit was performed to determine the zero time displacement(c_0), the slope correction(c_1), and the charge-slewing correction(c_2) constants. The calibration constants and pedestal values are used to create new lookup tables that are downloaded into the L0_ADC boards.

The small size of the short tiles allows for an excellent time resolution. Figure 4 shows the time resolution of a typical tile. The average time resolution of the short tiles, $240ps$, matches the required vertex position accuracy. Despite being viewed at both ends by photomultipliers, the long tiles had a poorer time resolution, $510ps$, as seen from a typical channel in Figure 5. This is due to the multiplicity of particles hitting each long tile. Although still useful for the slow vertex, the multiple hits per tile made this resolution disappointingly large.

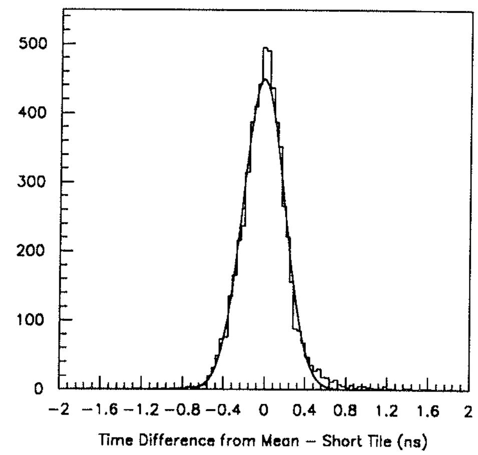

Figure 4: Timing resolution of a short tile.

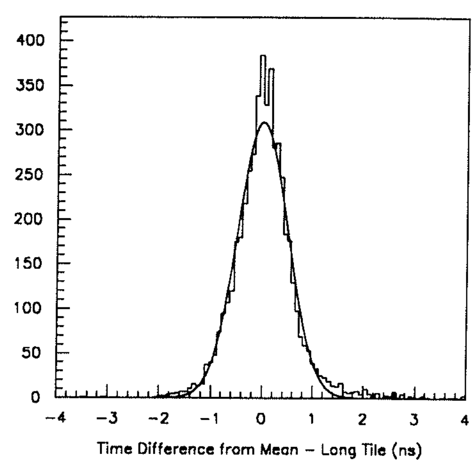

Figure 5: Timing resolution of a long tile.

In addition, light pulses from a UV laser [15] are distributed to each PMT via fiber optics for use in calibration and monitoring the trigger.

V. Results

The efficiency of the Level 0 trigger was determined by examination of data taken using a zero bias trigger, a minimum bias trigger, a fast vertex veto trigger, and the DØ physics trigger. The zero bias trigger fires on random beam crossings with only a prescale used to prevent saturation of the data acquisition system. The minimum bias trigger fires for beam crossings with a valid fast vertex ($|z_f| < 97cm$). The fast vertex veto trigger fires on beam crossings with a $15GeV$ jet of particles in a narrow cone as measured in the DØ calorimeter that failed to find a valid fast vertex. The DØ physics trigger fires on a wide ranging set of possible lepton and jet signatures in the DØ detector indicating a hard scattering process and includes a valid fast vertex requirement.

Analysis of the data indicated four sources of inefficiency: beam halo, interactions occurring in the previous rf bucket (satellite-satellite), the fast vertex cut at $|z_f| < 97cm$, and no particles hitting the short tiles. The beam halo and satellite-satellite rates were measured in a zero bias run taken at high luminosity, $5 \times 10^{30} cm^{-2} s^{-1}$. These processes fire the fast vertex trigger outside the expected time window resulting in inefficiencies of 1% and 0.1%, respectively, at the given luminosity. Since the Tevatron vertex distribution has a $30cm$ width, a small number ($< 1\%$) of interactions have a fast vertex position outside the fast vertex position cut. It is desirable to eliminate these kinds of events and the Level 0 trigger was designed to reject them.

The last source of inefficiency occurs when no particles hit the short tiles. This can be attributed to incomplete coverage, charged particles passing through tile corners, and failure to detect single particles. We estimate this inefficiency by extrapolating the observed multiplicity of tile hits to zero. The number of short tiles hit per single interaction beam crossing with a valid slow vertex ($|z_s| < 100cm$) is shown in Figure 6 for minimum bias and physics triggers. The mean multiplicity of hits is 10.3 and 12.1 short tiles hit per interaction, respectively. A projection of the multiplicity distribution into the zero hit bin indicates that the short tiles in a Level 0 end array have no hits in 2% of the interactions for both minimum bias and physics triggers. Assuming the two Level 0 arrays are uncorrelated, we estimate a 4% inefficiency for the physics trigger and the minimum bias counting rate used to calculate the luminosity.

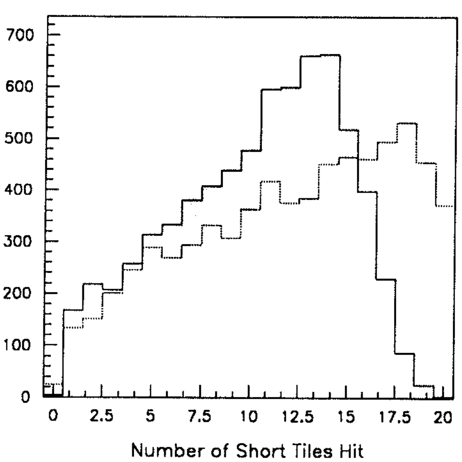

Figure 6: Number of short tiles hit per single interaction beam crossing with a valid slow vertex. Data were taken from minimum bias (solid) and physics (dots) triggers.

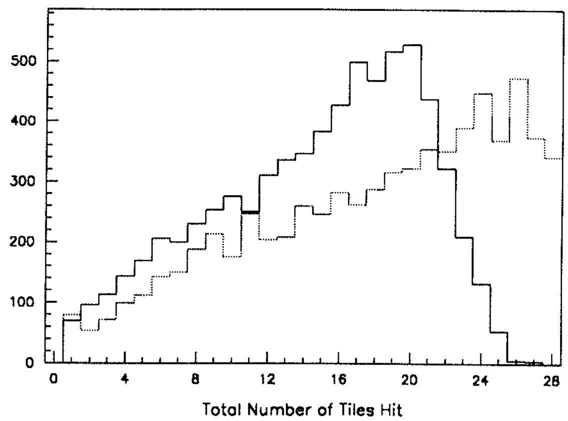

Figure 7: Total number of tiles hit per single interaction beam crossing with a valid slow vertex. Data were taken from minimum bias (solid) and physics (dots) triggers.

Distributions showing the total number of tiles hit, short and long together, is shown in Figure 7. The mean of the minimum bias triggers is 14.4 tiles hit per interaction and the mean of the physics triggers is 18.0 tiles hit per interaction. The projection into the zero hit bin indicates that a Level 0 end array has no hits in 0.6% of the interactions for both minimum bias and physics triggers.

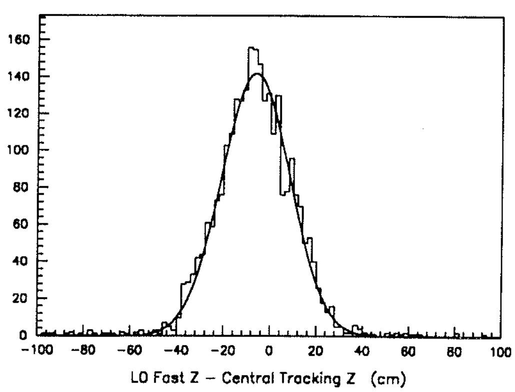

Figure 8: Fast Vertex Resolution.

The fast vertex veto triggers indicate similar results. A comparison of the trigger rates for interactions with a jet and a valid fast vertex compared to those with a jet and no valid fast vertex indicated that the valid fast vertex was 97.2% efficient for the physics trigger.

A comparison of the Level 0 vertex position measurements with those of the DØ central tracking detectors [16] shows a good agreement for both the fast and slow vertex position. The fast vertex position relative to the central tracking vertex has a standard deviation of 15*cm* for single interaction events. See Figure 8. Because of the discrete nature of the fast vertex solution (6.25*cm* bins), the fast vertex can not be shifted to be exactly centered on the tracking results and therefore a small mismatch in timing resulted in a 6*cm* offset. The slow vertex position relative to tracking has a standard deviation of 3.5*cm* for single interaction events. See Figure 9.

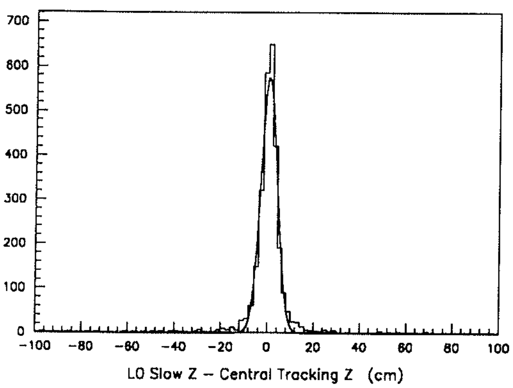

Figure 9: Slow Vertex Resolution.

Comparison of the number of events indicated as 'most likely single' and 'likely single' interactions for the physics triggers over the full range of luminosities seen is shown in Figure 10. Also shown is a curve indicating the expected single interaction fraction

$$P(1) = e^{-\mathcal{L}\sigma/\nu} \tag{3}$$

where σ is the inelastic cross-section, $\mathcal{L}$ is the luminosity, and $\nu = 285kHz$ is the Tevatron beam crossing frequency. The flag=1 rates follow the curve at roughly 70% efficiency. The over-estimation of flag=2 rates at higher luminosities is under study as it shows some contamination from multiple interactions. The Level 0 information is combined with the central tracking and calorimeter information forming a multiple interaction tool. The probability the tool indicates a single interaction (tool$\leq$ 2) matches the curve over the full luminosity range. See Figure 10.

VI. Luminosity Monitoring

The DØ luminosity is obtained by measuring the rate for non-diffractive inelastic collisions. Events are selected by requiring the fast vertex Level 0 coincidence with $|z_f| <$

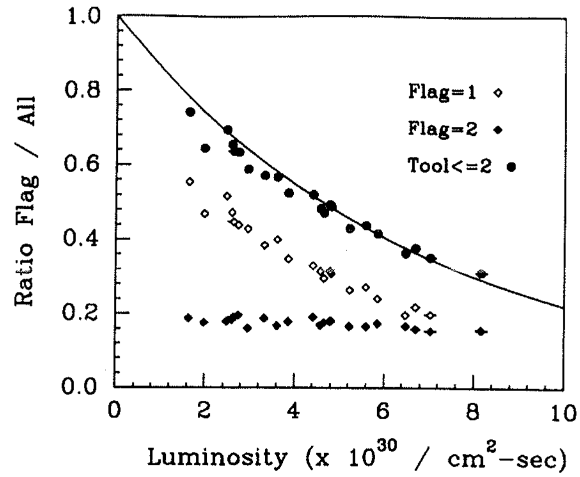

Figure 10: Level 0 Multiple Interaction flag and tool probabilities compared to the single interaction probability.

97*cm*. Scalers count live crossings, coincidences passing the vertex cut, and single hits in groups of similar tiles with and without valid coincidences. The scalers allow the luminosity to be measured independently for each beam bunch and provide feedback to accelerator operations. The effective cross section for the non-diffractive inelastic collisions, $\sigma_{lum} = 42.9mb$, was determined from published cross sections [17] and Monte Carlo estimates of efficiency. Corrections for multiple interactions are applied. The luminosity has an uncertainty of 12% due mostly to the cross section measurement and uncertainty in the efficiency.

VII. Conclusions

The Level 0 trigger functioned with great reliability and stability during the first data taking run for the DØ detector. It provided a fast interaction trigger with a vertex resolution of 15*cm* within 800*ns*. A slow vertex was provided with a resolution of 3.5*cm* within 2.1μs. At the same time, a multiple interaction flag indicated single interactions with a 70% efficiency. The Level 0 detectors were also used to determine the luminosity for the experiment.

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