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Central Muon Level-1 Trigger Electronics*

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Abstract

We present the level-1 trigger module used for the CDF central muon drift chambers. Addressable registers select trigger mode for calibration, debugging, or data acquisition. A transverse momentum cut on muons exiting the solenoidal magnetic field region is made by using drift time differences between aligned pairs of anode sense wires. Cosmic ray results studies are presented and track angle selection is shown to be better than 5 mR.

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Central Muon Level-1 Trigger Electronics

1. Introduction

Fast, online muon track identification is critical for many studies at the Fermilab Collider Detector Facility. The muon level-1 trigger electronics integrates the central muon system with the CDF trigger system. It not only generates trigger information for physics data acquisition but also allows for chamber calibration, system monitoring and debugging. This paper will describe the different trigger modes, give an overview of how they are implemented in the electronics, and present results obtained at Fermilab using cosmic rays.

2. System Description

Each central calorimeter wedge includes a set of three proportional drift chambers for muon detection, each of which has 16 rectangular cells. Wires from alternating cells in the same layer are connected together at the $\theta = 90°$ end of the wedge so that there are 8 anode sense wires per chamber. The 8 wires are divided into four layers (increasing radial distance from the $p\bar{p}$ interaction point) and two towers each covering about 2.5° in ϕ. The electron drift velocity is about 50 μM/ns in 50-50 argon-ethane gas with 1% ethanol. The maximum drift time for a single wire is about 700 ns. Figure 1 shows a cross section of a single chamber. A complete description of the chambers is provided in reference [1]. For each chamber, there is one RABBIT muon adc/tdc card (MAT), described elsewhere [2], which sits in the RABBIT crate on the wedge. For trigger purposes MAT asserts a TTL level when a signal arrives from a wire. This timing information is sent via a cable from a front panel connector to the muon level-1 trigger card (MTRG1), which is a RABBIT card sitting in the same crate. All three MATs are connected to a single MTRG1, so there is one per wedge to coordinate the drift time information from 24 wires.

The muon system operates in two distinct modes, calibration data acquisition and physics data acquisition. MTRG1 has to be able to identify two types of signals: tracks of penetrating particles, from $p\bar{p}$ collisions or from cosmic rays, and single wire hits from the Fe^{55} x-ray sources that are built into the chambers for fiducial measurement. MTRG1 makes a cut on the angle of a track by using the difference in drift times for pairs of radially aligned wires, $|t_4 - t_2|$ or $|t_3 - t_1|$, where the t_i are the drift times to each of the layers (figure 1). This amounts to a cut on the transverse momentum, p_t, for a charged particle emanating from the $p\bar{p}$ interaction region and passing through the solenoidal magnetic field. The angle cut is also used to vary the acceptance of the trigger when counting cosmic rays. MTRG1 allows for removal of noisy wires from the trigger, can require a trigger coincidence between both pairs of wires in a tower for a more stringent cut, and layers can be disabled for troubleshooting.

MTRG1 generates a separate trigger decision for each tower. The trigger logic depends on the contents of three 8-bit read/write registers on the card. Each tower has bits called OFF, SET, and AND. In addition, there is an ENBL bit for each of the four layers, a bit to disable a default cut on the drift time difference, and a bit to enable the Time Monitor, described below. The trigger logic for tower 0 is outlined in figure 2. A fourth 8-bit read/write register controls an 8-bit digital-to-analog converter (DAC).

Setting the OFF bit for a tower inhibits triggers from that tower, so that hot wires can be disabled. The SET bit permits a trigger from either wire of a pair, useful in both

Fe^{55} calibration data acquisition and in pattern generation for trigger level 2 testing. The AND bit for a given tower requires a coincidence between both wire pairs in a tower, as in cosmic ray data acquisition, while turning off the ENBL bit for a layer removes that layer from the trigger. The card is designed with normal data acquisition as a default state that is set when the card is powered up. All hits must coincide with a gate to generate a trigger, where the gate corresponds to the window when the MAT card can receive events. The gate derives from the RABBIT timing signals BFR1 and AFTR2, as $\bar{B} \cdot A$.

Output of the MTRG1 card is 8 differential ECL signals for trigger level-2 use. The 8 outputs are a trigger bit for each tower, a logical OR of the six tower triggers, and a pulse equal in width to the window set by the DAC for monitoring. All trigger bits are cleared by a RABBIT RESET signal.

3. Trigger Modes

Normal data acquisition. Figure 1 shows a cross-section of a muon chamber. In each tower there are two pairs of wires, and the wires of each pair fall on a line parallel to a radial line from the $p\bar{p}$ interaction point [3]. The two pairs are offset from each other by 2 mm to resolve the left-right ambiguity in track fitting. In general, a particle track makes an angle α with the radial line, and α is found from the difference in drift times for a pair of wires. Oblique tracks (large α) crossing the radial centerline can have a small drift time difference and will make a small contribution to the trigger rate. MTRG1 makes a cut on the drift time difference using the circuit in figure 2. V_{ref} is set so that a hit on a wire fires the first comparator immediately, while the capacitor charges gradually to V_{tim} before the second comparator fires. The DAC sets V_{tim}, so that the output of the first

AND gate is of variable width. A hit on the second wire of the pair generates a similar gate. A track satisfies the angle cut if the two gates overlap. Gate width is varied in 1 ns steps, and is available at the Time Monitor output. In summary, normal data acquisition mode requires a coincidence between either of the two aligned pairs of wires in a tower within a time window determined by a DAC.

For a 1.5 Tesla magnetic field, the impact parameter b of a track from a $p\bar{p}$ collision is b=(500mm)p_t^{-1}, with p_t in GeV. Since the muon chambers are 3470 mm from the collision vertex, the track angle is given by $\alpha = 0.14 p_t^{-1}$. Wires in a pair are separated by 55 mm, so the drift time difference ranges from about 160 ns for p_t=1 GeV to about 16 ns for p_t=10 GeV. Multiple scattering of a charged particle passing through the calorimeter varies from 150 ns to 15 ns over the same momentum range, so that the contribution to the error in momentum measurement from the MTRG1 electronics will be slight.

Cosmic ray trigger. Measurements of electron drift velocity in the chambers are made using cosmic rays and the 2 mm offset of the wire pairs from the radial centerline. That is,

$$v_{drift}^{-1} = [(t_1 - t_4) - 3(t_2 - t_3)]/4d$$

where t_1, t_2, t_3, and t_4 are the drift times for each of the four wires in a tower, and d is the offset. Only tracks with four hits are useful in determining v_{drift}, so MTRG1 requires a coincidence between both pairs of wires in a tower to eliminate false triggers that can occur in normal trigger mode. Four layer coincidence eliminates most of the tracks that cross the radial centerline and can give incorrect track angles, improving the v_{drift} measurement.

Source calibrations. Track position along the wire is measured using charge division.

The chambers operate in limited streamer mode and we have been able to attain spatial resolutions of 0.05% of the wire length in testbeam and cosmic ray studies[1]. The collimated Fe^{55} x-ray sources built into the chambers as fiducial markers are essential to obtain such precision. The trigger mode for source data acquisition consists of disabling all but one layer from the trigger inputs, and setting the SET bits. The result is that a hit on a single wire will generate a trigger. If SET is set for one tower at a time, sources with higher counting rates won't dominate the slower sources. The trigger rate for a typical wire is 50 to 100 s^{-1}, but some of the 4,608 sources in the central muon system vary by a factor of 2 from those rates.

MTRG1's ability to exclude combinations of towers and layers from the trigger is also useful in system troubleshooting. Hot wires producing false triggers can be located and disabled by writing the appropriate 8 bit data word to one of the MTRG1 registers.

4. Results

To test the angle cut made by MTRG1 we measured cosmic ray trigger rates for different DAC settings with CDF in the collision hall. Using a simplified model of a single tower with a $\cos^2\theta$ distribution of cosmic muons, we predict that the rates should increase for larger angle cuts in the proportions 1:2.1:4.2 for DAC settings of 28 ns, 55 ns, and 125 ns, respectively. These correspond to angle cuts of 25 mr, 50 mr, and 114 mr. A monte carlo simulation of the counting rates yields the same ratio. The model idealizes the wire cells as uniform, aligned rectangles with centered wires, whereas in actuality the cells are staggered slightly and have varying widths. Furthermore, we do not consider that for the topmost wedge oblique tracks will pass through the steel of the magnet yoke, which absorbs muons with less than about 700 MeV. Both these effects will reduce the rates for large angles compared to the simple model.The actual variation in rates we observed for the top wedge was $(1):(2.2 \pm .1):(2.8 \pm .2)$.

Figure 3 shows the azimuthal dependence of the trigger counting rates for the three different cuts. Absorbtion of muons in the wedges is seen by comparing the wedge at 15° with the wedge at 150°, which is beneath it but at the same angle from the vertical. The wedges around $\phi = 90°$ trigger on nearly horizontal cosmic rays, at a lower rate.

Figure Captions

Figure 1. Cross section of a single muon chamber, showing drift times t_i and the track angle α.

Figure 2. Trigger circuit for single tower. V_{tim} is set by an 8-bit DAC. Trigger mode is selected using OFF, SET, AND, and ENBL bits stored in adressable registers. HIT is converted to differential ECL before being output.

Figure 3. Cosmic ray trigger rates vs. azimuth angle for three different DAC settings. The wedge at 0° is vertical and at the top of the detector. Lower wedges are shielded from cosmic rays by the steel of the top wedges.

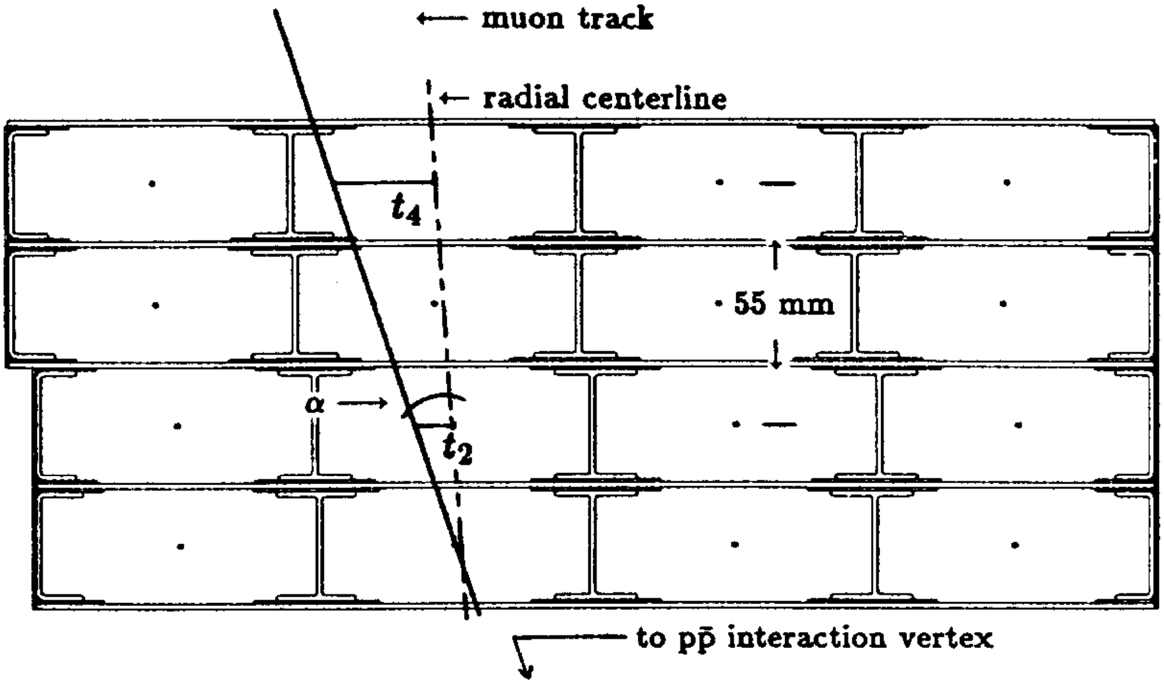
References

1. CDF NIM paper, section 4.1 'Central Muon Detector'

2. CDF NIM paper, section 7.3 'Rabbit Front End Electronics'

3. CDF NIM paper, section 4.1.1 'An Alignment System for the Central Muon Chambers'

Figure 1.



muon track
radial centerline
t_4
55 mm
α
t_2
to p$\bar{p}$ interaction vertex

Figure 2.

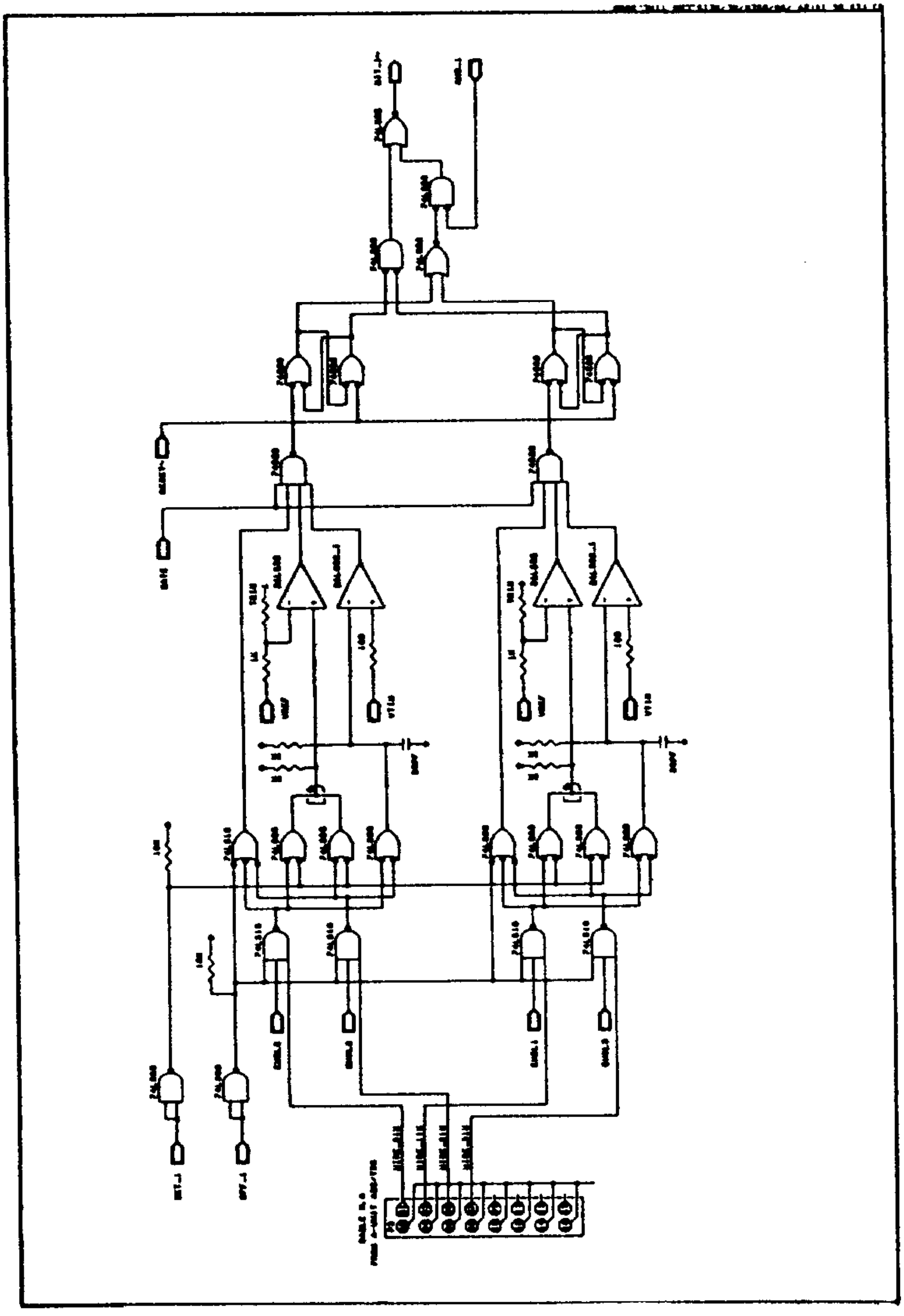
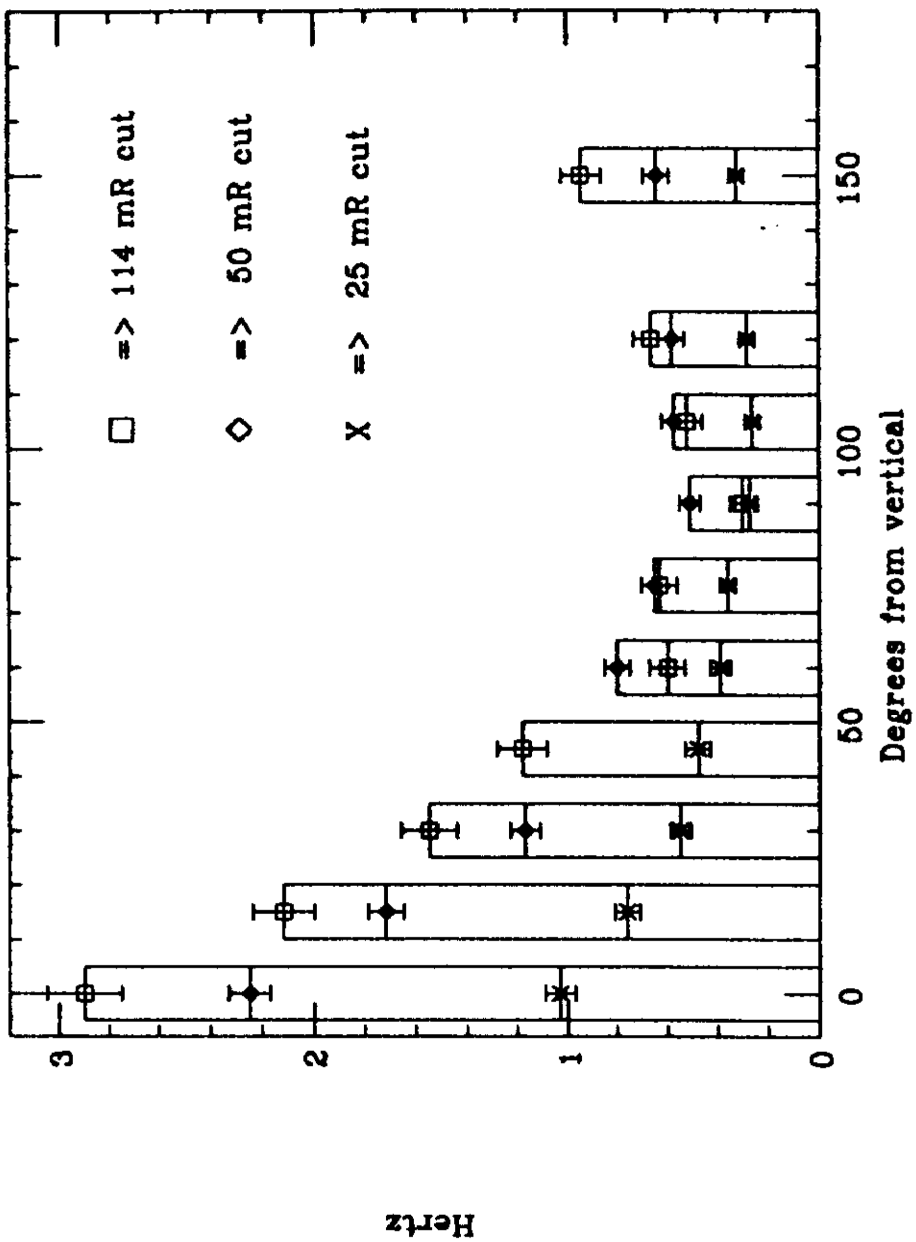


Figure 3.


□ => 114 mR cut
◇ => 50 mR cut
X => 25 mR cut
Hertz
0
1
2
3
Degrees from vertical
0
50
100
150