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Abstract

The trigger electronics for the muon system of the Fermilab D0 detector is described. The hardware trigger consists of VME-based cards designed to find probable tracks in individual chambers and then match these track segments. The fast trigger is highly parallel and able to discern probable tracks from about 15,000 trigger cells in under 200 ns from receipt of all bits in the counting house. There is a parallel confirmation trigger with a response time of 1 - 5 microseconds that provides a crude calculation of the momentum and charge of the muon.

I. OVERVIEW OF THE D0 MUON SYSTEM

The D0 muon system consists of five magnetized iron toroids and three layers of drift chambers. There is a central toroid covering a region between 40 degrees and 140 degrees with respect to the beam. The end toroids cover from 10 degrees to 40 degrees on each end of the detector and there are small angle toroids to cover from 3 degrees to 10 degrees from the beam. Drift chambers are situated to provide one measuring layer inside the toroids and two layers outside the toroids. Details of the drift chamber design are found in Ref. [1].

The wide angle muon system (WAMUS) consists of drift chambers fabricated as 164 separate modules [2], and will measure tracks that go through the central and end toroids. The wires in the modules run parallel to the field, so that the bending of the track will take place in the drift coorinate. Individual modules in the inner layer (A-layer) have maximum of 96 total cells, consisting of 4 staggered decks of up to 24 cells of 10 cm width. The modules in the layers outside of the toroid (B- and C-layers) have 3 staggered decks of 10 cm-wide cells each, to a maxumum of 72 cells per module.

For measuring tracks through the small angle toroids there are six stations of drift tubes (SAMUS), three on each end of the detector. Each SAMUS station consists of 448 drift cells, 3 cm wide, in an X,Y,U configuration [1,3]. Information from each plane of tubes in one station is read out as if it were two modules to permit use of the same readout electronics for both

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WAMUS and SAMUS. Each drift cell in both WAMUS and SAMUS provides a single latch bit into the trigger system -- a total of about 15,000 inputs. This data is transferred to the counting house using differential current drivers and "twist-and-flat" cable.

In the counting house signals are handled by four types of crates (Table 1). The crates are all 9U x 280 mm using the same custom backplane. The custom backplane matches extended VME specifications on J1 and J2. In addition the A and C lines of J2 are bussed throughout the backplane. The J3 connector is used to supply -5 volts, +15 volts and -15 volts which are not standard in VME crates. The J3 connector is also used to connect the differential signals from the modules into the individual card slots of the crate.

Table 1 Crate types for the D0 muon system

Data Crate (24):
1 Vertical Interconnect
1 68020-based microprocessor
1 VME Buffer-Driver
1 FANOUT card
5-11 Module Address Cards (MACs)
1-2 ADCs

Level 1 Trigger Crate (4):
10-16 Coarse Centroid Trigger (CCT) cards

Level 1.5 Trigger Crate (5):
1 Vertical Interconnect
1 68020-based microprocessor
1 VME Buffer-Driver
1 CCT data-latch card
1 OTC Manager
10-16 Octant Trigger Cards (OTCs)

Muon Supervisor Crate (1):
1 Vertical Interconnect
1 68020-based microprocessor
1 Trigger Monitor
12 TIMERs

The data crates, level 1.5 trigger crates and supervisor crate each have a 68020-based microprocessor to download data to the modules, perform in-situ testing of the electronics and oversee the event building. A "Vertical Interconnect" card is used to interface the crate to the host system [4]. Data crates and level 1.5 crates also have "VME Buffer-Driver" cards to transfer event data to a microprocessor farm for a second level trigger. Trigger information is transferred between the VME crates on twist-and-flat cable using differential RS-485 drivers.

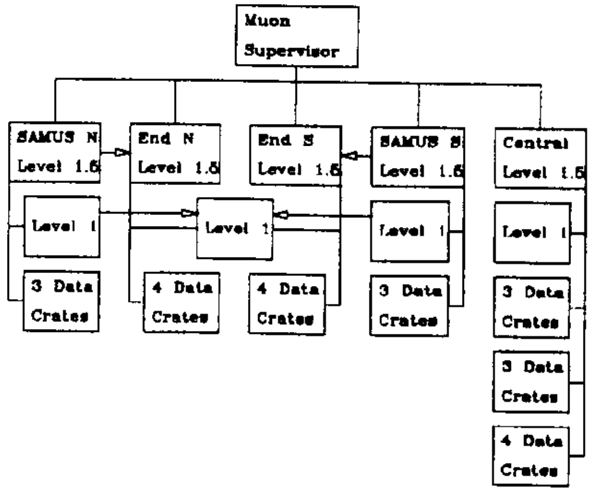

Fig. 1 Interrelationship of the of muon crates

The crates in the counting house are divided into groups based on the geographic location of the modules on the detector (Fig. 1). The supervisor crate is the interface to the system clock and to the trigger framework [5]. Muon trigger sectors are geographically based on the toroid the muon passes through. The five trigger sectors have four level 1 trigger crates (the two end sectors are able to fit in a single crate), and five level 1.5 trigger crates. Each sector has three to ten data crates divided into units of three or four crates for compatibility with the TIMER cards in the muon supervisor crate. Trigger crates in the end region include logic to handle the overlap between data in the SAMUS system and data in the end crates.

II. MODULE ADDRESS CARDS

A. Function of the Module Address Card

Each muon module has a Module Address Card (MAC) in a VME crate to interface that module with the rest of D0 (Fig. 2). The MAC acts to supply timing signals to the module front end, receive the latch bits, perform zero suppression for data acquisition and generate trigger patterns [6]. The MAC resides in a data crate with up to 11 other MACs. The data crate also has a FANOUT card to distribute signals to the MACs from a TIMER card in the supervisor crate.

The latch bits are sent to the MAC in three or four groups of 24, corresponding to decks, at 10 MHz and are demultiplexed and stored in a two stage buffer. Mask registers can be downloaded to remove hot bits in the data buffer. The buffered data is processed by eight EP900 PALs that can generate either a map of raw bits or a map of trigger bits based on the raw hits. The hit map is processed through a hit editor and priority encoder, which loads an output FIFO with the addresses of the bits.

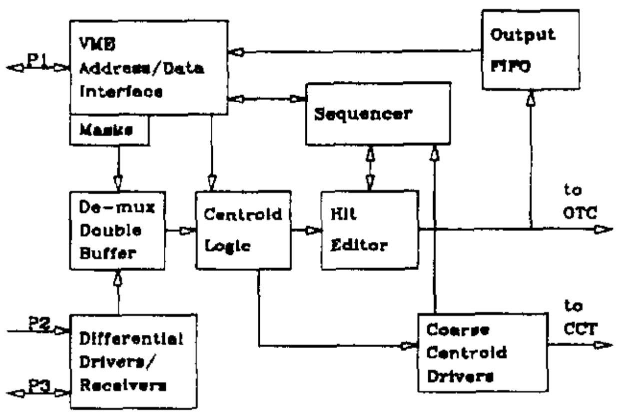

Fig. 2 Block diagram of Module Address Card (MAC)

The trigger bits from the MAC are termed "centroids". Centroids represent likely intersections of tracks with a muon module. The logic assumes that a particle will hit at least two out of three cells in a module within a three column band. This is consistent with 99% of the particles passing within 45 degrees of normal incidence.

The MAC produces centroids with two granularities. Centroids with half-cell localization are termed fine centroids. In WAMUS the fine centroids are localized to 5 cm and in SAMUS the fine centroids are localized to 1.5 cm, execpt in the SAMUS u-plane which only localizes the fine centroids to 3 cm. The MAC also produces a logical OR of the fine centroids, called coarse centroids. In WAMUS the coarse centroids are groups of 3 fine centroids. In SAMUS the coarse centroids are groups of 4 fine centroids.

During a live event cycle, the MAC is set to send coarse centroids for the fast, level 1 trigger. After the the last of the raw hits for that module has arrived, the MAC produces this coarse centroid trigger pattern in about 100 nsec. If a level 1 trigger is generated for the event, the Coarse-Centroid control line is released and the sequencer sends the fine centroids out the front panel to the level 1.5 trigger crates at 10 MHz. Then the sequencer toggles the centroid PALs to raw hits and the FIFO is loaded with the hit cells for readout by the data acquisition system. Because the raw hits are stored for use during readout, the MAC can then reset to receive new centroids for the next coarse centroid trigger.

B. Centroid Logic

The centroid logic was derived by considering all tracks passing through a module within 45 degrees of normal incidence. In WAMUS the tracks are projected to a single plane with resolution equal to half the width of a 10 cm cell. For 3-deck modules, the track is projected to the center line of the middle deck, and for 4-deck modules the track is projected to the midplane of deck 3, nearest the toroid. All combinations of pairs of cells in different decks were tallied and the assigned to the most likely half cell. An example of pairs of cells in the top two decks of a module in the C-layer, and the resulting centroids is shown in Fig. 3.

Figure 3 also shows how patterns repeat. The first and third pattern shown are identical except for translation by one cell. The resulting centroid is translated by two cells. Because the cell structure within the module repeats, the centroid logic is worked out for a block of cells, then applied to the entire module, simplifying the logic in the centroid PALs. The centroid PAL logic also prevents double counting of tracks by discarding centroids with odd addresses if an even address is present adjacent to the odd address.

Logic for SAMUS is simpler than WAMUS, since SAMUS only has two layers of tubes. Hits in SAMUS correspond to the OR of signals from two diagonally adjacent tubes. If a single isolated hit is reported, the centroid is assigned to the midpoint of that pair of tubes. If two adjacent hits a reported, the centroid is assigned to the midpoint of the four tubes. If three consectutive hits are found, a delta ray is assumed, and the centroid is assigned to the middle of the cluster. Clusters of more than three hits are treated as multiple tracks through the plane.

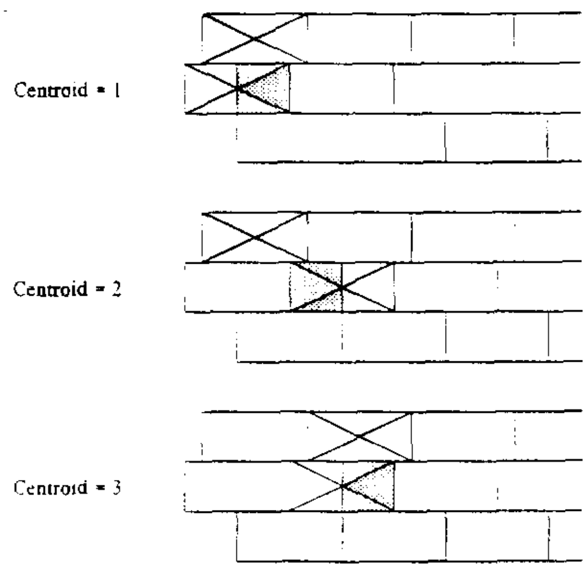

Fig. 3 Centroid patterns in a MAC. Diagram shown a cross section of one end of a C-layer module with two cells hit giving half cell resolution

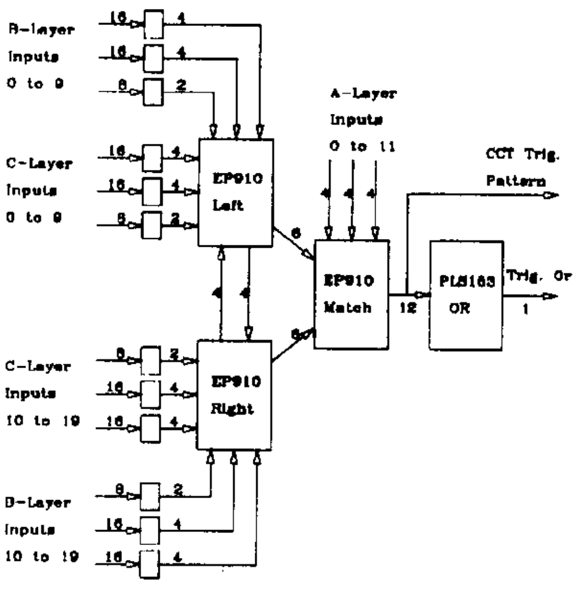

Fig. 4 Block diagram of Coarse Centroid Trigger (CCT)

III. COARSE CENTROID TRIGGER

The coarse centroids from the MAC are transmitted to a Coarse Centroid Trigger (CCT) card (Fig. 4). The CCT has 13 inputs from MACs, divided into 3 A-layer inputs, 5 B-layer inputs and 5 C-layer inputs. This matches the maximum number of modules in one 45 degree phi segment of the central muon system. On the CCT each of the 16-bit inputs passes through 4-fold ORs so that there are 4 bits from each module.

The resulting 20 B-layer and 20 C-layer bits are divided into groups of ten. The first 10 B-layer and first 10 C-layer inputs are inputs to an EP910 PAL. The remaining B and C-layer bits go into another EP910. These EP910s are programmed uniquely for each CCT in the muon system to reflect the geometry of those modules. Each EP910 provides 6 outputs for comparison to the A-layer bits and 4 ouputs to be used as crossover terms to the other input EP910. The comparison EP910 matches the 12 predicted tracks to the A-layer based only on the B and C-layers with the actual A-layer bits. Matches are output from the CCT board as track candidates.

The output of the CCT is available in 100 nsec and is designed to be compatible with the output of the MAC coarse centroids, permitting CCT output to become input to a second stage of CCTs. The output from all CCTs in each trigger sector are brought together in another CCT. This CCT performs counting of the good muons in that sector and sends a two bit muon count to the trigger monitor.

The five trigger sectors each supply the counts to the trigger monitor in the muon supervisor crate. The trigger monitor converts the 10 bits of information into a bit description sent to the AND-OR network of the trigger framework. The mapping from sector counts to physics channels is provided in a downloadable RAM on the trigger monitor card. The trigger framework compares muon physics information with information from other subsytems to determine if the event passes the level 1 trigger.

IV. FINE CENTROID TRIGGER

Upon receipt of a level 1 trigger, the TIMER cards in the muon supervisor crate will cause the MACs to send the fine centroids. The fine centroids are handled by octant trigger cards (OTCs) in the level 1.5 crates. A block diagram of the OTC shows the overall architecure (Fig. 5)

Like the CCTs, the OTCs are designed to handle data from a number of modules from each of the three layers. Unlike the CCTs, the OTCs have a single input from each of the layers and those modules which are grouped together for triggering purposes have MACs on the same fine centroid cable. To arbitrate the output of the centroids from the MACs, a carry (COUT) is daisy-chained between the MACs setting a particular order for readout and providing the OTC with notification that all MACs in the chain have sent data. A data strobe (DSTRB) is used to latch centroids in the OTC input buffer. To synchronize multiple MACs on a single cable a "permit to send" token is passed between cards.

The heart of the OTC is a 4x4 array of pairs of 256K x 1 static RAMs. All pairs are programmed with the full set of logic combinations for good tracks through the geographic section served by the OTC. On the first clock cycle after receiving data at the input of the OTC, an address from each of the three layers is loaded into the array; the A cell data going to the full array and the B and C cell going just to the first row or column of the array. On each successive 100 nsec cycle another B and C cell address is transferred into the next row and column until the array is filled. Subsequent cycles loop through the remaining A cells. If there are more than 4 B cells or C cells then the trigger processing logic goes through all possible combinations in the array.

If any combination of cells satisfies the RAM requirement, the cells' addresses are passed to the kinematic lookup memory. This 32K memory is loaded with the momentum and position information for each combination that would fire the RAM. This kinematic information is passed on through an OTC manager for the geographic sector, which counts the number of good particles and saves the maximum transverse momentum of any muon in the sector. This data is sent to the trigger monitor which translates the information from all five sectors into a 16-bit pattern usable by the trigger framework. The OTC managers store all successful addresses and kinematic data for inclusion in the data stream.

For a simple OTC trigger with only one hit per layer the trigger decision is made in 200 nsec. For an event that fills the array the trigger time is of the order of 1000 nsec. Requiring the OTC to cycle through multiple B-C array configurations will substantially add to this time up to a few microseconds, though the OTC will report to the trigger monitor that it is going to take longer than expected. Trigger times also increase if one uses the OTCs in the SAMUS mode (see below), where one OTC becomes the input to a second OTC.

V. SAMUS TRIGGERS

The small angle muon system (SAMUS) poses unique triggering problems due to the high rate of hits expected and the x,y,u tube geometry used. However the same MAC/CCT/OTC architecture can be used to form these triggers.

Each plane of the SAMUS station is divided into two halves, so that there are a total of 6 MACs servicing an entire station. A trigger bit represents a pair of staggered tubes, so that if either of the pair has data, the bit is set. Within a single plane the logic for finding centroids is straight-forward; the MAC reports a centroid at the wire if a single bit fires, or at the halfway point if two adjacent bits fire. This gives half-cell resolution in the plane.

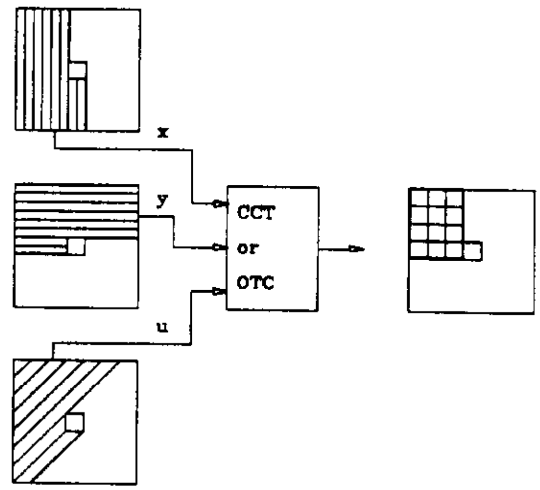

Fig. 6 SAMUS x,y,u pair trigger

The first class of SAMUS triggers involve those particles that pass through the SAMUS A-layer and or B-layer, then complete their trajectory through the wide angle C-layer. For these particles the SAMUS A and B layers are used to find x-y pairs in the CCTs/OTCs for each quarter of the station (Fig. 6). The x-y pairs are then passed to a second CCT/OTC level for combination with ouput from wide angle MACs.

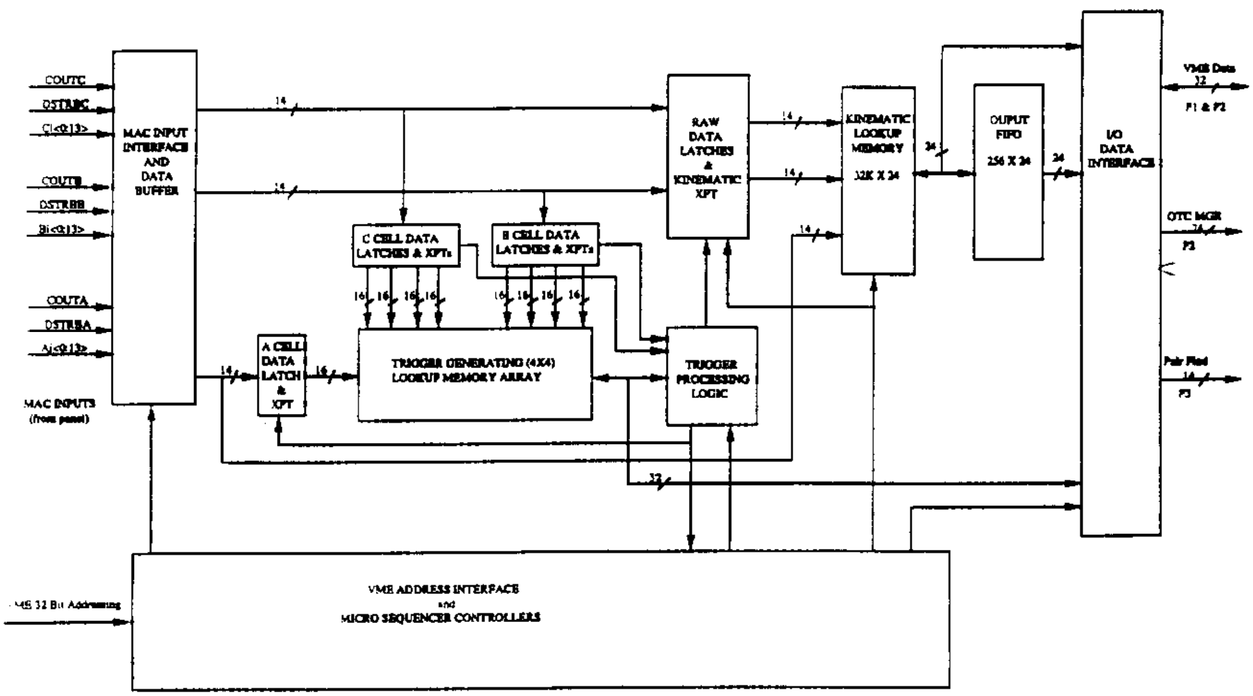

Fig. 5 Block diagram of Octant Trigger Card (OTC)

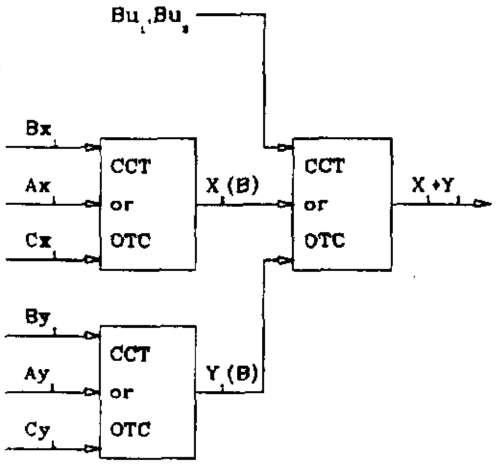

Fig. 7 SAMUS road trigger

For those particles that pass through all three SAMUS stations, the pair finding trigger would be unable to ignore the large number of hits near the beam pipe producing fake tracks. For this region the first stage of CCT/OTC calculate a trajectory in just the x or y view (Fig. 7). The output of the cards is the projection of the roads on the B-layer, which should have the least amount of background noise. The x-roads and y-roads are combined as inputs to a second stage of CCTs/OTCs. These clean hits at the B-layer are then matched to the u-hits of the B-layer to find a space point. The momentum is determined from the momenta in the x and y-views.

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