Fermi National Accelerator Laboratory

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The CDF Forward Muon System*

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Abstract

The general properties of the toroids, drift chambers and trigger counters in the CDF Forward Muon system are discussed. The operation of the PSL time-to-digital converter and the UW HOPU (Half Octant Pattern Unit) module is also described. The Forward Muon Level 1 trigger is presented.

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1 Introduction

In investigating the dynamics of high-energy particle interactions, the identification of final-state muons is particularly useful because they couple directly to the intermediate vector bosons which mediate the electro-weak force. In addition, muons are a characteristic signature of the weak decays of heavy quarks. The CDF Forward Muon System will measure muon position and momentum for polar angles between 3 and 16 degrees (the Forward Region) and between 164 and 177 degrees (the Backward Region).[1] In addition, a Forward/Backward muon trigger is being constructed to allow for easy identification of single and multiple high transverse momentum muon events. The system will take its first data during the 1986 CDF run.

2 The CDF Forward Muon System

2.1 General Features

The CDF Forward Muon System consists of a pair of magnetized iron toroids instrumented with three sets of drift chambers and two planes of scintillation trigger counters.[2] A given plane of chambers or counters form a 24-sided figure with each wedge-shaped detector subtending an angle of 15 degrees in azimuth as shown in Figure 1. Each wedge in a plane is staggered relative to its neighbors to form overlap regions which eliminate detector dead spots at the wedge boundaries. The drift chambers come in three different sizes depending on their distance from the beam crossing and are supported by a "spider-web" type structure hung from the top of the toroids. The counters are supported by mounts welded to the face of the magnets.

2.2 The Toroids

The Forward Muon analyzing magnets are 7.6 m o.d. x 1.0 m i.d. x 1.0 m wide toroids. Two of the 395 ton cast steel magnets are located in each of the Forward and Backward detector regions. Each toroid has 4 rectangular coils consisting of 28 turns of copper conductor to provide an azimuthal field in the steel. The toroids are built from 12 steel blocks ranging from 22 to 40 tons in weight. The blocks are constructed from 25 cm thick vertical slabs of continuous cast steel and are machined on the mating surfaces. The magnets are made in two halves which separate at the vertical centerline with a 3 mm gap at the top allowed for magnetic field measurements. At a current of 1000 amps through the coils a field of 1.8 Tesla is produced at a radius of 2.0 m. The field varies from 2.0 Tesla at the inner radius to 1.6 Tesla at the outer radius.

Particle displacement due to bending in the toroidal fields is expected to be 140./p (in cm) where p is the particle momentum in GeV/c. Multiple scattering in the steel is given by 18./p (in cm). These quantities combine to give a momentum resolution of 13% for the Forward Muon system.

2.3 The Drift Chambers

The drift field in the Forward Muon (FMU) drift chambers is shaped by an equilibrium distribution of charges on the inside surfaces of insulating chamber walls.[3] Each chamber is composed of two planes of drift cells. The "coordinate" plane is closest to the beam crossing point and consists of 56 cells. The "ambiguity" plane consists of 40 cells staggered relative to the coordinate cells in order to resolve the left-right ambiguity of a particle track. Each cell contains a 63 micron diameter stainless steel anode wire which is strung along a chord of the wedge to provide a polar angle measurement of a passing muon. The two sides of a chamber share a common copper foil cathode plane which is divided into 15 cathode pads. Each pad covers a region which is 5 degrees in azimuth by $\sim$ 3 degrees in polar angle.

The chamber cells are graded (size proportional to polar angle) and projective. Each cell subtends a constant pseudo-rapidity bite of $\sim$ 0.03. This configuration results in a roughly constant cell occupancy and provides for the simple high transverse momentum trigger described below. In actual practice, chamber cell sizes are averaged in groups of 8 yielding 7 different coordinate cell sizes and 5 different ambiguity sizes. The variation in anode voltage is between 3.0 to 6.0 kilovolts and the maximum drift distance is $\sim$ 5.0 cm. The drift velocity in a 50/50 Argon-Ethene mixture is 5.0cm/microsecond and a position resolution of 130 microns has been achieved with the drift chamber in a test beam.[4]

The signal from each chamber cell is sent to a pre-amplifier circuit which is mounted on the chamber. After a x40 amplification, the signal is sent to an amplifier/discriminator board located on the "spider-web" supporting structure. A single channel of the amplifier/discriminator board actually receives the inputs from cells at the same polar angle for three adjacent chambers (an octant of chambers). This provides a factor of three savings in electronics while the azimuthal resolution is reduced to 45 degrees. The resolution is however restored to 15 degrees by the scintillation counters in time for the trigger and improved to 5 degrees by pads at readout time. The ECL pulse from the amplifier/discriminator board is then sent to a time-to-digital converter (TDC) located $\sim$ 75 m away in the counting room.

A pulse line, capacitively coupled to the ends of the sense wires opposite to the pre-amplifier, is provided on each wedge to test the chamber electronics. In addition, four wedges per plane contain Fe 55 sources (one for each cell size) and special readout electronics to monitor gain drifts.

2.4 The Scintillation Counters

The Forward Muon counters consist of 13 mm thick 10% Napthalene-doped acrylic scintillator pieces instrumented with light pipes and photomultiplier tubes. Each wedge is 3.3 m long x 1.0 m x 14 cm at the large and small ends respectively. Three Amperex 2202B phototubes are coupled to the large end and one to the small end through a clear acrylic light pipe/180 degree bend combination. The use of the 180 degree bend allows the light pipe/phototube/phototube shield package to rest on the scintillator surface which in turn meets space and mechanical constraints. Two thin high permability mu-metal layers and a soft iron 1 cm wall cylinder surround each phototube. The entire scintillator assembly is placed in a protective sheet metal box.

A Schmitt-trigger circuit has been placed in the phototube base of the Forward Muon counters to provide an ECL logic pulse for each anode pulse exceeding the 10 millivolt threshold. The signals from each of the four phototubes making up a trigger counter are then sent to a logical "OR" circuit located inside the protective metal box. The output from this circuit is latched at the appropriate time to determine the presence of an in-time (beam crossing) or out-of-time (beam halo) hit. The detection efficiency of the counters has been measured to be > 99.5 % over their entire surface.

In order to monitor the condition of the trigger counters, a light emitting diode (LED) pulsing scheme has been implemented. The high voltage for one phototube in each counter will be turned on, an LED which is optically coupled to the scintillator will be fired and a phototube coincidence sought. This straightforward procedure helps to checkout the electronics and searches for dead phototubes.

3 Forward Muon Electronics

3.1 The PSL Time-to-Digital Converter

The University of Wisconsin Physical Sciences Laboratory has developed a time-to-digital converter (TDC) for general use in High Energy Physics.[5] The particular features of the PSL TDC include a time resolution of 1 nanosecond, sparse readout, multihit capability and a FASTBUS Standard interface. In addition, a dynamic range of up to 40 microseconds is available.

The TDC board is made with Multiwire technology using a double ground/supply plane to ensure low noise. A single board has 8 TDC units each of which can accept 12 inputs. The 96 channels of TDC per board are thus nicely matched to the 96 cells in each drift chamber.

The operation of the PSL TDC starts with a discriminated pulse arriving from a chamber, entering the unit and being sent along a 100 ohm impedance tapped delay line which has a 16 nsec delay with 16 taps. See Figure 2. In each of the 8 units on a board, a 16 deep x 40 bits wide RAM with 32 bits/word is clocked regularly (every 10 nsec) to record:

a) 12 bits of a counter (incremented by 1 each clock). This records the time 0-4095 counts (i.e. up to 40 microseconds). As an option, only 8 bits need be used for a fully dynamic range of 2.5 microseconds.

b) 16 bits from the tapped delay line. This acts as a vernier to divide the 10 nsec clock period into 1 nsec intervals since the leading edge of an incoming pulse will be recorded as it propagates along the delay line.

c) 12 bits from the incoming pulse lines. This is to record which line or lines had hits.

If a pulse is seen on a delay line, the RAM address is incremented so that the current hit information is retained and new memory is made available for successive hits. Typically, only 15 nsec is needed between hits into a TDC unit in order that no information be lost. In addition to the above, a bit is set for each TDC unit that received hits. These 8 bits can be checked before reading out the RAMs. The CDF version of the SLAC Scanner Processor (SSP) will be used to read out and reformat the hit information from the TDCs.

3.2 RABBIT Electronics

The Forward Muon system will use RABBIT electronics to read out and perform analog-to-digital conversion of the cathode pad signals from the drift chambers.[6] The good sensitivity of the RABBIT strip cards (65535 counts per picoCoulomb) is well matched to the small pad signals. It is hoped to use the pad pulse height information to flag multiple hits on single pad. Seventy-two strip cards and two MX scanners will be provided by the Fermilab Particle Instrumentation group.

3.3 The Half Octant Pattern Unit

The Half Octant Pattern Unit or HOPU contains the Level 1 trigger coincidence logic for the FMU system. This in-house designed Multiwire device monitors the input lines to the TDCs for the inner 28 or outer 28 cells of the 56 cell coordinate plane for three octants of chambers (recall that the chambers are hardwired into octants). While the HOPU module resides in a FASTBUS crate, it uses only the FASTBUS auxiliary connector to receive its data from the TDCs and is not a FASTBUS slave device. Front panel connectors are used to pass on its Level 1 trigger information.

4 The Forward Muon Trigger

The primary background to direct muon production in the forward region arises from decay in flight of pions and kaons. The spectrum of such secondary muons is a steeply falling function of their transverse momentum. The trigger rate can be reduced to a tolerable level by the imposition of a transverse momentum threshold of a few GeV/c. By virtue of the drift chamber design, this can be accomplished by simple coincidence logic.

4.1 Level 1

Three Level 1 trigger thresholds have been implemented in the Forward Muon system. They are known as:

a) The 300% trigger threshold. This requires a coincidence between hits in the nth cell of an octant in the 1st plane and hits in either the n+1th, the nth, or the n-1th cells in planes 2 and 3. This is the lowest trigger threshold.

b) The 100% trigger threshold. This consists of a coincidence between hits in the nth cell of an octant each chamber plane. Figure 3 shows a particle track satisfying the 100% trigger threshold.

c) The 50% trigger threshold. This is identical to the 100% trigger threshold except that the threshold is increased with a drift time gating scheme by requiring that the hit in the rear chamber cell be less than some fraction of the maximum drift time. This allows one to have a variable trigger threshold with an increase in threshold gained at the expense of efficiency.

The logical "AND" of trigger cells into towers of psuedo-rapidity bite 0.2 are formed for each threshold and put into coincidence with same azimuth trigger counters by the HOPU. The HOPU then provides to the Level 1 trigger system the number of tower triggers at each threshold. This allows for a mixed trigger with a low threshold for multiple muon events and a higher threshold for single muons.

This simple scheme provides a constant high transverse momentum trigger due to the projective and graded nature of the chamber cells. Each trigger coincidence requires a minimum momentum in order that a track not be bent outside the trigger cell in the rear chamber. Since the cell size is proportional to the size of the polar angle, a constant threshold in transverse momentum results. Figure 4 shows a Monte Carlo calculation of the trigger efficiency as a function of muon transverse momentum for each of the three trigger thresholds.[7] For the 50% trigger threshold, the muon hit in the last plane was required to be within half the maximum drift time. The 300% threshold trigger is expected to be around 80% efficient at a transverse momentum of 6 GeV/c.

The trigger rates due to pion decay in flight are estimated to be 60 Hz, 2.8 Hz, and 0.5 Hz for the 300%, 100% and 50% (half maximum drift time cut) threshold triggers at a luminosity of 10^{30} cm^{-2} sec^{-1}. Because the trigger rate is dominated in all cases by low transverse momentum particles, the rate estimates depend critically on the exact shape of the secondary muon transverse momentum spectrum and the trigger efficiency functions. The 50% variable threshold has been provided as a backup in case the actual trigger rates are higher.

4.2 Level 2

Through the use of additional circuitry, the Forward Muon trigger makes available to the Level 2 system the trigger threshold (300%, 100%, 50%) for any hit in each of the 480 trigger towers. Thus one can correlate forward muons with forward jets, with central muons, etc. It is at this point that the power of the CDF trigger really comes into play. One has a number of building blocks such as jets, muons, missing transverse momentum, etc., which one can combine to efficiently search for very detailed physics processes.

5 Summary

The Forward Muon system at CDF has been described. Principle features of the system include the use of a pair of large toroidal magnets and specially designed drift chambers to provide a constant transverse momentum muon trigger. For the future, designs similar to that of the FMU system are being proposed to provide muon coverage between 16 and 55 degrees.

6 References

[1] Design Report for the Fermilab Collider Detector Facility (CDF) (August 1981), Fermilab, Batavia, Illinois, USA, unpublished.

[2] L.G. Pondrom, Proc. of the SSC/LHC Muon Detection Workshop Madison, Wisconsin (April 1985).

[3] J. Allison et al., Nucl. Instr. and Meth. 201 (1982) 341.

[4] L.G. Pondrom, Proc. of the CDF Forward Detectors Workshop Madison, Wisconsin (April 1984).

[5] M. Thompson et al., Multihit Time to Digital Converter, PSL Internal Report (February 1985).

[6] G. Drake et al., IEEE Trans. Nucl. Sci., Vol. NS-33, No.1, pp. 92-97, Feb 1986.

[7] D.L. Carlsmith, Fermilab Internal Report, CDF-308 (May 1985), Fermilab, Batavia, Illinois, USA, unpublished.

7 Figure Captions

1. Elements of the FMU detector planes.

2. Operation of the PSL TDC.

3. A particle track satisfying the 100% threshold trigger.

4. Trigger efficiency for the 300%, 100%, and 50% threshold triggers.

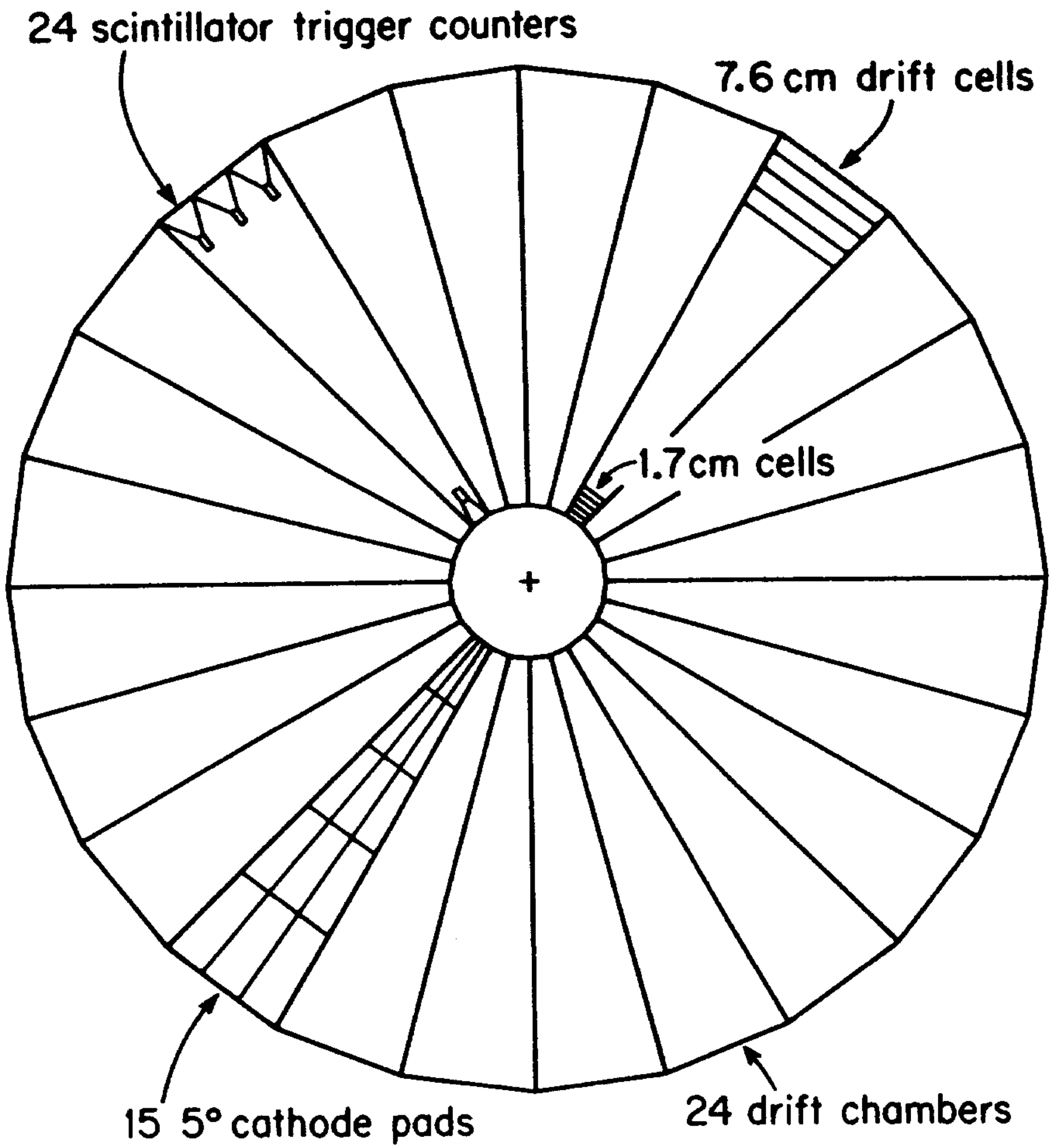
24 scintillator trigger counters
7.6 cm drift cells
1.7cm cells
15 5° cathode pads
24 drift chambers

Figure 1

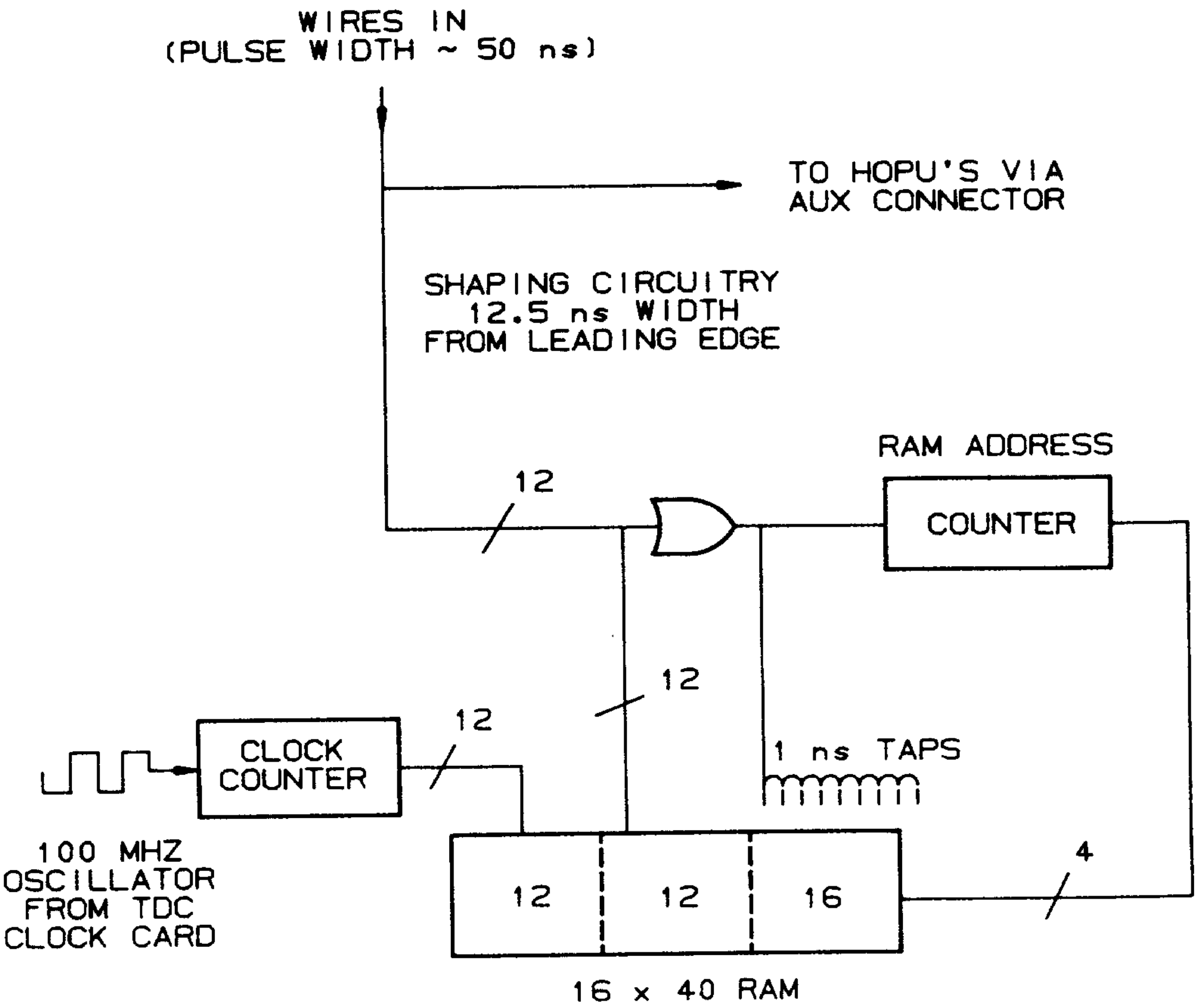
WIRES IN
(PULSE WIDTH ~ 50 ns)
TO HOPU'S VIA
AUX CONNECTOR
SHAPING CIRCUITRY
12.5 ns WIDTH
FROM LEADING EDGE
RAM ADDRESS
COUNTER
12
12
12
1 ns TAPS
CLOCK
COUNTER
100 MHZ
OSCILLATOR
FROM TDC
CLOCK CARD
12
12
16
4
16 x 40 RAM

Figure 2

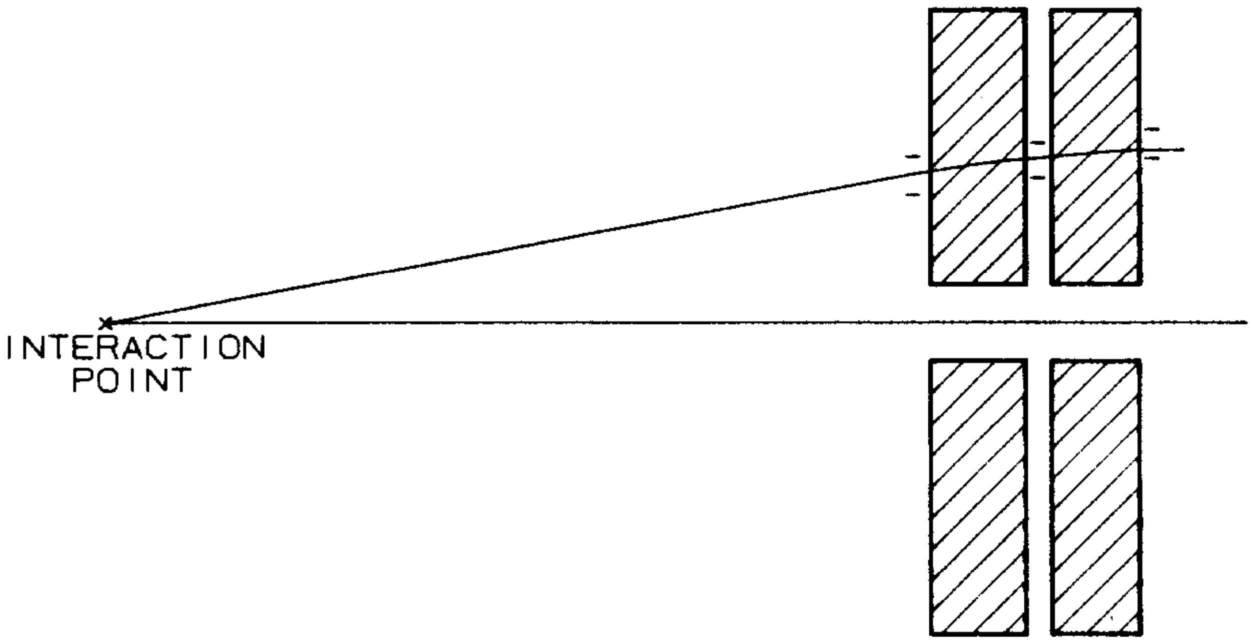

Figure 3

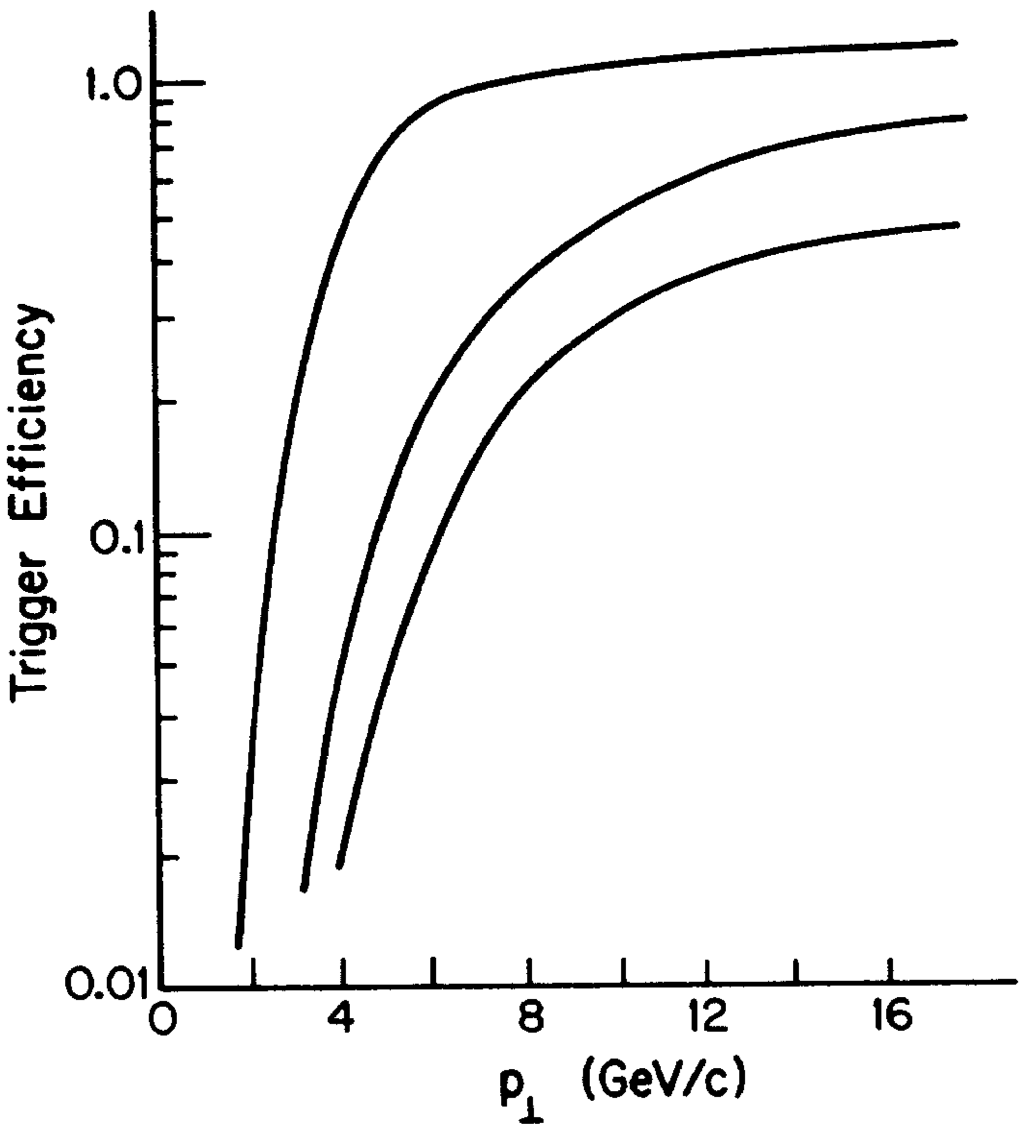

Figure 4