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D0 Note 706

The Level One Calorimeter Trigger for D0

October 25, 1988

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I. Introduction

This note describes the operation of the Level One Calorimeter Trigger for D0. We start with a functional description of the trigger in terms of its inputs and outputs. The inputs include the physics information from the calorimeter and the control information supplied by the host computer and the outputs are comprised of the set of bits generated by the Calorimeter Trigger and forwarded to the Framework[1] for use in specific trigger definition. This is followed by a description of the path a trigger tower signal takes through the various cards that constitute the trigger. Finally we present a timing diagram of the trigger operation. We note that this trigger is designed to operate without deadtime in conditions where the time between successive beam crossings is as short as 132 ns, which corresponds to having protons and antiprotons in every 7th RF bucket at the Tevatron.

II. Information Transfer

A. Overview

The Level One Trigger occupies a central part of the triggering system as shown in Figure 1 which depicts, in simplified form, the major elements of the D0 trigger system.

B. Inputs to the Calorimeter Trigger from Experiment

1. From the Calorimeter

From the viewpoint of the trigger, the calorimeter is divided into 1,280 projective trigger towers with 32 sub-divisions in the azimuthal angle, ϕ, and 40 in the pseudo-rapidity[2] variable, η. This sub-division and the numbering convention are shown in Figure 2 where individual trigger towers are specified by a pair of numbers, the first referring to the pseudo-rapidity, η, and the second to the azimuthal angle, ϕ. In depth, each tower is segmented into three pieces: an inner section consisting of about 20 radiation lengths, called the electromagnetic (EM), followed by a hadronic section (H) and a coarse hadronic (CH). Only the EM and H sections are included in the trigger as the CH, by virtue of its large capacitance and small sampling fraction, generally introduces more noise than signal.

To make up a trigger tower, the finely segmented read-out towers (0.1x 0.1 in $\Delta\eta$ x $\Delta\phi$) are added[3] 2 x 2 laterally to give trigger towers 0.2 x 0.2 in ϕ and η. The addition is not necessary near the beam pipe as the towers themselves are doubled in size. In depth, the EM trigger towers are comprised of seven readout segments and the H of three with some variations depending on whether one is considering the central calorimeter (CC) or the two end cap calorimeters (EC). The inputs to the trigger are then the 1,280 EM and 1,280 H signals representing the energies deposited in their corresponding towers but, these values are scaled[4] to correspond to transverse energies before being digitized.

2. From the Level 0 Trigger

The Level 0 Trigger consists of sets of scintillation counter hodoscopes mounted on the EC calorimeters. On the basis of the relative timing of secondaries from interactions, it determines

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[1]For a description of the Framework see D0 Note 705: "The Level One Trigger Framework: D0 Note 328 Revised" by Maris Abolins, Daniel Edmunds, Philippe Laurens, James Linnemann and Bo Pi. May 26, 1988.

[2]The pseudo-rapidity is defined as $\eta = -\ln(\tan\theta/2)$. In the narrative we have assumed 40 subdivisions in this variable whereas in actuality this number may be somewhat larger. This change will not affect the basic parameters of this note.

[3]The addition is done by analog summing circuitry on the base line subtractor (BLS) cards on the platform.

[4]This is done by using the average sin Θ's of the calorimeter towers forming a trigger tower referenced to an interaction having its vertex centered in the detector.

whether a beam-beam (as contrasted to a beam-gas) interaction has taken place and whether there has been more than one interaction in the given crossing. In the case of single beam-beam interactions it provides information about the location of the interaction vertex in the direction along the beam axis. On the basis of the CDF experience, the interactions are expected to be distributed in a Gaussian manner with a standard deviation (σ) of about 35 cm. This position information will be encoded in three bits and then passed to the Calorimeter Trigger[5].

C. From the Trigger to the Framework

1. Types of Triggers

The Calorimeter Trigger uses the inputs from the calorimeter, 1,280 EM transverse energies, EMt_i, and 1,280 hadronic transverse energies, Ht_i, to construct a number of quantities which are then compared to criteria supplied by the host computer to generate a series of bits representing whether or not those criteria have been satisfied. Combinations of these bits are formed into specific triggers by the AND-OR network in the Framework. The quantities generated by the Trigger fall in two general categories: Global Quantities and Clusters. Among the Global quantities are the transverse electromagnetic energy:

$$EMt = \sum_{i=1}^{1,280} EMt_i$$

the transverse hadronic energy:

$$Ht = \sum_{i=1}^{1,280} Ht_i$$

the total transverse energy:

$$Et = Ht + EMt$$

and the missing transverse energy:

$$MPt = \sqrt{(EM_x + H_x)^2 + (EM_y + H_y)^2}$$

where

$$EM_x = \sum_{i=1}^{1,280} EMt_i \cos \Phi_i \quad \text{and} \quad EM_y = \sum_{i=1}^{1,280} EMt_i \sin \Phi_i$$

with corresponding constructions for the hadronic components H_x and H_y. The Φ_i, above, are of course the individual trigger tower azimuthal angles.

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[5]This information is also supplied to the Framework where it can be used to choose triggers according to their vertex position.

We also construct the corresponding energies as contrasted with the transverse energies:

$$EM = \sum_{i=1}^{1,280} \frac{EMt_i}{\sin \Theta_i} \quad \text{and} \quad H = \sum_{i=1}^{1,280} \frac{Ht_i}{\sin \Theta_i}$$

Here Θ_i refers to the angle with the beam line, made by a line connecting the interaction vertex with trigger tower "i".

All of the quantities, EMt, Ht, Et, MPt, EM, and H are available for the formation of triggers. They may be tested against a number of thresholds which can be as high as 32. It should be noted that the memory look-up method we are using is extremely flexible. In the illustrations above we have chosen the energies and transverse energies as quantities of interest. By simply reprogramming the memories some completely different energy related quantities could be used for triggering purposes.

In addition to these Global quantities, the trigger does tests on the transverse energy deposited in single electromagnetic or total energy trigger towers. The trigger counts the number of towers exceeding any of four preset thresholds, separately for the electromagnetic and for the total energies. For the EM towers, provision is made for the tower to be vetoed by hadronic energy in its corresponding H tower. A total of four hadronic energy levels can be used for the veto, one for each EM threshold.

2. Detailed Bit Counts

In Table I we summarize the total number of bits, sent from the Calorimeter Trigger to the Framework, that represent conditions on the variables mentioned above.

Table I

Bits Sent from Calorimeter Trigger to Framework

	Calorimeter Information Test	Number of Bits Sent to Framework	
A.	EM > Threshold	1 per Threshold	4 - 32
B.	H > Threshold	1 per Threshold	4 - 32
C.	EMt > Threshold	1 per Threshold	4 - 32
D.	Ht > Threshold	1 per Threshold	4 - 32
E.	Et>Threshold	1 per Threshold	4 - 32
F.	MPt>Threshold	1 per Threshold	4 - 32
G.	Twrs. w. EMt >Thrsld.	4 per Thrsld x 4 Thrslds:	16
H.	Twrs. w. Et > Thrsld.	4 per Thrsld x 4 Thrslds:.	16
		Total	56 - 224

Thus, for example, in item C, above, the EMt is compared to a number of different thresholds and a bit is set for every threshold that is exceeded. The number of thresholds could be as high as 32 and probably will never be less than 4 as this is the number that naturally comes from the construction of the CAT2 cards. The maximum number of 224 will not be reached as this would use up nearly all of the 256 bits currently available for trigger programming.

In items G and H, there are four Et threshold sets available for trigger towers of each type. For each threshold, a count is made of the number of trigger towers whose energy exceeds that threshold. This count is then compared to each of the four count limits and a bit is set if the count is greater than or equal to that limit. For example, if, for a particular threshold, the count limits were set to 1, 2, 3, 4 then the bits would represent ≥ 1, ≥ 2, ≥ 3 and ≥ 4 trigger towers passing this particular threshold.

D. From Trigger to TRD

In addition to the information sent to the Framework, the Trigger prepares a list of EM shower candidates for each detector quadrant that it transmits to the TRD trigger for use in identifying electrons. This feature is discussed more fully in the section dealing with the CHTCR card.

E. From Trigger to Level 2

The Calorimeter Trigger is designed to provide to the Level 2 Trigger lists of the locations of the significant energy deposits in the Calorimeter. These "Jet Lists" are included as part of the First Level Trigger Data Block.

Two lists are made, one containing the locations of the significant EMt energy deposits and the other the locations of the significant Et energy deposits. These lists are made by merging the lists of Trigger Towers that passed one of the 4 EMt Thresholds (for the EMt list) or one of the 4 Et Thresholds (for the Et list).

Each of the lists can contain up to 16 entries (space has been provided for more if necessary). In each list the ϕ, η address of a Trigger Tower that is over threshold is provided as a one dimensional index that points to the location, in the First Level Trigger Data Block, where the value representing the energy in that Trigger Tower is stored. This format provides both the ϕ, η location of Trigger Towers over threshold and rapid access to the related energy values.

In addition to the "Jet List" information described above there are two other pieces of information provided with each list:

1. There is one byte of status information provided with each list which indicates if there were more Trigger Towers above threshold than there was room for in the list.

2. Each Trigger Tower entered in one of the two lists has an accompanying four byte mask. Each bit in this mask represents one of the 32 Specific Triggers. A bit in the mask associated with one of the Trigger Towers is set if both of the following conditions are met: if the Specific Trigger that it represents has fired and if this Trigger Tower could have contributed to the firing of this Specific Trigger.

F. Inputs To the Trigger from the Host

1. Global Sum Programming

The host must download to the trigger the necessary threshold information used by the comparators discussed above. For each of the 6 global quantities, A through F in Table I, we need up to 32 separate thresholds. If these are given as two byte numbers[6] then the total information is as given in Table II:

[6]Assuming a least count of 0.25 GeV, the maximum threshold will be 16,384 GeV, more than eight times the maximum collision energy of the Tevatron.

Table II
Programming Information from the Host to the Calorimeter Trigger

	Type of Information	Number of Bytes
A.	EM Comparator References	2 bytes per Comp. = 64
B.	H Comparator References	2 bytes per Comp. = 64
C.	EMt Comparator References	2 bytes per Comp. = 64
D.	Ht Comparator References	2 bytes per Comp. = 64
E.	Et Comparator References	2 bytes per Comp. = 64
F.	MPt Comparator References	2 bytes per Comp. = 64
	Total	384

2. Tower Count Programming

For items G and H in Table I, we must supply 4 sets of thresholds for both the EM and E = EM + H sections. Each threshold may be set individually for each tower. In addition, we must furnish 4 numbers for each threshold that will be used to test the number of towers that have transverse energies exceeding each of the thresholds and 4 numbers representing the corresponding hadronic energy thresholds used in the vetos. If we pick each of the Et and Ht thresholds as one byte[7] and each of the number thresholds as two bytes[8], we arrive at a total of 2x4x1x1,280 = 10,240 bytes for the Et thresholds plus 4x4x2 = 32 bytes for the number thresholds. These are itemized in Table III below.

Table III
Programming Information Needed

	Item	Number of Bytes
A.	From Table II	384
B.	EMt Comparator References	5,120
C.	Ht Veto References	5,120
D.	EMt Count Thresholds	32
E.	Et Comparator References	5,120
F.	Et Counter Thresholds	32
	Total	15,808

3. Memory Look-up programming

As explained in more detail below, immediately after being received on the CTFE cards, the analog signals from the trigger towers are digitized with 8 bit flash Analog to Digital Converters (FADC's). On one path these 8 bits are used as low order addresses to fast look-up memories to generate the quantities Et, E =E/sinΘ, P_x=Et cosΦ and P_y=Et sinΦ. As two memories are used to generate two numbers each, one more address bit is needed to indicate which of the two quantities is being "looked-up". To accommodate the differences in sinΘ resulting from different "z" positions, we must add the 3 address bits supplied by the Level 0 trigger. Thus a

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[7] A 0.25 GeV least count makes the largest threshold 64 GeV

[8] We anticipate here the (remote) possibility that the number of towers with energy in excess of a given threshold, may exceed 256, the maximum number representable by one byte.

total of 8 + 1 + 3 = 12 address bits must be used to specify which of 4,096 8 bit numbers is to be used. This means that each memory used for the look-up of EM, H and P must be at least 32,768 bit wide and the host must download a total of 32,768 x 3 x 1,280 bits ≈ 15 Mbytes. This number clearly dominates the ≈ 16 Kbytes required by the rest of the programming.

We have chosen 0.25 GeV as least count for the transverse energies as an appropriate compromise between energy resolution and full scale saturation energy for each trigger tower.

4. Pedestal Programming

Each of the 2x1,280 FADC's can have a pedestal set by the trigger control computer as part of its initialization procedure. This is done by supplying an 8 bit number to a Digital to Analog Converter (DAC) and then adding the resulting voltage to the input of the FADC. This is not only a convenient way of adjusting all the pedestals to be the same but, also a way of testing the apparatus with analog inputs during maintenance periods as these signals can be set as high as about one third full scale of the FADC. As each channel requires one byte for programming, the total amount of information to be down-loaded from the host for this purpose is 2x1,280 = 2,560 bytes.

5. Data Compression

The global sum and tower count thresholds must be explicitly given to the First Level Trigger Control Computer since they may be all different. The pedestals are also likely to be all different and, moreover, need adjustment every time any of the front end hardware is changed (BLS or CTFE cards).

The energy look-up memories and the energy threshold reference sets are addressable on a tower by tower basis. We do, however, anticipate that the amount of data needing to be transferred through the network during set-up can be reduced significantly by noting that:

i. it may be possible to specify ranges of coordinates in η and ϕ over which the data to be loaded is constant and letting the trigger control computer perform the addressing and loading tasks. For example, the energy cut of 10 GeV may apply for $\eta \leq 3$ and $1 \leq \phi \leq 32$ necessitating the transfer of only the coordinate limits and the energy threshold.

ii. formulas may be used to specify the values of output variables and the trigger control computer could compute the numbers and address the individual trigger towers. As an example we could compute $E = Et/ \sin\Theta$ for each tower in the detector.

III. Signal Paths

A. General

Figure 3 shows, in block form, the essential components of the Level One trigger and the main signal flow paths which are discussed below.

B. CTFE

1. Analog Front End

A trigger tower energy signal from the BLS travels to the moving counting house on shielded differential signal lines and there is connected to the analog front end section of a Calorimeter Trigger Front End (CTFE) card. The front end section contains a differential line receiver and scales the energy signal to its transverse component using discrete resistors. The front end section also incorporates the DAC circuitry for down-loading pedestals to the FADC's as was discussed above. A schematic diagram of a cell of a CTFE is shown as Figure 4. Each cell handles one pair of EM and H signals from the calorimeter and each CTFE card contains four cells.

2. ADC

Immediately after the analog front end, the signal is turned into an 8 bit number by fast (20 ns from input to output) FADC's. With a least count equal to 0.25 GeV this gives a maximum value of 64 GeV transverse energy for any tower output.

3. MUX and Latch

The 8 bit numbers from the FADC are clocked into latches with a synchronizing clock. The latches can also be selected to gate in test signals thus permitting a completely general digital exercise of the whole system starting at this point. At this point all of the calorimeter data arriving by whatever paths is synchronized in time.

4. Double Buffered Memory Array

One of the outputs from the ADC is fed into a byte-wide pipeline register which stores the data sequentially but, permits random access reads. The contents of these registers will be read out into the Level One Trigger Data Block (cf Appendix A) and, as they record the history of past interactions, may need to be many stages long when running at high luminosity. We have constructed the pipeline register to be eight stages deep although, for the present time, only two stages will be used, one for the current interaction and another for the previous. To implement double buffering, each ADC will be connected to two of these byte-wide memories. The two pipelines will switch when readout starts on one of them.

5. Look-up Memories

In parallel with the path leading to the pipeline registers, each ADC signal is used as the low order 8 bit address to a Look Up Memory. The content of the memory location specified by the address is an 8 bit number representing a desired transformation of the input number which is essentially the energy. In the simplest case the number returned could be identical to the input "address" number. In other instances it could be a number with energy cut-off or a more complicated function such as $E_x = Et/\sin\Theta \cos\phi$. If, for any reason, the output of a tower need be suppressed, it will be done here by simply returning 0 as the output. We note that, in the drawing certain memories generate two numbers e.g. Ht and H for the lowest one. In principle, one memory could be used to sequentially look-up all desired quantities. At the present time, it was deemed impractical to do that because of the cost and power demands of faster memories. We have already discussed the demands these memories place on the host for downloading programming information.

6. Energy Derived Quantities

The outputs of the memory look-ups are processed further by two distinct parallel paths. On one of these they are forwarded to the Adder Trees to be "Added". The signals that proceed in this way include all the quantities that involve energy: P_x and P_y for the sum of EM and H energies, and Et and E for both the EM and H sections. A more detailed treatment of this subject is to be found below. The other distinct path treats the countable quantities i.e. the number of trigger towers above an energy threshold.

7. Countable Quantities

The transverse energy in each EM section of a calorimeter tower is compared to four different thresholds. A bit is set for each of the thresholds surpassed if it is not vetoed by the corresponding H section exceeding its threshold (there are four of these, one for each EM threshold) and these four bits are passed on to Counter Trees. The sum of the EM and H transverse energies is likewise tested against four thresholds and the resulting bits are passed onto their counter trees. In addition, this summed energy in each tower is kept as a 9 bit number. This is done in anticipation of having more powerful hardware processors in the future that would use these quantities, the total transverse energies in each tower, as inputs to a more sophisticated analysis.

C. Countable Signals

1. CHTCR

Each Calorimeter Trigger Front End Card (CTFE) contains 4 sets of EM and 4 sets of H signals. The information from the EMt and E_t cluster threshold comparators, proceeds to the Calorimeter Hot Tower Counting and Registering cards. Figure 5 shows the outputs from the cluster threshold comparators of eight CTFE cards as inputs to a CHTCR card. This card has a number of functions:

i. It performs a fast "OR" to decide whether there were any towers over each of the four thresholds in either the EM or Et sections. This kind of information could be the basis of a very fast pre-trigger in extreme luminosity situations.

ii. It counts the number of towers over each of the four thresholds and passes these partial sums to the CAT2 cards (discussed below) for final summation. It (the CHTCR card) is thus the first tier of the counter trees.

iii. It forms a list of addresses of possible EM showers for transmission to the TRD trigger by choosing the towers exceeding one of the energy thresholds.

iv. It prepares the list of candidate tower energies for transmission to Level Two.

a. CHTCR Sub-section

Figure 6a shows an expanded view of the counting circuitry for the CHTCR discussed in section ii above. The outputs, in the form of a Fast Trigger and a First Tier Count, are indicated. The Counter uses 5 bits to accommodate the 32 inputs that each CHTCR card can process, necessitating 40 such cards for the whole detector.

b) Hot Tower Table Builder

i) General

The Hot Tower Table contains the list of EM cluster candidates for the TRD Trigger. A Trigger Tower is in the Hot Tower Table if its Electromagnetic Transverse Energy deposit is greater than a pre-programmed threshold and if it has not been vetoed by its corresponding H veto.

The Hot Tower Table is segmented into four separate sections corresponding to the four azimuthal detector quadrants and is sent to the TRD Trigger crates over four independent cables: Hot Tower Cable First Quadrant ($x>0,y>0$), Second Quadrant ($x<0,y>0$), Third Quadrant ($x<0,y<0$), and Fourth Quadrant ($x>0,y<0$).

A Hot Tower is identified in the Table by a ϕ coordinate, followed by an η coordinate. Each coordinate is one byte long and an even number of bytes is always sent to the TRD Trigger for each Section. The Data are sent over the four cables independently but simultaneously. The information sent does not represent actual ϕ or η values, but the Trigger Tower ϕ and η numbers: $1 \leq \phi \leq 32$ and $-20 \leq \eta \leq 20$ (excluding $\eta = 0$).

The TRD Trigger is concerned only with that portion of the detector that has TRD coverage and therefore the lists are arranged to have the eligible towers come first. The list is truncated at eight in the interest of speed and simplicity.

A new Hot Tower Table is sent after each Level One Trigger Decision that requires a subsequent Level 1.5 validation. At that time, all the 40 CHTCR cards start a Hot Tower Registering Sequence.

ii) The Hot Tower Registering Sequence

Figure 6b shows details of the Hot Tower Registering Circuitry. During a Hot Tower Registering Sequence, each CHTCR card scans the state of its 32 inputs coming from 8 different CTFE cards. The Hot Tower Registering Circuits store (for up to 8 beam crossings) the states of these 32 inputs so that, in the event of a First Level trigger decision, the state of the inputs causing this decision, can be retrieved. Each of the inputs is related to a single EM Trigger Tower and a logical "1" on a given input indicates that the energy deposit in that particular Trigger Tower exceeded the #1 threshold programmed for it by the trigger control computer.

For each line found in a logical "1" state a ROM on the CHTCR is addressed to generate the two bytes of coordinate information characterizing its EM Trigger Tower. A maximum of 8 Towers can be registered on a given CHTCR Card. These two bytes of information are pushed onto a stack (LIFO memory) to be later sent over the table bus and forwarded to the TRD Trigger during the Hot Tower Table Building Sequence.

The Hot Tower Registering Sequence will take about 3 microseconds to execute.

iii) The Hot Tower Table Building Sequence

After all 40 individual Registering Sequences have been completed, the four Hot Tower Table Builder Cards will start reading out the four separate sets of 10 CHTCR cards.

When an empty LIFO is found, no information is sent to the TRD Trigger and the next card in line is interrogated. When a LIFO holding Hot Tower information is encountered, all data bytes are pulled, one by one, out of the LIFO stack and sent to the TRD Trigger. The LIFO is read until it is empty and then the next CHTCR card in line is interrogated.

The Hot Tower Table Builder Circuitry does not need to be double buffered since the Trigger Framework waits for the answer from the TRD Trigger before generating any further level 1 Trigger Decisions and the subsequent Hot Tower Registering or Building Sequences.

The time spent building the Hot Tower Table varies with the number of towers registered, from about 2 microseconds for an empty table to a maximum of about 5 microseconds. Thus the maximum time that could elapse between the First Level Trigger Decision and the completion of the transfer of the four Hot Tower Tables will be about 8 microseconds.

2. Counter Tree Structure

The basic element in the tree structure is the CAT2 card shown in Figure 7. It consists of 3 layers of binary adders followed by a subtractor section. The counting continues through two levels of CAT2 cards, labeled the 2nd and 3rd tiers as shown in Figure 8. After tier 3, two sets of 16 bits are available to the Framework, one dealing with EM E_t and the other with EM + H E_t. The 16 bits summarize whether any of 4 thresholds have been exceeded by enough trigger towers to exceed any of 4 preset reference numbers.

Figure 9 shows the counter tree structure from another viewpoint emphasizing the geographical features which are contiguous in the three tiers. The requirement of keeping together adjacent pieces of the detector imposes constraints on the organization of the Calorimeter Trigger in the moving counting house. The actual arrangement is shown in Figure 10 where the crates are labeled by their geographical addresses.

D. Energy Signals

1. First Section of the Adder Trees

Unlike the counter trees, the first energy sums are performed on the CTFE cards themselves and the results are passed to the first tiers of the adder trees.

2. CAT2 Adder Tree

After the CTFE cards, the signals pass on to CAT2 cards, eight CTFE cards feeding one CAT2 (Figure 11). The organization of the signals is such, that geographically contiguous regions are kept together (Figure 12). This permits the creation of intermediate energy clusters over larger regions of the detector. Although these will not be used in the current trigger, they form "hooks" for the attachment of more sophisticated cluster handling hardware that may be developed later.

An alternate version of the CAT2 card is needed as well to accommodate six, 16-bit inputs instead of the usual eight inputs of 12 bits each. This insures that all sums are passed without the need of truncating higher order bits and thereby, possibly losing accuracy.

To avoid the nuisance of carrying signs in our additions, we need to keep separate sums of the positive and negative components of P_x and P_y. Figures 13 and 14 indicate how this is accomplished.

3. Final Decisions

Another stage of logic is needed, after the P_x and P_y values have been determined, to obtain MPt or to form the total Et from the EM and H components. To form the scalar Et, the EM and H components are simply added. Computation of MPt involves squaring two numbers, adding them and then taking the square root of the sum. The simplest procedure in this case is a memory look-up which incorporates also the logic of testing whether any of the (maximum 32) preset thresholds have been exceeded. The results of the look-up are 1's and 0's which are passed to the Framework for trigger definition. This is shown schematically in Figure 15.

IV. Timing Diagram

A. General Considerations

It is useful to consider the flow of information through the trigger by referring to a timing diagram (Figure 16).

1. Clock Definitions

The Calorimeter Trigger is controlled by two timing signals: the Clock Signal, which runs at the Beam Crossing frequency, and another, which runs at twice the rate. Their positive-going edges are synchronized.

2. Skewing Limitations

The phase of the Clock, relative to the Beam Crossings, is adjusted so that the peak of the trigger pick-off signal from the BLS lies in the interval between the positive edge of the Clock and a point 30 ns before the next positive edge of the Clock. This is to allow time for the FADC conversion and for the set-up of the latch following the FADC. At full design luminosity (a beam crossing every 131.8 ns) this implies that the relative skews of the pick-off signals must be kept below 100 ns. On each CTFE card all the FADC's are clocked at the same time and therefore, all the signals on a given card should peak at the same time (± 20 ns). The pick-off signals will peak within this time window because all of the signals on a given CTFE card are from calorimeter elements at the same ϕ angle and thus have cables of about the same length.

B. Detailed Timing Discussion

Referring to the positive going edges after beam crossing, as shown in the detailed timing diagram of Figure 16, we can follow the essential operation of the Trigger (the beam crossing is at edge #1):

Edge #	Trigger Activity
1.0 to 2.0	Between edge #1 and 30 ns before edge #2 the FADC's are clocked and their outputs have settled by the time of edge #2.

2.0 At edge #2 the FADC MUX-LATCHes are clocked and output the information from the beam crossing.

The high order (Z position) addresses for the Energy Memory look-up and for the Momentum Memory look-up have settled.

2.0 to 2.5 FADC data from the FADC MUX-LATCH is processed in three ways:
1) It settles in the Double Buffer Memory Array.
2) It begins passing through the EM+H Raw Adder, the Momentum Look-Up Memory, and the CTFE Momentum Channel Adder.
3) The address specificed by this data is accessed in the Energy Look-Up Memory.

2.5 The Energy Memory Data Latches are clocked and then output the data from the first Energy Memory look-up.

The Double Buffer Memory Array is clocked and now holds a copy of the data from the FADC MUX-LATCH as it's newest data.

2.5 to 3.0 Data from the first Energy Memory look-up passes through the CTFE Energy Channel Adder on the CTFE card and settles in the inputs of the Energy Adder Tree 1st tier CAT2's.

The CTFE EM+H LUM (Look-up Memory), Adder and CTFE Threshold Comparators are processesing data that came from the first Energy Memory look-up.

The data from the FADC MUX-LATCH continues passing through the EM+H Raw Adder, the Momentum Look-Up Memory and the CTFE Momentum Channel Adder. This momentum data settles in the inputs of the 1st tier of the Momentum Adder Tree.

3.0 The input latches in the 1st tier of the Energy Adder are clocked and now hold the data that came from the first Energy Memory look-up.

The Energy Memory Data Latches are clocked and then output data from the second Energy Memory Look-Up.

The input latches in the 1st tier of the Momentum Adder are clocked and now hold the data from the Momentum look-up.

3.0 to 3.5 Data from the second Energy Memory look-up passes through the CTFE Energy Channel Adder and settles in the inputs of the Energy Adder Tree 1st tier CAT2's.

The Energy Adder Tree1st tier processes the data that came from the first Energy Memory look-up, an the results settle in the input latches of the 2nd tier.

The Momentum Adder Tree 1st tier processes the data from the Momentum Memory look-up and the results settle in the input latches of the 2nd tier.

The data from the CTFE Threshold Comparators is settling in the input latches of the CHTCR.

3.5 The Energy Adder Tree 1st tier input latches are clocked and now hold data that came from the second Energy Memory look-up.

The Energy Adder Tree 2nd tier input latches are clocked and now hold data that came from the first Energy Memory look-up and has been processed by the 1st tier of the Energy Adder Tree.

The Momentum Adder Tree 2nd tier input latches are clocked and now hold data that has been processed by the 1st tier of the Momentum Adder Tree.

The 1st tier Counter Tree CHTCR input latches are clocked and now hold the data from the CTFE Threshold Comparators.

3.5 to 4.0 The 1st tier of the Energy Adder tree is processing data that came from the second Energy Memory look-up and the results settle in the input latches of the 2nd tier.

The 2nd tier of the Energy Adder Tree is processing data that came from the first Energy Memory look-up and the results settle in the input latches of the 3rd tier.

The 2nd tier of the Momentum Adder Tree is processing the data that came from the 1st tier and the results are settling in the input latches of the 3rd tier.

The CHTCR cards in the 1st tier of the Counting Trees are counting the number of CTFE Threshold Comparators that are over threshold and the results are settling in the input latches of the 2nd tier of the Counter Tree. The Pre-Trigger "OR" gates on the CHTCR cards send their results to the Pre-Trigger global "OR" cards.

4.0 The 2nd tier Energy Adder Tree input latches are clocked and now hold data that came from the second Energy Memory look-up and has been processed by the 1st tier of the Energy Adder Tree.

The 3rd tier Energy Adder Tree input latches are clocked and now hold data that came from the first Energy Memory look-up and has been processed by the 1st and 2nd tiers of the Energy Adder Tree.

The 3rd tier Momentum Adder Tree input latches are clocked and now hold data that has been processed by the 1st and 2nd tiers of the Momentum Adder Tree.

The 2nd tier Counter Tree input latches are clocked and now hold data that has been processed by the 1st tier Counter Tree CHTCR cards.

4.0 to 4.5 The 2nd tier of the Energy Adder Tree is processing data that come from the second Energy Memory look-up and the results are settling in the input latches of the 3rd tier.

The 3rd tier of the Energy Adder Tree is processing data that came from the first Energy Memory look-up and the results are settling in the input latches of the Final Sum stage of the Energy Adder Tree. The results of the 3rd tier Comparators are send to the Trigger Framework IML (Intermediate Latch).

The 3rd tier of the Momentum Adder Tree is processing the data from the 2nd tier and the results are settling in the input latches of the Final Stage of the Momentum Adder Tree.

The 2nd tier of the Counter Tree is processing the data from the CHTCR cards in the 1st tier of the Counting Trees and the results are settling in the 3rd tier.

The Pre-Trigger Global "OR" cards process the data from the CHTCR Pre-Trigger "OR" gates and make the Pre-Trigger signal available.

4.5 The input latches in the Total Sum Stage of the Energy Adder Trees are clocked and now hold data from the first Energy Memory look-up that has been processed by the 1st, 2nd and 3rd tiers of the Energy Adder Trees.

The 3rd tier Energy Adder Tree input latches are clocked and now hold data from the second Energy Memory look-up that had been processed by the 1st and 2nd tiers of the Energy Adder Trees.

The input latches in the Final Stage of the Momentum Adder Tree are clocked and now hold the data that has been processed by the 1st, 2nd , and 3rd tiers of the Momentum Adder Trees.

The 3rd tier Counter Tree input latches are clocked and now hold data that has been processed by the 1st and 2nd tiers.

4.5 to 5.0 The Total Sum stage of the Energy Adder Tree is processing data that came from the first Energy Memory look-up. The results of the Total Sum Stage comparators are sent to the Trigger Framework IML.

The 3rd tier of the Energy Adder Tree is processing data that came from the second Energy Memory look-up and the results are settling in the input latches of the Total Sum stage of the Energy Adder Tree. The results of the 3rd tier comparators are sent to the Trigger Framework IML.

The Final Stage of the Momentum Adder Tree is processing data from the 3rd tier and the results are sent to the Trigger Framework IML.

The 3rd tier of the Counter Trees is processing data from the second tier and the results are sent to the Trigger Framework IML.

5.0 The input latches of the Total Sum stage of the Energy Adder Tree are clocked and now hold data from the second Energy Memory look-up that has been processed by the 1st, 2nd, and 3rd tiers of the Energy Adder Tree.

The input latches of the Busy Signal TLM (Trigger Latch Module) are clocked and this card now holds the state of all 32 Busy Signals from the Trigger-Acquisition Synchronization Cables. This data is driven onto the Busy DIGIMEM backplanes.

5.0 to 5.5 The Total Sum stage of the Energy Adder Trees is processing data that came from the second Energy Memory look-up. The results of the Total Sum stage Comparators are sent to the Trigger Framework IML.

The Busy DIGIMEM cards process the Busy Signals into one of the components that will be used on the FSTD cards to determine the Enable-Disable status for each Specific Trigger.

5.5 The Trigger Framework IML's are clocked and now hold and are driving onto the AND-OR backplanes all of the data that will be used to make the trigger decisions.

5.5 to 6.0 The AND-OR cards are processing the data from the IML's and the results are sent to the AND-OR inputs of the FSTD's.

The Busy DIGIMEM cards finish processing their Busy Signal inputs and send their results to the FSTD cards as one of the components that is used to determine the Enable-Disable status for each Specific Trigger.

6.0 The Enable-Disable status of the FSTD's is updated by clocking the FSTD Disable clock.

6.0 to 6.5 The AND-OR cards finish their processing and their results are validated on the FSTD cards by the AND-OR Strobe Signal and combined with the Enable-Disable status for each Specific Trigger before the results are sent from the FSTD cards to the input latches on the Specific Triggers Fired TLM card.

6.5 The input latches on theSpecific Triggers Fired TLM card are clocked and this card now holds the state of each Specific Trigger and drives this information onto the Start Digitizing DIGIMEM backplane. The Specific Triggers Fired Data is also sent out from the Trigger Framework on the Specific Triggers Fired Cables and will be followed later by the Specific Triggers Fired Strobe Signal.

6.5 and 7.0 The Start Digitizing DIGIMEM's process the Specific Triggers Fired Data into Start Digitizing Signals. The Start Digitizing Signals are routed to the inputs of the Start Digitization TLM Driver card.

7.5 The Start Digitizing TLM Driver Card input latch is clocked and this card now outputs valid Start Digitization Signals. These signals are connected to the Trigger Acquisition Synchronization Cables where they are joined by the Trigger Number Data and the Hold Transfer Signals. All "triggering signals" have left the Trigger Framework on either one of the 9 Specific Triggers Fired Cables or on one of the 32 Trigger Acquisition Synchronization Cables.

V. Level One Trigger Fixed Data Block

The detailed contents of the Level One Trigger Fixed Data Block for six bunch on six bunch operation are given in Appendix A.

VI. List of Figures

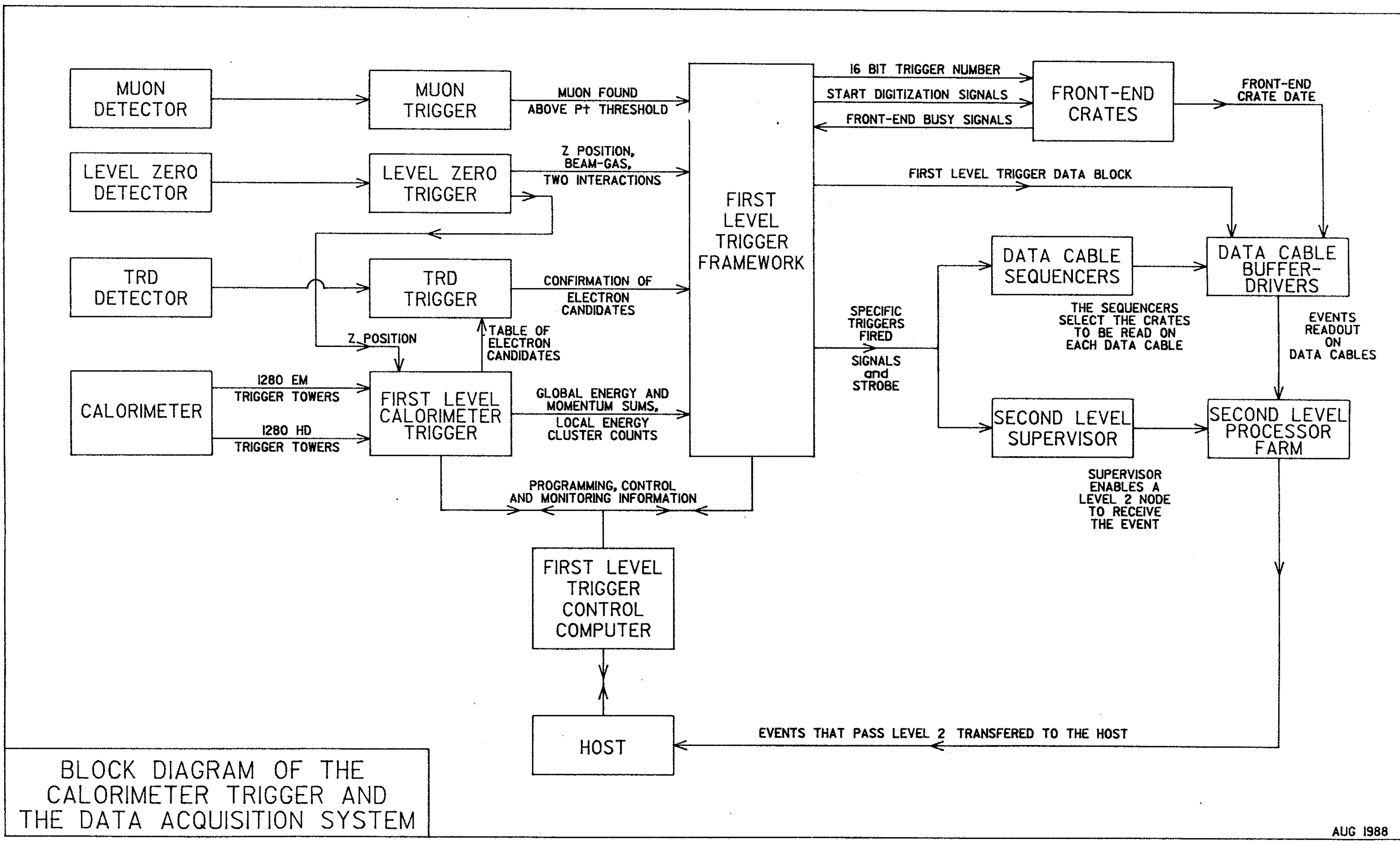
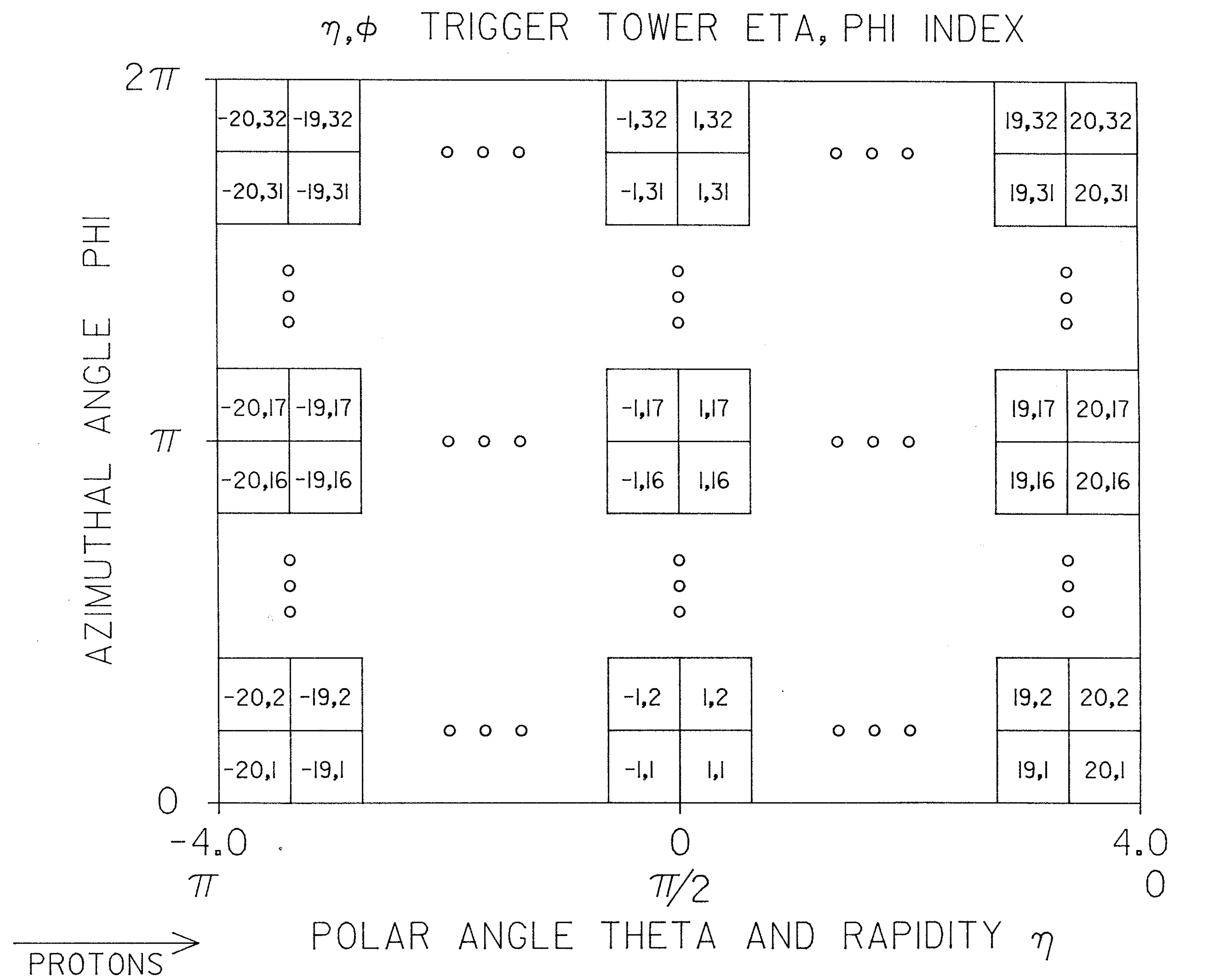

MUON DETECTOR
LEVEL ZERO DETECTOR
TRD DETECTOR
CALORIMETER
MUON TRIGGER
LEVEL ZERO TRIGGER
TRD TRIGGER
FIRST LEVEL CALORIMETER TRIGGER
1280 EM TRIGGER TOWERS
1280 HD TRIGGER TOWERS
Z POSITION
TABLE OF ELECTRON CANDIDATES
MUON FOUND ABOVE Pt THRESHOLD
Z POSITION, BEAM-GAS, TWO INTERACTIONS
CONFIRMATION OF ELECTRON CANDIDATES
GLOBAL ENERGY AND MOMENTUM SUMS, LOCAL ENERGY CLUSTER COUNTS
FIRST LEVEL TRIGGER FRAMEWORK
16 BIT TRIGGER NUMBER
START DIGITIZATION SIGNALS
FRONT-END BUSY SIGNALS
FRONT-END CRATES
FRONT-END CRATE DATE
FIRST LEVEL TRIGGER DATA BLOCK
SPECIFIC TRIGGERS FIRED
SIGNALS and STROBE
DATA CABLE SEQUENCERS
THE SEQUENCERS SELECT THE CRATES TO BE READ ON EACH DATA CABLE
DATA CABLE BUFFER-DRIVERS
EVENTS READOUT ON DATA CABLES
SECOND LEVEL SUPERVISOR
SUPERVISOR ENABLES A LEVEL 2 NODE TO RECEIVE THE EVENT
SECOND LEVEL PROCESSOR FARM
PROGRAMMING, CONTROL AND MONITORING INFORMATION
FIRST LEVEL TRIGGER CONTROL COMPUTER
HOST
EVENTS THAT PASS LEVEL 2 TRANSFERED TO THE HOST
BLOCK DIAGRAM OF THE CALORIMETER TRIGGER AND THE DATA ACQUISITION SYSTEM
AUG 1988

FIGURE 1

FIRST LEVEL TRIGGER COORDINATE SYSTEM



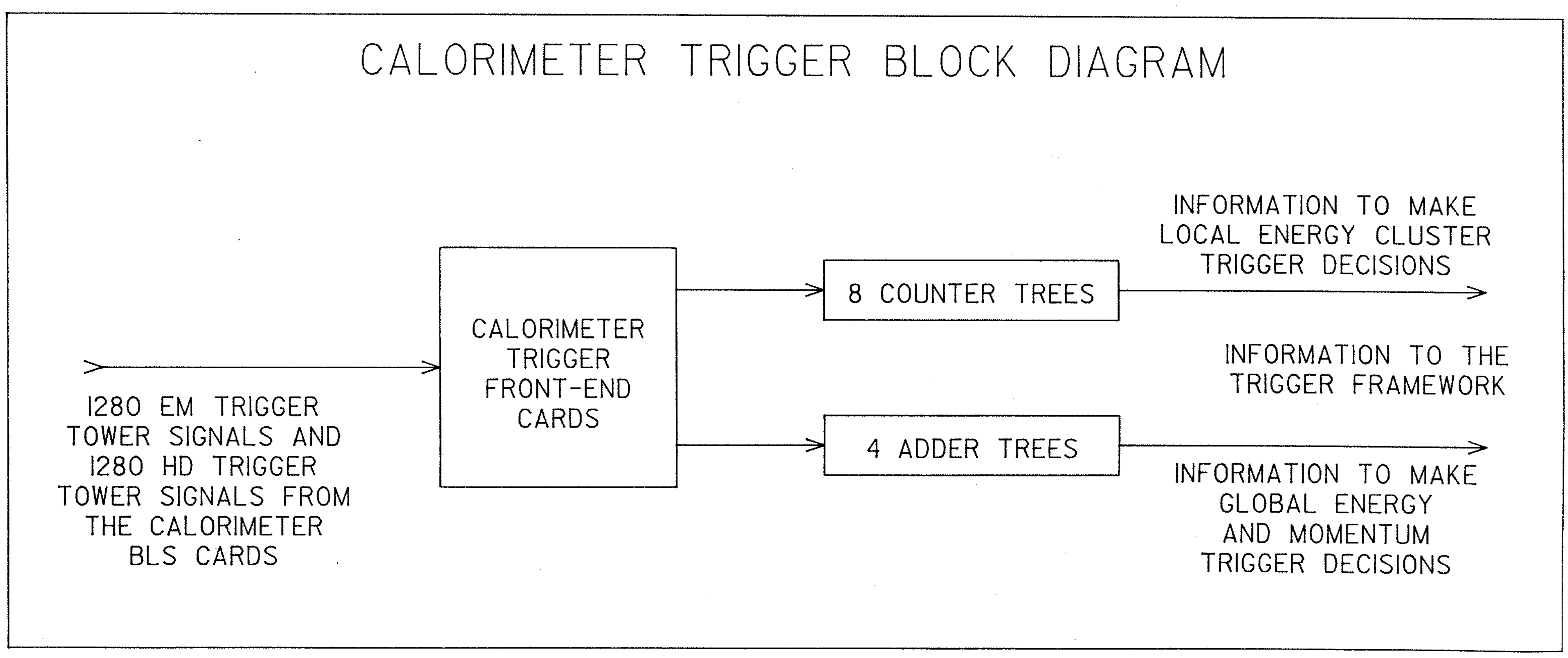

CALORIMETER TRIGGER BLOCK DIAGRAM
1280 EM TRIGGER TOWER SIGNALS AND 1280 HD TRIGGER TOWER SIGNALS FROM THE CALORIMETER BLS CARDS
CALORIMETER TRIGGER FRONT-END CARDS
8 COUNTER TREES
4 ADDER TREES
INFORMATION TO MAKE LOCAL ENERGY CLUSTER TRIGGER DECISIONS
INFORMATION TO THE TRIGGER FRAMEWORK
INFORMATION TO MAKE GLOBAL ENERGY AND MOMENTUM TRIGGER DECISIONS

FIGURE 3

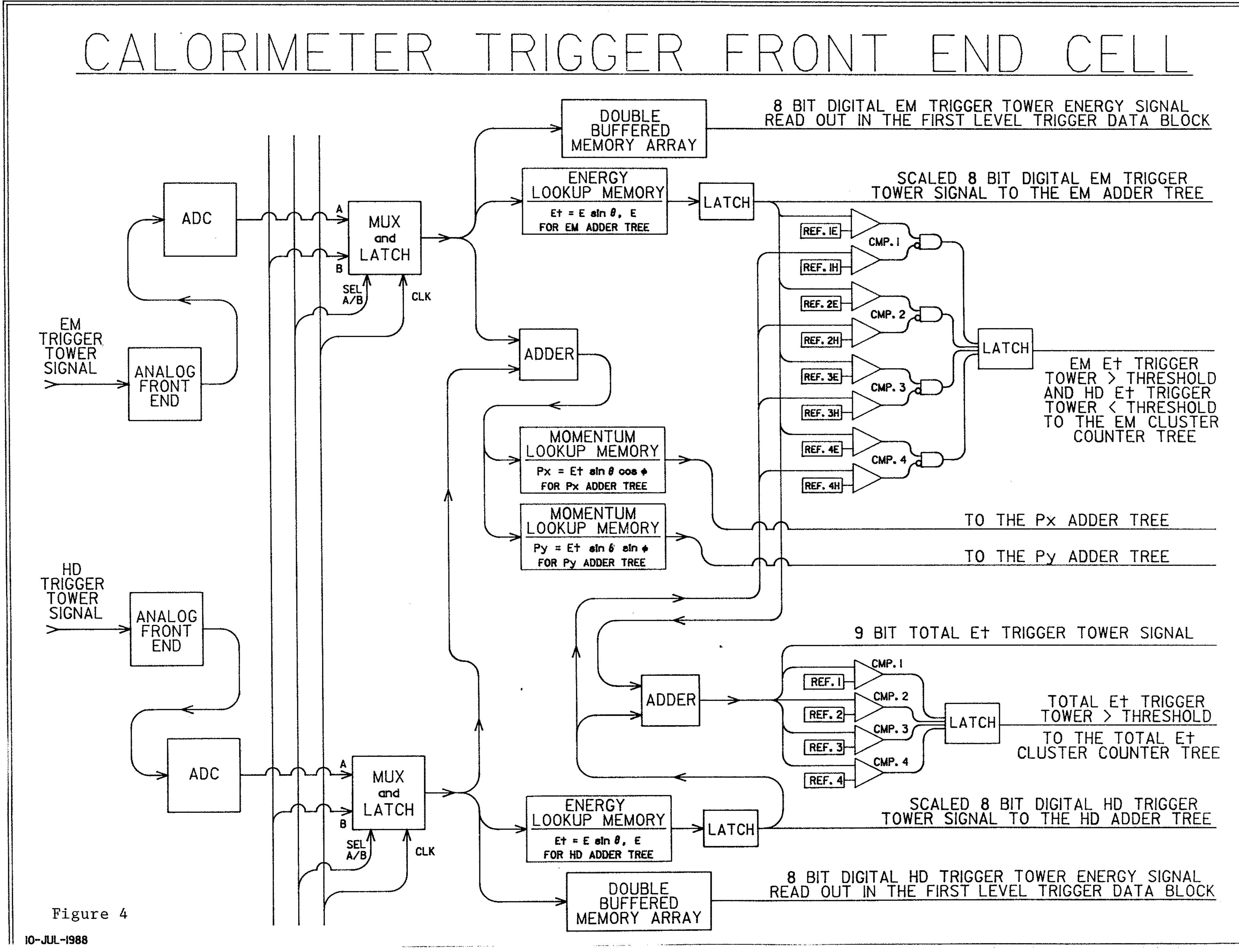


Figure 4

10-JUL-1988

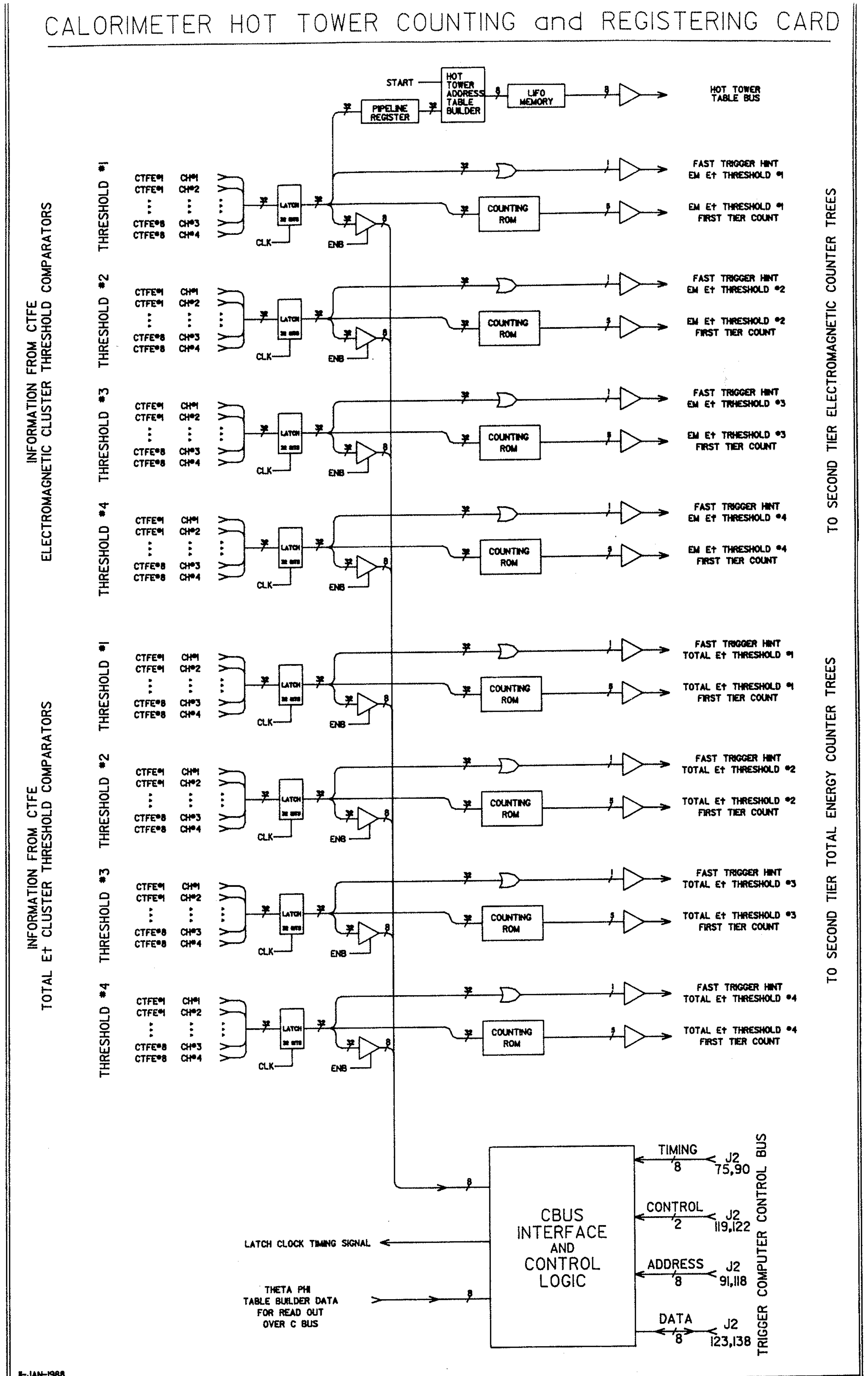
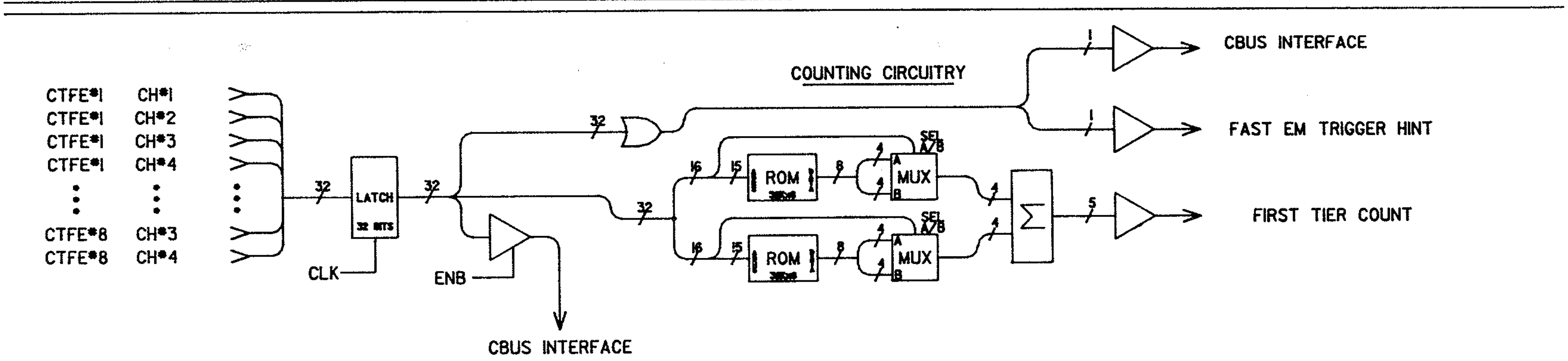
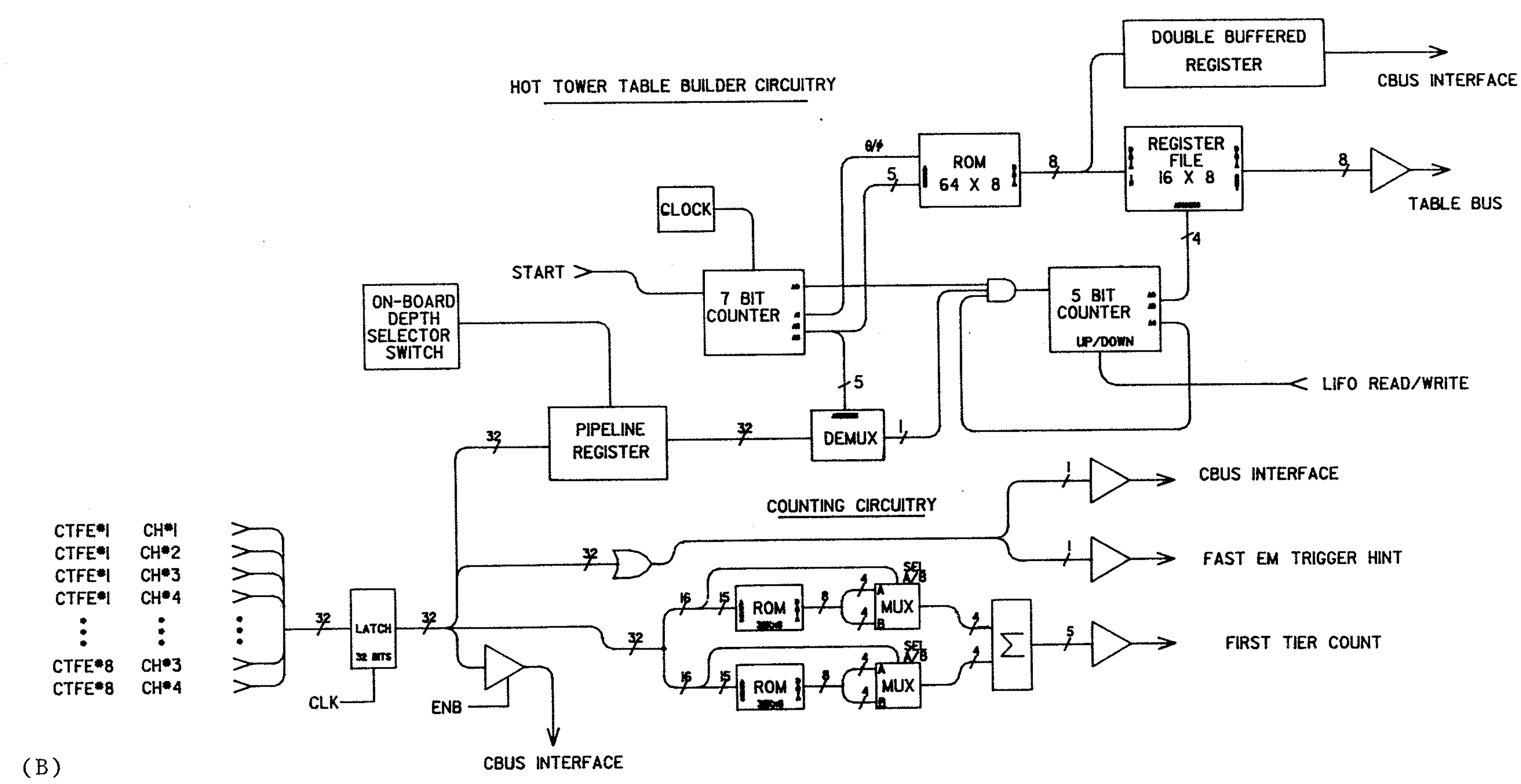

CALORIMETER HOT TOWER COUNTING and REGISTERING CARD
START
HOT TOWER ADDRESS TABLE BUILDER
PIPELINE REGISTER
LIFO MEMORY
HOT TOWER TABLE BUS
INFORMATION FROM CTFE ELECTROMAGNETIC CLUSTER THRESHOLD COMPARATORS
INFORMATION FROM CTFE TOTAL Et CLUSTER THRESHOLD COMPARATORS
THRESHOLD #1
THRESHOLD #2
THRESHOLD #3
THRESHOLD #4
CTFE#1 CH#1
CTFE#1 CH#2
CTFE#8 CH#3
CTFE#8 CH#4
LATCH
CLK
ENB
COUNTING ROM
FAST TRIGGER HINT EM Et THRESHOLD #1
EM Et THRESHOLD #1 FIRST TIER COUNT
FAST TRIGGER HINT EM Et THRESHOLD #2
EM Et THRESHOLD #2 FIRST TIER COUNT
FAST TRIGGER HINT EM Et TRHESHOLD #3
EM Et TRHESHOLD #3 FIRST TIER COUNT
FAST TRIGGER HINT EM Et THRESHOLD #4
EM Et THRESHOLD #4 FIRST TIER COUNT
FAST TRIGGER HINT TOTAL Et THRESHOLD #1
TOTAL Et THRESHOLD #1 FIRST TIER COUNT
FAST TRIGGER HINT TOTAL Et THRESHOLD #2
TOTAL Et THRESHOLD #2 FIRST TIER COUNT
FAST TRIGGER HINT TOTAL Et THRESHOLD #3
TOTAL Et THRESHOLD #3 FIRST TIER COUNT
FAST TRIGGER HINT TOTAL Et THRESHOLD #4
TOTAL Et THRESHOLD #4 FIRST TIER COUNT
TO SECOND TIER ELECTROMAGNETIC COUNTER TREES
TO SECOND TIER TOTAL ENERGY COUNTER TREES
CBUS INTERFACE AND CONTROL LOGIC
TIMING 8 J2 75,90
CONTROL 2 J2 119,122
ADDRESS 8 J2 91,118
DATA 8 J2 123,138
TRIGGER COMPUTER CONTROL BUS
LATCH CLOCK TIMING SIGNAL
THETA PHI TABLE BUILDER DATA FOR READ OUT OVER C BUS
11-JAN-1988

Figure 5

CALORIMETER HOT TOWER COUNTING and REGISTERING CARD



(A) TYPICAL ELECTROMAGNETIC OR TOTAL Et SUB-SECTION LOGIC DIAGRAM



(B) ELECTROMAGNETIC CLUSTER THRESHOLD #1 SUB-SECTION

11-JAN-1988

Figure 6

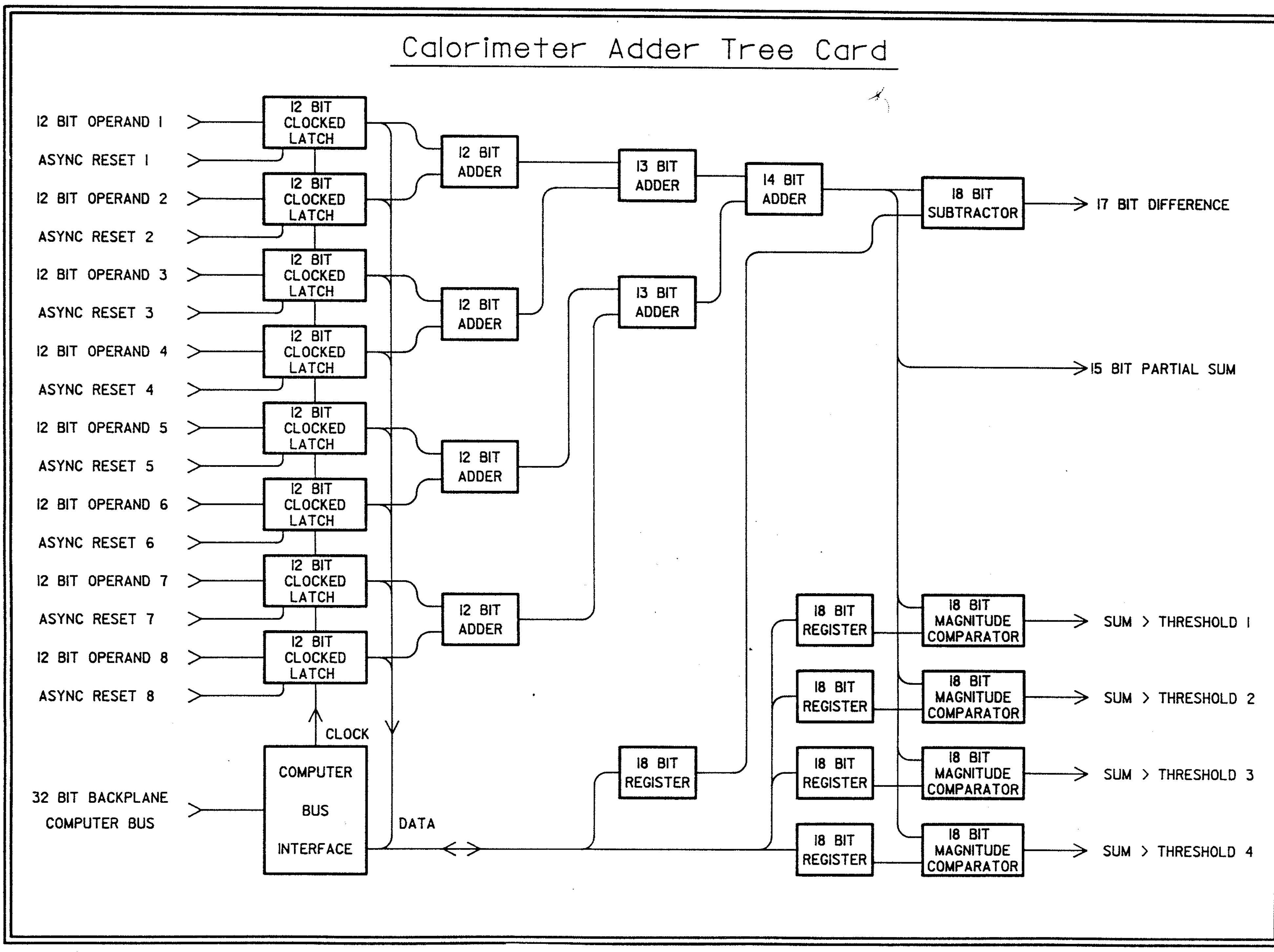

Calorimeter Adder Tree Card
12 BIT OPERAND 1
ASYNC RESET 1
12 BIT OPERAND 2
ASYNC RESET 2
12 BIT OPERAND 3
ASYNC RESET 3
12 BIT OPERAND 4
ASYNC RESET 4
12 BIT OPERAND 5
ASYNC RESET 5
12 BIT OPERAND 6
ASYNC RESET 6
12 BIT OPERAND 7
ASYNC RESET 7
12 BIT OPERAND 8
ASYNC RESET 8
32 BIT BACKPLANE COMPUTER BUS
12 BIT CLOCKED LATCH
12 BIT ADDER
13 BIT ADDER
14 BIT ADDER
18 BIT SUBTRACTOR
18 BIT REGISTER
18 BIT MAGNITUDE COMPARATOR
COMPUTER BUS INTERFACE
CLOCK
DATA
17 BIT DIFFERENCE
15 BIT PARTIAL SUM
SUM > THRESHOLD 1
SUM > THRESHOLD 2
SUM > THRESHOLD 3
SUM > THRESHOLD 4

Figure 7

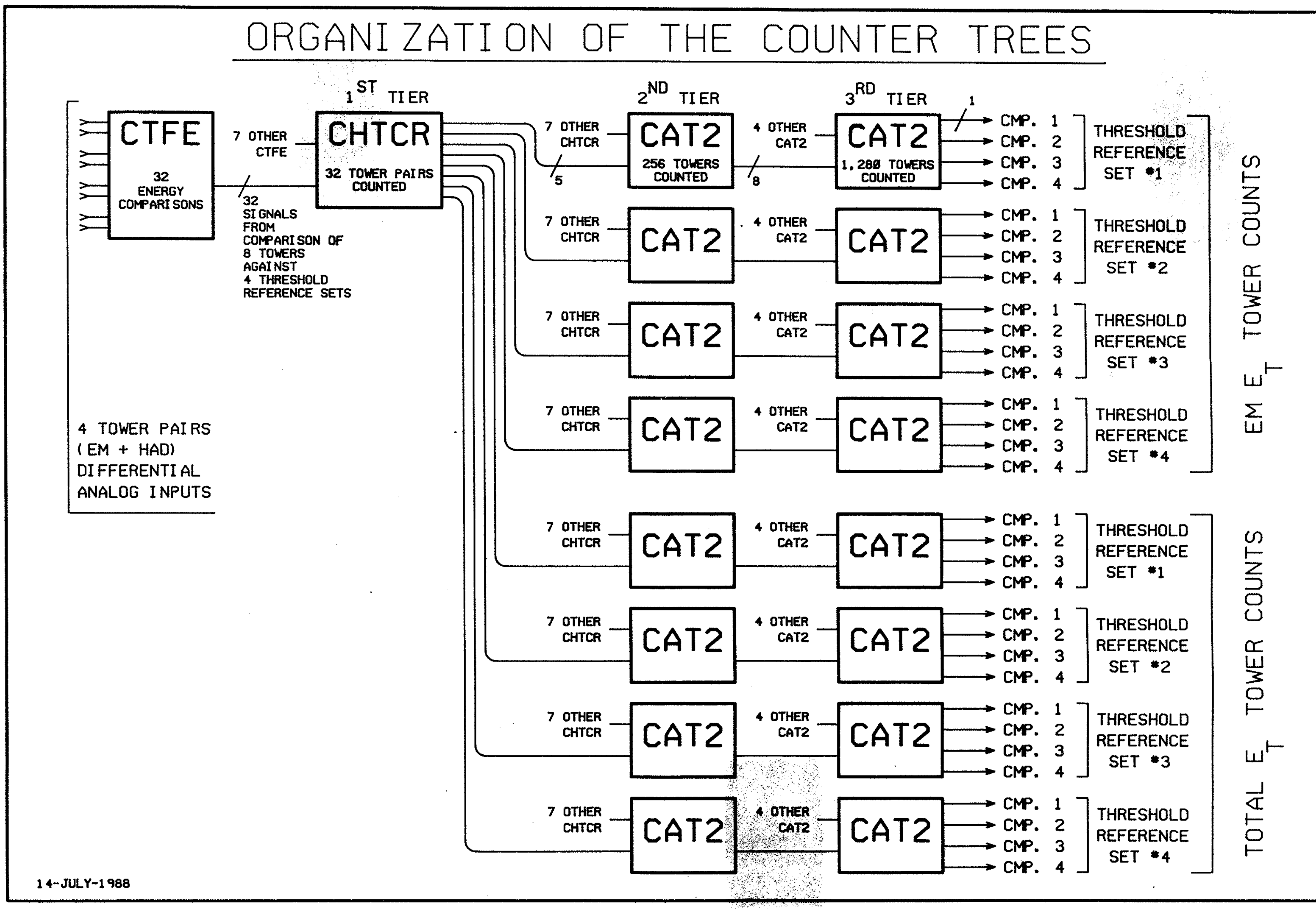

ORGANIZATION OF THE COUNTER TREES
1ST TIER
2ND TIER
3RD TIER
CTFE
32 ENERGY COMPARISONS
7 OTHER CTFE
32 SIGNALS FROM COMPARISON OF 8 TOWERS AGAINST 4 THRESHOLD REFERENCE SETS
CHTCR
32 TOWER PAIRS COUNTED
7 OTHER CHTCR
5
CAT2
256 TOWERS COUNTED
4 OTHER CAT2
8
1,280 TOWERS COUNTED
1
CMP. 1
CMP. 2
CMP. 3
CMP. 4
THRESHOLD REFERENCE SET #1
THRESHOLD REFERENCE SET #2
THRESHOLD REFERENCE SET #3
THRESHOLD REFERENCE SET #4
EM E_T TOWER COUNTS
TOTAL E_T TOWER COUNTS
4 TOWER PAIRS (EM + HAD) DIFFERENTIAL ANALOG INPUTS
14-JULY-1988

Figure 8

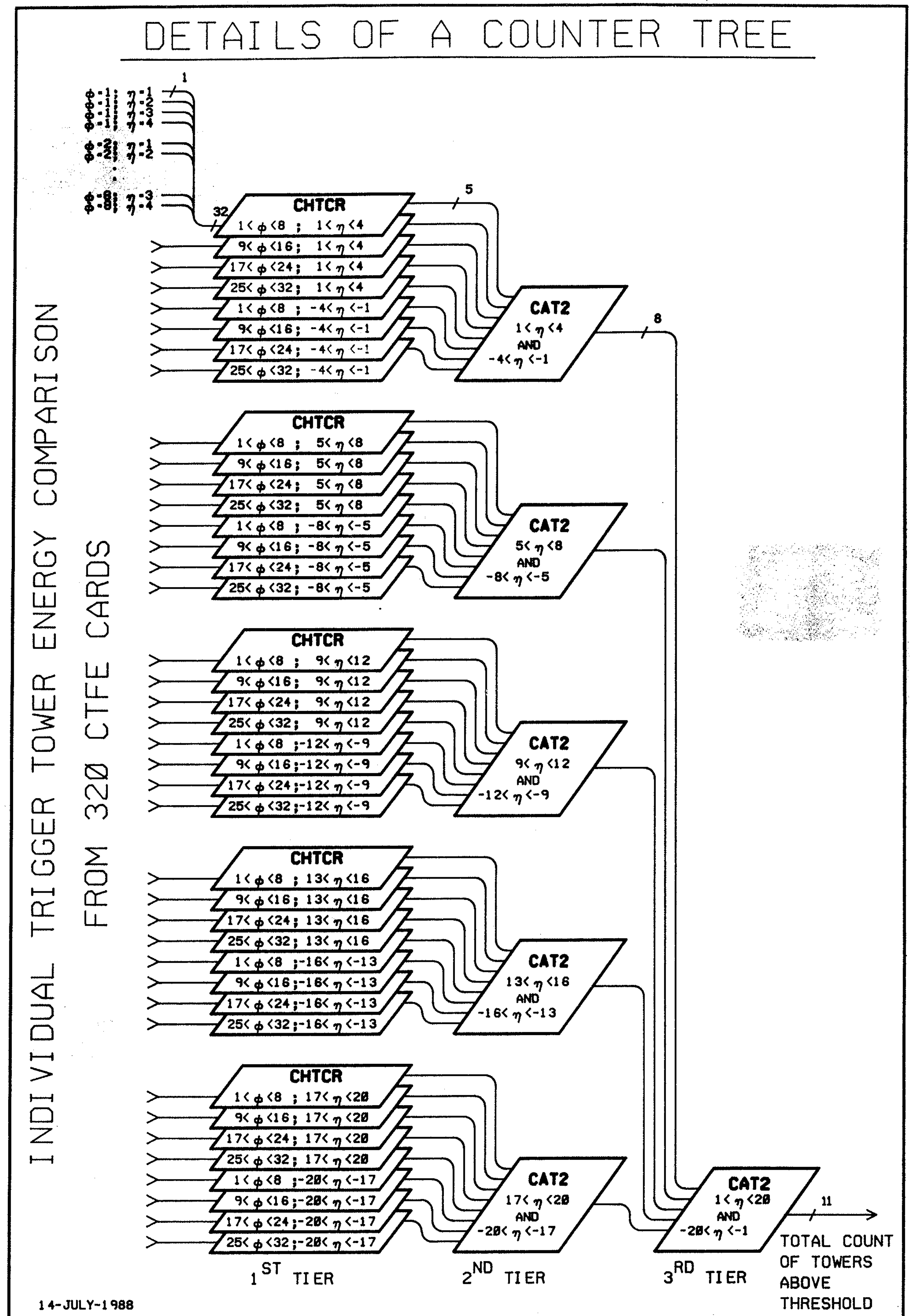
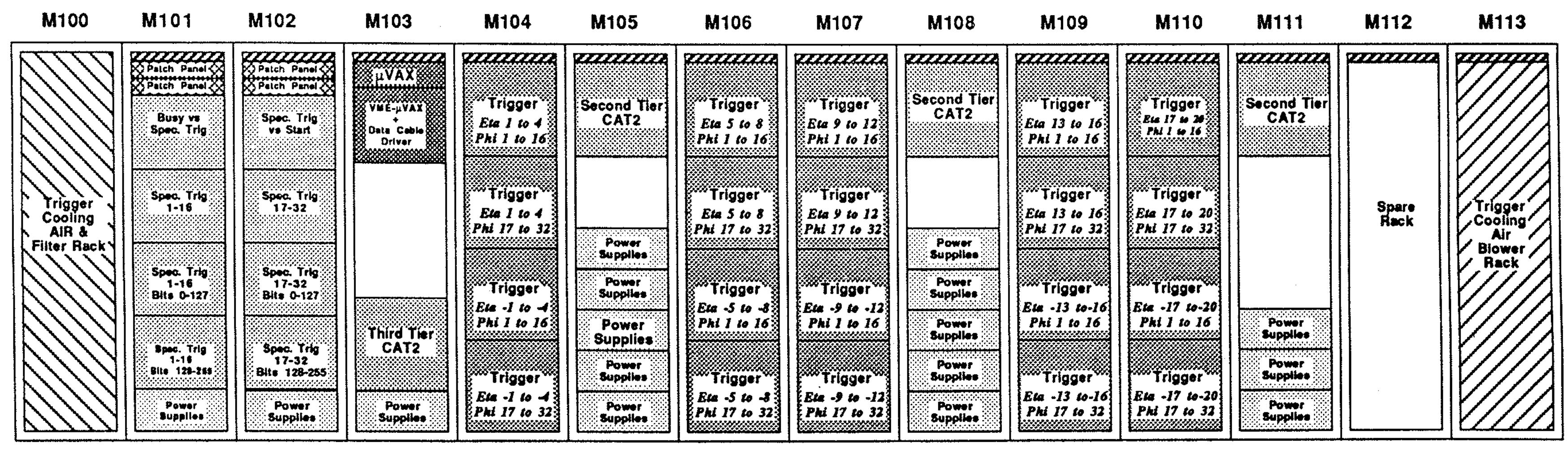
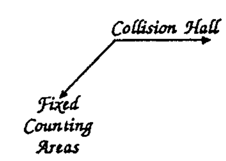

DETAILS OF A COUNTER TREE
INDIVIDUAL TRIGGER TOWER ENERGY COMPARISON
FROM 320 CTFE CARDS
CHTCR
1< φ <8 ; 1< η <4
9< φ <16; 1< η <4
17< φ <24; 1< η <4
25< φ <32; 1< η <4
1< φ <8 ; -4< η <-1
9< φ <16; -4< η <-1
17< φ <24; -4< η <-1
25< φ <32; -4< η <-1
CAT2
1< η <4
AND
-4< η <-1
CHTCR
1< φ <8 ; 5< η <8
9< φ <16; 5< η <8
17< φ <24; 5< η <8
25< φ <32; 5< η <8
1< φ <8 ; -8< η <-5
9< φ <16; -8< η <-5
17< φ <24; -8< η <-5
25< φ <32; -8< η <-5
CAT2
5< η <8
AND
-8< η <-5
CHTCR
1< φ <8 ; 9< η <12
9< φ <16; 9< η <12
17< φ <24; 9< η <12
25< φ <32; 9< η <12
1< φ <8 ;-12< η <-9
9< φ <16;-12< η <-9
17< φ <24;-12< η <-9
25< φ <32;-12< η <-9
CAT2
9< η <12
AND
-12< η <-9
CHTCR
1< φ <8 ; 13< η <16
9< φ <16; 13< η <16
17< φ <24; 13< η <16
25< φ <32; 13< η <16
1< φ <8 ;-16< η <-13
9< φ <16;-16< η <-13
17< φ <24;-16< η <-13
25< φ <32;-16< η <-13
CAT2
13< η <16
AND
-16< η <-13
CHTCR
1< φ <8 ; 17< η <20
9< φ <16; 17< η <20
17< φ <24; 17< η <20
25< φ <32; 17< η <20
1< φ <8 ;-20< η <-17
9< φ <16;-20< η <-17
17< φ <24;-20< η <-17
25< φ <32;-20< η <-17
CAT2
17< η <20
AND
-20< η <-17
CAT2
1< η <20
AND
-20< η <-1
TOTAL COUNT
OF TOWERS
ABOVE
THRESHOLD
1ST TIER
2ND TIER
3RD TIER
14-JULY-1988

Figure 9



Racks Viewed from Front

040788



Moving Counting House
First Floor

Figure 10

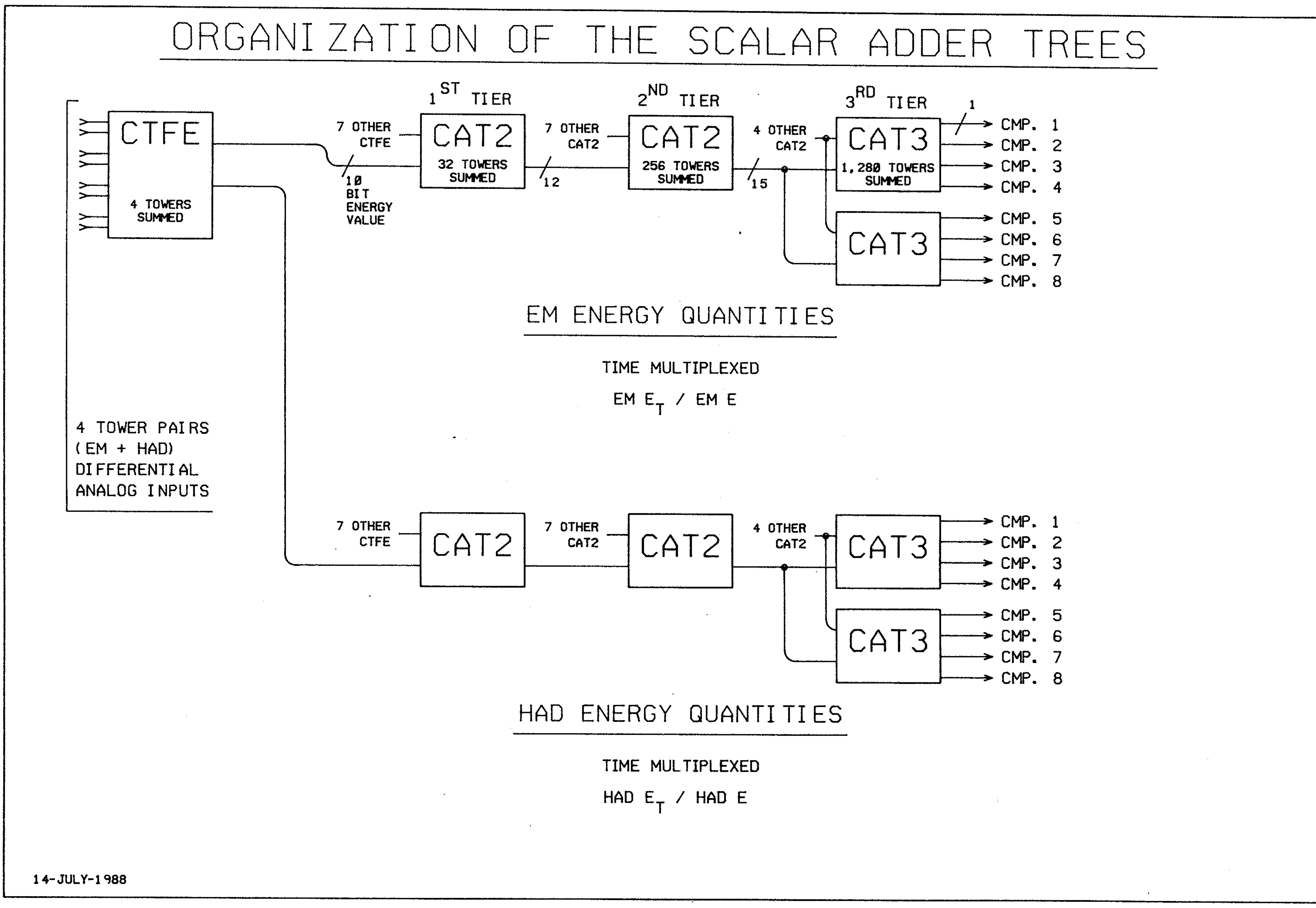

ORGANIZATION OF THE SCALAR ADDER TREES
CTFE
4 TOWERS SUMMED
4 TOWER PAIRS (EM + HAD) DIFFERENTIAL ANALOG INPUTS
7 OTHER CTFE
10 BIT ENERGY VALUE
1ST TIER
CAT2
32 TOWERS SUMMED
7 OTHER CAT2
12
2ND TIER
CAT2
256 TOWERS SUMMED
4 OTHER CAT2
15
3RD TIER
CAT3
1,280 TOWERS SUMMED
1
CMP. 1
CMP. 2
CMP. 3
CMP. 4
CAT3
CMP. 5
CMP. 6
CMP. 7
CMP. 8
EM ENERGY QUANTITIES
TIME MULTIPLEXED
EM E_T / EM E
7 OTHER CTFE
CAT2
7 OTHER CAT2
CAT2
4 OTHER CAT2
CAT3
CMP. 1
CMP. 2
CMP. 3
CMP. 4
CAT3
CMP. 5
CMP. 6
CMP. 7
CMP. 8
HAD ENERGY QUANTITIES
TIME MULTIPLEXED
HAD E_T / HAD E
14-JULY-1988

Figure 11

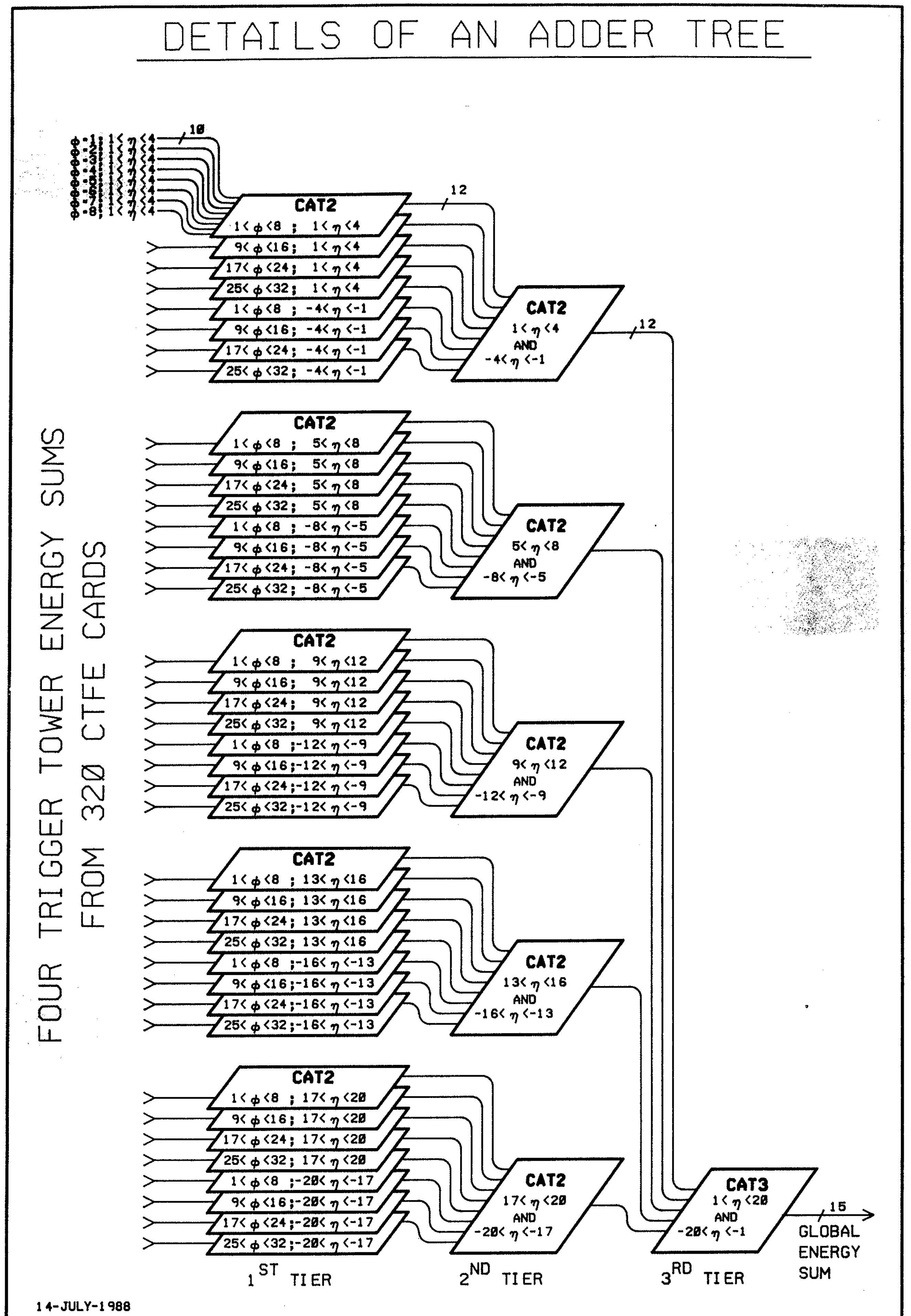
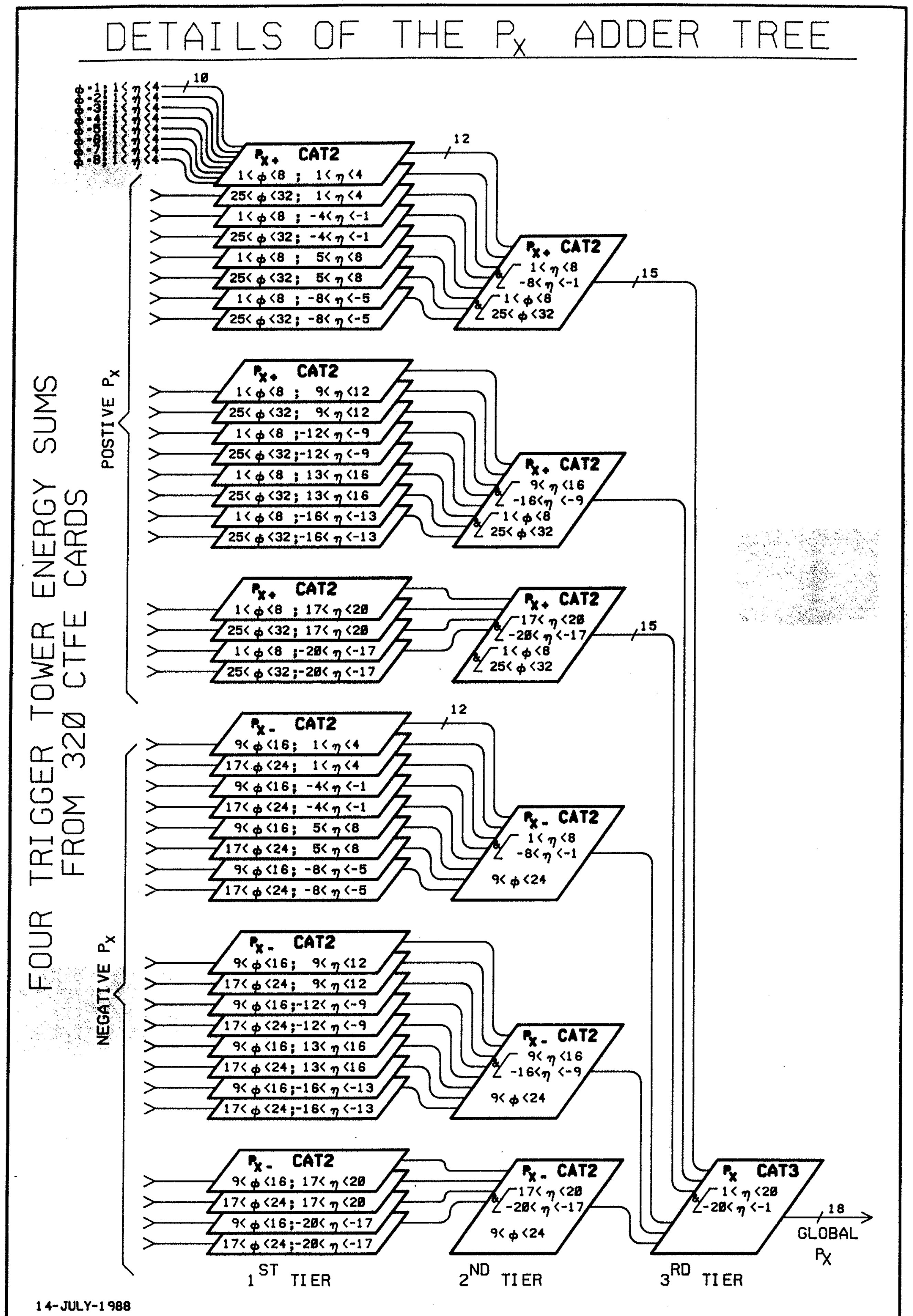
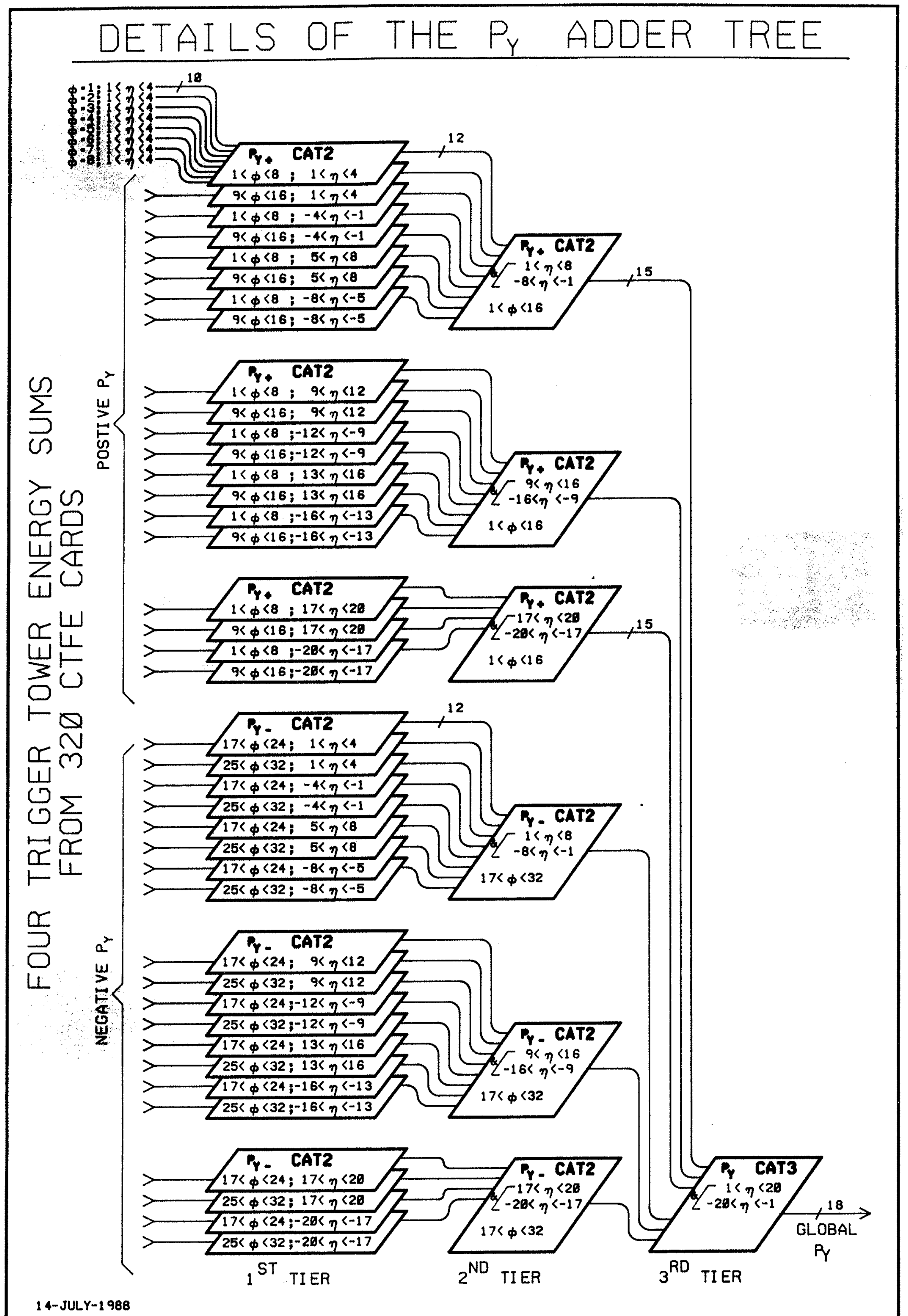

DETAILS OF AN ADDER TREE
FOUR TRIGGER TOWER ENERGY SUMS
FROM 320 CTFE CARDS
10
12
CAT2
1< φ <8 ; 1< η <4
9< φ <16; 1< η <4
17< φ <24; 1< η <4
25< φ <32; 1< η <4
1< φ <8 ; -4< η <-1
9< φ <16; -4< η <-1
17< φ <24; -4< η <-1
25< φ <32; -4< η <-1
CAT2
1< η <4
AND
-4< η <-1
12
CAT2
1< φ <8 ; 5< η <8
9< φ <16; 5< η <8
17< φ <24; 5< η <8
25< φ <32; 5< η <8
1< φ <8 ; -8< η <-5
9< φ <16; -8< η <-5
17< φ <24; -8< η <-5
25< φ <32; -8< η <-5
CAT2
5< η <8
AND
-8< η <-5
CAT2
1< φ <8 ; 9< η <12
9< φ <16; 9< η <12
17< φ <24; 9< η <12
25< φ <32; 9< η <12
1< φ <8 ;-12< η <-9
9< φ <16;-12< η <-9
17< φ <24;-12< η <-9
25< φ <32;-12< η <-9
CAT2
9< η <12
AND
-12< η <-9
CAT2
1< φ <8 ; 13< η <16
9< φ <16; 13< η <16
17< φ <24; 13< η <16
25< φ <32; 13< η <16
1< φ <8 ;-16< η <-13
9< φ <16;-16< η <-13
17< φ <24;-16< η <-13
25< φ <32;-16< η <-13
CAT2
13< η <16
AND
-16< η <-13
CAT2
1< φ <8 ; 17< η <20
9< φ <16; 17< η <20
17< φ <24; 17< η <20
25< φ <32; 17< η <20
1< φ <8 ;-20< η <-17
9< φ <16;-20< η <-17
17< φ <24;-20< η <-17
25< φ <32;-20< η <-17
CAT2
17< η <20
AND
-20< η <-17
CAT3
1< η <20
AND
-20< η <-1
15
GLOBAL
ENERGY
SUM
1ST TIER
2ND TIER
3RD TIER
14-JULY-1988

Figure 12



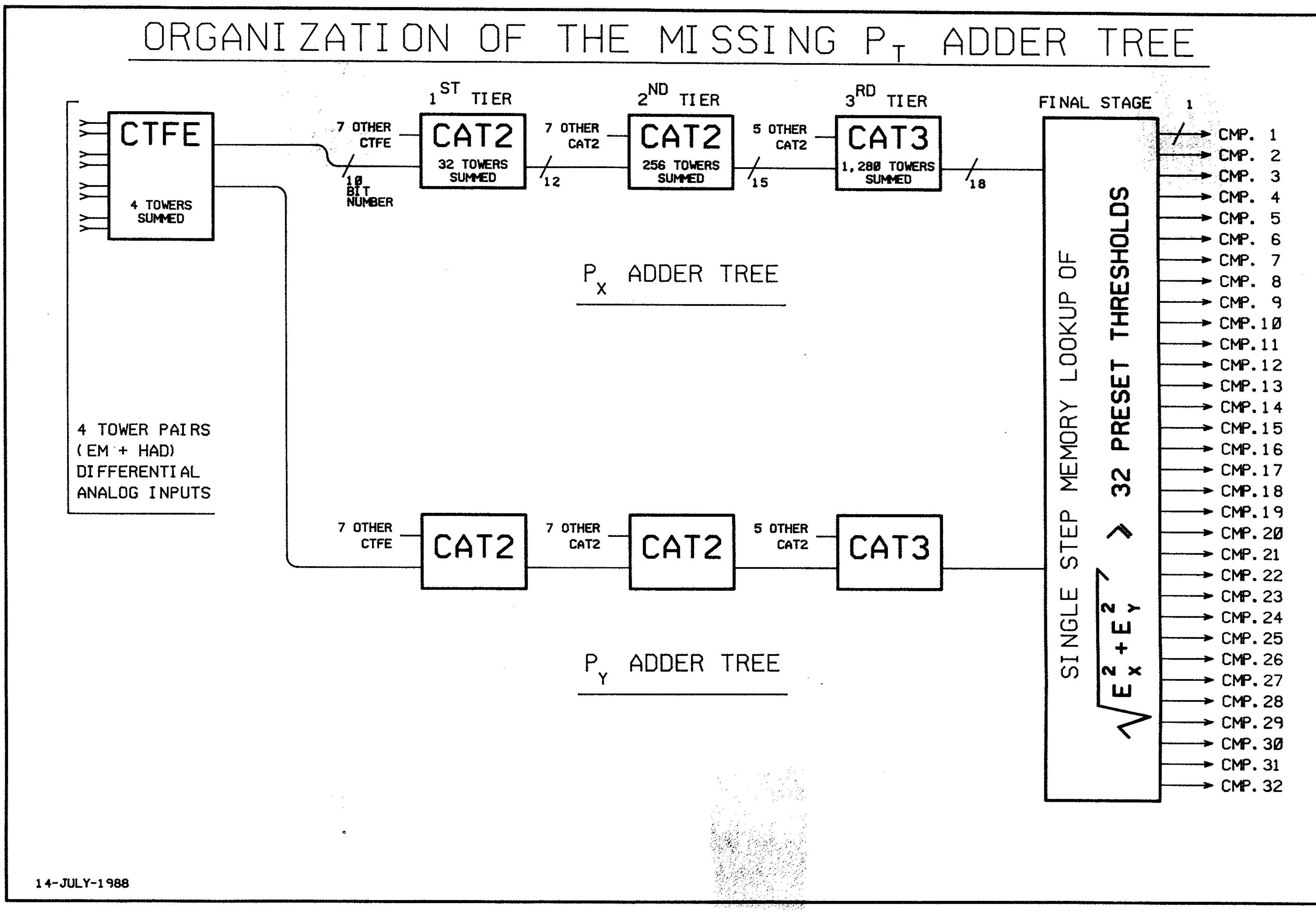
DETAILS OF THE Px ADDER TREE
FOUR TRIGGER TOWER ENERGY SUMS FROM 320 CTFE CARDS
POSTIVE Px
NEGATIVE Px
Px+ CAT2
1< φ <8 ; 1< η <4
25< φ <32; 1< η <4
1< φ <8 ; -4< η <-1
25< φ <32; -4< η <-1
1< φ <8 ; 5< η <8
25< φ <32; 5< η <8
1< φ <8 ; -8< η <-5
25< φ <32; -8< η <-5
Px+ CAT2
1< η <8
-8< η <-1
1< φ <8
25< φ <32
Px+ CAT2
1< φ <8 ; 9< η <12
25< φ <32; 9< η <12
1< φ <8 ;-12< η <-9
25< φ <32;-12< η <-9
1< φ <8 ; 13< η <16
25< φ <32; 13< η <16
1< φ <8 ;-16< η <-13
25< φ <32;-16< η <-13
Px+ CAT2
9< η <16
-16< η <-9
1< φ <8
25< φ <32
Px+ CAT2
1< φ <8 ; 17< η <20
25< φ <32; 17< η <20
1< φ <8 ;-20< η <-17
25< φ <32;-20< η <-17
Px+ CAT2
17< η <20
-20< η <-17
1< φ <8
25< φ <32
Px- CAT2
9< φ <16; 1< η <4
17< φ <24; 1< η <4
9< φ <16; -4< η <-1
17< φ <24; -4< η <-1
9< φ <16; 5< η <8
17< φ <24; 5< η <8
9< φ <16; -8< η <-5
17< φ <24; -8< η <-5
Px- CAT2
1< η <8
-8< η <-1
9< φ <24
Px- CAT2
9< φ <16; 9< η <12
17< φ <24; 9< η <12
9< φ <16;-12< η <-9
17< φ <24;-12< η <-9
9< φ <16; 13< η <16
17< φ <24; 13< η <16
9< φ <16;-16< η <-13
17< φ <24;-16< η <-13
Px- CAT2
9< η <16
-16< η <-9
9< φ <24
Px- CAT2
9< φ <16; 17< η <20
17< φ <24; 17< η <20
9< φ <16;-20< η <-17
17< φ <24;-20< η <-17
Px- CAT2
17< η <20
-20< η <-17
9< φ <24
Px CAT3
1< η <20
-20< η <-1
10
12
15
18
GLOBAL Px
1ST TIER
2ND TIER
3RD TIER
14-JULY-1988

Figure 13



DETAILS OF THE P_Y ADDER TREE
FOUR TRIGGER TOWER ENERGY SUMS FROM 320 CTFE CARDS
POSTIVE P_Y
NEGATIVE P_Y
CAT2
CAT3
GLOBAL P_Y
1ST TIER
2ND TIER
3RD TIER
14-JULY-1988

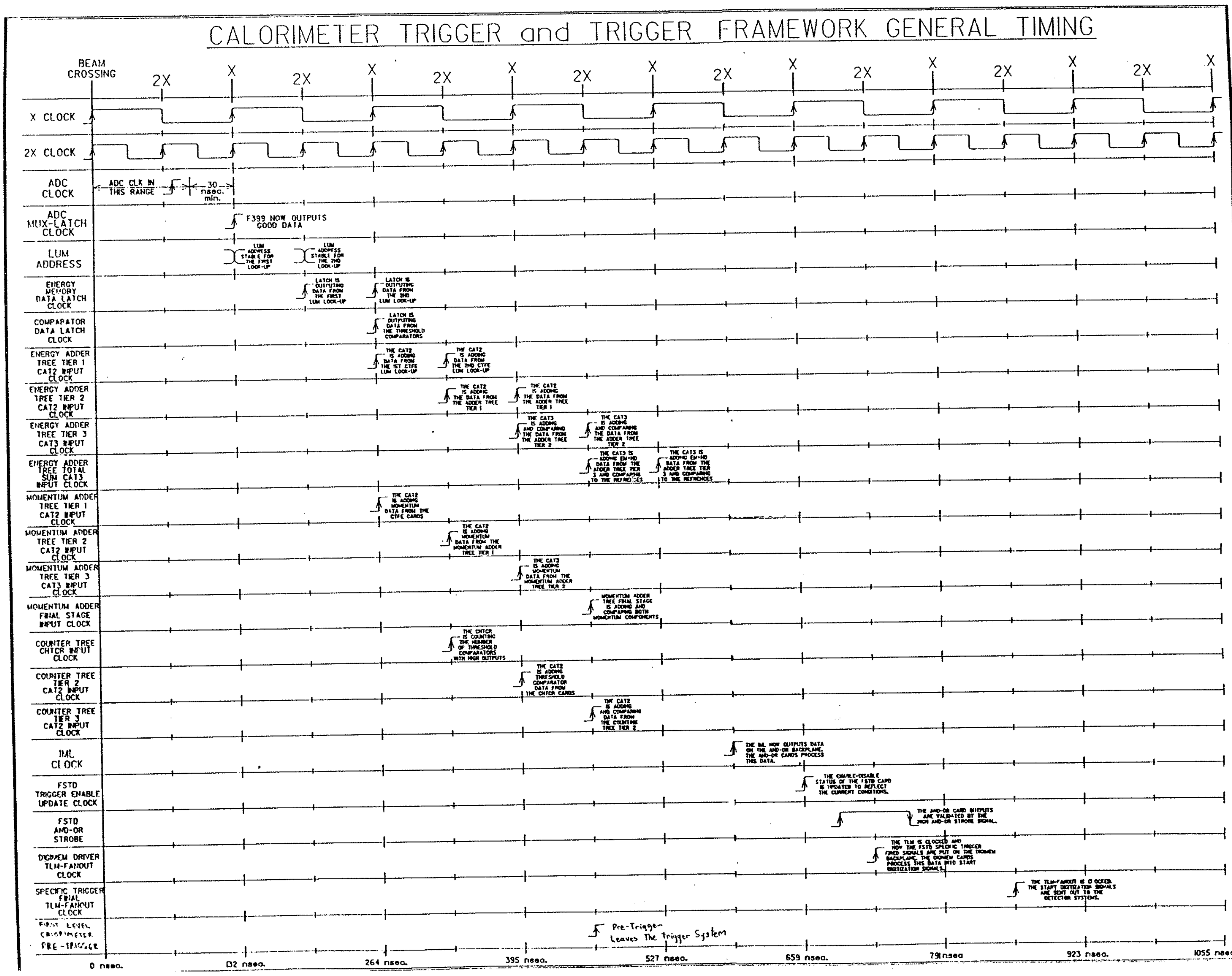
Figure 14



ORGANIZATION OF THE MISSING P_T ADDER TREE
1^{ST} TIER
2^{ND} TIER
3^{RD} TIER
FINAL STAGE
CTFE
4 TOWERS SUMMED
7 OTHER CTFE
10 BIT NUMBER
CAT2
32 TOWERS SUMMED
7 OTHER CAT2
12
CAT2
256 TOWERS SUMMED
5 OTHER CAT2
15
CAT3
1,280 TOWERS SUMMED
18
SINGLE STEP MEMORY LOOKUP OF
$\sqrt{E_x^2 + E_y^2} > 32$ PRESET THRESHOLDS
1
CMP. 1
CMP. 2
CMP. 3
CMP. 4
CMP. 5
CMP. 6
CMP. 7
CMP. 8
CMP. 9
CMP. 10
CMP. 11
CMP. 12
CMP. 13
CMP. 14
CMP. 15
CMP. 16
CMP. 17
CMP. 18
CMP. 19
CMP. 20
CMP. 21
CMP. 22
CMP. 23
CMP. 24
CMP. 25
CMP. 26
CMP. 27
CMP. 28
CMP. 29
CMP. 30
CMP. 31
CMP. 32
P_X ADDER TREE
4 TOWER PAIRS
(EM + HAD)
DIFFERENTIAL
ANALOG INPUTS
7 OTHER CTFE
CAT2
7 OTHER CAT2
CAT2
5 OTHER CAT2
CAT3
P_Y ADDER TREE
14-JULY-1988

Figure 15

Figure 16


CALORIMETER TRIGGER and TRIGGER FRAMEWORK GENERAL TIMING
BEAM CROSSING
X CLOCK
2X CLOCK
ADC CLOCK
ADC MUX-LATCH CLOCK
LUM ADDRESS
ENERGY MEMORY DATA LATCH CLOCK
COMPARATOR DATA LATCH CLOCK
ENERGY ADDER TREE TIER 1 CAT2 INPUT CLOCK
ENERGY ADDER TREE TIER 2 CAT2 INPUT CLOCK
ENERGY ADDER TREE TIER 3 CAT3 INPUT CLOCK
ENERGY ADDER TREE TOTAL SUM CAT3 INPUT CLOCK
MOMENTUM ADDER TREE TIER 1 CAT2 INPUT CLOCK
MOMENTUM ADDER TREE TIER 2 CAT2 INPUT CLOCK
MOMENTUM ADDER TREE TIER 3 CAT3 INPUT CLOCK
MOMENTUM ADDER FINAL STAGE INPUT CLOCK
COUNTER TREE CHTCR INPUT CLOCK
COUNTER TREE TIER 2 CAT2 INPUT CLOCK
COUNTER TREE TIER 3 CAT2 INPUT CLOCK
IML CLOCK
FSTD TRIGGER ENABLE UPDATE CLOCK
FSTD AND-OR STROBE
DIGMEM DRIVER TLM-FANOUT CLOCK
SPECIFIC TRIGGER FINAL TLM-FANOUT CLOCK
ADC CLK IN THIS RANGE
30 nsec. min.
F399 NOW OUTPUTS GOOD DATA
Pre-Trigger Leaves The Trigger System
0 nsec.
132 nsec.
264 nsec.
395 nsec.
527 nsec.
659 nsec.
791 nsec.
923 nsec.
1055 nsec.

Appendix A

```
                          DATA BUILT INTO THE FIRST LEVEL TRIGGER DATA BLOCK          REV.    25-OCT-1988
                          ------------------------------------------------------

          ITEM #
HEX       DECIMAL    FIRST BYTE                                                       SECOND BYTE
---       -------    ----------                                                       -----------
0000           0     NOT USED                                                         NOT USED
                     Note: all bytes of information defined as NOT USED are null bytes.
---------------------------------------------------------------------------------------------------------
CURRENT BEAM CROSSING
=====================
0002           1
.    10t-9:10t-5     TRIGGER COUNT SPEC. TRIG. t (5 bytes,low first)    (t=1,32)      NOT USED
.    10t-4:10t       ENABLE  COUNT SPEC. TRIG. t (5 bytes,low first)    (t=1,32)      NOT USED
0280         320
0282         321
.                    TRIGGER NUMBER SCALER       (5 bytes,low first)                  NOT USED
028A         325
028C         326
.                    7 SCALERS, NOT ASSIGNED YET (5 bytes,low first)                  NOT USED
02D0         360
02D2         361
.          361+n     FSTD FOR SPECIFIC TRIGGERS 4n+1 thru 4n+4           (n=0,7)       NOT USED
.                          LSB bit #1 spec. trig. 4n+1 enabled
.                              bit #2 spec. trig. 4n+2 enabled
.                              bit #3 spec. trig. 4n+3 enabled
.                              bit #4 spec. trig. 4n+4 enabled
.                              bit #5 spec. trig. 4n+1 ANDOR fired
.                              bit #6 spec. trig. 4n+2 ANDOR fired
.                              bit #7 spec. trig. 4n+3 ANDOR fired
.                          MSB bit #8 spec. trig. 4n+4 ANDOR fired
02E0         368
02E2         369
.          369+n     ANDOR INPUT BIT 8n thru 8n+7 FOR SPEC. TRIG. 1 -16 (n=0,31)      NOT USED
.          401+n     ANDOR INPUT BIT 8n thru 8n+7 FOR SPEC. TRIG. 17-32 (n=0,31)      NOT USED
.                          LSB is andor input bit 8n
.                          MSB is andor input bit 8n+7
0360         432
```

0362	433			
.	433+n	FRONT-END BUSY ON TRIG-ACQ CABLES 8n thru 8n+7	(n=0,3)	NOT USED
.	437+n	FRONT-END BUSY ON TRIG-ACQ CABLES 8n thru 8n+7	(n=0,3)	NOT USED
.	441+n	FRONT-END BUSY ON TRIG-ACQ CABLES 8n thru 8n+7	(n=0,3)	NOT USED
.	445+n	FRONT-END BUSY ON TRIG-ACQ CABLES 8n thru 8n+7	(n=0,3)	NOT USED
.		LSB is front end busy 8n		
.		MSB is front end busy 8n+7		
0380	448			
0382	449			
.	449+n	SPEC TRIG FIRED 8n thru 8n+7	(n=0,3)	NOT USED
.	453+n	SPEC TRIG FIRED 8n thru 8n+7	(n=0,3)	NOT USED
.	457+n	SPEC TRIG FIRED 8n thru 8n+7	(n=0,3)	NOT USED
.	461+n	SPEC TRIG FIRED 8n thru 8n+7	(n=0,3)	NOT USED
.		LSB is spec. trig. 8n		
.		MSB is spec. trig. 8n+7		
03A0	464			
03A2	465			
.	465+n	START DIGITIZE ON TRIG-ACQ CABLES 8n thru 8n+7	(n=0,3)	NOT USED
.		LSB is cable 8n		
.		MSB is cable 8n+7		
03A8	468			
03AA	469			
.	469+n	FRONT END BUSY DISABLE SPEC. TRIG. 8n thru 8n+7	(n=0,3)	NOT USED
.		LSB is spec. trig. 8n		
.		MSB is spec. trig. 8n+7		
03B0	472			
03B2	473			
.	473+n	2ND LEVEL DISABLE SPEC. TRIG. 8n thru 8n+7	(n=0,3)	NOT USED
.		LSB is spec. trig. 8n		
.		MSB is spec. trig. 8n+7		
03B8	476			
03BA	477	CBUS TSS		NOT USED
03BC	478:480	Et EM (3 bytes, low first)		NOT USED
03C2	481:483	Et HAD (3 bytes, low first)		NOT USED
03C8	484:486	Px Total (3 bytes, low first,signed 2's complement)		NOT USED
03CE	487:489	Py Total (3 bytes, low first,signed 2's complement)		NOT USED
03D4	490			
.	.	NOT ASSIGNED		NOT USED
03DA	493			
03DC	494:496	Et Total (3 bytes, low first)		NOT USED
03E2	497:499	Missing Pt (3 bytes, low first)		NOT USED

03E8	500		
.	.	NOT ASSIGNED	NOT USED
03FA	509		
03FC	510:511	EM Et Threshold # 1 final count (2 bytes, low first)	NOT USED
0400	512:513	EM Et Threshold # 2 final count (2 bytes, low first)	NOT USED
0404	514:515	EM Et Threshold # 3 final count (2 bytes, low first)	NOT USED
0408	516:517	EM Et Threshold # 4 final count (2 bytes, low first)	NOT USED
040C	518:519	Total Et Threshold # 1 final count (2 bytes, low first)	NOT USED
0410	520:521	Total Et Threshold # 2 final count (2 bytes, low first)	NOT USED
0414	522:523	Total Et Threshold # 3 final count (2 bytes, low first)	NOT USED
0418	524:525	Total Et Threshold # 4 final count (2 bytes, low first)	NOT USED
041C	526		
.	509+16e+p	EM Et TRIGGER TOWER ADC EMTT(η,ϕ)=(+e,p) (e=1,24;p=1,16)	EMTT(η,ϕ)=(+e,p+16)
071A	909		

notes: All energy values are scaled to Et assuming the interaction was centered at z=0.
All energy values built in the data block are positively biased with a constant offset.
The energy least count and the bias will be defined later.
Current plans call building hardware for 40 subdivisions in rapidity. In the data block, however, we have resrved space for 48.

071C	910		
.	893+16e+p	EM Et TRIGGER TOWER ADC EMTT(η,ϕ)=(-e,p) (e=1,24;p=1,16)	EMTT(η,ϕ)=(-e,p+16)
0A1A	1293		
0A1C	1294		
.	1277+16e+p	HAD Et TRIGGER TOWER ADC HADTT(η,ϕ)=(+e,p) (e=1,24;p=1,16)	HADTT(η,ϕ)=(+e,p+16)
0D1A	1677		
0D1C	1678		
.	1661+16e+p	HAD Et TRIGGER TOWER ADC HADTT(η,ϕ)=(-e,p) (e=1,24;p=1,16)	HADTT(η,ϕ)=(-e,p+16)
101A	2061		

101C	2062	NOT USED	NOT USED

PREVIOUS BEAM CROSSING

101E 2063

.

The same information as above is available for the beam crossing directly preceding the event that caused the First Level Trigger to fire.

.

2036 4123

EM Et JET LIST

(fixed starting address, variable length, no duplicated entry, merged from the result of the 4 threshlold reference sets)

2038 4124 Number of entries (N can vary from 0 to 16) 0=complete list, 128=incomplete.
note: the maximum number of towers in a list may change to accomodate the users of these lists.

203A

. Entry n (n = 1,N)

. 4124+n:4125+n 32 bit mask showing the specific triggers that include at least one comparison on one of the counts of Trigger Towers hit above a threshold reference set met by this tower cndidate.

. LSB of longword 4124+n:4125+n represents specific trigger 1

. MSB of longword 4124+n:4125+n represents specific trigger 32

. 4125+n 16 bit relative address of the EM Et of this particular tower in the Data Block with respect to EMTT(η,ϕ)=(1,1)

.

.

20F6 4219

Total Et JET LIST

(fixed starting address, variable length, no duplicated entry, merged from the result of the 4 threshlold reference sets)

20F8 4220 Number of entries (N can vary from 0 to 16) 0=complete list, 128=incomplete.
note: the maximum number of towers in a list may change to accomodate the users of these lists.

```
20FA
.                      Entry n       (n = 1,N)
. 4220+n:4221+n        32 bit mask showing the specific triggers that include at least one comparison on
.                      one of the counts of Trigger Towers hit above a threshold reference set met by this
.                      tower cndidate.
.                          LSB of longword 4220+n:4221+n represents specific trigger  1
.                          MSB of longword 4220+n:4221+n represents specific trigger 32
.        4222+n        16 bit relative address of the EM Et of this particular tower in the Data Block
.                      with respect to EMTT(η,φ)=(1,1)
.
.
2126         4315
-----------------------------------------------------------------------------------------------
Masks of Jet Patterns
=====================
21B8         4316
.                       768 items reserved for the source information used to build the Jet Lists
27B6         5083
-----------------------------------------------------------------------------------------------
TRD Hot Tower Table Information
===============================
27B8         5084
.                       384 items reserved for information related to the Hot Tower Table
.                       sent to the TRD Trigger for Level 1.5 confirmation
2AB6         5467
-----------------------------------------------------------------------------------------------
```