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Conceptual Design of the L1 Calorimeter Trigger for the Run II Upgrade

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Abstract

The trigger and front-end electronics are being upgraded for Run II to operate with shorter bunch spacing (132 – 396 ns) and higher luminosity ($\approx 10^{32}$). The upgrade trigger system consists of a synchronous pipelined Level1 and an asynchronous pipelined level 2 with data buffered at both Level 1 and Level 2 to provide for near deadtimeless operation[1, 2, 3]. The task of the L1 trigger in the upgrade will be to reduce the input crossing rate, 7.5 MHz for 132ns operation, to the 40-50 kHz (assuming a fully deadtimeless system) input capacity of Level 2. This note describes the design of the L1 Calorimeter portion of the upgrade trigger.

1 General Overview of the Calorimeter Trigger

The goal of Level 1 calorimeter trigger is to trigger on electrons, photons, jets, total event transverse energy (ΣE_T) and missing transverse energy ($\not{E}_T$). The calorimeter triggers are divided into two types: object triggers (electrons, photons and jets) and global triggers (ΣE_T and $\not{E}_T$). The object triggers are formed by applying thresholds to individual calorimeter trigger towers while thresholds for the global triggers are applied after summing energies from all towers. In turn the object triggers have two types: single object triggers (e.g. electrons from $W \rightarrow e\nu$) where finding one in the event is sufficient to generate a L1 accept and di-object triggers where the rate is too high to trigger only only one (e.g. electrons from $\psi \rightarrow ee$).

Through each board of the trigger there are two parallel paths: one for the object triggers and one for the global triggers. In the object trigger path thresholds are applied to the individual tower energies then the number of towers passing each threshold is counted. For the single object triggers this is a 1 bit sum (0, 1 or more towers) and for the di-object triggers is is a 2 bit sum (0, 1, 2, 3 or more towers). Electron and photon triggers are formed applying energy thresholds to the Electromagnetic (EM) energy in a tower while jet triggers are formed using the total (EM + HAD) energy in a tower. To reduce the rates of low E_T electrons, tracks from the Level 1 track processor (XFT) are available for matching to the towers and towers with significant HAD energy can be rejected. The global path sums the total energy (HAD+EM) in all the towers (with appropriate weighting for $\not{E}_T$ calculation) and applies thresholds to these sums.

A total of 16 object trigger bits are available for use by all single and di-object triggers. The default system configuration parses the 16 bits into 10 single object triggers and 3 di-object triggers. There is a limited capability to reconfigure the bit usage to allow for more or fewer di-object triggers. There is also flexibility in how many can be Electromagnetic and how many Jet with a limitation of no more than 8 of either kind. A total of 4 thresholds are available for the global triggers: 2 for ΣE_T triggers and 2 for $\not{E}_T$ triggers. The result is a 20 bit word presented to the final Level 1 decision card summarizing the calorimeter triggers.

In Run 2 all calorimeter elements will be digitized every 132 ns with the digital data stored on the front-end cards while the Level 1 and Level 2 trigger decisions are made. The input data for both the Level 1 and Level 2 calorimeter triggers are the raw digitized tower energies from the front-end electronics. On the front-end cards towers are summed into trigger towers and weighted to yield transverse energy ($E_T \equiv E \sin\theta$). Studies of Level 1 trigger rates for Run II[4, 5] indicate that the tower segmentation of the original CDF trigger provides acceptable rates. The existing segmentation[6] of the central and wall calorimeters, with towers of approximately $0.2\eta \times 15°\phi$, is carried into the new plug calorimeter resulting in a 24×24 map in $\eta - \phi$ space. The same segmentation is used for both the hadronic and electromagnetic calorimeters. There are an additional $2\eta \times 24\phi$ towers which result from an overlap of the Central and Endwall hadronic calorimeters.

2 Description of the Trigger Hardware

The general structure of the calorimeter trigger is shown in Figure 1. The whole system is pipelined with each stage taking less than 132 ns and processing a new event every 132 ns. The digitized calorimeter data are summed into trigger tower energies and weighted by $\sin\theta$ on the front-end cards. The data are transmitted upstairs to the trigger as 10 bit parallel words with a least count of 125 MeV resulting in a full scale E_T of 128 GeV[7]. Since the same data is used for both the Level 1 and Level 2 triggers, data received by the L1 calorimeter trigger is immediately retransmitted to the Level 2 cluster finder. Only 8 bits of the trigger tower energy are used for Level 1 processing, the least significant and most significant bits are dropped giving a least count of 250 MeV and a full scale of 64 GeV.

The bulk of the L1 processing takes place on 16 Digital Information Receive And Compare (DIRAC) boards in each of 6 L1 calorimeter VME crates. The DIRAC boards are arranged in sets of four handling the data from a 15° wedge of the calorimeter: West Plug, West Central, East Plug and East Central as shown in Figure 2. Each DIRAC card has 12 channels covering 6 EM towers and the 6 corresponding HAD towers. The central cards each cover 5 towers in the central and the first tower in the plug reaching $\eta = \pm 1.3$. A summary of the results from 8 DIRAC boards (2 wedges) is sent to a Cratesum board which is located between two sets of 4 DIRAC boards.

Combining the information from the 96 DIRAC boards is a two step process involving a pair of CRATESUM boards in each L1 CAL crate and PreFRED modules in the GLOBAL L1 crate.

A more detailed view of the L1 data flow is presented in Figure 3 along with approximate propagation times through each step. We now present a step by step description of the components of the system.

Front End Cards (ADMEM) and Cables:

Calorimeter signals are digitized on ADMEM front-end boards every 132 nsec. The digitized signals are summed into trigger towers, weighted by $\sin\theta$ and truncated to 10 bits with a least count of 125 MeV. If the tower energy is above the 127 GeV full scale then the output is 127 GeV (3FF in Hex). For each trigger tower there is one ten twisted pair SCSI type cable. A total of 1200 cables, each 220 feet long, are needed to cover the 1152 towers plus 48 overlapping hadron towers.

Auxiliary Receiver Cards and Endwall Sum:

The input signals from the ADMEM are received on a 9U X 120mm VME auxiliary (L1AUX) board which then stuffs them through the P3 connector to the DIRAC board on the other side of the backplane. Each Auxiliary card provides 12 input towers (120 bits) to DIRAC. Since there is an overlap of one tower in the Hadron between the Central and Wall calorimeters (trigger tower 3), the auxiliary cards will have 13 input towers and sum together the overlapping towers. Since there is no analogous tower in the plug this input will be unused on the auxiliary cards for the plug region. Although a delay of about 30 ns is introduced in summing of the endwall channel this is much less than the 132 ns period during which the data for each event is valid.

DIRAC Card

Each DIRAC card performs the local L1 trigger processing for one quarter of $15° \phi$ slice of the calorimeter. It also outputs the unprocessed data for input to the L2 cluster finder. The DIRAC card forms trigger objects using tower thresholds and track requirements and counts how many of each object are found on the board. It also sums the total energy in the card for use in ΣE_T and $\not{E}_T$ triggers.

The algorithm of DIRAC is to truncate the data, time align it with track information coming from the XFT, and make triggers by requiring the tower energy to pass programmable thresholds and optionally match a track to the tower. A summary of how many towers passed each threshold is then made. Simultaneously the E_T sum for all towers on the board is calculated.

Figure 5 shows the DIRAC board and its mating L1AUX input card. At the beginning of the first stage, data from each of the 12 channels are latched. At this point any of the towers can be masked off to block noisy channels from both L1 and L2. The 12 channels of data are organized into 6 towers combining the HAD and EM data. There are 4 outputs of the first processing stage:

1. 8 Bits EM tower energy (250 MeV LSB, 64 GeV FS),
2. 8 Bits Total (EM + HAD) tower energy (250 MeV LSB, 64 GeV FS),
3. 3 least significant bits of HAD energy (for HAD/EM),
4. 10 bits HAD and 10 bits EM for L2 (with masking).

The first three items are fed into an alignment FIFO to wait for data from the track processor. The alignment FIFO is deep enough to hold the data for up to 256 crossings. As shown in Figure 3, in normal operation calorimeter data will spend approximately 3-4 crossings in this FIFO. The total energy is also sent directly into a set of summers to form ΣE_T for the board. Item 4 is sent via front panel connectors to the L2 cluster finder boards.

Eight bits of track data per DIRAC card are received from the XFT via the extrapolation (XTRP) boards. The XTRP projects tracks found by the XFT track processor to each calorimeter wedge and sends the highest P_T track found in that wedge to the two corresponding central DIRAC cards. Since all 12 channels on each

DIRAC card are at the same ϕ, only one set of track P_T bits are needed for each card. The same path is provided on the plug cards in case high η tracks can be provided. The eight bits are envisaged to include 6 bits P_T, 1 bit for track isolation and 1 bit to flag higher η. The 8 bits are fanned-out into 3 bits for each trigger tower using an SRAM to apply thresholds to the track. An SRAM is used to allow for future redefinition of the input bits from the XTRP.

The tower threshold cuts and track P_T cuts are performed in two 32kbyte SRAMs per tower, one for jet triggers and one for electromagnetic triggers. The inputs to a jet trigger SRAM are 8 bits of Total energy and 3 bits of P_t data for the presence of a track at this ϕ. The SRAM for electrons and photons receives 8 bits of EM energy and 3 bits of P_t data and the 3 least significant bits of HAD energy for HAD/EM. Each of these SRAMs has an 8 bit output corresponding to 8 possible triggers (combination of threshold(s) and track condition). For example a low E_T electron trigger might consist of a tower over 3 GeV of energy and a track with P_T greater than 3.0 GeV/c and no more than 250 MeV of HAD energy. A photon trigger would consist of just a tower threshold. Note that the cuts for a particular trigger could be different for different regions of η since each tower has it's own SRAM.

The next stage summarizes how many towers passed each of the thresholds on the board. For the single object triggers the output is just the OR of that trigger for all towers on the board. For the di-object triggers a 2 bit adder is used. Although there are 16 possible thresholds on the board (8 jet, 8 EM) there are only 16 total output bits. The allocation of these among EM and Jet is programmable as is the number of di-object triggers. The 16 bit summary is transmitted to the CRATESUM card using 16 dedicated lines on the P3 backplane.

In parallel to alignment FIFO and the tower threshold SRAMs there is a series of adders which calculates the total ΣE_T for the board. The input to these adders is the 8 bit sum of HAD+EM energy for each of the 6 towers. The output is an 8 bit word which is transmitted on the P3 backplane to the CRATESUM card. Since all the towers on a given DIRAC card are at the same ϕ, this information can be used for both global ΣE_T and $\not{E}_T$.

After the leaving the input latch and EM+HAD summing the two data paths are no longer time aligned. The data for the ΣE_T path leaves the board several crossings before the triggered tower data. The data is treated this way since the processing of the ΣE_T data requires more pipeline stages in the CRATESUM and PreFRED cards. Any mismatch in timing is corrected using FIFOs on the PreFRED modules.

The DIRAC, CRATESUM and PreFRED cards are all addressable through VME to download constants and thresholds and to read out trigger information [8] into the event stream in the event of a L2 accept. There are also registers that can be loaded or read back through VME for diagnostic purposes. The L1AUX card has no VME interface and no interface to the TRACER.

The Crate Summary Card

The Level 1 Crate Summary card is shown schematically in Figure 6. It receives the 16 bits of trigger data and 8 bits of ΣE_T data from each of 8 DIRAC cards. The 16 bits of trigger data for 8 DIRAC cards are summarized into 16 bits for the half crate (i.e. 8 DIRAC cards) in the same fashion as on DIRAC. Just as on the DIRAC there are 2 bit triggers and one bit triggers. The 16 bit summary from each CRATESUM is transmitted differentially over twisted pair cable to the TOWTRG PreFRED module in the GLOBAL Level 1 Crate.

CRATESUM also forms the ΣE_T for each of the 2 wedges covered by its 8 DIRAC cards. The 10 bit summary for each wedge is transmitted differentially over twisted pair cable to the SUMET PreFRED modules in the GLOBAL Level 1 Crate. As on the DIRAC board the two data streams flow independently with separate timing signals.

Global Level 1 Crate

The global level 1 crate is shown in Figure 7 [9]. It consists of a series of input (PreFRED) modules from the different detector elements. These modules summarize the information from the detector element and forward it to the L1 decision card (FRED). For the calorimeter there are 3 modules: one for the tower over threshold triggers (TOWTRG) and two for the ΣE_T (SUMET) triggers. The TOWTRG PreFRED receives the 16 bit tower summary words from 12 CRATESUM boards and condenses them in the same fashion as the CRATESUM.

Each of the SUMET PreFREDs receives the ΣE_T word from 12 wedges (6 CRATESUMS). These E_Ts are used to calculate the total ΣE_T for the detector and to calculate $\not{E}_T$. The summing is done as a 2 stage process with each board forming the sum for half the detector then both half sums are read into one board and the total calculated. Finally thresholds are applied to ΣE_T and $\not{E}_T$ and the results are transmitted via the P3 backplane to the L1 Decision card. As shown in Figure 1 the last step of the ΣE_T module is a FIFO that aligns the ΣE_T data with the tower threshold triggers. In fact all PreFRED modules must have FIFOs to ensure that the data presented on the P3 backplane is correctly aligned.

VME Crate and Rack Design

The DIRAC, CRATESUM and PreFRED cards all use a 9U x 400mm VME crate for signal processing [8]. and a 9U x 120 mm AUX card crate for signal receiving and transmitting. Figure 8 shows the arrangement of the VME crates. The main cards and the AUX cards share a custom J3 backplane. Two crates are mounted in each relay rack with an air-water heat exchanger and fan-blower unit below each crate. Power supplies for the bottom crate are mounted in the bottom of the rack and for the top crate in the top of the rack. Since the system is completely digital, switching power supplies can be used resulting in a much lower heat load. The lower crate in the rack is used for the L1CAL crates and the upper crate for the L2 Cluster finder cards. Input trigger signals for the DIRAC cards come up through the floor in the rear of the rack and connect to L1AUX cards. The data flows from the L1AUX through the P3 connection to the mated DIRAC card. Data for the L2 cluster finder is retransmitted out the front on cables to the cluster finder in the upper crate of the same rack.

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[8] T. Shaw and G.Sullivan, *A CDF standard VME readout crate for the Upgrade*, CDF/DOC/TRIGGER/CDFR/2388, 1993.

[9] K. Ohl and G.Sullivan, *Preliminary Design for the 1993 Global Level 1 Trigger Crate*, CDF/DOC/TRIGGER/CDFR/xxxx, 1993.

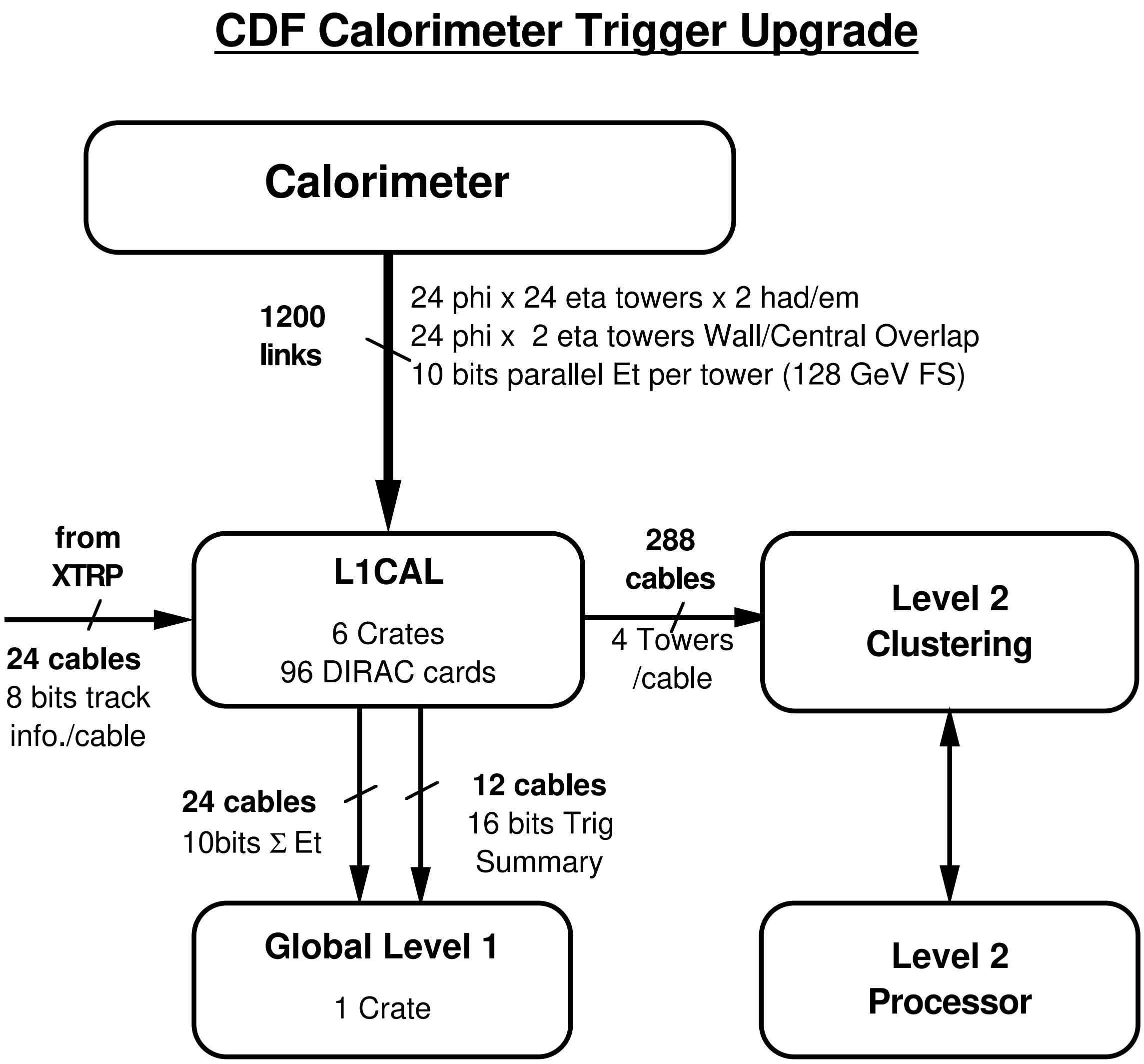

Figure 1: Overview of the calorimeter trigger. Trigger tower energies are transmitted as 10 bit parallel words of E_T. Towers in the Endwall overlap regions are summed together to make a complete trigger towers on the Auxiliary cards in the L1CAL. The 1152 towers (+48 overlaps) are received by 6 crates of DIRAC cards, where their energies are processed to make tower over threshold triggers. Crate summaries from the 6 L1 trigger crates are received by the Global Level 1 trigger crate where a final L1 decision is made. Calorimeter tower data are also transmitted to the Level 2 calorimeter cluster finder used by the level 2 trigger.

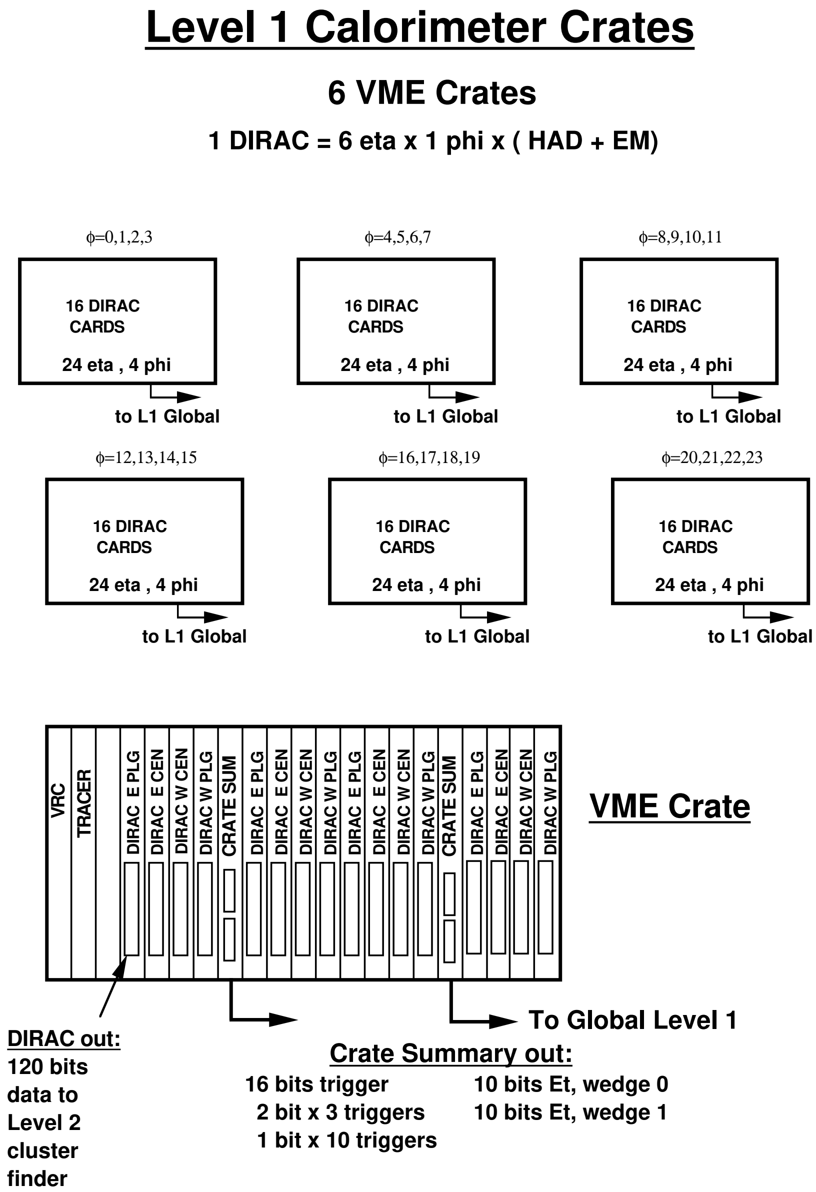

Figure 2: The Level 1 calorimeter trigger crates. The Level 1 crates containing the DIRAC and Crate Summary cards are organized into 6 VME crates. Each crate covers covers 4 full wedges of the detector for both the EM and HAD compartments using 16 DIRAC cards. For each wedge there are 4 DIRAC cards: East Plug, East Central, West Central and West Plug. Each card has 12 input channels covering the EM and HAD compartments of 6 wedges. The lower figure shows the configuration for the crate. Each Crate Summary card services 8 DIRAC cards.

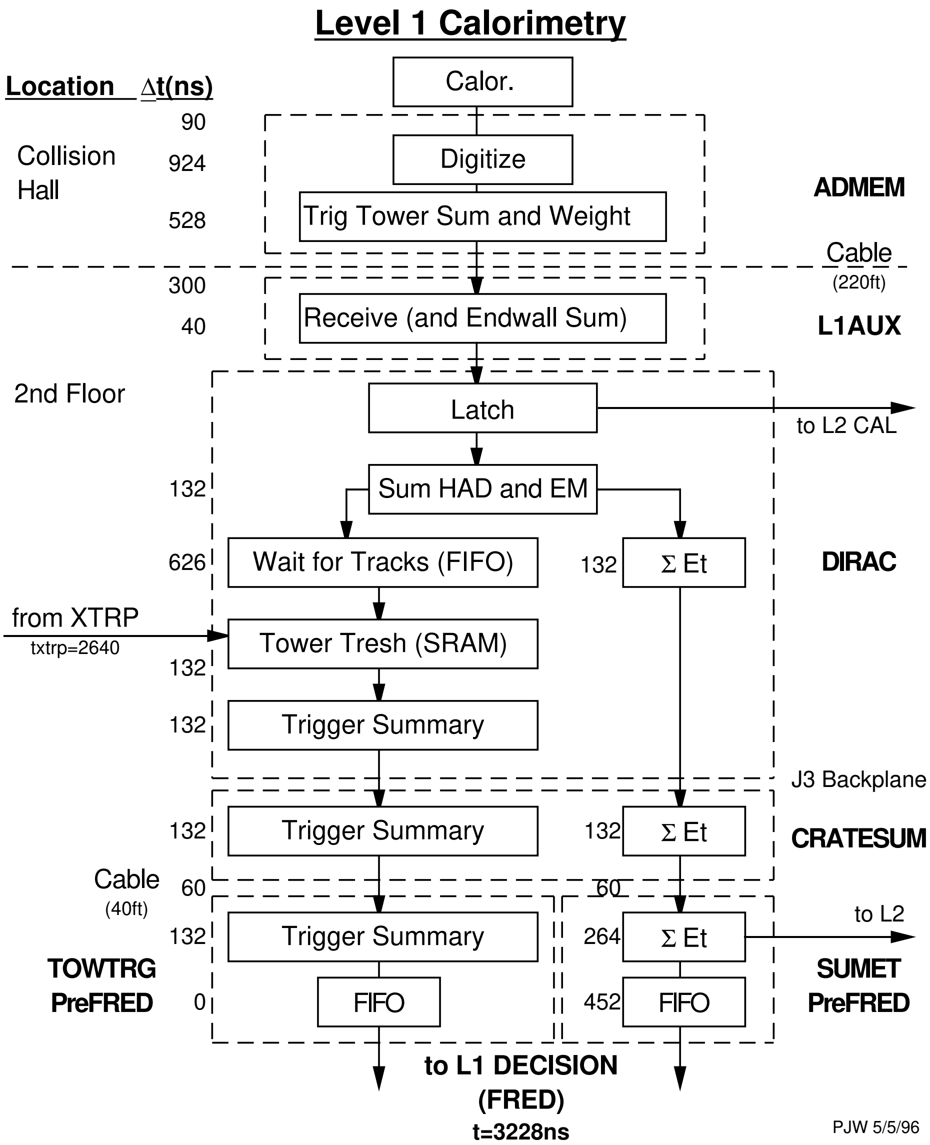

Figure 3: Block diagram of the Level 1 calorimeter trigger. The dashed outlines indicate different cards in the L1 CAL system. Tower energies are digitized and summed into trigger towers on ADMEM front-end cards. On the DIRAC cards, tower over threshold cuts are applied along with cuts on the presence of a track. Simultaneously, the tower energies are summed for ΣE_T. A summary of the tower triggers and ΣE_T is passed to the CRATESUM cards which summarize the crate. These summaries are then sent three summary modules in the Global Level 1 crate to summarize the whole calorimeter. The output of these cards goes to the Global Level 1 decision module. An estimate of the elapsed time for each block is also shown.

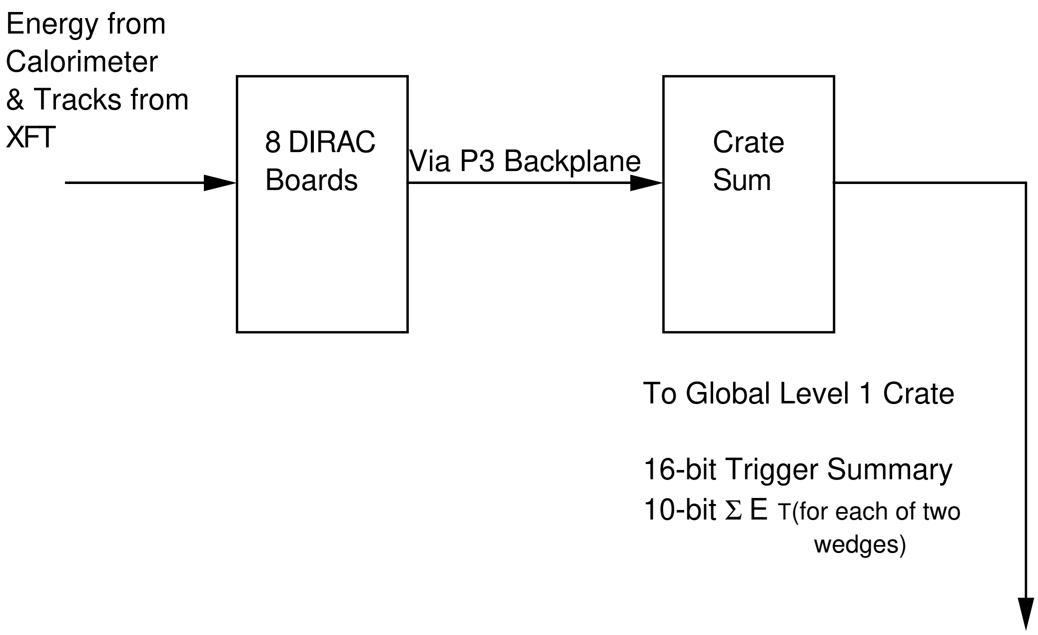

Figure 4: The Level 1 calorimeter trigger crate data flow. The calorimeter data for each DIRAC card comes in through the P3 backplane from an Aux card. Each DIRAC card processes its 6 towers and transmits its trigger data on the P3 backplane to the Crate Summary. One Crate Summary card receives data for 8 DIRAC cards. The Crate summary outputs a 16 bit trigger summary and two 10 bit ΣE_T words to the global Level 1 crate.

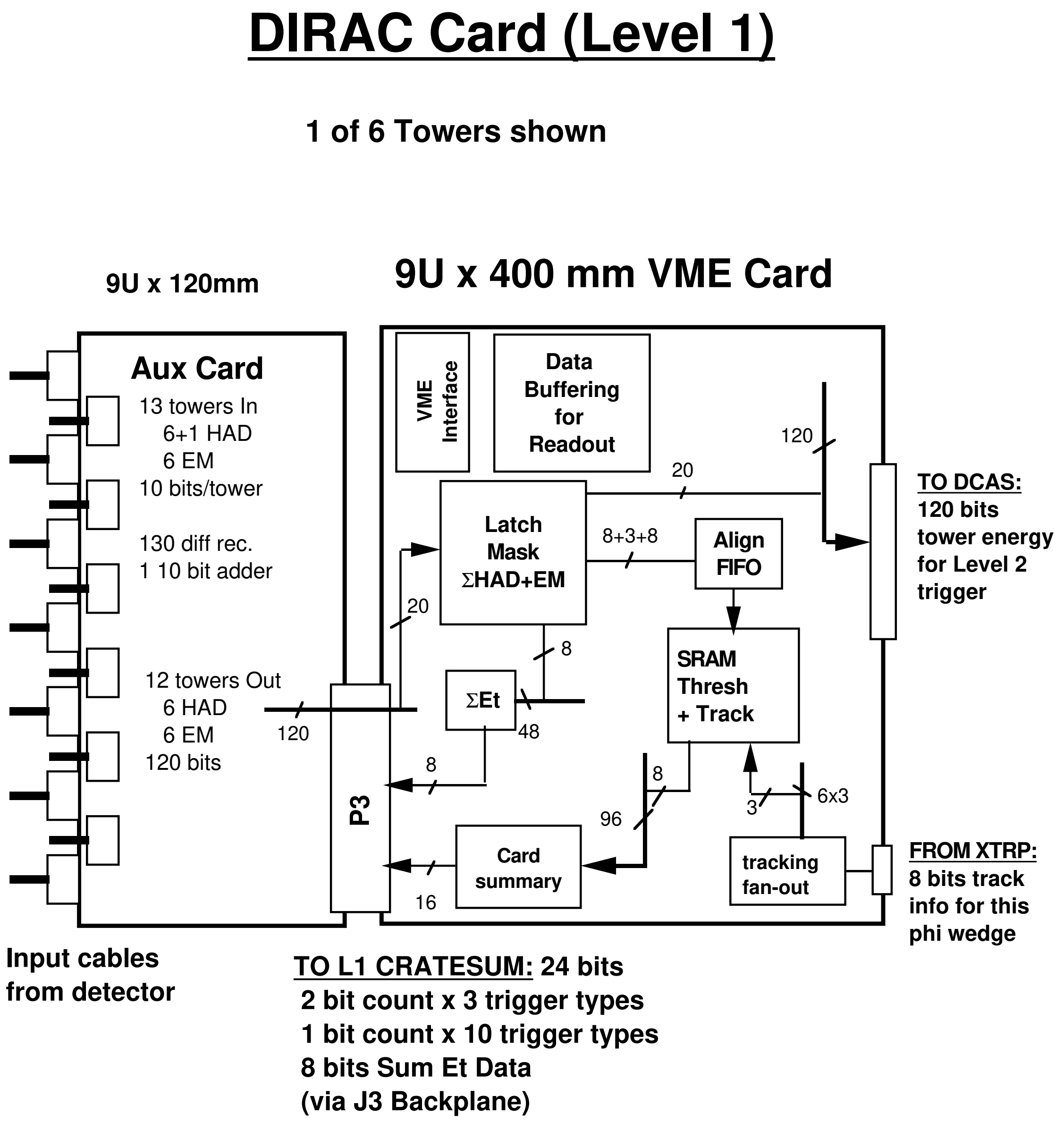

Figure 5: The Digital Information Receive And Compare (DIRAC) card. Calorimeter tower energy data, for 6 η towers (EM + HAD) of one wedge, are received through the P3 backplane via auxiliary cards. The data is received as 10 bit parallel E_T. The data is latched and the HAD and EM compartments summed for each tower. A FIFO is used to time-align the data with that from the track processor (XFT). The calorimeter and tracking data is sent to two SRAMs as the address bits. The SRAMs are downloaded such that each 1 of the 8 output bits represent a particular trigger (e.g. tower energy over 8 GeV and track P_T bin 2, or tower energy over 15 GeV, etc...). A total of 13 triggers are summarized in a 16 bit word: 10 with one bit each and 3 with two bits each. The 16 bit trigger word, along an 8 bit ΣE_T word, are transmitted out the P3 connector to the Crate summary cards.

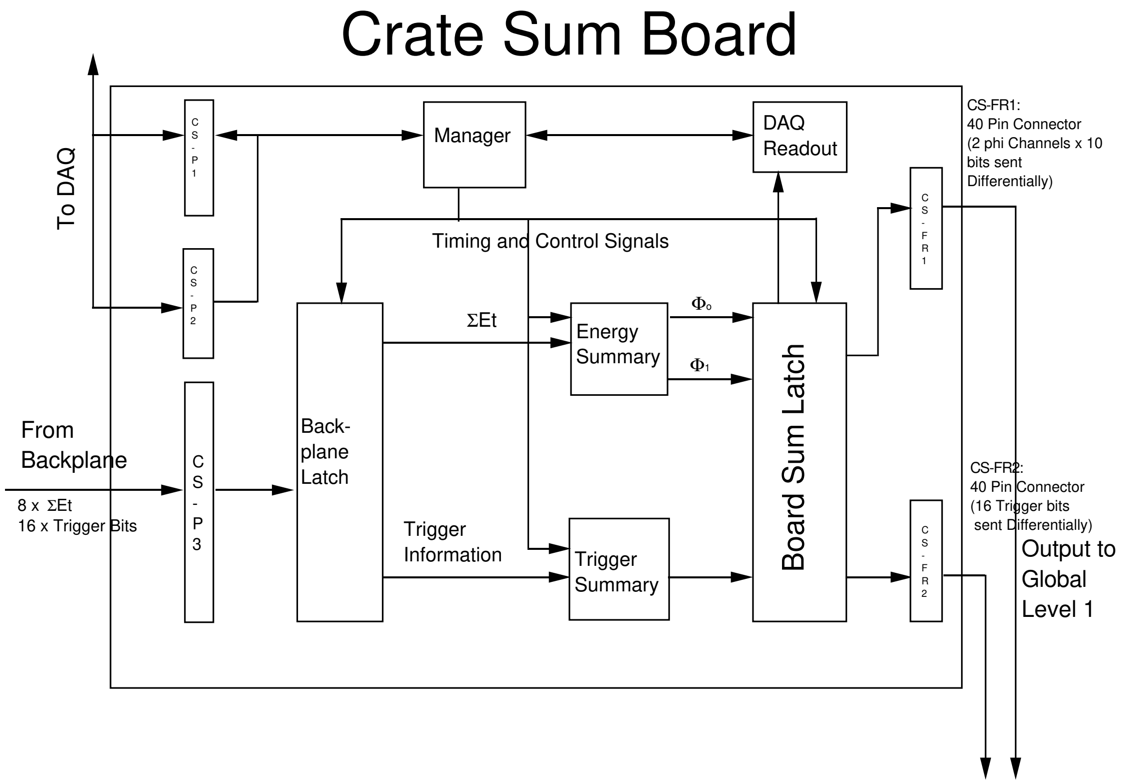

Figure 6: The Level 1 Crate Summary card. The Level 1 Crate Summary card receives the 16 bits trigger data and 8 bits sum E_T data from 8 DIRAC cards. The 16 bits of trigger data for 8 DIRAC cards are summarized into 16 bits for the half crate just as on the DIRAC card summary. The E_T from each card is summed with the other 3 from that wedge to form the ΣE_T for the wedge. The out 16 bit trigger word and two 10 bit ΣE_T words are transmitted to the Global Level 1 Trigger Crate.

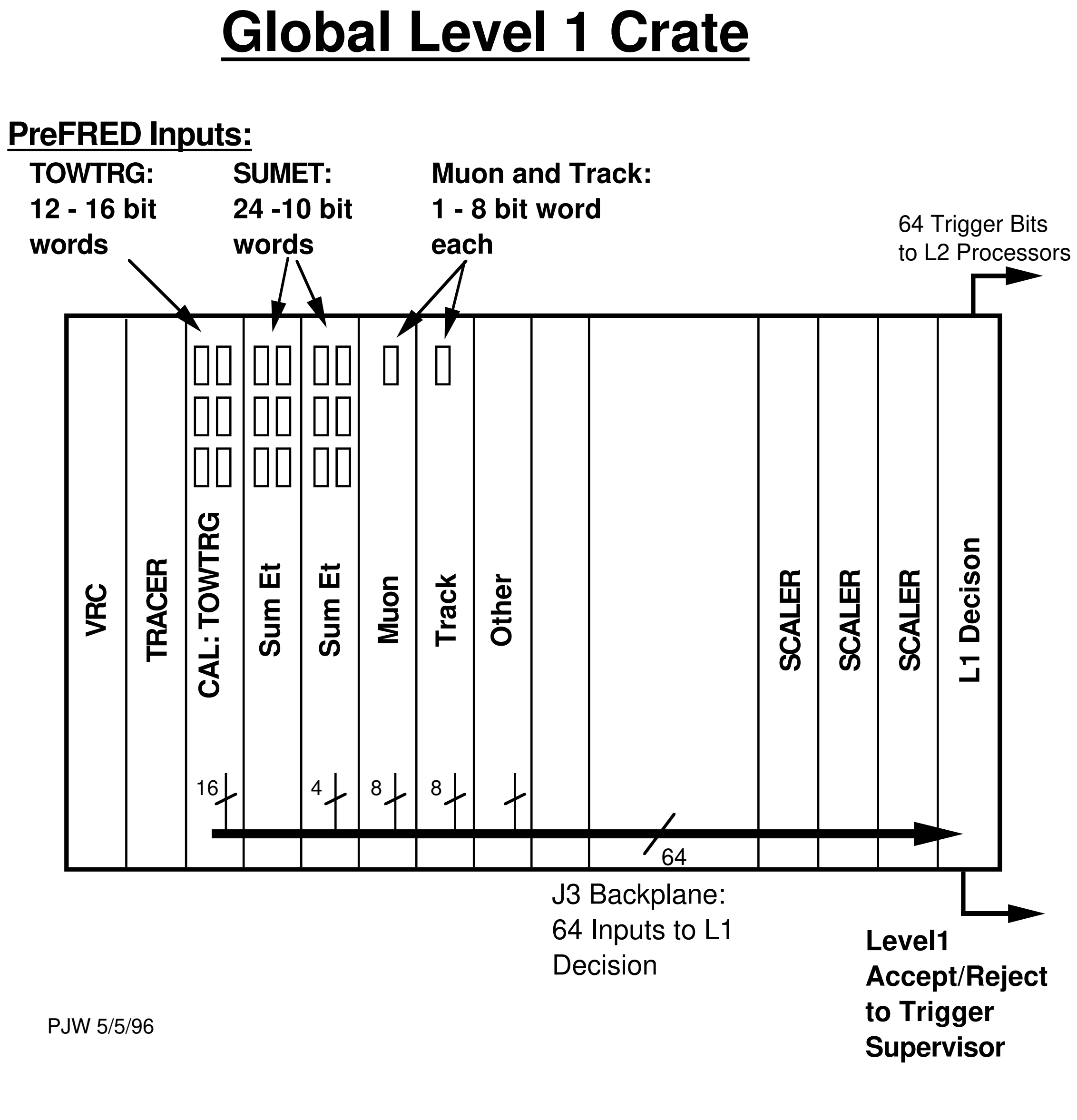

Figure 7: The Global Level 1 Decision Crate. The Global Level 1 crate has 3 modules to accept Level 1 trigger from the calorimeter. One receives the 16 bit trigger data from the calorimeter trigger. Each of the other two receives the ΣE_T data from 6 CRATESUM cards.

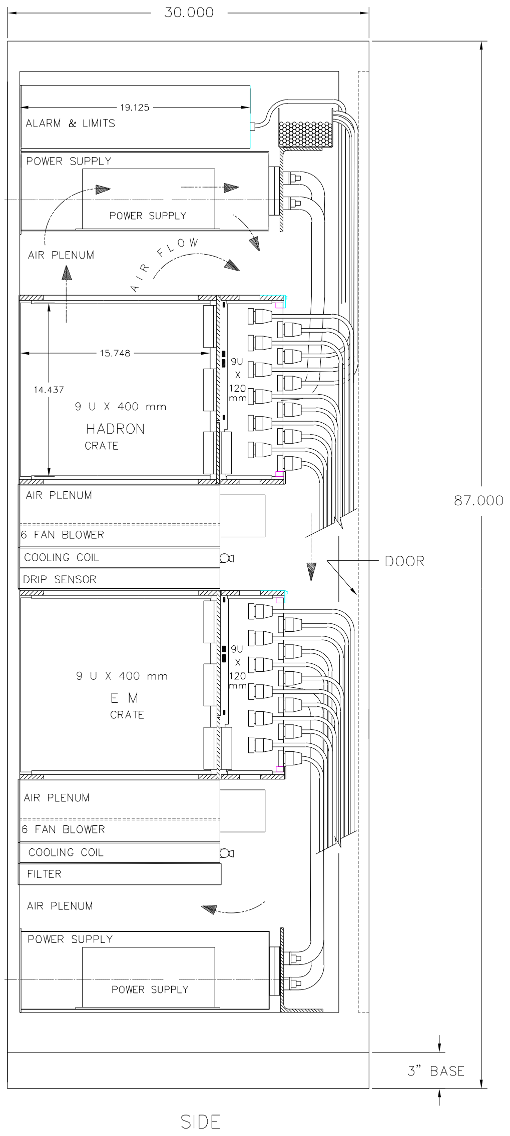

Figure 8: Detail side view of the Calorimeter trigger VME Crate arrangement. 4 This view shows the 12 cables from the calorimeter towers connecting to 9U x 120 mm Auxiliary cards. The data is received differentially and transmitted through the P3 connector single ended to the corresponding DIRAC card. Below each crate are a air-water heat exchanger and fan blower unit. Power supplies are mounted in the top and bottom of the rack.