

TRIGGERS IN UA2 AND IN UA1.

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The UA2 and UA1 trigger systems are described as they will be used after the upgrade of the CERN SPPS. The luminosity of the collider will increase to $3 \cdot 10^{30}$. The bunch spacing is 4 microseconds, comparable to the time available for a second level trigger at the SSC. The first level triggers are very powerful and deliver trigger rates of about 100 Hz. The UA1 second level trigger operates on the final digitizings with a combination of special and general purpose processors. At the highest trigger levels a small farm of processors performs the final reduction.

The UA2 Experiment

Figure 1 shows the calorimeter of the UA2 detector. It is segmented in θ and in ϕ into 10° by 15° towers with 2 partitions in depth. Each cell is read out by two phototubes. The output pulse heights are proportional to E_t . The calorimeter covers η 's (pseudo rapidity) up to 3 units. Only η 's smaller than 2 are used in the trigger. The inner region of the detector is completely renewed for the upgrade. The various components are summarized in Table 1 that also gives the amount of data generated by each component. The bulk of the data comes from the Scintillating Fiber Detector. The light from the fibers is amplified by image intensifiers and measured by CCD's. The digitization electronics suppress empty channels. Nevertheless 40 kbyte of data are expected. The readout time is 5 ms.

UA2 DETECTOR OVERVIEW

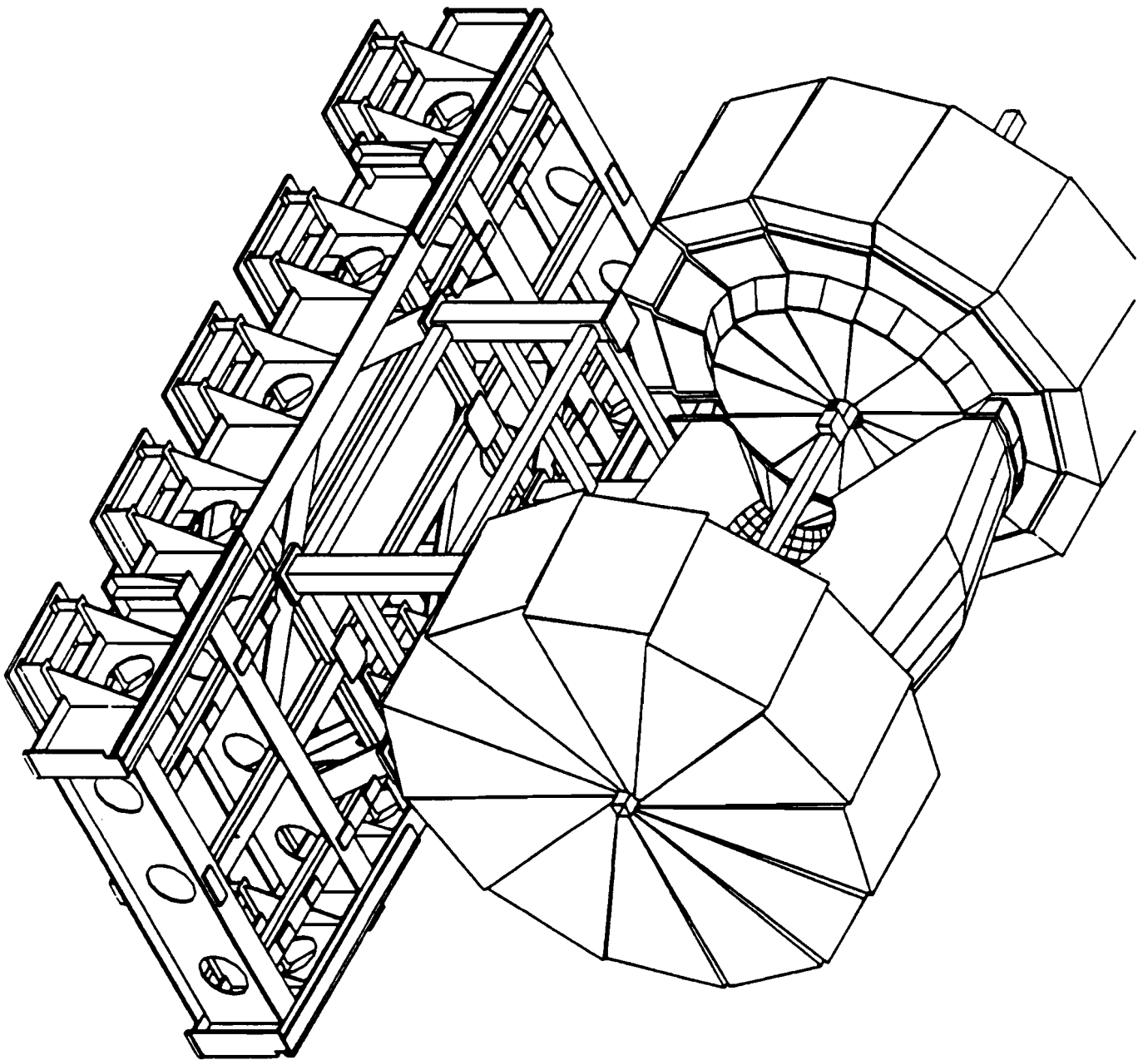


Figure 1.

Table 1. Detector elements in UA2

<u>Element</u>	<u>channels</u>	<u>data bytes</u>	<u>levels</u>
Mini vertex	600	1,200	-
Silicon hodoscope	3,024	3,024	-
Transition Radiation Detector (Li)	2,000	4,000	-
Scintillating Fiber Detector	1,500,000	40,000	3(?)
Calorimeter	960	2,000	1,2,3

Trigger Levels and Readout Structure

The UA2 trigger has three levels and is mainly based on information from the calorimeter. The analog first level trigger uses the full granularity (480 cells) for the electron trigger. It makes all possible cluster sums of 2 by 2 electro-magnetic cells. The jet trigger adds all cells in θ to obtain sums for slices in ϕ . It may be necessary to make partitions in ϕ as well. The analog sums are compared to the output level of a ramping DAC. By latching the comparator outputs at different times, several different thresholds can be applied to each sum. The first level trigger is operational each beam crossing and gives about 100 triggers per seconds.

The second level trigger uses its own 10 bit ADC's. The data are processed by a fast XOP processor with cycle times of 50/100 ns. The processor is micro and nano programmed in machine language. It checks the depth profile of electrons and performs clustering for jets. The decision time is 1 ms; the trigger rate is reduced to 10 Hz.

For every second level trigger the event is fully digitized in about 5 ms. Fastbus 68020 processors read the data into a multi-event data buffer and perform data reduction. The data is transported via Fastbus.

The third level trigger is done by 5 Fastbus 68020's. They use the final calibration and perform physics cuts. Maybe the information from the pre-converter inside the SFD will be used to validate electron candidates. The event rate is reduced to 3 Hz. Accepted events are written to tape by a VAX.

The UA1 experiment

The detector elements of the upgraded UA1 detector are listed in table 2. With the present UA1 calorimeter it is impossible to sustain the high luminosity obtained after the collider upgrade. A new uranium calorimeter replaces the old electro-magnetic one. It has a very good granularity of 10 cm by 12 cm and is segmented in depth into four e.m. plus two hadronic layers. It is backed up by the present hadron calorimeter that measures the 5 to 10% leakage energy.

Table 2. Detector elements in UA1

<u>Element</u>	<u>channels</u>	<u>data bytes</u>	<u>levels</u>
Micro vertex	768	1,500	-
Central Detector	1,500,000	130,000	3
Uranium calorimeter	20,000	20,000	1,2,3
Hadron calorimeter	1,184	2,000	1,2,3
Forward chamber	2,000	6,000	-
larocci muon streamer chambers	40,000	3,000	2?,3
Muon chambers	6,000	500	1,2,3

Trigger Levels and Readout Structure

Figure 2 shows a schematic diagram of the UA1 readout. The main bottle neck in the system is the enormous volume of data produced by the Central Drift Chamber. Digitization only takes 4 microseconds but data reduction and readout require 25 ms. As a consequence the first and second level triggers must reduce the trigger rate to well below 40 Hz; These trigger levels cannot use the CD information.

In UA1 two separate two level trigger systems are used, based on the muon chambers and on the calorimeter. The first level triggers are allowed to deliver a rate of 100 Hz. The full digital information for an event is stored in a 'double buffer' in 200 microseconds. The second level triggers operate on this buffer and can take 3 ms per event. During

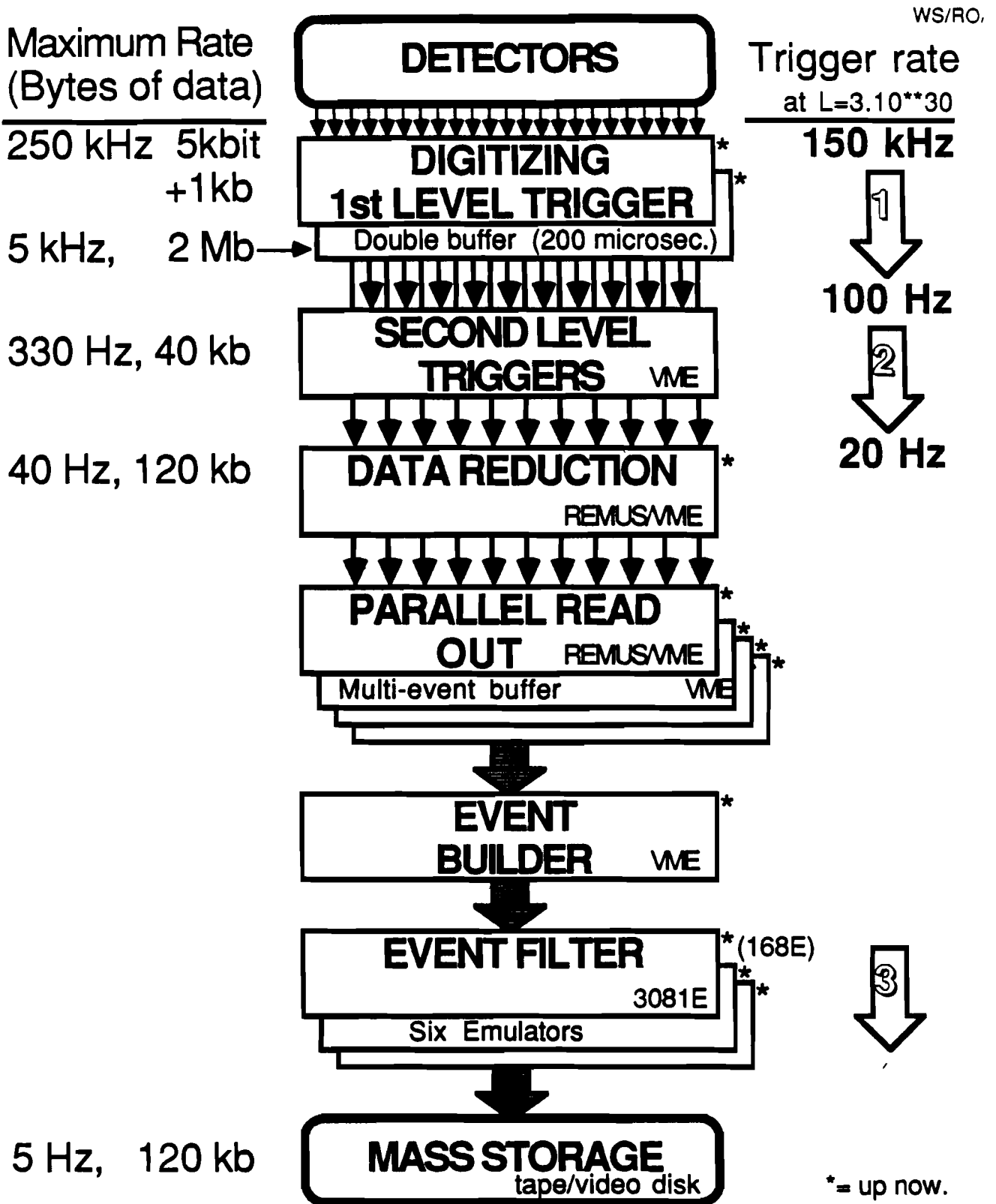


Figure 2. Overview of UA1 trigger levels and data acquisition. At the left the maximum possible rates of the different levels are indicated. The right column gives the target rates for the trigger. The dead time will be <10 %

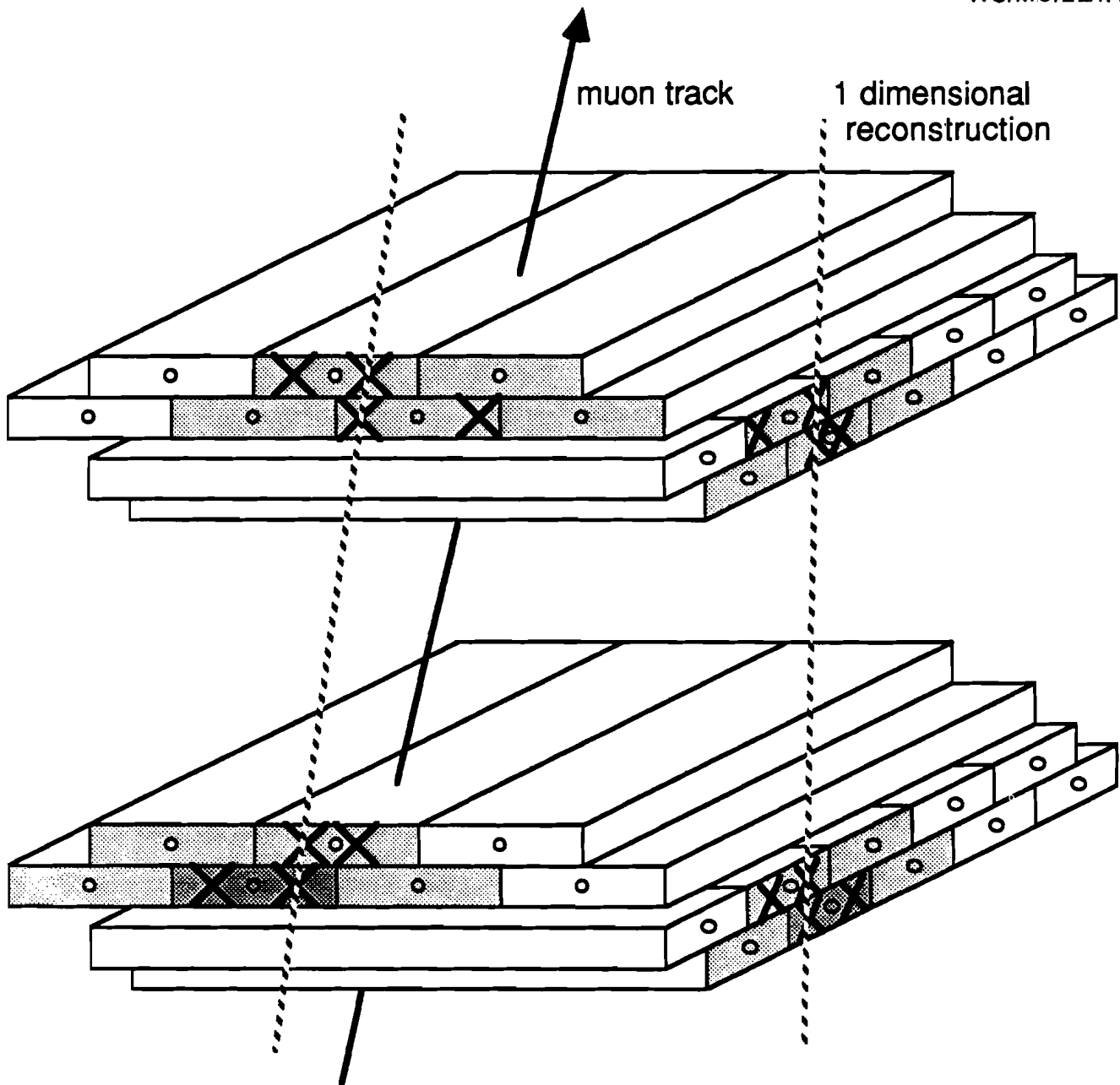


Figure 3. Muon trigger. For the first level trigger the signals from each group of 10 tubes (shaded) are used to address a lookup table. The table selects tube combinations that point at the center of the detector. The second level uses the drift times to compute hit positions and fits tracks. This level has more precise pointing requirements.

these 3 ms the first level can accept one more event. For each second level trigger the full event information is transported to the third level by the VME readout. During readout the second level trigger continues to operate on subsequent events.

Third level trigger algorithms run in six 3081 emulators. They can take up to 300 ms per event and must reduce the rate by a factor 7. Accepted events are written to tape or to video disc. The emulator farm is also used for production when the collider is off.

First Level Muon Trigger

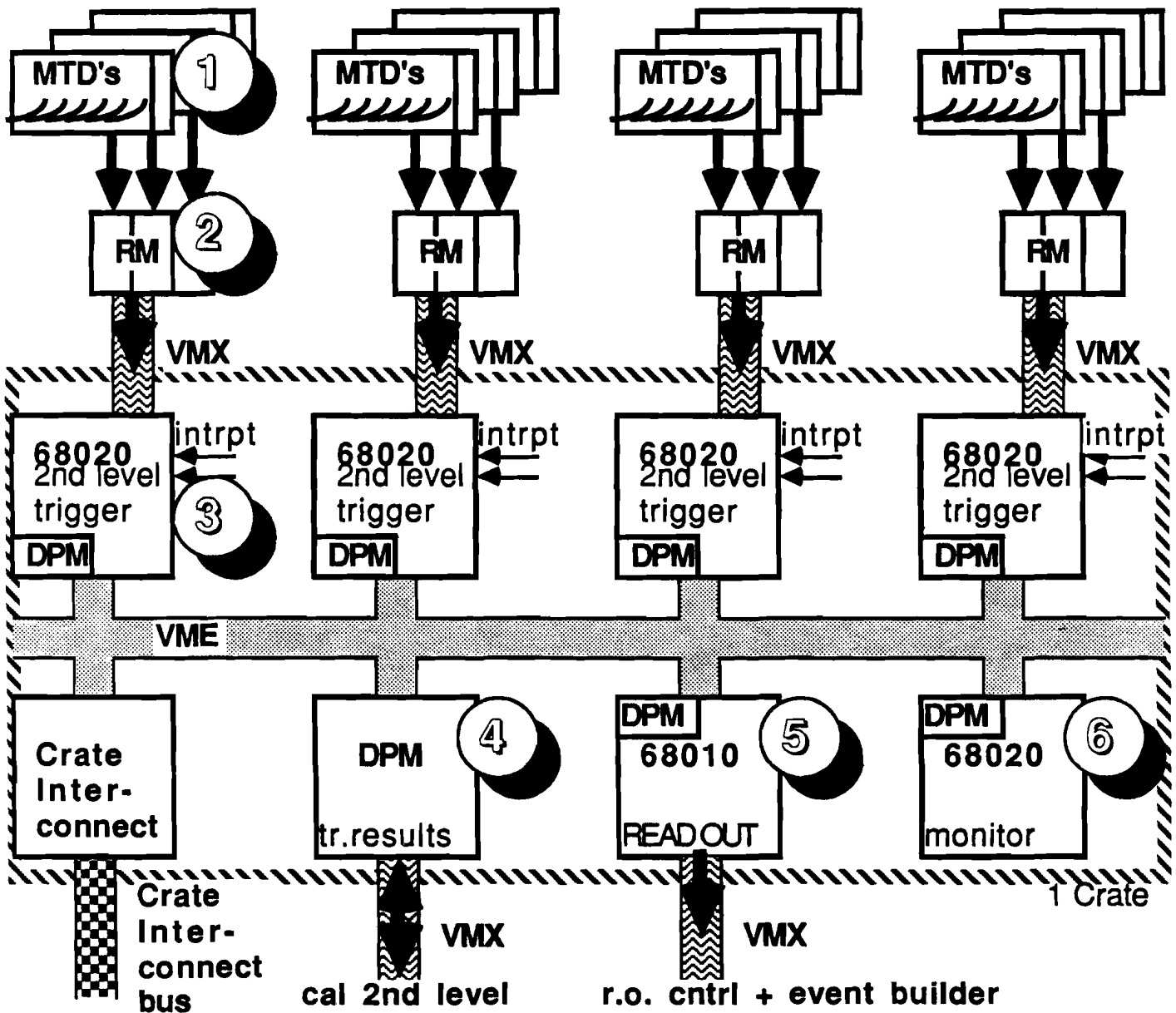
The first level μ trigger uses the information on which drift tubes in the muon chambers are hit. The 15 cm wide tubes are grouped into eight layers, four layers for each projection (figure 3). In the first level trigger an angular resolution of 80 mrad is obtained. The signals from groups of 10 wires are combined (hard wired) to form an address into a lookup table. The table determines whether tube combinations correspond to a track coming from the center of the detector. An event is accepted if two projections of a μ chamber have such a track. The requirement to point to the center of the detector discriminates against hadronic punch through and low momentum μ tracks that are more likely to be bent by the magnetic field and by multiple scattering. It is feared, however, that future trigger rates might be too high, especially in the forward directions. We are investigating whether magnetizing of the additional shielding iron will reduce the rate to acceptable levels.

Second Level Muon Trigger

At the second level the full drift time information is used. Hits in the chambers are read by special, hardwired controllers that also provide the double buffer. The controllers, the so called Reordering Memories, sort the data by wire number. They are read by VME

MUON READ OUT

STRUCTURE OF READ OUT AND TRIGGER



1. Multiple Time Digitisers measure drift times in muon chambers.
2. Read out controller (R M) reads and sorts data. (100 microseconds; double buffer.)
3. 68020s read data into DPM on VME bus. Find tracks in one dimension.
Combine tracks in space. Apply trigger cuts on track pointing angles.
4. Muon trigger results are combined with trigger results of 2nd level calorimeter trigger.
5. A 68010 transports data and trigger results for accepted events to event builder crates.
6. A 68020 performs system monitoring.

Figure 4.

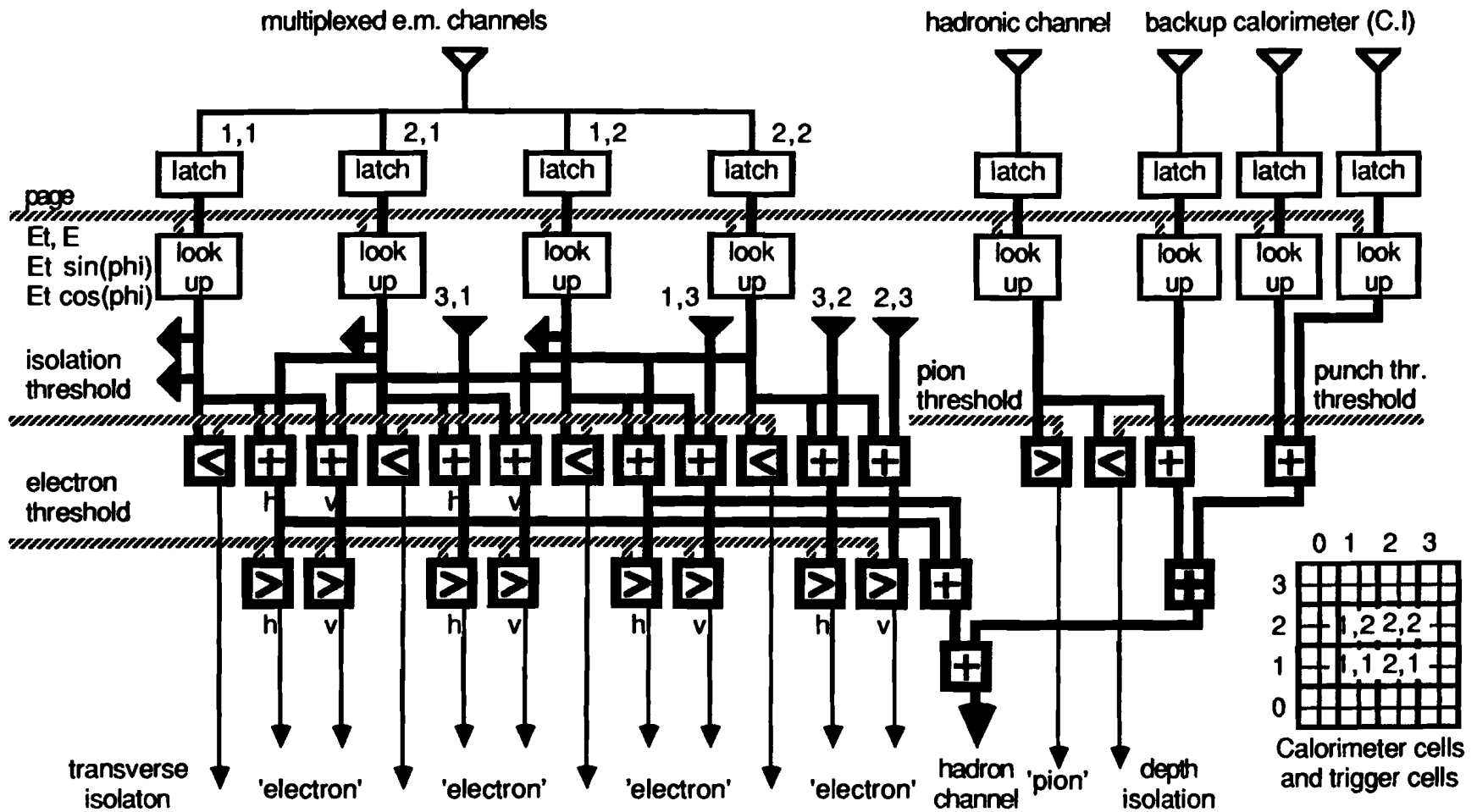
68020 CPU's that transport wire numbers and drift times to a Dual Port Memory accessible from the VME bus (figure 4). Each CPU that is ready with the transport performs track finding. Track parameters are stored in the DPM's. Consequently tracks are combined in space. The track angles are compared to cut values that depend on the precise position of the track in the detector. Angular resolution is 4 mrad; cut angles vary between 30 and 120 mrad. Unfortunately the reduction in the μ rate is not larger than 4. In the future we will have to combine information from the second level μ trigger with that from the calorimeter trigger. This information can be passed via a Crate Interconnect. Muon data and the trigger results for accepted events are copied by a 68010 CPU to the data acquisition via a VMX link. It might also be possible to verify that potential μ tracks are seen by the larocci streamer chambers.

At the third level the tracks seen in muon chambers are validated in the CD and their momentum is determined. The complete event information is combined to make physics cuts.

First Level Calorimeter Trigger

In order to keep the number of first level trigger channels within reasonable limits, groups of cells are added by analog electronics. E.m. channels are formed by adding 2·2·4 e.m. cells. Hadronic channels sum 4·4·2 hadronic cells. The first level trigger also uses the information from the old hadron backup calorimeter (C's and I's). In total 1500 trigger channels are used; each one is equipped with an eight bit FADC. The digital information is transported on 300 fiber links to the digital trigger logic and is available within one microsecond. The raw data words address lookup memories that contain the corresponding E_t 's. An adding tree is used to sum E_t 's into all possible 2 by 1 clusters of e.m. channels (figure 5), into jet size regions and into global sums (figure 6). These sums are compared to threshold values for the electron, jet and total E_t

CALORIMETER READ OUT FIRST LEVEL TRIGGER FRONT END

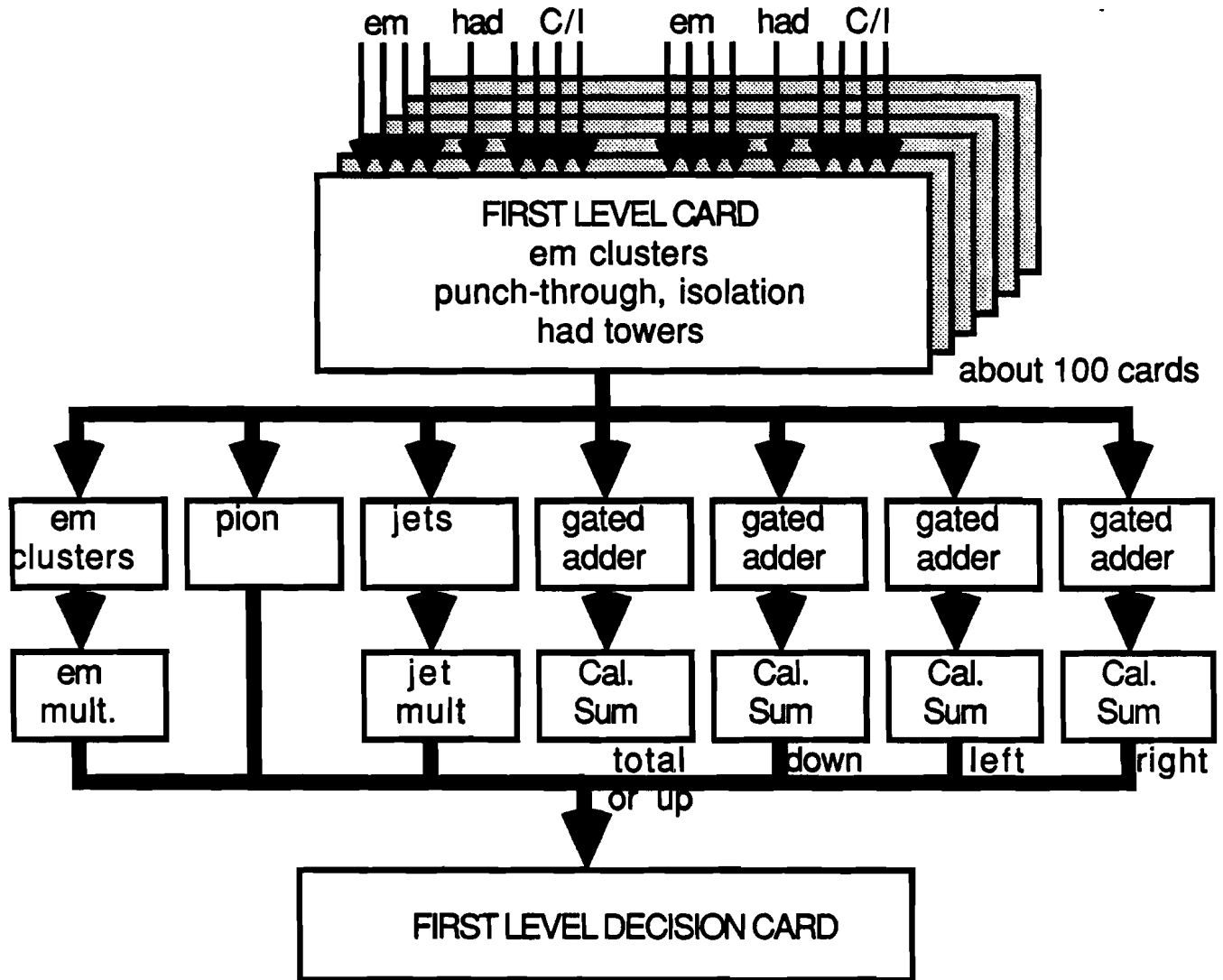


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Figure 5. Adder and comparator card used in the digital first level calorimeter trigger. Sums are made for all possible horizontal and vertical clusters of 1 by 2 trigger cells to trigger on electrons. The electron threshold can be lowered and signals are provided to apply isolation criteria. An overall energy sum is made to compute global quantities with.

CALORIMETER READ OUT

FIRST LEVEL TRIGGER



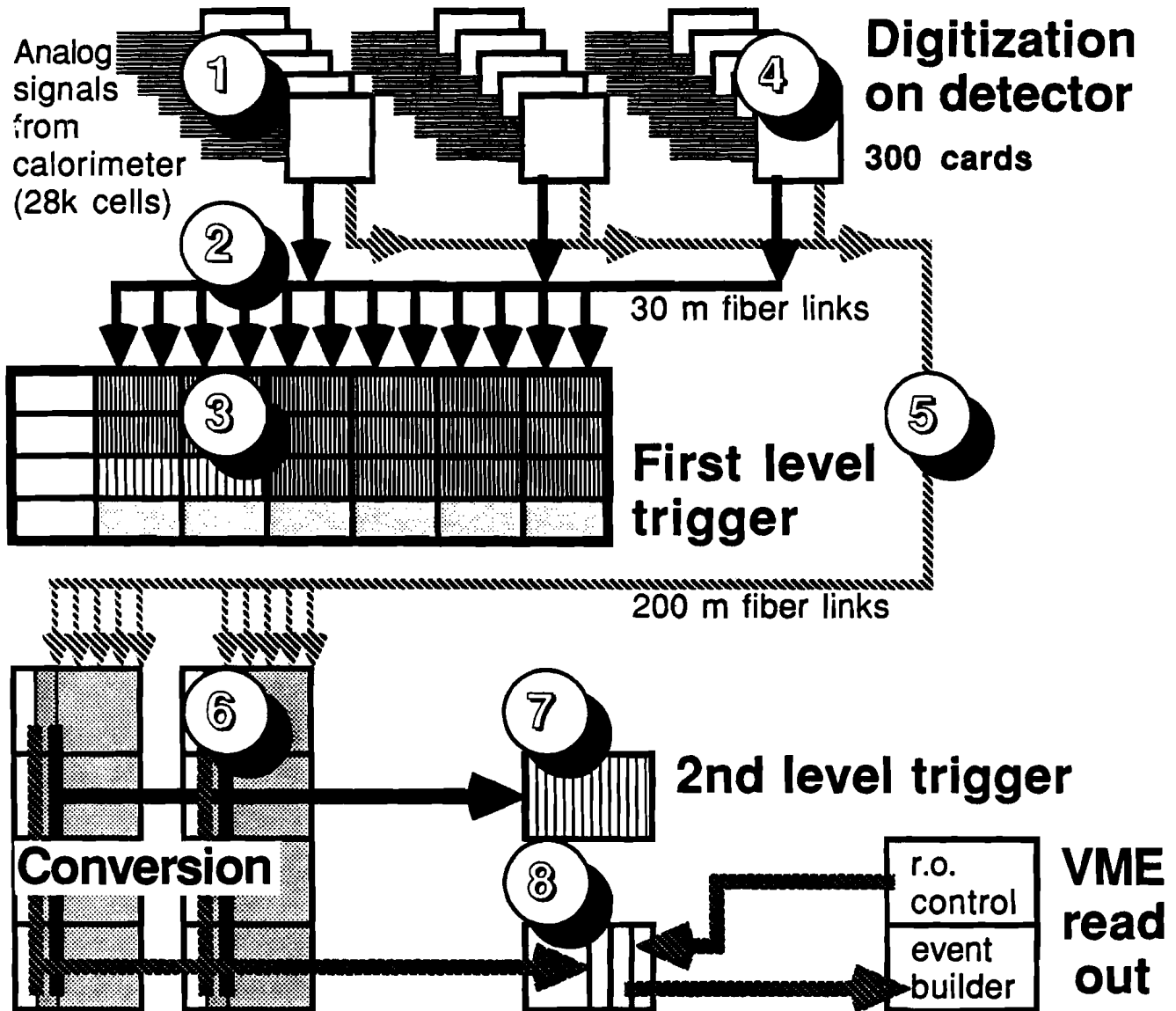
Cells are added (analog) on readout cards on detector.
 (2*2*4 electro-magnetic, 4*4*2 hadronic)
 Digitise on detector, 8 bit FADC per channel.
 Data are transported on fibers
 Data are converted to energy using lookup tables
 Sums ripple down the adding trees to form calorimeter sums
 Partial sums are compared with thresholds

In subsequent cycles the lookups give E_t , E , $E_t \sin(\phi)$ and $E_t \cos(\phi)$

Figure 6

CALORIMETER READ OUT

STRUCTURE OF READ OUT AND TRIGGER



1. Analog sums + flash ADC for first level trigger (<math><500\text{ ns}</math>).
2. Transport to first level trigger over 300 serial fiber links (100 Mbd).
3. First level trigger decision (2.5 micro seconds).
4. Digitise on detector in 300 ADC's, each one multiplexed for 96 ch. (100 microsec.).
5. Transport to conversion logic over 300 fibers at 16 Mbd (double buffer).
6. Convert to energy for read out and to Et for 2nd level trigger, suppress noise.
7. Second level trigger decision (3 milliseconds).
8. Transport to VME read out (5 milliseconds).

Figure 7.

triggers. The logic runs through several cycles during which the thresholds are lowered. At the lower thresholds an 'electron' can be vetoed if the hadronic segment behind it has too much energy or if it is not isolated laterally. The trigger logic also computes the multiplicity of electrons and jets. In two additional cycles different pages in the lookup tables are addressed to obtain the global sums of $E_T \sin(\phi)$ and $E_T \cos(\phi)$. These sums are used to estimate the energy imbalance for the missing E_T trigger.

Second Level Calorimeter Trigger

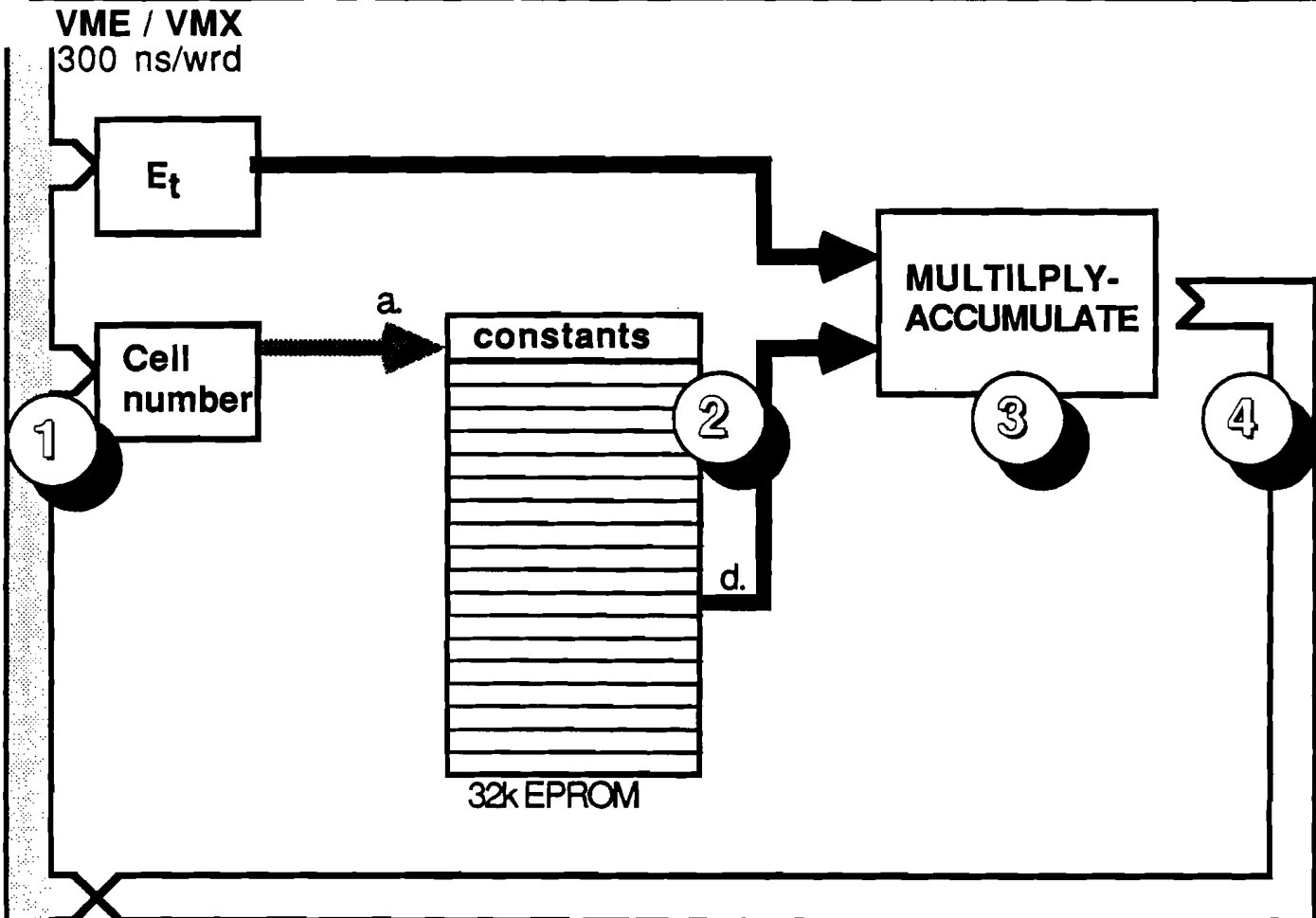
The second level trigger uses the final digital data, the best available calibration constants and the full calorimeter granularity. The pulse heights in the calorimeter are digitized by FADC's on the detector. The data is transported on three hundred fibers to the control room (figure 7). There the pedestal values are subtracted and empty channels are suppressed. Remaining values are multiplied with the calibration constants and channels above a certain noise threshold are stored in FIFO's. Two separate sets of multiplication units are used, one for the readout that is calibrated in units of Energy and one for the second level trigger, calibrated in units of E_T .

The second level algorithm is split in two phases: a number crunching phase when the data is pre-processed, sorted and accumulated with special purpose hardware and a pattern recognition phase performed with standard CPU's. During the first phase the calibrated calorimeter data is sent to the trigger crate. The 15 bit E_T values and the cell numbers are broadcast on the VME bus and are simultaneously processed by many hard wired processors. We have designed three types of such special purpose units:

- 1) The Event Image unit. This is a memory in which the E_T for each cell is stored.
- 2) The global summer (figure 8). This unit multiplies and accumulates the E_T values with a constant that is specific for the corresponding cell number. The accumulated

CALORIMETER READ OUT

2nd LEVEL TRIGGER - GLOBAL SUMMER



For each cell (above the noise threshold):

1. Broadcast E_t (Data) and cell number (Address) on VME bus.
2. Address lookup table with multiplicative constant.
3. Multiply with E_t and accumulate.
4. When all cells are done the SUMs are accessible from VME and from VMX.

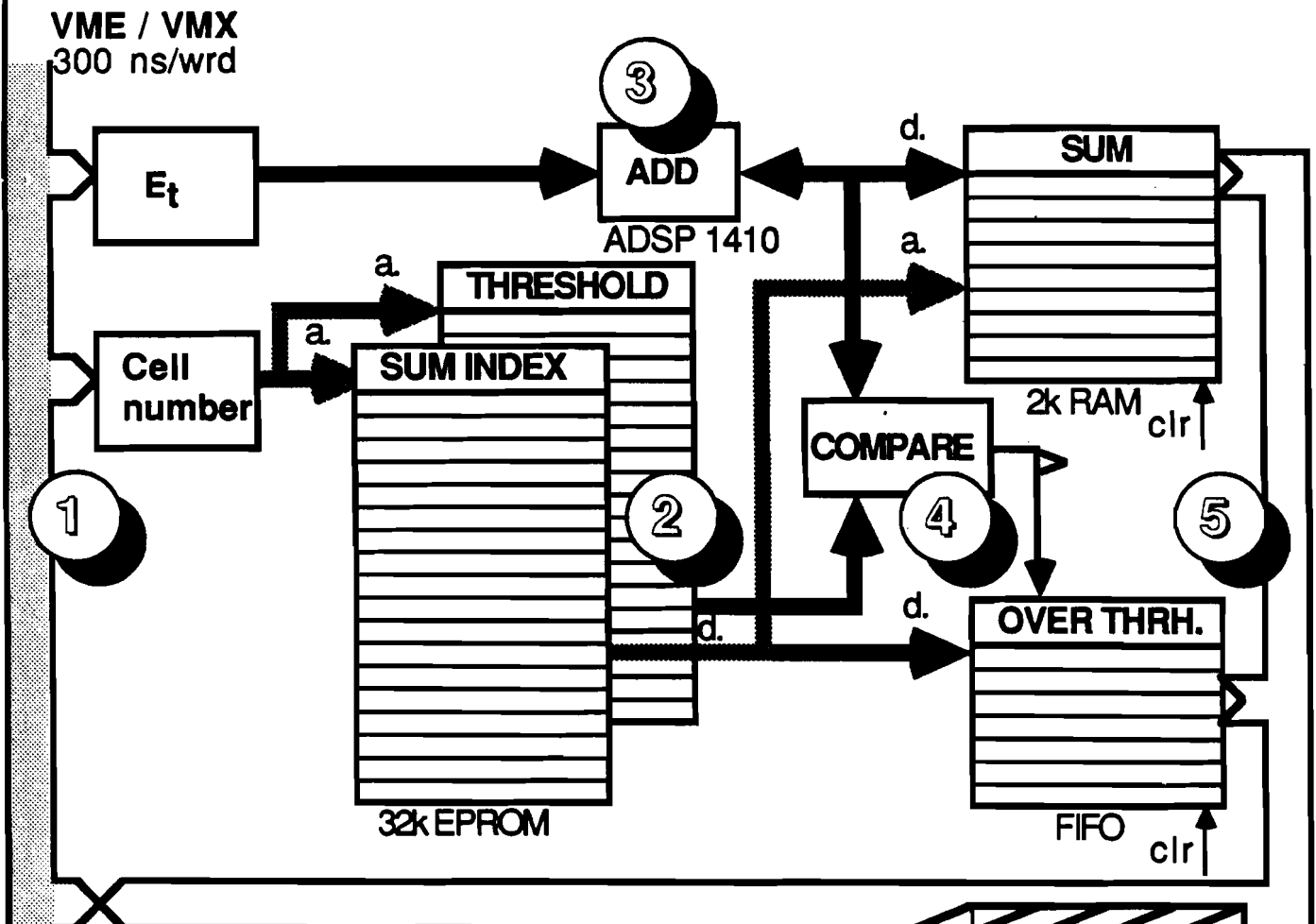
4 global summers fit in one VME module.

The constants used are: 1 for sum E_t , $\sin(\phi)$, $\cos(\phi)$ for missing E_t and $1/\cos(\theta)$ for the total E .

Figure 8.

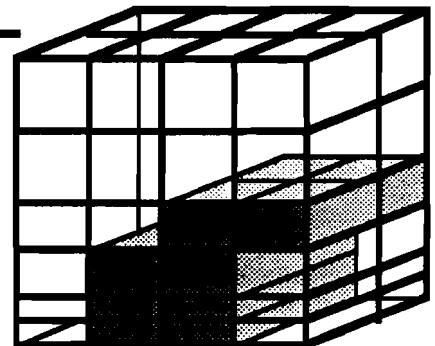
CALORIMETER READ OUT

2nd LEVEL TRIGGER - LOCAL SUMMER



Each SUM represents the total E_t in a region of the calorimeter. For example, all cells in the shaded area would have the same SUM index to form an electromagnetic tower.

Each summer has its own mapping.



1. Broadcast E_t (Data) and cell number (Address) on VME bus.
2. Address lookup tables with cell number \rightarrow SUM index and threshold.
3. Add E_t to old sum value and store back into SUM memory.
4. Compare new SUM with threshold.
5. When over threshold first time, store index of SUM in FIFO.
6. Sum memory and FIFO are accessible from VME and from VMX.

Figure 9.

sums are accessible from the VME and from the VMX bus. Four global summers fit into one VME module.

- 3) The local summer (figure 9). This unit is used to accumulate E_t in well defined regions of the calorimeter. The definition of the regions is cast into an EPROM that contains a sum index for each cell of the calorimeter and a threshold value. As soon as a certain sum is over its threshold the index of that sum is stored in a FIFO. The sum values and the FIFO are accessible via VME and via VMX. One VME unit contains four local summers.

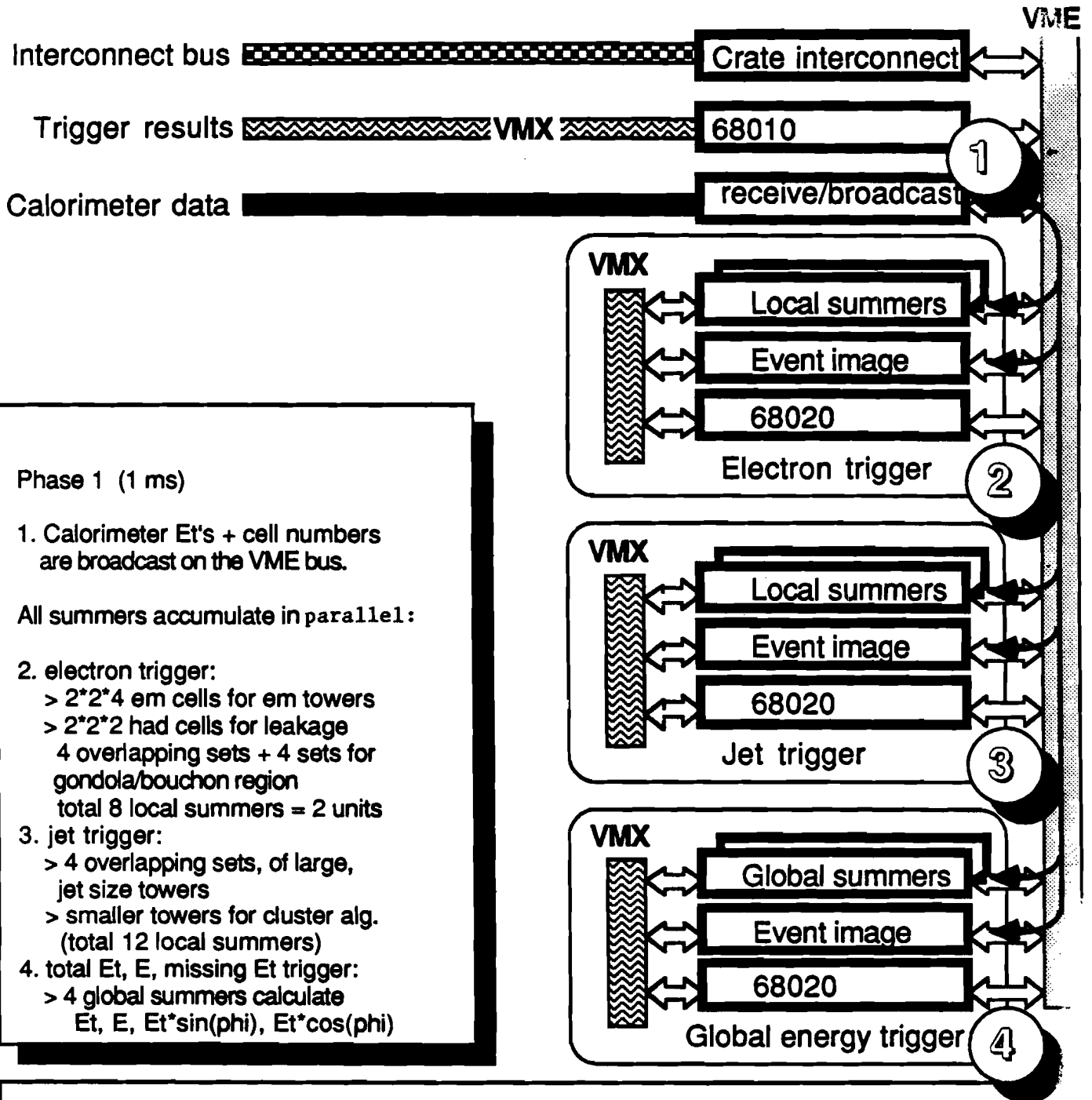
Eight local summers are used by the electron trigger to accumulate E_t in e.m. towers of $2 \cdot 2 \cdot 3$ e.m. cells and the E_t in the hadronic compartments behind them. Each local summer contains a set of towers that completely covers the detector. Four overlapping sets of towers are used; shifted by one cell in ϕ , in θ or in both directions; to trigger on electrons that divide their energy over adjacent cells. The mapping of the detector deals efficiently with the complicated regions where the gondola calorimeter overlaps the bouchon calorimeters.

The jet trigger uses local summers to compute E_t sums in overlapping jet size regions, in smaller η - ϕ bins, and in regions that sum e.m., hadronic and leakage energy for topologies that are relevant to validate jet and missing energy triggers.

The global trigger uses four global summers to accumulate the total E_t , $E_t \sin(\phi)$, $E_t \cos(\phi)$ and the total Energy. The process of digitization, data transport, pedestal subtraction, calibration and accumulation is fully pipelined. In 1 ms the data from the calorimeter is fully processed. The total processing power of the system is about 600 Mips.

During the second phase the pre-processed data is available to a number of 60820 CPU's (figure 10). One CPU is used for each trigger function and accesses the summers via the VMX bus to avoid bus contention on the VME back plane. Each CPU has its own program.

CALORIMETER READ OUT SECOND LEVEL TRIGGER STRUCTURE



Phase 1 (1 ms)

1. Calorimeter Et's + cell numbers are broadcast on the VME bus.

All summers accumulate in parallel:

2. electron trigger:
 - > $2 \times 2 \times 4$ em cells for em towers
 - > $2 \times 2 \times 2$ had cells for leakage
 - 4 overlapping sets + 4 sets for gondola/bouchon region
 - total 8 local summers = 2 units
3. jet trigger:
 - > 4 overlapping sets, of large, jet size towers
 - > smaller towers for cluster alg. (total 12 local summers)
4. total Et, E, missing Et trigger:
 - > 4 global summers calculate Et, E, $Et \cdot \sin(\phi)$, $Et \cdot \cos(\phi)$

Phase 2 (1 ms):

The 68020's validate the triggers and produce a list of electrons, jets and (missing) energy sums.

This information is combined with the muon information for the second level trigger decision.

Figure 10.

The electron algorithm reads the FIFO and retrieves the corresponding E_t sums. To validate electrons it can inspect the punch-through energy in the hadronic compartment or calculate the energy in the surrounding cells. It can validate the electro-magnetic profile using the E_t values in the event image memory.

The jet algorithm can validate the jet depth profile of a jet candidate and perform clustering to obtain the precise jet energy and the number of jets.

The missing and total E_t trigger algorithm tries to recognize topologies typical for cosmics and beam associated background.

The algorithms take about one ms; the results of the trigger are stored in a Dual Port Memory and are combined with the muon results. For accepted events the results are passed to the data acquisition for use by the third level trigger and for checking purposes.

The third level algorithms use CD information to validate electrons and jets. Physics cuts can be made on isolation of muons and electrons and on combinations of muons, electrons, jets, total E_t and missing E_t .