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The HERA-B electromagnetic calorimeter pre-trigger system

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Summary. — In this document the pretrigger system developed for the electromagnetic calorimeter of the HERA-B experiment is described. The system owns a lot of frontier features for calorimetry-based triggers and its design performances are such that some possible implementations of it can be foreseen for the future high-energy collider experiments.

PACS 28.52.Lf – Components and instrumentation.

1. – Introduction

HERA-B [1] is the experiment running at the DESY HERA proton ring aiming to measure CP violation in the B-meson system and to investigate many fundamental topics in B physics. The B's are produced in hadron collisions, and background rejection factors of the order of 10^{-10} are typically needed to detect the interesting signal channels. For this reason a very selective and efficient trigger system has been developed, with high flexibility in applying cuts on invariant masses and high transverse momentum of particles since the very early stage of the data processing.

One of the fundamental features of the HERA-B experiment relevant to design the trigger system is that a lot of information has to be processed (about 100 kbit per event) but the occupancy per event is low (at the level of 10% or less) like the number of candidates per event.

In the specific case of the HERA-B electromagnetic (e.m.) calorimeter (ECAL) the main task at pretrigger level is to inspect, by applying a proper algorithm, the full detector acceptance (about 6000 readout channels) to identify an average number of two electromagnetic cluster candidates per bunch crossing (BX). The other HERA-B trigger systems

(muon, high-p_t) have to face the same problem: select a few tracks per BX starting from some 10^6 "roads" for tracks within the parameter space allowed to the trigger system.
To summarize: a large amount of data readout is provided by the detectors involved in the trigger system, but only a small quantity of them have to be processed.
As a consequence of this characteristic, a general strategy has been adopted for the HERA-B first level trigger (FLT) through the following steps [1]:

– *Track seeding*: scanning over all the particle identification (ID) detectors (ECAL, muon, high-p_t) to find candidates and addressing regions of interest (ROI) in the tracking system. Create from the pretrigger stages *messages* that contain all the relevant track parameter and the address of the ROI.

– *Track finding*: updating (refining) of the messages at each step of a back tracking performed with a Kalman filter inspired algorithm.

– *Trigger decision*: last step for the definition of the track candidates parameters (starting from the messages), and calculation of the physical quantities (masses of pairs, high momentum cuts) necessary to trigger on specific channels.

This strategy allows *to limit the number of processors* needed by moving processes to data: the processors perform operations only on the small amount of data addressed by the (few) messages. This approach leads to a *consistent reduction of the number of processors without loosing trigger algorithm flexibility* (data processing is performed by look-up tables (LUT)).
In the following it will be shown first how these aspects have been achieved in the HERA-B electron trigger system [2]: by about one hundred processing units only it is possible to perform all the pretrigger algorithm on electromagnetic clusters on the 6000 ECAL readout channels.
In sect. **2** of this paper a description of the electron trigger developed for HERA-B will be given.

2. – The HERA-B electron trigger

In the following we will refer to the front end driver cards especially designed for the ECAL readout, which are fully described in ref. [3].

2˙1. *The electromagnetic calorimeter and the readout system.* – The HERA-B electromagnetic calorimeter is a shashlik type one. It is divided into three regions (*Inner*, *Middle*, *Outer*) having different granularity in order to get an occupancy uniformly distributed at 10% level. The main structure of the detector is a *module* consisting in a square cross section calorimeter tower having 11.15 cm side. In the *Inner* ECAL a module is subdivided in 5x5 readout cells having tungsten as converter and scintillator tiles as active material. Due to the tungsten Molière radius (1.3 cm) an em shower develops itself mainly in one readout cell having about 2.23 cm side. This allows to keep particle pile-up at a reasonable level even in the hottest region of ECAL. In the *Middle* ECAL a module is subdived in 2x2 readout cells having lead as converter, and in the *Outer* ECAL a module (lead as converter) coincides with a readout cell. The total number of modules is a matrix of 56 columns times 42 rows (see fig. 1) and the total number of readout channels is about 6000 equally shared among the three ECAL sections. The cells are readout by

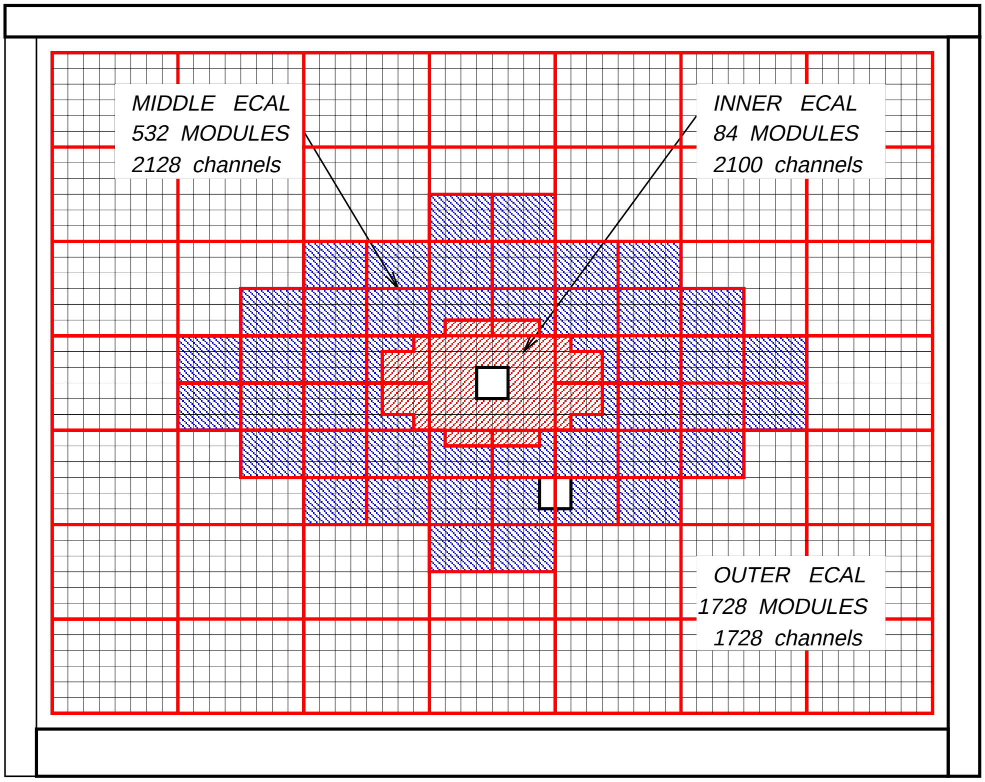

Fig. 1. – The HERA-B ECAL partition in shashlik type modules. In this picture it is also shown the partition (dashed lines) in pretrigger boards (one processor per board). The partition is in 8x6 readout channels matrix for the *Middle* and *Outer* ECAL, and in 10x5 readout channels matrix for the *Inner* (two close modules in the horizontal direction). This latter is not highlighted by dashed lines for clarity's sake.

means of photomultipliers. Signals from photomultipliers are sent into about 40 m long coaxial cables and then fed into the front end driver card (fed). The analog signal is here pole-zero compensated and shaped by means of a 60 ns gated integrator. A 13-bit dynamic range with 12-bit ADC resolution is got by means of a dual slope transfer function with an analog technique based on a fast clamping amplifier [3]. The 12-bit digitized data are stored into DPRAM 256 cells deep for the data acquisition (daq) second level buffer. This early digitization is an important feature for the HERA-B ECAL pretrigger system, since it allows, after a data conversion made by LUTs in the fed card [3], to obtain absolutely energy calibrated data and to perform digital processing of the data themselves in order to extract all the relevant quantities for the electron trigger algorithm. An important feature implemented on the readout board is the availability of a fast (< 100 ns shaping time) analog sum over its 32 channels. Starting from this signal a fast inhibit system based on the rejection of events with too large a deposit of energy in the Inner ECAL has been designed.

2·2. *The HERA-B electron trigger strategy*. – An electromagnetic cluster in ECAL is looked for in a 3x3 matrix of readout cells. For each readout cell an energy threshold

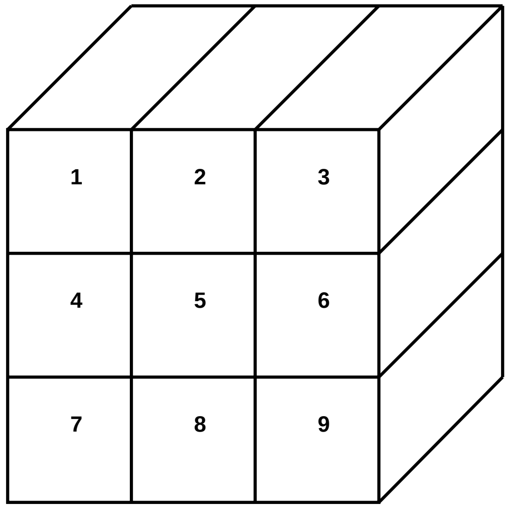

Fig. 2. – A 3x3 ECAL readout cells matrix.

$E_{\rm th}$ function of the cell coordinates is defined as $E_{\rm th} = K_{\rm trig} \cdot \left(\frac{1}{\sqrt{x^2+y^2}} + \frac{1}{\sqrt{x^2+|y|^3}} \right)$ ([1]), where x and y are the center of cell coordinates and $K_{\rm trig}$ is an adjustable parameter. The algorithm adopted to individuate an electromagnetic cluster (candidate) is the following (refer to fig. 2):

1) $E_5 > \frac{E_{\rm th}}{2}$
2) $E_5 = max(E_1 ... E_9)$
3) $\sum_{i=1}^{9} E_i = E_{\rm tot} > E_{\rm th}$.

If a candidate satisfying conditions from 1 to 3 it is found, the pretrigger should calculate also the following quantities to form the messages to be passed to a ROI in the tracking system:

– center of gravity of the electromagnetic cluster corrected for the non uniformity of response of the calorimeter cell;

– address of the ROI;

– a flag which indicates whether the electromagnetic cluster transverse momentum is above a preset threshold (to trigger on high-$p_{\rm t}$ photon candidates);

– the energy loss by the electromagnetic cluster for bremsstrahlung (BS) photon radiation (if any).

([1]) This formula represents essentially an electromagnetic shower transverse momentum threshold function keeping into account (in the second operand) the asimmetry in the x and y particle distribution due to the bending magnet of the HERA-B experiment

The guidelines to face these tasks and underlying the HERA-B electron pretrigger design are the following:

– follow the general HERA-B experiment FLT criteria: minimize number of processors by moving the processes to the stored events data rather than all the data to distributed processing units,

– keep flexible the processing unit calculation capability, using LUT based processors.

These criteria have been fulfilled by the following hardware implementation of the required algorithm:

i) apply condition 1 at the very early stage of the data readout (in the FED boards);

ii) apply a fast local energy maxima algorithm (condition 2) at the very early stage of the pretrigger board.

Step i) gives a strong reduction on the possible electromagnetic clusters to be processed; step $ii)$ is fundamental to address the central cell of a cluster as well as the eight neighbour cells, and to pass the nine energy values and central cell coordinates to the data processing unit that evaluates all the parameters relevant for the FLT. In the global design of the pretrigger system the three different ECAL regions are treated as independent; Monte Carlo simulations have shown that this simplification worsens the overall electron pretrigger efficiency for the $B^0 \longrightarrow J/\psi K_S{}^0$ channel by a 2%. A system of patch panels from the front end boards fans out the signals belonging to the borders of regions covered by close pretrigger boards (see ECAL partition in pretrigger boards in fig: 1). In this way there is no loss of efficiency due to pretrigger cards border effects.

2˙3. *Technical description*. – On the readout board the ADC output 12-bit data is fed into a 4kbyte LUT that gives as an output a 8-bit word in which 7 bits represent an absolutely calibrated energy datum compressed following a $\sqrt{E}$ law (the error on the energy resulting thereby constant all over the energy range). The 8th bit is a flag containing the information whether the energy of the readout calorimeter cell fulfills the condition 1 of the electron pretrigger algorithm (since the constant term for the calorimeter towers energy resolution is at level of 1%, it makes no sense to use more than a 7-bit information for the calculation that can be performed at pretrigger level). This 8-bit data is sent to the pretrigger card according to a serial synchronous protocol. Two groups of 4 bits each are transmitted by means of two wires at a clock frequency of 4 times the one of the HERA-B clock (running at 10.4 MHz). In fig. 3 a block diagram of the HERA-B ECAL pretrigger card is shown. A pretrigger card can process the data from a 10x5 (or 8x6) matrix of central cells and 34 (or 32) border cells (see fig. 1).
The logic blocks shown in fig. 3 perform the following operations:

– Input Interface (IIF): it accepts the 8-bit serial data, converts it into parallel and stores it into a DPRAM 64 events deep.

– Local Maxima Finder Unit (LMFU): It is the most important block to perform the clustering algorithm: 8-bit serial data from each of the 50 (48) input channels are processed in a serial way, condition 2 (see sect. **2**˙2) is checked only for the data that have

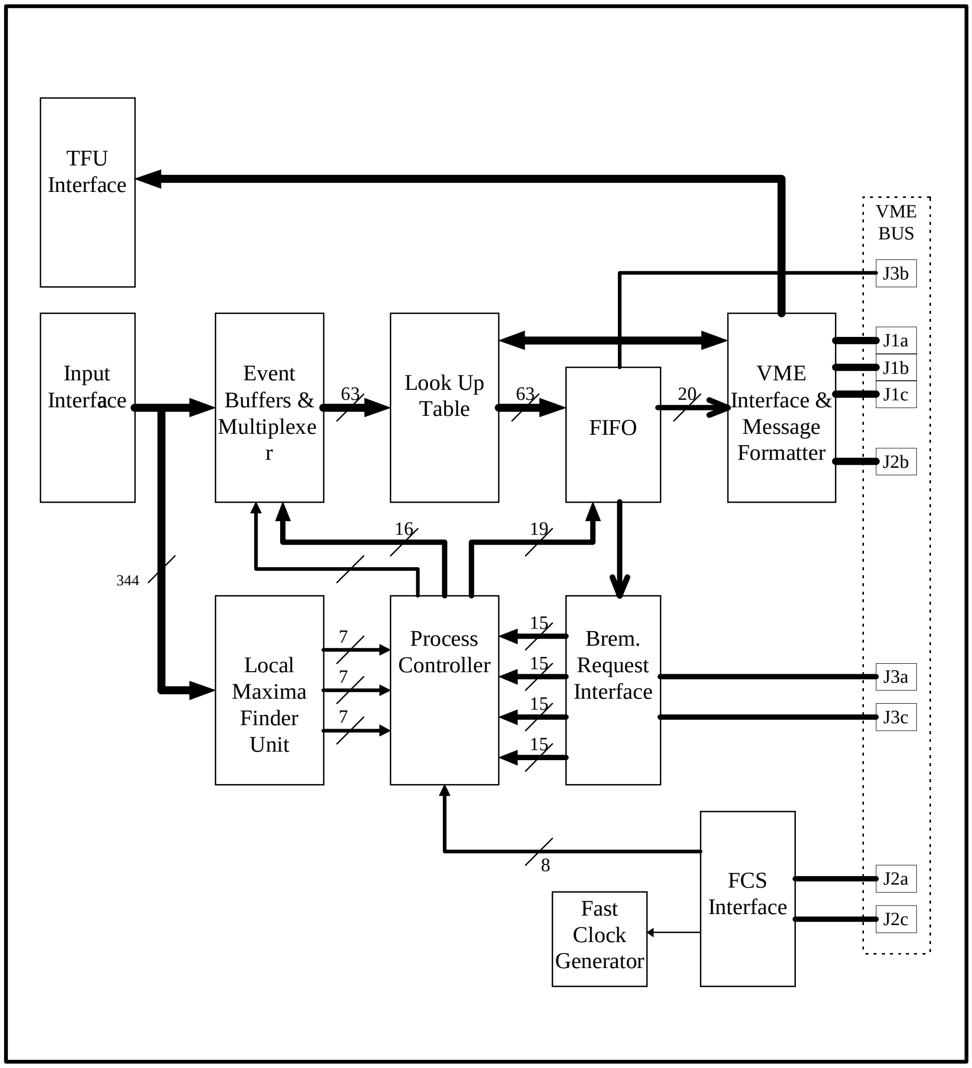

Fig. 3. – The HERA-B ecal pretrigger card block diagram.

passed condition 1 (8th bit issued), and the coordinates of the local energy maxima are found. The algorithm performed by this unit represents an original feature of the pretrigger board design and it is described in detail in ref. [4].

– Process Controller (PC): it performs a 16 events deep three-fold pipelining of the addresses of the candidates found by the Local Maxima Finder Unit and a 16 events deep four-fold pipelining of the addresses found by the Bremmstrahlung Request Interface (see below). A priority logic decides which one of the seven pipelines has to be depleted at each clock cycle according to an algorithm described in ref. [5]. This algorithm allows to process up to 3 candidates per board which is well beyond the rate of electron candidates per BX expected in HERA-B (2 per BX all over ECAL).

– Event Buffer and Multiplexer (EBM): it allows to extract, starting from the central cell address given by the Local Maxima Finder Unit, the 7-bit energy values of the central cell itself and of the eight neighbour cells.

– LUT (Data Processing Unit, DPU): it is the data processor. It is implemented in LUTs (see fig. 5) that perform all the computation needed to form the electron pretrigger message starting from the 9 (3x3) cluster energy values sent by the Event Buffer and Multiplexer and the cluster central cell coordinates. This unit is flexible as far as concerns the pretrigger algorithm choice and possible updating of it. The DPU processing time to extract all the parameters relevant to the FLT is 1.25 HERA-B clock cycles (about 125 ns).

– Bremsstrahlung Request Interface (BRI): It represents another original and important feature of the design of the electron pretrigger for the HERA-B experiment. Due to the presence of material between the interaction point and ECAL, the electrons/positrons may undergo radiative energy loss by means of BS radiation. If the loss of energy happens before the magnet, the distance between the electron/positron and the photon impact points on ECAL are fixed by the kinematics. The algorithm implemented in the HERA-B electron pretrigger boards (in order to associate the possible photon energy to the main electron/positron candidate) is the following (see fig. 4):

a) starting from the total electron/positron energy evaluated in the DPU the ECAL coordinates where the possible BS photon energy has to be searched are calculated;

b) these coordinates are sent to the BRI which issues a request either to the PC inside the board itself or to the two PCs of two (due to the electron/positron ambiguity) external boards (by means of J3a/J3c connectors in the VME bus);

c) the PC addresses the EBM and the total energy (on a 3x3 matrix) of the BS photon is evaluated by the DPU; if the evaluated datum belongs to an external board with respect to the requesting one, it is sent back via J3b to this latter board;

d) when this cycle of operations has been accomplished, the final message is composed in the FIFO on the board with the electron/positron candidate;besides the candidate energy, the message to be delivered to the TFUs contains at this point also the two possible values of the BS photon energy.

– VME interface and Message Formatter (MF): An 80-bit message is formed here containing all the quantities elaborated by the DPU and necessary to the FLT track finding unit (TFU) processors to elaborate the trigger algorithm. These messages are then sent to the *TFU Interface (TFUI)* that transmits them in four 20-bit packets at a clock frequency of 100 MHz. A prompt logic signal is also formed in this unit when an electron candidate satisfying all the algorithm requirements has been found. This output allows to trigger ECAL also in standalone mode without TFUs for debugging purposes, or to give a further condition to the FLT concerning the total number of candidates in the whole electromagnetic calorimeter per event.

– FCS Interface (FCSI): it is the interface, common to all the subdetectors, to the clock of the experiment. A 7-bit BX number is delivered to this interface that is used for data addressing and labelling.

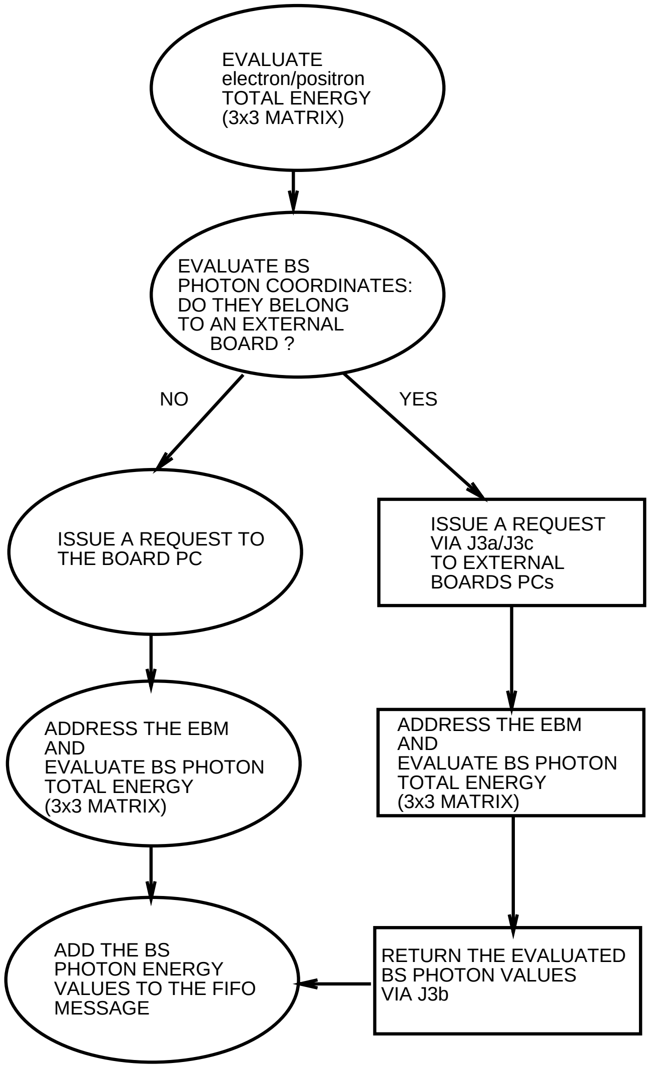

Fig. 4. – The bremsstrahlung recovery algorithm flow diagram. Processes performed in the board of the electron/positron candidate are in the elliptic blobs, while processes performed on boards external to the candidate one are in the rectangular blobs.

The electron trigger system works synchronously with the BX up to the Message Formatter stage, while the transmission of data to the FLT TFU is as well as the remaining logic of the FLT are asynchronous .
The whole pretrigger logic is implemented in 4000 Series XILINX FPGAs.
All the logic operations inside the board are performed with a clock running at about 40 MHz (4 times the HERA-B clock frequency).
The total latency to process one candidate (without taking into account the BS recovery operation) is 15 HERA-B clock cycles (about 1.5 μ s).

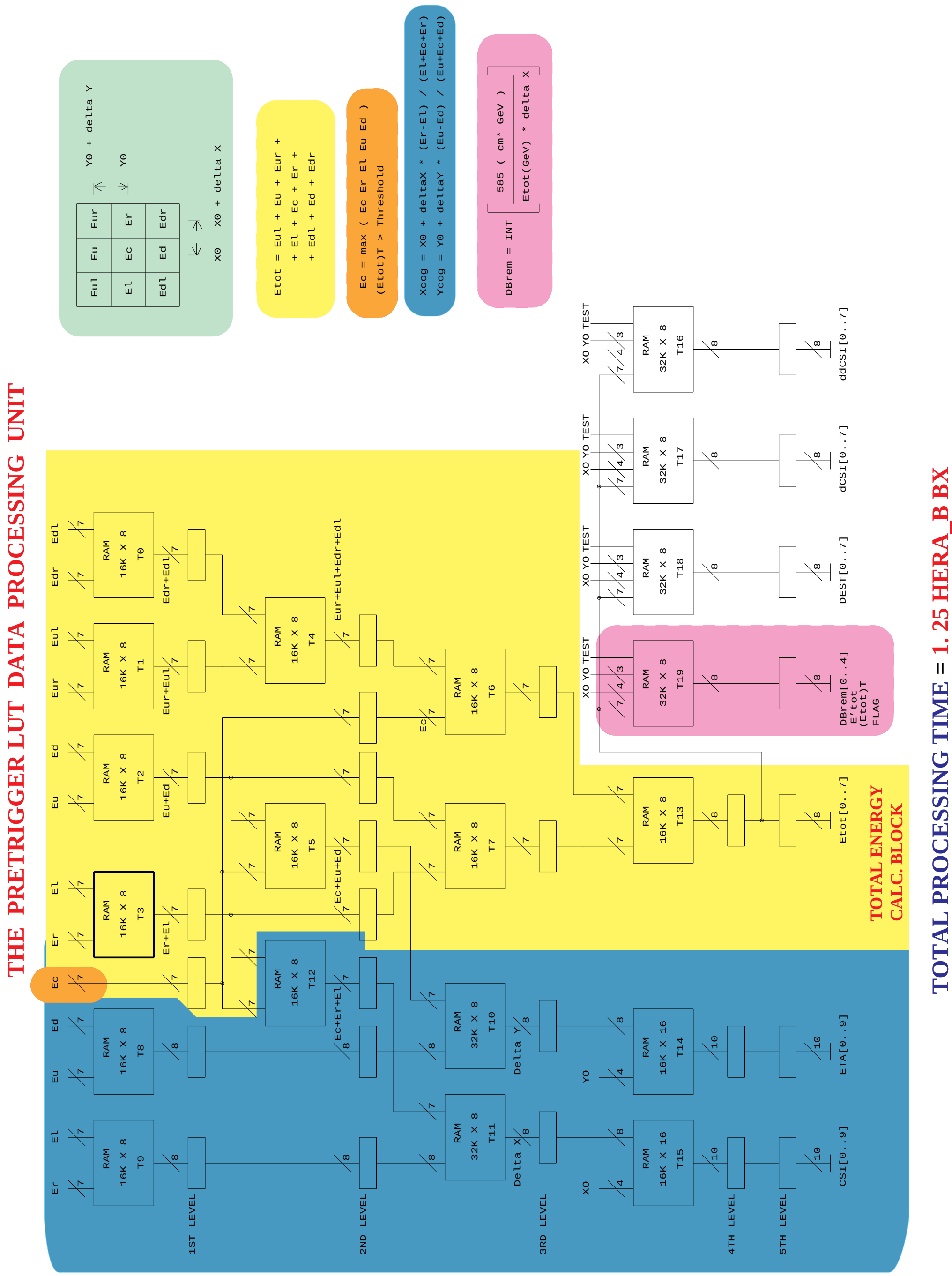

Fig. 5. – The HERA-B ecal pretrigger data processing unit. The different shadowing in the picture refers to different computational blocks.

3. – Conclusions

The ECAL pretrigger system developed for the HERA-B experiment has been described. Prototype versions of pretrigger boards have already been tested on bench and on beam. The interfacing of the pretrigger card to the readout board and to a prototype version of a TFU board has also been tested successfully. Common data taking with the prototypes of HERA-B subdetectors presently (October '97) installed in the experimental area with the electron trigger active (exploiting some of its functions) is being intensively tested .

The designed system is flexible and allows for all the calculations needed for a fast trigger on electromagnetic showers, comprehensive of recovery of energy losses by electrons for photon radiation.

The present performances make it appealing also for future implementation for similar purposes at the future high-energy collider experiments [6].

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