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THE MISSING TRANSVERSE MOMENTUM TRIGGER ELECTRONICS OF UA2

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Abstract

A special purpose electronics module is described which provides a fast ($< 1.5 \mu\text{s}$) first level trigger decision for events with missing transverse momentum in the upgraded UA2 experiment at the CERN $\bar{p}p$ Collider. The module is based on an array of 50 MHz 8-bit Flash ADCs and on two 4 Kbyte 10-bit look-up tables.

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1. INTRODUCTION

In proton-antiproton collider physics experiments a clear signature for events in which a high energy neutrino or any other undetected particle is produced in the interaction is the presence of a large missing transverse momentum (a non-zero vector sum of the transverse momenta of all the detected particles in the event).

An effective way of measuring this quantity is surrounding the interaction region with a calorimeter. One can thus define E_T^{miss} as

$$E_T^{\text{miss}} = |\sum E_T^i \vec{u}_i|$$

where E_T^i is the transverse energy deposited in cell i of the calorimeter, $\vec{u}_i$ is the unit vector pointing from the interaction vertex to the center of the cell, and the sum i is extended over all the cells of the calorimeter. The missing transverse energy is measured instead of the missing energy since the longitudinal component cannot be measured at hadron colliders due to the fact that many particles escape through the beam pipe.

The characteristics required from a calorimeter in order to allow a good E_T^{miss} measurement are [1]:

- good hermeticity (no cracks through which particles can escape undetected), and coverage over a fraction of the polar angle as large as possible.
- high segmentation, both in azimuth and in polar angle, and good energy resolution.

A major effort in the upgrade of the UA2 experiment [2] has been made to improve the hermeticity of the calorimeter, by replacing the original forward backward electromagnetic calorimeters with new End Cap calorimeters extending the full calorimetric coverage down to about 5° from the beam, with full azimuthal coverage and with a segmentation matched to that of the existing central calorimeter (15° in azimuth and 0.2 units in pseudorapidity) [3].

This fine granularity, combined with the accurate cell-to-cell energy response calibration (better than 1.5 %), obtained by calibrating every cell of the calorimeter in a test beam, enable a very efficient use of the calorimeter for the online selection of events with a large E_T^{miss} .

This paper describes the detailed implementation of this selection in the UA2 first level trigger system. Section 1 gives a general overview of the logic steps in the implementation, Section 2 describes a special purpose CAMAC module developed at CERN for this trigger, Section 3 describes the performances of the system during the 1988 $\bar{p}p$ collider run.

2. DESIGN CONSIDERATIONS

The insertion into the existing framework of the jet triggers of the UA2 experiment and the operation in the environment of the SPS $\bar{p}p$ Collider impose some explicit design constraints on the E_T^{miss} trigger.

- The time between two beam crossings is $3.8 \mu\text{s}$. In order not to generate dead time the first level trigger decision has to be taken within about $1.5 \mu\text{s}$, given the required clearing time of the UA2 readout electronics of $\sim 2.5 \mu\text{s}$.
- The E_T^{miss} trigger logic uses the basic building blocks for the jet triggers as input. These consist of 12 pulses, each of which is the weighted sum of the photomultiplier signals from all calorimeters cells making up a wedge extending over 30° in azimuth and over a pseudorapidity range $|\eta| < 2$. The integral of each pulse is proportional to the transverse energy deposition in the corresponding wedge.

Starting with these inputs the E_T^{miss} trigger logic performs the following sequence of operations :

- integrates the 12 input pulses
- builds the vector sum of the 12 signals in order to obtain E_x and E_y in digital form, where E_x and E_y are the two orthogonal components of E_T^{miss}
- calculates $E_T^2 = E_x^2 + E_y^2$
- applies a threshold on E_T^2

Once the two transverse energy components are available, the last two steps in the procedure can easily be implemented using standard electronics modules. A particularly suitable choice for our environment is the MBNIM [4] standard in which modules able to perform such operations with the required speed (about 100 ns for the full procedure) exist already, with the additional advantage of retaining homogeneity with the rest of the first level triggers, which are also implemented in MBNIM.

For the first step we decided to use 12 ISH (Integrating Sample and Hold) [5] circuits, already extensively used in constructing the other triggers of the UA2 experiment [6]. They provide an output voltage of up to 3 Volts which is stable to a few mV over a time span of several microseconds. The integration time is dictated by the width of the summed photomultiplier pulses and is about 350 ns.

In order to build the vector sum a special CAMAC module was developed at CERN. The twelve input signals are digitized by an array of 50 MHz 8-bit FADCs (Flash Analog to Digital Converters), weighted by the sines and the cosines of the azimuthal angles of the 12 wedges

using two 4-Kbyte 10-bit look-up tables, and the results are summed using fast ALU (Arithmetic Logic Unit) chips. The results are presented on two 10-bit busses in the MBNIM standard. The two look-up tables are separately accessible through CAMAC in read/write mode for easy loading and checking of calibration constants.

The choice of a completely digital design, rather than a simpler and faster analog implementation of the same algorithm, was dictated by the following considerations. The rejection power of the E_T^{miss} trigger relies crucially on a very good azimuthal balance in the response of the calorimeter; possible small differences in the gain and in baseline offsets inherent in the analog electronics chains which build up the twelve 30° wedges from the calorimeter signals, could very easily bias the trigger and provide a source of "fake" E_T^{miss} . A system is needed which is capable of compensating for effects of this kind by allowing a fast online calibration of the inputs. The use of look-up tables whose content can be periodically updated through a standardized calibration procedure is an efficient answer to this requirement.

3. THE MODULE

The purpose of the MISSPET CAMAC module is to calculate the components E_x and E_y of the transverse energy deposited in the UA2 calorimeter. It accepts input signals with levels from 0 to -3 V and exhibits an input impedance of 100 Ohms. A block diagram of the unit is shown in Fig. 1. The module contains 15 channels of which 12 are used in the UA2 application. The STROBE signal triggers the "flash" analog to digital conversion of the ISH levels at the inputs. A fast look-up table MEM (two 4Kx10bit memory banks) is then sequentially addressed thus allowing for :

- gain and pedestal corrections to equalize the response of the different channels, together with a calculation of the projected values XDT (9:0) and YDT (9:0) along the x and y coordinates;
- a summing of the x and y components into two accumulating arithmetic units ALU1 and ALU2.

Each of these 4Kx10bit memories is subdivided into banks of 256 words. These banks are selected by the signals lines CHSL (3:0) and the words are addressed through the ADR (7:0) bus. The CHSL (3:0) select lines are used by the CONTROL block not only to multiplex the result of each of the FADCs onto the ADR (7:0) bus, but also to drive 2 subgroups of 256 words : one for the E_x and the other for the E_y calculations.

The outputs of the accumulators (10 bits wide) drive two MBNIM busses which, in turn, feed a system of MBNIM RAHM and ALU16 modules [4] to calculate the transverse

energy and to select event candidates. The MBNIM data ready signal DTRD is issued at the end of the scan over the 12 (15 maximum) FADCs : it can be used to validate the data and show whether the conversion/calculation cycle is in progress. The cycle time is ≈ 80 ns per channel thus leading to a total dead time of 960 ns for the whole module.

The logic is interfaced to CAMAC and different modes of operation can be selected for the module by means of a 2-bit Control Register (CR):

- front panel operation, selected by setting the CR to 0, with no access to the memory from the CAMAC dataway, is used for normal data taking operation.
- CAMAC separate read/write access to the two 256 words memory sub-groups, selected setting CR to either 1 or 2, is used for calibration, testing, and loading of the coefficient table.

The module is equipped with an internal switch to allow for the selection of the number of active channels (12 instead of 15 for UA2).

Special care was taken to design the CAMAC interface functionality in order to ease the control of the module in the REMUS [7] environment widely used in experiments at CERN. The design makes extensive use of ECL 10 K integrated circuits wire-wrapped on double sided printed circuit boards with a ground plane. However, each 50 MHz Flash converter (SONY CXA 1056 P), together with its output gates (2 x 10104), are laid on a small printed circuit daughter board as shown in Fig. 2. Fifteen of these sub-cards plug into the right hand side wire-wrapped board of the 4 unit wide module. The left hand side control board can be seen in the photograph in Fig. 3. Ninetytwo integrated circuits are packed on the somewhat limited space of the CAMAC card. They include: the CAMAC interface (2 x 20L8 PALs together with a few bistables and the MEMADD counter followed by TTL/ECL level shifters), the look-up memories (24 x 10474-15 1Kx4bit memory chips), the ALUs (6 x 10181) and the MBNIM bus drivers.

Modern Computer Aided Engineering (CAE) methods were used for schematic capture and digital simulation of the design prior to the physical implementation. They involved a DAISY Personal Logician 386 workstation interfaced to the CERN WRAP4 wirewrap software [8]. The Flash converter was modelled as a random number generator in order to provide an input to the simulation of the digital parts of the circuit. It is worth noting that no remaining design errors appeared after the construction and testing of the two modules now in operation in UA2.

The very good performance of the MISSPET module is shown by the histogram in Fig. 4. In this test, a low output impedance signal generator drives the 15 inputs in parallel and the module is triggered at random; moreover, the contents of the look-up tables are such that

they correspond to the value of the address multiplied by the cosine (or the sine for YDT) of the azimuth angle associated with the channel number. It is readily seen that under these conditions, the output values on the MBNIM busses are expected to be always zero within a few counts. For a full scale sine wave at the input, the standard deviation is 0.7 counts and the full width at the base is 6 counts.

4. PERFORMANCE OF THE TRIGGER

The trigger described above was implemented in the UA2 experiment for the 1988 $\bar{p}p$ running period at the CERN SPS collider. It operated reliably during the whole of the period giving a trigger decision within 1.45 μs of the leading edge of the master gate of the experiment.

For standard running conditions, the threshold was set at a nominal value of approximately 16.5 GeV, which corresponds to full efficiency for events having E_T^{miss} in excess of 20 GeV. Using this threshold, at a luminosity of $1.5 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$, the first level rate from this trigger was 3 Hz.

In order to illustrate the sharpness of the threshold Fig. 5 shows the E_T^{miss} distribution calculated in the pseudorapidity range $|\eta| < 2$ for a sample of jet triggers. The full calorimeter information is used including the offline calibration constants. Superimposed are the distributions of the same quantity for the events in the sample which are accepted by the E_T^{miss} trigger for two different threshold settings. For events with $E_T^{\text{miss}} > 15 \text{ GeV}$, we estimate for the fast first level E_T^{miss} measurement a precision of $\sigma \approx 10\%$.

5. CONCLUSION

Since 1988 the UA2 experiment is taking data with a missing transverse momentum first level trigger based on a special purpose CAMAC module performing a fast digitization and vector sum of 12 analog inputs using Flash ADCs and look-up tables. The system proved to be a good solution for the requirements of reliability and good channel-to-channel equalization properties providing smooth and efficient data-taking operation.

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FIGURE CAPTIONS

- 1. Functional block diagram of the MISSPET module.
- 2. Photograph of the Flash ADC daughter board.
- 3. Photograph of the 4 unit wide CAMAC module.
- 4. a) Test system and b) results obtained using look-up table contents computed to produce an expected sum of the cosine component equal to zero.
- 5. Missing E_T spectrum (GeV) calculated in the pseudorapidity range $|\eta| < 2$ for a) Jet triggers, b) and c) E_T^{miss} triggers with hardware threshold respectively set at 14 and 16.5 GeV.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5