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A FASTBUS-BASED SOFTWARE TRIGGER FOR THE MARK II DETECTOR AT THE SLC*†

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1. INTRODUCTION

An intensive commissioning effort is currently under way to establish e^+e^- collisions at a center of mass energy of 93 GeV in the new SLAC linear collider or SLC. This machine was designed and built both to test the ideas of a new linear collider technology[1] and for the production of Z^0 bosons for physics analysis.[2,3] The initial physics run will be made with an upgraded Mark II detector, a veteran of two previous electron-positron colliders: SPEAR and PEP.

A new software trigger scheme has been developed to augment and enhance the existing charged and neutral triggers by providing sensitivity to new event topologies and some level of control over accelerator-induced backgrounds. Historically, the Mark II existed with two primary trigger components: a charged track finder based upon the central and vertex drift chambers and the time-of-flight counters; and an electromagnetic trigger based upon the total energy deposited in each of ten calorimeter modules. The trigger component of the new system is based upon the Mark II electromagnetic calorimetry but with significantly increased granularity and the inherent flexibility of software. Trigger processing also benefits from the relatively long period of time (up to 8.3 ms) between SLC beam crossings.

The production of long-lived neutral particles provides an example of an event topology which would not have triggered in the old system. By decaying beyond the first few drift chamber layers, such particles avoid the charged particle trigger, yet could produce clear signals in the calorimeters. Another example is the class of events containing a single photon as the only visible particle such as occur in the reaction $e^+e^- \rightarrow Z^0\gamma \rightarrow \nu\nu\gamma$. Sensitivity to this reaction is necessary to measure the number of neutrino generations. One goal of the new trigger is to achieve nearly 100% efficiency for single photons of energy above 750 MeV. Such a trigger necessarily depends upon a very low and well understood accelerator background for success. A minimum ionizing particle trigger will provide good efficiency for $Z^0 \rightarrow \mu\mu$ or $\tau\tau$ at the angles covered by the end cap calorimeters which increases the capabilities for measuring the forward-backward asymmetries. And finally, an improved trigger is more sensitive to complete surprises.

A system of ionization chambers, proportional tubes and wire chambers placed around the Mark II detector and in the SLC tunnels comprise the background monitor system. As the patterns of accelerator-induced background particles in the detector become understood they will be taught to the new trigger system and used for event vetoing.

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2. HARDWARE

The Mark II detector and data acquisition system have been described elsewhere.[4,5] A schematic diagram of the new software trigger electronics is shown in figure 1. The calorimeter portion of the trigger consists of 656 energy measurements from the liquid argon and end cap calorimeters.

2.1 *Liquid Argon*

The Mark II liquid argon electromagnetic calorimeter consists of eight identical modules arranged around the solenoid magnet covering 2π in ϕ and from about 45° to 135° with respect to the beam axis in θ. Each module is a cryogenically sealed compartment containing 18 physical lead/liquid argon layers ganged together into six readout layers (three in ϕ, two in θ and one at a relative orientation of 45°). The total thickness of lead and argon is 14 radiation lengths per module. Analog signals from sets of eight adjacent channels are summed to produce 42 sums per module or a total of 336 sums for the entire liquid argon system. Figure 2(a) shows a cosmic muon event in the plane perpendicular to the beam axis. The calorimeter octants show a grid indicating the segmentation of the trigger information in this projection. Figure 2(b) shows the complete segmentation for the bottom right module in the previous figure. These sums are buffered and digitized by four LeCroy 1885N FASTBUS ADC modules.

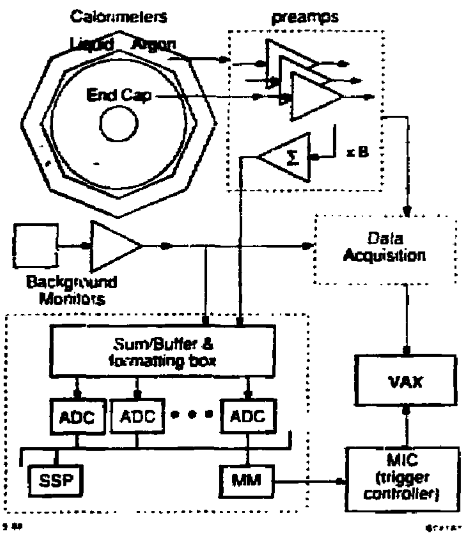

Figure 1. Trigger hardware components.

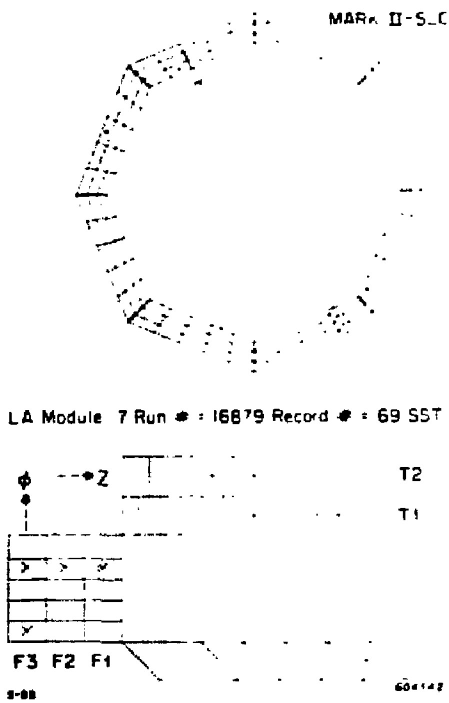

Figure 2. (a) Liquid argon calorimeter ϕ projection; (b) single module segmentation.

2.2 End Cap

Each end of the Mark II contains a retractable door supporting a lead/proportional tube electromagnetic calorimeter covering an angular range from about 15° to 45°. An end cap calorimeter consists of 36 physical layers ganged together into ten readout layers representing four orientations: vertical (three layers), horizontal (three layers) and both 45° diagonals (two layers each).

Total material thickness sums to 18 radiation lengths per end cap. Signals are summed in groups of eight analogously to the liquid argon system. Figure 3 shows a beam background muon event with two muons passing through the detector. The segmentation of the trigger information is indicated by the displays of the end caps four orientations. The 320 sum channels are buffered and digitized by four FASTBUS ADC modules as for the liquid argon system.

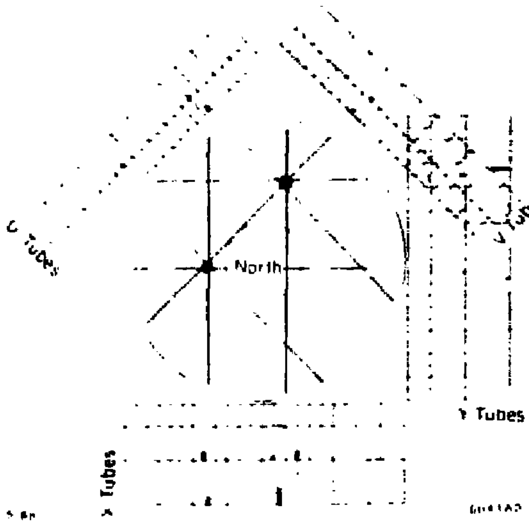

Figure 3. Endcap calorimeter segmentation.

3. READOUT

Data from the ADC modules are read by a single SLAC Scanner Processor (SSP).[6,7] The SSP is a general-purpose FASTBUS device consisting of CPU and I/O sections. The CPU is a 32-bit emulator of the IBM/370 integer instruction set and can be programmed in assembly language or FORTRAN. It is equipped with memory for 4K instructions and 0.5 Mbytes of data memory. As a FASTBUS device, the SSP acts as a master or slave on both the crate and cable segments. The basic clock period of 120 ns is shortened to 80 ns during FASTBUS block transfers resulting in data transfer rates in the range of 20 to 25 Mbytes/s. During event acquisition the contents of SSP memory is read directly into a VAX 8600 for logging to tape.

4. SOFTWARE

Online software for the SSP module is represented by the block diagram in figure 4. The beam crossing frequency at the SLC is sufficiently low that only a single level of triggering is required to maintain an event logging rate of a few Hertz. The SSP is started for every beam crossing (8.33 ms at 120 Hz) at which time all ADCs are read out and the trigger algorithm performed. This processing branch is labeled "TRIG" in figure 4. Results of the algorithm are communicated via a special-purpose FASTBUS module ("MM" in figure 1) to the Master Interrupt Controller (MIC) which, depending upon the results of its own internal logic, may issue a trigger. The time required for the trigger processing will vary with the particular trigger and veto algorithms used, but is expected to be in the range of 5 ms, in addition to the 1.5 ms ADC digitization and readout time. For triggered events, the SSP is started a second time to complete its data acquisition tasks of making gain corrections and formatting the data into a tape buffer; this is indicated by the branch labeled "DAQ" in figure 4.

Various trigger algorithms are being developed. The simplest algorithm computes individual energy sums for each of the ten calorimeter modules. Overall energy deposition and crude topologies based upon the 10 calorimeter modules may then be determined. Another approach is to reconstruct localized energy towers within each calorimeter based upon the patterns of energy deposition. This algorithm compares raw ADC counts with a set of three threshold values on a channel-by-channel basis. Execution of such a tower-finding algorithm consumes a significant number of CPU cycles while looping over different layer combinations much like tracking code. However, techniques to restrict this looping to meaningful combinations yields

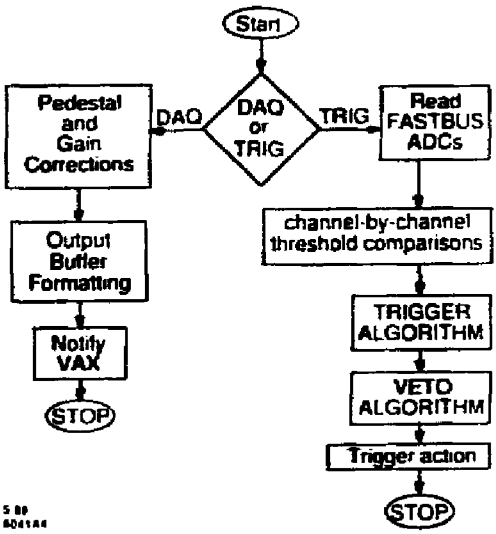

Figure 4. Trigger software components.

an execution time within the desired range. The flexibility of the overall design allows for rapid installation and testing of new algorithms. The algorithms used are expected to evolve reflecting the needs of the experiment and the accelerator environment.

5. RESULTS

Trigger calorimeter data have been recorded for both cosmic ray and beam background events and have been analyzed offline. The first cosmic ray data provided a clean sample of events containing a single μ particle going through the detector. Events were reconstructed using the Mark II central drift chamber and projected into the liquid argon calorimeter. Observed single μ signals were determined to deposit approximately 15 MeV on average per physical layer, representing 2.3–4.0 σ above the equivalent noise charge. Muons in the end cap calorimeter deposit approximately 10 MeV on average per physical layer which is nearly 15 σ above the noise. These results reflect improvements made both to the liquid argon and end cap electronics. They also show the sensitivity to minimum ionizing particles, particularly in the end cap.

Part of the SLC commissioning effort is dedicated to understanding the accelerator-induced backgrounds present at the interaction point. The backgrounds observed in the calorimeters have been due to muons from sources far upstream in the beamline and low energy electrons and photons from local sources. The end cap's trigger data has become an important commissioning tool due to its ability to identify and measure the muon and electromagnetic components. Its high sensitivity also promises to result in a very clean minimum ionizing particle trigger once backgrounds have been reduced.

6. STATUS

All hardware and software components of a new Mark II trigger system have been installed. The triggering scheme has been thoroughly tested with cosmic ray and beam background events. Offline analysis has produced preliminary results on the hardware performance. Work continues to tune the algorithms for physics runs.

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