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DEVELOPMENT AND PERFORMANCE OF A CALIBRATION SYSTEM FOR A LARGE CALORIMETER ARRAY*

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Introduction

Experiment 609 at Fermilab is a study of the properties of high-p_t collisions using a large segmented hadron calorimeter. The calibration and monitoring of such a large calorimeter array is a difficult undertaking. This paper describes the systems developed by E609 for automatic monitoring of the phototube gains and performance of the associated electronics.

The calorimeter array consists of four layers, each divided into 132 segments. The first layer (A') is a lead-scintillator sandwich for detection of electromagnetic showers; the remaining three (A,B,C) are steel-scintillator sandwiches. Each of the 528 (4 × 132) modules is viewed by a single 2" photomultiplier. More detailed descriptions of the module design have been given in previous papers.[1,2] Figure 1 shows the overall structure of the calorimeter, which subtends the full solid angle $30^\circ < \theta_{cm} < 120^\circ$. It is contained in six independent "supermodules", each containing the left or right half of a hadron layer. (The electromagetic layer is also contained in the front pair of supermodules). The calibration systems were designed around this modular structure.

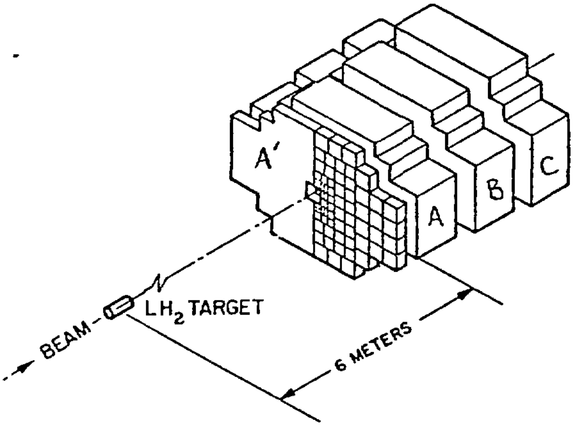

Figure 1. The E609 calorimeter.

The initial calibration, or balancing, of the calorimeter was done with minimum-ionizing particles (muons). A rotating dipole magnet was used to steer a muon beam into all segments of the calorimeter. The high voltage (HV) of each phototube was set to produce a pedestal-subtracted (net) signal of the desired amplitude. However, this calibration could not be rechecked while the experiment was in data-taking mode, because it was necessary to remove the steering magnet from the beamline after balancing. Two separate systems were used for monitoring the calorimeter performance during the run. An LED in each module was pulsed to measure the phototube gain; in addition, computer-controlled relays switched the input of each ADC channel between the phototube and a pulser. While the LED system checked phototube stability, the pulser system tested the triggering electronics.

System Overview

Figure 2 is a block diagram of the electronics for an individual segment, with inputs from one module in each of the four layers.

The relay panels control which input is used for the signal source. By computer control, one can connect an individual channel to the pulser system while the other channels remain connected to their phototubes. This ability has proved to be a very useful diagnostic tool for isolating problems in failed channels. The user can discover within a minute or two the operating status of the calorimeter and its associated electronics. All aspects of a particular channel, i.e., HV, LED, relay, and ADC, can be examined without leaving the computer console. Interfaces to the electronics are CAMAC controlled by input/output registers connected to experimenter designed buses.

The LEDs are controlled by 16 LED drivers, each capable of driving 36 phototubes. The LED drivers are controlled by 8 bits from a CAMAC output register. Each register was capable of controlling 4 LED drivers. Two driver units are mounted inside each supermodule.

The pulser system consists of 8 pulser distribution panels. Each panel controls 66 channels, each with its own relay, i.e., one half-layer of the calorimeter. The panels were mounted as bulkheads in the light-tight skin of the supermodules. Each pulser distribution panel is connected in series on a bus and is individually addressable.

Each channel of the summing-and-weighting modules forms the linear sum of signals from the four modules in a single segment. The input from the electromagnetic (A') layer has a weighting factor which can be adjusted from 0.75 to 0.95. Three channels are contained in a double-width NIM module.

Not drawn in the figure is the computer-controlled HV system, consisting of LRS HV4032 units with CAMAC interface.

LED Calibration System

A major problem associated with large calorimeter arrays is that of monitoring the stability of individual channels on a day to day, week to week basis throughout the lifetime of the experiment. To this end E609 developed a novel and relatively inexpensive LED calibration system which allowed automatic monitoring of the phototube gains together with the associated electronics.

During the assembly process of each module, a Monsanto V552 LED was glued to the light pipe approximately 2 inches from the face of the phototube. The selection of the particular type of diode used in the experiment was determined by the spectral frequencies of its emitted light, which approximately matched the output of the calorimeter.

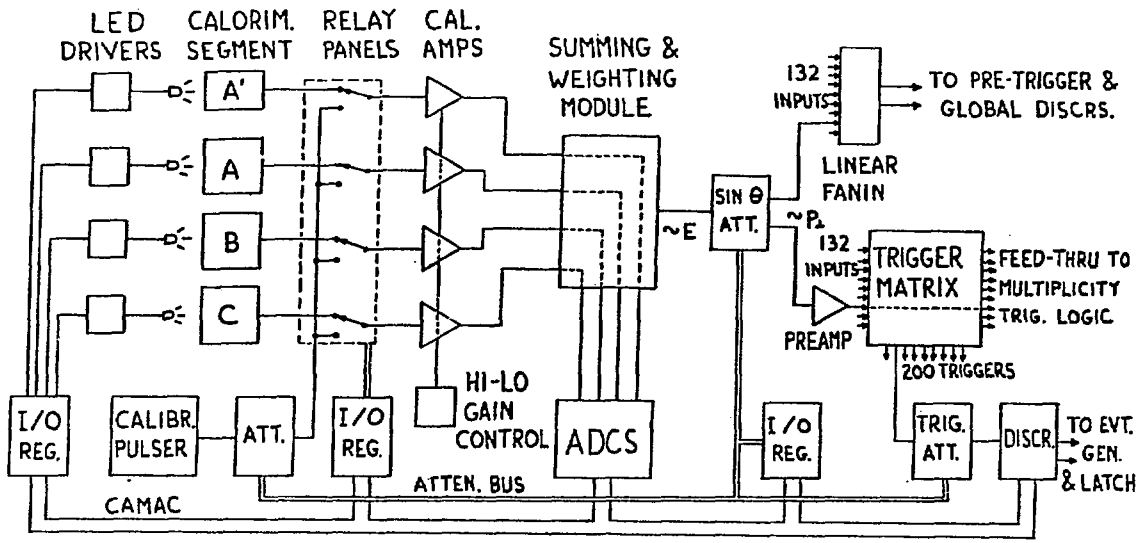

Figure 2. Calorimeter electronics.

The light intensity emitted by the diode is controlled by the amplitude of the voltage pulse applied to it. The E609 diodes operate in the 2 to 3 volt range with a pulse duration of approximately 30 nanoseconds FWHM.

In order to monitor the channel gains, a system is required that is capable of producing a well defined stable voltage pulse which remained insensitive to temperature and humidity variations as well as long term drift. To provide the automatic capability, the voltage pulse amplitude to the LEDs must be controllable by the computer.

Each LED driver circuit uses a small lumped delay line as a pulse forming network to drive 33 LEDs in parallel. This technique allows data to be taken on many channels simultaneously and thus keeps the time associated with monitoring to a minimum. With a standard CAMAC output resister, the on-line computer selects voltages using 8 bits of a 10-bit Analogue Devices AD561JD digital to analogue converter (DAC). This reference voltage is used in a gain of 2.5 feedback loop to define the charging voltage on the delay line. The 8-bit resolution permits voltage increments of 15 mV with a quoted error of 4 mV. The output pulse is produced by discharging the delay line through a 100 MHz 6A9201A SCR. The delay line itself is a very simple device.

The unit consists of a base plate of 1/16th inch G10 approximately 4 inches by 8 inches, one side of which was covered with adhesive copper tape. A second piece of G10, 1 inch by 7 inches, also covered with copper tape, is held firmly to the baseplate with plastic bolts. The mutual inductance of the two copper strips separated by 1/16th inch of G10 is approximately 4.7*10-9 H/in. The copper strips are connected at 1 inch intervals with a 3000 pF capacitor, thus creating a 7-cell delay line with an impedance of 1.25 ohms and a time constant of approximately 3.75 nanoseconds per cell. a very stable and reproducible output pulse is produced.

An additional feature built into each driver module is a stand-alone mode. By flipping a front panel switch, the computer controlled reference voltage is replaced by an internal voltage level adjusted by a potentiometer on the front panel. This capability proved very useful during the initial set-up of the system.

Pulser Calibration System

Each electronic channel may be tested individually by the pulser calibration system. At the level of CAMAC, a Standard Engineering 612 register drives a bus which is distributed to eight calibration panels. The bus has 16 bits of data, 3 bits of sub-address, 3 bits of module ID, a broadcast clear bit, and a strobe bit. Each calibration panel may be addressed with module ID, and within each panel are five sub-chassis which are addressed by the sub-address bits. On each sub-chassis, the sixteen data bits may be latched by toggling the strobe bit. Each latched data bit then drives a relay which can connect an individual phototube to its electronic channel or to a 50 Ω load and at the same time connect the electronic channel to a distributed pulser input.

The pulse is generated by a 2N6661 VMOS FT which discharges a coaxial line. This 50 Ω system is attenuated by two six-section, computer-controlled attenuator modules. These modules each have six mercury wetted relay controlled pi section attenuator circuits providing attenuation from zero to 31-1/2 db in 1/2 db steps. At the level of CAMAC, a Kinetic Systems 3061 Register drives a bus which can address the attenuator modules, and 6-bit data words can be latched to define the attenuation. The output of the attenuators is fanned out to CALAMP inputs. Each CALAMP output drives TWINAX 70 Ω cable to one calibration panel where the signal is stepped down by five paralleled 2:1 pulse transformers. The signal is then distributed to the five sub-chassis on 12.5 Ω strip line. At the sub-chassis, the signal is again stepped down by four parallel 2:1 transformers and distributed over a small non-inductive bus to four 50 Ω relay circuits. Accordingly, with the exception of the CALAMP, the entire system is passive and matched.

Computer-Controlled Attenuators

A crucial element in the successful running of the experiment was the use of computer-controlled variable attenuators. As Figure 2 shows, these attenuators are used at three points in the signal flow:

1. The amplitude of the calibration pulse is adjusted before it enters the relay panels. (Because the testing programs cycled this unit so often, a special three-channel attenuator with mercury-wetted relays was built).

2. The output of the summing-and-weighting module—proportional to total energy deposited in the segment—is attenuated by a factor proportional to $(\sin\theta)^{-1}$ to yield a signal proportional to p_t.

3. Each of the 200 outputs of the trigger matrix, as well as the pretrigger and global trigger, used an attenuator to control the signal level to its discriminator.

The attenuator modules are built as single width NIM modules. Each module provides eight channels of attenuation, each with 64 possible values from 0 to 31-1/2 db in 1/2 db steps. The channel has six relays, each associated with a Pi section attenuator - the impedance being held at 50 Ω while the Pi sections provide 1/2, 1, 2, 4, 8 and 16 db.

A CAMAC register, Kinetic Systems 3061, writes and reads to a bus which ties to the attenuator modules among other things. The bus protocol has 6 bits for module address, 3 bits for sub-address, 1 bit for strobe, 6 bits of write data, and 6 bits of read data. Each attenuator module has a 6-bit module ID which is set internally by a switch. When the module is addressed and the strobe bit toggled, one of the eight channels is identified by the 3-bit sub-addresses, and the six data bits are latched in a latch associated with that channel. The value of the bits which are latched may be read back on the 6 read lines associated with the bits. Each of the 6 latched bits may activate a relay associated with one of the attenuator sections. A power fail bit capable of being wire-orred is also provided.

Software and System Performance

Operating Environment

The software for the data acquisition used the FNAL standard RT-multi. It was highly modified for use in the experiment, but remains within the prescribed guidelines as described in the FNAL documentation.[3]

New commands were implemented to control the specialized electronics. The HV, relays, attenuators, and LEDs all have individual MULTI commands of the format:

<command>   <address>,<value>

Besides the "manual" interface, there are various routines that allowed automated control of the electronics. Since the electronics is organized in segments, the software was designed to access information according to segments. A disk file was constructed that maps all the individual channels into their assigned segment. The file contained the HV mainframe and channel number, the initial, current, and maximum HV setting, the desired net ADC signal for muons, the relay address consisting of panel number and channel number, and other pertinent information about each channel within the segment. The angle and current for the rotating steering magnet were also stored in the file.

Muon Balancing Program

The program that set the HV on muons required the segment number and layer as input. Then under computer control, the following actions were executed:

1. The necessary information was read from the disk file.

2. The initial HV was set in the corresponding HV mainframe and channel.

3. The magnet had the correct current set and was rotated to the correct position.

4. The program took a specified number of triggers using muons and then calculated an average of the pulse height spectrum for the triggers.

5. It compared this value to the value from the file. If it was acceptable, the program took a larger number of triggers at this HV, printed out the results, and stored them on the calorimeter data file along with the current operating HV.

6. If the value was not acceptable, the program would modify the HV according to a simple algorithm, check to see that the HV did not exceed the upper limit specified for that PMT, and then repeat steps 4 and 5. This process was repeated until the correct HV was obtained or until a specified number of attempts was completed or until the HV exceeded the upper limit of the phototube which in turn printed an error message.

This software allowed the experimenter to set the HV for an individual a phototube in three to four minutes when the beam was running smoothly.

LED Program

The automatic LED program has been used at least once a day throughout the data-taking period of E609. Its action is summarized as follows:

1. The experimenter selects a "cycle" number. This refers to a list of settings for the LED DACs, kept on disk file. The DACs are set according to this list.

2. The LEDs are pulsed until a preset number of events (typically 300) are logged.

3. The mean and sigma of the pulse-height distribution for each module is calculated. A typical distribution is plotted in Figure 3.

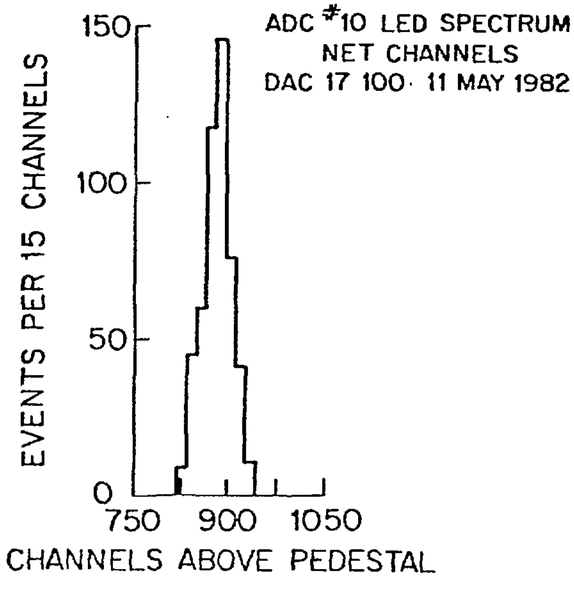

Figure 3. A typical LED pulse-height spectrum.

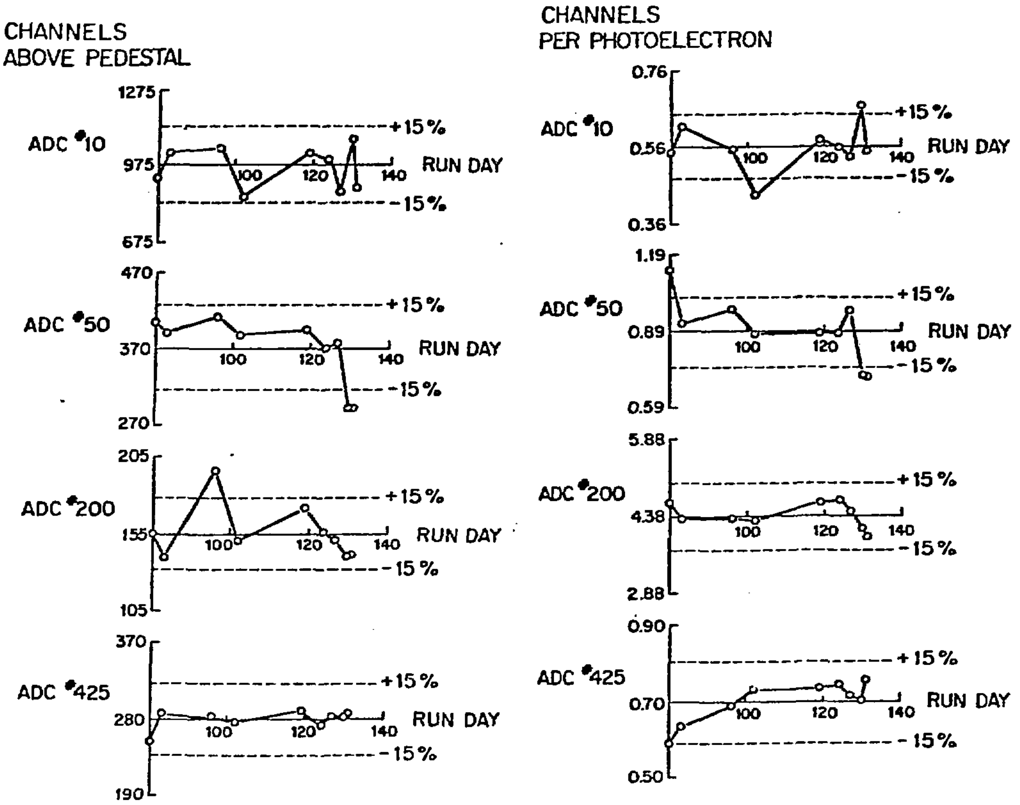

Figure 4. Time variations in LED response.

4. Mean channel values are compared with disk files containing means saved from previous runs of the LED program. Discrepancies greater than a preset value (typically 3%) result in warning messages.

5. Pedestals are subtracted from the means, and the number of photoelectrons for each module is calculated. $(N_{pe} = net^2/\sigma^2)$.

6. If no problems are detected, the new means are saved on disk for future comparisons.

The need for multiple cycles of DAC settings arises from the fact that LED pulser outputs cannot be controlled individually, but in groups of 33. It was not feasible to select the LEDs so that all the LEDs connected to each DAC would have the same operating range of input pulse amplitude. Three cycles have proved adequate to put all the LEDs in good running ranges. (In addition, this program uses "cycle zero" to measure pedestals).

It is important to note that the photoelectron calculation allows separation of changes in the phototube gain from drifts in the electronics. In Figure 4, the results of the program for four modules are plotted as a function of time. Long-term stability of the calorimeter system is seen to be generally at the 10% level. Correction factors derived from the LED runs can be applied to the calorimeter data to remove the principal effects drifts.

Trigger-Testing Program

The automatic testing program using the calibration pulser was run less frequently than the LED program, because of the excellent stability displayed by the electronics. It required considerably more time than the LED program, as a result of testing each segment and each trigger individually. About 45 minutes are needed to run all of its functions. It has three modes of operation:

1. Segment test. The experimenter selects a layer in the calorimeter. The channel for each module in the layer, in turn, is connected to the pulser; all other channels remain connected to their phototubes. The pulser attenuator begins at maximum value and is stepped downward until the global trigger discriminator fires for half of the pulses. This "threshold" setting is displayed and stored on disk.

2. Trigger test. All of the segments which are added to form a specific trigger in the trigger matrix are connected to the pulser. Again, the pulser attenuator is lowered until the threshold is reached.

3. Crosstalk test. Each module in turn is connected to the pulser with a low attenuator setting (large pulse). The trigger discriminators which fire are compared with the list of actual connections in the trigger matrix which forms 200 linear sums of different combinations of segments), and discrepancies are printed out.

In a fashion similar to the LED program, the thresholds found in modes 1 and 2 are compared with previous values stored on disk files, and discrepancies caused warning messages. The stability of the system was such that disagreements of more than 0.5 dB were seldom observed, except when a channel or trigger failed completely.

Conclusion

This paper has described the instrumentation developed by the E609 collaboration for calibrating and monitoring a large calorimeter array. With these systems, it has been possible to operate the calorimeter over periods of many months while maintaining its stability of response within ± 2%. However, continuing efforts are being made to refine and improve the performance of the monitor systems for use in future calorimeter experiments.

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*Work performed under the U.S. Department of Energy.

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