Lawrence Berkeley National Laboratory

Recent Work

Title

AN LED MONITORING SYSTEM FOR A LARGE LEAD-GLASS COUNTER ARRAY

Permalink

<https://escholarship.org/uc/item/002797x0>

Author

Madaras, R.J.

Publication Date

1978-08-01

Submitted to Nuclear Instruments
and Methods

RECEIVED
LAWRENCE
BERKELEY LABORATORY

UC-37
LBL-6767 c.1
Preprint

JAN 11 1979

LIBRARY AND
DOCUMENTS SECTION

AN LED MONITORING SYSTEM FOR A
LARGE LEAD-GLASS COUNTER ARRAY

R. J. Madaras, B. Pardoe, and R. Pecyner

August 1978

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

For Reference

Not to be taken from this room

LBL-6767
c.1

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-6767
August 1978

AN LED MONITORING SYSTEM
FOR A
LARGE LEAD-GLASS COUNTER ARRAY*

Ronald J. Madaras, Barrie Pardoe, and Ruben Pecyner

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

We have built and operated a system which monitors the gains of 318 lead-glass counters as a function of time with an accuracy of 1-2%. The light source is a single high-intensity yellow light-emitting diode (LED), and the light is transmitted to each of the counters by low-attenuation plastic optical fibers. The intensity of the LED light is measured by a reference scintillation counter whose gain is known from frequent $^{241}\text{Am-NaI}$ light source and cosmic ray measurements. We present here details of the system and of its performance during a nine-month experiment at SPEAR.

I. INTRODUCTION

A set of 318 lead-glass Čerenkov counters and 3 magnetostrictive spark chambers was added to one octant of the Stanford Linear Accelerator Center-Lawrence Berkeley Laboratory (SLAC-LBL) Mark I Magnetic Detector¹

* Work supported by the High Energy Physics Division of the U.S. Department of Energy.

in order to study² the production of electrons, photons, and π^0 's in high-energy electron-positron collisions in an experiment at the SPEAR storage ring at SLAC. The lead-glass counters are arranged in two walls.³ The first wall consists of two rows of 26 lead-glass "active converters," each one 3.3 radiation lengths (X_0) deep, 10.8 cm wide, and 90 cm tall. The second wall consists of 266 lead-glass "back blocks," each one 15 cm x 15 cm x 10.5 X_0 deep, arranged in an array of 14 rows by 19 columns. The anode signals from the photomultiplier tubes on each counter are sent to analogue-to-digital converters (ADC's) in a LBL Large-Scale Digitizer System⁴ in order to measure their pulse heights.

The total energy deposited by a particle in the lead-glass system (E_{LGW}) at any time (t) during the experiment at SPEAR is given by the expression:

$$E_{LGW} = \sum_{i=1}^{318} (C_i \cdot PH_i) / G_i(t) \quad (1)$$

where: C_i is the absolute calibration constant for lead-glass counter i
 PH_i is the ADC pulse height for counter i (after subtraction of the ADC pedestal)

$G_i(t)$ is the gain of counter i, normalized such that $G_i(0) = 1.0$
 $t = 0$ is when the lead-glass counters were initially calibrated, at the beginning of the experiment.

The calibration constants, C_i , were initially determined at $t = 0$ by using several ²⁴¹Am-NaI light sources which were themselves previously calibrated with several lead-glass counters in an electron beam at SLAC. The final determination of the calibration constants was done using electrons from Bhabha scattering events ($e^+e^- \rightarrow e^+e^-$) obtained during

the first two months of data taking at SPEAR. These events provide electrons whose energy is equal to the beam energy and is thus well-known. With this method the calibration constants are determined by minimizing the square of the energy resolution of the lead-glass counters for the Bhabha electrons, with the constraint that the average energy deposited in the counters is equal to the actual energy of the electrons.

The purpose of the LED monitoring system described in this paper is to monitor the normalized gain, $G_i(t)$, of each lead-glass counter as a function of time during the nine-month life of the experiment. An accurate knowledge of the normalized gains is crucial both to the measurement of the counter calibration constants (since they are determined from Bhabha events over a long period of time), and to the maintenance of good energy resolution and accuracy of the whole lead-glass system throughout the experiment.

The criteria we had in mind when designing the monitoring system were:

- a) The system should monitor the normalized gains as a function of time with an accuracy of 2% or better in order not to degrade the energy resolution of the lead-glass system.
- b) The system should be operated rapidly under complete computer control in order to make it fast and easy to use and safe from human error.
- c) The light levels delivered to the counters by the system should be comparable to those actually produced in the experiment (equivalent to electrons having an energy of a couple of GeV), so that the gains of

the counters are measured in the normal range of operation of the counters and electronics.

A general description of our monitoring system which satisfies the above criteria is given in Section II of this paper and a detailed description of its components is given in Section III. Results of its performance during our experiment at SPEAR are given in Section IV, and show that it maintained the absolute calibration and energy resolution of the lead-glass system to an accuracy of 1-2% under actual running conditions over a nine-month period.

II. GENERAL DESCRIPTION OF THE MONITORING SYSTEM

The monitoring system is shown schematically in Figure 1. The light from a single high-intensity light-emitting diode (LED) is transmitted by low-attenuation plastic optical fibers to each of the lead-glass counters and to three additional reference scintillation counters. These reference counters also have permanently attached $^{241}\text{Am-NaI}$ light sources. Only one of the reference counters is used in measuring the gains of the lead-glass counters. The two others are spares which are used for internal checks of the system.

In this system the average LED pulse height of each lead-glass counter is measured relative to the average LED pulse height of the reference counter while the absolute gain of the reference counter is measured using its $^{241}\text{Am-NaI}$ source. By comparing these measurements to those of an

earlier time one can thus easily calculate how much the gain of each lead-glass counter has changed. The stability of the source on the reference counter is periodically checked using cosmic rays which pass through the scintillator of the reference counter.

During a monitoring run at time "t":

1) LED pulse height spectra are taken for all the counters, including the reference counter (RC), and the mean of each spectrum is calculated ("LED MEAN").

2) A ^{241}Am -NaI source pulse height spectrum is taken for the reference counter (RC) and the mean of the spectrum is calculated ("SOURCE MEAN").

3) The pedestals of the ADC's are measured ("PED").

These three items are then used to calculate the gain, G_i , of lead-glass counter "i" with the following formulae:

$$g_i(t) \equiv \left[\frac{(\text{LED MEAN} - \text{PED})_i}{(\text{LED MEAN} - \text{PED})_{\text{RC}}} \cdot (\text{SOURCE MEAN} - \text{PED})_{\text{RC}} \right] \quad (2a)$$

$$G_i(t) = g_i(t)/g_i(0) \quad (2b)$$

The gain, $G_i(t)$, is normalized so that it equals 1.0 at $t = 0$, which was when the lead-glass counters were initially calibrated. It is seen that $G_i(t)$ is independent of any long term drifts in the LED light intensity and is independent of any gain changes in the reference counter (RC).

For $G_i(t)$ to be an accurate measure of the gain of a lead-glass counter it is seen from Equation 2 that the following conditions must be satisfied:

a) The ratio of source pulse height to LED pulse height for the reference counter must be independent of gain changes of the reference counter.

b) The relative fraction of LED light seen by the lead-glass counter and the reference counter must be constant in time.

c) The intensity of light from the radioactive source must be constant in time.

The results presented in Section IV will show that the first two conditions have been met. As will be explained later, we did have problems with source stability, but we were able to detect those problems rapidly and compensate for them.

Each monitoring run is done under the complete control of the Xerox Data Systems Sigma-5 computer at SPEAR. The computer sets the proper trigger and ADC gate widths, turns on the LED, accumulates the LED, source and pedestal data, calculates the means of the pulse height distributions, checks to see that the means are reliable, calculates the gains of the lead-glass counters, prints out messages if any gain has changed significantly, writes the latest gains and pedestals on a disk file to be used by the on-line and off-line analysis computer programs, writes the gains on a large disk file which contains a history of the gains of each counter, and displays the latest gains on a CRT display. This all takes less than two minutes, and is usually done by the computer without outside intervention. A monitoring run is usually done once during each eight hour data-taking shift.

The monitoring system also contains a wheel of twelve neutral

density filters which can be used to vary the amount of LED light seen by the counters. This is useful for measuring the linearity of the photomultiplier-ADC system.

III. DETAILED DESCRIPTION OF THE MONITORING SYSTEM COMPONENTS

A. LED Pulser

A simple 60 Hz mercury relay⁵ line pulser is used to drive the LED. The DC voltage applied to the pulser is 100 volts and a 10 ohm, 32 ns charging line is used. The output impedance is approximately matched to 10 ohms by putting a 1 ohm resistor in series with the LED. Thus the current pulse applied to the LED has an amplitude of 5 amps and a width of 64 ns. The pulser can be turned on and off manually or by the computer and has a timer which will shut it off automatically after a preset time in order to conserve the life of the LED and the mercury relay. The pulser is free-running and part of the main pulse is picked off and sent as a trigger pulse to the electronics and computer.

B. Light Emitting Diode (LED)

As outlined in Section II, a light source is needed whose distribution is such that the relative fraction of light seen by the lead-glass counters

and the reference counter is constant in time. In addition, it is very useful to have a light source whose intensity is stable on a pulse-to-pulse basis, whose light pulses are short and fast with no appreciable tail, and whose light intensity is constant throughout the experiment. For these reasons we chose a single LED as the light source for the monitoring system.

In order to match the spectral sensitivity of the lead-glass counter photomultiplier tubes (EMI 9531R and EMI 9618R) and the transmission of the lead-glass (Schott F-2) the wavelength of the LED light must be in the range of 4000 to 6000 angstroms. This excludes a red LED. In order to have the LED light in each counter be the equivalent of a 1-2 GeV electron, one needs a very high intensity LED. The highest intensity LED we found in the required spectral range is a yellow Monsanto MV5352 LED⁶. Its luminous intensity is typically 45 mcd and its spectral response is centered at 5850 angstroms, with a FWHM of 350 angstroms. Its light is from an effective point source and is peaked forward, with the intensity dropping by about 20% at 7° from the central axis (which corresponds to the edge of our bundle of optical fibers, as is seen in Figure 1). Its rated peak forward current is 5 amps, which is the amplitude of our driving pulse, and we have even operated this LED with 20 amp pulses for short periods of time.

The LED was quite reliable. As will be seen below, the intensity of the LED light was stable to about $\pm 1\%$ during the nine-month life of the experiment, and the LED did not have to be replaced during this time.

C. Filter Wheel

A stepping motor is used to turn a wheel of twelve neutral density filters⁷, in order to vary the amount of LED light as seen by the counters. The motor can be stepped manually or by the computer and the position of the wheel is both read by the computer and visually displayed. The transmission values of the filters are 1.00, 0.90, 0.79, 0.63, 0.50, 0.40, 0.32, 0.20, 0.10, 0.05, 0.01, and 0.0.

D. Optical Fibers

We chose DuPont PFX 0715 plastic optical fiber cables⁸ to transmit the LED light to the counters because of their low attenuation and relatively low cost. We use fiber cables that are 10-17 feet long and the transmission is 84-74% at the wavelength of our LED (5850 angstroms). Each optical fiber cable is made up of seven optical fibers covered with a jacket of opaque polyethylene, and thus care had to be taken with the coupling at each end of the fiber cable.

To prepare the end of the cable in the light distribution box (see Fig. 1) each optical fiber cable had its outer plastic jacket stripped away for about 8 inches and the bare optical fibers were strung through a 2 inch long, 1 inch diameter phenolic cylinder. A tension of 2 pounds was applied to each fiber, so that they were as straight as possible in the cylinder. After all the fibers were strung, the cylinder was filled with epoxy⁹. After the epoxy cured the end of the cylinder was cut off and hand polished. It is this polished bundle of tightly held fibers which is illuminated by the LED light. It was necessary to epoxy together the bundle of fibers to insure that the relative fraction

of LED light received by the counters did not change with time.

The optical fiber cables are coupled to the lead-glass counters via glass prisms¹⁰ (see Figure 1) because there isn't enough space to connect the fiber cables perpendicular to the counter faces. Each optical fiber cable is firmly crimped into a special connector¹¹ which holds the fiber cable tight enough so that the individual fibers can't move relative to one another, and then the end of the fiber cable is hand polished. The connector's mate is epoxied¹² to the glass prism and the connector containing the polished optical fiber cable firmly screws onto its mate on the prism. It is important that the optical fiber cables be securely held and firmly attached to the counters so that the relative fraction of LED light received by the counters does not change with time.

While operating the monitoring system for a year 2 of the 318 optical fiber cable connectors became separated from the prisms because of a failure in the epoxy bond. This problem can be cured by putting less stress on the optical fiber cables (and thus the connectors), or by making the prisms larger and thus providing a larger surface to which to epoxy the connector.

E. Reference Counters

The reference counters (see Figure 1) see signals from the LED, from permanently attached radioactive light sources, and from cosmic rays passing through their scintillators. Using the sources to monitor the

reference counter gains the counters then are able to monitor the LED light. The sources are checked periodically using the cosmic rays.

The photomultiplier tubes of the reference counters are the same as those of the active converter lead-glass counters (EMI 9531R), in order that they have the same response to the LED light. The plastic scintillator¹³ used in the reference counters has dimensions of 3/8" x 3" x 16". It would have been better to use thicker scintillator in order to match the pulse heights from the cosmic rays and sources more closely. The pieces of scintillators are not glued to the phototubes but are held against them with pressure in order to avoid any aging problems with glue.

The LED light is coupled to the reference counter phototubes through polished lucite light guides. The optical fiber cables are attached to the lucite using the same connectors as those described in the last section for the lead-glass blocks. The lucite, like the scintillator, is held against the phototube just with pressure.

The radioactive sources on the reference counters are hermetically sealed thallium--activated sodium iodide (NaI) scintillation crystals diffused with an alpha emitter, ²⁴¹Americium.¹⁴ These light sources are mounted on the end of the lucite light guides so that the LED and source illuminate approximately the same part of the photocathode surface. We found that some of the ²⁴¹Am-NaI sources were quite unreliable

because the NaI crystals in these sources turned yellow, causing a decrease in the light intensity from the source. This yellowing was presumably due to moisture contamination of the NaI crystals, which could occur if the seals of the crystal holder deteriorate. Because we were able to check one reference counter against another, and also because we could check the source signals against the cosmic ray signals, we were able to detect rapidly that the sources on the reference counters were turning yellow and were able to replace them.

F. Computer Control

The entire monitoring system is run under the complete control of a Xerox Data Systems Sigma-5 computer. At the user's option, a full monitoring run can be done automatically at the end of a physics data-taking run, or a full or partial (for example, LED pulse height spectra only) monitoring run can be initiated by the user at any time.

At the beginning of a monitoring run the computer program sets up the proper trigger (i.e. LED, source or pedestal) and sets the proper gate widths for the ADC's. The ADC gate width for the ^{241}Am -NaI source trigger is long (1 microsecond) because the NaI gives a light pulse with a long tail, while the ADC gate width for the LED trigger is shorter (400 nanoseconds). The computer program also positions the LED filter wheel. All of this is done with CAMAC instrumentation.

The computer program then enables the trigger, and takes LED, source or pedestal data. Pulse height histograms are incremented for

-13-

selected counters and running sums of the pulse height and square of the pulse height are accumulated for each counter. When a set number of triggers has been accepted (100 LED, 200 source or 50 pedestal triggers), the trigger is disabled, and the mean and RMS width (sigma) of the pulse height distribution of each counter are calculated in double precision (64 bits) from the accumulated running sums. The sigmas are checked to insure that the calculated means are meaningful. If there is any problem with the data, that part of the monitoring run can be repeated. If all the data are acceptable (or if the user wishes to continue anyway), the means and sigmas of the pulse height distributions are printed out on the line printer and written on magnetic tape. Tables on a disk file containing the latest values of the pedestals for each ADC are updated for those counters having acceptable data and the program tells the user if an ADC has not had its pedestal value updated in the last four monitoring runs.

The computer program then calculates the normalized gain, $G_i(t)$, for each counter using Equation 2. The program tells the user if the normalized gain differs from unity by more than, say, 10%, and also compares the new gain to the last calculated gain and tells the user if it has changed by more than, say, 5%. Another table on the disk file containing the latest gains for each counter is updated for those counters having acceptable data, and again, the program tells the user if a counter has not had its gain updated in the last four monitoring runs. The latest gains are displayed automatically on a CRT display,

printed out on the line printer, and are written into a large disk file which contains a history of the gains of each counter. At any time this large file can be used to produce a plot of gain vs time for any counter, either on the CRT display or on the line printer. This was found to be valuable for checking long term drifts in the gains of the counters.

In addition to displaying the gain history of any counter, one is also able to display histograms of the latest gain, LED mean, or pedestal as a function of counter number, and also display the full pulse height distributions of selected counters.

A typical monitoring run doing the above tasks takes less than two minutes of real time, and is usually done by the computer without outside intervention. A monitoring run is usually done once during each eight hour data-taking shift, and also after any changes to the counters or the ADC's.

IV. PERFORMANCE OF THE MONITORING SYSTEM

A. LED Light

In Figure 2 we see the distribution of pulse heights from a typical lead-glass counter in response to the LED light. The mean of the pulse height distribution is at 360 ADC channels, which corresponds to an equivalent electron shower energy of 1.6 GeV. Thus it is seen that the LED light delivered to the lead-glass counters is comparable to the light obtained from showering particles during the experiment. Note that the

-15-

horizontal scale has a suppressed zero and that the pulse height distribution is actually very narrow: the RMS width (σ) of the distribution divided by its mean is 1.9%. This is the value one expects just from the statistics on the number of photoelectrons (~ 1700 photoelectrons per GeV of equivalent shower energy), which means there are no appreciable fluctuations of the LED light during the measurement time of 15 seconds.

In Figure 3 we see the distribution of the average LED pulse heights for all 266 back-block lead-glass counters. It is seen that the LED light varies considerably from counter to counter. This is probably due to the following reasons: 1) Because the LED light is strongly peaked in the forward direction, the optical fibers near the edge of the bundle of fibers receive less light; 2) Those optical fibers whose axes are at an angle with respect to the LED light (due to their being misaligned, or being at the edge of the fiber bundle) will have a smaller acceptance for the LED light; and 3) Bends in the optical fibers attenuate the light and the fibers are bent different amounts. This variation of LED light from counter to counter is not a serious problem for the system, however, as its function was to monitor the lead-glass counters for gain changes rather than calibrate them absolutely.

The LED was quite reliable and very stable during the nine-month life of the experiment. In Figure 4 we see the average LED light for all counters (normalized to 1.0 at $t = 0$) as a function of time. Note that the

ordinate has a suppressed zero. The gaps in the distribution are due to shutdowns during the experiment. It is seen that the average LED light was stable to about $\pm 1\%$ over the period of nine months.

B. Reference Counters

It was pointed out above that for $G_i(t)$ of Equation 2 to be an accurate measure of the gain of a lead-glass counter, the ratio of source pulse height to LED pulse height for the reference counter must be independent of gain changes of the reference counter. This has been verified to be true by changing the gain of a reference counter (by changing its high voltage) and measuring the variation of the mean pulse height due to the source and to the LED light. The results are shown in Figure 5. We see that the mean source pulse height (and thus the gain) of the reference counter increased by 45% when the voltage was increased from 1120 to 1180 volts. However, the ratio of the mean source pulse height to the mean LED pulse height varied by less than 0.5% during this time, indicating that the above requirement has been well satisfied.

C. Precision of the Gain Measurement

To determine the precision with which the monitoring system measures the gains of the lead-glass counters two monitoring runs were done a few minutes apart and the gains of the counters from the two runs were compared. The results are presented in Figure 6, in which we see the distribution of the percentage difference between the gains from the two consecutive monitoring runs for all the counters. The mean and sigma of this distribution are -0.02% and 0.3% respectively,

indicating that the monitoring system measures the gains of the counters with high precision.

D. Overall Performance

One way to measure the overall performance of the monitoring system is to use electrons of a given energy and calculate with Equation 1 the energy deposited in the lead-glass by these electrons at two different times. If the monitoring system has been accurately monitoring the gains of the lead-glass counters, the calculated energy should be the same both times. This comparison is done here for two periods of time, eight months apart, when 2.1 GeV electrons from Bhabha scattering ($e^+e^- \rightarrow e^+e^-$) were entering the lead-glass wall during our experiment at SPEAR. For each of these electrons the energy in the lead-glass counters is calculated using Equation 1. The distribution of this energy divided by the electron's momentum is shown in Figure 7, for the two periods of time. The curves are Gaussian fits to the histograms. It is seen that:

$$\text{for } t = 1 \text{ week} \quad \text{mean} = 0.995 \pm 0.003$$

$$\frac{\text{sigma}}{\text{mean}} = (6.2 \pm 0.2)\%$$

$$\text{for } t = 33 \text{ weeks} \quad \text{mean} = 1.002 \pm 0.002$$

$$\frac{\text{sigma}}{\text{mean}} = (6.4 \pm 0.1)\%$$

We see that the means of the energy distributions are the same within 1%. We also see that any effects tending to increase the width (and thus energy resolution) of the distribution with time are less than 2%, assuming such effects contribute in quadrature. If for the second period of time ($t = 33$ weeks) one calculates the energy in the lead-glass counters using the gains, $G_i(t)$, from the first period of time ($t = 1$ week), then the resulting energy distribution has a mean of 1.053 ± 0.002 and a sigma/mean

of $(8.3 \pm 0.2)\%$. We see that when the monitoring system is not used to track the lead-glass counter gains, both the mean and width of the lead-glass energy distribution are degraded (due mostly in our case to intentional changes of the lead-glass counter high voltages). Thus from the comparison of the lead-glass energy distributions we conclude that when the monitoring system is used, the absolute calibration and energy resolution of the 318 lead-glass counters are maintained to an accuracy of 1-2% over a period of eight months. The fact that the energy resolution and accuracy are not degraded during this time demonstrates the effectiveness of the monitoring system in tracking the lead-glass counter gains as a function of time.

Another way to measure the overall performance of the monitoring system is to compare, for a particular counter, the measurement of its gain using the monitoring system to a direct measurement of its gain using a source. Since the extra reference counters (which are not used to calculate the gains in the monitoring system) have sources on them, this comparison can be made for them. In Figure 8 we see the ratio of a spare reference counter's gain as measured with its source to its gain as measured with the monitoring system, as a function of time. The ratio has been normalized to 1.0 at $t = 0$, and the ordinate has a suppressed zero. It is seen that except at $t = 6-8$ weeks, this ratio is constant to $\pm 1\%$ over the entire nine-month period, again showing the effectiveness of the monitoring system in tracking the counter gains as a function of time. It was at $t = 6-8$ weeks that the source on this reference counter became yellow, thus decreasing the source pulse height. The source was replaced at $t = 11$ weeks, and operated satisfactorily after that.

V. CONCLUSION

We have given a detailed description of the construction and operation of an LED and fiber optics system which monitors the gains of a large array of lead-glass counters as a function of time. It has been shown that the energy resolution and absolute calibration of the whole lead-glass system has been maintained to an accuracy of 1-2% under actual running conditions over a period of nine months, thus demonstrating the effectiveness of the monitoring system in tracking the gains of the lead-glass counters with time.

When we first designed the monitoring system we thought that the intensity of the LED light might change appreciably with time, so we included in the system the reference counters with $^{241}\text{Am-NaI}$ light sources which we thought would be very stable with time. As we described in this paper, the situation turned out to be the opposite: the LED light was very stable but the radioactive light sources yellowed and had to be replaced. If we were to redesign the monitoring system for another similar experiment, we would probably rely more on the stability of the LED light. We would still include a means of verifying that there are no long term changes in the LED light though, but we wouldn't use the $^{241}\text{Am-NaI}$ light sources unless new ones were proven to be stable. Instead of the light sources we would use the Bhabha scattering electrons of known energy in the lead-glass system to check on the average LED light intensity, or we would try to find a direct means of measuring the LED light independent of the lead-glass counters (perhaps using a sensitive photodiode).

We would like to thank Edward Lee, Garth Smith and Robert Smits for their technical assistance, and Angela Galtieri, Joseph Feller, and Alan Litke for their initial contributions to this system.

Footnotes and References

1. J.E. Augustin et al., Phys. Rev. Lett. 34, 233 (1975)
2. A. Barbaro - Galtieri et al., Phys. Rev. Lett. 39, 1058 (1977)
D. L. Scharre et al., Phys. Rev. Lett. 40, 74 (1978)
J. M. Feller et al., Phys. Rev. Lett. 40, 274 (1978)
J. M. Feller et al., Phys. Rev. Lett. 40, 1677 (1978)
D. L. Scharre et al., Phys. Rev. Lett. 41, 1005 (1978)
3. More details on the lead-glass detector can be found in J. M. Feller et al., IEEE Trans. Nucl. Sci. NS-25, 304 (1978)
4. R. F. Althaus et al., IEEE Trans. Nucl. Sci. NS-24, 218 (1977)
and NS-24, 408 (1977)
5. The mercury relay is model HG-1003, C.P. Clare Co., Chicago, Illinois
6. Monsanto Electronics Division, Palo Alto, California
7. Eastman Kodak Wratten Gelatin ND Filters, Eastman Kodak, Rochester, New York
8. DuPont PFX 0715 plastic optical fiber cables are made up of seven optical fibers grouped in a close-packed hexagonal array, jacketed with opaque polyethylene. Each individual optical fiber has an outside diameter of 0.0146 inches, and consists of a polymethyl methacrylate core sheathed in an optical insulator of lower refractive index. The complete optical fiber cable has an outside diameter of 0.075 inches. The manufacturer, E.I. duPont de Nemours & Co., Plastics Department, Wilmington, Delaware, says the new designation for this optical fiber cable is PFX P740.
9. Stycast 1266, a casting resin from Emerson & Cuming Inc., Canton, Massachusetts, was used with a small amount of black color concentrate (Resinform 130, from Resin Formulators Co., Division EVRA, Culver City, California).
10. Right-angle glass prisms (18 mm x 13 mm x 13 mm, 13 mm wide) are glued to the back-blocks, and 30° glass prisms (25 mm x 21 mm x 13 mm, 13 mm wide) are glued to the active converters. The prisms were glued to the lead-glass counters with Eastman Kodak HE-10 Cement, Eastman Kodak, Rochester, New York.
11. AMP Optical Fiber Termination Kit No. 530530-3, AMP Special Industries, Valley Forge, Pennsylvania.
12. Extra Fast Setting Epoxy, Hardman, Inc., Belleville, New Jersey
13. Pilot F Scintillator from Nuclear Enterprises Inc., San Carlos, California
14. The Harshaw Chemical Company, Solon, Ohio

List of Figures

1. A schematic diagram of the LED monitoring system for a large lead-glass counter array.
2. LED pulse height distribution for a typical lead-glass counter.
3. Distribution of the average LED pulse heights for all 266 back-block lead-glass counters.
4. Average LED light as a function of time. The ordinate has a suppressed zero.
5. Comparison of the mean source pulse height and mean LED pulse height of a reference counter, as a function of its high voltage.
6. Distribution of the percentage difference between the gains from two consecutive monitoring runs, for all 318 lead-glass counters.
7. Distribution of the measured energy of 2.1 GeV Bhabha scattering electrons in the lead-glass system divided by the electron's momentum, for two different time periods. The curves are Gaussian functions which are fit to the data, with the resulting means and widths as shown.
8. The ratio of a spare reference counter's gain as measured with its source to its gain as measured with the monitoring system, as a function of time. The ordinate has a suppressed zero.

XBL 774-813

Figure 1

XBL 774-816

Figure 2

XBL 774-815

Figure 3

XBL 789-2685

Figure 4

00004804698
-25-

XBL 774-814

Figure 5

XBL 774-817

Figure 6

XBL 7811 - 12758

Figure 7

XBL 789-2686

Figure 8

00004801700
-29-

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720