Fermi National Accelerator Laboratory

FERMILAB-Conf-84/21-E
7000.705

A MEASUREMENT OF THE ENERGY RESOLUTION AND RELATED PROPERTIES OF AN SCG1-C SCINTILLATION GLASS SHOWER COUNTER ARRAY FOR 1-25 GeV POSITRONS*

D. E. Wagoner, B. Cox, D. J. Judd, G. Hale, P. O. Mazur,
C. T. Murphy, R. Rameika, and F. Turkot
Fermi National Accelerator Laboratory, Batavia, Illinois 60510 USA

S. Conetti, M. Haire, P. Lebrun, C. Leroy, T. Ryan, and L. Turnbull
McGill University, Montreal, PQ H3A 2T8, Canada

R. A. Gearhart
Stanford Linear Accelerator Center, Stanford, California 94305 USA

S. Tzamarias
University of Athens, Athens, Greece

January 1984

*Submitted to the 1983 Nuclear Science Symposium, San Francisco, California, October 19-21, 1983.

A MEASUREMENT OF THE ENERGY RESOLUTION AND RELATED PROPERTIES OF AN SCG1-C SCINTILLATION GLASS SHOWER COUNTER ARRAY FOR 1-25 GeV POSITRONS

D.E. Wagoner, B. Cox, D.J. Judd, G. Hale, P.O. Mazur,
C.T. Murphy, R. Rameika and F. Turkot
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

S. Conetti, M. Haire, P. Lebrun,* C. Leroy,
T. Ryan** and L. Turnbull
McGill University
Montreal, PQ H3A 2T8, Canada

R.A. Gearhart
Stanford Linear Accelerator Center
Stanford, California 94305

S. Tzamarias
University of Athens
Athens, Greece

Summary

We report the measurement of the energy resolution of a 4x4 array of SCG1-C scintillation glass counters (Ohara Optical Glass Manufacturing Co., Ltd.) exposed to positrons in the energy range of 1 to 25 GeV. Each element of the array was 20.5 radiation lengths long. The resolution of the array was measured both with and without a 3.5 radiation length SCG1-C scintillation glass active converter and 0.2 radiation length hodoscopes used to measure shower position. We obtained an energy resolution $\sigma/E = (1.63 + 1.46/\sqrt{E})\%$ without the active converter and $\sigma/E = (0.64 + 3.94/\sqrt{E})\%$ with the active converter. Performing a partial correction for the average energy loss in the 0.2 radiation length hodoscopes resulted in an energy resolution of $\sigma/E = (0.50 + 3.43/\sqrt{E})\%$ for the active converter measurement. We also report on the measurement of the absolute number of photons produced by 1 GeV showers, the

optical attenuation length for the light produced by showers, the fraction of the total light output that is due to Cerenkov light relative to scintillation light for showers, and the radiation darkening sensitivity of the scintillation glass.

* Present address: Fermi National Accelerator Laboratory

**Present address: Physics Dept., Cornell University, Ithaca, New York 14853

Introduction

Results[1] of a test of a single piece of 18.4 radiation length (X_o) SCG1-C scintillation glass (Ohara Optical Glass Manufacturing Co., Ltd.) has encouraged us to construct and test an array of this glass in the configuration needed for Fermilab experiment E-705.[2] The blocks for the tests were configured in a 4x4 array with each element of size 15x15x89.2 cm^3 (20.5 X_o in length). Active converter elements of SCG1-C 15 cm thick (3.5 X_o) followed by 0.2 X_o thick position hodoscopes in which the location of the shower centroid was measured were positioned in front of the array.

Beam

The measurements reported in this paper were performed using the positron test beam 19 in the B end station at the Stanford Linear Accelerator Center (SLAC). The beam had a momentum spread, $\Delta P/P$ (FWHM) = 0.25%, and a small spot size with 90% of the beam particles contained within a radius of 1 mm. The contamination of this beam by muons and pions was negligible over the entire energy range. The energy was tuneable from 1 to 25 GeV. The beam was operated at 10 pulses per second with an average of less than 0.3 positrons per the 150 ns pulse. Beam pulses with more than 1 positron were identified and later rejected in the off-line analysis.

Experimental Apparatus

The arrangement of the 4x4 scintillation glass array along with its active converter and position hodoscopes is shown in Fig. 1. This array and the active converter are composed of SCG1-C scintillation glass. The composition of the SCG1-C scintillation glass is given in Table I.

Table I

Composition of SCG1-C Scintillation Glass[3]
(by weight)

BaO	43.4%
SiO_2	42.5%
Li_2O	4.0%
MgO	3.3%
K_2O	3.3%
Al_2O_3	2.0%
Ce_2O_3	1.5%

Barium rather than lead is the dominant heavy element. The glass has a radiation length of 4.35 cm and a density of 3.36 g/cm^3. The Ce_2O_3 acts as a scintillating component and a wavelength shifter for short wavelengths. This glass produces greater than five times the number of photons than is observed for the comparable number of radiation lengths of SF5 lead glass.[1]

Each element of the 4x4 array was composed of a block of SCG1-C 15x15x89.2 cm^3 in size. The active converter was composed of the same size blocks but positioned on end 11.1 cm in front of the 4x4 array so that the beam passed through the 15 cm dimension. Each glass block was viewed through an optical grease (Dow-Corning Q2-3067) joint by an EMI 9791KB photomultiplier tube. The entire calorimeter was mounted on a movable table permitting the beam to be positioned transversely within the array to ±1 mm. Each counter of the array had a green LED (Hewlett-Packard HLMP-3950) mounted on the end of the counter opposite the phototube for the purpose of gain monitoring. The 4x4 array and active converter were contained in separate insulated boxes fitted with thermoelectric coolers. Temperature variations were limited to less than 0.5°C, so that gain changes due to temperature fluctuations were kept at a negligibly small level. The pulse heights were digitized using LeCroy 2249W ADC's with a 256 ns gate length. Data were written on magnetic tape using an LSI-11 minicomputer. A detailed description of the 0.2 X_o position hodoscopes placed between the active converter and 4x4 array is given elsewhere.[4]

Experimental Results

Energy Resolution

Calibration coefficients for each element of the array without the active converter in place were generated using an iterative minimization technique.[1,5] With the active converter elements in place, the deposited energy is shared between the active converter and the blocks of the 4x4 array. The calibration coefficients of the active converter element and the block of the 4x4 array centered on the beam in this configuration were determined simultaneously.

The energy resolution of the array was determined by centering the beam successively on each of the 4 central blocks with and without the active converter and recording a few thousand showers at energy settings of 1, 1.5, 2, 4, 6, 10, 16 and 25 GeV. With the beam in one of the blocks, representative energy spectra measured by the array without the active converter are shown in Fig. 2a,b for 1 and 25 GeV, respectively. Superimposed on the distributions are gaussian fits to the spectra. Corresponding spectra at the same energies but with the active converter in place are shown in Fig. 3a,b.

The energy resolution of the array only is shown in Fig. 4 plotted against $1/\sqrt{E}$. The data were fitted to the form $\sigma/E = a + b/\sqrt{E}$. The energy resolution is $(1.63 \pm 0.05)\% + (1.46 \pm 0.10)\%/\sqrt{E}$ for the array without the active converter in place. This is comparable with our earlier test with an 18.4 X_o block where we measured $(1.64 \pm 0.14)\% + (1.13 \pm 0.33)\%/\sqrt{E}$.[1]

The energy resolution of the array with the active converter is shown in Fig. 5. For the 4x4 array together with the active converter the resolution is $(0.64 \pm 0.06)\% + (3.94 \pm 0.14)\%/\sqrt{E}$. The energy resolution at higher energies with the active converter is smaller than that measured without the active converter for two reasons. First, active converter information was used to correct for conversion point fluctuations within the glass. Second, energy leakage fluctuations are smaller because of the extra length of active converter material. The energy resolution at lower energies with the active converter however is larger than that without the active converter. The primary reason for this degradation is the 0.2 X_o thick position hodoscopes placed after the 3.5 X_o thick active converter. An EGS[6] Monte Carlo predicts that the fluctuation of the energy deposition in the inactive material of the position hodoscopes is 1.9% at 1 GeV and 0.7% at 25 GeV. When a partial correction for the average energy loss in the position hodoscopes was performed we improved the energy resolution to (0.50 ± 0.08)% + (3.43 ± 0.18)%/$\sqrt{E}$ as shown in Fig. 5. The fluctuations in the energy loss about the average in the position hodoscopes can not be corrected for in the measurement and still contribute to the resolution. If position hodoscopes with a small radiation length were used one could expect to improve further this energy resolution for the low energy points.

Photon Yield

A measurement of the absolute number of photons produced by a shower was also made. The absolute gain and relative quantum efficiency of each of the EMI 9791KB phototubes were measured. Using these values together with the pulse heights for 1 GeV showers in each element of the 4x4 array and a mean absolute quantum efficiency of 0.27 for the 9791KB photocathode, the yield of photons was calculated for each piece of glass. The average number of photons from a 1 GeV shower arriving at the back face of the 4x4 array counters was found to be $1.6\pm0.4 \times 10^4$ photons/GeV. The number of photons expected from the 1.46±0.10%/$\sqrt{E}$ term of the measured energy resolution of the 4x4 array is $3.1\pm0.5 \times 10^4$ photons/GeV if the 1/$\sqrt{E}$ dependence of this energy resolution was due entirely to photon statistics.

Optical Attenuation Length

We have made a separate measurement of the attenuation of light from showers in an SCG1-C block by a longitudinal scan with a 10 GeV beam transverse to the block. From this measurement we find the optical attenuation length to be 190±60 cm.

Measurement of the Cerenkov Light to Scintillation Light Output of SCG1-C

We have observed that the light produced by SCG1-C has two components: a fast Cerenkov component produced directly by particles above Cerenkov threshold, and a slow scintillation component produced by particles both above and below Cerenkov threshold. Several tests were done to quantitatively separate the scintillation and Cerenkov fractions of the light. A block of SCG1-C was viewed with a fast phototube, the RCA C31000M. For a 4 GeV shower, oscilloscope photographs were taken of the phototube signal both with the phototube positioned on the downstream end of the block antiparallel to the beam (normal configuration) and with the phototube positioned on the upstream end of the block parallel to the beam (reversed configuration). These photographs are shown in Fig. 6. To correct for the different attenuation of the glass in the two cases, the two signals have been normalized to give the same value at 100 ns. In the normal configuration the photograph shows a fast Cerenkov component that does not appear in the photograph from the reversed configuration. From the photographs, the Cerenkov fraction is estimated to be

15±2%. With this phototube the exponential decay time for the scintillation light is measured to be 90±5 ns.

In another test with the same block and fast phototube, the signal was passively divided and fed into different ADC's with gate lengths of 32 and 264 ns, respectively. Fitting a form C+S(1-exp(-t/90 ns)) where C is the Cerenkov component, S is the scintillation component, and t is the gate length, we also find that the Cerenkov signal represents 16±8% of the total light output from scintillation glass for electromagnetic showers.

Radiation Darkening Sensitivity

The sensitivity of SCG1-C to radiation darkening relative to that of SF5 lead glass was measured using the 100 MeV proton synchrocyclotron at McGill University. Samples of SCG1-C and SF5 each 1 cm thick were exposed to protons of kinetic energy 55 MeV. The optical transmission at wavelengths of 436 nm, 547 nm and 570 nm were measured after exposure of the samples to a proton flux. The transmission T along the incident proton axis relative to that before irradiation T_o is shown in Fig. 7a for SCG1-C and Fig. 7b for SF5. We find that for a large proton flux SCG1-C is approximately 150 times more resistant than SF5 to radiation darkening of the glass at 436 nm.

Conclusions

The energy resolution of a 20.5 radiation length SCG1-C scintillation glass shower counter array with a 3.5 radiation length SCG1-C active converter and 0.2 radiation length position hodoscopes was measured to be 0.50% + 3.43%/$\sqrt{E}$. The low energy behavior of the energy resolution was degraded by the inactive material of the position hodoscopes and could be improved for energies less than 4 GeV by having very little material between the active converter and the array. We have also measured the photon yield for SCG1-C to be 1.6 x 10^4 photons/GeV, the attenuation length for light from showers in SCG1-C to be 190 cm, the fraction of the light output due to Cerenkov light relative to the total light output for showers in SCG1-C to be 15%, and a radiation darkening resistance for SCG1-C that is 150 times larger than that for SF5 lead glass.

Acknowledgments

We wish to thank the SLAC operating staff. We would also like to acknowledge the U.S. Department of Energy, the Natural Sciences and Engineering Research Council of Canada, the Quebec Department of Education, and the Hellenic Science and Technology Agency for their support.

References

1. B. Cox, et al., IEEE Trans. Nuc. Sci., NS-30, 127 (1983).
2. Fermilab Proposal E-705 (1981).
3. Ohara Optical Glass Manufacturing Co., Ltd., private communication.
4. R. Rameika, et al., Measurement of Electromagnetic Shower Position and Size with a Saturated Avalanche Tube Hodoscope and a Fine Grained Scintillation Hodoscope, Paper 3A5, 1983 Nuclear Science Symposium, San Francisco, CA.
5. J.E. Brau, et al., Nucl. Inst. and Methods, 196 (1982).
6. R.L. Ford and W.R. Nelson, SLAC-210 (1978).

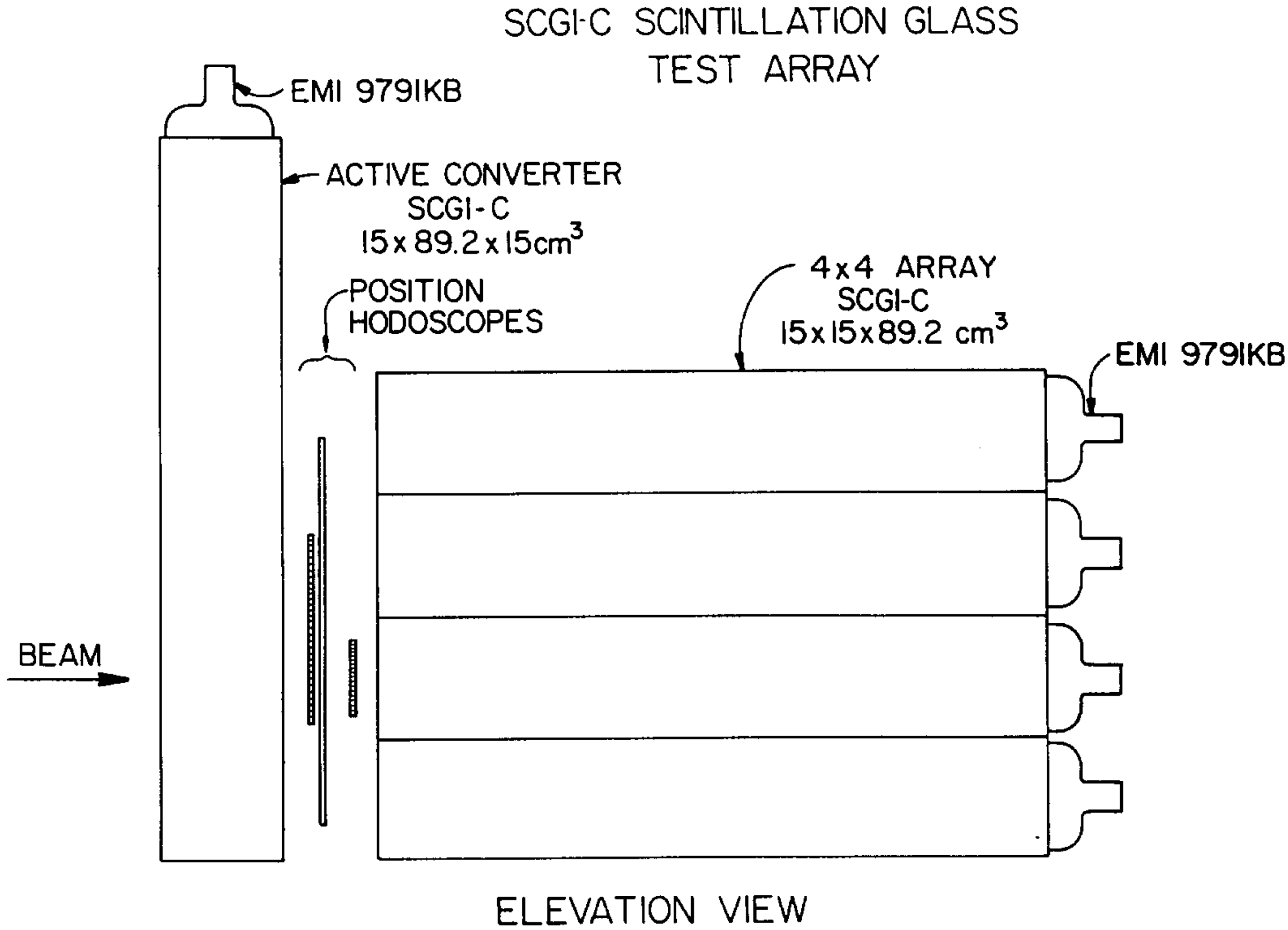

SCGI-C SCINTILLATION GLASS
TEST ARRAY
EMI 9791KB
ACTIVE CONVERTER
SCGI-C
15 x 89.2 x 15cm^3
POSITION
HODOSCOPES
4x4 ARRAY
SCGI-C
15x15x89.2 cm^3
EMI 9791KB
BEAM
ELEVATION VIEW

FIGURE 1

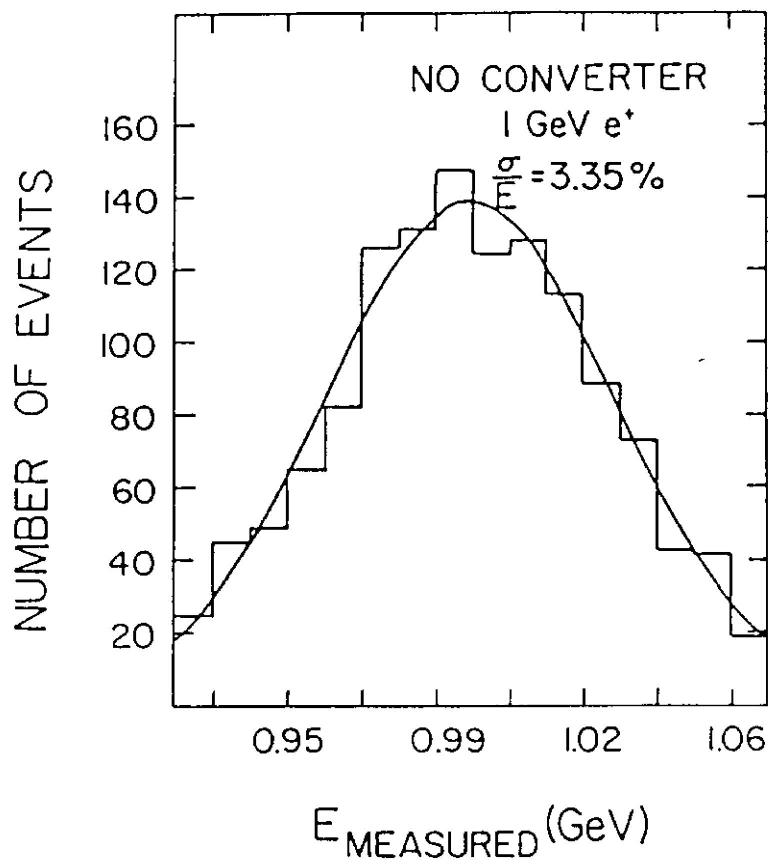


FIGURE 2a

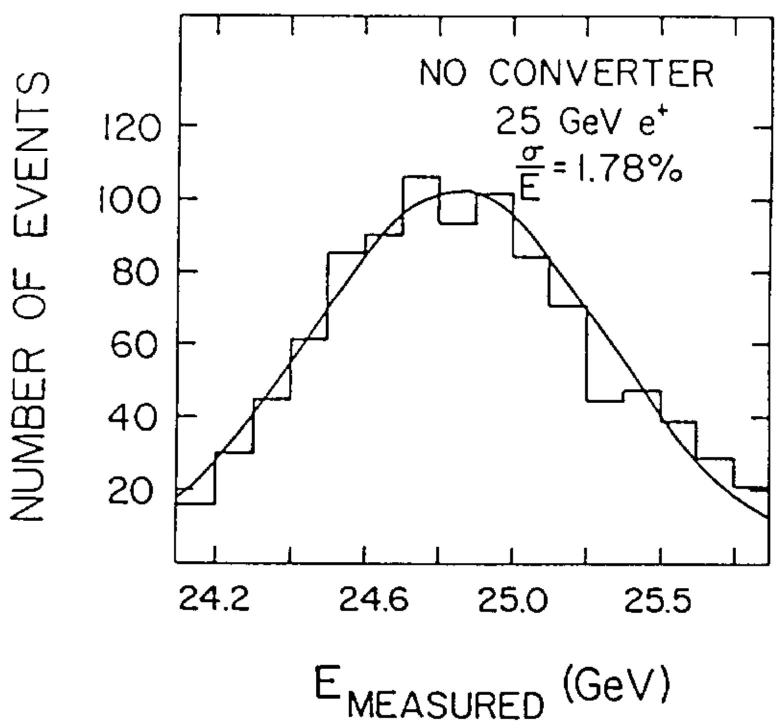


FIGURE 2b

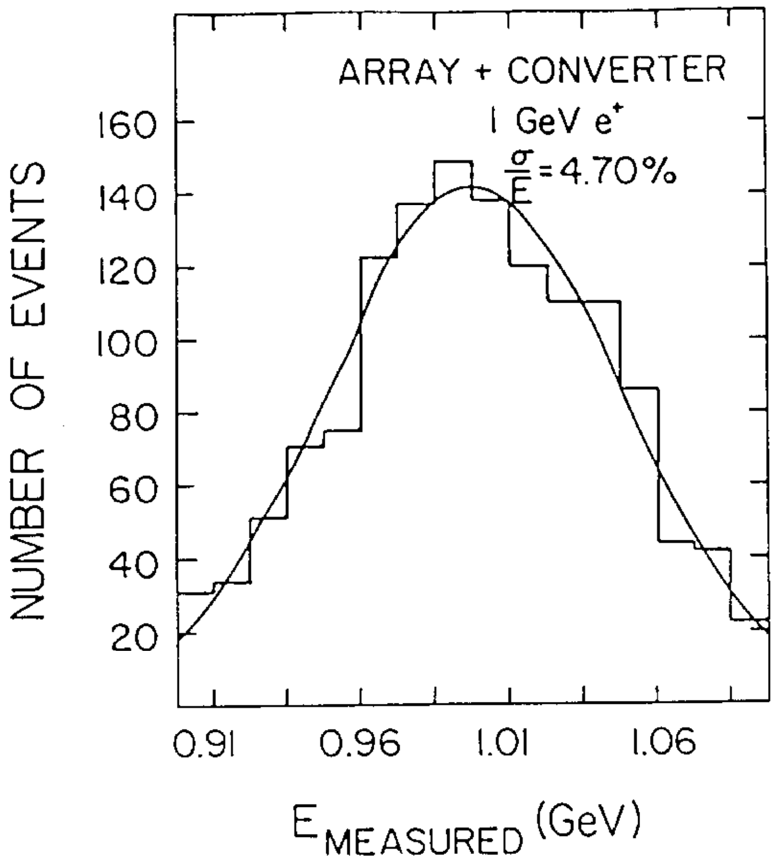


FIGURE 3a

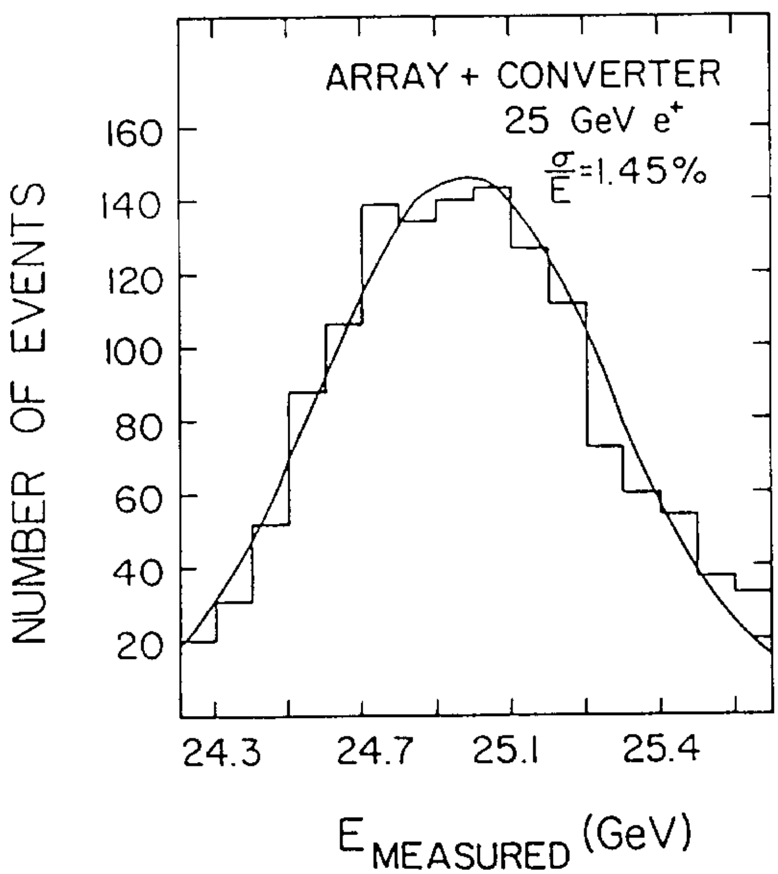


FIGURE 3b

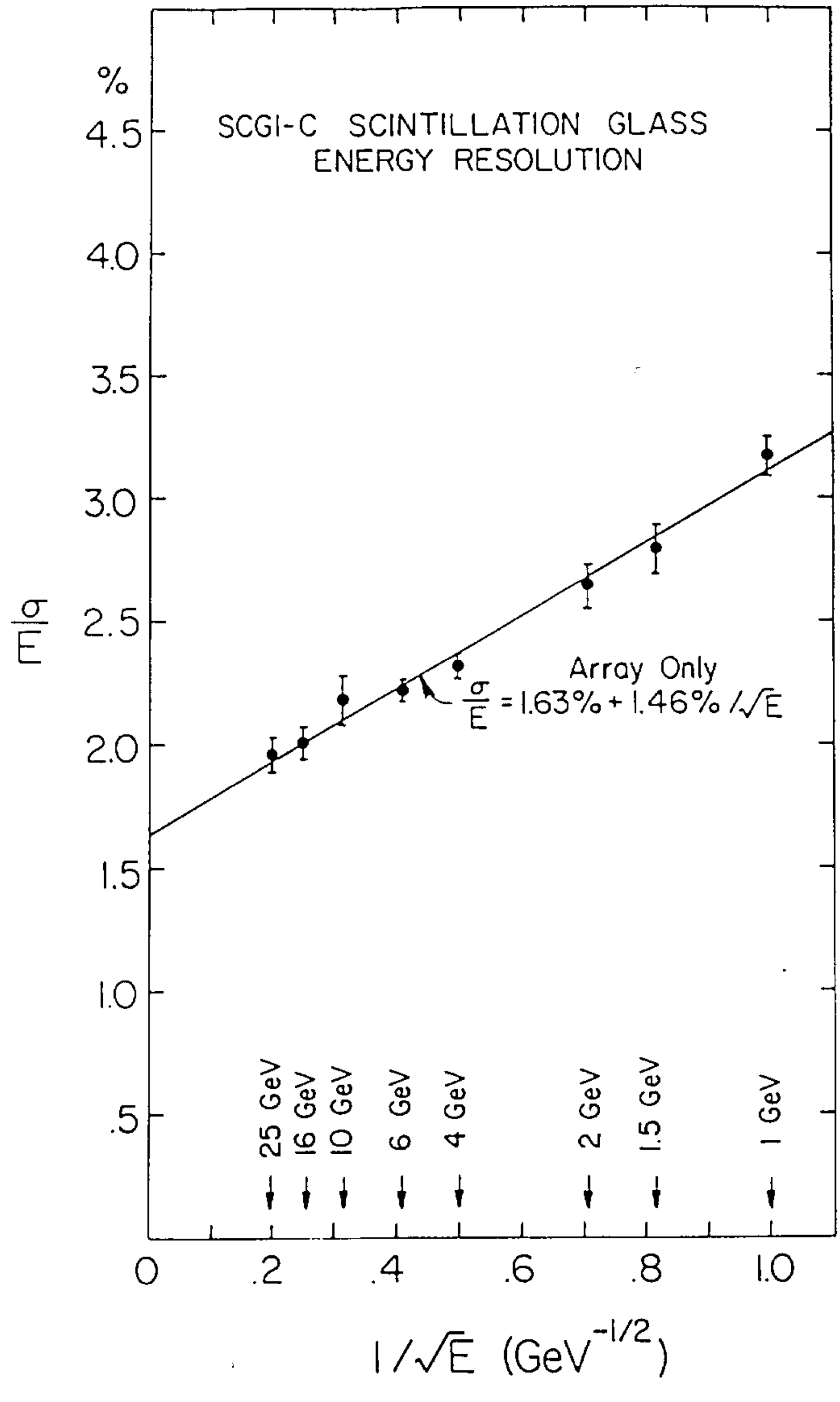
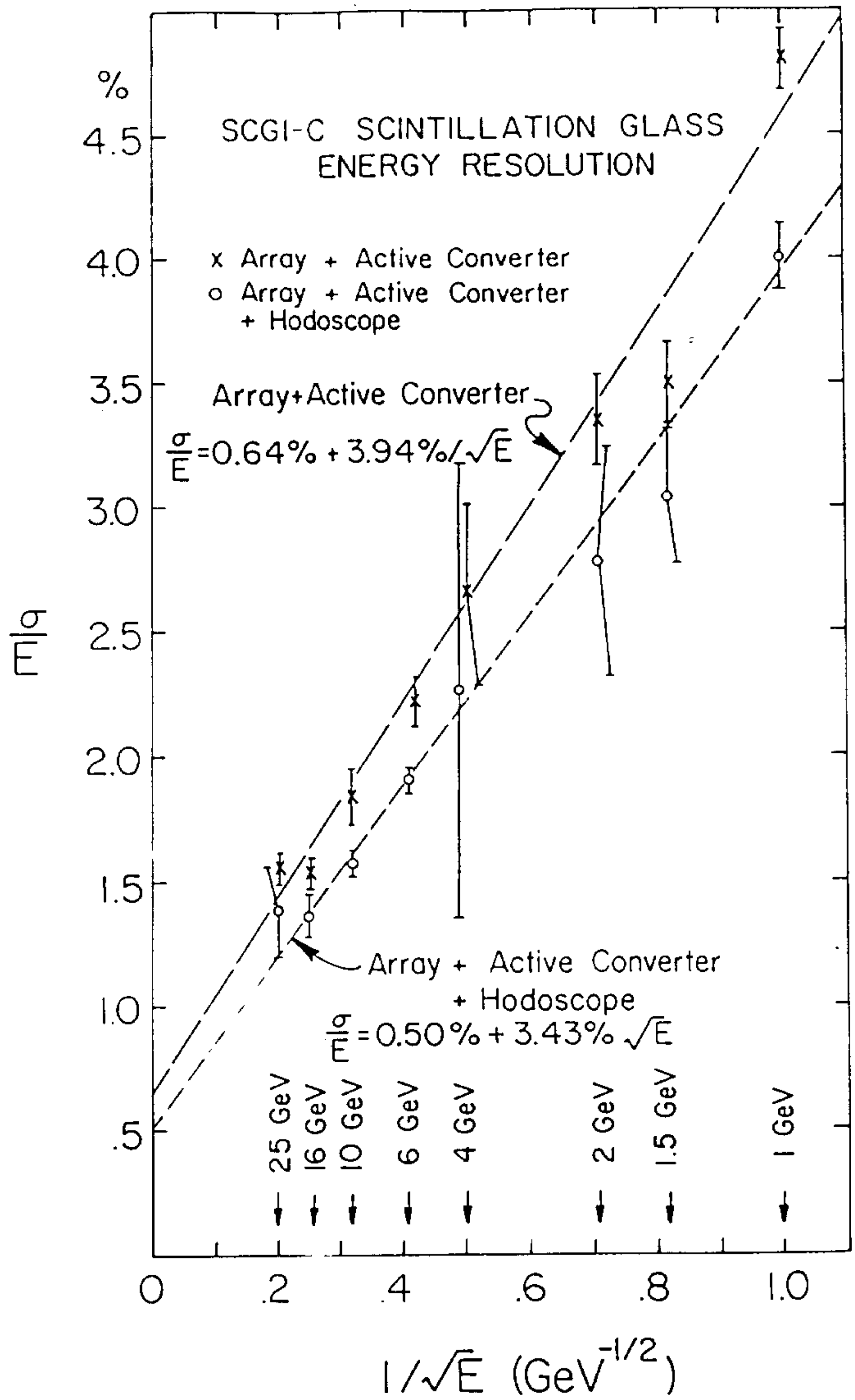
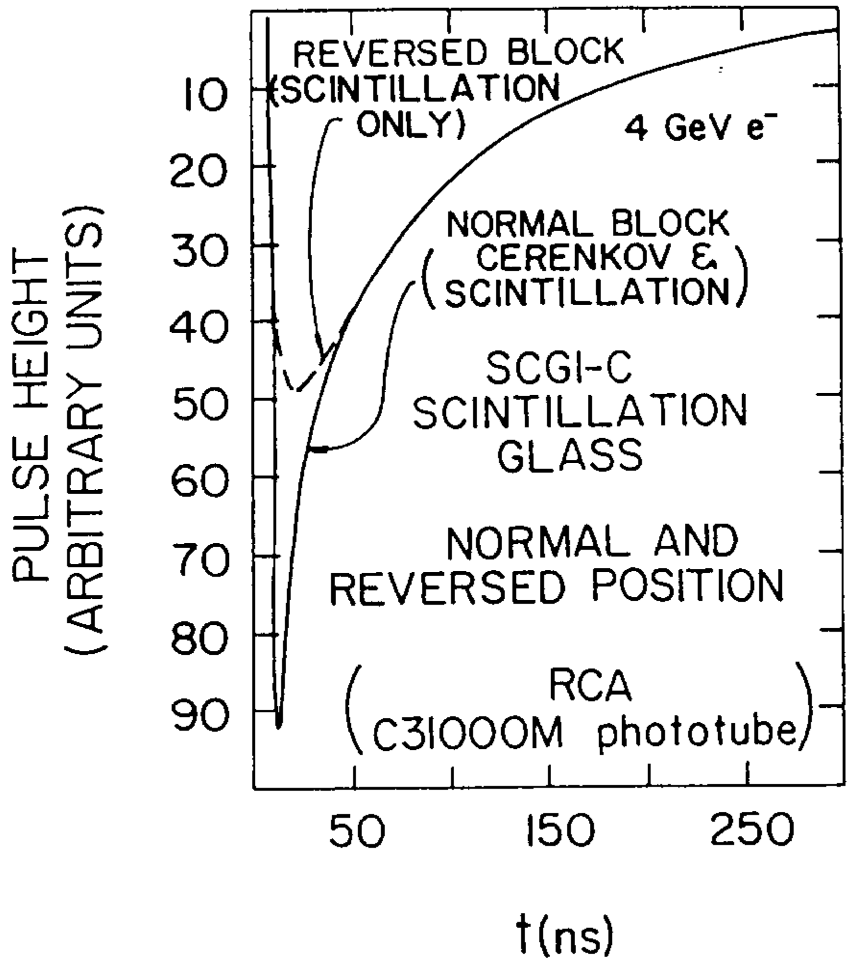

%
SCGI-C SCINTILLATION GLASS
ENERGY RESOLUTION
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
σ/E
Array Only
σ/E = 1.63% + 1.46% /√E
25 GeV
16 GeV
10 GeV
6 GeV
4 GeV
2 GeV
1.5 GeV
1 GeV
0
.2
.4
.6
.8
1.0
1/√E (GeV^-1/2)

FIGURE 4



SCGI-C SCINTILLATION GLASS
ENERGY RESOLUTION
x Array + Active Converter
o Array + Active Converter
+ Hodoscope
Array+Active Converter
σ/E=0.64% + 3.94%/√E
Array + Active Converter
+ Hodoscope
σ/E=0.50% + 3.43% √E
%
σ/E
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
25 GeV
16 GeV
10 GeV
6 GeV
4 GeV
2 GeV
1.5 GeV
1 GeV
0
.2
.4
.6
.8
1.0
1/√E (GeV^-1/2)

FIGURE 5



PULSE HEIGHT
(ARBITRARY UNITS)
10
20
30
40
50
60
70
80
90
REVERSED BLOCK
(SCINTILLATION
ONLY)
4 GeV e⁻
NORMAL BLOCK
(CERENKOV &
SCINTILLATION)
SCGI-C
SCINTILLATION
GLASS
NORMAL AND
REVERSED POSITION
(RCA
C31000M phototube)
50
150
250
t(ns)

FIGURE 6

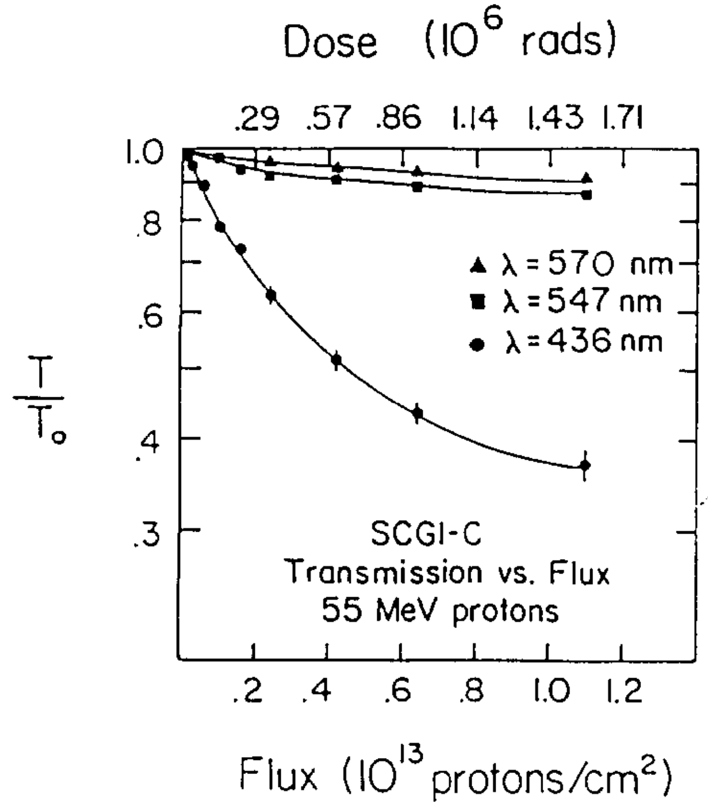


FIGURE 7a

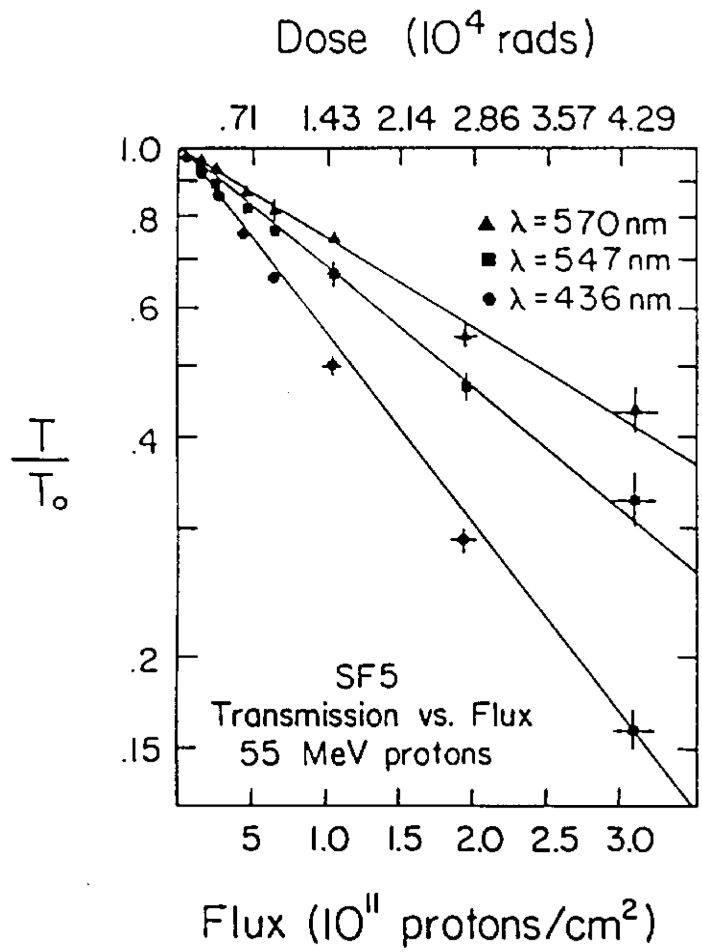


FIGURE 7b