CORRECTION OF LIGHT ATTENUATION IN
LARGE SHOWER COUNTERS*

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ABSTRACT

A simple procedure, based on elementary shower theory, has been devised to compensate for attenuation losses over the surface of large sandwich-type shower counters. It uses tapered lead sheets in place of the usual flat plates and is capable of compensating for attenuation of as much as a factor of two.

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I. INTRODUCTION

In an experiment at SLAC,¹ lead-lucite sandwich-type shower counters² were used as an electron trigger. A new type of lucite³ was used in order to get maximum light output. A problem arose of correcting for severe light attenuation over the surface of the counter. (As the counters were used for triggering, it was essential that the response be reasonably flat.) This letter describes the method of correction that produced flat pulse-height distributions, without having much effect on counter resolution.

II. THE COUNTERS

A new type of lucite doped with a wave-shifter which absorbs in the UV and reemits in the visible blue has been developed.³ In a simple geometry the pulse height for this new lucite was about a factor of two greater than that for UVT lucite,⁴ but in more practical configurations, which tend to be less efficient for collecting the highly directional primary Cerenkov radiation, a bigger improvement might be expected.

Eleven shower counters were constructed and assembled in a 254×137 cm² triggering array which was used to select 3-15 GeV scattered electrons in a spark-chamber experiment to study electroproduced hadrons.¹ Each counter had an active area of 63.5×46 cm² and consisted of 16 sheets of 6.35 mm thick doped lucite interleaved with sheets of lead. The light collection is inefficient, about 12% of the available light being collected by five 5 cm diameter phototubes attached to each counter. The main design criteria were simplicity, ruggedness, low cost and the availability of many 5 cm photomultiplier tubes, rather than resolution which was about 15% at 18 GeV.

Before being assembled into the array, each counter was calibrated using an electron beam of known energy (5-18 GeV) incident at different points on the counter surface. Figure 1 curve A shows a "horizontal" scan, in which the relative pulse height is displayed as a function of the distance from the point of incidence of the beam to the row of photomultiplier tubes. The slope, caused by the attenuation of light by the lucite,⁵ would have given rise to undesirable triggering anomalies if uncorrected. The situation was corrected by adjusting the amount and distribution of lead in the counter. The next section describes the calculation of this adjustment.

III. SHOWER THEORY

The development of electromagnetic showers, resulting from the passage of high-energy electrons or photons through dense media, is fairly well understood through analytic⁶ and Monte Carlo^{7,8} calculations and through direct measurement.^{8,9} Figure 2, a so-called shower development curve for 6 GeV electrons in lead, shows the energy E deposited per unit length in an infinite block of material as a function of penetration depth t . Such a curve enables us to make use of the following very naive model of a sandwich-type shower counter. Consider for example a lead-lucite counter and let us make the assumptions that no energy is lost out of the sides and that the lucite sheets merely sample the energy loss density at various depths, but are sufficiently thin as to have no appreciable effect on shower development or attenuation. We can immediately write down the contribution a_i to the total output pulse amplitude from the i 'th lucite sheet:

$$a_i = c_i E_i(t_i)$$

where t_i is the total thickness of lead upstream of the i 'th lucite sheet and E_i is the ordinate of the shower development curve (Fig. 2) at a depth t_i . The proportionality constant c_i depends upon the thickness and optical properties of the i 'th lucite sheet, and upon a multitude of other factors. If the total number of lucite sheets is n , then the total amplitude 'a' is simply:

$$a = \sum_{i=1}^n a_i = \sum_{i=1}^n c_i E_i(t_i)$$

If all the lucite sheets have equal thickness and optical properties, then the c_i 's will all be equal:

$$a(x,y) = c(x,y) \sum_{i=1}^n E_i(t_i(x,y))$$

where the dependence on position is shown explicitly to emphasize that the attenuation (which is contained in c) varies over the surface of the counter. Thus if we construct a counter in which the lucite sheets and optics remain the same, but in which lead sheets of arbitrary size, shape and thickness can be added or subtracted at will, once the response for a particular lead configuration is known (i.e., $c(x,y)$ is mapped out), the response for any other configuration may be calculated. A configuration should be chosen which gives the best compromise between flat response, high photon yield, low shower leakage and minimum fluctuations in the partition of energy between lead and lucite.

IV. ADJUSTMENT AND RESULTS

Correction of the problem described in Section 2 was effected by simply tapering the lead plates by precisely the amount predicted by Eq. (1) to compensate for the slope. To simplify the casting of the tapered plates, only one

standard mold was used, tapering from 8.1 mm to 0.5 mm, and Eq. (1) then served to establish the numbers and positions of both flat and tapered plates for each counter. Further simplification was afforded by using a linear taper and by using type-metal (83% Pb 17% Sb, $X_0 = 0.67$ cm, M. P. = $\sim 270^\circ\text{C}$) which is easier to cast than lead ($X_0 = 0.58$ cm, M. P. = 327.5°C).

Table 1 shows the configuration used for our typical counter, and Fig. 2 curve B shows the response with this configuration. It can be seen that the pulse height variation across the counter has been reduced from a factor of two to about $\pm 5\%$ (at 18 GeV) over a distance of 40 cm out of the total counter width of 46 cm. The deterioration in resolution observed as a result of this radical departure from traditional shower counter design is quite small (14.5% became 16% at 18 GeV). It should be pointed out however that the resolution is already quite poor due to photon statistics since only 12% of the light is collected. By replacing the five 5 cm phototubes with three 12 cm tubes, the photon yield could be increased by a factor of four. At this point we might begin to see effects of fluctuations in the partition of energy between lead and lucite, which will presumably be worse with the new irregular geometry, and of fluctuations in shower leakage. Shower leakage is as high as 30% (at 6 GeV) in the region where the total thickness is only 9.1 radiation lengths. The logarithmic dependence of this leakage on particle energy (38% at 12 GeV, 23% at 3 GeV) ensures that there will be no severe energy dependences over the range of interest.

In this letter we have discussed the correction of light attenuation in counters of moderate size. However, using the better samples⁵ of doped lucite (attenuation length = 250 cm), the response of a counter two meters long could be made flat to $\pm 5\%$ by this method.

REFERENCES

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2. C. A. Heusch, Proc. Intern. Conf. Electron-Photon Interactions, Hamburg II, 408 (1965).
3. Isolite 4000; Pilot Chemicals, Watertown, Massachusetts.
4. Two 7.5 cm cubes, one of Isolite and one of UVT lucite were alternately mounted on the face of a 56 AVP phototube. Pulse heights from cosmic ray muons were recorded on a pulse-height analyser.
5. The attenuation length of the doped lucite varied greatly (from counter to counter) from the almost acceptable value of 250 cm to the extremely poor value of 65 cm. Figure 1 shows a scan of one of the poor counters later replaced at Pilot's expense.
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FIGURE CAPTIONS

1. Output pulse height of a typical shower counter for 18 GeV electrons plotted as a function of the distance from the point of incidence of the particles to the row of phototubes. Curve A shows the original response using flat uniform lead plates of thickness 4.1 mm. Curve B shows the response when these were replaced with the highly non-uniform configuration given in Table 1.
2. Monte Carlo calculation⁸ of the longitudinal shower development for 6 GeV electrons in lead. The ordinate gives the percentage of incident energy absorbed in one plate of thickness X_0 .

TABLE 1

Lead Configuration for Counter 1

Plate Position i	Shape	Material	Edge Near Phototubes			Edge Away From Phototubes		
			Thickness mm	t_i rad. lengths	E_i from Fig. 1	Thickness mm	t_i rad. lengths	E_i from Fig. 1
1	flat	lead	12.2	2.1	3.2	12.2	2.1	3.1
2	flat	lead	8.1	3.5	7.1	8.1	3.5	7.1
3	tapered	type-metal	8.1	4.7	9.4	0.5	3.6	7.4
4	tapered	type-metal	8.1	5.9	10.2	0.5	3.65	7.5
5	tapered	type-metal	8.1	7.1	9.6	0.5	3.7	7.6
6	flat	lead	8.1	8.5	7.9	8.1	5.1	9.9
7	tapered	type-metal	8.1	9.8	6.0	0.5	5.2	9.9
8	tapered	type-metal	8.1	11.0	4.5	0.5	5.3	10.0
9	tapered	type-metal	8.1	12.2	3.3	0.5	5.35	10.1
10	flat	lead	8.1	13.6	2.3	8.1	6.75	9.9
11	tapered	type-metal	8.1	14.8	1.7	0.5	6.85	9.9
12	tapered	type-metal	8.1	16.0	1.2	0.5	6.9	9.8
13	tapered	type-metal	8.1	17.2	0.8	0.5	7.0	9.7
14	flat	lead	4.1	17.9	0.7	4.1	7.7	9.1
15	flat	lead	4.1	18.6	0.6	4.1	8.4	8.0
16	flat	lead	4.1	19.3	0.5	4.1	9.1	7.0
Total Contribution			$\sum E_i(t_i) =$					
			69.1			136.2

Fig. 1

Fig. 2