LARGE-AREA PLASTIC SCINTILLATION COUNTER

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LARGE-AREA PLASTIC SCINTILLATION COUNTER

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SUMMARY

The construction and performance of a large-area plastic scintillation counter \((50 \times 30 \times 2 \text{ cm}^3)\) of especially simple design is described. Pulse-height spectra were measured with a beam of minimum ionizing particles hitting different points of the counter. The results are compared with theory. The percentage of light collection and the pulse height are calculated absolutely. The influence of magnetic fields on the performance were determined experimentally.

A hundred of these counters are used in the CERN neutrino experiment to give the triggering signal for the spark chambers.

\(^{\circ}\) University of Geneva.
1. DESIGN OF THE COUNTER

1.1 Mechanical

The counter consists of (see Fig. 1):

one sheet of plastic scintillator, $50 \times 80 \times 2$ cm$^3$;

one light guide of highly-polished plexiglas, flat, trapezoidal, 2.5 cm thick, 14 cm long, 50 cm wide at the plastic scintillator, 5 cm wide at the phototube;

one photomultiplier with 11 stages, Philips 53 AVP$^w$).

All these pieces have been glued together with EPOXY$^{**}$) plastic ERL 2795 hardener ERL 2793
cured at room temperature.

The whole assembly is wrapped loosely with aluminium foil. The phototube is covered by a cylinder of mumetal, 9 cm long, 0.8 mm wall thickness.

1.2 Electrical

The voltage of the accelerator grid (pin 1 of 53 AVP) has been adjusted for a sample of 12 tubes to give maximum pulse output. The pulse height depends strongly on the voltage between cathode and accelerator grid, if this voltage is less than approximately 8.0% of the full phototube voltage. It is practically independent of this voltage if it is greater than 8.8% of the full voltage. We have chosen the values of the resistors (Fig. 2) to give an accelerator-to-cathode voltage of 9.4% of the full tube voltage.

The counters operate in a region practically free of machine background, and with low counting rates. Therefore, small storage capacitors of 1000 pF and a low parallel current in the divider of typically 1 mA are used.

$^w$) La Radiotechnique, Paris.

$^{**}$) Union Carbide.
The 53 AVP tubes have been selected for high-pulse output at a given illumination by an irradiated scintillator. Approximately 80% of regular unselected tubes delivered by the manufacturer passed the criterion.

2. **PERFORMANCE**

2.1 **Mechanical**

Because of the rigid construction, handling and mounting of the counters is very easy. With the glue used, the strength of the joint between light pipe and phototube is such that as a result of unconventionally rough handling of a counter, it is the joint that breaks apart rather than the glass of the tube.

2.2 **Pulse output for traversing particles**

Test beams of minimum ionizing particles have been passed perpendicularly through the counter sheet at various places, specified by the co-ordinates \((x,y)\) of Fig. 1, and the pulse-height distribution has been measured. The beam size was \(3 \times 5\) cm\(^2\). Since there was no observable difference in pulse height for beams passing at different lateral positions (i.e. positions with different values of \(x\), but the same values of \(y\)), only the results for measurements on the middle axis \((x = 0)\) of the plastic sheet are presented.

Figure 3 gives typical pulse-height spectra for a beam passing through the scintillator close to the phototube, in the middle, and at the far end, respectively. For reasons of clarity of Fig. 3, the dots as given by the pulse-height analyser are shown for the curve \(y = 40\) cm only.

Figure 4 shows the pulse height of the peaks of the spectra of Fig. 3, plotted as a function of the position \(y\) of the passing beam. The vertical flags denote the uncertainty of the peak position, the horizontal flags the beam size in the \(y\) direction. (Some more measurements, not shown in Fig. 3, have been included here.)
For each spectrum a pulse height, $H_0$, has been determined such that 98% of all pulses of that spectrum exceed $H_0$. If, for example, a discriminator level is set at $H_0$, the arrangement counter discriminator would count 98% of all particles passing through the scintillator at the position $y$ in question. The pulse height $H_0$ is indicated in Fig. 4.

2.3 Influence of magnetic fields

A counter was placed in a locally uniform magnetic field perpendicular to the axis of the phototube. The height of the pulses due to a test source was observed, when the counter was rotated around the geometrical axis of the tube. Table 1 gives the anisotropies and the maxima of the angular distribution of the pulse heights. In the spark chamber neutrino experiment\(^1\), the Helmholtz coils\(^2\), when running at 2500 A, produce a field behind the iron shield wall of less than 5 Oe at the position of the plastic counters. Direct measurements in place have shown that the pulse height is then influenced by less than 10%.

Table 1

<table>
<thead>
<tr>
<th>Magnetic Field</th>
<th>Anisotropy $A$</th>
<th>Maximum pulse height (normalised to zero magnetic field)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Oe</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.17</td>
<td>1</td>
</tr>
<tr>
<td>10.5</td>
<td>0.20</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>0.06</td>
<td>0.8</td>
</tr>
</tbody>
</table>

\(^{1}\) Helmholtz coils
\(^{2}\) Spark chamber neutrino experiment
3. **TESTING, EQUALIZING**

A mercury-relay pulse generator, calibrated by a voltmeter, has been used to set the level of a CERN discriminator\(^3\) to a standard value (0.18 V). A reference source of 100 μC of Co\(^{60}\) at a well-defined position at the far end of the plastic sheet \((y = 75 \text{ cm})\) produces test pulses. The high voltage of the phototube is set such that a given number of pulses per sec \((5000/\text{sec})\) pass the discriminator. To test roughly the uniformity, the source is placed at \(y = 5 \text{ cm}\) and the signal attenuated until the original counting rate is restored. A counter was accepted if the attenuation factor was between 2 db and 6.5 db and if the noise was less than 2000/\text{sec}.

Once the counters are mounted in the neutrino set-up\(^1\), they cannot be tested any more with a source. Therefore, another equivalent criterion using cosmic rays was established.

Put the counter in an upright position (such that cosmic rays pass preferably at small angles through the sheet). Set the high voltage of the tube such that 15 pulses/sec exceed a height of 0.72 V at the anode. Then, the absolute calibration of the pulse height of Fig. 3 applies.

4. **CALCULATION OF THE LIGHT COLLECTION**

The amount of light produced in the plastic scintillator, which reaches the photomultiplier after some (total) reflections at the walls of the sheet, was calculated according to a method devised by one of us\(^4\). This method makes systematic use of the fact that light originating from a point source leaves a plane mirror after reflection, as if it had come directly from the mirror image of the source. One also notes that the light paths have the same length. It can be shown that the light coming from a point source placed in a rectangular (three-dimensional), totally reflecting box to a (small) photomultiplier is the same as the light coming directly (without
reflections) from a sort of lattice of **equally intense light sources**. For any position of the real light source, this lattice can be easily constructed from the geometry of the box. The absorption in the scintillator is taken into account by recognizing that the direct path from the virtual source in question is equal to the real path in the reflecting box, for example, by having the virtual light sources embedded in virtual scintillator.

We apply this to our counter, using the fact that the side surfaces are small as compared to the two large planes of the scintillator. Furthermore, the light pipe is assumed to have the same optical constants as the plastic scintillator. The light is assumed to come from a point source in the middle between the two reflecting surfaces. Light hitting the small sides and light which is not totally reflected is neglected. Light reflected from the end surface $y = 80 \text{ cm}$ is taken into account. The situation is represented in Fig. 5. Two light paths are given as examples. $L_1$ and $L_2$ are the two (one-dimensional, in this approximation) lattices, $L_2$ being the mirror image of $L_1$ with respect to the back surface of the reflecting box.

Suppose each virtual light source emits $s$ photons per sterad in the frequency band accepted by the phototube. Then the light collected by the multiplier surface $F$ coming from the source of index $\nu$ of $L_1$ is given by

$$ \eta_{\nu i} = s \cdot \frac{F}{\lambda_{\nu i}^2} \cdot \frac{a_i^2}{\lambda_{\nu i}} \cdot e^{-\lambda_{\nu i} \mu} \quad i = 1, 2, $$

where

$$ \lambda_{\nu i} = a_i^2 + (\nu d)^2 \cdot $$

$$ 1/\mu = \text{absorption length of light in the plastic scintillator}. $$
The total light collected by $F$ is then

$$\eta = s \cdot F \cdot \sum_{i=1}^{2} a_i \sum_{\nu=-N}^{+N} \frac{1}{\lambda_{\nu i}} \cdot e^{-\lambda_{\nu i} \cdot \mu}$$

(1)

Under our assumption, the limits $\pm N$ are given by the angle for total reflection:

$$N = \text{integral part} \left( \frac{a_1}{d} \cdot \sqrt{n^2 - 1} \right),$$

where $n$ is the index of refraction of the plastic scintillator.

5. **Comparison with Experiment**

5.1 **Light collection**

The curve in Fig. 4 has been calculated with the following numerical values:

- source strength $s$ to be fitted to experiment;
- utilized surface of photomultiplier $F$ 10 cm$^2$;
- distance: far end to photomultiplier, $l$: 94 cm;
- absorption length $1/\mu$ 150 cm;
- source distance $a_1$ $x + 14$ cm;
- index of refraction 1.5.

The value of the absorption length has been found so as to give the curve the required shape. A deviation by $\pm 50$ cm of $1/\mu$ from the value of 150 cm changes the curve considerably and makes a reasonable fit impossible. This compares well with an absorption length of $130 \pm 15$ cm at 4300 Å as given by the manufacturer.

5.2 **Width of spectra**

We estimate the number of photoelectrons under the following assumptions.
Energy loss in plastic scintillator for minimum ionizing particles is 2 cm × 2 MeV/cm = 4 MeV, and the number of photons produced in the sensitive spectral region of the photomultiplier is 2000 MeV⁻¹ × 4 MeV = 8000. Therefore in Eq. (1) we have to put

\[ s = 8000/4 \mu \text{m}. \]

For \( y = 40 \text{ cm} \) the numerical calculation gives a light collection efficiency of 1%. Assuming an efficiency of the photocathode of 0.08, one obtains 6.1 photoelectrons for a minimum ionizing particle passing through the middle of the plastic scintillator. Considering only the statistics of the number of photoelectrons, one expects a full-width at half height of the pulse-height spectrum of approximately 67%. The observed value, which includes the Landau fluctuation in ionization loss, is approximately 84% (Figs. 3 and 4).

5.3 Absolute pulse height

We assume as a typical value for the current gain \( A \) of our phototube \( A \approx 10^7 \). The expected anode pulse height \( V \) on a cable with \( Z_0 = 125 \Omega \) characteristic impedance (parallel to its terminating resistor) is, with the values estimated above,

\[ V \approx 0.2 \text{ V} \] (within a factor of, say, 3),

assuming a decay time of the plastic scintillator of \( 3 \cdot 10^{-9} \text{ sec} \). The measured pulse height is 0.26 V.

** REFERENCES **


4. H. Faissner, Light collection in specularly reflecting containers, to be published.
Figure captions

Fig. 1 Assembly of plastic counter.

Fig. 2 Voltage divider for high output pulse operation.

Fig. 3 Pulse-height spectra for beams passing at different positions through the counter, measured at the anode output of the photomultiplier.

Fig. 4 Pulse height as a function of position of test beam; round dots pulse height of peak of spectrum; flags estimated uncertainty of the peak position of the spectrum; curve calculated; the absolute height of the calculated curve is arbitrarily fitted to coincide at \( y = 60 \text{ cm} \); squares pulse height \( H_0 \) which is exceeded by 98% of the pulses of the spectrum.

Fig. 5 Equivalence of reflected light paths with paths coming from a lattice of light sources \( L_1 \) and \( L_2 \).

* * *

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FIG. 3

Number of Pulses

Pulseheight (V)

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

100

far end  middle  close to phototube

\( y = 73 \text{ cm} \)  \( y = 40 \text{ cm} \)  \( y = 13.5 \text{ cm} \)