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A SIMPLE LIGHT GUIDE FOR COUPLING TO THIN SCINTILLATOR SHEETS

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A simple light guide configuration for coupling to thin scintillator sheets is described. Its light collection properties are similar to those of the more conventional "twisted strip" guide and it offers the advantages of compactness and reduced cost.

1. Introduction

The "twisted strip" light guide has been widely used to couple scintillator sheets to photomultiplier tubes since its introduction by Gorenstein and Luckey [1]. These guides provide efficient and uniform light collection but are relatively expensive to produce and take up a good deal of space. This paper describes a new cylindrical light guide which is suitable for coupling to thin scintillator sheets (≲4 mm thick) and has a light collection efficiency similar to that of the "twisted strip" guides. However, the new guide is cheaper, simpler, and more compact.

Sections 2–4 discuss the design and construction of the cylindrical light guide and the results of bench tests performed with an electron source. The final section describes briefly a telescope of five counters employing these guides. This assembly has been used for detecting and identifying protons and heavier charged particles in the focal plane of the 900 MeV/c magnetic spectrometer [2,3] at the Bates Linear Accelerator Laboratory. Typical pulse height spectra obtained with this detector system are presented.

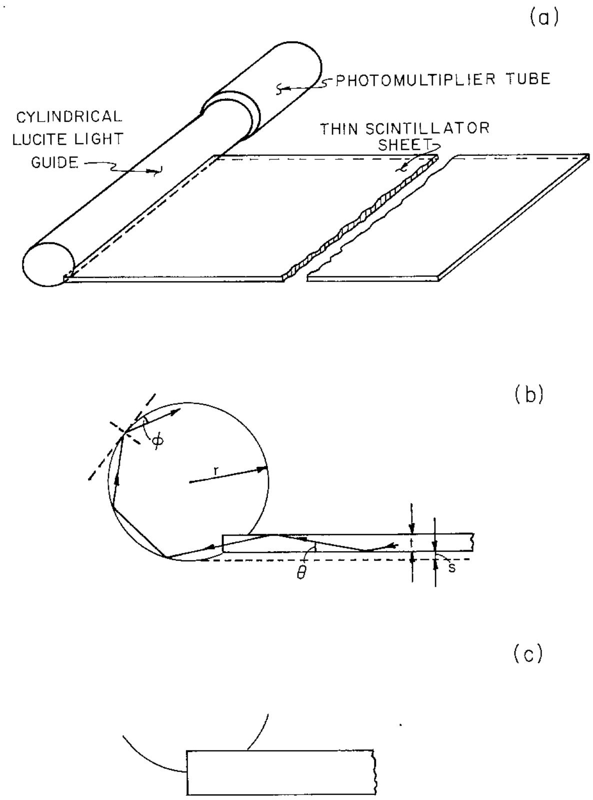

Fig. 1. The layout of the scintillator, light guide, and photomultiplier tube is shown schematically in (a). The coupling between a thin scintillator sheet and the light guide is shown in (b), which also notes the variables used in the text. The modified coupling employed for thick scintillators (>6.4 mm) is shown in (c).

2. Design considerations

Figure 1(a) shows a schematic diagram of the cylindrical light guide. Efficient light collection is achieved if a large fraction of the light entering the cylinder from the scintillator is "captured" and circulates in a totally internally reflected mode until it reaches the photomultiplier tube, either directly or after reflection at the far end of the cylinder. Simplified calculations have been made of the light capture efficiency and of the loss per turn as the light circulates within the guide. The results suggest that the capture probability for light transmitted inside the scintillator at $\theta \lesssim 20°$ is close to unity for a range of values of the parameters t/r and s/r [see fig. 1(b)]. The overall performance is limited mainly by losses during circulation in the guide which increase as a larger fraction of its circumference is removed to couple the guide to the scintillator sheet edge. A reasonable performance is predicted for a small value of the offset, $s/r \approx 0.05$, and for scintillator thickness and guide radius such that $t/r \lesssim 0.15$. Introducing the offset produces a distinct improvement both by reducing the scintillator-guide coupling area and by minimizing the fraction of light captured into a lossy circulating mode at small values of the angle ϕ [see fig. 1(b)].

The cylindrical guide is in one sense inefficient since the concentration of light near the surface of the cylinder means that $\lesssim 30\%$ of the photocathode area is illuminated. Several schemes for collecting light from this annular area onto a smaller photomultiplier tube have been devised, but for the small diameter (4.5 cm) cylindrical guides which have been tested it is not clear that the extra complexity is worthwhile.

3. Construction

The counters whose performance has been investigated were constructed by machining a groove along a lucite rod into which the edge of the scintillator sheet was glued using optical epoxy cement. This assembly was then wrapped in aluminized mylar, covered with black tape, and mounted in a support frame. The open end of the lucite rod was coupled with optical grease to the photomultiplier tube. The tubes used were RCA type 8575 * with a 5.1 cm diameter cathode coupled to the 4.5 cm diameter, 33 cm long lucite light guide. The NE110 scintillator sheets ** had dimensions 76 cm by 25 cm, and several thicknesses between 1.6 mm and 12.7 mm were used. Initially the counters were constructed with zero offset, $s/r = 0.0$. For the two smallest scintillator thicknesses additional counters were built with an offset of $s/r = 0.05$ in order to test the prediction, discussed above, of increased light collection efficiency. For scintillator sheets thicker than 6.4 mm, in which the light output and transmission are high, the construction shown in fig. 1(c) was adopted to keep the circulation losses at an acceptable level. Although the cylindrical guide is in principle less suitable than the "twisted strip" guide for use with these thicker scintillators, a comparison with earlier results showed no difference in the overall performance of detectors employing the two types of guide.

* Manufactured by RCA Electro-optics Division, Lancaster, Pennsylvania, USA.

** Manufactured by Nuclear Enterprises, Inc., San Carlos, California, USA.

4. Bench tests

Tests to determine the uniformity and efficiency of the counters were carried out using a source of approximately monoenergetic 1.8 MeV electrons (from a ^{90}Sr source mounted in a small magnetic spectrometer). The same photomultiplier tube and base were used in all of the measurements and a set of test points was adopted [see fig. 2(a)]. Figs. 2(b), (c) and (d) show the results for a 1.6 mm thick counter with zero offset and two 3.2 mm thick counters, one with zero offset and the other with a 1.1 mm offset ($s/r = 0.05$). To determine the absolute magnitude of the collection efficiency, pieces of 1.6 mm and 3.2 mm NE110 scintillator were coupled through a 5.1 cm long, 4.5 cm diameter lucite spacer to the photomultiplier and the output pulse height for excitation by the 1.8 MeV electrons was measured.

A significant variation in the collection along the length of the scintillator, as observed, is unavoidable for long, thin sheets. However, the side-to-side variation reflects the light losses which occur during circulation in the cylindrical guide. The increase in collection efficiency due to the offset is clearly shown, and to a lesser extent the uniformity is also improved. The collection efficiencies observed are comparable in magnitude with those reported for "twisted strip" guides [4]. Although such a guide of the correct thickness was not available for direct comparison, a test of the 3.2 mm counter coupled to a 12.7 mm × 25 cm "twisted strip" guide indicated that its collection efficiency was, if anything, somewhat inferior to that of the cylindrical guide.

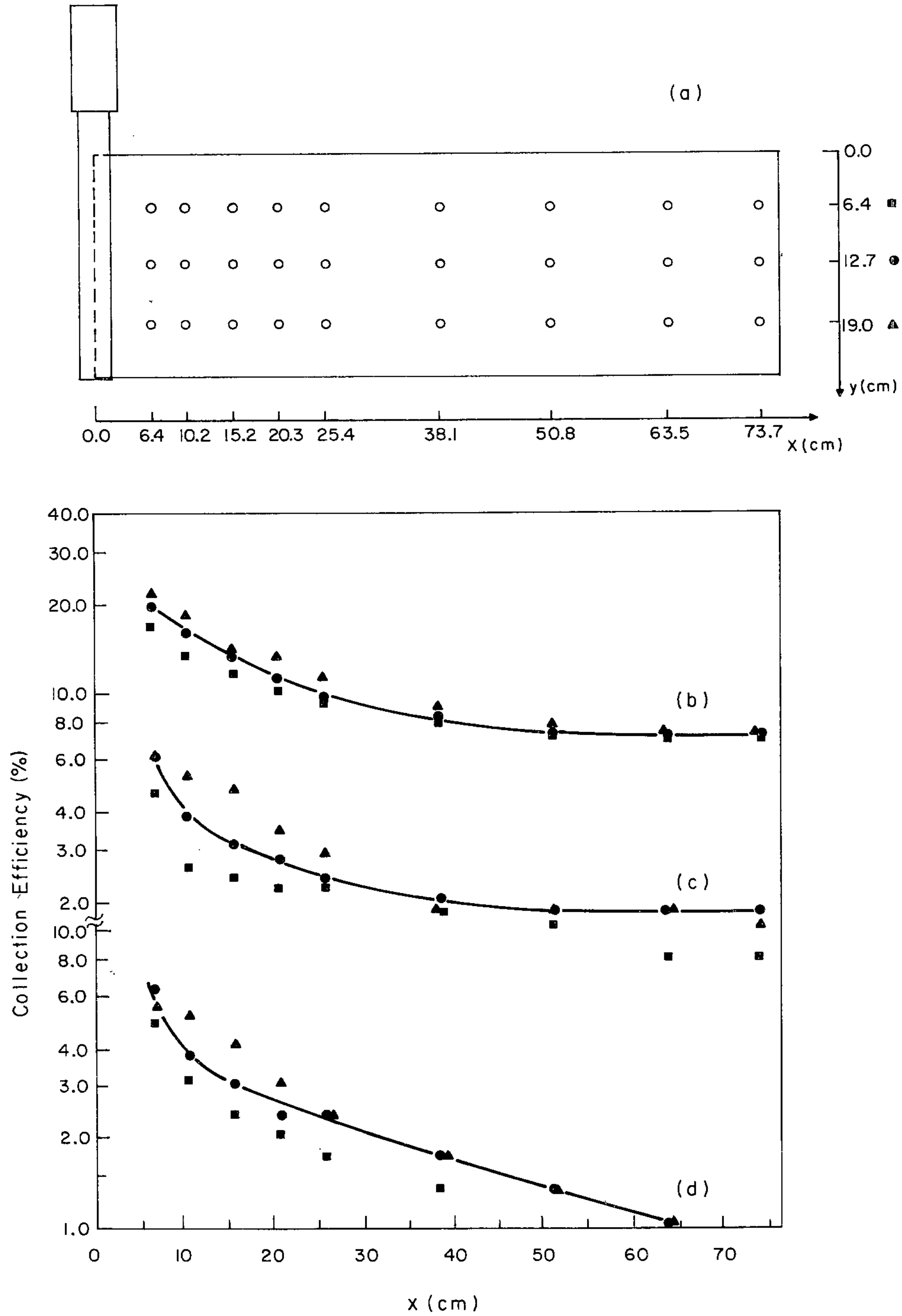

Fig. 2. The upper part of the figure, (a), shows the location of the test points used to measure the counter response. The collection efficiencies of three counters are shown in the lower part, viz. (b) 3.2 mm thick scintillator (t/r = 0.14) with a 1.1 mm offset (s/r = 0.05), (c) 3.2 mm thick scintillator (t/r = 0.14) with zero offset, and (d) 1.6 mm thick scintillator (t/r = 0.07) with zero offset. The points ■, ●, and ▲, correspond to lateral positions y = 6.4, 12.7 and 19.0 cm respectively.

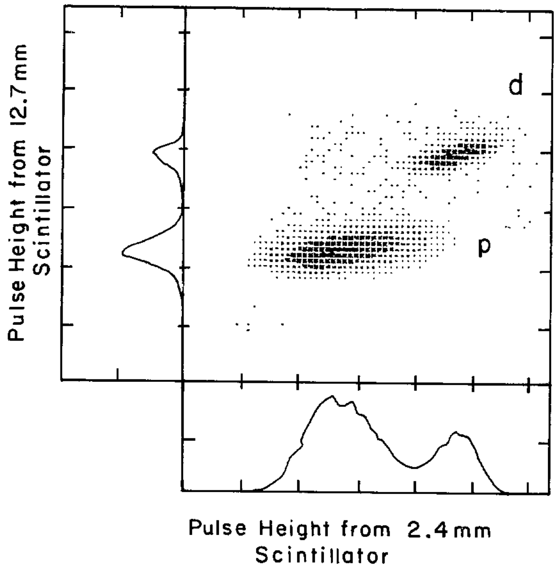

Fig. 3. Pulse height spectra for 150 to 166 MeV protons and 75 to 83 MeV deuterons passing through 2.4 mm thick and 12.7 mm thick counters and the correlation between these pulse heights.

5. Operational experience

Figures 3 and 4 show typical spectra obtained with a telescope of five counters using cylindrical guides when detecting 150 to 166 MeV protons and 75 to 83 MeV deuterons in the focal plane of the 900 MeV/c spectrometer at the Bates Laboratory. The pulse height spectra from the second (2.4 mm thick) and third (12.7 mm thick) counters in the telescope and the correlation between these pulse heights is shown in fig. 3. The pulse height resolution is not significantly different from that obtained previously with "twisted strip" guides. Fig. 4 shows the uniformity obtained over a limited part of the counter length in the same measurements. The particle separation is reasonably good; and by using a telescope of counters with increasing thickness, this separation can be maintained for a wide range of particle types and momenta.

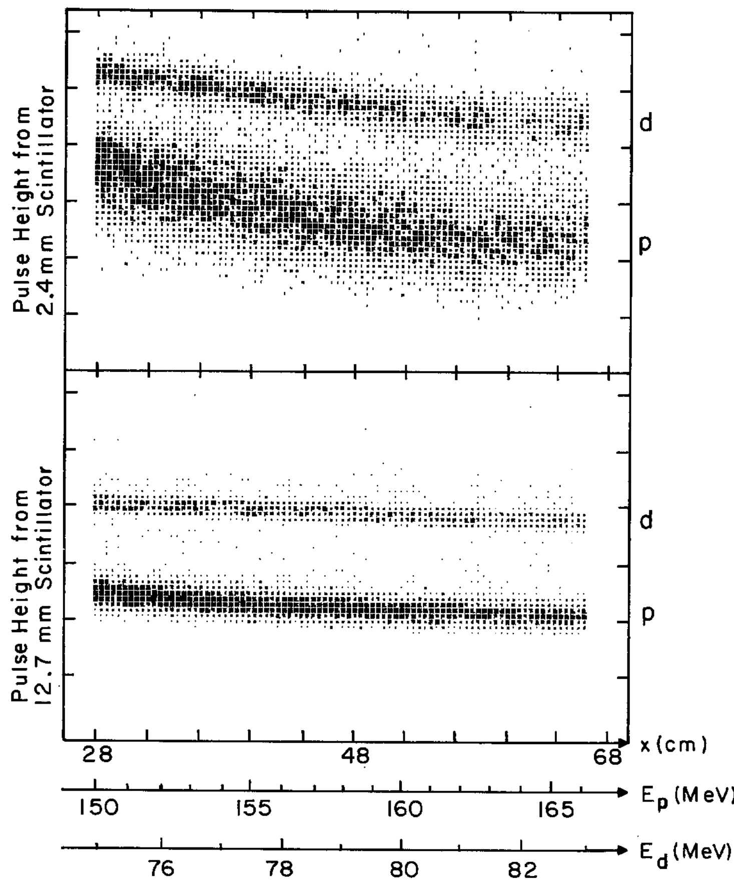

Fig. 4. Variation of pulse height from 2.4 mm thick and 12.7 mm thick counters with position, x, along the length of the scintillator. The approximate energies of the protons and deuterons as they enter the thinner counter are also shown.

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