Univerza v Ljubljani

Institut "Jožef Stefan" , Ljubljana

61 111 Ljubljana, Jamova 39, pp 100 / Tel :+386 61 177 3900 / Fax : +386 61 125 7074

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Acceptance of some light guide based light collection systems for the HERA-B RICH

R. Pestotnik[a,c]

[a] *"J. Stefan" Institute, Ljubljana, Slovenia,*

[c] *Faculty of Mathematics and Physics, University of Ljubljana, Slovenia*

Abstract

As a part of my diploma thesis [1] a study was carried out to understand the performance of light guides as possible light collectors for the HERA-B RICH counter.

1 Introduction

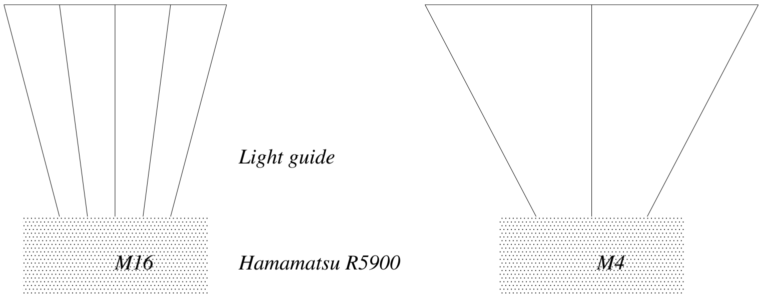


Figure 1: Light guides coupled to two different multianode PMT types.

The Hamamatsu R5900 photomultiplier tubes employed in the HERA-B RICH consist either of 4×4 anodes (R5900-M16 type), each occupying an active area of 4.5mm$\times$4.5mm, or of 2×2 anodes with two times larger sides (R5900-M4 type). On the other hand, the R5900 tube covers an area of 30mm$\times$30mm. Hence, the active surface fraction amounts to only 36% in the case of dense tube packing. The loss of Čerenkov photons would be unacceptably high in this case. The active area can be increased by a system of light guides, as shown in Fig. 1. Such a system would also allow for varying granularity over the photon detector area. While in the peripheral part of the detector a coarser granularity is sufficient (e.g. 27 mm$\times$27 mm in combination with a R5900-M4 type PMT), in the central part it has to be finer (e.g. 9 mm$\times$9 mm in combination with a R5900-M16 type PMT). In addition, an intermediate granularity of 16 mm$\times$16 mm in combination with R5900-M16 is considered as well.

2 Performance of light guides

By using computer simulation, I have compared several possible solutions. I have tried to simulate as realistically as possible the processes in the light guides. Due to the symmetry of the system (I have assumed the distribution of incident angles as expected in the HERA-B RICH, and have assumed that it is axially symmetric at each PMT tube) I have only simulated one quadrant of the system. The simulation was used to calculate the efficiency for light guides, consisting of tetrahedrons with exit windows parallel to the PMT entry window, and entry windows which were either parallel to the exit window or or slanted. I have varied the length of the light guide and the angle of the entry window relative to the exit window.

The following processes were simulated in each event:

- generation of a polarized photon uniformly over the entry area according to a given angular distribution,
- refraction at the entry window,
- photon tracing to the nearest wall,
- reflection at the wall,
- photon tracing to the exit window and subsequent refraction,
- photon tracing over the gap to the entry window of the photomultiplier tube,
- absorption in the matter.

Let me note that a comparison with results of test beam measurements has shown that the simulation describes well the losses, such that there was a good agreement of measured and calculated light collection efficiencies.

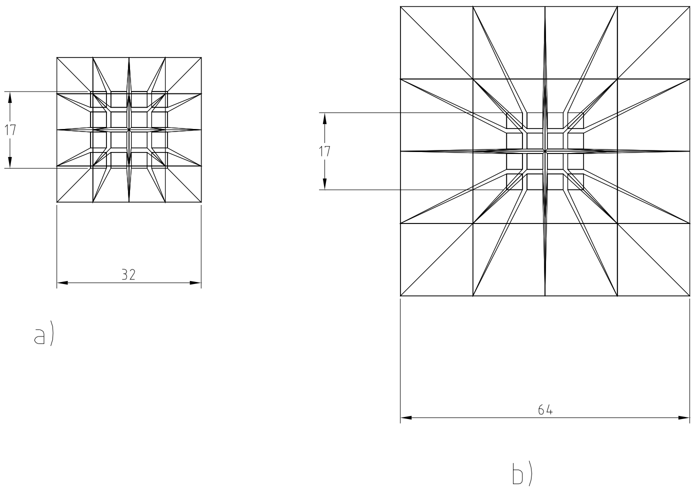


Figure 2: Light guides front view: entry windows have pads of 8mm×8mm (left) and 16mm×16mm (right), exit windows are 3.5mm×3.5mm.

When designing light guides of solid materials I have taken advantage of the fact that inside the light guide for incidence angles higher than the angle of total internal reflection the reflectivity R equals to one. For angles smaller than the total internal reflection angle

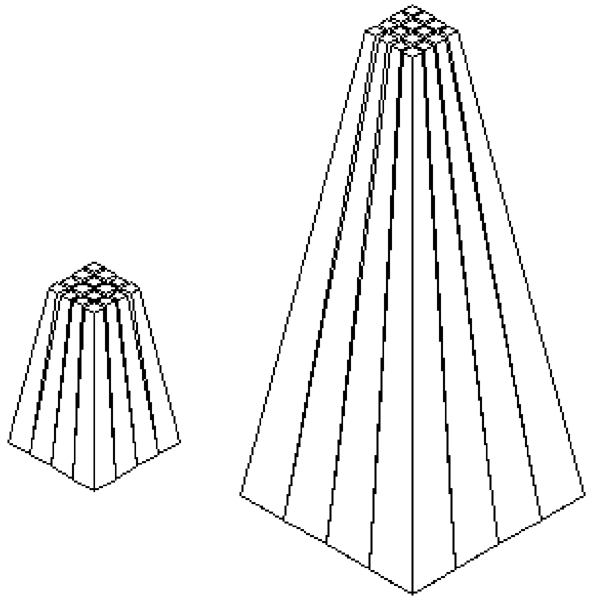


Figure 3: A three-dimensional view of $8mm \to 3.5mm$ and $16mm \to 3.5mm$ light guides.

the reflectivity quickly drops to a few percent, and the photon gets refracted out of the light guide. In shorter light guides the fraction of refracted light exiting the light guide at the side walls is rather high. In longer light guides this loss is reduced, but the absorption can become the dominant loss mechanism, in particular in acrylic materials.

We have to note that in order to make use of the total internal reflection, the individual light guides have to be separated at the exit surface. As a result, the exit windows have to be somewhat smaller than the PMT pad pitch, e.g. 3.5 mm (or 4 mm) instead of 4.5 mm. Since the angular distribution of photons exiting the light guide is considerably broader than the incoming distribution, such a separation is also necessary to minimize the optical cross-talk between neighboring channels.

I have studied the performance of light guides made of quartz, two types of acrylic and an air based light guide with reflective walls. Fig. 4 shows the transmission of the two IV transmitting acrylic materials [2]. The transmission of quartz was assumed as given in [3].

In particular the side and corner units are in the case of short light guides inefficient (Fig. 6). While such kind of loss is less significant if the light guides are longer, the performance becomes in this case limited by absorption. The longer light guide case might also be problematic because of the weight of the material which would have to fit to the surface of PM tubes.

The significance of the length problem critically depends on the demagnification required, i.e. it is much less pronounced in the case of peripheral units with a demagnification from 27mm$\to$9mm (reaching the maximal efficiency of 55% at the length of about 6cm) than in the case of the 16mm $\to$ 3.5mm demagnification light guides (with a length of 15 cm (Fig. 9).

I have also studied light guides with reflective walls. There the advantage is the absence

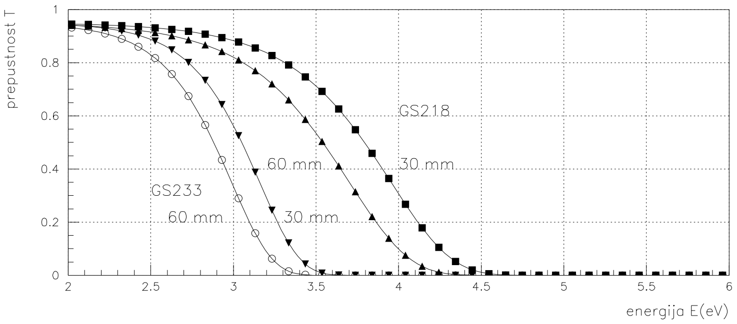


Figure 4: Transmission of acrylic materials GS218 and GS233 for 30 mm and 60 mm thickness.

of attenuation in the bulk. Assuming a reflectivity of $R = 0.90$ we observe (Figs. 7 and 5) that for longer light guides the transmission is again decreasing due to an increased number of reflections.

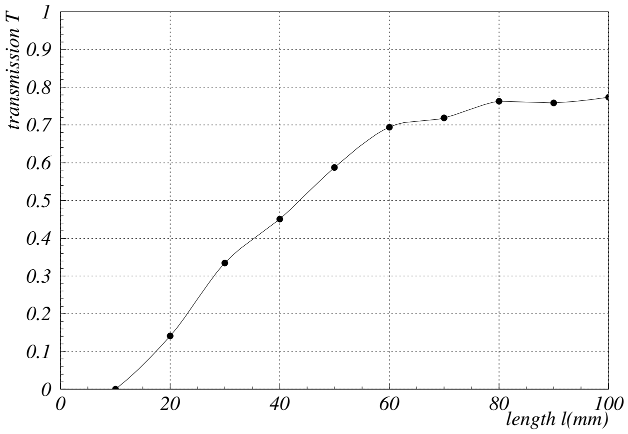
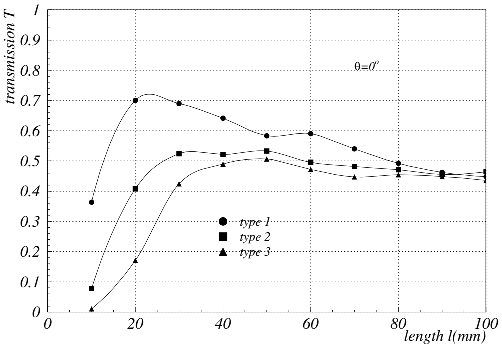


Figure 5: Transmission of a light guide with reflective walls and a demagnification of 27mm$\times$27mm$\rightarrow$9mm$\times$9mm, as a function of the length of the light guide.

Clearly the ideal material would be quartz due to its small absorption, but the question is whether out of quartz such forms as shown in Figs. 2 and 3 can be fabricated at all, and what would the cost of production be. In the case of acrylic material the production is expected to be much less problematic, since one would probably be able to use molds as in the fabrication of plastic lenses.

One way how to decrease the number of reflections and the path length is to employ light guides with entry surfaces at an angle relative to the exit surfaces as shown in Fig. 8. With such slanted entry surfaces the number of reflections is decreased, and so is the path length. As a result, the homogeneity over the entry surface is improved. In Fig. 6 the efficiency of light collection is plotted for light guides of acrylic GS218 material for the slanted case with a relative angle of $\theta = 35^0$ for side elements (and a corresponding larger angle for the corner elements), and parallel ($\theta = 0^0$) entry surface. We observe that by using slanted entry surfaces the differences in transmission among the corner light guide elements (type 3) and the central elements (type 1) are greatly reduced.



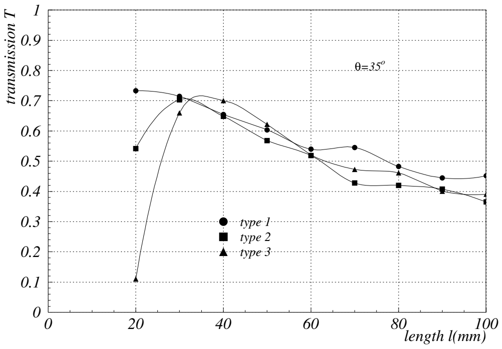


Figure 6: Efficiency of light collection for light guides of acrylic GS218 with slanted ($\theta = 35^0$ for side elements) (right) and non-slanted $\theta = 0^0$ (left) entry surfaces, shown separately for the corner light guide elements (type 3), sides (type 2) and the central elements (type 1) of the 4x4 matrix.

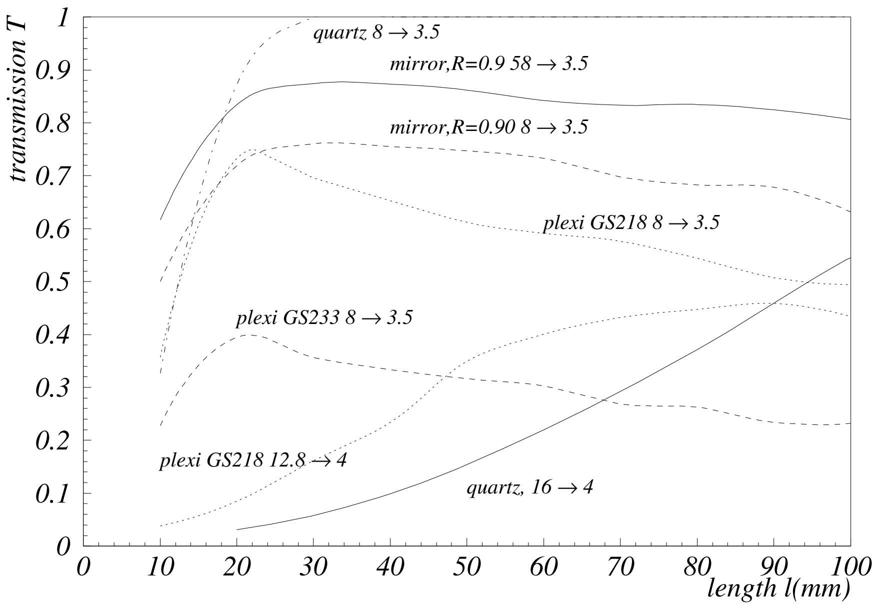


Figure 7: Transmission of light guides made of various materials, all in optical contact with the PMT entry window.

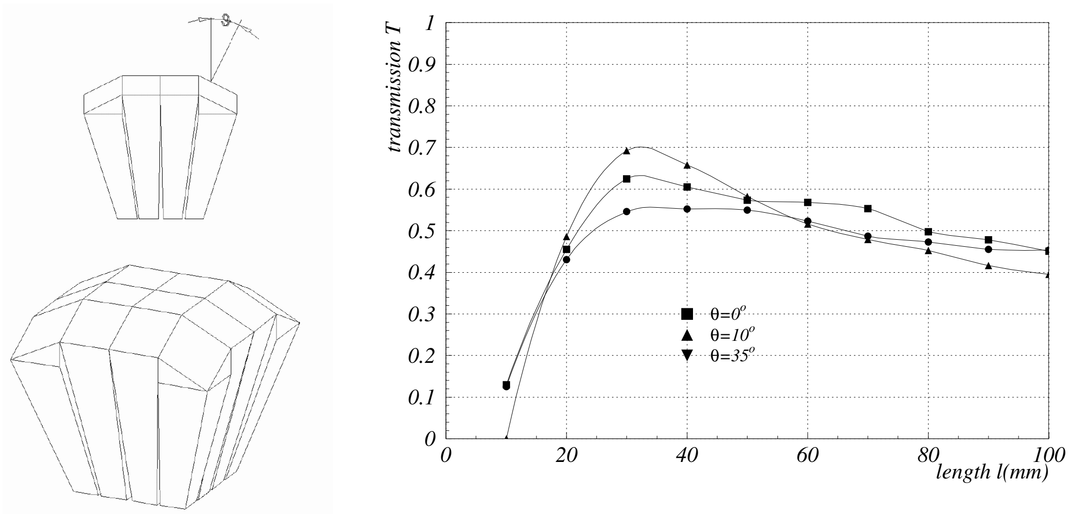


Figure 8: Transmission of light guides of GS218 UV acrylic 8mm→4mm with slanted entry surfaces, for three different values of the side element angle ϑ. Between exit surfaces of the light guide and the entry window of the photomultiplier tube a 0.5 mm wide gap was assumed.

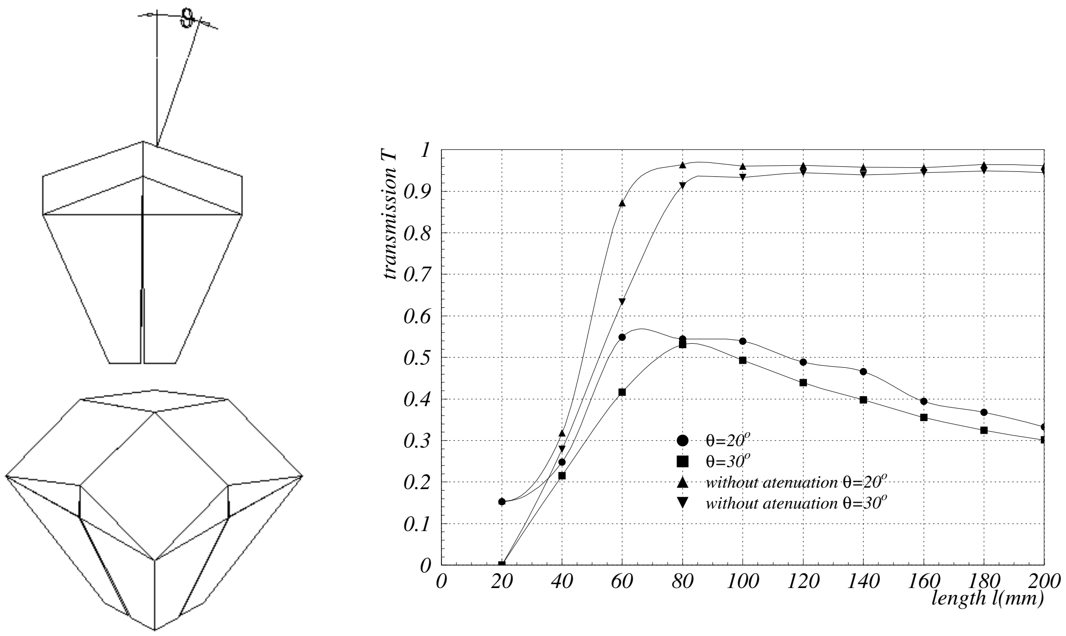


Figure 9: Transmission of light guides with a demagnification of 27mm→9mm with slanted entry surfaces, for two different angles. Two different materials were considered, acrylic and quartz. A 0.5 mm wide gap was assumed between the exit surface of the light guide and the entry window of the photomultiplier tube.

3 Summary

In a study carried out within my diploma work which was primarily aimed at testing the multianode PMTs as detectors of single photons [5], I have also investigated various systems for light collection with light guides. The results show that a light guide of demagnification $8 \times 8 \rightarrow 3.5 \times 3.5$ transmits about 70% of incident Čerenkov photons in the case of the HERA-B RICH. The study showed that for this both a light guide made of UV acrylic material with slanted walls as well as a light guide with reflective walls (R=0.9) of 30 mm length could be used.

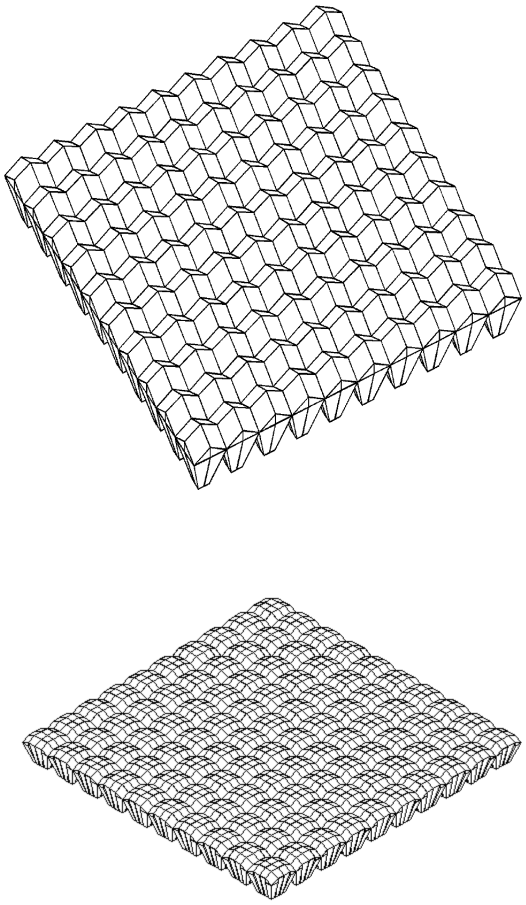


Figure 10: One of the possible solutions of layout of the system of light guides from Figs. 8 and 9.

For a coarser focal plane granularity with a demagnification of $27 \times 27 \rightarrow 9 \times 9$ somewhat longer (about 60 mm) light guides are needed. As a result the acrylic based light guide transmits less Čerenkov light (about 50%), while a light guide with reflective walls would have a transmission of 70%. This latter number is derived under the assumption that a reflectivity of 0.9 at each reflection can be achieved, which may be quite realistic, since most of reflections are under grazing angles.

In Fig. 10 it is shown how such an array of light guides could be designed. If produced in a mold, a multiple of the individual cell could already be fabricated, which would greatly simplify the installation and relative alignment.

References

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[3] Suprasil 2 data sheet, Haereus GmbH, Germany.

[4] Hamamatsu, Final test sheets of the photomultiplier tubes H6568-30 ser. no. 5M26C6, 16A19C4, and H6568 ser.no. 6C22C1., Hamamatsu Photonics K.K., Shimokanzo 1996

[5] R. Pestotnik et al., submitted to Nucl. Inst. Meth. A.