Timing Characteristics of Scintillator Strips

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Abstract

The proposed Hall D detector at Jefferson Lab (JLab) will have a time-of-flight detector composed of long and narrow scintillator strips. We have evaluated the time resolution of two strip prototypes in particle beams at the Institute for High Energy Physics (IHEP) in Protvino, Russia. The strips are 2.0 m long and have square cross sections of size $(2.5\ cm)^2$ and $(5.0\ cm)^2$ respectively. In this paper we present results on how the signal size, timing, and time resolution of each of these strips depend on the entry position of the beam into the scintillator, on the material used for scintillator wrapping and on the phototube used for the readout.

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1 Introduction

The proposed Hall D [1] project at Jefferson Lab in Virginia will use a hermetic detector to search for photoproduced mesons which carry quantum numbers (J^{PC}) that are exotic, i.e. cannot be formed from a simple $q\bar{q}$ combination. The detector is optimized for incident photon energies from 8 to 10 GeV. In order to carry out the spin analysis needed to identify exotic quantum numbers, all charged particles in an event, including the decay products of mesons, must be momentum analyzed and identified as π, K or proton (p). This identification will be carried out using an atmospheric gas (C_4F_{10}) Cerenkov counter and a time-of-flight (TOF) wall. The latter will consist of two orthogonal planes of scintillator strips. The strips will be 2 m long with square transverse cross-section of dimension yet to be determined. The width will be between 2.5 and 5.0 cm. The timing resolution must be less than 100 ps.

In this paper we report on measurements of time resolution as a function of the scintillator wrapping and type of phototube for 2-m-long scintillar strips of different transverse dimensions.

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2 Experimental Arrangement

The two strips that were tested were 2 *m* long and had a square cross section of $(2.5\ cm)^2$ and $(5.0\ cm)^2$ respectively. The scintillator is type EJ-200, purchased from the Eljen Corporation. This scintillator has a decay time of 2.1 *ns*, a bulk attenuation length of 4 *m*, an index of refraction of 1.58, a peak in the emission spectrum at 425 *nm*, and a light output equal to 64% of that of Anthracene. The surfaces of two of the four long sides of each strip were in contact with the casting form and had no other preparation. The other two long sides and the two ends of each strip were diamond fly-cut in order to minimize loses due to surface imperfections. A phototube was placed on each end of each strip. The two strips, with their phototubes, were placed in a light-tight box. The beam was a low energy positive beam with variable energy. The $e/\pi/K/p$ composition varied with beam momentum. We ran at momenta from 3.3 to 40 GeV/c, but just utilize the 40 GeV/c data here to show general features of our results in the next section. At 40 GeV/c over 99% of the beam was either pions or protons. The strips were either bare or wrapped, and a partition inside the light tight box prevented optical cross talk between the strips.

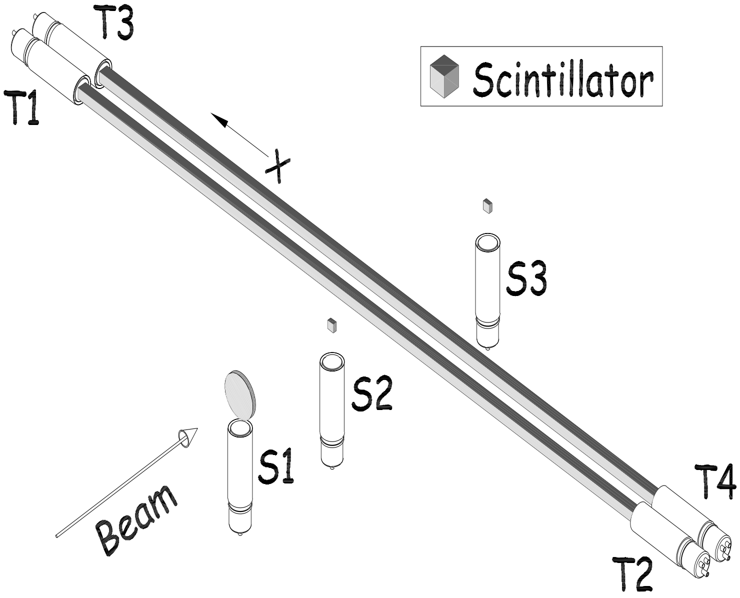

Fig. 1. Experimental setup for TOF measurements.

The layout of the apparatus at IHEP is shown in Fig. 1. Phototubes T1 through T4 were placed at the ends of the strips. The T phototubes were coupled with BC-630 Silicone Optical Grease (index of refraction 1.465) from Bicron. The strips could be moved transverse. to the beam. We define x as the position of the center of the long scintillator relative to the beam.

We operated at a maximum beam intensity of $5 \cdot 10^5$ particles per 1-second spill. The beam defining counters shown in Fig. 1 are S1, S2, and S3. The cross sectional size of the beam was large compared to the 2 cm by 2 cm size of S2 and S3. S2 and S3 were each 1.25 cm thick and both coupled to an XP2020 phototube with a 5 cm air gap. S1 was not used for timing purposes or to define the effective size of the beam.

3 ADC and TDC Results

In Figure 2 we show how the log of the maximum ADC value (as determined from the Moyal fit) depends on the beam entry position along the x-axis. The data deviate noticeably from a exponential-line fit, shown in the figure. Thus the ADC data do not have an exponential dependence on x. However, a Monte Carlo investigation shows that the shape of the data are consistent with a model of photon propagation in which there is a bulk attenuation of 4 m and a loss per surface reflection of 1%.

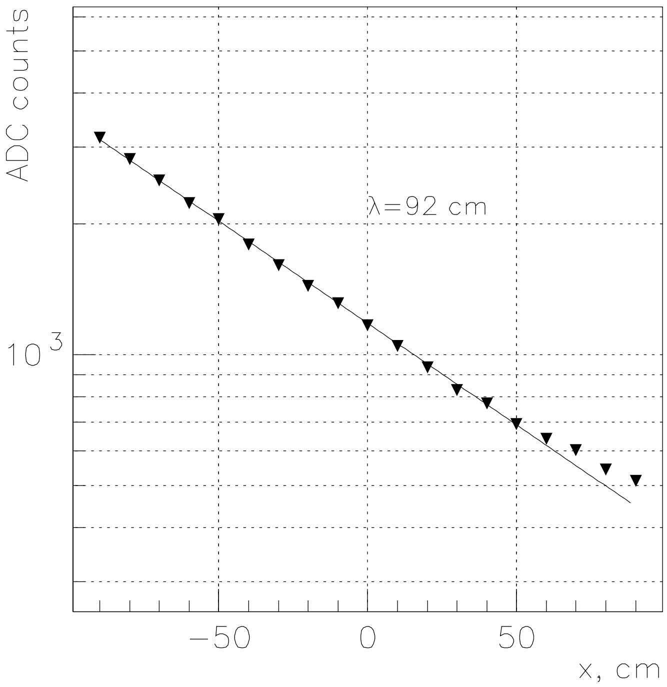

Fig. 2. Average ADC versus x position.

The average T1 TDC time versus x is plotted in Figure 3. The slope of this line leads to an effective speed of light along the x-axis of 15.6 cm/ns. Using the index of refraction of the scintillator, we conclude that the average angle of the light with respect to the x-axis is 35 degrees. This result does not depend on the bar size or the wrapping of the bar or the beam momentum.

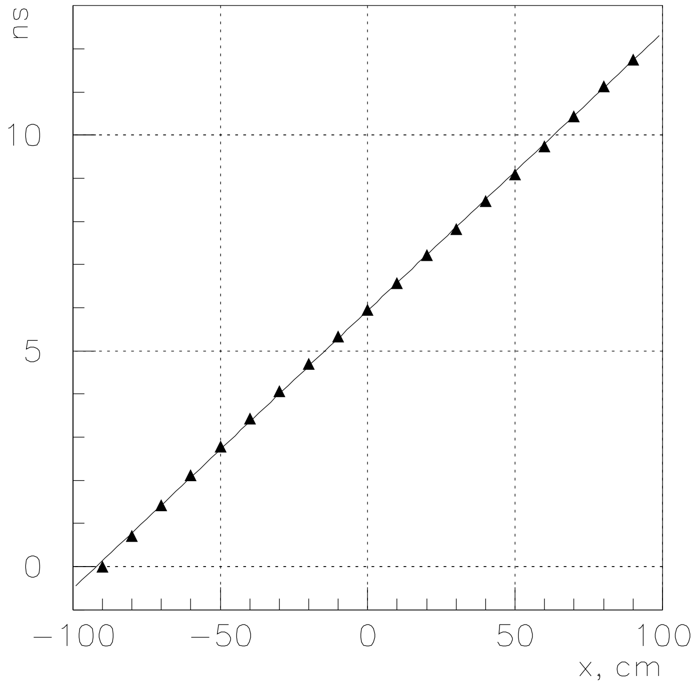

Fig. 3. The average T1 TDC time versus x.

Figure 4 shows the time resolution versus x. As expected, the resolution improves when the beam gets closer to T1 or T2 due to the increased pulse height. Specifically,

$$T_{av} = \frac{T_1 \sigma^2(T_2) + T_2 \sigma^2(T_1)}{\sigma^2(T_1) + \sigma^2(T_2)}, \tag{1}$$

where T_1 represents the time of the pulse from T_1 (corrected for travel time along the strip) and $\sigma(T_1)$ is the time resolution of T_1. (σ is the standard deviation of the Gaussian shape of the time resolution function.) σ depends on the signal size and thus on where the particle hits the strip along the x-axis of the strip. From this relationship we can calculate the time resolution of T_{av}, $\sigma(T_{av})$, from that of T_1 and T_2.

$$\frac{1}{\sigma^2(T_{av})} = \frac{1}{\sigma^2(T_1)} + \frac{1}{\sigma^2(T_2)} \tag{2}$$

In Figure 4 we indicate $\sigma(T_{av})$ versus x, open circles for the 5.0 *cm* bar and closed triangles for the 2.5 *cm* bar. We note that the time resolution is worse where the beam goes through the center of the strip, at $x = 0$. Also, the time resolution in the center is poorer for the 2.5 *cm* bar (101 *ps*) than for the 5.0 *cm* bar (87 *ps*). (These time resolutions are about 10% higher than those obtained by correcting for the finite size of the trigger counters.)

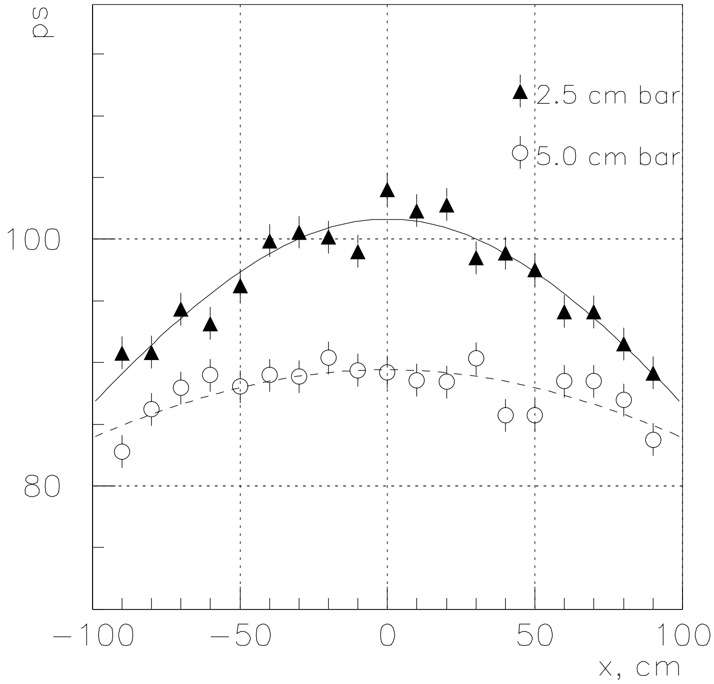

Fig. 4. $\sigma(T_{av})$ time resolution versus x.

4 Dependence on Wrapping

We investigated scintillator wrapping and phototubes in the 40 GeV/c beam. For this work, no optical coupling was used between the phototubes and the scintillator strip. Table 1 shows how the light attenuation length and time resolution depend on the three wrapping conditions, bare (no wrapping), Aluminum foil (shiny side in) and Tyvek. The error on the time resolution is approximately ±2 *ps* .

A fit of the ADC data to an exponential yields an attenuation length which depends on the number of data points used in the fit, since the data themselves are not exponential in nature.This is shown for T1 in Figure 2. In Table 1 we show the attenuation length from an exponential fit to the three data points farthest from the phototube, to be used as a figure-of-merit. In Table 1 we correct for the common start time resolution but not for the finite size of the

Table 1
Attenuation length and time resolution for the 2.5 and 5.0 cm bars with different wrappings. The error on quoted time resolutions in all cases is 2 *ps*

	Attenuation Length (cm)	Time Resolution in Center of Bar (ps)	Time Resolution 10 cm from Bar End (ps)
2.5 cm Bar			
Bare	141 ± 14	100	85
Aluminum Foil	143 ± 14	102	81
Tyvek	134 ± 13	107	96
5.0 cm Bar			
Bare	248 ± 25	86	80
Aluminum Foil	292 ± 29	89	86
Tyvek	217 ± 22	97	89

trigger counters.

We conclude from Table 1 that the 5.0 *cm* bar has a smaller attenuation length than the 2.5 *cm* bar, with a typical effective attenuation length of about 250 *cm* versus 140 *cm*. (The errors on the attenuation length are estimated, largely from comparing the redundant results coming from the two phototubes.) There is no large variation between the three wrapping states, though there is an indication that Tyvek has the poorest (smallest) attenuation length.

As is the case for the attenuation length, the time resolution in the center of the bar and at the bar end show a small (if any) dependence on wrapping, though (again) there is a definitely superior time resolution for the 5.0 *cm* bar compared to the 2.5 *cm* bar. In Table 1 the time resolution is for T_{av}, after correcting for the common start time resolution but without correcting for the height of the trigger counters. The 2.5 *cm* data indicate that the Tyvek wrapping has a somewhat inferior time resolution, a result consistent with a smaller signal due to more light attenuation. In the 5.0 *cm* data the Tyvek time resolution is closer to the other two conditions, presumably because of an abundance of light. (The 5.0 *cm* strip has double the light produced, and the attenuation of its light is much less, as discussed above.) We conclude that wrapping of Aluminum foil is slightly preferred to Tyvek, but a much clearer choice is the use of 5.0 *cm* strips instead of 2.5 *cm* strips.

Table 2
Time resolution for various phototubes.

Phototube	T_{av} Time Resolution (ps)
2.5 cm Bar	
XP2020	102
FEU 115	172
Hamamatsu R5506	167
Hamamatsu R5946	102
5.0 cm Bar	
XP2020	89
XP2020/UR	82

5 Studies of Phototubes

We used five different phototubes on for the strip readout. In the first comparison we placed four of them all on the 2.5 *cm* strip that was wrapped with Aluminum foil and sent the bean through the center of the strip. The top of Table 2 shows the time resolution, T_{av}, for each of the four tubes. We only had one of each the Hamamatsu phototubes (the last two phototubes in the table entries) so $\sigma(T_{av})$ was calculated (following the procedure similar to that described above) from the time resolution of a single phototube. As in Table 1, the time resolution is corrected for the common start time resolution of 80 *ps* but is not corrected for the size of trigger counter.

In the next comparison we put an XP2020/UR on one end of the 5.0 cm bar and an XP2020 on the other end. From the individual time resolutions for each tube we calculate a time resolution for T_{av} as in Table 2. The results are in the bottom section of Table 2. We conclude that the time resolution of the Hamamatsu R5946 and the XP2020 are about the same, while the XP2020/UR has a slightly better resolution.

6 Conclusion

of scintillator strips for a negative 40 GeV/c hadron beam. The strip sizes and beam energies were chosen to be appropriate for the Hall D experiment planned for Jlab. We also investigated the dependence of these characteristics on scintillator wrapping and type of phototube. We appreciate financial support from the US Department of Energy and the Russian RFBR, and valuable contributions from I. Polezhaeva, A. Godov, A. Romadanov, I. Beljakov, S. Zvjagintsev, I. Shvabovid, and A. Soloviev.

References

[1] http://dustbunny.physics.indiana.edu/HallD/