FIBER SCINTILLATORS COUPLED TO A MULTIANODE PHOTOMULTIPLIER
AS A HIGH RATE TRACKING DETECTORM. Salomon, H. Coombes, M. Nissen and J.G. Rogers
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Summary

We have studied the properties of a photomultiplier with two sets of orthogonal anode wires. We measured the gain and the position response of this device using a point light source, extended scintillators and fibre scintillators in several geometries. Tests were done with sources and in a pion beam. In addition we studied the high rate capabilities of the device.

Introduction

During the last two years we have studied¹ the properties of photomultipliers with imaging capabilities.² These devices consist of a flat photocathode, followed by several transmission dynodes and some type of segment anode. They have all the properties of normal photomultipliers but are also capable of giving information on the initial photon position.

This property can be very useful in many applications, for instance in medicine where single and coincidence photon detection has been used in scanners and tomographs. In particle physics it can be used in imaging Cerenkov devices or, as will be shown in this paper, in conjunction with fibre scintillators³ as a tracking device. Although the use of these scintillators is not new, they have received recent impetus with the need to observe short-lived particles and as very fast position detectors.

There are several types of anode segmentations now available. A set of parallel anode wires, useful as a one-dimensional position device, two sets of anode wires for (X,Y) identification, and also a set of pads forming a regular grid. The choice of geometry will depend on the requirements of each application. The manufacturers of these devices are Hamamatsu⁴ and Philips.⁵

General Properties

The photomultiplier described here (R2486) was manufactured by Hamamatsu and has external dimensions of 7.6 cm diameter and 5.5 cm long. It has a flat bi-alkali photocathode, 11 transmission dynodes, two sets

of anode wires and a reflecting dynode. A section is shown in Fig. 1. The two sets of anode wires form a 12x12 grid in the X and Y direction. They have a pitch of 4 mm and their length is 5 cm.

The tube was mounted on a support which contained the divider chain (100 k Ω between each dynode and 300 k Ω between the cathode and first dynode). The tube was operated at 1400 V. (The maximum recommended voltage is 1500 V.).

Initial tests were done connecting all anodes together and using a NaI(Tl) scintillator (7.5 cm diameter and 7.5 cm long) with a ²²Na gamma source as well as a plastic scintillator (1x2x2 cm³) with a ²⁰⁷Pb electron source. From these measurements we determined the gain of the tube to be $(1.0 \pm 0.2) \times 10^6$ at 1400 V and a photocathode efficiency of $(20 \pm 5)\%$, assuming 1 photon/35 eV in NaI and 1 photon/140 eV in the plastic scintillator. With this last scintillator the rise time of the pulses was 4 ns and the total pulse duration was 14 ns. The energy resolution obtained with the ²²Na source was 8% FWHM for the 511 keV peak.

Response to a Collimated Light Source

We studied first the response of the phototube to a collimated light source of 0.4 mm diameter, obtained with a small green light emitting diode which could be moved remotely and was mounted inside a dark box as shown in Fig. 1. Independent signals from all anodes and the last two dynodes could be measured and plotted. Operating in the dc mode we recorded the current in the individual anodes while sweeping the light source across the cathode surface. The results are shown in Fig. 2.

A similar procedure was used for the dynodes 11 and 12. These results are shown in Fig. 3.

Fig. 1. Experimental set-up to test the phototube with a collimated light source. The LED which operated in a dc or pulsed mode could be moved accurately and remotely across the cathode face in both X and Y directions.

Fig. 2. The current output of individual anodes while sweeping the light centrally across the cathode perpendicular to the recorded anodes.

Fig. 3. The current from dynode 11 while sweeping the light in the X and Y directions through the centre of the cathode.

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Fig. 4. The light source now operating in the pulsed mode and positioned at 5 points on the cathode separated by 1 mm. The digitized charges of the anodes were used to calculate the centre of gravity GY in Eq. (1) with an on-line computer.

Several conclusions can be drawn from these measurements. First, there is a ripple present in the X direction which, after inspection of the tube, was discovered to be produced by a parallel grid that supports the dynodes. It degrades details that are of the order of its pitch, which is 0.6 mm. From the dynode response we determine that uniformity of the cathode and the gain in the dynodes is of the order of 10%. The two peaks in the Y scan correspond to two supporting wires running perpendicular to the parallel grid described above.

The anodes have gain differences of up to 25% but more serious is the nonuniformity of their position. Direct inspection of the tube showed anode misalignments of up to 15% of the pitch. There were distortions near the edges which reduce the imaging region of the cathode surface to approximately 5 cm in diameter. The average Y anode gain was 20% larger than that of the X anodes.

Operating the LED in the pulsed mode, and using a system described in our previous papers,¹ we determined the position resolution of the device using the centre-of-gravity method:

$$\begin{aligned} GX &= \sum_i X_i C_i Q_i / \sum_i C_i Q_i, \\ GY &= \sum_j Y_j C_j Q_j / \sum_j C_j Q_j. \end{aligned} \quad (1)$$

The X_i and Y_j terms were determined from the maxima locations of Fig. 2, the C_i coefficients correcting for the different gains of each anode were obtained as the reciprocal of the peak height of each anode, and the Q_i are the charges collected in anodes i for each event and digitized in two Lecroy 2249 W ADC.

In Fig. 4 we show the quantity GX obtained with the light pulser in 5 different positions separated by 1 mm near the centre of the tube. These results indicate a FWHM resolution of 0.2 mm. The number of photons per pulse was approximately 10^4 .

Response with Fibre Scintillators

We have tested two types of scintillating fibres. Both had a styrene base and a square cross section. One, manufactured by Fiber Optics Development,⁶ had a 1 mm side and thin acrylic cladding, and the other, manufactured by Bicon,⁷ had 2 mm sides and no cladding. Both had an attenuation length of about 30 cm in the first 60 cm but a reduced attenuation at longer distances. This is due to the different contributions

Fig. 5. The centre-of-gravity plot GX vs GY for events produced using a picket fence of scintillating fibres placed at 45° with respect to the anodes. The scintillators were exposed to a ^{106}Ru source.

to light loss along a fibre. They include self absorption, surface defects, thickness fluctuations and overlap of the emission and absorption spectra.

Both fibres produced about the same number of initial photons, 1 photon per 150 eV deposited, as measured with the Compton edge of the gamma rays of ^{60}Co and electrons from a ^{106}Ru source. This is comparable to standard plastic scintillators. In the tests described below we used mostly the Bicon fibres.

Two geometries were tested. A picket fence of 25 parallel fibres, each 5 cm long and separated by 3.5 mm from each other, were placed in a straight line and directed perpendicular to the photocathode surface. No optical coupling was used. The fibre ends were polished and each fibre was optically isolated with aluminized mylar wrapping. The line of fibres was placed at 45° with respect to the X and Y anodes. They were illuminated with a ^{106}Ru source. A large scintillator behind the fibres in coincidence with any anode signal defined a valid event. Again the centre-of-gravity method was used as described in the previous section. A plot of GX vs GY obtained in this fashion is shown in Fig. 5. The average energy loss of the electrons in the fibre was 500 keV. The FWHM of the peaks obtained was 1.4 mm.

The second geometry used was a bundle of 7×7 fibres close packed in a square configuration, also optically separated by aluminized mylar. The average separation of the fibres was now 2.1 mm. They were mounted in the centre of the photocathode perpendicular to its surface. Again no optical coupling was used and the ends of the fibres were polished. Tests with a ^{60}Co source producing Compton electrons in one or two fibres could be identified. As the bundle had a thickness larger than the range of electrons from ^{106}Ru , it was necessary to test the fibre bundle in a penetrating beam.

Tests in a Pion Beam

In order to test the device with tracking particles we used the two above-mentioned geometries in a pion beam in the M9 pion channel at TRIUMF. The beam momentum was 96 MeV/c and scintillators in front and behind the fibres helped to define a beam of known geometry. The event definition included these scintillators and any of the anodes of the photomultiplier.

The result with the picket fence fibres is shown in Fig. 6 and indicates a resolution of 0.8 mm FWHM. This value is better than the result with sources because of a larger energy loss of pions and a better

Fig. 6. A histogram of G_Y for the picket fence geometry of fibres. Here the events are produced by a 96 MeV/c pion beam.

defined geometry. Also evident are the distortions due to incorrect values of Y_i near the edges.

Several angles between the beam and the fibre bundles were tested. If one assumes a single track per event and that the particle did not react in the bundle, it is possible to calculate the slope of the track with respect to the anode wires by calculating the second moment of the anode charge distribution. We define the quantity "slope" S as

$$S = \frac{\sqrt{Y^2 - GY^2} - DY0}{\sqrt{X^2 - GX^2} - DX0}, \quad (2)$$

where $DY0$ and $DX0$ are two parameters obtained experimentally. The variable S is calculated on line during the data-taking and the result is shown in Fig. 7 for the 45° case. The FWHM or resolution was 5° . Similar values were obtained at other angles with the same resolution.

High Rate Tests

The tests to determine the high rate capabilities of this device were performed with the picket fence fibres and sources. We used a ^{106}Ru and a ^{60}Co source,

Fig. 7. A histogram of the slope S defined in Eq. (2) as calculated on line for a pion beam traversing a bundle of fibre scintillators. The beam was directed at 45° with respect to the anode wires.

both of about 1 mCi intensity. Placing one source near one fibre and then the second one on the same or another fibre and scaling the corresponding anodes individually, we could determine the rate capability of the photomultiplier. We also modified slightly the divider chain by replacing the last two resistors between dynodes 10,11 and the anode by Zener diodes providing voltage drops of 100 V each. Each anode was coupled to a discriminator with a 5 ns output pulse fed to a scalar with 100 MHz capability.

A single anode could count at a rate of 8 MHz without significant loss (less than 1%). Two consecutive anodes could count at 20 MHz with similar loss. Therefore, for a uniform illumination of the cathode we expect this phototube to have a rate capability in excess of 100 MHz.

Conclusions

We have studied the properties of a photomultiplier with two-dimensional position information coupled to an array of scintillating fibres in two different geometries. We also studied the imaging characteristics of the photomultiplier using a point light source.

The studies indicate that the device is useful over a cathode area of about 5 cm diameter, has an intrinsic resolution of about 0.4 mm which deteriorates with decreasing number of photoelectrons and requires a centre-of-gravity calculation to extract position information. It can be used in conjunction with fibre scintillators in several possible geometries which must be tailored to the requirements of each experiment. If multitrack resolution is required, the anodes should be further segmented into pads. It can operate at a very high rate, up to about 100 MHz, making it the fastest imaging photon detector available.

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