A hybrid pixel detector for readout of scintillating fibres

RD 19 Collaboration
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Abstract

A pixel detector for visible photons has been developed for low-cost, high-speed readout of scintillating fibres and imaging applications. The device is a hybrid assembly of a high-resistivity silicon detector array, bump-bonded to a CMOS binary readout chip. Sensitivity to visible photons is obtained by modifying the rear metal contact on the detector. The 2-D hybrid array presently consists of 1006 pixels of 75 \( \mu \text{m} \times 500 \mu \text{m} \) dimensions. Scintillating fibre ribbons are coupled to the detector array using one stage of light amplification provided by a micro-channel plate (MCP) image intensifier with fibre-optic faceplates. The device currently used has a maximum photon gain of \(~ 1000\) with a photocathode spectral sensitivity matched to the emission spectrum of SCSF-38 blue scintillating fibres. With this set-up, tracks from a \(^{90}\text{Sr}\) collimated \(\beta\)-source in a five-layer ribbon of 500 \( \mu \text{m} \) diameter fibres have been clearly observed. A test has been performed in a high-energy particle beam and a maximum detection efficiency of 51% measured. Performance limitations are understood and plans made to improve the system.

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1 INTRODUCTION

We have developed a novel readout system for scintillating fibres based on the combination of a silicon pixel detector and a micro-channel plate (MCP) image intensifier. Light emitted from the fibres is amplified in the MCP device and picked up by the photo-sensitive pixel detector. This system could offer considerable cost savings on multi-anode photomultipliers.

Pixel detectors offer the combined advantages of very high spatial precision and high readout rate. In its present form, the pixel detector has a matrix of 1006 sensitive elements, each with dimensions of 75 μm × 500 μm [1]. Although it was designed for direct particle detection the detector can be adapted to make it sensitive to visible photons [2]. Obviously, the present rectangular shape of the pixel is not well adapted for fibre applications, but the aim of our study was to prove the feasibility of such an approach.

Firstly, we describe the set-up of the system along with its calibration. Following calibration we performed radioactive source measurements in the laboratory. As these gave encouraging results, we then made a test with a high energy particle beam in order to understand the detection efficiency of the system. Finally, we discuss the performance limits of the present system and how these could be overcome by the new approach.

2 SYSTEM SETUP AND CALIBRATION

Figure 1 shows the set-up we used to calibrate our system. The image intensifier is the 1450R from DEP [3]. At the input to the image intensifier is a type S20 photocathode with a peak sensitivity at 420 nm and a maximum quantum efficiency of 22%. This is followed by the MCP, which provides the amplification, and then by a type P46 phosphor screen. This screen emits light at 530 nm with a decay time (fast component) of ~ 100 ns.

A first test was performed in order to verify the gain of the MCP. The light from a green LED was focused through a diaphragm onto the photocathode of the image intensifier and the light output from the phosphor screen was detected by a calibrated photodiode. The same photodiode was later used to measure the incidental light, giving a direct measurement of the image intensifier photon-gain as a function of the applied voltage across the MCP. The results thus obtained are shown in Fig. 2. These correspond very well to the manufacturer's data sheet. The maximum gain obtained was ~ 1000 for an applied voltage of ~ 900 V. Our standard operating condition was for a gain of 800, corresponding to an applied voltage of 875 V.

We then replaced the photodiode with the photopixel matrix in order to be able to look at the image of the 300 μm diaphragm. The image thus obtained is shown in Fig. 3. The FWHM of the image covers four pixels in the short dimension, corresponding to the 300 μm diameter.

3 TESTING WITH A RADIOACTIVE SOURCE

Having calibrated the system, we then attached the scintillating fibre ribbon as shown in Fig. 4. The fibres were Kuraray type SCSF-38 [4] with a diameter of 500 μm and a peak emission at 430 nm corresponding to the peak sensitivity of the S20 photocathode. The fibre length was 15 cm. The attenuation length of this kind of fibre has been measured at ~ 2 m. The 90Sr β-source, which has a 2 mm collimator, was placed 6 cm from the image intensifier. Random triggers were given to the pixel detector and the beam profile shown in Fig. 5 was...
accumulated. We clearly observed the 2 mm collimation corresponding to 4 pixels in the long dimension, and that there are around 29 pixels hit in the short dimension, corresponding to the 2.1 mm thickness of the fibre ribbon. In this way we verified that the proposed set-up works.

4 BEAM TEST RESULTS

In order to measure the detection efficiency of the system, we used the H6 test beam at the CERN SPS fixed target site. This facility provided 120 GeV/c pions acting as Minimum Ionizing Particles (MIPs). The only modification made to the set-up in Fig. 4 was that the fibre ribbon was replaced by a ribbon of 1.5 m length. The fibre ribbon was then inserted into the RD-19 pixel telescope described in [5]. The geometry of the telescope with the fibres added is shown in Fig. 6. The beam was defined by the crossover of scintillating fibres S3 and S4, which formed a 1 mm × 1 mm area. The distance between this crossover point and the image intensifier was 65 cm. Data was accumulated in all three planes, while the threshold current of the photopixel plane was varied.

To make a first estimate of overall detection efficiency, we selected events with a track in planes 1 and 2 and looked for at least one correlated hit in plane 3. The curve of efficiency versus threshold is shown in Fig. 7. For reference, we added data from a 300 μm silicon pixel detector placed directly in the beam. We observed that the detection efficiency of the fibre set-up measured in this way is around 40%. As each incident particle crosses several fibres, we expected more than one hit in plane 3. Therefore, we defined a track in plane 3 as an event with two or more correlated hits. The track detection efficiency, also shown in Fig. 7, was at best 18%. A further test was made by increasing the MCP bias voltage to ~ 900 V in order to increase the gain of the MCP. In this case the detection efficiency had a maximum of 51.2% and the track detection efficiency a maximum value of 23%.

This leads us to an analysis of the system's limitations. Typically, the number of photons produced by an MIP crossing a fibre and reaching its end is ~ 20 [6]. This means that at 875 V MCP bias one MIP will produce ~ 29 000 photons at the output of the image intensifier. We have corrected the gain measured in the green with the photocathode quantum efficiency at 430 nm. With a quantum efficiency in the green of 70% the pixel detector collects ~ 20 000 e⁻. In the case of the MCP bias voltage of 900 V, the charge delivered to the pixel is typically ~ 25 000 e⁻. In addition, light emitted from one fibre is spread over several pixels (the small pixel dimension is 75 μm whilst the fibres are 500 μm in diameter). As the lowest threshold of the pixel detector is around 8 000 e⁻, the low-track detection efficiency is consistent with the limitations of our system.

A beam profile is shown in Fig. 8. The two columns corresponding to the 1 mm scintillator crossover are clearly evident. Compared with the source measurements there is a large number of background hits. These are not present when the beam is off, and can be explained by particle hits to the fibres outside our 1 mm × 1 mm coincidence.

5 CONCLUSIONS AND FURTHER WORK

We conclude that a system which combines silicon pixel detector and MCP image intensifier offers a very interesting alternative to multi-anode photo-multipliers for readout of scintillating fibres. While the advantages of a high spatial resolution are maintained, system cost is kept to a minimum. The pixel detector offers a much greater readout speed than that offered by CCDs. The image intensifier chosen behaved exactly according to the manufacturer's...
specifications. Tracks were detected by the pixel detector both using a radioactive source and a high-energy particle beam. The total detection efficiency is limited at present by the quantum efficiency of the photocathode, the minimum threshold of the pixel detector and the shape of the pixel itself.

There are several ways of optimizing this system in a future version. We are studying the use of an image intensifier produced by Intevac [7] which uses a GaAsP photocathode with a peak quantum efficiency of 39%. A new pixel readout chip is being developed with a lower minimum threshold. It would also be beneficial if the pixel dimensions were better matched to the fibre diameter.

There may be applications in medical imaging for such a system.

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REFERENCES


Fig. 1. The set-up used for calibration of the MCP image intensifier. The diameter of the diaphragm is 300 μm.

Fig. 2. The gain versus applied voltage characteristic of the MCP image intensifier. This curve agrees well with the manufacturer's specifications.
Fig. 3. The accumulated profile of the diaphragm. The FWHM is 4 pixels, which corresponds to the 300 μm diaphragm hole.

Fig. 4. The set-up used for the radioactive source measurements.
Fig. 5. The accumulated beam profile for the collimated radioactive source.

Fig. 6. The RD 19 pixel telescope with the fibre ribbon added. Triggers are produced by the coincidence in scintillators S1, S2, S3 and S4. This forms a 1 mm x 1 mm area in pixel planes 1 and 2. The beam itself is, of course, much wider than this.
outside the coincidence are due to untriggered particle tracks.

Fig. 8. The accumulated beam profile in the fibre plane. The 1 mm wide coincidence is clearly evident. The hits outside the coincidence are due to untriggered particle tracks.

Fig. 7. The efficiency versus threshold curve for the fibre ribbon. The 300 μm Si curve is added for reference.