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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Tests of a multianode PMT for the HERA-B RICH

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Abstract

A new multianode photomultiplier tube, type H6568 manufactured by Hamamatsu company, has been tested in view of using it for measuring Cherenkov rings in the HERA-B experiment. The results of measurements of single-photoelectron pulse-height distributions, uniformity of response, cross-talk, photon detection efficiency, rate dependence of the gain and ageing will be presented and discussed. In addition, the response of the PMT to scintillations of perfluorobutane (C_4F_{10}), argon and air has been measured.

1. Introduction

The HERA-B detector at the HERA e–p collider at DESY in Hamburg, will measure CP violation parameters in the B-meson system using thin-strip, fixed targets in the halo of the 820 GeV proton beam [1, 2]. B-mesons will be thus produced in proton-nucleus collisions and their decays to $J/\psi\ K^0_S$ will be measured. Tagging of the B-meson flavour will be performed by identification of the charged kaon into which the associated B-meson decayed. For this purpose a Ring Imaging Cherenkov (RICH) counter will be used. The RICH detector will consist of 2.7 m of perfluorobutane (C_4F_{10}) gas radiator, spherical mirrors of 5.7 m focal length and about 6 m^2 of photon detectors with a pixel size of approximately 1 cm^2. In order to separate kaons from pions up to about 50 GeV/c, the RICH would have to detect at least 20 photons per Cherenkov ring. In addition, the RICH signals should be collected in less than the 96 ns bunch crossing time in HERA. The proton–nucleus reaction rate, necessary to detect a few thousand $B \rightarrow J/\psi K^0_S \rightarrow l^+l^-\pi^+\pi^-$ events in one year, also poses extra demands on the photon detectors. The most exposed parts of the detector will have to operate at a few MHz per pixel, which could cause ageing or rate problems.

Previous studies have been concerned with CsI photocathodes in an asymmetric multiwire chamber [3] and with a TMAE based photon detector [4]. The attempts to routinely produce and maintain the CsI photocathodes with a sufficiently high quantum efficiency were unfortunately unsuccessful. At larger accumulated charges ($\sim$10 mC/cm^2), the TMAE based photon detector showed signs of ageing in the form of prohibitive loss of anode wire gain [5]. A third possibility for position sensitive photon detection in HERA-B is studied in this work. Results of various measurements of the new Hamamatsu multianode photomultiplier tube (MA-PMT) H6568 are presented.

2. The experimental apparatus

The PMT has been tested with single daylight photons as well as with Cherenkov radiation emitted by ^{90}Sr β-electrons in a crystal radiator (Fig. 1) and by 3 GeV/c beam electrons in 5 m of argon gas radiator (Fig. 2).

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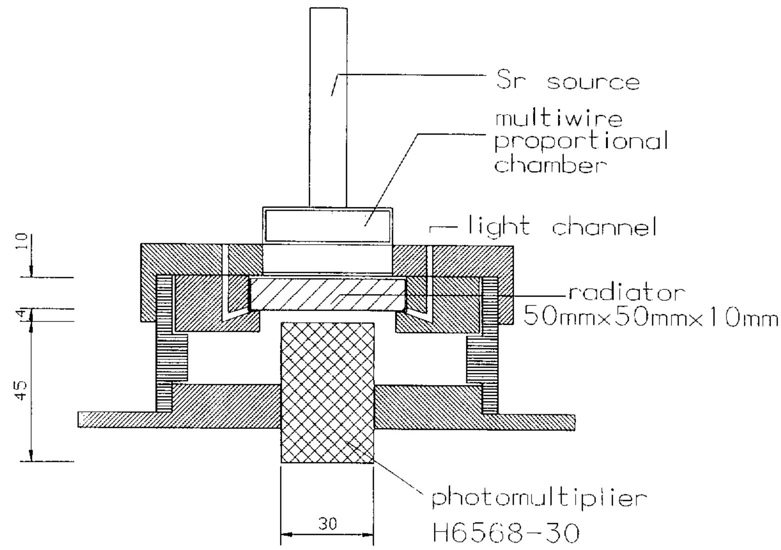

Fig. 1. The set-up for measuring Cherenkov photons emitted by ^{90}Sr β particles in a crystal radiator.

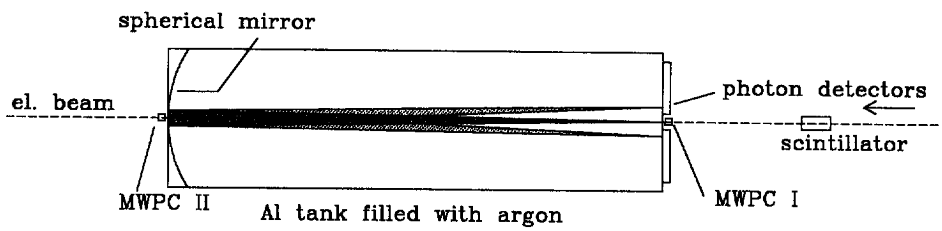

Fig. 2. The set-up for measuring Cherenkov photons emitted by 3 GeV/c, test-beam electrons in a 5 m long, argon gas radiator. The photons are reflected from a spherical mirror on the downstream flange and focused onto the detectors on the upstream flange. The read out is triggered by two tracking MWPCs and a scintillator. The set-up is situated at the T24 test beam at DESY.

A special container has been constructed for the measurement of the scintillations of C_4F_{10} gas. The gas flows through the gas tight container into which an ^{241}Am source can be inserted or removed. The scintillations induced by the α particles are seen by the photomultiplier at the opposite end of the container.

The height of the anode pulses has been measured with a 12-channel LeCroy CAMAC analog-to-digital converter (ADC 2249A). In some cases, when the ADC was not available a CAMAC 16-channel discriminator (Philips 7106) or a 16-channel time-to-digital converter (Lecroy 4291B) were used for pulse counting. A trigger pulse on the ^{90}Sr β-electrons was provided by a miniature 18 × 18 mm^2 MWPC (Fig. 1), while for the beam measurements, the read out was triggered by coincident signals in two tracking MWPCs and one scintillator (Fig. 2).

The new Hamamatsu H6568 multianode photomultiplier has a bialkali photocathode with the anode divided into 16 pads of 4 × 4 mm^2 each. The outer dimensions of the PMT are 30 × 30 mm^2, so the photocathode occupies only about

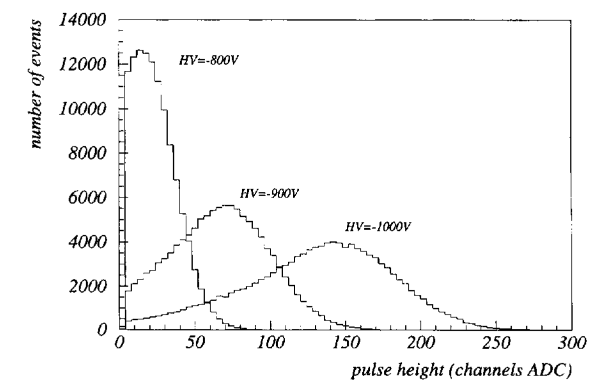

Fig. 3. The measured pulse-height distributions of the H6568 PMT due to single photoelectrons for different high voltage values.

30% of the surface. The 12-stage, metal-foil dynode system [6] allows for good single-photoelectron resolution as may be seen in Fig. 3. The quantum efficiency of the H6568

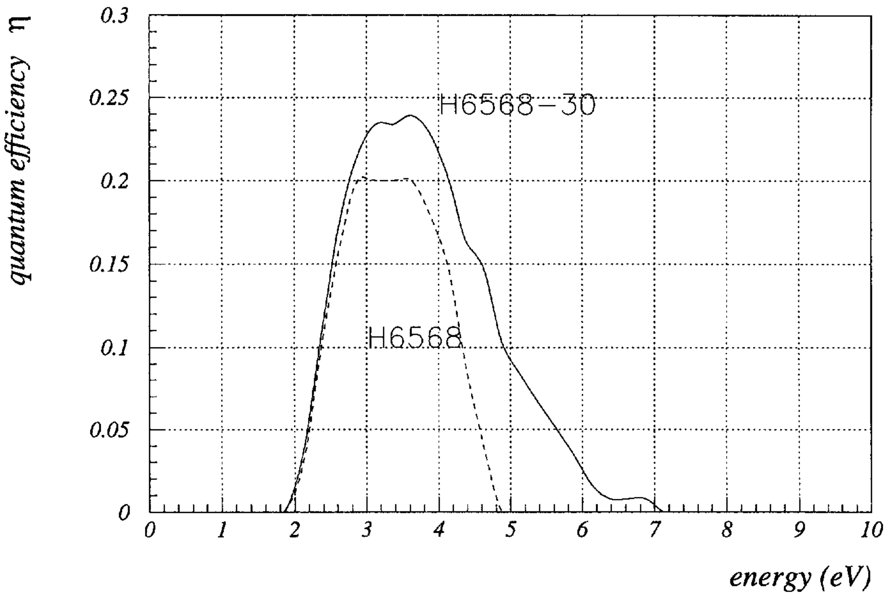

Fig. 4. The quantum efficiency of the H6568 PMT with borosilicate window (dotted line) and of the H6568-30 PMT with a quartz window (full line) [7].

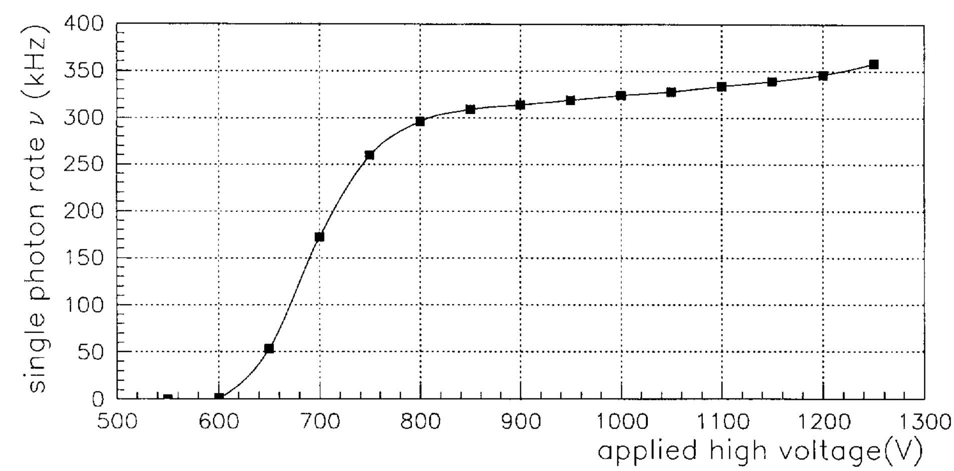

Fig. 5. The plateau curve of the single photon count rate for one channel of the MA-PMT versus high voltage (for constant illumination, amplification 200 and discrimination at 30 mV).

photocathode, with borosilicate window, has a broad plateau in the wavelength region between 300 and 500 nm with a maximum value of 20% (Fig. 4). The UV-extended version H6568-30 has a quartz window, which seems to improve the quantum efficiency as shown in Fig. 4. In the present tests, the photocathode quantum efficiencies of Fig. 4 were assumed in calculations in which an additional multiplication factor was allowed. This factor is attributed to the photoelectron collection efficiency and is adjusted for best agreement between calculations and results of measurements. The other PM characteristics such as the required cathode high voltage ($\leq$1000 V), the current amplification (10^7), dark current ($\sim$1 nA), pulse rise time (0.8 ns), transit time spread (0.3 ns), etc. also seem to be satisfactory [6].

3. Measurements and results

Three multianode PMTs were tested; one with borosilicate glass window (Ser. No. 6A19C4) and two with quartz

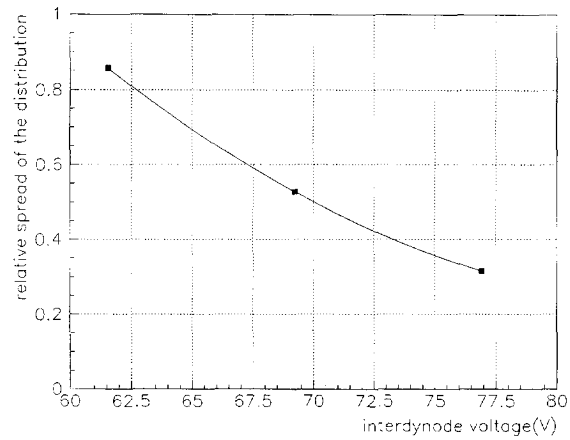

Fig. 6. The relative width of the single-photoelectron peak as a function of the voltage between successive dynodes.

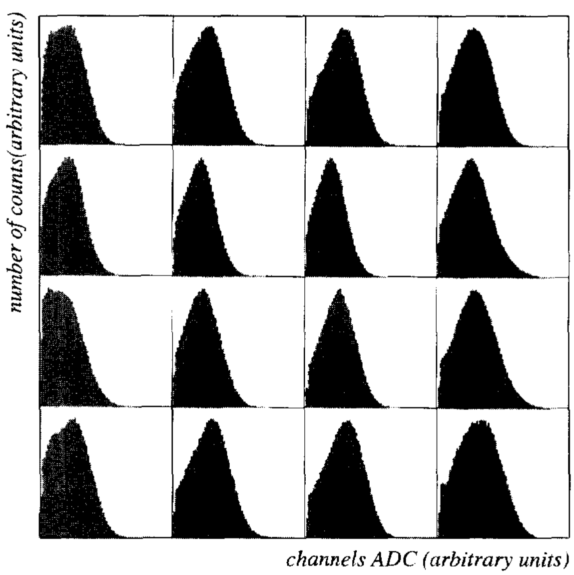

Fig. 7. The single-photoelectron pulse height distributions for all 16 channels of the H6568 PMT.

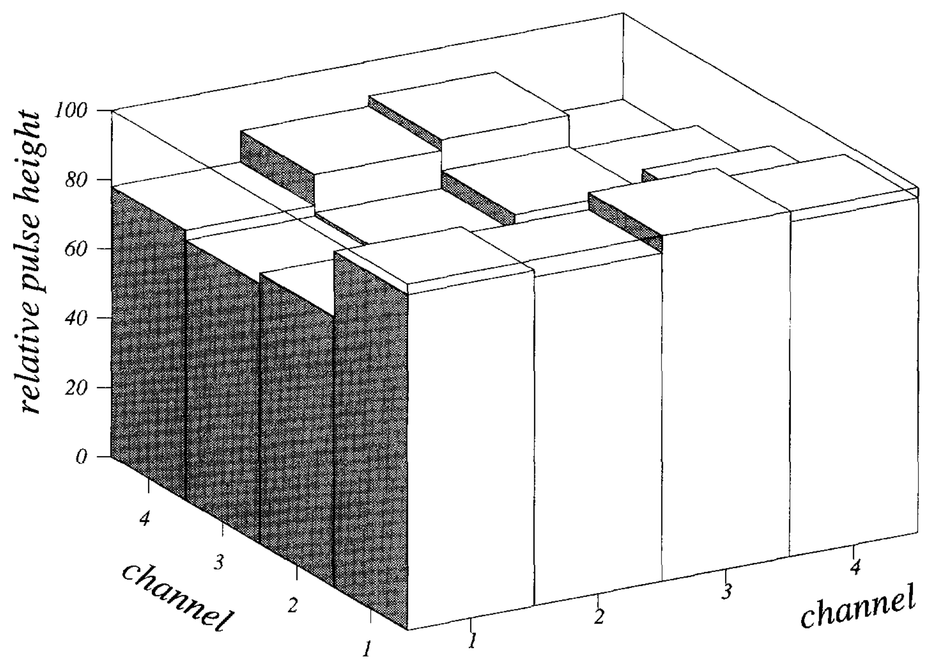

Fig. 8. Lego plot of the average single-photoelectron pulse-heights normalized to the pad with the largest average pulse height.

windows (Ser. No. 5M26C6 and Ser. No. 6C22C5). The single-photon count rate versus high voltage and the relative width of the single-photoelectron peak for one PMT are shown in Figs. 5 and 6, respectively. The pulse-height distributions on the 16 pads of one photomultiplier for single photoelectrons are shown in Fig. 7 and the average pulse height on each pad is shown in Fig. 8. These data were obtained by allowing a small leak of daylight into the crystal radiator from which the photon reached the photocathode more or less uniformly illuminating its surface.

Cross talk has been estimated by observing simultaneous pulses on adjacent pads, when the pulse on one pad has been recorded to be above a certain threshold. The pulse-height spectra, triggered by pad number 7 are shown in

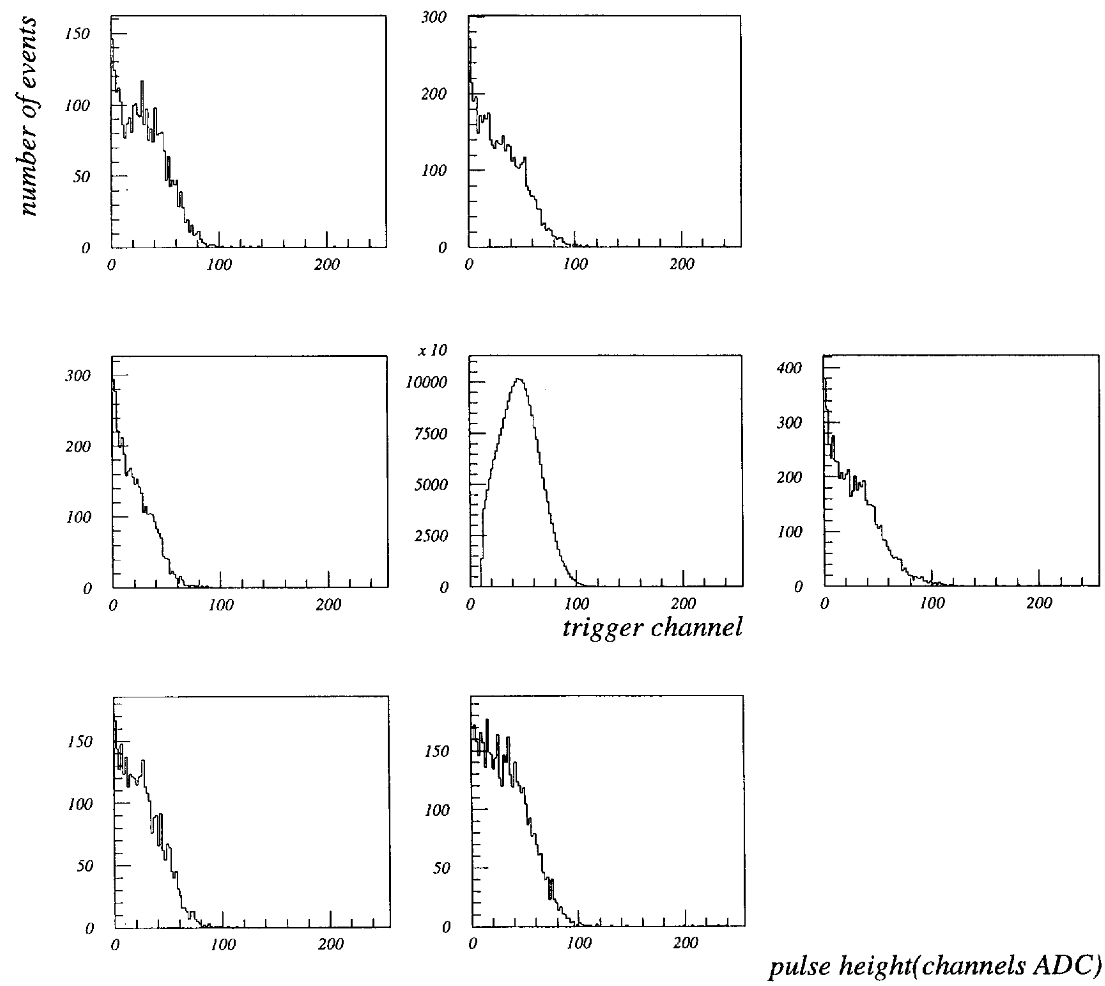

Fig. 9. Cross talk has been measured by triggering on channel 7 and observing simultaneous pulses on the neighbouring channels.

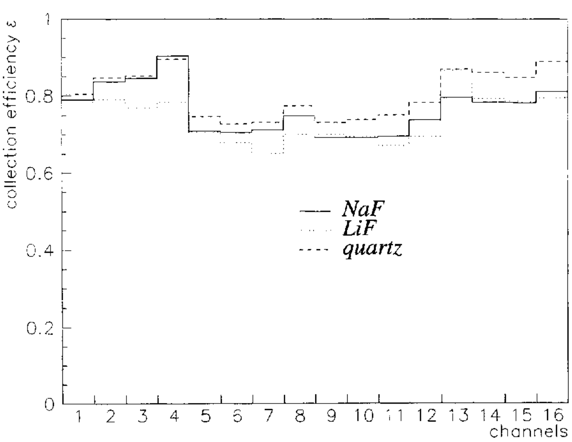

Fig. 10. Histograms of the photoelectron collection efficiency (see text) for all the pads, measured by detecting Cherenkov photons from three different crystal radiators.

Fig. 9. The cross talk is estimated from this figure to be 0.2% between direct neighbours and only 0.1% between diagonal neighbours.

The photon detection efficiencies of the multianode photomultiplier tubes have been determined by comparing measured and simulated numbers of detected Cherenkov photons. The Cherenkov photons have been generated by β particles from a ^{90}Sr source in NaF, LiF or quartz crystal radiators (Fig. 1). The simulation takes into account all the known parameters of the source, the crystal radiator and the detector. In particular, the photocathode quantum efficiencies used in simulation were those shown in Fig. 4. By dividing the measured number of hits per β-electron which triggered the multiwire chamber, with the corresponding number of simulated Cherenkov photons detected by each pad, one obtains an estimate of the performance of the individual anode pad expressed as an additional

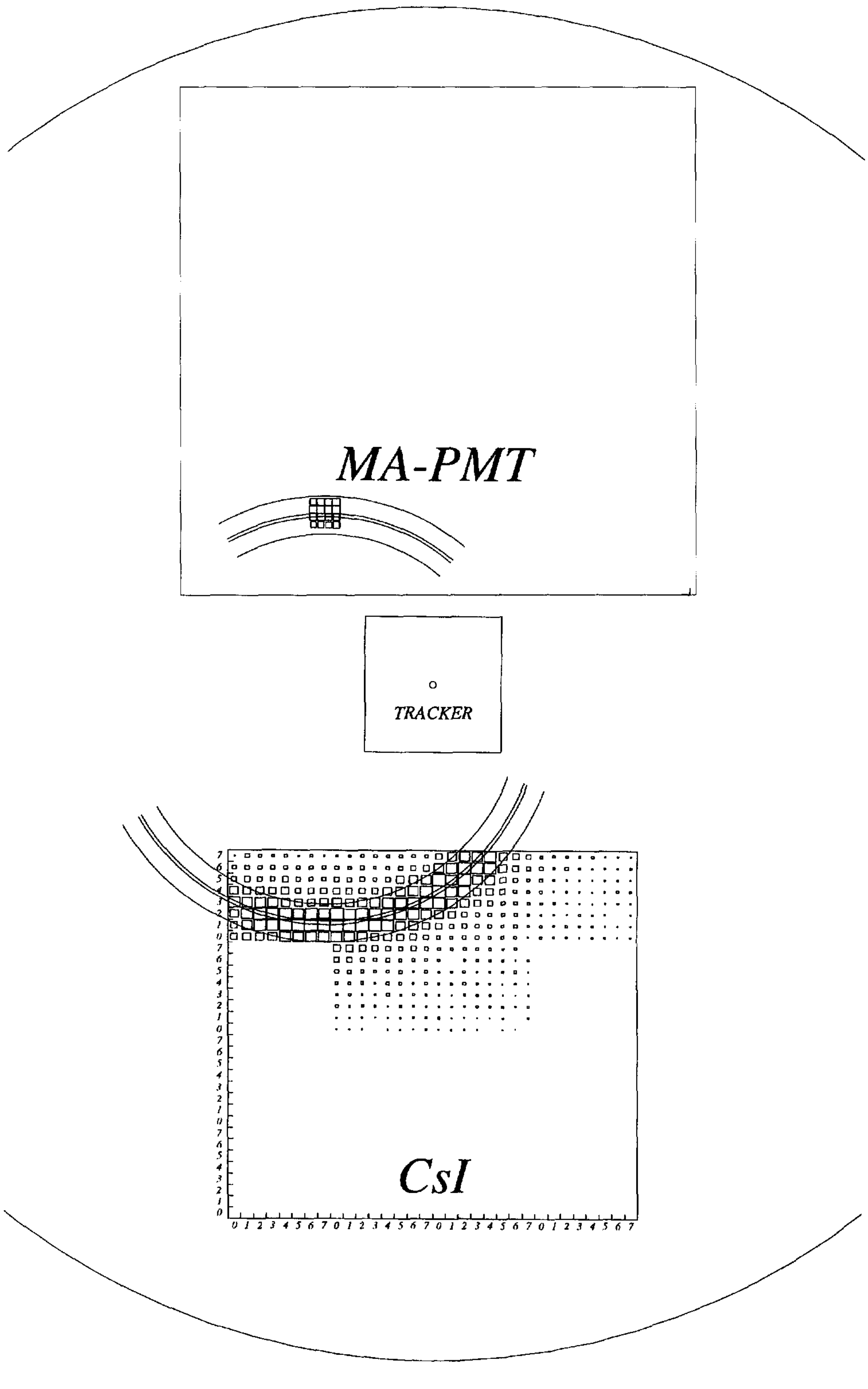

Fig. 11. The Cherenkov rings due to 3 GeV/c electrons in 5 m of argon gas, measured by the CsI-MWPC and the H6568 PMT in the set-up shown in Fig. 2. The insert shows the distribution of hits on the MA-PMT.

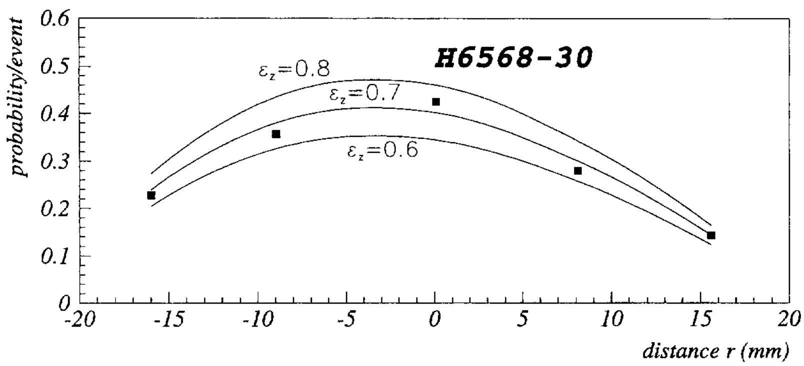

Fig. 12. The average number of hits per event as a function of position of the Cherenkov ring relative to the PMT (at $r = 0$ the ring passes through the PMT photocathode centre). The best agreement of the measured data points and the calculations (full lines) is obtained for $\varepsilon_c = 0.7$. The upper and lower curves correspond to ε_c values increased and decreased by 0.1.

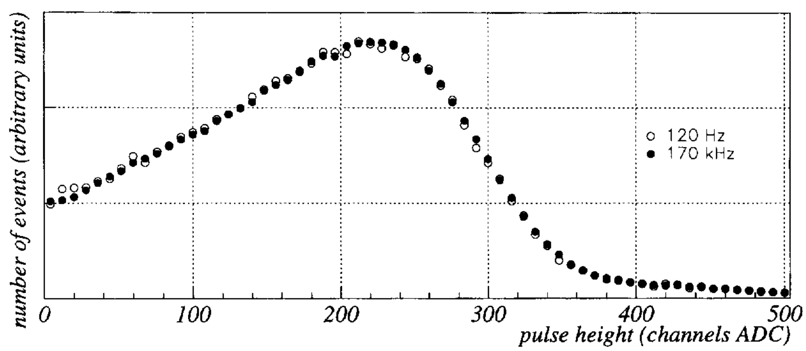

Fig. 13. Normalized pulse height distributions for Cherenkov signals caused by β-electrons from two different ^{90}Sr sources resulting in count rates of 120 Hz/pad (empty circles) and 170 kHz/pad (full circles).

efficiency factor. This additional efficiency factor ε_c is presumably due to less than perfect collection of the photoelectrons by the metal-foil dynode system. Fig. 10 shows the photoelectron collection efficiencies obtained for three different crystal radiators.

An independent estimate of the MA-PMT photon detection efficiencies has been obtained from measurements with 3 GeV/c beam electrons (Fig. 2). The average number of photons detected per beam electron has been measured for different positions of the Cherenkov ring with respect to the multianode PMT. The relative position of the Cherenkov ring has been varied by tilting the spherical mirror on the inside of the downstream flange and has been measured with the CsI-MWPC (Fig. 11). The average number of detected Cherenkov photons has also been calculated from the known geometry, the parameters of the argon gas radiator, mirror reflectivity, photocathode quantum efficiency given in Fig. 4 and for different values of the photoelectron collection efficiency. The collection efficiency of the photomultiplier has been thus determined from the best agreement between the measured and the calculated values (Fig. 12). The number of Cherenkov photons, that would be detected if the entire Cherenkov ring is intercepted by the sensitive photocathode surface (i.e. no dead space), would be 23 for the H6568 ($\varepsilon_c = 0.85$) and 31 for the H6568-30 ($\varepsilon_c = 0.7$) PMT. If instead of 5 m of argon, the radiator is 2.7 m of C_4F_{10} gas, as in the HERA-B RICH, these two numbers would increase to 55 and 74 detected photons/ring, respectively. Just by closely packing the MA-PMTs without any collection or focusing of light, the dead surface would reduce the number of detected Cherenkov photons for about 70%. Different light guides are being studied in order to collect the photons from a larger surface and concentrate them on the PMT photocathode pads.

At high rates, one might expect a reduction of gain and consequently of pulse height, due to large currents through the last dynode stages. Pulse height spectra at counting rates of 120 Hz and 170 kHz have been measured. No significant difference in their shape has been observed, as may be seen in Fig. 13.

Ageing was studied by illuminating the photocathode pads with a 5 W neon bulb through a small hole at one side of

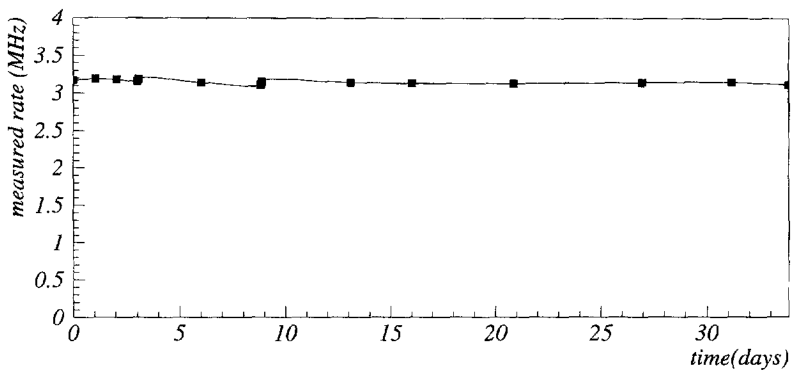

Fig. 14. The count rate as a function of time for one of the 16 channels illuminated with a neon lamp. No ageing effects have been noticed during one month of operation at 3 MHz/channel.

a 1 m long, 10 cm diameter black plastic tube with the PM on the other side. The counting rate as a function of time for one of the channels is shown in Fig. 14. As can be seen from the figure, no reduction of the 3 MHz counting rate has been observed over a 30 d period of continuous illumination and operation.

Measurements of the scintillation yields for argon, air and perfluorobutane (C_4F_{10}) have been made with two PMTs. For the H6568 PMT, the results for C_4F_{10} (0.4 detected photons per GeV of deposited energy) and for air (0.45 photons/GeV) are approximately equal and are both 4 to 5 times lower than for argon gas (1.8 photons/GeV). For the H6568-30 UV extended PMT, C_4F_{10} (1.5 photons/GeV) gives about two times more counts than air (0.7 photons/GeV), but about 8 times less counts than argon (11.2 photons/GeV). Taking into account the ratio of solid angles of the HERA-B photon detector to the solid angle of the apparatus for scintillation measurements and for ~2 GeV of energy absorbed per event by the C_4F_{10} gas radiator, one expects to detect a few scintillation photons/event, which is negligible in comparison with the number of Cherenkov photons detected for each HERA-B event.

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