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The characterisation of the multianode photomultiplier tubes for the RICH-1 upgrade project at COMPASS

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ABSTRACT

A major upgrade of the Cherenkov photon detection system of COMPASS RICH-1 has been performed and it has been in operation since the 2006 physics run. The inner part of the photon detector has been replaced by a different technology in order to measure Cherenkov photons at high photoelectron rates, up to several times 10^6 per second and per channel. Cherenkov photons from 200 to 750 nm are detected by 576 multianode photomultiplier tubes (MAPMTs) with 16 channels each, coupled to individual fused silica lens telescopes and fast, high sensitivity and high time resolution electronics read-out. To guarantee an optimal performance of the complete system, parameters like dark current, gain, uniformity, relative quantum efficiency have been measured for a totality of more than 600 MAPMTs (about 10 000 channels) in a fully automated test-stand, developed for this purpose. The ideal working point for each individual pixel could be ascertained by these measurements. In 2006 the newly equipped detector exhibited an excellent performance: about 56 detected photons per ring at saturation and a time resolution of better than 1 ns.

We report about the MAPMT characterisation and the quality control set-up, protocol and results.

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1. Introduction

The Common Muon and Proton Apparatus for Structure and Spectroscopy (COMPASS) experiment at CERN [1] is a fixed target experiment, providing two large acceptance spectrometer

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stages [2] in order to study selected topics in hadron physics. Particle identification is an important requisite of the COMPASS apparatus. Charged hadron identification up to about 50 GeV/c and in a wide angular range (about 200 mrad) is performed by RICH-1 [3]. To better cope with the high luminosity requirements, an important upgrade of the RICH-1 photon detection system has been undertaken and completed between autumn 2004 and spring 2006. This upgrade project is described somewhere else in these proceedings [4–6].

We report here about the characterisation and quality control of the multianode photomultiplier tubes (MAPMTs) forming the central part of this new photon detection set-up.

2. Multianode photomultiplier tube

In order to detect with high efficiency single photons at high beam intensities and trigger rates, the photon sensor should have rate independent response up to more than 1 MHz per pixel, provide a quantum efficiency of more than 20%, gain factors of about 10^7 and exhibit low dark current.

For the RICH-1 upgrade, the MAPMT type R7600-03-M16 by Hamamatsu has been chosen. It provides a common bi-alkali photocathode followed by 16 independent channels, arranged in a 4×4 pixel matrix with $4 \times 4 \text{ mm}^2$ size each, while the gap between two adjacent pixel is 0.5 mm.

The photocathode itself is vapour deposited on an UV-extended glass window, allowing a spectral sensitivity from 200 to 750 nm. Relative signal amplitude variations (uniformity) of all 16 channels are specified better than 1:3 (selected MAPMTs) and the cross-talk between neighbouring channels obtained with the RICH-1 read-out chain has been measured to be less than 1% [7]. The electron multiplication is done with a 12 stage metal-channel type dynode structure, resulting in a typical gain of 6×10^6 at 850 V (maximum voltage: 1000 V). Using the MAPMT equipped with the standard voltage divider circuit proposed by Hamamatsu, it was shown that no significant gain reduction occurs even at single photon rates above 5 MHz per channel [7]. An outstanding parameter of this device is the dark current, which is specified to be less than 2 nA per channel (selected MAPMTs).

3. Automated test set-up

To guarantee that the complete set of 576 MAPMTs, used in the upgraded RICH-1 detector, fulfills all specified parameters and that all the 9216 channels are operated at the optimum working point, a fully automated test set-up was designed and assembled (Fig. 1).

An LED pulsing system illuminates homogeneously the photocathode of the MAPMT and concurrently generates a trigger signal as gate for the charge-to-digital converter (QDC). The frequency of the LED pulses can be adjusted from 1 Hz up to 2 MHz. To study single photon response, polarisation filters placed directly in front of the LED are used. The MAPMT output signals are amplified by a factor of 10 by LeCroy PMA 612A modules and then digitised by CAMAC charge sensitive ADCs of type LeCroy 2249A (10 bit, 0.25 pC per bin). The data acquisition system is based on CAMAC (CC16 by Wiener). Due to basic limitations of the CAMAC ISA controller, the trigger signal is prescaled and therefore the read-out reduced to 1 kHz. The high voltage for the MAPMT is provided and monitored by a four channel HV power supply by WENZEL. Dark current measurements by a Keithley picoammeter model 6485, and signal inspection at the scope are performed upstream of the PMA stage and a 16-fold relay circuit allows to switch

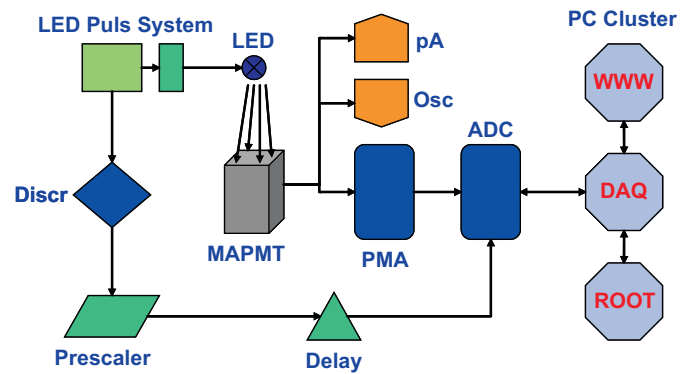


Fig. 1. Scheme of the test set-up showing charge-to-digital converter (QDC), dark current measurement (pA), oscilloscope analysis (osc), data acquisition (DAQ), online analysis (ROOT), data storage and web hosting (WWW).

among different channels and measurements. The complete system is fully controlled via a Debian Linux system based on kernel 2.6x.

The measurement protocol of each MAPMT lasts 2 h and it includes: the visual inspection of the cathode surface, the recording of QDC spectra at five different high voltage values (from 850 to 970 V in steps of 30 V) for two different wavelength values each (360 and 480 nm), recording of oscilloscope images, and the analysis of the amplitude spectra of all the channels at maximum high voltage level. Right before and after data recording, the dark current of all 16 channels is measured. During each test, no significant ambient room temperature changes occurred. The measurement procedure is immediately followed by data analysis, determining uniformity, relative quantum efficiency and gain. The raw data as well as the results of the analysis are stored in a mirrored RAID5 server platform. In addition, all data are hosted on a webserver and are accessible via a graphical user interface based on the state-of-the-art, object oriented RubyOnRails technology [8]. More than 600 MAPMTs (576 plus spares) were characterised in terms of all relevant parameters. During the complete period of the measurements, more than 120 days, 12 h a day, the automated test set-up collected data continuously without failures.

4. Results

All tested photomultiplier tubes apart 20 units accomplished all test criteria and their parameters are significantly better than the maximum allowed values. Twenty MAPMTs did not fulfill the dark current limit of less than 2 nA for each individual channel, exhibiting at most 2 out of 16 channels with higher dark current. In general, the dark current registered at the end of the 2 h measurement protocol, is an order of magnitude less than specified (Fig. 2). The uniformity behaviour turned out to be excellent with amplitude variations of only 20–30%.

Fig. 3 shows one of the typical single photon QDC distributions obtained. Beside the QDC pedestal, two main components are visible. The main peak includes the signals of the photoelectrons subjected to the full 12-step amplification chain, whereas the smaller amplitude peak is due to those photoelectrons, for which at least an amplification stage is missed. For the foreseen usage in RICH-1, both contributions are equally important. Mean value and standard deviation of each contributing peak is determined by a double Gaussian fit. The uniformity of each MAPMT and the gain behaviour of each individual channel are extracted from these parameters (Fig. 4).

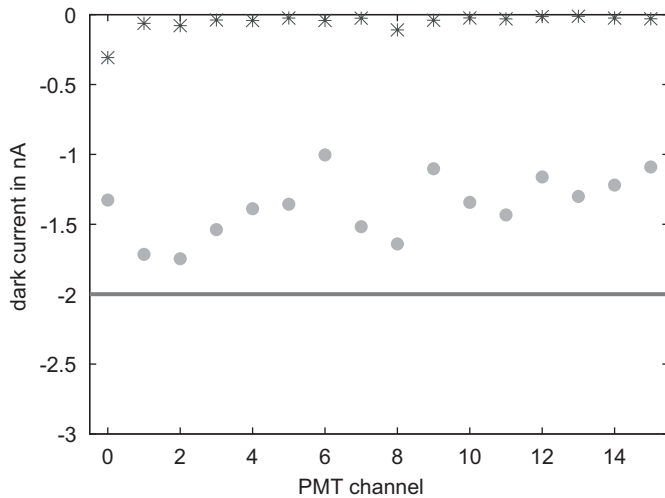


Fig. 2. Dark current values for the 16 channels of a MAPMT before (circles) and after (stars) the measurement procedure. The line marks the specification limit.

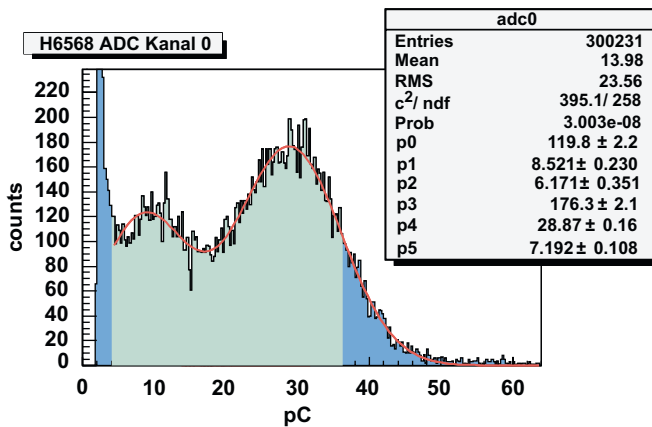


Fig. 3. Typical single photoelectron response measured at 970V using 360 nm photons. The shaded area shows the $\pm 1\sigma$ region of each of the two contributing peaks.

The ideal high voltage setting for each MAPMT is the minimum value which guarantees at least 95% efficiency for all the MAPMT channels coupled to the front-end read-out chain, based on the MAD4 discriminator boards [5,7]: 1.7 pC (gain $\sim 10^7$). The HV setting is deduced from an exponential fit to the measured gain data. Fig. 5 shows the calculated high voltages for a subsample of 556 MAPMTs. These values are Gaussian distributed around 890 V with a standard deviation of ~ 40 V. The central value corresponds pretty well to the typical value given by Hamamatsu (~ 910 V for an amplification of $\sim 10^7$).

5. Conclusion

More than 600 MAPMTs with 16 individual channels each have been measured in terms of uniformity, gain, dark current and relative quantum efficiency in a fully automated test-stand, developed for this purpose. From the analysis of these data, the ideal working point for each individual photomultiplier tube has been extracted.

Since 2006, the RICH1 upgraded detector is taking data successfully in the COMPASS environment with excellent performance, exhibiting a resolution of the measured Cherenkov angle of $\sigma_{\text{ring}} = 0.3 \text{ mrad}$ (before $\sigma_{\text{ring}} = 0.6 \text{ mrad}$) and a number of photons per ring of ~ 56 (before ~ 14).

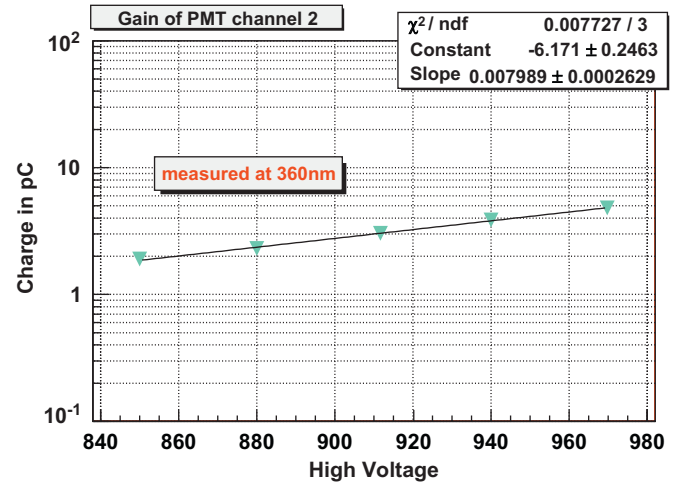


Fig. 4. Gain values measured at 360 nm wavelength for a channel of an MAPMT. The curve is the exponentially fitted function.

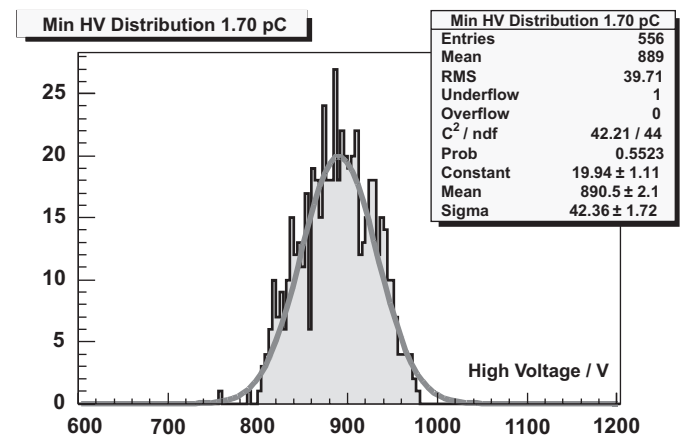


Fig. 5. Distribution of the high voltage value needed to get a minimum output charge of 1.7 pC for a sample of 556 MAPMTs.

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