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Wavelength shifting films on multianode PMTs with UV-extended window for the CBM RICH detector

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ABSTRACT

Electron identification in the Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion Research (FAIR) will be performed using a gaseous RICH detector. Due to the UV transparency of the CO_2 radiator, a high photon detection efficiency of the PMTs in use at small wavelengths is favourable. The use of wavelength shifting (WLS) films aims at increasing the integral quantum efficiency of the photon sensors. WLS films absorb UV photons and re-emit photons at longer wavelengths where the quantum efficiency of common photocathodes is higher. As photon sensors, multianode PMTs (MAPMTs) with bialkali or superbialkali photocathodes and UV-extended windows are envisaged. We present quantum efficiency measurements with and without WLS coating for different types of MAPMTs as well as results from a beam test at the CERN PS. An increased photon yield was observed when using WLS films. In addition, we discuss the effect of WLS films on the spatial resolution of MAPMTs.

1. Introduction

The CBM experiment is the dedicated heavy ion experiment at FAIR and will explore the phase diagram of nuclear matter at high net baryon densities and moderate temperatures using nucleus–nucleus collisions from 8 AGeV/c to 45 AGeV/c beam energy [1]. For the clean and efficient identification of electrons, a RICH detector will be built. It needs to operate with a large acceptance and in the momentum range of up to 8 GeV/c which requires a gaseous radiator in order to separate electrons from the large abundance of pions created in a heavy ion collision. The CBM RICH detector will make use of CO_2 as a radiator gas and a high UV reflectivity mirror consisting of an $Al+MgF_2$ coating on a glass substrate [2]. The absorption length of CO_2 equals the radiator length of the detector at approximately 185 nm [3]. Hence, it is favourable to extend the sensitivity of the photon detector into this wavelength region to maximize the Cherenkov photon yield. Chromatic dispersion is not expected to play a significant role above 185 nm [4].

The usage of organic molecules as WLS films on phototubes with standard glass windows in a gaseous Cherenkov detector was already proposed in 1973 [5]. Incident UV photons are absorbed by the molecules of the WLS film and form excited molecular states

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which can de-excite by the emission of photons at longer wavelengths [6]. For p-Terphenyl (PT), a decay time of these excited states of the order of 1–2 ns is reported [5]. In Ref. [7] it was shown that fluorescence photons are emitted isotropically in a certain thickness range.

Several groups studied evaporated WLS films on top of photon detectors with standard glass as an alternative to expensive devices with LiF, MgF_2, or GaF_2 windows [6,8,9], which, furthermore, were not available as large-area sensors. Dip-coated films were first mentioned in Ref. [10].

So far, no results on the performance of WLS films on MAPMTs or PMTs with UV-extended windows have been reported. This paper discusses the increase of quantum efficiency when measured as a function of wavelength as well as the Cherenkov photon yield and the ring resolution we achieved with WLS films on MAPMTs with a UV-extended window.

2. Sample preparation

Initial experiments with single anode PMTs coated with PT and Tetraphenyl-butadiene revealed that PT is a suitable molecule for the use as a wavelength shifter deposited on the front window of PMTs [11]. Therefore, films with PT as wavelength shifting molecules were used for the study presented here. The WLS films were applied directly on the MAPMT front windows from solution by means of dip-coating. For the coating process, the MAPMTs were placed in a tight housing with only the front window being exposed to the solution which contains PT, paraloid as a binder, and dichloromethane as a solvent. Films of approximately 200 nm thickness were produced.

The performance of dip-coated WLS films on three types of Hamamatsu MAPMTs was investigated: H8500D-03 (size 2 in. × 2 in., bialkali (BA) photocathode, window thickness 1.5 mm), H10966A-103 (2 in. × 2 in., superbialkali (SBA) photocathode, window thickness 1.5 mm), and R11265-103-M16 (1 in. × 1 in.), BA photocathode, window thickness 0.8 mm). All MAPMTs investigated have a pixel size of $6 \times 6\ mm^2$.

3. Quantum efficiency

Quantum efficiency (*QE*) measurements were performed by illuminating the MAPMTs with monochromatic light from a deuterium–tungsten–halogen hybrid light source attached to a monochromator. The current of photoelectrons from the cathode to the shorted first three dynodes was measured while applying a voltage difference of −100 V between cathode and dynodes. Longpass filters in the optical path were used for the suppression of higher orders in the diffraction pattern of the monochromator. The absolute *QE* was then calculated by normalizing to the photo current measured with a calibrated photo diode. The measurement error was determined from the uncertainty of the photo diode calibration and the picoamperemeter in use, and adds up to a relative error of 5–10%. For every MAPMT, the absolute *QE* was measured as a function of wavelength (*QE* curve) with the WLS film and subsequently re-measured after removing the WLS film.

Fig. 1 shows averaged *QE* curves for four pieces of H8500D-03 and four pieces of R11265-103-M16 with and without WLS films. In addition, the result of a H10966A-103 is shown. For comparison, the *QE* of a single anode PMT with a borosilicate window is also depicted.

It can be seen that for all MAPMT types, WLS films significantly increase the *QE* below 280 nm while not decreasing the *QE* in the visible wavelength range compared to uncoated MAPMTs.

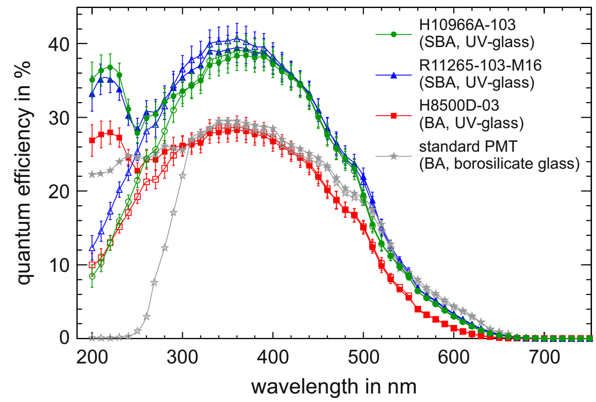

Fig. 1. Wavelength dependent quantum efficiency for H10966A-103, R11265-103-M16, and H8500D-03 MAPMTs with (full symbols) and without WLS coating (open symbols). With coating, an increased *QE* for all MAPMT types can be observed in the UV and no decrease in the visible wavelength range. For comparison, also the curves of a single anode PMT with a standard borosilicate window is shown.

4. Beam test setup and data analysis

The influence of WLS coated MAPMTs on the detection of Cherenkov rings under real conditions in a gaseous RICH detector was studied in a beam test at the CERN PS with a full-scale CBM RICH prototype using a secondary beam of electrons and negatively charged pions at momenta between 2 GeV/c and 10 GeV/c. Two strategies were pursued in order to evaluate the hit multiplicity per Cherenkov ring. In a first test, Cherenkov rings, which have a mean diameter of 92 mm in the case of electrons, were focussed onto an array of two by two MAPMTs. Using a tiltable mirror, the ring was then focussed on an array of two by two uncoated reference MAPMTs. Since the WLS coated MAPMTs differ from the reference MAPMTs, a thorough correction for variations in the single photon detection efficiency for every pixel of each MAPMT was done by illuminating all MAPMTs homogeneously with single photons from a pulsed LED. A second test was done by first measuring Cherenkov rings on an array of two by two MAPMTs with WLS films, then cleaning these MAPMTs, and measuring a second time on the same MAPMTs without WLS coverage. When measuring in this way, the efficiency correction can be omitted at the expense of a correction for variations of the refractive index due to temperature and pressure changes during the cleaning process. Both methods lead to results that are in agreement with the respective Monte Carlo simulations. For the results presented in the following, the second method has been used.

Since electrons are ultrarelativistic in the used momentum range, ring parameters from electrons are momentum independent. Therefore, electron rings were selected for all analyses presented here by using information of two additional threshold Cherenkov counters installed in the beam line.

5. Beam test results

5.1. Hit multiplicity

In the following, the term hit multiplicity refers to the number of photoelectrons after ring finding and ring fitting [12]. The uncertainty was determined by comparing results from different runs with the same detector settings. Taking into account temperature and pressure correction, it was quantified to be of the order of 1.5%.

Fig. 2 shows the hit multiplicity distribution for coated and uncoated MAPMTs of the H8500D-03 type. The analysis shows an

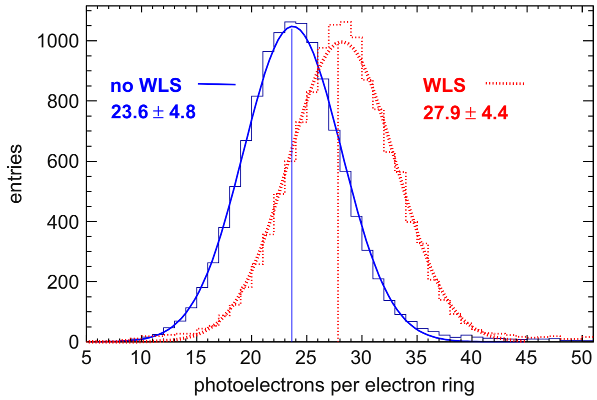

Fig. 2. Number of photoelectrons per electron Cherenkov ring on H8500D-03 MAPMTs with the WLS film in comparison to the same MAPMTs after film removal. Numbers show mean and sigma of Gaussian fits to the distributions.

Table 1
Hit multiplicity gain due to WLS films on different MAPMT types in data and Monte Carlo (MC) simulation.

MAPMT type	Hit multiplicity gain data	Hit multiplicity gain MC
H10966A-103	$(21.2 \pm 1.4)\%$	$(23.1 \pm 4.8)\%$
H8500D-03	$(18.2 \pm 1.5)\%$	$(18.3 \pm 4.7)\%$
R11265-103-M16	$(18.0 \pm 1.4)\%$	$(14.8 \pm 3.9)\%$

increased hit multiplicity for all WLS coated MAPMTs. When comparing different MAPMT types, the following result is obtained: The gain with WLS films is 21.2% for 2 in. MAPMTs with SBA photocathode and UV-extended window, 18.2% for 2 in. MAPMTs with BA photocathode and UV-extended window, and 18.0% for 1 in. MAPMTs with SBA photocathode and UV-extended window (see Table 1). This hierarchy is also seen in full Monte Carlo simulations using the measured wavelength dependent *QE* for the different MAPMT types. The larger gain in hit multiplicity of the H10966A-103 compared to the H8500D-03 type can be understood when considering that, in the case of SBA photocathodes, the UV photons are shifted to a wavelength range with higher *QE* when compared to BA photocathodes. The comparison between both SBA MAPMT types, H10966A-103 and R11265-103-M16, reveals that the thinner front glass of the 1 in. R11265-103-M16 is more UV transparent than the thicker glass of the 2 in. H10966A-103 and thus makes the use of WLS films less effective.

5.2. Ring resolution

When using WLS films on the MAPMTs, in principle, two effects can lead to a decrease of the ring sharpness. First, due to the isotropic fluorescence of WLS films, the majority of wavelength shifted photons pass the MAPMT front window under a more inclined angle than without the WLS film. Since the window has a certain thickness, wavelength shifted photons will thus enter the photocathode at a different position compared to the point of incidence on the window surface and the ring sharpness is therefore expected to decrease. Second, since chromatic dispersion is more pronounced in the UV range, the enhanced UV sensitivity with WLS coating may lead to a decrease in ring sharpness. In the following, the ring sharpness is quantified by the parameter *dR*, which is defined as RMS of the distribution of the distance between each hit and the circular ring fit.

Fig. 3 shows such a distribution for Cherenkov rings detected with H8500D-03 MAPMTs. The parameter *dR* has a value of

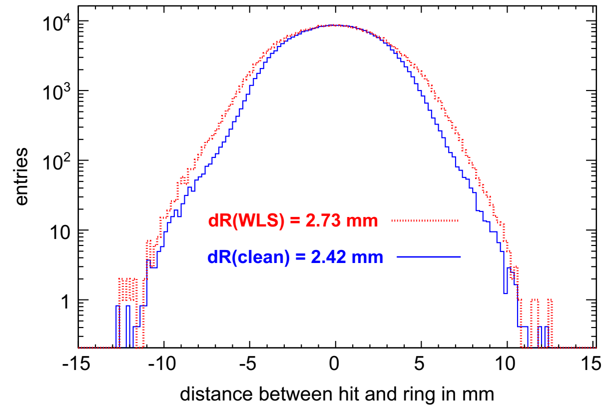

Fig. 3. Distribution of the distance between each hit and the ring fit for WLS coated and uncoated MAPMTs. *dR* is defined as the RMS of the distribution.

2.73 mm with WLS films and 2.42 mm without. The difference of ≈ 0.3 mm is small compared to the absolute value of *dR*. Given the pixel size of 6 mm and the resulting spatial resolution of the MAPMTs under test of $(6/\sqrt{12})\ \text{mm} = 1.7\ \text{mm}$, the effect on the ring sharpness is not significant.

6. Summary

The use of dip-coated WLS films on MAPMTs with a UV-extended window has been studied. It was found that a performance gain in terms of quantum efficiency in the UV wavelength region is achieved leading to an increased hit multiplicity measured with the gaseous CBM RICH prototype detector in a beam test. Approximately 20% more photoelectrons are detected with the applied WLS films compared to uncoated MAPMTs. The gain is slightly larger for SBA than for BA photocathodes and larger for thicker than for thinner front windows. The effect of WLS films on the ring sharpness can be neglected under the given experimental conditions.

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