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Design and construction of the fast photon detection system for COMPASS RICH-1

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ABSTRACT

New photon detectors, based on the use of multi-anode photo-multiplier tubes coupled to individual lens telescopes and read out with a dedicated read-out electronics system, equip the central region of the Cherenkov imaging counter RICH-1 of the COMPASS experiment at CERN SPS. They are characterised by high photon yield, fast response and high rate capability and are successfully in operation since the 2006 COMPASS data taking. The photon detection system fully matches the expected performance.

The design and construction of the photon detectors are described in detail.

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1. Introduction

The COMPASS experiment [1,2] at the CERN SPS is dedicated to hadron physics with a two-fold programme: the nucleon spin structure is studied using the CERN SPS polarised muon beam and solid state deuterium or hydrogen targets, longitudinally or transversely polarised; hadron spectroscopy is explored using

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pion and proton beams. All features of the experimental setup are described in Ref. [3]. Here we recall that the whole COMPASS research programme requires high luminosity, namely working at high beam and trigger rates. Another overall request is to perform hadron identification in difficult environments, characterised by large rates of uncorrelated background events due to either the large dispersed halo accompanying the muon beam, extended over square metres, or the secondary particles generated by the hadron beam interactions in the apparatus material.

In COMPASS, hadron identification is performed with RICH-1 [4], a large size Ring Imaging CHerenkov counter in operation at COMPASS since 2002. During the years 2001–2004, photon detection with RICH-1 has been performed by Multi-Wire Proportional Chambers (MWPC) equipped with CsI photocathodes [5]. Some characteristic features of these photon detectors and of its associate front-end read-out electronics (Section 2) limit the RICH-1 performance in the COMPASS environment, reducing the efficiency in particular for particles scattered at small angles and introducing some dead-time in the experiment data acquisition. To overcome these limitations, the photon detection system of the RICH-1 counter has been upgraded.

In the peripheral region, which amounts to 75% of the active surface, the photon detectors are unchanged since the level of uncorrelated background is not very large. The read-out, however, is now based on a new system [6] with the APV chip [7] with negligible dead-time and improved time resolution. The central photon detection area (25% of the active surface) is both highly populated by uncorrelated background images with photon rates up to 1 MHz per channel, corresponding to an $8 \times 8\,\text{mm}^2$ pad, and it includes the large majority of the high momentum hadron images, as these particles are scattered at small angles. The uncorrelated background signals can be rejected by finer time resolution, while good Cherenkov angle resolution is the handle for effective identification of high momentum hadrons. These requisites, together with high rate capability, dictate the main design criteria of the new photon detection system. This system is now in operation since the 2006 data taking.

The present article is dedicated to the new photon detection system of the central region of COMPASS RICH-1. The performance of RICH-1 before the upgrade is recalled in Section 2. The new photon detection system is outlined in Section 3. Sections 4–7 present the design, description and construction of the various system components. In Section 8 the performance of the new photon detectors is given. Section 9 is dedicated to conclusions.

2. COMPASS RICH-1 performance before the counter upgrade

COMPASS RICH-1 [4] is a gaseous RICH with large transverse size to match the acceptance of the first stage of the COMPASS spectrometer [3]. Its main components are the radiator gas, C_4F_{10}, included in a gas tight vessel, pressure controlled and purified with a dedicated gas system [8], the UV mirror system [9] and the photon detectors, namely MWPCs with CsI photo-cathode with photon conversion capability in the VUV domain, below 200 nm. The active surface is $5.3\,\text{m}^2$. The MWPC gas is separated from the radiator vessel one by fused silica windows, which are not transparent below ~ 165 nm. The images collected in the photon detectors are pseudo-circular[4] and we will refer to them as rings. The basic parameters characterising the detector performances are the mean number of detected photons: 14 per particle with $\beta \to 1$, the single photon resolution on the measured Cherenkov angle, σ_{ph}: 1.2 mrad for particle with $\beta \to 1$, the global resolution on the measured Cherenkov angle, σ_{ring}: 0.6 mrad for particle with $\beta \to 1$, a PID efficiency larger than 95% for Cherenkov angles larger than 30 mrad and a $2{-}\sigma$ $\pi{-}K$ separation at 43 GeV/c [4,10].

In spite of these remarkable figures, there are some performance limitations. The presence of the CsI photo-converter imposes to operate the MWPCs at a rather low gain (below 5×10^4) to guarantee their electrical stability. The first stage of the electronics read-out system is based on a modified version of the front-end Gassiplex-chip [11], amplifying and shaping the signal with a rather long integration time (0.6 μs) to compensate for the reduced gain. The typical noise figure obtained is 1100 electrons equivalent. The low gain, the integration time and an effective threshold at 3–3.5 times the noise level result in a detection efficiency for single photoelectrons, which ranges around 70%.

The Gassiplex integration time acts as a detector memory: each event image collected by the photon detectors includes the information of uncorrelated background events. Due to the nature of the background, the related rings cluster in the central region of the photon detectors. The high level background limits both the RICH-1 efficiency and the resolution.

The efficiency drops for very forward scattered particles, due to the combination of two effects, namely the high level background images present in the central photon detector region and due to photon losses: part of the Cherenkov photons generated by the forward scattered particles are lost due to the central dead zones of RICH-1, present to screen the photon detectors from the photons generated by the non-interacting beam.

The background also limits the RICH-1 resolution in the measured Cherenkov angle. This effect is evident considering the measured resolution values of the Cherenkov angle. σ_{ph} and σ_{ring} do not scale according to the square root of the number of photons: the actual value of σ_{ring} is almost a factor of two worse, due to the presence of the high level background.

3. The new photon detection system of the central region of COMPASS RICH-1

The new photon detectors of COMPASS RICH-1 [12] are based on the use of Multi-Anode Photo-Multiplier Tubes (MAPMTs) as active elements. MAPMTs, intrinsically fast and with sub-ns time resolution, are read out via a digital system based on highly sensitive amplifier-discriminators and high resolution Time to Digital Converters (TDCs) [13]. The choice of a digital system matches well the MAPMT characteristics: the spread amplitude spectrum provided by this photon detector (Section 4) would limit the effectiveness of the photon counting via amplitude measurement. The MAPMTs are coupled to individual telescopes of fused silica lenses to enlarge the effective detection area. A compact setup with negligible dead zones and able to ensure both light and gas tightness has been obtained with a careful design, construction and assembly of the mechanical components of the setup.

MAPMTs coupled to lens telescopes have already been successfully employed for single photon detection in the HeraB RICH counter [14,15]. They have been proposed as one of the options for photon detection in LHCb RICHes [16]. Our approach is characterised by some novel features:

- the photon wavelength domain is extended to the UV range, thanks to the use of MAPMTs with UV extended window, that allows to convert photons down to 200 nm wavelength, and to the choice of telescopes formed by fused silica lenses;

[4] The ideal circular image is distorted, mainly because it is formed on the planar detector surface, which approximates the spherical focal surface of the mirror wall.

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