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The COMPASS RICH-1 fast photon detection system

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ABSTRACT

A fast photon detection system has been built as a part of the upgrade of the COMPASS RICH-1 detector: it is based on 576 multi-anode photomultiplier tubes (MAPMTs) coupled to individual fused silica lens telescopes and fast readout electronics. This system has replaced the MWPCs with CsI photo-cathodes in the central region (1.3 m^2, 25% of the total area) of the COMPASS RICH-1 photon detectors and has successfully been operated during the data taking in 2006 and 2007. We report about the fast photon detection system design, construction and commissioning, in particular about the design optimization and the validation tests of the lens telescopes. Preliminary values for the increased performances of COMPASS RICH-1 after the upgrade are also presented.

1. Introduction

The COMPASS Experiment [1] at CERN SPS is dedicated to the study of the nucleon spin structure and the hadron spectroscopy; it has a high luminosity fixed target setup with a large acceptance double spectrometer.

Hadron identification is required in COMPASS for a wide particle momentum range, at high rate, and over more than ±200 mrad angular acceptance.

Since 2002, these requirements have been fulfilled by COMPASS RICH-1 [2], a Ring Imaging Cherenkov Detector with 3 m C_4F_{10} gas radiator, a 21 m^2 surface of spherical UV mirrors and a set of MWPCs with CsI photo-cathodes covering 5.2 m^2.

Before its upgrade, COMPASS RICH-1 was providing a mean number of 14 detected photons for $\beta = 1$ particles, a measured

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Cherenkov angle resolution of 1.2 mrad for single photons and a PID efficiency larger than 95% over most of the acceptance, allowing 2σ $\pi-\mathrm{K}$ separation at 43 GeV/c.

The large uncorrelated background present in the RICH-1 environment was however limiting the global resolution on the measured Cherenkov angle, for a particle at saturation, to 0.6 mrad on average and significantly lowering the efficiency in the very forward region.

2. The upgrade of RICH-1

To cope with the increased beam intensity and trigger rates foreseen by COMPASS, and to get rid of the large uncorrelated background, RICH-1 has undergone an important upgrade between autumn 2004 and spring 2006: the central region of the photon detectors (25% of the total surface) has been instrumented with a new fast detection system [3], based on MAPMTs coupled to individual fused silica lens telescopes and read out via sensitive front-end digital electronics and high resolution TDCs. The outer regions have been upgraded by equipping the existing photon detectors with a new readout system [4] not discussed in this article.

3. The MAPMTs

The central elements of the upgrade are 576 MAPMTs, Hamamatsu[4] R7600-03-M16, 16 channels, with UV extended glass window, equipped with custom compact voltage dividers and individual soft iron boxes for protection against a ~200 Gauss magnetic field.

More than 600 MAPMTs have been submitted, in a fully automated test-setup [5], to a complete quality control protocol: a 2 h procedure including visual inspection, measurements of dark current and measurements of gain at five different applied voltages. The rejection rate has been of the order of 2%, mostly due to the requirement of a dark current lower than 2 nA for each single channel; the typical gain is about 10^7 at 900 V and the gain uniformity is excellent. No MAPMT gain reduction was observed up to single photoelectron rates of at least 5 MHz per channel.

4. The lens telescopes

A challenging part of the upgrade project is the light concentration system, which is required to transmit photons in the range from 200 to 700 nm, to provide a large demagnification factor (for the project to be cost affordable) and to have a wide angular acceptance; it should exhibit minimal image distortion in order to avoid pixel cross-talk, comply with space limitations on the detector and allow for manufacturing within reasonable time and cost.

After investigation and tests of different solutions the final design [6] consists of individual optical telescopes (see Fig. 1) for each MAPMT; the telescopes are 11.5 cm long and provide an image reduction of a factor 7.3 in area, a full angular acceptance of 8.3° and a 50% acceptance as large as 9.3°. The telescopes have been optimized by Monte Carlo simulations using Zemax[5] software; they are made of two fused silica lenses: a field lens and a condenser lens.

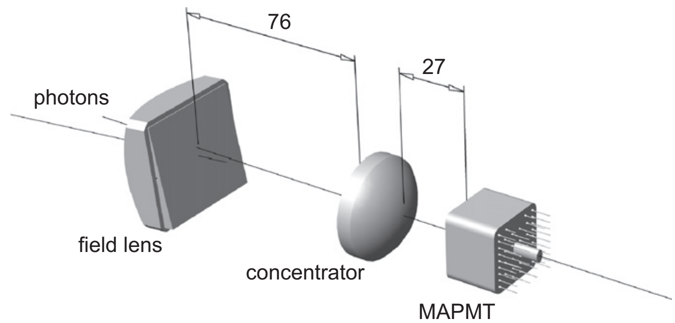

Fig. 1. Scheme of the two-lenses telescope system.

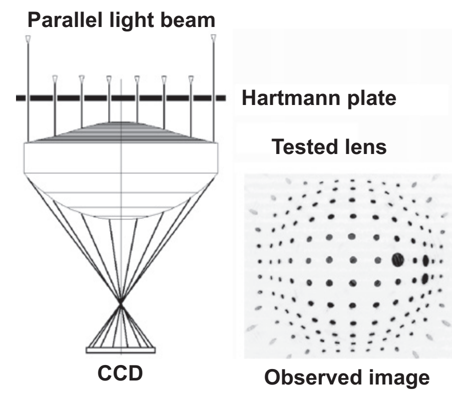

Fig. 2. Scheme of the principle and observed image of the Hartmann validation test for the condenser (aspheric) lens.

The field lens, placed in the focal plane of the mirrors, is plano-convex with a 5° wedge (an axial system is not allowed due to the limited space), and bends the incoming light to the condenser lens; it guarantees the large field of view of the system and the possibility to have no dead areas between telescopes. The condenser lens is biconvex with one aspherical surface, providing the large demagnification with reduced image distortions; it projects the image to the plane of the MAPMT photo-cathode with a total spot size r.m.s. less than 1 mm, to be compared to the 4.5 mm pitch of the MAPMT pixels. The fused silica HPFS Standard Grade, Corning[6] code 7980, 5D has been used to produce the lenses by grinding and polishing procedure: tight tolerances for surface quality and shape, and for the machining of the field lens edges have been required and achieved. All lens surfaces have been coated with a MgF_2 antireflection layer (corresponding to an increase of about 8% in the number of the collected photons).

Each lens and each complete telescope have been controlled [7] employing the Hartmann method [8] (Fig. 2) by a custom setup and analysis code, providing individual characterization of wavefront distortions with respect to ideal optics. The final image displacement introduced by optics imperfections is below 50 μm for 70% of the telescopes, and in all cases below 150 μm. An elaborated mechanical design of the lenses support frames (Fig. 3) allows to reduce the dead areas below 2% of the surface.

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