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The fast photon detection system of COMPASS RICH-1

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Abstract

A fast photon detection system has been built for the upgrade of COMPASS RICH-1, the large size gaseous RICH detector in use at the COMPASS Experiment at the CERN SPS since 2001. The photon detectors of the central region have been replaced by a new system based on multi-anode photomultipliers coupled to individual fused silica lens telescopes and a fast readout electronics system, while in the outer region the existing MWPCs with CsI photocathodes have been equipped with a new readout system, based on the APV chip. RICH-1 has been successfully operated in its upgraded version during the 2006 run. We report on the upgrade design and construction,

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and on the preliminary characterization of the upgraded RICH-1 performances: at saturation about 60 photons per ring have routinely been obtained and the background level has drastically been reduced thanks to the good time resolution of the new system, leading to a 2σ π–K separation above 55 GeV/c.

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Keywords: COMPASS; RICH; Multi-anode photomultiplier tubes; UV lenses; Photon detection

1. Introduction

COMPASS [1,2] is a high luminosity experiment at the CERN SPS, dedicated to the study of the nucleon spin structure and spectroscopy. The experiment requires to identify pions, kaons and protons in a wide momentum range, over a ± 200 mrad angular acceptance. To meet these requirements RICH-1 [3], a large size Ring Imaging Cherenkov (RICH) detector with a 3 m C_4F_{10} gas radiator, has been built and operated at COMPASS since 2001.

With a mean number of 14 detected photons for $\beta = 1$ particles and a measured Cherenkov angle resolution of 1.2 mrad for single photons, RICH-1 was already before the upgrade providing a particle identification efficiency of more than 95% over most of the acceptance and a 2σ π–K separation at 43 GeV/c. The presence of a large uncorrelated background in the COMPASS environment was however limiting the global resolution on the measured Cherenkov angle for a particle at saturation to 0.6 mrad on average and lowering the efficiency in the very forward region.

To cope with the increased beam intensity and the trigger rates foreseen by COMPASS, and to get rid of the large uncorrelated background, RICH-1 has undergone an important upgrade: the central photon detection area (25% of the surface) has been instrumented with a new fast detection system [4], based on multi-anode photomultipliers (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, namely MWPCs with CsI photocathodes, with a new readout system [5], based on the chip APV, with very low dead-time and increased time resolution.

2. Design and construction

The central elements of the upgrade are 576 MAPMTs, Hamamatsu R7600-03-M16 with 16 channels and a UV extended glass window, equipped with custom-made compact voltage-dividers and individual soft iron boxes for protection against a ~200 G magnetic field. Six hundred and twelve MAPMTs have been submitted 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 was in the order of 1–2%, mostly due to the low dark current requirement; the accepted MAPMT gain variation between pixels is in a range of 1:2.8. No MAPMT gain reduction was observed up to a single photoelectron rate of at least 5 MHz per channel.

In front of each MAPMT there is a fused silica lens telescope (see Fig. 1), designed to provide an image reduction by a factor 7.3 in area, while minimizing image distortions and optimizing photon collection, angular acceptance and manufacturing parameters: the resulting telescopes are formed by two lenses (one with an aspherical surface), they are 11.5 cm long and have an angular acceptance of $\pm 9.5°$. The r.m.s. of the total spot size is ~1 mm. All lens surfaces have been coated with a MgF_2 anti-reflective layer. Each lens and each complete telescope has been tested employing the Hartmann method by a custom setup and a corresponding analysis code. The image displacement introduced by optics imperfections is below 50 μm for most of the telescopes, and in all cases below 150 μm.

The signals from the MAPMTs are read by a digital electronics system. The front-end stage is based on the MAD4 [6] front-end chip, characterized by its small noise level (5–7 fC, to be compared to a typical mean signal at front-end input of 500 fC), essential for good efficiency. A threshold tuning allowed to suppress the MAPMTs cross talk while keeping the single photoelectron detection efficiency of the MAPMT coupled to the MAD4 chip at ~95% [4]. The MAD4 can operate up to ~1 MHz per channel, but an upgraded version of the chip, called CMAD, has been designed in CMOS technology, to match the specific features of the MAPMT readout: it provides full efficiency up to 5 MHz per channel input rates

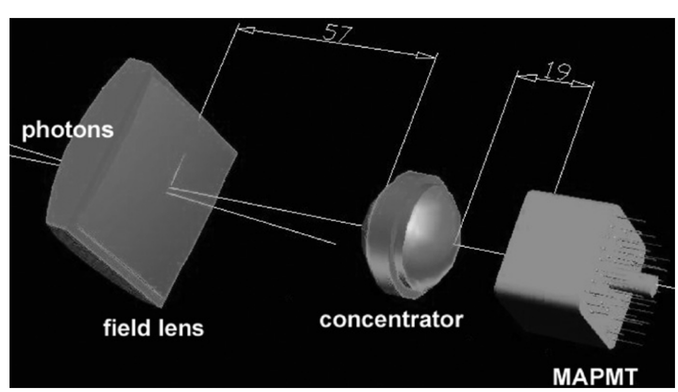

Fig. 1. Optical arrangement of the MAPMT and the fused silica lens telescope.

and it is planned to be implemented on the RICH-1 for the 2008 run.

The good time resolution of the MAPMTs is fully exploited with the help of digital cards, called DREISAM, housing the dead-time free F1 TDC [7], which has a time resolution of ~110 ps and can stably operate up to a 10 MHz per channel input rate and a 100 kHz trigger rate. Data from the front-end cards are transferred via optical links to the COMPASS readout and data acquisition system [8].

The MWPCs with CsI photocathodes covering the outer region (75% of the photon detection surface, corresponding to 62 208 electronics channels) have been equipped with a new readout system based on the APV25-S1 chip [9]: a 128-channel preamplifier and shaper ASIC whose output is sampled at a frequency of 40 MHz and stored in a 192 cell deep analogue pipeline. When an event is triggered, the cells to be read are multiplexed into a single differential output; two additional samples taken at the beginning and at the middle of the rising edge of the signal (300 and 150 ns before the maximum) are read to extract timing information. A 10-bit flash-ADC and a FPGA are used to perform digitization and on-line zero suppression. The measured noise level is ~680e$^-$ to be compared to the average collected signal amplitude of ~9000e$^-$.

All the electronics components of the RICH-1 readout system are mounted directly on the detector, forming a very compact setup. Each printed-circuit board is coupled to a copper plate providing both efficient electromagnetic shielding and good cooling power: thermalized water circulates in underpressure conditions through thin copper pipes brazed onto the copper plates.

3. Performances in 2006

The upgrade was fully designed and implemented between November 2005 and May 2006, and data were collected with the upgraded RICH between June and November 2006. An example of the on-line event display for the central region is presented in Fig. 2. Full rings of $\beta = 1$ particles have on average ~60 hits, and a negligible background level from uncorrelated physics events.

The new APV-based readout has provided the expected large improvement in time resolution (now better than 25 ns for ~90% of the detected photons), has increased the signal/noise ratio and reduced the dead-time to minimal levels, making the whole RICH-1 able to cope with trigger rates in the range of 100 kHz.

A preliminary estimate of the effect of the upgrade in terms of global resolution on the measured Cherenkov angle in the central region has been performed on 2006 data: it gives ~0.3 mrad at saturation (it was 0.6 mrad before); particle identification has improved at both low and high momenta: the minimum Cherenkov angle for efficient reconstruction is now ~20 mrad, while it was ~30 mrad, and the increased resolution allows 2σ π–K separation up to above 55 GeV/c (this value was 43 GeV/c before the upgrade).

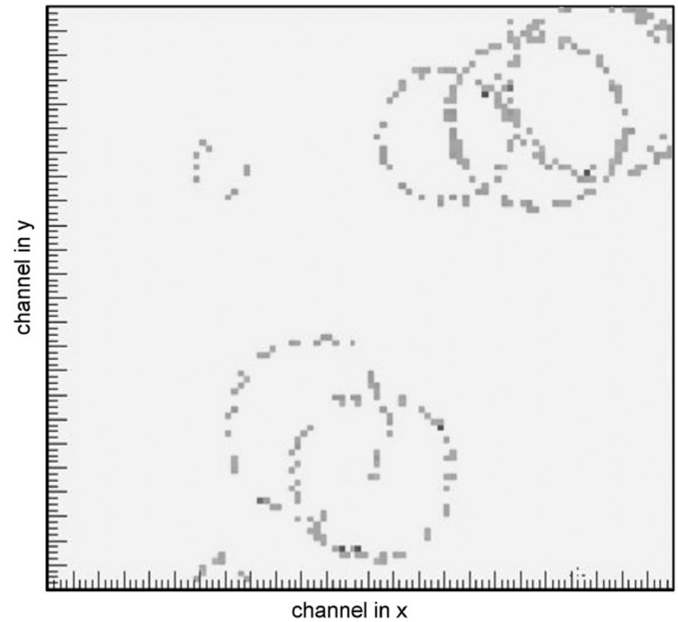

Fig. 2. Single physics event in the central region of the RICH detector. Only hits in the time window of ±5 ns around the trigger time are displayed.

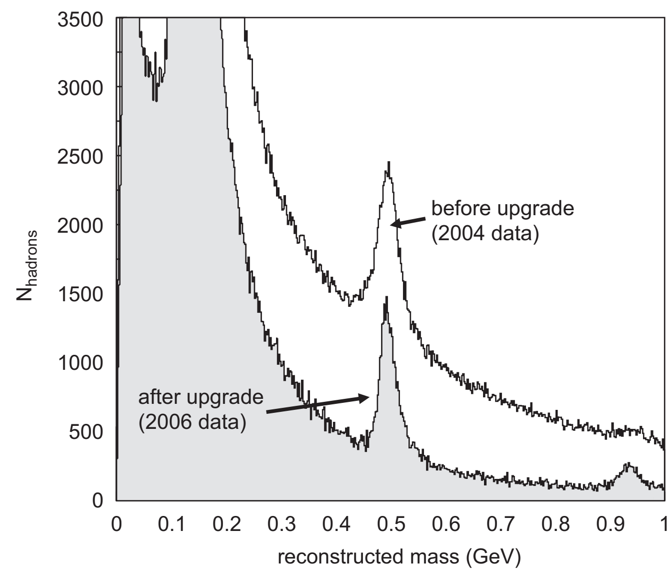

Fig. 3. RICH-reconstructed kaon mass peak before (2004 data) and after the RICH upgrade (preliminary 2006 data).

Making use of K$^\pm$ from the ϕ meson decay, a preliminary evaluation of the identification efficiency for kaons in the range between 10 and 60 GeV/c has provided values above 90%, including the very forward region. The purity of identified kaons in the same momentum range has been studied with $\pi^\pm$ from the K$_S$ decay, providing preliminary estimates of the misidentification probability in the range of 1% or smaller. The effect of improved efficiency and purity can be seen in the comparison of the kaon mass peaks for 2004 data and preliminary 2006 data, presented in Fig. 3.

4. Conclusions

A fast photon detection system for the upgrade of COMPASS RICH-1 has been designed and implemented on the time scale of one year and a half, and has successfully improved the performances of RICH-1 during the 2006 data taking, especially in the very forward region. With about 60 detected photons per ring at saturation, a 2σ π–K separation above 55 GeV/c and the possibility to cope with trigger rates in the range of 100 kHz, the COMPASS RICH-1 has really outstanding performances.

Acknowledgments

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