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The upgrade project of the RICH-1 of the COMPASS Experiment

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Summary. — A major upgrade of the RICH-1 of the COMPASS Experiment at CERN has been designed and implemented in less than two years, during the SPS shut-down period and the upgraded detector is successfully in operation since the 2006 SPS run. It is a twofold project: in the peripheral

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region the existing Multi Wires Proportional Chambers with CsI are unchanged but they have been equipped with a new faster read-out electronics, while the photon detectors of the central region have been replaced with a completely new fast photon-detection system. It is based on the use of Multi-Anode Photo-Multipliers (MAPMTs) coupled to individual fused silica lens telescopes and read out by a fast electronics based on the MAD4 preamplifier-discriminator chip and the F1 TDC chip. For the 2009 SPS run an upgraded version of the MAD4 chip, the CMAD, has been designed in CMOS technology and implemented on the RICH-1, in order to match the specific features imposed by the fast MAPMTs, which guarantee full efficiency up to 5 MHz per channel, thus overcoming the limitation of MAD4 at 1 MHz per channel. We present the photon-detection design and construction and its characterization and measured performances. The full-custom ASIC CMAD will be also shortly described together with its performances.

PACS 29.40.Ka – Cherenkov detectors.
PACS 42.79.Pw – Imaging detectors and sensors.
PACS 85.40.-e – Microelectronics: LSI, VLSI, ULSI; integrated circuit fabrication technology.

1. – Introduction

COMPASS is a high-luminosity experiment [1], at CERN SPS, dedicated to hadron physics, with an extended research program both in nucleon spin physics, with the use of muon beam, and hadron spectroscopy, using hadron beam. For both scientific programs, as for many HEP experiments, a very efficient particle identification (PID) is mandatory. In the COMPASS spectrometer hadronic particle identification in the multi-decade GeV/c range is performed by RICH-1 [2], a large-size RICH counter in operation since 2001. During years 2001-2004 RICH-1 was fully instrumented with Multi-Wires Proportional Chambers (MWPCs) equipped with CsI photocathodes for single-photon detection, operated at low gain, as imposed by the presence of CsI photocathodes.

The read-out system was based on the Gassiplex front-end chip [3], with long integration time, related to the reduced gain, and a not negligible dead time due to the baseline restoration of the front-end chip used. These features limited the performances of RICH-1, especially in the central detector region, where the large muon beam halo, intrinsic to the CERN muon beam, causes a high-rate uncorrelated background.

To overcome these limitations and to cope with the higher trigger rates, of up to 100 kHz, foreseen by the COMPASS Experiment from 2006 on, an ambitious upgrade project has been developed and implemented during the SPS shut down period, between Autumn 2004 and Spring 2006.

It consisted in a complete replacement of the photon-detectors of the central region, corresponding to 25% of the active surface, with the new fast photon-detection system based on MAPMTs, while in the peripheral region the existing MWPCs with CsI photocathodes are unchanged, but read out by a new electronic system based on APV preamplifiers and flash ADC chips [4].

We focus here on the fast photon-detection system. The MAPMTs are coupled to individual telescopes of fused-silica lenses, to enlarge the effective active area of the photon detectors, and are read out by a fast electronic based on the MAD4 preamplifier-discriminator and the high-resolution dead-time free F1 TDC.

The whole system has been installed on RICH-1 during Spring 2006 and has been successfully operated in 2006, 2007 and 2008 data taking. For the 2009 SPS run the MAD4 chip has been replaced with a new full-custom ASIC, produced in 0.35 μm CMOS technology, able to cope with a single channel rate above 5 MHz, thus completely fulfilling the requirements imposed by the fast MAPMTs and matching the increased event rate that the system has to sustain with hadron beam.

The present paper describes the MAPMT-based fast photon-detection system: an overall description is given is sect. **2**; sect. **3** is dedicated to the system performances; the CMAD is presented in sect. **4**; the conclusions are reported in sect. **5**.

2. – The fast photon-detection system

Multi-anode photo-multiplier tubes (MAPMTs) by Hamamatsu, type R7600-03-M16, with 16 anode channels, have been chosen to detect single photons at high rates: they have bialkali photocathodes with $18 \times 18\,\text{mm}^2$ active surface and UV extended glass window, to enlarge the range of the detectable Cherenkov light spectrum (200–700 nm). MAPMTs are coupled to individual telescopes of two lenses in order to increase the geometrical acceptance; image distortion is avoided by an accurate telescope design; lenses are made of fused silica to match the wavelength range of the PMT.

A custom voltage-divider compact circuit, which also provides connections between MAPMT anodes and the read-out chain, has been realised; it is based on the standard circuit [5] proposed by Hamamatsu, which, as proved by laboratory test, ensures high efficiency in single photo-electron detection also at high rate: in fact no gain reduction has been observed up to rates larger than 5 MHz per anode.

The whole electronics system is arranged in a very compact set-up, free from cable connections to minimise the electrical noise and to take into account the limited space in front of the RICH-1 detector. The small analog boards, populated with preamplifier-discriminator chips [6], are directly linked via a connector to the voltage divider boards. A deck board, the Roof board, provides services to eight analog boards: power, threshold settings and input/output data transfer from and to the digital board; it also acts as a mechanical fixation of the other elements of the read-out system.

The digital data from the Digital RICH ElectronIc Sampling (DREISAM) boards are transferred via optical links to the HOT-CMC receiver boards, explicitly developed for this project, mounted on the common read-out driver of the COMPASS experiment: the COMPASS Accumulate, Transfer and Control Hardware (CATCH) [7].

The main task of the front-end electronics is to amplify the signals from the MAPMTs, to discriminate them and send the differential LVDS signals to the digital board. Low-noise level and good efficiency in single photo-electron detection are required, together with a good resolution and a wide range in threshold settings outside the noise and crosstalk region, and with negligible photo-electron losses. The digital board, the DREISAM, hosts eight F1 TDC chips [8] for the read-out of four MAPMTs. The F1-TDC is a high-resolution dead-time free TDC chip, that can provide time measurement with different resolution modes: normal, high and latch mode. For our application a normal resolution mode with a digitisation bin width of 108.7 ps has been chosen. In the selected mode the F1 chip can operate at input data rates of up to 10 MHz per channel and trigger rates of up to 100 kHz.

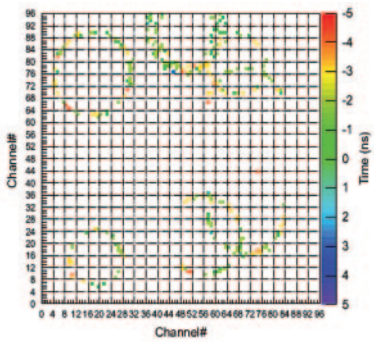

Fig. 1. – Hadron Cherenkov rings from the online single event display.

3. – Performances in the real environment

Before the upgrade, RICH-1 was providing 14 detected photons per ring at saturation but the presence of the large uncorrelated background was limiting the 2σ pi-K separation to 43 GeV/c.

The fast photon detection system provides an average number of 56 detected photons per ring at saturation thanks to the enlarged wavelength sensitivity of MAPMTs with respect to MWPC with CsI, and the improved time resolution allows to cut out almost completely the uncorrelated background as can be seen in fig. 1, showing a typical event with a color code corresponding to the hit time assignment.

The time distribution of the detected photons in one quarter of the MAPMT detector system is illustrated in fig. 2, where the standard deviation of the TDC peak is about 1 ns, being determined by the different path lengths of the photons, thanks to the sub-nanoseond resolution of the photon detection system.

4. – CMAD: a full custom front-end ASIC for the COMPASS RICH-1

In order to further improve the rate capability of the detector, limited around 1 MHz per channel by the MAD4, a new front-end chip, the CMAD, has been developed and implemented for the 2009 COMPASS run.

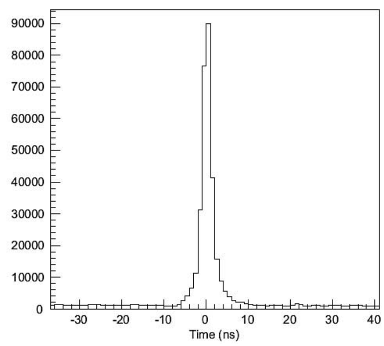

Fig. 2. – Physics signal and background, in real environment.

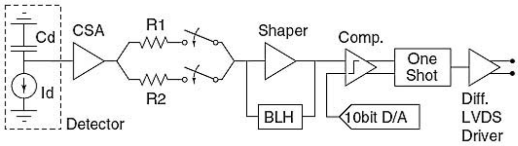

Fig. 3. – Architecture of a single channel.

An integrated circuit includes eight channels. Each channel features a low-noise transimpedance amplifier, a shaper with 10 ns peaking time, a baseline holder (BLH), a comparator, a programmable oneshot, to maintain the backward compatibility with the existing read-out system, and a LVDS driver. Figure 3 shows the architecture of a single channel. The Charge Sensitive Amplifier (CSA) has a programmable gain from 0.4 mV/fC to 1.2 mV/fC in steps of 0.08 mV/fC. It consists of a basic amplifier with a capacitive feedback C_f, a voltage buffer B and a resistive feedback R_f as resetting device. The gain of the preamplifier is strongly dependent on the resistive feedback value R_f, while C_f has to be adjusted in order to keep the time constant the same and preserve the optimum signal shape. The first stage (CSA) drives the second stage (shaper) with a current signal through an adjustable resistive connection (R_1 and R_2) which allows to select between two different gain modes (1× and 4×).

The fast shaper (see fig. 4) is based on a class AB operational amplifier [9] around which two feedback networks are implemented: a fast path (shaper) performs high-frequency filtering while a slow baseline holder feedback (BLH) provides the AC coupling with the previous stage and guarantees baseline stabilization. The BLH circuit, which includes a fast unity gain buffer with limited slew rate, is designed to reduce baseline shift to less than 3 mV for output pulses of 3 V in amplitude and at a 10 MHz rate. The new design of the baseline holder circuit provides, with respect to MAD4, a higher speed of more than 5 MHz per channel with a low power consumption of 26 mW. Moreover baseline and threshold levels are adjustable in the comparator on a channel-by-channel basis via a local 10-bit digital-to-analog converter (D/A). Figure 5 shows the efficiencies of CMAD compared with MAD4 as a function of event rate, demonstrating that the new ASIC is effectively able to match the specific features imposed by multi-anode photomultipliers, overcoming the limitation of MAD4 at 1 MHz per channel and being fully efficient above 5 MHz per channel.

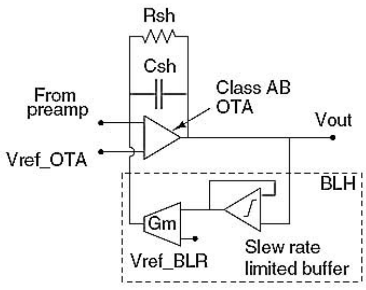

Fig. 4. – Architecture of the shaper with baseline holder (BLH).

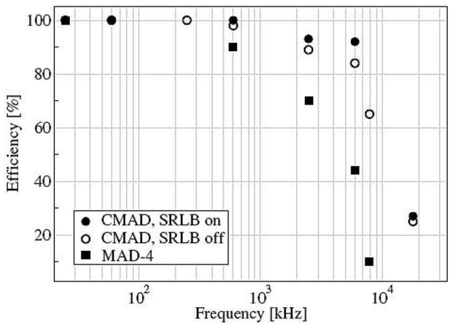

Fig. 5. – Channel efficiency measurements both for CMAD and MAD4 as a function of event rate. The CMAD data were acquired both with the slew rate limiting buffer (SRLB) enabled (filled circles) and disabled (empty circles).

5. – Conclusions

A fast photon-detection system has been designed and successfully implemented, as a part of a global upgrade project of the COMPASS RICH-1, between November 2004 and May 2006, during the SPS shut down period. The system has been operated during 2006, 2007, 2008 data-taking periods: its performances entirely fulfill the expectations. For the 2009 SPS run a new upgrade has been implemented on the RICH-1, with the replacement of the MAPMTs front-electronics based on MAD4 chip with a new one based on a new full-custom ASIC, named CMAD, developed on purpose for the RICH-1 fast photon detection system based on multi-anode photo-multipliers.

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