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# The COMPASS RICH-1 detector upgrade

P.Abbon[11], M.Alekseev[12], H.Angerer[9], M. Apollonio[13], R.Birsa[13], P.Bordalo[7], F.Bradamante[13], A.Bressan[13], L.Busso[12], M.Chiosso[12], P.Ciliberti[13], M.L.Colantoni[1], S.Costa[12], S.Dalla Torre[13], T.Dafni[11], E.Delagnes[11], H.Deschamps[11], V.Diaz[13], N.Dibiase[12], V.Duic[13], W.Eyrich[4], D.Faso[12], A.Ferrero[12], M.Finger[10], M.Finger Jr[10], H.Fischer[5], S.Gerassimov[9], M.Giorgi[13], B.Gobbo[13], R.Hagemann[5], D.von Harrach[8], F.H.Heinsius[5], R.Joosten[2], B.Ketzer[9], K.Königsmann[5], V.N. Kolosov[3] , I.Konorov[9], D.Kramer[6], F.Kunne[11], A.Lehmann[4], S.Levorato[13], A.Maggiora[12], A.Magnon[11], A.Mann[9], A.Martin[13], G.Menon[13], A.Mutter[5], O.Nähle[2], F.Nerling[5] , D.Neyret[11], P.Pagano[13], S.Panebianco[11], D.Panzieri[1], S.Paul[9], G.Pesaro[13], J.Polak[6], P.Rebourgeard[11], F.Robinet[11], E.Rocco[13], P.Schiavon[13], C.Schill[5], W.Schröder[4], L.Silva[7], M.Slunecka[10], F.Sozzi[13], L.Steiger[10], M.Sulc[6], M. Svec[6], F.Tessarotto[13], A.Teufel[4], H.Wollny[5]

[1] INFN, Sezione di Torino and University of East Piemonte, Alessandria, Italy
[2] Universität Bonn, Helmholtz-Institut für Strahlen- und Kernphysik, Bonn, Germany
[3] CERN, European Organization for Nuclear Research, Geneva, Switzerland
[4] Universität Erlangen-Nürnberg, Physikalisches Institut, Erlangen, Germany
[5] Universität Freiburg, Physikalisches Institut, Freiburg, Germany
[6] Technical University of Liberec, Liberec, Czech Republic
[7] LIP, Lisbon, Portugal
[8] Universität Mainz, Institut für Kernphysik, Mainz, Germany
[9] Technische Universität München, Physik Department, Garching, Germany
[10] Charles University, Prague, Czech Republic and JINR, Dubna, Russia
[11] CEA Saclay, DSM/DAPNIA, Gif-sur-Yvette, France
[12] INFN, Sezione di Torino and University of Torino, Torino, Italy
[13] INFN, Sezione di Trieste and University of Trieste, Trieste, Italy

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**Abstract.** The COMPASS experiment at CERN provides hadron identification in a wide momentum range employing a large size gaseous Ring Imaging CHerenkov detector (RICH). The presence of large uncorrelated background in the COMPASS environment was limiting the efficiency of COMPASS RICH-1 in the very forward regime. A major upgrade of RICH-1 required a new technique for Cherenkov photon detection at count rates of several $10^6/s$ per channel in the central detector part, and a read-out system allowing for trigger rates of up to 100 kHz. To cope with these requirements, the photon detectors of the central region have been replaced with a fast photon detection system described here, while, in the peripheral regions, the existing multi-wire proportional chambers with CsI photo-cathodes have been equipped with a new read-out system based on APV preamplifiers and flash ADC chips.
The new system consists of multi-anode photo-multiplier tubes (MAPMTs) coupled to individual fused silica lens telescopes, and fast read-out electronics based on the MAD4 amplifier-discriminator and the dead-time free F1 TDC chip. The project was completely designed and implemented in less than two years: The upgraded detector is in operation since the 2006 CERN SPS run. We present the photon detection design, constructive aspects and test studies to characterise the single photon response of the MAPMTs coupled to the read-out system as well as the detector performance based on the 2006 data.

**PACS.** 29.40.Ka Cherenkov detectors – 42.79.Pw Imaging detectors and sensors – 84.30.-r Electronic circuits – 84.30.Sk Pulse and digital circuits – 85.60.Gz Photodetectors – 85.60.Ha Photomultipliers; phototubes and photocathodes

## 1 Introduction & motivation

The fixed target experiment COMPASS [1] at CERN SPS is a two stage spectrometer dedicated to the investigation of perturbative and non-perturbative QCD. The broad research program includes both physics with a muon and hadron beams, including the study of the nucleon spin structure and charm spectroscopy.

Particle identification of hadrons in the multi-decade GeV/c range [2] is performed by COMPASS RICH-1, a

*Send offprint requests to*: F. Nerling[5]
*Correspondence to*: Frank.Nerling@cern.ch

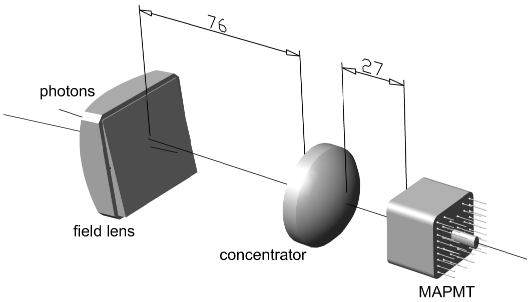


**Fig. 1.** *Scheme of the two-lenses telescope system, measures being given in mm.*

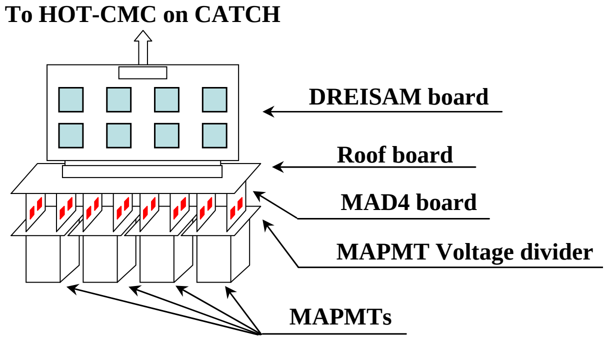


**Fig. 2.** *Scheme of a basic read-out unit.*

large size gas radiator RICH detector in operation since 2001. For the single photon detection, multi-wire proportional chambers (MWPCs) with CsI photo-cathodes operated at low gain (below $5 \times 10^4$) as imposed by the presence of the CsI photo-cathode had been used. The read-out was based on the Gassiplex front-end (FE) chip [3] with a long integration time (0.5 - 1 $\mu$s) to cope with the reduced gain. In addition, the base-line restoration time of the Gassiplex output takes about 3.5 $\mu$s, thus generating data acquisition dead-time. These features and the dominant background due to uncorrelated muon beam halo particles in the central detector region had significantly reduced the detector performance, especially for particles under small angles. Furthermore, the planned increase of the beam intensity from 40 to 100 MHz, and trigger rates from 20 kHz in the past to 100 kHz, made upgrading the COMPASS RICH-1 mandatory in terms of a faster photon detection system. The central quarter of the 5.3 $\mathrm{m}^2$ photon detection area has been fitted with a new detection system based on MAPMT [4], which is discussed in detail in this paper, whereas the outer regions stay unchanged and are read out by a new system [5] characterised by negligible dead-time and better time resolution. The upgrade of the RICH-1 detector has been proposed and implemented during the SPS shut down period between Autumn 2004 and Spring 2006, and successfully operated during the 2006 COMPASS data taking.

## 2 Description of the system

The new fast photon detection system consists of 576 MAPMTs (Hamamatsu R7600-03-M16) with 16 channels per PMT, each coupled to an individual fused silica telescope, see Fig. 1. The purpose of the optics is to focus the Cherenkov photons on the sensitive cathodes to gain a factor of approximately 7 in sensitive surface. Moreover, the telescope has been designed to minimise image distortions, provide an angular acceptance of $\pm 9.5^{\circ}$, and perform a spot size of $\sim 1$ mm (r.m.s).

The read-out is performed by 4 sensitive MAD4 chips [7] on 2 FE cards per MAPMT, and high-resolution F1 TDCs [8]. One so-called DREISAM card housing 8 F1 TDCs reads 4 MAPMT, see Fig. 2. The electronic cards are water-cooled via copper water line plates. One panel of MAPMT fully equipped with FE electronics is shown in Fig. 3. The digital data from the DREISAM boards are transferred via optical links to HOT-CMC cards mounted on the CATCH boards, and then sent to the read-out farm of the COMPASS experiment. The HOT-CMC board has been developed for this project, while the CATCH board is standard in the COMPASS data acquisition system [9].

A typical amplitude spectrum as response of the MAPMT to single photo-electrons is shown in Fig. 4. At very small amplitudes, the tail of the pedestal signal distribution is visible, followed by two signal peaks: At larger amplitudes, the signals correspond to the single photo-electrons that have been multiplied by the whole 12-dynode chain of the MAPMT, whereas the peak at smaller amplitudes is due to photo-electrons having escaped one of the multiplication stages. For our application, the detection of the photo-electron signal of both peaks is equally important.

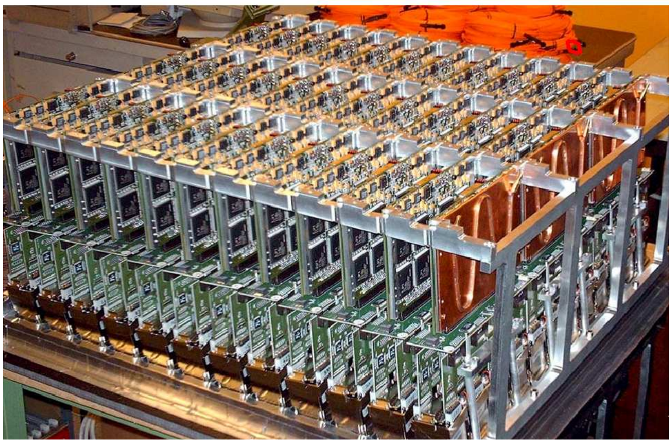

**Fig. 3.** *First quadrant: One quadrant of the new detection system comprising 144 MAPMT, fully equipped with FE electronics. The FE cards are water-cooled by single waterline copper plates, as indicated by the three DREISAM boards in the front.*

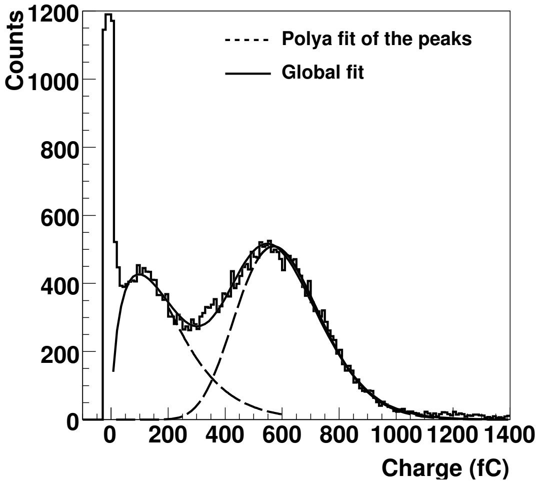


**Fig. 4.** *Typical amplitude spectrum obtained with a MAPMT R7600-03-M16 by Hamamatsu at 900 V illuminating the photo-cathode in single photo-electron mode. The noise pedestal is visible, as well as two signal peaks, the lowest one corresponding to photo-electrons skipping a multiplication stage. The dashed curves are individual fits of the two peaks with Polya functions; the solid curve is a global fit with a sum of two Polya functions.*

### 2.1 FE electronics

The analogue front-end electronics exhibit a small noise in the range of 5 - 7 fC, to be compared with the typical single photo-electron signals of 500 fC, and is capable to sustain an event rate up to 1 MHz per channel, see e.g. [10]. The new FE chip version CMAD, that will be available for the 2008 run, will operate up to rates of 5 MHz per channel. The F1-TDC operates stably for input rates up to 10 MHz per channel at 100 kHz trigger rates, and the time resolution of 80 ps [11] further ensures that the background level from uncorrelated physics events is negligible.

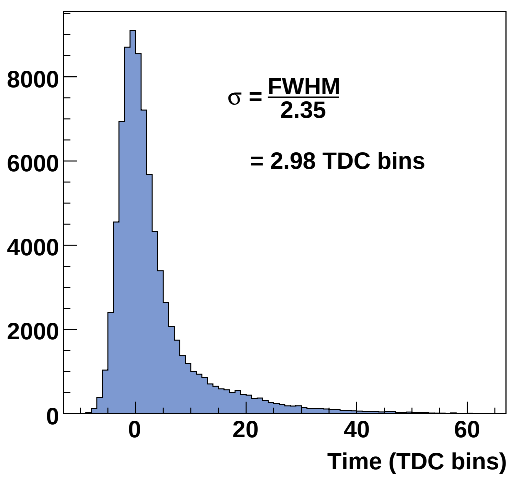


**Fig. 5.** *MAPMT time spectrum (1 TDC bin = 108.3 ps), for discussion see text.*

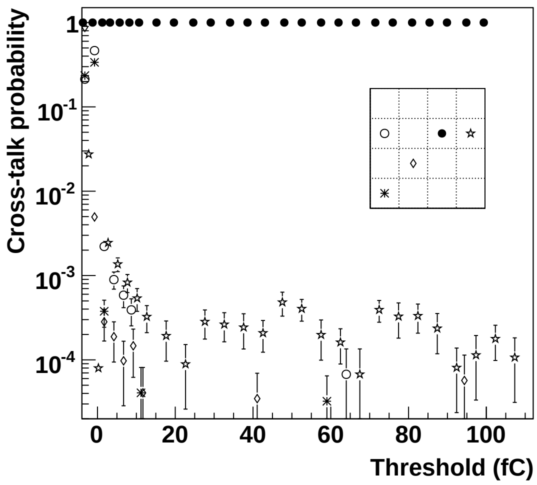


**Fig. 6.** *Cross-talk measurement: Hit rates of the illuminated reference pixel (closed circle) and in different neighbouring channels, each normalised to the reference pixel.*

## 3 System performances

Numerous tests have been done to verify that the new photon detection system fulfils the expected performances. The described measurements in the laboratory have been performed with a sub-unit consisting of one MAPMT, two MAD4 boards, one Roof board and one DREISAM board.

### 3.1 Laboratory studies

For the overall time resolution of the system, optical pulses have been generated using a laser diode[1] and collimating optics to generate optical pulses of a width of $\sim$ 45 ps. These pulses have been sent through a neutral grey filter to attenuate the signals in order to have single photons and a 300 $\mu$m pinhole onto the MAPMT photo-cathode.

The time distribution of the MAPMT signals in response to single photons relative to the trigger time gives the total jitter of the complete read-out system: MAPMT, MAD4 board, Roof board, DREISAM board and the optical fibre, which distributes the clock signal to the TDC. The time spectrum is shown in Fig. 5. The central peak has a width of $\sigma = 324$ ps. In addition, there is a tail of later signals related to photons impinging on the photo-cathode close to the border between two neighboured channels [11].

The cross-talk between neighbouring channels has been determined by illuminating an isolated MAPMT pixel by the laser diode through the pinhole of about 300 $\mu$m diameter, and measuring the number of hits in the other channels. The results of the measurements are shown in Fig. 6. The measured cross-talk level for thresholds above 10 fC is well below $10^{-3}$ for all channels and therefore negligible.

[1] PiLas EIG1000D by *Advanced Laser Diode Systems GmbH*

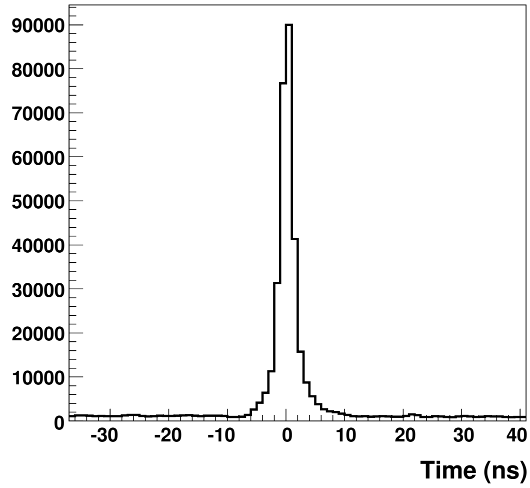


**Fig. 7.** *Physics signal and background - real environment, for discussion see text.*

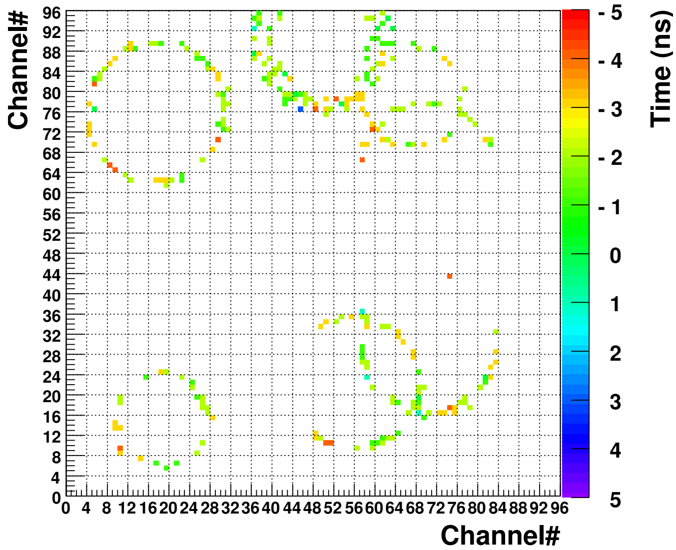


**Fig. 8.** *Online single event display: Hadron-generated Cherenkov rings detected in 2006.*

### 3.2 Real environment

The upgraded RICH-1 detector, including the new MAPMT detector part, was successfully commissioned at the beginning of the COMPASS 2006 data taking [10]. The time spectrum of a whole quadrant of the MAPMT detector part is displayed in Fig. 7. The time peak of about $\sigma = 1$ ns corresponds to Cherenkov photons created by particles in the triggered physics events. The width of the peak is determined by the different geometrical path lengths of the photons in one Cherenkov ring travelling from the particle track via the mirrors to the photon detection system, as confirmed in Monte Carlo simulations. The time resolution of the photon detection system including read-out electronics is significantly smaller, namely 324 ps, cf. Sec. 3.1. The background below the peak is created by uncorrelated photons mainly from Cherenkov photons of particles of the muon beam halo traversing the radiator gas. The time window of the TDC is set to ± 50 ns around the physics signal peak.

The RICH MAPMT online event display showing multiple hadron Cherenkov rings detected in a single physics event is shown in Fig. 8. The time window applied is 10 ns: The time resolution of a few ns within a single Cherenkov ring can be appreciated. Already from this display, the benefit in assigning hits to rings due to the excellent time resolution of the whole read-out system described in this paper is obvious. While the hardware time window of the TDC has been set to 100 ns around the trigger time, an offline time cut of ±5 ns is applied to the data.

### 3.3 Performances based on 2006 data

The achieved performances (all values to be taken as preliminary) can be summarised as follows [12] (corresponding values of RICH-1 before the upgrade given in parenthesis): The time resolution of single photons is better than 1 ns (before: 3 $\mu$s) and the average number of detected photons per ring is about 56 for saturated rings (before: 14). As a result of the increased photon number, the resolution on the Cherenkov angle is about 0.3 mrad (before: 0.6 mrad). Finally, a Pion to Kaon separation at a two-sigma-level is possible for hadrons of up to 55 GeV/c. The preliminary particle identification efficiency as a function of the hadron momenta is exemplary shown in Fig. 9.

## 4 Conclusions

A major upgrade of the COMPASS RICH-1 detector has been performed to withstand the high rate foreseen for the COMPASS data taking from 2006 onwards. The upgrade project is two-folded: A new, fast photon detection system

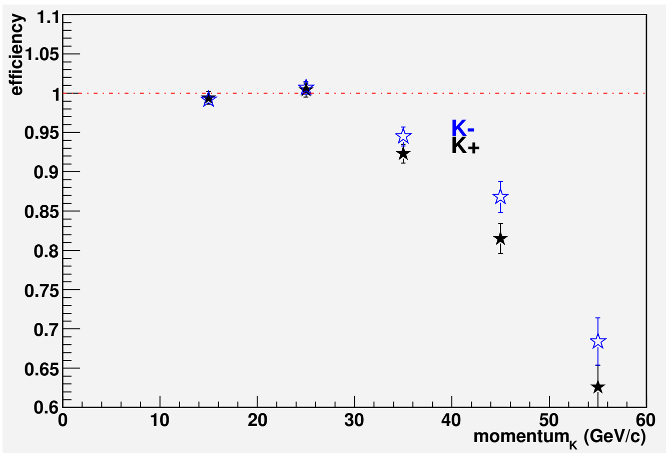


**Fig. 9.** *Efficiency versus particle momenta (Kaons): For smaller Kaon momenta, the efficiency is 100 %, whereas for higher momenta, the efficiency decreases due to the Cherenkov emission angle becoming practically equal for different particles at high momenta.*

based on MAPMTs has been proposed and developed for the central part of RICH-1, whereas for the outer detector region, the read-out electronics of the CsI MWPCs have been exchanged by new ones with negligible dead-time and better time resolution,

The whole upgrade project has been designed, constructed and implemented on a time scale of less than two years; it has successfully been operated during the 2006 COMPASS data taking. The particle identification capability is extended to both - high particle momenta and near threshold. The performances obtained, both in the laboratory and based on the 2006 data, entirely fulfil the original design, improving future COMPASS physics results.

## 5 Acknowledgements

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