

Fast photon detection for COMPASS RICH-1

P.Abbon^k, M.Alexeev^{a,1}, H.Angererⁱ, R.Birsa^o, P.Bordalo^{g,2}, F.Bradamanteⁿ, A.Bressanⁿ,
M.Chiosso^l, P.Cilibertiⁿ, M.L.Colantoni^m, T.Dafni^k, S.Dalla Torre^o, E.Delagnes^k,
O.Denisov^m, H.Deschamps^k, V.Diaz^o, N.Dibiase^l, V.Duicⁿ, W.Eyrich^d, A.Ferrero^l,
M.Finger^j, M.Finger Jr^j, H.Fischer^e, S.Gerassimovⁱ, M.Giorgiⁿ, B.Gobbo^o, R.Hagemann^e,
D.von Harrach^h, F.H.Heinsius^e, R.Joosten^b, B.Ketzerⁱ, V.N.Kolosov^{c,3}, K.Königsmann^e,
I.Konorovⁱ, D.Kramer^f, F.Kunne^k, A.Lehmann^d, S.Levoratoⁿ, A.Maggiora^m, A.Magnon^k,
A.Mannⁱ, A.Martinⁿ, G.Menon^o, A.Mutter^e, O.Nähle^b, F.Nerling^e, D.Neyret^k,
D.Panzieri^a, S.Paulⁱ, G.Pesaroⁿ, C.Pizzolotto^d, J.Polak^{f,o}, P.Rebourgeard^k, F.Robinet^k,
E.Rocco^l, P.Schiavonⁿ, C.Schill^e, P.Schoenmeier^d, W.Schröder^d, L.Silva^g, M.Slunecka^j,
F.Sozziⁿ, L.Steiger^j, M.Sulc^f, M.Svec^f, S.Takekawaⁿ, F.Tessarotto^{o,*}, A.Teufel^d, H.Wollny^e

^aINFN, Sezione di Torino and University of East Piemonte, Alessandria, Italy

^bUniversität Bonn, Helmholtz-Institut für Strahlen- und Kernphysik, Bonn, Germany

^cCERN, European Organization for Nuclear Research, Geneva, Switzerland

^dUniversität Erlangen-Nürnberg, Physikalisches Institut, Erlangen, Germany

^eUniversität Freiburg, Physikalisches Institut, Freiburg, Germany

^fTechnical University of Liberec, Liberec, Czech Republic

^gLIP, Lisbon, Portugal

^hUniversität Mainz, Institut für Kernphysik, Mainz, Germany

ⁱTechnische Universität München, Physik Department, Garching, Germany

^jCharles University, Praga, Czech Republic and JINR, Dubna, Russia

^kCEA Saclay, DSM/DAPNIA, Gif-sur-Yvette, France

^lINFN, Sezione di Torino and University of Torino, Torino, Italy

^mINFN, Sezione di Torino, Torino, Italy

ⁿINFN, Sezione di Trieste and University of Trieste, Trieste, Italy

^oINFN, Sezione di Trieste, Trieste, Italy

Abstract

A fast photon detection system has been built as 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 m², 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 presented: 56 detected photons on average per $\beta=1$ particles, an angular resolution of less than 0.3 mrad per ring, a time resolution better than 1 ns, providing a π -K separation at 2σ -level at 55 GeV/c.

Key words: COMPASS, RICH, MAPMT, UV lenses, photon detection

PACS: 29.40.Ka, 42.79.Pw, 85.60.Gz

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 described in ref. [2].

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 [3], a Ring Imaging Cherenkov Detector with 3 m C_4F_{10} gas radiator, a 21 m² surface of spherical UV mirrors and a set of MWPCs with CsI photo-cathodes covering 5.2 m².

Before its upgrade COMPASS RICH-1 was providing a mean number of 14 detected photons for $\beta = 1$ particles, a measured Cherenkov angle resolution of 1.2 mrad for single photons and a PID efficiency larger than 95% over most of the acceptance, allowing 2σ π -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 [4], 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 [5] based on the APV preamplifier [6] with sampling ADCs providing almost negligible dead-time and better time resolution; this part of COMPASS RICH-1 upgrade will not be discussed in this article.

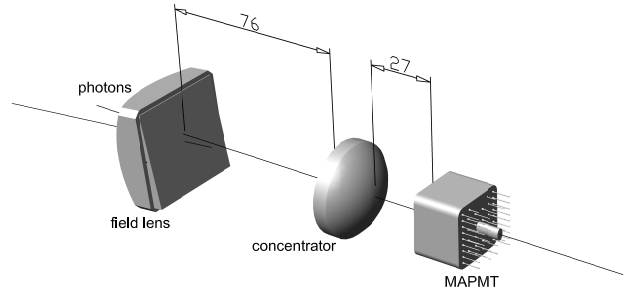


Fig. 1. Scheme of the two-lenses telescope system.

3. The MAPMTs

The central elements of the upgrade are 576 MAPMTs, Hamamatsu 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 [7], to a complete quality control protocol: a two-hour procedure including visual inspection, measurements of dark current and measurements of gain at 5 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 rate 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 [8] 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 simula-

* corresponding author

¹ on leave from JINR, Dubna, Russia

² also at IST, Universidade Técnica de Lisboa, Lisbon, Portugal

³ on leave from IHEP, Protvino, Russia

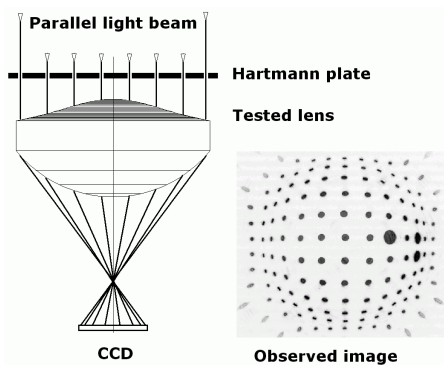


Fig. 2. Scheme of the principle and observed image of the Hartmann validation test for the condenser (aspheric) lens.

tions using Zemax⁴ software; they are made of two fused silica lenses: a field lens and a condenser 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, Corning⁵ 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 MgF₂ 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 [9] employing the Hartmann method (see 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 (see Fig. 3) allows to reduce the dead areas below 2% of the surface.

⁴ ZEMAX Development Corporation, 3001 112th Avenue NE, Suite 202, Bellevue, WA 98004-8017 USA.

⁵ Corning Incorporated, One Riverfront Plaza, Corning, NY 14831 USA.

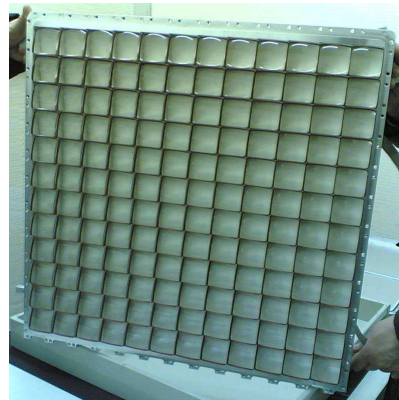


Fig. 3. One of the frames hosting the field lenses.

5. The readout electronics

The signals from the MAPMTs are read by a fast digital electronics system [10] based on the MAD4 preamplifier-discriminator[11], characterized by small noise level (5-7 fC). An optimization of the design of the front-end boards allowed to suppress the MAPMTs cross talk while keeping at $\sim 95\%$ the single photoelectron detection efficiency of the MAPMT coupled to the MAD4 chip. The MAD4 can operate up to ~ 1 MHz per channel, but its upgraded version in CMOS technology, called CMAD, has been shown to provide full efficiency up to an input rate of 5 MHz per channel.

The good time resolution of the MAPMTs is fully exploited thanks to digital cards, called DREISAM, housing the dead-time free F1 TDC [12], which has a time resolution of ~ 110 ps and can stably operate up to 10 MHz per channel input rate and 100 kHz trigger rate.

Data from the front-end cards are transferred via optical links to the COMPASS readout and data acquisition system [2].

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

6. Commissioning and performances

The upgrade was fully designed and implemented between November 2005 and May 2006, and data were collected with the upgraded RICH during the

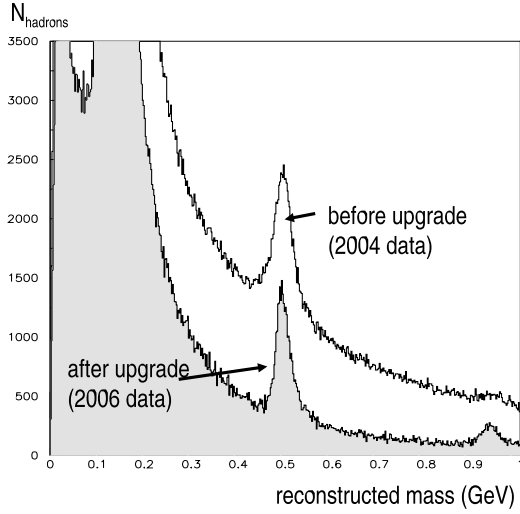


Fig. 4. RICH-reconstructed kaon mass peak before (2004 data) and after (preliminary 2006 data) the RICH upgrade.

2006 and 2007 COMPASS runs in stable conditions. Full rings of particles with $\beta = 1$ have on average 56 detected photons, and a very low background level from uncorrelated physical events.

The global resolution on the measured Cherenkov angle after the upgrade has been estimated [13] to be less than 0.3 mrad at saturation; particle identification has improved at both low and high momentum: 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 55 GeV/c (it was 43 GeV/c).

Making use of a sample of kinematically reconstructed ϕ mesons, preliminary evaluations of the efficiency for kaon identification in the range between 10 and 60 GeV/c provide values above 90%, including the very forward region. The purity of identified kaons in the same range has been studied too: the misidentification probability is estimated to be 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 in the reconstructed mass spectra for 2004 data and preliminary 2006 data presented in Fig. 4.

7. Conclusions

A fast photon detection system for the upgrade of COMPASS RICH-1, based on MAPMTs coupled to fused silica lens telescopes and high resolution TDCs, has been designed and implemented on the time scale of one year and a half and has success-

fully improved the performances of RICH-1 during 2006 and 2007 data taking, especially in the very forward region. With an average of 56 detected photons per ring at saturation, 2σ π -K separation up to 55 GeV/c and the possibility to cope with trigger rates in the range of 100 kHz, COMPASS RICH-1 is adequate for the future challenges of the COMPASS Experiment running at high rates.

Acknowledgements

We acknowledge help from the CERN/PH groups PH/TA1, TA2 and DT2 and TS/SU and the support of BMBF (Germany) and of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (Hadron Physics, contract number RII3-CT-2004-506078).

References

- [1] The COMPASS Collaboration, CERN/SPSLC/96-14, SPSLC/P 297, March 1, 1996; CERN/SPSLC/96-30, SPSLC/P 297, May 20, 1996; Phys. Lett. **B 612** (2005) 154; Phys. Rev. Lett. **94** (2005) 202002; Eur. Phys. J. **C 41** (2005) 469; Phys. Lett. **B 633** (2006) 25; Phys. Lett. **B 647** (2007) 8; Phys. Lett. **B 647** (2007) 330; Nucl. Phys. **B 765** (2007) 31; Eur. Phys. J. **C 52** (2007) 255.
- [2] P. Abbon et al., Nucl. Instr. and Meth. **A 577** (2007) 455.
- [3] E. Albrecht et al., Nucl. Instr. and Meth. **A 553** (2005) 215 and ref. therein.
- [4] M. Alekseev et al., Nucl. Instr. and Meth. **A 553** (2005) 53; P. Abbon et al., Czech. J. Phys. **56**, Suppl. F (2006) 307; Nucl. Instr. and Meth. **A 567** (2007) 114; Nucl. Instr. and Meth. **A 572** (2007) 419; Nucl. Instr. and Meth. **A 580** (2007) 906; Nucl. Instr. and Meth. **A 581** (2007) 419.
- [5] P. Abbon et al., Nucl. Instr. and Meth. **A 567** (2006) 104.
- [6] M. J. French et al., Nucl. Instr. and Meth. **A 466** (2001) 359.
- [7] The characterization of the multi-anode photomultiplier tubes for the RICH-1 upgrade project at COMPASS, P. Abbon et al., these proceedings.
- [8] P. Abbon et al., Czech. J. Phys. **56**, Suppl. F (2006) 315.
- [9] P. Abbon et al., Czech. J. Phys. **56** Suppl. F (2006) 323.
- [10] The Fast Read-out System for the MAPMTs of COMPASS RICH-1, P. Abbon et al., these proceedings; P. Abbon et al., accepted for publication in Nucl. Instr. and Meth. **A**, NIMA-D-07-00850.
- [11] F. Gonnella and M. Pegoraro, CERN-LHCC-2001-034, pp.204-8.
- [12] H. Fischer et al., IEEE Trans. Nucl. Sci. **49** (2002) 443; Nucl. Instr. Meth. **A 461** (2001) 507.
- [13] Pattern recognition and PID for COMPASS RICH-1, P. Abbon et al., these proceedings.