Fast photon detection for the COMPASS RICH detector

P.Abbon[a], M.Alekseev[b], H.Angerer[c], M.Apollonio[d], R.Birsa[d], P.Bordalo[e], F.Bradamante[d], A.Bressan[d], L.Busso[b], M.Chiosso[b], P.Ciliberti[d], M.L.Colantoni[f], S.Costa[b], S.Dalla Torre[d], T.Dafni[a], E.Delagnes[a], H.Deschamps[a], V.Diaz[d], N.Dibiase[b], V.Duic[d], W.Eyrich[g], D.Faso[b], A.Ferrero[b], M.Finger[h], M.Finger Jr[h], H.Fischer[i], S.Gerassimov[c], M.Giorgi[d], B.Gobbo[d], R.Hagemann[i], D.von Harrach[j], F.H.Heinsius[i], R.Joosten[k], B.Ketzer[c], K.Königsmann[i], V.N.Kolosov[l] *, I.Konorov[c], D.Kramer[m], F.Kunne[a], A.Lehmann[g], S.Levorato[d], A.Maggiora[b], A.Magnon[a], A.Mann[c], A.Martin[d], G.Menon[d], A.Mutter[i], O.Nähle[k], F.Nerling[i], D.Neyret[a], P.Pagano[d], S.Panebianco[a], D.Panzieri[f], S.Paul[c], G.Pesaro[d], J. Polak[m], P.Rebourgeard[a], F.Robinet[a], E.Rocco[d], P.Schiavon[d], C.Schill[i] †, W.Schröder[g], L.Silva[e], M.Slunecka[h], F.Sozzi[d], L.Steiger[h], M.Sulc[m], M.Svec[m], F.Tessarotto[d], A.Teufel[g], H.Wollny[i]

[a] *CEA Saclay, DSM/DAPNIA, Gif-sur-Yvette, France*
[b] *INFN, Sezione di Torino and University of Torino, Torino, Italy*
[c] *Technische Universität München, Physik Department, Garching, Germany*
[d] *INFN, Sezione di Trieste and University of Trieste, Trieste, Italy*
[e] *LIP, Lisbon, Portugal*
[f] *INFN, Sezione di Torino and University of East Piemonte, Alessandria, Italy*
[g] *Universität Erlangen-Nürnberg, Physikalisches Institut, Erlangen, Germany*
[h] *Charles University, Prague, Czech Republic and JINR, Dubna, Russia*
[i] *Universität Freiburg, Physikalisches Institut, Freiburg, Germany*
[j] *Universität Mainz, Institut für Kernphysik, Mainz, Germany*
[k] *Universität Bonn, Helmholtz-Institut für Strahlen- und Kernphysik, Bonn, Germany*
[l] *CERN, European Organization for Nuclear Research, Geneva, Switzerland*
[m] *Technical University of Liberec, Liberec, Czech Republic*

Particle identification at high rates is a central aspect of many present and future experiments in high-energy particle physics. The COMPASS experiment at the SPS accelerator at CERN uses a large scale Ring Imaging CHerenkov detector (RICH) to identify pions, kaons and protons in a wide momentum range. For the data taking in 2006, the COMPASS RICH has been upgraded in the central photon detection area (25% of the surface) with a new technology to detect Cherenkov photons at very high count rates of several $10^6 s^{-1}$ per channel and a new dead-time free read-out system, which allows trigger rates up to 100 kHz. The Cherenkov photons are detected by an array of 576 visible and ultra-violet sensitive multi-anode photomultipliers with 16 channels each. Lens telescopes of fused silica lenses have been designed and built to focus the Cherenkov photons onto the individual photomultipliers. The read-out electronics of the PMTs is based on the MAD4 amplifier-discriminator chip and the dead-time free high resolution F1-TDC. The 120 ps time resolution of the digital card guarantees negligible background from uncorrelated physical events. In the outer part of the detector, where the particle rates are lower, the present multi-wire proportional chambers (MWPC) with Cesium Iodide photo-cathodes have been upgraded with a new read-out electronic system based on the APV preamplifier and shaper ASIC with analog pipeline and sampling ADCs. The project was fully designed and implemented in the period November 2004 until May 2006. The upgraded detector showed an excellent performance during the 2006 data taking: the number of detected Cherenkov photons per ring was increased from 14 to above 60 at saturation. The time resolution was improved from about 3 microseconds to about one nanosecond which allows an excellent suppression of the background photons from uncorrelated events.

Keywords: COMPASS, RICH, particle identification, multi-anode photomultiplier tubes.
PACS: 20.40.Ka, 42.79.Pw, 85.60.Gz

*On leave from IHEP Protvino, Russia.
†Corresponding author, mail: `Christian.Schill@cern.ch`

1. Introduction

The COMPASS experiment [1] at the CERN SPS investigates key issues in hadron physics by scattering high-energy polarized muons and hadrons off polarized and unpolarized solid state targets. The produced particles are detected in a large size two-stage forward spectrometer which covers a wide kinematic range ($10^{-5} < x_{Bj} < 0.5$, $10^{-3} < Q^2 < 100$ (GeV/c)^2). One of the key features of the COMPASS spectrometer is an excellent particle identification which allows to separate scattered electrons, muons, pions, kaons and protons. It is performed by electromagnetic and hadron calorimeters, muon walls and a large scale Ring Imaging Cherenkov detector (RICH) [2]. The RICH detector uses C_4F_{10} as radiator gas inside a 5×6 m^2 wide and 3 meter deep vessel. The produced Cherenkov photons are reflected by a 20 m^2 mirror wall onto a set of photon-detectors: up to 2004 multi-wire proportional chambers (MWPC) with Cesium Iodide photo-cathodes, covering a total active surface of about 5.5 m^2 and including in total about 80.000 read-out channels.

2. Motivation of the upgrade

The read-out system of the COMPASS RICH photon detectors in use till 2004 consisted of Gassiplex front-end chips [3] connected to the MWPCs, which have an integration time of about 3 microseconds. In the experimental environment of the COMPASS setup there is a large flux of Cherenkov photons especially in the centre of the detector, since the CERN muon beam is accompanied by 10% to 20% of halo muons which pass through the detector and create Cherenkov rings. At high beam intensities of 0.4 to 1.0×10^8 muons per second, these halo rings create a considerable background of overlapping rings in the centre of the detector, which reduces the particle identification efficiency and purity, especially for particles in the very forward direction.

A fast detection system for Cherenkov photons is needed to distinguish by time information the photons originating from scattered particles in the physics events from the background from uncorrelated halo muons. The upgrade of the COMPASS RICH detector consists of two parts. In the central part of the detector (25% of the sensitive area) where the photon flux is largest the MWPCs with Cesium Iodide photo-cathodes have been replaced by multi-anode photomultipliers [4] and a fast read-out system based on the MAD4 [5] discriminator front-end chip and the dead-time free F1 TDC [6] (see Fig. 1). In the outer part, the existing MWPC chambers have been equipped with a faster read-out based on the APV preamplifier with sampling ADCs [7]. In addition, the upgraded detector allows a high rate operation at increased trigger rates from 20 up to 100 kHz and small dead-time [8].

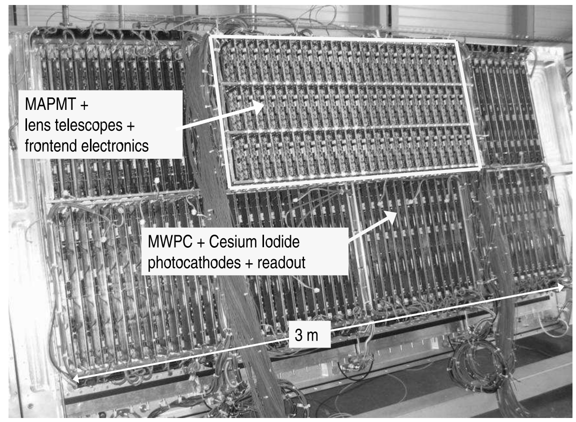

Figure 1. Lower half of the COMPASS RICH photon detector before installation. The central part (marked by the white line) of the MWPCs has been replaced by lens telescopes, MAPMTs and fast read-out electronics consisting of MAD4 discriminators and F1 TDC.

3. The upgrade of the central region

The central region upgrade is performed by replacing the central part of the MWPC photon detector set by an array of 576 UV-sensitive 16 channel multi-anode PMTs H7600-03-M16 from Hamamatsu [4]. The sensitive wavelength range of these photomultipliers extends from 200 nm up to 700 nm compared to the effective sensitive range of the Cesium-Iodide photo-cathodes of 160 nm to 200 nm. Therefore the number of

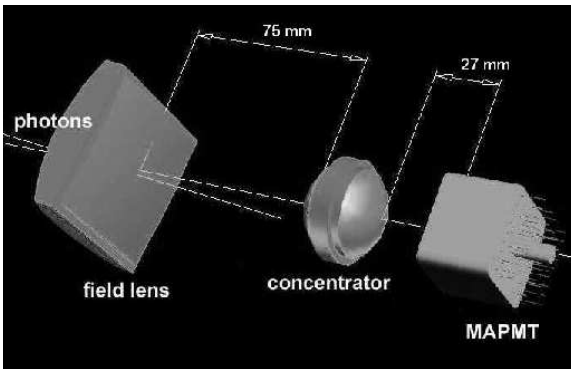

Figure 2. Optical arrangement of the MAPMT and the fused silica lens telescope.

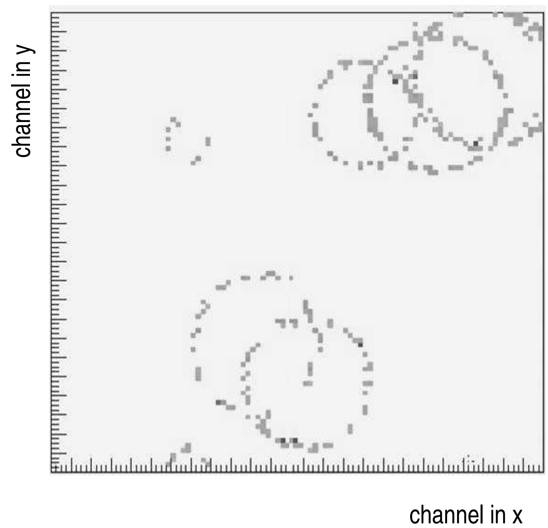

Figure 3. Single physics event in the RICH detector, central region, after applying a time cut of 5 ns around the physics trigger. One can see Cherenkov rings of several hadrons.

detected photons per ring is expected to be about 4 times larger. In addition, the ring resolution is improved by the larger number of detected photons from 0.6 to 0.3 mrad. This will increase the upper limit of the kinematic region of the 2σ pion from kaon separation from 44 to above 50 GeV/c hadron momentum.

The Cherenkov photons are focused onto the PMTs by 576 individual lens telescopes from UV-transparent fused silica lenses (see Fig. 2). The telescopes have been customly designed from one spherical and one aspherical lens and offer a large angular acceptance for the photons of $\pm 9.5^o$ and a minimum image distortion. The image reduction is of a factor of about 7 in area; the PMT pixels are of 4.5×4.5 mm^2, the effective pixel size of the new detector is 12×12 mm^2. All PMTs have been shielded by soft iron boxes to protect them from the residual 200 Gauss field of the 1 Tesla open spectrometer magnet few meters away.

The PMTs are read out by frontend electronics mounted directly on the detector, which consists of the MAD4 preamplifier and discriminator and the F1 TDC chip. The MAD4 chip [5] has a low noise level of $5 - 7$ fC compared to the average PMT signal of about 500 fC. It is able to handle signals up to 1 MHz rate. In 2007, the MAD4 will be replaced by C-MAD chips, which have a rate capability up to 5 MHz. The digital part of the read-out consists of the dead-time free F1 TDC [6] mounted on the DREISAM[3] frontend card. It has a time resolution of better than 120 ps and can handle input rates up to 10 MHz at trigger rates of up to 100 kHz. The data from one frontend card with 64 read-out channels are transferred via optical links to the COMPASS read-out system [8]. All read-out electronics is mounted in a very compact setup directly on the detector.

[3]Digital REad-out Integrating and SAMpling card.

4. Detector performance after the upgrade

In the COMPASS beam-time 2006, all data have been taken with the upgraded RICH detector (see Figs. 3, 4 and 5). The detector shows excellent performance: the number of photons per ring has increased from 14 before the upgrade to above 60 at saturation ($\beta \approx 1$). The increased statistics in the number of photons has improved the ring resolution to 0.3 mrad from 0.6 mrad before. While the increased number of photons has improved the particle identification capability at lower momenta, the better ring resolution extends the particle identification towards higher momenta. The time resolution for single photons (see Fig. 4) is about 1 ns, which allows an almost complete rejection of the background from uncorrelated halo muon Cherenkov signals.

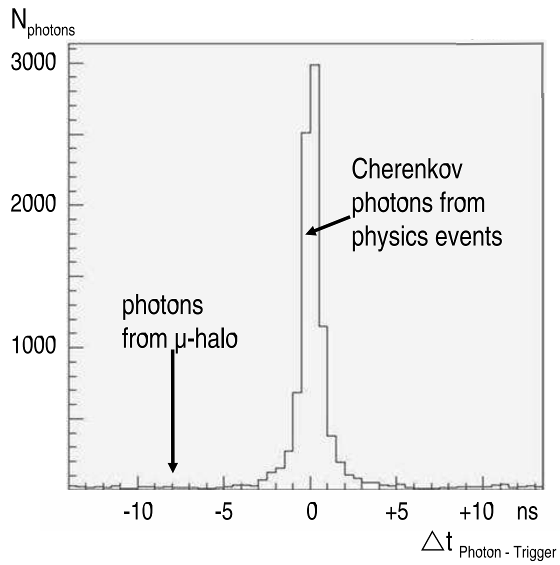

Figure 4. Time distribution of the Cherenkov photons relative to the physics trigger. One can see an excellent time resolution of about 1 ns.

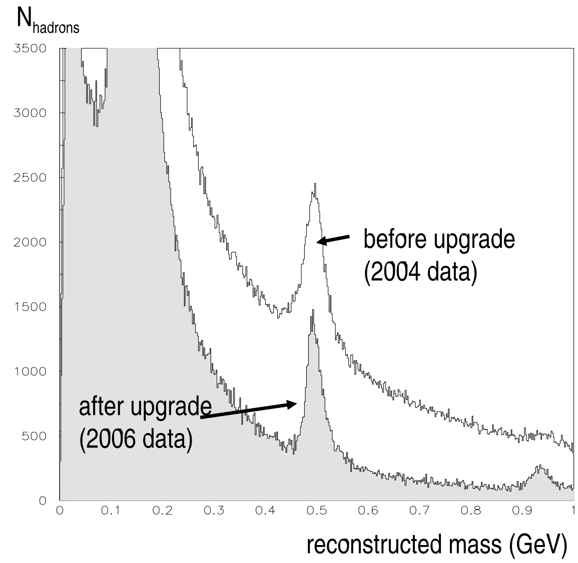

Figure 5. RICH-reconstructed kaon mass-peak before (2004 data) and after (preliminary 2006 data) the RICH upgrade.

5. Conclusions

A fast photon detection system with multi-anode photomultipliers and fast read-out electronics based on the MAD4 discriminator and the F1 TDC has been designed and constructed to upgrade the Ring Imaging Cerenkov (RICH) detector of the COMPASS experiment. The upgraded detector was ready for the beam-time in 2006 and first data show an excellent performance of the new photon detection system. The time resolution of about 1 ns allows an almost complete rejection of the background Cherenkov photons from uncorrelated muon halo events, which improves efficiency and purity (see Fig. 5) of the particle identification especially in the very forward direction. The increased number of detected photons extends the particle identification performance of the COMPASS RICH both towards lower Cherenkov angles and at high particle momenta above 50 GeV/c.

Acknowledgments

We acknowledge support from the CERN/PH groups PH/TA1, TA2, DT2, TS/SU, and support by the BMBF (Germany) and the European Community-research Infrastructure Activity under the FP6 program (Hadron Physics, RII3-CT-2004-506078).

REFERENCES

1. The COMPASS Collaboration, Proposal, CERN/SPSLC 96-14 and 96-30, 297 (1996).
2. E. Albrecht et al., Nucl. Instr. Meth. A **553**, 215-219 (2005).
3. C. Santiard et al., *Proc. 6th Pisa Meeting on Advanced Detectors*, La Biodola, Italy, May 1994, Phys. Rev. **C52**, 2072 (1995).
4. P. Abbon et al., Fast photon detection for COMPASS RICH-1, accepted for publ. in Nucl. Inst. Meth. A.
5. F. Gonnella and M. Pegoraro, CERN-LHCC-2001-034, 204-8 (2001).
6. H. Fischer et al., Nucl. Instr. Meth. A **461**, 507-510 (2001).
7. D. Neyret et al., *4th Intern. Conf. on New Developments in Photondetection*, Beaune, France (2005).
8. L. Schmitt et al., IEEE Trans. Nucl. Sci. 51, 439 (2004).