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Pattern recognition and PID for COMPASS RICH-1

P. Abbon^l, M. Alexeev^{a,1}, H. Angererⁱ, R. Birsas^o, P. Bordalo^{g,2}, F. Bradamante^o, A. Bressan^o, M. Chiosso^m, P. Ciliberti^o, M.L. Colantoniⁿ, T. Dafni^l, S. Dalla Torre^p, E. Delagnes^l, O. Denisovⁿ, H. Deschamps^l, V. Diaz^p, N. Dibiase^m, V. Duic^o, W. Eyrich^d, A. Ferrero^m, M. Finger^{j,k}, M. Finger Jr.^{j,k}, H. Fischer^e, S. Gerassimovⁱ, M. Giorgi^o, B. Gobbo^p, R. Hagemann^e, D. von Harrach^h, F.H. Heinsius^e, R. Joosten^b, B. Ketzerⁱ, V.N. Kolosov^{c,3}, K. Königsman^e, I. Konorovⁱ, D. Kramer^f, F. Kunne^l, A. Lehmann^d, S. Levorato^o, A. Maggioraⁿ, A. Magnon^l, A. Mannⁱ, A. Martin^o, G. Menon^p, A. Mutter^e, O. Nähle^b, F. Nerling^e, D. Neyret^l, D. Panzieri^a, S. Paulⁱ, G. Pesaro^o, C. Pizzolotto^d, J. Polak^{f,p}, P. Rebourgeard^l, F. Robinet^l, E. Rocco^m, P. Schiavon^o, C. Schill^e, P. Schoenmeier^d, W. Schröder^d, L. Silva^g, M. Slunecka^j, F. Sozzi^{o,*}, L. Steiger^j, M. Sulc^f, M. Svec^f, S. Takekawa^o, F. Tassarotto^p, A. Teufel^d, H. Wollny^e

^a INFN, Sezione di Torino and University of East Piemonte, Alessandria, Italy^b Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Bonn, Germany^c CERN, European Organization for Nuclear Research, Geneva, Switzerland^d Physikalisches Institut, Universität Erlangen-Nürnberg, Erlangen, Germany^e Physikalisches Institut, Universität Freiburg, Freiburg, Germany^f Technical University of Liberec, Liberec, Czech Republic^g LIP, Lisbon, Portugal^h Universität Mainz, Institut für Kernphysik, Mainz, Germanyⁱ Physik Department, Technische Universität München, Garching, Germany^j Charles University, Praga, Czech Republic^k JINR, Dubna, Russia^l CEA Saclay, DSM/DAPNIA, Gif-sur-Yvette, France^m INFN, Sezione di Torino and University of Torino, Torino, Italyⁿ INFN, Sezione di Torino, Torino, Italy^o INFN, Sezione di Trieste and University of Trieste, Via Valerio 2, 34127 Trieste, Italy^p INFN, Sezione di Trieste, Trieste, Italy

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ABSTRACT

A package for pattern recognition and PID by COMPASS RICH-1 has been developed and used for the analysis of COMPASS data collected in the years 2002–2004, and 2006–2007 with the upgraded RICH-1 photon detectors. It has allowed the full characterization of the detector in the starting version and in the upgraded one as well as the PID for physics results. We report about the package structure and algorithms, and the detector characterization and PID results.

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1. Introduction

COMPASS [1] is a fixed target experiment at CERN SPS. The COMPASS physics program is focused mainly on the study of the nucleon spin structure and on hadron spectroscopy. COMPASS has collected data in 2002–2004 and 2006–2007 using a muon beam of 160 GeV/c. The apparatus includes a polarized target for spin structure studies, a large acceptance double spectrometer,

* Corresponding author.

E-mail address: federica.sozzi@ts.infn.it (F. Sozzi).¹ On leave from JINR, Dubna, Russia.² Also at IST, Universidade Técnica de Lisboa, Lisbon, Portugal.³ On leave from IHEP, Protvino, Russia.

electromagnetic and hadron calorimeters and muon filters [2]. Charged hadron identification (PID) is performed by means of a focusing Ring Imaging Cherenkov detector of large dimensions, the COMPASS RICH-1 [3]. RICH-1 is a Cherenkov imaging detector with large angular acceptance (± 180 mrad vertical, ± 250 mrad horizontal). The radiator gas is C_4F_{10} at atmospheric pressure and the typical particle path length in the radiator is 3 m. Image focusing is obtained by two spherical surfaces, formed by hexagonal and pentagonal mirror elements, resulting in a reflecting surface with a total area larger than 20 m^2 . Images are collected on two sets of photon detectors, placed above and below the detector acceptance region. Until 2004, the photon detectors used were eight MWPCs with segmented CsI photo-cathodes, covering a surface of 5.2 m^2 . In 2006, an important upgrade of the photon detector system was completed. The upgrade is based on two complementary techniques for the central and peripheral regions of the photon detectors. The central part, corresponding to four of the 16 MWPC photo-cathodes, has been equipped with multi-anode photomultiplier (MAPMT) with UV extended glass window (Hamamatsu R7600-03-M16) coupled to individual telescopes of fused silica lenses and a fast digital read-out system [4]; in the peripheral part, a new readout system [5], based on the APV chip [6], almost dead-time free and characterized by improved time resolution, has been installed on the already existing CsI MWPCs.

From the point of view of the software data handling, the upgrade results in two main consequences:

- The geometry and the spatial resolution of the central and peripheral detectors are different: the size of the pads in the peripheral part is $8 \times 8\text{ mm}^2$, while in the central part the *pseudopads* (the MAPMT pixels projected through the optical telescope onto the plane previously housing the CsI photo-cathodes) have a dimension of about $12 \times 12\text{ mm}^2$; the different spatial resolution is one of the elements that requires different detector characterization in the two parts.
- The spectrum of the detected Cherenkov photons is different in the central part (200–750 nm) respect to the spectrum of the peripheral part (165–200 nm); this implies that the average effective value of the radiator refractive index is different according to the type of the photon detector involved; the mean values of the effective refractive index, as evaluated offline from a data sample, are respectively: $n - 1 \sim 0.001345$ for the MAPMT detectors and $n - 1 \sim 0.001528$ for the CsI MWPC detectors. The difference in the effective refractive indexes implies also that the rings detected in the MAPMT and the CsI region have different radii: the radius of the rings detected in the peripheral region are about 30% larger than those detected in the MAPMT region.

2. RICH-1 software

The analysis of the RICH data can be divided in two main steps: the ring reconstruction and the particle identification. The aim of the RICH in the experiment is to give an answer to the latter point, nevertheless a complete understanding of the RICH performances is needed before any attempt to identify particles, and for this purpose the ring reconstruction is largely used.

The reconstruction of the RICH-1 data is performed with RICHONE, a dedicated class of the COMPASS reconstruction programme, CORAL. As starting point of the reconstruction, the RICH digits in both the MAPMT and the CsI MWPC part are used; the hits are rearranged in clusters in the CsI MWPC part only, since the MAPMT crosstalk is completely negligible. Using the cluster position on the detector surface, and assuming as emission point

the middle point of the particle trajectory inside the radiator, the photon emission angles respect to the particle trajectory ($\theta_{\text{ch}}, \phi_{\text{ch}}$) are computed using the Hough transformation, following a recipe well known in the literature [7]. The trajectory is provided by the tracking package in the CORAL reconstruction programme.

The ring reconstruction is mainly used for the analysis of the RICH performances. For all the clusters contained in a region of 70 mrad around the particle trajectory, the emission angles ($\theta_{\text{ch}}, \phi_{\text{ch}}$) are computed. Since a ring is characterized by a fixed value of θ_{ch} , a peak in the θ_{ch} distribution is searched for through a scan with a fixed size window of $\pm 3\sigma_{\text{ph}}$, where σ_{ph} is the single photon resolution. For the ring reconstruction, the Cherenkov angles of the photons detected in the MAPMT region are normalized to the angles in the CsI MWPC region, so as to combine, for rings not completely included in a single detector region, the information coming from the two different regions. One of the main advantages of the simple recipe described above is the automatic handling of events of different complexity, as is the case of the split rings. In fact, due to the RICH-1 detector architecture, photons emitted by particles scattered at small vertical angles, illuminate both mirror surfaces, and are then reflected partially onto the upper and partially onto the lower photon detector set, forming a full ring image in a detector set and a partial ring in the other one.

The particle identification algorithm relies on a likelihood function built from all the photons associated to the particle in the fiducial region of 70 mrad. A Poissonian probability is used to describe the expected number of detected photons (both signal and background contribution) as a function of the parameters of the particle trajectory. The likelihood is computed for five mass hypothesis (e, ν , π , K, p) and for the background, corresponding to the hypothesis of absence of signal. For a given mass M, and for N photons, the likelihood expression reads:

$$L_M = \frac{(S_M + B)^N}{N!} e^{-(S_M + B)} \prod_{j=1}^N \frac{S_M(\theta_j, \phi_j) + b(\theta_j, \phi_j)}{S_M + B} \quad (1)$$

The background term, $b(\theta_j, \phi_j)$, is evaluated pad by pad from a map of the integrated cluster distribution, taken from the data themselves. S_M and B are the signal and background photons integrated on the particle fiducial region, defined above. The signal term $S_M(\theta_j, \phi_j)$ is taken as a Gaussian, with mean value the Cherenkov angle evaluated from the kinematics corresponding to the mass M and with the width of the single photon resolution:

$$S_M(\theta_j, \phi_j) = \frac{S_0}{\sqrt{2\pi}\sigma_{\text{ph}j}} \cdot e^{-1/2(\theta_j - \Theta_M)^2 / \sigma_{\text{ph}j}^2} \varepsilon(\theta_j, \phi_j) \quad (2)$$

S_0 is the expected number of photons evaluated using the Frank and Tamm equation; the ε term is the probability of detecting a photon, taking into account the dead zones in the detector.

3. Detector characterization

RICH-1 has been fully characterized in both the old and the upgraded version, monitoring in operative conditions all the relevant observables: the number of detected photons, the angular resolution and the PID efficiency.

The number of signal photons emitted at saturation has been evaluated through a fit of the number of photons per ring as a function of the Cherenkov angle, using a function of the type $N_0 \sin^2(\theta_{\text{ch}})$. The number of detected photons at saturation is around 14 before the RICH-1 upgrade and, after the upgrade, in the peripheral regions, while it has increased up to 56 (Fig. 1) in the upgraded RICH, central regions. Moreover, the ratio of the signal to the background in each ring is increased because the

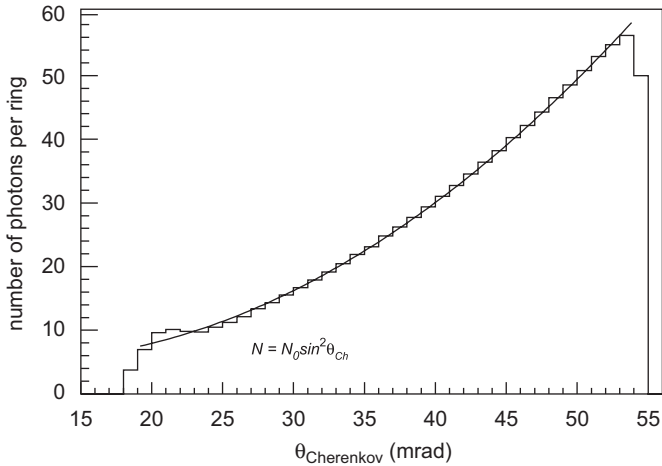


Fig. 1. Number of photons per ring as a function of the Cherenkov angle, for rings detected in the MAPMT part only; the curve is a fit with a function of the type $N = N_0 \sin^2(\theta_{Ch})$. The number of photons at saturation after background subtraction is around 56.

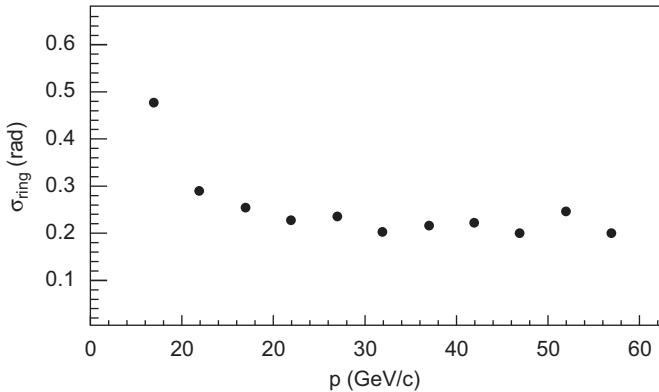


Fig. 2. Standard deviation of the $\theta_{ring} - \theta_{\pi}$ distribution, for particles identified as pions, as a function of the particle momentum; ring detected in the MAPMT detector only.

number of background clusters per ring has been reduced by a factor $\sim 30\%$ in the central part.

The single photon resolution is evaluated from the width of the distribution $\theta_{ph} - \theta_{\pi}$, where θ_{ph} is the Cherenkov angle of a photon belonging to the ring and θ_{π} is the angle for the pion mass hypothesis. In RICH-1 before the upgrade, the mean value of the resolution is around 1.2 mrad, while the resolution on the ring angle is around 0.6 mrad. The two numbers do not scale with the square root of the number of detected photons per ring due to the large background contribution in each reconstructed ring, diluting the signal. After the upgrade, the single photon resolution in the central part is around 2 mrad, while the ring angular resolution less than 0.3 mrad (Fig. 2); the better scaling of the ring resolution with the number of photons is due to the fact that the background contribution per ring is small.

The PID efficiency has been evaluated selecting with kinematics criteria a sample of exclusively produced ϕ mesons; the sample has a purity of about 90%. The efficiency has been evaluated separately for K^+ and K^- , using the positive or negative track coming from the ϕ decay. In Figs. 3 and 4, the K efficiency is shown as a function of the particle polar angle, both for the old and for the upgraded RICH. The curve corresponding to the old RICH shows clearly that the efficiency increases at large polar angle, since at small angles it is limited by the presence of an important background coming from the muon beam halo. The

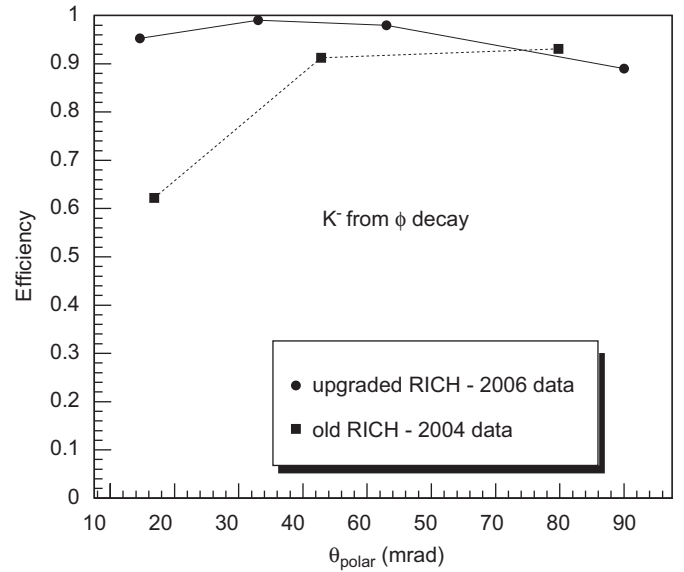


Fig. 3. PID efficiency for K^- , evaluated on a sample of particles from ϕ decay, as a function of the particle polar angle. The two sets of data points correspond to the old and to the upgraded versions of RICH-1.

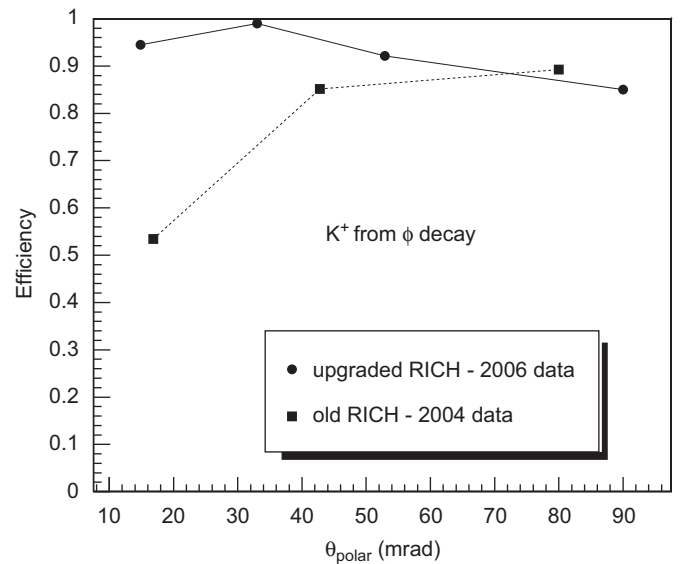


Fig. 4. Same as Fig. 3, for K^+

impact of the upgrade on the RICH efficiency is clearly visible from the corresponding efficiency curve: also at small polar angle the efficiency is above 90%.

4. Conclusions

The RICH-1 reconstruction software is based on a simple recipe, allowing an easy handling of events of different complexity. The ring pattern recognition and the PID are fully independent and are used for different purposes: detector characterization and data analysis, respectively. The complete RICH-1 characterization, both in the old and in the upgraded version, has been presented and confirms a large improvement of the RICH-1 performance in its upgraded version.

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