# PARTICLE IDENTIFICATION IN THE HERA-B RICH DETECTOR

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**Abstract**

An extended maximum likelihood method used for identification of charged particles ($\pi$, $K$ and $p$) in the RICH detector is described.

The main contribution to the background in the RICH detector arises from Čerenkov photons emitted by charged particles coming from the same event. A typical GEANT simulated event, where three inelastic events were generated on top of the benchmark reaction $pA \to J/\psi K_S X$ produces a hit pattern that can be seen in Fig. 1. To separate the signal from the high background an extended maximum likelihood method similar to those described in references [1] and [2] was used.

All detected photons were taken into consideration for each track within an event. From the position of the hit on the detector (that is from the Čerenkov angle of the photon) the velocity $\beta_i$ was calculated for each track for the $i$-th photon. For each mass hypothesis $\beta_{hyp}$ was calculated from the track momentum as well. The variable used in the extended likelihood method was because of its convenience:

$$x_i = \frac{\beta_i - \beta_{hyp}}{\sigma_{RICH}}$$

with $\beta_i$ being calculated from the position of each photon as if it came from the observed track and $\sigma_{RICH}$ being the photon detector precision (see ref. [3], p.104). The shape of the background was assumed to be well described by a line. The probability density is then:

$$P_i^{hyp} \;=\; \frac{N^{hyp}}{\sqrt{2\pi}}\, e^{x_i^2/2} \;+\; a^{hyp} \cdot x_i \;+\; b^{hyp}. \tag{1}$$

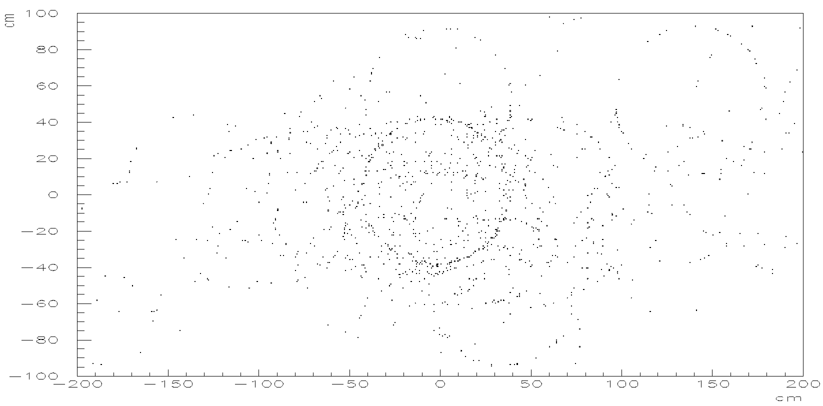


Figure 1: Hits on the photon detector showing one event.

The number of expected Čerenkov photons is $N^{hyp}$, while $K^{hyp}$ is the number of background photons if one assumes all other particles to be pions. This assumption holds well since the predominant particles really are pions. We shall denote the number of all measured photons as $n$. The background parameters $a^{hyp}$ and $b^{hyp}$ are related to $K^{hyp}$ by

$$\int (a^{hyp} \cdot x_i + b^{hyp})\, dx \;=\; K^{hyp}. \tag{2}$$

The probability that the track corresponds to a mass hypothesis consists of two parts, the probability density to see a signal from the photon at each of the locations $x_i$ (the order in which photons come does not matter hence the $\frac{1}{n!}$ term):

$$P_1^{hyp} \;=\; \frac{1}{n!}\prod_i^n P_i^{hyp}, \tag{3}$$

and the probability of not seeing any photons anywhere else:

$$\begin{aligned} P_2^{hyp} &= \prod_i^n (1 - P_i^{hyp}) \\ \ln P_2^{hyp} &= \sum_i^n \ln(1 - P_i^{hyp}) \end{aligned}$$

$$
\begin{aligned}
&= -\sum_i^n P_i^{hyp} \\
&= \int P_i^{hyp}\, dx \\
&= -(N^{hyp} + K^{hyp}) \\
P_2^{hyp} &= e^{-(N^{hyp}+K^{hyp})}. \qquad (4)
\end{aligned}
$$

Equations (3) and (4) combined give the probability [1]:

$$P^{hyp} = \frac{1}{n!} e^{-(N^{hyp}+K^{hyp})} \prod_i^n P_i^{hyp}. \qquad (5)$$

To minimize the influence of the background shape on the identification only those $x_i$ for which the relation

$$-3 \leq x_i \leq 3 \qquad (6)$$

holds, were taken into account when calculating probability densities. So in effect only the data in these windows was taken into account. Not only was the probability density (5) for a certain hypothesis calculated, but the other two hypotheses were demanded to be null, thus their windows were to contain nothing but background. This demands were archieved by multiplying (5) with the probability density for the assumed background shape in the other two windows:

$$
\begin{aligned}
P^{hyp1} = & \frac{1}{(n_1+n_2+n_3)!} e^{-(N^{hyp1}+K^{hyp1})} e^{-K^{hyp2}} e^{-K^{hyp3}} \prod_i^{n_1} P_i^{hyp1} \\
& \prod_j^{n_2} (a^{hyp2} \cdot x_j + b^{hyp2}) \prod_k^{n_3} (a^{hyp3} \cdot x_k + b^{hyp3}) \ . \qquad (7)
\end{aligned}
$$

At large momenta windows (6) start to overlap. To avoid counting the same photons twice and to avoid ascribing the signal photons to the background, windows were joined. Background parameters were calculated for the whole window and again probabilities were calculated as the sum of the appropriate gaussian and the background line.

The pion-kaon separation is shown on Fig. 2, where the logarithm of probabilities ratio ($\ln(P^\pi/P^K)$) is plotted against the particle momentum. As expected, the efficiency and fake probability depend on the cuts in the

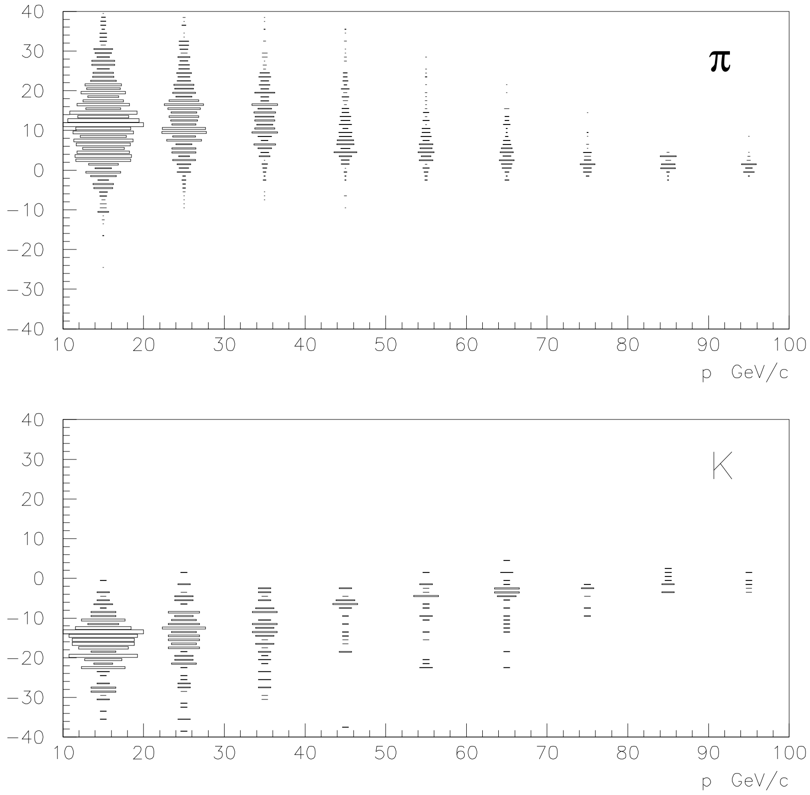


Figure 2: Pion and kaon separation. The quantity plotted for pions and kaons against the momentum is $\ln P_{\pi} - \ln P_K$. The number of detected Čerenkov photons is 20 for a $\beta = 1$ particle.

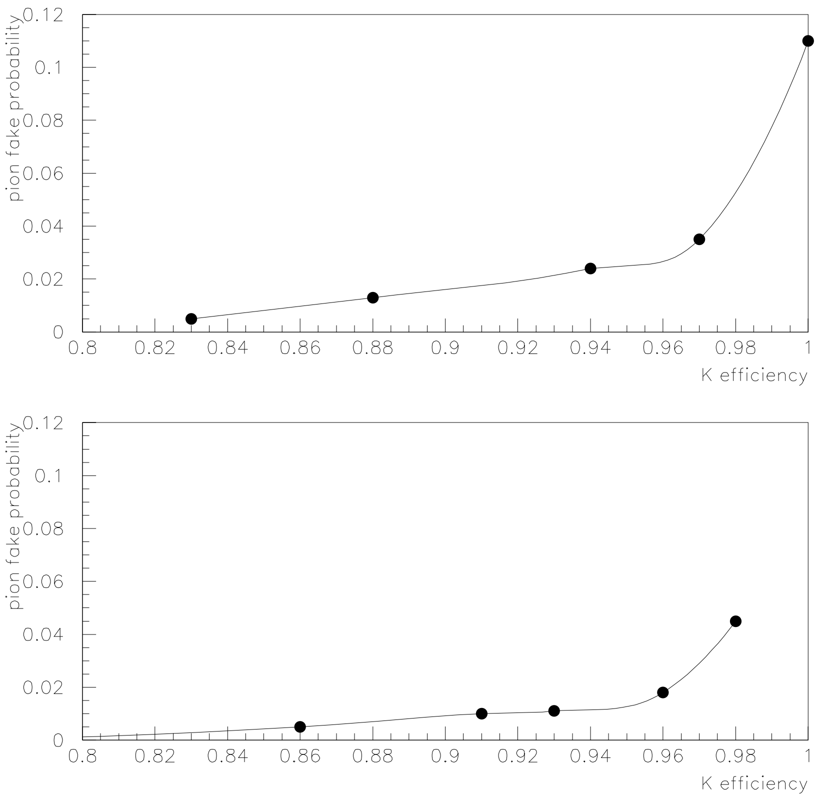


Figure 3: Pion fake probability as a functiuon of kaon detection efficiency for two momentum intervals: 10-20GeV/c (above) and 20-30GeV/c (below).

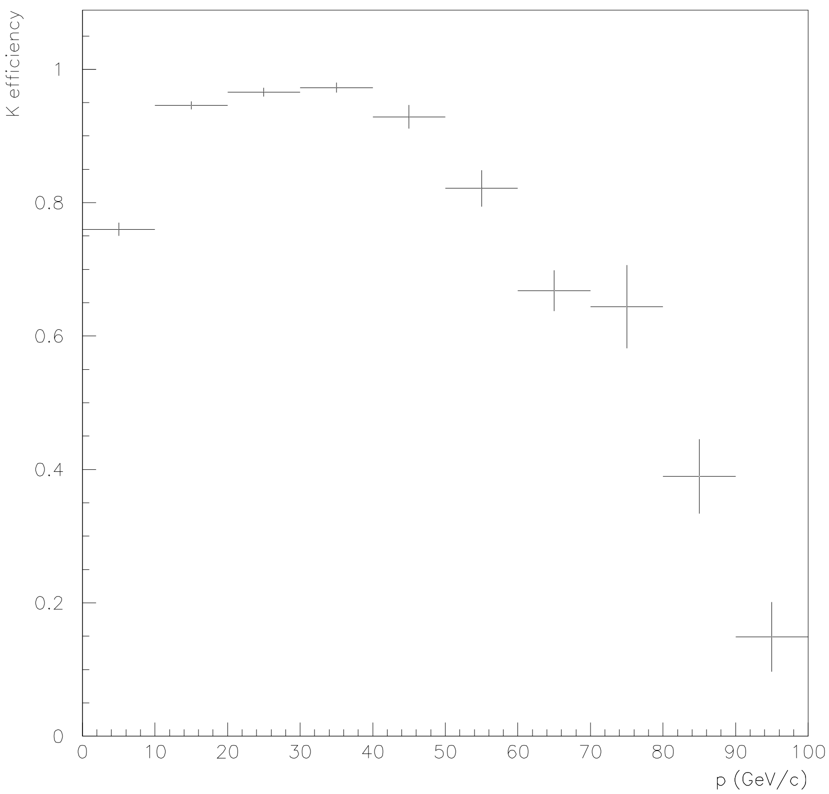


Figure 4: Kaon detection efficiency for a fixed pion fake probability of 2% as determined by the extended likelihood method. The number of detected Čerenkov photons is 20 for a $\beta = 1$ particle. In the first bin only kaons with $p > 3$GeV/c were considered.

likelihood ratio applied to separate pions from kaons. In Fig. 3 the pion fake probability is shown as a function of kaon detection efficiency for two momentum intervals. Finally, the efficiency of the method is shown in Fig. 4 for a fixed pion fake probability of 2%.

Particles below Čerenkov threshold ( 2.4 GeV/c, 8.6 GeV/c and 16.4 GeV/c for pions, kaons and protons, respectively) do not produce any signal so there is no use in calculating anything in windows (6) for a hypothesis below its threshold. Yet some information can still be extracted from other hypotheses above threshold. To veto an above-threshold hypothesis the data in its window (6) was fitted with a gaussian and a line. The gaussian average (in our case 0), standard deviation (in our case 1) and background parameters were fixed. The number of photons in the gaussian $N^{hyp}$ was left to vary freely. The hypothesis was vetoed if $N_{fit}^{hyp} < N_{cut}$. For smaller momenta ($3GeV/c < p < 3.5GeV/c$) $N_{cut} = 2$ and for larger momenta ($3.5GeV/c < p < 10GeV/c$) $N_{cut} = 4$ was chosen (see Fig. 5) to separate kaons from pions. The resulting kaon detection efficiency amounts to 0.82 at a pion fake probability of 0.04.

To conclude we note that in the analysis a conservative value for the number of detected photons was used (20 instead of 40 as expected for the proposed RICH [3]). In addition, while only kaons with 4.5GeV/c$< p <$ 50GeV/c were considered in calculations of tagging efficiency as given in the Letter of Intent, this analysis shows that this range can be extended up to 70GeV/c. Moreover, the influence of fake kaons upon tagging efficiency and dilution was studied and no significant effect could be seen for fake probabilities below 5%.

Finally, it is worth noting that there certainly is room for improvement of the method described in this report. In particular, the fact that most of the background hits actually belong to other tracks in the event suggests that some kind of iterative procedure could reduce the background level. One of the possible methods is already under study.

# References

[1] P.Baillon, Cherenkov ring search using a maximum likelihood technique, Nucl. Instr. and Meth. A238 (1985) 341.

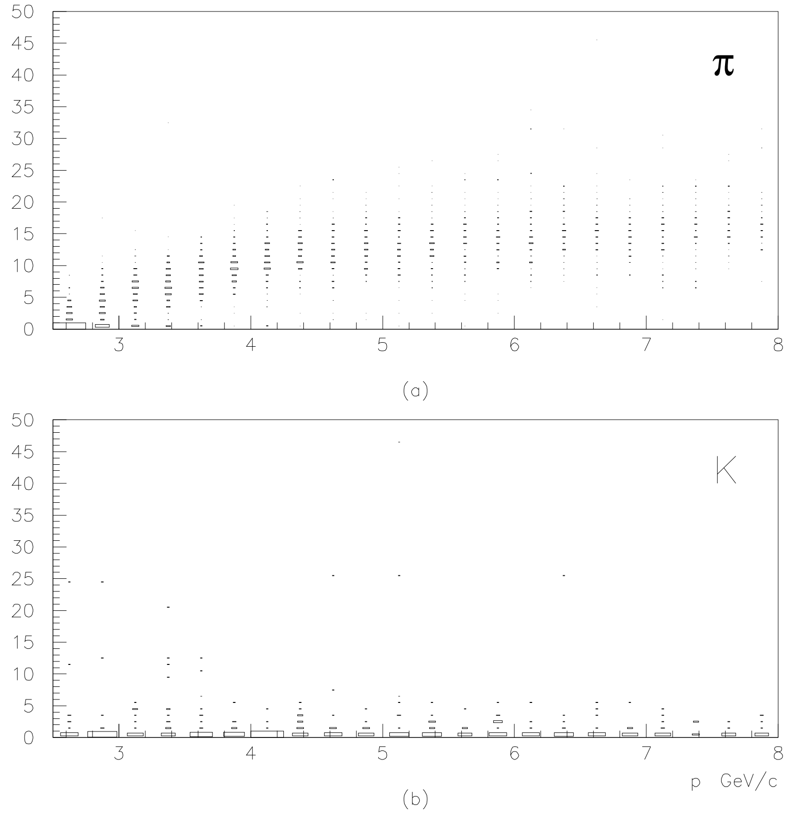


Figure 5: The number of fitted photons for (a) pions and (b) kaons below the kaon threshold. The number of detected Čerenkov photons is 20 for a $\beta = 1$ particle.

[2] L.Lyons, *Statistics for nuclear and particle physicists*, Cambridge Univ. Press, Cambridge, 1986.

[3] H.Albrecht et al., An Experiment to Study CP Violation in the $B$ System Using an Internal Target at the HERA Proton Ring, Letter of Intent, DESY preprint, DESY-PRC 92/04, October 1992.