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RESEARCH OF PARTICLE IDENTIFICATION MODELS IN THE HERA-B RING IMAGING CHERENKOV COUNTER

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Method and numerical results of the comparative analysis of two different models for particle identification by RICH in the HERA-B experiment are considered. The momentum dependence of the identification efficiency and misidentification rate of both approaches have been investigated on experimental data using sample of pions from $K_S^0 \to \pi^+\pi^-$ decays. Additionally, tracks detected by the MUON system with high values of the muon hypothesis likelihood are used for this study.

Рассматривается методика и результаты сравнительного анализа двух различных моделей идентификации частиц в детекторе RICH установки HERA-B. Исследование эффективности идентификации и уровня статистических ошибок второго рода в зависимости от импульса частиц проведено для обоих подходов с использованием зарегистрированных установкой пионов из распада $K_S^0 \to \pi^+\pi^-$. Для анализа также были использованы траектории мюонов, идентифицированные с высокой степенью достоверности мюонной системой установки.

The HERA-B setup (Fig. 1) consists of Vertex Detector (VDS), Main Tracker (Outer and Inner Tracker), Ring Imaging Cherenkov Counter (RICH), Electromagnetic Calorimeter (ECAL) and Muon Detector (MUON). There are two programs for particle identification in the HERA-B RICH [1], based on completely different models: RITER [2] and RISE [3]. RITER uses Main Tracker segments as seeds for the «Cherenkov radius histogram» method. An iterative procedure is applied to sort photon hits by weight. Weighted photon hits are used for the calculation of likelihoods for different particle hypotheses. RISE performs a ring pattern recognition in some restricted area in the RICH image plane. This area is defined by the parameters of a track found in the Main Tracker. Fitting the center of the ring, RISE determines the value of the Cherenkov angle and then calculates likelihoods.

To study the identification in both methods two track samples are used: pions from $K_S^0 \to \pi^+\pi^-$ decays and tracks defined by the MUON system [4]. The analysis was done with a set of the HERA-B experimental data.

To produce a clean pion sample, tracks originating from the decay $K_S^0 \to \pi^+\pi^-$ are selected. The following selection criteria and cuts have been used to isolate the K_S^0:

• Use a «clone-free» sample of tracks having VDS and Main Tracker segments.

• Select two-prong vertices with oppositely charged tracks with a vertex χ^2 probability of > 0.001.

• Since the decay products are both pions, their momenta should be more or less symmetric: require $0.25 < |p_1|/|p_2| < 4$.

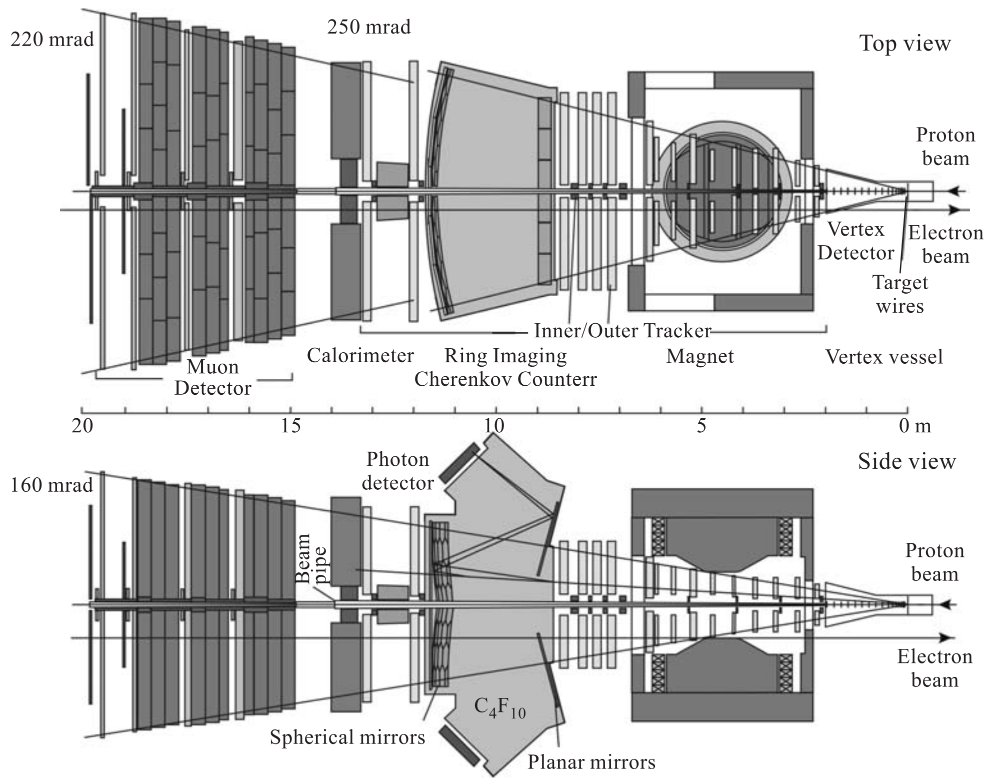

Fig. 1. Two projections view of the HERA-B experimental setup

• Cut on the flight distance $c\tau$ between the primary and the decay vertices measured in the K_S^0 rest frame: $c\tau \equiv \Delta z\, M_{\pi\pi}/p > 0.25$ cm.

• Cut on the transverse momentum $p_\perp^+$ of the positively charged track relative to the direction of K_S^0: $p_\perp^+ > 0.1$ GeV/c.

The resulting mass spectrum approximated by the superposition of 1st degree polynomial and Gaussian function is shown in Fig. 2. The values of parameters are calculated using ROOT framework. Almost background-free sample contains 5370 ± 74 K_S^0 decay candidates.

Tracks with MUON trigger, having Main Tracker and VDS segments, with $p > 5$ GeV/c and $p_\perp > 1$ GeV/c, are used for the muon track sample. A cut value of 0.95 is implemented on the muon hypothesis likelihood defined by the MUON system.

The packages RITER and RISE perform particle identification in different ways. Thus the algorithms have different track identification ability, which is defined as the ratio $N_{\mathrm{id.flag}}/N$, where $N_{\mathrm{id.flag}}$ is the number of tracks having some identification, and N is the total number of tracks passed through the RICH detector. Figure 3 shows the identification ability versus momentum for clear pions from K_S^0 decays. It is obvious that more tracks have some identification by RITER than by RISE.

Figure 4 shows the distributions of muon likelihoods L_μ for muon tracks found by RITER and RISE. The peak at $L_\mu = 1/3$ in the distribution for RITER corresponds to the

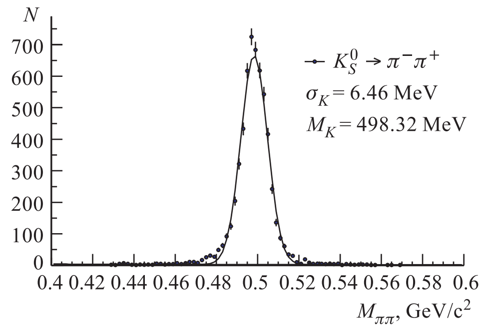

Fig. 2. Invariant mass spectrum of $\pi^+\pi^-$ systems

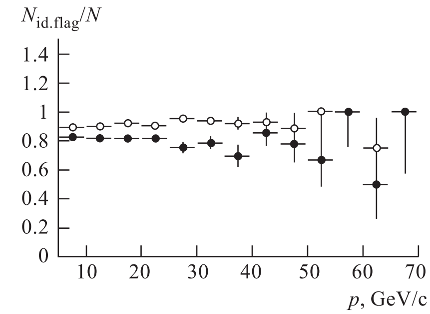

Fig. 3. Fraction of tracks having some identification by RITER (○) and RISE (●) for pions from K_S^0 decays

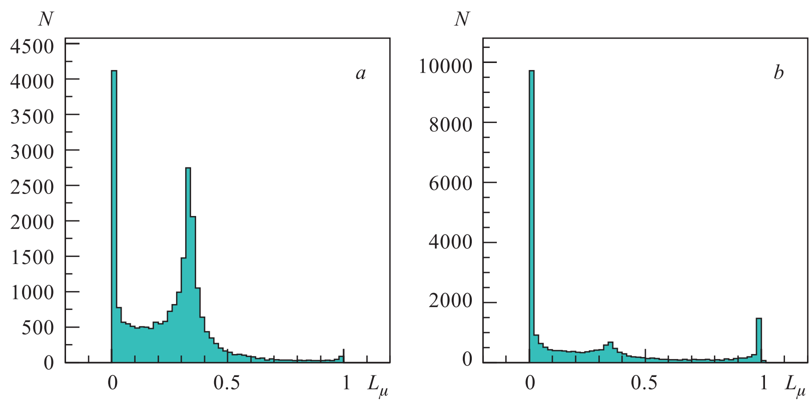

Fig. 4. RITER (*a*) and RISE (*b*) muon likelihood distributions for muon tracks

situation when, at high momenta, a separation between pion, muon, and electron hypotheses is impossible. In RISE, the corresponding peak is much smaller. A lot of tracks have values of the likelihood close to zero or to one. RISE claims a unique identification of pions, muons, and electrons.

This behavior is illustrated by Fig. 5, which shows the momentum dependence of the RISE identification efficiency and misidentification rate for the sample of pions from K_S^0 decays which consist of about 99% pions. RISE identifies tracks as clear pions, muons or electrons with high values of the respective likelihood (L_e, L_μ or L_π) even at high momenta where such a separation is impossible. According to [5], pion–electron separation with more than 2σ is impossible for tracks with momentum above 17 GeV/c. Many pions are wrongly identified by RISE as clear electrons with high values of the electron likelihood.

RITER provides a unique identification (Fig. 6) of pions, muons, and electrons but, as expected, only at low momenta. Thus, these particles can be identified either by applying a cut on low values of the particular likelihood (for example, $L_\pi > 0.1$), or by applying a cut on the sum of the indistinguishable hypotheses $L_e + L_\mu + L_\pi$.

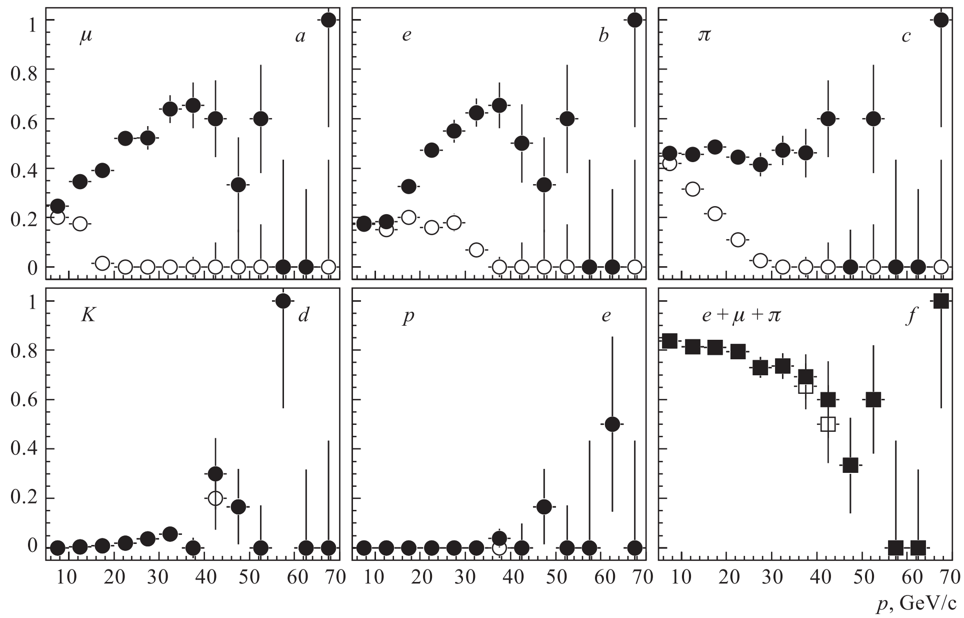

Fig. 5. Momentum dependence of the identification efficiency and misidentification rate of pions determined by RISE. Two fixed cutoff values are applied on RISE likelihoods of the particular hypotheses: 0.1 (●), 0.9 (○). Cutoff values of 0.1 (■) and 0.95 (□) were implemented on the sum of pion, muon, and electron likelihoods

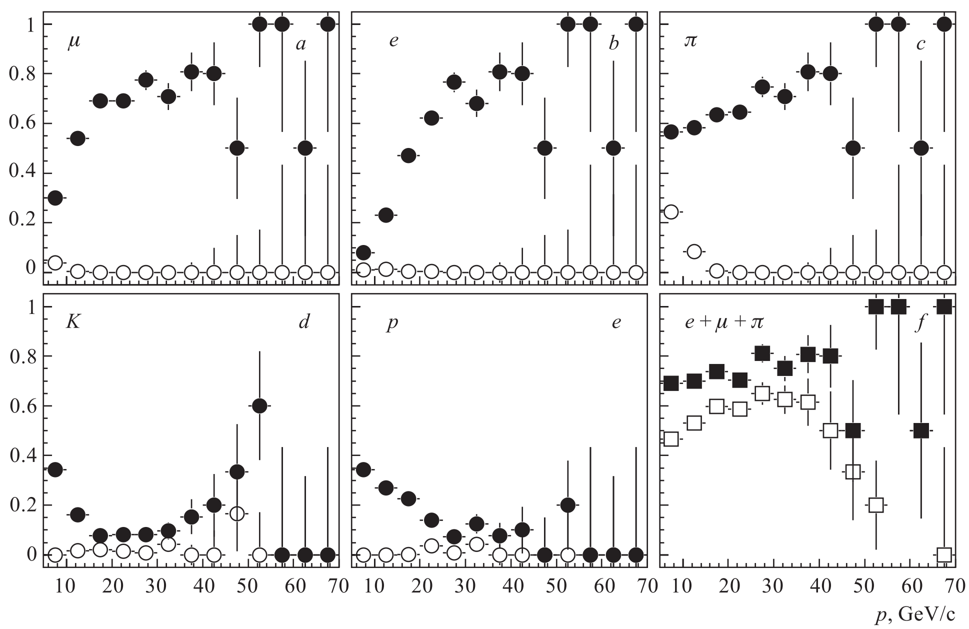

Fig. 6. The same as Fig. 5, but for RITER

Figure 7, *a* shows the r2p2 plot [5] for the pion sample from K_S^0 decays as obtained from RISE. A clear and narrow electron band is observed. Real electrons should have momenta close to the energy loss $E_{\rm ECAL}$ in the ECAL. The $E_{\rm ECAL}/p$ distribution is presented in Fig. 7, *b* for tracks that are identified by RISE as electrons, selected by a rectangular cut around the electron band. There is no indication of a peak located around $E_{\rm ECAL}/p = 1$. Therefore definitely nonelectron tracks are identified as electrons by RISE with high values of the electron likelihood.

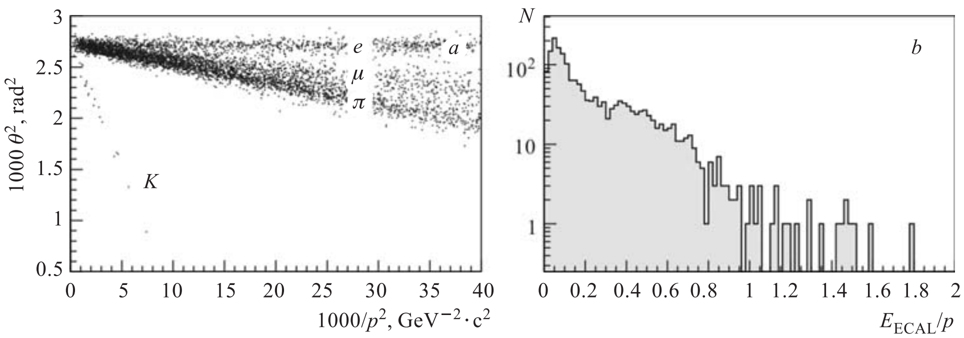

Fig. 7. *a*) r2p2 plot for pions from K_S^0 decays. A clear electron band can be observed. *b*) $E_{\rm ECAL}/p$ distribution for pion tracks in the electron band selected by a rectangular cut in the r2p2 plot. No enhancement around $E_{\rm ECAL}/p \approx 1$ can be seen

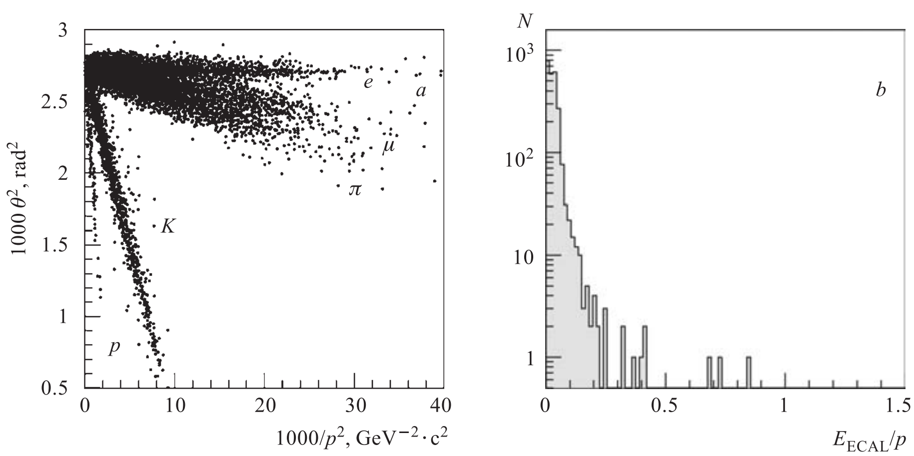

Fig. 8. *a*) r2p2 plot for the muon track sample. A clear electron band can be observed. *b*) $E_{\rm ECAL}/p$ distribution for muon tracks in the electron band selected by a rectangular cut in the r2p2 plot. There is no peak around $E_{\rm ECAL}/p = 1$

Figure 8 illustrates the same behavior of RISE for the muon sample. The θ^2 distribution is demonstrated in Fig. 9, which shows the width of r2p2 bands for muons with

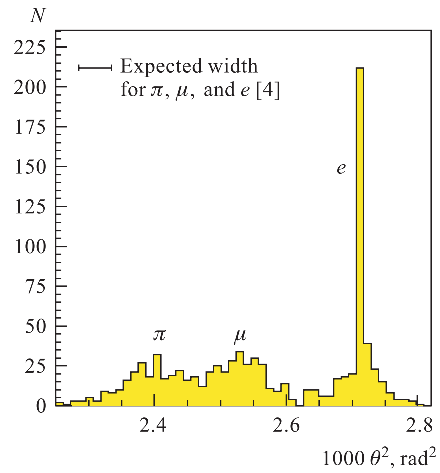

Fig. 9. θ^2 distribution for the muon track sample with $7.5 < p < 8$ GeV/c

$7.5 < p < 8$ GeV/c. The width of the electron band is too small and does not agree with the expected value [5].

SUMMARY

The currently available implementation of RISE claims to be able to unambiguously distinguish between e, μ, and π, even in cases where the particles momenta are high and a distinction is impossible. Furthermore, it seems to favour the electron hypothesis and gives an unreasonably narrow distribution of the Cherenkov angle θ_C for these tracks. RITER on the other hand reveals less unexpected behaviour and is recommended for particle identification in the HERA-B experiment.

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