Particle Identification with the Silicon Detectors of the PHOBOS Experiment

Abstract

Numerical simulation of the particle identification of charged particles in the PHOBOS experiment is presented. The particle identification(PID) is based on the mass dependence of the energy loss measured in silicon detectors at low particle momenta. The paper describes a PID algorithm and its results for the separation of charged pions, kaons and protons.

Introduction

The goal of the PHOBOS experiment [1] is to search for the onset of the new physics in nucleus-nucleus collisions at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven. The acceleration of heavy ion beams to the highest energy ever obtained in laboratory, opens at RHIC a new and challenging field of study. According to the theoretical calculations at these energies the conditions for the creation of the Quark Gluon Plasma (QGP) will be well fulfilled. Many observables to probe the existence of the QGP were proposed. The PHOBOS detector is optimized to look for a number of specific signatures like e.g. abundant production of some species of particles, multiparticle correlations, structures in p_t distributions or change in properties of some particles (e.g. ϕ-mesons). Some of those observables can be investigated on an event-by-event basis, the other will be obtained from high statistics measurements.

PHOBOS Spectrometer

At the heart of the PHOBOS detector is the high quality multiparticle spectrometer. Other systems, like the vertex and multiplicity detectors, time of flight wall and the trigger detectors are mainly built to make the measurement by the spectrometer possible, or extend its functionality and provide the global characteristics of events.

In the two spectrometer arms 1% of charged particles emitted at large angles (central rapidity region) will be measured. The spectrometer arms are placed horizontally on both sides of the beam pipe (z direction in Fig.1) in a 2 Tesla field of a conventional magnet. Each arm of the spectrometer contains several (up to 16 - see Fig.2) detector layers composed of Si sensors, with geometrical shapes optimized for a good acceptance of particles with low transverse momenta. First few silicon planes are located in a weak field to facilitate the reconstruction of particle trajectories. From the curvature of reconstructed trajectories in the magnetic field, particle momenta will be measured with a very good resolution[1].

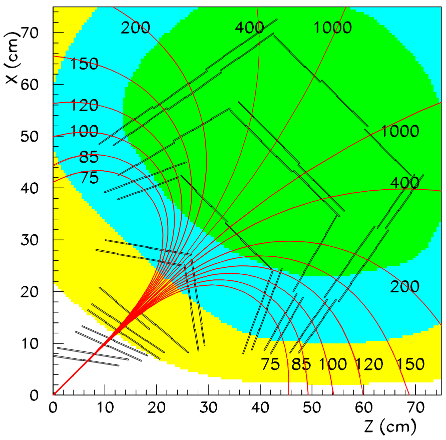


Fig.1 The PHOBOS, plan view showing the arrangement of the detector planes in one of the spectrometer arms. Curves show trajectories of pions with different momenta (in MeV/c) in the PHOBOS magnetic field (increasing darkness of the field map corresponds to the strength of the field of 0.2, 1.0 and 1.8 Tesla).

Particle Identification Method

The particle identification (PID) algorithm has been constructed to determine the particle identification capability of the PHOBOS detector[2]. To accomplish this, the standard PHOBOS Monte Carlo (PMC) code was used to generate large samples of pions, kaons and protons uniformly distributed in the polar angle, in the azimuth and in the initial particle momentum. Each simulated track used in the PID study was required to have hits (signals in silicons) in at least

12 layers. This set of layers included all layers except for the three layers inside the magnet which are not fully equipped with silicon wafers (layers labelled in Fig2 as: 11, 13 and 15). Because the sixth and the seventh layer are displaced in the perpendicular direction to the incoming tracks a hit in one of them was required. Numbers of selected tracks from the pion, kaon and proton samples were 899000, 503000 and 531000 respectively. The large samples of particles were used for defining the algorithm but later, for testing the algorithm performance standard HIJET events were used.

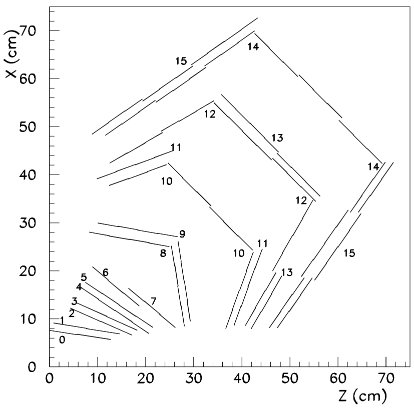


Fig.2 The plan view of the detector silicon planes showing layer numbers.

Energy losses of these PMC particles traversing different components of the PHOBOS detector were described by the standard Geant option (the Landau distribution) taking into account the most accurate descriptions of the detector geometry and materials. For each track the mean $< dE/dx >$ was calculated out of all hits the track had in the spectrometer silicon plains using the simulated energy loss (dE) and the distance traversed by the particle in silicon (dx) at each hit. While calculating the average we have rejected the biggest values of dE/dx. This procedure, called truncation, lowers the smearing of the PID performance due to the Landau fluctuations of the energy loss (dE). For experimental reasons it seemed reasonable to reject also the smallest dE/dx value (but the number of truncations is defined as the number of rejections of the biggest dE/dx values). We have tested several types of truncations - rejecting from 0 to 7 (out of 13-16 possible) the biggest values of dE/dx. The mean $< dE/dx >_{tr}$ depend on the particle type and its momentum(Fig.3). From Fig.3 we see that particles of one type form a band in the scatter plot $< dE/dx >_{tr}$ vs. momenta. The PID band can be enclosed by two lines at a distance depending on the size of the energy loss fluctuations. The determine the two lines (PID band) for pions, kaons and protons we assumed that the PID band should contain 95% of particles inside. The remaining 5% of particles should be equally distributed on both sides of the band. To fit the lines, the scatter plots were sliced in the momentum range from 0 GeV/c to 2.0 GeV/c in 100 bins each 20 MeV/c wide. Each slice projected on the $< dE/dx >_{tr}$ axis had tails cut off. The lowest and the biggest values of these tailored $< dE/dx >_{tr}$ are represented (after interpolation) by solid lines in Fig.3a for 2 truncations and in Fig.3b for 7 truncations. For larger number of truncations the bands become thiner and they start to overlap at higher particle momenta.

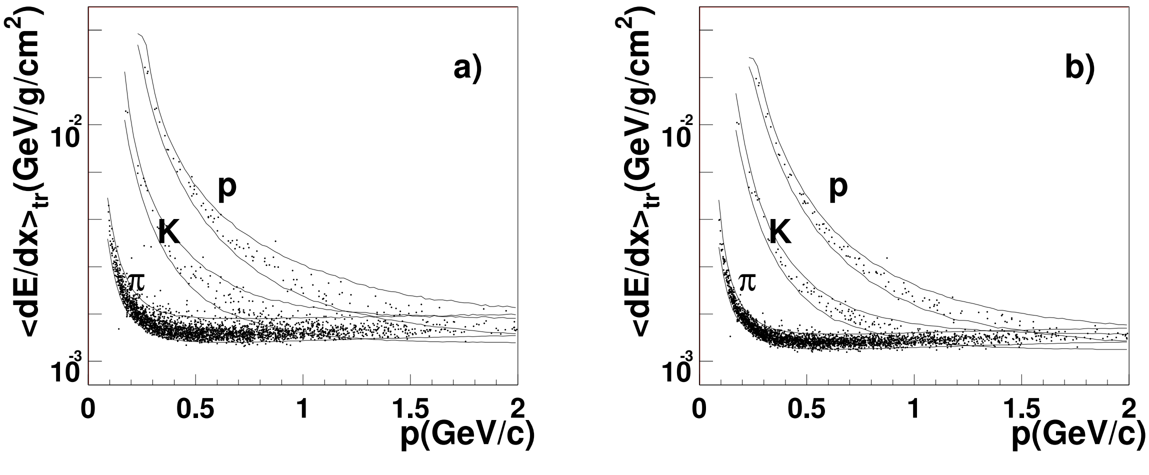
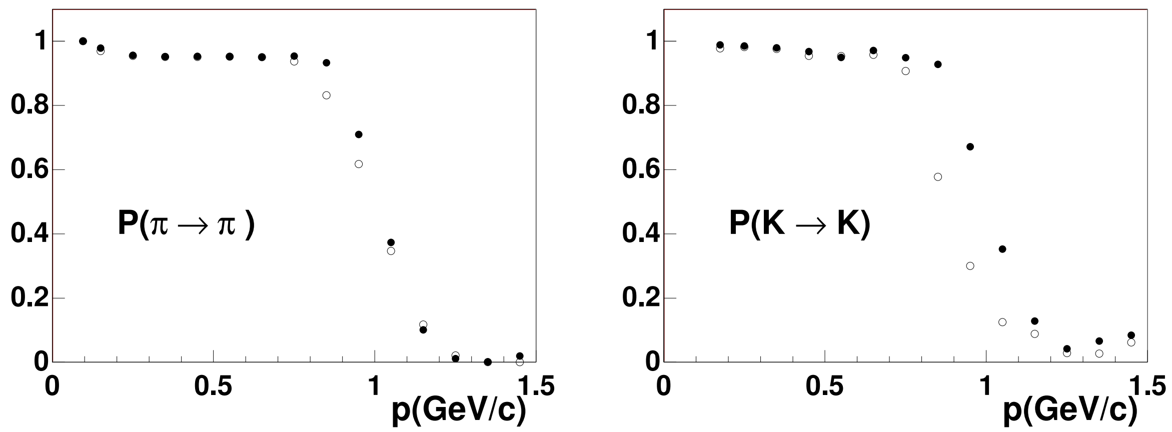


Fig.3 PID bands (solid lines) in the $< dE/dx >_{tr}$ vs. the particle momentum scatter plot for 2 (a) and 7 (b) truncations. Dots are PHOBOS Monte Carlo results for $< dE/dx >_{tr}$ for one hundred central Au(100 GeV/ nucl) - Au(100 GeV/ nucl) events from HIJET.

The algorithm for particle identification based on PID bands was defined as follows: if a particle with the measured $< dE/dx >_{tr}$ and momentum p falls inside one and only one PID band corresponding to a particle of type A then the particle is identified as A. The above definition excludes all areas (in the $< dE/dx >_{tr}$ vs. p plot) outside bands and also those where PID bands overlap. As it is shown in the next Section such simple algorithm gives a large pion contamination in the samples of identified kaons and protons at large momenta. Extension of the algorithm is necessary to lower this contamination.

Efficiency of the Particle Identification

We have applied the PID algorithm to the sample of 9000 central HIJET events to find efficiencies for particle identification and contaminations in the identified samples of particles by other particles. We have selected only those particles hitting the spectrometer planes (in two arms) which fulfilled the selection criterion described in the previous Section. In Fig.4 the efficiencies i.e. probabilities $P(A \to A)$ that a particle of type A is identified as a particle of the same type A for pions, kaons and protons versus particle momentum for 2 and 7 truncations are shown. The contaminations i.e. probabilities that a particle identified as A is in fact a particle of a type different than A in samples of particles identified as pions, kaons and protons are shown in Fig.5.



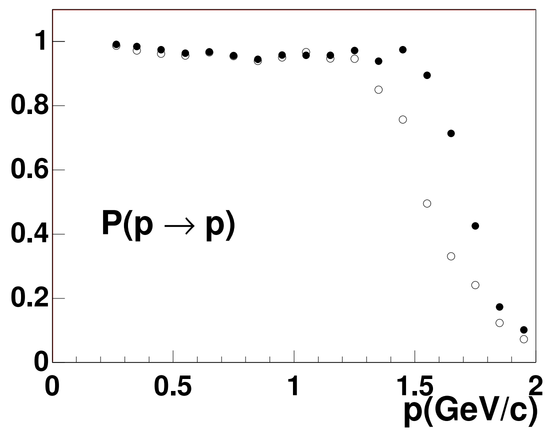


Fig.4 Efficiencies of identification of π, K and p for two (open circles) and seven (full circles) truncations as a function of the particle initial momentum.

For two truncations in the momentum range up to 0.75 GeV/c for pions and kaons the efficiencies are about 95 % (this is the full expected efficiency due to cutting of the tails of the $< dE/dx >_{tr}$ distributions). For protons such high efficiency is observed up to 1.25 GeV/c. For higher momenta (above 0.75 GeV/c for π and K, and above 1.25 GeV/c for p) the efficiencies sharply fall down when the bands overlap. For seven truncations these upper limits are moved to higher momenta by about 100 MeV/c for pions and kaons. For protons the 95 % efficiency momentum range is extended by about 200 MeV/c.

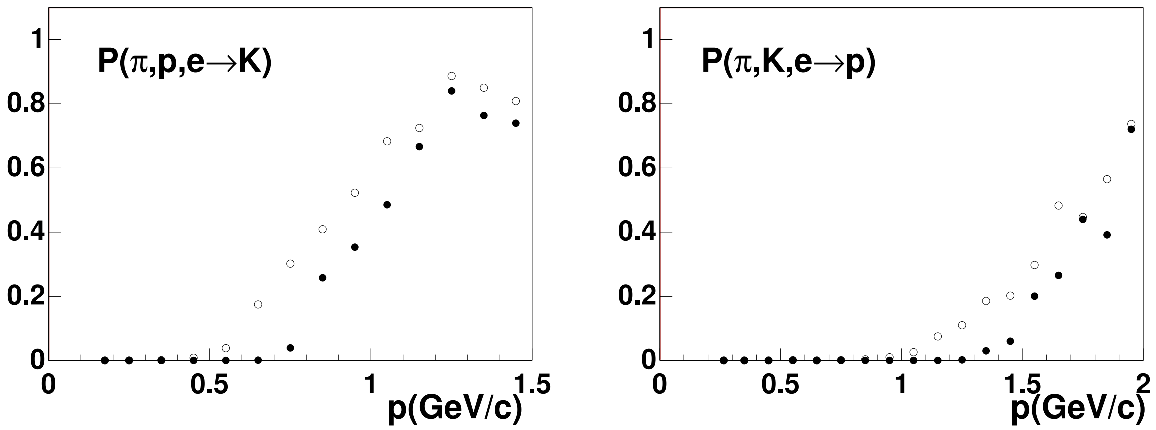


Fig.5 Contaminations in the samples of identified K and p particles for two (open circles) and seven (full circles) truncations as a function of the particle initial momentum.

In Fig.5 one can see that there is no contamination in K sample up to about 0.55 GeV/c for two truncations (for seven truncations up to 0.75 GeV/c). Then the contamination starts to increase to about 80 % at 1 GeV/c. There is no contamination in p sample up to 0.95 GeV/c. For seven truncations the contamination is negligible up to 1.35 GeV/c. For two (seven) truncations 10 % contamination is attained at 0.6 GeV/c (0.8 GeV/c) and 1.25 GeV/c (1.5 GeV/c) for kaons and protons respectively. The contamination is mainly due to pions but all particles: pions, kaons, protons and electrons were taken into account. The electron contribution to the contaminations is negligible in comparison to pions. Detail results on the electron efficiencies and contaminations were presented in [2].

The contamination levels depend on relative π, K and p abundances. The contamination in the kaon and proton samples is caused by pions lying above the pion band with large $< dE/dx >_{tr}$ values (2.5% of pions). In the momentum intervals above 0.9 GeV/c for kaons and 1.7 GeV/c for protons the contamination is large as the number of 2.5 % of all pions is comparable with the total number of kaons. (Relative abundances in HIJET do not depend on momentum and are equal respectively 1:0.045:0.035). In order to obtain a sample with lower contamination we can restrict the momentum range. This procedure is however not very efficient since it rejects also some kaons and protons with high momenta which are far from the pion band - sufficiently far to be identified.

Extension of the Particle Identification to Higher Momenta

To make the particle identification more efficient we propose a new method to extend the PID algorithm to higher particle momenta. The extended PID algorithm uses in addition to the PID bands, described in the previous Section, a set of functions which are fitted to $< dE/dx >_{tr}$ distributions for different particle types and momenta. These functions together with the relative ratios of the numbers of pions, kaons and protons produced in nucleus-nucleus collisions can be used to calculate probabilities that a particle with a given momentum and $< dE/dx >_{tr}$ is π, K or p. At lower momenta (less than 0.5(0.8) GeV/c for π and K, (p)) where the PID bands are well separated the algorithm described previously is used and within bands the probabilities are set correspondingly to 1 or 0. The contaminations in these low momentum ranges are negligible.

Data from simulations used to obtain PID bands were also used to fit the functions. Tracks were selected in the same way and the number of truncations was set to 7. The $< dE/dx >_{tr}$ versus momentum scatter plots were sliced in the momentum range from 0.4 GeV/c to 2.0 GeV/c for

π and K in 100 MeV/c wide bins. For protons the momentum range was taken from 0.7 GeV/c to 2.0 GeV/c. Each slice projected on the $(log_{10}) < dE/dx >_{tr}$ axis was fitted with a Gaussian function. As an example the $< dE/dx >_{tr}$ distribution and the fitted Gaussian function are presented in Fig.6 for pions with momenta from 0.9 GeV/c to 1.0 GeV/c. The shape of the Gaussian function reproduces the $< dE/dx >_{tr}$ distribution well since the long Landau tail is suppressed by the large number of truncations.

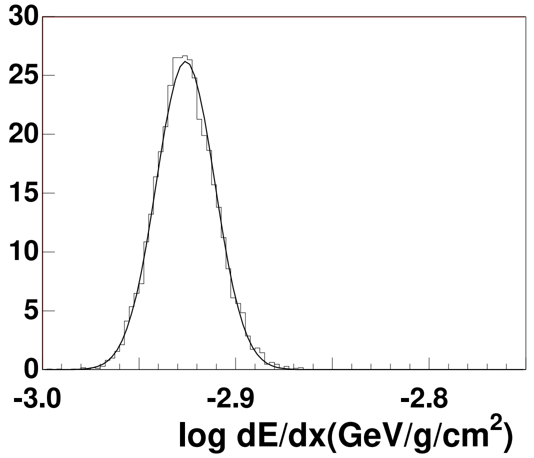


Fig.6 $< dE/dx >_{tr}$ distributions for pions in the momentum range from 0.9 GeV/c to 1.0 GeV/c. The solid line is a Gaussian fit to the distribution. The histogram normalization was set to 1.

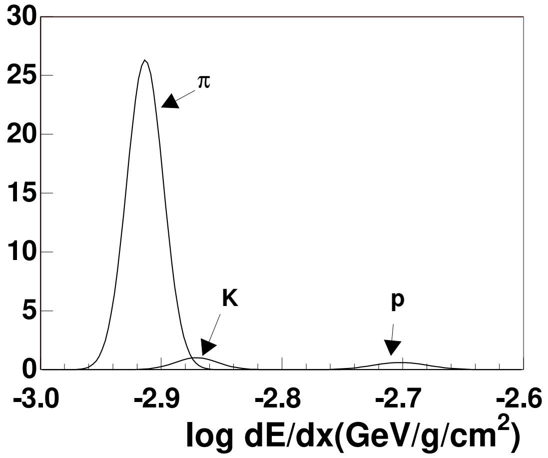


Fig.7 Gaussian functions fitted to $< dE/dx >_{tr}$ distributions for π, K and p in the momentum range from 0.9 GeV/c to 1.0 GeV/c. Functions are normalized to the relative π, K and p abundances in HIJET.

In Fig.7 Gaussian functions for pions, kaons and protons particles with relative weights corresponding to HIJET particle multiplicities are presented in the same momentum interval. From Fig.7 we can see that some fraction of kaons can be correctly identified even though the contamination shown in Fig.5 for this momentum range is about 40-60 % depending on the number of truncations. With these pre-calculated functions we can evaluate a probability for each reconstructed particle to be π, K or p with the following expressions:

$$P_\pi = \frac{C_\pi}{C}, \qquad P_K = \frac{C_K}{C}, \qquad P_p = \frac{C_p}{C}, \tag{1}$$

where

$$C_i = w_i \exp(-((log_{10} < dE/dx >_{tr} - \alpha_i)/\beta_i)^2), \qquad C = C_\pi + C_K + C_p. \tag{2}$$

Parameters w_i $(i = \pi, K, p)$ are the relative HIJET π, K and p abundances. Parameters α_i and β_i are parameters obtained from Gaussian fits for each momentum bin. To get α_i and β_i parameters for a given value of momentum a linear interpolation between the parameters obtained for the two neighbour bins was done. Since, for momenta less then 0.8 GeV/c the p band is well separated from π and K bands the expressions in this momentum range are only used for π and K (with two Gaussian functions, w_p=0). At these momenta probability to have p is either 1 or 0 depending on the $< dE/dx >_{tr}$ value. The same procedure was applied to π and K below 0.5 GeV/c.

As an example in Fig.8 we show efficiencies for K and p identification with additional cut on the calculated probability: $P_K, P_p > P_{cut}$, where $P_{cut} =$ 0.95 (applying higher cuts would require much higher statistics to study efficiencies and contaminations as a function of momentum). From Fig.8 one can see a significant decrease in the efficiencies for K and p identification. This is mainly due to the fact that now (with the probability cut) the samples of particles identified as kaons or protons are not only required to fall into one K or p band but also they have to be at some distance (in $< dE/dx >_{tr}$ vs. momentum plane) from the pion band. The distance is determined by the value of P_{cut} and the fitted functions. With the probability cut applied the full 95% efficiency for kaons is observed up to 0.75 GeV/c. Then it sharply falls down to a few percent at 1 GeV/c and for higher momenta to zero. For protons we observe the full 95% efficiency up to about 1.35 GeV/c. Then it sharply decreases to a few percent at 1.75 GeV/c.

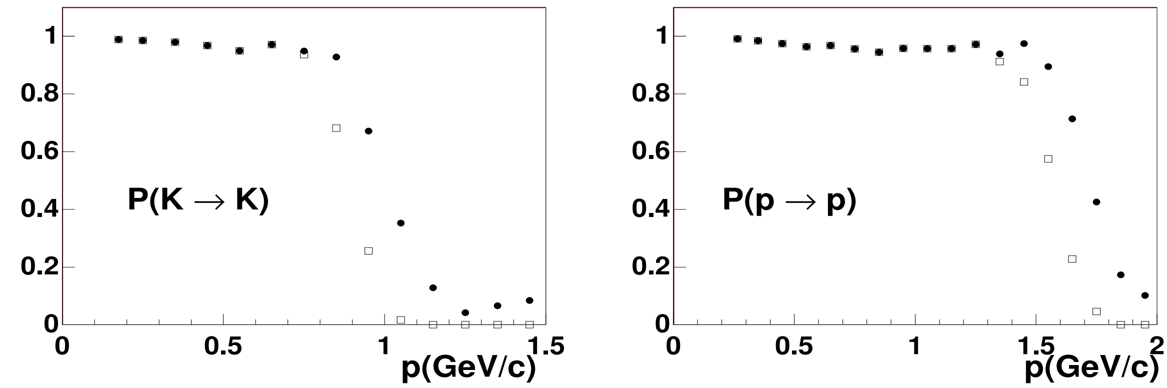


Fig.8 Efficiencies of identification of K and p particles for seven truncations. Full circles denote efficiencies shown in Fig.4 and open one correspond to $P_K > 0.95$ and $P_p > 0.95$.

The contaminations in samples selected with the probability cut are limited by the P_{cut} parameters. In the analyzed example contaminations in K and p samples should be of the order of 5%. In Fig.9 we can see that the largest contaminations of about 3% were found in the momentum ranges from 0.8 to 0.9 GeV/c and from 1.6 to 1.7 GeV/c for K and p respectively. Using this method we can select clean samples of identified particles which represent some fractions of tracks at higher momenta.

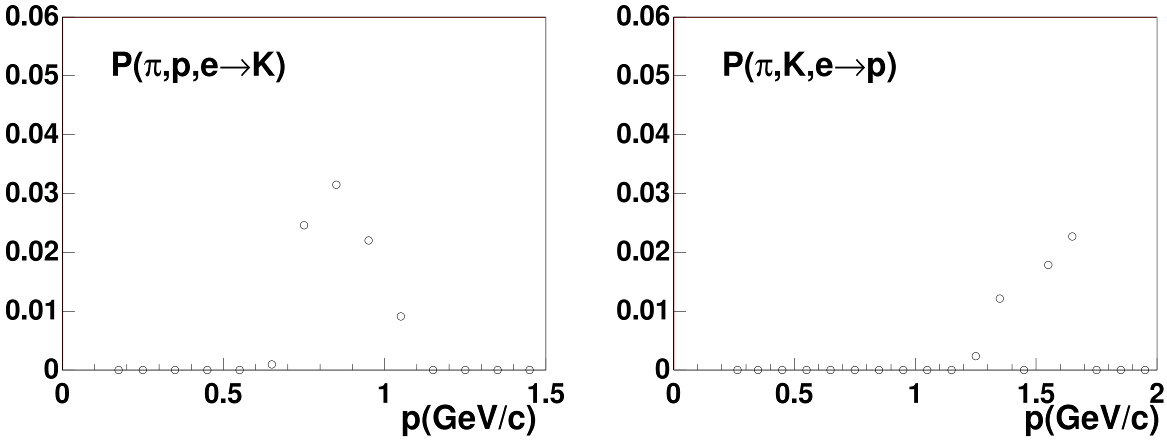


Fig.9 Contaminations in identified samples of K and p particles for seven truncations with probability cuts $P_K > 0.95$ and $P_p > 0.95$.

Conclusions

The study of the PHOBOS PID performance with the help of the PID algorithm shows that for well defined tracks we will be able to identify particles in the spectrometer with a very good efficiency at low momenta. The PHOBOS detector we will be able to separate pions and kons with full efficiency and at very low level of contamination up to 0.75 GeV/c (for seven truncations). The separation of protons and pions will be possible up to 1.35 GeV/c. The larger the number of truncations the larger is the momentum interval where particles can be identified. At largest values of momenta, where the efficiency is still 95%, the contamination in the identified kaon and proton samples are only a few percent. Although at higher momenta where bands are overlapping the pion contamination in the kaon and proton samples sharply increases, it will be possible to obtain a clean samples of identified particles for some fraction of produced particles using the extended PID algorithm.

In the PHOBOS detector the particle identification for high particle momenta ($\simeq 1\ GeV/c$) will be also performed by the TOF detectors[3]. It will provide a cross-check of the identification based on measured dE/dx and extend the identification to particles with higher momenta. The overall TOF acceptance is different from the acceptance of the PHOBOS spectrometer. Therefore a positive verification of the dE/dx method with the TOF wall may allow us to obtain more data on identified particle from the PHOBOS spectrometer.

Acknowledgements

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References

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