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SIMULATION dE/dx ANALYSIS RESULTS FOR SILICON INNER TRACKING SYSTEM OF ALICE SET-UP AT LHC ACCELERATOR

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The particle identification by using dE/dx analysis in the ALICE silicon Inner Tracking System (ITS) was studied by simulations. Correction procedures were considered and used to improve charge collection and resolution. Particle identification efficiencies and contamination rates depending on the function of momentum were obtained by the probability weight calculation for each particle species ($\pi^{\pm}$, $K^{\pm}$, p/$\overline{\text{p}}$).

The investigation has been performed at the Laboratory of High Energies, JINR.

Результаты dE/dx анализа моделированных событий для силиконовой внутренней трековой системы установки ALICE ускорителя LHC

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С помощью моделирования исследована возможность идентификации частиц по потерям энергии в силиконе (из dE/dx анализа) для силиконовой внутренней трековой системы установки ALICE. Рассмотрены некоторые процедуры коррекции потерь заряда, позволяющие улучшить разрешение по заряду и информацию о полном заряде, образующемся при прохождении частиц через силиконовые слои. Определены эффективности идентификации частиц и доли примеси (как функции импульса частиц) посредством вычисления вероятностных весов для частиц каждого сорта ($\pi^{\pm}$, $K^{\pm}$, p/$\overline{\text{p}}$).

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. INTRODUCTION

The mesurement of the energy loss in thin silicon detectors can be used for particle identification (PID) in the nonrelativistic ($1/\beta^2$) region. This ionization information may be combined with the TPC one and with the TOF measurements to improve the quality and the range over which the PID can be done. Besides, this information is unique in the ALICE ITS for the slow tracks which do not reach the outer detectors because of decays, energy loss or curling but the tracking and momentum resolution is possible with six silicon layers of the ITS. Some simulation of PID for the ALICE ITS has been presented in the ALICE TP (see Section 11.4.1 in [1]). In this note more detailed simulation analyses were carried out and the separation power was defined for charged hadrons (pions, kaons, protons) in different momentum regions with the aid of PID weights obtained for each particle.

2. DETECTOR SIMULATION

The detailed simulation model (in the frame of GEANT) is described in Refs. 2,3 . Some detector parameters have been modified with respect to the ALICE TP (see Sect. 2.1 of [1]). The two pixel layers were not considered since they are digital devices, for the dE/dx analysis. We considered two layers of silicon drift detectors (SDD) with anode pitch of 210 μm, and a drift direction transverse to the beam line; and two layers of double-sided microstrip detectors (SSD) with a strip pitch of 95 μm and a stereo angle of 30 mrad. Some details for the mechanical support and cooling systems and the beam pipe were included also in the simulation. The overall matter budget was $5.5\%(X/X_0)$ and consisted of:

- $0.28\%(X/X_0)$ for the beam pipe,
- $1.50\%(X/X_0)$ for two pixel layers,
- $1.66\%(X/X_0)$ for two SDD layers,
- $1.42\%(X/X_0)$ for two double-sided strip layers,
- $0.72\%(X/X_0)$ for outer shell.

3. CHARGE COLLECTION AND ANALYSIS

The GEANT procedure generates charge (energy loss) Landau distribution for each single hit and, in general, this charge is collected in a number of anodes/strips (i.e., a cluster is

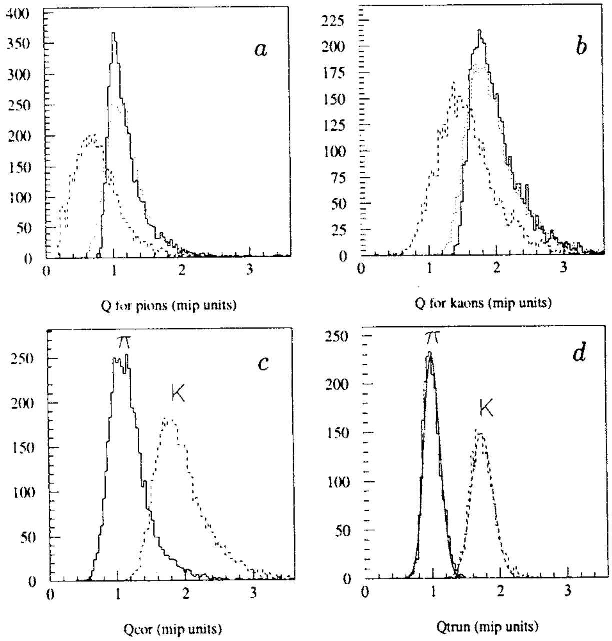

Fig. 1. Charge distributions for π and K in the momentum interval (470÷530) MeV/c (the different distributions are explained in the text)

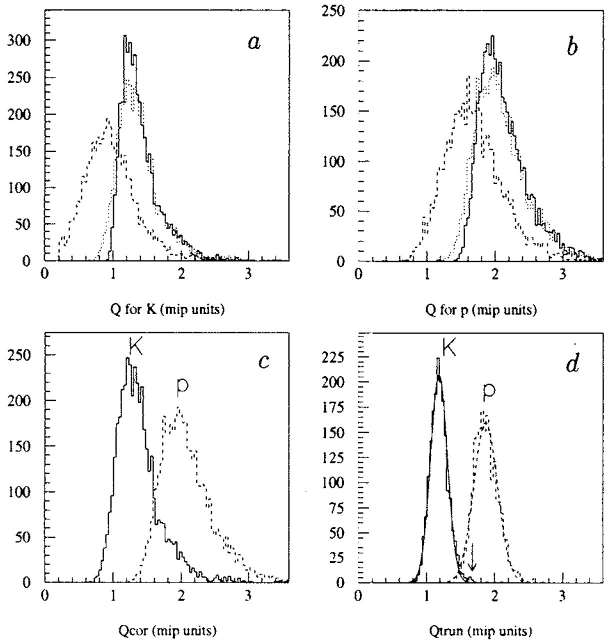

Fig. 2. Charge distributions for K and protons in the momentum interval (830÷930) MeV/*c* (the different distributions are explained in the text)

produced) [3]). In this case a variable fraction of the charge can be lost below a noise threshold if zero suppressed data are used. The charge loss depending on the cluster size is most important for the SDD and very small for the SSD. In Ref. 3, a special correction function was suggested that is used in the present analysis. The second problem relates to the fact that the charge value depends not only on particle kind and momentum but also on the path length inside the silicon (depending on the angle of particle). A correction for this effect has been done in addition.

Figs.1*a* and *b* show (for the SDD) the charge distributions generated with the GEANT package (solid lines), those obtained from the cluster analysis with due account of the noise but without the correction (dashed lines), and after the correction function using (dotted lines). The charge unit is taken as minimum particle ionization (1 mip is 20500 e^-). The distributions have been obtained for π^+ and K^+ in the momentum region of 470÷530 MeV/*c* (2000 particles of each kind have been generated). The same distribution but for K^+ and protons at the momenta of 830÷930 MeV/*c* is shown in Figs.2*a* and *b*. A strong influence of the charge threshold cut and a satisfactory result of the correction procedure is observed. It should be noted that a pessimistic noise value with $\sigma_{\text{noise}} = 500$ e^- was used for the simulation (the threshold was taken of $3\times\sigma_{\text{noise}}$), and in some realistic case, for example for OLA electronics, the equivalent noise charge was measured to be $\simeq 230$ e^- ([4]) and the shift of the charge distributions in Figs.1(*a*, *b*) and Figs.2(*a*, *b* may be decreased by a factor of nearly 1.4. On the other hand, a real experimental test of the charge collection is under study now. For example, the analysis of the nonzero-suppressed data leads to the independence of

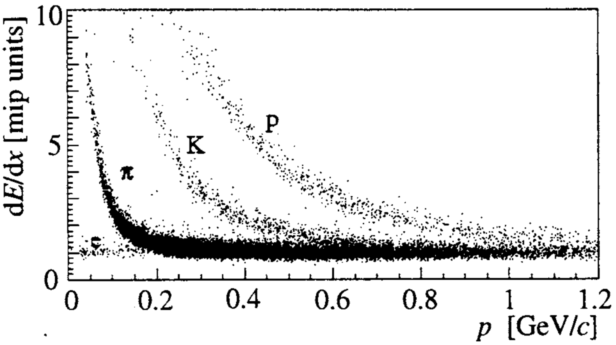

Fig. 3. Energy loss — momentum scatter plot for four silicon layers of ALICE ITS and for different particles (e, π, K, p)

the collected charge of the drift time for the SDD (see Fig. 4.5 in Ref. 4), i.e., from the cluster size. Fig.1 *c* and Fig.2 *c* show the charge distributions for particle pairs π,K and K,p in the same narrow momentum regions (for each pairs of particles) considered before. It is seen that Landau distributions are strongly overlapping.

To improve the situation the truncated mean method using the m lowest of n measurements was applied. Only measurements with four or three hits in the ITS were selected ($\simeq$ 90% from all hits, see Sect. 11.4.1 of Ref.1), and the truncated mean was constructed using two out of four or two out of three hits, respectively. The results are shown, for example, in Fig.1 *d* and Fig.2 *d* (see also Sect. 11.4.1 of Ref.1 and Ref.3). One can see that the charge distributions become nearly gaussian (the curves are results of the gaussian fit) and particle separation possibility is much better.

Figure 3 shows charge-momentum scatter plot for the charge (dE/dx) obtained after the corrections and truncated mean procedure for five central Pb-Pb events generated by the HIJING code [5] with a mean rapidity density of charge particles $dN/dy \simeq$ 6000 at y = 0 (gamma conversions and other secondary particle production have been included). Well separated densities are clearly seen for the different particle species.

4. PARTICLE IDENTIFICATION

It is seen from Fig.3 that there are wide enough momentum regions where particles may be separated by simple cuts in the charge, but some additional probability method is necessary if the deposited charges of the different particle kinds are rather similar.To study the situation in more detail the samples of 2000 one-particle-events were generated in subsequent momentum intervals. The intervals were chosen to correspond to $\pm 3\sigma$ of the TPC proton momentum resolution (see Fig.11.9 of [1]), i.e. track reconstruction in the TPC was supposed. At the next step, the charge cuts were chosen if the simple separation is possible or, otherwise, mean charge values ($< q >$) and gaussian fit sigmas (σ_q) were obtained for the next procedure of probability weights (PID weights) calculation.

Table 1 presents the simple charge cut values and information about the PID weights calculation for different momentum regions. "No PID" means that the charge distributions of pions and kaons are practically identical and the particle identification is impossible. Table 2 presents the $< q >$ and σ_q values for kaons and protons in the momentum intervals where

PID weights were calculated. For pions these values are equal to 1.0 mip and 0.12 mip, respectively for all these momentum intervals.

Table 1. Simple charge cut values and information about a need of PID weights calculation for the different momentum intervals

Momentum	Charge cut (mip)		
(MeV/c)	π	K	p
50÷120	all		
120÷200	< 6	≥ 6	
200÷300	< 3.5	3.5÷9	> 9
300÷410	< 1.9	1.9÷4	> 4
410÷470	PID weights		> 3.5
470÷530	- // -		> 3.0
530÷590	no PID		> 2.7
590÷650	- // -		> 2.5
650÷730	- // -		> 2.0
730÷830	- // -		PID weights
830÷930	- // -		- // -
930÷1030	- // -		- // -

Table 2. Mean charge values and sigmas of charge distributions for kaons and protons in the different momentum intervals

Momentum	$< q(\mathrm{K}) >$	$\sigma_q(\mathrm{K})$	$< q(\mathrm{p}) >$	$\sigma_q(\mathrm{p})$
MeV/c	(mip)			
410÷470	1.98	0.17		
470÷530	1.75	0.16		
730÷830	1.25	0.13	2.14	0.20
830÷930	1.18	0.125	1.88	0.18
930÷1030	1.13	0.12	1.68	0.155

The PID weights were calculated as follows:

The charge distributions for $\pi^{\pm}$ and $\mathrm{K}^{\pm}$ are compared in the momentum regions of (410÷470) and (470÷530) MeV/c and a charge cut equal to a chosen number of $\sigma_q(\mathrm{K})$ is applied to the left from $< q(\mathrm{K}) >$ (for example, such a cut is shown by the arrow in Fig.2*d* for K and p). All particles are considered as pions if the charges are below the cut value, otherwise, the PID weights ω_K and ω_π are calculated from the equations:

$\omega_\pi / \omega_K = \mathrm{R}_{\pi K}$, $\omega_\pi + \omega_K = 1$ (the normalization),

where $\mathrm{R}_{\pi K}$ is defined as a ratio of π and K rates limited by the cut value in the respective charge distributions (the smaller particle rates are taken). As a results, the weights are calculated as:

$\omega_K = 1/(1 + \mathrm{R}_{\pi K})$, $\omega_\pi = 1 - \omega_K$.

The weights for protons in the narrow momentum intervals (see Table 1 from 730 MeV/c) are calculated in the same way(π and K are not separated from each other at these momenta). It should be noted that the proton charge distributions have been compared only with the kaon

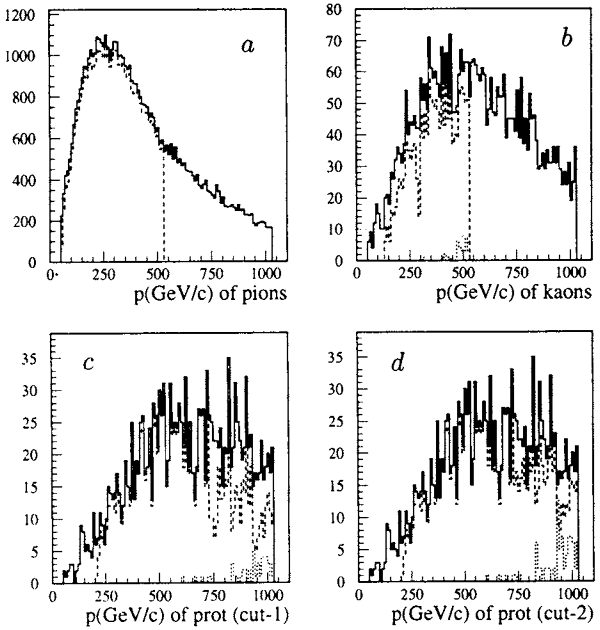

Fig. 4. Momentum distributions for $\pi^{\pm}(a)$, $K^{\pm}(b)$, protons(c and d for cut-1 and cut-2, see text). Solid lines — generated distributions, dashed lined — obtained after ITS simulation and PID procedure (see text), dotted lines — contamination(see text)

ones, since they are always nearer than the pion charge distributions, i.e., the mean proton PID weight is slightly underestimated.

5. RESULTS AND DISCUSSION

The PID procedure described in Sect.3 has been applied for 6 full SHAKER ([6]) events with a charged particle rapidity density of dN/dy = 8000 (at y = 0). All primary particles were generated in polar angle range of $45^\circ \div 135^\circ$ and at the momenta of $(0.03 \div 10.0)$GeV/c. The PID weight was obtained for each particle and each momentum interval according to Table 1.

The results are shown in Figs.4(a – d) where the generated momentum spectra (the solid lines) of pions(a), kaons(b) and protons(c, d) are compared with the ones obtained after detector simulation taking into account the PID weights (the dashed lines). Note, that the track reconstruction efficiency was not included, i.e., the particle losses due to interactions, decays, hit numbers smaller than 3 (see Sect.3), and the PID inefficiency due to contamination (the dotted lines in Fig.4) were considered. The first three factors are the most important at the smallest momenta, where significant losses of kaons and protons are observed. The PID inefficiency (the contamination) manifests itself in the regions, where the PID weight calculation is necessary. A cut of -$1\sigma_q$(K) has been chosen for π-K separation (see Sect.3) resulting in a total $\pi^{\pm}$ contamination of $K^{\pm}$ of 2%. Figures 4c and d show the results of proton separation at two cuts of $-1\ \sigma_q$(p) (cut-1) and $-\ 1.5\sigma_q$(p) (cut-2), respectively. The corresponding contamination over the full momentum range, by π/K are 3.5% and 5.8%. It is seen, of course, that when the cut value decreases, both the efficiency of the proton separation and the contamination, increase. The value of the cut applied has to be optimized with respect to the specific physics requirements.

It is necessary to emphasize that the TPC tracking information has been included to this analysis, and that the dE/dx information of the TPC may also be combined to the one of the ITS. The low energy tracking possibility, using the ITS only, is under study now and the corresponding ITS dE/dx analysis will be done in the near future.

6. CONCLUSIONS

The simulation of the particle identification dE/dx analysis in the ALICE ITS has been done, and the particle separation power (PID efficiency and contamination) has been obtained for pions, kaons and protons in narrow momentum intervals between 0.05 and 1.03 GeV/c. The total contamination rates did not exceed 2% for kaons (in the range 150÷530 MeV/c), and (4÷6)% for protons (in the range 200÷1030 MeV/c).

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