ELLIPTIC EMISSION OF $K^{\pm}$ and $\pi^{\pm}$ IN 158 A·GeV Pb+Pb COLLISIONS

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Relativistic heavy-ion collisions provide a unique tool for the study of nuclear properties at high temperature and density. The study of collective motion in the final state of the produced hadrons is expected to provide information on both the dynamics of heavy-ion collisions and the equation of state [1].

The azimuthal distribution of particles in the final state relative to the reaction plane is also expected to be sensitive to the in-medium potential of particle species. The measurement of azimuthal distributions of identified particles might differentiate the in-medium potential of each particle. In particular, it is interesting to study the distributions of K^+ and K^- mesons, because the kaon-nucleon potential in nuclear matter is expected to be repulsive for K^+ but attractive for K^- mesons [2, 3, 4].

The reaction plane is determined from the azimuthal direction of the total transverse momentum vector of fragments (p, d, and t) detected by the Plastic Ball detector. The azimuthal angle of the reaction plane, Φ_0 is thus determined as

$$\Phi_0 = \tan^{-1}\left(\frac{\sum_{i=1}^{N} p_{Ti}\sin(\phi_i)}{\sum_{i=1}^{N} p_{Ti}\cos(\phi_i)}\right) , \qquad (1)$$

where the sum runs over all fragments. Here ϕ_i and p_{Ti} are the azimuthal angle in the laboratory coordinate and the transverse momentum of the i-th fragment, respectively.

Recently it has been suggested to analyze azimuthal anisotropies of the particle emission by means of a Fourier expansion [5, 6]. The Fourier coefficients $v_n (n = 1, 2)$ are extracted from the azimuthal distribution of identified particles with respect to the reaction plane;

$$\frac{1}{N}\frac{dN}{d(\phi - \Phi_0)} = 1 + 2v_1'\cos(\phi - \Phi_0) + 2v_2'\cos(2(\phi - \Phi_0)), \qquad (2)$$

where ϕ is the measured azimuthal angle with respect to Φ_0. The Fourier coefficient v_1' quantifies the directed flow, whereas v_2' quantifies the elliptic flow. The coefficient v_2' is negative for an out-of-plane emission and positive for an in-plane emission.

Figure 1 shows the azimuthal distributions of K^+, K^-, π^+, and π^- mesons with respect to the reaction plane for semi-central ($50 < E_T < 250$ GeV in MIRAC) and central ($320 < E_T < 500$ GeV) Pb+Pb collisions. In semi-central collisions, a clear $\cos(2(\phi - \Phi_0))$ component, namely elliptic flow, is visible for all particle types, while in central collisions, the distributions have less structure as expected from the azimuthal symmetry of the collision. For K^- and $\pi^{\pm}$ mesons in semi-central collisions, the azimuthal distributions exhibit maxima at $\phi - \Phi_0 = 0^o$ and $\phi - \Phi_0 = \pm 180^o$, which indicates an enhanced emission in the reaction plane. On the other hand, the K^+ azimuthal distribution in semi-central collisions exhibits maxima at $\phi - \Phi_0 = \pm 90^o$ which clearly demonstrates an enhanced emission out of the reaction plane. The elliptic emission axes of the K^+ and K^- mesons are oriented orthogonally to each other, while those of the π^+ and π^- mesons are both in-plane. To check

for detector effects such as geometrical acceptance and detector efficiency, fake events were created using mixed-events which were then analyzed in the same manner as the real events. The mixed-event results are shown as histograms in Fig. 1. The azimuthal distributions for the mixed-events are flat which indicates that the observed anisotropies are not due to detector effects.

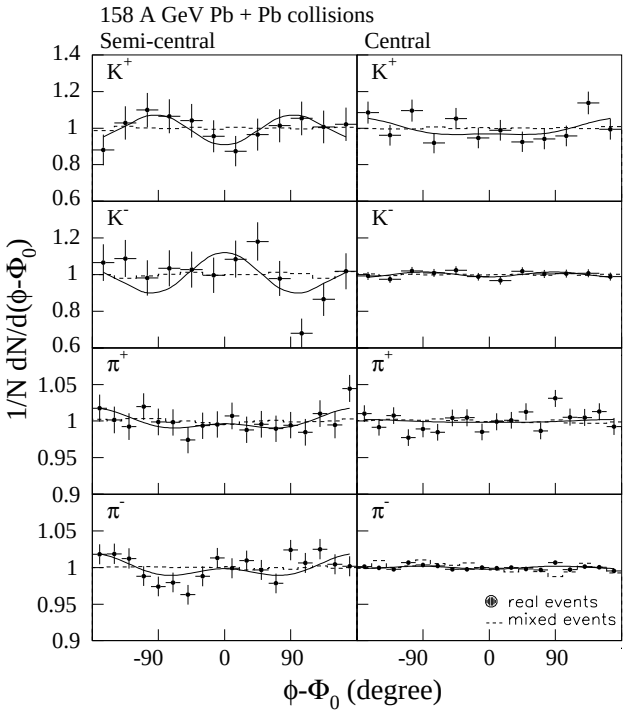

Figure 1: The azimuthal distributions of K^+, K^-, π^+, and π^- mesons with respect to the reaction plane for semi-central and central 158 A·GeV ^{208}Pb+^{208}Pb collisions. The solid curves show the fits using Eq.(2). Solid circles show the results for real events. Dashed histograms show the mixed event results.

The results of the Fourier analysis with Eq.(2) for semi-central collisions are listed in Table 1. The values have been corrected for the reaction plane resolution. As expected, the values of v_1, indicating the strength of the directed flow, are small compared to the statistical errors for all particle types. The disappearance of directed flow at mid-rapidity is expected by symmetry arguments. The value of v_2 for K^+ mesons is negative with a 2σ separation from zero, while the value of v_2 for K^- mesons is positive, but with only a 1σ separation from zero. The values of v_2 for π^+ and π^- mesons are positive and the same within statistical errors.

To compare the present results with other measurements, the v_2 values for protons, pions, and kaons near mid-rapidity are plotted as a function of the beam energy in Fig. 2. For both protons and pions, a transition from out-of-plane to in-plane elliptic flow occurs at around 5-10 A·GeV. At SPS energy, results from NA49 [7] have shown that protons and pions exhibit in-plane elliptic flow near mid-rapidity. Our $\pi^{\pm}$ data agree with the NA49 results

Particle	y	p_T (GeV/c)	v_1	v_2
K^+	2.2 $\sim$ 2.8	0.0 $\sim$ 0.6	-0.024 $\pm$ 0.050	-0.445 $\pm$ 0.221
K^-	1.4 $\sim$ 2.3	0.0 $\sim$ 1.0	0.071 $\pm$ 0.057	0.521 $\pm$ 0.239
π^+	2.4 $\sim$ 3.6	0.0 $\sim$ 1.0	-0.015 $\pm$ 0.009	0.044 $\pm$ 0.037
π^-	2.0 $\sim$ 3.2	0.05 $\sim$ 1.0	-0.015 $\pm$ 0.006	0.054 $\pm$ 0.028

Table 1: Results of the fit with Eq.(2) to the azimuthal distributions of K^+, K^-, π^+, and π^- mesons with respect to the reaction plane for semi-central 158 A·GeV ^{208}Pb+^{208}Pb collisions. The values are integrated over the indicated y and p_T ranges. The v_1 and v_2 values are corrected for the experimental resolution of the reaction plane determination. The statistical fit errors are given.

within errors. The present data for K^- mesons also suggest in-plane elliptic flow. However, the K^+ mesons exhibit out-of-plane elliptic flow similar to observations for 1 A·GeV Au+Au collisions [8]. It is interesting that the magnitude of the v_2 parameter for K^+ mesons is comparable at 1 A·GeV and at 158 A·GeV.

Results of RQMD model calculations (v2.3 cascade mode) [9] filtered with the experimental acceptance are also shown in Figure 2. The RQMD results show in-plane elliptic flow for $K^\pm$, $\pi^\pm$, and protons. The RQMD calculation agrees with the measured results for $\pi^\pm$ and protons, but it fails for K^+ meson completely and seems to predict less than observed K^- elliptic flow. These results suggest that a new ingredient to the calculation such as the in-medium kaon potentials of the K^+ and K^- mesons are required.

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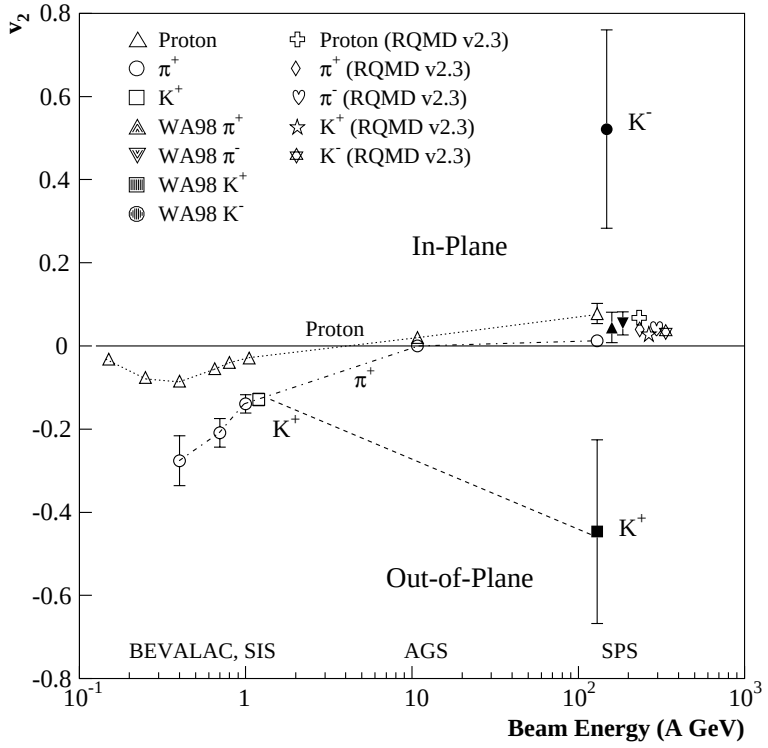

Figure 2: Beam-energy dependence of the v_2 parameter near mid-rapidity. Solid symbols indicate the present data. Note that the region in y, p_T is different for each experiment. The RQMD (v2.3 cascade mode) calculations for proton, $\pi^{\pm}$, and $K^{\pm}$ in 158 A·GeV Pb+Pb collisions are also shown for the impact parameter range $b = 6.5 - 12$ fm with the RQMD results filtered by the experimental acceptance. The data points are shifted horizontally where they would overlap.