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Kaon Spectra from pBe to PbPb Collisions

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Abstract. The yields and inverse slopes of $K^{\pm}$ M_T distributions at central rapidity are presented for pBe, pS, pPb, SS, SPb and PbPb collisions. The ratios of K^-/K^+ and $\bar{p}/p$ decrease with system size and centrality. Comparing the slopes of pions, kaons and protons suggests that transverse flow is present in AA collisions but not in pPb collisions. For PbPb collisions the inverse slopes of the K^- and K^+ M_T spectra are very close but for pPb the inverse slope of K^+ exceeds that of K^-. These results suggest that thermal equilibrium is reached in central heavy ion collisions but not in pPb collisions.

1. Introduction

The nature of Quantum Chromodynamics, QCD, is such that at low energy and baryon density quarks and gluons are confined into hadrons. However the theory also predicts that at sufficiently high energy or baryon density the normal hadrons will lose their identity. A deconfined phase of quarks and gluons, a Quark Gluon Plasma, QGP, will be formed. In such a system strange quarks may reach thermal and chemical equilibrium with the up and down quarks, [1]. The final abundances of hadrons will then simply be determined by the chemical potentials of their constituent quarks and the temperature. In such a picture the invariant cross sections would be exponentials in the transverse mass, $M_T = \sqrt{P_T^2 + M^2}$ where P_T is the transverse momentum and M the mass of the particle. If thermal equilibrium is established particles and antiparticles should have the same slope. In the presence of transverse flow, [2], the inverse slope, T, is related to the thermal temperature

T_0 and the transverse flow velocity β by

$$T = T_0 + 1/2 * \beta^2 * mass. \quad (1)$$

By studying hadron spectra from pBe to PbPb collisions it may be possible to detect the onset of flow and thermal equilibrium.

2. NA44

Experiment NA44 is a focusing spectrometer designed to measure two particle correlations and single particle spectra for heavy ion collisions at central rapidity with a large range of transverse momentum. Superconducting quadrupoles and conventional dipole magnets produce a magnified image of the target on three scintillating hodoscopes, [3]. The positions of a particle on the hodoscopes define its momentum and the flight time its velocity. This allows us to calculate its mass. Two Čerenkov counters aid particle identification. A scintillator near the target allows us to trigger on central interactions. Offline the centrality selection is refined using a silicon pad array. The centrality cut was 9% for SS 11% for SPb. For PbPb we took data at 20% and 5% centrality.

2.1. Inverse Slopes

Within the NA44 acceptance the invariant spectra can be described as exponentials in M_T. The inverse slopes of these distributions are shown in Figure 1. The pp data is from an ISR measurement, [4] at $\sqrt{s} = 31$GeV. The inverse slopes increase markedly from pp to pPb collisions but the inverse slopes do not increase linearly with mass. Thus the pA data show no evidence of flow and the increase of inverse slopes from pBe to pPb is probably due to rescattering. For pPb the difference in inverse slope between K^+ and K^- is 28$\pm$ 3MeV. For $\bar{p}$ and p the difference is 45 $\pm$ 3MeV. These differences may be due to the large annihilation cross section for K^- and $\bar{p}$ with protons which prevents them from gaining a large transverse momentum by multiple collisions with protons. If thermal equilibrium of different quarks is achieved we would expect there to be no difference in the inverse slopes of particles and antiparticles. Thus it seems that in pPb collisions thermal equilibrium is not reached.

For AA collisions the inverse slopes increase linearly with the mass of the particles [5, 6]. This behavior is consistent with transverse flow, [2]. Most of the systematic errors in Figure 1 cancel if we take the ratio of K^-/K^+ without doing any corrections for acceptance. Figure 2 shows that in PbPb collisions K^- and K^+ have a difference in inverse slope of 1$\pm$2 MeV/c at mid rapidity. The ratios for SS and SPb collisions also show no slope difference. It has been suggested that at high baryon density a mean field may be created by the baryons that would repel K^+ and attract K^- and cause a difference in the slopes, [7]. This appears not to be the case at these energies. Such a field seems unlikely to be the cause of the slope

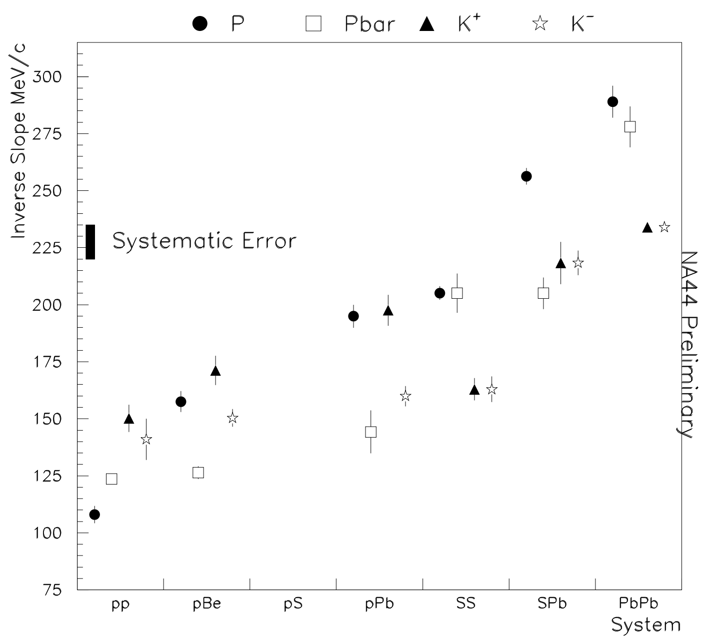

Figure 1: Inverse slopes to exponential fits of M_T spectra for rapidity of 2.4 to 3.5. The fitting range was from $M_T - M = 0.$ to .9 GeV/c for kaons and 0. to .68 GeV/c for protons. The inverse slopes of pions are around 150 MeV/c for all systems. The centrality cut was 5% for PbPb.

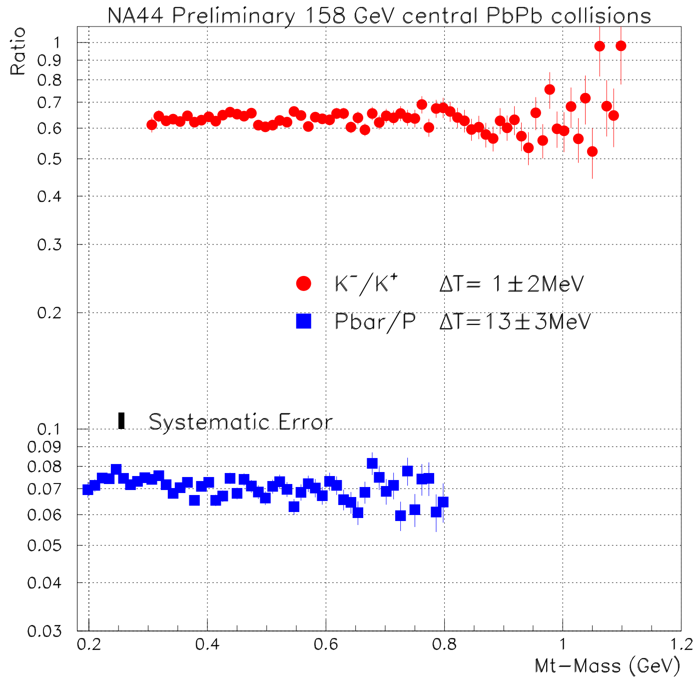

Figure 2: The ratios K^-/K^+ and $\bar{p}/p$ for PbPb collisions. The centrality cut was 20%. Δ T is the difference in inverse slope.

difference for K^+ and K^- from pPb collisions since the baryon density at central rapidity is small in these collisions.

At 14.6 A GeV/c, [8], the inverse slope of K^- is about 20MeV below that of K^+ for SAl and SAu collisions. However the K^-/K^+ ratio is flat for central AuAu collisions at 10.8 A GeV/c , [9], suggesting that thermal equilibrium may be reached for the largest systems even at 10.8 A GeV/c.

The difference in inverse slope between p and $\bar{p}$ is 13 $\pm$ 3MeV/c. This is only 4% of the mean inverse slope of 285 $\pm$ 7MeV. Since antiprotons have such a large annihilation cross section it may be that the ones that survive have suffered fewer collisions on average than the protons, most of which were not produced in the reaction.

3. Particle Yields

We have measured the yield dN/dy of charged kaons by integrating dN/dM_T/dy within our acceptance and using the measured M_T slopes to extrapolate out to

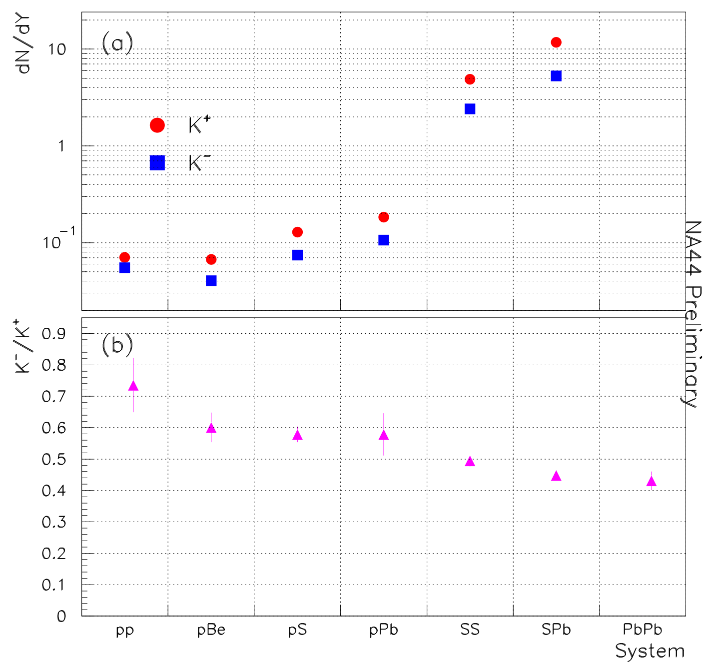

Figure 3: (a) dN/dY of $K^{\pm}$ versus system. The rapidity range was 2.3 to 2.9. The systematic errors are of order 12%. (b) The ratio of K^-/K^+ versus system.The systematic errors are of order 3%. The centrality of the PbPb data is 5%

infinite M_T. This extrapolation is always less than 15%. Figure 3(a) shows the yield of K^+ and K^- versus system. Note the strong rise as one goes to larger systems. Figure 3(b) shows that K^-/K^+ drops as the system get larger. This trend continues as a function of centrality within PbPb collisions. The yields of both K^+ and K^- increase with centrality but K^+ grows more rapidly than K^- and the proton yield grows more rapidly than the antiproton yield. The steady fall of K^-/K^+ with system size may be due to the increased baryon density of the larger systems, see [5, 6]. The extra baryons pushed into the central region make it more difficult to create pairs of $u, \bar{u}$ quarks and thus suppress $\bar{p}$ and K^- production. In the language of chemical equilibrium as the baryon density increases the baryon chemical potential increases. For SAl and SAu collisions at 14.6 A GeV/c, [8], K^-/K^+ is constant as the size of the system increases and is about 1/6, much lower than our data. This is probably due to the higher baryon density at the lower energy.

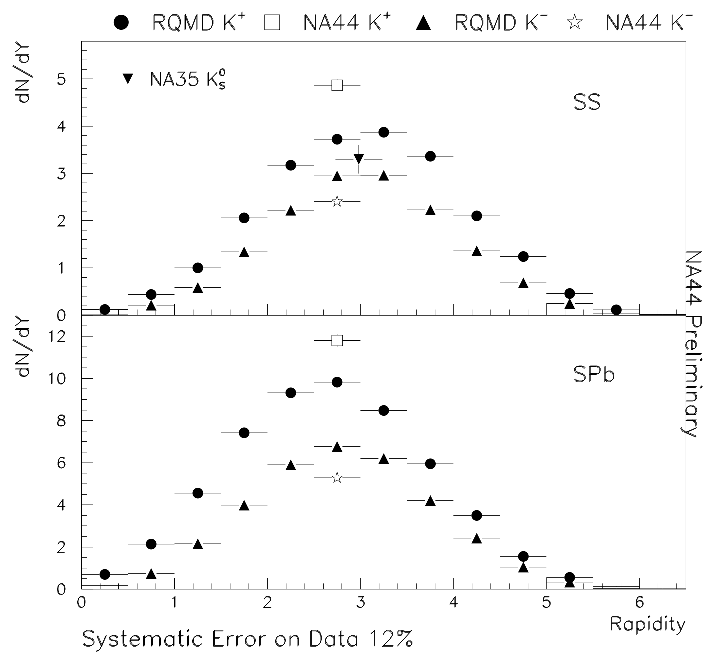

Figure 4: Comparison of charged kaon production to neutral kaons and RQMD.

4. Comparison to RQMD

The RQMD model, version 1.08 [10],[11], is a microscopic phase space approach to hadronic physics. Resonances and QCD strings are excited and fragmented. They may suffer subsequent hadronic collisions. Figure 4 shows a comparison of Kaon yields from NA44 with RQMD for SS and SPb collisions. For SS the NA35 measurement of K^0_S, see [12], is also shown. From isospin conservation this should equal the average of our K^+ and K^- yields. The agreement with NA35 is excellent. RQMD makes a reasonable prediction for the sum of the K^+ and K^- yields but under estimates the K^+ and over estimates the K^- yields for both SS and SPb. This is also true for PbPb collisions, see [6]. Figure 5 compares the M_T dependence of K^-/K^+ of the data and RQMD, for PbPb collisions. While the data is flat RQMD shows an increase of the ratio with M_T implying that the model is further from thermal equilibrium than the data.

5. Conclusions

The ratios K^-/K^+ and $\bar{p}/p$ decrease with system size and centrality. For SS, SPb and PbPb collisions RQMD does not reproduce K^-/K^+ but does a reasonable job predicting the sum of K^- and K^+. For PbPb collisions RQMD predicts that

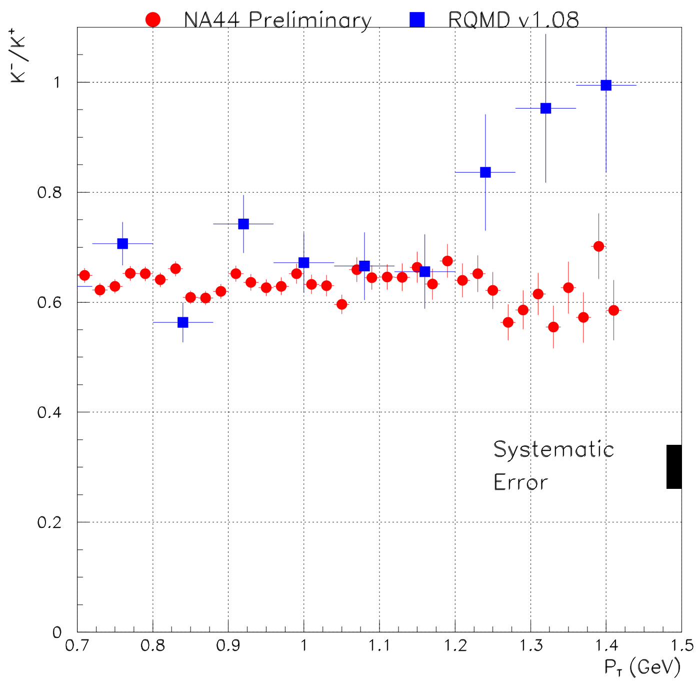

Figure 5: M_T dependence of K^-/K^+ for data and RQMD. The centrality cut was 20% for both data and RQMD.

K^-/K^+ depends on M_T but this is not seen in the data. The inverse slopes of hadrons from central SS, SPb and PbPb scale with mass. This is consistent with flow. No such scaling is seen for pA collisions. For PbPb collisions the inverse slopes of K^- and K^+ differ by 1 ± 2MeV but for pPb difference is 28 ± 3MeV. Our data suggest that thermal equilibrium is reached in central heavy ion collisions but not in pPb collisions.

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