Kaon and Proton Ratios from Central Pb+Pb Collisions at the CERN SPS

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K^-/K^+ and $\bar{p}/p$ ratios measured in 158 A·GeV Pb+Pb collisions are shown as a function of transverse momentum P_T and centrality in top 8.5% central region. Little centrality dependence of the K^-/K^+ and $\bar{p}/p$ ratios is observed. The transverse mass m_T distribution and dN/dy of K^+, K^-, p and $\bar{p}$ around mid-rapidity are obtained. The temperature T_{ch} and the chemical potentials for both light and strange quarks (μ_q, μ_s) at chemical freeze-out are determined by applying simple thermodynamical model to the present data. The resultant μ_q, μ_s and T_{ch} are compared with those obtained from similar analysis of SPS S+A and AGS Si+A data. The chemical freeze-out temperature T_{ch} at CERN energies is higher than thermal freeze-out temperature T_{fo} which is extracted from m_T distribution of charged hadrons. At AGS energies T_{ch} is close to T_{fo}.

1. INTRODUCTION

Studies of particle ratios address the nature of high energy/baryon density states formed in ultra relativistic heavy ion collisions. In the collisions, the energetic beam makes the hot and dense collision complex. Lots of hadrons are created and a huge number of collisions occurs many of these produce strangeness. Therefore, thermo-chemical model seems adequate to describe the system. After the high density era, the system expands and it becomes out of equilibrium. In this situation, we can discuss thermodynamical quantities at the time of chemical and thermal freeze-out from the particle ratios and transverse momentum spectra. In SPS and AGS experiments, the transverse mass distributions of hadrons suggest that there are local thermal equilibrium state and some indications of transverse flow.

2. NA44 EXPERIMENT

The NA44 focusing spectrometer is designed to measure one and two particle momentum distribution of charged hadrons around mid rapidity. The TOF resolution is 100ps. Particle identification is done by TOF and two different threshold Cherenkov counters. Momentum resolution $\delta p/p$ is about 0.5% and the centrality is measured by multiplicity counters behind the target. Details about the spectrometer can be found in Ref. [1].

3. PARTICLE RATIOS AND THERMODYNAMICAL ANALYSES

3.1. Kaon and proton distributions around mid-rapidity

Fig. 1 shows K^-/K^+ and $\bar{p}/p$ ratios as a function of centrality and P_T. The centrality of event is defined by pulse height of the multiplicity counter which is proportional to number of relativistic particles in forward direction. We select three groups of highly central events; the most central 3.5%, 3.5-6.0% and 6.0-8.5%. The particle ratios both K^-/K^+ and $\bar{p}/p$ vary weakly in the three groups. The m_T distributions of K^+, K^-, p and $\bar{p}$ in the top 8.5% central region are shown in Fig. 2. The line in the figures is fit of a single exponential function: $A\exp(m_T/T)$, where T is the slope parameter. The values of T and dN/dy derived from integration of the fit function are in Table 1.

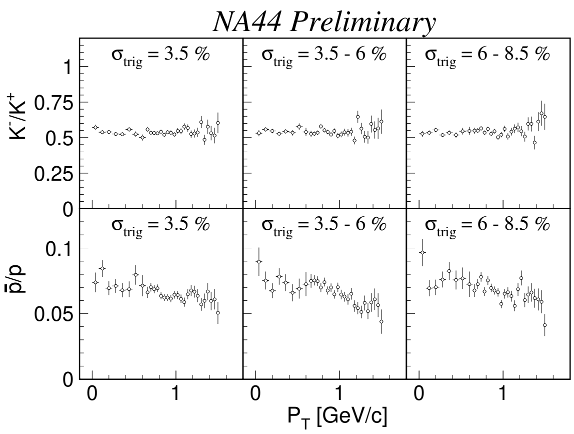

Figure 1. K^-/K^+ and $\bar{p}/p$ ratio as a function of P_T and centrality.

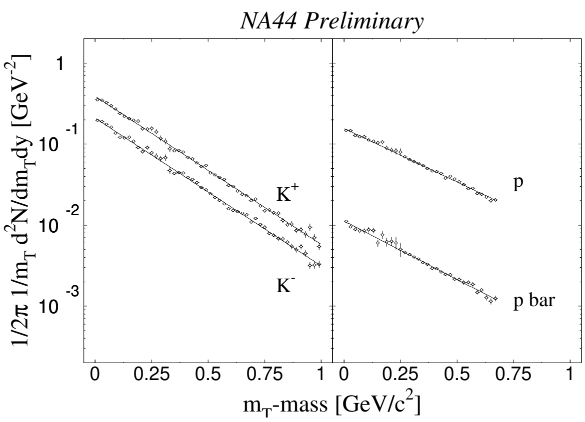

Figure 2. m_T distribution of K^+, K^-, p and $\bar{p}$. The vertical axis is absolute cross section.

Table 1
The slope parameter and dN/dy. The systematic errors are less than 4% for slope parameter and less than 20% for dN/dy. The values with correction of Λ and Σ^+ decay effect for proton yield are shown in the bracket. The systematic errors in the bracket are from the correction factor only.

	slope parameter[MeV]		dN/dy		y
K^+	237 ± 3		21.3 ± 0.8		2.4-3.5
K^-	238 ± 3		11.5 ± 0.4		
p	303 ± 6	$(331 \pm 10 \pm 11)$	25.3 ± 1.0	$(20.1 \pm 1.2 \pm 1.3)$	2.3-2.9
$\bar{p}$	281 ± 8	$(316 \pm 13 \pm 15)$	1.64 ± 0.09	$(1.11 \pm 0.19 \pm 0.11)$	

It is noted that particle identification is made about 20 m downstream from target. Thus, observed particle yield should be corrected to take into account decays of unstable particles. We estimate the effect of Λ and Σ^+ decays to proton yield by a Monte Carlo simulation. The inputs of simulation are parameterised dN/dy and m_T slopes distributions by RQMD (V1.08) and experimental results from Ref. [2]. The values with correction of Λ and Σ^+ decay effect are shown in the bracket on the Table 1. To estimate the systematic error, the ratio $(\Lambda+\Sigma^+)/p$ were increasied and decreased by a factor 1.5.

3.2. Strangeness neutral hadron gas model

A system in chemical equilibrium is described by temperature and chemical potentials. Here, we analyse the present data by a thermo-chemical model of Ref. [3](Strangeness neutral model). It considers chemical equilibrium between strange and antistrange hadrons under a condition of zero net strange charge. The model assumes full chemical equilibrium for u and d quarks. On the other hand, there is strangeness saturation factor γ_s; $\gamma_s = 1$ means full chemical equilibrium for s quark. In this model, we assume hadron gas including well-established higher mass resonances up to 2.0 GeV.

3.3. μ_q, μ_s and T_{ch} at the chemical freeze-out

We determined chemical potentials, temperature and γ_s at the chemical freeze-out in the following way. μ_s is given as a function of μ_q and T_{ch} for different γ_s from the model. The ratios from K^+, K^-, p and $\bar{p}$ are re-described by μ_q, μ_s, T_{ch} and γ_s. Since net strange charge is zero, three of the four parameters μ_q, μ_s, T_{ch} and γ_s are independent. For the ratios, χ^2 map for various μ_q, T_{ch} and γ_s is made. As a region of χ^2 minimum + 1, T_{ch} is obtained as $155 \sim 170$ MeV, $\mu_q = 75 \sim 85$ MeV, $\mu_s = 22 \sim 31$ MeV and $\gamma_s = 0.75 \sim 0.95$.

Fig. 3 (a) shows a compilation of results for μ_q and T_{ch} at SPS and AGS energies including those of different combinations of projectile and target. As seen in the Fig. 3 (a), the T_{ch} at SPS energies is higher than at AGS energies, whereas μ_q at SPS energies is lower than at AGS energies. This is consistent with higher baryon stopping at AGS energies. Fig. 3 (b) show μ_s. It is 3~40 MeV at SPS energies, while 60~120 MeV at AGS energies.

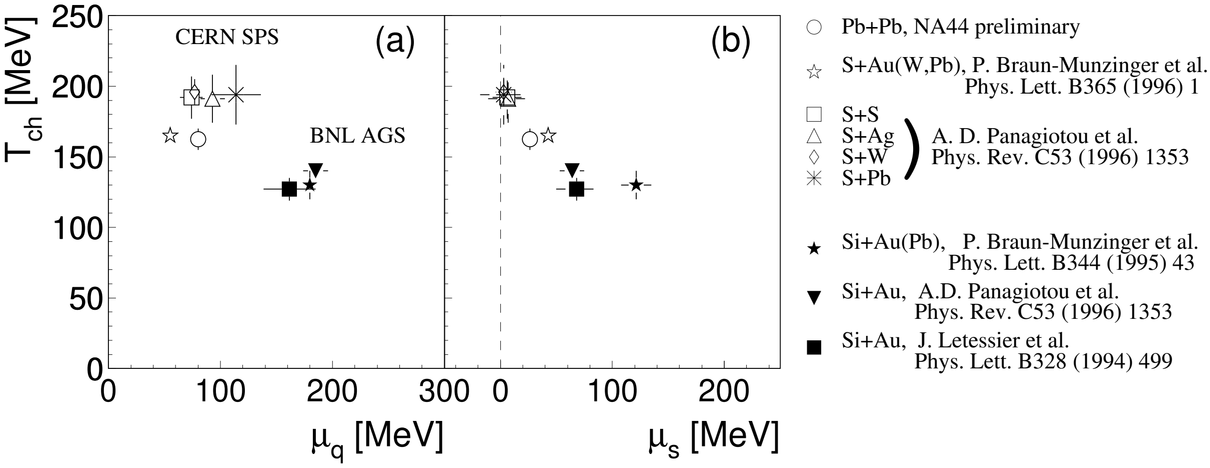

Figure 3. Various μ_q, μ_s and T_{ch} in heavy ion collisions at the SPS energies and the AGS energies. The points for S+A and for Si+A are referred from Ref.s [6-9].

In this compilation, dependence of μ_q, μ_s and T_{ch} on collision system is less clear than $\sqrt{s}$ dependence, since variation between different analysis is not negligible.

The thermal equilibrium temperature T_{fo} is independent of the collision system at AGS and SPS energy region and seems to saturate form AGS energies. The saturation temperature is about 145 MeV[4]. The T_{ch} is higher than T_{fo} at SPS energies. On the other hand, T_{fo} at AGS energies T_{ch} is close to T_{fo}.

4. SUMMARY

We report K^-/K^+ and $\bar{p}/p$ ratios of Pb+Pb central collisions at SPS energies as a function of P_T and centrality. We observe little centrality dependence in either kaons and protons ratios in the top 8.5% central region. The m_T distribution and dN/dy of K^+, K^-, p and $\bar{p}$ around mid-rapidity are shown. The inverse slope parameters of K^+ and K^- are the same within errors. On the other hand, the inverse slope parameter of $\bar{p}$ is smaller than one of p. Assuming the system around mid-rapidity is in chemical equilibrium, from ratios of K^+, K^-, p and $\bar{p}$, the chemical freeze-out temperature is found to be $T_{ch} = 155 \sim 170$ MeV, the chemical potential of light and strange quark was calculated to be: $\mu_q = 75 \sim 85$ MeV and $\mu_s = 22 \sim 31$ MeV, $\gamma_s = 0.75 \sim 0.95$, respectively. The chemical freeze-out temperature is larger than the freeze-out temperature. Those results are quite natural with the view point of thermodynamics.

We compile the value of μ_q, μ_s and T_{ch} in heavy ion collisions at SPS and AGS energies. The general trend is that μ_q and μ_s (T_{ch}) at SPS energies is lower (higher) than at AGS energies. The T_{ch} is larger than T_{fo} in S+A and Pb+Pb collisions at SPS energies. At AGS energies, both temperatures are close to each other.

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