Romanian Reports in Physics, Vol. 58, No. 1, P. 19–24, 2006

EFFECT OF RESONANCE DECAYS ON EXTRACTED KINETIC FREEZE-OUT PARAMETERS IN HEAVY ION COLLISIONS AT RHIC

LEVENTE MOLNAR, OLGA BARANNIKOVA, FUQIANG WANG

Purdue University, West Lafayette, USA

(Received November 15, 2005)

Abstract. Statistical model fit to particle ratios in Au+Au collisions at RHIC suggests chemical freeze-out near phase transition boundary. Model interpretations of evolution from chemical to kinetic freeze-out vary. Results of the blast-wave fit to the STAR experimental data, where resonance contributions are not accounted for, suggest significant cooling and expansion between the freeze-outs for central Au+Au collisions. Other models including resonances, argue for instant single freeze-out with temperature close to the phase transition temperature. By combined thermal and blast-wave model parametrization including resonances, we systematically investigate the effect of resonance decays on the extracted kinetic freeze-out parameters.

Key words: particle ratios, statistical model, resonance decays, freeze-out parameter, phase transition.

1. INTRODUCTION

Freeze-out properties are extensively studied in heavy ion collisions from SIS to RHIC energies. Chemical freeze-out conditions are extracted from particle ratios within the thermal models [1,2]; kinetic freeze-out properties are extracted from transverse momentum (p_T) spectra of bulk particles ($\pi^{\pm}$, $K^{\pm}$, $\overline{p}$ and p) within the blast-wave model [3]. A long standing question is how resonance decay contributions to the bulk particle spectra affect the extracted values of kinetic freeze-out properties. We present a systematic study on the effect of resonance decays without imposing the restriction of simultaneous chemical and kinetic freeze-out. We utilize the identified particle spectra measured by STAR at low transverse momenta and mid-rapidity in the 5% most central Au+Au collisions at 200 GeV [4].

2. MODEL DESCRIPTION

The study is based on the thermal freeze-out model by Wiedemann and Heinz [5]. Several changes are implemented with respect to the original code to provide the same basis for the calculation as in data [4]. The model [5] calculates the relative particle abundances and p_T spectra of thermal particles and decay products from resonances assuming the same freeze-out temperature. We allow different temperatures for chemical and kinetic freeze-out. We use the chemical freeze-out models [1, 2] to fit the measured particle ratios [4] and extract the chemical freeze-out parameters: chemical freeze-out temperature $T_{ch} = 160$ MeV, baryon chemical potential $\mu_B = 22$ MeV, strangeness chemical potential $\mu_S = 1.4$ MeV, and the strangeness suppression factor $\gamma_S = 0.98$. These parameters determine the relative proportions of particles and resonances which are fixed in the subsequent calculations. More resonance particles are included in our study: ρ, ω, η, η′, K^{*0}, $K^{*\pm}$, ϕ and Λ, Δ, Σ, Ξ, Λ_{1520}, Σ_{1385}, Ω. The box flow profile is chosen, similarly to [4]: $\beta = \beta_S (r/R)^n$, where n is fixed to be 0.82 as found in [4]. Flat rapidity distribution is implemented at mid-rapidity.

The p_T spectra of resonance particles are calculated and combined with primordial ones. Spin, isospin degeneracies and decay branching ratios are properly taken into account. Measured $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra are then fitted by the obtained p_T distributions to extract kinetic freeze-out temperature (T_{kin}) and average transverse flow velocity ($\langle\beta\rangle$).

3. FIT RESULTS

The fit results of π^-, K^- and $\bar{p}$ are shown in Fig. 1 (top left panel) together with the measured data [4]. Fits are performed to the six measured spectra simultaneously. Fig. 1 also shows the data/calculation ratios. For comparison blast-wave fits without resonances are shown in black. Table 1 lists the extracted parameters and χ^2/NDF values. Both fits (including and excluding resonances) can described the measured data well.

The χ^2/NDF values, 0.37–0.60, are smaller than unity because we included in the fit the point-to-point systematic errors (dominate over statistical ones), which may be partially correlated. If we scale the χ^2/NDF such that the minimum is unity, then we get somewhat smaller statistical errors on the fit parameters. We also fit the measured spectra with a single, fixed kinetic freeze-out temperature $T_{kin} = T_{ch} = 160$ MeV including resonances. The fitted $\langle\beta\rangle$ is ~ 0.520 with $\chi^2/NDF \approx 20$. A single temperature scenario is thereforehighly disfavored by data.

Fig. 2 shows the various resonance contribution, labeled by the initial resonance particle (*e.g.* a π emerging from the $\eta' \to \eta \to \pi$ decays is labeled as $\pi_{\eta'}$).

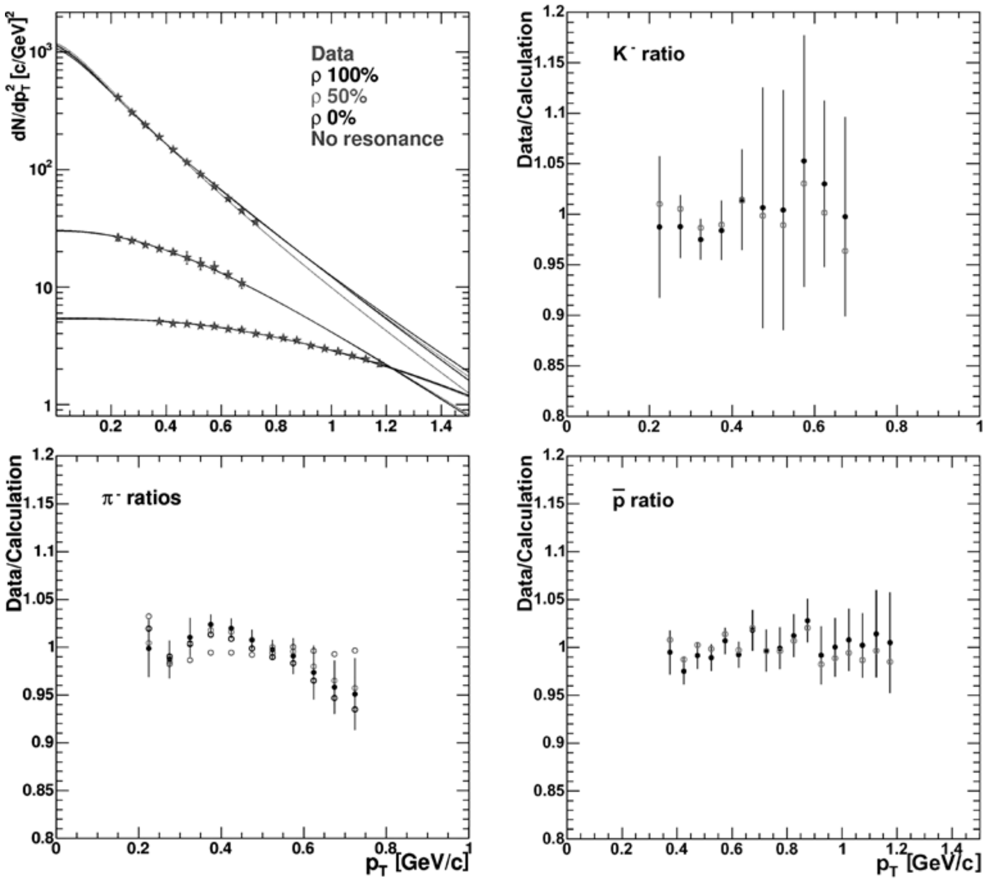

Fig. 1 – Top left panel: Fit of the calculated spectra to the measured ones in top 5% central Au+Au collisions at 200 GeV [4]. Four calculated spectra are shown for π^- (upper curves): including resonances with three different ρ contributions and excluding resonances. Only two calculated curves are shown for K^- (middle curves) and $\bar{p}$ (lower curves): including resonances with 100% ρ contribution and excluding resonances. Other panels: data / calculation ratios. Error bars are from statistical and point-to-point systematic errors on the data, and are shown for only one set of the data points.

The calculated inclusive pion spectra include contributions from Λ_{1520} which are not plotted in Fig. 2 and do not contain weak decay pions, similarly to [4]. The right panels of Fig. 2 show the resonance contributions to the inclusive spectra relative to the primordial one. The inclusive kaon and antiproton spectra do not show significant changes in the spectral shapes compared to the primordial ones. Although the shape of the inclusive π spectrum is affected by light meson contributions (ρ, ω and η) at low and high p_T, the effect in the STAR measured p_T range is not significant. This is the primary reason why the blast-wave model, both including and excluding resonances, can describe the measured data well.

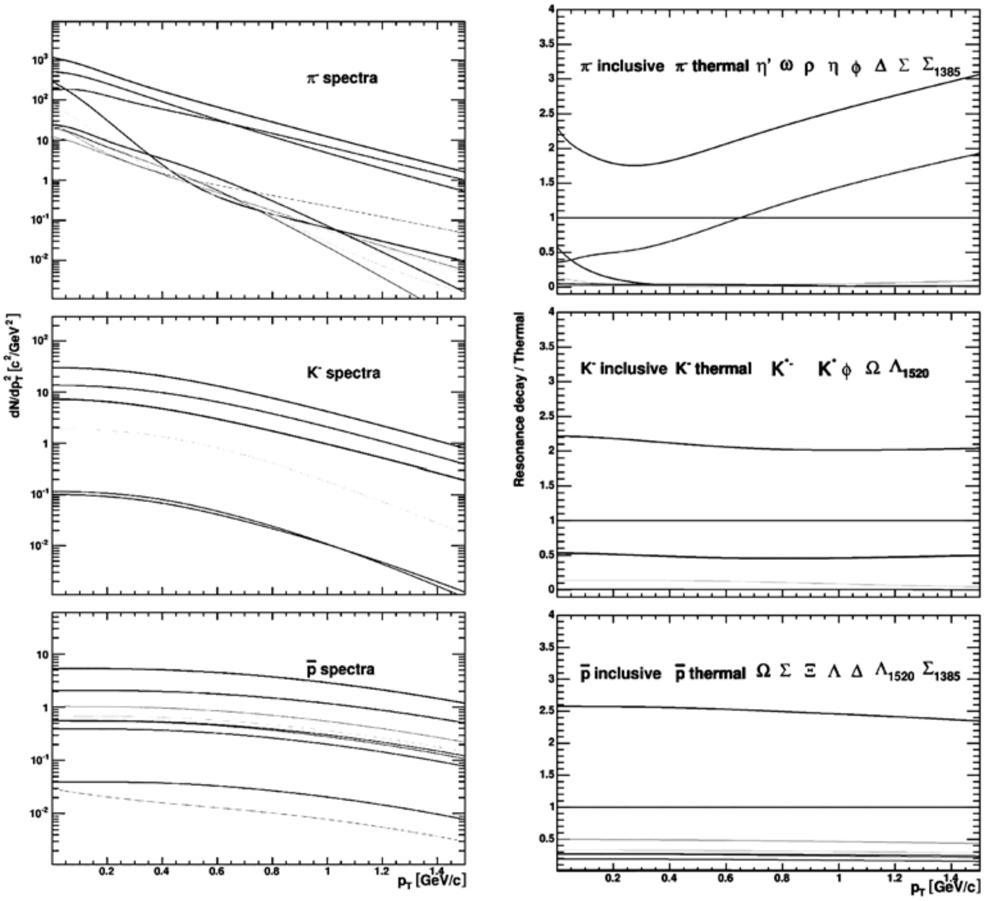

Fig. 2 – Left panels: Calculated particle spectra (π^-, K^- and $\overline{p}$) including thermal and resonance contributions. Right panels: Resonance contributions relative to the thermal spectrum.

4. SHORT LIVED RESONANCES

In the above results we have assumed that short lived resonances have the final kinetic freeze-out temperature and velocity, given by the blast-wave parameterization, and then decay. However, it is an open question what flow velocity and temperature should be assigned to the short lived resonances, such as ρ and Δ, because these resonances decay with short lifetimes and are expected to be constantly regenerated during the system evolution. Processes of $\rho \to \pi\pi$ and $\pi\pi \to \rho$, for example, constantly occur during the dynamical evolution of the system. Thus, it is reasonable to expect that the final ρ decay pions carry the same flow information as the primordial pions do. The regenerated ρ gains negligible flow velocity during its short life span except the inherited flow from the two resonant pions.

We studied three cases for the ρ:

Case I (100% ρ) ρ acquires flow as given by kinetic freeze-out temperature and transverse flow velocity, and the decay pions are calculated from decay kinematics. This case gives the largest flow effect because of the large ρ mass. This is the default case for resonances as discussed above.

Case II (0% ρ) ρ decay pions have the same p_T spectral shape as the primordial pions.

Case III (50% ρ) Half of the ρ contribution is taken like in (I) and the other half as in (II).

Table 1 shows the fit results for the three cases (together with results without including resonances). The pion spectra from the three cases are compared to data in Fig. 1. The model describes data well in the measured p_T range with all the three cases of ρ.

Table 1

Extracted kinetic freeze-out parameters and fit χ^2/NDF. The flow profile is $\beta = \beta_S(r/R)^n$, where the n parameter is fixed to 0.82. See text for the description of the different resonance cases. The fit errors are obtained with the point-to-point errors included in the spectra fit.

Set	T_{kin} [MeV]	$\langle\beta\rangle$	χ^2/ndf
No resonances	$86.8^{+0.7}_{-0.6}$	$0.595^{+0.002}_{-0.003}$	0.26
Resonances Case I.	$94.6^{+0.9}_{-1.0}$	$0.603^{+0.004}_{-0.002}$	0.37
Resonances Case II.	$87.4^{+0.9}_{-1.1}$	$0.605^{+0.002}_{-0.002}$	0.45
Resonances Case III.	$77.2^{+0.8}_{-0.9}$	$0.604^{+0.004}_{-0.003}$	0.60

Fit results are found to be less sensitive to the kinetic freeze-out temperature than the flow velocity. Fitted T_{kin} and β values with all three cases of ρ contributions agree with that obtained without including resonances within systematic error of ± 10 MeV [4]. In other words, resonance decays appear to have no significant effect on the extracted kinetic freeze-out parameters. This is primarily due to the limited p_T ranges of the data, where resonance decay products have spectral shapes similar to those of primordial particles, as mentioned above.

5. CONCLUSIONS

We carried out a rigorous study of resonance decay effect on the extracted kinetic freeze-out parameters by a combined chemical and kinetic freeze-out model. Resonance decays appear to have no significant effect on the extracted parameters in the investigated transverse momentum range. Different evolution scenarios are also considered for short lived resonances such as ρ; the extracted parameters agree with those obtained without including resonance decays within systematic uncertainties. Single freeze-out temperature scenario fit cannot describe data in our model calculation.

REFERENCES

1. P. Braun-Munzinger, I. Heppe and J. Stachel, Phys. Lett. B **465**, 15 (1999).
2. N. Xu and M. Kaneta, Nucl. Phys. A **698**, 306 (2002).
3. E. Schnedermann, J. Sollfrank and U. W. Heinz, Phys. Rev. C **48**, 2462 (1993).
4. J. Adams *et al.* (STAR Collaboration), Phys. Rev. Lett. **92**, 112301 (2004).
5. U. A. Wiedemann and U. W. Heinz, Phys. Rev. C **56**, 3265 (1997).