Strange Resonance Production in p+p and Au+Au Collisions at RHIC Energies

Christina Markert † for the STAR collaboration ‡
† Physics Department, Yale University, New Haven, CT 06520, USA
‡ For the full author list and acknowledgements see Appendix "Collaborations" in this volume.

Abstract. Resonance yields and spectra from elementary p+p and Au+Au collisions at √sNN = 200 GeV from the STAR experiment at RHIC are presented and discussed in terms of chemical and thermal freeze-out conditions. Thermal models do not adequately describe the yields of the resonance production in central Au+Au collisions. The approach to include elastic hadronic interactions between chemical freeze-out and thermal freeze-out suggests a time of Δτ >5 fm/c.

1. Introduction

Short-lived resonances and their decay products may interact strongly with the hadrons from the fireball medium from the time of chemical freeze-out until the system breaks up at kinetic freeze-out. In order to try to understand the evolution and expansion of this hot and dense medium we compare particle resonance yields and spectra from elementary p+p and heavy ion collisions. The observed decrease of the strange resonance to non-resonance particle ratio in Au+Au collisions compared to p+p collisions suggests that medium effects are indeed present in heavy ion collisions. These ratios, along with a knowledge of the resonance lifetime and interaction cross-sections, allow us to place limits on the chemical freeze-out temperature and the duration of the hadronic interactions in these collisions.

2. Data Analysis

The K(892), Σ(1385) and Λ(1520) resonances are reconstructed by measuring their decay daughters with the STAR Time Projection Chamber (TPC). Charged decay particles are identified via energy loss (dE/dx) and their measured momenta (K(892)→K + π and Λ(1520)→p + K). The neutral strong decays such as Λs from a Σ(1385) decay are reconstructed via topological analysis (Λ(→p+π) + π). The resonance signal is obtained by the invariant mass reconstruction of each daughter combination and subtraction of the combinatorial background calculated by mixed event or like-sign techniques (figure1). The resonance ratios, spectra and yields are measured at mid-rapidity. The central trigger selection for Au+Au collisions takes the 5% of most central inelastic interactions. The setup for the proton+proton interaction is a minimum bias trigger.
3. Strange Resonances in p+p Collisions at $\sqrt{s_{NN}} = 200$ GeV

The integrated invariant mass spectrum at mid-rapidity in p+p collisions after background subtraction are shown in figure 1 for $\Lambda(1520)$ and $\Sigma(1385)^{+/-}$ [2]. The mass and width are in agreement with the values from the PDG [3], once the expected contributions of the momentum resolution and detector acceptance are included.

![Invariant mass spectrum](image)

**Figure 1.** Invariant mass distributions in p+p collisions at $\sqrt{s_{NN}} = 200$ GeV after mixed-event background subtraction for $\Lambda(1520) \rightarrow p + K^-$ (left panel) and $\Sigma(1385) \rightarrow \Lambda + \pi$ (right panel). The $\Xi$ and the $\Sigma(1385)$ share the same decay channel. Hence we also observe a strong $\Xi$ peak in the $\Lambda + \pi$ decay channel.

The transverse momentum distributions of $K(892)$ [4], $\Sigma(1385)$ [2] and $\Lambda(1520)$ from p+p collisions are shown in figure 2. The inverse slope parameter, $T$, and the mean transverse momentum, $\langle p_T \rangle$, are obtained by an exponential fit (see table below). The transverse momentum coverage for the resonance yields is approximately 80-95%. The mean transverse momentum as a function of mass in figure 3 (left panel) shows a mass dependence for stable (circles) and resonance (squares) particles. A fit to the ISR data shown by the curve includes $\pi$, $K$ and $p$ from p+p collisions at $\sqrt{s_{NN}} = 26$ GeV [5] and predicts a much less pronounced mass dependence in good agreement with the $\pi$, $K$ and $p$ data from $\sqrt{s_{NN}} = 200$ GeV. The resonances with mass higher than 1 GeV/$c^2$ and the $\Xi$ indicate a stronger $\langle p_T \rangle$ dependence which is not represented by the fit to the ISR data.

| Particle     | $T$ [MeV] | $\langle p_T \rangle$ [GeV] |
|--------------|-----------|----------------------------|
| $K(892)^0$   | 223 ± 9   | 0.68 ± 0.03 ± 0.03          |
| $\Sigma(1385)$ | 380 ± 50  | 1.10± 0.02 ± 0.01           |
| $\Lambda(1520)$ | 345 ± 42  | 1.08 ± 0.09± 0.11           |

**Table 1.** $T$ and $\langle p_T \rangle$ for resonances in p+p interactions.

4. Strange Resonances in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV

For a comparison of resonance production in different collision systems, the resonances are divided by non-resonance particle yields to eliminate the need for a volume and energy normalization. Figure 3 right shows the different resonance to stable particle ratios for p+p and Au+Au collisions as a function of the mid-rapidity charged particle
Figure 2. $p_T$ distributions for $K(892)$, $\Sigma(1385)$ and $\Lambda(1520)$ for $p+p$ collisions. The errors for $K(892)$ and $\Lambda(1520)$ are statistical errors only for the $\Sigma(1385)$, the systematic errors are included. The systematic errors are 10-15%.

Figure 3. Left: $\langle p_T \rangle$ as a function of particle mass in $p+p$ collisions at $\sqrt{s_{NN}}=200$ GeV. The black curve is a fit to measured ISR $p+p$ data ($\pi$, K and p) at a collision energy of $\sqrt{s_{NN}}=26$ GeV [5]. Right: Resonance/non-resonance ratios of $\phi/K^-$, $\Delta^{++}/p$, $\rho/\pi$, $K(892)/K^-$ and $\Lambda(1520)/\Lambda$ for $p+p$ and Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV. The ratios are normalized to the $K^*(892)/K^-$ $p+p$ ratio. Statistical and systematic errors are included.

yields $N_{\text{charge}}$. All the ratios are normalized such that their $p+p$ ratio equals that of the $K(892)/K^-$ $p+p$ value. The $K(892)/K^-$ and $\Lambda(1520)/\Lambda$ ratios decreases from $p+p$ to Au+Au collision systems. This behavior shows that the resonance production in Au+Au is not a simple superposition of $p+p$ interactions. It is also an indication that the surrounding extended medium of a Au+Au collision has an influence on the resonances and/or their decay particles. The thermal model is able to fit the ratios of the stable particles [10]. The results from these fits predicts $\Lambda(1520)/\Lambda = 0.07$ and $K(892)/K^- = 0.32$ at a chemical freeze-out temperature of $T=170$ MeV. The measured value for central Au+Au collisions at mid-rapidity are $\Lambda(1520)/\Lambda = 0.034 \pm 0.011 \pm 0.013$ and $K(892)/K^- = 0.19 \pm 0.05$, significantly lower than the thermal model predictions. A thermal description of these measured ratios would lead to a 30-50 MeV smaller chemical freeze-out temperature.
5. Time Scale for Au+Au collisions

In-medium effects such as elastic interactions of the decay particles with other particles in the created medium (mostly pions) may result in a signal loss. Regeneration will have the reverse effect. Microscopic model calculations (UrQMD [11, 12]) predict $\Lambda(1520)/\Lambda = 0.03$ and $K(892)/K^- = 0.25$ (lifetime: $\tau_{K(892)} = 4$ fm/c and $\tau_{\Lambda(1520)} = 13$ fm/c). Meanwhile the UrQMD calculation for $\Delta^{++}/p = 0.28$ is compatible with the data, $\Delta^{++}/p = 0.240 \pm 0.037$. Since the $\Delta^{++}/p$ ratio in Au+Au is nearly the same as it is for p+p collisions, either the regeneration of the signal is of the same order as the rescattering or there is no rescattering. The $\Delta^{++}$ has a short lifetime of 1.3 fm/c therefore the rescattering of the decay daughters is expected to be large. Due to the long life-time of the $\phi$ resonance (44 fm/c) we would expect no significant signal loss by rescattering of the daughters since most of the decays happen outside of the fireball, which is in agreement with our observation. Using the measured values of $K(892)/K$ and $\Lambda(1520)/\Lambda$ a thermal model, including rescattering, but no regeneration, predicts the lifetime interval between chemical and kinetic freeze-out to be $>5$ fm/c. [15] [14]. The decrease of the $\Lambda(1520)/\Lambda$ and $K(892)/K^-$ ratio from p+p to Au+Au collisions occurs already for very peripheral collisions (50-80%) and remains nearly constant up to the most central collisions (5%). In terms of the lifetime of the system between chemical and thermal freeze-out, $\Delta\tau$, these result suggests the same $\Delta\tau$ for peripheral and central Au+Au collisions.

6. Conclusions

Resonances are a unique tool to probe the time span $\Delta\tau$ between chemical and thermal freeze-out in heavy ion collisions. The measured $\Lambda(1520)/\Lambda$ and $K(892)/K^-$ together with a thermal model and rescattering suggest a lower limit of $\Delta\tau >5$ fm/c. Furthermore, the high mass particles show a stronger mass dependence of $\langle p_T \rangle$ in p+p collisions than predicted from the stable particles below 1 GeV.

REFERENCES

[1] L. Gaudichet et al., J.Phys. G30 (2004) 549.
[2] S. Salur et al., nucl-ex/0403009.
[3] Particle Data Group, Eur. Phys. J. C3 (1998).
[4] H. Zhang at al., J.Phys. G30 (2004) 577.
[5] M. Bourquin and J.-M. Gaillard, Nucl. Phys. B114 (1976) 334.
[6] J. Ma et al., J.Phys. G30 (2004) 543.
[7] H. Zhang et al., nucl-ex/0403010.
[8] P. Fachini et al., J.Phys. G30 (2004) 565.
[9] C. Markert et al., Proc. 19th Winter Workshop on Nuclear Dynamics (2003) 71.
[10] P. Braun-Munzinger, D.Magestro, K. Redlich and J.Stachel, Phys. Lett. B518 (2001) 41.
[11] M. Bleicher and J. Aichelin, Phys. Lett. B530 (2002) 81, hep-ph/0201123.
[12] M. Bleicher and H. Stöcker, J.Phys. G30 (2004) 111, private communication.
[13] J. Ma et al., J.Phys. G30 (2004) 543.
[14] C. Markert, G. Torrieri, J. Rafelski, Campos do Jordao 2002, New states of matter in hadronic interactions 533, hep-ph/0206200.
[15] G. Torrieri and J. Rafelski, Phys. Lett. B509 (2001) 239-245, J.Phys. G28 (2002) 1911-1920.