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Resonance production in heavy ion collisions

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Abstract Resonances and their decay products may interact strongly with the hadrons in the fireball medium from the time of chemical freeze-out until the system breaks up at kinetic freeze-out. In order to try to further our understanding of the evolution and expansion of this hot and dense medium we compare resonance particle yields and spectra from elementary p+p and heavy ion collisions.

Key words resonance • strangeness • baryon • freeze-out • lifetime • fireball

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Introduction

Resonances are produced in heavy ion collisions. A fraction of them decay due to their short lifetimes inside the fireball medium. In addition, pseudo elastic interactions can rescatter the decay products and the resonances or regenerate the resonances. Two freeze-out conditions of the fireball expansion can be characterized by the end of inelastic interactions (chemical freeze-out) and the end of elastic interactions (kinetic freeze-out). Thermal models are successful in describing the production yield of stable particles with one temperature at chemical freeze-out. To make a statement about thermally produced resonances we have to take into account the elastic interactions that occur between the time of chemical freeze-out and kinetic freeze-out. Some yield changes may take place due to rescattering of the decay daughters causing a loss of signal in the invariant mass reconstruction. The regeneration of resonances will have the opposite effect. The rescattering of the resonances may change their momentum distribution. For stable particles elastic interactions do not change their yields. If the time between chemical and thermal freeze-out is very short, the contribution of rescattering of decay daughters and regeneration of resonances is also small. Elastic interactions with the resonances and regeneration can change their phase space distribution, for example, the transverse momentum distribution. The time between chemical and thermal freeze out can be verified by comparing yields of resonances with different lifetimes. Transport model calculations may be able to describe medium effects at a microscopic level [1]. These calculations have only been developed recently, since heavy ion experiments are capable of measuring resonances with short lifetimes. The early signal can be changed during the expansion of the fireball source, when inelastic and elastic interactions may have an additional effect on the masses and widths of the resonances.

Table 1. Resonances from PDG [11].

Particle	Mass (MeV/c^2)	Width (MeV/c^2)	Lifetime (fm/c)	Decay channel
$K(892)^0$	896.1 ± 0.27	50.7 ± 0.6	3.89	$K + \pi$
$\Sigma(1385)^+$	1382.8 ± 0.4	35.8 ± 0.8	5.5	$\Lambda(\to p+\pi) + \pi^+$
$\Sigma(1385)^-$	1387.2 ± 0.5	39.4 ± 2.1	5.0	$\Lambda(\to p+\pi) + \pi^-$
$\Lambda(1520)$	1519.5 ± 1.0	15.6 ± 1.0	12.6	$p + K$
$\Xi(1530)^0$	1535.0 ± 0.6	9.9 ± 1.9	19.9	$\Xi(\to\Lambda+\pi) + \pi$

Resonance reconstruction

Experimentally, resonances in heavy ion collisions have been measured at the NA49 collaboration at $\sqrt{s_{NN}} = 17$ GeV and at the STAR collaboration at $\sqrt{s_{NN}} = 200$ GeV. The resonances are reconstructed from their decay daughters (see Table 1). Charged particles are identified via energy loss (dE/dx) and their measured momenta in the Time Projection Chamber (TPC). The Λs and Ξs are reconstructed via topological analysis [10]. The resonance signal is obtained by the invariant mass reconstruction of each daughter combination and subtraction of the combinatorial background calculated by the mixed event technique [7]. The resonance ratios, spectra and yields are at mid-rapidity for the STAR data and 4π values for the NA49 data.

Strange resonances in p+p collisions at $\sqrt{s_{NN}} = 200$ GeV

The masses and the experimental widths of the strange resonances K(892) [14], Σ(1385) [10], Λ(1520) [7, 8] and Ξ(1530) [13] are shown in Fig. 1 and from the integrated invariant mass spectra are at mid-rapidity in p+p collisions. They are in agreement with the values from the PDG [5] and the expected width and mass from the simulation of the momentum resolution and the acceptance of the detector (Fig. 1). The inverse slope parameter T, the mean transverse momentum $<p_T>$ and the yield for p+p collision systems are obtained by an exponential fit to the transverse momenta distributions with: $T_{K(892)} = 223 \pm 9$ MeV, $T_{\Lambda(1520)} = 326 \pm 42$ MeV and $<p_T>_{K(892)} = 0.68 \pm 0.03 \pm 0.03$,

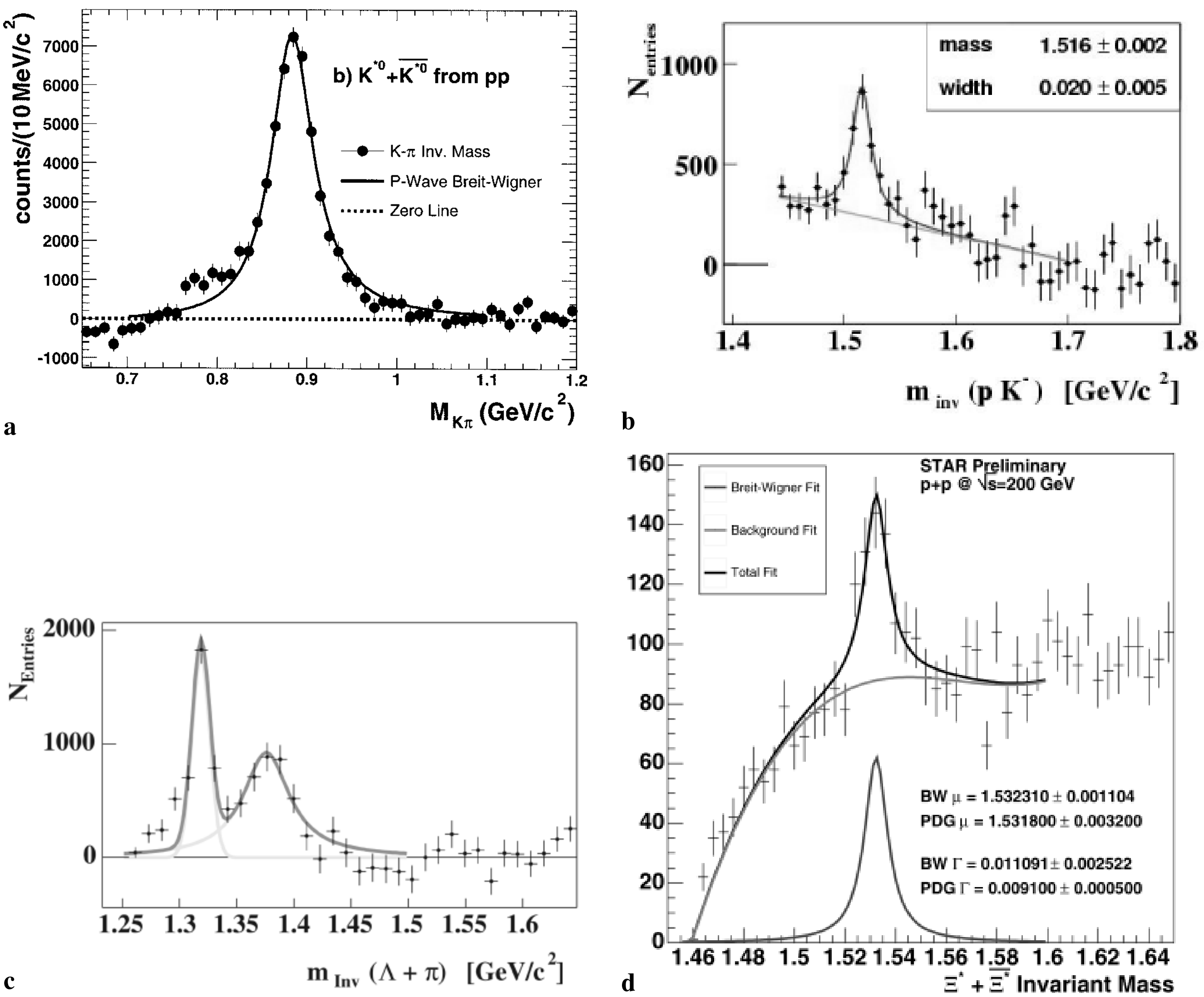

Fig. 1. Invariant mass distributions of resonances in p+p collisions at $\sqrt{s_{NN}} = 200$ GeV after mixed-event background subtraction. a – K(892) (p+K^- pairs); b – Λ(1520) (p+K^-pairs); c – Σ(1385)(Λ+π pairs); d – Ξ(1530) (Ξ+π pairs).

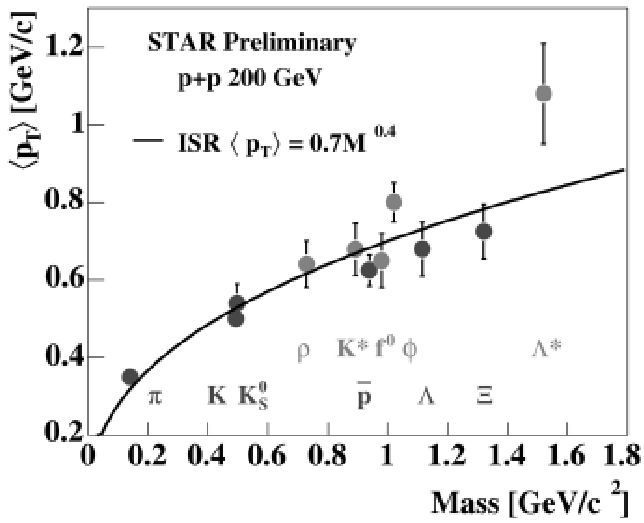

Fig. 2. Mean transverse momentum as a function of particle mass in p+p collisions $\sqrt{s_{NN}}$ = 200 GeV. Black line is the fit to measured ISR data (π, K and p) at a collision energy of $\sqrt{s_{NN}}$ = 26 GeV [3].

$<p_T>_{\Lambda(1520)}$ = 1.04 ± 0.09 ± 0.10 including the statistical and systematical error T_K.

The mean transverse momentum as a function of mass indicates that resonances with mass higher than 1 GeV/c^2 show a different trend than the stable particles (see Fig. 2). The black line in this Figure is a fit to the ISR data (π, K and p) for p+p collisions at $\sqrt{s_{NN}}$ = 26 GeV [3]. The mean transverse momentum of the resonances are obtained via an exponential fit, while the Λ and the Ξ spectra are fitted with a power-law function. An exponential fit for these particles would increase their mean transverse momentum. The prediction derived from the ISR data for higher mass particles does not describe our resonances. This could be an indication that a fraction of resonances comes from jet fragmentation, which contributes to the higher momentum of the particles.

Strange resonances in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

The masses and the experimental widths of the strange resonances K(892), Σ(1385) and Λ(1520) [8, 10, 14] over the phase space integrated invariant mass spectra in Au+Au collisions are compatible with the values from the PDG [5] and the width expected from the momentum resolution of the detector.

For a comparison of resonance production in different collision systems, the resonance divided by non-resonance particle ratios eliminate the need for a volume and energy normalization. Figure 3 shows K(892)/K and the Λ(1520)/Λ ratios for p+p and Au+Au collisions as a function of the number of participants. The ratio decreases from p+p to Au+Au collision systems. This behavior shows that the resonance production in Au+Au is not a superposition of p+p interactions. This is an indication that the surrounding extended medium of a Au+Au collision may have an influence on the resonances and/or their decay particles. The question remains whether the initial resonance yield is changed and/or whether the decay particles taken to reconstruct the resonance have been affected by the medium.

The thermal model that fits the ratios of stable particles very well predicts Λ(1520)/Λ = 0.7 at the chemical freeze-out temperature of T = 170 MeV [4]. The measured value for central Au+Au collisions at mid-rapidity is Λ(1520)/Λ = 0.034 ± 0.011 ± 0.013, lower than the thermal model prediction. A thermal description of this ratio would lead to a 30–50 MeV smaller chemical freeze-out temperature. Medium effects like elastic interactions of the decay particles with particles of the medium (mostly pions) may result in a signal loss in the invariant mass reconstruction region of the resonances, if the contribution from rescattering is larger than that of regeneration. This depends strongly on the time between chemical and thermal freeze-out. Resonances that decay into pions have a much larger contri-

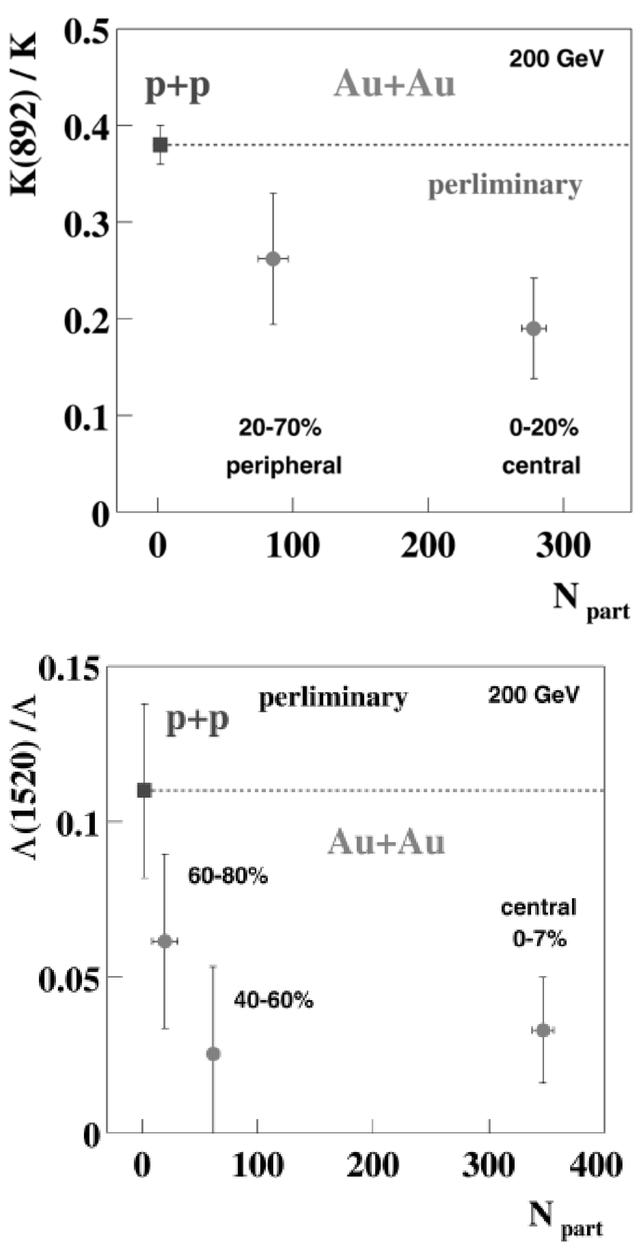

Fig. 3. Resonance/non-resonance ratios (upper figure: K*(892)/K [14], lower figure: Λ(1520)/Λ) for p+p and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, peripheral Au+Au data from [7]. Statistical and systematical errors are included.

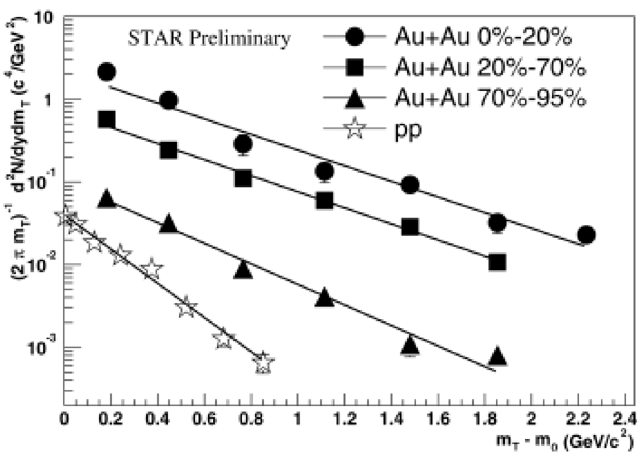

Fig. 4. Transverse mass spectra for K(892) in p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [14].

bution from regeneration due to all the surrounding pions in the medium compared to resonances like the Λ(1520) that regenerate from a proton and kaon.

Microscopic model calculations (UrQMD [1, 2]) predict the ratio Λ(1520)/Λ = 0.03 including a 30% signal loss from rescattering. The predicted value for K(892)/K in central Au+Au collisions are compatible with the data where K(892)/K = 0.19 ± 0.05. Furthermore, we would expect a more dominant signal loss in the low momentum region. This would lead to an increase in the inverse slope parameter in an exponential fit of the transverse momentum spectrum.

Figure 4 shows the transverse mass distribution of K(892) where the inverse slope parameter T is obtained with $T_{K(892)} = 223 \pm 9$ MeV for p+p interactions and $T_{K(892)} = 350 \pm 23$ MeV for the 70–80% most peripheral Au+Au collisions. This strong increase of 100 MeV in the inverse slope parameter is not observed for the stable particles.

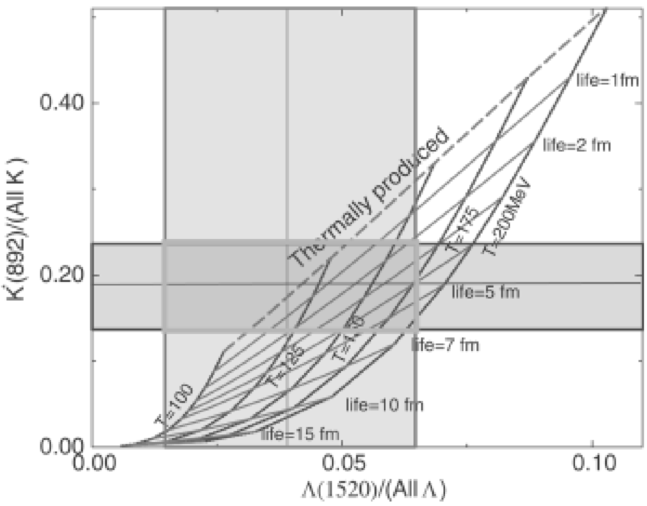

Fig. 5. Dependence of lifetime and chemical freeze-out temperature of a fireball source given by the two particle ratios Λ(1520)/Λ and K(892)/K including limits from the STAR data for cental Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [11, 12].

Time scale for A+A collisions

Model calculations that start with the particle yields from thermal production and include a lifetime for the system after chemical freeze-out predict a signal loss for the measured resonances. The signal loss depends on the length of the lifetime between chemical and thermal freeze-out where a cross-section for the rescattering of the decay daughters for the resonances is applied, but no regeneration. Using the measured values of K(892)/K and Λ(1520)/Λ from RHIC energies, and a chemical freeze-out temperature of 160 MeV the lower limit for a lifetime interval between chemical and kinetic freeze-out is estimated to be 5 fm/c [9, 11, 12] (see Fig. 5). More resonance measurements are necessary to put additional limiting conditions on the temperature and the lifetime between chemical and thermal freeze-out to verify this model. From thermal model predictions we expect a Σ(1385)/Λ ratio of 0.5 which means that 50% of all the produced Λ's come from the Σ(1385) decay.

Energy and system size dependence

The measured Λ(1520)/Λ ratio in central Pb+Pb collisions at $\sqrt{s_{NN}} = 17$ GeV is 0.028 ± 0.006 [6] which also cannot be described by the thermal model only. A suppression factor of 2 is needed to reproduce the multiplicity measured by the NA49 Experiment. The Λ(1520)/Λ ratios for p+p collisions are in agreement for the SPS and RHIC energies. The decrease of this ratio from p+p to heavy ion collisions is observed at both SPS and RHIC energies. The decrease of the resonances over non-resonance ratio for K(892) and Λ(1520) is observed in the very peripheral Au+Au collision at RHIC energies and stays constant up to the most central collisions (see Fig. 3). To test a very small medium we are currently analyzing the resonance production in d+Au collisions.

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