Resonance Production in STAR

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Abstract. The recent results from resonance production in central Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV from the STAR experiment at RHIC are presented and discussed.

Keywords: resonances, lifetime, rescattering
PACS: 25.75.Dw

1. Introduction

The short lifetimes of resonances, a few fm/c, are of the same order of the lifetime of the fireball source in a heavy ion collision at RHIC. Measurements of the yields, widths, mass and momentum distributions of resonances can provide information about hadronization and the time span between chemical and thermal freeze out. The resonances that we are currently investigating in the STAR experiment are $\rho$ (1.3 fm/c), $\Delta$ (1.7 fm/c), $K^*(892)$ (4 fm/c), $\Sigma^*(1385)$ (6 fm/c), $\Lambda(1520)$ (13 fm/c) and $\phi$ (40 fm/c) (listed in table I). Comparison of these resonances in heavy ion collisions with elementary p+p and $e^+e^-$ collisions may provide evidence for possible medium effects in the extended volume of a heavy ion reaction. By varying the centrality (impact parameter) and beam species in heavy ion collisions, we can investigate the effect of the fireball medium on the resonances.

2. Analysis

The resonances are reconstructed from their charged decay daughters (see table I) identified via energy loss ($dE/dx$) and their measured momenta in the Time Projection Chamber (TPC). 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-signed techniques. The resonance ratios, spectra and yields are measured at mid-rapidity. The central trigger selection for Au+Au collisions takes 7\% of the most central inelastic interactions. The setup for the proton+proton interaction is a minimum bias trigger.
Table 1. Resonances from PDG [19] decay channel

| Particle | Mass (MeV) | Width (MeV) | Lifetime (fm/c) | Decay Channel |
|----------|------------|-------------|----------------|---------------|
| \( \rho(770) \) | 771.1 ± 0.9 | 149.2 ± 0.7 | 1.32 | \( \pi + \pi \) |
| \( \Delta(1232) \) | 1232 ± 2 | 120 ± 5 | 1.64 | \( p + \pi \) |
| \( K(892)^0 \) | 896.1 ± 0.27 | 50.7 ± 0.6 | 3.89 | \( K + \pi \) |
| \( \phi(1020) \) | 1019.5 ± 0.02 | 4.26 ± 0.05 | 46.2 | \( K + K \) |
| \( \Sigma(1385)^+ \) | 1382.8 ± 0.4 | 35.8 ± 0.8 | 5.5 | \( \Lambda(\rightarrow p + \pi) + \pi^+ \) |
| \( \Sigma(1385)^- \) | 1387.2 ± 0.5 | 39.4 ± 2.1 | 5.0 | \( \Lambda(\rightarrow p + \pi) + \pi^- \) |
| \( \Lambda(1520) \) | 1519.5 ± 1.0 | 15.6 ± 1.0 | 12.6 | \( p + K \) |

3. Resonances in Medium

During the expansion of the hot and dense fireball of a heavy ion collision, resonances are produced and a fraction of them decay due to their short lifetimes inside the fireball medium. Two freeze out conditions during such a fireball expansion can be characterized by the end of the inelastic interactions (chemical freeze out) and the end of elastic interactions (kinetic freeze out). Elastic interactions of particles in the surrounding medium (mostly pions) with resonances and their decay daughters can have different effects. Elastic interactions with the resonances can change their phase space distribution, for example the transverse momentum distribution. Meanwhile elastic interactions with the decay particles can result in a signal loss from invariant mass reconstruction. Regeneration of the resonances can increase the yield and also change the momentum distribution, because particles forming a new resonance came from the medium. Resonances that decay mostly into particles that are not pions will have a smaller contribution from regeneration. The time between chemical and thermal freeze out can be verified by comparing resonances with different lifetimes. Transport model calculations maybe able to describe medium effects at a microscopic level [5, 6]. These calculations were developed recently, since heavy ion experiments are capable to measure resonances with short lifetimes. The initial motivation for the measurement of resonances was mass shifts and width broadenings of the mass signal due to an influence of the medium (recent papers [13, 14]). This signal can be "washed out" during the expansion of the fireball source, when inelastic and elastic interactions have an additional effect on the resonances and their decay particles. Furthermore a width broadening would result in a shorter lifetime. This would mean a higher probability of signal loss for the hadronic decay channels due to rescattering of the decay particles. The measurement from leptonic decay channels would not have this effect. Therefore it is very important for our understanding to measure the resonances through both hadronic and leptonic decay channels.
4. New Measurements

With the data set from the √s_{NN} = 200 GeV run of p+p and Au+Au collisions, STAR has sufficient statistics to measure the Λ(1520) resonance for the first time. Figure 1 shows the invariant mass signal of the Λ(1520) after mixed-event background subtraction, fitted with a Breit-Wigner function plus a line fit in p+p (left) and central Au+Au (right) collisions. The p_t range is chosen in respect to the best significance for the Λ(1520) signal (p+p: p_t = 0.0-2.0 GeV/c, Au+Au: p_t = 0.9-1.5 GeV/c). Due to the low background for the p+p data we receive the best signal by integration over the full range. The extracted mid-rapidity yield for p+p is ⟨Λ(1520)⟩|y|<0.5 = 0.0041 ± 0.0006 (stat) ± 10% (sys). For central Au+Au, with an assumption of an inverse slope parameter T = 350 MeV, the measured yields is ⟨Λ(1520)⟩|y|<0.5 = 0.058 ± 0.021 (stat) ± 30% (sys).

5. Meson Resonances

The ρ meson is a special resonance with its low mass of 770 MeV, broad width of 150 MeV and short lifetime of 1.3 fm/c. There are several theory predictions for medium effects on the mass and the width for the leptonic decay channels. STAR is capable of measuring the mass and width of the ρ meson (in a corresponding “cocktail” plot) from the hadronic decay channel in p+p and Au+Au collisions (see figure 2). The width of 160 MeV (nominal width + detector resolution) is in agreement with the data [10]. A mass shift of 40 MeV of the ρ meson from p+p to Au+Au interactions has been observed. There is also a mass shift in p+p interactions, it is not clear if this shift scales with the Au+Au interactions. This is still under discussion. E.V. Shuryak gave a possible theoretical description of the relative mass shift at this workshop so we won’t discuss this topic further here (see...
The extracted $\rho/\pi$ yield for p+p and Au+Au interactions are consistent within the statistical errors.

6. Strange Resonances

The masses and the experimental widths of the strange resonances $K^*(892)$, $\Sigma^*(1385)$ and $\Lambda(1520)$ over the phase space integrated invariant mass spectrum in p+p collisions are compatible with the values from the PDG [19] and the expected width coming from the momentum resolution of the detector. Anti-particle over particle ratios of $\bar{\Lambda}(1520)/\Lambda(1520) = 0.84 \pm 0.32$ (stat+sys) and $\bar{\Lambda}/\Lambda = 0.81 \pm 0.01$ (stat) are in agreement ($\Lambda$ taken from [4]) within errors. For a comparison of resonance production in different collision systems, the resonance over non-resonance particle ratio will take care of the volume and the energy normalization. Figure 3 shows the $K^*(892)/K$ and the $\Lambda(1520)/\Lambda$ ratio for p+p and Au+Au collisions as a function of the number of participants. The ratio decreases from p+p to extended 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 has an influence on the resonance and/or their decay particles. Data from NA49 experiment, at an energy which is a factor $\sim 10$ lower ($\sqrt{s} = 17$ GeV) show that the $\Lambda(1520)/\Lambda$ in Pb+Pb collisions are a factor of 2 lower than in p+p collisions [8]. The $K^*(892)/K$ ratio at $\sqrt{s_{NN}} = 200$ GeV, shown in figure 3, decreases from p+p to more central Au+Au collisions. This can be interpreted as direct influence of increasing the volume of the medium. The resonance yield relative to other particles is smaller in heavy ion collisions than in p+p collisions. The question remains whether the initial resonance yield is different changed and/or whether the decay particles taken to reconstruct the resonance have been affected by the medium.
7. Rescattering

UrQMD predicts a signal loss in the low transverse momentum region \cite{5, 6} due to rescattering of the decay daughters in the medium, leading to a larger inverse slope. The inverse slope for the K*(892) in p+p collisions is $T = 210 \pm 8$ MeV and it increases to $T = 350 \pm 23$ MeV in the 70-80% most peripheral Au+Au collisions (see figure 3) \cite{24}. While the inverse slope for the Kaons in p+p and in the 70-80% most peripheral Au+Au collisions, exhibits little difference \cite{2} (see table 7). Thus, an increase is observed in the slope of the K*(892) and not for the Kaons when going from p+p interactions (with no medium) to an extended medium in Au+Au collisions, even for the most peripheral collisions which represent the smallest medium. This behavior was predicted by UrQMD \cite{5, 6}. It would also be interesting if UrQMD sees an increase of the inverse slope going from peripheral to more central collisions.

Table 2. Inverse slope parameters of transverse mass distributions for K*(892) and K^- for $\sqrt{s_{NN}} = 200$ GeV p+p and Au+Au interactions \cite{9, 24, 2}

| Centrality            | Inverse Slope K*(892) [MeV] | Inverse Slope K^- [MeV] |
|-----------------------|-----------------------------|-------------------------|
| 0% - 20% Au+Au        | 459 ± 32                    | 321 ± 8                 |
| 70% - ~ 80% Au+Au     | 350 ± 23                    | 202 ± 7                 |
| pp                    | 210 ± 8                     | 182 ± 5                 |

8. Time Scale

According to thermal model predictions \cite{17} (becattini) the production yield of the K*(892)/K in heavy ion collisions at $\sqrt{s_{NN}} = 200$ GeV is within the errors a factor
Fig. 4. Transverse mass distribution at mid-rapidity for \((K^*(892)+K^*(892))/2\) from Au+Au an p+p interactions with statistical errors [24].

of 2 smaller than the predicted value. Due to the large errors for the K*(892) yield in the \(\sqrt{s_{NN}} = 130\) GeV data we were not previously sensitive to this ratio discrepancy with the thermal model predictions [1]. Also the first \(\Lambda(1520)\) yield measurement show a 50% lower value than that predicted by thermal models. Model calculations that include particle yields from thermal production and a lifetime for the system after chemical freeze-out, where the cross section of rescattering but not regeneration for the decay daughters is included, predict a signal loss for the measured resonances. Using the measured values of \(K(892)/K\) and \(\Lambda(1520)/\Lambda\), and a chemical freeze out temperature of 175 MeV the lifetime between chemical and kinetic freeze out is estimated to be 4-6 fm/c [22, 23, 16]. Additional measurements from particle correlations gives 9-10 fm/c for the total lifetime in rough agreement with this number [12, 18, 17].

Acknowledgements

I would like to thank the organizers who invited me to such a well organized workshop which left enough time for detailed and long discussions. I also would like to thank the STAR collaboration for support in presenting this data. My research is supported by the Humboldt Foundation, Germany.
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