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Resonance production in RHIC collisions

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Abstract. Short lived resonances are sensitive to the properties of the medium produced in heavy ion collision, in particular the temperature, density and expansion velocity. Thermal models underpredict the yield of $K(892)$ and $\Lambda(1520)$ in Au + Au collisions which allows us to conclude that an extended hadronic interaction phase exists between chemical and thermal freeze-out. During this time the decay particles of resonances will re-scatter and coalesce to regenerate resonances. These mechanisms affect the resonance yield mostly in the low momentum region below 1 GeV/c. Therefore the nuclear suppression factor R_{AA} of resonances with more re-scattering than regeneration will be suppressed compared to stable particles in that p_{T} range. It is interesting to study the R_{AA} of resonances at higher momenta where the spectra of non-resonant particles exhibit effects such as enhancement through constituent quark recombination and quenching in the dense partonic medium. In addition the R_{AA}'s of strange particles show the effect of canonical suppression on the nuclear suppression factor which leads to a significant difference between R_{AA} and R_{CP}, in particular for strange baryons. Therefore the R_{AA} and the elliptic flow v_2 for strange resonances in comparison to strange particles are investigated.

1 Introduction

Resonances can be used to measure the hadronic lifetime from the chemical freeze-out to the kinetic decoupling of the nuclear medium in a heavy ion reaction. Together with the pion HBT lifetime measurement which determines the time from the beginning of the collision to kinetic freeze-out, one is able to extract a partonic lifetime, under the assumption that the chemical freeze-out takes place shortly after hadronization [5]. In elementary $p+p$ and $d+$Au interactions the hadronic lifetime is expected to be very short and therefore any resonance yield and the momentum spectrum can be described by a statistical model. The extended hadronic medium in heavy ion reactions will change the yield and spectra due to the rescattering of the decay particles and possible regeneration of resonances. This can be described with a microscopic transport model (UrQMD) having a lifetime between chemical and kinetic freeze-out of $\Delta\tau = 10 \pm 3$ fm/c. Alternatively suppression of the $\Lambda(1520)$ and $K(892)$ yields in Au + Au collisions and a thermal model with an additional rescattering phase [1–4] was used to estimate a hadronic lifetime of $\Delta\tau > 4$ fm/c [5].

2 Interaction of resonances in nuclear medium

The measured resonance to stable particle ratios for $p+p$ and Au + Au collision systems show a suppression for the $\Lambda(1520)$ and $K(892)$, while the $\Sigma(1358)$ and the $\varphi(1020)$ are constant within their errors (see Fig. 1) [5, 6]. The deviation of the ratio in Au + Au collisions from $p+p$ collisions indicates a late hadronically interacting medium where decay of resonances and the re-scattering of the decay particles is larger than the regeneration of reso-

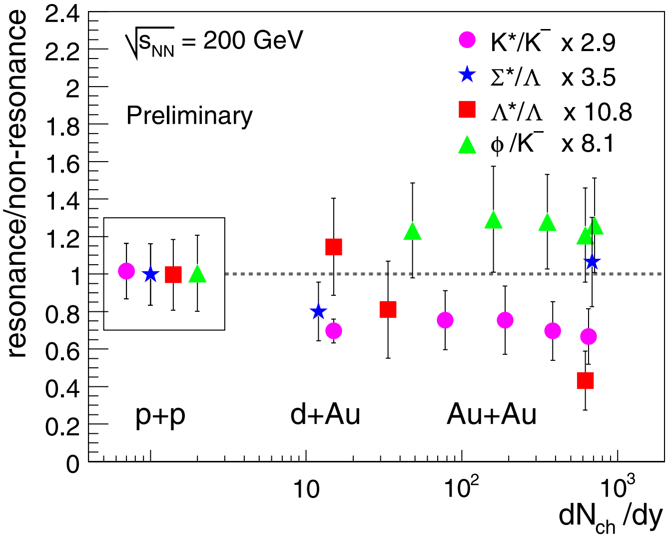

Fig. 1. Resonance to stable particle ratios of $\Sigma(1385)/\Lambda$, φ/K^-, $K(892)/K^-$ and $\Lambda(1520)/\Lambda$ for $p+p$, $d+$Au and Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The ratios are normalized to unity in $p+p$ collisions. The quadratic sum of statistical and systematic uncertainties are included in the *error bars*

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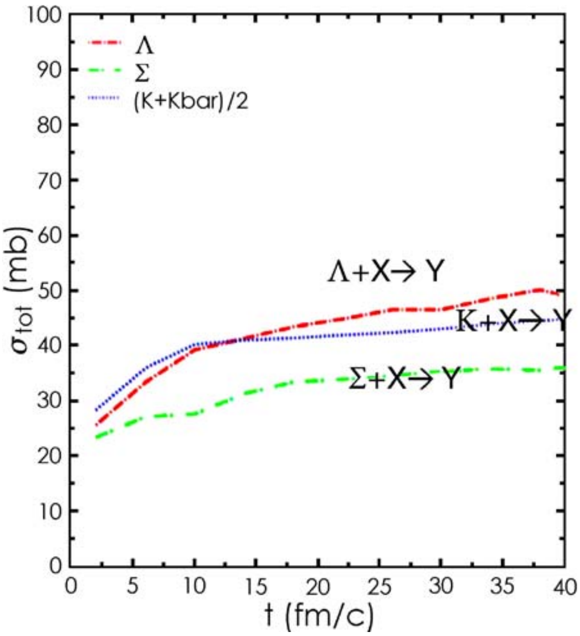

Fig. 2. Microscopic calculations (UrQMD) of regeneration cross sections of resonances for Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV for $\Lambda + \pi \to \Sigma(1385)$, $K + \pi \to K(892)$ and $\Sigma + \pi \to \Lambda(1520)$ [10]

nances. A ranking of the overall regeneration over rescattering cross section can be derived from the data as follows: $R_{K+p\to\Lambda(1520)} < R_{K+\pi\to K(892)} < R_{\Lambda+\pi\to\Sigma(1358)}$ while the lifetime follows the order $(c\tau_{K^*} < c\tau_{\Sigma^*} < c\tau_{\Lambda^*})$.

Microscopic model (UrQMD) calculations by Sascha Vogel are shown in Fig. 2 for particular regeneration cross sections which confirm the ranking as derived from the data [10]. The same model predicts a signal loss of reconstructed resonances in the low momentum region due to rescattering.

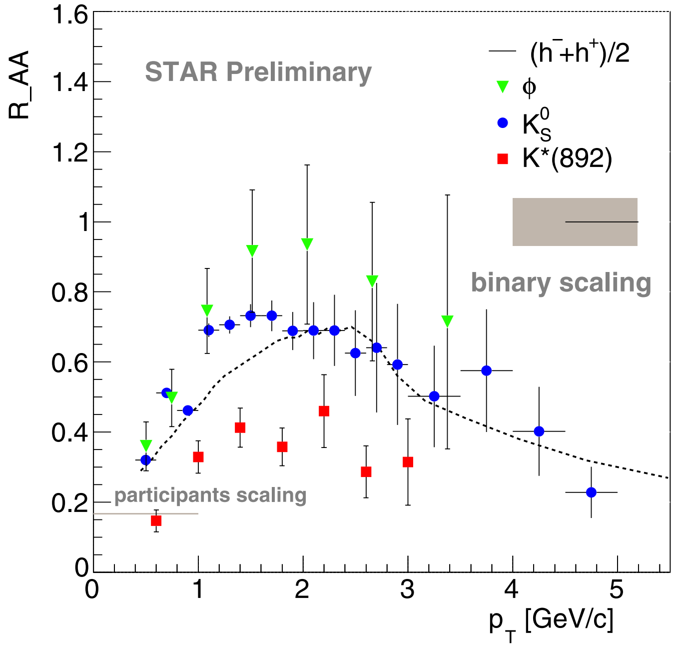

Fig. 3. The ratio of yields for Au + Au divided by $p + p$ collisions as a function of transverse momentum normalized to the number of binary collisions

A comparison of the transverse momentum spectrum of $p+p$ and Au + Au collisions using the nuclear modification factor R_{AA} shows for the $K(892)$ a larger suppression in the momentum region from $p_T = 0$–2 GeV/c compared to the long lived φ and the K^0_S (Fig. 3). These data support the concept of a hadronic interacting medium after chemical and before kinetic freeze-out which changes the measured resonance yield and the momentum spectra. Thermal model predictions by W. Florkowski et al. which describe the momentum spectra of non-resonant particles (e.g. K^0_S) are in disagreement with the $K(892)$ resonance spectrum. The data show a lower yield in the low momentum region [11]. Therefore nuclear suppression factors (R_{AA}) of resonances are not directly comparable to those of stable particles as long as the momentum dependent signal loss of resonances in the hadronic phase is not taken into account.

3 Extended medium in $d +$ Au collisions?

Since one would expect no creation of an extended hadronic medium in $d +$ Au collisions, the momentum distribution and the yield of resonances in $p + p$ and $d +$ Au collisions are expected to be similar. The ratios of yields of resonances to stable particles as a function of the charged particle multiplicity are presented in Fig. 1. The ratios are normalized to unity in $p + p$ collisions to study variations in $d +$ Au relative to $p + p$. The $\Sigma(1385)/\Lambda$ and the $\Lambda(1520)/\Lambda$ ratios in $p + p$ and $d +$ Au collisions are in agreement within errors. This observation is consistent with the absence of a hadronic interacting medium. However the $K(892)/K$ ratio in $d +$ Au exhibits a suppression compared to $p + p$ interactions. This observation is not yet understood. A more precise look at the yield as a function of

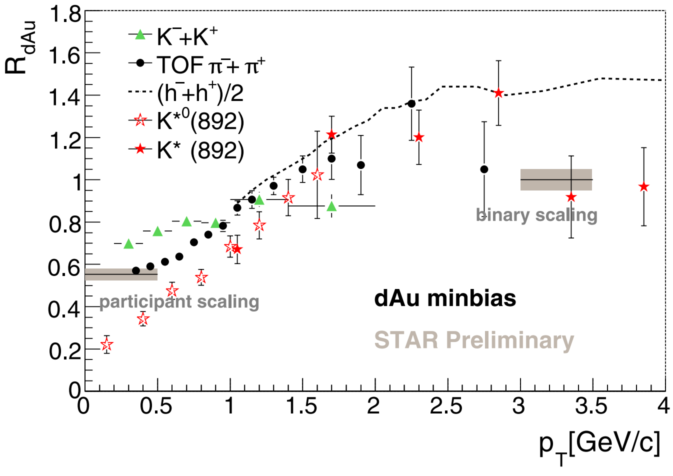

Fig. 4. The ratio of yields for $d +$ Au divided by $p + p$ collisions as a function of transverse momentum normalized to the number of binary collisions for mesons

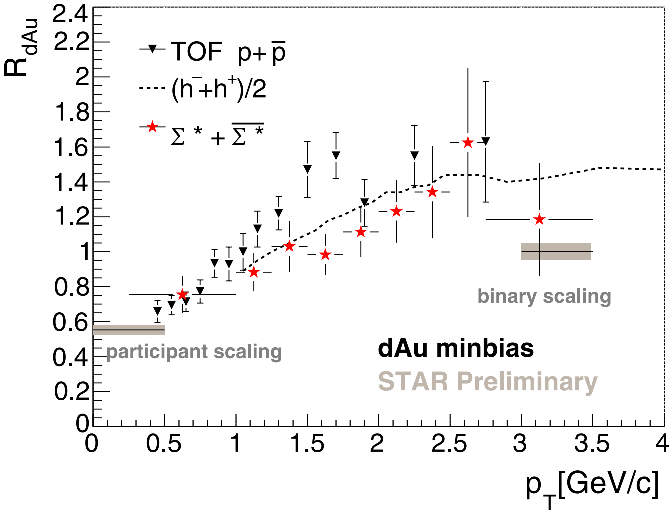

Fig. 5. The ratio of yields for $d+\mathrm{Au}$ divided by $p+p$ collisions as a function of transverse momentum normalized to the number of binary collisions for baryons

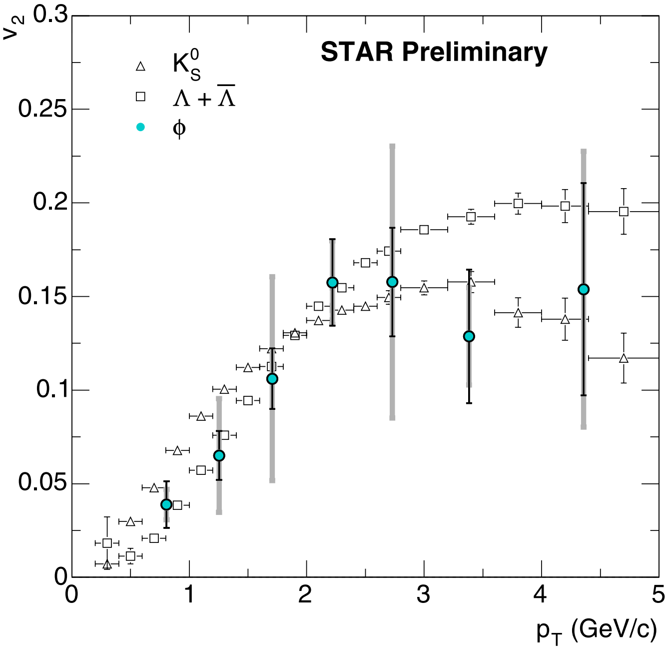

Fig. 6. The v_2 of φ meson compared to K^0_S meson and Λ baryon as a function of p_T. Statistical and systematical errors are included [15]

the momentum can be performed via $R_{d\mathrm{Au}}$, which is the transverse momentum distribution in $d+\mathrm{Au}$ collision normalized by the $p+p$ spectra and the number of binary collisions. Figures 4 and 5 show the $R_{d\mathrm{Au}}$ of mesons and baryons. The $R_{d\mathrm{Au}}$ of $\Sigma(1385)$ seems to follow the proton $R_{d\mathrm{Au}}$, while the $K(892)$ deviates from the K and π to lower values in the low momentum region. This result is unexpected if we assume no extended hadronic medium. The data have to be further investigated to explain this kind of effect in $d+\mathrm{Au}$ collisions on the $K(892)$ but not on the $\Lambda(1520)$.

An interesting effect which motivates further investigations is the apparent difference of R_CP and R_{AA} for strange baryons [12–14]. The R_CP for Λ's is almost identical to the R_{AA}, i.e. the suppression factors reach unity at mid p_T (2 GeV/c) likely due to recombination and then shows enhanced quenching at high p_T. The R_{AA} though shows a strong enhancement at mid and high p_T and effectively show no suppression compared to binary scaling. This effect can possibly be attributed to canonical suppression of strange baryon production in $p+p$ for all Λ momenta. Thus the effect is not limited to the soft sector. The question arises whether strange baryon resonance production follows the same trends, although effect such as recombination and re-scattering affects the p_T spectrum considerably as shown in Fig. 3 for strange mesons. Studies of R_{AA} for $\Sigma(1385)$, $\Xi(1530)$ and $\Lambda(1520)$ are underway.

4 Elliptic flow v_2

Anisotropic flow results are often cited as strong evidence for the formation of the QGP in Au+Au collisions at RHIC. The magnitude and centrality dependence of the elliptic flow v_2 is generally considered indicative of early thermalization. The so-called mass splitting, the characteristic dependence of $v_2(p_\mathrm{T})$ on the particle mass, is well described when using a QGP equation of state. In addition the constituent quark scaling in the intermediate transverse momentum region is often cited as proof of deconfinement and partonic (pre-hadronic) collectivity. One therefore would like to study the elliptic flow of resonances in order to test the probability of formation at the early stage of the collision and the effect the expansion dynamics of the source, including re-scattering and regeneration of resonances, will have on their v_2. As shown in Fig. 6 the elliptic flow of the long lived φ meson resonance shows the expected mass dependence in the low momentum region and a constituent quark scaling similar to the K^0_S meson in the intermediate transverse momentum region. In the near future we will analyze the elliptic flow of the short lived $\Delta(1232)$ resonances and the $K(892)$ to higher transverse momentum. Late hadronic regeneration would enhance v_2 in the higher transverse momentum region of $p_\mathrm{T}=4\,\mathrm{GeV}/c$ due to the larger constituent quark scaling factors 4 (meson + meson) and 5 (baryon + meson) [16].

5 Conclusions

Resonances are a unique probe of the hadronic medium in heavy ion collisions. They allow us to estimate the lifetime of the hadronically interacting medium and derive the re-scattering over regeneration cross section ranking for different resonances. Using microscopic models actual regeneration cross sections can be determined based on the data. Furthermore we gain a better understanding of the hadronic interaction probabilities which helps us distinguish between early and late decoupling of particle species from the hadronic medium. The interpretation of the resonance measurement of $\Sigma(1385)$ and $\Lambda(1520)$ in $d+\mathrm{Au}$ collisions leads to the conclusion that no extended hadronic medium is formed and that the system behaves similar to $p+p$ interactions. The $K(892)$ does not follow this interpretation and exhibits suppression of the yield in the low transverse momentum region even in $d+\mathrm{Au}$ reactions; explanations for this behavior are unknown. Future measurements of R_{AA} and v_2 of strange baryonic resonances will allow us to understand and distinguish the different production mechanism in $p+p$ and $A+A$ collisions.

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