Baryonic Resonance Studies with STAR

Sevil Salur (for the STAR Collaboration)
Yale University, 272 Whitney Ave., New Haven, CT 06520 USA
E-mail: sevil.salur@yale.edu

Abstract. Yields and spectra of Σ(1385) are measured in p+p, d+Au and Au+Au collisions at √s_{NN}=200 GeV. The nuclear modification factors in d+Au collisions are presented. The p_T dependent medium effects are investigated via the nuclear modification factors. The implications of these results on various models are discussed.

1. Introduction

Strongly interacting, high density matter is produced in heavy ion collisions at the Relativistic Heavy Ion Collider. Hadronic resonances, due to their short lifetimes, can be used to investigate the freeze-out mechanisms after hadronization. The production of the strange baryonic resonance Σ(1385) is investigated for the first time in heavy ion collisions and, through comparison with other resonances, the evolution of the fireball is investigated. The collision dynamics are studied with the Σ(1385)/Λ ratio in comparison to other resonance/stable particle ratios to explore the re-scattering and regeneration effects between chemical and thermal freeze-out [1, 2].

2. Analysis and Particle Identification Techniques

The direct identification and measurement of the Σ(1385) (→ Λ + π) in the detectors is not possible due to its short life-time (cτ_{Σ(1385)} = 6 fm). Instead, the Σ(1385) is identified by reconstructing the invariant mass distribution from its decay products via a combinatorial technique. In this technique, Σ(1385) baryons are identified by combining the topologically reconstructed Λ baryons with π mesons that are identified via their dE/dx and momentum information from the STAR Time Projection Chamber. Figure 1-a shows the clear signal of the invariant mass spectrum of Σ(1385) after mixed-event background subtraction. Taking into account our detector resolution and the measurement uncertainties, the measured widths of the Ξ− and Σ(1385) are in agreement with the PDG [3]. Corrected mid-rapidity (|y| < 0.5) m_T − m_0 spectra are presented in Figure 1-b for the Σ(1385) (closed circles) and Σ(1385) (open circles) from minimum bias d+Au collisions at √s_{NN}=200 GeV. The error bars presented correspond to both statistical and bin-by-bin systematic uncertainties.
3. Results and Discussions

The $p_T$ spectra and $\langle p_T \rangle$ are also measured in $p+p$ and Au + Au collision environments [1, 2]. Table 1 summarizes the results from the corrected spectra of the $\Sigma(1385)$ with the statistical and systematic errors in all three collision systems.

Table 1. The $\langle p_T \rangle$ and yield $(dN/dy)$ from exponential fits to the $\Sigma(1385)$ ($\Sigma^*$) $p_T$ spectra [1, 2]. The yields for $p+p$ are from non-singly diffractive collisions.

| Particle | Collision | Centrality | $\langle p_T \rangle$ [GeV/$c$] | $(dN/dy)_{y=0}$ |
|----------|-----------|------------|-----------------------------|------------------|
| $\Sigma^\pm$ | $p+p$ | min-bias | 1.02 ± 0.02 ± 0.07 | $(10.7 \pm 0.4 \pm 1.4) \times 10^{-3}$ |
| $\Sigma^\pm$ | $p+p$ | min-bias | 1.01 ± 0.01 ± 0.06 | $(8.9 \pm 0.4 \pm 1.2) \times 10^{-3}$ |
| $\Sigma^\pm + \Sigma^*$ | Au+Au | 0-5% | 1.28 ± 0.15 ± 0.09 | 9.3 ± 1.4 ± 1.2 |
| $\Sigma^\pm$ | $d+Au$ | min-bias | 1.14 ± 0.05 ± 0.08 | $(3.23 \pm 0.15 \pm 0.42) \times 10^{-2}$ |
| $\Sigma^\pm$ | $d+Au$ | min-bias | 1.12 ± 0.05 ± 0.08 | $(3.15 \pm 0.15 \pm 0.41) \times 10^{-2}$ |

A comparison of the $\langle p_T \rangle$ as a function of measured particle mass is presented in Figure 2-a for $p+p$ and Au + Au collisions at $\sqrt{s_{NN}}=200$ GeV. The triangles represent the resonances and the circles signify long-lived ‘stable’ particles. The black curve is an empirical fit to the ISR $\pi$, K, and p data in $p+p$ collisions and the band is a blastwave fit using $\pi$, K, and $p$ in STAR for Au+Au collisions [4, 5]. The empirical parametrization for the ISR data at $\sqrt{s} = 25$ GeV in $p+p$ collisions, can describe the $\langle p_T \rangle$ of the lower mass particles, such as $\pi$, K, and $p$, despite the fact that our collision energy is an order of magnitude higher. However, this empirical parametrization does not reproduce the behavior of the higher mass particles in $p+p$ collisions. Similarly, the blastwave
parametrization which can describe the \( \langle p_T \rangle \) of the lower mass particles (~98% of all the particles observed) in Au + Au collisions, fails for the higher mass particles.

![Figure 2](image-url)

**Figure 2.** (a) The \( \langle p_T \rangle \) vs particle mass measured in \( p+p \) and Au + Au collisions at \( \sqrt{s_{NN}}=200 \text{ GeV} \). (b) Comparison of the \( \Sigma(1385) \) spectrum with Pythia predictions for two different values of the K factor. See text for details.

The heavy particles in \( p+p \) and Au + Au collisions show a similar magnitude of \( \langle p_T \rangle \). It is expected that resonances with higher transverse momentum are more likely to be reconstructed because of their longer relative lifetimes due to their ultra-relativistic velocities. This means they are more likely to decay outside the medium and hence their daughter particles will interact less with the medium in Au + Au collisions. Any loss of low \( p_T \Sigma(1385) \) baryons will cause an increase in the measured \( \langle p_T \rangle \) of the observed \( p_T \) spectra for the central Au + Au collisions with respect to \( p+p \) collisions. However we do not see any significant increase in the \( \langle p_T \rangle \) for the \( \Sigma(1385) \) from minimum bias \( p+p \) to the most central Au + Au collisions within the statistical and systematic errors. It is possible that the production of the higher mass particles in \( p+p \) collisions is biased towards higher multiplicity collisions. If the higher mass particles are produced in more violent (mini-jet) \( p+p \) collisions compared to lower mass particles, the \( \langle p_T \rangle \) for heavy particles in \( p+p \) collisions would be larger.

A comparison of the \( \Sigma(1385) \) spectrum with a leading order pQCD model, Pythia 6.3 [6], is presented in Figure 2b. It is possible to model the \( \Sigma(1385) \) spectrum with Pythia with the factor K=3 while the default (K=1) spectrum is too soft. This K-factor, which represents a simple factorization of next-to-leading order processes (NLO) in the Pythia leading order (LO) calculation, is directly related to the \( p_T \) spectrum. An increase in the K factor implies that larger NLO contributions (mini-jet events) are required to describe the \( \Sigma(1385) \) production. The high (K=3) factor is also needed to describe heavy strange baryons such as the \( \Lambda \) and the \( \Xi \), while the spectra predicted with this high K factor are too hard for the light mesons [7]. In Au + Au collisions, there is evidence that heavier particles flow radially with a smaller boost velocity due
to their smaller cross section than the lighter mass particles. These two independent effects in $p + p$ and $Au + Au$ collisions may cause the apparent merging of the $\langle p_T \rangle$.

In a thermal model, the measured ratios of resonance to non-resonant particles with identical valence quarks are sensitive to the chemical freeze-out temperature, as all of the quark content dependencies cancel out \[8\]. While these models predict the measured $\Sigma(1385)/\Lambda$ ratio correctly within errors, they suggest a higher ratio than the measured $\Lambda(1520)/\Lambda$ in the most central $Au + Au$ collisions. This suggests an extended hadronic phase of elastic and pseudo-elastic interactions after chemical freeze-out, where re-scattering of resonance decay particles and regeneration of resonances will occur.

The nuclear modification factor for the $\Sigma(1385)$ in comparison to other mesons and baryons in $d + Au$ collisions can be found in Figure 3. The $R_{dAu}$ measurements, for mesons on the left and for baryons on the right, mostly follow participant scaling at low momenta. At higher momentum, baryons show a greater enhancement over the binary scaling than the mesons. The $\Sigma(1385)$ baryon follows a similar trend to $h^\pm$. The enhancement over binary scaling can be described by the Cronin effect, a generic term for the experimentally observed broadening of transverse momentum spectra at intermediate $p_T$ in $p+A$ collisions as compared to $p+p$. It is surprising that the $\rho$ meson shows no enhancement above binary collisions and even falls below $\pi$ mesons, while the other resonances and their stable particles show no clear difference in their $R_{dAu}$.

References

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