Production of $K^{(892)^0}$ mesons in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract. Collisions of small systems such as p/d/$^3$He+Au are important for the investigation of quark-gluon plasma (QGP) in relativistic heavy ion collisions. These experiments distinguish the effects of the initial state of cold nuclear and the final state of hot matter. The research of light hadron production is one of the leading directions in the effects of the cold and hot nuclear matter studies. Due to a short lifetime and strange quark content, the $K^{*0}$-meson is sensitive to the properties of the hot dense matter and strangeness production from an early partonic phase (i.e. QGP). This report presents invariant transverse momentum spectra and nuclear modification factors ($R_{HeAu}$) of $K^{*0}$-meson as a function of $p_T$ measured in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the PHENIX experiment. In results, the nuclear modification factors for $K^{*0}$, $\varphi$, and $\pi^0$ mesons are equal within uncertainties in all centrality bins in the whole $p_T$ range. In conclusion, the obtained results might indicate that CNM effects are not responsible for the differences of $K^{*0}$ and $\varphi$ to $\pi^0$ suppression level seen in heavy ion collisions.

1. Introduction
The study of the nuclear matter properties under extreme conditions is an important goal in the field of high-energy nuclear physics. A deconfinement state called quark-gluon plasma (QGP) is obtained in these conditions. The QGP properties under laboratory conditions can be investigated in the collision of ultra-relativistic nuclei [1].

One of the main signs of the QGP formation is the jet-quenching effect, which manifested in a suppression of particle yields at high transverse momentum $p_T$ in central collisions of heavy nuclei due to energy loss of quarks and gluons in the QGP. Cold nuclear matter (CNM) effects have been suggested to possibly contribute to the measured suppression of particle yields in heavy-ion collisions. CNM effects include a few mechanisms by which the jet cross section in a nucleus-nucleus collision can be modified with respect to a pp collisions, aside from energy loss due to a deconfined phase of the collision [2].

Collisions of small systems (such as p+Au, d+Au, and $^3$He+Au) is one way to test the influence of cold nuclear matter effects on the suppression of hadron yields at high transverse momentum [3]. In addition, non-zero elliptic flow and a hint of suppression of high transverse momentum hadrons suggests that mini-QGP can be formed in collisions of light and heavy nuclei [3, 4].
The study of QGP and CNM effects is conducted using light hadron production. Due to a short lifetime and strange quark content, the $K^{*0}$-meson is sensitive to the properties of the hot dense matter and strangeness production from an early partonic phase (i.e. QGP) [5].

This paper presents invariant transverse momentum spectra and nuclear modification factors of the $K^{*0}$-meson. The results are measured in $^3\text{He}+\text{Au}$ collisions at $\sqrt{s_{NN}} = 200$ GeV in the transverse momentum range 1.55 - 5.75 GeV/c using the PHENIX detector at the RHIC [6].

2. Data Analysis

This paper presents the data obtained by the PHENIX detector at RHIC in $^3\text{He}+\text{Au}$ collisions. The $K^{*0}$-mesons are reconstructed via $K^{*0} \rightarrow K^{+}\pi^{-}$ ($K^{*0} \rightarrow K^{-}\pi^{+}$) decay channel with a branching ratio $Br = 0.67$.

The yields of $K^{*0}$-mesons were obtained using the following detector systems of the PHENIX experiment: a drift chamber (DC) and a time-of-flight chamber (TOF). To correct measurement of the $K^{*0}$-meson yields at the experiment, the detector acceptance and reconstruction efficiency $\epsilon_{eff}$ are determined using a full GEANT [7] simulation of the PHENIX detector.

The $K^{*0}$-meson yields were extracted via invariant mass distribution of $K^{\pm}$ and $\pi^{\mp}$ mesons. Oppositely charged particles which are registered in a single collision are combined into pairs. This distribution contains both the signal or foreground (FG), combinatorial backgrounds or mixed-event BG as shown in the Figure 1(a) and noncombinatorial backgrounds. Combinatorial background arises due to decays of other particles and can be into account by comparing invariant mass distribution with the artificial mass distribution, obtained by combining tracks from one event with tracks from another event of the same centrality and vertex class. This procedure is called mixed-event technique. The residual background, which mostly comes from other meson decays, looks like a smooth function of mass, so the $K^{*0}$-meson signal can be well distinguished.

In the Figure 1(b) shown the invariant mass distribution of pairs $K^{\pm}\pi^{\mp}$ is fitted with relativistic Breit–Wigner function and the second order polynomial, which describe the signal and the noncombinatorial background, respectively.

![Figure 1](image_url)  

**Figure 1.** (a) The invariant mass distribution in $^3\text{He}+\text{Au}$ collisions and (b) the invariant mass distribution of pairs $K^{\pm}\pi^{\mp}$ is fitted with relativistic Breit–Wigner function and the second order polynomial.
Then invariant $p_T$-spectra of $K^{*0}$-mesons are calculated as:

$$\frac{1}{2\pi p_T} \frac{d^2N}{dp_T dy} = \frac{1}{2\pi p_T} \cdot \frac{1}{\Delta p_T} \cdot \frac{1}{\Delta y} \cdot \frac{N(S)}{N_{evt} \cdot Br \cdot \epsilon_{eff} \cdot N_{(\Delta p_T)}}$$

(1)

where $p_T$ is the transverse momentum of $K^{*0}$-meson; $\Delta p_T$ is the bin width in transverse momentum; $\Delta y$ - bin width in rapidity; $N(S)$ is the number of observed mesons (meson yield); $N_{evt}$ - the number of sampled events within the relevant centrality selection; $\epsilon_{eff}$ is the reconstruction efficiency of $K^{*0}$-meson; $Br$ is the branching ratio on the channel $K^{*0} \rightarrow K^+\pi^-$ ($K^{*0} \rightarrow K^-\pi^+$); $\frac{1}{2}$ points to the average of $K^{*0}$ and $K^{*0}$.

Nuclear modification factors of particles in collisions of small systems are used to study collective effects that affect the particle production spectra as function of the transverse momentum, and are calculated in accordance with the formula:

$$R_{HeAu} = \frac{c_{bias}}{N_{coll}/\sigma_{pp}^{inel}} \cdot \frac{d^2N_{HeAu}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

(2)

where $d^2N_{HeAu}/dydp_T$ is the $K^{*0}$ yield in $^3$He+Au collisions for selected centrality bin, $d^2\sigma_{pp}/dydp_T$ is the cross-section in pp collisions, $c_{bias}$ is the bias factor, $N_{coll}$ is the average number of binary collisions per event in $^3$He+Au collisions and $\sigma_{pp}^{inel}$ is the total inelastic cross-section, which is 42.2±3 mb.

3. Results

Figure 2 shows the results of invariant $p_T$-spectra which were measured for $K^{*0}$-meson in Run14 $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in different centrality bins as described in Eq. 1.

![Figure 2. Transverse momentum spectra measured for $K^{*0}$-mesons in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with systematic uncertainties. Statistical uncertainties are smaller than the marker size. Open boxes correspond to systematic uncertainties.](image)

The nuclear modification factor $R_{AB}$ as a function of transverse momentum $p_T$ in d+Au and $^3$He+Au collisions is shown in the Figure 3. The $K^{*0}$-meson nuclear modification factors in intermediate and high $p_T$ range in the central and MinBias collisions are in a good agreement.
This result suggests that $K^*0 \ R_{AB}$ values do not depend on projectile size in collision of small systems.

**Figure 3.** The comparison of nuclear modification factors for the $K^*0$-meson in $^3$He+Au to $R_{AB}$ for $K^*0$ in d+Au in the most central 0-20% (a) and MinBias 0-88% (b) $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Error bars and open boxes around points show statistical and $p_T$-dependent systematic uncertainties. Boxes at the unity shows $p_T$-independent systematic uncertainties.

The comparison of $K^*0$ to $\varphi$ and $\pi^0$-meson [9] nuclear modification factors in $^3$He+Au in all centralities values exhibit similar shape as shown in the Figure 4. This result might indicate that CNM effects are not responsible for the differences between of $K^*0$ and $\varphi$ to $\pi^0$ suppression level seen in heavy ion collisions [10].

**Figure 4.** Nuclear modification factors of $K^*0$, $\varphi$, and $\pi^0$ mesons measured as a function of $p_T$ in the most central 0-20% (a) and the most peripheral 60-88% (b) $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Error bars and open boxes around points show statistical and $p_T$-dependent systematic uncertainties. Boxes at the unity shows $p_T$-independent systematic uncertainties.
4. Summary
This paper presents the invariant spectra and nuclear modification factors of $K^{*0}$ mesons in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the range of the transverse momentum $1.55 < p_T < 5.75$ GeV/c, and for five centrality bins.

Comparison of $K^{*0}$-meson results in d+Au and He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and comparison of $K^{*0}$, $\varphi$, and $\pi^0$ results in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV has been carried out. The nuclear modification factors of $K^{*0}$-meson in d+Au and $^3$He+Au collisions are in a good agreement, therefore $K^{*0}$ $R_{AB}$ values does not dependent on projectile size in collision of small systems. Values of $R_{HeAu}$ of $K^{*0}$, $\varphi$, and $\pi^0$ mesons are equal to unity within uncertainties in all centrality bins in the whole $p_T$ range. The obtained results might indicate that CNM effects are not responsible for the differences of $K^{*0}$ and $\varphi$ to $\pi^0$ suppression level seen in heavy ion collisions.

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