Production of $K^*(892)^0$ mesons in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 192$ GeV

A Ya Berdnikov, Ya A Berdnikov, V S Borisov, D O Kotov and Iu M Mitrankov

Peter the Great Saint Petersburg Polytechnic University, 29 Polytechnicheskaya st., Saint-Petersburg, Russia

E-mail: borisov_vs@spbstu.ru

Abstract. Studying the properties and evolution of the QGP is one of the main goals in modern heavy ion physics. Due to strange quark content $K^0$ meson is a good probe for the study of QGP formed in heavy-ion collisions. $K^0$-meson production was previously measured by PHENIX in symmetric Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. $K^0$-meson production in asymmetric Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and spherically asymmetric uranium nuclei at $\sqrt{s_{NN}} = 192$ GeV was performed for continuation the study of the QGP properties. This report presents invariant transverse momentum spectra and nuclear modification factors of $K^0$-mesons which were measured in Cu+Au collisions at the energy of $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at the energy of $\sqrt{s_{NN}} = 192$ GeV. In results, $K^0$-mesons yields are less suppressed than the yields of non-strange mesons, which might indicate that additional particle production mechanisms are involved in the $K^0$-meson production. The production of the $K^0$-mesons in Cu+Cu, Cu+Au, and U+U collisions scales with $N_{part}$ and seems to depend on nuclear overlap size, but not on its geometry.

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 [1]. The QGP properties under laboratory conditions can be investigated in the collision of heavy ultra-relativistic nuclei [2].

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 [3,4]. Another QGP effect observed in collisions of heavy nuclei is a strangeness enhancement, which manifests itself as an increase of the yields of hadrons containing strange quarks. Chiral symmetry restoration in the QGP is the reason which reduces the energy threshold for strangeness production. Then the production of a $s\bar{s}$ pair becomes more efficient than the production of $u\bar{u}$ and $d\bar{d}$ pairs [5]. Therefore, study of a vector $K^*(892)^0$-meson production, which is measurable at high-$p_T$ and contains strange quark, is an effective way to investigate the properties of QGP [6].

This paper presents invariant transverse momentum spectra and nuclear modification factors of the $K^0$ meson. The results are measured in Cu + Au collisions at the energy of $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at the energy of $\sqrt{s_{NN}} = 192$ GeV in the pseudo-rapidity range $|\eta| < 0.35$ and in the transverse momentum range 1.55-5.75 GeV/c using the PHENIX detector at the RHIC [7, 8].

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
2. Data Analysis

This paper presents the data obtained by the PHENIX detector at RHIC in Cu+Au and U+U datasets from 2012. The $K^{*0}$-mesons are reconstructed via $K^{*0}(\bar{K}^{*0}) \to K^{\pm}\pi^{\mp}$ 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), a third layer of pad chamber (PC3), and a time-of-flight chamber (TOF). The transverse momentum of $K$ and $\pi$ mesons is measured in DC and PC3. The $K$ and $\pi$ mesons are identified in TOF. The yields of $K^{*0}$- and $\bar{K}^{*0}$-mesons are measured in the hadron decay channels $K^+ + \pi^-$ and $K^- + \pi^+$. Oppositely charged particles that are registered in a single collision are combined into pairs. The mass of the $K$-meson or $\pi$-meson is assigned to the charge particle depending on the decay channel and charge. 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 background, respectively.

The Cu+Au and U+U system analysis was performed using three techniques with independent sources of systematic uncertainties. These techniques cover different $p_T$-range and measure the yields of $K^{*0}$ mesons in the wide $p_T$-range that is possible in these collision systems. The particle identification (PID): “two-leg PID”, “one-leg PID”, and “no-PID”.

1. "Two-leg PID" or “fully identified” is the first technique. The $K$-meson and $\pi$-meson are identified in TOF.
2. “One-leg PID” or “kaon identified” is the second technique. The $K$-meson is identified in TOF.
3. “No-PID” or unidentified is the third technique. The $K$-meson mass is assigned to one of the particles, and the $\pi$-meson mass is assigned to another particle that passed DC.

The analysis method is described in details in [4].

Then invariant $p_T$-spectra of $K^{*0}$-mesons are calculated as:

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

(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; $N(\Delta p_T)$ is the number of observed mesons (meson yield); $N_{\text{evt}}$ - the number of sampled events within the relevant centrality selection; $\varepsilon_{\text{eff}}$ is the reconstruction efficiency of $K^{*0}$-meson; $Br$ is the branching ratio on the channel $K^{*0}(\bar{K}^{*0}) \to K^{\pm}\pi^{\mp}$; $\frac{1}{2}$ is the average of $K^{*0}$ and $\bar{K}^{*0}$.

Nuclear modification factors of particles in collisions of heavy nuclei 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:

$$R_{AB} = \frac{d^2N_{AB}(p_T)/dydp_T}{N_{\text{col}}/\sigma_{pp}^{\text{inel}} \cdot d^2\sigma_{pp}/dydp_T}$$

(2)

where $d^2N_{AB}/dydp_T$ is the particle yield measured in nucleon (A) – nucleon (B) collisions, $d^2\sigma_{pp}/dydp_T$ is an inclusive differential cross-section of the particle in $p+p$ collisions at the same energy, $N_{\text{col}}$ is an average number of binary inelastic nucleon-nucleon collisions, $\sigma_{pp}^{\text{inel}} = 42\pm 3$ mb is the total inelastic proton-proton cross-section [9].

3. Results

Figure 1 shows the results of invariant $p_T$-spectra which were measured for $K^{*0}$-meson in Run12 Cu+Au collisions at the energy of $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at the energy of $\sqrt{s_{NN}} = 192$ GeV in different centrality bins as described in Eq. 1.
Figure 1. Invariant transverse momentum spectra measured for $K^{*0}$ mesons in Cu+Au collisions at the energy of $\sqrt{s_{NN}} = 200$ GeV (a) and U+U collisions at the energy of $\sqrt{s_{NN}} = 192$ GeV (b). Statistical uncertainties are smaller than the marker size. Open boxes correspond to systematic uncertainties.

The nuclear modification factor $R_{AB}$ as a function of transverse momentum $p_T$ in Cu+Au collisions is shown in Figure 2. $R_{AB}(p_T)$ in U+U collisions is shown Figure 3. The nuclear modification factors for $K^{*0}$ and $\phi$ mesons are less suppressed in the most central collisions (Figure 2a, 3a) in the intermediate $p_T$-range than $R_{AB}$ values for $\pi^0$ and $\eta$ mesons in central collisions. This can be explained by strangeness enhancement effect. Yields of $K^{*0}$, $\phi$, $\pi^0$, and $\eta$ mesons are suppressed compared to ones in p+p collisions in the most central collisions at the high-$p_T$ suggesting that jet-quenching effect is observed. The nuclear modification factors in the most peripheral collisions (Figure 2b, 3b) have the same level of suppression within the systematic uncertainties for all considered mesons.

Figure 2. Nuclear modification factors of $K^{*0}$, $\phi$, $\pi^0$, and $\eta$ mesons measured as a function of $p_T$ in the most central 0-20% (a) and the most peripheral 60-80% (b) Cu+Au collisions at the energy of $\sqrt{s_{NN}} = 200$ 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 results of measuring the invariant spectra and nuclear modification factors of $K^{*0}$ mesons in Cu + Au collisions at an energy of $\sqrt{s_{NN}} = 200$ GeV in the range of the transverse momentum $2.0 < p_T < 5.75$ GeV/c, and for five centrality bins in the pseudo-rapidity range $|\eta| < 0.35$ and U + U collisions at an energy of $\sqrt{s_{NN}} = 192$ GeV in the range of the transverse momentum $1.55 < p_T < 4.25$ GeV/c, and for four centrality bins in the pseudo-rapidity range $|\eta| < 0.35$. 
In central Cu+Au and U+U collisions in the intermediate transverse momentum range, $\phi$ and $K^{*0}$ meson yields are less suppressed than the yields of non-strange mesons such as $\pi^0$, $\eta$, and $\omega$ [12], which might indicate that additional particle production mechanisms are involved in the $K^{*0}$-meson production. Yields of $K^{*0}$, $\phi$, $\pi^0$, and $\eta$ mesons are suppressed compared to ones in p+p collisions in the most central collisions at the high transverse momentum range suggesting that jet-quenching effect is observed. The comparison with previously obtained PHENIX data on the $K^{*0}$-meson production in symmetric Cu+Cu systems at $\sqrt{s_{NN}} = 200$ GeV has been carried out. The production of the $K^{*0}$-mesons in Cu+Cu, Cu+Au, and U+U collisions scales with $N_{\text{part}}$ and seems to depend on nuclear overlap size, but not on its geometry.

References
[1] Adcox K et al. 2005 Nucl. Phys. A 757 184-283
[2] Accardi A et al. 2004 Phys. Lett. B 586 244-253
[3] Berdnikov A et al. 2018 J. Phys.: Conf. Ser. 1135 012044
[4] Adare A et al. 2014 Phys. Rev. C 90 054905
[5] Kordatev V P and Feofilov G A 2011 Elementary Particle and Nuclear Physics 42(6)
[6] Ilner A et al. 2017 Phys. Rev. C 95 014903
[7] Arsene I et al. 2005 Nucl. Phys. A 757 1–27
[8] Lokesh K 2015 EPJ Web of Conferences 97 00017
[9] Adare A et al. 2011 Phys. Rev. D 83 052004
[10] Mitrankov I 2018 Proceedings of Science 345
[11] Berdnikov Y 2018 Physics of Particles and Nuclei 49 665-669
[12] Berdnikov A et al. 2019 J. Phys.: Conf. Ser. 1400 055052