Study of strange mesons in $p+p$, $d+Au$ and $Cu+Cu$ collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract. The PHENIX experiment at RHIC has measured invariant transverse momentum ($p_T$) spectra and nuclear modification factor ($R_{AB}$) of strange mesons $K^{*0}$ and $K^0_S$, in $p+p$, $d+Au$ and $Cu+Cu$ collisions at center of mass energy 200 GeV. The $p_T$ range of these measurements spans from 1.1 to 8.5 GeV/c for $K^{*0}$ and from 2 to 13 GeV/c for $K^0_S$. Similar to the other light-quark mesons measurements, both these strange mesons show no cold-nuclear-matter effects in the measured $p_T$ range in $d+Au$ collisions. The nuclear modification factor for $d+Au$ ($R_{dAu}$) $\approx 1$ and is almost constant as a function of $p_T$. In case of $Cu+Cu$ peripheral collisions, no suppression is registered with respect to the $p+p$ yields scaled with number of binary collisions. In central $Cu+Cu$ collisions, both mesons suffer substantial amount of suppression at high $p_T$ ($>5$ GeV/c), which is similar to the suppression suffered by light-quark mesons. In the intermediate $p_T$ range ($2 < p_T < 5$ (GeV/c)), the strange mesons are less suppressed than light-quark mesons ($\pi^0$) and more suppressed than baryons ($p$, $\bar{p}$).

1. Introduction

Lattice QCD calculations predict phase transition from hadronic phase to quark gluon plasma (QGP) above an energy density of 1 GeV/fm$^3$ [1]. The high energy heavy ion colliders, RHIC and LHC, provide the means to create a quark gluon plasma in the laboratory and study its properties. Particles traversing this hot/dense medium suffer significant energy loss which results in the modification of fragmentation functions and softening of the particle spectra. The modification of the spectra due to the medium can be quantified by the "nuclear modification factor", defined as the ratio of the yield in heavy ion collisions ($A+B$) to the yield in $p+p$ collisions scaled by the number of binary collisions ($N_{coll}$). Analytically, it is expressed as, $R_{AB} = \frac{d^2N_{AB}/dy dp_T}{N_{coll} d^2N_{pp}/dy dp_T}$. The deviation of the value of $R_{AB}$ from 1, is a manifestation of medium effects. In heavy ion collisions, the energy loss by high $p_T$ partons is reflected by the suppression of the yield (i.e. $R_{AB} < 1$). Figure 1 shows the $R_{AA}$ for different particles for the most central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. It is seen that for $p_T > 5$ GeV/c, the $R_{AA}$ value is around 0.2 which is similar for all particles irrespective of quark content. At intermediate $p_T$ ($2 < p_T$ GeV/c $< 5$), the medium-effects for particles with different quark content are different. Different bulk phenomenons (e.g. flow, recombination, Cronin effect) may play important roles towards hadron production in this $p_T$ range. The measurement of strange hadrons is important to study collective effects in the intermediate $p_T$ and the parton energy-loss effects in the high $p_T$ range. These proceedings present the overview of $K^0_S$ and $K^{*0}$ measurements at midrapidity by PHENIX detector in $p+p$, $d+Au$ and $Cu+Cu$ collisions at $\sqrt{s_{NN}} = 200$ GeV. The measurements
Figure 1. (color online) Nuclear modification factor as a function of $p_T$ for $\pi^0$, $p$, $\gamma$, $\eta$, $\phi$, $J/\psi$, $\omega$, $e^\pm$, $K^\pm$ for the most central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Plot taken from Ref. [3].

include the invariant yield transverse momentum spectra and nuclear modification factor for different centrality bins [2]. This article mainly focuses on the results related to the nuclear modification factor obtained in $d+Au$ and $Cu+Cu$ collisions.

2. PHENIX detector

The results presented here are obtained with the help of global, tracking and PID detectors of PHENIX [4]. The event information is obtained from the Beam Beam Counters (BBC), located at $|\eta| < 0.35$ and covering $2\pi$ in azimuth. The track reconstruction and momentum determination are done with the help of the Drift Chambers (DC) and first layer of the Pad Chambers (PC). The second and third layers of PC help to suppress contribution of the secondary tracks originating from the decay of long-lived particles or from the interaction of tracks with the detector material. The Time of Flight (TOF) detector identifies charged hadrons. The Electro-Magnetic Calorimeter (EMCal) measures the position and the energy of photons and electrons.

3. Analysis

The $K^0_S$ and $K^{*0}$ mesons are reconstructed from $K^0_S \rightarrow \pi^0(\rightarrow \gamma\gamma)\pi^0(\rightarrow \gamma\gamma)$ and $K^{*0} \rightarrow K^\pm\pi^\mp$ channels respectively. $K^0_S$ reconstruction is done in two steps. Initially, $\pi^0$'s are reconstructed from photon pairs after applying kinematic and analysis cuts. Then $K^0_S$ meson is reconstructed from $\pi^0$ pairs within the same event. For $K^{*0}$ reconstruction, a pair of oppositely charged tracks with $p_T > 0.3$ GeV/c is required. To have measurement in a wider $p_T$ range, three different exclusive and statistically independent techniques are used for $K^{*0}$ analysis. In one of the techniques both tracks are identified in TOF as pions and kaons; it is used to measure $K^{*0}$ production at low $p_T$. In other approach, tracks are not identified but matched in PC3 and given the masses of kaons and pions. This technique extends the measurement to highest possible $p_T$. The intermediate $p_T$ range is obtained by identifying kaon in TOF and matching the other track in PC3 before assigning the mass of pion. For analysis details one may refer [2].
4. Results
The nuclear modification factor for $K_S^0$ and $K^{*0}$ in $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV for the most central and the most peripheral bins are shown in Fig. 2. A comparison with $\pi^0$ [5], $\phi$ [6] and protons [7] are also shown. The statistical and systematic errors are shown with error bars and boxes respectively. It is observed that $R_{dAu}$ is consistent with unity within uncertainties for all measured centrality bins for $p_T > 1$ GeV/c. In the most central bin, there is a slight hint of Cronin enhancement in the intermediate $p_T$ (2-5 GeV/c) range and suppression at $p_T > 6-8$ GeV/c. The comparisons with $\pi^0$ and $\phi$ mesons show that cold nuclear matter effects do not play a significant role in these mesons productions. However, the proton shows an enhancement in the central collisions at intermediate $p_T$, which can be explained by recombination models [8].

The nuclear modification factor for $K_S^0$ and $K^{*0}$ along with $\pi^0$ [9] and $\phi$ [6] in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV for the most central (0-20%), minimum bias (0-94%) and the most peripheral (60-94%) collisions are shown in the left panel of Fig. 3. The statistical and systematic errors are shown with error bars and boxes respectively. Particles are suppressed in minimum-bias and most central collisions for $p_T > 5$ GeV/c, whereas, in the most central collisions, $R_{CuCu}$ reaches a value around 0.5. In the intermediate $p_T$ (2-5 GeV/c) range, $K^{*0}$ and $\phi$ are less suppressed than $\pi^0$ and below 2 GeV/c, neither of $K^{*0}$ and $\phi$ are suppressed. Peripheral collisions follow binary scaling within uncertainties for all these mesons in the measured $p_T$ range. Figure 3 (right panel), compares the suppression of mesons and baryons for the central and peripheral collisions. The data for $K^{*0}$, $\phi$ [6] and $\pi^0$ [9] are shown for Cu+Cu collisions and the data for $K^\pm$ [7] and protons [7] are shown for Au+Au collisions for similar $\langle N_{part} \rangle$ values. The statistical and systematic errors are shown with error bars and boxes respectively. For the central collisions, $\pi^0$ is the most suppressed meson and has a flat behavior in the measured $p_T$ range. In the intermediate $p_T$, the mesons, $K^{*0}$ and $\phi$ are less suppressed than $\pi^0$ but more suppressed than protons. At high $p_T$, all particles are suppressed and seem to have similar $R_{AA}$ values within uncertainties, irrespective of their valence quark content. In peripheral collisions, $R_{AA}$ for all particles, except protons are consistent with unity within error bars for $p_T > 2$.
Figure 3. (color online) Left panel: Nuclear modification factor as a function of $p_T$ for $K^0_S$, $K^{*0}$ for different centralities in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. Results from $\pi^0$ [9] and $\phi$ [6] are also shown. Right panel: Comparison of the nuclear modification factor of $\pi^0$ [9], $\phi$ [6], and $K^{*0}$ in Cu+Cu collisions and proton [7] and kaon [7] in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. For details see text.

5. Conclusions

Measurements of $K^0_S$ and $K^{*0}$ mesons via $\pi^0\pi^0$ and $K^{\pm}\pi^{\mp}$ decays respectively, in $p+p$, $d+Au$ and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV, with PHENIX are presented. In $d+Au$ collisions, in the measured $p_T$ range, no significant cold nuclear matter effect is seen for both mesons. In Cu+Cu collisions, no suppression is observed in peripheral collisions. In the most central collisions, for $p_T > 5$ GeV/$c$, $K^0_S$ and $K^{*0}$ show a suppression similar to $\pi^0$ and $\phi$ within uncertainties. However, for $2 < p_T$ (GeV/$c$) < 5, baryons show no suppression, $\pi^0$s are the most suppressed species and particles with strange quark content show an intermediate behavior. These results provide additional constraints to the modelisation of hadron energy loss in medium.

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