Recent PHENIX Results on High-$p_T \pi^0$ and $\eta$ Production in Cu+Au and U+U Collisions

To cite this article: Murad Sarsour and PHENIX Collaboration 2018 J. Phys.: Conf. Ser. 1070 012011

View the article online for updates and enhancements.
Recent PHENIX Results on High-\(p_T\) \(\pi^0\) and \(\eta\) Production in Cu+Au and U+U Collisions

Murad Sarsour (for the PHENIX Collaboration)
Georgia State University, Atlanta, Georgia 30303, USA
E-mail: msar@gsu.edu

Abstract. One of the key signatures of the Quark-Gluon Plasma (QGP), is the modification of hadron transverse momentum differential cross-sections in heavy-ion collisions as compared to \(p+p\) collisions. Suppression of hadron production at high transverse momenta (\(p_T\)) in heavy ion collisions has been explained by the energy loss of the partons produced in the hard scattering processes that traverse the deconfined quantum chromodynamics (QCD) matter. Recent RHIC runs with asymmetric Cu+Au collisions and non-spherical nuclear U+U collisions provide the means to systematically study suppression pattern of hadrons in different nuclear overlap geometry and different energy density and surface biases compared to Au+Au collisions. These studies provide an important input to improve theoretical description of parton energy loss in QGP. In this proceeding, we present results from \(\pi^0\) and \(\eta\) production in Cu+Au and U+U systems and discuss how these results further our understanding of parton energy loss.

1. Introduction

Ever since RHIC announced the discovery of the hot and dense state of strongly interacting matter called Quark-Gluon Plasma (QGP) \([1, 2]\) the main objective has been to characterize its properties. Jet quenching, manifested in suppression of high-\(p_T\) hadron production in \(A+A\) collisions relative to that in \(p+p\) collisions, was one of the early evidences to the existence of QGP \([3]\) and provides an excellent way to characterize its properties. The suppression, which is explained by the energy loss of the hard scattered partons in the QGP medium, is studied by measuring the nuclear modification factor, \(R_{AB}\). \(R_{AB}\) is defined as the ratio of the hadron yields in \(A+B\) collisions to \(p+p\) collisions scaled by the number of nucleon-nucleon collisions in the \(A+B\) system, \(N_{\text{coll}}\) \([4]\), and is calculated as:

\[
R_{AB} = \frac{d^2N_{AB}/dydp_T}{\langle N_{\text{coll}} \rangle \times d^2N_{pp}/dydp_T},
\]

where \(d^2N_{AB}/dydp_T\) is the per-event yield of particle production in heavy ion collisions and \(d^2N_{pp}/dydp_T\) is the per-event yield of the same process in \(p+p\) collisions. In PHENIX, we use leading hadrons, \(\pi^0\) and \(\eta\), as proxy for jets. \(\pi^0\) is abundantly produced and can be measured to a high \(p_T\) while \(\eta\) has hidden strangeness and allows studying hadron suppression as a function of flavor and mass. At RHIC, jet quenching was studied extensively in symmetric collisions such as Au+Au and Cu+Cu, recent asymmetric Cu+Au collisions at \(\sqrt{s_{NN}} = 200\) GeV and non-spherical nuclear U+U collisions at \(\sqrt{s_{NN}} = 193\) GeV provided the opportunity to study jet
quenching in different nuclear overlap geometry and different energy density and surface biases. Cu+Au collision is the first asymmetric system and differs from symmetric systems by special form of nuclear overlap region while U+U collision is the largest heavy collision system with the largest density.

2. Experimental setup

The PHENIX detector [5] has a high rate capability utilizing a fast DAQ and specialized triggers, high granularity detectors, and good mass resolution and particle ID. Detection of $\gamma$, $\pi^0$ and $\eta$ utilizes the finely grained electromagnetic calorimeter (EMCal). The very forward beam-beam counters (BBC) are used to determine the collision vertex position and time, the beam luminosity and form a minimum bias trigger.

In 2012, the PHENIX collaboration collected data from Cu+Au and U+U collisions provided by the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). Results from these data sets are presented in this proceeding.

3. Results

$\pi^0$ and $\eta$ are identified through their photon decay channel. The photons are reconstructed in the finely segmented EMCal with high efficiency. The invariant mass spectrum is formed from all pairs of the reconstructed photons, as shown in Figure 1, and the combinatorial background is estimated using mixed-event technique and subtracted from it. The $\pi^0$ yield is then extracted by fitting the $\pi^0$ region (0.10 - 0.17 GeV/c$^2$) by a Gaussian and a first order polynomial while the $\eta$ yield is extracted by fitting the $\eta$ mass region (0.48 - 0.62 GeV/c$^2$) by a Gaussian and a second order polynomial, as shown in inserts (b) and (c) of Figure 1.

3.1. Cu+Au collisions

To extract $R_{AB}$ of $\pi^0$ and $\eta$ in Cu+Au collisions, the PHENIX collaboration measured the $\pi^0$ and $\eta$ $p_T$-spectra over a wide $p_T$ range in different centrality classes, as shown in Figure 2.

The ratio of $\eta$ to $\pi^0$, shown in Figure 3, is consistent between all centrality classes and consistent with that measured in $p+p$, $p+A$ and $A+A$ collisions at different energies [6,7].

Figure 4 shows $R_{AB}$ of $\pi^0$ and $\eta$ versus $p_T$ using the spectra shown in Figure 2. This figure shows that in central and semi central Cu+Au collisions $\pi^0$ and $\eta$ are suppressed while in peripheral Cu+Au collisions we observe a hint of $\pi^0$ and $\eta$ enhancement. In addition, $\pi^0$
The invariant $p_T$-spectra of $\pi^0$ (left) and $\eta$ (right) measured in different centrality classes of Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The spectra are scaled by arbitrary factors for clarity.

Figure 3. Ratios of $\eta$ to $\pi^0$ yields as a function of $p_T$ in different centrality classes of Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The dashed curve shows the $m_T$ scaling curve normalized to 0.5 at high momentum.

Figure 2.

3.2. U+U collisions

Figure 5 shows the $\pi^0$ and $\eta$ $p_T$-spectra over a wide range in all centrality classes. However, to extract $R_{AA}$ one needs to carefully select the collision geometry since the Uranium nucleus is deformed. Therefore in the Monte Carlo Glauber based approach [9], the nucleon density
Figure 4. $R_{AJ}$ of $\pi^0$ (black) and $\eta$ (red) as a function of $p_T$ in different centrality classes of Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

distribution is parameterized by a deformed Woods-Saxon profile [10],

$$\rho = \frac{\rho_0}{1 + \exp([r - R']/a)},$$  \hspace{1cm} (2)

$$R' = R[1 + \beta_2 Y^2_2(\theta) + \beta_4 Y^4_4(\theta)],$$  \hspace{1cm} (3)

where $\rho_0$ is the normal nuclear density, $R$ and $a$ denote the radius of nucleus and the surface diffuseness parameter, respectively. The spherical harmonic functions and the $\beta$ values introduce the deformation from spherical shape in the Uranium nucleus. Table 1 summarizes the two sets of Wood-Saxon parameters that were used in Glauber MC.

Table 1. Parameter sets for Uranium nucleus [11, 12].

| Parameter | Set1/Glauber1 [11] | Set2/Glauber2 [12] |
|-----------|-------------------|-------------------|
| $R (fm)$  | 6.81              | 6.86              |
| $a (fm)$  | 0.61              | 0.42              |
| $\beta_2$ | 0.286             | 0.265             |
| $\beta_4$ | 0.093             | 0                 |
Figure 5. The invariant $p_T$-spectra of $\pi^0$ (left) and $\eta$ (right) measured in different centrality classes of U+U collisions at $\sqrt{s_{NN}} = 193$ GeV. The spectra are scaled by arbitrary factors for clarity.

Figure 6. $R_{AA}$ of $\pi^0$ as a function of $p_T$ in different centrality classes of U+U collisions at $\sqrt{s_{NN}} = 193$ GeV. The U+U results are compared to those of Au+Au at $\sqrt{s_{NN}} = 200$ GeV.

Figure 6 shows $\pi^0$ $R_{AA}$ in U+U collisions as a function of $p_T$ for both sets of parameters at different centralities. The data are also compared to $\pi^0$ $R_{AA}$ in Au+Au collisions. At the same $N_{coll}$ values, $R_{AA}$ in Au+Au and U+U collisions are consistent in most- to mid-central
collisions which implies that $\pi^0$ production depends on the size of the nuclear overlap but not on its density. However, the most peripheral collisions show larger suppression in U+U collisions.

**Figure 7.** $R_{AA}$ of $\pi^0$ (magenta) and $\eta$ (blue) as a function of $p_T$ in different centrality classes of U+U collisions at $\sqrt{s_{NN}} = 193$ GeV.

Figure 7 shows $\eta R_{AA}$ compared to that of $\pi^0$ for different centrality classes. Similar to the case of Cu+Au collisions, $R_{AA}$ of $\eta$ and $\pi^0$ are consistent over all centralities.

Comparisons of the integrated $R_{AB}$ versus $N_{part}$ between the different collision systems, Cu+Cu, Cu+Au, Au+Au and U+U, are shown in Figures 8. Additional comparison of $R_{AB}$ versus $p_T$ for the most peripheral collisions in Cu+Cu, Cu+Au, and Au+Au is shown in Figure 9. These comparisons show that at $N_{part} > 50$ all studied systems are consistent with each other. However, at $N_{part} < 50$, although consistent within uncertainties, there seems to be ordering in the medium modification, Cu+Au > Cu+Cu > Au+Au > U+U.

4. Summary

PHENIX has measured $p_T$ spectra and nuclear modification factors for $\pi^0$ and $\eta$ in Cu+Au and U+U collisions at 200 and 193 GeV, respectively. $R_{AB}$ factors for $\pi^0$ and $\eta$ are consistent within uncertainties at all momenta and centralities which indicates that they have similar fragmentation function modification by the medium in the accessed $p_T$ range. We also observed very consistent centrality dependent medium modification to previous jet measurements.

In central and semi-central A+B collisions: $\pi^0$ and $\eta$ production depend on the size of the nuclear overlap but not on its shape or density. However, there is a hint of dependence on both in most peripheral, Cu+Au > Cu+Cu > Au+Au > U+U.
Figure 8. $R_{AB}$ as a function of $N_{part}$ for Cu+Au collisions compared with Au+Au collisions (left) and for U+U collisions (two sets) compared with Au+Au collisions (right).

Figure 9. $R_{AB}$ as a function of $p_T$ for peripheral Cu+Au collisions compared with peripheral Cu+Cu and Au+Au collisions.

References
[1] Adcox K et al. 2005 Nucl. Phys. A 757 184 – 283
[2] Adams J and other 2005 Nucl. Phys. A 757 102 – 183
[3] Afanasiev S et al. 2012 Phys. Rev. Lett. 109 152302
[4] Adare A et al. 2013 Phys. Rev. C 87(3) 034904
[5] Adcox K et al. (PHENIX Collaboration) 2003 Nucl. Instrum. Methods Phys. Res., Sec. A 499 469
[6] Adler S S, et al. 2007 Phys. Rev. C 75 024909
[7] Reader F et al. 1975 Phys. Lett. B 55 232 – 236
[8] Timilsina A 2016 Nucl. Phys. A 956 637 – 640
[9] Miller M L, Reygers K, Sanders S J and Steinberg P 2007 Annu. Rev. Nucl. Part. Sci. 57 205–243
[10] Hagino K, Lwin N W and Yamagami M 2006 Phys. Rev. C 74(1) 017310
[11] Masui H, Mohanty B and Xu N 2009 Phys. Lett. B 679 440 – 444
[12] Shou Q, Ma Y, Sorensen P, Tang A, Videbk F and Wang H 2015 Phys. Lett. B 749 215 – 220