High-\(p_T\) \(\pi^0\), \(\eta\), Identified and Inclusive Charged Hadron Spectra from PHENIX

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PHENIX has extended the measurement of the \(\pi^0\), \(\eta\), identified and inclusive charged hadron up to 20 GeV/c, and extended the measurement to the Cu+Cu collision system. A strong suppression is observed for both \(\pi^0\) and charged hadron yields in central Au+Au and Cu+Cu collisions. Comparing Au+Au and Cu+Cu systems, \(R_{AA}\) becomes independent of \(p_T\) above 5 GeV/c. Its centrality dependence is compared with two models in order to test for universal \(N_{\text{part}}\) scaling that is independent of system; results are inconclusive. The results are compatible with energy loss predictions. In addition, the ratio of \(\eta\) to \(\pi^0\) approaches, within uncertainties, a constant value of 0.4 \(\sim\) 0.5 at high \(p_T\) in p+p, d+Au, and Au+Au, while the ratio of \(K_s\) to \(\pi^0\) is also consistent with a constant value at high \(p_T\) in d+Au and p+p. These results are compatible with normal jet fragmentation.

1. Physics Motivation

We have previously observed that \(\pi^0\), \(\eta\) and charged hadron yields are significantly suppressed especially for the high \(p_T\) region (\(p_T \geq 4 \sim 5\) GeV/c) in Au+Au collision at 200 GeV compared with p+p collisions.\(^{[1]}\)[2][3][4] Since there is no suppression in d+Au collisions at high \(p_T\),\(^{[3]}\) it is understood that the suppression occurs due to the final state interaction at the collision such as the gluon radiation in the hot dense matter. Another evidence for the suppression being a final state effect comes from the non-suppression of the direct photon yield in Au+Au collisions.\(^{[5]}\) To understand the character of the suppression more, the comparison between different system size (p+p/d+Au/Cu+Cu/Au+Au) measurements has been studied, and an extended \(p_T\) reach to 20 GeV/c has been afforded by the long Run4 Au+Au dataset.

2. Data Analysis, \(\pi^0\), \(K_s\), charged hadron, and \(\eta\)

We newly measured the following spectra.

- \(\pi^0\) spectra with extended \(p_T\) range in Au+Au at 200GeV
- \(\pi^0\) and charged hadron spectra in Cu+Cu at 200GeV
- \(K_s\) spectra in d+Au and p+p at 200GeV \(^{[11]}\)

\(^{*}\)For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume.
The PHENIX experiment consists of four spectrometer arms (two central arms and two muon arms) and a set of global detectors. Each central arm covers the pseudorapidity range $|\eta| \leq 0.35$ and 90 degrees in azimuth. Charged particles are tracked by a drift chamber (DC) and pad chambers (PC) in each central arm. The electromagnetic calorimeters (EMCal) are used to measure $\gamma$ energy deposit and construct the invariant masses of $\pi^0 \rightarrow 2\gamma$, $K_s \rightarrow 2\pi^0 \rightarrow 4\gamma$ and $\eta \rightarrow 2\gamma$. [12][16]

3. The Nuclear Modification Factor $R_{AA}$

3.1. $\pi^0$, Charged Hadron and $\eta$

The Fig.1 shows the comparison of $R_{AA}$ for $\pi^0$ and charged hadrons in 0-10 % most central Au+Au and Cu+Cu collisions as function of $p_T$. Both $\pi^0$ and charged hadron are strongly suppressed in both Au+Au and Cu+Cu collision. The difference between $\pi^0$ and charged hadron for $p_T \leq 5$ GeV/c comes from the proton contribution. For more central collision, the suppression is getting stronger and the difference between $\pi^0$ and charged hadron is getting larger. Above 5 GeV/c, $\pi^0 R_{AA}$ becomes flat out to 20 GeV/c. These results are consistent with the model predicting parton energy loss in the medium [10] and the model predicting shadowing, Cronin effect, and parton energy loss in the medium.[9] In addition, $\eta$ is also suppressed in central Au+Au collisions and the suppression pattern is similar to $\pi^0$. [12]

![Figure 1](image-url)

Figure 1. The comparison of $R_{AA}$ for $\pi^0$ and charged hadron at 0-10 % centrality bin in Au+Au (left) and Cu+Cu (right) collisions as a function of $p_T$ with theoretical prediction (Red [9] and purple [10] lines). The error bars are statistical error, and the boxes are systematic error.

3.2. Comparison between Au+Au and Cu+Cu

In Fig.2(a), the comparison of $R_{AA}$ in Au+Au to that in Cu+Cu with similar $N_{part}$ is shown. The suppression is similar for similar $N_{part}$ at mid-centrality. Though a universal $N_{part}$ scaling is roughly suggested,[7] due to the size of the uncertainties, it is unclear whether a single scaling curve can exactly describe the suppression ($R_{AA}$) in both systems simultaneously. In Fig.2(b), we show the integrated $R_{AA}$ of $\pi^0$ at $7.0 \leq p_T \leq 20.0$ GeV/c with two different theoretical curves [8][9] as a function of $N_{part}$. Both models are consistent with the data from central to mid-central collisions.
Figure 2. (a) The comparison between $\pi^0$ $R_{AA}$ in Au+Au and Cu+Cu at similar $N_{part}$ (\(\sim 74\)). (b) The integrated $R_{AA}$ at $7 \leq p_T \leq 20$ GeV/c with theoretical curves [8][9] as a function of $N_{part}$.

4. The Particle Ratio

The ratio of $\eta$ to $\pi^0$ is $\sim 0.4 - 0.5$ in all systems and for all centralities as shown in fig.\[12\]. Also, the ratio of $K_s$ to $\pi^0$ at p+p and d+Au becomes flat at high $p_T$ as shown in fig.\[11\]. Therefore, the mesons are affected by the medium in the same way in different collision systems. These results are consistent with jet fragmentation at high $p_T$.

Figure 3. The ratio of $\eta$ to $\pi^0$ in Au+Au (left), d+Au (right) and p+p (right) as a function of $p_T$ at $\sqrt{s} = 200$ GeV. The error bars are statistical error, and the boxes are systematic error.
5. Summary

We have studied $\pi^0, \eta, K_s$ and charged hadron spectra in Au+Au, Cu+Cu, d+Au and p+p at high $p_T$. For $\pi^0$ and charged hadron, we observed the suppressions in both Cu+Cu and Au+Au collisions compared with p+p collisions, and no suppression is observed in d+Au collisions. The $R_{AA}$ comparison between Au+Au and Cu+Cu indicates that the suppression is almost the same for similar $N_{\text{part}}$. A universal $N_{\text{part}}$ scaling of $R_{AA}$, independent of system, describes the data in an approximate sense, but it cannot be confirmed exactly due to experimental uncertainties. In addition, the high $p_T \pi^0$ suppression is flat out to 20 GeV/c and its magnitude is quantitatively consistent with parton energy loss model calculations. $\eta$ has a similar suppression pattern as $\pi^0$ does. The ratio of $\pi^0$ to $\eta$ is independent of centralities and system size. Similarly, the $K_s$ to $\pi^0$ ratio is constant within uncertainties at high $p_T$ for both p+p and d+Au. These particle ratios are consistent with normal jet fragmentation.

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