PROCEEDINGS OF SCIENCE

Scaling Properties of High-p_T Light Hadrons from Small to Large Systems by PHENIX

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Abstract. To study properties of quark-gluon plasma (QGP) PHENIX has performed measurements of light hadrons (π^0, η and other hadrons with masses up to ~1GeV) in a broad set of projectile-target combinations including p+Au, d+Au, ^{3}He+Au, Cu+Cu, Cu+Au, Au+Au, and U+U. This rich collection of data sets allows for detailed studies of parton energy loss in large systems, exploring various scaling behaviors from RHIC to LHC. We also explore the evolution of the hadron spectra with system size. In particular, the multiplicity dependence of hadron production in small systems is examined for signs of energy loss at high p_T, and collective effects at low p_T.

International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
30 September - 5 October 2018
Aix-Les-Bains, Savoie, France

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PoS(HardProbes2018)108

1. Introduction

One of the major objectives in the field of high-energy nuclear physics is to quantify and characterize the properties of quark-gluon plasma (QGP), formed in relativistic ion collisions, representing an ideal liquid with partonic degrees of freedom. The study of hadron production in p+p, p+A, A+A collisions provides an excellent way to characterize properties of QGP. At high-p_T hadron production is suppressed in central heavy ion collisions which is usually explained by energy loss of hard scattered partons in the hot and dense medium. This effect was called jet quenching and was one of the first evidences of the existence of QGP at RHIC[1]. However, in the intermediate transverse momentum range the so-called baryon puzzle occurs [2], which manifests itself in different suppression patterns of hadrons species. The PHENIX collaboration measured light hadron production (π^0, η, K_S, φ, ω) in a broad set of collisions (p+Au, d+Au, ^{3}He+Au, Cu+Cu, Cu+Au, Au+Au, and U+U). Different hadron species allow for a systematic study of jet quenching effect as a function of flavor and mass: π^0 mesons are abundantly produced and are measurable up to high transverse momenta, η, K_S and φ have hidden strangeness, φ and proton masses are approximately equal and ω comprises light valence quarks similar to the π^0 and η but has a larger mass and a spin.

Jet quenching was experimentally observed in central collisions of symmetric Au+Au and Cu+Cu systems [3]. Now the Cu+Au asymmetric system and the system of non-spherical U+U nuclei are under consideration. Cu+Au is the first asymmetric heavy-ion collision system which provides unique initial geometrical configurations and U+U is the heavy ion collision system in which the largest energy density in central collisions can be achieved at RHIC.

The study of small systems such as p+Au, d+Au, ^{3}He+Au provides an opportunity to understand whether high-p_T hadron suppression in large systems is due to final state effects or because of cold nuclear matter (CNM) effects [4]. CNM effects include multiple scattering of an incident proton in a target nucleus, initial-state energy loss, k_T broadening and so on. The large amount of accumulated data allows to study scaling properties of light hadron production from small to large systems: parton energy loss in heavy ion collisions, CNM effects in small systems.

2. Experimental setup

All results presented in this paper were obtained using the central arms of the PHENIX detector which is described in [5]. Each central arm of the PHENIX spectrometer, western and eastern, covers 90° in azimuthal angle and $|\eta|<0.35$ in pseudo-rapidity and provides detection of photons, electrons and charged hadrons originating from the nuclei collision region. Beam-beam counters (BBC) are used for z-vertex measurement and centrality classification of the nuclear collisions events. The electromagnetic calorimeter (EMCal) of the PHENIX consists of six lead-scintillator sectors and two lead-glass sectors. EMCal provides measurements of photon kinematic properties and serves as an effective tool for neutral meson reconstruction. The main central arms tracking system consists of Drift Chambers (DC) and Pad Chambers (PC). A set of time of flight systems (ToF) is used for charged hadron identification.

3. Results

Light mesons π^0, η, K_S, φ, ω were identified as peaks in invariant mass distributions. π^0 and η invariant mass distributions were formed by combining pairs of γ clusters in the EMCal, K_S – by combining pairs of π^0 in the EMCal, ω – by combining pairs of π^0 and γ in the EMCal, φ – by combining pairs of K^+ and K^- in the DC and ToF. Combinatorial background was reduced using the event-mixing technique [6,7] and residual background was estimated by polynomial functions. Light mesons raw yields were obtained as the difference between the integral of the invariant mass distribution in a 2 sigma region centered at the peak and the polynomial background function in the same region.

To investigate particle suppression in A+A collisions, nuclear modification factors are calculated according to the relation:

$$\mathrm{R_{AA}} = \frac{1}{\langle T_{AA}\rangle}\frac{dN_{AA}/dp_T dy}{d\sigma_{pp}/dp_T dy} \qquad (1)$$

Where $dN_{AA}/dp_T dy$ is the inclusive hadron production spectrum in A+A collisions, $d\sigma_{pp}/dp_T dy$ is the inclusive differential cross section for the same hadron production in p+p collisions at the same center-of-mass energy, $\langle T_{AA}\rangle = \langle N_{coll}\rangle/\sigma_{INEL}^{NN}$ is the nuclear overlap function, which is estimated with the Glauber-model Monte-Carlo simulation.

To extract nuclear modification factors the p_T distributions of light mesons were calculated in wide p_T range up to 20 GeV/c and for different centrality bins.

3.1. Large systems

Nuclear modification factors for π^0, η, K_S, φ, ω in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV were measured for 1 to 20 GeV/c in p_T and for 4 centrality bins and are shown in Fig. 1. π^0, η, K_S, ω show similar suppression values in Cu+Au collisions.

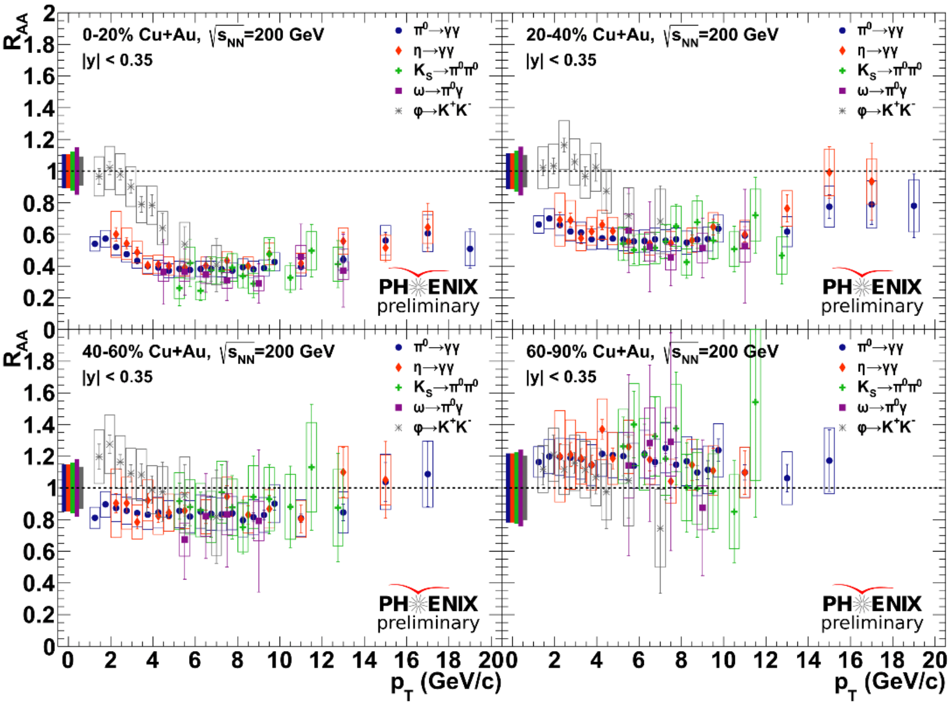

Figure 1. Nuclear modification factors measured for π, η, K_S, φ, ω in Cu+Au collisions at $\sqrt{s_{NN}}$=200 GeV

At the same time for central collisions up to 40-60% φ shows less suppression than other light mesons in the intermediate transverse momentum range of 2 to 5 GeV/c. At higher transverse momentum values p_T>5 GeV/c the φ R_{AA} approaches and becomes comparable to the π^0, η, K_S, ω R_{AA}. The same light meson behavior was observed in symmetric Cu+Cu and Au+Au collisions [2, 8], which implies that production and suppression of the light mesons seems to scale with the average size of the nuclear overlap region and does not depend on the details of its shape. In peripheral collisions light mesons R_{AA}'s show hint of enhancement.

The R_{AA} of π^0 and η were also measured in U+U collisions as a function of p_T and for 4 centrality bins. We considered two parametrizations of the deformed Woods-Saxon distribution for Uranium for Monte Carlo Glauber calculations (SET1 and SET2) [9]. The comparison of π^0 and η R_{AA} in U+U collisions at $\sqrt{s_{NN}}$=192 GeV with Au+Au results at $\sqrt{s_{NN}}$=200 GeV and at the similar number of nucleon-nucleon collisions (N_{coll}) is shown in Fig. 2. At the same N_{coll} values, nuclear modification factors are consistent in central collisions, thus production and suppression of π^0 and η depends on the size of the nuclear overlap region, but not on its energy density. The most peripheral collisions show a hint of larger suppression in U+U collisions.

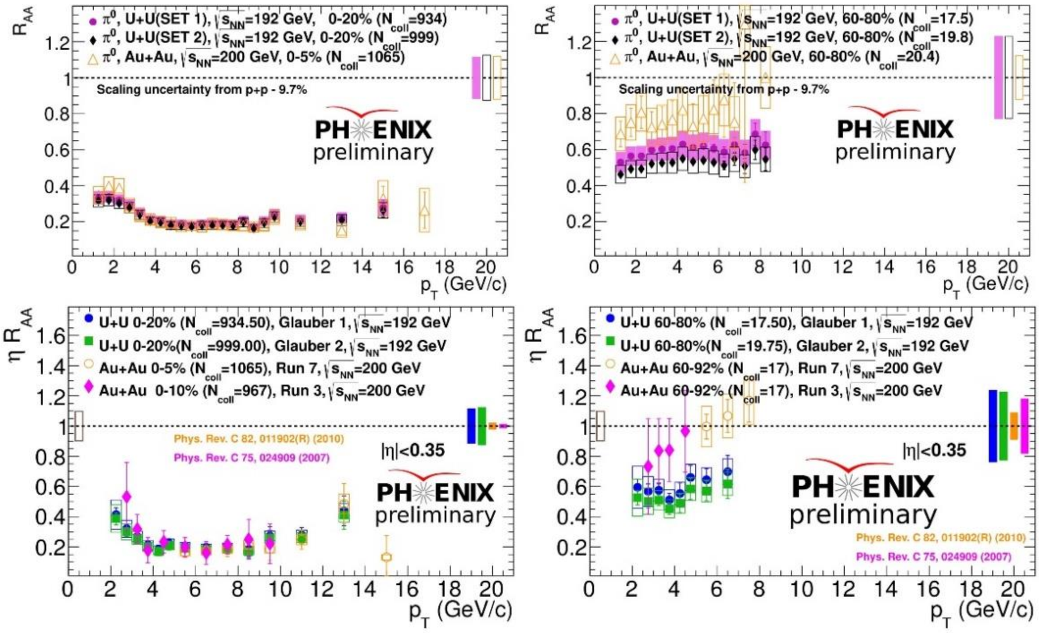

Figure 2. Nuclear modification factors measured for π^0 and η in U+U collisions at $\sqrt{s_{NN}}$=192 GeV. The U+U results are compared to those of Au+Au at $\sqrt{s_{NN}}$=200 GeV at same N_{coll}.

3.2. Small systems

Nuclear modification factors for π^0-mesons measured in p+Au, d+Au, ^{3}He+Au collisions at $\sqrt{s_{NN}}$=200 GeV are shown at Fig. 3. Nuclear modification factors were measured for 1 to 20

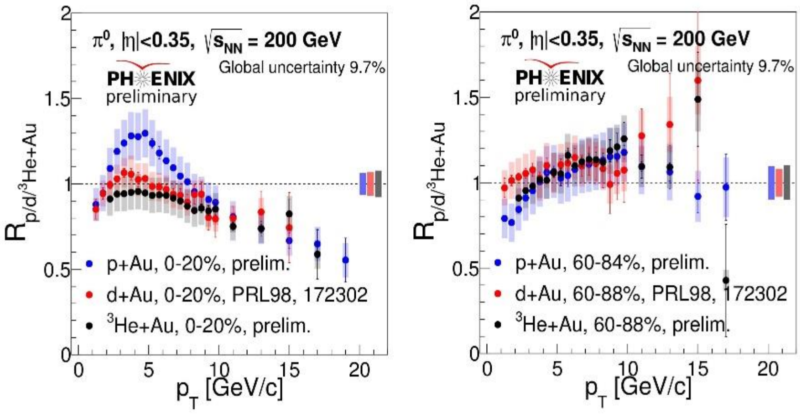

Figure 3. Nuclear modification factors measured for π^0 in p/d/^{3}He+Au collisions at $\sqrt{s_{NN}}$=200 GeV.

GeV/c in p_T and for 4 centrality bins. π^0 R_{AA}'s for light systems show that light systems are consistent with each other at high-p_T. In the most central collisions a hint of suppression at high-p_T is observed. In the most central collisions, in the intermediate transverse momentum range ordering is seen. The enhancement observed in this region shows indications for a system size dependence: R_{pAu}>R_{dAu}>R_{HeAu}.

4. Summary

The PHENIX experiment has measured p_T spectra and nuclear modification factors for π^0, η, K_S, φ, ω in Cu+Au and U+U collisions at 200 and 193 GeV, respectively.

Light mesons nuclear modification factors in U+U, Au+Au, Cu+Cu and Cu+Au collisions for similar N_{part} values exhibit similar shape. Production and suppression of the light mesons seems to scale with nuclear overlap size regardless of its geometry and its energy density.

The φ-meson exhibits a different suppression pattern compared to lighter mesons in large systems. In central collisions the φ-meson is less suppressed than lighter mesons in the intermediate p_T range. At higher p_T values, all lighter mesons show similar suppression values. Recombination and radial flow are two alternative explanations of experimental results [2].

R_{AA}'s of π^0 are consistent at high-p_T in small system p/d/^{3}He+Au collisions at all centralities. In central collisions at moderate p_T enhancement scales with system size: R_{pAu}>R_{dAu}>R_{HeAu}

5. Acknowledgment

We acknowledge support from Russian Ministry of Education and Science, state assignement 3.1498.2017/4.6

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