PROCEEDINGS OF SCIENCE

Recent results on high-p_T particles and jets from PHENIX experiment

Pavel Radzevich for the PHENIX collaboration[∗†]
Peter the Great St.Petersburg Polytechnic University
E-mail: radzevichp@gmail.com

Extensive study of heavy ion collisions at RHIC has resulted in discovery of a new state of matter - strongly coupled Quark Gluon Plasma (sQGP). Measurements of high-p_T particles and jets contributes to systematic study of the properties of sQGP. Reconstructed jets are directly associated with partons in the medium, their spectra and nuclear modification factors can be measured up to the high transverse momenta (40 GeV/c at RHIC energies). Yields of leading particles such as π^0 and η mesons can be measured with high precision at high transverse momenta, which also presents a good opportunity for hard probe measurements. Study of high-p_T observables in different collision systems allows the investigation of the path length dependence of energy loss in the medium. Cu+Au is a first asymmetric heavy ion collision system, available for the analysis. U+U presents an opportunity to research non-spherical heavy ion collision system with highest energy density in central collisions. Non-zero elliptic flow and a hint of suppression of high-p_T hadrons suggests that mini-QGP can be formed in collisions of light and heavy nuclei characterized by high charged particle multiplicities. To address the question of collective behaviour in small systems RHIC provided series of geometry controlled experiments with highly asymmetric systems (p+Au, d+Au, ^3He+Au). This paper will present the most recent PHENIX results on π^0, η and reconstructed jets production in various collision systems such as p+Au, d+Au, ^3He+Au, Cu+Au and U+U. Results will be presented as functions of p_T and centrality.

12th International Workshop on High-pT Physics in the RHIC/LHC Era
2-5 October, 2017
University of Bergen, Bergen, Norway

∗Speaker.
†A footnote may follow.

PoS(High-pT2017)007

1. Introduction

The production of a strongly coupled quark-gluon plasma (sQGP) has been discovered in central relativistic heavy ion collisons (A+A) at RHIC energies [1]. Jet-quenching [2] is the one of the sQGP effects (so-called Hot Nuclear Matter or HNM effects), which is observed as a suppressed production of hadron yields at high transverse momentum ($p_T >$ 4-6 GeV/c) when compared to the binary scaled yields, measured in elementary proton-proton (p+p) collisions. The effect of jet-quenching is the result of parton energy loss in the formed quark-gluon medium.

The modification of the hadron p_T-spectra in A+A is not the only result of jet-quenching. The Cold Nuclear Matter (CNM) effects, such as Cronin effect and nuclear shadowing effect [3], are not connected with the sQGP formation, but also influence hadron production. Thus, the distinction between the HNM and CNM effects is especially important for the study of sQGP properties, as well as jet-quenching mechanisms.

Quantitatively the modification of particle production is studied with the nuclear modification factor (R_{AA}):

$$R_{AA}(p_T) = \frac{1}{N_{coll}} \frac{dN_{AA}(p_T)/dp_T}{dN_{pp}(p_T)/dp_T}, \tag{1.1}$$

where dN_{AA}/dp_T is yield measured in A+A collisions, dN_{pp}/dp_T is yield measured in p+p collisions, N_{coll} is the number of binary inelastic nucleon-nucleon collisions [4].

There are two different approaches of jet quenching studies. The first approach uses the direct event-by-event jet reconstruction. Such an approach is useful, because jets are directly related of the properties of fragmented partons. Another approach uses the study of leading particle (for example, π^0 or η) production, which serve as a good proxy for jets. π^0 mesons are copiously produced in nuclear interactions and can be measured up to a transverse momenta of 40 GeV/c. η mesons have hidden strangeness thus their production measurement gives a good opportunity to study parton energy loss as a function of flavour and mass of the fragmented parton.

Recently, PHENIX has measured the production of π^0 and η mesons and reconstructed jets in p+Au, d+Au, ^{3}He+Au, Cu+Au and U+U collisions. Cu+Au is an asymmetric heavy ion-collision system, which has a different nuclear overlap geometry compared to symmetric A+A collisions. U+U is the largest available collision system, which provides the largest energy density formed in its central collisions. Since the formation of sQGP is not observed in small collision systems (p+Au, ^{3}He+p or d+Au), measurement of hadron production in these systems provide excellent probability for the probes of CNM effects. Thus the systematic study of high-p_T hadron production in these systems provides the reference for jet quenching studies in A+A and can help to better discriminate between different theoretical models and better understand parton energy loss mechanisms.

2. Neutral Meson and Jet Reconstruction

All results presented in this paper are obtained with the central arms of the PHENIX spectrometer. Each arm covers $\pi/2$ in azimuthal angle and ± 0.35 range in pseudo-rapidity. Collision centrality is determined in beam-beam counters (BBC)[5], values of N_{coll} are determined using a

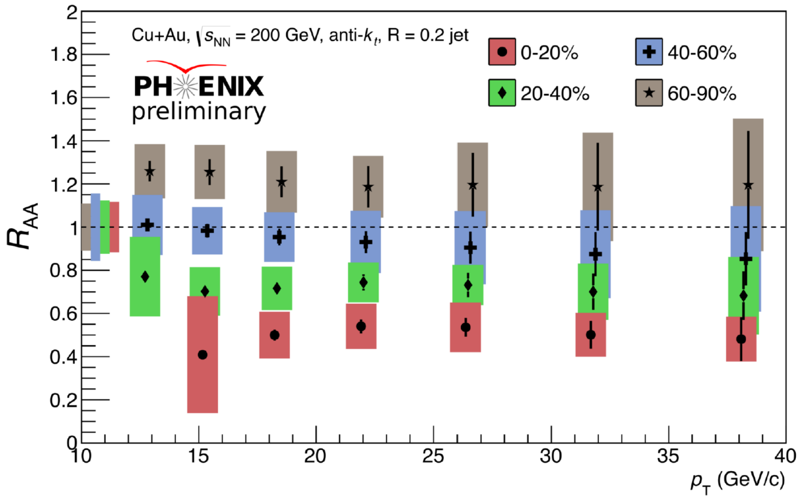

Figure 1: Nuclear modification factors of reconstructed jets measured as a function of p_T and centrality in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Error bars show statistical uncertainties. Open boxes show systematic uncertainties. Boxes at unity show the scaling uncertainty.

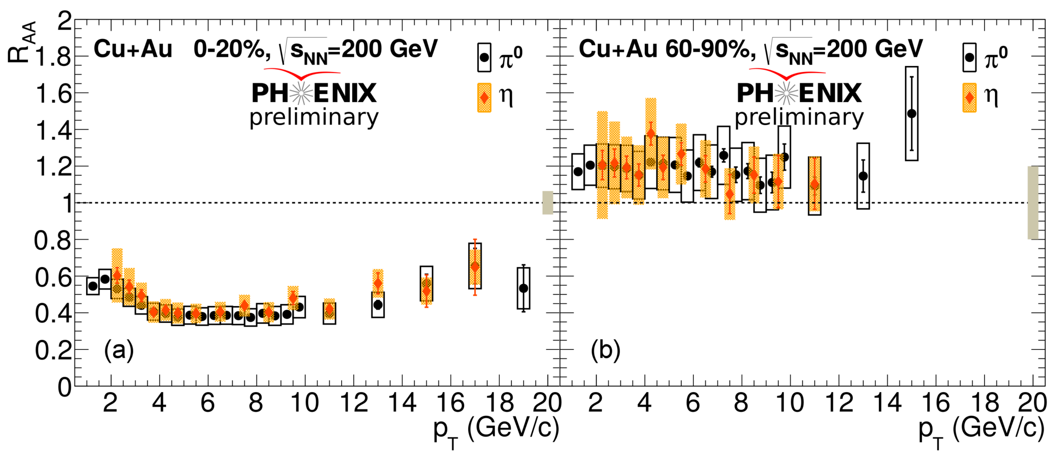

Figure 2: Nuclear modification factors of π^0 and η mesons measured as a function of p_T in central (a) and peripheral (b) Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Error bars show statistical uncertainties. Open boxes show systematic uncertainties. Boxes at unity show the scaling uncertainty.

MC simulation of the BBC response based on a Glauber model [4]. The description of different PHENIX subsystems can be found elsewhere in [6].

π^0 and η are reconstructed in the $\gamma\gamma$ decay channel using the electro-magnetic calorimeter (EMCal) [7]. Measured yields are corrected for the limited acceptance and detector effects with the reconstruction efficiency obtained using GEANT 3 based Monte-Carlo simulation. Simulated π^0 (η) mesons are embedded into real events to account high occupancy effects in the detector.

Jets are reconstructed with the anti-k_t algorithm. Charged tracks are reconstructed with the drift chambers (DC)[8] and photon clusters are reconstructed using EMCal. The anti-k_t algorithm is defined elsewhere in [9]. The jet resolution parameter R is taken equal to 0.2. A larger R would increase contribution of the underlying event and a lower R would reduce the amount of captured

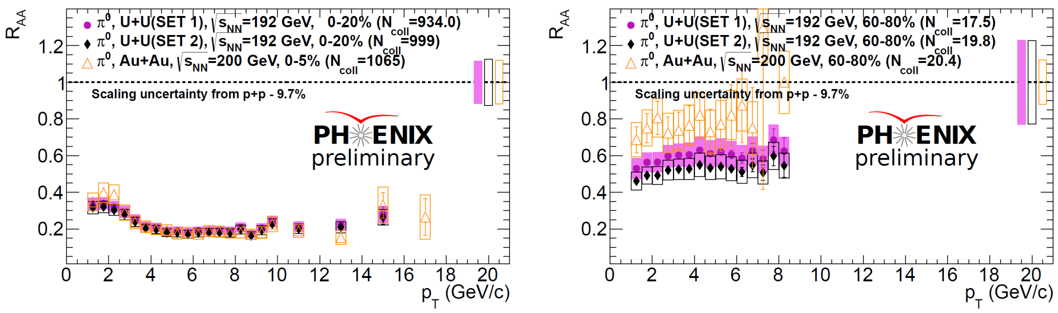

Figure 3: Comparison of R_{AA} in U+U collisions at $\sqrt{s_{NN}} = 192$ GeV and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [10] at similar N_{coll}. Sets 1 and 2 are defined in the text. Results are shown for different centrality intervals. Error bars and open boxes show statistical and systematic uncertainties, respectively. Boxes at unity show scaling uncertainty.

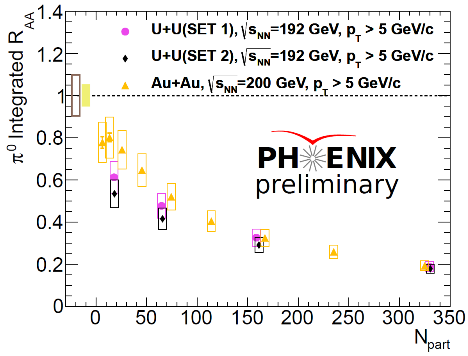

Figure 4: Comparison of integrated R_{AA} in U+U at $\sqrt{s_{NN}} = 192$ GeV and in Au+Au at $\sqrt{s_{NN}} = 200$ GeV [10]. Sets 1 and 2 are defined in the text. Error bars and open boxes show statistical and systematic uncertainties, respectively. Boxes at unity show scaling uncertainty.

energy increasing systematic uncertainties. The contribution of fake jets is statistically subtracted by a data driven method. Jet spectra are corrected for detector effects and underlying event using unfolding with the SVD method.

3. Results

Figure 1 presents nuclear modification factors of reconstructed jets measured as a function of p_T and centrality measured in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Jets are measured over a wide p_T range, up to 40 GeV/c. In central collisions reconstructed jets are suppressed by approximately a factor of two. Although, in peripheral Cu+Au collisions there is a hint of enhancement of jet production, the measured R_{AA} values are still consistent with $R_{AA} = 1$ within large statistical and systematic uncertainties.

Figure 2 presents π^0 and η mesons nuclear modification factors measured as a function of p_T in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. One can see that nuclear modification factors for π^0 and η mesons are consistent within uncertainties in all centrality intervals and the whole p_T range. Production of mesons is suppressed by approximately a factor of two in central collisions.

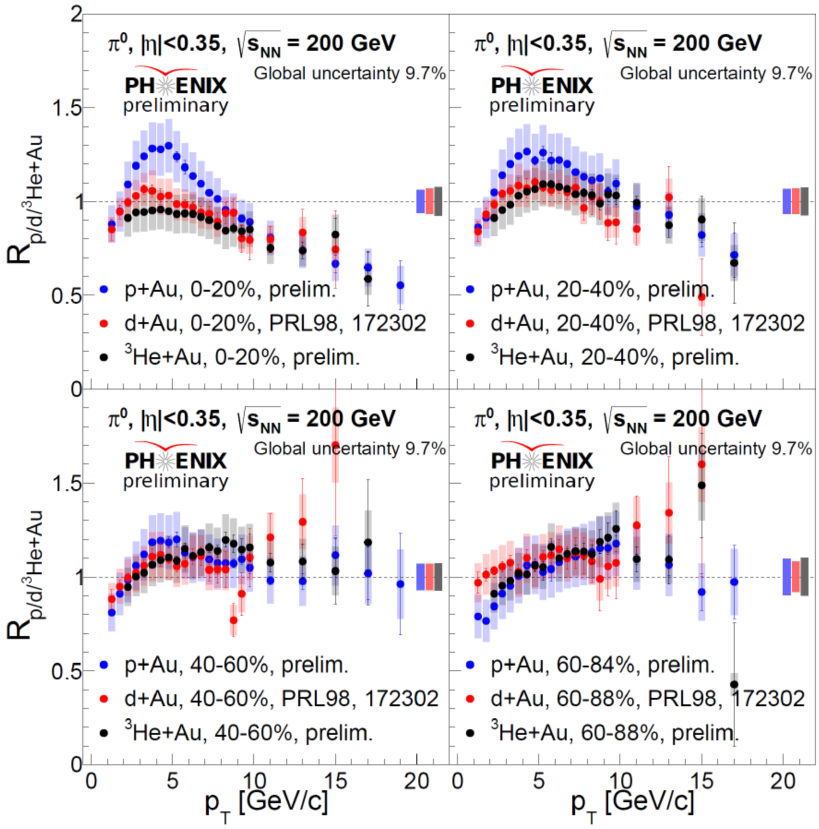

Figure 5: π^0 R_{AA} measured in p+Au, d+Au[11], and ^3He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Error bars and open boxes show statistical and systematic uncertainties, respectively. Boxes at unity show scaling.

Although in most peripheral collisions a hint of enhancement of π^0 and η yields is observed, but R_{AA} values are still consistent within uncertainty with the $R_{AA} = 1$ value. Also, nuclear modification factors of π^0 and η show similar suppression patterns as the ones measured for reconstructed jets in all centrality intervals.

Figure 3 compares π^0 nuclear modification factors measured as a function of p_T in U+U and Au+Au[10] collisions at $\sqrt{s_{NN}}$ = 192 GeV and $\sqrt{s_{NN}}$ = 200 GeV, respectively and similar N_{coll}. Left panel is for central and the right one is for peripheral collisions. Production of π^0 is strongly suppressed in central collisions for both colliding systems. Uranium is a highly asymmetric nucleus, thus its radius depends on the polar angle. "Set 1" and "Set 2" are two different sets of N_{coll} parameters obtained from two different parametrizations of this dependence in the Woods-Saxon distribution in the Glauber Model Monte-Carlo simulation. [12, 13]. The suppression of π^0 in U+U collision is consistent with the one measured in Au+Au collisions. In peripheral U+U collisions suppression of π^0 is slightly stronger than in Au+Au, but still consistent within large uncertainty.

Figure 4 presents p_T-integrated ($p_T > 5$ GeV/c) π^0 nuclear modification factors measured as a function of the number of participating nucleons (N_{part}) in U+U and Au+Au[10] collisions at $\sqrt{s_{NN}}$ = 192 GeV and $\sqrt{s_{NN}}$ = 200 GeV, respectively. The integrated nuclear modification factors are slightly more suppressed in U+U collision, but consistent within uncertainties.

Figure 5 compares π^0 nuclear modification factors measured in p+Au, d+Au and ^3He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in different centrality intervals. At high p_T ($p_T > 10$ GeV/c) a centrality dependent nuclear modification factor is observed at high transverse momentum. Also hint of R_{AA} ordering is observed in different colliding systems at intermediate transverse momentum: the level of enhancement is the largest in p+Au collisions and smallest in ^{3}He+Au, but on the other hand all R_{AA} values are consistent within large uncertainties.

4. Conclusion

This paper presents π^0, η and reconstructed jets R_{AA} measurements in U+U collisions at $\sqrt{s_{NN}} = 192$ GeV, Cu+Au, p+Au, d+Au and ^{3}He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at PHENIX. Reconstructed jets are suppressed by a factor of two in central collisions. In peripheral collisions there is a hint of jet enhancement, but R_{AA} values are still consistent within large uncertainties. In Cu+Au collisions the R_{AA} of π^0 and η mesons are consistent within uncertainties in the whole p_T range and in all centrality intervals. Also, the suppression pattern of these mesons is similar to the one observed with reconstructed jets. Suppression of π^0 yields in U+U is the same as in Au+Au at similar energy and the numbers of binary collisions in central collisions within uncertainties. Nuclear modification factors of π^0 measured in different small systems are consistent in different centrality bins at high transverse momentum. A hint of the systems ordering is observed in central collisions at intermediate transverse momentum.

Acknowledgements

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

References

[1] K. Adcox et al., Nucl. Phys. A. 2005. V. 757. P. 184

[2] D. d'Enterria, J. Phys. G. 2007. V.53 P.34

[3] A. Accardi et al.,Phys.Lett. 2004 V.586 P.244

[4] M. Miller et al., Ann. Rev. Nucl. Part. Sci. 2007. V. 57 P. 205

[5] M. Allen et al., Nucl. Instrum. Meth. A. 2003 .Vol. 499. P. 549

[6] K. Adcox et al., Nucl. Instr. Meth. A. 2003. V. 499. P. 469

[7] L. Aphecetche et al., Nucl. Instr. Meth. A. 2003. V. 499. P. 521

[8] V. Ryabov, Nucl. Instrum. Meth. A. 1998. V. 419 P. 363

[9] Gregory Soyez et al., JHEP 2008 V. 804 P. 63

[10] A. Adare et al., Phys. Rev. Lett. 2008. V. 101, 232301

[11] G. Papp et al., The European Phys. J. 2008 V. 155 P.89

[12] A. Adare et al., Phys.Lett. B. 2008. V. 679, P. 440

[13] A. Adare et al., Phys.Lett. B. 2015 V749, P. 215