Systematic study of identified particle production in PHENIX

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Large enhancement of (anti)protons relative to pions has been observed at intermediate $p_T \sim$ 2-5 GeV/c in central Au+Au collisions at RHIC. To investigate the possible source of this baryon enhancement, we performed a systematic study of identified hadron spectra in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV, and Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV. The data set allows us to study the energy dependence and system size dependence of the baryon enhancement. We also compare the nuclear modification factors on hadron production in two different collision systems.

1. INTRODUCTION

One of the most remarkable observations in central heavy ion collisions at RHIC is a large enhancement of baryons and antibaryons at intermediate $p_T \sim$ 2-5 GeV/c, while neutral pions and inclusive charged hadrons are strongly suppressed compared to p+p collisions. [1–3]. The (anti)proton to pion ratio is enhanced by almost a factor of 3 when one compares most central Au+Au events to peripheral or p+p events. In this p_T region, fragmentation process dominates the particle production in p+p collisions. It is expected that the fragmentation is independent of the collision system - hence the large baryon fraction observed at RHIC comes as a surprise. This behavior is usually called "baryon anomaly at RHIC". By performing a control experiment - d+Au collisions, in which only cold nuclear matter is present - we found that the suppression of particle yields comes not from initial state interactions, but from final state interactions (*i.e.* jet quenching) [4]. On the other hand, the observed enhancement is explained several different ways: (1) strong radial flow which pushes the heavier particles to larger p_T [5], (2) recombination of shower quarks with quarks from the thermalized medium [6–8]. To investigate the origin of this anomaly, we use data sets from several RHIC runs, including the most recent data set of Cu+Cu collisions taken in 2005 by the PHENIX experiment. The data set allows us to study the collision energy and system size dependences of hadron production.

2. DATA ANALYSIS

Data presented here includes Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV, and Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV. Events with vertex position along the beam axis within $|z| < 30$ cm were triggered by the Beam-Beam Counters (BBC) located at

*For the full list of PHENIX authors and acknowledgments, see Appendix 'Collaborations' of this volume.

$|\eta| = 3.0$-3.9. Using BBC, the triggered events are classified in collision centrality classes. Charged particles are reconstructed at mid-rapidity $|\eta| < 0.35$ using a drift chamber and multi-wire proportional chambers with pad readout. Particle identification is based on particle mass calculated from the measured momentum and the velocity obtained from time-of-flight and path length along the trajectory. The measurement uses the time-of-flight detector with a resolution of $\sigma \sim 130$ ps. Corrections to the charged particle spectrum for geometrical acceptance, decay in flight, reconstruction efficiency, and momentum resolution are determined using a single-particle GEANT Monte Carlo simulation. Multiplicity-dependent corrections are evaluated by embedding simulated tracks into real events. Any feed-down corrections from weak decays are not applied to these results. The detailed analysis methods are described in [1].

3. RESULTS

3.1. Baryon Enhancement - p/π ratios at $\sqrt{s_{NN}} = 62.4$ GeV

To study the excitation function of hadron production at a beam energy between SPS and RHIC, Au+Au data at $\sqrt{s_{NN}} = 62.4$ GeV were taken at RHIC in Run-5 (2005). These lower energy data provide important information on the baryon production and transport at mid-rapidity between SPS and earlier RHIC energies. Figure 1 shows the p/π^+ and $\overline{p}/\pi^-$ ratios in central Au+Au collisons at 62.4 GeV and 200 GeV [9]. Compared to the 200 GeV data, the 62.4 GeV data show a slightly larger proton contribution at intermediate p_T, while there is less antiproton contribution. The larger value of p/π is explained by the larger difference between the slopes of spectra from fragmentation and recombination processes at 62.4 GeV than that at 200 GeV [10].

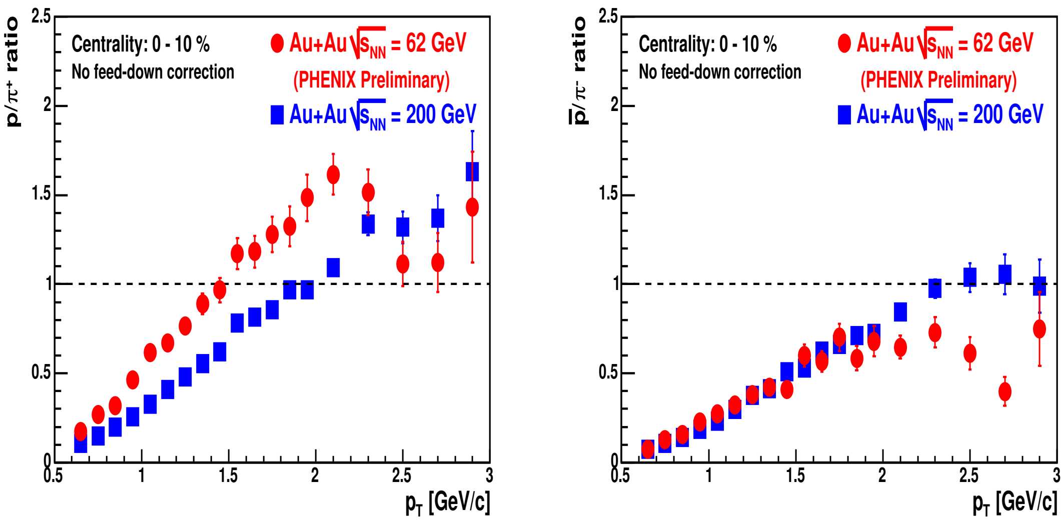

Figure 1. p/π^+ (left) and $\overline{p}/\pi^-$ (right) ratios in central (0-10%) Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV and 200 GeV. Note that the feed-down corrections from weak decays are not applied.

Figure 2 shows antibaryon-to-baryon ratios as a function of collision energy. In 62.4 GeV Au+Au collisions, $\overline{p}/p$ ratio is about 0.5, independent of p_T, and follows the smooth curve from SPS to RHIC. It is consistent with the preliminary $\overline{\Lambda}/\Lambda$ ratio measured by STAR. This indicates that the baryon chemical potential is larger at 62.4 GeV than that at 200 GeV in Au+Au collisions.

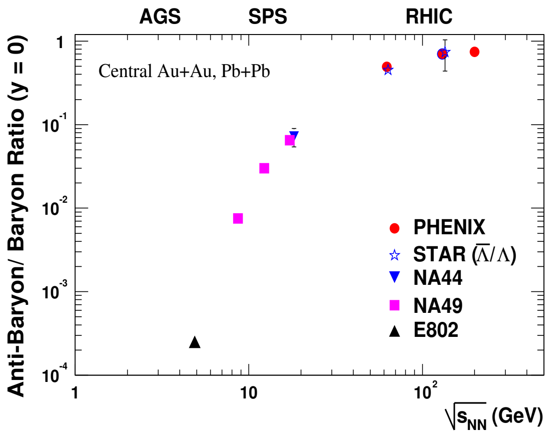

Figure 2. Beam energy dependence of antibaryon-to-baryon ratios from AGS to RHIC. The data point at 62.4 GeV from PHENIX is a preliminary result.

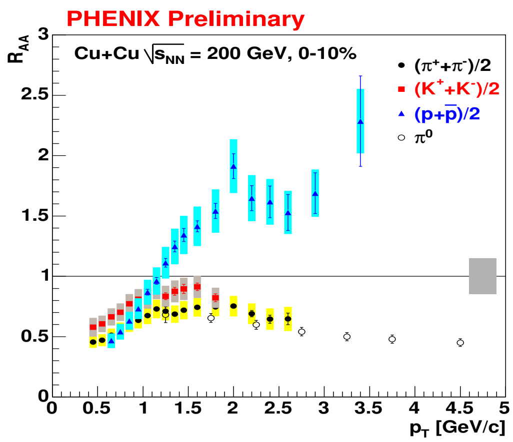

Figure 3. Nuclear modification factors R_{AA} for pions, kaons, and protons in central Cu+Cu ($N_{part} \sim 98$) collisions at $\sqrt{s_{NN}} = 200$ GeV.

3.2. N_{part} Scaling - Cu+Cu vs. Au+Au

3.2.1. Nuclear Modification Factors R_{AA}

Figure 3 shows nuclear modification factors R_{AA} (ratio of the yields to the $p+p$ yields scaled by the number of binary collisions) for different particle species in central Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. When about the same number of participants (N_{part}, representing the system size) is chosen in Cu+Cu and Au+Au collisions, similar R_{AA} trends can be seen in both collision systems in terms of (1) magnitude of the enhancement / suppression (2) p_T dependence and (3) particle species dependence. This could be called N_{part}-scaling of R_{AA} between different collision systems at the same energy.

3.2.2. p/π Ratios

Figure 4 shows the $\overline{p}/\pi^-$ ratio as a function of p_T (left) and as a function of N_{part} at $p_T = 2$ GeV/c (right) in Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The N_{part} is associated with centrality using a Glauber model calculation. The Cu+Cu data show similar p_T and system-size (N_{part}) dependences as seen in 200 GeV Au+Au, despite the slight difference in magnitude. N_{part}-scaling is also observed in the p/π^+ and K/π ratios (not shown). This is another manifestation of N_{part}-scaling of particle ratios as well as R_{AA}.

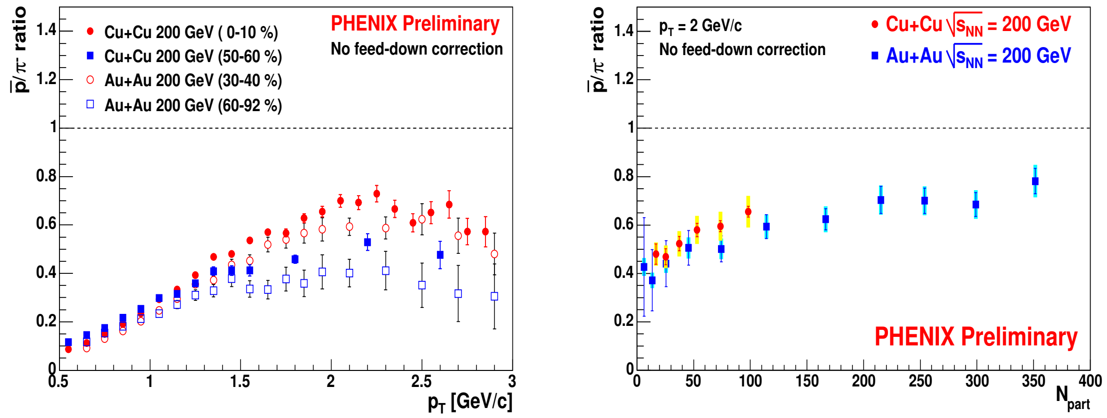

Figure 4. $\overline{p}/\pi^-$ ratio as a function of p_T (left) and as a function of N_{part} at $p_T = 2$ GeV/c (right) in Cu+Cu and Au+Au collisons at $\sqrt{s_{NN}}$ = 200 GeV. Note that the feed-down corrections from weak decays are not applied.

4. SUMMARY

Results on identified particle production in Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4 GeV are presented. The baryon enhancement at intermediate p_T is observed in all collision systems. The 62.4 GeV Au+Au data show a slightly larger proton contribution at intermediate p_T as seen in 200 GeV Au+Au, while there is a less antiproton contribution compared to the 200 GeV results. These behaviors indicate that the hadron production at intermediate p_T is due to multiple processes like fragmentation and recombination, and that the baryon chemical potential is larger at 62.4 GeV than that at 200 GeV in Au+Au collisions. The 200 GeV Cu+Cu data show similar N_{part} scaling of p/π (and K/π) ratios as seen in Au+Au data at the same energy. N_{part} scaling of the nuclear modification factor is also observed in terms of the magnitude and particle species dependences.

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