Identified charge hadron spectra and ratios in Au+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract. PHENIX has recently reported [1] measurements of identified charged hadron spectra and ratios in Au+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Identified hadrons are an important probe of both hot and cold nuclear matter. The intermediate p_T region, 2–5 GeV/c, is of particular interest. In Au+Au collisions, the production of mesons is suppressed in this p_T region relative to that in p+p collisions, while the production of baryons is nearly unmodified. On the other hand, in d+Au collisions, the meson production exhibits a slight enhancement in this p_T region while the baryon production exhibits a much stronger enhancement. In these proceedings, the p_T spectra and ratios of identified charged hadrons $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$ in 5 different centrality classes for each collision species will be discussed.

1. Introduction

The content presented this talk and in these proceedings is from a recent PHENIX paper on identified charged hadrons [1]. The particles are identified using the time-of-flight detector in the west arm (TOFW) of the PHENIX central spectrometer. The TOFW provides excellent PID capabilities, with 4σ π/K separation up to p_T of 2.5 GeV/c, and 4σ K/p separation up to p_T of 4 GeV/c. The p_T reach can be extended greatly by exclusion cuts, where in addition to requiring that the m^2 of the particle is within 2σ of the mean, a further requirement that the m^2 of the particle is beyond 2σ of the mean of the other particles is also employed. In this analysis, this allows identification of pions and protons up to 6 GeV/c (5 GeV/c) in p_T and kaons up to 4 GeV/c (3.5 GeV/c) in p_T in Au+Au (d+Au) collisions.

2. Spectra

The p_T spectra for all species and both collision systems are presented in Ref. [1]. In principle all the information reported therein and in these proceedings is encoded in the spectra. Particle ratios, however, often help illustrate differences between particle species, centrality classes, collisions systems, etc. There has been tremendous interest at this conference and elsewhere in hydrodynamical flow in small systems like d+Au and p+Pb, which is best evinced in the spectra themselves. The author anticipates and encourages theoretical studies of these spectra. The spectra are not shown in these proceedings in the interest of not exceeding the page limit.

3. Ratios

3.1. p/π and K/π ratios

Presented in Figures 1 and 2 are the K^+/π^+ (upper panels) and K^-/π^- (lower panels) as a function of p_T for Au+Au and d+Au collisions, respectively. PHENIX data from p+p collisions [2] are shown as a reference. The K/π ratio in Au+Au shows a weak centrality dependence, with the ratio rising slightly as the collisions become more central. This is indicative of the well-known strangeness enhancement in the medium. The enhancement is also p_T dependent, with the ratios being roughly equal at low p_T and then the enhancement steadily increasing up to $p_T \approx 2$ GeV/c, above which the enhancement levels off and is flat. This detailed measurement of the p_T dependence of this ratio can hopefully shed light on the strangeness production mechanism(s) in the medium. In d+Au collisions this effect is notably absent, as no centrality dependence is seen whatsoever, with the caveat that the span of N_{part} values is small. Finally, note that for the most peripheral Au+Au and all d+Au centralities the K/π ratios are consistent with those in p+p collisions in the overlapping p_T region.

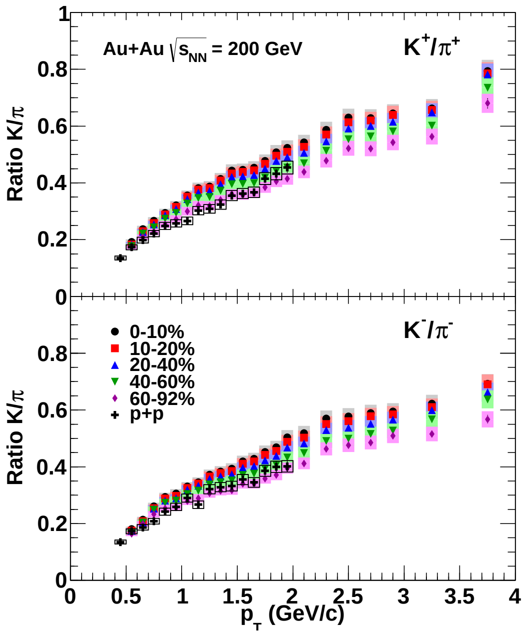


Figure 1. K^+/π^+ (upper panel) and K^-/π^- (lower panel) as a function of p_T in Au+Au collisions.

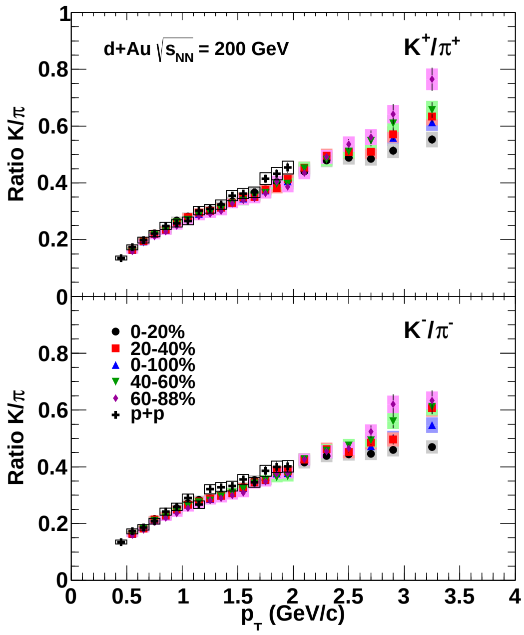
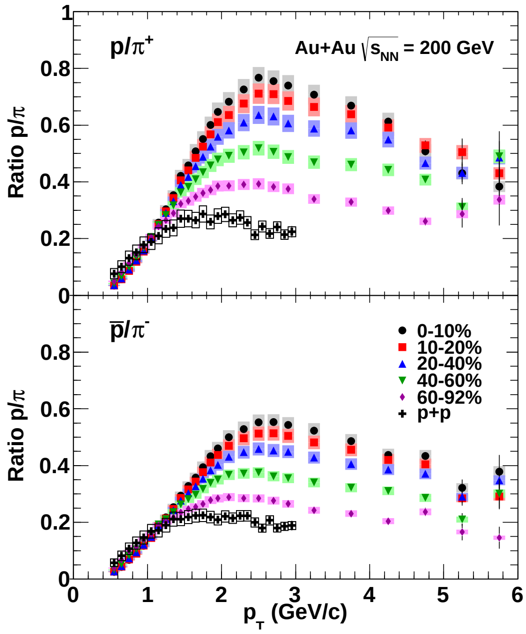


Figure 2. K^+/π^+ (upper panel) and K^-/π^- (lower panel) as a function of p_T in Au+Au collisions.

Presented in Figures 3 and 4 are the p/π^+ (upper panels) and $\bar{p}/\pi^-$ (lower panels) as a function of p_T for Au+Au and d+Au collisions, respectively. PHENIX data from p+p collisions [2] are shown as a reference. The p/π ratio in Au+Au shows a strong centrality dependence. In d+Au the centrality dependence at first appears weak, but in fact should be regarded as quite strong given the small range of N_{part} in the d+Au centrality selections. In both collision systems, the ratio rises quickly, reaches a maximum between 2–2.5 GeV/c in p_T, and then falls off slowly. This maximum point is closer to 2 GeV/c in d+Au. There appears to be a centrality dependence to this maximum in Au+Au, as for example the maximum for peripheral Au+Au appears to be closer to 2 GeV/c (like the d+Au) but closer to 2.5 GeV/c for the most central.



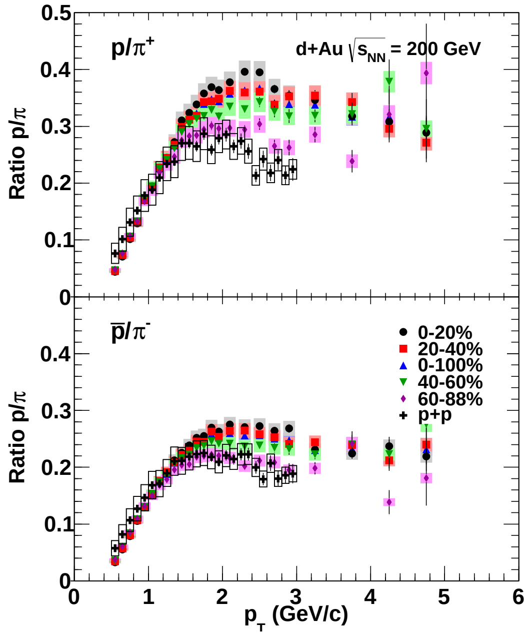


Figure 3. p/π^+ (upper panel) and $\bar{p}/\pi^-$ (lower panel) as a function of p_T in Au+Au collisions.

Figure 4. p/π^+ (upper panel) and $\bar{p}/\pi^-$ (lower panel) as a function of p_T in d+Au collisions.

3.2. Nuclear modification factors

Shown in Figures 5 and 6 are R_{AA} and R_{dA}, respectively, as a function of p_T in the various centrality classes. The p+p reference data for $\pi/K/p$ are from Ref. [2]. Also shown are π^0 data taken from Refs. [3, 4] and ϕ data taken from Ref. [5].

As exhibited in the R_{AA}, charged and neutral pions show fairly significant suppression. The charged kaons exhibit a very similar p_T shape as the charged pions, although an overall higher level. The ϕ meson is at a yet higher level in turn. All three mesons π, K, and ϕ are suppressed but with decreasing suppression in that order. This ordering cannot be attributed to mass alone since the ϕ is heavier than the proton but has a significantly lower R_{AA}. On the other hand, this ordering also coincides with increasing strangeness content, meaning it could be attributable to strangeness enhancement. In the R_{dA} all mesons exhibit essentially identical behavior, showing little or no modification. This suggests that any differences in particle production between d+Au and p+p collisions are not attributable to particle mass or strangeness content.

In both the R_{AA} and R_{dA} the protons exhibit a strong enhancement relative the mesons, which is also seen in the p/π ratios. The behavior is clearly consistent with different behaviors for baryons and mesons. The physical origin of differences between baryons and mesons has been frequently attributed to hadronization by parton recombination, which has some success in describing the experimental data [6]. However, an alternative explanation, such as that involving baryon junctions, should not be forgotten, and the author invites further theoretical investigation of the present work.

3.3. Comparison between peripheral Au+Au and central d+Au

As alluded to in previous sections, there are remarkable similarities between peripheral Au+Au and central d+Au. A direct comparison between the two is justified by this alone. However, this can be further motivated by the very similar Glauber parameters for the two systems. The N_{coll} values are 14.8±3.0 and 15.1±1.0 for peripheral Au+Au and central d+Au, respectively; the

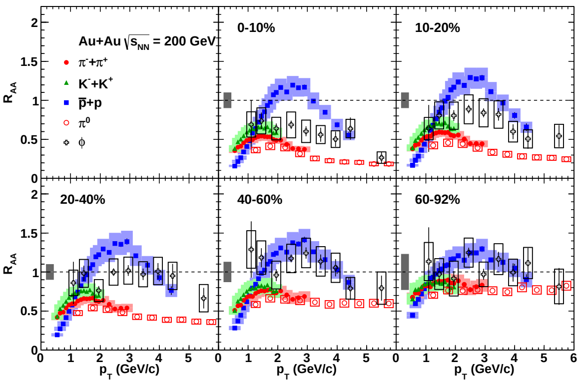


Figure 5. R_{AA} as a function of p_T. A dashed line is drawn at unity indicating non-modification as a visual aid.

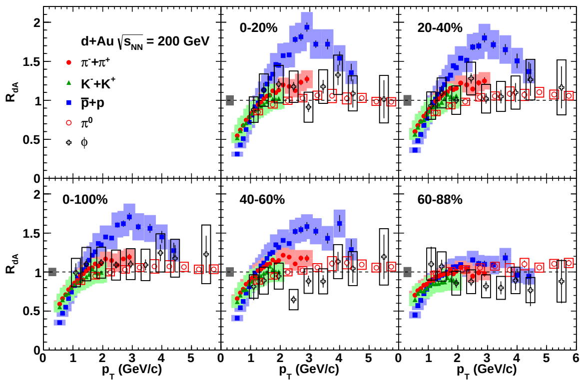
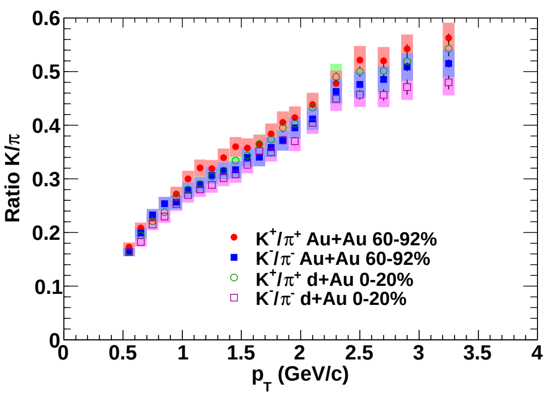


Figure 6. R_{dA} as a function of p_T. A dashed line is drawn at unity indicating non-modification as a visual aid.

N_{part} values are 14.7±2.9 and 15.3±0.8 for peripheral Au+Au and central d+Au, respectively.

Shown in Figures 7 and 8 are the K/π and p/π ratios, respectively, as a function of p_T in both peripheral Au+Au and central d+Au. As can be seen, the ratios are essentially identical in the two systems.



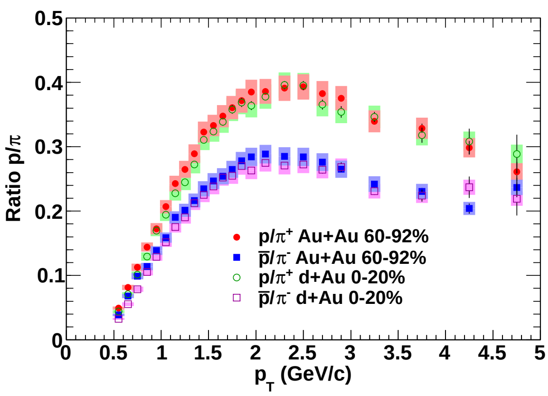


Figure 7. K^+/π^+ and K^-/π^- as a function of p_T in peripheral Au+Au collisions and central d+Au collisions.

Figure 8. p/π^+ and $\bar{p}/\pi^-$ as a function of p_T in peripheral Au+Au collisions and central d+Au collisions.

A direct ratio of the spectra in the two systems is presented in Figure 9. No scaling is applied. However, as noted above, the respective N_{coll} and N_{part} are very similar, so a scaling by either of these values would result in a negligible change.

This ratio is very striking. For p_T values of 2.5 GeV/c and higher, the ratio is flat and independent of p_T, and is further identical for each particle species. This indicates that the baryon enhancement in each system is quantitatively the same and that the baryon enhancement is likely driven by the same mechanism. This in turn provides significant theoretical constraints.

At lower p_T the ratio trends upwards. A mass and/or particle type separation may be evident, although the three species are consistent within systematic uncertainties. There are many potential physical effects at play. For example, there is a rapidity shift in soft particle production in d+Au collisions due to the participant asymmetry [7]. This naturally creates a

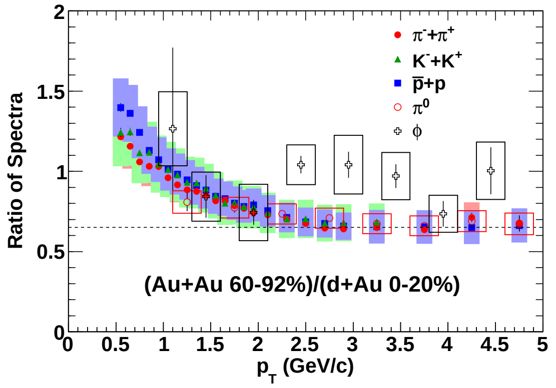


Figure 9. Ratio of spectra in peripheral Au+Au to central d+Au. No scaling is applied. A dashed line is drawn at 0.65 as a visual aid.

deficit of particle production at low p_T and could explain the observed upward trend in this ratio. Additionally, if there is radial flow in central d+Au collisions and it is stronger than that in peripheral Au+Au, that could also explain this trend, with additional benefit of explaining the mass ordering that may be present.

References

[1] Adare A *et al* 2013 *Phys. Rev.* C **88** 024906
[2] Adare A *et al* 2011 *Phys. Rev.* C **83** 064903
[3] Adler S S *et al* 2007 *Phys. Rev. Lett.* **98** 172302
[4] Adare A *et al* 2008 *Phys. Rev. Lett.* **101** 232301
[5] Adare A *et al* 2011 *Phys. Rev.* C **83** 024909
[6] Zhu L and Hwa R C 2013 *Preprint* 1307.3328
[7] Back B B *et al* 2004 *Phys. Rev. Lett.* **93** 082301