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## SYSTEMATICS OF IDENTIFIED HADRON SPECTRA AT PHENIX

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Mid-rapidity transverse momentum distributions for  $\pi^\pm$ ,  $K^\pm$ ,  $p$  and  $\bar{p}$  are measured by the PHENIX experiment at RHIC in Au+Au, d+Au and p+p collisions at  $\sqrt{s_{NN}}=200\text{GeV}$  up to 2–4 GeV. Also particle ratios of  $\pi^-/\pi^+$ ,  $K^-/K^+$ ,  $\bar{p}/p$ ,  $p/\pi$  and  $\bar{p}/\pi$  are measured, as well as the nuclear modification factor, all as a function of  $p_t$  and in every of the above collision systems. Finally, the measured p+p and Au+Au spectra are compared to the Buda-Lund hydro model.

### 1. Introduction

The motivation for ultra-relativistic heavy-ion experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is the study of nuclear matter at extremely high temperature and energy density with the hope of creating and detecting deconfined matter consisting of quarks and gluons – the quark gluon plasma (QGP).

The PHENIX experiment at RHIC published spectra measurements in Au+Au collisions<sup>1</sup> and in p+p and d+Au collisions<sup>2</sup>, all at  $\sqrt{s_{NN}}=200\text{GeV}$ . In this paper, we present a comparison of the  $\sqrt{s_{NN}}=200\text{GeV}$  Au+Au, d+Au and p+p results.

### 2. Measurements

The PHENIX experiment<sup>3</sup> has a unique hadron identification capability in a broad momentum range. Pions and kaons are identified up to 3 GeV/ $c$  and 2 GeV/ $c$  in  $p_t$ , respectively, and protons and anti-protons can be identified up to 4.5 GeV/ $c$  by using a high resolution time-of-flight detector<sup>4</sup>.

We compare here identified particle production in d+Au, p+p and peripheral and central Au+Au collisions.

First, we calculate the nuclear modification factor by taking the Au+Au and d+Au spectra, scaling them down by the number of binary nucleon-nucleon collisions (denoted as  $N_{coll}$  and taken from Glauber calculations<sup>5</sup>

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for each centrality class separately) and dividing them by spectra measured in p+p collisions (where  $N_{\text{coll}}$  is obviously one). Now, if a Au+Au or a d+Au collision would be nothing but a combination of a lot of nucleon-nucleon collisions, this ratio would be one. In contrary, if there are effects due to the high  $N_{\text{coll}}$ , eg. some type of medium is produced, this ratio can deviate from one. Furthermore, from hydro, one would expect scaling with the number of participants rather than the number of collisions.

Fig. 1 compares the nuclear modification factors for pions, kaons and (anti)protons in Au+Au and d+Au collisions. Pions show a much lower  $R_{\text{AuAu}}$  at high  $p_t$  in central than in peripheral Au+Au collisions, as expected from the large energy loss suffered by the quarks in central collisions. The nuclear modification factor is slightly larger in d+Au than in peripheral Au+Au, despite the comparable number of binary collisions, but we can not draw a definite conclusion due to the large systematic error of the peripheral  $R_{\text{AuAu}}$ . The proton and antiproton nuclear modification factors show a quite different trend, however.

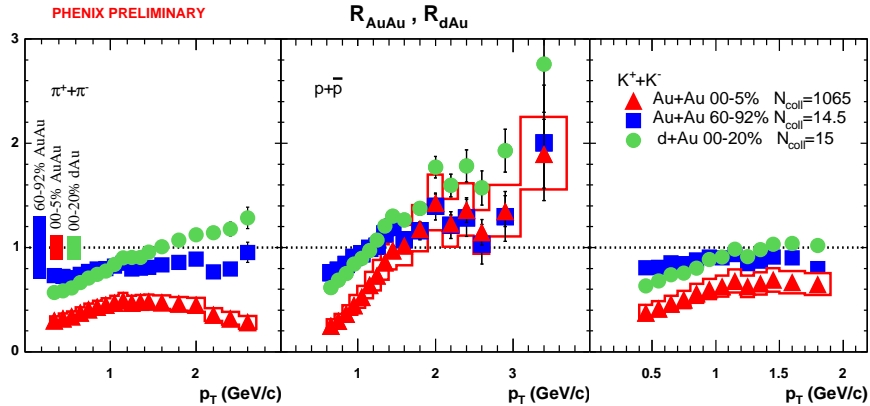


Figure 1. Nuclear modification factors for different particles and collision species. Solid bars on the left indicate  $p_t$ -independent normalization uncertainties, error bars indicate statistical errors. Empty boxes indicate systematical errors.

Another important thing is to compare particle over antiparticle ratios. What we see is that all collision species result in a particle over antiparticle ratio of one, independently of transverse momentum or centrality, except in the case of  $\bar{p}/p$ , where the ratio is a bit smaller than one but still independent of collision type and  $p_t$  as it is seen on Fig. 2. We can interpret the flat and collision species independent ratios of one as a sign of thermaliza-

tion, and the difference between protons and antiprotons tells us that there is a small but nonzero net baryon density or bariochemical potential. The lack of centrality dependence indicates that the (hadro-chemical) freeze-out parameters are independent of the centrality of the collisions<sup>1,6</sup>.

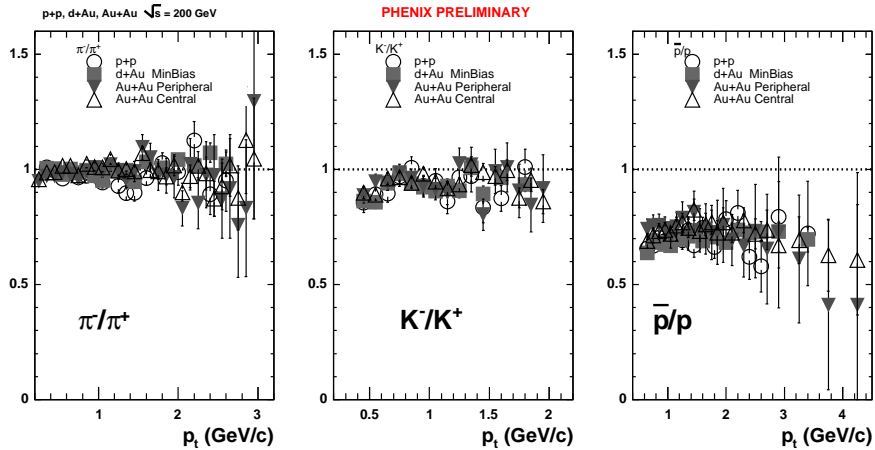


Figure 2. Proton to pion ratios for different collision species

Last, but not least, we also calculate proton to pion ratios, which will give us insight into collective dynamics effects, and also tell us something about a possible baryon yield enhancement mechanism.

The  $p/\pi$  ratio in d+Au is very similar to that in peripheral Au+Au collisions, and lies slightly above the p+p ratio. The  $p/\pi$  ratio in central Au+Au collisions is, however, much larger. All are plotted on Fig. 3. The difference between the ratio in central and peripheral Au+Au clearly indicates that baryon yield enhancement is not simply an effect of sampling a large nucleus in the initial state, but it requires the presence of a substantial volume of nuclear medium with high energy density and pressure that generate a strong radial flow.

Now let us pick a model to compare it to our results. We choose the Buda-Lund hydro model<sup>7</sup> which is successful in describing the BRAHMS, PHENIX, PHOBOS and STAR data on identified single particle spectra and the transverse mass dependent Bose-Einstein or HBT radii (and so the  $R_{out}/R_{side} \approx 1$  behavior) as well as the pseudorapidity distribution of charged particles in Au+Au collisions both at  $\sqrt{s_{NN}} = 130$  GeV<sup>8</sup> and at  $\sqrt{s_{NN}} = 200$  GeV<sup>9</sup>.

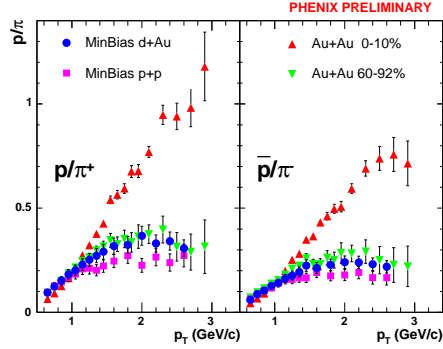


Figure 3. The ratio of protons to  $\pi^+$  and antiprotons to  $\pi^-$  in minimum bias p+p and d+Au compared to peripheral and Au+Au collisions. Statistical error bars are shown.

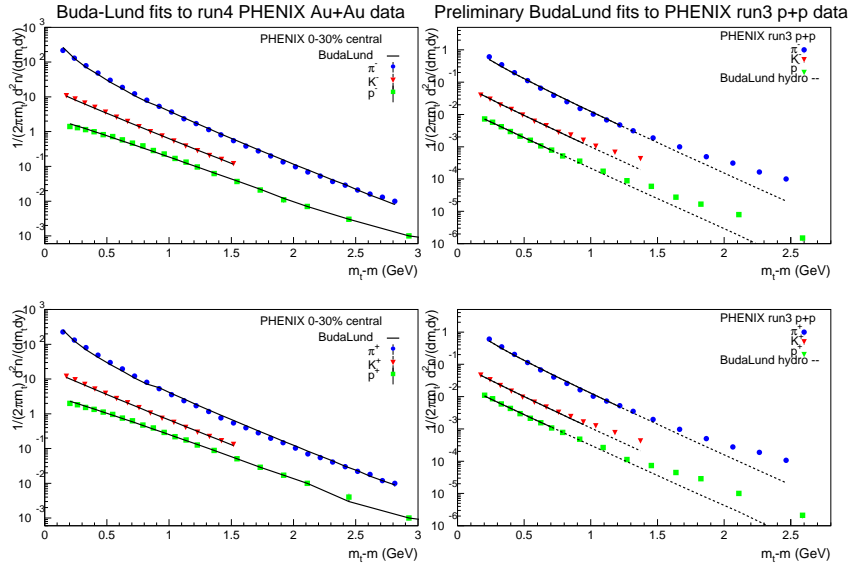


Figure 4. This figure shows a Buda-Lund fit to 200GeV Au+Au and p+p data, latter is preliminary. The dashed line in the left panel is a not fitted region, where jets start to dominate particle production.

In Au+Au collisions, we see a clear evidence for a 3-dimensional Hubble-expansion, as the longitudinal and transverse flow is the same<sup>9</sup>.

The result of the Buda-Lund fits to p+p data at  $\sqrt{s_{NN}} = 200\text{GeV}$  indicate that there is no radial flow ( $\beta_t = 0.0 \pm 0.19$ ) in p+p collisions and the flow has a one-dimensional (Bjorken) flow profile. This also means, that

the spectra slopes correspond to the temperature of the system.

Furthermore the temperature distribution  $T(x)$  in the model is characterized with a central temperature  $T_0$  and a radius  $R_s$  where the temperature drops to the half of the central one.  $T_0$  is found to be greater than the critical value calculated from lattice QCD<sup>10</sup>:  $T_c = 164 \pm 3\text{MeV}$ , and  $T_0 = 196 \pm 13\text{MeV}$  in Au+Au<sup>9</sup> and  $T_0 = 239 \pm 21\text{MeV}$  in p+p. The Buda-Lund fits thus indicate quark deconfinement at RHIC.  $R_s$  is found to be finite and this is an indication for temperature inhomogeneity and for the presence of a cross-over instead of a phase transition, where no hadrons could emerge from a (superheated) region with  $T > T_c$ . In fact, the temperature inhomogeneity also explains why  $R_{\text{out}} \approx R_{\text{side}}$ <sup>11</sup>.

### 3. Summary

The nuclear modification factor of pions, kaons and also protons observed in d+Au is similar to the one observed in peripheral Au+Au collisions. Pions are suppressed in central Au+Au, and do not scale with  $N_{\text{coll}}$ .  $R_{\text{AuAu}}$  for protons and antiprotons confirms previous observations that the production of high  $p_t$  baryons in Au+Au scales with the number of binary nucleon-nucleon collisions. Particle over antiparticle ratios are near to one for pions and kaons, and slightly below one for protons, independently of  $p_t$  and collision type. This can be interpreted as a sign of thermalization. The proton to pion ratio in p+p and d+Au is similar to that in peripheral Au+Au. In central Au+Au we see a barion yield enhancement, which can be caused by the presence of a hot and dense nuclear matter with a strong radial flow. Buda-Lund fits to  $p_t$  spectra show us an evidence for a 3d Hubble flow in Au+Au and a 1d Bjorken flow in p+p collisions, and an indication of deconfinement temperatures reached in both reactions.

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