Particle Production at RHIC

Aneta Iordanova\textsuperscript{1,}a (for the STAR collaboration)

\textsuperscript{1} University of Illinois at Chicago, Department of Physics, 845 W. Taylor St, M/C 273, Chicago, IL, 60607, USA

Abstract. Identified hadron spectra and ratios provide a unique tool to study the bulk particle production in heavy-ion collisions and explore the QCD phase diagram. In these proceedings we present the analysis of charged pion, kaon and (anti)proton distributions from $\sqrt{s_{NN}} = 200$ and 62.4 GeV Cu+Cu collisions, collected by the STAR experiment. New measurements extend the systematic studies of bulk properties, addressing the energy and the system size dependence of freeze-out parameters at RHIC. The available centrality selection of Cu+Cu data bridge the gap between the smaller d+Au and larger Au+Au systems, allowing a detailed study of baryon relative to meson and strangeness production as function of system size.

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1. Introduction

Identified low momentum $\pi^\pm$, $K^\pm$ and $p(\bar{p})$ particle spectra provide a tool to study the bulk properties and to explore the QCD phase diagram [1]. The STAR experiment has collected an impressive set of data at different center-of-mass energies and collision systems. In this paper we analyze the Cu+Cu data at $\sqrt{s_{NN}} = 200$ and 62.4 GeV over a broad centrality range, bridging the gap between the smaller d+Au and larger Au+Au systems and allowing for a detailed study of hadro-chemistry as a function of system size. The measurement of species abundances and their transverse momentum distributions provide information about the final stages of the collision evolution at chemical and kinetic freeze-out.

Prior studies of the freeze-out parameters in $\sqrt{s_{NN}} = 200$ and 62.4 GeV Au+Au collisions [2, 3] within a chemical and kinetic equilibrium model, showed an increasing radial flow with centrality and a similar chemical freeze-out temperature for both center-of-mass energies. Changes in $T_{\text{kin}}$ and $\beta$ are found to be consistent with higher energy/pressure in the initial state for more central events. The centrality
independence of the extracted chemical freeze-out temperature was interpreted as medium evolution to the same chemical freeze-out, despite differences in the initial conditions. Furthermore, the values of the chemical freeze-out temperature and the predicted critical temperature for QCD phase transition, are found to be similar for all centralities, suggesting that the chemical freeze-out coincides with hadronization and therefore provides a lower limit estimate for a temperature of prehadronic state [4]. Most measured bulk properties are found to show a smooth systematic change with the charged hadron multiplicity and appear to follow the common systematics with lower-energy collisions data. The addition of the Cu+Cu measurements extends these systematic studies of bulk particle production at RHIC by addressing not only the energy, but the system size and the inferred energy density dependence of the freeze-out parameters.

2. Particle identification

At low-p_T, charged π±, K± and p(¯p) are identified using their distinct ionization energy loss (dE/dx) patterns in the STAR Time Projection Chamber (TPC) [5]. The analysis is performed at mid-rapidity (|y| < 0.1) and in six 10% centrality bins, representing the top 60% of the inelastic collision cross-section. The particle spectra are obtained from the mean \langle dE/dx \rangle distribution, normalized by the theoretical expectation for different particle types. The normalized distribution is divided into narrow bins of transverse momentum (\Delta p_T = 50 MeV). For a given momentum and centrality bin the projections of dE/dx are fit with a four-Gaussian function, representing the different particle species (π, K, p and e) which can be statistically identified in this transverse momentum region (0.2 < p_T < 0.8 GeV/c for π±, k± and 0.4 < p_T < 1.2 GeV/c for p(¯p)). The integral of each Gaussian provides the raw particle yield. These yields are further corrected for detector acceptance, tracking inefficiency and background contributions. The described analysis technique [2] is consistently applied to all low-p_T particle spectra measurements at both \sqrt{s_{NN}} = 200 and 62.4 GeV center-of-mass energies and both Cu+Cu and Au+Au collision systems.

3. Particle production

3.1. Chemical freeze-out properties

In the framework of the statistical model [6], ratios of particle yields can be used to provide information about the chemical freeze-out properties of the system. The particle ratios for each centrality bin of Cu+Cu data are fit with statistical model to derive four parameters: the chemical freeze-out temperature (T_{ch}), the baryon and strangeness chemical potentials (\mu_B, \mu_S) and the strangeness suppression factor (\gamma_S). In this work only π±, K±, p(¯p) ratios are used \{b\}.

The chemical freeze-out temperature as a function of baryon-chemical potential for different systems and colliding energies is shown in the left panel of Fig. [1].
Fig. 1. Left panel: Chemical freeze-out temperature, $T_{ch}$, versus the baryon chemical potential, $\mu_B$, for central Au+Au (0-5%, circles) and Cu+Cu collisions (0-10%, squares). Minimum-bias p+p data at 200 GeV are also shown (star). Right panel: $T_{ch}$ ($T_{kin}$) versus charged hadron multiplicity at $\sqrt{s_{NN}}$ 62.4 (open symbols) and 200 GeV (closed symbols) for Cu+Cu and Au+Au collisions. For comparison, results for minimum-bias p+p collisions at 200 GeV are also shown.

The value of $T_{ch}$ appears to be universal. For all systems and center-of-mass energies $T_{ch}$ is constant as a function of $\mu_B$ as well as the charged particle mid-rapidity multiplicity ($dN_{ch}/d\eta$), right panel of Fig. 1. The constant value of $T_{ch}$ for collisions with different initial conditions (energy and net-baryon densities) points to a common hadronization temperature across the systems studied. The value of the baryon chemical potential reflects the decrease in baryon density from $\sqrt{s_{NN}} = 62.4$ to 200 GeV. At the same center-of-mass energy $\mu_B$ is higher for the larger system.

The strangeness suppression factor $\gamma_S$ in Cu+Cu is consistent with the results for the Au+Au data [2] within the systematic errors on the fit parameters. This parameter shows a similar dependence with $dN_{ch}/d\eta$, as observed in the Au+Au system. The value of $\gamma_S$ approaching unity for the central collisions implies that the produced strange quark is in approximate equilibrium with $u$ and $d$ quarks.

3.2. Kinetic freeze-out properties

To characterize the final freeze-out state we fit all particle spectra within a given centrality bin by the Blast-wave model [7]. The model assumes a radially expanding thermal source. The hydro-motivated fits provide information about the radial flow velocity ($\beta$) and the kinetic freeze-out temperature ($T_{kin}$) at final freeze-out. The effects from resonance contributions to the pion spectral shape are reduced by excluding the very low-$p_t$ pion data points ($< 0.5$ GeV/$c$) {c}. 

The particle spectra are well described by a common set of freeze-out parameters for all colliding energies. When measured in collisions with similar $dN_{ch}/d\eta$, $T_{\text{kin}}$ and $\beta$ exhibit similar centrality dependences in both Cu+Cu and Au+Au collisions, evolving smoothly from the lowest (p+p) to the highest (central Au+Au) available multiplicities. $T_{\text{kin}}$ decreases with centrality and thus indicating that the freeze-out occurs at a lower temperature in more central collisions (see the right panel of Fig. 1). The particle mean-$p_T$ increase with $dN_{ch}/d\eta$, which is consistent with an increase in radial flow $\beta$ with centrality [8].

In conjunction with Color Glass Condensate model [9] the number of produced charged particles can be connected with the initial gluon density of the colliding system, leading to the interpretation that the bulk freeze-out properties are most probably determined at the initial stages of the collision and are driven by the initial energy density.

3.3. Baryon and meson production

The ratio of baryons (inclusive $p + \bar{p}$) to mesons ($\pi^+ + \pi^-$) as a function of $p_T$ for p+p, Cu+Cu and Au+Au systems at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 2 (left panel). At all momenta the number of baryons is less than the number of produced mesons. There is no centrality dependence for low transverse momenta and the relative production in A+A is very similar to that in elementary p+p collisions. At intermediate-$p_T$ the baryon to meson ratio is enhanced relative to the p+p system. A strong centrality dependence is observed, with the ratio reaching a maximum for central collisions at $p_T \sim 2$ GeV/c. For $p_T > 5$ GeV/c in Cu+Cu ($p_T > 7$ GeV/c in Au+Au) the baryon to meson production is found to be the same as p+p and independent of centrality. Ratios formed from particles containing strange quarks ($\Lambda/K^0_S$) [10] show similar features in the baryon to meson production as a function of $p_T$ and centrality.

The baryon to meson production at different energies in Au+Au data is studied in the right panel of Fig. 2. The ratio of protons to pions (and $\bar{p}/\pi^-$) at 62.4 GeV is compared to that in 200 GeV. The baryon to meson production at a given centrality in 62.4 GeV has the same transverse momentum dependence as that in 200 GeV.

3.4. Strangeness production

The ratio of charged kaon and pion yields in Cu+Cu and Au+Au allows us to gain some insight about the strangeness production as a function of the system size. The centrality dependence of $K/\pi$ ratio in Cu+Cu collisions shown as function of $dN_{ch}/d\eta$, {d} follows the same trend as previously found in Au+Au data at the top RHIC energy [2 8]. There is no strong evidence for additional strangeness enhancement of the kaon yield relative to the pion reference in the smaller system, as observed at AGS and SPS energies [17 18], despite the observed increase in the integrated particle spectra yields with respect to p+p data for a given value of $N_{\text{part}}$ [16].
4. Summary

The STAR collaboration has presented measurements of identified charged hadron spectra in Cu+Cu collisions for two center-of-mass energies, 200 and 62.4 GeV. These new results of $\pi^\pm$, $K^\pm$, $p$($\bar{p}$) have further enriched the variety of low-$p_T$ spectra measurements at RHIC. The data have been studied within the frameworks of statistical and Blast-wave model in order to characterize the properties of the final hadronic state of the colliding system and explore the freeze-out systematics as a function of system size, collision energy, centrality and the inferred energy density.

This multi-dimensional systematic study reveals remarkable similarities between the systems studied. In both Cu+Cu and Au+Au collisions, mid-rapidity baryon production is enhanced compared to that of mesons at intermediate $p_T$ indicating the coalescence process for hadronization. There is no strong evidence for additional strangeness enhancement in the smaller Cu+Cu system in comparison to Au+Au. When measured in collisions with similar $dN_{ch}/d\eta$, $T_{kin}$ and $\beta$ exhibit similar centrality dependences in both Cu+Cu and Au+Au collisions.

The obtained freeze-out parameters are found to be intrinsically related for all collision systems and center-of-mass energies. A smooth evolution with $dN_{ch}/d\eta$ and similar properties at the same number of produced charged hadrons are observed. The assumption that the number of produced charged particles is representative of the initial gluon density of the colliding system [9] can be used to interpret that
the bulk freeze-out properties are most probably determined at the initial stages of
the collision and are driven by the initial energy density.

Notes

a. E-mail: aiorda1@uic.edu
b. For results using multi-hadron fits see [19].
c. Studies show that inclusion of resonance decays (at RHIC energies) do not affect
significantly the fit results.
d. When compared at the same center-of-mass energy, the “k/p” ratios are the
same in both centrality representations, dN_ch/dη and N_part.

References

1. F.Karsch, J.Phys.Conf.Ser. 46 (2006) 122.
2. J.Adams et al., Phys. Rev. Lett. 92 (2004) 112301.
3. L.Molnar et al., arXiv: nucl-ex/0507027
4. O.Baramnikova et al., arXiv: nucl-ex/0403014
5. M. Anderson et al., Nucl. Instrum. Meth. A499 (2003) 659.
6. P.Braun-Munzinger, I.Heppe and J.Stachel, Phys. Lett. B465 (1999) 15.
7. E.Schnedermann, J.Sollfrank and U. Heinz, Phys. Rev. C48 (1993) 2462.
8. A.Iordanova et al., J.Phys.G: Nucl.Part.Phys. 35 (2008) 044008.
9. L.McLerran, Acta Phys. Polon. B34 (2003) 3029; D.Kharzeev and E.Levin,
Phys. Lett. B523 (2001) 79; D.Kharzeev, E.Levin, L.McLerran Phys. Lett.
B561 (2003) 93.
10. M. Lamont J.Phys.Conf.Ser. 50 (2006) 192-200; J.Phys. G32 (2006)
S105-S114.
11. B. Abelev et al., Phys. Rev. Lett. 97 (2006) 152301.
12. R. Hollis et al., Acta Physica Hungarica A1 Proc. 23rd Winter Workshop on
Nuclear Dynamics (2007) 33-40.
13. J.Adams et al., Phys. Lett. B616 (2005) 8.
14. J.Adams et al., Phys. Lett. B637 (2006) 161.
15. B. Abelev et al., Phys. Lett. B655 (2007) 104.
16. A. Timmins et al., J.Phys.G: Nucl.Part.Phys. 35 (2008) 044061.
17. S.V.Afanasev et al., Nucl. Phys. A715 (2003) 474, arXiv:
nucl-ex/0209018v1
18. C. Alt et al. Phys. Rev. Lett. 94 (2005) 052301, arXiv: nucl-ex/0406031v2.
19. J. Takahashi et al., these proceedings.