Rapidity Dependence of Charged Hadron Production in Central Au+Au Collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ at RHIC with BRAHMS

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Abstract. The rapidity dependence of yields dN/dy for $\pi^{\pm}$, $K^{\pm}$ and p, $\bar{p}$ in the 5% most central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV have been measured by the BRAHMS experiment at RHIC. The average rapidity loss per participant nucleon is 2$\pm$ units of rapidity. The strange to non–strange meson ratios K/π are found to track variations of the baryo–chemical potential μ_B in energy and rapidity.

Introduction

In ultra-relativistic heavy ion collisions, final state hadrons are used as a probe of the different reaction stages, with a special focus on observables that may reveal the existence of an early color deconfined phase, the so–called quark gluon plasma. The bulk properties of the collision dynamics, derived from particle yields and spectral analyzes, are becoming well understood at mid–rapidity ($|y| \lesssim 0.5$). However, in Au+Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$, where the beam rapidity is $y_b = 5.36$, this corresponds to no more than 10% of the whole rapidity range ($2 \times y_b$). One of the goals of the BRAHMS experiment is to explore the broadest rapidity range achievable. In this paper, we report on our latest results from the 5% most central Au+Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ over the rapidity range $-0.1 \lesssim y \lesssim 3.5$, i.e. $2 \times 32\%$ of the whole rapidity range (by reflection around $y = 0$ due to the mass symmetry).

Charged Hadron Yields

BRAHMS consists of two hadron spectrometers, a mid–rapidity arm (MRS) and a forward rapidity arm (FS), as well as a set of detectors for global event characterization [1]. Collision centrality is determined from charged particle multiplicities, measured by tile and silicon multiplicity arrays located around the nominal interaction point. The interaction vertex is measured with a resolution of 0.6 cm by arrays of Čerenkov counters positioned on either side of the nominal vertex. Pion–kaon (kaon–proton) separation for momenta below 2 (3.5) GeV/c is performed via time–of–flight (TOF) in the MRS. In the FS, TOF capabilities allow π–K (K–p) separation up to 4.5 (7.5) GeV/c, and is further extended up to 20 (35) GeV/c using a ring imaging Čerenkov detector.

Particle spectra were obtained by combining data from several spectrometer settings (magnetic field and angle), each of which covers a portion of the phase–space (y, p_T). The data have been corrected for the limited acceptance of the spectrometers using a Monte-Carlo calculation simulating the geometry and tracking of the BRAHMS detector system. Detector efficiency, multiple scattering and in–flight decay corrections have been estimated using the same technique, but the data have not been corrected for feed–down from resonance and hyperon decays. Details can be found in [1, 2] and references therein.

The invariant yields, dN/dy, were calculated by extrapolating and integrating functions that fitted the data over the whole p_T range. For pions, a power law $A(1 + p_T/p_0)^{-n}$ was found to describe the data well. For kaons, the fit function was an exponential in $m_T - m_0$, $A \exp\left(\frac{m_T - m_0}{T}\right)$, with m_0 the kaon rest mass. For protons, a Gaussian fit was used. The systematic errors on dN/dy, including errors from extrapolation and normalization, amount to $\sim 10\%$ in the range $0 \lesssim y < 1.3$ and $\sim 15\%$ for $y > 1.3$. Rapidity densities and mean transverse momenta are shown in Fig. 1. Negative and positive pions are found in nearly equal amounts within the

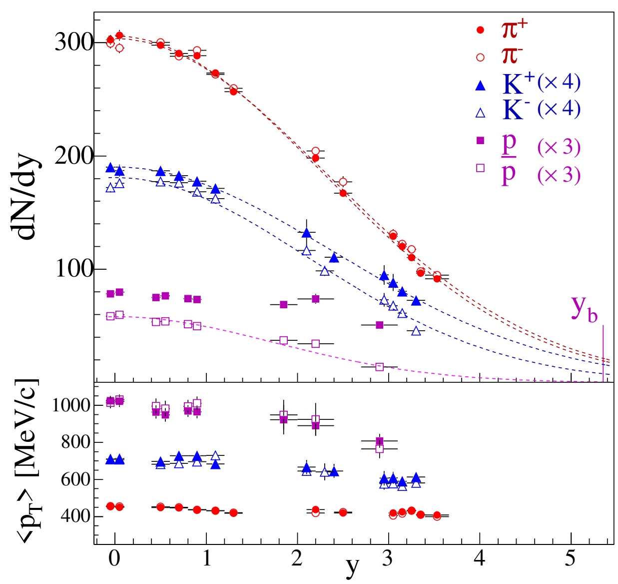

Figure 1. Pion and kaon rapidity densities as a function of rapidity (a) and mean transverse momentum $\langle p_T \rangle$ (b). Errors are statistical. The dashed lines in (a) are fits to the dN/dy distributions (see text).

rapidity range covered. In contrast, an excess of K^+ (p) over K^- ($\bar{p}$) is observed to increase with rapidity [3]. Figure 1(b) shows the rapidity dependence of $\langle p_T \rangle$. There is no significant difference between positive and negative particles of a given mass. In order to extract full phase space densities for $\pi^\pm$ and $K^\pm$ we have investigated several fit functions: a single Gaussian centered at $y = 0$ (G1), a sum of two Gaussians (G2) or Woods-Saxon (WS) distributions placed symmetrically around $y = 0$. Our data do not distinguish among these functions, all give a χ^2 per d.o.f. of ~ 1, and have the same total integral to within 2% In Tab. 1 are reported the G1 integrals.

Table 1. Full phase–space yields of $\pi^{\pm}$ and $K^{\pm}$ extracted from fits to the dN/dy distributions (see text). Errors reported here are statistical, systematic errors are of the order of 8%.

π^+	π^-	K^+	K^-	$\bar{p}$
1742 ± 15	1767 ± 16	286 ± 5	242 ± 4	85 ± 4

Nuclear Stopping

The energy available for particle production is determined from the energy loss ΔE of the original nuclei and is related to the degree of stopping. Due to the conservation of the baryon number during the reaction, the final state net–baryon $(B-\bar{B})$ distribution contains information on ΔE. The nuclear stopping is quantified by the rapidity loss $\langle \delta y \rangle$, which, for mass symmetric collisions, is defined by $\langle \delta y \rangle = y_b - \langle y \rangle$, where $\langle y \rangle$ is the mean net–baryon rapidity after the collision:

$$\langle y \rangle = \int_0^{y_b} y \, \frac{dN_{(B-\bar{B})}(y)}{dy} \, dy \tag{1}$$

It is therefore necessary to know the distribution of baryons in the whole rapidity range. BRAHMS has measured the yields of p and $\bar{p}$ up to $y \sim 3$. A Monte-Carlo simulation provided corrections factors for the non–detected neutrons, and strange baryons such as Λ's and Σ's. Only mid–rapidity hyperon yields are known experimentally, so we made assumptions for more forward rapidities. More details can be found in [4]. Since the data do not cover the entire rapidity range, the missing information has been extrapolated from the measured data by fitting the latter with a function that is continuous and whose integral is equal to the number of participants (357 ± 9 for the 5% most central collisions after a Glauber simulation). Figure 2 shows the net–baryon distribution as a function of y (insert) and $\langle \delta y \rangle$ as a function y_b (main panel). Two functions were used: a sum of Gaussians symmetrically positioned

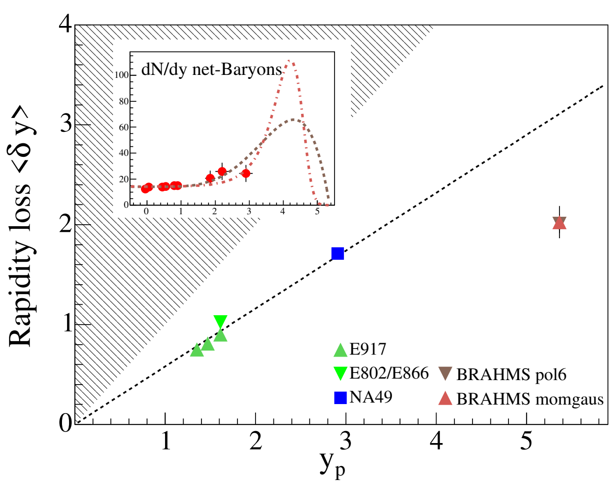

Figure 2. Net-baryon rapidity densities as a function of rapidity (a) and average rapidity loss per participant nucleon as a function of beam rapidity (b). Errors are systematic. The dashed lines in (a) are fits and extrapolation to the distributions (see text).

around mid–rapidity, and a six order polynomial (dashed lines in insert). In both cases, $\langle \delta y \rangle$ amounts to 2.0 ± 0.2. This result is significantly lower than the expectation from the empirical scale $\langle \delta y \rangle \propto y_b$. Even in non–realistic scenarios where the non–detected baryons are all placed at y_b or $y = 3.5$, the deviation is still significant. The energy loss, calculated after the net–baryon fits, is found to be $\Delta E = 72 \pm 6$ GeV per participant, i.e. 25.7 ± 2.1 TeV for the corresponding centrality class.

Strange to Non–strange Meson Ratio

Figure 3 shows the ratio K/π ratios as a function of $\sqrt{s_{NN}}$ (a) and rapidity (b). In the rapidity range $y \lesssim 1$, the ratios are flat. A fit to a straight line give

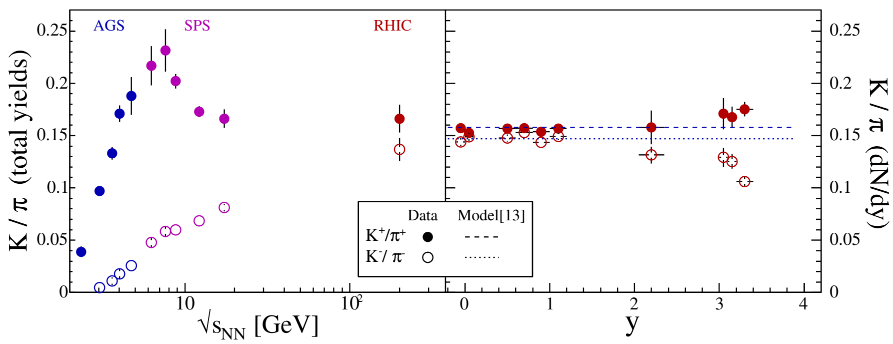

Figure 3. Full phase–space K/π ratios as a function of $\sqrt{s_{NN}}$ (a) and rapidity systematics at $\sqrt{s_{NN}} = 200$ GeV (b). The dashed and dotted lines in (b) are predictions of the statistical model [5]. Errors are statistical and systematics in (a), only statistical in (b). AGS Data are from [6, 7], SPS data from [8, 9, 10].

$K^+/\pi^+ = 0.156 \pm 0.023$ (stat + syst) and $K^-/\pi^- = 0.146 \pm 0.016$. The dashed and dotted lines are predictions of the hadron gas statistical model [5], where a chemical freeze–out temperature T of 177 MeV and baryo–chemical potential μ_B of 29 MeV have been used. The model is restricted to the rapidity range $|y| < 0.5$. As can be seen, the agreement with the data is excellent. However, the data deviate from a straight line at higher rapidities, due to the increasing excess of K^+ w.r.t. K^- noticed in Fig. 1(a). This is consistent with an increase of μ_B with increasing rapidity, as already mentioned in [11], where a calculation by Becattini *et al* [12] of K^+/K^- vs $\bar{p}/p$ at constant T (varying μ_B) agrees well with the rapidity dependence of the experimental ratios.

The energy systematics of the K/π ratios are shown in Fig. 3(a). The ratio K^+/π^+ shows a fast increase from low AGS to low SPS energies ($\sqrt{s_{NN}} =$ (GeV8)), followed by a decrease to with increasing SPS energy (to $\sqrt{s_{NN}} =$ (GeV17)) . We find, at $\sqrt{s_{NN}} = 200$ GeV, a value of 0.165 ± 0.019 (syst) for the ratios of total yields, consistent with the SPS ratio at the highest energy. In contrast, K^-/π^- shows a monotonous increase but remains below K^+/π^+. At $\sqrt{s_{NN}} = 200$ GeV, it reaches a value of 0.136± 0.016 (syst), which is close to K^+/π^+. The full phase –space ratios are not significantly different from those observed in the mid–rapidity "plateau" ($y \lesssim 1$). The chemical freeze–out temperature T_{fo} extracted from the statistical model varies strongly in the AGS energy range. However, it shows little variation from SPS to RHIC energies [need ref]. In this particular energy domain, the K/π systematics is thus mainly driven by changes of μ_B, therefore the qualitative similarity with the rapidity dependence at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$.

Summary and Conclusion

In summary, we have measured transverse momentum spectra and inclusive invariant yields of charged meson $\pi^{\pm}$ and $K^{\pm}$. The particle yields show a maximum at mid–rapidity and decrease by more than a factor 3 towards y$>$ 3. The ratio of strange to non strange mesons, e.g. the K/π ratios are well reproduced by the hadron gas statistical model [5] that assumes strangeness equilibration. The increasing difference between K^+ and K^- yields at higher rapidities can be explained by a change of the baryo–chemical potential μ_B with increasing rapidity. We find that pion rapidity distributions overall agree well with the predictions of the Landau hydrodynamical model, although the overall width and the behavior of the distributions around mid-rapidity suggest increased longitudinal expansion at RHIC energies reminiscent of the Bjorken picture.

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