Rapidity Dependence of Strangeness Production in Central Au+Au Collisions at RHIC

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Abstract. We have measured the rapidity distributions dN/dy of charged hadrons, in particular kaons, in central Au+Au collisions at $\sqrt{s_{NN}} = 200\,\text{GeV}$. Preliminary transverse momentum spectra at $\sqrt{s_{NN}} = 62.4\,\text{GeV}$ are also presented. This new measurement is used to complete and further discuss the energy and rapidity systematics of strangeness production and its dependence on the variations of the baryo–chemical potential.

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 energy systematic of the strange quark production has long been proposed as a probe for outstanding phenomenons such as a phase transition [1, 2]. It has been studied by e.g. the CERN–SPS experiment NA49 [3] at intermediate energies. While these studies often focus on integrated yields (over the full phase–space) or the mid–rapidity zone, one can also learn significant and important information on the production mechanisms by exploring the rapidity (y) dependence of strangeness production by measuring its most abundant outcome, namely the kaon meson, at given beam energies [4, 5]. The BRAHMS experiment [6] at RHIC is unique among the four RHIC experiments because of its ability to identify particles over a broad range of rapidity and transverse momentum p_T. An illustration for kaons is shown in Fig. 1. In this paper are discussed the main results from BRAHMS on strangeness production in the 5% most central Au+Au collisions at $\sqrt{s_{NN}} = 200\,\text{GeV}$. Preliminary data at $\sqrt{s_{NN}} = 62.4\,\text{GeV}$ are also presented.

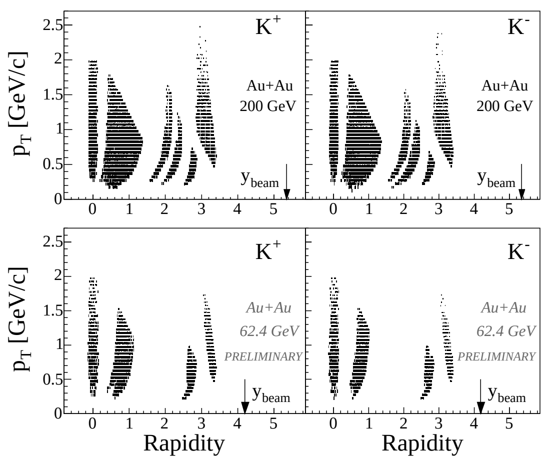

Figure 1. The $y - p_T$ distributions of kaons collected during RHIC Run II (top) and IV (bottom).

BRAHMS consists of mid and forward rapidity charged hadron spectrometers, as well as detectors for global event characterization [6]. 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. Details on the experimental setup and the data analysis can be found in [6, 5, 7].

Figure 2 show transverse mass $m_T - m_0$ spectra of charged kaons measured during RHIC run II ($\sqrt{s_{NN}} = 200\,\mathrm{GeV}$) and run IV ($\sqrt{s_{NN}} = 62.4\,\mathrm{GeV}$), m_T being defined as $\sqrt{p_T^2 + m_0^2}$ and m_0 the rest mass of the kaon. At both beam energies, the kaon spectra

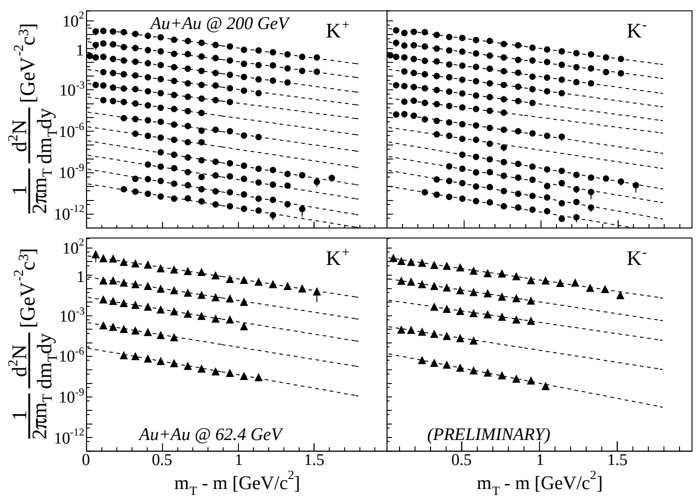

Figure 2. Transverse mass spectra of kaons at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ (top panels) and 62.4 GeV (bottom panels). The spectra span ~ 3 units of rapidity from the top ($y \sim 0$) to bottom ($y \sim 3$) of each panel. They were scaled by a successive power of 10 for clarity.

are well described at all rapidities by an exponential function $\propto exp\,[-(m_T - m_0)/T]$. T is called the inverse slope parameter and is often interpreted as an *effective temperature* of the system (i.e. thermal temperature at freeze–out and transverse collective expansion). As can be seen, the acceptance does not cover the full p_T or m_T range. This introduces a systematic error which is in the order of 10% below $y \sim 1.5$ and 15% above.

The rapidity and energy systematics of the inverse slope parameter T (extracted from the fits) are shown in Fig. 3. The rapidity systematics (Fig. 3 left) show a weak and smooth dependence at both RHIC energies, implying a decrease of the transverse expansion with y. The maximum is observed at mid–rapidity with values of the order of 300 MeV at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ and 250 MeV at $\sqrt{s_{NN}} = 62.4\,\mathrm{GeV}$. However, the lower energy data are systematically lower than the top RHIC energy. This indicates less transverse collective expansion at the lower energy. The right panel of Fig. 3 shows the mid–rapidity inverse slope parameter as a function of $\sqrt{s_{NN}}$ from the low AGS to top RHIC energies. While a very fast increase is noticeable at low energies, there is no significant dependence within the SPS energy regime ($\sqrt{s_{NN}} \lesssim 20\,\mathrm{GeV}$). An increase at a much lower rate sets in as $\sqrt{s_{NN}}$ reaches the RHIC energies. This

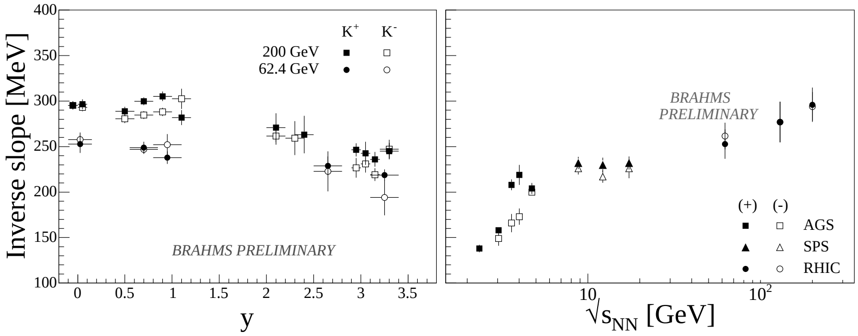

Figure 3. Inverse slope parameter of kaons as a function of rapidity (left) and mid–rapidity data as a function of $\sqrt{s_{NN}}$ (right). AGS data are from [8], SPS data from [9].

behavior has already been reported in [10], where it is interpreted as an evidence that a phase transition occurs at an energy of the order of $\sqrt{s_{NN}} \sim 10\,\text{GeV}$. However, it is still not clear whether it can solely be explained by a change in the dynamics of the net–baryon density with beam energy. Indeed, it has been already reported that the net–baryon density peaks at the top AGS energy at mid–rapidity (in the center of mass frame), starts depleting as $\sqrt{s_{NN}}$ increases (top SPS energy), for finally exhibiting an almost depleted zone around $y \sim 0$ at $\sqrt{s_{NN}} = 200\,\text{GeV}$ (see e.g. [11, 12] and references therein). The dynamical observables of kaon production seem to be strongly correlated to the evolution of the net–baryon densities with beam energy, as illustrated in Fig. 4.

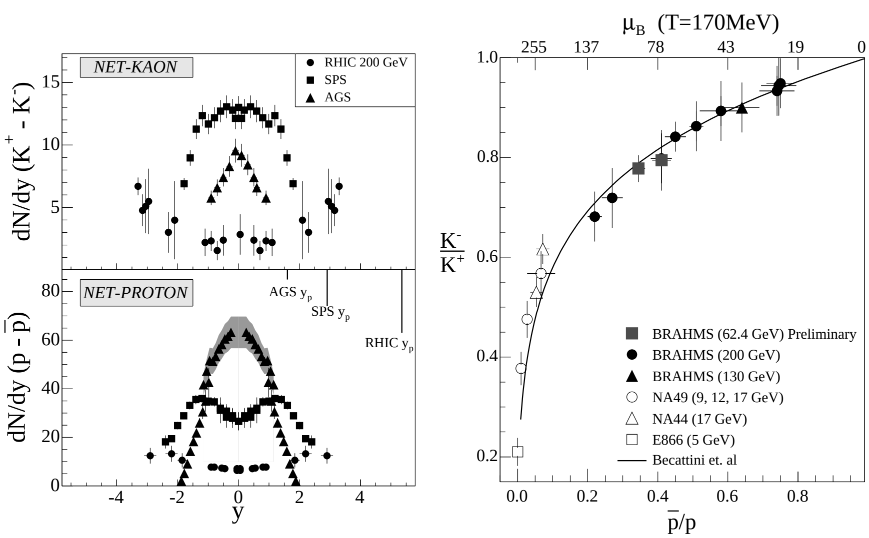

Figure 4. Left: Net–kaon $K^+ - K^-$ (top) and net–proton $p - \bar{p}$ (bottom) densities at different beam energies. Right: Kaon ratio K^-/K^+ as a function of the $\bar{p}/p$ ratio. The BRAHMS data points correspond to different rapidities whereas the lower energy points are mid–rapidity measurements only. The solid curve is a calculation by Becattini *et al.* (see [4] and references therein).

The left panels of Fig. 4 shows the strong similarity at the RHIC energy between both the net–kaon and net–proton rapidity distributions. As already reported in [5], the excess of K^+ may be due to an excess of baryons, as opposed to anti–baryons. This mechanism is called associated strangeness production, e.g. $p + p \rightarrow K^+ + \Lambda + p$ (in contrast, K^- is created by pair with K^+). Furthermore, the right panel of Fig. 4 shows that the kaon ratio K^+/K^- is not only strongly correlated to the $\bar{p}/p$ ratio but can also be described by theoretical calculations based on the statistical model of particle production proposed by Becattini *et al.*. In this context, the proton ratio translates into the baryo–chemical μ_B. This correlation implies that whether one looks in the rapidity space or scans the beam energy, the important quantity is μ_B. The preliminary data at $\sqrt{s_{NN}} = 63\,\mathrm{GeV}$ seem to follow such a picture. The higher rapidity data at this energy, although not available as of the time of writing this paper, will be of importance in order to quantify the role and predominance of μ_B in strangeness production in relativistic heavy ion collisions.

In summary, we have measured transverse momentum spectra and inclusive invariant yields of charged kaons $K^{\pm}$ for the 5% most central events in Au+Au at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$. We also started analyzing data from the short RHIC run at $\sqrt{s_{NN}} = 62.4\,\mathrm{GeV}$ in the same fashion. We found that kaon spectra at both energies and at all covered rapidities can be well described by an exponential in $m_T - m_0$. The inverse slope parameter, related to the transverse collective expansion, shows a smooth decrease as y increases at both energies but is systematically lower at the lower RHIC energy. The energy systematic of the slope parameter at $y = 0$ exhibits an anomaly around the SPS energy regime, where a change in the net–baryon dynamic takes place. Whether the latter is the main factor for the evolution of strangeness production with beam energy (or rapidity) in heavy ion collisions at relativistic energies remains an open question. However, a further analysis of the $\sqrt{s_{NN}} = 62.4\,\mathrm{GeV}$ data may constrain the answer to the question. Indeed, the BRAHMS acceptance at this energy is broad enough to cover most of the net–proton distribution and therefore allows for a complete rapidity study of the relation between kaon production and baryo–chemical potential μ_B.

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