Particle production in Au-Au collisions at RHIC, recent results from BRAHMS

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Abstract.
This work reports recent results from the BRAHMS experiment at RHIC. Particle production in rapidity space extending from y=0 to $y \sim 3$, as well as transverse momentum distribution of fully identified charged particles. These results were obtained from the 5% most central Au-Au collisions recorded during RHIC Run-2 at $\sqrt{s_{NN}} = 200$ GeV.

INTRODUCTION

BRAHMS is the only RHIC experiment that is able to study particle production and energy flow in a wide range of rapidities (from y=0 to y=4 for pions). This coverage that almost reaches the fragmentation regions, is ideal for studies of the bulk properties of the system formed in heavy ion collisions at RHIC energies. This work reports recent results obtained from the analysis of data collected with the BRAHMS spectrometers in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Detailed description of the BRAHMS experimental setup can be found in [5]. All results shown here are preliminary and were obtained from a sample of the 5% most central events. The centrality of the collision is extracted from the multiplicity of charged particles measured with BRAHMS TMA [11].

PARTICLE PRODUCTION

Momentum distributions of fully identified charged particles were obtained with conventional magnetic spectrometers instrumented with state-of-the-art time-of-flight and ring imaging and threshold Čerenkov detectors. Invariant yields in $p_{\rm T}$ and rapidity space were extracted from the data. For a particular value of rapidity, these distributions include measurements from different field and angle settings. These invariant yields are corrected for spectrometer acceptance and tracking efficiency. For each particle type, the density in rapidity space is obtained by integration over the $p_{\rm T}$ dependence of these distributions. These distributions drop fast as $p_{\rm T}$ grows and a good fraction of the integral comes from unmeasured yields at low $p_{\rm T}$. An extrapolation is thus necessary to cover the unmeasured region without introducing too big an error to the result. In this work, pion yields were fit to a power law $\frac{A}{(1+\frac{p_T}{p_0})^n}$, and kaon distributions were well reproduced by a single exponential in p_T. Protons were fit with a single exponential in

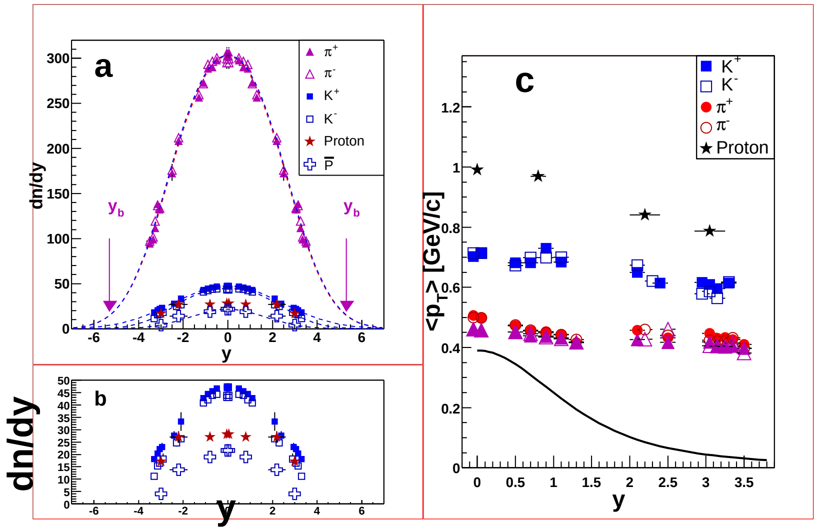

FIGURE 1. a) and b) Rapidity density distributions for identified charged particles extracted from the 5% most central events. c) Mean ransverse momentum as function of rapidity

$m_T = \sqrt{p_T^2 + m^2}$.

The resulting rapidity density distributions are shown in panels a and b of figure 1. Panel a shows the densities for all charged particles. Because pions dominate this figure, panel b zooms in on the kaon, proton and antiproton distributions.

The remarkable feature of these distributions is their bell shape. This fact has a possible qualitative explanation based on the postulate that particle production with momenta in the range measured in the present experiment is driven mainly by the distribution of partons in the colliding ions. As the energy of the collisions increases, the parton distributions can be resolved to smaller and smaller values of x (fraction of the total momentum of the hadron) and their shapes, specially the ones of gluons, tend to adopt the form of half a bell. The initial form of dn/dy of produced particles in symmetric systems has thus a bell shape centered around y=0, its left side corresponding to the parton distributions functions of the ions moving from right to left, and the right side to the one from the ions moving from left to right. This distribution may evolve in later stages through secondary interactions, but it retains its bell shape. There is no wide plateau connecting the two fragmentation regions as Feynman intuition had it [2]. Or a boost invariant longitudinal expansion proposed by Bjorken [1].

A good summary of all the p_T distributions extracted in this analysis is shown in panel c of figure 1; the average transverse momentum with which the detected particles are produced at different rapidities. Worth noting in this result is the near flatness and linear behavior of the pion and kaon average p_T as function of y. For comparison, a calculated average p_T is also drawn in panel c. The curve was obtained with a single thermal source described by a Boltzmann distribution with a temperature of 200 MeV.

An inspection of the transverse momentum distributions, specially around mid-rapidity, shows the more massive particles with a very clear curvature in the spectra as the value of p_T approaches zero (see Figure 2). That fact, together with the almost

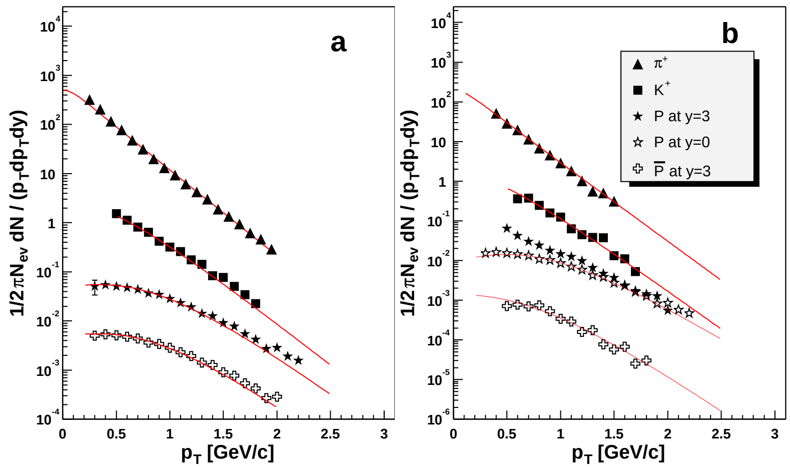

FIGURE 2. "Blast wave" fits to pions, kaons and protons at rapidity y=0 (panel a) and y=3 (panel b)

TABLE 1. Results of blast wave fits

Rapidity	Temperature [MeV]	Velocity
0	138	0.53
1	115	0.57
2	135	0.47
3	140	0.42

exponential shape of the distributions, is well reproduced by a functional form based on a thermalized system expanding radially . In that approach, each volume element is in thermal equilibrium, and moves out radially. The measured momentum distributions are reproduced by counting the number of particles that cross a hyper-surface beyond which they stop interacting [4] (this approach allows for particle emission from the volume of the source).

After integration over y and azimuthal angle and assuming that a Boltzmann distribution describes the system, the following functional form is obtained, and is used to fit the spectra:

$$\frac{dn}{m_T dm_T} = Am_T \int_0^R r dr K_1\left(\frac{m_T cosh\rho}{T}\right) I_0\left(\frac{p_T sinh\rho}{T}\right)$$

where $\beta_T = tanh\rho$ is the transverse velocity of the flow in units of c.

Several functions that describe the radial dependence of the flow velocity have been proposed, but to add simplicity to these fits, the transverse flow velocity is assumed to be a constant at all radii. This choice may be inadequate, but the purpose of this exercise is to evaluate changes as function of rapidity, and this parametrization of the data can certainly do the job. The table 1 summarizes the fits.

Even though the shape of the distributions is well reproduced by the fits, and the numbers shown in table 1 indicate a 20 % reduction in transverse velocity, the proton distributions at y=0 (open circles) and y=3 (filled circles) can be compared by eye in panel b of figure 2. Based only on this comparison, one could advance the statement that transverse flow at y=3 is much reduced. Also visible in panel b of figure 2 is the fact that there is a clear difference between anti-protons and protons at that rapidity. A more thorough analysis of this forward data is needed to elucidate this interesting difference.

The measured net proton at mid-rapidity was an early subject of much discussion in the community because it went against an expected baryon free region around $y \sim 0$; the energy of the colliding beams was so high that the initial baryon number if tied to the valence quarks should end up in the fragmentation regions. But the first results extracted at y=0 indicated otherwise, the net-proton number was not equal to zero. Some mechanism was transporting baryon number to mid-rapidity. D. Kharzeev [3] had a prediction in which the x distributions of gluons of the initial baryon extend to very small values of x. At the time of the collision these distributions would overlap and after "dressing" with quarks from the sea they would bring baryon numbers to mid-rapidity. This effect would have a rapidity dependence as $Acosh(\frac{y}{b})$. Figure 3a shows the net charge measured up to rapidity 3 and a fit to the function mentioned above, The result of the fit is $b = 2.45$

Another result that attracted much attention as soon as identified particle distributions were available at RHIC Run-1 was the large proton or anti-proton ratio to pion at moderate transverse momentum ($\sim 2-3GeV/c$). If particles with those momenta are the result of indepedent single parton hadronization, it is expected that light particles like pions would be produced abundantly. Measurements in e^+e^- collisons do show such behavior [10]. One of the first explanations put forward would have transverse flow increasing the momentum of the massive particles more efficiently. As transverse flow was measured in excess of half of the speed of light, this mechanism was suggested to explain the measurements. Other explanations have been presented, all have in common the assumption that partons instead of hadronizing independently combining with quarks and anti-quarks from the vacuum, can also coalesce with other partons present in a high density deconfined system that seems to have been formed at RHIC [6], [8] and [7]. As the momentum of the resulting charged particle is the sum of momenta of its partons; baryons would tend to be produced with higher momentum.

In panel b of figure 3 the ratio of anti-protons to negative pions is shown as a function of transverse momentum for three different values of rapidity. For rapidities ranging from 0 to 2 the behavior is basically identical, but at y=3 the ratio shows a drastic change. At this rapidity this ratio behaves more like the one measured in e^+e^- interactions at $\sqrt{s} = 91GeV$ [10]. This dramatic change seems to indicate that the system formed in central Au-Au collisions at RHIC changes drastically between rapidities 2 and 3. This conjecture is consistent with another recent BRAHMS result that shows that high p_T suppression is still present at y=2 [9]. The high density colored system where jets are losing energy extends beyond rapidity 2; hadronization is affected by this medium by coalescence or flow, but at y=3 the medium is absent and partons hadronize independently.

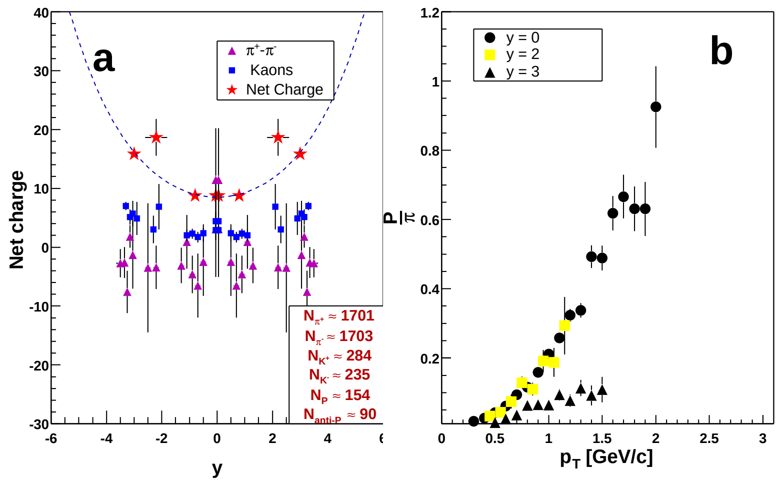

FIGURE 3. Panel a shows the net charge as function of rapidity with filled star symbols. Filled square symbols show the difference $K^+ - K^-$, and the filled triangles show the difference $\pi^+ - \pi^-$. The dashed line is the fit to the function refered in the text. Panel b shows the ratio of $\bar{p}$ to π^- at y=0,1,2 and 3. All errors in both panels are statistical

SUMMARY

Analysis of the most central data sample collected during RHIC Run-2 (Au-Au at $\sqrt{s_{NN}} = 200$ GeV) is consistent with a thermalized system with a decoupling temperature around 135 MeV, and a strong radial flow $\beta_{\mathrm{T}} \sim 0.6$. The shapes of the distributions at y = 3 and the behavior of the $\frac{\bar{p}}{\pi^-}$ as function of p_T indicate a change in the system between rapidities 2 and 3.

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