High Rapidity Physics with the BRAHMS Experiment

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Abstract. We report the nearly rapidity independent Nuclear modification factor R_{AuAu} extracted by the BRAHMS Collaboration from Au+Au collitions at top RHIC energy. It is hypothesized that the ratio $\bar{p}/\pi^-$ can serve as a probe of the density and degree of thermalization of the medium formed by the collision. The rapidity independence of the R_{AuAu} may be the result of the combined effects of energy loss in a dense and opaque medium and modifications of the wave function of the high energy beams in the initial state.

Keywords: RHIC, QGP, Nuclear modification factor, high rapidity.
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INTRODUCTION

The BRAHMS Collaboration has completed a thorough program exploring the particle production from several AA systems and different energies at RHIC. The wide and almost continuous rapidity coverage of the BRAHMS spectrometers stands out in the RHIC program because of its ability to probe the beam wave functions deeper into smaller values of the longitudinal momentum fraction carried by its partons. The particle production from A+A collisions has been compared to p+p yields measured at the same energy and with the same detectors, the yields from p+p collisions are scaled by the estimated number of binary collisions in the A+A systems $< N_{coll} >$. The comparisons are done with the so called Nuclear modification factor: $R_{AA} = Y^{AA}/ < N_{coll} > Y^{pp}$ where Y^{AA} denotes the invariant yield extracted from A+A collisions, and Y^{pp} the one from p+p collisions. If the A+A system is an incoherent superposition of nucleon+nucleon collisions the ratio show be constant and equal to one. The result of the measurements has been a dramatic suppression (by as much as a factor of 5 at the highest energy) that extends to high values of transverse momentum ($\sim 20GeV/c$). All RHIC experiments have already reported these results at mid-rapidity and they are now considered as a consequence of a formation of a dense and opaque medium dubbed sQGP [1]. Such a conclusion was reached after the nuclear modification factor extracted for d+Au collisions showed a Cronin type enhancement at mid-rapidity implying that the suppression seen in Au+Au events is a final state effect. The study of d+Au collisions as function of rapidity has generated as well, renewed interest in the contribution from the partons with smallest longitudinal momentum fraction x to particle production in hadron-hadron interactions. The high rapidity suppression measured in d+Au colisions [2] has been described as the result of the modification of an already saturated gluonic system present at RHIC energies, by additional gluon emission as well as gluon fusion, all in the initial state of the interaction [3, 4]. Such modification of the nuclei wave

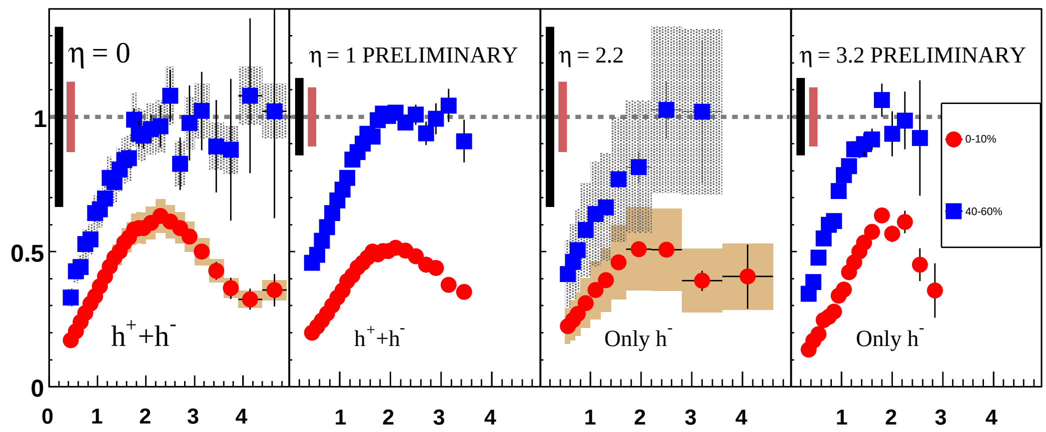

FIGURE 1. Nuclear modification factor R_{AuAu} extracted from two centrality samples: central 0-10% shown with filled circles (red online) and semi-central 40-60% shown with filled squares (blue online), at four values of pseudo-rapidity: $\eta = 0$ and 1. for charged particles $h^- + h^+$, and $\eta = 2.2$ and 3,2 for negative hadrons h^-. Statistical errors are shown with bars and the estimated systematic errors are shown with boxes, the normalization errors are shown on the left of each panel and centered at the value of 1.

function should also be present in A+A collisions but may be masked by the fact that any measurement at high rapidity probes the projectile as well as the target fragmentation regions of both beams (here, for convenience, we borrow the naming scheme familiar in fixed target p+A physics).

THE NUCLEAR MODIFICATION FACTOR R_{AuAu} AS FUNCTION OF RAPIDITY.

The nuclear modification factor as function of transverse momentum extracted from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV/c is shown in Fig. 1. Starting from the left, each panel shows the R_{AuAu} factor extracted at mid-rapidity ($\eta = 0$) for charged hadrons from two centrality samples: 0-10% shown with filled circles (red online), and 40-60% with filled squares (blue online). The next panel shows the factor at $\eta = 1$, followed by the same factors at $\eta = 2.2$ and $\eta = 3.2$ extracted this time from negative hadrons. The results at $\eta = 0$ and 2.2 have been published and more details about the analysis can be found in [5].

The most remarkable feature of Fig. 1 is the almost constant value of the maximum reached by the R_{AuAu} as the rapidity changes from 0 on the left-most panel to 3.2 on the right. If all these measurements were to show the effects of energy loss in a dense and opaque system formed after the collisions, a naive expectation would have something like a factor of 2 less suppression at $\eta = 3.2$ because the measured pion yield shown in Fig. 2 does change by that amount between mid-rapidity and y=3. If we make use of the parton-hadron duality hypothesis, this variation in the pion density will also be present in the gluon density of the formed medium.

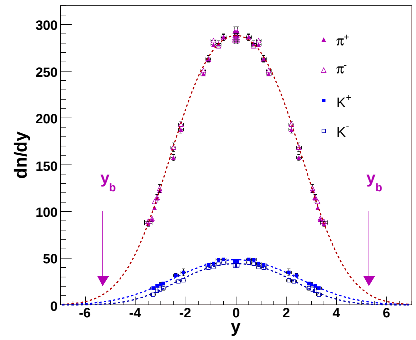

FIGURE 2. Rapidity density for charged pions and kaons produced in the 0-5% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

The absence of rapidity dependence in the R_{AuAu} is a puzzle that may be difficult to solve because many effects compete in the transverse momentum range of the measurement, and the description of the hydrodynamical expansion of the sQGP, or the mechanisms of energy loss in that medium are not yet well understood. We propose in this work the use of the $\bar{p}/\pi^-$ ratio as a tool to characterize the evolution of that system with rapidity; The comparison of yield of anti-protons and the one of negative pions shows a strong rapidity dependence that can be contrasted with the one found to be practically absent in the R_{AuAu} ratio.

THE $\bar{p}/\pi^-$ RATIO AS FUNCTION OF RAPIDITY

The parametrization of the $\bar{p}/\pi^-$ ratio function of transverse momentum in e^+e^- annihilations around the Z pole is small and it doesn't exceed 0.2 [6]. This ratio is the result of single parton fragmentation in the vacuum that favors the production of many particles sharing the original parton momentum, and because the parton is colored, it will produce more mesons in an assumed string breaking mechanism. In A+A collisions at RHIC the p_T dependence of the $\bar{p}/\pi^-$ and p/π^+ ratios has been found to reach values close to 1 and in some cases, even bigger than 1. In a medium with high parton density, fragmentation and recombination compete in the formation of hadrons and recombination by its additive nature may be more efficient at forming particles at higher values of p_T. The same mechanism would also generate generate more protons at some intermediate p_T as a result of the sum of momenta of three partons in contrast to the two required to form a meson. These measured high values of the $\bar{p}/\pi^-$ and p/π^+ ratios have been explained as resulting from the recombination of partons present in the thermalized medium [7].

The $\bar{p}/\pi^-$ ratio extracted from Au+Au collisions at top RHIC energy is shown in Fig. 3 with filled circles. The left-most panel shows the ratio at mid-rapidity reaching values as high as 4 times the values found for the so called fragmentation in the vacuum. As rapidity changes to y=1 the maximum of the ratio decreases visibly and at the highest rapidity (y=3.2) on the right of the figure, the ratio reaches its smallest value. For comparison, the same ratio extracted from p+p collisions by the PHENIX collaboration at y=0 is shown in the left-most panels as well as the same ratio measured by BRAHMS

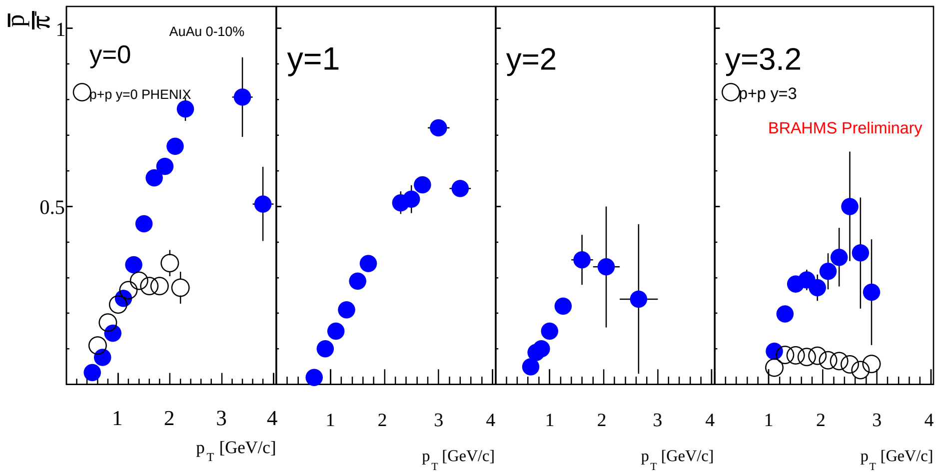

FIGURE 3. The $\bar{p}/\pi^-$ ratio extracted from Au+Au collisions as function of transverse momentum at four values of rapidity. The ratios were extracted from central events 0-10%. The same ratio extracted from p+p collisions is shown with open circles at y=0 and y=3.2. The errors are statistical.

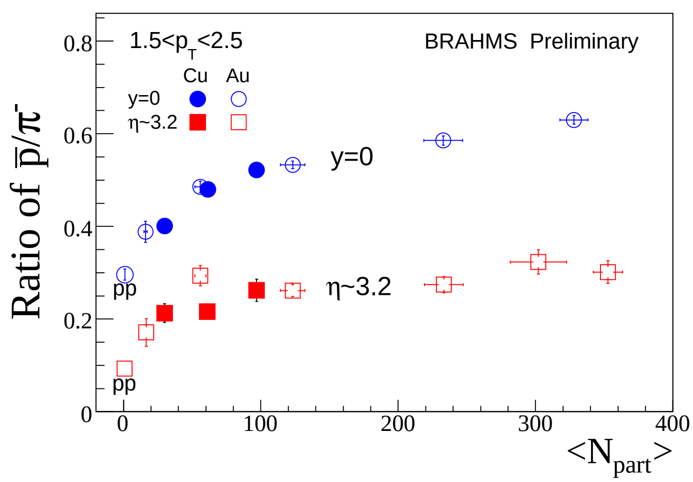

FIGURE 4. Compilation of the integral of the $\bar{p}/\pi^-$ over the $1 < p_T < 2.5$ GeV/c interval for various colliding systems at $\sqrt{s_{NN}} = 200$ GeV. The integral for Cu+Cu collisions at y=0 shown with filled circles (blue online), and y=3.2 with filled squares (red online). The results obtained from Au+Au collisions are shown with open circles (blue online) at y=0, and open squares (red online) at y=3.2. The p+p results are shown with similar symbols and are located at $< N_{part} >$.

at y=3.2 in p+p collisions shown on the right-most panel.

Figure 4 summarizes the variation of the $\bar{p}/\pi^-$ ratio with the size of the system which correlates well with the calculated mean number of participant nucleon $< N_{part} >$ at a determined centrality of the collision. The integral over p_T in an interval that includes the maxima seen in all panels of Fig. 3, should convey the evolution of this ratio in shape as well as magnitude as function of rapidity. For the purpose of this report, the main feature in Fig. 4 is the fact that the $\bar{p}/\pi^-$ ratio extracted from the most central Au+Au collisions at y=3 has the same value as the one measured at mid-rapidity in to p+p collisions at the same energy.

If recombination is the effect that drives the $\bar{p}/\pi^-$ ratio, its clear rapidity dependence seen in Fig. 3 puts in doubt any explanation of the suppression measured with the R_{AuAu} factor at high rapidity as being solely produced by energy loss in a dense medium. The behavior of the $\bar{p}/\pi^-$ ratio seems to indicate that the sQGP does not extend to high rapidity, or if it does its effects on partons traversing it at high rapidity cannot be as strong as the measured one at y=0 and the small values of the R_{AuAu} factor at high rapidity are rather due to other effects that may stand out as the effect of energy loss weakens at one approaches the beam fragmentation regions. One such effect at high rapidity must be the modification of the beam wave functions as they are now probed into even smaller values of x.

SUMMARY

We have shown the almost rapidity independent nuclear modification factor R_{AuAu} extracted from Au+Au collisions at two centralities. The suppression of the R_{AuAu} at mid-rapidity is produced by energy loss in the dense and opaque sQGP formed early in the Au+Au collisons. We postulated the use of the $\bar{p}/\pi^-$ to probe the density and degree of thermalization of that medium at different rapidities. The strong rapidity dependence of the $\bar{p}/\pi^-$ ratio led us to conclude that the effects of the dense and opaque sQGP do not extend to high rapidity because its density changes much more rapidly than the R_{AuAu} factor. The continued suppression seen in the R_{AuAu} factor may then be the result of a compromise between energy loss in the sQGP that dominates around mid-rapidity and the modification of the beam wave functions that become apparent at high rapidity.

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REFERENCES

1. I. Arsene *et al.* (BRAHMS), Nucl. Phys. A **757**, 1 (2005); K. Adcox *et al.* (PHENIX), Nucl. Phys. A **757**, 184 (2005); B. B. Back *et al.* (PHOBOS), Nucl. Phys. A **757**, 28 (2005); J. Adams *et al.* (STAR), Nucl. Phys. A **757**, 102 (2005).
2. I. Arsene *et al.*, Phys. Rev. Lett. **93** 242303, (2004).
3. R. Baier, A. Kovner and U. Wiedemann Phys. Rev. **D68**, 054009 (2003).
4. D. Kharzeev, Y. Kovchegov and K. Tuchin Phys. Rev. **D68**, 094013 (2003).
5. I. Arsene *et al.*, BRAHMS Collaboration, Phys. Rev. Lett. **91**, 072305 (2003).
6. P. Abreu *et al.*, Eur. Phys. J. **C17**, 207, (2000); R. Barate *et al.*, Phys. Rept **294**, 1-165, (1998).
7. R.C. Hwa and C.B. Yang, Phys. Rev. C **67**, 034902 (2003); R.J. Fries, B. Muller, C. Nonaka, and S.A. Bass, Phys. Rev. Lett. **90**, 202303 (2003); V. Greco, C.M. Ko, and P. Levai, Phys. Rev. Lett. **90**, 202302 (2003); V. Greco, C.M. Ko, and P. Levai, Phys. Rev. C **68**, 034904 (2003); R.J. Fries, B. Müller, C. Nonaka, and S.A. Bass, nucl-th/0306027; D. Molnar ans S.A. Voloshin, Phys. Rev. Lett. **91**, 092301 (2003).