Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physics Letters B 607 (2005) 42–50
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Forward and midrapidity like-particle ratios from $p + p$ collisions at $\sqrt{s} = 200$ GeV

BRAHMS Collaboration

I.G. Bearden [f], D. Beavis [a], C. Besliu [j], B. Budick [e], H. Bøggild [f], C. Chasman [a], C.H. Christensen [f], P. Christiansen [f], J. Cibor [c], R. Debbe [a], E. Enger [l], J.J. Gaardhøje [f], M. Germinario [f], K. Hagel [h], A. Holm [f], A.K. Holme [l], H. Ito [a], E. Jakobsen [f], A. Jipa [j], F. Jundt [b], J.I. Jørdre [i], C.E. Jørgensen [f], R. Karabowicz [g], T. Keutgen [h], E.J. Kim [a,k], T. Kozik [g], T.M. Larsen [l], J.H. Lee [a], Y.K. Lee [d], G. Løvhøiden [l], Z. Majka [g], A. Makeev [h], M. Mikelsen [l], M.J. Murray [h,k], J. Natowitz [h], B.S. Nielsen [f], J. Norris [k], K. Olchanski [a], D. Ouerdane [f], R. Płaneta [g], F. Rami [b], C. Ristea [j], D. Röhrich [i], B.H. Samset [l,*], D. Sandberg [f], S.J. Sanders [k], R.A. Scheetz [a], P. Staszel [f], T.S. Tveter [l], F. Videbæk [a], R. Wada [h], A. Wieloch [g], Z. Yin [i], I.S. Zgura [j]

[a] *Brookhaven National Laboratory, Upton, NY 11973, USA*
[b] *Institut de Recherches Subatomiques and Université Louis Pasteur, Strasbourg, France*
[c] *Institute of Nuclear Physics, Krakow, Poland*
[d] *Johns Hopkins University, Baltimore, MD 21218, USA*
[e] *New York University, NY 10003, USA*
[f] *Niels Bohr Institute, Blegdamsvej 17, University of Copenhagen, Copenhagen 2100, Denmark*
[g] *Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland*
[h] *Texas A&M University, College Station, TX 17843, USA*
[i] *Department of Physics, University of Bergen, Bergen, Norway*
[j] *University of Bucharest, Romania*
[k] *University of Kansas, Lawerence, KS 66045, USA*
[l] *Department of Physics, University of Oslo, P.b. 1048 Blindern, 0316 Oslo, Norway*

Received 22 September 2004; received in revised form 8 December 2004; accepted 10 December 2004

Available online 29 December 2004

Editor: W.-D. Schlatter

* Corresponding author.
E-mail address: b.h.samset@fys.uio.no (B.H. Samset).

doi:10.1016/j.physletb.2004.12.064

Abstract

We present a measurement of π^-/π^+, K^-/K^+ and $\bar{p}/p$ from $p+p$ collisions at $\sqrt{s}=200$ GeV over the rapidity range $0<y<3.4$. For $p_T<2.0$ GeV$/c$ we see no significant transverse momentum dependence of the ratios. All three ratios are independent of rapidity for $y \lesssim 1.5$ and then steadily decline from $y\sim 1.5$ to $y\sim 3$. The π^-/π^+ ratio is below unity for $y>2.0$. The $\bar{p}/p$ ratio is very similar for $p+p$ and 20% central Au + Au collisions at all rapidities. In the fragmentation region the three ratios seem to be independent of beam energy when viewed from the rest frame of one of the protons. Theoretical models based on quark–diquark breaking mechanisms overestimate the $\bar{p}/p$ ratio up to $y \lesssim 3$. Including additional mechanisms for baryon number transport such as baryon junctions leads to a better description of the data.

PACS: 25.75.q; 25.40.-h; 13.75.-n

Keywords: Proton collisions; Particle ratios; Forward rapidity; Limiting fragmentation; Baryon junctions

1. Introduction

The ratios of particle production in hadronic interactions are important indicators of the collision dynamics [1]. By comparing large and small systems over a wide range of phase space, one can address both reaction mechanisms in simpler systems and the properties of hot and dense nuclear matter in large systems. A thorough understanding of $p+p$ collisions at ultrarelativistic energies is necessary both as input to detailed theoretical models of strong interactions, and as a baseline for understanding the more complex nucleus–nucleus collisions at RHIC energies. Soft particle production from ultrarelativistic $p+p$ collisions is also sensitive to the flavor distribution within the proton, quark hadronization and baryon number transport. Extensive data exist near midrapidity, but less is known about the forward rapidity region where fragmentation and isospin effects are important.

In this Letter we present measurements of like-particle charged hadron ratios from $p+p$ collisions at a center-of-mass energy of $\sqrt{s}=200$ GeV as a function of rapidity $y=0.5\ln((E+p_z)/(E-p_z))$ and transverse momentum p_T, and make a comparison with similar BRAHMS results from the 20% most central Au + Au collisions at the same energy. We show that the $p+p$ and Au + Au results on pion, kaon and proton like-particle ratios are consistent over three units of rapidity, in spite of the expected large differences in dynamics between these systems.

In $p+p$ collisions at RHIC energies two main mechanisms for particle production are expected. At midrapidity the Bjorken picture [2] predicts that particles will be formed mainly from string fragmentation, yielding values of antiparticle-to-particle ratios close to unity. At forward rapidities, close to the beam rapidity ($y_b=5.3$ at $\sqrt{s}=200$ GeV), cross-sections are instead known to be dominated by leading particles and projectile fragments (the fragmentation region). This means that the conservation of charge and isospin will become increasingly important for particle production as one approaches y_b. The present data on π^-/π^+, K^-/K^+ and $\bar{p}/p$ show that in $p+p$ collisions at $\sqrt{s}=200$ GeV there is a midrapidity region extending out to $y\sim 1.5$ where the particle ratios agree with the Bjorken picture. Above this point the ratios start to decrease, indicating the onset of fragmentation region physics. Shifting the ratios by the beam rapidity and comparing to lower energy data, we find a broad rapidity range where ratios of like-particle production are independent of the incident beam energy when viewed from the rest frame of one of the protons (limiting fragmentation [3]).

The traditional quark–diquark breaking picture of a $p+p$ collision fails to reproduce baryon transport in available midrapidity data, which has been taken as evidence for several additional mechanisms being important at higher energies [4–7]. In this Letter we provide a comparison of different model predictions with experimental data, which, especially away from midrapidity, provides new constraints for calculations. We show that the commonly used event generator PYTHIA [8] does not reproduce the ratio of antiproton to proton production seen in the data at any rapidity, while the additional hypothesis of a baryon junction within the HIJING/B [9] model yields a good agreement with both the magnitude and rapidity dependence of the observed $\bar{p}/p$ ratio.

2. The analysis

The data presented in this Letter were collected with the BRAHMS detector system during 2001. BRAHMS consists of two movable magnetic spectrometers and a suite of detectors designed to measure global multiplicity and forward neutrons [10]. In addition, eight rings of plastic scintillator tiles were used to find the collision point and provide a minimum bias trigger [11]. To reduce the contribution of background events valid hits in the outer three rings were required as part of the offline analysis. Using a GEANT simulation with the HIJING event generator [12] as input, it was estimated that this trigger setup saw $71 \pm 5\%$ of the 41 mb $p + p$ total inelastic cross-section. Spectrometer triggers that required hits in several hodoscopes were used in each of the two spectrometers to enhance the event sample of $p + p$ collisions with tracks. For this analysis data taken at nine angle settings with respect to the beam were used, ranging from 90° to 3° and yielding a rapidity coverage of $0 < y < 3.4$ for pions.

Identification of charged hadrons (π, K, and p) was done primarily through time-of-flight measurements. Tracks having a measured inverse velocity (β^{-1}) within a $\pm 2\sigma$ band of the theoretical value for the appropriate momentum and mass, were selected for analysis. In the forward spectrometer where particles in general have higher momenta, identification was also provided through the recorded radius in a Ring Imaging Cherenkov detector, and via momentum dependent cuts in the response of a threshold Cherenkov detector. The details of the particle identification and analysis methods used are similar to those described in [13,14], but because of the lower particle yield our time-of-flight calibration is worse than for Au + Au. This mainly affects the midrapidity spectrometer, which only has time-of-flight systems. For the present analysis a separation of p/K up to $p = 2.6$ GeV/c and K/π up to 1.6 GeV/c was achieved here.

Charged particle ratios were measured by dividing transverse momentum spectra, normalized to the minimum bias trigger. By measuring positive and negative particles at the same angular setting but with opposite magnet polarities, most corrections for geometrical acceptance and detector efficiencies cancel out. Fig. 1 shows the resulting like-particle ratios as a function of p_T at the extreme measured rapidities of $y \sim 0$ and $y \sim 3$. Within our statistical errors there is no significant dependence on p_T. The ratios were therefore fitted to a constant over a p_T range matching the limits of our acceptance (see Fig. 1). For most settings this range was $0.5 < p_T < 1.5$ GeV/c, varying by $< \pm 0.5$ GeV/c for the different spectrometer angles.

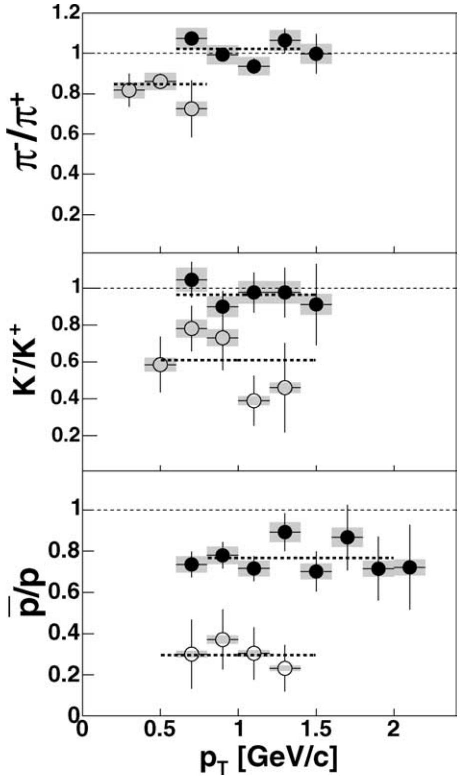

Fig. 1. Particle ratios vs. p_T at $y = 0$ (solid circles) and $y \sim 3$ (open circles). The lines show the result of fitting a constant to the data, over the indicated range. The shaded area shows our estimate of the systematic error.

The ratios have been corrected for particle absorption and in-flight decay as discussed in Ref. [13]. In addition corrections were applied for antiproton absorption in the spectrometer trigger slats, which removed $\sim 10\%$ of the $\bar{p}$ yield at $p < 1$ GeV/c, dropping to $\sim 5\%$ at $p = 2$ GeV/c. Primary particles were selected by requiring the tracks to point back to the beam line, with an achieved resolution of $\sigma \sim 0.7$ cm.

For π^-/π^+ and K^-/K^+ a 3σ cut was used, while for $\bar{p}/p$ a 2σ cut was set to further eliminate knock-out protons from the beampipe. Since the spectrometers have a small solid angle the effects of feed-down from weak decays are not large and tend to cancel in the ratios [14]. The $\bar{p}/p$ ratio is exceptional since it is sensitive to the evolution with rapidity of the Λ/p ratio. To estimate the upper limits of this effect, a GEANT simulation with published STAR data from $p+p$ collisions $y=0$ [15] as input has been used. Taking $\Lambda/p \sim 0.5$, assuming a constant behavior with rapidity and that $\bar{\Lambda}/\Lambda \sim \bar{p}/p \cdot K^+/K^-$ (see, e.g., [16]), the feed-down from Λ and $\bar{\Lambda}$ were found to cause a net increase of $\bar{p}/p$ at all rapidities. At midrapidity the possible contribution is $< 5\%$, and at forward rapidity $< 10\%$, within our acceptance.

3. Particle ratios vs. rapidity

Fig. 2 shows the resulting ratios of antiparticle-to-particle yields as a function of rapidity (left panel). Two independent analyzes were performed. By comparing these, and by varying both the rapidity and p_T intervals, and the cuts on the particle identification and projection to the interaction point, our point-to-point systematic errors are estimated to be $< 2\%$ for pions and protons, and $< 3\%$ for kaons. Ratios from measurements with different magnet polarities allow us to investigate systematic effects from geometry and normalization. The combined residual systematic uncertainties from these effects and from the absorption corrections are found to be $< 5\%$.

For all three ratios in Fig. 2 there is a clear midrapidity plateau and subsequent decrease with rapidity. The midrapidity values of the ratios are $\pi^-/\pi^+ = 1.02 \pm 0.01 \pm 0.07$, $K^-/K^+ = 0.97 \pm 0.05 \pm 0.07$ and $\bar{p}/p = 0.78 \pm 0.03 \pm 0.06$, consistent within statistical errors with values extracted from identified particle spectra reported by STAR [17]. Numbers at other rapidities are given in Table 1. At midrapidity, proton and antiproton production from quark–antiquark pairs can be assumed to be identical. Proton excess, defined as $(N_p - N_{\bar{p}})/(N_p + N_{\bar{p}})$, is therefore due to the transport of baryon number from the initial beam. Our $\bar{p}/p$ ratio would in this interpretation imply a proton excess

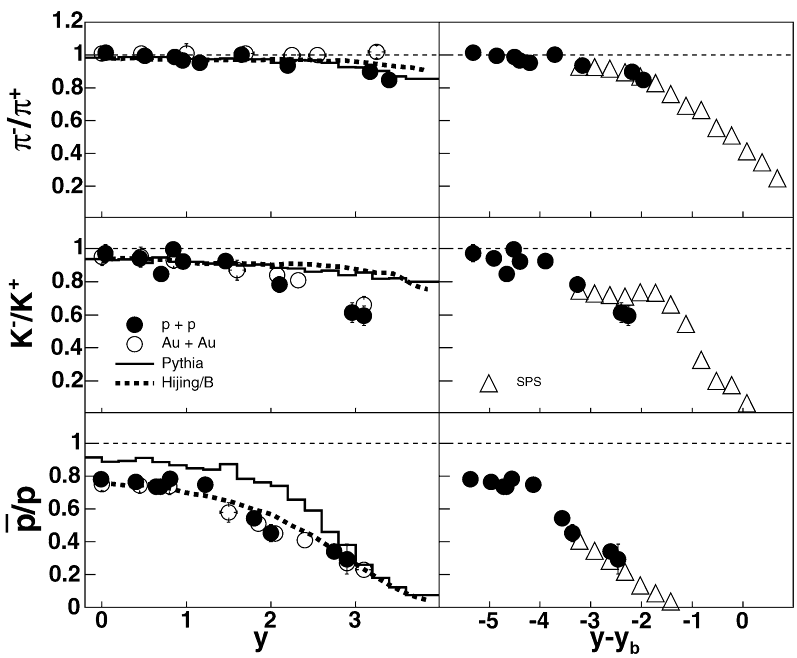

Fig. 2. Left: charged particle ratios from $p+p$ at $\sqrt{s} = 200$ GeV (solid points) compared with Au + Au [13] (open points), and predictions from PYTHIA [8] (solid histogram) and HIJING/B [9] (thick dashed line). Right: ratios shifted by y_b, compared with data from NA27 (triangles) at $\sqrt{s} = 27.5$ GeV [19].

Table 1
Numerical values for charged particle ratios as a function of rapidity. Errors are statistical only. In addition a combined systematic error of 7% for π^-/π^+ and K^-/K^+, and 8% for $\bar{p}/p$ is estimated

Rapidity	π^-/π^+	Rapidity	K^-/K^+	Rapidity	$\bar{p}/p$
0.0	1.02 ± 0.01	0.0	0.97 ± 0.05	0.0	0.78 ± 0.03
0.5	1.00 ± 0.01	0.4	0.94 ± 0.04	0.4	0.76 ± 0.03
0.9	0.99 ± 0.01	0.7	0.85 ± 0.04	0.6	0.74 ± 0.03
1.0	0.97 ± 0.01	0.8	1.00 ± 0.04	0.7	0.74 ± 0.02
1.2	0.95 ± 0.01	1.0	0.92 ± 0.04	0.8	0.78 ± 0.03
1.7	1.00 ± 0.01	1.5	0.93 ± 0.03	1.2	0.75 ± 0.02
2.2	0.94 ± 0.01	2.1	0.78 ± 0.05	1.8	0.54 ± 0.03
3.2	0.90 ± 0.01	3.0	0.61 ± 0.06	2.0	0.45 ± 0.05
3.4	0.85 ± 0.03	3.1	0.60 ± 0.06	2.7	0.34 ± 0.04
				2.9	0.29 ± 0.09

of 12% at midrapidity, carrying baryon number that has been transported from the beam region at $y = 5.3$ [4]. We note that it has been shown (see [18]) that one may need to correct for isospin effects before generalizing these results from $p + p$ to hadron–hadron collisions, due to the presence of neutrons.

At $y \lesssim 1.5$ the Au + Au ratios for the 20% most central collisions reported in [13] are noticeably similar to the present results. Above $y = 1.5$ the pion ratios in $p + p$ start to drop below those for Au + Au and consequently below unity, while the kaon and proton ratios remain consistent with the Au + Au results over our entire acceptance range. This is surprising in view of the different dynamics one might expect for the two systems. A heavy ion system has multiple initial collisions as well as significant rescattering and may reach thermal equilibrium before freezeout occurs, while the significantly smaller $p + p$ system should not interact much beyond the initial reactions. For all three species the ratios start to decrease above $y = 1.5$, indicating a transition from the string breaking dominated regime at midrapidity to the fragmentation region. The drop in the pion ratio at high rapidity can be attributed to isospin and charge conservation in the fragmentation region, an effect not seen for Au + Au where the high pion multiplicity drives the system towards isospin equilibration.

The right panel of Fig. 2 shows the present data and data from NA27 at $\sqrt{s} = 27.5$ GeV [19] (open triangles) shifted by the respective beam rapidities. Overlaying the two datasets the ratios appear to be independent of the incident beam energy when viewed from the rest frame of one of the protons, in the region where our rapidity coverage overlaps with that of NA27. This is consistent with the idea of limiting fragmentation that has also been observed for charged hadrons in nucleus–nucleus collisions [20]. This hypothesis states that the excitation of the leading protons saturates at a moderate energy, leaving more available kinetic energy for particle production below the beam rapidity. We also note a transition in behavior at $y - y_b \sim -4$, indicative of a boundary between the midrapidity and fragmentation regions. Below this, at RHIC energies we observe a region of constant relative particle production that was not present at $\sqrt{s} = 27.5$ GeV.

4. Predictions from models

To interpret these results further, predictions from theoretical models of hadron–hadron collisions are confronted with the data. The curves in the left panel of Fig. 2 compare our results to the predictions of two such calculations, PYTHIA Version 6.303 [8][1] and HIJING/B [9], using the same p_T range as the present analysis. Both models give a good description of the pion data and for kaons at midrapidity, but do not reproduce the magnitude of the decrease with rapidity seen for K^-/K^+ as the rapidity approaches that of the fragmentation region. Also, PYTHIA clearly overestimates the $\bar{p}/p$ ratios. This is a well-known problem since PYTHIA employs only quark–diquark breaking of the initial protons, while several authors have

[1] PYTHIA version 6.3 is at the time of writing still labeled as ‘experimental’, but we find no difference in the results between this version and the latest in the 6.2 series.

pointed out [4,5] that to describe stopping at midrapidity in high energy hadronic collisions one needs an additional mechanism to transport baryon number away from the beam rapidities.

Based on $p+p$ data from the ISR it has been proposed that other mechanisms than quark–diquark breaking, e.g., destruction of the diquark, can transport baryon number over a large rapidity range [7]. Subsequently a description was formulated of the baryon transport process as arising from gluonic degrees of freedom, with an additional transport component slowly changing with incident energy [4]. This can lead to a significant net baryon content at midrapidity. Also, data from HERA [21] show a baryon asymmetry, defined in lepto-production as $2(N_p - N_{\bar{p}})/(N_p + N_{\bar{p}})$, that is significantly different from zero. This indicates that baryon transport over 7 units of rapidity is indeed possible. Together, these theories and observations form the basis for implementing the baryon junction [4,22]. This mechanism allows for easy transport of baryon number toward midrapidity, while energy balance is maintained through an increased production of forward mesons. The baryon junction scenario, incorporated as a model prediction in the HIJING/B event generator [9], has successfully predicted the slow $\sqrt{s}$ dependence of the $p+p$ and $\bar{p}+p$ cross-sections [4]. In Fig. 2 the dashed lines showing the HIJING/B prediction for $\bar{p}/p$ at $\sqrt{s} = 200$ GeV, exhibit a much better agreement with the data than PYTHIA, both in terms of overall magnitude and the width of the distribution.

In Ref. [23] a baryon junction extension to a quark–diquark breaking model of particle production is suggested. It is shown that it is possible to describe baryon stopping in $p+p$ and Au + Au collisions using the same parameters for the baryon junction couplings, but with different parameter values for SPS and RHIC energies. For RHIC, this leads to a prediction that the shapes of the rapidity distributions for $p+p$ and Au + Au will be similar for $|y| \lesssim 2$. The similarity shown here of $\bar{p}/p$ in $p+p$ and Au+Au up to $|y| < 3$ supports this prediction.

5. Particle ratio excitation functions

The present data allow for an extended study of the excitation function of the particle ratios around midrapidity. In Fig. 3 the present data at $y = 0$ and $y \sim 1$ are shown, together with fits to ISR data [24] from $p+p$ collisions in the range $23 < \sqrt{s} < 63$ GeV. Where possible the fits have been made over the same p_T range as our data, the notable exception being the $\bar{p}/p$ ratios at $y = 1$ where the ISR data cover $2.0 < p_T < 4.0$ GeV/c. Points from NA27 at $\sqrt{s} = 27.5$ GeV are also shown. Both at midrapidity and at $y = 1$ the ratios depend logarithmically on $\sqrt{s}$, but the slope of this dependence is steeper at $y = 1$. At lower energies there is a significantly larger fraction of K^- and antiprotons at $y = 0$ than at $y = 1$, but this effect is much smaller at RHIC energies. This again indicates that at RHIC there is a midrapidity source that is almost free of net strangeness and baryon number.

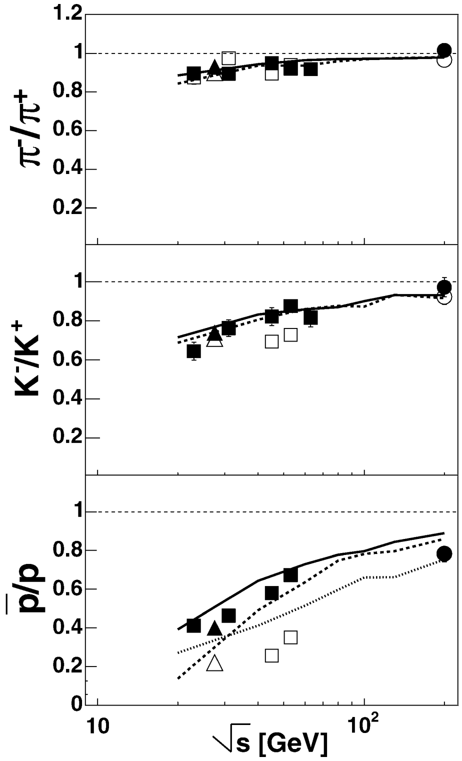

Fig. 3. $\sqrt{s}$ dependence of particle ratios at $y = 0$ (closed symbols) and $y \sim 1$ (open symbols). Circles are the present data, errors are statistical only. Also shown are $p+p$ data from ISR (squares) and NA27 (triangles) [19,24]. Solid lines: PYTHIA prediction for $p+p$ at $y = 0$. Dashed lines: same for $y = 1$. Dotted line in bottom panel: HIJING/B prediction for $\bar{p}/p$ at $y = 0$.

The solid and dashed lines in Fig. 3 show the prediction for the particle ratio excitation function from

PYTHIA at $y = 0$ and $y = 1$, respectively. At midrapidity the ratios are well reproduced at all values of $\sqrt{s}$, except for the $\bar{p}/p$ ratio at RHIC energies, but at $y = 1$ the K^-/K^+ and $\bar{p}/p$ do not seem well described at lower energies. The dotted line shows the prediction for $\bar{p}/p$ from HIJING/B at $y = 0$, reproducing the result at $\sqrt{s} = 200$ GeV but underpredicting the results at lower energies. For pions and kaons HIJING/B reproduces the PYTHIA curves shown.

6. Ratio correlations over three units of rapidity

For nucleus–nucleus collisions at ultrarelativistic energies it has been observed that almost all particle production ratios can be reproduced by a grand canonical model description of the emitting source, i.e., with temperature T and baryochemical potential μ_q as independent parameters [25]. The strange quark chemical potential μ_s is fixed by conservation of strangeness [26]. In such an approach antiparticle-to-particle ratios are controlled by the light and strange quark fugacities, μ_q/T and μ_s/T, respectively, predicting, e.g.,

$$K^-/K^+ = e^{2\mu_s/T} e^{-2\mu_q/T} = e^{2\mu_s/T} (\bar{p}/p)^{1/3}. \qquad (1)$$

For an ideal quark–gluon plasma one can expect $\mu_s = 0$, a condition that is difficult to achieve for a hadron gas [27]. The analysis in Ref. [13] on data from Au + Au collisions at $\sqrt{s} = 200$ GeV showed that one can parametrize the kaon and proton ratios at different rapidities as a power law: $K^-/K^+ = (\bar{p}/p)^\alpha$, with $\alpha^{\mathrm{Au+Au}} = 0.24 \pm 0.02$. Expressing this in terms of chemical potentials gives $\mu_s \approx 0.28\mu_q$ for Au + Au collisions.

Fig. 4 shows a similar analysis based on the present data, where the K^-/K^+ ratios have been interpolated to the same rapidities as the $\bar{p}/p$ data. A power law fit to the present points gives an exponent of $\alpha^{p+p} = 0.32 \pm 0.04$, with $\chi^2/\mathrm{NDF} = 1.22$. Fig. 4 also shows the corresponding results for $p + p$ collisions at $\sqrt{s} = 27.5$ GeV at rapidities $0 < y < 3.5$, and midrapidity data at ISR energies [19,24]. The ISR results are consistent with the power law fit to our data, while the $\sqrt{s} = 27.5$ GeV data seem to follow a different trend.

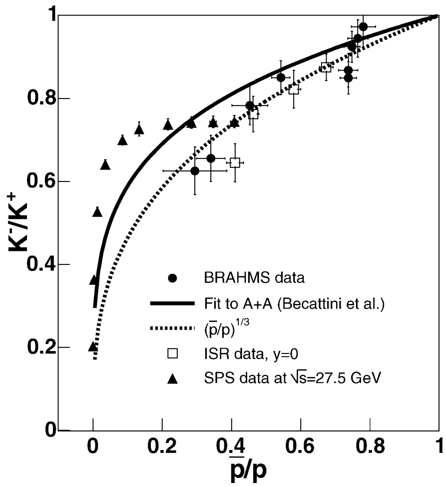

Fig. 4. Correlation between K^-/K^+ and $\bar{p}/p$ at different rapidities from the present data and data at lower energies. The lines show grand canonical model calculations for the limit of vanishing strangeness chemical potential $\mu_s = 0$ (dashed) and for a constant temperature of 170 MeV with unit strangeness saturation [28] (solid).

The solid line in Fig. 4 is the prediction of a grand canonical calculation for a constant temperature of 170 MeV [28]. This curve gives a good description of our Au + Au data, as well as lower energy heavy ion results. For $y < 2.0$ the $p + p$ data are also consistent with this curve, but at more forward rapidities they fall below it. Ideally for $p + p$ collisions one would use a microcanonical approach in order to exactly conserve quantum numbers in each event. Such a description is being developed, e.g., by the authors of Refs. [29,30], but they also show that the K^-/K^+ and $\bar{p}/p$ ratios change by < 4% when going from the canonical to the microcanonical description.

The limit of a canonical ensemble can be reached from a grand canonical description by letting all chemical potentials approach 0. In $e^+ + e^-$ collisions such a canonical approach has been successful in describing particle ratios [30], but this does not imply that such collisions constitute an ideal quark–gluon plasma. Rather it may reflect properties of the hadronization process. In the above grand canonical approach, a power law exponent of $\alpha = 0.33$ implies that $\mu_s = 0$ (see the dashed line in Fig. 4 and Eq. (1)). The fit made to the present data suggest that this is the case for all covered rapidities in $p + p$ collisions at $\sqrt{s} = 200$ GeV.

7. Conclusions

In conclusion, the BRAHMS experiment has measured ratios of charged antihadron to hadron production from $p+p$ collisions at $\sqrt{s}=200$ GeV. All ratios are independent of transverse momentum within errors for $p_T < 2.0$ GeV/c. For kaons and protons we find an overall consistency with results from Au + Au collisions at the same energy over three units of rapidity. The π^-/π^+ ratio falls steadily below the Au + Au results for $y = 2.0$–3.4, as expected from conservation of initial charge and isospin. When viewed from the rest frame of one of the protons all ratios seem to be independent of the projectile beam energy over a range of at least one unit of rapidity. Models based on quark–diquark breaking of the initial protons give a reasonable description of π^-/π^+, but cannot describe our $\bar{p}/p$ ratios unless additional mechanisms of baryon transport are invoked. Introducing a baryon junction scheme to provide additional baryon transport to midrapidities yields a good description of our $\bar{p}/p$ data over our full coverage of $0 < y < 2.9$.

Note added

After submission we have learned about a midrapidity analysis similar to the one presented here, made by the PHOBOS experiment [31]. Their result for $\bar{p}/p$ at $y = 0$ is somewhat higher than ours, but within errors the ratios reported by PHOBOS are consistent with the ones presented in this Letter.

Acknowledgements

This work was supported by the Division of Nuclear Physics of the Office of Science of the US Department of Energy under contracts DE-AC02-98-CH10886, DE-FG03-93-ER40773, DE-FG03-96-ER40981, and DE-FG02-99-ER41121, the Danish Natural Science Research Council, the Research Council of Norway, the Jagiellonian University Grants, the Korea Research Foundation Grant, and the Romanian Ministry of Education and Research (5003/1999, 6077/2000).

References

[1] N. Hermann, et al., Annu. Rev. Nucl. Part. Sci. 49 (1999) 581;
H. Satz, Rep. Prog. Phys. 63 (2000) 151, hep-ph/0007069.
[2] J.D. Bjorken, Phys. Rev. D 27 (1983) 140.
[3] J. Benecke, T.T. Chou, C.N. Yang, E. Yen, Phys. Rev. 188 (1969) 2159.
[4] D. Kharzeev, Phys. Lett. B 378 (1996) 238, nucl-th/9602027.
[5] A. Capella, B.Z. Kopeliovich, Phys. Lett. B 381 (1996) 325, hep-ph/9603279.
[6] F.M. Liu, J. Aichelin, M. Bleicher, H.J. Drescher, S. Ostapchenko, T. Pierog, K. Werner, Phys. Rev. D 67 (2003) 034011.
[7] B.Z. Kopeliovich, B.G. Zakharov, Z. Phys. C 43 (1989) 241.
[8] T. Sjostrand, P. Eden, C. Friberg, L. Lonnblad, G. Miu, S. Mrenna, E. Norrbin, Comput. Phys. Commun. 135 (2001) 238, hep-ph/0010017.
[9] S.E. Vance, M. Gyulassy, X.N. Wang, Phys. Lett. B 443 (1998) 45, nucl-th/9806008.
[10] M. Adamczyk, et al., BRAHMS Collaboration, Nucl. Instrum. Methods A 499 (2003) 437.
[11] I. Arsene, et al., BRAHMS Collaboration, nucl-ex/0401025, Phys. Rev. Lett., in press.
[12] X.N. Wang, M. Gyulassy, Phys. Rev. D 44 (1991) 3501.
[13] I.G. Bearden, et al., BRAHMS Collaboration, Phys. Rev. Lett. 90 (2003) 102301, nucl-ex/0207006.
[14] I.G. Bearden, et al., BRAHMS Collaboration, Phys. Rev. Lett. 87 (2001) 112305, nucl-ex/0106011.
[15] J. Adams, et al., STAR Collaboration, nucl-ex/0309012;
J. Adams, M. Heinz, STAR Collaboration, nucl-ex/0403020.
[16] V.V. Anisovich, V.M. Shekhter, Nucl. Phys. B 55 (1973) 455.
[17] J. Adams, et al., STAR Collaboration, Phys. Rev. Lett. 92 (2004) 112301, nucl-ex/0310004.
[18] H.G. Fischer, NA49 Collaboration, Nucl. Phys. A 715 (2003) 118, hep-ex/0209043.
[19] M. Aguilar-Benitez, et al., Z. Phys. C 50 (1991) 405.
[20] I.G. Bearden, et al., BRAHMS Collaboration, Phys. Rev. Lett. 88 (2002) 202301, nucl-ex/0112001;
P. Deines-Jones, et al., Phys. Rev. C 62 (2000) 014903, hep-ex/9912008;
B.B. Back, et al., PHOBOS Collaboration, Phys. Rev. Lett. 91 (2003) 052303, nucl-ex/0210015.
[21] C. Adloff, et al., H1 Collaboration, Contributed to 29th International Conference on High-Energy Physics (ICHEP 98), Vancouver, Canada, 23–29 July, 1998.
[22] G.C. Rossi, G. Veneziano, Nucl. Phys. B 123 (1977) 507.
[23] A. Capella, Phys. Lett. B 542 (2002) 65.
[24] B. Alper, et al., British–Scandinavian Collaboration, Nucl. Phys. B 100 (1975) 237.
[25] P. Braun-Munzinger, D. Magestro, K. Redlich, J. Stachel, Phys. Lett. B 518 (2001) 41, hep-ph/0105229.
[26] J. Rafelski, Phys. Lett. B 262 (1991) 333.
[27] J. Letessier, A. Tounsi, U.W. Heinz, J. Sollfrank, J. Rafelski, Phys. Rev. D 51 (1995) 3408, hep-ph/9212210;
J. Sollfrank, M. Gazdzicki, U.W. Heinz, J. Rafelski, Z. Phys. C 61 (1994) 659.

[28] F. Becattini, J. Cleymans, A. Keranen, E. Suhonen, K. Redlich, Phys. Rev. C 64 (2001) 024901, hep-ph/0002267.
[29] F.M. Liu, J. Aichelin, K. Werner, M. Bleicher, Phys. Rev. C 69 (2004) 054002, hep-ph/0307008.
[30] F. Becattini, L. Ferroni, hep-ph/0407117.
[31] B.B. Back, et al., PHOBOS Collaboration, nucl-ex/0409003.