Investigation of Antiproton to Proton Ratio by HIJING at RHIC Energies*

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Abstract The HIJING 2.0 is used to generate Monte Carlo events for Au + Au minimum biased collisions at RHIC energies—— $\sqrt{s_{NN}}$ = 130 and 200 GeV. Using the Monte Carlo event sample, it is shown that the impact parameter has approximately a linear dependence on multiplicity. Both of them can be used as characteristic quantity for centrality. The results on the $\bar{p}/p$ ratio show that this ratio does not change remarkably with centrality, transverse momentum and rapidity, and is independent of the reaction plane within the HIJING model.

Key words HIJING, $\bar{p}/p$ ratio, centrality, reaction plane

The existence of quark-gluon plasma (QGP) at high energy density is a prediction of QCD. Many theorists and experimentalists are searching for the probable signals of the formation of such a new phase. The primary goal of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) is to create and study this deconfined state. The formation of this state depends on the initial conditions of the matter created at the early stage of heavy ion collisions. Baryon number transport (or stopping), achieved mostly at the early stage, is one of the important observables[1,2]. The information on baryon transport may be accessed by the measurement of the ratio of the anti-proton to proton yield ($\bar{p}/p$).

It is interesting to study the dependence of $\bar{p}/p$ ratio on centrality. This dependence can reflect the degree of baryon stopping in different parts of the colliding nuclei and thus characterize the physical processes going on in heavy ion collisions.

On the other hand, the study of collective flow in nuclear collision at high energies has attracted increasing attention of both theorists and experimentalists[3—6]. Elliptic flow, which is sensitive to the early evolution of the system[7], is the anisotropic emission of particles "in" or "out of" the reaction plane. The reaction plane is defined by the beam and impact parameter directions in the non-central collisions. Thus, it is very interesting to discuss the $\bar{p}/p$ ratio in or out of the reaction plane.

In the present letter, we study the p/p ratio of Au + Au minimum biased collisions at RHIC energies by using HIJING Monte Carlo event generator[8]. Since RHIC has run at a center-of-mass energy $\sqrt{s_{NN}}$ = 130 GeV in last year, we investigate the $\bar{p}/p$ ratio both at this energy and at the top energy $\sqrt{s_{NN}}$ = 200 GeV of RHIC. For each energy, the event number used is 105000.

In principle, centrality is defined by the magnitude of impact parameter. But in experiment, it is very difficult to measure the impact parameter directly, so centrality is usually characterized by the relative charged multiplicity n_{ch}/n_{max}, i.e. event charged multiplicity to maximum charged multiplicity. In Monte Carlo study, however, the impact parameter is given precisely and can be used directly as the measure of centrality. It is shown in Fig.1 the correlation between the impact parameter and the relative charged

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multiplicity. It can be seen from the figure that with the increase of the impact parameter, the relative charged multiplicity n_{ch}/n_{max} decreases monotonously and almost linearly. So both of them can be used as characteristic quantity for centrality.

In Fig.2 (a) and (b) the impact parameter dependences of p̄/p ratio are shown as open circles in the range of $|y| < 1$ and $0.6 < p_t < 0.8$ for $\sqrt{s_{NN}} = 130$ and 200 GeV, respectively. It can be seen from Fig.2 (a) that p̄/p ratio at 130 GeV is almost consistent with a constant within the range $0 \leqslant b \leqslant 10$, and the ratio has a weak tendency of going up when $10 \leqslant b \leqslant 13$. For impact parameter larger than 13, the p̄/p ratio has large fluctuations because the number of produced p̄ and p becomes very small when b is large. Fig.2 (b) shows that p̄/p ratio at 200 GeV has qualitatively the same feature, but the tendency of going up at $10 \leqslant b \leqslant 13$ is much weaker and is consistent with a constant within the statistical errors.

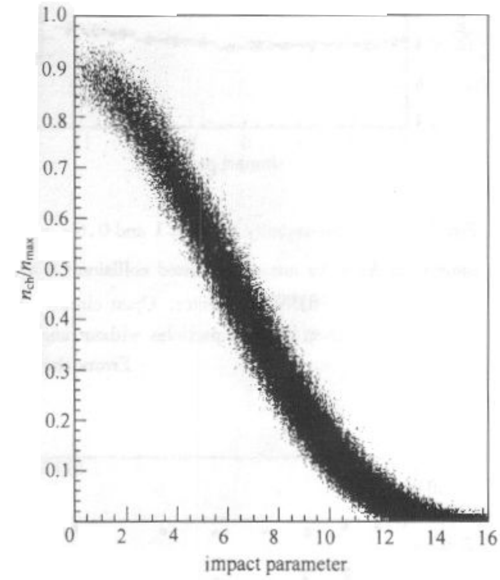

Fig.1. The corresponding relation between impact parameter and centrality defined as n_{ch}/n_{max}.

The independence of p̄/p ratio on impact parameter can be interpreted as following: when the collision energy increases, because of the Lorentz contraction in the longitudinal direction, the difference in thickness between the central and peripheral parts of the colliding nuclei decreases, reducing the difference in the baryon stopping and/or nucleon-p̄ annihilation. This effect is stronger for $\sqrt{s_{NN}} = 200$ GeV than for $\sqrt{s_{NN}} = 130$ GeV.

The solid triangles and the star markers in Fig.2 represent the results in and out of reaction plane, respectively. The former (in plane) is defined as the particles lying within two planes with angles $\pm 30°$ relative to the reaction plane. The latter (out plane) is defined in the same way but is relative to a plane perpendicular to the reaction plane. It can be seen that the results for in and out of reaction plane are close to the one without reaction plane cuts. It means that the impact parameter dependence of p̄/p ratio has little relation with the reaction plane within the HIJING model.

In order to compare with the experimental data[9], p̄/p ratios as a function of relative charged multiplicity are shown (open circles) in the range of $|y| < 0.3$ and $0.6 < p_t < 0.8$ for $\sqrt{s_{NN}} = 130$ and 200 GeV in Fig.3 (a) and (b). The two figures have the same tendency as Fig.2 (a) and (b), respectively, except for a reflection between left and right. This again proves that both impact parameter and relative charged multiplicity can be used as characteristic quantity for centrality. Comparing with experimental data (solid circles in Fig.3(a)), the tendency of p̄/p ratio versus relative charged multiplicity from HIJING (open circles) is similar, except for a global upward shift. This is because that the late stage rescattering has not been included in the HIJING model. If the final state rescattering effect was taken into account, the antiproton could be annihilated with the incident nucleon, causing the p̄/p ratio to be reduced.

In Fig.4 are shown the minimum biased p̄/p ratios as a function of p_t in the range of $1 < |y| < 2$ for the whole sample (open circles), and for the in and out of plane subsamples (solid triangles and star markers), respectively. Also, the ratio is consistent with a constant in the measured p_t range and at the same time has little relation with reaction plane.

In Fig.5 are shown the p̄/p ratios integrated over $0.6 < p_t < 0.8$ as a function of rapidity for the

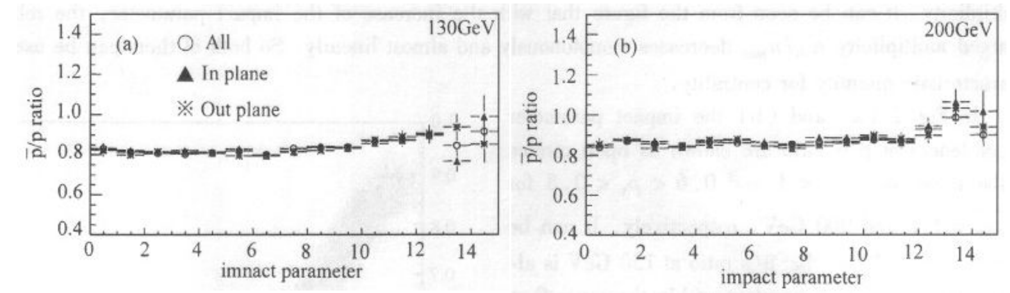

Fig.2. The mid-rapidity ($|y|<1$ and $0.6<p_t<0.8$) anti-proton to proton ratio as a function of impact parameter in Au + Au minimum biased collision ($b=0-2R_{Au}$) at (a) $\sqrt{s_{NN}}=130$ GeV, (b) $\sqrt{s_{NN}}=200$ GeV by using HIJING generator. Open circles, solid triangles and stars, respectively represent the results from charged particles without angle cuts, with in-plane, and out-of-plane cuts. Errors shown are statistical only.

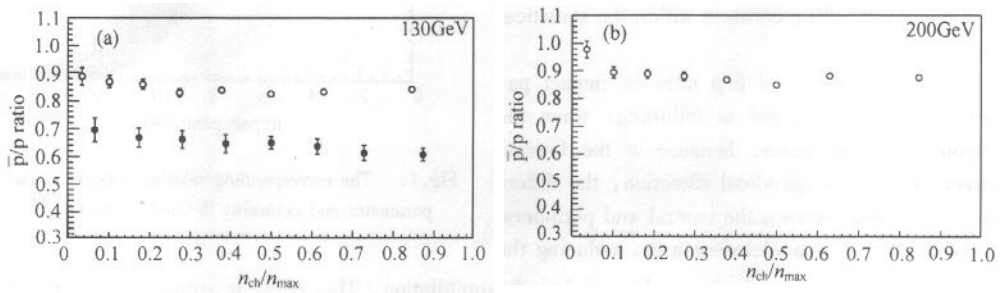

Fig.3. The mid-rapidity ($|y|<0.3$ and $0.6<p_t<0.8$) anti-proton to proton ratio as a function of relative charged multiplicity in Au + Au minimum biased collision at (a) $\sqrt{s_{NN}}=130$ GeV, (b) $\sqrt{s_{NN}}=200$ GeV by using HIJING generator(open circles). The solid circles in (a) are the data from the RHIC experiment of Au + Au collisions at 130 GeV. The experiment data are taken from Ref. [9].

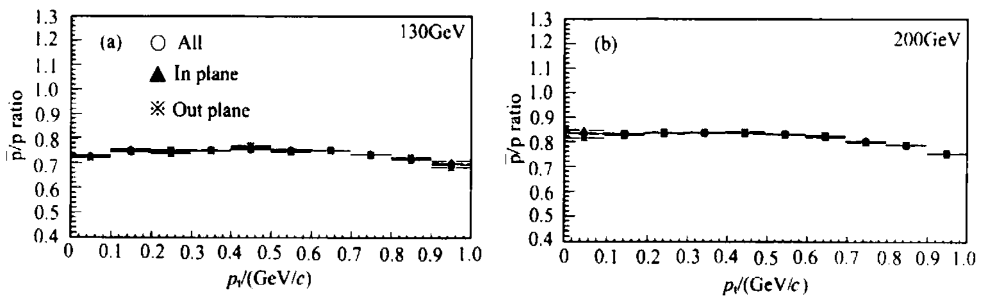

Fig.4. The anti-proton to proton ratio as a function of transverse momentum p_t in Au + Au minimum biased collisions at (a) $\sqrt{s_{NN}}=130$ GeV, (b) $\sqrt{s_{NN}}=200$ GeV. The rapidity range is $1<|y|<2$. Open circles, solid triangles and stars, respectively represent the results from charged particles without angle cuts, with in-plane, and out-of-plane cuts. Errors shown are statistical only.

whole sample (open circles), and for the in and out of plane subsamples (solid triangles and star markers) respectively. It can be seen from the figure that the ratio is approximately constant within errors and is independent of the reaction plane within the studied range.

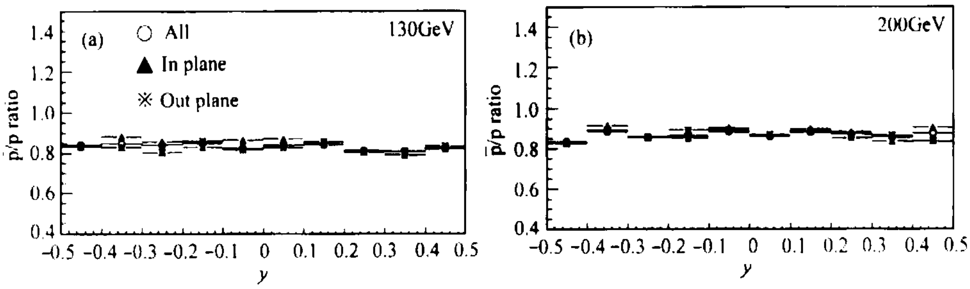

Fig.5. The anti-proton to proton ratio integrated over the transverse momentum range $0.6 < p_t < 0.8$ as a function of rapidity in Au + Au minimum biased collisions at (a) $\sqrt{s_{NN}}$ = 130 GeV, (b) $\sqrt{s_{NN}}$ = 200 GeV. Open circles, solid triangles and stars, respectively represent the results from charged particles without angle cuts, with in-plane, and out-of-plane cuts. Errors shown are statistical only.

On the other hand, it has been shown[9] that there is a dramatic increase in the mid-rapidity p̄/p ratio in heavy ion collisions from AGS to SPS and to RHIC. Here, using HIJING event generator, p̄/p ratios in Au + Au collisions at mid-rapidity $|y| < 0.3$ averaged over $0.6 < p_t < 0.8$ are shown in Fig.6 (solid triangles). The experimental points in heavy ion collisions and p + p collisions are also shown. It can be seen that at $\sqrt{s_{NN}}$ = 130 GeV, p̄/p ratio from Monte Carlo simulation is larger than experimental one. The two ratios from HIJING 2.0 keep the trend of going up when center-of-mass energy $\sqrt{s_{NN}}$ increases from 130 GeV to 200 GeV.

In summary, using HIJING Monte Carlo event generator, Au + Au minimum biased collisions at $\sqrt{s_{NN}}$ = 130 and 200 GeV are generated and the p̄/p ratios as functions of centrality, transverse momentum and rapidity are studied. The results show that the dependence of p̄/p ratio on centrality tends to disappear with $\sqrt{s_{NN}}$ going from 130 to 200 GeV, and the p̄/p ratio has no remarkable correlation with transverse momentum and rapidity. These coincide with the experimental results. Also, p̄/p ratio is insensitive to the effect of reaction plane. This may be due to the fact that HIJING does not incorporate the mechanism for final state interactions. Further study on this problem is needed.

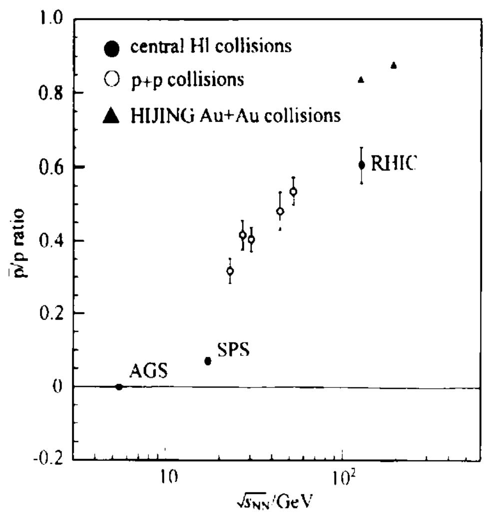

Fig.6. Mid-rapidity ($|y| < 0.3$ and $0.6 < p_t < 0.8$) anti-proton to proton ratio in Au + Au minimum biased collisions from HIJING 2.0 (solid triangles). The filled circles and open circles are mid-rapidity anti-proton to proton ratio measured in central heavy ion collisions and elementary p + p collisions from experiments. The experimental data are taken from Ref.[9].

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利用HIJING产生器对RHIC能区质子反质子产额比的研究*

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摘要 利用HIJING 2.0 Monte Carlo事件产生器产生了RHIC能区(质心系能量130GeV和200GeV)的Au + Au最小无偏碰撞事件. 对产生的事件样本进行分析表明:碰撞参数与事件的多重数有近似线性依赖关系,两者都可用来表征碰撞的对心度;质子反质子产额比不明显依赖于碰撞对心度、横动量、快度和事件平面.

关键词 HIJING 质子反质子产额比 对心度 事件平面

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