Baryon rapidity distribution in nucleus-nucleus collisions at ultrarelativistic energies

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The baryon rapidity (or pseudorapidity) distributions in nucleus-nucleus collisions in the SPS energy region have been described by the thermalized cylinder picture. The calculated results are in agreement with the experimental data of the reactions ^{32}S+S at 200*A* GeV, ^{16}O+Au, Ag, Cu at 60 and 200 *A* GeV bombarding energy. The limiting fragmentation of the target spectator is achieved for a given projectile in the concerned energy region. [S0556-2813(99)01502-2]

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The knowledge of baryon rapidity (y) or pseudorapidity (η) distributions in high-energy nucleus-nucleus collisions is of great importance [1]. The plastic ball of the WA80 experiment identifies protons around target rapidity [2]. The NA34 Collaboration measures protons in a small portion of phase space by covering $0.9\leqslant\eta\leqslant2.0$ with a slit spectrometer [3]. The NA35 Collaboration measures an excess of positive over negative tracks (+− procedure) for $y<y_{\rm c.m.}$ which is, for symmetric collisions, attributed to protons, where $y_{\rm c.m.}$ is the c.m. rapidity of the participant system [4]. The EMU01 Collaboration measures gray tracks in emulsion and the angular distributions have been obtained [5]. It was shown that the angular distributions of gray tracks are similar for different incident energies and impact parameters in the SPS energy region. None of the CERN experiments is really capable of measuring the baryon distribution with complete coverage. The experimental data are, on the other hand, described by VENUS [6], RQMD [7], and MCFM [8] models. A full cascade of secondary particles in the target spectator matter has to be considered.

Based on the one-dimensional string model [9] and the fireball model [10], we have developed the thermalized cylinder picture [11] and described the rapidity (or pseudorapidity) distributions of relativistic singly charged particles [12] in the incident energy range from 3.7*A* GeV up to 100*A* TeV. In the thermalized cylinder picture, the contributions of the projectile and target participants and spectators have been considered.

For the purely baryon rapidity or pseudorapidity distributions, can the thermalized cylinder picture describe the experimental data? We shall answer this question in this paper.

First of all, let us consider the simplest pictures of the one-dimensional string model [9] and the fireball model [10]. In high-energy nucleon-nucleon collisions, a string is formed consisting of two end points acting as energy reservoirs and the interior with constant energy per length. Because of the asymmetry of the mechanism, the string will break into many substrings along the direction of incident beam. The distribution length of substrings will define the distribution width of pseudorapidity. According to the fireball model, the incident nucleon penetrates through the target nucleon, then a fire streak is formed along the direction of incident beam. The length of fire streak will define the width of pseudorapidity distribution. In high-energy nucleus-nucleus collisions, many strings or fire streaks are formed along the incident direction. Finally, a thermalized cylinder is formed because of these strings or fire streaks mix in the transverse direction.

In the laboratory reference frame, we assume that the thermalized cylinder formed in high-energy nucleus-nucleus collisions is in the rapidity range $[y_{\rm min},\ y_{\rm max}]$. The emission points with the same rapidity y_x in the thermalized cylinder form a cross section (emission plane) in the rapidity space. For the thermalized cylinder, the initial extension of the nuclei is not important because of Lorentz contraction.

Under the assumption that the particles are emitted isotropically in the rest frame of the emission plane, we know that the pseudorapidity distribution of the particles produced in the emission plane with rapidity y_x in the laboratory reference frame is

$$f(\eta,y_x)=\frac{1}{2\cosh^2(\eta-y_x)}. \tag{1}$$

If $y_x=y_{\rm min}$ or $y_x=y_{\rm max}$, Eq. (1) will describe the pseudorapidity distributions of leading target or projectile nucleons.

In final state, the pseudorapidity distribution can be written as

$$f(\eta)=\frac{1-K_T-K_P}{y_{\rm max}-y_{\rm min}}\int_{y_{\rm min}}^{y_{\rm max}}f(\eta,y_x)+K_Tf(\eta,y_{\rm min})+K_Pf(\eta,y_{\rm max}), \tag{2}$$

where K_T and K_P denote the contributions of the leading target and projectile nucleons, respectively. The contribution of the thermalized cylinder is $1-K_T-K_P$.

If we consider the contributions of the participants and spectators, respectively, as well as the two-source emission of the nuclear light fragments [13], a more complex structure of pseudorapidity distribution in the target and projectile fragmentation regions can be given by the thermalized cyl-

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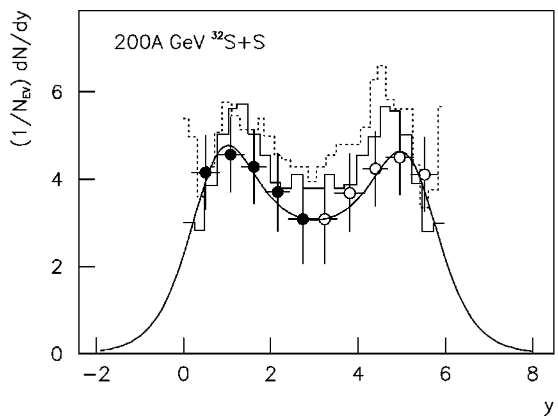

FIG. 1. Rapidity distribution of protons obtained by $+-$ procedure for the reactions $^{32}S+S$ at 200A GeV bombarding energy [4]. The black circles are experimental data of the NA35 Collaboration, the white circles are obtained from reflection symmetry at $y_{\rm c.m.}$ [4]. The solid and dotted histograms are results of VENUS [6] and RQMD [7] models, respectively [1]. The solid curve is our calculated result by the thermalized cylinder picture.

inder picture. In Eq. (2), replacing η by y due to $\eta \approx y$, the rapidity distribution can be obtained.

The experimental data give usually a part of rapidity (or pseudorapidity) distributions described by the thermalized cylinder picture. For central or nearly central nucleus-nucleus collisions, at least one of the contributions of target and projectile spectators can be neglected. In the present accelerator energy region, we do not need to consider the contribution of leading target nucleons in the case of studying the rapidity (or pseudorapidity) distributions of relativistic singly charged particles due to the nonrelativity of target nucleons. If we study the baryon rapidity (or pseudorapidity) distributions in the target or projectile fragmentation regions, the contributions of the projectile or target nucleons can be neglected.

Figure 1 shows the result of the $+-$ procedure for the reactions $^{32}S+S$ at 200A GeV bombarding energy. The experimental proton rapidity for $y<y_{\rm c.m.}$ is given by black circles. The white circles for $y>y_{\rm c.m.}$ are from reflection symmetry. Both black and white circles are quoted from Ref. [4]. The solid and dotted histograms are results of VENUS [6] and RQMD [7] models, respectively [1]. If we take $y_{\rm min}=0.8$, $y_{\rm max}=5.2$, and $K_T=K_P=0.25$, the calculated result by the thermalized cylinder picture is given by solid curve, where the values of these parameters can be regarded as a result by fitting the result of the $+-$ procedure for the reaction $^{32}S+S$ at 200A GeV. The yield of protons is given by the normalized condition in the concerned rapidity region. The value of $\chi^2/N_{\rm DF}$ is 0.024.

One can see that the calculated result by the thermalized cylinder is in good agreement with the experimental data of the $+-$ procedure. The calculated results by VENUS [6] and RQMD [7] models are partly in agreement with the experimental data.

Figure 2 presents the baryon pseudorapidity distributions in the target fragmentation region for the reactions $^{16}O+Au$, Ag, Cu at 60 and 200A GeV bombarding energy. The crosses are the experimental data quoted from Ref. [2], and the black and white circles show a calculation within Ranft's

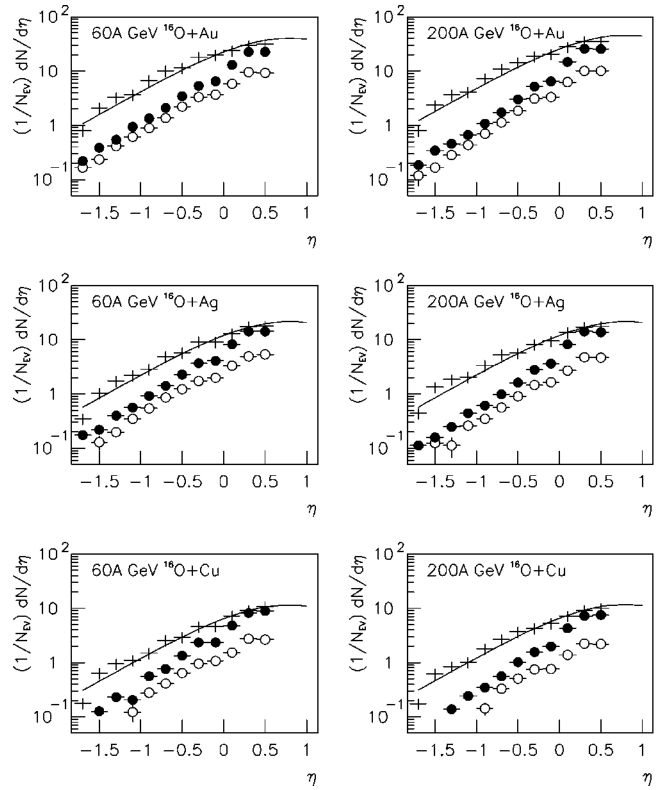

FIG. 2. The baryon pseudorapidity distributions of the reactions $^{16}O+Au$, Ag, Cu at 60 and 200A GeV bombarding energy. The crosses are the experimental data of the WA80 Collaboration [2]. The black and white circles show a calculation within Ranft's MCFM [8], assuming a formation zone parameter τ_0 of 5 and 10 fm/c, respectively. The solid curves are our calculated results by the thermalized cylinder picture.

MCFM [8], assuming a formation zone parameter τ_0 of 5 and 10 fm/c, respectively [2], where τ_0 denotes the formation-time of a particle. If τ_0 is very small, the particle may be formed close to the interacting point. If τ_0 is very great, the particle may be formed outside the nucleus. The calculated results by the thermalized cylinder picture are given by the solid curves. Only the contribution of leading target nucleons is considered, i.e., $K_T=1$, $K_P=0$, and $1-K_T-K_P=0$ in Eq. (2), then $f(\eta)=f(\eta,y_{\rm min})$. For all six kinds of collisions, there is only one parameter $y_{\rm min}$ in our calculation of the thermalized cylinder picture. According to our previous work [11], the energy loss of leading projectile nucleon in the target gives $y_{\rm min}=0.8\sim1.5$ in the SPS energy region. In our calculation in this paper, we take $y_{\rm min}=0.8$ for different bombarding energies and target sizes. The yield of baryons is given by the normalized condition in the experimental pseudorapidity region. The values of $\chi^2/N_{\rm DF}$ for 60A GeV $^{16}O+Au$, Ag, and Cu are 0.434, 0.126, and 0.059, and for 200A GeV $^{16}O+Au$, Ag, and Cu are 0.417, 0.171, and 0.057, respectively.

As can be seen, the calculated result by the thermalized cylinder picture is in good agreement with the experimental data. In the region of $\eta>0.5$, the distribution trend is given by our model. For two kinds of bombarding energies and three kinds of heavy targets, the values of $y_{\rm min}$ in the thermalized cylinder picture are the same. This indicates that limiting fragmentation [14] of the target spectator is achieved in the concerned interacting system and energy region.

The number of baryons in the target pseudorapidity region is not sufficiently accounted for in a leading-order cascade of secondary particles in the target spectator matter in the MCFM [8]. In particular, at backward angles ($\eta < 0$) the discrepancy is large. Even for the very small formation-time parameter $\tau_0 = 5$ fm/c the yield of baryons is not described by the MCFM. If we normalize the MCFM's results to the experimental data, the distribution shape of the MCFM is not in agreement with the experimental data. In the recent version of the MCFM, now equipped with a full cascade of secondary particles in the target spectator matter, is reported to reproduce the backward baryon yield satifactorily [1]. Similarly, the VENUS [6] and RQMD [7] do reproduce the baryon yield with a full cascade.

As a conclusion, the thermalized cylinder picture can give a good description of the baryon rapidity (or pseudorapidity) distributions in the midrapidity region and target fragmentation region. The thermalized cylinder picture is very simple and useful in analyses of rapidity (or pseudorapidity) distributions in high-energy nucleus-nucleus collisions. The limiting fragmentation of the target spectator is achieved for a given projectile in the concerned energy region.

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