RATIOS OF ANTIBARYON/BARYON YIELDS IN HEAVY ION COLLISIONS

Yu.M.Shabelski 1
Petersburg Nuclear Physics Institute,
Gatchina, St. Petersburg 188300 Russia

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Abstract

We discuss the model predictions for antibaryon/baryon production ratios in high energy heavy ion collisions. The role of string junction mechanism of baryon number transfer seems to be very important here and we consider some quantitative results.

The first RHIC experimental data collected in [1] show that the values of antibaryon/baryon production ratios in midrapidity region of Au-Au central collisions at $\sqrt{s_{NN}} = 130$ GeV are rather small in comparison with the most of theoretical predictions. Really, the values of the order of 0.6 for $\bar{p}/p$ and $0.73 \pm 0.03$ for $\bar{\Lambda}/\Lambda$ were measured whereas the standard Quark-Gluon String Model (QGSM) [2, 3, 4, 5] predicts in both cases the values more than 0.9 and in the String Fusion Model [1] the predicted values are about 0.8 and about 0.87, respectively.

The main part of $B$ and $\bar{B}$ should be produced at high energies as $B - \bar{B}$ pairs. It means that the additional source of the baryons in the midrapidity region is needed. The realistic source of the transfer of baryons charge over long rapidity distances can be realized via the string junction (SJ) diffusion where it can comain three sea quarks into a secondary baryon (but not antibaryon), see [6].

In such a picture where the transfere of baryon charge is connected with SJ exchange there exist three different possibilities to produce a secondary baryon which are shown in Fig. 1 [7].

1E-mail SHABELSK@THD.PNPI.SPB.RU
This additional transfer of baryon number to the midrapidity region is governed by contribution [7]

\[ G_{uu}^p = G_{ud}^p = a_N \sqrt{z}[v_0 \epsilon'(1 - z)^{1 - \alpha_{SJ}} + v_q z^{3/2}(1 - z) + v_{qq} z^2] , \] (1)

where the items proportional to \(v_{qq}, v_q\) and \(v_0\) correspond to the contributions of diagrams Fig. 1a, 1b and 1c, respectively. The most important in the midrapidity region at high energies is the diagram Fig. 1c which obeys the baryon number transfer to rather large rapidity region.

In agreement with the experimental data the parameter \(\epsilon\) in Eq. (1) is rather small. However different data are in some disagreement with each other, see the detailed analyses in [7]. Say, \(x_F\)-distributions of secondary protons and antiprotons produced at 100 and 175 GeV/c and at \(\sqrt{s} = 17.3\) GeV are in better agreement with \(\epsilon = 0.05\), whereas ISR data and the \(p/\bar{p}\) asymmetry at HERA energy are described better with \(\epsilon = 0.2\).

Some part of this disagreement can be connected with different energies. In Fig. 1c, as a minimum, two additional mesons \(M\) should be produced in one of the strings, as it is shown in this Fig., that can give the additional smallness [8] at not very high energy due to decrease the available phase space. Another source of disagreement of the data at low and high energies can come from the fact that the suppression of baryon number transfer to large rapidity distance \(\delta y\) should be proportional to

\[ e^{-(\alpha_{SJ} - 1)\Delta y} , \] (2)

and the effective value of \(\alpha_{SJ}\) depends on the energy due to Regge cut contribution [9].

In the case of \(\pi^- p \rightarrow \Omega X, \bar{\Omega} X\) reactions the contribution (1) leads to the contradiction with the simplest version of additive quark model [10] because experimentally (see [7]) the yields of \(\Omega\) in the central region is permanently larger than the yields of \(\bar{\Omega}\).

Let us note that it is rather dangerous to use large value of \(\epsilon\) as well as the value of \(\alpha_{SJ}\) close to unity in Eq. (1). The reason is that the string junction mechanism can not transfer more baryon charge than we have in an incident state. The hadron content of sea-quark baryons can be written [11] as

\[ (u + d + \lambda s)^3 = 4p + 4n + 12\lambda(\Lambda + \Sigma) + ... , \] (3)

where \(\lambda\) is the suppression factor for strange quark production. So the integral multiplicity of the protons produced via SJ mechanism from one incident baryon can not be larger than \(W_p = 4/(8 + 12\lambda) \approx 0.3 - 0.4\) (for \(\lambda = 0.2 - 0.4\)):

\[ \epsilon \int_0^\infty e^{(\alpha_{SJ} - 1)\Delta y} d\Delta y \leq W_p \] (4)

The HERA data on \(p/\bar{p}\) asymmetry can be described [7] with the parameters which are near to the presented boundary, namely \(\alpha_{SJ} = 0.5, \epsilon = 0.2\). However, if we use the large part of the initial baryon charge for its diffusion to the mid-rapidity region, the
multiplicity of secondary baryons in the fragmentation region should significantly decrease. It will result in additional mechanism of Feynman scaling violation in the fragmentation region in comparison with the estimations which were claimed in [12].

In the case of hadron-nucleus collisions the yields of secondaries can be calculated in QGSM by similar way [3, 12] and also with including SJ contributions.

Figure 1: Three different possibilities of secondary baryon production in \( pp \) collisions: SJ together with two valence and one sea quarks (a), together with one valence and two sea quarks (b), together with three sea quarks (c).

In the case of heavy ion (A-B) collisions the multiple scattering theory allows one to account for the contribution of all Glauber-type diagrams only using some Monte Carlo method where the integrals with dimension of about \( 2 \cdot A \cdot B \) should be calculated in coordinate space [13, 14]. The analytical calculations allow one to account only some classes of diagrams [15, 16, 17]. One of approaches here is so-called rigid target approximation where it is assumed that for the forward hemisphere we can neglect the binding of projectile nucleons (i.e., consider them as a beam of free nucleons and every of them can interact with target nucleus). The last one is considered as a dense medium. And vice versa, for the backward hemisphere we consider the target nucleons as a beam of free nucleons and every of them can interact with dense medium of projectile nucleus. All details and needed formulae can be found in [5]. The resulting expression for secondary \( h \) production in \( A - B \) collisions reads as

\[
\frac{1}{\sigma_{\text{prod}}^{\text{AB}}} \frac{\sigma_{\text{prod}}^{\text{AB}}}{dy} \cdot AB \rightarrow hX = \theta(y) \langle N_A \rangle \frac{1}{\sigma_{\text{prod}}^{\text{NB}}} \frac{\sigma_{\text{prod}}^{\text{NB}}}{dy} \cdot NB \rightarrow hX + \\
\theta(-y) \langle N_B \rangle \frac{1}{\sigma_{\text{prod}}^{\text{NA}}} \frac{\sigma_{\text{prod}}^{\text{NA}}}{dy} \cdot NA \rightarrow hX,
\]

where \( \langle N_A \rangle \) and \( \langle N_B \rangle \) are the average numbers of interacting nucleons in nuclei \( A \) and \( B \). They depend on the \( A - B \) impact parameter, \( A/B \) ratio, etc. [18].
Table 1: Antibaryon/baryon yields for secondaries produced at RHIC in midrapidity region at $\sqrt{s}=130$ GeV.

|       | QGSM | Exper. |
|-------|------|--------|
| $\epsilon = 0.05$ | $0.83$ | $0.67$ | $\sim 0.6$ |
| $\epsilon = 0.2$  | $0.83$ | $0.64$ | $0.73 \pm 0.03$ |

The calculated ratios of $\bar{p}/p$ and $\bar{\Lambda}/\Lambda$ production in $Au - Au$ collisions at RHIC, predicted by Eq.(5) with accounting for the percolation effects [19] are presented in Table 1 [20]. One can see that small, $\epsilon = 0.05$, SJ contribution can not explain the data. Comparatively large contribution ($\epsilon = 0.2$), close to the upper limit (4) gives the ratios more close to their experimental values. The more accurate accounting of inelastic shadowing/percolations (multipomeron interactions) [19, 21] can lead to better agreement with the data.

In conclusion we note that $\bar{B}/B$ asymmetry in midrapidity region at RHIC energies is rather large. It can be explained by large SJ contribution that is in reasonable agreement with HERA data.

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