Calculation of Secondary Multiplicities in pp Collisions at RHIC and LHC Energies

G.H. Arakelyan[1], C. Merino[2], C. Pajares[2], Yu.M. Shabelski[3]

1 Yerevan Physics Institute
Yerevan, Armenia
2 Departamento de Física de Partículas
Instituto Galego de Altas Enerxías (IGAE)
Universidade de Santiago de Compostela
Galicia, Spain
3 Petersburg Nuclear Physics Institute
Gatchina, St.Petersburg, Russia

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Main Aim:

Analysis of the contribution of the String Junction (SJ) mechanism to the calculation of the inclusive densities of different secondaries in the frame of the Quark Gluon String Model (QGSM).

Comparison with recent RHIC data for pp collisions at $\sqrt{s} = 200$ GeV.

Predictions for secondary production at LHC energies are also given.

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In QCD hadrons are composite bound state configurations built up from the quark and gluon fields.

In the string models the baryon wave function can be defined as a Star-Y configuration (Fig. 1).

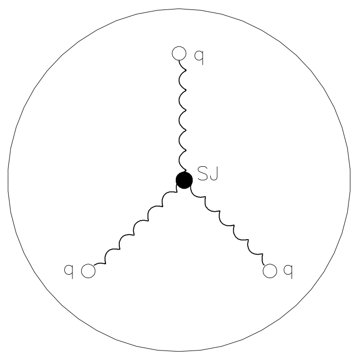


Figure 1: Composite structure of a baryon in string models.

In the case of inclusive reactions the baryon number transfer to large rapidity distances in hadron-nucleon reactions can be explained by SJ diffusion.

At very high energies all fragmentation functions, which are usually written as $G_q^h(z) = a_h(1-z)^\beta$, are constants,

$$G_q^h(x_+/x_1) = a_h \ ,$$

and lead to the following inclusive spectra for a secondary hadron:

$$\frac{dn}{dy} \ = \ g_h \cdot (s/s_0)^{\alpha_P(0)-1} \sim a_h^2 \cdot (s/s_0)^{\alpha_P(0)-1} \, .$$

This corresponds to the one-Pomeron exchange diagram in Fig. 2, which is the only diagram contributing to the inclusive density in the central region (AGK theorem).

The intercept of the supercritical Pomeron

$$\alpha_P(0) = 1 + \Delta, \Delta = 0.139 \ ,$$

is used in the numerical calculations.

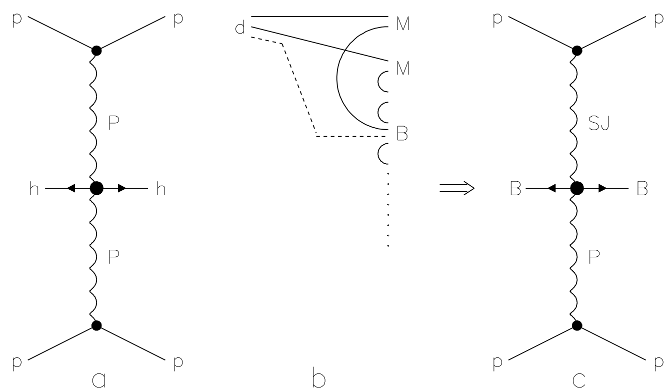
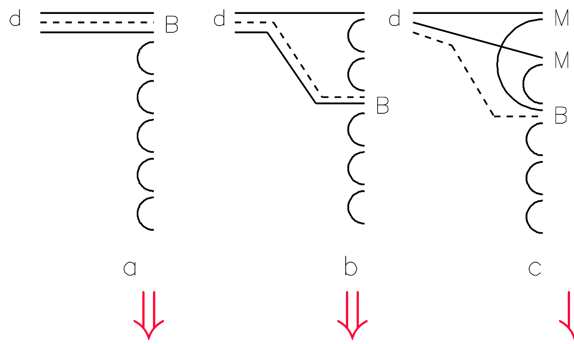


Figure 2: (a) One-Pomeron-pole diagram determining secondary hadron h production. (b) String Junction (shown by dashed line) diffusion that leads to asymmetry in baryon/antibaryon production in the central region, and (c) the Reggeon diagram which describes this process.

The diagram in Fig. 2a predicts equal inclusive yields for each particle and its antiparticle, but some corrections to the spectra of secondary baryons appear in rapidity space for processes which present SJ diffusion (Fig. 2c). Significant difference of baryon and antibaryon yields in midrapidity region for the current energies. This difference vanishes very slowly when energy increases.

Figure 3: QGSM diagrams describing secondary baryon B production by diquark d: (a) initial SJ together with two valence quarks and one sea quark, (b) together with one valence quark and two sea quarks, and (c) together with three sea quarks.



$$G \sim \left[v_{qq} \cdot (a) + v_q \cdot (b) + v_0 \cdot (c)\right] \cdot z^{\beta}$$

$$G^B_{qq}(z) = a_N v_{qq} \cdot z^{2.5} ,$$
$$G^B_{qs}(z) = a_N v_{qs} \cdot z^2(1-z) ,$$
$$G^B_{ss}(z) = a_N \varepsilon v_{ss} \cdot z^{1-\alpha_{SJ}}(1-z)^2 ,$$

where a_N is the normalization parameter, and v_{qq}, v_{qs}, v_{ss} are the relative probabilities for different baryons production that can be found by simple quark combinatorics.

The fraction of the incident baryon energy carried by the secondary baryon decreases from (a) to (c), whereas the mean rapidity gap between the incident and secondary baryon increases.

The first two processes can not contribute to the inclusive spectra in the central region, but the third contribution is essential if the value of the intercept of the SJ exchange Regge-trajectory is $\alpha_{SJ} \sim 1$.

The contribution of the graph in Fig. 3c has a coefficient ε which determines the small probability of such baryon number transfer.

All experimental data can be described with the parameter values

$$\alpha_{SJ} = 0.9 \text{ and } \varepsilon = 0.024$$

Comparison with RHIC Data

The normalization constants a_π (pion production), a_K (kaon production), $a_{\bar{N}}$ ($B\bar{B}$ pair production), and a_N (baryon production due to SJ diffusion) were determined from the experimental data at fixed target energies, where the fragmentation functions are not constants.

The values of corresponding constants for hyperons have been calculated by quark combinatorics. For sea quarks one has

$$\begin{aligned} & p \quad : n : \Lambda + \Sigma : \Xi^0 : \Xi^- : \Omega \\ = \;& 4L^3 \quad : 4L^3 : 12L^2 S : 3LS^2 : 3LS^2 : S^3 \,. \end{aligned}$$

The ratio $\lambda = S/L$ determines the strange suppression factor, and $2L + S = 1$.

In the numerical calculation we have used the value $\lambda = S/L = 0.25$ that leads to the best agreement with the STAR Collaboration data (B.I. Abelev *et al.*, STAR Collaboration, nucl-ex/0607033).

The calculated inclusive densities of different secondaries at RHIC, $\sqrt{s} = 200.$ GeV, energies are presented in Table 1:

Particle	RHIC ($\sqrt{s} = 200.$ GeV)		
	$\varepsilon = 0$	$\varepsilon = 0.024$	STAR Collaboration
π^+	1.27		
π^-	1.25		
K^+	0.13		0.14 ± 0.01
K^-	0.12		0.14 ± 0.01
p	0.0755	0.0861	
$\overline{p}$	0.0707		
Λ	0.0328	0.0381	0.0385 ± 0.0035
$\overline{\Lambda}$	0.0304		0.0351 ± 0.0032
Ξ^-	0.00306	0.00359	0.0026 ± 0.0009
$\overline{\Xi}^+$	0.00298		0.0029 ± 0.001
Ω^-	0.00020	0.00025	*
$\overline{\Omega}^+$	0.00020		*

$$^*dn/dy(\Omega^- + \overline{\Omega}^+) = 0.00034 \pm 0.00019$$

Table 1 The QGSM results for midrapidity yields dn/dy ($|y| < 0.5$) for different secondaries at RHIC energies. The results for $\varepsilon = 0.024$ are presented only when different from the case $\varepsilon = 0$.

The agreement of the QGSM calculations with RHIC experimental data is reasonably good.

The ratios of $\bar{p}/p$ production in pp interactions at $\sqrt{s} = 200.$ GeV as functions of the rapidity have been calculated in the QGSM and they are in reasonable agreement with the experimental data if the SJ contribution with $\varepsilon = 0.024$ is included, while the disagreement is evident for the calculation without SJ contribution (i.e. with $\varepsilon = 0$).

In Table 1 we see that at the RHIC energies the SJ contribution makes the deviation of $\bar{p}p$ from unity in the midrapidity region about three times bigger than in the calculation without SJ contribution.

The QGSM calculations predict practically equal values of $\bar{B}/B$ ratios in midrapidity region independently on baryon strangeness, what is qualitatively confirmed by the RHIC data on Au-Au collisions.

In the case of $\Omega/\bar{\Omega}$ production in pp collisions we obtain a non-zero asymmetry (i.e. more Ω than $\bar{\Omega}$), that is necessarily absent in the naive quark model or in all recombination models, since both Ω and $\bar{\Omega}$ have no common valence quarks with the incident particles.

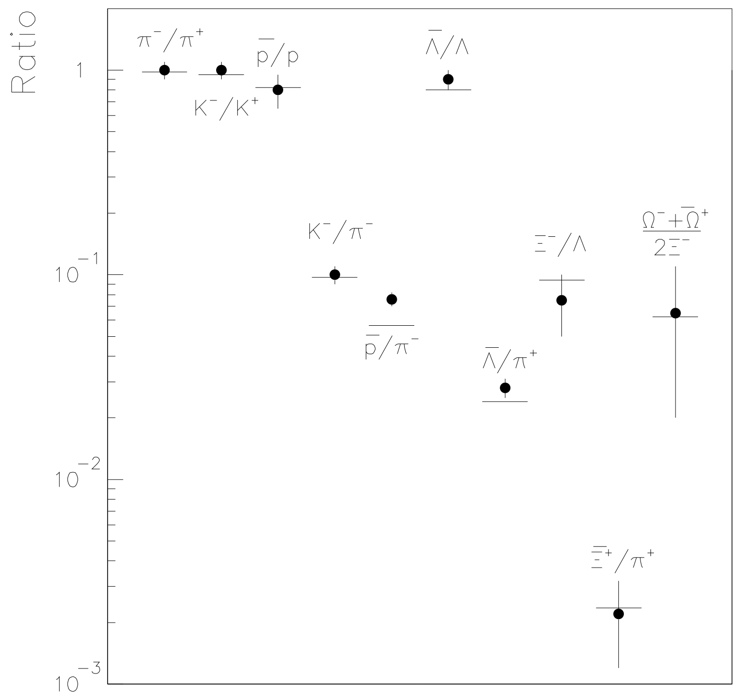


Figure 4: Ratios of different secondaries produced in midrapidity region in pp collisions at $\sqrt{s} = 200.$ GeV. Short horizontal solid lines show results of the QGSM calculations.

Agreement is good except for only the $\bar{p}/\pi^-$ ratio.

The universal value for the parameter λ, $\lambda = 0.25$, describes the ratios of Λ/p, Ξ/Λ, and Ω/Ξ production in a reasonable way.

Predictions for LHC

The calculated inclusive densities of different secondaries at LHC, $\sqrt{s} = 14.$ TeV, energies are presented in Table 2:

Particle	LHC ($\sqrt{s} = 14.$ TeV)	
	$\varepsilon = 0$	$\varepsilon = 0.024$
π^+	2.54	
π^-	2.54	
K^+	0.25	
K^-	0.25	
p	0.177	0.184
$\overline{p}$	0.177	
Λ	0.087	0.0906
$\overline{\Lambda}$	0.0867	
Ξ^-	0.0108	0.0112
$\overline{\Xi}^+$	0.0108	
Ω^-	0.000902	0.000934
$\overline{\Omega}^+$	0.000902	

Table 2 The QGSM results for midrapidity yields dn/dy ($|y| < 0.5$) for different secondaries at LHC energies. The results for $\varepsilon = 0.024$ are presented only when different from the case $\varepsilon = 0$.

The QGSM predicts a 3-4% deviation of the $\bar{p}p$ ratios from unity due to SJ contribution even at the LHC energy.

Without the SJ contribution these ratios are exactly equal to unity.

Conclusions

The inclusion of the SJ contribution provides a reasonable description of the main bulk of the existing experimental data on the baryon charge transfer to the midrapidity region in pp collisions at RHIC.

The calculations of the baryon/antibaryon yields and asymmetries without SJ contribution clearly diverge for most of the experimental data, where this contribution should be important.

Predictions for the LHC energy are also given.