Possible Odderon Effects at LHC

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 Física de Altas Enerxías
Universidade de Santiago de Compostela
Galiza, Spain
3 Petersburg Nuclear Physics Institute
Gatchina, St.Petersburg, Russia

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Main Aims:

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

To present the QGSM predictions for the contribution of SJ to the secondary production at LHC energies.

G.H. Arakelyan, C. Merino, C. Pajares, and Yu.M. Shabelski,
Eur. Phys. J. C54:577-581, 2008, and hep-ph/0707.1491
Proceedings od the 43rd Rencontres de Moriond on QCD and Hadronic Interactions, la Thuile, Italy, 8-15 March 2008, and arXiv:08052248[hep-ph]

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).
G.C. Rossi and G. Veneziano, Nucl. Phys. B123, 507, 1977

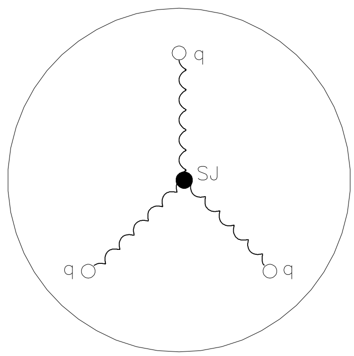


Figure 1: Composite structure of a baryon in string models.

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

SJ is a soft phenomenon.

Inclusive Spectra of Secondary Hadrons in the QGSM

The inclusive spectra of a secondary hadron h is determined in QGSM by the expression

$$\frac{dn}{dy} = \frac{x_E}{\sigma_{inel}} \cdot \frac{d\sigma}{dx_F} = \sum_{n=1}^{\infty} w_n \cdot \varphi_n^h(x_F)$$

with $x_E = E/E_{max}$, and

$$w_n = \sigma_n \Bigg/ \sum_{n=1}^{\infty} \sigma_n$$

the weight of the diagram with n cut Pomerons.

The function $\varphi_n^h(x_F)$ determines the contribution of the diagram in which n Pomerons are cut. In the case of pp collisions this function has the form:

$$\varphi_n^{pp\to h}(x_F) = f_{qq}^h(x_+, n) \cdot f_q^h(x_-, n) + f_q^h(x_+, n) \cdot f_{qq}^h(x_-, n) + 2 \cdot (n-1) \cdot f_s^h(x_+, n) \cdot f_s^h(x_-, n) \; ,$$

with

$$x_\pm = \frac{1}{2} \cdot \left[\left(\frac{4m_\perp^2}{s} + x_F^2 \right)^{\frac{1}{2}} \pm x_F \right] \; ,$$

where f_{qq}, f_q, and f_s correspond to the contributions of diquarks, valence quarks, and sea quarks, respectively.

The contributions of the incident particle and the target proton are determined by the convolution of the diquark and quark distributions with the fragmentation functions, e.g.,

$$f_q^h(x_+, n) = \int_{x_+}^{1} u_q(x_1, n) \cdot G_q^h(x_+/x_1) \cdot dx_1.$$

The diquark and quark distributions, as well as the fragmentation functions, are determined through Regge intercepts.

At very high energies both x_+ and x_- are negligibly small in the midrapidity region, and so all fragmentation functions, which are usually written as $G_q^h(z) = a_h \cdot (1-z)^\beta$, are taken as constants in this region:

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

what leads to:

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

This corresponds to the one-Pomeron exchange diagram in Fig. 2a, which, following the Abramovski-Gribov-Kanceli (AGK) Theorem, is the only diagram contributing to the inclusive density in the central region.

The intercept of the supercritical Pomeron

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

is used in the numerical calculations.

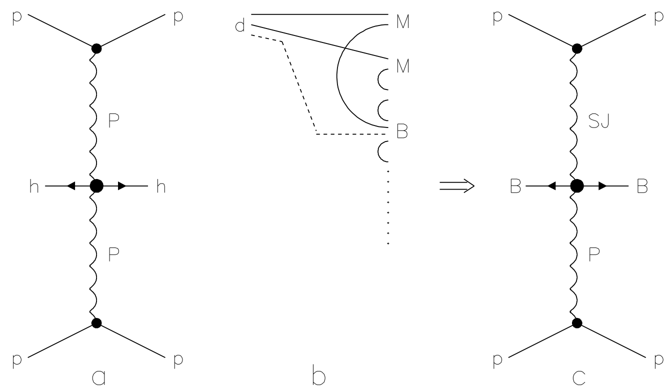


Figure 2: (a) One-Pomeron-pole diagram determining secondary hadron h production. (b) String Junction (shown by dashed line) diffusion leading to asymmetry in baryon/antibaryon production in the central region, and (c) the Reggeon diagram which describes this process.

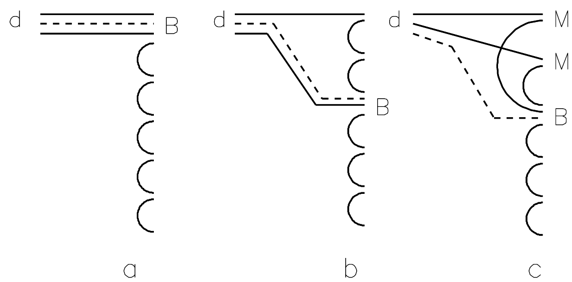
The one-Pomeron-pole diagram (Fig. 2a) predicts equal inclusive yields for each particle and its antiparticle.

On the contrary, some corrections to the spectra of secondary baryons appear in rapidity space for processes in which the SJ diffusion diagram (Fig. 2c) is present.

For the current energies there is a significant difference of baryon and antibaryon yields in midrapidity region.

This difference vanishes when energy increases, but it does so very slowly.

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) initial SJ together with one valence quark and two sea quarks, and (c) initial SJ together with three sea quarks.



Fragmentation Functs. $\Downarrow$ $\Downarrow$ $\Downarrow$

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

$$(a)\ G_{qq}^{B}(z) = a_N \cdot v_{qq} \cdot z^{2.5} ,$$

$$(b)\ G_{qs}^{B}(z) = a_N \cdot v_{qs} \cdot z^{2} \cdot (1-z) ,$$

$$(c)\ G_{ss}^{B}(z) = a_N \cdot \varepsilon \cdot v_{ss} \cdot z^{1-\alpha_{SJ}} \cdot (1-z)^2 ,$$

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

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 value of α_{SJ} is actually not known.

At low energies we know that the usual ω-contribution (standard Reggeon exchange with $\alpha_{SJ} \sim 0.4 - 0.5$) should be present, but it seems clear that to correctly describe both low and high energies two different contributions are needed (the second one with α_{SJ} closer to 1).

How and when does this second contribution start counting?

When taking into account only very high energies, this second contribution with a higher value of α_{SJ} can be the only significant one.

In 2002 all then available experimental data but those by HERA were explained by using a value $\alpha_{SJ} = 0.5$ (which corresponds to the behaviour of the annihilation cross-section), though two different values of ε were needed for the correct description of the data at moderate and high energies.

G.H. Arakelyan, A. Capella, A.B. Kaidalov, and Yu.M. Shabelski, Eur. Phys. J. C26, 81, 2002, and hep-ph/0103337

One has to note here that QGSM reflects the asymptotic Regge behaviour, so the validity of its description at low energies is not stablished.

As mentioned, the HERA data existing in those days could not be included in a global correct description. Though in principle HERA data were interesting since they implied a larger rapidity range than other experimental data, they were affected by a large background signal which distorted the asymmetry measurement, and today they are still unpublished.

In 2004, a correct global description of the available experimental data, with RHIC data by the BRAHMS Collaboration already included in the analysis, was obtained by taking the parameter values

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

F. Bopp and Yu.M. Shabelski
Eur. Phys. J. A28:237-243, 2002, and hep-ph/0603193
Phys. Atom. Nucl. 68:2093-2099, 2005,
Yad. Fiz. 68:2155-2161, 2005, and hep-ph/0406158

Nevertheless, the existing experimental data are neither enough nor good enough for the determination of the SJ parameters with the needed accuracy, and so this solution is not supported by a good χ^2 analysis.

IMPORTANT POINT: If the solution with $\alpha_{SJ} = 0.9$ was to be confirmed by further and more accurate experimental data, such a SJ would be the first experimental manifestation of a contribution by the Odderon (Reggeon with $\alpha_{Odd} \sim 1$ and negative signature).

Comparison with RHIC Data

The probabilities ω_n are calculated in the frame of Reggeon theory.

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 $(2L + S = 1)$:

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

The ratio $\lambda = S/L$ determines the strange suppression factor.

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 energies, $\sqrt{s} = 200.$ GeV, 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 ($\alpha_{SJ} = 0.9$) for midrapidity yields dn/dy ($|y| < 0.5$) integrated over p_T 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 $\alpha_{SJ} = 0.9$ and $\varepsilon = 0.024$ 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 not common valence quarks with the incident particles.

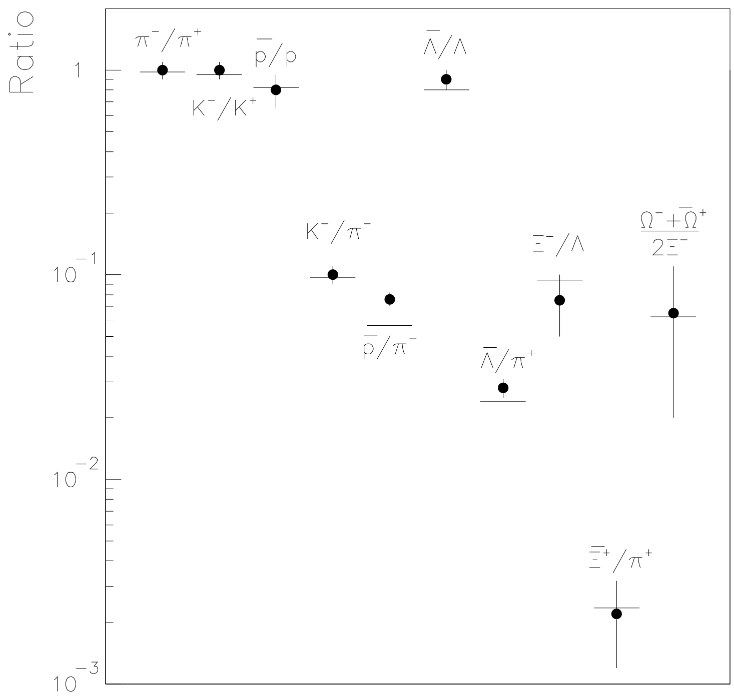


Figure 4: Ratios of different secondaries produced in midrapidity region in pp collisions at $\sqrt{s} = 200.$ GeV. Short horizontal solid lines show results of the QGSM calculations obtained with $\alpha_{SJ} = 0.9$ and $\epsilon = 0.024$.

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.

LHC data will represent a huge gain in terms of the available rapidity range.

Thus, highly accurate LHC data will become crucial in determining the value of α_{SJ} and the presence of one Odderon contribution at high energies.

Predictions for LHC

The QGSM predictions for antibaryon/baryon yields ratios in pp collisions in midrapidity region ($|y| < 0.5$) and integrated over p_T at $\sqrt{s} = 900.$ GeV, are presented in Table 2:

Ratio	$\sqrt{s} = 900.$ GeV		
	$\varepsilon = 0$	$\alpha_{SJ} = 0.5$	$\alpha_{SJ} = 0.9$
$\overline{p}/p$	0.981	0.955	0.892
$\overline{\Lambda}/\Lambda$	0.976	0.949	0.887
$\overline{\Xi}^+/\Xi^-$	0.992	0.965	0.909
$\overline{\Omega}^+/\Omega^-$	1.0	0.905	0.907

Table 2 The QGSM predictions for antibaryon/baryon yields ratios in pp collisions in midrapidity region ($|y| < 0.5$) at $\sqrt{s} = 900.$ GeV. Three scenarios have been considered: no SJ contribution ($\varepsilon = 0$), $\alpha_{SJ} = 0.5$ (ω-Reggeon contribution), and $\alpha_{SJ} = 0.9$ (Odderon contribution).

To obtain highly accurate measurements at $\sqrt{s} = 900.$ GeV is a very important goal:

This is a middle point between RHIC energies, $\sqrt{s} = 200.$ GeV, and LHC energies, $\sqrt{s} = 14.$ TeV (the energy dependence in the model is logarithmic $\sim \log s$), and so it is well suited to investigate whether the Odderon contribution that seems to appear at RHIC energies is confirmed here.

If this is the case, one has to check up whether already at these high energies the ω-Reggeon contribution can be neglected.

The calculated inclusive densities of different secondaries at LHC, $\sqrt{s} = 14.$ TeV, energies are presented in Table 3:

Particle	LHC ($\sqrt{s} = 14.$ TeV)	
	$\varepsilon = 0$	$\alpha_{SJ} = 0.9$, $\varepsilon = 0.024$
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 3 The QGSM results ($\alpha_{SJ} = 0.9$) for midrapidity yields dn/dy ($|y| < 0.5$) and integrated over p_T for different secondaries at LHC energies. The results for $\varepsilon = 0.024$ are presented only when different from the case $\varepsilon = 0$.

The QGSM predictions for antibaryon/baryon yields ratios in pp collisions in midrapidity region ($|y| < 0.5$) and integrated over p_T at $\sqrt{s} = 14.$ TeV, are presented in Table 4:

Ratio	$\sqrt{s} = 14.$ TeV		
	$\varepsilon = 0$	$\alpha_{SJ} = 0.5$	$\alpha_{SJ} = 0.9$
$\overline{p}/p$	0.998	0.994	0.960
$\overline{\Lambda}/\Lambda$	0.992	0.993	0.955*
$\overline{\Xi}^+/\Xi^-$	0.999	0.995	0.966
$\overline{\Omega}^+/\Omega^-$	1.0	0.995	0.965

Table 4 The QGSM pedictions for antibaryon/baryon yields ratios in pp collisions in midrapidity region ($|y| < 0.5$) at $\sqrt{s} = 14.$ TeV. Three scenarios have been considered: no SJ contribution ($\varepsilon = 0$), $\alpha_{SJ} = 0.5$ (ω-Reggeon contribution), and $\alpha_{SJ} = 0.9$ (Odderon contribution).

* The case of Λ production is very important since Λ production cross-section is very large.

The QGSM predicts, already for the value $\alpha_{SJ} = 0.5$, 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.

The third column in Table 4 represents one unique chance to find for the first time an experimental proof of the existence of the Odderon (a well defined theoretical object known for many years but up to now not experimentally confirmed)*.

*See one updated analysis of the experimental situation of the Odderon question in C. Merino, M.M. Ryzhinskiy, and Yu.M. Shabelski, arXiV:0810.1275.

To get a clear-cut experimentally confirmed difference between columns 2 and 3 in Table 4, 1% experimental accuracy should be attained in these measurements.

No other experimental data can perform the same analysis since, for total cross-section data, accuracies of the order of 1 mbarn will be needed, and experimental data on $\sigma_{p\bar{p}}$ would also have to enter in the analysis.

Conclusions

- The inclusion of a SJ contribution with $\alpha_{SJ} = 0.9$ 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 from RHIC data, where this contribution should be important.
- To obtain highly accurate measurements at $\sqrt{s} = 900.$ GeV (or at $\sqrt{s} = 2.36$ TeV) is a very important goal in order to determine whether the Odderon contribution that seems to appear at RHIC energies is confirmed, and, if so, whether at these already high energies the ω-Reggeon contribution can be neglected.

- High accuracy measurements of the antibaryon/baryon ratios at $\sqrt{s} = 14.$ TeV will represent one unique chance to find for the first time the experimental proof of the existence of the Odderon.
- ALICE Collaboration is looking at it.