SOFT POMERON AND ODDERON AT LHC

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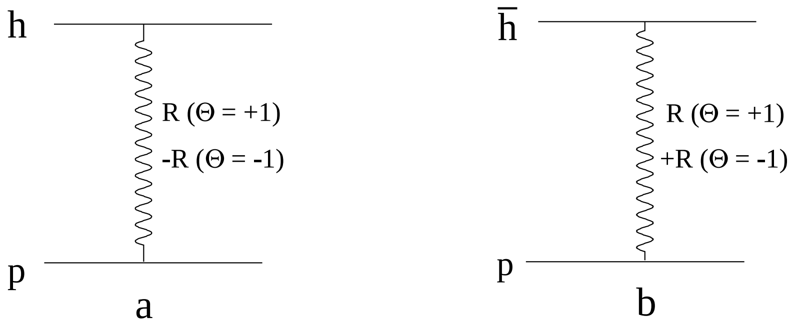
1 Pomeron and Odderon exchanges

One Regge-pole R exchange corresponding to the scattering amplitude



$$A(s,t) = g_1(t) \cdot g_2(t) \cdot \left(\frac{s}{s_0}\right)^{\alpha_R(t)-1} \cdot \eta(\Theta) \ , \tag{1}$$

where $g_1(t)$ and $g_2(t)$ are the couplings of a Reggeon to the beam and target hadrons, $\alpha_R(t)$ is the R-Reggeon trajectory, and $\eta(\Theta)$ is the signature factor which determines the complex structure of the scattering amplitude (Θ equal to $+1$ and to -1 for reggeon with positive and negative signature (C-parity), respectively):

$$\eta(\Theta) = \begin{cases} i - \tan^{-1}(\frac{\pi\alpha_R}{2}) & \Theta = +1 \\ i + \tan(\frac{\pi\alpha_R}{2}) & \Theta = -1 \ , \end{cases} \tag{2}$$

so the amplitude $A(s, t = 0)$ becomes purely imaginary for positive signature and purely real for negative signature when $\alpha_R \rightarrow 1$.

The values of hadron-nucleon total cross sections are determined at high energies by exchange of one or several Pomerons

$$\alpha_P(t) = 1 + \Delta + \alpha'_P\, t \ , \ \ \Delta > 0 \ . \tag{3}$$

The one-Pomeron contribution to σ_{hN}^{tot} equals

$$\sigma_P = g_1(t) \cdot g_2(t) \cdot e^{\Delta\xi}, \ \ \xi = \ln s/s_0 \ , \tag{4}$$

To obey the s-channel unitarity, and the Froissart bound in particular, this contribution should be screened by the multi-pomeron discontinuities. A simple eikonal treatment yields

$$\sigma_{hN}^{tot} \sim \log^2 s/s_0 \ . \tag{5}$$

The difference in the total cross section of high energy particle and antiparticle scattering on the proton target is determined by Reggeons with negative C-parity

$$\Delta\sigma_{hp}^{tot} = \sum_{R(\Theta=-1)} 2 \cdot g_1(0) \cdot g_2(0) \cdot \left(\frac{s}{s_0}\right)^{\alpha_R(0)-1} \cdot Im\,\eta(\Theta = -1)\ . \qquad (6)$$

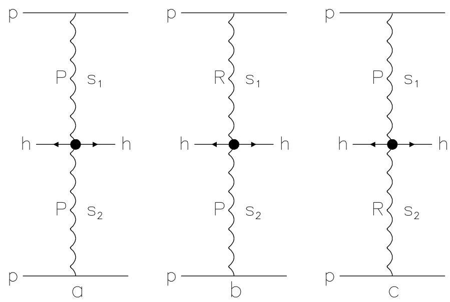
The most important at high energies should be the Odderon contribution.

The Odderon is a singularity in the complex J-plane with intercept $\alpha_{Od} \sim 1$ and negative C-parity

In QCD the Odderon singularity is connected to the colour-singlet exchange of **three** reggeized gluons in t-channel.

J. Bartels, L.N. Lipatov, and G.P. Vacca, Phys. Lett. **B477**, 178 (2000) and hep-ph/9912423.

2 Inclusive particle and antiparticle production



The inclusive production cross section of hadron h with transverse momentum p_T in high energy pp collisions :

$$F(p_T, s_1, s_2, s) = \frac{1}{\pi^2 s} g_R^{pp} \cdot g_P^{pp} \cdot g_{RP}^{hh}(p_T) \cdot \left(\frac{s_1}{s_0}\right)^{\alpha_R(0)} \cdot \left(\frac{s_2}{s_0}\right)^{\alpha_P(0)} , \tag{7}$$

where

$$\begin{aligned} s_1 &= (p_a + p_h)^2 = m_T \cdot s^{1/2} \cdot e^{-y^*} \\ s_2 &= (p_b + p_h)^2 = m_T \cdot s^{1/2} \cdot e^{y^*} , \end{aligned} \tag{8}$$

with the rapidity y^* defined in the center-of-mass frame.

V.A. Abramovsky, O.V. Kancheli, and I.D. Mandzhavidze, Yad. Fiz. **13**, 1102 (1971).

At very high energies only one-Pomeron exchange diagram contributes to the inclusive density in the central region that leads to

$$\frac{dn}{dy} \sim (s/s_0)^{\alpha_P(0)-1}\,, \tag{9}$$

Now we can estimate the intercept of the supercritical Pomeron. The energy dependencies of dn/dy and $dn/d\eta$ in midrapidity region practically coinside. Such an analysis was provided in ref.

G.J. Alner et al., UA5 Collaboration, Z. Phys. **C33**, 1 (1986).

in the energy interval $\sqrt{s} = 15 - 900$ GeV and the value

$$\Delta = \alpha_P(0) - 1 = 0.105 \pm 0.006 \tag{10}$$

was obtained.

Recent LHC data (ALICE Coll.) allow one to estimate the intercept of the supercritical Pomeron at higher energies. The measured values of $dn_{ch}/d\eta$ in midrapidity region at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV lead to

$$\Delta = \alpha_P(0) - 1 = 0.110 \pm 0.008 \tag{11}$$

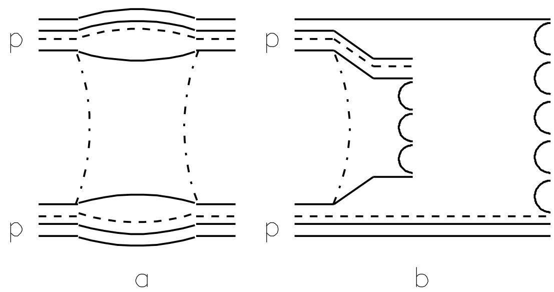
that show very stable behaviour.

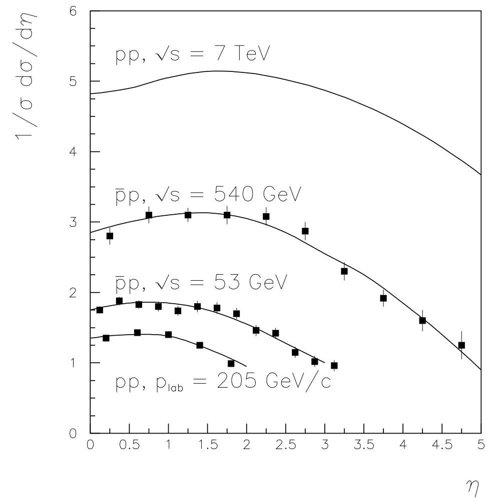
3 Inclusive spectra of secondary hadrons in the Quark-Gluon String Model

A.B. Kaidalov and K.A. Ter-Martirosyan, Yad. Fiz. **39**, 1545 (1984); **40**, 211 (1984).

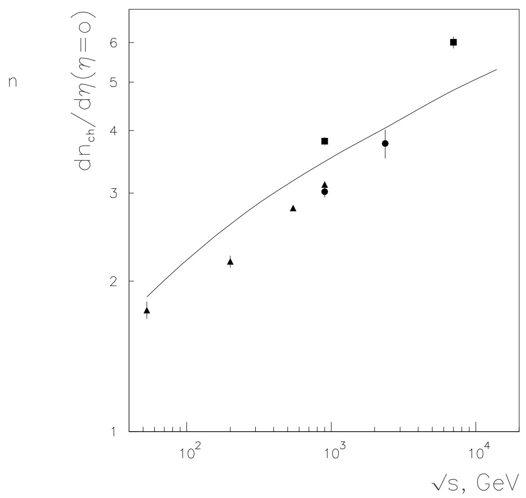
In QGSM high energy hadron-nucleon collisions are considered as taking place via the exchange of one or several Pomerons, all elastic and inelastic processes resulting from cutting through or between Pomerons.

Each Pomeron corresponds to a cylindrical diagram, and thus, when cutting one Pomeron, two showers of secondaries are produced. The inclusive spectrum of a secondary hadron h is then determined by the convolution of the diquark, valence quark, and sea quark distributions $u(x, n)$ in the incident particles with the fragmentation functions $G^h(z)$ of quarks and diquarks into the secondary hadron h.

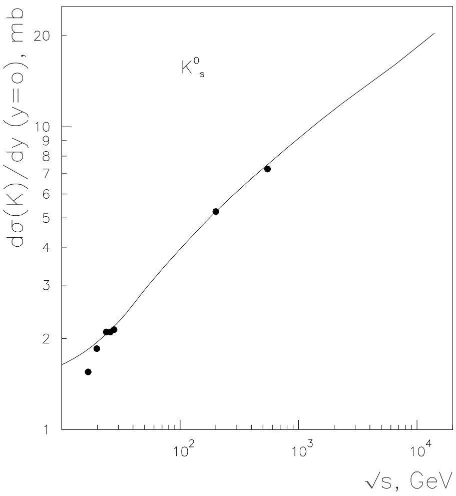


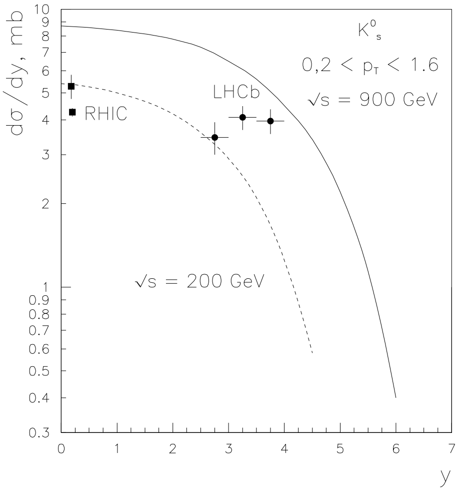


pp, √s = 7 TeV
p̄p, √s = 540 GeV
p̄p, √s = 53 GeV
pp, plab = 205 GeV/c
1/σ dσ/dη
η



n
dnch/dη(η=o)
√s, GeV


dσ(K)/dy (y=o), mb
K⁰s
√s, GeV


dσ/dy, mb
K⁰s
0,2 < pT < 1.6
√s = 900 GeV
LHCb
RHIC
√s = 200 GeV
y

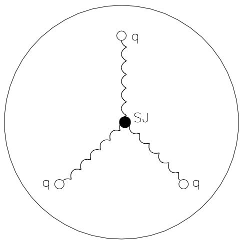
4 $\bar{B}/B$ asymmetry

In the string models, baryons are considered as configurations consisting of three connected strings (related to three valence quarks) called string junction (SJ).

X. Artru, Nucl. Phys. B **85**, 442 (1975).

M. Imachi, S. Otsuki, and F. Toyoda, Prog. Theor. Phys. **52**, 346 (1974); **54**, 280 (1976); **55**, 551 (1976).

G.C. Rossi and G. Veneziano, Nucl. Phys. B **123**, 507 (1977).



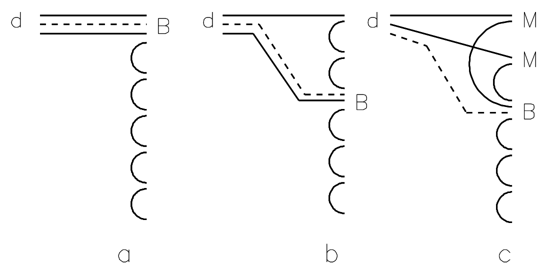
$$B = \psi_i(x_1) \cdot \psi_j(x_2) \cdot \psi_k(x_3) \cdot J^{ijk}(x_1, x_2, x_3, x)\,, \qquad (12)$$
$$J^{ijk}(x_1, x_2, x_3, x) = \Phi^i_{i'}(x_1, x) \cdot \Phi^j_{j'}(x_2, x) \cdot \Phi^k_{k'}(x_3, x) \cdot \epsilon^{i'j'k'}\,,$$

where x_1, x_2, x_3, and x are the coordinates of valence quarks and SJ, respectively. Such a baryon structure is supported by lattice calculations.

V.G. Bornyanov et al., Uspekhi Fiz. Nauk. **174**, 19 (2004).

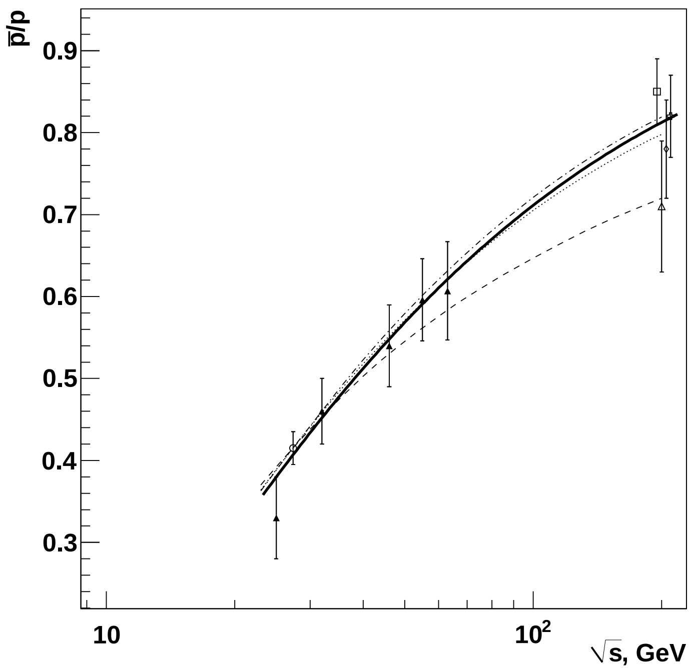
To obtain the net baryon charge, we consider three different possibilities.

G.H. Arakelyan, A. Capella, A.B. Kaidalov, and Yu.M. Shabelski, Eur. Phys. J. C **26**, 81 (2002) and hep-ph/0103337.



The first one (a) is the fragmentation of the diquark giving rise to a leading baryon. A second possibility (b) is to produce a leading meson in the first break-up of the string and a baryon in a subsequent break-up. In the third case (c) both initial valence quarks recombine with sea antiquarks into mesons M while a secondary baryon is formed by the SJ together with three sea quarks.

The ratio of $\bar{p}$ to p yields at $y^* = 0$ calculated with the QGSM is shown below. The results with $\alpha_{SJ} = 0.9$, $\alpha_{SJ} = 0.6$, and $\alpha_{SJ} = 0.5$ are presented by dashed, dotted, and dash-dotted curves, respectively.



The quantitative theoretical description of the baryon number transfer via SJ mechanism was suggested in the 90's and used to predict

B.Z. Kopeliovich and B. Povh, Z. Phys. C **75**, 693 (1997); Phys. Lett. B **446**, 321 (1999).
the $p/\bar{p}$ asymmetry at HERA energies then experimentally observed

C. Adloff et al., H1 Collaboration, submitted to the 29th Int. Conf. on High Energy Physics ICHEP98, Vancouver, July 1998.

$$A_p = 2\frac{N_p - N_{\bar{p}}}{N_p + N_{\bar{p}}} = (8.0 \pm 1 \pm 2.5)\% \qquad (13)$$

Our result is $A_p = 10\%$ for $\alpha_{SJ} = 0.9$ and $A_p = 2.5\%$ for $\alpha_{SJ} = 0.5$

5 Predictions for LHC

The QGSM predictions for antibaryon/baryon yields ratios in pp collisions in midrapidity region ($|y| < 0.5$) for energies $\sqrt{s} = 900$ GeV. and $\sqrt{s} = 7$ TeV :

With odderon ($\alpha_{SJ} = 0.9$)

$$\frac{\bar{B}}{B} \simeq 0.89 \text{ (900GeV) and } 0.95 \text{ (7TeV)} \tag{14}$$

Without odderon

$$\frac{\bar{B}}{B} \simeq 0.95 \text{ (900GeV) and } 0.99 \text{ (7TeV)} \tag{15}$$

$$B = p,\ \Lambda,\ \Xi,\ \Omega \tag{16}$$

More predictions can be found in

G.H. Arakelyan, C. Merino, C. Pajares, and Yu.M. Shabelski, Eur. Phys. J. **C54**, 577 (2008) and hep-ph/0709.3174.

C. Merino, CM.M. Ryzhinskiy, and Yu.M. Shabelski, hep-ph/0906.2659.

C. Merino, CM.M. Ryzhinskiy, and Yu.M. Shabelski, Eur. Phys. J. **C62**, 491 (2009)

6 Conclusion

In the inclusive production of particles and antiparticles in central (midrapidity) region in pp collisions we could not see an evident contribution by the Odderon. The energy for the possible Odderon exchange is perhaps too small. Actually, the only evidence for the Odderon exchange with $\alpha_{Odd}(0) \simeq 0.9$ are is experimental point for $\bar{p}$ to p production asymmetry by the H1 Collaboration. This point is until now not published.

We expect that the LHC data will make the situation more clear.