Evolution of the unitarity saturation in the pp & np total cross section to the asymptotic limit

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Abstract
By using the interplay between the growth of the transverse size of the proton in the high energy limit, and the gluonic matter density, with unitarity saturation based on a grey disk model. We explore the evolution of the unitarity saturation in the pp and np total cross section to the asymptotic limit to the geometric scaling.

Introduction

Recent measurements of the pp cross sections of the Auger and LHC experiments had increased the interest in the discussions on the possibility of a proton developing asymptotically into a **Black Disk**[1].

The Geometric Scaling in the Froissart's limit gives

$$\mathrm{Im}F(s,t) = \mathrm{Im}F(s,0)\varphi(\tau), \tag{1}$$

where $\mathrm{Im}F(s,t)$ is the imaginary part of the amplitude and φ is the entire function of the scaling variable $\tau = -t\sigma^{\mathrm{tot}}$. Following the optical theorem one neglects the real part, thus the average of the imaginary part of the elastic amplitude is related to gluonic saturation scale, $f(s)$:

$$\langle \mathrm{Im}G(\beta)\rangle \simeq f(s), \tag{2}$$

where $G(s,b)$ is the Fourier transformation of $F(s,t)$. As $s\to\infty$, $f(s)\to 1$ and $\sigma^{\mathrm{el}}/\sigma^{\mathrm{tot}} \to 1/2$, which means Black Disk behavior[2].

Parametrization

From the above, two relevant variables emerge, $R(s)$ which measures the transverse size of the proton as function of energy, and the gluonic matter density $f(s)$ also energy dependent. By making use of a grey disk model, neglecting real part contribution, and considering the asymptotic high energy regime, the total and elastic cross section can be given by:

$$\sigma^{\mathrm{tot}} = 2\pi \int db^2 ImG(s,b) = 2\pi R^2(s) f(s), \tag{3a}$$

$$\sigma^{\mathrm{el}} = \pi \int db^2 [ImG(s,b)]^2 = \pi R^2(s) f^2(s), \tag{3b}$$

where $R(s)$ is proportional to a maximum angular momentum $L(s)$ as required by the Froissart bound. We have consider $R(s)$ with a logarithmic dependence on energy with the same parametrization used in [3]

$$R(s) = R_0 + \beta \ln\left(\frac{s}{s_0}\right) \tag{4}$$

where $\sqrt{s_0}$ is an energy threshold parameter, R_0 is a constant related to the valence quark content of beam and target particles, and the second term is a universal behavior.

For $f(s)$ we have $f(s) = 2(\gamma_1 + \gamma_2 \ln s + \gamma_3 \ln^2 s)$, as used in [4], one can reduce the parameters with out losing generality with the parametrization $f(s) = (\alpha + \gamma \ln(s/s_1))^2$ where s_1 is a threshold parameter for the Froissart bound and the t-slope $\sim \ln^2(s/s_1)$.

$$\frac{\sigma^2_{\mathrm{tot}}}{2\sigma_{\mathrm{el}}} = 2\pi R^2(s) \equiv \sigma_{BD} \tag{5}$$

gives the Black Disk formation at the very high energy, it predicts no analytic dependence on $f(s)$ and thus one can fix the parametrization for the radius with data in Fig. 1. By assuming the same $R(s)$ growth on np collisions we found the corresponding values to describe $f(s)$ in np collisions. This parametrization allow us to estimate the profile function for elastic cross section using unitarity relation which leads to the probability of the inelastic interaction for a given b as $1-|1-\Gamma(b)|^2$. This means that at high energies the memory of the colliding particles is not longer maintain and the growth of the gluon production generates the blackening interaction, this is in agreement with Unitarization and Universality [7,8] which leads that the ratio of total cross section for any colliding particle should become one as seen in Figure 2.

References

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Results

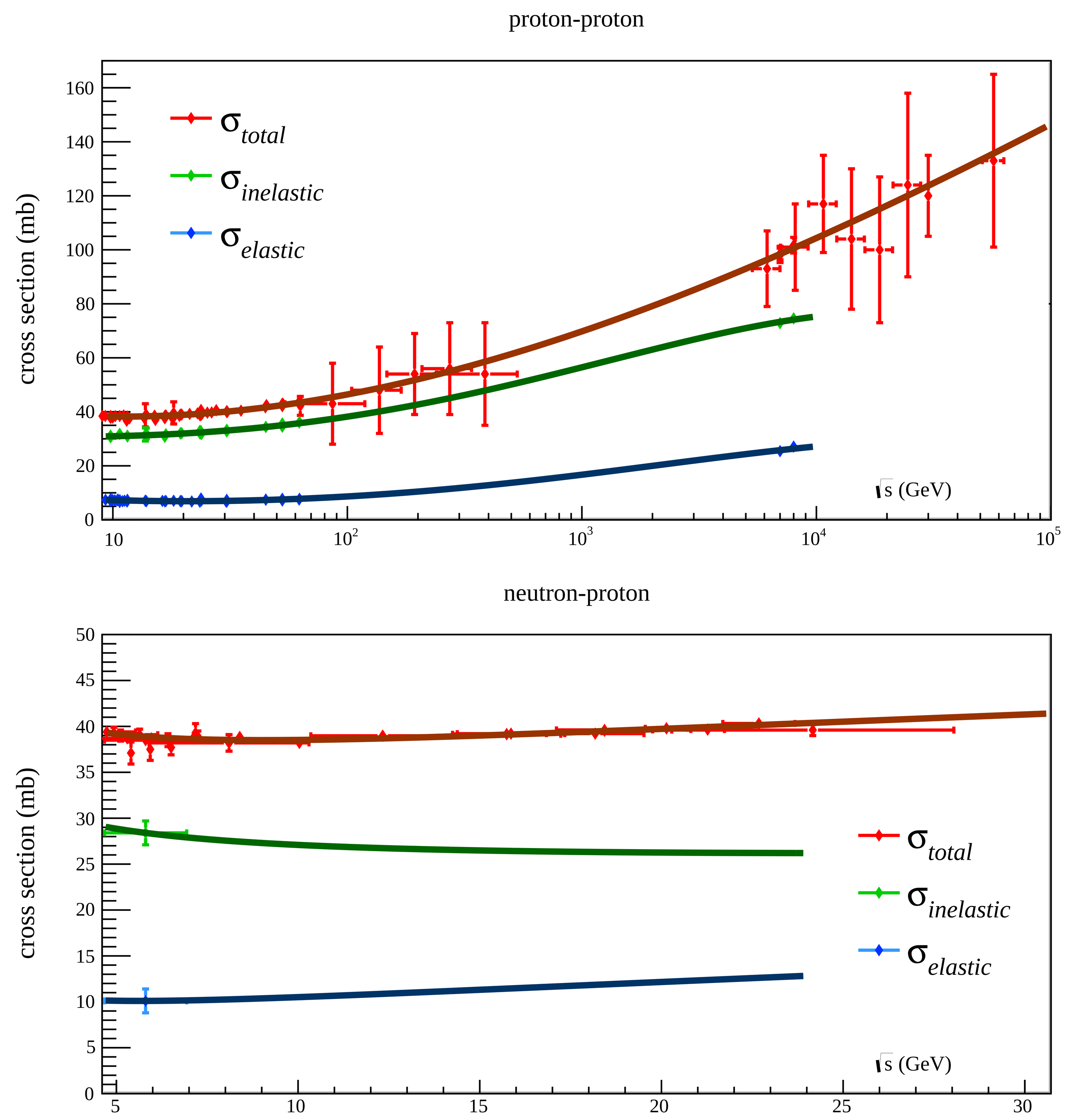

Figure 1: Multi-fit over total, elastic and inelastic cross section, pp and np data from [6]

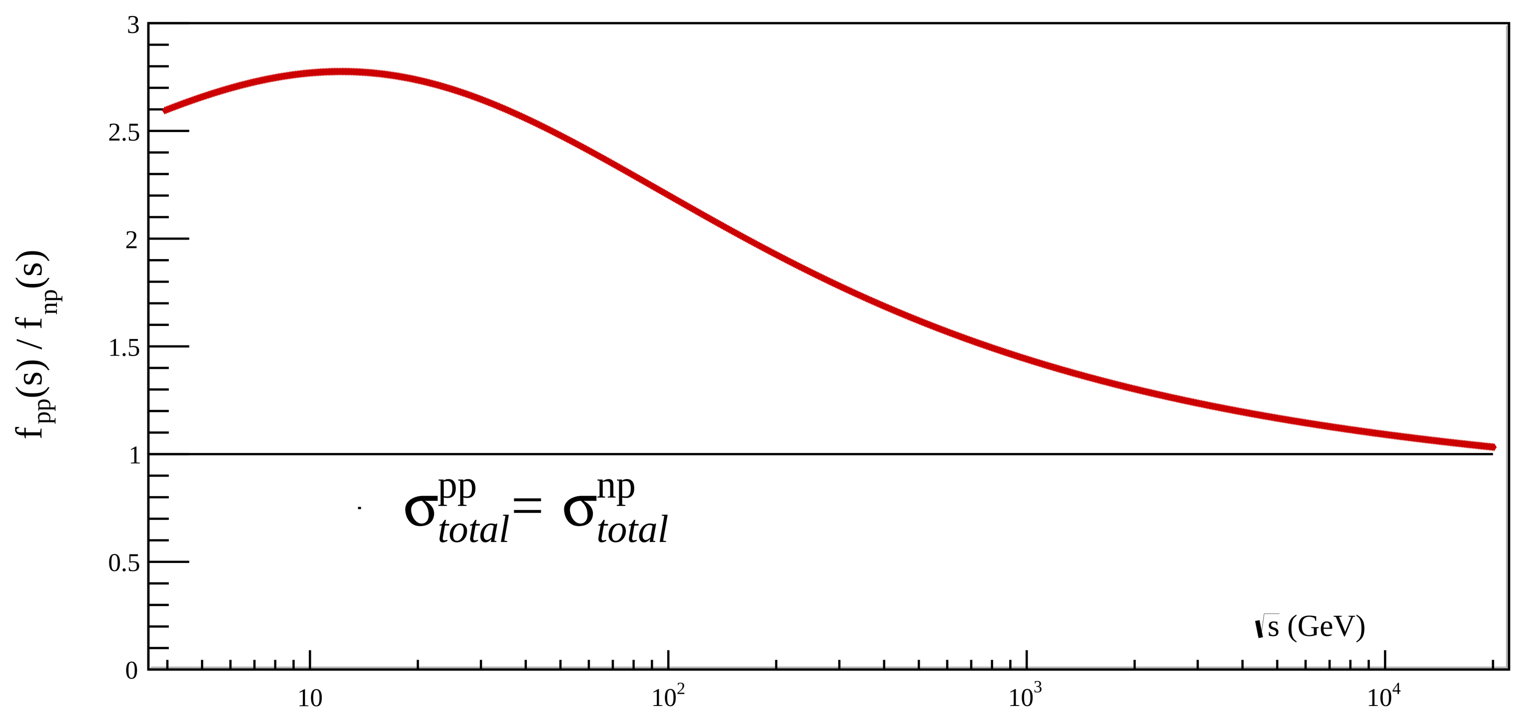

Figure 2: The comparison between the $f(s)$ for pp and np which leads at high energy with the universality approaching to 1.

	pp	np
R_0	3.977 ± 0.0192	
β	-0.2410 ± 0.005	
s_0	23.797 ± 0.005	
γ_1	0.2563 ± 0.002277	1348 ± 0.0004
γ_2	-0.0218 ± 0.00359	-0.0189 ± 0.000037
γ_3	0.00264 ± 0.00005	0.00169 ± 0.000008

Table 1: Parameters obtained by fitting cross section in pp collisions up to 20 TeV.

Conclusions

The behavior of the pp-np gluon production ratio near the black disk limit is shown in Fig.2, this result shows to be consistent with Universality, which reflects the universal dependence on the impact parameter of the Pomeron exchange (soft peripheral interactions)