HARD-SOFT POMERON TRANSITION FROM
QCD SATURATION IN THE DIPOLE PICTURE

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We pose the question: how far can we push the QCD dipole model and
the idea of QCD saturation to the kinematical regions traditionally as-
sociated with soft nonperturbative physics? The answer is that it works
sufficiently well allowing a smooth transition from hard (BFKL) pomeron
to the soft one.

1 Introduction

We continue to develop a new global QCD analysis based on a solution of
the Balitsky-Kovchegov (BK) non-linear evolution equation [1]. The general
motivation rises from three main problems related to the DGLAP evolu-
tion. First, it predicts a steep growth of parton distributions at low $x$
which will eventually violate the unitarity constraints. Second, the twist OPE breaks
down at low $x$, when the higher twists become of the same order as the leading
one. Finally, the DGLAP evolution is totally unable to describe low $Q^2$ data.
Moreover, NLO corrections do not solve any of these problems.

The BK equation (BKE) is essentially the LO BFKL + unitarization (non-
linearity). We believe that this equation is a solution to the above problems.
It accounts for the saturation effects due to high parton densities. It sums high
twist contributions and allows extrapolation to large distances.

In order to investigate the question formulated in the abstract we adopt
the following strategy. First, we construct a new saturation model ($\sigma_{dipole}$) by
solving the BKE and fitting free parameters to the low $x F_2$ data. Then use
thus obtained model beyond the limits of its formal applicability.
2 Results

In Ref. [2] we have constructed a saturation model based on a solution of the BKE. All available low $x$ data on the $F_2$ structure function was successfully described. It includes the description at very low photon virtuality down to $Q^2 = 0.045 \text{(GeV}^2) \approx \Lambda_{QCD}^2$.

One of the quantities associated with $F_2$ is $\lambda = d\ln F_2 / d\ln(1/x)$. In DIS $\lambda$ measures an effective pomeron intercept. For high $Q^2$, $\lambda \approx 0.3 - 0.4$ which is consistent with the data and in agreement with the BFKL intercept. This is of no surprise since the linear term in the BK equation is the LO BFKL. Fig. 1 is our result for $\lambda$ at low $x$ and low $Q^2$. In this kinematics $\lambda$ approaches the value $0.08 - 0.1$ which is the soft pomeron intercept.

Our saturation model provides a smooth interpolation between intercepts of the hard (BFKL) pomeron and the soft one.

![Figure 1: $\lambda$ at low $x$ and low $Q^2$.](image)

Being inspired by the success of the low $Q^2$ description of the $F_2$ data we decided to push even further in the nonperturbative domain and consider total
photoproduction [3]. To do so, we need to introduce an additional nonperturba-
tive parameter $Q_0$ which relates the energy of the process $W$ to the Bjorken $x$:

$$x = \frac{Q_0^2}{W^2}.$$  

We find $Q_0^2 = 4m_q^2$ with the effective quark mass $m_q \simeq 0.15 \text{GeV}$. The two curves in Fig. 2 differ by the form of the secondary trajectory \(^1\) added in order to describe the low energy data.

![Figure 2: Total photoproduction.](image)

Finally we would like to consider the hadron-hadron collision within the same dipole approach [4]. We are pushing the dipole model deep into the domain of nonperturbative QCD. We compute a hadron-proton cross section as

$$\sigma_{H-\text{proton}}(x) = \int d^2r_\perp |\psi_H(r_\perp)|^2 \sigma_{\text{dipole}}(r_\perp, x)$$

We again introduce a nonperturbative scale $Q_0 \propto M_H$ such that $x = Q_0^2/s$. $\sigma_{\text{dipole}}$ is the same dipole cross section which was constructed to describe $F_2$ data. For the projectile hadron wave function $\psi_H$ a Gaussian profile is used.

\(^1\)The evolution of the secondary trajectories is beyond the scope of our model.
Figs. 3 and 4 present our results for meson-proton and proton-proton collisions. Except for $K$-meson a contribution of secondary reggeon $\propto s^{-0.45}$ was added. We observe a reasonable agreement with the data.

![Figure 3: Meson-proton collision.](image)

3 Summary

- A new approach to global QCD analysis based on the BKE is developed.
- Low $x$ data on the $F_2$ structure function is reproduced.
- Our method allows extrapolation of the parton distributions to the LHC energies and to low photon virtualities $Q^2 \ll 1\, GeV^2$.
- We find $\lambda \simeq 0.25 - 0.4$ at large $Q^2$ (hard BFKL pomeron) while $\lambda \simeq 0.08 - 0.1$ at very low $x$ and $Q^2$ well below $1\, GeV^2$. A result which agrees with the ”soft pomeron” intercept without soft physics involved.
- The dipole picture pushed to a nonperturbative region works sufficiently well. It describes high energy photoproduction. Soft hadron interaction data are reproduced with quite satisfactory accuracy.

Within the dipole picture and QCD saturation, the soft pomeron is a phenomenon of multiple rescattering of the hard (BFKL) pomeron.
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References

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