Energy Conservation and Pomeron Loops in High Energy Evolution

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High Energy QCD

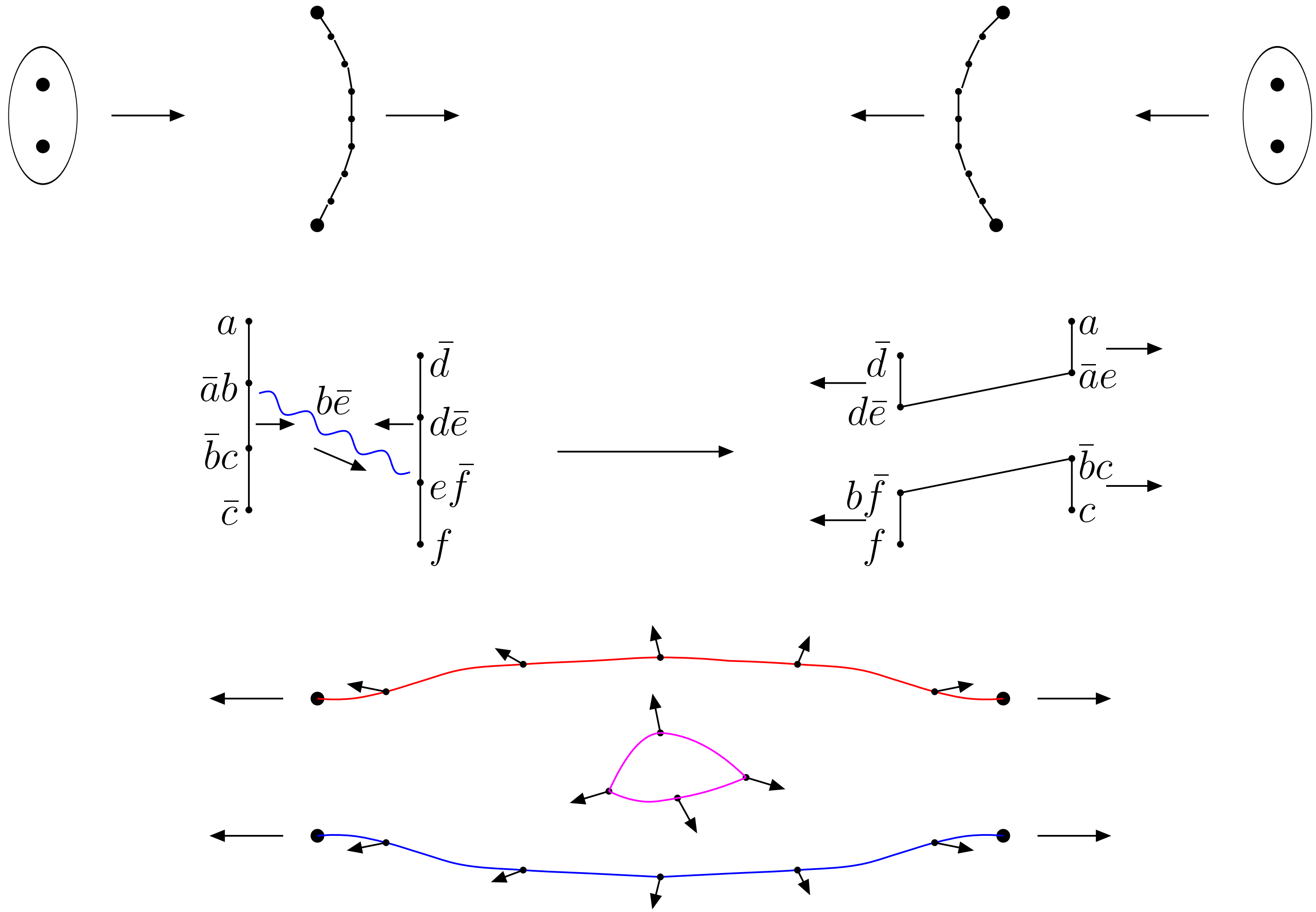
A decade ago Mueller formulated, in large N_c, a Dipole Model for high energy evolution which goes beyond the BFKL approach and includes unitarisation effects.

Within this formalism Kovchegov derived an equation for the dipole amplitude which satisfies unitarity.

This equation also follows as a MF version of the hierarchy of equations first proposed by Balitsky.

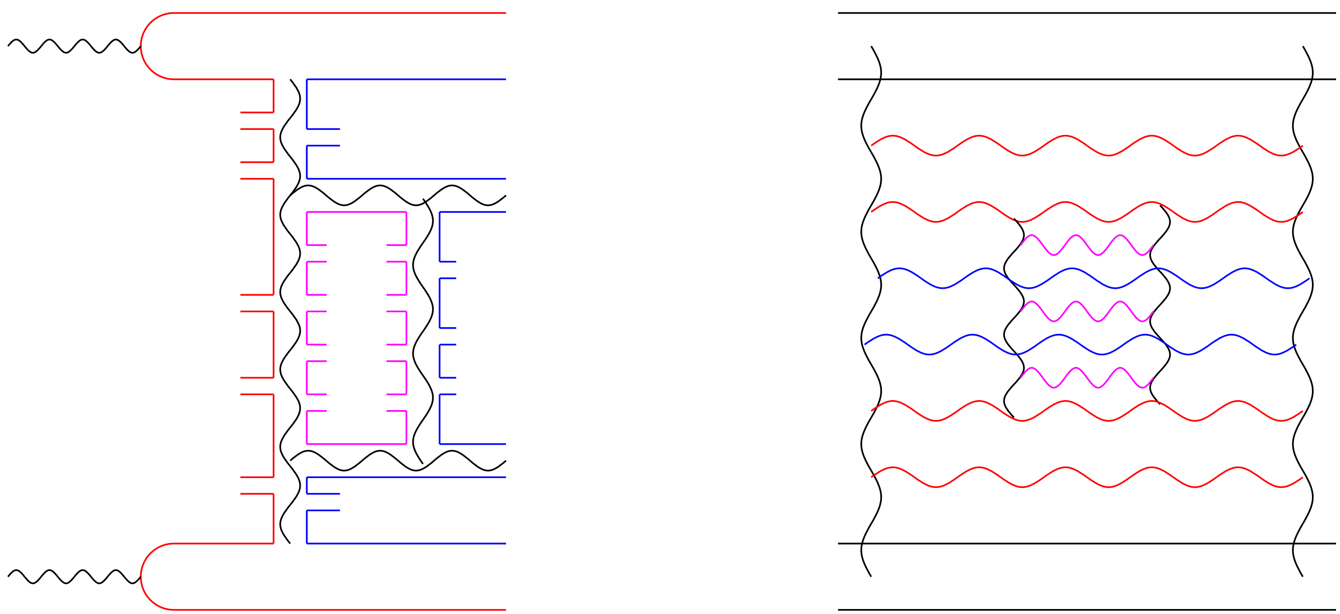
A different approach is the CGC in which the small-x quantum gluon fields are radiated by a classical random colour source.

Strings and Dipoles in HE Collisions



From Dipoles to Pomerons

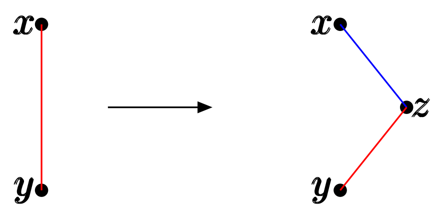
Multiple interactions will generate colour loops. The colour loops in the inelastic amplitude, when squared, give rise to pomeron loops in the elastic amplitude.



The Dipole Model

In the dipole model the splitting kernel is given by

$$\mathcal{M}(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}) = \frac{\bar{\alpha_s}}{2\pi}\frac{(\boldsymbol{x}-\boldsymbol{y})^2}{(\boldsymbol{x}-\boldsymbol{z})^2(\boldsymbol{z}-\boldsymbol{y})^2}$$



This expression diverges when integrated over $d^2\boldsymbol{z}$. A cutoff, $\rho^2 \geq (\boldsymbol{x}-\boldsymbol{z})^2, (\boldsymbol{y}-\boldsymbol{z})^2$, is needed to regulate the divergence.

Even though the divergence cancels against virtual emissions, the cut off, ρ, has to be kept in a MC.

Conserving Energy-Momentum

A small dipole corresponds to two well localized gluons.

$\Longrightarrow$ large $p_T \sim 1/r$ for these gluons. The emission of such gluons violates EM conservation.

These emissions are compensated by virtual emissions.

$\Longrightarrow$ σ_{tot} is determined by real emissions. Keeping only these we get a closer correspondence between the cascade and exclusive final states.

Effects of EM conservation: hep-ph/0503181

Going beyond large N_c

Dipole degrees of freedom are natural only in $N_c \to \infty$ limit. Beyond large N_c the dipole basis is overcomplete.

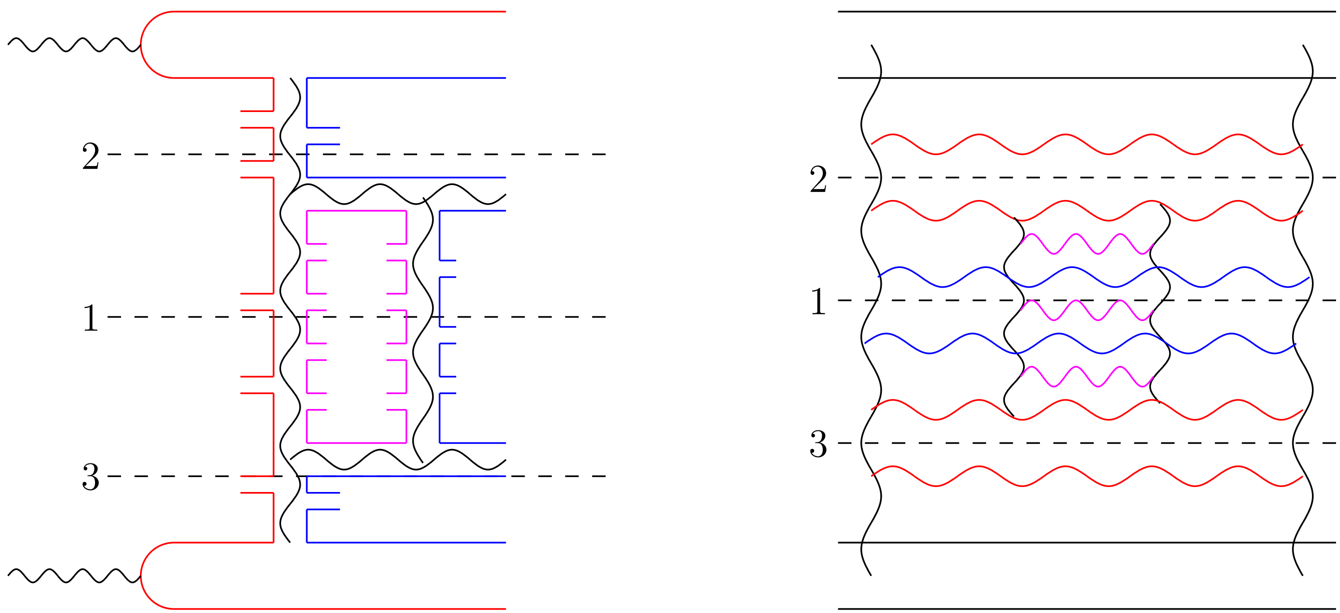
For example, a $r\bar{r}r\bar{r}$ system can be combined in two different ways using the dipole basis.

Such a system can be represented by four Wilson lines, $S(\boldsymbol{x}_1\boldsymbol{y}_1\boldsymbol{x}_2\boldsymbol{y}_2) = \frac{1}{N_c}\mathrm{tr}(V^\dagger_{\boldsymbol{x}_1}V_{\boldsymbol{y}_1}V^\dagger_{\boldsymbol{x}_2}V_{\boldsymbol{y}_2})$.

However, it is possible to approximate such a quadrupole with two dipoles.

Frame Independence

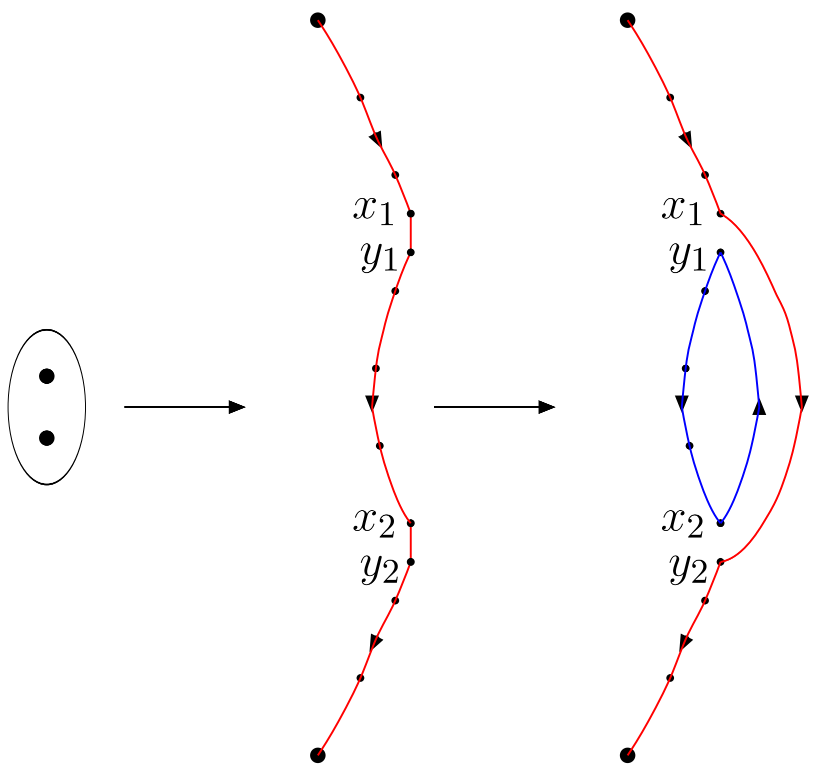
Dipole model is not frame independent since loops can only be formed due to multiple scatterings.



To obtain frame independent formalism it is necessary that loops can be formed at any time during the evolution.

Colour recombination or Dipole swing

To take into account such effects we include a $2 \to 2$ transition (suppressed by $1/N_c^2$). This can be seen as a colour recombination, or a dipole swing: $(x_1, y_1), (x_2, y_2) \to (x_1, y_2), (x_2, y_1)$.



Let's Swing

The dipole swing has been included in the dipole model by Levin and Lublinsky as a part of a $2 \to 3$ vertex.
They proceed in two steps: First make a dipole swing and then let one of the dipoles decay through the usual $1 \to 2$ vertex.

We conjecture the $2 \to 2$ transition to be a good approximation to effects which go beyond the leading N_c approach.

The transition favours dipoles formed by nearby colour charges. Result is essentially frame independent.

The γ^*p Cross Section

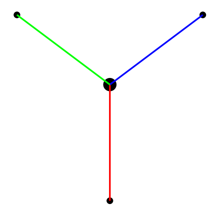
To simulate DIS events we picture the γ^* fluctuate into a $q\bar{q}$ pair which initiates the dipole cascade. Similarly we will think of the proton as a collection of colour dipoles.

The $\gamma^* \to q\bar{q}$ vertex is given by the wavefunctions $\psi_T(z, \boldsymbol{r})$ and $\psi_L(z, \boldsymbol{r})$.

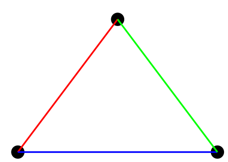
$$\begin{aligned}
\sigma^{tot}_{\gamma^* p} = \sigma_T + \sigma_L &= \int d^2\boldsymbol{r} \int_0^1 dz(|\,\psi_T\,|^2 + |\,\psi_L\,|^2)\sigma(z, \boldsymbol{r}) \\
\sigma(z, \boldsymbol{r}) &= 2\int d^2\boldsymbol{b}\langle 1 - \exp(-\sum_{ij} \mathcal{T}_{ij})\rangle \\
\mathcal{T}_{ij} &= \frac{\alpha_s^2}{8} \log^2\{\frac{(\boldsymbol{x}_i - \boldsymbol{y}_j)^2(\boldsymbol{y}_i - \boldsymbol{x}_j)^2}{(\boldsymbol{x}_i - \boldsymbol{x}_j)^2(\boldsymbol{y}_i - \boldsymbol{y}_j)^2}\}
\end{aligned}$$

The Proton

In the string model a proton is represented by a Y shaped topology where the 3 valence quarks are connected through a “junction” at the center.



As an approximation we use a Δ shaped topology in which 3 partons are connected through 3 colour dipoles.



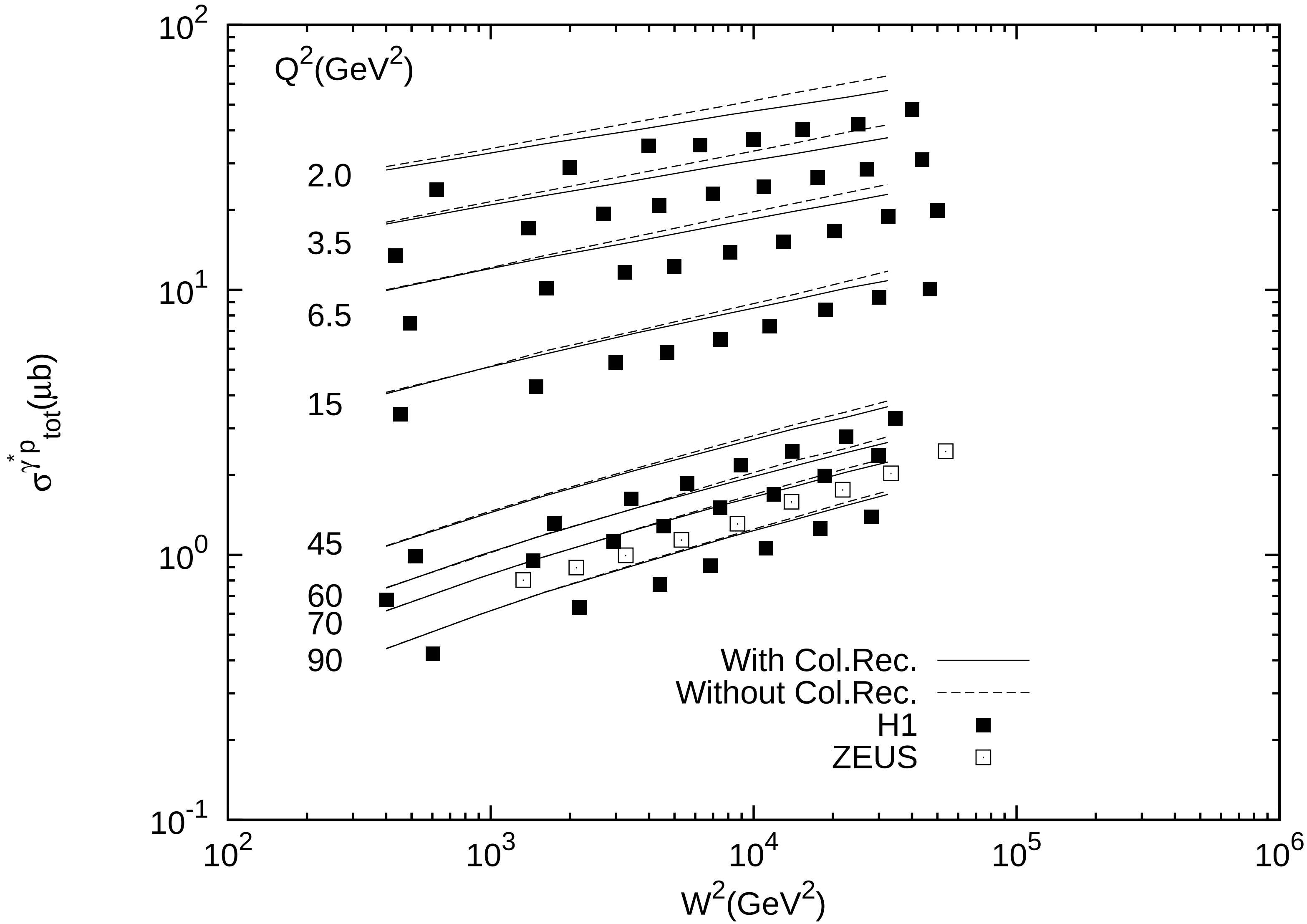
Getting to the Results

We will consider the case of 3 massless quark flavors.

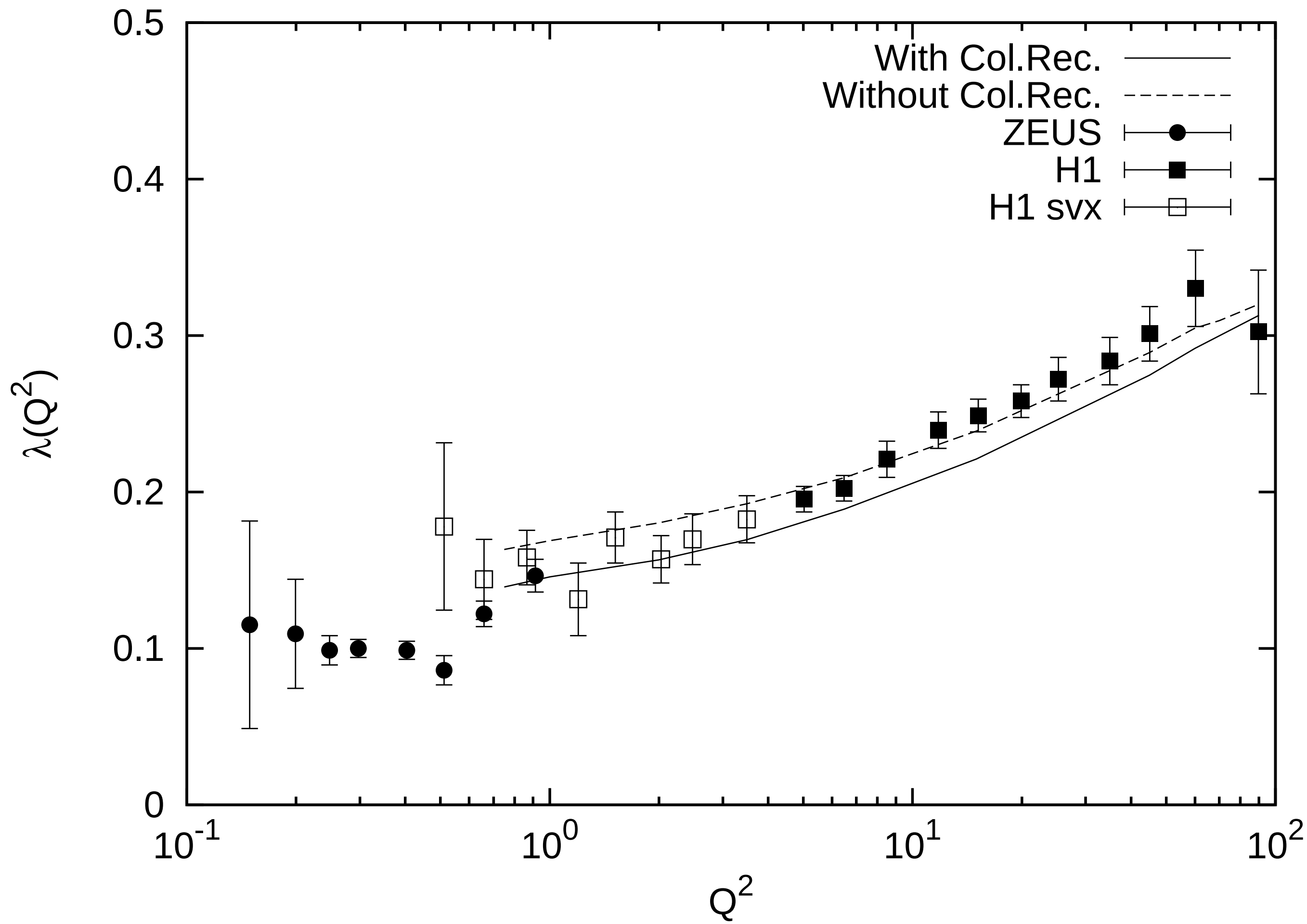
Calculations are performed using a running α_s. This makes the cascade sensitive to infrared physics so the formation of large dipoles has to be suppressed.

Besides the results for σ_{tot} in $\gamma^* p$ and pp collisions we also show the result for the logarithmic slope $d \log F_2 / d \log(1/x)$ in DIS.

Finally: Result for DIS

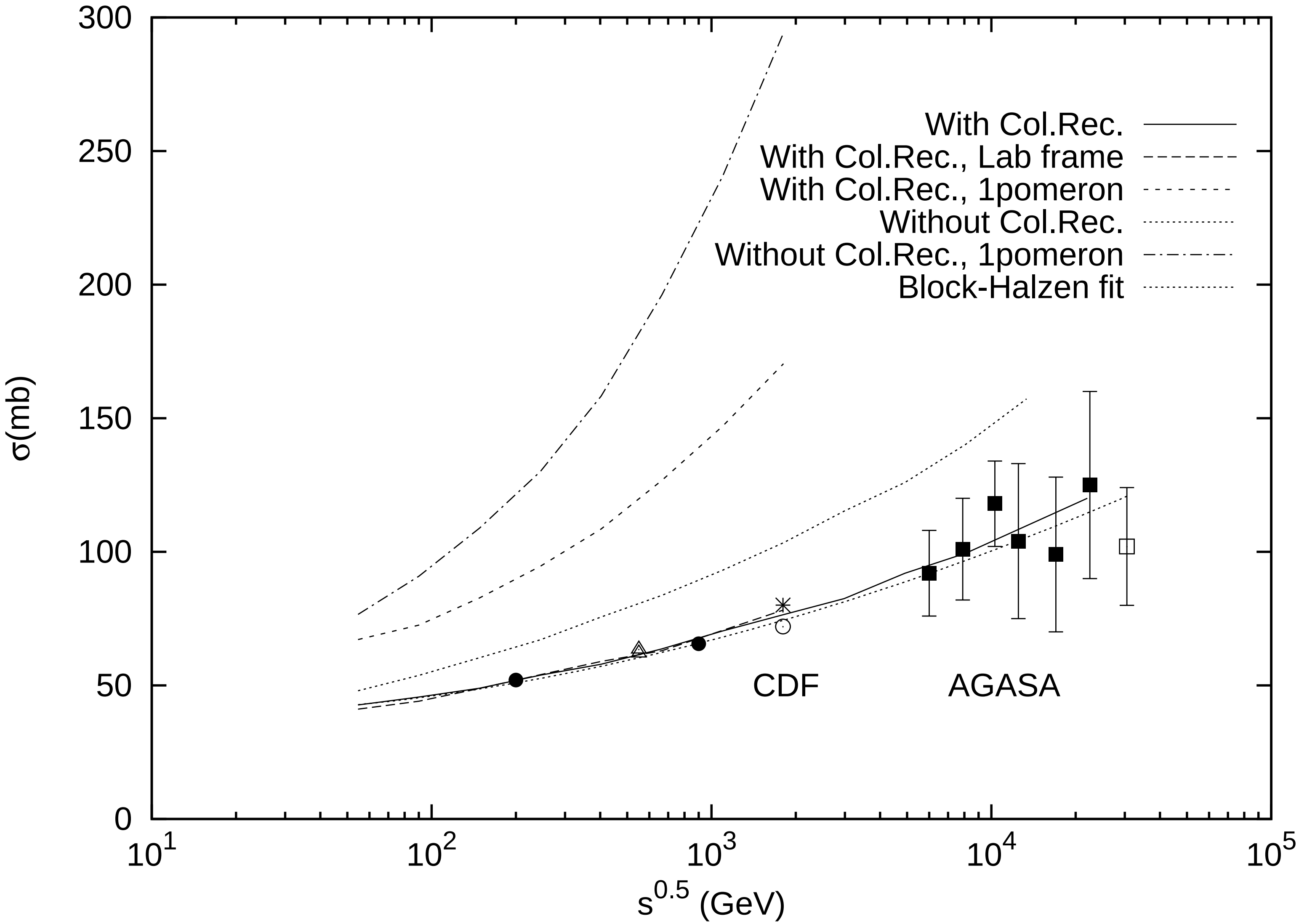


F_2 at HERA



With Col.Rec.
Without Col.Rec.
ZEUS
H1
H1 svx
0.5
0.4
0.3
0.2
0.1
0
$\lambda(Q^2)$
10^{-1}
10^{0}
10^{1}
10^{2}
Q^2

Results for pp



Summary

Using a simple method to enforce EC conservation in Mueller's Dipole Model we are able to obtain a good agreement with data both for DIS at HERA and pp collisions up to Tevatron energies.

We have included some effects beyond the leading N_c approximation. These lead to the formation of colour loops during the evolution.

These subleading-N_c effects are less important for DIS but very important for pp collisions.

Outlook

Obtain an explicitely frame independent formalism for subleading N_c effects in dipole language.

Eliminate virtual dipoles in the formalism and obtain results for exclusive final states.