The Relation Good–Walker - Triple-Regge in Diffractive Excitation

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Work in collaboration with Christoffer Flensburg
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Content

1. Diffractive excitation often treated by two mechanisms:

   a) Low mass: Good–Walker
   b) High mass: Triple Regge

   How are these related?

2. High mass diffractive excitation in Good–Walker picture

3. Bare pomeron in Good–Walker picture

Eikonal approximation

Diffraction and saturation more easily described in impact parameter space

Scattering driven by absorption into inelastic states i, with weights $2f_i$

$\Rightarrow$ Elastic amplitude $T = 1 - e^{-F}$, with $F = \sum f_i$

For a structureless projectile we find:

$$\begin{cases} d\sigma_{tot}/d^2b \sim \langle 2T \rangle \\ \sigma_{el}/d^2b \sim \langle T \rangle^2 \\ \sigma_{inel}/d^2b \sim \langle 1 - e^{-\sum 2f_i} \rangle = \sigma_{tot} - \sigma_{el} \end{cases}$$

Good – Walker

If the projectile has an internal structure, the mass eigenstates can differ from the eigenstates of diffraction

Diffractive eigenstates: Φ_n; Eigenvalue: T_n

Mass eigenstates: $\Psi_k = \sum_n c_{kn} \Phi_n$ $(\Psi_{in} = \Psi_1)$

Elastic amplitude: $\langle \Psi_1 | T | \Psi_1 \rangle = \sum c_{1n}^2 T_n = \langle T \rangle$

$d\sigma_{el}/d^2b \sim (\sum c_{1n}^2 T_n)^2 = \langle T \rangle^2$

Amplitude for diffractive transition to mass eigenstate Ψ_k:

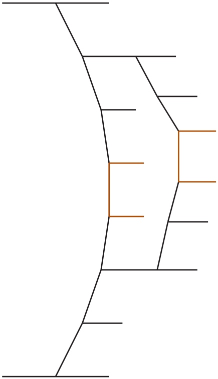
$\langle \Psi_k | T | \Psi_1 \rangle = \sum_n c_{kn} T_n c_{1n}$

$d\sigma_{diff}/d^2b = \sum_k \langle \Psi_1 | T | \Psi_k \rangle \langle \Psi_k | T | \Psi_1 \rangle = \langle T^2 \rangle$

Diffractive excitation determined by the fluctuations:

$d\sigma_{diff\ ex}/d^2b = d\sigma_{diff} - d\sigma_{el} = \langle T^2 \rangle - \langle T \rangle^2$

High energy collisions driven by parton-parton subcollisions (à la PYTHIA)

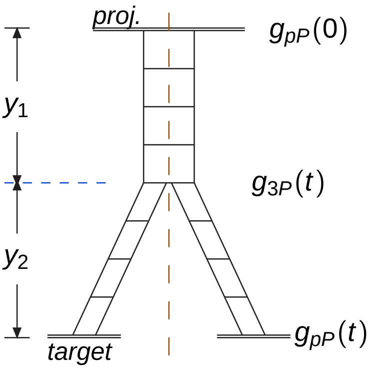


BFKL evolution

Multiple subcollisions
$\Rightarrow$ saturation

Diffractive cross sections

Triple-Regge

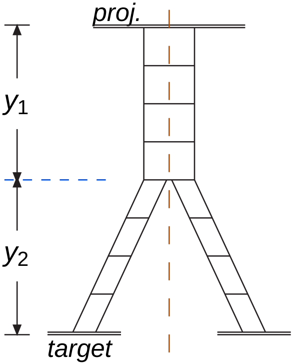


Traditionally fluctuations not taken into account

Reggeon parameters and couplings fitted to data

Diffractive cross sections

Good-Walker



BFKL: Large fluctuations (Mueller–Salam)

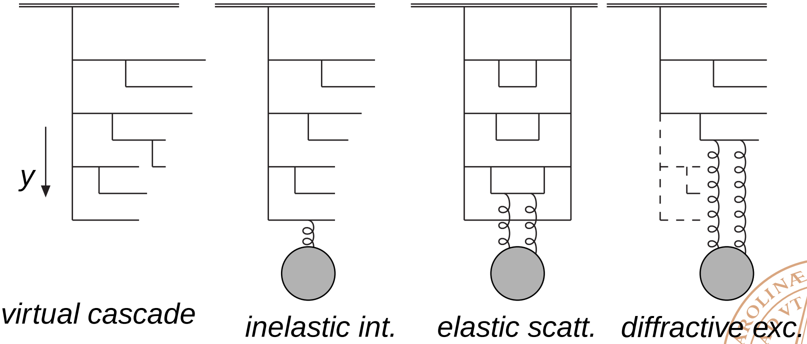
Can this reproduce the triple-regge result?

$\langle\langle T\rangle^2_{targ}\rangle_{proj}$ gives diffractive scattering with $M_X^2 < exp(y_1)$

Vary y_1 gives $d\sigma/dM_X^2$

Diffractive eigenstates

Parton cascades, which can come on shell through interaction with the target

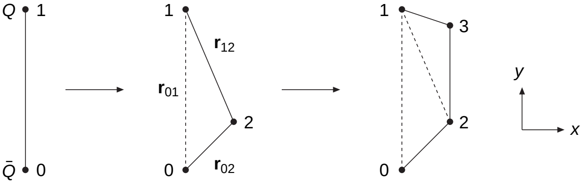


Cf. Miettinen–Pumplin (1978), Hatta *et al.* (2006)[1]

[1] Hatta-Iancu-Marquet-Soyez-Triantafyllopoulos

Dipole cascade models

Mueller Dipole Model: Formulation of LL BFKL in transverse coordinate space



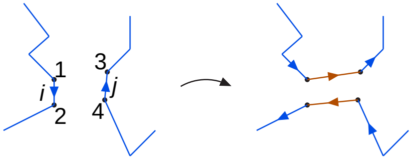
Emission probability: $\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$

Color screening: Suppression of large dipoles

$\sim$ suppression of small $k_\perp$ in BFKL

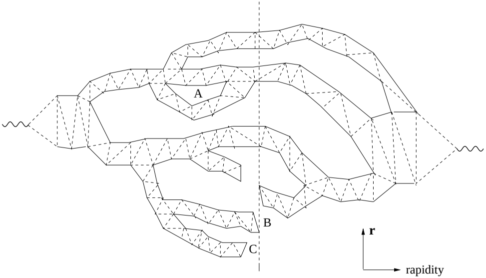
Dipole-dipole scattering

Single gluon exhange ⇒ Color reconnection



Born amplitude:

$$f_{ij} = \frac{\alpha_s^2}{2} \ln^2 \left(\frac{r_{13} r_{24}}{r_{14} r_{23}} \right)$$



Lund Dipole Cascade model[2]

The Lund model is a generalization of Mueller's dipole model, with the following improvements:

- Include NLL BFKL effects
- Include Nonlinear effects in evolution
- Include Confinement effects

MC: DIPSY

Initial state wavefunctions:

γ^*: Given by perturbative QCD. $\Psi_{T,L}(r, z; Q^2)$

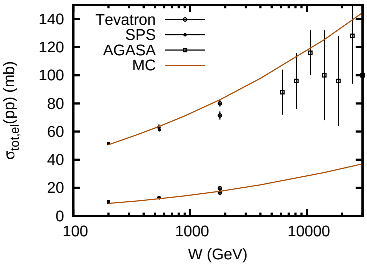
proton: Dipole triangle

[2] Avsar-Flensburg-GG-Lönnblad

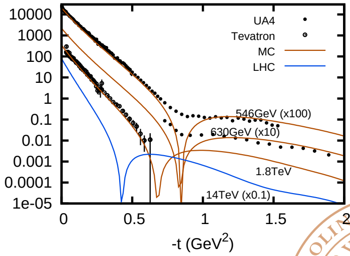
Total and elastic cross sections

pp

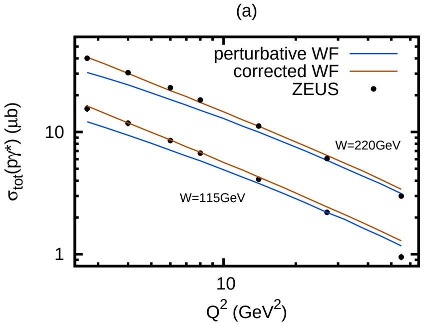
σ_{tot} and σ_{el}

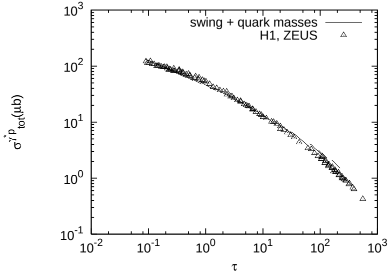


$d\sigma/dt$



$\gamma^* p$





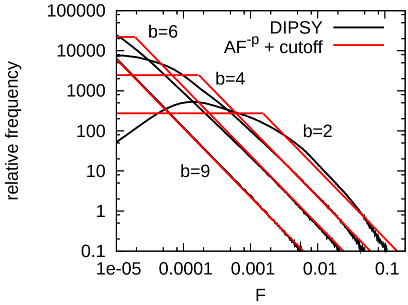
Satisfies geometric scaling

How large are the fluctuations?

$\gamma^* p$: $\frac{dP}{dF} \approx A\,F^{-p}$ (with cutoff for small F-values)

$\Rightarrow d\sigma_{diff.ex.}/d\sigma_{tot} \approx (1 - 1/2^{2-p})$

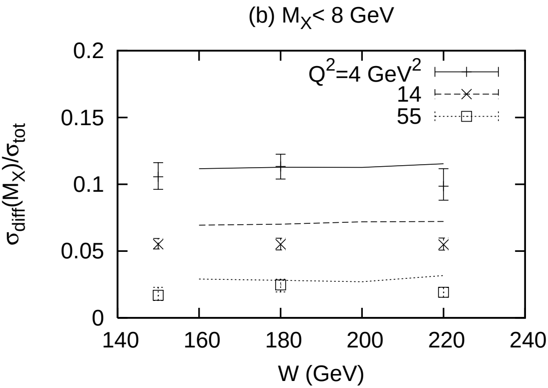
$W = 220\ Q^2 = 14$



The power p is independent of b (but grows slowly with Q^2)

$\gamma^* p$

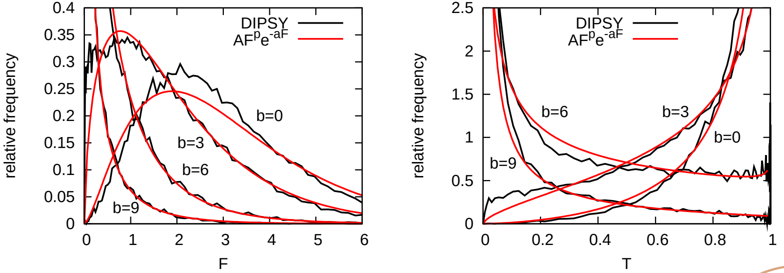
Example $M_X < 8$ GeV, $\quad Q^2 = 4, 14, 55\,\mathrm{GeV}^2$.



pp: Born approximation: large fluctuations

$$\frac{dP}{dF} \approx A\,F^p\,e^{-aF}$$

Born ampl. $W = 2\,TeV$ Uniterized ampl.

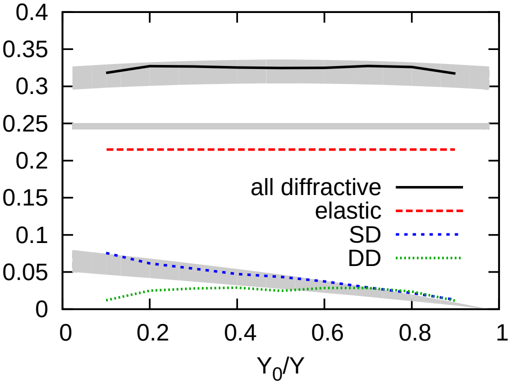


a is independent of b. $d\sigma_{d.ex.}/d\sigma_{tot}|_{Born} = 1/2a \sim 1/3$

$\langle F \rangle$ is large $\Rightarrow$ Unitarity effects important

$\sim$ enhanced diagrams in triple-regge formalism

pp 1.8 TeV

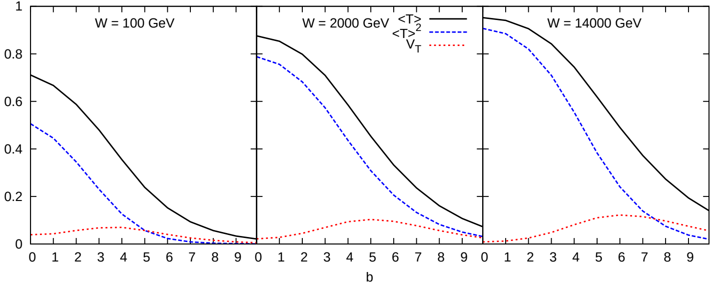


Saturation⇒ Factorization breaking in diffractive excitation

Impact parameter profile

Central collisions: $\langle T \rangle$ large $\Rightarrow$ Fluctuations small

Peripheral collisions: $\langle T \rangle$ small $\Rightarrow$ Fluctuations small

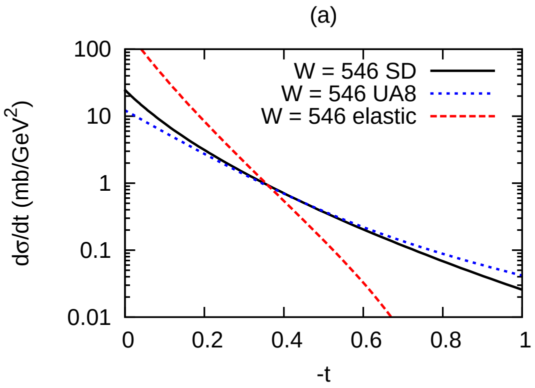


Largest fluctuations when $\langle F \rangle \sim 1$ and $\langle T \rangle \sim 0.5$

Circular ring expanding to larger radius at higher energy

t-dependence

Single diffractive and elastic cross sections

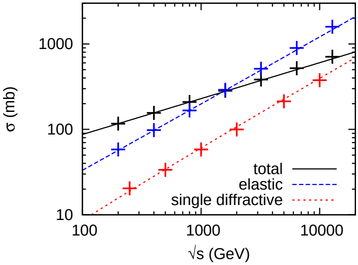


Agrees with fit to UA8 data

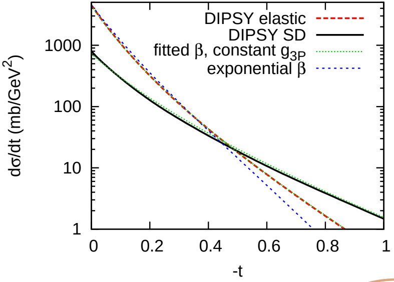
Triple-Regge parameters

BARE pomeron without saturation effects

$\sigma_{\rm tot}, \sigma_{\rm el}, \sigma_{\rm SD}$



$d\sigma_{\rm el}/dt, d\sigma_{\rm SD}dt$



Triple-Regge fit with a single pomeron pole

$$\alpha(0) = 1.21, \quad \alpha' = 0.2\,\mathrm{GeV}^{-2}$$

$$g_{pP}(t) = (5.6\,\mathrm{GeV}^{-1})\,e^{1.9t}, \quad g_{3P}(t) = 0.31\,\mathrm{GeV}^{-1}$$

Compare with triple-regge fits:

$\alpha(0) = 1.21, \quad \alpha' = 0.2\,\text{GeV}^{-2}$

$g_{pP}(t) = (5.6\,\text{GeV}^{-1})\,e^{1.9t}, \quad g_{3P}(t) = 0.31\,\text{GeV}^{-1}$

Ryskin *et al.*: $\alpha(0) = 1.3, \quad \alpha' \leq 0.05\,\text{GeV}^{-2}$

Kaidalov *et al.*: $\alpha(0) = 1.12, \quad \alpha' = 0.22\,\text{GeV}^{-2}$

Goulianos: $\alpha(0) = 1.21, \quad \alpha' = 0.2\,\text{GeV}^{-2}$

Note:

Fit $\sim$ single pomeron pole (not a cut)

g_{3P}: magnitude $\sim$ pert. QCD estimate by Bartels-Ryskin-Vacca ($\pi g_{3P} \sim 0.2 - 1.7\,\text{GeV}^{-1}$)

Summary

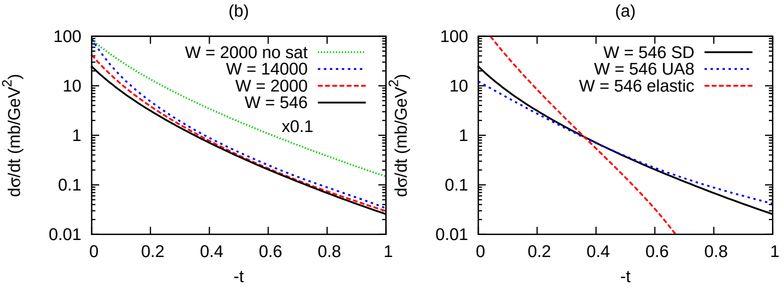
- In the eikonal approximation diffractive excitation is directly determined by the fluctuations in the scattering process
- The fluctuations in BFKL evolution are large
- Implemented in the Lund Dipole Cascade Model they reproduce the triple-pomeron formula for diffractive excitation to small and large masses in $\gamma^* p$ and pp collisions, with no extra parameters
- In pp the fluctuations are large for the Born amplitudes, but strongly suppressed by unitarity above $\sim$ 20 GeV
  $\Rightarrow$ Factorization breaking
- The model result gives a bare pomeron, which is a simple pole with $\alpha(0) = 1.21$ and $\alpha' = 0.2\,\mathrm{GeV}^{-1}$
  and with $g_{3P}(t)$ approximately constant $= 0.31\,\mathrm{GeV}^{-1}$
  (With saturation the cross section grows $\sim s^{0.1}$ up to $\sim$50 TeV)

Extra slides

Triple-pomeron formulae:

$$
\begin{aligned}
\sigma_{\mathrm{tot}} &= \beta^2(0)s^{\alpha(0)-1}, \\
\frac{d\sigma_{\mathrm{el}}}{dt} &= \frac{1}{16\pi}\beta^4(t)s^{2(\alpha(t)-1)}, \\
M_{\mathrm{X}}^2\frac{d\sigma_{\mathrm{SD}}}{dtd(M_{\mathrm{X}}^2)} &= \frac{1}{16\pi}\beta^2(t)\beta(0)g_{3\mathrm{P}}(t)\left(\frac{s}{M_{\mathrm{X}}^2}\right)^{2(\alpha(t)-1)}\left(M_{\mathrm{X}}^2\right)^{\alpha(0)-1}. \\
\beta(t) &\equiv g_{pP}(t)
\end{aligned}
$$

Energy dependence and effect of saturation on $d\sigma/dt$

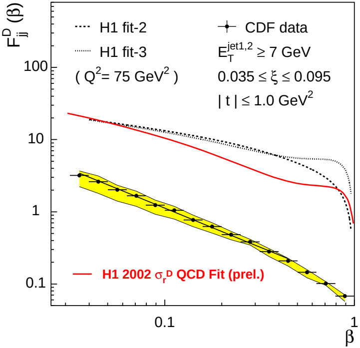


Energy dependence, and result without saturation at 2 TeV

546 GeV compared with a fit to UA8 data, and with elastic scattering

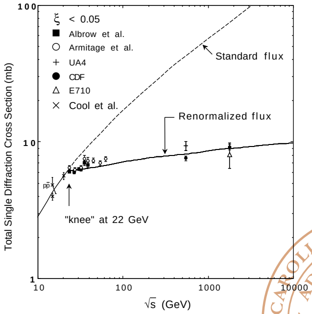
Factorization breaking

Difference between
pp and $\gamma^* p$



Cf. Goulianos' saturation of pomeron flux

pp scattering



pp scattering

$\langle T \rangle$ and V_T for the simple parametrization $\frac{dP}{dF} \approx AF^p e^{-aF}$

$$\langle T \rangle = 1 - (\tfrac{a}{a+1})^{p+1} = 1 - (\tfrac{a}{a+1})^{a\langle F \rangle} \rightarrow 1 \text{ when } \langle F \rangle \rightarrow \infty$$

$$V_T = (\tfrac{a}{a+2})^{p+1} - (\tfrac{a}{a+1})^{2p+2} \rightarrow 0 \text{ when } \langle F \rangle \rightarrow \infty$$

Diffractive final states

Coherence effects important for subtracting el. scatt.

$$d\sigma_n = c_n^2 \left(\sum_m d_m^2 \, t_{nm} - \langle t \rangle \right)^2$$

$$\langle t \rangle = \sum_n \sum_m c_n^2 \, d_m^2 \, t_{nm}$$

Toy model

(Abelian emissions; no saturation)

$\Psi_{in} = \prod_i(\alpha_i + \beta_i)|0\rangle$

parton i produced with prob. $|\beta_i|^2$, interacts with weight f_i

Diff. exc. states:

$\Psi_j = (-\beta_j + \alpha_j)\prod_{i\neq j}(\alpha_i + \beta_i)|0\rangle$

$d\sigma_{el} \sim (\sum_i \beta_i^2 f_i)^2$

$d\sigma_j \sim \alpha_j^2 \beta_j^2 f_j^2$