Fluctuations and Saturation in Diffractive Excitation

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Work done with Christoffer Flensburg and Leif Lönnblad

Questions

- What is the dynamics of diffractive excitation?
- Diffractive excitation often treated by two mechanisms:

  a) Low mass: Good–Walker, determined by the fluctuations in the process

  b) High mass: Triple Regge, determined by fitted parameters

  Are these related?

  What is the nature of the fluctuations?
- Saturation effects large in *pp* collisions.

  How can we describe gap survival form factors and factorization breaking?

Outline of the talk

1. Introduction
2. Effects of fluctuations
3. Effects of saturation – “Enhanced diagrams”
4. Relation Good-Walker – Triple Regge

Introduction

Eikonal approximation

Diffraction, saturation, and multiple interactions more easily described in impact parameter space

Convolution in transv. mom. $\sim$ Multiplication in **b**-space

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

$\Rightarrow$ Elastic amplitude $t = 1 - e^{-\sum f_i}$

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:

$\langle\Psi_k|t|\Psi_1\rangle = \sum_n c_{kn} t_n c_{1n}$

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

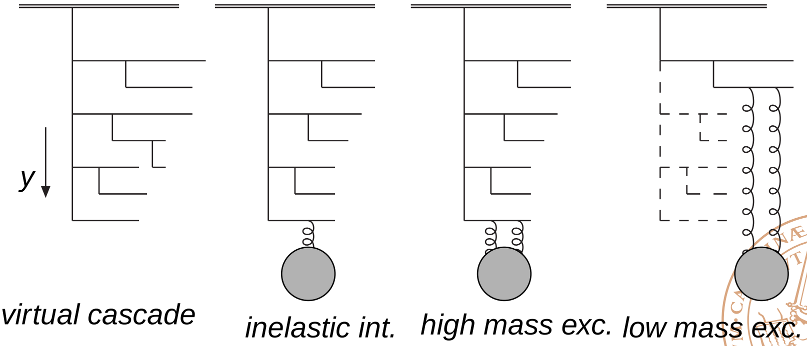
Diffractive excitation determined by the fluctuations:

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

What are the diffractive eigenstates?

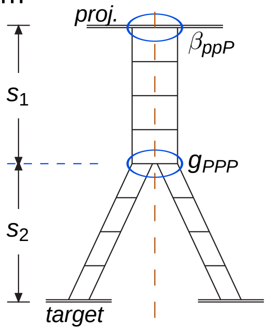
Miettinen–Pumplin (1978), Hatta *et al.* (2006)

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



Triple Regge

High mass diffraction usually described by triple Regge formalism



$$\sigma_{tot} \sim \beta_{ppP}^2\, s^{\epsilon};\;\; \epsilon = \alpha_P(0) - 1$$

$$\sigma_{diff.ex.} \sim \beta_{ppP}^3\, g_{PPP}\, s_1^{\epsilon}\, s_2^{2\epsilon}$$

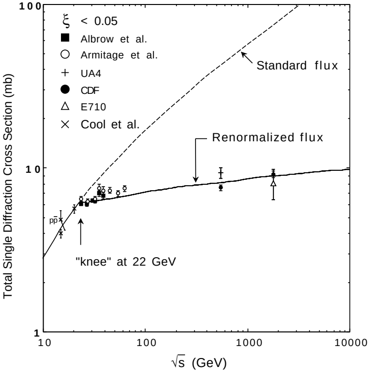
(Durham group: 3 different pomerons for different impact parameters)

Why not the Good-Walker formalism? Fluctuations in the pomeron ladder unknown

Dipole cascade: Large fluctuations in the pomeron ladder

Can Good-Walker describe also high mass excitation?

Saturation

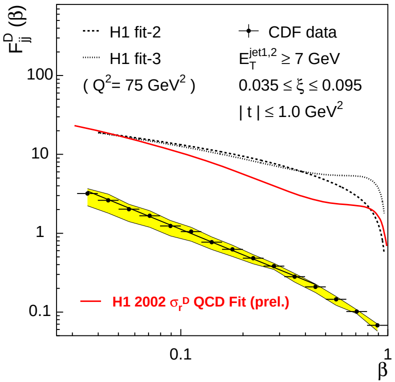


pp scattering

Goulianos:
Saturation of pomeron flux

Difference between *pp* and $\gamma^* p$

Factorization breaking in pomeron exchange

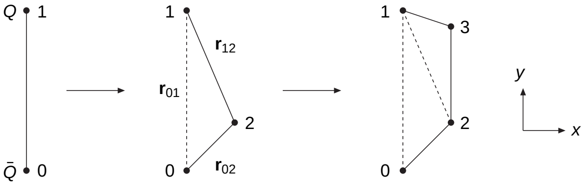


Effect of unitarization?

Dipole cascade models

Mueller Dipole Model

Evolution in transverse coordinate space



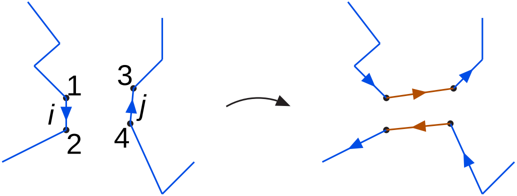
Emission probability: $\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2\, r_{12}^2}$

Color screening: Suppression of large dipoles

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

Dipole-dipole scattering

Single gluon exhange $\Rightarrow$ Color reconnection



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

Reproduces LL BFKL

Lund Dipole Cascade model[1]

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 Confimement effects

Remove virtual emissions $\longrightarrow$ Final states

MC: DIPSY

[1] E. Avsar-Flensburg-GG-Lönnblad

Applications

Initial state wavefunctions:

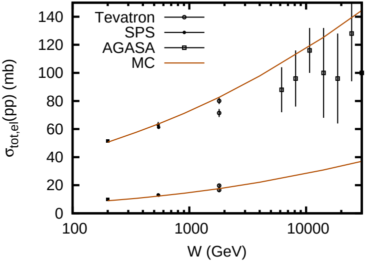
γ^*: Given by perturbative QCD. $\Psi_{T,L}(r, z; Q^2)$

proton: Dipole triangle

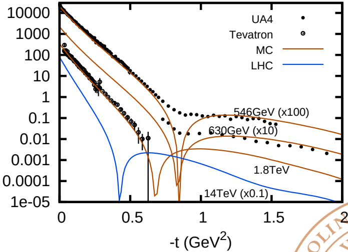
Total and elastic cross sections

pp

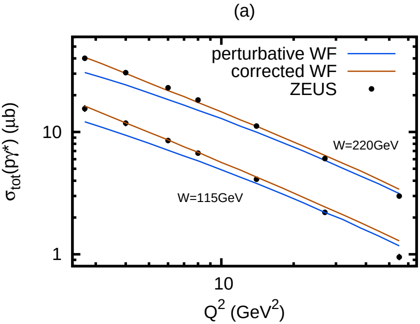
σ_{tot} and σ_{el}

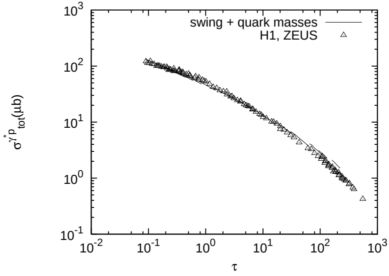


$d\sigma/dt$



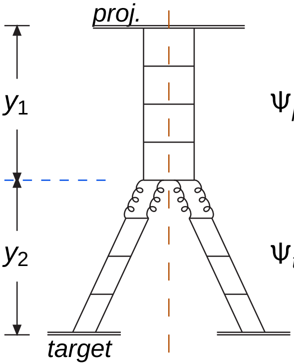
$\gamma^* p$





Satisfies geometric scaling

Diffractive cross sections



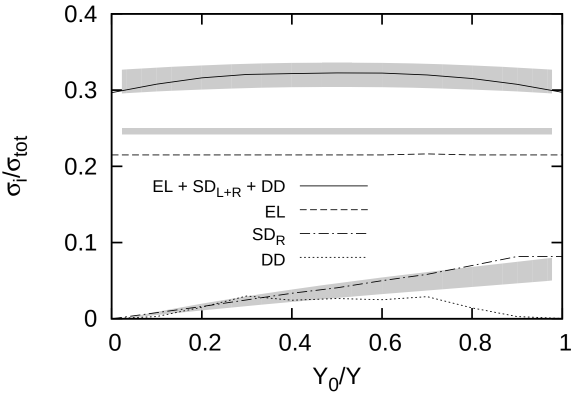
$$\Psi_{proj} = \sum_n c_n \Phi_{p,n}$$

$$\Psi_{target} = \sum_m d_m \Phi_{t,m}$$

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

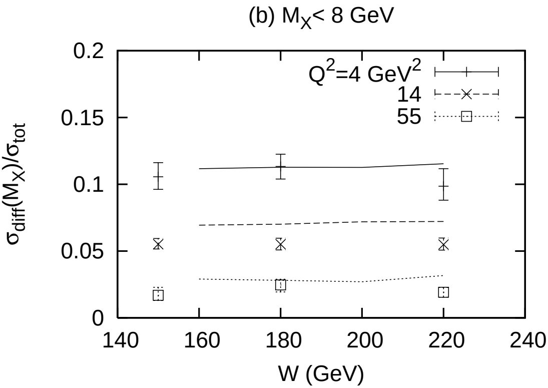
Vary y_1 gives $d\sigma/dM_X^2$

pp 1.8 TeV


0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
σ_i/σ_{tot}
Y_0/Y
EL + SD_{L+R} + DD
EL
SD_R
DD

$\gamma^* p$

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



What is the nature of the fluctuations?

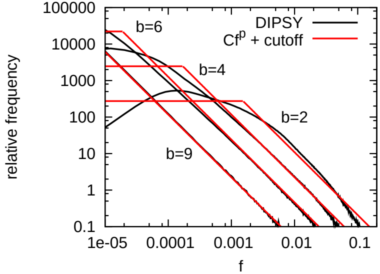
$\gamma^* p$: Power spectrum $\frac{dP}{df} \approx A\, f^{-p}$

(with cutoff for small and large f-values)

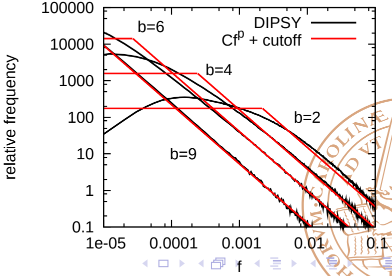
The power p is independent of b, but grows slowly with Q^2,

~ 1.7 at $Q^2 = 14 GeV^2$; ~ 1.8 at $Q^2 = 50 GeV^2$ for $W = 220$.

$W = 220\ Q^2 = 14$



$W = 1000,\ Q^2 = 14$



Born approximation small $\Rightarrow$ Unitarity effects small;
$t \approx f = \sum f_{ij}$

The distribution is wide. The parametrization gives

$\langle t \rangle = -A\,\Gamma(1-p)$, $\langle t \rangle^2$ small

$V_t \approx \langle t^2 \rangle = 2(1 - 1/2^{2-p}) \times \langle t \rangle$

The ratio depends only on p; same for all b-values

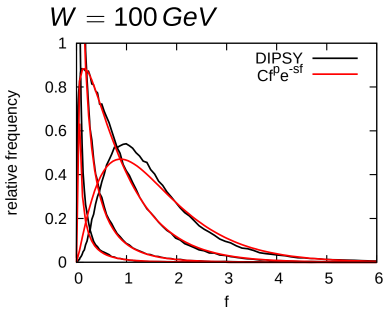
$\frac{\sigma_{diff}}{\sigma_{tot}} = 1 - 1/2^{2-p}$

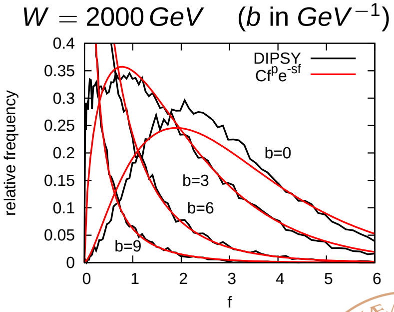
or

$\frac{\sigma_{diff}}{\sigma_{tot}} \sim 0.18$ for $Q^2 = 14\,\mathrm{GeV}^2$ falling to ~ 0.13 at $Q^2 = 50\,\mathrm{GeV}^2$.

pp:

Born approximation large. Distribution $\frac{dP}{df} \approx A\, f^p\, e^{-af}$





a is independent of b, but falling with energy,

$a \approx 1.4$ for $W = 100$ GeV and ≈ 0.8 for $W = 2000$ GeV

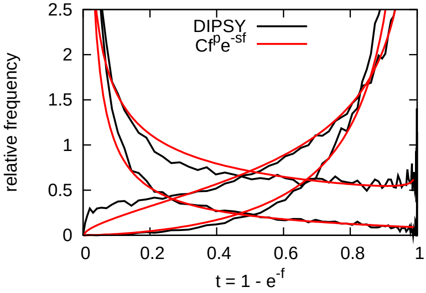
Fix energy $\Rightarrow p$ (and $\langle f \rangle$) decreases for larger b

Saturation

The variance in the Born amplitude is similar to $\gamma^* p$ for lower Q^2-values

$\langle f \rangle = \frac{p+1}{a}$; $\frac{V_f}{2\langle f \rangle} = \frac{1}{2a} \sim 0.35$ for $W = 100$ GeV

However: $\langle f \rangle$ is large $\Rightarrow$ Unitarity effects important



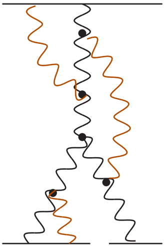
t-distribution

$W = 2000$ GeV

$b = 0, 3, 6, 9\ GeV^{-1}$

Saturation reduces the fluctuations

Corresponds to the “enhanced diagrams” in multipomeron diagrams

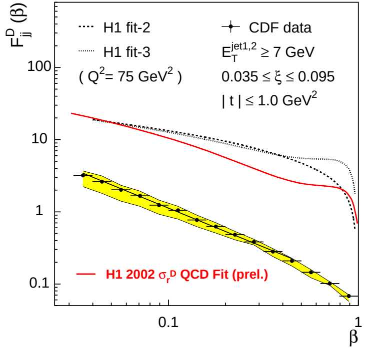


Saturation ⇒

Factorization breaking in diffractive excitation

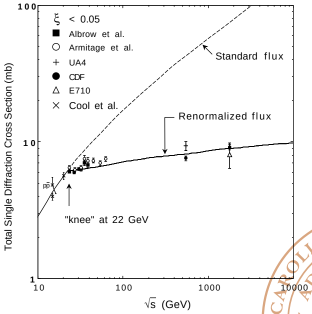
Factorization breaking

Difference between
pp and $\gamma^* p$



Cf. Goulianos' saturation of pomeron flux

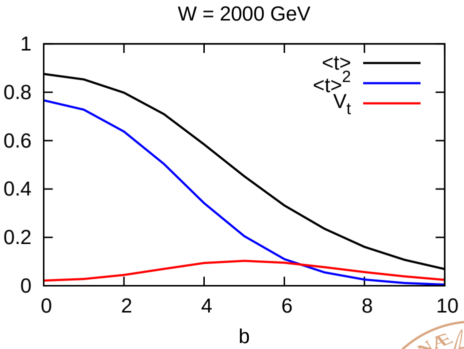
pp scattering



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

Relation to Triple-Regge

Does the result describe the Regge formulae?

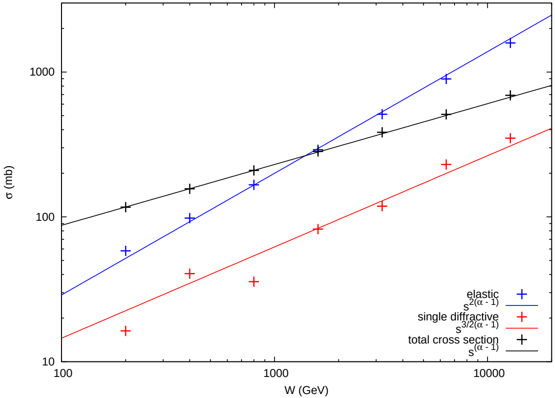
For the bare pomeron we have:

$$\sigma_{tot} \sim \beta_{ppP}^2 \, s^{\epsilon}$$

$$\sigma_{el} \sim \beta_{ppP}^4 \, s^{2\epsilon}$$

$$\sigma_{d.exc.} \sim \beta_{ppP}^3 \, g_{PPP} \, s^{1.5\epsilon}$$

(with logarithmic corrections for σ_{el} and $\sigma_{d.exc.}$)



Works well with $\alpha_P(0) \approx 1.2$

(*Cf.* Durham 1.3, Goulianos 1.11)

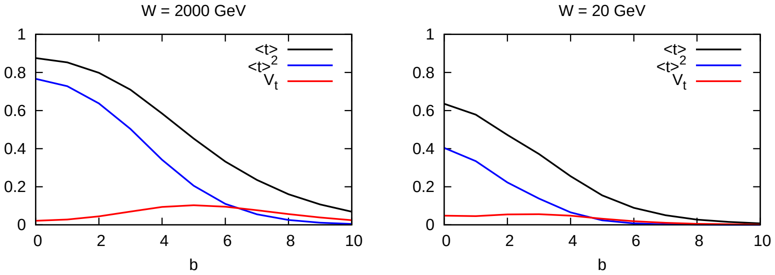
Summary

- In the eikonal approximation diffractive excitation is directly determined by the fluctuations in the scattering process.
- The fluctuations in the dipole cascade evolutions are large
- It reproduces the triple-pomeron results without new free parameters. (The bare pomeron intercept is $\alpha_P \approx 1.2$.)
- It can describe the large diffractive cross section in DIS.
- In *pp* the fluctuations are large for the Born amplitudes, but strongly suppressed by unitarity above $\sim$ 20 GeV.
- Diffr. exc. in *pp* is an expanding ring in *b*-space.

Conclusion: The Dipole Cascade Model can describe diffractive excitation in $\gamma^* p$ and *pp*, to small and large masses, in a unified formalism, without new parameters (besides those determined by the total and elastic cross sections).

Extra slides

Impact parameter profile



As observed earlier, diffractive excitation is a peripheral process

Circular ring expanding to larger radius at higher energy.

Extrapolate to smaller energy ⇒

The hole closed for $W \sim 20$ GeV. Agrees with Goulianos' estimate!

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:

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

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

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

pp scattering

$$\langle t \rangle = 1 - (\frac{a}{a+1})^{p+1} = 1 - (\frac{a}{a+1})^{a\langle f \rangle} \rightarrow 1 \text{ when } \langle f \rangle \rightarrow \infty$$

$$V_t = (\frac{a}{a+2})^{p+1} - (\frac{a}{a+1})^{2p+2} \rightarrow 0 \text{ when } \langle f \rangle \rightarrow \infty$$