Fluctuations and Saturation in Diffractive Excitation

Gösta Gustafson

Department of Theoretical Physics
Lund University

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Work in collaboration with Christoffer Flensburg

Content

1. Diffractive excitation often treated by two mechanisms:

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

   How are these related?

2. Fluctuations

3. Saturation – “Enhanced diagrams”

4. Bare pomeron in Good–Walker picture

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 $T = 1 - e^{-F}$, 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:

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

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

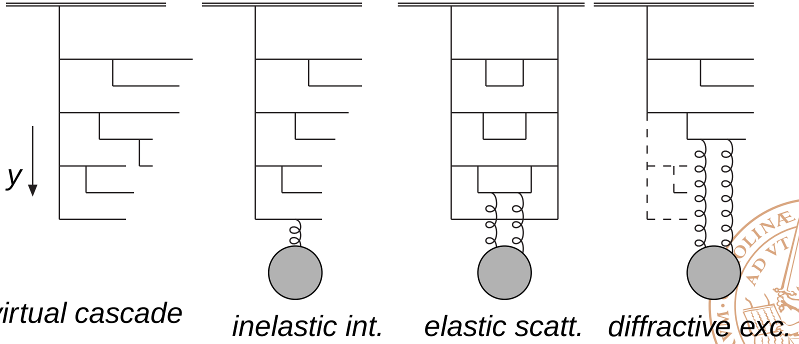
Diffractive excitation determined by the fluctuations:

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

What are the diffractive eigenstates?

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

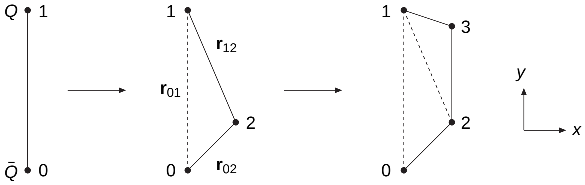
Parton cascades, which can come on shell through interaction with the target



Dipole cascade models

Mueller Dipole Model

Evolution in transverse coordinate space



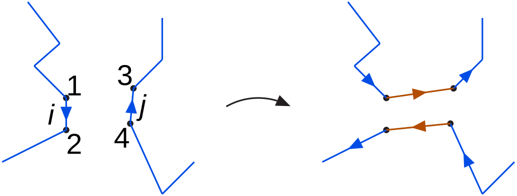
Emission probability: $\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$

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 Confinement effects

MC: DIPSY

Initial state wavefunctions:

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

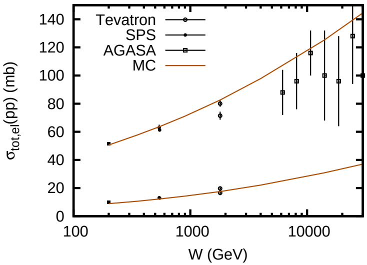
proton: Dipole triangle

[1] E. Avsar-Flensburg-GG-Lönnblad

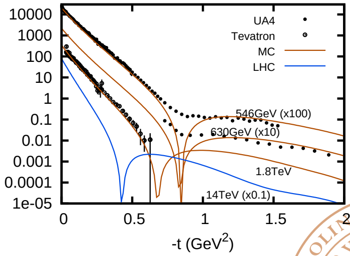
Total and elastic cross sections

pp

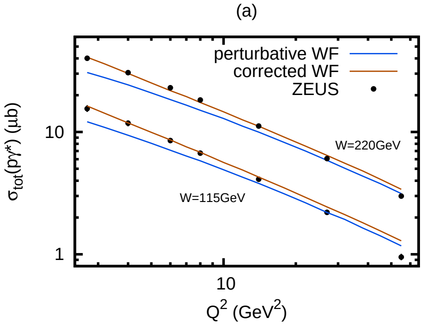
σ_{tot} and σ_{el}

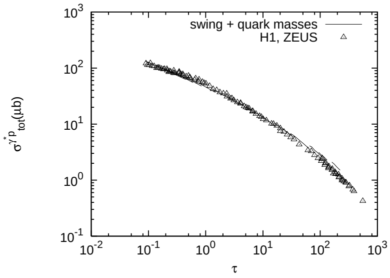


$d\sigma/dt$



$\gamma^* p$

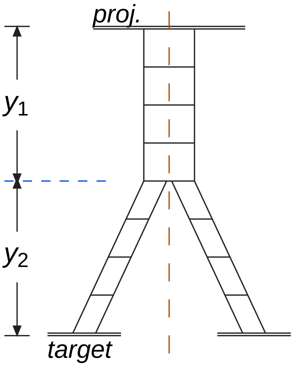




Satisfies geometric scaling

Diffractive cross sections

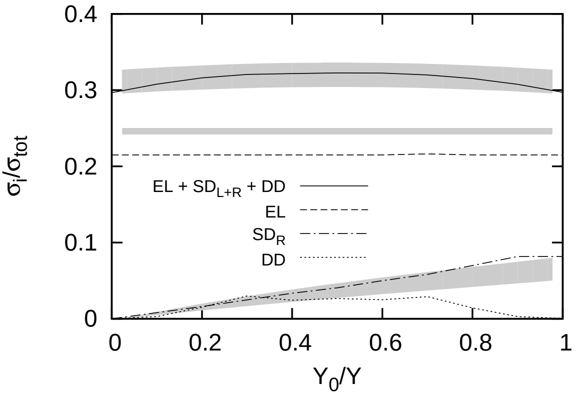
Relation Good-Walker — Triple Regge



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

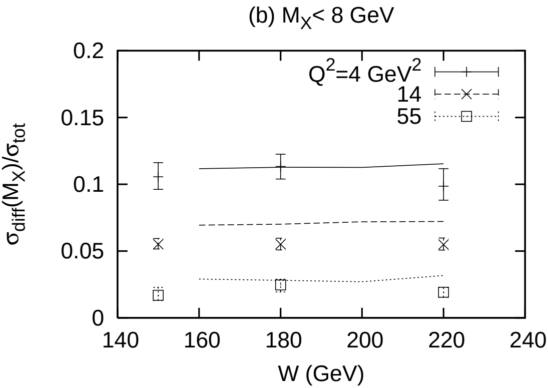
Vary y_1 gives $d\sigma/dM_X^2$

pp 1.8 TeV



$\gamma^* p$

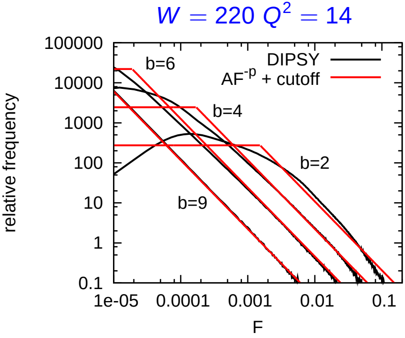
Example $M_X < 8$ GeV, $\quad Q^2 = 4, 14, 55\,\mathrm{GeV}^2$.



What is the nature of the fluctuations?

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

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

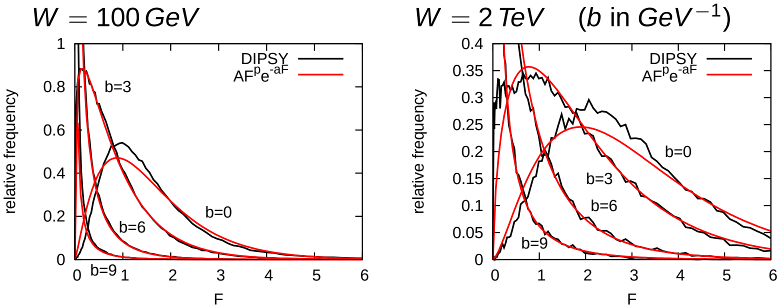


The power p is independent of b (but grows slowly with Q^2)

$\frac{\sigma_{diff}}{\sigma_{tot}} \sim 0.18$ 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),

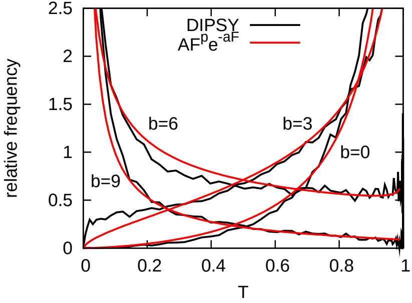
$$\frac{d\sigma_{d.ex.}}{d\sigma_{tot}} = \frac{1}{2a} \sim 0.35 \text{ for } W = 100 \text{ GeV}$$

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

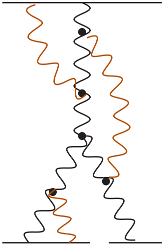
Saturation reduces the fluctuations

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

T-distribution, $W = 2$ TeV



"Enhanced diagrams"

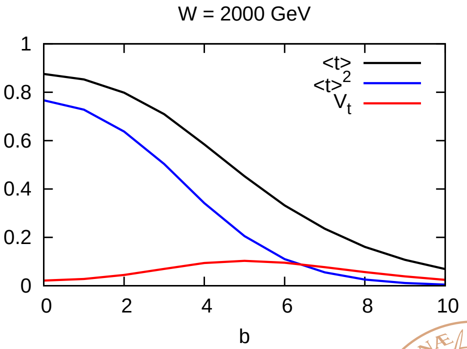


Saturation $\Rightarrow$ Factorization breaking in diffractive excitation

Impact parameter profile

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

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



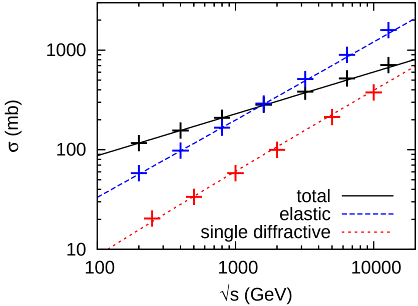
Largest fluctuations when $\langle F \rangle \sim 1$ and $\langle T \rangle \sim 0.5$

Circular ring expanding to larger radius at higher energy

Relation Good–Walker — Triple-Regge

BARE pomeron without saturation effects

Total, elastic and singel diffractive cross sections



Lines are triple-Regge fit with a single pomeron pole

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

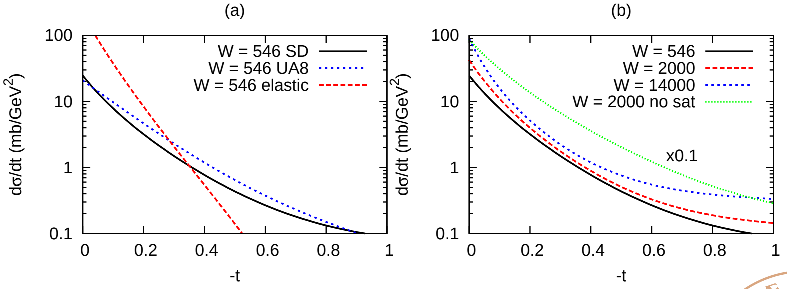
$$g_{pP}(t) = (5.6\,\text{GeV}^{-1})\,e^{1.9t}, \quad g_{3P}(t) = 0.31\,\text{GeV}^{-1}$$

Summary

- In the eikonal approximation diffractive excitation is directly determined by the fluctuations in the scattering process
- The Lund Dipole Cascade Model can describe *pp* and $\gamma^* p$ total, elastic, and diffr. exc. to small and large masses
- The fluctuations in the cascade evolutions are large
- $\Rightarrow$ Diffractive excitation is large in $\gamma^* p$ collisions
- 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
- Neglecting saturation, the dipole model reproduces the triple-Regge result for a bare pomeron, which is a simple pole with $\alpha(0) = 1.21$ and $\alpha' = 0.2$
  (With saturation the cross section grows $\sim s^{0.1}$ up to $\sim$50 TeV)

Extra slides

t-dependence for single diffraction

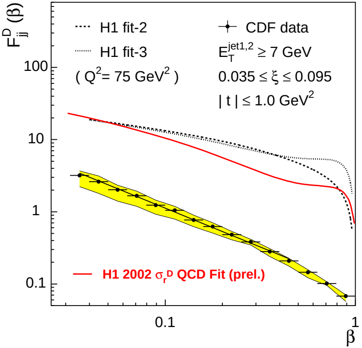


546 GeV compared with a fit to UA8 data, and with elastic scattering

Energy dependence, and result without saturation at 2 TeV

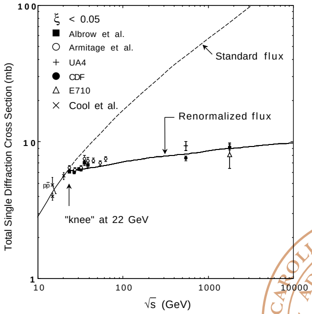
Factorization breaking

Difference between
pp and $\gamma^* p$



Cf. Goulianos' saturation of pomeron flux

pp scattering

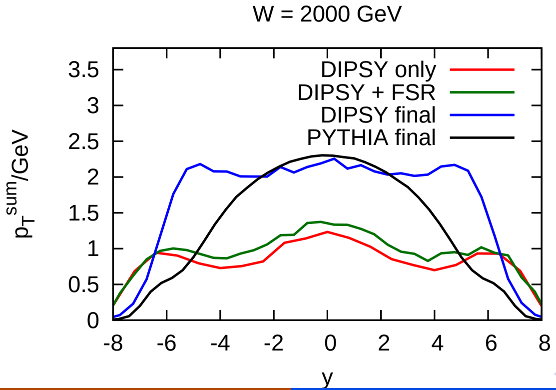


Final states

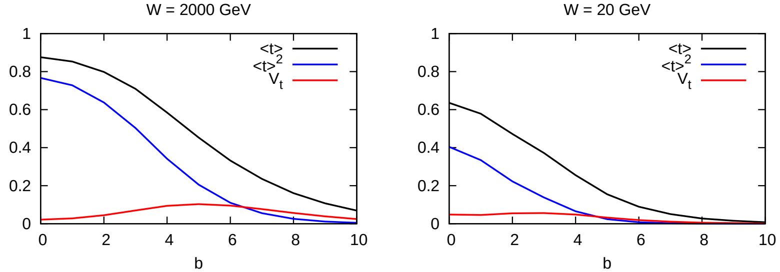
Remove branches which have not interacted. What is left corresponds to "$k_\perp$-changing emissions"

Add final state radiation and hadronization

Very preliminary result:



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 $\Rightarrow$

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

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

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