Saturation, Fluctuations, and Diffractive Excitation in High Energy Collisions

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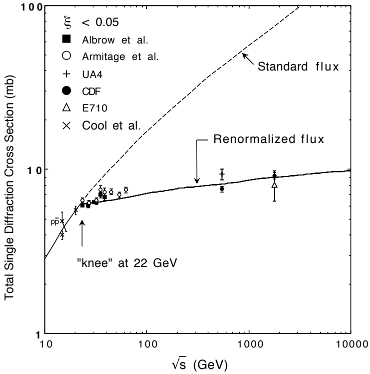
Work done with Christoffer Flensburg

Introduction

Diffractive Excitation

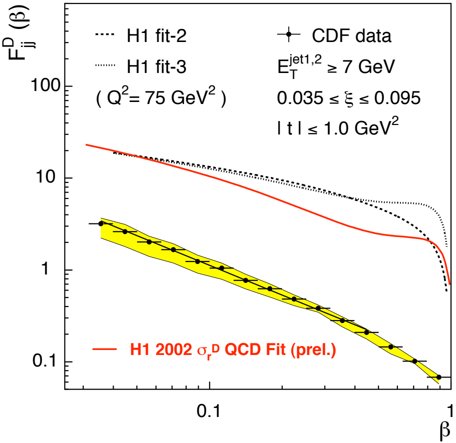
Factorization breaking in pomeron exchange



pp scattering

Goulianos:
Saturation of pomeron flux

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



Effect of unitarization?

Many features of diffraction are successfully described by dipole models

Eikonal approximation: unitarity and saturation accounted for

Diffractive excitation determined by fluctuations in the interaction

Lund dipole cascade model (DIPSY)[1] describes successfully not only total and elastic cross section, but also diffractive excitation in *pp* and $\gamma^* p$ collisions

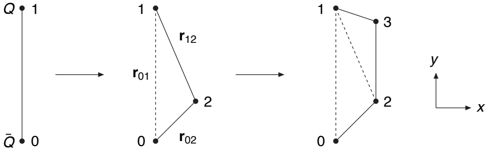
- What is the nature of saturation in the dipole cascade model?
- Is there a relation between this formalism and Dino's description?

[1] Avsar-Flensburg-GG-Lönnblad

Mueller Dipole model

Cascade evolution

- Evolution in rapidity of dipoles in transverse coordinate space.

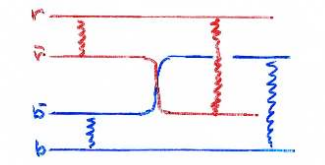


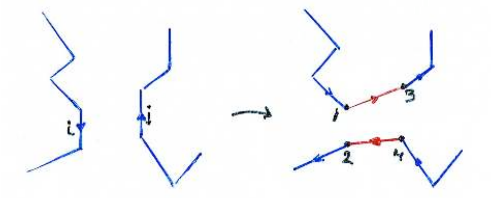
- Emission probability

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

Dipole-dipole scattering

Single gluon exhange ⇒ Color reconnection





Born amplitude

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

Eikonal approximation → Unitarity

$t \equiv 1 - e^{-\sum f_{ij}}$

Total, diffractive and elastic cross sections:

$\sigma_{tot} \sim d^2b \, \langle 2t \rangle$

$\sigma_{diff} \sim d^2b \, \langle t^2 \rangle$ (incl. elastic)

$\sigma_{el} \sim d^2b \, (\langle t \rangle)^2$

Diffractive excitation

$\sigma_{diff\ exc} \sim d^2b \, (\langle t^2 \rangle - \langle t \rangle^2)$

is determined by the fluctuations

Lund Dipole Cascade model

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 → Final states

See talk by Christoffer Flensburg

Applications

Initial state wavefunctions:

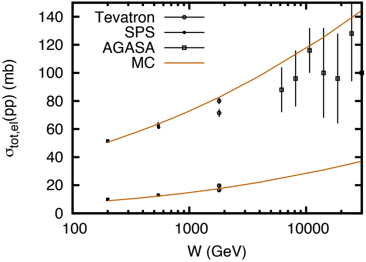
γ^*: Given by perturbative QCD. $\Psi_{T,L}(r, z; Q^2)$

proton: Dipole triangle

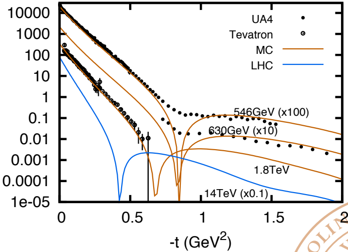
Total and elastic cross sections

pp

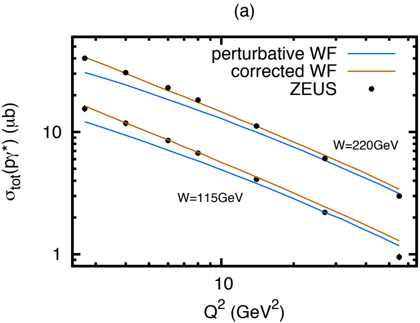
σ_{tot} and σ_{el}

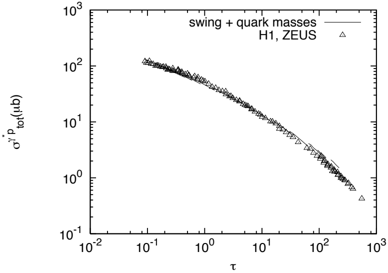


$d\sigma/dt$



$\gamma^* p$



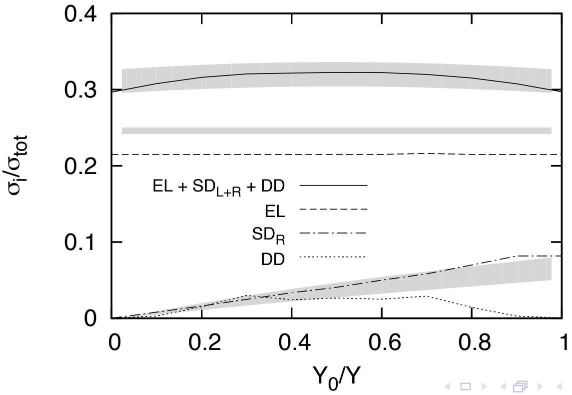


Satisfies geometric scaling

Diffractive cross sections

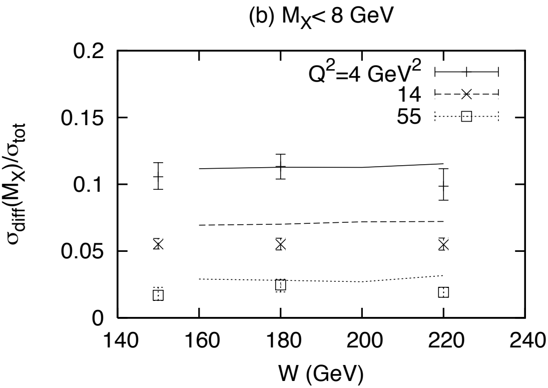
Basic assumption: The parton, or dipole, states are the eigenstates of absorption (*Cf.* Miettinen-Pumplin 1978)

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?

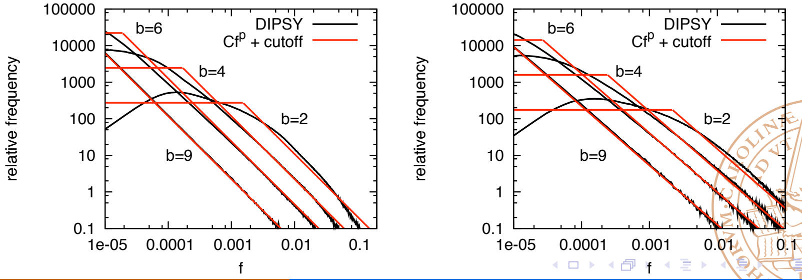
$\gamma^* p$: Power spectrum $\frac{dP}{df} \approx A\, f^{-p}$

(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 $W = 220$.

$W = 220\ Q^2 = 14$ $\qquad$ $W = 1000,\ Q^2 = 14$



Born approximation small $\Rightarrow$ Unitarity effects small; $t \approx f$

The distribution is wide. The parametrization gives

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

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

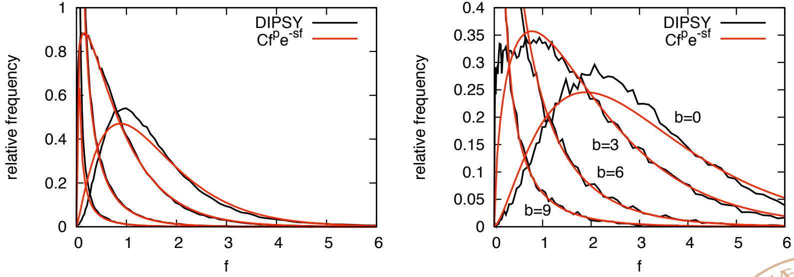
or

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

pp:

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

$W = 100\; GeV$ $\qquad$ $W = 2000\; GeV$ $\quad$ (b in GeV^{-1})



a is independent of b, but falling with energy,

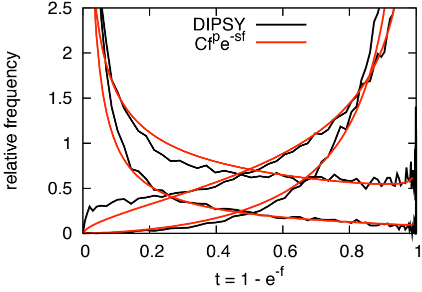
$a \approx 1.4$ for $W = 100$ GeV and ≈ 0.8 for $W = 2000$ GeV

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

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

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

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

Central collisions:

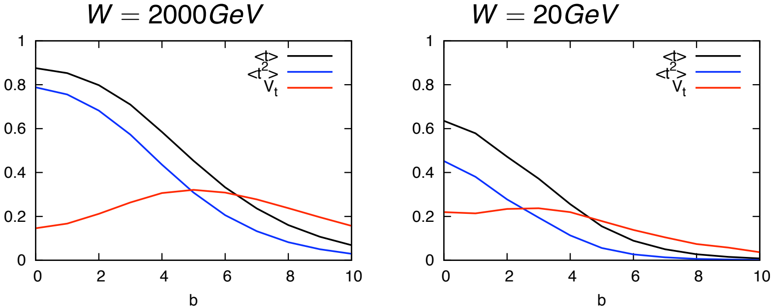
$\langle t \rangle$ large $\Rightarrow$ Fluctuations small

Peripheral collisions:

$\langle t \rangle$ small $\Rightarrow$ Fluctuations small

Largest fluctuations when $\langle f \rangle \sim 1$ and $\langle t \rangle \sim 0.5$

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!

Summary

- Diffractive excitation can be well described by the dipole formalism
- The Lund Dipole Cascade Model gives a good description of *pp* and $\gamma^* p$ collisions
- In the eikonal approximation diffractive excitation is directly determined by the fluctuations in the scattering process
- The fluctuations in the cascade evolutions are large
- Therefore 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
- Dominant contribution to diffractive excitation in *pp* from peripheral collisions, with Born amplitude of order 1
- These results are in qualitative agreement with Goulianos' approach, but the relationship needs further study