Multiple Interactions, Diffraction, and the BFKL Pomeron

Gösta Gustafson

Department of Theoretical Physics
Lund University

XL ISMD, Antwerp, 21-25 Sept. 2010

Work in collaboration with C. Flensburg and L. Lönnblad

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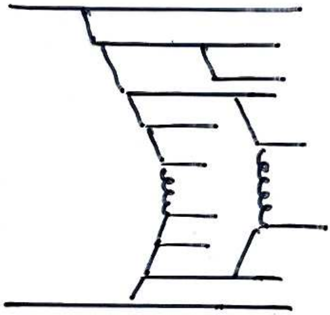
1. Relation BFKL evol. — Diffraction

Assumption: HE collisions driven by partonic subcollisions (cf. PYTHIA)

Gluon cascades
Small x: BFKL



Gluon exchange ⇒ inelastic interaction

Multiple subcollisions ⇒ saturation

Eikonal approximation

Diffraction and saturation more easily described in impact parameter space

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

Structureless projectile

Optical theorem $\Rightarrow$

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

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

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:

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

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

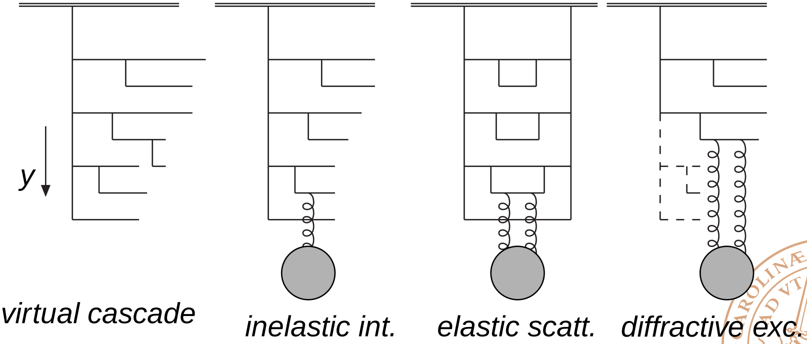
Diffractive excitation determined by the fluctuations:

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

Proton substructure: parton cascade

Depends on energy, *i.e.* on Lorentz frame

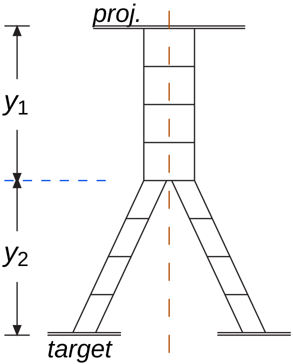
Can fill a large rapidity range ⇒ high mass excitation possible



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

Diffractive cross sections

Good-Walker



BFKL evol.: Large fluctuations (Mueller–Salam)

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

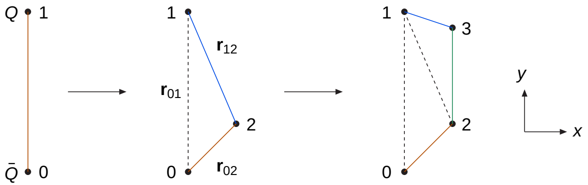
Vary y_1 gives $d\sigma/dM_X^2$

Can this reproduce the triple-regge result?

Mueller Dipole Model:

A color charge is always associated with an anticharge

Formulation of LL BFKL in transverse coordinate space



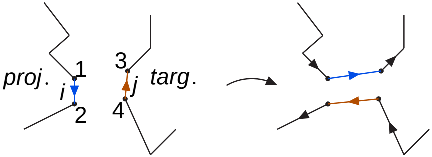
Emission probability: $\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$

Color screening: Suppression of large dipoles

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

Dipole-dipole scattering

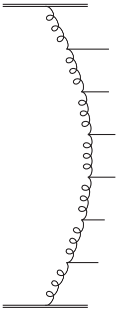
Gluon exchange
$\Rightarrow$ Color connection
projectile–target



Interaction probability:

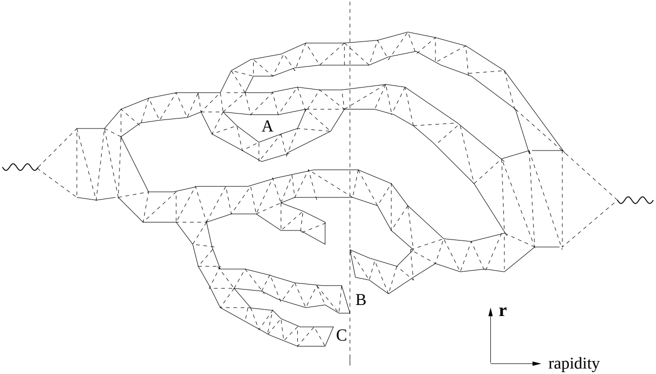
$$2f_{ij} = \alpha_s^2 \ln^2\left(\frac{r_{13}r_{24}}{r_{14}r_{23}}\right)$$

BFKL evol.:
frame independent



Largest $k_\perp$ can be any-where in the evolution

Multiple interactions ⇒ Dipole chains and color loops



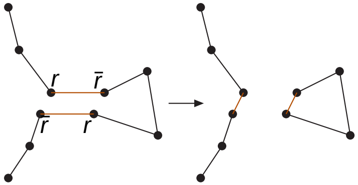
Frame independent formalism ⇒ dipole loops in the evolution

Note that

Gluon emission $\sim \bar{\alpha} = \frac{N_C}{\pi}\alpha_s$

Gluon exchange $\sim \alpha_s$. Color suppressed
$\Rightarrow$ Also loop formation color suppressed $\sim \alpha_s$

Related to identical colors.



Quadrupole $\sim$ recoupled dipole chains

Gluon exchange $\rightarrow$ same effect

2. Lund Dipole Cascade model

(Avsar–Flensburg–GG–Lönnblad)

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

- Include NLL BFKL effects
- Include Nonlinear effects in evolution (loop formation)
- Include Confinement effects

MC: DIPSY (CF, LL)

Initial state wavefunctions:

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

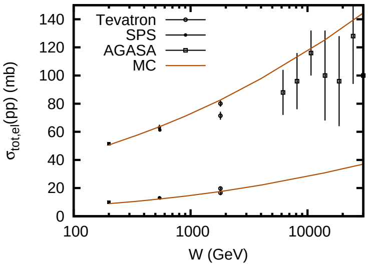
proton: Dipole triangle

2 tunable parameters: proton size and Λ_{QCD}

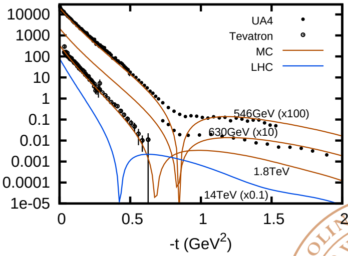
Total and elastic cross sections

pp

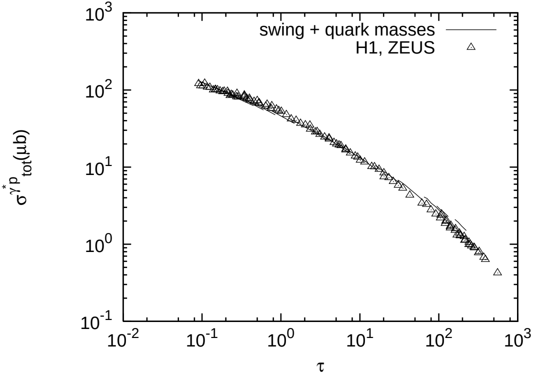
σ_{tot} and σ_{el}



$d\sigma/dt$



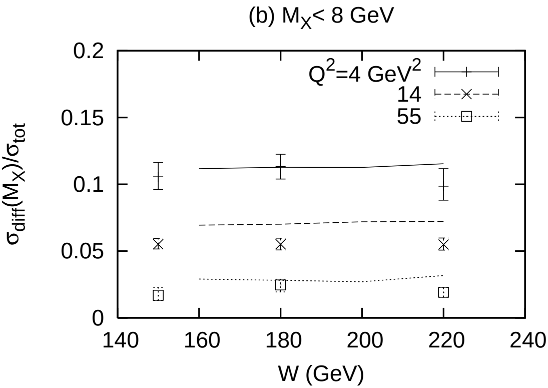
$\gamma^* p$



Satisfies geometric scaling

Diffractive excitation: $\gamma^* p$

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

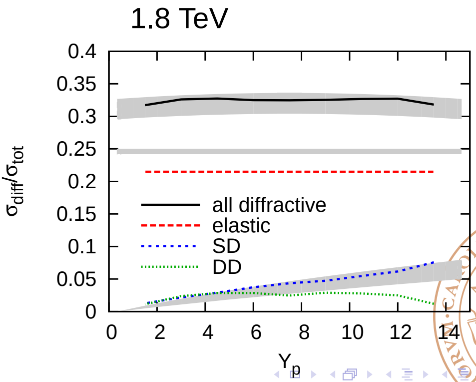


pp

Only events with a rapidity gap at $y = 0$, in the frame used for the calculation, are treated as diffractive.

In other frames they are classified as inelastic.

pp coll. in a frame, where the projectile is evolved Y_p rapidity units



3. Relation Good–Walker – Multi-regge

(C. Flensburg-GG: arXiv:1004.5502)

$\gamma^* p$: Fluctuations

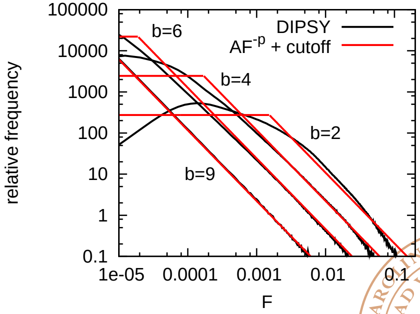
Prob. distrib. for
Born ampl. $F = \sum f_{ij}$

$dP/dF \approx A F^{-p}$

Wide distribution

$\langle F \rangle$ small
$\Rightarrow T = 1 - e^{-F} \approx F$

$W = 220 \; Q^2 = 14$

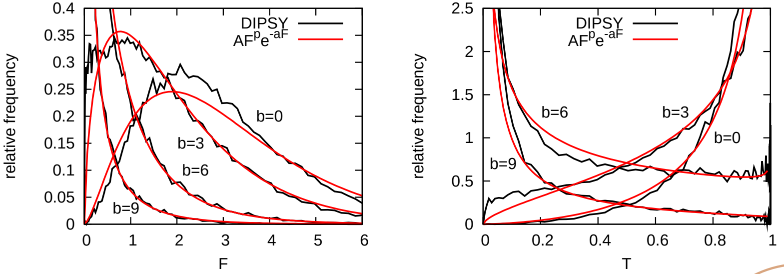


$d\sigma_{diff.ex.}/d\sigma_{tot} \sim 10\%$, decreasing with Q^2

pp: Born approximation: large fluctuations

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

Born ampl. F $W = 2\,TeV$ Uniterized ampl. $T = 1 - e^{-F}$



$\langle F \rangle$ is large: Unitarity important $\Rightarrow$ fluctuations suppressed

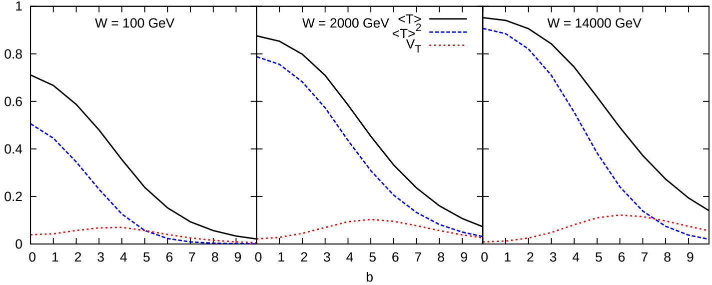
($\sim$ enhanced diagrams in multi-regge formalism)

Factorization broken between DIS and *pp*

Impact parameter profile

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

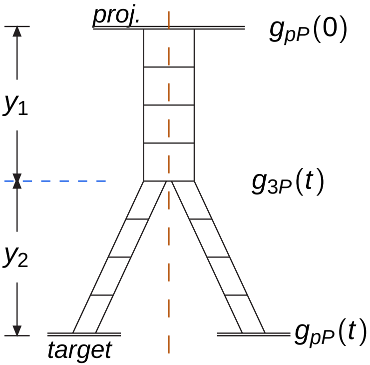
Peripheral collisions: $\langle T \rangle$ small $\Rightarrow$ Fluctuations small



Largest fluctuations when $\langle T \rangle \sim 0.5$

Circular ring expanding to larger radius at higher energy

Triple-Regge parameters



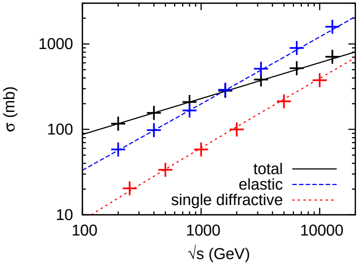
Traditionally fluctuations not taken into account

Reggeon parameters and couplings fitted to data

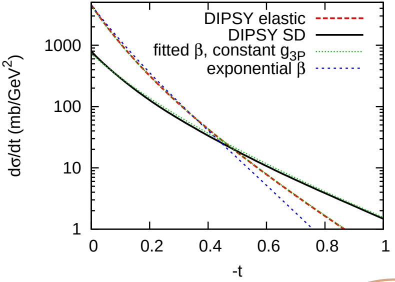
Bare pomeron

Born amplitude without saturation effects

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



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



Agrees with triple-regge form, with a single pomeron pole

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

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

Compare with multi-regge analyses:

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

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

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

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

Note:

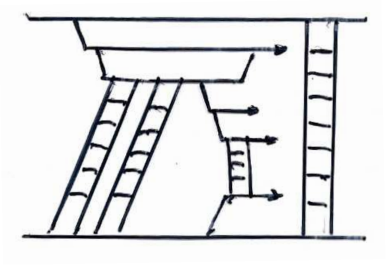
Fit $\sim$ single pomeron pole (not a cut or a series of poles)

$g_{3\text{P}}$ approx. constant (*cf* LL BFKL $\sim 1/\sqrt{|t|}$),

4. Can diffraction be uniquely defined?

Multipomeron diagrams

are included in the dipole picture, with fixed multi-pomeron couplings

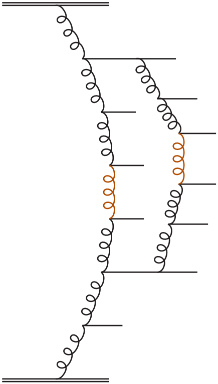


However, all events with no gap are classified as inelastic

Cf KMR: A large cross section for overlapping double diffraction

How to define diffraction?

Attempt: Two separate color singlet systems, containing the original valence quarks?



Exchange of two gluons forming color singlet?

But the gap can be filled by FSR or nonpert. strings

or formed by color reconnection

Cannot be uniquely calculated in pQCD

Conclusion:

The definition of diffraction varies between different schemes

For one event, the diffractive capacity is not an observable

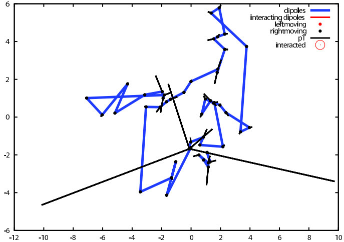
Solution: Study observables, gap events!

5. Preliminary final state results

1. Remove virtual emissions, which do not come on shell in the interaction
(only preliminary results, due to technical problems in the MC)

2. Add final state radiation

3. Hadronize (no color recon.)



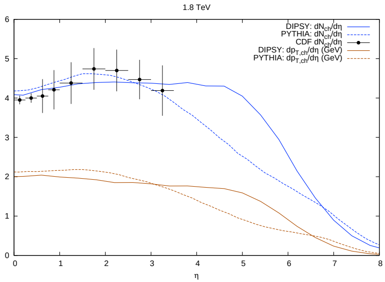
Note: No input structure fcns. No quarks, only gluons, and only 2 free parameters

No precision results should be expected

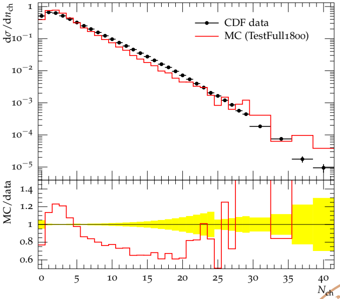
We hope to reproduce the qualitative features, and get insight into the basic mechanisms

CDF 1.8 TeV

$dN_{ch}/d\eta$



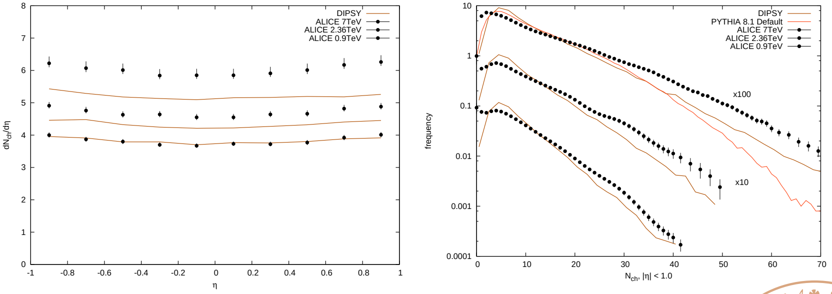
dP/dN_{ch}



The BFKL evolution gives more activity forward than PYTHIA

ALICE

Rapidity distribution and Multiplicity frequency.



Bad simulation, or indication for new effects at higher energy?

Note also enhanced production of strangeness and baryons

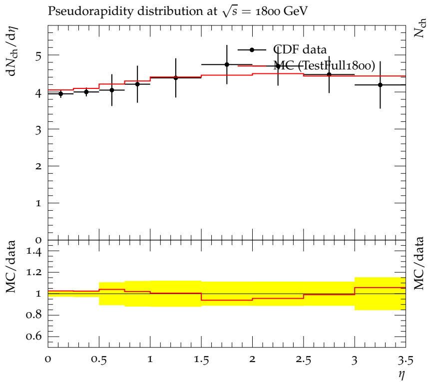
Summary

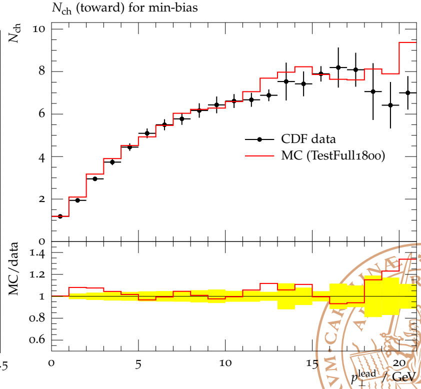
- Parton cascades fill the whole rapidity range between projectile and target, in a frame-independent way.
- The fluctuations in BFKL evol. are large. Besides enhanced forward activity, it can describe diffractive excitation within the Good–Walker formalism (with no extra parameters.)
- In central *pp* collisions diffractive excitation is suppressed by saturation. This leads to factorization breaking.
- The result corresponds to a bare pomeron, which is a simple pole, and an almost constant triple-pomeron coupling.
- Diffractive excitation is scheme dependent, and cannot be uniquely defined. Study gap events.
- Prelim. results were presented for exclusive final states.

Extra slides

CDF

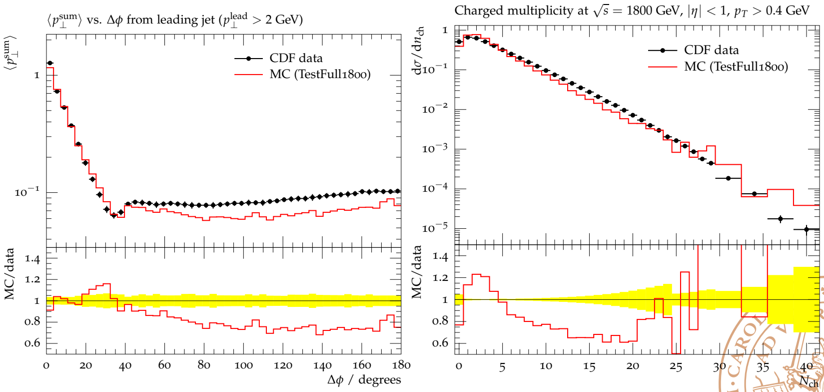
Pseudorapidity distribution and N_{ch} in towards region.





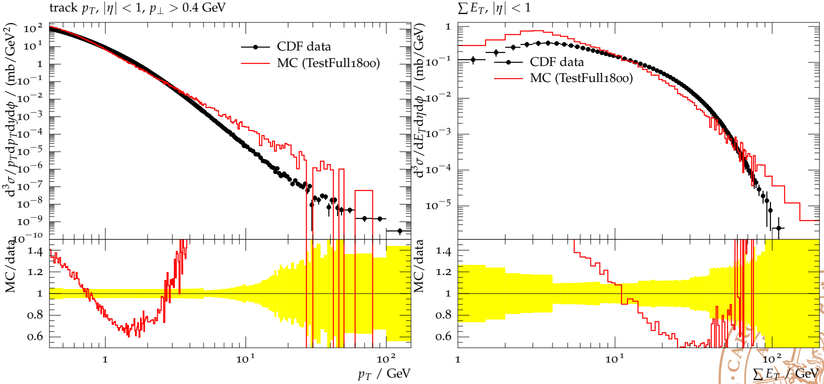
CDF

Angular distribution and multiplicity frequency.



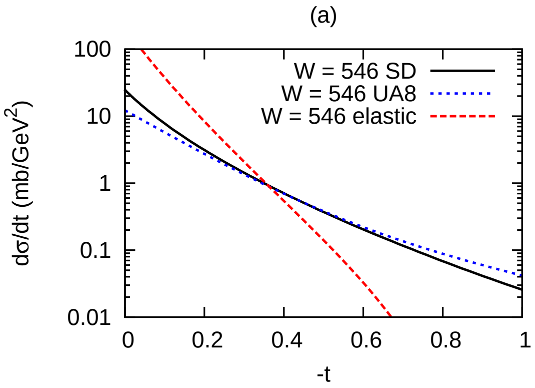
CDF

Track p_T and $\sum E_T$ distributions.



t-dependence

Single diffractive and elastic cross sections



Agrees with fit to UA8 data

Effective multipomeron vertex $\sim \gamma^{n+m}$

cf Ostapchenko: $\sim \gamma^{n+m}$

KMR: $\sim nm\gamma^{n+m}$

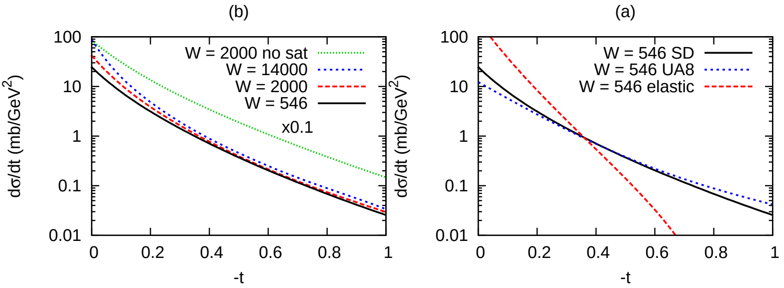
Tel Aviv: Only triple-pomeron vertices

Note: Overlapping double diffraction has a very large cross section in the KMR multi-regge approach, with a corresponding (or even larger) reduction of the inelastic cross section

Triple-pomeron formulae:

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

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

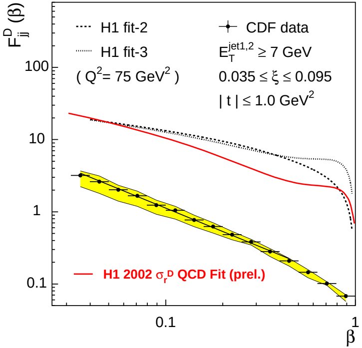


Energy dependence, and result without saturation at 2 TeV

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

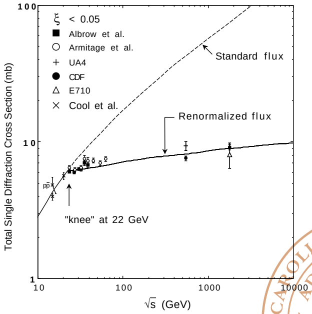
Factorization breaking

Difference between
pp and $\gamma^* p$



Cf. Goulianos' saturation of pomeron flux

pp scattering



Diffractive excitation approximations

$\gamma^* p$ scattering: $dP/dF \approx A\,F^{-p}$

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

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

pp scattering: $dP/dF \approx AF^p e^{-aF}$

$$\sigma_{tot} \sim 2\langle T\rangle = 2(1-(\tfrac{a}{a+1})^{p+1}) = 2(1-(\tfrac{a}{a+1})^{a\langle F\rangle}) \rightarrow 1 \text{ when } \langle F\rangle \rightarrow \infty$$

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

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:

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

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

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