Minireview on models for diffr. excit. and The Lund cascade model DIPSY

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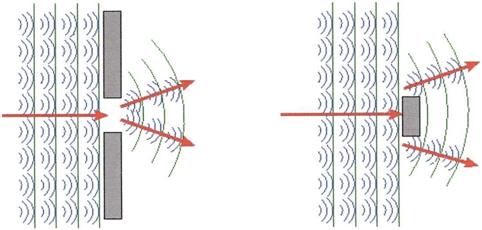
A. Minireview on models for diffractive excitation

Content

1. Optical analogy and Good–Walker
2. Reggeon theory
3. Diffraction in DIS
4. Hard diffraction
5. Alternative approaches
   a) Renormalized pomeron (Goulianos)
   b) Soft color reconnection or soft rescattering (Uppsala)
6. Comment on central exclusive Higgs

1. Optical analogy and Good–Walker

Optics: A hole equivalent to a black absorber



Forward peak

$$\theta \sim \frac{\lambda}{\text{opening width}}$$

Diffraction and rescattering more easily treated in impact parameter space

Rescattering $\Rightarrow$ convolution in $\mathbf{k}_\perp$-space $\rightarrow$ product in $\mathbf{b}$-space

b $(= L/k)$ conserved: $S(b) = S_1(b)S_2(b)S_3(b)$

Optical theorem:

$$\mathrm{Im}A_{el} = \frac{1}{2}\{|A_{el}|^2 + \sum_j |A_j|^2\}$$

Structureless projectile (*e.g.* a photon): Diffraction = elastic scattering driven by absorption into inelastic channels

Inel. cross sect.:
(prob. NOT to be absorbed into state j) $= e^{-2f_j}$

$$d\sigma_{inel}/d^2b = 1 - \prod_j e^{-2f_j} = 1 - e^{-2\sum f_j}$$

Optical theorem $\Rightarrow \mathrm{Im}A \equiv T = 1 - e^{-\sum f_j}$

$$d\sigma_{el}/d^2b = (1 - e^{-\sum f_j})^2$$

$$d\sigma_{tot}/d^2b = 2(1 - e^{-\sum f_j})$$

Projectile with a substructure: Good–Walker formalism

The mass eigenstates can differ from the eigenstates of diffraction

Diffractive eigenstates: Φ_n; Amplitude: 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:

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

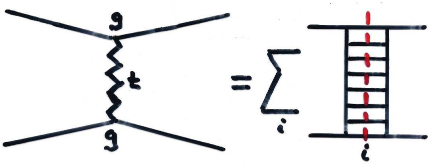
$d\sigma_{diff}/d^2b = \sum_k \langle\Psi_1|T|\Psi_k\rangle\langle\Psi_k|T|\Psi_1\rangle = \langle T^2\rangle$

Diffractive excitation determined by the fluctuations:

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

2. Reggeon theory

Pomeron exchange



$d\sigma_{el}/dt \sim (g^2 \cdot s^{\alpha(t)})^2 = g^4 s^{2(\alpha(0)-1)} e^{2(\ln s)\alpha' t}$

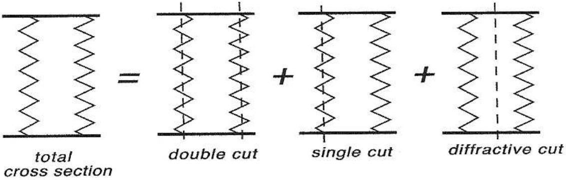
$\sigma_{tot} \sim g^2 s^{\alpha(0)-1}$

Note: $\alpha(0) > 1 \Rightarrow \sigma_{el} > \sigma_{tot}$ for large s:

Multi-pomeron exchange important

AGK cutting rules

Ex.: 2 pomeron exchange



Rel. weights: 2 -4 1

σ_{tot} reduced but $\frac{d\sigma}{dy}$ unchanged

Sum over any number of cut and uncut pomerons $\Rightarrow$

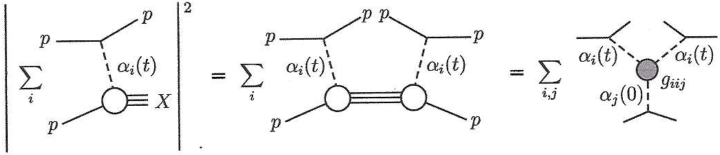
$$\sigma_{inel} = 1 - e^{-2F}$$
$$\sigma_{el} = [1 - e^{-F}]^2$$
$$\sigma_{tot} = 2[1 - e^{-F}]$$

$\frac{d\sigma}{d\eta}$ is still given by

the Born amplitude F

Inelastic diffraction

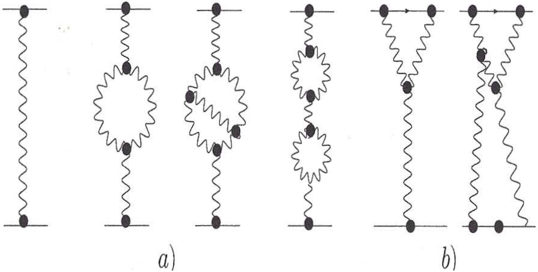
Mueller triple-Regge formalism



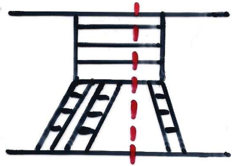
Triple pomeron coupling: g_{3P}

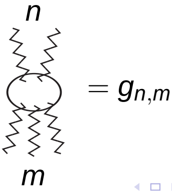
$$\sigma \sim g_{pP}^2(t) g_{pP}(0) g_{3P} \left(\frac{s}{M_X^2}\right)^{2(\alpha(t)-1)} \left(M_X^2\right)^{(\alpha(0)-1)}$$

Unitarity corrections



Multi-pomeron vertex:





3 groups:

Ostapchenko (based on Kaidalov and coworkers)

Durham (KMR)

Tel Aviv (GLM)

Low mass diffr.: G-W, mostly only 1 excited state N^*

High mass diffraction: Cut pomerons

1, 2, or 3 pomerons

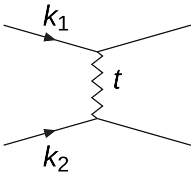
At low energies also Reggeon: $\alpha(0) \approx 0.5$

- Ostapchenko
  2 pomerons, $\Delta_{soft} = 0.17$, $\Delta_{hard} = 0.31$
  2-channel Good-Walker
  multi-pomeron couplings $g_{n,m} \sim \gamma^{n+m}$
- Tel Aviv
  Single pomeron: $\Delta_P = 0.2$, $\alpha' \approx 0$
  $\Rightarrow$ pomeron propagator $\sim \delta(\mathbf{b})$, no diffusion in **b**-space
  Only 3-pomeron vertices
  Resummation á la Mueller's dipole cascade
- Durham ≤ 2010
  3 pom. simultate cut in LL BFKL ($p_\perp \sim 0.5$, 1.5, 5 GeV)
  2-channel Good-Walker
  α' small $\Rightarrow$ no diffusion in **b**-space
  Resummation of pomerons with $g_{n,m} \sim nm\gamma^{n+m}$
  favours large n, $m \Rightarrow$ stronger absorption

Problem:

Gribov's reggeon calculus based on multiperipheral picture without quarks and gluons

BFKL pomeron propagator depends besides the momentum transfer t also on virtualities $k_{\perp 1}$ and $k_{\perp 2}$



Saturation scale: absorption for $k_\perp < Q_s(x)$

New KMR model (May 2011)

Eikonal $\Omega(b, Y) \rightarrow \Omega(\mathbf{b}, \mathbf{k}_\perp, Y)$

Stronger absorption for small $k_\perp \Rightarrow$ single pomeron sufficient

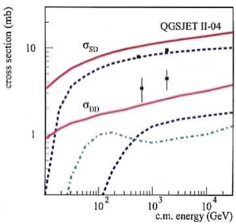
$\Delta \approx 0.32$, α' small

adopts Ostapchenko's vertex $g_{n,m} \sim \gamma^{n+m}$

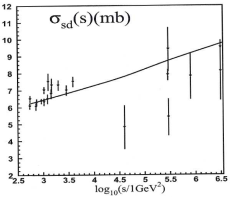
Results

	1.8 TeV (old)			7 TeV			14 TeV (old)			100 TeV (old)		
	GLM	KMR	OSTAP	GLM	KMR	OSTAP	GLM	KMR	OSTAP	GLM	KMR	OSTAP
$\sigma_{tot}\, mb$	74.4	72.8 73.7	73.0	91.3	89.0		101.0	98.3 91.7	114.0	128.0	127.1 108.0	
$\sigma_{el}\, mb$	17.5	16.3 16.4	16.8	23.0	21.9		26.1	25.1 21.5	33.0	35.6	35.2 26.2	
$\sigma_{sd}\, mb$	8.9	11.4 13.8	9.6	10.2	15.4		10.8	17.6 19.0	11.0	12.7	24.7 24.2	
$\sigma_{dd}\, mb$	4.5		3.9	6.4			6.5		4.8	7.8		
S_H^2	0.11			0.06	0.024		0.04	0.015				

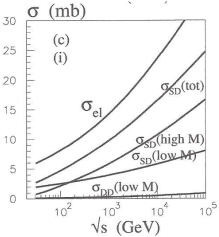
Ostapchenko



Tel Aviv



Durham



Some remaining problems:

Propag. and coupl. $\sim \delta(\mathbf{b}) \Rightarrow$ no diffusion in **b**-space
Dynamical evolution only in $\mathbf{k}_\perp$-space

$\Rightarrow$ At high energies σ determined by the tail of initial proton wavefunction

(If exponential tail $\sim e^{-b/R}$:
effective radius obtained when eikonal $F(b) \sim e^{-b/R} s^\Delta = \mathcal{O}(1)$
$\Rightarrow b_{eff} \sim R\Delta \ln s$ and $\sigma \sim \ln^2 s$)

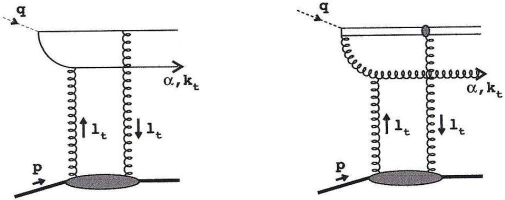
Effects of fluctuations are not included

Gluons mix: BFKL pomerons exchange gluons with probability $\sim 1/N_C^2$ (Bartels and coworkers).

3. Diffraction in DIS

Events with a large rapidity gap are observed by H1 and ZEUS at HERA

Dipole model, Golec-Biernat – Wüsthoff



The photon fluctuates into a $q\bar{q}$ or $q\bar{q}g$ state

Elastic scattering of this state gives a hadronic state with a gap to the target proton

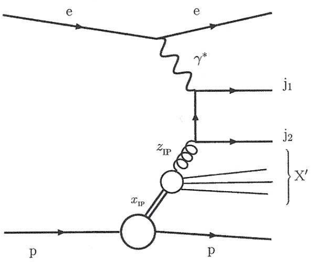
optical theorem $\Rightarrow \sigma^D$

4. Hard diffraction

UA8 at CERN $Sp\bar{p}S$ collider (= UA2 central detector + roman pots at 630 GeV) observed high $p_\perp$ jets in diffractive events

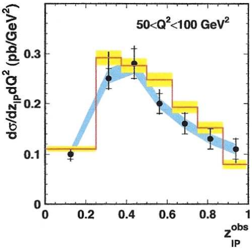
Also observed in gap events at HERA and the Tevatron.

Ingelman-Schlein model:

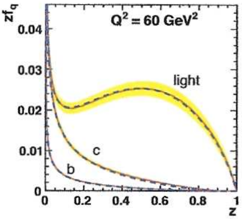


Assumes the pomeron has parton substructure $f_{q,g}^{P}(z, Q^2)$

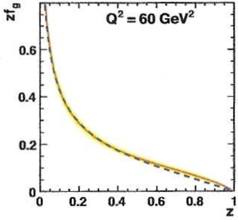
Fit with NLO DGLAP evolution to HERA data for hard and soft diffraction (ZEUS)



z_P^{obs}-distr.



extracted q distr.



extracted g distr.

Gluon dominated

Implemented in MC RAPGAP and PYTHIA8

5. Alternative approaches

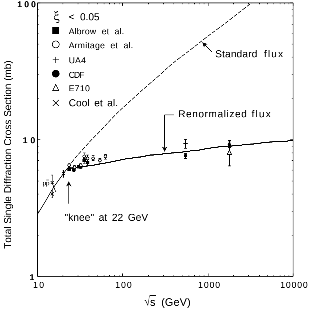
Renormalized pomeron (Goulianos)

$$M_X^2 \frac{d\sigma_{SD}}{dt\, d(M_X^2)} = \left\{ \frac{1}{16\pi} g_{pP}^2(t) g_{pP}(0) g_{3P} \left(\frac{s}{M_X^2} \right)^{2(\alpha(t)-1)} \right\} (M_X^2)^{(\alpha(0)-1)}$$

Saturation $\Rightarrow$ Renormalization of pomeron flux:

divide by $\quad const. \cdot \int dt\, d\ln M_X^2 \{\ldots\}$

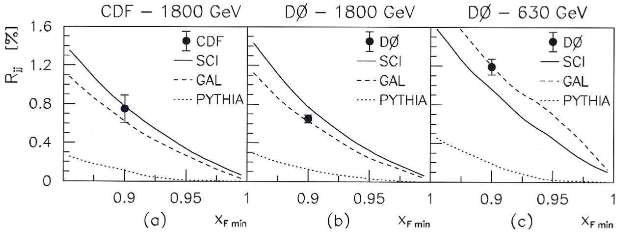
pp scatt.



Suppresses diffraction

in pp, but not in $\gamma^\star p$

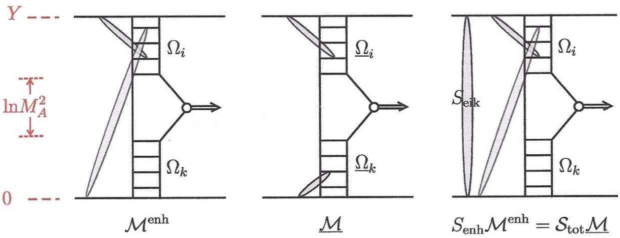
Soft color reconnection or soft rescattering can give rapidity gaps in “normal” inelastic events (Ingelman and coworkers)



Not possible to tell whether or not an event is the shaddow of absorption (*i.e.* classical diffraction)

6. Central exclusive Higgs production

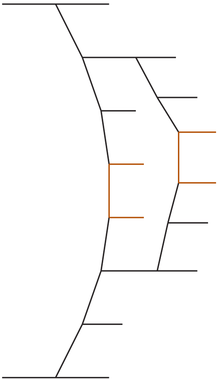
Gap survival



$\lvert S_H\rvert^2$	7 TeV	14 TeV	
Tel Aviv	0.06	0.04	
Durham (*i*)	0.013	0.008	
Durham (*ii*)	0.024	0.015	favoured over (*i*)

B. The Lund cascade model, DIPSY MC

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



Low x: BFKL evolution

High $p_\perp$ also within evolution

Multiple int. $\Rightarrow$ saturation

Pomeron loops

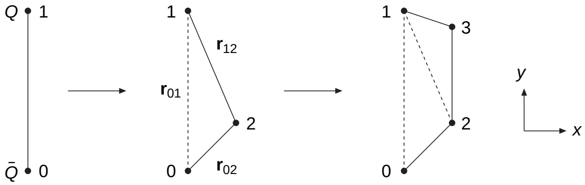
Fluctuations

Diffractive exc., Correlations, Ridge?

1. Small x evolution

Mueller Dipole Model:

Formulation of LL BFKL in transverse coordinate space



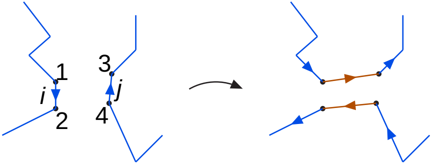
Emission probability: $\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$

Colour screening: Suppression of large dipoles

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

Dipole-dipole scattering

Single gluon exhange $\Rightarrow$ Colour reconnection



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

The Lund model includes also nonleading effects in the evolution

- Energy conservation ($\sim$ non-sing. terms in $P(z)$)

  small dipole — high $p_\perp \sim 1/r$

  Cascade ordered in p_+

  $\Rightarrow$ small dipoles suppressed for small δy

- "Energy scale terms" $\sim$ "consistency constraint"

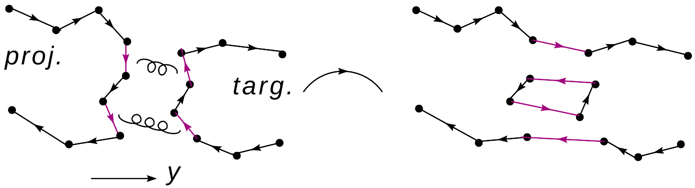
  $\Rightarrow$ Cascade ordered in p_-

  A single chain is left-right symmetric

- Running α_s

2. Saturation

Multiple interactions ⇒ colour loops



Multiple interaction in one frame

⇒ colour loop within evolution in another frame

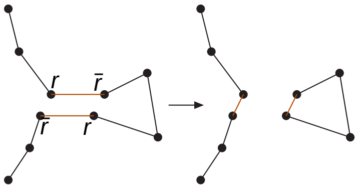
Colour swing

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

Gluon scattering $\sim \alpha_s^2$. Color suppressed
$\Rightarrow$ Loop formation color suppressed. Related to identical colors.

Two dipoles with same colour form a quadrupole

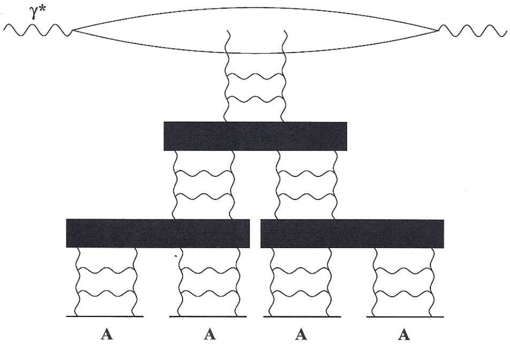
May be better described by recoupled smaller dipoles



Weight favouring small dipoles $\Rightarrow$ near frame indep. result

Cf. Mueller's cascade: Only loops formed by multiple interactions

Also BK eq.: No loops in evolution



3. Confinement is also important

Purely perturbative evolution violates Froissart's bound

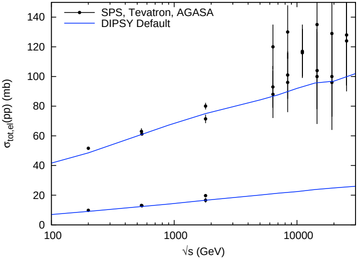
Confinement treated by an effective gluon mass

4. Inclusive reactions

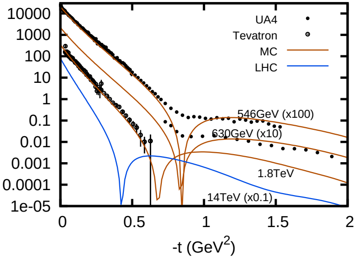
Initial proton wavefunction ∼ three dipoles in a triangle

pp

σ_{tot} and σ_{el}



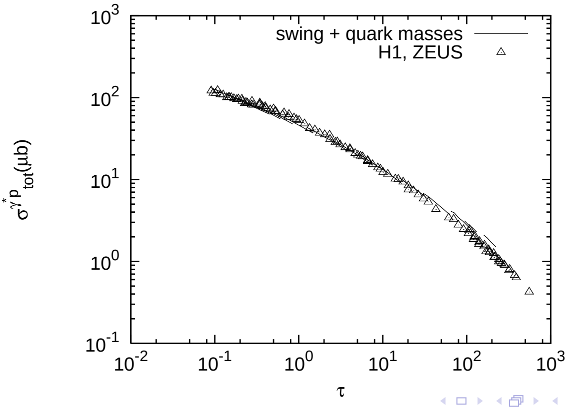
$d\sigma/dt$



$\gamma^* p$ cross section

$\gamma^\star \rightarrow q\bar{q}$ dipole wavefunction from QED

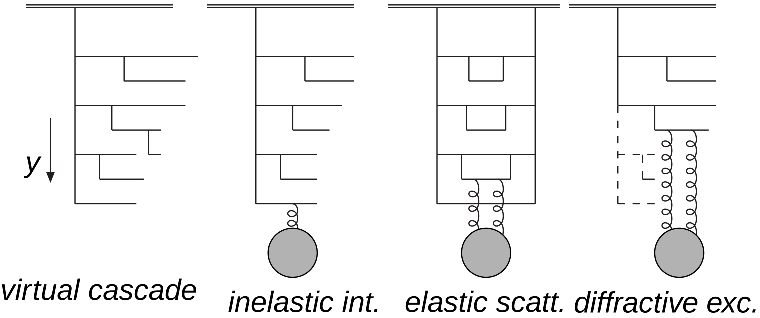
The result satisfies geometric scaling



Diffractive excitation

Diffractive eigenstates:

Parton cascades, which can come on shell through interaction with the target.
Large fluctuations give also high mass diffraction

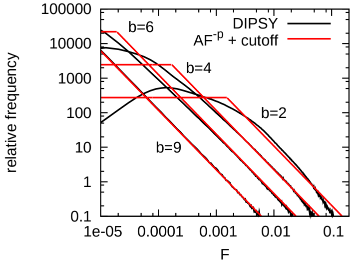


Cf. Miettinen–Pumplin (1978), Hatta *et al.* (2006)

Prob. distrib. for $\gamma^* p$ amplitudes

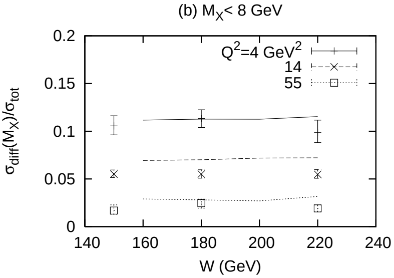
Born ampl. $F = \sum f_{ij}$

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

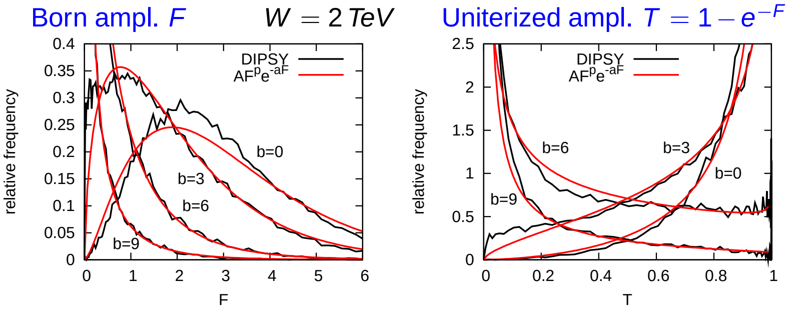


Diffractive cross section (Data from ZEUS)

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



Prob. distrib. for *pp* amplitudes



Born approximation: large fluctuations

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

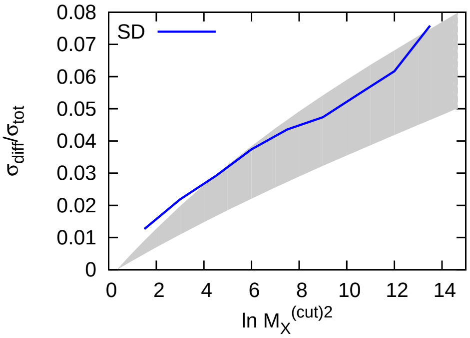
$\sim$ enhanced diagrams in triple-regge formalism

Fluctuations strongly reduced for central collisions

pp 1.8 TeV

Single diffractive cross section for $M_X < M_X^{(cut)}$

Shaded area: Estimate of CDF result

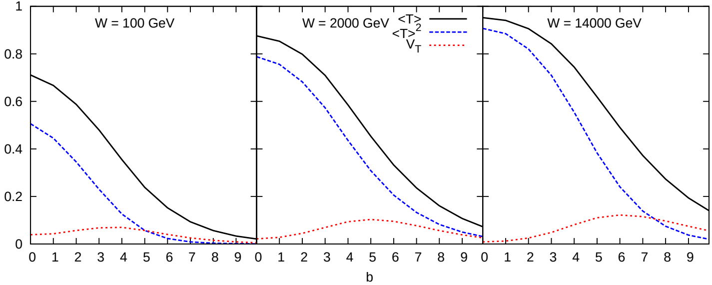


Saturation⇒ Factorization broken between *pp* and DIS

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

Triple-Regge parameters

Switch off unitarization $\Rightarrow$

The result agrees with triple-Regge formalism and a bare pomeron with

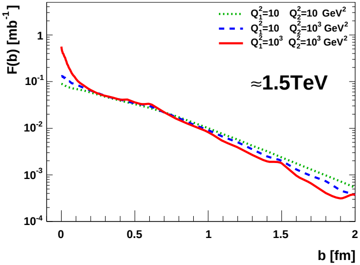
$$\alpha(0) = 1.21, \quad \alpha' = 0.2\,\mathrm{GeV}^{-2}$$

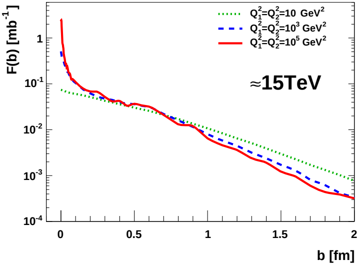
$$g_{pP}(t) = (5.6\,\mathrm{GeV}^{-1})\,e^{1.9t}, \quad g_{3P} = 0.31\,\mathrm{GeV}^{-1}$$

Correlations: Double parton distributions

$$\Gamma(x_1, x_2, b; Q_1^2, Q_2^2) \equiv D(x_1, Q_1^2)\, D(x_2, Q_2^2) \cdot F(b; x_1, x_2, Q_1^2, Q_2^2)$$

Correlation function $F(b)$ depends on x and Q^2



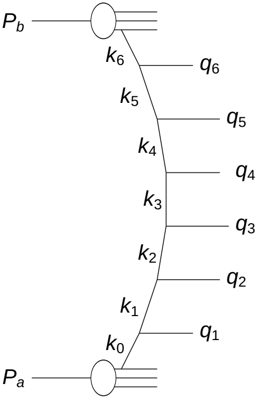


[arXiv:1103.4320]

5. Final states

BFKL: Inclusive   Exclusive: CCFM

In momentum space



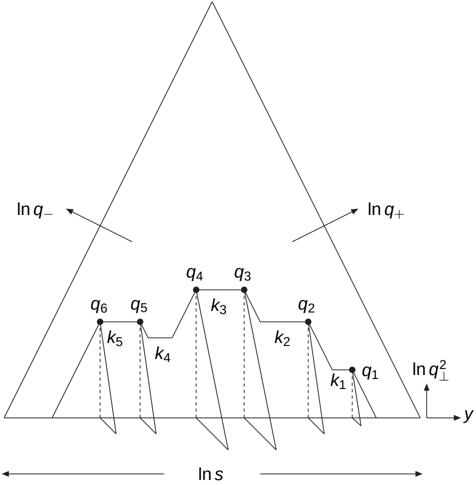
Inclusive cross section determined by “$k_\perp$-changing” or “backbone” emissions (Lund 1996, Salam 1999)

either $k_{\perp i} \gg k_{\perp i-1};\ q_{\perp i} \simeq k_{\perp i}$

or $k_{\perp i} \ll k_{\perp i-1};\ q_{\perp i} \simeq k_{\perp i-1}$

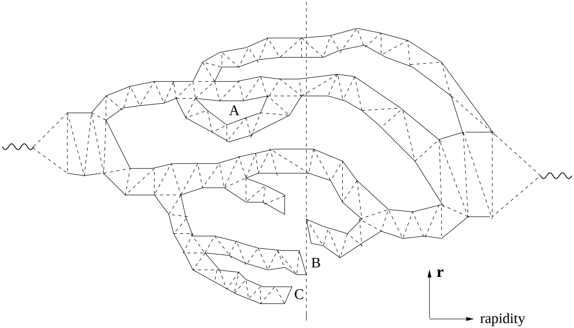
Exclusive states

Softer emissions added as final state radiation below the horizontal lines



BFKL: Stochastic process

Prob. for interaction $= 1 - e^{-2f_{ij}}$



Non-interacting branches cannot come on shell.

Virtual and reabsorbed.

To get final states

1. Generate cascades for projectile and target
2. Determine which dipoles interact
3. Absorbe non-interacting chains
4. Determine final state radiation
5. Hadronize

Main problem: The cascades contain many small dipoles

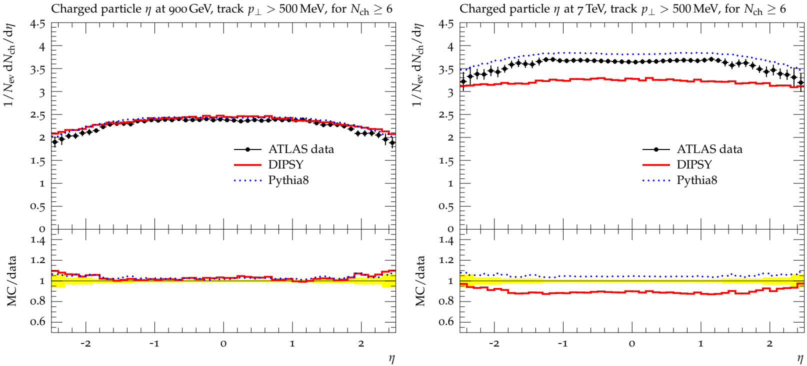
Inclusive: Low cross section $\Rightarrow$ no big problem

Exclusive: Small dipoles have high $p_\perp$ $\Rightarrow$ large effect on final state $\Rightarrow$ high sensitivity to treatment of non-interacting dipoles

Our aim to get dynamical insight;
not to give precise predictions

Comparisons to ATLAS data

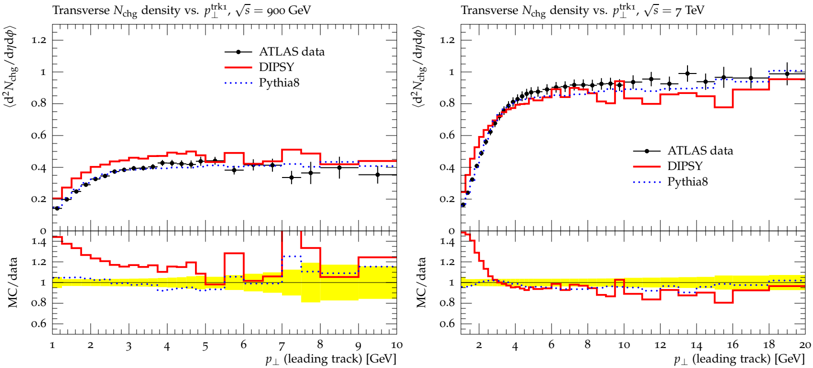
η distrib. of charged particles at 0.9 and 7 TeV



[arXiv:1103.4321]

ATLAS

Underlying event



N_{ch} in transverse region *vs* $p_\perp$ of leading charged particle.

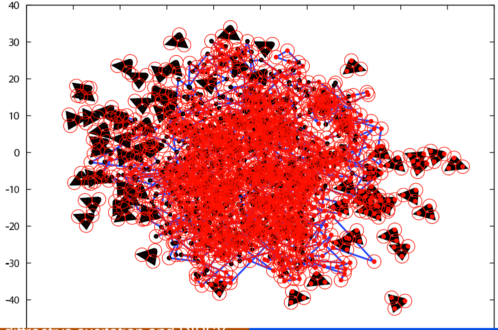
6. Nucleus collisions

Gives full partonic picture:

Energy & momentum density $\sim$ initial conditions in hydro

Fluctuations $\Rightarrow$ *e.g.* v_3

Ex.: $Pb - Pb$ 200 GeV/N



7. Summary

A partonic model for interactions at high energy and density.

It includes:

- important non-leading effects in BFKL
- saturation within the evolution
- confinement
- fluctuations and correlations
- MC implementation
- also nucleus collisions

Good description of inclusive *pp*, *ep*

Diffr. excit. described by Good–Walker, but reproduces triple-pomeron form

Fair descrition of exclusive final states (min. bias and underlying event)

C Questions and problems to be studied further

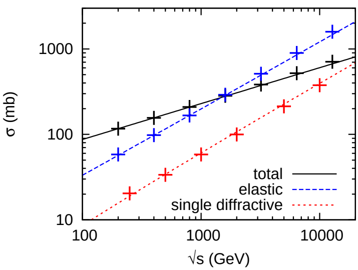
- Fluctuations
  Understand the relation between Good–Walker and Regge
  Asymmetries like triangular flow, v_3, in *pp*, *pA*, *AA*, DIS
- Correlations
  e.g dependence of $\sigma_{\rm eff}$ on Q^2, s, and η
- Final states in diffraction
  Min. bias and underlying events (ISR: stringlike)
- Effects of colour
  Soft colour reconnection: needed in PYTHIA, gap events?
  Pomeron mixing
- Can diffraction be well defined?
  Is it possible (in theory) to separate diffraction from inelastic events with gap?

Extra slides

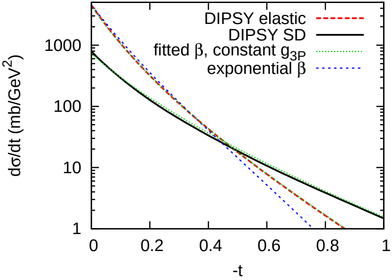
Triple-Regge parameters

BARE pomeron (Born amplitude without saturation effects)

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



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



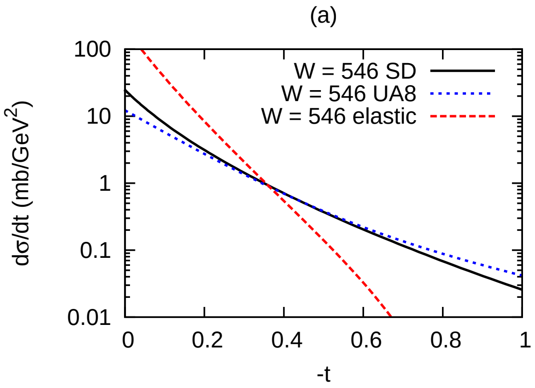
Triple-Regge fit with a single pomeron pole

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

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

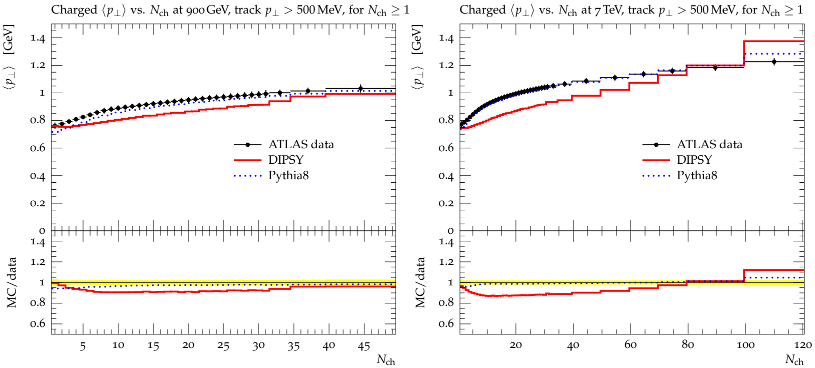
t-dependence

Single diffractive and elastic cross sections



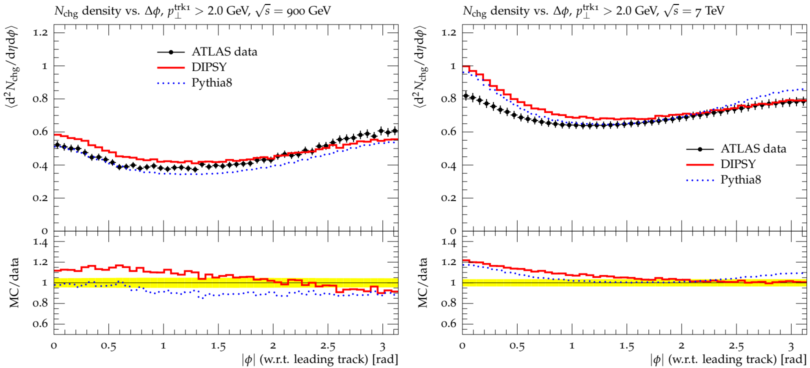
Agrees with fit to UA8 data

ATLAS



$\langle p_\perp \rangle$ *vs* N_{ch} at 0.9 and 7 TeV.

ATLAS



Multiplicity *vs* azimutal angle w.r.t. leading charged particle of at least 2 GeV.

Effective cross section: $\sigma^D_{(A,B)} = \frac{1}{(1+\delta_{AB})} \frac{\sigma^S_A \sigma^S_B}{\sigma_{\text{eff}}}$

σ_{eff} depends strongly on Q^2 for fixed $\sqrt{s}$

Q_1^2	Q_2^2 [GeV^2],	x_1,	x_2	σ_{eff} [mb]	$\int F$
1.5 TeV, midrapidity					
10	10	0.001	0.001	35.3	1.09
10^3	10^3	0.01	0.01	23.1	1.06
15 TeV, midrapidity					
10	10	0.0001	0.0001	40.4	1.11
10^3	10^3	0.001	0.001	26.3	1.07
10^5	10^5	0.01	0.01	19.6	1.03

Stronger correlations for larger Q^2

Part of the correlations is due to fluctuations
No fluct. $\Rightarrow \int d^2b\, F(b) = 1$; the MC gives ~ 1.1

Pomeron nets in the Tel Aviv approach