Diffractive and total cross sections in high energy pp, pA and γ*A reactions with the dipole formalism

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Motivation

The PYTHIA MC-model is the most successful description of inelastic reaction in DIS and pp collisions.

But: there are simplified assumptions about correlations and diffraction. It needs input structure function from data.

Our goal: to understand underlying dynamics in more detail.

- evolution of parton densities
- correlations and fluctuations
- diffraction
- nuclear collisions
Motivations - correlations

Earlier *Sjöstrand and van Zilj* assumed that the dependence of double-parton density on kinematic variables ($x, Q^2$) and on the separation in impact parameter space ($b$) factorizes.

Implemented in PYTHYA and HERWIG event generators

Problem: how to extrapolate to higher energies (LHC)

Our solution: detailed dynamical model for parton evolution (Lund Dipole Cascade Model)
The **Lund Dipole Cascade Model** is based on BFKL evolution equations and Müller’s dipole cascade model:


The Lund Dipole Cascade Model

It improves BFKL evolutions:

- LL BFKL is not good enough. NLL corrections are very large.
- Non-linear effects in the evolution are not included.
- Massless gluon exchange implies a violation of Froissart’s bound.
- It is difficult to include fluctuations and correlations; the BK equation represents a mean field approximation.
- They can only describe inclusive features, and not the production of exclusive final states.
- Analytic calculations are mainly applicable at extreme energies, well beyond what can be reached experimentally.
The Lund Dipole Cascade Model

Dipole cascades:

**LL BFKL evolution in transverse coordinate space**

Gluon emission probability:

$$\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2r_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$$
The Lund Dipole Cascade Model

Dipole-dipole scattering:

Single gluon exchange $\Rightarrow$ Colour reconnection between projectile and target

Born amplitude:

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

Multiple interactions:

Stochastic process $\Rightarrow$ Born ampl. $F = \sum_{ij} f_{ij}$

Unitarity: Eikonal approx. in imp. parameter space

Uniterized ampl.: $T = 1 - e^{-\sum f_{ij}}$ (neglecting fluctuations)

$$ \frac{d\sigma_{el}}{d^2b} = T^2, \quad \frac{d\sigma_{tot}}{d^2b} = 2T $$
The Lund Dipole Cascade Model

Saturation:

Multiple interactions $\Rightarrow$ colour loops $\sim$ pomeron loops

Multiple interaction in one frame $\Rightarrow$ colour loop within evolution in another frame


The Lund Dipole Cascade Model

Inclusive observables:

\[ \sigma_{tot} = 2 \int d^2 b \langle 1 - e^{-F(b)} \rangle \]

\[ \sigma_{el} = \int d^2 b \langle 1 - e^{-F(b)} \rangle^2 \]

\[ \sigma_D = \int d^2 b \left( \langle (1 - e^{-F(b)})^2 \rangle - \langle 1 - e^{-F(b)} \rangle^2 \right) \]

\[ \sigma_{inND} = \int d^2 b \langle 1 - e^{-2F(b)} \rangle \]

With the ikonal form of the transition probability:

\[ T(b) = 1 - e^{-F(b)} \]
The Lund Dipole Cascade Model

In the (Glauber like) black disk limit: \( T(b) = \Theta(R - b) \)

\[
\begin{align*}
\sigma_{tot} &= 2 \int d^2 b \Theta(R - b) = 2\pi R^2 \\
\sigma_{el} &= \int d^2 b \Theta(R - b)^2 = \pi R^2 \\
\sigma_D &= 0 \\
\sigma_{inND} &= \int d^2 b \left( 1 - (1 - T(b))^2 \right) = \pi R^2
\end{align*}
\]

Hence:

\( \sigma_{inND} = \sigma_{el} = \sigma_{tot}/2 \)
Application in MC code DIPSY

It includes:

- important not-leading effects in BFKL (E cons., running $\alpha_s$)
- saturation in pomeron loops in the evolution
- confinement
- correlations and fluctuation
- collision between e,p,A
Application in MC code DIPSY

Dipole interactions:
Application in MC code DIPSY

Sample Au-Au event:  (nucleons are dipole triangles here)
Application in MC code DIPSY

Sample Au-Au event:
Application in MC code DIPSY

Sample Au-Au event:
Preliminary results

Simulations are based on **tunes** to pp total cross sections because some tune parameters are inevitable in MC. For example, $\Lambda_{\text{QCD}}$:

$$\alpha_s(Q) = \frac{1}{b \ln(Q^2/\Lambda^2)} \quad (\text{LO})$$

hep-ex/0407021
Preliminary results

DIPSY parameters:

\( R_{\text{max}} \): Non-perturbative regularization
\( R_p \): Proton size (\( \approx R_{\text{max}} \))
\( w_p \): Fluctuations in the initial proton size (small)
\( \Lambda_{\text{QCD}} \): in the running \( \alpha_s \)
\( \lambda_r \): Swing parameter (saturated)
Preliminary results

With, for example:

$$\Lambda_{\text{QCD}} = 0.23 \text{ GeV}$$
Preliminary results

![Graph showing pp total cross-sections with different data sets and fitting lines.](image)
Preliminary results

Based on the Wood-Saxon nucleus charge density*:

\[
\rho(r) = \frac{\rho_0(1 + wr^2/R^2)}{1 + exp((r - R)/a)}
\]

Modified by GLISSANDRO for the nucleon center density for MC**

** : W. Broniowski et al., GLISSANDRO, nucl-th/0710.531v3
Preliminary results

pPb data of total inelastic cross sections:
- CMS: preliminary
- LHCb: first measurement
Preliminary results

\[ \sigma_{\text{inel}}(7\text{TeV}) = 148 \text{ mb} \]
Preliminary results

pA total cross-sections

$\sigma_{\text{tot}} \text{ [mb]}$

$E_{\text{CMS(NN)}} \text{ [TeV]}$

- pPb
- pCu
- pO
- pp

$5 \times 10^3$

Preliminary results

pA/pp total cross-section ratios

\[ \frac{\sigma_{\text{tot,}pA}}{A\sigma_{\text{tot,}pp}} \]

\( E_{\text{CMS(NN)}} \) [TeV]

- pO
- pCu
- pPb
Preliminary results
Preliminary results
Preliminary results
Preliminary results

\( \gamma^* \text{Cu total cross-sections} \)

\( \sigma_{\text{tot}} \) [\( \mu \text{b} \)]

\( E_{\text{CMS} (eN)} \) [TeV]

\( Q^2 = 5 \text{GeV}^2 \)
\( Q^2 = 25 \text{GeV}^2 \)
\( Q^2 = 100 \text{GeV}^2 \)

(2TeV = 49 \( \mu \text{b} \))
Preliminary results

\[ \frac{\sigma_{\text{tot, eAu}}}{A \sigma_{\text{tot, ep}}} \]

\( E_{\text{CMS(eN)}} \) [TeV] vs. \( Q^2 \) [GeV^2]

- \( Q^2 = 2.5 \text{GeV}^2 \)
- \( Q^2 = 5 \text{GeV}^2 \)
- \( Q^2 = 25 \text{GeV}^2 \)
- \( Q^2 = 100 \text{GeV}^2 \)

\( pPb/pp \)
Preliminary results

Total cross-section ratios

Swing effects

\[ \frac{\sigma_{\text{tot, noswing}}}{\sigma_{\text{tot}}} \]

\[ E_{\text{CMS(eN)}} \left[ \text{TeV} \right] \]

\[ \gamma^* \text{O} \left( Q^2 = 5 \text{GeV}^2 \right) \]

\[ p\text{O} \]

\[ p\text{Pb} \]
Preliminary results

Conditions set to the same:
- same WS distribution
- same R-hard-core = 0.45 fm
- same sigma_tot(pp)
- same sigma_inelND
Preliminary results

Further ongoing simulations are for:

- AA collisions (take lots of execution time)
- $dn/dy$ distributions
Outlook

Things to do:

- speed-up large ion calculations
- final state effects
- diffractive final states
- NLL effects
- ...

Summary

Lund Dipole Cascade Model offers unique possibility to study gluon evolution inside hadrons at small $x$.

Reconstruction of pp cross sections and pPb inelastic cross sections from RHIC to LHC energies was successful.

Predictions for diffractive and total cross sections in various pA, $\gamma^*A$ high energy reactions were made.