Saturation at hadron colliders

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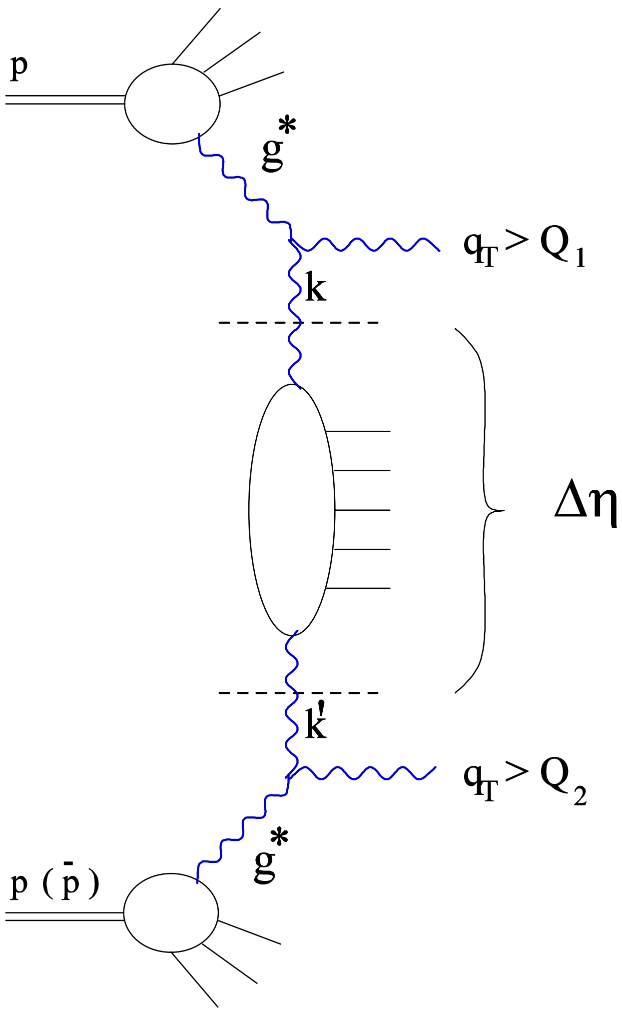
Gluon-initiated processes



- Mueller-Navelet jets (1987): considered to test the BFKL evolution at the Tevatron

  $Q_1, Q_2 \gg \Lambda_{QCD}$ $\exp(\Delta\eta) \gg 1$

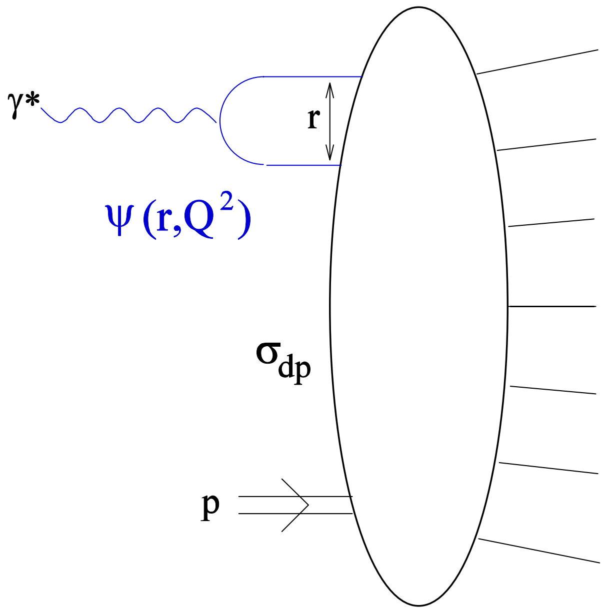
  prediction:

  $$\sigma_{BFKL} \propto \exp(\lambda \Delta\eta) \quad \left(>(\Delta\eta)^2 \right)$$

- Production of heavy-flavored and vector mesons
- Can we reach saturation in these processes?

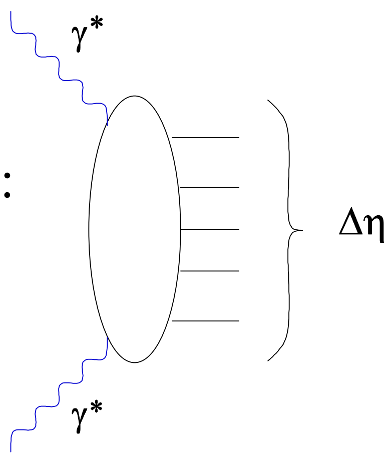
  at the Tevatron or LHC ?
- How does one formulate saturation in such processes?

Saturation and the GBW model



- DIS: the Golec-Biernat and Wüsthoff (GBW) model (1998) for the dipole-proton cross-section

$$\sigma_{dp}(r) = \sigma_0\left\{1 - \exp\left(-r^2 / 4R_0^2(x_{Bj})\right)\right\}$$



- photon-photon with an extension of the GBW model: a model for the dipole-dipole cross-section

$$\sigma_{dd}(\Delta\eta, r_1, r_2) / \sigma_0 = 1 - \exp\left\{-r_{eff}^2 / 4R_0^2(\Delta\eta)\right\}$$

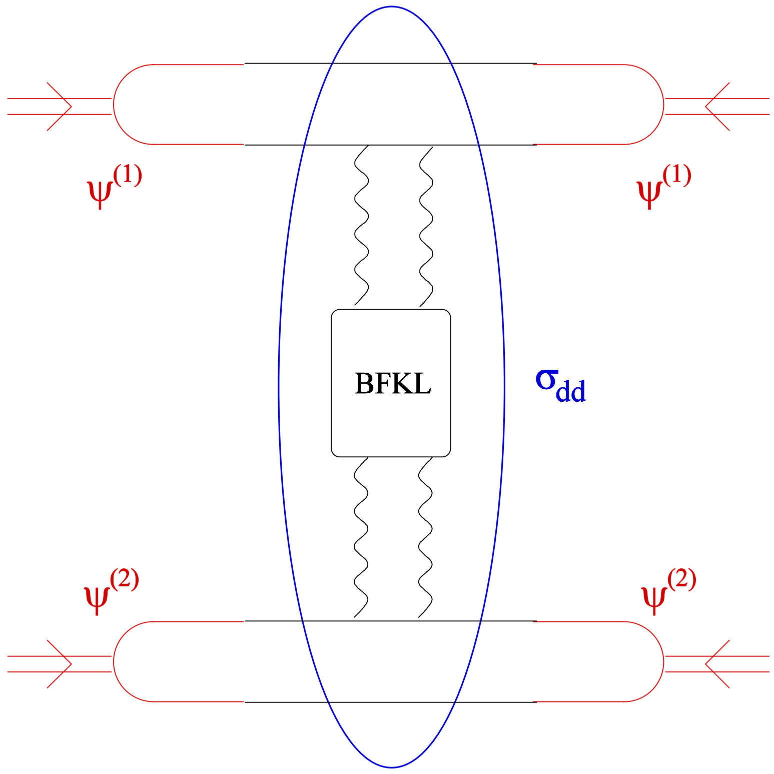
Tîmneanu, Kwiecinski and Motyka (2002)

Dipole factorization for hard cross-sections

$$\sigma = \int d^2 r_1 \int d^2 r_2 \, \phi^{(1)}(r_1, Q_1^2)\, \phi^{(2)}(r_2, Q_2^2)\, \sigma_{dd}(\Delta\eta, r_1, r_2)$$

- equivalent to BFKL+ k_T-factorization
- in the present work, we assume this factorization property to hold in the presence of saturation

$$\phi(r, Q^2) \equiv \left|\psi(r, Q^2)\right|^2$$



Extension of the GBW model

TKM (2002)

$$\sigma_{dd}(\Delta\eta, r_1, r_2)/\sigma_0 = 1 - \exp\left\{-r_{eff}^2/4R_0^2(\Delta\eta)\right\}$$

- the saturation radius is $R_0(\Delta\eta) = \frac{1}{Q_0}\exp\left\{-\frac{\lambda}{2}(\Delta\eta - \Delta\eta_0)\right\}$

  we use the same parameters as those of dipole-proton
  $\lambda = 0.288$, $\Delta\eta_0 = 8.1$ for $Q_0 \equiv 1$ GeV (universal saturation scale)

- the three scenarios we consider are

1. $r_{eff}^2 = \frac{r_1^2 r_2^2}{r_1^2 + r_2^2}$ 2. $r_{eff}^2 = r_<^2$

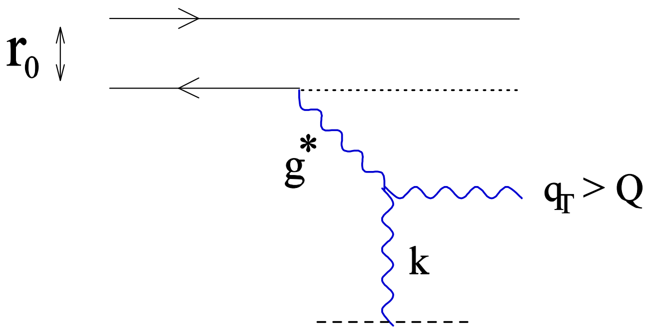
3. $r_{eff}^2 = r_<^2\left\{1 + \ln(r_>/r_<)\right\}$

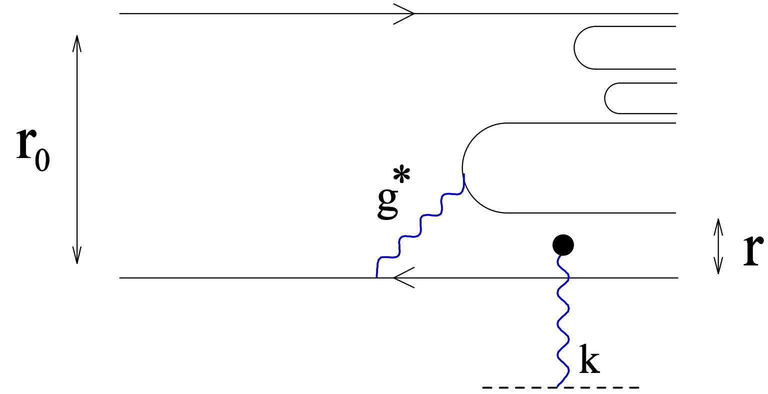
$r_< = \min(r_1, r_2)$ $r_> = \max(r_1, r_2)$

- the three models exhibit color transparency $\sigma_{dd} \underset{r_< \to 0}{\sim} r_<^2$
- the model 3 corresponds to the two-gluon exchange between the dipoles

Forward-jet in terms of dipoles

Munier (2001), C.M. and R. P. (2003)





$$f(k^2, Q^2, r_0) \equiv \int_0^\infty d^2r\ \phi(r, Q^2)\ f^0(r, k^2)$$

$$f^0(r, k^2) = \frac{2\bar{\alpha}}{k^2}(1 - J_0(kr))$$

- the onium allows a perturbative calculation and the interpretation in the dipole formalism; in the collinear limit $r_0 Q \gg 1$, f factorizes:

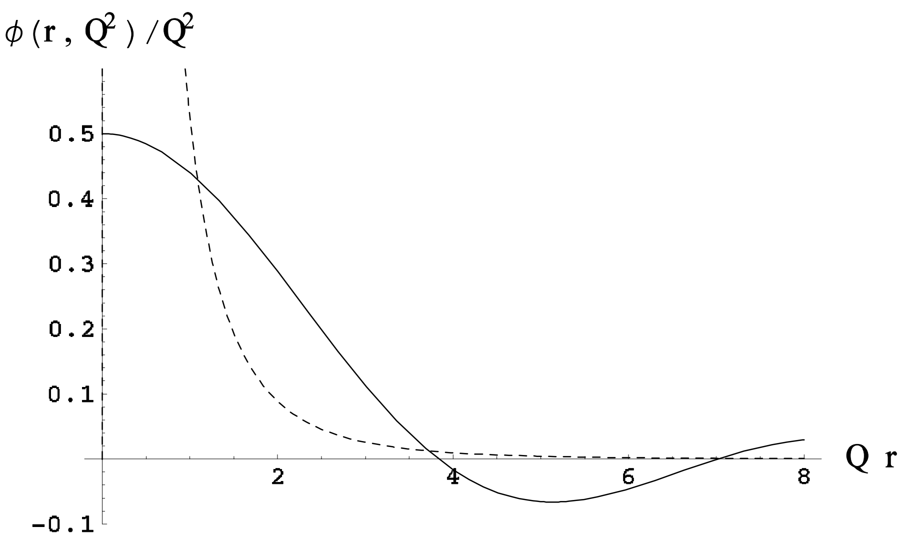
$$f(k^2, Q^2, r_0) \approx \underbrace{\left\{2\bar{\alpha}\ln\frac{1}{x}\ln Q r_0\right\}}_{\text{collinear factorization}} \underbrace{\int_0^\infty d^2r\ \frac{Q}{2\pi r} J_1(Qr)\ f^0(r, k^2)}_{\text{dipole factorization}}$$

The dipole distribution in a forward jet

Peschanski (2000), C.M. and R. P. (2003)

$$\phi\,(r, \mathrm{Q}^2) = \frac{\mathrm{Q}}{2\pi r}\, J_1(\mathrm{Q}r)$$

- large-size dipoles have a contribution to ϕ ; this is not the case for ϕ^γ in a photon-initiated process
- ϕ cannot be seen as a probability distribution
- the BFKL cross-sections calculated with ϕ are positive



Formulae for the hard total cross-sections

C.M. and R. Peschanski (2003)

$$\frac{\sigma_i}{\sigma_0} = 1 - 2Q_1Q_2R_0^2 \int_0^\infty \frac{du}{f_i(u)} \exp\left\{-(Q_1^2 + Q_2^2 u^2)R_0^2 / f_i(u)\right\} I_1\left(2Q_1Q_2R_0^2\, u / f_i(u)\right)$$

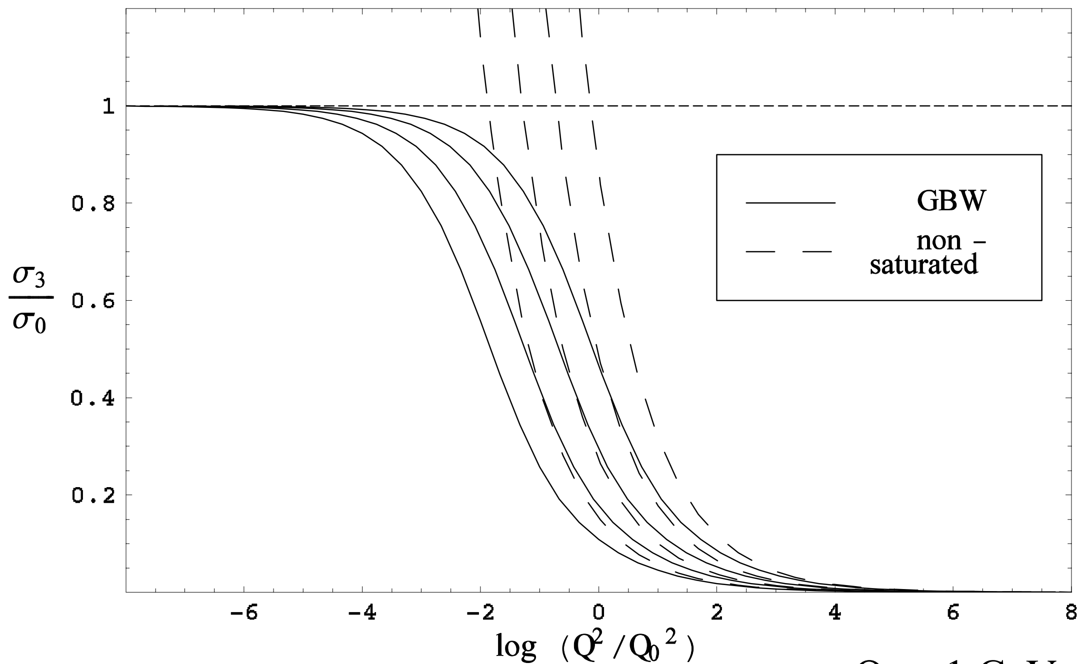
for the different models :

$$f_1(u) = \frac{u^2}{1+u^2} \qquad f_2(u) = \begin{cases} u^2 \text{ si } u < 1 \\ 1 \text{ si } u > 1 \end{cases} \qquad f_3(u) = \begin{cases} u^2(1-\ln u) \text{ si } u < 1 \\ 1+\ln u \text{ si } u > 1 \end{cases}$$

- the cross-sections are positive $\sigma_i > 0$
- however σ_2's high-Q limit (no saturation) does not behave as $1/Q^2$

Saturated cross-sections

- model 3 with $Q_1 = Q_2 \equiv Q$
- the plot shows the expected trend: a suppression of σ_3 in the domain $Q < Qs \equiv 1/R_0(\Delta\eta)$



$Q_0 = 1$ GeV

The rapidity intervals for the different curves are: $\Delta\eta = 4, 6, 8, 10$

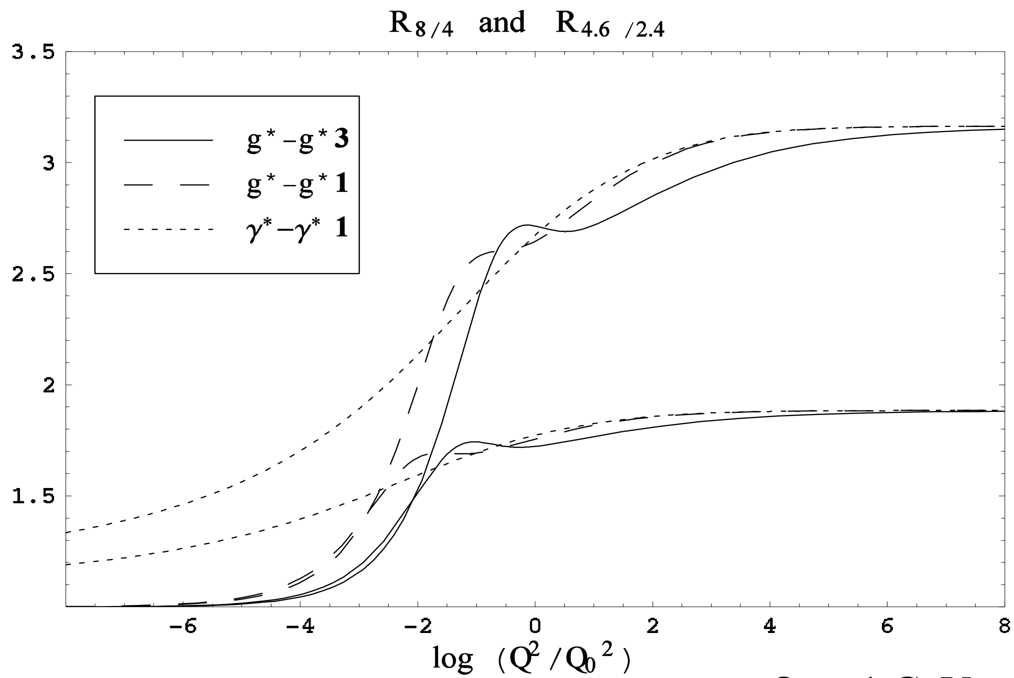
A suitable measurement

$$\mathrm{R}_{i/j} \equiv \frac{\sigma(\mathrm{Q}_1, \mathrm{Q}_2, \Delta\eta_i)}{\sigma(\mathrm{Q}_1, \mathrm{Q}_2, \Delta\eta_j)}$$

- a ratio studied to test the BFKL evolution at the Tevatron (DØ collaboration, 1999)
- shows the influence of saturation in a more quantitative way
- experimentally, R was obtained working at fixed x_1 and x_2 using the factorization of the structure functions in the total cross-sections: $$\frac{d\sigma_{tot}^{pp\to jj+X}}{dx_1 dx_2} = F(x_1,\mathrm{Q}_1^2)F(x_2,\mathrm{Q}_2^2)\,\sigma(\mathrm{Q}_1, \mathrm{Q}_2, \Delta\eta)$$
- R at LHC?

An potentially interesting signal

- the value of R goes down from the transparency limit towards the saturation regime where $R \to 1$
- one can observe a sharper transition in the case of the gluon-initiated process
- the values of Q at the transition are weak for jet cuts at the Tevatron
- along with BFKL studies, the signal deserves to be studied at the LHC
- alternatives to bypass the small-Q problem?



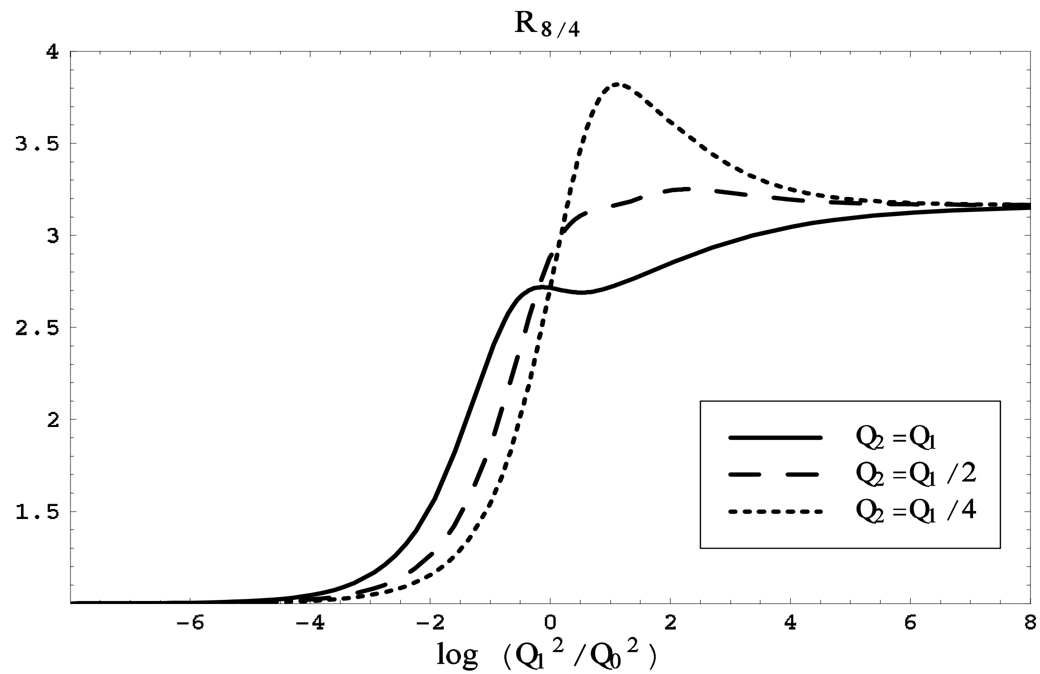
$Q_0 = 1$ GeV

$R_{4.6/2.4}$: ratio studied at theTevatron

$R_{8/4}$: ratio realistic for the LHC

Other configurations

- asymmetric configurations ?
  ◊ the transition towards saturation becomes really steep
  ◊ more interesting: the transition is shifted towards higher Q



$Q_0 = 1$ GeV

- alternatives to jets:
  ◊ heavy vector mesons *J/Ψ* or *Y*
  ◊ D mesons with c quarks or B mesons with b quarks
  ◊ in asymmetric configurations?

Conclusion and outlook

- Introduction of the dipole formalism in the description of hadron-induced hard processes, such as Mueller-Navelet jets
- Studies of saturation effects in these processes using an extension of the Golec-Biernat and Wüsthoff model
- Proposal and predictions for an observable at hadron colliders

To do

- Studies of feasability for the Tevatron and LHC: can we access the ratio R experimentally? for which values of Q? using jets or alternatively heavy vector mesons, heavy flavors?

Theoretical extensions

- Improve our description of gluon-initiated processes in terms of dipoles: taking into account saturation effects in the emission vertex and kT-factorization breaking
- Studying pQCD saturation beyond GBW models