Diffractive photon dissociation in the saturation regime

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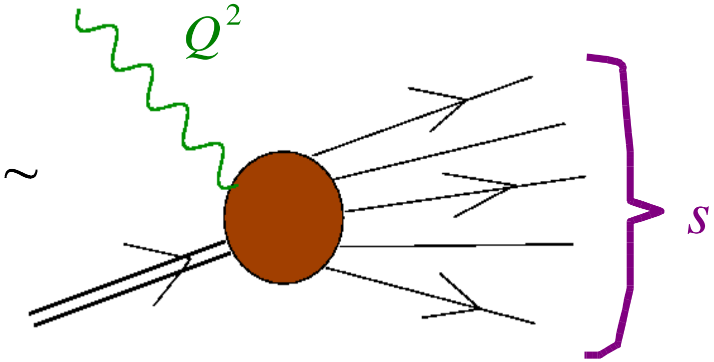
Topology and kinematics

Inclusive DIS

$F_2 \sim$



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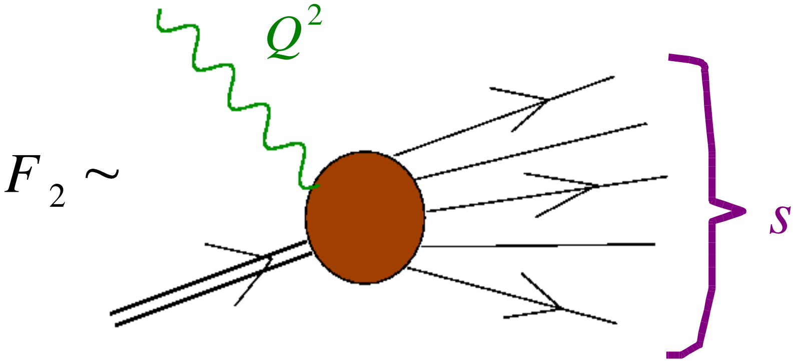
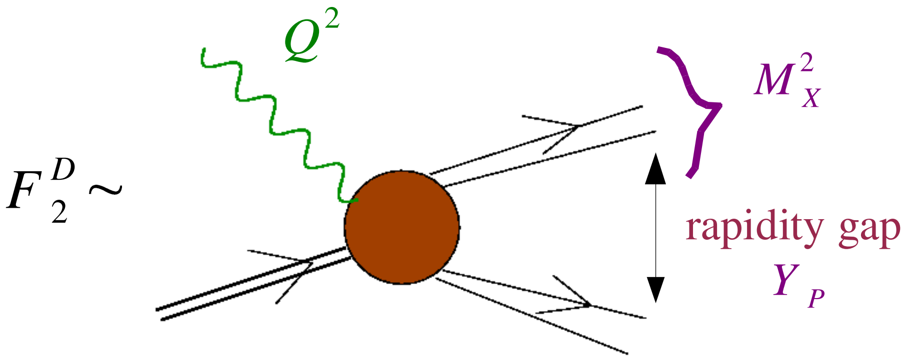


Diffractive DIS



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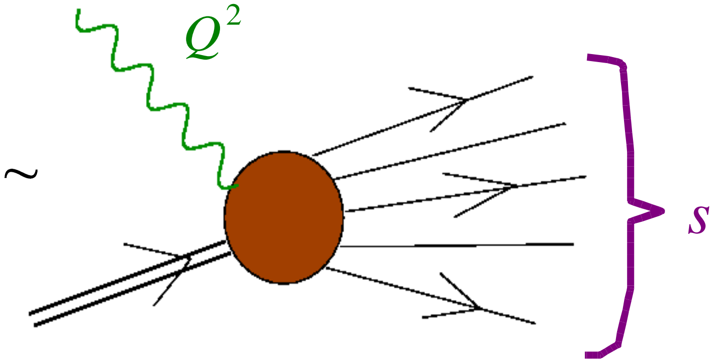
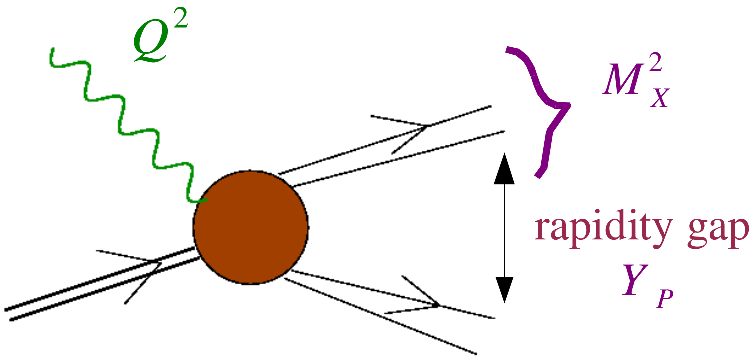


Diffractive DIS

$F_2^D \sim$



High energy kinematics:

$$s \gg Q^2 \gg \Lambda^2$$

$$x = \frac{Q^2}{Q^2 + s} \ll 1$$

[rapidity $Y = \log(1/x)$]

$$\beta = \frac{Q^2}{Q^2 + M_X^2}$$

$\beta \sim 1$	quasi-elastic
$\beta \ll 1$	photon dissociation

Outline

- Physical observables in the dipole model. The Good-Walker picture.
- High mass diffraction. Phenomenology of the HERA data.

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The dipole factorization

Nikolaev, Zakharov;
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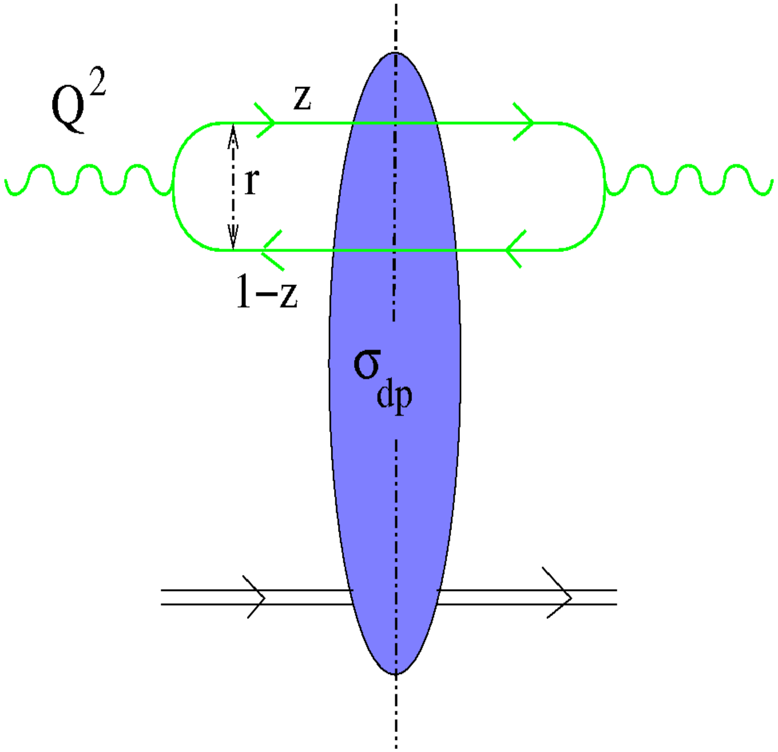

longitudinal momentum fraction

transverse size

$$|\gamma> = |\gamma>_{bare} + \int d^2r\,dz\;\; \psi(z,r)|z,r> + \ldots$$

no hadronic interaction

onium (dipole) state

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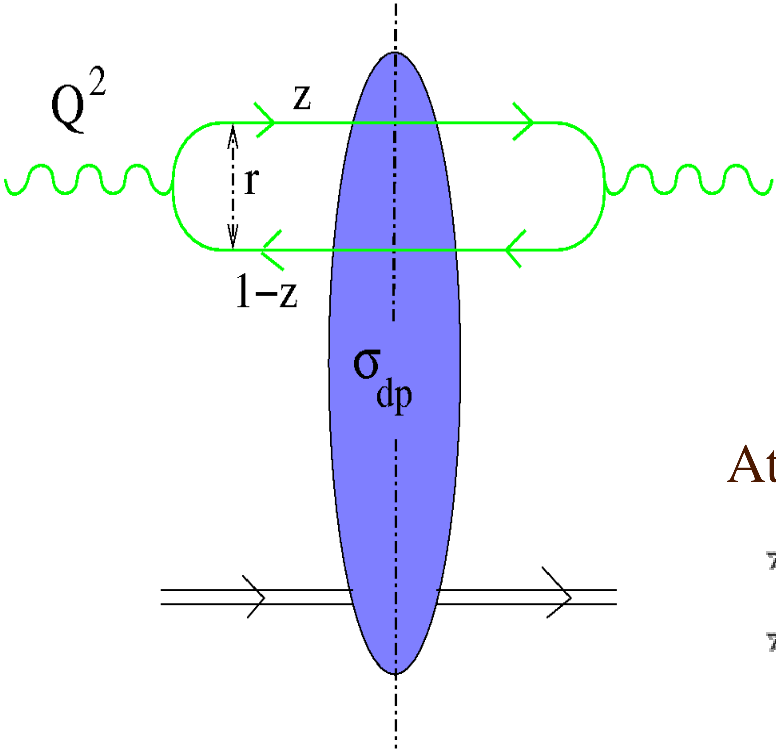

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$$|\gamma\rangle = |\not{\gamma}\rangle_{bare} + \int d^2r\,dz\;\;\psi(z,r)\,|z,r\rangle + \dots$$

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At high energy:

- lifetime of quark pair much larger than interaction time
- motion in transverse plane frozen

$$\sigma(Y,Q^2) = \int d^2r \int dz\, |\psi(z,r)|^2\, \sigma_d(Y,r)$$

[leading $\log(1/x)$]

forward dipole-proton amplitude (includes total, elastic, diffractive final states)

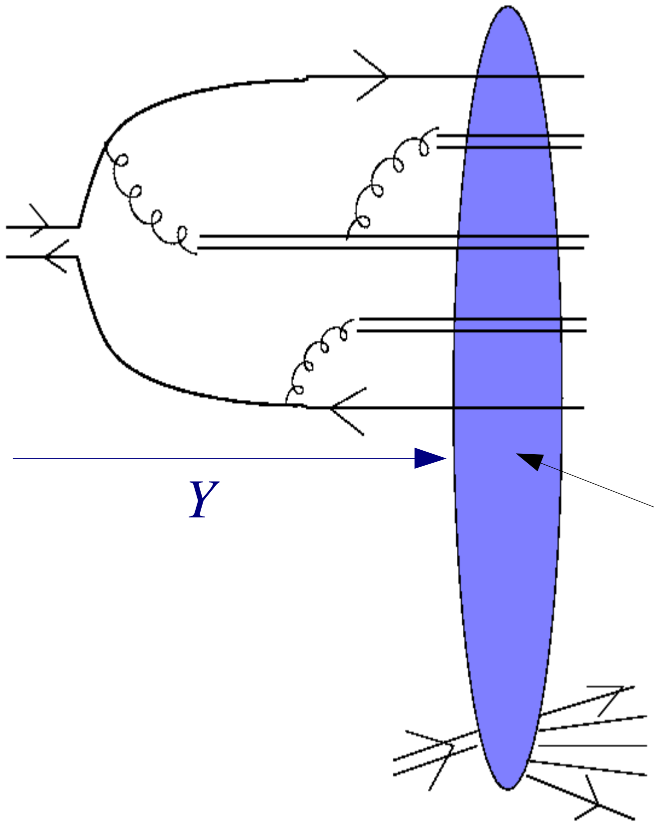
Fundamental quantity! How can one compute it in QCD?

Dipole amplitude in the target rest frame

Mueller (1994)

With increasing energy, ***Fock states with high occupation number become dominant***

Large $N_c \Rightarrow$ Fock states expanded on dipole basis



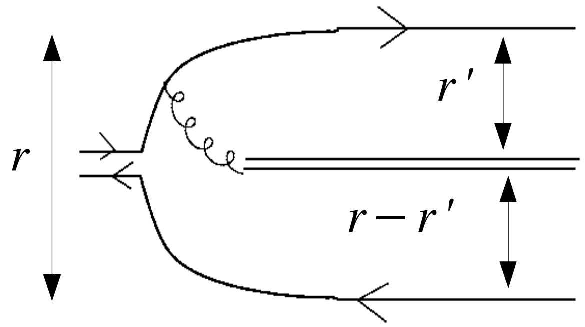
From the point of view of the target:
these dipole states are ***asymptotic***

« color glass condensate »

scattering of a ***frozen*** dipole configuration
at zero rapidity

Rapidity evolution of the onium

Mueller (1994)



☆ Large $N_c \Rightarrow$ Fock state expanded on dipole basis

$$|r> = |r>_{bare} + \int d^2r \;\; \psi_1(r')|r-r', r'> + \ldots$$

(longitudinal momentum variable understood)

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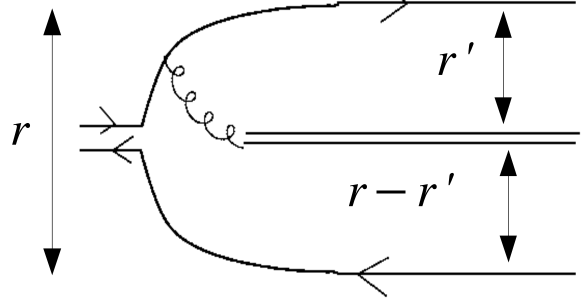

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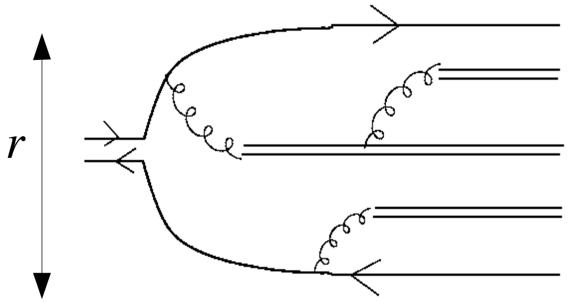

☆ Each dipole becomes the seed of a new ***independent*** evolution

[large N_c + leading log $(1/x)$]

tree structure $\Rightarrow$ dipole number density $n(Y) \sim \sum |\psi_n(r)|^2 \sim e^{\lambda Y}$

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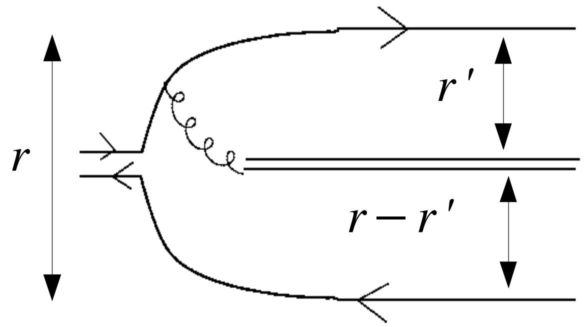

* Large $N_c \Rightarrow$ Fock state expanded on dipole basis

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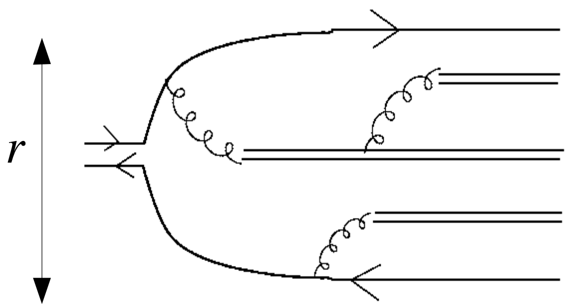

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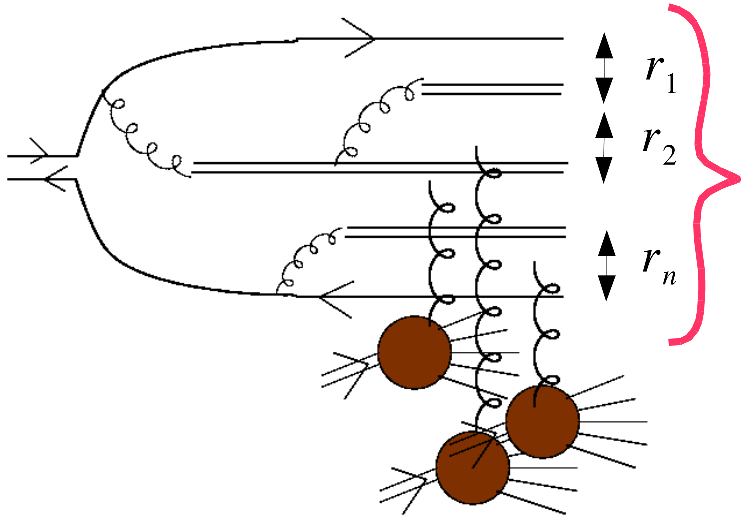
* Detailed calculation: n obeys the BFKL equation

$$\partial_Y n(Y,r) = \frac{\overline{\alpha}}{2\pi} \int d^2 r' \frac{r^2}{r'^2 (r-r')^2} \big(n(Y,r') + n(Y,r-r') - n(Y,r) \big)$$

branching probability — newly created dipoles — destroyed dipoles

Physical observables



$\omega(Y) =$ dipole configuration $(r_1, \ldots, r_n)$ at rapidity Y

$T(\omega) =$ amplitude for scattering of ω at zero rapidity

$= 1 - S(r_1, \ldots, r_n) = 1 - S(r_1) \ldots S(r_n)$

if the dipoles interact ***independently!***

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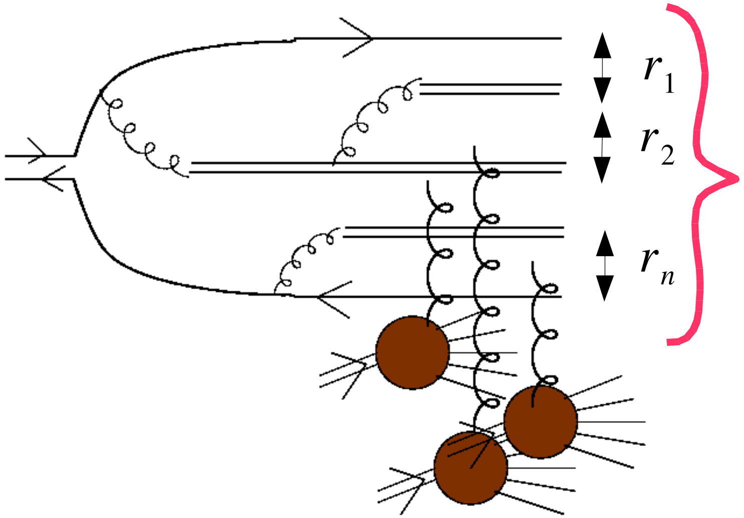

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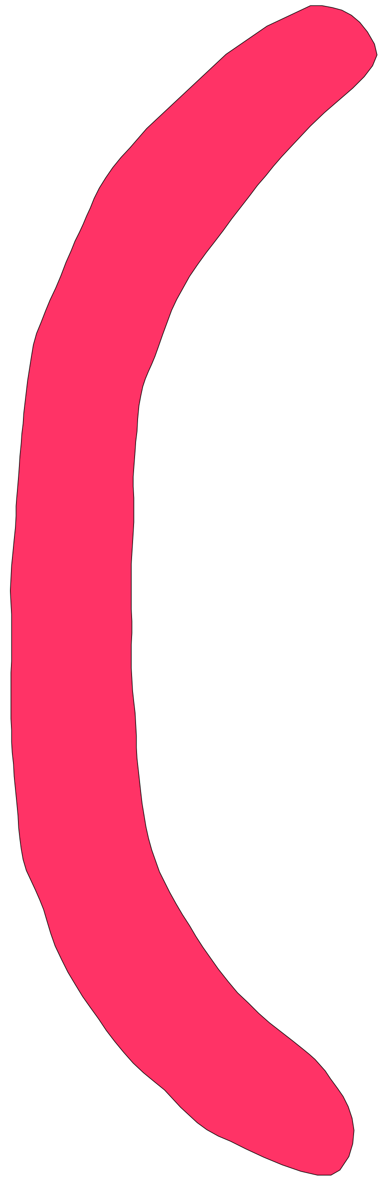
- Total: $\frac{d\sigma_{tot}}{d^2 b} = 2 \langle T(\omega) \rangle_{\omega(Y)}$
- Elastic: $\frac{d\sigma_{el}}{d^2 b} = \langle T(\omega) \rangle^2_{\omega(Y)}$
- Diffractive: $\frac{d\sigma_{diff}}{d^2 b} = \langle T^2(\omega) \rangle_{\omega(Y)}$
- Dissociative: $\frac{d\sigma_{dissoc}}{d^2 b} = \langle T^2(\omega) \rangle_{\omega(Y)} - \langle T(\omega) \rangle^2_{\omega(Y)}$

diffraction – elastic

Good, Walker (1960);
Miettinen, Puplin (1978)



Diffractive *vs* total cross sections (I)

From this picture, a straightforward calculation shows that ***up to the initial condition*** the ***total*** and the ***diffractive*** cross sections obey the same nonlinear equation,

the BK equation

Balitsky (1996); Kovchegov (1999)

$$\partial_Y N(Y,r) = \frac{\bar{\alpha}}{2\pi} \int d^2r' \frac{r^2}{r'^2 (r-r')^2} \Big(\underbrace{N(Y,r') + N(Y,r-r') - N(Y,r)}_{\text{BFKL}} - \underbrace{N(Y,r')N(Y,r-r')}_{\text{tames the growth when } N \text{ is of order 1}} \Big)$$

$N = \sigma_{tot}$ or σ_{diff}

BFKL

tames the growth when *N is* of order 1

Diffractive *vs* total cross sections (II)

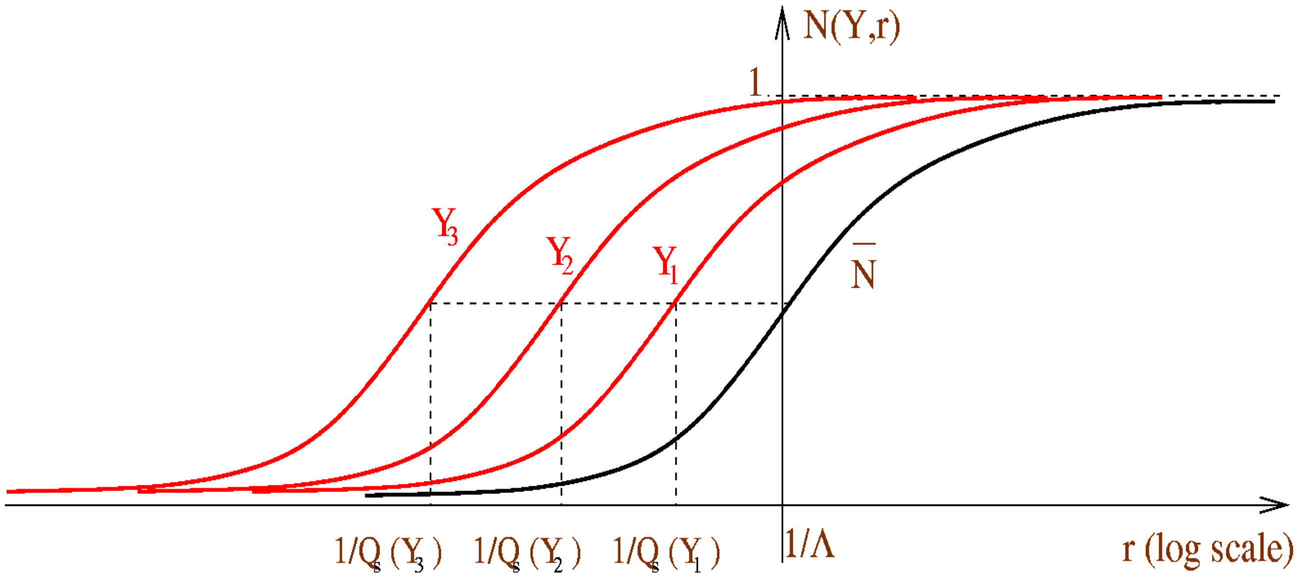
Solving BK

Asymptotic solution: traveling waves

S.M., Peschanski (2003,2004)

$$N(Y,r) = N\left(\log r^2 - \log 1/Q_s^2(Y)\right)$$

Also seen on numerical solutions:
Braun (2000); Levin, Lublinsky (2001);
Golec-Biernat, Motyka, Stasto (2002);
Albacete, Armesto, Kovner, Salgado, Wiedemann (2003)



$Q_s(Y) =$ saturation scale
$=$ typical momentum
of exchanged gluons

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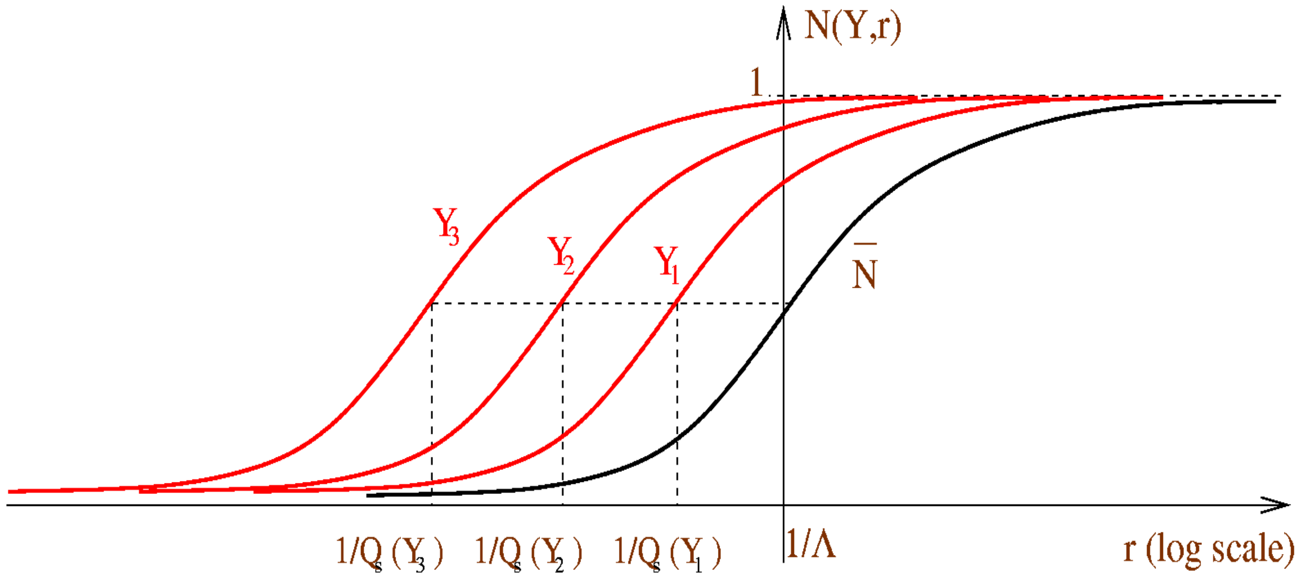

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The asymptotic solutions are in general **NOT** independent of the initial condition
except for a particular class of initial conditions
Both the **diffractive** and the **inclusive** cross sections belong to that class.

Diffractive *vs* total cross sections (III)

That might explain why the
ratio diffractive/total appears independent
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✔ Yes, for total diffraction and large Y but...

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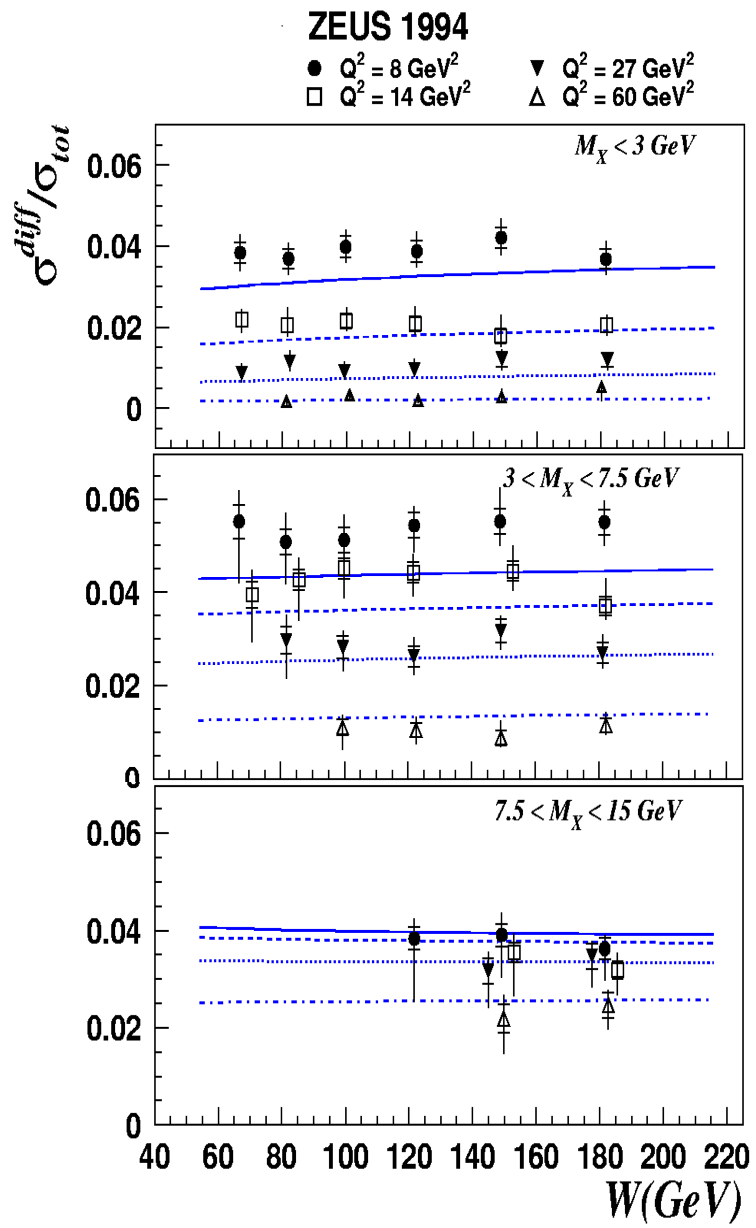
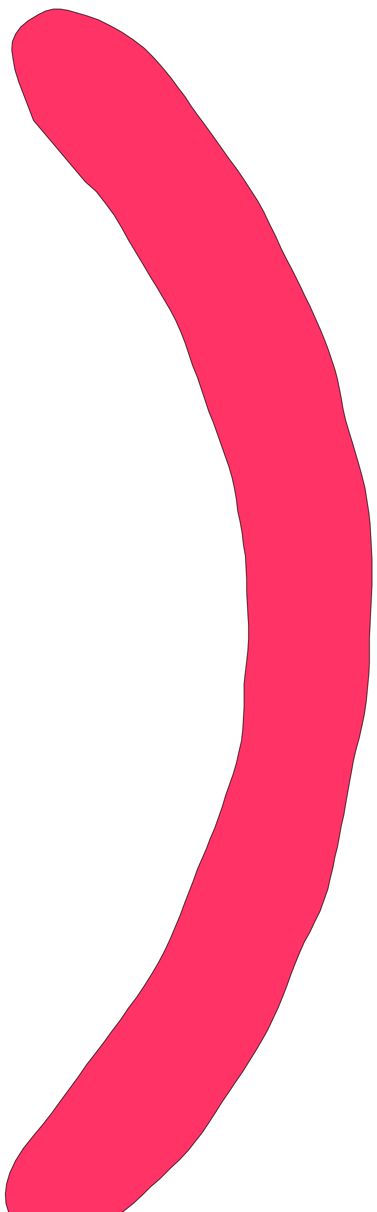


That might explain why the ratio diffractive/total appears independent of the energy?

✔ Yes, for total diffraction and large Y but...
✗ not in bins of M_X^2 ! Subasymptotics?

See also Kovchegov, Levin (1999);
Numerical work: Levin, Lublinsky (2001)



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High mass diffraction

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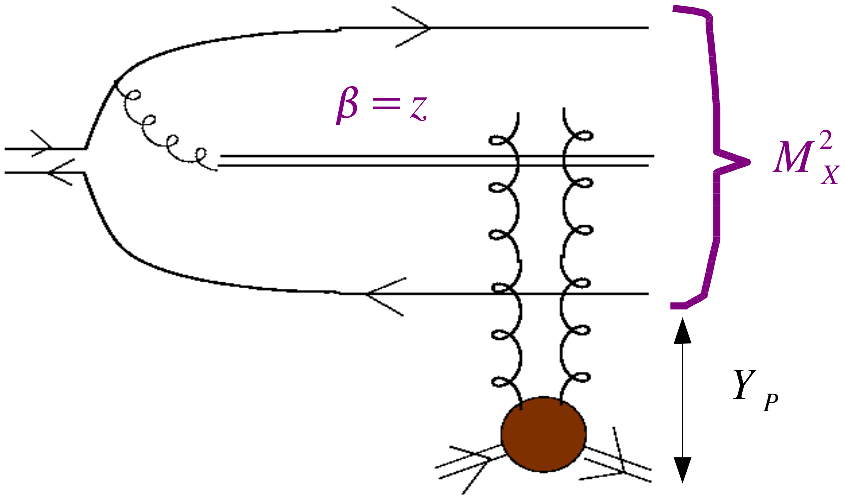
$$M_X^2 \gg Q^2\,, \quad Q_s^2 \sim Q^2$$



Frame chosen such that the diffracted system comes from the evolution of the wavefunction of the onium

Apply Good-Walker with one 1 gluon in the Fock state

rapidity gap

$$\frac{d\sigma_{dissoc}}{d^2b\,d\beta} = \frac{\alpha_s N_c}{2\pi^2} \int d^2r' \frac{r^2}{r'^2 (r-r')^2} \big(S(r', Y_P) S(r-r', Y_P) - S(r, Y_P) \big)$$

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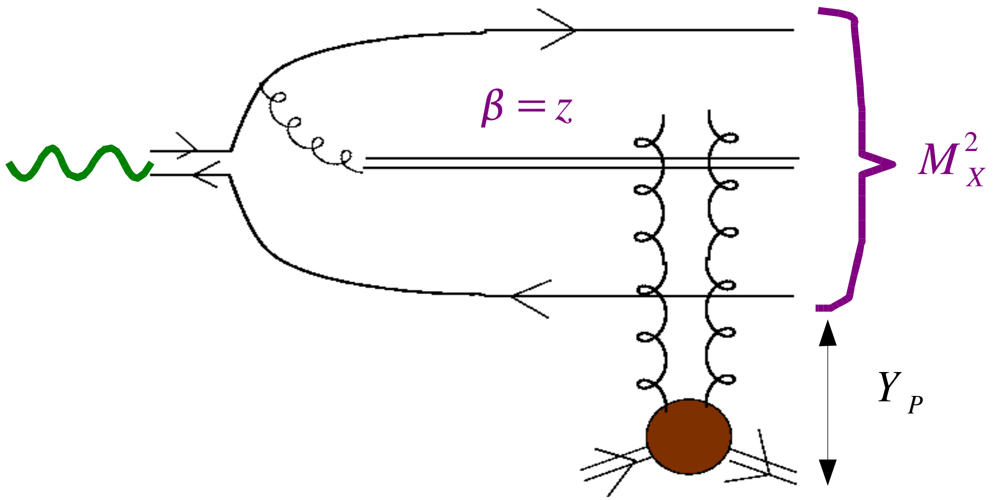

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$$\frac{d\sigma^{\gamma}_{dissoc}}{dM_X} = \frac{2}{M_X} \int d^2 r \int dz |\psi(z,r)|^2 \int d^2 b \frac{d\sigma_{dissoc}}{d^2 b\, d^2 \beta}$$

Phenomenology

$$\frac{d\sigma^{\gamma}_{dissoc}}{dM_X} = \frac{\alpha_s N_c}{\pi^2 M_X} \int d^2 r \int dz |\psi(z,r)|^2 \int d^2 b \int d^2 r' \frac{r^2}{r'^2 (r-r')^2} \left(S(r', Y_P) S(r-r', Y_P) - S(r, Y_P) \right)$$

neglect *b*-dependence gives an overall factor

e.g. Golec-Biernat Wüsthoff (elastic) *S*-matrix or full color glass condensate

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Golec-Biernat-Wüsthoff model for *S*:

Golec-Biernat, Wüsthoff (1999)

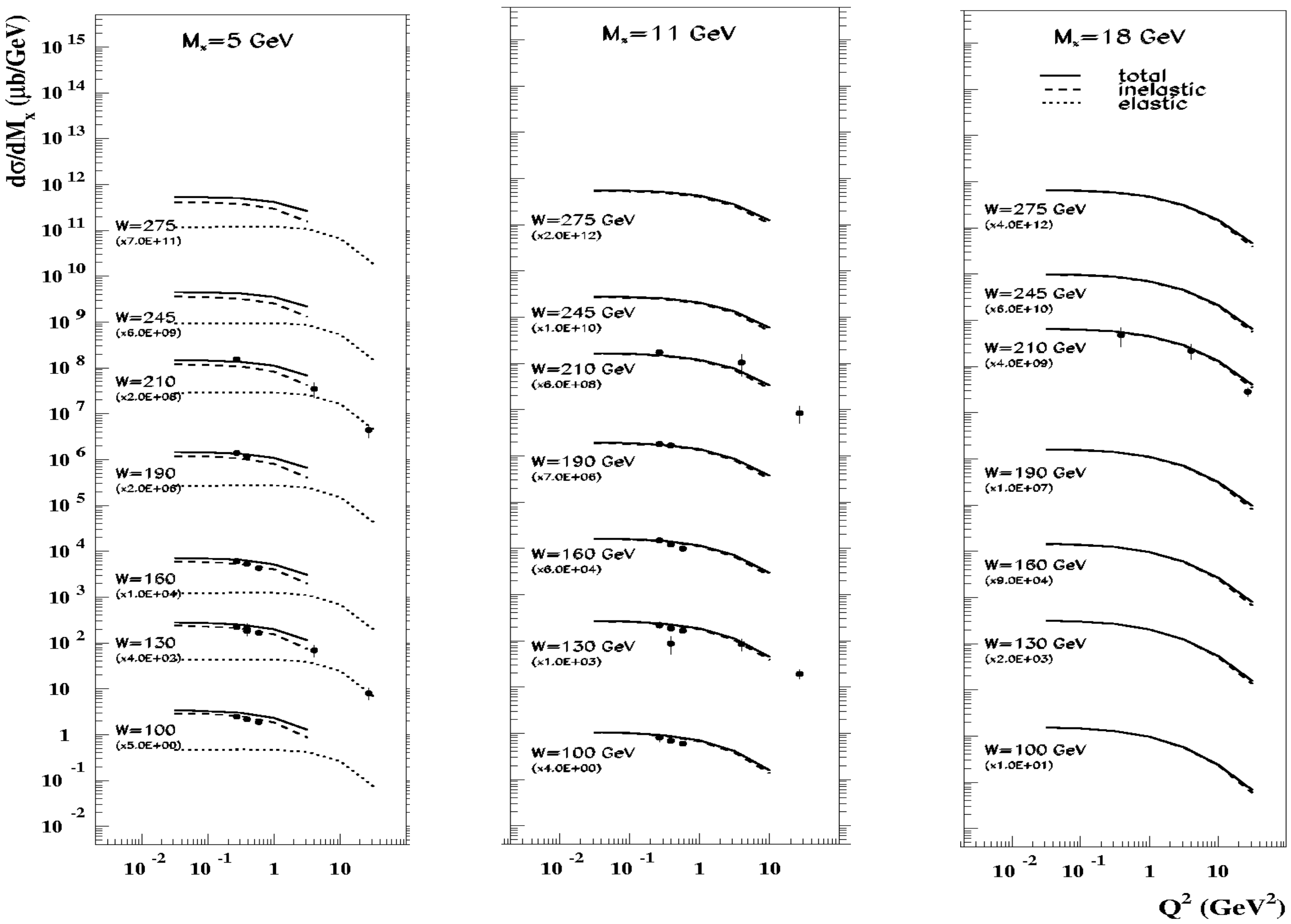
$$S(r,Y_P) = \exp\left(-\frac{r^2 Q_s^2(Y_P)}{4} \right)$$

$$Q_s^2(Y_P) = \left(\frac{x}{x_0} \right)^{-\lambda} \text{GeV}^2$$

- 2 parameters only for *S* fixed from a fit to inclusive cross sections+overall normalization
- Saturation scale at 1 GeV at HERA: a scale high enough to justify a perturbative treatment of the diffracted system?

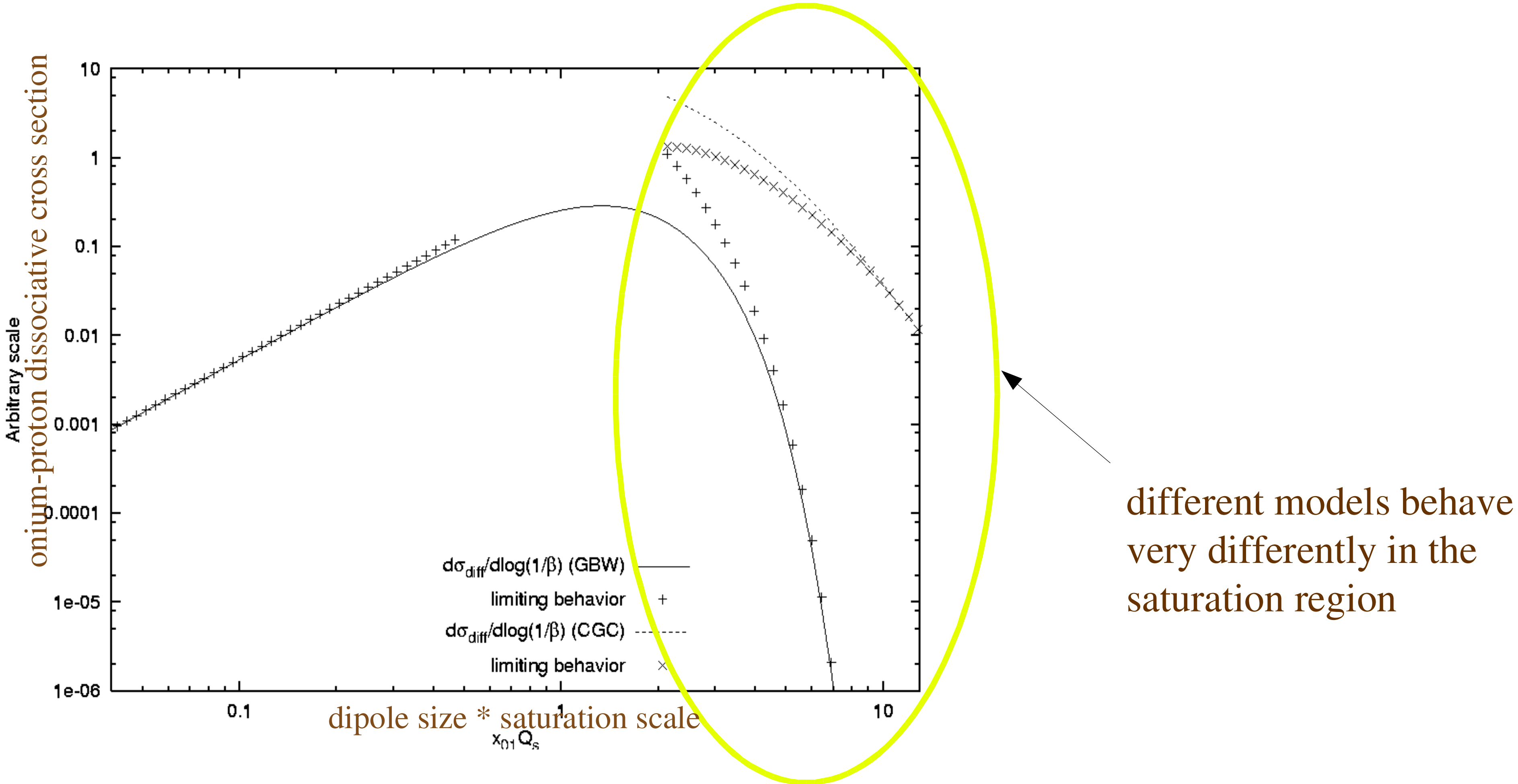
Validity: $Y_P \gg 1, \ \beta \ll 1$

Comparison to the HERA data



Data: ZEUS (2002)

A more discriminative observable?



But it is smeared by the photon wave function

only an observable like $\frac{d\sigma^{\gamma}_{dissoc}}{dQ^2}$ can discriminate

See also Gay Ducati, Gonçalves, Machado (2001)

Summary

Theory:

- ✔ formulation of photon dissociation in the saturation regime in terms of the dipole model
- ✔ a specific formulation is needed (previous approaches are not appropriate)
- ✗ such a formulation may help to understand the ratio diffractive/total?

Bartels, Ellis, Kowalski, Wüsthoff (1999)

Phenomenology:

- ✔ one free-parameter description of the new HERA data

Summary

and outlook

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Phenomenology:

- ✔ one free-parameter description of the new HERA data

Outlook:

- ✔ impact parameter dependence could be important
- ✔ take account of the transverse momentum of the produced gluons
- ✔ add more gluons in the final state?
- ✔ more exclusive observables could help discriminating saturation models