Large momentum transfer hard diffractive processes at HERA and LHC

$\gamma\,(\gamma^*) + p \rightarrow J/\Psi + \text{rapidity gap} + X$

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based on B.Blok, L. Frankfurt,M.Strikman

arXiv hep-ph 1001.2469 (Eur. J. of Physics C, **C67:99-109,2010**) and

hep-ph 1002.3048 (**Phys.Lett.B690:159-163,2010)**

Low x 2010 Kavala Greece

This process has basic advantages: a clear experimental signal and a possibility to calculate the two cross-section in pQCD. Recently a new experimental data became available on energy dependence of the cross-section of this process that contradicted to previous theoretical analysis. This lead us to study in detail the energy dependence of these processes for kinematic range of HERA and ultra-peripherhral processes at LHC

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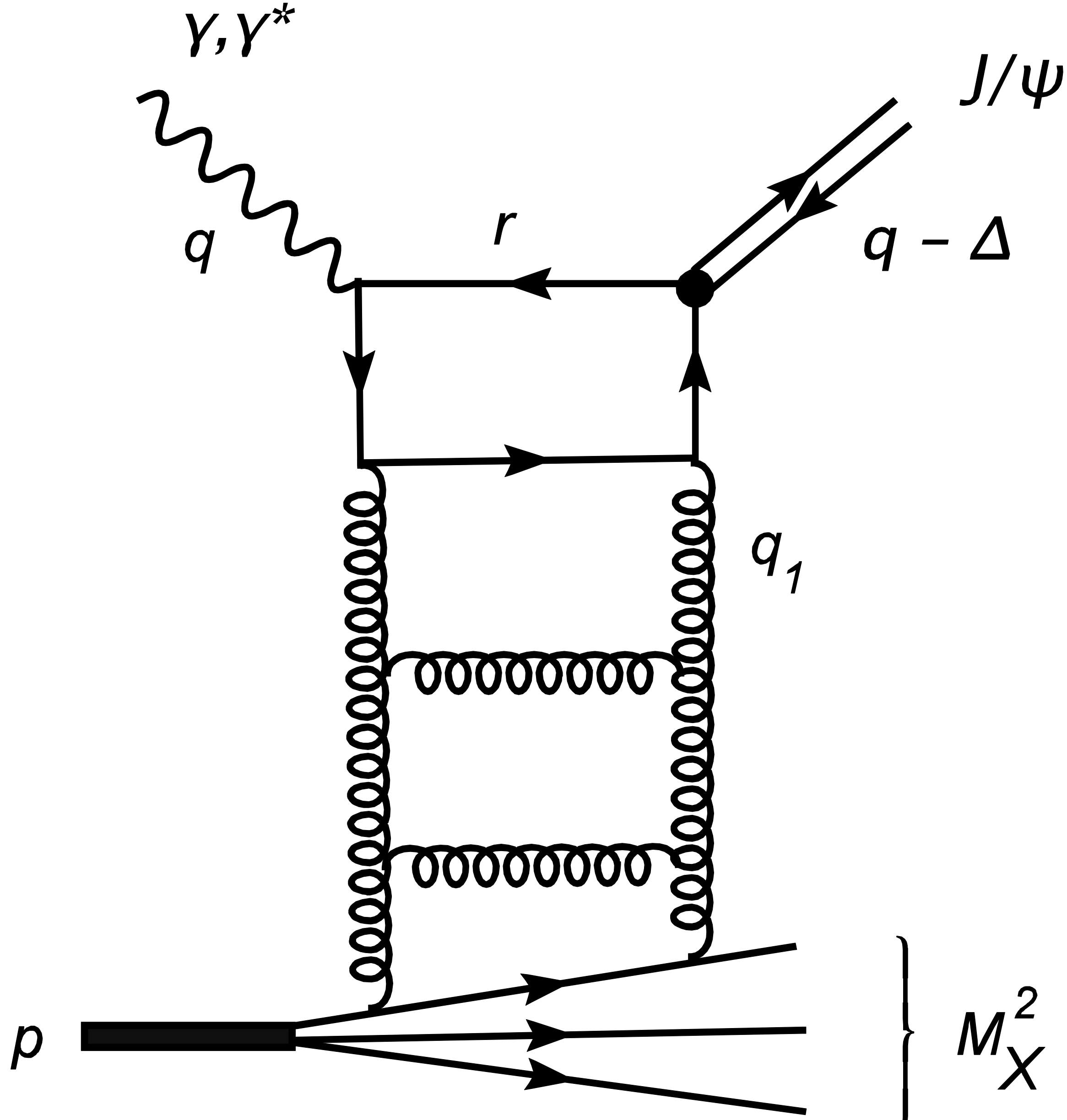
Main results

1) We study in detail the energy dependence of a double and single differential cross-sections $d\sigma/dt$, $d\sigma/(dtdx\_J)$
in the DGLAP framework, including a running coupling constant. In addition we obtain evolution equations for nondiagonal parton distributions (nonzero –t). We work in a trpple pomeron limit. Our results give all dependence on energy, invaraint masses M^2_X and x_J while leaving undetermined overall coefficient depending only on momentum transfer –t.. This coefficient depends on details of the quarkonium wave function.
2) We are able to explain, using tripple-reggeon kinematics
the recent experimental results at HERA, in particular the increase of the rate of energy increase of the total cross-section with –t. We argue that perturbative pomeron/multiRegge gluons do not give any contributions at HERA, and all experimental data can be explained in DGLAP approximation.
3)We see that in the DGLAP approach in a model-independent
way and in all orders of perturbation theory the double diffeential cross-section is independent of energy for momentum transfer $-t>M^2_V$ where V is the vector meson under question. On the other hand this cross-section is strongly dependent on energy if we take into account multiRegge gluons. This makes the observation of these processes

a **Golden Plate** for finally observing perturbative (BFKL, resummed models) pomeron experimenatlly in unambiguous way.
I This process that will be observed already at the first year of LHC

Contents:

1) calculations details
2) DGLAP answer
3) comparison with experimental data
4) double logs versus perturbative pomeron
5) conclusion



γ,γ*
q
r
J/ψ
q − Δ
q1
p
M2X

Kinematics:

$$-t_{\min} = (M_X^2 - m_p^2)(M_V^2 + Q^2)/2s. \qquad x_J = -t/(M_X^2 - m_p^2 - t),$$

$$\delta y = \ln \frac{s}{\sqrt{(M_V^2 - t)(M_X^2 - t)}}.$$

For the double differential cross section we have in the tripple pomeron limit (Frankfurt,Strikman 1989)

$$\frac{d\sigma}{dt dx_j} = \frac{d\sigma_{\gamma+j\to V+j}}{dt}\left((81/16)G(x_J,t) + \sum_i (q_i(x_J,t) + \bar{q}_i(x_J,t))\right).$$

Here the first factor is a convolution of the impact factor and non-diagonal gluon distribution D^G_G

$$\frac{d\sigma}{dt} = \frac{|f|^2}{16\pi}$$

It is possible to prove that although we must, strictly speaking use here the generalised parton distribution with

$$x_1 = (M^2 + Q^2)/(s' + Q^2); x_2 = (M^2 - M_V^2)/(s' + Q^2)$$

with a good accuracy we can use nongeneralized D with x=(x1+x2)/2

Ladder calculation. The calculation proceeds in two steps: first, we calclate the nondiagonal ladder with a fixed coupling constant. The calculations show that only one tensor structure gives rise to log contributions:

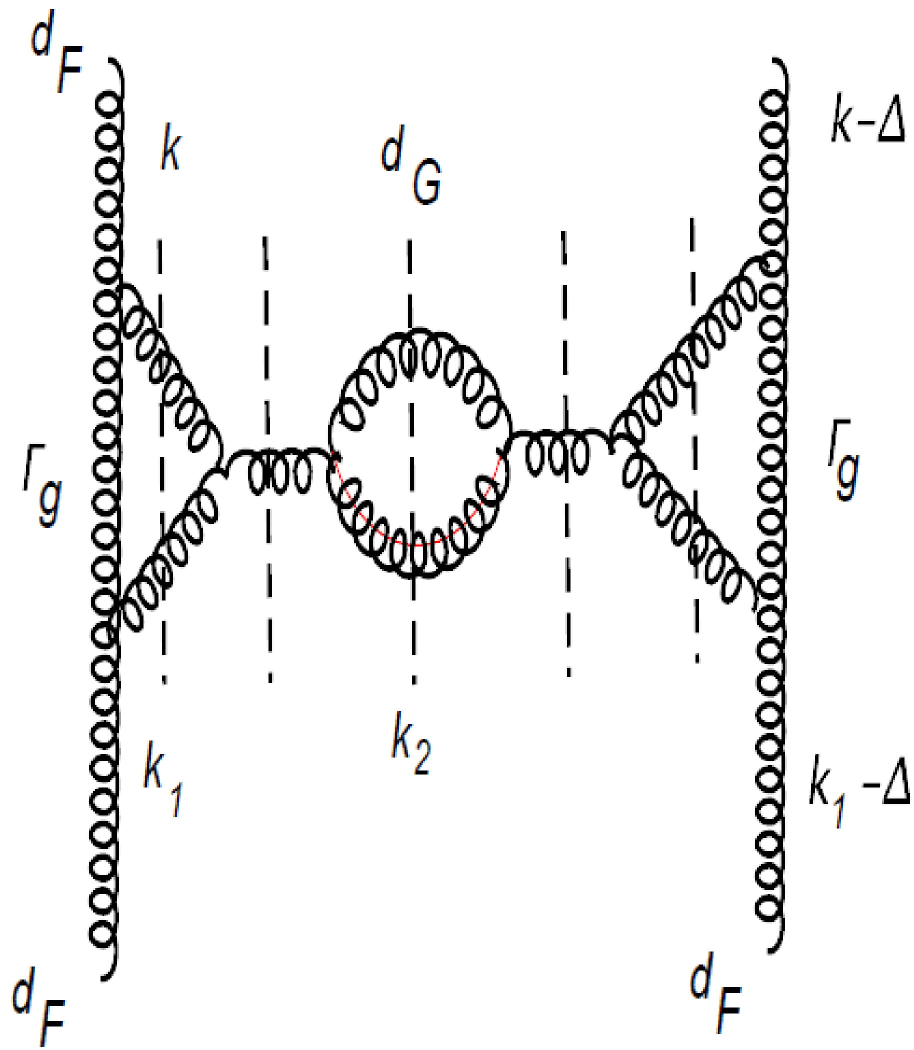
$$g^t_{\mu\nu} \equiv g_{\mu\nu} - (p^\nu q^\mu + p^\mu q^\nu)/pq$$

the same as for the diagonal case. The final answer is the same as in the DGLAP ladder, with the change of the transverse integral in the ladder cell, that now becomes :

$$I(\Delta) = \frac{1}{2\pi}\int d^2k_t \left[\frac{1}{(\vec{k}_t - \vec{\Delta})^2} + \frac{1}{k_t^2} - \frac{\Delta^2}{k_t^2(\vec{\Delta} - \vec{k}_t)_t^2}\right]$$
$$= \log(Q^2)/(Q_0^2 - t)) + \text{non logarithmic terms},$$

(the answer coincides with the previous work (i.e. Bartels, BFKL) for fixed coupling constant, though it was used for different processes)

The second step is the inclusion of the running coupling constant (renormalistion of the ladder) Running coupling constant; we follow the DDT(Diakonov,Dokshitzer,Troyan, 1981) approach to take into account the renormalisation.



Summing all the cuts and taking into account the structure of the transverse integral for the nondiagonal ladder we obtain that the effect of nonzero –t is the replacement of the argument in the DGLAP evolution equations:

$$\int_{-t}^{Q^2} d^2k_t \alpha_s(k_t^2)/k_t^2 \equiv \chi' = \frac{1}{b}\log\left(\frac{\log(Q^2/\Lambda^2)}{\log(-t+Q_0^2)/\Lambda^2}\right),$$

$$\alpha_s(k_t^2) = \frac{4\pi}{b\log(k_t^2/\Lambda^2)}, b = 11 - 2N_f/3.$$

For t=0 we obtain the familiar argument of the DGLAP equation, As a result the solution of the evolution equations for the Nondiagonal ladder (nonzero –t) has the same functional form as for usual DGLAP, with the change of argument. In particular in DLA we obtain for gluon distribution In a gluon D needed for us an expression:

$$xD(x, Q^2, Q_0^2, t) = 8N_c\chi' I_1(u)/u,$$

$$u = \sqrt{16N_c \log(x/x_J)\chi'}.$$

The only remaining ingredient that is needed is an impactfactor.

However it is easy to prove that

since

$$r^2 \sim (Q^2 + M_V^2)/4$$

For characteristic momenta in the impact-fatcor, the energy dependence in the energy dependence factors out, and is fully determined by the non-diagonal ladder described above. The impact-factor gives only an overall t-dependent factor

•The final answer:

We now have all ingredients to write the final answer for the differential cross-section in the DGLAP approximation:

$$\frac{d\sigma}{dt dx_J} = \Phi(t, Q^2, M_V^2)^2 \frac{(4N_c^2 I_1(u))^2}{\pi u^2} G(x_J, t).$$

$$u = \sqrt{16 N_c \log(x/x_J)\chi'}, \chi' = \frac{1}{b}\log(\frac{\log((Q^2+M_V^2)/\Lambda^2)}{\log(-t+Q_0^2)/\Lambda^2}),$$

$$x_J = -t/(M_X^2 - m_p^2 - t), x \sim 3(Q^2+M_V^2)/(2s),\ b = 11 - 2/3N_f, N_c = 3, s = W_{\gamma p}^2$$

For $-t \leq Q^2 + M_V^2$ and

$\frac{d^2\sigma}{dx_J dt} = \text{const.}$ for $-t \geq M_V^2$

Comparison with experimental data •

Our results clearly show that in DGLAP approximation the rate of increase of differential cross-section with energy decreases with the increase of the energy transfer –t This seems to be in contradiction with a new experimental data from HERA that seem to show the opposite dependence on -t

S. Chekanov *et al.* [ZEUS Collaboration], arXiv:0910.1235 [hep-ex].

The result is however easily explained if we take into account
1) the actual experimental results are not for the double differential cross-section that we calculated, but for the total cross-section integrated with energy dependent cuts:

$$\frac{d\sigma(s,t)}{dt} = \int_{B(s)}^{A(s)} dM_X^2/(M_X^2-t)^2 d^2\sigma/(dtdx_J)(x_J,s,t)$$

$$A(s) = 0.05s-t, B(s) = 1\ \mathrm{GeV}^2,$$

In particular for large –t they actually measure

$$\frac{d\sigma(s,t)}{dt} = U(t)\int_{B(s)}^{A(s)} G((-t/(M_X^2 - t),t)dM_X^2 .$$

i.e. the integral of the structure function.

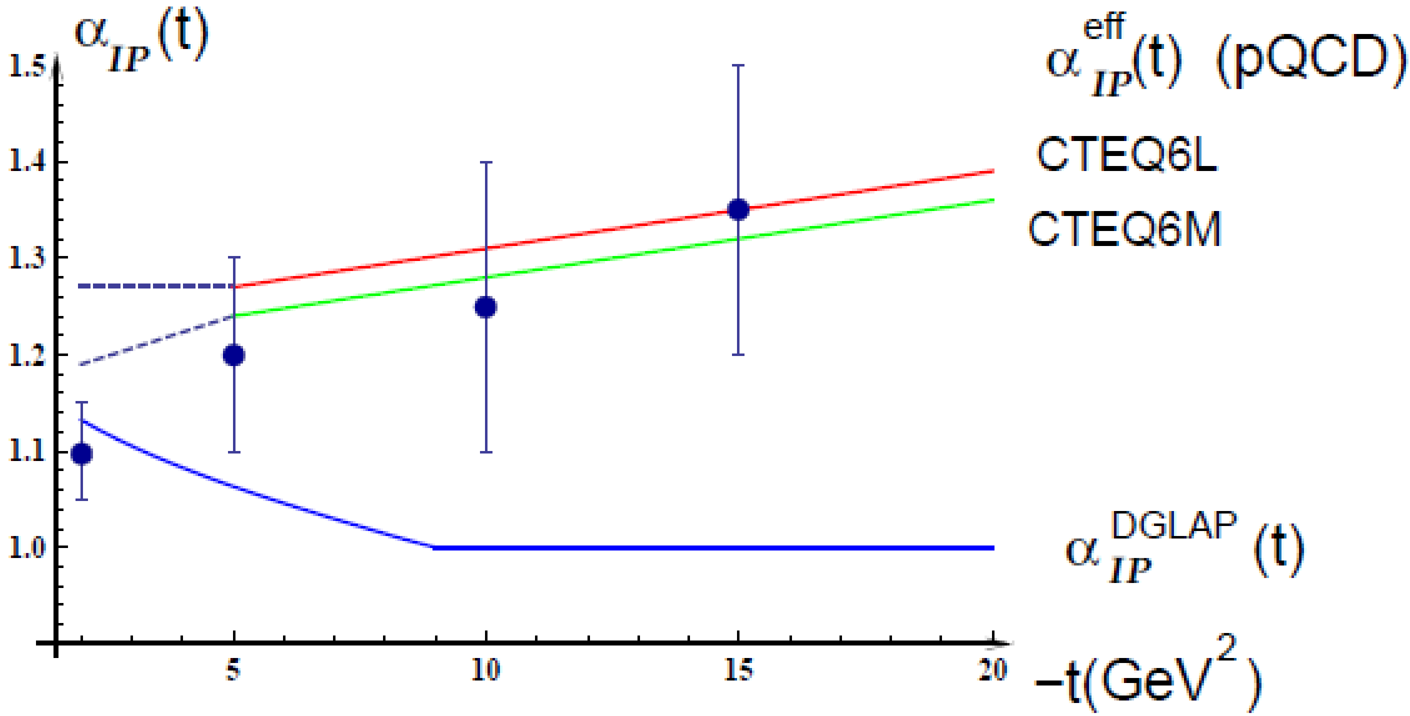
(2) The structure function increase rate strongly depends on –t,
i.e xG(x,t) increases with energy as (x<0.01).

$(x_0/x)^{\kappa(Q^2)}$, the exponent $\kappa(Q^2)$ is increasing with virtuality $\kappa(Q^2) = 0.048\log(Q^2/\Lambda^2)$

We have claculated the logarithmic derivative

$$I(s,t) = \frac{1}{2} d\log(d\sigma/dt)/dlog(s)$$

And compare it to the experimental data



the HID cross section at HERA for the "effective Pomeron" $\alpha_P^{\rm eff}(t)$, i.e. (1/2) logarithmic derivative of the cross section $d\sigma/dt$, obtained after integrating between the energy dependent cuts, as given in the text. The dashed curve means large theoretical uncertainties in the corresponding kinematic region. The values are given at for $W_{\gamma p} = 150$ GeV. In the same figure we depict also "true (DGLAP) "Pomeron", i.e. logarithmic derivative $\alpha_P(t)^{\rm DGLAP}\ 0.5\frac{d(d\sigma/)dtdx_J))}{dlog(x/x_J)}$ at this energy. $\Lambda_{\rm QCD} = 300$ MeV.

Good agreement between experimental data and DGLAP

DGLAP versus BFKL

1. HERA-we have seen that the experimenatl data on hard diffraction is in a good agreement with the DGLAP results

No need for BFKL contribution. The reason is probably simple:

The radiation of multiRegge gluons demands a large longitudinal phase space, i.e. 2-2.5 units in rapidity for each radiated gluon.

This results follows both from the NLO calculation and the success of the veto based approaches (Frankfurt,Strikman 1999,

C. Schmidt 1999, Ross,Forshaw,Sabio Vera 1999)

This result is in good agreement with the resummed models that show that there is a large interval in rapidity where DGLAP dominates).

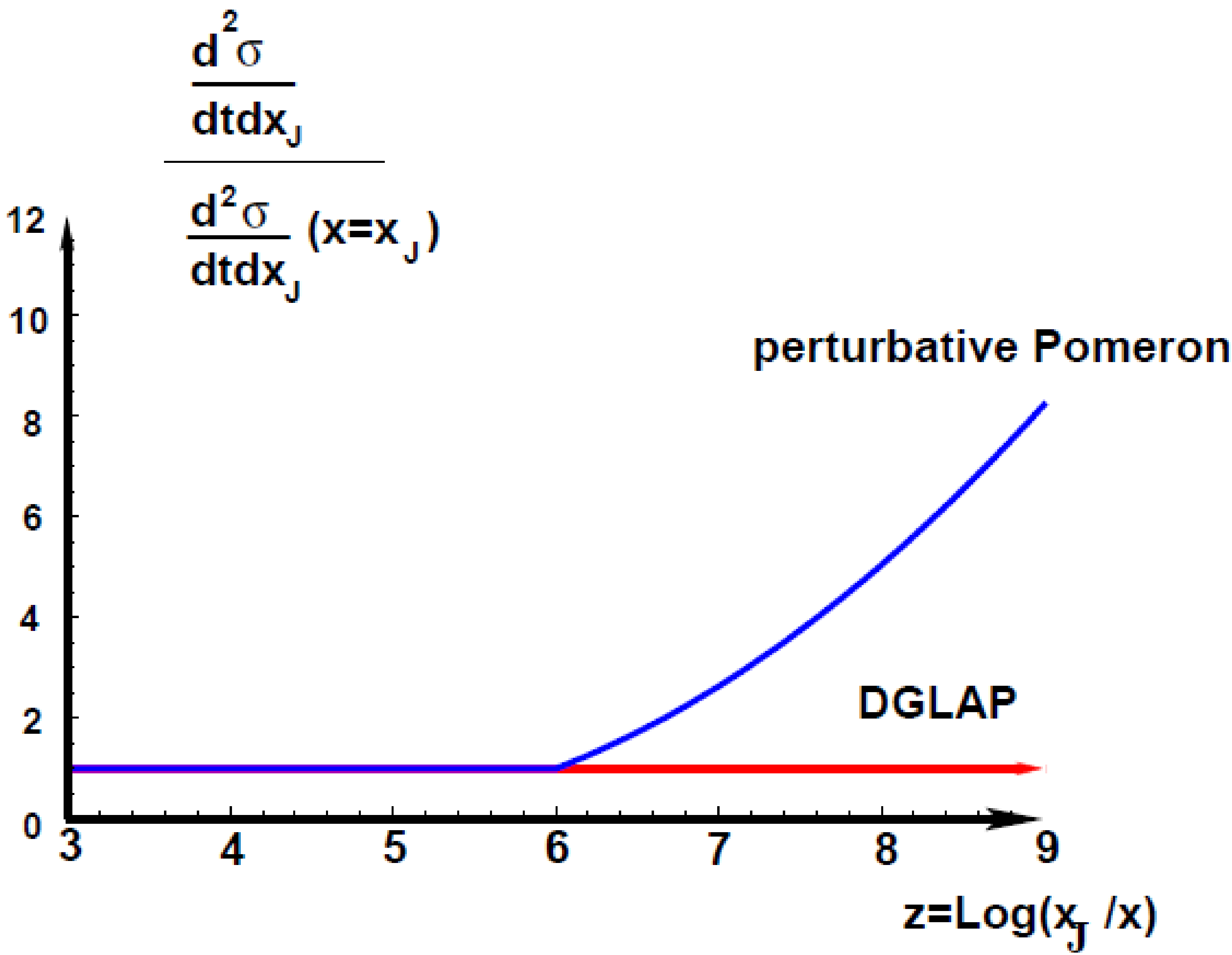
For HERA kinematics we have at most 4-5 units in rapidity ladder,i.e. at most one MR gluon can be radiated giving at most logarithmic correction to the DGLAP results.

2. On the other hand at ultra-peripheral processes in LHC, for the region

$-t > M_V^2$

In DGLAP approximation the double differential cross-section Is energy independent, while if the perturbative pomeron exists, It will rapidly increase with energy, thus enabling first unambiguous observation of perturbative pomeron

(a Golden Plate process)



$\frac{\frac{d^2\sigma}{dtdx_J}}{\frac{d^2\sigma}{dtdx_J}(x=x_J)}$
12
10
8
6
4
2
0
3
4
5
6
7
8
9
perturbative Pomeron
DGLAP
z=Log(x_J /x)

•Conclusions:

•1. We derived the excplicit formula for the differential cross-section of the hard diffraction processes with large rapidity gap in the DGLAP approximation using the tripple pomeron limit (pQCD version).

•2. We have shown that DGLAP results are in good agreement

With the recent experimental data at HERA, in particular the

Observed increase with –t of the energy increase rate of the total

Cross-section (integrated over invariant masses of produced hadrons)

•3. We have seen that the DGLAP results for the hard diffraction for $-t>M_V^2$ Includng double log gluons are in a sharp contrast with the perturbative pomeron behavior, thus allowing for the first time unambiguous observation of multiRegge gluons not spoiled by double logs.

•4. The same approach can be used for the production of other vector nesons (ρ-meson, bottomium) in the right kinematic regions.

•5. Similar results-for photon diffraction photon+p-→ photon+rapidity

•gap +X (H1, 2008) .. Hard to compare directly, the authors give only

•averaged over –t value of energy exponents (B.B., L. Frankfurt,M. Strikman, in preparation). This is another example of one scale

•Process, and have very small statistics 8249 events). Can be reanalysed

•Using above formulae