

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
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arXiv hep-ph 1002.3048
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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

Main results

1) We study in detail the energy dependence of a double and single differential cross-sections $d\sigma/dt$, $d^2\sigma/(dtdx_J)$

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 triple pomeron limit. Our results give all dependence on energy, invariant masses M_x^2 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 triple-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

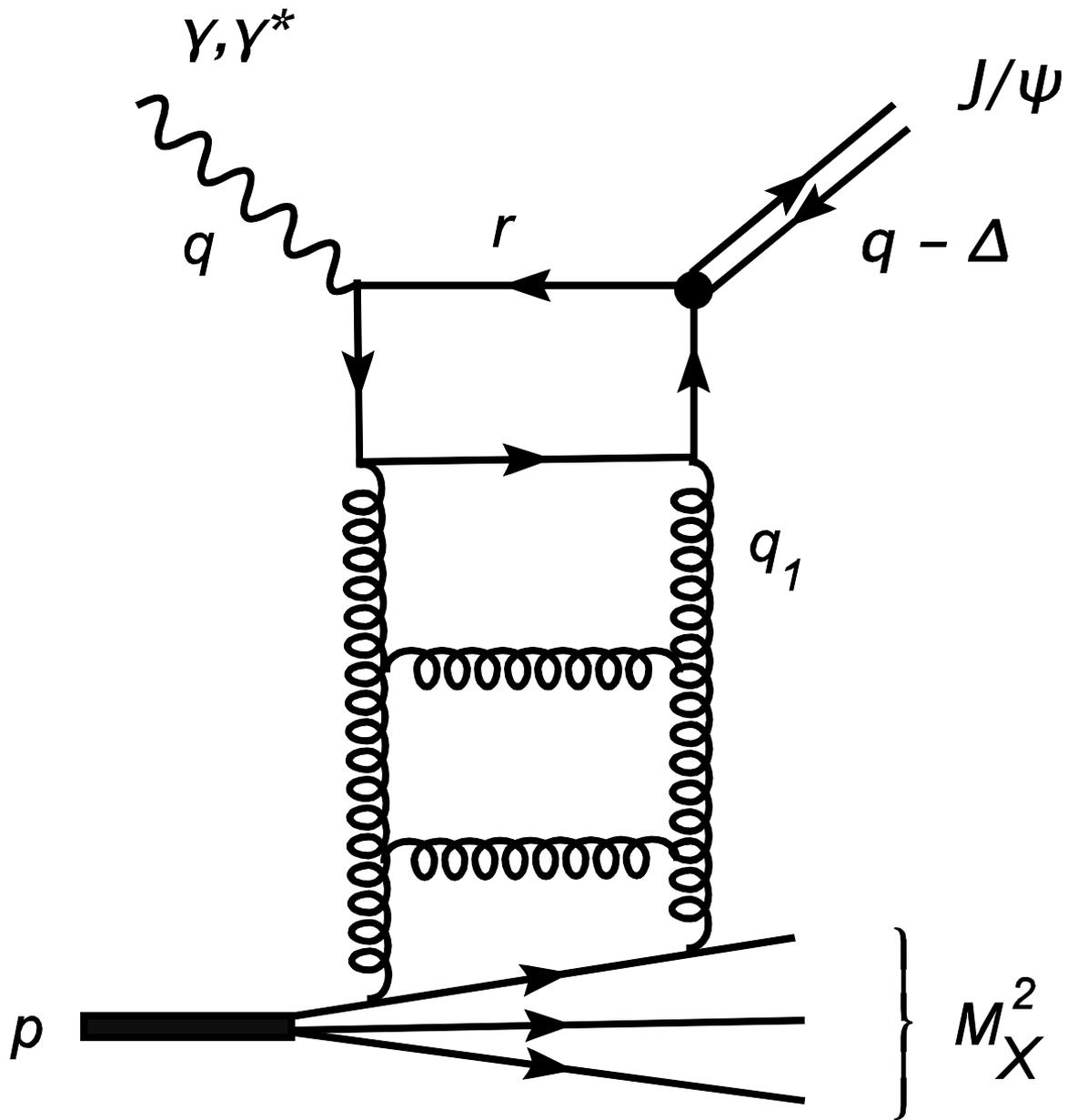
way and in all orders of perturbation theory the double differential cross-section is independent of energy for momentum transfer $-t > M_V^2$ where V is the vector meson under question. On the other hand this cross-section is strongly dependent on energy if we take into account multiRegge gluons. This makes the observation of these processes

a **Golden Plate** for finally observing perturbative (BFKL, resummed models) pomeron experimentally in unambiguous way.

| 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



:Kinematics

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

$$x_J = -t/(M_X^2 - m_p^2 - t),$$

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

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

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

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 $x=(x_1+x_2)/2$

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

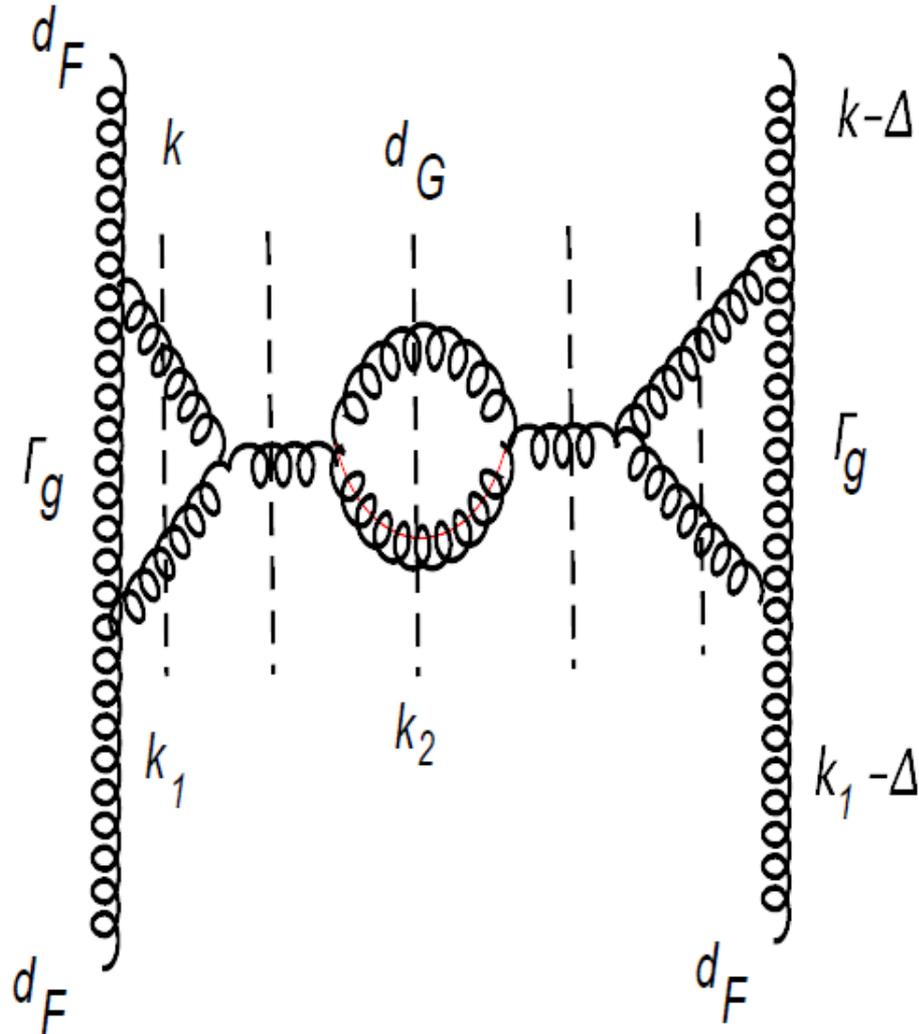
$$g_{\mu\nu}^t \equiv g_{\mu\nu} - (p^\nu q^\mu + p^\mu q^\nu)/pq$$

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 :

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

(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 (renormalisation 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-factor, 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:

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

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

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

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

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

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 the actual experimental results are not for the double differential (1) cross-section that we calculated, but for the total cross-section integrated :with energy dependent cuts

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

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

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

,The structure function increase rate strongly depends on $-t$ (2)

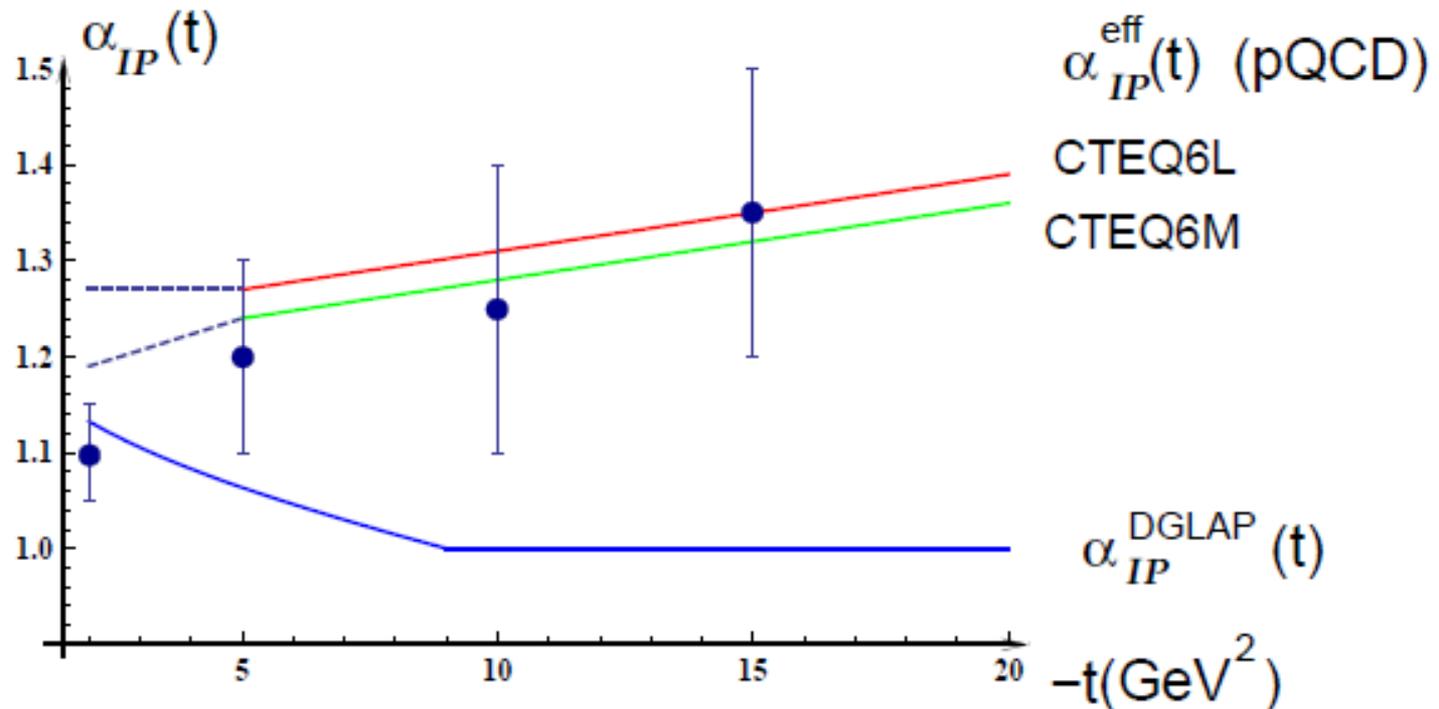
.(i.e $xG(x,t)$ increases with energy as $(x < 0.01$

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

We have calculated the logarithmic derivative

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

And compare it to the experimental data



the HID cross section at HERA for the "effective Pomeron" $\alpha_P^{eff}(t)$, 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 $x_P(t)^{DGLAP} = 0.5 \frac{d(d\sigma/dtdx_J)}{d\log(x/x_J)}$ at this energy. $\Lambda_{QCD} = 300$ MeV.

Good agreement between experimental data and DGLAP

DGLAP versus BFKL

1. HERA-we have seen that the experimental 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 multi-Regge gluons demands a large longitudinal phase space, i.e. 2-2.5 units in rapidity for each radiated gluon.

This result 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

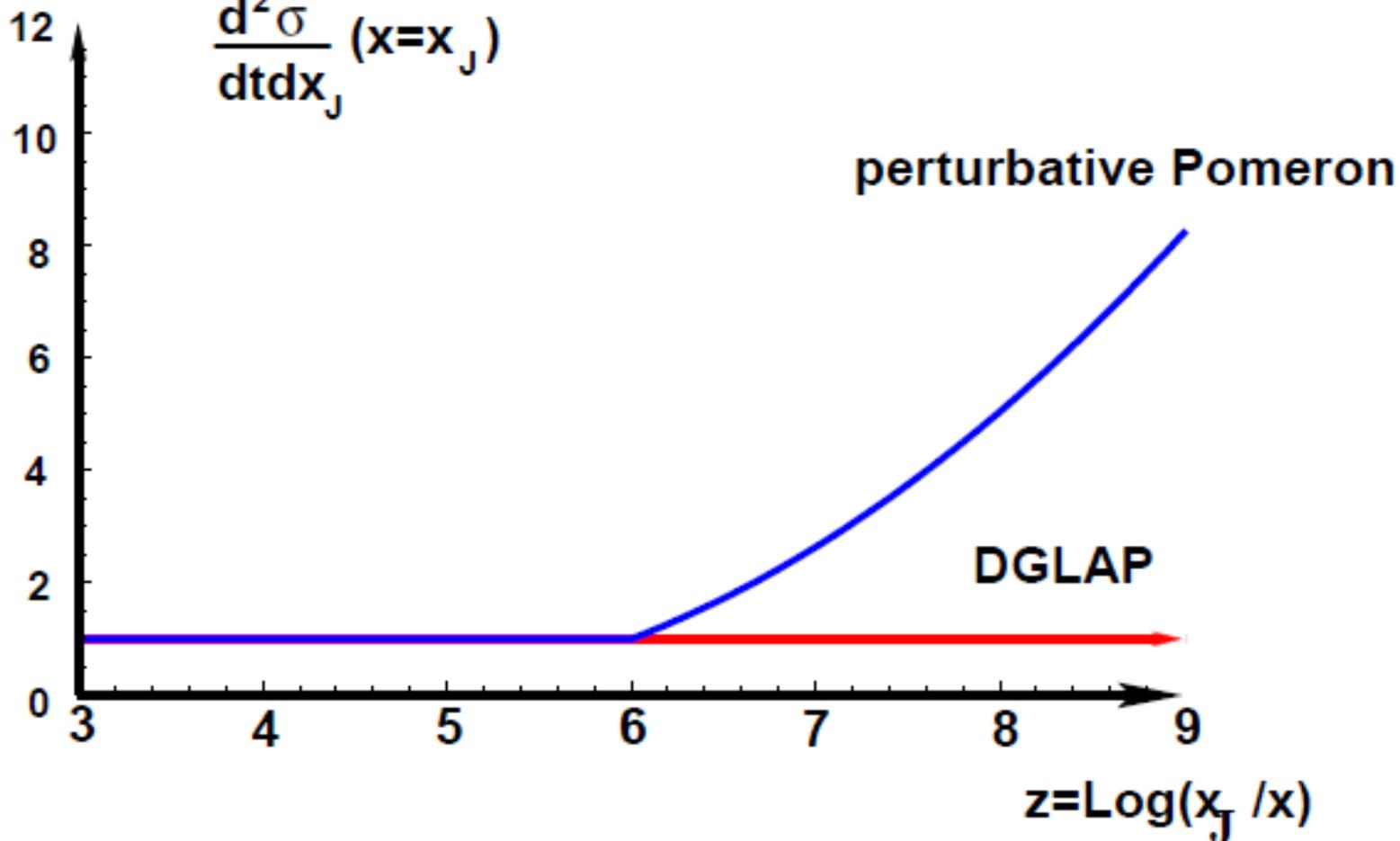
$$-t > M_V^2$$

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)

$$\frac{d^2 \sigma}{dt dx_j}$$

$$\frac{d^2 \sigma}{dt dx_j} (x=x_j)$$



•Conclusions:

- 1. We derived the explicit formula for the differential cross-section of the hard diffraction processes with large rapidity gap in the DGLAP approximation using the triple 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 $-t > M_V^2$ Including 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 mesons (ρ -meson, bottomium) in the right kinematic regions.
- 5. Similar results-for photon diffraction $\text{photon}+p \rightarrow \text{photon}+\text{rapidity gap} +X$ (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.