Low x 2009, Ischia island

Interface between soft & hard dynamics in DVCS and in vector meson production

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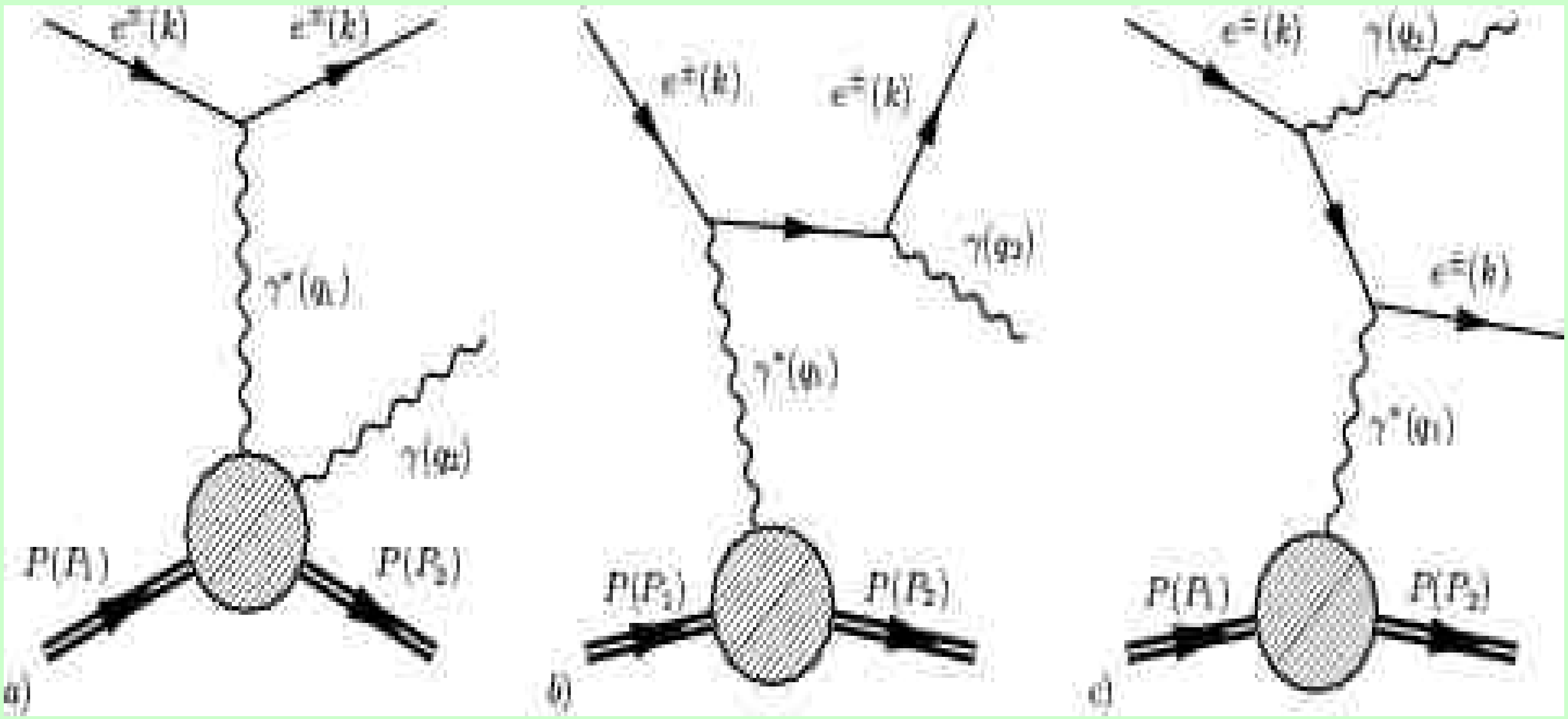
Abstract

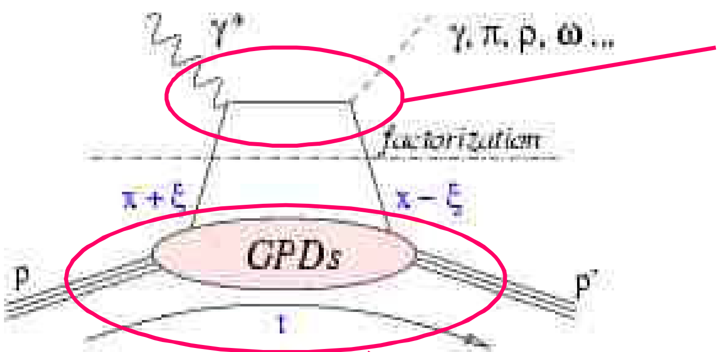
An explicit model for with a non-linear Pomeron trajectory is proposed to describe deeply virtual Compton scattering (DVCS) and vector meson production VMP). The parametrs are fitted to HERA data.

Open questions are highlighted and hints to partial answers are discussed. Are DVCS and VMP similar?

DVCS & Bethe-Heitler



QCD-factorized form of a DVCS scattering amplitude (“box” ⊗ GPD)

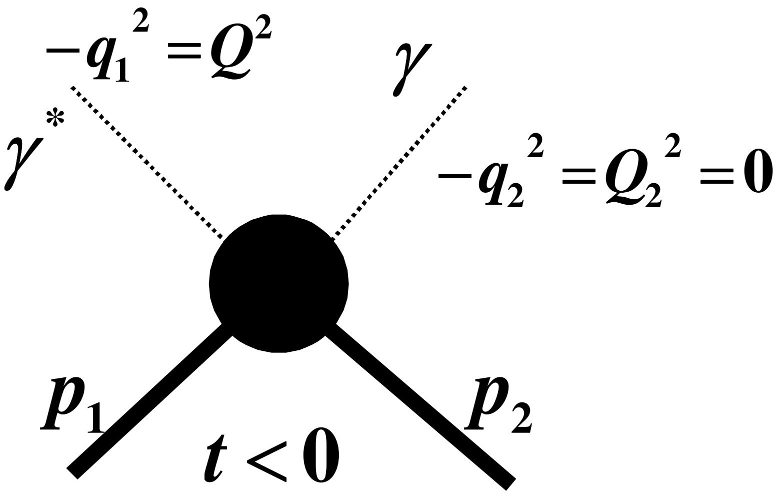


non-perturbative region

Scopes:

1. Extracting GPD;
2. Extracting the parameters of the Pomeron trajectory;
3. Studies of saturation effects in the nuclear matter at high partonic densities

DVCS kinematics



$$P = p_1 + p_2,\ q = (q_1 + q_2)/2$$

$$\Delta = p_2 - p_1,\quad t = \Delta^2$$

$$x_B = \frac{-q_1{}^2}{2p_1q_1} = \frac{Q^2}{2p_1q_1}$$

$$\xi = \frac{-q^2}{2Pq} = x_B \frac{1 + \frac{\Delta^2}{2Q^2}}{2 - x_B + x_B \frac{\Delta^2}{Q^2}}$$

$$\eta = \frac{\Delta q}{Pq} = -\xi \left(1 + \frac{\Delta^2}{2Q^2}\right)^{-1}$$

Matching soft and hard physics (combining Regge pole models and DGLAP evolution)

$$F_2(x,Q^2) \sim f(Q^2)x^{-\Delta} \leftrightarrow \exp\left(\sqrt{\ln\ln(Q^2/Q_0^2)\ln(x_0/x)}\right)$$

P. Desgrolard, L.J., and F. Paccanoni, Interpolating between soft and hard dynamics in DIS, EPJ, 7 (1999) 263;

A. Donnachie and P.V. Landshoff, *Perturbative QCD and Regge poles: closing the circle*. hep-ph/0111427, 9 Apr. 2002;

L. Csernai, L. J., J. Kontros, and A. Magas, Paccanoni*, From Regge behavior to DGLAP evolution,* Eur. Phys. **J. C24** (2002) 205-211.

A similar solution for exclusive reactions (e.g. DVCS) is highly desirable!

The basic object of the theory

$$A(s,t,Q^2)$$

$$A(s,t,Q^2=m^2) \text{ (on mass shell)}$$

$$\Im m A(s,t=0,Q^2) \sim F_2 \quad \text{DIS}$$

Reconstruction of the DVCS amplitude from DIS

$$F_2 \sim \Im m A(\gamma^* p \to \gamma^* p)\Big|_{t=0} \to \Im m A(\gamma^* p \to \gamma p)\Big|_{t=0}$$

$$\to A(\gamma^* p \to \gamma p)\Big|_{t=0} \to A(\gamma^* p \to \gamma p)$$

or

$$\Im m A(\gamma^* p \to \gamma^* p)\Big|_{t=0} \sim F_2(x_B,Q^2) = x_B q(x_B,Q^2)$$

$$q(x_B,Q^2) \to q(\xi,\eta,t,x_B,Q^2) \quad \rightarrow$$

$$\rightarrow \xi q(\xi,\eta,t,x_B,Q^2) \overset{?}{=} GPD(\xi,\eta,t,x_B,Q^2)$$

Basic inputs/assumptions (models/theories):
Factorization (QCD and Regge) :
1. QCD (x,Q^2) * f(t) (or f(b)); 2. Regge (s,t) * F(Q^2);
a) pQCD1: dipole (multipole, pancake, point-like,…);
b) pQCD2: factorized GPD (non-perturbavie)*"handle";
c) Nonperturbative (Regge poles) models.

Variables: $s = W^2, \quad t, \quad -q_1^2 = Q_1^2, \quad Q_2^2 = M_V^2,$ 0, or $l\bar{l}$ squared missing mass.

Assumptions

1: $\tilde{Q}_1^2 = Q_1^2 + M_V^2$, or $\tilde{Q}_1^2 = Q_1^2 = (Q_1^2 + M_V^2)/4$;

2. $\tilde{Q}_1^2 = Q_1^2 + M_V^2 - t$;

"Hardening" both in t and in Q^2!

Alternative/coomplementary approaches to hard exclusive (s, t, Q^2, M^2)) processes: 1) Start from partonic (gluonic) desnities, e.g. (e.g. S.J. Brodsky *et al.*, Phys. Rev. D **50** (1994) 3134) $\frac{d\sigma_L}{dt}|_{t=0} \sim \alpha_S(Q^2)[xg(x,Q^2)]^2$, to be extended (multiplied by) some t dependence.

2) Start from an elastic on-shall scattering amplitude e.g. (A. Donnachie, P.V. Landshoff, hep-ph/0803.0686):

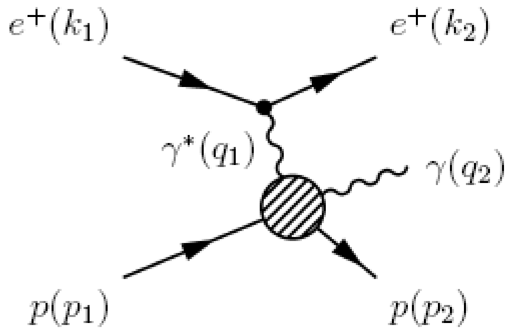
$$T(s,t) = i\sum_i X_i F(t)_A F(t)_B(t) e^{-i\pi\alpha_i(t)/2}(\nu_i)^{\alpha_i - 1},$$

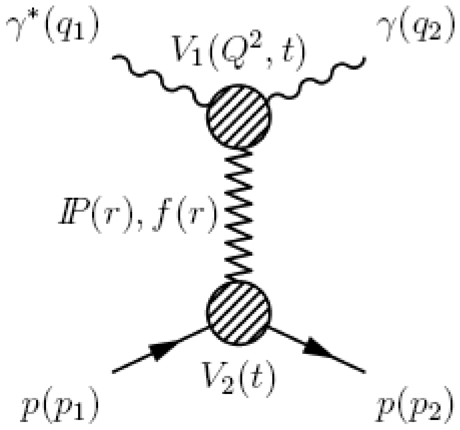
$\nu = (s-u)/2$, $\alpha_1(t) = 1.08+0.25t$, $\alpha_2(t) = 0.45+0.93t$, $F(t) = (1-t/0.5)$; $X_0 = 0.069$, $X_1 = 5.33$, $X_2 = 21.1$, extended by a Q^2-dependent multiplier, also mimmicing DGLAP evolution

The sub-process γ*p → γp in a Regge-factorized form:

$$A(s,t,Q^2) \sim V_1(Q^2,t)V_2(t)s^{\alpha(t)}$$

$r^2 = t = (q_1 - q_2)^2$ r is the four-momentum of the Reggeon exchanged in the t channel,and $s = W^2 = (q_1 + p_1)^2$ is the squared centre-of-mass energy of the incoming system.





What is the photon "radius"?

$$d\sigma/dt \sim \exp(2B(Q^2, M^2 t));$$

$$B_{\gamma\to\rho} = B_{(\gamma^*_{(Q^2=M_\rho^2)}\to\gamma)}?$$

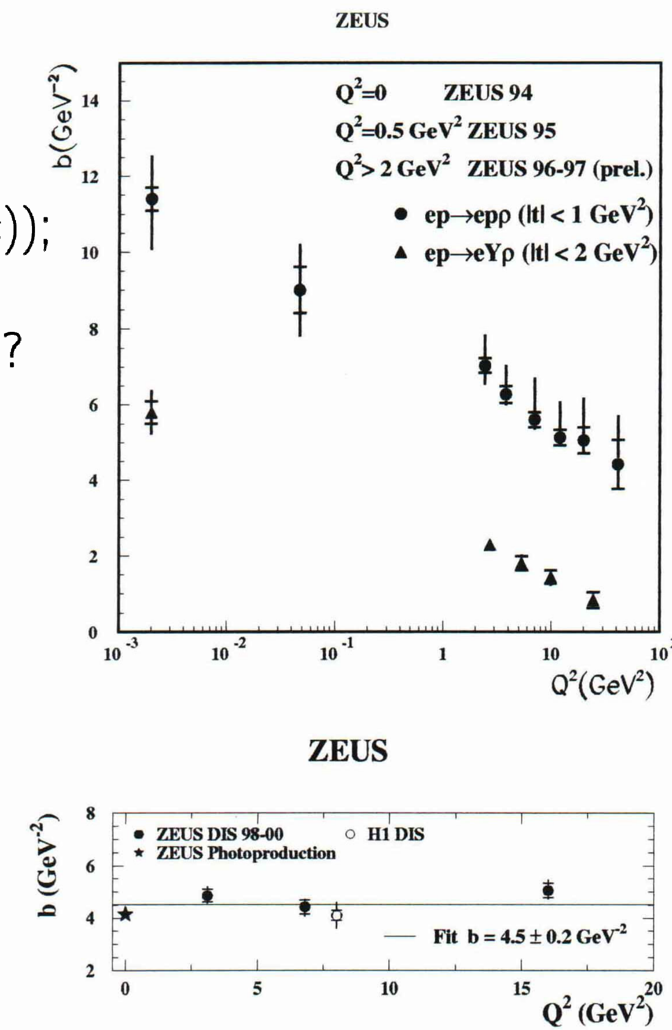


Figure 60: *The preliminary ZEUS data on diffraction slope b for elastic and proton-dissociative production of the ρ (upper box, [84]) and (bottom box) recent ZEUS [90] and H1 [89] data for elastic production of the J/ψ mesons as a function of* Q^2.

In: **M. Capua, S. Fazio, R. Fiore, L. Jenkovszky, and F. Paccanoni*****A Deeply Virtual Compton Scattering Amplitude*****, Phys. Letters B645 (2007) 161, arXiv: hep-ph/0605319** ***and*** **R. Fiore, L.J., V. Magas, and A. Prokudin**, ***Interplay between Q^2- and t-dependences in DVCS*****. In the Proceedings of the Crimean Conf., Yalta, 2005 a factorized Regge-pole model for deeply virtual Compton scattering is suggested. The use of an effective logarithmic Regge-Pomeron trajectory provides for the description of both "soft" (small |t|) and "hard" (large |t|) dynamics. The model contains explicitly the photoproduction and the DIS limits and fits the existing HERA** data on deeply virtual Compton scattering and vector meson production.

The DVCS amplitude can be written as

$$A(s,t,Q^2)_{\gamma^* p\to\gamma p} = -A_0 V_1(t,Q^2) V_2(t) (-is/s_0)^{\alpha(t)},$$

where A_0 is a normalization factor, $V_1(t,Q^2)$ is the $\gamma^* P\gamma$ vertex, $V_2(t)$ is the pPp vertex and $\alpha(t)$ is the exchanged Pomeron trajectory, which we assume to be in a logarithmic form:

$$\alpha(t) = \alpha(0) - \alpha_1 \ln(1-\alpha_2 t).$$

Such a trajectory is nearly linear for small $|t|$, thus reproducing the forward cone of the differential cross section, while its logarithmic asymptotics provides for the large-angle scaling behavior, typical of hard collisions at small distances, with power-law fall-off in $|t|$, obeying quark counting rules.

The basic idea is that Q^2 and t, both having the meaning of a squared mass of a virtual particle (photon or Reggeon), should be treated on the same footing, by means a new variable, defined as

$$z = q_1^2 + t = -Q^2 + t, \tag{1}$$

in the same way as the vector meson mass squared is added to the squared photon virtuality, giving $\tilde{Q}^2 = Q^2 + M_V^2$ in the case of vector meson electroproduction

For convenience, and following the arguments based on duality, the t dependence of the pPp vertex is introduced via the $\alpha(t)$ trajectory: $V_2(t) = e^{b\alpha(t)}$ where b is a parameter. A generalization of this concept is applied also to the upper, $\gamma^* P\gamma$ vertex by introducing the trajectory

$$\beta(z) = \alpha(0) - \alpha_1 \ln(1 - \alpha_2 z),$$

where the value of the parameter α_2 may be different in $\alpha(t)$ and $\beta(z)$.

Hence the scattering amplitude, with the correct signature, becomes

$$A(s,t,Q^2)_{\gamma^* p\to\gamma p} = -A_0 e^{b\alpha(t)} e^{b\beta(z)} (-is/s_0)^{\alpha(t)} =$$

$$-A_0 e^{(b+L)\alpha(t)+b\beta(z)},$$

where $L \equiv \ln(-is/s_0)$.

Photoproduction- and DIS limits (a consistency check)

In the $Q^2 \to 0$ limit the scattering amplitude becomes

$$A(s,t) = -A_0 e^{2b\alpha(t)}(-is/s_0)^{\alpha(t)}$$

where we recognize a typical Regge-behaved photoproduction (or, for $Q^2 \to m_H^2$, on-shell hadronic (H)) amplitude. The related deep inelastic scattering structure function is recovered by setting $Q_2^2 = Q_1^2 = Q^2$ and $t = 0$, to get a typical elastic virtual forward Compton scattering amplitude:

$$A(s,Q^2) = -A_0 e^{b(\alpha(0)-\alpha_1 \ln(1+\alpha_2 Q^2))} e^{(b+\ln(-is/s_0))\alpha(0)} \propto$$

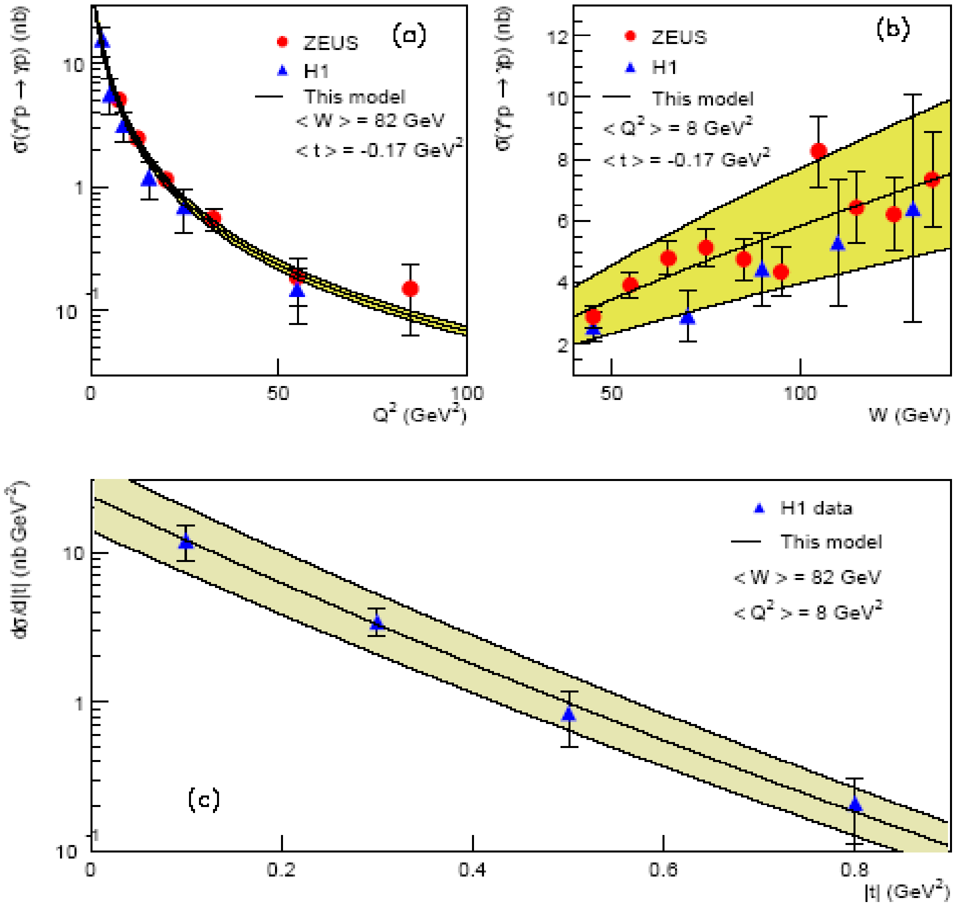
$$-(1+\alpha_2 Q^2)^{-\alpha_1}(-is/s_0)^{\alpha(0)}.$$

In the Bjorken limit, when both s and Q^2 are large and $t = 0$ (with $x \approx Q^2/s$ valid for large s), the structure function is given by:

$$F_2(s,Q^2) \approx \frac{(1-x)Q^2}{\pi\alpha_e} \Im A(s,Q^2)/s,$$

Fits to the $ep \to e\gamma p$ data

$$\frac{d\sigma}{dt}(s,t,Q^2) = \frac{\pi}{s^2}|A(s,t,Q^2)|^2 \qquad A = A^P + A^f$$



parameter	σ_{DVCS} vs Q^2	σ_{DVCS} vs t	σ_{DVCS} vs W
$\lvert A_0\rvert^2$	0.08 ± 0.01	0.11 ± 0.24	0.06 ± 0.01
b	0.93 ± 0.05	1.04 ± 0.91	1.08 ± 0.10
$\chi^2/ndof$	0.57	0.15	1.15

Refitting the model, extended by (work in progress):

1) A two-term Pomeron:

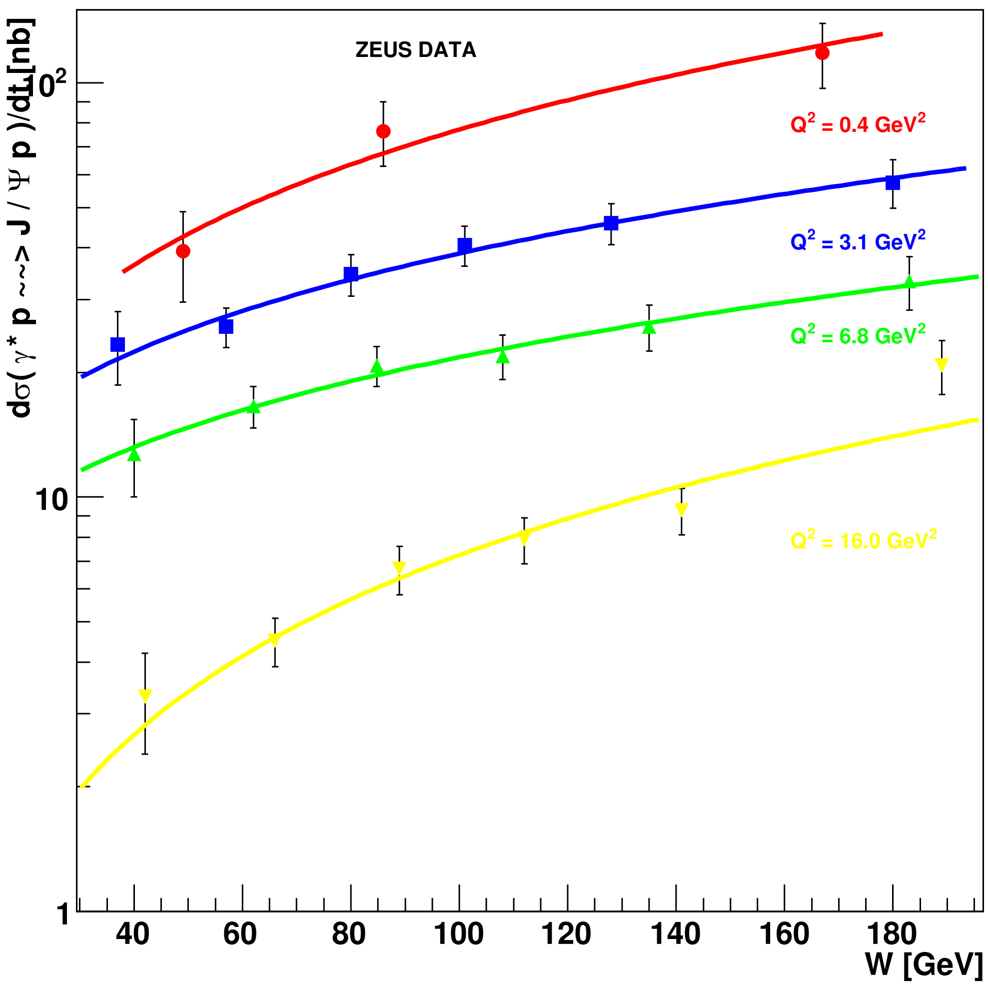
$$P(s,t,Q^2) = G_s(t,Q^2,M_V^2)(-is/s_0)^{\alpha_s(t)} + G_h(t,Q^2,M_V^2)(-is/s_0)^{\alpha_h(t)},$$

and $\sigma_L = R(Q^2)\sigma_T$, where

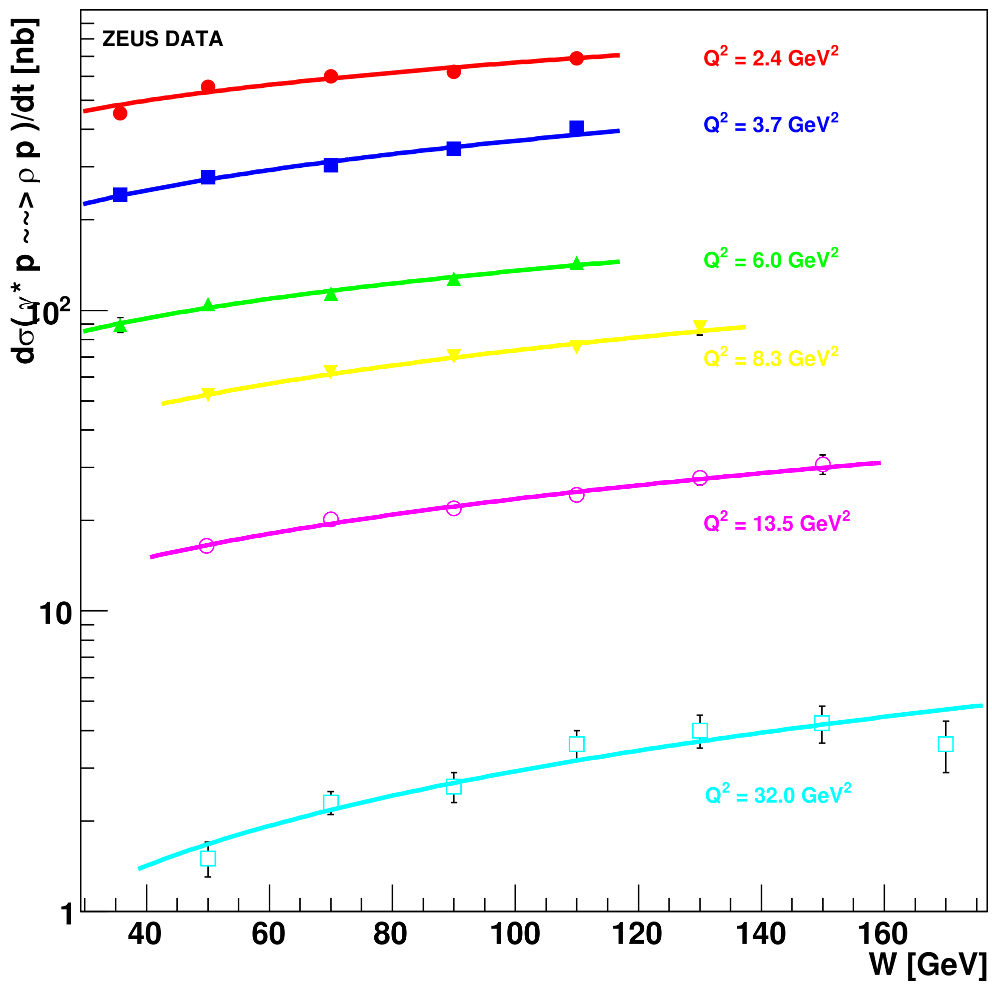
$$R(Q^2) = \left(\frac{aM_V^2 + Q^2}{aM_V^2}\right)^n - 1.$$

Fits (preliminary) to the HERA data on DVCS and on vector meson producton.

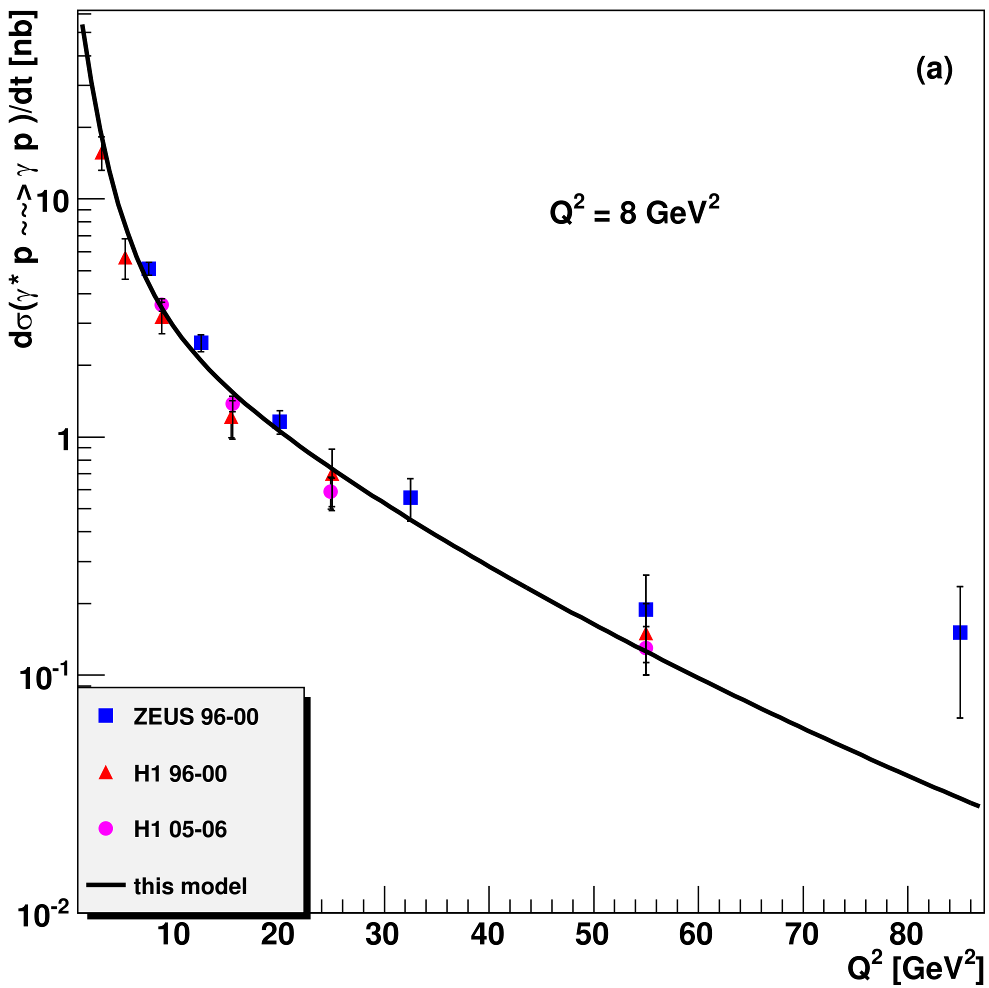
Predictions (preliminary) for LHeC (1.4 TeV^2).



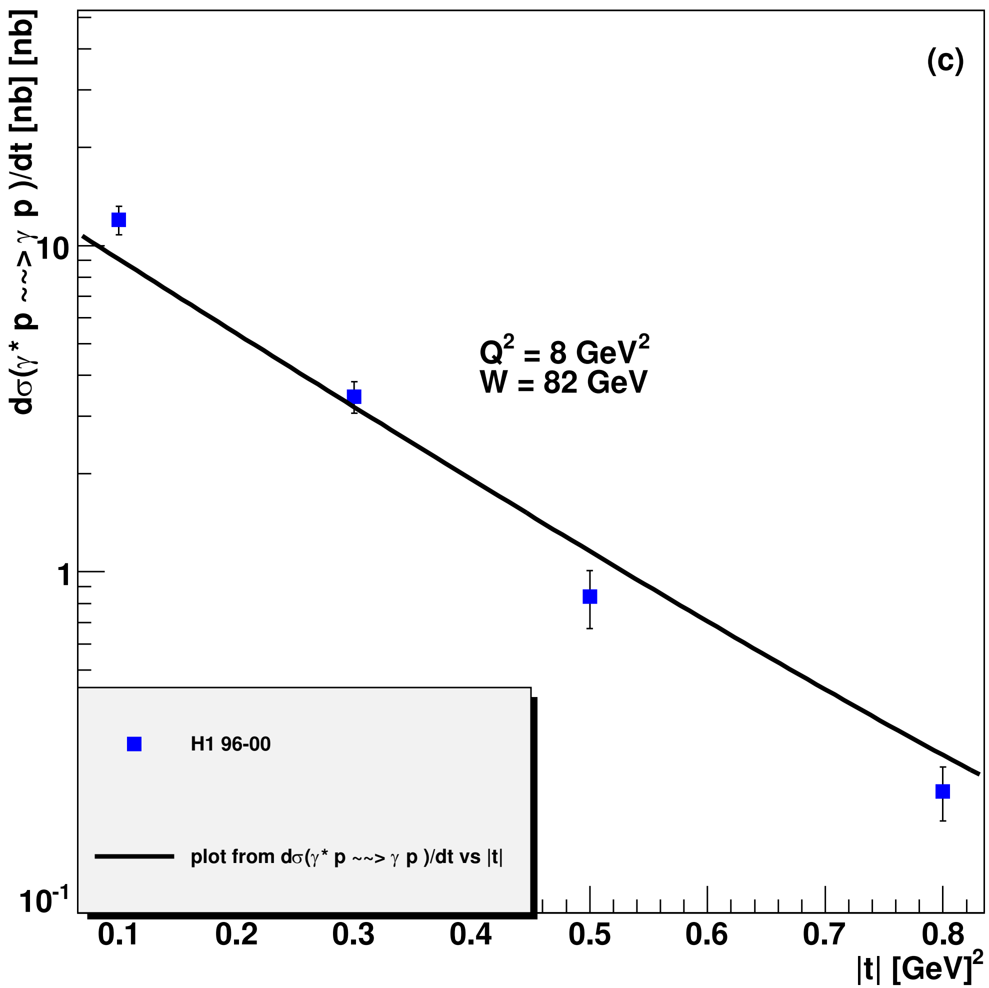
ZEUS DATA
dσ(γ* p ~~> J / Ψ p)/dt [nb]
10²
10
1
Q² = 0.4 GeV²
Q² = 3.1 GeV²
Q² = 6.8 GeV²
Q² = 16.0 GeV²
40
60
80
100
120
140
160
180
W [GeV]



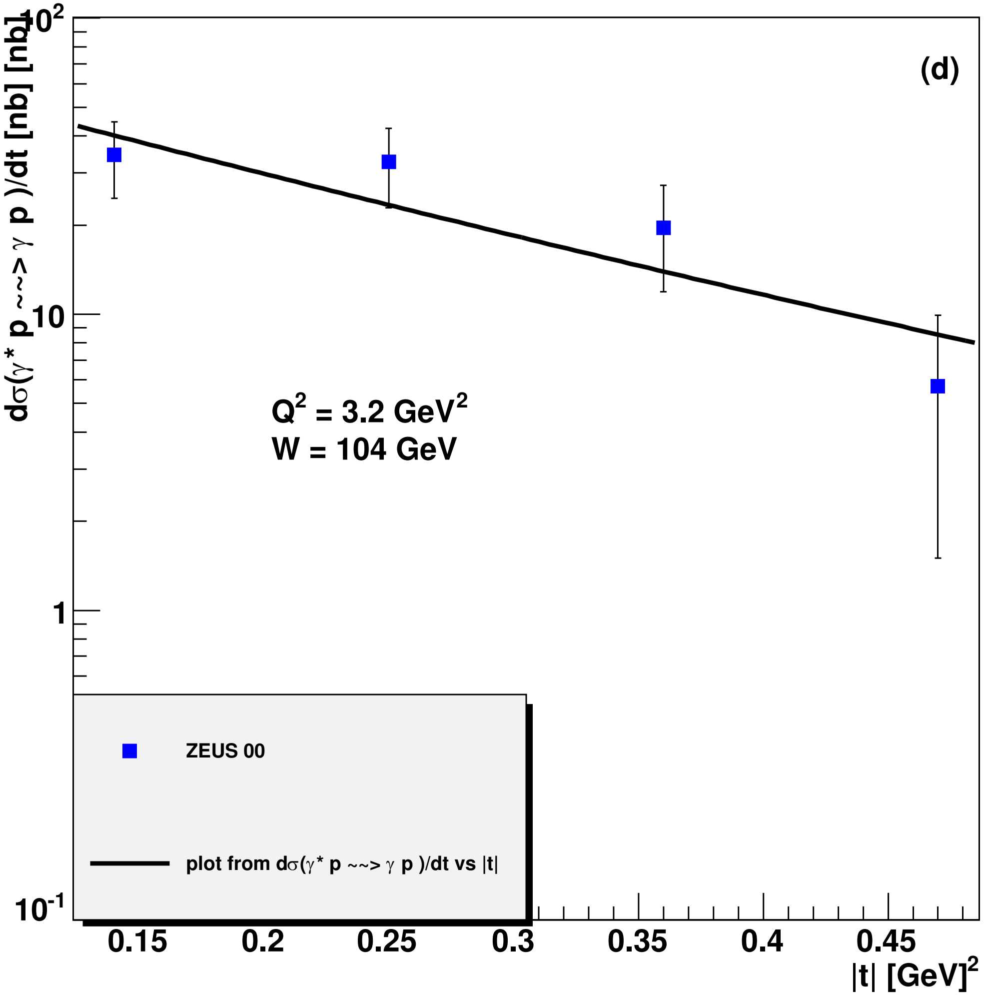
ZEUS DATA
Q^2 = 2.4 GeV^2
Q^2 = 3.7 GeV^2
Q^2 = 6.0 GeV^2
Q^2 = 8.3 GeV^2
Q^2 = 13.5 GeV^2
Q^2 = 32.0 GeV^2
dσ(γ* p ~~> ρ p)/dt [nb]
10^2
10
1
40
60
80
100
120
140
160
W [GeV]

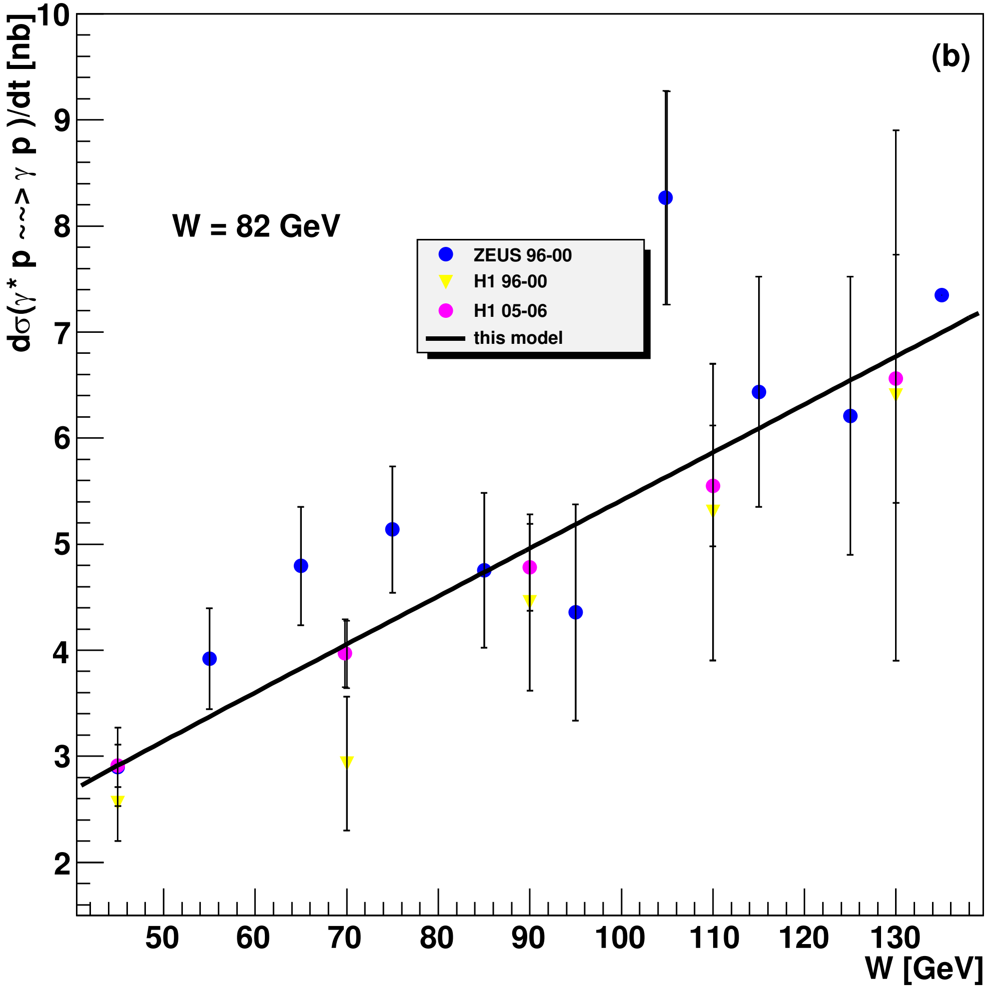


(a)
Q^2 = 8 GeV^2
dσ(γ* p ~~> γ p)/dt [nb]
Q^2 [GeV^2]
10
1
10^-1
10^-2
10
20
30
40
50
60
70
80
ZEUS 96-00
H1 96-00
H1 05-06
this model

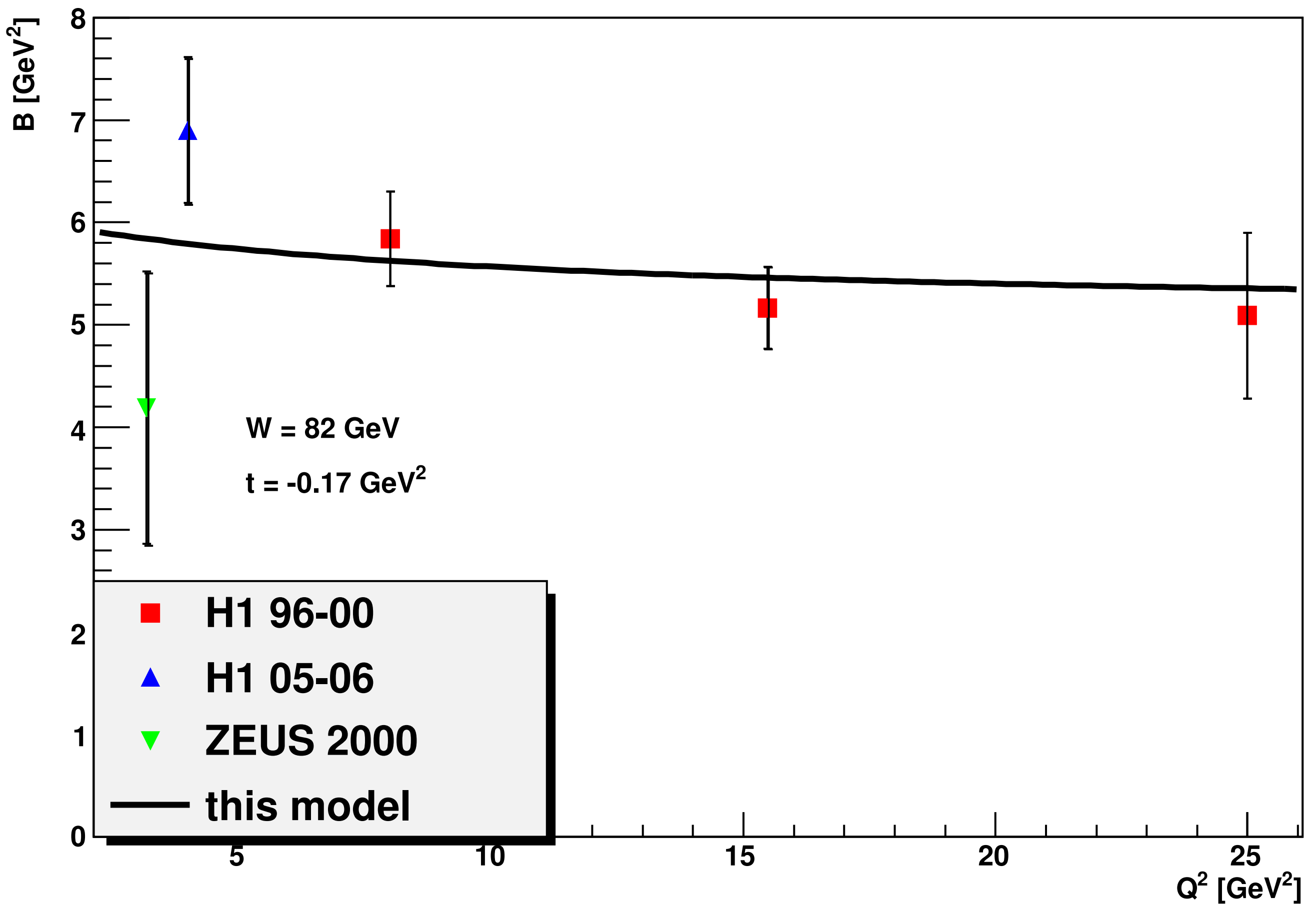


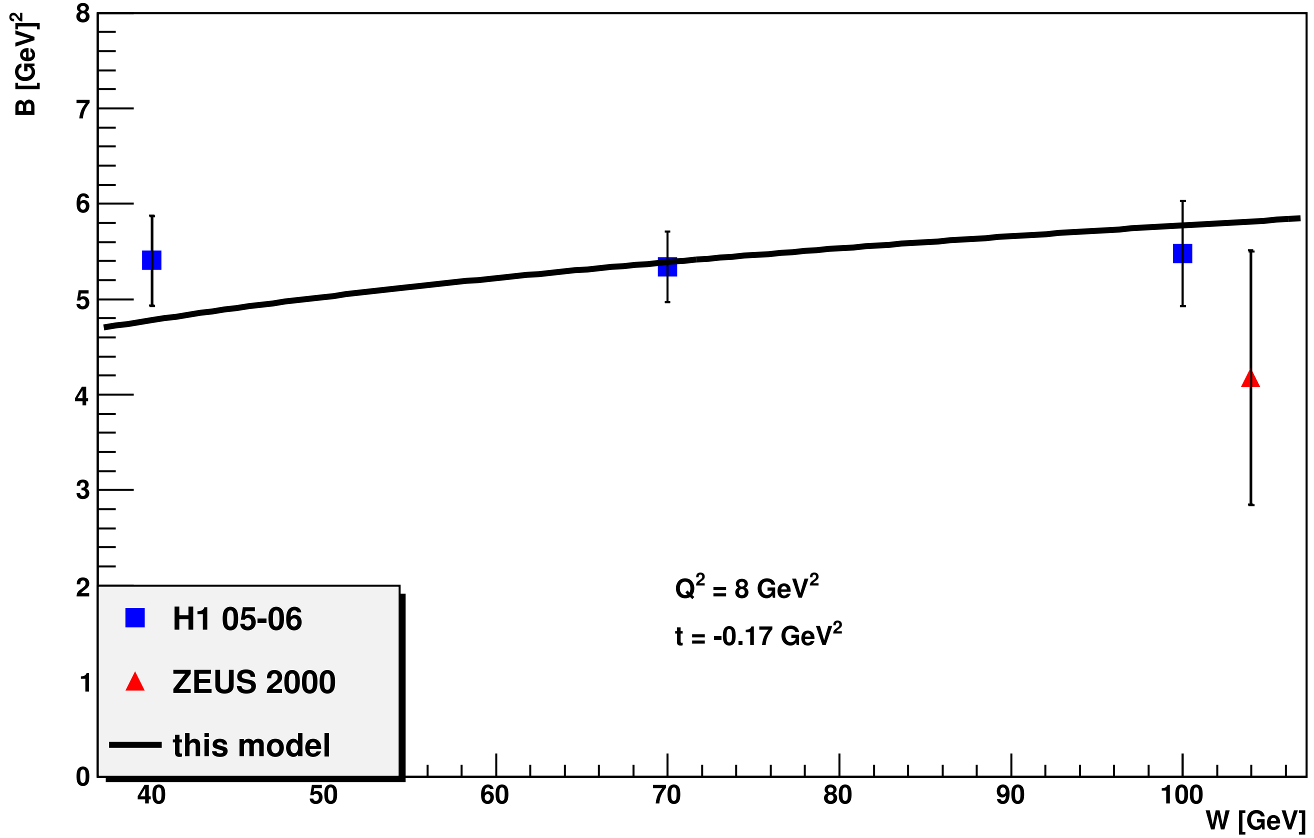
dσ(γ* p ~~> γ p)/dt [nb] [nb]
(c)
Q^2 = 8 GeV^2
W = 82 GeV
10
1
10^-1
H1 96-00
plot from dσ(γ* p ~~> γ p)/dt vs |t|
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
|t| [GeV]^2


dσ(γ* p ~~> γ p)/dt [nb] [nb]
(d)
Q² = 3.2 GeV²
W = 104 GeV
ZEUS 00
plot from dσ(γ* p ~~> γ p)/dt vs |t|
10²
10
1
10⁻¹
0.15
0.2
0.25
0.3
0.35
0.4
0.45
|t| [GeV]²



(b)
W = 82 GeV
ZEUS 96-00
H1 96-00
H1 05-06
this model
dσ(γ* p ~~> γ p)/dt [nb]
W [GeV]


B [GeV²]
8
7
6
5
4
3
2
1
0
5
10
15
20
25
Q² [GeV²]
W = 82 GeV
t = -0.17 GeV²
H1 96-00
H1 05-06
ZEUS 2000
this model


B [GeV]^2
W [GeV]
H1 05-06
ZEUS 2000
this model
Q^2 = 8 GeV^2
t = -0.17 GeV^2

Does GS imply saturation? Not necessarily!

$ImH(s,b) = |h(s,b)|^2 + G_{in}(s,b)$, (h is associaed with the "opacity), Here from: $0 \leq |h(s,b)|^2 \leq \Im h(s,b)) \leq 1$. The Black Disc Limit (BDL) corresponds to $\Im h(s,b) = 1/2$, provided $h(s,b) = i(1 - \exp[i\omega(s,b)]/2$, with an imaginary eikonal $\omega(s,b) = i\Omega(s,b)$.

There is an alternative solution, that with the "minus" sign in $h(s,b) = [1 \pm \sqrt{1 - 4G_{in}(s,b)}]/2$, giving (S.Troshin and N.Tyurin (Protvino)): $h(s,b) = \Im u(s,b)/[1 - iu(s,b))]$,

Conclusions:

1) QCD and Regge pole models are two different/complementary approaches to lepton- and hadron induced reactions. Matching the two is a challenge for the theory;

2) The Pomeron may be much more complicated than just a single (and simple) Regge pole, however:

3) There is only one Pomeron in the nature (call it “soft” or “hard”), and the parameters of the Pomeron trajecetory are the same e.g. in hadronic or lepton-hadron (e.g. DIS) reactions. The precision of the hadronic data is much higher than in DVCS or VMP.

Thank you!