Comments on J/ψ exclusive and semiexclusive processes

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- J/ψ as a probe gluon GPDs
- Rapidity gap processes with J/ψ and DGLAP
- α'_{IP} for J/ψ production: pQCD and nonpQCD mechanisms
- Transitional form factors - can one probe constituent quark model, look for gluon enriches states

Rutgers Univ. workshop, March 15,2010

Reminder: Summary of conclusions of FKS[Frankfurt,Koepf, MS] 95, 97 for VM production

How big are HT effects? Structure of the answer:

$$\sigma_L \propto \frac{Q^2}{(Q^2+M^2)^4}$$

$$A_L \propto Q \int dz d^2k_t \psi_V(z,k_t) \left(\frac{1}{Q^2+M^2_{q\bar{q}}}\right)^2$$

extra power - from scattering operator
= Laplacian applied to ψ_L

$$M^2_{q\bar{q}} = \frac{m_q^2+k_t^2}{z(1-z)}$$

mass^2 of the intermediate quark- antiquark state
- ≥ 1 GeV^2 for light mesons & for J/ψ a factor of 1.5 larger than $m^2_{J/\psi}$

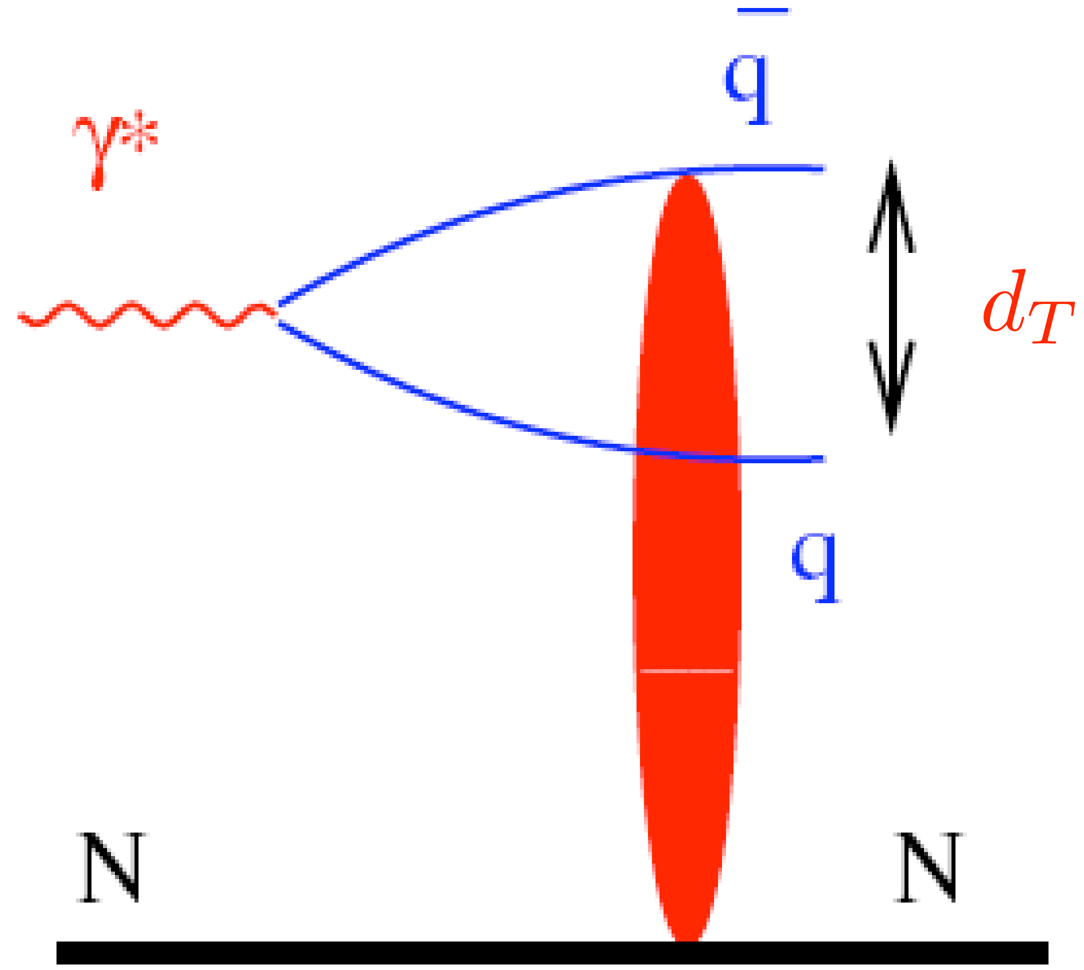
LT≡ $M^2_{q\bar{q}} \ll Q^2$

Fermi motion of quarks

$$\left(\frac{1}{Q^2+M^2}\right)^4 = \frac{1}{Q^8}(1-4M^2/Q^2+10M^4/Q^4+....)$$

- HT are large up to $Q^2 \sim 20$ GeV^2
- HT $1/Q^4$ are large up to $Q^2 \sim 5$ GeV^2
- Transverse momenta rapidly increase with Q^2 - squeezing is effective !!

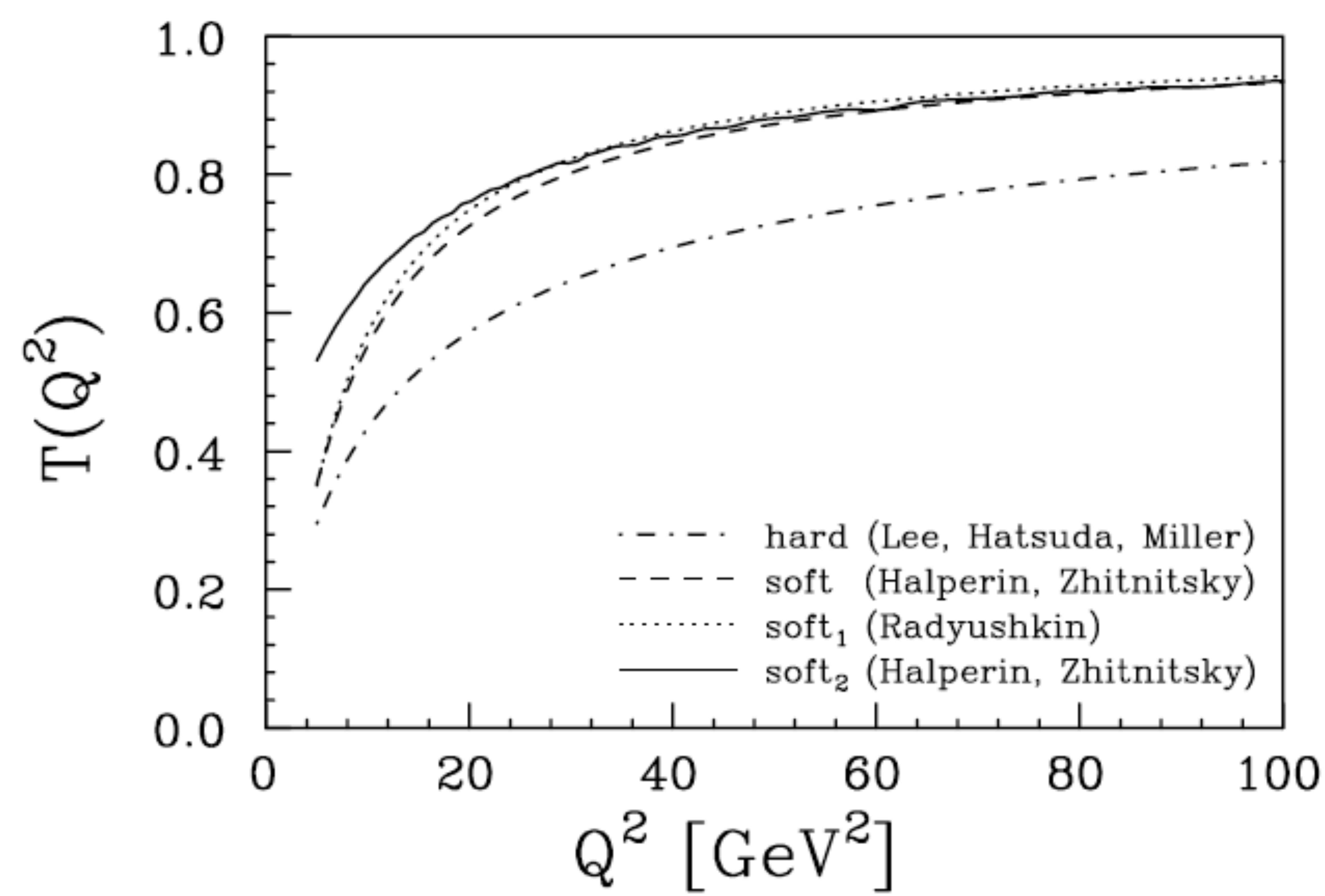
Warning - HT increase with increase of -t



$$d_T \propto \frac{1}{Q}\left(\frac{1}{m_c}\right) \ll r_N$$

FKS95

$$T(Q^2) \propto \frac{\left|\int d^2b\,dz\,\Psi_{\gamma_L^*}(z,\mathbf{d})\sigma(q\bar{q}-N)\phi_V(z,\mathbf{d})\right|^2}{\left|\int d^2b\,dz\,\Psi_{\gamma_L^*}(z,\mathbf{d})\sigma(q\bar{q}-N)\phi_V(z,0)\right|^2}$$



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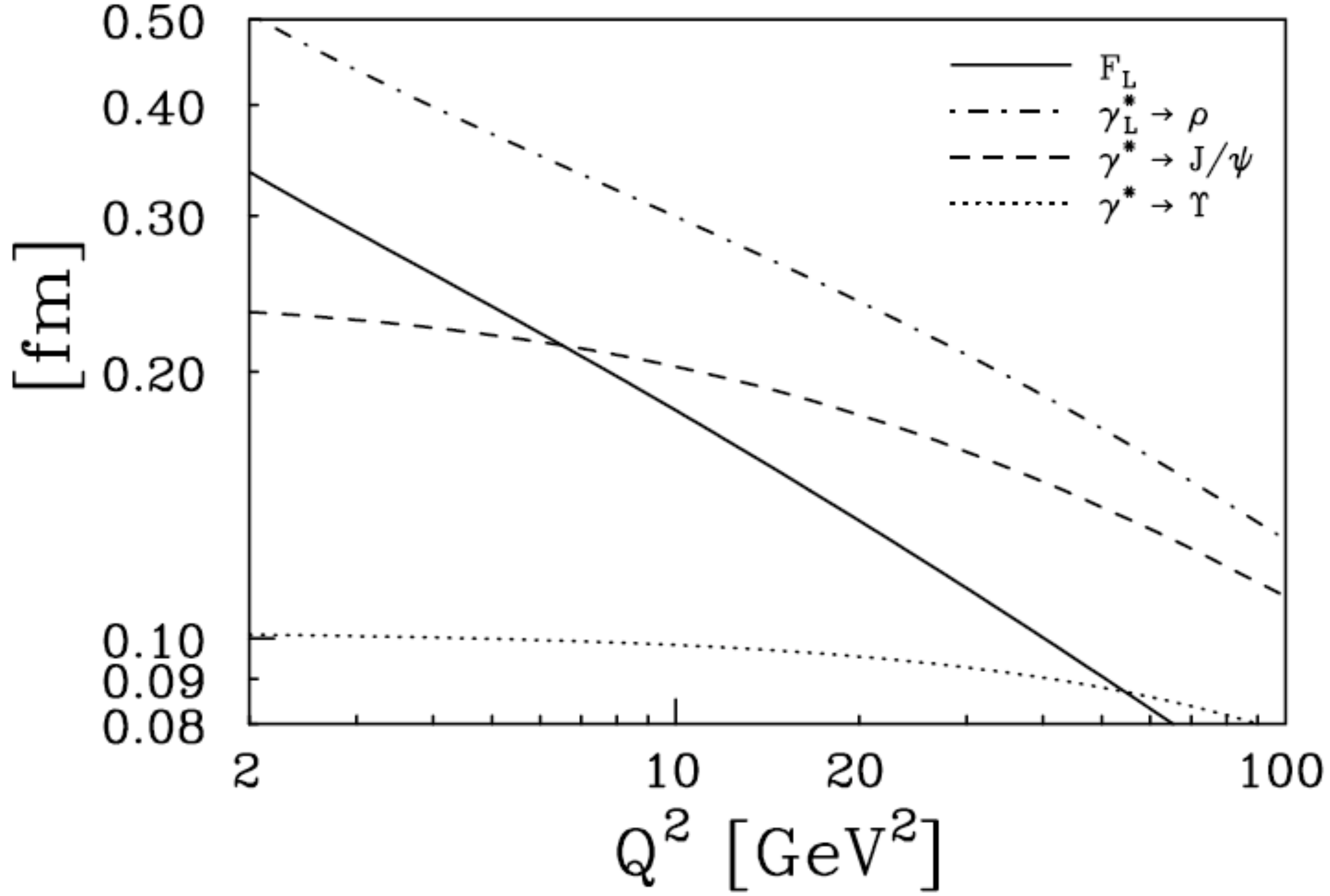
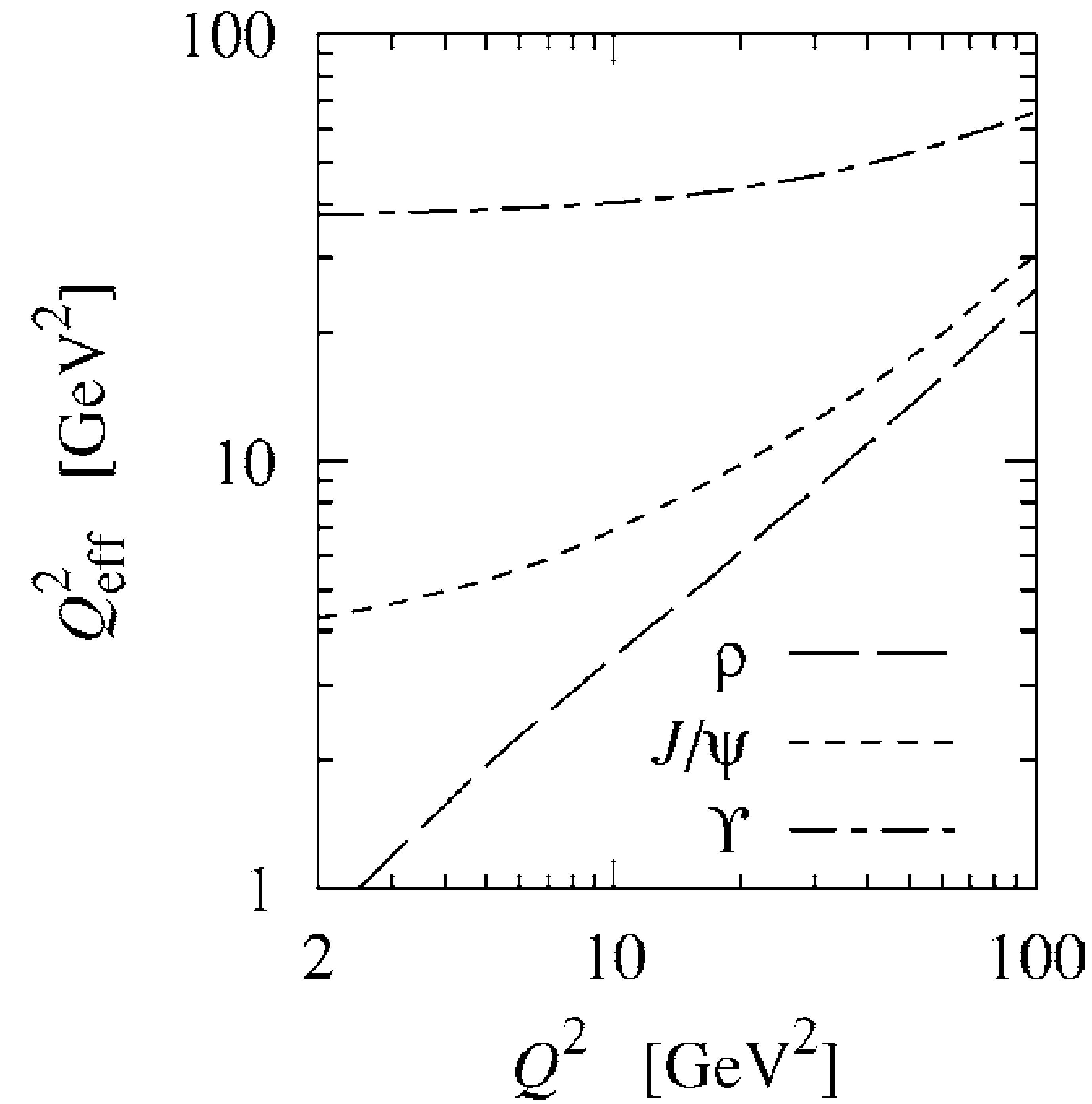




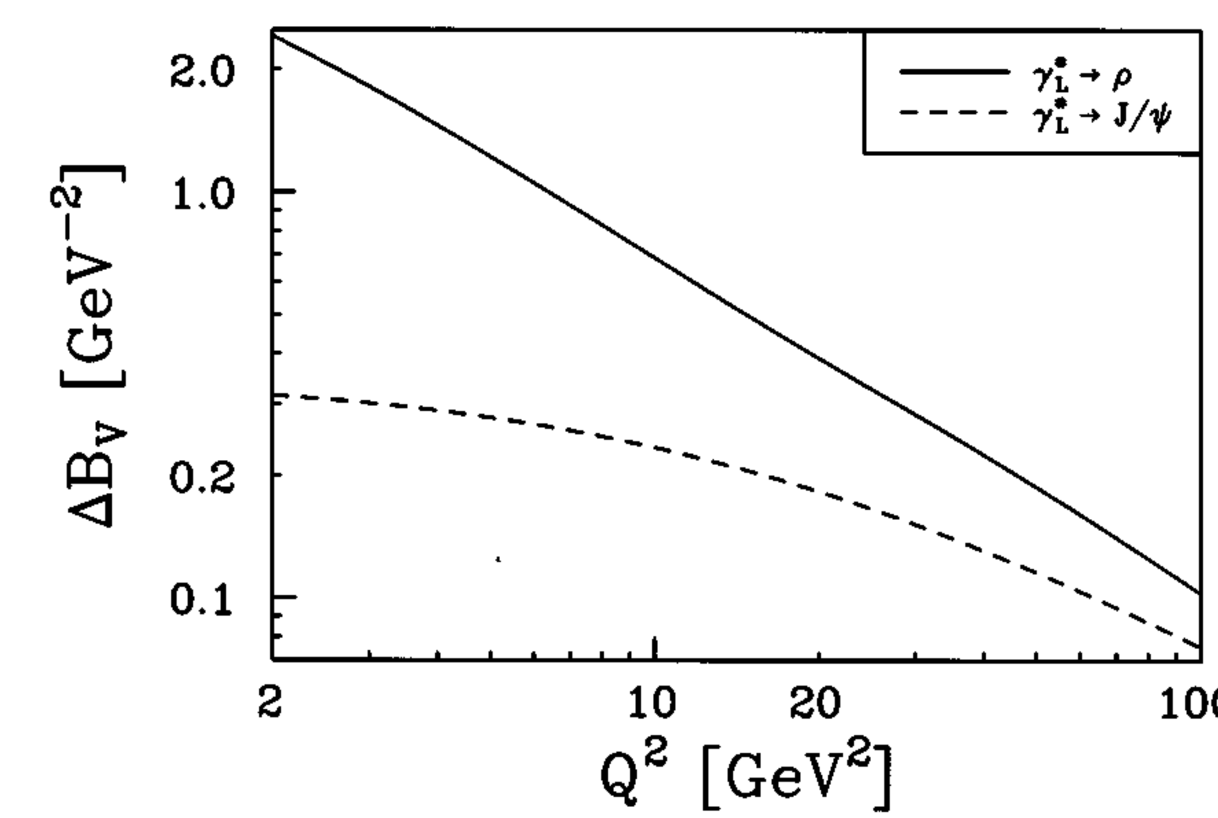
Large NLO effects:

$Q^2_{eff} << Q^2$

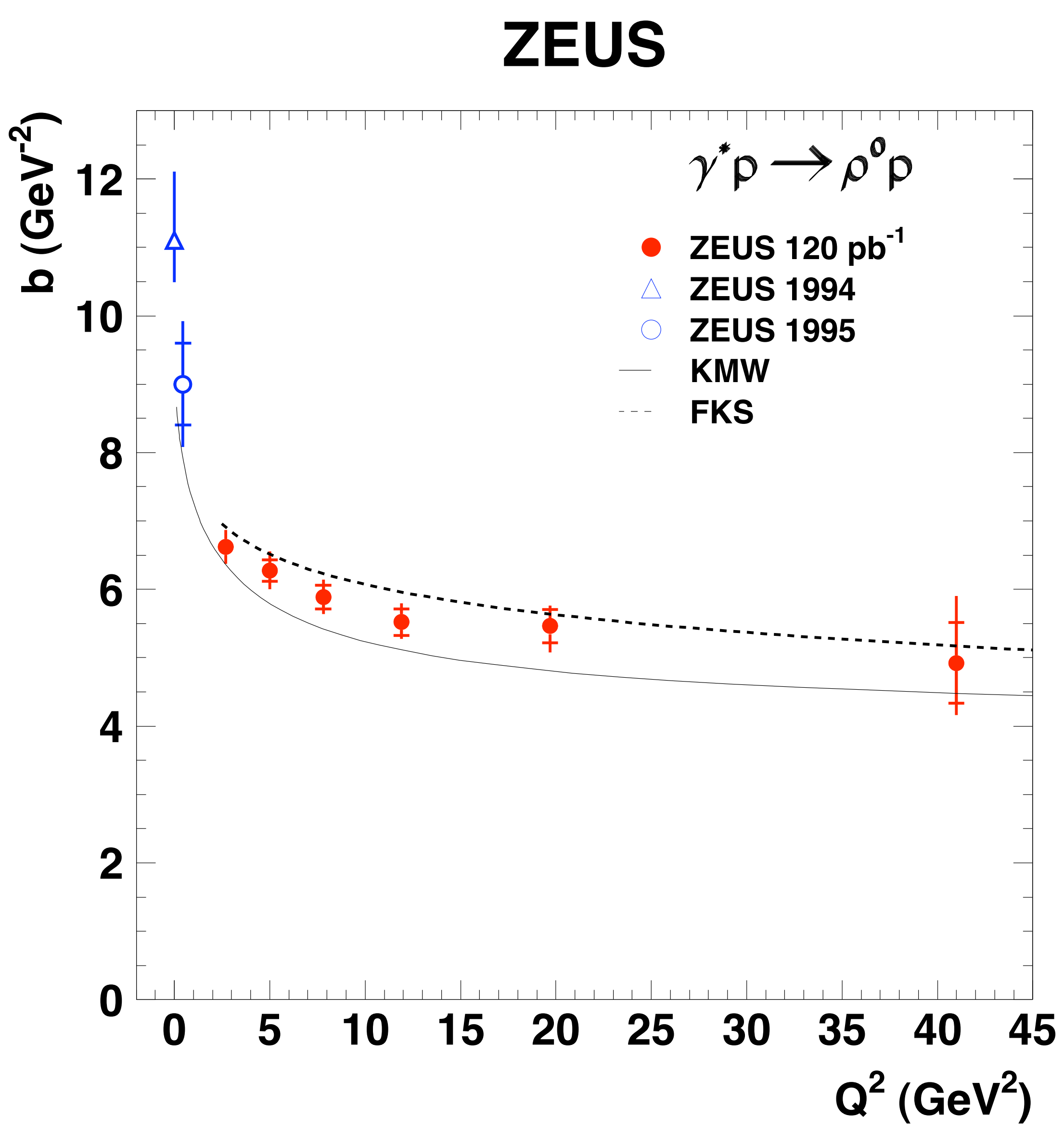
Predictions:

- A rather slow convergence of the t-slopes B of ρ and J/ψ at large Q
- Weak Q dependence of B(J/ψ)
- Onset of fast increase of σ(γ*→ρ) only at large Q

$$\frac{d\sigma}{dt} \propto \exp(Bt)$$



Implications for color transparency studies with nuclei



$$\frac{B(Q^2) - B_{2g}}{B(Q^2=0) - B_{2g}} \sim \frac{R^2(dipole)}{R_\rho^2}$$

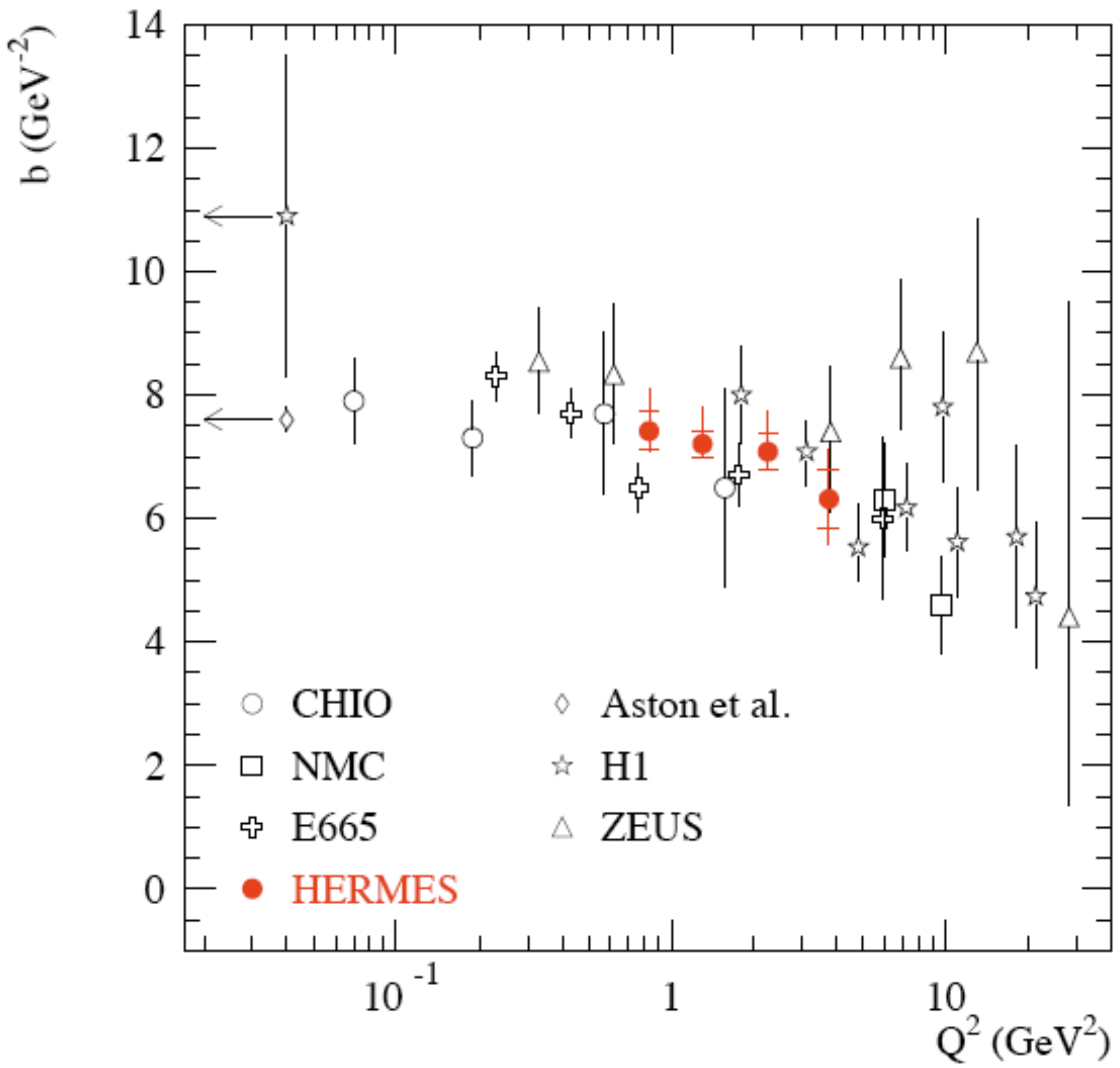
$$\frac{R^2(dipole)(Q^2 \geq 3\mathrm{GeV}^2)}{R_\rho^2} \leq 1/2 \div 1/3$$

Convergence of B for ρ-meson electroproduction to the slope of J/ψ photo(electro)production - **direct proof of squeezing.**

Expect significant CT effects for meson production for $Q^2 \geq 3\mathrm{GeV}^2$

sensitivity already at Jlab 6 &12, at collider - possible shift to higher Q^2 due on set of black regime and nuclear shadowing

Where transition from soft to hard dynamics occurs?
Is there a significant squeezing for $Q^2=2$ GeV^2?



Small change of the slope for $Q^2=2$ GeV^2? as compared to $Q^2=0$ GeV^2? HERMES: $\Delta B < 1$ GeV^2

$r^2(Q^2=2\ \text{GeV}^2)/\ r^2(Q^2=0\ \text{GeV}^2) \geq 2/3$

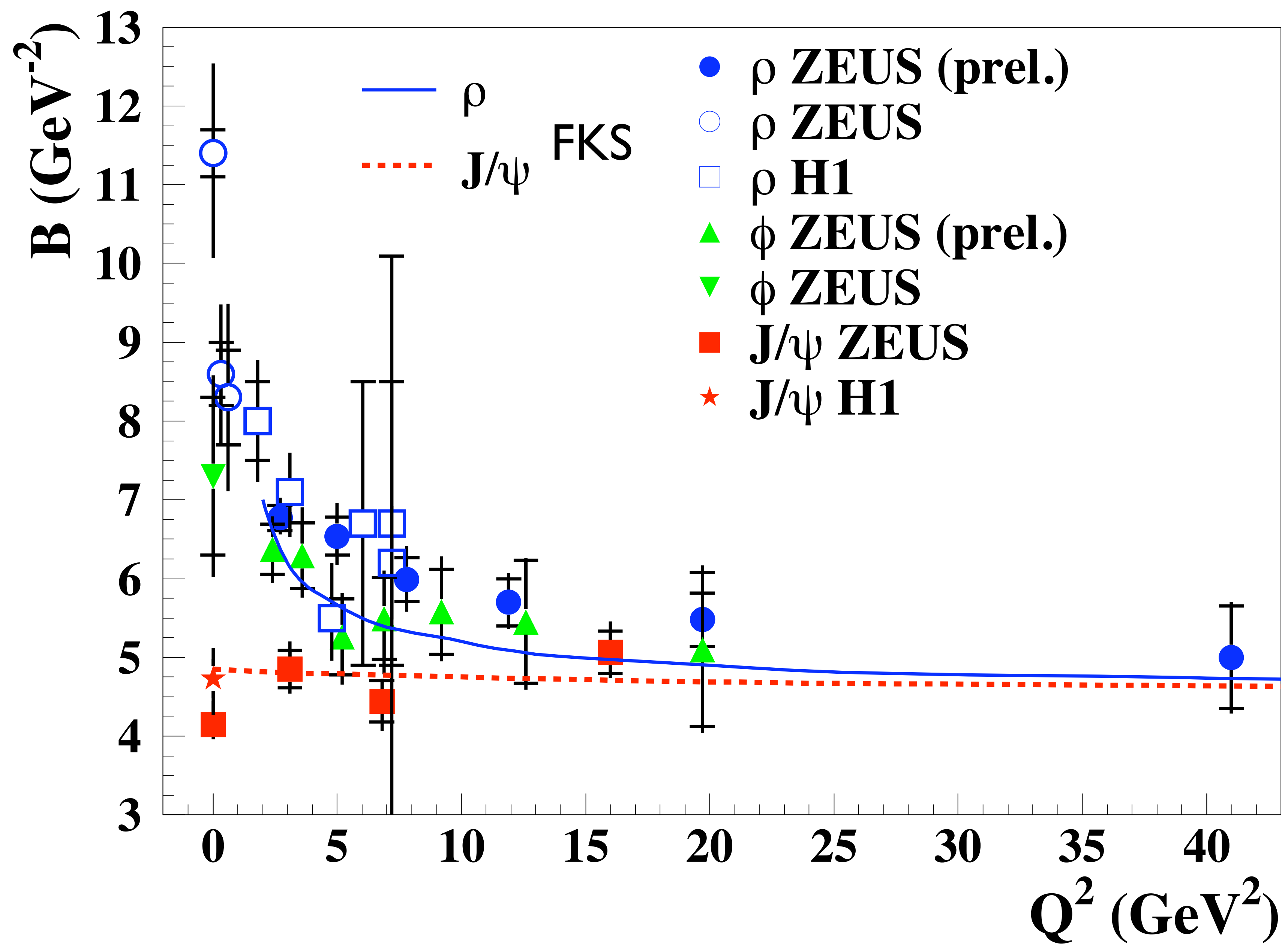
Extraction of information on GPDs from data at $Q^2=2 \div 3$ GeV^2 is problematic

Need CT data for π & ρ production at $Q^2=2 \div 4$ GeV^2 , $q_0 \sim 10 \div 20$ GeV

HERMES?

- Universal t-slope: process is dominated by the scattering of quark-antiquark pair in a small size configuration - t-dependence is predominantly due to the transverse spread of the gluons in the nucleon - two gluon nucleon form factor, $F_g(x,t)$. $d\sigma/dt \propto F_g^2(x,t)$.

  Onset of universal regime FKS 97.



Convergence of the t-slopes, B - $\frac{d\sigma}{dt} = A\exp(Bt)$), of ρ-meson electroproduction to the slope of J/ψ photo(electro)production.

$\Rightarrow$ Transverse distribution of gluons can be extracted from $\gamma + p \to J/\psi + N$

Issue: precision.

Upsilon - the smallest hadron - are HT corrections large for photoproduction?

FMS - Frankfurt, McDermott, Strikman 98 dipole approximation - HT a factor of two suppression; large effect of real part and skewedness. $Q^2_{eff} \sim 40$ GeV^2

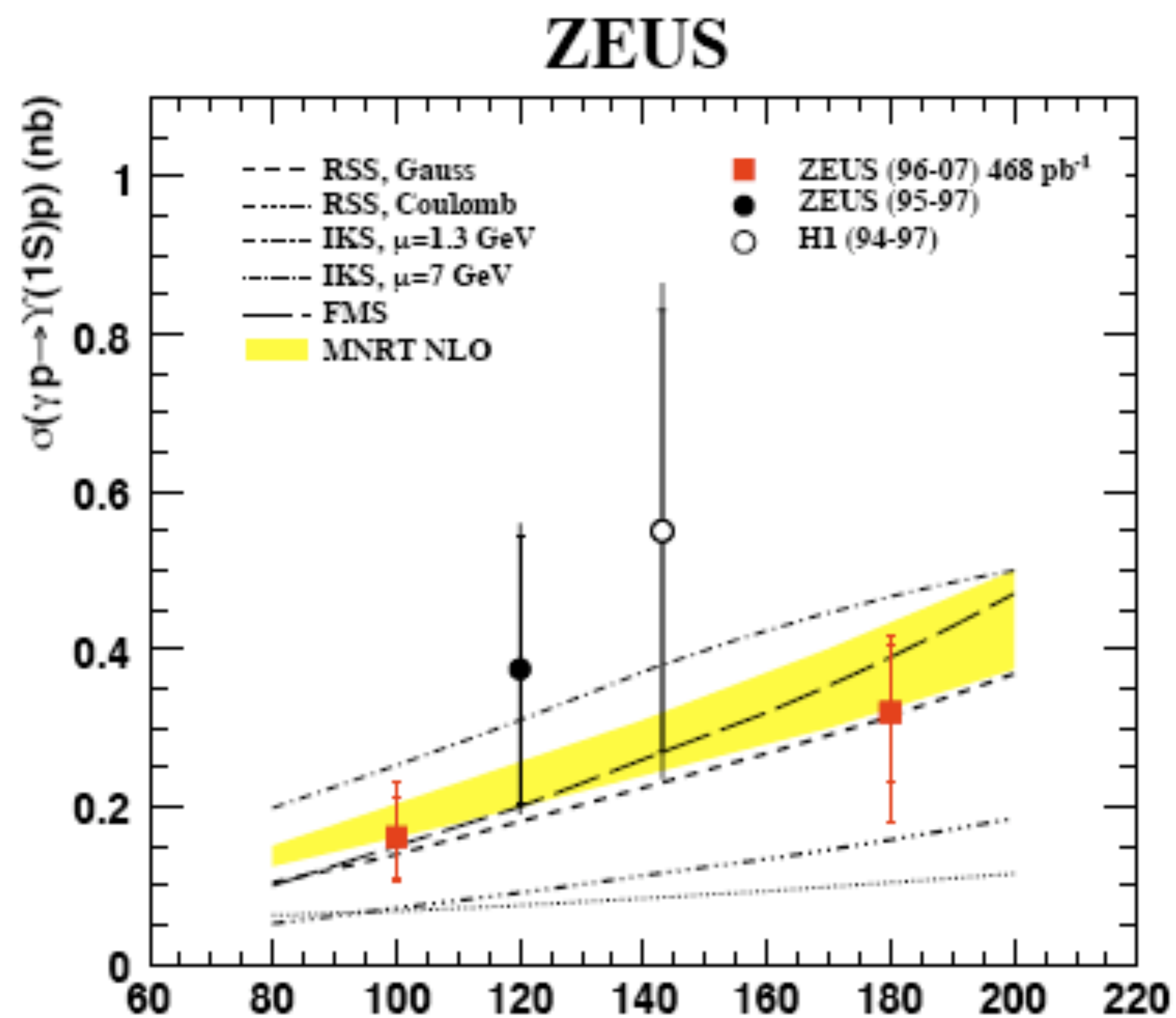
NLO calculations:

Ivanov, Krasnikov, Szymanowski 05 Strong dependence of NLO result on μ_R.

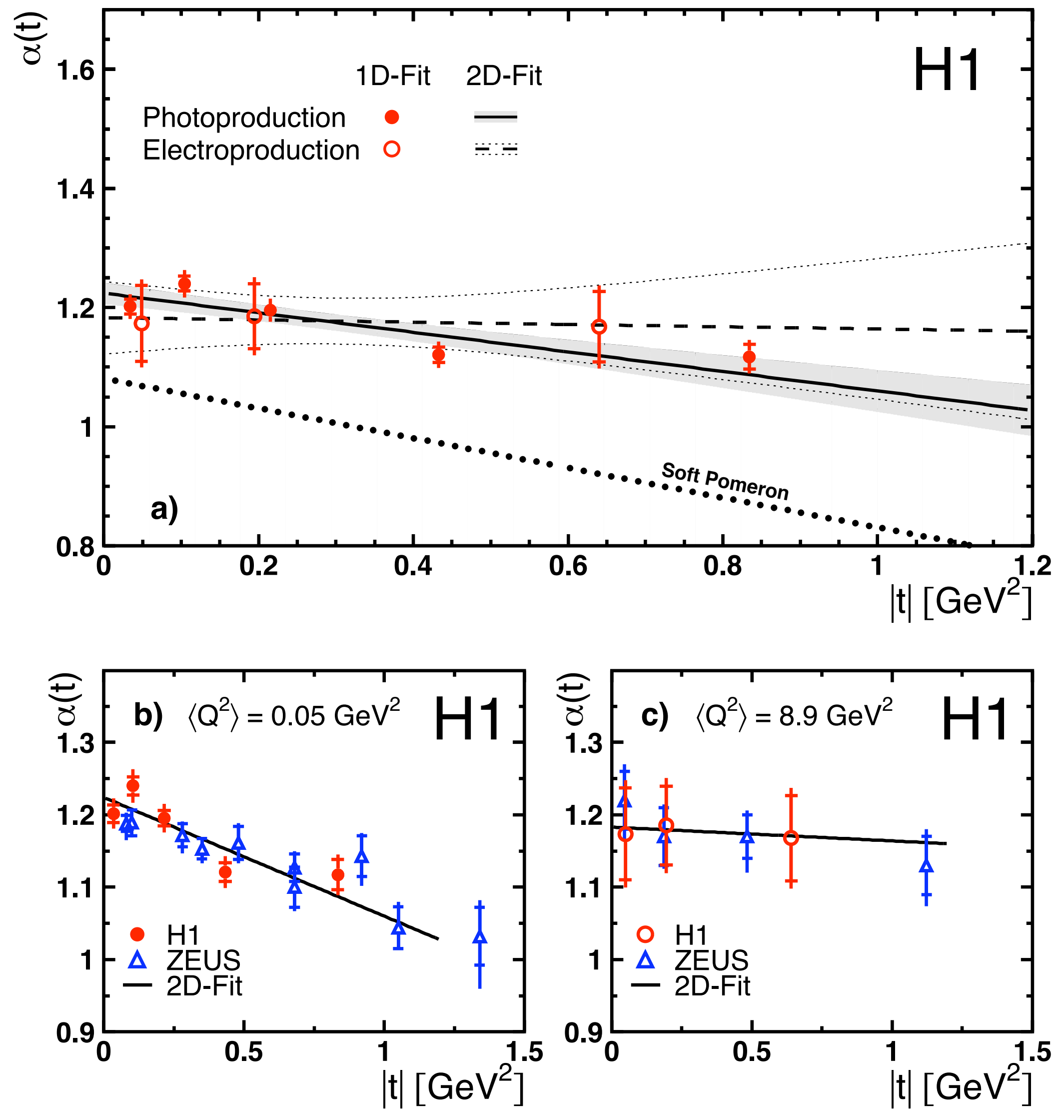
Data described for very small μ_R

Martin et al 08 much smaller sensitivity?

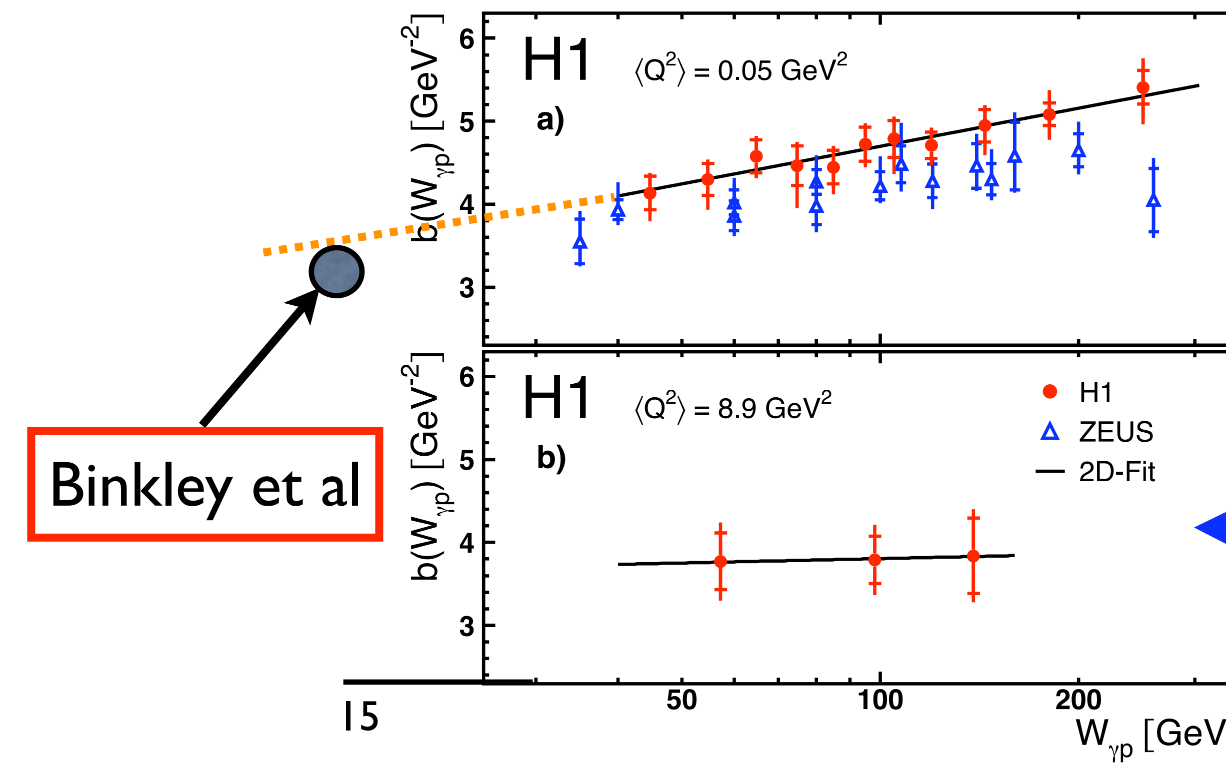
open questions - energy conservation and related issues with gauge invariance. treatment of the meson wave function



J/ψ elastic photo and electro production



The effective trajectory $\alpha(t)$ as a function of $|t|$ in the range $40 < W_{\gamma p} < 305$ GeV

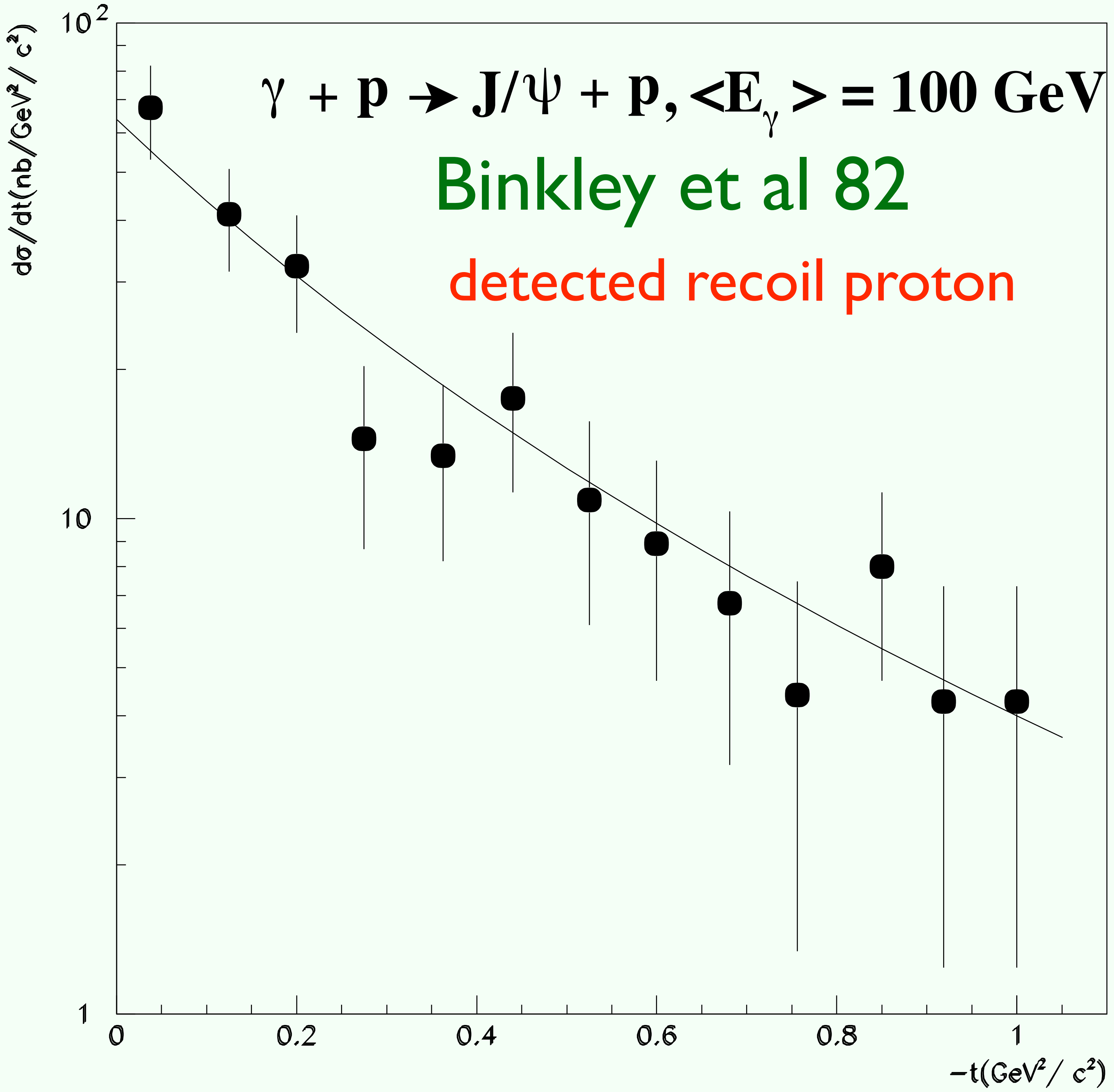


α' consistent with zero!!!

t-slope for J/ψ especially at Q^2=9 GeV^2 is systematically lower than for DVCS and for ρ - production

pQCD (DGLAP approximation) - rather weak Q evolution of α' - Frankfurt, MS, Weiss

Experimental problems - poor resolution in t for -t < 0.1 GeV^2(large difference for these t for dipole exp fits), proton is practically never detected while veto relies on soft Regge model - while dynamics changes with increase of -t where inelastic dominates.



Theoretical analysis of J/ψ photoproduction at corres $100\ GeV \geq E_\gamma \geq 10\ GeV$ n factor of the nucleon for

$$0.03 \leq x \leq 0.2,\ Q_0^2 \sim\ 3\ GeV^2, -t \leq 2\ GeV^2$$

$$F_g(x,Q^2,t) = (1 - t/m_g^2)^{-2}.\ m_g^2 = 1.1\ GeV^2$$

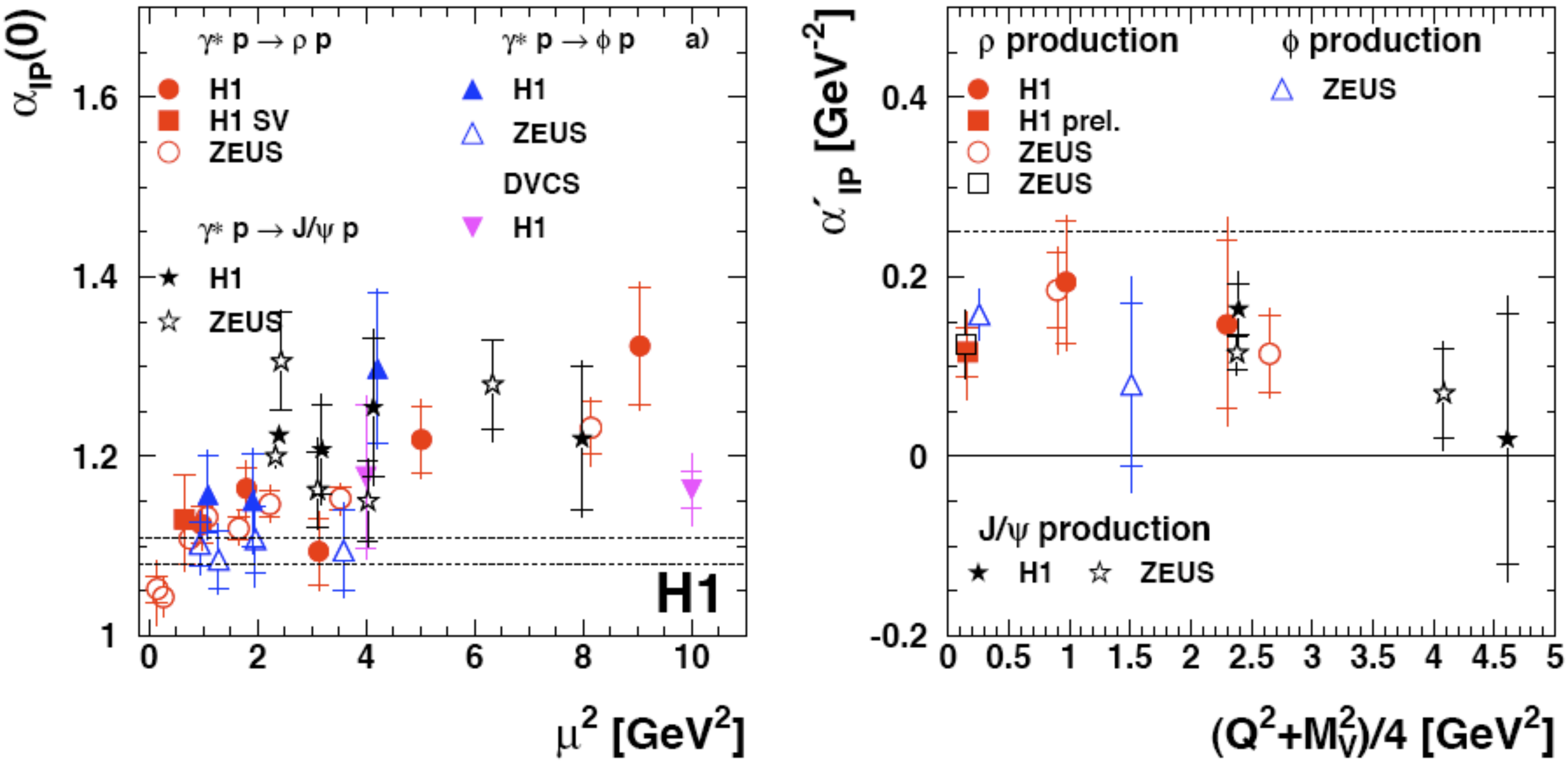
which is larger than e.m. dipole mass

$$m_{e.m.}^2 = 0.7\ GeV^2. \qquad \text{(FS02)}$$

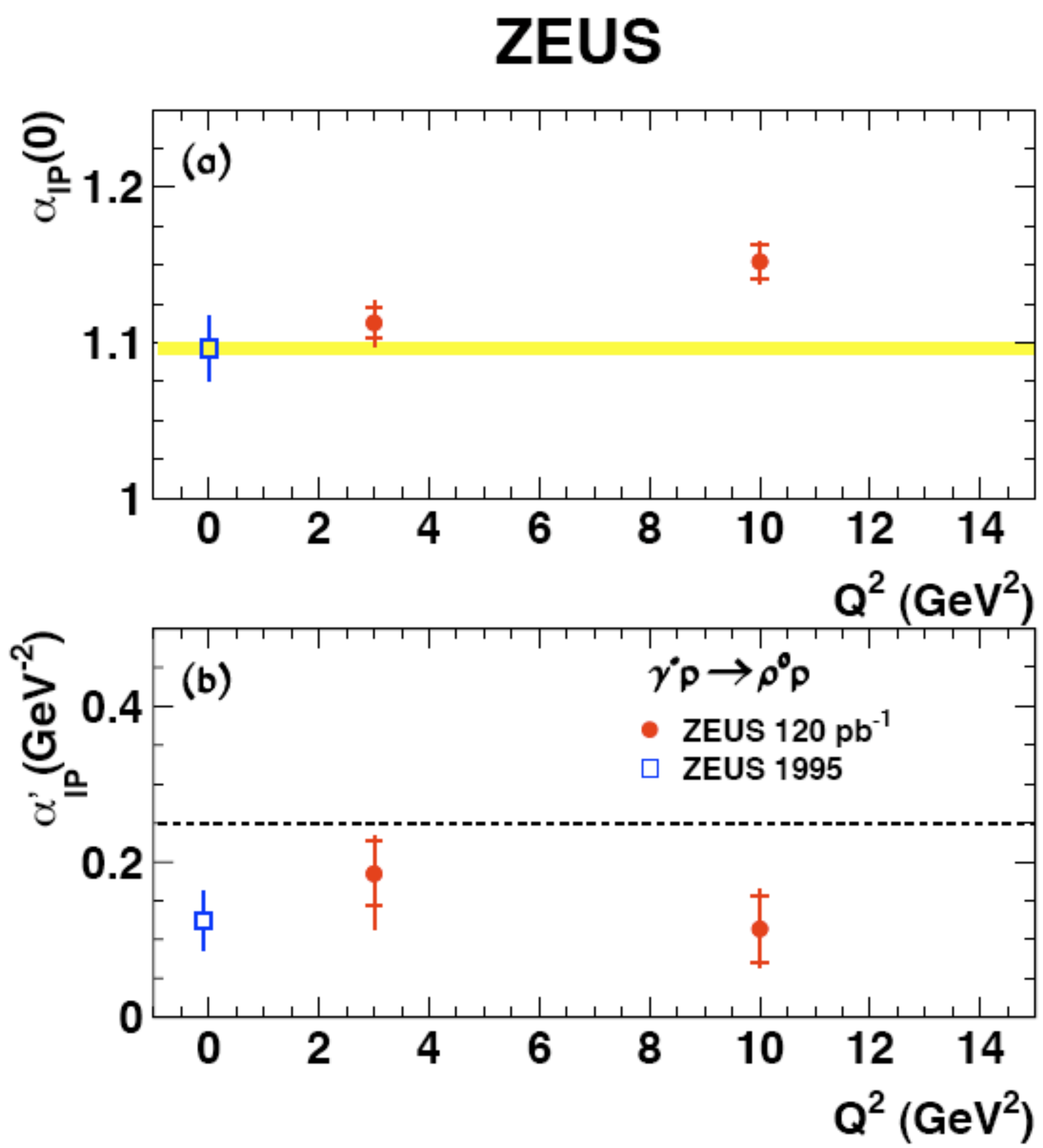
Significant contribution to the difference isdue to the chiral dynamics - lack of scattering off the pion field at x>0.05 (Weiss &MS 03)

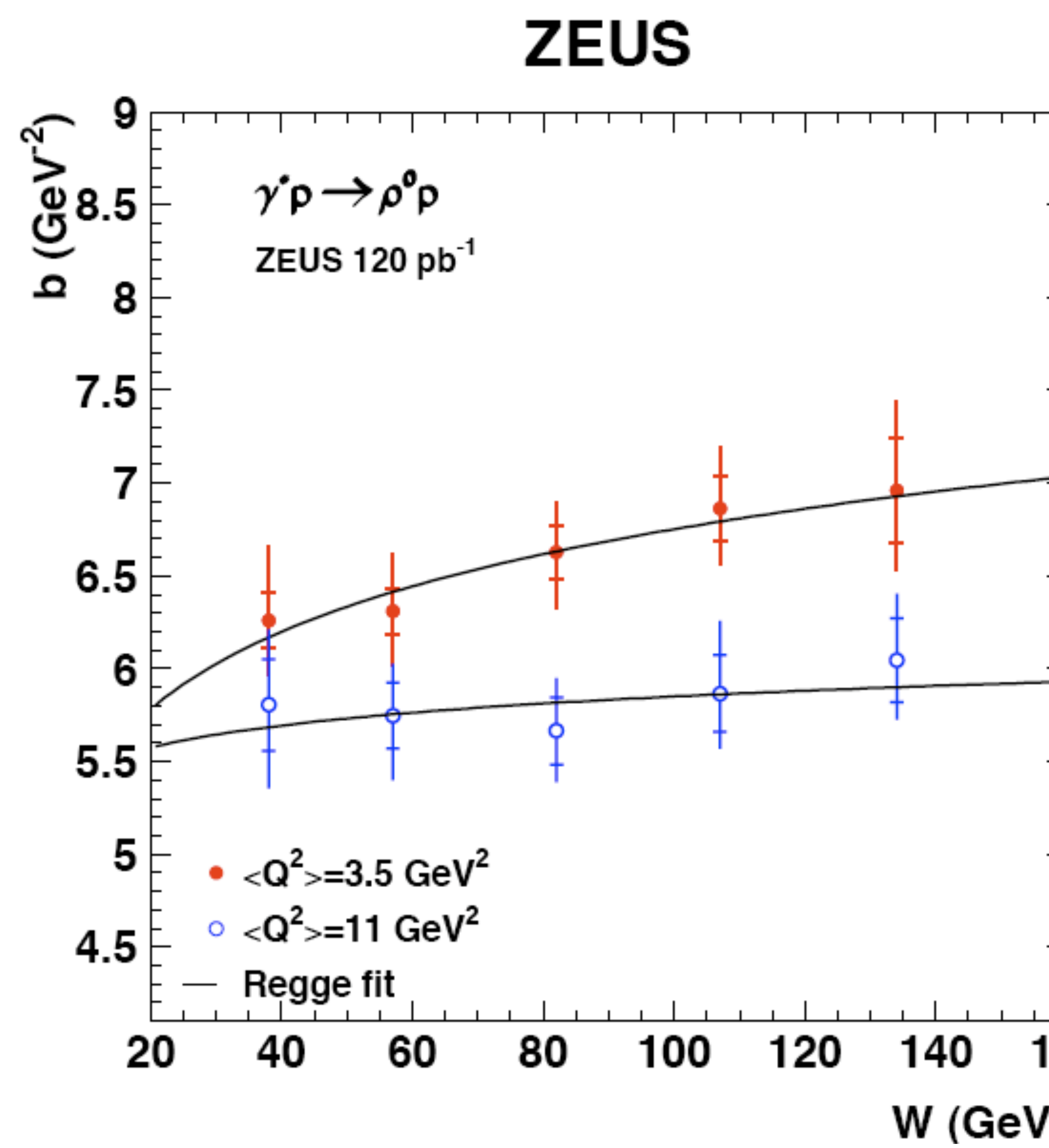
Large difference between impact parameters of soft interactions and hard interactions especially for $x_{parton} > 0.01$.

Enters into calculation of the gap survival probability in the double Pomeron exclusive Higgs production in a very sensitive way



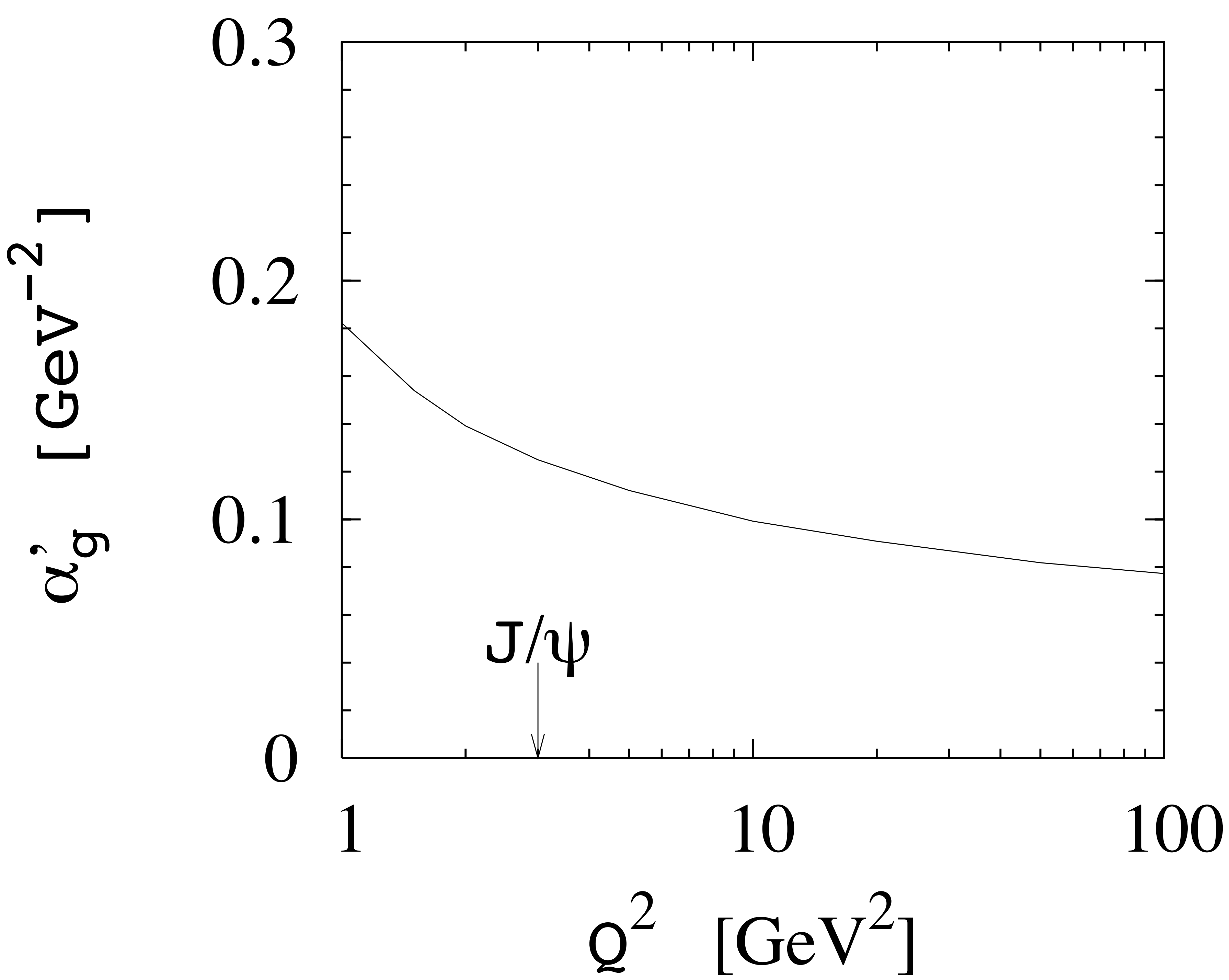
$\mu^2 = (Q^2 + M_V^2)/4$ for VM production and $\mu^2 = Q^2$ for DVCS





$$B = B_0 + 2\alpha'_{I\!P} \ln(x_0/x)$$

Figure 23: *The parameters of the effective Pomeron trajectory in exclusive* ρ^0 *electroproduction, (a)* $\alpha_{I\!P}(0)$ *and (b)* $\alpha'_{I\!P}$*, as a function of* Q^2*. The inner error bars indicate the statistical uncertainty, the outer error bars represent the statistical and systematic uncertainty added in quadrature. The band in (a) and the dashed line in (b) are at the values of the parameters of the soft Pomeron [19, 20].*



pQCD (DGLAP approximation) - rather weak Q evolution of α' - Frankfurt, MS, Weiss 03

Change of transverse spread with x due to DGLAP evolution - leads to effective α´ which drops with Q but still remains finite even at very high Q.

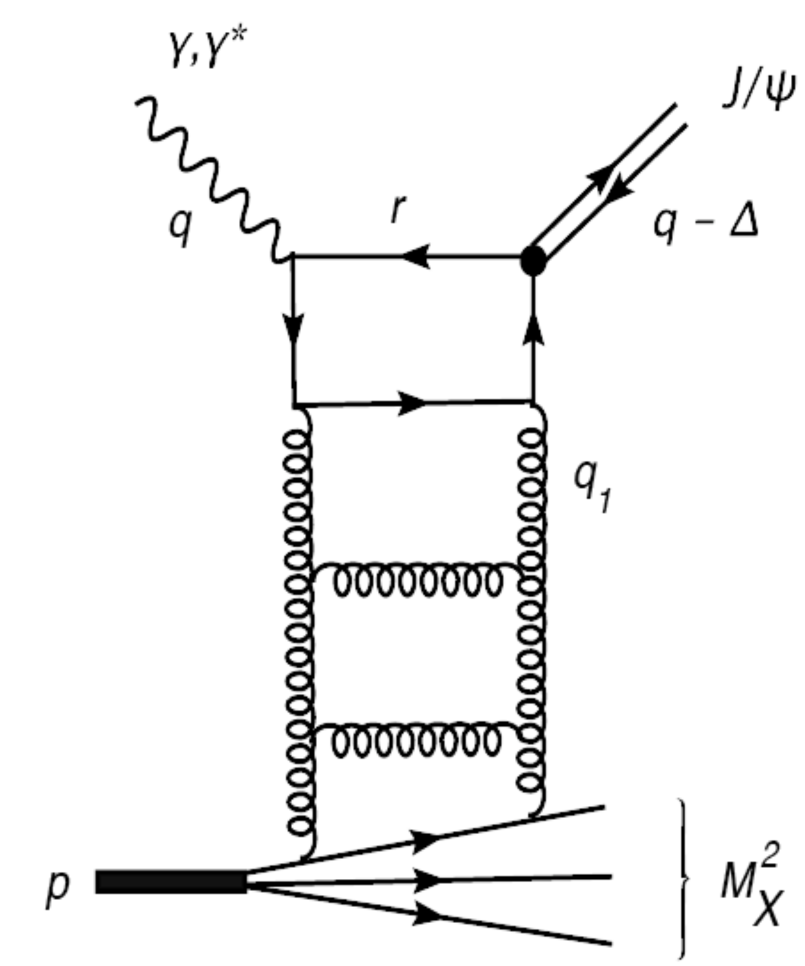
Another mechanism for effective α´ is fluctuations in the transverse size is due to HT in the J/psi wave function: on the amplitude level 10 -20 % of large size configurations for real photon case - can lead to drop of α´ between $Q^2=0$ and 10 GeV^2 (McDermott & F&S) of the order 0.5 GeV^{-2}

New effect - DGLAP at large t

CFS factorization theorem derived in the limit $-t \ll Q^2$

For $-t \sim Q^2$, in the double log approximation essentially no energy dependence of the ladder - hence α_{IP} is close to one - effectively looks as presence of α' of the order of 0.07 GeV^{-2}- but effect does not reflect increase of the transverse distribution of partons !!! (Blok, FS, 10)

Consider process for $-t \leq Q^2 + M_V^2$



Elementary reaction - scattering of a hadron (γ, γ^*) off a parton of the target at large $t=(p_\gamma-p_V)^2$

FS 89 (large t pp→p +gap + jet), FS95

Mueller & Tung 91

Forshaw & Ryskin 95

$$x_J = \frac{-t}{-t + M_X^2 - m_N^2}$$

$$\frac{d\sigma_{\gamma+p\to V+X}}{dtdx_J} = \frac{d\sigma_{\gamma+quark\to V+quark}}{dt}\left[\frac{81}{16}g_p(x_J,t)+\sum_i(q_p^i(x_J,t)+\bar{q}_p^i(x_J,t))\right]$$

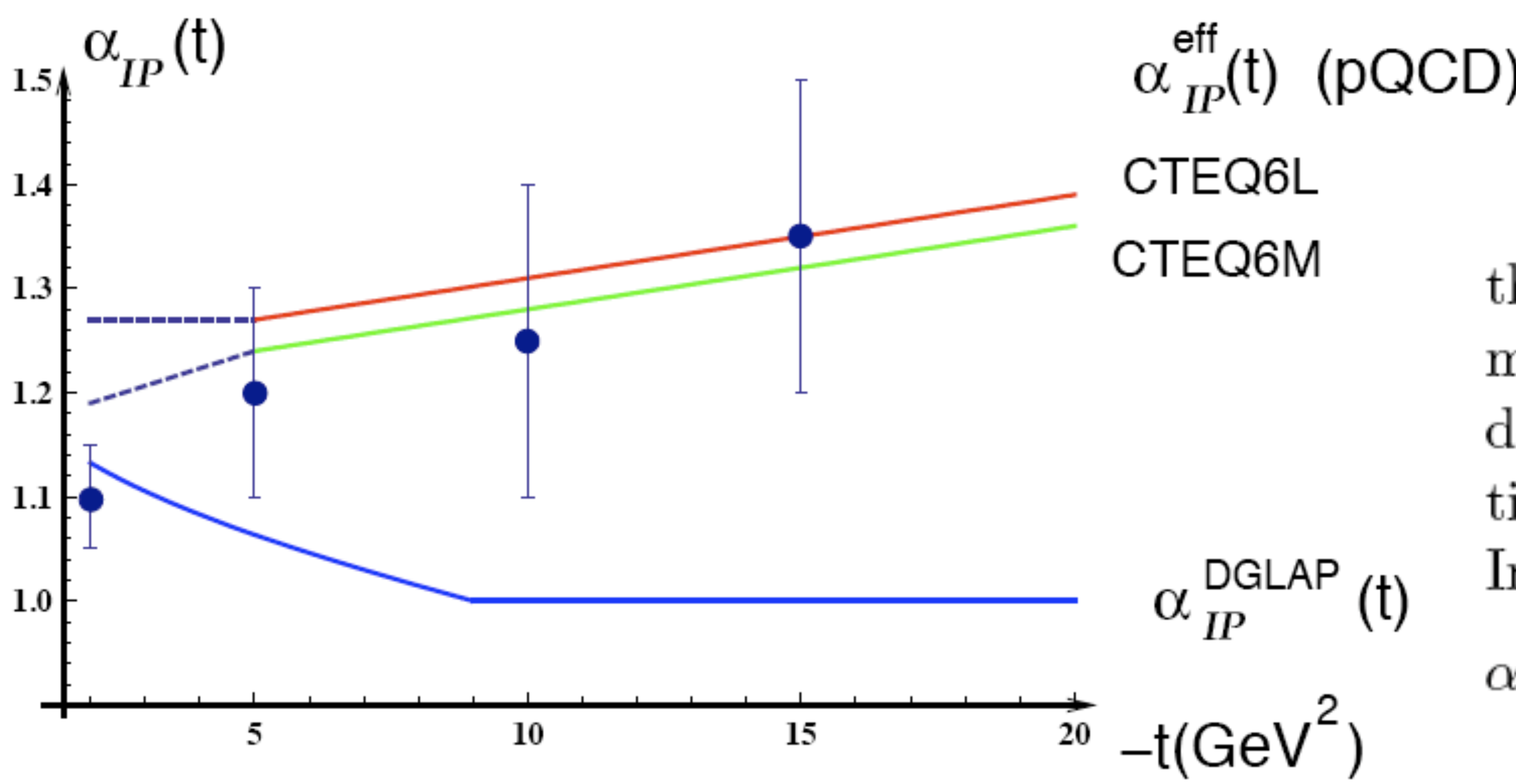
For $-t \leq Q^2 + M_V^2$

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

Here

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

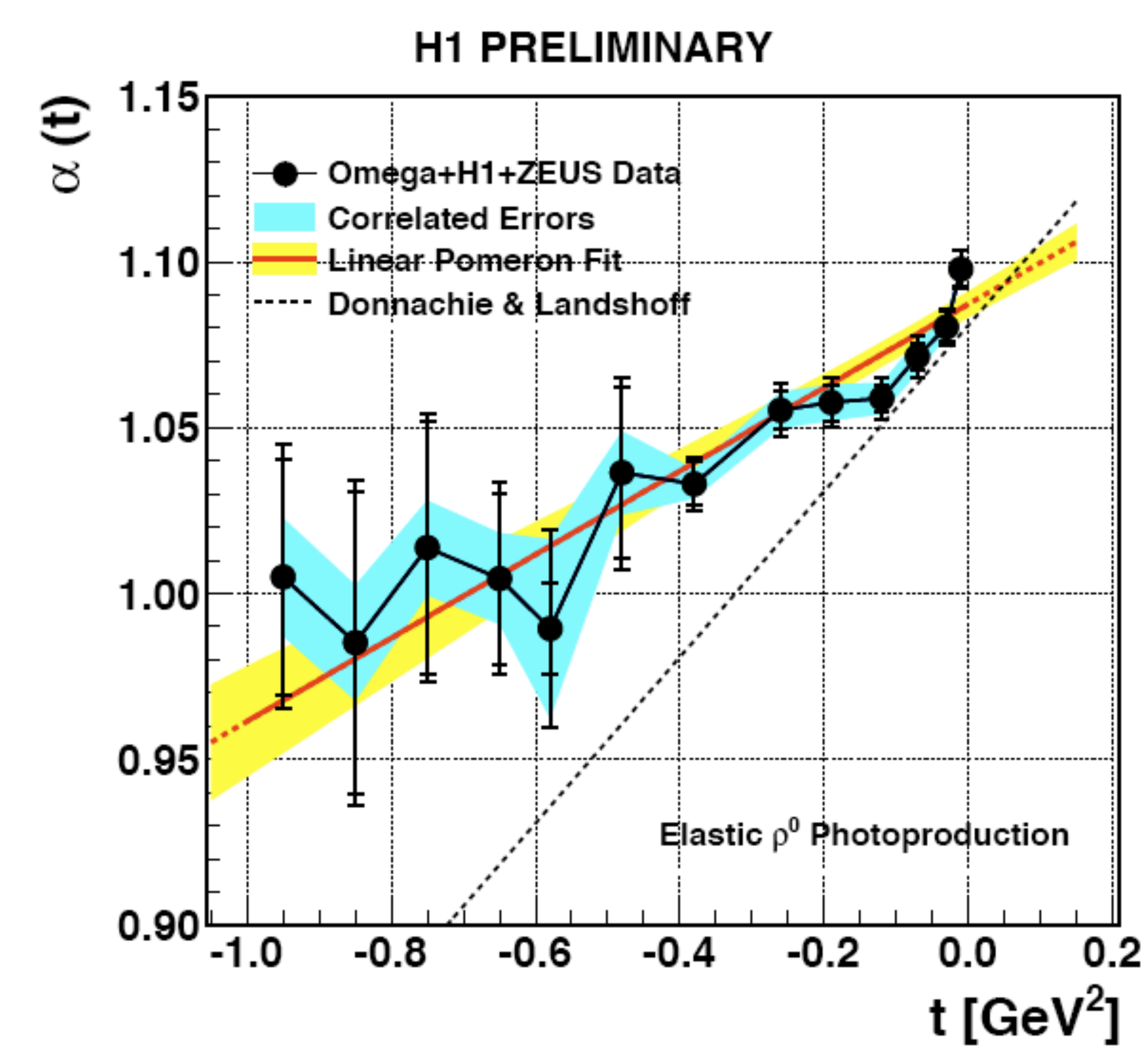
$$x_J = -t/(M_X^2 - m_p^2 - t), x \sim 3(Q^2+M_V^2)/(2s),\ b = 11 - 2/3N_f,\ N_c = 3,\ s = W_{\gamma p}^2$$



The comparison between the experimental data and theoretical prediction for 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.

Note that in this calculation the scale governing the J/ψ production was taken to be M_V^2. More realistic estimate (at least for exclusive photoproduction is 3 GeV^2)

Maybe relevant for the explanation of the pattern observed in photoproduction of ρ-mesons. No diffusion if -t is larger than the soft scale.



Early scaling in DIS - mechanism of inelastic diffraction is likely to change at $-t \sim 1\ \mathrm{GeV}^2$. Hence subtraction for these t is especially problematic.

☛ *Need a design of the detector with proton detection up to large t*

Slow convergence of the Fourier transform of $F_{2g}(t)$ for dipole fit. For b=0

$$\int_0^{-t_{max}} F_{2g}(t)dt = \frac{1}{1 - t_{max}/M_{2g}^2}$$

☛ To probe small b large Q^2 are necessary - otherwise factorization in the form given by CFS is broken

$$\frac{d\sigma_{\gamma+p\to V+X}}{dtdx_J} = \frac{d\sigma_{\gamma+quark\to V+quark}}{dt}\left[\frac{81}{16}g_p(x_J,t)+\sum_i(q_p^i(x_J,t)+\bar{q}_p^i(x_J,t))\right]$$

☛ - $t \sim 1 \div 2$ GeV^2 + strong enhancement of interactions with gluons - unique way to excite gluonic modes in nucleon at $x_J \sim 0.2$. Novel baryon I=1/2 spectroscopy if gluons and not strongly coupled with valence quarks - in any case - a new tool - price - good forward detector not only for protons and neutrons but also for mesons. Interesting effects in the case of polarized proton are possible - need further analysis.

☛ Can also check chiral dynamics in near threshold πN production, Polyakov et al

Strength of the gluon field should depend on the size of the quark configurations - for small configurations the field is strongly screened - gluon density much smaller than average.

Do we know anything about such fluctuations?

Yes - MS + LF + C.Weiss, D.Treliani PRL 08

Consider $\gamma_L^* + p \to V + X$ for Q^2 > few GeV^2

In this limit the QCD factorization theorem (BFGMS03, CFS07) for these processes is applicable

Expand initial proton state in a set of partonic states characterized by the number of partons and their transverse positions, summarily labeled as $|n\rangle$

$$|p\rangle = \sum_n a_n |n\rangle$$

Each configuration n has a definite gluon density $G(x, Q^2| n)$ given by the expectation valu the twist--2 gluon operator in the state $|n\rangle$

$$G(x, Q^2) \;=\; \sum_n |a_n|^2 G(x, Q^2|n) \;\equiv\; \langle G \rangle$$

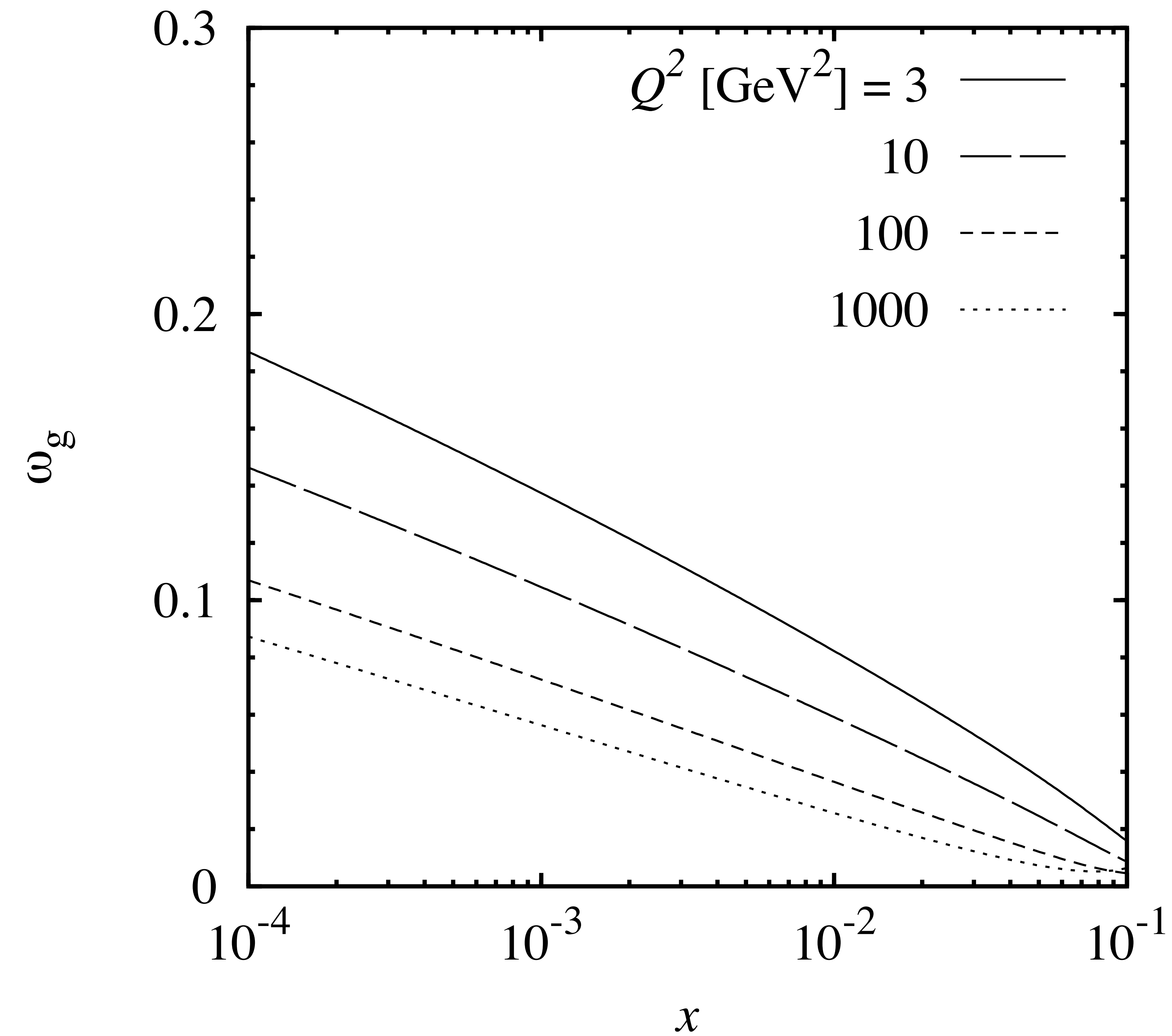
Making use of the completeness of partonic states, we find that the elastic($X = p$) and total diffractive (X arbitrary) cross sections are proportional to

$$(d\sigma_{\rm el}/dt)_{t=0} \quad \propto \quad \left[\sum_n |a_n|^2 G(x,Q^2|n)\right]^2 \equiv \langle G\rangle^2,$$

$$(d\sigma_{\rm diff}/dt)_{t=0} \quad \propto \quad \sum_n |a_n|^2 \left[G(x,Q^2|n)\right]^2 \equiv \langle G^2\rangle.$$

Hence cross section of inelastic diffraction is $\sigma_{\rm inel} = \sigma_{\rm diff} - \sigma_{\rm el}$

$$\Rightarrow \quad \boxed{\omega_g \equiv \frac{\langle G^2\rangle - \langle G\rangle^2}{\langle G\rangle^2} = \frac{d\sigma_{\gamma^*+p\to VM+X}}{dt} \Bigg/ \frac{d\sigma_{\gamma^*+p\to VM+p}}{dt}\Bigg|_{t=0}.}$$



The dispersion of fluctuations of the gluon density, ω_g, as a function of x for several values of Q^2, as obtained from the scaling model we developed which connects fluctuations of σ and fluctuations of color. We naturally reproduce the observed magnitude of the ratio measured experimentally at HERA.

Conclusions

- HERA left plenty of open questions related to the dynamics of exclusive VM production and characteristics of GPDs - especially the gluon GPD which dominates at small x.

- QCD factorization theorem for exclusive processes imposes a condition on t which could be probed at given Q for the purposes of studying GPDs

- Rapidity gap processes provide tests of elastic hard scattering in QCD at large t and also serve as a new tool for studying $N \to N^*$ form factors involving gluons

- Key for a successful experimental research in this field is a sufficiently hermetic detector in the nucleon fragmentation region.