Soft -hard transition in exclusive processes
+ few comments of gluon GPDs

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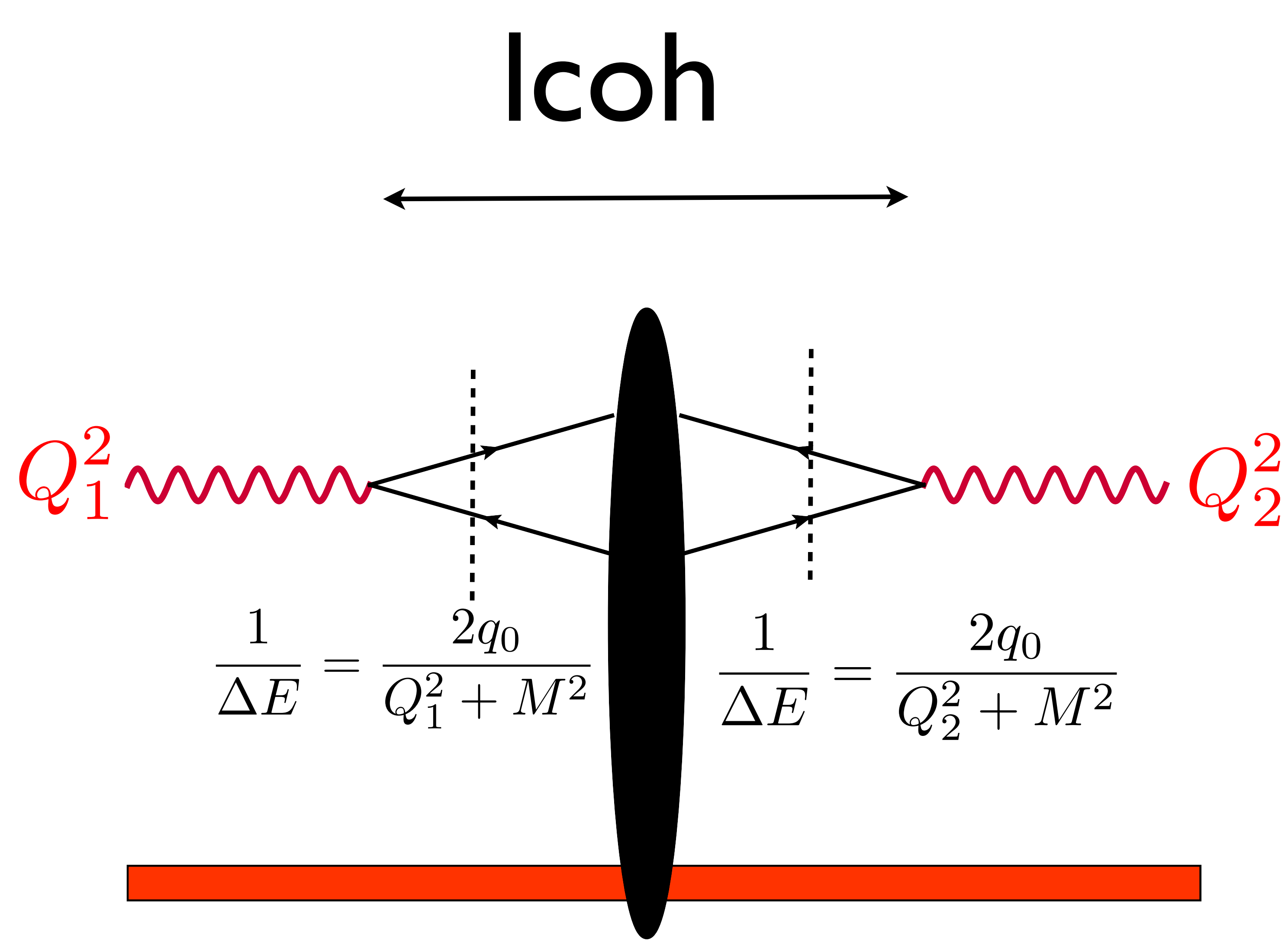
DVCS meeting, Bochum
10 -12 February, 2014

Space time picture of DIS/ DVCS at sufficiently small x



average longitudinal distance between current operators in the expression for the scattering amplitude $\langle p|[j_\mu(y), j_\lambda(0)]|p\rangle$

DIS: $l_{coh}(Q^2 \sim \text{few GeV}^2) \sim \frac{2q_0}{Q^2+M^2} \sim \frac{1}{2m_N x}$

FS88

DIS - very small x - slower increase of l_{coh} with decrease of x -- Kovchegov & MS

Different space time picture for $l_{coh} > r_N$ and $l_{coh} < r_N$

x≤ 0.1

scattering off quark-antiquark pairs

x≥0.2

scattering off valence quarks

$$l_{coh}^{DVCS}(Q^2 \sim \text{few GeV}^2) \sim \left(\frac{2q_0}{Q^2+M^2} + \frac{2q_0}{M^2}\right) \Rightarrow l_{coh}^{DVCS}(Q^2, \nu) \approx \frac{3}{2} l_{coh}^{DIS}(Q^2, \nu)$$

$$\sigma_{tot}(\gamma^* N) = \frac{\alpha}{3\pi}\int_{M_0^2}^{\infty} \frac{\sigma_{tot}(``AJM" - N) R^{e^+e^-}(M^2) M^2 \frac{3\langle k_{0\ t}^2\rangle}{M^2}}{(Q^2+M^2)^2} dM^2$$

$\frac{3\langle k_{0\ t}^2\rangle}{M^2}$ is the phase volume of aligned jets

$$\frac{1}{s} Im A(\gamma^* + N \to \gamma + N)_{t=0} = \frac{\alpha}{3\pi}\int_{M_0^2}^{\infty} \frac{\sigma_{tot}(``AJM" - N) R^{e^+e^-}(M^2) M^2 \frac{3\langle k_{0\ t}^2\rangle}{M^2}}{(Q^2+M^2) M^2} dM^2$$

$$R = \frac{A_{DVCS}(W, Q^2, t=0)}{A_{\gamma^* p \to \gamma^* p}(W, Q^2)} = \frac{Q^2 + M_0^2}{Q^2} \ln(1 + Q^2/m_0^2)$$

Prediction: $R(Q^2 \sim 3\ \mathrm{GeV}^2, x \sim 0.01) \approx 2$ Freund, LF, MS 97

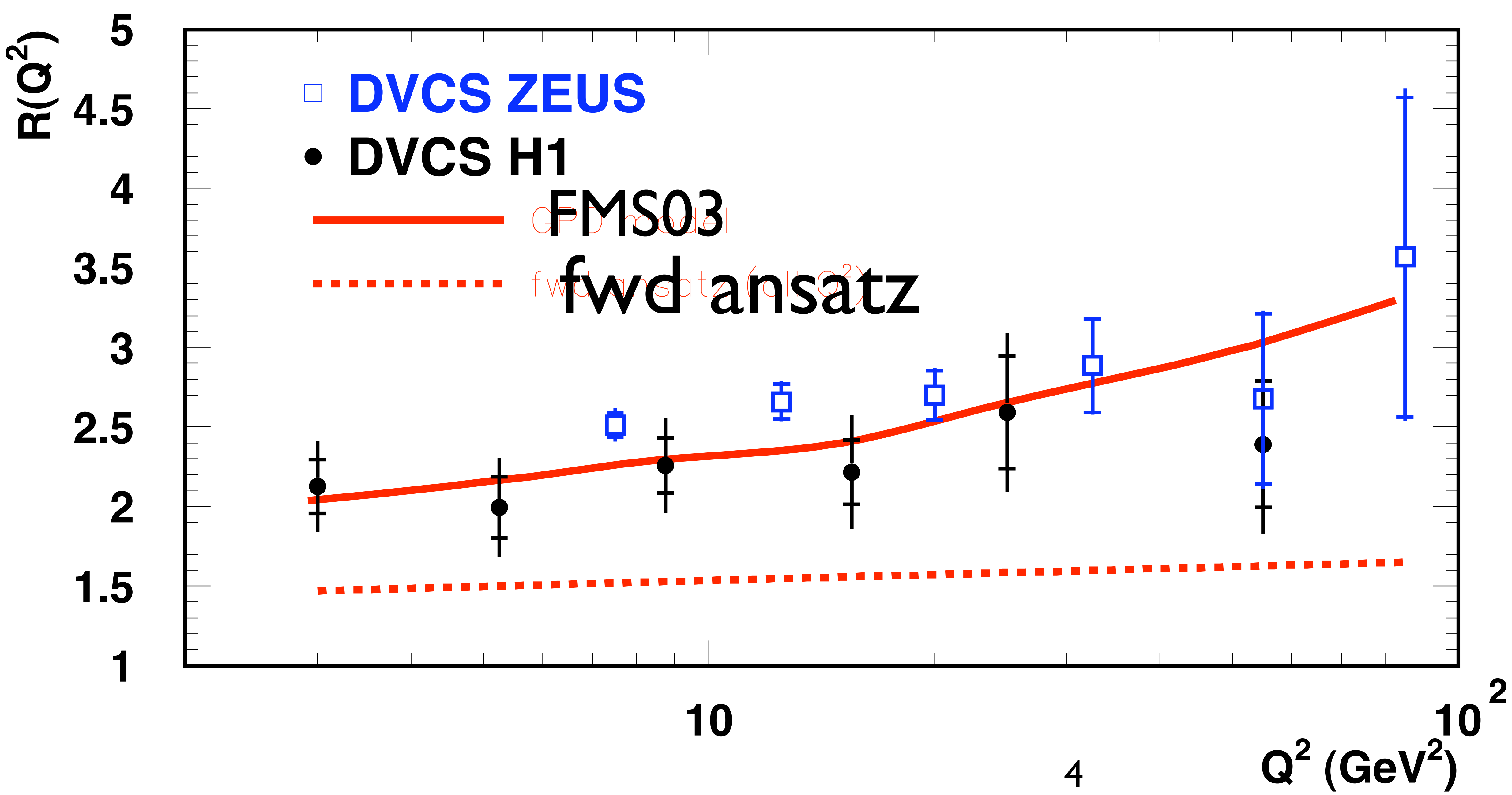
and slowly increasing with Q

Soft boundary condition for GPDs

Question - at large Q GPD evolution dilutes information about skewness of the initial condition. Is there any sensitivity left? Analysis of L.Schoeffel, 07 of R - ratio of DVCS and diagonal amplitudes at t=0 (uncertainties in PDFs are canceled)

$$R = \frac{A_{DVCS}(W, Q^2, t=0)}{A_{\gamma^* p \to \gamma^* p}(W, Q^2)}$$

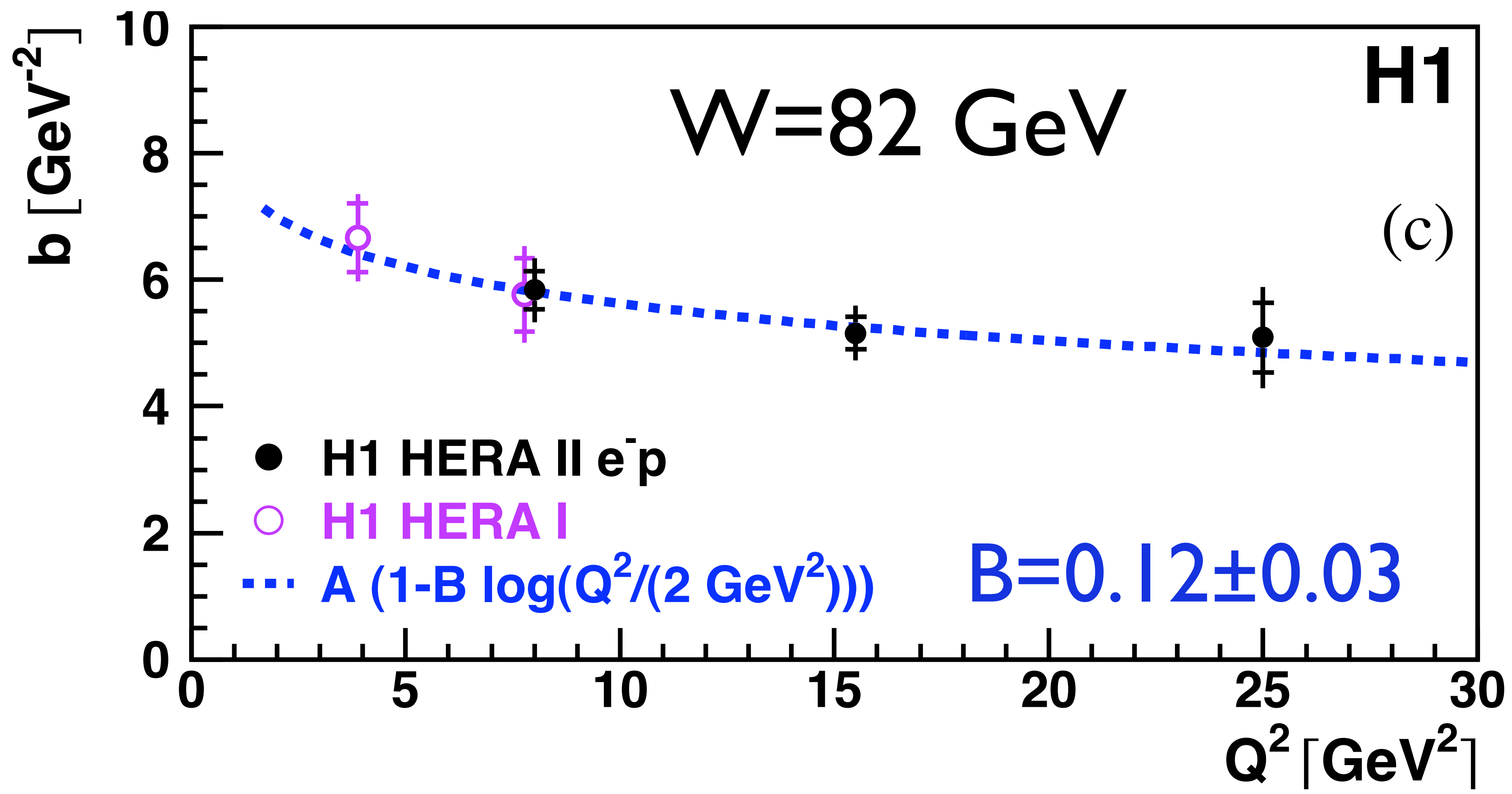
$$R = \frac{4\sqrt{\pi\,\sigma_{DVCS}\,b(Q^2)}}{\sigma_T(\gamma^* p \to X)\sqrt{(1+\rho^2)}} = \frac{\sqrt{\sigma_{DVCS}\,Q^4\,b(Q^2)}}{\sqrt{\pi^3}\,\alpha_{EM} F_T(x, Q^2)\sqrt{(1+\rho^2)}},$$

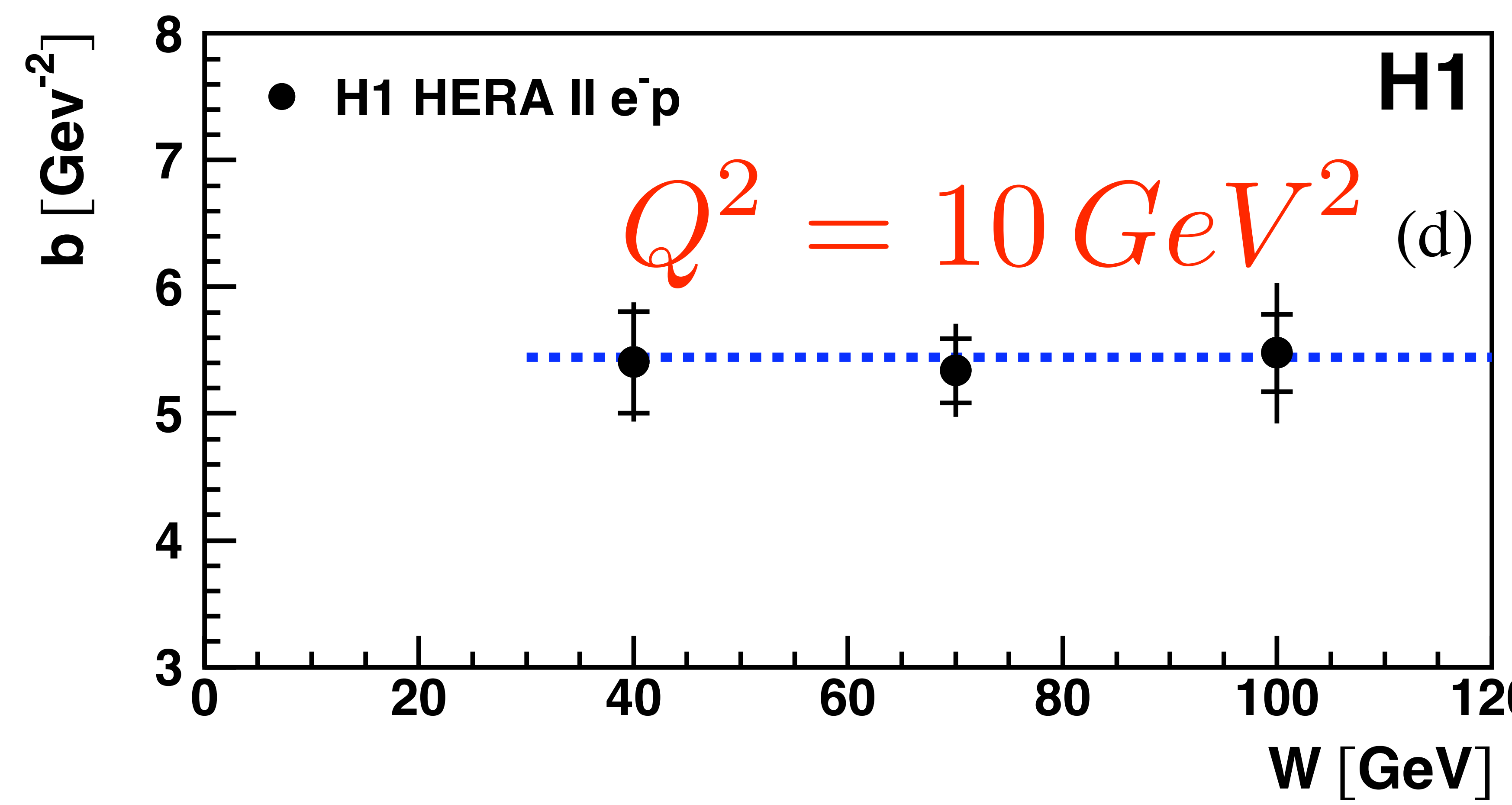


FMS03= Freund, McDermott, MS - NLO with soft boundary condition

Soft boundary condition at Q^2=2 GeV^2 - consistent with impact parameter analysis and observation at HERA of early LT QCD factorization (Collins theorem) for diffraction and $\alpha_{Pomeron}$ (diffraction)=1.11 practically the same as the soft value of 1.10.

Higher twist effects: expect change of the t-slope in the dipole logic





Difficult to explain the observed pattern due to α'~0.12 GeV^{-2}: $b = b_0 + 2\alpha' \ln(x/x_0)$

Higher twist effect due the finite transverse size of γ* seems to provide natural explanation - similar to the trend in ρ production. Still b systematically larger than for J/ψ. Possible solution - in NLO qGPD and gGPD enter with opposite sign in 2:1 ratio ⇒ difference in B_q

and B_g is amplified by a factor of 2 . Crucial to measure both DVCS and onium exclusive production: B_q - B_g ~ 0.5 GeV^{-2} would be sufficient (MS06) - pion effect? (MS & Weiss)

Three interesting limits of $x < .1$ (virtual) Compton scattering

- $Q^2 < M^2$ down to $Q^2 = 0$

- fixed x, $Q^2 > M^2$ DGLAP + HT (?)

- fixed Q^2, $x \to 0$

$Q^2 < M^2$ down to $Q^2 = 0$

Q^2 dependence for fixed ν

$Q^2 = 0$ - real Compton scattering

$\sigma_{tot}(\gamma N)$ is measured in wide range - soft: $\alpha_{Pomeron}(t=0) = 1.10$

Contribution to the cross section of ρ, ω, φ- mesons is ~ 60%

40% from masses above 1 GeV --- the lowest mass state is ρ’ at ~1.25 GeV

⬇

$\langle M^2 \rangle$ in the integral over masses in $\sigma_{tot}(\gamma N)$ are $\gtrsim 1\ GeV^2$

t - slope ---Energy dependence for $\gamma+p \rightarrow \gamma+p$

Contribution of small masses:

slopes, B_1, like for photoproduction of ρ, ω, φ- mesons

Contribution of large masses:

much lower slopes in diffraction $\gamma+p \rightarrow M+p$, B_2: $\Delta B \sim 3 \div 4$ GeV^{-2}

$E_\gamma \sim 100$ GeV.

$$d\sigma(\gamma+p \rightarrow \gamma+p)/dt \propto 0.6 \exp(B_1 t) + 0.4 \exp(B_2 t)$$

Interesting scenario - for $E_\gamma \sim$ few GeV heavy masses suppressed - larger slope? Drop of the slope with increase of E_γ ? Anti Pomeron behavior? Nondoagomal transitions --Difference between slopes of

$$\gamma+p \rightarrow M+p \text{ and } M_1+p \rightarrow M_2+p \text{ ?}$$

Current data are at $E_\gamma < 20$ GeV where heavy masses are suppressed and errors of the data of < 1978 are pretty large. Also problem with matching slopes for ρ's with $E_\gamma \sim 100$ GeV

Q^2 dependence for fixed ν

$$A(\gamma^*+p \rightarrow \gamma+p) \xrightarrow[Q^2\rightarrow 0]{} f(\nu)$$

Naively, extrapolation of LT is $A(\gamma^*+p \rightarrow \gamma+p) \propto 1/Q^2$

Caveat: LT fixed x. But ν dependence is pretty weak for low Q

Guess based on dispersion relation:

$$\left.\frac{A(\gamma^* + p \rightarrow \gamma + p)}{A(\gamma + p \rightarrow \gamma + p)}\right|_{t\sim 0} \approx \frac{1}{1 + Q^2/M^2} \rightarrow \frac{M^2}{Q^2} \cdot \left(1 - \frac{M^2}{Q^2} + \dots\right)$$

$M^2 \gtrsim 1\,\mathrm{GeV}^2$

Large HT effects

+ different t dependence due to large high mass contribution at finite Q fixed x, $Q^2 > M^2$ — R=2 and slowly increasing with Q due to slow increase of Q^2/M^2

fixed Q^2, $x \to 0$ — Essential masses grow since cross section of dipole - nucleon interaction grows with 1/x and in the limit of small x

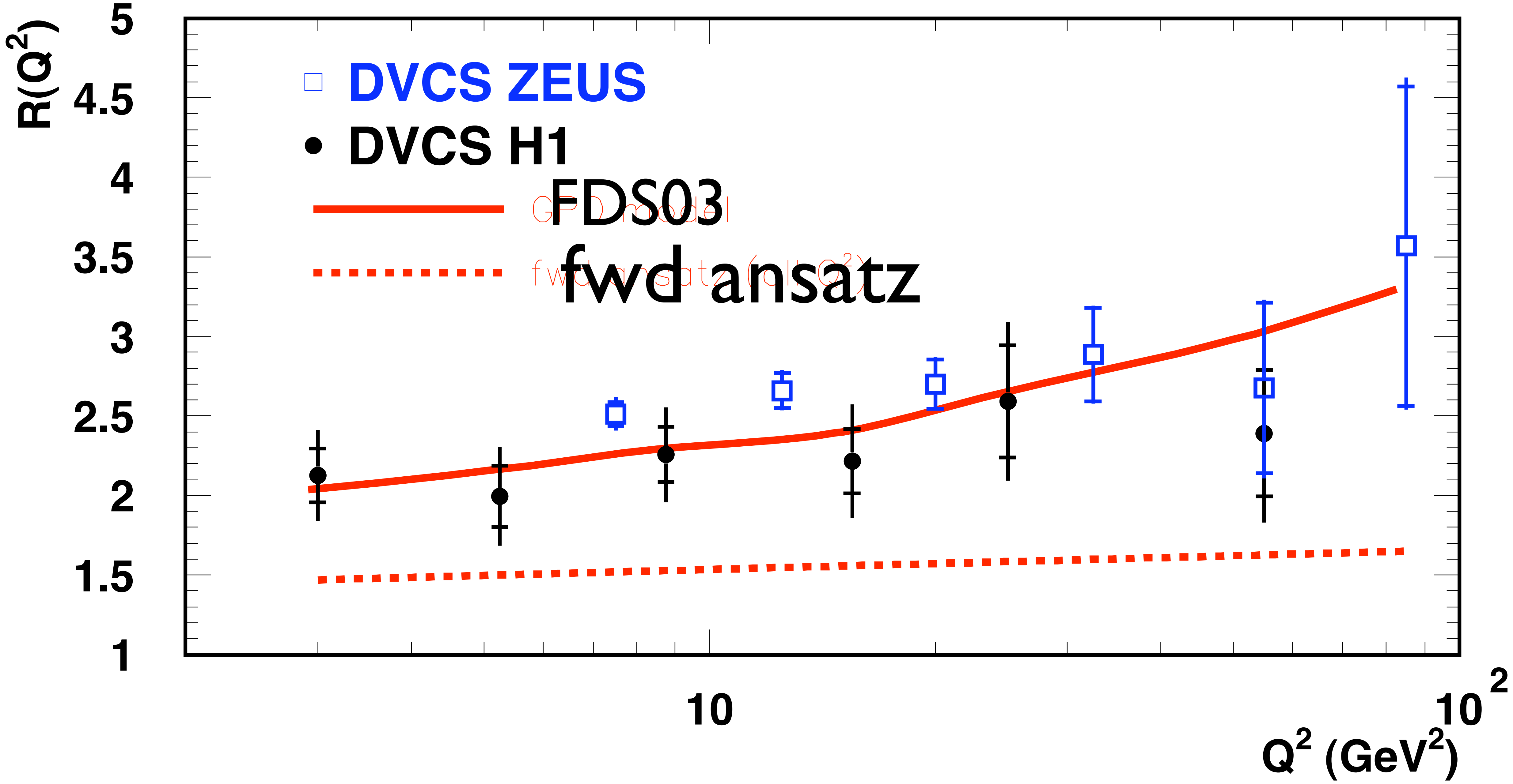
Asymptotically the Black disk regime is reached for all $M^2 \lesssim Q^2$

Guzey et al 01

Can neglect Q^2 in the dispersion integral over the masses

$R \to 1$ for Q^2 =const, $x \to 0$

$$R = \frac{4\sqrt{\pi\,\sigma_{DVCS}\,b(Q^2)}}{\sigma_T(\gamma^* p \to X)\,\sqrt{(1+\rho^2)}} = \frac{\sqrt{\sigma_{DVCS}\,Q^4\,b(Q^2)}}{\sqrt{\pi^3}\,\alpha_{EM} F_T(x,Q^2)\,\sqrt{(1+\rho^2)}},$$



FDS= Freund et al - NLO
with soft boundary condition

Nuclear Shadowing for CS & DVCS

$$l_{coh}^{CS} = \frac{2\nu}{M^2} > r_{NN} \sim 2fm$$

shadowing is present already at Jlab12

Gribov theory works well - tested up to Eγ ~150 GeV for $\sigma_{tot}(\gamma A)$ but precision of measurements for Eγ ~10 GeV is low - so no accurate tests for the limit:

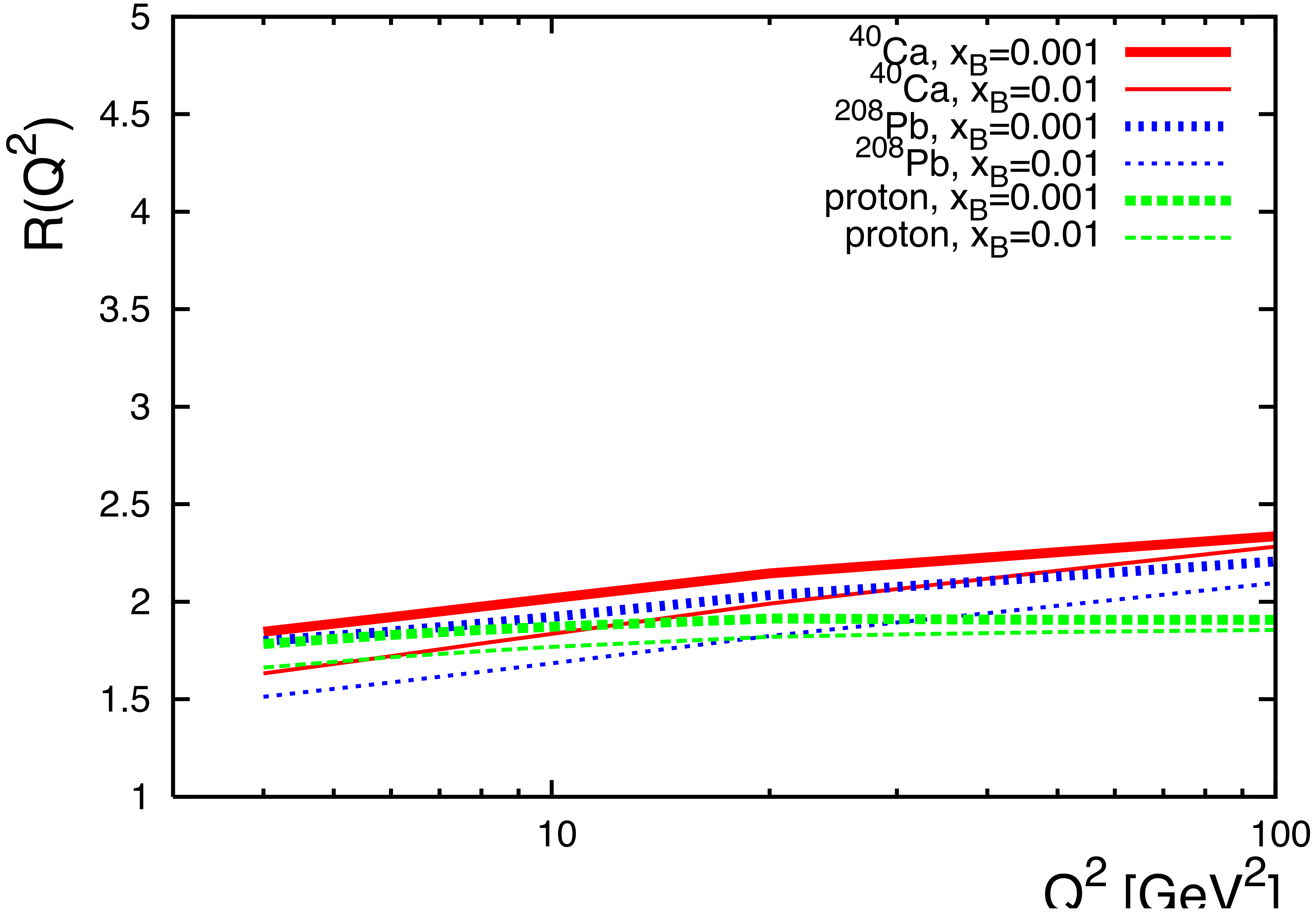
$$2R_A > l_{coh}^{CS} > r_{NN}$$

$$l_{coh}^{DVCS} > r_{NN} \sim 2fm$$

difference with DIS - a factor of ~1.5 -
a bit earlier onset of shadowing

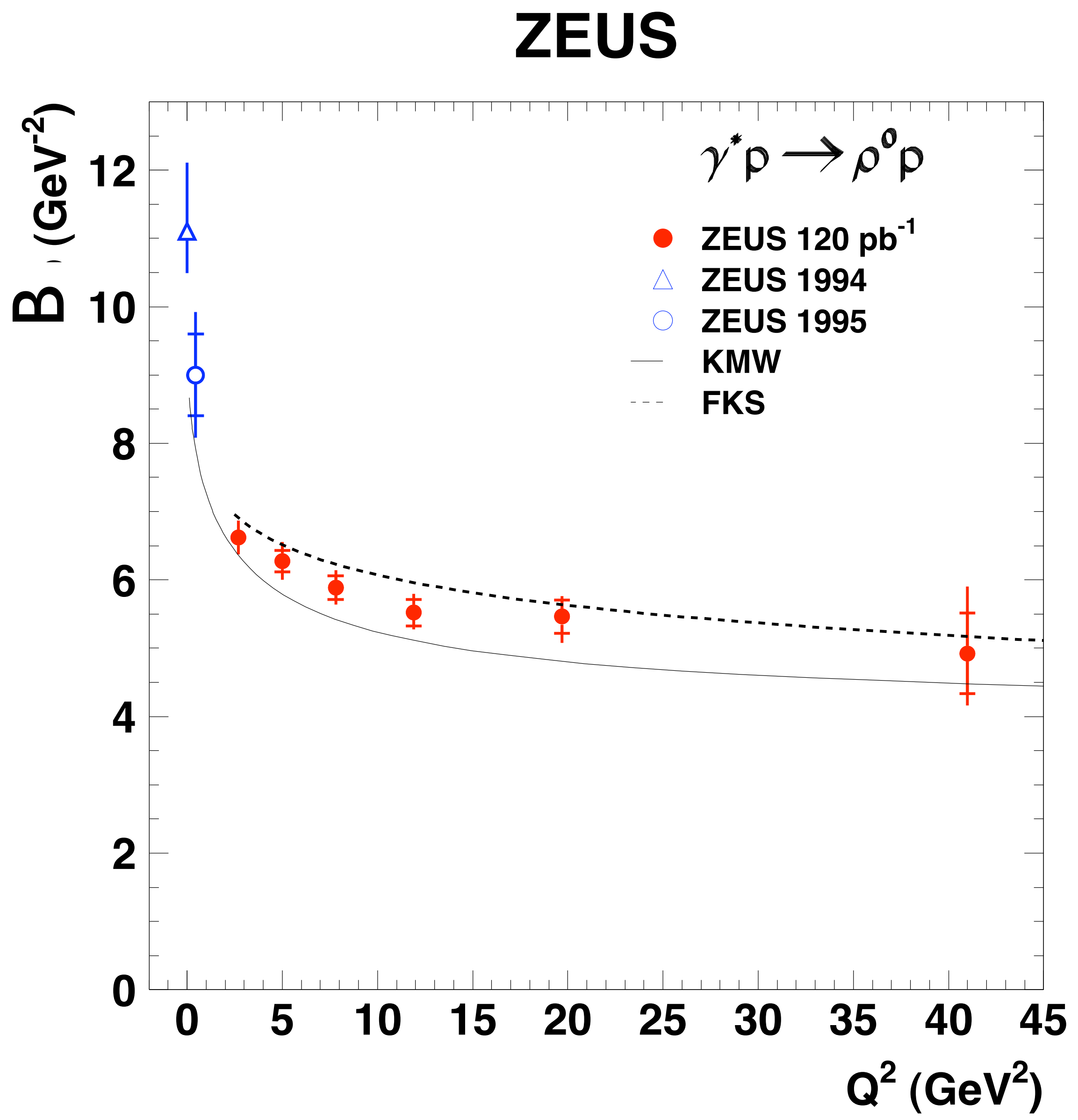
Small M^2 -- larger nuclear shadowing - so trend to have larger M^2/Q^2 in the integral

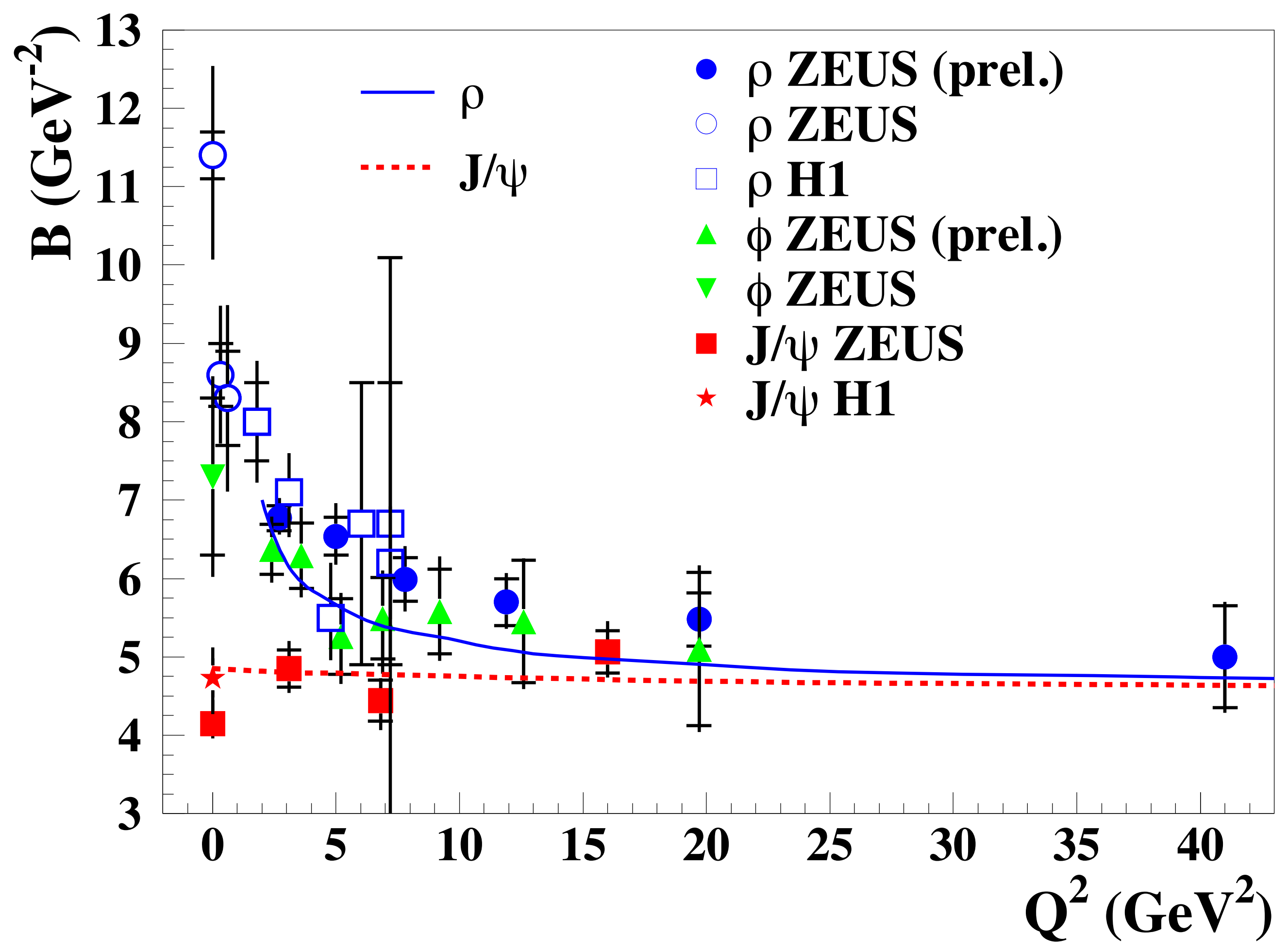
➟ R is somewhat smaller at moderate Q^2 than in proton DVCS



R calculated in Polyakov - Shuvaev model including LT nuclear shadowing effects, Guzey 07

Few comments on gluon GPD - necessary for NLO of DVCS





Drop of B is well reproduced by dipole approximation (in case of FKS actually a prediction of 12 years ago). HT effect.

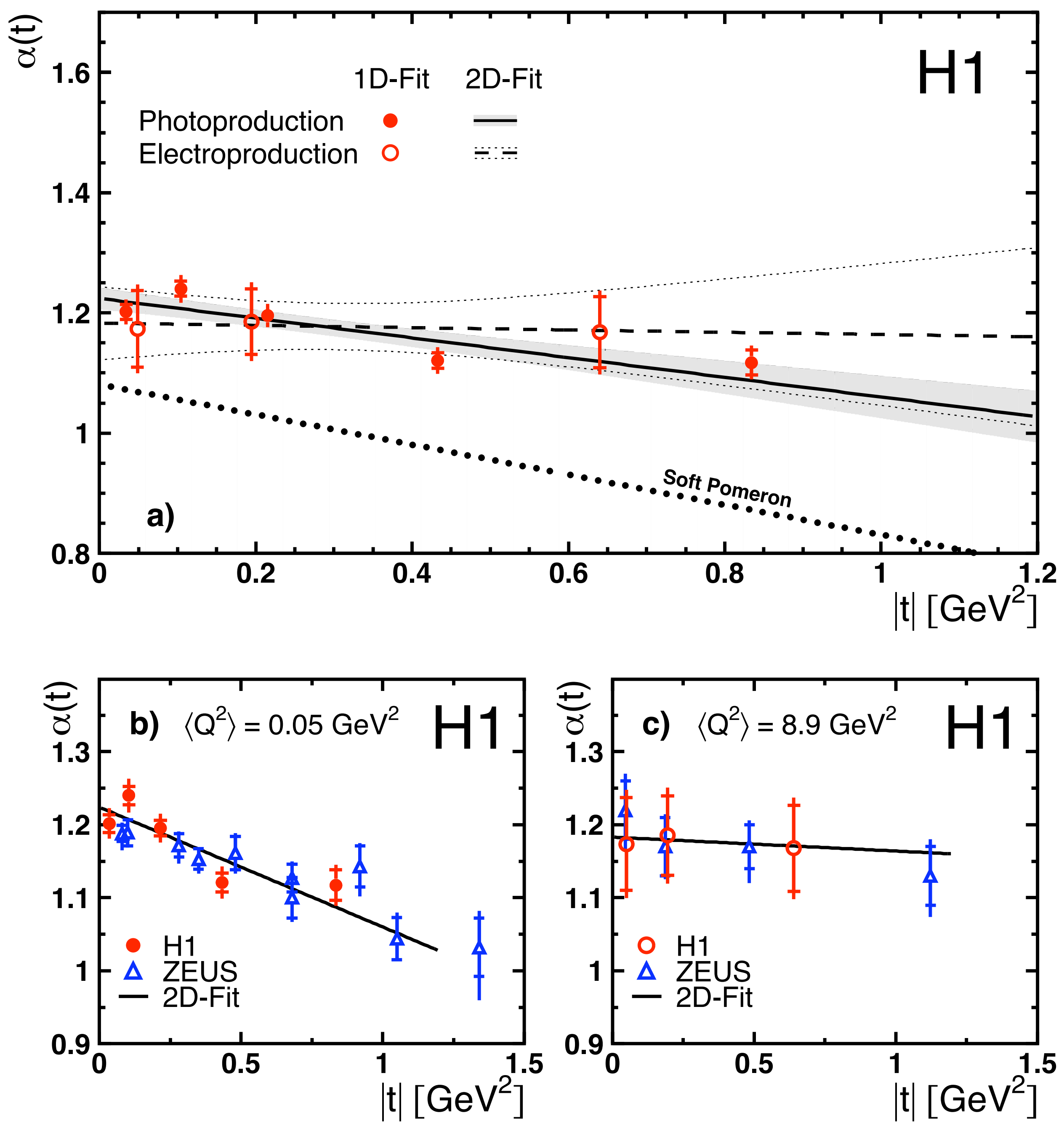
Convergence of t-slope, B of ρ-meson electroproduction to the slope of J/ψ photo(electro)production.

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

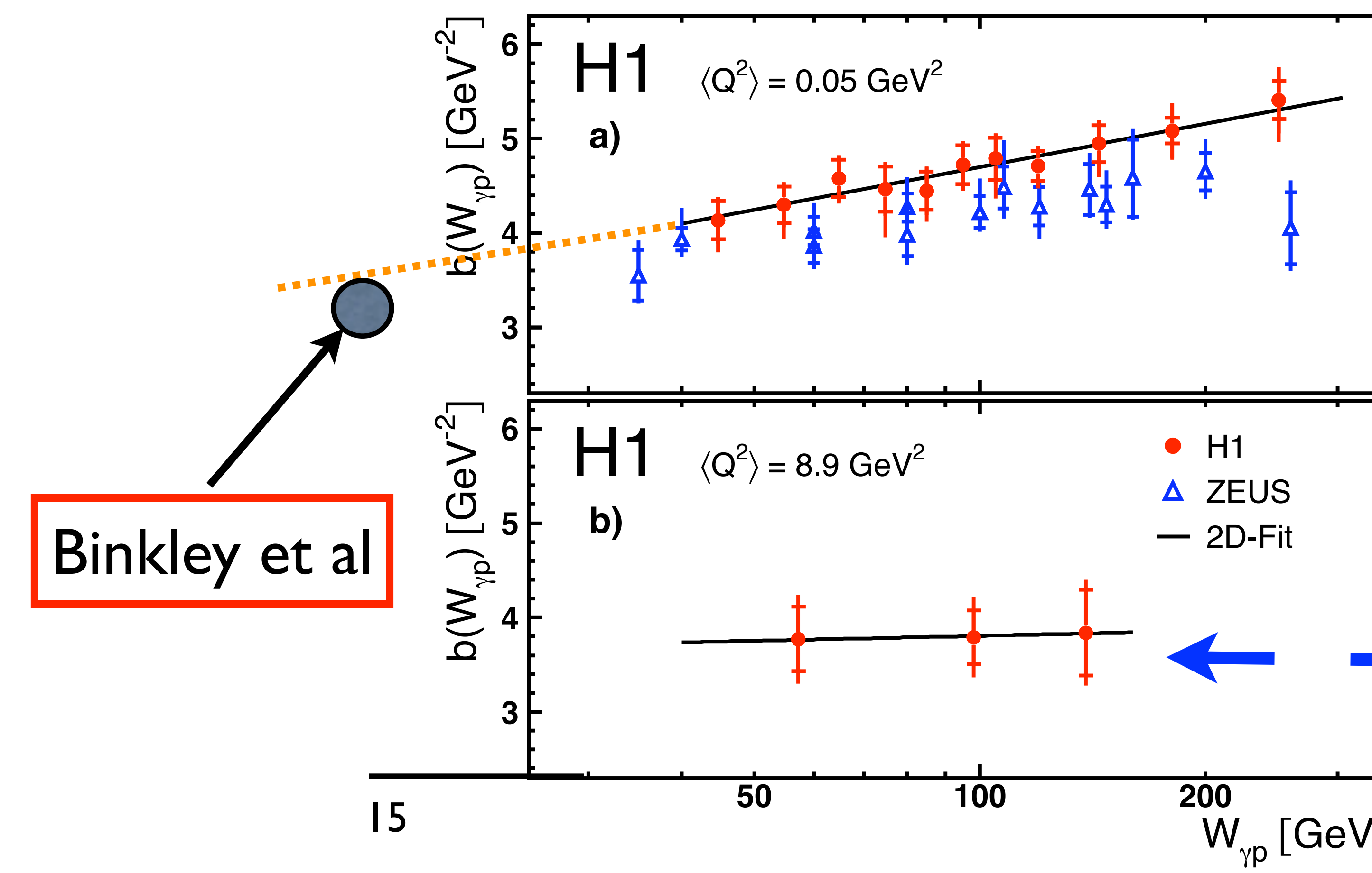
Note that for photoproduction of J/ψ - skewness is relatively small: $x_1 \sim 1.5\ x$, $x_2 \sim 0.5\ x$.

⇒ For ρ-mesons soft may dominate up to higher Q at say HERMES energies (s-dependence of small dipole cross section of interaction with proton). Data???

J/ψ elastic photo and electro production

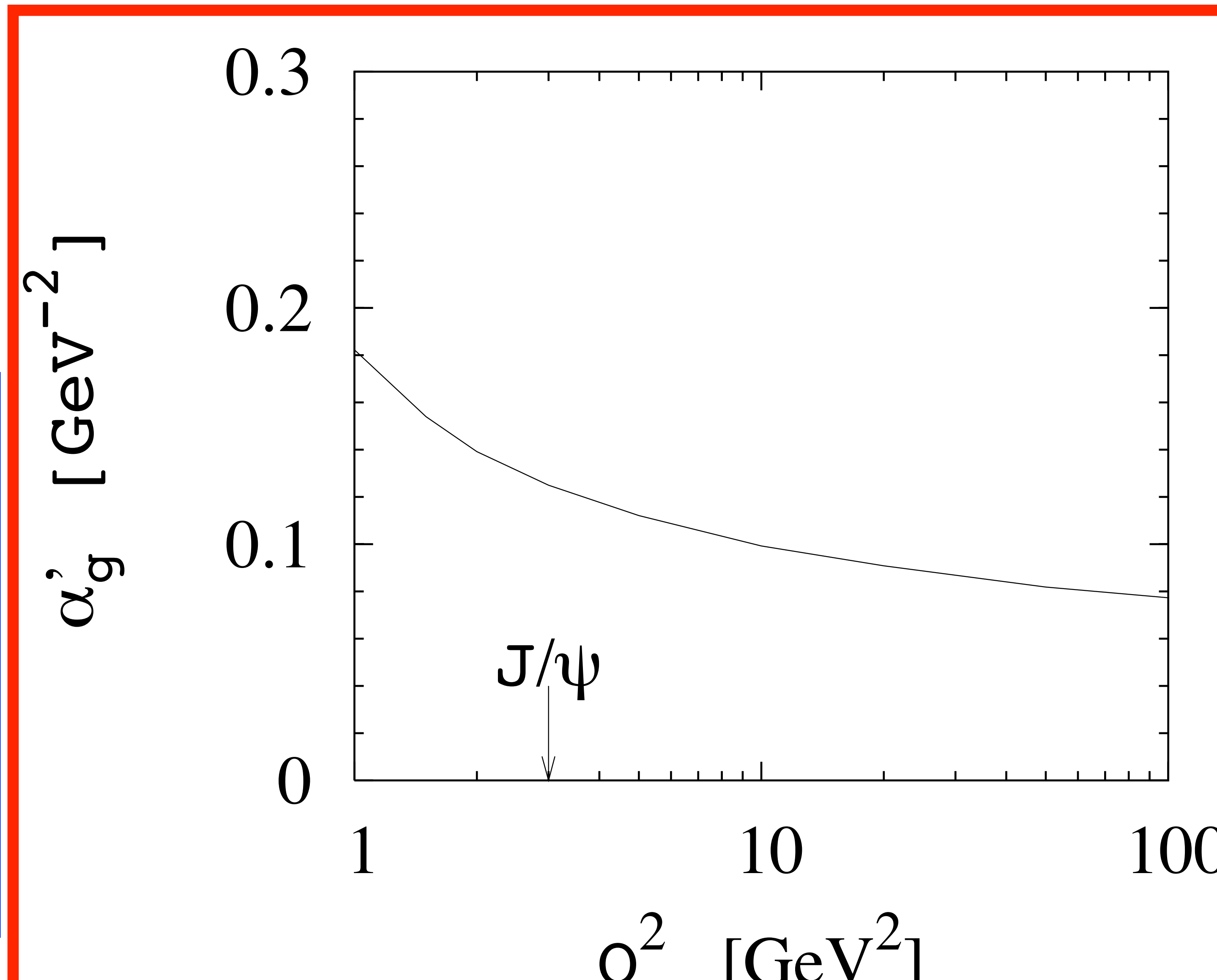


The effective trajectory $\alpha(t)$ as a function of $|t|$ in the range $40 < W_{\gamma p} < 305\,\mathrm{GeV}$



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) - Q evolution of α’ - Frankfurt, MS, Weiss

Dipole fit with x-independent $M^2 \sim 1.0\ \text{GeV}^2$:

$$\frac{d\sigma(\gamma + p \to J/\psi + p)}{dt} \propto \frac{1}{(1 - t/M^2)^4}$$

gives a reasonable description of the data for E ≲ 100 GeV F &S 02. Evidence for locality.

$$F_{2g}(t) = \frac{1}{(1 - t/m_g^2)^2},\ m_g^2 \sim 1.1\ \text{GeV}^2 \qquad m_g^2 \gg m_{e.m.}^2 \approx 0.7\ \text{GeV}^2$$

$$m_g^2 - M^2 \approx 0.1\ GeV^2$$ correction due to the finite size of J/ψ

gluon distribution is more compact than quark one for x ~ 0.02- 0.05 - can be quantitatively explained as effect of soft pions - Weiss & MS 04. Many implications for LHC and correlations of partons in nucleons.

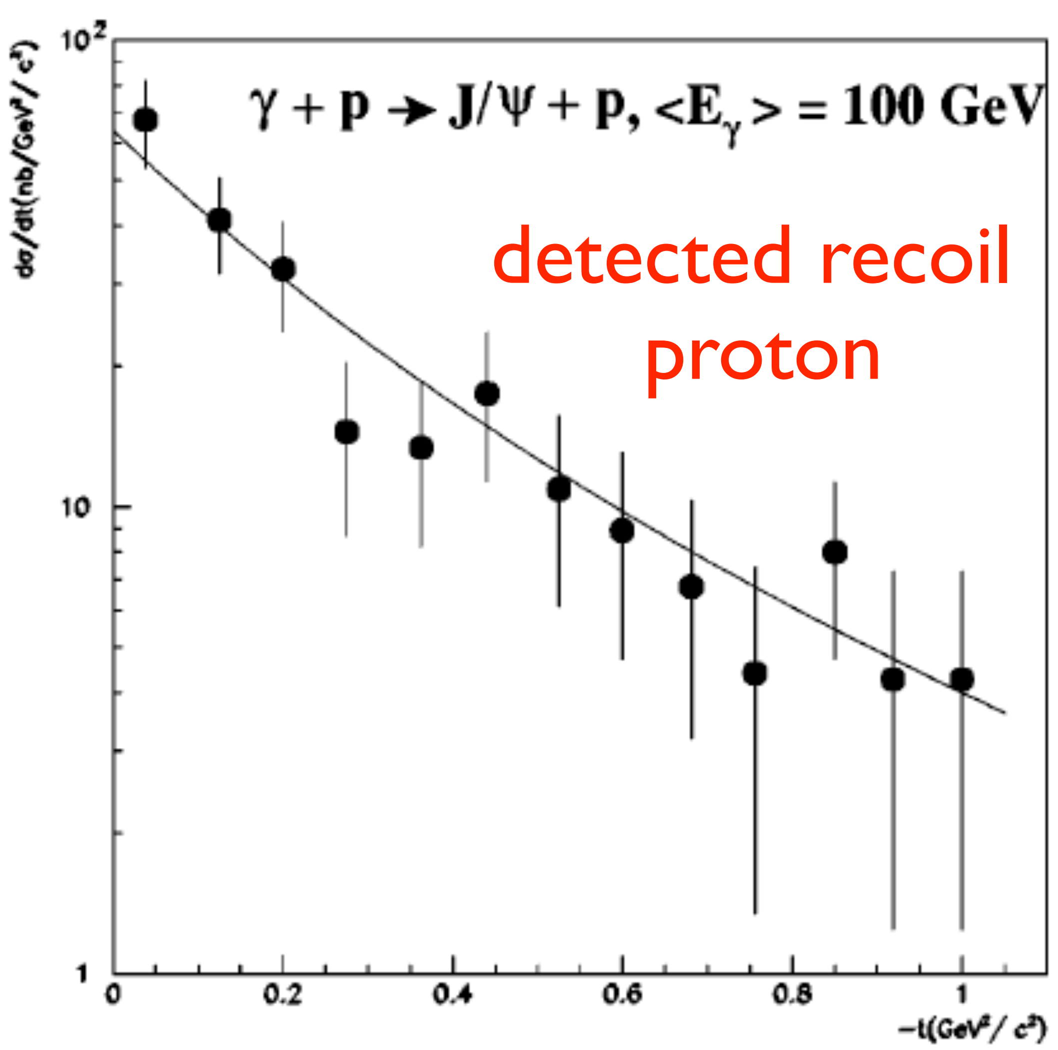


FIG. 1. Comparison of the dipole parametrization of Eq. (6) of the $d\sigma^{\gamma+p\to J/\psi+p}/dt$ with the data of [16] at $\langle E_\gamma \rangle = 100$ GeV.

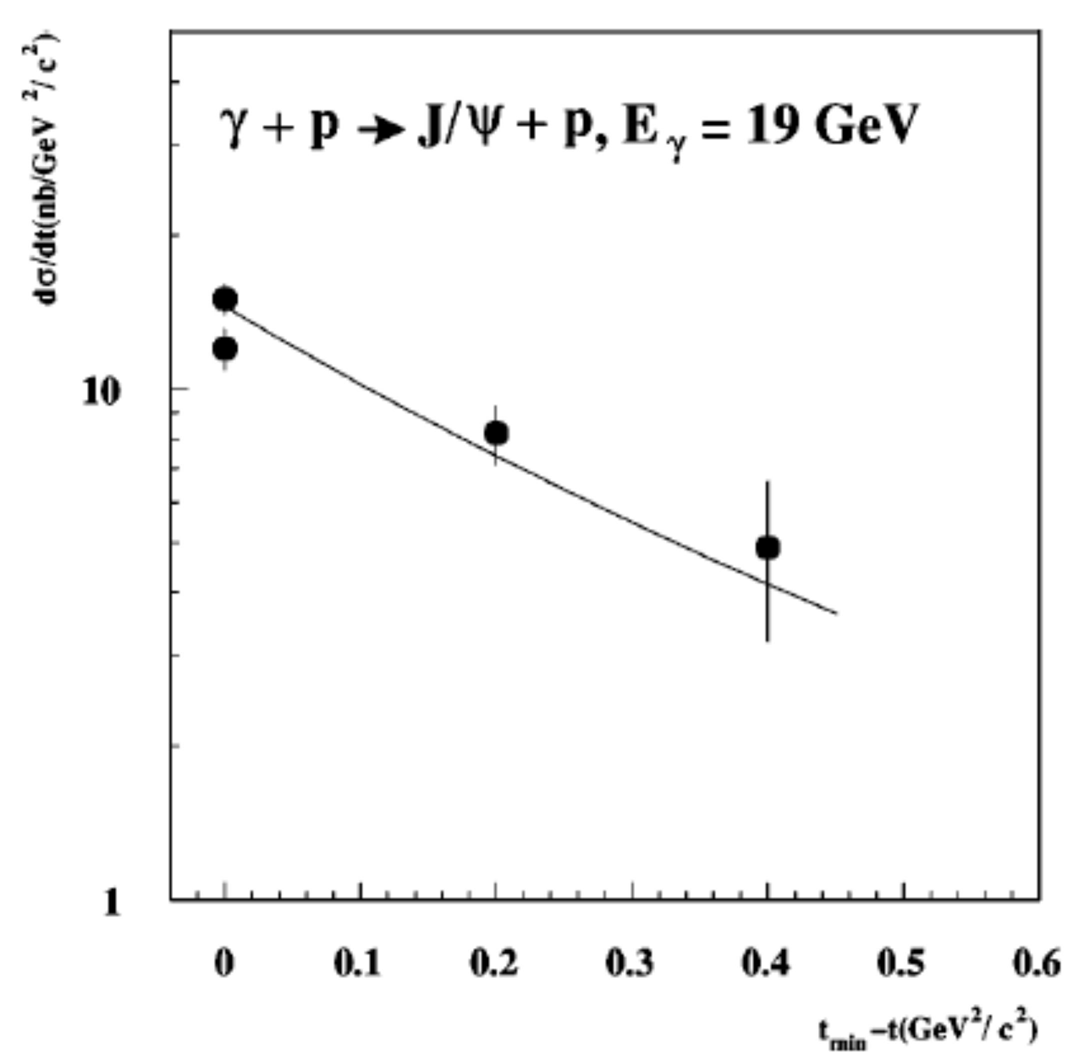
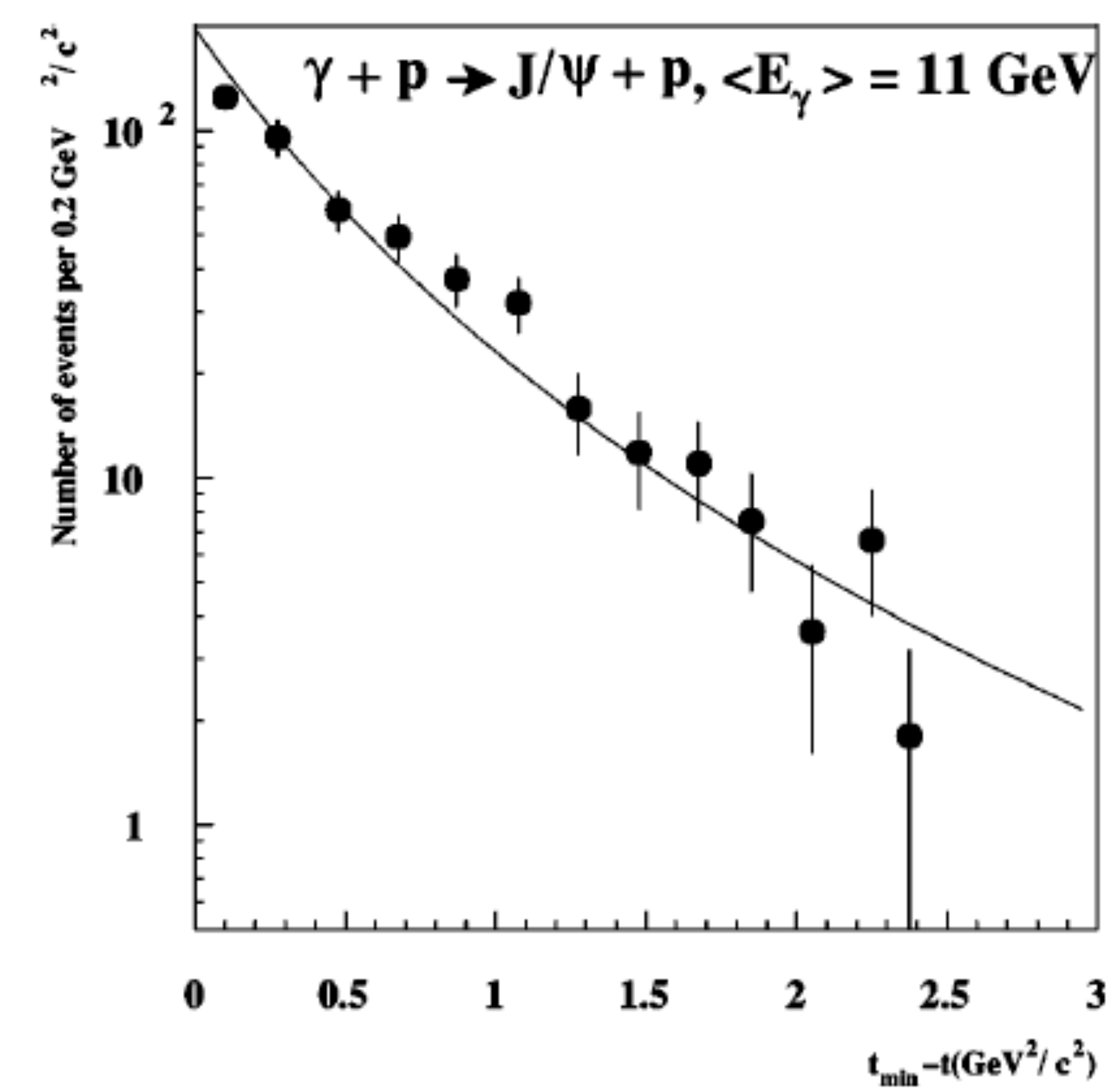


FIG. 2. Comparison of the dipole parametrization of Eq. (6) of the $d\sigma^{\gamma+p\to J/\psi+p}/dt$ with the data of [17] at $E_\gamma = 19$ GeV.



$-t_{min} = 0.5\ \text{GeV}^2$

FIG. 3. Comparison of the dipole parametrization of Eq. (6) of the $d\sigma^{\gamma+p\to J/\psi+p}/dt$ with the data of [18] at $\langle E_\gamma \rangle = 11$ GeV.

Small size of J/ψ - t-dependence of J/ψ photo/electro production measures the two gluon f.f. of nucleon and hence transverse spread of gluons. Note that for photoproduction of J/ψ - skewness is relatively small: $x_1 \sim 1.5\,x$, $x_2 \sim 0.5\,x$.

Gluon distribution is more compact than quark one for x ~ 0.02- 0.05 - can be semi quantitatively explained as effect of soft pions - Weiss & MS 04. Many implications for LHC and correlations of partons in nucleons. Example - allows to explin correlation between multiplicity of hadrons in pp at the LHC and jet production.

Conclusions

- Soft- hard connection seems to work for small x - necessary to extend studied to higher x ~ 10^{-2}

- Study of real & low Q photon Compton scattering may help to establish role of HT effects

- Studies of J/ψ photo/electro production are critical for getting gluon GPDs and hence for NLO studies of DVCS