Exclusive Diffraction and Leading Baryons at HERA

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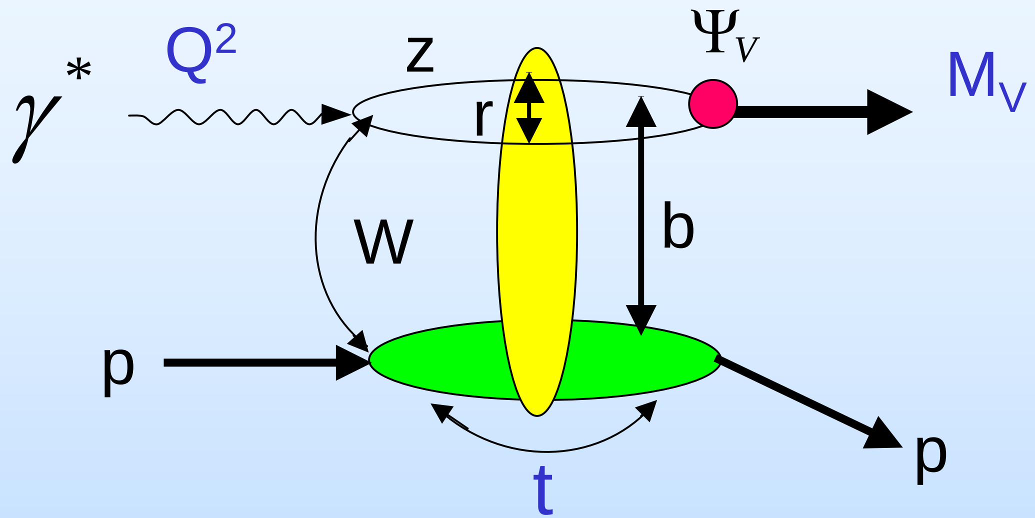
Exclusive Vector Meson Production

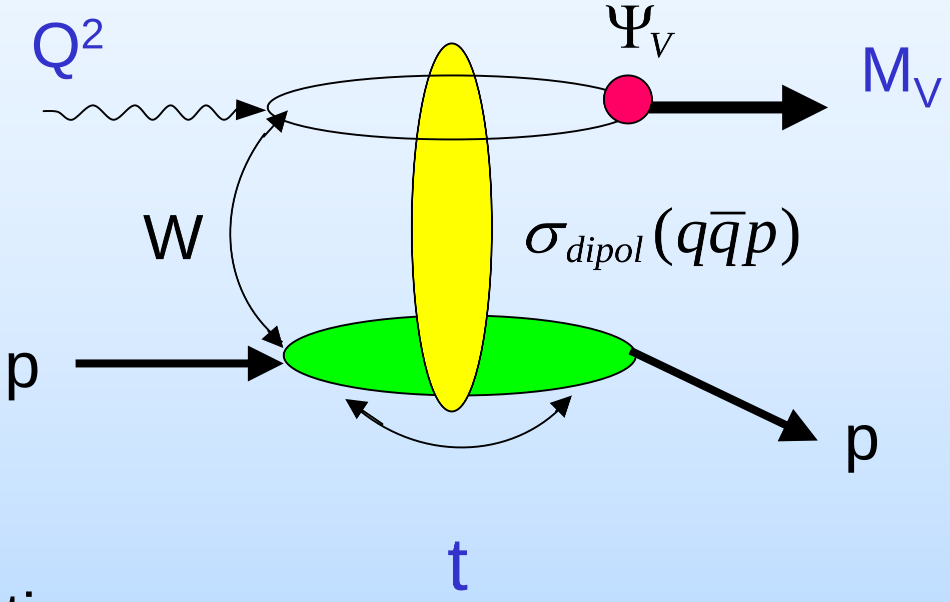


Factorization:

- $\gamma^* \to q\bar{q}$ $\Psi_\gamma(z,r)$ QED
- dipole–proton interaction
  Ampl ~ $\Psi_\gamma(r,z) \otimes \sigma_{dip}(r,z,b) \otimes \Psi_V(z,r)$
- $q\bar{q} \to V$ Ψ_V model
  parton-hadron duality

Continuous transition soft $\to$ hard physics

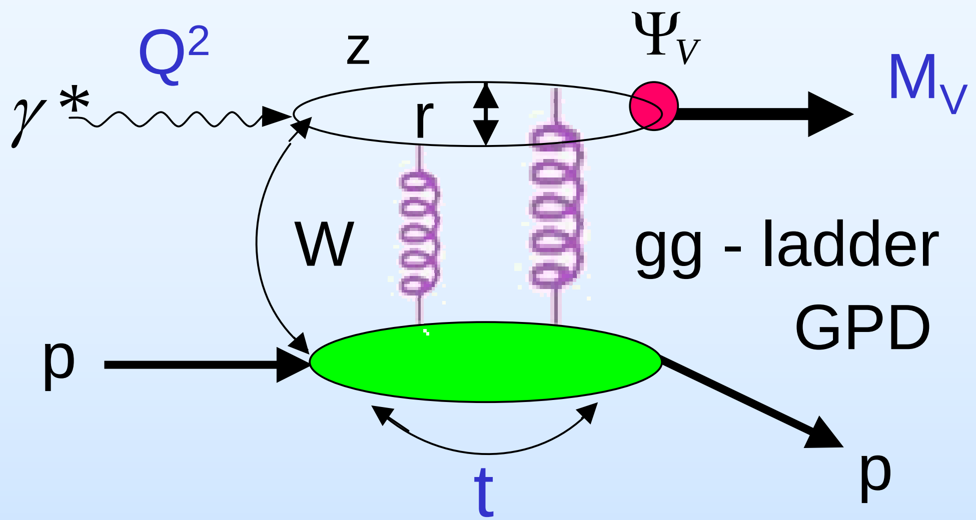
Dipole scattering:



- small Bjorken x: factorization
- valid also at low Q^2
- σ_{dipol} universal: applicable to DIS, DDIS and VM production
- Saturation included

pQCD

LO 2–gluon exchange



Expectation:

- steep rise with W: $\sigma \sim (xg(x,Q^2))^2$ $\quad x \approx Q^2/W^2$

  steep rise of g(x) with x decreasing $\rightarrow$ $\sigma \sim W^\delta$

  δ increases with M_V, Q^2

- r decreases with Q^2 , M_V

  $\overline{Q}^2 = z(1-z)(Q^2 + M_V^2)$ in perturbative domain:

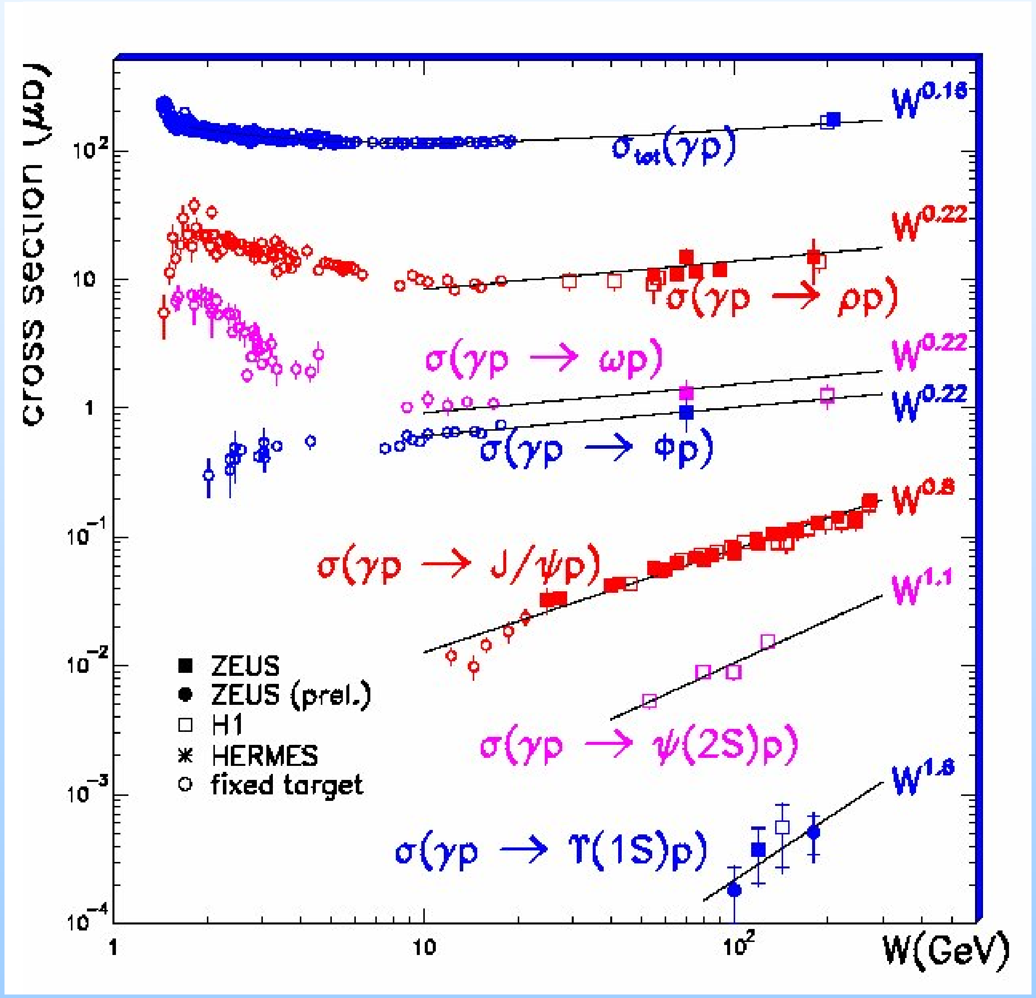
  A_L $\quad z \approx 1/2$ $\quad$ scale variable $\quad \overline{Q}^2 = 1/4(Q^2 + M_V^2)$

  A_T : contribution at z = 0, 1 $\Rightarrow$ scaling delayed

Hard scale: M_V

$\gamma\, p \to V\, p$

Photoproduction: $\sigma \sim W^{\delta}$



Regge model

$d\sigma/dt \sim (W)^{4(\alpha(t)-1)}$

$\alpha(t) = 1.08 + \alpha' \, t$

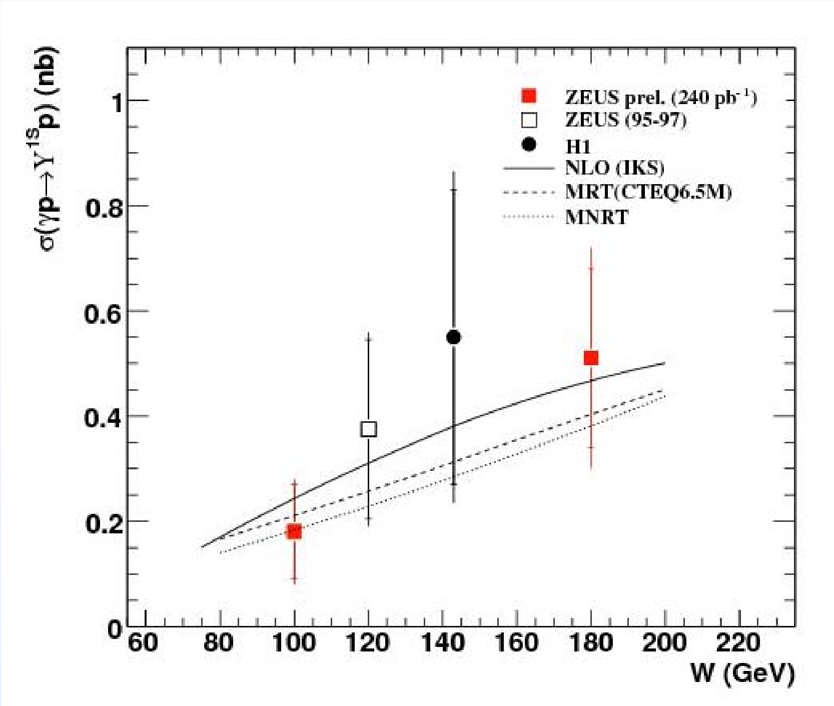
pQCD

M_V hard scale for

$\Psi(1S), \Psi(2S), \Upsilon(1S)$

$\Psi(2S)$ special case: zero of wave function $\to$ smaller dipole

Comparison with models: $\gamma\ p \rightarrow \Upsilon(1S)\ p$



$\sigma \sim W^{\delta}$, $\delta \approx 1.8$

M_{Ψ} , M_{Υ} hard scale

Models:

Ivanov, Krasnikov,Szymynowski (IKS): NLO,GPD

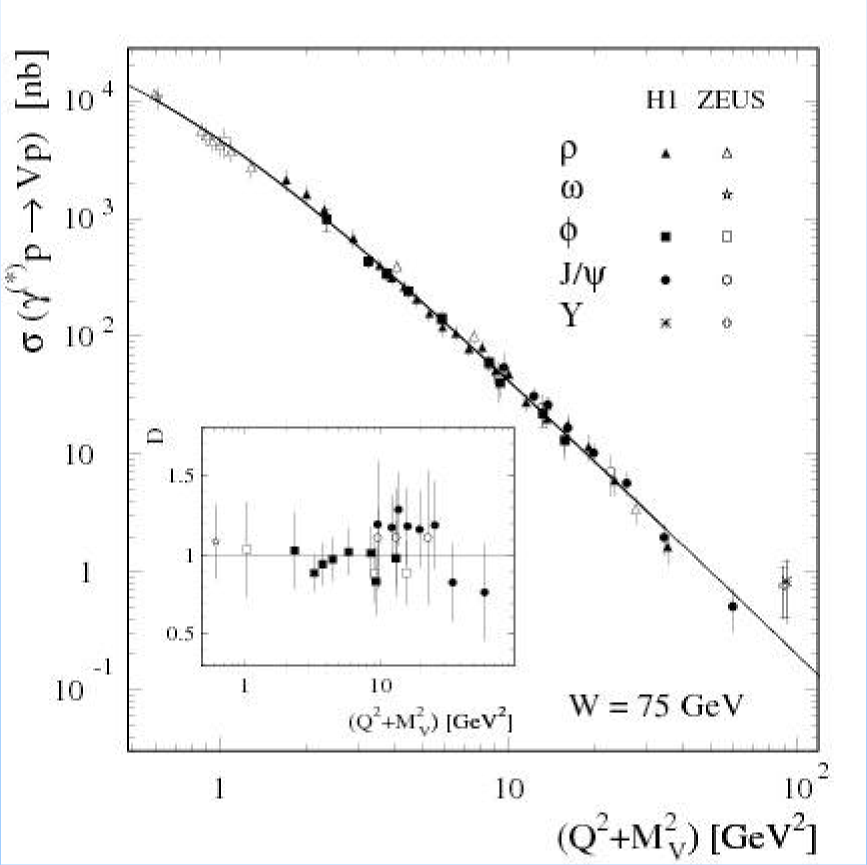
Martin, Ryskin, Teubner(MRT): NLO, skewed gluons
CTEQ6.5M gluon

MRT +Nockles (MNRT): gluons from Ψ(1S) data

Hard scale: Q^2

$\gamma^* p \rightarrow V p$

Scaling of vector meson elastic cross sections:



SU(4) flavor factors considered

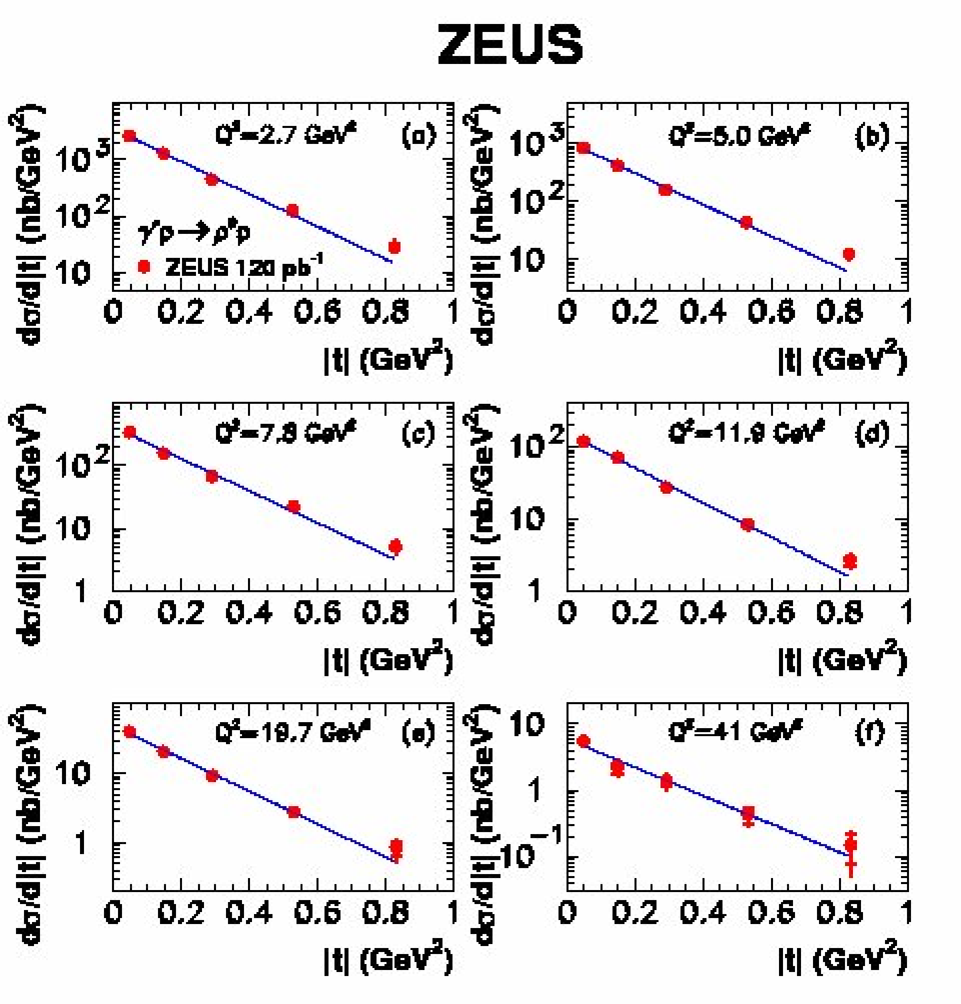
Universal scale: $\mathbf{Q^2 + M_V^2}$

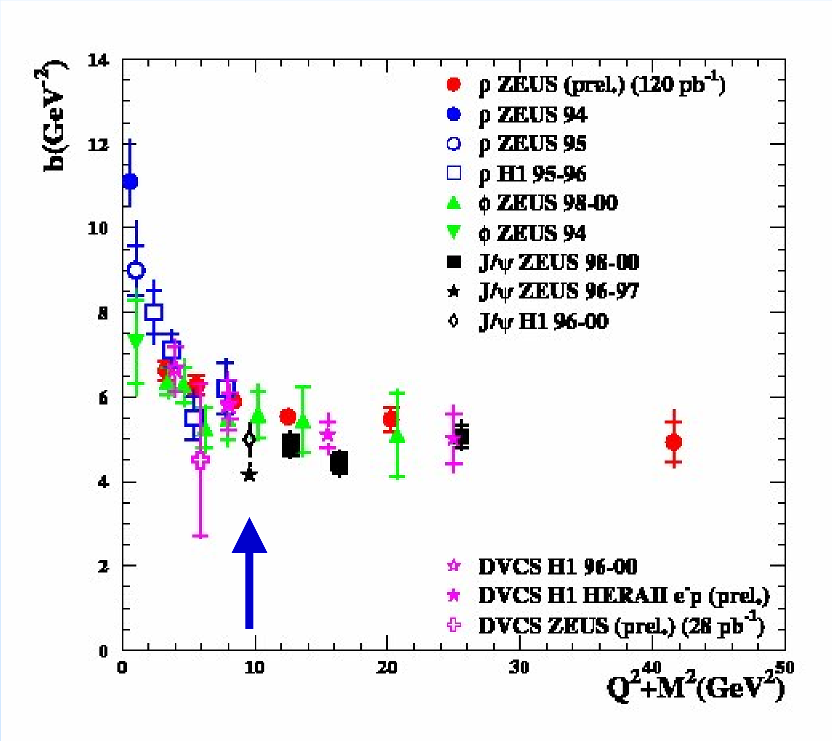
Transition to hard scale:

$\gamma^* p \rightarrow V p$

$d\sigma/dt \sim \exp(-b\ t)$

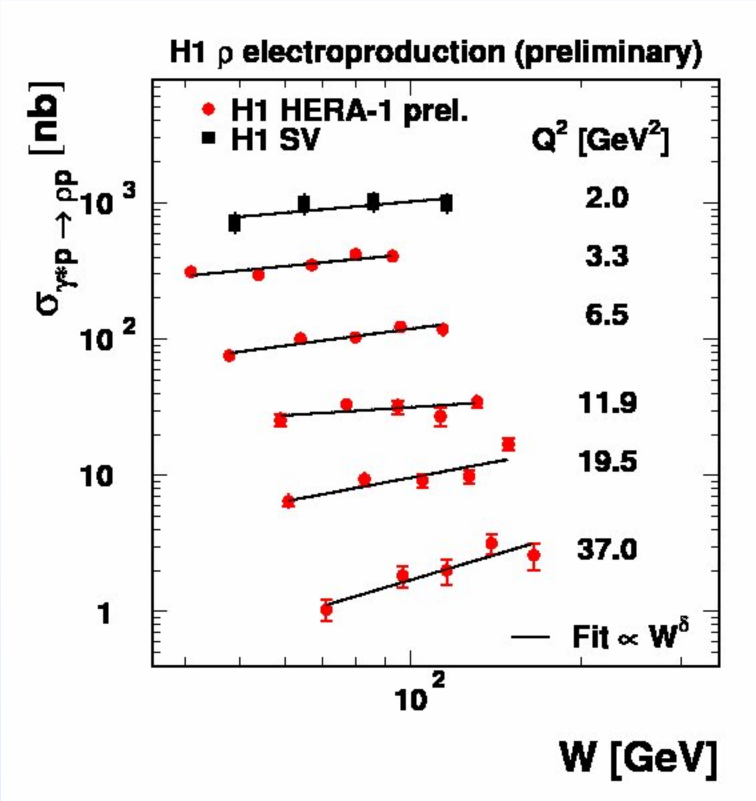
$b = b_{dip} \oplus b_{nucleon}$





$Q^2 > 10\ GeV^2$ hard scale:

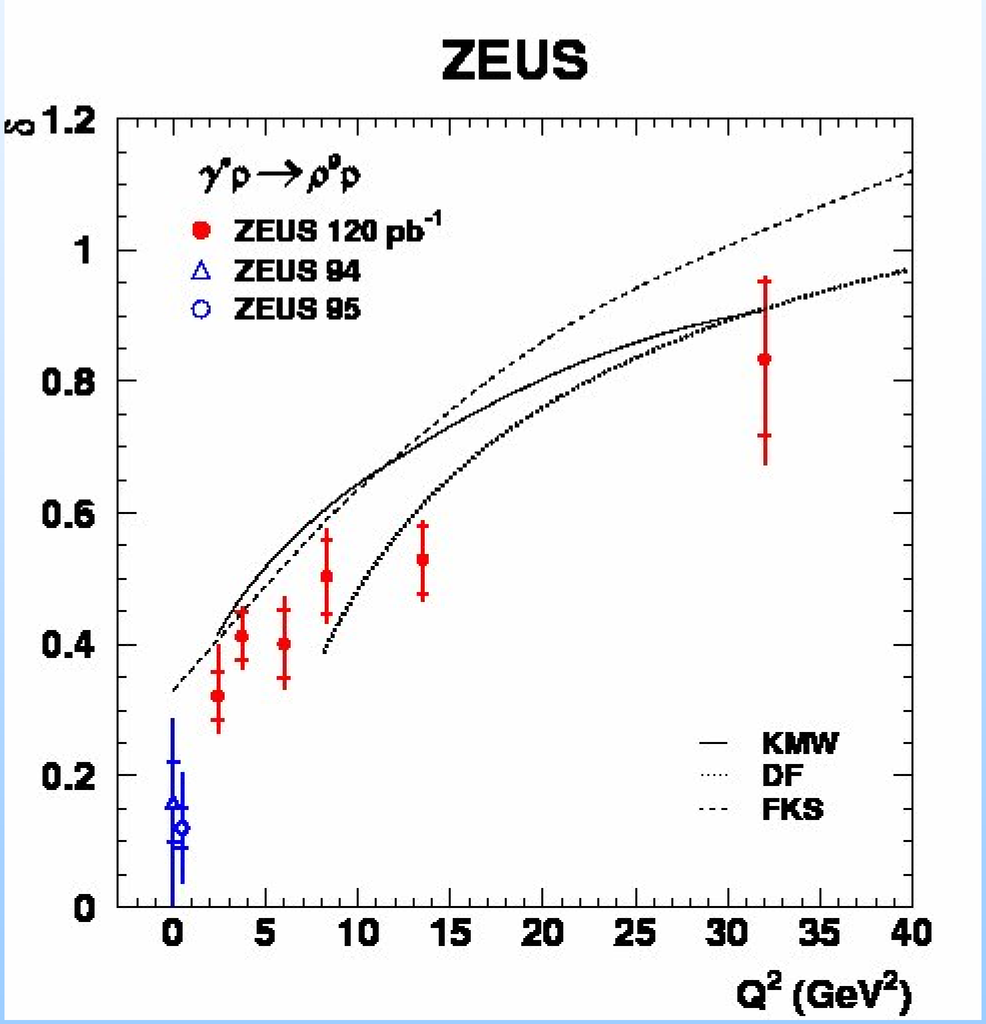
point like dipole probes gluon cloud of proton



$\gamma^* p \rightarrow \rho^0 p$

$\sigma \sim W^{\delta}$, $\delta = \delta(Q^2)$

- Harder with increase of Q^2



Model predictions:

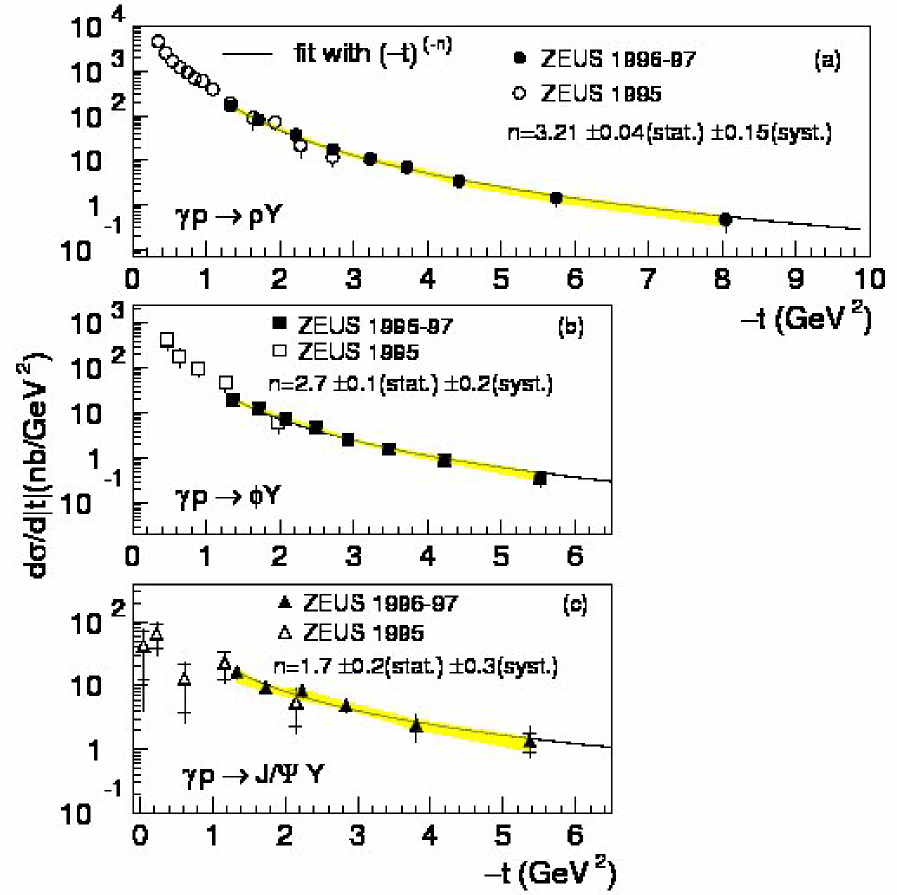
- FKS:2-gluon exchange, gluons from fit to DIS
- KMW: saturation model, b dependence, DGLAP
- DF: σ_{dip} Wilson loop

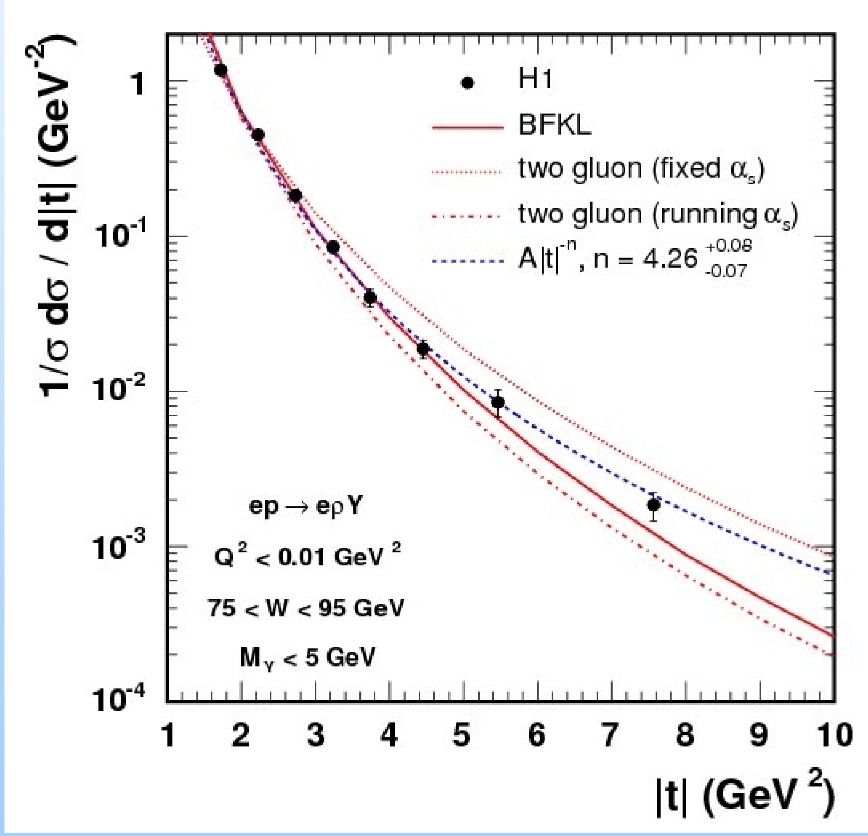
Hard scale t:

$\gamma\, p \rightarrow V\, Y$

Reminder: high p_t physics in pp reactions:

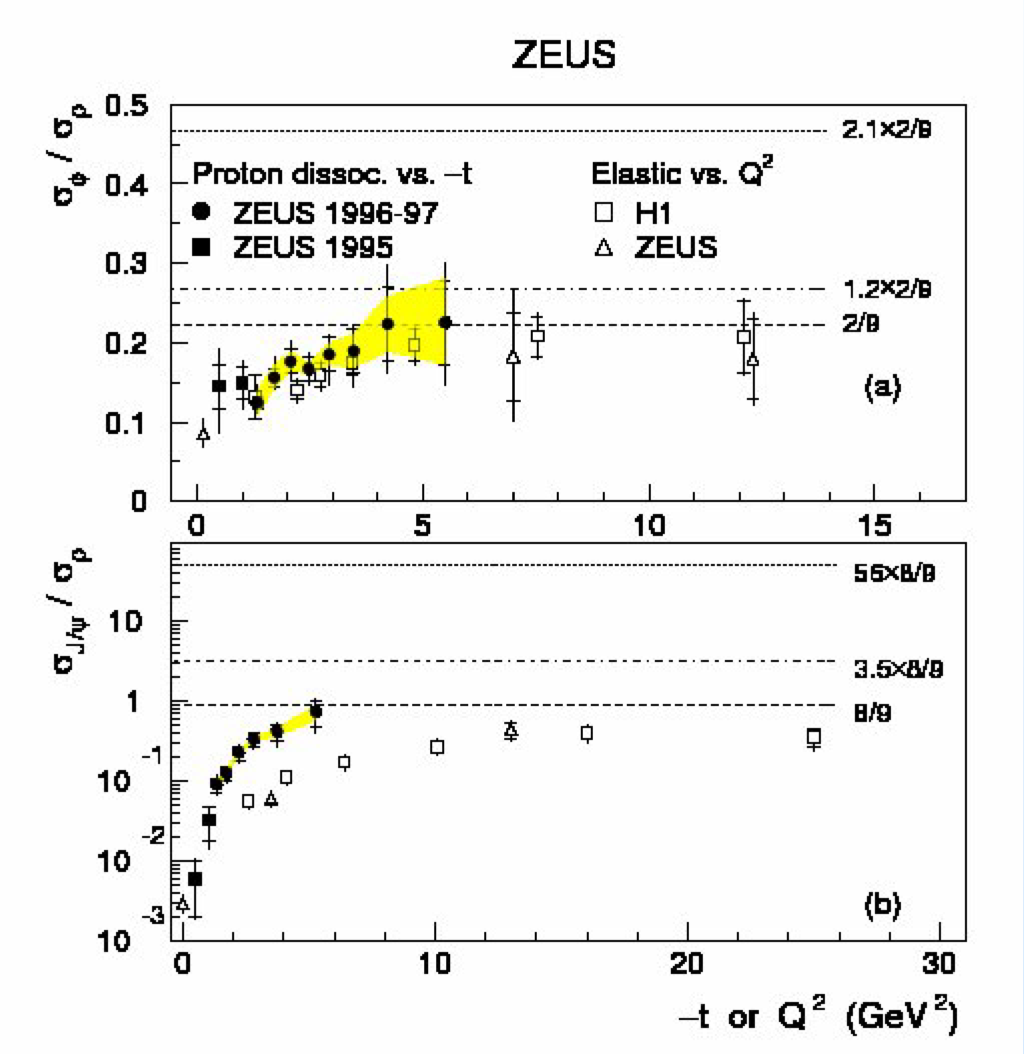
power law behavior of $d\sigma/dp_t^2 \sim p_t^{-2n}$





Assume vertex factorization

Flavor restoration at similar values of t and Q^2



- t distribution proton vertex $\gamma^* \, p \rightarrow V \, Y$

□ Q^2 distribution photon vertex $\gamma^* \, p \rightarrow V \, p$

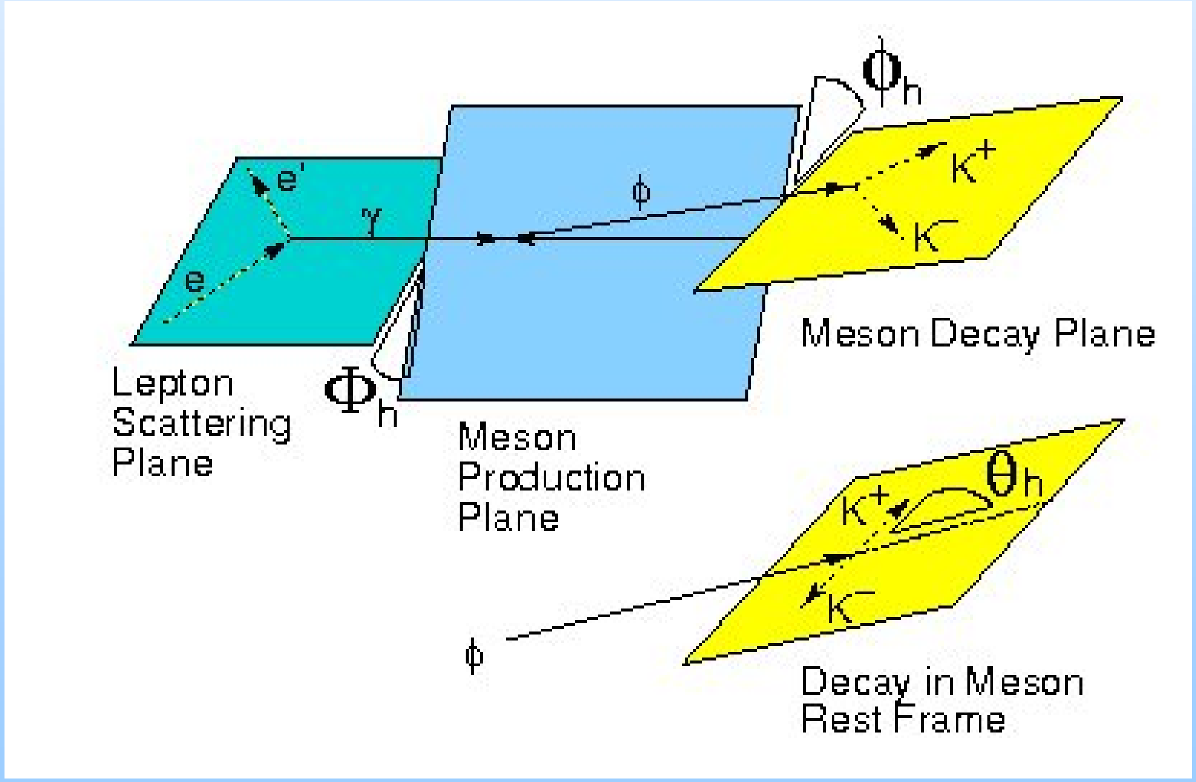
M_V, Q^2 , t hard scales $\rightarrow$ pQCD applicable

Helicity amplitudes $T_{\lambda\rho,\lambda\gamma}$:

3 angles, 15 spin density matrix elements, 6 helicity amplitudes:

SCHC: T_{00} , T_{11} single flip: T_{01} , T_{10} double flip T_{1-1},T_{-11}

pQCD ($|t| < Q^2$) prediction: T_{-11} ,T_{10} < T_{01}< T_{11}< T_{00}



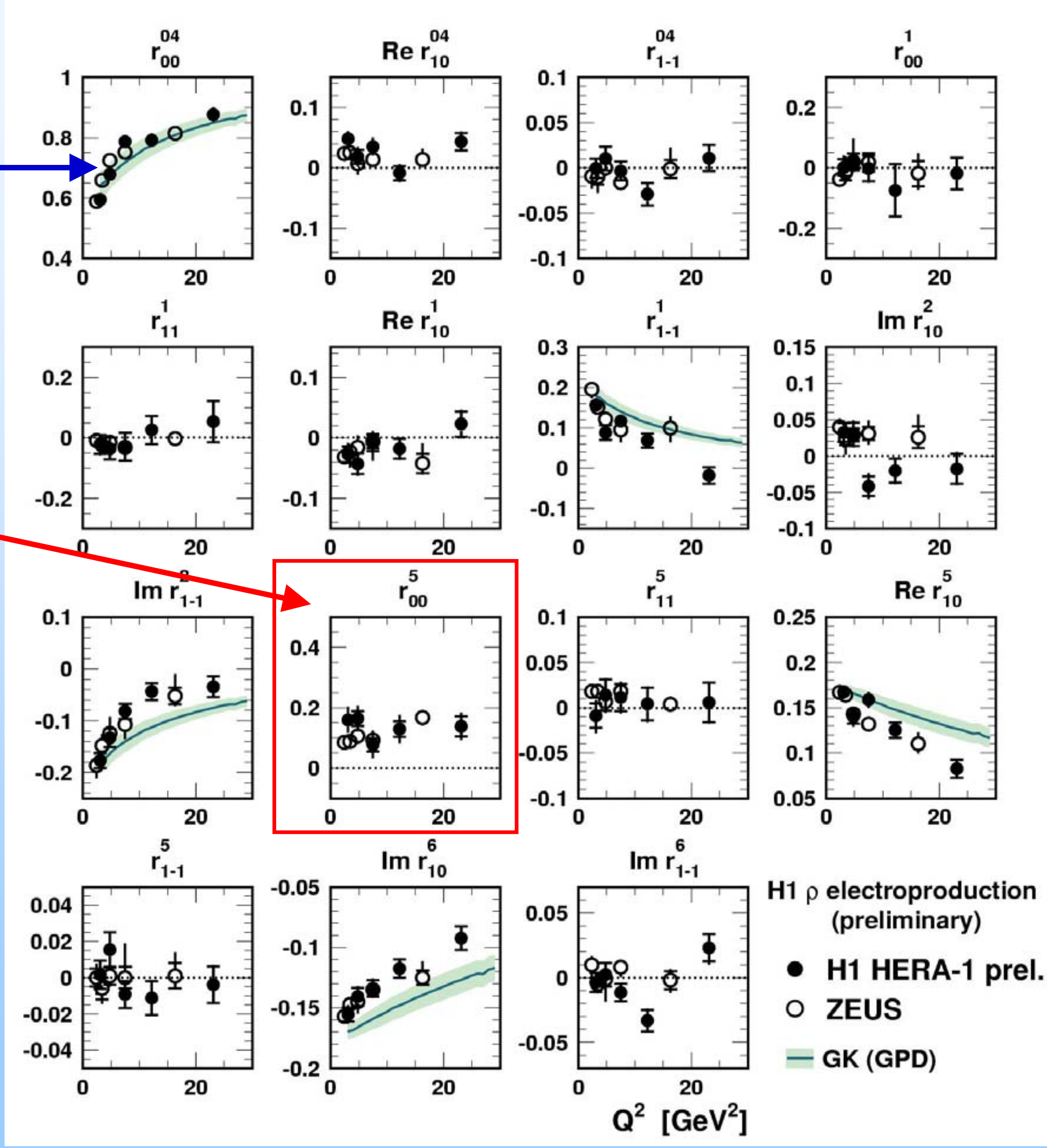
Spin Density Matrix Elements $r^{ij}_{kl}(Q^2)$ t < 3 GeV²

- 5 SCHC ME ≠ 0 agree with GPD (GK) calculation
- other agree with SCHC prediction (---)
- except $r^5_{00} \sim T_{10}T^*_{00}$

Goloskokov - Kroll (GK) consider skewed GPD

$\gamma^* p \rightarrow \rho^0 Y$

Vertex factorization



Helicity amplitudes – t dependence $r^{ij}_{kl}(t)$

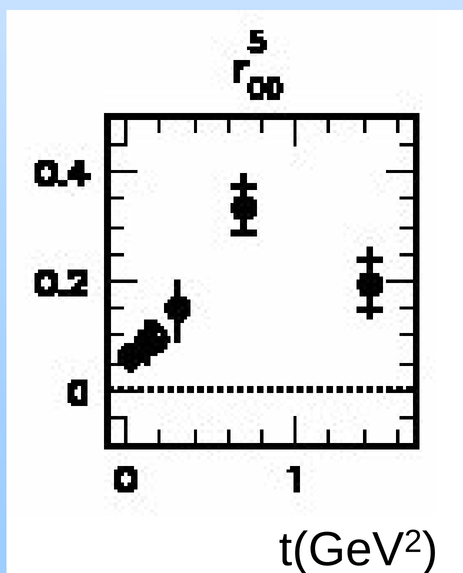
$\gamma^* \, p \rightarrow \rho^0 \, Y$

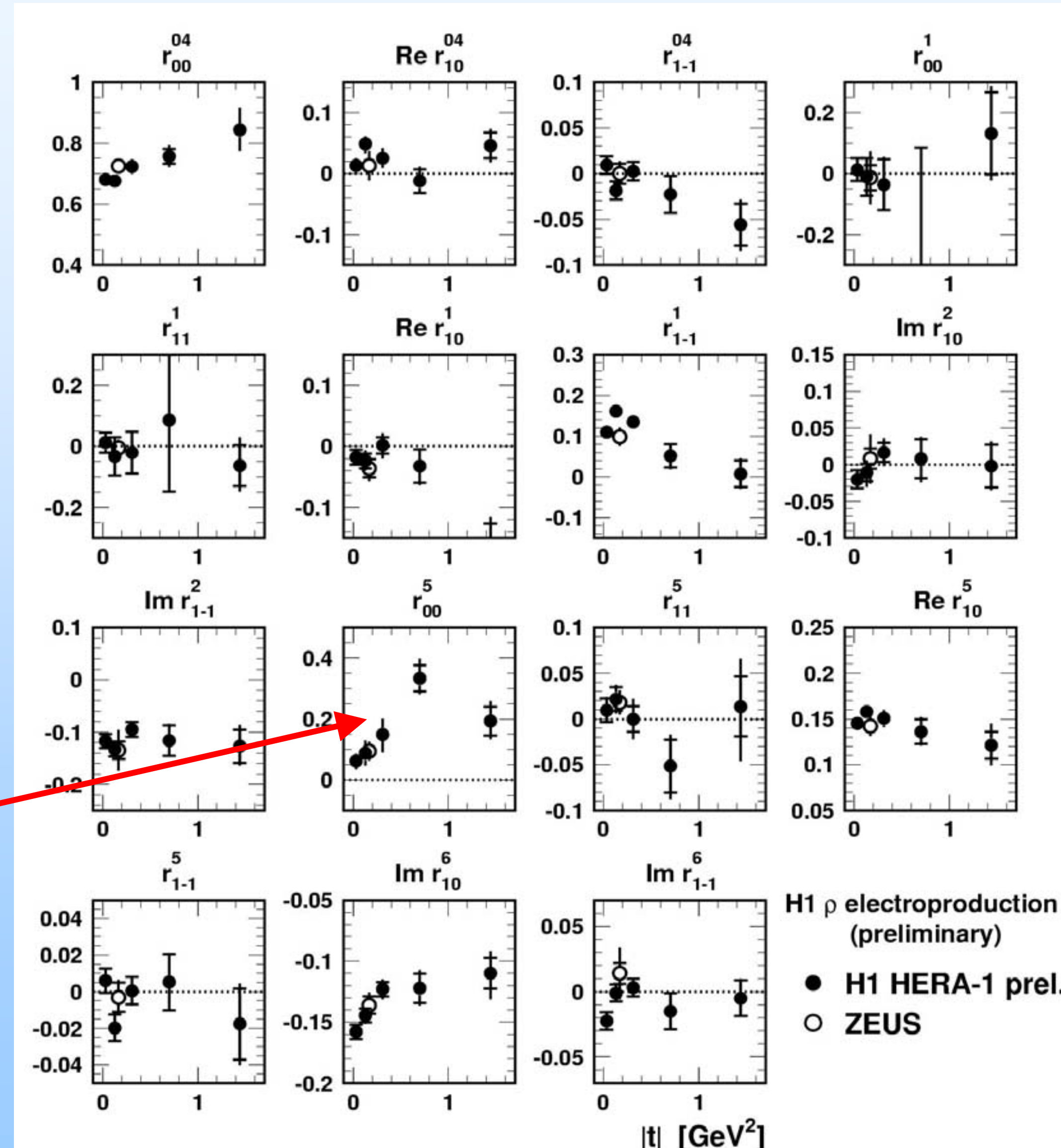
Vertex factorization

SCHC (·········)

single helicity flip

$$r^5_{00} \neq 0$$



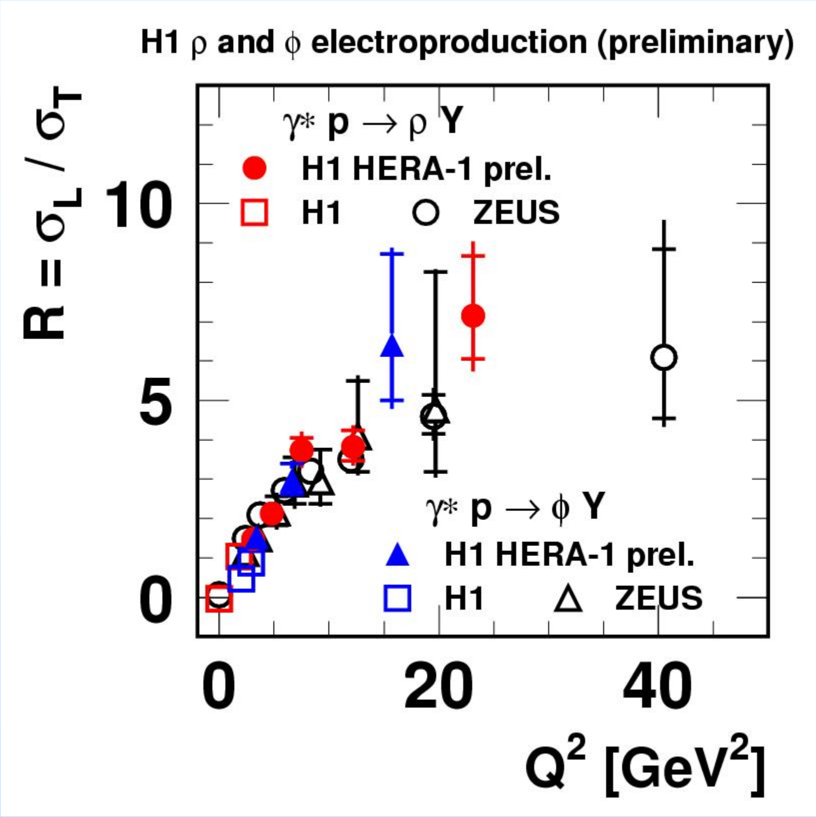


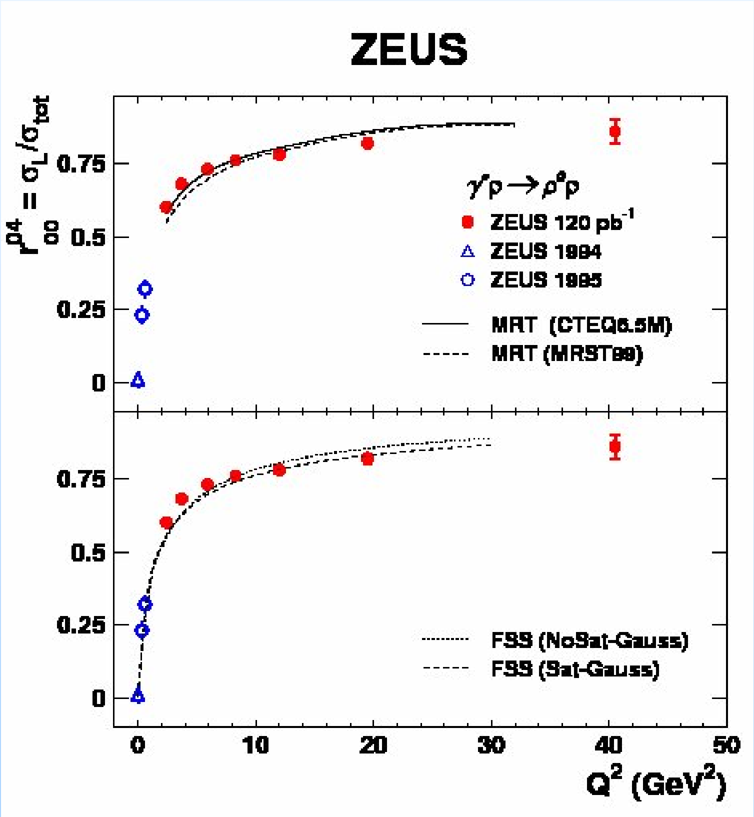
$$\sigma_{tot} = \sigma_T + \varepsilon \cdot \sigma_L$$
$$\langle \varepsilon \rangle = 0.98$$

$$R = \sigma_L / \sigma_T = \varepsilon^{-1} \cdot r_{00}^4 / (1 - r_{00}^4)$$

for $r_{00}^4 \to 1$

error of R large and asymmetric





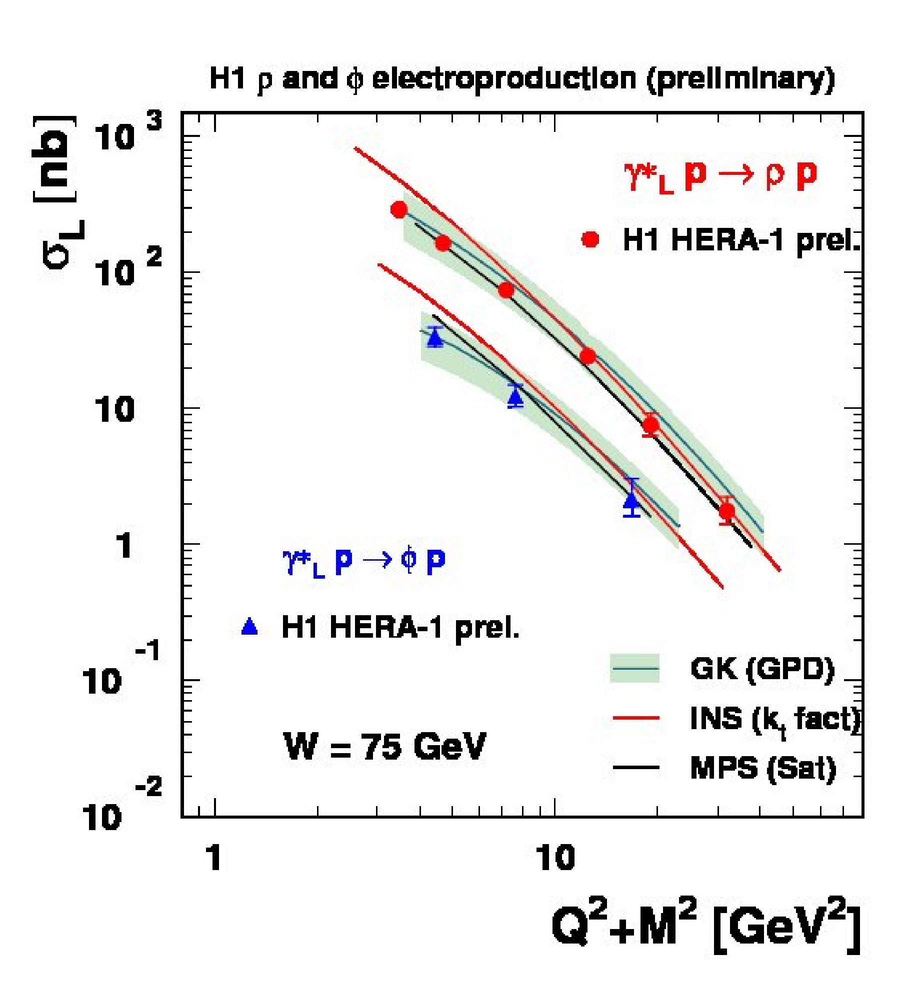
$\gamma^* p \to \rho^0 Y$

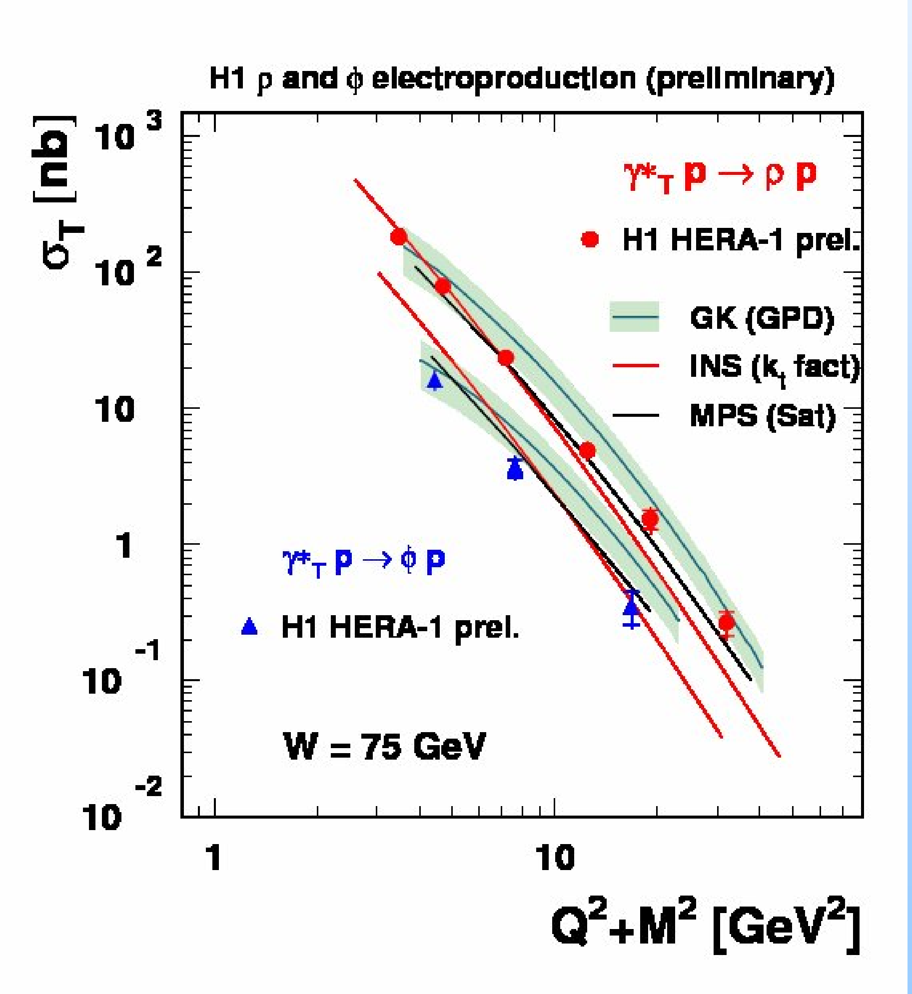
- $R \sim Q^2$
- Leveling off for $Q^2 > 10$ GeV^2
- σ_L dominates at large Q^2

$\gamma^* p \to \rho^0 p$

- σ_L and σ_T different Q^2 dependence
- $\sigma_L \to 0$ for $Q^2 \to 0$ gauge invariance
- σ_L dominates at large Q^2
- GK describes σ_L better than σ_T

$\gamma^* p \to \rho^0 p$

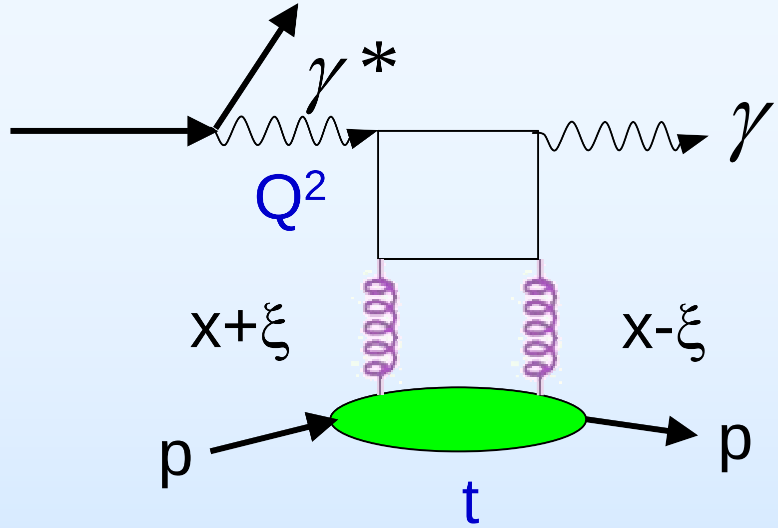




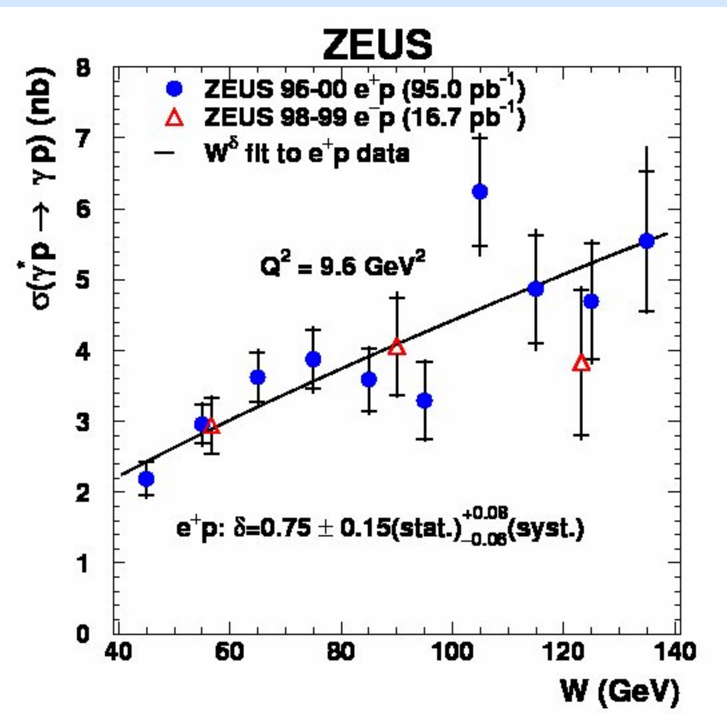
DVCS

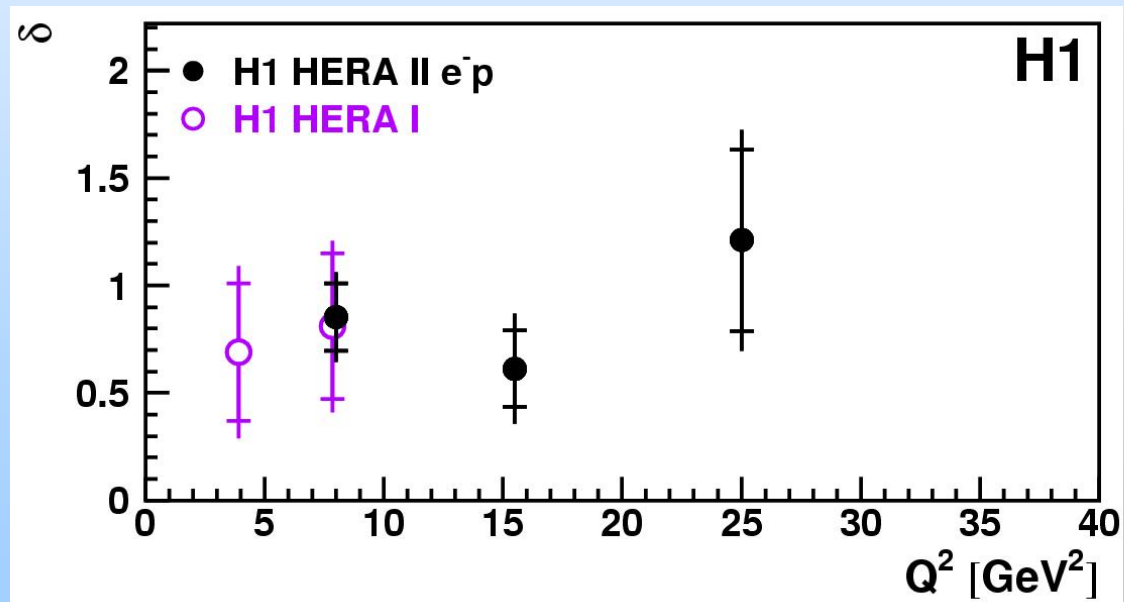
$\gamma^* p \rightarrow \gamma p$

$$\boxed{\sigma \sim W^{\delta}}$$



Skewing





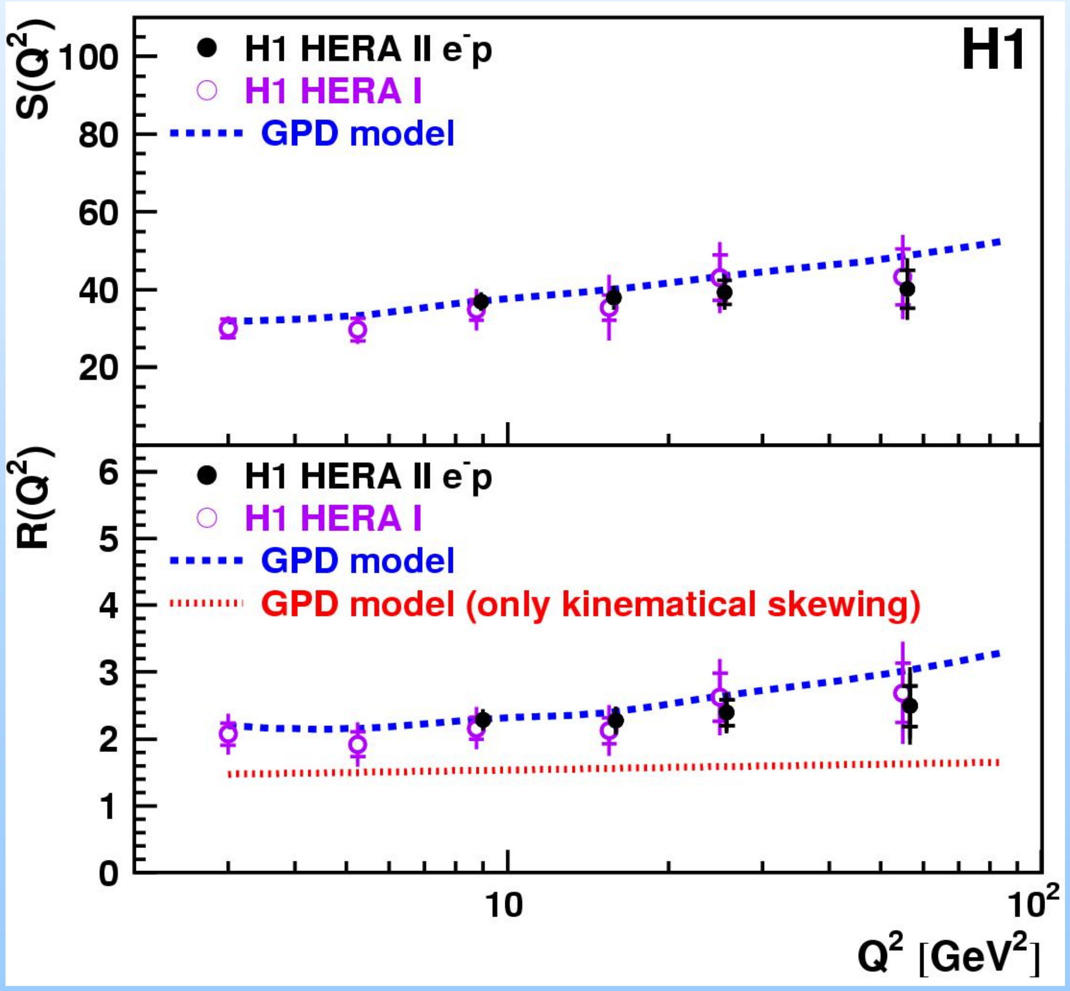
hard process

Dimensionless observables:

$$S=\sqrt{\frac{\sigma_{DVCS}\cdot Q^4\cdot b(Q^2)}{1+\rho^2}}$$

Q^2-dependence of GPD

$$R(Q^2)=\frac{\operatorname{Im}A(\gamma^* p\to\gamma p)_{t=0}}{\operatorname{Im}A(\gamma^* p\to\gamma^* p)_{t=0}}=\frac{\sqrt{\pi\sigma_{DVCS}b(Q^2)}}{\sigma_T(\gamma^* p\to X)\sqrt{(1+\rho 2)}}\sim\frac{GPD}{pdf}$$



- GPD model (A. Freund) P.R. D68 (2003) 096006

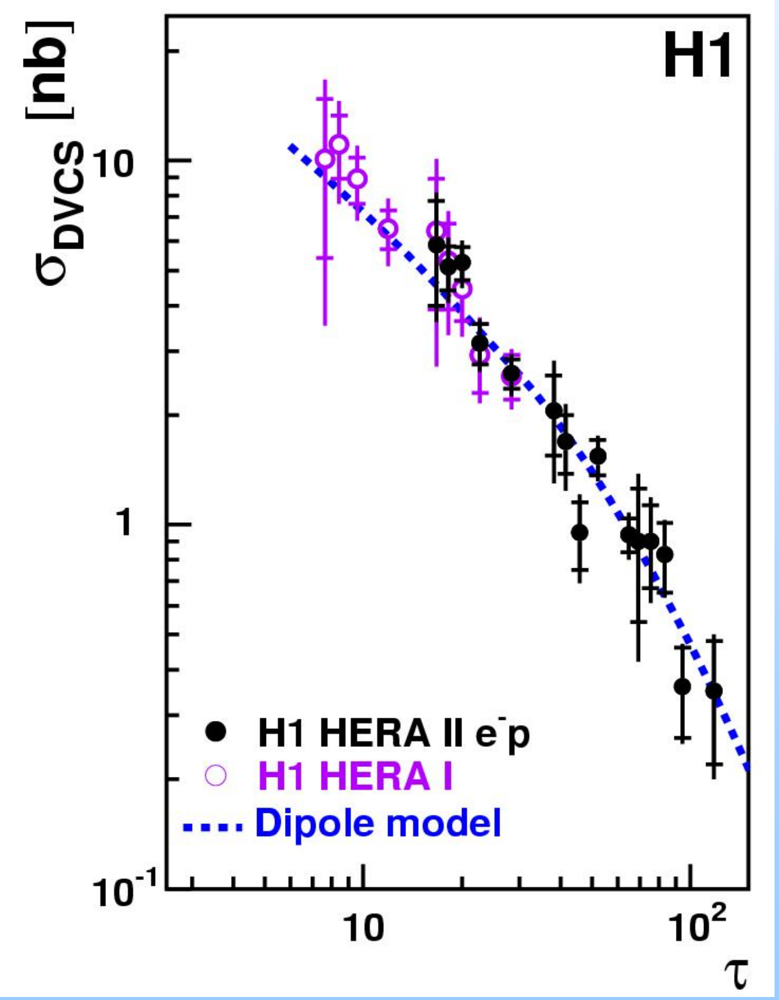
$\gamma^* p \to \gamma p$

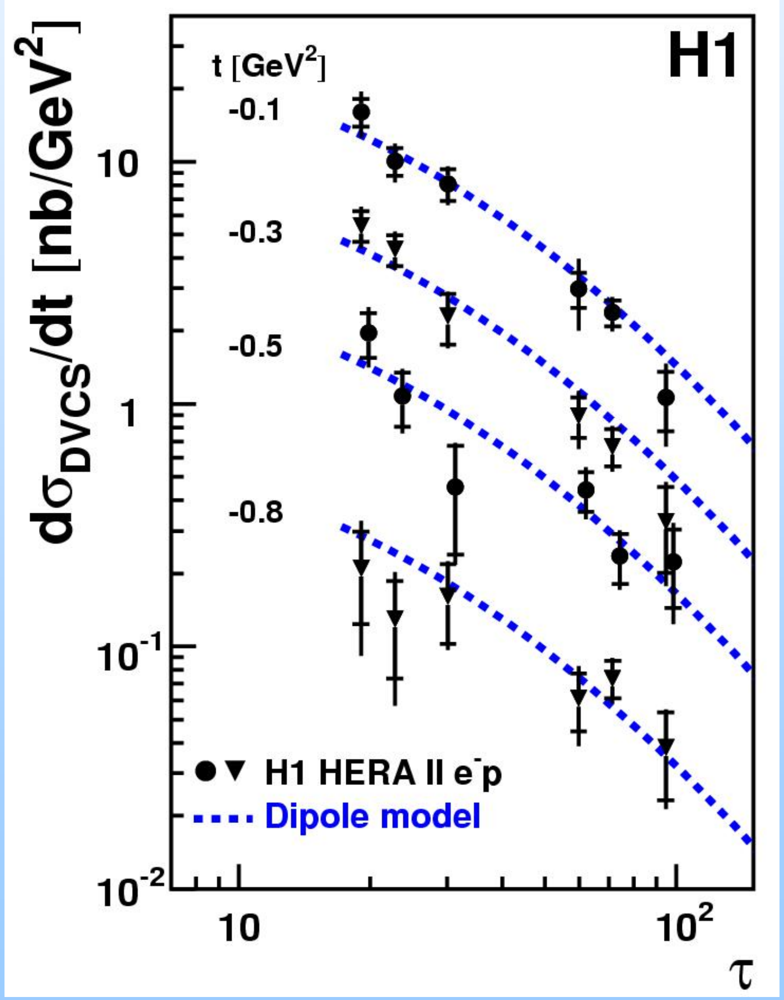
kinematical skewing not sufficient

Dipole model predicts geometrical scaling

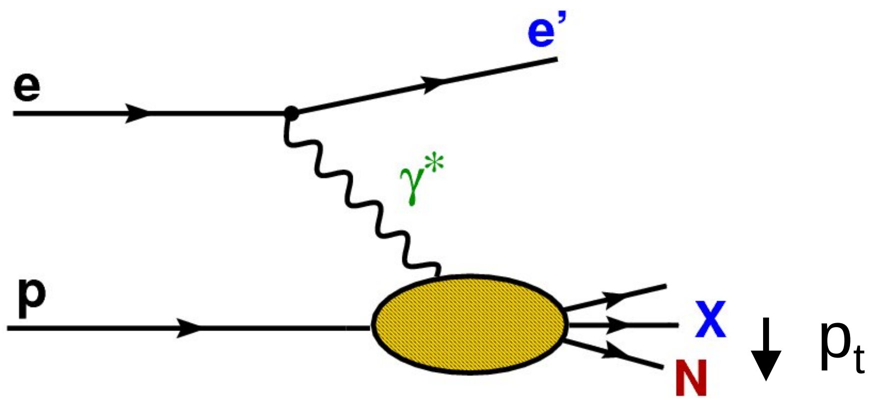
$$\sigma_{tot}^{\gamma^* p}(x, Q^2) = \sigma_{tot}^{\lambda^* p}(\tau = Q^2 / Q_s^2)$$

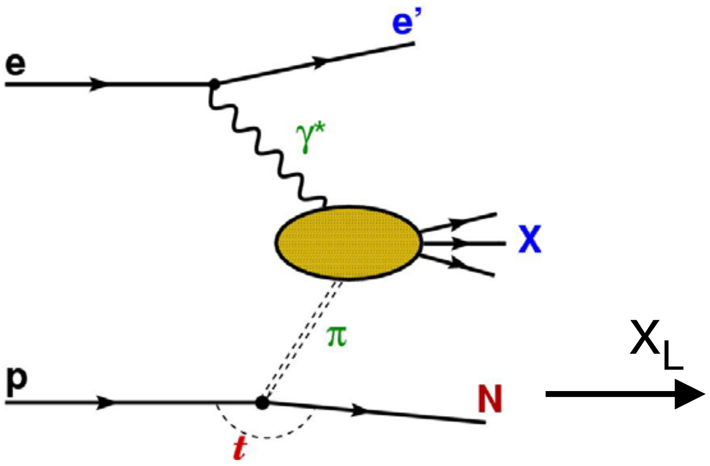
$$Q_s(x) = Q_0 (\frac{x_0}{x})^{\lambda/2}$$ saturation scale



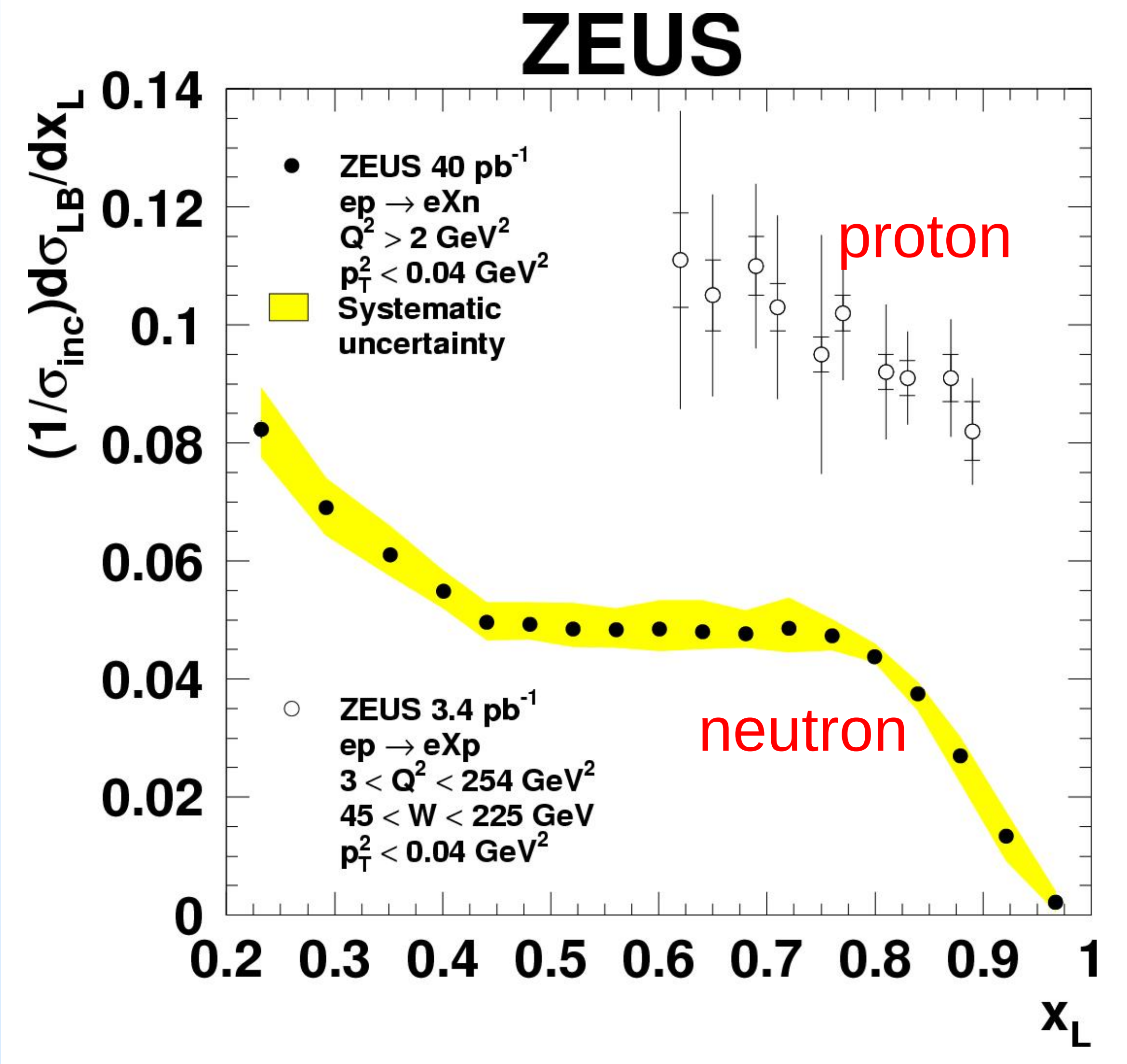


Leading baryons in e p → e N X reactions





- Comparison with standard fragmentation models
- Limiting fragmentation
  $$d^2\sigma / dx_L dp_t^2 (W^2, Q^2, x_L, p_t^2)$$
  $$= g(x_L, p_t^2) G(W^2, Q^2)$$
  compare $\gamma p \rightarrow NX$ with
  $$\gamma^* p \rightarrow NX$$
- π exchange, factorization
  $$d^2\sigma(W^2, Q^2, x_L, t) / dx_L dt$$
  $$= f_{\pi/p}(x_L, t) \cdot \sigma_{\gamma^*\pi}((1-x_L)W^2, Q^2)$$
- $F_2^\pi(x, Q^2)$?
- absorption / migration



$$e\,p \to e\,n\,X$$

$$r = \frac{\sigma(ep \to epX)}{\sigma(ep \to enX)} \approx 2$$

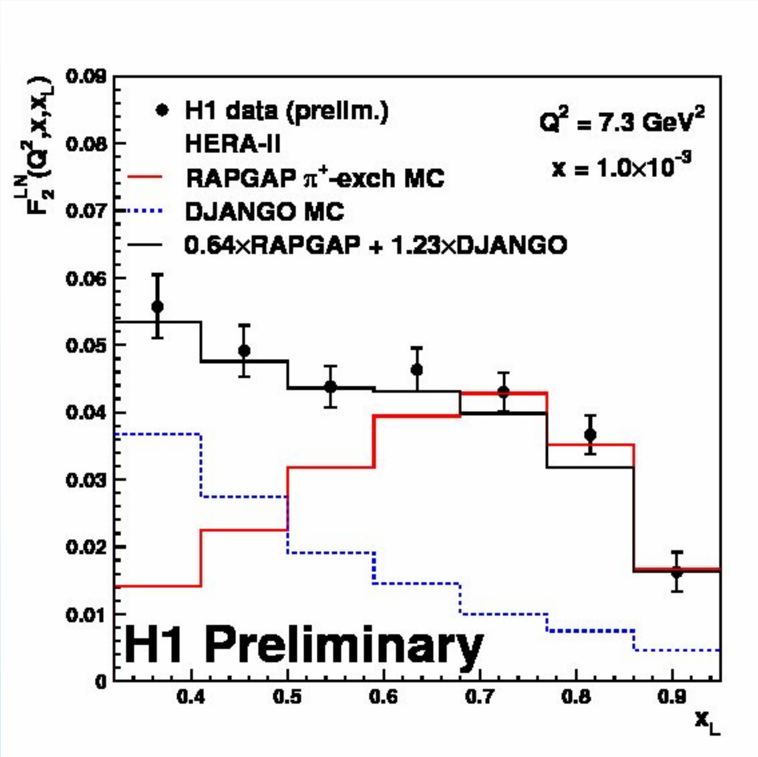
isospin 1 exchange:

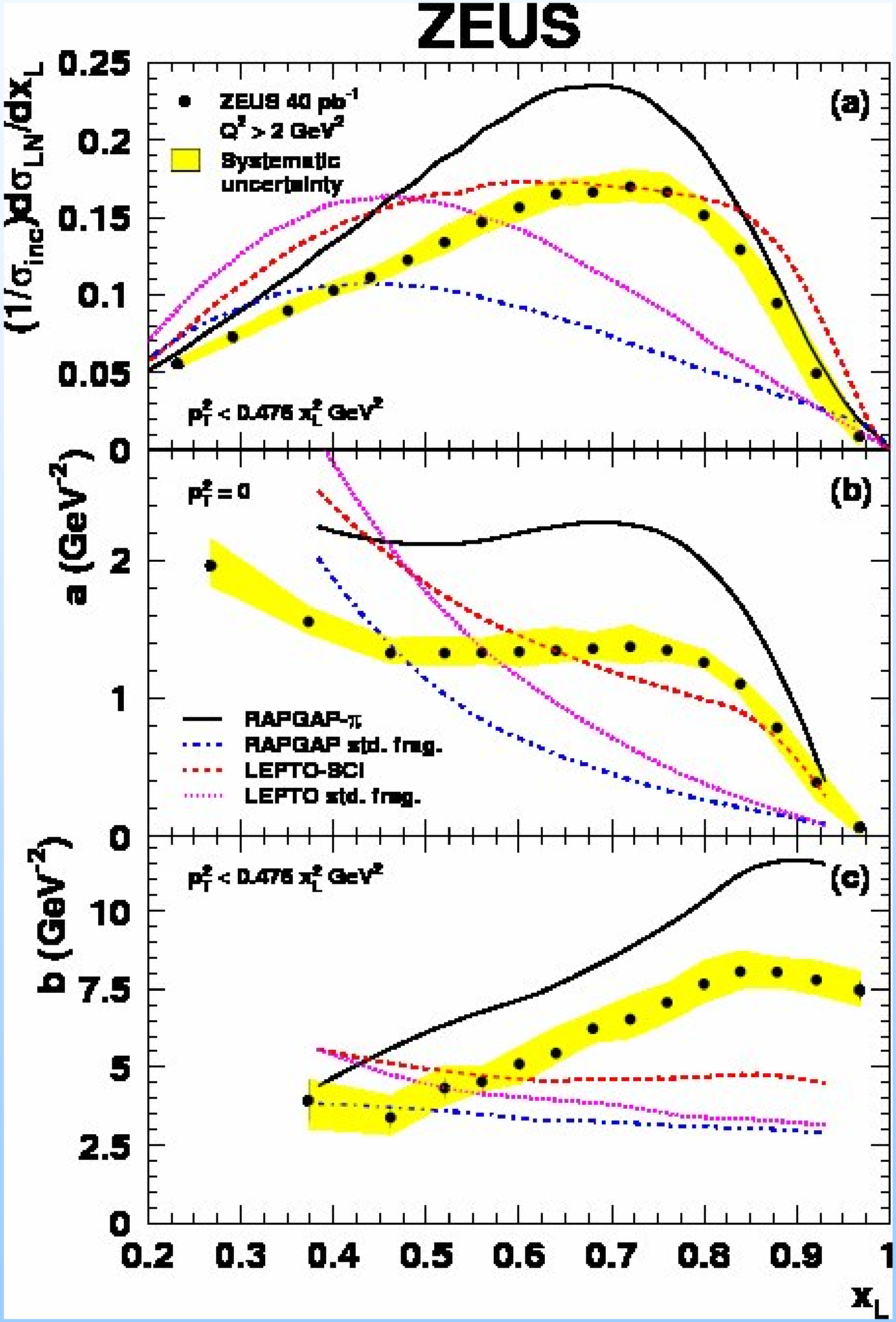
$$r = \frac{1}{2}$$

$$\frac{1}{\sigma_{incl}} \cdot \frac{d^2\sigma_{LN}}{dx_L \cdot dp_T^2} = a(x_L) \cdot \exp(-b(x_L)\, p_T^2$$

$e\,p \to e\,n\,X$

Comparison with models:



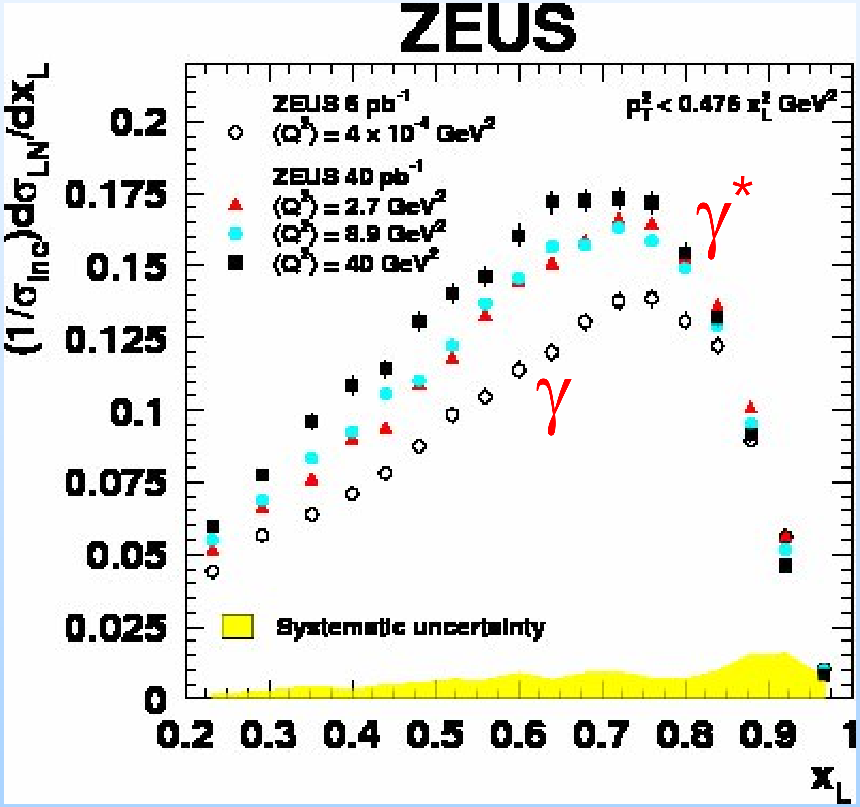


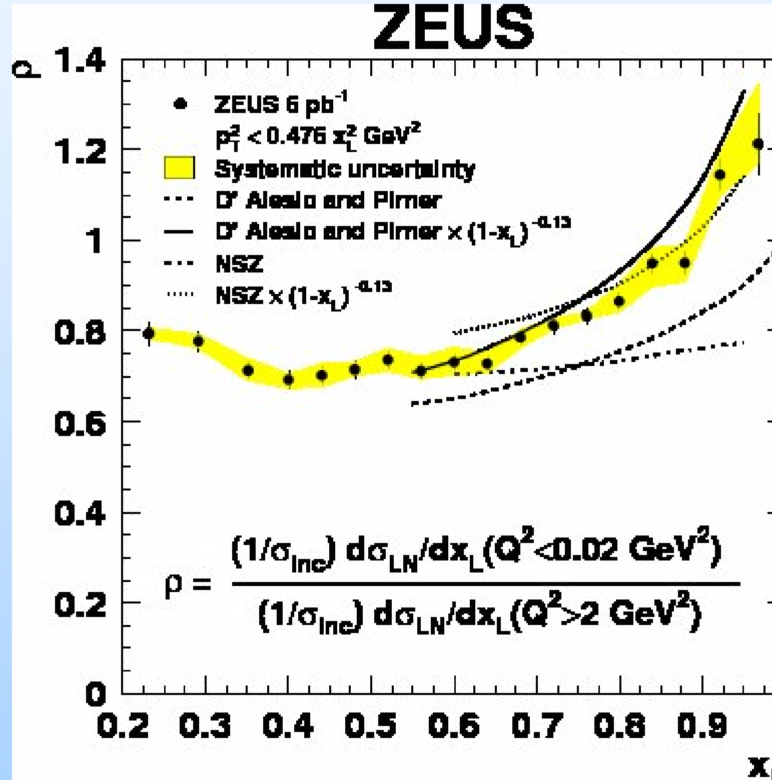
- all fragmentation models fail
- best mixture of Django + RAPGAP π–exchange

$$\Rightarrow F_2^{\pi}(x,Q^2)$$

Absorption / migration effects $e\,p \rightarrow e\,n\,X$

Compare photoproduction / DIS





Absorption large

- large photon size $Q^2 \approx 0$
  depletion for photoproduction

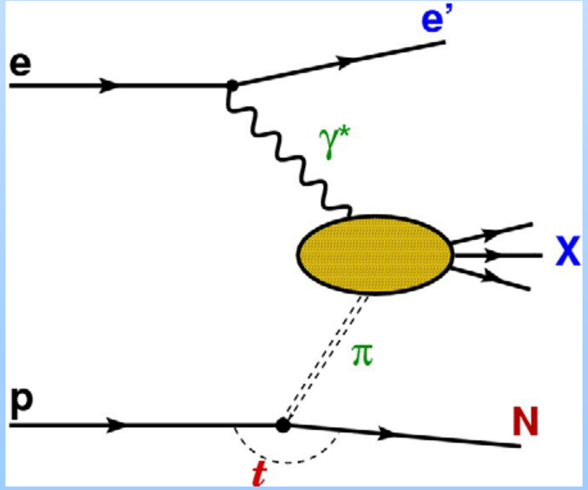
- absorption models
- migration $x_L < 0.5$

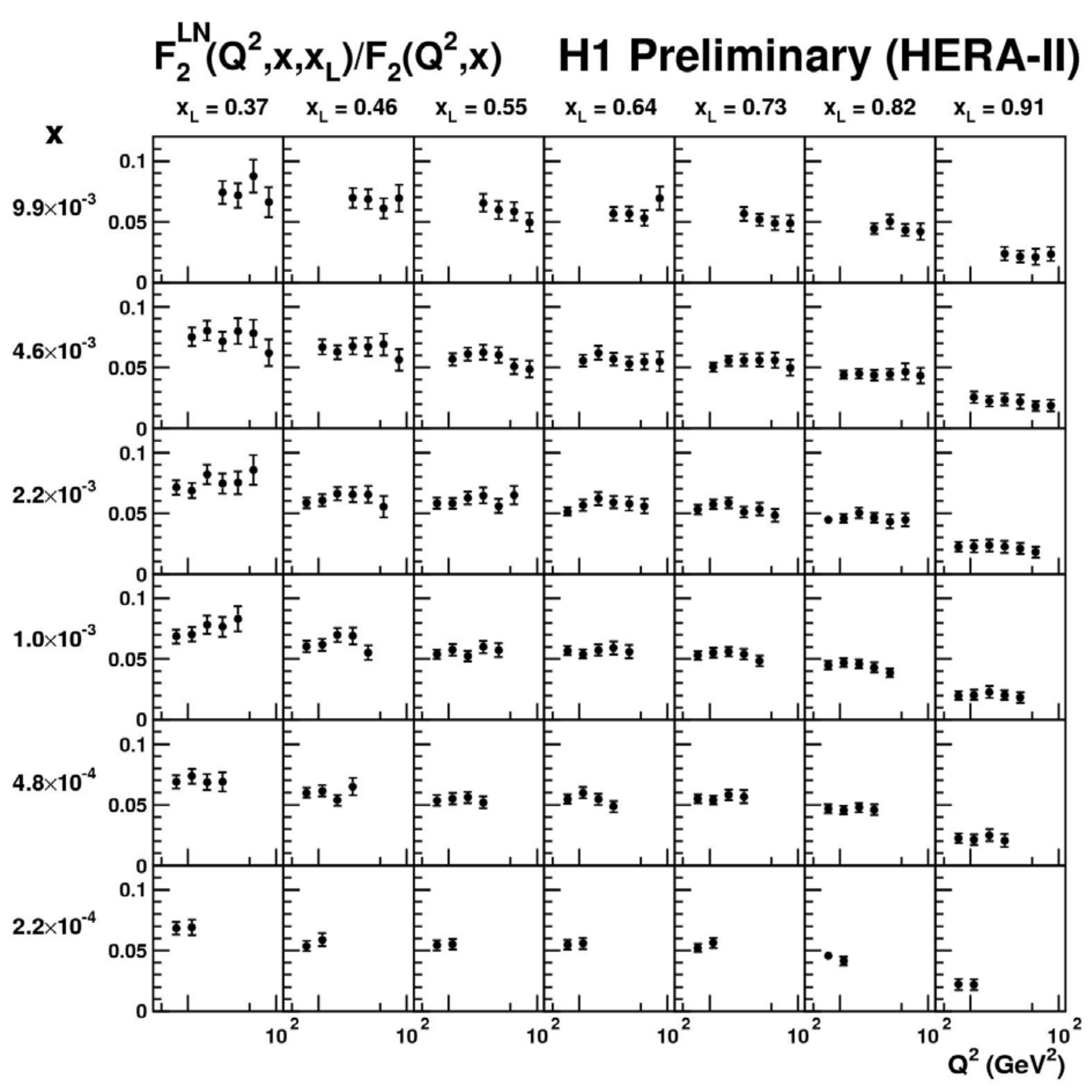
$e\,p \rightarrow e\,n\,X$

- $$\frac{F_2^{LN(3)}(x,Q^2,x_L)}{F_2(x,Q^2)}$$

  independent of x,Q^2

- factorization of vertices





Summary

- ep $\rightarrow$ eVp hard process: $M_V = M_\Psi, M_\Upsilon; Q^2$, t large
- described by

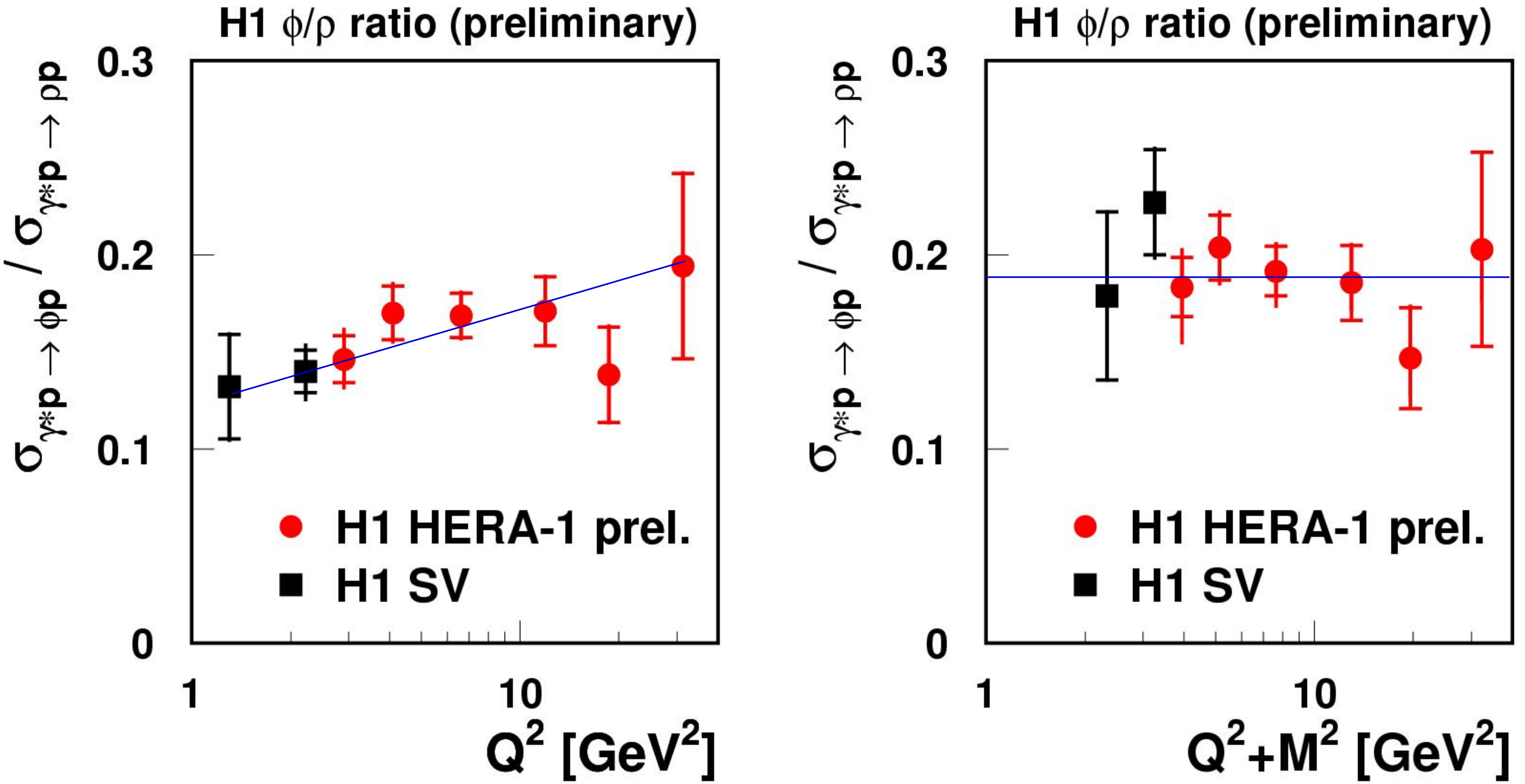
  $$\left.\begin{array}{l}\text{dipole}\\ \text{2-gluon exchange}\\ \text{GPD}\end{array}\right\}\ \text{models}$$

- constrain gluon structure function at small x
- improved theoretical calculations needed

- leading particles : ep $\rightarrow$ eNX observed
- standard fragmentation models fail
- violated: vertex factorization / limited fragmentation
- absorption/migration effects observed
- π structure function estimated

BACK UP :

$\gamma^* p \to V p$



$Q^2 + M_V^2$ hard scale

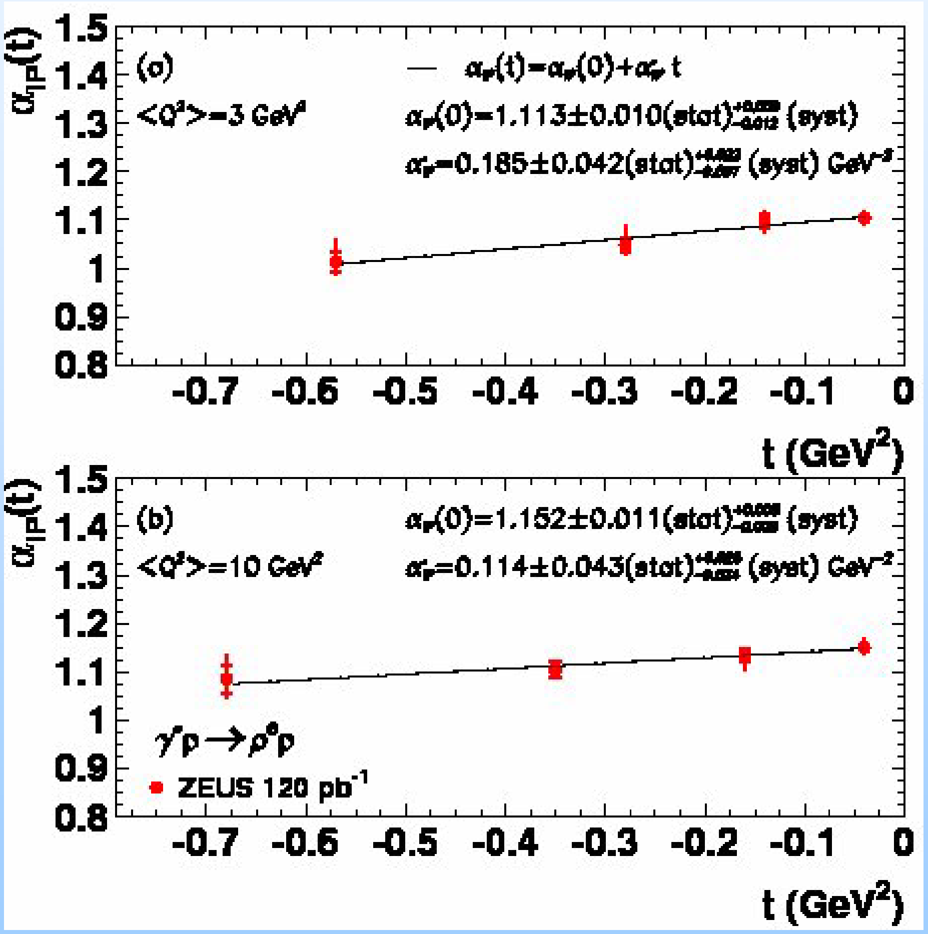
Regge inspired description

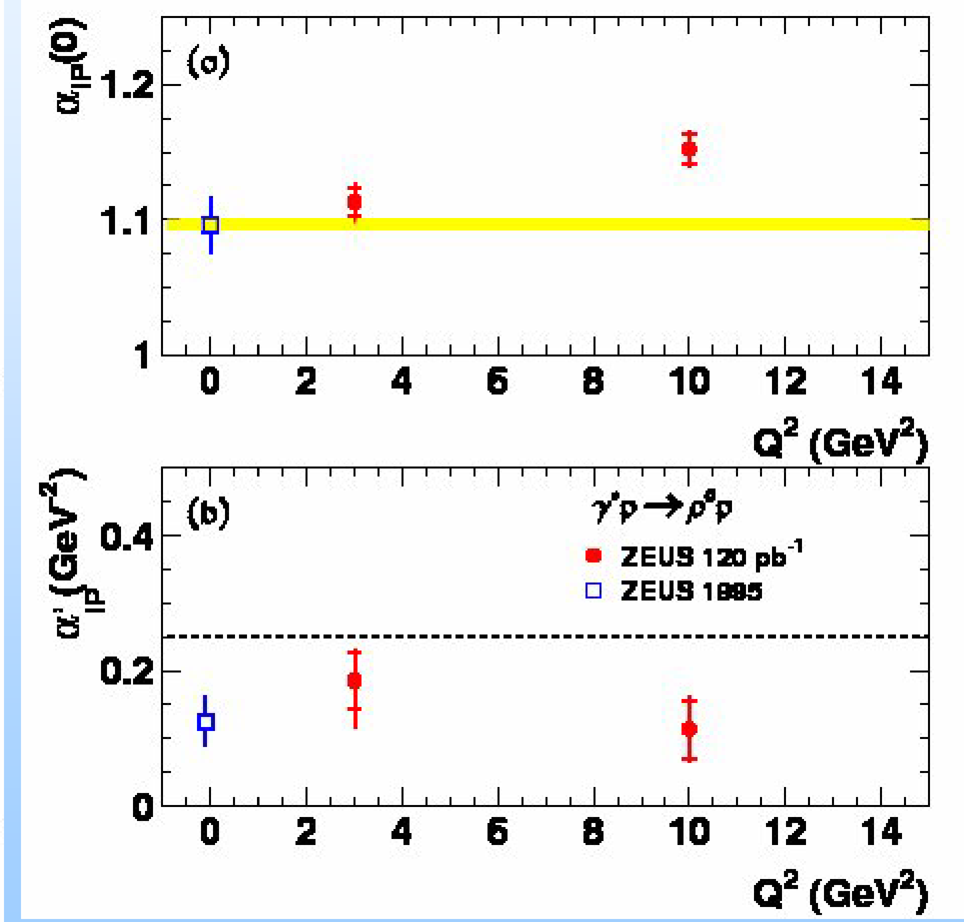
$$\frac{d\sigma}{dt} \sim F(t) \cdot W^{4\cdot(\alpha(t)-1)}$$

$\gamma^* p \to \rho^0 p$

$$\alpha_p(t) = \alpha_p(0) \cdot + \alpha_p' \cdot t$$

W dependence analyzed for t = const





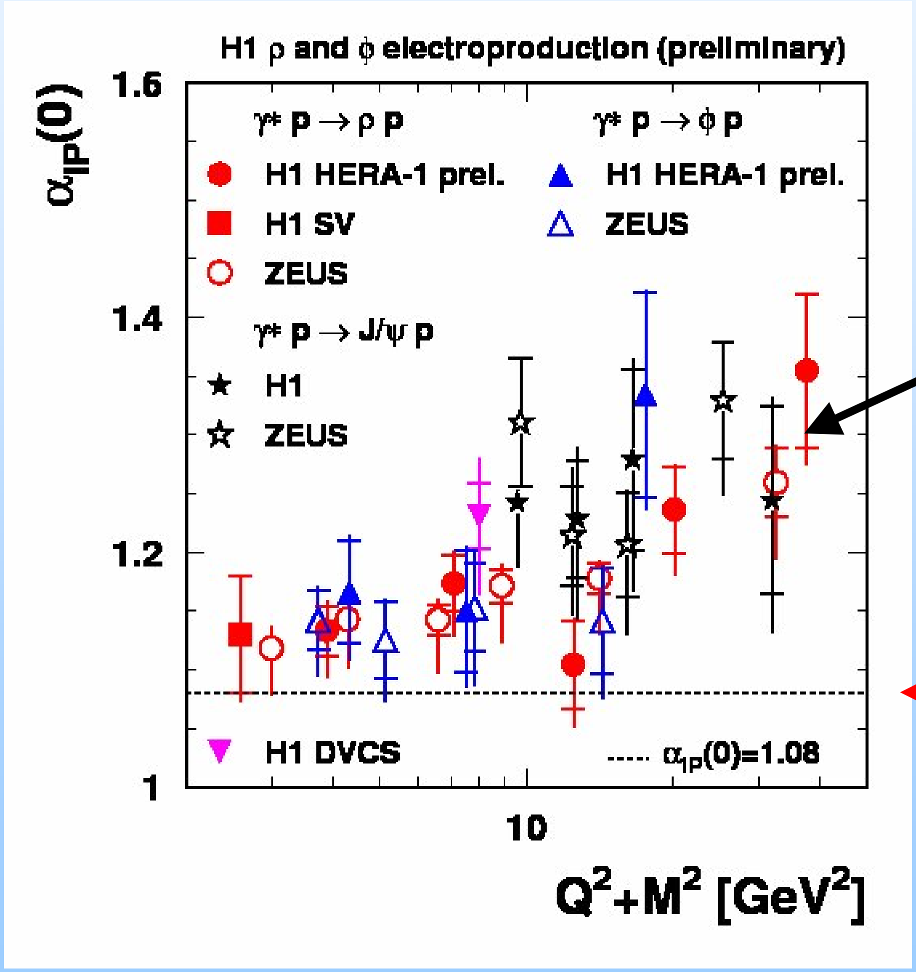
$\alpha_P(0)$ grows with Q^2

α'_P independent of Q^2 ?

Regge inspired description:

$d\sigma/dt \sim F(t)\, W^{4(\alpha(t)-1)}$, analyzed for t = const

$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}\, t$



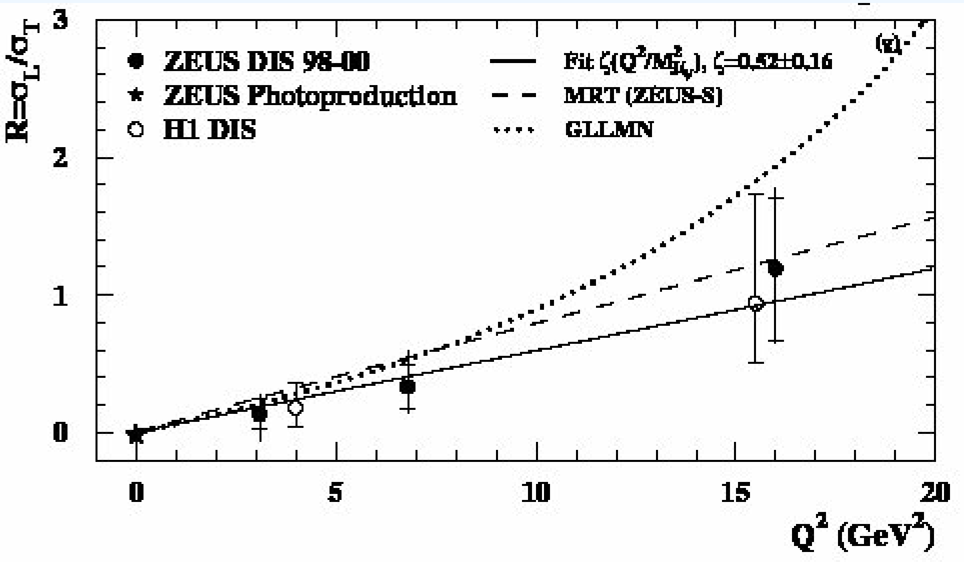
$\gamma\, p \rightarrow V\, p$

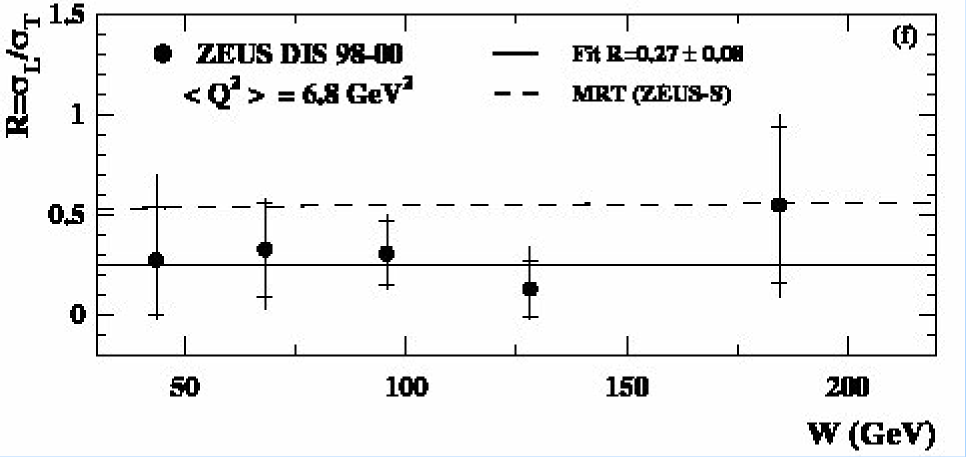
hard Pomeron

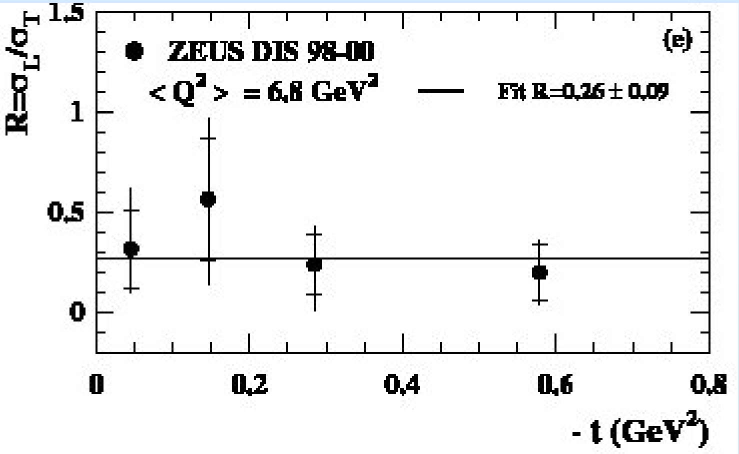
soft Pomeron

Scaling in $Q^2 + M_V^2$

$\gamma^* \, p \rightarrow \Psi(1S) \, p$



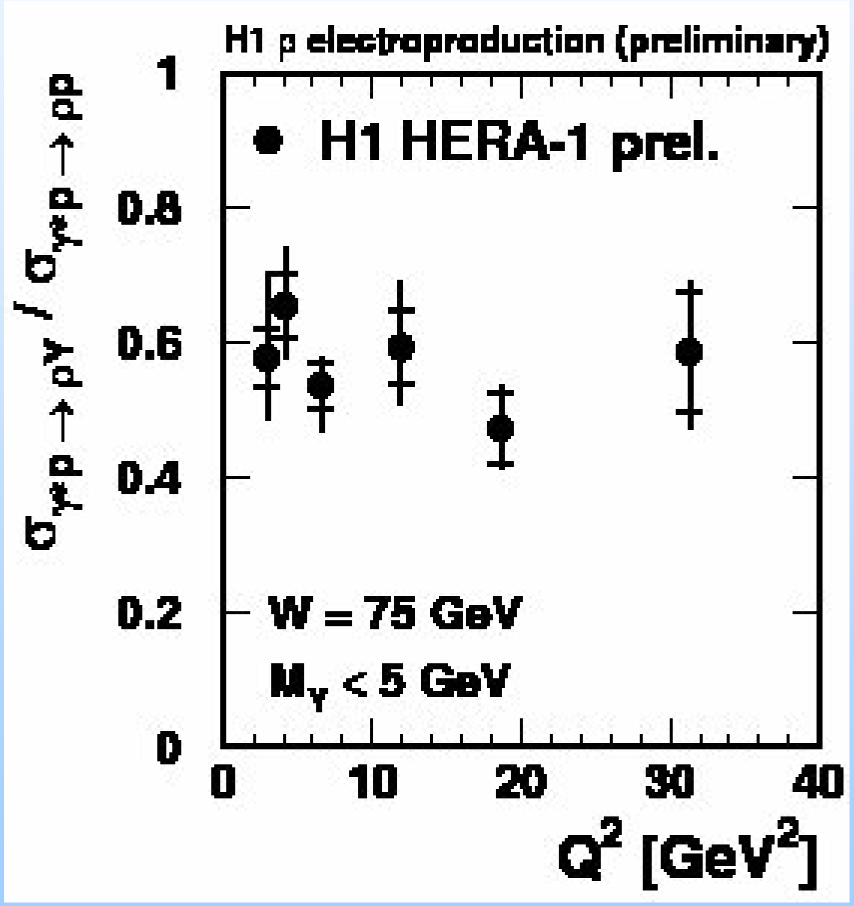


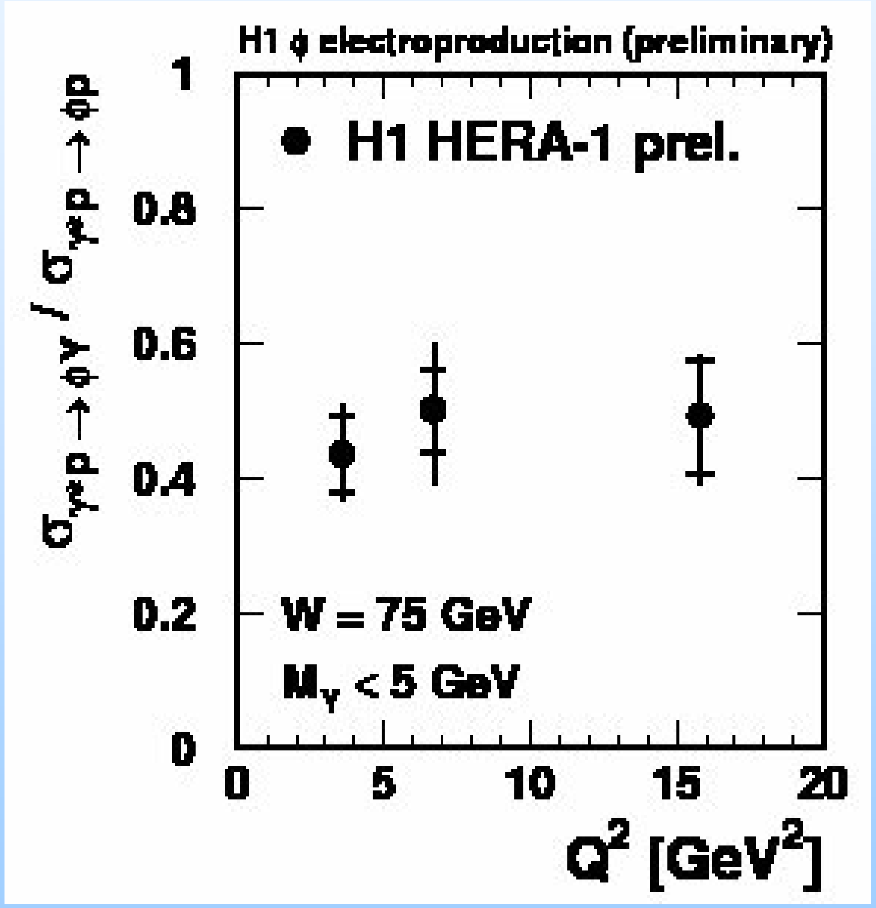


- R ~$Q^2/M^2 \rightarrow$ slower increase for Ψ than ρ, Φ
- no W, t dependence of R

Vertex factorization:

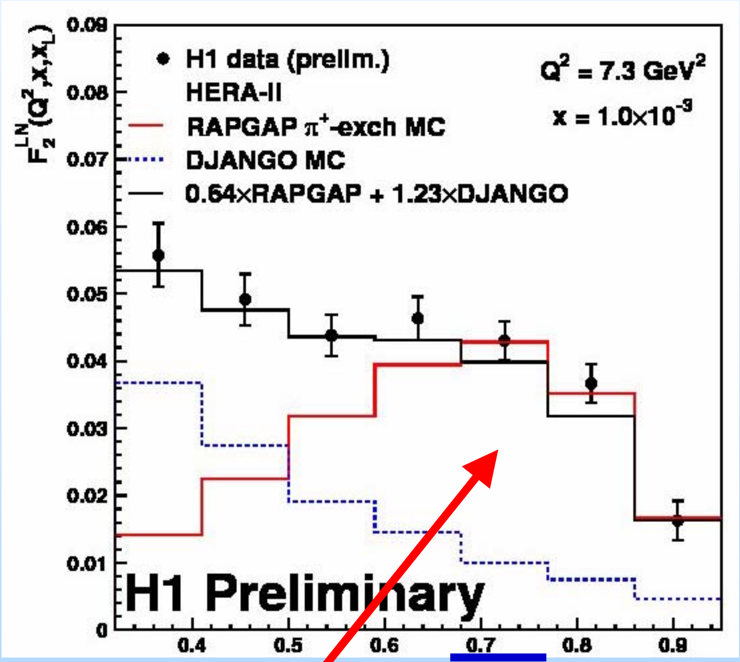
elastic / proton dissociation: universality of Q^2, W dependence, helicity amplitudes





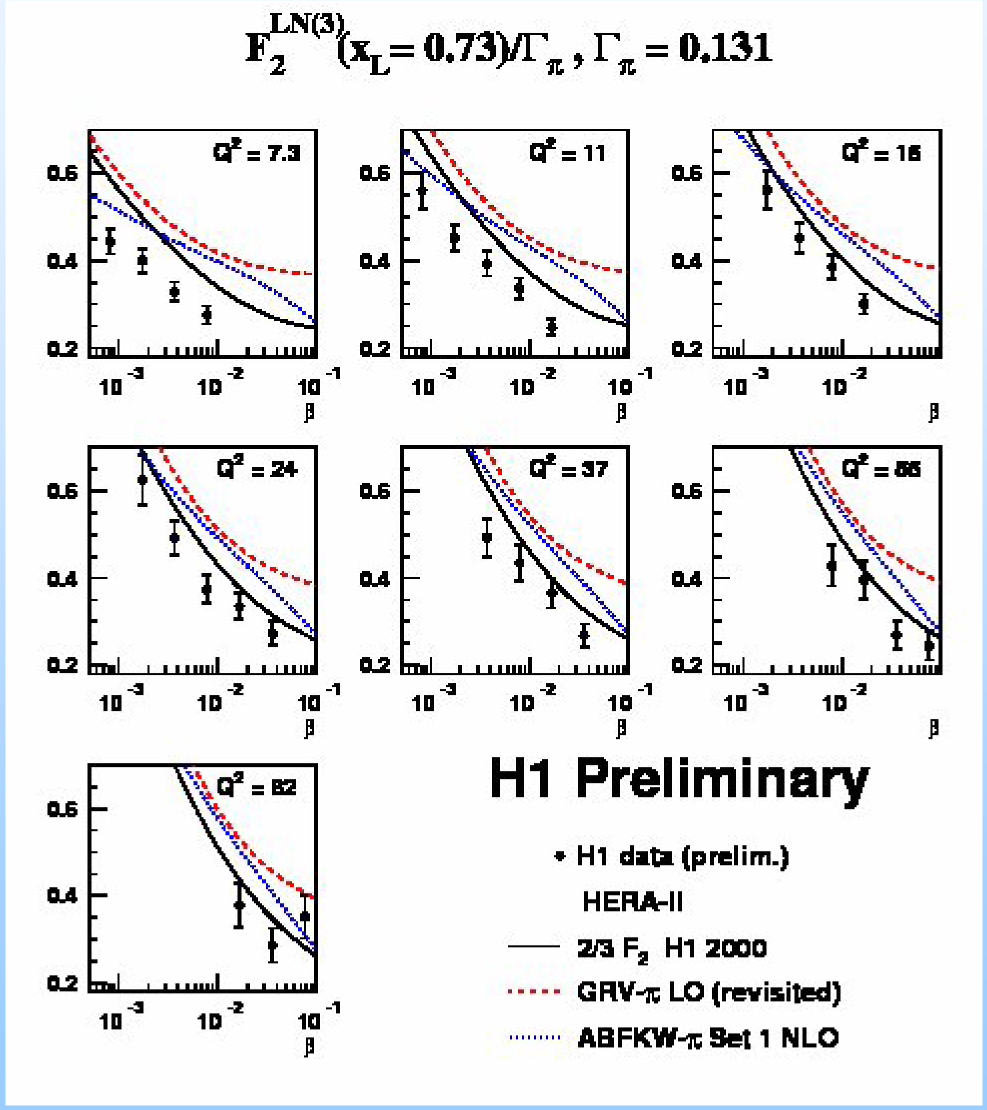
π structure function:

$$F_2^{LN(3)}(\beta, Q^2, x_L) = f_{\pi/p}(x_L) \cdot F_2^{\pi}(\beta, Q^2) \qquad \beta = x/(1-x_L)$$



x_L

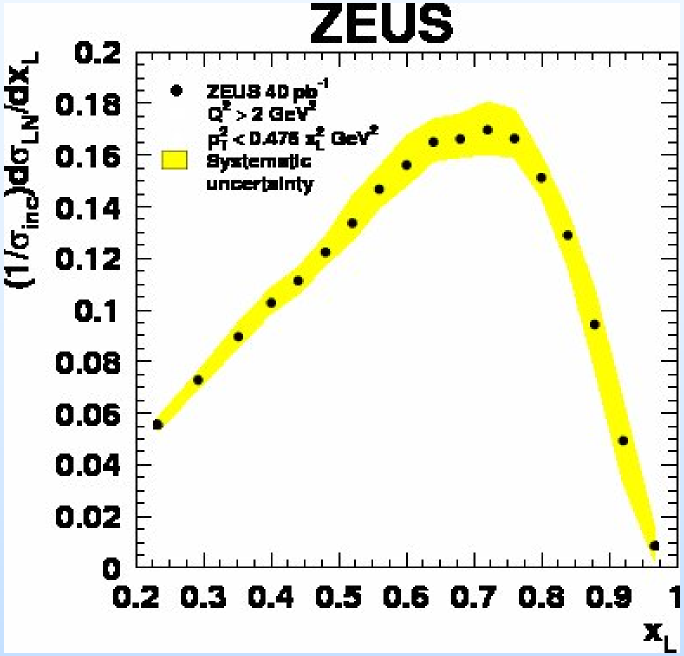
π exchange

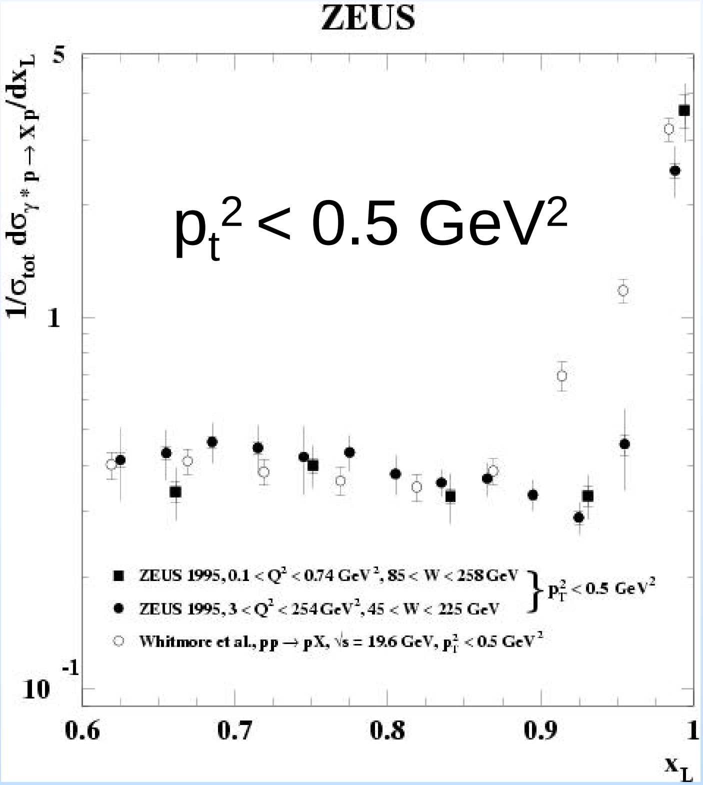


additive quark model

$$F_2^{\pi} = 2/3 \cdot F_2^{p}$$

$$p_t^2 < 0.48 \cdot x_L^2$$





$e\,p \rightarrow e\,n\,X$

$e\,p \rightarrow e\,p\,X$

- $x_L \rightarrow 1$ n yield $\rightarrow$ 0
- similarity to p p $\rightarrow$ n X

- $x_L \rightarrow 1$ diffractive peak
- similarity to p p $\rightarrow$ p X
- flat for $x_L < 0.95$