Vector Mesons and DVCS

Latest results from HERA

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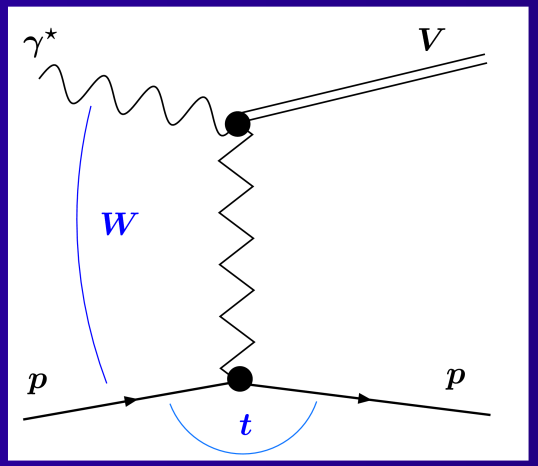
On behalf of the
H1 & ZEUS
Collaborations

$$\gamma^\star p \to V p \qquad V = \gamma, \rho, \phi, J/\Psi, \Upsilon$$

Motivation

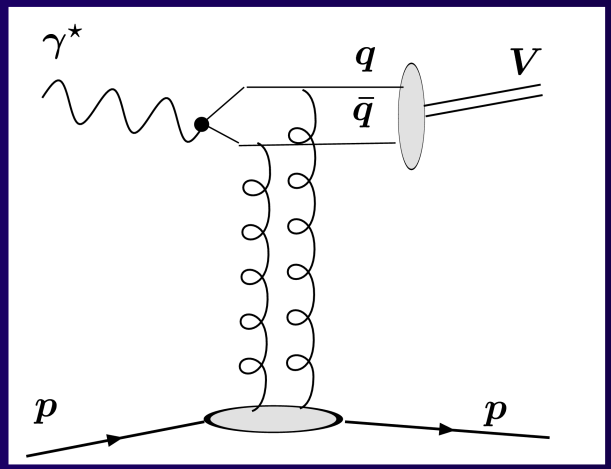
soft



$$\sigma(W) = W^{\delta}$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = e^{-b|t|}$$

hard

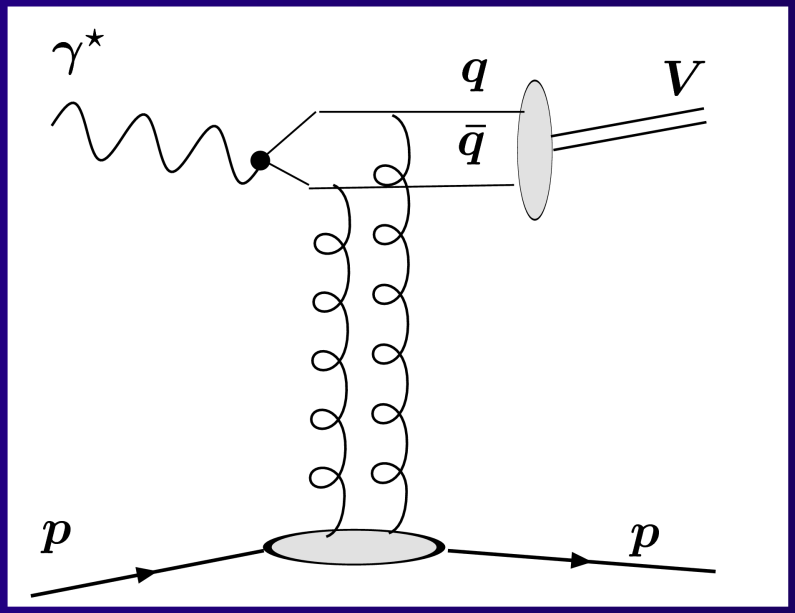


- Expect δ to increase from soft (≈ 0.2) to hard (0.7-0.8) given by $\sigma \propto [xg(x, Q^2)]^2$
- Expect b to decrease from soft (10 GeV^{-2}) to hard (4-5 GeV^{-2})

$$x = \frac{Q^2}{Q^2 + W^2}$$

$$x = \frac{M^2}{W^2} \quad \text{PHP}$$

Motivation



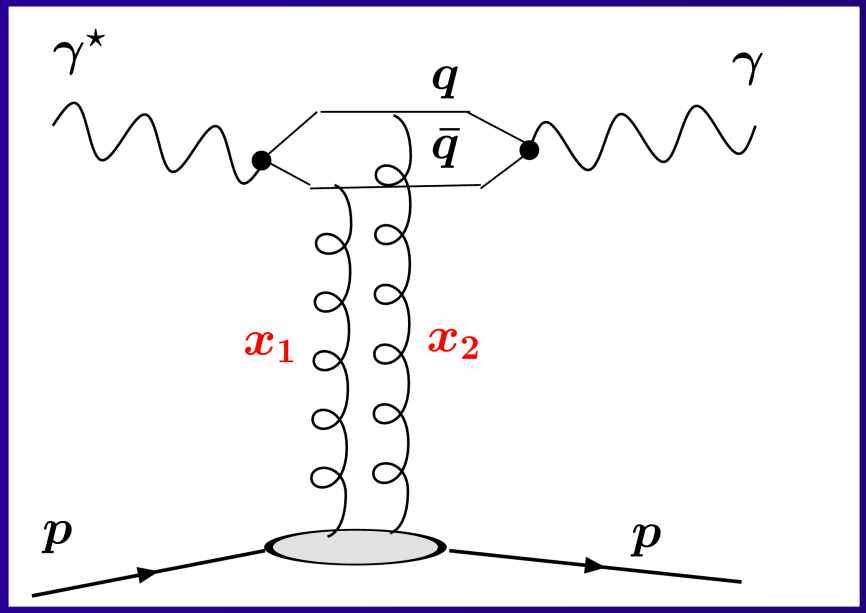
$\gamma \to q\bar{q}$ use QED photon wave function

$q\bar{q}\ p$ scat. constrain gluon density in the proton

$q\bar{q} \to V$ study properties of V wave function

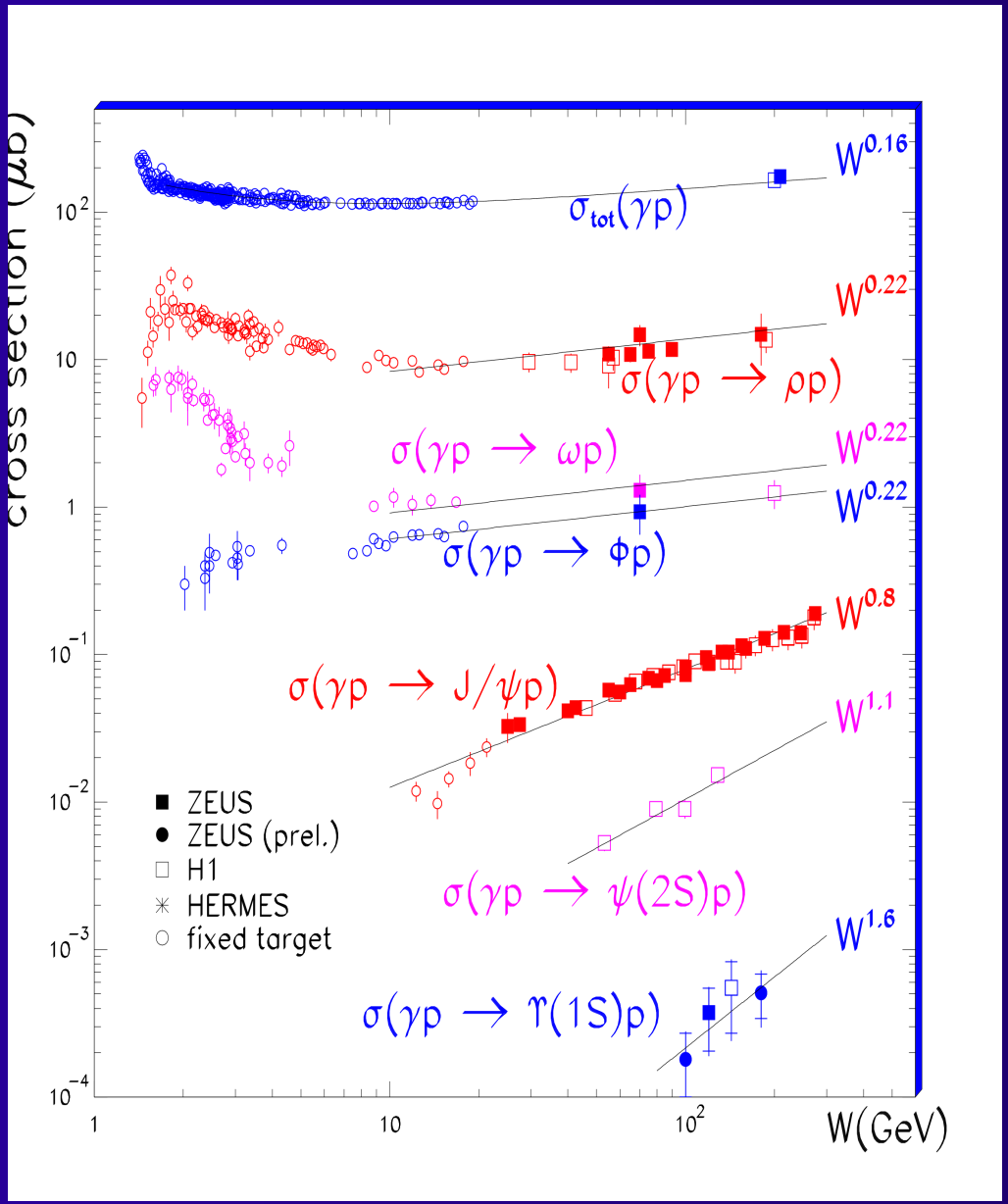
$R_{q\bar{q}} \propto \frac{1}{\sqrt{Q^2+m_q^2}}$ look for scaling in $Q^2 + M_V^2$

Motivation DVCS



- Similar to VM production
- No wave function uncertainty
- Access to GPDs Generalised (skewed) PDFs
- Hard scale given by large Q^2

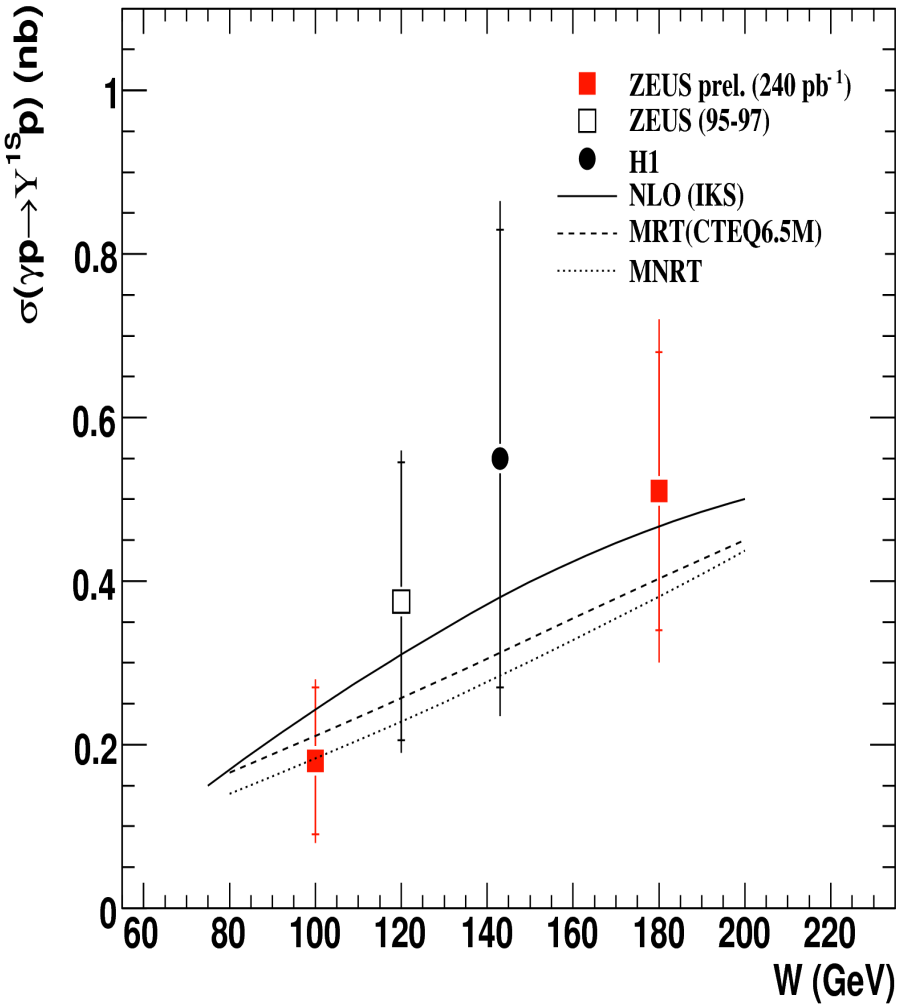
Photoproduction ($Q^2 = 0$)

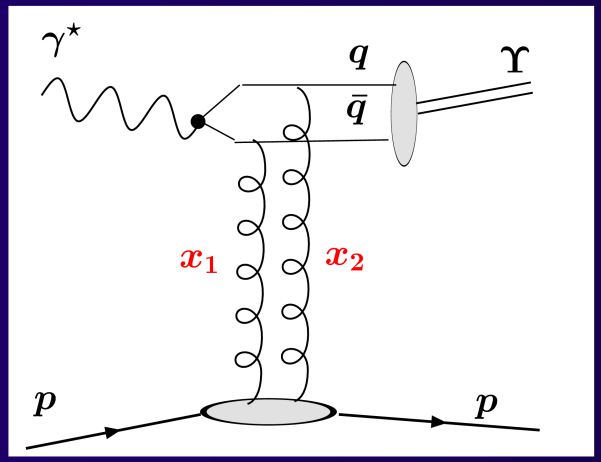


$$\sigma(W) = W^{\delta}$$

- light V (soft regime) ρ, ω, ϕ
- process becomes hard as mass becomes larger $J/\Psi, \Psi', \Upsilon$
- M_V sets hard scale

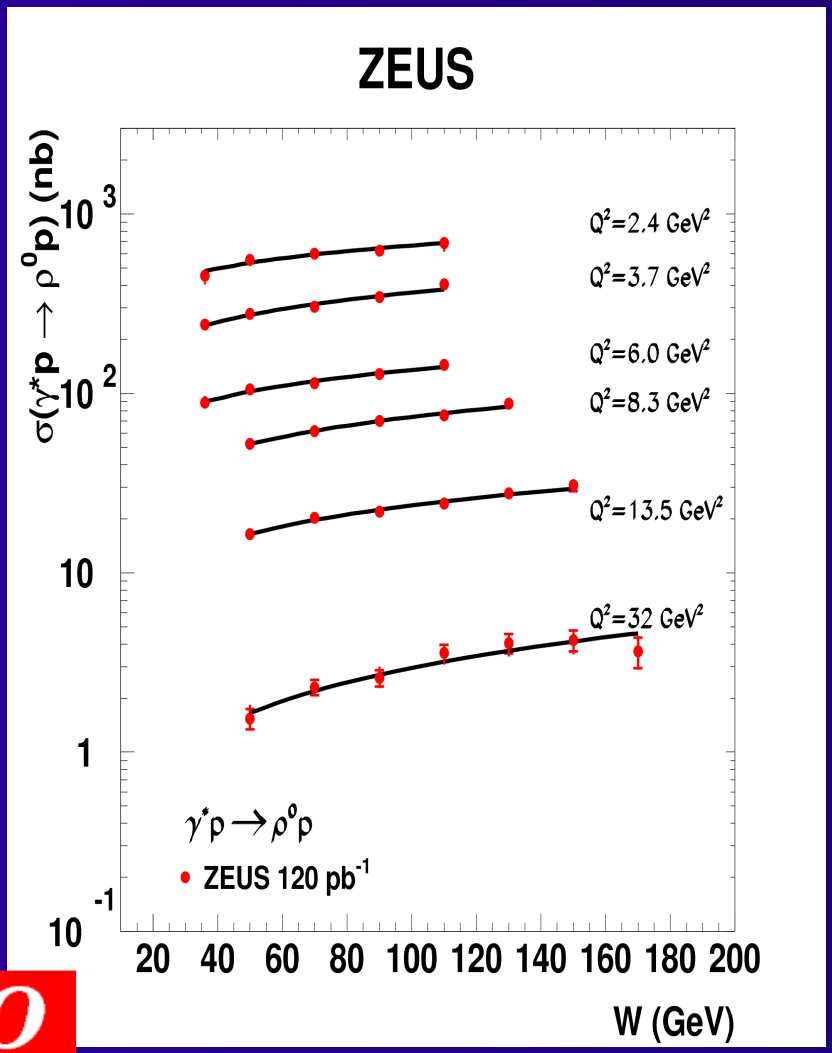
Photoproduction ($Q^2 = 0$)



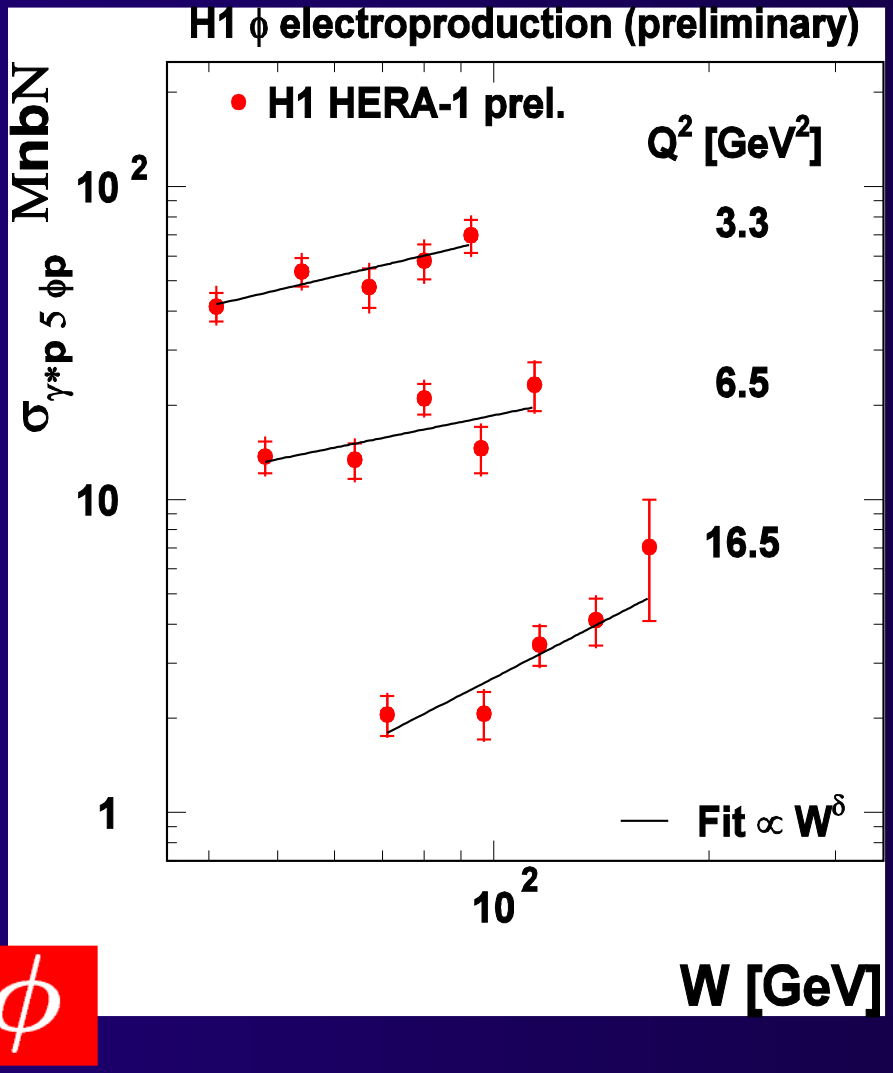


Data in agreement with pQCD predictions including skewing

$\sigma(W) = W^{\delta}$ DIS



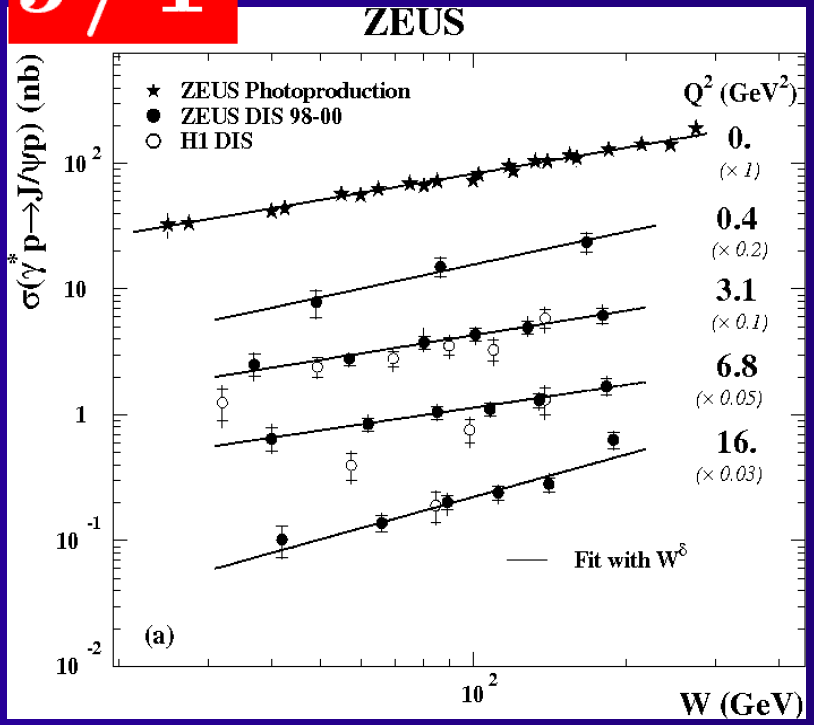
ρ



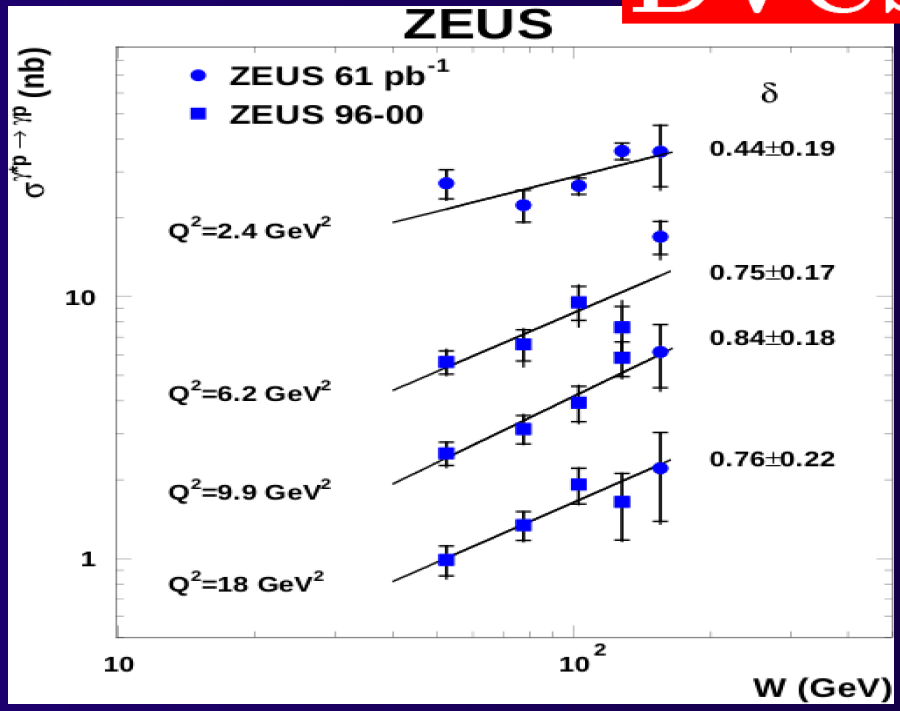
ϕ

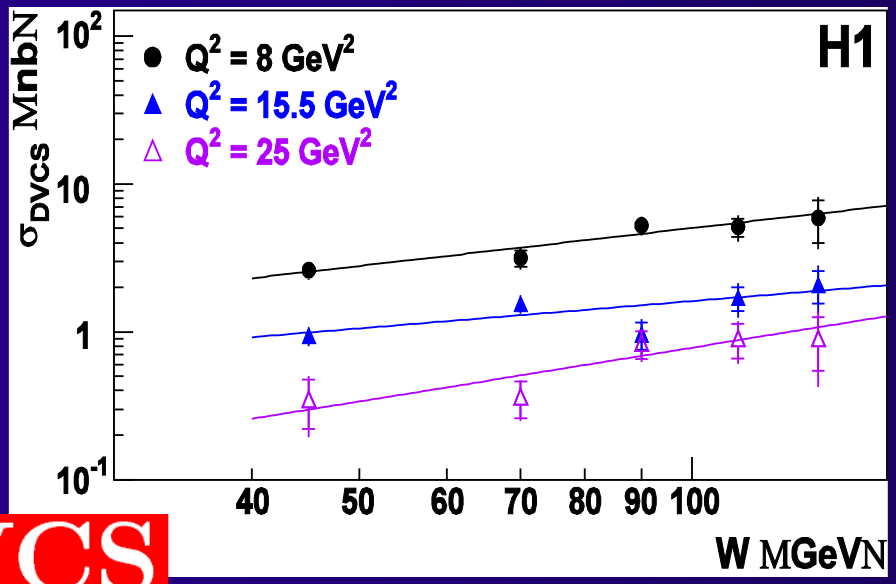
$\sigma(W) = W^{\delta}$

J/Ψ



DVCS



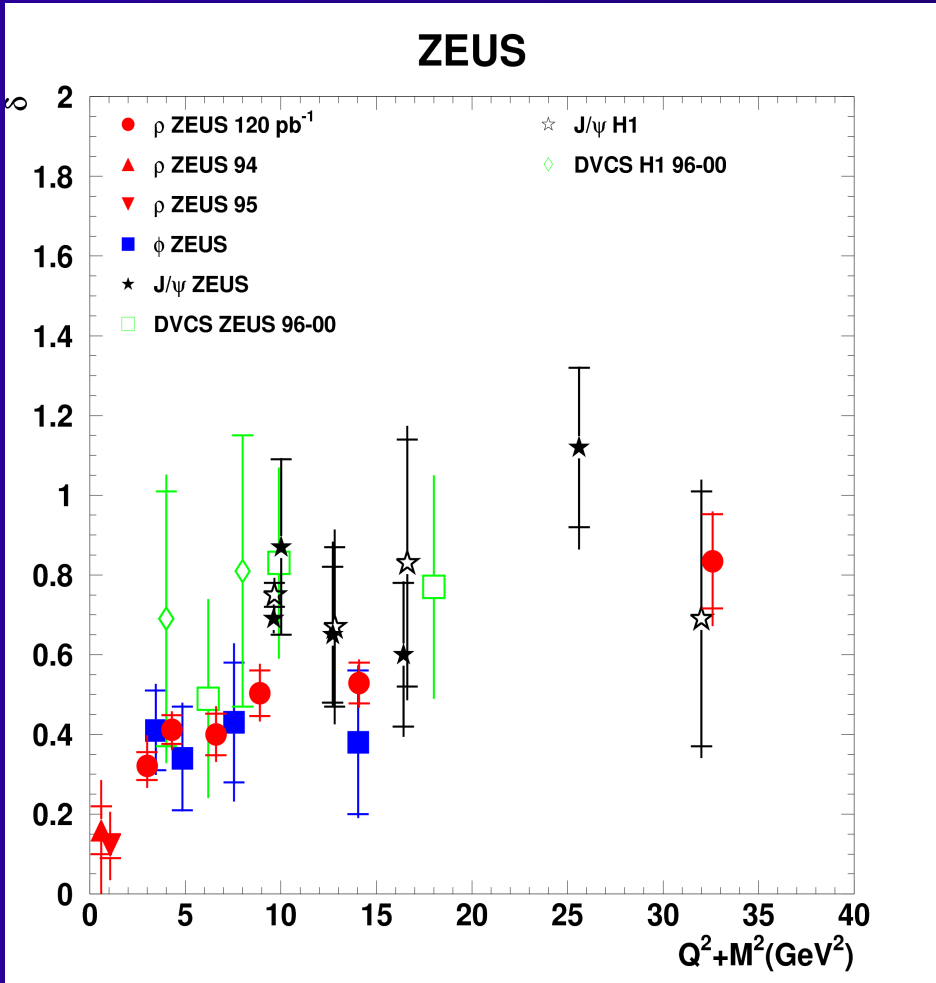


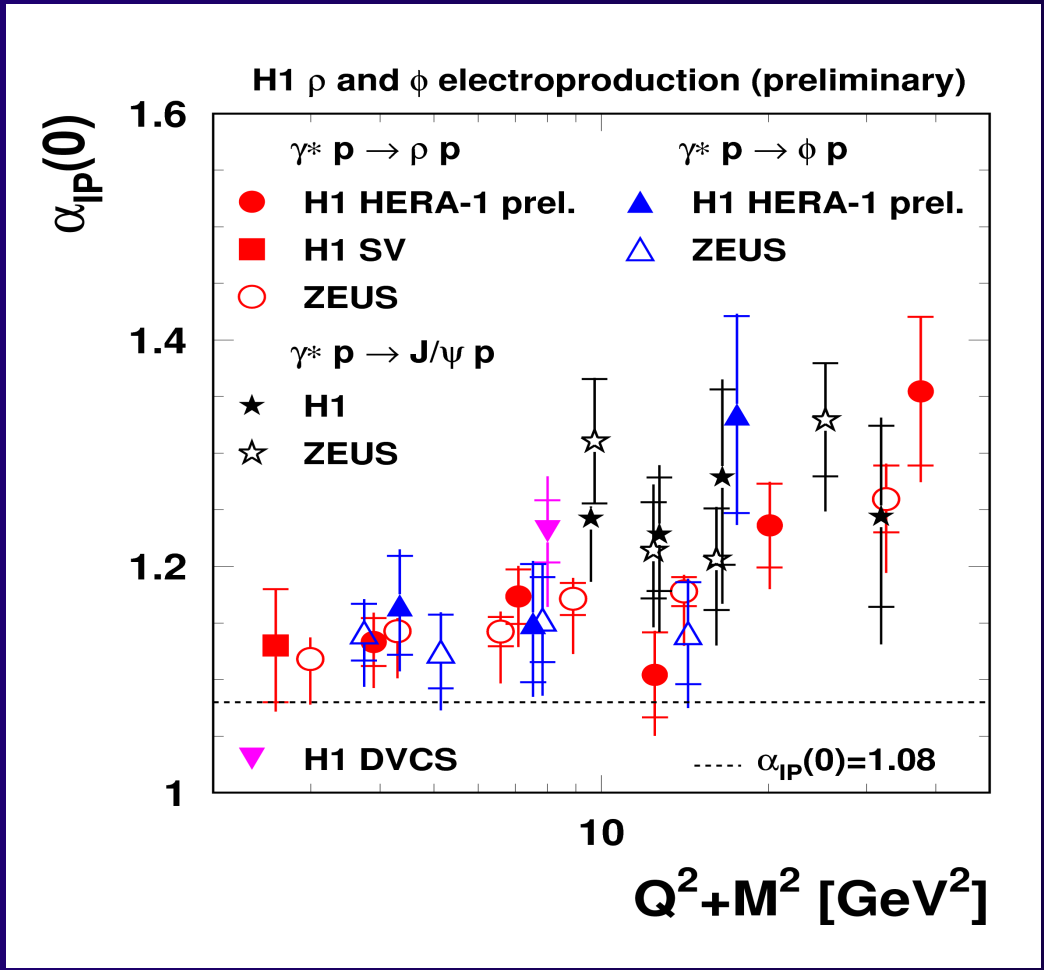
DVCS

$\sigma(W) = W^{\delta}$

δ vs. $Q^2 + M^2$

$$\alpha_{IP}(0) = 1 + \delta/4 + \alpha' \langle |t| \rangle$$





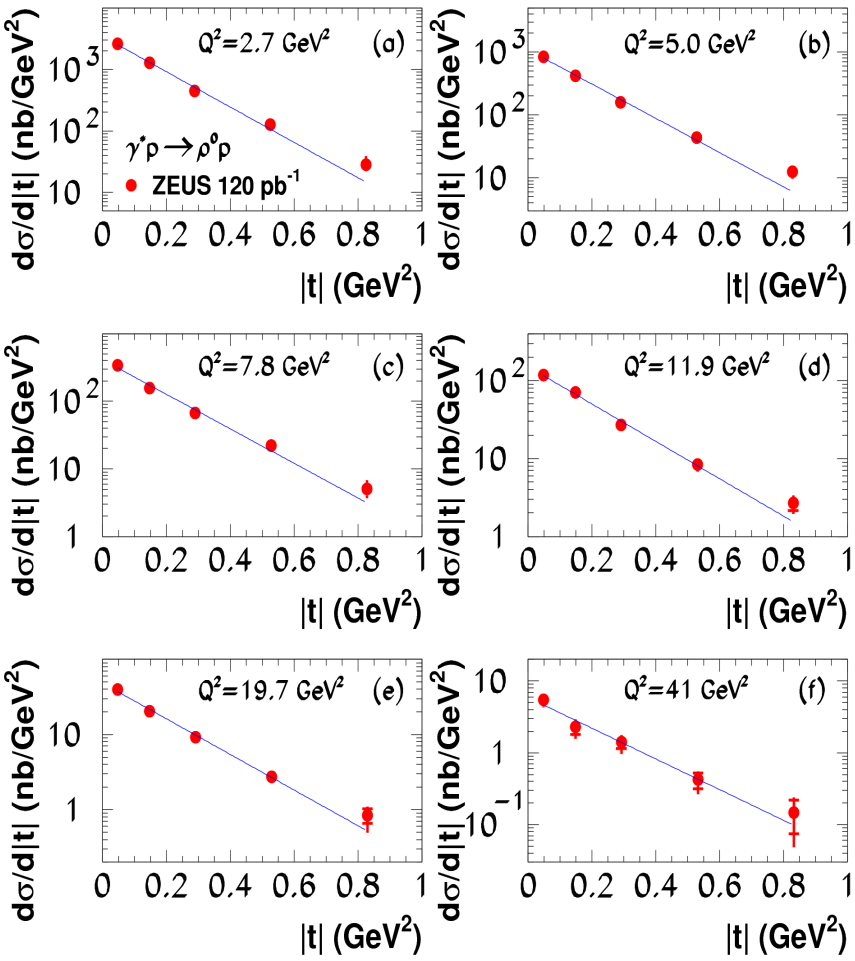
published VM+DVCS

preliminary ρ and ϕ

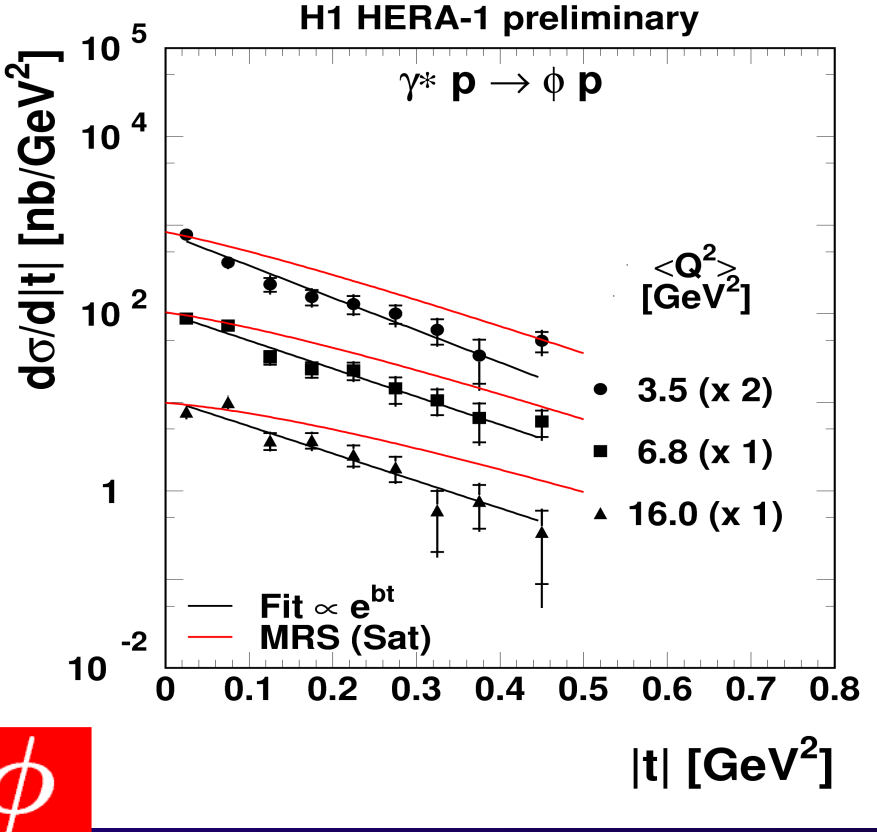
$\delta(Q^2 + M^2)$ same dependence for all VM and DVCS

$d\sigma/dt = e^{-b|t|}$ DIS

ρ

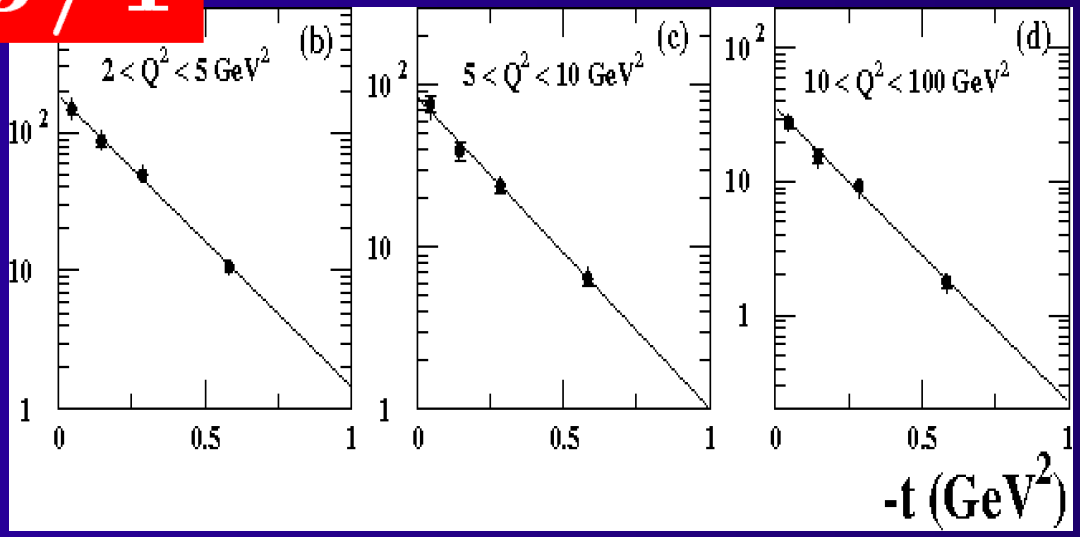


ϕ



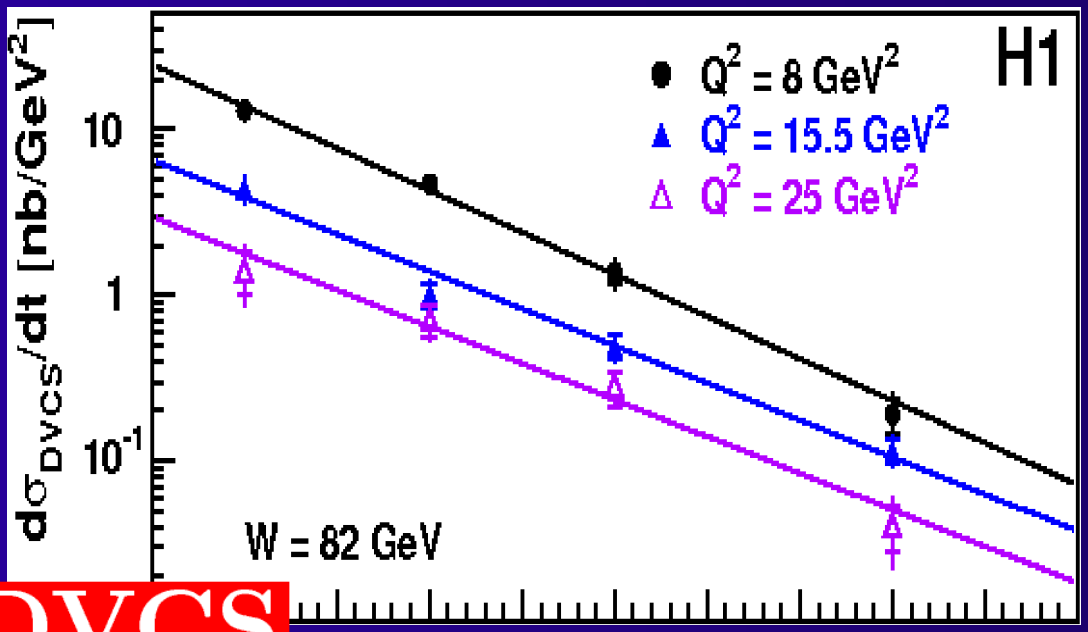
$$d\sigma/dt = e^{-b|t|}$$

J/Ψ

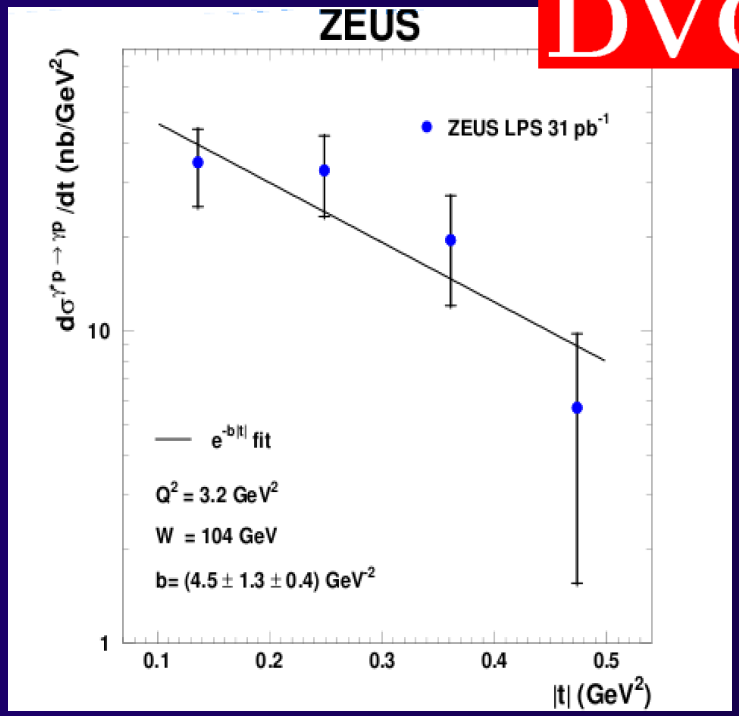


first direct measurement of t in DVCS analysis using LPS

DVCS

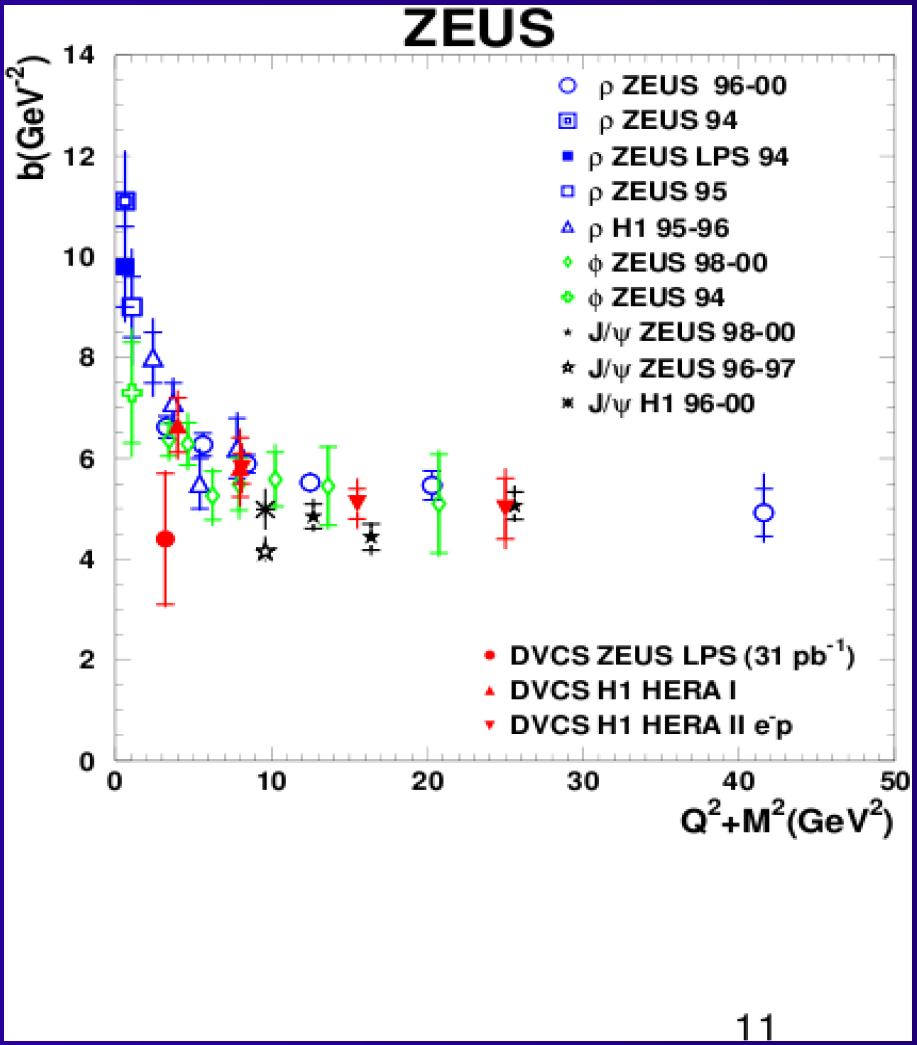


DVCS



$d\sigma/dt = e^{-b|t|}$ b vs. $Q^2 + M^2$

published VM+DVCS



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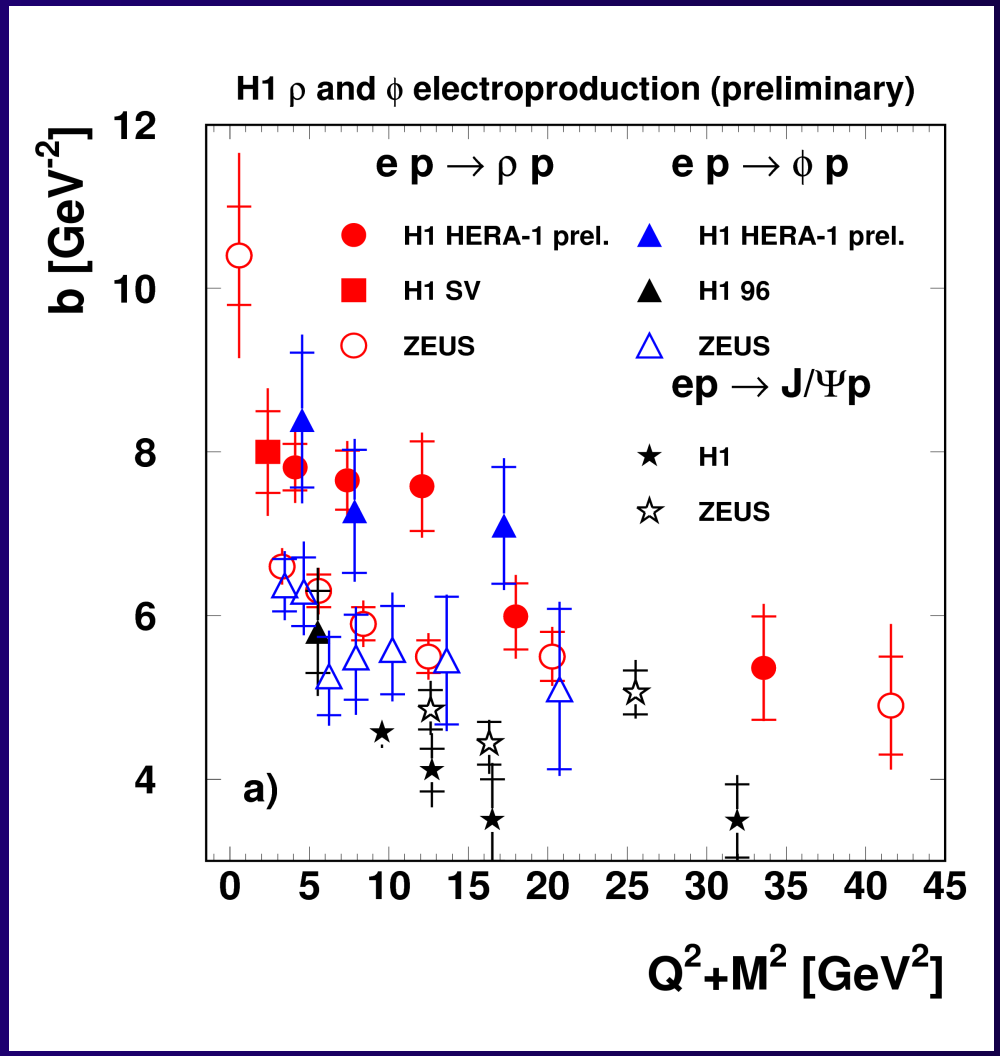
preliminary ρ and ϕ

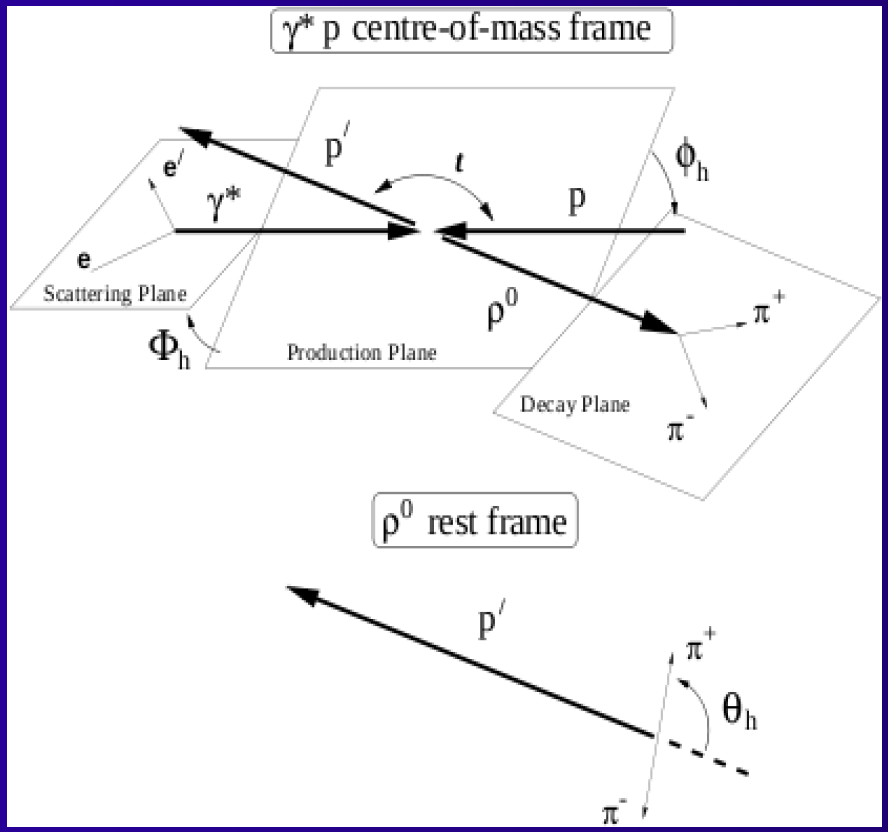


b is related to the size of the interaction

$R_{\text{proton}} \approx 0.8$ fm while $R_{\text{gluon cloud}} \approx 0.56$ fm

Vector Meson Polarisation

Information about VM polarisation obtained in helicity frame

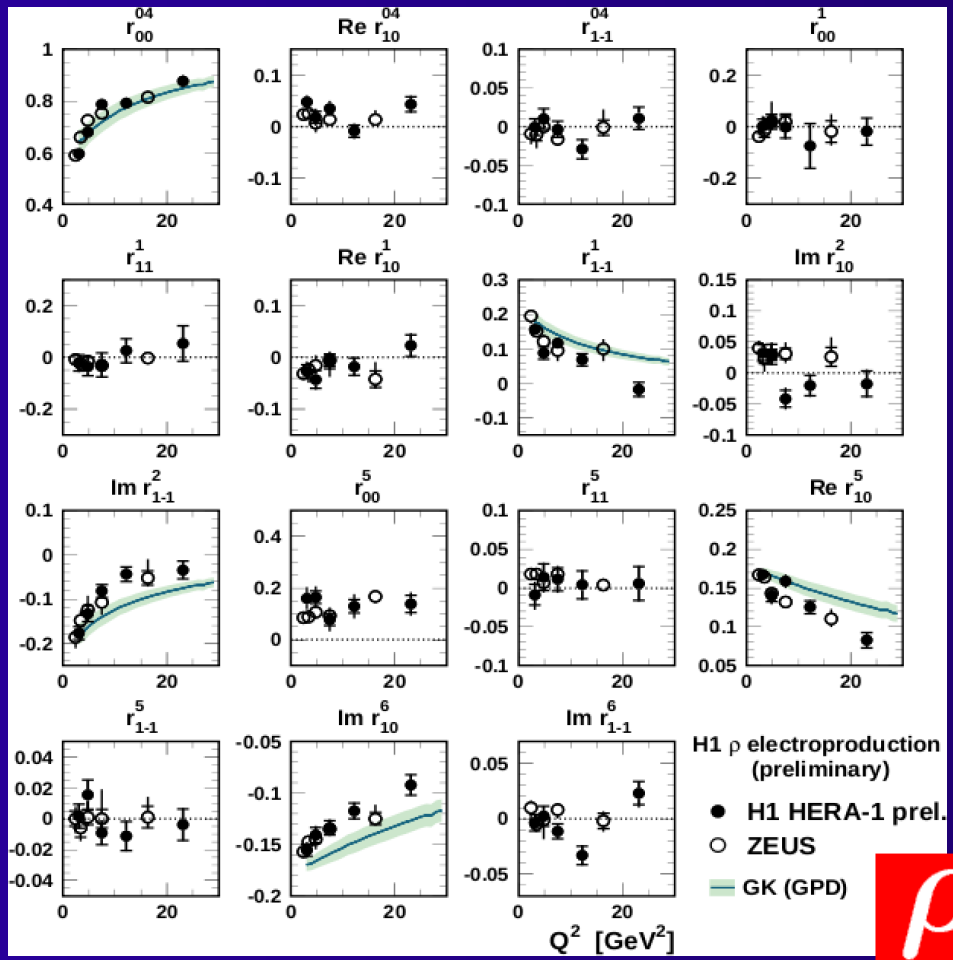


3D angular distributions sensitive to helicity amplitudes: $T_{\lambda_\gamma \lambda_V}$

In experiment directly measured 15 spin density matrix elements (SDME) related to products of $T_{\lambda_\gamma \lambda_V}$

s-channel helicity conservation (SCHC)
helicity of photon transferred to VM $\lambda_\gamma = \lambda_V$

SDME vs. Q^2



high precision differentially in Q^2

Goloskokov-Kroll

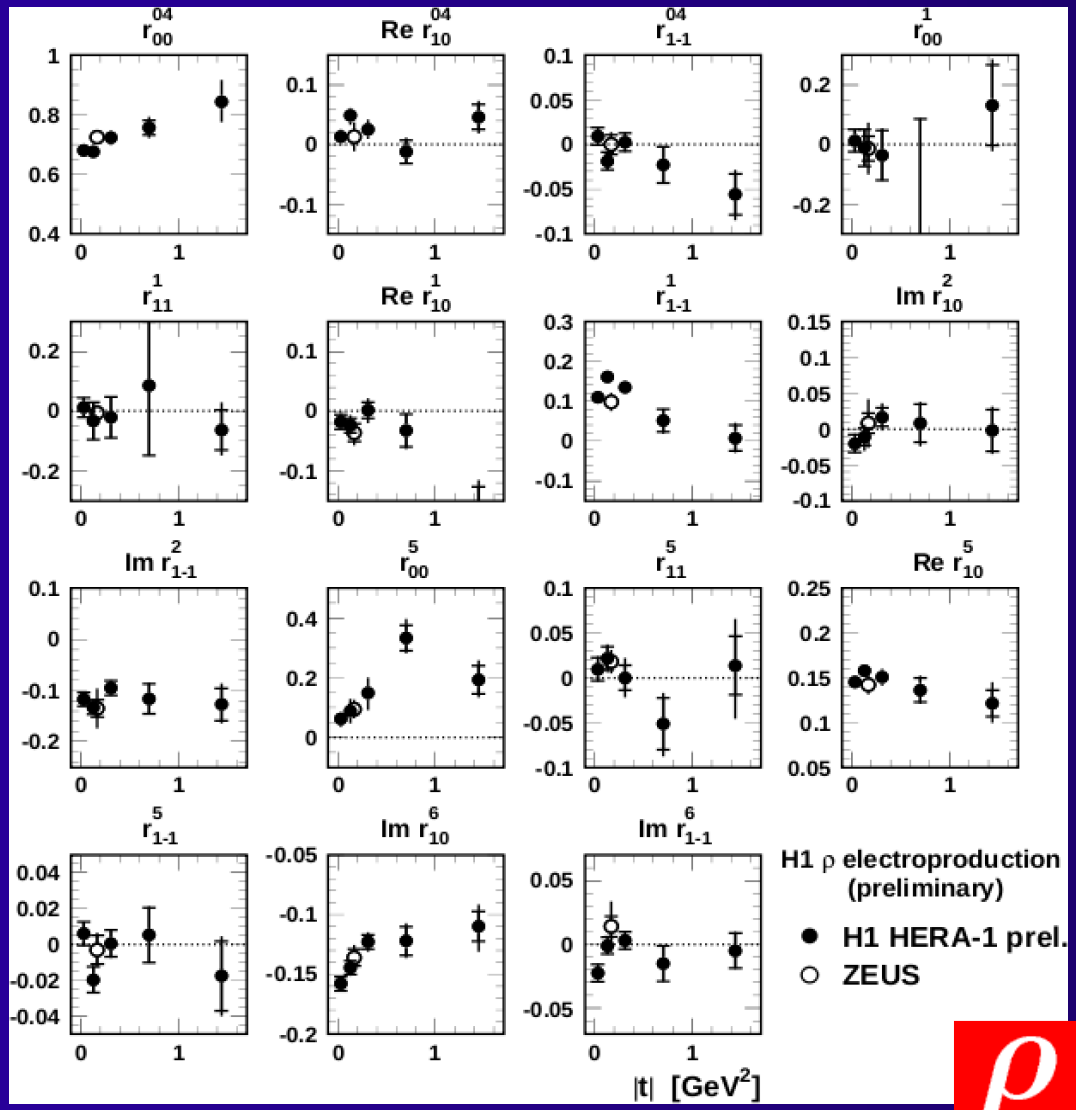
- 2 gloun exchange
- use GPD obtained from CTEQ6 PDF
- assume SCHC

Fair description by Goloskokov-Kroll (GPD)

r^{04}_{00} increases with Q^2

r^{5}_{00} violates SCHC

SDME vs. $|t|$

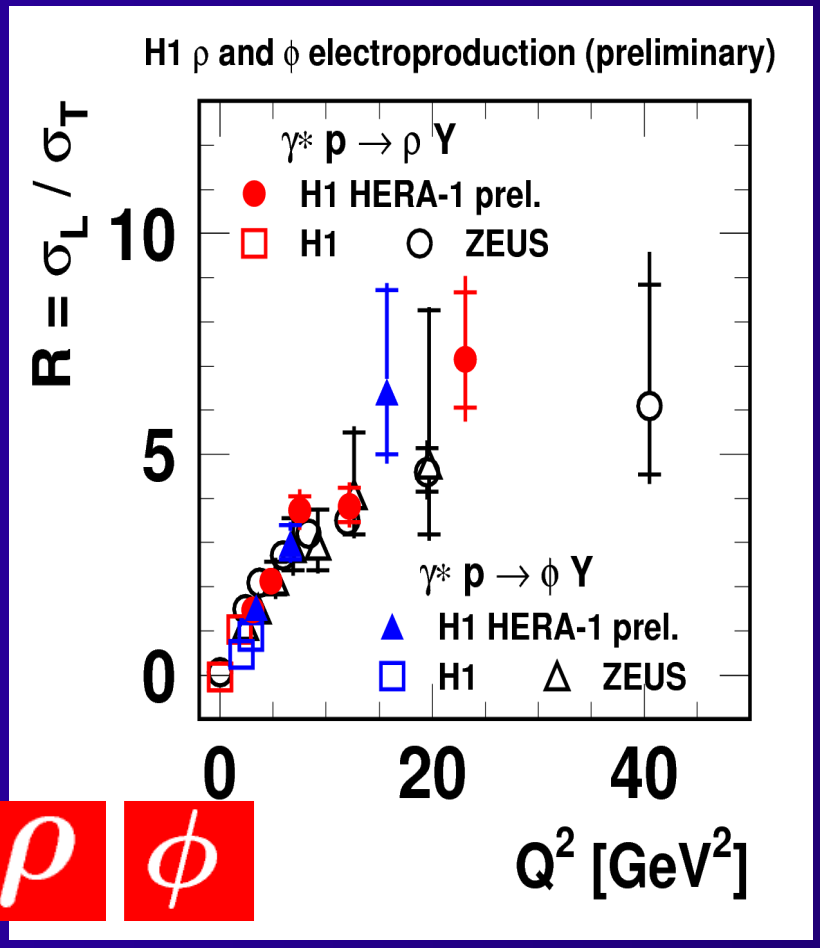


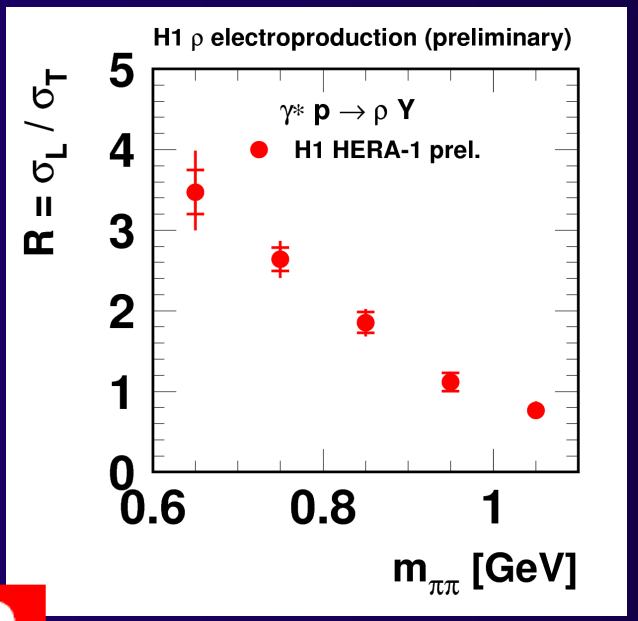
r^{04}_{00} increases with $|t|$

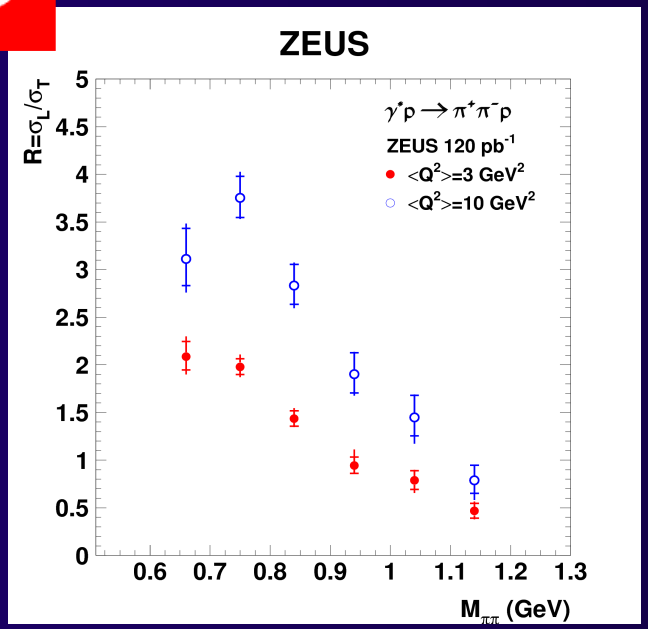
r^{5}_{00} violates SCHC efect increases with $|t|$

$R = \sigma_L/\sigma_T$ vs Q^2

Obtained in SCHC approximation



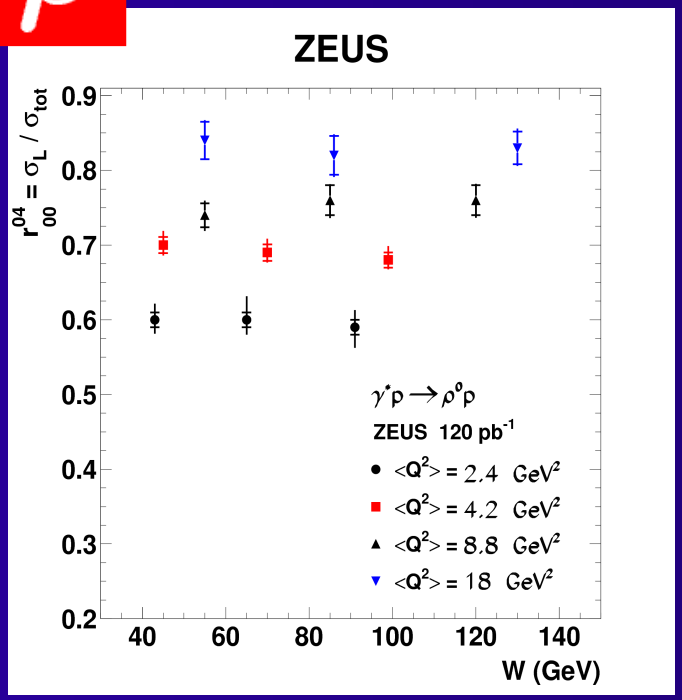


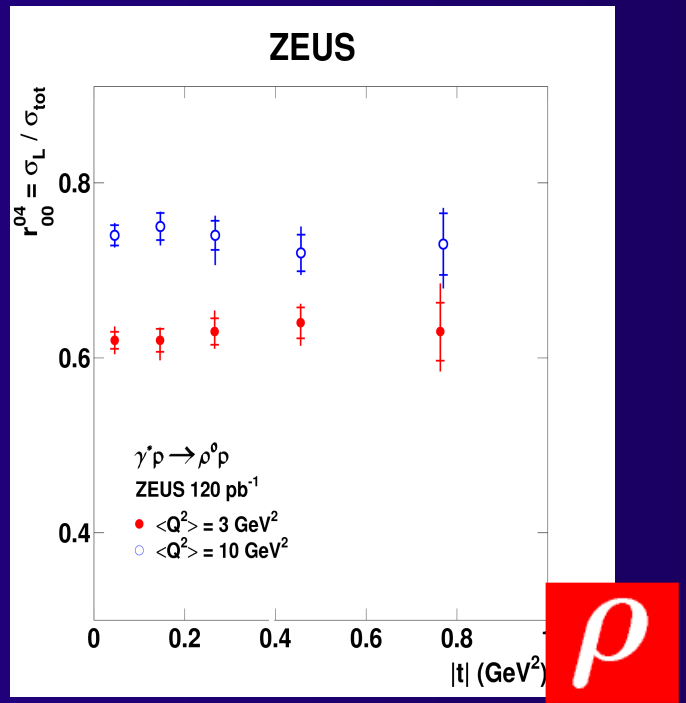


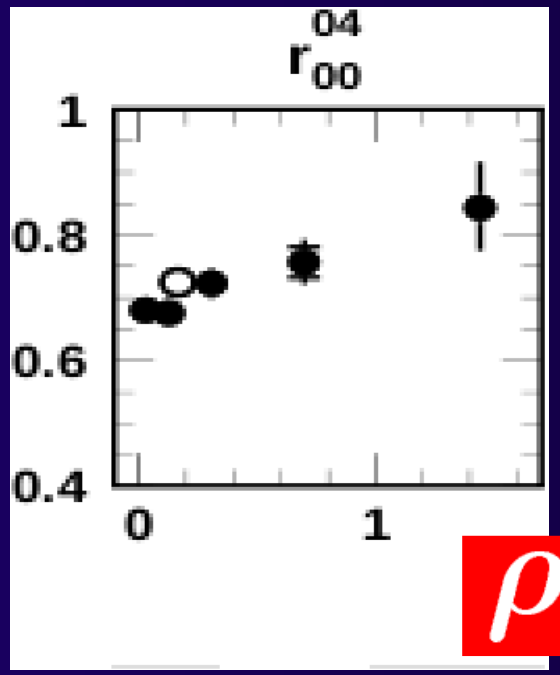
But strong invariant mass dependence in ρ case

r_{00}^{04} vs W and $|t|$

H1 preliminary







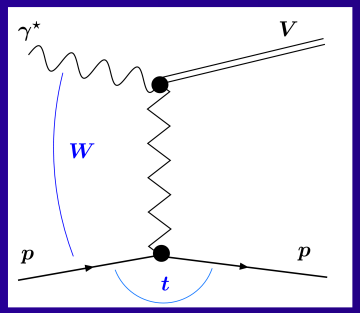
$$r_{00}^{04} = \frac{\sigma_L}{\sigma_L + \sigma_T}$$ assuming SCHC

ZEUS σ_L and σ_T same W and t dependence
suggest that size of $\gamma_L \approx \gamma_T$
large configuration of γ_T suppresed.

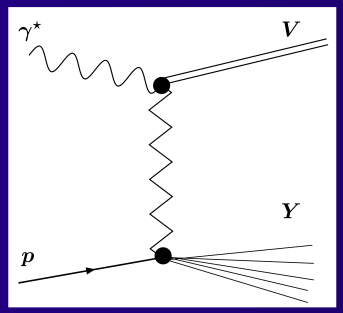
H1 σ_L/σ_T increases with $|t|$, size of $\gamma_L < \gamma_T$

Proton vertex factorization vs Q^2

elastic

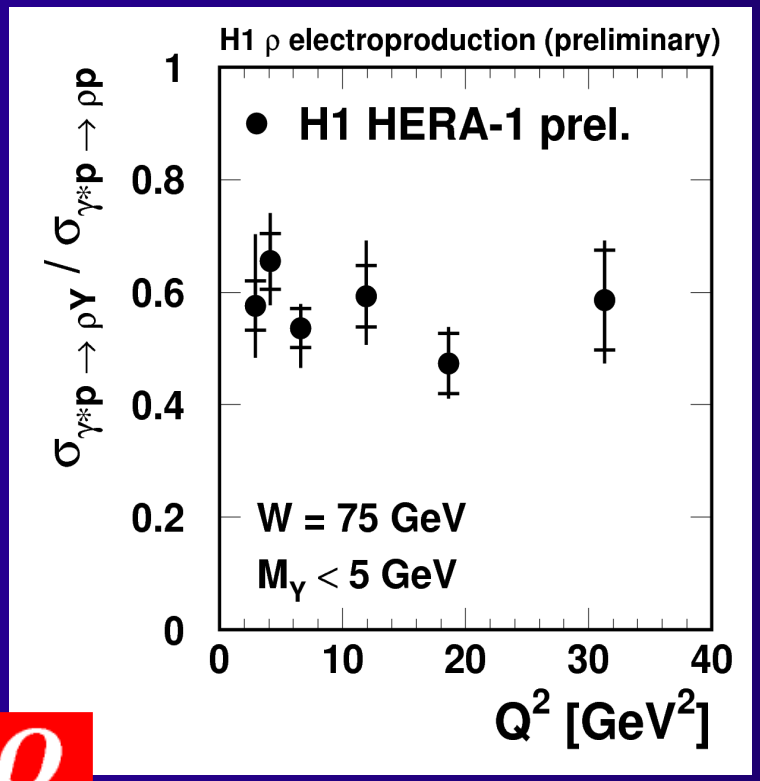


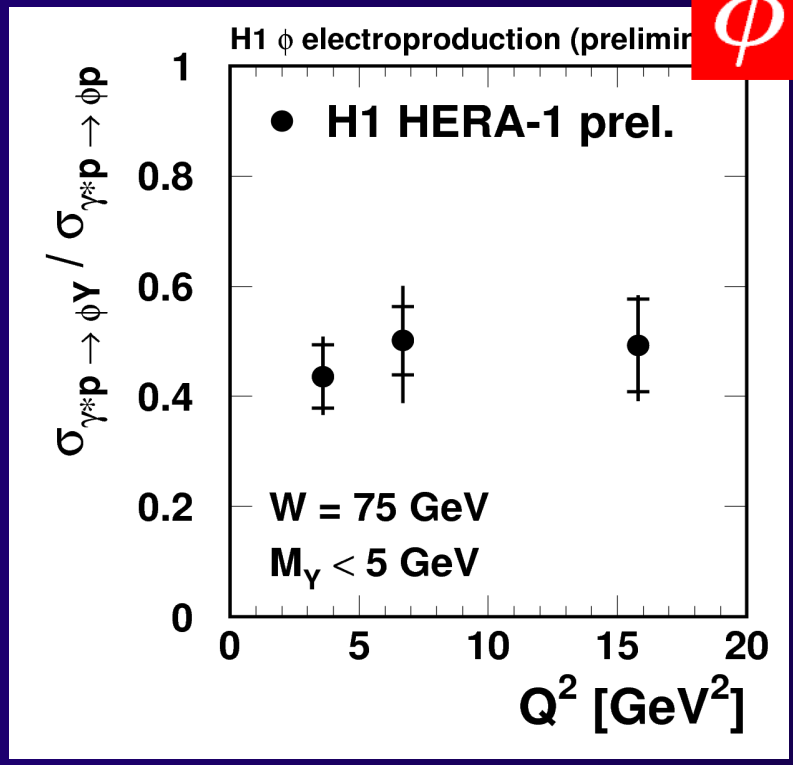
p-dissociation



no dependence on Q^2

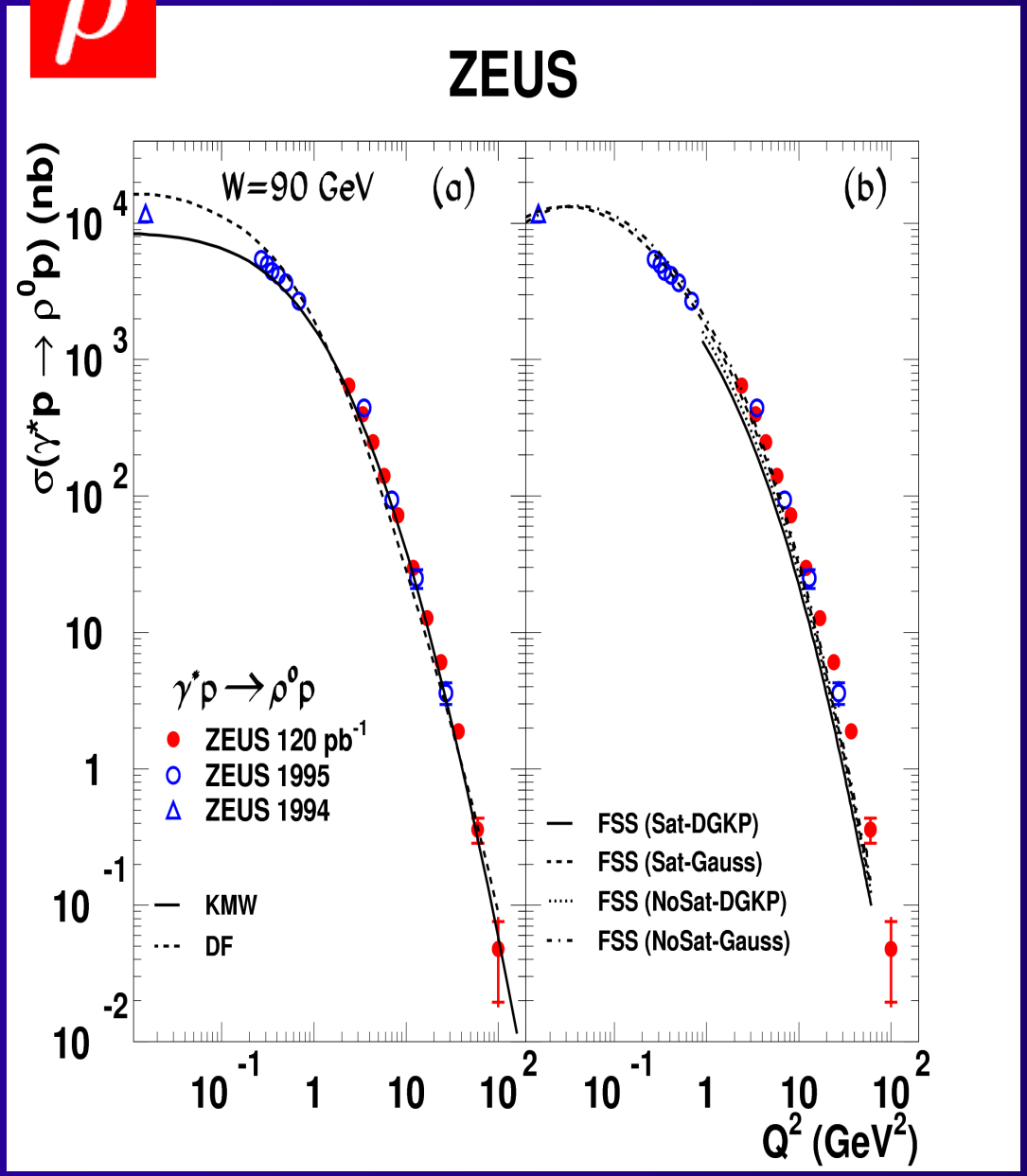
similar ratio for ρ and ϕ

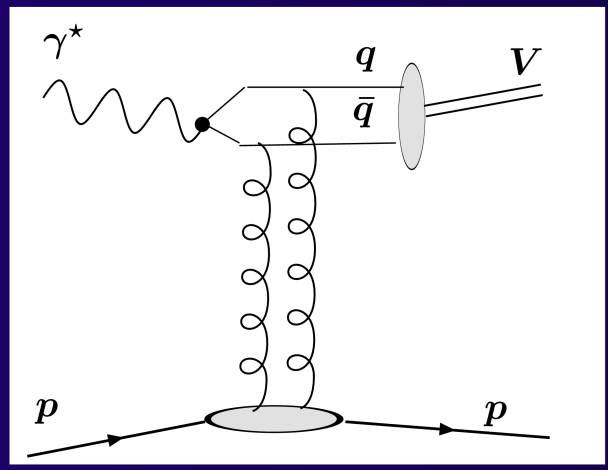




Proton vertex factorization in DIS

Comparison to models $\sigma(Q^2)$



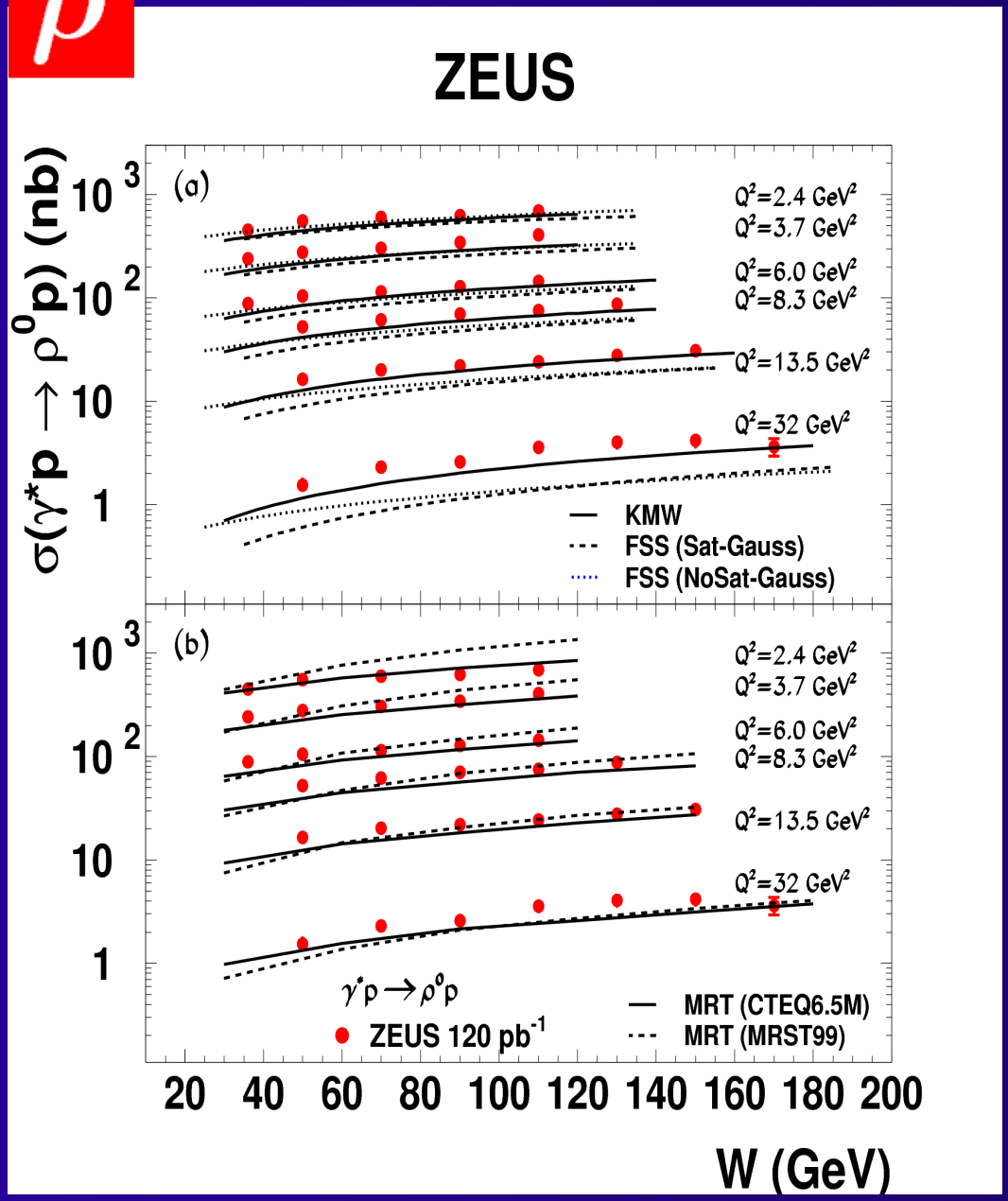


Q^2 dependence sensitive to properties of wave function

KMW(Kowalski,Motyka,Watt) good for $Q^2 > 2\text{GeV}^2$

FSS(Forshaw,Sandapen,Shaw) better gaussian ρ wave function than DGKP

Comparison to models $\sigma(W)$



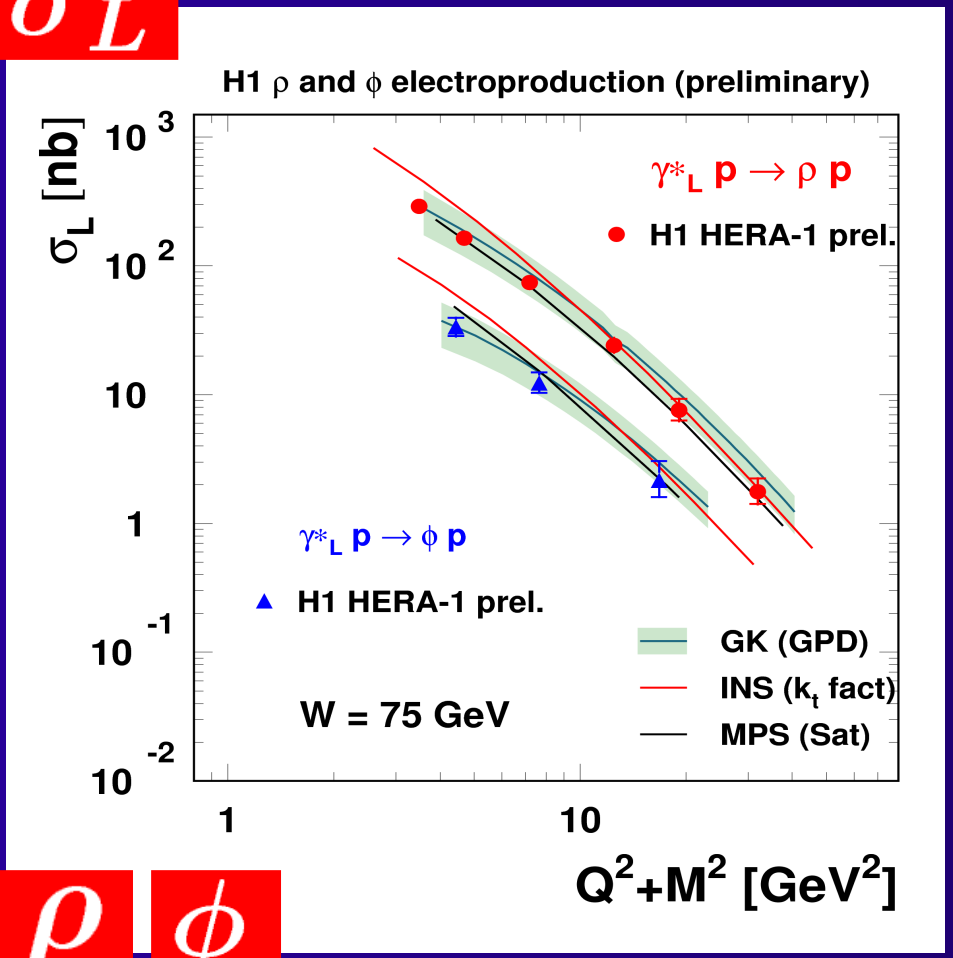
W dependence sensitive to gluon distribution

KMW(Kowalski, Motyka, Watt)
fair description

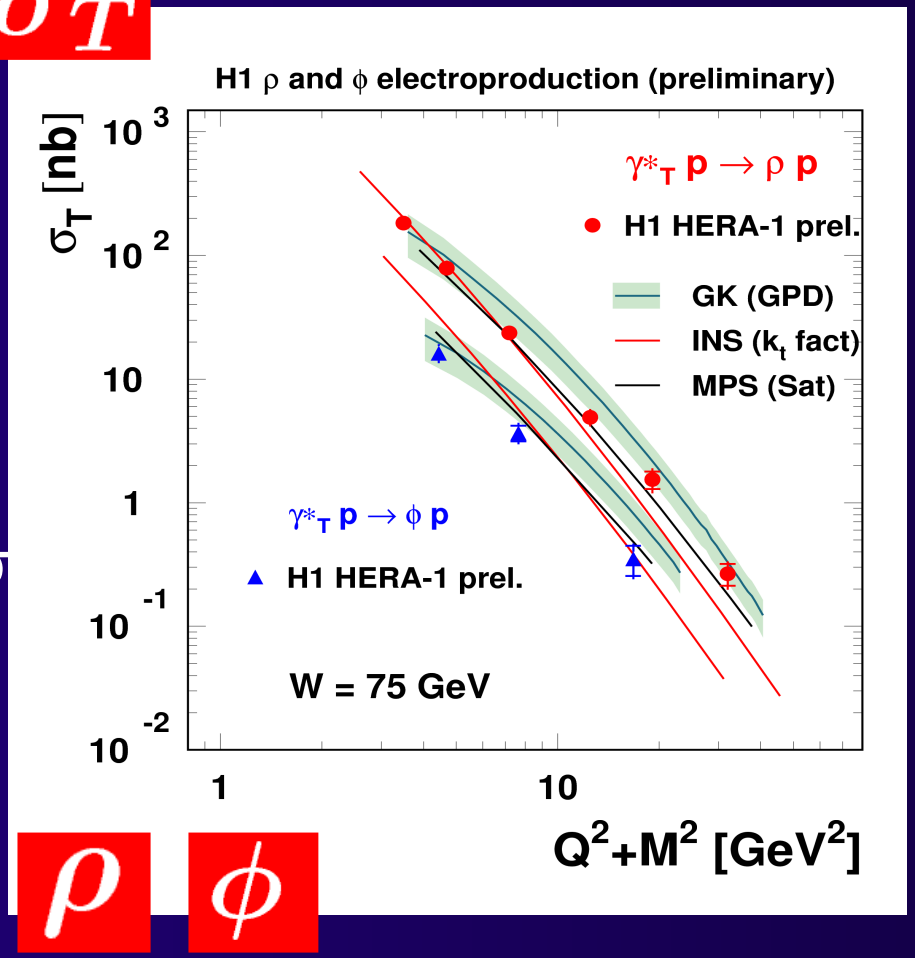
FSS(Forshaw, Sandepen, Shaw)
good W-dependence
wrong normalization

Comparison to models $\sigma_{L,T}(Q^2 + M^2)$

σ_L



σ_T

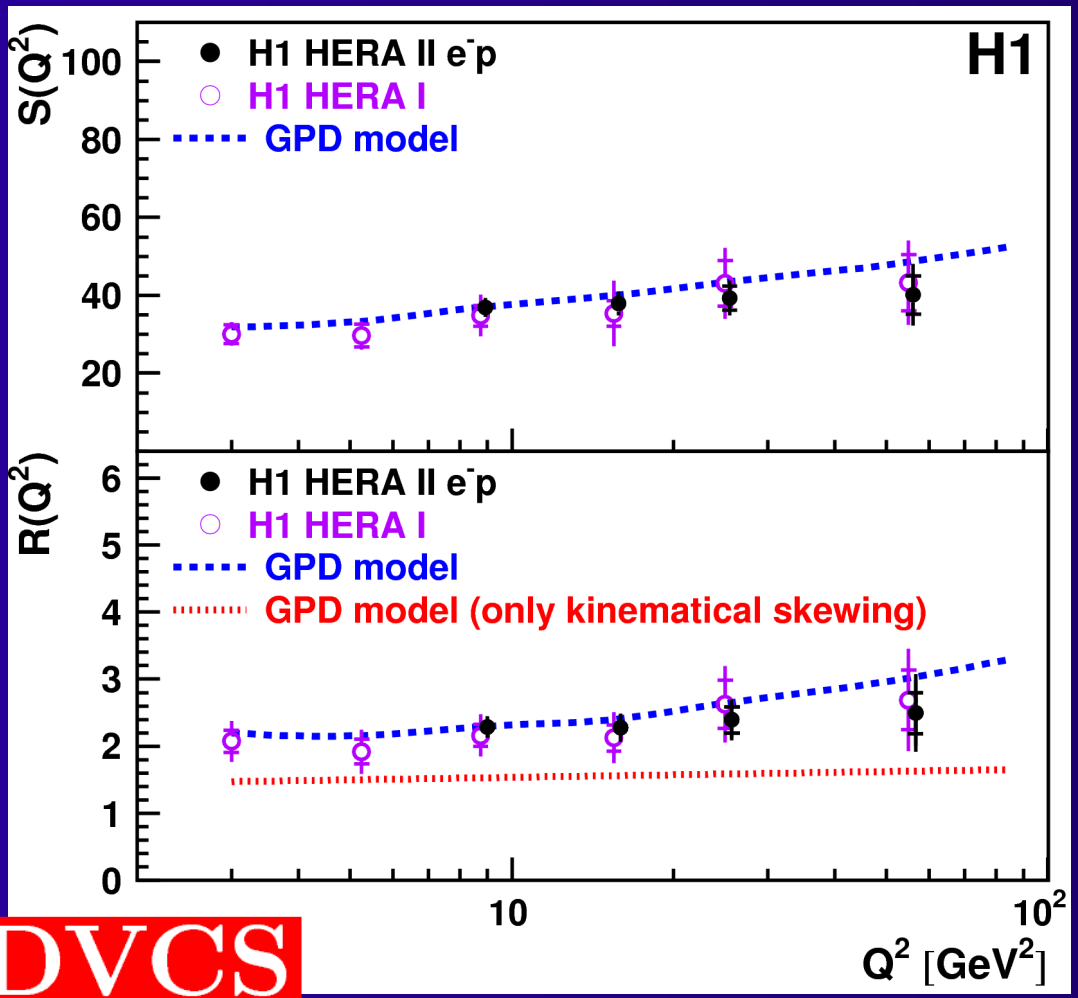


ρ ϕ ρ ϕ

- σ_L and σ_T have different $Q^2 + M^2$ dependence
- pQCD models describe well σ_L but not σ_T

Comparison to models

$$S = \sqrt{\frac{\sigma_{\mathrm{DVCS}} Q^4 b(Q^2)}{1+\rho^2}} \qquad R = \frac{\Im\mathcal{A}(\gamma^\star p \to \gamma p)}{\Im\mathcal{A}(\gamma^\star p \to \gamma^\star p)} = \frac{4\sqrt{\pi} S}{Q^2 \sigma(\gamma^\star p \to X)}$$



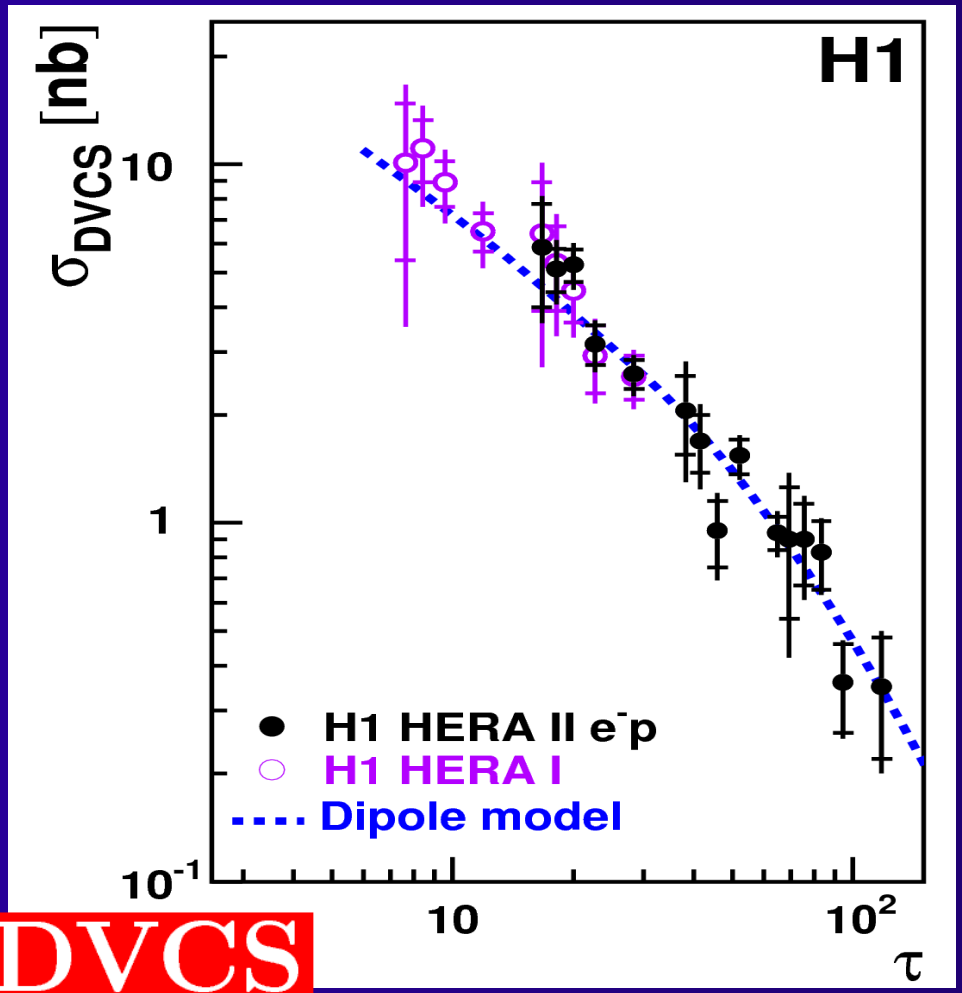
DVCS

- S measures Q^2 evolution of GPD
- R measures the magnitude of skewing effect

GPD - Freund et all

Geometric scaling

Dipole model in saturation regime $\rightarrow$ geometric scaling



$$\sigma(x, Q^2) = \sigma(\tau)$$

$$\tau = Q^2 / Q_s^2(x)$$

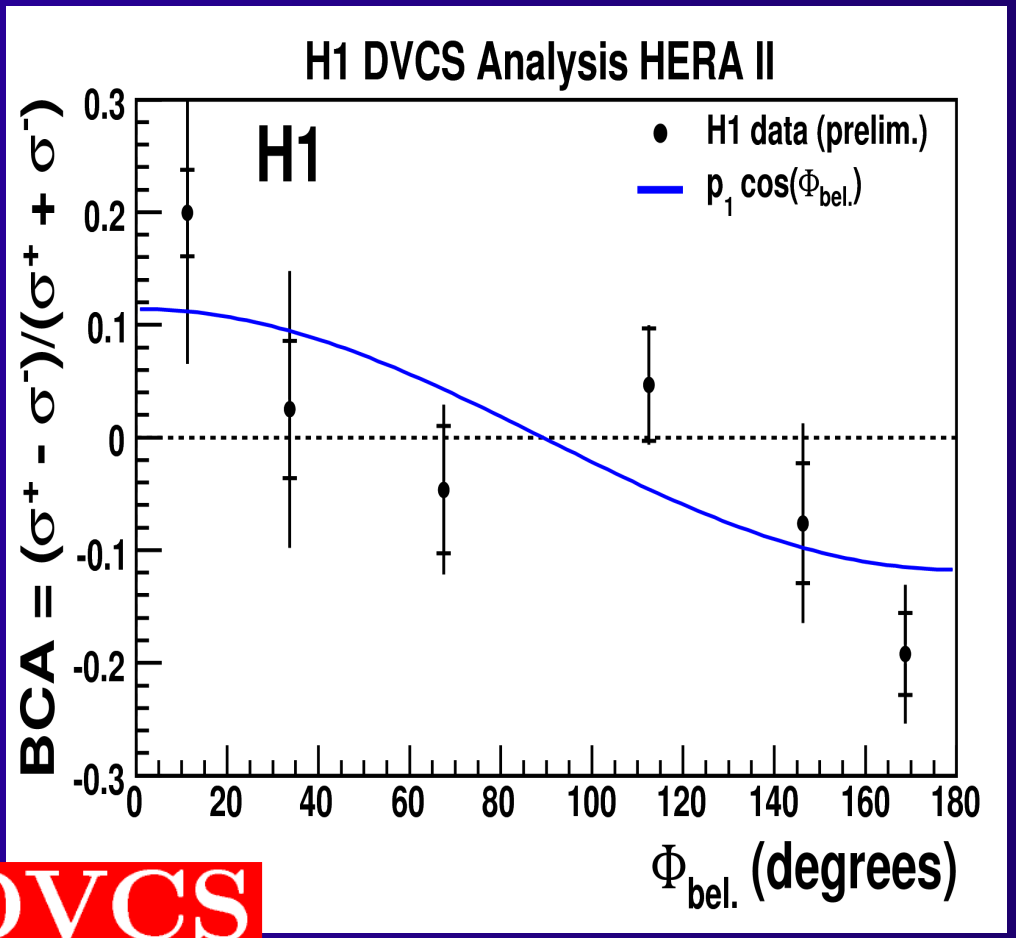
$$Q_s^2(x) = Q_0^2 (x/x_0)^{\lambda}$$

Observed to hold for total DIS cross section as well as for inclusive diffractive DIS cross sec.

Geometric scaling property is verified also for DVCS

Beam Charge Assymetry

DVCS BH



DVCS

$$\sigma^{\pm}(\Phi) = \sigma_{\mathrm{DVCS}} + \sigma_{\mathrm{BH}} \pm \sigma_{\mathrm{Inter.}}$$

$-$ for e^- incoming beam

$+$ for e^+ incoming beam

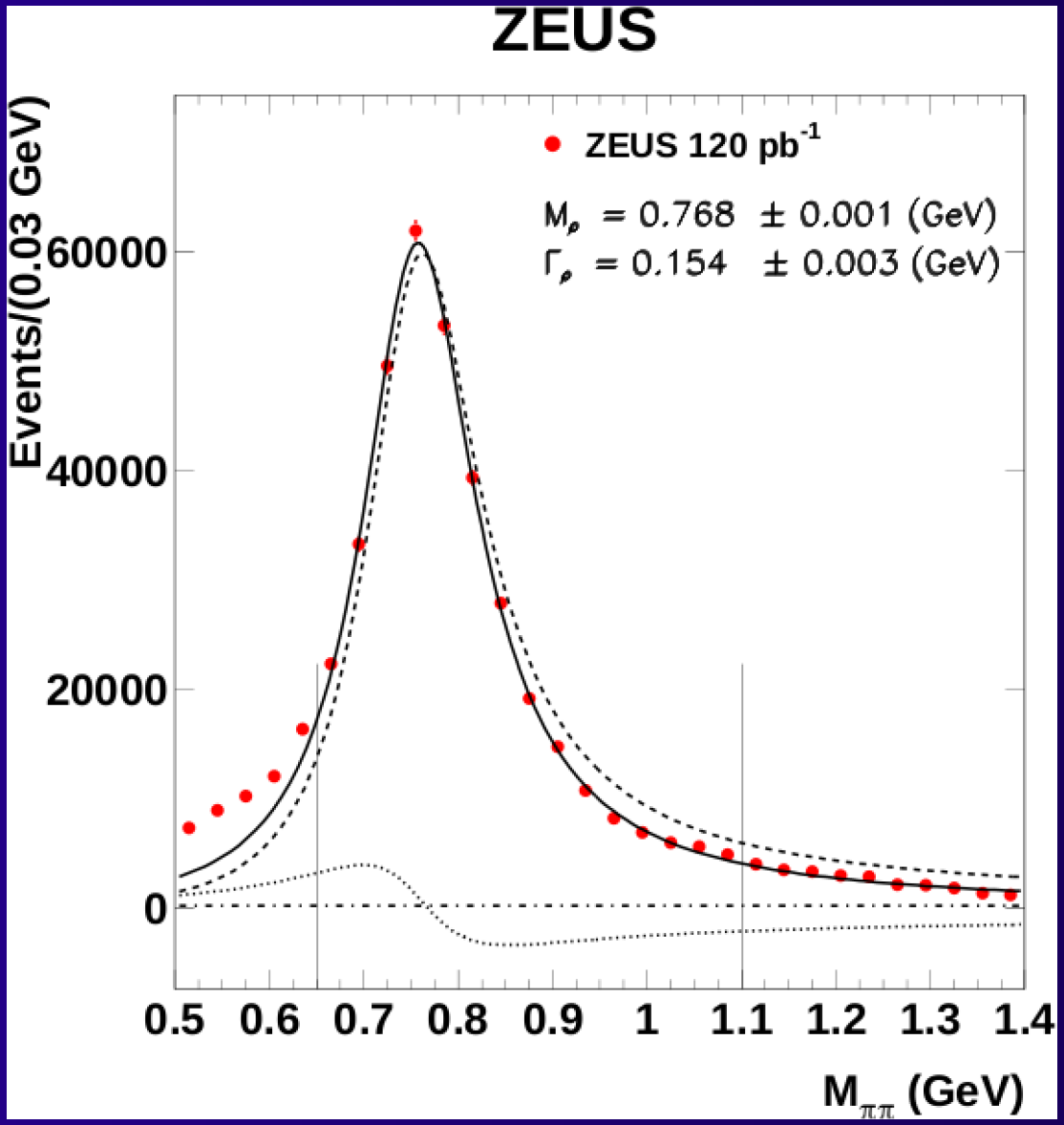
$$p_1 = 0.17 \pm 0.03(\mathrm{stat} \pm 0.05(\mathrm{sys})$$

first measurement GPD's appear linearly in $\sigma_{\mathrm{Inter.}}$

Conclusions

- New high statistics measurements on ρ and ϕ electroproduction and DVCS
- δ and b approximatelly scales in $Q^2 + M^2$ for all VM and DVCS
- All observed features are compatible with pQCD predictions but many quantitative descriptions still lacking
- First measurement of BCA for DVCS by H1 estimates the interference between DVCS and BH

Backup


ZEUS
ZEUS 120 pb-1
Mρ = 0.768 ± 0.001 (GeV)
Γρ = 0.154 ± 0.003 (GeV)
Events/(0.03 GeV)
60000
40000
20000
0
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
Mππ (GeV)