Diffractive Vector Meson Production and DVCS at HERA

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On Behalf of the H1 and ZEUS Collaborations

Workshop on Low-x Physics

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The HERA ep Collider

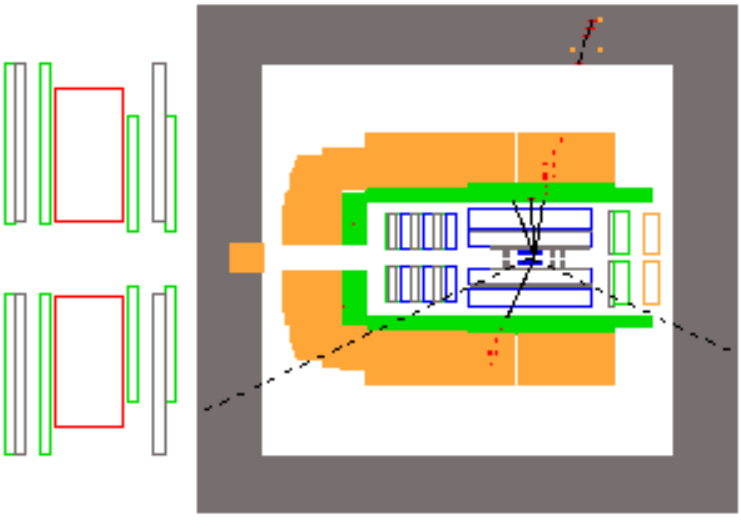
$e^{\pm} \Rightarrow \sqrt{s} = 300/320\,\text{GeV} \Leftarrow p$

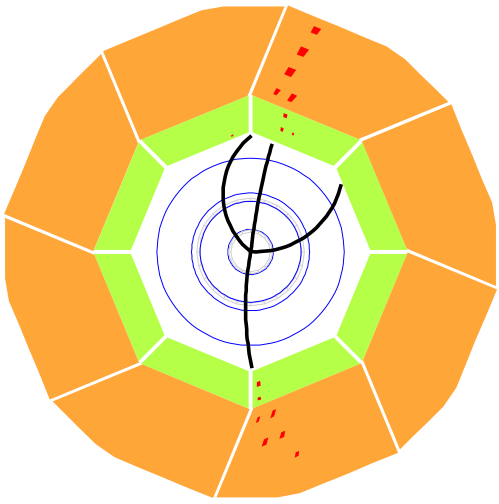
27.5 GeV 820/920 GeV

- HERA-I provided $\sim 130\,\text{pb}^{-1}$ (> 1994)
- About $68\,\text{pb}^{-1}$ after mid-1999

H1 and ZEUS Detectors:

4 Identified Tracks, No Forward Activity.





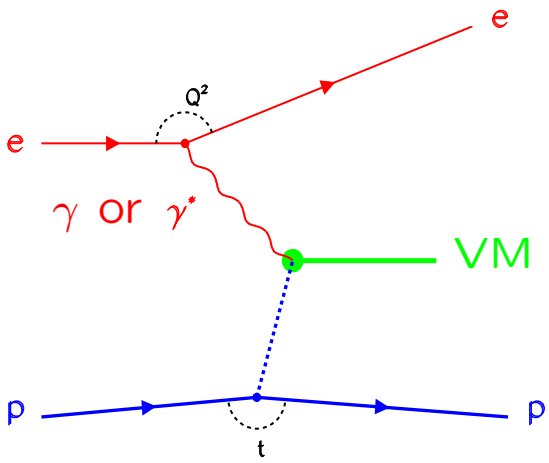
$\psi(2S) \longrightarrow J/\psi\,\pi^+\pi^-$

$\hookrightarrow \mu^+\mu^-$

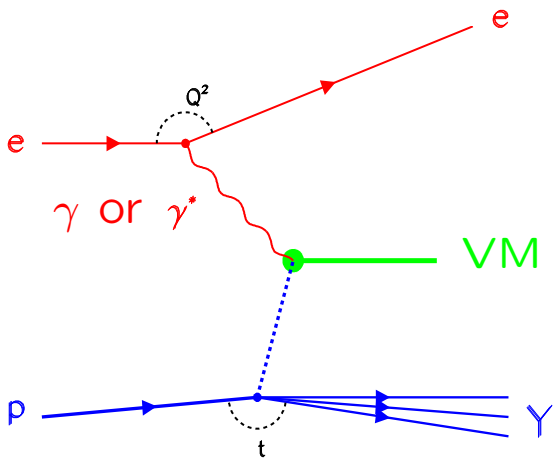
Events Distinguished using Forward Detectors
- Forward Tagged $\sim$ Proton Dissociative
- Forward Untagged $\sim$ Proton Elastic

Diffractive Vector Meson Production at HERA

proton elastic



proton dissociative



Q^2	γ^* Virtuality	$\sim 0 < Q^2 < 100\,\mathrm{GeV}^2$
$W_{\gamma p}$	CM Energy of $\gamma^* p$ system	$20 < W_{\gamma p} < 290\,\mathrm{GeV}$
t	(4-mom. transfer at p vertex)^2	$\sim 0 < \lvert t \rvert < 20\,\mathrm{GeV}^2$
VM	Vector Meson	$\rho^0,\ \omega,\ \phi,\ J/\psi,\ \psi',\ \Upsilon$

$\Rightarrow$ Simultaneous Probe of Different Kinematical Quantities.

pQCD and the Pomeron

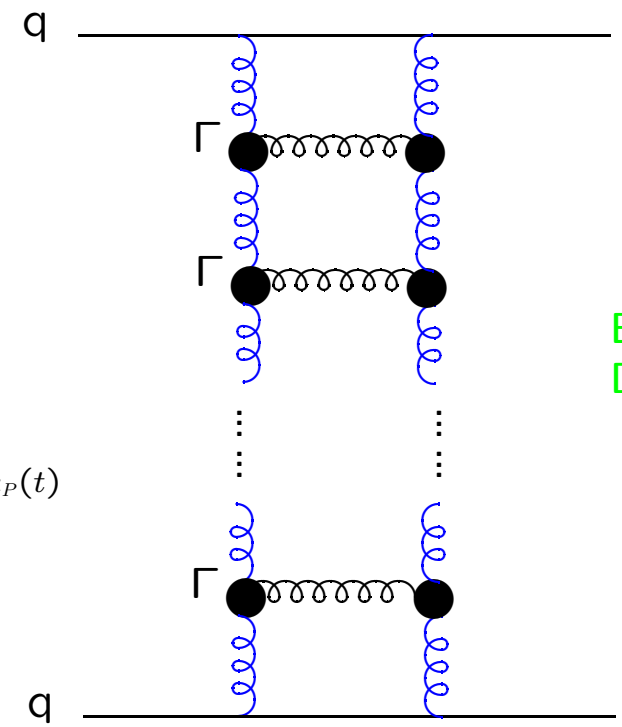
BFKL Formulism

Perturbative series in α_s

Reggeized Gluon Ladder

BFKL iteration adds a rung to the ladder

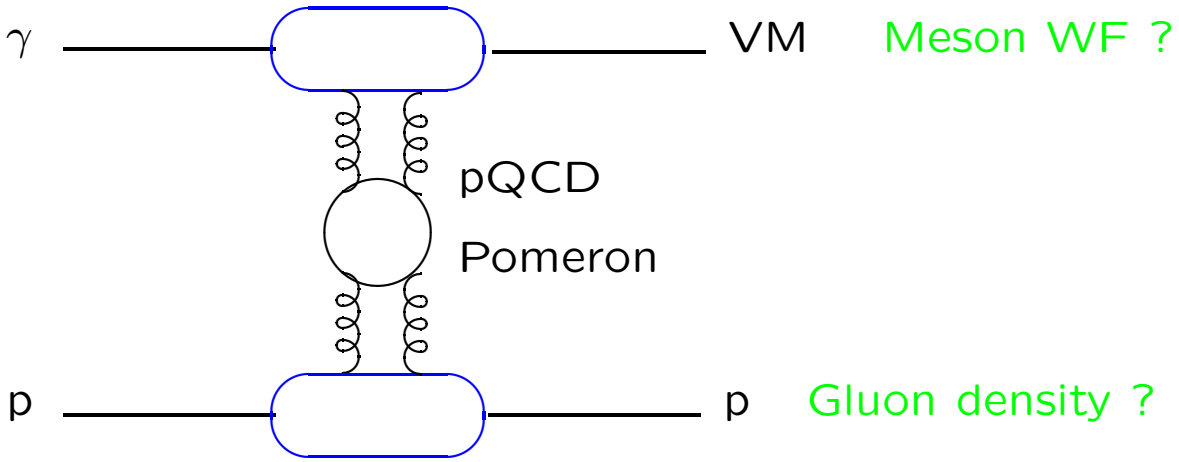
Scattering Amplitude $\sim s^{\alpha_P(t)}$
where $\alpha_P(t) = 1 + 4\bar{\alpha}_s \; ln2$



Effective Diagram

Diffractive VM Production:

Need Impact Factors



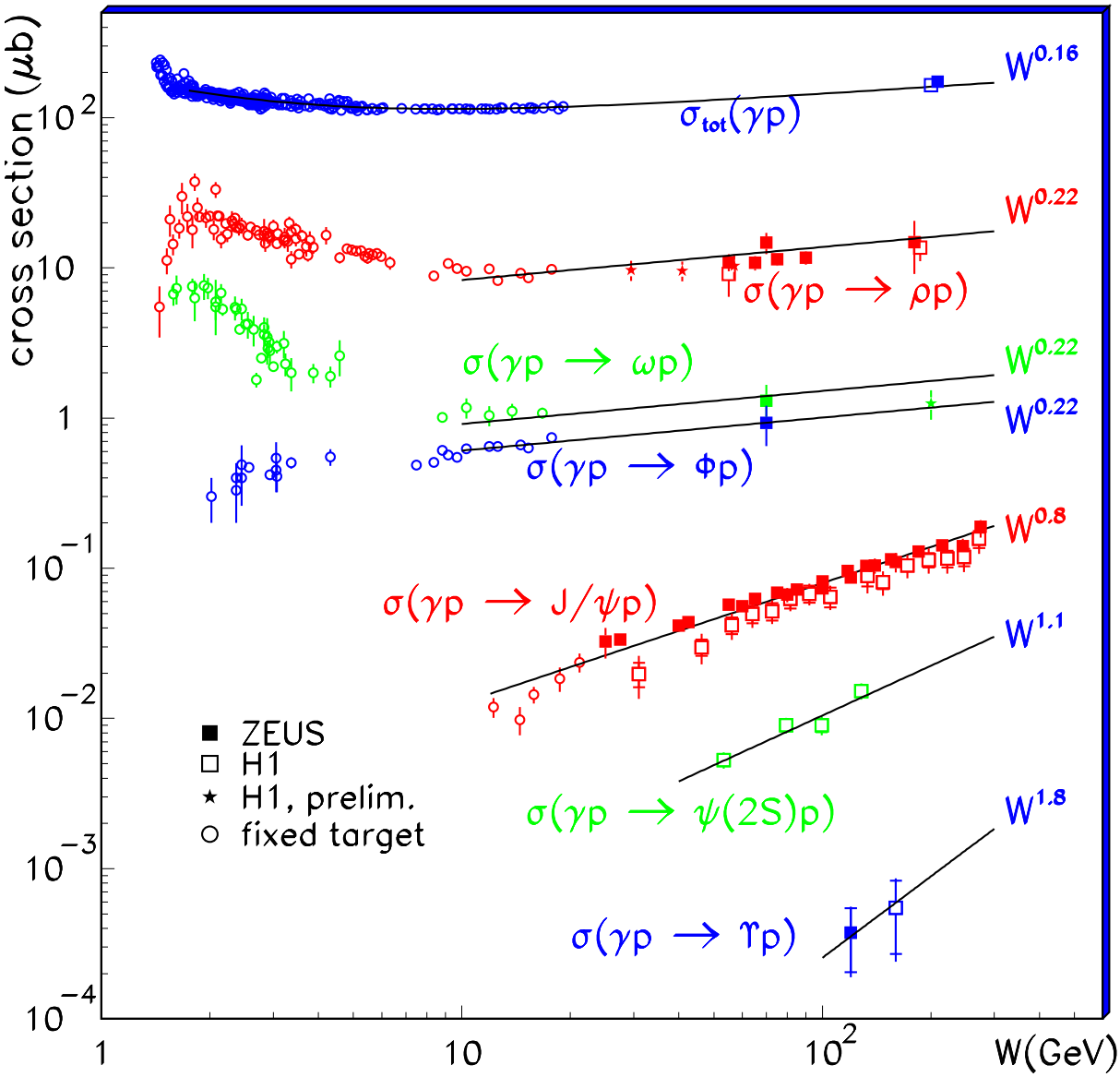
Meson WF ?

Gluon density ?

Need hard scale $\rightarrow$ $|t|$,Q^2,M_V^2

Elastic Photoproduction $\gamma\, p \longrightarrow V\, p$

$Q^2 \approx 0$, $|t| \approx 0$ $\Rightarrow M_{\mathrm{VM}}$ provides hard scale



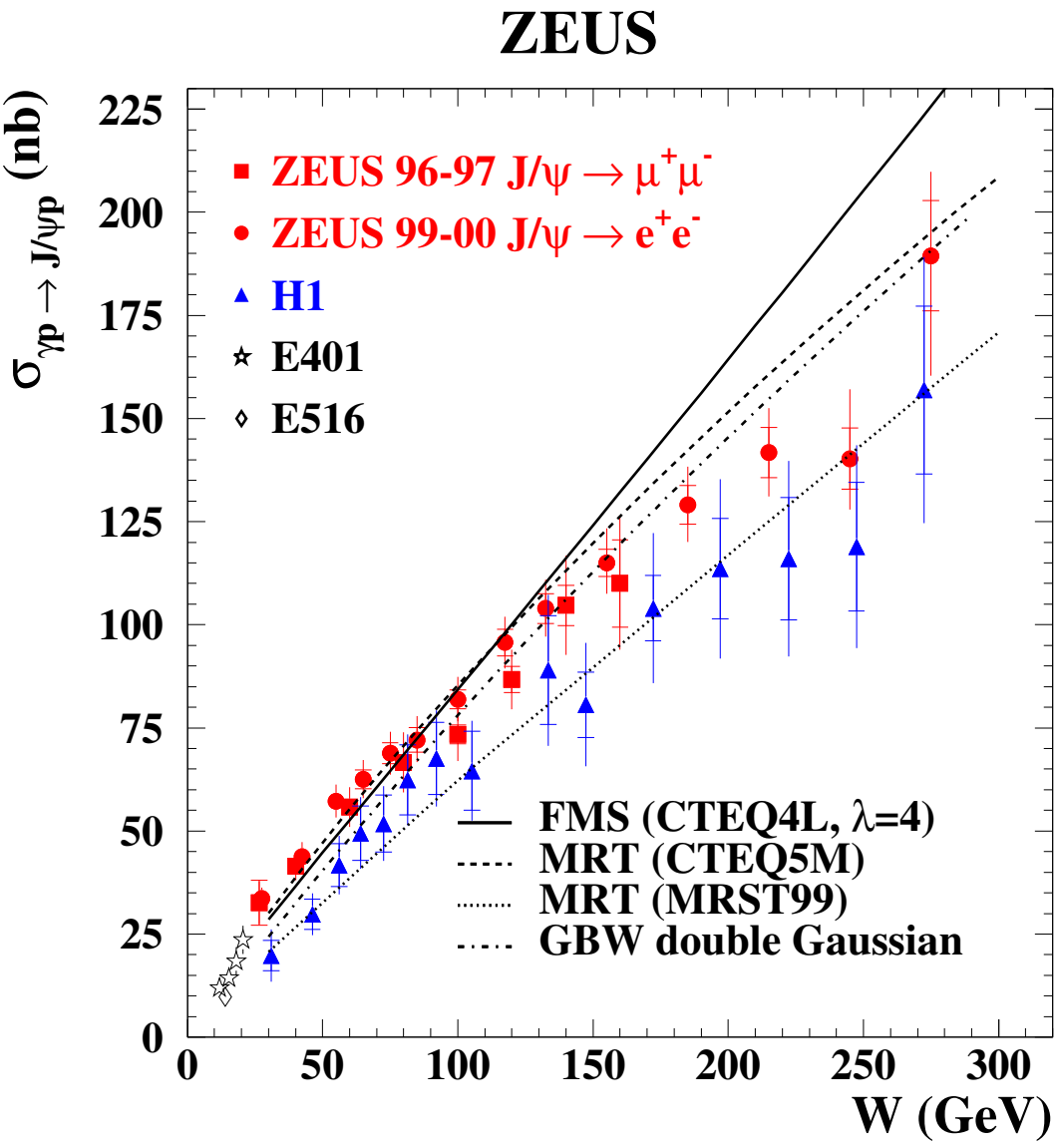
$\Rightarrow$ Steeper rise in the J/ψ cross section

Elastic Photoproduction $\gamma p \to J/\psi p$

ZEUS Collaboration

$Q^2 < 1\,\mathrm{GeV}^2$ $\quad 38\,\mathrm{pb}^{-1}$ $(J/\psi \to \mu^+\mu^-)$

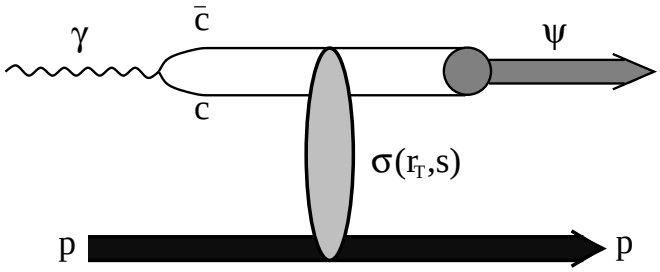
$20 < W_{\gamma p} < 290\,\mathrm{GeV}$ $\quad 55\,\mathrm{pb}^{-1}$ $(J/\psi \to e^+e^-)$



• pQCD predictions: sensitive to the gluon density:

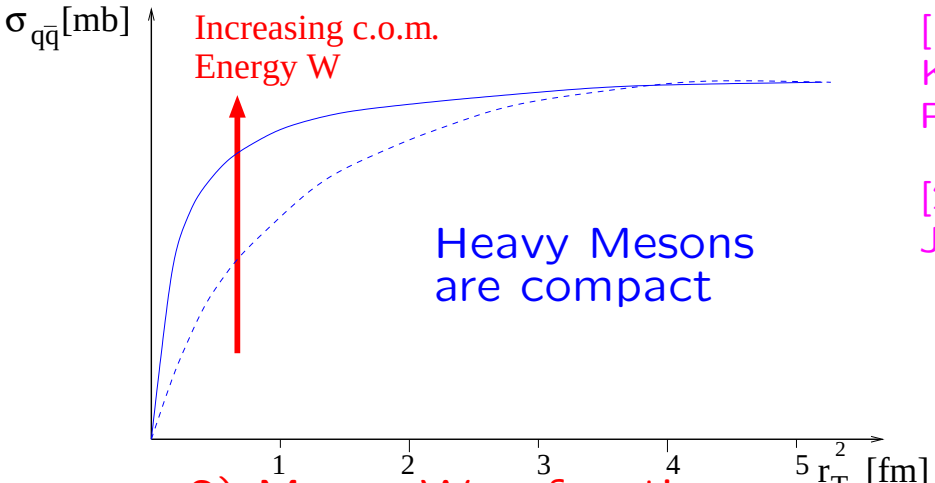
$$\sigma \propto [xg(x, Q^2)]^2$$

Diffractive $\psi(2S)$ Production in the Colour Dipole Model



1) Total Dipole Cross Section

- Depends on $q\bar{q}$ separation and $s = W^2_{\gamma p}$



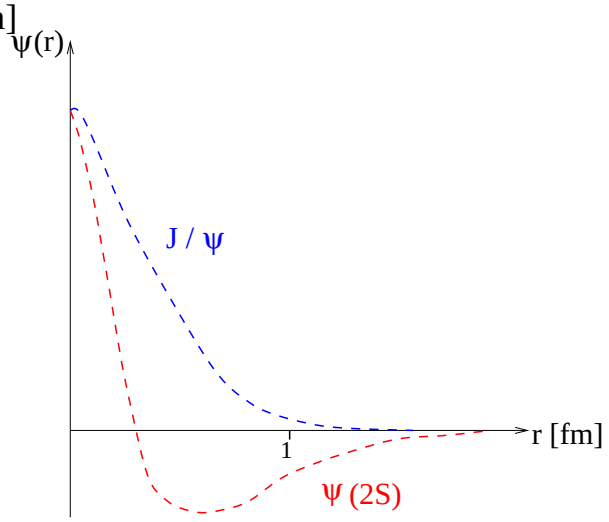
[1] Hüfner, Y.P.Ivanov, Kopeliovich et al., Phys.Rev. D62(2000)

[2] Nemchik et al., J.Exp.Theor. 86(1998)

2) Meson Wavefunction

- First radial excitation $\psi(2S)$ differs from J/ψ:

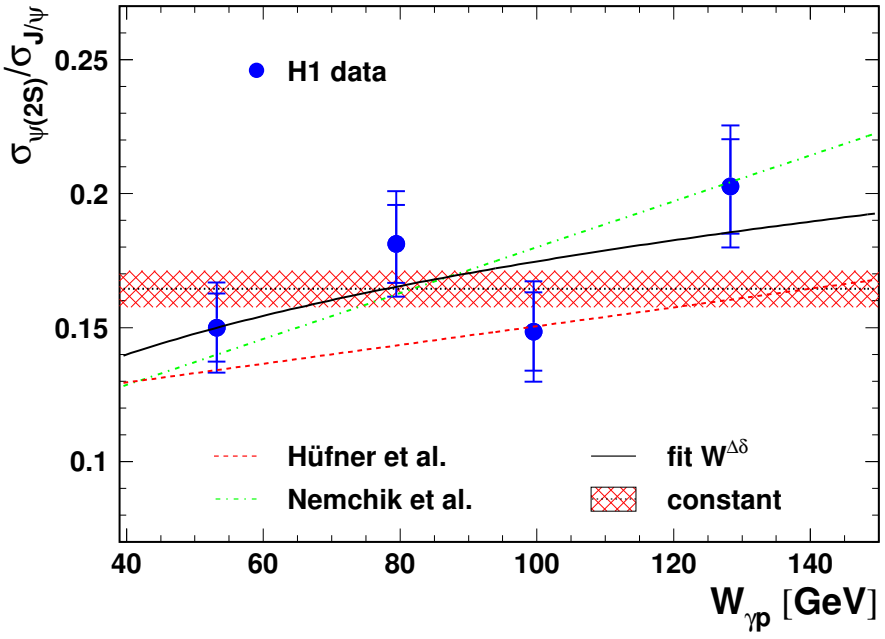
a) ⟨radius⟩ larger than J/ψ
b) Wavefunction has a node



$\Rightarrow$ $\psi(2S)$ production suppressed
$\Rightarrow$ slightly steeper rise in $W_{\gamma p}$
$\Rightarrow$ $|t|$ dependence : $\exp(-b|t|)$: $b_{\psi(2S)} \lesssim b_{J/\psi}$

Diffractive $\psi(2S)$ Photoproduction

- Measured Ratio (proton elastic + dissociative)



H1 Result

$Q^2 < 1\,\text{GeV}^2$

$40 < W_{\gamma p} < 150\,\text{GeV}$

$77\,\text{pb}^{-1}$

$z > 0.95$ (p-diss. events)

2 Prong Events:

$\psi(2S) \to l^+l^-$

4 Prong Events (Cascade Decays):

$\psi(2S) \to (J/\psi \to l^+l^-)\pi^+\pi^-$

- Average Ratio:

$\langle R \rangle = 0.166 \pm 0.007(stat.) \pm 0.008(sys.) \pm 0.007(BR)$

$\Rightarrow$ Agreement with previous measurements (H1/ZEUS)

- Fit $\sim W_{\gamma p}^{\Delta\delta}$ where $\Delta\delta$ rise relative to the J/ψ;

$$\Delta\delta = 0.24 \pm 0.17$$

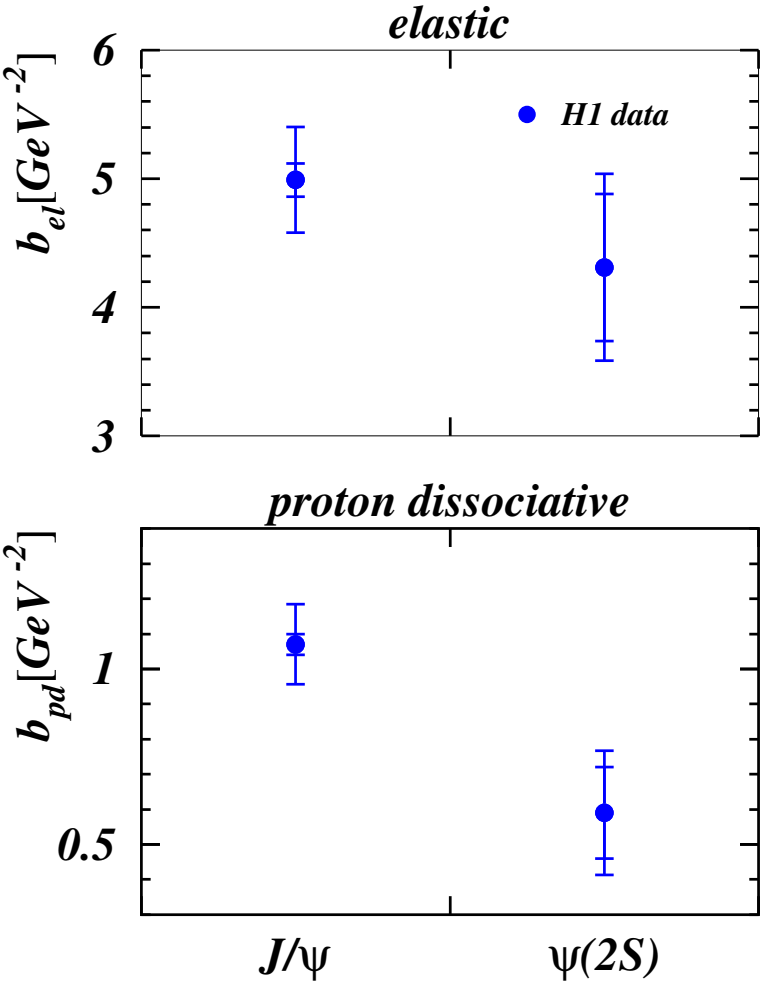
$\Rightarrow$ $\sigma_{\psi(2S)}$ similar / possibly steeper than $\sigma_{J/\psi}$
$\Rightarrow$ Colour Dipole Models can reproduce ratio

Diffractive $\psi(2S)$ Photoproduction

- Elastic and proton-dissociative b-slopes

$\Rightarrow$ Two slopes extracted from two samples (Forward Tagged and Forward Untagged)

$\Rightarrow$ Iterative Procedure is used: Fit $\sim A\exp(-b|t|)$



- Measured elastic and proton-diss. b-slopes;

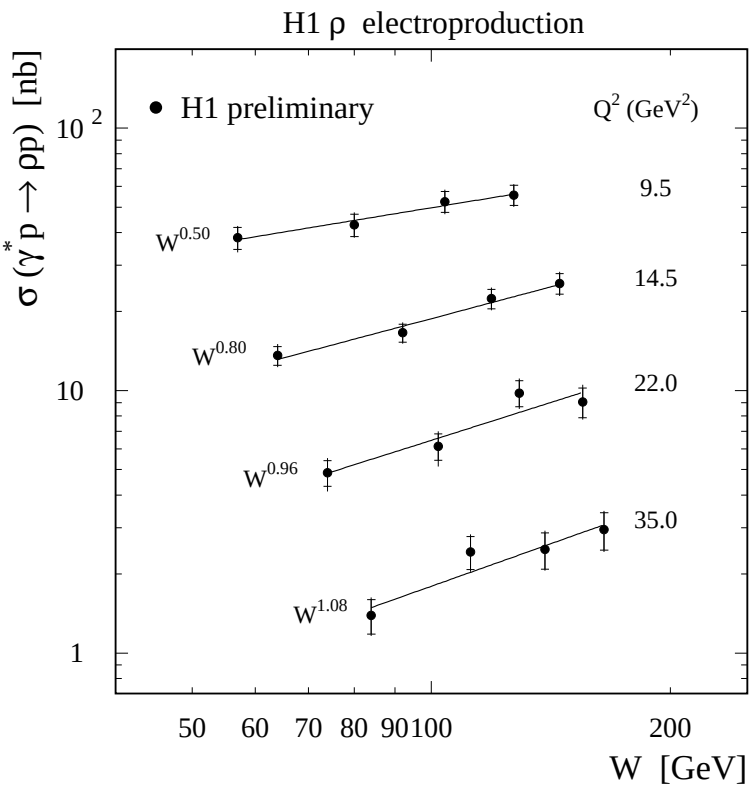
$\gamma p \to \psi(2S)p \quad b_{el}^{\psi(2S)} = (4.31 \pm 0.57 \pm 0.45)\,\text{GeV}^{-2}$

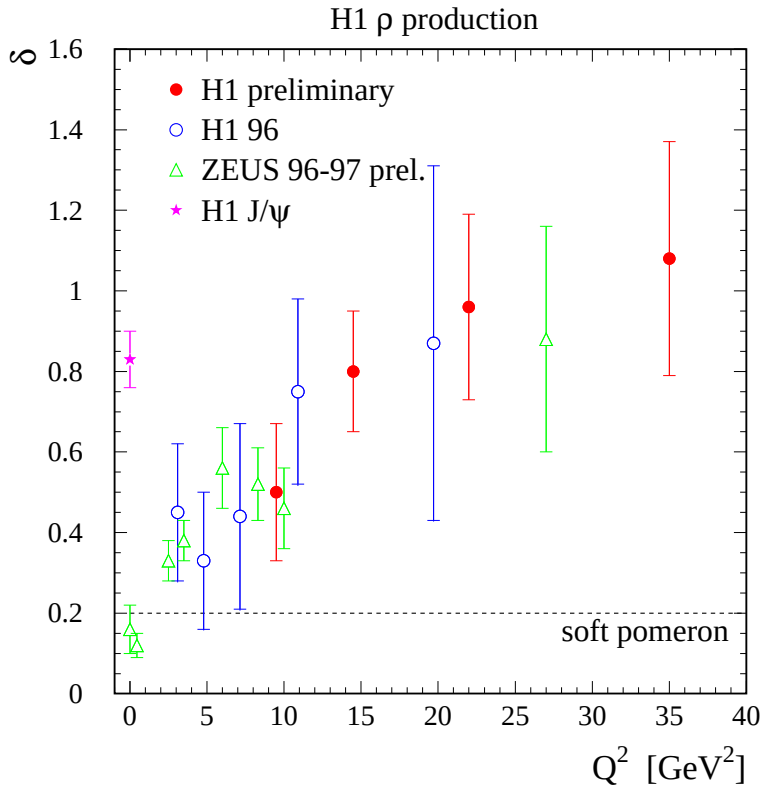
$\gamma p \to \psi(2S)Y \quad b_{pd}^{\psi(2S)} = (0.59 \pm 0.13 \pm 0.12)\,\text{GeV}^{-2}$

- Elastic $\psi(2S)$ and J/ψ: as expected in CDM
- Proton Diss.; No Proton Form Factor

Elastic Electroproduction $\gamma^* p \to \rho p$

$|t| \approx 0$, Allow Q^2 to become large
$\Rightarrow$ squeeze the transverse size of the $q\bar{q}$ pair





H1 Collaboration.

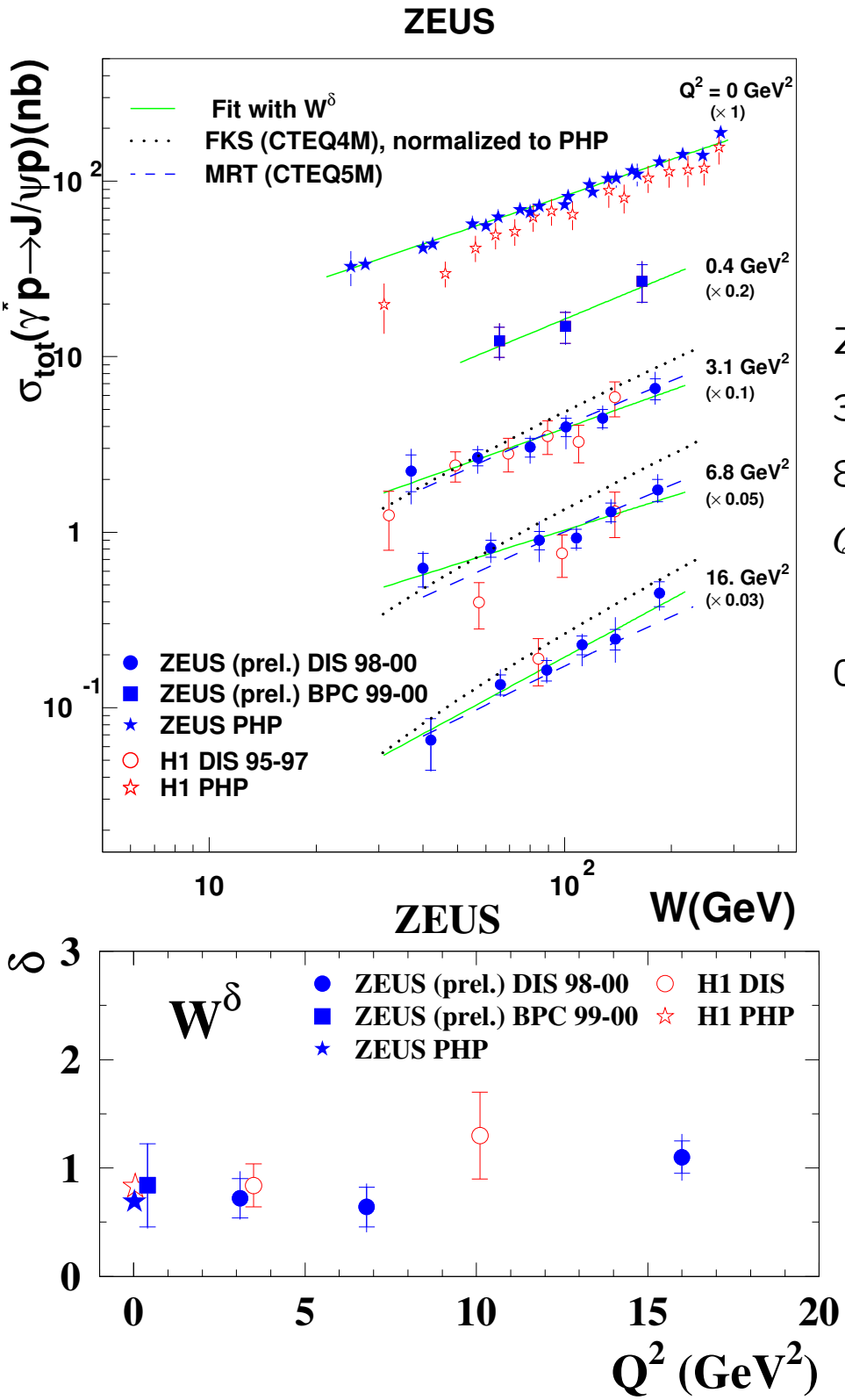
$40 < W_{\gamma p} < 180\,\text{GeV}$, $Q^2 > 2\,\text{GeV}^2$
$42\,\text{pb}^{-1}$, $|t| < 0.5\,\text{GeV}^2$

- The $W_{\gamma p}$ dependence of lighter vector mesons evolve as a function of Q^2

- For large enough Q^2:

$\Rightarrow$ behave as heavy vector mesons at $Q^2 \approx 0$

Elastic Electroproduction $\gamma^* p \to J/\psi\, p$



ZEUS Collaboration

$30 < W_{\gamma p} < 220$ GeV

82 pb^{-1}

$Q^2 > 2$ GeV^2:

$J/\psi \to l^+ l^-$

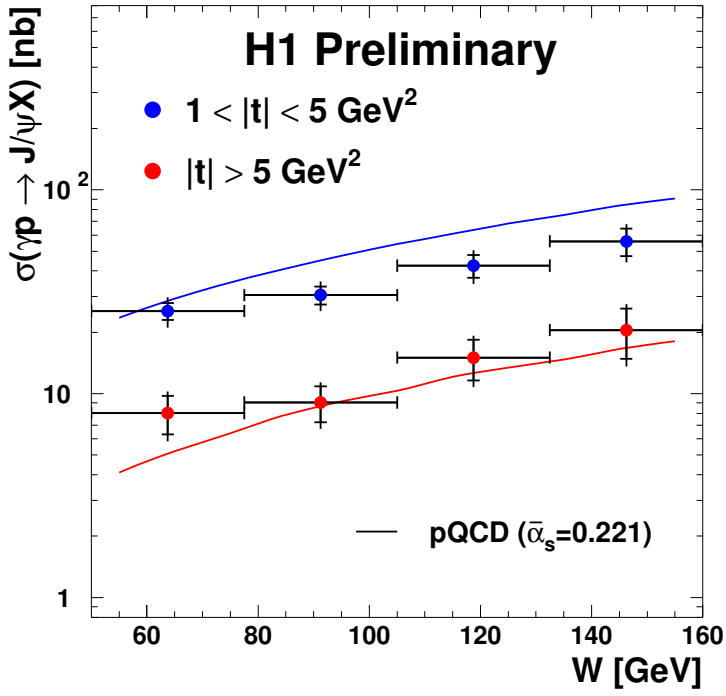
$0.15 < Q^2 < 0.8$ GeV^2 :

$J/\psi \to e^+ e^-$

- No Strong Variation in $\sigma(W)$ as a Function of Q^2

Heavy vector mesons: J/ψ production at Large $|t|$

- Squeeze transverse size of the BFKL pomeron
- Similar rise ($\delta \sim 1$) as for J/ψ at low $|t|$



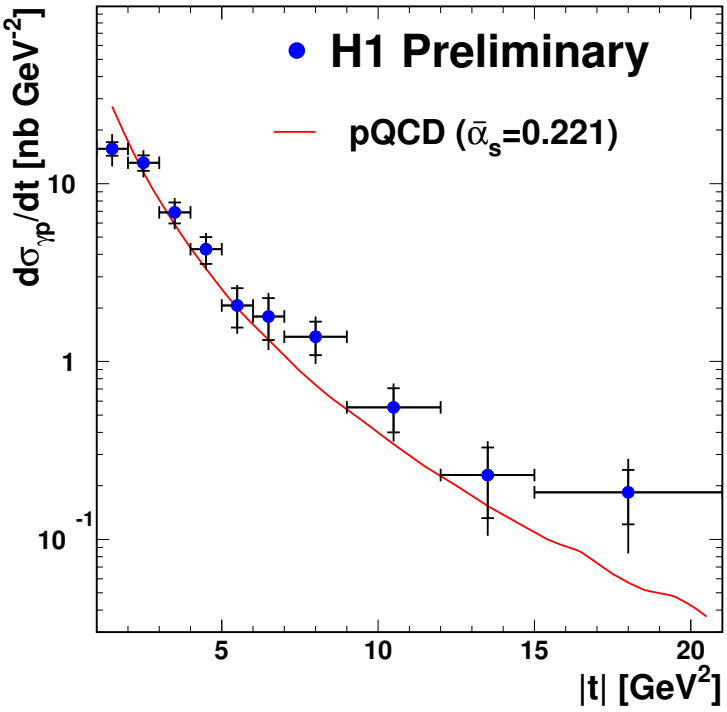
H1 Collaboration

$Q^2 < 1\,\text{GeV}^2$

$50 < W < 160\,\text{GeV}$

$19\,\text{pb}^{-1}$

$1.0 < |t| < 21.0\,\text{GeV}^2$



[1] Forshaw and Ryskin, Z. Phys.C68 (1995) 137-148

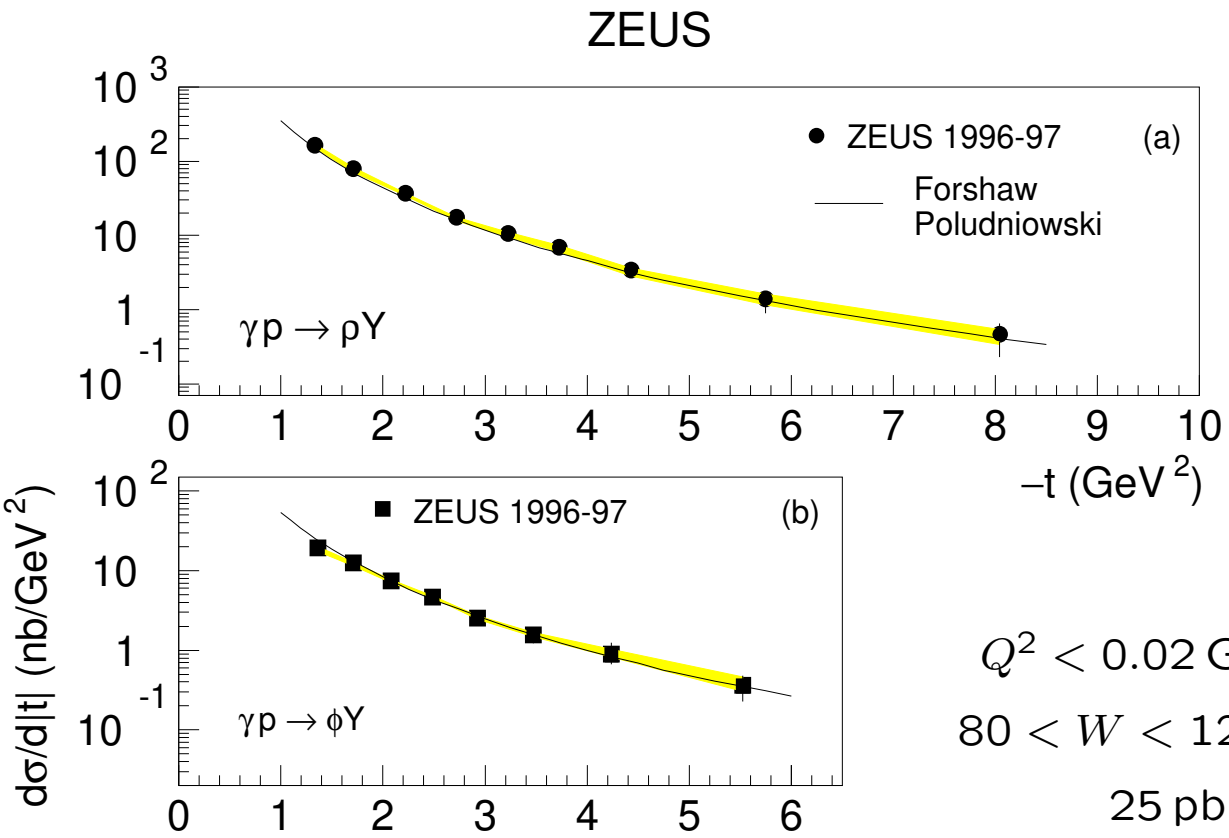
[2] Bartels, Forshaw, Lotter, Wüsthoff, Phys.Lett.B375 (1996) 301-309

HERA explores $z \sim \bar{\alpha}_s \ln(xW^2/\Lambda^2)$ in the region 0.1 - 1.0

$\Rightarrow$ BFKL Model ($\bar{\alpha}_s \sim 0.2$) describes behaviour

Light Vector Meson Production at High $|t|$

Proton dissociative photoproduction of ρ, ϕ



$Q^2 < 0.02\,\mathrm{GeV}^2$

$80 < W < 120\,\mathrm{GeV}$

$25\,\mathrm{pb}^{-1}$

J.R. Forshaw, G. Poludniowski, preprint hep-ph/0107068,2001

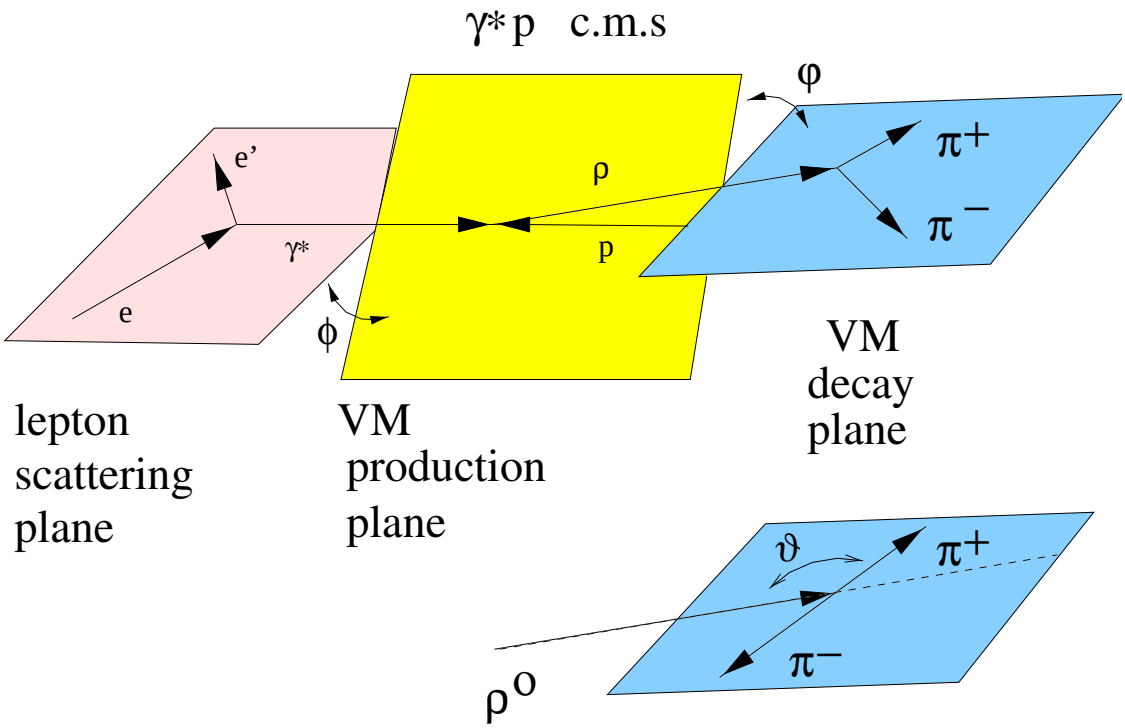
- How sensitive is large $|t|$ region to meson WF?

Try heavy meson wavefunction
$\rightarrow$ Good description of data

- At large $|t|$, correction for WF small (?)

Helicity Studies

Define three angles in the Helicity system



Normalised decay angular distribution (W) is a function of $\cos(\vartheta), \varphi, \Phi$

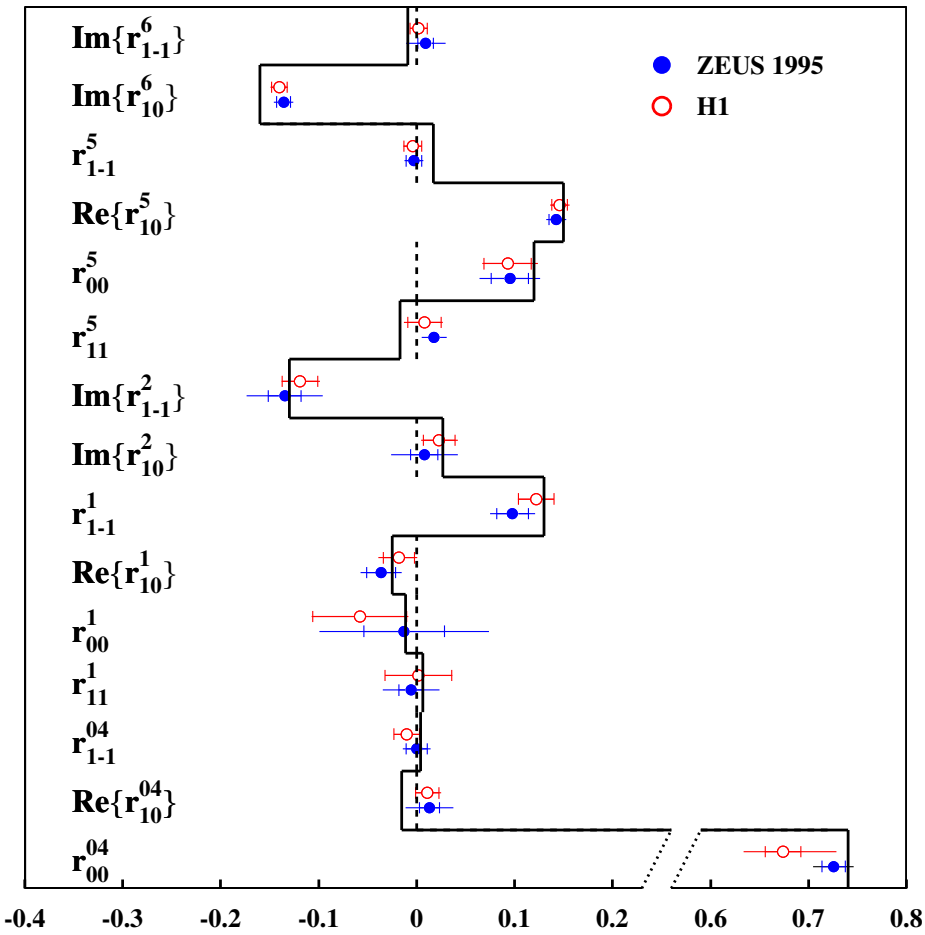
Written as a function of 15 independent linear combinations (r) of spin density matrix elements

For: SCHC, NPE:

expect 5 combinations to be non-zero.

Elastic Electroproduction $\gamma^* p \to \rho p$

Combinations of spin density matrix elements



r^5_{00}: $\to$ Production of Longit. Pol. Vector Meson

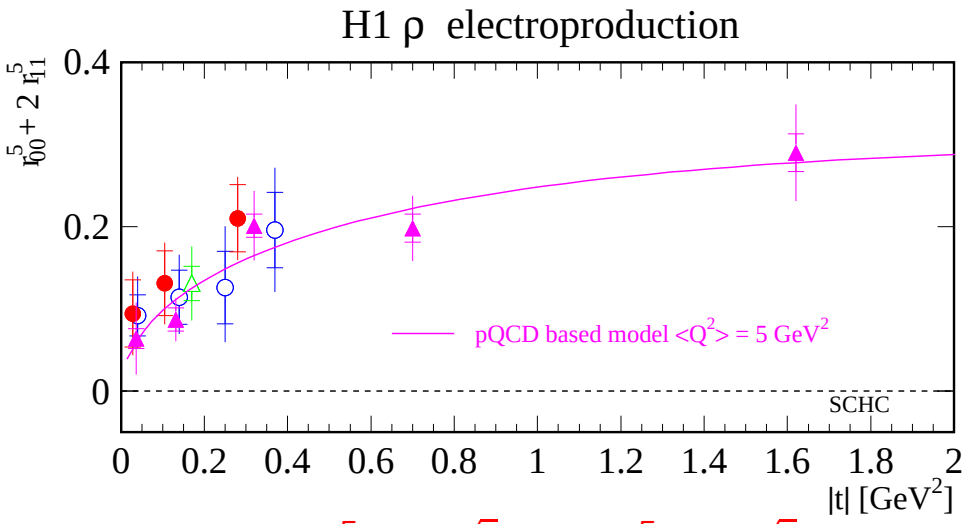
D.Yu.Ivanov,R.Kirschner Phys. Rev. D58 (1998) 114026

- pQCD model (solid line) predicts violation
- Wavefunction considers momentum distribution of quarks in meson.

Electroproduction of ρ at high $|t|$

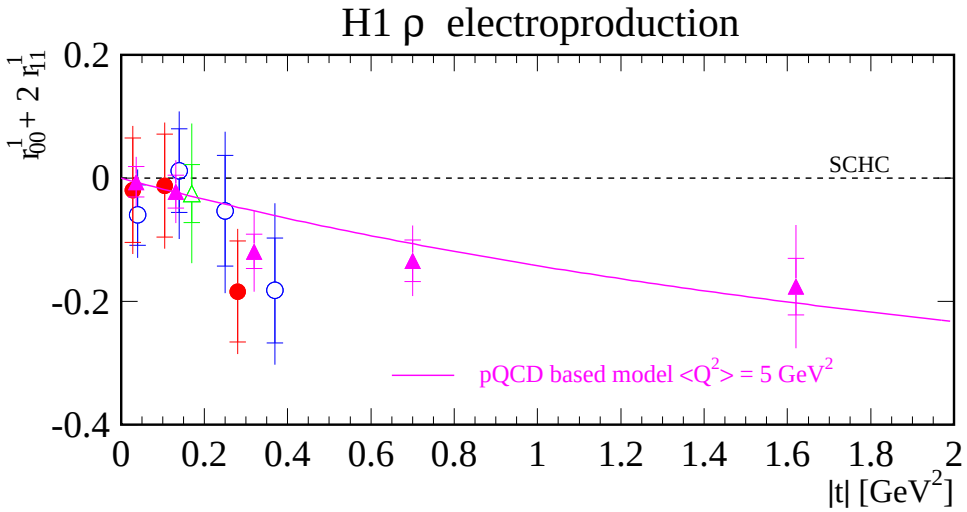
H1 Measurement:

$2.5 < Q^2 < 60\,\text{GeV}^2,\ 40 < W < 120\,\text{GeV},\ 6\,\text{pb}^{-1}$



pQCD expects $r^5_{00} \propto \sqrt{t}$ and $r^5_{11} \propto \sqrt{t}$

Violation increases with t as expected



- H1 preliminary <Q²> = 15.9 GeV²
- H1 97 diffractive <Q²> = 5 GeV²
- H1 96 elastic <Q²> = 5 GeV²
- ZEUS 95 <Q²> = 6.3 GeV²

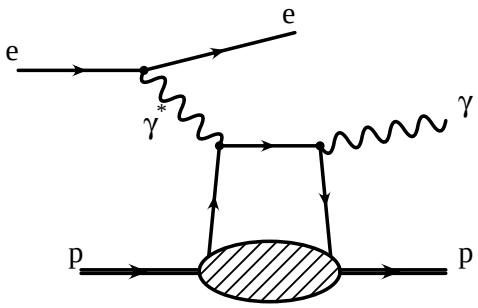
pQCD expects $r^1_{00} \propto -|t|$ and $r^1_{11} \propto |t|$

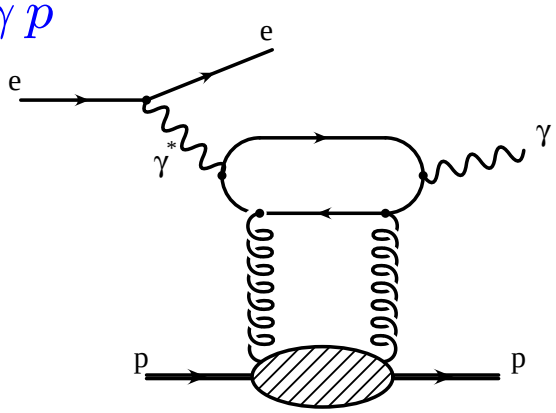
$\propto |t|$ as expected

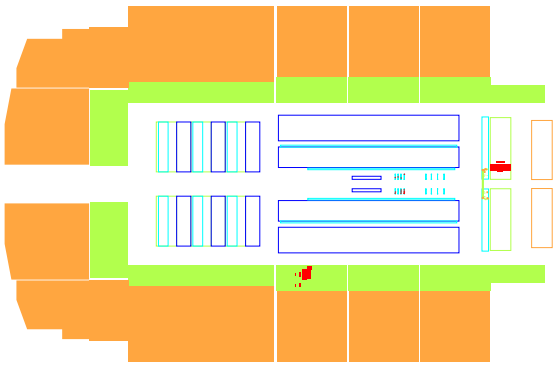
r^1_{00} dominates (depends on single flip T_{01})

Deeply Virtual Compton Scattering

$$e\,p \rightarrow e\,\gamma\,p$$







H1 Collaboration

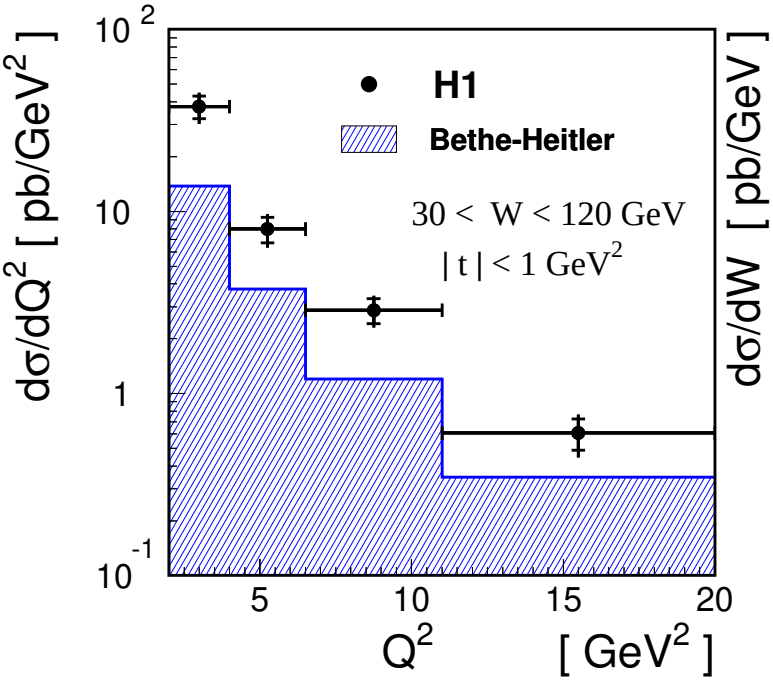
$2 < Q^2 < 20\ \mathrm{GeV}^2$

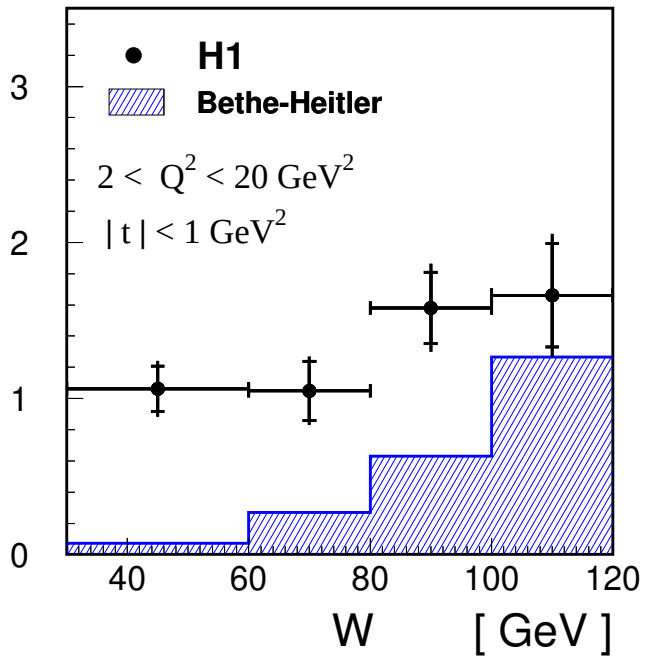
$30 < W_{\gamma p} < 120\ \mathrm{GeV}$

$|t| < 1.0\ \mathrm{GeV}^2$

$8\ \mathrm{pb}^{-1}$

Ratio DVCS / Bethe-Heitler $\Rightarrow$ forward photons
Integration over ϕ $\Rightarrow$ Interference term ~ 0

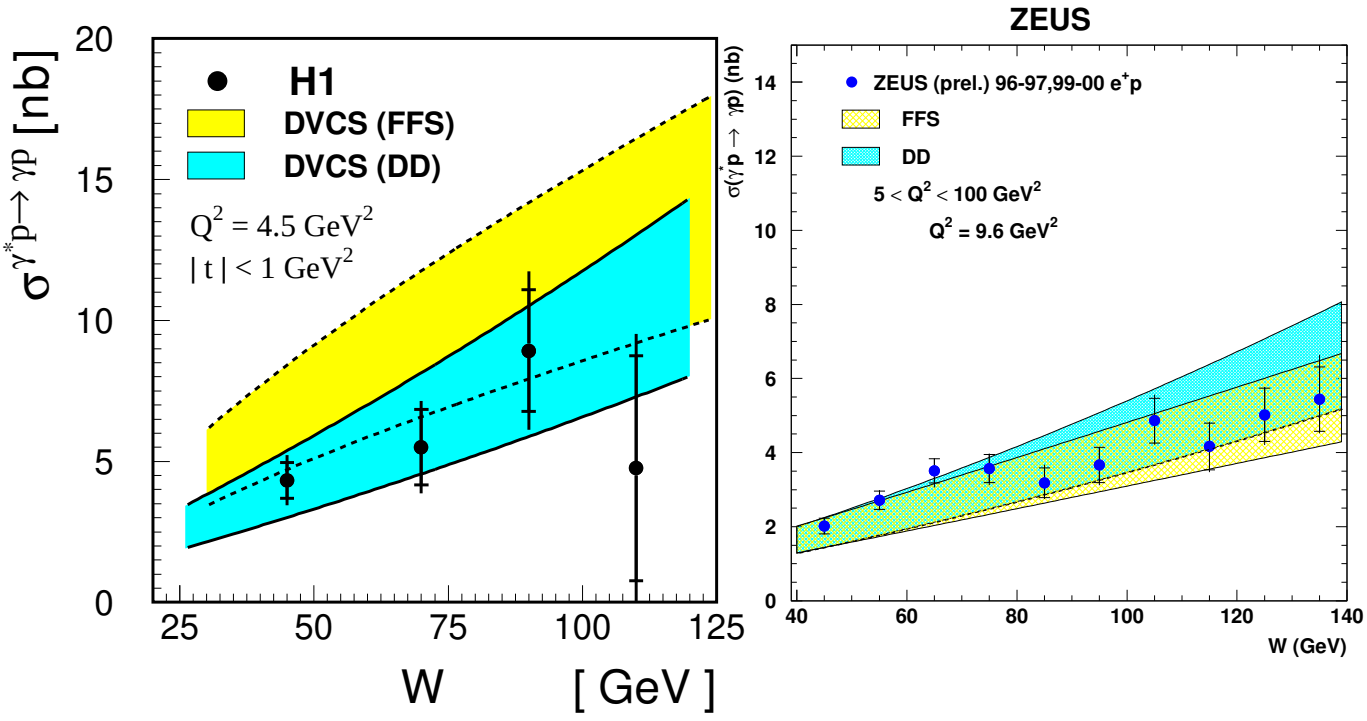




Deeply Virtual Compton Scattering

ZEUS collaboration
$5 < Q^2 < 100\,\text{GeV}^2$
$40 < W < 140\,\text{GeV}$
$e^+p = 95\,\text{pb}^{-1}$ and $e^-p = 17\,\text{pb}^{-1}$

e^+p Measurements:

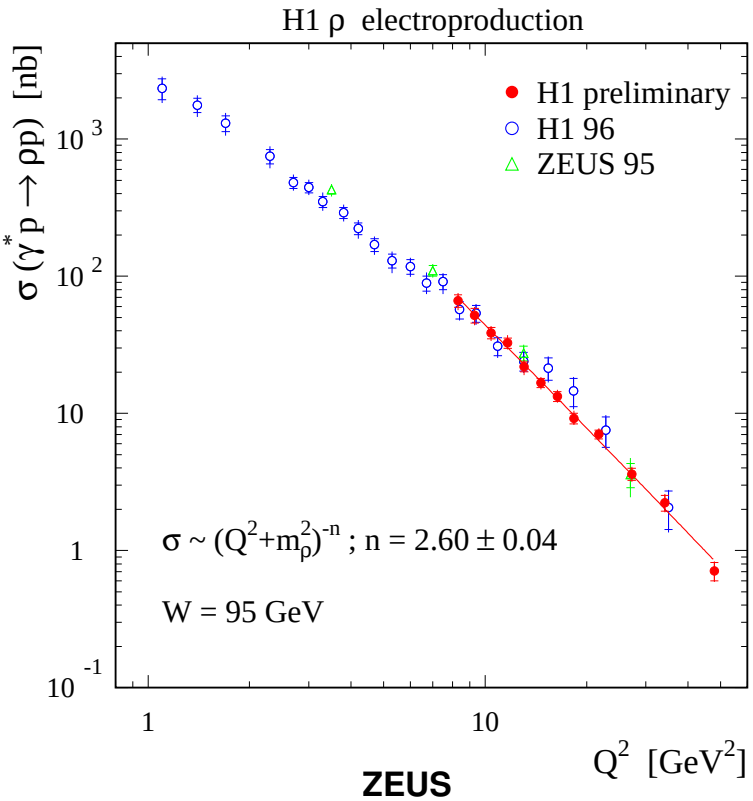


- In both models: soft and hard contributions
- Bands vary assumed $|t|$ dependence

- ZEUS Fit $W^\delta \Rightarrow \delta = 0.78 \pm 0.10$

$\Rightarrow$ Similar rise as J/ψ in Photoproduction

DVCS and Vector Meson Production

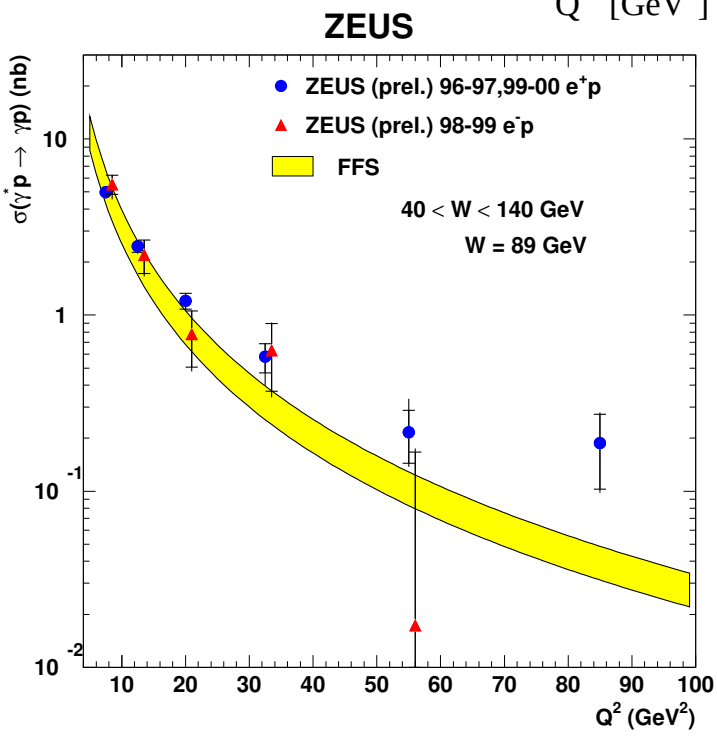


pQCD

$\sigma \propto \alpha_s^2(Q^2)/Q^6\ [xg(x,Q^2)]^2$

- Fit $\propto (Q^2 + m_\rho^2)^{-n}$:

  $n = 2.60 \pm 0.04$



pQCD

$\sigma \sim 1/Q^4$

- Fit $\propto (Q^2)^{-n}$:

  $n = 1.47 \pm 0.07$

- A hierarchy in ρ and DVCS Q^2 dependencies born out by the data

Conclusions

- Measurements of Diffractive Vector Meson Production and DVCS providing insight:
  - into wavefunctions
  - the gluon density in proton

  (First Measurements of ψ(2S) in W and |t|

  $\Rightarrow$ extended probe of excited state WFs)

- pQCD predictions already giving good agreements
  - for Large M_{VM}, Q^2 and/or $|t|$

- Future increase in statistics (e.g large Q^2)

  $\Rightarrow$ higher precision tests over larger kinematic region