Diffractive Vector Meson Production at HERA

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DESY

On Behalf of the H1 and ZEUS Collaborations

Workshop on Low-x Physics

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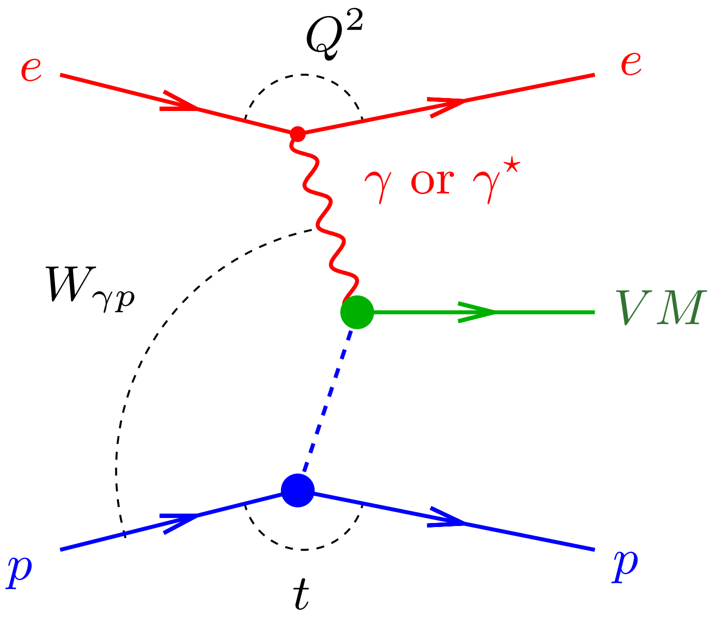
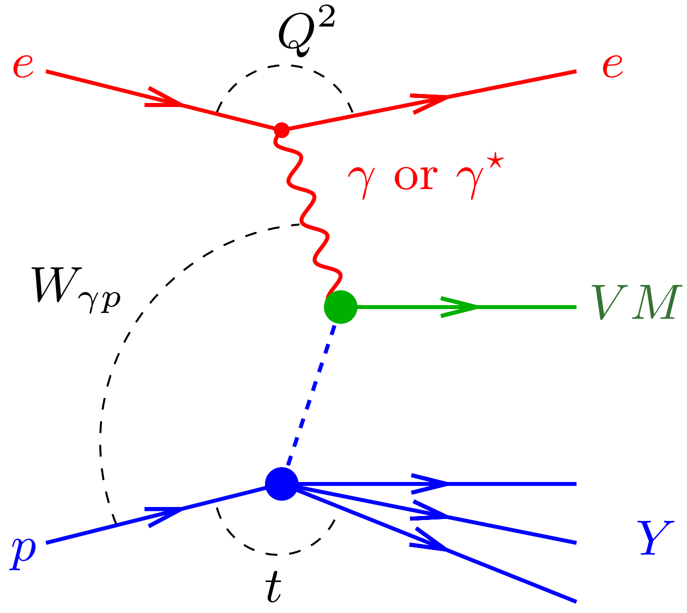


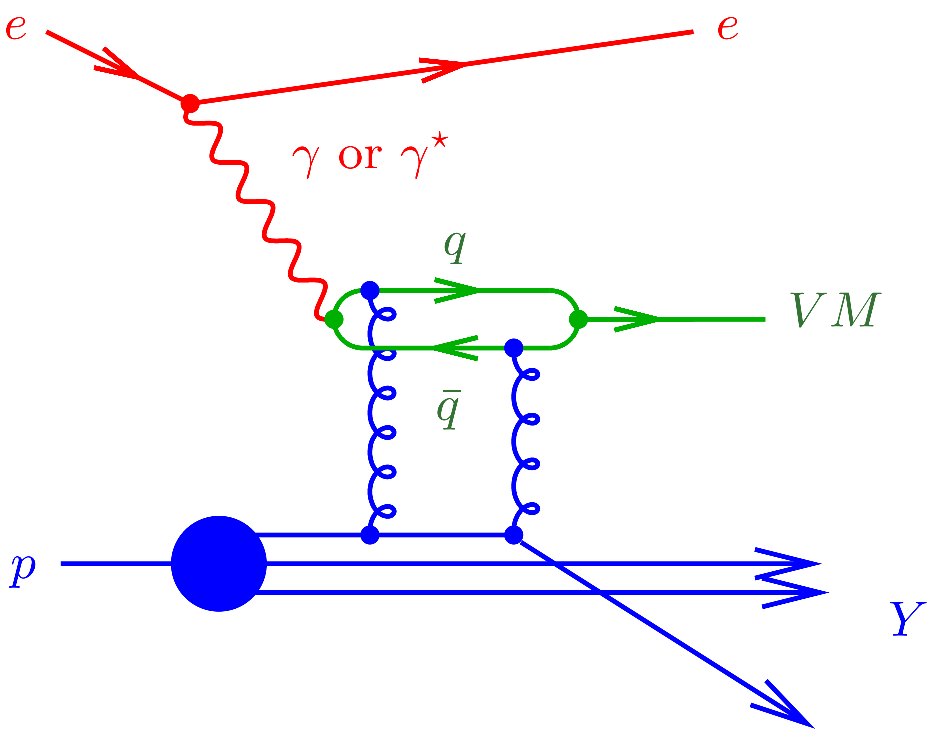


Q^2	γ^* Virtuality	$\sim 0 < Q^2 < 100\,\mathrm{GeV}^2$
$W_{\gamma p}$	CM Energy of $\gamma^*\,p$ system	$20 < W_{\gamma p} < 290\,\mathrm{GeV}$
t	(4-mom. transfer at p vertex)^2	$\sim 0 < \lvert t\rvert < 30\,\mathrm{GeV}^2$
VM	Vector Meson	$\rho^0,\ \omega,\ \phi,\ J/\psi,\ \psi',\ \Upsilon$

$\Rightarrow$ Simultaneous Probe of Different Kinematical Quantities

Diffractive Vector Meson Production

- In Perturbative QCD



(1) Photon Fluctuates into $q\bar{q}$ Pair

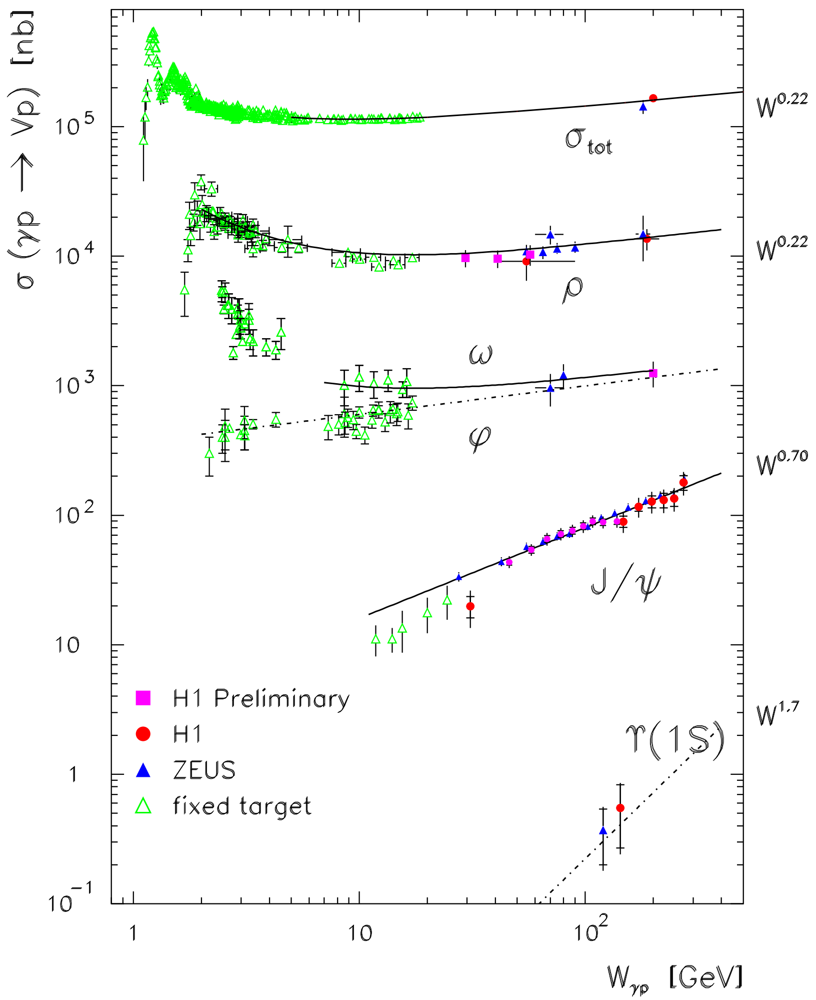
(2) Lowest Order Exchange: 2 Gluons

(3) Need Meson Wavefunction to form VM

- Calculations Require hard-scale M_V^2,Q^2,$|t|$

- Elastic Photoproduction $\gamma p \to VMp$

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

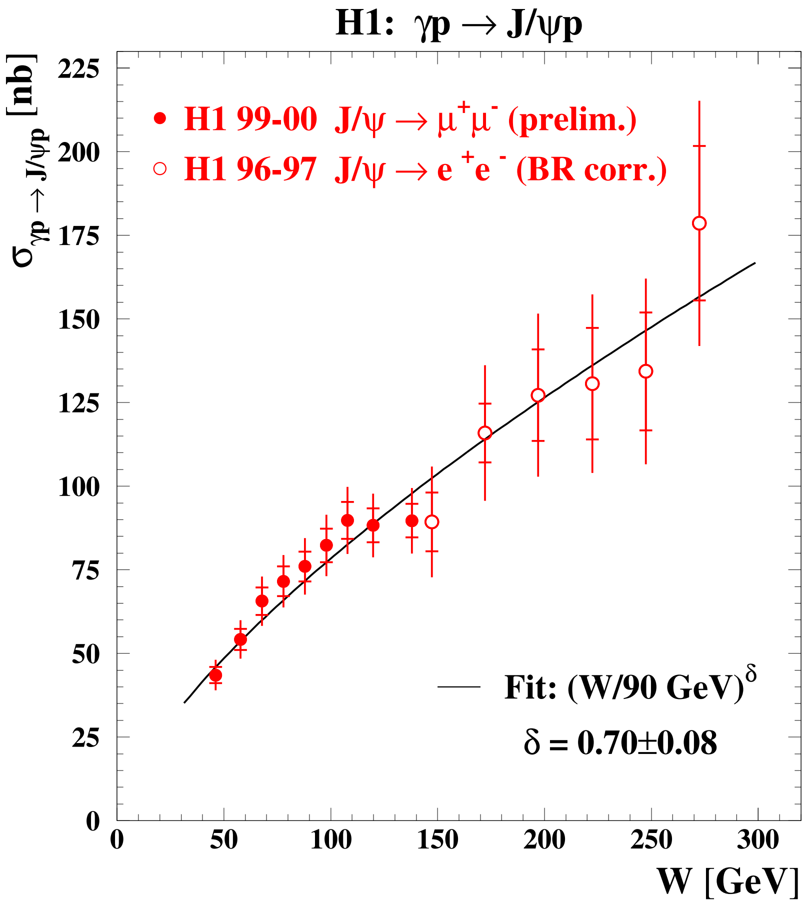


$\Rightarrow$ Light Vector Mesons $\sigma \sim W^{\delta}$: $(\delta \approx 0.22)$

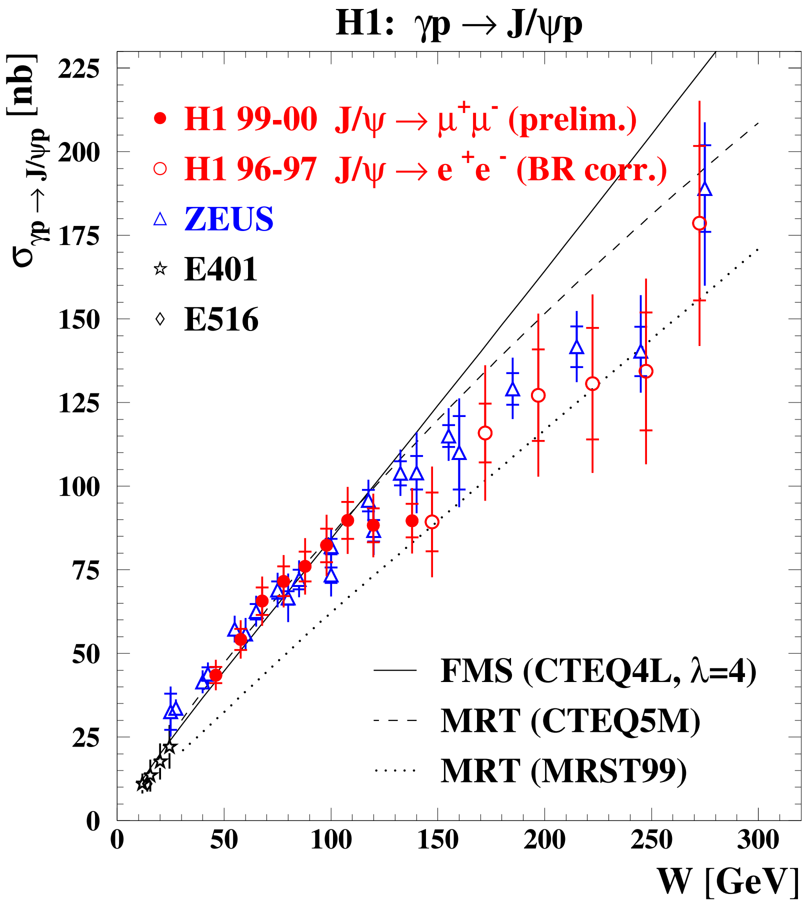
$\Rightarrow$ Steeper Rise in the J/ψ Cross Section

Elastic Photoproduction of J/ψ Mesons at Low $|t|$

H1 Preliminary: $Q^2 < 1\,\mathrm{GeV}^2$, $40 < W < 150\,\mathrm{GeV}$, $|t| < 1.2\,\mathrm{GeV}^2$,
$54.8\,\mathrm{pb}^{-1}$(1999 and 2000 data samples), $J/\psi \to \mu^+\mu^-$



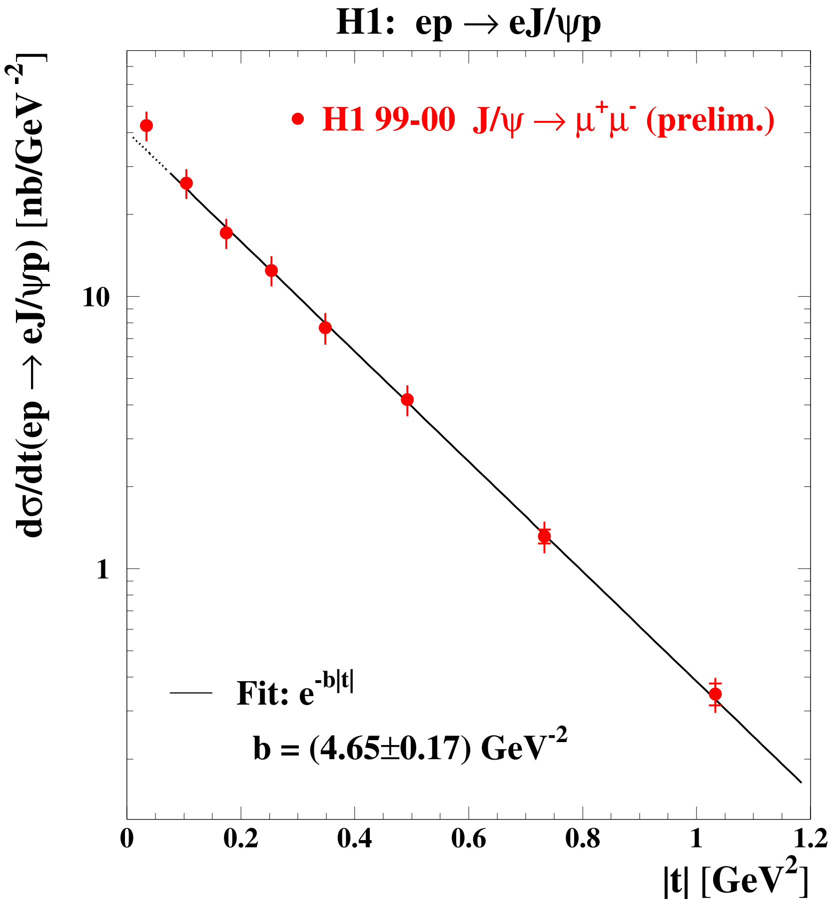
Fit W^δ gives good description
$\Rightarrow \delta \approx 0.7$



QCD models qualitatively
describe steep rise

Elastic Photoproduction of J/ψ Mesons at Low $|t|$

- Elastic J/ψ $|t|$ Dependence

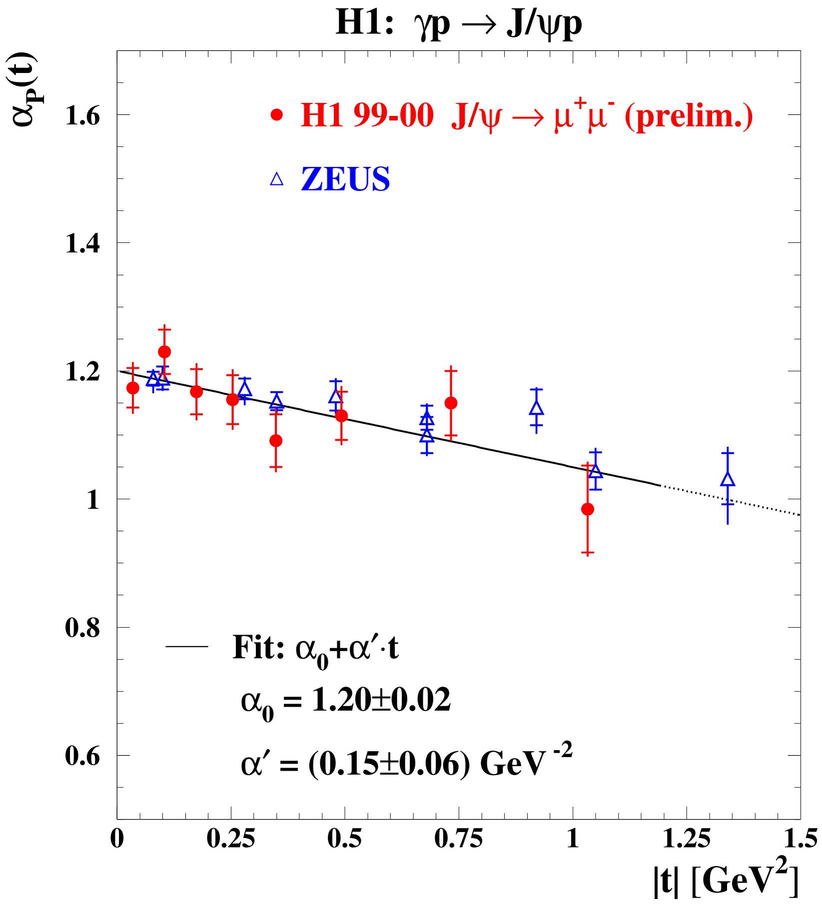


Exponential fit $d\sigma/d|t| \propto e^{bt}$

$\Rightarrow$ Good Description

$\Rightarrow$ $b \approx 4.7$ GeV^{-2}

- Fit $\sigma \propto W^{(4\alpha_{I\!P}-4)}$ in bins of $|t|$



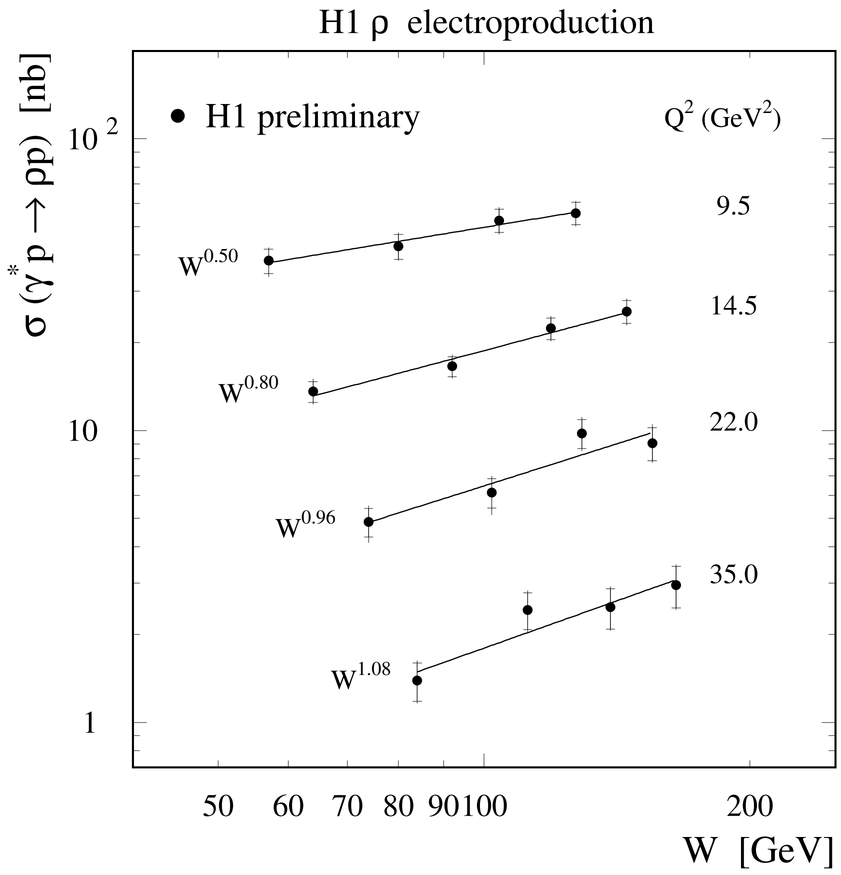
$\Rightarrow$ Effective Pomeron Trajectory

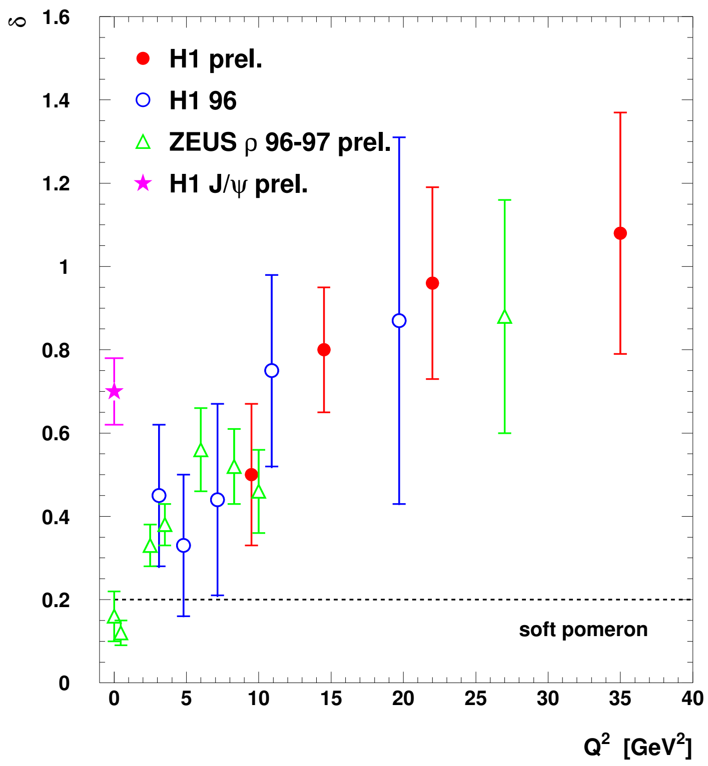
$\Rightarrow$ compatible with moderate shrinkage

$\Rightarrow$ $\alpha' \approx 0.15$ GeV^{-2}

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

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





H1 Collaboration.

$40 < W_{\gamma p} < 180\,\mathrm{GeV}$, $Q^2 > 2\,\mathrm{GeV}^2$

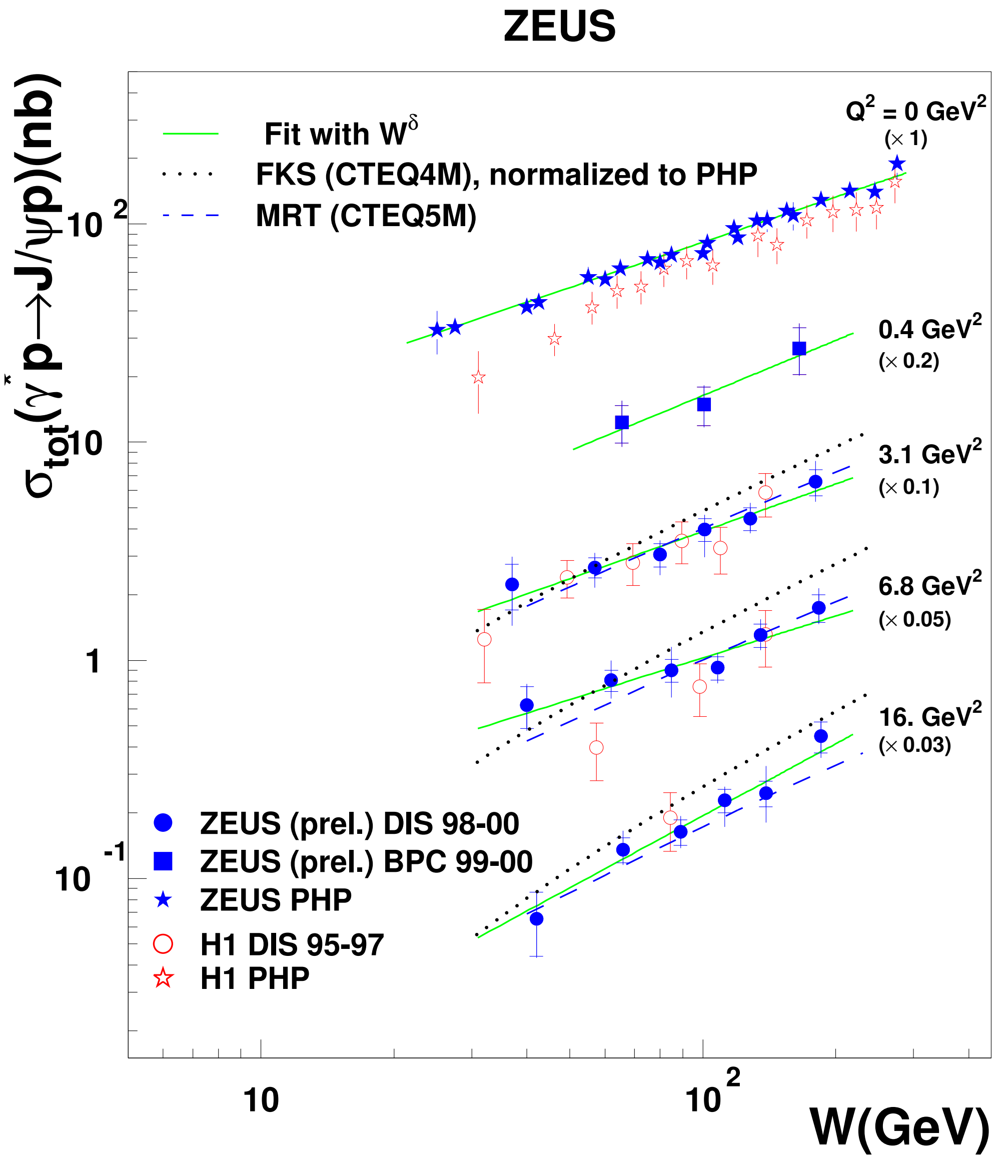
$42\,\mathrm{pb}^{-1}$, $|t| < 0.5\,\mathrm{GeV}^2$

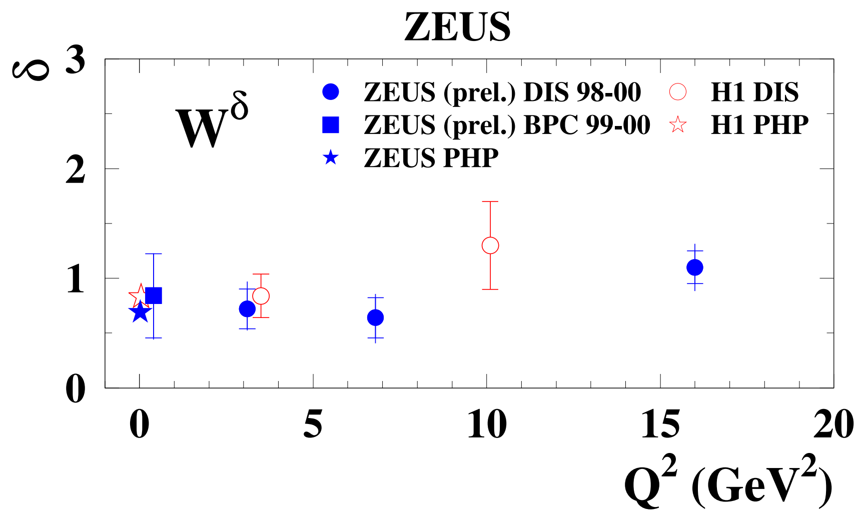
$\Rightarrow$ High Precision at High Q^2

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

  $\Rightarrow$ behave as J/ψ at $Q^2 \approx 0$

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





<u>ZEUS Collaboration</u>

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

$82\,\mathrm{pb}^{-1}$

(1) $Q^2 > 2\,\mathrm{GeV}^2$:

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

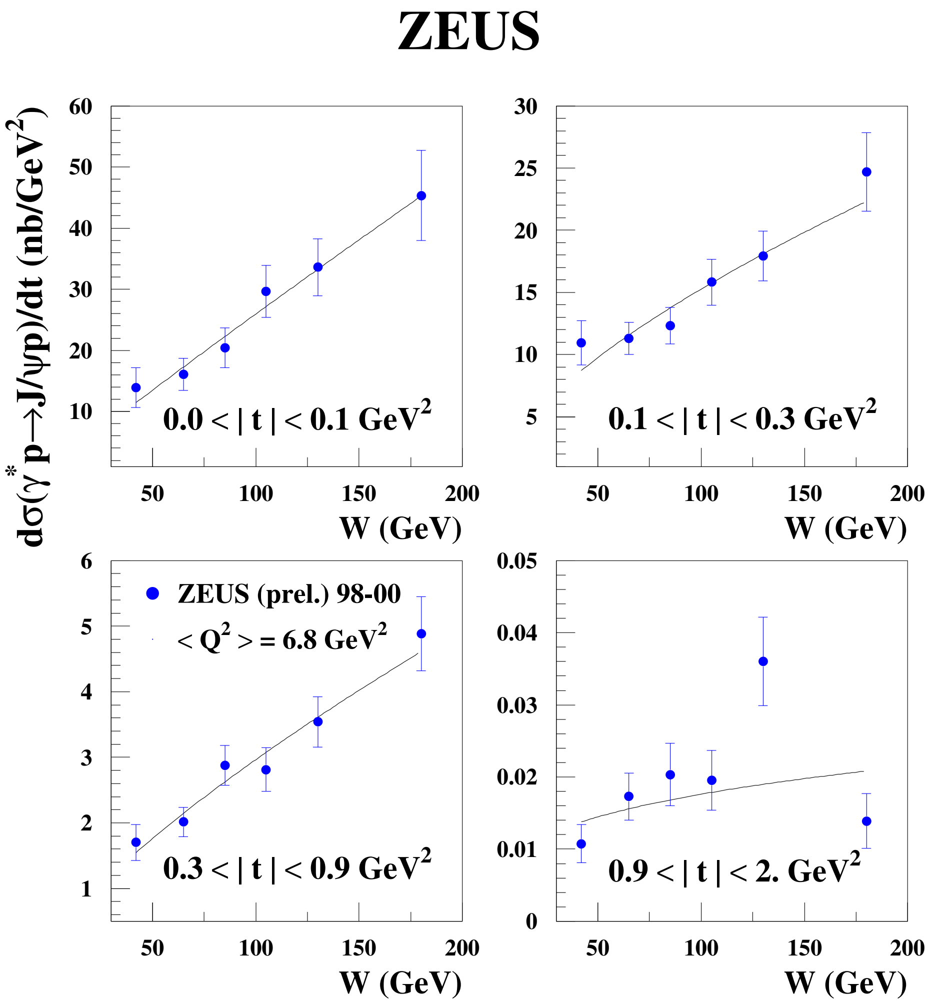
(2) $0.15 < Q^2 < 0.8\,\mathrm{GeV}^2$:

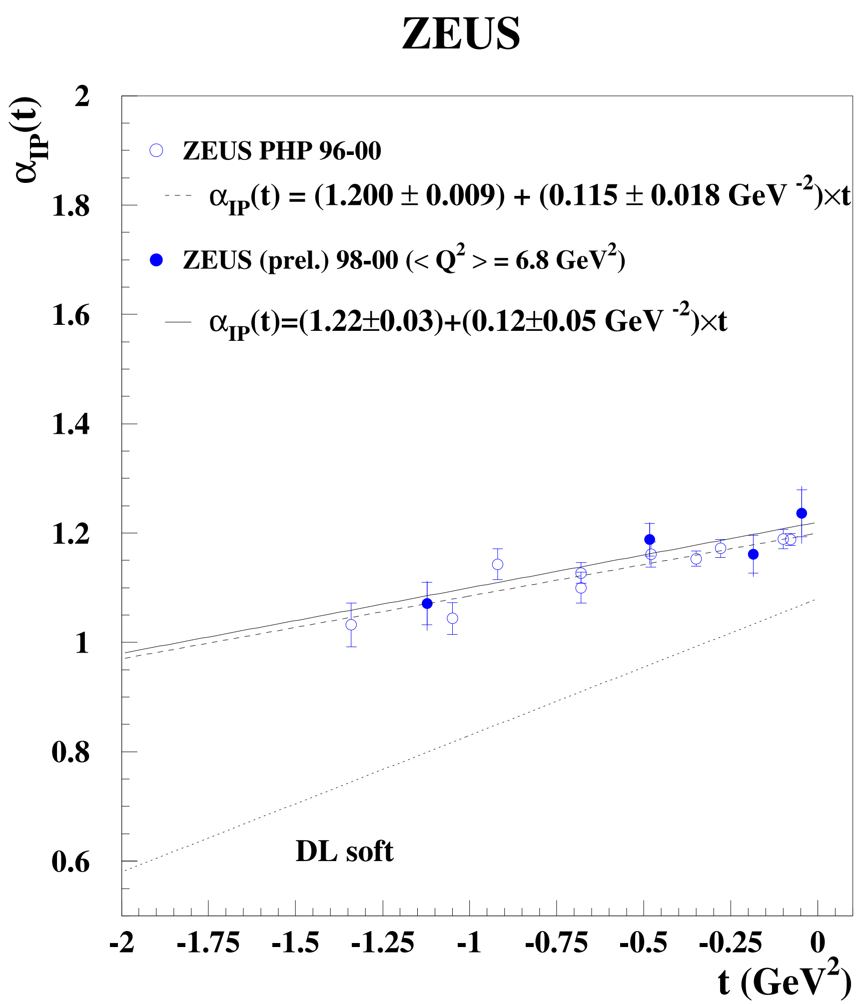
$J/\psi \to e^+ e^-$

$\Rightarrow$ No Strong Variation in $\sigma(W_{\gamma p})$ as a Function of Q^2

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

- Fit $\sigma \propto W^{(4\alpha_{I\!P}-4)}$ in bins of $|t|$
- Effective trajectory at $\langle Q^2 \rangle = 6.8$ GeV^2

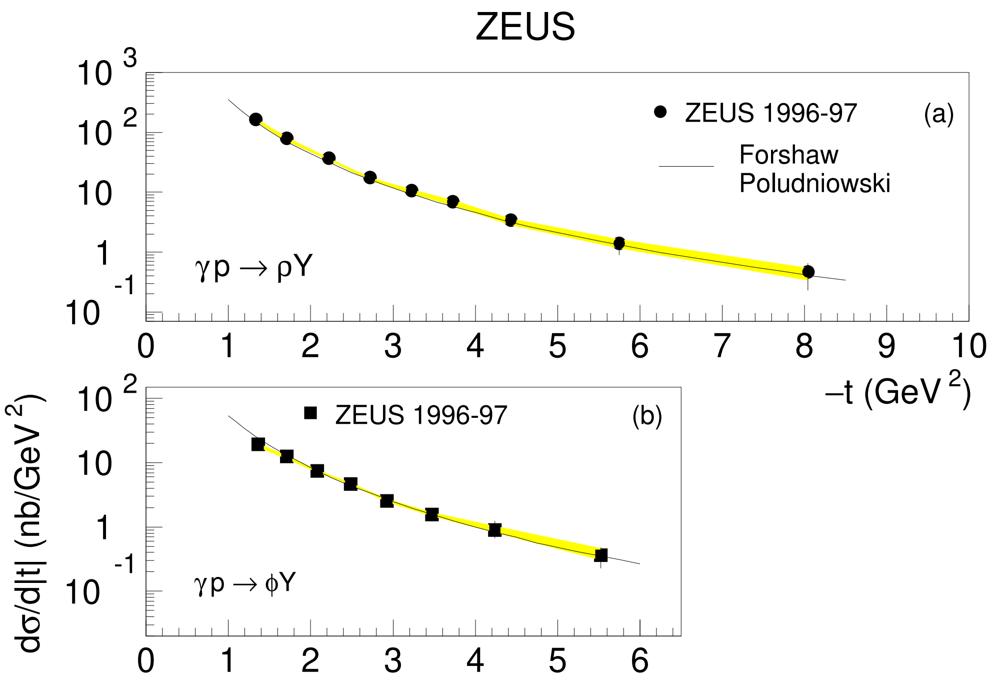




$\Rightarrow$ Compatible with moderate shrinkage at larger Q^2

Light Vector Meson Production at High $|t|$

- Allow $|t|$ to become large, squeeze transverse size of the pomeron
- Proton dissociative photoproduction of ρ, ϕ



ZEUS Collaboration

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

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

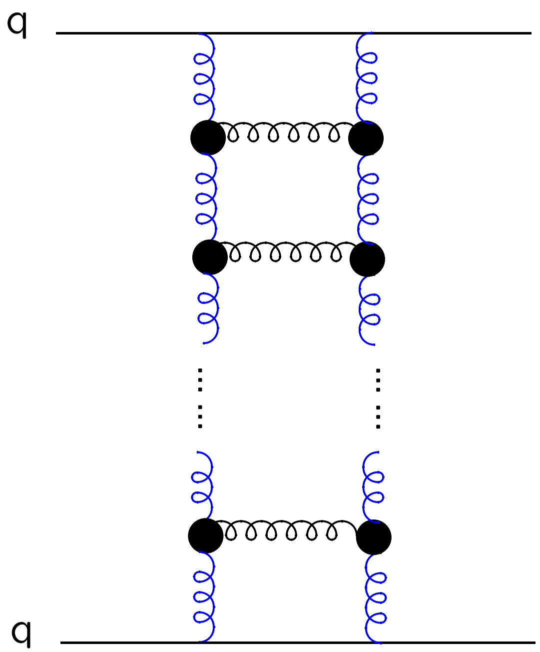
$25\,\mathrm{pb}^{-1}$

- Large |t| Dependence $\propto |\mathrm{t}|^{\mathrm{n}}$ with $n \sim -3$ for both ρ and ϕ
- BFKL Model gives good description of the |t| Dependence

Large $|t|$ pQCD Predictions

- Higher Order Exchange
- Non-Trivial Effective Gluonic Exchange

(Reggeized Gluon Ladder)



- Leading Log (LL) Approximation

Predictions using BFKL Evolution

- Unordered momenta along gluon ladder

(1) Bartels, Forshaw, Lotter, Wüsthoff

Phys. Lett. B375 (1996) 301

(2) Forshaw, Ryskin Z.Phys. C68 (1995) 137

- Number of recent extensions:

(1) **BFKL LL** (inc. higher conformal spin)

(2) **BFKL LL + NL**

(estimate of Non-Leading corrections)

(3) **BFKL LL + NL + running** α_s

Enberg, Motyka, Poludniowski [hep-ph/0207027]

Predictions using DGLAP Evolution

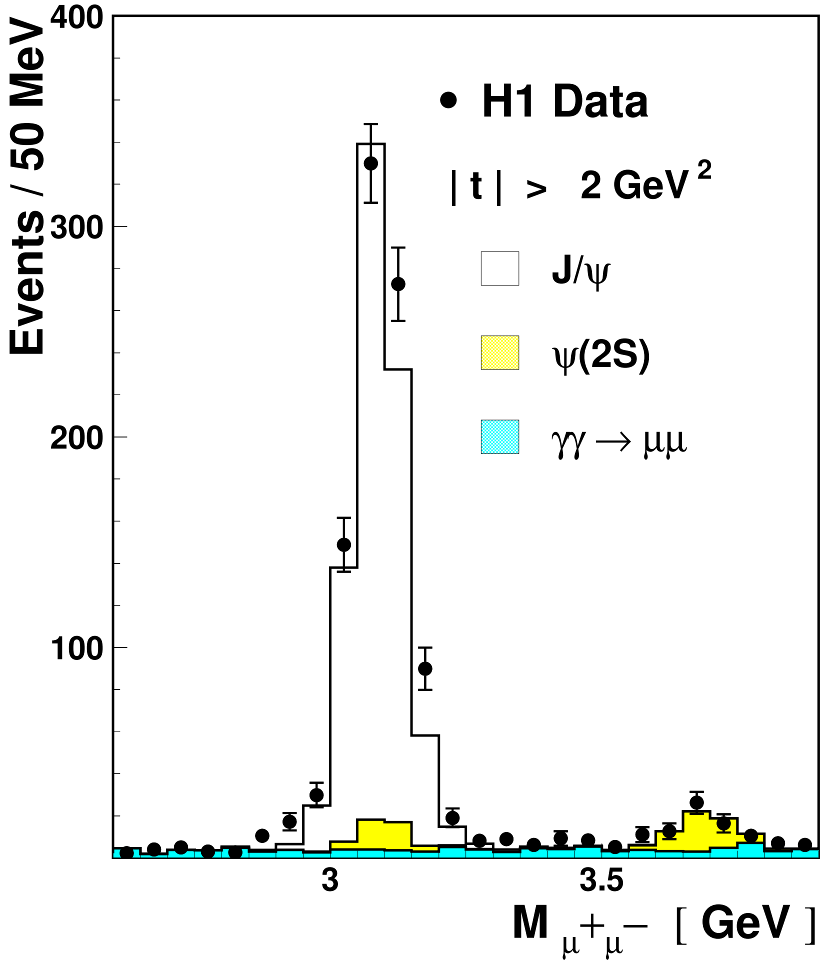
- Ordered momenta along gluon ladder

(1) **DGLAP LL** applicable for $|t| < M^2_{J/\psi}$

Gotsman, Levin, Maor, Naftali Phys. Lett. B352 (2002) 37

Event Selection: HERA I Event Sample

H1 Detector : Integrated luminosity 78 pb^{-1}



H1 Result

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

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

$50 < W_{\gamma p} < 150\,\mathrm{GeV}$

$2 < |t| \simeq |p^2_{t,J/\psi}| < 30\,\mathrm{GeV}^2$

$z = \frac{p \cdot p_{J/\psi}}{p.q} > 0.95$

- Signal sample $\sim$ 850 events
- Signal MC uses BFKL LL model

- Non-resonant background at large $|t|$ is small
- Contribution from $\psi(2S)$

Diffractive J/ψ Photoproduction at Large Momentum Transfer

- Dependence at large $|t|$: $\propto (-t)^{-n}$

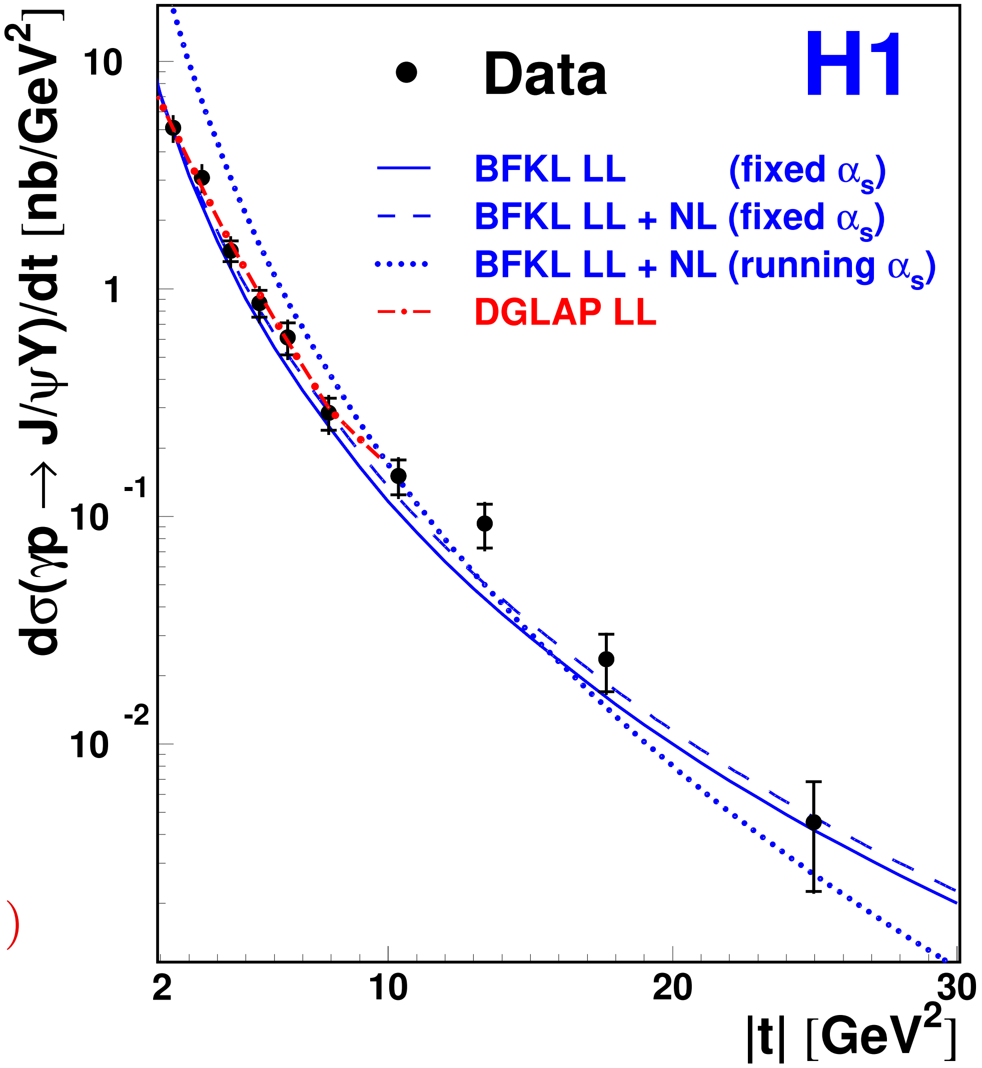
  $\Rightarrow n = 3.00 \pm 0.08(stat.) \pm 0.05(sys.)$

  for $|t| > 3.5$ GeV^2
- Increase $|t| \Rightarrow$ sys. increase in n
- BFKL LL and BFKL LL + NL (fixed α_s)

  $\Rightarrow$ both describe data
- Prescription for running α_s

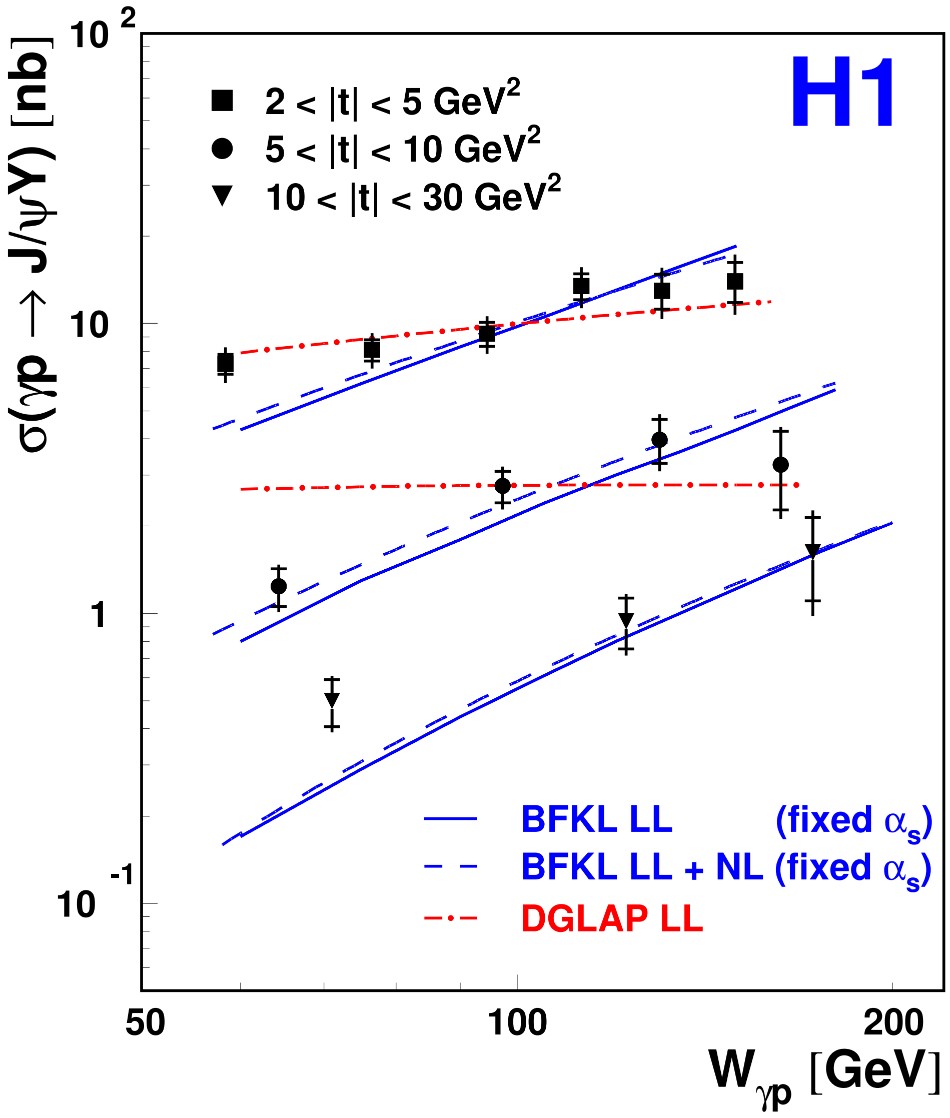
  $\Rightarrow$ steeper t-dependence
- DGLAP LL in range of model ($|t| \leq 10$ GeV^2)

  $\Rightarrow$ describes data



Extension of t range

Diffractive J/ψ Photoproduction at Large Momentum Transfer



$\delta = 0.77 \pm 0.14$ (stat.) ± 0.10 (sys.)

$\delta = 1.29 \pm 0.23$ (stat.) ± 0.16 (sys.)

$\delta = 1.28 \pm 0.39$ (stat.) ± 0.36 (sys.)

Extension of $W_{\gamma p}$ range with increasing $|t|$

- BFKL LL and BFKL LL + NL (fixed α_s)

  $\Rightarrow$ reasonable description of data

  (Inputs from simultaneous fit to ρ, ϕ, J/ψ data at lower $|t|$ (ZEUS))

- DGLAP LL:

  $2 < |t| < 5$ GeV^2: good description

  $5 < |t| < 10$ GeV^2: flat dependence

- Fit form $\sigma \propto W_{\gamma p}^{\delta}$, $\delta = 4\alpha(t) - 4$

  $\Rightarrow$ Similar rise ($\delta \sim 1$) as elastic J/ψ

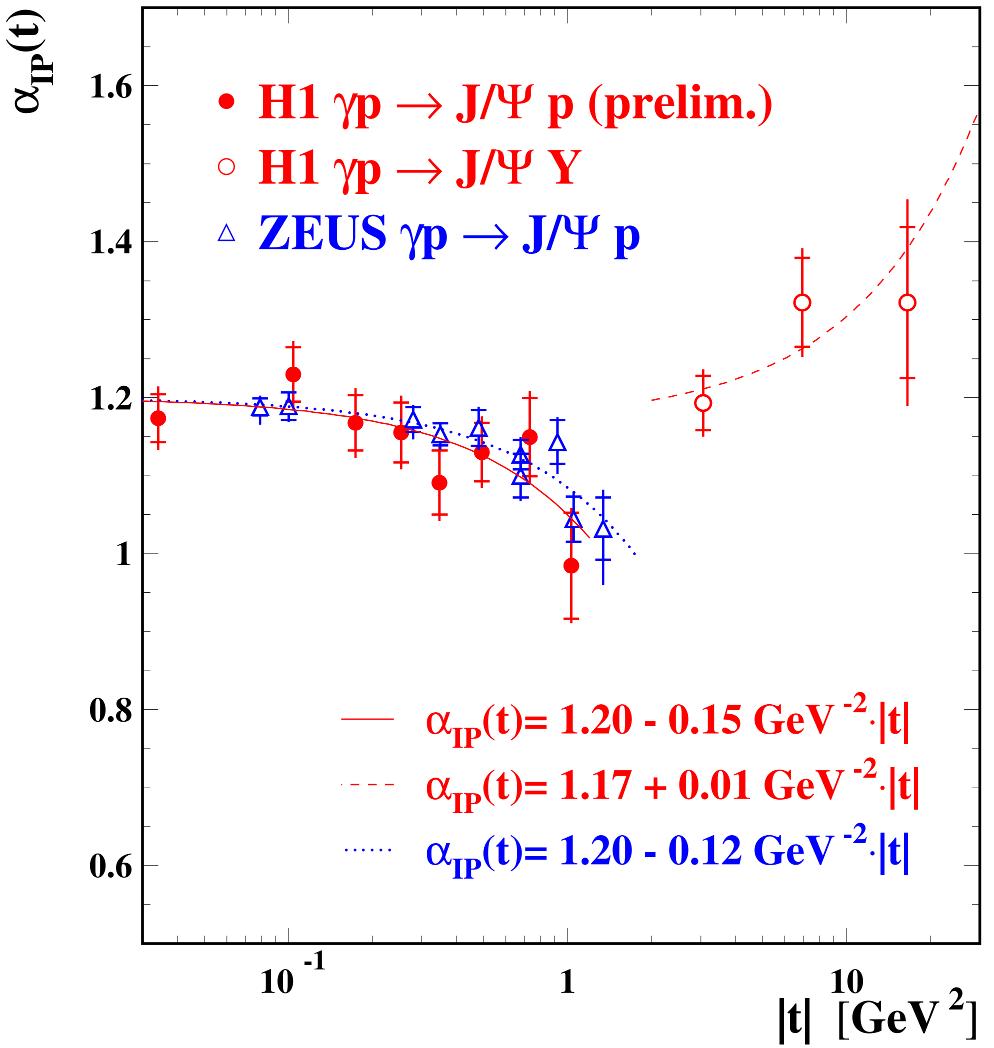
Effective Pomeron Trajectory at Large $|t|$

- $\underline{\gamma p \rightarrow J/\psi Y}$

$\alpha' = -0.013 \pm 0.007_{stat.} \pm 0.005_{sys.}$

$\alpha(0) = 1.167 \pm 0.048_{stat.} \pm 0.024_{sys.}$

$\Rightarrow$ Shrinkage consistent with zero



- $\underline{\gamma p \rightarrow J/\psi p}$

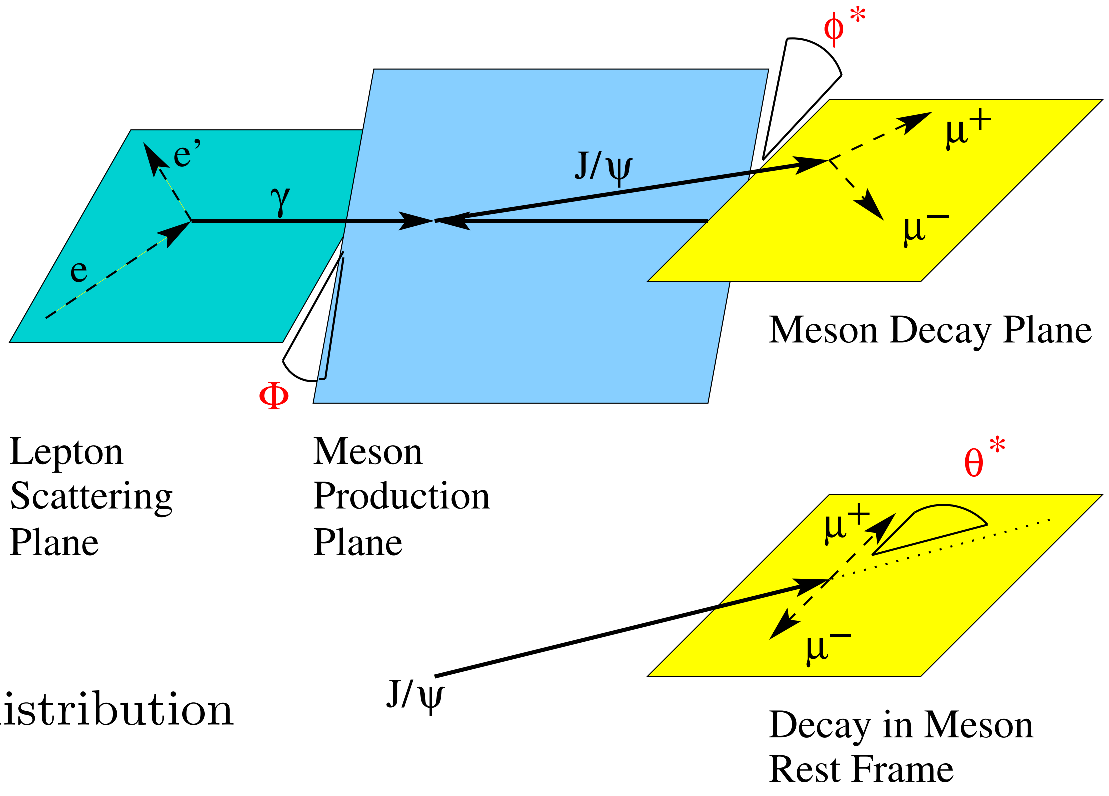
$\alpha'_{H1} = 0.154 \pm 0.054_{stat.} \pm 0.023_{sys.}$

$\alpha'_{ZEUS} = 0.115 \pm 0.018_{stat.} \pm^{0.008}_{0.015}\ {}_{sys.}$

$\Rightarrow$ Moderate shrinkage observed

Helicity Studies

Define Three Angles in the Helicity System



Normalised decay angular distribution is a function of

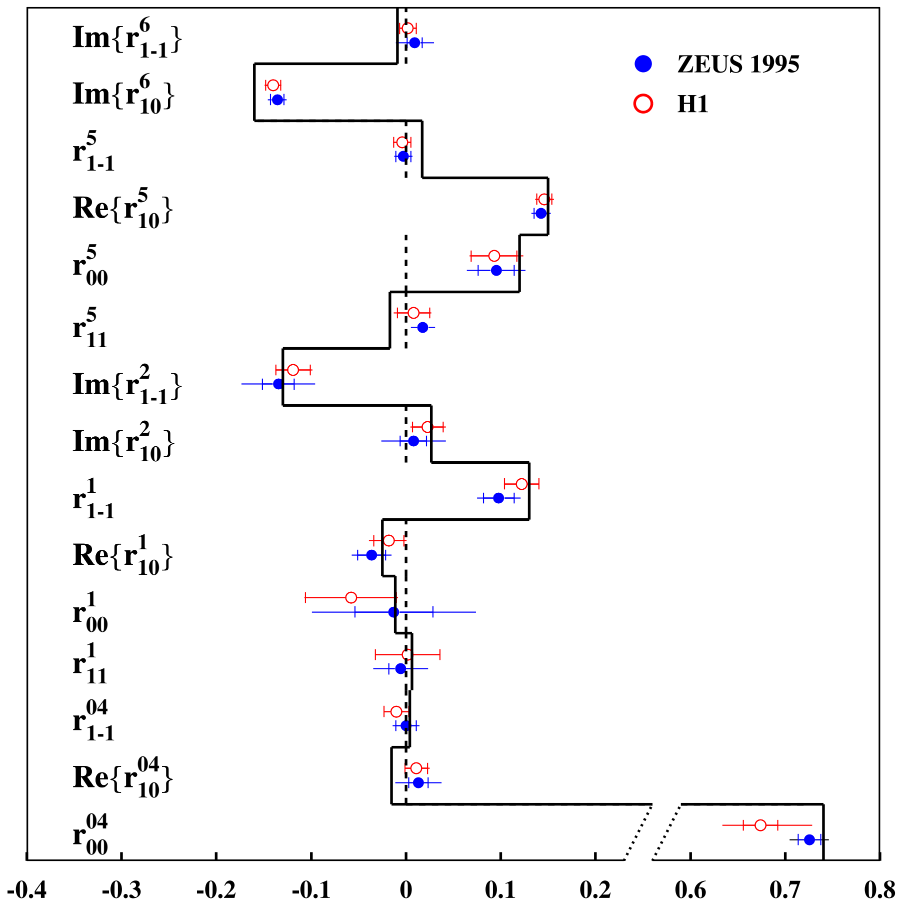
1) 3 Angles ϑ^*, φ^* and Φ

2) 15 Indep. Linear Combinations of spin density matrix elements:

For SCHC, NPE expect 5 combinations to be non-zero

Elastic Electroproduction of ρ: $\gamma^* p \to \rho p$

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



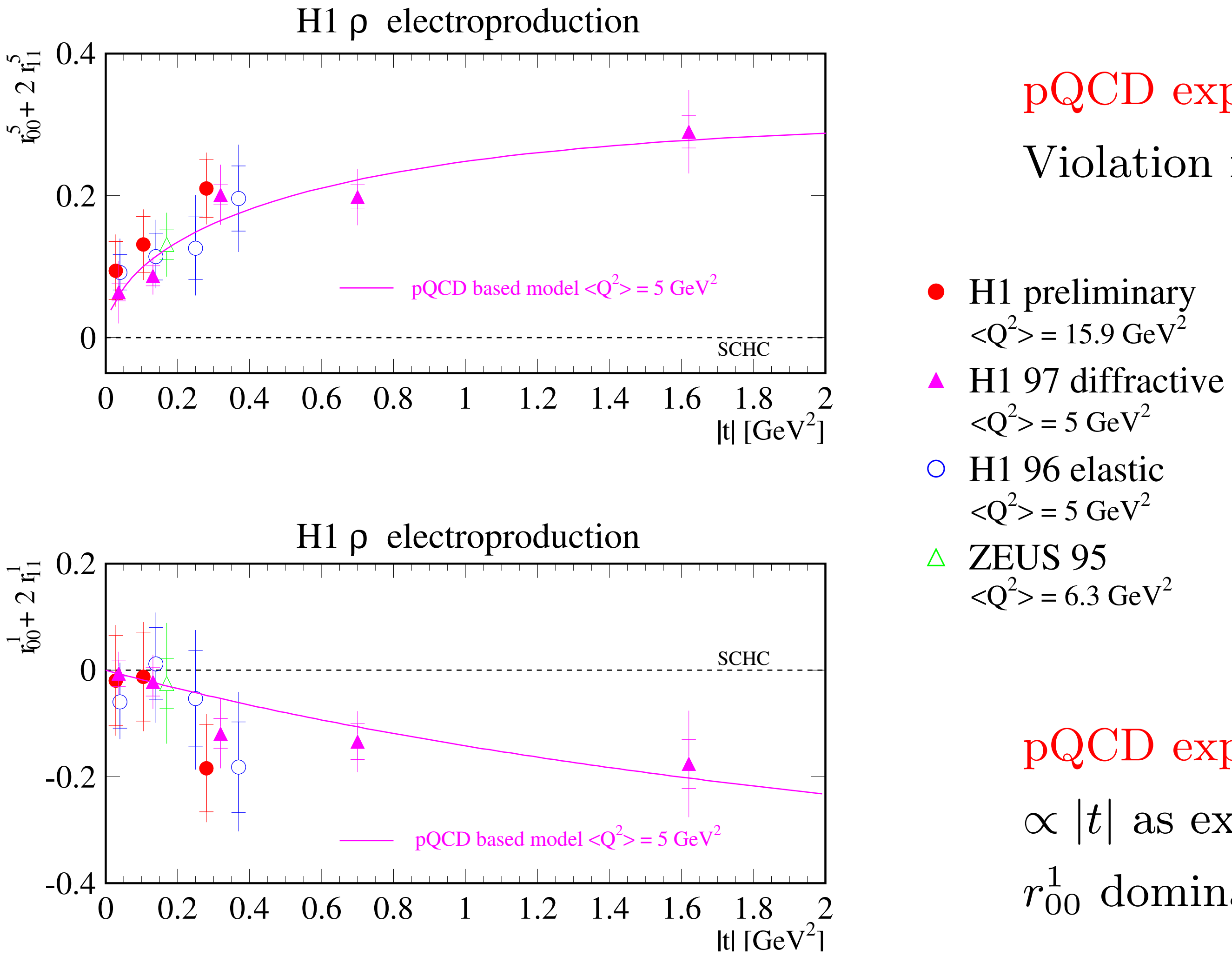
- pQCD model (solid line) predicts violation

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

- Wavefunction considers momentum distribution of quarks in meson

Electroproduction of ρ at High $|t|$

H1 Measurement: $2.5 < Q^2 < 60\,\mathrm{GeV}^2$, $40 < W < 120\,\mathrm{GeV}$, $6\,\mathrm{pb}^{-1}$



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

Violation increases with $|t|$ as expected

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

$\propto |t|$ as expected

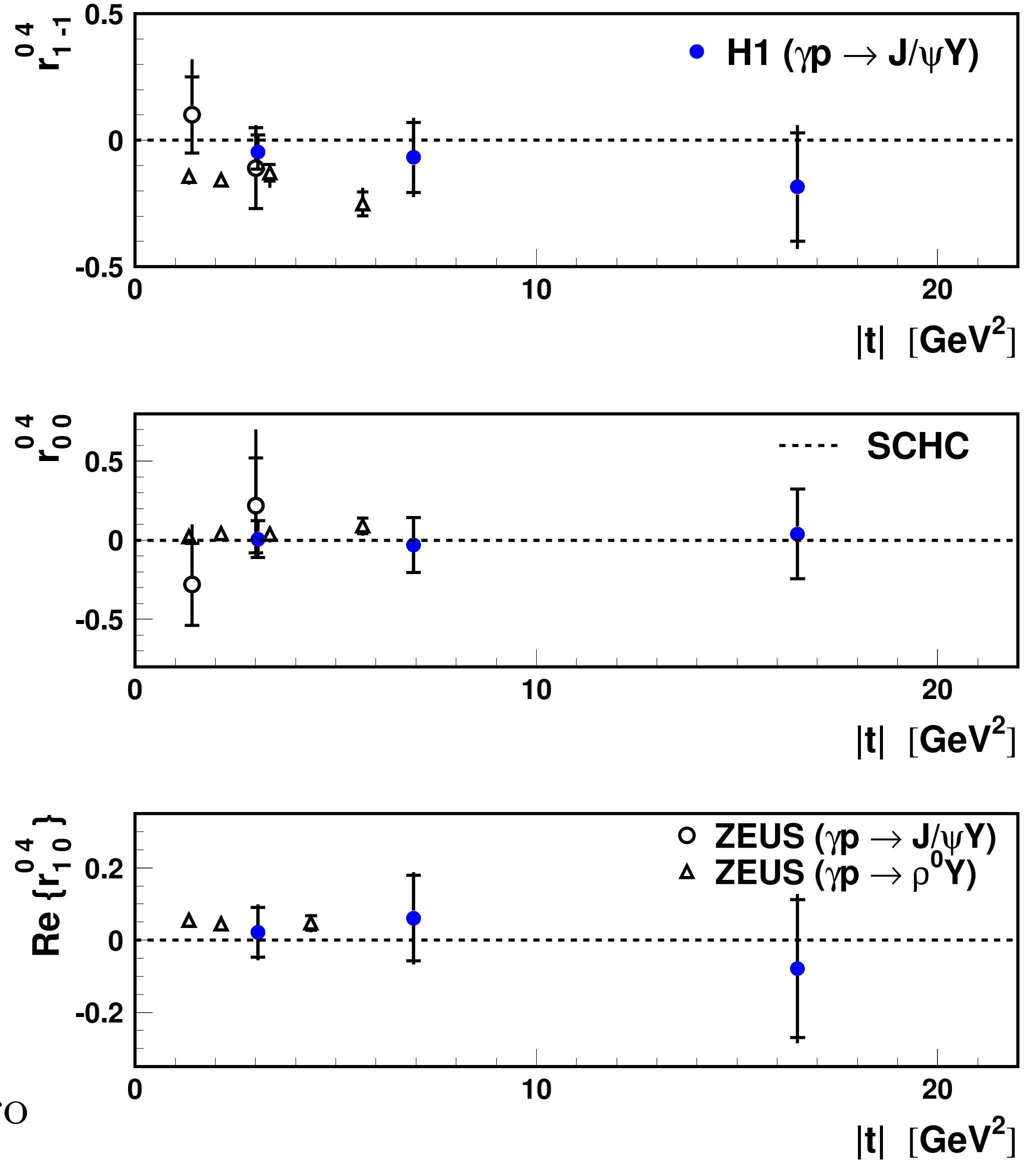
r^1_{00} dominates (depends on single flip T_{01})

Diffractive J/ψ Photoproduction Measurements at Large $|t|$

- Normalised decay angular distribution is a function of
  1) 2 Angles ϑ^*, φ^*
  2) 3 Indep. Linear Combinations of spin density matrix elements

- s-channel helicity conservation:
  $\Rightarrow$ J/ψ retains helicity of photon
  $\Rightarrow$ $r^{04}_{00} = r^{04}_{1-1} = \mathrm{Re}\{r^{04}_{10}\} = 0$

- 2D fit used to extract SDMEs simultaneously



- Measured J/ψ SDMEs consistent with zero

$\Rightarrow$ Consistent with s-channel helicity conservation

Conclusions

- Measurements of Diffractive Vector Meson Production Providing Insight into:
  - Helicity Structure / Meson Wavefunctions
  - Structure of Diffractive Exchange

  (Double Differential J/ψ Measurements:

  $\Rightarrow$ Extended Probe of Effective Trajectory to Large Q^2 and Large $|t|$)

- pQCD Predictions $\longrightarrow$ Good Agreements
  - for Large M_{V}^2, Q^2 and/or $|t|$

- Future Increase in Statistics (e.g Large Q^2)

Higher Precision Tests over Larger Kinematic Region.