Diffractive Photon and Vector Meson Production at Large $|t|$ at HERA

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DESY

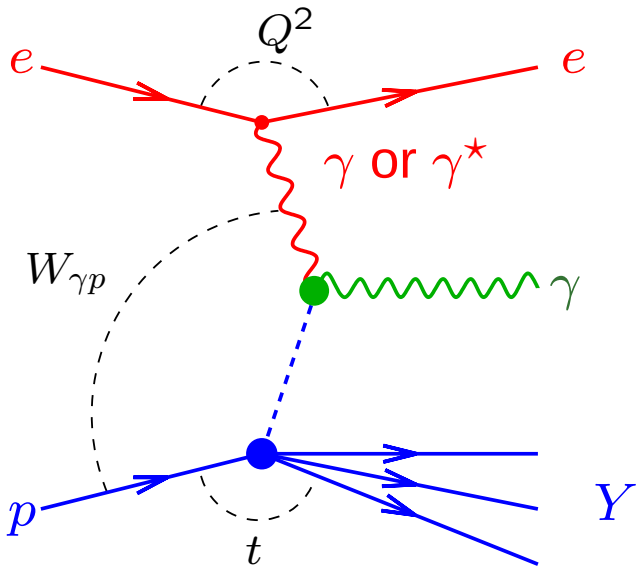
On Behalf of the H1 and ZEUS Collaborations

Small-x and Diffractive Physics Workshop

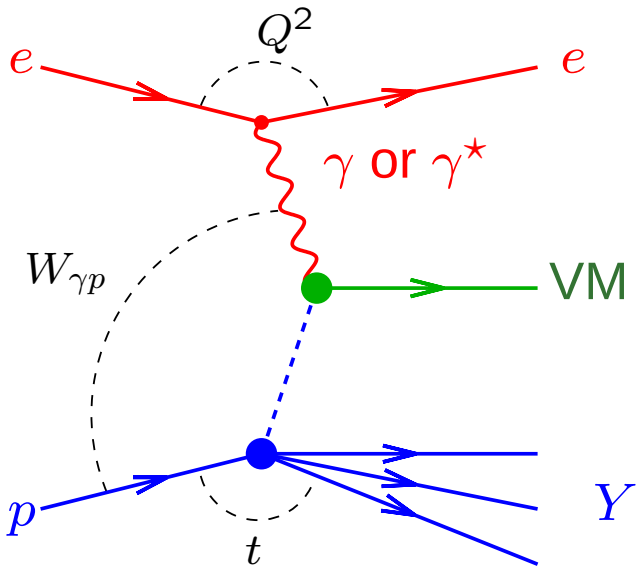
Fermilab, September 17 2003

Exclusive Diffractive Processes at Large |t| at HERA

Diffractive Photon Production



Diffractive VM Production



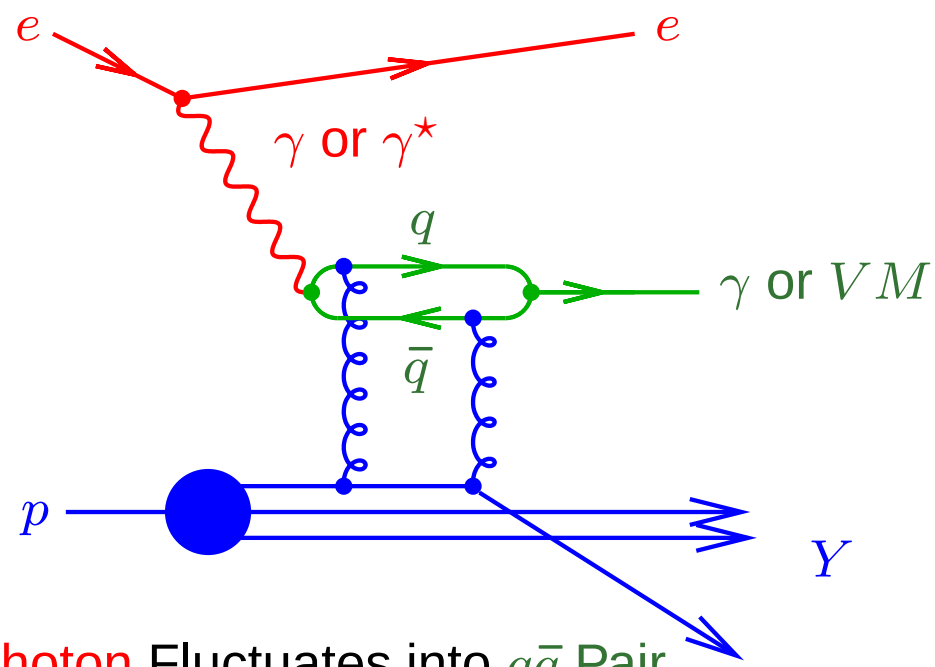
Proton Dissociation Dominates at Large |t|

Q^2	Incoming γ^* Virtuality	$0 < Q^2 < 100\,\mathrm{GeV}^2$
$W_{\gamma p}$	CM Energy of $\gamma^* p$ system	$20 < W_{\gamma p} < 290\,\mathrm{GeV}$
t	(4-mom. transfer at p vertex)^2	$0 < \lvert t\rvert \leq 30\,\mathrm{GeV}^2$
γ or VM	$J^{PC} = 1^{--}$	$\gamma,\ \rho^0,\ \omega,\ \phi,\ J/\psi,\ \psi',\ \Upsilon$

$\Rightarrow$ Simultaneous Probe of Different Kinematical Quantities

Exclusive Diffraction

- In Perturbative QCD



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

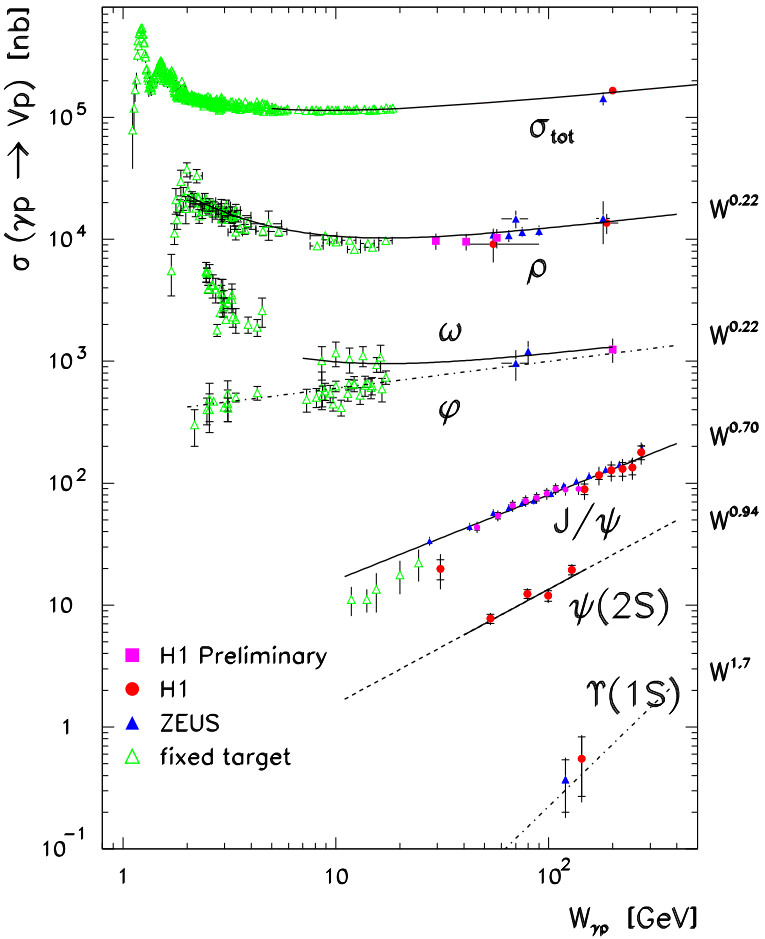
(2) Lowest Order Exchange: 2 Gluons

(Need Meson Wavefunction to form VM)

- Calculations Require hard-scale:

e.g $Q^2, M^2_{VM}, |t|$

- Elastic Photoproduction $\gamma p \rightarrow$ VM p



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

$\Rightarrow$ Steeper Rise for J/ψ Cross Section

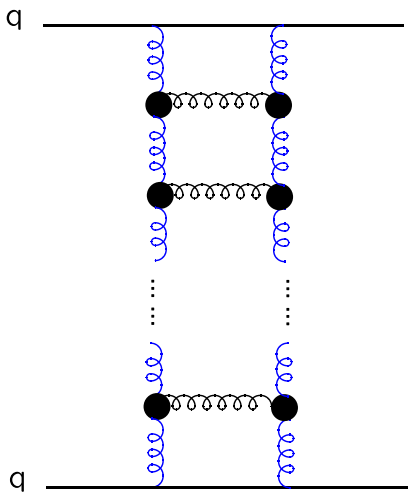
Diffractive VM Predictions at Large |t| in pQCD

- Evolve to Higher Orders in Leading Log (LL) Approximation

$\Rightarrow$ Non-Trivial Effective Gluonic Exchange

- Predictions using BFKL Evolution

$\Rightarrow$ Unordered momenta along gluon ladder



(Reggeized 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

$\Rightarrow$ Ordered momenta along gluon ladder

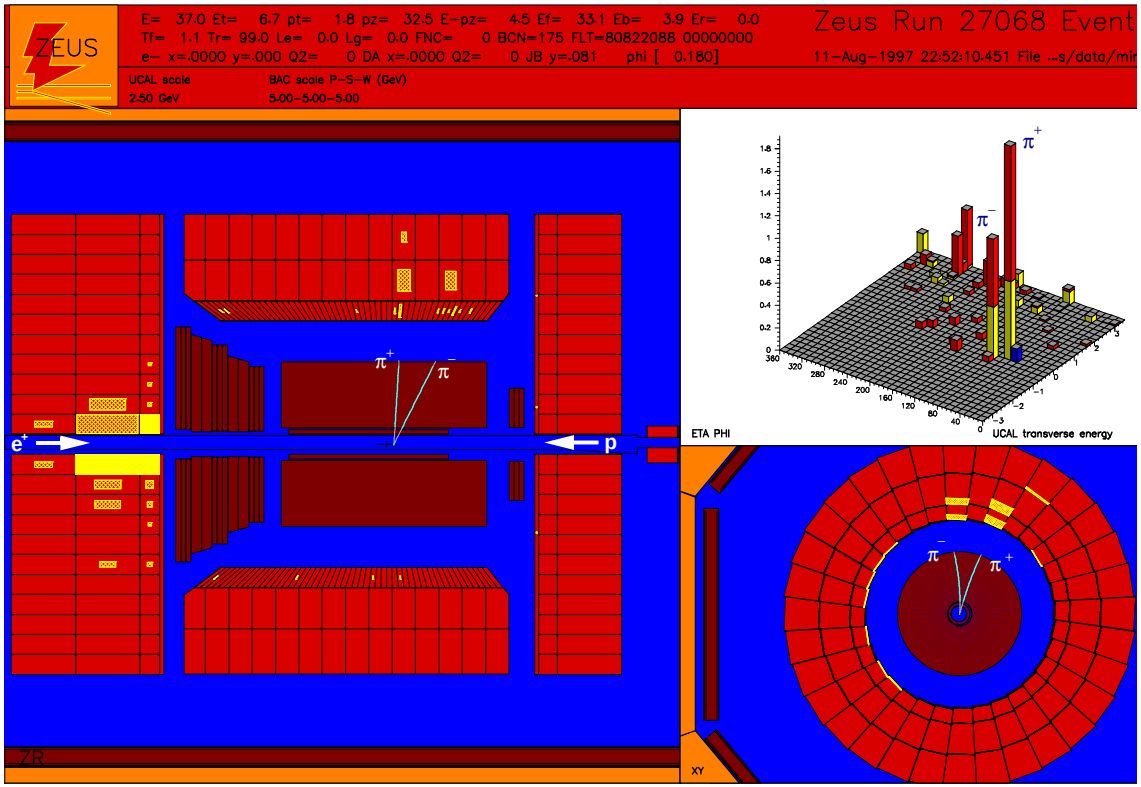
$$G(x, Q^2) \Rightarrow G(x, \bar{Q}^2, t)$$

(1) **DGLAP LL** applicable for $|t| < M_{VM}^2$

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

Large $|t|$ Experimental Signature

- Large $|t|$ Photoproduction Events



- Incoming Lepton Scatters through Small Angle

$\Rightarrow$ No Scattered Lepton in Main Detectors

- High Energy Proton dissociates

$\Rightarrow$ Energy deposits in forward detectors.

- 2-Prong Signature (VM Decays)

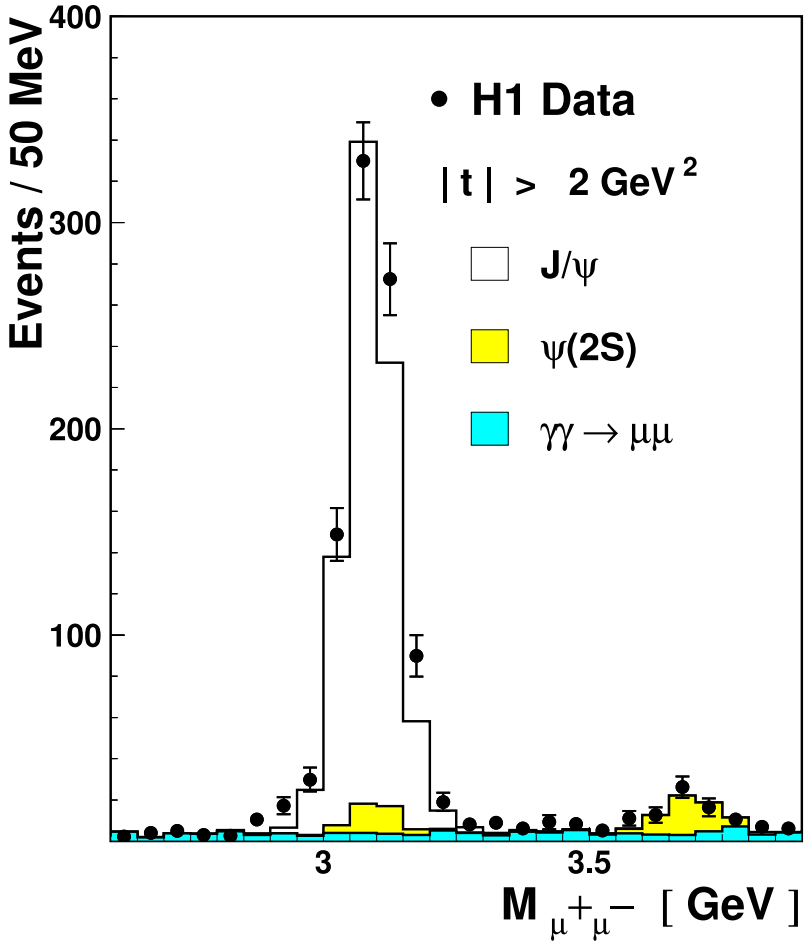
- Can Reconstruct $|t|$ from two Large p_T Tracks

$\Rightarrow \rho^0$ Candidate at Large |t| in Photoproduction.

Diffractive J/ψ Photoproduction at Large Momentum Transfer

Event Selection: HERA I Event Sample

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



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

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 ~ 850 J/ψ events
- Signal MC uses BFKL LL model

A. Aktas *et al.* [H1 Collaboration]
Phys. Lett. B **568** (2003) 205

Diffractive J/ψ Photoproduction at Large Momentum Transfer

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

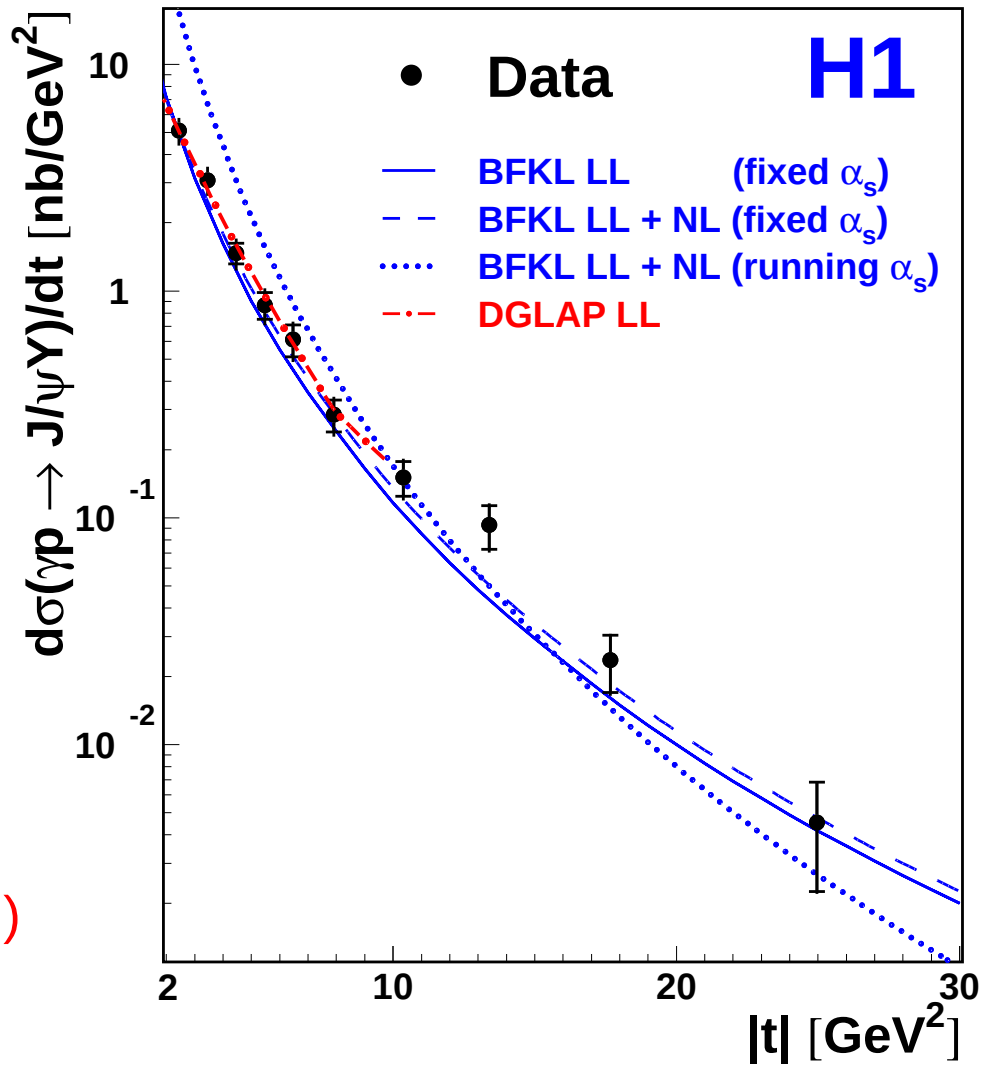
$\Rightarrow n = 3.00 \pm 0.08(stat.) \pm 0.05(sys.)$
for $|t| > 3.5$ GeV^2

- Increase $|t| \Rightarrow$ sys. increase in n

- BFKL LL and BFKL LL + NL (fixed α_s)
$\Rightarrow$ both describe data

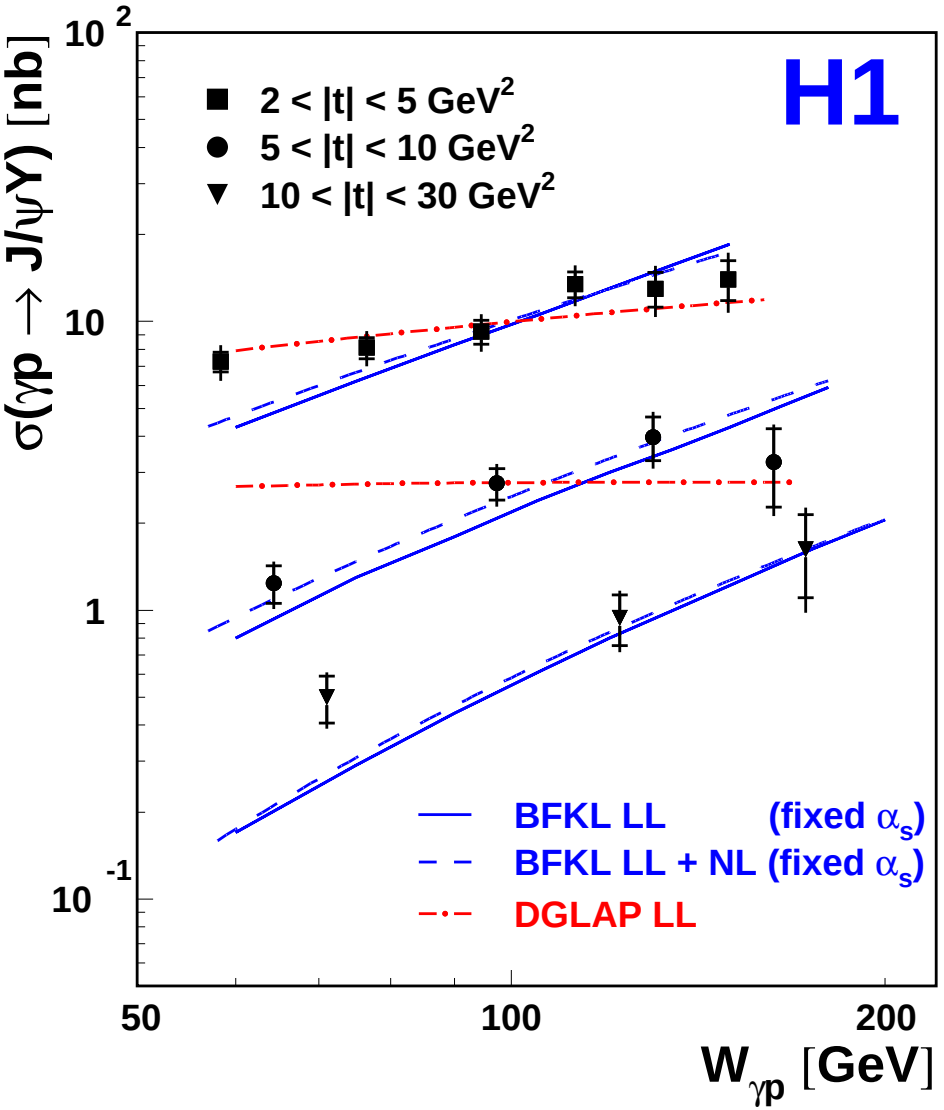
- Prescription for running α_s
$\Rightarrow$ steeper t-dependence

- DGLAP LL in range of model ($|t| \leq M_{VM}^2$)
$\Rightarrow$ describes data



Probes Region $|t| > M_{J/\psi}^2$

Diffractive J/ψ Photoproduction at Large Momentum Transfer



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

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

$\delta = 1.28$
$\pm$ 0.39 (stat.)
$\pm$ 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

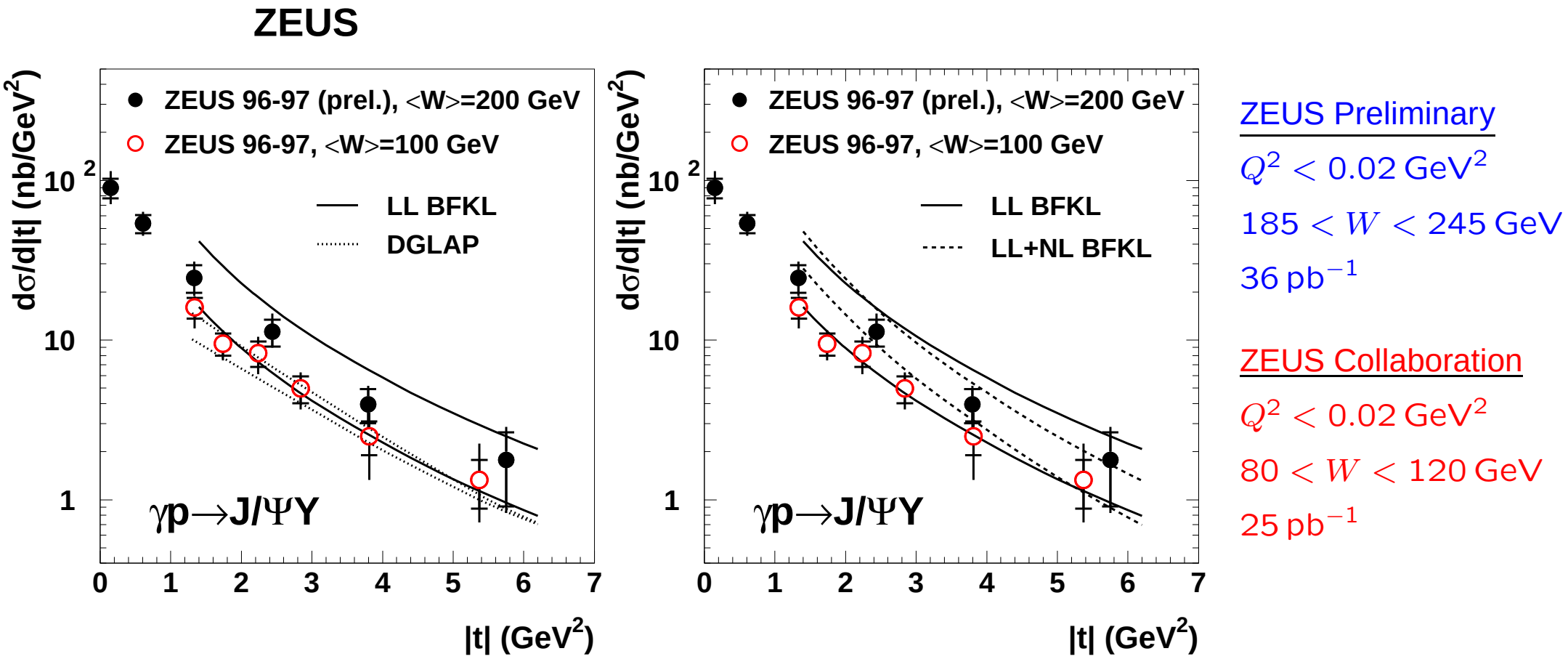
(Inputs from simultaneous fit to ρ, ϕ, J/ψ data at lower $|t|$ (ZEUS))

- 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

Diffractive High |t| J/ψ Production at High W

- Proton Dissociative Photoproduction of J/ψ



ZEUS Preliminary

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

$185 < W < 245\,\mathrm{GeV}$

$36\,\mathrm{pb}^{-1}$

ZEUS Collaboration

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

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

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

- Dependence at Large |t|: $\propto |t|^{-n}$ with $n \sim 1.7$ for Medium and High W
- No Significant Change with Increasing Energy.

(Model Inputs from Fits to H1/ZEUS Data at Medium $\langle W \rangle$)

Effective Pomeron Trajectory at Large $|t|$

Fit Form $\sigma \propto W_{\gamma p}^{\delta}$; $\delta = 4\alpha(t) - 4$ in Regions of $|t|$

- $\gamma p \to J/\psi Y$ (Large $|t|$)

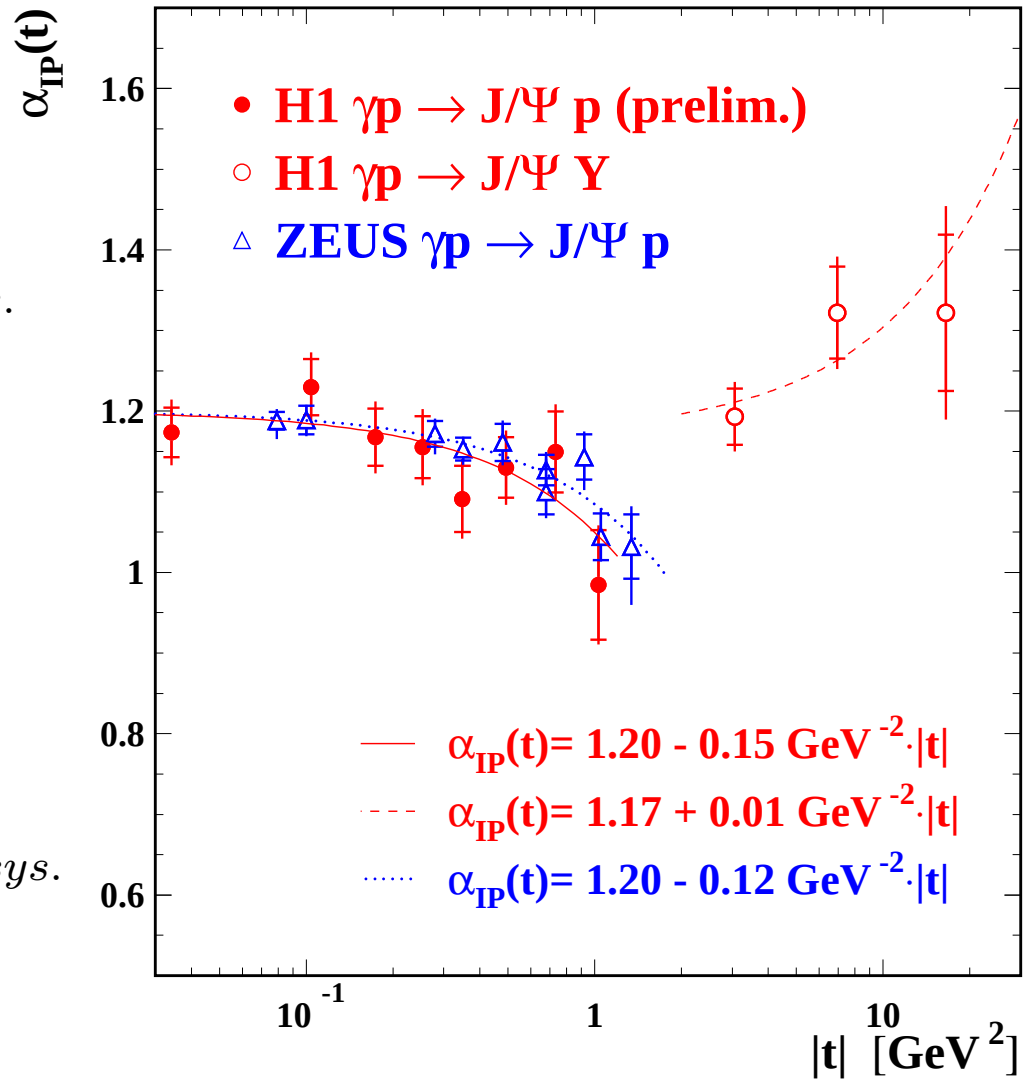
$\alpha' = -0.013 \pm 0.007_{stat.} \pm 0.005_{sys.}$
$\alpha(0) = 1.167 \pm 0.048_{stat.} \pm 0.024_{sys.}$

$\Rightarrow$ Shrinkage consistent with zero

- $\gamma p \to J/\psi p$ (Low $|t|$)

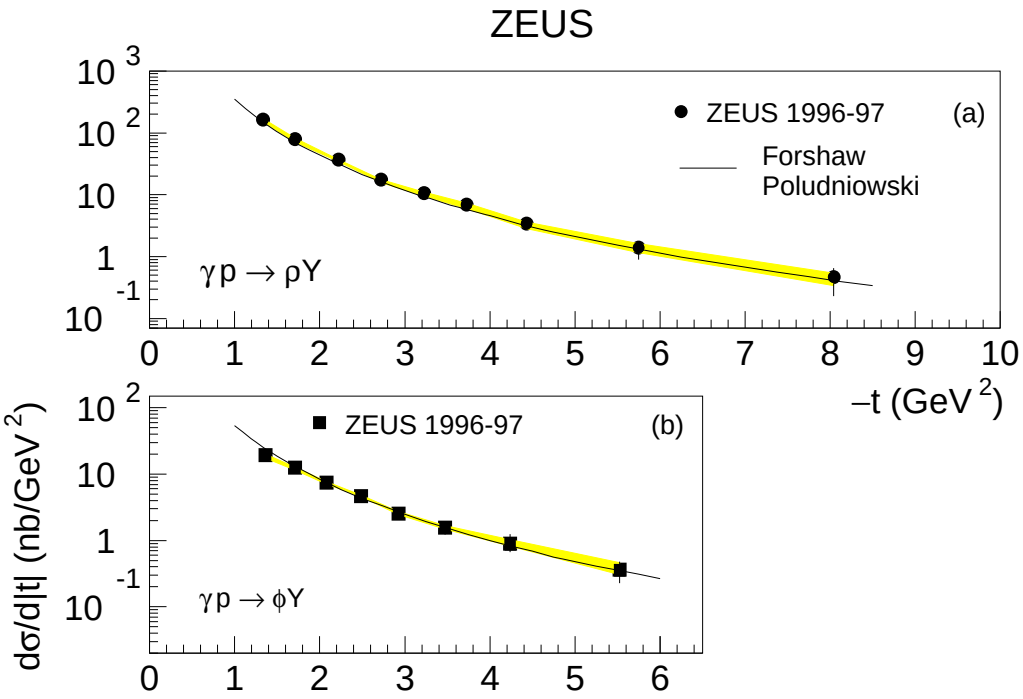
$\alpha'_{H1} = 0.154 \pm 0.054_{stat.} \pm 0.023_{sys.}$
$\alpha'_{ZEUS} = 0.115 \pm 0.018_{stat.} \pm^{0.008}_{0.015}{}_{sys.}$

$\Rightarrow$ Moderate shrinkage observed



Light Vector Meson Production at High |t|

- Proton dissociative photoproduction of ρ, ϕ



ZEUS Collaboration

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

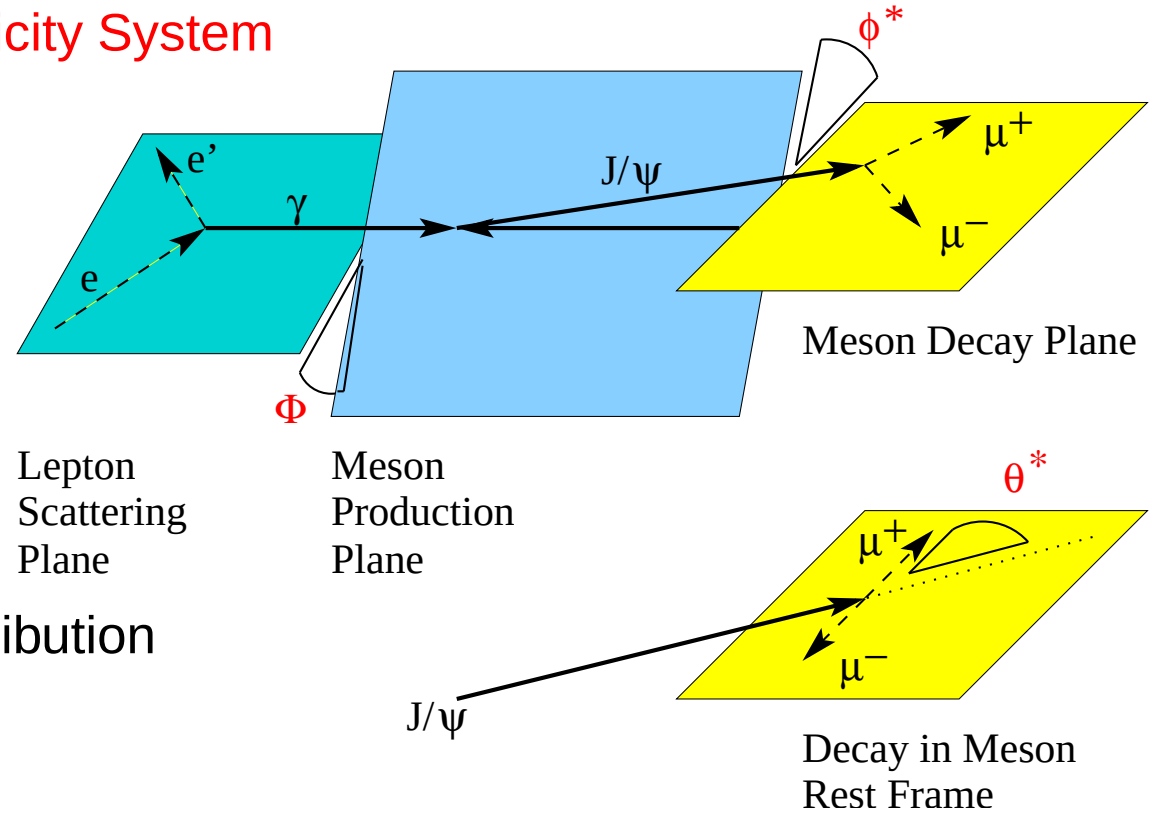
$80 < W < 120\,\mathrm{GeV}$

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

- Large $|t|$ Dependence $\propto |t|^{-n}$ with $n \sim 3$ for both ρ and ϕ
- BFKL Model (simple non-relativistic meson WF) gives good description of the $|t|$ Dependence

Helicity Studies

Define Three Angles in the Helicity System



Normalised decay angular distribution is a function of

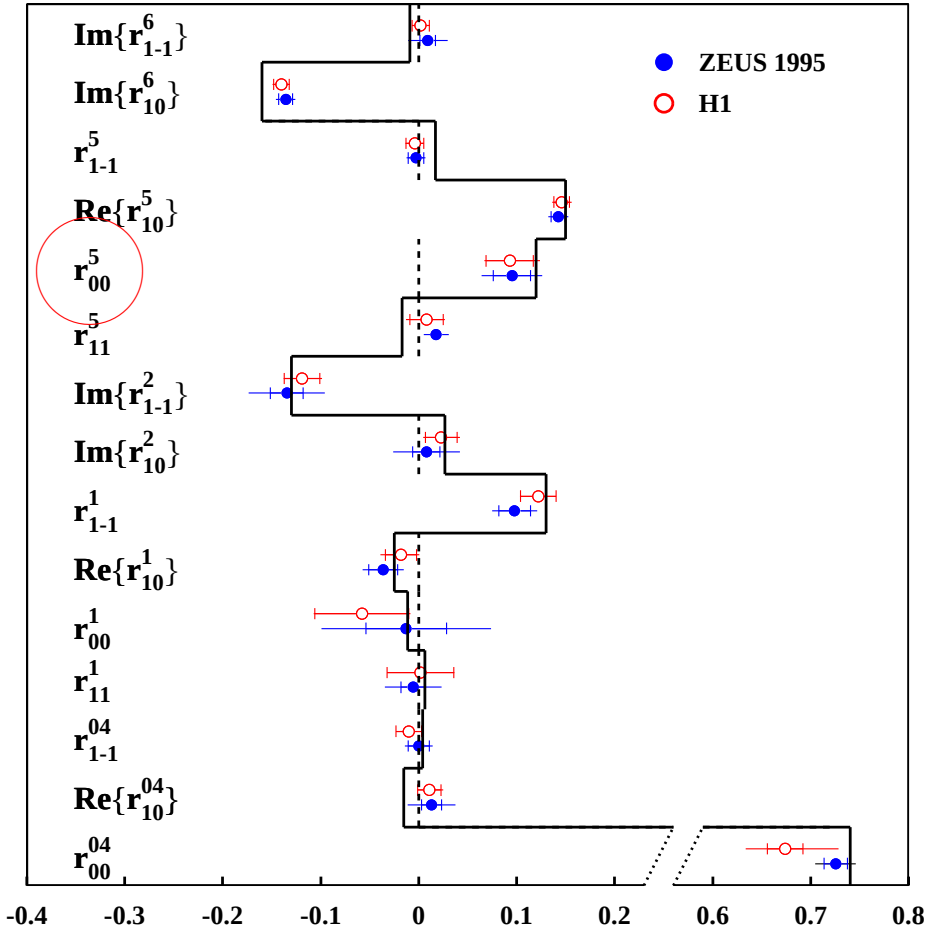
1) 3 Angles ϑ^*, φ^* and Φ

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

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

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

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



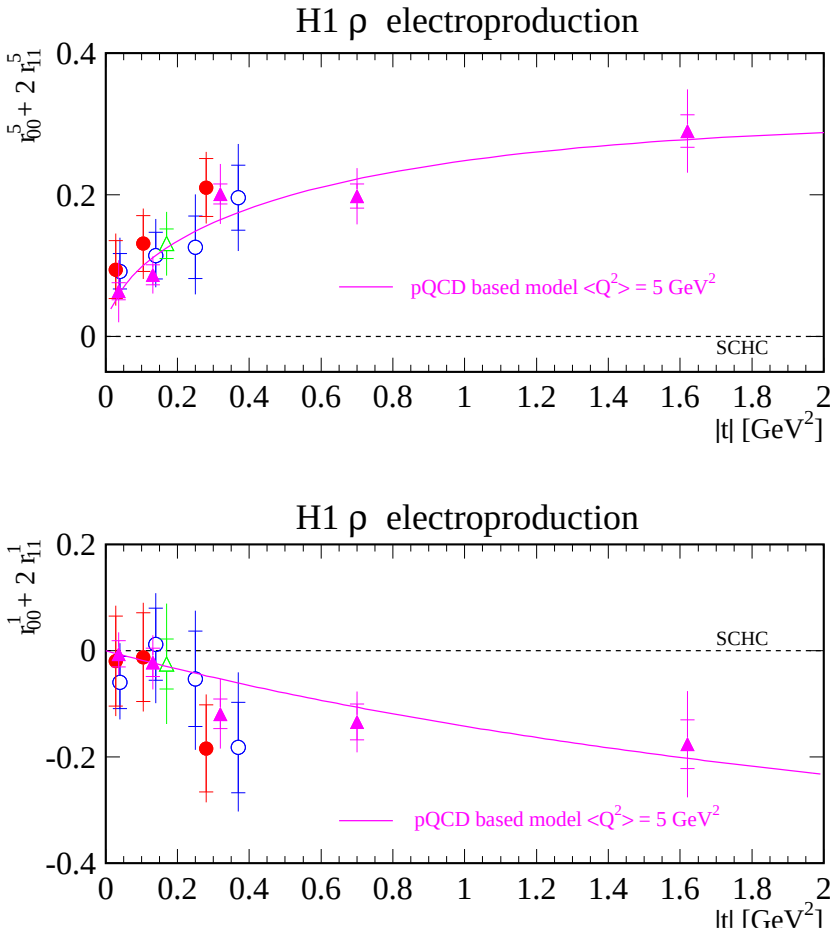
- pQCD Model (solid line) Predicts Violation

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



- 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 $r^5_{00} \propto \sqrt{|t|}$ 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 $|t|$

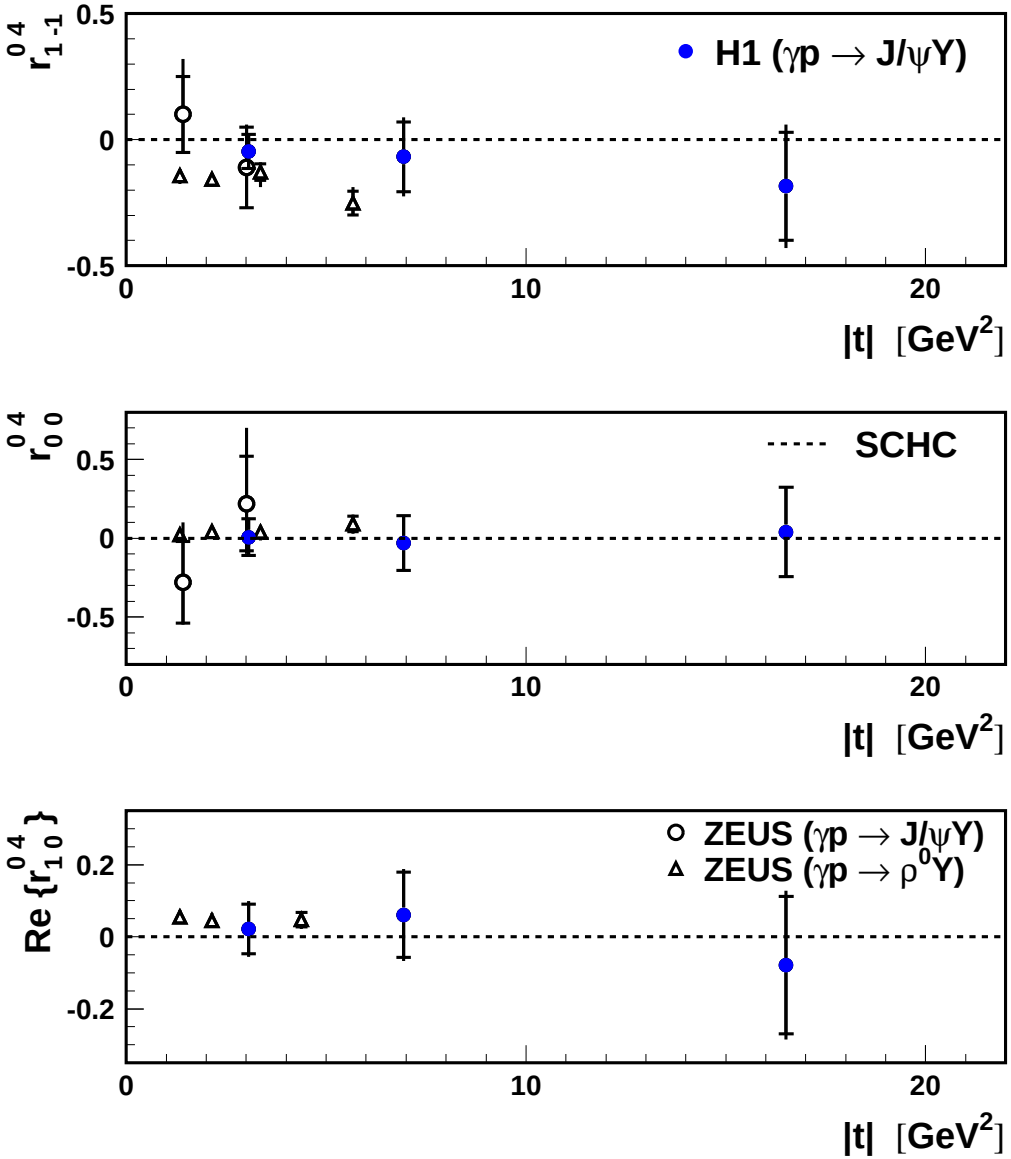
- Normalised decay angular distribution is a function of
  1) 2 Angles ϑ^*, φ^*
  2) 3 Indep. Linear Combinations of spin density matrix elements

- 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

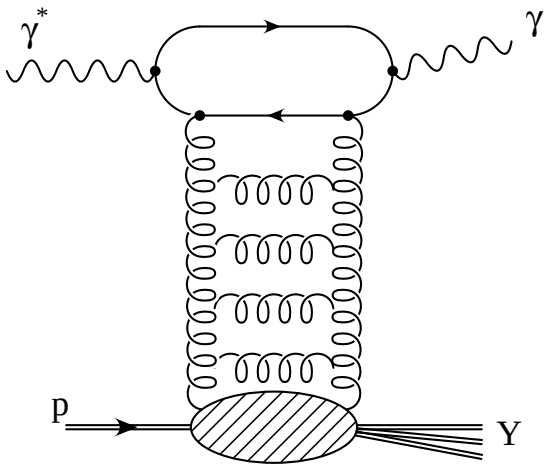
- Measured J/ψ SDMEs consistent with zero

$\Rightarrow$ Consistent with s-channel helicity conservation



Diffractive High |t| Photon Production

- Leading Log Predictions using BFKL



D. Yu. Ivanov and M. Wüsthoff, Eur. J. Phys. C **8** (1999) 107

N. G. Evanson and J. R. Forshaw, Phys. Rev. D **60** (1999) 034016

$\Rightarrow$ Leading Dependence:

$$\frac{d\sigma}{dx_{I\!P}} \sim \frac{1}{W^2_{\gamma p}} \left(\frac{1}{x_{I\!P}}\right)^{2\omega_0+2} ; x_{I\!P} \approx \frac{p_t^2}{W^2}$$

$\Rightarrow$ Avoids Inputs for Meson WF

- H1 Preliminary (99/00 Data,40 pb^{-1})

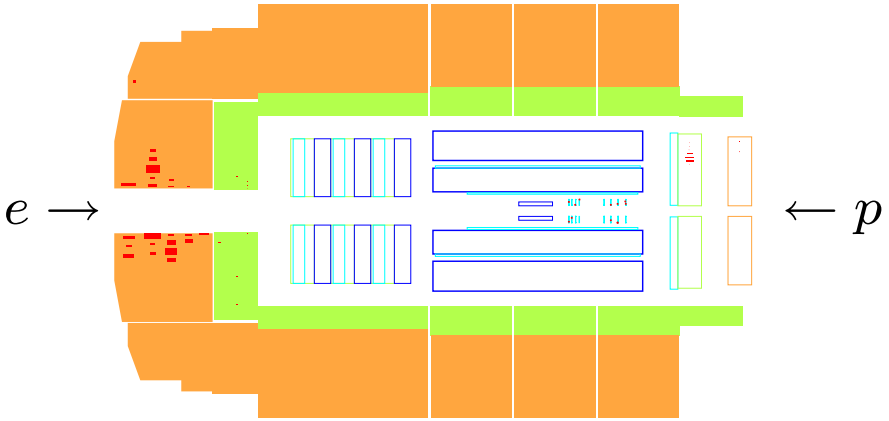
Tagged Photoproduction:

$Q^2 < 0.01\ \mathrm{GeV}^2$

$175 < W < 247\ \mathrm{GeV}$

$y_{I\!P} = \frac{\Sigma_Y (E - Pz)}{2E_\gamma} < 0.018$

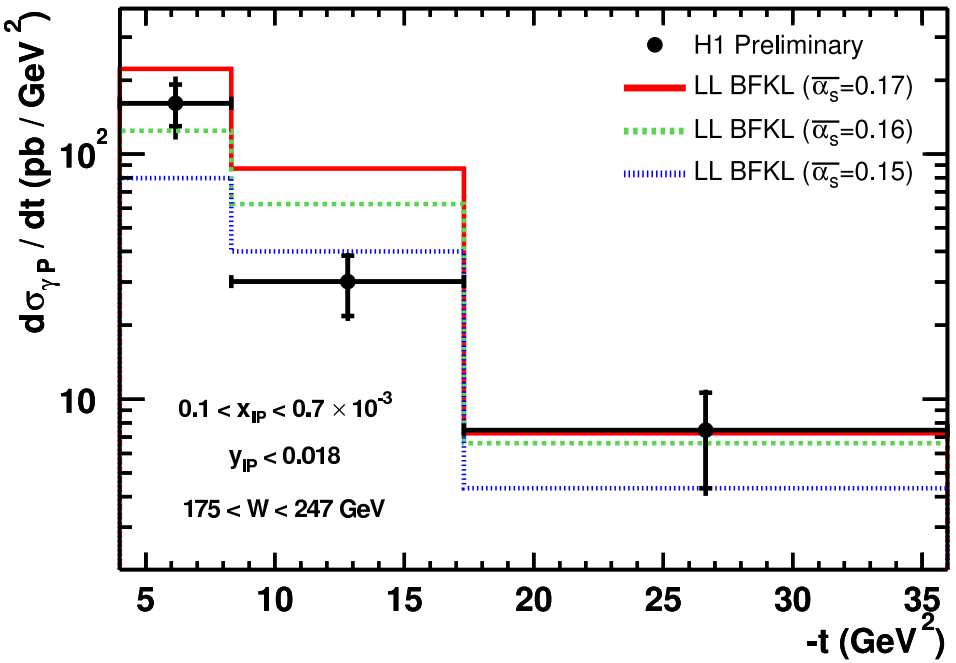
$\Delta\eta > 2$

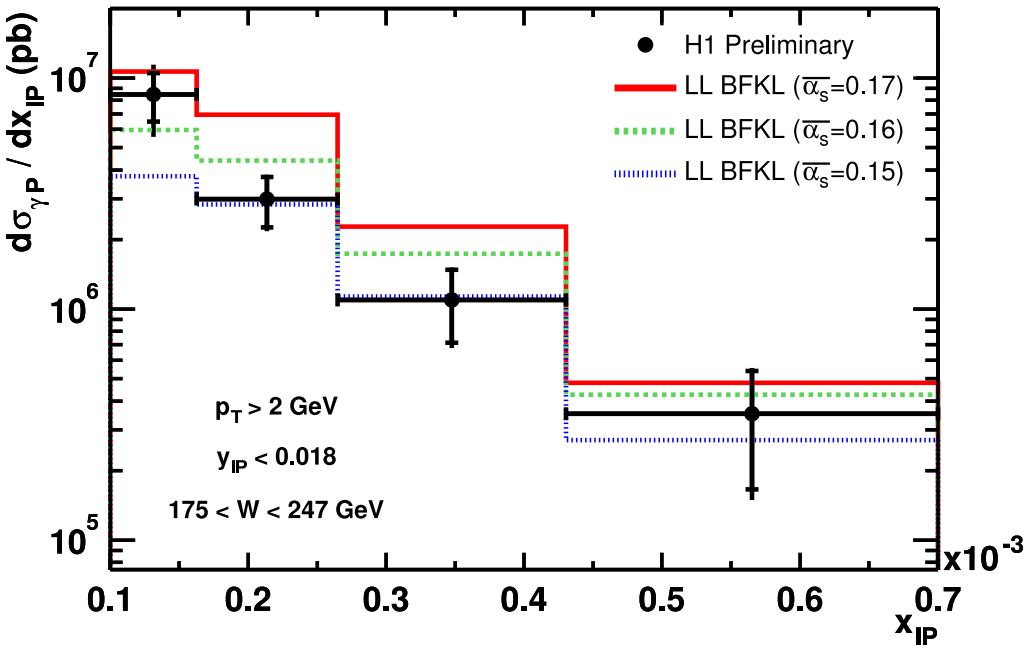


$\Rightarrow$ At Large $|t|$ Bethe Heitler kinematically suppressed

First Measurement of Diffractive High |t| Photons

H1 Preliminary: $Q^2 < 0.01\,\text{GeV}^2$, $40\,\text{pb}^{-1}$, $175 < W < 247\,\text{GeV}$, $y_{I\!P} < 0.018$





- BFKL Model Implemented into Signal MC

  B. E. Cox and J. R. Forshaw, J. Phys. G **26** (2000) 702

Steep Rise towards Small $x_{I\!P}$

- LL BFKL Predictions (from MC) $\Rightarrow$ Basic Description of Main Features

Conclusions

- Measurements of Exclusive Diffractive Processes at Large $|t|$ at HERA
  Providing Insight into
  – Structure of the Diffractive Exchange
  – Helicity Structure / Meson Wavefunctions

- Measurements Now Extend to much Larger Values of $|t| \sim 30\,\mathrm{GeV}^2$
  and Larger Values of W

- pQCD Models Giving Good Agreements within Large Region
  covered by Data

Future Increase in Statistics (e.g. Larger Q^2):
– Higher Precision Tests over a Larger Kinematic Region