DIS 2004

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Diffractive Photoproduction of J/ψ and Single Photons at Large $|t|$

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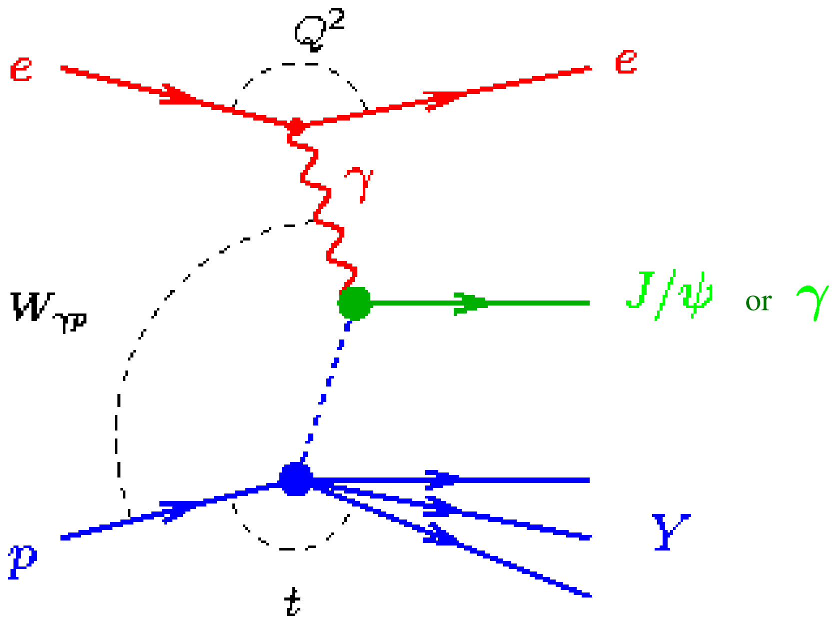
For the H1 and ZEUS Collaborations

Kinematic Variables



Q^2 — **Photon Virtuality**
Photoproduction: $Q^2 \sim 0$

$W_{\gamma p}$ — **CM – energy of γp – system**

t — **(Mom. transfer at p – vertex)^2**

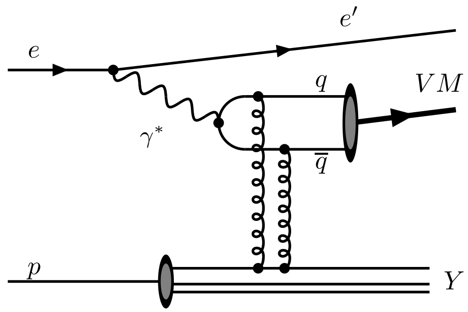
$$|t| \simeq (p_t^2)_{J/\psi,\ \gamma}$$

Large $|t|$ $\Rightarrow$ Proton dissociates to system Y

Hard Scales for pQCD in Photoproduction: $M_{J/\psi}$, t

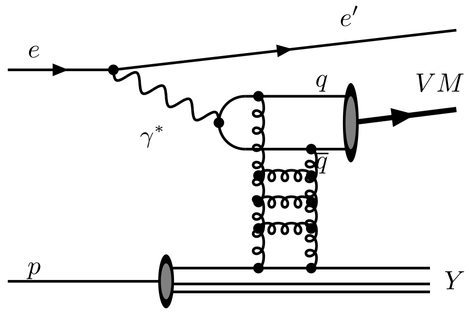
Motivation: Study nature of the Diffractive Exchange in limit of large t and large $W_{\gamma p}$ (small x)

Diffractive VM Production as Factorized Process



- The Photon fluctuates into a Colour Dipole, $q\bar{q}$
- Colour Singlet Exchange between $q\bar{q}$ and single Parton in the Proton
- $q\bar{q}$ forms a Vector Meson VM

Colour Singlet Exchange



- In lowest order Exchange of 2 Gluons
- Becomes a "Gluon Ladder" in Leading Log Approximations
- **DGLAP Evolution:**
  Ordered momenta along the "ladder rungs"
  Describes the inclusive cross-section very well over large range of x and Q^2
- **BFKL Evolution:**
  Unordered momenta in ladder
  Expected to be important at low values of x

pQCD Models in Leading Log Approximation for Large $|t|$

BFKL

Authors:

Forshaw, Ryskin	Z.Phys. C68 (1995) 137
Bartels, Forshaw, Lotter, Wüsthoff	Phys.Lett. B375 (1996) 301
Enberg, Motyka, Poludniowski	Eur.Phys.J. C26 (2002) 219
Forshaw, Poludniowski	Eur.Phys.J. C26 (2003) 411

Predictions:

- Power law behaviour of t – dependence, $|t|^{-n}$
  n is a function of t
- Steep Increase of $d\sigma/dt$ with increasing $W_{\gamma p}$
  Increase $\sim$ independent of value of t
- S-Channel Helicity Conservation
  Follows from the used non-relatistic wavefunction model of J/ψ, with $q\bar{q}$ sharing the photon momentum equally.
  Note: SCHC Violation for low t and low VM masses !

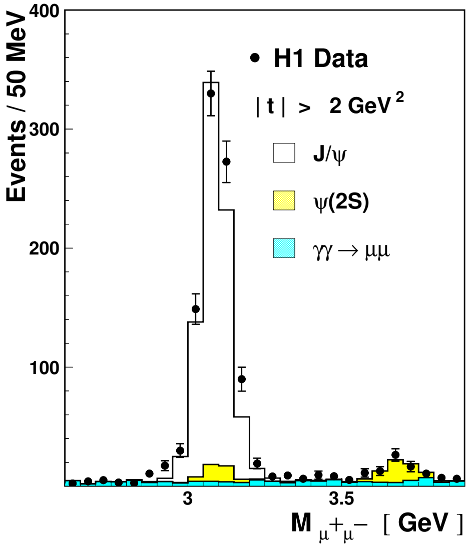
DGLAP

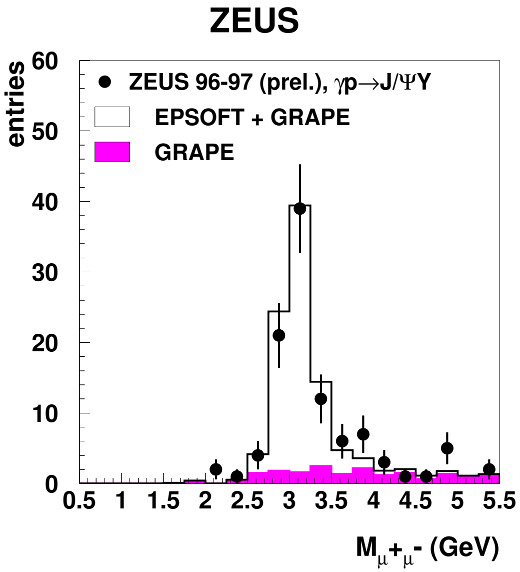
Authors: Gotsman, Levin, Maor, Naftali Phys.Lett. B352 (2002) 37

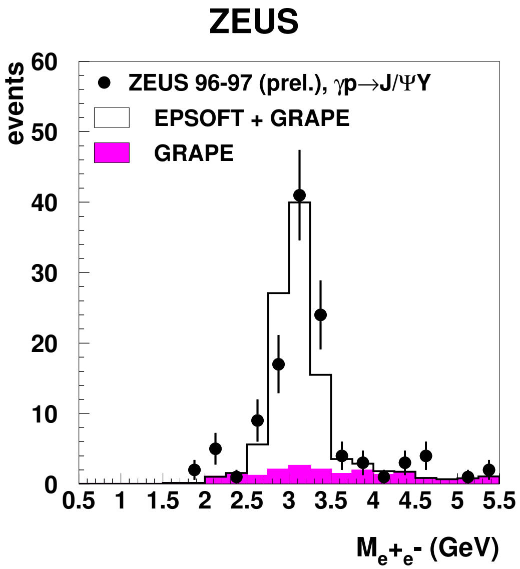
Predictions:

- Weak Increase of $d\sigma/dt$ with increasing $W_{\gamma p}$
- Model validity limited to $1 < |t| < M^2_{J/\psi}$ GeV^2

DIFFRACTIVE PHOTOPRODUCTION OF J/ψ AT LARGE $|t|$







1999-2000 **78 pb^{-1}**

Untagged: $Q^2 < 1$ GeV^2

$\langle Q^2 \rangle \simeq 0.06$ GeV^2

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

$2 < |t| < 30$ GeV^2

$z > 0.95, \Rightarrow M_Y < 30$ GeV

$$z = p \cdot p_{J/\psi}/p \cdot q \simeq 1 - (M_Y^2 - t)/W_{\gamma p}^2$$

$\sim$ 850 events $J/\psi \to \mu^+\mu^-$

Phys.Lett.B568 (2003) 205

1996 – 97 **36 pb^{-1}**

Tagged: $Q^2 < 0.02$ GeV^2

$185 < W_{\gamma p} < 245$ GeV

$1.1 < |t| < 7$ GeV^2

$M_Y < 30$ GeV

$\sim$ 200 events $J/\psi \to \mu^+\mu^-,\ e^+e^-$ **Preliminary**

$80 < W_{\gamma p} < 120$ GeV **25 pb^{-1}**

Eur.Phys.J.C26 (2003) 389

t – dependence

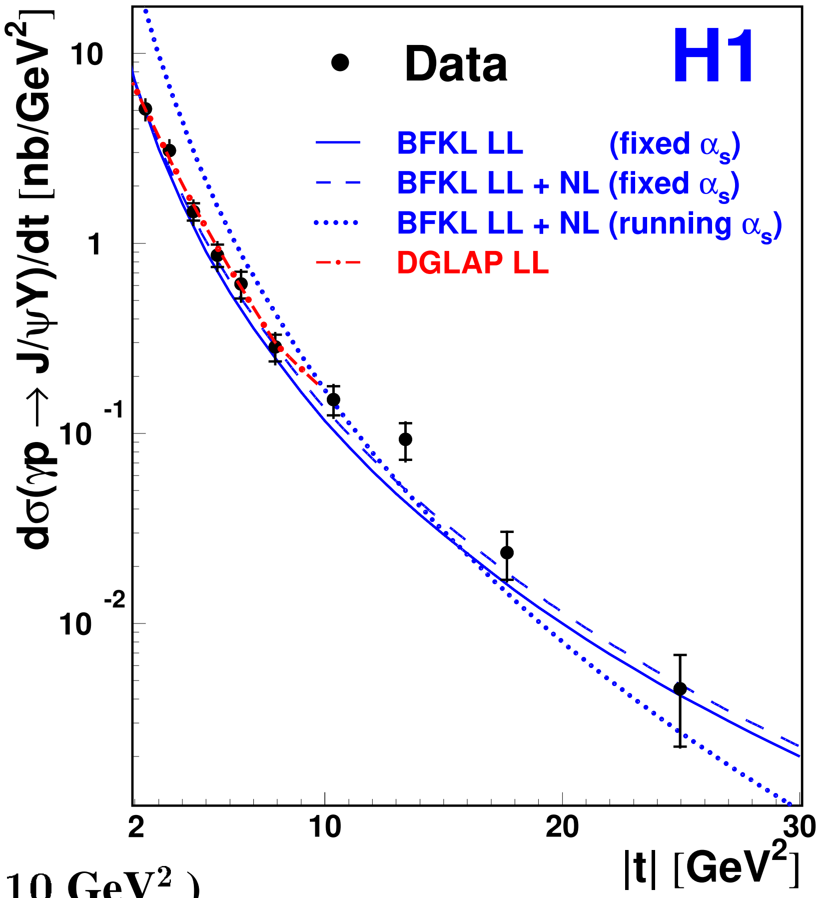
Data incompatible with Exponential dependence

BFKL

- **Describes t–dependence in LL approximation**
  (fixed) $\alpha_s = 0.18$ $W_0 = M_{J/\psi}/2$
- **Adding NL corrections: Small difference only**
- **Using running α_s: Steeper than the data.**
- **Power Law behaviour, $d\sigma/dt \sim |t|^{-n}$**
  (Not shown)

$$n = 3.00 \pm 0.08 \pm 0.05 \qquad (|t| > 3.45 \text{ GeV}^2)$$

Increasing the starting $|t|$–value
$\Rightarrow$ n also increases systematically.



DGLAP

- **Describes the data in its Domain of Validity** $(|t| < 10 \text{ GeV}^2)$

$W_{\gamma p}$ – dependence

Data

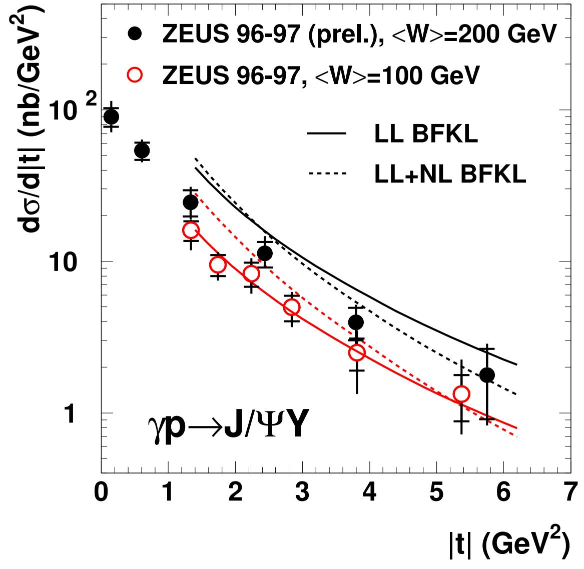
- Cross-Section clearly increases from 100 to 200 GeV
  $d\sigma/dW_{\gamma p} \sim W_{\gamma p}^{\delta} \quad \rightarrow \quad \delta = 0.8 \pm 0.5$ at high $|t|$
- Steep t – dependence
  $d\sigma/dt \sim |t|^{-n} \quad \rightarrow \quad n = 1.7 \pm 02 \pm 0.3$

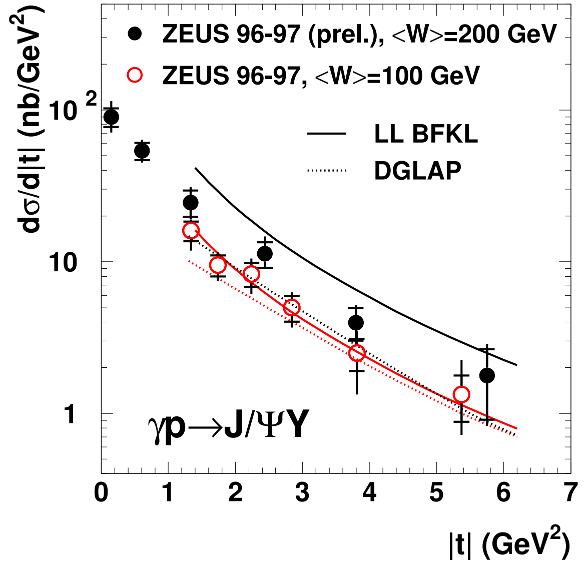
BFKL

- Model tuned with data at $\langle W_{\gamma p} \rangle = 100$ GeV
- The BFKL LL curve overshoots the data at 200 GeV
- BFKL LL with NL corrections, using running α_s, has too steep t – dependence
- However, BFKL reproduces the general trend of the data

DGLAP

- Model does not reproduce the increase in cross-section
- $W_{\gamma p}$ – dependence almost flat between 100 and 200 GeV





$W_{\gamma p}$ – dependence

- **Three intervals of $|t|$**
- $d\sigma/dW_{\gamma p} \sim W_{\gamma p}^{\delta}$

$$\boxed{\begin{array}{l} \delta = 0.77 \pm 0.14 \pm 0.10 \\ \delta = 1.29 \pm 0.23 \pm 0.16 \\ \delta = 1.30 \pm 0.39 \pm 0.36 \end{array}}$$

Similar to case of Elastic J/ψ – production $(\delta \sim 1)$

- **Assuming:** $d\sigma/dt = F(t) W_{\gamma p}^{4(\alpha(t)-1)}$, $\alpha(t) = \alpha(0) + \alpha' t$

$\Longrightarrow$

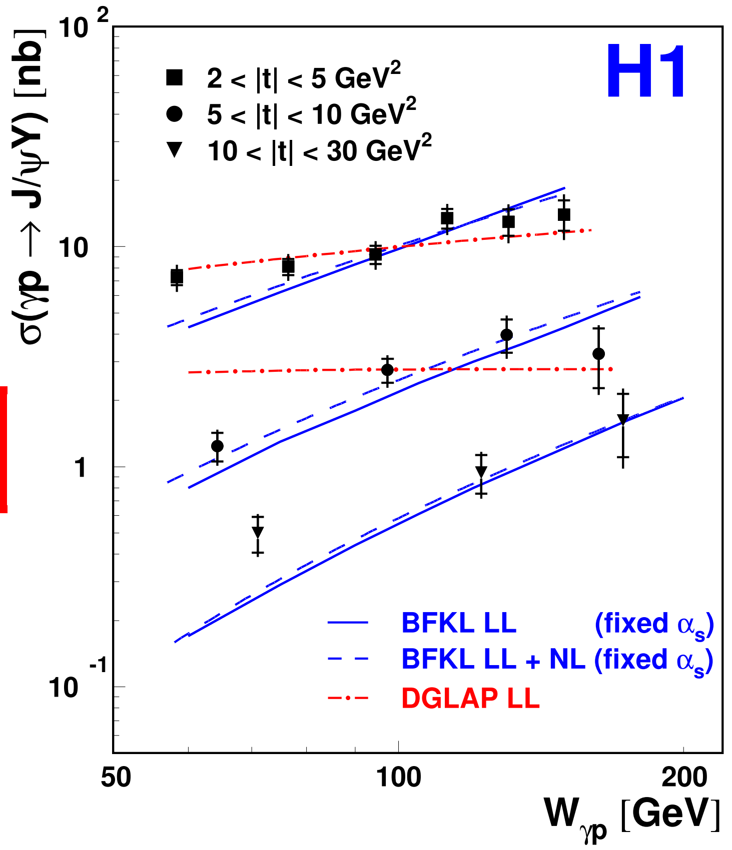
$$\boxed{\begin{array}{lclclcl} \alpha(0) & = & 1.167 & \pm & 0.048 & \pm & 0.024 \\ \alpha' & = & -0.0135 & \pm & 0.0074 & \pm & 0.0051\ \mathrm{GeV}^{-2} \end{array}}$$

At low $|t|$ – values ZEUS previously found

Eur.Phys.J.C24(2003)345 $\alpha(0) = 1.200 \pm 0.009^{+0.004}_{-0.010}$

$\alpha' = 0.115 \pm 0.018^{+0.008}_{-0.015}\ \mathrm{GeV}^{-2}$

- **BFKL Describes the data rather well**
- **DGLAP Good description at low $|t|$ – values, but $W_{\gamma p}$ – dependence too shallow at higher $|t|$**



J/ψ Decay Angular Distribution

- **Decay angles ϕ^*, θ^*,**
  3 combinations of Spin Density Matrix Elements

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta^*\,d\phi^*} = \frac{3}{4\pi}\Big[\tfrac{1}{2}(1+r^{04}_{00}) - \tfrac{1}{2}(3r^{04}_{00}-1)\cos^2\theta^* + \sqrt{2}Re\{r^{04}_{10}\}\sin 2\theta^*\cos\phi^* + r^{04}_{1-1}\sin^2\theta^*\cos 2\phi^*\Big]$$

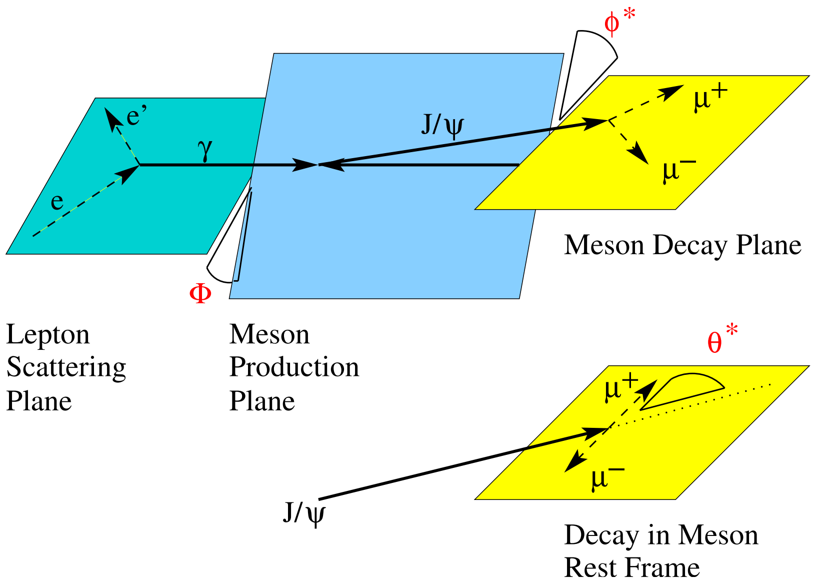
- **1-dim. Projections:**

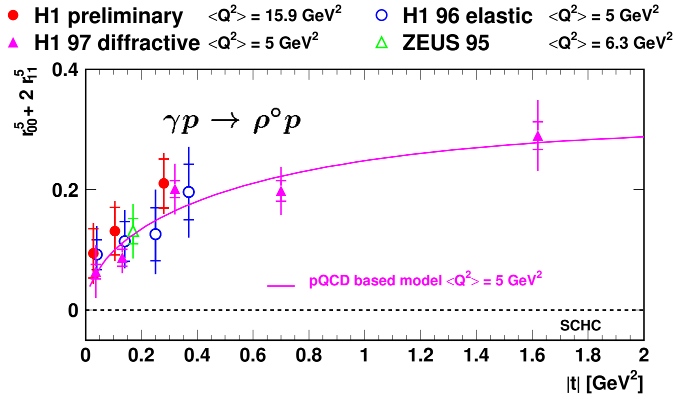
$$d\sigma/d\cos\theta^* \;\propto 1 + r^{04}_{00} + (1-3r^{04}_{00})\cos^2\theta^*$$
$$d\sigma/d\cos\phi^* \;\propto 1 + r^{04}_{1-1}\cos^2 2\phi^*$$

- **SCHC:**
  Expect r^{04}_{00}, r^{04}_{1-1} and $\mathrm{Re}\{r^{04}_{10}\}$ all zero

2-dim. Log Likelihood Fit of data $\Longrightarrow$

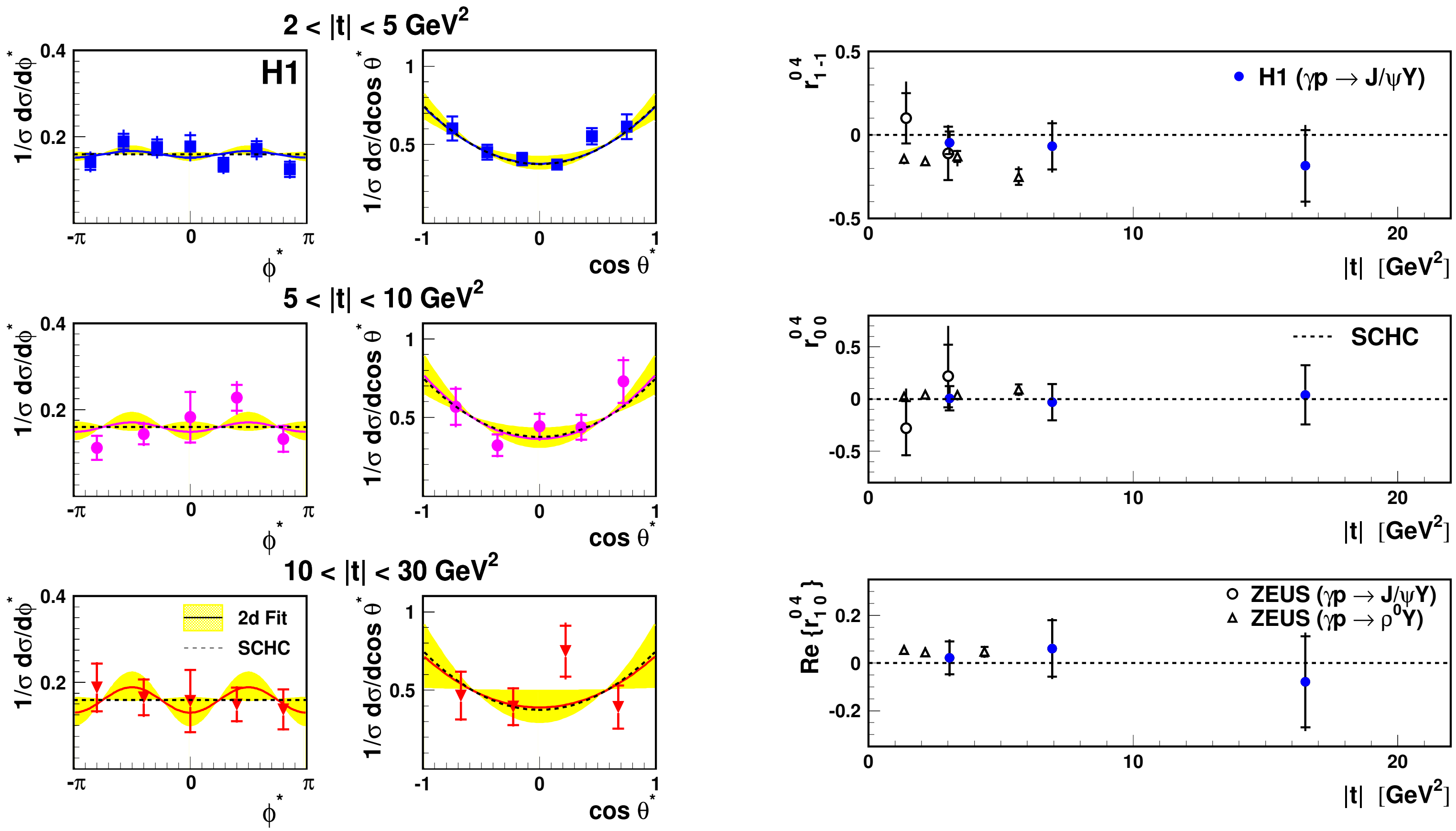
HELICITY SYSTEM





SCHC Violation

Light VM
Small $|t|$

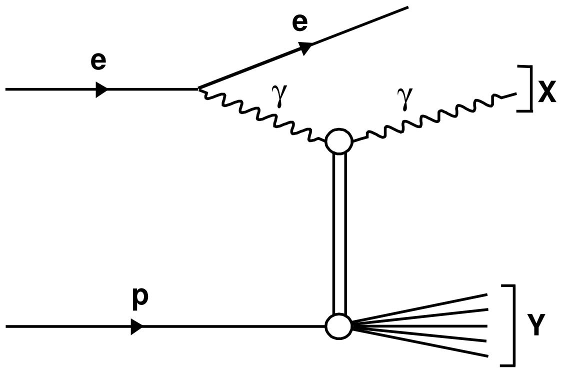


Data compatible with SCHC

Contrast to light VM case

Supports assumptions made in the BFKL model

Motivation:



- **Simplest possible final state X, no VM wavefunction**
- **Larger Rapidity Gap selection possible**

  $\Delta\eta \simeq \log(\hat{s}/(p_t^\gamma)^2)$ $\rightarrow$ **large $\hat{s}$ can be reached (BFKL LL appr.)**
- **Complements the DVCS process ($Q^2 > 0$): "high-$|t|$ VCS"**
- **BFKL LL Approximation discussed in recent papers**

Ivanov, Wüsthoff	Eur.Phys.J.C8(1999)107
Evanson, Forshaw	Phys.Rev.D60(1999)034016
Cox, Forshaw	J.Phys.G26(2000)702

- **Model Implementation in the HERWIG generator**

Parameters of the model

α_s **enters in 2 ways**

▷ **4th power in prefactor of cross-section**

▷ **in Pomeron intercept $1 + \omega_0$**

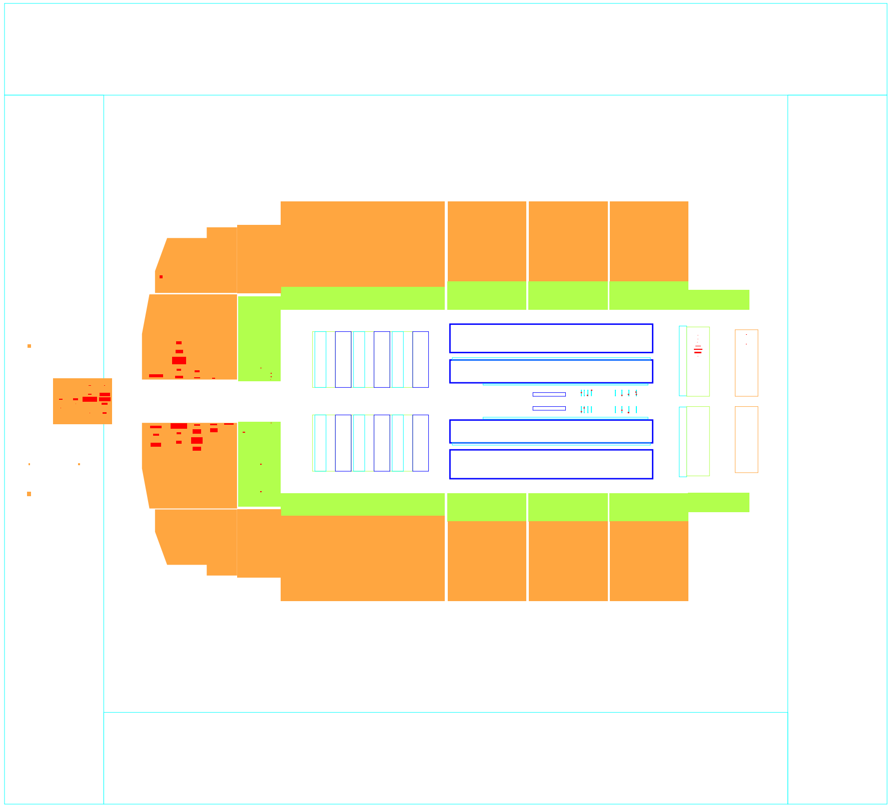
$$\omega_0 = (3\alpha_s/\pi)4\ln 2$$

$\rightarrow$ **Set equal:** $\overline{\alpha_s}$

Kinematic Variables:

- $t \simeq -(p_t^\gamma)^2$
- $x_{I\!P} = \frac{q\cdot(P-Y)}{q\cdot P} \simeq \frac{(E+P_z)_\gamma}{2E_p} \simeq \frac{(p_t^\gamma)^2}{W_{\gamma p}^2}$
- $y_{I\!P} = \frac{P\cdot(q-X)}{q\cdot P} \simeq \frac{\sum_Y(E-P_z)}{2E_\gamma} \simeq e^{-\Delta\eta}$

Event Sample



- **48 pb^{-1}, 1999-2000 data**
  ($E_{e^+} = 27.5$ GeV, $E_p = 920$ GeV)
- e **– Tagged Photoproduction**

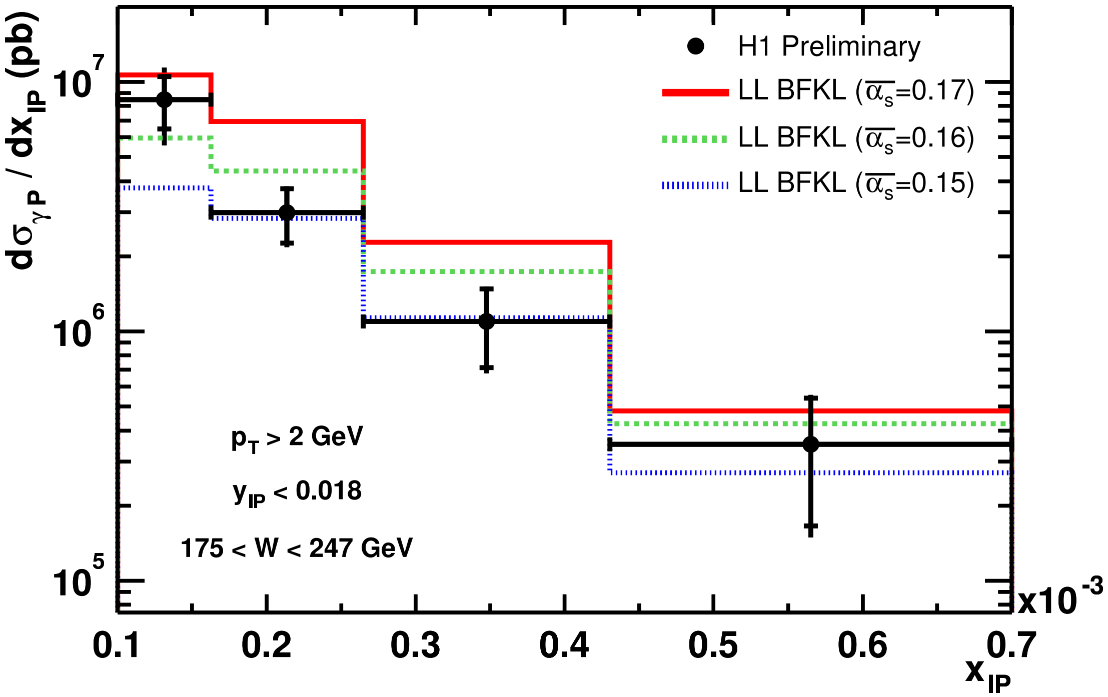
  $Q^2 < 0.01$ GeV^2,
  $0.3 < y < 0.6$,
  $175 < W_{\gamma p} < 247$ GeV
- **Rapidity Gap:**

  $\Delta\eta > 2$ (γ <—> Y – edge),
  $y_{I\!P} < 0.018$
- $p_t^{\gamma} > 2$ GeV $E_{\gamma} > 8$ GeV
- **Background:**

Inclusive, diffractive photoproduction: $< 9\%$, **subtracted bin by bin**
Diffractive, high – $|t|$ ω **– production,** $\omega \rightarrow \gamma\pi^{\circ}$: **negligible**

FIRST MEASUREMENT OF THIS PROCESS

Steep rise of data at small $x_{I\!P}$ – values



BFKL predicts this rise

"driven by the BFKL Kernel"

$$d\sigma / dx_{I\!P} \sim 1/W^2_{\gamma p}\, (1/x_{I\!P})^{2(1+\omega_0)}$$

Slope of the $x_{I\!P}$ – distribution given by choise of α_s in Pomeron intercept

Data basically described in shape and normalization by the model implementation

$$\overline{\alpha_s} = 0.15 - 0.17$$

$\alpha_s = 0.18$ **was found to describe J/ψ – production at large $|t|$**

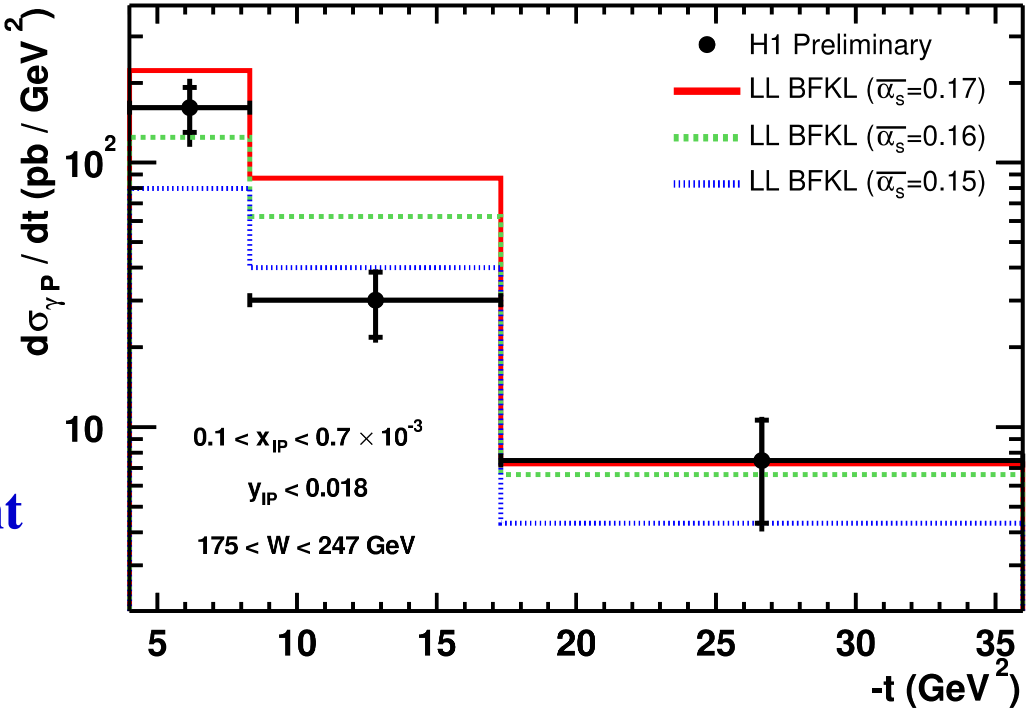
t – distribution:

poorly described

But:

LLA has intrinsic uncertainty in the normalization,

Higher order effects may be important



Need more theoretical work

Need more precise measurements (much more data !)

SUMMARY

J/ψ – Photoproduction at Large $|t|$

- Data extend to large values of $|t|$ and $W_{\gamma p}$
- Steep rise of Cross-Section with $W_{\gamma p}$, $\sim$ independent of $|t|$
- Shrinkage: Low or none t – Dependence: $|t|^{-n}$
- Basic features of data described by pQCD models in LL Approximation
  - ▷ BFKL successful up to highest values of $|t|$ and $W_{\gamma p}$
  - ▷ DGLAP describes data in validity domain $1 < |t| < 10$ GeV^2
- S – Channel Helicity Conservation compatible with data at all values of $|t|$

Photoproduction of Single High – p_t Photons

- Process measured for the first time
- Basic features of data described by a BFKL LL model
- More theoretical work and more precise measurements are needed

Both processes will profit very much from the HERA-II increase in statistics !