Measurement of the J/ψ photoproduction at large momentum transfer at HERA

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on behalf of the ZEUS Collaboration

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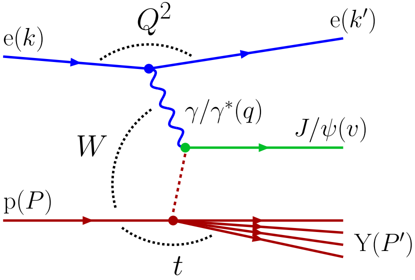
Recent paper by ZEUS Collaboration
ZEUS Collab., DESY-09-137, accepted by JHEP
Results preliminary since a while, presented at DIS05 and ICHEP06:

http://www-zeus.desy.de/physics/diff/pub/prelim/05-006/dszuba-dis05.pdf
http://www-zeus.desy.de/physics/phch/conf/ichep06/diff/6/ZEUS-prel-05-006.ps

Similar results published by H1 Collaboration:
Diffractive Photoproduction of J/ψ Mesons with Large Momentum Transfer at HERA
A. Aktas et al., Phys Lett B568 (2003) 205-218
see also the talk of Boris Blok at this workshop:
DGLAP versus perturbative Pomeron in hard diffractive processes large momentum transfer at HERA and LHC

$\gamma p \to J/\psi Y$ at large $|t|$ - kinematics



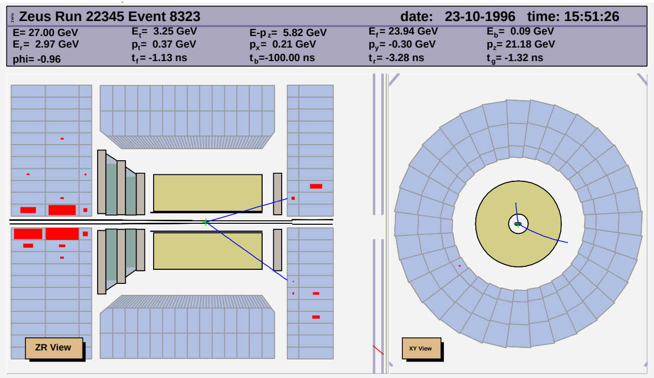
Kinematic variables

- Q^2, virtuality of the exchanged photon
- W, γp centre-of-mass energy
- t, 4-momentum transfer squared at the p-vertex
- M_Y mass of the p-dissociative state

- Usually the inelasticity variables z is introduced, fraction of the γ energy transferred to the J/ψ:
  $z = \frac{p_{J/\psi} \cdot p}{q \cdot p} \simeq 1 - \frac{M_Y^2 + |t|}{W^2} \simeq 1$ for semi-exclusive processes

At HERA (ep 27.5-820/920 GeV^2), a wide range in W, t and M_Y can be accessed

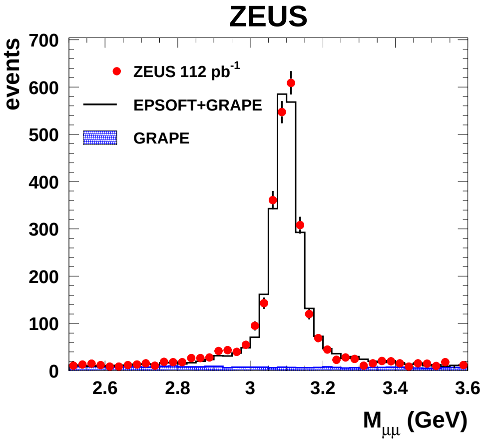
$\gamma p \to J/\psi Y$, $J/\psi \to \mu^+\mu^-$ experimental signature



- two tracks well reconstructed in the central tracking detector
- each track associated with a muon candidate in CAL and to a hit in the muon detector (trigger)
- some energy in the forward region, nothing else
- scattered electron not observed

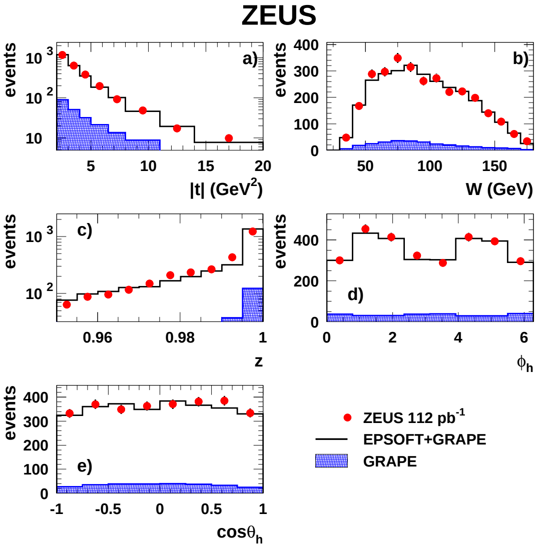
J/ψ at large $|t|$, extraction of the signal

- HERA I data, 1996-2000, 112 pb^{-1} of luminosity
- $30 < W < 160$ GeV
- $2 < |t| < 20\ \mathrm{GeV}^2$
- $z > 0.95$, inelasticity cut
- 2817 events in $2.6 < M_{\mu\mu} < 3.5$ GeV



Background from exclusive channel $ep \rightarrow e\mu^+\mu^- p$ suppressed
Background from $ep \rightarrow e\mu^+\mu^- Y$ subtracted ($\simeq 6 - 10\%$)

J/ψ at large $|t|$, control plots



Kinematic region

- $30 < W < 160$ GeV
- $|t| > 2$ GeV^2
- $z > 0.95$ ($M_Y < 30$ GeV)

MC EPSOFT $\gamma p \to J/\psi Y$

MC GRAPE $\gamma p \to \mu^+\mu^- Y$

Kinematic variables well described by the Monte Carlo

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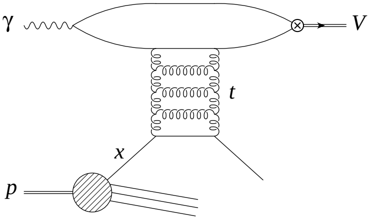
$\gamma p \to J/\psi Y$



Hard inelastic diffractive process

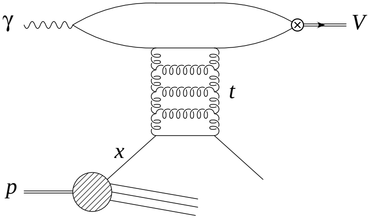
- For hard scales pQCD can be applied
- Two scales: $M_{J/\psi}$ and t
- In perturbative QCD the VM production is mediated by an exchange of a gluon ladder in a colour singlet state

- $x = \frac{|t|}{M_Y^2 - M_p^2 + |t|} \simeq \frac{|t|}{(1-z)W^2}$
- large $|t|$ domain allows to investigate QCD dynamics vs x

Challenge is to describe all the variables simultaneously

QCD dynamics, DGLAP vs BFKL

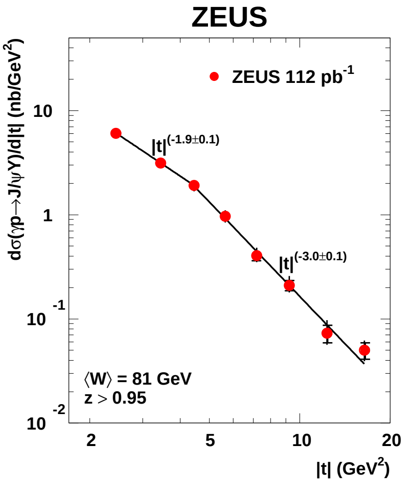
QCD dynamics: $\alpha_S \ln \frac{x_0}{x} \ln \frac{Q^2}{Q_0^2}$



- DGLAP dynamics driven by terms $\ln \frac{M^2_{J/\psi}}{Q_0^2 - t}$
- BFKL evolution is driven by terms $\alpha_S^n \ln^n(W^2/|t|) \Rightarrow$ expected to dominate at larger $|t|$

- GLMN (Gotsman, Levin, Maor, Naftali 2002), DGLAP evolution tamed for $|t| \simeq M^2_{J/\psi}$
- FSZ (Frankfurt, Strikman, Zhalov 2008), increase of σ with t due to increase of $xG(x, Q^2)$ on Q^2
- EMP (Enberg, Motyka, Poludniowski 2003), BFKL evolution

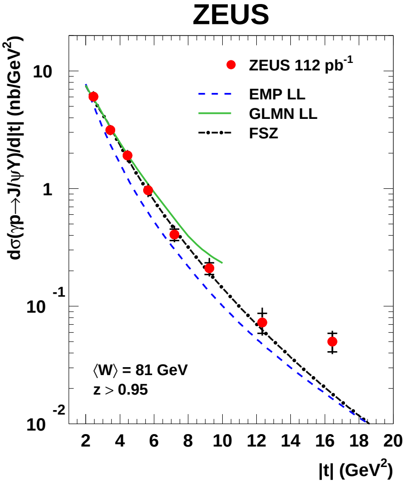
J/ψ at large $|t|$, $|t|$ dependence

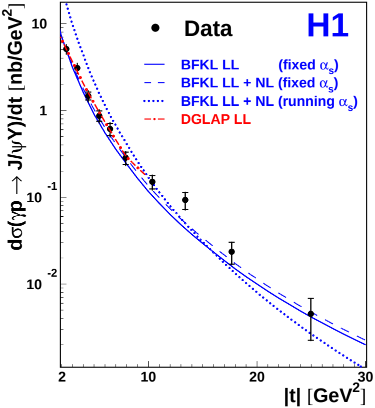


Fit $d\sigma/dt \simeq |t|^n$

- Data cannot be described by a single exponential fit $d\sigma/dt \simeq e^{bt}$ neither by a single power $d\sigma/dt \simeq |t|^n$
- All models predicts a power-law t-dependence, with n depending on t range

J/ψ at large $|t|$, $|t|$ dependence - model comparison





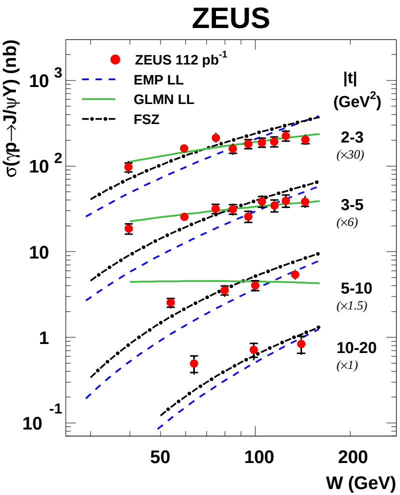
EMP (BFKL) below data

GLMN (DGLAP) validity range of $|t| < M^2_{J/\psi}$

FSZ describe data up to 12 GeV^2

Models able to describe data but not for the full t (x) range

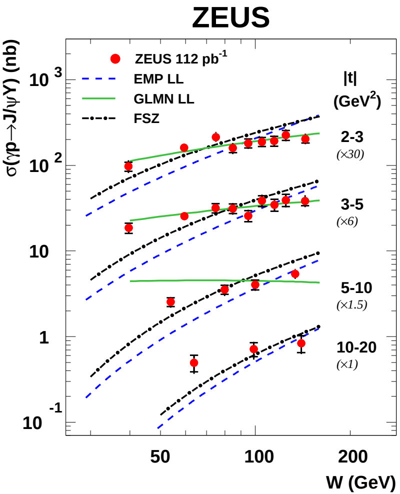
J/ψ at large $|t|$, W dependence - model comparison

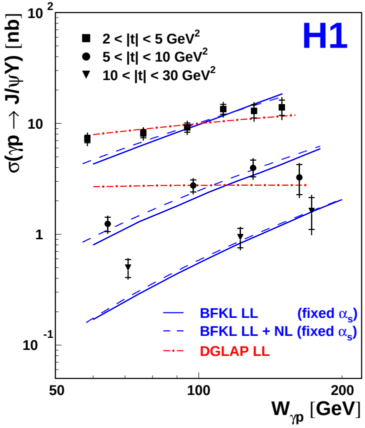


$$x = \frac{|t|}{M_Y^2 - M_p^2 + |t|} \simeq \frac{|t|}{(1-z)W^2}$$

- Data rise with W for all t region
- BFKL (EMP) predictions too steep
- DGLAP (GLMN) approach fails to describe σ rise at low x
- FKS: increase of σ due to gluon distribution in the proton

J/ψ at large $|t|$, W dependence - model comparison

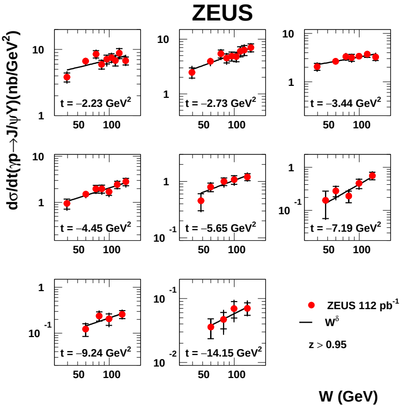


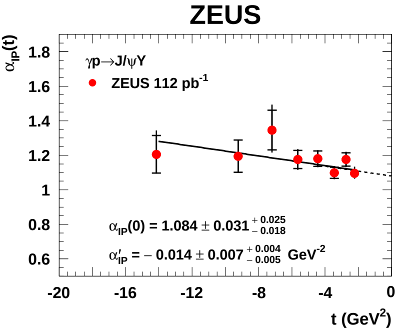


ZEUS results *are in good agreement with those of H1 in the common kinematic region*

J/ψ at large $|t|$, W dependence as a function of t

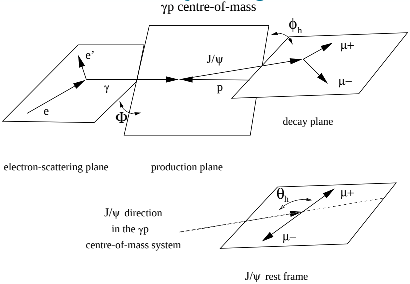
Effective Pomeron trajectory $d\sigma/dt = F(t) \cdot W^{4(\alpha_P(t)-1)}$





- Pomeron intercept consistent with soft $\alpha_P(0) = 1.0808$
- Pomeron slope consistent with BFKL Pomeron
- H1 $\alpha_P(0) = 1.167 \pm 0.048(stat) \pm 0.024(syst)$
- H1 $\alpha'_P = -0.0135 \pm 0.0074(stat) \pm 0.0051(syst)$

Decay angular distribution - helicity frame

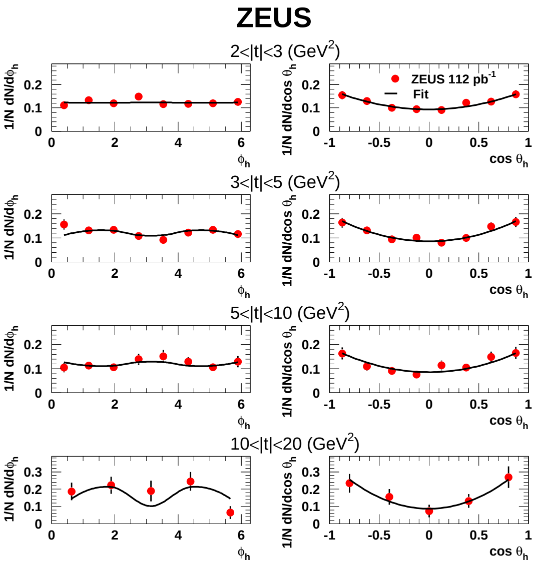


θ_h, ϕ_h angles of decay muons in the meson rest frame
Φ angle between scattering and production plane
Angular distribution are related to the spin of the γ^* and the meson

Angular distr. $\longrightarrow$ spin density matrix elements r_{ij}^{kl}, $\longrightarrow$ helicity amplitudes $T_{\lambda_{VM}\lambda_\gamma}$

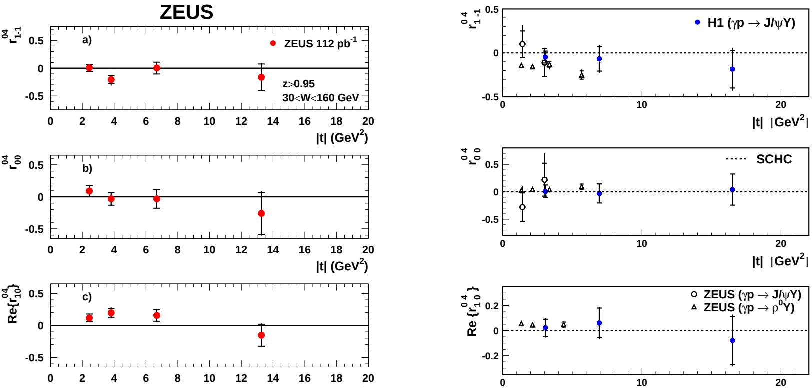
s-channel helicity conservation: the outgoing VM retains the γ helicity
pQCD: during the interaction, the orbital angular momentum of $q\bar{q}$ can be modified due to the transfer of momentum of the gluons;
$\Rightarrow$ the helicity of the outgoing VM differs from the one of the γ, helicity flip between photon and meson is possible

Decay angular distributions in $|t|$ bins



- θ_h, ϕ_h angles of decay muons in the meson rest frame estimated in different t bins
- Spin density matrix elements are extracted from fit to the angular distributions

Helicity spin density matrix elements as a function of $|t|$



r^{04}_{1-1} is related to interference between non-flip and double-flip amplitude

r^{04}_{00} represents the probability that $J\psi$ has 0 helicity

$Re(r^{04}_{10})$ is proportional to the single flip amplitude

These spin density elements expected to be 0 in SCHC

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Summary

- $\gamma p \rightarrow J/\psi Y$ studied by ZEUS for t up to 20 GeV^2
- DGLAP models are able to describe data, but up to $|t| < 5$ GeV^2
- BFKL models not yet able to describe data over all the kinematic range
- in general, no model gives a good description of all variables

NB: The discussion at the workshop has been added in next slide

Discussion at DIS2010

Comments raised by Boris Blok

- the model of Frankfurt, Strikman and Zhalov should be replaced by the model described in the recent papers
  DGLAP versus perturbative Pomeron in large momentum transfer hard diffractive processes at HERA and LHC

  `B. Blok, L. Frankfurt, M. Strikman, arXiv:1002.3048`

  and *The energy dependence of the hard exclusive diffractive processes in pQCD as the function of momentum transfer*

  `B. Blok, L. Frankfurt, M. Strikman, arXiv:1001.2469`

  This DGLAP model is able to describe data on the entire t range
- The α_P measured by ZEUS is an effective value and cannot be compared to the trajectory of the *soft* Pomeron or to the BFKL Pomeron