International Europhysics Conference
on High Energy Physics

Aachen, 17 – 23 July 2003

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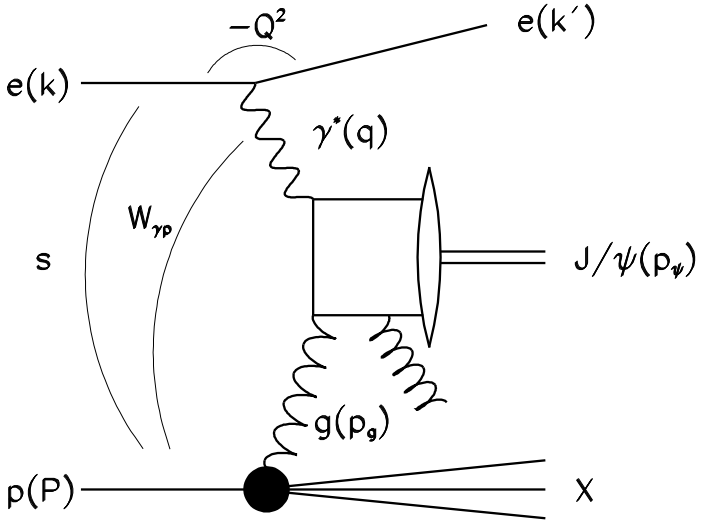
on behalf of the
H1 and ZEUS collaboration

Inelastic J/ψ production at HERA

Outline

- Introduction
- J/ψ Production Mechanisms
- Inelastic J/ψ Photoproduction
- Inelastic J/ψ Electroproduction
- Polarisation Measurements
- Conclusions & Outlook

Introduction - I



kinematic variables:

$$Q^2 = -q^2 = -(k - k')^2$$

$$s = (P + k)^2$$

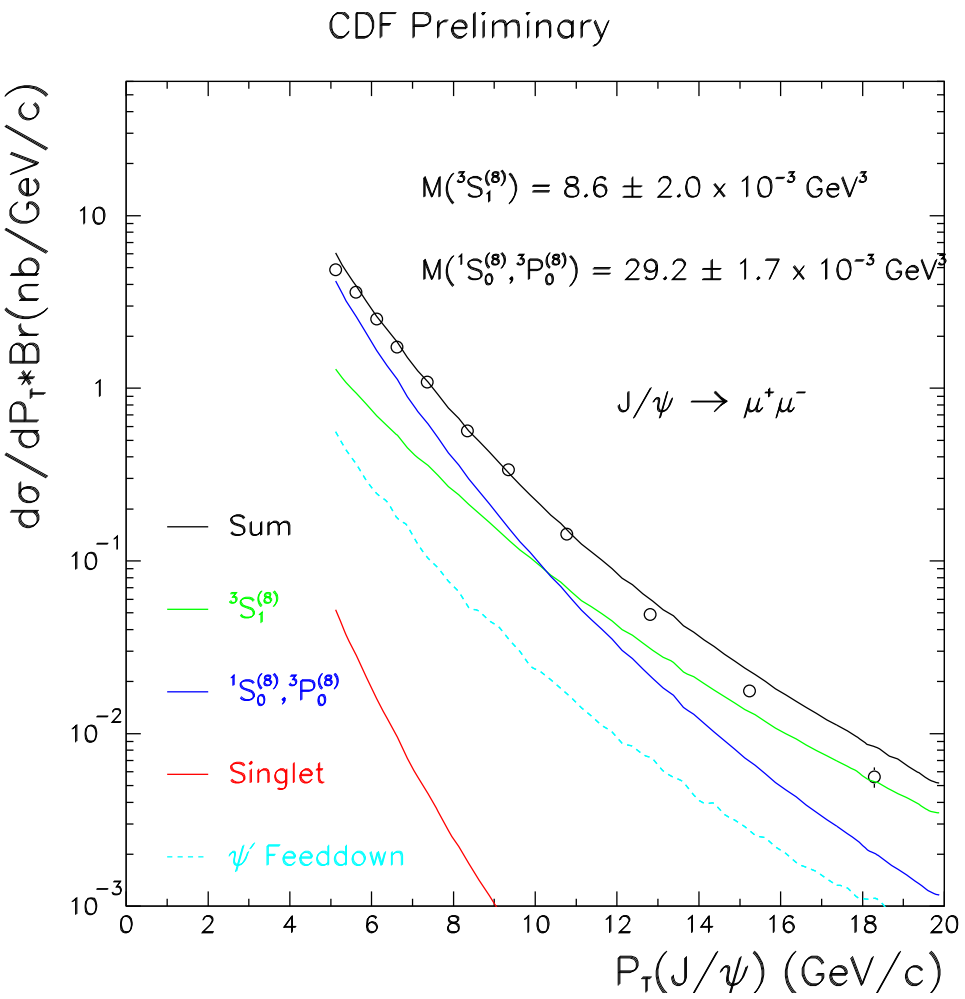
$$W_{\gamma p} = \sqrt{(P + q)^2}$$

$$z = p_\psi \cdot P / q \cdot P$$

$$= E^*_\psi / E^*_\gamma \text{ in proton rest frame}$$

- **photoproduction ($Q^2 < 1$ GeV^2):**
  scattered e not seen in the main detector
- **electroproduction ($2 < Q^2 < 100$ GeV^2):**
  scattered e detected in calorimeter
- **J/ψ detected through:**
  $\mu^+\mu^-$, e^+e^- decay modes

Introduction - II



How is the charmonium produced ?

Colour Singlet Model (CSM)

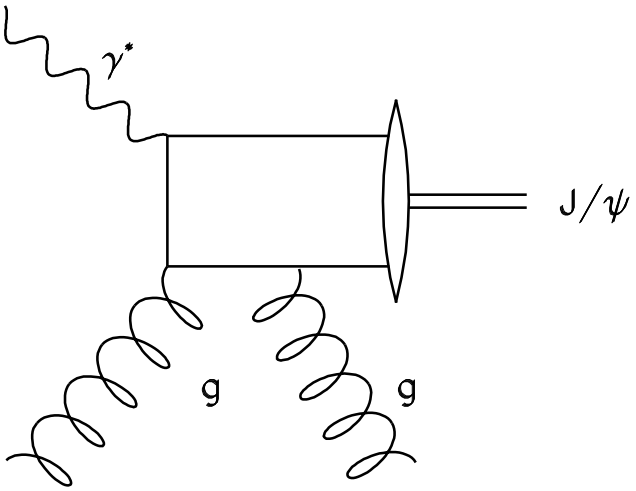
orders of magnitude too low

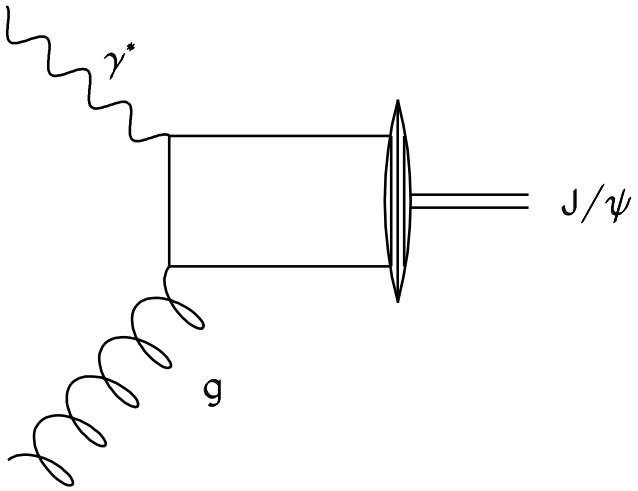
⇓

non-relativistic QCD (NRQCD)

Production Mechanisms – I

direct photon gluon fusion: $z \gtrsim 0.2$





Colour Singlet Model

$c\bar{c}$ must have J/ψ quantum numbers
one parameter fixed from $\Gamma_{\psi \to l^+ l^-}$

CSM

non-relativistic QCD

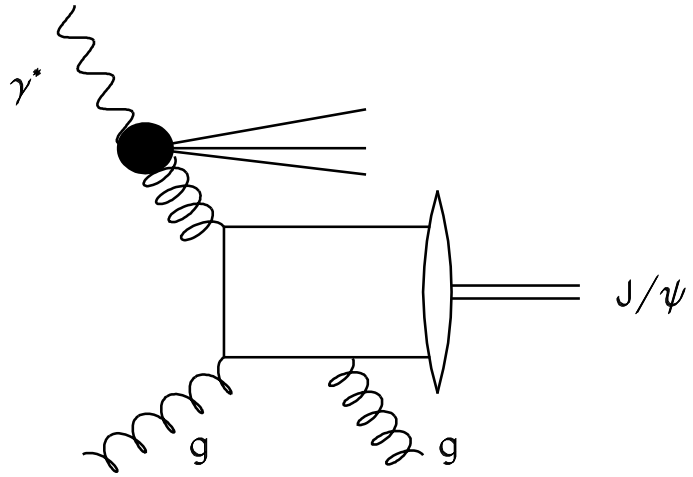
$c\bar{c}$ also in colour octet state
additional free parameters
long distance matrix elements "LDMEs"
LDMEs not calculable $\rightarrow$ from experiment

CS + CO

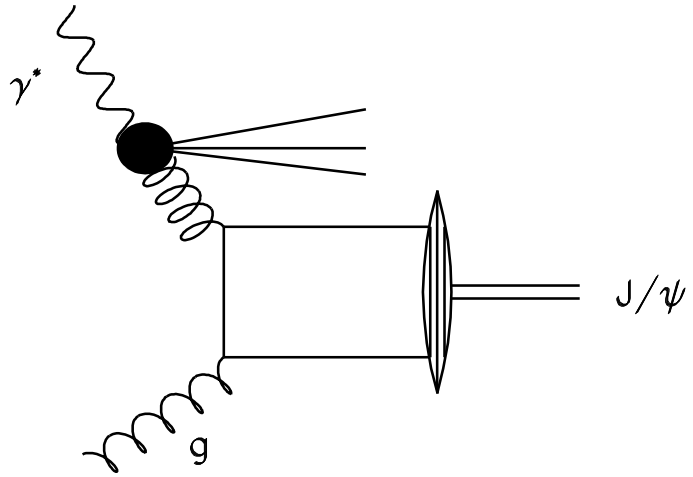
Production Mechanisms – II

resolved photon processes (gluon gluon fusion): $z \lesssim 0.2$

suppressed with increasing Q^2

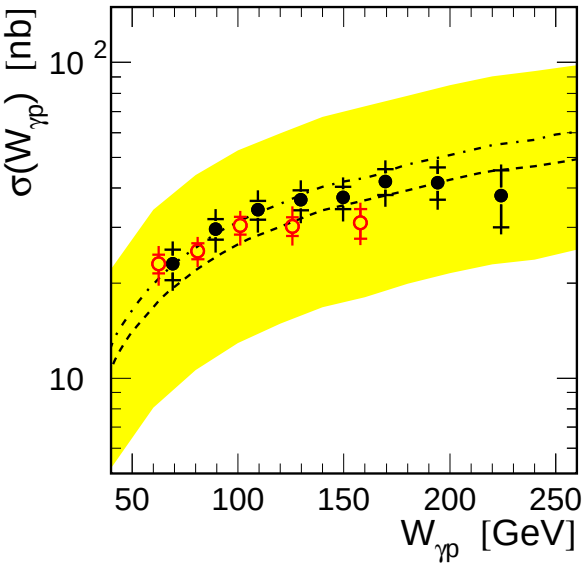


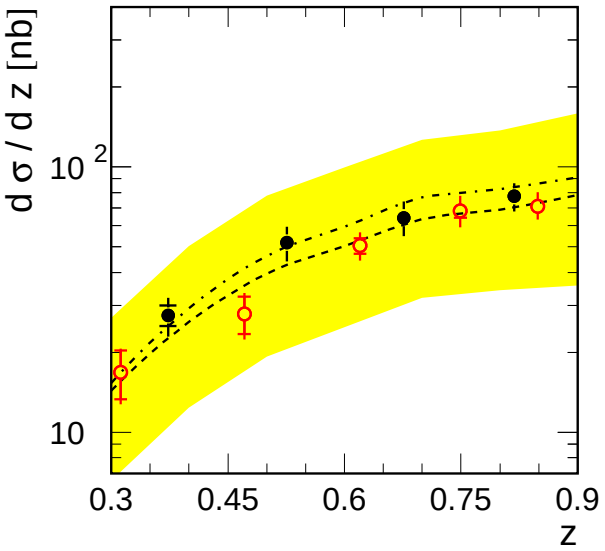
Colour Singlet Model

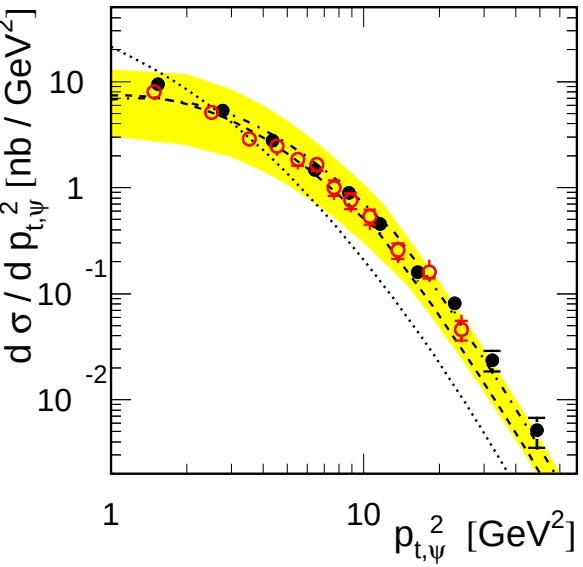


non-relativistic QCD

Photoproduction: Comparison with CSM NLO







- H1
- CSM NLO
- CSM LO
- ZEUS (scaled)

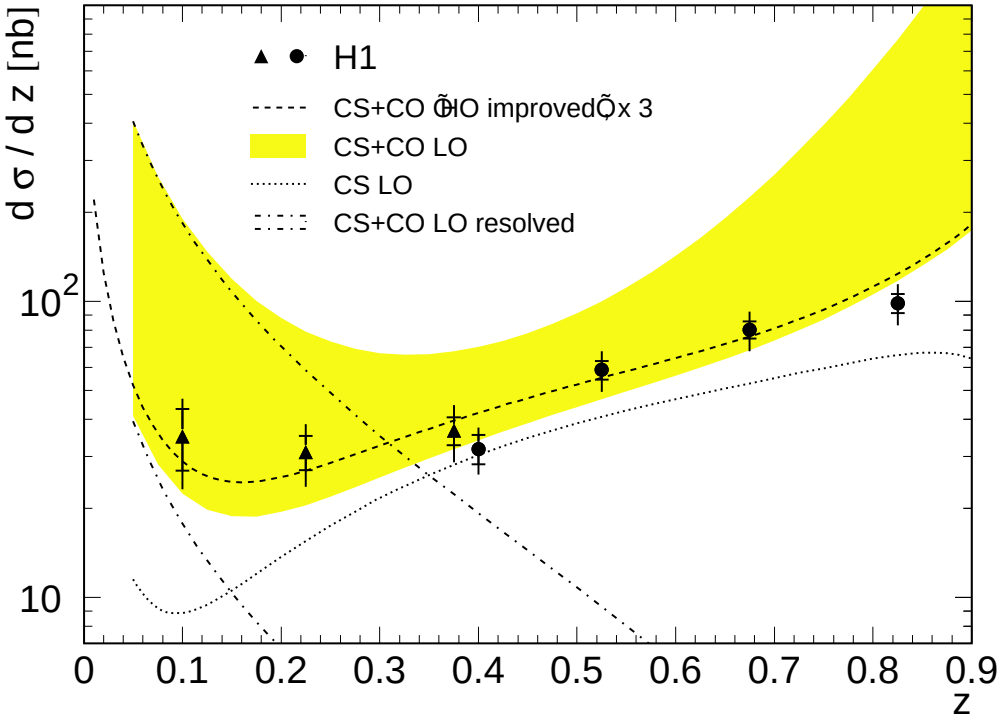
(to H1 phase space)

♣ Agreement between H1 and ZEUS data

♣ full NLO calculation of the direct γ gluon fusion in the CSM (M.Krämer)

♣ within the large theoretical uncertainties, the prediction is in agreement with the data, both in shape and normalization

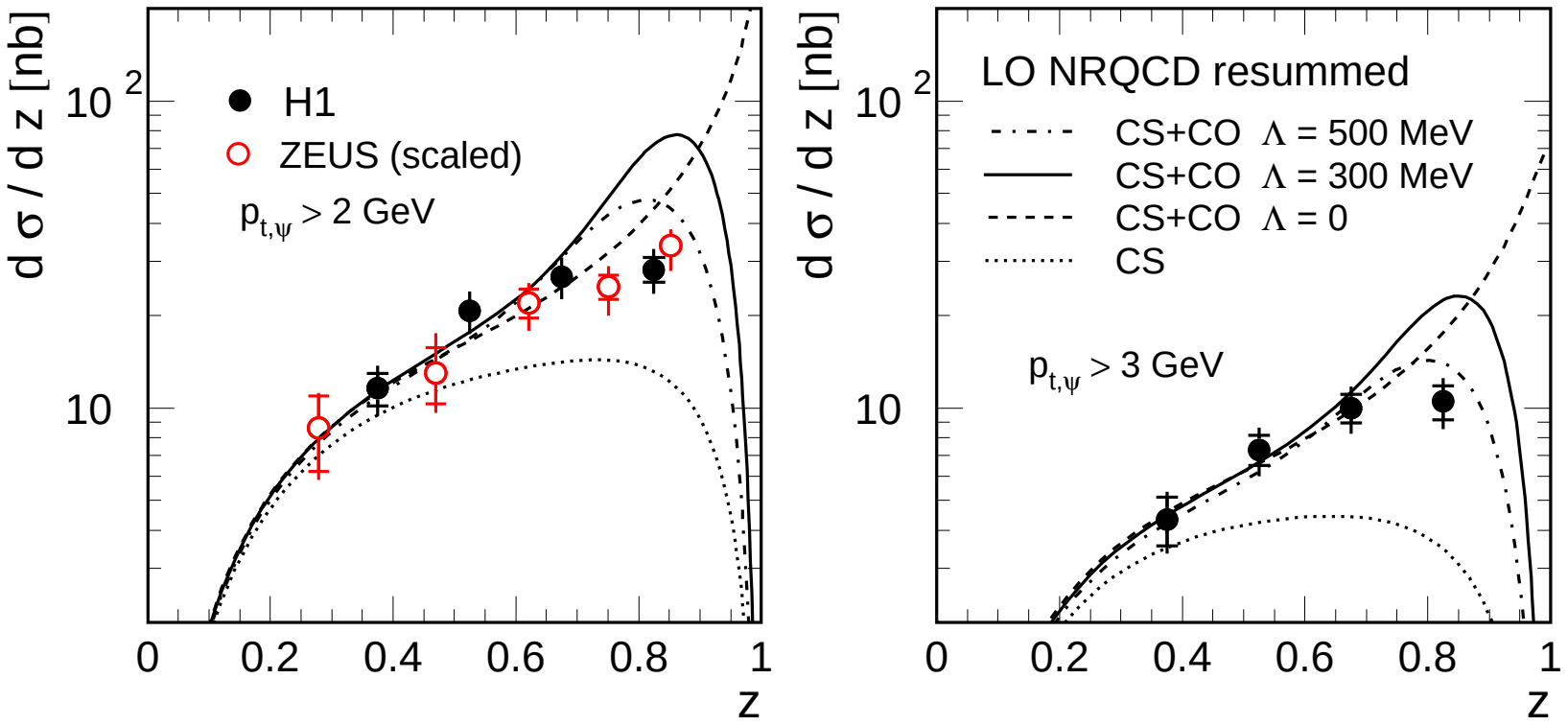
Photoproduction: Comparison with NRQCD (LO)



The measurements explore the low z region: $z = 0.05$ for H1, $z = 0.1$ for ZEUS

- LO NRQCD calculation including direct and resolved photon processes (M. Krämer and M. Cacciari) give a fair description of whole z range with small LDMEs
- large uncertainties in calculation due to LDMEs extracted from CDF data
- large values of LDMEs are excluded here

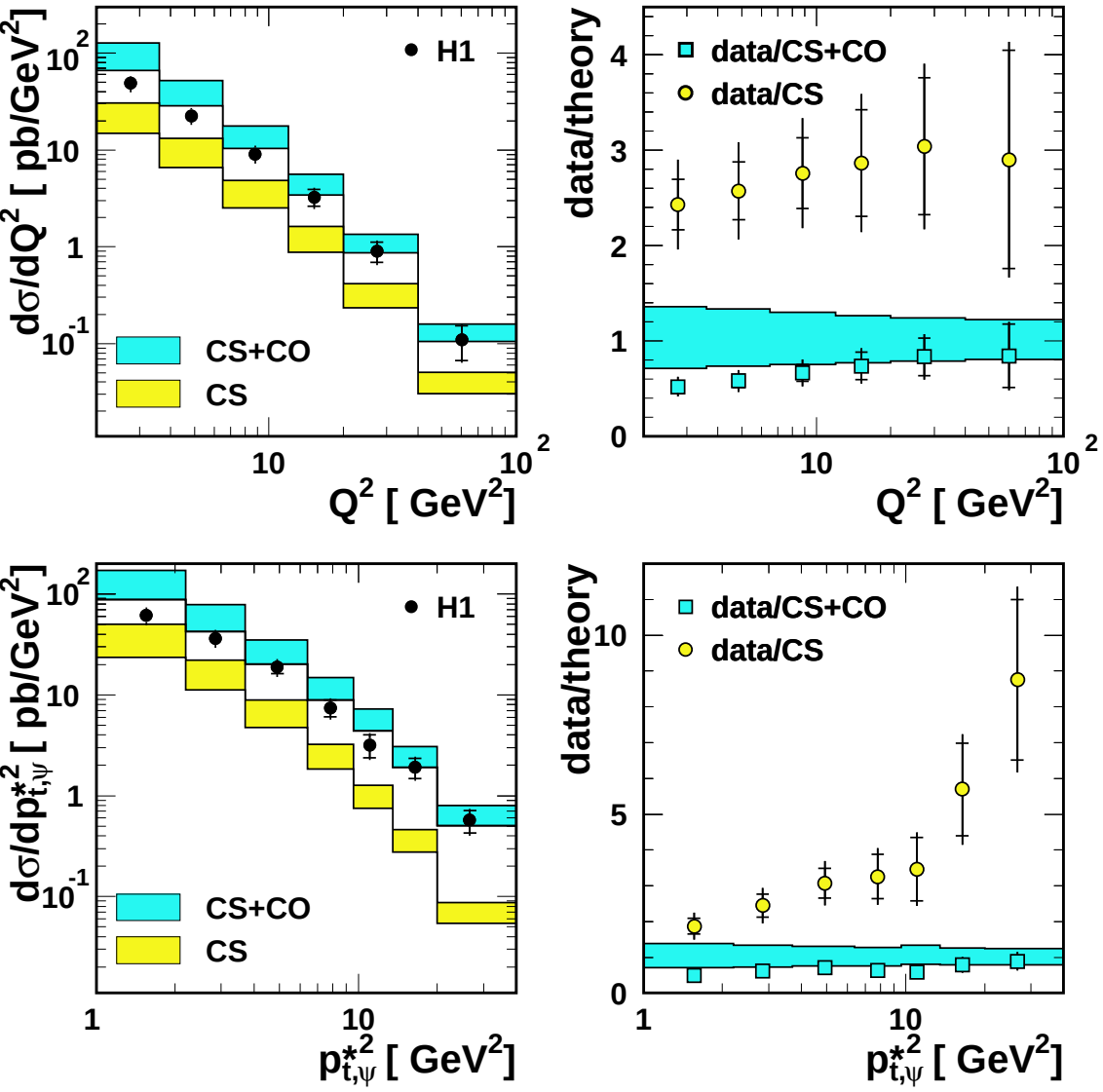
Photoproduction: Comparison with NRQCD (LO)



- LO NRQCD calculation resumming soft contributions at high z (M.Beneke, G.A. Schuler and S. Wolf)
- Λ: Energy loss of J/ψ due to soft gluon radiation

$\Rightarrow$ **resummation reduces discrepancy at high z**

Electroproduction: Q^2 and $p^*_{t,\psi}$ Dependence

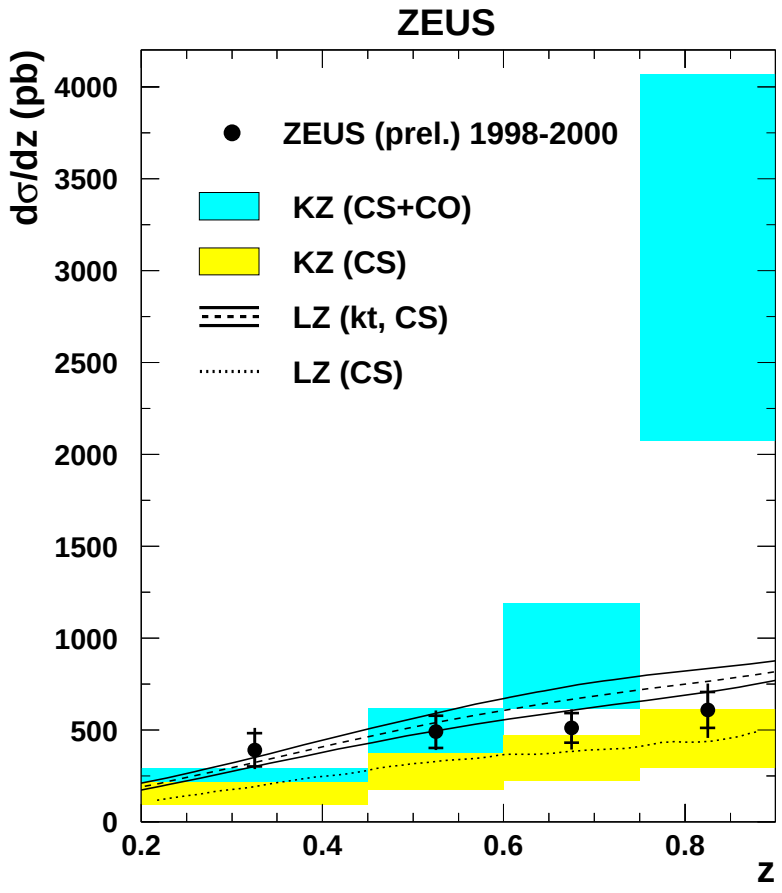


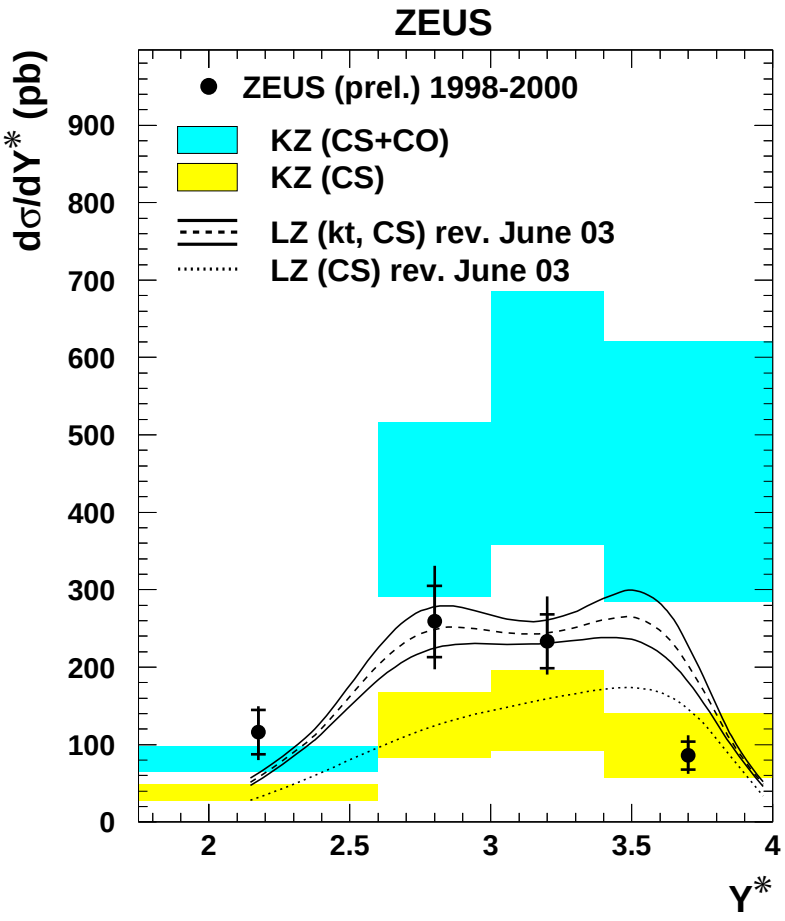
♣ comparison with LO NRQCD calculation and CS contribution (B.A. Kniehl and L.Zwirner)

♣ CS contribution too low by a factor ~ 2.7
CS too steep in $p^{*2}_{t,\psi}$
$\Rightarrow$ missing higher orders?

♣ CS+CO too high at low Q^2,$p^{*2}_{t,\psi}$ (factor ~ 2)
CS+CO description improves at high Q^2,$p^{*2}_{t,\psi}$ (smaller theoretical errors)

Electroproduction: z and rapidity Dependence





♢ z: missing resummation of soft terms for CS+CO

♢ CS below the data but shape consistent with the data CS+CO above the data

Polarization Measurements

- **Polarization of J/ψ provides information on production process independent of normalization uncertainties**

- polarization is measured in decay angular distributions in J/ψ rest system

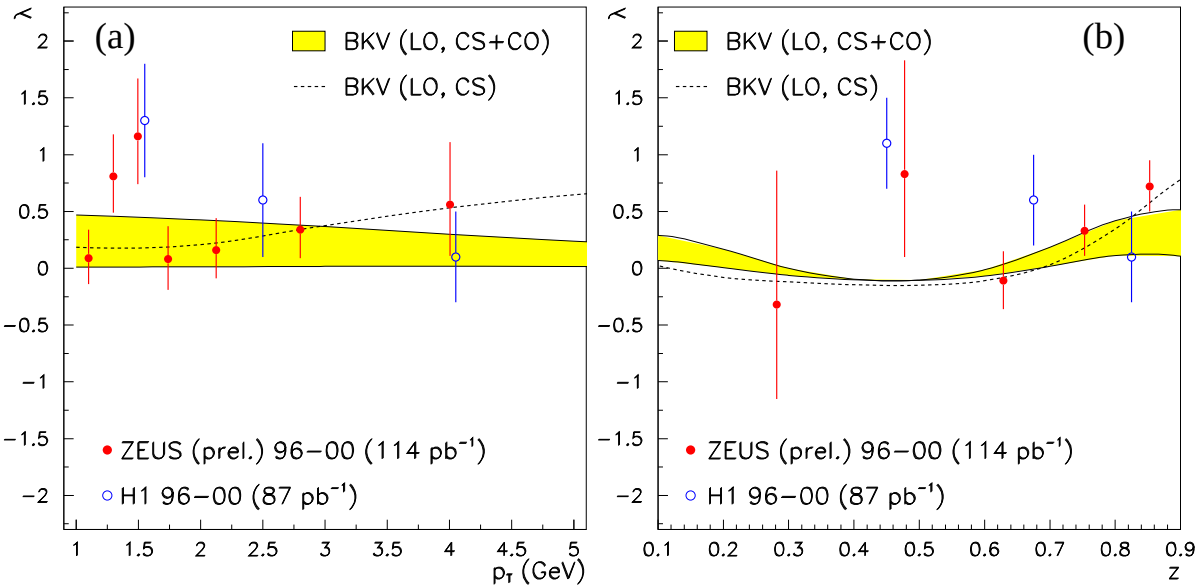
  θ^*: angle μ^+ to z' axis, direction opposite to that of the proton

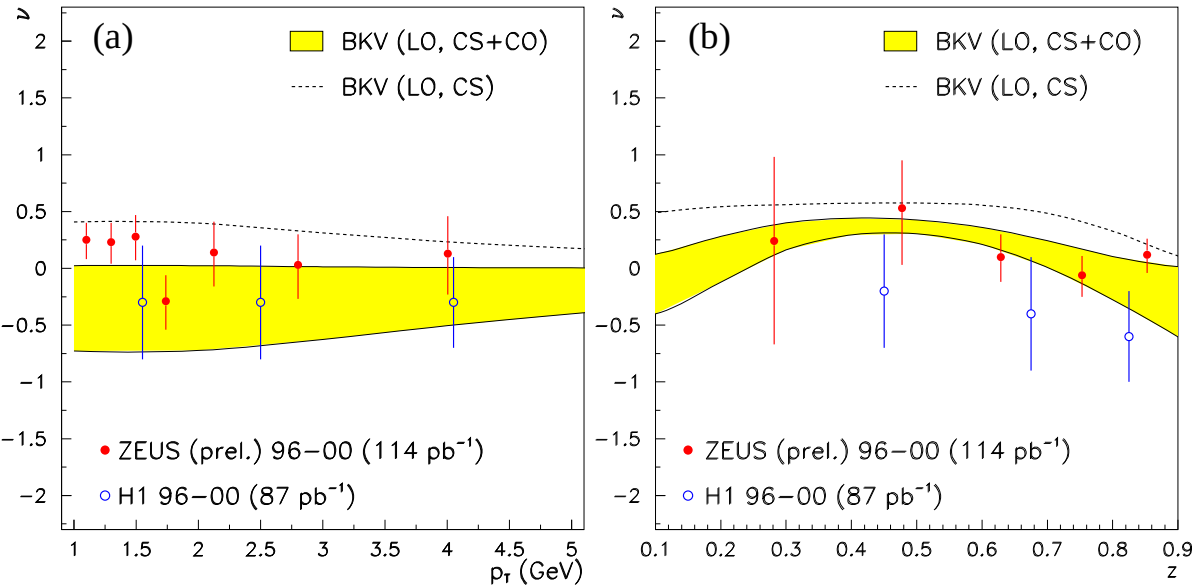
  ϕ^*: angle μ^+ to plane determined by incoming photon and proton

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} \propto 1 + \lambda\cos^2\theta^* \qquad \lambda(=\alpha) = +1 : \text{transverse polarization}$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\phi^*} \propto 1 + \frac{\lambda}{3} + \frac{\nu}{3}\cos 2\phi^* \qquad \lambda(=\alpha) = -1 : \text{longitudinal polarization}$$

Polarization Measurements: Photoproduction





♠ ν more promising variable in order to disantagle the problem

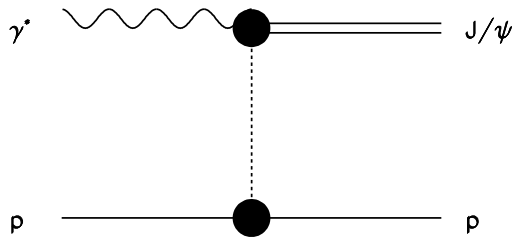
♠ $\Rightarrow$ more data needed for decision on production mechanism

Conclusions and Outlook

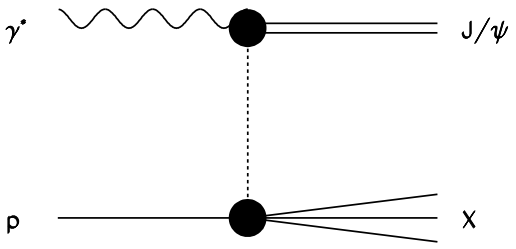
- **photoproduction:**
  - medium z: good agreement with CSM NLO calculations
  - low z: resolved photon contributions improve agreement
  - NRQCD with small LDMEs gives reasonable description
- **electroproduction:**
  - CS (LO) alone too low, wrong $p^{*2}_{t,\psi}$ dependence
  - NRQCD OK at high Q^2 and $p^{*2}_{t,\psi}$ but problems in z
- major improvement in data statistics needed for conclusions from polarization measurements $\Rightarrow$ only possible with HERA II data
- **$\Rightarrow$ NLO calculations in NRQCD (both for electro- and photoproduction) needed !**

Production Mechanisms – III (background)

- **diffraction** (subtracted in ZEUS data ($\approx 10\%$), not subtracted in H1 data ($< 2\%$))



elastic diffraction
$z = 1$



proton dissociation
$z \approx 1$

suppressed by cuts on:
- z ($z < 0.9$)
- $p^*_{t,\psi}$ ($\approx p_{t,\psi}$ in photoproduction)
- additional activity in the detector

- decay of **diffractively or inelastically produced ψ' mesons**: $\psi' \to J/\psi\pi\pi$; not subtracted in data!
- **decay of χ_c mesons**: $\chi_c \to J/\psi\gamma$ (low z); not subtracted in data!
- **decay of B mesons**: $B \to J/\psi X$ (low z, high $p_{t,\psi}$); not subtracted in data!