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Hyperons, Charm and Beauty Hadrons

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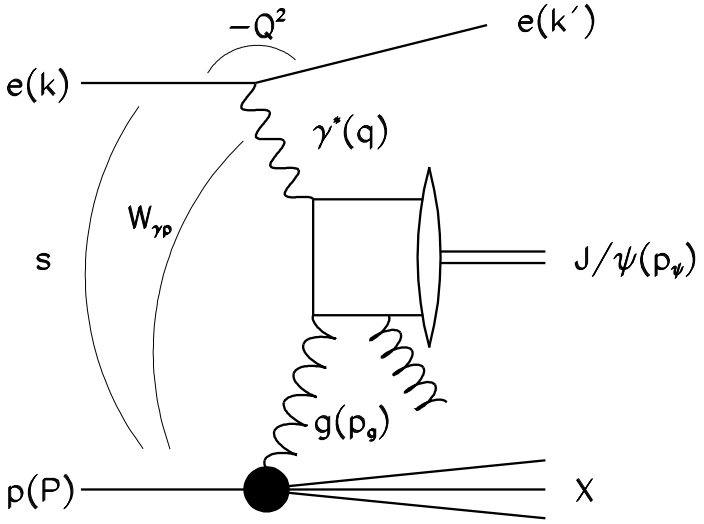
on behalf of the
H1 and ZEUS collaboration

Inelastic J/ψ production at HERA

Outline

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

Introduction - I



kinematic variables:

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

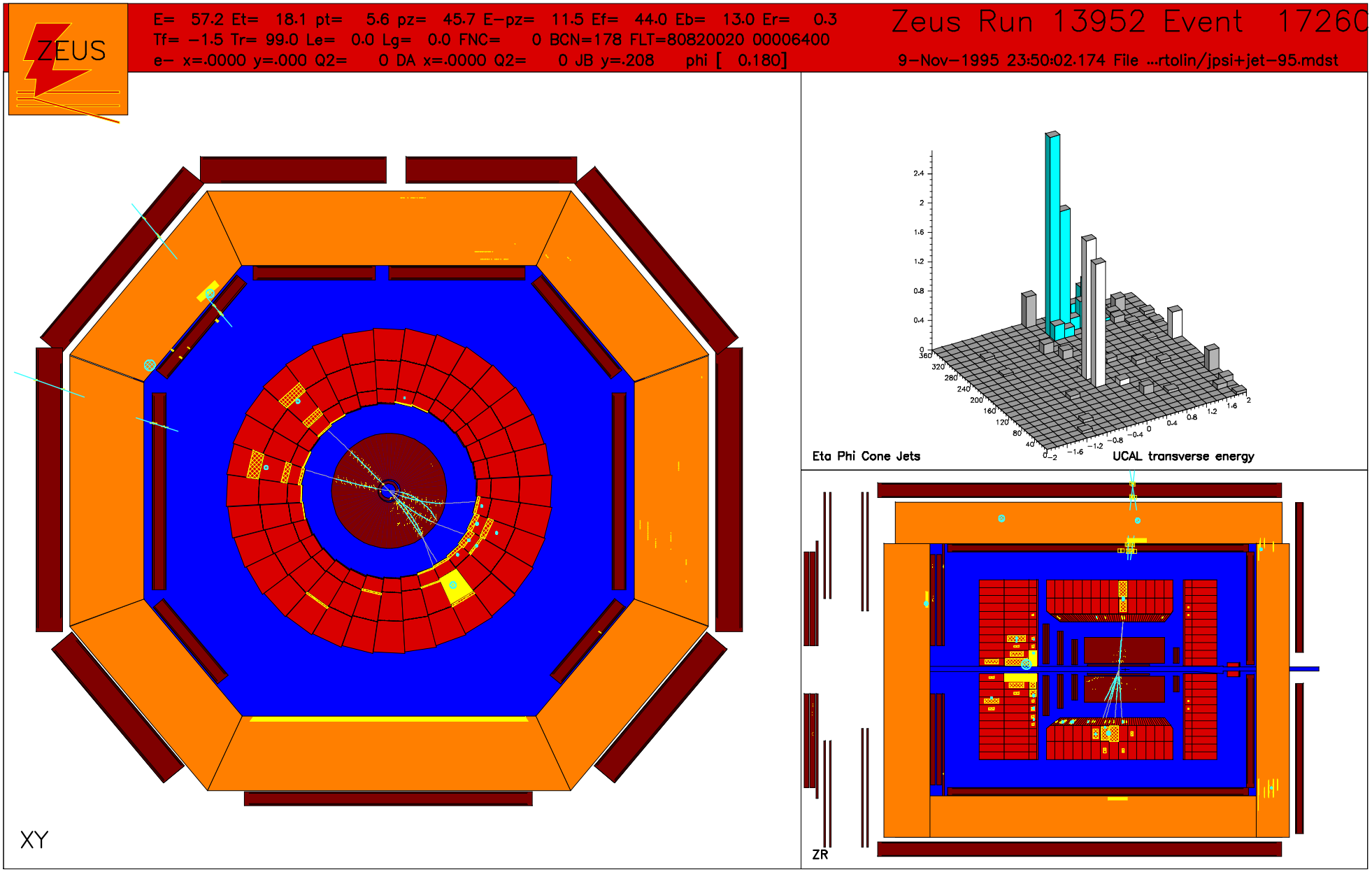
$$s = (P + k)^2$$

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

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

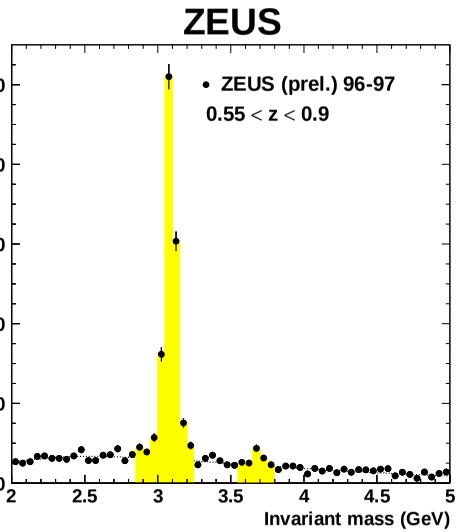
$$= E^*_\psi / E^*_\gamma \text{ in proton rest frame}$$

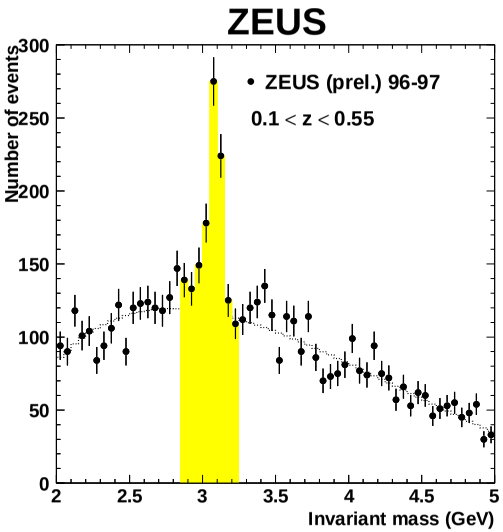
- **photoproduction ($Q^2 < 1$ GeV^2):**
  scattered e not seen in the main detector
- **electroproduction ($2 < Q^2 < 100$ GeV^2):**
  scattered e detected in calorimeter


ZEUS
E= 57.2 Et= 18.1 pt= 5.6 pz= 45.7 E-pz= 11.5 Ef= 44.0 Eb= 13.0 Er= 0.3
Tf= -1.5 Tr= 99.0 Le= 0.0 Lg= 0.0 FNC= 0 BCN=178 FLT=80820020 00006400
e- x=.0000 y=.000 Q2= 0 DA x=.0000 Q2= 0 JB y=.208 phi [0,180]
Zeus Run 13952 Event 17260
9-Nov-1995 23:50:02.174 File ...rtolin/jpsi+jet-95.mdst
Eta Phi Cone Jets
UCAL transverse energy
XY
ZR

Introduction - II

HERA I data almost completely or completely analyzed: $36 \rightarrow 80$ pb^{-1}





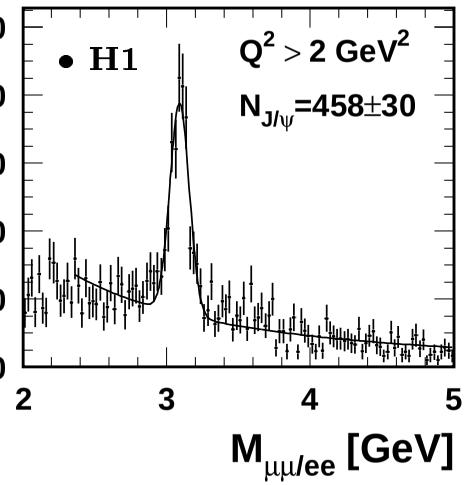
photoproduction: $Q^2 < 1$ **GeV**^{2}

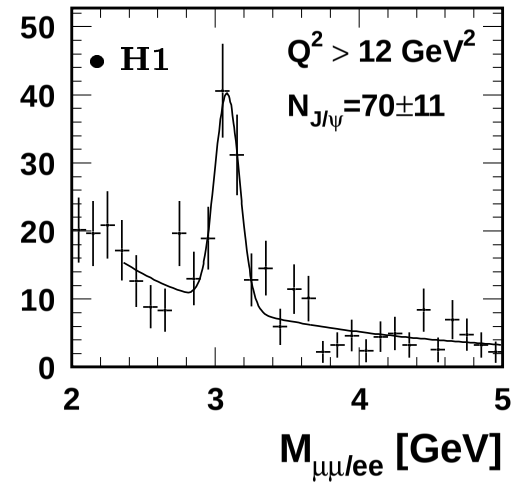
$0.05 < z < 0.9$

$50 < W_{\gamma p} < 260$ GeV

$1 < p^2_{t,\psi} < 60$ GeV^2

larger statistics





e-production: $2 < Q^2 < 100$ **GeV**^{2}

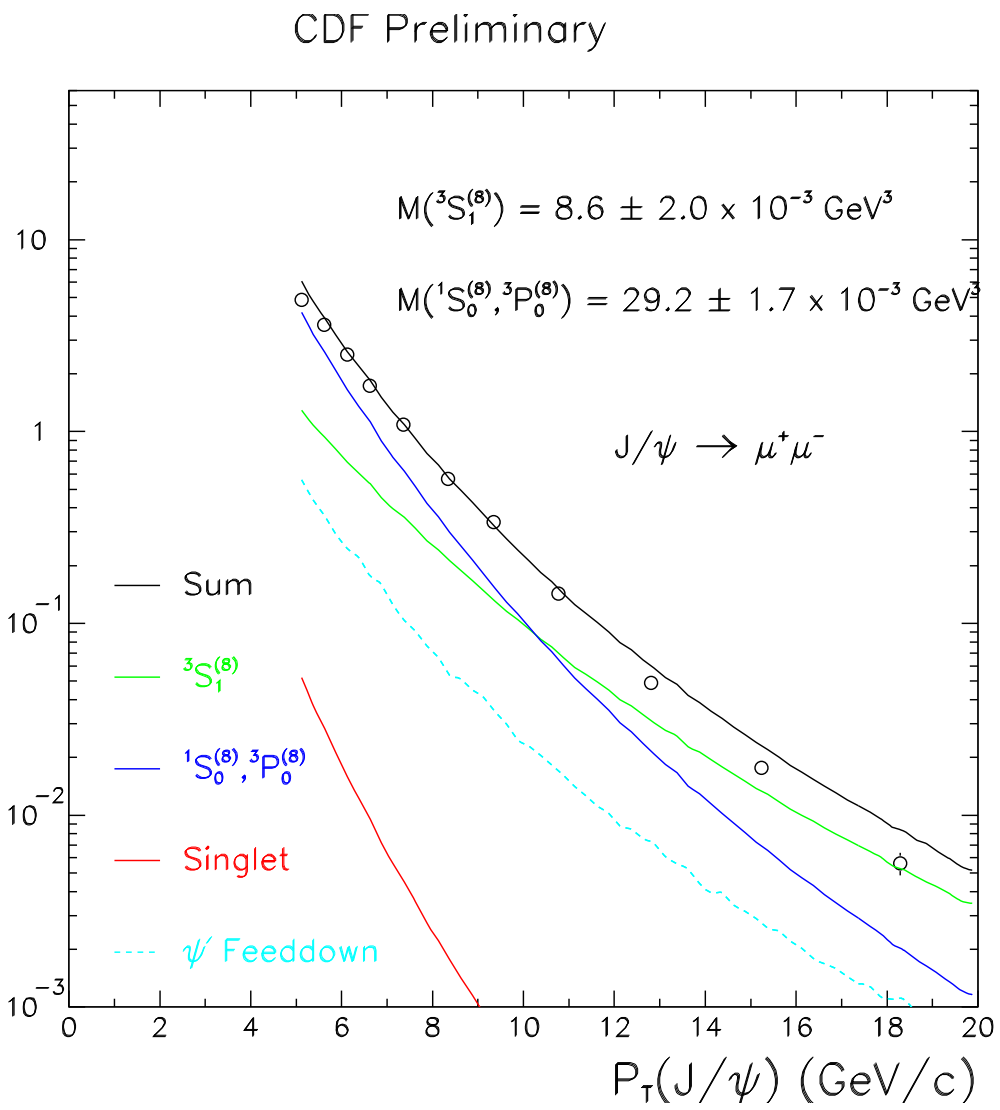
$0.3 < z < 0.9$

$50 < W_{\gamma p} < 225$ GeV

$1 < p^{*2}_{t,\psi} < 40$ GeV^2

less theoretical uncertainties

Introduction - III



Colour Singlet Model (CSM)

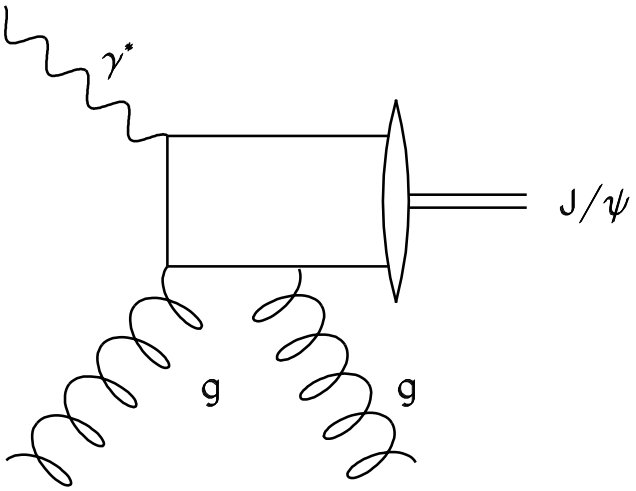
orders of magnitude too low

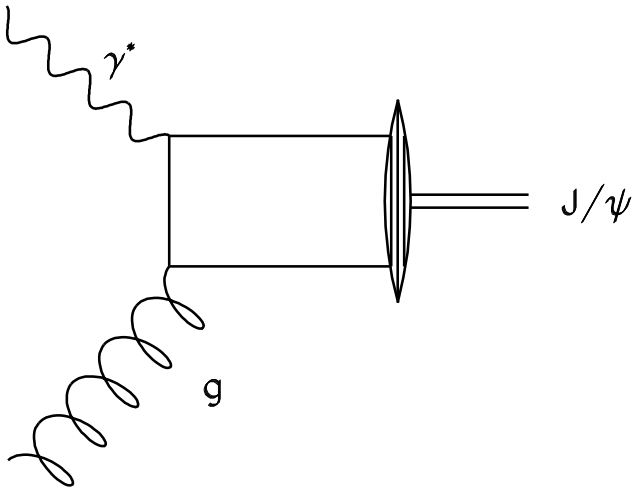
⇓

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

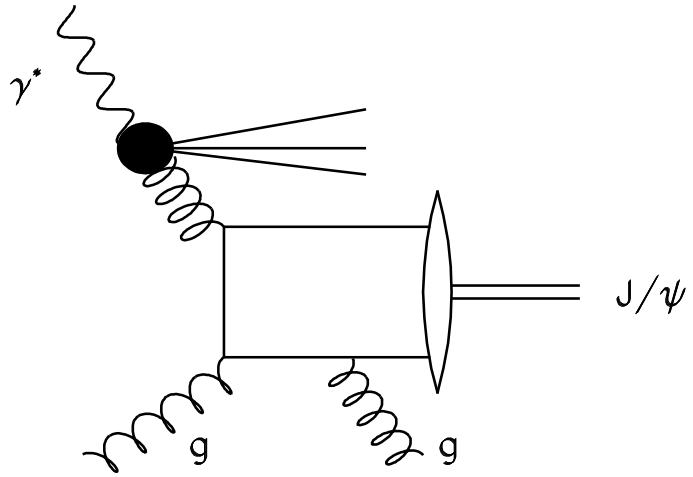
$c\bar{c}$ also in colour octet state
additional free parameters
long distance matrix elements "LDMEs"
LDMEs not calculable → from experiment

CS + CO

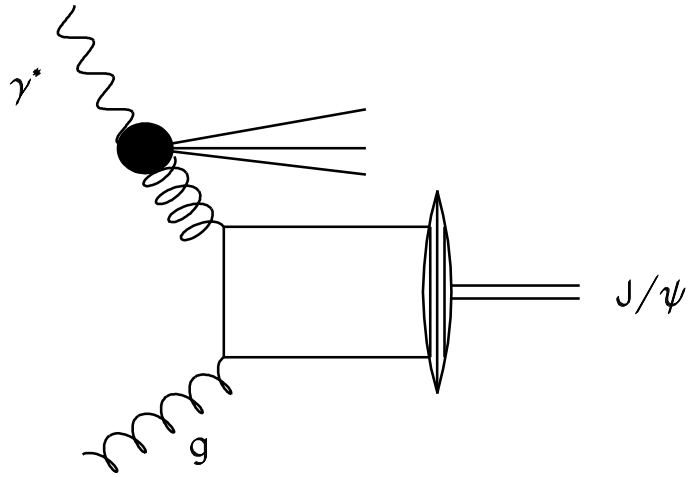
Production Mechanisms – II

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

suppressed with increasing Q^2



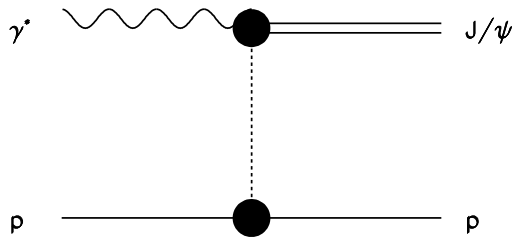
Colour Singlet Model



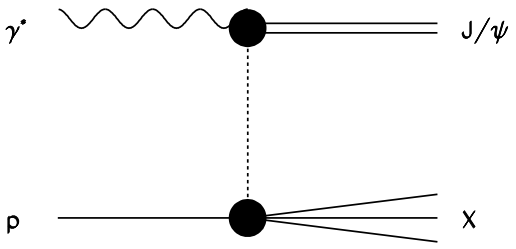
non-relativistic QCD

Production Mechanisms – III (background)

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



elastic diffraction
$z = 1$

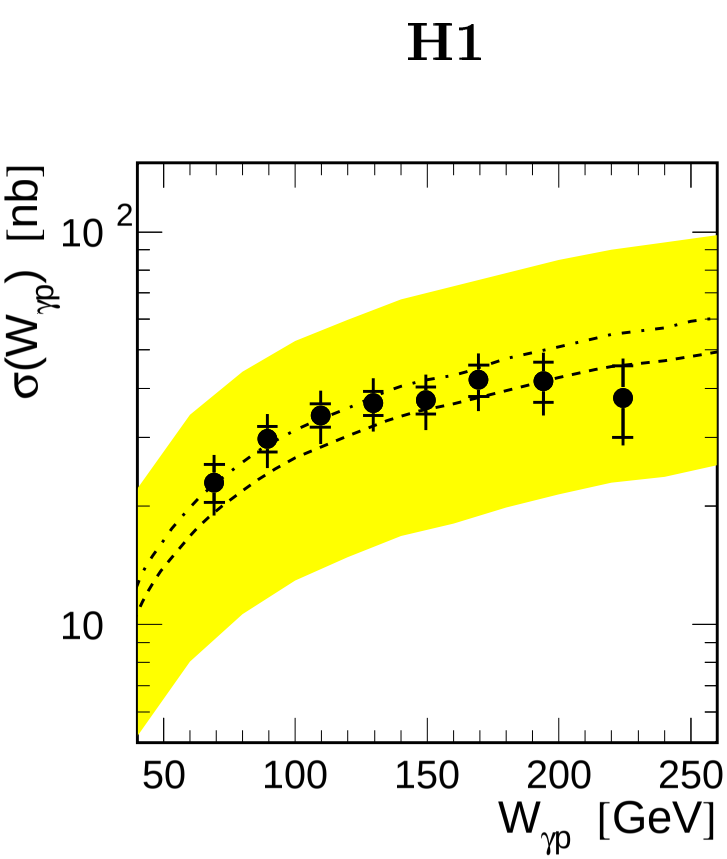


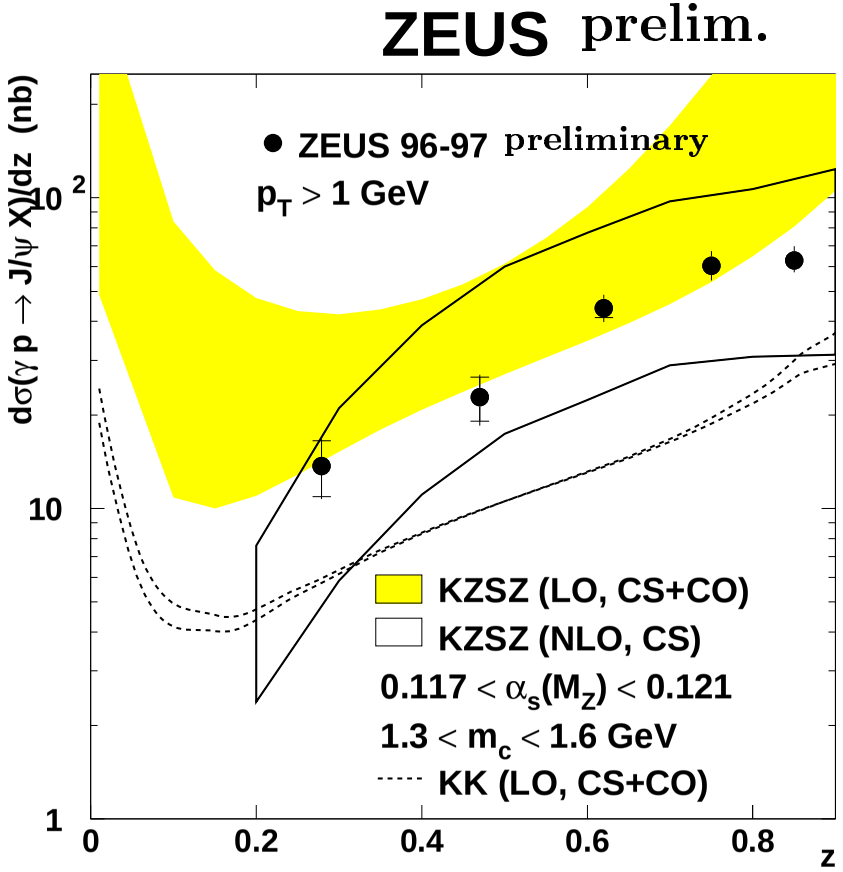
proton dissociation
$z \approx 1$

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!

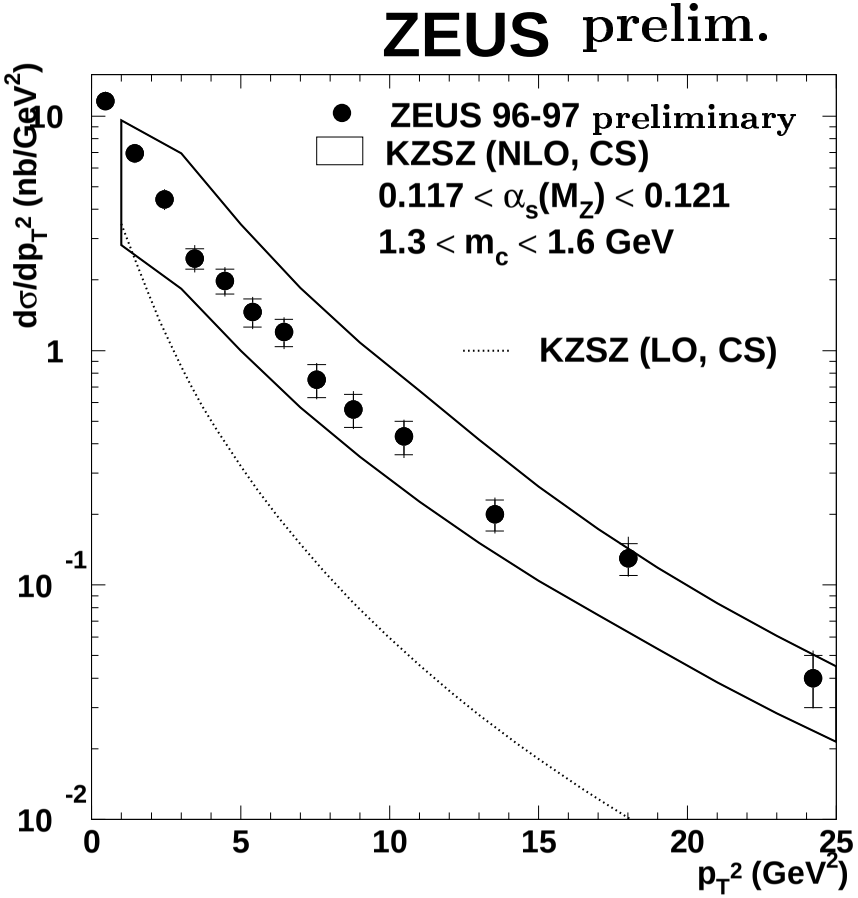
Photoproduction: Comparison with CSM NLO

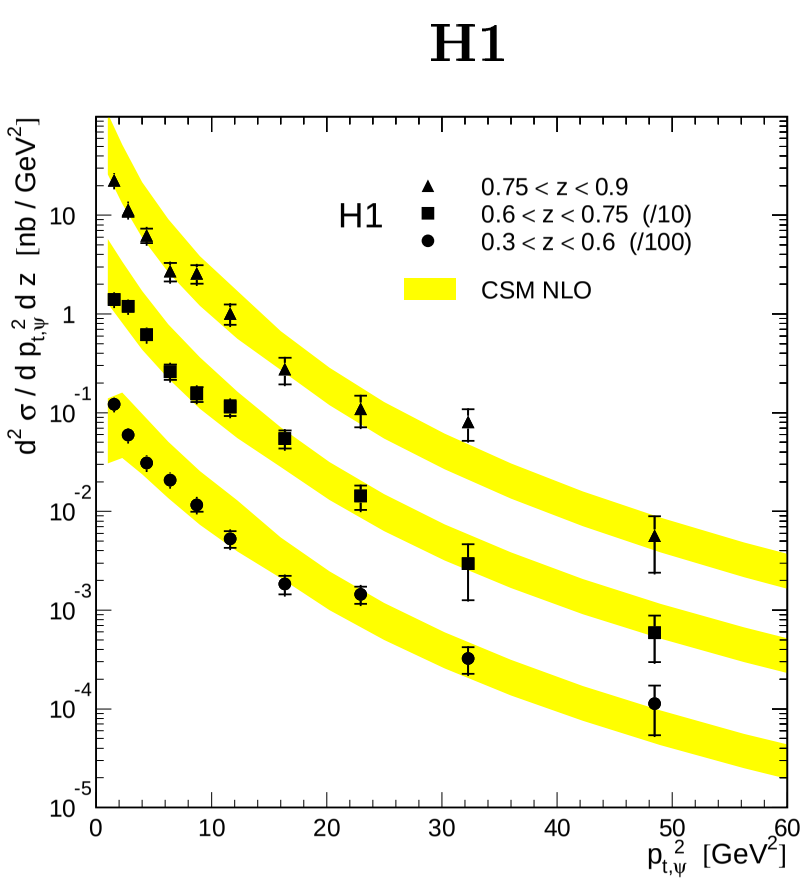




- full NLO calculation of the direct photon gluon fusion in the CSM (M. Krämer)
- within the large theoretical uncertainties, the prediction is in agreement with the data, both in shape and normalization

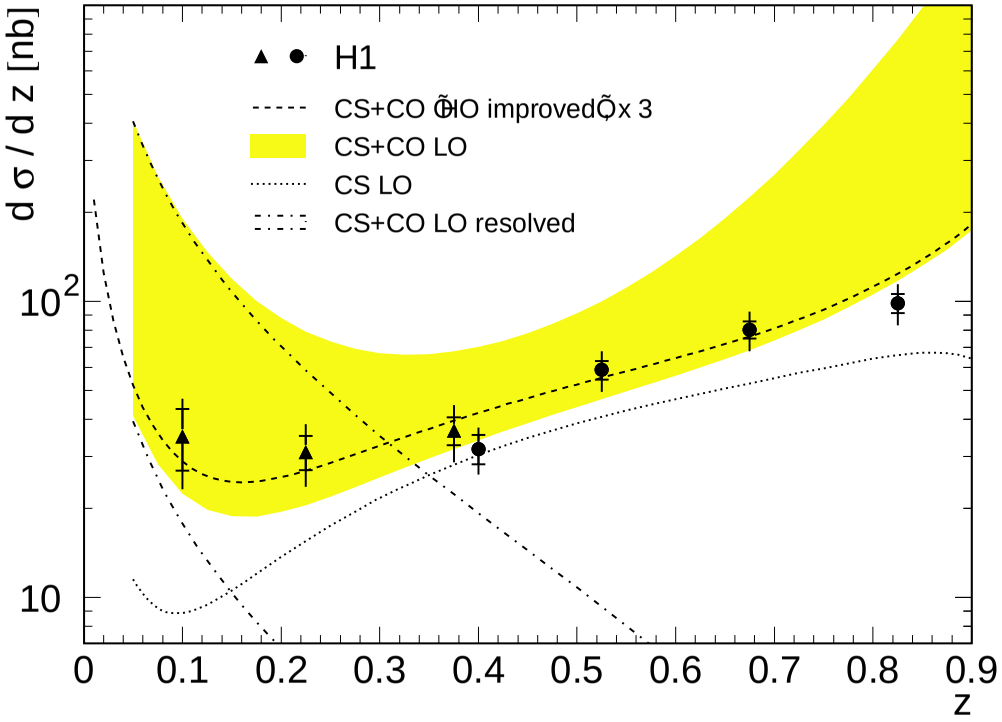
Photoproduction: Comparison with CSM NLO





- CSM NLO good description of the $p_{t,\psi}^2$ distribution, LO too steep in $p_{t,\psi}^2$
- CSM NLO gives reasonable description in all z regions $\rightarrow$ important, since NRQCD contributions expected to depend on z

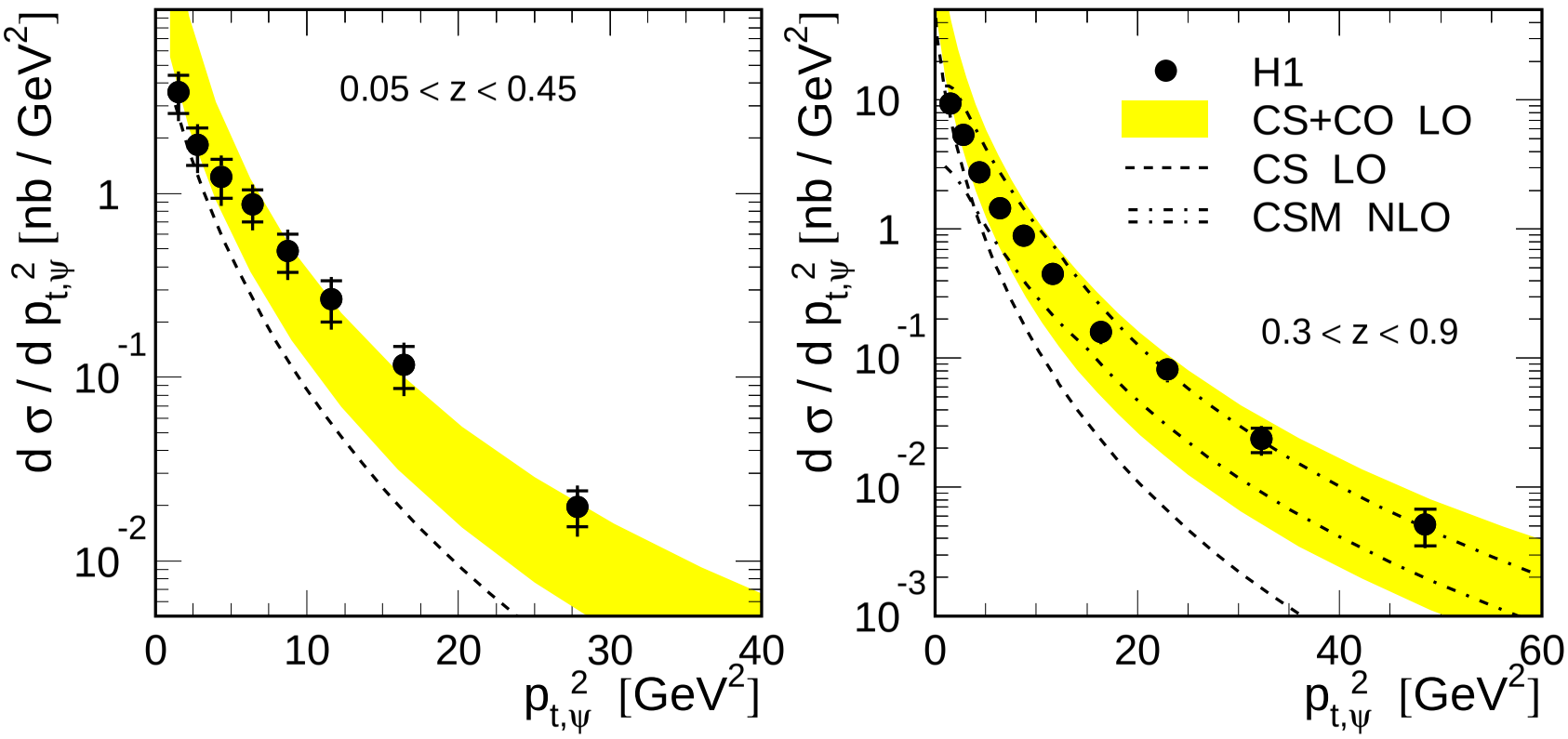
Photoproduction: Comparison with NRQCD (LO)



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

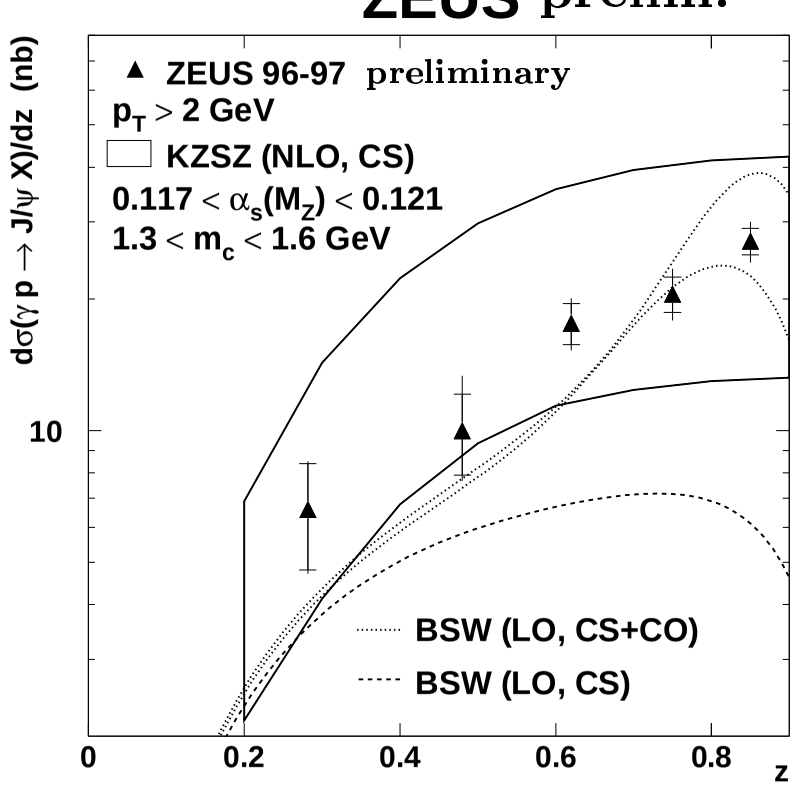
Photoproduction: Comparison with NRQCD (LO)

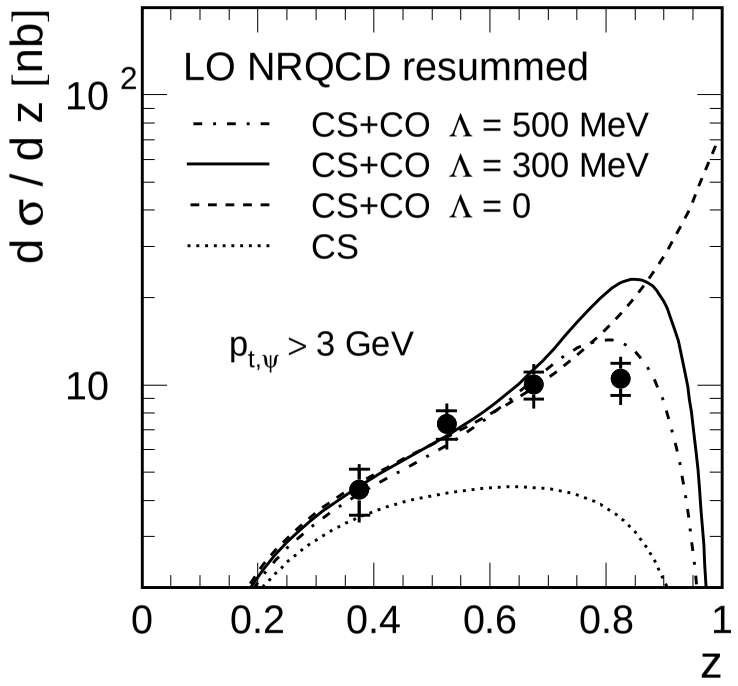


- $p^2_{t,\psi}$ dependence similar at low z and medium z
- CS (LO) contribution alone too steep
- NRQCD (CS+CO) shows a tendency to fall too steeply

$\Rightarrow$ B decay contribution in data?

Photoproduction: Comparison with NRQCD (LO)

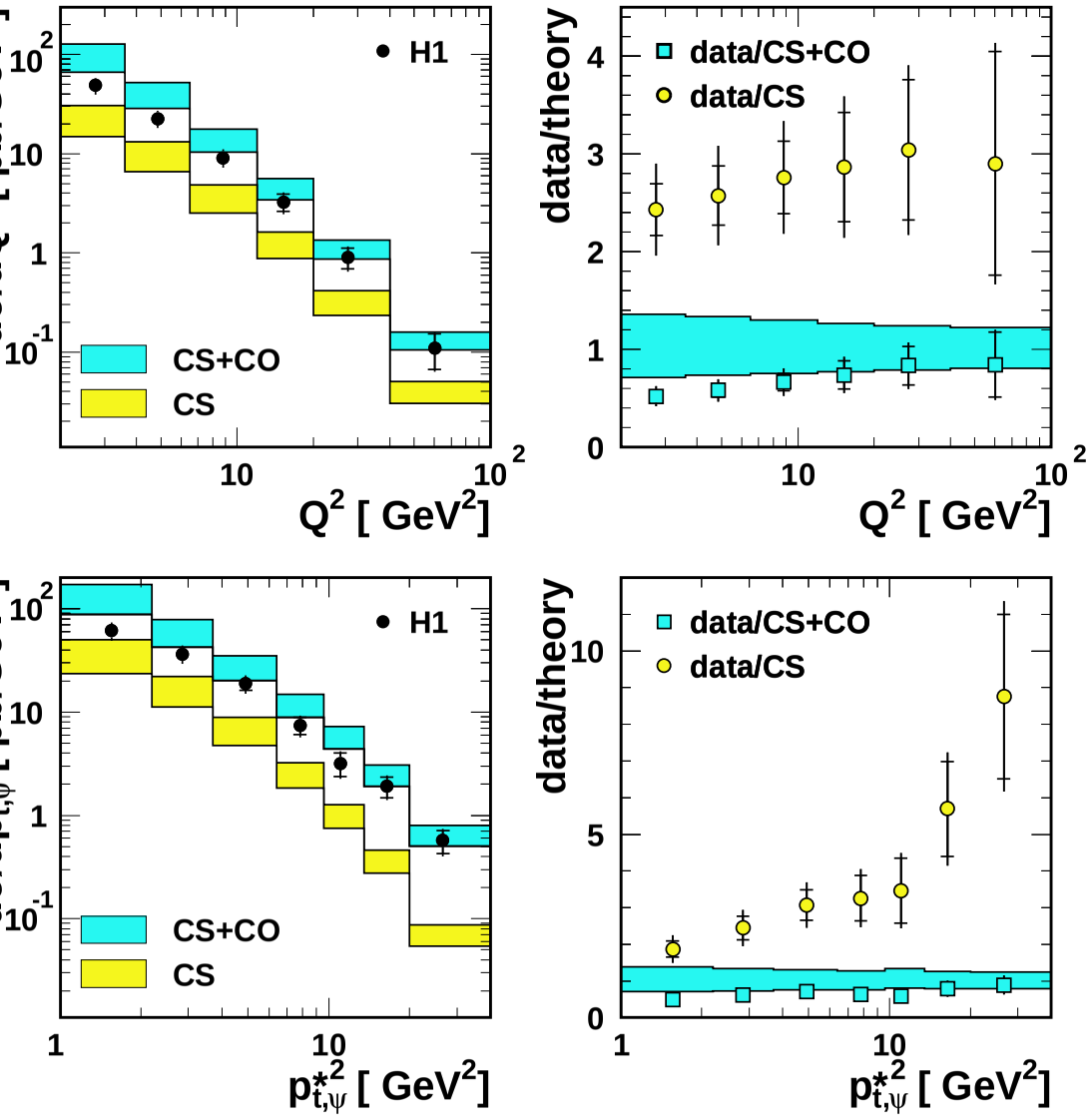




- LO NRQCD calculation resumming soft contributions at high z (M.Beneke, G.A. Schuler and S. Wolf)
- Λ: Energy loss of J/ψ due to soft gluon radiation

$\Rightarrow$ resummation reduces discrepancy at high z

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

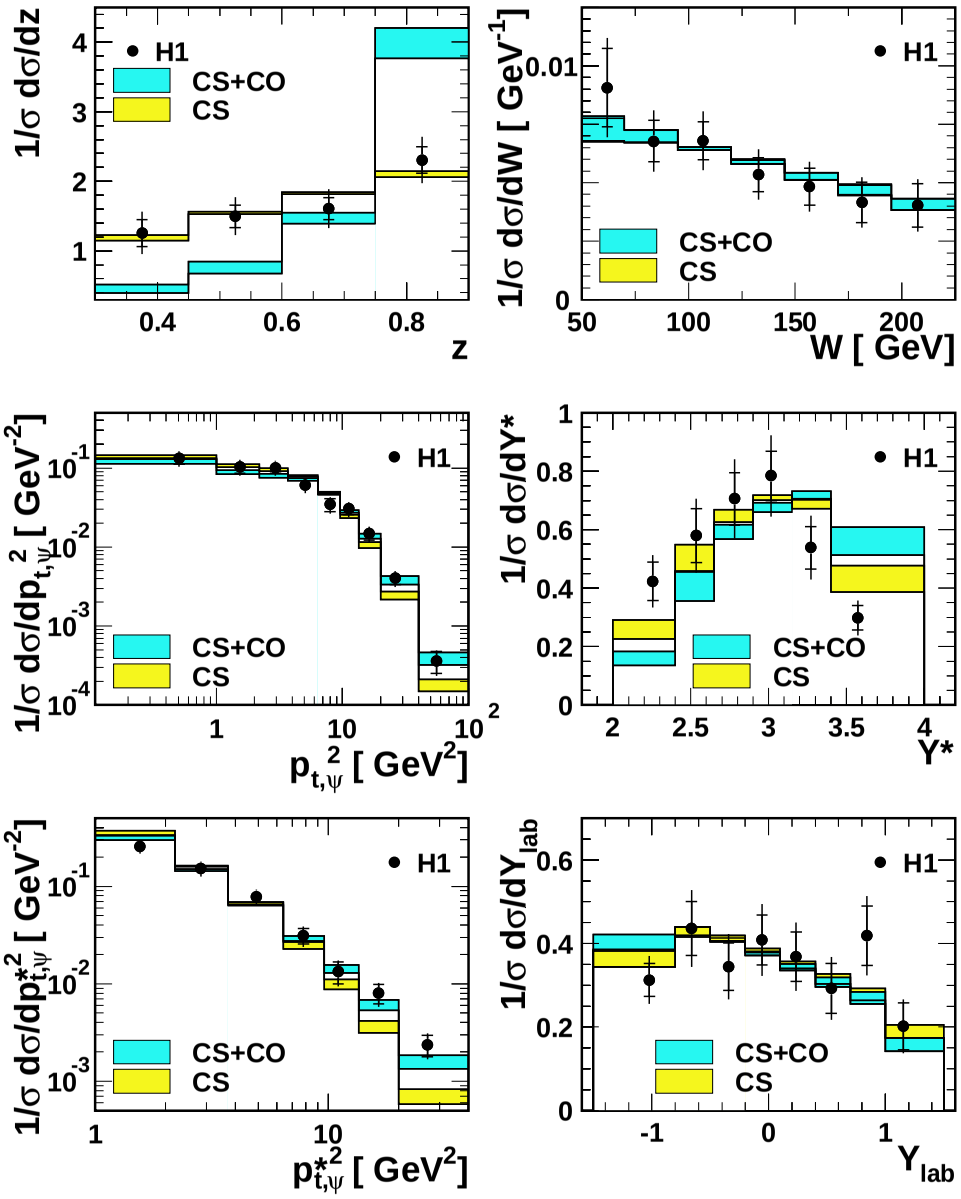


♣ comparison with LO NRQCD calculation and CS contribution (B.A. Kniehl and L.Zwirner)

♣ 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: Normalized Cross Sections $Q^2 > 2$ GeV^2



♢ **normalized x-sections to facilitate shape comparison**

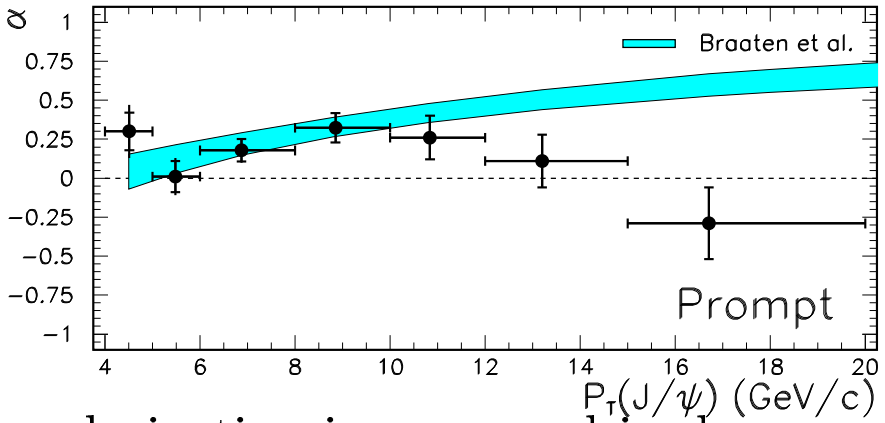
♢ Y^* (Y_{lab}): J/ψ **rapidity in** γp **cms (lab system)**

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

♢ $p^2_{t,\psi}, p^{*2}_{t,\psi}$: **missing higher orders for CS?**

Polarization Measurements

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



CDF measurement compared to NRQCD calculation

- 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

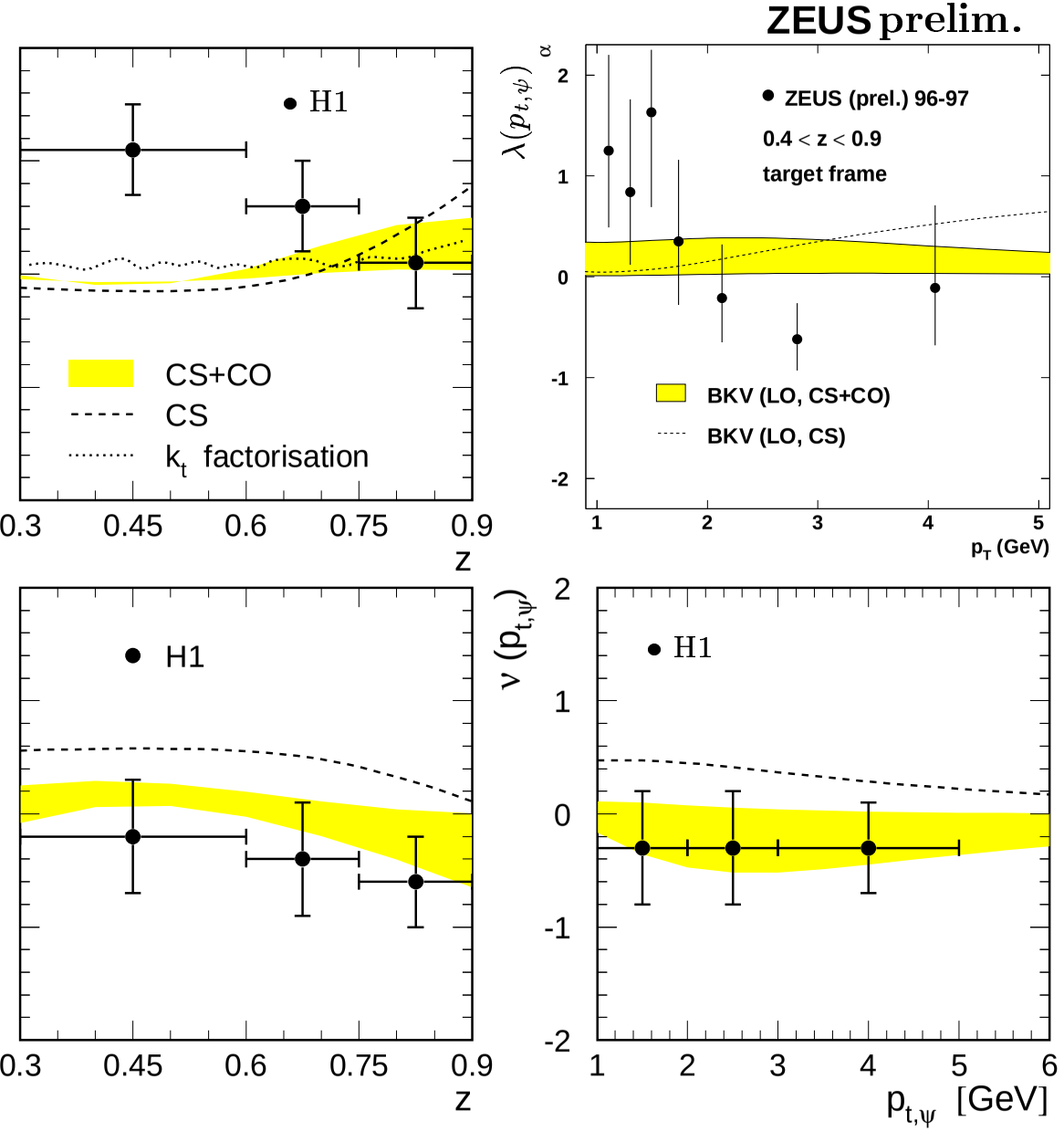
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} \propto 1+\lambda\cos^2\theta^*$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\phi^*} \propto 1+\frac{\lambda}{3}+\frac{\nu}{3}\cos 2\phi^*$$

$\lambda(=\alpha) = +1$: transverse polarization

$\lambda(=\alpha) = -1$: longitudinal polarization

Polarization Measurements: Photoproduction



- tendency for decrease of λ with z and $p_{t,\psi}$
- ν independent of z and $p_{t,\psi}$?
- $\Rightarrow$ 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 for electroproduction and in NRQCD needed !**