Charmonium Production at HERA

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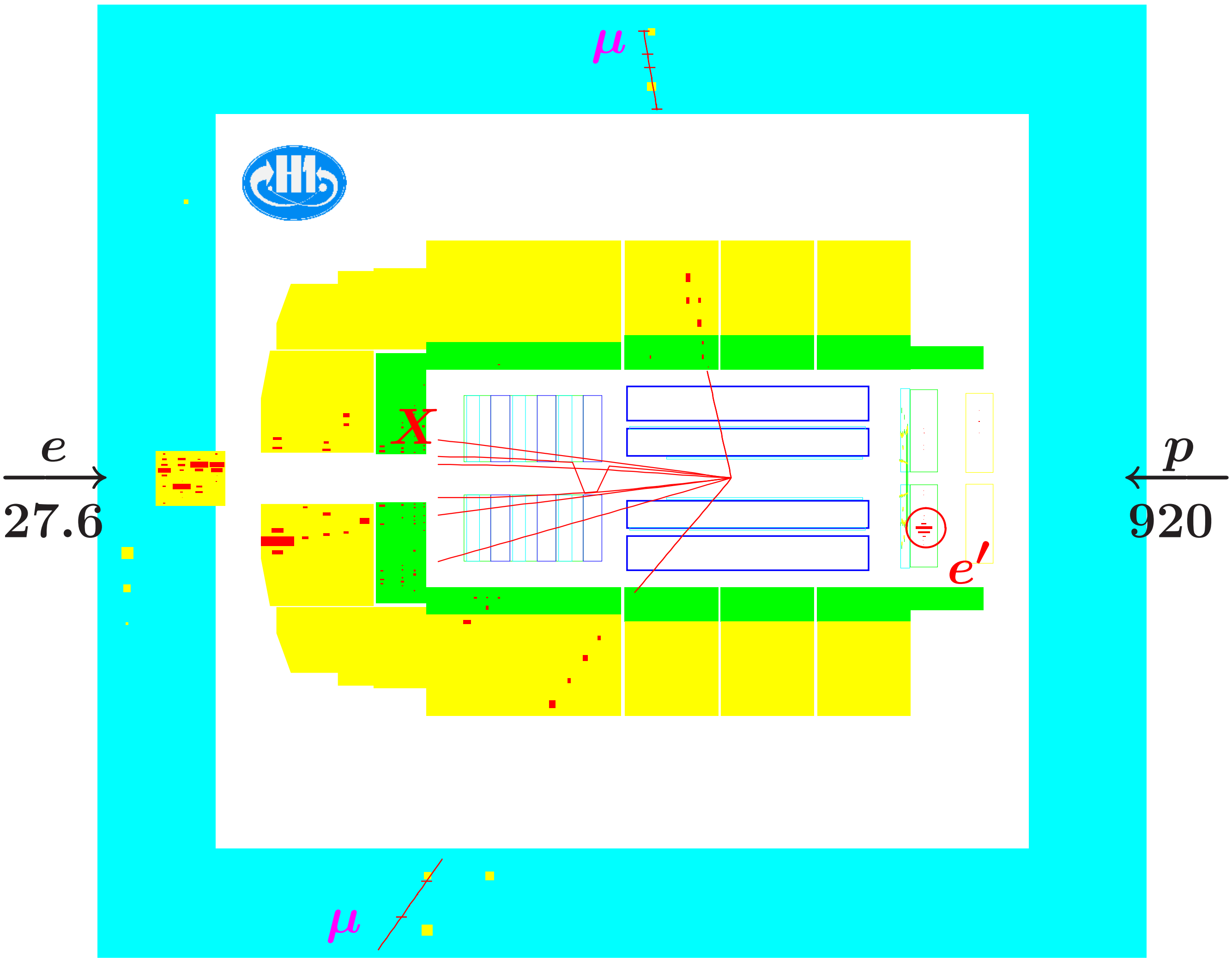
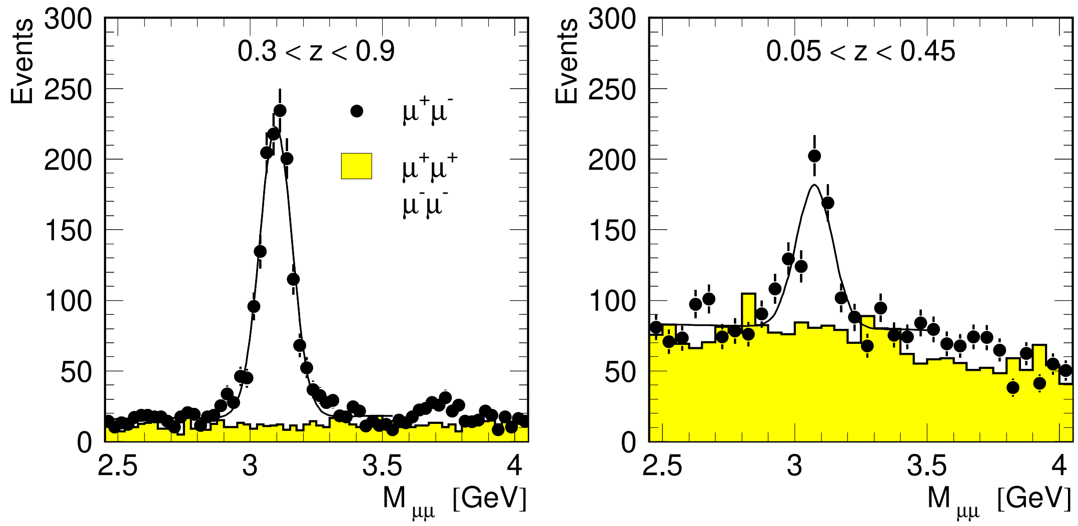
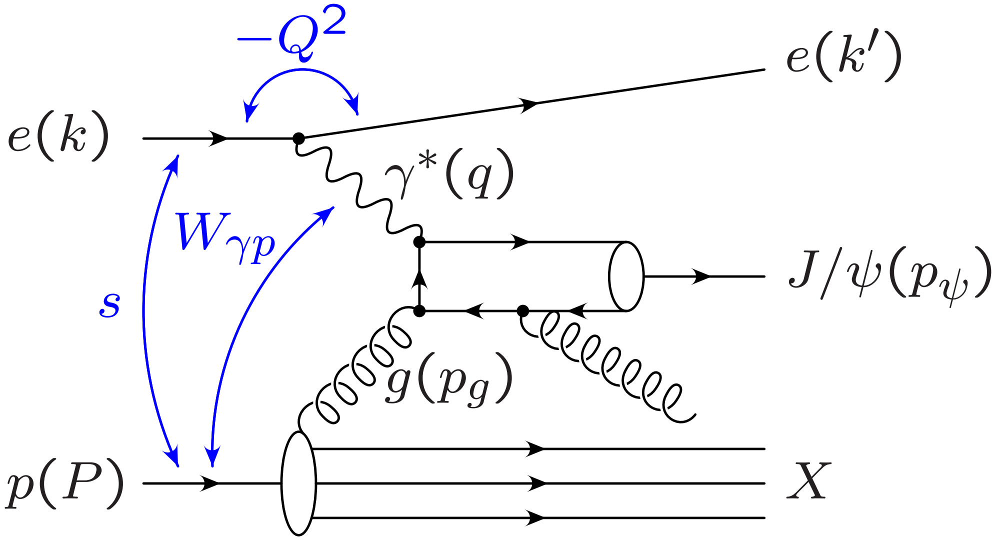
ep -Interactions at HERA



$ep \rightarrow eJ/\psi X$ $\sqrt{s} = 320$ GeV $\int \mathcal{L}dt \sim 80$ pb^{-1}



Event Kinematics



kinematic variables:

$$
\begin{aligned}
Q^2 &= -q^2 \\
s &= (P+k)^2 \\
W_{\gamma p} &= \sqrt{(P+q)^2} \\
z &= \frac{p_\psi \cdot P}{q \cdot P} \\
&= \frac{E^*_\psi}{E^*_\gamma} \text{ in } p \text{ rest frame}
\end{aligned}
$$

photoproduction ($Q^2 < 1\,\text{GeV}^2$):
scattered e not seen in main detector

electroproduction ($2 < Q^2 < 100\,\text{GeV}^2$):
scattered e detected in backward calorimeter

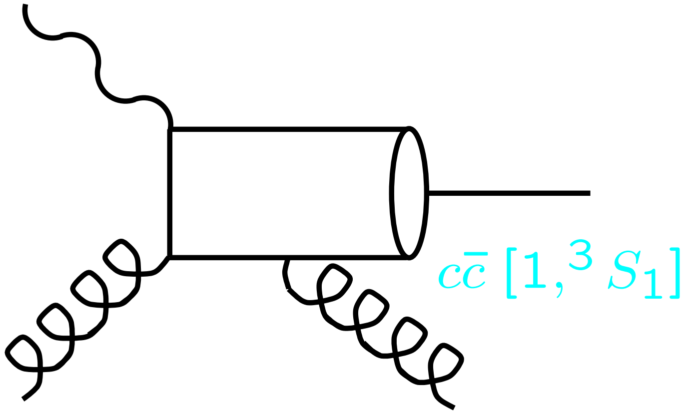
Production Mechanisms

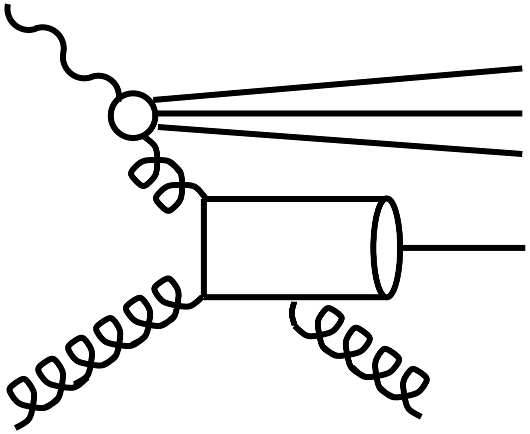
J/ψ is colourless

- Colour Singlet Model (CS) :

γ-'direct': $\gamma g \to c\bar{c}g$ $z \gtrsim 0.3$

γ-'resolved': $gg \to c\bar{c}g$ $z \lesssim 0.3$
(photoproduction only)





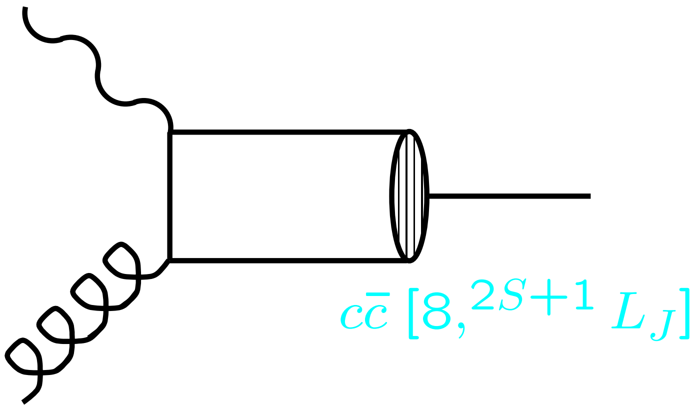
CS: one parameter:
fixed from $\Gamma(J/\psi \to l^+l^-)$

LO: Berger et al, Baier et al, 1981
NLO (direct): Krämer et al, 1995

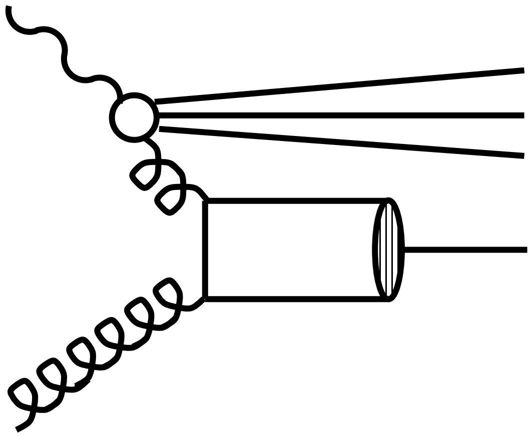
Production Mechanisms

- Colour Octet Model (CO):

direct: $\gamma g \to c\bar{c}$



resolved: $gg \to c\bar{c}$



$c\bar{c} \to J/\psi$ (+ soft gluons)

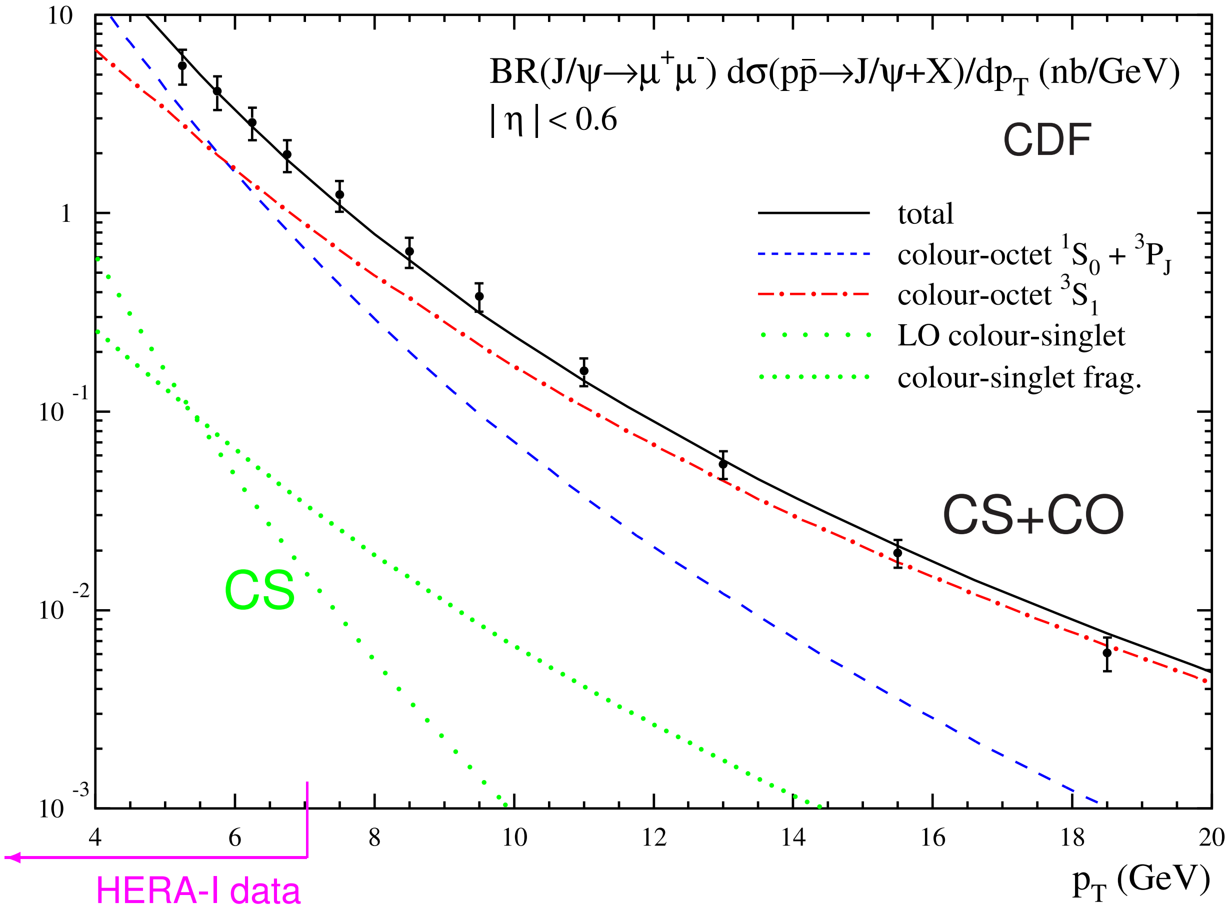
NRQCD+factorization:

Bodwin, Braaten, Lepage, 1995

$$\sigma(\gamma^{(*)}p \to J/\psi X) = \sum \hat{\sigma}(\gamma p \to c\bar{c}[n]X) \times \mathrm{LDME}[n])$$

LDME not calculable, but universal, fixed from $p\bar{p}$

Prompt J/ψ Hadroproduction



CS Model: Too low
by orders of magnitude

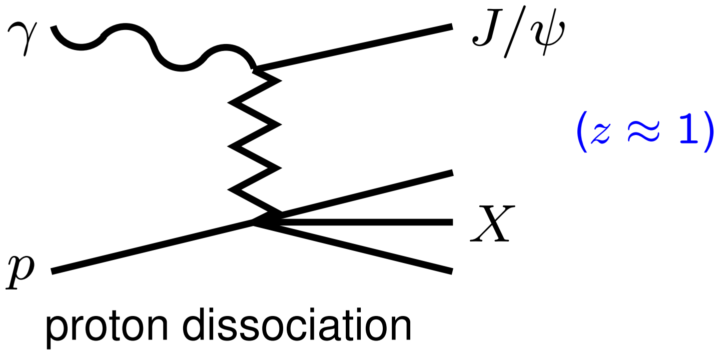
CO Model: Normalization
and shape well described

Test universality: LDME(Tevatron) $\longrightarrow$ HERA

Background Contributions

from other J/ψ production processes

- diffractive J/ψ production



suppressed ($\sim 2\%$) by cuts on:

– $z < 0.9$
– $p^*_{t,\psi} > 1$ GeV
– # tracks ≥ 5 (H1)

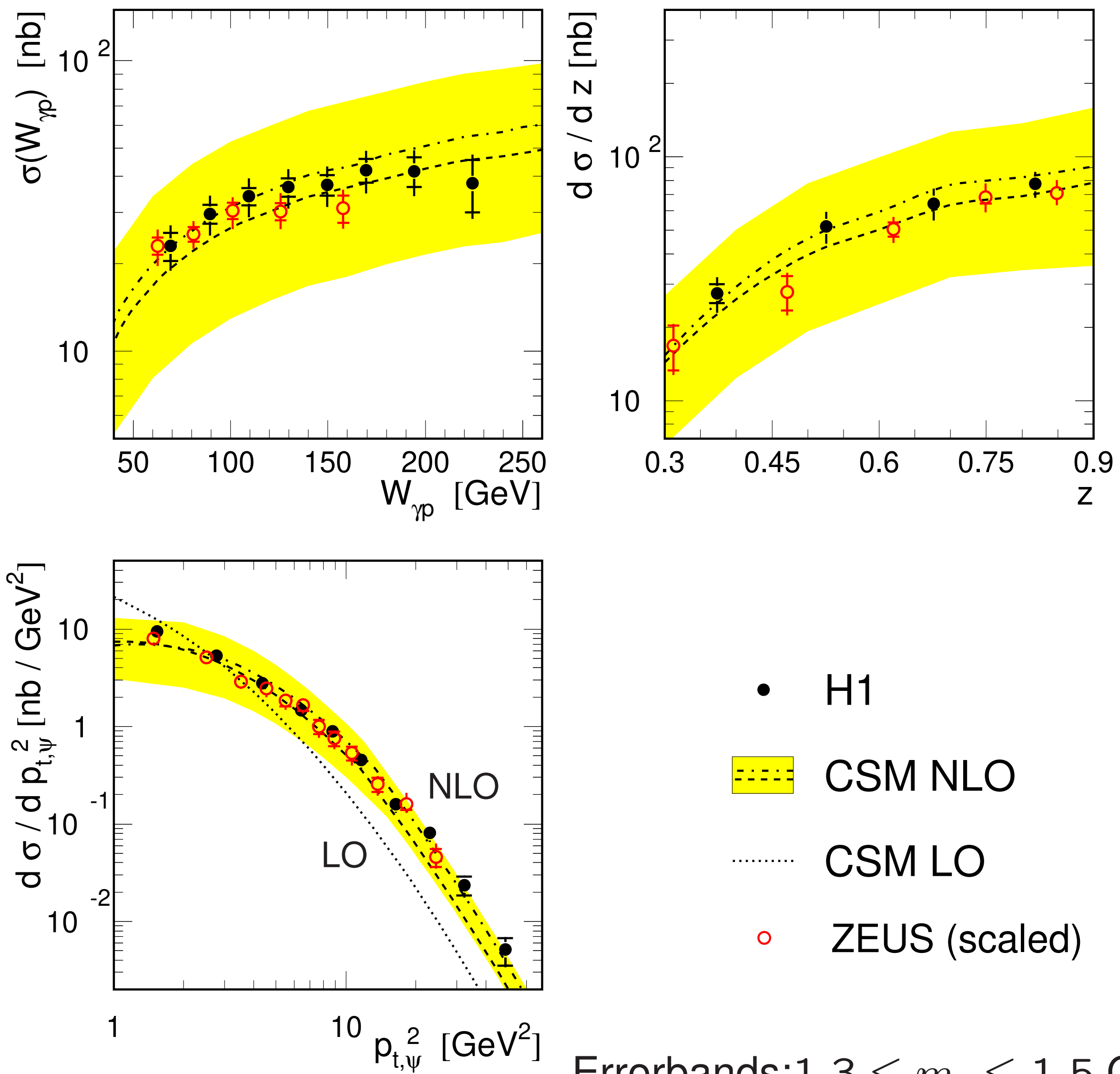
- J/ψ from ψ' decays: $\psi' \to J/\psi\,\pi\,\pi$
($\sim 15\%$)

- J/ψ from χ_c decays: $\chi_c \to J/\psi\,\gamma$
(1% up to 7% at the lowest z)

- J/ψ from B decays: $B \to J/\psi\,X$
(5% up to 25% at the lowest z)

these backgrounds are not subtracted

Photoproduction
Comparison with CS NLO

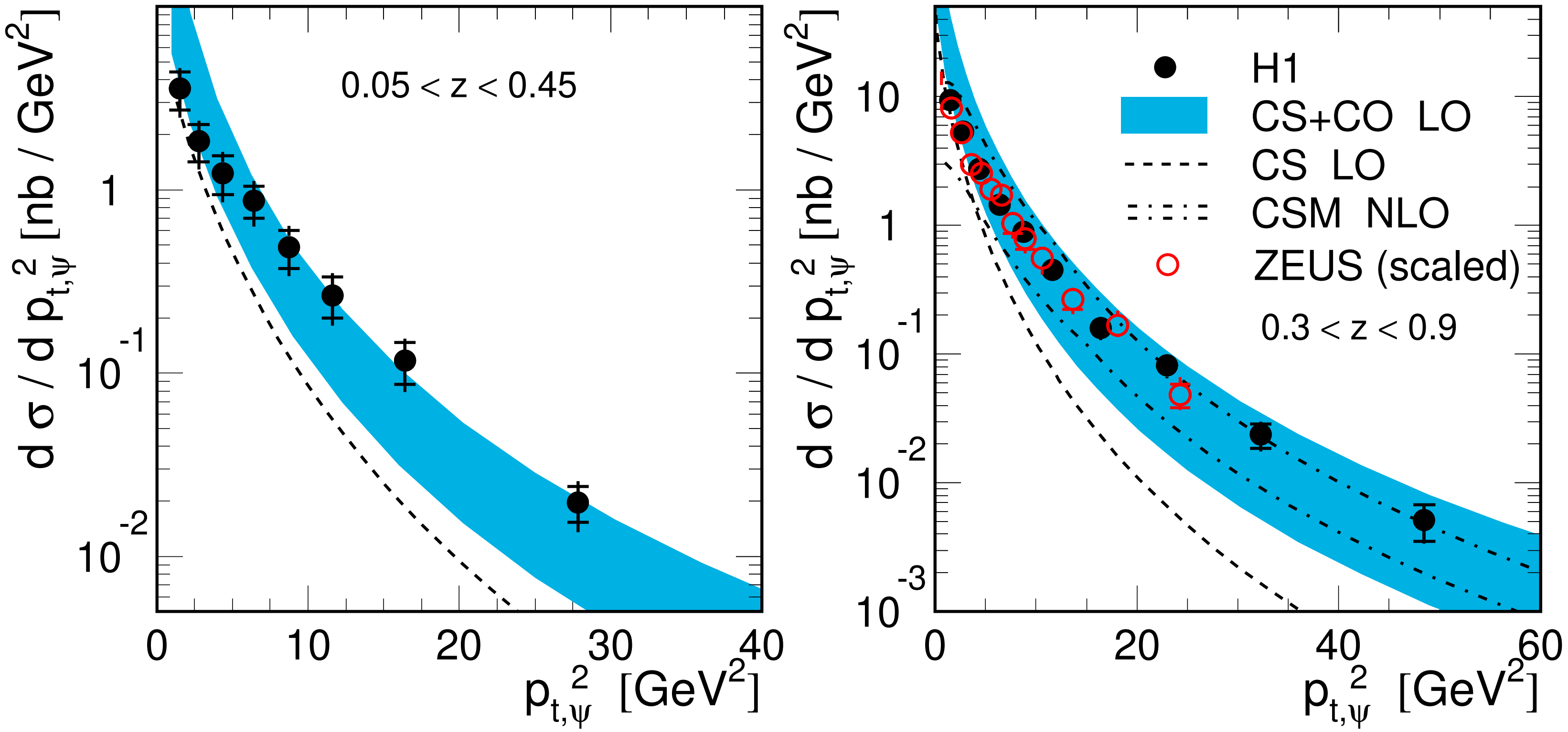


Errorbands: $1.3 \leq m_c \leq 1.5$ GeV
$0.1175 \leq \alpha_s(M_Z) \leq 0.1225$

- Good agreement between H1 and ZEUS
- CS: full NLO calculation of direct photon gluon fusion ($z \gtrsim 0.3$) M.Krämer

$\Rightarrow$ LO: too steep
NLO: good description

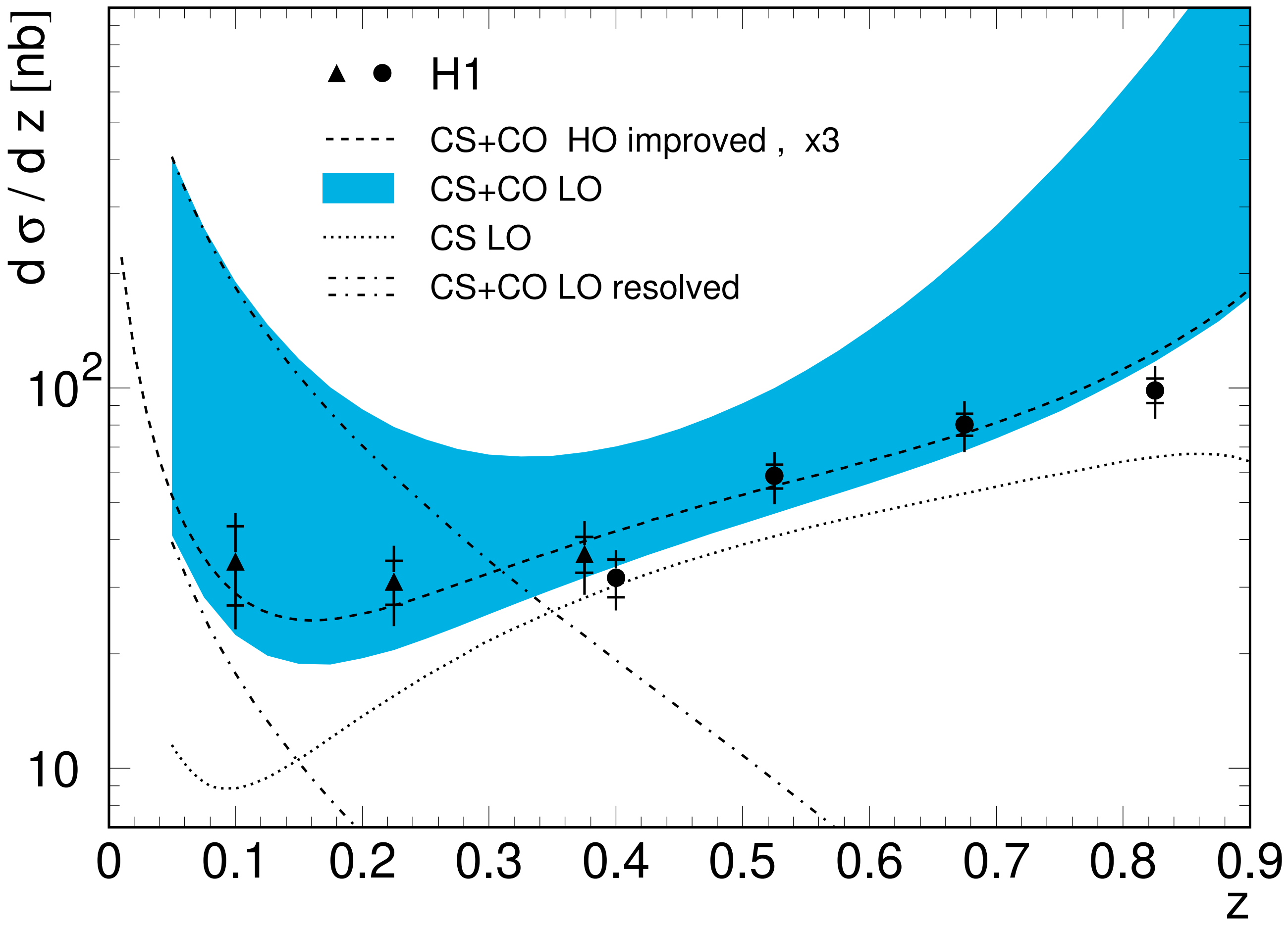
Photoproduction: Comparison with NRQCD (CS+CO)



- $p_{t,\psi}^2$ spectra similar at low and medium z
- NRQCD (CS+CO): tendency to fall too steeply

  contributions from B-decays in data?

Photoproduction
Comparison with NRQCD (CS+CO)

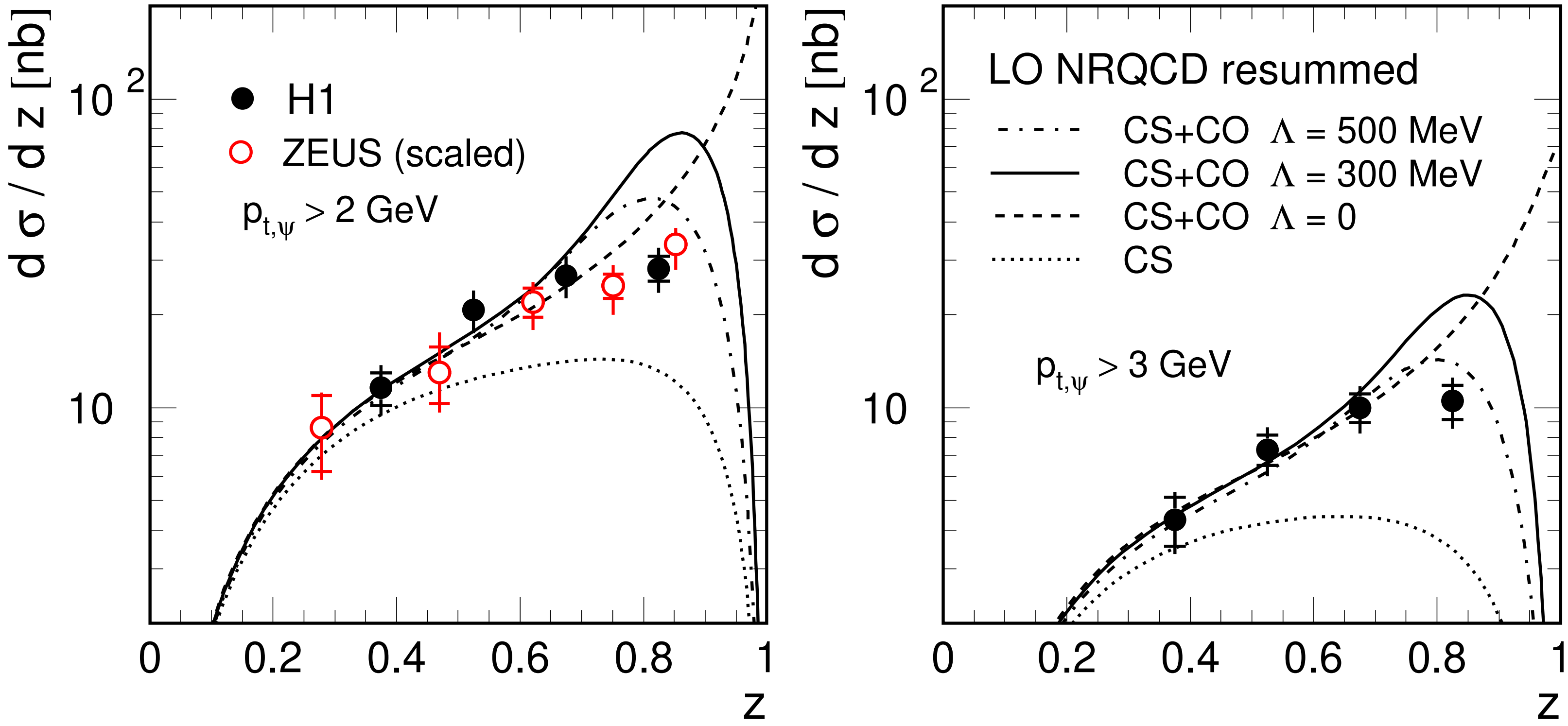


- NRQCD (CS+CO): LO calculation including direct and resolved photon processes M.Krämer
- LDME from taken from NRQCD fit to $p\bar{p}$ data

$\Rightarrow$ Leading order NRQCD (CS+CO):
Fair description of whole z range

HERA data favour smaller values of LDME than CDF

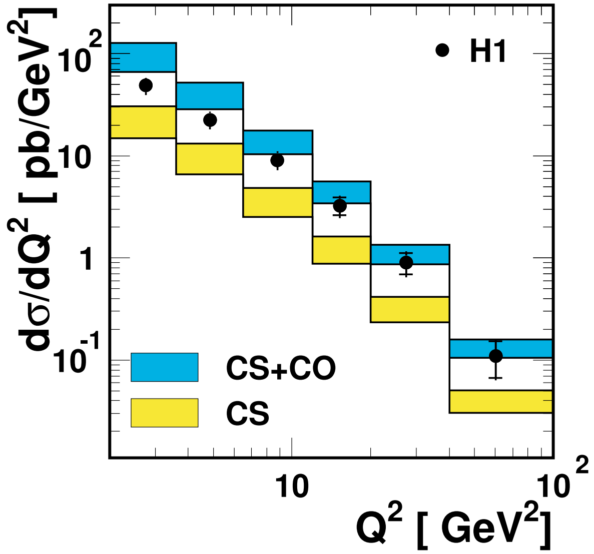
Photoproduction: NRQCD at large z

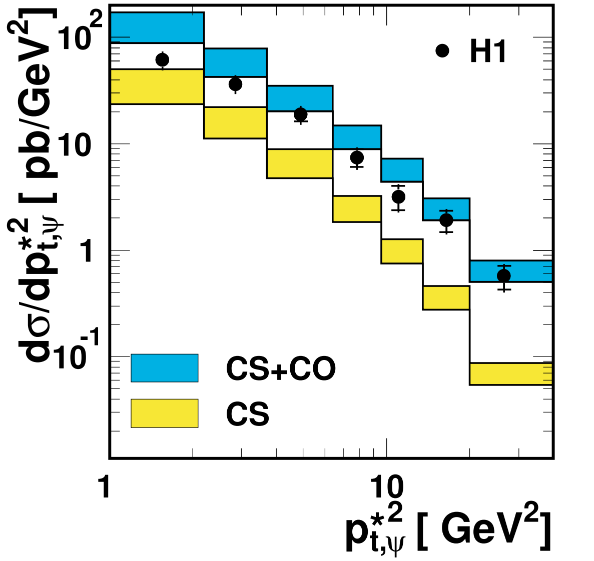


- NRQCD too high at large z ($z \gtrsim 0.8$)
- Contributions from soft gluons at high z resummed M.Beneke, G.A.Schuler, S.Wolf
- Λ: Energy loss due to soft gluon radiation

shape discrepancies reduced (normalization adjusted)

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





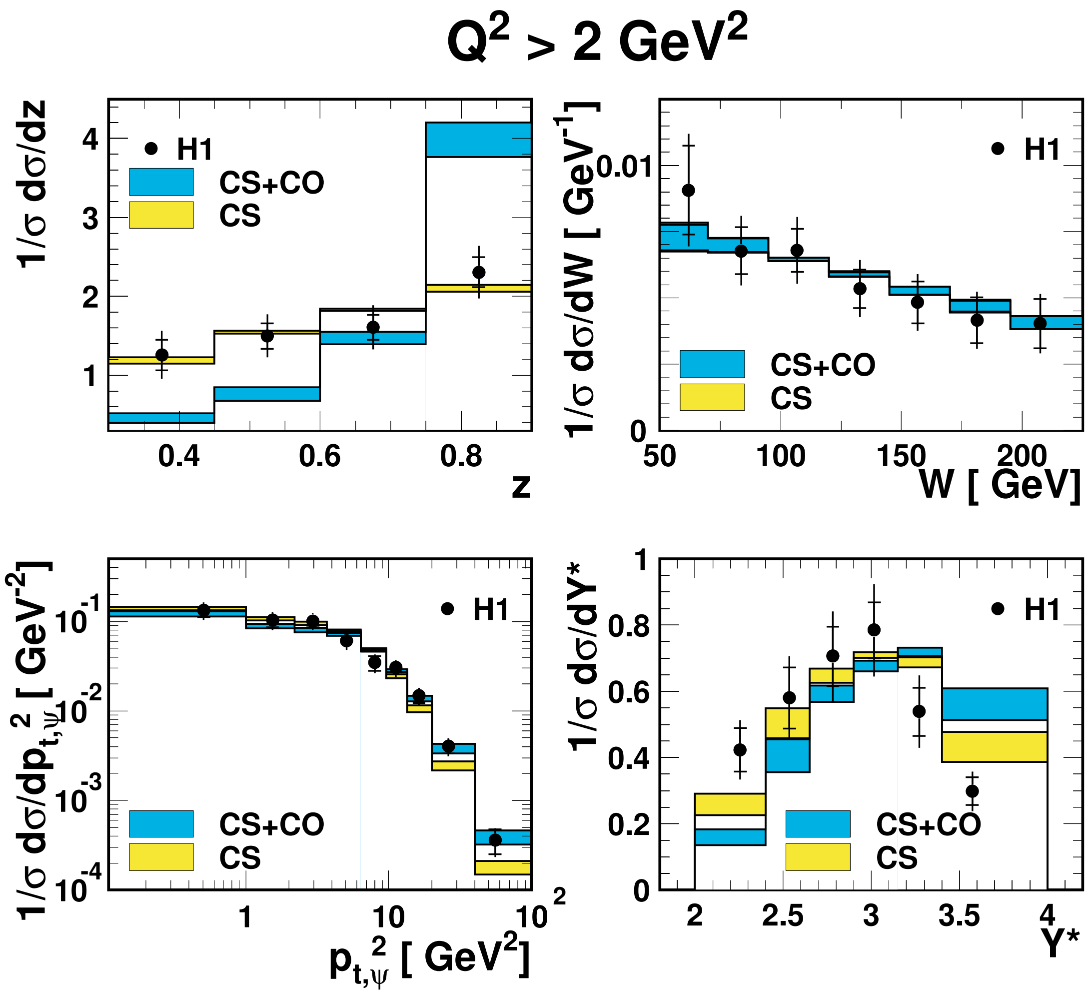
- Compare data with CS and NRQCD (CS+CO)
  B.A.Kniehl, L.Zwirner

- CS contribution alone:
  too low and too steep in $p_{t,\psi}$

- NRQCD (CS+CO):
  too high at low Q^2 and $p_{t,\psi}$,
  improves at high Q^2 and $p_{t,\psi}$
  (smaller theoretical errors)

$\Rightarrow$ Need NLO calculations
and more data at larger Q^2 and $p^2_{t,\psi}$

Electroproduction
Shape Comparisons



Y^* Rapidity in γp CMS

$p_{t,\psi}^2$ CS+CO: ok

z CS+CO: large discrepancies in shape

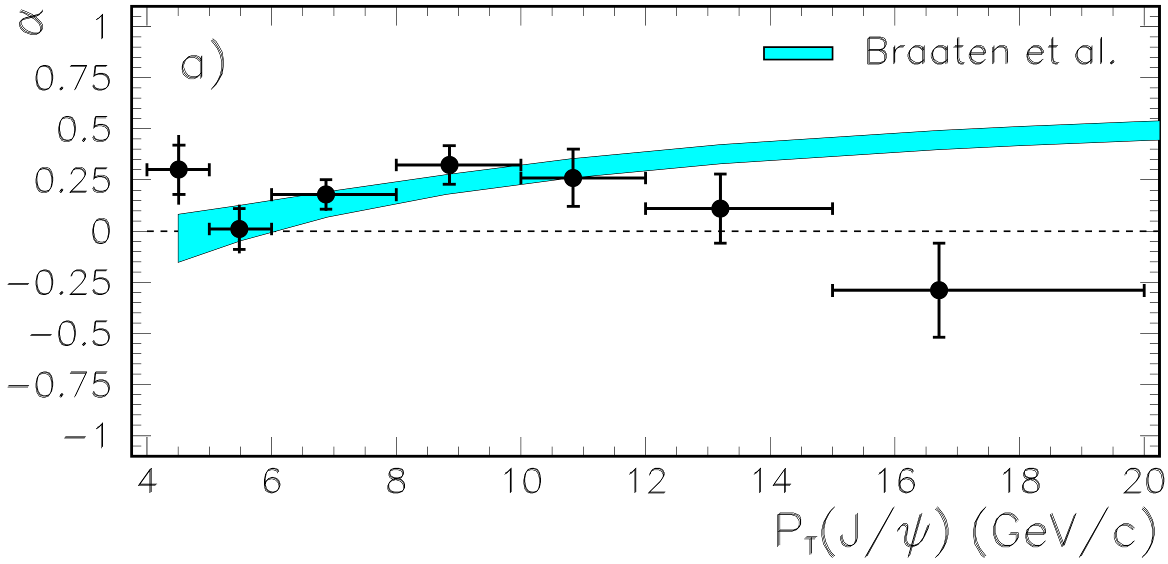
due to missing resummation of soft gluons?

J/ψ-Polarization

NRQCD predicts transverse polarization at large $p_{t,\psi}$

Test of NRQCD indep. of normalization uncertainties

CDF measurement:



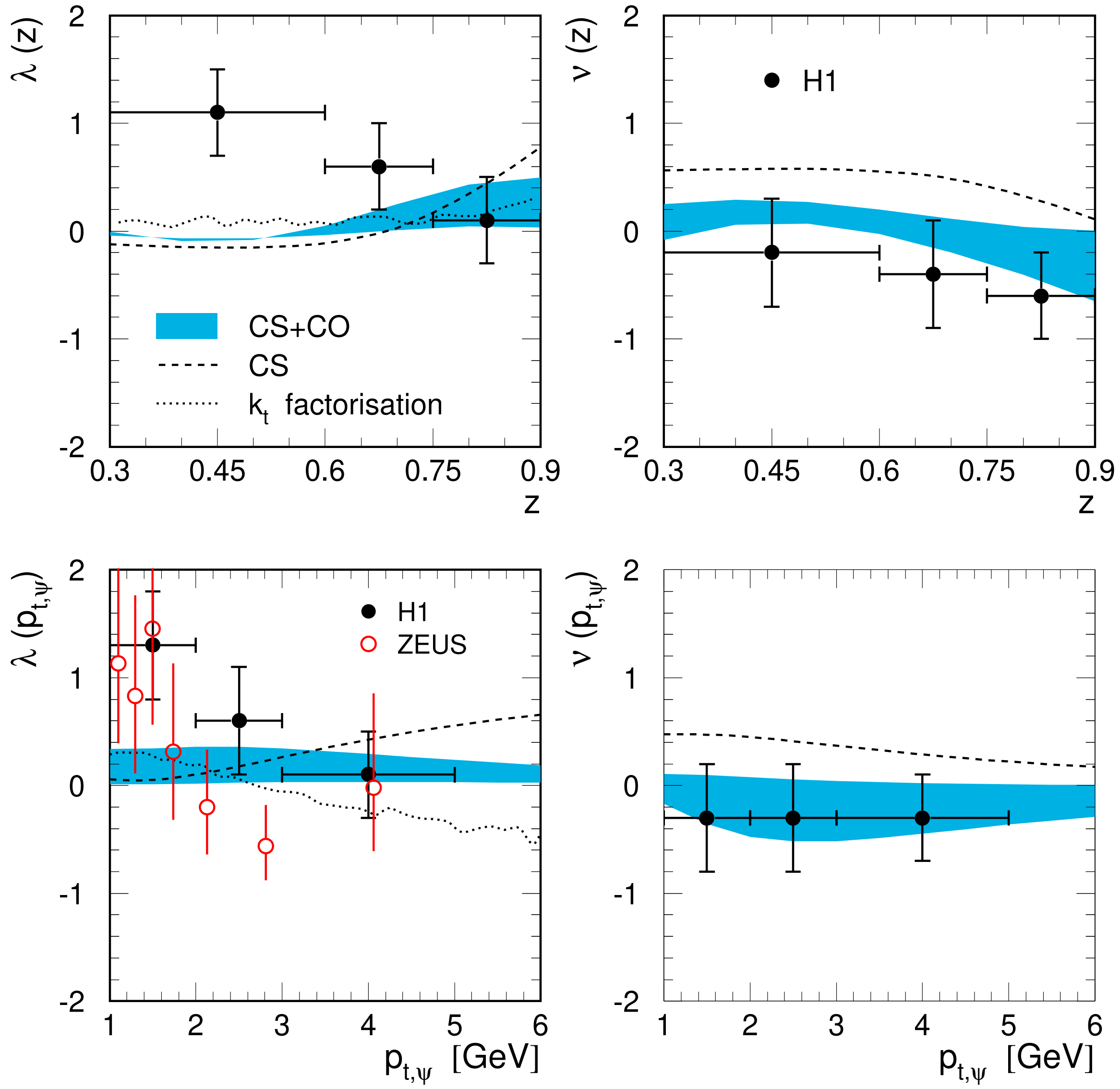
Measure J/ψ polarization in decay angular distributions

$\cos\theta^*$: angle of μ^+ relative to proton in J/ψ rest frame
$\cos\Phi^*$: angle of μ^+ in plane perpendicular to incoming photon

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

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

Polarization



- H1 and ZEUS in broad agreement
- Tendency for decrease of λ with z and $p_{t,\psi}$

More statistics and higher $p_{t,\psi}$ needed
to discriminate between models

Conclusions

Full HERA-I data set has been analysed (H1)

Photoproduction:
– Colour Singlet NLO calculations agree well with data
– NRQCD (LO) with small LDME also reasonable
$\Rightarrow$ NLO calculations are important
$\Rightarrow$ No hard evidence for Colour Octet contributions

Electroproduction:
– CS alone too low, wrong $p_{t,\psi}$ dependence
– NRQCD ok at high Q^2 and $p_{t,\psi}$, but problems in z
$\Rightarrow$ Need NLO calculations for CS and CO

Polarization studies:
$\Rightarrow$ Results so far statistics limited

Hera II (1 fb^{-1}): factor $\sim$ 10 in statistics
$\Rightarrow$ measure at larger Q^2 and $p_{t,\psi}$
$\Rightarrow$ polarization