Theoretical status of J/ψ production at HERA

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Outline

- Introduction
- Tree-level contributions to J/ψ photoproduction
- Colour-singlet at Next-to-Leading Order in α_s
- Conclusion

work done in collaboration with

J. Campbell, F. Maltoni, F. Tramontano,

see Phys. Rev. Lett. 102, 142001

Kinematics at Hera

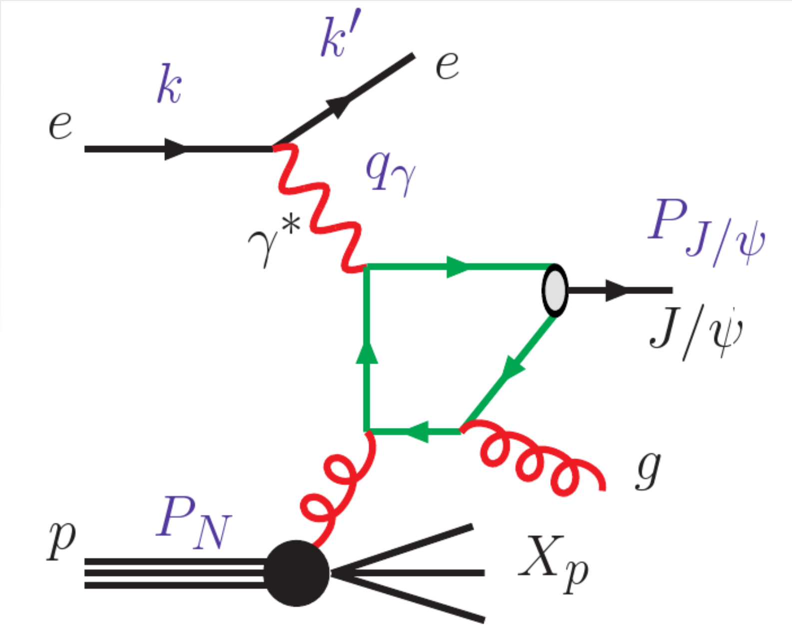
- relevant variables

$$S = (P_N + k)^2$$

$$Q^2 = -q_\gamma^2$$

$$z = \frac{P_N . P_{J/\psi}}{P_N . q_\gamma}$$

$$W^2 = (P_N + q_\gamma)^2$$



- **photoproduction** : $Q^2 \approx 0$
- $\sigma(ep \to J/\psi + X)$ converted into $\sigma(\gamma p \to J/\psi + X)$ using the **Weiszäcker-Williams approximation**

Factorization principle

- creation of a perturbative charm-quark pair over distances of order $1/m_c$ or smaller
- typical size of the J/Ψ is $1/vm_c$
- if v is small, these two scales are well separated, the cross section has a factorized form:

$$\sigma(ij \to \mathcal{Q} + X) \sim \sum_n \hat{\sigma}_\Lambda(ij \to Q\bar{Q}(n) + X)\langle \mathcal{O}^{\mathcal{Q}}(n)\rangle_\Lambda$$

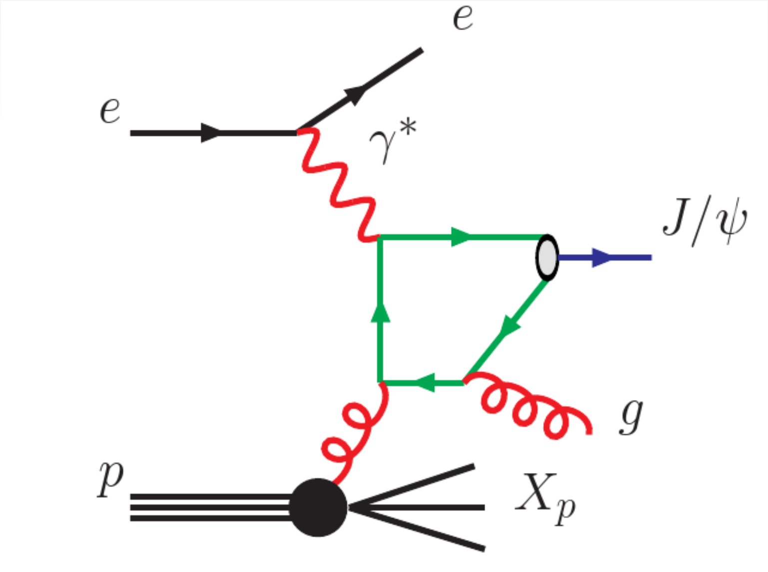
Short distance coefficients, expansion in α_s

Long distance matrix elements expansion in v

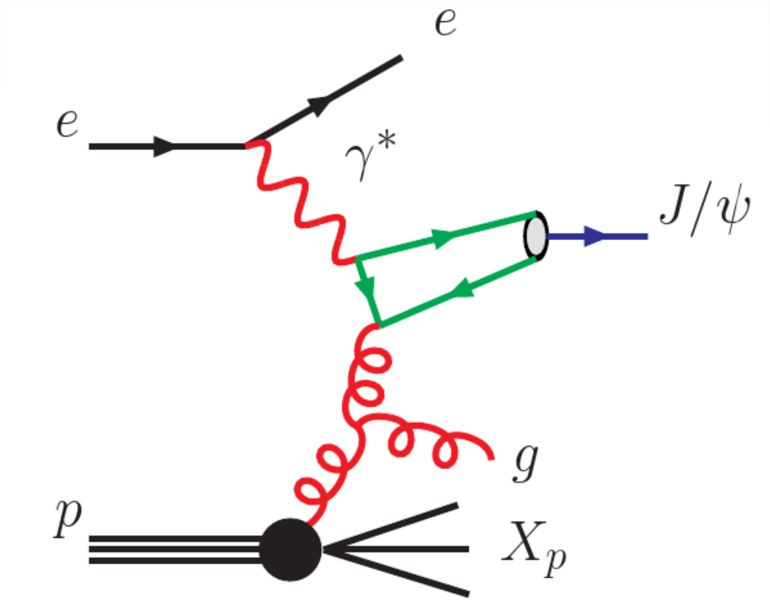
NRQCD Factorization

- Different transitions:

colour singlet: cc in $^3S_1^{[1]}$ state



colour octet: cc in $^1S_0^{[8]}$ or $^3P_J^{[8]}$ state



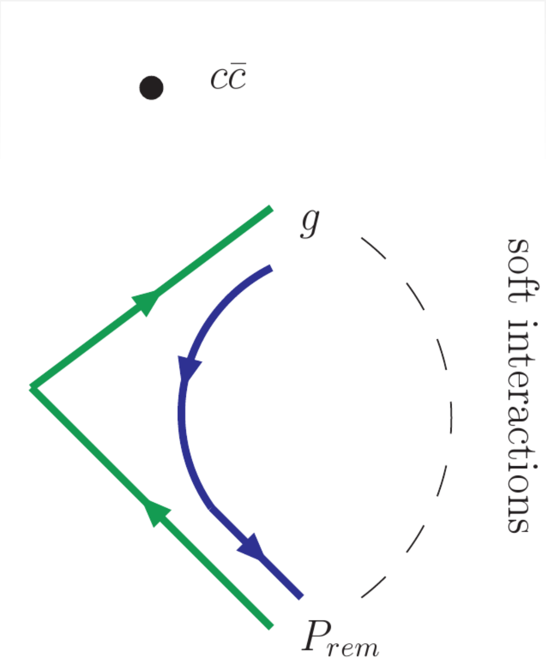
$$\boldsymbol{\sigma} = \hat{\boldsymbol{\sigma}}\left(c\bar{c}(^3S_1^{[1]})\right)\langle \mathcal{O}_{[1]}(^3S_1)\rangle_{J/\psi} + \hat{\boldsymbol{\sigma}}\left(c\bar{c}(^1S_0^{[8]})\right)\langle \mathcal{O}_{[8]}(^1S_0)\rangle_{J/\psi}$$

$$+\sum_J \hat{\boldsymbol{\sigma}}\left(c\bar{c}(^3P_J^{[8]})\right)\langle \mathcal{O}_{[8]}(^3P_J)\rangle_{J/\psi}$$

NRQCD Factorization

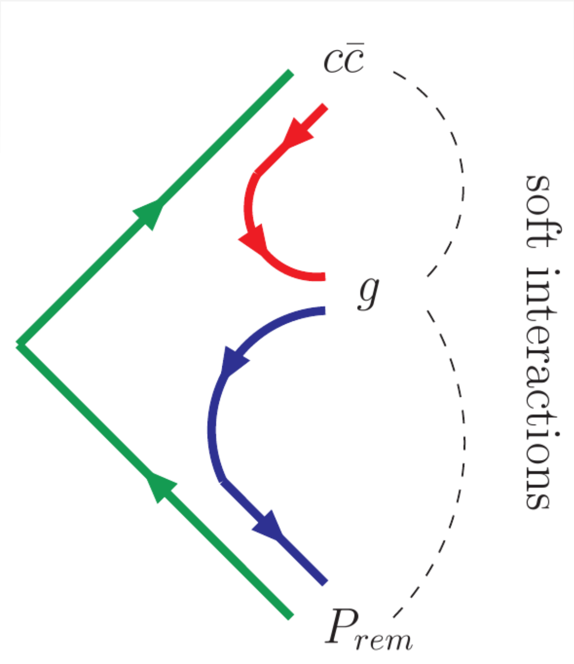
- Different transitions:

colour singlet: cc in $^3S_1^{[1]}$ state



No colour connection with the cc pair

colour octet: cc in $^1S_0^{[8]}$ or $^3P_J^{[8]}$ state



soft gluon emission with the cc pair

suppression in v: $\frac{\langle \mathcal{O}_{[8]}(^1S_0)\rangle_{J/\psi}}{\langle \mathcal{O}_{[1]}(^3S_1)\rangle_{J/\psi}} \sim v^4$

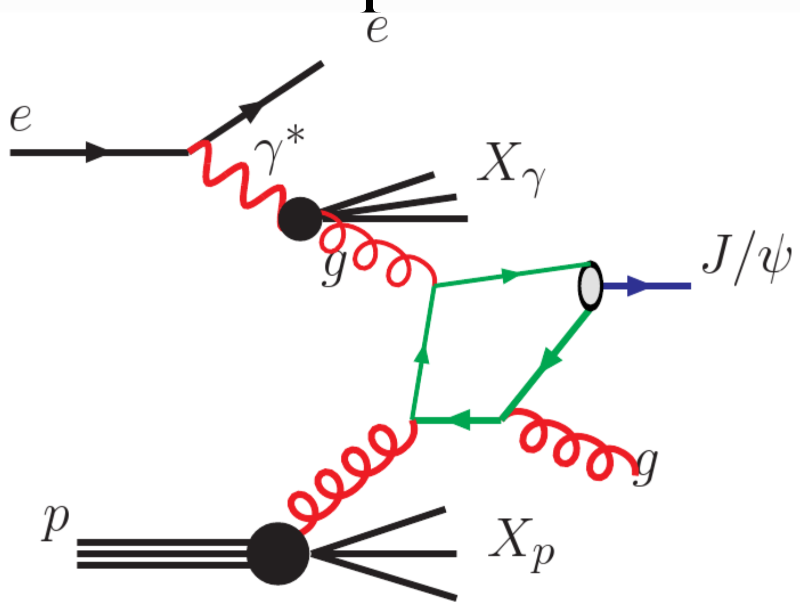
Non-direct contributions

- Feed down from excited states

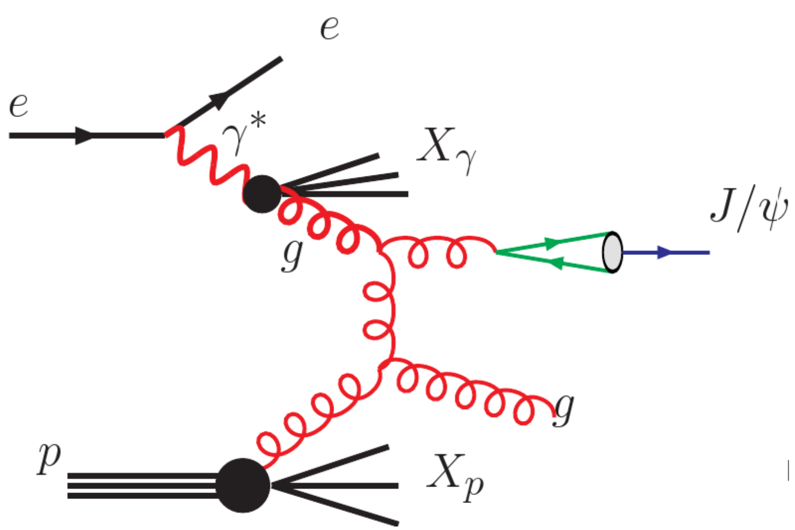
  $\psi' \to J/\psi + X$ 15% contribution at HERA

  $\chi_c \to J/\psi + \gamma$ negligible at HERA

- Resolved-photon contributions: relevant at low z



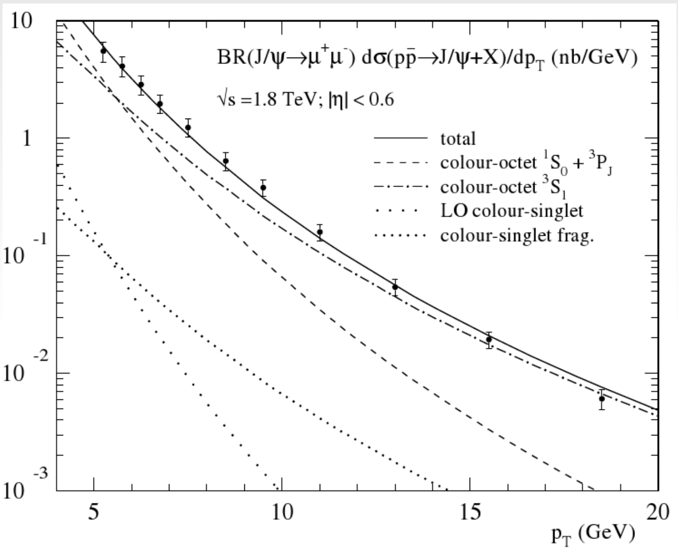
Colour singlet



Colour octet

Colour-octet LDME's

- Extraction from the Tevatron



Fit of the long distance matrix elements

$$\langle \mathcal{O}_{[8]}(^1S_0)\rangle_{J/\psi} + k\frac{\langle \mathcal{O}_{[8]}(^3P_0)\rangle_{J/\psi}}{m_c^2}$$

$$\langle \mathcal{O}_{[8]}(^3S_1)\rangle_{J/\psi}$$

to reproduce the Tevatron data

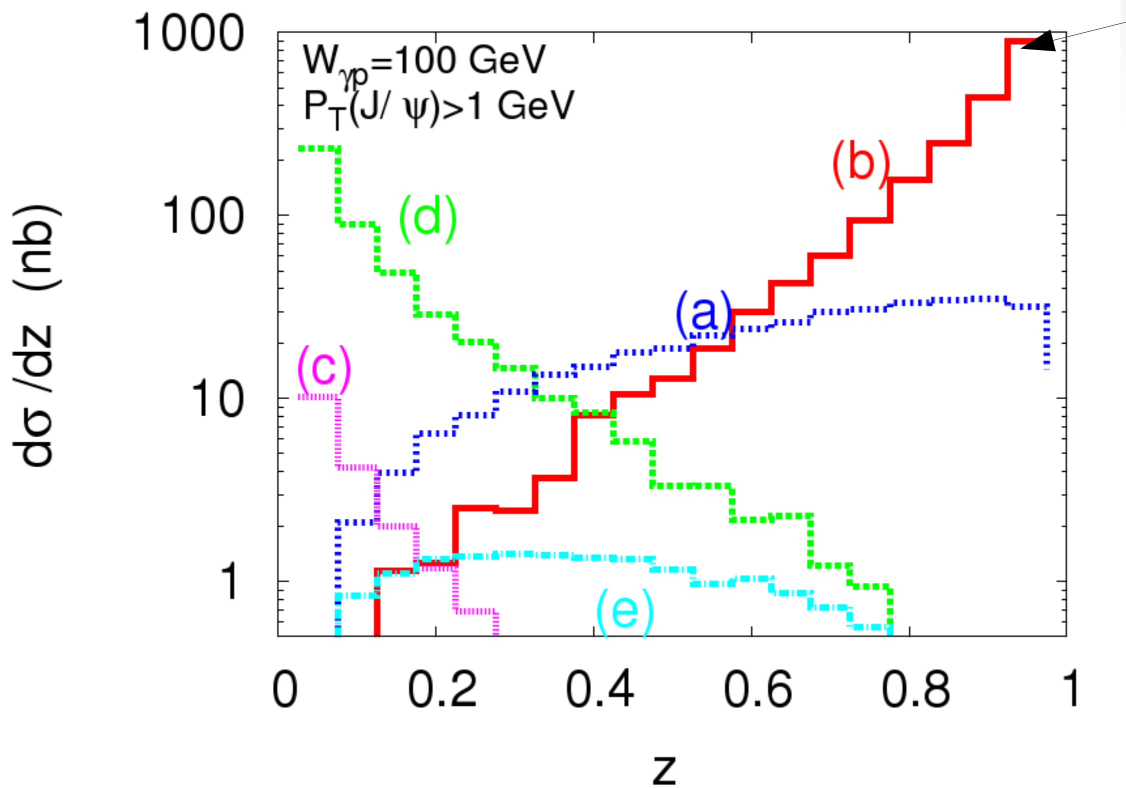
[from M. Kramer, Prog. Part. Nucl. Phys. 47 : 141-201,2001.
exp. data : F. Abe et al (CDF), Phys. Rev. Lett. 79 (1997)]

Here we consider the results from *Braaten et al, Phys. ReV D vol 62, 094005* and we will assume

$$\langle \mathcal{O}_{[8]}(^1S_0)\rangle_{J/\psi} = \frac{\langle \mathcal{O}_{[8]}(^3P_0)\rangle_{J/\psi}}{m_c^2}$$

Tree-level contributions

- CO/CS, direct/resolved as a function of z
  scale: $\mu_r = \mu_f = 2m_c$



Fixed order computation is not valid at z=1 (soft gluon emission must be resummed)

(a) direct CS yield

(b) direct CO yield

(c) resolved CS yield

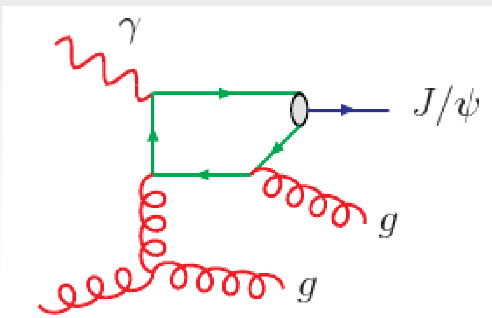
(d) resolved CO yield

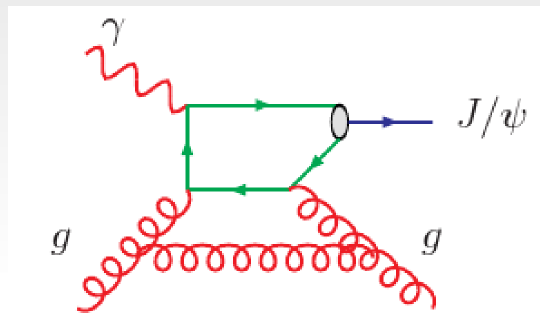
(e) direct $J/\psi + c\bar{c}$

Colour-singlet yield at NLO

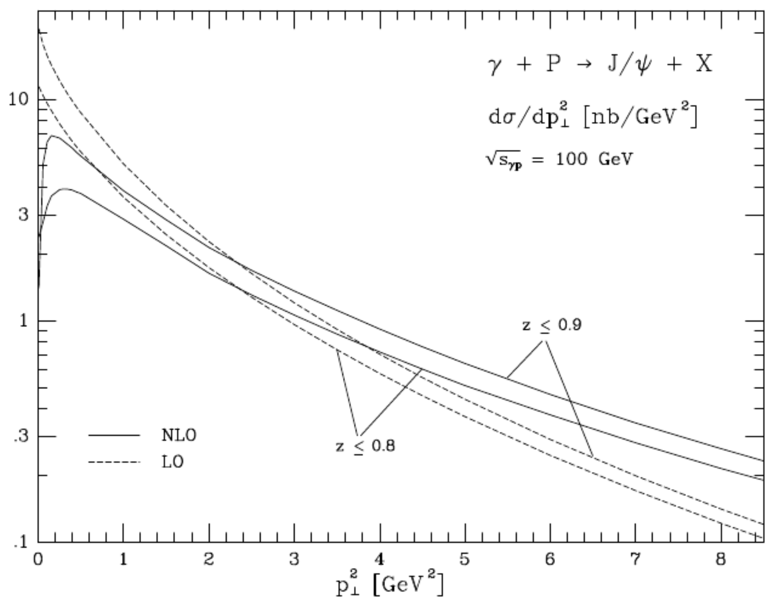
M. Kramer (1995)
P. A., J. Campbell, F. Maltoni, F. Tramontano (2009)
C.-H. Chang, R. Li, J.-X. Wang (2009)

- Typical Feynman diagrams:





- Differential cross section:



substantial enhancement at high transverse momentum (new kinematic contributions)

Kramer, Nucl.Phys.B459 :3-50,1996.

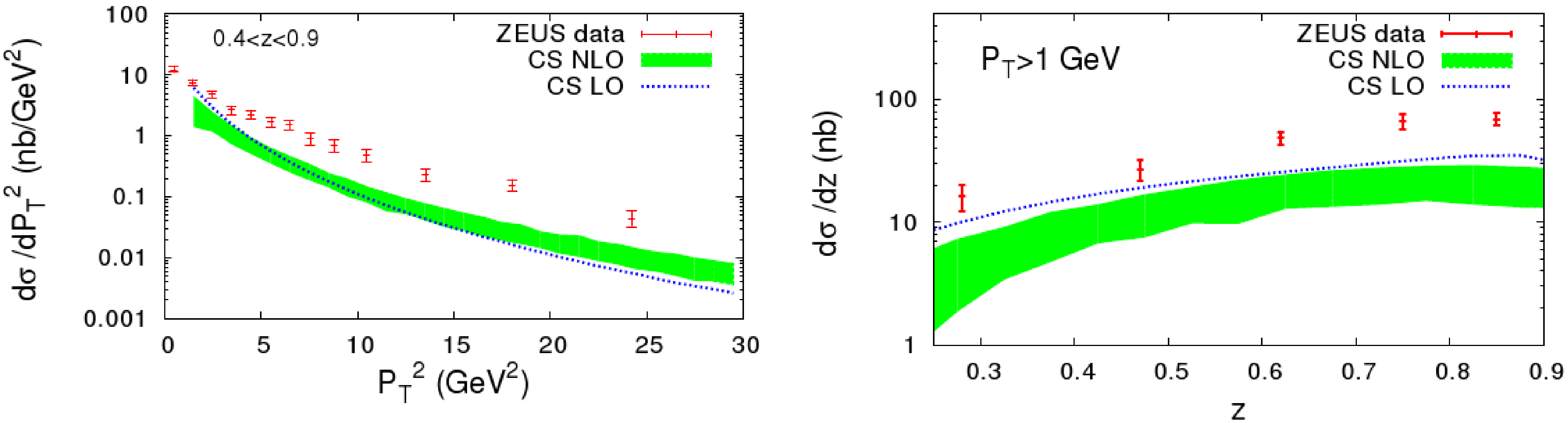
Comparison with the data

- Colour singlet yield at NLO undershoots the data

  mass uncertainty: $1.4 \text{ GeV} < m_c < 1.6 \text{ GeV}$

  scale uncertainty:

$$\mu_0 = 4m_c, \quad 0.5\mu_0 < \mu_r, \mu_f < 2\mu_0, \quad 0.5 < \frac{\mu_r}{\mu_f} < 2$$



J/Ψ Polarization

- J/Ψ polarization deduced from the angular distribution of the produced leptons
- spin quantization axis: $z = -\frac{\boldsymbol{P_N}}{|\boldsymbol{P_N}|}$ (target frame)
- angular distr. of the leptons in the J/Ψ rest frame

$$\frac{d\sigma}{d\Omega dy} \propto 1 + \lambda(y)\cos^2\theta + \mu(y)\sin 2\theta\cos\phi + \frac{\nu(y)}{2}\sin^2\theta\cos 2\phi$$

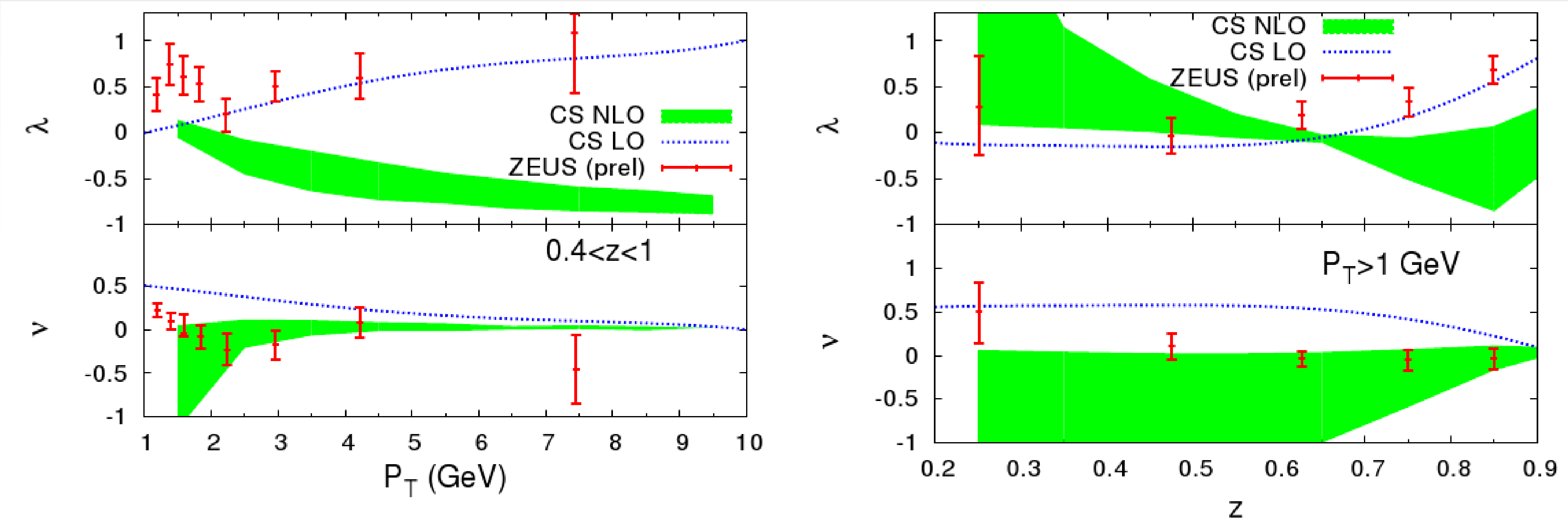
with respect to the spin quantization axis, and

$$\lambda = \frac{\rho_{11} - \rho_{00}}{\rho_{11} + \rho_{00}}, \quad \mu = \frac{\sqrt{2} Re \rho_{10}}{\rho_{11} + \rho_{00}}, \quad \nu = \frac{2\rho_{1,-1}}{\rho_{11} + \rho_{00}}$$

J/Ψ Polarization: CS at NLO

P. A., J. Campbell, F. Maltoni, F. Tramontano (2009)
see also C.-H. Chang, R. Li, J.-X. Wang (2009)

- Colour-singlet at NLO in α_s



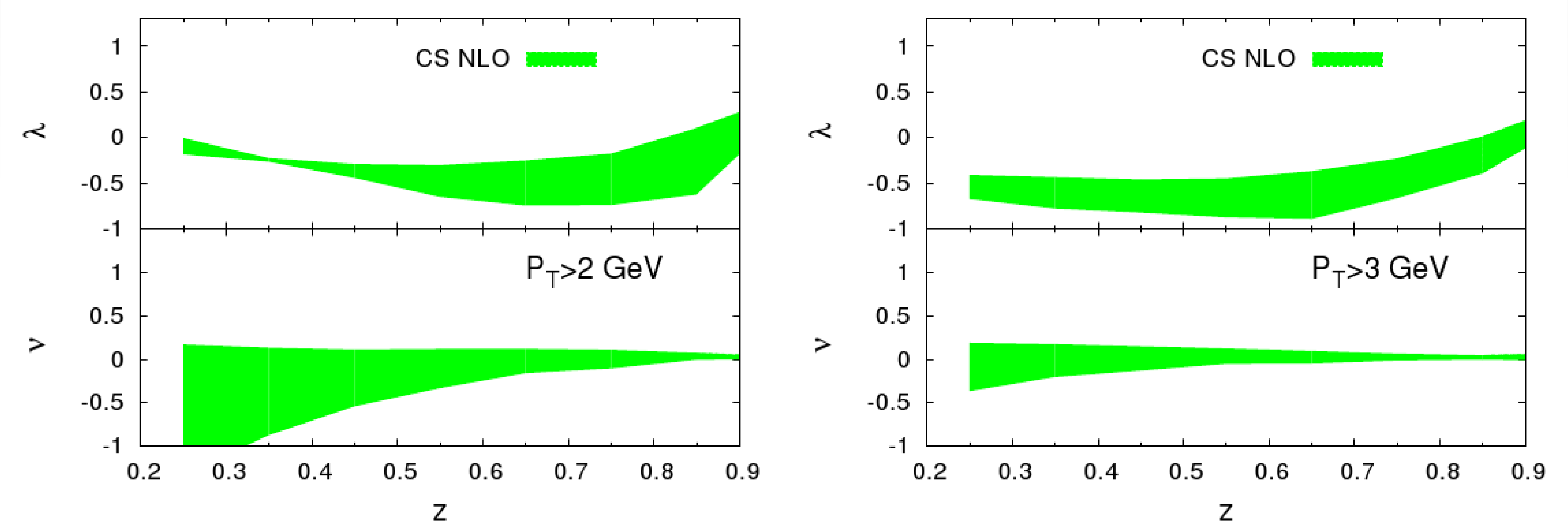
- Uncertainty band resulting from the variation of the scales:

$$\mu_0 = 4m_c, \quad 0.5\mu_0 < \mu_r, \mu_f < 2\mu_0, \quad 0.5 < \frac{\mu_r}{\mu_f} < 2$$

- Large theoretical uncertainties in the region close to P_T =1 GeV
- NLO colour-singlet prediction for λ is not supported by the ZEUS prel. data

J/Ψ Polarization: CS at NLO

- If we impose a more stringent cut in PT:



- Scale uncertainty is substantially reduced
- Waiting for the corresponding measurements

Conclusion

- New results on the polarization of the J/ψ in photoproduction (colour-singlet at NLO)
- Colour-singlet prediction alone does not describe all features of the data collected at HERA
- NLO computation of the polarization associated to the colour-octet P-wave transition may solve the current discrepancy