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Inelastic J/ψ and ψ' production at HERA

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Outline:

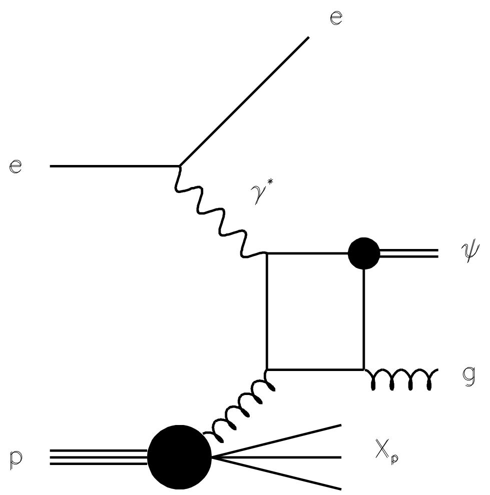
1. the processes
2. $\mathrm{d}\sigma/\mathrm{d}z$, $\mathrm{d}\sigma/p_t^2$, $\mathrm{d}\sigma/\mathrm{d}y$ at medium z
3. the helicity distribution
4. the low z region
5. inelastic ψ' production
6. summary

Inelastic Charmonium Production Processes

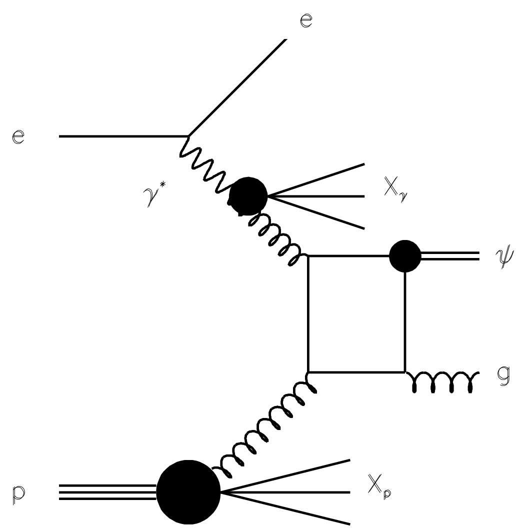
- Charmonium production processes can be distinguished by the elasticity variable:

$$z = \frac{P{\cdot}p_\psi}{P{\cdot}q} = E_\psi / E_{\gamma^*} \text{ (in the p-rest frame)}$$

- **Colour Singlet (CS) model**



direct photon
CS model
(dominates at medium z)



resolved photon
CS model
(present at low z)

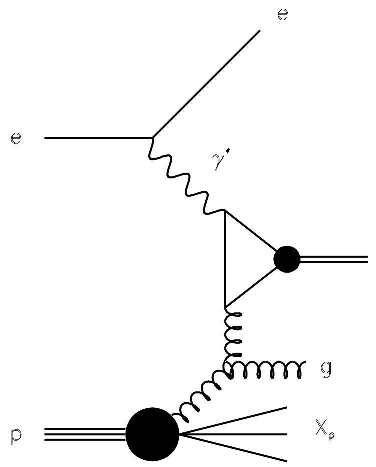
For the direct photon CS model exists a complete NLO calculation in α_s

- **Colour Octet (CO) model**

  The charmonium can be produced also in the following manner:

  1. firstly the heavy-quark antiquark pair is produced at short distances in a **colour octet state**
  2. subsequently the pair evolves non-perturbatively into a **physical quarkonium**, parametrized through **process-independent matrix elements:**

$$< 0|O^{\psi}[n]|0 >$$



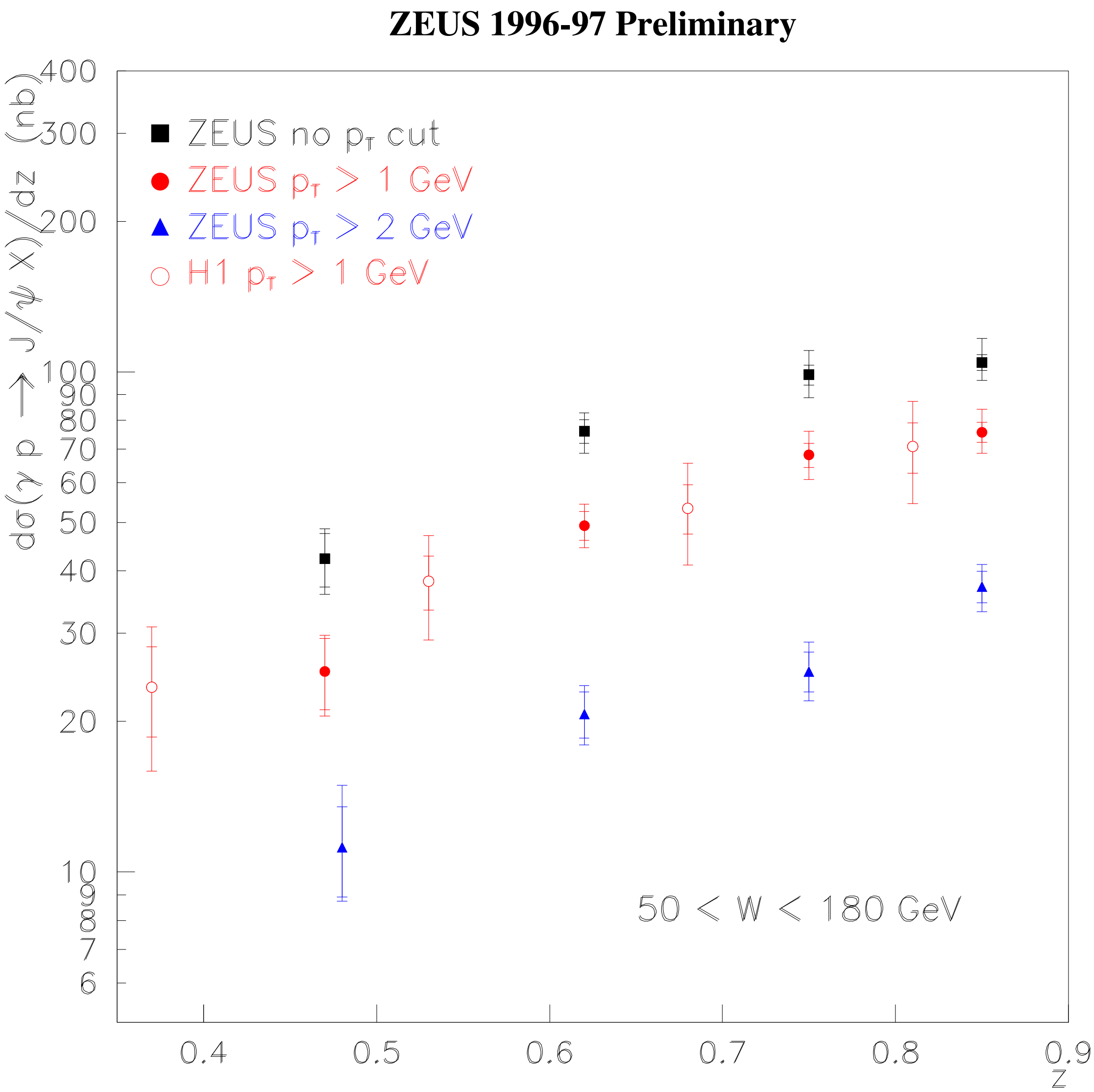
direct photon
CO model

- At HERA CO mechanism is expected to give sizable contribution:

  a) in the high z part of the $d\sigma/dz$ distribution (direct photon CO)

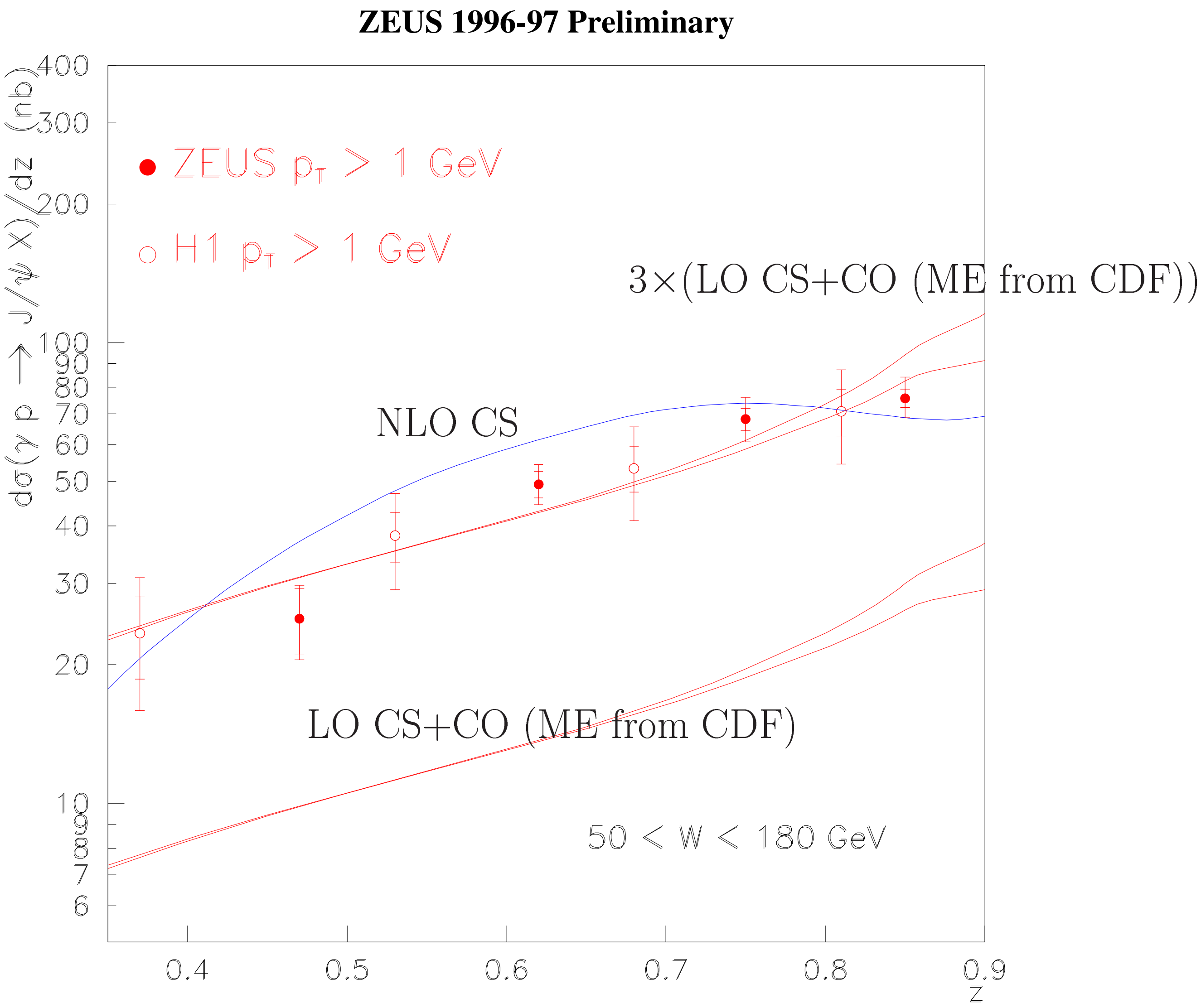
  b) in the low z region of the $d\sigma/dz$ distribution (resolved photon CO)

▶ z distribution



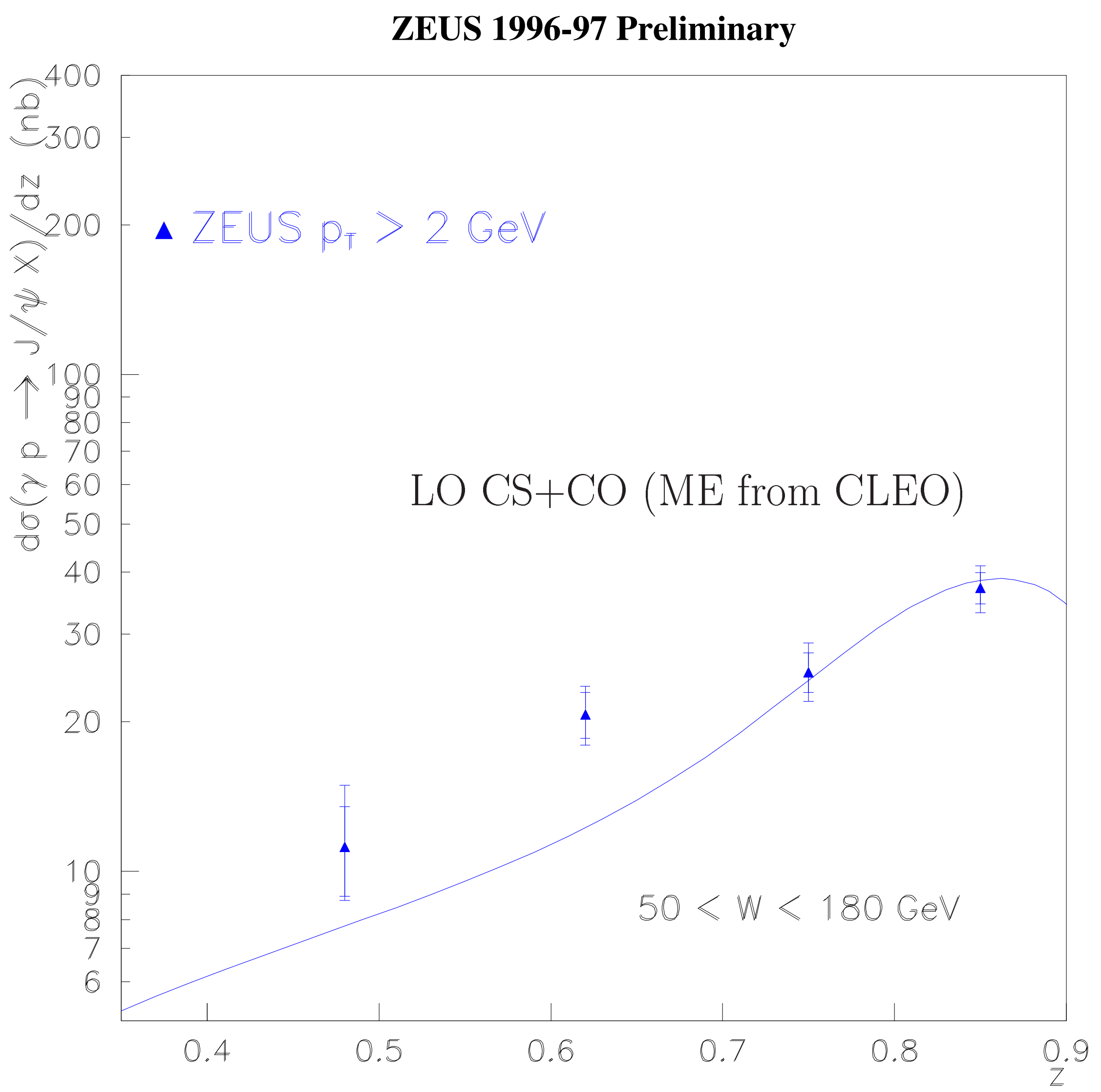
- similar shape $p_t > 1$ GeV and no p_t cut

► z distribution ...



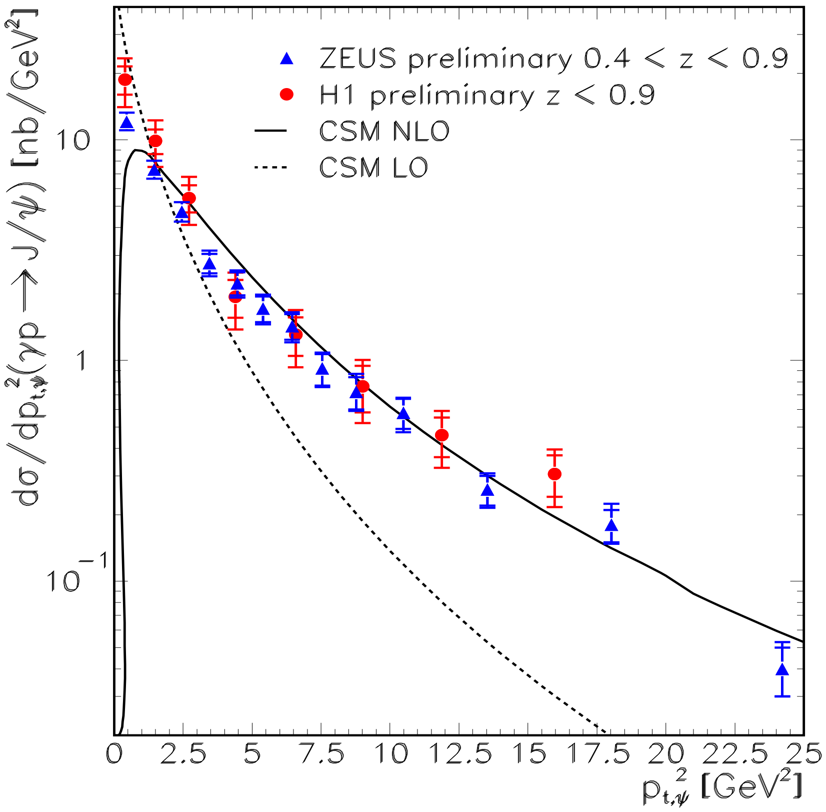
- NLO direct CS gives the right normalization and shape (using the following parameters: $m_c = 1.4$ GeV, $\Lambda^{(5)}_{\overline{MS}} = 300$ MeV and $Q^2 = \mu_R^2 = 2\ m_c^2$ as favoured by J/ψ low-energy data).
- LO CS + CO with matrix elements fixed by CDF data undershoots data but shape is fine.
- ... the upper cut on z ($z < 0.9$) kills the octet component, the bulk of the cross section comes from CS.

▶ z distribution ...

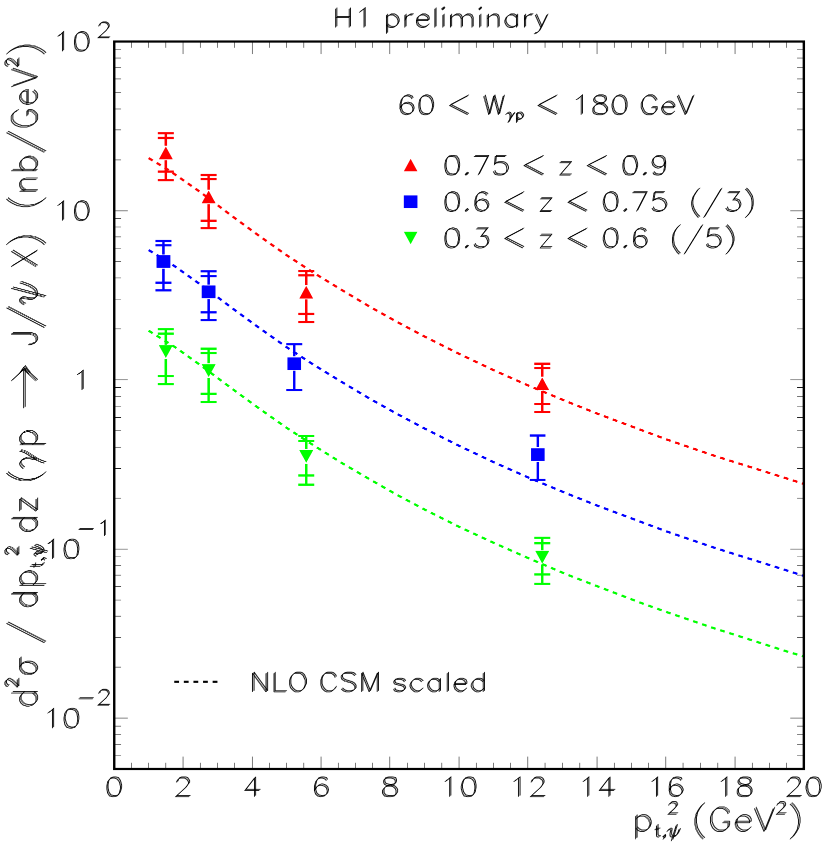


- CS + CO with matrix elements from CLEO looks interesting (no K-factor).

p_t^2 distribution ...

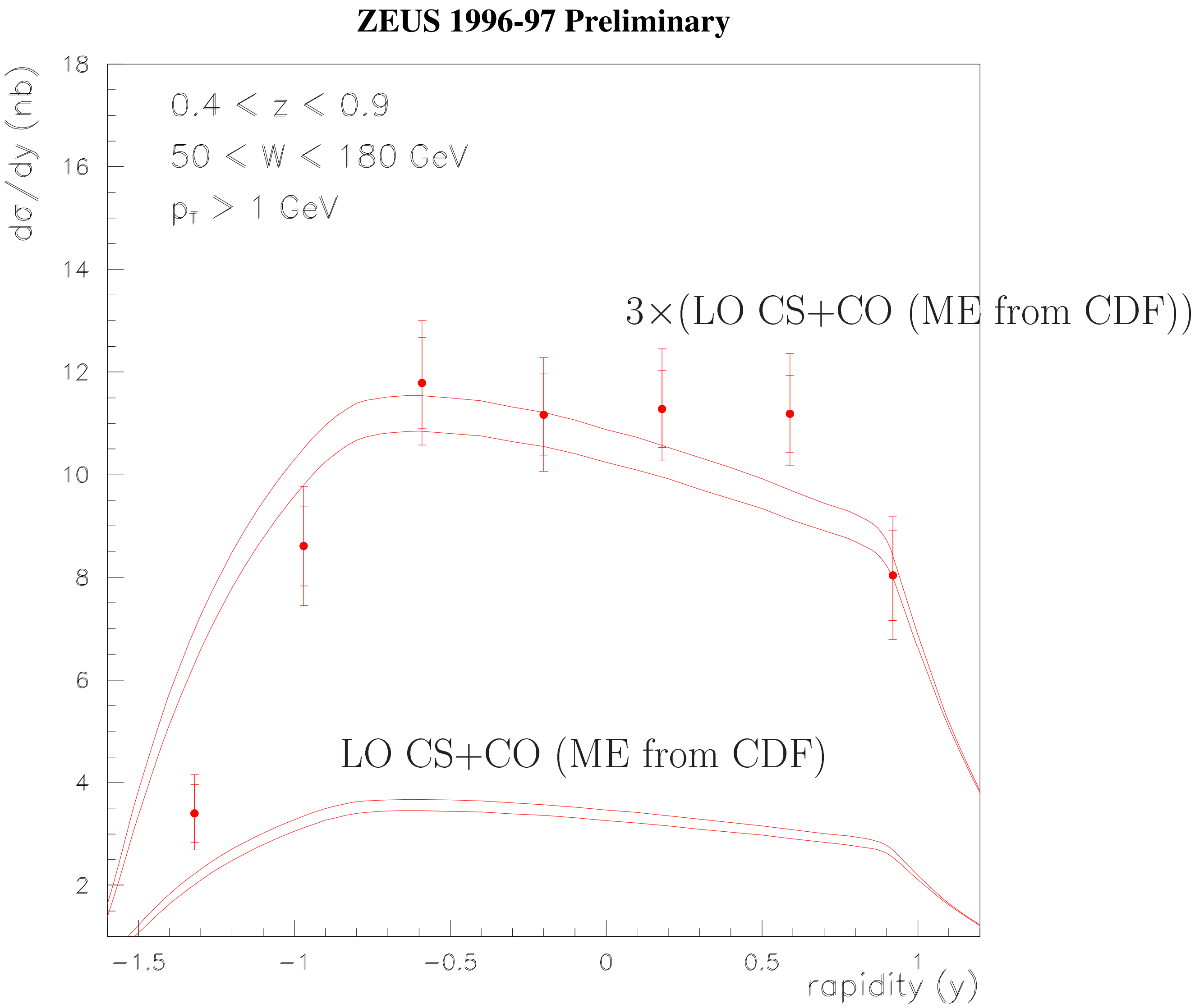


NLO direct CS
nicely reproduces shape
and normalization



$$\frac{d^2\sigma}{dz\,dp_t^2} = f(z)g(p_t^2)$$

▶ rapidity distribution ...



$$\text{rapidity y} = 1/2 \ln \frac{E(J/\psi)+p_z(J/\psi)}{E(J/\psi)-p_z(J/\psi)}$$

- LO CS + CO with CDF matrix elements undershoots the data (already seen).
- there is some shape discrepancy at negative y (incoming positron direction).
- other predictions are welcome.

► helicity distribution ...

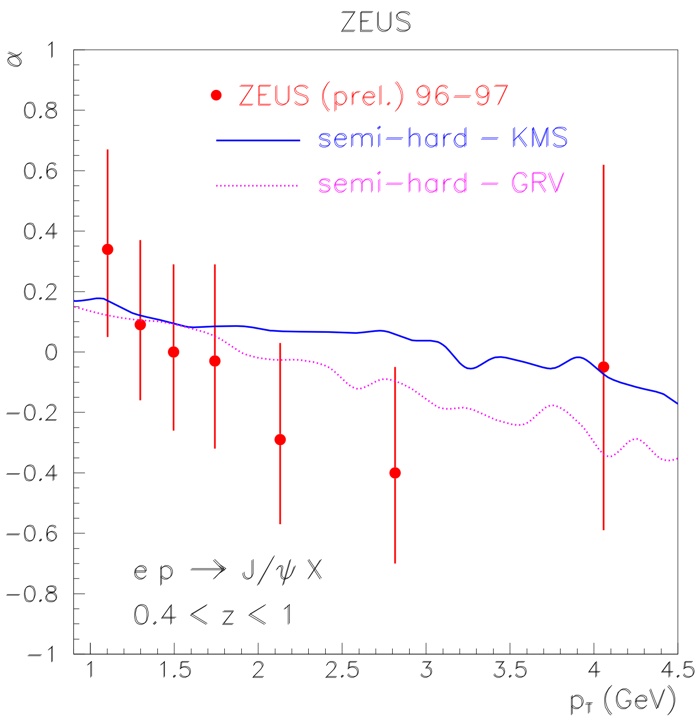
- helicity distributions are sensitive to the underlying production mechanism (singlet vs. octet)
- decay angular distribution parameters are normalized, the dependence on parameters such as: m_c, α_s, μ_R, μ_F, parton distribution cancels to a large extent
- $dN/d\cos\theta^* \propto 1 + \alpha\cos^2\theta^*$

  where:

  θ^*: opening angle between the J/ψ direction of flight in the lab. frame and the μ^+ direction of flight in the J/ψ-rest frame

  α: unknown parameter (-1 $\leq \alpha \leq +1$) can be studied as function of z and p_t
- available prediction in this reference frame: CS semi-hard calculations with different (KMS, GRV) unintegrated gluon distributions.

► helicity distribution ...

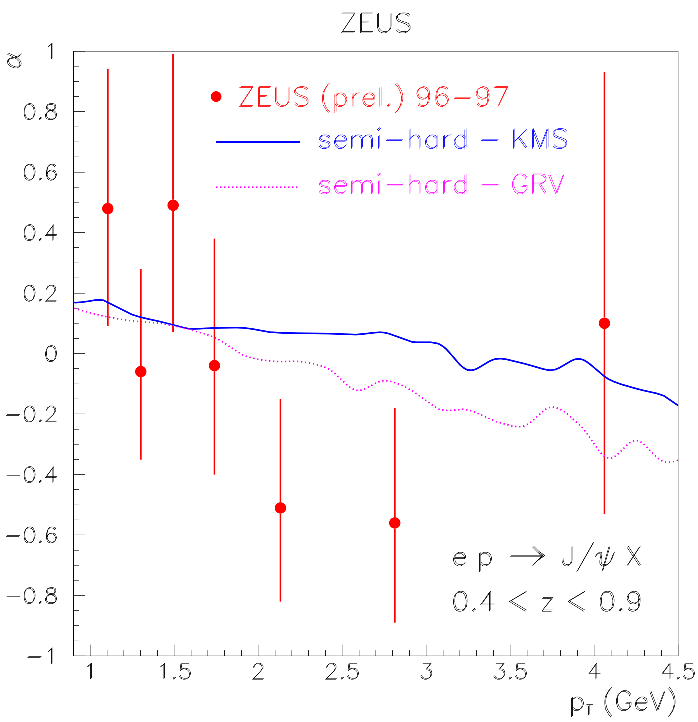


⟸ transverse polarization

$\alpha = +1$

$\alpha = -1$

⟸ longitudinal polarization

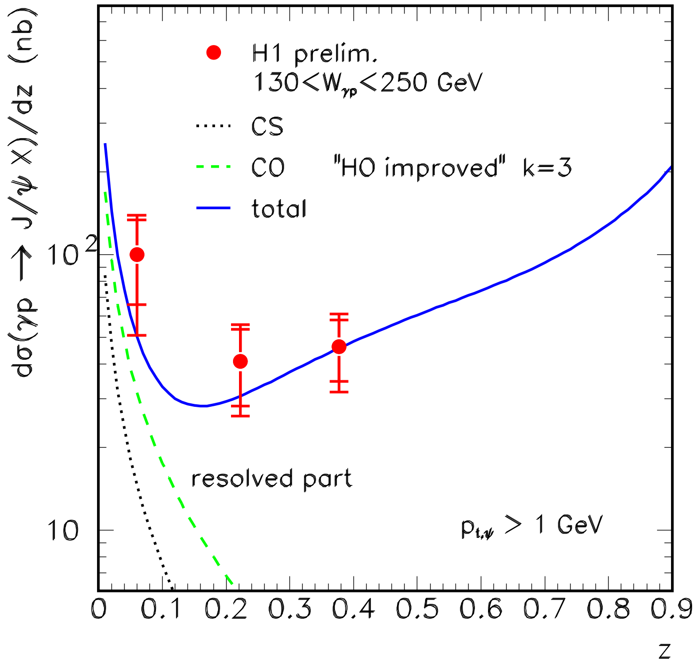


In the two plots the curves are a theoretical calculation using LO CS model taking into account the gluon virtuality $\Longrightarrow$ test for the non-collinear (BFKL) parton evolution

- waiting for CS+CO calculations in this reference frame

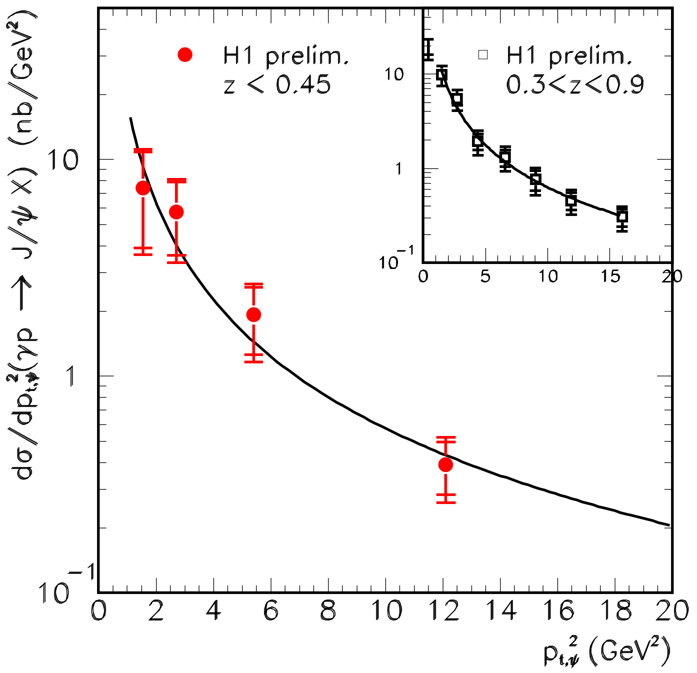
low z region ...

- low z region: never explored before HERA



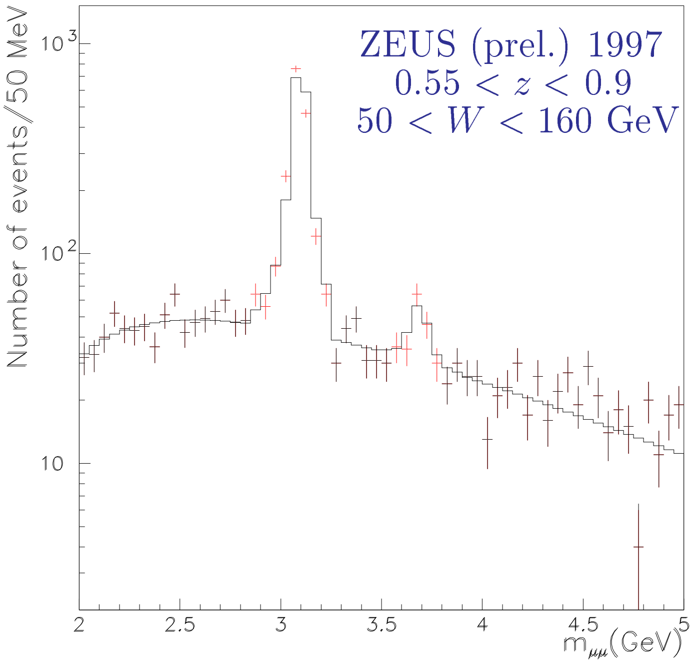
colour singlet + octet with CDF octet matrix elements undershoots data but shape is fine

sensitive to the resolved singlet + octet component

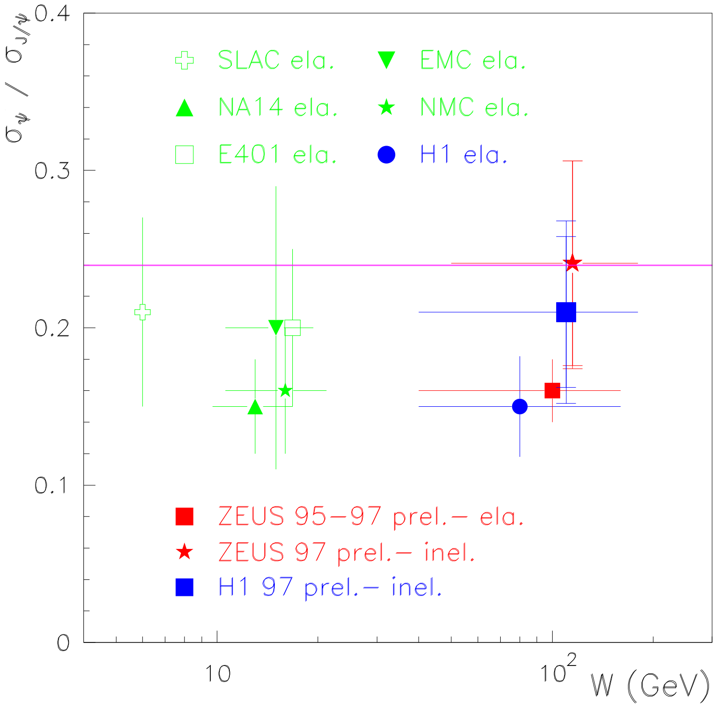


again the p_t^2 shape does not depend on z

▶ ψ' inelastic production



Results from HERA

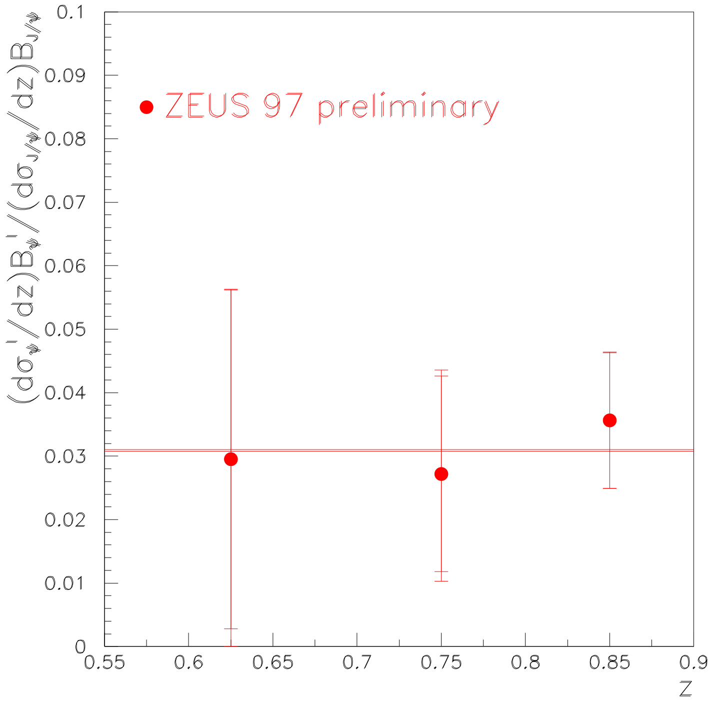


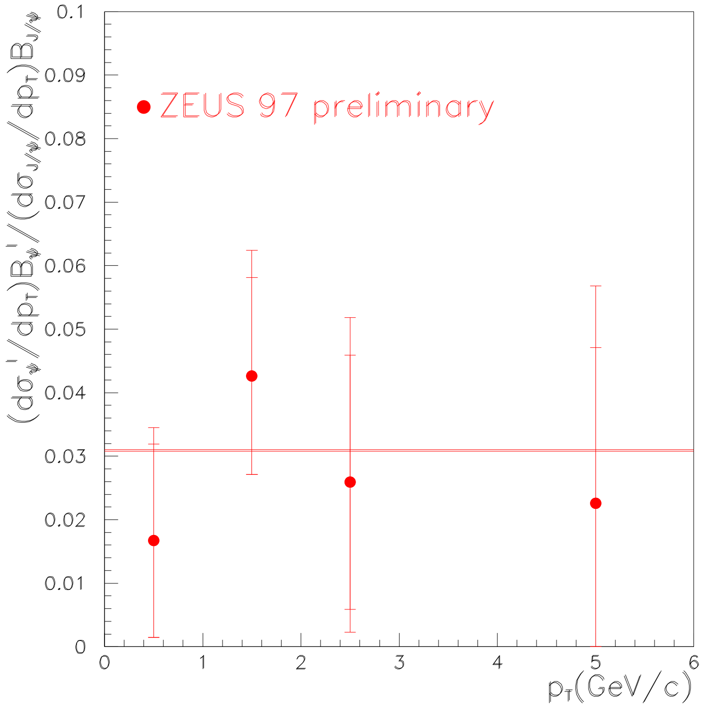
$\sigma(\psi')/\sigma(J/\psi)$ in agreement with the 24% expectation:

$$\frac{\sigma(\psi')}{\sigma(J/\psi)} \simeq \frac{\Gamma_{ee}^{\psi'}}{\Gamma_{ee}^{J/\psi}} \left(\frac{M_{J/\psi}}{M_{\psi'}}\right)^3 \simeq 24\%$$

cascade decays:
$\psi(2S) \rightarrow J/\psi(\rightarrow \mu^+\mu^-)X$
gives a 10% contribution to the J/ψ cross-section

► ψ' inelastic production ...





same production mechanism $\Rightarrow$ flat cross-section ratios

Summary

- accurate inelastic J/ψ photoproduction measurements for $0.4 < z < 0.9$:
  1. agree with the NLO CS direct photon process
  2. no need for large CO direct photon contribution: but still large space for improvements
  3. first helicity measurements
- first look at low z: we may need CO resolved photon
- first look at $\psi(2S)/J/\psi$: same production mechanism
- much more will come:
  1. on a short time scale adding 98 $\rightarrow$ 00 data
  2. on a longer time scale due to the HERA lumi upgrade: ($>$ 2001: 150 pb^{-1}/year)