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on behalf of the
ZEUS and H1 Collaborations

Inelastic J/ψ photoproduction at HERA

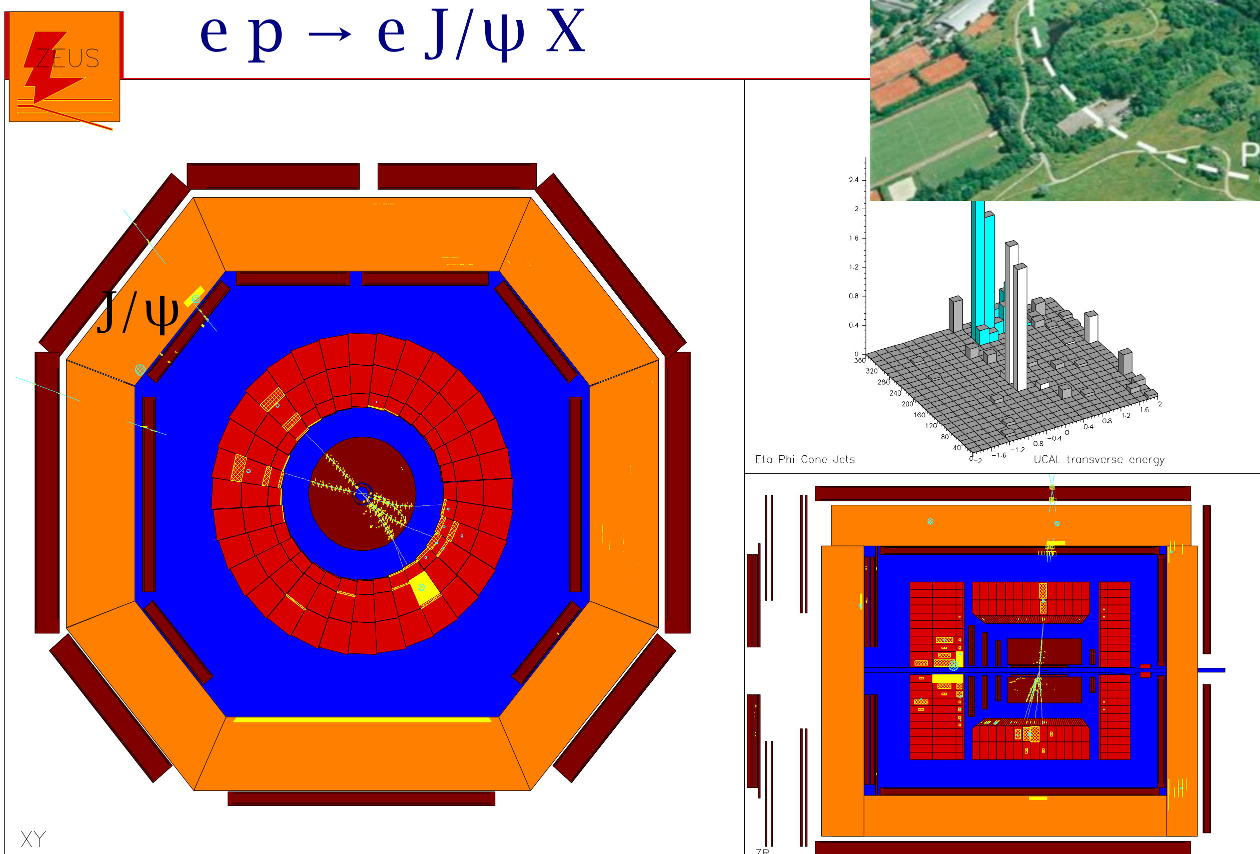
Outline:

- inelastic quarkonium at HERA
- H1 measurements and comparison with various theoretical predictions
- polarization measurements in PHP
- ZEUS measurements and comparison with various theoretical predictions
- conclusions

inelastic quarkonium at HERA

- *ep* collider at 318 GeV CMS energy
- running ended mid 2007 after about 2500 days of activity and ~ 0.5 fb^{-1} of integrated luminosity/experiment

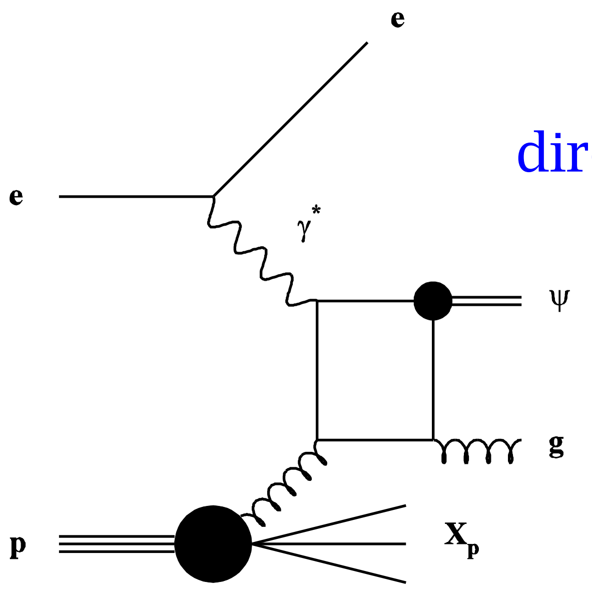
$e\, p \rightarrow e\, J/\psi\, X$



- No scattered electron: **photoproduction regime** $\rightarrow Q^2 \sim 0$ GeV^2
- Proton remnant + additional hadronic activity: **inelastic event**

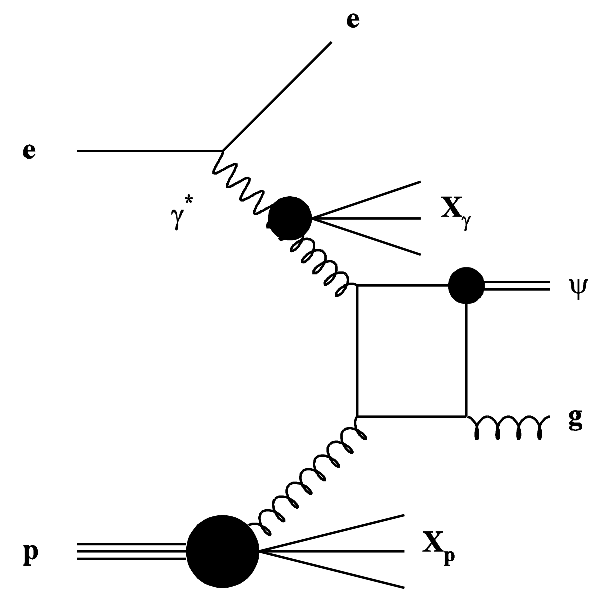
inelastic quarkonium at HERA

$z = E(J/\psi)/E(\gamma)$
p rest frame



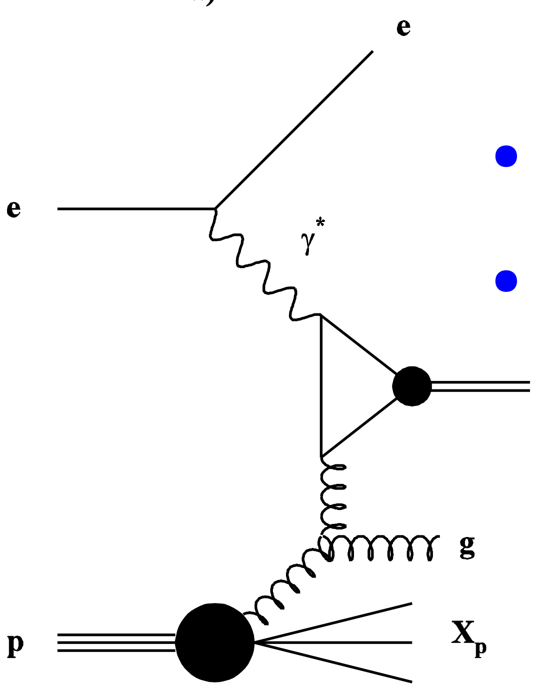
a)

direct γ, "CS model"
$0.2 < z < 0.9$



b)

resolved γ, "CS model"
$z < 0.2$



c)

direct γ, "CO model"

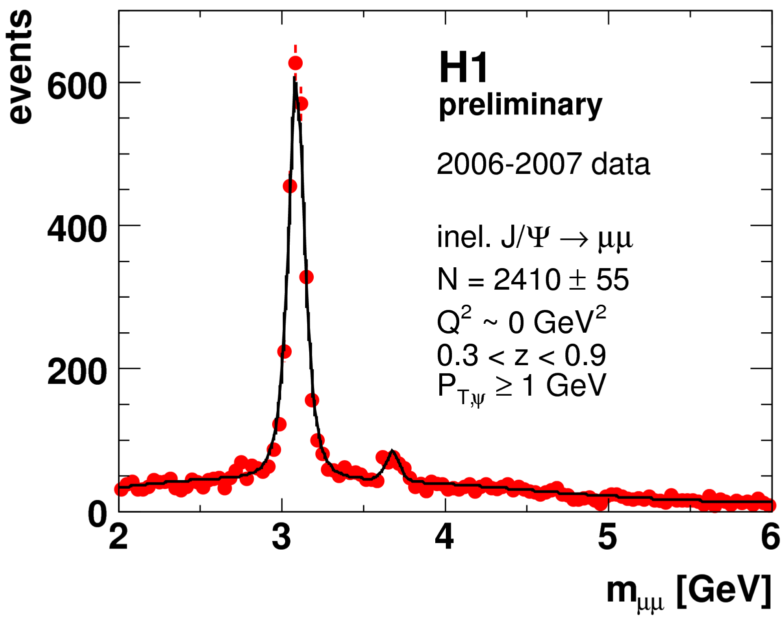
- this particular diagram
  $0.2 < z < 0.9$
- more "typical" ones:
  $z > 0.9$

+ other J/ψ production mechanisms:
  - J/ψ from diffraction
  - J/ψ from ψ' decays
  - J/ψ from *B* mesons decays

data samples and selections

H1 Collab. http://www-h1.desy.de

- $\mathcal{L} \approx 166\ pb^{-1}$ (2006–2007)
- $Q^2 \sim 0\ GeV^2$
- $60 < W_{\gamma p} < 240$ GeV
- $p_{T,\psi} > 1.0$ GeV
- $0.3 < z < 0.9$



backgrounds from other J/ψ production mechanisms

diffractive ψ(2S) feed down

- $\psi(2S) \to J/\psi\ \pi^+\pi^-$ (BR ~ 30%)

⇨ *suppression cut: Ntracks ≧ 5*

- corrected in measured cross sections

- **remaining contribution <u>not subtracted</u>:**
  - overall ~ 1.5 %
  - highest z bin < 5%

***B* meson decays**

- low z region
- high track multiplicity

- **remaining contribution <u>not subtracted</u>:**
  - overall ~ 2.5 %
  - lowest z bin < 10%

theoretical models

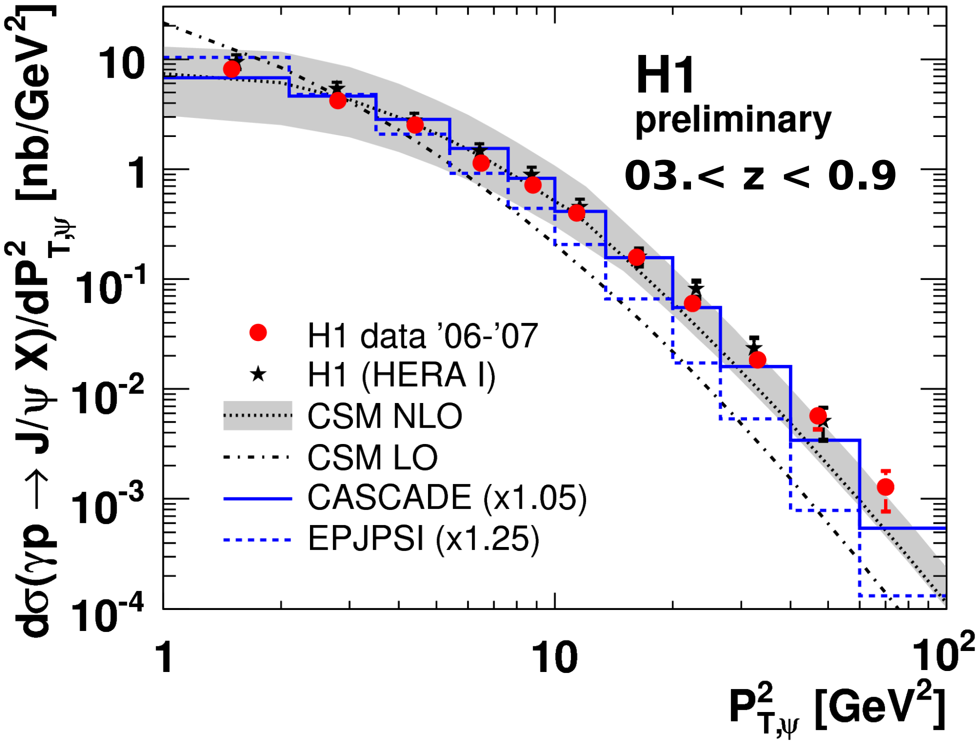
The differential cross sections are compared with:

- **LO CS model calculation**;
- **NLO CS model calculations** from
  M. Krämer, Nucl. Phys. B 459, 3 (1996) but
  also from *P. Artoisenet et al., arXiv:0901.4352*

and with Monte Carlos :

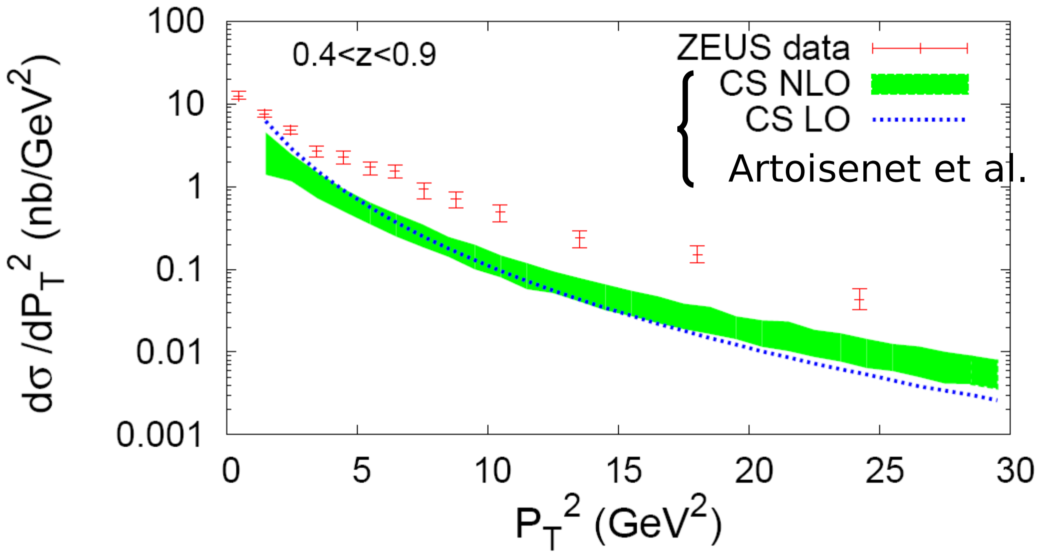
- **EPJPSI** (H. Jung): MC based on CS model + DGLAP evolution + collinear factorization;
- **CASCADE** (H. Jung): MC based on CS model + CCFM evolution + k_t factorization + incoming parton can be off-shell

cross section measurements in PHP



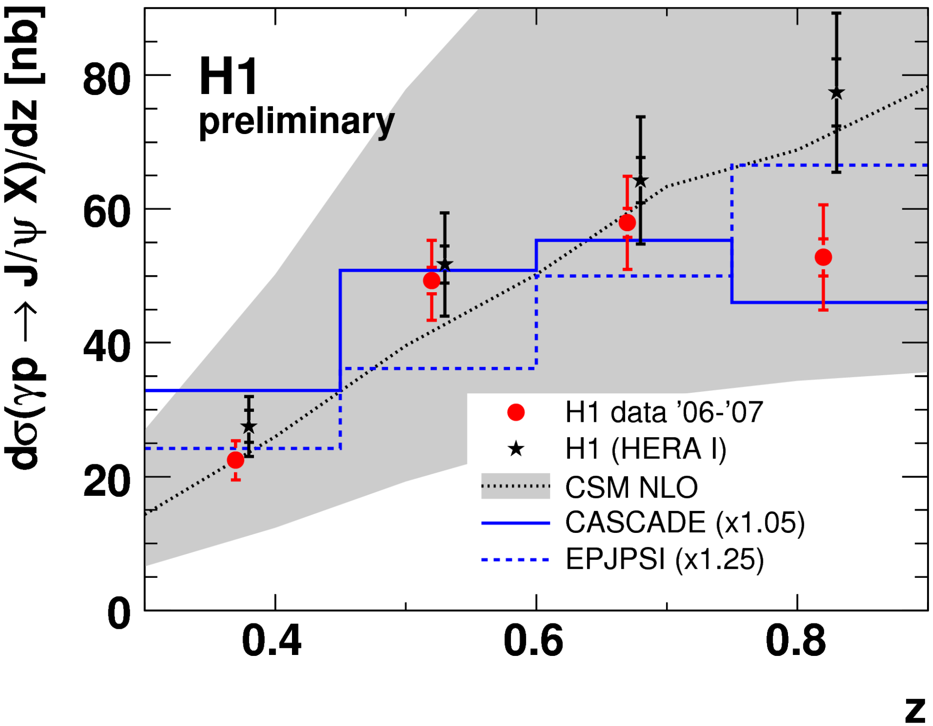
- **CS LO**
  – too steep in P^2_T
- **EPJPSI MC**
  – too steep in P^2_T
- **CS NLO** (M. Krämer 1996)*
  – data are well reproduced (large uncertainties)
- **CASCADE MC**
  – data are well reproduced it mimics NLO calcul.

... but a different CS NLO calculation (P. Artoisenet et al. 2009) using $\mu_r = \mu_f = 4\ m_c$ (with $m_c = 1.5$ GeV) *gives the same shape but different normalization*



$$^* \ \mu_f = \mu_r = \max\left[\sqrt{2}\,m_c, \frac{1}{2}\sqrt{m_c^2 + p_T^2}\right] \qquad 1.3 \leq m_c \leq 1.5\ \text{GeV}$$

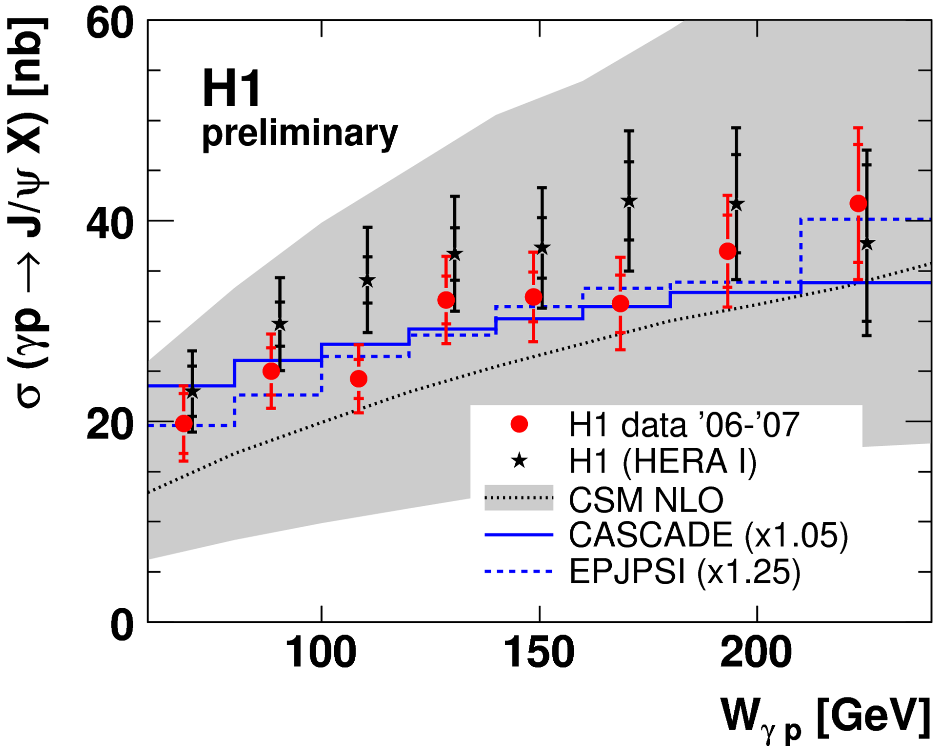
cross section measurements in PHP



- **EPJPSI MC**
  - rise towards large values of z (relativistic corrections)
- **CASCADE MC**
  - data are well reproduced
- **CS NLO** (M. Krämer 1996)*
  - data are well reproduced (large uncertainties)
- ... space for CO contributions
  - due to the large normaliz. uncertainties of the NLO

* $\mu_f = \mu_r = \max\left[\sqrt{2}\,m_c, \frac{1}{2}\sqrt{m_c^2 + p_T^2}\right] \quad 1.3 \leqslant m_c \leqslant 1.5$ GeV

cross section measurements in PHP

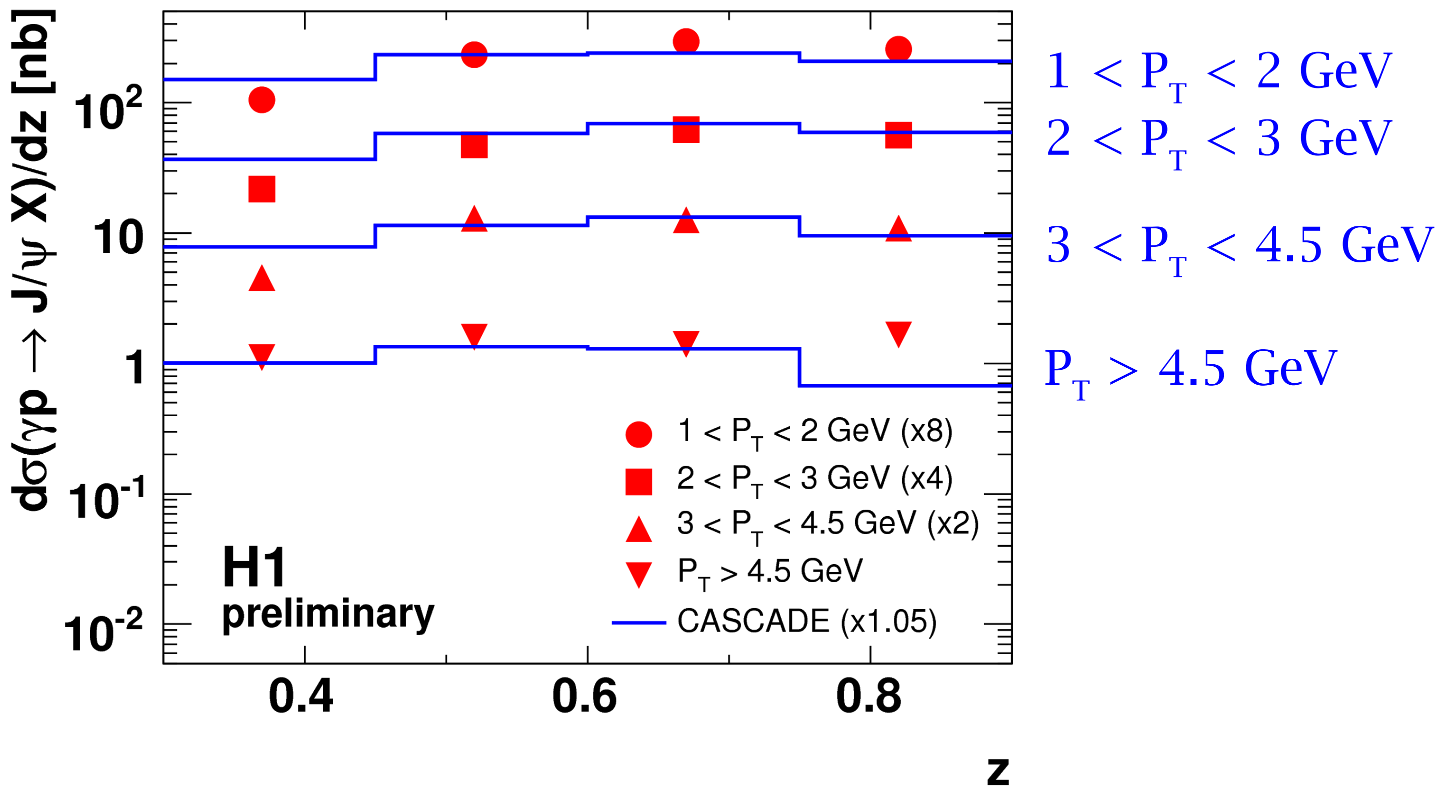


- **EPJPSI MC**
  - shape of $W_{\gamma p}$ well reproduced
- **CASCADE MC**
  - shape of $W_{\gamma p}$ well reproduced
- **CS NLO** (M. Krämer 1996)*
  - data are well reproduced (large uncertainties)
- ... space for CO contributions
  - due to the large normaliz. uncertainties of the NLO

$$^{*}\ \mu_f = \mu_r = \max\left[\sqrt{2}\,m_c, \frac{1}{2}\sqrt{m_c^2 + p_T^2}\right] \quad 1.3 \leqslant m_c \leqslant 1.5\ \text{GeV}$$

cross section measurements in PHP

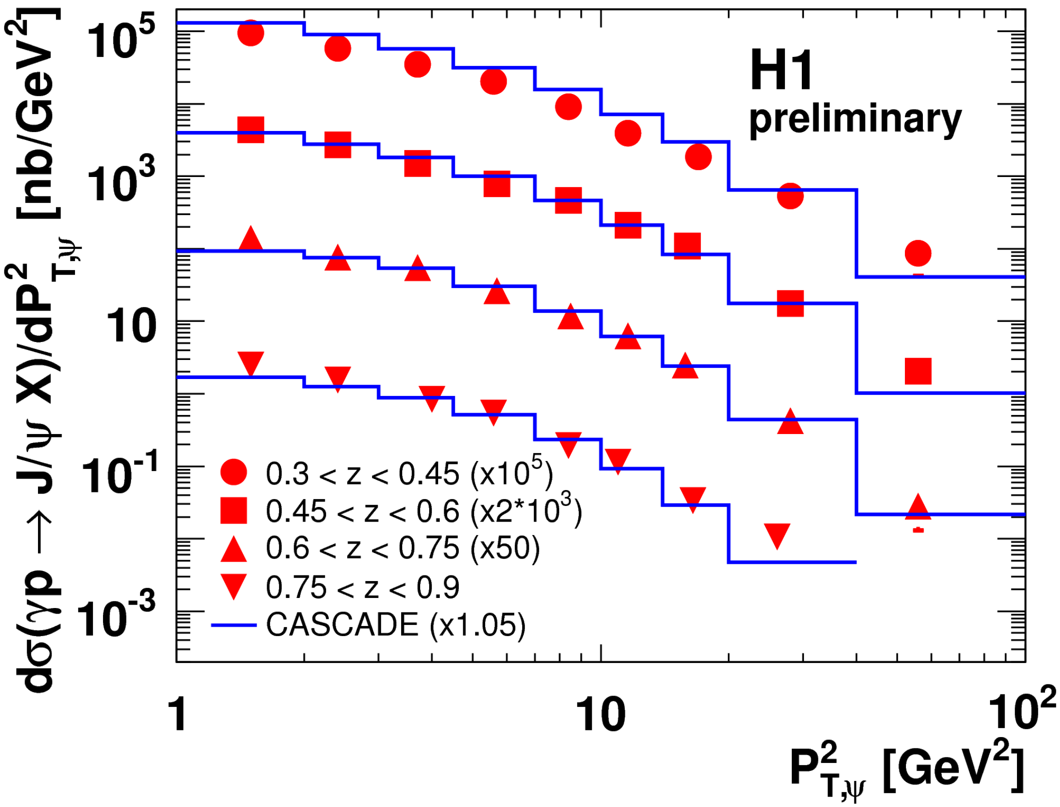
as function of inelasticity *z* in bins of P_T



◆ Data well modelled by CASCADE MC: – somewhat higher at low z
– somewhat lower at large z and P_T

cross section measurements in PHP

as function of P^2_T in bins of z



$0.3 < z < 0.45$

$0.45 < z < 0.6$

$0.6 < z < 0.75$

$0.75 < z < 0.9$

- Data well modelled by CASCADE MC: – somewhat higher at low z

polarization measurements (helicity parameters)

Main advantages:

- Since the decay angular distributions are **normalized quantities**
  → **largely independent** from normalization uncertainties.

- They are observables **sensitive** to the different production mechanisms.

- The resummation necessary in the endpoint region, important for $d\sigma/dz$ at z close to 1, affects the decay angular distributions to a lesser degree.

Main disadvantages:

- The decay angular distributions require the use of **large data sample**.

polarization measurements (helicity parameters)

The polarization is measured in decay angular distributions in the J/ψ rest frame.

- θ : angle μ^+ to z' axis, direction opposite to that of the proton
- φ: angle μ^+ to plane determined by incoming photon and proton

  (target frame)

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta\, dy} \propto 1+\lambda(y)\cos^2\theta$$

λ = **+1: transverse polarization**

λ = **−1: longitudinal polarization**

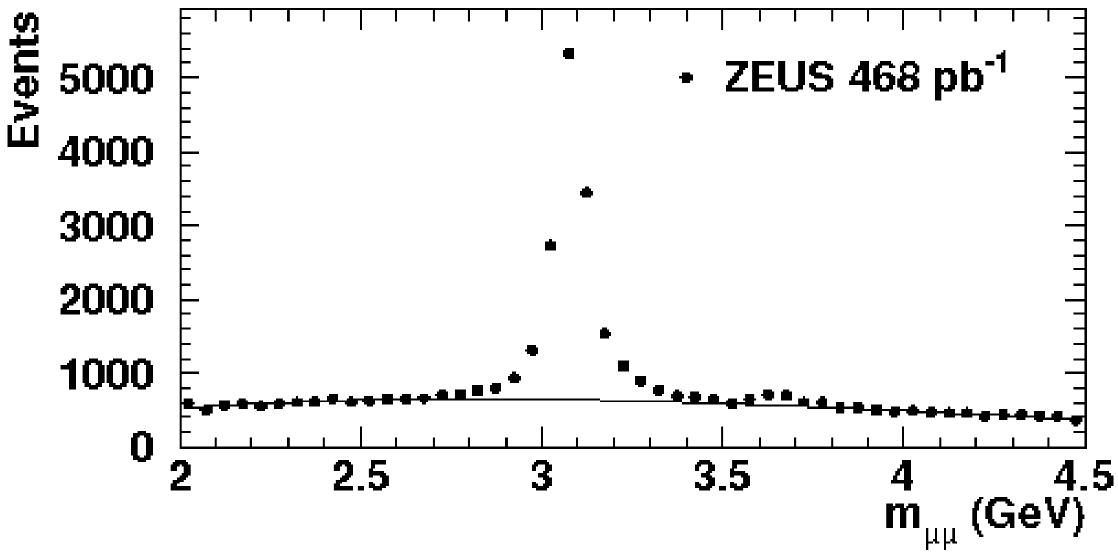
$$\frac{1}{\sigma}\frac{d^2\sigma}{d\varphi\, dy} \propto 1+\frac{\lambda(y)}{3}+\frac{\nu(y)}{3}\cos^2\varphi$$

y stands for a set of variables (*z* and p_T(J/ψ) are good candidates)

data samples and selections

ZEUS Collab. *DESY-09-077*

- $\mathcal{L}$ = 468 pb^{-1} (1996-2007)
- $Q^2 \sim 0$ GeV^2
- $50 < W_{\gamma p} < 180$ GeV
- $p_{T,\psi} > 1.0$ GeV
- $0.2 < z < 1$



backgrounds from other J/ψ production mechanisms

Diffractive J/ψ
- *cut: Ntracks* ≧ **3**
- overall ~ 6 %
- **contribution <u>not subtracted</u>**

ψ(2S) feed down (diff. + inel.)
- overall ~ 15 %
- **contribution <u>not subtracted</u>**

***B* meson decays**
- overall ~ 1.6 %
- **contribution <u>not subtracted</u>**

theoretical calculations

The measurements are compared with the following calculations:

- **LO–CS**: M. Beneke, M. Krämer and M. Vänttinen, Phys. Rev. **D 57**, 4258 (1998).
- **NLO–CS**: P. Artoisenet et al., arXiv:0901.4352

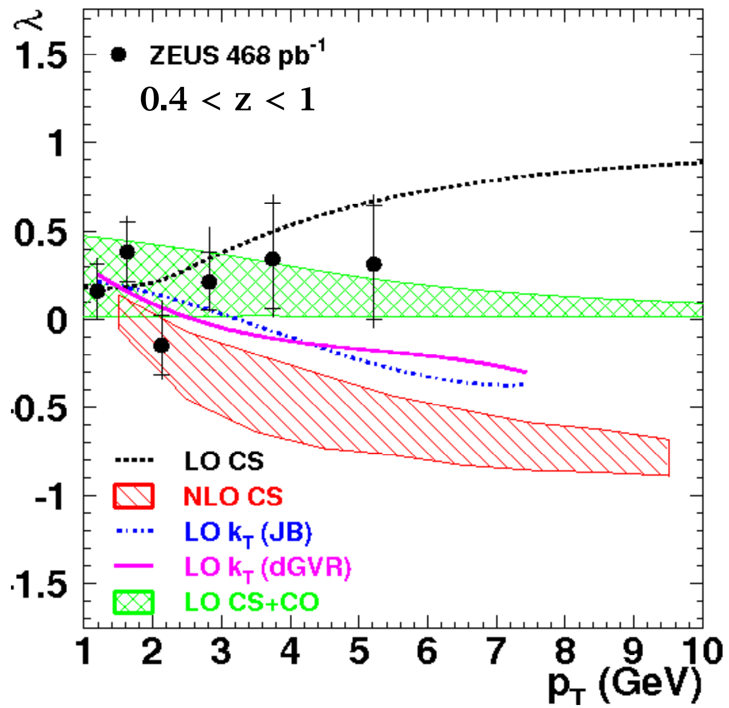
- **LO–CS+CO**: M. Beneke, M. Krämer and M. Vänttinen, Phys. Rev. **D 57**, 4258 (1998).

  The values and uncertainties of the matrix elements (which are universal functions) are extracted from experiments (TEVATRON, fixed target hadroproduction, $B \to J/\psi\ X$)

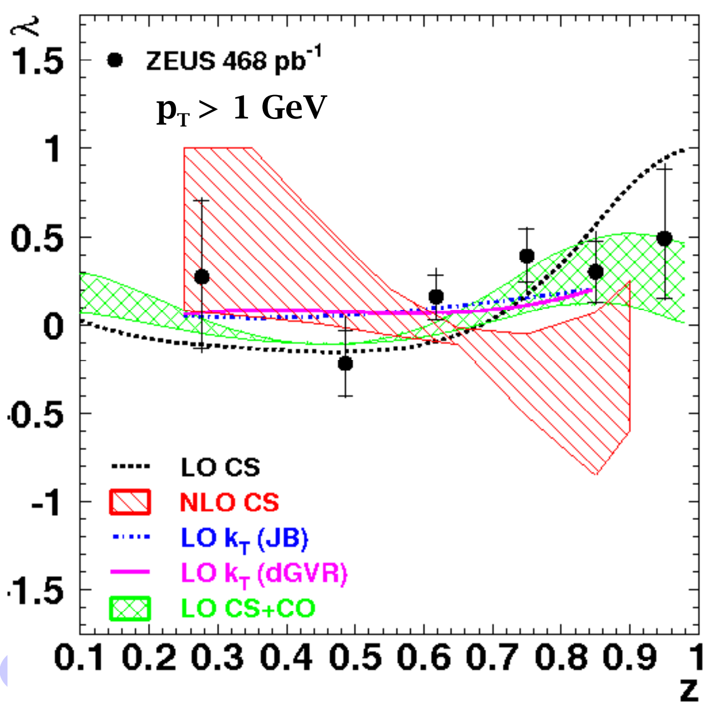
- **LO–k_T**: S. P. Baranov, JETP 88, 471 (2008)

  Only CS contribution taken into account + k_T factorization + unintegrated gluon distribution

polarization measurements

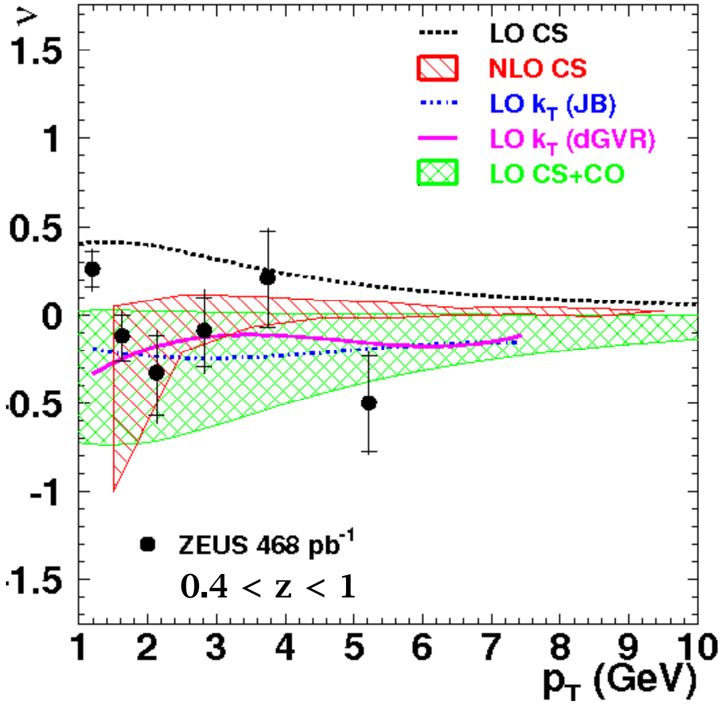


- ◆ LO CS and NLO CS predictions have opposite sign
- ◆ LO k_T CS has the same sign of NLO, parton transverse momentum, k_T, mimics NLO terms
- ◆ LO CS+CO is flat
- ◆ data are consistent with being flat in the probed p_T range
- ◆ proton dissociative background mostly at low p_T
- ◆ analysis redone for $z < 0.9$, effects in the sys. errors

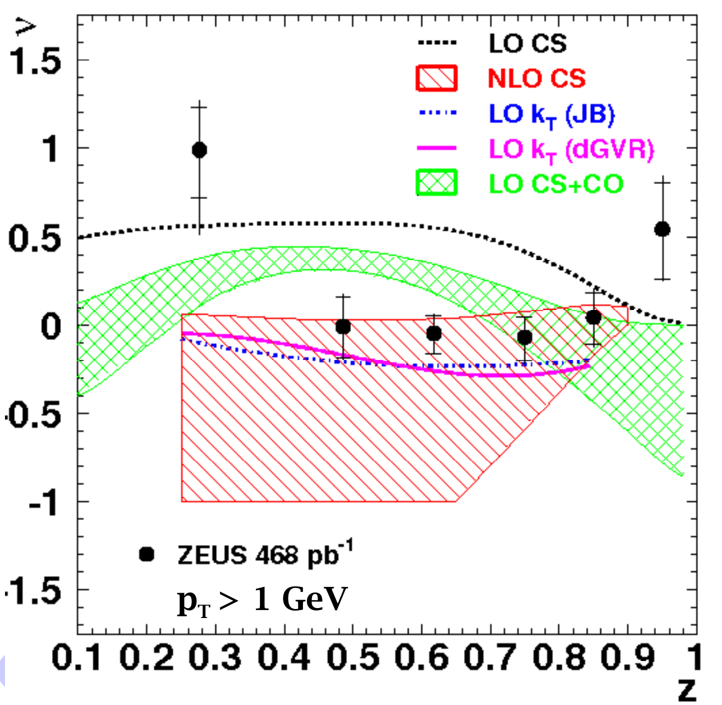


- ■ LO CS describe the data well
- ■ NLO CS has large uncertainties … negative … $p_T > 1$ GeV may be not enough …
- ■ LO k_T CS describe the data well
- ■ LO CS+CO is pretty much the same as LO CS
- ■ proton dissociative is at the 60 – 70 % level for $0.9 < z < 1$, $\ll 5$ % elsewhere

polarization measurements

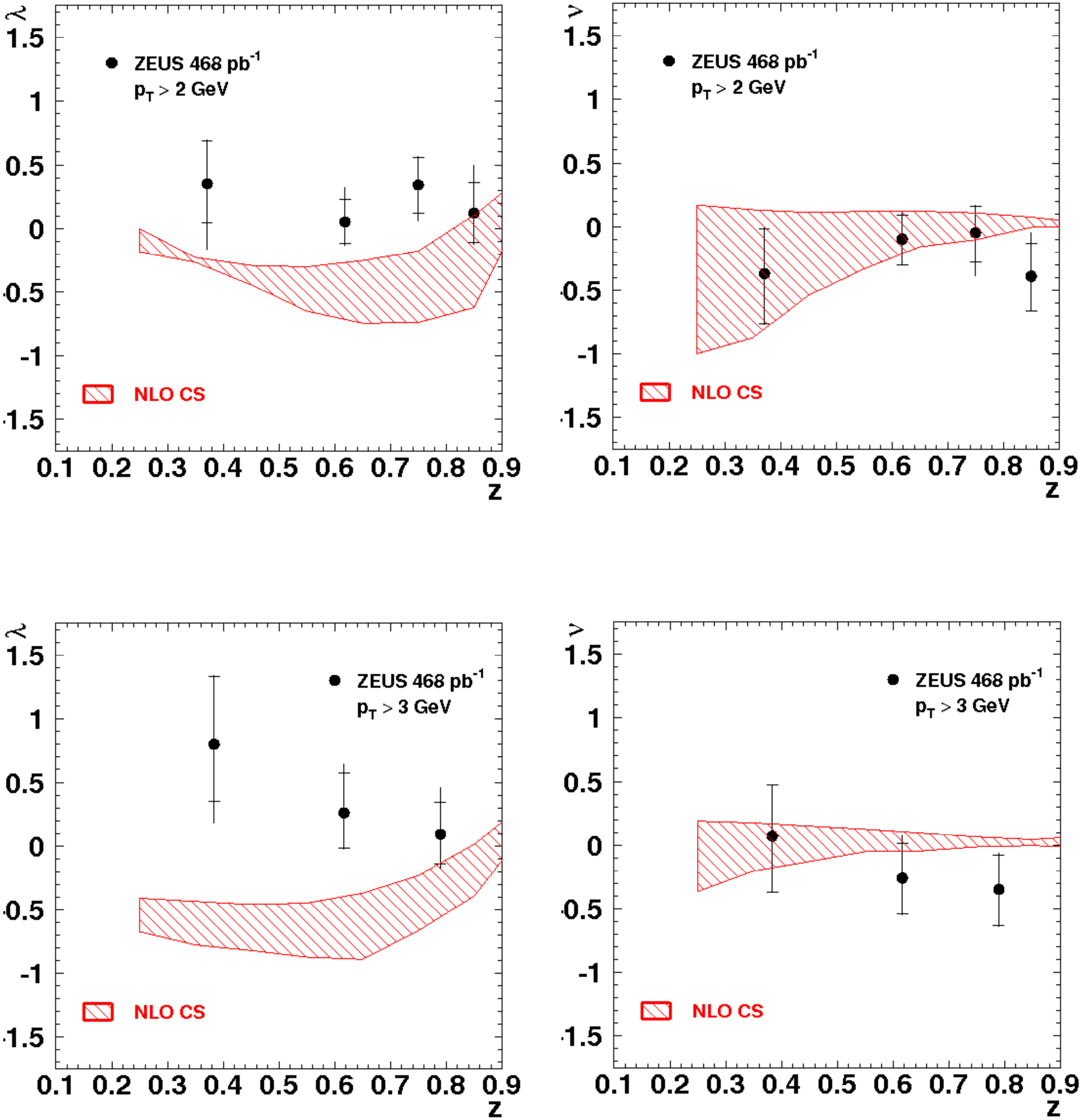


- LO CS is positive .... all other predictions are negative and in better agreement with the data
- LO k_T CS is pretty much as NLO CS
- LO CS+CO is flat
- data are consistent with being flat in the probed p_T range
- proton dissociative background mostly at low p_T
- analysis redone for $z < 0.9$, effects in the sys. errors



- LO CS does not describe the data, positive
- NLO CS has large uncertainties … negative … $p_T > 1$ GeV may be not enough …
- LO k_T CS fine … except at low z
- LO CS+CO does not describe the data, positive
- proton dissociative is at the 60 – 70 % level for $0.9 < z < 1$, $\ll 5$ % elsewhere

polarization measurements



NLO predictions for:

- $p_T(J/\psi) > 2$ GeV
- $p_T(J/\psi) > 3$ GeV

NLO calculation has reduced uncertainties … unlikely experimental errors grow … and the agreement between NLO and data does not really improve …

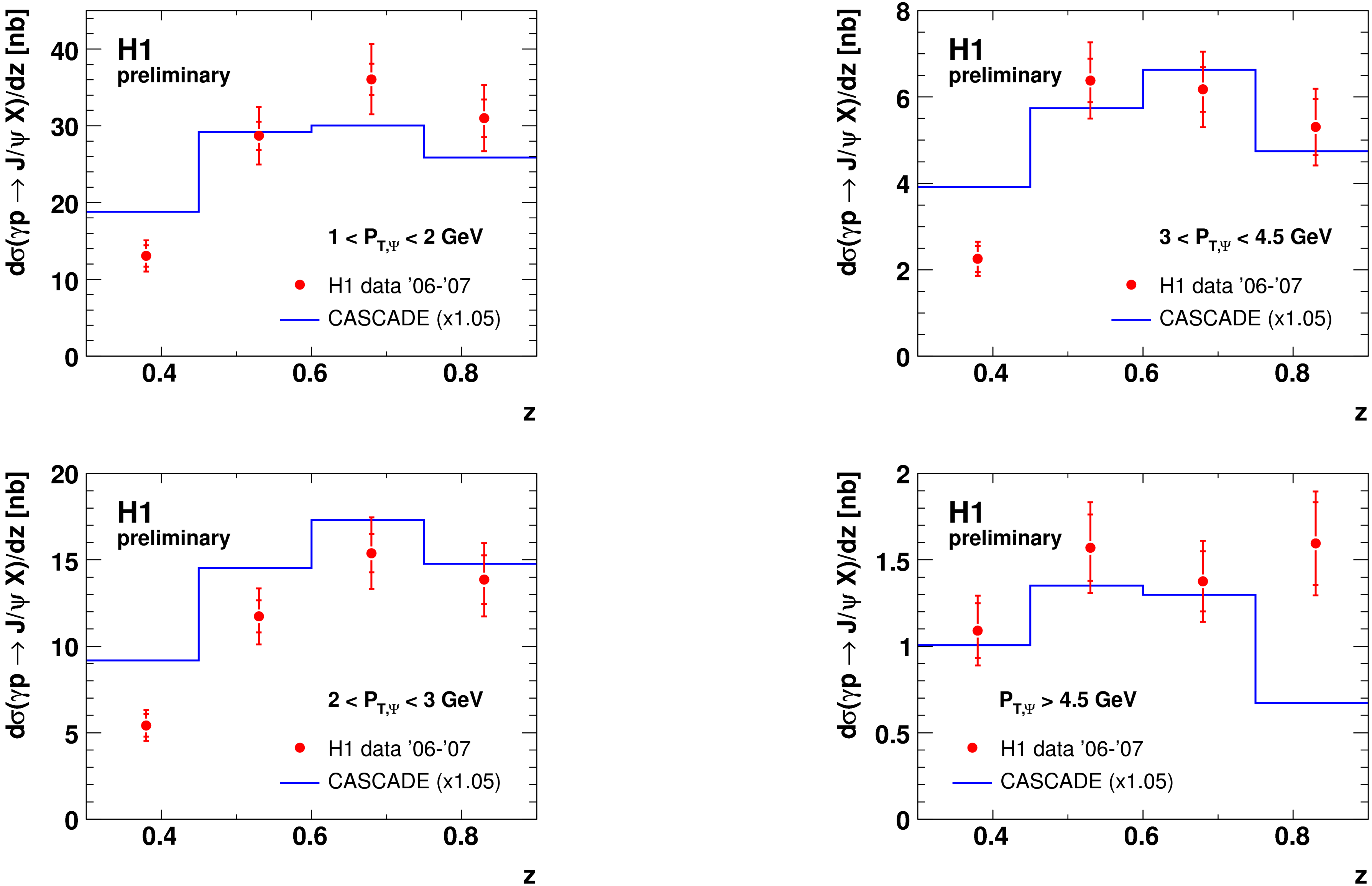
Conclusions

- new **H1** measurements of inelastic J/ψ photoproduction cross sections:
  - higher luminosity (HERAII)
  - smaller statistical and systematic uncertainties
- CS provides generally good description of the data
  - when using k_t factorization (CASCADE) or NLO
  - but large uncertainties are present in the NLO calculations
  - CO contributions: no firm conclusions can be obtained

- the **ZEUS** helicity measurement has been updated with all the HERA available statistics (468 pb^{-1}).
- LO CS, NLO CS, LO CS+CO, LO k_t CS predictions have been compared to the data.
- outcome: none of these predictions is able to describe all aspects of the data
- conclusion of the conclusions: **more refined theory is needed,** maybe NNLO CS, NLO CS + CO, ...

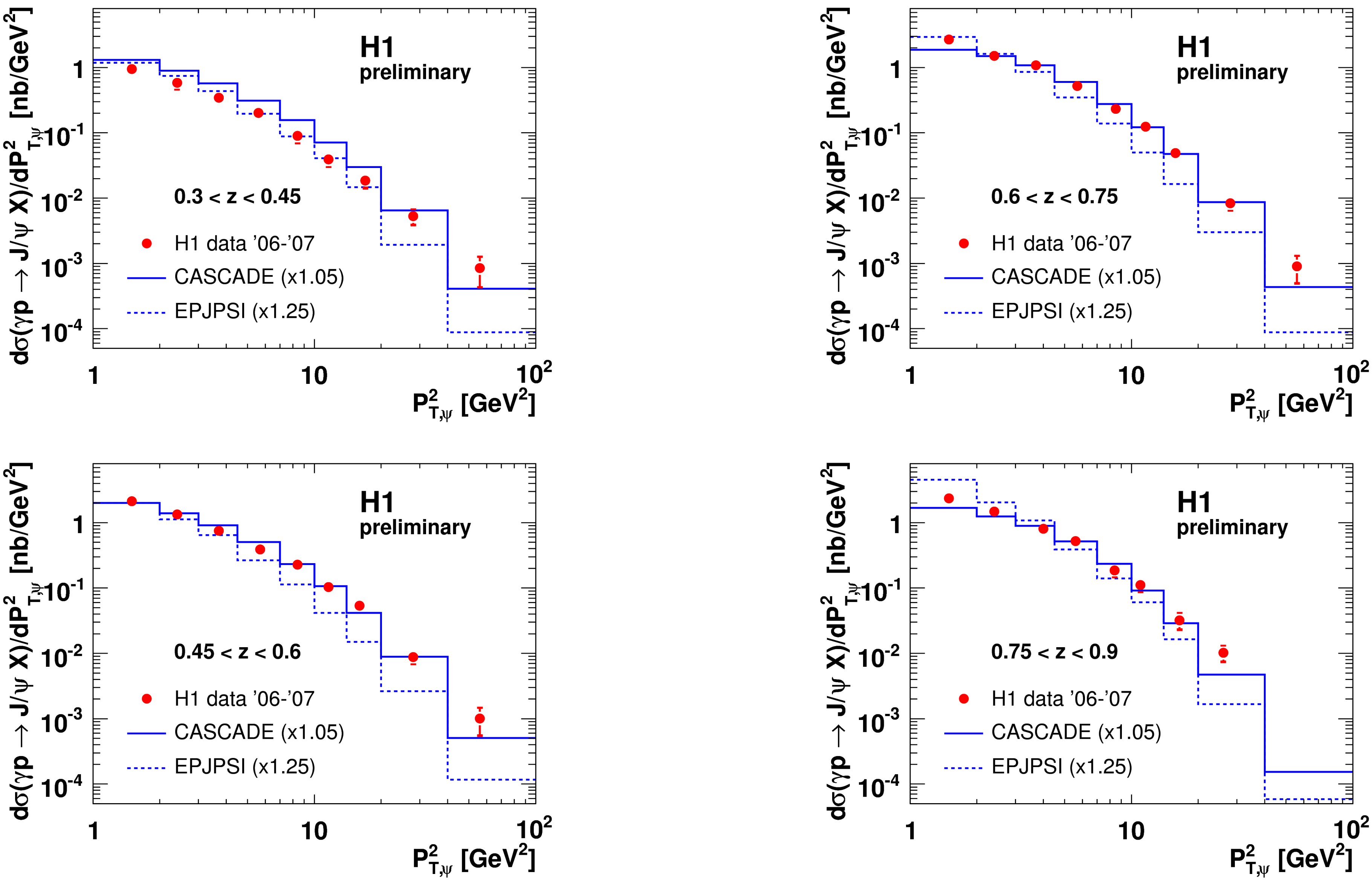
backup slides

cross section measurements in PHP



- Data well modelled by CASCADE MC: – somewhat higher at low z
  – somewhat lower at high z

cross section measurements in PHP



- Data well modelled by CASCADE MC: – somewhat higher at low z
- EPJPSI MC too steep.