



Measurement of J/ψ helicity distributions in inelastic photoproduction at ZEUS

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Outline:

- HERA and ZEUS
- charmonium cross section measurements: short summary
- J/ψ helicity parameters:
 - short introduction
 - ZEUS measurements
- conclusions

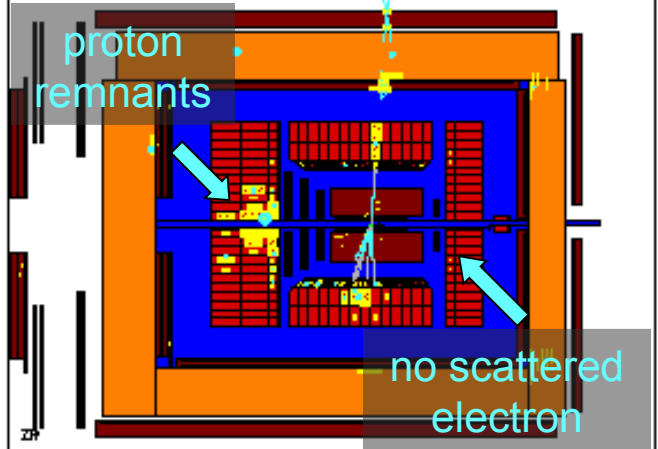
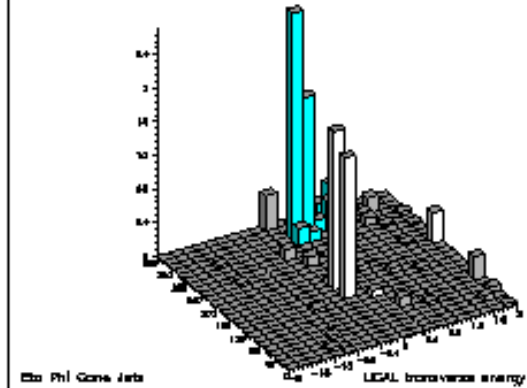
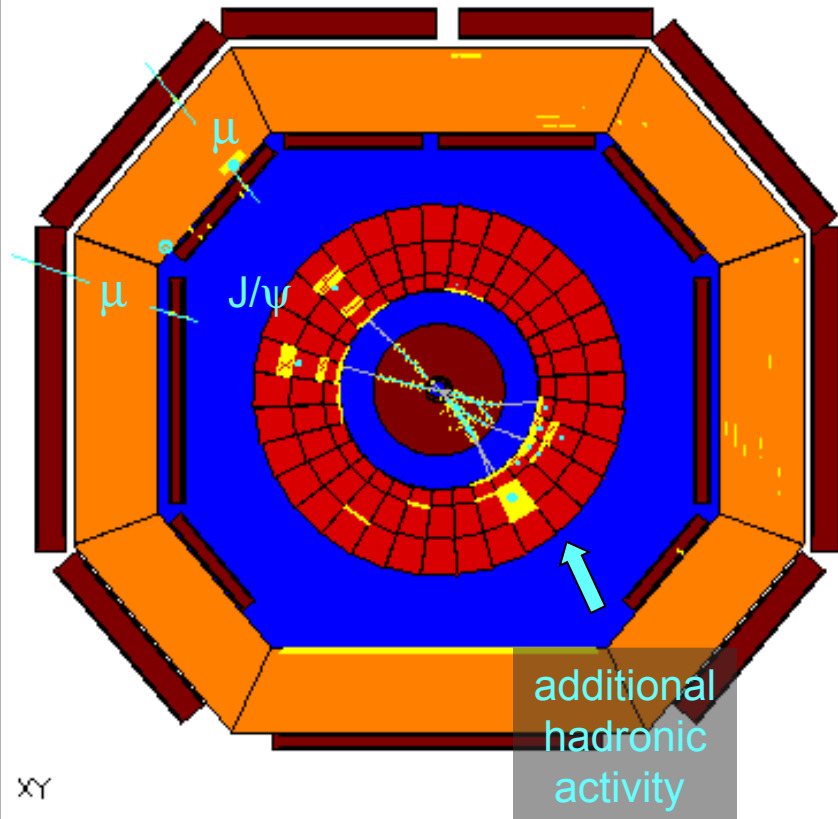
HERA and ZEUS: a brief introduction



- $e p$ collider at high CMS energy (like having an about 50 TeV e beam on fixed target)
- ZEUS: large multipurpose experiment
- running ended mid 2007 after about 2500 days of activity and 470 pb^{-1} of integrated luminosity

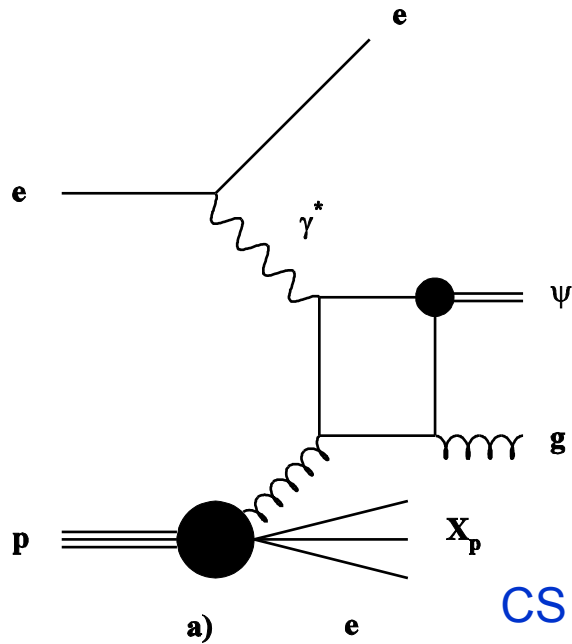


inelastic J/ψ event as seen in the ZEUS detector



- proton remnant + additional hadronic activity: **inelastic event**
- no scattered electron: **photoproduction regime**

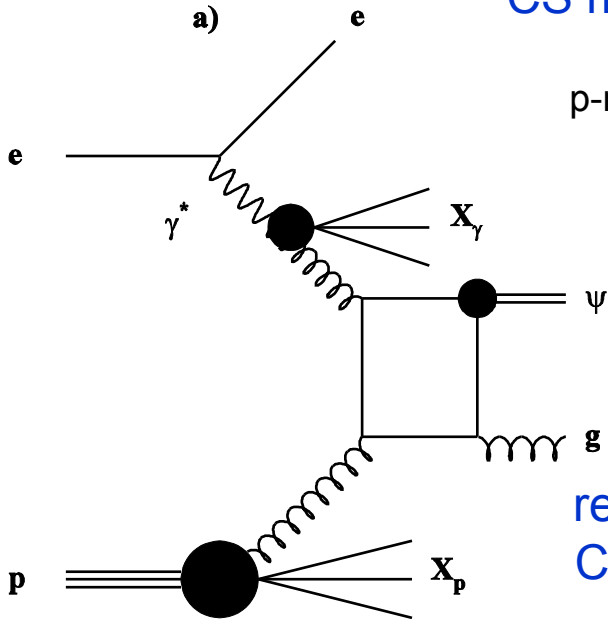
Charmonium production at HERA (J/ψ and $\psi(2S)$)



direct γ
CS model (cc q.n. = J/ψ q.n.)

$$0.2 < z < 0.9$$

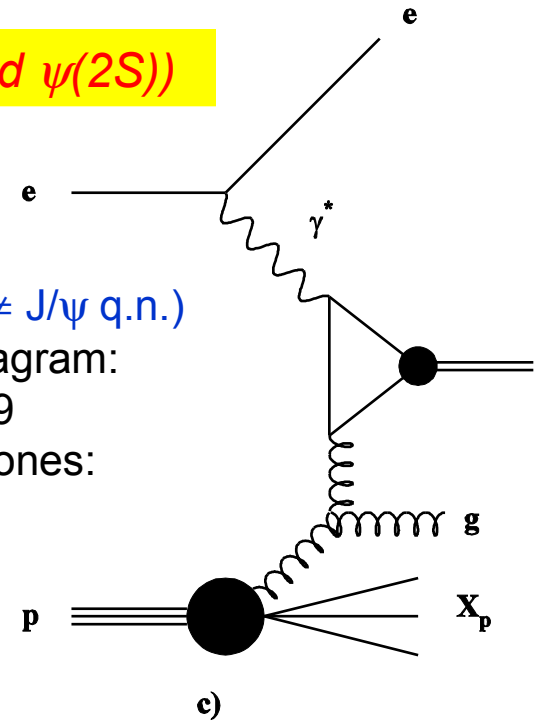
p-rest frame: $z = E(\psi)/E(\gamma^*)$



resolved γ
CS model
 $z < 0.2$

direct γ
CO model (cc q.n. $\neq J/\psi$ q.n.)

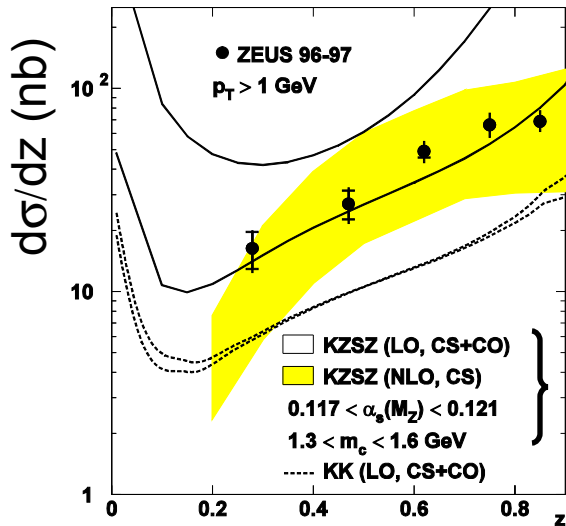
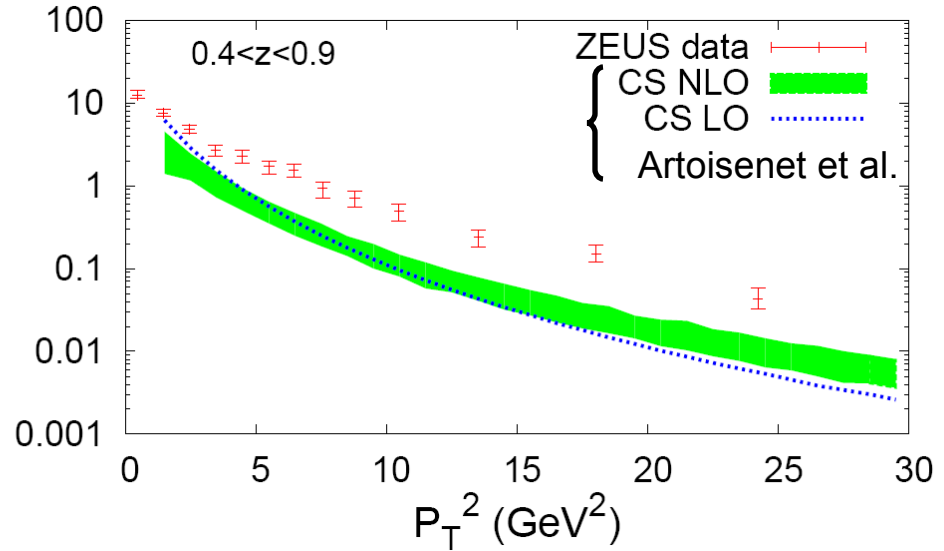
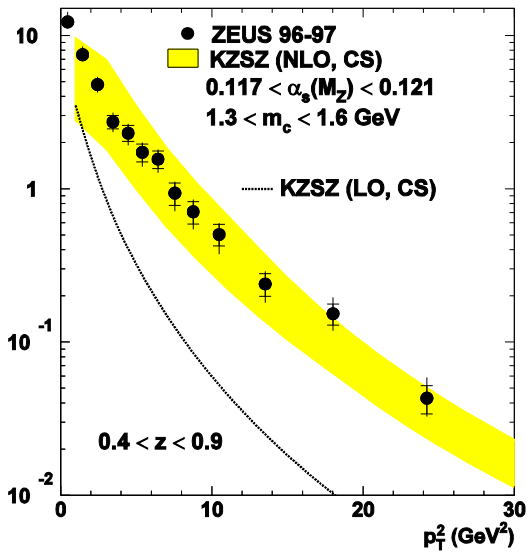
- this particular diagram:
 $0.2 < z < 0.9$
- more "typical" ones:
 $z > 0.9$



main background sources:

- $\psi(2S) \rightarrow J/\psi (\rightarrow \mu \mu) X$ decays
- J/ψ from proton dissociation
- J/ψ from B meson decays

ZEUS cross section measurements vs CS NLO



Kramer et al.

- measurements based on $< 1/10$ of the available luminosity
- inelasticity distribution is different for CS and CS+CO
- but CS NLO prediction has too large normalization uncertainties to reach any strong conclusion ... CS+CO at NLO not known at present ...

Decay angular distributions in the J/ψ rest frame \equiv helicity

□ simplest example first: assume that all J/ψ originate from the spin-less state $^1S_0^{(8)}$ then the J/ψ will be unpolarized and the μ decay angular distributions will be the ones of a state with spin 1

□ in general the μ decay angular distribution in the J/ψ rest frame is parameterized as:

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

where y stands for a set of variables, z and $p_T(J/\psi)$ are good candidates

- λ, μ, ν are related to the different CS + CO matrix elements involved
- λ, μ, ν depend on the definition of a coordinate system

main advantage:

“Since the decay angular distribution parameters are normalized, the dependence on parameters that affect the absolute normalization of cross sections, such as $m_c, \alpha_s, \mu_R, \mu_F$ and parton distribution, cancels to a large extent and does not constitute a significant uncertainty”

\Rightarrow a source of theoretical uncertainties is gone

main disadvantage:

for every y bin we have to fit a distribution

\Rightarrow unlikely requires large statistics

Decay angular distributions in the J/ψ rest frame \equiv helicity (cont.)

even using all the available luminosity we can not perform a double differential analysis without getting very large errors

but we can integrate the “helicity master formula”

- in φ

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

- in $\cos\theta$

$$1/\sigma \, d^2\sigma/d\varphi \, dy \propto 1 + 1/3 \lambda(y) + 1/3 v(y) \cos 2\varphi$$

can measure with good accuracy $\hat{\lambda}$ and v (two out of three helicity parameters)

which frame ? frame accessible experimentally using photoproduction events: target frame

- ❑ z axis (quantization axis): along the opposite of the incoming proton direction in the J/Ψ rest frame

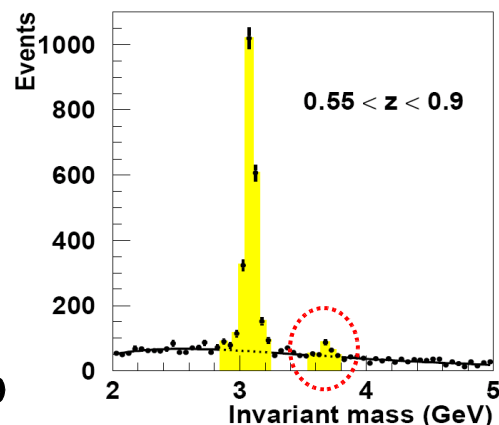
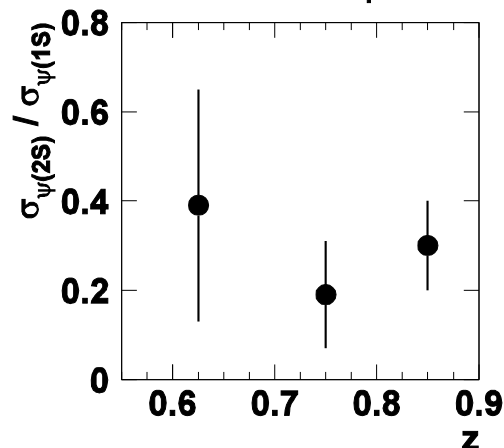
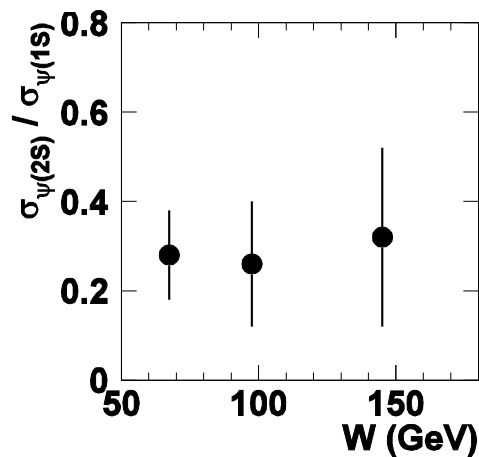
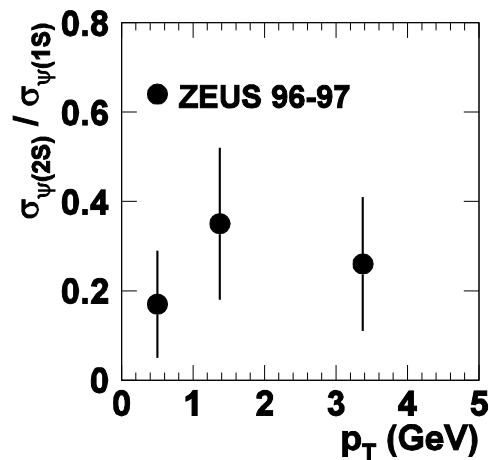
- ❑ x and y axis: chosen to complete a right-handed coordinate system in the J/Ψ rest frame according to some conventions we were given by the theorists

- ❑ θ : angle between the μ^+ vector in the J/ψ rest frame and the z axis

- ❑ φ : azimuthal angle in the x-y plane of the μ^+ vector in the J/ψ rest frame

Backgrounds to the inelastic signal

inelastic $\psi(2S)$ production:



- $< 1/10$ of the total available luminosity
- $\psi(2S)$ to $\psi(1S)$ cross section ratio consistent with being flat
- 15 % increase of the J/ψ cross section
- $\psi(2S) \rightarrow J/\psi (\rightarrow \mu \mu) X$ contribution NOT subtracted for the helicity analysis ... not easy/possible experimentally:

- would need to know the θ and ϕ distributions of the J/ψ from $\psi(2S)$ decays
- would need an inclusive reconstruction of the decay $\psi(2S) \rightarrow J/\psi (\rightarrow \mu \mu) X$

Backgrounds to the inelastic signal (cont.)

- charmonium from proton dissociation:

can observe the proton remnants but have only a little chance of observing any additional hadronic activity (no color connection between the J/ψ and X_p)

$2 \mu + \text{proton remnants} + \geq 1 \text{ track with } p_t > 0.125 \text{ and } |\eta| < 1.75$
 $\text{min. } p_t(\text{track}) \ll \text{min. } p_t(J/\psi) > 1 \text{ GeV} \Rightarrow \text{safe requirement}$

overall 6 % contribution

strongly peaked for $0.9 < z < 1$ where it grows to 60 – 70 %

NOT subtracted (... would need to know the θ and ϕ distributions of the proton dissociative J/ψ after the above cuts ...)

- charmonium from B meson decays:

much smaller B cross section than at TEVATRON

overall

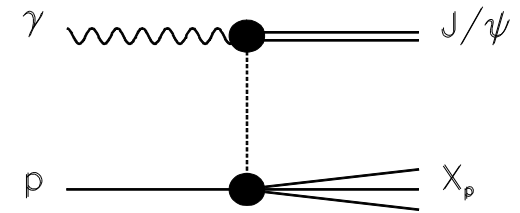
only 1.6 % of the J/ψ are from B meson decays

NOT subtracted

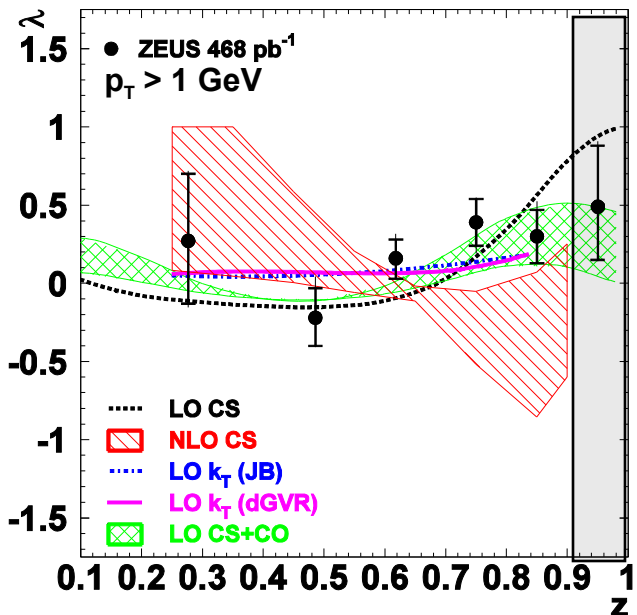
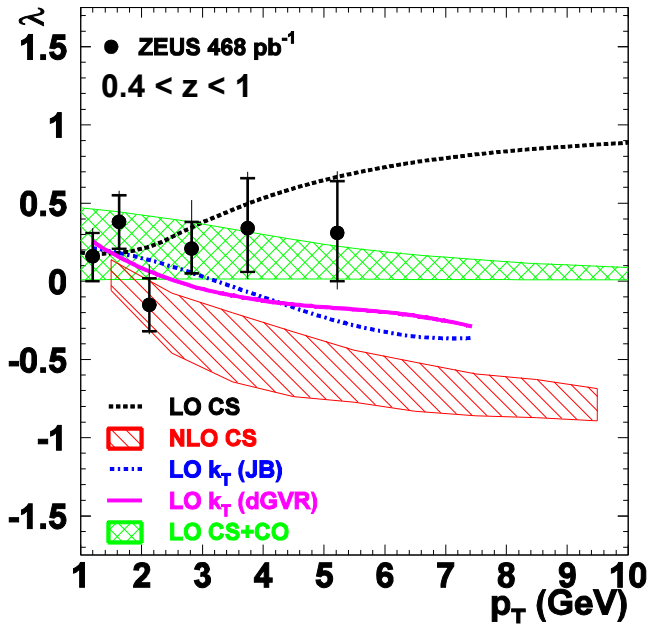
- χ contribution ($\chi \rightarrow \gamma J/\psi$): LO cross section is tiny at HERA

NOT subtracted

- elastic charmonium: gone asking for the proton remnants

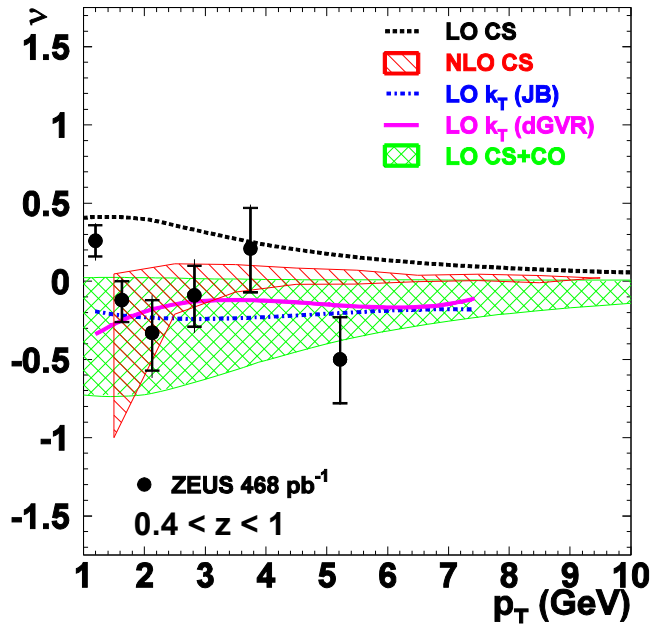


J/ψ helicity at HERA

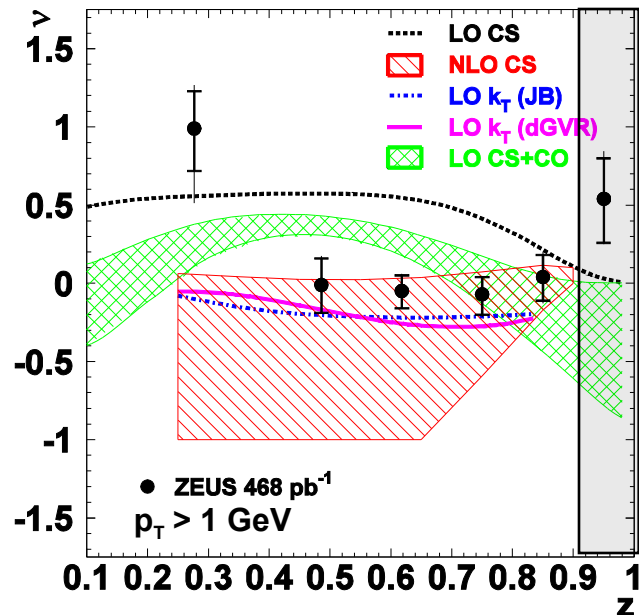


- LO CS and NLO CS predictions have opposite sign ... we initially thought NLO corrections would be small ...
- LO k_T CS has the same sign of NLO, parton transverse momentum, k_T, mimics NLO terms
- LO CS+CO is flat
- data are consistent with being flat in the probed p_T range
- proton dissociative 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 ... p_T > 1 GeV may be not enough ...
- LO k_T CS not too different from LO
- LO CS+CO is pretty much the same as LO CS
- proton dissociative is at the 60 – 70 % level for 0.9 < z < 1, << 5 % elsewhere

J/ψ helicity at HERA (cont.)

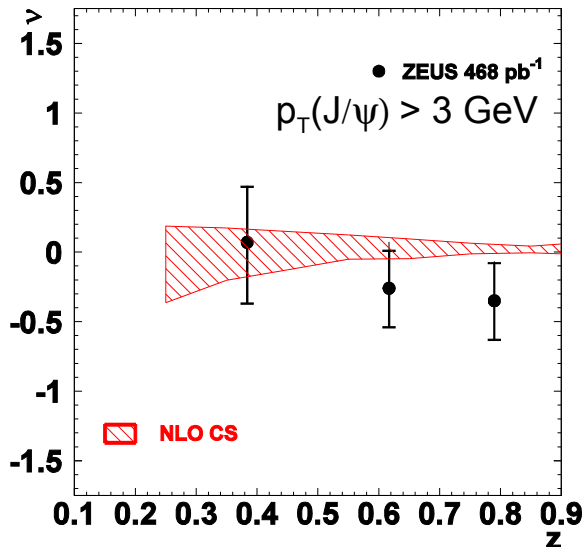
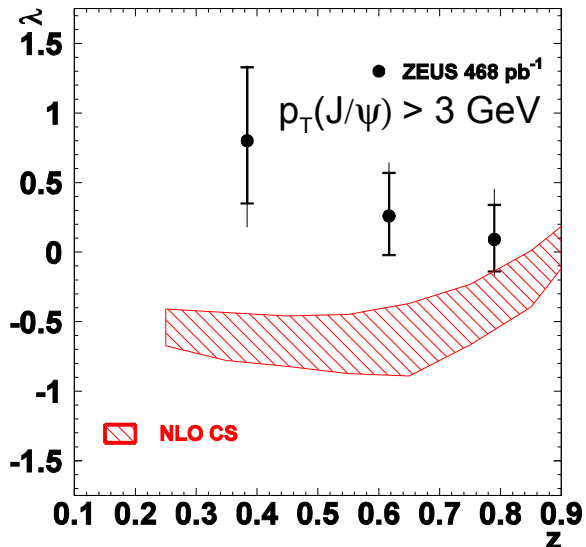
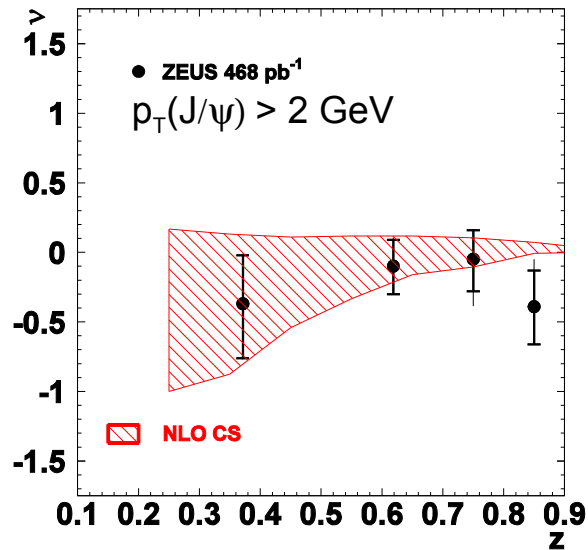
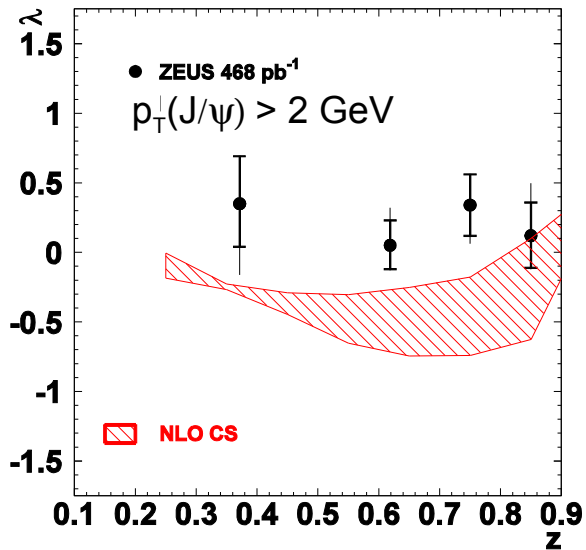


- LO CS is positive ... all other predictions are negative ... and in better agreement with the data
- LO k_T CS is pretty much as NLO CS
- LO CS+CO is flat
- data are consistent with being flat in the probed p_T range
- proton dissociative background mostly at low p_T
- analysis redone for z < 0.9, 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, << 5 % elsewhere

J/ψ helicity at HERA (cont.)



NLO predictions for:

- p_T(J/ψ) > 2 GeV
- p_T(J/ψ) > 3 GeV

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

Conclusions

- ZEUS cross section measurements are available and rather precise ... they can be redone with 10 time more statistics !
 - ZEUS also measured the helicity parameters using all the available statistics, measurements done again in $e p$ after a long time (EMC, NP B213 1982 1–30, integrating over z and p_T)
 - initial goal was to look for evidence of CO terms at HERA
 - LO CS, NLO CS, LO k_T CS and LO CS+CO predictions have been compared to the data
 - outcome: none of these predictions is able to describe all aspects of the data
 - QCD predictions also fail to describe J/ψ helicity at hadron colliders (CFD)
- ... something not yet understood or $m(J/\psi)$ is too small ?