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Inelastic J/ψ helicity distributions

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Outline:

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

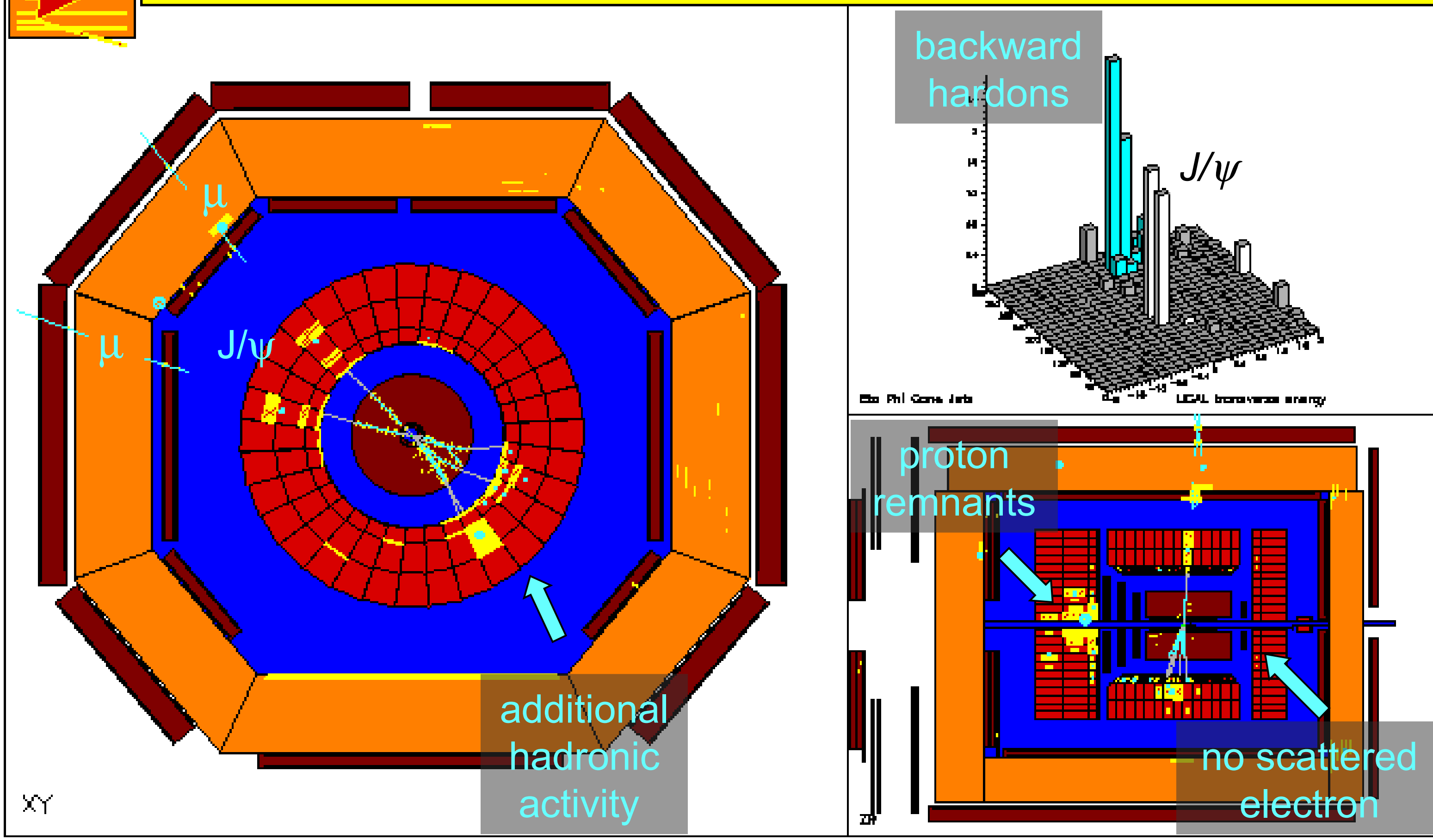
HERA and ZEUS: a brief introduction

• HERA was an *e p* collider at high CMS energy (like having an about 50 TeV *e* beam on fixed target)

• ZEUS was a large multipurpose experiment

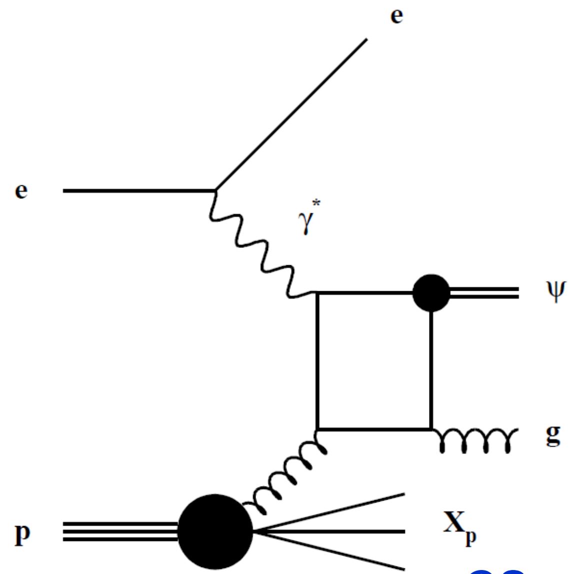
• running ended mid 2007 after about 2500 days of activity and 470 pb^{-1} of integrated luminosity

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 $\psi(2S)$)

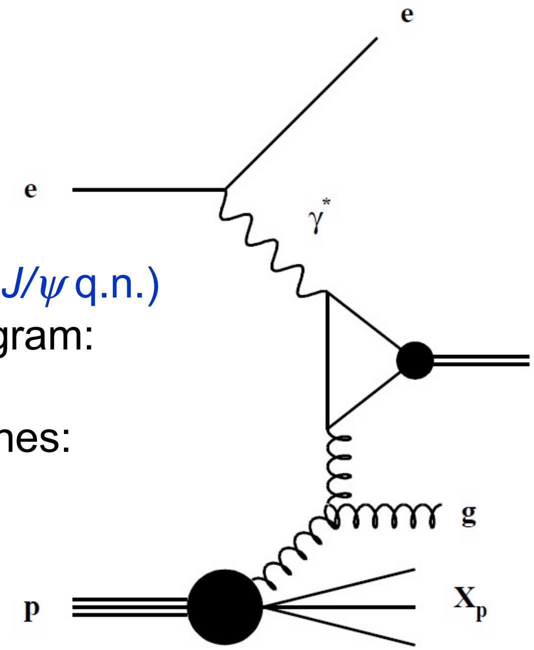


direct γ

CS model (cc q.n. = J/ψ q.n.)

$0.2 < z < 0.9$

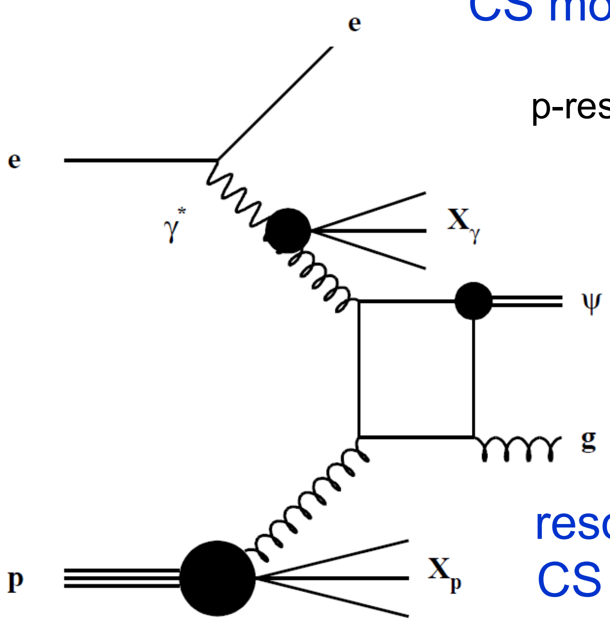
p-rest frame: $z = E(\psi)/E(\gamma^*)$



direct γ

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

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



resolved γ

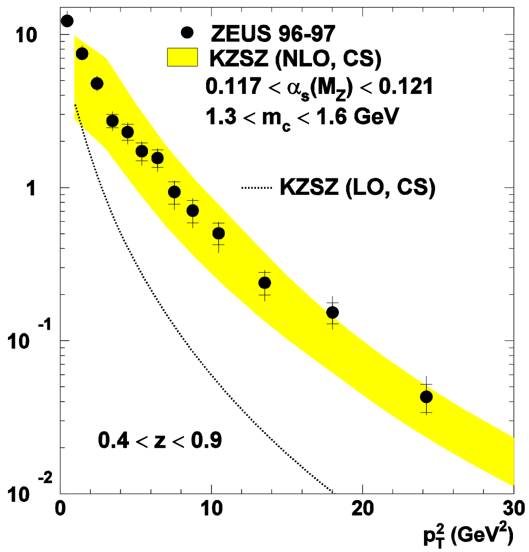
CS model

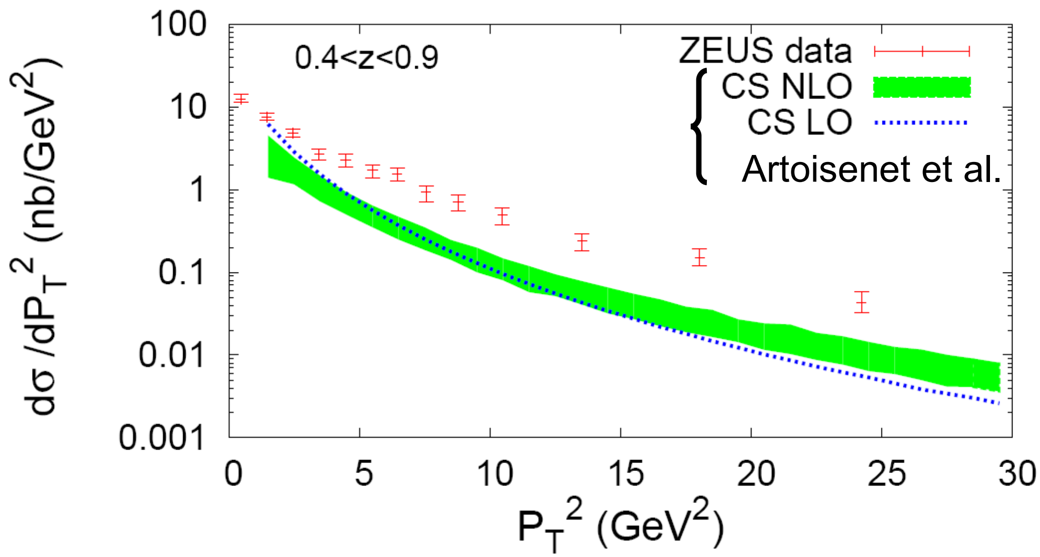
$z < 0.2$

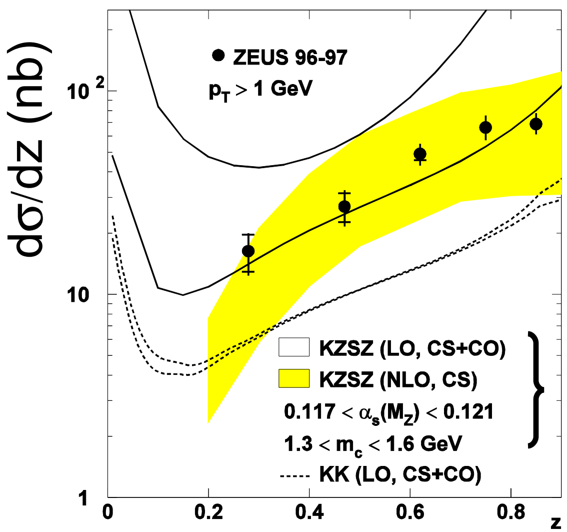
main background sources:

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

ZEUS cross section measurements vs CS NLO







Kramer et al.

- same ZEUS data points are shown in the two upper plots
- 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 ≡ 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, α_s, μ_R, μ_F and parton distribution, cancels to a large extent and does not constitute a significant uncertainty"

⇒ a source of theoretical uncertainties is gone

main disadvantage:

for every y bin we have to fit a distribution

⇒ 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 $\cos\theta$

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

can measure with good accuracy λ and ν (two out of three helicity parameters)

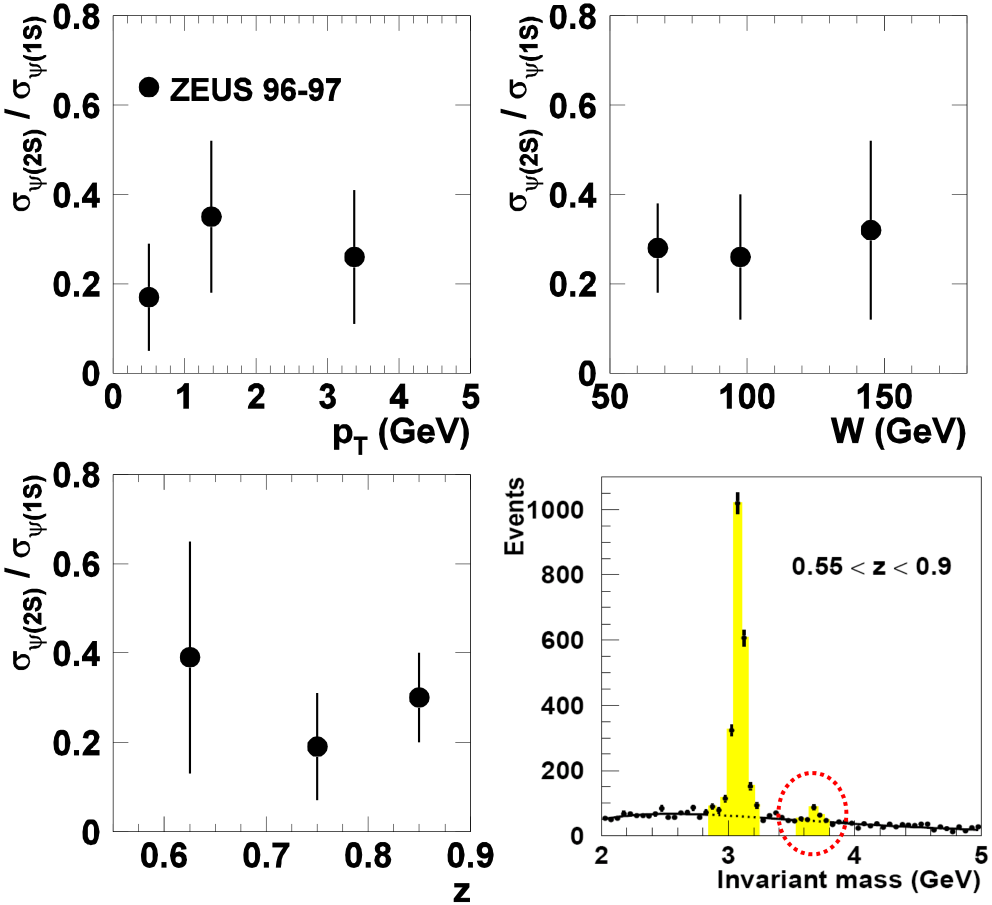
which frame ? frame accessible experimentally using photoproduction events: target frame

- ❑ 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

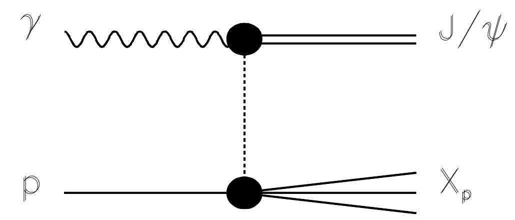
• 15 % increase of the J/ψ cross section

• $\psi(2S) \to J/\psi\,(\to \mu\,\mu)$ 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 $\psi(2S) \to J/\psi\,(\to \mu\,\mu)$ 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 μ + proton remnants + $\geq$ 1 track with $p_t > 0.125$ and $|\eta| < 1.75$
min. p_t(track) << min. pt(J/ψ) > 1 GeV $\Rightarrow$ safe requirement

overall 6 % contribution
strongly peaked for $0.9 < z < 1$ where is grows to 66 %

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

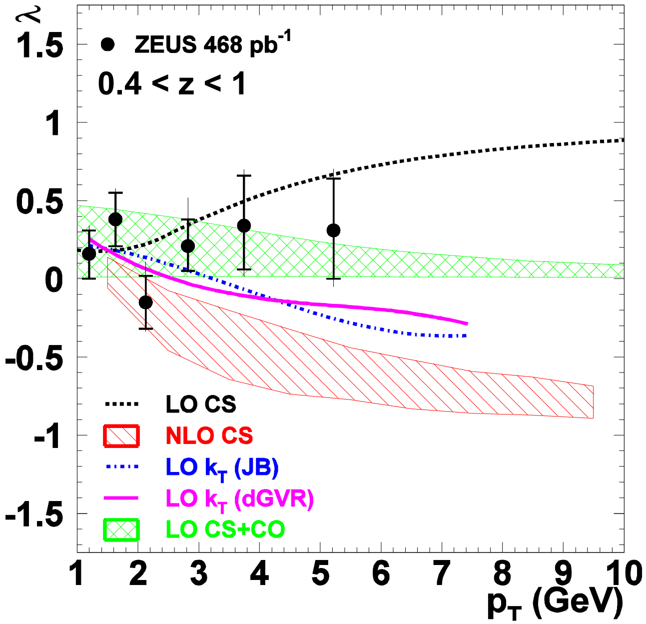
NOT subtracted

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

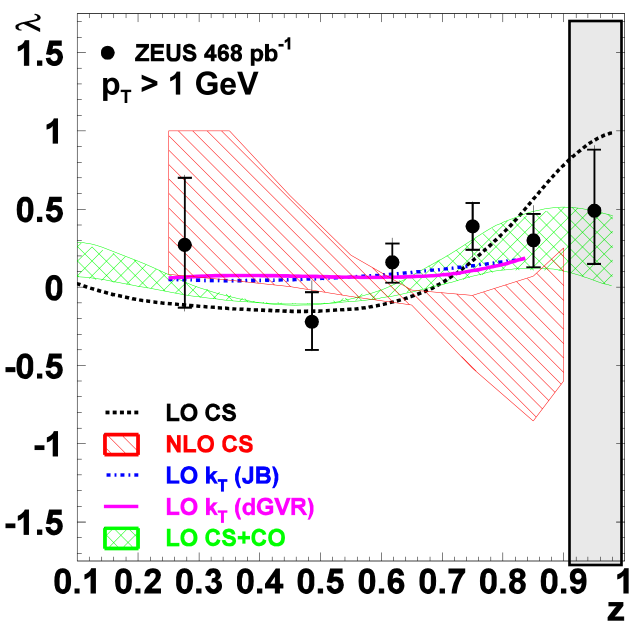
NOT subtracted

- elastic charmonimum: gone asking for the proton remnants

J/ψ helicity at HERA

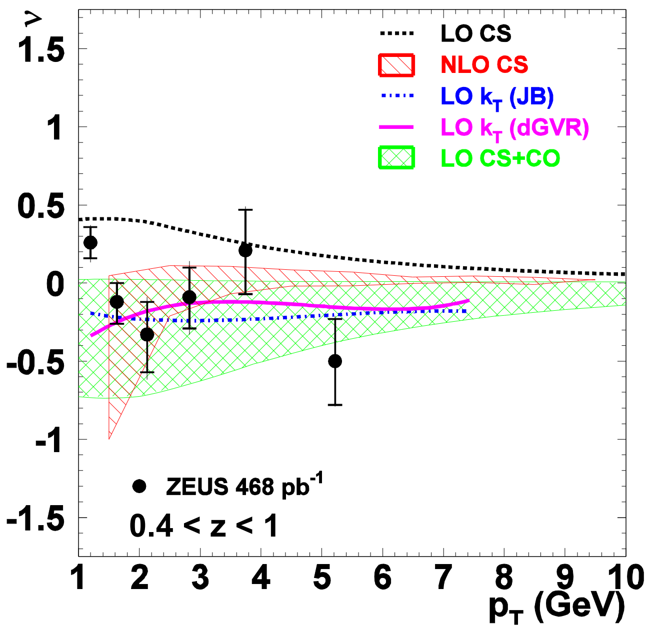


- LO CS and NLO CS predictions have opposite sign … we initially thought NLO corrections would be small …
- LO k_T CS has the same sign of NLO, parton transverse momentum, k_T, mimics NLO terms
- LO CS+CO is flat
- data are consistent with being flat in the probed p_T range
- proton dissociative background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

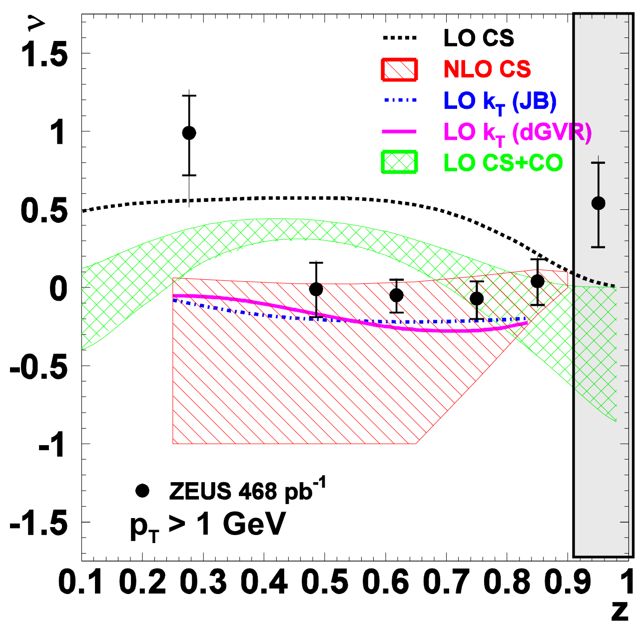


- LO CS describe the data well
- NLO CS has large uncertainties … p_T > 1 GeV may be not enough …
- LO k_T CS not too different from LO
- LO CS+CO is pretty much the same as LO CS
- proton dissociative is at the 60 – 70 % level for 0.9 < z < 1, << 5 % elsewhere

J/ψ helicity at HERA (cont.)

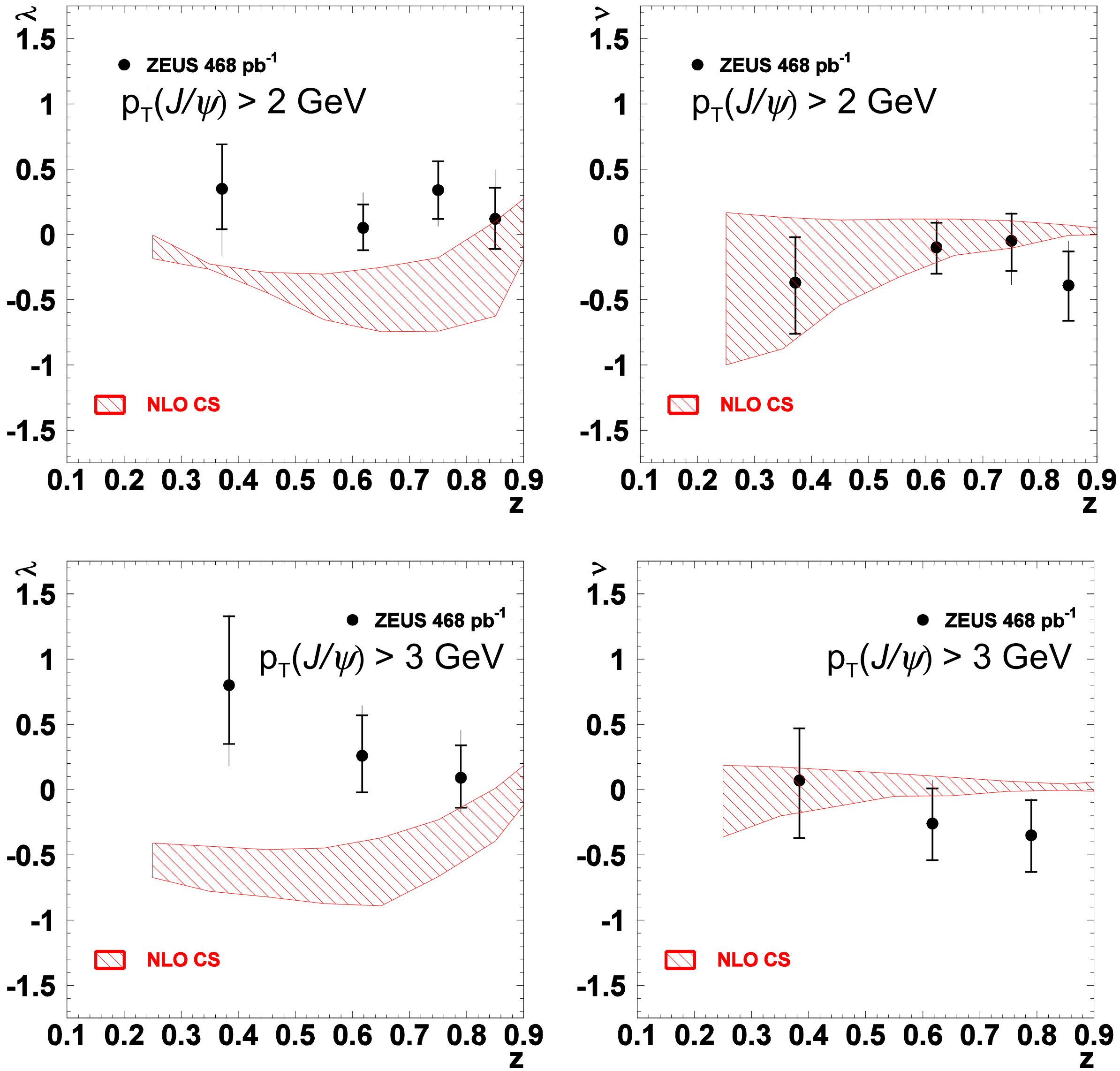


- LO CS is positive … all other predictions are negative … and in better agreement with the data
- LO k_T CS is pretty much as NLO CS
- LO CS+CO is flat
- data are consistent with being flat in the probed p_T range
- proton dissociative background mostly at low p_T
- analysis redone for z < 0.9, effects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

- $p_T(J/\psi)$ > 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

- 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

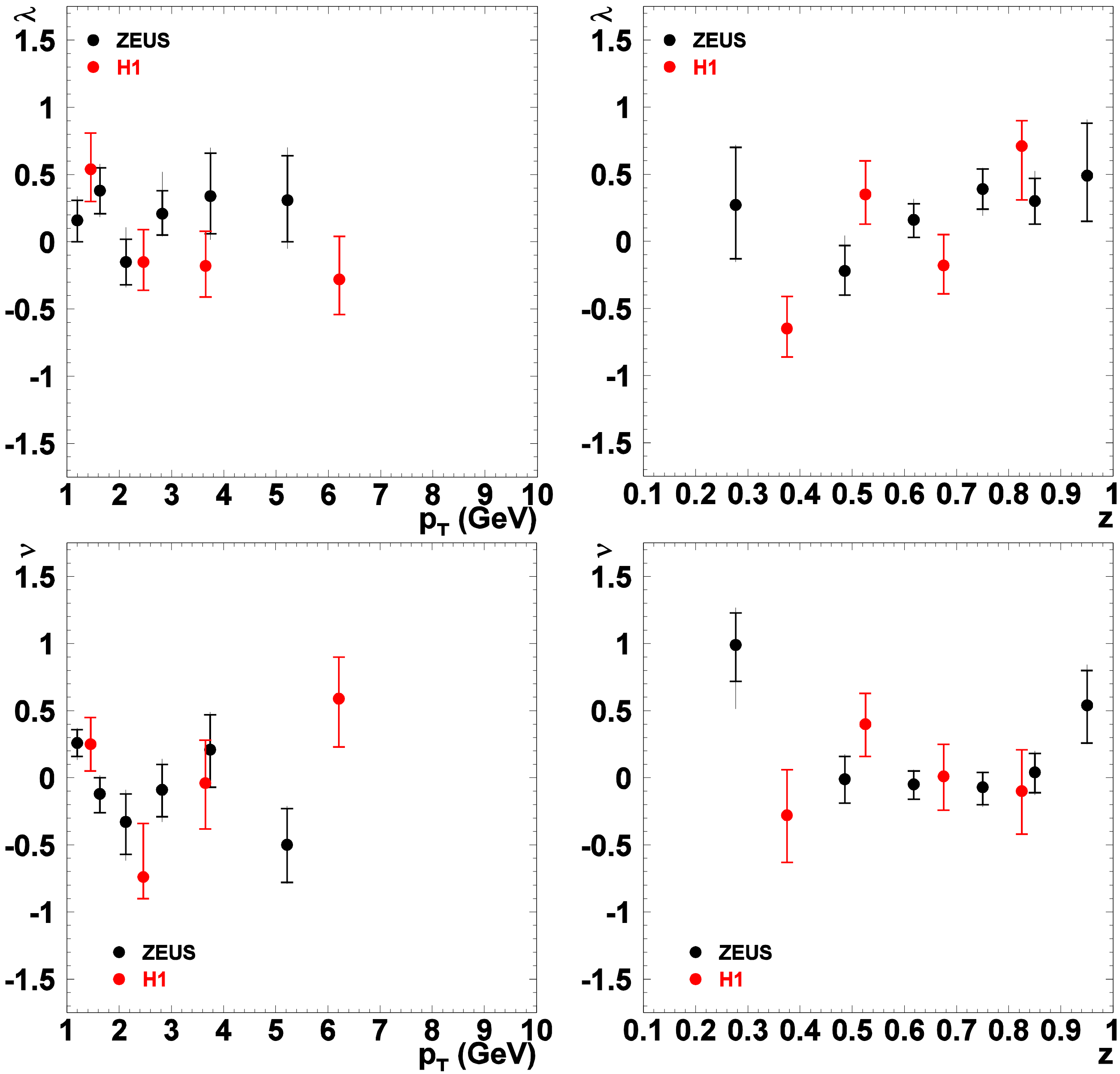
- QCD predictions also fail to describe J/ψ helicity at hadron colliders (CFD)

… something not yet understood or m(J/ψ) is too small ?

… backup slides …

ZEUS: JHEP12 (2009) 007

H1: arXiv:1002.0234v1



even if the ZEUS and H1 analyses differ in several details the overall results are compatible

All differences:

- luminosity: ZEUS 468 pb^{-1}, H1 165 pb^{-1}
- W range: ZEUS [50,180] GeV, H1 [60,240] GeV
- pt(J/ψ) $>$ 1 GeV: same for both
- z range for the analysis vs pt(J/ψ) : ZEUS [0.4,1], H1 [0.3,0.9]

for ZEUS the difference between [0.4,1] and [0.4,0.9] in included in the sys. errors

Additional remarks:

- ZEUS requires at least 3 vertex tracks AND some hadronic energy in the forward direction (in the main calorimeter, this alone is equivalent to $M_N > 4.4$ GeV/c^2)
- H1 requires “only” at least 5 vertex tracks
- for ZEUS as a cross check we tried at least 5 vertex tracks but no significant variation of the results has been found

… ignore this slide …