Measurement of inelastic J/ψ and ψ(2S) photoproduction at HERA
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Outline:

- HERA and ZEUS
- charmonium production at HERA
- recent charmonium photoproduction measurements by ZEUS:
  - ψ(2S) to J/ψ cross section ratio
  - J/ψ p_T^2 differential cross section
  - J/ψ inelasticity differential cross section
  - momentum flow against / along the J/ψ direction
- conclusions

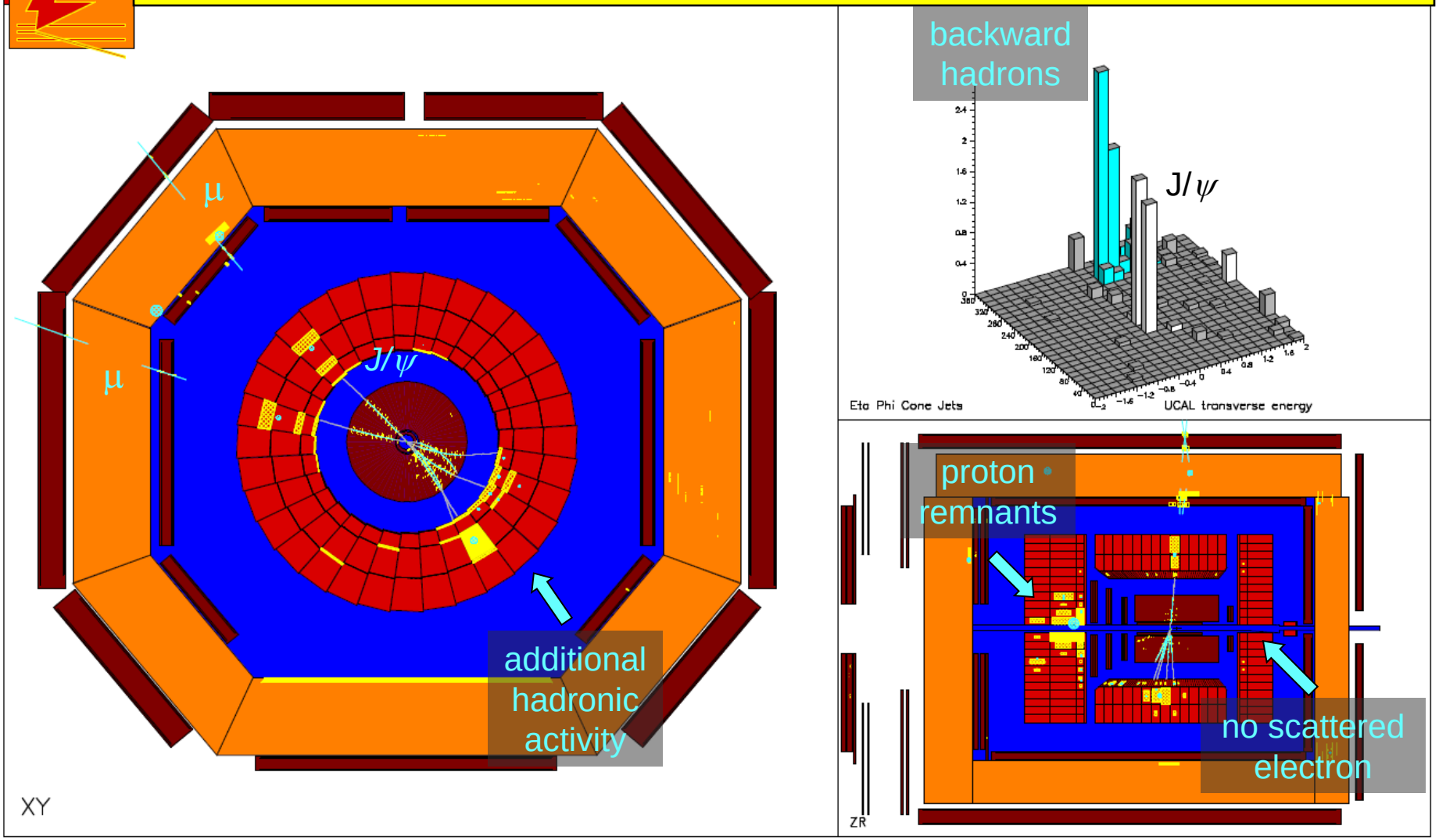
HERA and ZEUS: a brief introduction

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

• ZEUS was a large multipurpose experiment

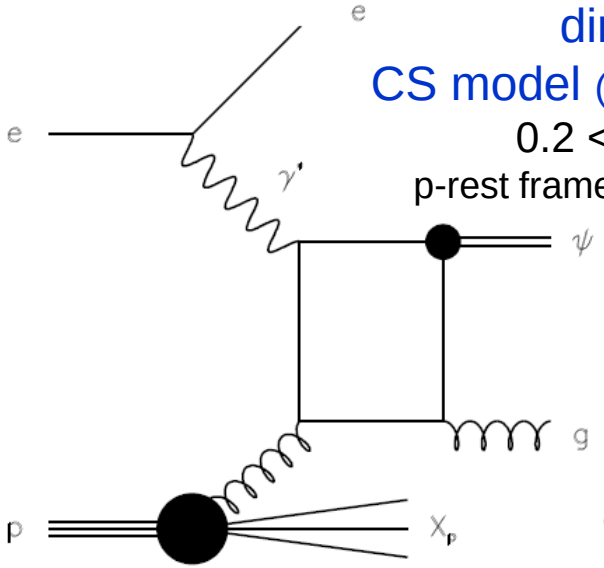
• running ended mid 2007, will see results integrating all the data taken since 1996: 11 years of activity and 468 pb^{-1} of integrated luminosity

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 ψ(2S))

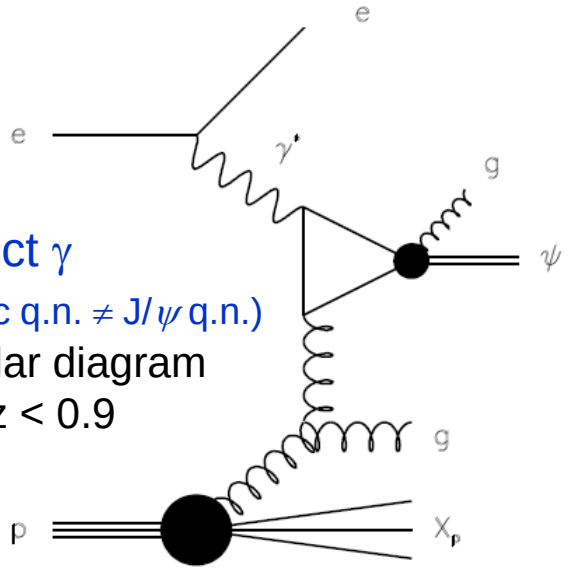


direct γ

CS model (cc q.n. = J/ψ q.n.)

0.2 < z < 0.9

p-rest frame: z ≡ E(ψ)/E(γ*)



direct γ

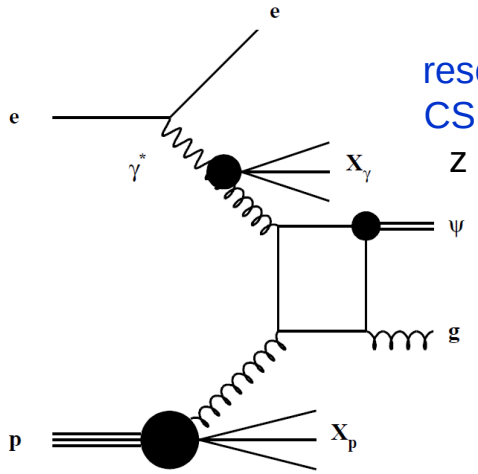
CO model (cc q.n. ≠ J/ψ q.n.)

this particular diagram

0.2 < z < 0.9

other key variables:

- p_T
- W ≡ γ p center of mass energy



resolved γ

CS model

z < 0.2

other contributions to the signal (decreasing size)**:**

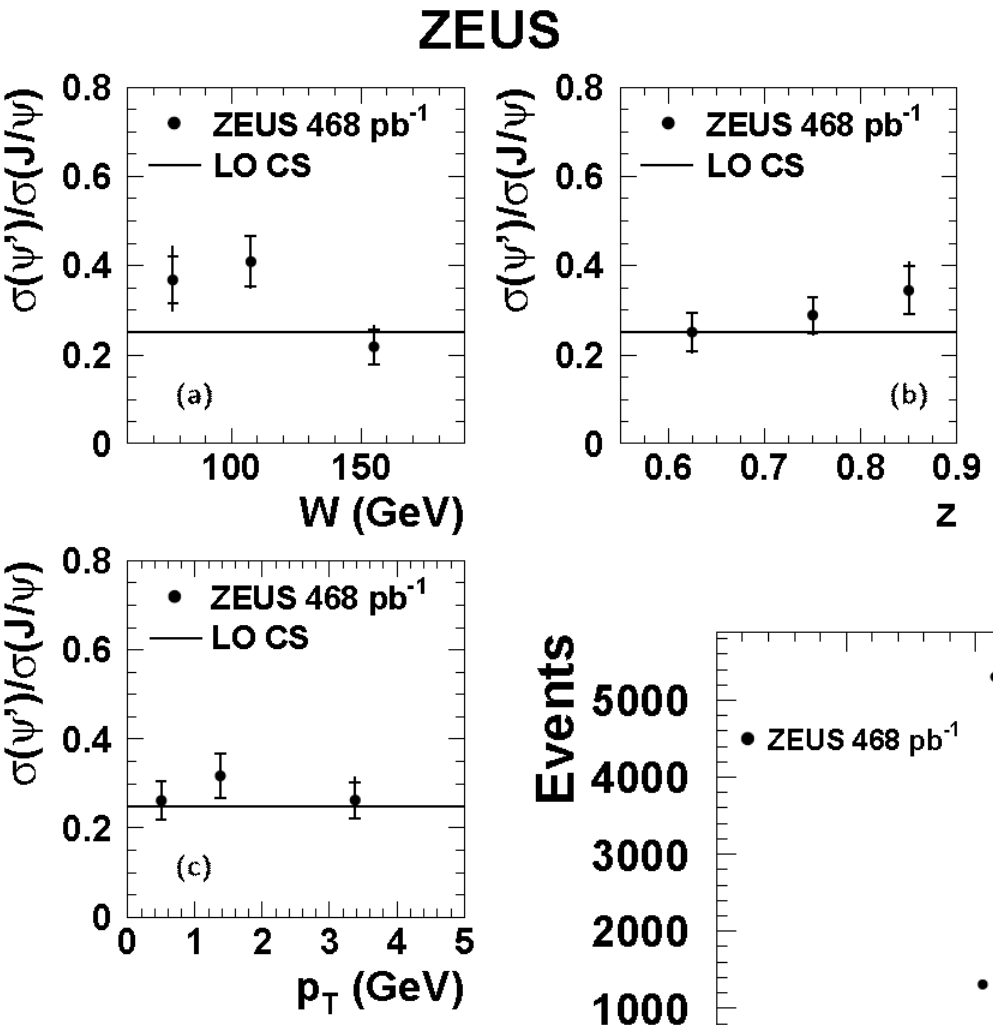
- ψ(2S) → J/ψ (→ μ μ) X decays
- J/ψ from B meson decays
- J/ψ from resolved photon processes

main background source:

- J/ψ from proton diffractive dissociation

other contributions to the signal

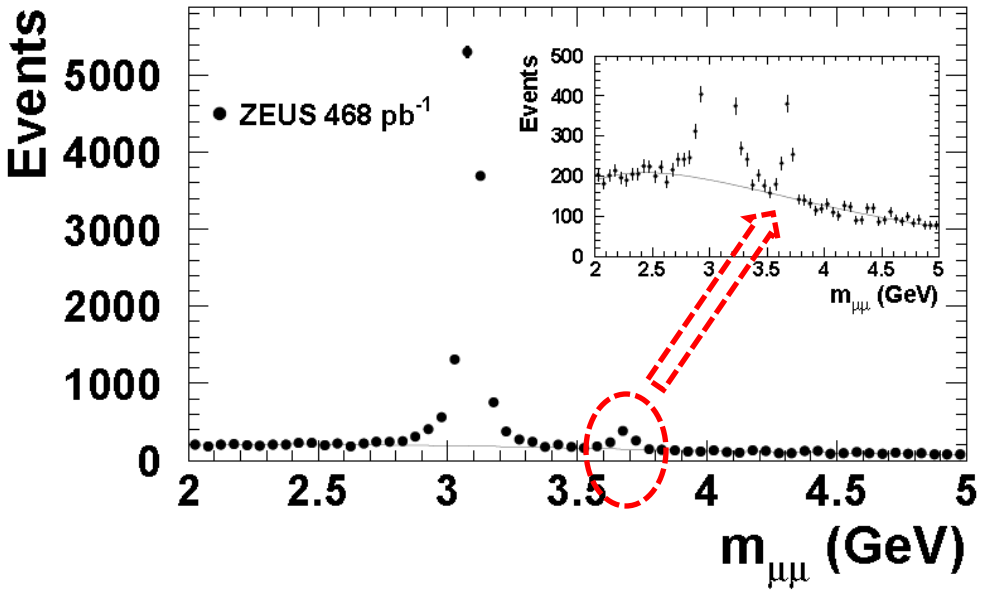
• inelastic ψ(2S) photoproduction:



- ψ(2S) to J/ψ cross section ratio vs W, z and p_T consistent with being flat
- LO CS model expectation: 0.25 (hor. line)
- via $\psi(2S) \rightarrow J/\psi\,(\rightarrow \mu\,\mu)$ X this results in a ~ 15 % increase of the J/ψ cross section

NOT subtracted

not possible experimentally … would need an inclusive reconstruction of the decay $\psi(2S) \rightarrow J/\psi\,(\rightarrow \mu\,\mu)$ X



11295 ± 114 J/ψ
448 ± 34 ψ(2S)

other contributions to the signal

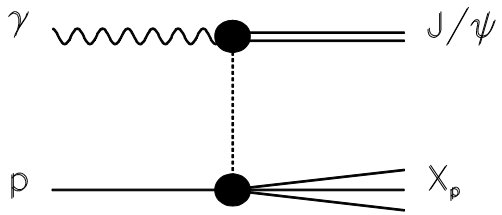
• charmonium from B meson decays: B prod. well tested at HERA, much smaller than at hadron colliders: on average 1.6 % of the J/ψ are from B meson decays, 4.5 % at low z and low p_T

NOT subtracted

• J/ψ from resolved γ processes (including $\chi_C \rightarrow J/\psi\,\gamma$): has never been measured explicitly in PHP up to now, LO cross section is tiny at HERA

NOT subtracted

main background



• charmonium from proton diffractive dissociation:

J/ψ produced at z > 0.9 but some are reconstructed with z < 0.9

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 $|\eta| < 1.75 \Rightarrow$ very strong suppression

(min. p_T(track) << min. $p_T(J/\psi)$ > 1 GeV $\Rightarrow$ safe requirement)

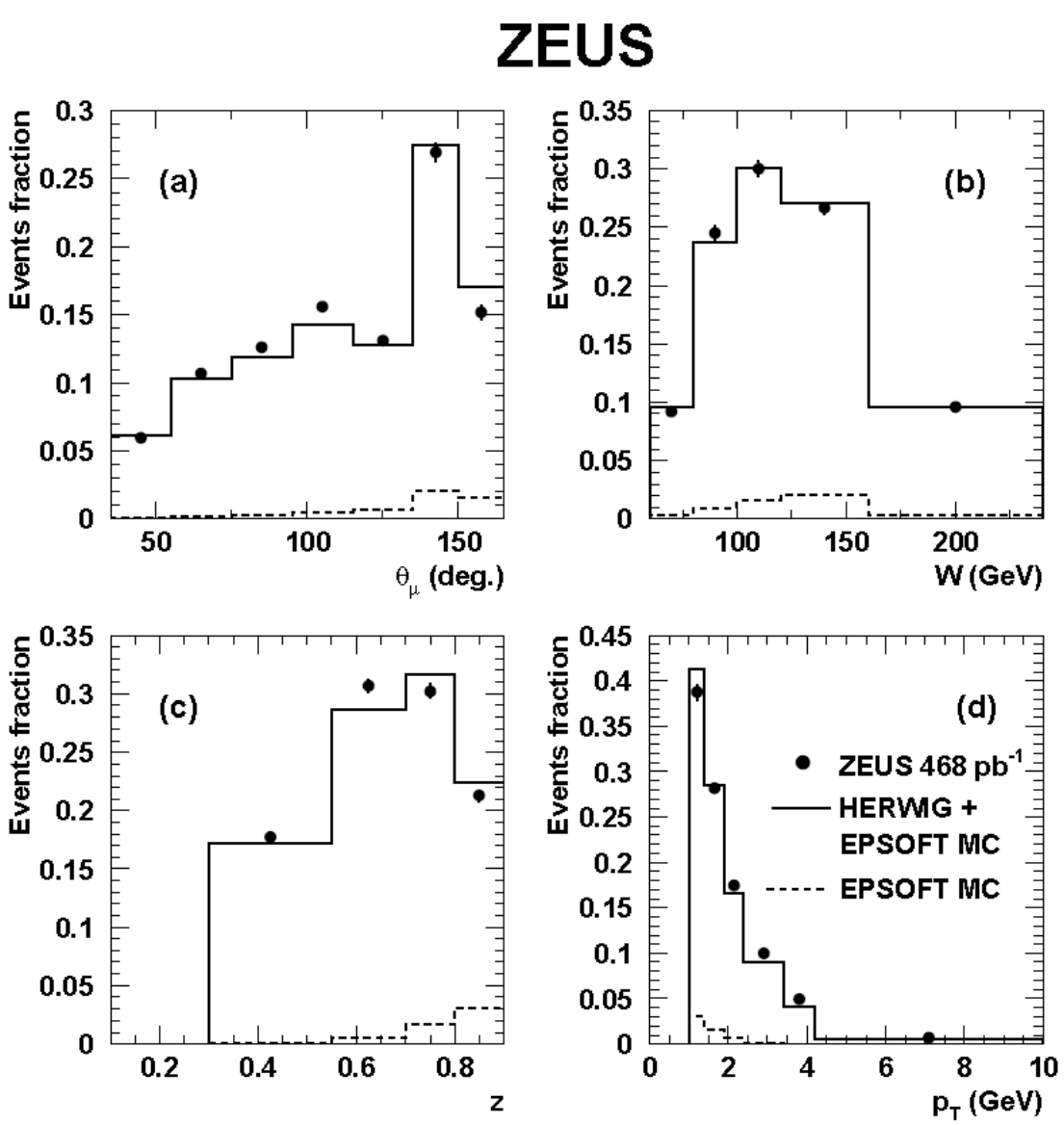
the remaining contribution is obtained by fitting the measured z distribution using the HERWIG MC for the signal and the EPSOFT MC for the background

overall: 4.6 % contribution, strongly peaked at high z

subtracted

reminder: elastic charmonimum: gone asking for the proton remnants

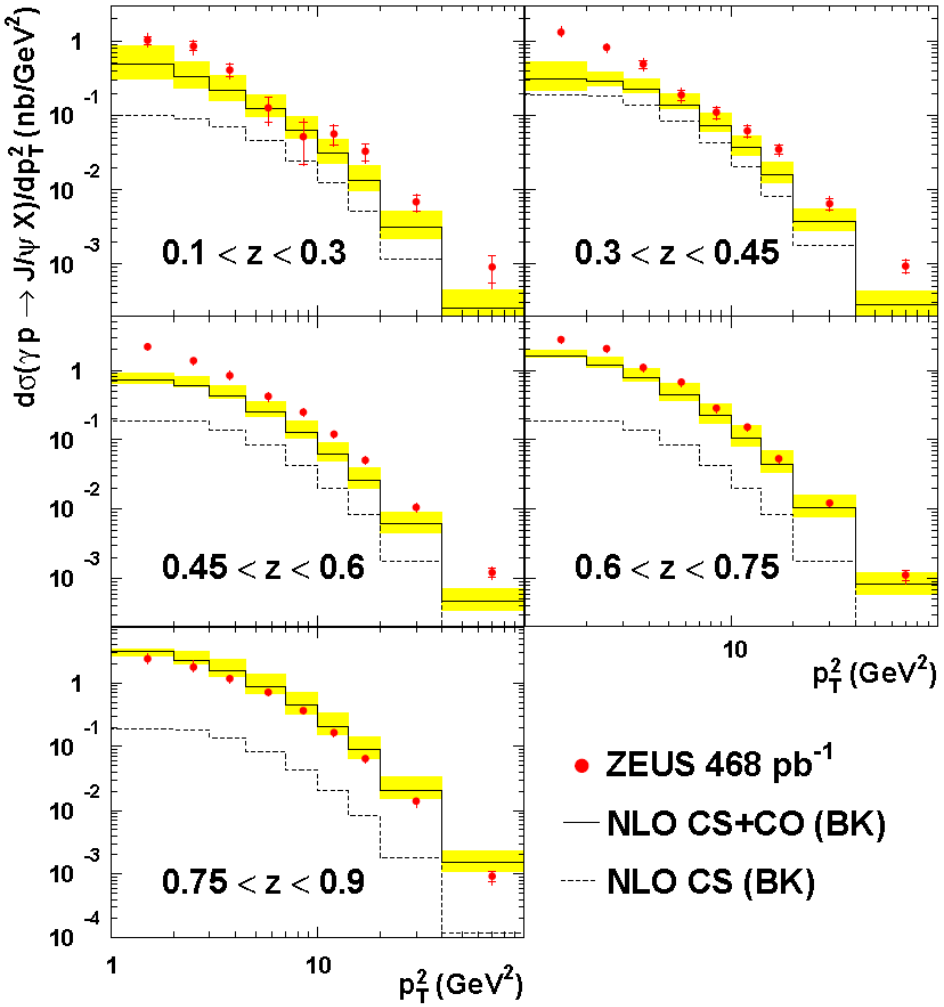
some control plots

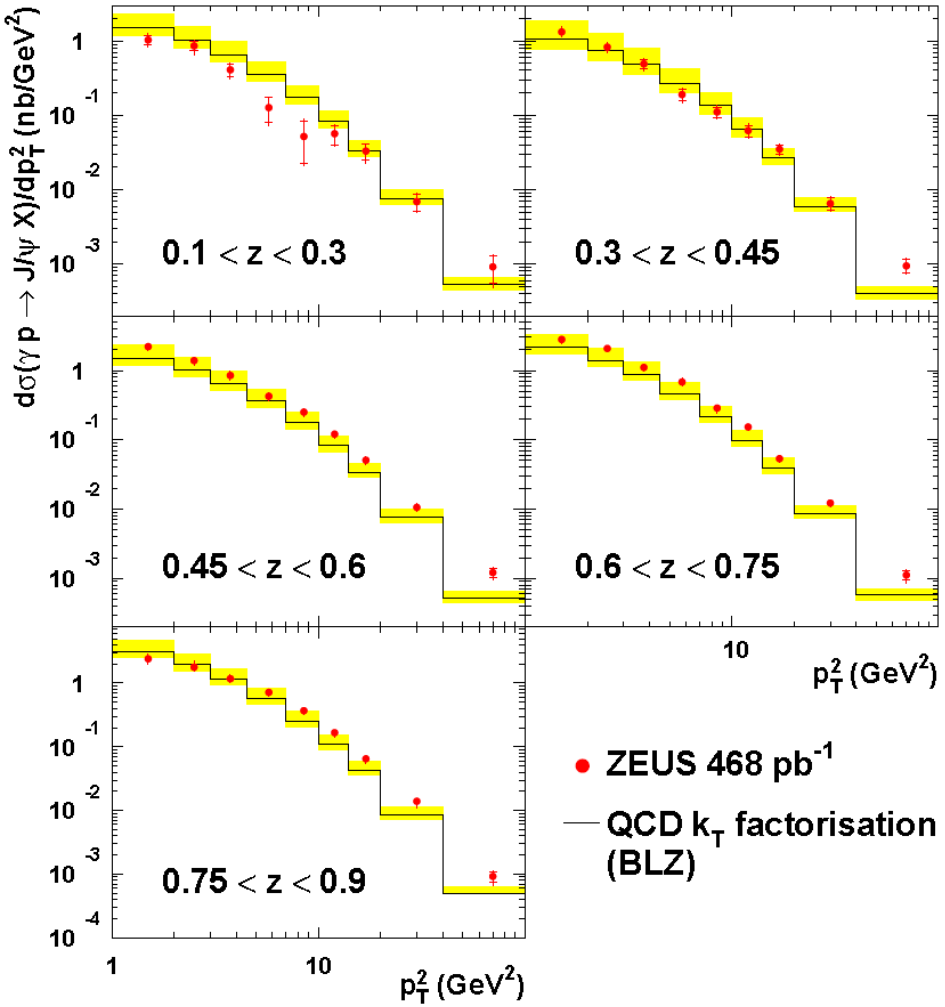


data stat. uncertainties are shown by the error bars (where visible)

p_T^2 differential cross section

60 < W < 240 GeV



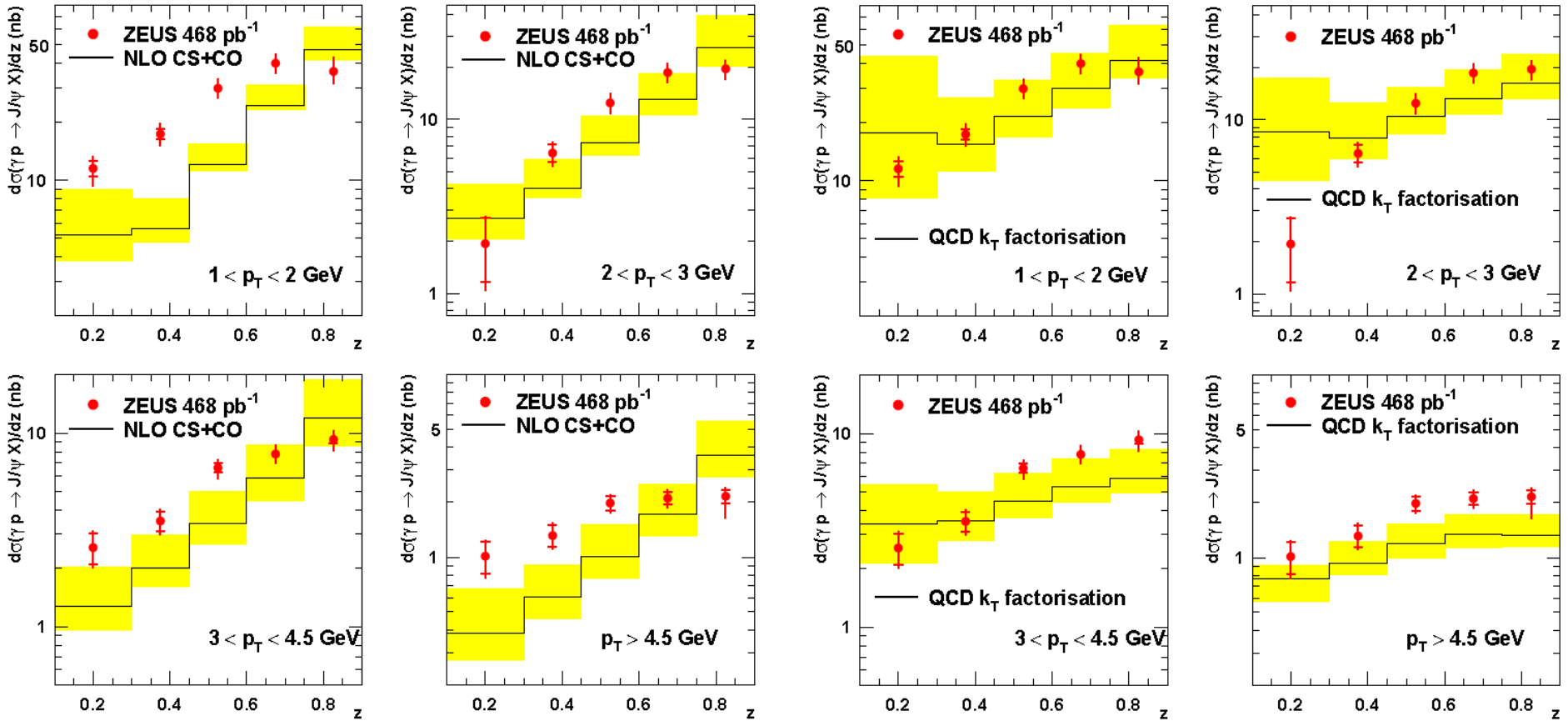


ZEUS data points on the left and right plots are the same
left theory: full NLO computation including CS and CO terms
right theory: LO CS model framework amended with non zero initial state gluons k_T

within large theoretical uncertainties overall better description of the data from k_T factorisation

z differential cross section

60 < W < 240 GeV



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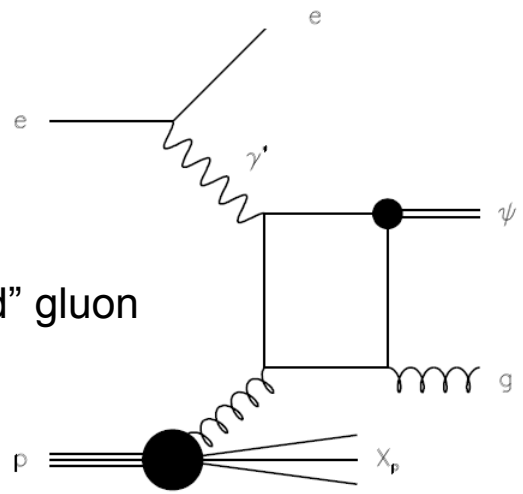
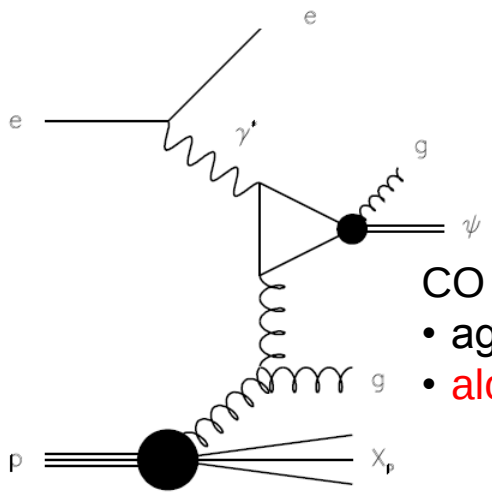
momentum flow against / along the J/ψ direction (vs J/ψ p_T)

a LO experimentalist approach …

CS model:
- against: a “hard” gluon
- along: nothing
- HERWIG MC





CO contribution:
- against: a “hard” gluon
- along: ≥ 1 “soft” gluons

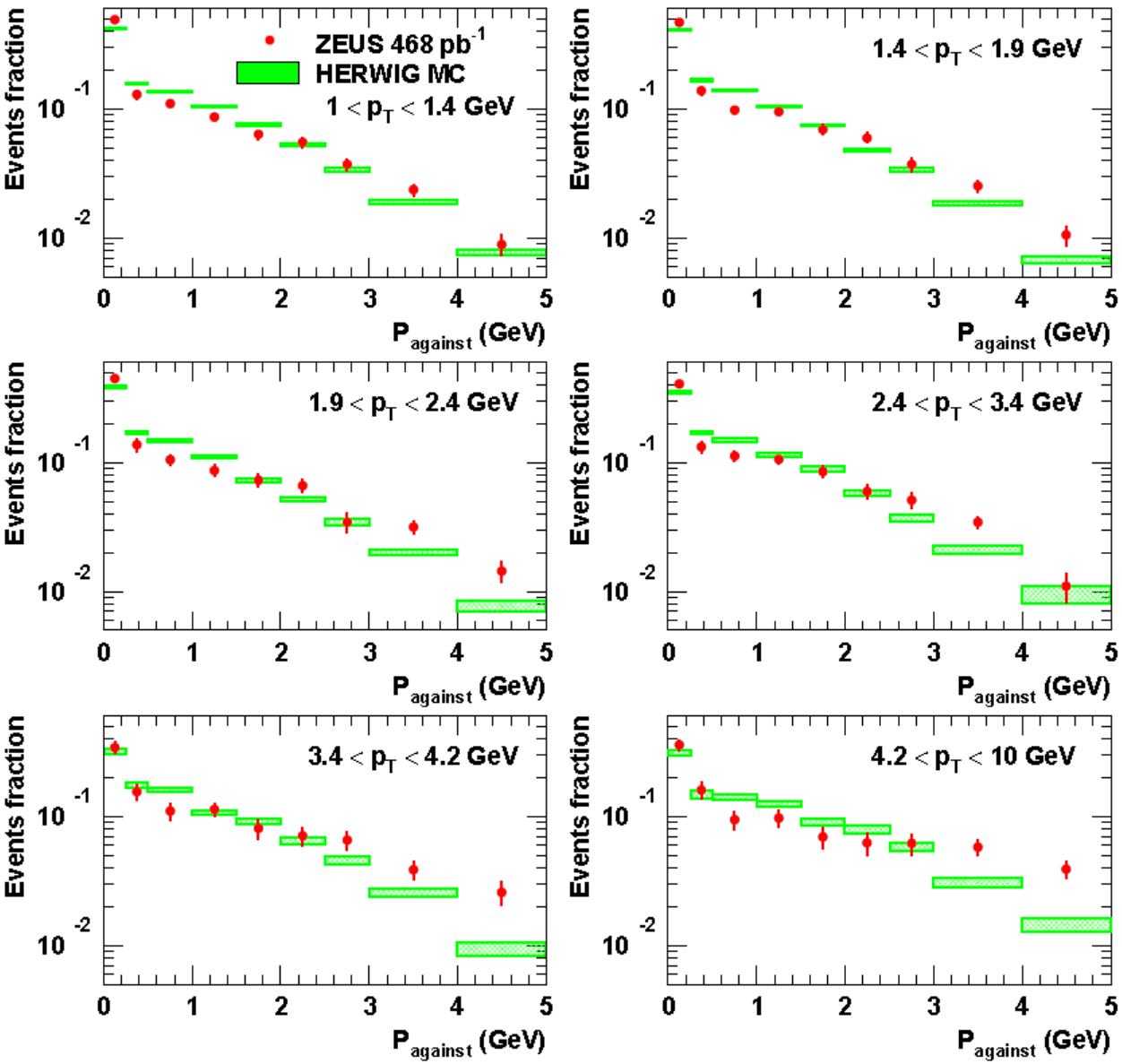
simple (naive) check: compare the momentum flow against / along the J/ψ direction to the HERWIG MC predictions (LO CS model + parton shower), shape comparison

- all quantities are defined in the laboratory frame
- momentum flow: (charged) tracks (from the primary vertex) only, with $p_T > 150$ MeV and $|\eta| < 1.75$, do not consider neutrals
- against / along: backward or same hemisphere w.r.t. the J/ψ line of flight
- analysis performed vs J/ψ p_T

- do NOT correct for detector effects, “raw data” comparison
- p_T range accessible at HERA: $p_T < 10$ GeV

momentum flow against the J/ψ direction (vs J/ψ p_T)

60 < W < 240 GeV
0.3 < z < 0.9

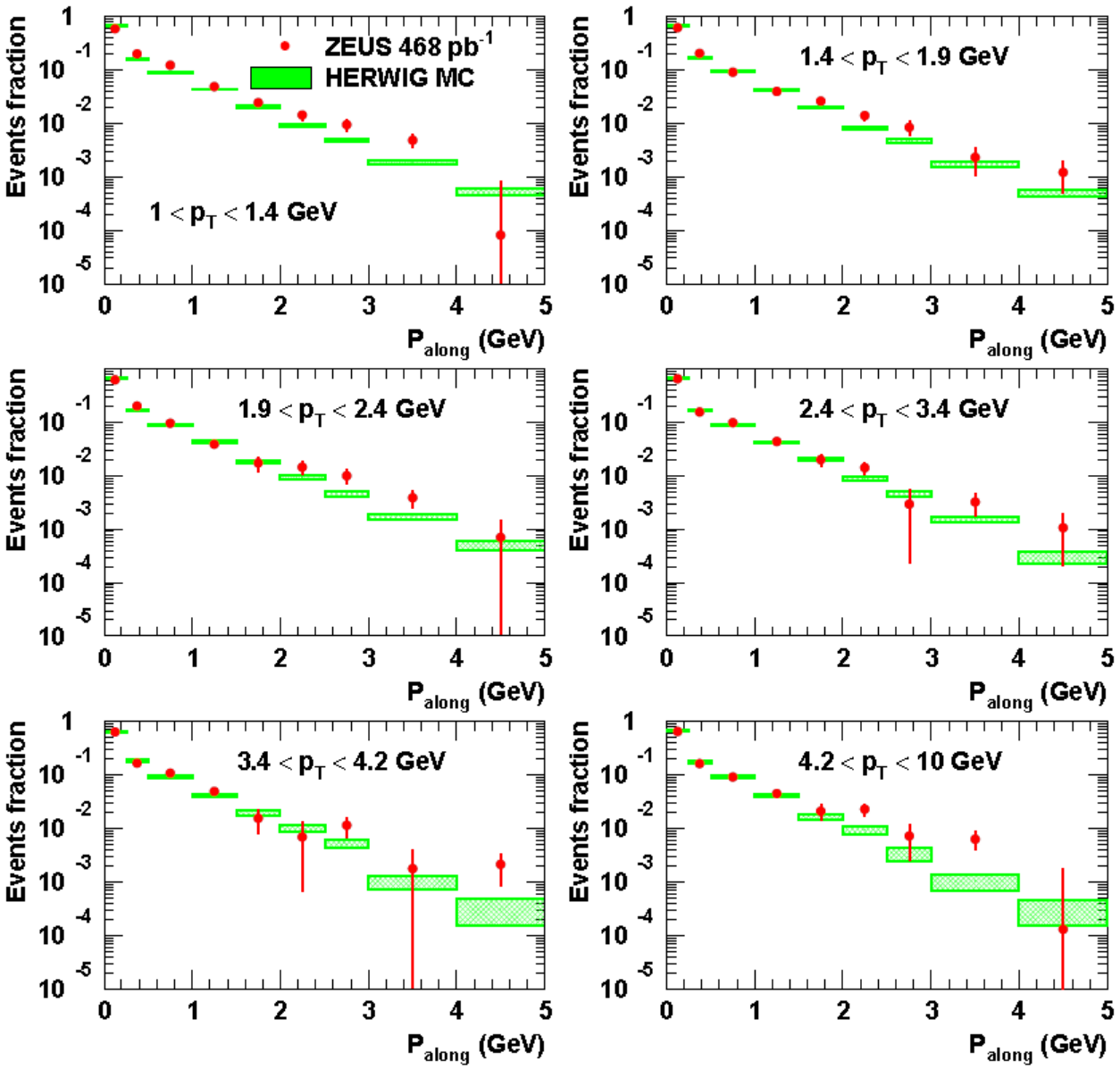


HERWIG MC:
CS model + parton shower

- both data and MC are normalized to 1
- generally do not observe a lot of momentum against the J/ψ direction, at HERA can probe the range up to a few GeV
- as the J/ψ p_T increases also the against momentum flow increases, consequence of transverse momentum conservation !
- the HERWIG MC reproduces the general features of the data

momentum flow along the J/ψ direction (vs J/ψ p_T)

60 < W < 240 GeV
0.3 < z < 0.9



HERWIG MC:
CS model + parton shower

- both data and MC are normalized to 1
- generally do not observe a lot of momentum along the J/ψ direction, at HERA can probe the range up to a few GeV
- the along momentum distribution does not seem to vary significantly as a function of the J/ψ p_T
- the HERWIG MC reproduces the general features of the data … does a better job along w.r.t. against !

conclusions

- new ZEUS inelastic J/ψ photoproduction cross section measurements are now available:
  - vs p_T^2, in z intervals
  - vs z, in p_T^2 intervals
  - full luminosity is being used
  - data are limited by systematics except at low z and high p_T^2
- ZEUS data are compared to a full NLO CS+CO calculation and to a LO CS model calculation in the k_T factorisation framework

these predictions have large uncertainties w.r.t the ZEUS data, the k_T factorisation framework provides an overall better description of the data

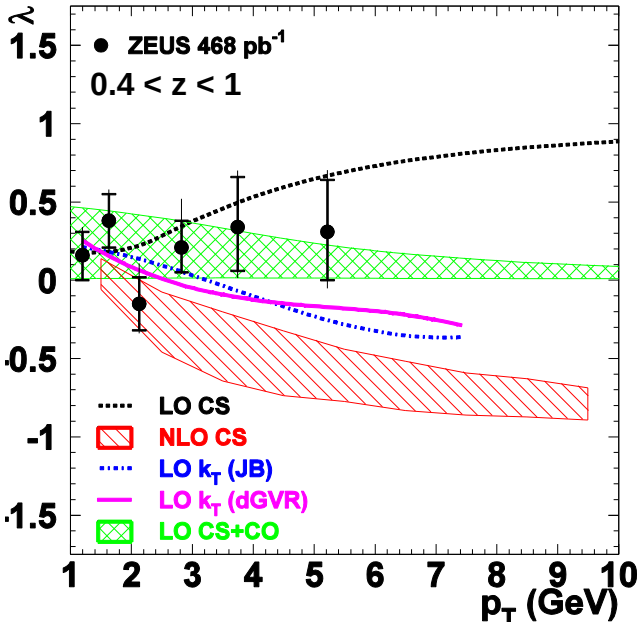
- the momentum flow against / along the J/ψ direction has been evaluated in p_T^2 intervals and compared to the predictions of the LO CS model + parton shower HERWIG MC

the HERWIG MC describe the general features of the measured shapes

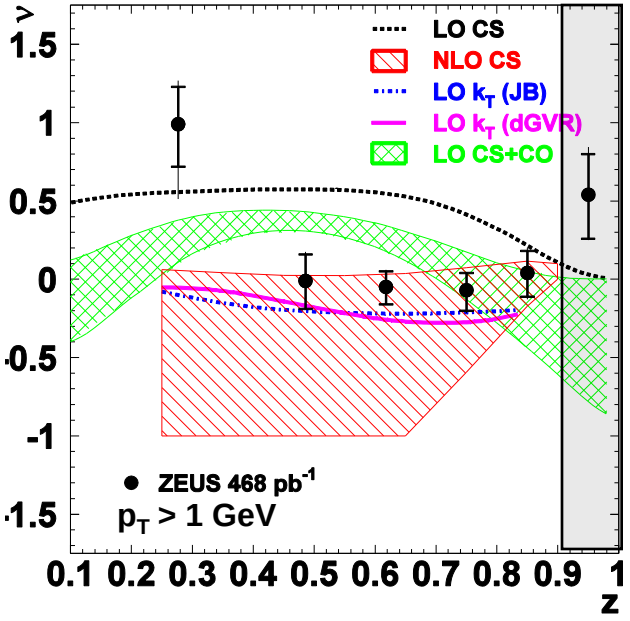
my experimentalist impression: still have a lot to learn about charmonium production …

... backup slides ...

J/ψ helicity measurements 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
- diffractive 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 … may be except at low z
- LO CS+CO does not describe the data, positive
- diffractive background decreases strongly with z

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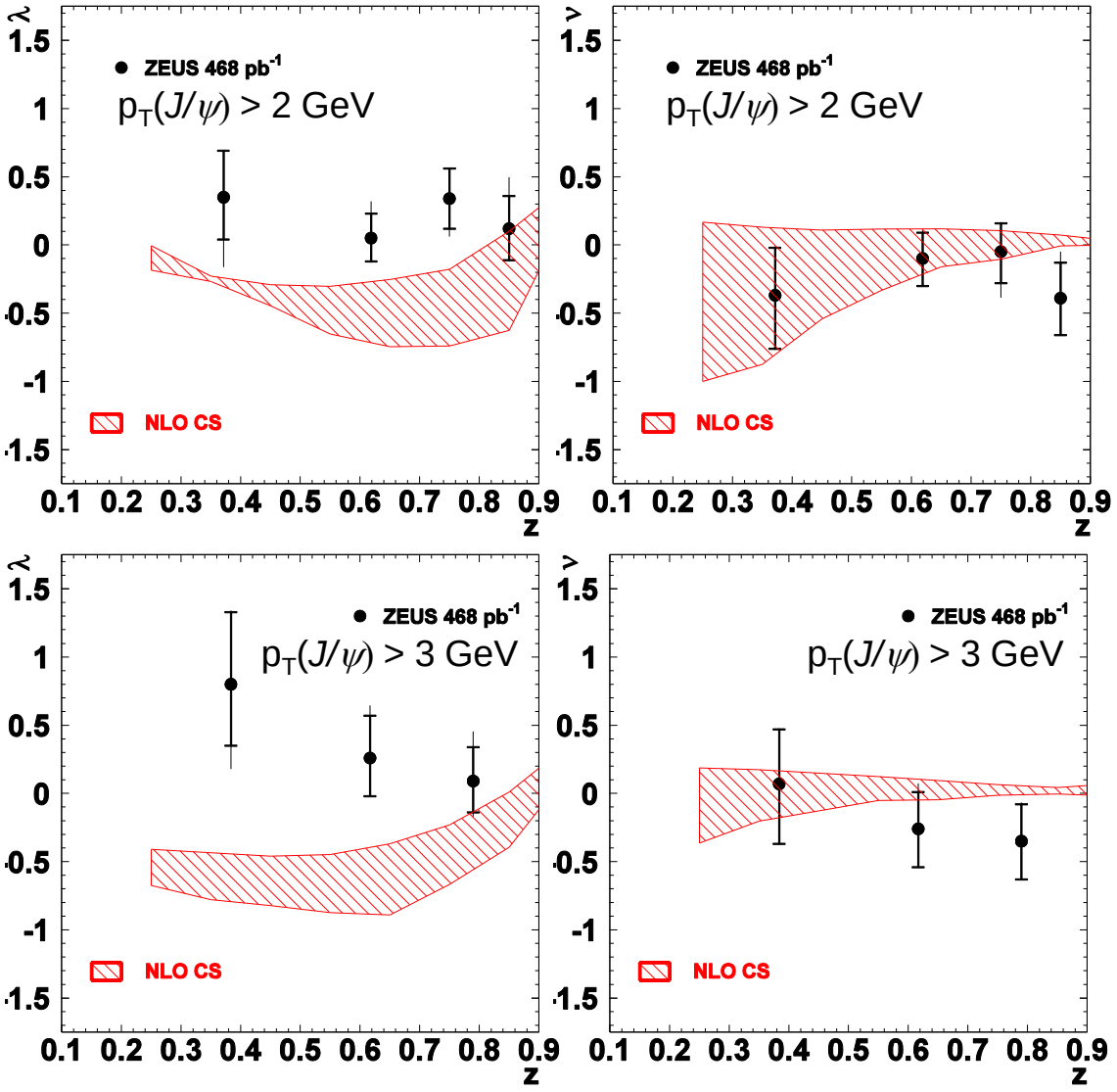
J/ψ helicity measurements at HERA

all available data used



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 …

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