The 2011 Europhysics Conference on High Energy Physics
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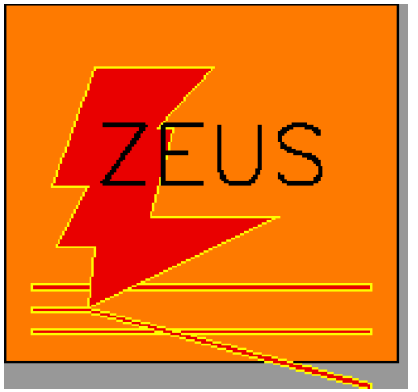
on behalf of the
ZEUS Collaboration



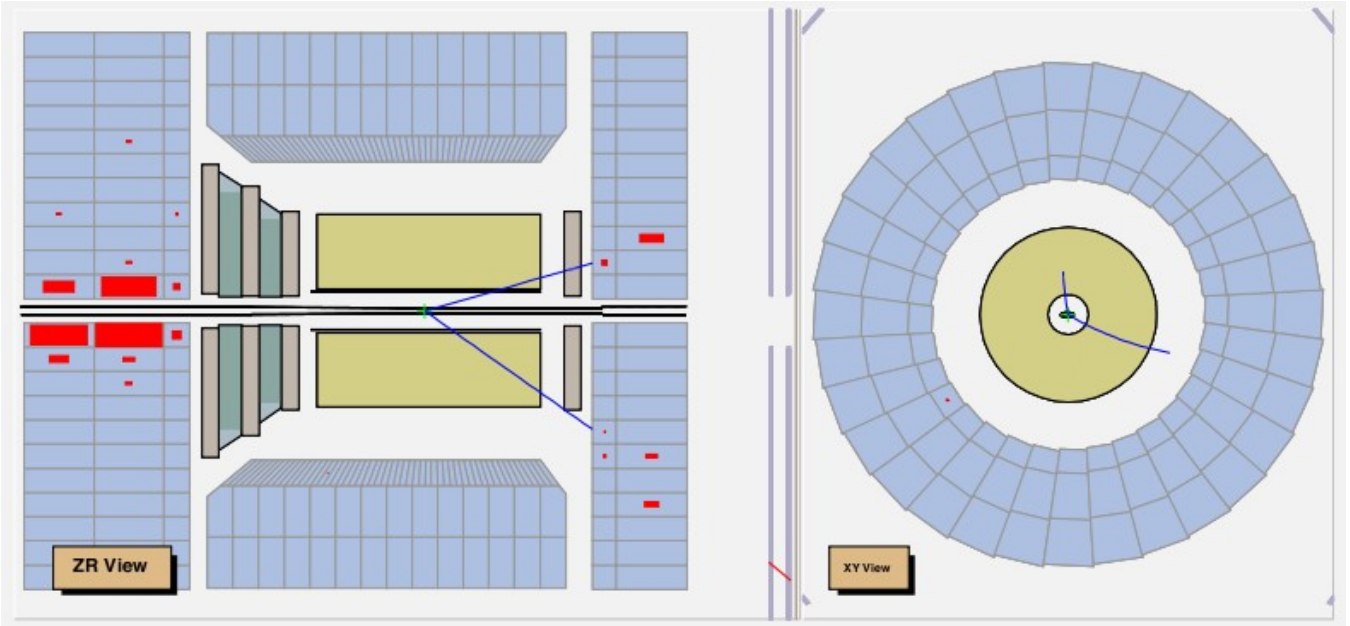
J/ψ photoproduction at HERA with ZEUS

Outline:

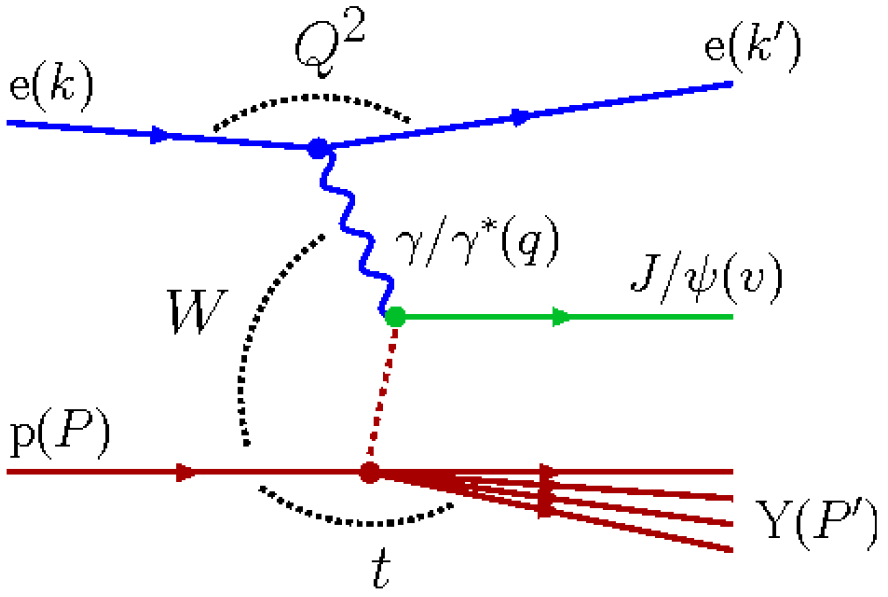
- **proton-dissociative diffractive** photoproduction of J/ψ mesons at large momentum transfer at HERA
- comparison with various theoretical models
- **inelastic** photoproduction of J/ψ mesons
- comparison with various theoretical models
- conclusions

p-dissociative diffractive γ-production of J/ψ

abstract - 313
S. Chekanov et al. ZEUS Collab.
JHEP 05, 1 (2010)



$$e\,p \rightarrow e\;\; J/\psi\;\; Y$$

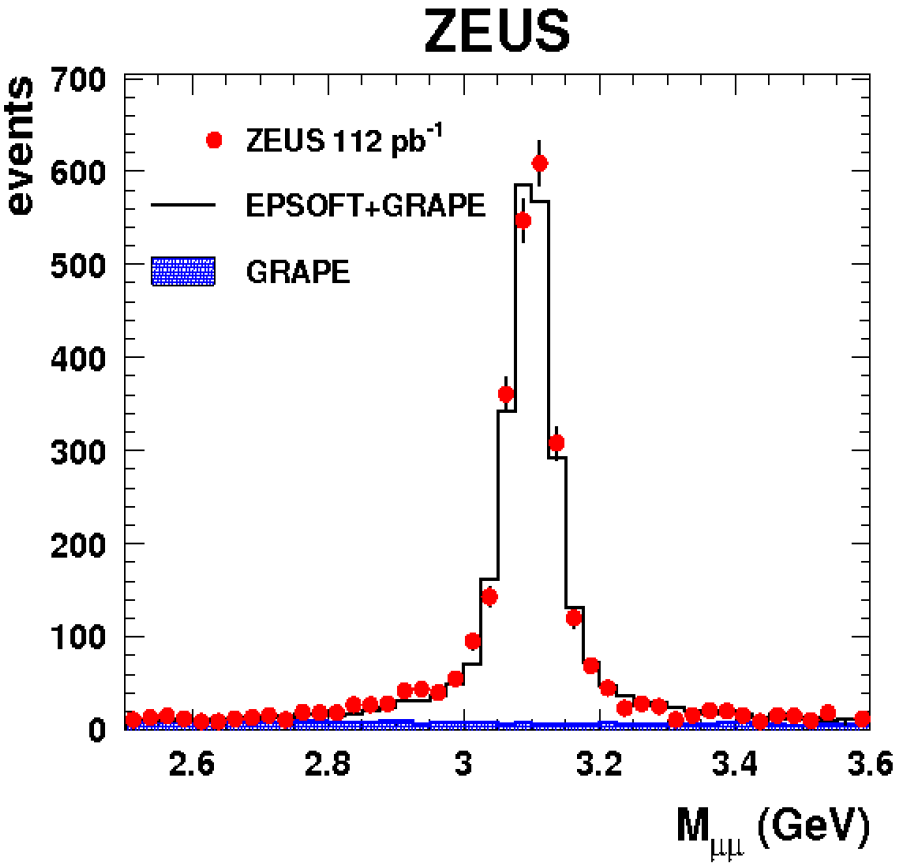


- $Q^2 \equiv -q^2 = -(k - k')^2$
  photon virtuality
- $W^2 = (q+P)^2$
  squared cms energy of the γp system
- $t = (P - P')^2 = (q - v)^2$
  squared 4-momentum transfer at the p vertex
- $z = (P \cdot v)/(P \cdot q)$
  inelasticity: E(J/ψ)/E(γ) in the p rest frame

data sample and selection

- $\mathcal{L}$ = 112 pb^{-1} (1996-2000)
- $Q^2 \sim 0$ GeV^2
- $30 < W < 160$ GeV
- $2 < |t| < 20$ GeV^2
- $0.95 < z$
- $M_Y = W^2 (1 - z) - |t| < 30$ GeV

  invariant mass of the Y system



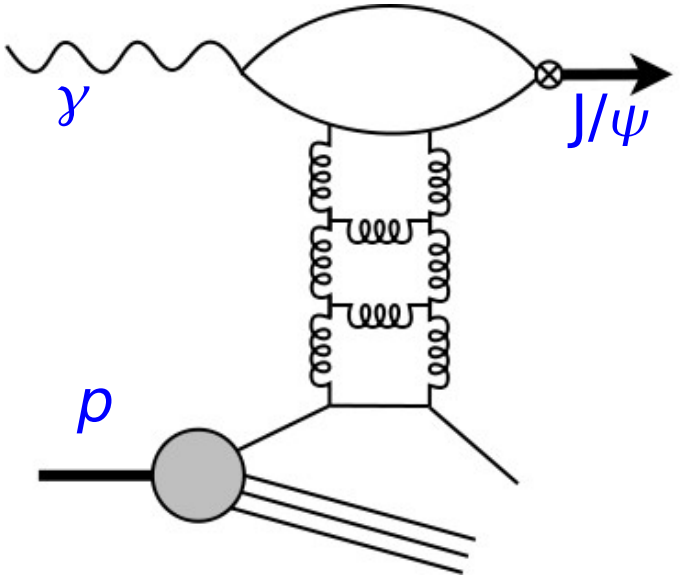
backgrounds

QED $\gamma\gamma$ processes (el+inel)
- from 6% to 10% increasing with t
- contribution subtracted

exclusive J /ψ production
- 5% for $2 < |t| < 3$ GeV^2
- negligible for $|t| > 3$ GeV^2
- contribution subtracted

ψ(2S) feed down
- < 1%
- contribution subtracted

theoretical calculations



three steps process

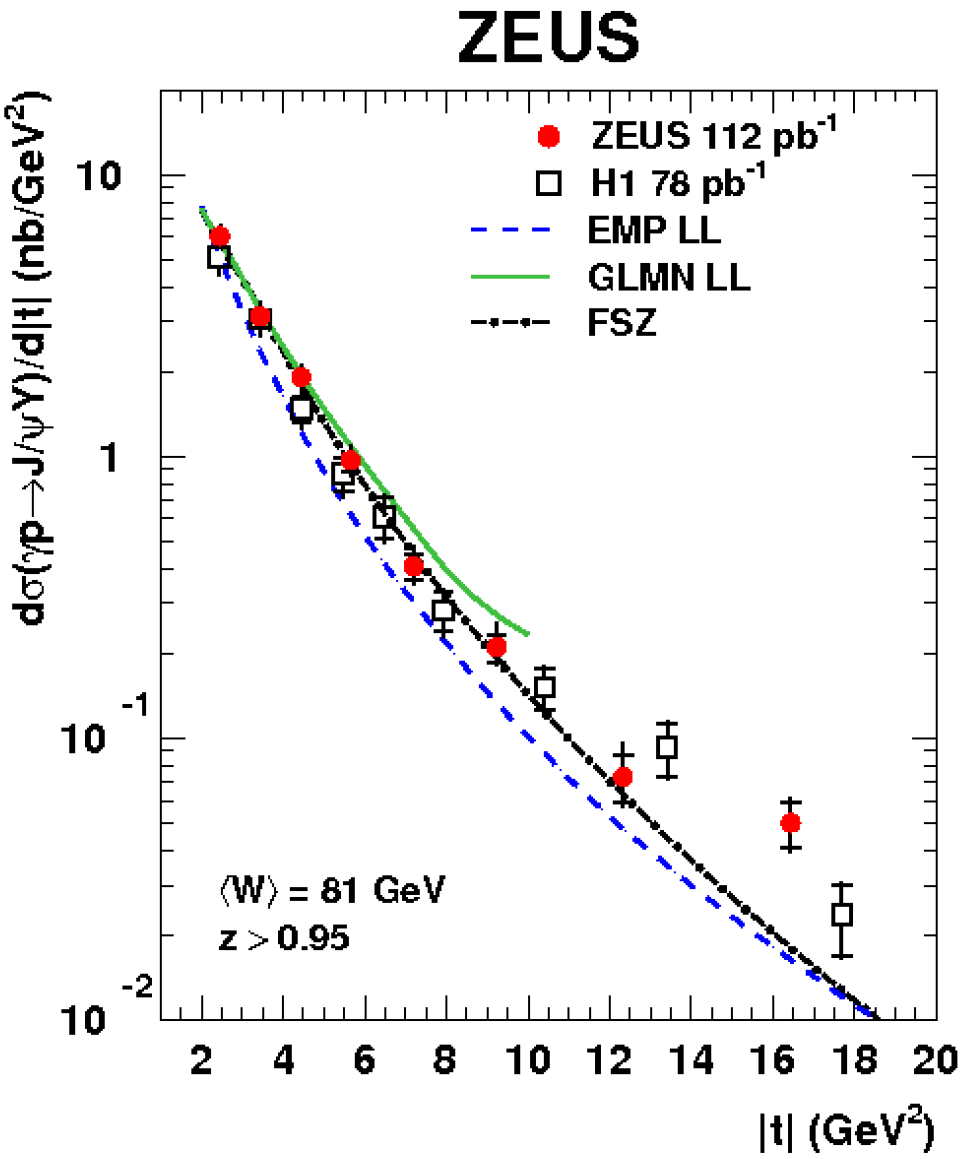
1) $\gamma \rightarrow q\bar{q}$
2) $q\bar{q}$ scatters off a single parton in p by the exchange of a colour singlet gluon ladder
3) $q\bar{q} \rightarrow J/\psi$; creation of the system Y

two energy scales:

- $m_{J/\psi}^2 \rightarrow$ controls the size of $q\bar{q}$ system
- $|t| \rightarrow$ controls the size of the gluon ladder

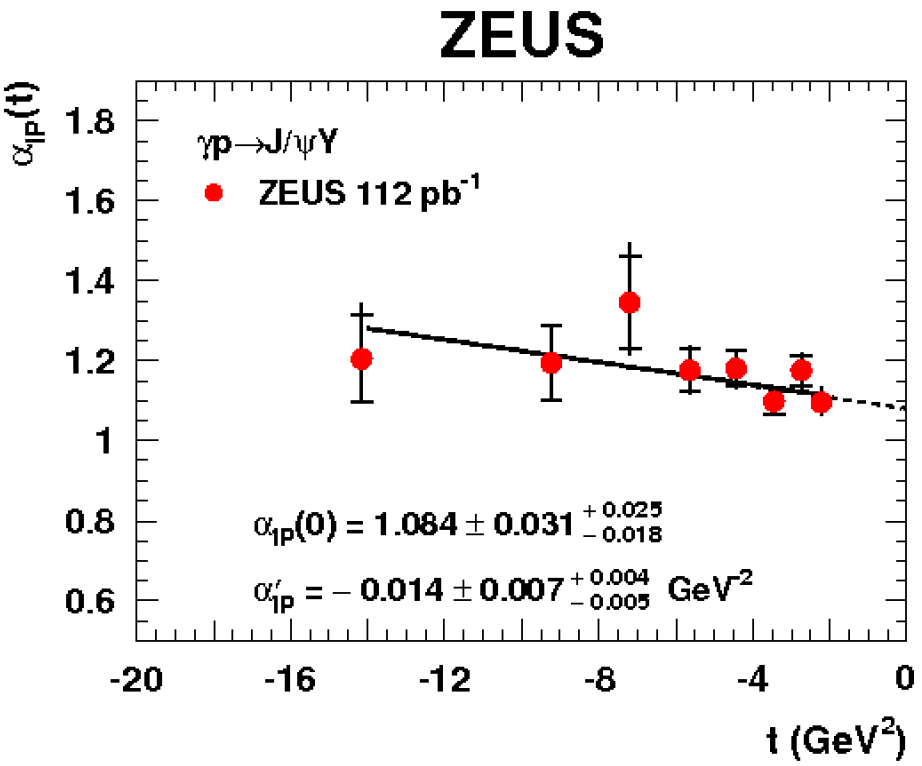
- $2 < |t| < 10$ GeV^2 → *gluon ladder momenta still ordered* (use of **DGLAP**)
  (E. Gotsman et al., Phys. Lett. **B 532**, 37 (2002) (**GLMN**))
- as $|t|$ increases **BFKL** *mechanism is expected to dominate*
  (R. Enberg et al., Eur. Phys. J. **C 26**, 219 (2003) (**EMP**))
- *QCD factorisation theorem* for large $|t|$ rapidity-gap processes and relationship with *exclusive* J/ψ *production* at $|t| \sim 1$ GeV^2
  (L. Frankfurt et al., Phys. Lett. **B 670**, 32 (2008) (**FSZ**))

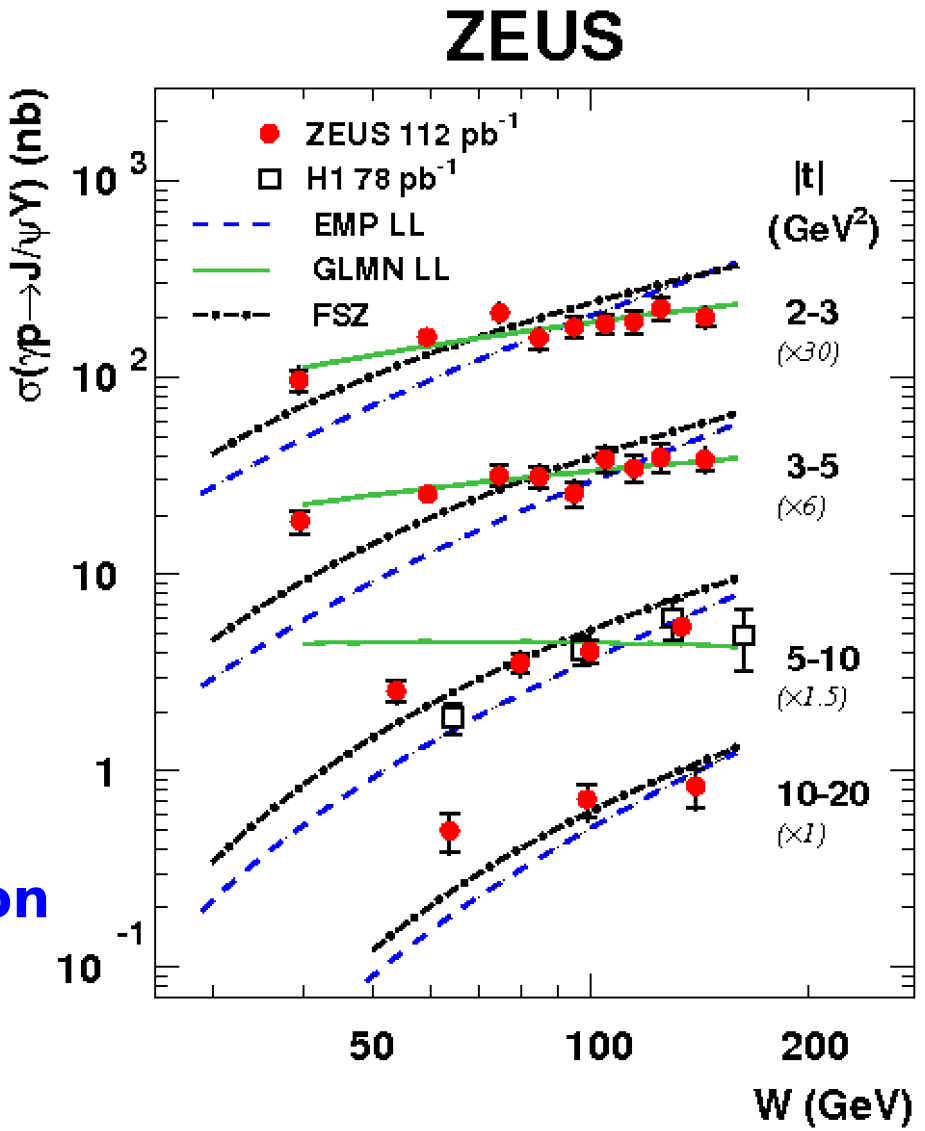
differential *t* cross section



- **GLMN**-LL good description up to ~ $|t|$ = 5 GeV^2, then fall off slower
- **EMP**-LL lies below the data in the whole range of $|t|$
  (α_s = 0.205 in the pre-factor, α_s = 0.16 in the BFKL evolution)
- **FSZ** describes the data well up to |t| of ~ 12 GeV^2 but falls-off too steeply at larger $|t|$
  (with pomeron trajectory $\alpha_{\mathbb{P}}(t)=\alpha_{\mathbb{P}}(0) +\alpha_{\mathbb{P}}' t = 1.1 +0.005\cdot t$)
- good agreement between ZEUS and H1 data

W dependence





$\alpha_{\mathbb{P}}(0)$ consistent with the **soft Pomeron** (1.0808)

$\alpha_{\mathbb{P}}'$ consistent with **BFKL Pomeron**

Clear rise with *W* in all |*t*| regions.

GLMN-LL agrees with the data only at low |*t*|

EMP-LL and **FSZ** predict a *W* dependence too step in all |*t*| ranges.

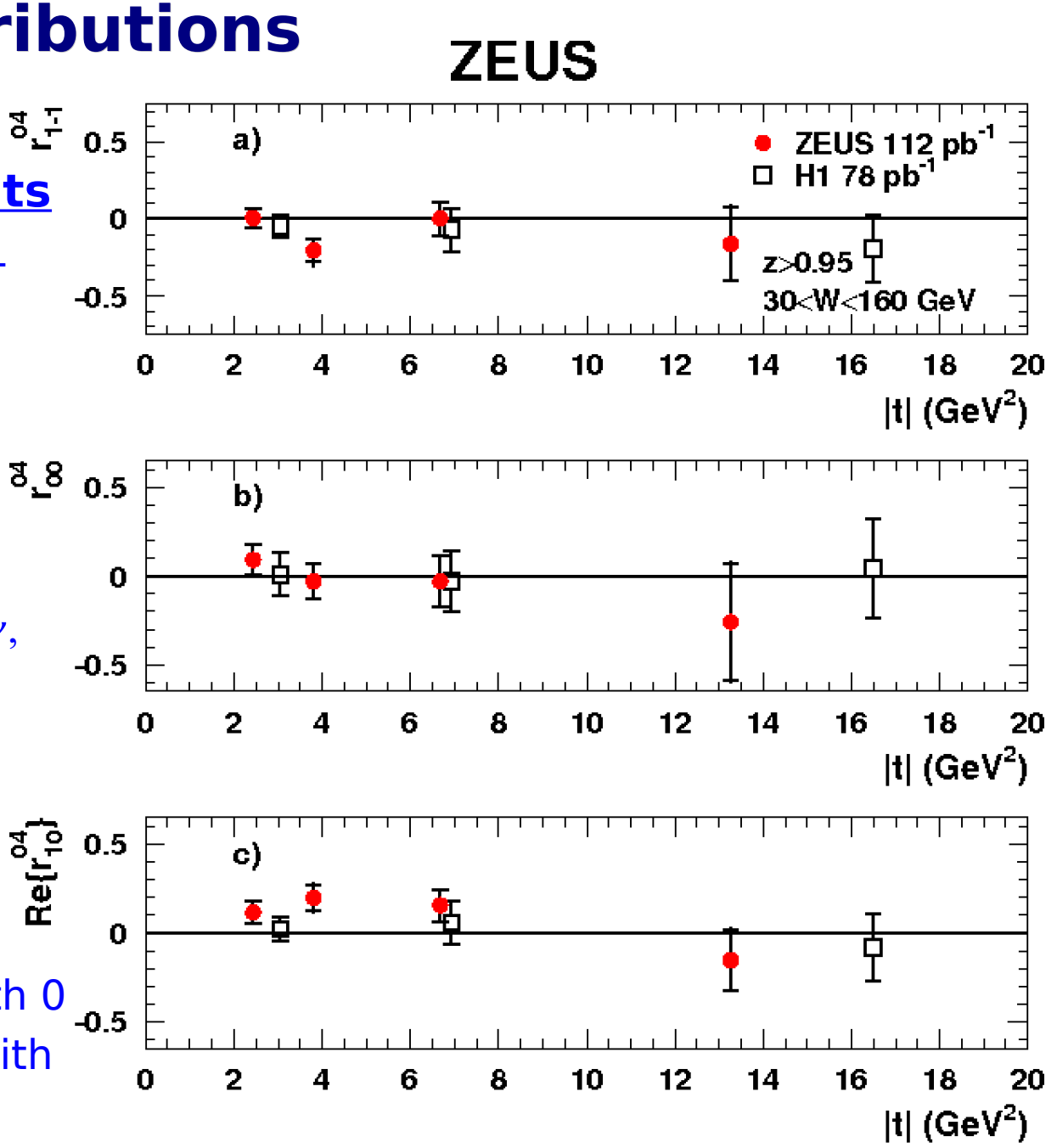
Good agreement between ZEUS and H1 data

decay angular distributions

spin density matrix elements

- r^{04}_{1-1}: interference between non-flip and double-flip amplitudes
- r^{04}_{00}: probability that J/ψ has helicity 0
- Re{r^{04}_{10}}: proportional to the single-flip amplitude

- If J/ψ retains the helicity of the γ, s-channel helicity is conserved (SCHC)
- If SCHC is valid: r^{04}_{1-1} ,$r^{04}_{00,}$ Re{r^{04}_{10}} are 0
- In all the previous theoretical predictions SCHC is conserved
- DATA: r^{04}_{1-1} ,r^{04}_{00} compatible with 0 and Re{r^{04}_{10}} non compatible with 0 for $|t| < 10$ GeV^2
- ZEUS and H1 data in good agreement

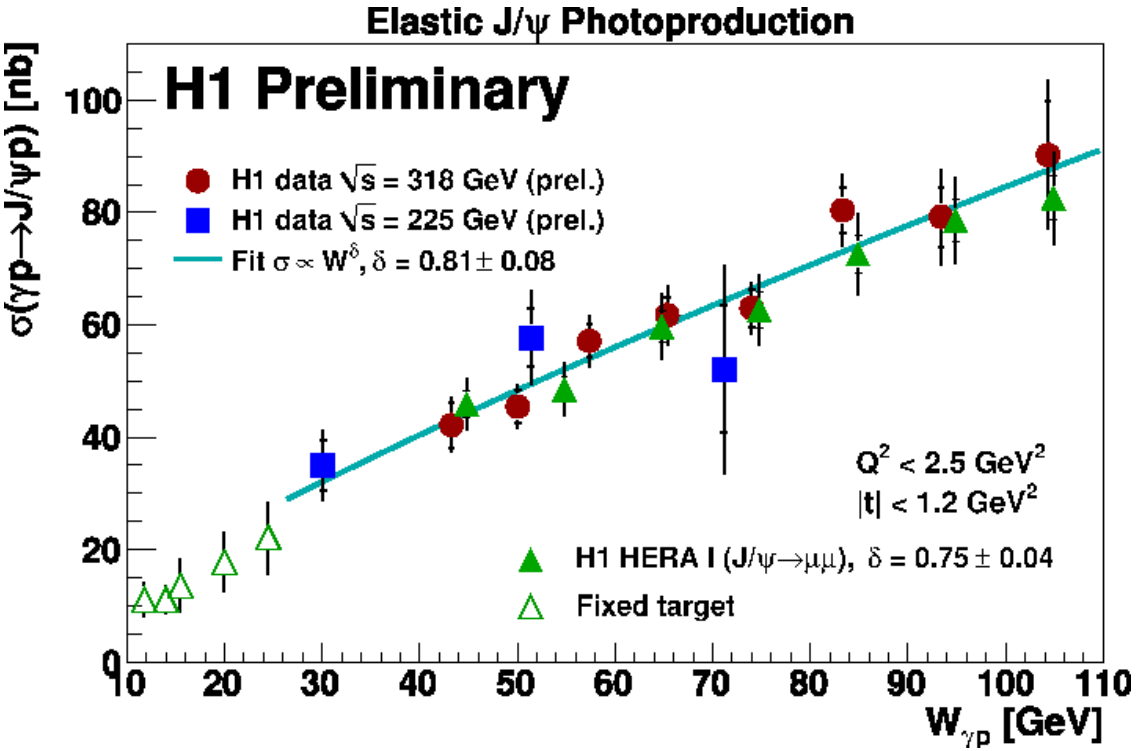


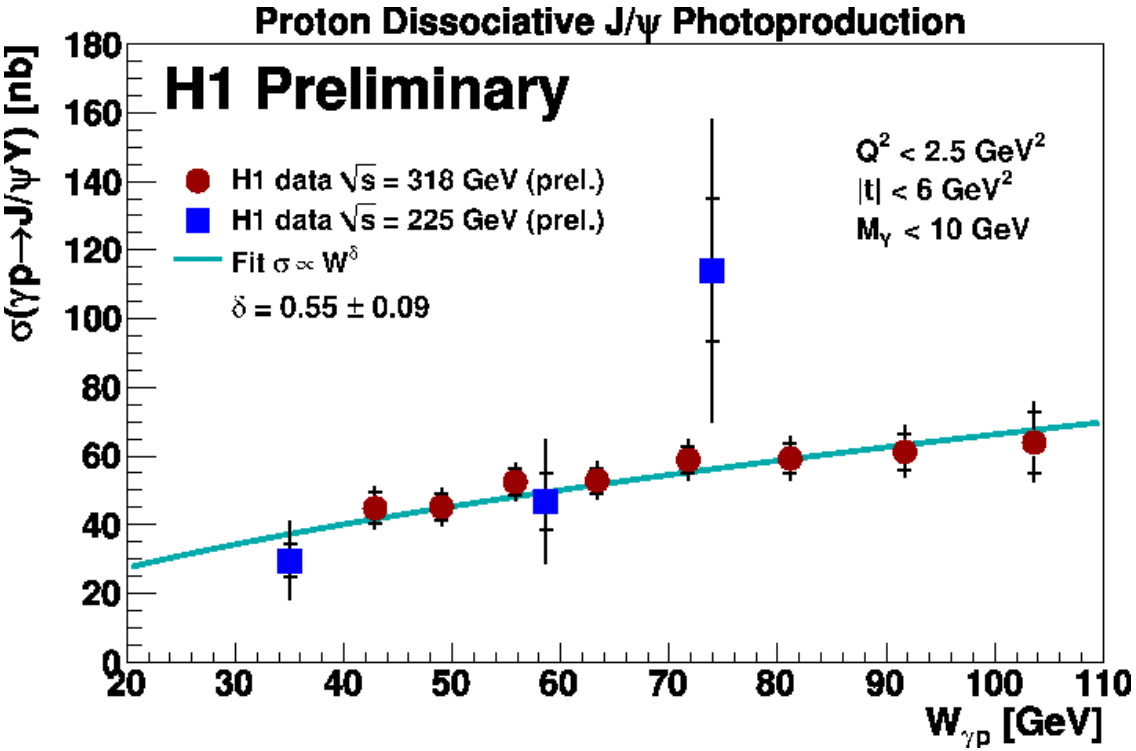
H1prelim-11-011

$J/\psi \rightarrow e^+e^-$
Data from nominal energy run ($\sqrt{s}$=318 *GeV*) and
Data from reduced energy run ($\sqrt{s}$=225 *GeV*)

Extension of the phase-space towards lower *W*.

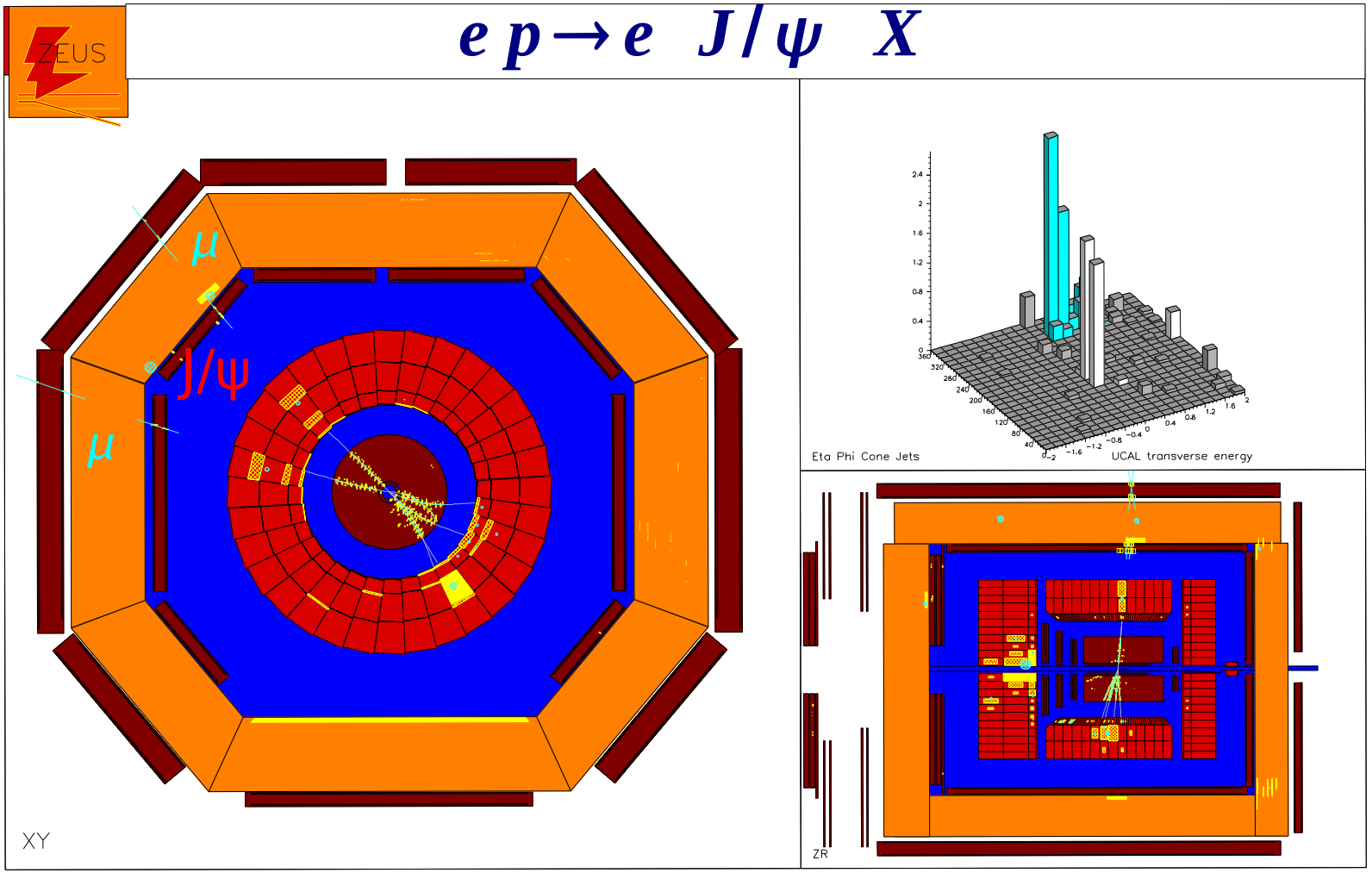
Simultaneous extraction of the exclusive and proton-diffractive components from the data.





inelastic J/ψ photoproduction

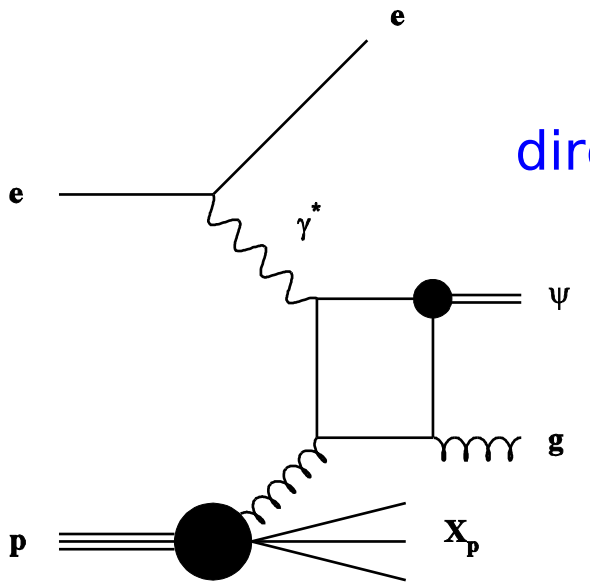
abs-321
ZEUS-prel-11-006



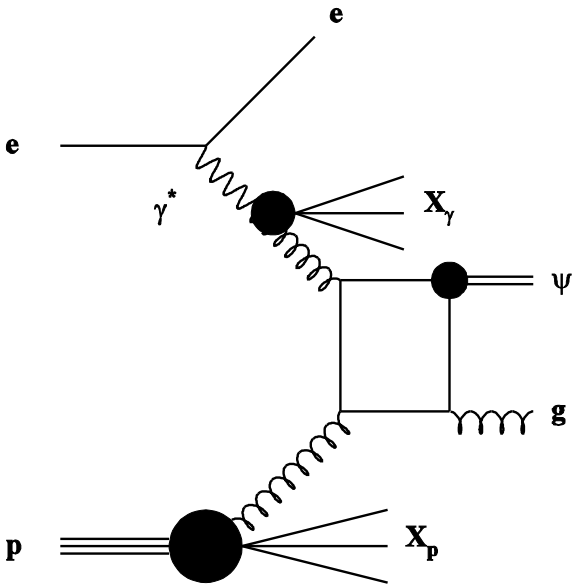
- No scattered electron:
  photoproduction regime
  → $Q^2 \sim 0$ GeV^2
- Proton remnant + additional hadronic activity:
  inelastic event

inelastic J/ψ photoproduction

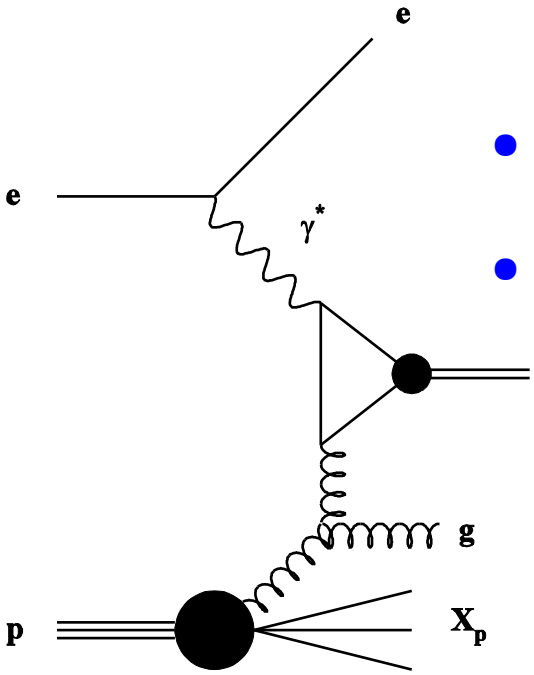
$z = E(J/\psi)/E(\gamma)$
p rest frame



direct γ, "CS model"
$0.2 < z < 0.9$



resolved γ, "CS model"
$z < 0.2$

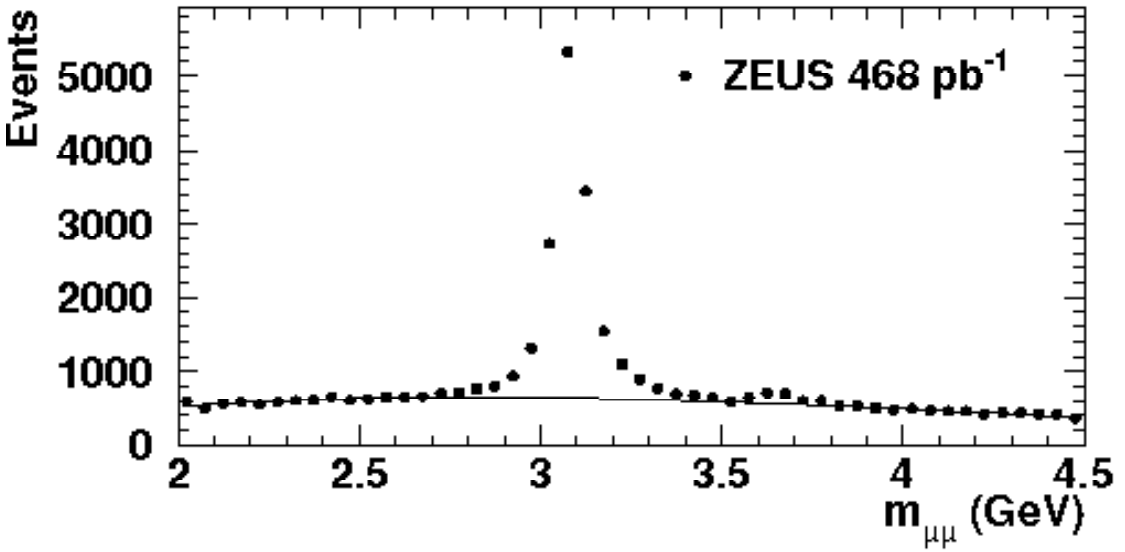


direct γ, "CO model"
- this particular diagram
  $0.2 < z < 0.9$
- more "typical" ones:
  $z > 0.9$

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

data sample and selection

- $\mathcal{L}$ = 468 pb^{-1} (1996-2007)
- $Q^2 \sim 0$ GeV^2
- $60 < W < 240$ GeV
- $p_{T,\psi} > 1.0$ GeV
- $0.1 < z < 0.9$



backgrounds from other J/ψ production mechanisms

p-diffractive J/ψ
- *cut: Ntracks* ≧ **3**
- overall ~ 6 %
- **contribution <u>subtracted</u>**

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

ψ(2S) feed down (diff. + inel.)
- overall ~ 15 %
- **contribution <u>partially subtracted</u>**

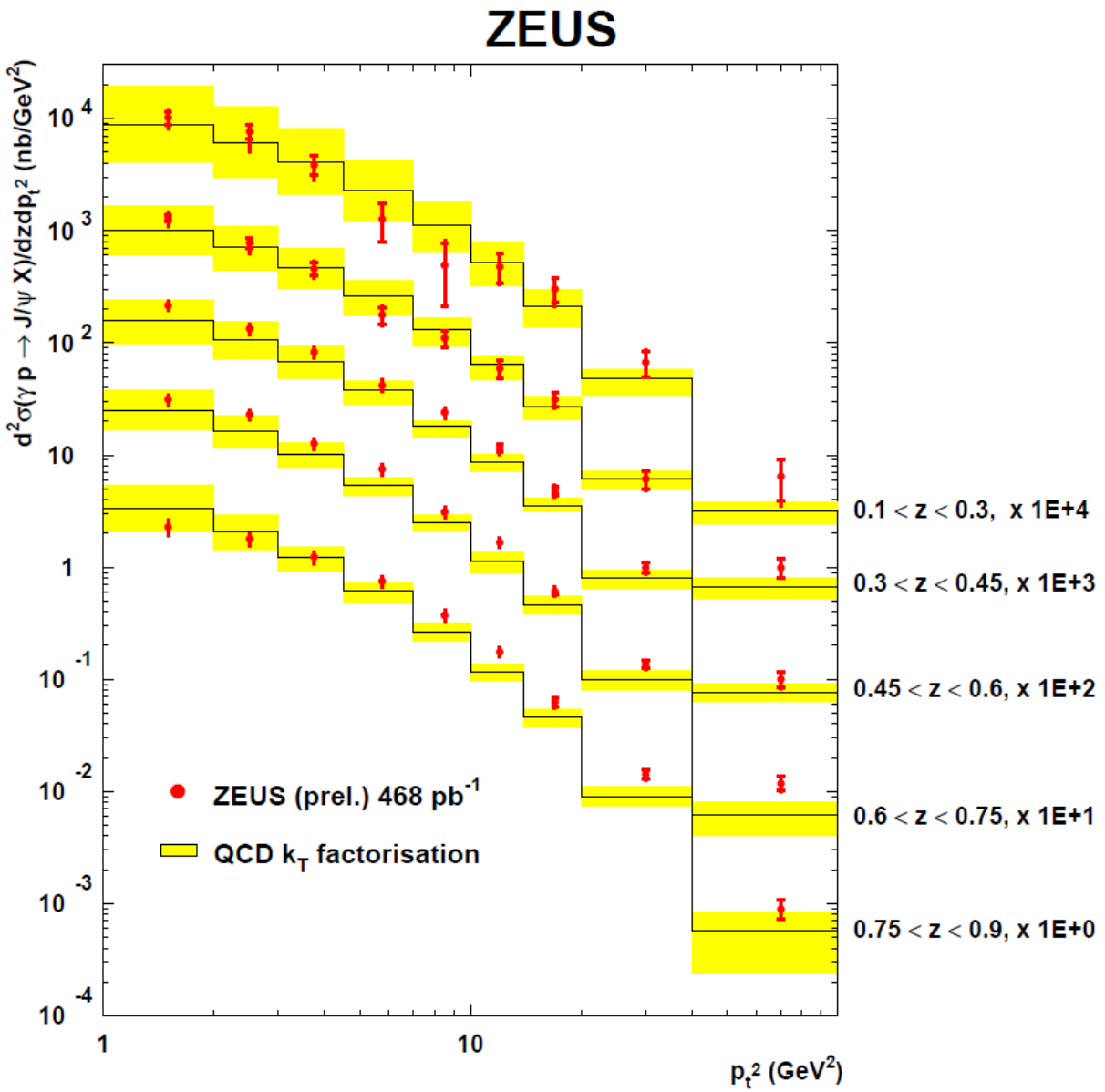
theoretical calculations

The measurements are compared with the following calculations:

- **NLO-CS+CO**: M. Butenschön, B. A. Kniehl, Phys. Rev. Lett. **104**, 072001 (2010).
  M. Butenschön, B. A. Kniehl, DESY 11-046 arXiv:1105.0820v1
  - the calculation contains both direct and resolved photon contributions
  - includes the full relativistic corrections due to $^1S_0^{[8]}$, $^3S_1^{[8]}$, $^3P_J^{[8]}$ CO states
  - CO long-distance matrix elements (universal function) extracted from all available high-quality data of inclusive J/ψ production

- **LO-k_T** : S.P. Baranov, A.V. Lipatov and N.P. Zotov, Eur. Phys. J. **C 71**, 1631 (2011)
  - only CS contribution taken into account
  - k_T factorization
  - unintegrated gluon distribution

double differential cross section

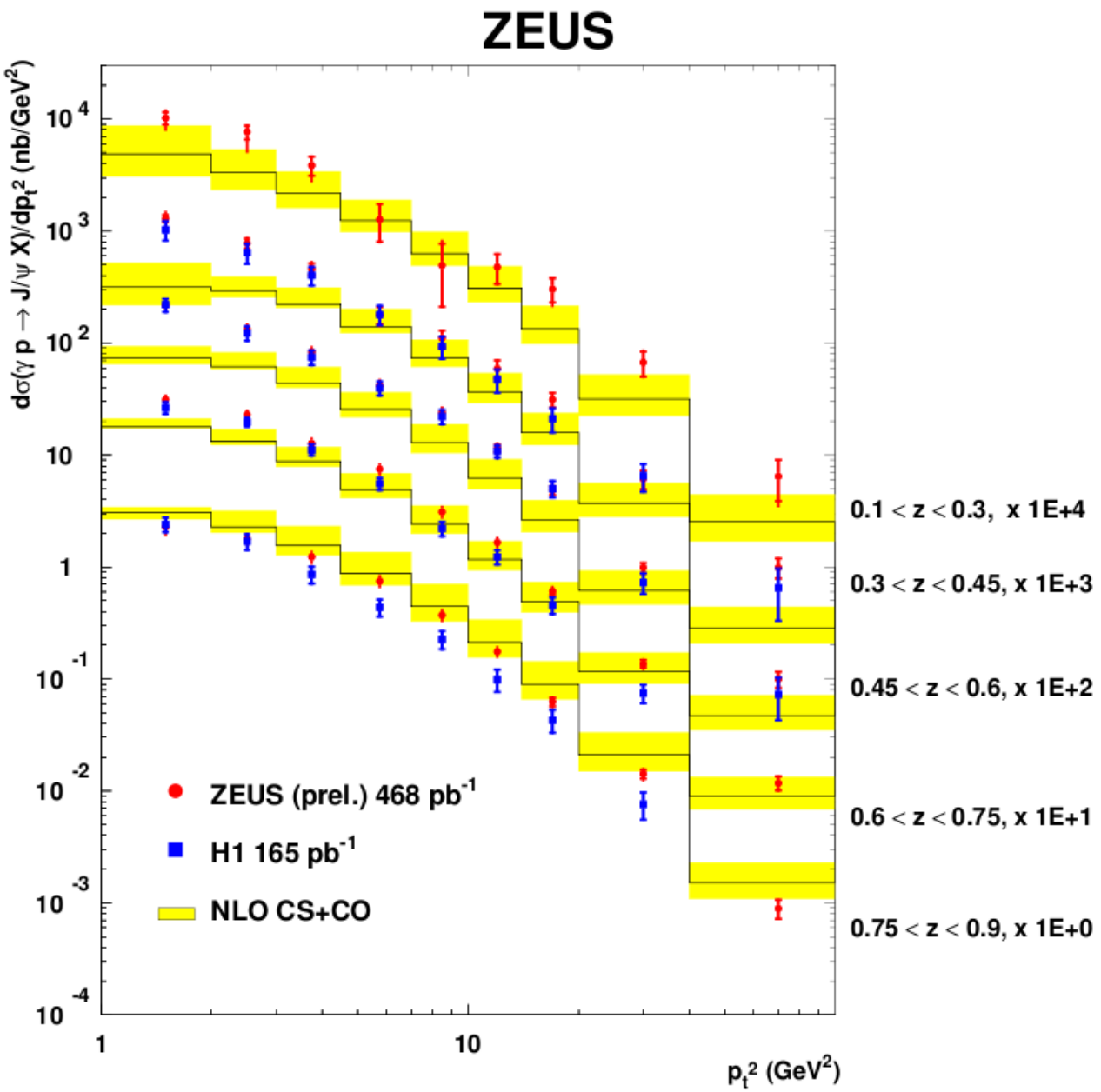


- inner (outer) error bar: stat (stat⊗sys)
- Stat are dominant except at low p_t^2

- QCD k_t factorization:
  m_c =1.5 GeV, $\alpha_s(M_Z^2)$=0.1232
  $\mu_R = \xi(m_\psi^2 + p_t^2)^{0.5}$
  $\mu_F = \xi(\hat{s} + Q_T^2)$
  central value $\xi = 1$
  band: ξ = ½ -2

- Data are significantly more precise than theory except at high p_t^2
- Good agreement between data and theory

double differential cross section



- ZEUS and H1 data in good agreement

- NLO-CS+CO:
  m_c =1.5 GeV,
  $\alpha_s^{(4)}(\mu^2)$ 2-loops
  $\mu_R = \mu_F = \xi(4m_c^2 + p_t^2)^{0.5}$
  $\mu_\Lambda = \xi m_c$
  central value $\xi = 1$
  band: ξ = ½ -2
  proton PDFs: CTEQ6M
  photon PDFs: AFG04_BF

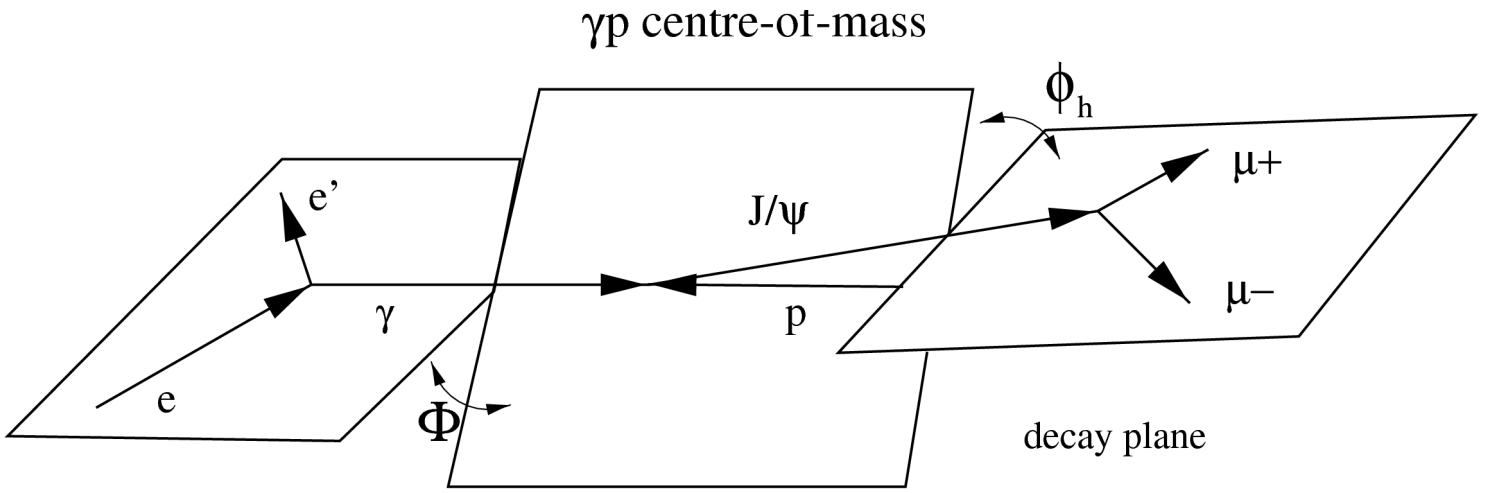
- Qualitative agreement between data and theory

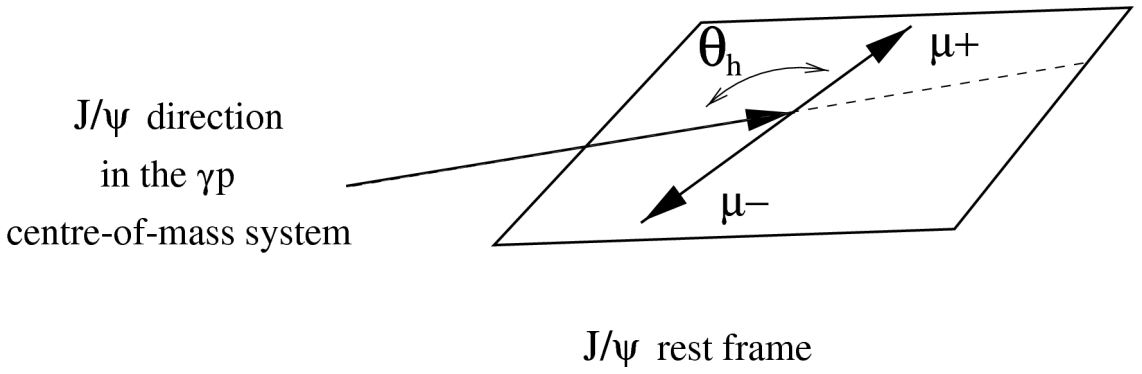
Conclusions

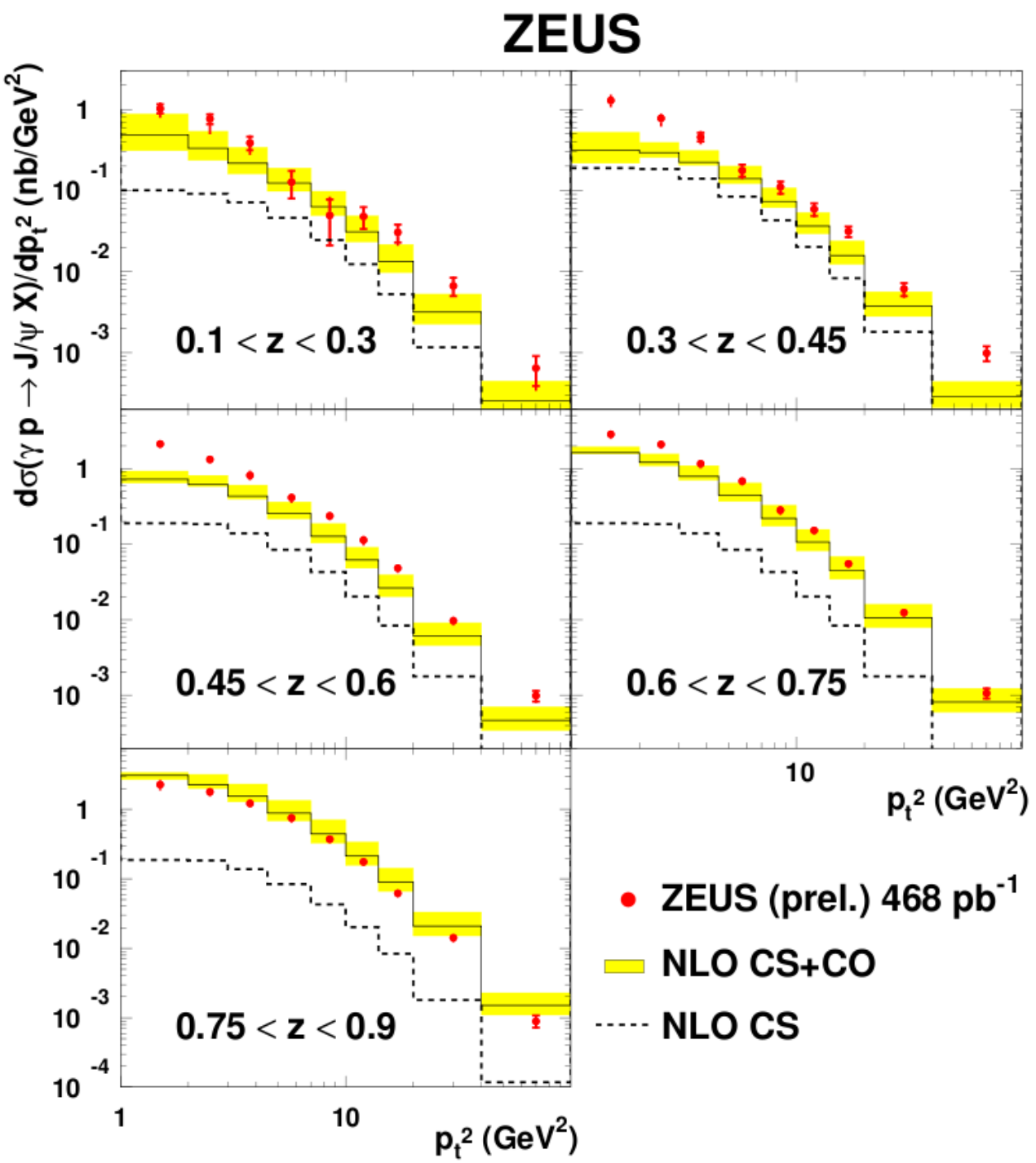
- The **proton-dissociative photoproduction** of J/ψ mesons at **large momentum transfer** has been studied with the ZEUS detector
  - |t| dependence of the dσ/d|t| ~ |t|$^{-n}$ with n increasing with |t|
  - effective Pomeron trajectory was measured: the slope is consistent with the BFKL Pomeron, the intercept is consistent with the “soft” Pomeron
  - $\sigma(\gamma p \to J/\psi\ Y)$ rises significantly with W in each |t| bin
  - DGLAP-motivated GLMN LL, BFKL-motivated LL, FSZ theoretical calculations were compared with the data, no calculation gives a full description
  - spin density matrix elements r^{04}_{00}, r^{04}_{1-1} are consistent with 0, (SCHC valid), Re$\{r^{04}_{10}\}$ not compatible with 0 for |t| < 10 GeV^2

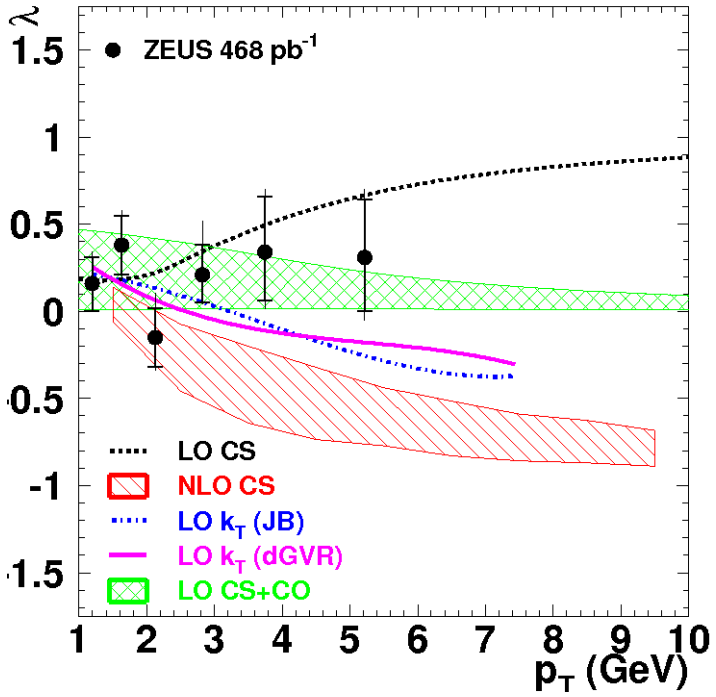
- The **double differential cross section** vs z and p_t^2 for **inelastic** J/ψ **photoproduction** was measured with the ZEUS detector using the **full HERA statistics**
  - A calculation based on k_T factorization gives a good description of the data in the full measured range
  - A NLO-CS+CO calculation gives a satisfactory description of the data, showing the importance of the CO processes

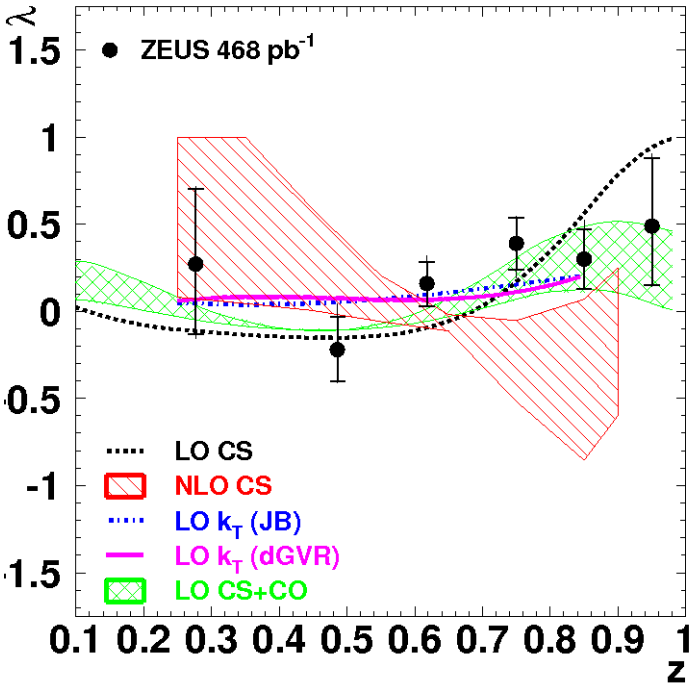
backup slides


γp centre-of-mass
ϕ_h
e'
J/ψ
μ+
μ−
γ
p
e
Φ
decay plane
electron-scattering plane
production plane

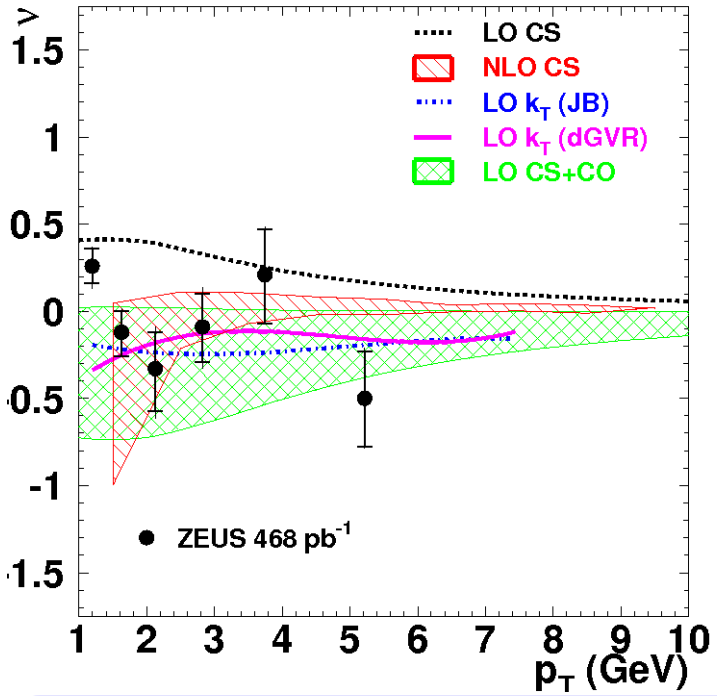

θ_h
μ+
J/ψ direction
in the γp
centre-of-mass system
μ−
J/ψ rest frame

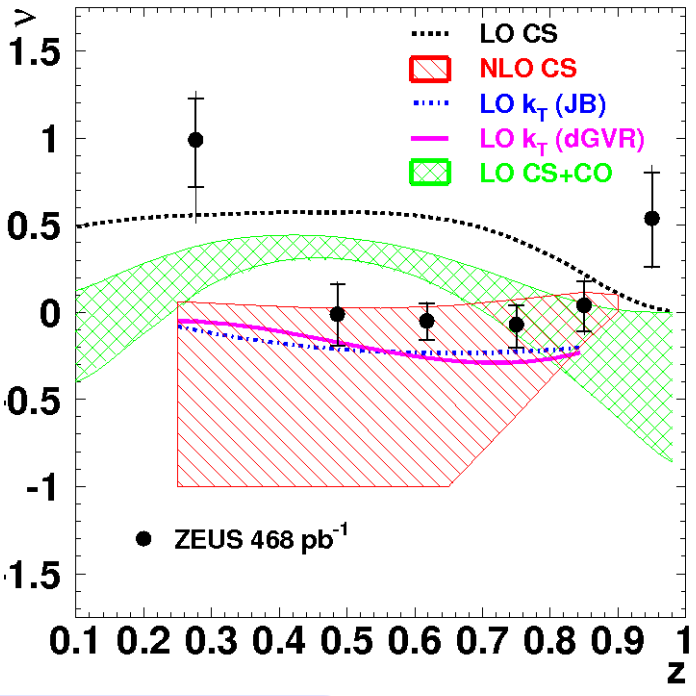

ZEUS
$d\sigma(\gamma p \to J/\psi X)/dp_t^2$ (nb/GeV^2)
0.1 < z < 0.3
0.3 < z < 0.45
0.45 < z < 0.6
0.6 < z < 0.75
0.75 < z < 0.9
p_t^2 (GeV^2)
ZEUS (prel.) 468 pb^{-1}
NLO CS+CO
NLO CS





ZEUS data: Helicity frame





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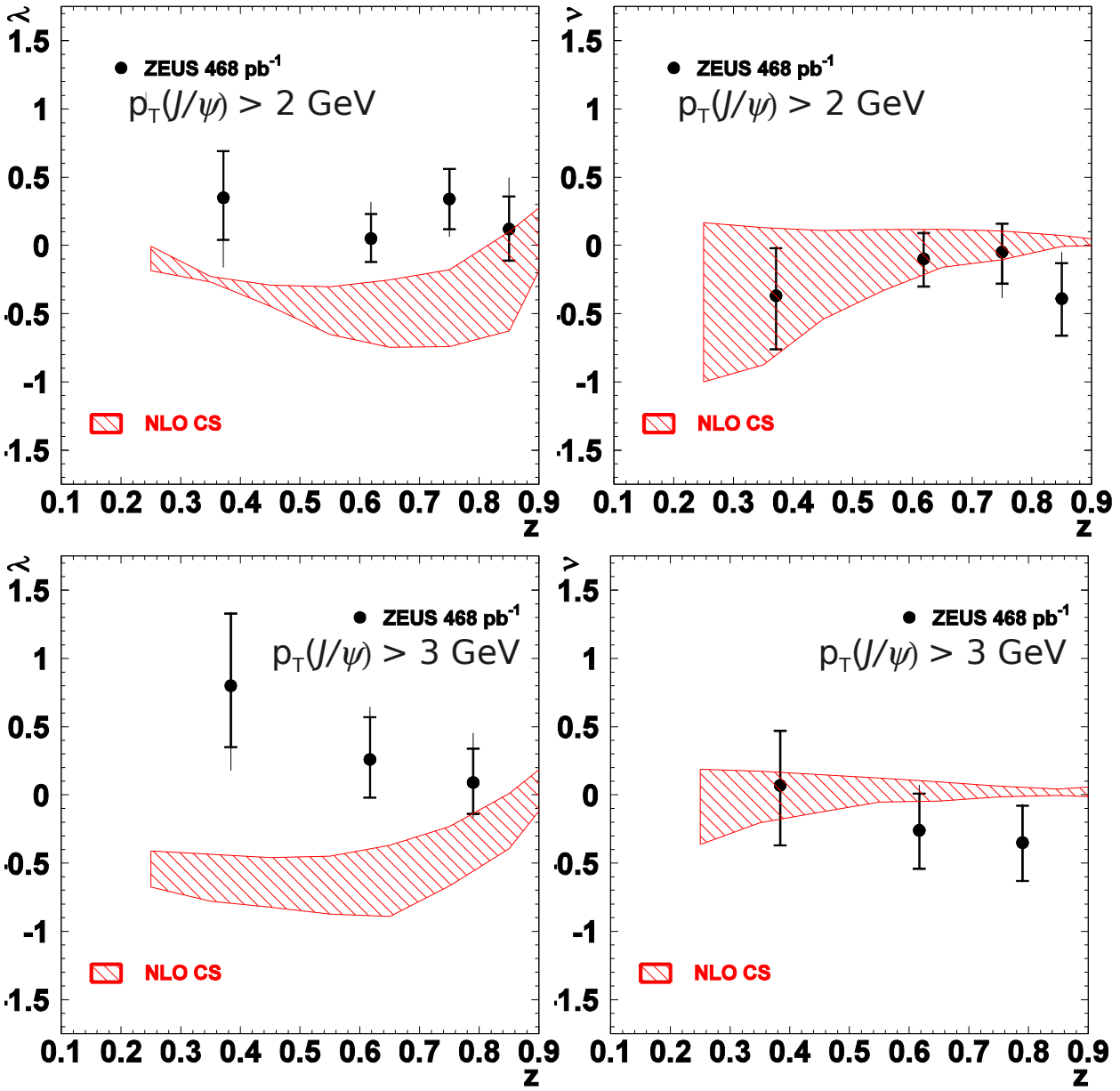
ZEUS data: Helicity frame



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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H1 data: Collins-Soper Frame

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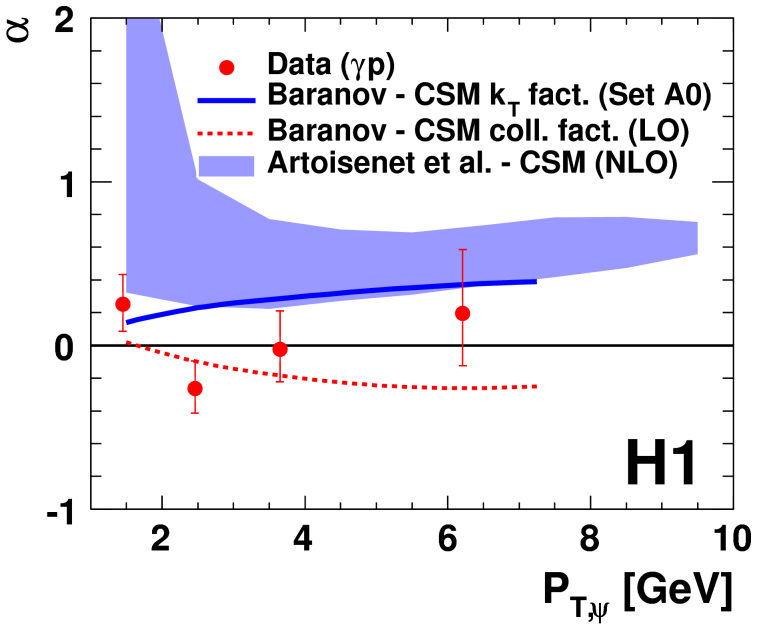
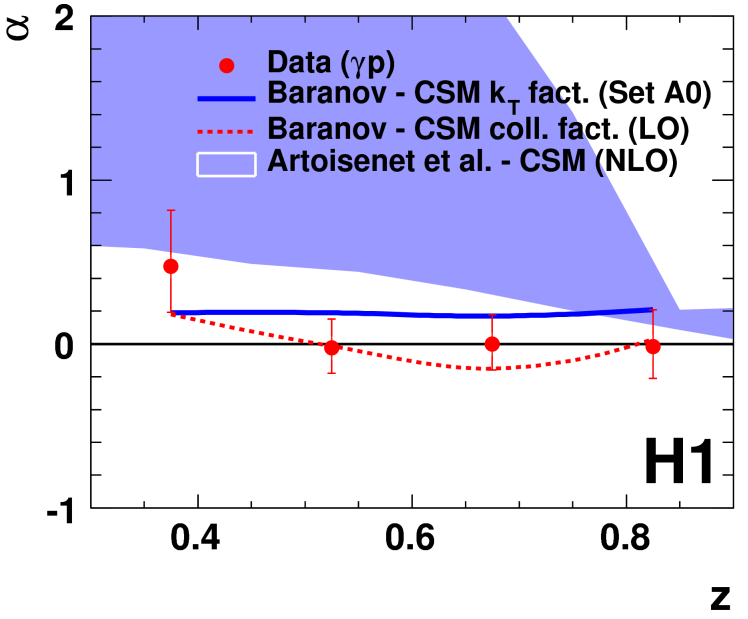
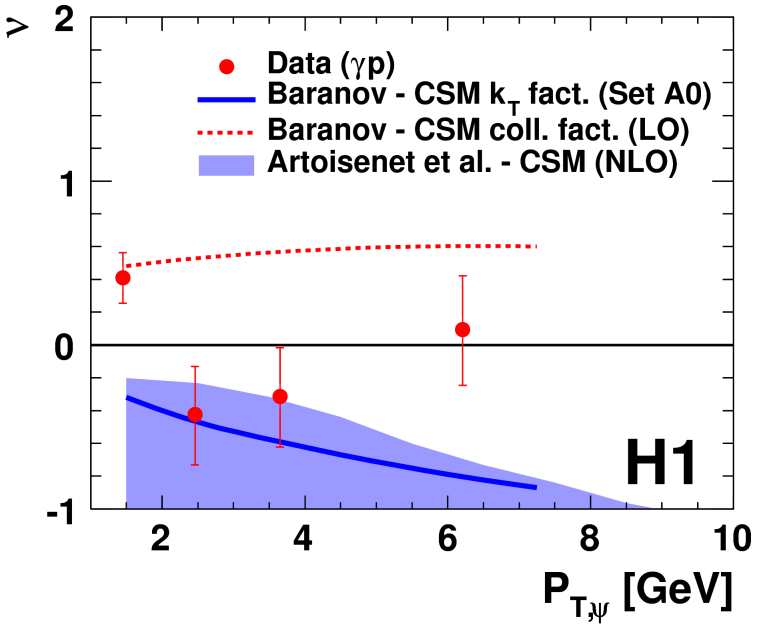
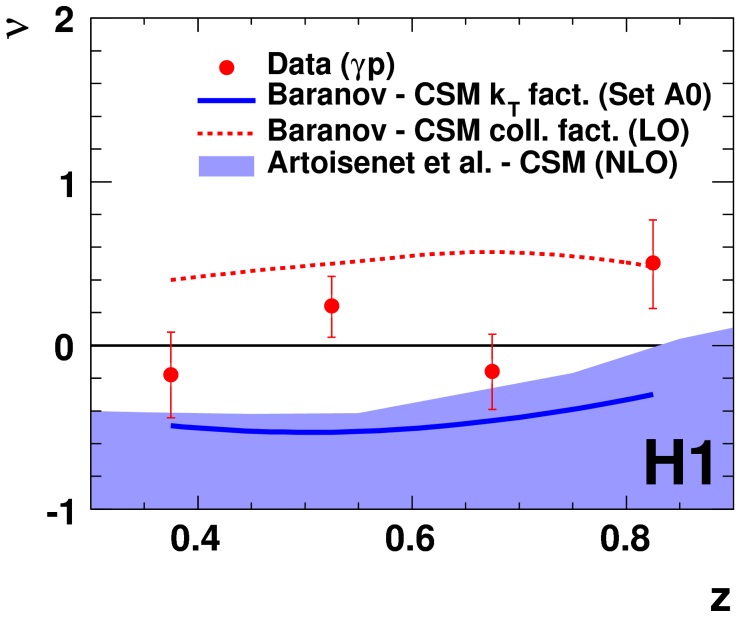


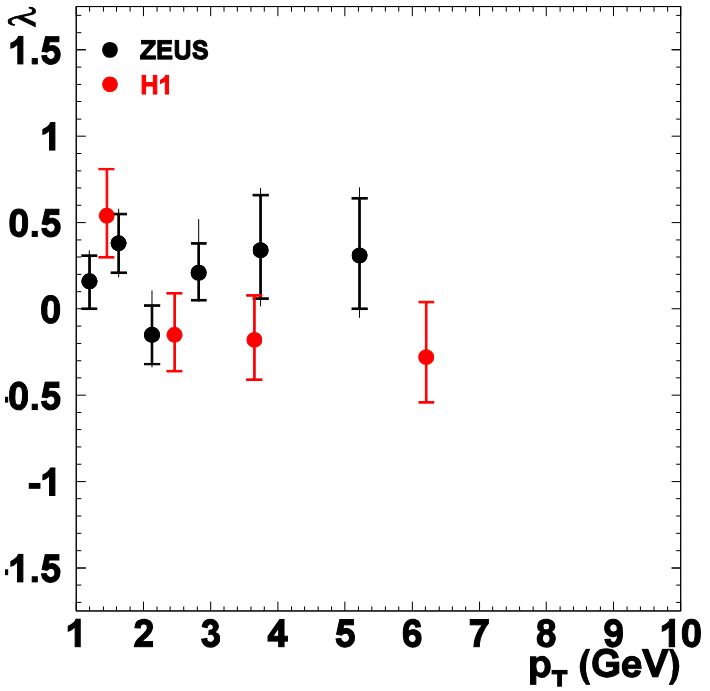


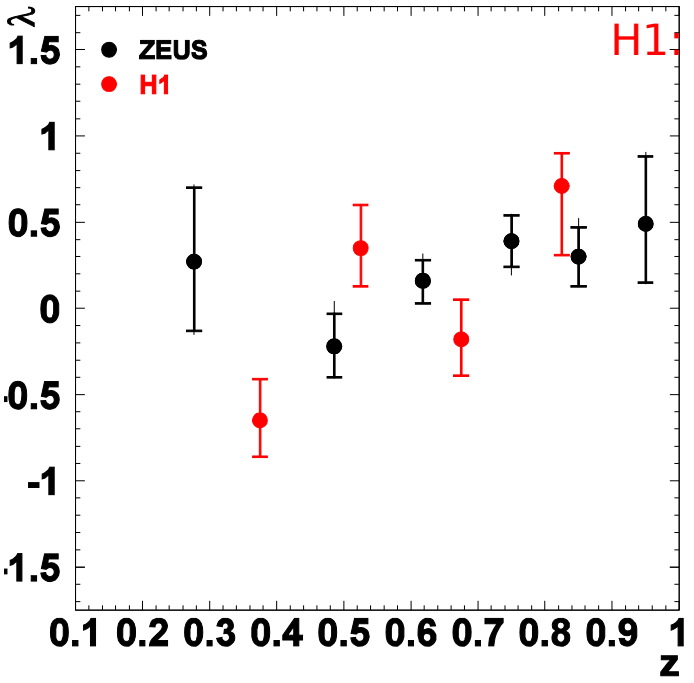


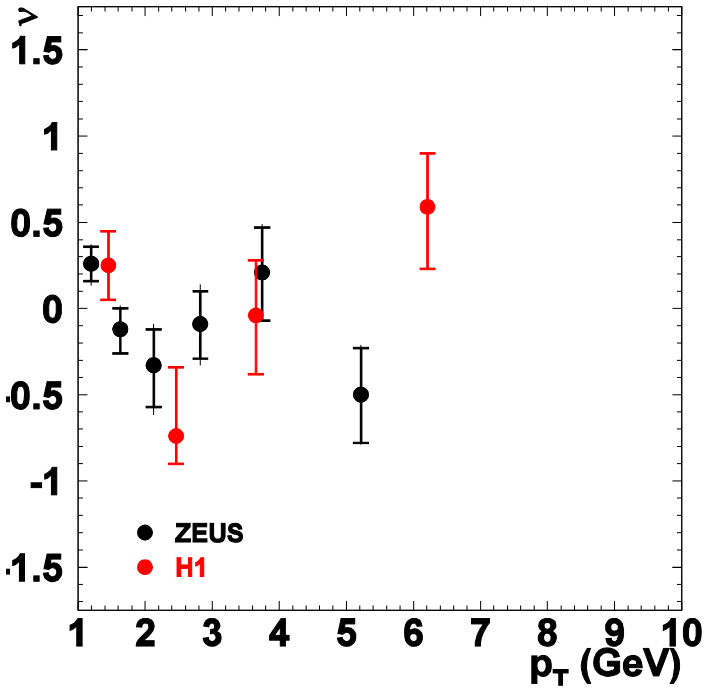


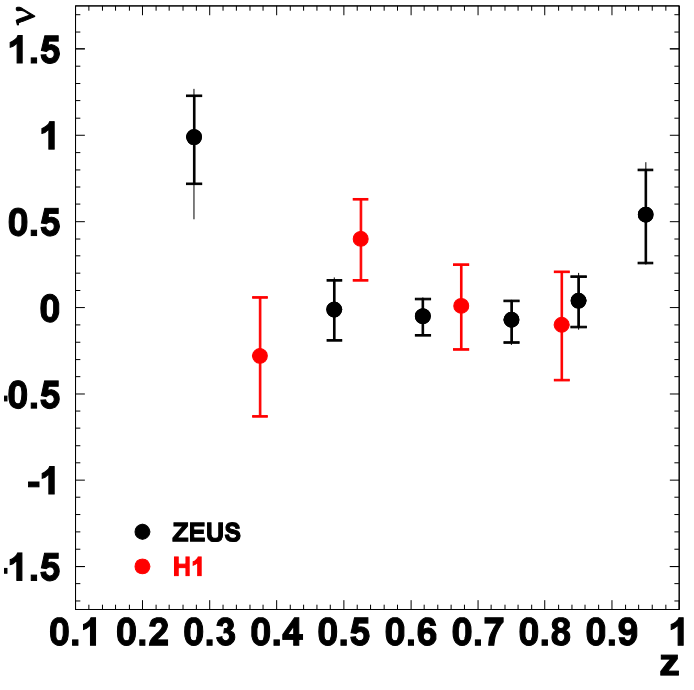
ZEUS: JHEP12 (2009) 007

H1: Eur. Phys. J. C 68 (2010) 401

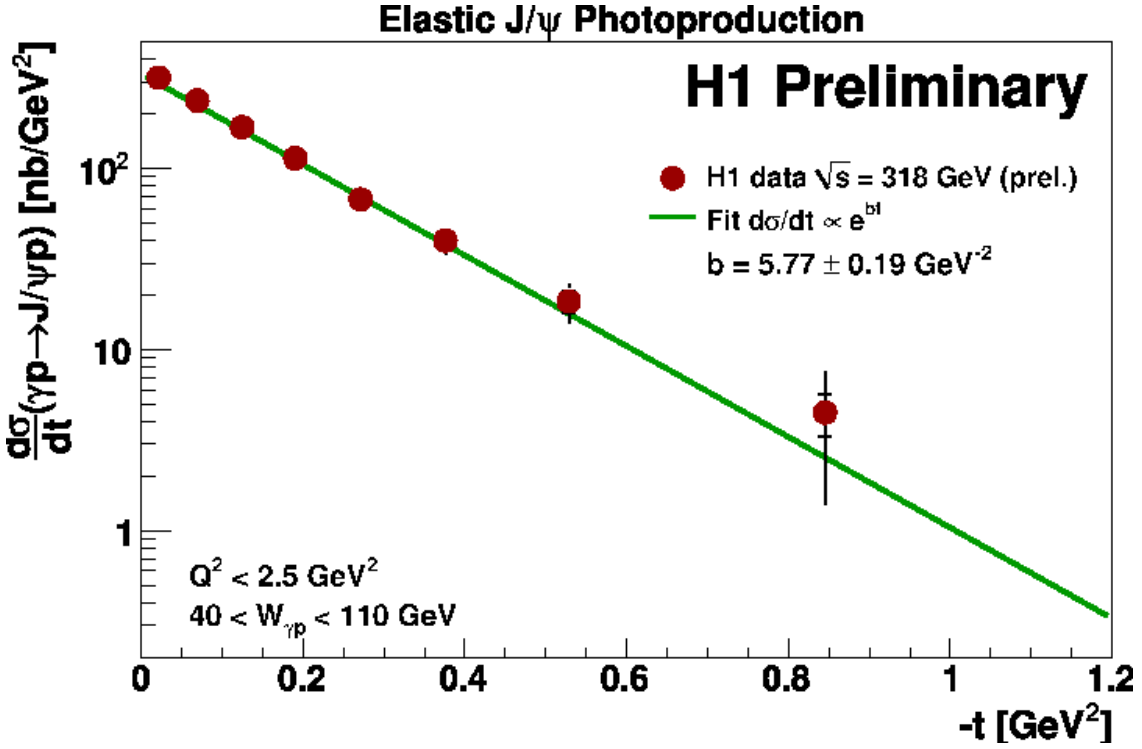


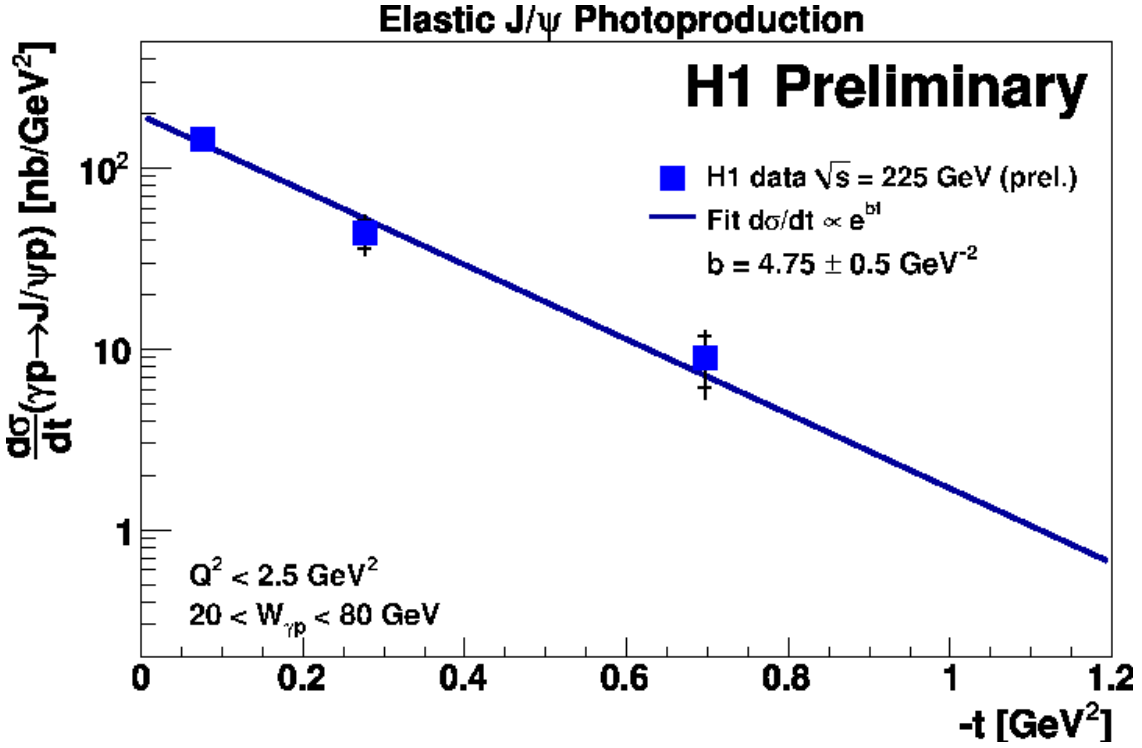


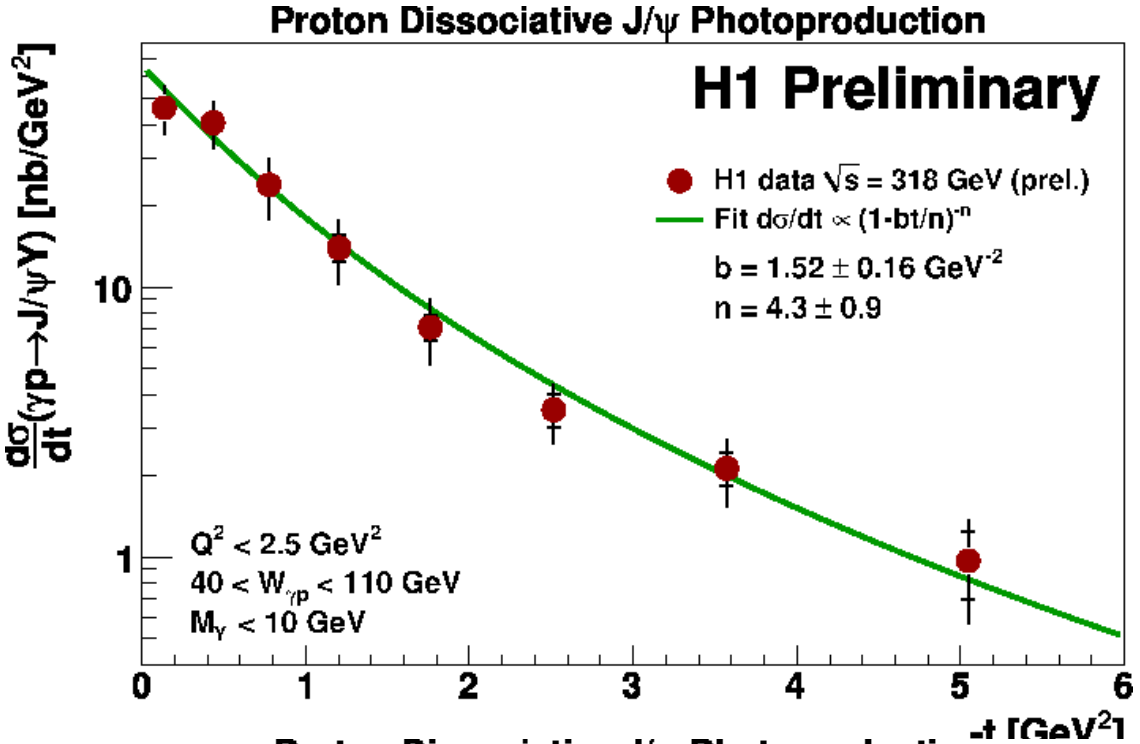


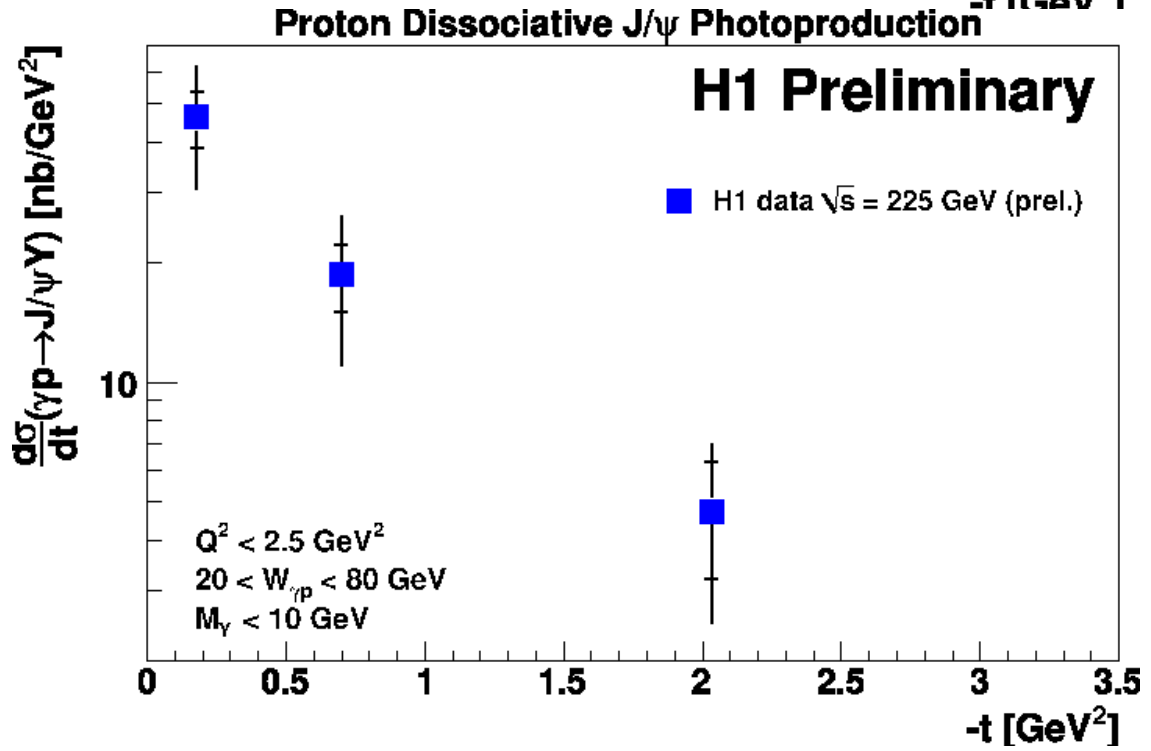


even if the ZEUS and H1 analysises differ in several details the overall results are compatible


Elastic J/ψ Photoproduction
H1 Preliminary
H1 data √s = 318 GeV (prel.)
Fit dσ/dt ∝ e^bt
b = 5.77 ± 0.19 GeV^-2
Q^2 < 2.5 GeV^2
40 < W_γp < 110 GeV
dσ/dt(γp→J/ψp) [nb/GeV^2]
-t [GeV^2]


Elastic J/ψ Photoproduction
H1 Preliminary
H1 data √s = 225 GeV (prel.)
Fit dσ/dt ∝ e^bt
b = 4.75 ± 0.5 GeV^-2
Q^2 < 2.5 GeV^2
20 < W_γp < 80 GeV
dσ/dt(γp→J/ψp) [nb/GeV^2]
-t [GeV^2]


Proton Dissociative J/ψ Photoproduction
H1 Preliminary
H1 data √s = 318 GeV (prel.)
Fit dσ/dt ∝ (1-bt/n)^-n
b = 1.52 ± 0.16 GeV^-2
n = 4.3 ± 0.9
Q^2 < 2.5 GeV^2
40 < W_γp < 110 GeV
M_Y < 10 GeV
dσ/dt(γp→J/ψY) [nb/GeV^2]
-t [GeV^2]


Proton Dissociative J/ψ Photoproduction
H1 Preliminary
H1 data √s = 225 GeV (prel.)
Q^2 < 2.5 GeV^2
20 < W_γp < 80 GeV
M_Y < 10 GeV
dσ/dt(γp→J/ψY) [nb/GeV^2]
-t [GeV^2]