Ringberg Workshop
New Trends in HERA Physics 2001

Heavy quarkonium in photoproduction and DIS

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on behalf of H1 and ZEUS Collaborations

ZEUS

FIGURES ONLY

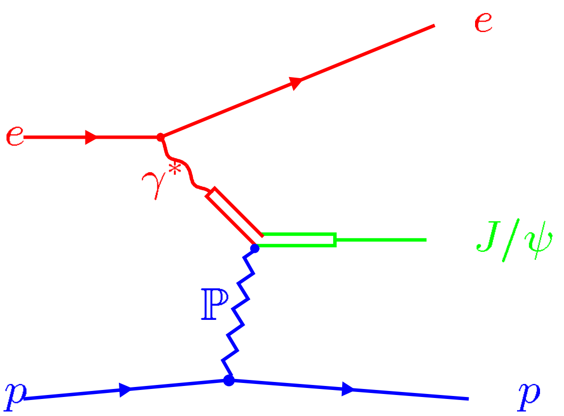
for full talk ask naroska@mail.desy.de

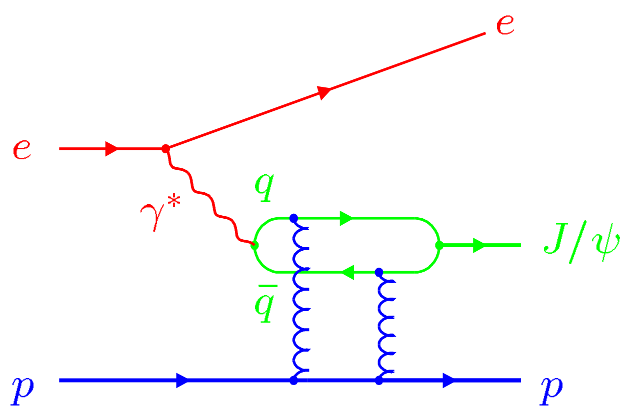
- Introduction
- Inelastic J/ψ production
  - Photoproduction: medium and low z
  - Colour Octet Contribution?
- Elastic J/ψ production
  - Photoproduction
  - Electroproduction
  - High $|t|$
- Conclusions

J/ψ Production Mechanisms at HERA

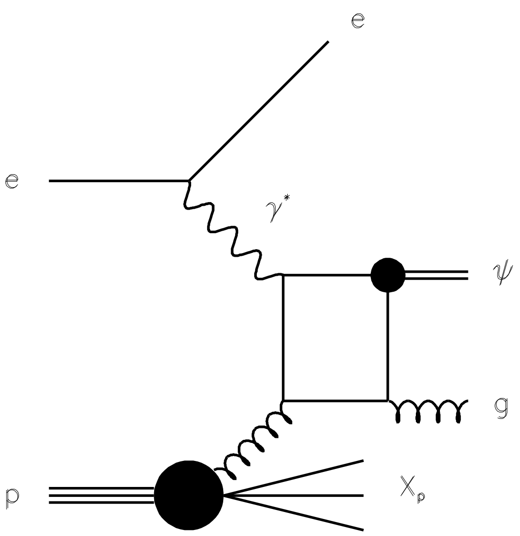
DIFFRACTIVE - elastic, proton dissociative

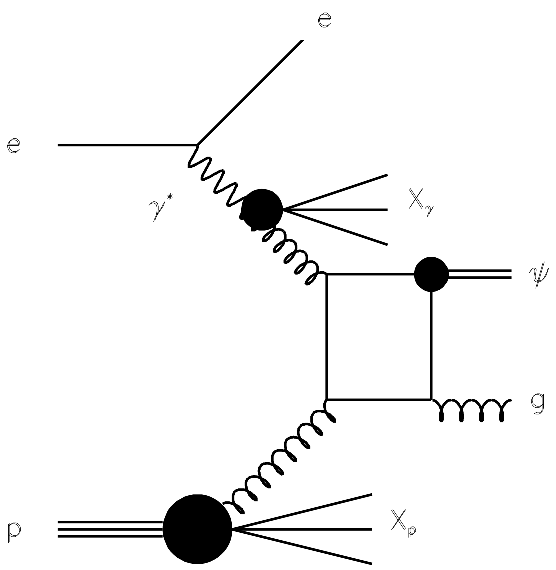
Regge Approach | pQCD Approach





INELASTIC processes: boson gluon fusion





DIRECT | RESOLVED Processes

$$W_{\gamma p}^2 = (q+P)^2 = -Q^2 + M_p^2 + y\,s \qquad y = \frac{q \cdot P}{k \cdot P}$$

$$z = \frac{P_\psi \cdot P}{q \cdot P} = \frac{E_\psi^*}{E_\gamma^*} \qquad \text{(p-CMS)}$$

J/ψ Production Mechanisms at HERA

Theoretical Competitors (pQCD) for description of charmonium production:

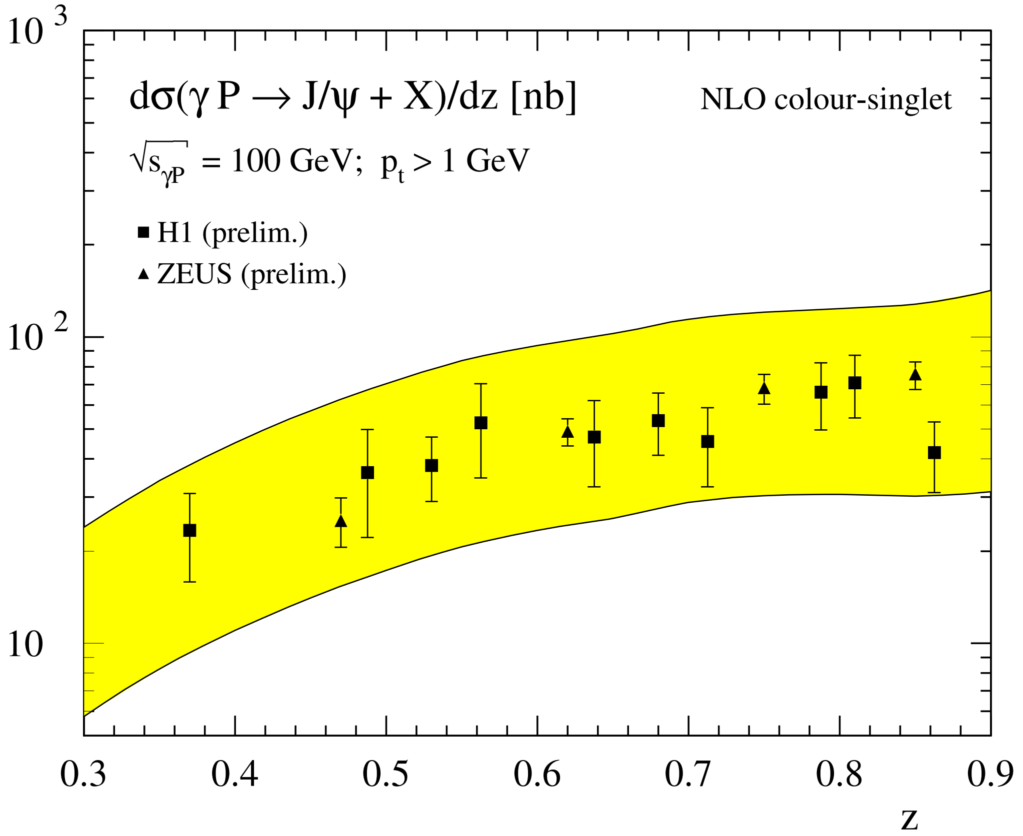
1. Colour singlet model (CSM)
2. NRQCD/factorisation approach
   Theoretically most attractive
   - colour octet contributions
   - CSM is contained
   - Additional parameters
3. Colour evaporation model
4. Soft colour interactions
5. ...

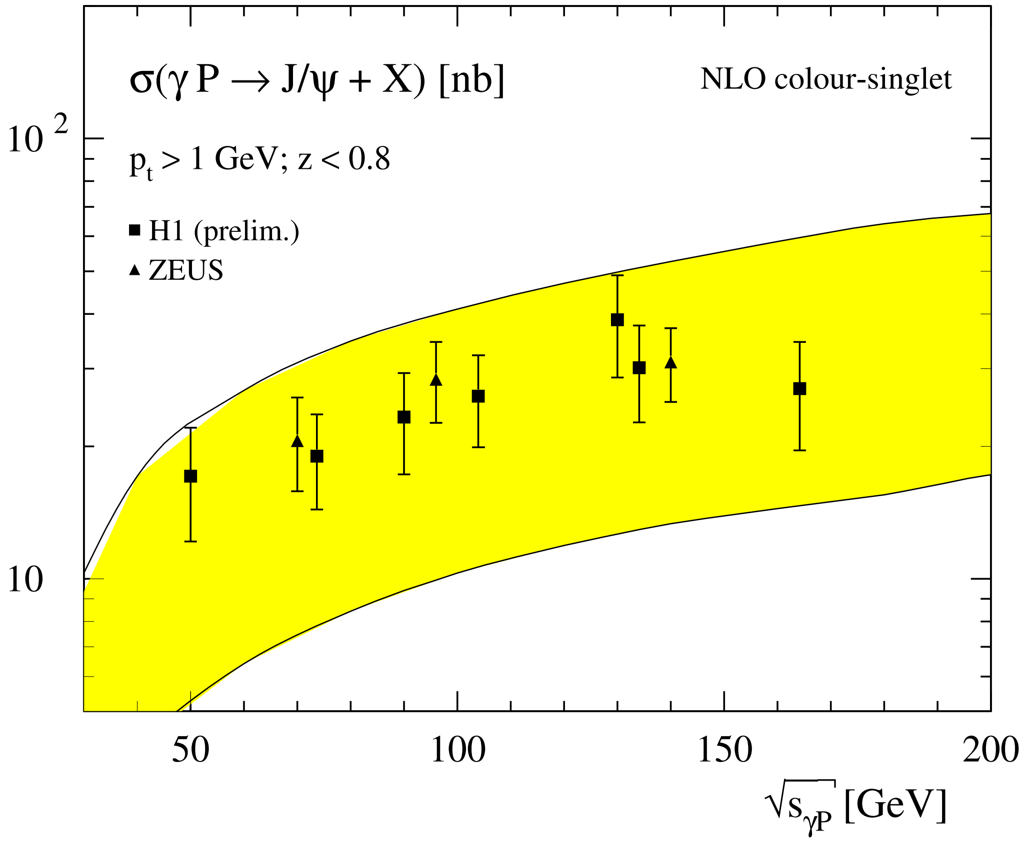
SIZE OF COLOUR OCTET CONTRIBUTIONS??
Large discrepancy of data in $p\bar{p}$ J/ψ production with LO CSM predictions has led to predictions of large contributions in $\gamma\, p$ interactions, which were not found.

– HERA in unique position: NLO calculations available for $\gamma\, p$ production
– removes a great part of the normalisation uncertainties
– First see how well NLO CSM does while we look at data sets

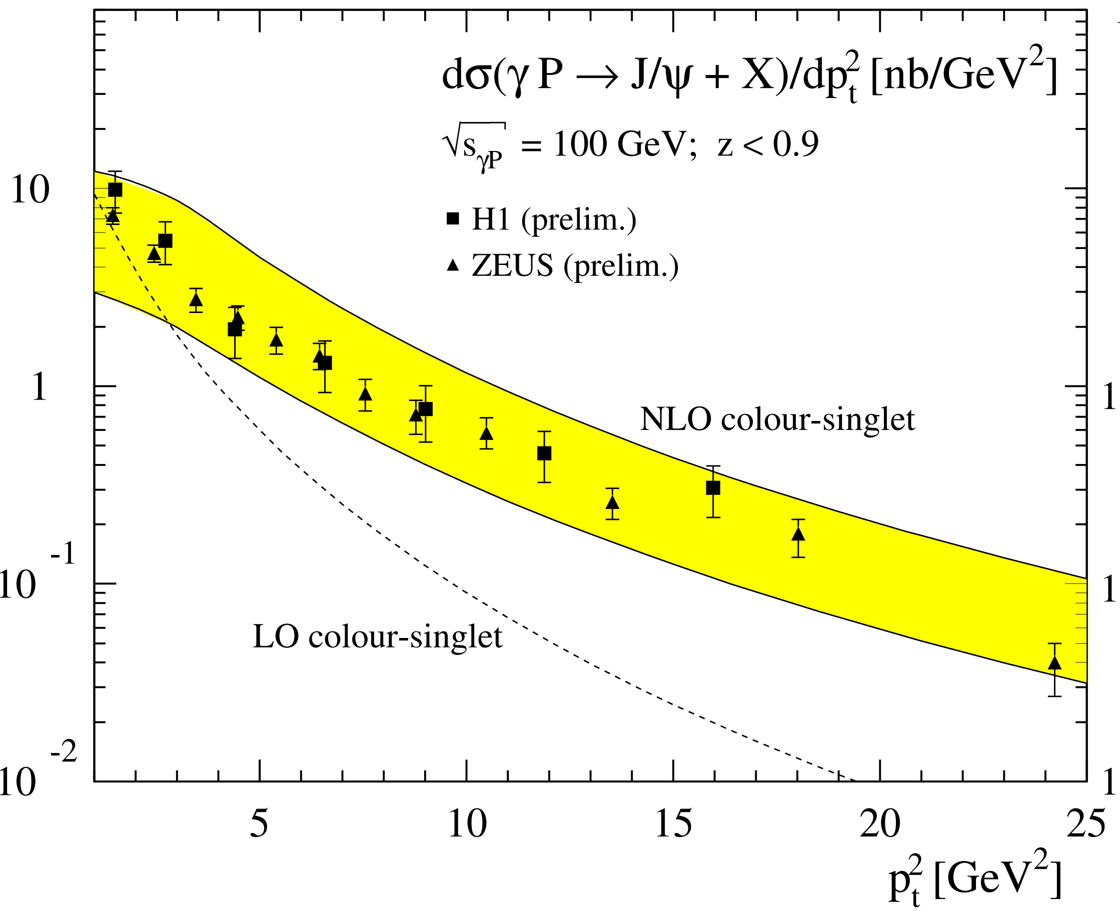
Review: M. Krämer, hep-ph/0106120

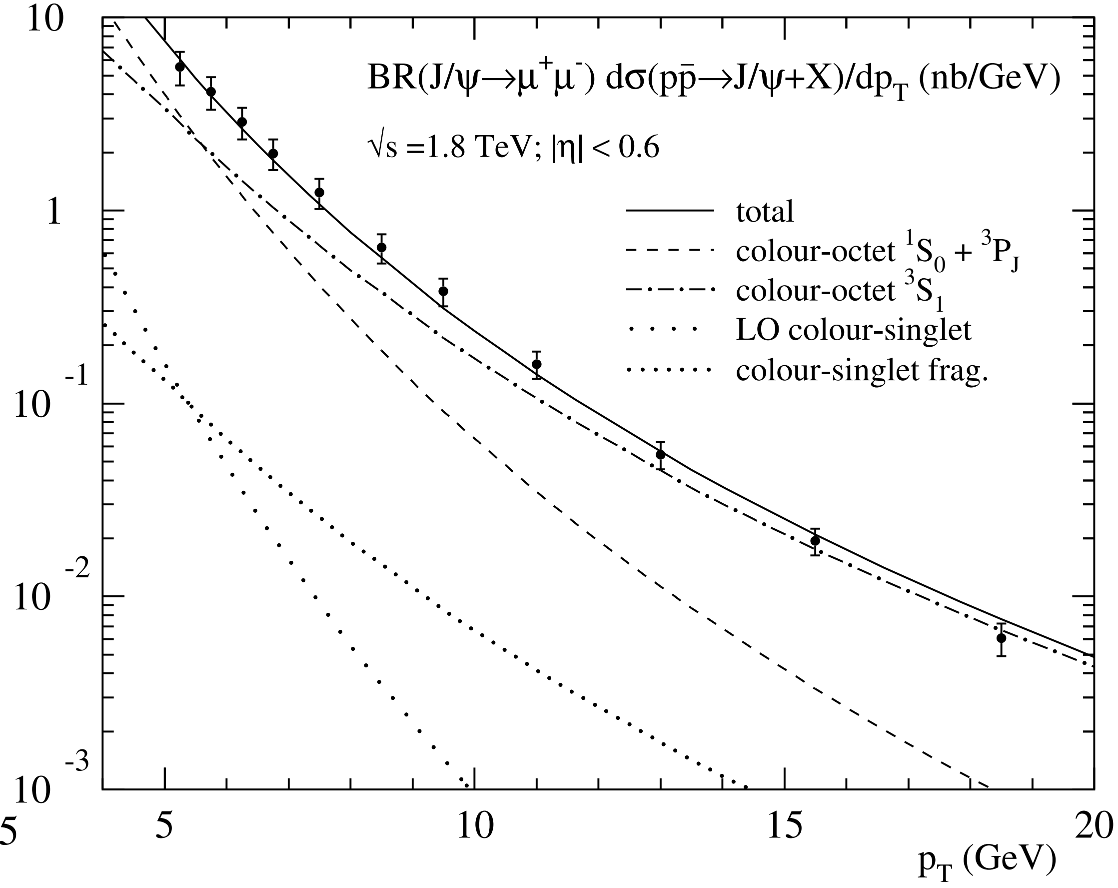
$W_{\gamma p}$, z Dependence



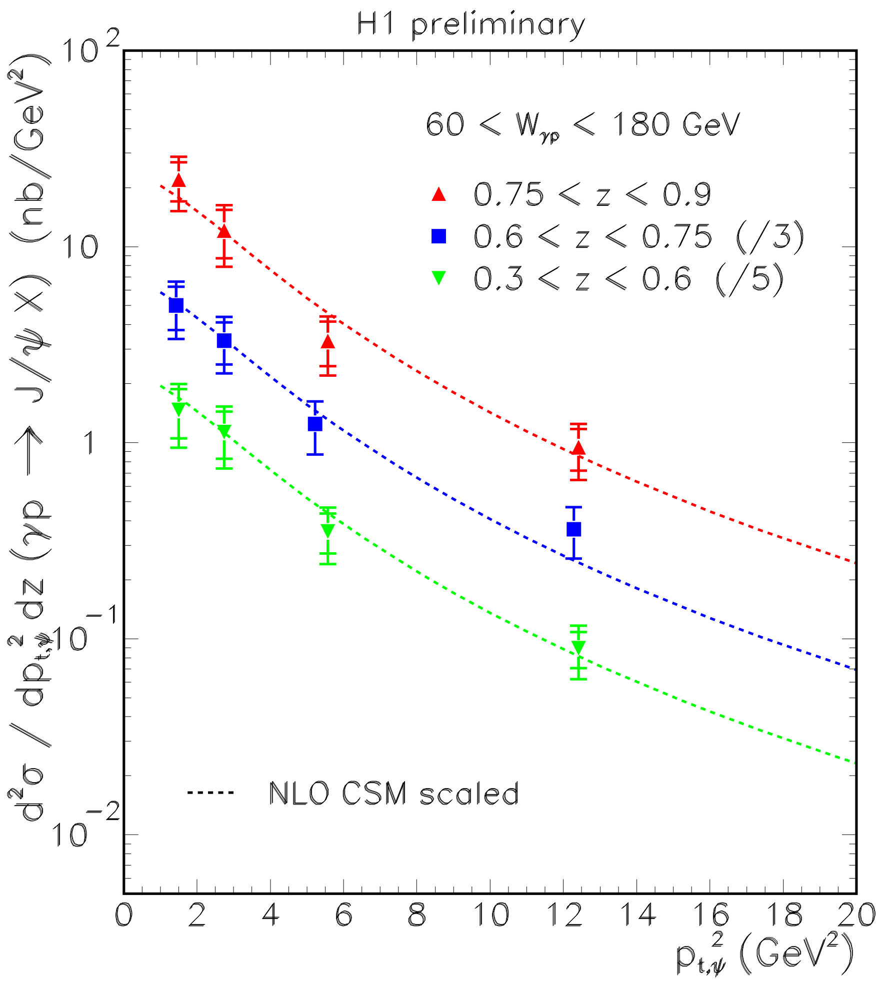


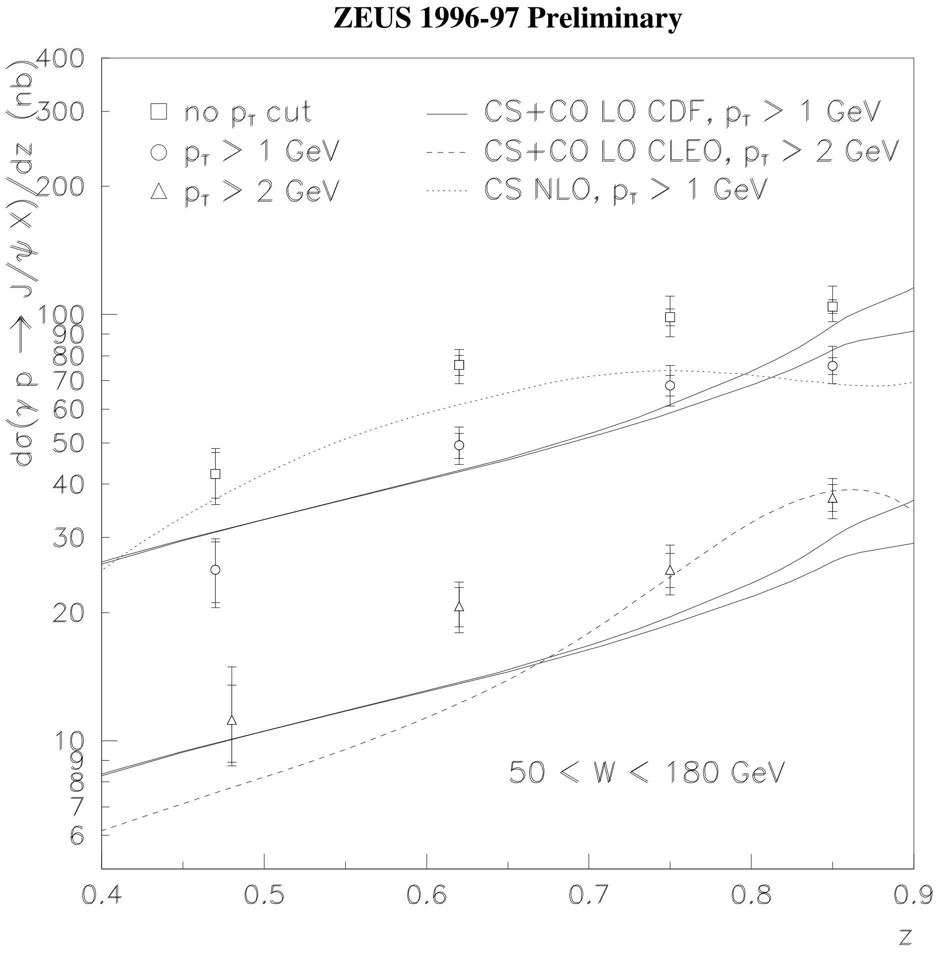
Inelastic Photoproduction





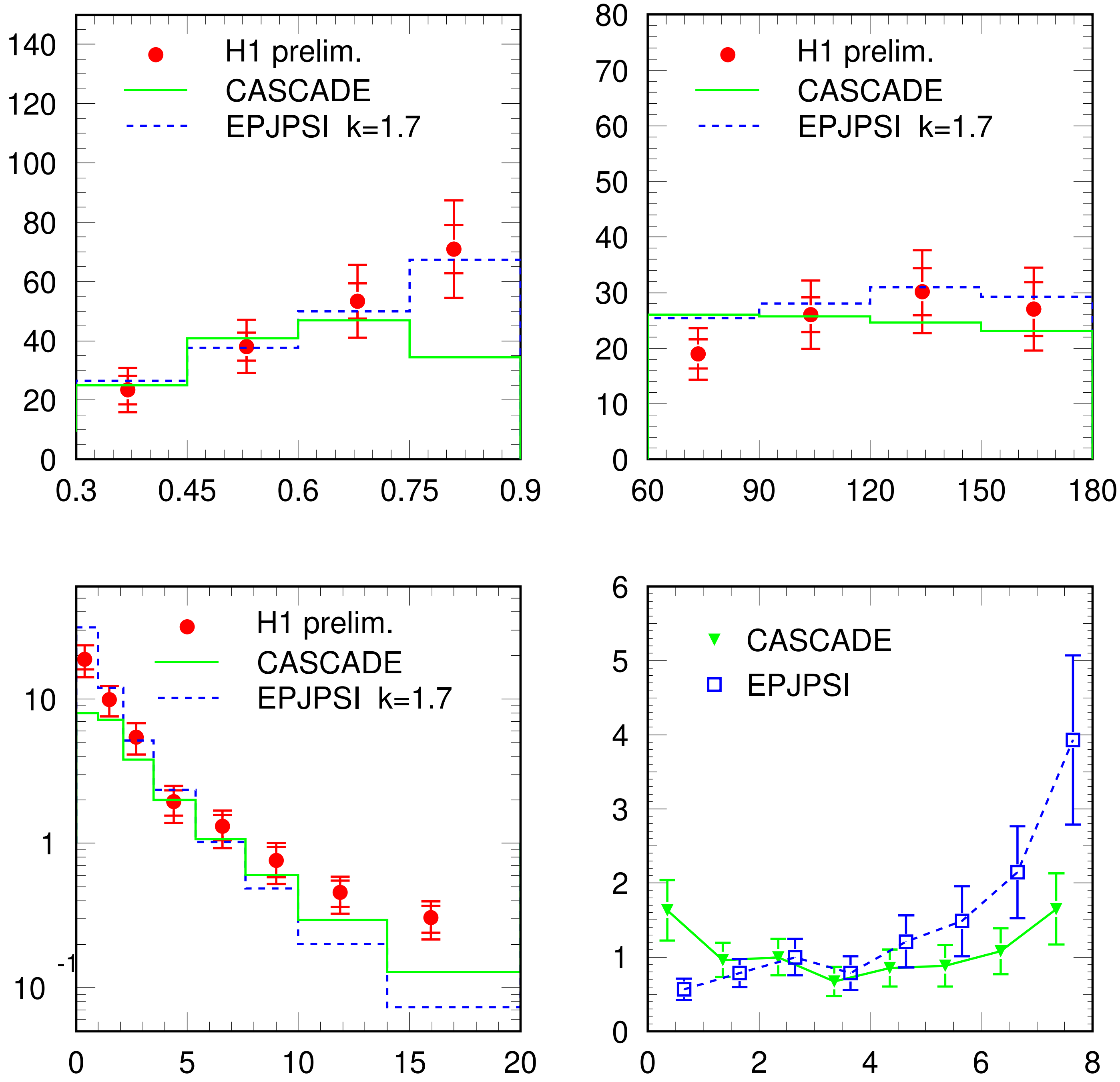
Inelastic Photoproduction





CASCADE: CCFM Equation

CASCADE: Unintegrated gluon distribution from F_2 fits ($\rightarrow$ H. Jung)
EPJPSI: LO CSM; MRSA' partons

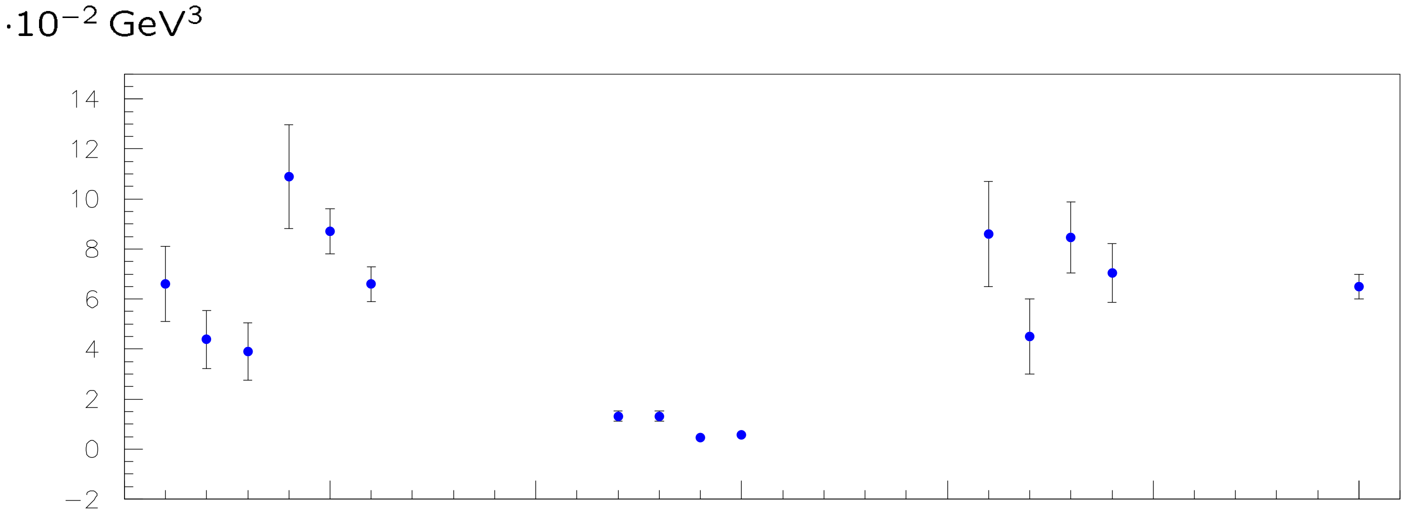


NOT BAD!

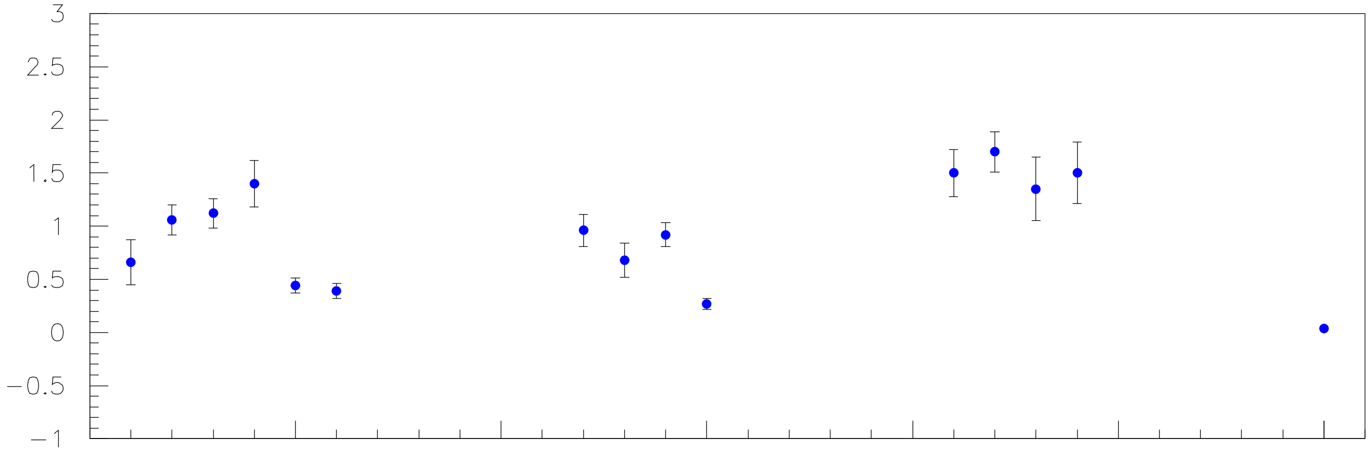
NRQCD/Factorisation Approach: Colour Octet Model

Long Range Matrixelements
$c\bar{c} \to J/\psi$

$$M_k = \mathcal{O}^{\psi}[8,{}^1S_0] + k\,\mathcal{O}[8,{}^3P_0]/m_c^2$$



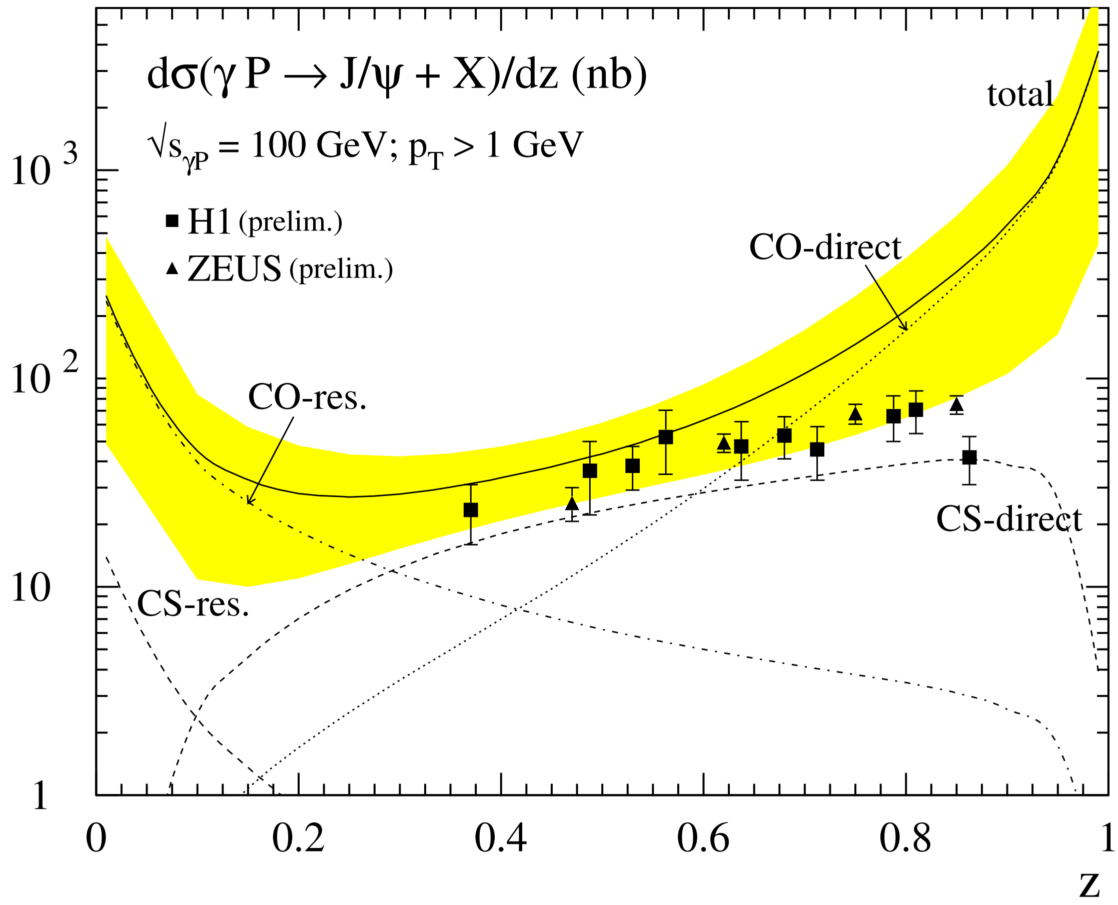
$$\mathcal{O}^{\psi}[8,{}^3S_1]$$



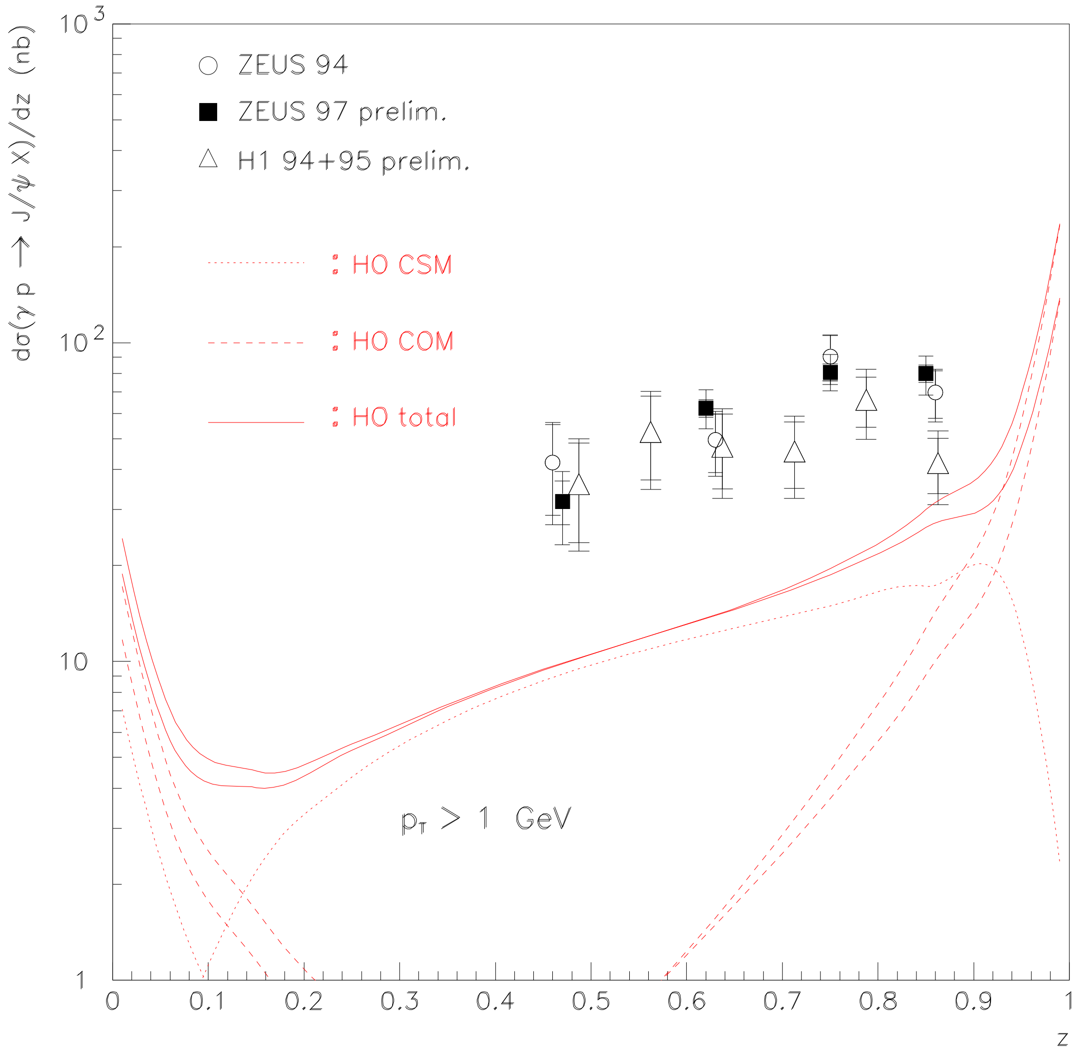
$\mathcal{O}^{\psi}[1,{}^3S_1] = 116\,10^{-2}\,\mathrm{GeV}^3$

Values available fom B-decays (CLEO) similar to PYTHIA corrected values

Coulor Octet Contributions?

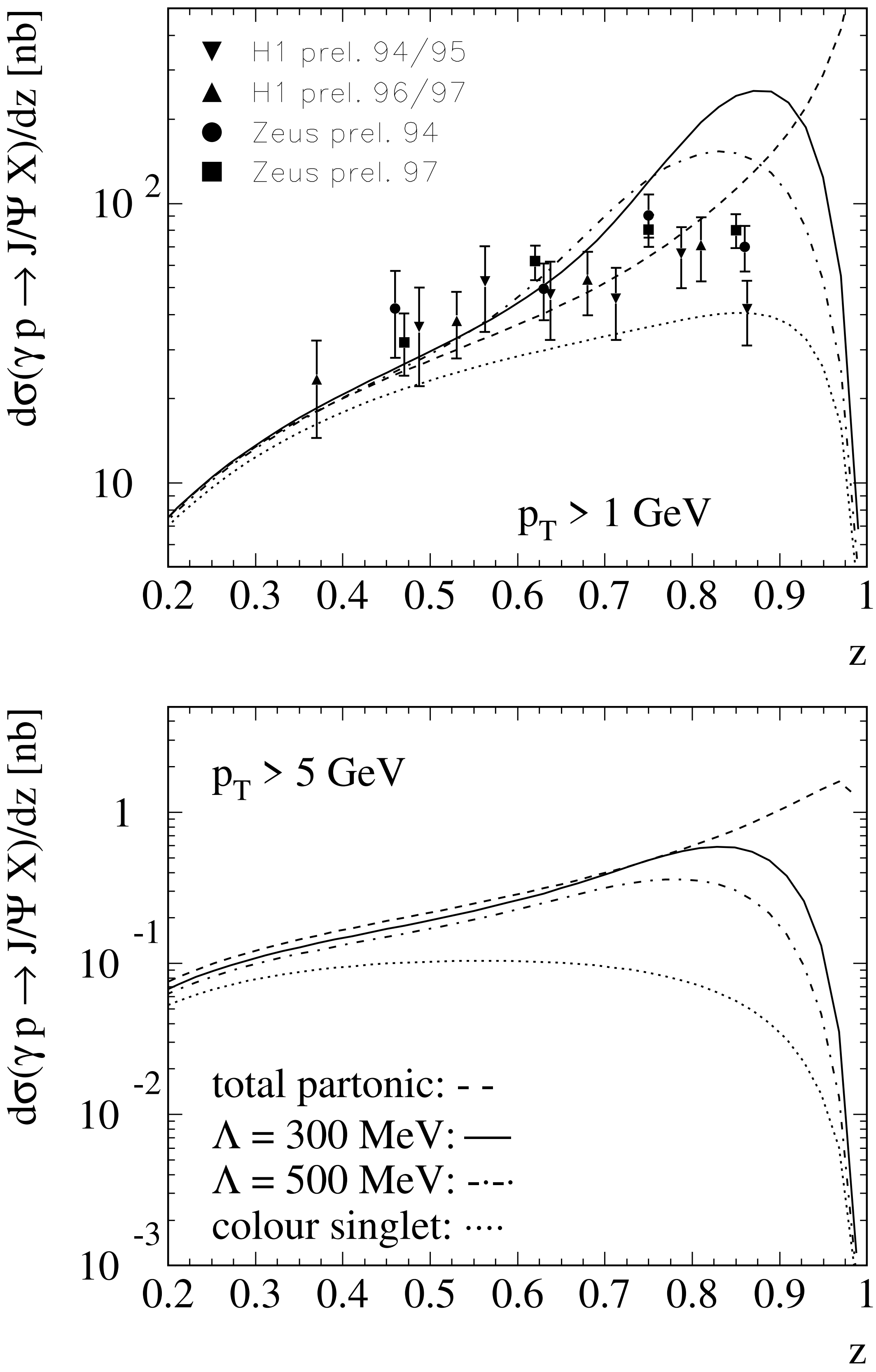


Coulor Octet Contributions?

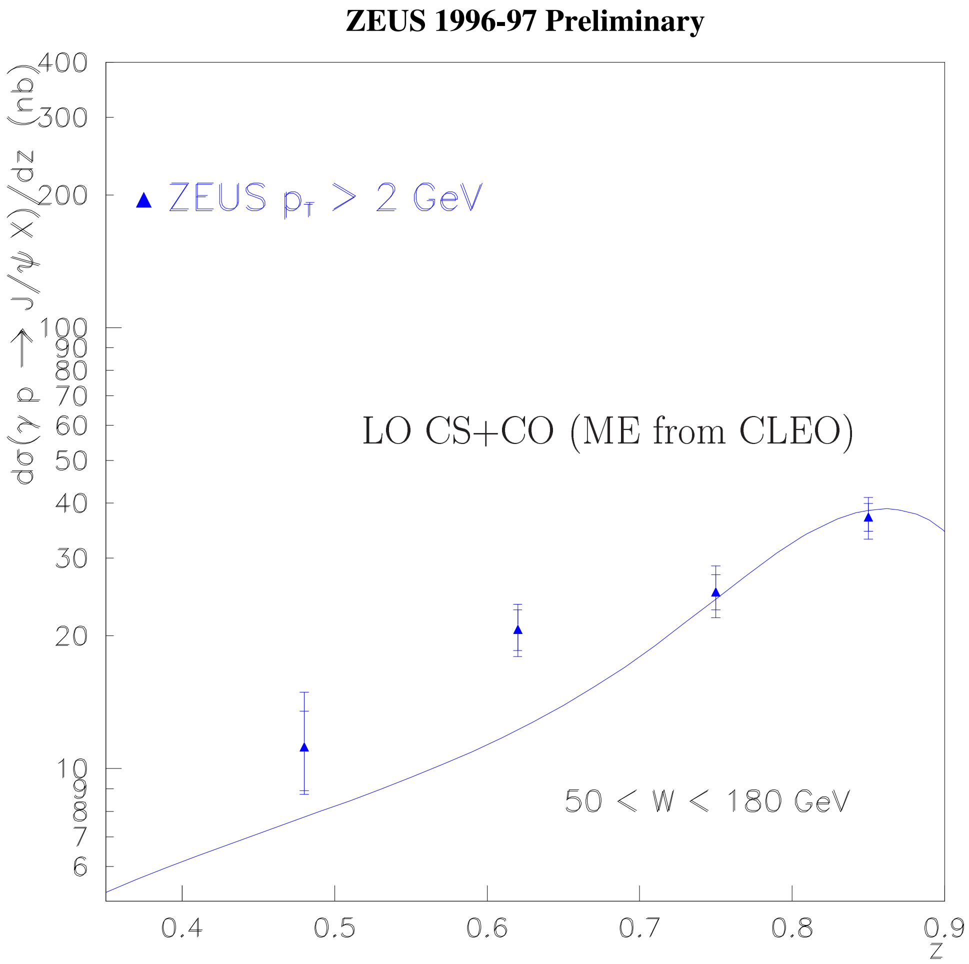


Shape Functions (Beneke,Schuler,Wolf)

Resummation of soft gluon emmissions at high z: Shape functions
Rise diminished, turn-over towards $z \sim 1$
BUT: no theoretical control at low p_t for $z > 0.7$
Authors: higher $z - cut$!!

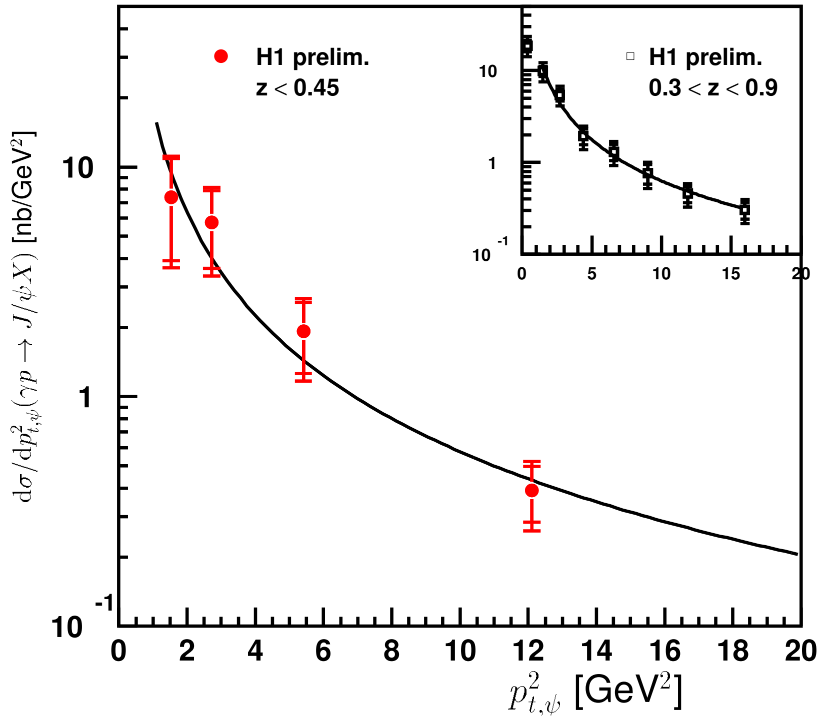


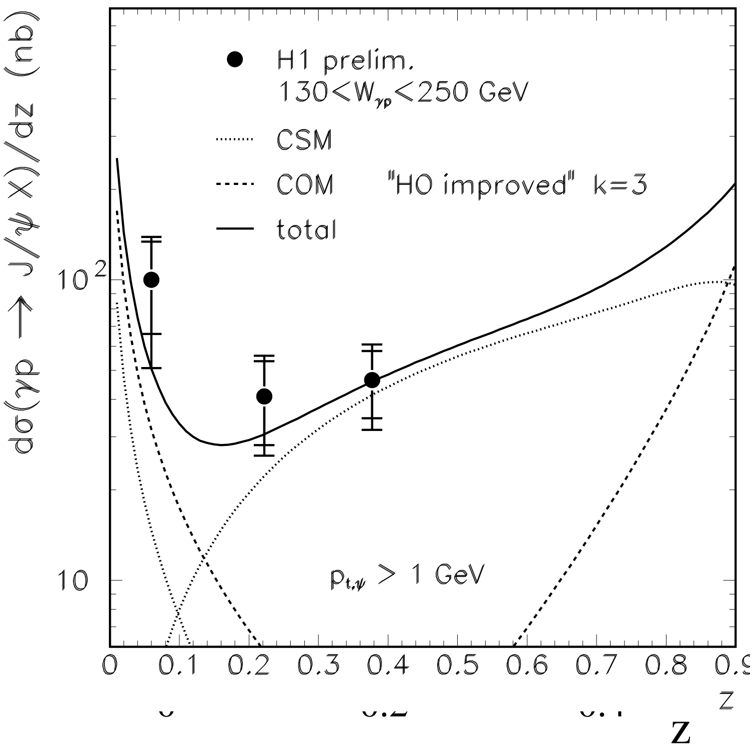
Inelastic Photoproduction

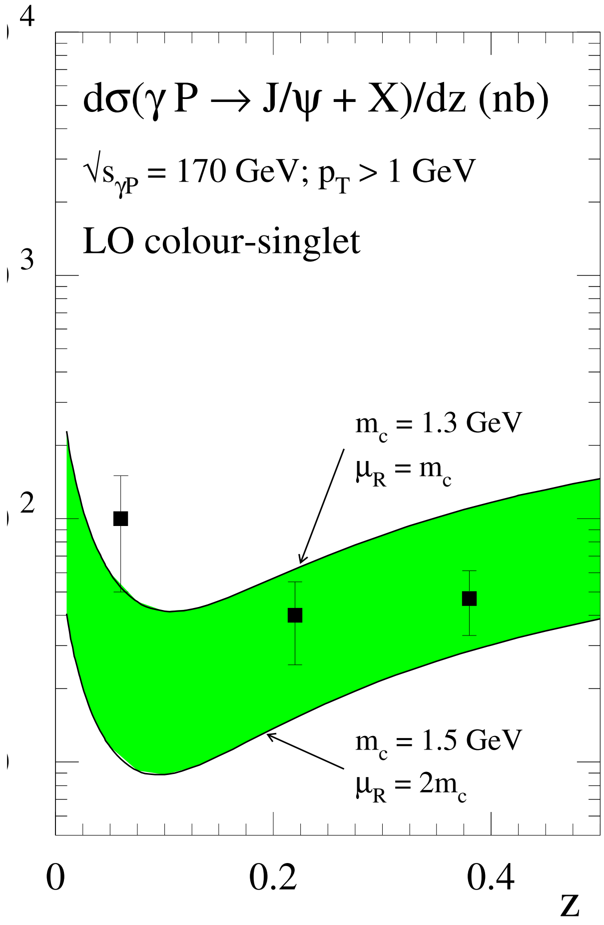


- CS + CO with matrix elements from CLEO looks interesting (no K-factor).

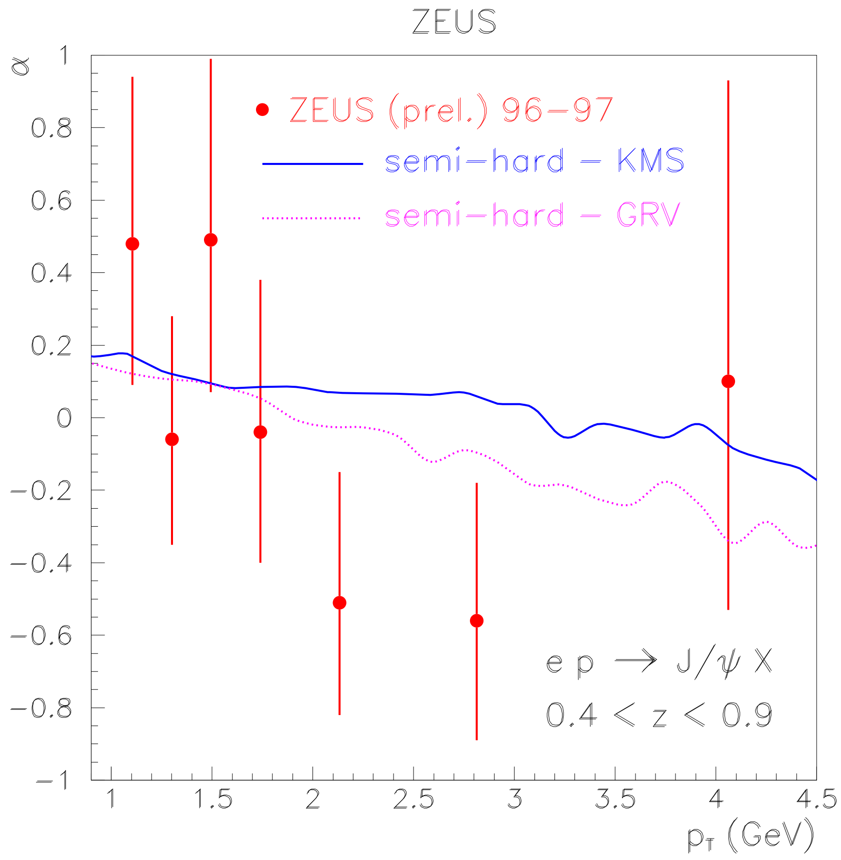
Low z: Resolved Contributions

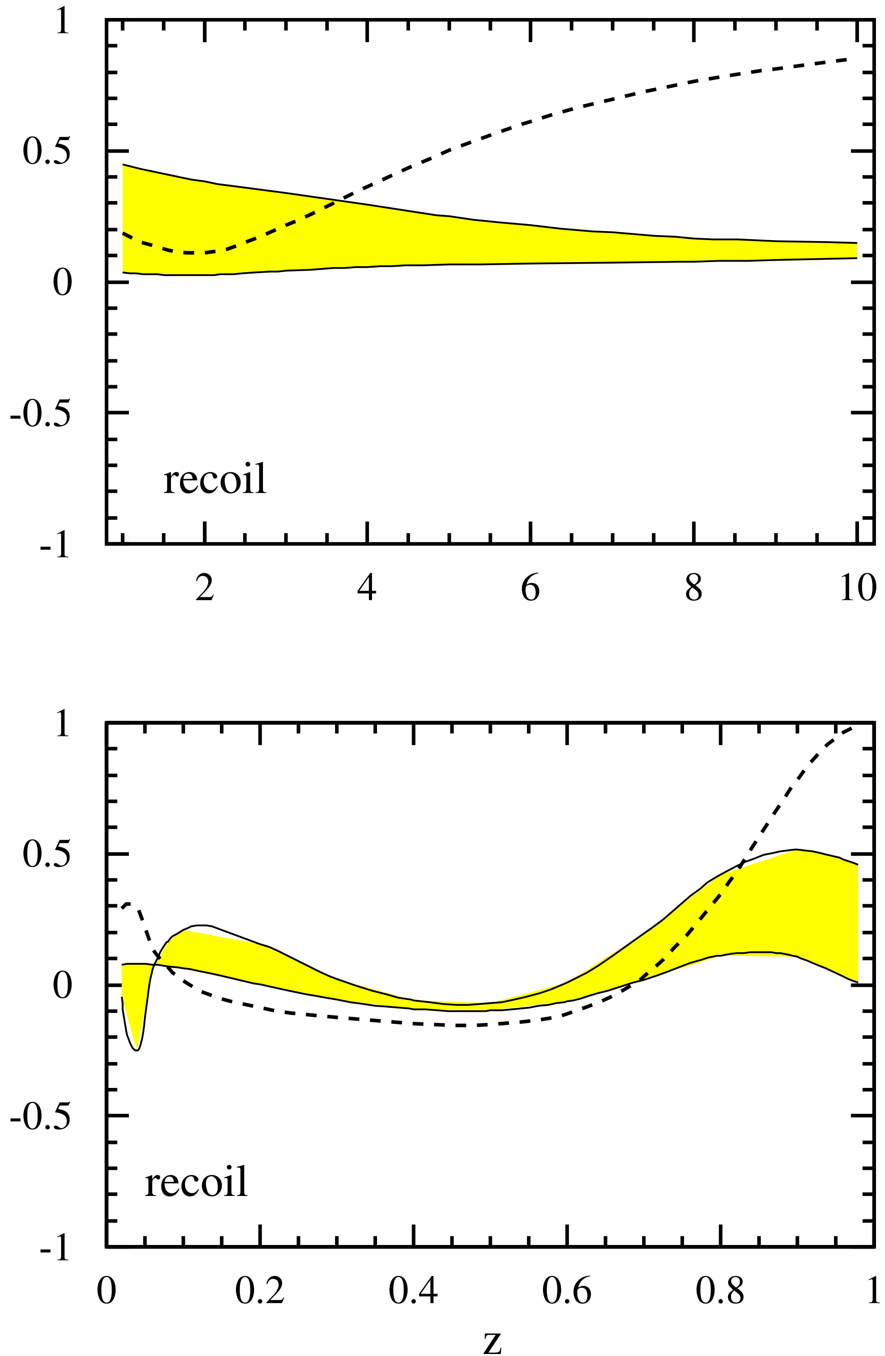




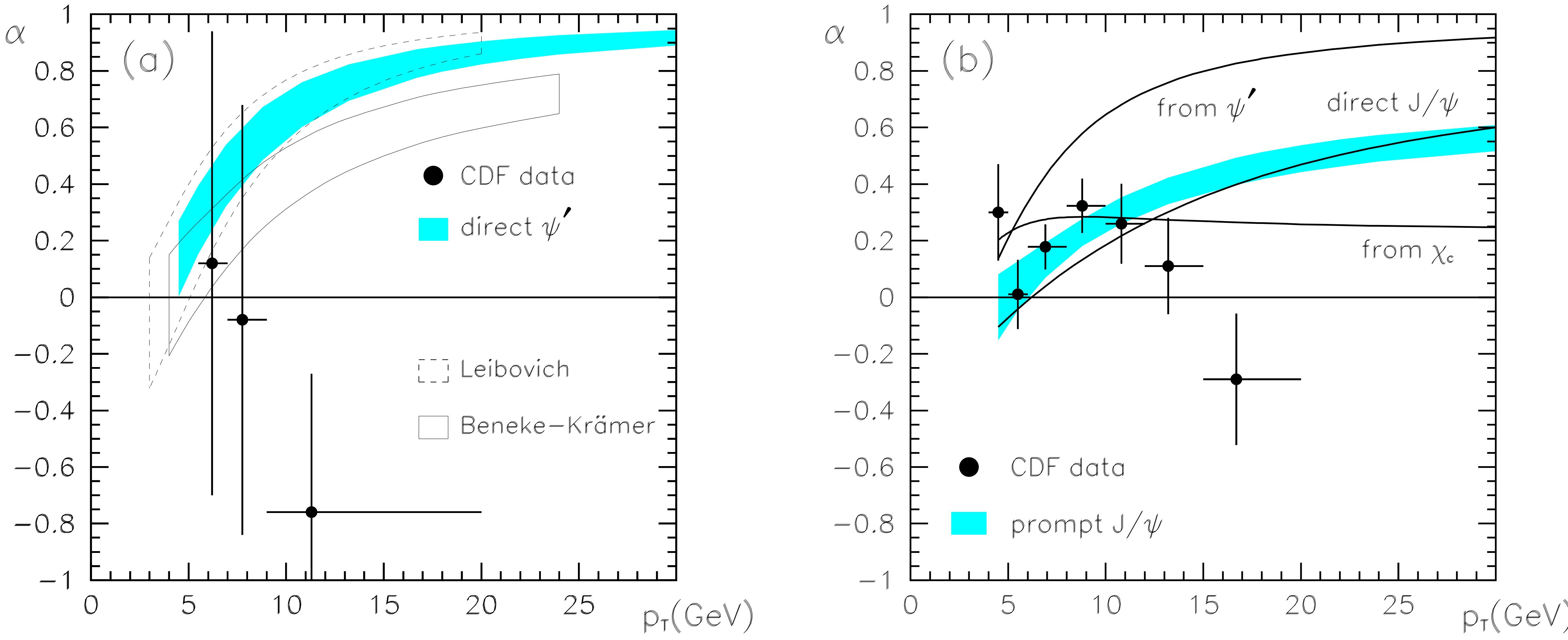


Polarisation

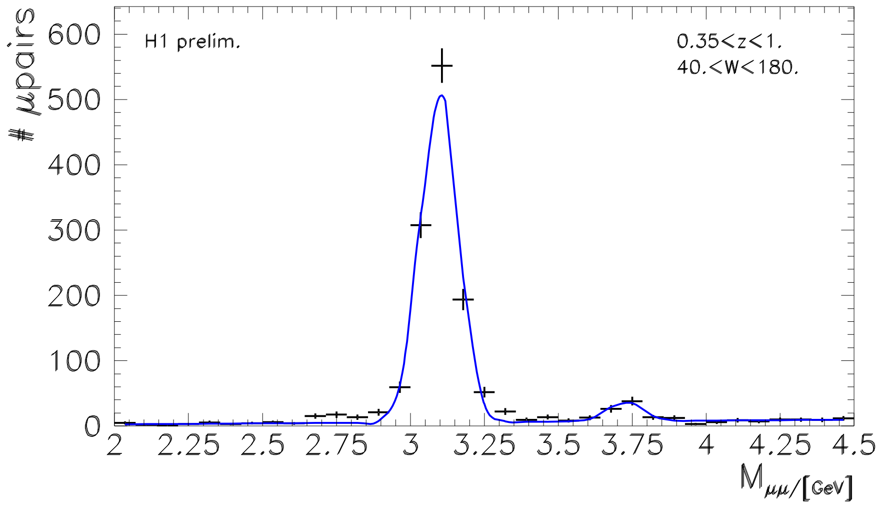


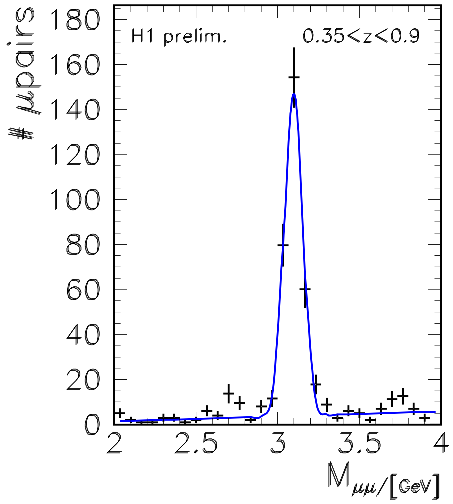


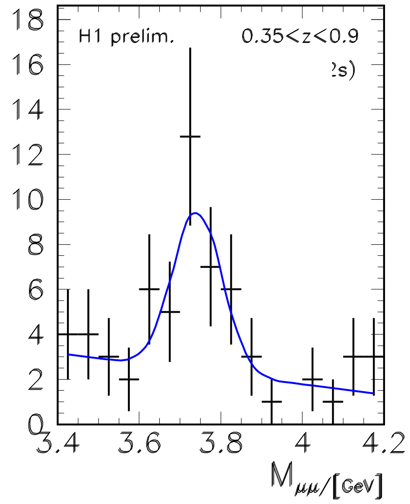
CDF TEVATRON

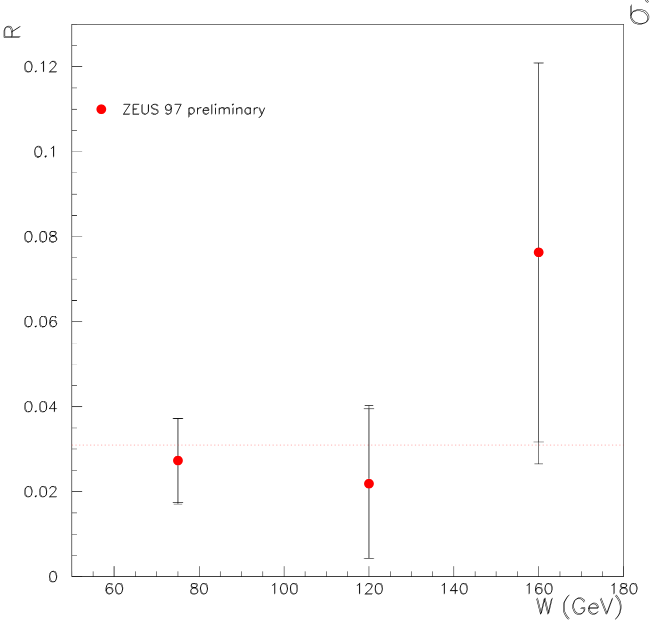


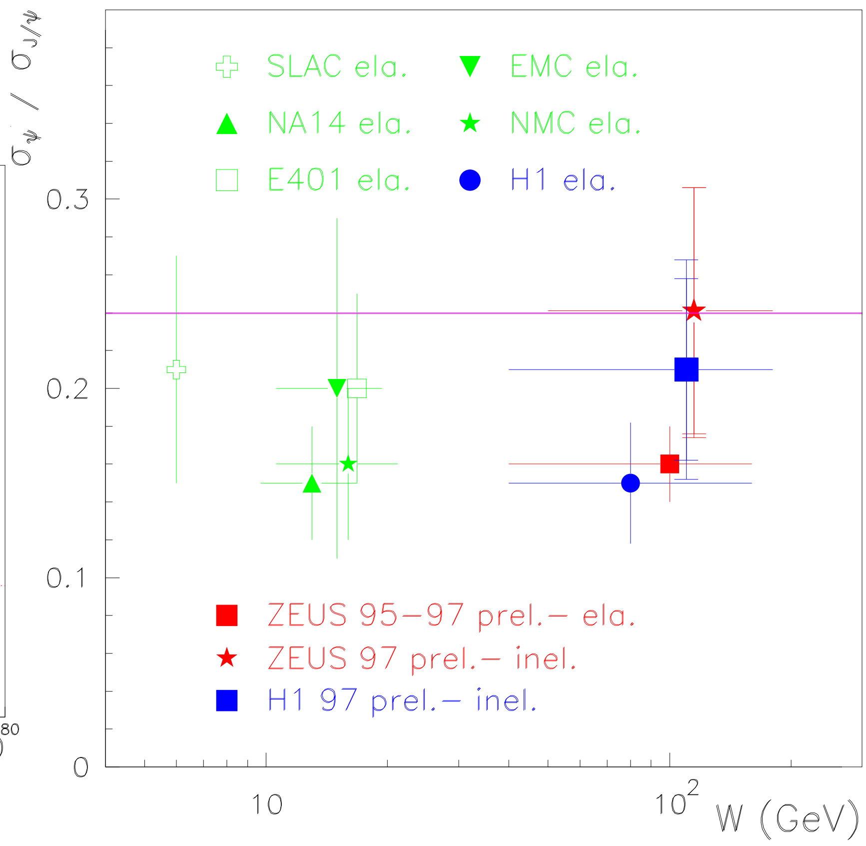
Inelastic ψ'







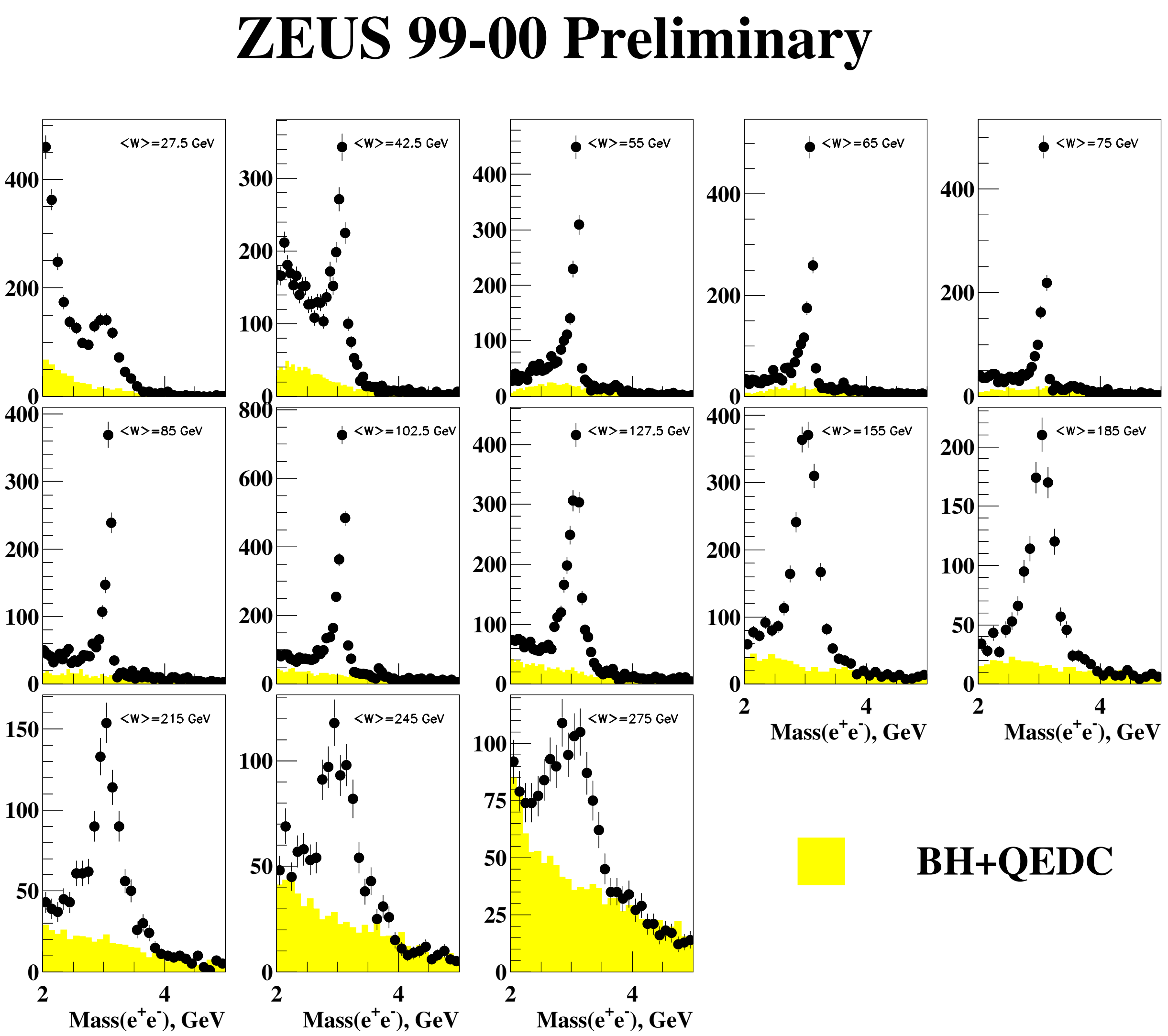




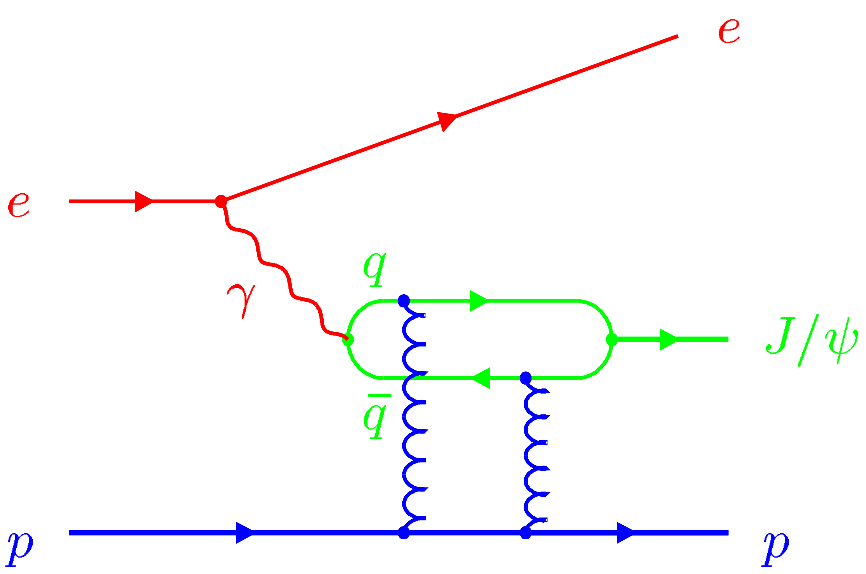
Elastic Photoproduction $\gamma\, p \to J/\psi\, p$

Elastic J/ψ Photoproduction
LOW t

published H1 data	preliminary ZEUS data
$Q^2 < 1$ GeV^2	$Q^2 < 1$ GeV^2
$26 < W_{\gamma p} < 285$ GeV	$20 < W_{\gamma p} < 290$ GeV
$J/\psi \to \mu^+\mu^-, e^+e^-$ 21 pb^{-1}	38 pb^{-1} $(J/\psi \to \mu^+\mu^-)$ 48 pb^{-1} $(J/\psi \to e^+e^-)$



Elastic Production $\gamma\, p \to J/\psi\, p$



Factorisation:

- fluctuation $\gamma \to q\bar{q}$
- interaction with proton
- formation of Vector Meson

LO: $d\sigma/dt|_{t=0} \propto [x\, g(x, \bar{Q}^2)]^2$

calculations of different groups include improvements to LO calculations, e.g.

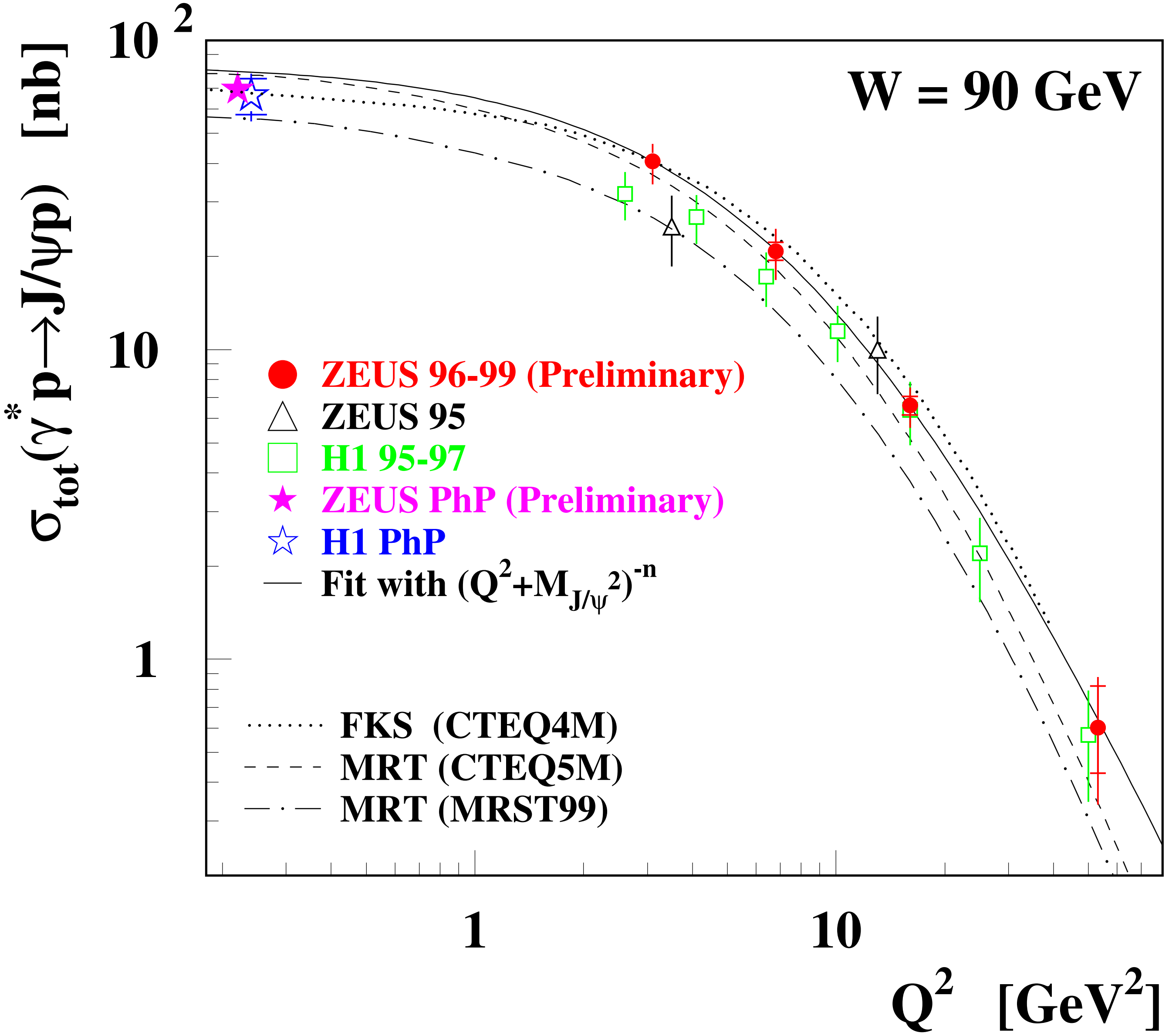
Martin, Ryskin, Teubner:

- parton hadron duality
- off-diagonal parton distributions

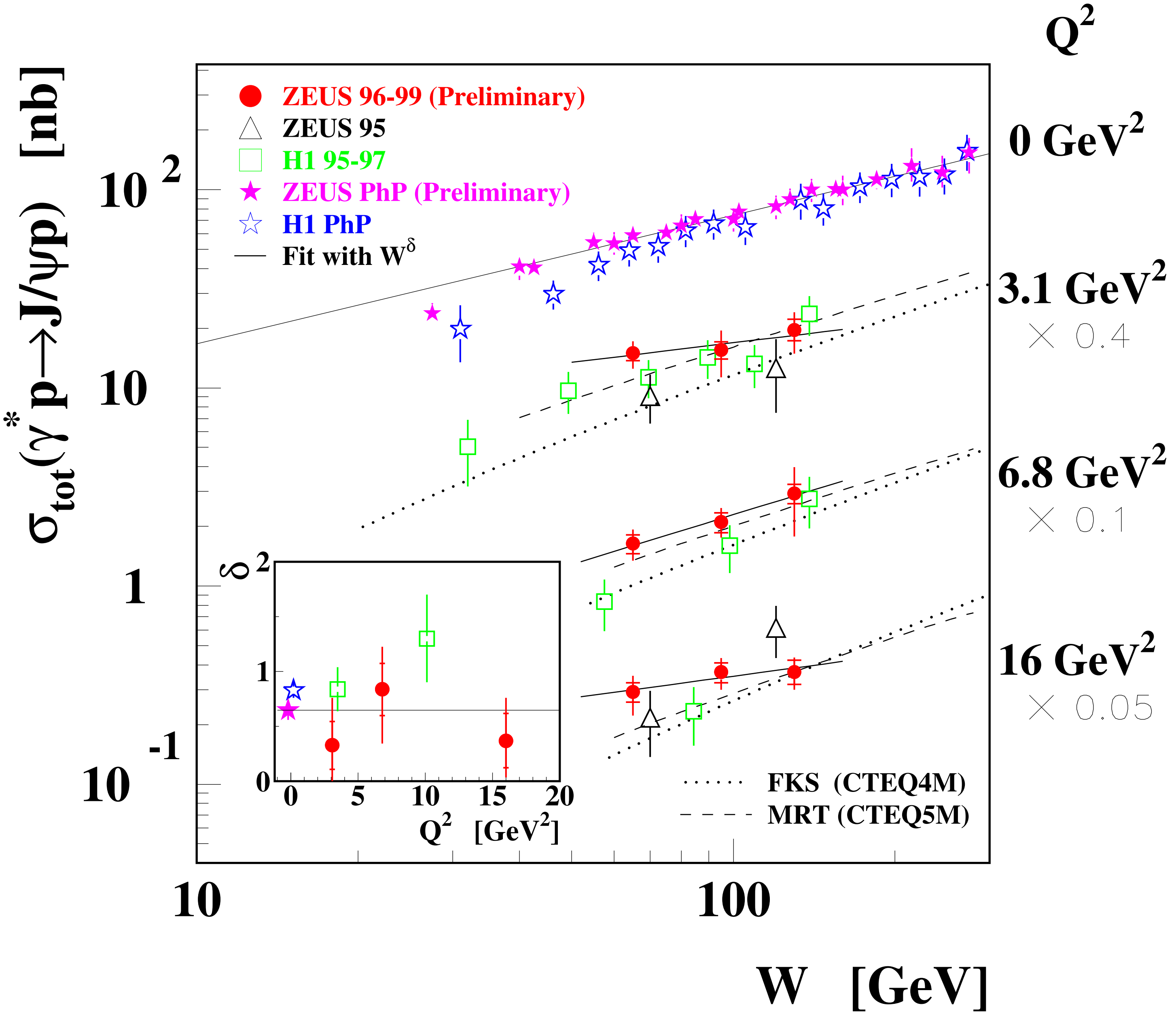
Frankfurt, Koepf, Strikman:

- J/ψ wave function to include Fermi motion of quarks
- rescaling $\bar{Q}^2 \gtrsim (Q^2 + m_\psi^2)/4$
- running quark mass $m(\bar{Q}^2)$

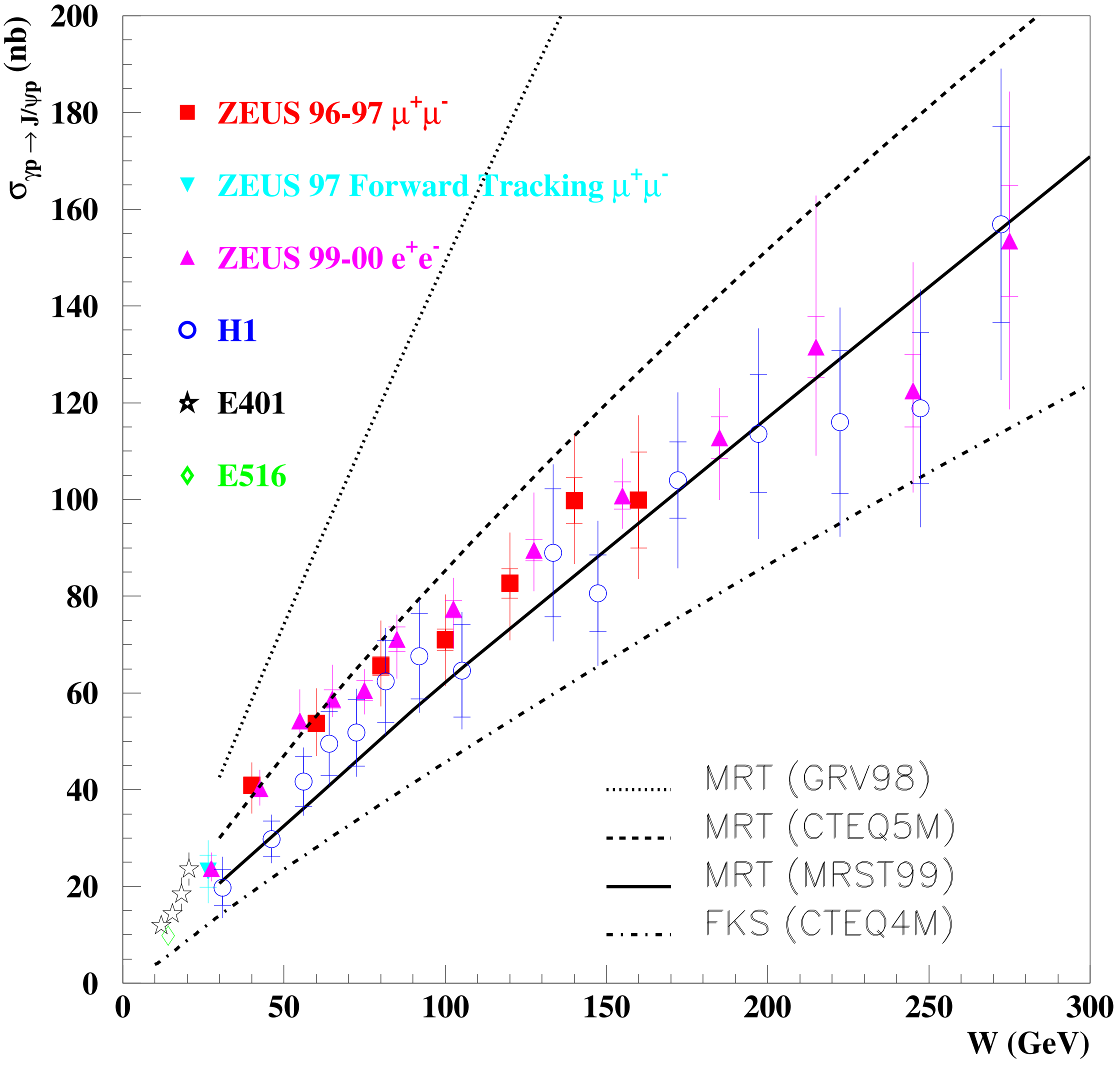
Elastic Electroproduction



Elastic Electroproduction



Elastic J/ψ: QCD Calculations



- $W_{\gamma p}$ range extended nearly to kinematical limit
- pQCD approach gives good description

  BUT: MRT and FKS achieve this via different "ingredients"
- sensitivity to gluon density in the proton

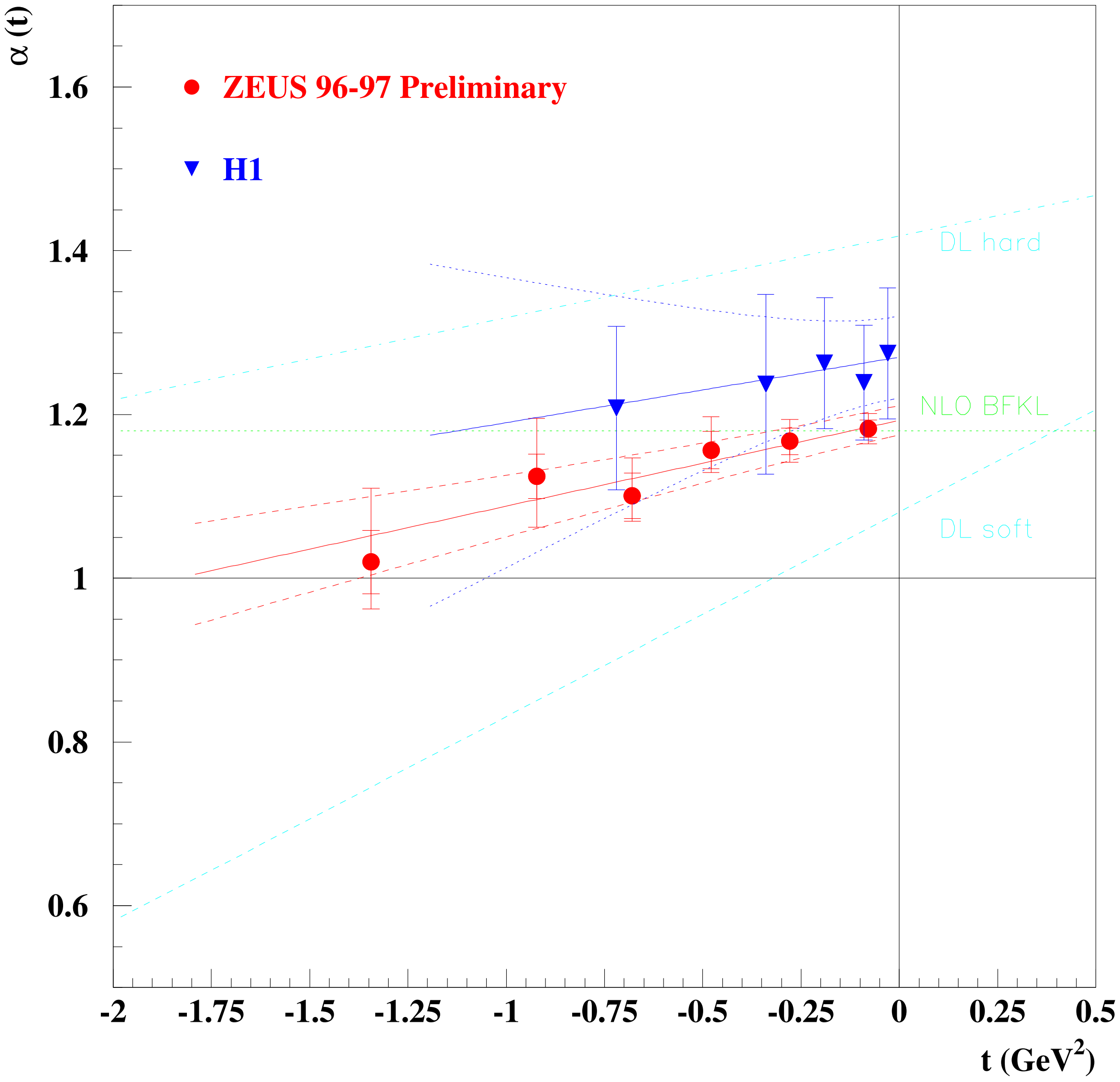
Martin, Ryskin, Teubner

Frankfurt, Koepf, Strikman

J/ψ "Trajectory"

Extraction of effective pomeron trajectory: fit $d\sigma/dt(W_{\gamma p})$ at fixed t

$$\frac{d\sigma}{dt} = f(t)\, W_{\gamma p}^{4\alpha(t)-4}$$
$$\alpha(t) = \alpha_0 + \alpha' t$$

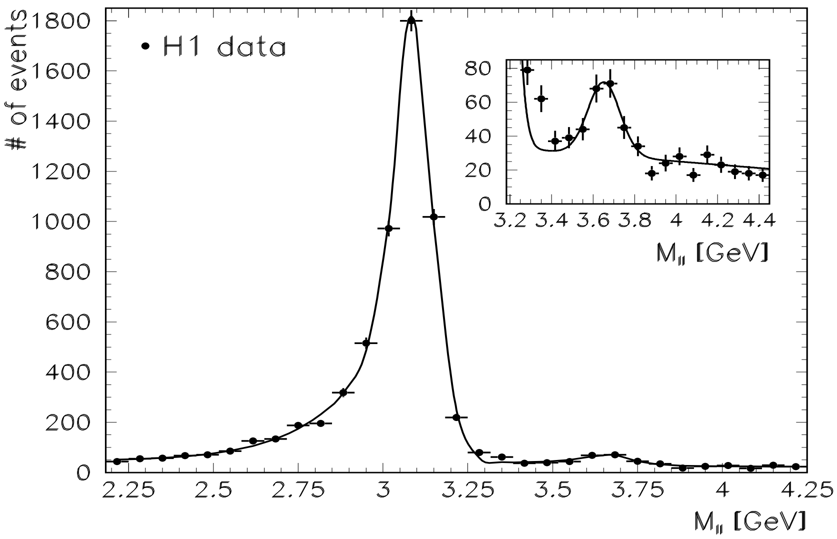


- trajectory lies between 'hard' and 'soft' pomeron

$\Rightarrow$ 'soft' pomeron alone ruled out

- α_0 in agreement with BFKL prediction

Elastic Photoproduction $\gamma p \to \psi' p$

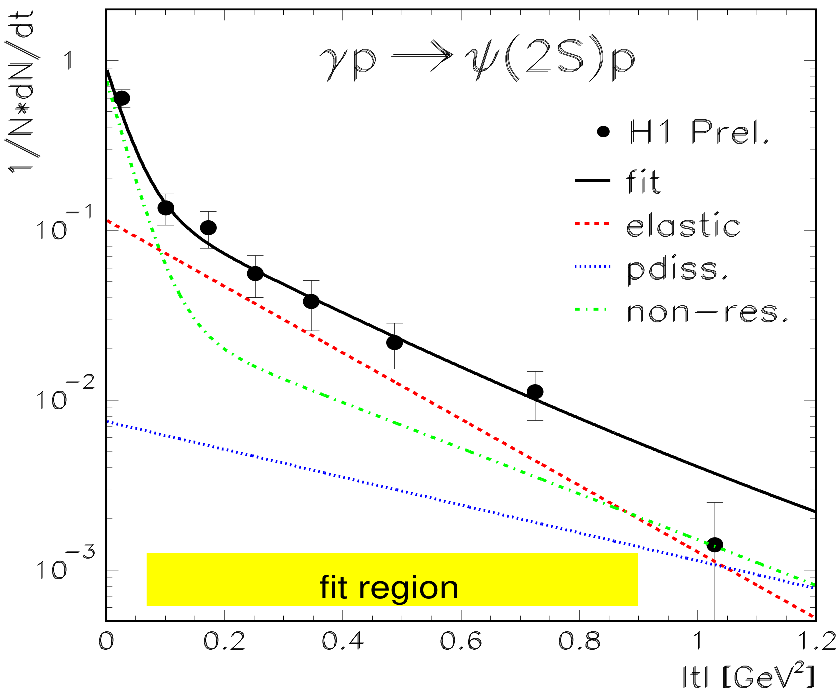


H1 preliminary

$Q^2 < 1\,\mathrm{GeV}^2$

$40 < W_{\gamma p} < 150\,\mathrm{GeV}$

$38\,\mathrm{pb}^{-1}$



$$b_{\psi'} = 4.5 \;\; \pm 1.2 \;\; {}^{+1.4}_{-0.7} \;\; \mathrm{GeV}^{-2}$$

for comparison: $b_{J/\psi} = 4.73 \pm 0.25^{+0.30}_{-0.39}\,\mathrm{GeV}^{-2}$

Expectations:

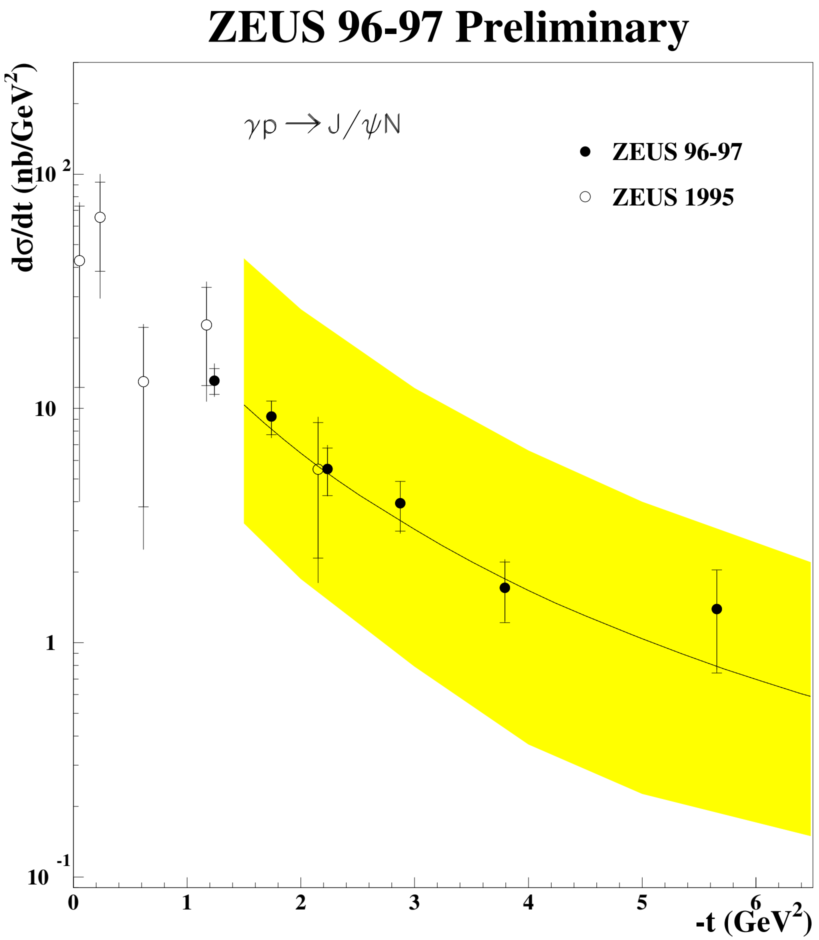
optical interpretation:
$b \propto R_p^2 + R_{\mathrm{VM}}^2$, $R_{\psi'} \approx 2R_{J/\psi} \;\Rightarrow$ $\qquad b_{\psi'} \gg b_{J/\psi}$

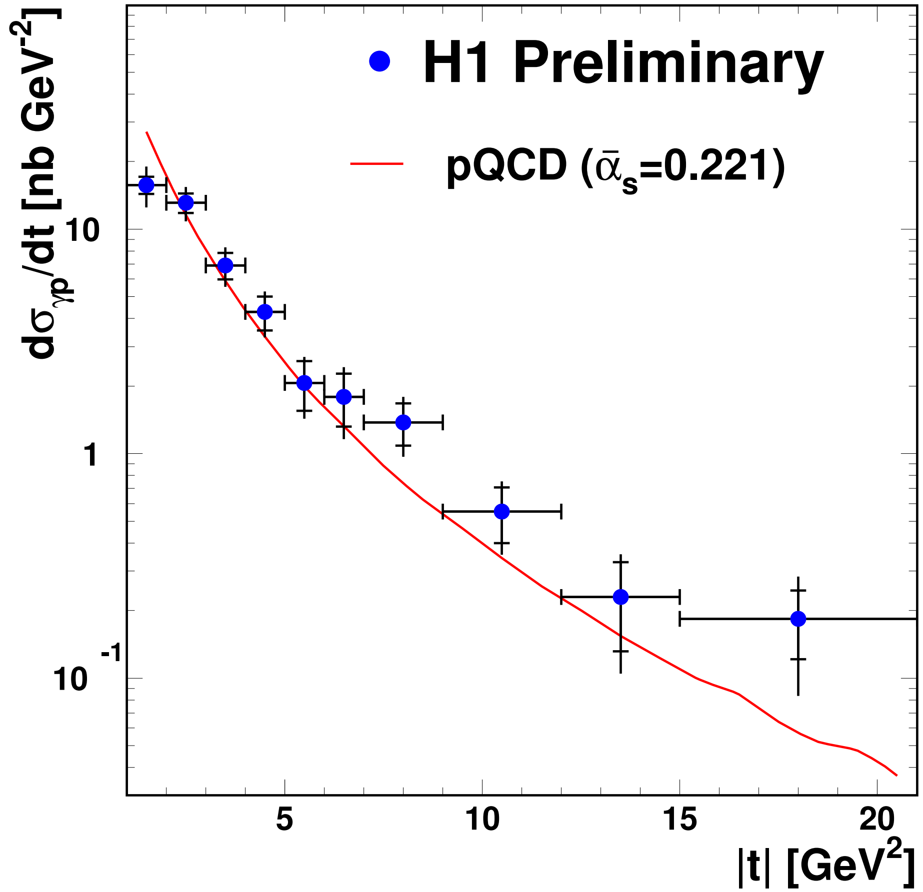
Nemchik et al.:
Colour Dipole Picture, ψ' wave function $\qquad b_{\psi'} \lesssim b_{J/\psi}$

J/ψ production at high $|t|$

$Q^2 < 0.02\,\text{GeV}^2$, $80 < W < 120\,\text{GeV}$

$Q^2 < 1\,\text{GeV}^2$, $50 < W < 160\,\text{GeV}$





- pQCD model based on BFKL ev. (Bartels et al.) describes data well
- large normalization uncertainties: α_s, scale
- $|t|^{-n}$, $n \sim 1.7$

Conclusions

INELASTIC J/ψ Production

- NLO CSM gives good description of data
- NLO/LO $\sim$ Factor 10 at $p_t \sim 4$ GeV
- CCFM + unintegrated gluon dens. (CASCADE) : adequate
- COLOUR OCTET CONTRIBUTIONS
  - Large z: too high
  - NRQCD Resummation at high z: higher p_t cut necessary
  - $p_t > 2$ GeV seems sufficient?
  - Low z: first look, sensitive to resolved contributions
  - Polarisation: promising; but sort out reference frames!!

Conclusions

ELASTIC J/ψ and ψ' Production

- $W_{\gamma p}$ range for J/ψ photoproduction extended nearly to kinematical limit
- pQCD calculations can describe $W_{\gamma p}$ and Q^2 dependence of elastic J/ψ production
- sensitvity to gluon density of the proton
- trajectory measurement excludes 'soft' pomeron
- t slope of J/ψ described up to 20 GeV^2 by pQCD/BFKL approch
- b slope of ψ' comparable to J/ψ