Vector meson production at HERA

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On behalf of the H1 and ZEUS collaborations

- Introduction/Motivations
- Kinematics
- Theory
- Results (inel J/ψ, excl φ and J/ψ, and dipion)
- Conclusions

Introduction

Is the production of vector mesons understandable in terms of pQCD?

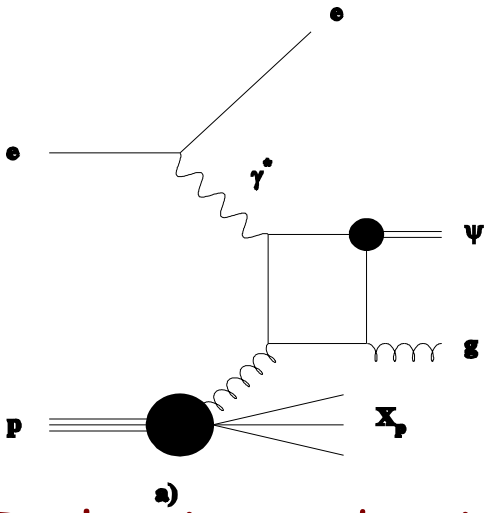
- mass of heavy quarks provides a hard scale (b,c,s), if not is there another one available?
- QCD factorisation theorem applicable
- separation between pQCD and npQCD
- strong sensitivity to gluons in proton

How is charm produced?

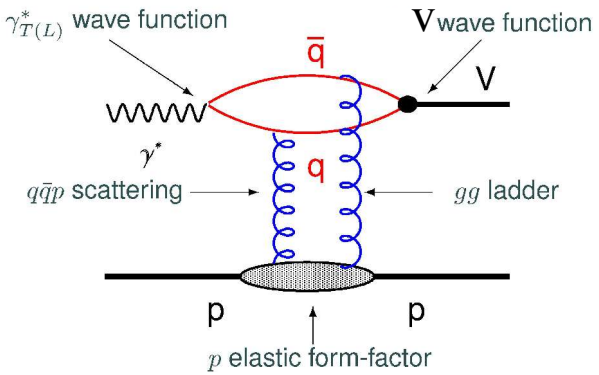
- Color Singlet Model at Tevatron is order of magnitude too small $\Rightarrow$ non-relativistic QCD (NRQCD)

How does the photon fluctuates in $q\ \bar{q}$ pairs?

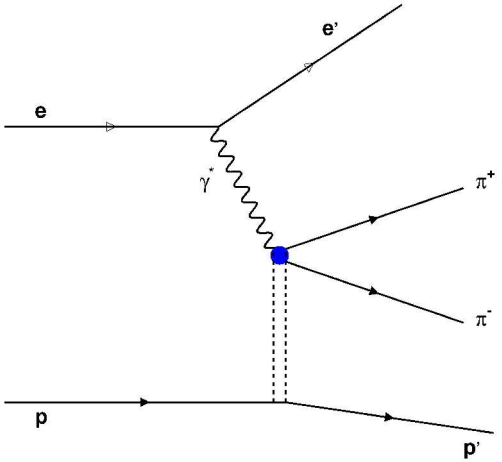
Processes



Inelastic production



Exclusive production



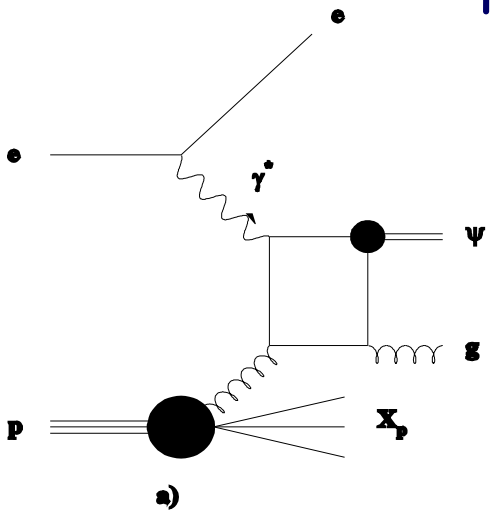
Non-resonant production

Theory, inelastic production

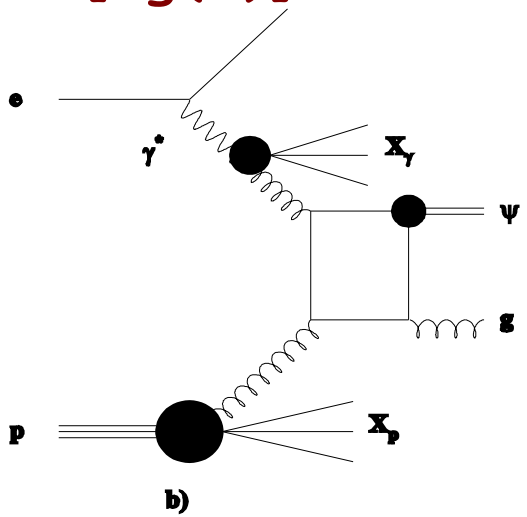
Charmonium can be created in colour singlet (CS) or colour octet (CO) state

➢In colour singlet model (CSM) only CS states contribute

- cross sections proportional to [xg(x)].



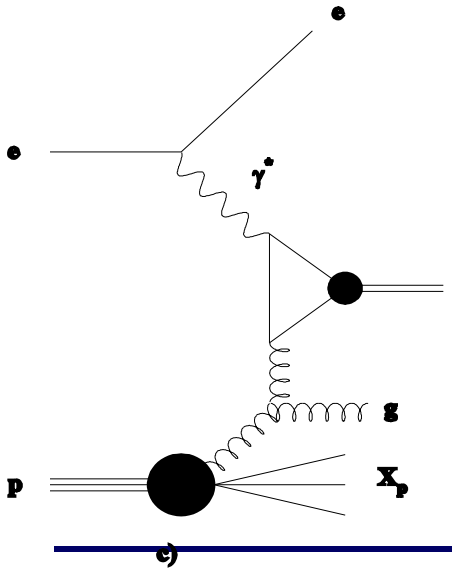
- colour **singlet** model
- direct photon



- colour **singlet** model
- resolved photon

Theory, inelastic production

- In the framework of non-relativistic QCD (NRQCD) both CS and CO contributions exist (parametrization derived from hadroproduction data).
  - CO essential to explain high-p_T charmonium production (pp)
  - p_T spectrum of J/ψ in $\gamma\gamma$ interaction at LEP2 reproduced
  - NRQCD does not explain J/ψ polarization pattern (CDF)
- cross sections proportional to [xg(x)]



- colour **octet** model

coloured

charm pair

- Evolving into colourless meson
- direct photon

Inelasticity

$z = (p_{J/\psi} \cdot P)/(q \cdot P)$

$= E^*_{J/\psi}/E^*_{\gamma}$ in proton rest frame

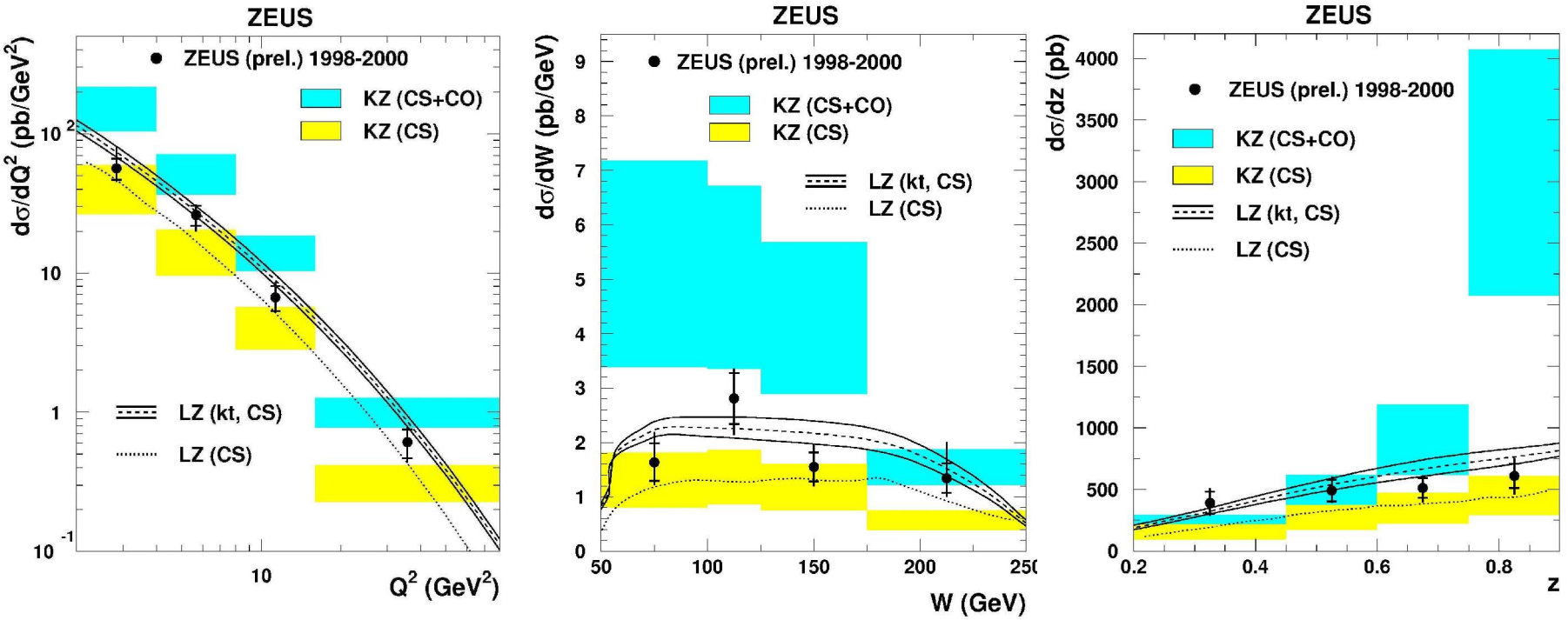
Rapidity

$Y_{J/\psi} = 1/2 \ln[(E+p_z)/(E-p_z)]$

Inelastic J/ψ production

1998-2000 data (L=73.3 pb^{-1}) $2<Q^2<80$ GeV^2, $50<W<250$ GeV, $0.2<z<0.9$, $-1.6<Y_{lab}<1.3$

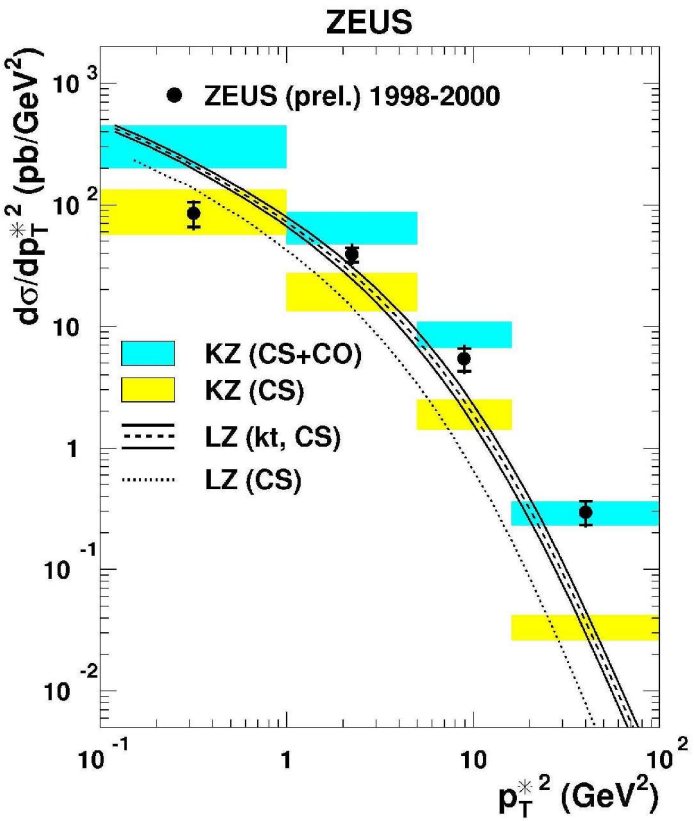
- missing resummation of soft terms for CS+CO

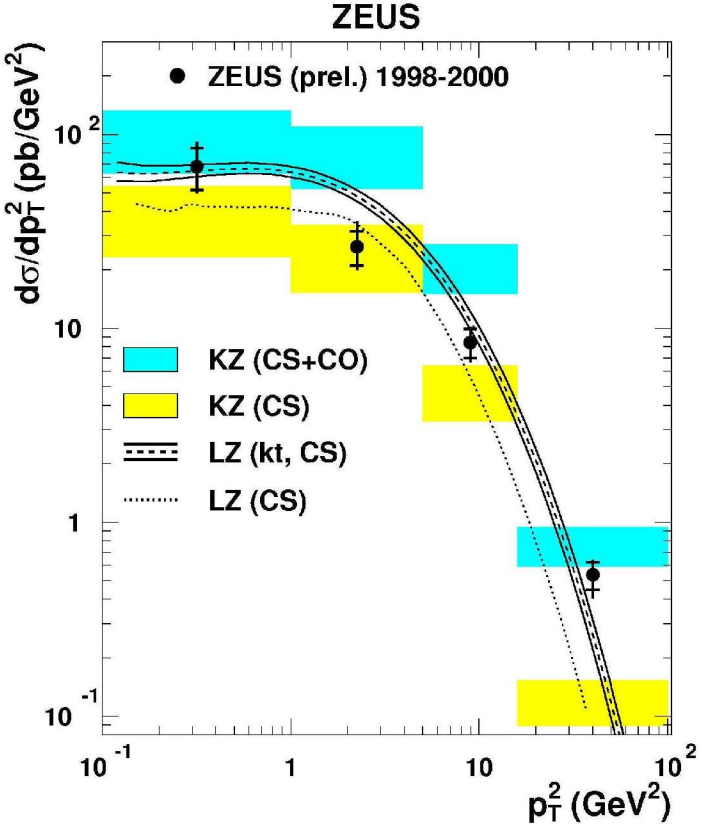


- CS below data but shape consistent with data, CS+CO above

Inelastic J/ψ production

theo-uncert m_c, renorm. and factor. scales

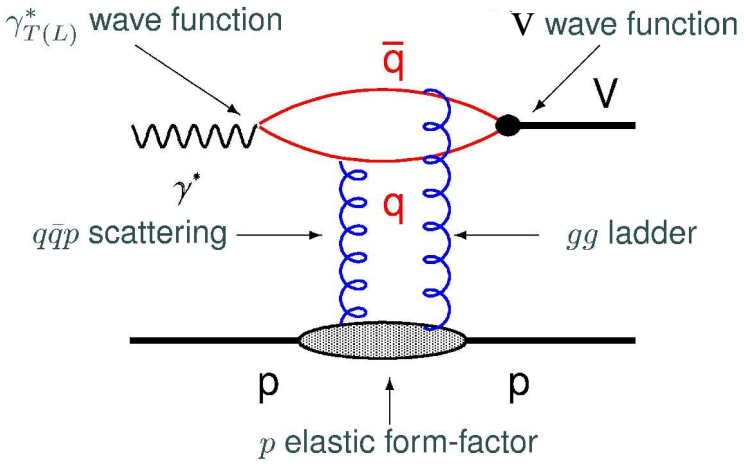




- CS vs p_t^2 too soft compared to data
- calculations based on k_T-fact. approach

reasonable description both in normalization and shape (LZ(k_T,CS)), but rather soft in p_t^2

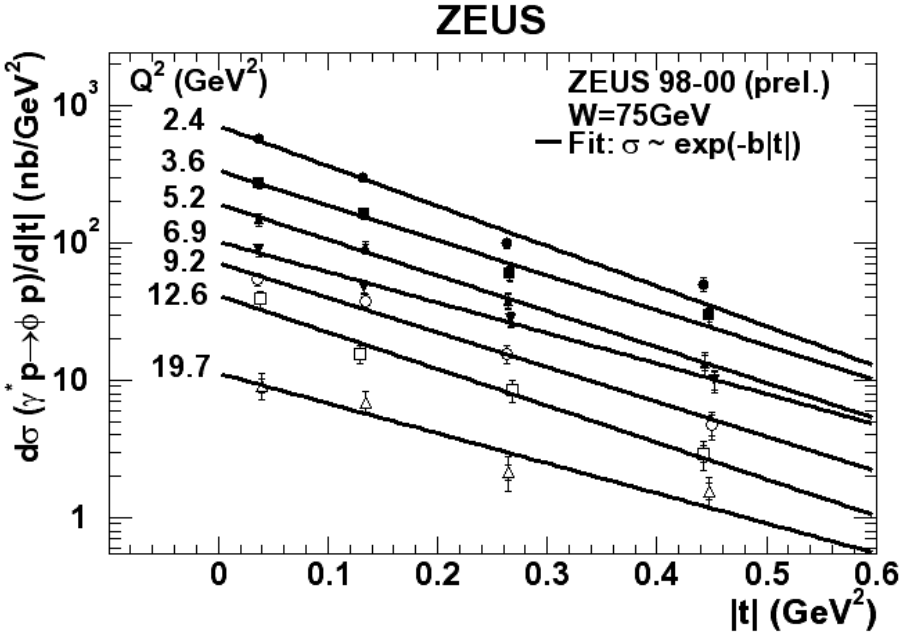
Theory, exclusive production

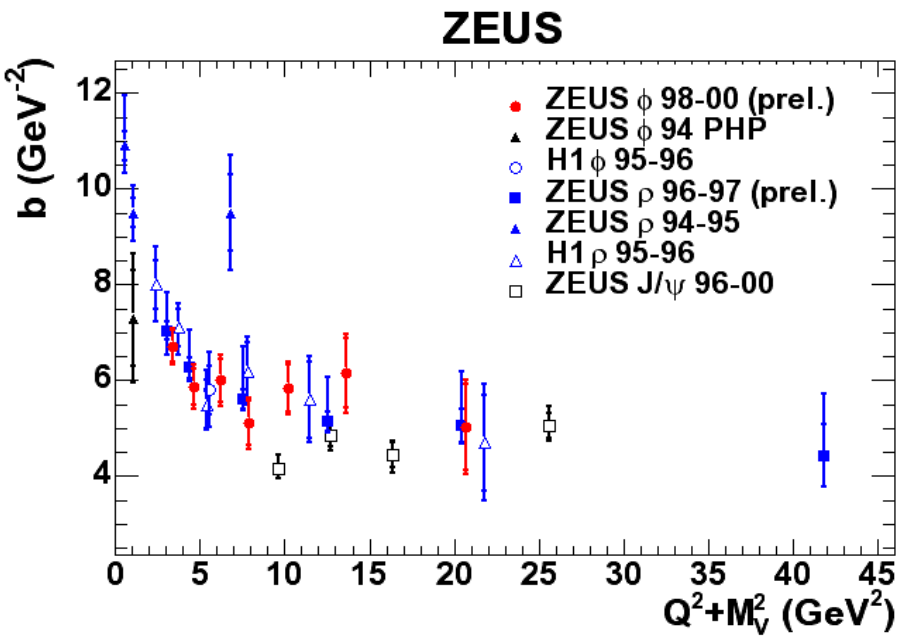


- cross sections proportional to $[xg(x)]^2$
  - cross sections proportional to W^2
  - gluon density rises at low x and large scale
- t-slope decreases as involved scale becomes large
  - transverse dimension of $q\bar{q}$ decreases at large scales

Exclusive φ production in DIS

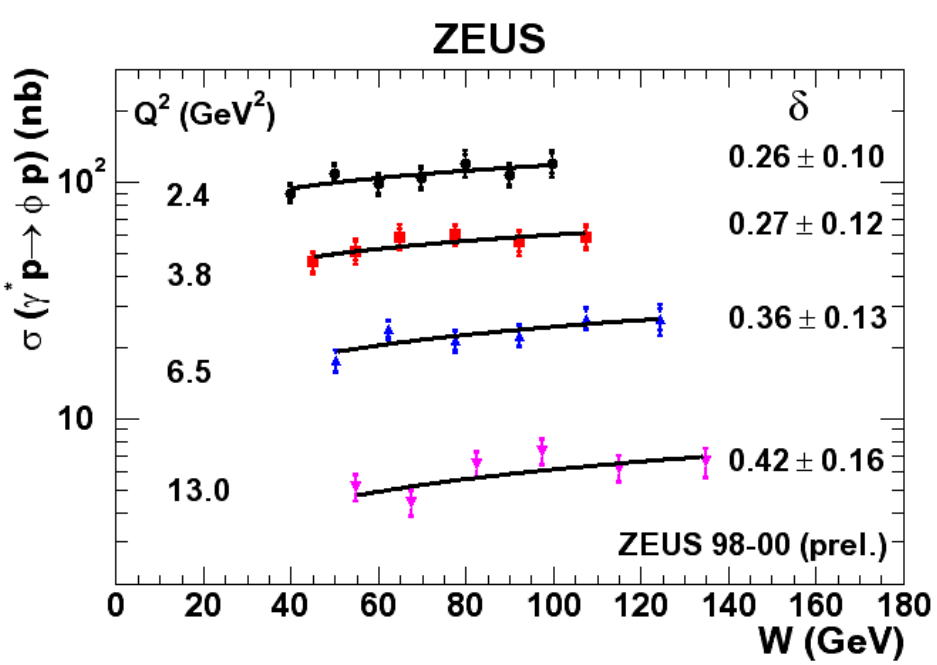
- $ep \to e\varphi p$, $(\varphi \to k^+k^-)$ 1998-2000 $e^{\pm}p$ data ($L=66.4\ pb^{-1}$)
- Large increase in statistics compared with previous results
- $2<Q^2<70\ GeV^2$, $-0.6(-1)<t<0\ GeV^2$, $35<W<145\ GeV$
- $d\sigma/dt \sim \exp(-b|t|)$
- data suggest scaling with $Q^2+M_V^2$
- decrease of b with $Q^2 \to$ high $Q^2 \Leftrightarrow$ small dipole size

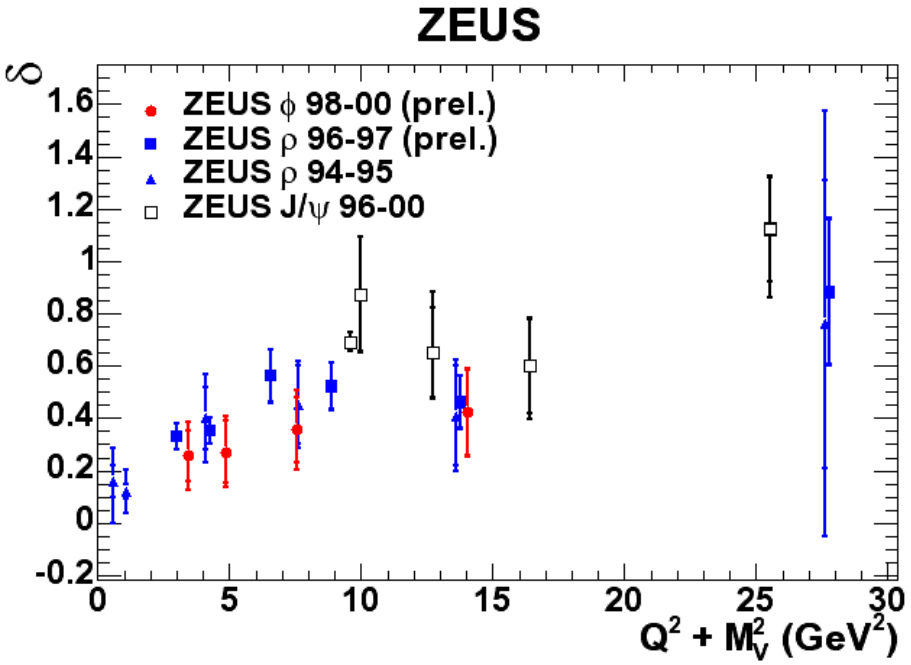




Exclusive φ production in DIS

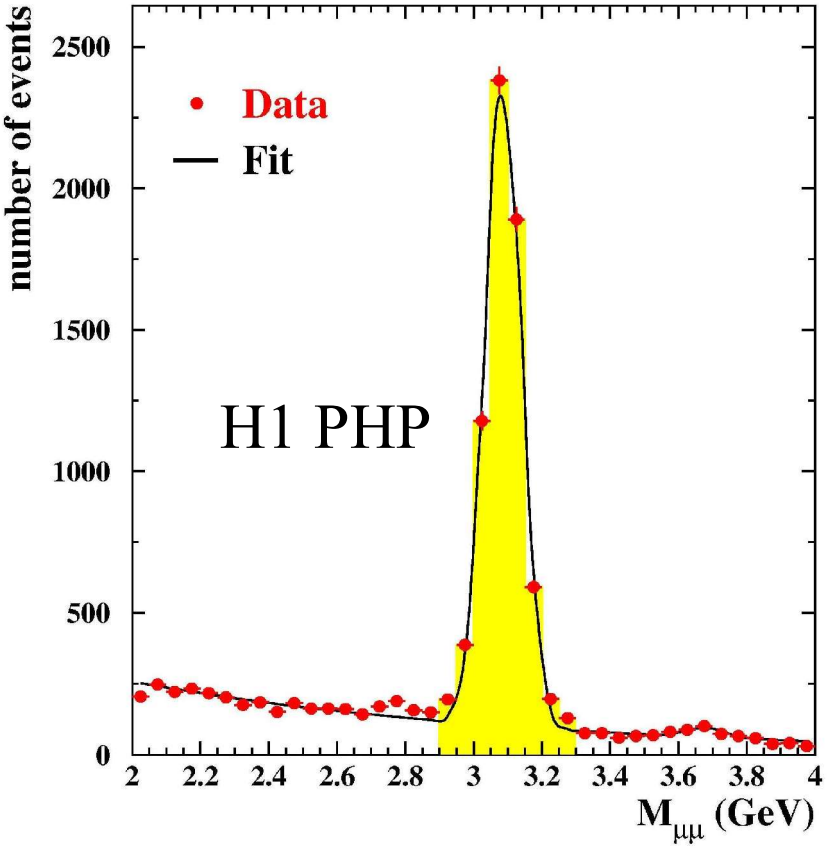
- fit to $\sigma \sim W^{\delta}$: δ varies as function of Q^2
- data further confirm scaling behaviour of cross section as seen from other vector mesons
- rise of δ with $Q^2+M^2_V$ observed:
  - ρ,φ: transition from soft to hard regime
  - J/ψ: hard already in photo-production

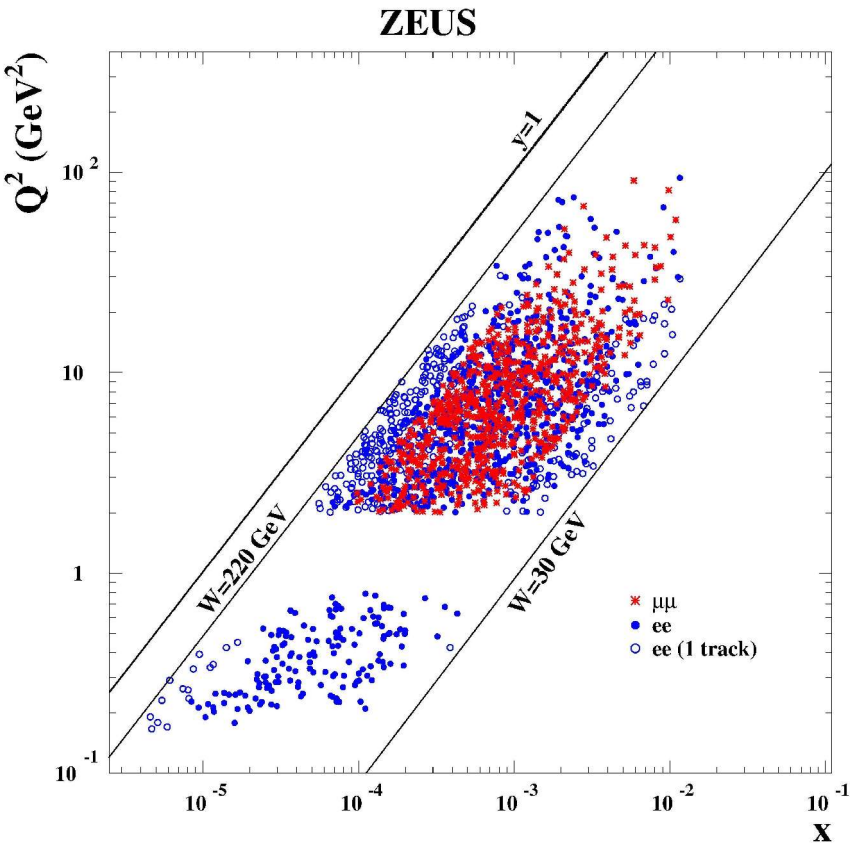




Exclusive J/ψ production

➢ep→eJ/ψp, J/ψ tagged both in the e^+e^- and $\mu^+\mu^-$ channels, in PHP, small Q^2 and DIS regimes

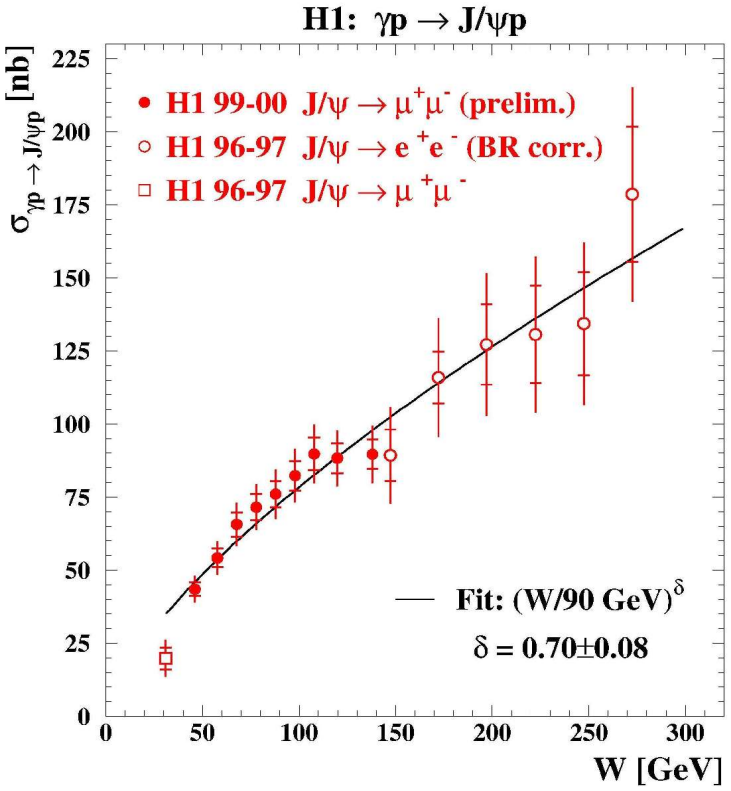


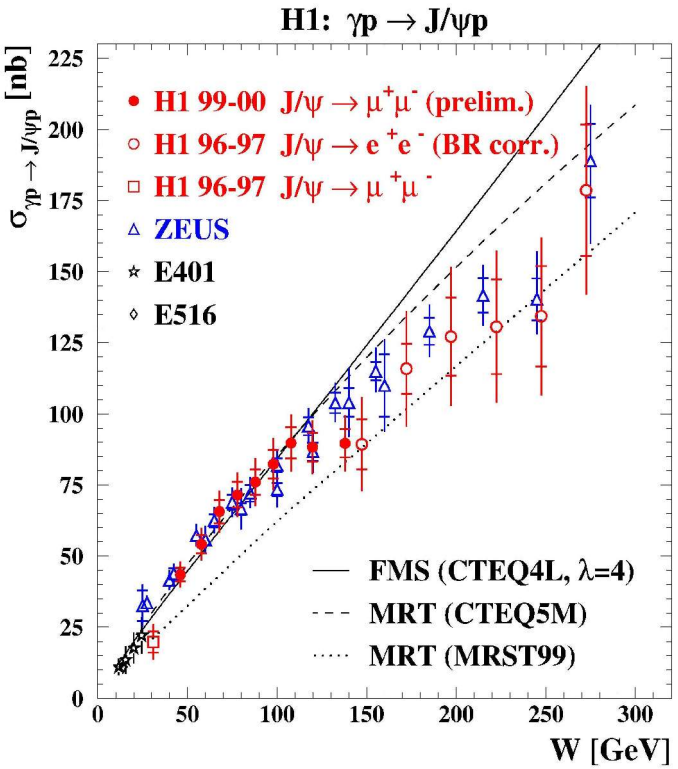


Exclusive J/ψ production

Photoproduction: $\sigma \propto W^{\delta}$

Q^2<1 GeV^2, 40<W<150 GeV, |t|<1.2 GeV^2 (L=54.8 pb^{-1})

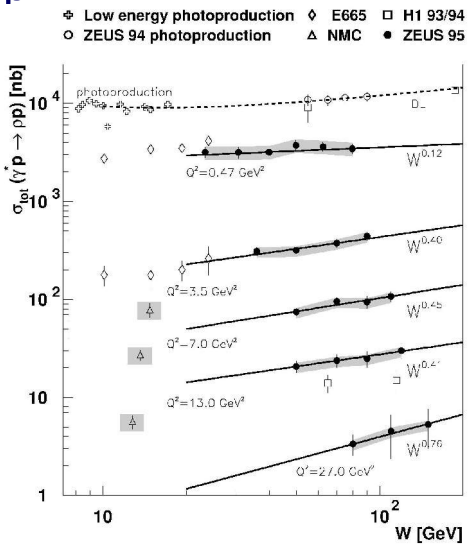




Exclusive J/ψ production

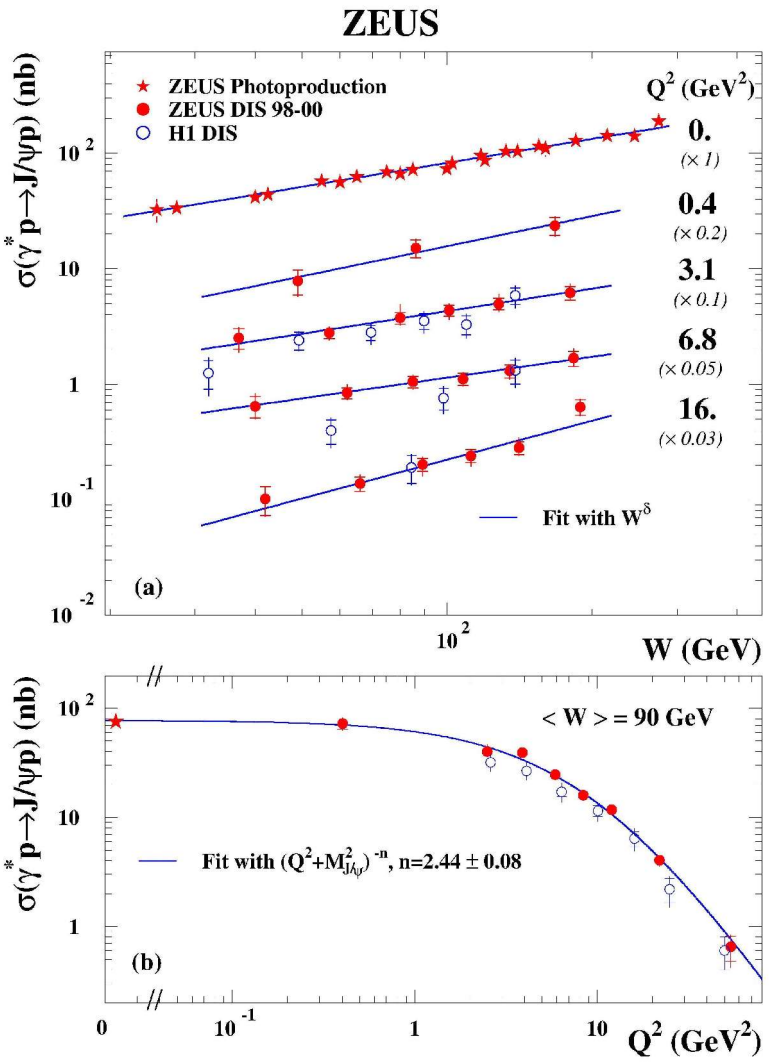
σ vs W in bins of Q^2

- $\sigma \propto W^{\delta}$, with δ=0.7
- No dependence of δ on Q^2
- Comparing with ρ



σ vs Q^2

- $\sigma \propto (Q^2+M^2_{J/\psi})^{-n}$
- At W=90 GeV, n=2.44±0.08



- 1999-2000 $e^{\pm}p$ data
- $0<Q^2<100$ GeV^2, -1.<t GeV^2, $30<W<220$ GeV

Exclusive J/ψ production

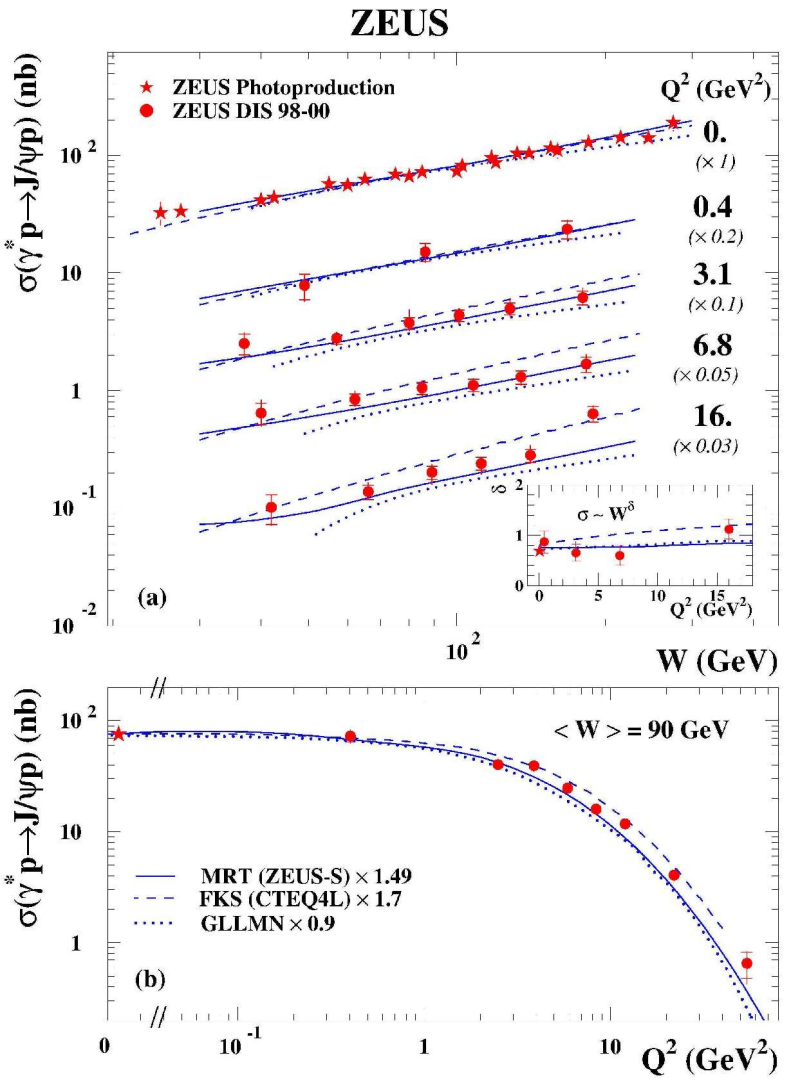
Comparison with QCD models

Martin, Ryskin, Teubner
Frankfurt, Koepf, Strikman
Gotsman, Levin, Lublisky, Maor, Naftali

models different in:

- Assumptions on c $\bar{c}$ wave function
- Corrections applied to LO calculations

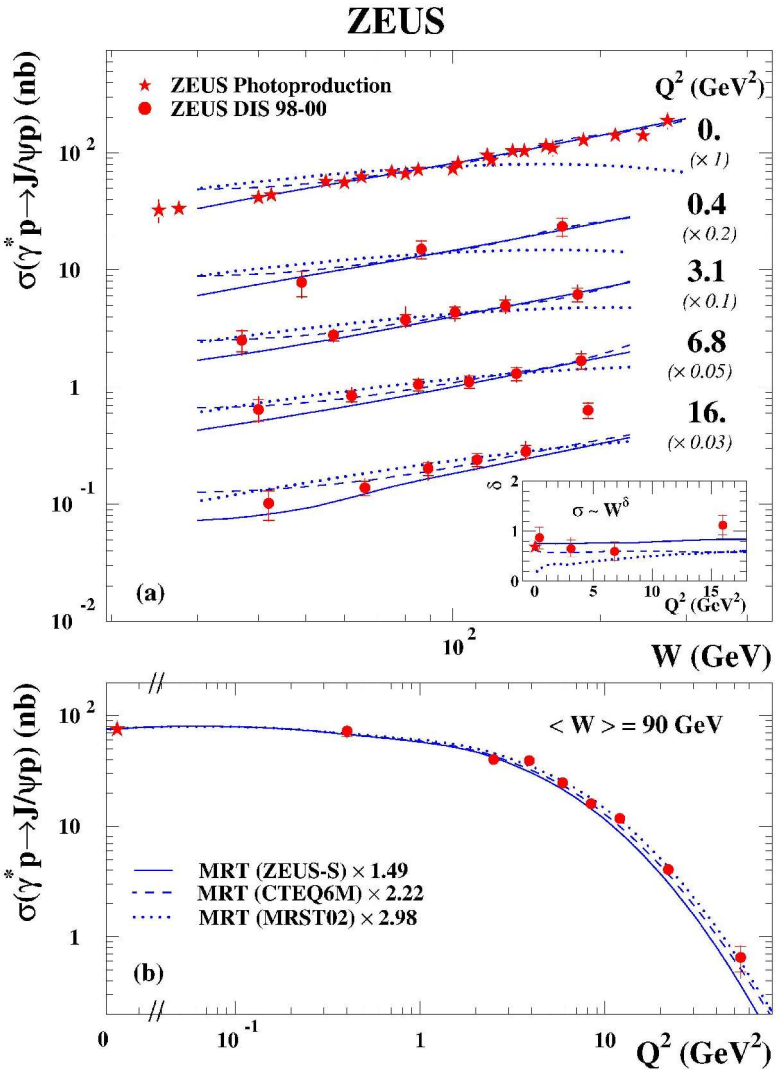
- Large uncertainty in normalization
- Models describe qualitatively data
- Rise of σ with W related to increase in gluon density at low x



Exclusive J/ψ production

Comparison for different PDFs within the MRT model

- CTEQ6M and ZEUS-S describe W and Q^2 dependence
- MRST02 has wrong shape in W (valence-like gluon)
- NLO needed



Exclusive dipion production $ep \to e\pi^+\pi^- p$

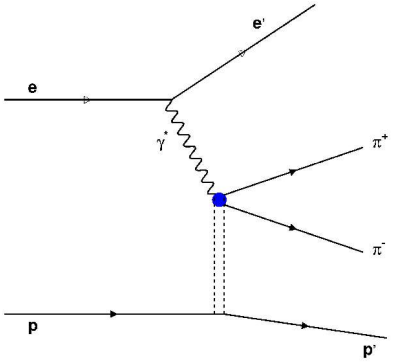
- 1999-2000 data (66 pb^{-1})
- $2<Q^2<20$ GeV^2,
  $1.2<M_{\pi\pi}<5$ GeV,
  $40<W<120$ GeV,
  -0.5 GeV$^2<t<0$
- Hadronic Light Cone Wave Function

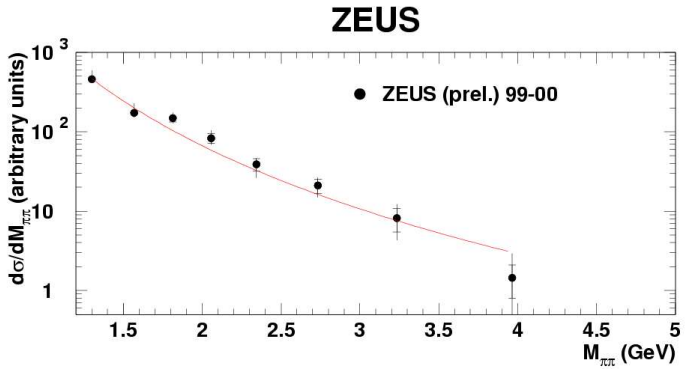
$$|\gamma>=a|\gamma_b>+b|l^+l^->+d|q\ \bar{q}>+...$$

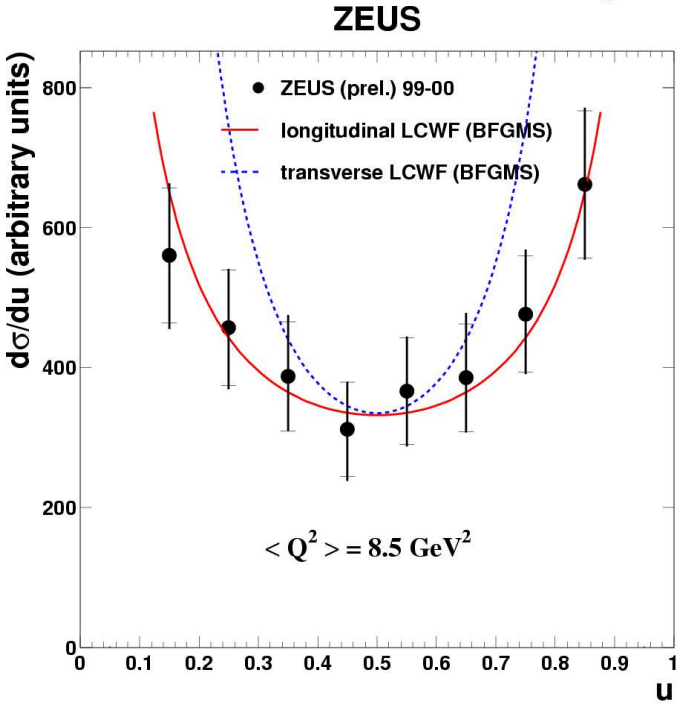
- $u=(E+p_{Z'})_{\pi+}/[(E+p_{Z'})_{\pi+}+(E+p_{Z'})_{\pi-}]$

(Z'=direction of the $\pi\pi$ system)
reflects the momentum share in $|q$ anti-$q>$

- $1/\sigma\ d\sigma/dM_{\pi\pi} \sim M_{\pi\pi}^{-4.5}$
- $d\sigma/du$ compatible with LCWF (Brodsky et al.)







Conclusions

Precise measurements in wide kinematic ranges have been presented

- pQCD models describe data
- where the low mass is not providing an hard scale, the presence of large Q^2's sets the scale (scaling of $\sigma \sim W^{\delta}$)
- data exhibit strong sensitivity to gluon density in proton (especially for exclusive J/psi production)
- full NLO calculations needed to constrain gluon
- consistency of data of exclusive production with phenomenological models
- puzzle of inelastic production of J/psi still unsolved
- consistency of dipion production with LCWF prediction for longitudinally polarized photons

Kinematics

$e(k)p(P) \rightarrow e(k')V(v)p(P')$

$Q^2 = -(k-k')^2$

$s = (k+P)^2$

$W^2 = (q+P)^2$

$y = (P \cdot q)/(P \cdot k)$

$x = Q^2/(2P \cdot q)$

$t = (P-P')^2$