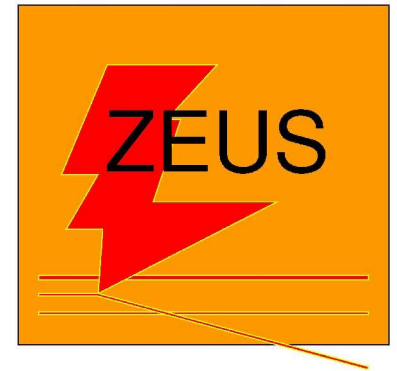


Vector meson production at HERA

ICHEP04 Beijing, China 16-22 August 2004

Nicola Coppola



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?

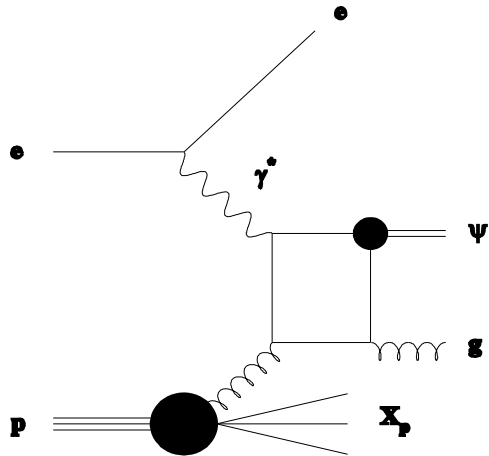
- mass of heavy quarks **provides** a hard scale (b,c,s), if not is there another one available?
- QCD factorisation theorem **applicable**
- **separation** between pQCD and npQCD
- **strong sensitivity** to gluons in proton

How is charm produced?

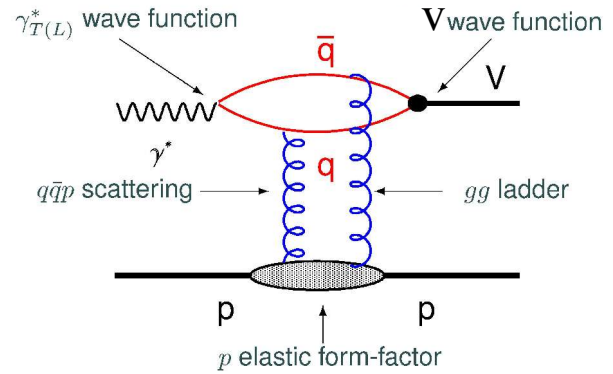
- Color Singlet Model at Tevatron is order of magnitude too small \Rightarrow non-relativistic QCD (NRQCD)

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

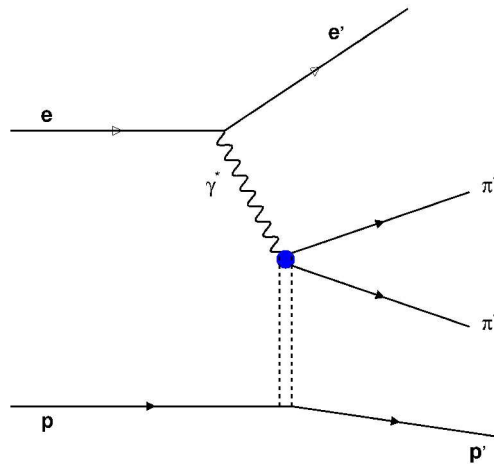
Processes



a)
Inelastic production



Exclusive production

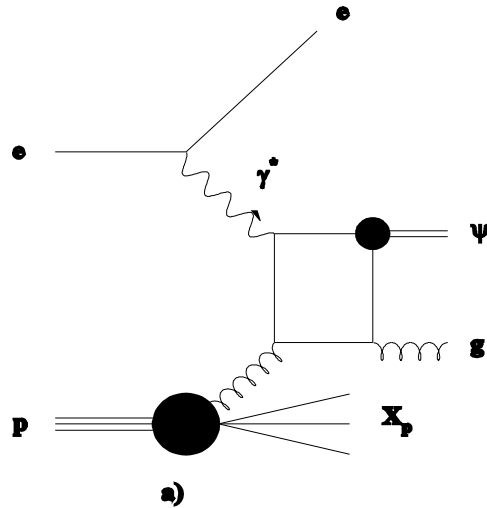


Non-resonant production

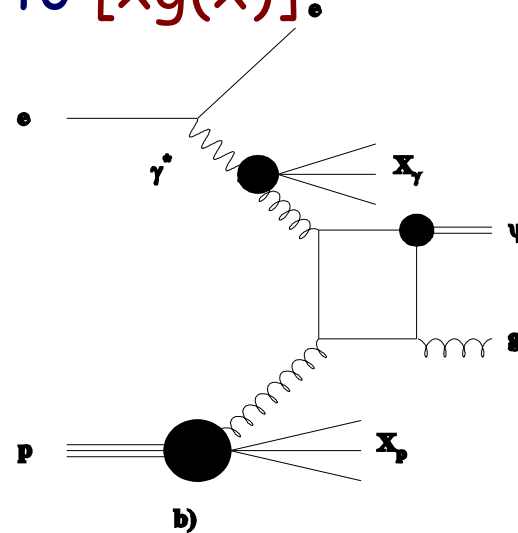
Theory, inelastic production

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 $[xg(x)]$.



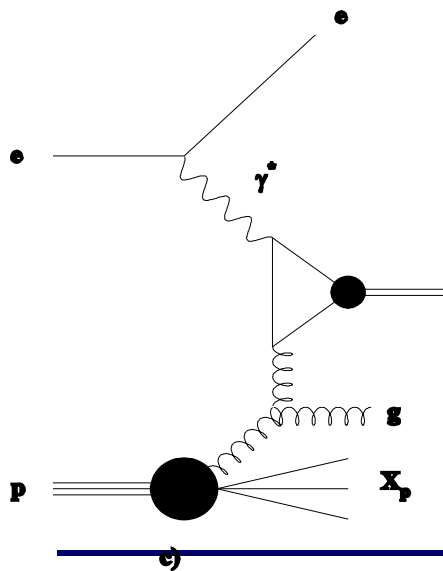
- colour **singlet** model
- direct photon



- 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

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

$$= E_{J/\psi}^* / E_{\gamma}^* \text{ in proton rest frame}$$

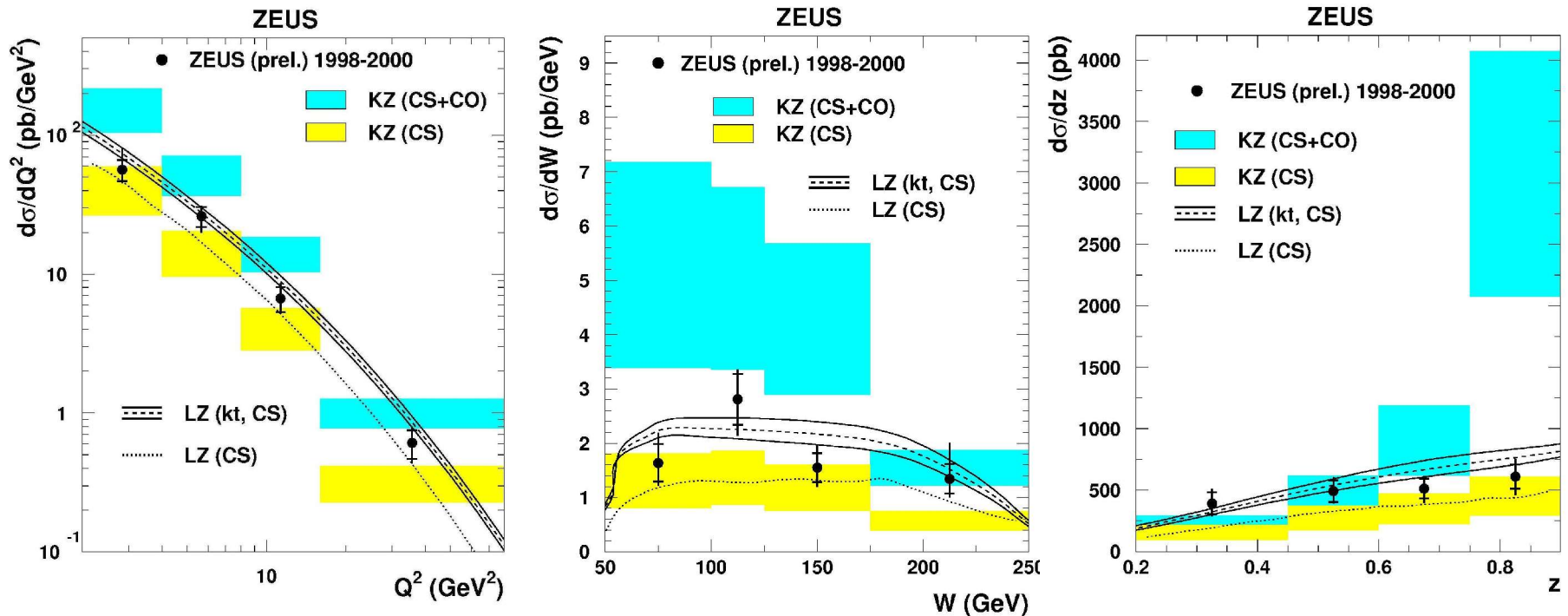
Rapidity

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

Inelastic J/ψ production

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

➤ 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_+^2 too

soft compared
to data

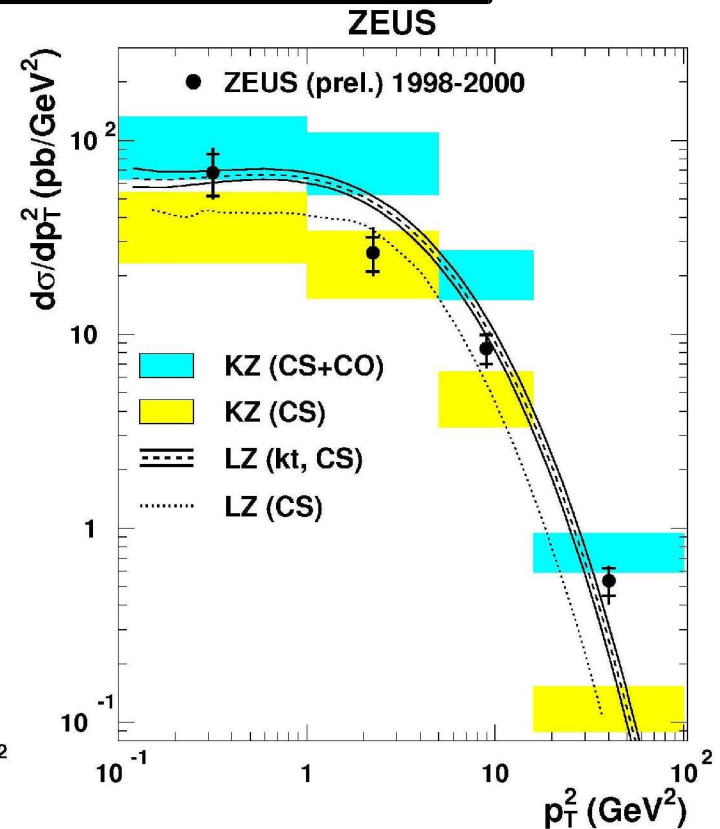
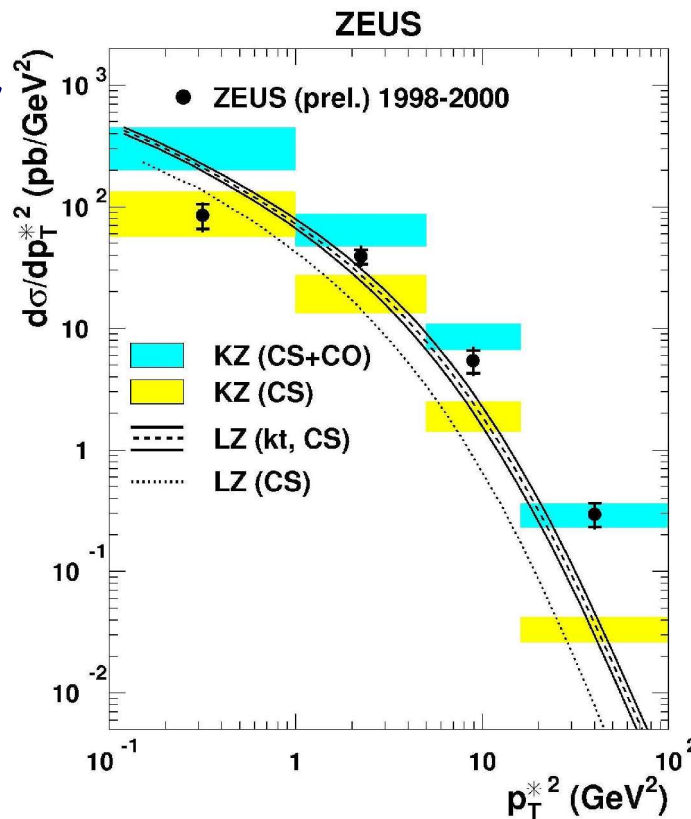
➤ calculations

based on

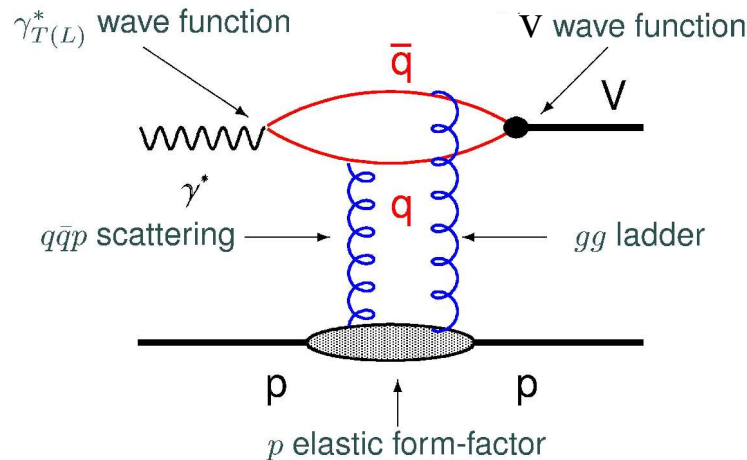
k_T -fact. approach

reasonable description both in normalization and shape ($LZ(k_T, CS)$),

but rather soft in p_+^2



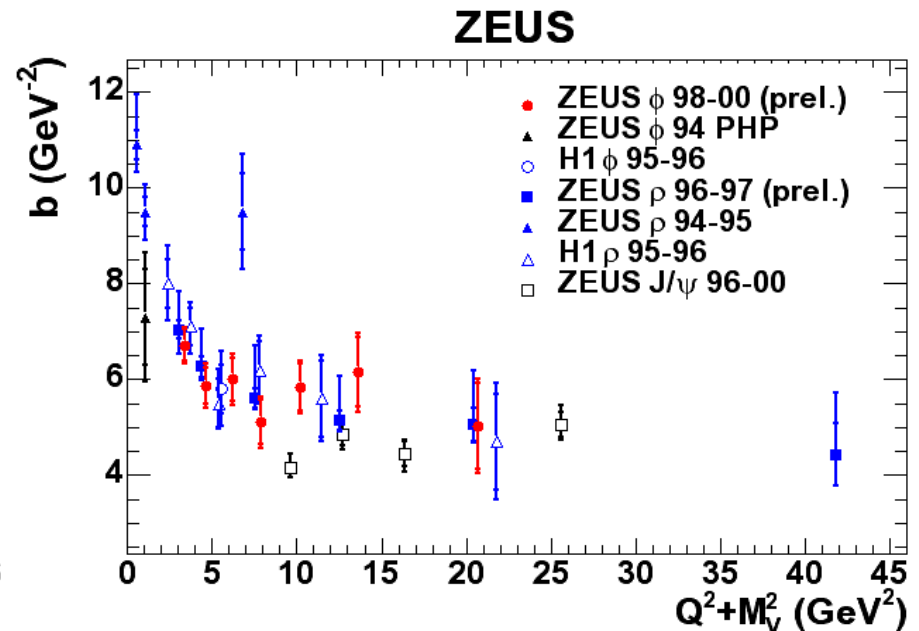
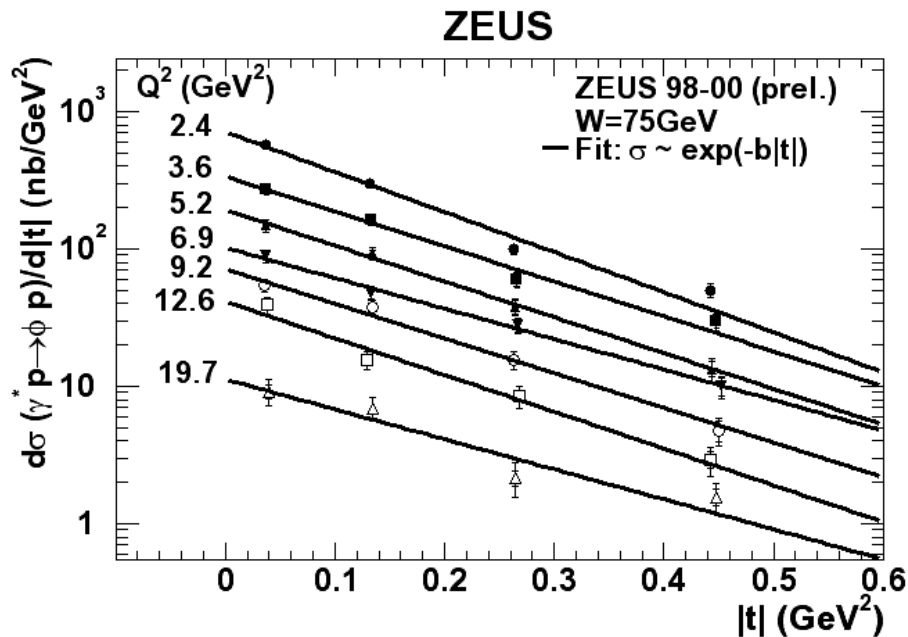
Theory, exclusive production



- 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

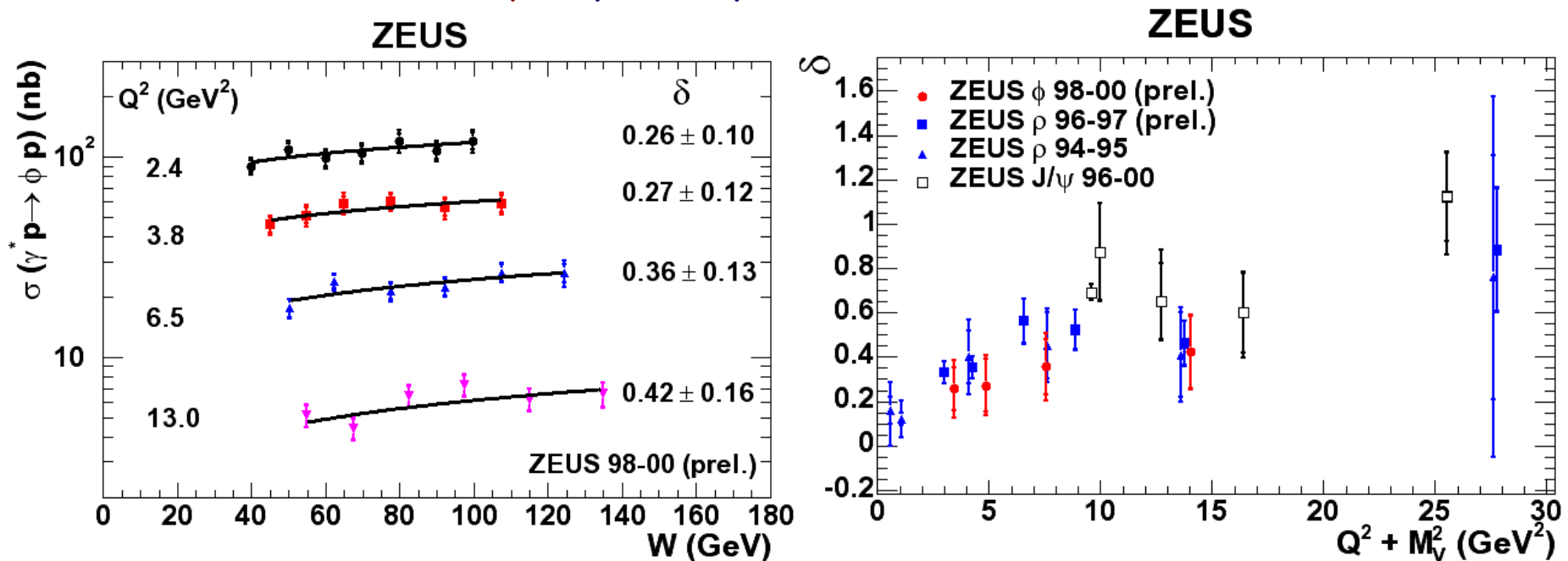
Exclusive ϕ production in DIS

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



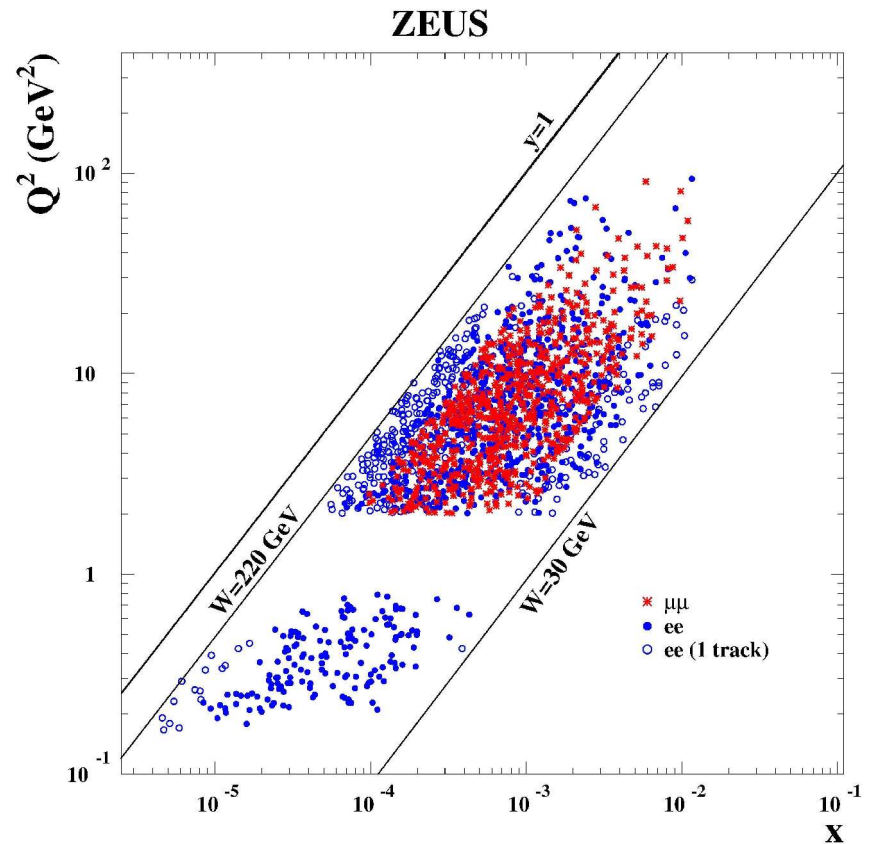
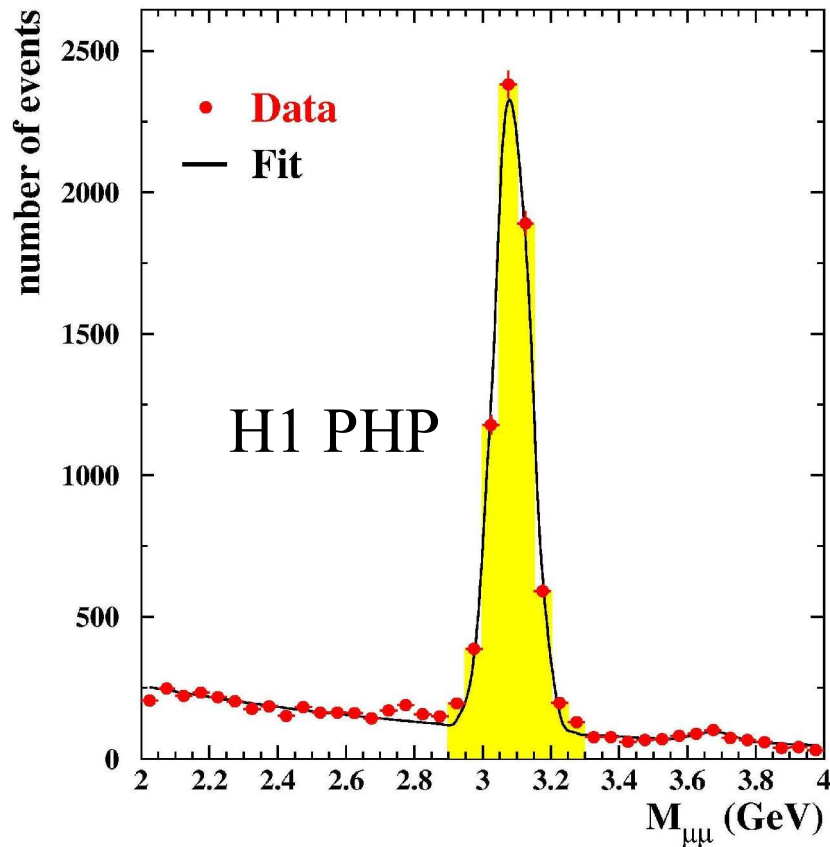
Exclusive ϕ production in DIS

- 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 $Q^2 + M_V^2$ observed:
 - ρ, ϕ : transition from soft to hard regime
 - J/ψ : hard already in photo-production



Exclusive J/ψ production

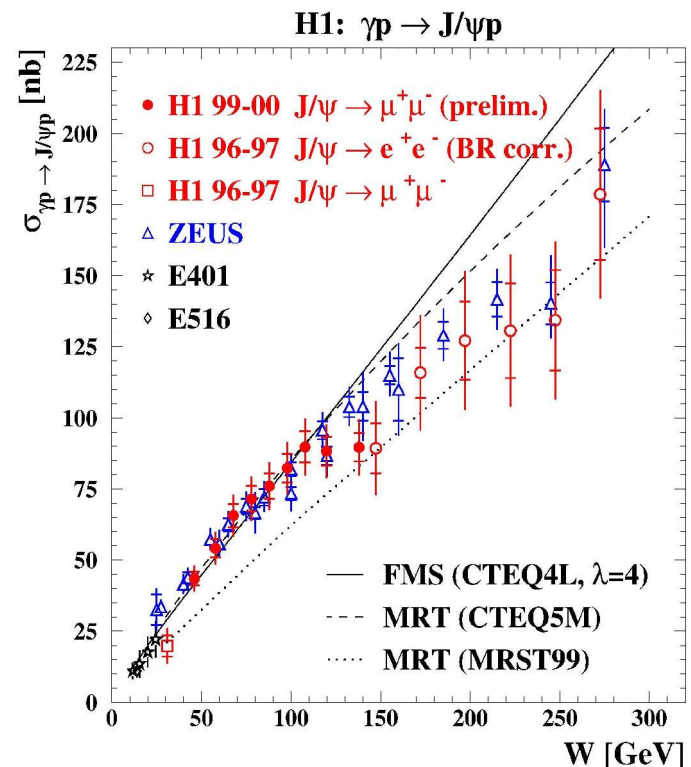
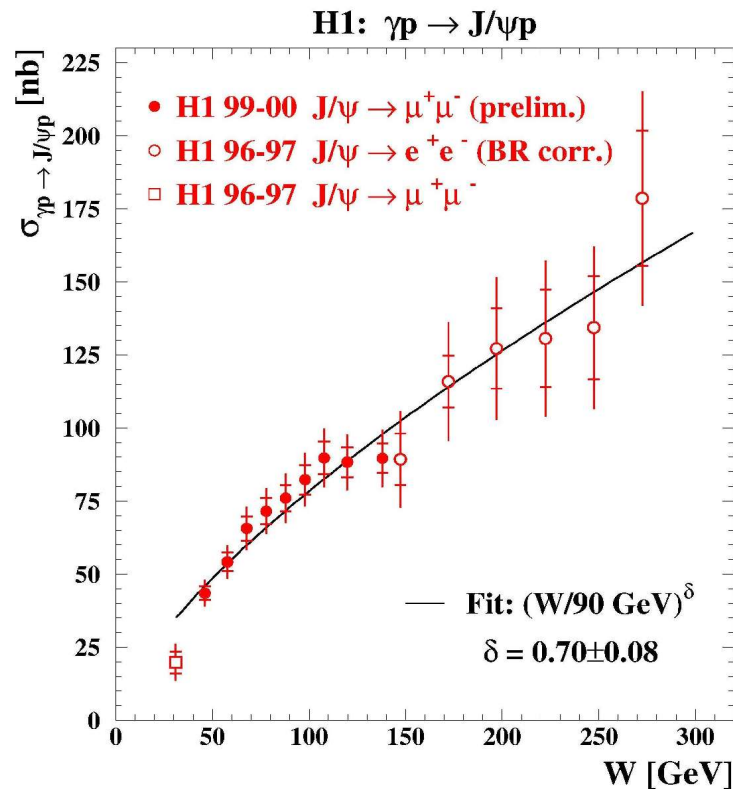
➤ $ep \rightarrow eJ/\psi p$, J/ψ tagged both in the e^+e^- and $\mu^+\mu^-$ channels, in PHP, small Q^2 and DIS regimes



Exclusive J/ψ production

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

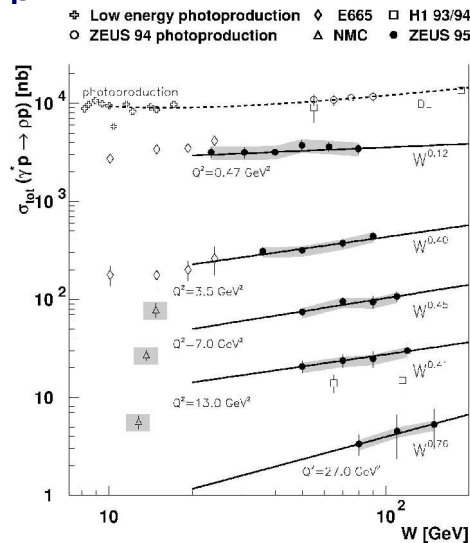
$Q^2 < 1 \text{ GeV}^2$, $40 < W < 150 \text{ GeV}$, $|t| < 1.2 \text{ GeV}^2$ ($L = 54.8 \text{ pb}^{-1}$)



Exclusive J/ψ production

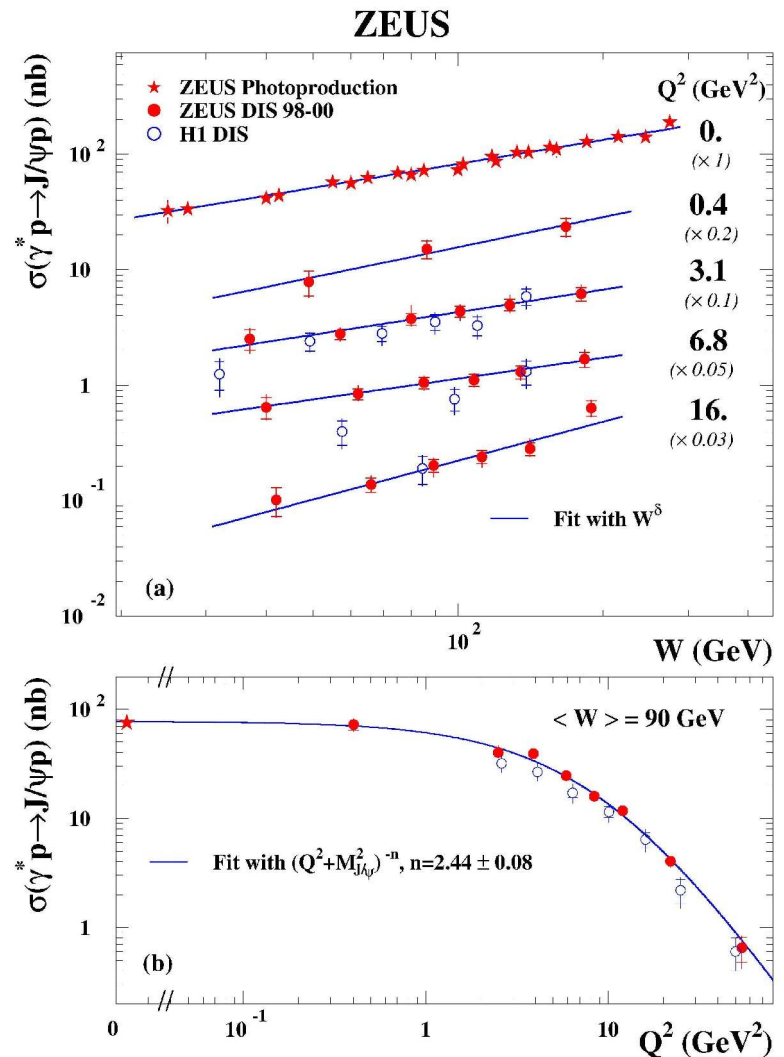
σ vs W in bins of Q^2

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



σ vs Q^2

- $\sigma \propto (Q^2 + M_{J/\psi}^2)^{-n}$
- At $W=90$ GeV, $n=2.44 \pm 0.08$
- 1999-2000 e^+p data
- $0 < Q^2 < 100$ GeV², $-1 < t < 1$ GeV², $30 < W < 220$ GeV



Exclusive J/ψ production

Comparison with QCD models

Martin, Ryskin, Teubner

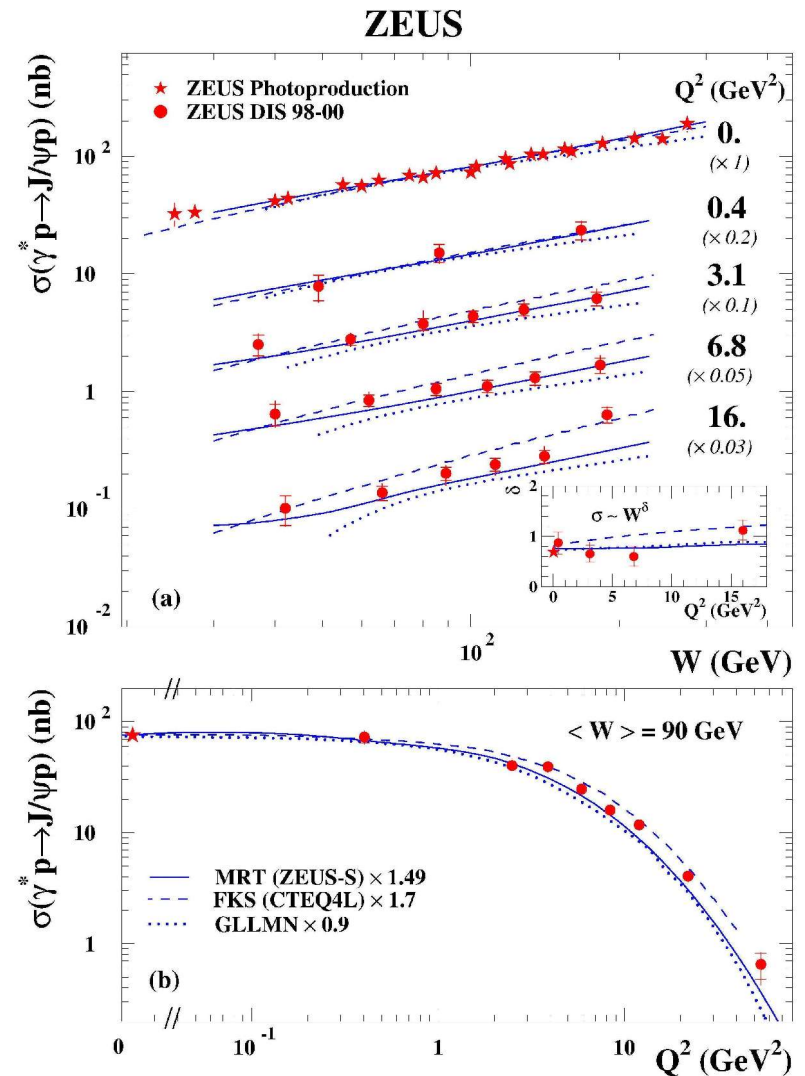
Frankfurt, Koepf, Strikman

Gotsman, Levin, Lublisky, Maor, Naftali

models different in:

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

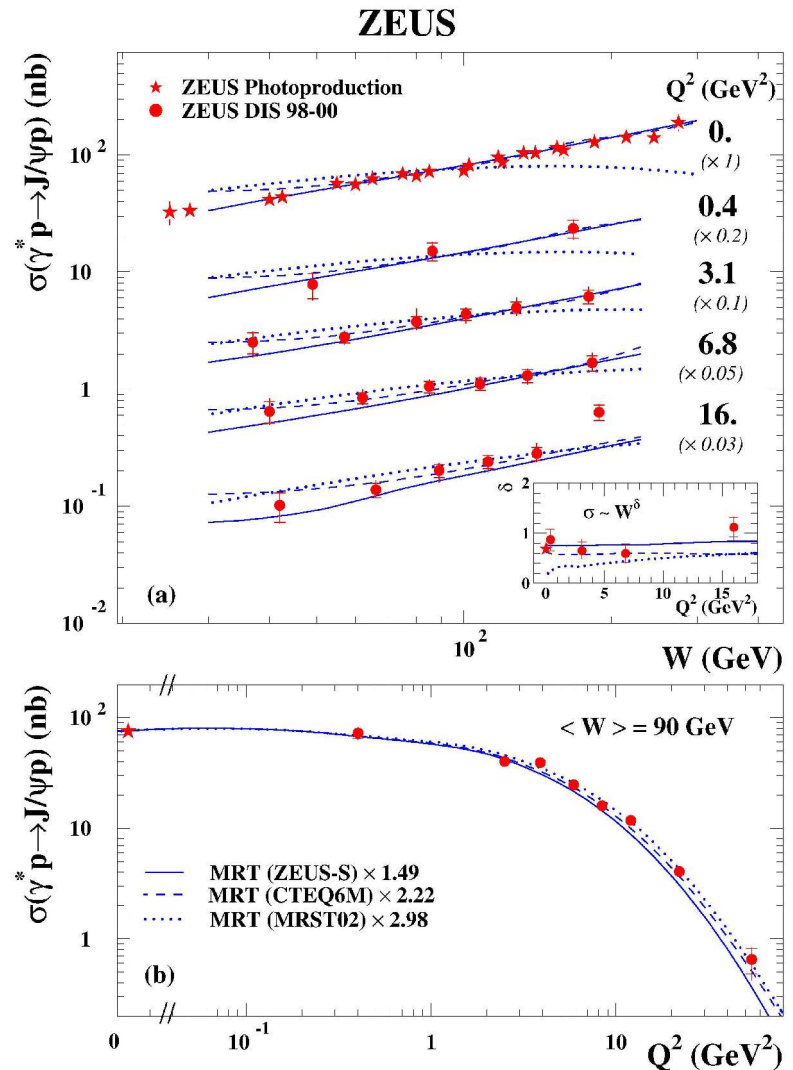
- Large uncertainty in normalization
- Models describe qualitatively data
- Rise of σ with W related to increase in gluon density at low x



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 $ep \rightarrow e\pi^+\pi^-p$

➤ 1999-2000 data (66 pb^{-1})

➤ $2 < Q^2 < 20 \text{ GeV}^2$,

$1.2 < M_{\pi\pi} < 5 \text{ GeV}$,

$40 < W < 120 \text{ GeV}$,

$-0.5 \text{ GeV}^2 < t < 0$

➤ Hadronic Light Cone Wave Function

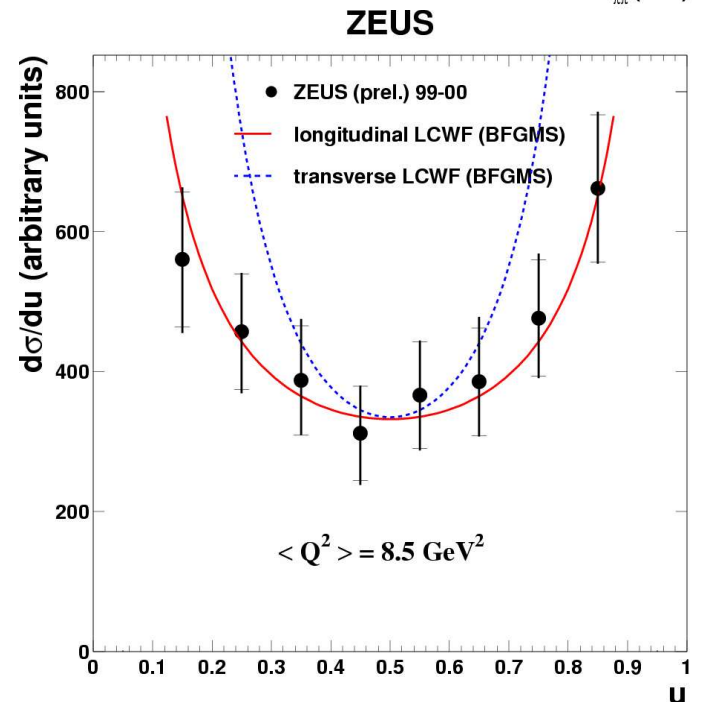
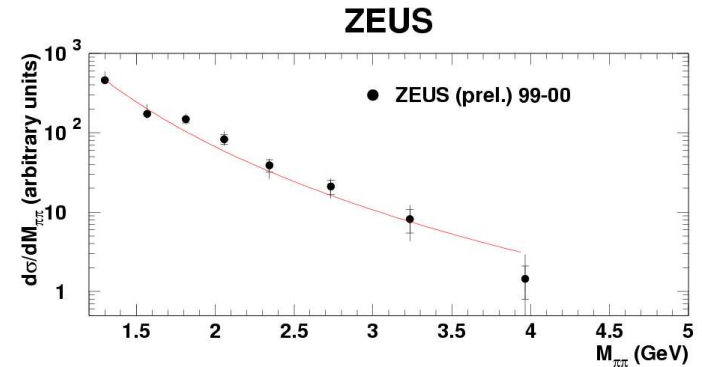
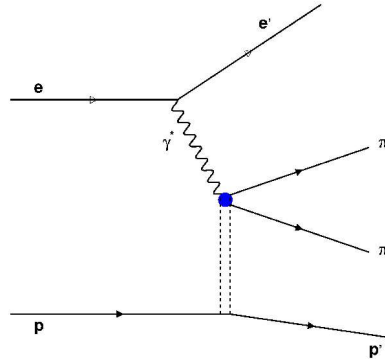
$$|\gamma\rangle = a|\gamma_b\rangle + b|l^+l^-\rangle + d|q\bar{q}\rangle + \dots$$

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

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

➤ $1/\sigma \frac{d\sigma}{dM_{\pi\pi}} \sim M_{\pi\pi}^{-4.5}$

➤ $d\sigma/du$ **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

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

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

$$s = (k + P)^2$$

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

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

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

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

