Diffractive Vector Meson Production at HERA

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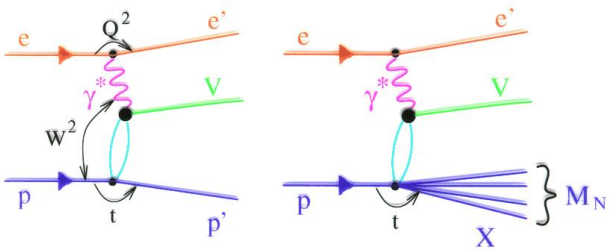
for H1 and ZEUS

- Introduction
- Vector Meson Photoproduction
- Vector Meson Production at low and high Q^2
- Conclusions

Introduction

Vector Meson production in ep scattering:



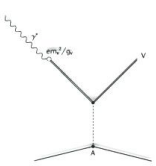
$V = \rho, \omega, \phi, \rho', J/\psi, \psi', \Upsilon$

At HERA we have large coverage in:
Q^2: 10^{-10} - 30 GeV^2 (photon virtuality)
W: 20 - 200 GeV ($\gamma^* p$ c.m.s energy)
$|t|$: 0 - 5 GeV^2 (squared mom. transfer at the p vertex)

$\Longrightarrow$ HERA is a unique tool to study Vector Meson production

Theoretical status

Regge theory and Vector Meson Dominance

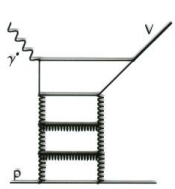


exchange of soft $\mathbb{P}$ trajectory
$\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} t$
$= 1.08 + 0.25t$ (DL)

What do we expect for Vector Meson production ?

- weak energy dependence $\sigma(W) \propto \frac{W^{4(\alpha_{\mathbb{P}}(0)-1)}}{b} \approx W^{0.22}$
- shrinkage of the forward peak $\frac{d\sigma}{dt} \propto \exp bt$
  $b = b_0 + 2\alpha'_{\mathbb{P}} \ln W^2$
- s-channel helicity conservation (SCHC)

Models based on pQCD; need hard scale (Q^2,M_V,t)

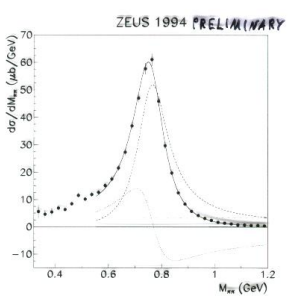


Different models:
Pomeron modeled
as a system of gluons

Predictions:

- strong energy dependence $\sigma(W) \propto [xg(x, Q^2)]^2$
- Q^2 and W dependence of $R = \sigma_L/\sigma_T$

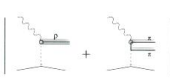
ρ photoproduction



$50 < W < 100$ GeV
$|t| < 0.5$ GeV^2

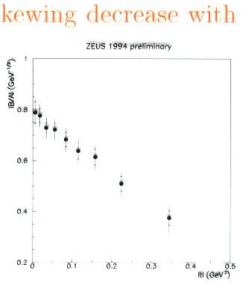
Mass spectrum is skewed

Söding model:



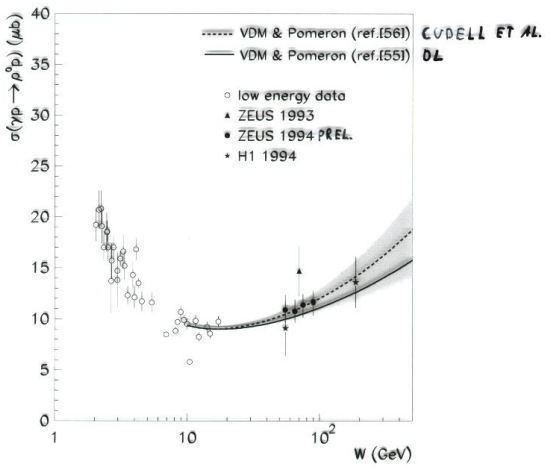
$$d\sigma/dM_{\pi\pi} = \left| A \frac{\sqrt{M_{\pi\pi} M_\rho \Gamma_\rho}}{M^2_{\pi\pi} - M^2_\rho + i M_\rho \Gamma_\rho} + B \right|^2$$

Amount of skewing decrease with increasing $|t|$



expected by Söding model

ρ photoproduction

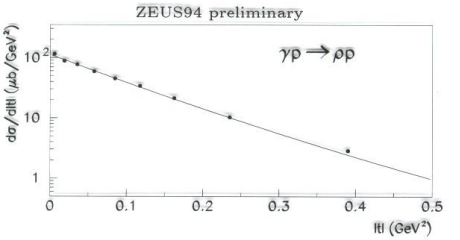


Fit to ZEUS94 prel. data only: $\sigma \propto W^{\epsilon}$

$\epsilon = 0.16 \pm 0.06^{+0.11}_{-0.14}$ (ZEUS prel.)

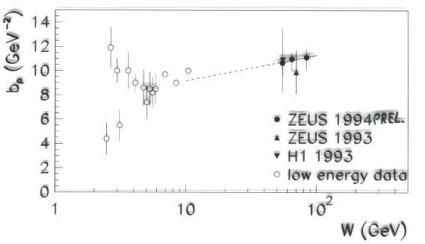
$\Longrightarrow$ consistent with soft $\mathbb{P}$ prediction

ρ photoproduction



Fit: e^{bt+ct^2}

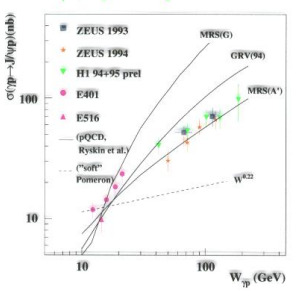
$b = 10.9 \pm 0.3^{+1.0}_{-0.5}$ GeV^{-2}, $c = 2.7 \pm 0.9^{+1.9}_{-1.7}$ GeV^{-4}



Fit to the ZEUS94 prel. data only:
$b = b_0 + 2\alpha'_{\mathbb{P}} \ln W^2$

$\alpha'_{\mathbb{P}} = 0.23 \pm 0.15^{+0.10}_{-0.07}$ GeV^{-2} (ZEUS prel.)

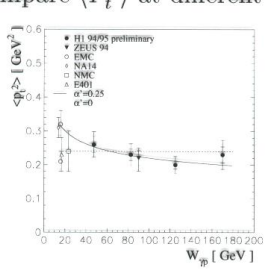
J/ψ photoproduction



Strong W dependence of σ for J/ψ photoproduction

Compatible with models based on pQCD ($\sigma \propto [xg(x,Q^2)]^2$)
Hard scale given by J/ψ mass

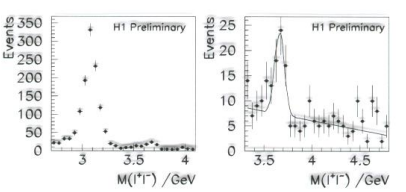
Compare $\langle P_t^2 \rangle$ at different W:



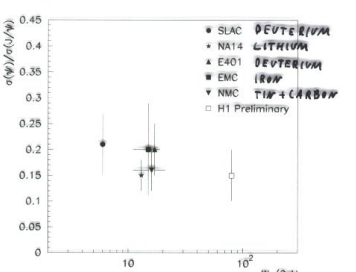
Shrinkage ?

ψ' production

H1: $\psi'(\psi(2S))$ identified through
$\psi' \to \mu^+\mu^-/e^+e^-$ and $\psi' \to J/\psi\pi^+\pi^-$
Signal for the 2 prong mode:



ψ' cross section:

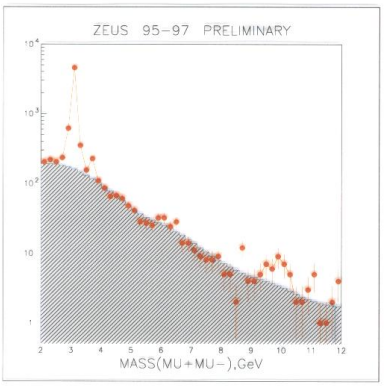


$\frac{\sigma(\psi')}{\sigma(J/\psi)} = 0.15 \pm 0.05$ (H1 prel.)
at W=80 GeV

compatible with fixed target measurements

Υ production

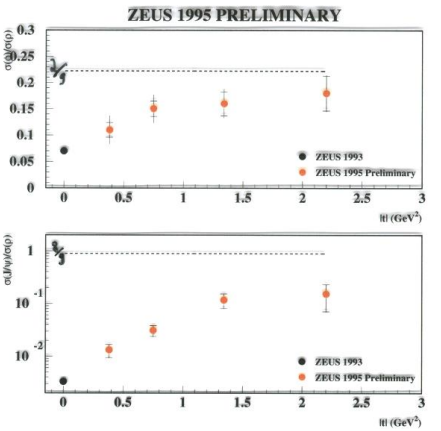
ZEUS: Υ measured in:
$\Upsilon \to \mu^+\mu^-$ ($\approx$ 20 events)



cross section (BR 2.48%):
$\sigma(\gamma p \to \Upsilon N, M_N \lesssim 4GeV) = 0.9 \pm 0.3 \pm 0.3$ nb (prel.)
for $80 < W < 280$ GeV
$O(1\%)$ of J/ψ photoproduction cross section

VM photoproduction at high $|t|$

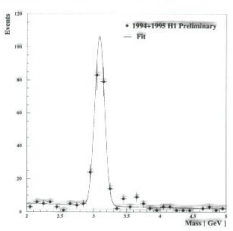
ZEUS: Measurement of the cross section for ρ, ϕ and J/ψ production at different values of $|t|$
$70 < W < 120$ GeV, $Q^2 < 0.01$ GeV^2
at high $|t|$ mainly $\gamma p \to VN$



Evidence for $|t|$ providing a hard scale

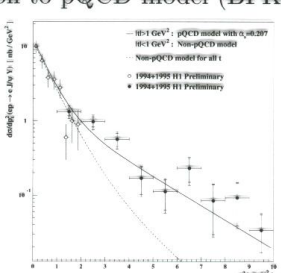
J/ψ photoproduction at high $|t|$

H1: measure $ep \to eJ/\psi N$, $J/\psi \to \mu^+\mu^-$



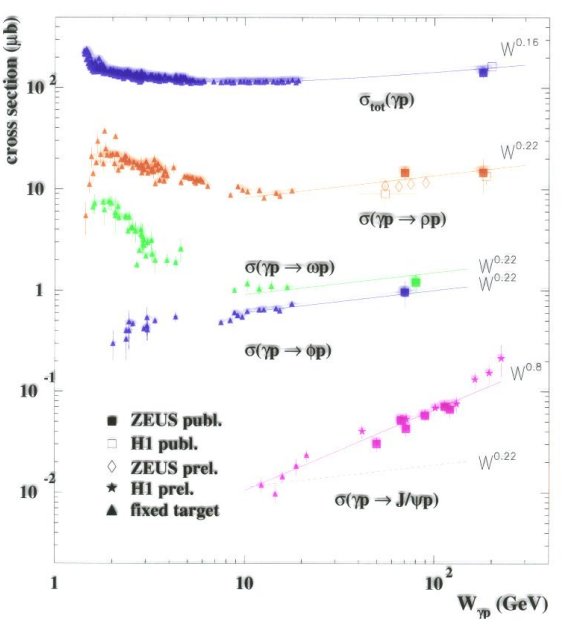
$30 < W < 150$ GeV
$1 < P_t^2 < 10$ GeV^2

Cross section:
$\sigma(ep \to eJ/\psi Y)|_{|t|>1\text{GeV}^2} = 4.1 \pm 0.3 \pm 0.6$ nb
Comparison to pQCD model (BFKL formalism):



pQCD model (Bartels et al.) describes well
t and W dependence

Summary: photoproduction of VM

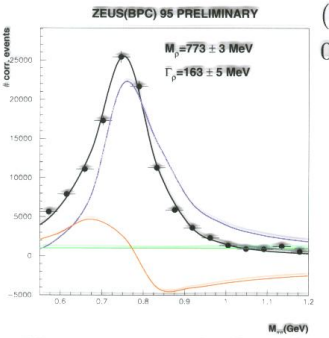


Summary: photoproduction of VM

- Photoproduction of light VM(ρ,ω,ϕ) shows the features typical of soft diffractive reactions
  - weak energy dependence of the cross section
  - shrinkage of the forward peak
- Photoproduction of J/ψ exhibits a steep W dependence, consistent with pQCD calculations
- First indication for similar energy dependence for ψ'
- Evidence for $|t|$ providing a hard scale
- s-channel helicity conservation holds at low $|t|$ (not shown)

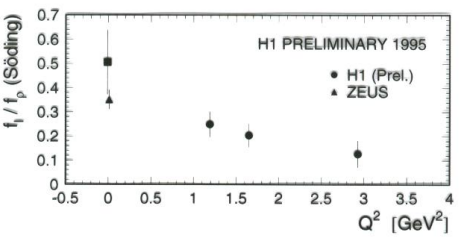
ρ electroproduction

ZEUS BPC
(beam pipe calorimeter)
$0.25 < Q^2 < 0.85$ GeV^2



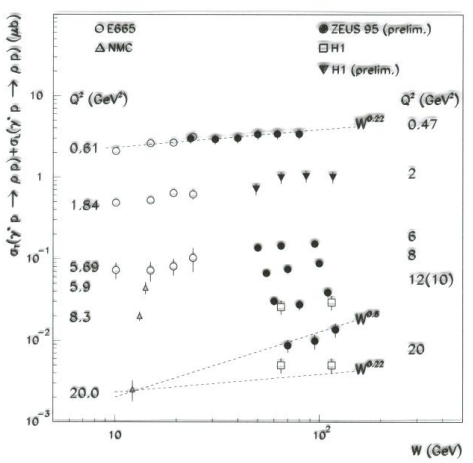
Mass spectrum is skewed

Amount of skewing decrease with increasing Q^2



ρ electroproduction

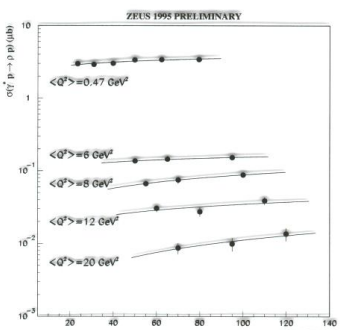
Energy dependence of the cross section for different Q^2



Normalization uncertainties ($\sim 20\%$)

ρ electroproduction

ZEUS: measure the energy dependence of the cross section within one experiment

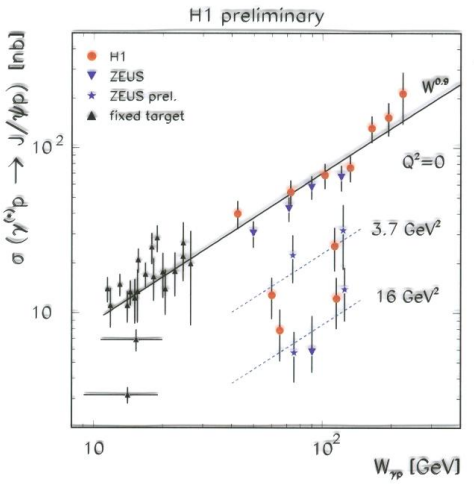


Fit: $\sigma \propto W^\epsilon$

$\langle Q^2 \rangle$ GeV^2	ϵ (prel.)
0.47	0.18±0.05±0.13
6.0	0.18±0.16±0.05
8.0	0.47±0.16±0.09
12.0	0.38±0.21±0.13
20.0	0.77±0.19±0.19

indication for Q^2 dependence of ϵ

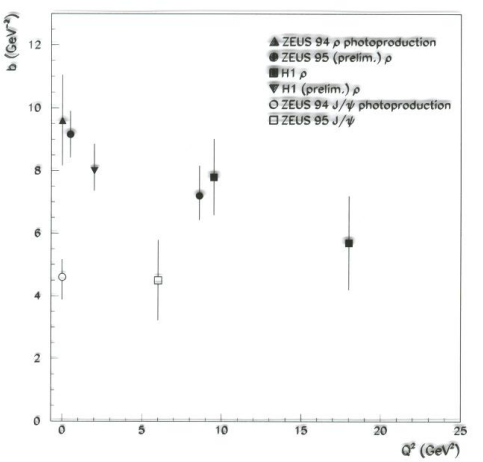
J/ψ production at high Q^2



Fit of the form $\sigma \propto W^{\epsilon}$ to the H1 php data yields: $\epsilon = 0.77 \pm 0.13$ (prel.)

J/ψ data at high Q^2 show a similar W dependence

t dependence of the cross section



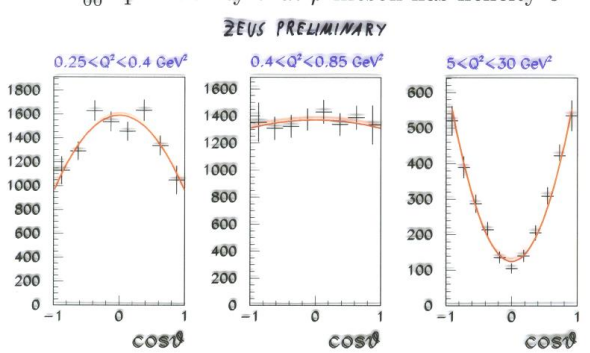
$\rightarrow$ b decreases with increasing Q^2 in case of ρ

Decay angular distributions

In general angular distributions consistent with SCHC (for $|t| < 0.6$ GeV^2)

$$W(\cos\theta) = \frac{3}{4\pi}\left[\frac{1}{2}\left(1 - r_{00}^{04}\right) + \frac{1}{2}\left(3r_{00}^{04} - 1\right)\cos^2\theta\right]$$

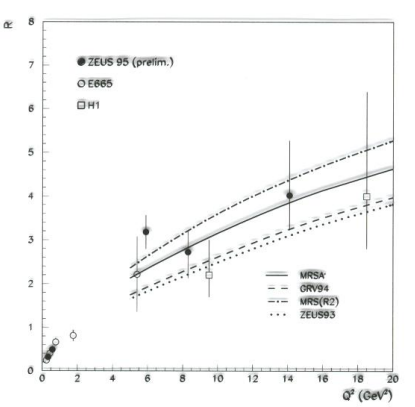
r_{00}^{04}: probability that ρ meson has helicity 0



r_{00}^{04} increases with Q^2

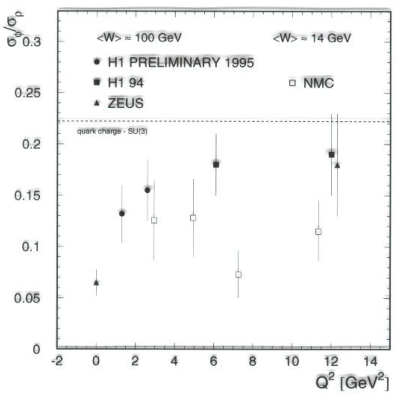
$R = \sigma_L/\sigma_T$

Assume SCHC: $R = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1-r_{00}^{04}}$



- Q^2 dependence of R not described by VMD
- pQCD model (Martin et al.) is able to describe the data

ϕ production at high Q^2



At large Q^2 ratio $\sigma(\phi)/\sigma(\rho)$ approaches 2:9
(like in php at high $|t|$)

Expected for SU(3) symmetry

Conclusions

- photoproduction of light VMs at low $|t|$ shows typical features of a soft diffractive process
- but HERA offers more variables: evidence for M_V, $|t|$ and Q^2 to quantitatively change the cross section behavior (hard scale)
  - steep rise of the J/ψ cross section consistent with pQCD calculations
  - ϕ/ρ cross section ratio rises with $|t|$ and Q^2
  - ratio of longitudinal to transverse cross section shows a non-liner rise with Q^2