

What we can learn from vector meson production at HERA?

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on behalf of the ZEUS and H1 Collaborations

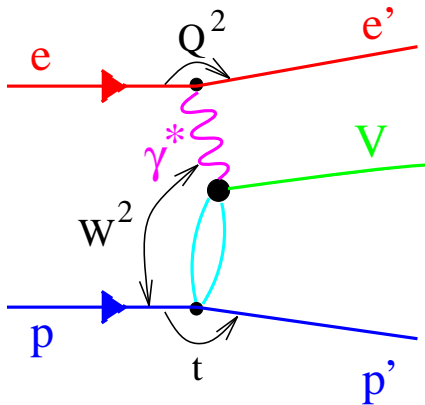


PHOTON09, Hamburg, May 14, 2009

Outline

- **Introduction**
- **Elastic Photo and Electroproduction of Vector Mesons and Deeply Virtual Compton Scattering (DVCS)**
 - W -dependence
 - Q^2 -dependence
 - t -dependence
 - **Helicity studies**
 - **Effective Pomeron trajectory**
- **Summary**

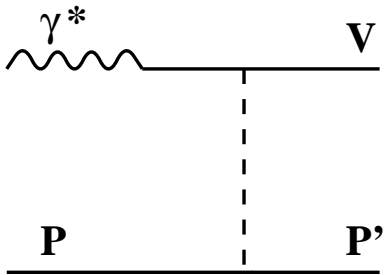
Vector meson production



$$V = (\gamma, \rho^0, \omega, \phi, J/\psi, \Upsilon)$$

- $Q^2 = -(e - e')^2$ photon virtuality
- W is γ^*p center of mass (CM) energy
- $t = (p - p')^2$ momentum transfer squared at the proton vertex

VDM and Regge theory (*soft physics*)



- The photon fluctuates into a vector meson, V , which carries the same quantum numbers as the photon ($\gamma p \rightarrow Vp$)
- The vector meson scatters elastically off the incoming proton ($Vp \rightarrow Vp$)

VDM and Regge theory (*soft physics*)

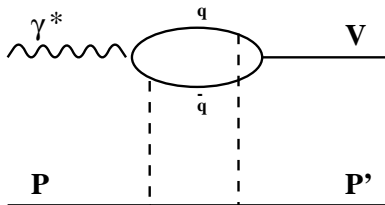
Predictions :

- $\frac{d\sigma(\gamma p \rightarrow Vp)}{dt} \propto e^{-bt} (W^2/W_0^2)^{2(\alpha(0)-1)}$

Experimental observations :

- $\alpha(t) = \alpha(0) + \alpha' t$
- $\alpha(0) = 1.096 \pm 0.003 \quad \alpha' = 0.25$
(DL – Donnachie, Landshoff parameterisation)
- Shrinkage of the diffractive peak
 $b(W) = b_0 + 4\alpha' \ln(W/W_0) \quad b_0 \sim 10 \text{ GeV}^{-2}$
- Weak energy dependence of cross section
 $\sigma \propto W^\delta, \quad \delta \simeq 0.2$

pQCD models (hard physics)

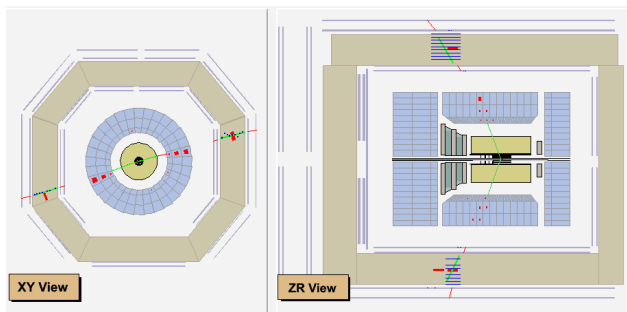


- the photon fluctuates into a $q\bar{q}$ state
- the $q\bar{q}$ pair scatters off the proton target
- the scattered $q\bar{q}$ pair turns into a vector meson.

Predictions :

- $\sigma_L \propto \frac{\alpha_S^2(Q)}{Q^6} |xG(x, Q^2)|^2$
- fast increase of the $\gamma^* p \rightarrow Vp$ cross section with energy W
- universal exponential t dependence,
 $b \sim 4 - 5 \text{ GeV}^{-2} \implies \alpha' \rightarrow 0?$

VM production $\gamma p \rightarrow Vp$

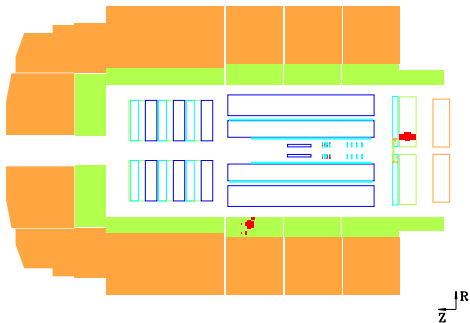


Kinematic range

$$\begin{aligned} Q^2 &\rightarrow 0 \div 100 \text{ GeV}^2 \\ W &\rightarrow 20 \div 300 \text{ GeV} \\ |t| &\rightarrow 0 \div 1 \text{ GeV}^2 \end{aligned}$$

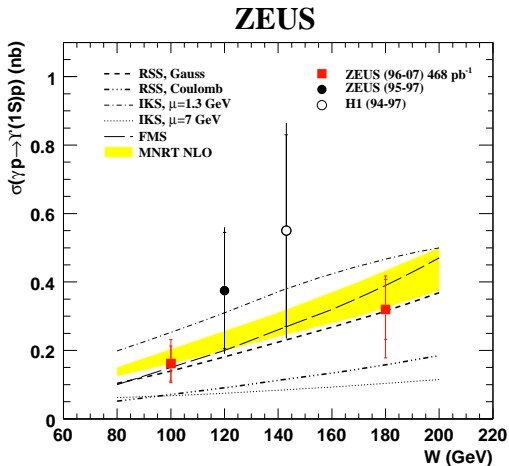
- Photoproduction: $Q^2 \approx 0$ (do not observe the scattered e^-)
- tracks reconstructed by tracking detector
- no energy deposits not associated with tracks or the positron

$$DVCS: \gamma^* p \rightarrow \gamma p$$



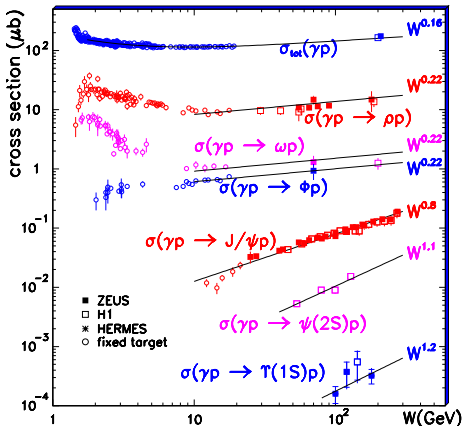
- DVCS event display
- Electroproduction: $Q^2 > 0$
(observe the scattered e in the main detector)

Elastic Photoproduction $\gamma p \rightarrow \Upsilon p$



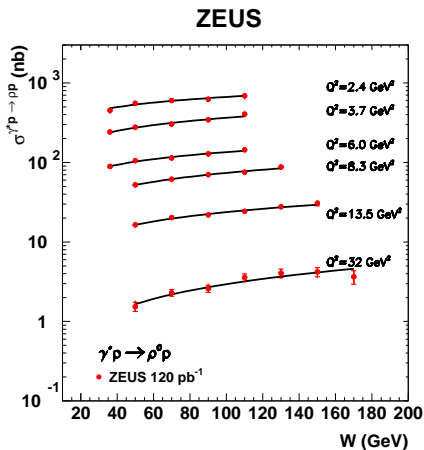
- cross section W dependence, $\sigma \sim W^\delta$:
- two measured points $\delta = 1.2 \pm 0.8$
- consistent with theoretical prediction, $\delta \sim 1.7$

Elastic Photoproduction



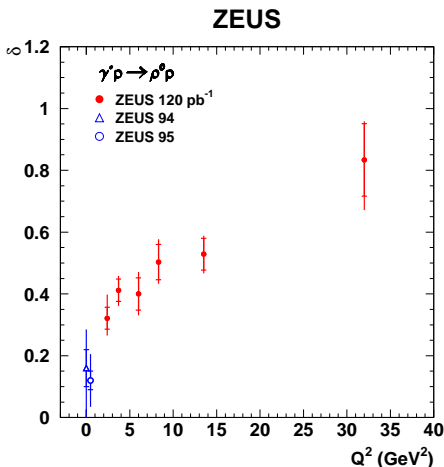
- fit: $\sigma \sim W^\delta$
- process becomes hard as scale (mass) becomes larger, $(M_{J/\psi}/M_\phi)^2 \sim 10$!

Elastic Electroproduction $\gamma^* p \rightarrow \rho p$



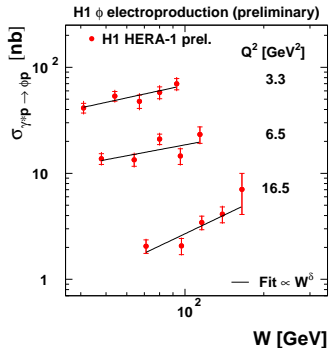
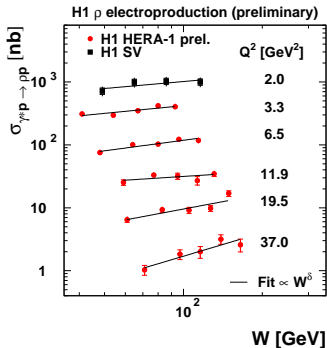
- fit: $\sigma \sim W^\delta$
- Cross section W dependence becomes steeper at high Q^2

Elastic Electroproduction $\gamma^* p \rightarrow \rho p$



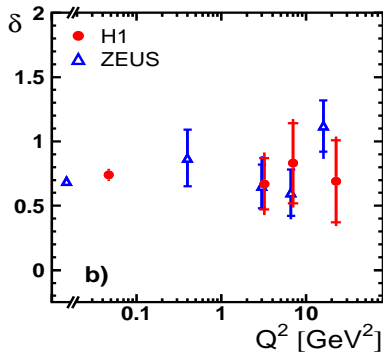
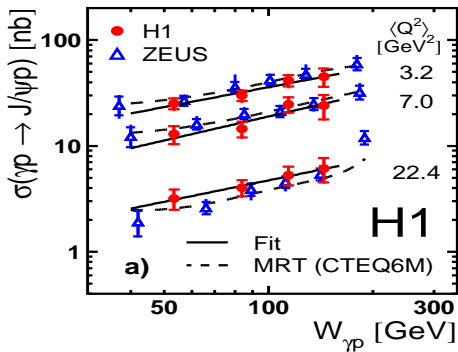
- $\sigma \sim W^\delta$
- **Soft physics predicts for energy dependence $\delta \sim 0.2$**

Elastic Electroproduction $\gamma^* p \rightarrow \rho(\phi) p$



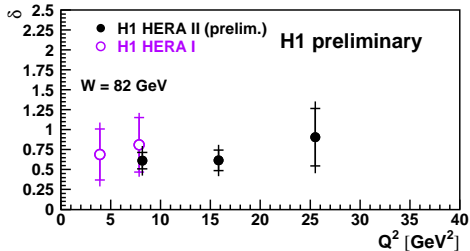
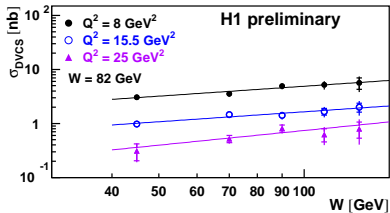
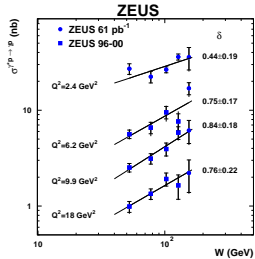
- similar behavior, cross section W dependence becomes steeper at high Q^2 , measured by H1 for ρ and ϕ mesons

Elastic Electroproduction $\gamma^* p \rightarrow J/\psi p$



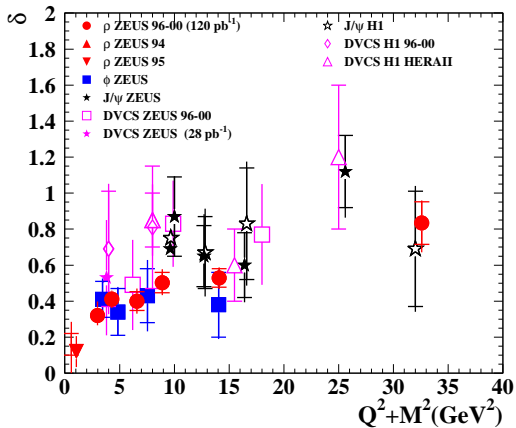
- cross section for J/ψ production as a function of W , $\sigma \sim W^\delta$
- $\delta(Q^2 = 0, M_{J/\psi}^2 \simeq 10 \text{ GeV}^2) \sim 0.7$

DVCS



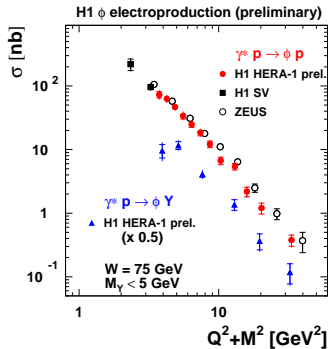
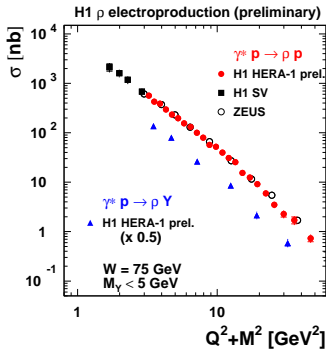
- H1: $\delta = 0.63 \pm 0.08 \pm 0.14$
- ZEUS: $\delta = 0.52 \pm 0.09$

Elastic Electroproduction: $\sigma \sim W^{\delta(Q^2)}$



- process becomes hard as scale ($Q^2 + M^2$) becomes larger

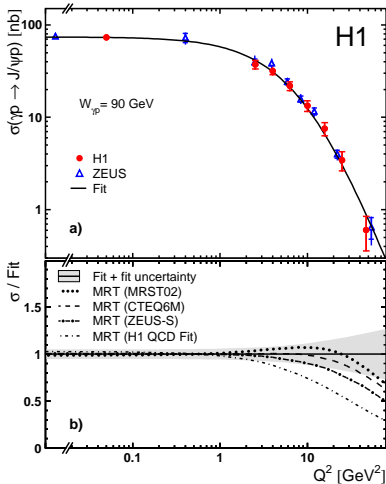
Q^2 dependence: $\gamma^* p \rightarrow \rho(\phi)p$



- **H1/ZEUS: perfect agreement**

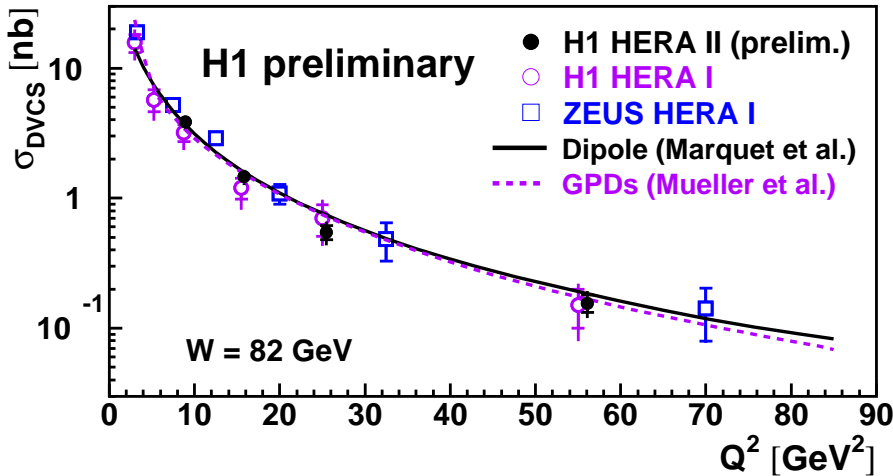
- **fit:** $\sigma \propto (Q^2 + M^2)^{-n} \implies \sigma_L \propto \frac{\alpha_S^2(Q)}{Q^6} |xG(x, Q^2)|^2$
- $Q^2 \geq 0 \text{ GeV}^2$, $n \simeq 2.00 \pm 0.01$, $\chi^2/\text{ndf} \sim 10$
- $Q^2 \geq 10 \text{ GeV}^2$, $n \simeq 2.5 \pm 0.02$, $\chi^2/\text{ndf} \sim 1.5$

Q^2 dependence: $\gamma^* p \rightarrow J/\Psi p$



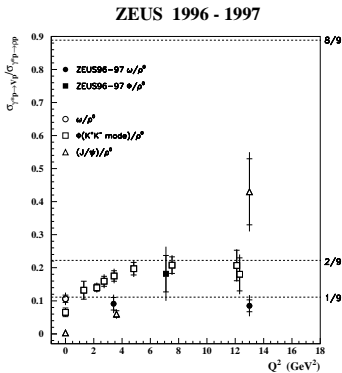
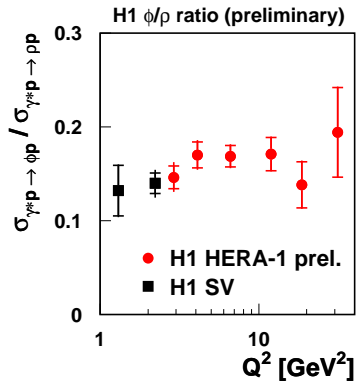
- **H1/ZEUS: perfect agreement**
- $\sigma \propto (Q^2 + M^2)^{-n}$
- $Q^2 \geq 0 \text{ GeV}^2$, $n = 2.486 \pm 0.08 \pm 0.068$

Q^2 dependence: DVCS



- **H1/ZEUS: perfect agreement**
- $\sigma \propto Q^{-2n}$
- $Q^2 \geq 1.5 \text{ GeV}^2, n = 1.54 \pm 0.05$

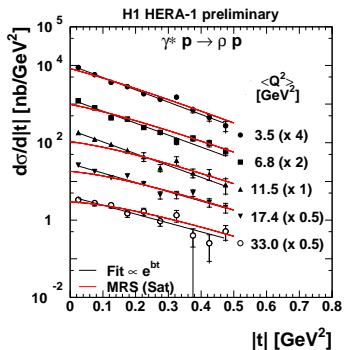
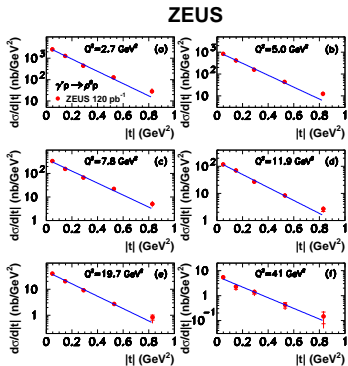
Q^2 dependence: Vector Mesons production ratio



- flavour independence:

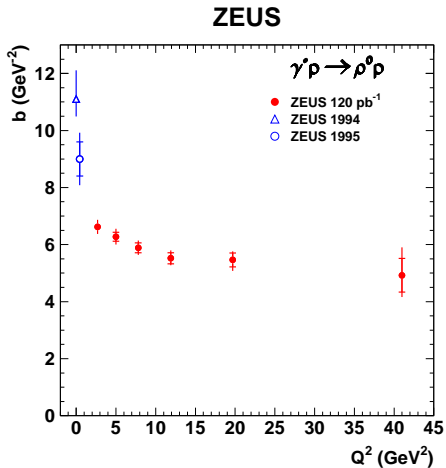
$$\rho : \omega : \phi : J/\psi = 9 : 1 : 2 : 8$$

t dependence



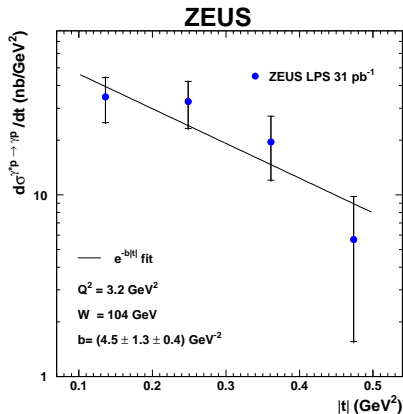
- $d\sigma/d|t| \sim \exp(-b|t|)$ for different bins of Q^2

t dependence: ρ -meson



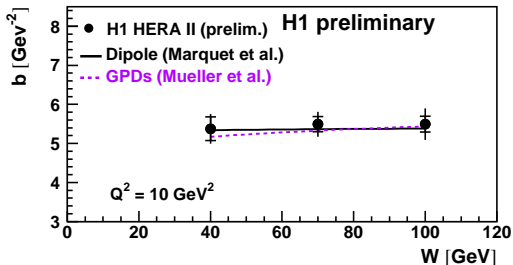
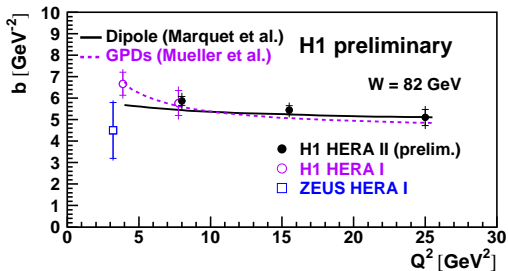
- b slope as a function of Q^2

t dependence: DVCS



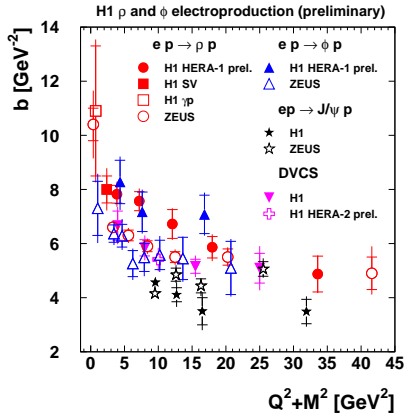
- $Q^2 = 3.2 \text{ GeV}^2, W = 104 \text{ GeV}$
- $b = 4.5 \pm 1.3 \pm 0.4 \text{ GeV}^{-2}$

t dependence: DVCS



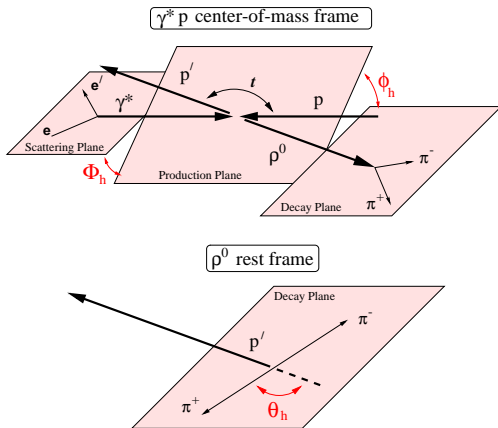
- b slope as a function of $W \implies$ no W dependence
- $b = 5.41 \pm 0.14 \pm 0.31$ GeV⁻²

$$b(Q^2 + M^2)$$



Value of b decreases from soft ($\sim 10 \text{ GeV}^{-2}$) to hard ($\sim 4-5 \text{ GeV}^{-2}$)

Helicity Studies

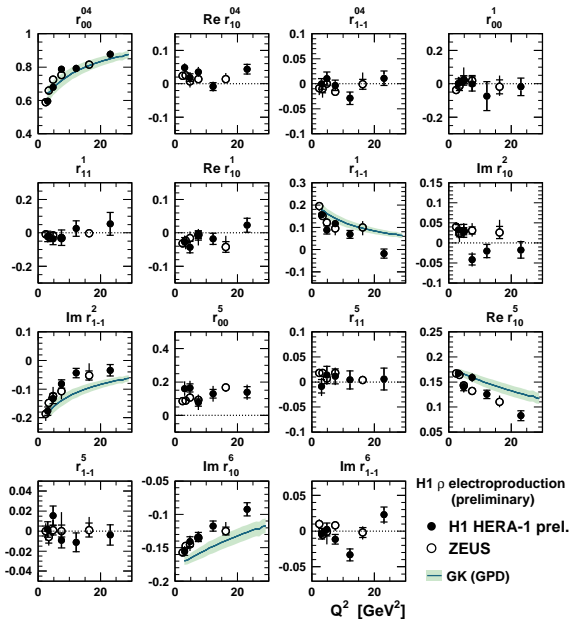


Angular distribution \implies 3 angles (θ_h , ϕ_h and Φ_h) and 15 combinations of spin-density matrix elements $r_{ij}^{kl} \implies$ helicity amplitudes $T_{\lambda_V \lambda_\gamma}$

Helicity Studies

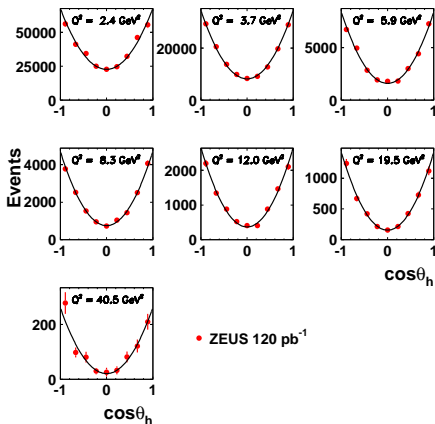
- **s-channel helicity conservation (SCHC)**
 - $\gamma_T^* \rightarrow \rho_T$
 - $\gamma_L^* \rightarrow \rho_L$
 - single flip, double flip amplitudes equal zero
- natural parity exchange ($P = (-1)^J$) in the **t-channel (NPE)**
- **5 non-zero spin-density matrix elements**
- **15 parameters fit to total angular distribution**
- $r_{00}^5 \sim$ single-flip amplitude, $\gamma_T^* \rightarrow \rho_L$
- r_{00}^5 deviates from zero !
- $r_{00}^5 = 0.095 \pm 0.019 \pm 0.024$ (ZEUS) and
 $r_{00}^5 = 0.093 \pm 0.024_{-0.10}^{+0.19}$ (H1)
- if SCHC holds $\rightarrow R = \sigma_L/\sigma_T = r_{00}^{04}/\epsilon(1 - r_{00}^{04})$
- if not: $r_{00}^{04} \rightarrow r_{00}^{04} - \Delta^2$, $\Delta \propto r_{00}^5/\sqrt{2r_{00}^{04}}$
- R(SCHC) - R(SCHNC) ~ 3 %

Helicity Studies: Q^2 -dependence



Helicity Studies

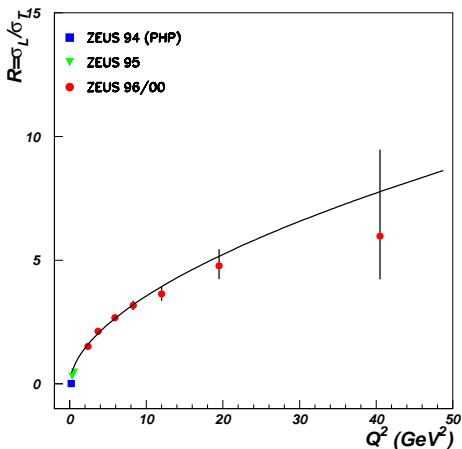
ZEUS



fit to $\cos\theta_h$:

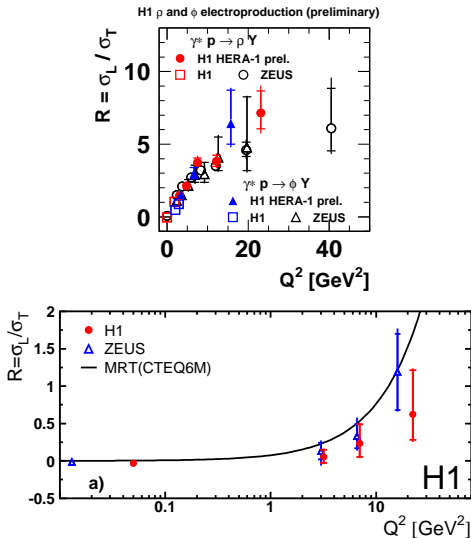
$$d\sigma/d\cos\theta_h \propto 1 - r_{00}^{04} + (3r_{00}^{04} - 1)\cos^2\theta_h$$

Helicity Studies



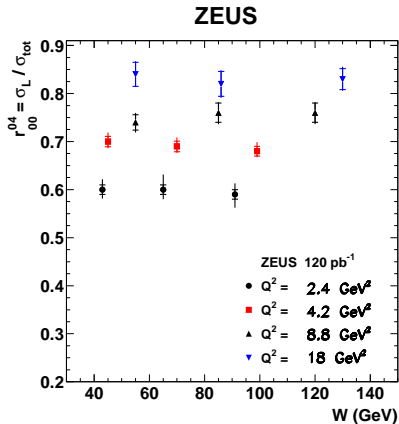
- $R = \sigma_L / \sigma_T = r_{00}^{04} / \epsilon(1 - r_{00}^{04}), \quad \epsilon \simeq 1$
- $Q^2 = 40 \text{ GeV}^2 \implies \sigma_L / \sigma_{\text{tot}} \sim 85\%$
- **fit to ZEUS only :** $R = \sigma_L / \sigma_T = \xi(Q^2 / M^2)^\kappa$
- $\xi = 0.74 \pm 0.04$ and $\kappa = 0.56 \pm 0.03$

Helicity Studies



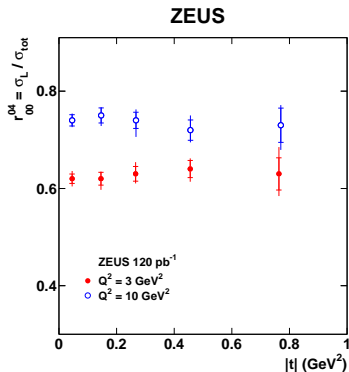
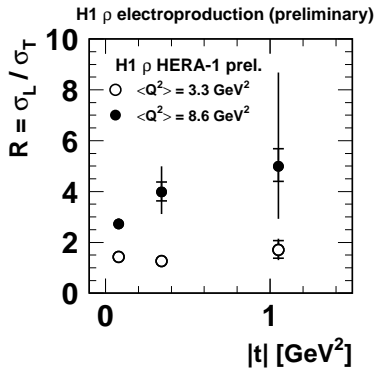
- σ_L / σ_T for ρ, ϕ and J/ψ mesons
- R increases with Q^2

Helicity Studies



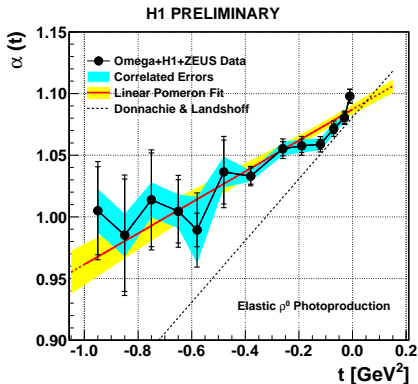
- $r_{00}^{04} = \sigma_L / \sigma_{tot}$ $R = \sigma_L / \sigma_T = r_{00}^{04} / \epsilon(1 - r_{00}^{04})$, $\epsilon \simeq 1$
- σ_L and σ_T have the same W dependence
- the typical dipole size contributing to ρ production - independent of the photon polarization

Helicity Studies



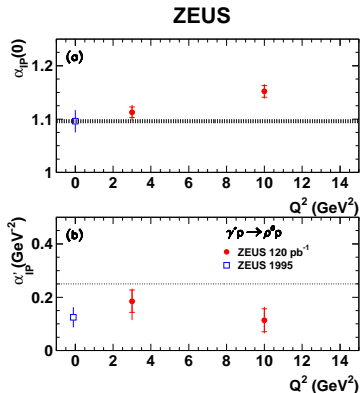
- $R = \sigma_L / \sigma_T \sim \exp(-(b_L - b_T)|t|)$
- **H1:** $b_L < b_T$
- **ZEUS:** $b_L \approx b_T$

Effective Pomeron trajectory: $\alpha(t) = \alpha(0) + \alpha' \cdot t$



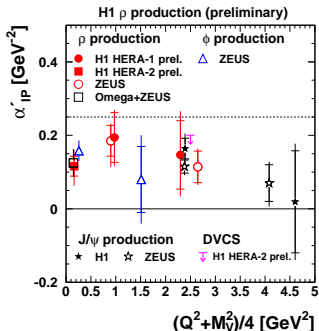
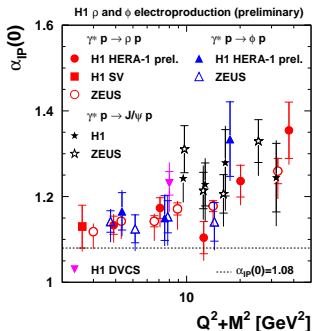
- **Global fit: ρ^0 Photoproduction, (Omega, H1, ZEUS)**
 $(1.0871 \pm 0.0026 \pm 0.003) + (0.126 \pm 0.013 \pm 0.012) \text{ GeV}^{-2} \cdot t$
- **H1:** $(1.093 \pm 0.003_{-0.007}^{+0.008}) + (0.116 \pm 0.027_{-0.046}^{+0.038}) \text{ GeV}^2 \cdot t$
- **ZEUS:** $(1.096 \pm 0.021) + (0.125 \pm 0.038) \text{ GeV}^{-2} \cdot t$

Effective Pomeron trajectory: $\alpha(t) = \alpha(0) + \alpha' \cdot t$



- **ZEUS, ρ^0 electroproduction:**
- $\alpha(0)$ increases with Q^2
- α' , within errors, is Q^2 independent
- lines \longrightarrow DL parameterization

Effective Pomeron trajectory: $\alpha(t) = \alpha(0) + \alpha' \cdot t$



- $\alpha(0)$: energy behavior of the total cross section, $\sigma_{tot} \sim W^{2(\alpha(0)-1)}$
- α' : shrinkage of the diffractive peak, $b(W) = b_0 + 4\alpha' \ln(W/W_0)$
- effective Pomeron trajectory: a larger intercept and smaller slope than expected from soft physics

Summary

What we have learnt from VM production?

H1, ZEUS based on HERA data show:

- **Vector Meson production and DVCS cross sections rise with energy if a hard scale, Q^2 or M^2 , is present.**
- **The exponential slope of the t distribution decreases with $Q^2 + M^2$ and levels off at $b \sim 5 \text{ GeV}^{-2}$**
- **The ratio, σ_L/σ_T , increases with Q^2 , but is independent of W**
- **The effective Pomeron trajectory has a larger intercept and smaller slope than those extracted from soft interactions**

All these features are compatible with expectations of hard diffraction \rightarrow pQCD