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DIFFRACTIVE PRODUCTION OF VECTOR MESONS AT HERA*

K. Piotrzkowski

representing the ZEUS and H1 Collaborations

DESY, Notkestraße 85, D–22607 Hamburg, Germany

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Recent measurements of the diffractive production of neutral vector mesons at HERA are reviewed. The issue of transition between 'soft' and 'hard' underlying production mechanism is discussed in context of the phenomenology of Regge theory and the predictions of the perturbative QCD.

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1. Introduction

Diffractive production of neutral vector mesons (V) in electron-proton collisions at HERA, $ep \to eVp$, has been extensively studied in a wide kinematical range, from quasi-real photoproduction to electroproduction at large photon virtualities $Q^2 \approx 20$ GeV^2 [1]. The kinematical range of photon-proton center-of-mass energy, W, was extended by about order of magnitude with respect to previous measurements, up to $W \approx 250$ GeV. Similarly, the range of four-momentum transfer squared at the proton vertex, t, was extended beyond $|t| = 10$ GeV^2. HERA, therefore, offers an unique opportunity to study transition between 'soft' and 'hard' diffraction which is characterized by presence of a hard scale in the scattering.

For high energy soft diffractive processes the cross section is weakly rising with W, and steep exponential t dependence is observed. These properties are well described in photoproduction within the framework of Regge phenomenology [3] and the Vector Meson Dominance model (VMD) [4], where exclusive vector meson production is assumed to proceed via fluctuation

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of a photon into a meson which later interacts by exchange of a pomeron trajectory. In this approach, the W and t dependences are coupled:

$$\frac{d\sigma}{d|t|} \propto \mathrm{e}^{-b_0|t|} \left(\frac{W^2}{W_0^2}\right)^{2(\alpha(t)-1)} ,$$

where $\alpha(t) = \alpha(0) + \alpha' t$. Fits to hadron–hadron scattering data give $\alpha(0) = 1.08$ and $\alpha' = 0.25$ GeV^{-2} [5]. The slope of the t distribution depends on the energy as $b = b_0 + 2\alpha' \ln(W^2/W_0^2)$ (shrinkage), while the effective power of the W dependence (after integrating over t) is $a \approx 4(\alpha_0 - 1 + \alpha'/b)$. Typically, values of $b \approx 10$ GeV^{-2} are found in the photoproduction of light mesons, leading to $a = 0.24$, in good agreement with measurements.

In contrast, when the hard scale, μ^2, is present the perturbative QCD models (pQCD) predict that W and t distributions should be independent (no shrinkage). The sharp rise of the cross sections with W, predicted in these models, is due to rise of the gluon density in proton for decreasing x, where $x \approx \mu^2/W^2$, and $\mu^2 \approx Q^2$ for example [6–8]. The b slope is expected to be universal.

Finally, it is interesting to find out how the diffractive meson production can be understood in context of the inclusive diffraction at HERA [9].

2. Diffractive photoproduction of vector mesons

Diffractive photoproduction of light vector mesons, ρ^0, ϕ and ω has been found to be consistent with soft diffraction [10]. Recently, the pomeron trajectory has been determined for exclusive production of ρ^0 and ϕ mesons: $\alpha(t) = (1.097 \pm 0.020) + (0.163 \pm 0.035)t$ and $\alpha(t) = (1.083 \pm 0.010) + (0.180 \pm 0.027)t$, were found respectively [11]. The measured J/ψ trajectory is much flatter, $\alpha(t) = (1.175 \pm 0.026) + (0.015 \pm 0.065)t$, see Fig. 1, indicating lack of shrinkage [12] and hard underlying production mechanism. This observation is in accord with earlier investigations of the W dependence of the J/ψ cross section [13] where it was found, see Fig. 2, that the cross section rises faster than expected for the soft pomeron phenomenology and is well described by pQCD. The b slope of about 5 GeV^{-2} was measured (see also Fig. 5).

The hard scale in J/ψ photoproduction seems to be given by its mass. Approximately an order of magnitude larger scale should be therefore involved in production of Υ mesons, the $b\bar{b}$ bound states.

First measurement of Υ photoproduction has been recently reported [15]. The Υ decays into $\mu^+\mu^-$ pairs were detected, and the $\gamma p \to \Upsilon p$ cross sections were found to be significantly larger than the pQCD expectations, see Fig. 3. It is very interesting to see further progress here, both on the experimental and theoretical side.

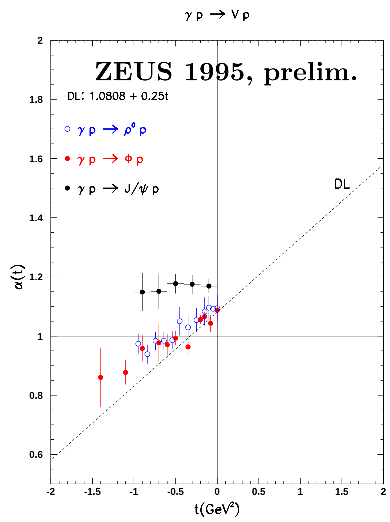

Fig. 1. The measured trajectories, $\alpha(t)$, compared the soft pomeron trajectory, $\alpha(t) = 1.08 + 0.25t$, advocated by Donnachie & Landshoff [5].

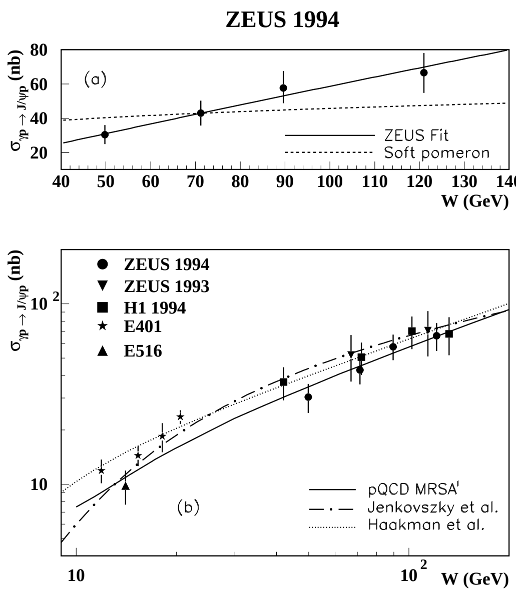

Fig. 2. The measured $\gamma p \to J/\psi p$ cross section as a function of W [14]. In the upper plot the ZEUS data is compared to the expectations assuming the soft pomeron exchange (dashed line). In the lower plot the compilation of various measurements and model predictions is shown.

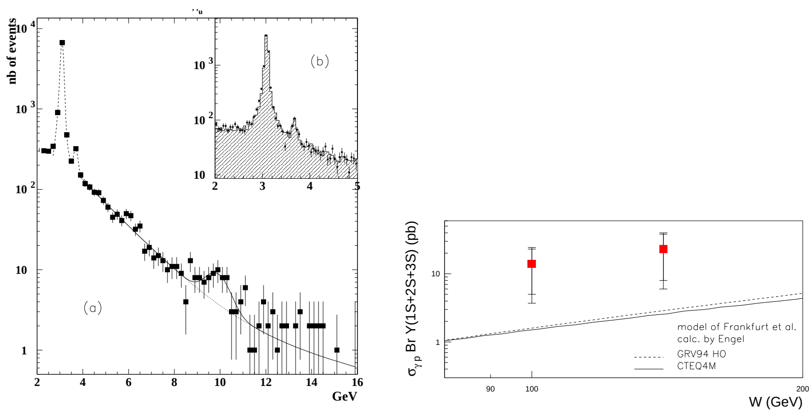

Fig. 3. (Left) Invariant mass distribution of the $\mu^+\mu^-$ pairs. The mass distribution around the J/ψ peak is shown also separately. (Right) The measured cross section for $\gamma p \rightarrow \Upsilon p$ is compared to pQCD predictions.

3. Exclusive electroproduction of vector mesons

The diffractive electroproduction of ρ^0 and ϕ at large Q^2 data seems to increase faster with W, see Fig. 4. The ϕ to ρ^0 cross section ratio is also increasing with Q^2, see Fig. 5, and approaches value of 2/9 which is expected if the virtual photon directly couples to the meson constituent quarks. The measured b slopes are approaching the value of the b slope observed in the J/ψ diffraction, see Fig. 5. These findings strongly suggest that also Q^2 might set the hard scale in diffraction [16, 17].

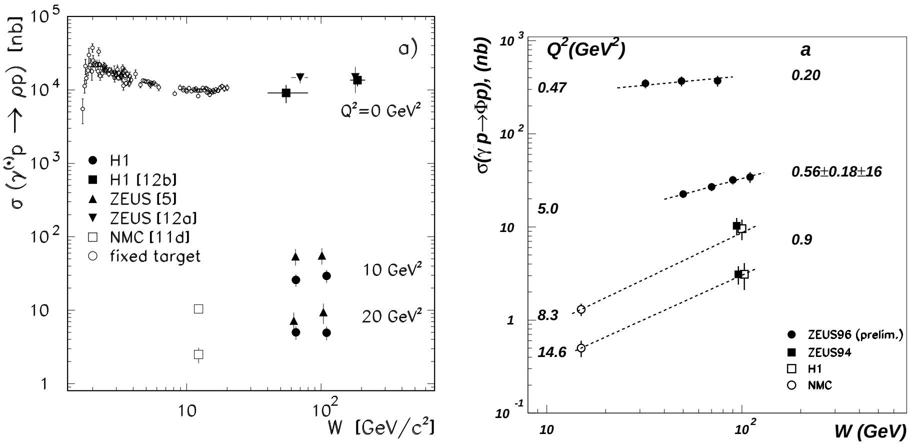

Fig. 4. The W dependence of the γp cross sections for exclusive production of ρ^0 (left) [16] and ϕ (right) [17]mesons at various values of Q^2.

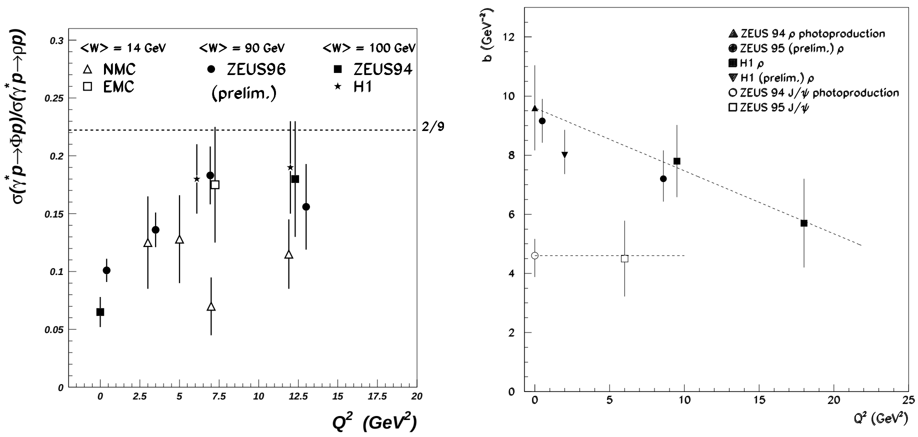

Fig. 5. (Left) ϕ to ρ^0 cross section ratio as a function of Q^2. (Right) Compilation of results on the b slope dependence on Q^2 [17].

Finally, in Fig. 6 the Q^2 dependence of the ψ' to J/ψ cross section ratio is shown [18]. The data indicate rise of this ratio with Q^2 as is expected according to pQCD calculations where wave-function effects of radial $c\bar{c}$ excitation are taken into account [19].

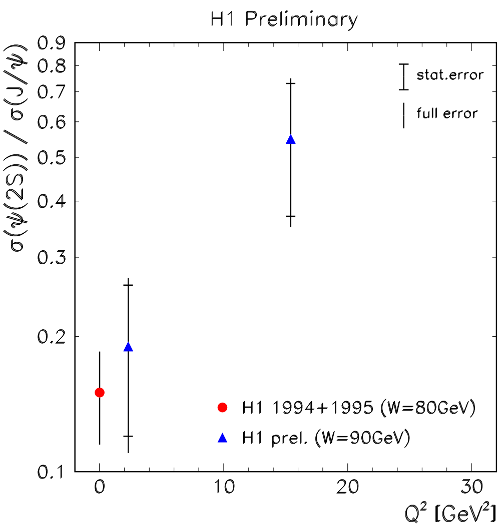

Fig. 6. The Q^2 dependence of the ψ' to J/ψ cross section ratio [18].

4. Summary

HERA provides wealth of data on the diffractive meson production and opens possibilities to study limits and to verify predictions of pQCD. The data indicate that the meson mass and possibly also Q^2 may set hard scale in the diffractive *ep* scattering.

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