ELASTIC AND DISSOCIATIVE PRODUCTION OF VECTOR MESONS AT SMALL AND LARGER Q^2 AT H1

J.H. KÖHNE

Max-PLanck-Institut für Physik, Werner-Heisenberg-Institut, Föhringer Ring 6, D-80805 München, Germany

The H1 experiment at the ep-collider HERA at DESY in Hamburg has investigated the diffractive production of vector mesons at negligible photon virtualities, $Q^2 \approx 0$ and at higher Q^2 where the scattered lepton is detected in the apparatus. The main characteristics of soft diffractive reactions are observed for the photoproduction of $\rho(770)$ whilst the heavier $J/\Psi(3097)$ deviates from this picture but meets the expectations of QCD-models which assign the vector meson's interaction with the proton to the intrinsic gluon content of the proton. At higher Q^2 the virtual photon proton cross sections are analysed in terms of the photon proton c.m.s. energy, $W_{\gamma p}$, Q^2, the proton momentum transfer squared, t and the vector meson's helicity. The production of the higher mass excitations ρ' and Ψ' has been observed. Studies of diffractive proton dissociation in the vector meson production reveal no significant deviations from the elastic case except for the slope of the fall-off with $|t|$.

1 Introduction

The diffractive process in vector meson production is sketched in figure 1. The process is regarded as a two step reaction. The lepton emits a photon which turns into a virtual hadronic state which undergoes a peripheral interaction with the proton. In the final state only the vector meson decay products and the scattered beam particles are detectable. The interaction can either be regarded as due to the exchange of a soft pomeron Regge-trajectory between a VDM-photon [a] and the proton [1] or due to the exchange of a pair of QCD-gluons (hard pomeron) between a virtual quark-antiquark pair and the constituents of the proton [2,3]. In the latter picture the cross section depends on the gluon density inside the proton.

1.1 H1 Detector

The vector meson analyses are based upon the charged particle reconstruction within the central tracking system consisting of two coaxial cylindrical drift chambers interleaved by proportional chambers. Lepton identification is possible using the surrounding liquid argon (LAr) calorimeter and the muon system housed in the iron return yoke of the solenoid magnet. The scattered

[a] Vector Meson Dominance Model

positron is detected in the rear lead scintillator calorimeter. The proton escapes in the beam pipe. In case the proton dissociates and forms a state Y with $m_Y > 1.6$ GeV the decay products become visible either in the forward part of the LAr-calorimeter, the forward muon system or in a set of scintillators mounted 24 m downstream on the proton beamline.

1.2 Kinematics

The kinematic variables of deep inelastic scattering are calculated from the decay products of the vector meson and - if available - from the scattered lepton. The four momenta k,k',q and P denote the in- and outgoing lepton, the virtual photon and the proton respectively. The preferred reconstruction method for $Q^2 = -q^2 = -(k-k')^2$ and $y = P \cdot q / P \cdot k$ is the double angle method [4]. The photon proton c.m.s. energy is calculated from $W_{\gamma p}^2 \approx ys$, s being the c.m. energy in the ep-sytem. The momentum transfer at the proton vertex is calculated from the vector sum of transverse momenta of the meson and the scattered lepton, $|t| \approx (\vec{p}_{\perp e} + \vec{p}_{\perp v})^2$. Following the two-step-view of the process the experimental results are given as virtual photon proton cross sections obtained from the electroproduction cross sections by unfolding the Weizsäcker-Williams photon flux approximation [5].

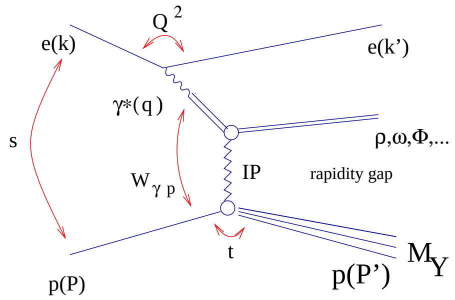

Figure 1: Diffractive production of vector mesons at HERA.

2 Results in Photoproduction

At $Q^2 < 4$ GeV^2 the scattered electron escapes detection in the backward calorimeter. Events of this type are regarded as photoproduction events. They have $< Q^2 >= 0.001 - 0.035$ GeV^2 decreasing with $W_{\gamma p}$. Due to the polar

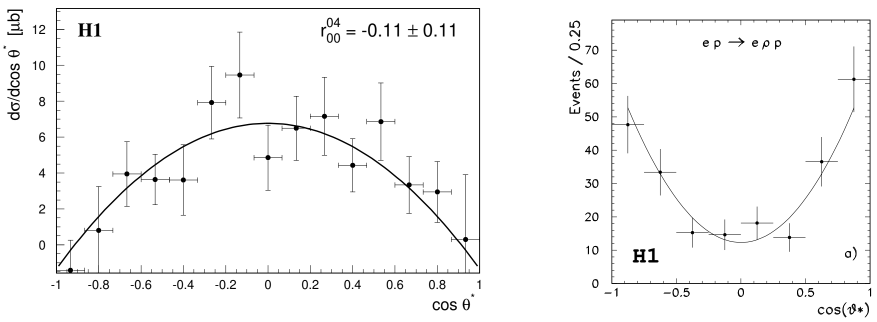

Figure 2: Decay angle distribution in the ρ^0-meson's rest frame: a) in photoproduction (left) and b) at high Q^2.

angle acceptance of the central tracking system the data cover a range of 30 GeV $< W_{\gamma p} <$ 150 GeV.

The result of the ρ^0 measurements in photoproduction [6] is a remarkable success of the VDM-photon plus Regge model. After extrapolating by more than one order of magnitude from the low energy measurements to HERA, the cross section continues a slow logarithmic rise typical for the pomeron trajectory with an universal intercept near unity. The sharp peak in forward direction of the cross section with an exponential fall-off with $|t|$ appears steeper than at low energy, however the precision of this rather early H1-measurement is limited, so that no final conclusions can be drawn. Assuming the polarisation of the vector meson reflects the polarisation of the original photon [b] one observes a predominantly transverse photon spectrum at low Q^2 as expected from a smooth transition to a real photon beam with no longitudinal degree of freedom for the photon helicity. The helicity of the vector meson is measured from the polar decay angle distribution $\cos\theta^*$ as given in figure 2 a).

While the photoproduction of $\rho^0(770)$ with a mass well below the typical hadronisation scale of 1 GeV is convincingly described by VDM plus soft pomeron exchange the heavy J/Ψ deviates strikingly from the expectations of this picture [7]. The cross section rises like $W_{\gamma p}^{\delta}$ with $\delta = 0.90 \pm 0.06$ [14] which has to be compared to $\delta = 0.32$ expected from soft pomeron exchange (neglecting any shrinkage). The QCD-models can accommodate such a steep rise. In figure 3 the measured cross sections [8] at different values of $W_{\gamma p}$ are

[b] This assumption is abbreviated SCHC (s-channel helicity conservation).

translated into a phenomenological gluon density $xg(x)$ as defined by Ryskin[2] at different values of $x \propto 1/W_{\gamma p}^2$. In addition, some of the most popular gluon density parametrisations are shown. Due to an overall normalisation uncertainty of 30% one should rather compare the shape of the spectra. It is a crucial question of consistency between the QCD-models whether the gluon densities obtained from the scaling violations in the F_2 measurements agree with this direct determination.

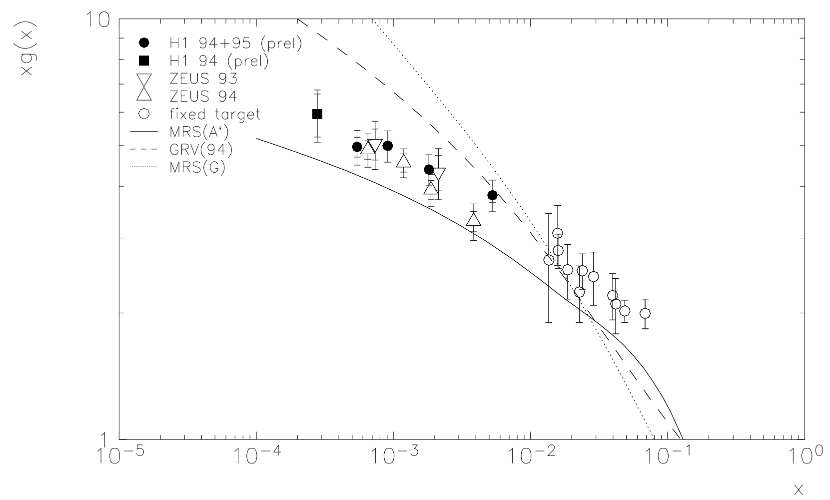

Figure 3: Gluon density $xg(x)$ obtained from J/Ψ-photoproduction as function of x.

The production of Ψ' decaying into $\pi^+\pi^- J/\Psi$ has also been observed in photoproduction [9]. The production ratio of Ψ' to J/Ψ is 0.16 ± 0.06 which is considerably higher when compared to the production of excited ρ' over the light ground state ρ [10].

3 Results at high Q^2

Going from photoproduction to events with high Q^2 introduces another energy scale into the consideration, in addition to $W_{\gamma p}$ and the vector meson mass. The data cover the range 6 GeV^2 $< Q^2 <$ 50 GeV^2. An important question is whether the production mechanism of vector mesons still is peripheral. The answer can be seen from the $|t|$-spectra in figure 4. The cross section is forward peaked and shows an exponential fall-off with $|t|$. The slope is smaller than in photoproduction which is plausible from the expectation of the optical model relating the slope parameter b to the transverse sizes of the scattering objects. The higher the Q^2 the smaller the size of the probing hadronic component of the photon and thus the flatter the $|t|$-distribution. Note that the flattening of the $|t|$-distribution is much less evident for the J/Ψ than for the ρ, consistent with the assumption that the mass of the J/Ψ already sets the hard scale.

A $\rho'(1600)$ state decaying into four pions via an intermediate ρ state has been observed at high Q^2. The cross section is of comparable size as the one of the ground state ($R_{\rho'/\rho} = 0.36 \pm 0.13$) in contrast to the situation in photoproduction [10]. This can be related to the larger tranverse size of the probing quark antiquark pair at low Q^2 which overlaps with an extended vector meson wavefunction with one or more radial nodes diminishing the convolution integral in the calculation of the photon coupling. At high Q^2 only the innermost part of the wave function contributes.

The differential virtual photon proton cross section as a function of Q^2 follows a steeply falling power law. The observation is parametrised following a Q^{-2n}-ansatz. For the J/Ψ $(Q^2+m^2)^{-n}$ is used. The results for ρ, ϕ and J/Ψ are $n = 2.5 \pm 0.5$ [4], $n = 2.0 \pm 0.6$ [11] and $n = 1.9 \pm 0.3$ [4].

The non-negligible photon virtuality allows for longitudinal polarisation of the vector mesons and indeed the major fraction [c] of $r^{04}_{00} = 0.73 \pm 0.5$ [11] of the ρ^0 mesons are longitudinally polarised. The change in helicity composition is seen in figure 2 b). The $W_{\gamma p}$-dependance of the J/Ψ-cross section is similar to the photoproduction case. How do the ρ and ϕ behave? The hard scale in Q^2 leads to the expectation of a steeper rise. H1 data[11] in combination with an old measurement of the NMC collaboration [12] seem to support this. However a recent $\sigma_{\gamma^* p \to \rho p}$-measurement of the E665-experiment [13] at an intermediate $W_{\gamma p}$ and high Q^2 allows an interpretation of the measurements in terms of soft pomeron exchange. So the question has to remain open for the time being.

4 Results on proton dissociation

As shown by detailed simulations the H1 detector allows the tagging of a proton excitation with mass above 1.6 GeV with well controlled systematics. Results have been obtained for J/Ψ-photoproduction [14] and for ρ^0 [11] at high Q^2. The cross sections with and without proton dissociation are of comparable size. The cross section rise with $W_{\gamma p}$ does not change drastically. The $W^{\delta}_{\gamma p}$-fit arrives at $\delta = 1.2 \pm 0.2$ for the J/Ψ. The vector meson polarisation seems not

[c] r^{04}_{00} denotes a bilinear combination of ρ production helicity amplitudes which corresponds to the probabilty of finding a longitudinally polarised vector meson from an unpolarised photon beam.

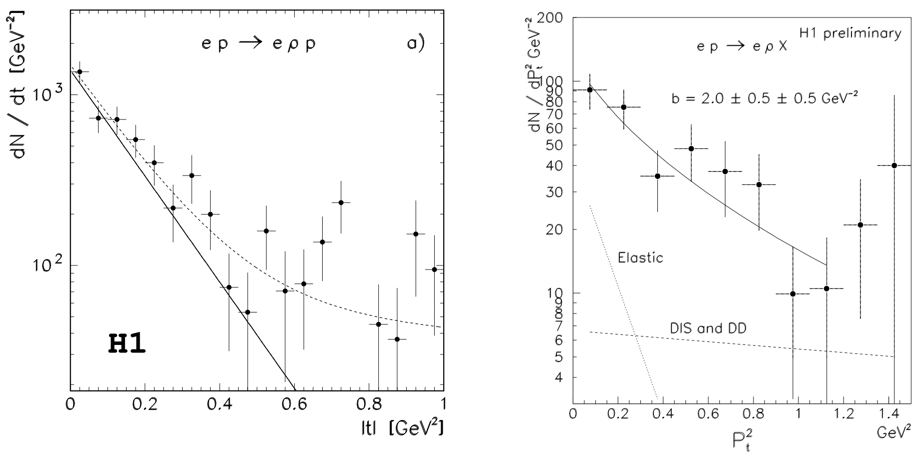

Figure 4: Spectra of squared transverse ρ^0-momenta in the high Q^2samples: elastic (a) and with proton dissociation (b).

to be affected by what happens to the proton. The results show no significant difference i.e. the J/Ψ are transversely polarised while the ρ at high Q^2 are predominantly longitudinally polarised as was the case without proton dissociation. The only significant impact of the break-up of the proton is on the shape of the forward peak. The t-distribution is shown in figure 4. Exponential fits in restricted p_T^2 ranges arrive at $b = 1.6 \pm 0.3$ GeV^{-2} for the J/Ψ and $b = 2.1 \pm 0.7$ GeV^{-2} for the ρ which have to be compared to the results for elastic production[4] $b = 4.0 \pm 0.3$ GeV^{-2} for the J/Ψ and $b = 7.0 \pm 0.9$ GeV^{-2} for the ρ. The slopes b are already below a value of about 4 GeV^{-2} corresponding to a diffractive scattering of objects with transverse dimensions well below the radius of the proton.

5 Conclusions

H1 has contributed analyses on diffractive production of light and heavy vector mesons in photoproduction and at high Q^2. The results in photoproduction show a good description of the light meson production by the model of VDM plus pomeron trajectory exchange. This description fails, as with the J/Ψ mass a hard energy scale enters the problem. However its failure in the presence of a high Q^2-scale in case of ρ-production is experimentally not yet settled. The

$|t|$-distributions are all consistent with a diffractive production mechanism. Going from photoproduction to higher photon virtualities leads to a flatter $|t|$-spectrum consistent with a smaller transverse size of the scattering object. The vector meson polarisation is purely transverse in photoproduction and mainly longitudinal at high Q^2. The Q^2 dependence of the production cross section follows a power law with Q^{-2n}, n around 2. Excitations Ψ' and ρ' have been observed. The production ratios in photoproduction seem to be more suppressed for the light ρ as for the heavy J/Ψ. The effect of proton dissociation is small for the general features of the vector meson cross section, with the exception of the $|t|$-distribution which is still peripheral but which much flatter slope than in the elastic case.

Acknowledgments

I thank the organisers of PHOTON 97 for their hospitality and support during the conference in Egmond. I thank very much Frank Gaede and John Dainton for helpful discussions.

References

1. A.Donnachie and P.V.Landshoff, *Phys. Lett.* B **348**, 213 (1995).
   A.Donnachie and P.V.Landshoff, *Phys. Lett.* B **296**, 227 (1992).
2. M.G.Ryskin, *Z. Phys.* C **57**, 89 (1993).
3. S.J.Brodsky et al., *Phys. Rev.* D **50**, 3134 (1994)
4. H1 Collab., *Nucl. Phys.* B **468**, 3 (1996).
5. E.J.Williams, *Proc. Roy. Soc. London* A **139**, 163 (1933)
   C.F.Weizsäcker, *Z. Phys.* **88**, 612 (1934)
6. H1 Collab., *Nucl. Phys.* B **463**, 3 (1996).
7. H1 Collab., *Phys. Lett.* B **338**, 507 (1994).
8. G.Schmidt, PhD thesis, University of Hamburg, Germany, 1996
9. H1 Collab., contrib. paper pa02-086, 28th International Conference on High Energy Physics 25-31 July 1996, Warsaw, Poland
10. H1 Collab., contrib. paper pa01-088, 28th International Conference on High Energy Physics 25-31 July 1996, Warsaw, Poland
11. H1 Collab., DESY-97-082, May 1997
12. NMC Collab.,*Nucl. Phys.* B **429**, 503 (1994)
13. E665 Collab., FERMILAB-PUB-97-103-E, April 1997
14. H1 Collab., *Nucl. Phys.* B **472**, 3 (1996).