ELASTIC VECTOR MESON PRODUCTION IN ep COLLISIONS

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The data from HERA provide us with excellent information on elastic vector meson production: $\gamma p \to Vp$ [1,2]. We have precise measurements of the Q^2, m_V and t dependences of the cross section, for different mesons (ρ, ϕ, J/ψ), as well as information on the transverse and longitudinal components of the cross section. Moreover H1 and ZEUS have found some indications of violation of the s-channel helicity conservation (SCHC). With J.R. Cudell we have studied ways of implementing Fermi motion in elastic vector-meson production, and have proposed a new approach which allows the quarks to be off-shell, and which naturally reproduces all the data [3]. I shall present here a very brief explanation of our model and show its results, including new results obtained on the helicity amplitudes.

1. CALCULATION OF THE AMPLITUDE OF THE PROCESS $\gamma p \to Vp$

We work at the quark and gluon level and the key point in our calculations is to get the leading term in the high energy limit i.e. $w^2 >> Q^2$, $w^2 >> M_V^2$, where w^2 is the γp center-of-mass energy and M_V the meson mass.

We shall assume a form of factorization and only concentrate on a hard scattering with three simple sub-models.

- At high energy, the process is dominated by pomeron exchange which we model by two gluons.
- For the proton, we only consider the three valence quarks, leading to a form factor which cancel the infrared divergences that would result from the gluons propagator [3,4].
- For the process generating the vector meson we will use a vertex function $\Gamma_\mu = \gamma_\mu \Phi(l^2)$. The quark and the antiquark have a four-momentum respectively equal to $V/2 - l$,$V/2 + l$, and have the same mass m_q. For $\Phi(l^2)$ we choose a falling gaussian distribution:

$$\Phi = N exp(\frac{-l^2}{p_f^2}) \tag{1}$$

the dependence on the meson mass is restated as a dependence on a Fermi momentum scale p_f and N is a proportionality constant fixed to reproduce the decay rate $V \to e^+e^-$.

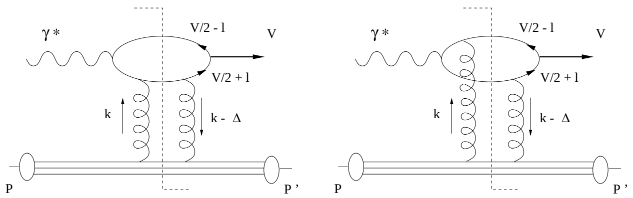

Figure 1. The two diagrams accounting for the transition $\gamma^* p \to Vp$. The dashed line represents the cut which puts the intermediate state on-shell.

We insist on the fact that we use a vertex function instead of a wave function for the meson as we found that the analytic structure of the propagator of the quark $(V/2 + l)$, which is usually included in the definition of a wave function, plays an important role in the reproduction of the plateau observed at HERA at high Q^2 in the ratio σ_L/σ_T.

Now we have everything to calculate the amplitude of the process which reduces to the sum of the two diagrams of Fig. 1.

Thanks to the use of the vertex function for the meson, we study the role of the propagator of the quark of momentum $V/2+l$. This propagator has a pole, the amplitude is then composed of two terms:

$$\mathcal{A} = \sqrt{\mathcal{A}_1^2 + \mathcal{A}_2^2} \tag{2}$$

The first term comes from the discontinuity where the quark is put on shell. This term is equivalent to the use of a wave function for the meson. The second term comes if we allow the quark to go off-shell. It is the interplay between those two parts which gives the plateau in the ratio of cross sections σ_L/σ_T at high Q^2, so that we cannot neglect this second part if we want to reproduce the data observed at HERA.

2. RESULTS

This model gives many remarkably good results, the main ones being:
- the Q^2 dependence of the cross sections (Fig. 2). Up to a common factor we are able to reproduce the data for the ρ, ϕ and J/ψ even in photoproduction. We can also understand the hierarchy of cross sections between the different mesons and the flatness of the Q^2-dependence of the J/ψ compared to the ρ.
- We are able to reproduce the ratio of the longitudinal cross section to the transverse cross section. One can see (Fig. 3) that this ratio increases linearly with Q^2 at low Q^2 but seems to reach a plateau at high Q^2 which is in good agreement with the data.

3. HELICITY STUDY

Recently H1 and ZEUS measured 15 spin density matrix elements related to the angular distribution of the decay of the ρ meson. If we assume s-channel helicity conservation (SCHC: the helicity of the photon is retained by the meson), all those matrix elements reduce to zero except five (Fig. 4):

$$r_{00}^{04},\ r_{1-1}^{1},\ \mathrm{Im}\ r_{1-1}^{2},\ \mathrm{Re}\ r_{10}^{5},\ \mathrm{Im}\ r_{10}^{6}$$

However, it was observed that one of them is significantly different from zero: r_{00}^5. This spin matrix element indicates a violation of SCHC.

Those spin matrix elements are related to helicity amplitudes $T_{\lambda_\rho \lambda_\gamma}$ [5] that we can calculate with our model. We still observe that the

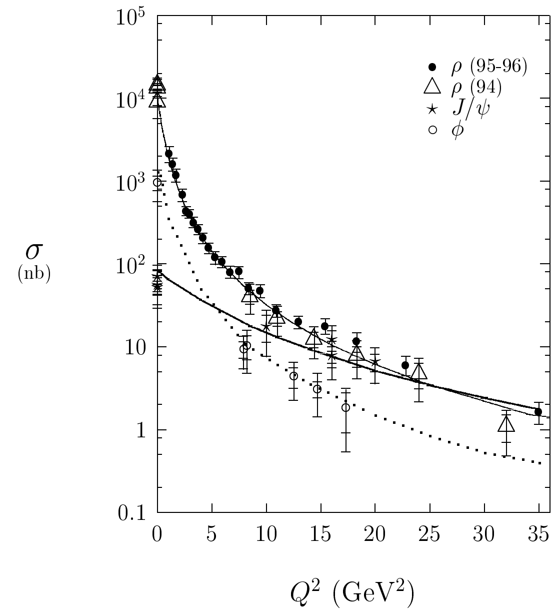

Figure 2. Cross sections for ρ, ϕ and J/ψ as function of Q^2 compared with data from H1[1] and ZEUS [2] at $< w > \approx 100$ GeV.

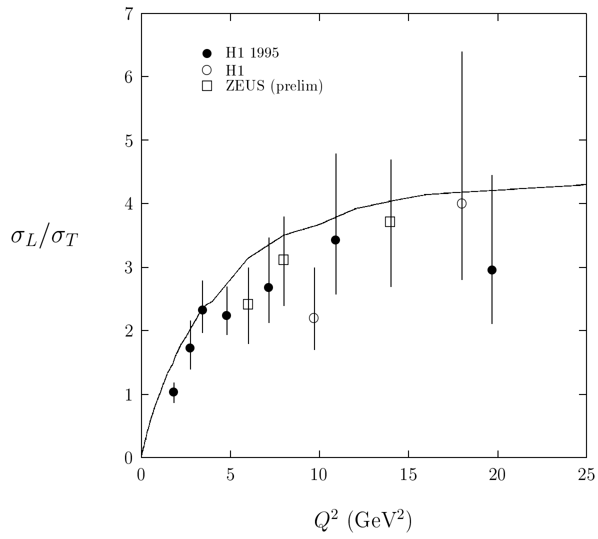

Figure 3. Ratio of cross sections for ρ as functions of Q^2 at $< w > \approx 100$ GeV, compared with data from H1 [1] and ZEUS [2]

two conserving helicity amplitudes (T_{00} where the photon and the meson are both longitudinally polarized and T_{11} where both of them are transverse) are dominant, but the single spin flip helicity amplitude T_{01}, where a longitudinal meson is produced by a transverse photon, is not negligible. r^5_{00} is related to this particular single spin flip helicity amplitude as follow:

$$\frac{|T_{01}|}{\sqrt{|T_{11}|^2+|T_{00}|^2}} \approx \frac{|T_{01}|}{|T_{11}|\sqrt{1+R}} \approx r^5_{00}\sqrt{\frac{1+R}{2R}}$$

So we can also derive the spin matrix elements from our model and compare to the data. On Figure 3, is shown what our model predicts for those elements. We have also extrapolated our results for small values of Q^2 and one can see that within measurement precisions, our model fares well and describe the data for r^5_{00}. H1 measured a helicity violation of about $8\pm3\%$, and we obtain $10\pm4\%$.

4. CONCLISION

This model is the only one which reproduces all these features:
- the Q^2 dependence of all measured vector meson cross sections,
- the mass m_V dependence of all measured vector meson cross sections,
- the t dependence of the differential cross section for the ρ in photoproduction,
- the ratio of the longitudinal and transverse cross sections,
- a violation of the s-channel helicity conservation where a transverse photon produce a longitudinal meson.

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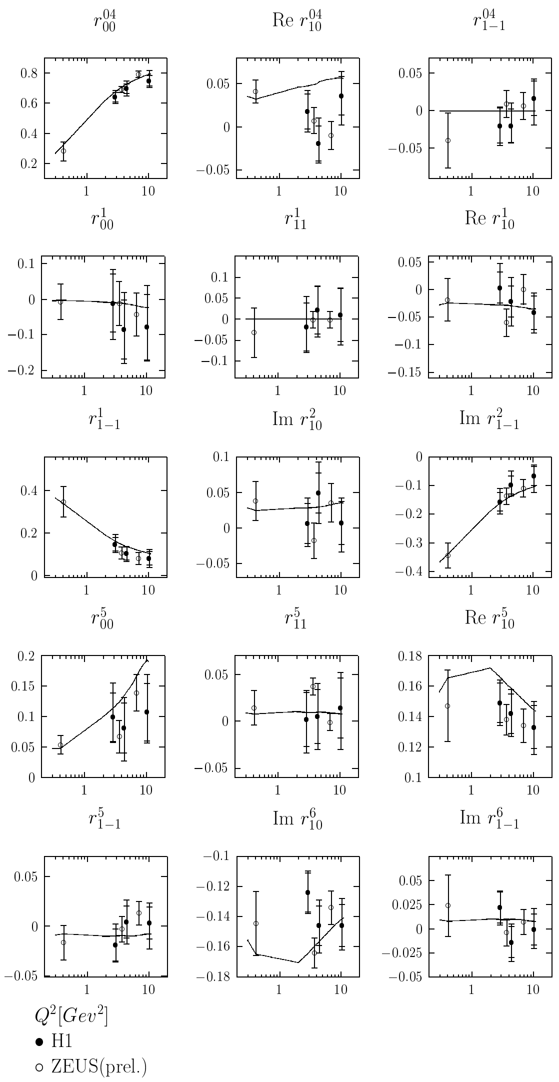

Figure 4. Q^2 dependence of the 15 spin density matrix elements for elastic electroproduction of ρ mesons, compared with data from H1 [1].