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Helicity Conservation in Diffraction and the Contribution by ZEUS

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Diffractive leptoproduction of vector mesons is studied at HERA in processes referred to as *elastic* and *proton dissociative* to distinguish the case in which the proton remains intact from that in which the proton dissociates. The term *elastic* is a misnomer, since rest mass is created in the final state. That creation of rest mass, together with the virtuality of the exchanged photon, results in a kinematically required minimum momentum transfer to the proton. This minimum value decreases as the fourth power of the photon-proton cm energy. Thus, the high energy available at HERA provides a big advantage over other experiments in studying the steep t distributions in diffraction, as well as in studying its characteristically weak energy dependence. We will see that the relationship between the vector meson rest mass and the momentum transfer t plays a definitive role in the consideration of helicity conservation in diffractive processes.

The helicity structure of this process is of particular interest in the context of pQCD calculations, since longitudinally polarized quark-antiquark states can provide the arbitrarily small configurations which yield convergence of the perturbative expansion. The polarization state of the vector meson thus yields information on the question of whether Q^2, M_{V}^2 and t all may serve as the necessary hard scale used in determining the pertinent values of α_s and the gluon density in the proton. Theoretical uncertainties in these calculations arise from those in the vector meson wave function and those in the mechanism used to describe the soft momentum transfer to the proton.

Schilling and Wolf have developed a widely-used formalism for parameterizing the decay angular distributions in terms of linear combinations of spin-density matrix elements, which are determined by the helicity amplitudes describing the interaction. These angular distributions thus characterize the dynamics of this diffractive process, in which a virtual photon diffracts into a massive state.

The produced rest mass introduces an ambiguity in the definition of the spin quantization axis, since the reference frames of the photon and vector meson do not coincide. I know of no theoretical bias in favor of quantizing the spin along the incoming photon direction rather than along the outgoing vector meson momentum vector in the photon-proton cm system. The former case corresponds to calculating the helicity amplitudes (and decay angles, etc) in the Gottfried-Jackson (t-channel) frame; the latter case corresponds to the so-called Helicity (s-channel) frame. These two frames differ only for values of t comparable to the vector meson mass. Modulo a phase of 180 degrees, the two frames are identical if t is either much greater or much less than the vector meson mass. (At time of writing this minute I decided that this remark is wrong if the magnitude of Q^2 is comparable to either that of M_{V}^2 or that of t. Possibly the formula in my transparencies should be modified by replacing M_{V}^2 with $M_{\mathrm{V}}^2 + \mathrm{Q}^2$, but this is just a sort of guess on my part. My discussion pertains to photoproduction.) This means, for example, that it is experimentally much easier to distinguish the two frames in ρ^0 production than it is to do so in psi production, owing to the steeply falling t distribution.

In 1972 a bubble chamber experiment at SLAC using a linearly polarized photon beam to "elastically" produce ρ^0 mesons found that when they calculated the density matrix elements from the ρ^0 decay angle distribution in the helicity frame, the ρ^0 appeared to be purely transversely polarized, like the initial-state photons. Performing the calculation in the GJ frame yielded an apparent longitudinal polarization. This result, along with those of other experiments (e.g. streamer chamber at DESY) motivated the concept of *s-channel helicity conservation* (SCHC), which was thus empirically found to characterize diffractive ρ^0 photoproduction. Since even in the helicity frame they found significant longitudinal polarization at their highest point in $|t|$, they restricted their claim of SCHC to $t < 0.4$ GeV^2. The degree of helicity violation in the t channel, which they also published, shows the same t dependence as the angle between the two frames. The violation appears turn over and begin decreasing for $|t|$ values higher than the squared ρ^0 mass.

Since s-channel and t-channel amplitudes can be calculated one from the other (if you can figure out the algebra), SCHC means that helicity is violated in the t channel IN A VERY SPECIFIC WAY. The aspect of the phenomenon which I find most difficult to get used to is that it is inconsistent with the t-exchange of an object of ANY specific helicity. Of course, in pQCD the process is necessarily higher order (need at least two gluons to conserve color), and, indeed, the recent calculation of Ivanov and Kirschner using two-gluon exchange yields SCHC approximately. In the early eighties Humpert and Wright did a similar calculation for psi photoproduction, and also found SCHC. (While writing this, however, it occured to me to wonder if this result was simply due to kinematics, as mentioned above.)

The early ZEUS BPC ρ^0 results showed that the polar decay angle distributions exhibited a strong Q^2 dependence. Something about the dynamics was clearly changing in that low Q^2 region. Including the DIS results at Q^2 of about 10 GeV^2, we have shown that the longitudinal cross section increases relative to the transverse one, exceeding it for Q^2 values above a few GeV^2. We have also shown that the W dependence of the ratio is weak. This is important, since the simple consideration that the transverse cross section should have the weak dependence shown at low Q^2 implies that the ratio should show the steep dependence expected from the hard process determining the longitudinal cross section. It makes you think there might be a perturbative contribution to the transverse cross section. It made Martin, Ryskin and Teubner think that, but their model continues to cause some controversy among phenomenologists. The preliminary results for the ratio in H1's Vancouver paper on high-Q^2 ρ^0 production, where they have impressive statistics from the 1996/97 data sample, indicate the ratio may be levelling off for Q^2¿10 GeV^2.

ZEUS has also shown that this ratio for psi production is much smaller than that for the ρ^0 at similar Q^2, and we emphasized that this means that Q^2 and the squared mass play dissimilar roles in determining the hard scale. In the preliminary results described in our Vancouver paper (Abstract 793) we also show that the phi behaves in a manner similar to the ρ^0 in this regard.

This past summer a lot of excitement was caused by the pQCD calculation of the helicity amplitudes by Ivanov and Kirschner, based on the model of Martin, Ryskin and Teubner. They predicted s-channel-helicity-violating characteristics of the DIS ρ^0 decay angular distributions which we had seen in our data, but not made public. I conclude this summary of my talk with a synopsis of their paper:

Ivanov and Kirschner (hep-ph/9807324) have shown that, for photon virtualities exceeding the hadronic mass scale, perturbative calculations of diffractive vector-meson leptoproduction yield a significant probability for producing longitudinally polarized vector mesons from transverse photons. Integrating over the spin structure at the proton vertex, they calculate five amplitudes based on the t-channel exchange of a pair of gluons: two helicity-conserving amplitudes, two single-flip amplitudes, and the double-flip amplitude. The strong Q^2 dependence of the gluon density predicted in pQCD renders the amplitudes for the transverse photons finite, overcoming logarithmic divergences arising from endpoint contributions in the momentum distribution of the q and $\overline{q}$ states in the photon (see also Martin, Ryskin and Teubner). The single-flip amplitudes are found to be proportional to $\sqrt{t}$, and to be of higher twist. In particular, the amplitude for producing longitudinal vector mesons from transverse photons is of sufficient magnitude to be experimentally accessible via its interference with the dominant helicity-conserving longitudinal amplitude. Its measurement represents a confirmation of the pQCD prediction of a broad wave function for the ρ^0, since it vanishes in the symmetric nonrelativistic approximation $z = 1/2$. The general features of this calculation have been confirmed by Kuraev et al.