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Compton Scattering and ρ^0 Photoproduction at High Energies*

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A recently proposed model for high-energy vector-meson photoproduction is extended to Compton scattering. The predicted differential cross section is in agreement with experiment in both shape and magnitude.

The vector-dominance model (VDM)[1] for Compton scattering relates this amplitude to the scattering amplitudes for vector meson ρ^0, ω, and φ. The predictions of the model have met with varying degrees of success when confronted with the experimental data. In particular, there have been recent measurements of Compton scattering on protons at SLAC[2] for photon energies between 5 and 17 GeV and four-momentum transfer squared, t, in the range $0.06 \leq -t \leq 1.1$ $(\mathrm{GeV}/c)^2$, and a similar experiment at DESY[3] which was done using a bremsstrahlung beam of energy 5–7 GeV and for the t range -0.06 to -0.60 $(\mathrm{GeV}/c)^2$. There is also a more recent measurement at SLAC[4] which uses photon energies of 8 and 16 GeV but concentrates on the near forward direction, $0.014 \leq -t \leq 0.17$ $(\mathrm{GeV}/c)^2$.

All experimental results indicate that the differential cross sections are larger than those predicted by VDM if one uses the vector-meson–photon coupling constants obtained from the colliding-beam experiments.[5] The use of vector-meson–photon coupling constants extracted via VDM from the experimental data on ρ, ω, and φ photoproduction[6] (which should be the same, according to VDM) only increased the disagreement between theory and experiment.

The purpose of this note is to show how the processes of Compton scattering and vector-meson photoproduction are related by an extension of an alternative model for vector-meson photoproduction which we have described in detail elsewhere.[7] In this model, the incident photon dissociates into a charged pion or kaon pair, one of the virtual mesons scatters, and then the pair combines to form a vector meson. The amplitudes constructed have several theoretically desirable characteristics, such as (i) analyticity and correct singularity structure in the mass squared for the photon and (ii) approximate unitarity in the crossed channel. The agreement of the model with present high-energy experimental data is good insofar as s-channel helicity conservation is obtained and differential cross sections have the correct shape. However, some results, notably the energy dependence, appear to be in disagreement with experiment.

The basic diagrams which define the model for vector-meson photoproduction from nucleons are shown in Fig. 1. The scattering amplitude is given by the usual Feynman rules, except that the meson-nucleon scattering "blob" at the bottom vertex is interpreted as an S-matrix element. As we have shown previously, the differential cross section for ρ^0 photoproduction may be written

$$\frac{d\sigma}{dt}(\gamma p \to \rho^0 p) = A(s,t)\,|g_{\rho\pi\pi}T^{(+)}_{\pi p} + g_{\rho KK}T^{(+)}_{Kp}|^2 , \qquad (1)$$

where $g_{\rho\pi\pi}$ and $g_{\rho K\bar{K}}$ are the coupling constants for the $\rho\pi\pi$ and $\rho K\bar{K}$ vertices, respectively. The function $T^{(+)}_{\pi p}$ ($T^{(+)}_{Kp}$) is just the sum of the π^+p and π^-p (K^+p and K^-p) scattering amplitudes; $A(s,t)$ is a function which depends on the model, but is slowly varying in s (at most logarithmic) and in t (a polynomial). The exponential shape of the photoproduction differential cross section is determined by the corresponding shape for the πp and Kp elastic scattering reactions.

It is straightforward to extend the model to Compton scattering; the diagrams which define the model are obtained by replacing the vector meson V by a photon. The result is that

$$\frac{d\sigma}{dt}(\gamma p \to \gamma p) = 4\pi\alpha A(s,t)\,|T^{(+)}_{\pi p} + T^{(+)}_{Kp}|^2 , \qquad (2)$$

where α is the fine-structure constant and the other functions have been described above. The important point to note is that the contributions of πp and Kp scattering are exactly the same, since the pion and kaon charges are equal. (We are neglecting form-factor effects here as we did previously.)

Now, although we have found some difficulty in our model with the $A(s,t)$ computed, if we take ratios then this function drops out and we obtain the basic relation of the present note,

$$\frac{d\sigma}{dt}(\gamma p \to \gamma p) = 4\pi\alpha \left|\frac{T^{(+)}_{\pi p} + T^{(+)}_{Kp}}{g_{\rho\pi\pi}T^{(+)}_{\pi p} + g_{\rho KK}T^{(+)}_{Kp}}\right|^2 \frac{d\sigma}{dt}(\gamma p \to \rho^0 p) . \qquad (3)$$

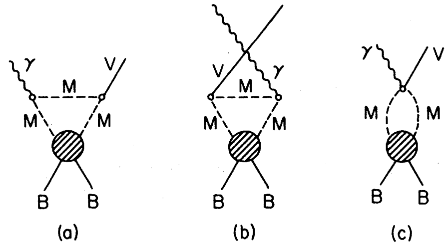

FIG. 1. Diagrams which determine the model for vector-meson photoproduction functional forms are given in Ref. 7.

In order to make use of this relation we must evaluate the ratio of scattering amplitudes that appears. Above 5-GeV laboratory energy and for momentum transfer t larger than, say, 0.1 GeV^2 it is probably a good approximation to take $T_{\pi p}^{(+)} = T_{Kp}^{(+)}$; furthermore, as a first guess we might use SU(3) to relate the coupling of ρ to 2π and to $K\bar{K}$, so that $g_{\rho\pi\pi} = 2g_{\rho KK}$. With these assumptions, we find

$$\frac{d\sigma}{dt}(\gamma p \to \gamma p) = \frac{16}{9}\,\frac{4\pi\alpha}{g_{\rho\pi\pi}{}^2}\,\frac{d\sigma}{dt}(\gamma p \to \rho^0 p)\,. \tag{4}$$

In order to make the comparison with the VDM clear, we use the relation

$$g_{\rho\pi\pi} = 2\gamma_\rho\,, \tag{5}$$

which follows from ρ dominance of the pion electromagnetic form factor (theoretically, a much firmer relation than the now general ones given by the VDM); the result is

$$\begin{aligned}\frac{d\sigma}{dt}(\gamma p \to \gamma p) &= \frac{16}{9}\,\frac{\pi\alpha}{\gamma_\rho{}^2}\,\frac{d\sigma}{dt}(\gamma p \to \rho^0 p)\\ &= \frac{16}{9}\,\frac{d\sigma}{dt}(\gamma p \to \gamma p;\,\mathrm{VDM})\,.\end{aligned} \tag{6}$$

Actually VDM relates the Compton amplitude to a combination of ρ, ω, and φ photoproduction amplitudes; however, the ω and φ contributions to Eq. (6) are small and have been neglected here. Thus, we predict that Compton scattering should be a factor of $\frac{16}{9}$ larger than predicted by the VDM, if we use the rough estimates described above.

Actually, Kp elastic-scattering differential cross sections have a somewhat different shape than do πp; Kp scattering is not as sharply peaked forward and is smaller than πp in the forward direction, larger for large momentum transfer.

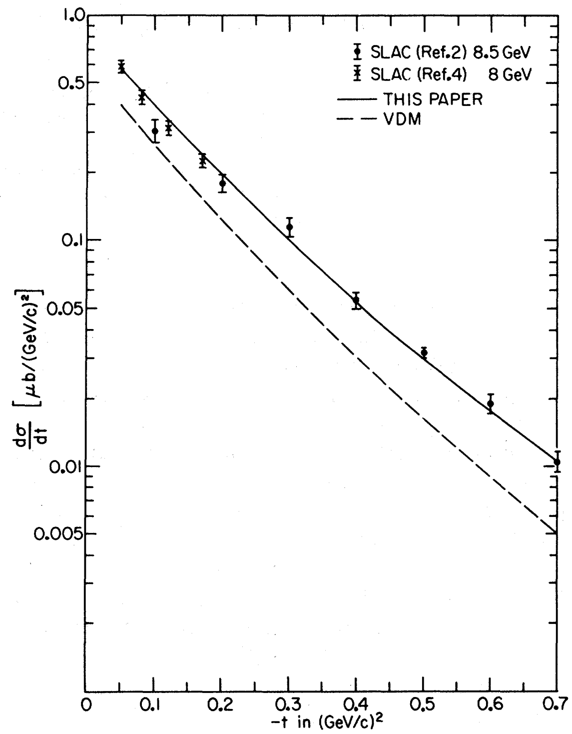

FIG. 2. $d\sigma/dt$ in μb(GeV/c)$^{-2}$ vs t for $\gamma p \to \gamma p$. The solid line is the prediction of this work; the dashed line is the vector-dominance-model prediction.

This is reflected in a t dependence for the ratio of our predicted Compton cross section to the VDM prediction. In order to determine this t dependence, we used the experimental data[8] for πp and Kp elastic scattering at 10 GeV, since the existing data at 8 GeV do not extend over a wide enough range in t to be useful here. Moreover, the relation is quite sensitive to the relative size of the coupling constants $g_{\rho\pi\pi}$ and $g_{\rho KK}$. The difficulty is that there is no direct measurement of $g_{\rho KK}$ possible. The only existing determination of $g_{\rho KK}$ was made by fitting K-nucleon elastic scattering with a model that includes ρ exchange in the crossed channel.[9] The result was

$$g_{\rho KK}/g_{\rho\pi\pi} = 0.57 \pm 0.06\,, \tag{7}$$

where SU(3) would give exactly $\frac{1}{2}$. We will use the SU(3) value for the coupling-constant ratio, although our results are not appreciably modified if we use Eq. (7). We find good agreement with experiment, as shown in Fig. 2.

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Comment on $\gamma\pi \rightarrow \pi\pi$ in the Veneziano Model

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It is shown that the Veneziano-type amplitude of Cooper for the process $\gamma\pi \rightarrow \pi\pi$ does not reproduce the experimental data as extracted from $\pi N \rightarrow \pi N\gamma$.

(1) The matrix element of the reaction

$$\pi_\alpha(p_1) + \pi_\beta(p_2) \rightarrow \pi_\gamma(p_3) + \gamma(k) \tag{1}$$

may be written in the form

$$M_{fi} = i\epsilon_{\alpha\beta\gamma}\,\epsilon_{\lambda\mu\nu\sigma}p_1^\lambda p_2^\mu p_3^\nu \epsilon^\sigma(k) A(s,t,u), \tag{2}$$

where $A(s,t,u)$ is the invariant amplitude depending on the Mandelstam variables s, t, u. If now $A(s,t,u)$ is known from some model, we may go to the ρ pole and equate the residue to that from the Feynman diagram, obtaining

$$\lim_{s\to m_\rho^2}(s - m_\rho^2)A(s,t,u) = 2g_{\rho\pi\pi}g_{\rho\pi\gamma}\ . \tag{3}$$

From this we get $g_{\rho\pi\gamma}$, and consequently we may calculate the width $\Gamma(\rho\rightarrow\pi\gamma)$, for which, experimentally, only an upper bound is known[1]:

$$\Gamma(\rho\rightarrow\pi\gamma)\Gamma^{-1}(\rho\rightarrow\pi\pi) \lesssim 0.002. \tag{4}$$

The process (1) has been analyzed experimentally[2] by an extrapolation procedure, using the fact that it dominates[3] the high-frequency part of the photon spectrum in pion-nucleon bremsstrahlung ($\pi N\rightarrow \pi N\gamma$). The result of this analysis, consistent with (4) via (3), may be expressed in the equivalent form (in units $m_\pi = 1$)

$$K \equiv \left| \frac{A(4, -0.5, -0.5)}{\lim_{s\to m_\rho^2}(s - m_\rho^2)A(s,t,u)} \right| \gtrsim 1.2\,, \tag{5}$$

where K is the ratio of the value of the amplitude at threshold ($s = 4$, $t = u = -0.5$) to its residue at the ρ pole. In evaluating this ratio we have used the fact that at threshold as well as at the ρ pole the full amplitude $A(s,t,u)$ reduces to its first partial wave, in terms of which the experimental situation has been analyzed in Ref. 2.

(2) After the success of the Veneziano amplitude for $\omega\pi\rightarrow\pi\pi$, it has been an appealing possibility to use a similar amplitude for $\gamma\pi\rightarrow\pi\pi$, since there is a great resemblance between these two processes from the kinematical point of view. Thus, only the transverse polarizations of ω and only isoscalar photons contribute; only the mass-shell conditions are different.

In a previous paper,[4] the Virasoro amplitude[5] for $A(s,t,u)$ has been used, containing no adjustable parameter besides a multiplicative factor. This, however, drops out from (5) and we get $K\approx 0.1$, in disagreement with (5).

(3) It has been the hope of Murtaza and Harun-Ar-Rashid[6] that the recently proposed amplitude of Cooper,[7]

$$A(s,t,u) = 2\beta[V(s,t) + V(s,u) + V(t,u)]\,, \tag{6}$$