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where i and j can be +, −, or 0.

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Photoproduction of Neutral Vector Mesons in a Regge-Pole Model with Cuts

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Photoproduction of vector mesons in $\gamma p\to\rho V^0$ reactions is considered in a model with P, P', A_2, and π trajectories and PP cuts. The contributions of cuts are described phenomenologically; SU(3) symmetry is used for vertices. The results obtained are in good agreement with all existing experimental data.

The photoproduction of ρ, ω, and ϕ mesons in reactions

$$\gamma N\to V^0 N \tag{1}$$

is considered in the model which takes into account P, P', A_2, and π Regge poles and phenomenologically parametrized PP cuts.

Reactions (1) are described by 12 helicity amplitudes. Following the standard procedure[1,2] we construct the kinematic-singularity-free t-channel helicity amplitudes and get three conspiracy relations

$$\bar f^-_{00}-i\bar f^-_{10}=O(\sqrt{t}\,), \tag{2a}$$

$$\bar f^-_{01}-i\bar f^+_{11}=O(\sqrt{t}\,), \tag{2b}$$

$$\bar f^-_{02}-i\bar f^+_{12}=O(\sqrt{t}\,). \tag{2c}$$

We have chosen an evasive solution to these equations for contributions of the Regge trajectories and a conspirative solution for the cut. Thus, the kinematical factors for the pole part of the amplitudes are[3]

$$\begin{aligned}
K^+_{00}&=2(t-\mu^2)^{-1}(t-4m^2)^{-1/2}, & K^-_{00}&=\tfrac{1}{2}t^{1/2}(t-\mu^2)^{-1},\\
K^+_{01}&=1, & K^-_{01}&=\tfrac{1}{2}t^{1/2}(t-4m^2)^{1/2},\\
K^+_{02}&=\tfrac{1}{2}(t-\mu^2)(t-4m^2)^{1/2}, & K^-_{02}&=\tfrac{1}{2}(t-\mu^2)(t-4m^2)^{1/2},\\
K^+_{10}&=1, & K^-_{10}&=\tfrac{1}{2}t^{1/2}(t-4m^2)^{1/2},\\
K^+_{11}&=t^{1/2}, & K^-_{11}&=\tfrac{1}{2}(t-4m^2)^{1/2},\\
K^+_{12}&=\tfrac{1}{2}t^{1/2}(t-\mu^2)(t-4m^2)^{1/2}, & K^-_{12}&=\tfrac{1}{4}(t-\mu^2)(t-4m^2),
\end{aligned} \tag{3}$$

where m is the nucleon mass and μ is the meson mass. The threshold and pseudothreshold of the γV vertex degenerate to $t=\mu^2$, yielding the conditions[3] for the natural-parity amplitudes,

$$\bar{f}^+_{00}+\sqrt{2}\cos\theta_t\bar{f}^+_{01}+\cos^2\theta_t\bar{f}^+_{02}=x_1(t)(t-\mu^2),$$
$$-\cos\theta_t\bar{f}^+_{10}+\sqrt{2}\cos\theta_t\bar{f}^+_{11}+\cos^2\theta_t\bar{f}^+_{12}=x_2(t)(t-\mu^2),\qquad(4a)$$
$$(t-\mu^2)(\bar{f}^+_{00}-\cos^2\theta_t\bar{f}^+_{02})=x_3(t)(t-\mu^2),$$
$$(t-\mu^2)(\cos\theta_t\bar{f}^+_{10}+\cos^2\theta_t\bar{f}^+_{12}+\cos\theta_t\bar{f}^-_{12})=x_4(t)(t-\mu^2),$$

and for the amplitudes with unnatural parity,

$$\bar{f}^-_{00}+\sqrt{2}\cos\theta_t\bar{f}^-_{01}+\cos^2\theta_t\bar{f}^-_{02}=y_1(t)(t-\mu^2),$$
$$-\cos\theta_t\bar{f}^-_{10}+\sqrt{2}\cos\theta_t\bar{f}^-_{11}+\cos^2\theta_t\bar{f}^-_{12}=y_2(t)(t-\mu^2),\qquad(4b)$$
$$(t-\mu^2)(\bar{f}^-_{00}-\cos^2\theta_t\bar{f}^-_{02})=y_3(t)(t-\mu^2),$$
$$(t-\mu^2)(\cos\theta_t\bar{f}^-_{10}+\cos\theta_t\bar{f}^+_{12}+\cos^2\theta_t\bar{f}^-_{12})=y_4(t)(t-\mu^2).$$

$x_i(t)$, $y_i(t)$ are slowly varying functions finite at $t=\mu^2$.

Retaining in Eqs. (4) only leading terms on $s-u$ we can get the following relations between the pole parts of reduced amplitudes:

$$\begin{aligned}
\bar{f}^+_{02}&=\frac{4}{\mu^2(s-u)^2}\bar{f}^+_{00}, & \bar{f}^-_{02}&=\frac{2}{\mu^2(s-u)^2}\bar{f}^-_{00},\\
\bar{f}^+_{01}&=-\frac{2\sqrt{2}}{\mu(s-u)}\bar{f}^+_{00}, & \bar{f}^-_{01}&=-\frac{\sqrt{2}}{\mu(s-u)}\bar{f}^-_{00},\\
\bar{f}^+_{12}&=-\frac{2}{\mu^2(s-u)}\bar{f}^+_{10}, & \bar{f}^-_{12}&=-\frac{2}{s-u}\bar{f}^-_{10},\\
\bar{f}^+_{11}&=\frac{\sqrt{2}}{\mu}\bar{f}^+_{10}, & \bar{f}^-_{11}&=\sqrt{2}\,\mu\bar{f}^-_{10}.
\end{aligned}\qquad(5)$$

The same relations take place for the conspirative-cut part, but $\bar{f}^+_{10}$ and $\bar{f}^-_{00}$ are multiplied by μ^2. Following Ref. 3 we assume that the reduced amplitudes are smooth enough and relations (5) can be continued to the negative-t region. The assumption made essentially simplifies the calculations; as we shall see later on, it does not contradict the experimental data.

We parametrize the pole part of the natural-parity amplitude in the following manner:

$$\bar{f}^+_{\lambda\mu}=\frac{1+e^{-i\pi\alpha}}{\sin\pi\alpha}g_{\lambda\mu}(\alpha)\gamma^{+\alpha}_{\lambda\mu}(\alpha+1)\times\frac{\Gamma(\alpha+\frac{3}{2})}{\sqrt{\pi}\,\Gamma(\alpha+1)}\left(\frac{s-u}{s_0}\right)^{\alpha-\max(|\lambda|,|\mu|)},\qquad(6)$$

where $\gamma^{+\alpha}_{\lambda\mu}(t)$ is a residue of an appropriate Regge pole and $g_{\lambda\mu}(\alpha)$ is the ghost-eliminating factor. It is a noncompensation mechanism for P, P' and a Gell-Mann mechanism for A_2 which prove to give the best fit to experimental data.

The contribution of the π trajectory to the $\bar{f}^-_{00}$ amplitude is taken in a form corresponding to the Reggeized Born pole exchange,[3]

$$\bar{f}^{-\pi}_{00}=\frac{1+e^{-i\pi\alpha_\pi}}{2\sin\pi\alpha_\pi}|t|^{1/2}|t-\mu^2|\pi\alpha_\pi'(m_\pi^2)\times\frac{g_{\gamma\pi V}g_{\pi NN}}{\mu}\left(\frac{s-u}{s_0}\right)^{\alpha_\pi(t)},\qquad(7)$$

where we use the following radiative widths:

$$\Gamma_{\rho\to\pi\gamma}=0.06\text{ MeV},\quad\Gamma_{\omega\to\pi\gamma}=0.5\text{ MeV},\quad\Gamma_{\phi\to\pi\gamma}=0.$$

The PP cut is parametrized in the following form:

$$\bar{f}^{c\pm}_{\lambda\mu}=a^\pm_{\lambda\mu}\frac{e^{bt-i\pi\alpha_c/2}}{\ln[(s-u)/s_0]+d-\frac{1}{2}i\pi}\left(\frac{s-u}{s_0}\right)^{\alpha_c-\max(|\lambda|,|\mu|)}\qquad(8)$$

In order to simplify calculations, we take the parameters b and d independent of helicity indices. The conspiracy relations (2) and Eqs. (5) give the relation

$$a^-_{00}=-ia^+_{10}.\qquad(9)$$

The amplitude $\bar{f}^-_{10}$ has a contribution only from the PP cut and enters into Eq. (2a), which has only an evasive solution. So this amplitude is negligible at small t and in the following $\bar{f}^-_{10}$ is disregarded.

Finally in the model we have ten free parameters for ρ^0-photoproduction amplitudes: six residues from P, P', and A_2 poles in $\bar{f}^+_{00}$ and $\bar{f}^+_{10}$, and four parameters from cuts $-a^+_{00}$, a^+_{10}, b, and d. Applying the SU(3) symmetry to the vertices we can construct the amplitudes for ω and ϕ photoproduction using the same ten parameters. The best fit is obtained by supposing that the P trajectory is a unitary singlet. In accordance with the existing experimental data[4] the slope of the P trajectory has been taken equal to 0.5 GeV^{-2}. The other trajectories are

$$\begin{aligned}\alpha_{P'}&=0.5+0.95t,\\ \alpha_{A_2}&=0.4+0.95t,\\ \alpha_\pi&=-0.02+0.95t.\end{aligned}\qquad(10)$$

To obtain the free parameters, we have fitted our curves to the experimental data on ρ^0- and ω-photoproduction differential cross sections using 134 experimental points at different energies.[5] The best fit has been obtained for the values of the parameters given in Table I, corresponding to $\chi^2=70.3$ at a confidence level of 99%. The calculated curves for $d\sigma/dt$ of ρ^0, ω, and ϕ mesons, and parity asymmetry P_σ for the ϕ meson are shown in

TABLE I. The values for the parameters at $\chi^2 = 70.3$.

$\tilde{f}^{+}_{00}$		$\tilde{f}^{-}_{10}$	
γ^{P}_{00} ($\mu b^{1/2}$ GeV^2)	23.946	γ^{P}_{10} ($\mu b^{1/2}$ GeV^4)	0.652
$\gamma^{P'}_{00}$ ($\mu b^{1/2}$ GeV^2)	−2.163	$\gamma^{P'}_{10}$ ($\mu b^{1/2}$ GeV^4)	−110.25
$\gamma^{A_2}_{00}$ ($\mu b^{1/2}$ GeV^2)	65.02	$\gamma^{A_2}_{10}$ ($\mu b^{1/2}$ GeV^4)	13.742
a^{+}_{00} ($\mu b^{1/2}$ GeV^2)	−34.869	a^{-}_{10} ($\mu b^{1/2}$ GeV^4)	−23.273
$b = 1.551$ GeV^{-2}		$d = 1.955$	

Fig. 1.

The contribution of the PP cut is found to be essential. There are some interesting effects due to the interference between poles and cuts. So the differential cross section of the ω meson has a dip at low energies and $|t| \sim 0.6$ GeV^2 resulting from the maximal destructive interference between the P trajectory and the PP cut in the $\tilde{f}^{+}_{10}$ amplitude in the region where $\alpha_{P'} \approx \alpha_{A_2} \approx 0$. With increasing energy the cut contribution decreases, the dip disappears, and for $K \gtrsim 9$ GeV the differential cross section of the ω meson becomes similar to that of the ρ^0 meson. The existing experimental data do not contradict such a behavior. Therefore it will be necessary to have more accurate detailed experimental data in this region of t and in the energy interval between 2 and 10 GeV. For the ρ^0-meson photoproduction the above-mentioned mechanism is suppressed owing to the large contribution of the P trajectory.

The differential cross section of the ϕ meson predicted by the model has a small spike in the forward direction at low energies resulting from the contribution of the conspirative PP cut and the destructive interferences between the P, P', and

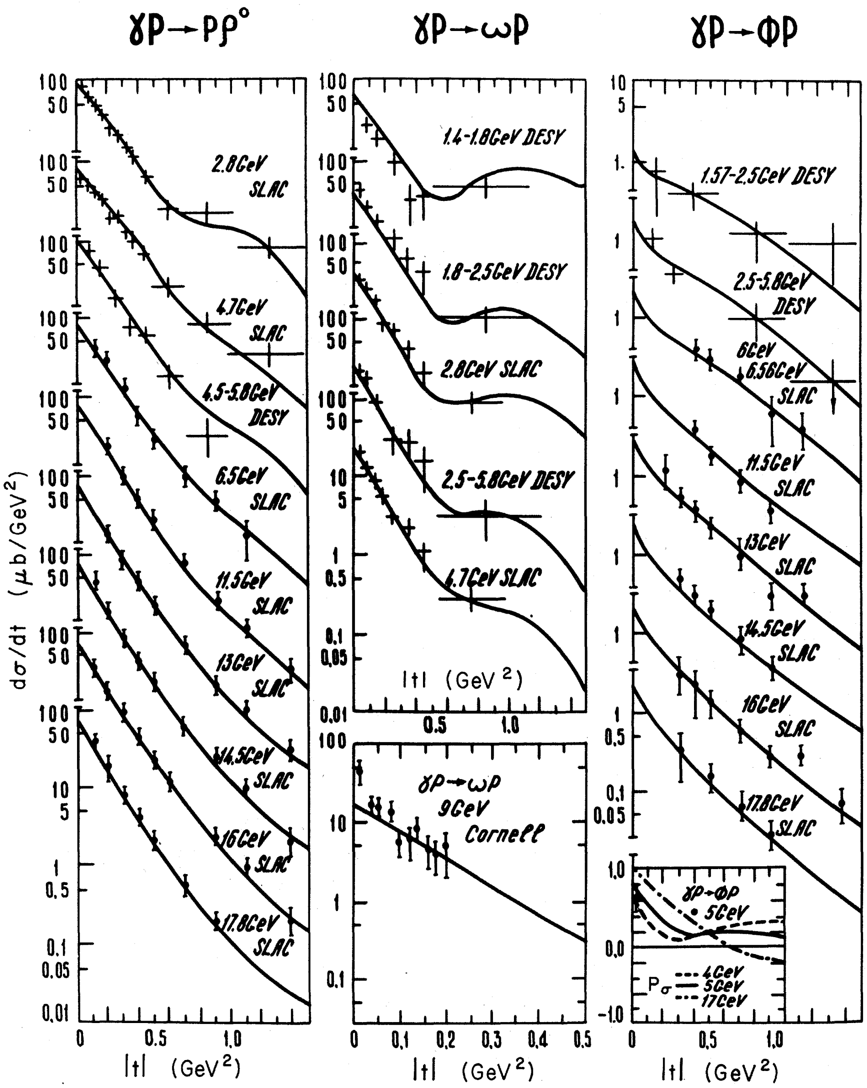

FIG. 1. The fit to the differential cross section for ρ^0 and ω photoproduction and the predictions for ϕ-meson photoproduction differential cross section and parity asymmetry. The data are from Ref. 5.

A_2 poles. When the energy increases, the spike flattens and disappears because of the decreasing cut contribution.

It was believed that ϕ meson photoproduction is purely diffractive because of the absence of the contribution of the π-meson trajectory. The preliminary results of the experiment at Cornell[5] have shown that the asymmetry parameter $\Sigma(\gamma P \to \phi P) = 0.6 \pm 0.2$ when $\langle K \rangle = 5$ GeV. The contribution of the PP cut to the $\bar{f}_{00}^{-}$ amplitude ensures the value of P_σ which does not contradict these data.

Predictions of the model for spin density-matrix elements of ρ^0 and ω mesons defined in Ref. 6 are drawn in Fig. 2. When s-channel helicity is conserved, all matrix elements in the helicity frame must be equal to zero, aside from $\rho^1_{1\,-1}$ and $\mathrm{Im}\rho^2_{1\,-1}$, which are equal to 0.5.[6]

It is seen from Fig. 2 that in ρ^0 photoproduction the conservation of s-channel helicity holds at least for small $|t|$, but in ω photoproduction the s-channel helicity is not conserved owing to large contributions of the π trajectory and the unnatural part of the PP cut. When the energy increases, however, the diffractive mechanism dominates and leads to s-channel helicity conservation and the curves for the matrix elements of the ω meson become similar to that of the ρ^0 meson.

The parity asymmetry $P_\sigma = (\sigma^N - \sigma^U)/(\sigma^N + \sigma^U)$ for ρ^0 and ω mesons is shown in Fig. 2. In ρ^0 photoproduction a dominance of the exchanges with natural parity is evident, but for the ω meson the contributions from exchanges with natural and unnatural parities are approximately equal. Here, the necessity for introducing the cut is especially clear; using only π exchange within the frame of SU(3) it is impossible to have at the same time a large contribution from unnatural-parity exchanges in ω photoproduction and a small contribution in ρ^0 photoproduction.

In Fig. 3 the predictions of the model for $(d\sigma/dt)_{t=0}$ for all three processes are given together with the experimental points; the agreement is

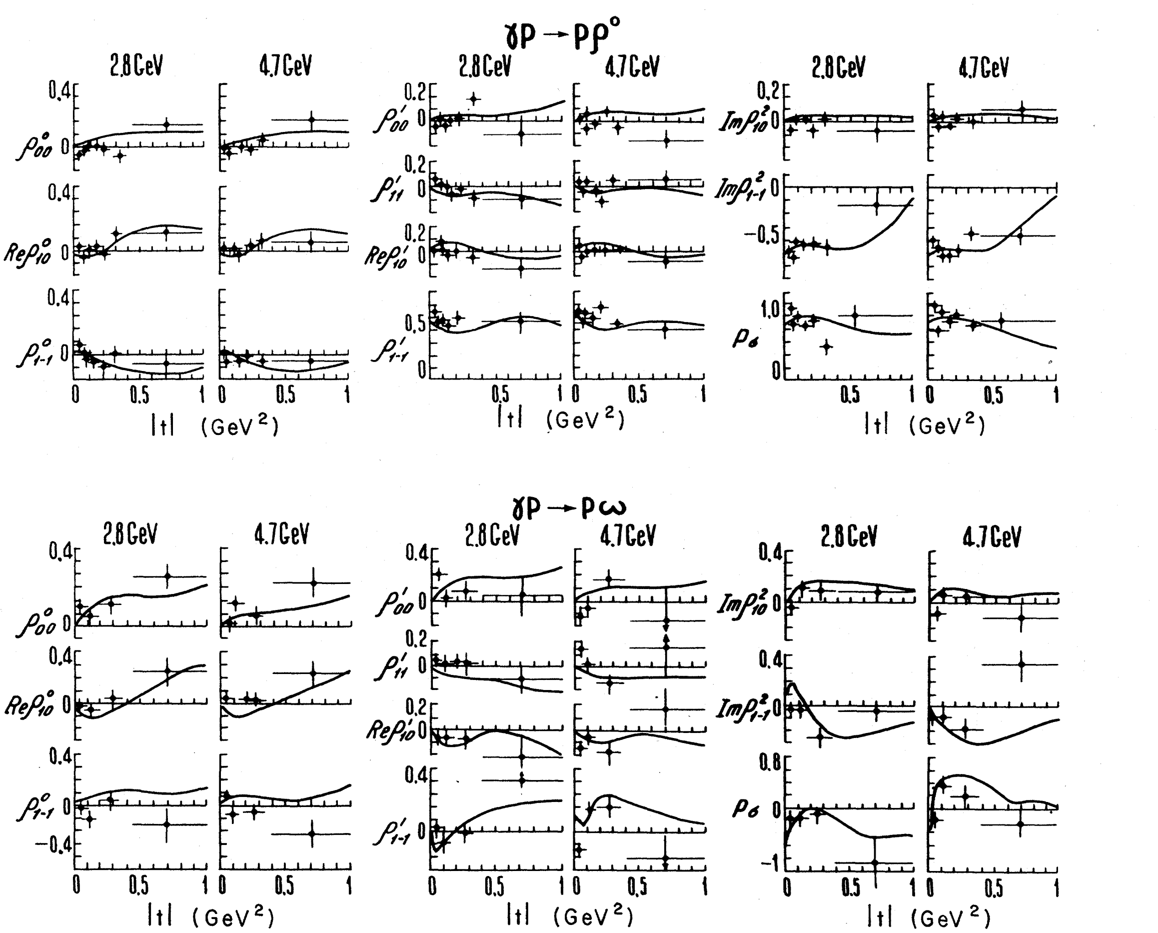

FIG. 2. The predictions for the spin density-matrix elements (helicity frame) and parity asymmetry for ρ^0 and ω photoproduction. The data are from Ref. 5.

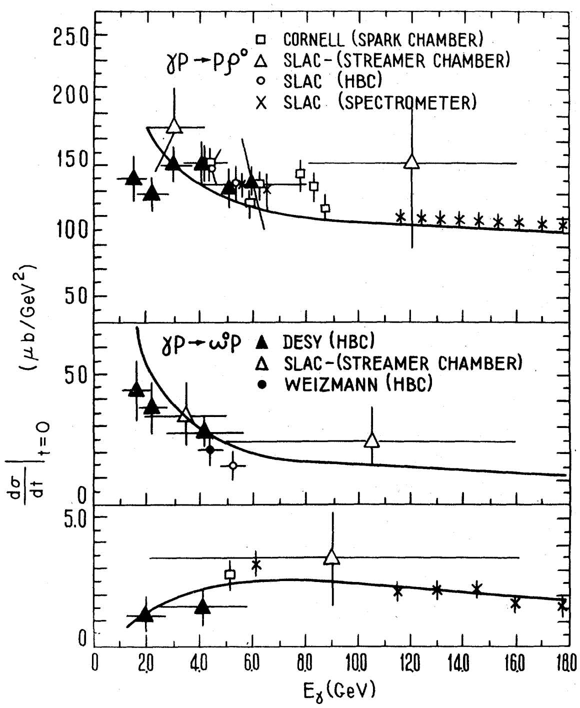

FIG. 3. The predictions for differential cross sections at $t=0$ in ρ^0, ω, and ϕ photoproduction.

also very good. As in previous theoretical papers[3,7] the suppression of ϕ photoproduction results from the destructive interference of P with P' and A_2 trajectories. In addition, the constructive interference of the PP cut with the same poles gives better agreement with the experimental data. The asymptotic ($K \gtrsim 50$ GeV) value $(d\sigma/dt)_{t=0} \approx 1.5$ μb/GeV^2 for ϕ photoproduction is reached from below.

The cross-sectional ratio for ρ^0 photoproduction on the proton and deuteron when $|t| \approx 0$ (using the Glauber correction) has also been calculated. The value obtained,

$$\frac{d\sigma}{dt}(\gamma d \to \rho^0 d) \Big/ \frac{d\sigma}{dt}(\gamma p \to \rho^0 p) \simeq 3.258,$$

is in good agreement with the experimental data, 3.36 ± 0.1.[5] Without taking into account the A_2 trajectory, this ratio is equal to 3.64.[8]

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