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PHOTOPRODUCTION OF NEUTRAL VECTOR MESONS IN REGGE POLE MODEL WITH CUTS

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Фоторождение нейтральных векторных мезонов рассмотрено в модели, учитывающей P, P', A_2 и π траектории и PP-разрезы. Разрезы описываются феноменологически; использованы соотношения $SU(3)$ симметрии для вершин. Свободные параметры модели определяются методом χ^2 из экспериментальных данных по дифференциальному сечению фоторождения ρ° и ω-мезонов.

Для различных значений энергий падающего фотона предсказаны дифференциальные сечения, элементы спиновой матрицы плотности, коэффициенты асимметрии, а также дифференциальное сечение фоторождения на дейтроне. Получено хорошее согласие со всеми имеющимися экспериментальными данными.

ABSTRACT

Photoproduction of neutral vector mesons is considered in the model when contributions of P, P', A_2, and π -trajectories and of PP cuts are taken into account.

The cuts are described phenomenologically; SU(3) relations for vertexes are used. The free parameters of the model are obtained by fitting the theoretical curves to experimental data on ρ° -and ω -photoproduction differential cross section.

For different energies of incoming photon the differential cross sections, density matrix elements, asymmetry coefficients as well as the differential cross section of photoproduction on deutron are predicted. A good agreement for [illegible]existing experimental data is obtained.

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

$$\gamma N \to V^\circ N \tag{I}$$

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

Reactions (I) 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 conspirative solution for the cut. Thus, the kinematical factors for pole part of the amplitudesare [3]

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

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

$$
\begin{aligned}
&\bar{f}^{+}_{00} + \sqrt{2}\cos\theta_t\,\bar{f}^{+}_{01} + \cos^2\theta_t\,\bar{f}^{+}_{02} = X_1(t)(t-\mu^2),\\
&-\cos\theta_t\,\bar{f}^{+}_{10} + \sqrt{2}\cos\theta_t\,\bar{f}^{+}_{11} + \cos^2\theta_t\,\bar{f}^{+}_{12} = X_2(t)(t-\mu^2),\\
&(t-\mu^2)(\bar{f}^{+}_{00} - \cos^2\theta_t\,\bar{f}^{+}_{02}) = X_3(t)(t-\mu^2),\\
&(t-\mu^2)(\cos\theta_t\,\bar{f}^{+}_{10} + \cos^2\theta_t\,\bar{f}^{+}_{12} + \cos\theta_t\,\bar{f}^{-}_{12}) = X_4(t)(t-\mu^2),
\end{aligned}
\tag{4a}
$$

and for the amplitudes with unnatural parity:

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

$X_i(t), y_i(t)$ 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 part of reduced amplitudes.

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

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

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

$$
\tilde{f}^{+}_{\lambda\mu} = \frac{1+e^{-i\pi\alpha}}{\sin\pi\alpha}\, g^{\alpha}_{\lambda\mu}\,\gamma^{+\alpha}_{\lambda\mu}(\alpha+1)\frac{\Gamma(\alpha+\frac{3}{2})}{\sqrt{\pi}\,\Gamma(\alpha+1)}\left(\frac{S-U}{S_0}\right)^{\alpha-max(|\lambda|,|\mu|)}
\tag{6}
$$

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

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

$$
\tilde{f}^{-\pi}_{00} = \frac{1+e^{-i\pi\alpha_\pi}}{2\sin\pi\alpha_\pi}|t|^{\frac{1}{2}}|t-\mu^2|\,\pi\alpha'_\pi(m^2_\pi)\,\frac{g_{\gamma\pi V}\,g_{\pi NN}}{\mu}\left(\frac{S-U}{S_0}\right)^{\alpha_\pi(t)}
\tag{7}
$$

where we use the following radiative widths

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

P P – cut is parametrized in the following form

$$
\tilde{f}^{c\pm}_{\lambda\mu} = a^{\pm}_{\lambda\mu}\,\frac{e^{bt-\frac{1}{2}i\pi\alpha_c}}{\ln\left(\frac{S-U}{S_0}\right)+d-\frac{i\pi}{2}}\left(\frac{S-U}{S_0}\right)^{\alpha_c-max(|\lambda|,|\mu|)}
\tag{8}
$$

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

$$
a^{-}_{00} = -i\,a^{+}_{10}\,.
\tag{9}
$$

The amplitude $\tilde{f}^{-}_{10}$ has a contribution only from P P – cut and enters in eq. (2a) which has only evasive solution. So this amplitude is negligible at small t and in following

$\tilde{f}_{10}^{-}$ is disregarded.

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

$$\alpha_{P'} = 0.5 + 0.95t \; ; \; \alpha_{A_2} = 0.4 + 0.95t \; ; \; \alpha_{\pi} = -0.02 + 0.95t \qquad (10)$$

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 99%. The calculated curves for $d\sigma/dt$ of ρ^{0} -, ω - and φ - mesons, and parity asymmetry P_σ for φ-meson are shown in fig.I.

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

The differential cross section of φ - meson predicted by the model has a small spike in forward direction at low energies resulted from the contribution of the conspirative PP-cut and destructive interferences between P-, P' - and A_2- poles. When energy increases, the spike smoots and disappears due to decreasing of the cut contribution.

It was believed that φ- meson photoproduction is pure diffractive because of the absence of the contribution of π - meson trajectory. The preliminary results of the experiment at Cornell[5] have shown that the asymmetry parameter $\Sigma(\gamma p \to \varphi p) = 0.6 \pm 0.2$ when $\langle K \rangle = 5$ GeV. The contribution of PP - cut in $\tilde{f}_{00}^{-}$ 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 [6] are drawn in fig.2. When S-channel helicity is conserved, all matrix elements in helicity frame must be equal to zero, aside from ρ^{1}_{1-1} and $Im\,\rho^{2}_{1-1}$ 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 due to large contributions of the π- trajectory and the unnatural part of PP -cut. When energy increases, however, the diffractive mechanism dominates and leads to S-channel helicity conservation and the curves for matrix elements of ω-meson become similar to that of ρ°- meson.

The parity asymmetry $P_{\sigma}=(\sigma^{N}-\sigma^{U})/(\sigma^{N}+\sigma^{U})$ for ρ°- and ω - mesons is shown in fig.2. In the ρ° - photoproduction a dominance of the exchanges with natural parity is evident, but for 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 one in ρ° - photoproduction.

In Fig.3 the predictions of the model for $(d\sigma/dt)(t=0)$ for all the three processes are given together with the experimental points; the agreement is also very good. As in the previous theoretical papers /3,7/ the suppression of φ- photoproduction is resulted from the destructive interference P with P'- and A_2 - trajectories. In addition the constructive interference of PP-cut with the same poles gives better agreement with the experimental data. The asymptotic ($K \geqslant 50$ GeV) value $(d\sigma/dt)_{t=0} \approx 1.5\ \mu b/\mathrm{GeV}^2$ for φ- photoproduction is reached from below.

The ratio of cross section for ρ°- photoproduction on proton and deutron when $/t/ \approx 0$ (using the Glauber correction) has also been calculated. The obtained value

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

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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Table I

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

$\tilde{f}^{+}_{00}$		$\tilde{f}^{-}_{10}$	
$\gamma^{P}_{00}\,(\mu b^{1/2}\,GeV^{2})$	23,946	$\gamma^{P}_{10}\,(\mu b^{1/2}\,GeV^{4})$	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
$b = 1{,}551\ GeV^{-2}$		$d = 1{,}955$	

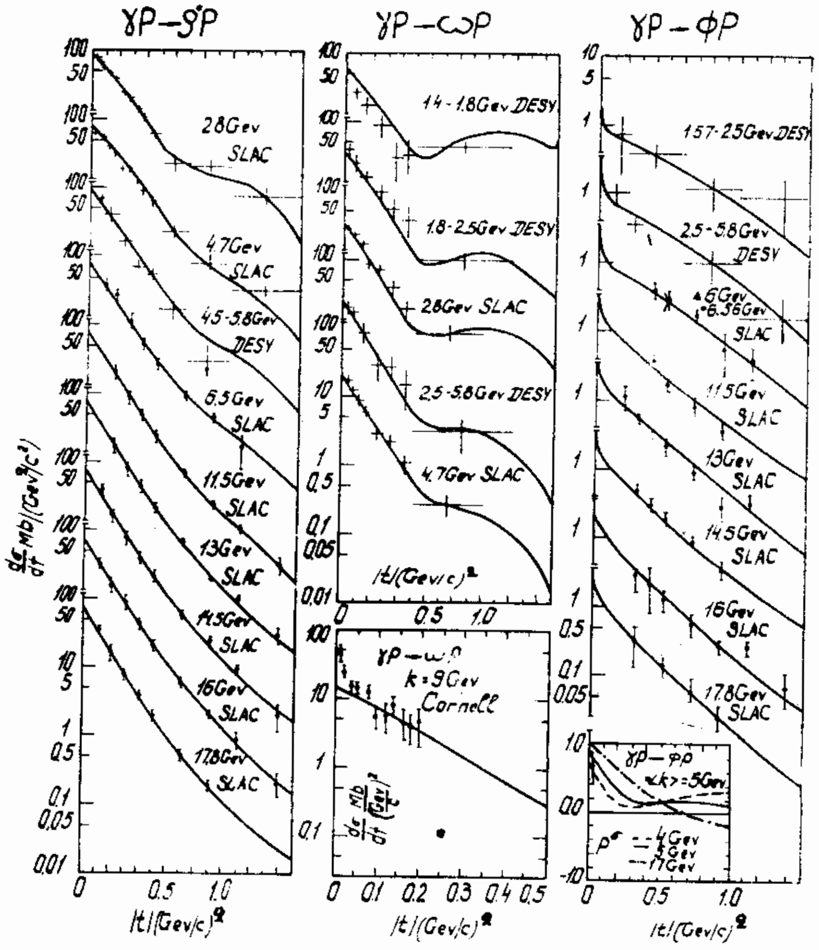

Fig.1

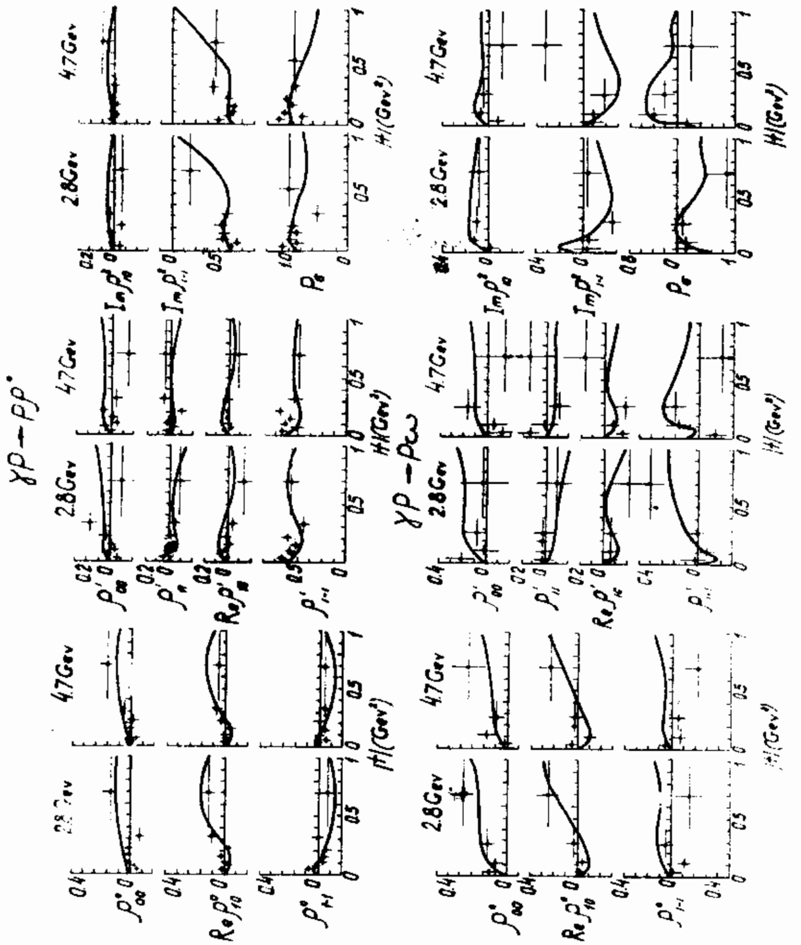

Fig 2

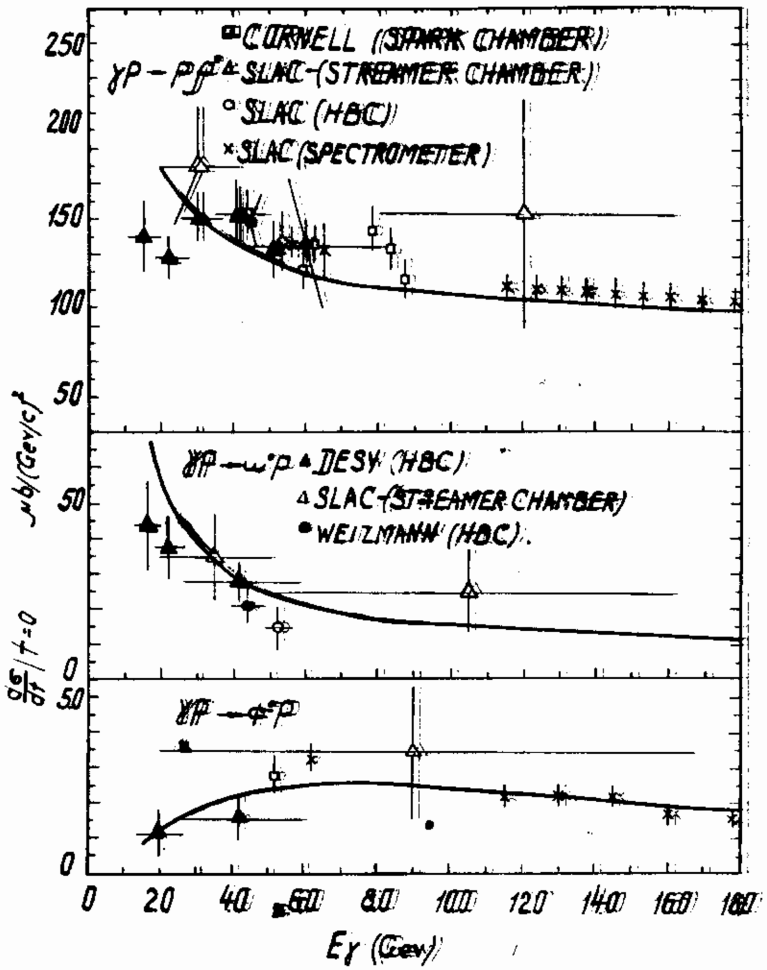
γP → Pρ°
CORNELL (SPARK CHAMBER)
SLAC (STREAMER CHAMBER)
SLAC (HBC)
SLAC (SPECTROMETER)
γP → ω°P
DESY (HBC)
SLAC (STREAMER CHAMBER)
WEIZMANN (HBC).
γP → φ°P
dσ/dt |t=0 μb/(Gev/c)²
Eγ (Gev)

Fig.3

Figure Captions

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].

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.

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