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ANALYSIS OF π^+, π^-, π^0 PHOTOPRODUCTION ON NUCLEONS IN RESONANCE REGION

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АНАЛИЗ ФОТОРОЖДЕНИЯ π^+ , π^- , π° НА НУКЛОНАХ В РЕЗОНАНСНОЙ ОБЛАСТИ

На основе метода дисперсионных соотношений с вычитанием [8] проведен анализ фоторождения π^+ , π^- , π° с минимально возможным числом фитируемых параметров с целью проверки двух наборов значений амплитуд, полученных в работе [1] , и выделения лучшего из них.

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Making use of the method of dispersion relations with subtraction [8] the analysis of π^+, π^-, π^0 meson photoproduction on nucleons with the minimum number of fitting parameters is carried out in order to single out the best of the two sets of the resonance couplings obtained in Ref. [1].

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1. As is well known, the pion photoproduction on nucleons in the resonance region is of great interest to get information on amplitudes of radiative decays of nucleon resonances $N^* \to N\gamma$, which is important for hadron structure investigation, testing of their classification and for the study of hadron electromagnetic current properties.

The most efficient method of extracting the $N^* \to N\gamma$ couplings from the experimental data is the one based on the use of fixed-t dispersion relations (DR).

In this method the arbitrariness in constructing the real parts of the amplitudes is less as compared with the Walker phenomenological approach [2] used in Refs. [2-4]. However, in spite of the essential restrictions on a construction of the real parts of the amplitudes, the number of fitting parameters in this method remains extremely large. This is due to the high-energy contributions in DR which lead to the essential increase of the number of fitting parameters. For example, the total number of the fitting parameters is 68 in Ref. [5], and 92 in Ref. [6]. At such number of parameters it may turn out that the solutions obtained are not unique and do not correspond to a global minimum of χ^2.

From the qualitative analysis of data of Ref.[1] there were extracted two sets of solutions (I) and (II) which mostly correspond to the peculiarities of the resonance behaviour of the experimental data in the I, II and III resonance regions. In solution (I) agreeing well with all the analyses available (see, for example, Refs.[3-7]) the resonance behaviour of differential cross sections in the III resonance region is determined mainly by F_{15} (1688) resonance. In solution (II) this resonance behaviour is the manifestation of D_{15} (1670) resonance.

In order to compare the solutions (I) and (II) we have carried out in this work the analysis of experimental data on π^+, π^-, π^0 photoproduction in the I, II and III resonance regions by introducing a minimum number of fitting parameters additional to the resonance ones. With this aim we have used the subtraction method in DR proposed in Ref. 8 .

2. The imaginary part of the photoproduction amplitudes in the considered energy region is determined both by the contributions of S-channel resonances and background in amplitude $\mathcal{A}_{0+}$. The resonances masses and widths are given in the Table. We have used the Breit-Wigner parametrization [2] for the resonance contributions into the imaginary parts of photoproduction partial amplitudes. The constants determining the resonance contribution into the partial amplitudes are the unknown parameters which are inferred by fitting the experimental data.

The fixed-t dispersion relations with the subtraction at $\nu=\nu_S$ for the invariant amplitudes $\mathcal{A}_i(\nu,t)$ $(i=1,2,3,4)$ have the following form:

$$Re\,\mathcal{A}_i(\nu,t)=\begin{pmatrix}1\\ \frac{\nu}{\nu_S}\end{pmatrix}Re\,\mathcal{A}_i(\nu_S,t)+R_i\,\frac{2(\nu^2-\nu_S^2)}{(\nu_B^2-\nu^2)(\nu_B^2-\nu_S^2)}\begin{pmatrix}\nu_B\\ \nu\end{pmatrix}+ \qquad (1)$$

$$+\frac{P}{\pi}\left\{\int\limits_{\mathrm{I,\,II,\,III\text{-}res.\ region}} \mathrm{Im}\,A_i(\nu',t)\begin{pmatrix}\nu'\\ \nu\end{pmatrix}\frac{2(\nu^2-\nu_s^2)}{(\nu'^2-\nu^2)(\nu'^2-\nu_s^2)}\,d\nu' +\right.$$

$$\left.+\int\limits_{\mathrm{IV\text{-}res.\ region\ and\ above}} \mathrm{Im}\,A_i(\nu',t)\begin{pmatrix}\nu'\\ \nu\end{pmatrix}\frac{2(\nu^2-\nu_s^2)}{(\nu'^2-\nu^2)(\nu'^2-\nu_s^2)}\,d\nu'\right\},$$

where the upper and lower lines in parentheses correspond to even and odd amplitudes, $\nu = E-\nu_1$, $\nu_1=(t-\mu^2)/4m$, $\nu_B=-\nu_1$, E is the photon laboratory energy, μ and m are masses of pion and nucleon, respectively.

If the energy $E_s\,(E_s=\nu_s+\nu_1)$ is in the interval from the threshold up to 0.5 GeV, then the amplitudes $A_i(\nu_s,t)$ are known well enough from the phase shift analyses carried out in this region without help of any models (see, e.g. [9, 10]). Let us take E_s = 0.5 GeV in order to obtain the widest t-region: $0<|t|<|t_s|$ = 0.45 GeV^2 in which the amplitudes $A_i(\nu_s,t)$ are known. Note that just this region of t gives most of the uncertainty to the high-energy contributions to the dispersion integrals since in this region the amplitudes $A_i(\nu',t)$ are great. At larger $|t|$ these amplitudes are essentially less.

We have analyzed the experimental data over the energy region from the threshold up to 1 GeV which includes the I, II and almost the whole III resonance regions. At these energies the contribution of dispersion integrals over the IV resonance region and above is at least 3 times as suppressed owing to the subtraction done, and turned out less than the uncertainties introduced by phase shift analyses into the amplitudes $A_i(\nu_s,t)$. We have carried out the analysis assuming that the contributions of these high-energy integrals to DR (1) are zero.

At $|t|>|t_s|$ we have parametrized the amplitudes $A_i(\nu_s,t)$ as follows: $A_i(\nu_s,t)=A_i(\nu_s,t_s)+a_i(t-t_s)+b_i(t-t_s)^2$ $(i=1,2,3,4)$. It turned out that the uncertainties in the parameters a_i and b_i are lesser than the errors in the amplitudes $A_i(\nu_s,t_s)$, therefore when obtaining the final results we took $a_i=b_i=0$.

To take into account the uncertainties introduced by the phase shift analyses into the amplitudes $A_i(\nu_s,t)$ we have given the multipoles A_{0+}, A_{1-}, B_{1+}, A_{1+}, B_{2-} and A_{2-} at E_s = 0.5 GeV as fitting parameters varied in the limits given by the phase shift analyses [9, 10].

3. Thus our analysis of π^+, π^-, π^0 mesons photoproduction on nucleons at the energies up to 1 GeV includes a relatively small number of fitting parameters. Besides 31 resonance couplings the analysis comprises as fitting parameters 18 multipoles determining the amplitudes $A_i(\nu_s,t)$. With these parameters we have carried out the fit to the experimental data using the limits given by solutions (I) and (II) of Ref.[1] for the resonance couplings. From the fits it turned out that the solution (I) with χ^2 per data point $\cong$ 5.7 was much better than the solution (II) with χ^2 per data point $\cong$ 15.6. Note that the χ^2 per data point for the solution (I) is larger than the analogous one in the other analyses. This is due to the fact that we have used a lesser number of fitting parameters, by what reason the analysis became less flexible. Recall, however, that our purpose is to reduce maximally the fitting parameters number so that to be sure that the obtained solution is unique and coincides with the global minimum of χ^2.

The set of obtained resonance parameters corresponding to the solution (I) is given in the Table, where for comparison the results of other analyses [6, 7] and quark model predictions are presented.

One can see from the Table that the results of all analyses for the amplitudes $A^{p}_{1/2,3/2}(P_{33}(1232))$, $A^{p,n}_{1/2}(P_{11}(1470))$, $A^{p,n}_{1/2}(S_{11}(1535))$,

$A^{p,n}_{3/2}(D_{13}(1520))$, $A^{n}_{1/2}(D_{13}(1520))$, $A^{n}_{3/2}(D_{15}(1670))$,

$A^{p}_{1/2,3/2}(D_{33}(1670))$, $A^{p}_{3/2}(F_{15}(1688))$

which are great and defined well by sign being in agreement with each other. All these amplitudes excepting $A^{p}_{1/2}(P_{11}(1470))$ agree well with the quark models predictions. The rest of the amplitudes are poorly defined in all the analyses and we cannot draw certain conclusions as to their agreement with the quark models predictions.

The authors should like to express their deep gratitude to H.A.Vartapetyan for his permanent interest and assistance in the work.

Table

Multiplet	Resonance	Amplitude	Mass (GeV)	Width (GeV)	Photoproduction analyses BCP [6]	Tokyo [7]	Our analysis	Quark models KI [11]	ABT [12]
$[56,0^+]$	P33(1232)	$A_{1/2}$	1.231	0.111	-142±7	-145±2	-139±10	-103	-121
		$A_{3/2}$			-271±10	-261±4	-246±10	-179	-210
$[56,0^+]_R$	P11(1470)	$A^p_{1/2}$	1.417	0.331	-75±15	-66±10	-76±20	-24	-28
		$A^n_{1/2}$			59±16	19±31	58±25	16	33
	P33(1690)	$A_{1/2}$	1.69	0.225			-17±20	-16	-30
		$A_{3/2}$					-41±25	-46	-52
$[70,1^-]$	S11(1535)	$A^p_{1/2}$	1.511	0.3	82±19	80±19	76±21	147	98
		$A^n_{1/2}$			-112±34	-75±47	-130±50	-119	-89
	S11(1700)	$A^p_{1/2}$	1.694	0.193	48±17	61±12	17±25	88	4
		$A^n_{1/2}$			-45±24	8±51	-31±28	-35	9
	D13(1520)	$A^p_{1/2}$	1.503	0.135	-16±8	-32±10	-22±11	-23	17
		$A^p_{3/2}$			157±8	162±7	142±16	128	157
		$A^n_{1/2}$			-55±14	-71±30	-57±27	-45	-50
		$A^n_{3/2}$			-141±15	-148±24	-100±28	-122	-142
	D13(1700)	$A^p_{1/2}$	1.719	0.126	-33±21	-29±17	-29±15	-7	-19
		$A^p_{3/2}$			-14±25	14±13	23±18	11	2
		$A^n_{1/2}$			50±42	-55±81	94±48	-15	13
		$A^n_{3/2}$			35±30	-35±63	40±52	-76	-30
	D15(1670)	$A^p_{1/2}$	1.68	0.192	22±10	+6±10	10±10	12	
		$A^p_{3/2}$			15±6	29±11	23±11	16	
		$A^n_{1/2}$			-66±20	-25±71	-39±20	-37	
		$A^n_{3/2}$			-73±14	-71±58	-79±16	-53	
	S31(1650)	$A_{1/2}$	1.662	0.18	34±28	-26±20	-3±24	59	81
	D33(1670)	$A_{1/2}$	1.629	0.216	130±37	130±16	80±42	100	11
		$A_{3/2}$			98±36	50±9	89±29	105	151
$[70,0^+]$	P11(1780)	$A^p_{1/2}$	1.721	0.167	1±39	-12±14	3±35	-47	-30
		$A^n_{1/2}$			-28±45	11±57	-5±37	-21	45
$[56,2^+]$	F15(1688)	$A^p_{1/2}$	1.68	0.119	-5±15	-26±8	-7±15	0	
		$A^p_{3/2}$			138±21	122±9	+90±30	91	
		$A^n_{1/2}$			37±10	28±38	-17±38	26	
		$A^n_{3/2}$			-38±18	-29±44	-19±42	25	

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