ONE-MESON CONTRIBUTION TO PHOTOPRODUCTION OF π^- MESONS ON PROTONS

L. V. LAPERASHVILI and S. G. MATINYAN

Physics Institute, Academy of Sciences, Georgian S.S.R.

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Quantitative agreement between Drell's theory and the experiments on photoproduction of negative π mesons on protons can be obtained by taking into account the correction suggested by the Salzmans.

THE role of peripheral interactions of elementary particles caused by the exchange of a single virtual pion[1,2] has recently become of considerable interest. Along with the "polology" approach of Chew and Low,[1] connected with extrapolations of cross sections into the unphysical region of values of the 4-momentum transfer squared ($\Delta^2 = -m_\pi^2$), many authors[3-9] have viewed the one-meson contribution as dominant in the region of small, but physical, values of $\Delta^2 \approx m_\pi^2$.

A similar approach has been recently proposed by Drell[6] for photoproduction by high energy photons. In particular, for the photoproduction of π^- on protons

$$\gamma + p \rightarrow \pi^- + \pi^+ + p\,, \qquad (1)$$

one can show, according to Drell, that the diagram shown in Fig. 1 will dominate all contributions to the cross section provided that the energy of the emitted π^-, ω, is comparable with the photon energy k, and the angle θ of emission of the π^- in the barycentric frame of the colliding particles is of the order of m_π/ω:

$$\omega \approx k \gg m_\pi\,, \qquad \theta \lesssim m_\pi/\omega \qquad (\Delta^2 \approx m_\pi^2).$$

The differential cross section for process (1) has then the form

$$d^2\sigma(k,\theta,\omega) = \frac{\alpha}{2\pi}\,\frac{\sin^2\theta}{(1-\beta\cos\theta)^2}\,\frac{d\Omega}{4\pi}\,\frac{\omega(k-\omega)}{k^3}\,d\omega\,\sigma_{\pi^+ p}(Q)\,. \qquad (2)$$

Here $\alpha = 1/137$, β is the velocity of the π^- ($\hbar = c = 1$), $d\Omega$ is the solid angle element into which the π^- is emitted, $\sigma_{\pi^+ + p}(Q)$ is the elastic scattering cross section for scattering of real π^+ mesons on protons, which is a function of only Q —the kinetic energy of the final π^+ meson and nucleon in their barycentric frame. Special experiments on photoproduction of π^- mesons in hydrogen were performed to test Eq. (2).[10] The dependence on ω (or Q) of $d^2\sigma(\theta, \omega)/d\Omega d\omega$ found at the angles

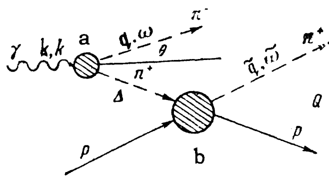

FIG. 1

θ = 10.5, 17.5 and 25° is shown in Figs. 2—4 (k = 1230 Mev in the laboratory frame). [Experimental data at larger angles (θ = 38 and 55°) correspond to $\Delta^2 > 4m_\pi^2$, where Drell's hypothesis does not apply.] The dashed curves appearing in the same figures were constructed using Eq. (2).

It is clear from the figures that Drell's formula correctly reflects the general behavior of the cross section as a function of Q and clearly points to its connection with the $^3\!/_2\,{}^3\!/_2$ resonance in πN scattering. Quantitatively, however, theory and experiment do not agree—Eq. (2) gives too low a value for the cross section even at θ = 17.2°, where it

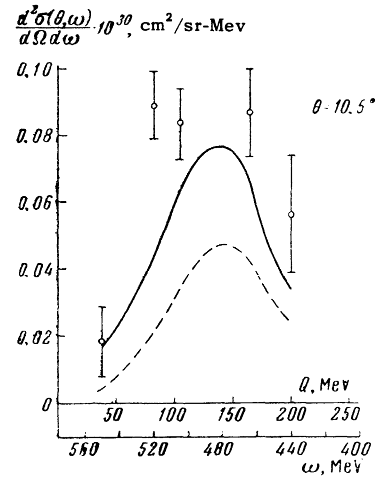

FIG. 2

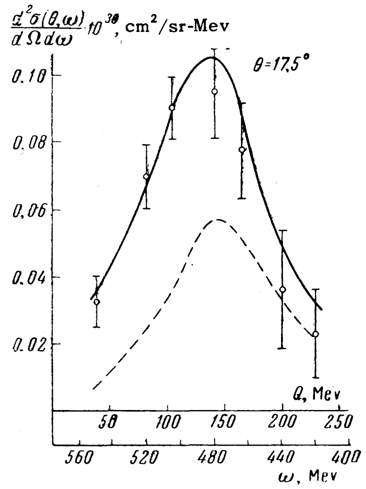

FIG. 3

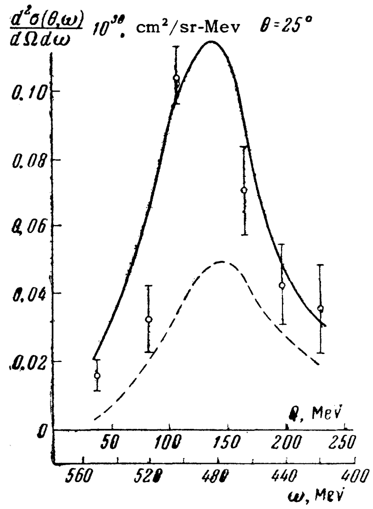

FIG. 4

has a maximum as a function of θ ($\cos\theta_{\max} = \beta$) for maximum value of $\sigma_{\pi^+ + p}(Q)$.*

It must be further noted that the reproduction of the resonance curve of the πN interaction in process (1) can be obtained to a larger or lesser extent in any isobar model, therefore a real test of Drell's hypothesis requires rigorous quantitative agreement between theory and experiment in that region of angles where the contribution from the diagram of Fig. 1 is supposed to be dominant.

It will be shown below that the discrepancy between theory and experiment is apparent only, and that after an appropriate modification of Eq. (2) quantitative agreement between theory and experiment is obtained.

Indeed, the cross section $\sigma_{\pi^+ + p}(Q)$ appearing in Eq. (2) refers to the scattering of a real π^+ meson whereas for physical values of Δ^2 a virtual pion is absorbed in the blob of vertex b (Fig. 1). As was shown by the Salzmans,[8,9] for small physical values of Δ^2 such a meson behaves as an "almost real" incident (in the $\pi^+ + p$ barycentric system) meson. Its energy is approximately equal to the energy $\tilde{\omega}$ of the real π^+ emitted from the blob in the vertex b, while the momenta of these mesons are substantially different—the virtual meson, being off the mass shell, has a three-dimensional momentum Δ significantly larger in magnitude than the momentum $\mathbf{q}$ of the real π^+ meson. As was shown by the Salzmans,[8] this almost trivial circumstance must be taken into account.

*As regards very small angles ($\theta \ll m_\pi/\omega$) where the one-meson approximation is, generally speaking, very good, the hypothesis of the dominant role played by the diagram of Fig. 1 is in all probability false: at small angles the cross section (2) tends to zero and the contribution of other left out diagrams may turn out to be substantial.

In the case under consideration the energies Q are such that one may apply to the blob at the vertex b, where the π^+ meson is absorbed, the statistical model which gives a good description of the $\frac{3}{2}\,\frac{3}{2}$ resonance of the πN system.

And so, following the Salzmans,[8] we replace in Eq. (2) the experimental cross section $\sigma_{\pi^+ + p}(Q)$ by* $(\Delta^2/\tilde{q}^2)\,\sigma_{\pi^+ + p}(Q)$. The solid curves shown in Figs. 2 — 4 are obtained when the Salzmans' correction is included in Eq. (2). Figures 3 and 4 show the quantitative agreement between the theory of Drell and experiment for $\theta = 17.5°$ and $\theta = 25°$. Figure 2, apparently, reflects the fact that for $\theta \lesssim 10°$ the referred to previously (see first footnote) circumstance, connected with the decrease of the cross section at small angles, begins to be felt.

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[3] C. Goebel, Phys. Rev. Lett. **1**, 337 (1958).

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*By applying kinematic considerations to the four-legged vertex b we find easily that

$$\Delta^2/\tilde{q}^2 = [(W - M)^2 + \Delta^2]\,/\,[(W - M)^2 - m_\pi^2],$$

where $W = Q + M + m_\pi$ is the total energy of the π^+ and proton in their c.m.s.; M stands for the nucleon mass.

[6] S. D. Drell, Phys. Rev. Lett. **5**, 278 (1960).
[7] S. D. Drell, Phys. Rev. Lett. **5**, 342 (1960).
[8] F. Salzman and G. Salzman, Phys. Rev. **120**, 599 (1960).
[9] F. Salzman and G. Salzman, Phys. Rev. Lett. **5**, 377 (1960).
[10] Kilner, Diebold, and Walker, Phys. Rev. Lett. **5**, 518 (1960).

Translated by A. M. Bircer
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ERRATA

Vol	No	Author	page	col	line	Reads	Should read
13	2	Gofman and Nemets	333	r	Figure	Ordinates of angular distributions for Si, Al, and C should be doubled.	
13	2	Wang et al.	473	r	2nd Eq.	$\sigma_\mu = \frac{e^2f^2}{4\pi^3}\omega^2(\ln\frac{2\omega}{m_\mu} - 0.798)$	$\sigma_\mu = \frac{e^2f^2}{9\pi^3}\omega^2\left(\ln\frac{2\omega}{m_\mu} - \frac{55}{48}\right)$
			473	r	3rd Eq.	$(e^2f^2/4\pi^3)\,\omega^2 \geqslant \ldots$	$(e^2f^2/9\pi^3)\,\omega^2 \geqslant \ldots$
			473	r	17	242 Bev	292 Bev
14	1	Ivanter	178	r	9	1/73	1.58×10^{-6}
14	1	Laperashvili and Matinyan	196	r	4	statistical	static
14	2	Ustinova	418	r	Eq. (10) 4th line	$[-\frac{1}{4}(3\cos^2\theta - 1)\ldots$	$-\left[\frac{1}{4}(3\cos^2\theta - 1)\ldots\right.$
14	3	Charakhchyan et al.	533	Table II, col. 6 line 1		1.9	0.9
14	3	Malakhov	550	The statement in the first two phrases following Eq. (5) are in error. Equation (5) is meaningful only when s is not too large compared with the threshold for inelastic processes. The last phrase of the abstract is therefore also in error.			
14	3	Kozhushner and Shabalin	677 ff		The right half of Eq. (7) should be multiplied by 2. Consequently, the expressions for the cross sections of processes (1) and (2) should be doubled.		
14	4	Nezlin	725	r	Fig. 6 is upside down, and the description "upward" in its caption should be "downward."		
14	4	Geĭlikman and Kresin	817	r	Eq. (1.5)	$\ldots\left[b^2\sum_{s=1}^{\infty}K_2(bs)\right]^2$	$\ldots\left[b^2\sum_{s=1}^{\infty}(-1)^{s+1}K_2(bs)\right]^2$
			817	r	Eq. (1.6)	$\Phi(T) = \ldots$	$\Phi(T) \approx \ldots$
			818	l	Fig. 6, ordinate axis	$\frac{\varkappa_s(T)}{\varkappa_n(T_c)}$	$\frac{\varkappa_s(T)}{\varkappa_n(T)}$
14	4	Ritus	918	r	4 from bottom	two or three	2.3
14	5	Yurasov and Sirotenko	971	l	Eq. (3)	1 < d/2 < 2	1 < d/r < 2
14	5	Shapiro	1154	l	Table	2306	23.6