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SOME REMARKS ON DOUBLE PHOTOPRODUCTION

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It has recently been pointed out by Drell ¹⁾ that photons are more effective than nucleons, when colliding on the same target, for the production of high-energy pions, due to the effect of the diagram in Fig. 1a. It was also stated in reference ¹⁾ that the experimental data for double photoproduction in the GeV region ²⁾ provide a qualitative confirmation of such an effect.

Fig. 1

Since one expects a total cross-section for the Drell effect ^{*)} (DE) reduced by roughly the fine structure constant $\alpha' = 1/137$ from its geometric value ($\simeq 20$ mb), one sees that a priori the DE can be expected

^{*)} Drell effect is now referred to as DE

to be very important for the process

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

whose experimental cross-section is about $80 \mu\text{b}$ ²⁾. We have calculated the total cross-section for reaction (1) with the Drell diagram and found the behaviour reported in Fig. 2. The maximum value is at 1.2 GeV and is of about $10 \mu\text{b}$. In all the 0.5 - 1 GeV region the calculated cross-section is of an order of magnitude smaller than the experimental one. Since the c.m. forward peak of the π^- from (1) includes roughly 50% of the interactions ²⁾, we see that a mechanism different from the DE must be important for double photoproduction in the GeV region.

The smallness of the DE as compared with the photo-electric term in single photoproduction can be qualitatively attributed to the smallness of the pion - nucleon - (3,3) isobar coupling constant as compared with the $\pi - N$ one.

We thought it interesting to look at the typical effects of the pion - pion interaction as a primary mechanism contributing to reaction (1). The diagram is shown in Fig. 1b and has first been considered in detail by Boccaletti and Gualdi ³⁾ (PG*). For the sake of calculating it, one has to know a priori the matrix element of photoproduction of pions on pions. The knowledge of it has been reduced by Gourdin and Martin ⁴⁾ to the knowledge of the $T = J = 1$ $\pi\pi$ scattering amplitude and of an arbitrary constant Λ . While, on the one hand, there begins to be rather convincing evidence ⁵⁾ in favour of a $T = J = 1$ $\pi\pi$ resonance at a total c.m. energy of 5 pion masses, on the other hand Λ has been determined by De Tollis, Ferrari and Munczek ⁶⁾, by fitting the $d\sigma^-/d\sigma^+$ ratio in single photoproduction. The total cross-section for reaction (1)

*) Boccaletti and Gualdi are now referred to as BG

as obtained from the BG diagram using this information is shown in Fig. 2. A broad maximum is present at 1.3 GeV. The value of the theoretical cross-section at this energy is about 90 μb and, therefore, of the same size as the experimental one. This indicates that above .9 GeV the BG diagram probably becomes of primary importance for reaction (1).

For both the theoretical curves shown in Fig. 2, one has to keep in mind that they constitute only a very rough estimate of the corresponding diagrams. The most drastic simplification is probably the neglect of the various form factors. Therefore, the calculated cross-sections constitute an upper bound to the corresponding physical effects. However, they should not be wrong by more than a factor of two.

The origin of the big cross-section below 7-800 MeV looks rather mysterious in view of the present results. We note that the total c.m. energy of this 700 MeV maximum is the same as that of the 600 MeV resonance in πN scattering, where also the $T = \frac{1}{2}$ inelastic cross-section passes through a maximum. The origin of all these effects could thus be the same.

We give in the following a few details about the performed calculations. The 4-vectors are defined in the following way : k (photon) $q_2(\pi^-)$, $q_3(\pi^+)$, p_1 and p_2 (initial and final protons). For the DE we neglect the diagram in which π^- and P emerge from the same vertex because its contribution can be a priori estimated to be nine times smaller than that of the other one in which π^+ and P emerge together. Also the interference between these two diagrams is neglected. This is expected to be very small and in any case it is clear that it cannot change our conclusions about the smallness of the DE in the GeV region. The S matrix

4.

element for DE will therefore be

$$S_{fi} = (2\pi)^{-3/2} \left[\frac{q_{10}}{2k_0 q_{20}} \right]^{\frac{1}{2}} \frac{e \epsilon \cdot (q_2 - q_1)}{(q_2 - k)^2 + \mu^2} S_{\pi} \quad (2)$$

where q_1 is the 4-vector of the intermediate pion, the zero index indicates the energy component of a given vector, e is the electric charge

($\frac{e^2}{4\pi} = \alpha = \frac{1}{137}$) and ϵ is the polarization four vector of the photon.

$S_{\pi N}$ is a quantity which for $q_1^2 = -\mu^2$ reduces to the S matrix element for πN scattering. Formula (2) is calculated in the "pole approximation" ⁷⁾.

The total cross-section can be easily calculated from (2) and turns out to be

$$\sigma^{\text{tot}} = \frac{\alpha}{2\pi W^2 k_B^3} \int_{m+\mu}^{W-\mu} du \quad \sigma_{\pi N}(u) u^2 q^2 \left(\frac{1}{\beta} \log \frac{1+\beta}{1-\beta} - 2 \right) \quad (3)$$

where $W^2 = -(k+p_1)^2$, $k_B = (W^2 - m^2)/2W$, $u^2 = -(q_2+p_2)^2$, β is the c.m. velocity of the π^- and

$$q = \frac{1}{2u} \left[u^4 - 2u^2(m^2 + \mu^2) + (m^2 - \mu^2)^2 \right]^{\frac{1}{2}} \quad (4)$$

For the BG diagram we have

$$S_{fi} = i(2\pi)^{-7/2} m (8k_0 p_{10} q_{20} q_{30} p_{20})^{-\frac{1}{2}} \frac{\bar{u}(p_2) \gamma_r \gamma_5 u(p_1)}{(p_2 - p_1)^2 + \mu^2} \delta^4(p_f - p_i) M_{\gamma\pi} \quad (5)$$

where G_r is the rationalized and renormalized πN coupling constant, and

$$M_{\gamma\pi} = \frac{1}{2i} \varepsilon_{\lambda\mu\nu\sigma} q_1^\lambda q_2^\mu q_3^\nu e^\sigma F(\omega^2, r^2) \quad (6)$$

is the M matrix element for $\gamma\pi \rightarrow \pi\pi$ as defined in reference ⁴⁾. F is an invariant amplitude which principle should depend also on $(p_2 - p_1)^2$. In the spirit of the pole approximation we neglect this dependence. The invariants ω^2 and r^2 are given by $\omega^2 = -(q_2 + q_3)^2$, $r^2 = (q_2 - k)^2$. For F we have used the approximate solution given in Eq. (31) of reference ⁴⁾. The position and width of the $\pi\pi$ resonance which we have used are those of reference ⁸⁾. Finally, the arbitrary multiplicative constant which enters in this solution has been taken in agreement with the value found in reference ⁶⁾. We obtain in this way

$$\sigma^{\text{tot}} = \frac{G^2}{8\pi W_k^2} \int \frac{\Delta^2}{(\Delta^2 + \mu^2)^2} R(\omega^2) \mathcal{T}_{\gamma\pi}(\omega^2) d\Delta^2 d\omega^2 \quad (7)$$

where $G^2 = G_r^2/4\pi$, $\Delta^2 = (p_2 - p_1)^2$, $R(\omega^2) = (\omega^2 - \mu^2)/2$ and the limits of integration are (B is for c.m.)

$$(\Delta^2)_{\text{min}}^{\text{max}} = -2m^2 + 2p_{20}^B p_{10}^B \pm 2p_{21}^B p_{11}^B \quad (8)$$

on Δ^2 , for fixed ω^2 and $\omega_{\text{min}}^2 = 4\mu^2$ and $\omega_{\text{max}}^2 = (W - m)^2$.

With the stated use of the published literature we can write

$$\sigma_{\gamma\pi}(\omega^2) = 0.06 \frac{\omega^2 - 1}{2} \left(\frac{\omega^2}{4} - 1 \right)^{3/2} e^{2\delta(\omega^2)} |\Phi(\omega^2)|^2 \quad (9)$$

where

$$e^{2\delta(\omega^2)} = \frac{165.5 + 19.3\omega^2}{[8.95 + 0.25\omega^2][(5.25 - 0.25\omega^2)^2 - 1 + 0.25\omega^2]} \quad (10)$$

and

$$|\Phi(\omega^2)|^2 = \left[0.95 \frac{60.4 - \omega^2}{57.4 + 2\omega^2} \right]^2 \quad (11)$$

In the formulae (9) to (11) we have put $\mu = 1$. The numerical coefficient in (9) is however such as to give $\sigma_{\gamma\pi}$ in mb.

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