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Costa, G ; Zimerman, A H

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Some Remarks about the Isovector Form Factors of the Nucleons and the ρ^0 Meson.

G. COSTA and A. H. ZIMMERMAN (*)

CERN - Geneva

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A recent experiment on $\bar{p}$ -p annihilation ⁽¹⁾ seems to indicate that the $\rho^0 \rightarrow 2\pi$ resonance is splitted into two components ρ_1^0 , ρ_2^0 with very narrow widths, of the order of 10 MeV. It seems that ρ_1^0 corresponds to a $J=0$, $I=0$ state, and ρ_2^0 to the neutral component of a $J=1$, $I=1$ state. In what follows we shall be interested only in the $J=1$, $I=1$ resonance, which we simply denote by ρ^0 .

It is obvious that a very narrow width for the ρ^0 resonance should imply that its effect would be negligible in the pion-nucleon scattering, unless a very strong ρ^0 -nucleon coupling is assumed. In fact, a narrow width implies a weak ρ^0 -pion coupling.

In this note we shall examine the consequences of the hypothesis of a very narrow width for ρ^0 on the isovector electromagnetic form factors of the nucleons, and try to obtain some information about the ρ^0 -nucleon coupling. It is generally believed that such resonance plays a very important role in the isovector form factors ⁽²⁾.

In this discussion we follow the work of BOWCOCK, COTTINGHAM and LURIÉ ⁽³⁾. Their results on the isovector form factors $F_1^V(t)$, $F_2^V(t)$ are based on subtracted dispersion relations in which only the two-pion resonance contribution is taken into account explicitly, in terms of the pion electromagnetic form factor. Their results can be written in the Clementel-Villi form ⁽²⁾, as

$$(1) \quad F_1^V(t) = \frac{1}{2} \left(1 - a_V + \frac{a_V t_R}{t_R - t} \right),$$

$$(2) \quad F_2^V(t) = \mu_V \left(1 - b_V + \frac{b_V t_R}{t_R - t} \right),$$

(*) On leave of absence from « Instituto de Física Teórica », São Paulo, Brazil; Ford Foundation Fellow, CERN, Geneva.

⁽¹⁾ B. C. MAGLIĆ: *CERN Seminar* (Nov. 1961); J. BUTTON, G. R. KALBFLEISCH, G. LYNCH; B. C. MAGLIĆ, A. R. ROSENFELD and M. L. STEVENSON; to be published.

⁽²⁾ S. BERGIA, A. STANGHELLINI, S. FUBINI and C. VILLI: *Phys. Rev. Lett.*, **6**, 367 (1961); S. FUBINI: *Report at the Aix-en-Provence Conference* (Sept. 1961).

⁽³⁾ J. BOWCOCK, W. N. COTTINGHAM and D. LURIÉ: *Nuovo Cimento*, **16**, 981 (1960).

where $\mu_V = \frac{1}{2}(\mu_p - \mu_n)$, and t_R is the resonance squared energy. We quote ref. (3) for the explicit expression for a_V , b_V .

We want now simply to replace the value of the width $\Gamma \simeq 100$ MeV used in ref. (3), by the much smaller value $\Gamma \simeq 10$ MeV. The same analysis can be used *a priori*, the only difference being possibly in the ρ^0 -nucleon and ρ^0 -pion couplings.

To make explicit use of coupling constants, we prefer to use for a_V , b_V the expressions obtained by the «bipion» model, in which the ρ^0 resonance is considered as a «stable» particle (4). The interactions of this particle with pions, nucleons and photons are given respectively by (4,5)

$$(3) \quad \begin{cases} i\lambda_\pi(q_1 + q_2)_\mu \varrho_\mu^0, \\ i\bar{u}(p_2) \left[C_1 \gamma_\mu + \frac{C_2}{2M} \sigma_{\mu\nu} (p_1 - p_2)_\nu \right] u(p_1) \varrho_\mu^0, \\ \lambda_V A_\mu \varrho_\mu^0. \end{cases}$$

Then one can easily obtain

$$(4) \quad a_V = \frac{2C_1 \lambda_V}{t_R}, \quad b_V = \frac{C_2 \lambda_V}{\mu_V t_R},$$

We now use the expressions of ref. (3) for the electromagnetic pion form factor which, for a small width, reduces to

$$(5) \quad F_\pi(t) \simeq \frac{t_R}{t_R - t},$$

and which, in the bipion model, is written as

$$(6) \quad F_\pi(t) = \frac{\lambda_\pi \lambda_V}{t_R - t}.$$

The relations (4) can then be replaced by

$$(7) \quad a_V = \frac{2C_1}{\lambda_\pi}, \quad b_V = \frac{C_2}{\mu_V \lambda_\pi}.$$

Using directly the values $a_V \simeq b_V \simeq 1.62$, $t_R \simeq 25\mu^2$ obtained in a recent fit (6), we get (7)

$$(8) \quad C_1 \simeq 0.81\lambda_\pi, \quad C_2 \simeq 1.62\mu_V \lambda_\pi.$$

(4) A. STANGHELLINI: *Nuovo Cimento*, **18**, 1258 (1960); M. GOURDIN, D. LURIÉ and A. MARTIN: *Nuovo Cimento*, **18**, 933 (1960).

(5) It is easy to show that an interaction of the form

$$(\partial_\nu \varrho_\mu - \partial_\mu \varrho_\nu)(\partial_\nu A_\mu - \partial_\mu A_\nu)$$

does not give contributions to the pion and nucleon form factors.

(6) S. BERGIA and A. STANGHELLINI: *Nuovo Cimento*, **19**, 155 (1961).

(7) The parameters given in ref. (6) correspond to $M_\rho = 700$ MeV; we believe, however, that the values (10) will not be much changed assuming $M_\rho = 780$ MeV.

Now, the simple relation between Γ and λ_π^2 gives: $\lambda_\pi \simeq 5e$ (where e is the electric charge). Then it follows that the coupling between the ρ^0 and the nucleons is rather weak; in fact one gets from (8): $C_1 \simeq 4e$, $C_2 \simeq 8\mu_\nu e$.

This result, if taken seriously, appears to be at first sight in contrast with the fact that the ρ^0 particle is strongly produced in the $\bar{p}$ - p annihilation⁽¹⁾.

The first argument to which one can appeal in trying to eliminate this difficulty is the following. The electromagnetic form factor of the pion given by (5), which was used by Bowcock *et al.*, takes into account only the effect of the ρ^0 resonance. But, if the ρ^0 -pion coupling is weak, it might be reasonable to assume that such effect is not so important in comparison with the contributions coming from other intermediate virtual states.

As a first approximation, one could modify the relation (5) into a subtracted form similar to the one used for the nucleons:

$$(9) \quad F_\pi(t) = 1 - \alpha + \frac{\alpha t_R}{t_R - t},$$

where α could be considered, in general, as energy-dependent. The relations (7) then modify into

$$(10) \quad a_\nu = \frac{2C_1}{\lambda_\pi} \alpha, \quad b_\nu = \frac{C_2}{\mu_\nu \lambda_\pi} \alpha.$$

One can obtain reasonable values for C_1 , C_2 in agreement with the abundant production of ρ^0 , by assuming that the bipion term in (9) is small in comparison with the other term $(1 - \alpha)$ coming from the other unknown contributions.

The above discussion applies to the case in which only one resonant state $J=1$, $I=1$ is taken into account in the explanation of the isovector form factors of the nucleons. It might well be that other resonances, as *e.g.* the newly discovered $I=1$ ζ -resonance ($M_\zeta \simeq 575$ MeV)⁽²⁾, play an important role in this problem. The presence of two $J=1$, $I=1$ resonant states with different masses would be useful, since it should perhaps be possible in this way to explain practically all the contributions to the isovector form factors of the nucleons. This does not happen if the isovector form factors are fitted with a single (ρ^0) vector meson⁽³⁾; in fact, the values $a_\nu \simeq b_\nu \simeq 1.62$ leave a large contribution to the high-energy states. The modification of the Clementel-Villi formula with the inclusion of two-pole terms (coming *e.g.* from the ρ and ζ particles) would probably eliminate, at least in part, the difficulty pointed out above.

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⁽¹⁾ R. BARLOUTAUD, J. HEUGHEBAERT, A. LEVEQUE, J. MEYER and R. OMNÈS: to be published on *Phys. Rev. Lett.*

⁽²⁾ It might also be that both ρ_1^0 and ρ_2^0 are isovector states. In this case, one could probably fit the isovector form factors of the nucleons by assuming reasonable couplings between each of the two ρ 's and the nucleons. The resulting expressions for the form factors would be still of the CV type, as in the case of a single resonance.