COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF-73/40
11 Luglio 1973

A. Bramon: ON THE EXISTENCE AND MAIN PROPERTIES OF THE $\rho'(1250)$ MESON.

Servizio Documentazione
dei Laboratori Nazionali di Frascati del CNEN
Casella Postale 70 - Frascati (Roma)

Laboratori Nazionali di Frascati del CNEN
Servizio Documentazione

LNF-73/40
11 Luglio 1973

A. Bramon[(x)]: ON THE EXISTENCE AND MAIN PROPERTIES OF THE ϱ'(1250) MESON. -

A considerable experimental effort has been devoted, during the last years, to search for new resonances predicted by the Veneziano[(1)] and other Regge models. The ϱ'(1600) observed both in e^+e^- annihilation[(2)] and in photoproduction experiments[(3)] represents, for the time being, the only positive result of this search. Its mass roughly coincides with that of the g meson ($J^P = 3^-$) fitting into the Veneziano spectrum as the second daughter of the ϱ. The so far unobserved first daughter, the ϱ'(1250), is the subject of the present paper, in which a model is proposed whose application to the available data concerning (mainly) the $e^+e^- \to \pi^+\pi^-$ cross section seems to indicate the existence of this ϱ'(1250) and allows us to deduce its main properties.

The only structure actually known[(4)] near the 1.25 GeV mass region is (apart from the isoscalar f meson) the $\omega\pi^{\pm}$ bump usually associated with the B(1235) meson. The absence of a similar $\pi\pi$ or $K\bar{K}$ enhancement is interpreted against the presence of a vector

---

(x) - On leave of absence from Dept. de Física Teórica, Barcelona.

meson state and in favour of an unnatural J^P assignement[4] (probably 1^+) for the B. There are, however, two independent experimental results that induce us to reconsider the situation. First of all, Frenkiel et al.[5] have shown that their data for the $p\bar{p} \to \omega\pi^+\pi^-$ annihilation cannot be explained by means of a single $\omega\pi$ resonance with $J^P = 1^+$. On the contrary, reasonable agreement was reached when a new $\omega\pi$ vector meson resonant state, with roughly the same mass and width as the B[4]

(1) $$m_{\varrho'} \simeq 1.24 \text{ GeV} \qquad \Gamma_{\varrho'} \simeq 0.12 \text{ GeV},$$

was introduced, in addition to the known B meson. Secondly, an $\omega\pi^o$ enhancement, with similar mass and width, has been detected in two photoproduction experiments[6] which quote the following values for the corresponding cross section

(2) $$\sigma_{\gamma p \to p(\pi\omega)} = 0.9 \pm 0.5\ \mu b, \quad \text{at} \quad E_\gamma = 2.8 \text{ GeV}$$
$$= 1.1 \pm 0.4\ \mu b, \quad \text{at} \quad E_\gamma = 4.7 \text{ GeV}$$

Its approximate independence from the photon energy suggests that we are really dealing with the above mentioned $J^P = 1^-$ state which is photoproduced through the usual diffraction mechanism.

Additional support for the existence of $\varrho'(1250)$ with the properties quoted in eqs. (1) and (2) may also be obtained from a previous model[7] proposed by Greco and the author. It is shown there that the extension of vector-meson dominance (EVMD) by simply including a higher mass 1^- nonet provides, with the help of the naive quark model, a satisfactory description of all the known decay rates of the pseudoscalar and vector mesons. The predicted ϱ' couples to the photon (we adopt the usual $em^2_{\varrho'}/f_{\varrho'}$ prescription) and to the $\omega\pi$ state in such a way that

(3) $$\lambda \equiv \frac{f_\varrho}{f_{\varrho'}} \frac{g_{\varrho'\omega\pi}}{g_{\varrho\omega\pi}} = -0.16 \pm 0.03$$

since the observed $\varrho'(1600)$ does not seem to decay[4,8] into $\omega\pi$ we shall assume from now on that the ϱ' involved in eq. (3) is the previously considered $\varrho'(1250)$. From the data quoted in eqs. (1) and from the value of $g_{\varrho\omega\pi}$ that one can deduce (see for instance ref. (7)) using $\Gamma_{\omega\to 3\pi} = 8.7$ MeV[4], one gets $g^2_{\varrho\omega\pi} \simeq 3\, g^2_{\varrho'\omega\pi}$ or, equivalently,

(4) $$(f_\varrho / f_{\varrho'})^2 \simeq 3\, \lambda^2$$

On the other hand, application of the usual VMD techniques to the photoproduction cross sections[6] of ϱ and ϱ' (note, in particular, that the total ϱp and $\varrho' p$ hadronic cross sections are assumed to be equal according to the quark model) leads to the relation

$$\sigma_{\gamma p \to p\varrho'}(E_\gamma) \simeq (f_\varrho / f_{\varrho'})^2\, \sigma_{\gamma p \to p\varrho}(E_\gamma) \simeq 1.2\ \mu b$$

at $E_\gamma = 4.7$ GeV, having used eqs. (3) and (4) and[6] $\sigma_{\gamma p \to p\varrho}(E_\gamma = 4.7) \simeq 15\ \mu b$. Comparison of this result with those quoted in eq. (2) provides a reasonable self-consistency check of our model.

The existence of the $\varrho'(1250)$ implies that the pseudoscalar meson pairs $\pi\pi$ (and $K\bar{K}$) must be somehow present as decay products in the B- ϱ' mass region. In fact, even in the case of a negligible $\varrho'\pi\pi$ coupling the $\varrho' \to \pi\pi$ transition may proceed through the chain $\varrho' \to \omega\pi \to \varrho \to \pi\pi$ so that, with $m_{\varrho'} \approx \sqrt{s} \equiv \pi\pi$-invariant mass,

(5) $$T_{\varrho' \to \pi\pi}(s) = T_{\varrho' \to \varrho}(s) \left[m_\varrho^2 - s - i m_\varrho \Gamma_\varrho(s) \right]^{-1} T_{\varrho \to \pi\pi}(s)$$

The imaginary part of the amplitude $T_{\varrho' \to \varrho}$ can be easily evaluated to be

$$\text{(6)} \qquad \text{Im}\, T_{\varrho' \to \varrho}(s) = \frac{g_{\varrho\omega\pi}}{g_{\varrho'\omega\pi}} \sqrt{s}\, \Gamma_{\varrho' \to \omega\pi}$$

If we neglect the $\text{im}_{\varrho} \Gamma_{\varrho}(s)$ term of the ϱ propagator in eq. (5) (it seems reasonable for $s \simeq m^2_{\varrho'} \simeq 3\, m^2_{\varrho}$), eq. (6) gives rise to the so called unitarity lower bound,

$$\text{(7)} \qquad \frac{\Gamma_{\varrho' \to \pi\pi}}{\Gamma_{\varrho' \to \omega\pi}} \gtrsim \frac{(\Gamma_{\varrho' \to \pi\pi})_{abs}}{\Gamma_{\varrho' \to \omega\pi}} \simeq 0.16$$

where the values[4] $m_{\varrho} = 770$ MeV, $\Gamma_{\varrho} = 146$ MeV have been used. We note that this bound for the $\pi\pi$ branching ratio is independent of the value of $\Gamma_{\varrho' \to \omega\pi}$ and represents by itself a non negligible effect. The real part of $T_{\varrho' \to \varrho}$, which cannot be evaluated, and an eventual direct $\varrho'\pi\pi$ coupling can only contribute to increase this rather high branching ratio (7). We feel that such an increase could easily be in conflict with the experimental fact that no clear $\pi\pi$ structure (possibly with the exception of the $e^+e^- \to \pi^+\pi^-$ case discussed below) has been detected in the 1.2 - 1.3 GeV mass region. Consequently, at least at the present level of sophistication, we shall adopt the rather conservative attitude of claiming that $T_{\varrho' \to \varrho}$ is mainly imaginary and that the $\approx$ sign essentially holds in expression (7).

One of the striking features of the preceeding assumption concerns the $\pi\pi \to \pi\omega$ cross section at C.M. energies, $\sqrt{s}$, near the $\varrho'(1250)$ peak. The amplitude for this process is given, apart from inessential kinematical factors, by a term due to the ϱ formation

$$T^{(\varrho)} = g_{\varrho\pi\pi} g_{\varrho\omega\pi} \left[m_\varrho^2 - s - i m_\varrho \Gamma_\varrho(s) \right]^{-1},$$

plus a ϱ' term that may be written as

$$T^{(\varrho')} = i \frac{\sqrt{s}\, \Gamma_{\varrho' \to \omega\pi}}{m_{\varrho'}^2 - s - i m_{\varrho'} \Gamma_{\varrho'}} \; T^{(\varrho)}$$

At $m_{\varrho'}^2 = s$, $T^{(\varrho')} = -(\Gamma_{\varrho' \to \omega\pi} / \Gamma_{\varrho'}) T^{(\varrho)} \approx -T^{(\varrho)}$ and a dip for the $\pi\pi \to \pi\omega$ cross section is predicted. It is interciting to note that in the analysis performed by Oh et al.[9] to extract the diffé-rent $\pi\pi$ cross sections, the inelastic $\pi^0\pi^-$ channel (which at the considered energies is dominated by the $\pi^-\omega$ final state) shows the predicted minimum at $\sqrt{s} \simeq 1.2$ GeV. This gives some support to the previous assumption that $T_{\varrho' \to \varrho}$ is mainly imaginary since an important $\mathrm{Re}\, T_{\varrho' \to \varrho}$ would distroy the dip.

The main consequences of our model concern the $e^+e^- \to \pi^+\pi^-$ annihilation. This cross section has been measured at Orsay[10], Novosibirsk[11] and Frascati[12, 13] and we have plotted their experimental results in Fig. 1. The point at $\sqrt{s} \simeq 1.6$ GeV is an

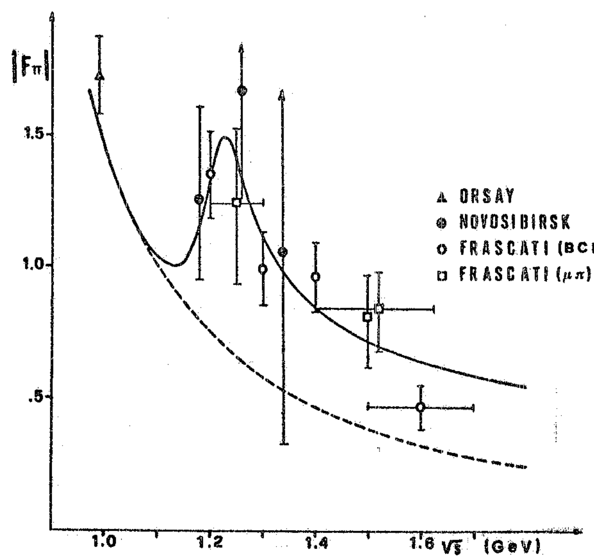

FIG. 1 - The pion form factor, $|F_\pi(s)|$, as predicted by the present model (solid line) and by simple ϱ dominance (dashed line). The experimental points are from Orsay[10], Novosibirsk[11] and Frascati[12-14].

average of three nearly measurements[12] once we have substracted the $K\bar{K}$ events making use of the results of ref. (14). If the only contribution to the $e^+e^- \to \pi^+\pi^-$ amplitude is given by the ρ tail the pion form factor is given by

$$F_\pi^{(\rho)}(s) \simeq \frac{g_{\rho\pi\pi}}{f_\rho} \frac{m_\rho^2}{m_\rho^2 - s - is\,\Gamma_\rho/m_\rho}$$

whose modulus has been plotted (dashed line) in Fig. 1, with[10] $g_{\rho\pi\pi}/f_\rho \doteq 1.12$. The experimental points lie above this curve indicating, particularly at $\sqrt{s} \sim 1.25$ GeV, that some structure is present. One can easily convince oneself that the introduction of a $\rho'(\sim 1250)$ directly coupled to the $\pi^+\pi^-$ final state or with a mainly real $T_{\rho' \to \pi\pi}$ amplitude cannot improve the situation[15]. In fact, the interference of this amplitude with that of the ρ tail changes sign near the ρ' mass and, either for $\sqrt{s} < m_{\rho'}$ or for $\sqrt{s} > m_{\rho'}$, $|F_\pi(s)|$ should lie below the ρ tail increasing the discrepancy. On the contrary, with a mainly imaginary $T_{\rho' \to \pi\pi}$ amplitude as in the present model, one obtains

$$(8) \quad F_\pi^{(\rho+\rho')}(s) \simeq F_\pi^{(\rho)}(s) \left\{ 1 + i \frac{f_\rho}{f_{\rho'}} \frac{m_{\rho'}^2}{m_\rho^2} \frac{g_{\rho\omega\pi}}{g'_{\rho\omega\pi}} \frac{\sqrt{s}\,\Gamma_{\rho' \to \omega\pi}(s)}{m_{\rho'}^2 - s - i m_{\rho'} \Gamma_{\rho'}(s)} \right\}$$

where $\Gamma_{\rho' \to \omega\pi}(s) = \Gamma_{\rho' \to \omega\pi}(m_{\rho'}^2) \left[p(s)/p(m_{\rho'}^2) \right]^3$ and p is the modulus of the ω momentum at the C.M. system. The quantities appearing in eq. (8) have been previously fixed so that our prediction contains no adjustable parameters. It has been plotted (solid line) in Fig. 1 showing a reasonable agreement with the experimental measurements.

The introduction of the so far neglected $\mathrm{Re}\, T_{\rho' \to \pi\pi}$ could obviously improve the situation but, at the present level, it seems quite superfluous. In a similar way the prediction for $\sqrt{s} > 1.5$ GeV can also be modified once the known $\rho'(1600)$ is taken into account.

Let's finally indicate that the most adequate experiment to give a conclusive answer about the existence of a ρ' resonance as postulated in the present model should be the measurement of the $e^+e^- \to \omega\pi$ cross section for $1.0 \lesssim \sqrt{s} \lesssim 1.4$ GeV. One expects $\sigma_{e^+e^- \to \omega\pi}(s=m^2_{\rho'}) \approx 40$ nb and a rapid fall off at higher energies where a destructive interference with the amplitude due to the ρ tail should take place.

It is a pleasure to thank M. Bernardini, M. Greco and Y. Srivastava for many valuable discussions.

REFERENCES. -

(1) - G. Veneziano, Nuovo Cimento 57A , 190 (1968).

(2) - G. Barbarino, F. Ceradini, M. Conversi, M. Grilli, E. Iarocci, M. Nigro, L. Paoluzzi, R. Santonico, P. Spillantini, L. Trasati, V. Valente, R. Visentin and G. T. Zorn, Lett. Nuovo Cimento 3, 689 (1972); A. Bramon and M. Greco, Lett. Nuovo Cimento 3, 693 (1972).

(3) - R. Diebold, Rapporteur Talk at the XVI Intern. Conf. on High Energy Physics, Batavia, (1972), and references therein; H. H. Bingham et al., Phys. Letters 41B, 635 (1972).

(4) - Particle Data Group, Phys. Letters 39B, 1 (1972) and Rev. Mod. Phys. 45, 51 (1973).

(5) - F. Frenkiel, C. Chesquiere, E. Lillestol, S. U. Chung, J. Diaz, A. Ferrando and L. Montanet, Nuclear Phys. B47, 61 (1972).

(6) - G. Wolf, Proceedings of the 1971 Intern. Conf. on Electron and Photon Interactions at High Energies, Cornell (1972), and references therein.

(7) - A. Bramon and M. Greco, Nuovo Cimento 14A, 323 (1973).

(8) - F. Ceradini et al., Phys. Letters 43B, 341 (1973).

(9) - B. Y. Oh et al., Phys. Rev. D1, 2494 (1970).

(10) - D. Benaksas et al., Phys. Letters 39B, 289 (1972).

(11) - V. E. Balakin et al., Phys. Letters 41B, 205 (1972).

(12) - A. Zichichi, Talk given at the XVI Intern. Conf. on High Energy Physics, Batavia (1972).

(13) - G. Barbiellini et al., Lett. Nuovo Cimento 6, 557 (1973).

(14) - A. Zichichi, Paper presented at the Frascati Meeting (1973) and M. Bernardini et al., submitted to Phys. Letters.

(15) - M. Greco and Y. Srivastava, Frascati Report LNF-73/7 (1973), have proposed a model which fits the experimental points assuming an important contribution coming from the $\varrho''(1600)$. More précisely, they assume $g_{\varrho''\pi\pi}/f_{\varrho''} \simeq 2\, g_{\varrho'\pi\pi}/f_{\varrho'} \simeq -0.1$.