

Laboratori Nazionali di Frascati

LNF-73/79

A. Bramon :

ON THE EXISTENCE AND MAIN PROPERTIES OF THE  $\rho'(1250)$ -MESON

Lett. Nuovo Cimento 8, 659 (1973).

## On the Existence and Main Properties of the $\rho'(1250)$ -Meson.

A. BRAMON (\*)

Laboratori Nazionali di Frascati del CNEN - Frascati

(ricevuto il 30 Luglio 1973)

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

The only structure actually known <sup>(4)</sup> 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-meson state and in favour of an unnatural  $J^P$  assignment <sup>(4)</sup> (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.* <sup>(5)</sup> have shown that their data for the  $p\bar{p} \rightarrow \omega\pi^+\pi^-$  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 <sup>(4)</sup>

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

(\*) On leave of absence from Departamento de Física Teórica, Barcelona.

<sup>(1)</sup> G. VENEZIANO: *Nuovo Cimento*, **57** A, 190 (1968).

<sup>(2)</sup> G. BARBARINO, F. CERADINI, M. CONVERSI, M. GRILLI, E. IAROCCI, M. NIGRO, L. PAOLUZI, R. SANTONICO, P. SPILLANTINI, L. TRASATTI, 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).

<sup>(3)</sup> R. DIEBOLD: rapporteur talk at the *XVI International Conference on High-Energy Physics* (Batavia, Ill., 1972) and references therein; H. H. BINGHAM, W. B. FRETTER, W. J. PODOLSKY, M. S. RABIN, A. H. ROSENFELD, G. SMADJA, G. P. YOST, J. BALLAM, G. B. CHADWICK, Y. EISENBERG, E. KOGAN, K. C. MOFFEIT, P. LEYBOTH, I. O. SKILLICORN, H. SPITZER and G. WOLF: *Phys. Lett.*, **41** B, 635 (1972).

<sup>(4)</sup> PARTICLE DATA GROUP: *Phys. Lett.*, **39** B, 1 (1972); *Rev. Mod. Phys.*, **45**, 51 (1973).

<sup>(5)</sup> F. FRENKIEL, C. GHESQUIÈRE, E. LILLESTØL, S. U. CHUNG, J. DIAZ, A. FERRANDO and L. MONTANET: *Nucl. Phys.*, **47** B, 61 (1972).

was introduced, in addition to the known B-meson. Secondly, an  $\omega\pi^0$  enhancement, with similar mass and width, has been detected in two photoproduction experiments <sup>(6)</sup> which quote the following values for the corresponding cross-section:

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

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 the  $\rho'(1250)$  with the properties quoted in eqs. (1) and (2) may also be obtained from a previous model <sup>(7)</sup> proposed by GRECO and the author. It is shown there that the extension of vector-meson dominance (EVM) 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  $\rho'$  couples to the photon (we adopt the usual  $em_\rho^2/f_{\rho'}$  prescription) and to the  $\omega\pi$  state in such a way that

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

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

$$(4) \quad (f_\rho/f_{\rho'})^2 \simeq 3\lambda^2.$$

On the other hand, application of the usual VMD techniques to the photoproduction cross-sections <sup>(6)</sup> of  $\rho$  and  $\rho'$  (note, in particular, that the total  $\rho p$  and  $\rho' p$  hadronic cross-sections are assumed to be equal according to the quark model) leads to the relation

$$\sigma_{\gamma p \rightarrow p\rho'}(E_\gamma) \simeq (f_\rho/f_{\rho'})^2 \sigma_{\gamma p \rightarrow p\rho}(E_\gamma) \simeq 1.2 \mu\text{b}$$

at  $E_\gamma = 4.7 \text{ GeV}$ , where eqs. (3) and (4) and <sup>(6)</sup>  $\sigma_{\gamma p \rightarrow p\rho}(E_\gamma = 4.7) \simeq 15 \mu\text{b}$  have been used. Comparison of this result with those quoted in eq. (2) provides a reasonable self-consistency check of our model.

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

$$(5) \quad T_{\rho' \rightarrow \pi\pi}(s) = T_{\rho' \rightarrow \rho}(s)[m_{\rho'}^2 - s - im_{\rho'}\Gamma_{\rho'}(s)]^{-1} T_{\rho \rightarrow \pi\pi}(s).$$

<sup>(6)</sup> G. WOLF: *Proceedings of the 1971 International Conference on Electron and Photon Interactions at High Energies* (Ithaca, N. Y., 1972), and references therein.

<sup>(7)</sup> A. BRAMON and M. GRECO: *Nuovo Cimento*, **14** A, 323 (1973).

<sup>(8)</sup> F. CERADINI, M. CONVERSI, S. D'ANGELO, L. PAOLUZI, R. SANTONICO, K. EKSTRAND, M. GRILLI, E. IAROCCHI, P. SPILLANTINI, V. VALENTE, R. VISENTIN and M. NIGRO: *Phys. Lett.*, **43** B, 341 (1973).

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

$$(6) \quad \text{Im } T_{\rho' \rightarrow \rho}(s) = \frac{g_{\rho\omega\pi}}{g_{\rho'\omega\pi}} \sqrt{s} \Gamma_{\rho' \rightarrow \omega\pi}.$$

If we neglect the  $im_{\rho} \Gamma_{\rho}(s)$  term of the  $\rho$  propagator in eq. (5) (this seems reasonable for  $s \simeq m_{\rho'}^2 \simeq 3m_{\rho}^2$ ), eq. (6) gives rise to the so-called unitarity lower bound:

$$(7) \quad \frac{\Gamma_{\rho' \rightarrow \pi\pi}}{\Gamma_{\rho' \rightarrow \omega\pi}} \gtrsim \frac{(\Gamma_{\rho' \rightarrow \pi\pi})_{\text{abs}}}{\Gamma_{\rho' \rightarrow \omega\pi}} \simeq 0.16,$$

where the values <sup>(4)</sup>  $m_{\rho} = 770$  MeV,  $\Gamma_{\rho} = 146$  MeV have been used. We note that this bound for the  $\pi\pi$  branching ratio is independent of the value of  $\Gamma_{\rho' \rightarrow \omega\pi}$  and represents by itself a nonnegligible effect. The real part of  $T_{\rho' \rightarrow \rho}$ , which cannot be evaluated, and a probable direct  $\rho'\pi\pi$  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  $e^+e^- \rightarrow \pi^+\pi^-$  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  $T_{\rho' \rightarrow \rho}$  is mainly imaginary and that the  $\approx$  sign essentially holds in expression (7).

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

$$T^{(\rho)} = g_{\rho\pi\pi} g_{\rho\omega\pi} [m_{\rho}^2 - s - im_{\rho} \Gamma_{\rho}(s)]^{-1},$$

plus a  $\rho'$  term that may be written as

$$T^{(\rho')} = i \frac{\sqrt{s} \Gamma_{\rho' \rightarrow \omega\pi}}{m_{\rho'}^2 - s - im_{\rho'} \Gamma_{\rho'}} T^{(\rho)}.$$

At  $m_{\rho'}^2 = s$ ,  $T^{(\rho')} = -(\Gamma_{\rho' \rightarrow \omega\pi}/\Gamma_{\rho'}) T^{(\rho)} \approx -T^{(\rho)}$ , and a dip for the  $\pi\pi \rightarrow \pi\omega$  cross-section is predicted. It is interesting to note that, in the analysis performed by OH *et al.* <sup>(9)</sup> to extract the differential  $\pi\pi$  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  $T_{\rho' \rightarrow \rho}$  is mainly imaginary since an important  $\text{Re } T_{\rho' \rightarrow \rho}$  would destroy the dip.

The main consequences of our model concern the  $e^+e^- \rightarrow \pi^+\pi^-$  annihilation. This cross-section has been measured at Orsay <sup>(10)</sup>, Novosibirsk <sup>(11)</sup> and Frascati <sup>(12,13)</sup> and

<sup>(9)</sup> B. Y. OH, A. F. GARFINKEL, R. MORSE, W. D. WALKER, J. D. PRENTICE, E. C. WEST and T. S. YOON: *Phys. Rev. D*, **1**, 2494 (1970).

<sup>(10)</sup> D. BENAKSAS, G. COSME, B. JEAN-MARIE, S. JULLIAN, F. LAPLANCHE, J. LE FRANÇOIS, A. D. LIBERMAN, G. PARROUR, J. P. REPOLLIN and G. SAUVAGE: *Phys. Lett.*, **39** B, 289 (1972).

<sup>(11)</sup> V. E. BALAKIN, G. I. BUDKER, L. M. KURDADZE, A. P. OМУCHIN, E. V. PAKHUSOVA, S. I. SEREDNYAKOV, V. A. SIDOROV and A. N. SKRINSKY: *Phys. Lett.*, **41** B, 205 (1972).

<sup>(12)</sup> A. ZICHICHI: talk given at the *XVI International Conference on High-Energy Physics* (Batavia, Ill., 1972).

<sup>(13)</sup> G. BARBIELLINI, M. GRILLI, E. IAROCCHI, P. SPILLANTINI, V. VALENTE, R. VISENTIN, F. CERADINI, M. CONVERSI, S. D'ANGELO, G. GIANNOLI, L. PAOLUZI, R. SANTONICO, M. NIGRO, L. TRASATTI and G. T. ZORN: *Lett. Nuovo Cimento*, **6**, 557 (1973).

we have plotted their experimental results in Fig. 1. The point at  $\sqrt{s} \simeq 1.6$  GeV is an average of three nearby measurements<sup>(12)</sup>, once we have subtracted the  $K\bar{K}$  events making use of the results of ref. (14). If the only contribution to the  $e^+e^- \rightarrow \pi^+\pi^-$  amplitude is given by the  $\rho$  tail, the pion form factor is given by

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

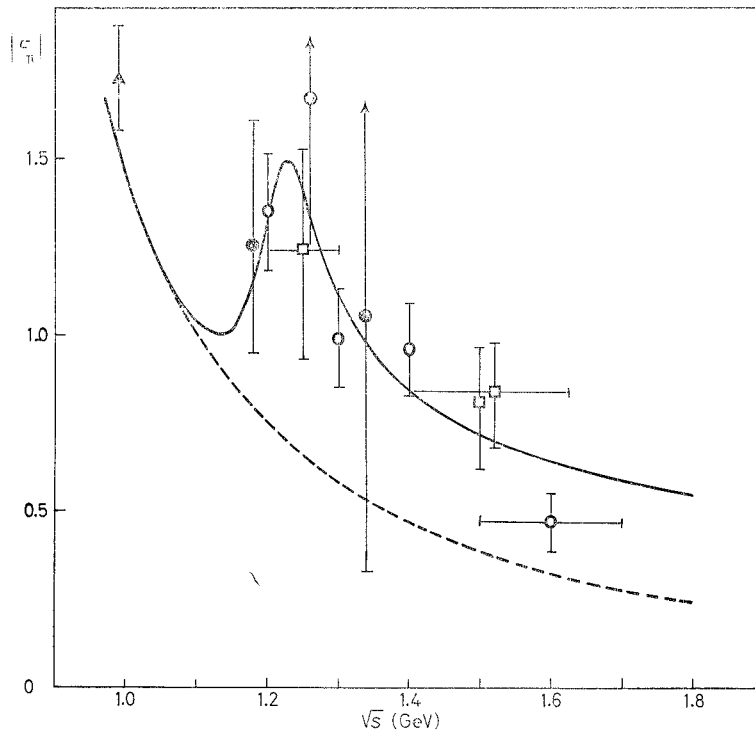


Fig. 1. - The pion form factor  $|F_{\pi}(s)|$  as predicted by the present model (solid line) and by simple  $\rho$  dominance (dashed line). The experimental points are from Orsay<sup>(10)</sup>, Novosibirsk<sup>(11)</sup> and Frascati<sup>(12-14)</sup>:  $\Delta$  Orsay,  $\bullet$  Novosibirsk,  $\circ$  Frascati (BCF),  $\square$  Frascati ( $\mu\pi$ ).

whose modulus has been plotted (dashed line) in Fig. 1, with<sup>(10)</sup>  $g_{\rho\pi\pi}/f_{\rho} = 1.12$ . 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  $T_{\rho' \rightarrow \pi\pi}$  amplitude cannot improve the situation<sup>(15)</sup>. In fact, the interference of this amplitude with that of the  $\rho$  tail changes sign near the  $\rho'$  mass and, either for  $\sqrt{s} < m_{\rho'}$  or for

(14) A. ZICHICHI: paper presented at the *Frascati Meeting* (1973); M. BERNARDINI, D. BOLLINI, P. L. BRUNINI, E. FIORENTINO, T. MASSAM, L. MONARI, F. PALMONARI, F. RIMONDI and A. ZICHICHI: submitted to *Phys. Lett.*

(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  $\rho'$  (1600). More precisely, they assume  $g_{\rho'\pi\pi}/f_{\rho'} \simeq 2g_{\rho\pi\pi}/f_{\rho} \simeq -0.1$ .

$\sqrt{s} > m_{\rho'}$ ,  $|F_{\pi}(s)|$  should lie below the  $\rho$  tail thus increasing the discrepancy. On the contrary, with a mainly imaginary  $T_{\rho' \rightarrow \pi\pi}$  amplitude as in the present model, one obtains

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

where  $\Gamma_{\rho' \rightarrow \omega\pi}(s) = \Gamma_{\rho' \rightarrow \omega\pi}(m_{\rho'}^2) [p(s)/p(m_{\rho'}^2)]^3$  and  $p$  is the modulus of the  $\omega$  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 reasonable agreement with the experimental measurements.

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

\* \* \*

It is a pleasure to thank M. BERNARDINI, M. GRECO and Y. SRIVASTAVA for many valuable discussions.