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R. Baldini-Celio, F. Celani, A. Codino, F. L. Fabbri, P. Laurelli, G. Rivellini, L. Satta, P. Spillantini and A. Zallo:

CONNECTIONS BETWEEN COHERENT PHOTOPRODUCTION OF HIGH MASS MESONS OFF NUCLEI AND e^+e^- ANNIHILATION.

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ABSTRACT.

Connections between total cross sections for coherent production of heavy vector mesons and e^+e^- annihilation are exploited.

Several arguments of physical interest to measure coherent photoproduction in FRAM are given.

1. - INTRODUCTION.

In this paper we examine the connections between coherent photoproduction of heavy vector mesons and e^+e^- annihilation. These connections can be done under different hypotheses, that we shall discuss together with the possible experimental checks of their validity.

Let us consider the coherent photoproduction cross section of a mass M on a nucleus, for a momentum transfer t. According to Simple Vector Dominance, Quark models and Glauber formalism, we shall demonstrate that:

$$R^{u,d}_{e^+e^-}(M) \simeq \frac{48\pi^2 M^2}{\alpha\, \sigma^2_{tot}(\varrho N) A^2 \left| F_A(\sigma_{tot}) \right|^2} \left(\frac{d^2\sigma\,(\gamma A \to MA)}{dt\, dM^2} \right)_{t\to 0} \qquad (1)$$

where α is the fine structure constant, $d^2\sigma/dt\,dM^2$ is the coherent photoproduction cross section of a mass M extrapolated to $t=0$, $F_A(\sigma_{tot})$ is the absorption factor of the nucleus A for a total cross section σ_{tot} and $R^{u,d}_{e^+e^-}(M)$ is the contribution due only to "u" and "d" quarks to the ratio $R_{e^+e^-}(M) = \dfrac{\sigma_{tot}(e^+e^- \to \text{hadrons})}{\sigma_{\mu\mu}}$.

There are several subjects of physical interest in a $R_{e^+e^-}$ measurement as derived from photoproduction.

First of all it is possible, through relation (1), verify the asymptotic prediction $R^{u,d}_{e^+e^-}(M \to \infty) = 3(q_u^2 + q_d^2)$ without the complications due to new quarks creation, which introduces steps in the value of R as measured in e^+e^- annihilation.

In addition several important results must be confirmed and several problems are still open in the present data on e^+e^- annihilation for $1 < M < 3$ GeV(1) (see Fig. 1), where in the

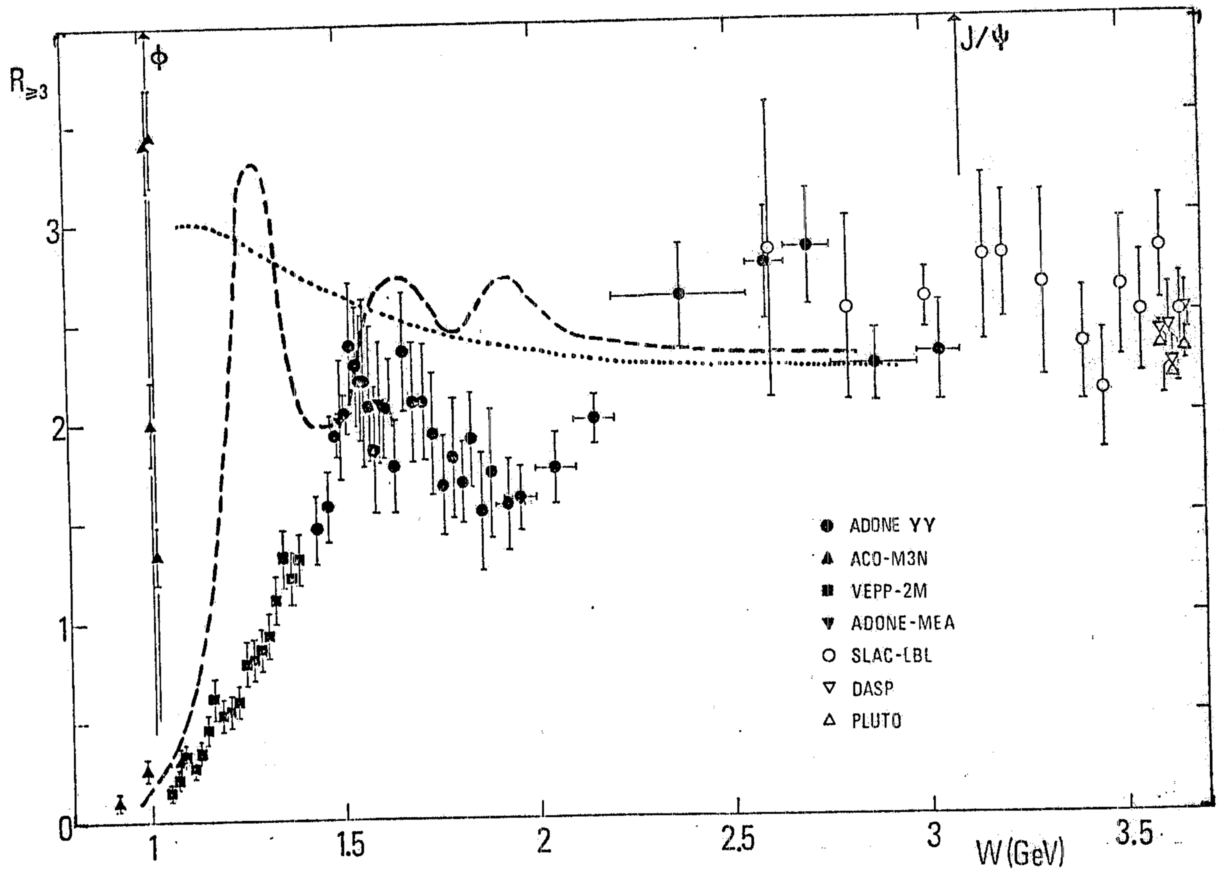

FIG. 1 - R values in the energy interval $1 < M < 3.5$ GeV. from ref. (1). DCI - M3N data, which are not reported for clearness, overlap Adone data, axcept at $W \simeq 1.65$ GeV. Dotted line represents QCD expectations as extrapolated from charm behaviour. Dashed line represents EVMD expectations, which should be dual to QCD expectations.

future only the DCI storage ring will continue to collect data. For instance:

a) $\varrho'(1250)$ search. The whole present set of data limits the available space for this resonance; in any case the e^+e^- coupling has to be much smaller than expected on the basis of the $\psi : \psi'$ and $\Upsilon : \Upsilon'$ ratios.

b) Study of the validity of the local duality. Let us consider a scheme in which the quarks creation takes place in a much shorter time than the quarks decay into hadrons. Then we expect the value of R, averaged on a large mass interval, to correspond to what predicted in absence of resonances. This doesn't seem to be confirmed by the present data[1] for $1 \lesssim M \lesssim 3$ GeV (see Fig. 1).

c) Study of the possible existence of several R plateaux. The present data seem to suggest two plateaux at energies below and above 2 GeV[1].

Tests of the hypotheses according to which relation (1) has been derived can be done by checking its dependence on s, t and A. Possible failures of the Simple Vector Dominance and Quarks models are an interesting measurement in themselves.

2. - LINK BETWEEN COHERENT PHOTOPRODUCTION AND e^+e^- ANNIHILATION.

We assume the validity of the Simple Vector Dominance scheme (SVD)[2] according to which a photoproduction process at small momentum transfer and high incident energies, can be drawn as in Fig. 2a. This means that photons transform into all possible vector mesons V proportionally to the e. m. coupling and then scatter elastically on the hadronic target. The vector meson production cross section is then given by[2]:

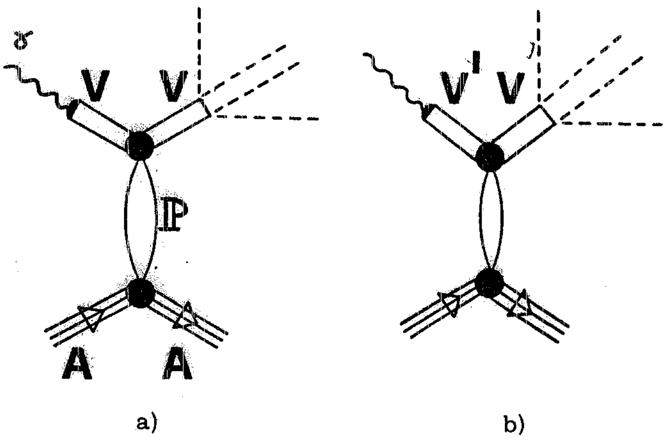

FIG. 2 - a) Simple Vector Dominance model; b) Generalized Vector Dominance model.

$$\left[\frac{d\sigma(\gamma A \to VA)}{dt}\right]_{t=0} = \alpha \frac{4\pi}{f_V^2}\left[\frac{d\sigma(VA \to VA)}{dt}\right]_{t=0} \qquad (2)$$

$$\frac{4\pi}{f_V^2} = \frac{3}{\alpha^2}\,\frac{\Gamma(V \to e^+e^-)}{M_V}$$

In the previous kinematical hypotheses, i. e. high energy and low momentum transfer, nuclear structure is usually introduced via a form factor which takes into account absorption in the final state[3]. Moreover, still in the high energy hypothesis, it's reasonable to assume the amplitude of the forward elastic scattering on nucleon to be dominated by its imaginary part. Then, using the optical theorem:

$$\frac{d\sigma(VA \to VA)}{dt} = \frac{1}{16\pi}\,\sigma^2_{TOT}(VN)\left|F(K, \sigma_{TOT}(VN))\right|^2$$

$$F(K, \sigma_{TOT}) \simeq \int d^2b\, \varrho(\vec{b}, z) e^{j\vec{K}\cdot\vec{r}} \int dz\, e^{-\frac{\sigma_{TOT}}{2}\int_z^{\infty} dz'\, \varrho(\vec{b}, z')} \qquad (3)$$

where K is the momentum transfer to the nucleus and $\varrho(r)$ the nuclear density.

The previous relations have been checked, within experimental errors, for the low lying vector mesons ϱ, ω, φ[4]. The cross sections $\sigma_{TOT}(VN)$ are in good agreement, still within experimental errors, with what we would expect if quarks were real particles: $\sigma_{TOT}(q\bar{q}N) = 2\sigma(qN)$, i.e. the cross section depends on the "flavour" of the quark and not on the binding energy of the $q\bar{q}$ system and on the relative quark wave function. For instance the identity $\sigma(\varrho N) \simeq \frac{\sigma(\pi^+N) + \sigma(\pi^-N)}{2} \simeq 25$ mb[3,4] supports nicely this hypothesis, taking into account the considerable mass difference between ϱ and π.

Let us consider the higher mass vector masons. Since[4]

$$\sigma^2_{TOT}(\varrho N) \simeq \sigma^2_{TOT}(\omega N) \simeq 625 \text{ mb}^2 \gg \sigma^2_{TOT}(\Phi N) \sim 100 \text{ mb}^2 \gg \sigma^2_{TOT}(\Psi N) \sim 1 \text{ mb}^2 , \tag{4}$$

the photoproduction process is dominated by the ϱ and ω families, that is by the bound states containing "u" and "d" quarks only.

Let us consider the $e^+e^- \to V$ annihilation process. In the hypothesis $\Gamma_{V/2} \ll M_V$, it is[5]:

$$\int_0^\infty \sigma(e^+e^- \to V)dM = \frac{6\pi^2}{M_V^2} \Gamma(e^+e^- \to V) . \tag{5}$$

Summing on all V recurrences we obtain the relation (1):

$$M^2\left(\frac{d^2\sigma}{dt\,dM^2}\right)_{t=0} = \frac{\alpha}{48\pi^2} \sigma^2_{TOT}(\varrho N)\left|F(A, \sigma_{TOT}(\varrho N))\right|^2 R^{u,d}_{e^+e^-}(M) \simeq 20\left|F\right|^2 R^{u,d}_{e^+e^-} \ \mu b \text{ GeV}^{-2}. \tag{6}$$

3. - ALTERNATIVE APPROACHES AND CHECKS.

Some experimental facts and theoretical arguments can cast doubts on the validity of the hypotheses on which relation (1) is based. However we can show that in most cases it is still possible to obtain $R^{u,d}_{e^+e^-}$ from the photoproduction data.

For instance let us consider the total cross section for photo and electroproduction on nuclei, as a function of the atomic number A and of the four-momentum Q^2 of the photon. Vector Dominance model takes care of the transition from real to virtual photons by introducing a propagator. This is not in agreement with the sharp difference between the A dependence of the photoproduction and electroproduction cross sections experimentally observed.

Let us now examine some alternative theoretical schemes and their implications in a measurement of coherent photoproduction:

a) More complicated Vector Dominance models. As a matter of fact it is reasonable to assume that, together with graphs of Fig. 1 (diagonal terms), contributions arise also from terms as sketched in Fig. 2b (non-diagonal terms). Introducing such terms we have a sufficient number of free parameters to obtain a total coherent picture of the various experimental data[2]. It has however been shown that their relative contributions decrease when the atomic number increases[6]. Then the experimental knowledge of the A dependence allows to take into account this correction to relation (1).

b) More generally, a dependence of $\sigma(VN)$ as $1/M_V^2$ has been suggested[7]. This does not contradict the experimental ratio $\sigma(\varrho N):\sigma(\omega N):\sigma(\varphi N):\sigma(\Psi N) \simeq 1/M_\varrho^2 : 1/M_\omega^2 : 1/M_\varphi^2 : 1/M_\psi^2$ even if it contrasts with the results $\sigma(\pi N) \simeq \sigma(\varrho N)$. Again the measurement of the A dependence of the photoproduction cross section allows an independent check of this dependence and the correct use of expression (1).

c) Models have been developed according to which in the high mass and energy limit the nucleus is seen by the photon as a system of partons rather than as a system of nucleons[3].

In this case the dynamical characteristics of the interaction would be really different from those of the e^+e^- annihilation and this would be in itself an interesting result.

It is interesting to note that if for photoproduction the ratio of diffractive to total cross section is the same as for pp interaction one can expect[13]:

$$M^2 \left[\frac{d^2\sigma\,(\gamma p \to Xp)}{dt\, dM^2} \right]_{t=0} \simeq 20\ \mu b\ GeV^{-2}\ . \qquad (7)$$

That is, since it is expected $R^{u,d}_{e^+e^-} \to 5/3$, about one half of what is predicted from (1).

4. - COMPARISON WITH EXISTING DATA.

A detailed check of the validity of relation (1) cannot be done todays since there is no measurement of the total coherent photoproduction cross section for $M \gtrsim 1$ GeV.

Nevertheless a partial check can be obtained by considering a specific multihadronic final state, since relation (1) implies a direct proportionality between $\left[\frac{d^2\sigma\,(\gamma A \to fA)}{dt\, dM^2} \right]_{t=0}$ and $\sigma(e^+e^- \to f)$. The $2\pi^+2\pi^-$ channel is the only multihadronic state for which the whole set of data is rather reliable.

Fig. 3 shows the most recent data obtained in e^+e^- annihilation[9] while Fig. 4 gives the most recent and accurate measurements of coherent photoproduction on carbon[10].

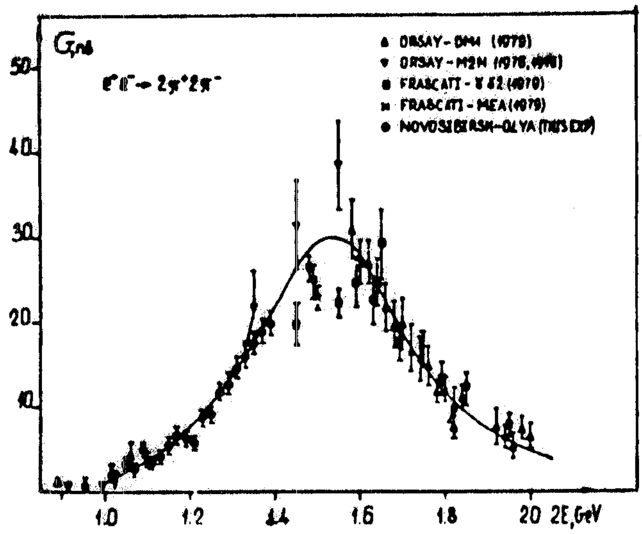

FIG. 3 - Cross section for the reaction $e^+e^- \to 2\pi^+2\pi^-$. Data from reference (9). Solid curve is a two resonance fit.

Direct proportionality between these two mass spectra is evident. To achieve a quantitative check of relation (1) we have assumed a uniform density for the Carbon nucleus and a radius $R \simeq 1.3\ A^{1/3}$ fm. For extrapolating to $t = 0$ a slope in momentum transfer $B \simeq \frac{R^2}{5} + b \simeq 55\ GeV^{-2}$ has been used ($b \simeq 7\ GeV^{-2}$ is the slope in photoproduction on proton), in rough agreement with the experimental value $B_{exp} = 64.6 \pm 0.6\ GeV^{-2}$[10].

The dashed line reported on Fig. 4 is obtained on the basis of prediction (1), assuming a cross section $\sigma(\varrho''(1600)N) = 18$ mb. Taking into account the number of hypothesis used and the roughness of the model the agreement seems fairly good.

Recent results concerning $2\pi^+2\pi^-$ diffractive photoproduction on proton are reported in Fig. 5. In these experiments the incident photon energy is not large enough to guarantee a real dominance of the diffractive contribution. Other experiments[12] consider $\varrho^0\pi^+\pi^-$ channel only, looking at the ϱ^0 angular distribution to separate $J^P = 1^-$ state. This channel however has not been isolated in e^+e^- annihilation into $2\pi^+2\pi^-$, so that the comparison is meaningfull only if this is the dominant decay channel.

Dashed line is again a prediction based on the hypotheses done before. Still there is a fair agreement in this range of masses.

In conclusion relating e^+e^- annihilation and coherent photoproduction according prediction (1) appears to be a promising approach.

5. - CONCLUSIONS.

The experimental set-up of FRAM, installed in the North Area of the SPS at CERN, is particularly suited to measure the quantities needed in relation (1).

It should be enough to make measurements on four or five nuclear targets. Indeed the results obtained in photoproduction of $2\pi^+2\pi^-$ show that no dramatic corrections must be applied at least for $M \lesssim 2$ GeV.

A rate of the order of 10^6 events/month is expected, in the 1-4 GeV mass interval, with the actual photon beam and nuclear targets[14], which is largerly sufficient for the aims of this measurement.

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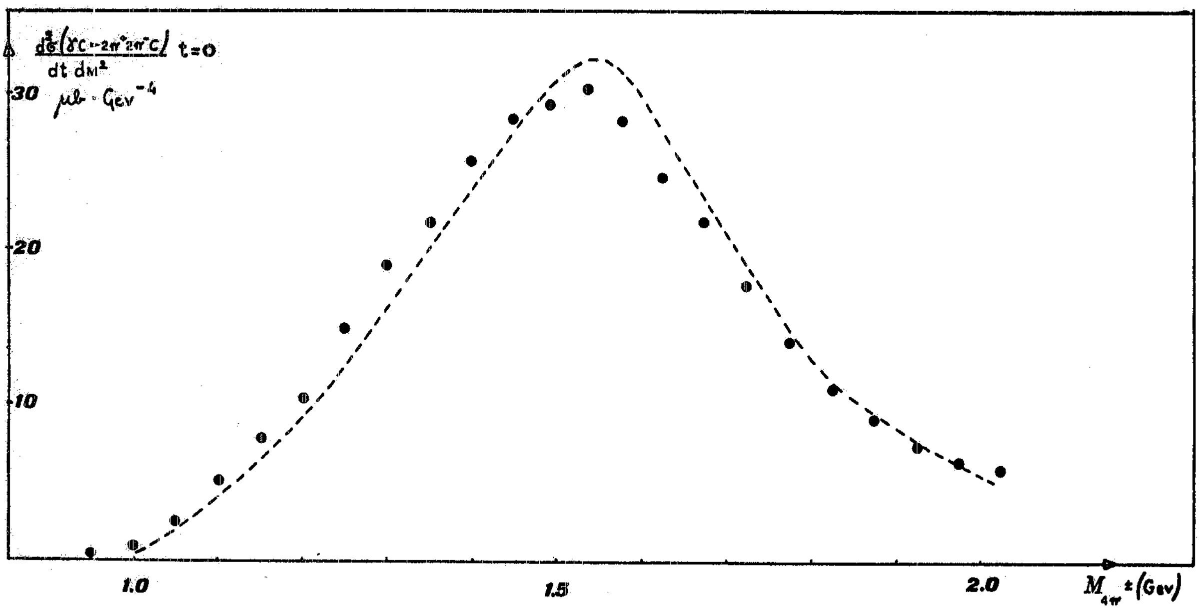

FIG. 4 - Cross section for $\gamma C \rightarrow 2\pi^+ 2\pi^- C$ from ref. (10). Solid curve is a prediction coming from the fit reported in Fig. 3, assuming $\sigma_{\rho''(1600)N} \simeq 18$ mb and a uniform density model for C.

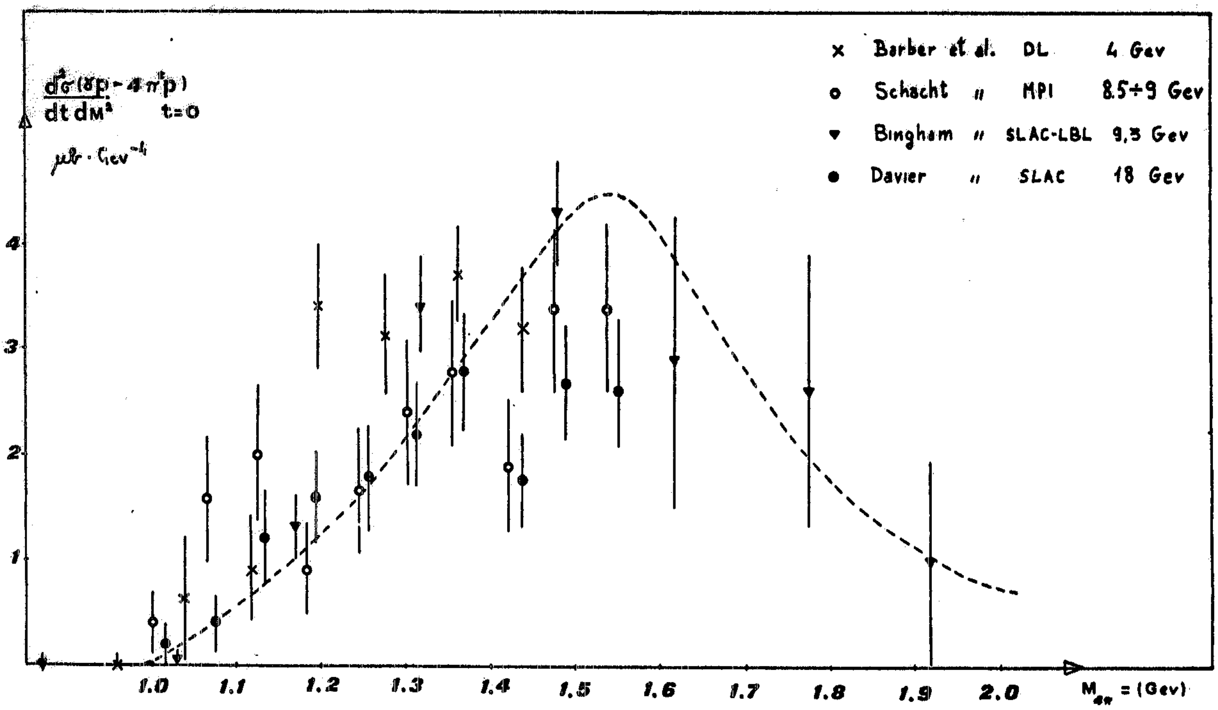

FIG. 5 - Cross section for $\gamma p \rightarrow 2\pi^+ 2\pi^- p$ from ref. (11). Solid curve is a prediction based on formula (1).

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