RECENT ρ-PRODUCTION EXPERIMENTS AND THE PREDICTIONS OF CHIRAL SYMMETRY*

D. A. Geffen and T. Walsh
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455
(Received 29 April 1968)

We show that the recent electron-positron colliding-beam experiment at Novosibirsk and ρ-photoproduction experiment at Deutsches Elektronen-Synchrotron yield ρ couplings which are consistent with the predictions of simple SU(2)⊗SU(2) effective Lagrangian theories containing an axial-vector meson. This includes the prediction of the virtual ρ mass dependence of $\gamma_{\rho\pi\pi}$.

The simplest chiral invariant Lagrangian containing π, ρ, and A fields was first proposed by Schwinger.[1] It can be obtained from the Lagrangian of Wess and Zumino[2] by setting their "anomalous moment" parameter κ equal to zero, or from the Ward-identity approach of Schnitzer and Weinberg[3] with $\delta = 0$. This Lagrangian satisfies the chiral field algebra and partial conservation of axial-vector currents. It predicts for $\gamma_{\rho\pi\pi}$

$$\gamma_{\rho\pi\pi}(m) = \gamma_\rho\left[1-\frac{1}{2}\left(\frac{m_A^2-m_\rho^2}{m_A^2}\right)\frac{m^2}{m_\rho^2}\right], \tag{1}$$

where m is the virtual ρ mass, m_A the mass of the axial-vector meson, and em_ρ^2/γ_ρ the ρ-γ coupling constant. If we identify the axial-vector meson with the still controversial A_1 meson, we find that $m_A \simeq \sqrt{2}\, m_\rho$ and

$$\gamma_{\rho\pi\pi}(m) = \gamma_\rho\left[1-\frac{1}{4}\frac{m^2}{m_\rho^2}\right]. \tag{2}$$

The cross section for the colliding-beam experiment,[4] $e^+ + e^- \rightarrow \pi^+ + \pi^-$, is proportional to $|F_\pi(m)|^2$, where F_π is defined for c.m. energy m by

$$\langle 0|J_\mu^{\text{e.m.}}|\pi^+\pi^-+\rangle = e(p_+ - p_-)_\mu F_\pi(m). \tag{3}$$

In a ρ-dominance model satisfying Eq. (1), F_π becomes

$$F_\pi(m) = \frac{[\gamma_{\rho\pi\pi}(m)/\gamma_\rho]m_\rho^2}{m_\rho^2 - m^2 - i\theta(m-2m_\pi)m_\rho\Gamma_\rho(m)} \tag{4}$$

with

$$m_\rho\Gamma_\rho(m) = [\gamma_{\rho\pi\pi}(m)]^2(m^2-4m_\pi^2)^{3/2}/48\pi m. \tag{5}$$

Equation (4) can also be thought of as a solution to the Omnès equation for F_π, with $\gamma_{\rho\pi\pi}(m)/\gamma_\rho$ a polynomial linear in m^2 multiplying the usual Omnès factor. Since $\gamma_{\rho\pi\pi}(0)/\gamma_\rho = 1$, $F_\pi(0) = 1$. Our expression for F_π should not be taken too seriously, however, for $|m^2| \gg m_\rho^2$. Figure 1 shows the colliding-beam data[4] for $|F_\pi(m)|^2$ together with theoretical curves obtained from Eq. (4), and taking

$$\gamma_{\rho\pi\pi}(m)/\gamma_\rho = 1-\lambda m^2/m_\rho^2, \tag{6}$$

$\Gamma_\rho(m_\rho) = 95$ MeV, and $\lambda = 0.1$, 0.2, and 0.3. We also have included the value for $|F_\pi|^2$ at $m = 775$ MeV recently reported by Augustin et al.[5] at Orsay. The two independently obtained values for $|F_\pi|^2$ near $m = m_\rho$ require $\lambda > 0$ for $\Gamma_\rho \simeq 100$ MeV. The Novosibirsk data for $|F_\pi|^2$ off the peak cannot be fitted for Γ_ρ much larger than 100 MeV or for values of m_ρ differing from 765 by more than 10 MeV. It must be emphasized that the colliding beam reaction $e^+ + e^- \rightarrow \pi^+ + \pi^-$ is the only way of establishing the parameters of the ρ resonance without the complicating presence of nuclear background and absorption effects.

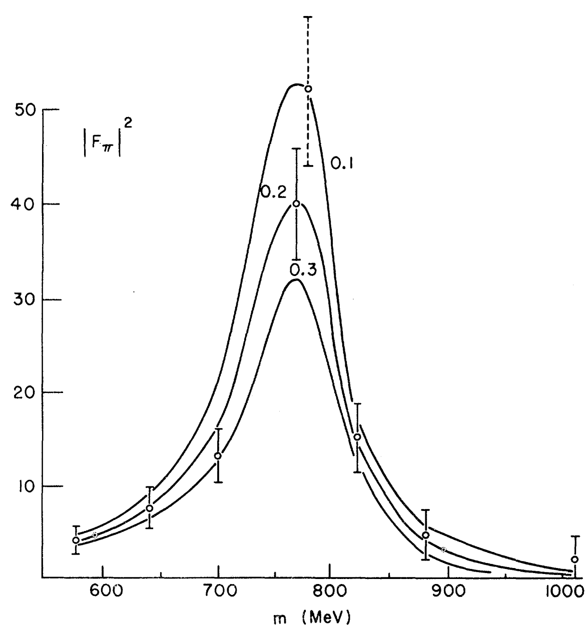

FIG. 1. The Novosibirsk experimental points for $|F_\pi|^2$ (and the Orsay point at $m = 775$ MeV), together with curves from Eq. (4) with Eq. (6) for $\lambda = 0.1$, 0.2, and 0.3; $m_\rho = 765$ and $\Gamma_\rho(m_\rho) = 95$ MeV.

The Deutsches Elektronen-Synchrotron (DESY)

ρ-photoproduction experiments[6] on carbon, $\gamma + C \to C + \rho$, have measured both the decays $\rho \to \pi^+ + \pi^-$ and $\rho \to e^+ + e^-$. Because of the uncertainties about background contributions and absorption effects, the analysis of this experiment is less straightforward. We adopt the method used by the DESY group to fit the π-pair mass distribution in the region of the ρ peak, but fix m_ρ at 765 and $\Gamma_\rho(m_\rho)$ at 100 MeV. As seen in Fig. 2, these parameters are not inconsistent with the data. The slight systematic discrepancy between the theoretical curve and the data in the mass region $650 < m < 900$ MeV is a reflection of the fact that ρ-photoproduction experiments have always suggested a lower value for m_ρ. We believe that this mass shift can be attributed to a background interference[7] or ρ-mass–dependent absorption effect. The DESY group analyzed their data by including a factor of m_ρ^4/m^4 in the ρ resonance shape. This factor was proposed by Ross and Stodolsky[8] as a diffraction effect in order to explain this shift in the ρ peak. We are unable to find any firm theoretical justification for this factor and agree with Gottfried[9] that this factor should not be present. Without the factor of m_ρ^4/m^4 present the DESY data cannot be fitted with a width much larger than 100 MeV.[10]

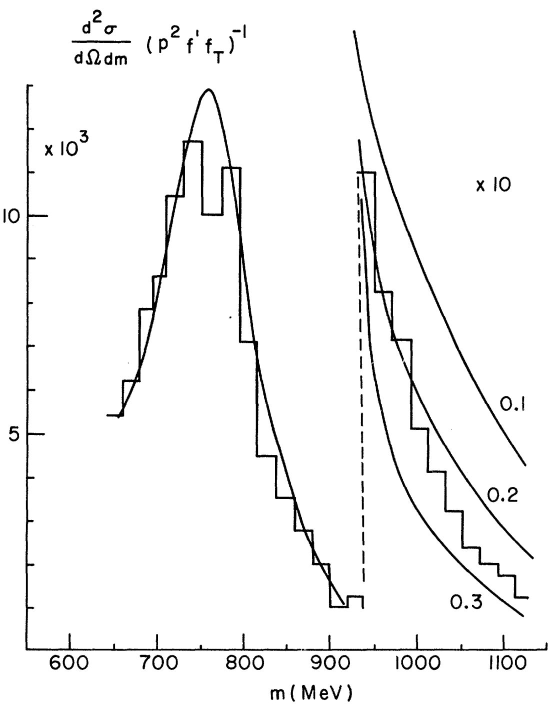

FIG. 2. The DESY data from 650 to 900 MeV, together with a theoretical curve with $m_\rho = 765$ MeV, $\Gamma_\rho(m_\rho) = 100$ MeV, and $\lambda = 0.2$. The background is shown as a dashed line. The curves from 950 to 1100 MeV have $\lambda = 0.1$, 0.2, and 0.3 with again $m_\rho = 765$ MeV and $\Gamma_\rho = 100$ MeV.

While the m dependence of $\gamma_{\rho\pi\pi}$ does not appreciably modify the π-pair mass distribution in the ρ peak region, it does become important in the tail of the distribution, $900 < m < 1100$ MeV. If we accept the hypothesis made by Asbury et al.[6] that the π pairs in this mass region are due almost entirely to virtual ρ decays, then their data, as seen in Fig. 2, provide dramatic corroboration of the colliding-beam results that $\lambda > 0$. In this case, values of λ near $\frac{1}{4}$ fit the data best. Again it is difficult to assess what mass-dependent ρ-carbon interaction effects or background contributions in the mass region 900 to 1100 MeV will do to modify the value of λ. It should be noted that the observed mass distribution drops off more rapidly than expected from ρ dominance with $\lambda = 0$. Consequently, if there is a contributing background with $\lambda = 0$, it must be interfering destructively with the contribution.

One consequence of a narrower width for the ρ is that the number of photoproduced π pairs attributed to the decay of ρ mesons is reduced by approximately 20%. This results in a 20% increase in the value for $\gamma_\rho^2/4\pi$ obtained from the ρ-photoproduction cross section using the diffraction production model. This becomes $\gamma_\rho^2/4\pi = 2.4 \pm 0.5$ (Asbury et al. use a definition of γ_ρ which is $\frac{1}{2}$ our γ_ρ). Since $\Gamma_\rho(m_\rho) = 100$ MeV yields $[\gamma_{\rho\pi\pi}(m_\rho)]^2/4\pi = 2.0$, we obtain $\gamma_{\rho\pi\pi}(m_\rho)/\gamma_\rho = 0.9 \pm 0.2$, a result consistent (if inconclusively) with $\lambda > 0$. The DESY analysis, using $\Gamma_\rho = 130$ MeV, finds $\gamma_{\rho\pi\pi}/\gamma_\rho = 1.1 \pm 0.2$.

The 20% decrease in the number of ρ's photoproduced increases by 20% the $\rho \to e^+ + e^-$ branching ratio reported in Ref. 6. The branching ratio, B_ρ, now becomes

$$B_\rho = \Gamma(\rho \to e^+ + e^-)/\Gamma(\rho \to \pi^+ + \pi^-) = (7.8 \pm 1.6) \times 10^{-5}. \quad (7)$$

This larger value for B_ρ makes the recent work of Parsons and Weinstein[11] at Northeastern, and Davier[12] at Stanford Linear Accelerator Center, particularly relevant. They point out that if the SU(3) estimate of the ω-γ coupling constant is correct, an estimate consistent with the observed ω photoproduction cross section, then photoproduced ω's decaying into $e^+ + e^-$ can interfere significantly with the electron pairs coming from ρ's. Taking ρ and ω production amplitudes with the same phase, as expected from the simple diffraction production model, they obtained[11] an increase of about 70% in the number of lepton pairs produced compared with the number expected from ρ decays alone. If this estimate is correct [large SU(3)-breaking corrections to the ω-γ coupling constant are possible], the true $e^+ + e^-$ branching ratio is obtained by dividing B_ρ in Eq. (7) by 1.7:

$$(B_\rho)_{\text{corrected}} = (4.6 \pm 1.3) \times 10^{-5}. \tag{8}$$

This corrected value for B_ρ leads to $\gamma_{\rho\pi\pi}(m_\rho)/\gamma_\rho = 0.95 \pm 0.20$, again consistent with $\lambda > 0$. Without the correction factor of 1.7, we would have obtained $\gamma_{\rho\pi\pi}(m_\rho)/\gamma_\rho = 1.25 \pm 0.25$. If we take the DESY analysis with $\Gamma_\rho = 130$ MeV and $B_\rho = (6.5 \pm 1.4) \times 10^{-5}$, we find $\gamma_{\rho\pi\pi}/\gamma_\rho = 1.4 \pm 0.3$. Both of these two values for $\gamma_{\rho\pi\pi}/\gamma_\rho$ are two standard deviations away from the colliding-beam value, $\gamma_{\rho\pi\pi}(m_\rho)/\gamma_\rho = 0.8 \pm 0.1$. Unfortunately, the DESY electron-pair mass distribution does not show any evidence of an ω peak, although the statistics are poor. Nevertheless, our interpretation of the ρ-production data does tend to support the presence of a large interference effect. Note that the consistent values for $\gamma_{\rho\pi\pi}/\gamma_\rho$ that are found for both $e^+ + e^- \to \pi^+ + \pi^-$ and $\gamma + \mathrm{C} \to \rho + \mathrm{C}$ indicate that the ρ-γ coupling constant is independent of the virtual-photon mass. This is to be expected in a field-algebra approach but is a result that is not unique to a field algebra alone.

If we accept this analysis of these two ρ-production experiments, we have additional evidence that the A_1 meson plays an important role in maintaining chiral symmetry among mesons. Notice that if we were to eliminate the A_1 from the effective Lagrangian, then we would predict an even larger value for λ, since eliminating the A_1 is equivalent to taking $m_A \to \infty$ in Eq. (1). This yields $\lambda = \frac{1}{2}$ and is clearly ruled out by experiment. There is some difficulty, however, with the width of the A_1 predicted by the simple effective Lagrangian with $\delta = 0$.[3] In this case, $\Gamma(A_1 \to \rho + \pi) \sim 224$ MeV, a value which is large. Aside from the fact that we cannot take seriously to better than 25% current-algebra predictions of widths, it is also possible to reduce the A_1 width substantially by introducing a small negative value for δ. Since we fix the ρ width at 100 MeV, the relevant quantity is $\Gamma(A_1 \to \rho + \pi)/\Gamma(\rho \to 2\pi) \simeq 2.24[(1+\frac{1}{2}\delta)/(1-\frac{1}{3}\delta)]^2$, so that $\delta = -0.4$ reduces $\Gamma(A_1 \to \rho + \pi)$ to 112 MeV while $\lambda = \frac{1}{4}(1+\delta) = 0.15$. It would be most useful to have improved statistics for the colliding-beam experiment and an extension of data to mass regions outside the ρ resonance.

Finally we observe that in Sakurai's[13] calculation of the πN scattering lengths, $a_1 - a_3$, using ρ exchange, one must use $\gamma_{\rho\pi\pi}(m)$ at $m = 0$. Hence, if $\lambda > 0$, $\gamma_{\rho\pi\pi}(0) > \gamma_{\rho\pi\pi}(m_\rho)$; and one must use an effective ρ width considerably larger than that observed in order to obtain the correct value for $a_1 - a_3$ or, using the soft-pion limit, the Kawarabayashi-Suzuki-Fayyazuddin-Riazuddin relation.[14] This should not be surprising since the effective Lagrangians are constructed to give $a_1 - a_3$ through ρ exchange.[2]

We wish to thank E. Coleman, S. Gasiorowicz, and H. Suura for helpful discussions. One of us (D.A.G.) would like to thank M. Davier, K. Gottfried, and R. Weinstein for discussing their results with him.

*Work supported in part by the U. S. Atomic Energy Commission, Contract No. AT (11-1)-1764.

[1]J. Schwinger, Phys. Letters 24B, 473 (1967).

[2]J. Wess and B. Zumino, Phys. Rev. 163, 1727 (1967). See also B. W. Lee and H. T. Nieh, Phys. Rev. 166, 1507 (1968). This paper contains many more references.

[3]H. J. Schnitzer and S. Weinberg, Phys. Rev. 164, 1828 (1967).

[4]V. L. Auslander et al., Phys. Letters 25B, 433 (1967).

[5]J. E. Augustin et al., Phys. Rev. Letters 20, 126 (1968).

[6]J. G. Asbury et al., Phys. Rev. Letters 20, 227 (1968). This paper contains earlier references reporting results of the experiment.

[7]For simplicity we have taken a linear mass dependence for the noninterfering background function used in Ref. 6. Shifts in the ρ peak are not restricted to photoproduction processes only but occur in ρ production processes induced by pions. For a discussion of these experiments, see M. Roos, CERN Report No. Th. 789 (unpublished).

[8]M. Ross and L. Stodolsky, Phys. Rev. 149, 1172 (1966).

[9]K. Gottfried, Bull. Am. Phys. Soc. 13, 175(T) (1968), and to be published.

[10]Asbury et al. reported the result of an analysis of their π-pair mass-distribution data made with the m_ρ^4/m^4 factor absent. They obtained as a best fit $\Gamma_\rho(m_\rho) = 104 \pm 15$ MeV and $m_\rho = 737 \pm 5$ MeV.

[11]R. G. Parsons and R. Weinstein, Phys. Rev. Letters 20, 1314 (1968).

[12]M. Davier, Stanford Linear Accelerator Report No. 397 (unpublished).

[13]J. J. Sakurai, Phys. Rev. Letters 17, 552 (1966).

[14]K. Kawarabayashi and M. Suzuki, Phys. Rev. Letters 16, 255 (1966); Fayyazuddin and Riazuddin, Phys. Rev. 147, 1071 (1966).