SLAC-PUB-397
March 1968

ρ AND ω LEPTONIC DECAYS IN PHOTOPRODUCTION*

M. Davier

Stanford Linear Accelerator Center
Stanford University, Stanford, California

Recent experiments on leptonic decays of photoproduced vector mesons[1,2] have clearly shown the decay $\rho \rightarrow \ell^+\ell^-$ but no evidence for $\omega \rightarrow \ell^+\ell^-$. In this letter we examine this problem in detail and investigate the possible consequences for the electromagnetic properties of vector mesons in the context of the vector dominance model (VDM).[3]

Let us consider the photoproduction of ρ and ω on a nucleus, followed by the decay into a lepton pair; the $\ell^+\ell^-$ mass spectrum in the ρ-ω region can be written as follows:

$$\frac{dy}{ds\,dt}(k,t,s) = \frac{1}{\pi}\left|\sum_{V=\rho,\omega} \frac{m_V^{1/2}\,A_V(k,t)\,F_V(k,t)\,D_V(s)}{s - m_V^2 + i\,\Gamma_V m_V}\right|^2 \tag{1}$$

where s is the $\ell^+\ell^-$ invariant squared-mass, t the invariant squared-momentum transfer to the nucleus (coherent production), $A_V(k,t)$ the photoproduction amplitude on the nucleon at a photon energy k, $F_V(k,t)$ a nuclear "form factor" and $D_V(s)$ the decay amplitude for $V \rightarrow \ell^+\ell^-$.

1. We calculate $F_V(k,t)$ using an optical model[4]; for a hard-sphere potential (constant nuclear density δ inside a radius R) one has

$$F_V(k,t) = \frac{2\pi\delta}{\frac{1}{2}\,\delta\,\sigma_V(k) + iq}\left\{e^{iqR}\left(\frac{R}{iq} + \frac{1}{q}\right) - \frac{1}{q^2} - \frac{1}{\left(\delta\sigma_V(k) + iq\right)^2}\right.$$

$$\left. + \; e^{-\left(\delta\sigma_V(k) + iq\right)R}\left[\frac{R}{\delta\sigma_V(k) + iq} + \frac{1}{\left(\delta\sigma_V(k) + iq\right)^2}\right]\right\} \tag{2}$$

where $t = q^2$ and $\sigma_V(k)$ is the total V-nucleon cross section $\left[\sigma_T\left(Vp\right)\right]$.

(submitted to Physics Letters)

*Work supported by the U.S. Atomic Energy Commission

This model has been applied to ρ photoproduction on nuclei[5] and describes adequately both the A and t dependence; the fit to the A dependence gives $\sigma_T(\rho p) \simeq 30$ mb at 3 GeV. $\sigma_T(\omega p)$ has not yet been measured and one notices that if $\sigma_T(\omega p)$ is different from $\sigma_T(\rho p)$ a phase ϕ_n appears between ρ and ω nuclear amplitudes, coming from different absorptive parts in $F_V(k,t)$; however, for 20 mb $< \sigma_T(\omega p) <$ 40 mb, ϕ_n is always small, typically $< 10^o$.

2. $A_V(k,t)$ describes the photoproduction process on the nucleon; only the nuclear coherent part gives an important contribution (Pomeranchon, 2^+ exchange); in particular 0^- exchange can only contribute incoherently and its effect is consequently much smaller.

More precisely we consider here the VDM (Fig. 1a); $A_V(k,t)$ is explicitly given by

$$A_V(k,t) = \sum_{V'} \frac{em_{V'}^2}{f_{V'}} B_{V'V}(k,t) \tag{3}$$

$B_{V'V}(k,t)$ being the scattering amplitude for $V'p \to Vp$ [6]; in fact we are dealing only with $B_{V'V}\left(k, t \simeq t_{min}\right)$ since the nuclear t dependence cuts off the large t contribution.

If only Pomeranchon exchange is important, both ρ and ω amplitudes are imaginary and the relative phase $\phi = \phi_\omega - \phi_\rho = 0$; if other exchanges play a role, then ϕ can possibly be $\neq 0$.

3. $D_V(s)$ is calculated in a straightforward way from the graph in Fig. 1b:

$$D_V(s) = \frac{em_V^2}{f_V} d \left(sm_V\right)^{-1/2} \tag{4}$$

where d is independent of V to the order of 1% and

$$\sum_{\text{polarizations } \ell^+\ell^-} |d|^2 = \frac{1}{12\pi}$$

Hence the spectrum is expressed by:

$$\frac{dy}{ds\,dt}(k,t,s) = \frac{1}{3}\left(\frac{e^2}{4\pi}\right)^2 \left| \sum_{VV'} \frac{m_V^2 m_{V'}^2\ F_V(k,t)\ B_{V'V}(k,t)}{f_V f_{V'} s^{1/2}\left(s - m_V^2 + i\ \Gamma_V m_V\right)} \right|^2 \tag{5}$$

We have used expression (5) to calculate the relative lepton pair yield; we have assumed $V \equiv V' = \rho$ or ω and treated the phase ϕ between ρ and ω amplitudes as a purely phenomenological parameter, although we have made attempts to include amplitudes where $V \neq V'$ and calculate ϕ in a Regge model.[7]

The following parameters have been used

$$m_\rho = 770 \text{ MeV} \qquad m_\omega = 783 \text{ MeV}$$

$$\Gamma_\rho = 120 \text{ MeV} \qquad \Gamma_\omega = 12 \text{ MeV}$$

$$\sigma_T(\rho p) = \sigma_T(\omega p) = 30 \text{ mb}$$

$$k = 3 \text{ GeV}$$

For the γ-V couplings we have tried two solutions:

$$f_\omega^2 = 9\, f_\rho^2 \qquad \text{exact SU(3)}$$

$$f_\omega^2 = 15\, f_\rho^2 \qquad \text{broken SU(3)}^{8} \qquad \left(\omega\text{-}\phi \text{ mixing angle } \tan\theta = \frac{1}{\sqrt{2}}\right)$$

Figure 2 shows a typical yield curve; the main feature is the narrow enhancement at the ω mass coming from the interference between ρ and ω amplitudes (at $s = m_\omega^2$ the two amplitudes are roughly in the ratio $\rho:\omega = 1:0.7$, and they interfere constructively).

In order to get a realistic picture we have included the effect of an experimental resolution; the curves in Fig. 3 are the result of a folding between the yield curves and a Gaussian resolution function with $\Delta m = \pm$ 15 MeV (similar to experiment (2)). Due to the poor experimental statistics, it is hopeless to fit these curves to the data, but we can estimate the integrated ω contamination to a pure ρ spectrum (Table I).

The comparison between $\Gamma(\rho \rightarrow \ell^+ \ell^-)$ measured in experiments 1, 2 and the value obtained with e^+e^- colliding beams[9] (clean ρ signal) indicates that a large ω contamination is unlikely; this supports the idea of a small γ-ω coupling as given by broken SU(3).[8] However at the present experimental stage, any attempt to settle quantitatively this problem is doomed to be inconclusive.

The same approach can be applied to the following process occurring in photoproduction:

1. ρ-ϕ interference in $\ell^+\ell^-$ decays.

   Since the ϕ photoproduction amplitude is small, it has a non-negligible interference with the ρ amplitude. Using

$$f_\phi^2 = 7\, f_\rho^2 \;,$$ [8]

the known photoproduction cross sections and assuming the validity of Eq. (1) away from the resonance, we estimate a 25% ρ interference in the ϕ peak if they interfere constructively, which is a reasonable assumption.

2. ρ-ω interference in $\pi^o\gamma$ decays.

   This could provide in principle a way to measure $\Gamma(\rho \rightarrow \pi\gamma)$ but it is unlikely to be successful because (1) the background substraction under the ω peak plays a major role and (2) $\Gamma(\omega \rightarrow \pi\gamma)$ is only known to 10%. Nevertheless we predict a 10% effect if $\Gamma(\rho \rightarrow \pi\gamma) = .1$ MeV; experimentally $\Gamma(\rho \rightarrow \pi\gamma)$ is only known to be $< .6$ MeV,[10] this value giving a 25% interference effect in $\pi^o\gamma$ photoproduction.

Acknowledgments

The author would like to thank Professors S. D. Drell and J. J. Sakurai for useful discussions.

REFERENCES AND NOTES

1. J. K. de Pagter, et al., Phys. Rev. Letters 16, 35 (1966); $\Gamma(\rho \rightarrow \mu^+\mu^-) = (7.1 \pm 1.8)$ keV.
2. J. G. Asbury, et al., Phys. Rev. Letters 19, 869 (1967); $\Gamma(\rho \rightarrow e^+e^-) = (7.8 \pm 1.7)$ keV.
3. For references, see S. Ting, Proceedings of the 1967 International Symposium on Electron and Photon Interactions at High Energy, Stanford Linear Accelerator, Stanford University, Stanford, California (September 1967).
4. S. D. Drell and J. S. Trefil, Phys. Rev. Letters 16, 552, 832(E) (1966).
5. J. G. Asbury, et al., Phys. Rev. Letters 19, 865 (1967).
6. We do not use the factor $\left(m_{V'}^2/s\right)^2$ introduced by M. Ross and L. Stodolsky, Phys. Rev. 149, 1172 (1966), on questionable grounds. If this factor brings no trouble in $(\pi^+\pi^-)$ photoproduction and even helps to fit the data, its effect is quite disastrous in (e^+e^-) photoproduction where the s threshold is by far smaller.
7. As it is well known $V' \equiv \phi$ does not contribute if $\tan\theta = 1/\sqrt{2}$ (θ is the ω-ϕ mixing angle) so we are left with three amplitudes: $(\rho p \rightarrow \rho p)$, $(\omega p \rightarrow \omega p)$ and $(\rho p \rightarrow \omega p)$. In a Regge model we describe these processes by Pomeranchon and 2^+ exchange; using Regge parameters fitted in πN and KN scatterings data, this model fits very well in the photoproduction data and gives $\phi \simeq 50^\circ \pm 30^\circ$ at 3 GeV. However, it should be noted that going from the proton to a nucleus is not free of difficulties concerning the coherence properties of the considered amplitudes.
8. R. J. Oakes and J. J. Sakurai, Phys. Rev. Letters 19, 1266 (1967).

9. V. L. Auslander, *et al.*, Physics Letters **25**, 433 (1967);

J. E. Augustin, *et al.*, Phys. Rev. Letters **20**, 126 (1968);

$\Gamma(\rho \to e^+e^-) = (7.4 \pm 1.2)$ keV.

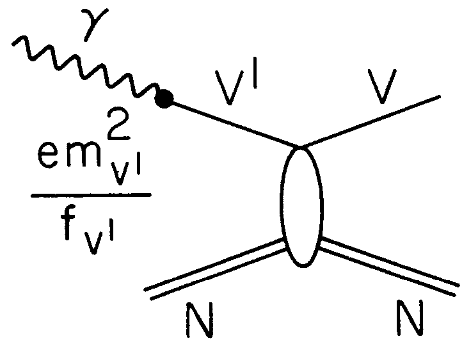
10. G. Fidecaro, *et al.*, Physics Letters **23**, 163 (1966).

After this work was completed, we have been informed that a somewhat similar work has been done on this subject by R. G. Parsons and R. Weinstein (to be published).

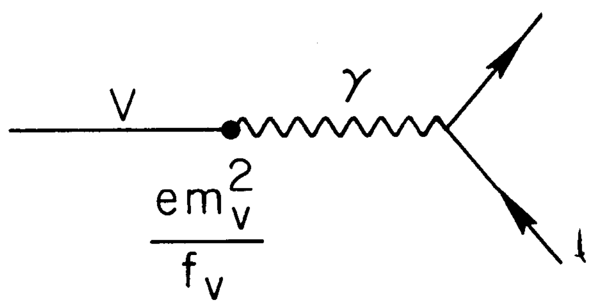
TABLE I

ω CONTAMINATION (IN %) IN TOTAL LEPTON PAIRS YIELD

ϕ (degrees)	- 60	- 30	0	+ 30	+ 60
$f_\omega^2 = 9\ f_\rho^2$	18	37	49	50	40
$f_\omega^2 = 15\ f_\rho^2$	9	20	27	28	22



a.



b.

Fig. 1

Feynman diagrams for V photoproduction in the VDM and $V \rightarrow \ell^+ \ell^-$.

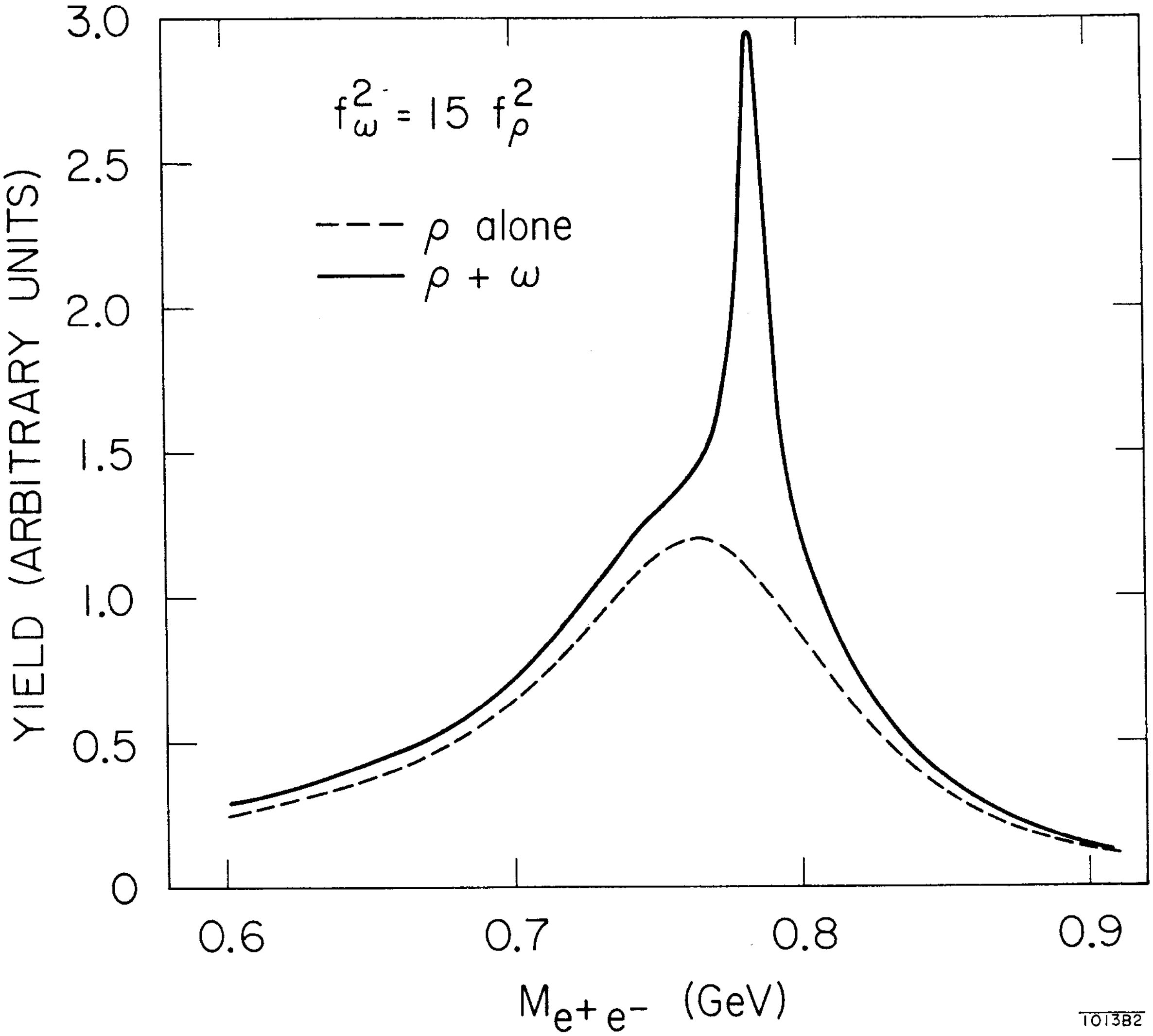


Fig. 2

Lepton pair yield from ρ and ω photoproduction in function of mass.

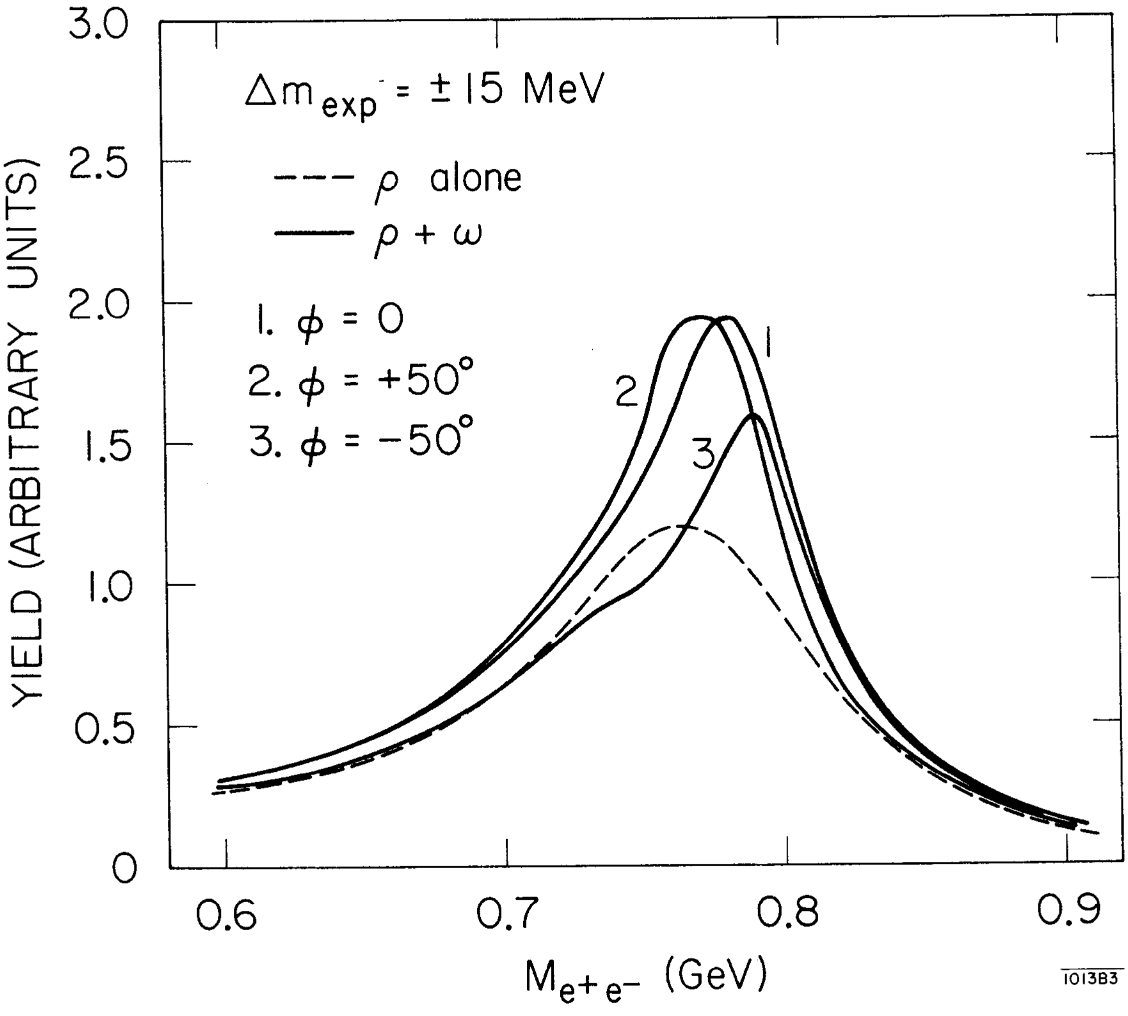


Fig. 3

Effect of the experimental resolution in the lepton pair yield for different phases between ρ and ω photoproduction amplitudes. $\left(f_\omega^2 = 15\ f_\rho^2\right)$.