ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E1 - 3770

R.G.Astvacaturov, M.A.Azimov, A.M.Baldin, A.S.Belousov, I.V.Chuvilo, J.Hladký, V.I.Ivanov, M.N.Khachaturyan, M.S.Khvastunov, A.T.Matyushin, V.T.Matyushin, L.N.Shtarkov, L.I.Zhuravleva

OBSERVATION OF THE $\phi \to e^+ e^-$ DECAY

ЛАБОРАТОРИЯ ВЫСОКИХ ЭНЕРГИЙ

1968

E1 - 3770

R.G.Astvacaturov, M.A.Azimov, A.M.Baldin,[x]
A.S.Belousov,[x] I.V.Chuvilo, J.Hladký, V.I.Ivanov,
M.N.Khachaturyan, M.S.Khvastunov,
A.T.Matyushin, V.T.Matyushin, L.N.Shtarkov,[x]
L.I.Zhuravleva

OBSERVATION OF THE $\phi \to e^+ e^-$ DECAY

Submitted to Physics Letters

[x] P.N.Lebedev Institute of Physics, Moscow, U.S.S.R.

The leptonic decays of vector mesons have been extensively investigated during the past few years. At present, there are mainly the data for the probability of the leptonic decays of ρ-mesons [1-9]. In order to experimentally test the vector dominance model and the strong interaction symmetry, it is also necessary to have the data on the leptonic decays of ω and ϕ-mesons. For the $\omega \to e^+e^-$ decay, there are at present, except evaluations [1,2], only the data [3] obtained using the SU(3) symmetry and the $\omega - \phi$ mixing hypothesis. As for the probability of the $\phi \to e^+e^-$ decay, there are only the evaluations of the upper limits [1,3,8], the first of which is based only on the statistical analysis of the opening angle distribution, the second one on the kinematic identification of a single event and the third one on small statistical deviations from the predictions of the quantum electrodynamics. Indication to the existence of the leptonic decays of ϕ-mesons has been also obtained by Wehmann et al. [4] and Asbury et al. [9].

The JINR 10 GeV proton synchrotron was used in our experiment.[x] Vector mesons were produced in a liquid hydrogen target by π^--mesons with the momentum of 4.0 GeV/c $\pm$ 1.5% in the reactions

---

x) The preliminary results of this experiment were presented at the International Conference on Electromagnetic Interactions in Stanford, 1967 (see 12).

$$\pi^- + p \to \{ \begin{matrix} \rho \\ \omega \end{matrix} \} + n \to e^+ + e^- + n, \qquad (1)$$

$$\pi^- + p \to \phi + n \to e^+ + e^- + n. \qquad (2)$$

The conditions of the experiment allowed to detect processes (1) and (2) to a high efficiency simultaneously. The e^+e^--pair detection efficiency was practically constant in the effective mass range from 500 to 1200 MeV for $t \leq 0.5\,(GeV/c)^2$. Detection techniques, etc. were described previously/3/.

The measurements were carried out in two runs. First, a liquid hydrogen target 7 x 10 x 50 cm^3 was used. As background sources, the following processes have been considered:

1. Simulation of e^+e^--pair by $\pi^+\pi^-$-pairs. The contribution of this effect was found to be smaller than 1%.

2. e^+e^--pair production via nonresonance states in the e^+e^--system. The contribution of these sources was found to be negligibly small for $M \geq 0.5$ GeV.

3. The $2\gamma \to 2(e^+e^-)$ conversion occuring in hydrogen in the target and spark chambers walls and in the air. It was found, that the largest contribution to the background is due to this effect. Its value was evaluated on the basis of the experimental opening angles and effective mass distributions for two-gamma events measured with the same apparatus simultaneously. This permitted to exclude possible systematic errors. The effective mass spectrum of the conversion background has a maximum at M = 550 MeV, and is decreased rapidly with increasing the mass.

In the first run, the conversion background value was about 30% of the observed e^+e^- events. In the second run the conversion background was greatly reduced by using a liquid hydrogen target of conical form with thin walls and was smaller than 10%.

Candidates for (1) and (2) reactions were selected from the pictures obtained and according to geometrical and kinematical criteria. Owing to picture selection, 2-gamma, 3-gamma events etc. were eliminated.

The geometrical reconstruction programme determines the point of the tracks intersection and fits the angular parameters of the tracks For the further analysis only the decays into two charged particles having the intersection point within the target volume were selected. Only events with $P(\chi^2) \geq 1\%$ were taken.

The kinematic selection of the events of the type (1) and (2) was made by the reaction-channel indentification programme. Using all available information on the angles and energies of π^-, e^+ and e^--particles, it was possible for us to apply both the kinematics of resonance production and that of the resonance decay. It enables to obtain a strong evidence, that the reactions (1) and (2) have been observed. The exact solution of this problem was performed on a computer by analysing the overdetermined system of the equations which relate the measured energy and angular parameters of each event. The events corresponding to (1) and (2) were selected by the χ^2-criterion. The resonance mass and its accuracy were computed using the fitted values of the parameters. In this case, the mass error due to electron energy errors was reduced more than two-times. The $\rho \to e^+e^-$ events were selected at the probability level $P(\chi^2) \geq 1\%$ taking into account the ρ-meson width. The ϕ-decays were selected at the level $P(\chi^2) \geq 32\%$ i.e. under more rigid conditions.

The e^+e^--pairs opening angle and effective mass distrubutions are shown in Figs. 1 and 2. The distributions include events measured in the first and second runs after background subtraction. The position of the peaks gives the evidence, that just the $\rho \to e^+e^-$, $\omega \to e^+e^-$ and $\phi \to e^+e^-$-decays have been observed. The width of the left peak in Fig. 2 is in agreement with that of the ρ-meson, taking into account the apparatus mass resolution of about ± 40 MeV. The numbers of ρ, ω amd ϕ-meson e^+e^--decays were determined by integrating the yields under the peaks in histogramms after background subtraction. Thus, 33 ρ, ω events and 5 ϕ-events were obtained. These numbers were also obtained independently using the reaction-channel identification programme.

Taking into account the data on the π^--flux, the hydrogen target length and the e^+e^--detection efficiency calculated by the Monte-Carlo method the results can be written as follows:

$$B_\rho \sigma_\rho + B_\omega \sigma_\omega (\epsilon_\omega / \epsilon_\rho) = (0.50 \pm 0.10) \cdot 10^{-4} \text{ mb} \quad (3)$$

$$B_\phi \cdot \sigma_\phi = (0.17 {}^{+0.12}_{-0.07}) \cdot 10^{-4} \text{ mb}, \quad (4)$$

where $B_v = \Gamma(v \to e^+e^-)/\Gamma(v \to \text{total})$ is the branching ratio for the v-mesons decays into e^+e^--pairs ($v = \rho$, ω and ϕ), σ_v is the v-mesons total production cross section in the reactions (1), (2), and ϵ_v is the detection efficiency.

The dependence of the efficiency on the density matrix elements ρ_{ik} can be written for our geometry as follows ϵ_v = const (ρ_{00}+ 1.44). For all V-mesons, ρ_{00} = 0.6 was taken according to the present experimental data. For ω-meson production, information on ρ_{00} is very poor. However, it is not essential for our results, since the ω-contribution to (3) is about 20% and the ϵ_v dependence on ρ_{00} is rather weak. The experimental error for ϕ-meson in (4) is so large that the uncertainties in ρ_{00} for this case can be neglected.

The branching ratio for the V-decays into e^+e^-pairs can be obtained/3/ from (3) using the SU (3) symmetry and the ω-ϕ mixing hypothesis. Assuming the value of 38° for the mixing angle and using the data of refs./10,11/ for the cross sections σ_ρ and σ_ω, we obtaine:

$$B_\rho = (5.3 \pm 1.1) \cdot 10^{-5}, \quad B_\omega = (6.5 \pm 1.3) \cdot 10^{-5}. \quad (5)$$

Here the errors are only statistical and do not include σ_ρ and σ_ω inaccuracy. In comparison to/3/ the data of the present work have been obtained with improved statistics under better experimental con-

ditions. The values in (3) and (4) are in a good agreement with our previous data/3/. The branching ratios (5) have some difference because in present paper use is made of more accurate data on differential cross sections for ρ and ω-mesons. The result (5) for B_ρ allows to calculate the constant γ_ρ of the vector dominance model

$$\gamma_\rho^2 / 4\pi = (0.49 \pm 0.10). \quad (6)$$

Using the experimental data on σ_ϕ /11/ we obtain from (4):

$$B_\phi = (66 {}^{+44}_{-28}) \cdot 10^{-5}, \quad (7)$$

where the error is only statistical. The value B'_ϕ using (3), the SU(3) symmetry and the ω-ϕ mixing hypothesis is equal to $B'_\phi = (43 \pm 8) \cdot 10^{-5}$. This is not in contradiction to (7).

It should be noted that $\sigma_\phi = 15\ \mu b$[11] used above (or measured in (4), using SU(3) and the ω-ϕ mixing hypothesis for obtaining B'_ϕ) is in contradiction with the peripheral model (ρ-meson exchange) prediction:

$$\sigma_\phi = f^2_{\rho\pi\phi} / f^2_{\rho\pi\omega} \times \sigma_\omega = 0.03 \times \Gamma(\phi \to \rho + \pi) / \Gamma(\omega \to \rho + \pi) \cdot \sigma_\omega \approx 0.19\ \mu b.$$

As far as only 5 events of the $\phi \to e^+e^-$ decays have been observed in this experiment, the possibility of this event simulation is of the greatest importance. We analyze two sources of such simulation. The first is due to the e^+e^--decays of the ρ-meson, having the broad mass distribution. The probability of smaller than 0.1% has been obtained in this case, using the p-wave Breit-Wigner distribution. The second is due to the fluctuations of the background average level. The probability of such a simulation does not exceed 0.1%.

The authors are gratefull to many people who generously contributed to this experiment particularly to the synchrotron staff for excellent accelerator operation during the experiment. We wish to express our thanks to L.B. Golovanov for designing the hydrogen

target, to G.I. Kopylov for preparing the Monte-Carlo calculations and to all people who participated in very usefull discussions.

References

1. R.A. Zdanis, L. Madansky, R.W. Kraemer, S. Hertzbuch and R. Strand. Phys.Rev.Letters, 14, 721 (1965).
2. D.M. Binnie, A. Duane, M.R. Jane, W.G. Jones, D.C. Mason A. Newth, D.C. Potter, IJAZ UR Rahman, J. Walters, B. Dickinson, R.J. Ellison, A.E. Harekham, M. Ibbotson, R. Marshall, R.F. Templeman, A.J. Wynroe. Phys.Letters, 18, 348 (1965).
3. M.N. Khachaturyan, M.A. Azimov, A.M. Baldin, A.S. Belousov, I.V. Chuvilo, R. Firkowski, J, Hladky, M.S. Khvastunov, J. Manca, A.T. Matyushin, V.T. Matyushin, G.A. Ososkov, L.N. Shtarkov, L.I. Zhuravleva. Phys. Letters, 24B, 349 (1967).
4. A. Wehmann, F. Engels, Jr.L.N. Hand, C.M. Hoffman, P.G. Innocenti, Richard Wilson, W.A. Blanpied, D.J. Drickey and O.C.Stairs. Phys.Rev.Letters, 17, 1113 (1966).
5. J.E. Auqustein, J.C. Bizot, J. Buon, J. Haissinski, D. Lalanne, P.C. Marin, J. Perez-y-Jorba, F.Rumpf, E. Silva, S.Taverier Preprint Orsay LAL. 1181 (1967).
6. V.L. Auslander, G.I. Budker, Ju.N. Pestov, V.A. Sidorov, A.N. Skrinsky and A.G. Khabakhpashev.Phys.Letters, 25B, 433 (1967).
7. G. Lütjens, U. Stierlin, P. Weilhammer, B.D.Hyams, W. Koch, D. Pellett, D. Potter, L. von Lindern. Preprint CERN 67/6415.
8. J.K. de Pagter, J.I. Friedman, G. Glass, R.C. Chase, M. Gettner, E. von Coeler, Roy Weinstein, and A.M. Boyarski. Phys.Rev.Letters, 16, 35 (1966)
   R.C. Chase, P. Rothwell and Roy Weinstein. Phys.Rev.Letters, 18, 710 (1967).
9. J.G. Asbury, U.Becker, W.K. Bertram, P. Joos, M. Rohde, and A.J.S. Smith, C.L. Jordan and Samuel C.C. Ting. Phys.Rev.Letters, 19, 869 (1967).
10. ABBBHLM Collaboration. Nuovo Cimento, 31, 720 (1964).
11. R.I. Hess, O.I. Dahl, L.M. Hardy, J. Kirz, and D.H. Miller, Phys.Rev.Letters, 17, 1109 (1966).
12. S.C.C. Ting. A Report to the 1967 International Simposium on Electron and Photon Interactions at High Energies, Stanford University.

13. H.O. Cohn, W.U. Bugg, A.T. Condo. Phys.Lett., 15, 344 (1965).
14. A.H. Rosenfeld, N. Barash-Schmidt, A. Barbaro-Galtieri, W.J. Podolski, L.R. Price, M. Roos, P. Söding, W.J. Willis, and C.A. Wohl. Data on Particles and Resonant States, UCRL-8030, September 1967.

Received by Publishing Department
on March 18, 1968.

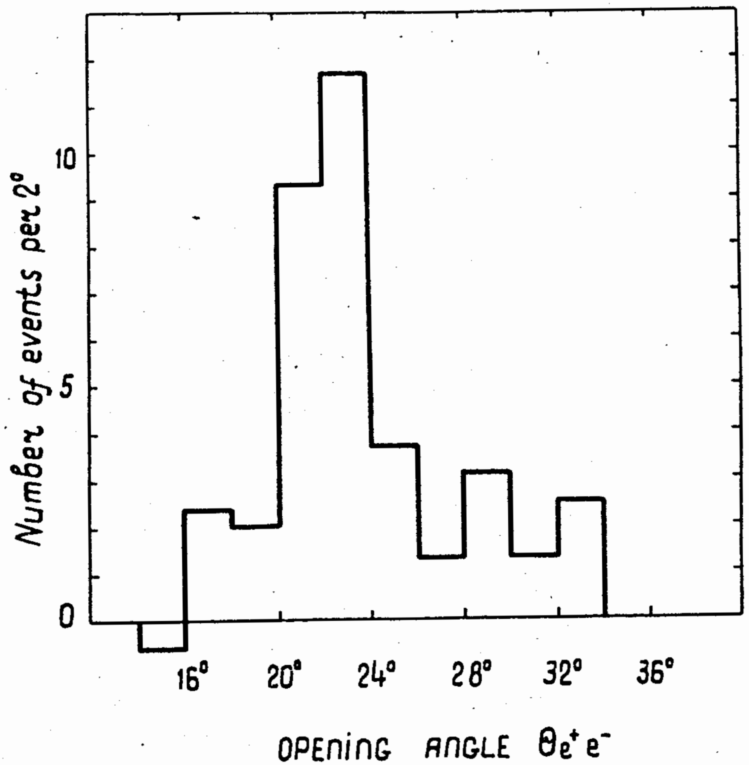

Fig. 1. Opening angle distribution for e^+e^- events after background subtraction.

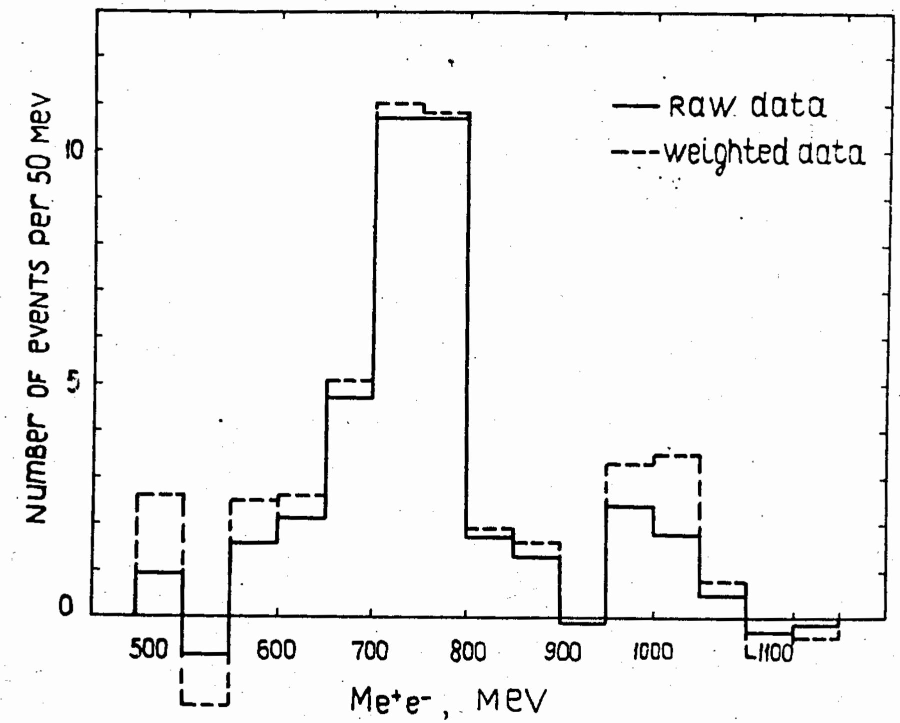

Fig. 2. Effective mass distribution for e^+e^- events after background subtraction. The solid line represents the measured events. The dotted line shows the events weighted on the registration efficiency.