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Observation of a Broad Peak in the Production of Four Charged Pions by e+e- Collisions around 1.6 GeV.

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(ricevuto il 27 Dicembre 1971)

Preliminary evidence for multihadron production by e+e- collisions in the GeV region was reported at the 1970 Kiev Conference [1]. These results were confirmed by the subsequent experimentation [2] and estimates of the cross-sections of the different reactions involved were recently reported at the Cornell Conference [3,4]. We present

[1] G. Barbiellini, M. Conversi, M. Grilli, A. Mulachié, M. Nigro, L. Paoluzi, P. Spillantini, R. Visentin and G. T. Zorn: Frascati report LNF-70/38 (1970); B. Bartoli, B. Coluzzi, F. Felicetti, G. Goggi, G. Marini, F. Massa, D. Scannicchio, V. Silvestrini and F. Vanoli: *Nuovo Cimento*, **70 A**, 615 (1970); V. E. Balakin, G. I. Budker, I. B. Vasserman, O. S. Koifman, L. M. Kurdadge, S. I. Mismnev, A. P. Onnuchin, S. I. Seredryakov, V. A. Sidorov, A. N. Skrinsky, G. M. Tumaikin, V. F. Turkin, A. G. Khabakhpashev and J. M. Smatunov: Novosibirsk report 62/70 (1970); see also the Rapporteur talk by R. Wilson: in the *Proceedings of the International Conference on High-Energy Physics* (Kiev, 1970).

[2] See invited talk by μπ group in the *Proceedings of the International Conference of E.P.S. on Meson Resonances and Related Electromagnetic Phenomena* (Bologna, 1971).

[3] B. Borgia, M. Conversi, M. Grilli, E. Iarocci, M. Nigro, L. Paoluzi, P. Spillantini, L. Trasatti, V. Valente, R. Visentin and G. T. Zorn: Frascati report LNF-71/62 (1971).

[4] C. Bacci, R. Baldini-Celio, G. Capon, C. Mencuccini, G. P. Murtas, G. Penso, A. Reale, G. Salvini, M. Spinetti and B. Stella: *International Symposium on Electron and Photon Interactions at High Energies, Cornell, 1971,* unpublished; B. Bartoli, F. Felicetti, H. Ogren, V. Silvestrini, G. Marini, A Nigro, N. Spinelli and F. Vanoli: *Phys. Lett.,* **36** B, 598 (1971); see also the Rapporteur talk by C. Bernardini: in the *Proceedings of the International Symposium on Electron and Photon Interaction at High Energies, Cornell, 1971,* unpublished.

in this letter results based on the first observed events of the specific reaction

$$ \text{(1)} \qquad\qquad e^+e^- = \pi^+\pi^-\pi^+\pi^- \, , $$

which is of particular physical interest. It can be used, in fact, i) to test the relevance, at Adone's energies, of the quasi–two-body processes (such as $e^+e^- = A_1^{\pm}\pi^{\mp}$, $\rho^0 f^0$, $\rho^0 \varepsilon^0$ ...) suggested by various authors on theoretical ground [5-8]; ii) to obtain information on the possible existence—in an extended version of the vector dominance model—of a heavier ρ-meson (ρ', with quantum numbers $J^P = 1^-$; $I^G = 1^+$). It will be shown that the cross-section of process (1) as a function of the total energy of the colliding beams ($2E = E_+ + E_-$) has a behaviour which can be taken as a preliminary evidence for the existence of a ρ'-meson of mass ~ 1600 MeV.

Events showing 4 charged particles in the spark chambers of our apparatus [9] were reconstructed kinematically starting from the measured angles and assuming that all observed particles are pions. This assumption has been shown to be valid within limits discussed elsewhere [2,3]. Events due to process (1) were taken out of the reconstructed 4-track events which satisfied energy-momentum balance after application of the corresponding conservation equations. The reconstruction procedure was previously tested with 4-track Monte Carlo generated events. The result of this test was that all the events coming from a $\pi^+\pi^-\pi^+\pi^-$ state were correctly reconstructed; on the other hand, about 30% of the events with more than four charged pions do simulate accidentally a four charged-pion event.

The results of our measurements and analysis are reported in Table I. For each of the six values of the total energy $2E$, listed in column 1), we have reported in the Table the time-integrated luminosity [9] (column 2)); the total number of detected 4-track events (column 3)); the number of 4-track events which satisfy the energy-momentum balance, corrected for the accidental reconstruction mentioned above («identified events», column 4)). The detection efficiencies of the apparatus (column 5)) have been derived from a phase-space Monte Carlo calculation. It should be pointed out, however, that both the absolute value and the energy dependence of the cross-section do not undergo any substantial charge, if a nonstatistical mechanism (such as the production of an intermediate $A_1^{\pm}\pi^{\mp}$ state) is assumed in the calculation.

The resulting cross-sections are also shown in Fig. 1 as a function of the beam total energy. For the sake of completeness also data from other experiments are reported in the Figure. No events has been observed at ACO, so that the point at $2E = 990$ MeV is an upper limit [10]. The « Boson Group » at Adone [11], through an overall fit of their data (mostly belonging to events with two charged noncoplanar particles), gives the values of the cross-section of process (1) shown in the same Figure.

[5] G. KRAMER, J. L. URETSKY and T. F. WALSH: *Phys. Rev.*, **3**, 719 (1971).
[6] M. T. VAUGHN and P. J. POLITO: *Lett. Nuovo Cimento*, **4**, 74 (1971).
[7] J. LAYSSAC and F. M. RENARD: *Lett. Nuovo Cimento*, **4**, 197 (1971).
[8] A. M. ALTUKOV and I. B. KHRIPLOVICH: Novosibirsk report 36/71 (1971).
[9] For a short description of the apparatus employed in this experiment see, *eg.*, G. BARBIELLINI, B. BORGIA, F. CERADINI, M. CONVERSI, M. GRILLI, A. MULACHIÉ, L. PAOLUZI, W. SCANDALE, P. SPILLANTINI and R. VISENTIN: *Phys. Lett.*, **35** B, 340 (1971). In addition, to the main apparatus used to detect events at wide angle (shown in Fig. 1 in this reference) a monitor system was also installed, at the same straight section of Adone, to measure countinuously the machine luminosity via small angle e^+e^- scattering.
[10] J. LEFRANCOIS: Rapporteur talk in the *Proceedings of the International Symposium on Electron and Photon Interaction at High Energies, Cornell, 1971*, unpublished.
[11] B. BERTOLI, F. FELICETTI, H. OGREN, V. SLVESTRINI, G. MARINI, A. NIGRO, N. SPINELLI and F. VANOLI: Frascati report LNF-71/91 (1971), to be published.

TABLE I. – *Results of measurements on the reaction* $e^+e^- = \pi^+\pi^-\pi^+\pi^-$.

Total energy	Time-integrated luminosity	Total number of 4-track events	Identified 4-charged pions events	Detection efficiency (^{a})	Cross section (nb) (^{b})
1)	2)	3)	4)	5)	6)
1.200	$\sim 5\cdot10^{33}$	0	0	3.2%	5 ± 4 (^{c})
1.500	$23.8\cdot10^{33}$	14	11	2.2	21 ± 6
1.650	$19.5\cdot10^{33}$	8	6	1.1	28 ± 12
1.875	$43.5\cdot10^{33}$	10	5	2.3	5 ± 3
2.100	$163.0\cdot10^{33}$	39	6	2.3	1.6 ± 0.7
2.400	$49.7\cdot10^{33}$	13	1	1.5	< 4

(a) The values of the efficiencies correspond to different trigger conditions and cannot be directly compared.

(b) The quoted errors are only statistical.

(c) This value has been calculated in the hypothesis that the two « 3-track » events detected at this energy, come from the $\pi^+\pi^-\pi^+\pi^-$ channel. The detection efficiency for this configuration is about 9 %.

The experimental values of the cross-section obtained at 1.5 GeV and 1.65 GeV are considerably larger than those predicted (^{5,7}) assuming that the $\pi^+\pi^-\pi^+\pi^-$ production arises from the ρ^0-resonance tail contribution. Also the energy dependence of the observed cross-section does not agree with that calculated in ref. (^{7}). Both findings can be interpreted assuming the existence of a ρ'-meson of mass $M_{\rho'} \simeq 1600$ MeV. Such
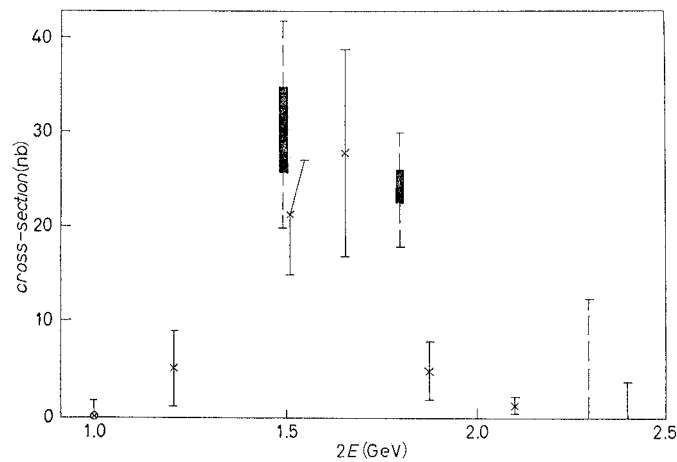

Fig. 1. – Experimental cross-section of the process $e^+e^- = \pi^+\pi^-\pi^+\pi^-$ *vs.* the total energy ($2E$). In addition to the results of this experiment, also the values determined by the Adone « Boson Group » through an overall fit of their data (^{11}) and the ACO result at 990 MeV (^{10}) are reported. The quoted errors are only statistical for the present experiment. For the Boson group's points the boxes represent the systematic uncertainty and the bars the statistical errors. The point at $2E = 2.4$ GeV is an upper limit (see Table I): ⊗ ACO, ■ Boson group, × this experiment.

an interpretation is consistent with that recently presented by DAVIER *et al.* [12] in their analysis of the process $\gamma p = p\pi^+\pi^-\pi^+\pi^-$ ($E_\gamma = 6 - 18$ GeV).

Other possible interpretations of our results will be discussed in a subsequent paper. The interpretation in terms of the ρ' meson is discussed in detail in the following letter [13].

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[12] M. DAVIER, I. DERADO, D. C. FRIES, F. F. LIU, R. F. MOZLEY, A. C. ODIAN, J. PARK, W. P. SWANSON, F. VILLA and D. YOUNT: SLAC preprint (June 30, 1971).
[13] A. BRAMON and M. GRECO: *The reaction* $e^+e^- = \pi^+\pi^-\pi^+\pi^-$ *and the* ρ' *meson* (following paper).