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B. Sechi-Zorn and G. T. Zorn: EVIDENCE FOR THE EXISTENCE  
OF A NEW VECTOR MESON OF MASS 1.82 GeV OBSERVED IN  
 $e^+e^-$  ANNIHILATION AT ADONE. -

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ABSTRACT. -

Evidence is presented for the occurrence in  $e^+e^-$  annihilation of a new vector meson of mass  $1821 \pm 16$  MeV and  $\Gamma = 31 \pm 15$  MeV.

Experimental results are reported on an enhancement in the total cross section in  $e^+e^-$  collisions:

$$e^+e^- \rightarrow n \text{ hadrons} \quad (n > 2) \quad (1)$$

at a total energy  $W = 1.82$  GeV. These results were obtained at the  $e^+e^-$  colliding beam machine Adone with the magnetic detector MEA. This research is part of a general program of study of the reaction (1) in the total energy range  $W = 1.5 - 3.1$  GeV.

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2.

A sectional view of the MEA detector is shown in Fig. 1. It has been described in detail in Ref. (1), (2). Briefly it consists of a system of narrow-gap and cylindrical wide-gap optical spark chambers ( $C_1, C'_1, C_2, C'_2$ ) operated in a solenoidal magnetic field trasverse to the  $e^+e^-$  beams. Cylindrical spark chambers external to the magnetic coil ( $C_3, C'_3$ ) were interleaved with lead and iron plates for particle identification and photon conversion. This system is triggered by scintillation counters ( $S_1, S_2, S_3, S_4$ ) and multiwire proportional chambers (MWPC). The trigger requires the coincidence of two charged particles in opposite

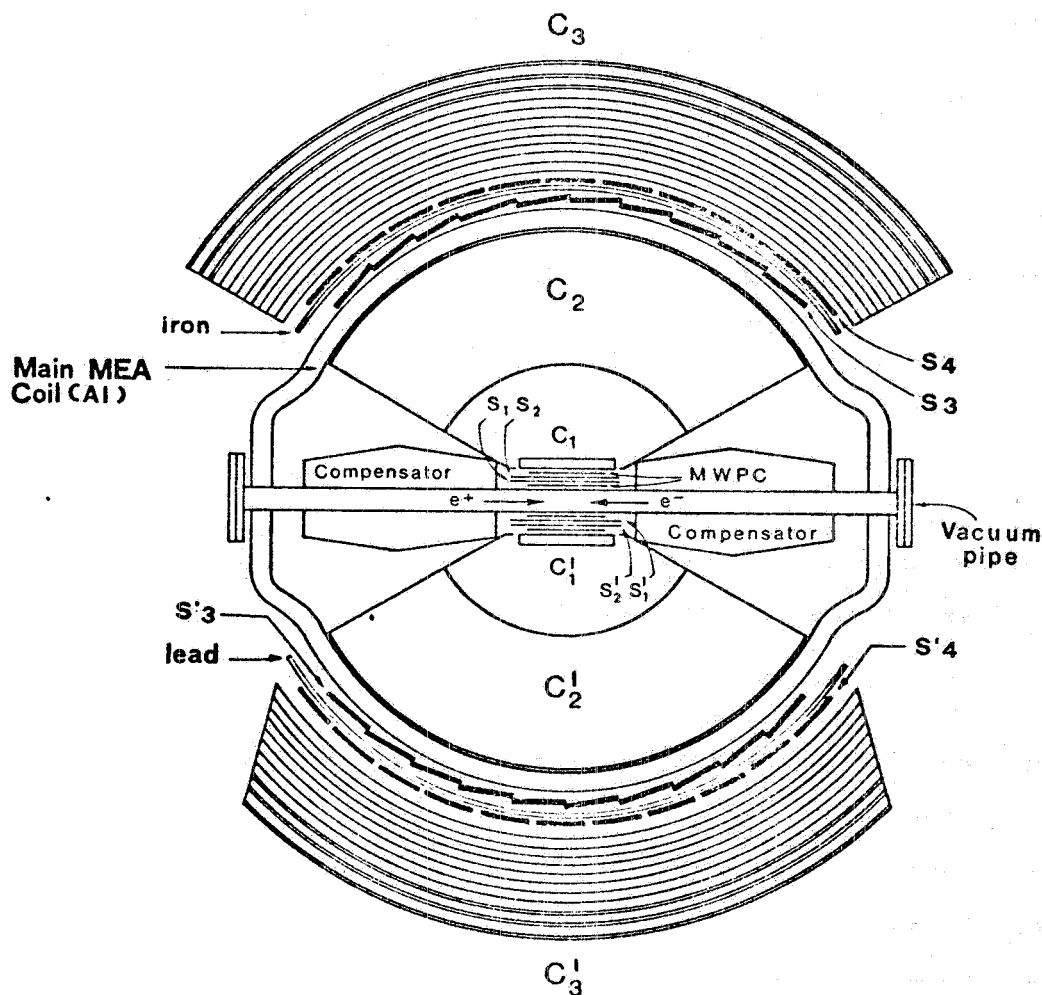


FIG. 1 - Vertical section of the experimental apparatus, MEA.  $C_1, C'_1$  are narrow-gap spark chambers;  $C_2, C'_2$  are wide-gap cylindrical spark chambers for momentum analysis;  $C_3, C'_3$  are thick-plate spark chambers for particle identification. MWPC are multiwire proportional chambers;  $S_1, \dots, S_4$  are scintillation counters.

halves of the apparatus. Penetration out to  $S_4$  and  $S_4'$  also is required, thus setting the minimum trigger energy for pions of  $\sim 130$  MeV and for kaons of  $\sim 190$  MeV.

Large-angle Bhabha scattering events, collected simultaneously during the runs, were used to measure the luminosity and to monitor the efficiency of the apparatus. Machine luminosity also was determined with small-angle Bhabha scattering ( $3^\circ < \theta < 6^\circ$ ) but at a different intersection region of the ring. The two determinations agree to within 10%.

In the analysis of the multihadron processes reported here, we have restricted our event selection to those with at least three charged tracks with or without photons, i. e.  $3c+n\gamma$ ,  $4c+n\gamma$ , . . . ., where  $n \geq 0$ . The tracks of selected events also were required to come from the direction of the  $e^+e^-$  interaction region within  $\sim 1$  cm as measured by the MWPC's. In this sample, background contamination from cosmic rays and from beam-gas interaction was found to be negligible.

A summary of data between 1.6 and 2.1 GeV is shown in Fig. 2. Here the numbers of events with at least three charged tracks ( $N_{\geq 3c+n\gamma}$ ),

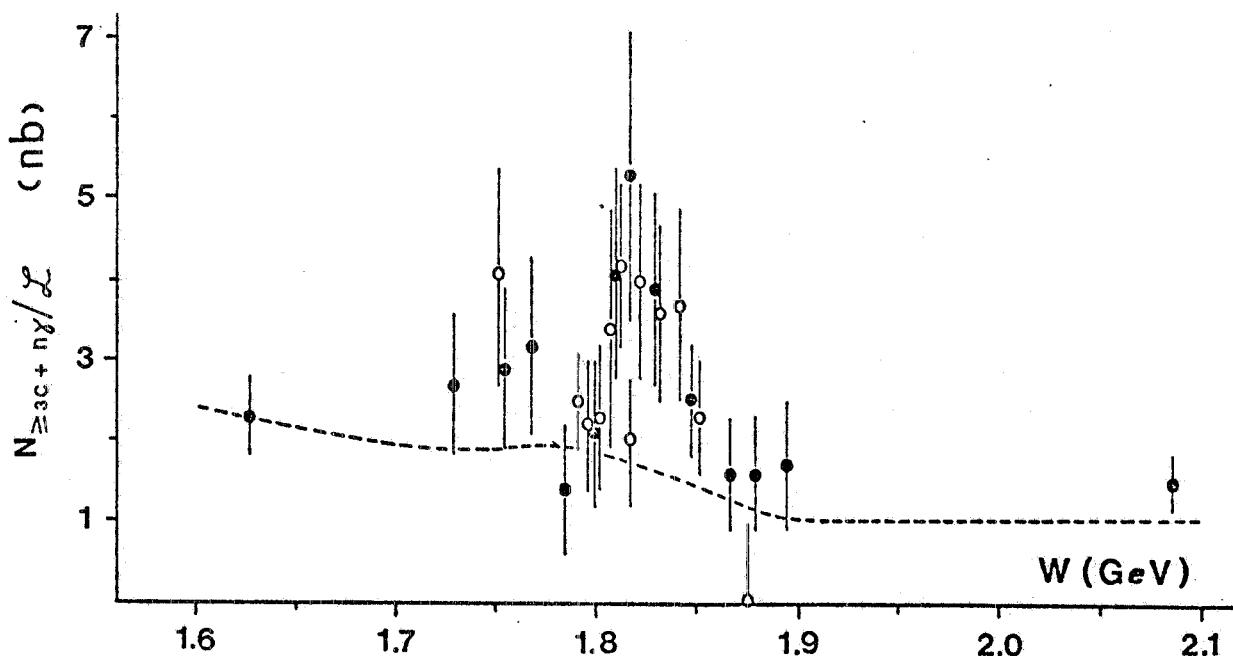


FIG. 2 - Number of events with at least 3 charged tracks ( $N_{\geq 3c+n\gamma}$ ) divided by the integrated luminosity,  $\mathcal{L}$ , plotted as a function of total  $e^+e^-$  energy,  $W$ ; Sept. -Oct. 1976 data -  $\bullet$ , Feb. -April 1977 data -  $\circ$ . Curve is Monte Carlo prediction of rate (see text).

4.

normalized to the same luminosity at each energy, are plotted. In this plot the data from two runs at Adone (Sept. -Oct. 1976 and Feb. -April 1977) are shown separately. Within statistical errors, the results are seen to agree. Both runs show a clear resonant structure centered at  $W \sim 1.82$  GeV. The events of these runs were combined and the overall results are summarized in Table I as a function of total energy. Also presented are the associated luminosities, and the number of events per

**TABLE I** - Summary of number of events observed at various energies and associated luminosities.

W (GeV)	$\mathcal{L}$ (nb <sup>-1</sup> )	MULTIHADRON EVENTS			$N_{\geq 3c+n\gamma}/\mathcal{L}$ (nb)
		$N_{3c+n\gamma}$	$N_{\geq 4c+n\gamma}$	$N_{\geq 3c+n\gamma}$	
1	2	3	4	5	6
1.625	9.13	17	4	21	$2.3 \pm 0.5$
1.728	3.30	8	1	9	$2.7 \pm 0.9$
1.750	5.25	16	2	18	$3.4 \pm 0.8$
1.767	2.81	8	1	9	$3.2 \pm 1.1$
1.783	2.11	2	1	3	$1.4 \pm 0.8$
1.790	6.03	11	4	15	$2.5 \pm 0.6$
1.795	3.57	8	0	8	$2.2 \pm 0.8$
1.799	5.47	12	0	12	$2.2 \pm 0.6$
1.806	3.90	13	2	15	$3.8 \pm 1.0$
1.810	3.77	12	4	16	$4.2 \pm 1.0$
1.815	4.65	10	5	15	$3.2 \pm 0.8$
1.820	2.97	10	2	12	$4.0 \pm 1.2$
1.829	5.66	15	6	21	$3.7 \pm 0.8$
1.840	4.76	8	5	13	$2.7 \pm 0.8$
1.850	7.58	14	6	20	$2.6 \pm 0.6$
1.865	3.19	4	1	5	$1.6 \pm 0.7$
1.877	5.05	3	3	6	$1.2 \pm 0.5$
1.893	2.85	4	1	5	$1.7 \pm 0.8$
2.085	19.04	21	8	29	$1.5 \pm 0.3$
Totals:	101.09	196	56	252	

unit luminosity. Similar results are also given in this Table for events with at least four charged tracks ( $N_{\geq 4c+n\gamma}$ ), which also show a resonant like structure but with less statistical significance.

The detection efficiencies of our apparatus for some typical reactions, as obtained by Montecarlo calculations, are given in Table II, for three total energies  $W = 1.6, 1.8$  and  $2.0$  GeV. The quoted efficiencies

TABLE II - Montecarlo detection efficiencies (in %) at  $W = 1.6, 1.8$  and  $2.0$  GeV.

FINAL STATE	1.6 (GeV)	1.8 (GeV)	2.0 (GeV)
$2\pi^+ 2\pi^-$	8.3	7.8	7.3
$2\pi^+ 2\pi^- \pi^0$	4.1	4.6	5.2
$2\pi^+ 2\pi^- 2\pi^0$	1.6	2.7	3.8
$3\pi^+ 3\pi^-$	3.1	6.0	8.8

refer to those processes which, at present, seem to give the dominant contribution in the production of final states with more than two charged particles. The curve shown in Fig. 2 is based on previous results from Adone<sup>(3, 4, 5)</sup> and from the DCI<sup>(6)</sup> and represents the expected rate of MEA events with at least three charged tracks produced by the reactions:

$$e^+e^- \rightarrow 3\pi^+ 3\pi^- , \quad (2)$$

$$e^+e^- \rightarrow \rho^+(1550) \rightarrow 2\pi^+ 2\pi^- , \quad (3)$$

$$e^+e^- \rightarrow X(1780) \rightarrow 2\pi^+ 2\pi^- \pi^0 . \quad (4)$$

Concerning these Montecarlo predictions it should be emphasized that invariant phase space was assumed for all processes, and does not include final state correlation effects. Also the experimental situation regarding the  $\rho^+(1550)$  is not completely settled. In spite of these uncer

tainties, the predictions seem to be in good agreement with the data outside the energy interval 1.80 - 1.85 GeV. It is important to note that the data are not inconsistent with the existence of the resonance at 1.778 MeV<sup>(6)</sup>; however, because of limited statistics and poor low-energy photon detection efficiency, they cannot be used to confirm its existence.

A model independent test of the significance of the observed effect can be obtained by fitting the data with a straight line. The confidence level obtained for this fit is very low ( $\chi^2/\text{d.f.} = 25/17$ ). A best fit straight line through the data points but excluding the 1.80 - 1.85 GeV region was made and is shown as a dashed line in Fig. 3, along with the data as given in Table I. A much better fit is realized ( $\chi^2/\text{d.f.} = 8/10$ )

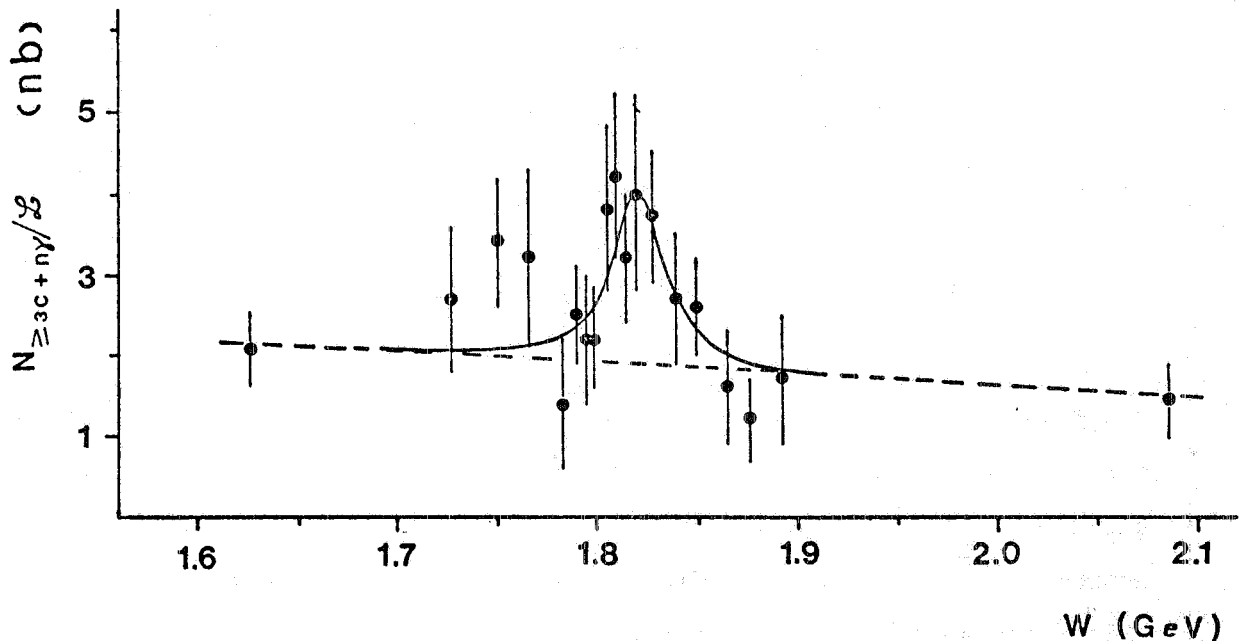


FIG. 3 - Number of events with at least 3 charged tracks ( $N_{\ge 3c+n\gamma}$ ) divided by the integrated luminosity,  $\mathcal{L}$ , plotted as a function of total  $e^+e^-$  energy,  $W$ ; ——— fit of data to straight line + Breit-Wigner; ----- straight-line fit excluding data between 1.801 - 1.850 GeV.

and it is seen to be in fair agreement with the Montecarlo predictions shown in Fig. 2. The number of events observed between 1.80 and 1.85 GeV, 112, is significantly above the expected background level of 66 events and represents an enhancement of 6 standard deviations above background. These results are suggestive of a genuine resonant effect at  $W \sim 1.82$  GeV.

To estimate the parameter of the resonance, a fit of the data to a simple Breit-Wigner plus a linear background was used ( $\chi^2/\text{d.f.} = 10/14$ ). The resulting resonance mass and width are  $1.821 \pm 0.016$  ( $\pm 0.002$ ) GeV and  $\Gamma = 31 \pm 15$  ( $\pm 10$ ) MeV. The error in the mass shown in parenthesis, represents the uncertainty in the calibration of beam energies at Adone and the error in  $\Gamma$  shown in parenthesis, reflects the uncertainty in the evaluation of the background. The estimated resonant contribution to the observed event rate is  $2.1 \pm 1.0$  ( $\pm 0.5$ ) events/nb. At the present time it is not possible to extract from our data the corresponding resonant cross section. The large corrections that are necessary, due to the small solid-angle coverage of our apparatus, require more detailed studies which will be reported at a later date.

As far as the nature of this resonance is concerned, it is natural to interpret it as an excited state of one of the known vector mesons,  $\rho$ ,  $\omega$ , or  $\phi$ . The total width of  $\Gamma \sim 30$  MeV however is small relative to  $\Gamma_{\rho(1550)}$ <sup>(4)</sup> and  $\Gamma_{X(1778)}$ <sup>(6)</sup> (\*) thus making unlikely the hypothesis that the observed resonance is a recurrence of the  $\rho$  or the  $\omega$  meson. Furthermore, theoretical models based on extended vector meson dominance<sup>(7)</sup> predict recurrences of the  $\phi$  at  $\sim 1.5, 1.8$  and  $2.1$  GeV. Thus it is speculated that the enhancement at  $\sim 1.82$  GeV reported here is an excited state of the  $\phi$ .

There exists also some additional data from the MEA group at Adone which would tend to reinforce this last conjecture. Here preliminary evidence for resonant  $K^*(892)$  production at  $\sim 2.1$  GeV (with  $\Gamma \lesssim 50$  MeV) has been obtained<sup>(8)</sup>.

We would like to express our appreciation to the staff of Adone for the efficient operation of the machine. It is also a pleasure to thank Prof. M. Greco and Dr. V. Valente for many helpful and stimulating discussions on the analysis and interpretation of the data.

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(\*) We are assuming that this new resonance be of the  $\omega$ -family as suggested by the authors of Ref. (6).



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