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e^+e^- ANNIHILATION INTO TWO HADRONS IN THE ENERGY INTERVAL 1400–2400 MeV

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The proof is given for the existence of the reaction $e^+e^- \to h^\pm h^\mp$ in the energy range 1400–2400 MeV, and its energy dependence is compared with that of $e^+e^- \to e^\pm e^\mp$, in the same experimental conditions of observation. The exponent of the s-dependence of the ratio $\alpha = (e^+e^- \to h^\pm h^\mp)/(e^+e^- \to e^\pm e^\mp)$ is measured to be $n = 2.08 \pm 0.45$, in the s-range (1.96 - 5.76) GeV^2, on the basis of 51 $e^+e^- \to h^\pm h^\mp$ events and 8918 $e^+e^- \to e^\pm e^\mp$ events observed.

Since our first experimental observation [1] that the reaction

$$e^+ + e^- \to h^\pm + h^\mp \qquad (1)$$

(where $h^\pm$ stands for $\pi^\pm$ and $K^\pm$) occurs with a rate comparable with that expected for a point-like coupling of the $h^\pm$ with the photon, in the time-like range ($1.96 \leqslant s \leqslant 5.76$) GeV^2, other preliminary results have been reported [2], in agreement with our findings.

The purpose of this letter is to report on the proof of the existence of reaction (1) and to give its energy dependence.

The experiment was performed at Frascati, using the e^+e^- storage ring ADONE. The experimental apparatus was constructed from four identical telescopes, mounted two on each side of the colliding beam axis, and covering a total range of azimuthal and polar angles of $\Delta\phi = 120°$ and $45° \leqslant \theta \leqslant 135°$, respectively. Each telescope consisted essentially of a system of thin-foil sparkchambers used for precise geometrical reconstruction, and of a system of heavy-plate spark-chambers for particle identification: electrons make showers, muons show only Coulomb scattering, while hadrons show all of the typical strong interaction patterns. This visual spark-chamber complex was coupled with a system of plastic scintillation counters, whose function was to provide "fast" information (for example, accurate time of flight, particle and pulse-height) which was recorded as well as being used in the electronic trigger. More details of the experiment set-up are given elsewhere [3]. The various ADONE energies, at which the data were recorded are given in table 1.

In order to establish the existence of reaction (1), two points are of vital importance.

The first is to establish the "hadronic" nature [6] of the final state in reaction (1). This identification was done using calibration data obtained at CERN in separate runs where known beams of π, μ and e, entered a telescope identical to the four which were used in the actual experiment. These calibration data were taken at various particle momenta: from a few hundred MeV/c up to 1000 MeV/c for electrons, muons and pions*. The calibrations with low electron momenta were particularly relevant because possible sources of hadron simulation are those ($e^\pm e^\mp$) events which have a large radiative emission, as expected from a theoretical calculation of radiative effects [4,7]. As well as these calibrations, a cross-check was made using "internal" calibration data to identify typical electron, muon and pion patterns [6]. From these calibrations, we estimate that the selected sample of had-

*The exact figures are: (170 - 1000) MeV/c for electrons; (250 - 1000) MeV/c for muons; (270 - 1000) MeV/c for pions.

Table 1
Summary of measurements and results

E (MeV)	s (GeV^2)	$N(e^{\pm}e^{\mp})$		$N(h^{\pm}h^{\mp})$		$\sigma(e^+e^- \to h^{\pm}h^{\mp})$ (10^{-33} cm^2)
700	1.96	582		10		9.6 ± 3.1
750	2.25	977		9		4.4 ± 1.5
950	3.61	1900		13		1.8 ± 0.5
970	3.76	668		4		1.5 ± 0.8
1050	4.41	2488		6		0.5 ± 0.2
1200	5.76	684		–		< 0.2
800	2.56	215		2		
825	2.72	233	623	1	3	1.55 ± 0.9
850	2.89	175		0		
875	3.06	204		1		
900	3.24	128	545	0	3	1.43 ± 0.8
925	3.42	213		2		
950	3.61	194	451	0	3	1.4 ± 0.8
1000	4.00	257		3		

The data listed in the second part of this table were taken at low luminosity, using an apparatus designed to work with a point-like interaction region, soon after the beginning of ADONE operation. These data are not included in the R and ϕ distributions (Figs. 1,2,3) because of the different experimental acceptances between the old and the new apparatus. However, after correction for these effects, they have been included in the s- dependence of α (fig.4).
E= energy of one ADONE beam; $s=(2E)^2$; $N(e^+e^-)$ = the number of observed $(e^{\pm}e^{\mp})$ pairs with $R \leqslant 10^{\circ}$; $N(h^{\pm}h^{\mp})$ = The number of observed (h^+h^-) pairs with $R \leqslant 7.5^{\circ}$. The effect of the radiative corrections due to the R-cuts on the s-dependence of α has been calculated and is negligible.

ronic events has a contamination from leptonic channels of less than one event. Other sources of background which have been studied are: i) beam-gas interactions; ii) cosmic rays. Their effect was found to be less than 10^{-2} of our sample of hadronic events.* Thus the probability that the events reported here are not π's or K's, produced in beam-beam interactions, is negligible.

The second vital problem is to prove that a pair of $(h^{\pm}h^{\mp})$ is a genuine two-body final state. This proof comes from the geometrical correlation of the observed tracks in the kinematic spark-chambers, since no magnetic field was available for momentum analysis and the rough energy limits defined by the surface density of the telescopes were inadequate to establish

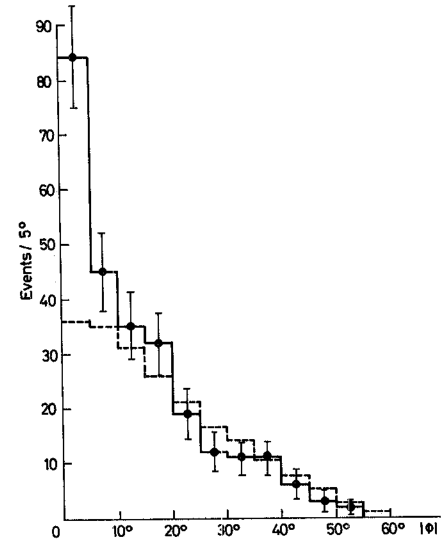

Fig. 1. The acoplanarity distribution of the 260 $(h^{\pm}h^{\mp})$ events observed. The dotted histogram is the expected shape of the $|\phi|$ distribution from multi-pion production reaction (2), normalized to the total number of $(h^{\pm}h^{\mp})$ events observed with $|\phi| > 7.5^{\circ}$. The peak at $|\phi| \leqslant 7.5^{\circ}$ is the proof for the existence of the coplanar events.

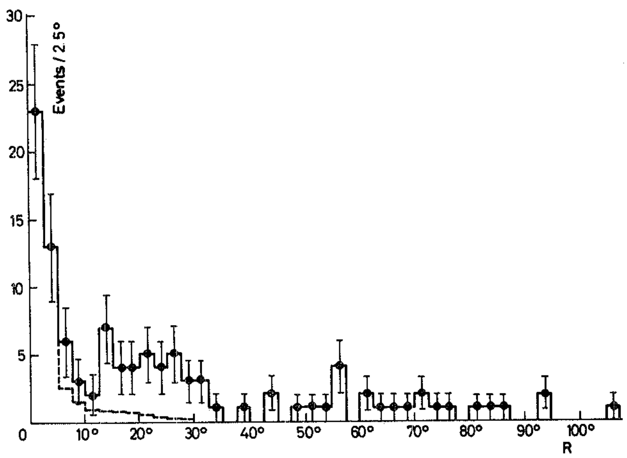

Fig.2. R-distribution for the $(h^{\pm}h^{\mp})$ pairs with $|\phi| \leqslant 7.5^{\circ}$. The dotted histogram is the expectation from first-order radiative corrections. The peak at $R \leqslant 7.5^{\circ}$ is the proof for the existence of collinear events.

the "two-body" character of an $(h^{\pm}h^{\mp})$ pair. A two-body event could in fact be simulated by the reaction

$$e^+ + e^- \to h^{\pm} + h^{\mp} + \text{anything}, \qquad (2)$$

* A description of these background studies can be found in refs. [1,3,6].

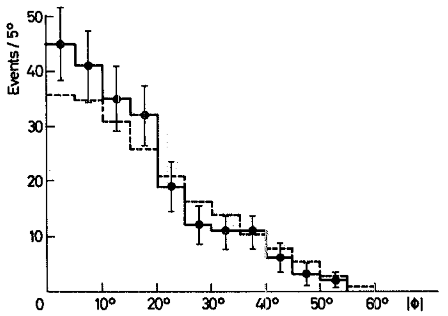

Fig. 3. $|\phi|$ distribution of the $(h^{\pm}h^{\mp})$ events with $R > 7.5°$. The dotted histogram shows Monte Carlo expectations normalized to the total number of events with $|\phi| > 7.5°$.

were "anything" escapes observation and the $(h^{\pm}h^{\mp})$ pair is collinear within the experimental angular resolution. The expected experimental resolution has been checked by studying the high statistics sample of $e^+e^- \rightarrow e^{\pm}e^{\mp}$ reactions collected during the same experiment, where the observations agree within statistical fluctuations with the expected experimental angular resolution folded into the broadening caused by radiative corrections [4,7]. In order to prove that $(h^{\pm}h^{\mp})$ pairs do belong to the "two-body" class, it is therefore necessary to reconstruct all $(h^{\pm}h^{\mp})$ pairs and to show that in the chosen "collinearity" interval the background from reaction (2) is small. This was done in two steps, as follows. Fig.1 shows the acoplanarity ϕ* distribution of all $(h^{\pm}h^{\mp})$ pairs. The dotted histogram shows the Monte-Carlo prediction for multi-body annihilation (reaction (2)), normalized to the total number of events with $|\phi| > 7.5°$. The peak at $|\phi| < 7.5°$ cannot be due to reaction (2). The second step is then to examine the events below $|\phi| = 7.5°$, to search for an excess of collinear events. Fig. 2 shows

* The acoplanarity ϕ is the angle between the two planes defined by each track and the beam axis.

** The acollinearity R is the angle between two tracks, defined in such a way that $R = 0$ corresponds to two collinear tracks.

*** As the experimental accuracy in ϕ is $(\pm 1)°$, $(h^{\pm}h^{\mp})$ pairs having $|\phi| < 7.5°$ are not from reaction (1) but from reaction (2). The losses of genuine two-hadron events produced with $|\phi| > 7.5°$ by 1st order radiative corrections, have been calculated to be negligible [4,7].

**** These are calculated assuming that all $(h^{\pm}h^{\mp})$ are $(\pi^{\pm}\pi^{\mp})$ pairs.

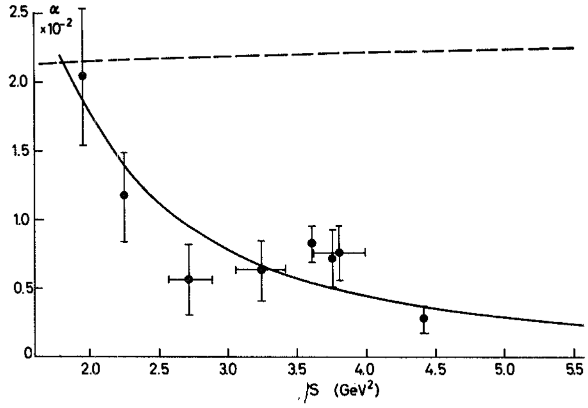

Fig. 4. The ratio α versus s is the number of $(h^{\pm}h^{\mp})$ pairs with $R \leqslant 7.5°$ divided by the number of $(e^{\pm}e^{\mp})$ pairs with $R \leqslant 10°$, observed in the same large angle telescope. The full line is the best fit. The data taken at low ADONE luminosity have been included in this graph and grouped as shown by the points with horizontal bars (see also table 1). The statistical errors in this graph correspond to the square root of the predicted number of events since for small numbers the distribution must be Poissonian. The dotted line is the theoretical expectation from point-like π-photon coupling.

the acollinearity R** distribution for all $(h^{\pm}h^{\mp})$ pairs with acoplanarity angle $|\phi| < 7.5°$***. The clear peak in the $R < 7.5°$ region is our proof of the existence of "two-body" $(h^{\pm}h^{\mp})$ pairs. The dotted line shows the R-distribution expected from first-order radiative corrections****. The tail observed cannot be explained by radiative corrections, and is in fact due to reaction (2). This is proved in fig. 3 where it is shown that the events with $R > 7.5°$ show no peaking in ϕ and that this ϕ distribution is fully accounted for by the Monte-Carlo expectation for multi-body annihilation (reaction (2)). Notice also that the expected shape of the R-distribution from multi body annihilation (not shown in fig.2 because here only the events with $|\phi| < 7.5°$ are reported) agrees with observation.

In order to derive the cross section for reaction (1) from the number of observed events, it is necessary to know:

i) the dimensions of the colliding beam region;
ii) the colliding beam luminosity;
iii) the geometrical acceptance of the apparatus;
iv) the detection efficiency for reaction (1);
v) the angular distribution of the produced final states.

The first three points were carefully studied [4] using the high rate reaction $e^+e^- \to e^\pm e^\mp$, and the fourth point was calculated on the basis of the calibration data mentioned above. The production angular distribution was taken from theoretical predictions [8], and was checked to be consistent with the observed angular distributions.

However in the ratio

$$\alpha = \frac{\text{number of } (h^\pm h^\mp) \text{ pairs}}{\text{number of } (e^\pm e^\mp) \text{ pairs}}$$

the uncertainties from the points (i), (ii) and (iii) are minimized when the $(e^\pm e^\mp)$ pairs are observed in the same angular interval and running periods as the $(h^\pm h^\mp)$ pairs.

The cross-section values for reaction (1) are given in the last column of table 1 under the hypothesis that the observed $(h^\pm h^\mp)$ pairs are $(\pi^\pm \pi^\mp)$ pairs.

The s-dependence of the ratio α, after correction for differences in acceptance and efficiency between electrons and hadrons, is shown in fig. 4. The efficiencies for the electronic trigger and for the scanning recognition of a hadron have been taken equal to that of a pion. The uncertainty introduced by this assumption is small compared with the statistical error. The overall systematic error is estimated to be ± 11%. A fit with a formula of the type

$$\alpha = a\, s^{-n}$$

where n is a free parameter and a is constrained so as to normalize the fit to the total number of events, gives $n = 2.08 \pm 0.45$, that is, the curve shown in fig. 4, where the dotted line is the value expected from point-like π-photon coupling.

A linear-pole structure of the meson-photon coupling would imply $n \approx 2$. This is supported by our experimental data in the time like region investigated.

We would like to express our gratitude to our technicians Messrs. J. Berbiers, G.F. Ferioli, W. Lelli, F. Martelli, F. Massera, G. Molinari, O. Polgrossi and V. Russo, for their skilful work at all stages of the experiment.

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