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Measurements of the e.m. Timelike Form Factors for Kaon and Pion at $\sqrt{s} = 1.5$ GeV.

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The cross-sections for e^+e^- annihilation into hadrons at centre-of-mass energies $W \leqslant 1$ GeV are explained adequately by the vector dominance model (VDM) via the production and decay of ρ, ω and φ mesons (1). The extension of these measurements to higher energies probes higher resonant states and makes further tests of theoretical models possible. In this letter, new results are reported on pion and kaon pair production in e^+e^- annihilations in the nergy range $W = \sqrt{s} = (1.45 \div 1.52)$ GeV.

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(**) Supported in part by the U.S. Department of Energy.
(1) See for example B. H. Wiik and G. Wolf: *Springer Tracts in Modern Physics*, Vol. **86** (Berlin).

Measurements of the total cross-section for the reactions

$$e^+e^- \to K^+K^- \,, \tag{1}$$

$$e^+e^- \to \pi^+\pi^- \,, \tag{2}$$

in the c.m. energy interval $W = (1.45 \div 1.52)$ GeV were made at Adone, the Frascati colliding-beam machine with the MEA magnetic detector. The integrated luminosity, $\mathscr{L}$ for these measurements was 30.7 nb^{-1}.

The MEA apparatus, described elsewhere (2), consists of a solenoid (radius 1 m, magnetic field 2 kG) with the axis perpendicular to the e^+e^- beam direction. Cylindrically-shaped wide-gap spark chambers with thin electrodes (0.15 radiation lengths) were used for momentum measurement and a system of scintillation counters was used for triggering and time-of-flight measurements (distance 1 m, $\sigma = 0.7$ ns). Outside of the coils a set of heavy-plate narrow-gap spark chambers (ESC) interleaved with lead and iron plates (8 radiation lengths, 0.8 collision lengths) were utilized for particle identification.

The initial selection of collinear events was done in a visual scan in which a rough collinearity limit of $\simeq 10^\circ$ was used. Bhabha scatterings ($e^+e^- \to e^+e^-$) were identified by requiring an associated e.m. shower in the ESC for at least one track.

Muon and hadron pair candidates ($e^+e^- \to \mu^+\mu^-$, h^+h^-) were selected by requiring tracks to originate from the interaction region and to have an event timing relative to the e^+e^- bunch collision time within 2.5 ns. A loose limit also was placed on the particle time of fligths. These events were measured and spatially reconstructed. Information on each event including track momentum, position and timing were recorded. Time-of-flight measurements for 50% of the data were amplitude and position corrected (*).

Muon pair production

$$e^+e^- \to \mu^+\mu^- \,, \tag{3}$$

was identified by requiring both tracks to have momenta < 1 GeV/c and to have traversed the ESC without a visible interaction. Rather loose limits were required to identify this reaction.

After cosmic-ray background subtraction, a total of 195 μ pair events was identified in the data sample. The shape of the distribution in the scattering angle θ was seen to follow $1 + \cos^2\theta$. These events were used to set the geometrical acceptance of the apparatus and the angular and momentum selection criteria for hadron pair events. The fiducial volume so selected resulted in $\Delta\Omega = 0.17 \times 4\pi$ (source length $\sigma = \pm 11$ cm) within which the efficiency of ESC system was demostrably high. The momentum measurement accuracy, as deduced from the muon track momentum distribution, was $\Delta p/p = \pm 0.07p$ (p in GeV/c). The μ-pair sample also was used to determine the effective luminosity.

Candidates for processes (1) and (2) were identified by requiring two nonshowering charged particles, coplanar with the beams to within $|\Delta\varphi| \leqslant \pm 8^\circ$ and collinear to within $|\Delta\theta| \leqslant 5^\circ$. It was further required that the difference between the intersection points along the beam line for the two tracks of each event, be less than 6 mm.

(2) W. W. ASH, D. C. CHENG, B. ESPOSITO, F. FELICETTI, A. MARINI, H. OGREN, I. PERUZZI, M. PICCOLO, F. RONGA, G. SACERDOTI, L. TRASATTI, G. T. ZORN, B. BARTOLI, B. COLUZZI, A.NIGRO, V. SILVESTRINI, F. VANOLI, D. BISELLO, A. MULACHIÈ, M. NIGRO, L. PESCARA, R. SANTANGELO, E.SCHIAVUTA, D. SCANNICCHIO, P. MONACELLI, L. PAOLUZI, G. PIANO-MORTARI and F. SEBASTIANI: *Nucl. Instr. Meth.*, **148**, 431 (1978).

(*) Technical problems prevented this correction from being applied to all the data.

Hadron pair candidates also were required to fulfill the following conditions:

a) correct time of flight for pions and kaons to witnin 2σ;

b) for K^-K^+ candidates, proper particle range or visible nuclear interaction occurring in the ESC for both tracks;

c) for $\pi^+\pi^-$ candidates at least one track associated with a nuclear interaction in the ESC system.

Events of reaction (1) also were accepted if one of the kaons decayed in the wide-gap chambers and the other satisfied criteria *a*) and *b*). One event of this type was observed and was included in our event sample.

Muon pair and cosmic-ray contamination of the hadron-pair sample were drastically reduced by criteria *b*) and *c*).

The contamination of e^+e^- events in hadronic pairs was evaluated from collinear Bhabha events with one track exhibiting a clear shower behaviour in ESC system and the other track simulating a nuclear-interaction pattern. The probability for an e^+e^- event to simulate a hadron pair was determined to be $\sim 1.5 \cdot 10^{-4}$. This probability gives a background of 0.4 pion pairs and 0.7 kaon pairs.

The contamination from multihadron events was calculated from a combined analysis of momentum and collinearity distributions for two-track events. The corresponding background is 0.2 events each for pion and kaon pairs.

For each event selected for reactions (1), (2) and (3) the following quantity was calculated:

$$\chi^2_\alpha = \left[\frac{p_1 - p_\alpha}{\sigma(p_1)}\right]^2 + \left[\frac{p_2 - p_\alpha}{\sigma(p_2)}\right]^2 \qquad (\alpha = \mu, K, \pi),$$

where p_1 and p_2 are the momenta of the tracks, σ the associated errors and p_α the expected momentum.

The observed χ^2_μ distribution for events of reaction (3) is statistically consistent with that expected for two degrees of freedom. K^+K^- and $\pi^+\pi^-$ events were selected by requiring a $\chi_{K,\pi}$ value less than 5. The numbers of events selected in this way were 12 K^+K^- and 11 $\pi^+\pi^-$ events.

The detection efficiencies for the apparatus both for triggering and event selection were estimated for these reactions by Monte Carlo simulations. These calculations took into account nuclear interactions and decays in the complex geometry of the detector.

The cross-sections for hadron production have been calculated using the following relation:

$$\sigma_{hh} = \frac{N_{hh}}{\varepsilon_{hh}} \frac{\varepsilon_{\mu\mu}}{N_{\mu\mu}} \sigma_{\mu\mu},$$

where N_{hh}, $N_{\mu\mu}$ are the total number of hadron and muon pairs observed, $\sigma_{\mu\mu} = 37.3$ nb is the QED cross-section for muon pair production and ε_{hh}, $\varepsilon_{\mu\mu}$ are the corresponding overall efficiencies for detection. These efficiencies have been calculated and include detection efficiency from the Monte Carlo calculation and the corrections resulting from the χ^2 selection of events.

The numbers of events observed along with their associated overall efficiencies are given in table I. The errors given for ε_{hh}, $\varepsilon_{\mu\mu}$ are systematic errors due to uncertainties in the nuclear interaction lengths and in the determination of the geometrical acceptance.

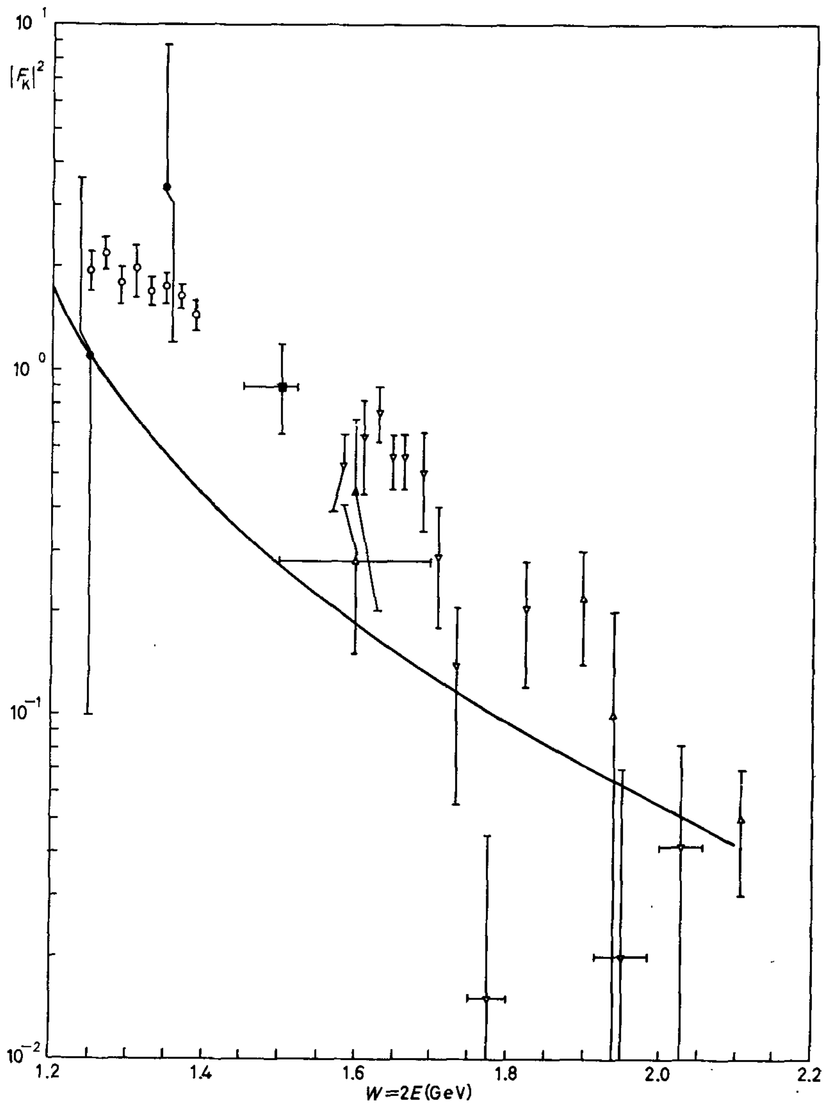

Fig. 1. – The kaon timelike electromagnetic form factor $|F_K|^2$ *vs.* the e^+e^- centre-of-mass energy W (GeV). The curve is the ρ, ω, φ VMD calculation including interference (⁶). References are given for other experimental results: ● (³), △ (⁴), ▲ (⁷), ▽ (⁸), ○ (⁹), ■ this experiment.

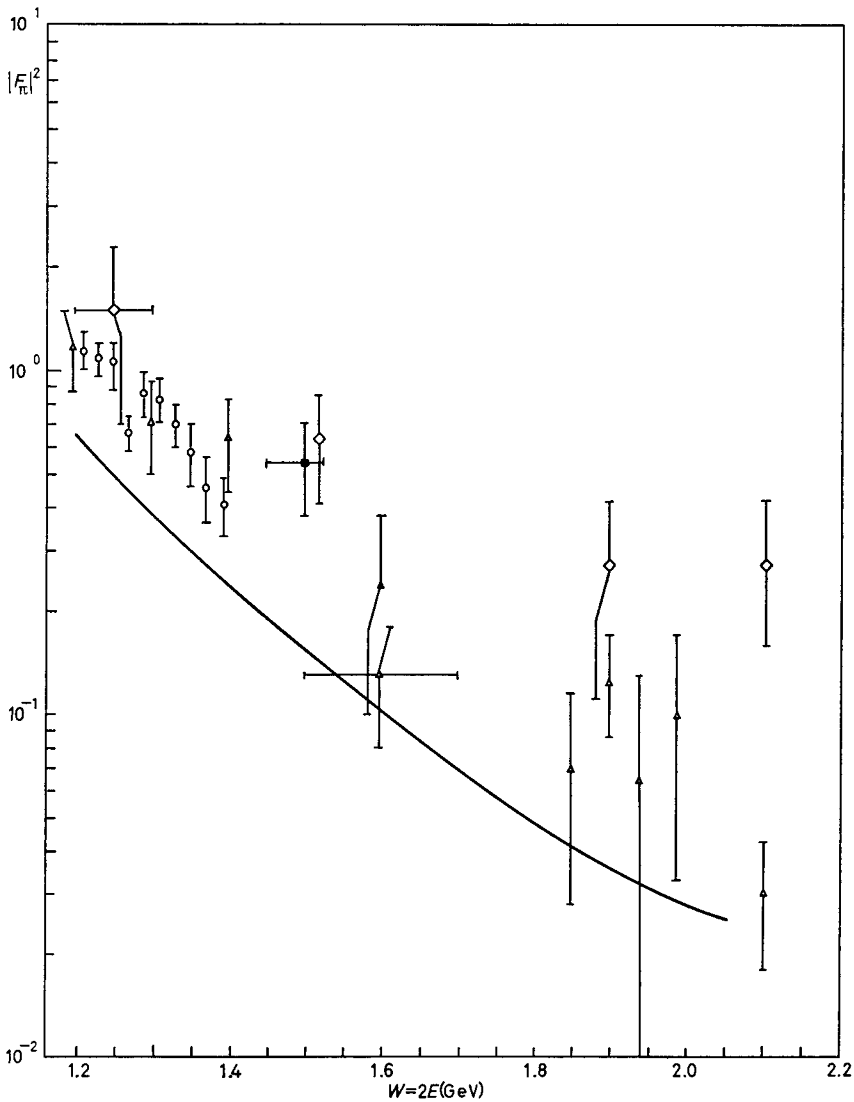

Fig. 2. – The pion timelike electromagnetic form factor $|F_\pi|^2$ *vs.* the e^+e^- centre-of-mass energy W (GeV). The curve is the ρ tail as calculated by GOUNARIS and SAKURAI ([11]). References are given for other experimental results: ◇ ([5]), △ ([6]), ▲ ([7]), ○ ([10]), ■ this experiment.

TABLE I. – *Summary of Results on* μ, π *and* K *Pair Production at* $W = (1.45 \div 1.52)$ GeV *for* $\mathscr{L} = 30.7\ \text{nb}^{-1}$.

Reaction	No. of events (observed)	No. of events (background subtracted)	Overall efficiency ε	Total cross-section (nb)	$\lvert F_h\rvert^2$
$e^+e^- \to \mu^+\mu^-$	230	195	0.17 ± 0.01	37.3	—
$e^+e^- \to \pi^+\pi^-$	11	10.4	0.07 ± 0.015	4.8 ± 1.4	0.54 ± 0.16
$e^+e^- \to K^+K^-$	12	11.1	0.10 ± 0.02	3.6 ± 1.0	0.90 ± 0.26

The timelike electromagnetic form factors for K, π have been calculated with the relation

$$|F_h|^2 = \frac{4\beta_\mu}{\beta_h^3}\frac{\sigma_{hh}}{\sigma_{\mu\mu}}, \qquad h = K, \pi .$$

The results on cross-sections and form factors are given in table I; the values obtained for kaon and pion form factors also are shown in fig. 1 and 2, respectively; the quoted errors are statistical only.

These figures summarize the measurements previously reported ([3-10]) on the kaon and pion form factors as a function of the e^+e^- centre-of-mass energy W between 1.1 and 2.1 GeV. In fig. 1 the curve shown for $|F_K|^2$ *vs.* W is based on a VMD calculation for ρ, ω, φ including interference ([9]). The curve in fig. 2 corresponds to the ρ tail as calculated by GOUNARIS and SAKURAI ([11]).

Our experimental results shown in fig. 1 and 2 are seen to lie above the tails of the well-established vector mesons ρ, ω, φ, but in good agreement with previous measurements made at higher and lower energies. These results taken together indicate a broad enhancement for kaon and pion form factors above these tails which is notably lacking in any structure that can be resolved with the present measurements.

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