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# Study of the kaon electromagnetic form factors in $e^+e^-$ annihilation and $\tau$ decays

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# Study of the kaon electromagnetic form factors in $e^+e^-$ annihilation and $\tau$ decays

**S I Serednyakov*[1,2], K I Beloborodov[1,2], V P Druzhinin[1,2]**

[1]Novosibirsk State University, 630090, Novosibirsk, Russia
[2]Budker Institute of Nuclear Physics, 630090, Novosibirsk, Russia

E-mail: `seredn@inp.nsk.su`

**Abstract.** The recent precise measurements of the $e^+e^- \to K^+K^-$ and $e^+e^- \to K_S K_L$ cross sections and the hadronic spectral function of the $\tau^- \to K^- K_S \nu_\tau$ decay are used to extract the isoscalar and isovector electromagnetic kaon form factors and their relative phase in a model independent way. The experimental results are compared with a fit based on the vector-meson-dominance model.

## 1. Introduction

The presented analysis is based on $e^+e^- \to K\bar{K}$ data from BABAR [1, 2], SND [3], CMD-3 [4, 5] and $\tau^- \to K^- K^0 \nu_\tau$ decay data from BABAR [6]. The $e^+e^- \to K^+K^-$ and $e^+e^- \to K_S K_L$ production cross sections are parametrized in terms of the charged $F_{K^+}$ and neutral $F_{K^0}$ kaon form factors as follows

$$\sigma_{K^+K^-}(s) = \frac{\pi\alpha^2\beta^3}{3s}\left|F_{K^+}\right|^2, \quad \sigma_{K_S K_L}(s) = \frac{\pi\alpha^2\beta^3}{3s}\left|F_{K^0}\right|^2, \tag{1}$$

where $s$ is the center of mass energy, $\beta = \sqrt{1 - 4m^2/s}$, and $m$ is the charged or neutral kaon mass. The charged and neutral kaon form factors, obtained from (1), are shown in figure 1. Assuming the conserved vector current (CVC) hypothesis and isospin invariance [7, 8], one can obtain the relations between the isovector (I=1) and isoscalar (I=0) form factors:

$$F_{K^+} = F_{K^+}^{I=1} + F_{K^+}^{I=0}, \quad F_{K^0} = F_{K^0}^{I=1} + F_{K^0}^{I=0}, \quad F_{K^0}^{I=0} = F_{K^+}^{I=0}, \quad F_{K^0}^{I=1} = -F_{K^+}^{I=1}. \tag{2}$$

The additional information about the isovector form form factor is taken from the $K^-K^0$ mass spectrum (figure 2) in the $\tau^- \to K^- K^0 \nu_\tau$ decay [6]:

$$\frac{dB}{BdM} = C(M)|F_{K^-K^0}(M)|^2 \tag{3}$$

where $B$ is the $\tau^- \to K^- K^0 \nu_\tau$ branching ratio, $M$ is the $K^-K^0$ mass, $C(M)$ is a theoretically known function [8], and $F_{K^-K^0} = -2F_{K^+}^{I=1}$.

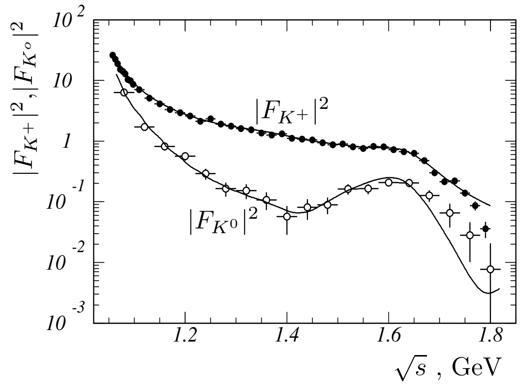


**Figure 1.** The charged $F_{K^+}$ and neutral $F_{K^0}$ kaon form factors squared. The curves represent the fit described in the text.

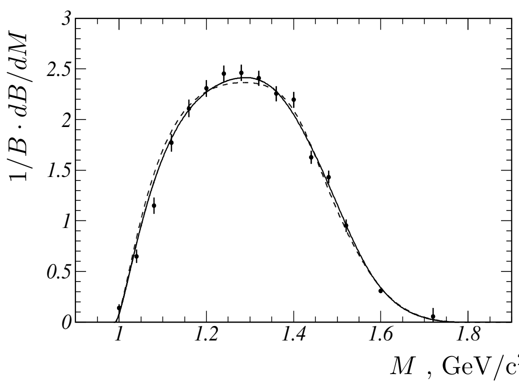


**Figure 2.** The $K^-K^0$ mass spectrum from $\tau^- \to K^-K^0\nu_\tau$ decay. The solid curve represent the fit described in the text.

## 2. Extraction of the isovector and isoscalar form factors

Using Eqs. (1), (2), (3) and $e^+e^-$ and $\tau$ data (figures 1, 2), we can obtain the isovector $|F^{I=1}_{K^+}|$ and isoscalar $|F^{I=0}_{K^+}|$ form factors and relative phase between them $\Delta\phi_{K^+} = \phi^{I=1}_{K^+} - \phi^{I=0}_{K^+}$:

$$|F^{I=1}_{K^+}|^2 = \frac{|F_{K^-K^0}|^2}{4},\ |F^{I=0}_{K^+}|^2 = \frac{|F_{K^+}|^2 + |F_{K^0}|^2}{2} - |F^{I=1}_{K^+}|^2,\ cos(\Delta\phi_{K^+}) = \frac{|F_{K^+}|^2 - |F_{K^0}|^2}{2|F^{I=1}_{K^+}||F^{I=0}_{K^+}|}, \quad (4)$$

whose distributions are shown in figures 3, 4, 5. Both isoscalar and isovector form factors decrease monotonically in the range below 1.5 GeV. An unexpected feature of the form factors is the almost constant, close-to-zero the relative phase $\Delta\phi_{K^+}$ in the energy range from 1.06 to 1.5 GeV, where there are significant contributions of the $\rho(1450)$ and $\omega(1420)$ resonances.

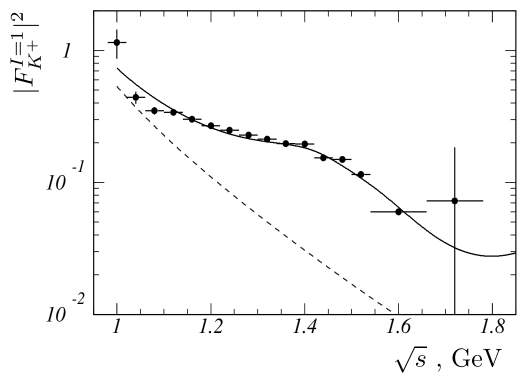


**Figure 3.** The isovector kaon form factor squared obtained from the $\tau^- \to K^-K^0\nu_\tau$ decay. The solid curve represents the fit described in the text. The dashed curve shows the $\rho(770)$ contribution.

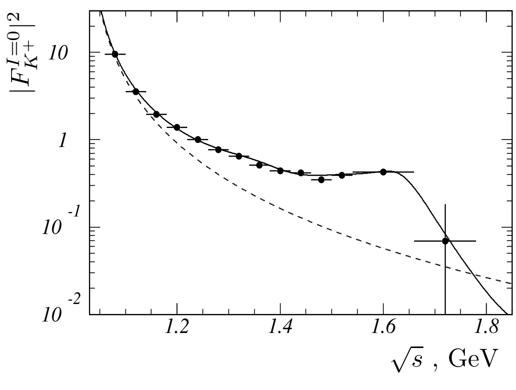


**Figure 4.** The isoscalar kaon form factor squared calculated in this work. The solid curve represents the fit described in the text. The dashed curve shows the $\omega(782)$ and $\phi(1020)$ contribution.

## 3. Fit to the form factor data

The second part of this article is devoted to the simultaneous fitting $e^+e^-$ and $\tau$ two-kaon data. In the vector meson-dominance model [8], the amplitude of the single-photon transition

$A_{\gamma^* \to K\bar{K}}$ is described as a sum of amplitudes of vector-meson resonances of the $\rho$, $\omega$, and $\phi$ families. The isovector resonances $\rho(770)$, $\rho(1450)$, $\rho(1700)$, and $\rho(2150)$ and isoscalar resonances $\omega(782)$, $\omega(1420)$, $\omega(1680)$, $\omega(2150)$, $\phi(1020)$, $\phi(1680)$, and $\phi(2170)$ are included into the fit. The resonance line shapes are described by the Breit-Wigner function $BW_V(s) = \frac{M_V^2}{M_V^2 - s - iM_V\Gamma_V(s)}$, where $M_V$ and $\Gamma_V(s)$ are the resonance mass and energy dependent width. The relative contribution of different resonances are free fit parameters.

The results of the fit are shown by the solid curves in figures 2 - 6. It is seen that $K^-K^0$ mass spectrum, both isovector and isoscalar form factors, the relative phase $\Delta\phi_{K^+}$ and measured $e^+e^- \to K_SK_L$ and $e^+e^- \to K^+K^-$ cross sections are described by this model rather well. The $\chi^2/\nu = 183/142$ of the fit is not quite good, but reasonable, taking into account that the systematic uncertainties of the measurements are not included into the fit. More details about fit results can be found in [8]. A large deviation from the quark model prediction is observed for the contributions of the $\rho(1450)$ and $\omega(1420)$ resonances. This deviation leads to the almost constant value of the relative phase $\Delta\phi_{K^+}$ in the energy range 1.06–1.5 GeV (figure 5).

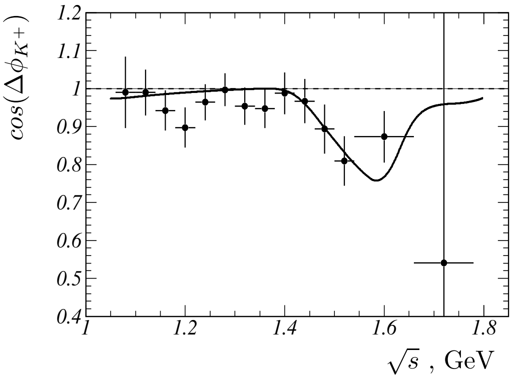


**Figure 5.** The cosine of the relative phase $\Delta\phi_{K^+}$ between the isoscalar and isovector form factors. The solid curve represents the fit described in the text.

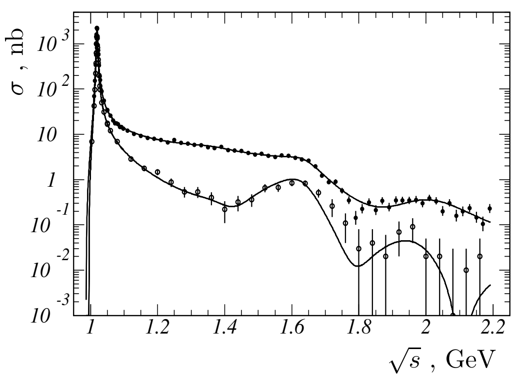


**Figure 6.** The $e^+e^- \to K^+K^-$ (top) and $e^+e^- \to K_SK_L$ (bottom) cross sections. The curves represent the fits described in the text.

## 4. Conclusions

Using recent precise measurements of the $e^+e^- \to K\bar{K}$ cross sections and the $K^-K^0$ mass spectrum in the $\tau^- \to K^-K^0\nu_\tau$ decay we separate the isoscalar and isovector electromagnetic kaon form factors and determine the relative phase between them. We have simultaneously fitted to the $e^+e^- \to K^+K^-$ and $e^+e^- \to K_SK_L$ cross-section data and the hadronic mass spectrum in the $\tau^- \to K^-K_S\nu_\tau$ decay in the framework of the VMD model. The fit reproduces data reasonably well.

## 5. Acknowledgements

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