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STRANGENESS-CHANGING VECTOR CURRENTS IN τ-LEPTON DECAYS

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Векторный ток с изменением странности
в распадах τ-лептонов

Рассмотрены запрещенные слабые Кабиббо-распады τ-лептонов на каон и нестранный псевдоскалярный мезон в U(3)-версии кварковой модели сверхпроводящего типа с учетом φA-смешивания. Вычислены полные и дифференциальные ширины четырех распадов τ-лептонов указанного типа. Получено ожидаемое число таких распадов в год на c-τ-фабрике. Отмечена роль φA-смешивания.

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Bednyakov V.A., Osipov A.A. E2-92-16
Strangeness-Changing Vector Currents
in τ-Lepton Decays

The Cabibbo suppressed τ-lepton decays into a kaon and a non-strange pseudoscalar meson have been investigated in the U(3)-version of the superconducting quark model with allowance for φA-mixing. The total and differential widths of four τ-lepton decays were obtained. The number of these decays per year at the c-τ-factory was calculated.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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The high luminosity of planned Charm-τ factories [1] will open good opportunities for investigations of Cabibbo suppressed τ-lepton decays. It is worth mentioning that systematic investigation of τ-lepton decays into open strange final states has only begun [2]. Observation and exploration of these decays will yield information about the structure of the strangeness-changing part of the weak hadron current in a new kinematic region. Here we bring a short review of our calculations of four τ-decays induced only by the vector part of the weak hadron current. We consider semileptonic τ-decays into strange and non-strange pseudoscalar mesons:

$$\tau^- \to \nu_\tau + \bar{K}^0 + \pi^- \tag{1}$$

$$\tau^- \to \nu_\tau + K^- + \pi^0 \tag{2}$$

$$\tau^- \to \nu_\tau + K^- + \eta \tag{3}$$

$$\tau^- \to \nu_\tau + K^- + \eta' \tag{4}$$

In our calculations we used the phenomenological effective meson Lagrangian of the Superconductor Quark Model (QMST) [3], which stemmed from the well-known 4-fermion Nambu-Jona-Lasinio theory and uniformly describes interactions of scalar, pseudoscalar, vector and axial vector meson nonets at low energy.

In the τ-lepton rest frame the differential widths of the τ-decays can be calculated by a standard formula

$$d\Gamma(\tau \to \nu_\tau \phi^- \phi^0) = \frac{\delta^4(p_\tau - p_\nu - p_0 - p_-)}{(2\pi)^5} \frac{\frac{1}{2}\Sigma|T|^2}{2m_\tau} \prod_{i=1}^{3} \frac{dp_i^3}{2E_i} \tag{5}$$

where $i = (\nu, 0, -)$ corresponds to the neutrino, neutral and charged final state mesons respectively.

The amplitudes of all decays can be expressed in the form

$$T(\tau \to \nu 2\phi) = -\frac{G_F}{2} \sin\theta_c \bar{\nu}_\tau (1+\gamma_5)\gamma_\mu \tau \{ f_+(q^2)p^\mu + f_-(q^2)q^\mu \}, \tag{6}$$

where $p = p_- - p_0$, $q = p_- + p_0$ and p_-, p_0 are the momenta of the charged and neutral final state mesons. Note that $m_0^2 = p_0^2$ and $m_-^2 = p_-^2$.

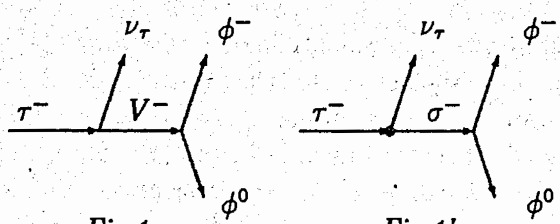

Fig.1a *Fig.1b*

Figure 1: Diagrams contributing to τ-decays

For example, in the case of the $\tau \to \nu_\tau \bar{K}^0 \pi^-$ reaction we have $p_- = p_{\pi^-}$, $p_0 = p_{\bar{K}^0}$. Two formfactors $f_+(q^2)$, $f_-(q^2)$ are determined by dynamics of strong interaction. We calculated them in QMST using two weak vertices depicted in Fig.1 (the filled dot in Fig.1b denotes a $V\sigma$-transition).

The first lepton weak vertex (Fig.1a) generates an intermediate vector (V) strange $K^*(892)$-meson with mass $m_{K^*} = 891.83 \pm 0.24$MeV and width $\Gamma_{K^*} = 49.8 \pm 0.8$MeV [4].

The other weak vertex (Fig.1b) appears in QMST due to $V\sigma$-mixing and generates exchange with a scalar strange meson — $K_0^*(1340)$. The full weak Lagrangian is:

$$\mathcal{L}_w = G_F \sin\theta_c \frac{m^2_{K^*}}{g_{K^*}} \bar{\nu}_\tau \gamma_\mu (1-\gamma_5) \tau \left[K_\mu^{*+} + i\kappa Z^{1/2}_{K_0^*} \partial_\mu K_0^{*+} \right] + h.c. \quad (7)$$

Here κ and $Z_{K_0^*}$ denote $V\sigma$-mixing and scalar field renormalization parameters and for K_0^*-meson are equal to

$$\kappa = \sqrt{\frac{3}{2}\frac{(m_s - m_u)}{m^2_{K^*}}} = 0.27\ GeV^{-1}$$
$$Z_{K_0^*} = \left(1 - \frac{3(m_s - m)^2}{2m^2_{K^*}}\right)^{-1} = 1.06 \quad (8)$$

In calculations we used $g_\rho = 6.15$ and QMST-determined quark masses $m \equiv m_u = m_d = 280\ MeV$ and $m_s = 450\ MeV$.

So for formfactors we obtain expressions:

$$f_+ = \frac{m_V^2}{q^2 - m_V^2} \frac{g(\phi^+\phi^0) - g(\phi^0\phi^+)}{g_V} \quad (9)$$

$$f_- = -\frac{m_-^2 - m_0^2}{m_V^2} f_+ - \frac{g(\phi^+\phi^0) + g(\phi^0\phi^+)}{g_V} - 2\kappa Z^{1/2}_{K_0^*} \frac{m_V^2}{q^2 - m_\sigma^2} \frac{g_s(\phi^0\phi^+)}{g_V} \quad (10)$$

Here squared masses of intermediate mesons are complex values $m_V^2 = m^2_{K^*} - i m_{K^*}\Gamma_{K^*}$, $m_\sigma^2 = m^2_{K_0^*} - i m_{K_0^*}\Gamma_{K_0^*}$ and $m^2_{K^*}$, Γ_{K^*}, $m^2_{K_0^*}$, $\Gamma_{K_0^*}$ are experimentally determined values [4].

Hadron vertex constants $g(\phi^+\phi^0)$, $g(\phi^0\phi^+)$ and $g_s(\phi^0\phi^+)$ are determined in the model after removing ϕA-mixing and pseudoscalar field renormalization. The constants can be obtained from hadron Lagrangians:

$$\mathcal{L}_{K^*-\phi^2} = K_\mu^{*-}\left[g(K\phi)\phi\partial_\mu K + g(\phi K) K \partial_\mu \phi\right] \quad (11)$$
$$\mathcal{L}_{K_0^*-\phi^2} = K_0^{*-} g_s(K\phi)\phi K. \quad (12)$$

In two equations above we assume summation over ϕ where ϕ denotes a physical π^+ field for $K \equiv K^0$ and physical fields π^0, η, η' for $K \equiv K^+$. Vertex constants are collected in Table 1. Here for pseudoscalar field renormalization constants Z with physical masses of appropriate axial-vector mesons $m_{a_1} = 1260\ MeV$, $m_{K_1} = 1270\ MeV$ and $m_{f_1} = 1425\ MeV$ one obtains

$$Z_\pi = \left(1 - \frac{6m^2}{m^2_{a_1}}\right)^{-1} = 1.43$$
$$Z_K = \left(1 - \frac{3(m+m_s)^2}{2m^2_{K_1}}\right)^{-1} = 2.04$$
$$Z_{\eta'} = \left(1 - \frac{6m_s^2}{m^2_{f_1}}\right)^{-1} = 2.70$$

Other vertex constants are expressed through those given above:

$$g(K^+\pi^0) = g(K^+\eta) = \frac{1}{\sqrt{2}} g(K^0\pi^+),$$
$$g(\pi^0 K^+) = g(\eta K^+) = \frac{1}{\sqrt{2}} g(\pi^+ K^0), \quad (13)$$
$$g_s(K^+\pi^0) = g_s(K^+\eta) = \frac{1}{\sqrt{2}} g_s(K^0\pi^+).$$

Table 1: Hadron vertex constants (see also (13))

Hadrons	$K^+\eta'$	$K^0\pi^+$
$g(K\phi)$	$ig_\rho\sqrt{\frac{Z_K Z_{\eta'}}{2}}\left[1-\frac{2m}{m+m_s}\left(\frac{Z_K-1}{Z_K}\right)\right]$	$-ig_\rho\sqrt{\frac{Z_K Z_\pi}{2}}\left[1-\frac{2m_s}{m+m_s}\left(\frac{Z_K-1}{Z_K}\right)\right]$
$g(\phi K)$	$-ig_\rho\sqrt{\frac{Z_K Z_{\eta'}}{2}}\left[1-\frac{3m_s-m)}{2m_s}\left(\frac{Z_{\eta'}-1}{Z_{\eta'}}\right)\right]$	$ig_\rho\sqrt{\frac{Z_K Z_\pi}{2}}\left[1-\frac{3m-m_s}{2m}\left(\frac{Z_\pi-1}{Z_\pi}\right)\right]$
$g_s(K\phi)$	$g_\rho 2m\sqrt{\frac{Z_{K_0^*}}{3}}$	$g_\rho 2m_s\sqrt{\frac{Z_{K_0^*}}{3}}$

With above formulae we calculated the total $\Gamma(\tau\rightarrow\nu\phi^-\phi^0)$ and differential width $d\Gamma/dq^2$ of decays (1)-(4). We used an SU(3) relation $g_{K^*}=g_\rho$. The relation yields good value for $Br(\tau\rightarrow\nu K^*)$.

The total widths (in GeV), $\Gamma(\tau)$, branching ratios, Br, contributions from f_+-proportional term, $\Gamma(f_+)$, and f_--proportional term, $\Gamma(f_-)$, contributions from K^*, $\Gamma(K^*)$, and K_0^*, $\Gamma(K_0^*)$, intermediate states and the expected number of useful events, N, per year for all decays in question are collected in Table 2. We used the input value of planned 10^7 τ-pairs per year and the total τ-decay width equal to $0.2\cdot 10^{-11}$ GeV [4]. The first two decays with "light" final state (1),(2) have a distinct resonance structure at q^2 in the vicinity of the K^* mass. This region yields general contribution to the total decay width. Accurate q^2-scanning of the resonance shape would bring a good chance for precise extraction of the mass and width of the intermediate strange vector meson. It is not *a priori* obvious that these parameters will coincide with the K^* mass and width extracted from pure hadronic reactions. The vector strange meson K^* dominates due to a big contribution to the formfactor f_+. In τ-decays the weak formfactor can be studied in another kinematic region which

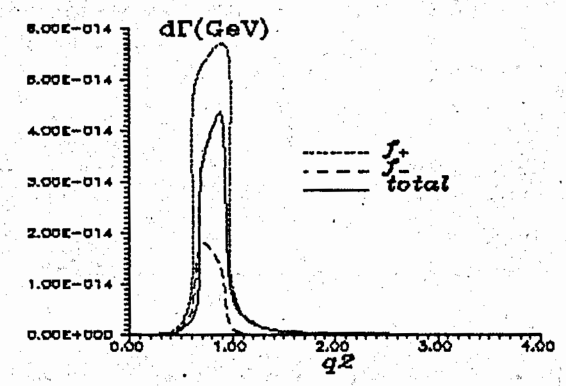

Figure 2: Differential width of decay $\tau^-\rightarrow\nu_\tau\bar{K}^0\pi^-$

differs from the low q^2-region of the K_{l3}-decay. The scalar strange meson K_0^* contributes only to formfactor f_-.

Due to a big τ-lepton mass the f_--formfactor contribution is sufficiently large as compared with that from K_{l3}-decay. In all kinematic domains the f_+-contribution disguises a near-three-time lower contribution from the formfactor f_-. But their destructive interference seems to bring good opportunities for experimental extraction of q^2-dependence of f_- for large momentum transferred. In accordance with the Ademollo-Gatto theorem [6], the ϕA-mixing practically doesn't contribute to formfactor f_+. Unfortunately, their contribution to f_- is not big enough to be noticeable in the decay width.

For example, differential widths $d\Gamma/dq^2$ of decay (1), contributions from f_+- and f_--proportional terms are depicted in Fig.2.

Those "heavy" τ-decays into η and η' (3),(4) do not have a distinct resonance structure due to a sufficiently great invariant mass of the final state, therefore the total widths are considerably smaller. But here the role of the intermediate scalar K_0^*-meson and the f_--proportional term becomes visible and important. Here we neglect η — η' mixing.

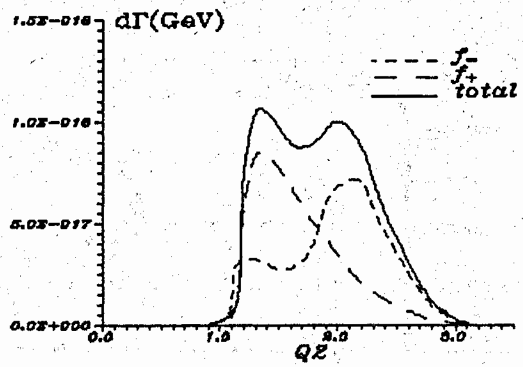

Figure 3: Differential width of decay $\tau^- \to \nu_\tau K^- \eta$

The most interesting case is the decay $\tau^- \to \nu_\tau K^- \eta$.

There is no significant ϕA-transition contribution to f_+, but the decay formfactor f_- is determined practically totally by the ϕA-transition and the f_--contribution becomes equal to f_+-ones (see Fig.3 and Table 2). As a result, due to the ϕA-transition, the total width is doubled.

As the detailed analysis shows, ϕA-mixing and K_0^*-meson destructively interfere, changing however f_-- q^2-dependence and the total differential width too (see Fig.3). Study the decay shape one might chance to obtain ϕA-mixing manifestations. Another way for that is to study the ordinary Dalitz-plot. The manifestations of ϕA-mixing are clearly seen from comparison of two plots in Fig.4.

The Cabibbo suppressed τ-lepton decays into a non-strange pseudoscalar meson and a kaon were investigated. Our calculations ware performed in the superconducting quark model on the basis of U(3)-violated effective Lagrangian from [3]. Two-particle vertices (Aϕ and $V\sigma$) in the Lagrangian were eliminated, which resulted in a new effective hadron Lagrangians (11),(12).

We used a tree-level approximation and, only for simplicity, U(3) protected relation $g_{K^*} = g_\rho$. This value for g_{K^*} doesn't contradict the experiment and can be made more precise due to extraction from the data if it is necessary.

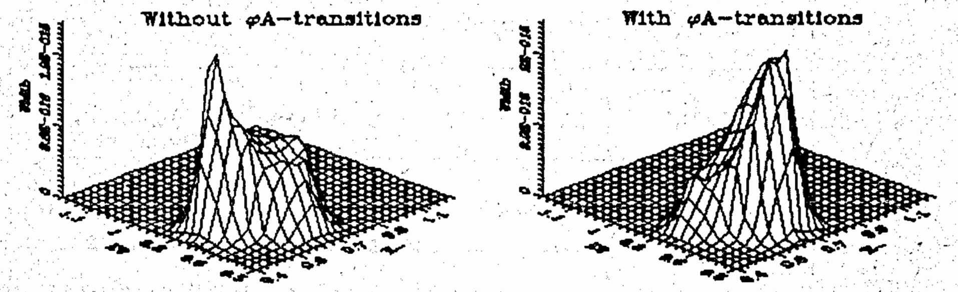

Figure 4: The role of ϕA-mixing in decay $\tau^- \to \nu_\tau K^- \eta$

We suppose that taking into account U(3) violation in determination of the g_{K^*} and consideration of loop contributions in our exploration of decays in question as well as a very important problem of background processes acquire real significance only in seting up a new special experiment or in processing data obtained.

The most interesting results are depicted in figures 2-4 and table 2. The open question is the role of axial-pseudoscalar and vector-scalar mixing in extension of the QMST to U(3) violated case. Experimental verification of these results is very important.

It is shown that the planned number of τ-interactions at the Charm-τ factory is practically enough for detailed investigation of all above mentioned decays without probably the $\tau^- \to \nu_\tau K^- \eta'$- one.

Up to now the structure of the strange component of the hadron weak vector current has been studied in detail only in ordinary K-meson decays. Due to smallness of the final state lepton mass only f_+-formfactor can be reliably determined. For τ-decays this limitation is lifted and one can try to investigate the f_- formfactor too.

Table 2: Calculated widths (in GeV)

	$\tau^- \to \nu_\tau \bar{K}^0 \pi^-$	$\tau^- \to \nu_\tau K^- \pi^0$	$\tau^- \to \nu_\tau K^- \eta$	$\tau^- \to \nu_\tau K^- \eta'$
$\Gamma(f_+)$	$2.013 \cdot 10^{-14}$	$1.044 \cdot 10^{-14}$	$0.669 \cdot 10^{-16}$	$0.240 \cdot 10^{-17}$
$\Gamma(f_-)$	$0.566 \cdot 10^{-14}$	$0.284 \cdot 10^{-14}$	$0.700 \cdot 10^{-16}$	$2.222 \cdot 10^{-17}$
$\Gamma(K^*)$	$1.437 \cdot 10^{-14}$	$0.740 \cdot 10^{-14}$	$1.270 \cdot 10^{-16}$	$0.248 \cdot 10^{-17}$
$\Gamma(K_0^*)$	$0.012 \cdot 10^{-14}$	$0.006 \cdot 10^{-14}$	$0.363 \cdot 10^{-16}$	$2.127 \cdot 10^{-17}$
$\Gamma(\tau)$	$1.442 \cdot 10^{-14}$	$0.756 \cdot 10^{-14}$	$1.286 \cdot 10^{-16}$	$0.635 \cdot 10^{-17}$
Br	$7.2 \cdot 10^{-3}$	$3.8 \cdot 10^{-3}$	$0.6 \cdot 10^{-4}$	$0.3 \cdot 10^{-5}$
N	7200	3800	600	30

References

[1] J.Kirkby, CERN-EP/87-210 (1987) Cτ-factory proposals

[2] Goldberg M. et al., Phys.Lett.B 251 (1990) p.223-228

[3] M.K.Volkov, Annals of Physics v.157 (1984) p.282

[4] Particle Data Group, Phys.Lett.B239 (1990) p.1

[5] D.Ebert,H.Reinhardt, Nucl.Phys. B271 (1986) p.188

[6] M.Ademollo, R.Gatto, Phys.Rev.Lett. 13 (1964) p.264

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