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The limits on CPT-odd part of CP violation from $K^0(\bar{K}^0)$ semileptonic decays.

MOSCOW 1994

УДК 530.1 М-16

THE LIMITS ON CPT-odd PART OF CP VIOLATION FROM $K^0(\bar{K}^0)$ SEMILEPTONIC DECAYS: Preprint ITEP 43-94/

K.Gusev, V.Demidov, E.Shabalin - M., 1994 - 8p.

The value of CPT-odd part of CP-violating parameter had been obtained using the data of two earlier experiments [7,8]. These data give the CPT-odd part of mass matrix of $K^0 - \bar{K}^0$ mesons: $\Delta = (0.018 \pm 0.020) + (0.021 \pm 0.037)i$.

Fig. - 3, ref.- 9

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To date we have no evidence that CP violation is accompanied by T violation so that CPT is kept unbroken. If CP violating interaction includes the T conserving part, the $K_{S,L}$ wave functions acquire the CPT violating parts described by the parameter Δ:

$$\begin{aligned} K_S &= [K_1 + (\varepsilon + \Delta)K_2]/\sqrt{1 + |\varepsilon + \Delta|^2}, \\ K_L &= [K_2 + (\varepsilon - \Delta)K_1]/\sqrt{1 + |\varepsilon - \Delta|^2}. \end{aligned} \tag{1}$$

Besides, CPT violation can occure in direct transitions of $K_{S,L}$ into the final states. Then, the additional CPT-odd parameters appear:

$$a = \frac{A(K_2 \to 2\pi, I = 0)}{A(K_1 \to 2\pi, I = 0)}, \tag{2}$$

$$y_l \cong \frac{1}{2}[1 - < l^+\nu\pi^- \mid K^0 > / < l^-\bar{\nu}\pi^+ \mid K^0 >^*]. \tag{3}$$

$$(x_l - x_l). \tag{4}$$

where x_l and $\bar{x}_l$ describe the deviations from $\Delta Q = \Delta S$ rule:

$$x_l = \frac{< l^+\nu\pi^- \mid \bar{K}^0 >}{< l^+\nu\pi^- \mid K^0 >}; \; \bar{x}_l = \frac{< l^-\bar{\nu}\pi^- \mid K^0 >^*}{< l^-\bar{\nu}\pi^+ \mid \bar{K}^0 >^*}. \tag{5}$$

At present the quantities Δ, a, y_l, and $(x_l - \bar{x}_l)$ are limited to the level $1 \div 2$ % [1], so further improvement of accuracy in measurement of these parameters is very desirable. One of the ways to do this is to study the proper-time rates of semileptonic decays of a particle produced at t=0 as K^0 (or $\bar{K}^0$) [2]:

$$N^+_{K^0}(l^+;t) = \left|\frac{F_l}{2}\right|^2 \cdot |(1 + 2\Delta + x_l - y_l)e^{-\gamma_S t} + (1 - 2\Delta - x_l - y_l)e^{-\gamma_L t}|^2, \tag{6a}$$

$$N^+_{\bar{K}^0}(l^+;t) = \left|\frac{F_l}{2}\right|^2 \cdot |(1 + 2\varepsilon + x_l - y_l)e^{-\gamma_S t} - (1 + 2\varepsilon - x_l - y_l)e^{-\gamma_L t}|^2, \tag{6b}$$

$$N^-_{K^0}(l^-;t) = \left|\frac{F_l}{2}\right|^2 \cdot |(1 - 2\varepsilon + \bar{x}_l^* + y_l)e^{-\gamma_S t} - (1 - 2\varepsilon - \bar{x}_l^* + y_l)e^{-\gamma_L t}|^2, \tag{6c}$$

$$N^-_{\bar{K}^0}(l^-;t) = \left|\frac{F_l}{2}\right|^2 \cdot |(1 - 2\Delta + x_l^* + y_l)e^{-\gamma_S t} + (1 + 2\Delta - x_l^* + y_l)e^{-\gamma_L t}|^2, \tag{6d}$$

where $\gamma_S = im_S + \frac{1}{2}\Gamma_S$, $\gamma_L = im_L + \frac{1}{2}\Gamma_L$; $m_S, m_L, \Gamma_S, \Gamma_L$ – are masses and widths of K_S and K_L mesons and

$$F_l = \frac{1}{2}(< l^+\nu\pi^- \mid K^0 > + < l^-\bar{\nu}\pi^+ \mid \bar{K}^0 >^*). \tag{7}$$

The behaviour of proper-time distributions (6) depends on 5 complex parameters, describing the violation of fundamental symmetries and $\Delta Q = \Delta S$ rule.

Up to now these distributions were studied in 22 experiments [3] only for extraction of the limits on $Re(x_l)$ and $Im(x_l)$ assuming that CPT is exact symmetry, that is, for the case $\Delta = 0$, $y_l = 0$ and $x_l = \bar{x}_l$. Meanwhile, the systematics of the light hadrons does not show any sign of existence of basic particles (quarks) presence of which could allow the transitions $\Delta Q = -\Delta S$ in the first order of weak interaction. Then, the parameters x_l and $\bar{x}_l$ must be very small– of order of $G_F m_K^2 \sim 10^{-6}$ (see also [4-6]) because they become different from zero in standart model in second order of weak interaction. So, searching for the parameters ε, Δ, y_l up to the values 10^{-5}, we may neglect $x_l(x_l)$ in the expression (6).

Then, the distributions (6) will give some information on ε, Δ and y_l.

Here we undertake an attempt to extract CPT-odd parameters Δ and y_l from two experiments [7,8] with the largest number of examined K^0 mesons.

To be convinced that we use the nondistorted values of the experimental points, we check first of all that for CPT=1 and $x_l \neq 0$ case we reproduce the very like results for x_l as in refs [7,8].

The results are shown in Table 1 and in Figures 1 and 2 by curves (1) and (3) respectively together with results from [7,8]. Curve (2) corresponds to the time dependence for the

Table 1: Results of fit for the case $x_l = \bar{x}_l \neq 0, \Delta = y_l = 0$.

	Experiment [7]		Experiment [8]	
	our fit	fit from paper [7]	our fit	fit from paper [8]
$Re(x_l)$	0.03 ± 0.04	0.04 ± 0.03	-0.02 ± 0.08	-0.03 ± 0.07
$Im(x_l)$	-0.07 ± 0.05	-0.06 ± 0.05	0.08 ± 0.07	0.09 ± 0.07

conservation of $\Delta Q = \Delta S$ rule ($x_l = 0$).

Under the adopted assumptions ($x_l = \bar{x}_l = 0$), in the first order of parameters ε, Δ, y_l the functions (6a) and (6c) have the form:

$$\begin{aligned} N^+(t) &\simeq C^+ \cdot \{[1 + 4Re\Delta]e^{-\Gamma_S t} + 2\cos(\beta t)e^{-\bar{\Gamma} t} - \\ &\quad -8Im\Delta \cdot \sin(\beta t)e^{-\bar{\Gamma} t} + [1 - 4Re\Delta]e^{-\Gamma_L t}\}, \qquad (8a) \\ N^-(t) &\simeq C^- \cdot \{e^{-\Gamma_S t} - 2\cos(\beta t)e^{-\bar{\Gamma} t} + e^{-\Gamma_L t}\}, \qquad (8b) \end{aligned}$$

where $\beta = m_L - m_S$ and $\bar{\Gamma} = \frac{\Gamma_L + \Gamma_S}{2}$;

$$C^+ - C^- = 4Re(\varepsilon - y_l). \ [2] \qquad (9)$$

Using the least squares method we have found the values of parameters C^+, C^-, S, $Re\Delta$, $Im\Delta$ (where S is the scale factor between the measured quantities $N^\pm$ in the experiment [8] (fig.2) respectively to [7] (fig.1) which correspond to minimum of the function

$$\chi^2 = \sum_{exp.} \left\{ \sum_k \left[\frac{N^+_{exp}(t_k) - N^+_{th}(t_k)}{\delta N^+_k} \right]^2 + \sum_k \left[\frac{N^-_{exp}(t_k) - N^-_{th}(t_k)}{\delta N^-_k} \right]^2 \right\}. \qquad (10)$$

where $N^\pm_{exp}(t_k)$ are the experimental rates at $t = t_k$, $N^\pm_{th}(t_k)$ are the rates given by eqs (8) at $t = t_k$ and $\delta N^\pm_k$ are the experimental errors of measured values of $N^\pm$ distributions.

The following values were obtained (see also fig.3):

$$\begin{aligned} C^+ = 0.56 \pm 0.05, \ C^- = 0.51 \pm 0.01, \ S = 185 \pm 6. \\ Re\Delta = 0.018 \pm 0.020, \ Im\Delta = 0.021 \pm 0.037. \qquad (11) \end{aligned}$$

Minimal value of χ^2 is equal to 46.5 for 44 degrees of freedom.

Using the obtained values C^+ and C^- and relation (9) we have the estimate:

$$Re(\varepsilon - y_l) = 0.012 \pm 0.013$$

or

$$-0.09 < Re(\varepsilon - y_l) < 0.033 \text{ at } 90\% \text{ C.L.}$$

Our limits on CPT-odd parameters were obtained using comparatively small number of K_{l_3} decays, namely, for $N_{K_{l_3}} = 6481$.

Investigation of the semileptonic decays at the DAPhNE machine and in CPLEAR experiment will allow to lower the above mentioned limits considerably. At DAPhNe for this purpose a search for A_{CPT} asymmetry can be used, where A_{CPT} is determined by difference between the numbers of events where the positive lepton is emitted before the negative one and vice versa. The expected accuracy in measurement of $Re\Delta$ is $\pm 3 \cdot 10^{-4}$[9].

In CPLEAR experiment, the distributions (6) can be measured directly and the expected sensitivity to $Re\Delta$ and $Im\Delta$ is close to $\pm(4 \div 5) \cdot 10^{-4}$.

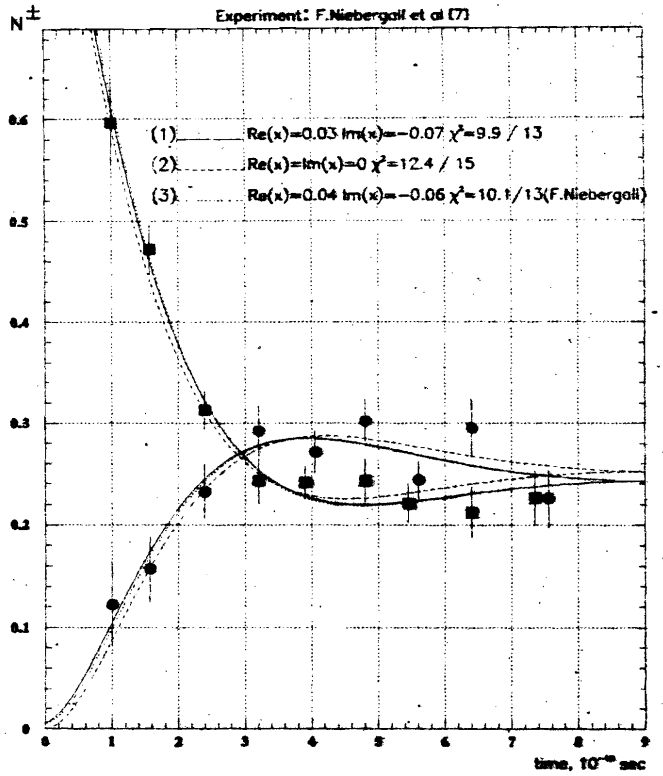

Figure 1: Time distribution for events in experiment [7] together with theoretical curves. The curve (1) corresponds to the best fit for the parameter $x_l = (0.03 \pm 0.04) + (-0.07 \pm 0.05)i$. Curves (2) and (3) correspond to $x_l = 0$ and $x_l = 0.04 - 0.06i$ (F.Niebergall et al solution) respectively.

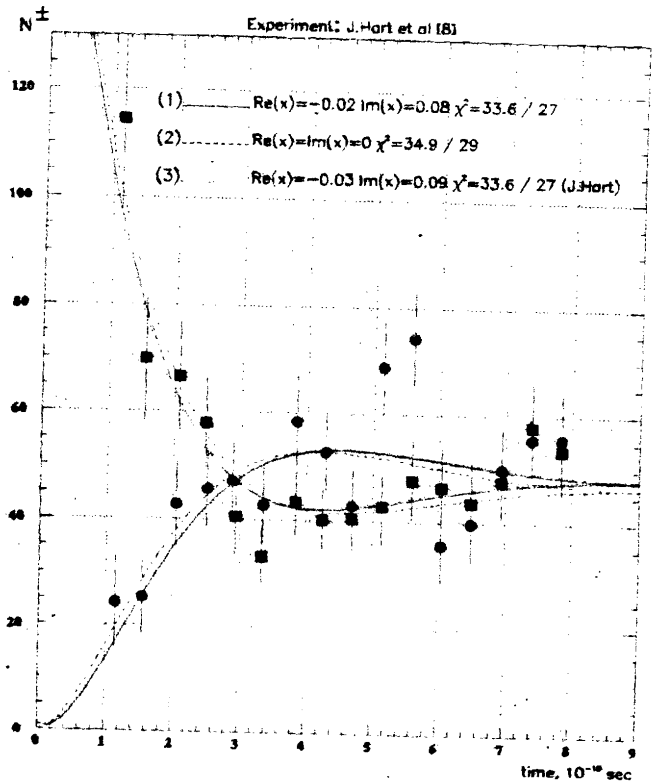

Figure 2: Time distribution for events in experiment [8] together with theoretical curves. The curve (1) corresponds to the best fit for the parameter $x_l = (-0.02 \pm 0.08) + (0.08 \pm 0.07)i$. Curves (2) and (3) correspond to $x_l = 0$ and $x_l = -0.03 + 0.09i$ (J.Hart et al solution) respectively.

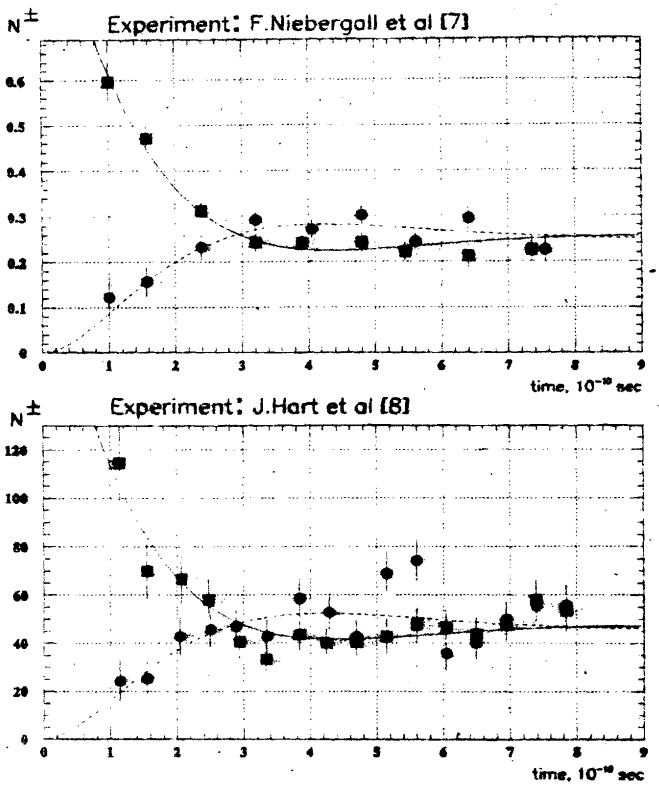

Figure 3: Time distribution for events $K^0 \to l^+\nu\pi^-$, $K^0 \to l^-\bar{\nu}\pi^+$ in experiments [7] and [8]. Theoretical curves correspond to the best fit giving values (11) at $x_l = 0$.

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Ограничение на CPT-нечетную часть CP-нарушающего взаимодействия в полулептонных распадах K^0 ($\bar{K}^0$).

Подписано к печати 24.05.94 Формат 60x90 I/I6 Офсетн.печ.
Усл.-печ.л.0,5 Уч.-изд.л.0,3 Тираж I23экз. Заказ 43
Индекс 3649

Отпечатано в ИТЭФ, II7259, Москва, Б.Черемушкинская,25