PROCEEDINGS OF SCIENCE

# A NEW $K_L^0$ DECAY CHANNEL

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In this letter the rate for the decay $K_L^0 \Rightarrow K^{\pm}e^{\mp}(\overline{\nu}/\nu)$ of (0.0979 ±0.0037) $s^{-1}$ has been calculated in the hypothesis of the Conserved Vector Current and, assuming the CP violation very small, the two rates for the decay $\overline{K_L^0} \Rightarrow K^- e^+ \nu$ and $K_L^0 \Rightarrow K^+ e^- \overline{\nu}$ are foreseen very similar.
Such a decay was never taken into account in the past, due to the very small phase space factor yielding a Branching Ratio for $K_L$ decay, B.R.=$(0.5071 \pm 0.0199) \times 10^{-8}$. Now, with the very intense $K$ beams foreseen at KEK, J-PARC, BNL, CERN and LNF, the observation of this decay seems feasible.
With samples of very large statistical significance a new measurement of the indirect CP violation parameter $\varepsilon$ could be done.

*Kaon International Conference*
*May 21-25, 2007*
*Laboratori Nazionali di Frascati dell'INFN*

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[*] Speaker.

## 1. Introduction

In this letter it is proposed to search for the decay channels $K_L^0 \Rightarrow K^{\pm}e^{\mp}(\overline{\nu}/\nu)$ for the following reasons :
a) these decay channels were neither investigated nor detected; hence they represent something new worth measuring.
They represent indeed a unique $\Delta S = 0$ weak transition starting from a strange meson.
b) The Conserved Vector Current (CVC) hypothesis predicts a well precise value for the decay rate $R = 0.0979 \pm 0.0037\ s^{-1}$ . So the measurement constitutes a further test of CVC.
c) The uncertainty on the CVC prediction is mainly due to the error on the mass difference $\Delta = M_{K^0} - M_{K^+}$; hence a high precision measurement of the decay rate and the CVC assumption can improve the precision on $\Delta$.
d) In the future, if the collected events will have a very small statistical error, the comparison of the $K^0 \Rightarrow K^+$ with the $\overline{K^0} \Rightarrow K^-$ rates will constitute a new investigation of CP Violation.
In the section II the particular kinematics of the K-beta decay is summarized; in section III the expected rates (following CVC) are calculated; in section IV the experimental opportunity to observe this decay in KLOE and in the future K factories are reviewed, and in section V a new possibility to measure the CP violating parameter $\varepsilon$ is discussed.

## 2. Kinematics of the decay

The measured value of $\Delta = M_{K^0} - M_{K^+}$ is $3.972 \pm 0.027$ MeV [3].
The Dalitz plot is reported in Fig.1.
The momentum distributions of the $K^+$ and $e^-$ in the Center of Mass System (CMS) of the $K_L$ are reported in Fig.2. In the case of low energy $K_L$ (for instance $P_{K_L} = 110\ MeV/c$) as in KLOE, the momentum distributions of the charged particles in the Laboratory System are reported in Fig.3.

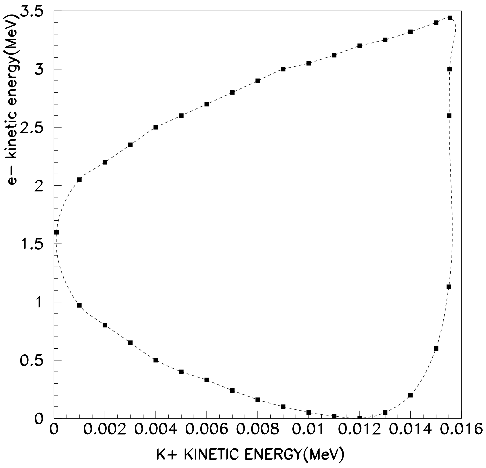

**Figure 1:** Dalitz plot contour of the $K_L^0 \Rightarrow K^{\pm}e^{\mp}(\overline{\nu}/\nu)$ decay.

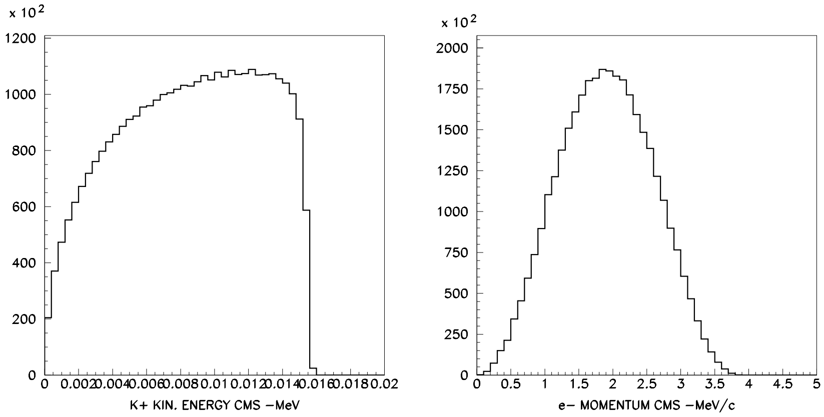

**Figure 2:** CMS distributions of the $K^+$ kinetic energy and of the $e^-$ momentum.

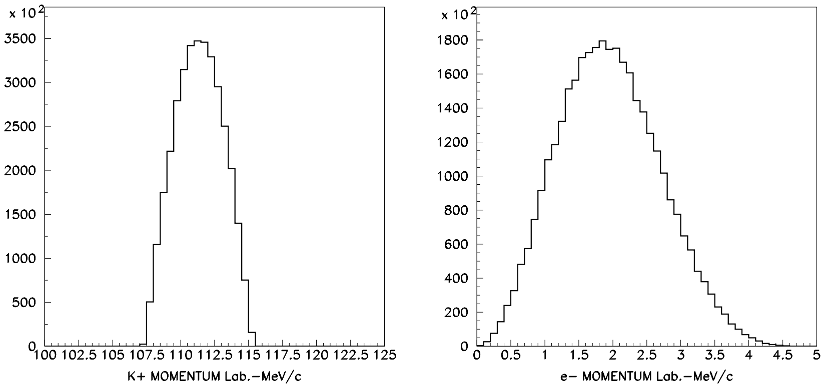

**Figure 3:** Momentum distributions of the $K^+$ and of the $e^-$ in the lab. syst.

## 3. Expected rate for the decay $K_L^0 \Rightarrow K^+e^-\overline{\nu}$ and $K_L^0 \Rightarrow K^-e^+\nu$

The rate for the kaon beta decay is directly related to the ft value for nuclear beta decay. Sirlin [1], has calculated the inverse lifetime $\frac{1}{\tau}$ for the $\pi$ beta decay ($\pi^+ \Rightarrow \pi^0 e^+ \nu$); the same expression has been used (with the obvious mass substitution and taking into account the isospin difference between kaons and pions) for the K beta decay:

$$\frac{1}{\tau_0} = \frac{G_{\beta V}^2}{60\pi^3}(1-\frac{\Delta}{2m_0})^3\Delta^5 F(\eta,\Delta) \tag{1}$$

$$\frac{1}{\tau} = \frac{1}{\tau_0}(1+\delta_K)$$

were $\tau_0$ is the lifetime in absence of radiative correction, $G_{\beta V}$ is the weak-interaction coupling constant for pure vector beta decay, $\Delta$ is the $K^0 - K^+$ mass difference, $m_0$ is the $K^0$ mass and the function F was evaluated as $0.9224 \pm 0.0010$.

The function $F(\eta,\Delta)$ was indeed calculated in such a way :

$$F(\eta,\Delta) = \sqrt{1-\eta}(1-\frac{9\eta}{2}-4\eta^2)+\frac{15}{2}\eta^2\ln\frac{1+\sqrt{1-\eta}}{\sqrt{\eta}}-\frac{3}{7}(\frac{\Delta}{m_+ + m_0})^2$$

where

$$\eta = (\frac{m_e}{\Delta})^2$$

The mean lifetime $t$ for nuclear beta decay is given by:

$$\frac{1}{t} = \frac{G_{\beta V}^2}{\pi^3} m_e^5 f \qquad (2)$$

were $f$ is the phase-space factor.
The CVC hypothesis is that $G_{\beta V}$ is the same in Eqs 1 and 2.
Following Sirlin [1], the radiative corrections are the same for meson and nuclear beta decays, except for a small energy release-dependent correction $\delta^0$.
Thus the following expression is obtained ($t^{'}$ is the half life):

$$\frac{1}{\tau} = \frac{\ln 2}{(60ft^{'})}(\frac{\Delta}{m_e})^5(1-\frac{\Delta}{2m_0})^3 F(\eta,\Delta)(1+\delta_K^0) \qquad (3)$$

Using the numerical value in table 1, the equation (3) gives:

$$\frac{1}{\tau} = (0.0979 \pm 0.0037)s^{-1}$$

and, using the $K_L$ lifetime, the calculated branching ratio for the $K_L$ beta decay is:

$$B.R. = (0.5071 \pm 0.0199) \times 10^{-8}$$

**Table 1:** Data used for the calculation of expected rate and branching ratio.

| Factor | Value | Ref. |
|---|---|---|
| $ft^{'}$ | $3083.4 \pm 3.0$ s | [2] |
| $\Delta$ | $3.972 \pm 0.027$ MeV | [3] |
| $m_+$ | $493.677 \pm 0.016$ MeV | [3] |
| $m_0$ | $497.648 \pm 0.022$ MeV | [3] |
| $m_e$ | $0.51099892 \pm 0.00000004$ MeV | [3] |
| $\delta_K^0$ | $0.0105 \pm 0.0015$ | [4] |
| $t_K$ | $(5.18 \pm 0.04) \times 10^{-8}$s | [3] |

**Table 2:** Experiments and future projects of high intensity $K_L$ beams.

| Exp. | Lumin. or Prot./pulse | Av.$K_L$ Mom. | Efficiency | Ref. | Expected events |
|---|---|---|---|---|---|
| KLOE-LNF | $2.0 fb^{-1}$ | 0.11 GeV/c | 39 % | [6] | 4.0 |
| KLOE2-LNF | $50.0 fb^{-1}$ | 0.11 GeV/c | 39 % | [7] | 99.5 |
| NA48-CERN | $1.1 \times 10^{12}$ | 110.0 GeV/c | 2.6 % | [9] | $5.0 \times 10^2$ |
| KTeV-99 FLab | $1. \times 10^{13}$ | 70 GeV/c | 2.1 % | [8] | $3.2 \times 10^2$ |
| E391A-KEK | $2. \times 10^{12}$ | 2. GeV/c | 4.3 % | [8] | $1.4 \times 10^3$ |
| JHF-J-PARC | $2. \times 10^{14}$ | 2. GeV/c | 4.3 % | [8] | $7.1 \times 10^5$ |

## 4. Possibility to detect the $K_L \Rightarrow K^+e^-\overline{\nu}$ AND $K_L \Rightarrow K^-e^+\nu$ decay

The evaluated number of decays of this type are reported in table 2 for actual experiments and for future facilities:

The particular topology of the events can help their selection , but background could be important. Some general considerations are reported here:

1) It is extremely important to detect the electron, which is of very low energy. In the third column of table 2, the average momentum of the $K_L$ is reported; the $e^-$ coming from the $\beta$ decay of the $K_L$ is however of low energy in any case.

In Fig.4 the expected momentum distributions of the electrons are reported in two cases, for 2 GeV/c (J-PARC and E391A) and for 10 GeV/c $K_L$.

2) It is also important to detect the $K^+$ decay in the most frequent decay mode $K^+ \Rightarrow \mu^+ + \nu$ (63.4 %).

3) In KLOE, the $K_L$ are originated by the $\Phi$ decay; so they are coupled to a $K_S$; on the contrary, $K^+$ are accompanied by a $K^-$ (so the signal $K_L^0 \Rightarrow K^+e^-\overline{\nu}$ must be associated to a $K_S^0$ and not to a $K^-$).

4) The topology of the events in any case should be:

a) an electron of low energy.

b) a muon (from $K^+ \Rightarrow \mu^+\nu_\mu$).

c) no other charged tracks.

5) This configuration is really typical but at least two kinds of background must be taken into account :

- the charge exchange reaction (in the tracker or in the residual gas of the decay region):

  $$K^0 p \Rightarrow K^+\pi^0 n$$

  where $K^+ \Rightarrow \mu^+\nu$ and $\pi^0 \Rightarrow e^+e^-\gamma$ (Dalitz mode), with a strongly asymmetric Dalitz pair; furthermore the $\gamma$ and the $e^+$ must escape the detection (this background reaction is forbidden for KLOE because under threshold).

- The leptonic decay :

$$K_L^0 \Rightarrow \pi^+ e^- \overline{\nu}$$

where the $\pi^+$ fakes a $K^+$ and the electron is in the corresponding energy region. If the detector is able to make accurate measurementes of the Specific Ionization, the $\pi^+$ can be easily distinguished from the $K^+$ and practically this background can be eliminated.

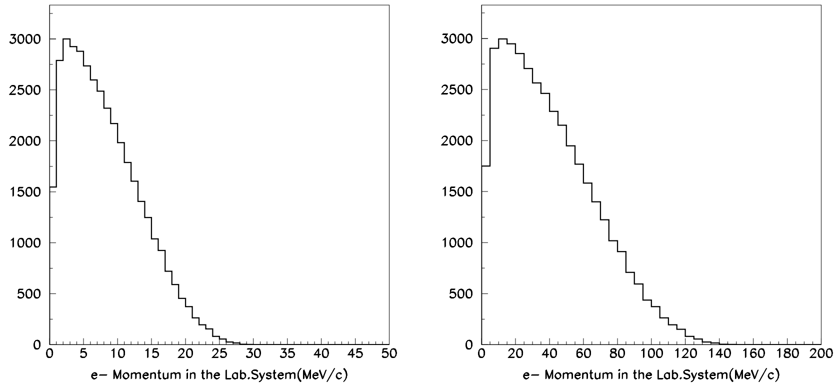

**Figure 4:** Momentum distributions of e$^-$, for 2 GeV/c and 10 GeV/c K$_L$.

The efficiencies reported in table 2 take into account only the probability of a decay in the fiducial volume.

The expected number of events reported in table 2 for KTeV-99, E391A-KEK and JHF refers to a running time as $3 \times 10^7$ s and a running efficiency as 50 % ; for NA48 this number refers to the total data collected in 1998 and 1999.

## 5. CP Violation

If the collected events will have a very small statistical error (order of magnitude $10^6$ events like at JPARC), a new way to measure the CP violation parameter $\varepsilon$ would be realized.

The two reactions $K_L^0 \Rightarrow K^+ e^- \overline{\nu}$ and $K_L^0 \Rightarrow K^- e^+ \nu$ are CP conjugated as the two semileptonic reactions $K_L^0 \Rightarrow \pi^+ e^- \overline{\nu}$ and $K_L^0 \Rightarrow \pi^- e^+ \nu$ .

The ratio

$$R = \frac{\sigma(K_L^0 \Rightarrow K^+ e^- \overline{\nu}) - \sigma(K_L^0 \Rightarrow K^- e^+ \nu)}{\sigma(K_L^0 \Rightarrow K^+ e^- \overline{\nu}) + \sigma(K_L^0 \Rightarrow K^- e^+ \nu)}$$

is expected to have the same absolute value and the opposite sign of the corresponding ratio for the semileptonic decays:

$$\simeq -2 \times Re(\varepsilon)$$

$\varepsilon$ is the usual indirect CP violation parameter.

## 6. Conclusions

In conclusion, the decay $K^0 \Rightarrow K^{\pm}e^{\mp}(\overline{\nu}/\nu)$ was never examined in the past, probably due to its very small phase space, but now is the time to see it and to test the CVC rule, in the frame of the first $\Delta S = 0$ weak decay of a strange meson.
*DAΦNE* and the projects of the new high intensity K factory (foreseen for instance to study the FCNC $K$ Decay like $K^0 \Rightarrow \pi^0\nu\overline{\nu}$) can easily study such a decay, test the CVC rule and, probably, investigate the CP violation in a new way.

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