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# Status of the measurement of $K_S \to \pi e \nu$ branching ratio and lepton charge asymmetry with the KLOE detector

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**Abstract.** We present the current status of the analysis of about 1.7 billion $K_S K_L$ pair events collected at DAΦNE with the KLOE detector to determine the branching ratio of $K_S \to \pi e \nu$ decay and the lepton charge asymmetry. This sample is ~ 4 times larger in statistics than the one used in the previous most precise result, from KLOE as well, allowing us to improve the accuracy on the measurement and related tests of CPT symmetry and $\Delta S = \Delta Q$ rule.

## 1 Introduction

The $\mathcal{CPT}$ symmetry assumes invariance of physical laws under the combination of the symmetries such as charge conjugation ($\mathcal{C}$), parity ($\mathcal{P}$) and time reversal ($\mathcal{T}$). One of possible ways to test violation of $\mathcal{CPT}$ symmetry and basic assumptions of the Standard Model in the neutral kaon system is based on the difference between charge asymmetries for short-lived kaon ($A_S$) and for long-lived kaon ($A_L$). Presently this difference is compatible with zero within errors, which suggests conservation of $\mathcal{CPT}$ symmetry, however the value of $A_L$ [1] was determined with a precision more than two orders of magnitude better than $A_S$ [2].

## 2 Charge asymmetry and experimental verification

According to the Standard Model, weak force is responsible for semileptonic decay of $K^0$ or $\bar{K}^0$. This implies that only two of four possible $K^0$ or $\bar{K}^0$ semileptonic decays occur (Figure 1, Table 1) and the change of strangeness ($\Delta S$) entails the corresponding change of electric charge ($\Delta Q$). This is the $\Delta S = \Delta Q$ rule. Semileptonic amplitudes can be parametrized as shown in Table 1 and connected to the conservation of discrete symmetries (Table 2) [3].

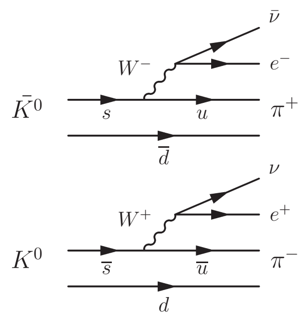


**Figure 1.** Feynman diagrams for $K^0$ and $\bar{K}^0$ semileptonic decays.

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**Table 1.** Relations between semileptonic decays of $K^0(\bar{K^0})$, introduced parametrization and discrete symmetries.

| According to the Standard Model | Decay | Matrix element parametrization | | |
|---|---|---|---|---|
| allowed | $K^0 \to \pi^- e^+ \bar{\nu}$ | $a + b$ | $= \langle \pi^- e^+ \nu \| H_{weak} \| K^0 \rangle$ | $=$ (if $\mathcal{CP}$) $= a^* + b^*$, |
| allowed | $\bar{K^0} \to \pi^+ e^- \nu$ | $a^* - b^*$ | $= \langle \pi^+ e^- \bar{\nu} \| H_{weak} \| \bar{K^0} \rangle$ | $=$ (if $\mathcal{CP}$) $= a + b$, |
| not allowed | $K^0 \to \pi^+ e^- \nu$ | $c + d$ | $= \langle \pi^+ e^- \bar{\nu} \| H_{weak} \| K^0 \rangle$ | $=$ (if $\mathcal{T}$) $= c^* - d^*$, |
| not allowed | $\bar{K^0} \to \pi^- e^+ \bar{\nu}$ | $c^* - d^*$ | $= \langle \pi^- e^+ \nu \| H_{weak} \| \bar{K^0} \rangle$ | $=$ (if $\mathcal{T}$) $= c + d$. |

**Table 2.** Relations between discrete symmetries and semileptonic amplitudes.

| | | Conserved quantity | | | |
|---|---|---|---|---|---|
| | | $\mathcal{CP}$ | $\mathcal{T}$ | $\mathcal{CPT}$ | $\Delta S = \Delta Q$ |
| Parameter | a | $Im = 0$ | $Im = 0$ | | |
| | b | $Re = 0$ | $Im = 0$ | $= 0$ | |
| | c | $Im = 0$ | $Im = 0$ | | $= 0$ |
| | d | $Re = 0$ | $Im = 0$ | $= 0$ | $= 0$ |

Semileptonic amplitudes can be associated to the $K_S$ and $K_L$ semileptonic decay widths through the charge asymmetry:

$$
\begin{aligned}
A_{S,L} &= \frac{\Gamma(K_{S,L} \to \pi^- e^+ \nu) - \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})}{\Gamma(K_{S,L} \to \pi^- e^+ \nu) + \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})} \\
&= 2\left[Re\,(\epsilon_K) \pm Re\,(\delta_K) + Re\left(\frac{b}{a}\right) \mp Re\left(\frac{d^*}{a}\right)\right] \\
&\text{if } \Delta Q = \Delta S \\
&= 2\left[Re\,(\epsilon_K) \pm Re\,(\delta_K) + Re\left(\frac{b}{a}\right)\right] \\
&\text{if } \mathcal{CPT} \text{ and } \Delta Q = \Delta S \\
&= 2\left[Re\,(\epsilon_K)\right].
\end{aligned}
$$

The charge asymmetry for $K_L$ was precisely determined from the KTeV experiment at Fermilab [1]:

$$A_L = (3.322 \pm 0.058_{stat} \pm 0.047_{syst}) \times 10^{-3}, \tag{1}$$

while the most precise measurement of $A_S$ was conducted by the KLOE collaboration [2]:

$$A_S = (1.5 \pm 9.6_{stat} \pm 2.9_{syst}) \times 10^{-3}. \tag{2}$$

The obtained charge asymmetry for $K_S$ decays is consistent, within error, with the charge asymmetry for $K_L$ decays, which suggests conservation of $\mathcal{CPT}$ symmetry. This result is dominated by the statistical uncertainty which is three times larger than the systematic contribution.

## 3 Measurement

The KLOE experiment is located at DAΦNE $e^+e^-$ collider that works at the center of mass energy of the $\phi$-meson mass ( $\sqrt{s} = m_\phi$). The KLOE detector was optimized for efficient detection of long-lived kaons. A 2 m radius drift chamber allows to register around 40% of long-lived kaon decays inside the chamber while the rest reach the electromagnetic calorimeter. Identification of events with long-lived kaon ensures occurrence of short-lived kaon near the interaction point and vice versa. In order to improve signal over background ratio kinematic selection is applied. On remaining events the time-of-flight technique, which aims at rejecting background and identifying the final charge states ($\pi^+e^-\bar{\nu}$ and $\pi^-e^+\nu$), is used. Altogether about $10^5$ $K_S \to \pi e \nu$ decays were reconstructed, which will be used for the measurement of the charge asymmetry and branching ratio for $K_S$ semileptonic decays. The analysis is still in progress, nevertheless it shows potential of reaching a twice better statistical error determination based on four times larger data sample. Also, due to the upgrade of KLOE detector and DAΦNE collider, further reduction of systematical and statistical uncertainties are expected in the future [4].


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