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

Daria Kamińska
on behalf of the KLOE-2 collaboration
Institute of Physics, Jagiellonian University, Cracow, Poland

Abstract

We present the current status of the analysis of about 1.7 billion $K_S K_L$ pair events collected at DAFNE 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 a previous KLOE analysis, allowing us to improve the accuracy of the measurement and of the related tests of $\mathcal{CPT}$ symmetry and $\Delta S = \Delta Q$ rule.

1 Introduction

A special role in $\mathcal{CPT}$ violation searches plays a neutral kaon system which, due to a sensitivity to a variety of symmetry violation effects, is one of the best candidates for such kind of studies. One of the possible tests is based on the comparison between semileptonic asymmetry in K_S decays (A_S) and the analogous asymmetry in K_L decays (A_L) [3]. So far the A_L [4] was determined with a precision more than two orders of magnitude better than A_S [5]. The present accuracy of A_S determination is dominated by the statistical uncertainty. Therefore the aim of this work is a determination of A_S with two times smaller statistical error due to four times bigger data sample and improved systematical uncertainties. Charge asymmetry is also an important source of information about the real and imaginary parts of the $\mathcal{CPT}$ violating parameter δ_K. Until now $Re(\delta_K)$ was known with much worse precision than $Im(\delta_K)$.

The measurement was performed using KLOE detector [1] located at DAΦNE accelerator [2] in the National Laboratory in Frascati, Italy. The experimental data used in this paper has been collected during data campaign in 2004-2005.

2 Charge asymmetry in neutral kaons semileptonic decays

Neutral kaons are the lightest particles which contain a strange quark. Observed short-living K_S and long-living K_L are linear combinations of strange eigenstates (K^0 and $\bar{K^0}$):

$$
\begin{aligned}
|K_S\rangle &= \frac{1}{\sqrt{2(1+|\epsilon_S|^2)}}\left((1+\epsilon_S)\,|K^0\rangle + (1-\epsilon_S)\,|\bar{K^0}\rangle\right), \\
|K_L\rangle &= \frac{1}{\sqrt{2(1+|\epsilon_L|^2)}}\left((1+\epsilon_L)\,|K^0\rangle - (1-\epsilon_L)\,|\bar{K^0}\rangle\right).
\end{aligned} \tag{1}
$$

where introduced small parameter ϵ_S and ϵ_L can be rewritten to separate $\mathcal{CP}$ and $\mathcal{CPT}$ violation parameters ϵ_K and δ_K, respectively:

$$
\begin{aligned}
\epsilon_S &= \epsilon_K + \delta_K, \\
\epsilon_L &= \epsilon_K - \delta_K.
\end{aligned} \tag{2}
$$

In the Standard Model decay of K^0 (or $\bar{K^0}$) state is associated with the transition of the $\bar{s}$ quark into $\bar{u}$ quark (or s into u) and emission of the charged boson. Change of strangeness (ΔS) implies the corresponding change of electric charge (ΔQ) (see Figure 1). This is so called $\Delta S = \Delta Q$ rule. Therefore decays of $K^0 \to \pi^- e^+ \nu$ and $\bar{K^0} \to \pi^+ e^- \bar{\nu}$ are present but $K^0 \to \pi^+ e^- \bar{\nu}$ and $\bar{K^0} \to \pi^- e^+ \nu$ are not. Decay amplitudes for semileptonic decays of states $|K^0\rangle$

	initial state		**final state**
S	1	$\longrightarrow$	0
Q	0	$\longrightarrow$	1

	initial state		**final state**
S	-1	$\longrightarrow$	0
Q	0	$\longrightarrow$	-1

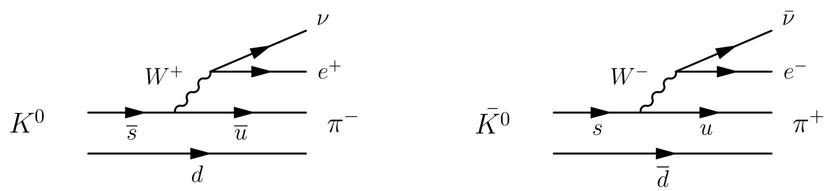

Figure 1: Feynman diagrams for K^0 and $\bar{K^0}$ semileptonic decay.

and $|\bar{K^0}\rangle$ can be written as follows [3]:

$$
\begin{aligned}
\langle \pi^- e^+ \nu | \, H_{weak} \, | K^0 \rangle &= a + b \\
\langle \pi^+ e^- \bar{\nu} | \, H_{weak} \, | \bar{K^0} \rangle &= a^* - b^* \\
\langle \pi^+ e^- \bar{\nu} | \, H_{weak} \, | K^0 \rangle &= c + d \\
\langle \pi^- e^+ \nu | \, H_{weak} \, | \bar{K^0} \rangle &= c^* - d^*
\end{aligned} \tag{3}
$$

where the H_{weak} is a part of Hamiltonian corresponding to the weak interaction and a, b, c, d parameters describe the semileptonic decay amplitudes. Applying the symmetry operators to above amplitudes a set of relations between them can be obtained (Table 1). Semileptonic decay amplitudes can be associated with the K_S and K_L semileptonic decay widths through the charge asymmetry ($A_{S,L}$):

$$
\begin{aligned}
A_{S,L} &= \frac{\Gamma(K_{S,L} \to \pi^- e^+ \nu) - \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})}{\Gamma(K_{S,L} \to \pi^- e^+ \nu) + \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})} \\
&= 2 \left[Re\left(\epsilon_K\right) \pm Re\left(\delta_K\right) + Re\left(\frac{b}{a}\right) \mp Re\left(\frac{d^*}{a}\right) \right] \\
&\text{if } \Delta Q = \Delta S \\
&= 2 \left[Re\left(\epsilon_K\right) \pm Re\left(\delta_K\right) + Re\left(\frac{b}{a}\right) \right] \\
&\text{if } \mathcal{CPT} \text{ and } \Delta Q = \Delta S \\
&= 2 \left[Re\left(\epsilon_K\right) \right]
\end{aligned} \tag{4}
$$

where above equation contains only the first order of symmetry-violating terms. Moreover, conservation of $\Delta Q = \Delta S$ rule and $\mathcal{CPT}$ symmetry simplifies Equation 4. Determination the value of charge asymmetry for K_S and K_L allows for tests the fundamental assumptions of Standard Model.

	$\mathcal{CP}$	$\mathcal{T}$	$\mathcal{CPT}$	$\Delta S = \Delta Q$
a	$Im = 0$	$Im = 0$		
b	$Re = 0$	$Im = 0$	$= 0$	
c	$Im = 0$	$Im = 0$		$= 0$
d	$Re = 0$	$Im = 0$	$= 0$	$= 0$

Table 1: Relations between discrete symmetries and semileptonic amplitudes.

The charge asymmetry for K_L decays was precisely determined by KTeV experiment at Fermilab [4]. The measurement was based on 1.9 millions $K_L \to \pi^{\pm} e^{\mp} \nu$ decays produced in collision of proton beam with BeO target. At present the most accurate measurement of K_S charge asymmetry was conducted by KLOE collaboration [5]. Obtained charge asymmetry for K_S decays is consistent in error limits with charge asymmetry for K_L decays which suggest conservation of $\mathcal{CPT}$ symmetry. However, this result is dominated by a statistical uncertainty which is three times larger than the systematic one. Nevertheless it can be improved by analysing 1.7 fb^{-1} total luminosity data sample acquired in 2004 and 2005.

3 Measurement

The KLOE experiment located at DAΦNE ϕ factory is specially suited for analysis of $K_S \to \pi e \nu$ decay. The KLOE detector is constituted by two main components: a drift chamber and an electromagnetic calorimeter, both inserted into an axial magnetic field (0.52 T). Due to the size of the KLOE drift chamber, about 40% of K_L mesons decay inside the detector while the rest reach the electromagnetic calorimeter. Detection of K_L interaction in the calorimeter allows to identify a K_S meson on the opposite side of ϕ meson decay point.

In order to select semileptonic decay of K_S meson, an additional kinematic selection is applied. It starts from a requirement of a vertex formed by tracks of two oppositely charged particles near the interaction point. Those tracks must be associated to calorimeter clusters. Obtained tracks parameters allow for identification of charged particles in the final state by applying a Time of Flight technique.

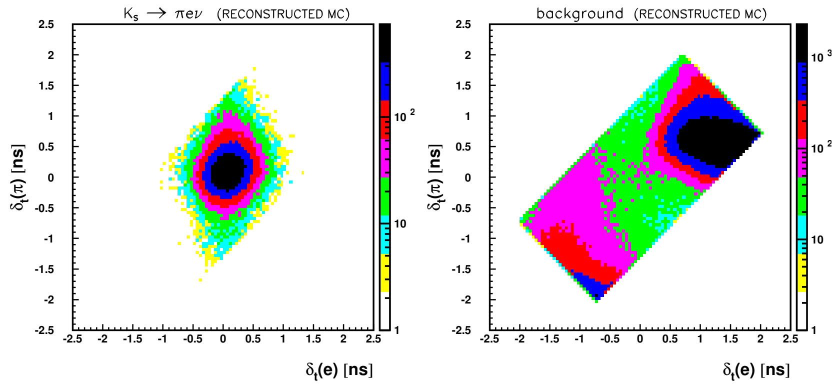

Figure 2: Distributions of the time difference for pion mass hypothesis ($\delta t(\pi)$) versus the time difference for electron mass hypothesis ($\delta t(e)$). Simulations of $K_S \to \pi e \nu$ and background events are shown on left and right plot, respectively.

For each particle, the difference δ_t between the measured time of associated cluster (t_{cl}) and time of flight is calculated assuming a given mass hypothesis, m_x:

$$\delta_t(m_x) = t_{cl} - \frac{L}{c \cdot \beta(m_x)}, \quad \beta(m_x) = \frac{P}{\sqrt{P^2 + m_x^2}}, \tag{5}$$

where L is a total length of particle trajectory and P is particle momentum measured by drift chamber. The Time of Flight technique aims at rejection of the background, which is mainly due to $K_S \to \pi^+\pi^-$ events, and at identification of the final charge states ($\pi^- e^+ \nu$ and $\pi^+ e^- \bar{\nu}$). The distribution of difference between missing energy and momentum ($\Delta E(\pi, e)$) shows remaining background components (see Figure 3). Altogether around 10^5 of $K_S \to \pi e \nu$ decays was reconstructed, which will be used to determine the

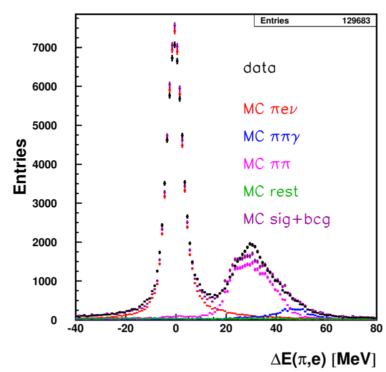

Figure 3: Distribution of $\Delta E(\pi, e) = E_{miss} - p_{miss}$ for all selected events after normalization procedure. Meaning of simulated histograms is described in the legends.

charge asymmetry and branching ratio for K_S semileptonic decays. The analysis is still in progress and preliminary results will be available soon [6].

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