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SEMILEPTONIC DECAYS OF NEUTRAL KAONS AT NA48

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ABSTRACT

In 2001 the NA48 experiment at CERN has performed a new measurement of the branching ratio of the semileptonic neutral kaon decay mode $\mathrm{BR}(K_L \rightarrow \pi^+\pi^0 e^- \nu) = (5.21 \pm 0.07_{\mathrm{stat}} \pm 0.09_{\mathrm{syst}}) \cdot 10^{-5}$ ($Ke4$). A fit of the Cabibbo-Maksymowicz variables for the Ke4 decay yielded new precise values for its form factors. For the decay $K_L \rightarrow \pi^\pm e^\mp \nu(\overline{\nu})$ the linear form factor q^2-dependency (λ_+) has been measured while observing no hint for *scalar* nor *tensor* couplings. In addition the relative branching ratio of the radiative K_{e3} decay was determined to $\mathrm{BR}(K_L \rightarrow \pi^\pm e^\mp \nu(\overline{\nu})\gamma / K_L \rightarrow \pi^\pm e^\mp \nu(\overline{\nu})) = (0.960 \pm 0.07^{+0.012}_{-0.011})\%$.

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1 The NA48 experiment at SPS (CERN)

The data samples used for the analysis presented here have been taken using the K_L beam of the two simultaneous kaon beams of the NA48 experiment dedicated to measure ϵ'. A detailed description of the experiment and the beam-line can be found elsewhere [1].

2 $K_L \to \pi^+\pi^0 e^-\nu$

2.1 Branching ratio

The investigation of the decay $K_L \to \pi^+\pi^0 e^-\nu$ (K_{e4}) represents a good testing-ground to check *ChPT* predictions for long distance meson interactions. A previous measurement of that decay has been performed by the experiment *E731* at *Fermilab* with a data sample of 729 events. Using data collected during a run in 2001 by NA48, 5464 selected signal events with an estimated background of 62 events have been recorded [2].

When measuring the branching ratio, the decay $K_L \to \pi^+\pi^-\pi^0$ ($K_{\pi 3}$), where one of the charged pions is mis-identified as an electron (positron), turns out to be the main source of background. To reject those events one requires a χ^2 variable, defined as

$$\chi^2_{3\pi} = \left(\frac{M_{3\pi} - M_K}{\sigma_M}\right)^2 + \left(\frac{p_t - p_{t_0}}{\sigma_p}\right)^2, \tag{1}$$

to be greater than 16, where $M_{3\pi}$ is the invariant mass of the visible particles under a 3π assumption, p_t is the transverse momentum, p_{t_0} is the maximum value of the p_t distribution, M_K is the kaon mass and σ is the corresponding resolution. In addition, a neural network which has been trained using well identified e and π from $K_{\pi 3}$ and K_{e3} events improved further the e/π distinction. Using the decay $K_L \to \pi^+\pi^-\pi^0$ with a branching fraction of $(12.58 \pm 0.19)\%$ as the normalization channel, the K_{e4} branching ratio has been determined to be:

$$\mathrm{BR}(K_{e4}) = (5.21 \pm 0.07_{\mathrm{stat}} \pm 0.09_{\mathrm{syst}}) \cdot 10^{-5}. \tag{2}$$

The systematic uncertainty of the result above is dominated by the error on the branching fraction of $K_{\pi 3}$ ($\pm 0.08 \cdot 10^{-5}$). The result measured by

NA48 is consistent with previous measurements [3) 4)] and more accurate by a factor of 2.5 (both statistically and systematically).

Since the neutral K_{e4} branching fraction is mainly sensitive to the chiral coupling parameter L_3 and very little to L_5 and L_9 one can deduce [5)]:

$$L_3 = (-4.1 \pm 0.2) \cdot 10^{-3}. \tag{3}$$

2.2 Form factors

The hadronic part of the matrix element ($V-A$ structure) can be parametrized by the relative (normalized to the g form factor) form factors $\overline{f}_s, \overline{f}_p$ for the vector part and $\overline{h}$ for the axial part. The $M_{\pi\pi}$ dependence of the g form factor is described by the parameter λ_g.

The form factor analysis has been performed by means of 5 kinematic variables, the so-called *Cabibbo-Maksymowicz* variables. A simultaneous fit of all one-dimensional projections was performed, yielding the following results:

$$\begin{aligned} \overline{f}_s &= 0.052 \pm 0.006_{\text{stat}} \pm 0.002_{\text{syst}}, \\ \overline{f}_p &= -0.051 \pm 0.011_{\text{stat}} \pm 0.005_{\text{syst}}, \\ \lambda_g &= 0.087 \pm 0.019_{\text{stat}} \pm 0.006_{\text{syst}}, \\ \overline{h} &= -0.32 \pm 0.12_{\text{stat}} \pm 0.07_{\text{syst}}. \end{aligned} \tag{4}$$

3 Relative branching ratio $K_L \to \pi^\pm e^\mp \nu(\overline{\nu})\gamma / K_L \to \pi^\pm e^\mp \nu(\overline{\nu})$ ($K_{e3\gamma}/K_{e3}$)

The so far most precise measurement of the relative branching fraction $K_{e3\gamma}/K_{e3}$ was reported by the *KTeV* experiment at *Fermilab* to be [6)]

$$Br^{\text{exp}}_{\text{KTeV}}(K_L \to \pi^\pm e^\mp \nu\gamma / K_L \to \pi^\pm e^\mp \nu) = 0.908 \pm 0.008^{+0.013}_{-0.012}\% \tag{5}$$

which is in disagreement with the theoretical predictions of

$$Br^{\text{theo}}(K_L \to \pi^\pm e^\mp \nu\gamma / K_L \to \pi^\pm e^\mp \nu) = (0.95 - 0.99)\%. \tag{6}$$

The NA48 experiment has performed a measurement of this relative branching fraction using a special 2 days run of the year 1999 dedicated to collect K_{e3} and $K_{e3\gamma}$ decays, applying only a minimum bias trigger. It turned out that the Monte Carlo simulation using the *PHOTOS* [7] package and the model by *Fearing, Fischbach* and *Smith* [8] [9] could not reproduce the recorded data very well. Hence in this analysis, in addition to the *PHOTOS* package, the angular distribution between the outgoing e and γ in the CMS system has been weighted to fit the data. This procedure also cured some discrepancies in other observables, for instance in the γ spectrum between data and MC.

Basing on 19000 $K_{e3\gamma}$ and $5.6 \cdot 10^6$ K_{e3} reconstructed events the relative branching ratio has been deduced:

$$Br^{\text{exp}}_{\text{NA48}}(K_L \to \pi^\pm e^\mp \nu\gamma / K_L \to \pi^\pm e^\mp \nu) = 0.960 \pm 0.07^{+0.012}_{-0.011}\%. \qquad (7)$$

This result is in a very good agreement with a recent calculation [10] predicting a theoretical value of:

$$Br^{\text{theo}}_{\text{Andre}}(K_L \to \pi^\pm e^\mp \nu\gamma / K_L \to \pi^\pm e^\mp \nu) = 0.956 \pm 0.01. \qquad (8)$$

4 Form factor measurement of the decay $K_L \to \pi^\pm e^\mp \nu(\overline{\nu})$

Since in former experiments [11] [12] evidence for non-zero scalar and tensor form factors have been reported, this issue is still of big interest when dealing with semileptonic kaon decays, although recent experiments could not confirm those observations on charged kaon decays [13] [14]. For the extraction of the form factors in the decay $K_L \to \pi^\pm e^\mp \nu(\overline{\nu})$, the data sample from the minimum bias run in 1999 was used as well, resulting in a total amount of $5.6 \cdot 10^6$ reconstructed K_{e3} events. The form factors have been measured by fitting the *Dalitz plot density* allowing for all possible Lorentz-covariant couplings, i.e.

- vector interaction $f_+(q^2) = f_+(0)(1 + \lambda_+ q^2/m_\pi^2)$
- scalar interaction f_S
- tensor interaction f_T

Thereby the following results have been obtained:

$$
\begin{aligned}
\lambda_+ \quad &= 0.0284 \pm 0.0007_{\rm stat} \pm 0.0013_{\rm syst}, \\
|f_S/f_+(0)| \quad &= 0.015^{+0.007}_{-0.010} \pm 0.012_{\rm syst}, \\
|f_T/f_+(0)| \quad &= 0.05^{+0.03}_{-0.04} \pm 0.03_{\rm syst}.
\end{aligned}
\tag{9}
$$

In this analysis no hint for scalar nor tensor couplings could be observed. The correlation of the result between the scalar and tensor form factor is shown in Figure 1.

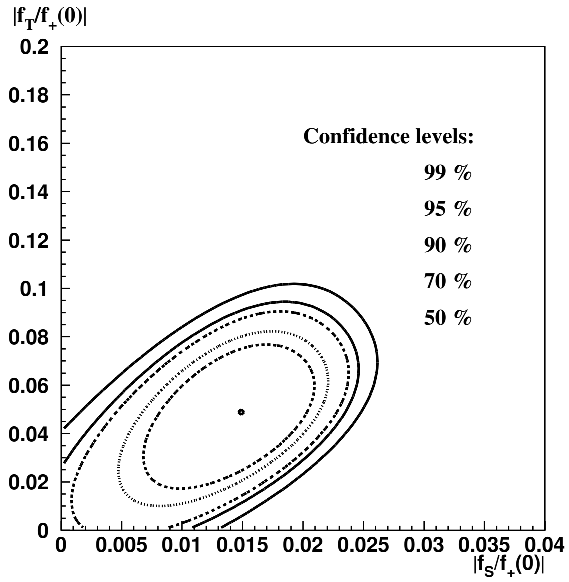

Figure 1: *Confidence levels contour plot in the* $|f_S/f_+(0)|, |f_T/f_+(0)|$ *plane.*

In addition to this general fitting procedure, a more constrained analysis, admitting only a vector form factor in accordance to pure V-A coupling, has been carried out. From this fit the following result for λ_+ has been obtained:

$$
\lambda_+ \quad = 0.0288 \pm 0.0005_{\rm stat} \pm 0.0011_{\rm syst}. \tag{10}
$$

This is in a good agreement with the value calculated above. The form factor measurements presented here are the most precise obtained so far.

5 Outlook

In 2003 and 2004 new measurements on semileptonic charged kaon decays have been performed. Results for the form factors and branching ratios in the charged kaon sector are expected to be reported soon. Other analysis dealing with the form factors of the decay $K_L \to \pi^{\pm}\mu\mp\nu(\overline{\nu})$ are underway. Besides new determinations of V_{us} derived from charged and neutral kaon decays are presented this summer on other conferences.

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