

CP measurements in $K^\pm \rightarrow \pi^\pm l^+ l^-$ and $K_S \rightarrow \pi^+ \pi^- e^+ e^-$ decays at NA48

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The search for and study of CP-violating effects in the kaon system has been a main goal of the NA48 fixed target experiments at the CERN SPS. NA48 made a precision measurement of direct CP violation using simultaneous K_L and K_S beams in 1997-2001. In 2002, the experiment NA48/1 continued with a high intensity K_S run to study rare K_S and hyperon decays. Finally, the beam line was modified to deliver simultaneous K^+ and K^- beams with the goal to search for direct CP violation in $K^\pm \rightarrow 3\pi$ decays (NA48/2). In this letter, we report on CP measurements in rare kaon decays.

The $K_S \rightarrow \pi^+ \pi^- e^+ e^-$ decay mode was investigated using the data collected in 2002 by the NA48/1 collaboration. With about 23k signal events and 59k $K_L \rightarrow \pi^+ \pi^- \pi_D^0$ normalization decays, the $K_S \rightarrow \pi^+ \pi^- e^+ e^-$ branching ratio was determined. This result was used to set an upper limit on the presence of an E1 direct emission term. Finally, the CP-violating asymmetry A_ϕ was measured.

For the measurements of the rare decays $K^\pm \rightarrow \pi^\pm e^+ e^-$ and $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$, the total NA48/2 data set was analyzed, leading to more than 7200 reconstructed candidates in the electronic channel and more than 3100 events in the muonic channel, the latter exceeding the total existing statistics by a factor of four, with low background at the percent level. For both decay modes we measured the branching ratios, the form factors with parametrizations according to different theoretical models, and the CP-violating charge asymmetry between K^+ and K^- .

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The study of the radiative decay $K^0 \rightarrow \pi^+ \pi^- \gamma^* \rightarrow \pi^+ \pi^- e^+ e^-$ provides an interesting ground for the investigation of CP noninvariance. In case of the mostly CP-even short-lived K_S , the decay amplitude is expected to be largely dominated by the CP-even inner bremsstrahlung transition, and no sizeable CP-odd component should be observed[1]. Therefore, the CP-violating asymmetry A_ϕ in the $\sin \phi \cos \phi$ distribution of $K_S \rightarrow \pi^+ \pi^- e^+ e^-$ events, where ϕ is the angle between the $\pi^+ \pi^-$ and $e^+ e^-$ planes in the kaon center of mass, is expected to be 0.

The first observation of $K_S \rightarrow \pi^+ \pi^- e^+ e^-$ was made by NA48; from the full data set recorded in 1998-1999, 677 events were found[2]. With the 2002 data, the statistical precision was significantly improved: in total, 22966 signal candidates with 103 background events were reconstructed. The branching ratio relative to the normalization channel $K_L \rightarrow \pi^+ \pi^- \pi_D^0$ (58983 events) was measured to be: $\text{BR}(K_S \rightarrow \pi^+ \pi^- e^+ e^-)/\text{BR}(K_L \rightarrow \pi^+ \pi^- \pi_D^0) = (3.28 \pm 0.07) \times 10^{-2}$. No E1 direct emission contribution was observed; an upper limit $|g_{E1}/g_{BR}| < 3.0$ at 90% CL was set relative to the inner bremsstrahlung term g_{BR} . The CP-violating asymmetry A_ϕ was found to be $A_\phi = (-0.4 \pm 0.8)\%$, consistent with zero. These results are in good agreement with a description of the $K_S \rightarrow \pi^+ \pi^- e^+ e^-$ decay amplitude dominated by the CP-even inner bremsstrahlung process. (Published in *Physics Letters B* 694 (2011) 301-309)

The flavor-changing neutral current processes $K^\pm \rightarrow \pi^\pm l^+ l^-$ have been described in the framework of Chiral Perturbation Theory[3]. The differential rate for these decays depends on the form factors, for which several models have been proposed[4-6]. Each of the models has two free parameters which can determine a model-dependent branching ratio.

The measurement of the $K^\pm \rightarrow \pi^\pm e^+ e^-$ decay is based on 7253 events, with a background of $(1.0 \pm 0.1)\%$. The very similar decay $K^\pm \rightarrow \pi^\pm \pi_D^0$ was used for normalization. The branching fraction in the full kinematic range has been measured to be $\text{BR}(K^\pm \rightarrow \pi^\pm e^+ e^-) = (3.11 \pm 0.12) \times 10^{-7}$. The shape of the form factor evaluated in the framework of four models gives consistent results with previous measurements. The first simultaneous observation of both charge kaon decays into $\pi^\pm e^+ e^-$ allowed to establish an upper limit for the CP violating asymmetry of K^+ and K^- decay rates of 2.1×10^{-2} at 90% CL. (Published in *Physics Letters B* 677 (2009) 246-254)

The $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$ analysis is based on 3120 reconstructed events, 4.5 times larger than the total world sample, with a background of $(3.3 \pm 0.5)\%$. For normalization, the abundant $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ channel has been used. The model-independent branching fraction has been measured to be $\text{BR}(K^\pm \rightarrow \pi^\pm e^+ e^-) = (9.62 \pm 0.25) \times 10^{-8}$. The form factor $W(z)$, where $z = (M_{\mu\mu}/M_K)^2$, was parametrized according to the four models. In particular, the slope of the linear form factor $W(z) = W_0(1 + \delta z)$ was measured to be $\delta = 3.11 \pm 0.57$. Upper limits of 2.9×10^{-2} and 2.3×10^{-2} on possible charge asymmetry and forward-backward asymmetry were established at 90% CL. (Published in *Physics Letters B* 697 (2011) 107-115)

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