NEW RESULTS ON RARE KAON DECAYS IN NA48

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The main purpose of the NA48 experiment at CERN is the measurement of the direct CP violation parameter $\Re(\epsilon'/\epsilon)$. In addition it offers a competitive program on rare $K_L$ and $K_S$ decays. In the following resent results of the decays $K_S \rightarrow \gamma\gamma$, $K_S \rightarrow \pi^0 e^+e^-$, $K_{S,L} \rightarrow \pi^+\pi^-e^+e^-$ and $K_L \rightarrow 3\pi^0$ are presented.

1 Introduction

Two simultaneous and almost collinear neutral beams converge towards the NA48 detector. The $K_L$ beam is produced from a 450 GeV/c SPS proton beam ($\sim 1.5 \times 10^{12}$ protons per puls (ppp)) 126 m upstream the decay region, for the $K_S$ beam a small fraction of the primary proton beam ($\sim 3 \times 10^7$ ppp) is redirected to a target 6 m upstream the decay region.

The main components of the NA48 detector are a magnetic spectrometer, a liquid krypton electromagnetic calorimeter (LKr), an iron-scintillator hadron calorimeter and a muon identification system. The magnetic spectrometer consisting of four drift chambers and a dipole magnet provides a mean momentum resolution of $\Delta p/p = 0.65\%$ at 45 GeV/c. The LKr is used to measure energy, position and time of electromagnetic showers. Its energy resolution is $\Delta E/E = 0.032/\sqrt{E[GeV]} + 90$ MeV/E $+ 0.42\%$, position and time resolution for a single photon are better than 1.3 mm and 300 ps, respectively. More details can be found elsewhere.

The results presented here are based on data recorded in 1998 and 1999 at different trigger and beam intensity conditions; the analysis of the decays $K_S \rightarrow \gamma\gamma$ and $K_S \rightarrow \pi^0 e^+e^-$ is based on data collected during a 2-day test run in 1999 using a $K_S$ beam only at high intensity ($\sim 6 \times 10^9$ ppp).

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2 Measurement of $\text{Br}(K_S \rightarrow \gamma \gamma)$

The $K_S \rightarrow \gamma \gamma$ decay is sensitive to higher order loop effects in Chiral Perturbation Theory. There are no short distance contributions and the theoretical prediction $^2$ of the branching ratio is $\text{Br}(K_S \rightarrow \gamma \gamma) = (2.3 \pm 0.2) \times 10^{-6}$. The previous measurement by NA31 $^3$ found a branching ratio of $(2.4 \pm 0.9) \times 10^{-6}$.

In order to select $K \rightarrow \gamma \gamma$ candidates the following requirements are made: At least two LKr clusters have to be found; the total energy of the selected cluster pair has to be between 60 GeV and 170 GeV; the center of gravity in the LKr has to be less than 7 cm; no hadronic energy, no drift chamber hits and no anti-counter hits in time can be found. The main contribution to the background comes from $K_S \rightarrow \pi^0 \pi^0$ with two photons lost. For these events the reconstructed vertex is shifted downstream by > 7 m. So the signal region was chosen to be $-2 \, \text{m} < z_{\text{vertex}} < 5 \, \text{m}$. After this cut 450 $K \rightarrow \gamma \gamma$ candidates remain, the vertex distribution of the events without the last cut can be seen in Figure 1. The $K_S \rightarrow \gamma \gamma$ branching ratio has been measured using a binned maximum likelihood method by comparing the data to the expected rates, leaving the branching ratio as a free parameter. The result of the fit is shown in Figure 2. The obtained branching ratio $^4$ is $\text{Br}(K_S \rightarrow \gamma \gamma) = (2.6 \pm 0.4_{\text{stat}} \pm 0.2_{\text{syst}}) \times 10^{-6}$.

3 Search for $K_S \rightarrow \pi^0 e^+ e^-$

A study of the $K_S \rightarrow \pi^0 e^+ e^-$ decay is important for the estimation of the indirect CP violation contribution to the decay $K_L \rightarrow \pi^0 e^+ e^-$. G. D'Ambrosio et al. $^5$ have calculated the branching ratio beyond leading order in the chiral expansion and found $\text{Br}(K_S \rightarrow \pi^0 e^+ e^-) \sim 5.2 \alpha_s^2 \times 10^{-9}$, where $\alpha_s$ is the strength of the indirect CP violating component in $K_L \rightarrow \pi^0 e^+ e^-$, is of the order of 1. The best upper limit on $\text{Br}(K_S \rightarrow \pi^0 e^+ e^-)$ was measured by NA31 to be $\text{Br}(K_S \rightarrow \pi^0 e^+ e^-) < 1.1 \times 10^{-6}$ at 90% CL.

$K_S \rightarrow \pi^0 e^+ e^-$ candidates were selected by requiring events with at least four clusters, two oppositely charged tracks and one vertex. The center of gravity of the clusters in LKr has to be $< 10 \, \text{cm}$; the invariant mass of the $\pi^0 e^+ e^-$ candidates was required to be within 2.5 $\text{MeV}/c^2$ (2.5 $\sigma$) with respect to the nominal $K^0$ mass and the invariant mass of the two LKr clusters with no associated tracks had to be within 2.5 $\text{MeV}/c^2$ (3 $\sigma$) within the nominal $\pi^0$ mass. A potentially severe background mode is the decay $K_S \rightarrow \pi_p^0 \pi_n^0$, where both $\pi^0$s undergo Dalitz decays $\pi^0 \rightarrow e^+ e^- \gamma$ and one electron and one positron from different $\pi^0$s are lost. To reject these events, the difference $|m_{ee} - m_{\gamma\gamma}|$ for both combinations of electron-photon pairs were required to be above 30 $\text{MeV}/c^2$. 

Figure 1: $z_{\text{vertex}}$ distribution

Figure 2: Fitted $K_S \rightarrow \gamma \gamma$ signal
The main background comes from $K_S \rightarrow \pi^0\pi^0_D$ and one photon lost. This background is rejected by requiring an invariant mass of the two electrons $> 165 \text{ MeV}/c^2$, based on a simulation of $0.6 \times 10^8 K_S \rightarrow \pi^0\pi^0_D$ decays (see Figure 3). This translates to less than 0.07 events expected to remain in the data sample. After all cuts no candidate was found. Using the value of the signal acceptance, calculated assuming the matrix element from the model, an upper limit was found for the branching ratio to be: $Br(K_S \rightarrow \pi^0\gamma\pi^-\gamma) < 1.4 \times 10^{-7}$ (at 90% CL).

4 Investigation of $K_L \rightarrow \pi^+\pi^-e^+e^-$

The investigation of the decay $K_L \rightarrow \pi^+\pi^-e^+e^-$ provides a novel way to probe the CP violation in the neutral kaon system. The amplitude for this decay is dominated by two components: one from the CP conserving direct photon emission with a magnetic dipole transition (M1), the other from the CP violating $K_L \rightarrow \pi^+\pi^-$ decay with inner bremsstrahlung. The interference causes a CP violating circular polarization of the virtual photon which gives rise to a large asymmetry in the distribution of the angle $\phi$ between the $\pi^+\pi^-$ and the $e^+e^-$ planes. From theoretical predictions, we expect an asymmetry of the order of 14%. The analysis for this decay is based on the data collected in 1998 and 1999. Events were selected requiring two positive and two negative tracks, for the electron/pion separation the $E/p$ value of the tracks is used. The invariant mass of the four particles $m_{\pi\pi\pi\pi}$ has to be between $482.7 \text{ MeV}/c^2$ and $507.7 \text{ MeV}/c^2$. Using the values $\beta_{M1} = 1.35 \pm 0.20$ and $a_1/a_2 = -0.72 \pm 0.3 \text{ GeV}^2/c^2$ measured by KTeV, we obtain the preliminary results for the asymmetry (see Figure 5) $A_{\pi\pi\pi\pi} = (13.9 \pm 2.7 \text{stat} \pm 1.4 \text{sys})\%$ and the branching ratio: $Br(K_L \rightarrow \pi^+\pi^-e^+e^-) = (3.1 \pm 0.1 \text{stat} \pm 0.2 \text{sys}) \times 10^{-7}$.

5 Observation of $K_S \rightarrow \pi^+\pi^-e^+e^-$

The main production process for $K_S \rightarrow \pi^+\pi^-e^+e^-$ is the CP conserving $K_S \rightarrow \pi^+\pi^-$ decay with inner bremsstrahlung therefore no significant asymmetry in the $\phi$ distribution is expected in this case. The first observation of this decay mode comes from a clean sample of 56 events obtained with the 1998 data. The analysis of this decay mode relies not only on the very good vertex resolution for $K_S/K_L$ separation but also on the $K_S$ tagging detector which provides an extra factor of 20 in the background suppression from the $K_L$ beam. Figure 4 shows the distribution of the invariant mass $m_{\pi\pi\pi\pi}$ for $K_S \rightarrow \pi^+\pi^-e^+e^-$ candidates. Based on the 1998 data we obtained a branching ratio of $Br(K_S \rightarrow \pi^+\pi^-e^+e^-) = (4.5 \pm 0.1 \text{stat} \pm 0.4 \text{sys}) \times 10^{-5}$. For the combined data of 1998 and 1999 including the $K_S$ high intensity run in 1999 we find a preliminary result of $Br(K_S \rightarrow \pi^+\pi^-e^+e^-) = (4.3 \pm 0.2 \text{stat} \pm 0.3 \text{sys}) \times 10^{-5}$ and no asymmetry is observed: $A_{\pi\pi\pi\pi} = (-0.2 \pm 3.4 \text{stat} \pm 1.4 \text{sys})\%$. 

Figure 3: $m_{\pi\pi\pi\pi}$ spectra for signal and background

Figure 4: Invariant $\pi^+\pi^-e^+e^-$ mass distribution for 1998 data
6 $K_L \to 3\pi^0$ Dalitz plot slope

The $K \to 3\pi^0$ Dalitz plot distribution can be simplified for $K_L \to 3\pi^0$ to $|M(R^2, \theta)|^2 \propto 1 + h \times R^2$. A positive/negative value of the quadratic slope parameter $h$ would mean that asymmetric/symmetric final states are favored. Combining the Dalitz plot slope parameter $h$ with the linear and quadratic slope parameters in the $K^\pm \to \pi^\pm \pi^\mp \pi^\mp$ decay allows to probe the validity of the $\Delta I = 1/2$ rule. The theoretical predictions\textsuperscript{11,12} for the parameter $h$ are varying from $(-12 \pm 4) \times 10^{-3}$ to $h \approx +1.4 \times 10^{-3}$ and there is only one previous measurement from 1992 by E731\textsuperscript{13}: $h = (-3.3 \pm 1.1_{\text{stat}} \pm 0.7_{\text{sys}}) \times 10^{-3}$.

The $K_L \to 3\pi^0 \to 6\gamma$ events were selected by requiring six clusters in the LKr with a center-of-gravity of the clusters in the LKr < 10 cm. This leads to $\approx 14.5 \times 10^9$ very clean $3\pi^0$ events with no background left. The data was divided by normalized MC($h = 0$) and fitted in the region $0 < R^2 < 1.9$ to avoid resolution effects at the edge, see Figure 6. We found the preliminary result: $h = (-6.1 \pm 0.9_{\text{stat}} \pm 0.5_{\text{sys}}) \times 10^{-3}$.

References