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NEW RESULTS FROM NA48 ON RARE NEUTRAL KAON DECAYS*

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NA48 has searched for rare neutral kaon decays in data collected in 1998 and 1999. These searches were performed with simultaneous $K_{\rm L}$ and $K_{\rm S}$ beams during the ε'/ε programme. Preliminary results for the decays $K_{\rm L} \to \pi^0\gamma\gamma$, $K_{\rm L} \to e^+e^-e^+e^-$ and $K_{\rm L} \to \mu^+\mu^-e^+e^-$ are presented.

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1. Introduction

The NA48 experiment at the CERN-SPS was primarily designed to measure direct CP-violation in neutral kaon decays to two pions. However, due to high resolution detectors and many triggers, the NA48 experiment also allows for the investigations of rare $K_{\rm L}$ and $K_{\rm S}$ decays.

The $K_{\rm L}$ and $K_{\rm S}$ particles are generated by aiming a beam of 450 GeV$/c$ protons onto two beryllium targets, located 126 m and 6 m, respectively, from the decay region. The experimental layout and detector descriptions can be found elsewhere [1].

2. $K_{\rm L} \to \pi^0\gamma\gamma$

Studies of the decay $K_{\rm L} \to \pi^0\gamma\gamma$ provide us with the opportunity of understanding low-energy hadron dynamics in the context of CHiral Perturbation Theory (CHPT) [2]. CHPT calculations of $\mathcal{O}(p^4)$ only predict

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1/3 of the measured rate for this decay [3]. Theoretical calculations performed to $\mathcal{O}(p^6)$ including a Vector Meson Dominance (VMD) contribution, parameterised by a_V, predict a rate compatible with current measurements. Furthermore, a tail at low $m_{\gamma\gamma}$ is predicted. This decay has additional importance by providing information on the CP conserving contribution to the decay $K_{\rm L} \to \pi^0 e^+ e^-$. The CP conserving contribution can be calculated using the VMD component in the decay $K_{\rm L} \to \pi^0\gamma\gamma$.

Results presented here, come from the 1999 and part of 1998 data sample. To normalise to the kaon flux, $K_{\rm L} \to \pi^0\pi^0$ was used. Both decays are accepted by the same neutral trigger [1]. The two decays are selected in the offline analysis by taking events with four clusters in the electromagnetic calorimeter and no hits in the drift chambers. The main background comes from $K_{\rm L} \to \pi^0\pi^0\pi^0$ decays, where photons escape experiment's acceptance or produce overlapping clusters in the calorimeter. In these cases, as a consequence of missing photon energy, the reconstructed kaon-decay vertex usually lies downstream of the true decay position. Therefore, most of the background events are rejected by requiring the kaon-decay vertex to occur in the first 20 m after the end of the beam collimator. Additionally, if two or three photon candidates are compatible with the reconstruction of one or two π^0, respectively, originating more than 6 m upstream of the kaon decay vertex, the event is rejected.

Using the aforementioned data sample, a signal of 1397 $K_{\rm L} \to \pi^0\gamma\gamma$ decays has been identified, above a background of about 30 events (see Fig. 1). The acceptance was determined using a simulation in which events were generated with $a_V = -0.45$. A preliminary measurement of the branching

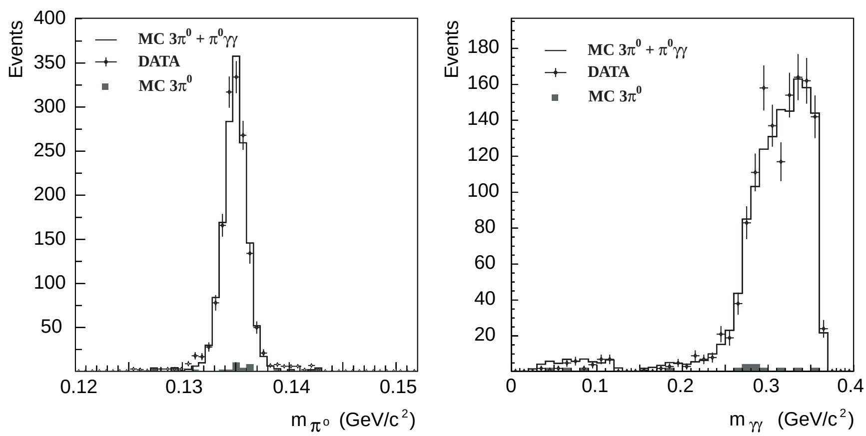

Fig. 1. Distributions of (left) m_{π^0} and (right) $m_{\gamma\gamma}$ for the $K_L \to \pi^0\gamma\gamma$ sample.

fraction gives:

$$\mathrm{Br}(K_{\mathrm{L}} \to \pi^0\gamma\gamma) = 1.51 \pm 0.05(\mathrm{stat}) \pm 0.20(\mathrm{sys}) \times 10^{-6}.$$

3. $K_{\mathrm{L}} \to l^+l^-e^+e^-$

The decay $K_{\mathrm{L}} \to l^+l^-e^+e^-$ proceeds via $K_{\mathrm{L}} \to \gamma^*\gamma^*$, hence being a source of information on $\gamma^*\gamma^*$ vertex. The theoretical predictions for the rates are 3.85×10^{-8} with a 4% effect due to the form factor for $l = e$ and 1.30×10^{-9} with a 30% effect due to the form factor for $l = \mu$ [4]. The $\gamma^*\gamma^*$ vertex has great significance in the decay $K_{\mathrm{L}} \to \mu^+\mu^-$.

3.1. $K_{\mathrm{L}} \to \gamma^*\gamma^*$ and ρ

There are two contributions to the rate of $K_{\mathrm{L}} \to \mu^+\mu^-$, the short and long distance interactions. The short distance interaction is of particular interest due to its dependence on the parameter ρ, from the Wolfenstein parameterisation of the CKM matrix. The short distance contribution to the rate can be expressed as [5]:

$$\begin{aligned} \mathrm{Br}(K_{\mathrm{L}} \to \mu^+\mu^-) \;=\; & \frac{\alpha^2 \mathrm{Br}(K^+ \to \mu^+\nu_\mu)}{\pi^2 \sin^4\theta_{\mathrm{W}}} \frac{\tau(K_{\mathrm{L}}{}^0)}{\tau(K^+)} \\ & \times \left(\left(1 - \frac{\lambda^2}{2}\right) Y_{\mathrm{NL}} + A^2\lambda^4(1-\rho) Y_{\mathrm{t}} \right)^2 , \end{aligned} \tag{1}$$

where A and λ are from the Wolfenstein parameterisation of the CKM matrix, Y_{NL} and Y_{t} incorporate next to leading order QCD corrections and θ_{W} is the Weinberg angle. The above equation shows how the short range contribution is dependent on ρ.

In order to extract the short range contribution, the rate of the decay $K_{\mathrm{L}} \to \mu^+\mu^-$ is required. This rate has been measured to $\pm$ 2.2 %. However, the contribution to the rate is dominated by the long distance interaction which proceeds by the $\gamma^*\gamma^*$ vertex. In order to extract the short range contribution, the $\gamma^*\gamma^*$ form factor must be determined. The $\gamma^*\gamma^*$ form factor can be calculated from $K_{\mathrm{L}} \to l^+l^-\ e^+e^-$ decays, hence being a reason for their importance.

3.2. $K_{\mathrm{L}} \to e^+e^-e^+e^-$

In order to identify electrons, the ratio E/p is required to be greater than 0.9. The transverse momentum must be smaller than $5{\times}10^-4$ $(\mathrm{GeV}/c)^2$ and the reconstructed invariant mass has to be within 0.475 and 0.525 GeV/c^2. The vertex of the decayed kaon is required to be between 700 and 9000 cm downstream of the K_{S} target. Finally, all events must fall within a time window of 3 ns.

The most probable sources of backgrounds for this decay are:

- $K_{\rm L} \to e^+e^-\gamma$ and $K_{\rm L} \to \gamma\gamma$, where one or both photons respectively convert ($\gamma \to e^+e^-$) in the Kevlar window, which precedes the electromagnetic spectrometer. These events are rejected by requiring a track separation of at least 2 cm in the first drift chamber.

- Simultaneous $K_{\rm L} \to \pi^\pm e^\mp \nu$, where the pions are misidentified as electrons. The high E/p cut reduces misidentification of the pions whilst the cut on the transverse momentum and the time window requirement of the event helps to reject simultaneous events.

After all cuts, 132 events remain in the signal region with negligible background (see Fig. 2). To normalise the kaon flux, the decay $K_{\rm L} \to \pi^+\pi^-\pi^0_D$ was used. The preliminary NA48 result is:

$$\mathrm{Br}(K_{\rm L} \to e^+e^-e^+e^-) = 3.67 \pm 0.32(\mathrm{stat}) \pm 0.26(\mathrm{sys}) \times 10^{-8}\,,$$

in agreement with the theoretical prediction.

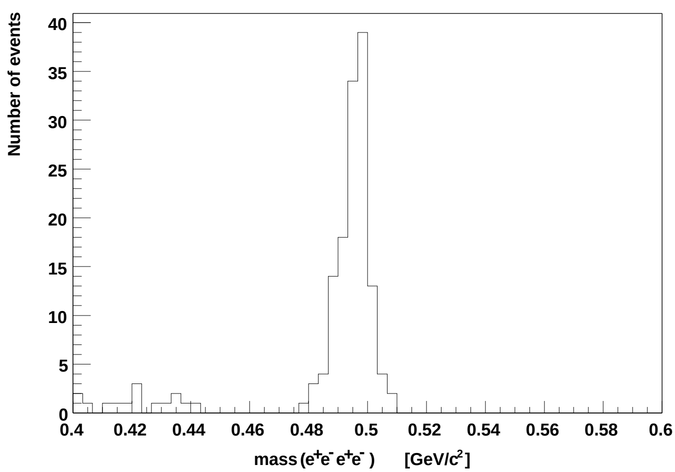

Fig. 2. 132 $K_{\rm L} \to e^+e^-e^+e^-$ candidates, with negligible background.

3.3. $K_{\rm L} \to \mu^+\mu^-e^+e^-$

The selection routine for this decay is similar to $K_{\rm L} \to e^+e^-e^+e^-$ except two of the charged particles deposit little energy in the electromagnetic calorimeter ($<$ 3 GeV is required). It is further required that the same charged particles register hits in the muon chambers.

The most probable sources of background for this decay are:

- $K_{\rm L} \to \mu^+\mu^-\gamma$ where the photon converts in the Kevlar window, which precedes the electromagnetic spectrometer. As mentioned above, conversions are rejected by requiring a track separation of at least 2 cm in the first drift chamber.

- Simultaneous $K_{\rm L} \to \pi^{\pm}e^{\mp}\nu$, where the pions decay to muons. A cut on the transverse momentum and the time window requirement of the event helps to reject simultaneous events. This forms a flat background which extends beyond the kaon mass (see Fig. 3).

- $K_{\rm L} \to \pi^+\pi^-\pi^0{}_D$, where the pions decay to muons. Cutting on the transverse momentum reduces the contribution of this background. More importantly, the lost energy carried away by the neutrino, after pion decay, prevents the event from reconstructing the kaon mass.

So far only one event has been published [6]. NA48 see a clear signal of 21 events in the signal region with a background of two events.

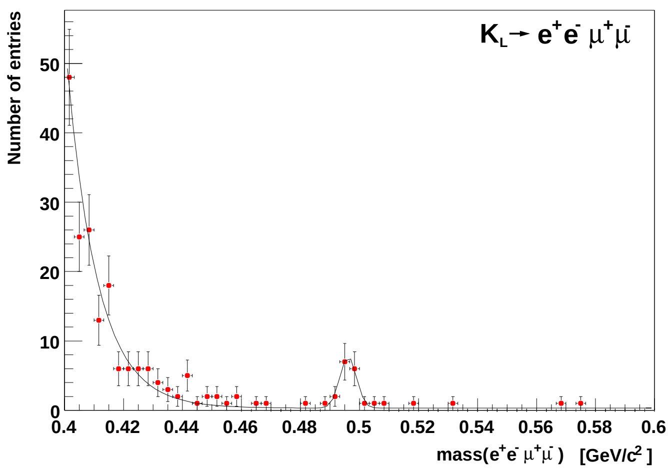

Fig. 3. 21 $K_{\rm L} \to \mu^+\mu^-e^+e^-$ candidates. Estimation of 2 background events due to simultaneous $K_{\rm L} \to \pi^{\pm}e^{\mp}\nu$.

To date, due to the small rate, not enough events have yet been observed in either $K_{\rm L} \to l^+l^-\ e^+e^-$ decay for a significant form factor measurement.

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