LFV and exotics at the NA62 experiment

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Abstract. The NA62 experiment at the CERN SPS is aimed at measuring the branching fraction of the ultrarare decay $K^+ \to \pi^+\nu\bar{\nu}$ with ∼10% precision by collecting $\sim 10^{13}$ kaon decays in two years of data taking. This amount of data will allow to carry out a wide program on searching for rare and forbidden (within the Standard Model, SM) K^+ and π^0 decays, including sterile neutrinos, lepton flavor violation modes, exotic particles (e.g. "dark photons"). The expected performances of the NA62 setup will allow to improve existing limits for several decay modes.

1. Introduction

Although the lepton flavor violation (LFV) was observed in neutrino mixing, the predictions for the branching ratios (BR) of LFV meson decays within SM are very small. From the other side, many extensions of the SM give rise to the lepton flavor and/or number violation. This leads to a straightforward conclusion that any observation of a LFV process in the meson decays is a clear signal of the New Physics beyond the SM.

High intensity of kaon beams and clear experimental signature allow to have a good sensitivity to LFV processes. At present the upper limits reach $10^{-11} - 10^{-12}$. Upper limits for the main decay modes are summarized in Table 1.

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Table 1. Current limits on the main LFV decay modes in charged kaon decays.

Decay mode	Upper limit (at 90% CL)	Experiment	Ref.
$K^+ \to \pi^+\mu^+\mathrm{e}^-$	1.3×10^{-11}	BNL E777/865	[1]
$K^+ \to \pi^+\mu^-\mathrm{e}^+$	5.2×10^{-10}	BNL E865	[2]
$K^+ \to \pi^-\mu^+\mathrm{e}^+$	5.0×10^{-10}	BNL E865	[2]
$K^+ \to \pi^-e^+\mathrm{e}^+$	6.4×10^{-10}	BNL E865	[2]
$K^+ \to \pi^-\mu^+\mu^+$	1.1×10^{-9}	NA48/2	[3]
$K^+ \to \mu^-\nu e^+e^-$	2.0×10^{-8}	Geneva-Saclay	[4]
$K^+ \to e^-\nu\mu^+\mu^+$	no data		

2. NA62 experiment

The main goal of the experiment is to measure the branching ratio of the decay $K^+ \to \pi^+\nu\bar{\nu}$ with ∼10% precision [5]. To achieve this goal, about 10^{13} kaon decays will be collected in two years of data taking [6]. This statistics provides good opportunities for improving the existing limits on the LFV decay modes listed in the Table above. In addition, there will be $\sim 2\times 10^{12}$ π^0 decays from the decay mode $K^+ \to \pi^+\pi^0$ (BR $\sim$ 21%) which can be used in other studies.

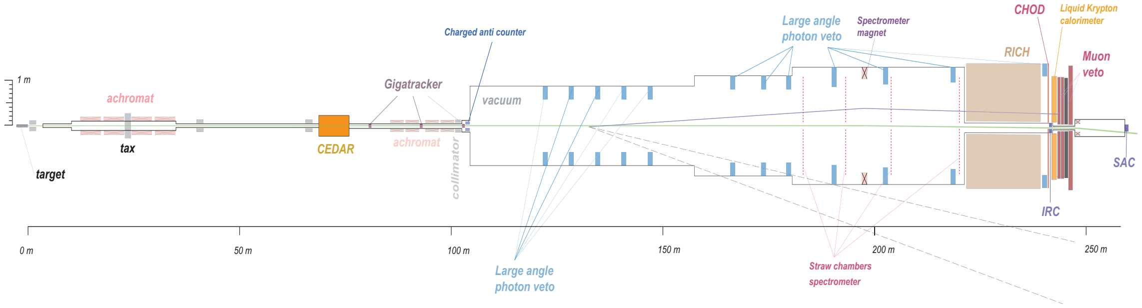

Figure 1. NA62 experimental setup.

The layout of the experimental setup is shown in Fig. 1. The high-intensity (750 MHz) unseparated (∼6% of positively charged kaons) hadron beam with a 75 GeV/c momentum is obtained from the SPS primary beam (protons with 400 GeV/c momentum) impinging on a Be target. Kaons are identified by a differential Cerenkov counter CEDAR. The momentum and direction of beam particles are measured by a silicon pixel beam spectrometer (Gigatracker) with a space resolution ∼0.2%. The decay region has a length ∼65 m and is evacuated to 10^{-6} mbar. The momentum of secondary charged particles (produced in kaon decays) is measured by a magnetic spectrometer composed of straw tubes (four stations) and a magnet with $p_T \sim 270$ MeV/c. The energy of secondary photons and electrons flying at small angles with respect to the beam axis is measured by a liquid krypton electromagnetic calorimeter, while large angle photons are detected by a system of 12 rings of lead-glass blocks. The identification of secondary particles (muon-pion separation at the level better than 1%) in the momentum range 15–35 GeV/c is done in a RICH detector filled with Ne at atmospheric pressure. A highly segmented muon identification system (Muon veto) is located behind the krypton calorimeter.

3. $K^+ \to \pi^-\mu^+\mu^+$ decay

Among various processes from Table 1 the decay $K^+ \to \pi^-\mu^+\mu^+$ provides a unique possibility to study the neutrinoless double beta decay in the second generation, since it implies the

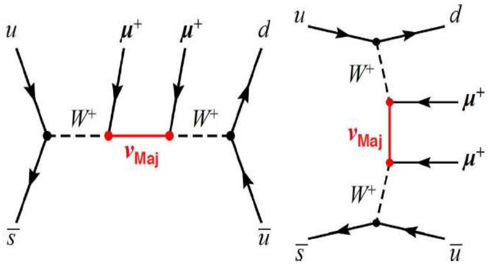

Figure 2. Lowest-order contributions to the decay $K^+ \to \pi^-\mu^+\mu^+$.

exchange of a virtual Majorana neutrino (Fig. 2).

The best upper limit on the BR of this decay was obtained by the NA48/2 experiment [3]. The result is based on 52 events in the signal region and a background estimation 52.6±19.8 obtained from Monte Carlo simulation. The upper limit was found to be $\mathrm{BR}(K^\pm \to \pi^\mp\mu^\pm\mu^\pm) < 1.1 \times 10^{-9}$(90% CL). The expected NA62 single-event sensitivity can reach 10^{-12}.

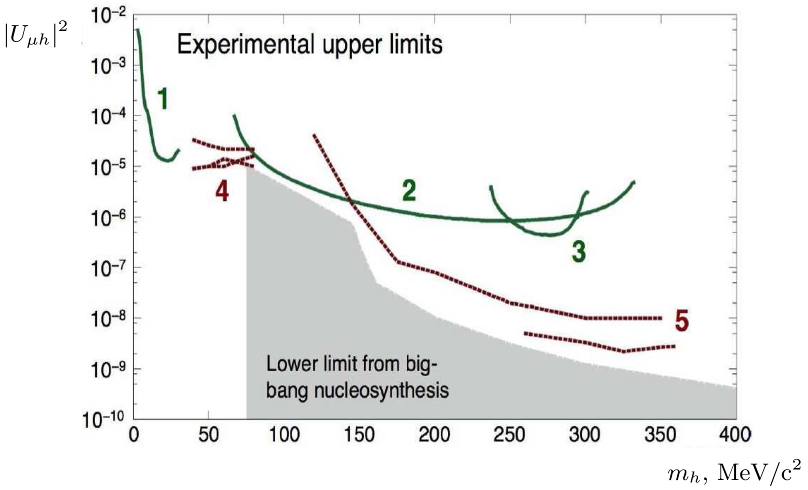

Figure 3. Heavy neutrino search in kaon and pion decays. Production searches are shown in green: 1) $\pi \to \mu\nu_h$, PSI 1981 [7]; 2) $K \to \mu\nu_h$, KEK 1982 [8]; 3)$K \to \mu\nu_h + inv$, LBL 1973 [9]. Decay searches are drawn in red: 4) $K \to \mu\nu_h, \nu_h \to \nu\gamma$ ($\tau_h = 10^{-9}, 10^{-10}, 10^{-11}$ s), ISTRA+ 2012 [10]; 5) $K \to \mu\nu_h, \nu_h \to \mu^\mp e^\pm \nu$ (above) and $\nu_h \to \mu^\mp\pi^\pm$ (below), PS191 1988 [11]. The grey area corresponds to the lower limit from the big-bang nucleosynthesis.

4. Search for heavy neutrinos in $K^+ \to \mu^+\nu_h$ decay

Searches for heavy neutrino in $K^+ \to \mu^+\nu_h$ decay can be of two types: production and decay. In the former case the lifetime should be large so that the heavy neutrino will not decay inside the detector acceptance, while in the latter the lifetime is short enough to have a relatively large acceptance for the decay of interest. The current status of heavy neutrino searches (limit on the mixing matrix element squared $|U_{\mu h}|^2$ vs ν_h mass) is shown in Fig. 3.

The ongoing analysis of the 2007 NA62 R$_K$ data [12] shows that in the absence of background the upper limit could be set at the level of 10^{-7} for the mass region $100 < m_h < 400$ MeV/c^2.

Preliminary studies including systematics indicate that the limits from Fig. 3 in the high mass region ($300 < m_h < 350$ MeV/c^2) can be improved.

5. Search for "dark photons" in π^0 decays

The U boson (or "dark photon") is a new light gauge boson that could mediate interactions with dark matter constituents explaining several unexpected astrophysical measurements (see [13], [14]) and the so called $(g-2)_\mu$ anomaly ($> 3\sigma$ discrepancy between measured and predicted values, see [15]). If the U boson mass is smaller than m_{π^0} it can be searched for in the decay $\pi^0 \to U\gamma, U \to e^+e^-$ (Fig. 4) with the same final state as the π^0 Dalitz decay. Fig. 5 (taken from [16]) illustrates the current status of the U boson search.

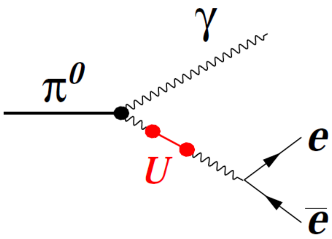

Figure 4. Contribution to the the $\pi^0 \to e^+e^-\gamma$ decay from U boson.

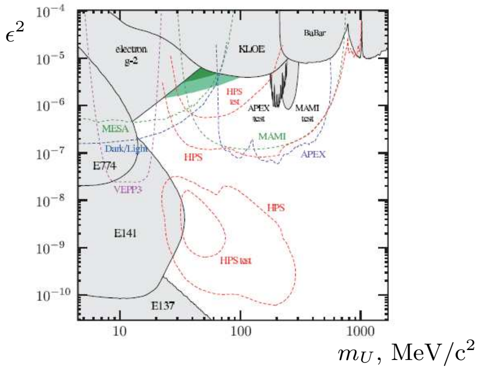

Figure 5. Constraints on the U boson search. Grey regions are excluded.

Kaon decays are an abundant source of π^0's tagged with the charged pion in $K^+ \to \pi^+\pi^0$ decay. The NA62 experiment can collect $\sim 10^8$ π^0 Dalitz decays/year with a mass resolution of ~ 1 MeV/c^2 for the e^+e^- pair. The expected sensitivity in the mass range $m_U < 100$ MeV/c^2 is $\sim 10^{-6}$.

6. Conclusions

NA62 provides a wide spectrum of studies beyond the baseline: LFV kaon decays, π^0 decays. These decays allow to study various phenomena like neutrinoless double beta decay in the second generation, heavy neutrinos, "dark photons" and more.

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