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Search for lepton number and flavour violation in K^+ and π^0 decays

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The NA62 experiment at CERN collected a large sample of charged kaon decays into the final states with multiple charged particles in 2016-2018. This sample provides the sensitivities to rare decays with branching ratios as low as 10^{-11}. The results from the searches for lepton flavour/number violating decays of the charged kaon and the neutral pion to the final states containing a lepton pair based on this data set are presented.

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1. Introduction

With the main goal to measure the branching ratio ($\mathcal{B}$) of the ultra-rare $K^+ \to \pi^+\nu\bar{\nu}$ decay with a precision similar to the theoretical predictions (~10%), in the first physics run (2016-2018) the NA62 experiment [1] collected the world's largest data sample of K^+ decays. Simultaneously with the trigger conditions required for the $K^+ \to \pi^+\nu\bar{\nu}$ analysis [2] a few additional trigger lines are used. In particular a multitrack (MT) trigger for events with more than one charged track in the final state. This proceedings reports the results of a search for lepton flavour and lepton number violating decays: $K^+ \to \pi^\pm\mu^\pm e^+$, $K^+ \to \pi^-\mu^+\mu^+$, $\pi^0 \to \mu^-e^+$ (with π^0 originating from $K^+ \to \pi^+\pi^0$ decay), and the results of searches for $K^+ \to \pi^-e^+e^+$ and $K^+ \to \pi^0\pi^-e^+e^+$ with the full Run1 dataset.

The NA62 experiment is located at the CERN SPS and is operating with a 75 GeV/c hadron beam with a 6% K^+ component. The schematic view of the NA62 detector layout is shown in the Figure 1, a detailed description of the detector and the beamline can be found in [3].

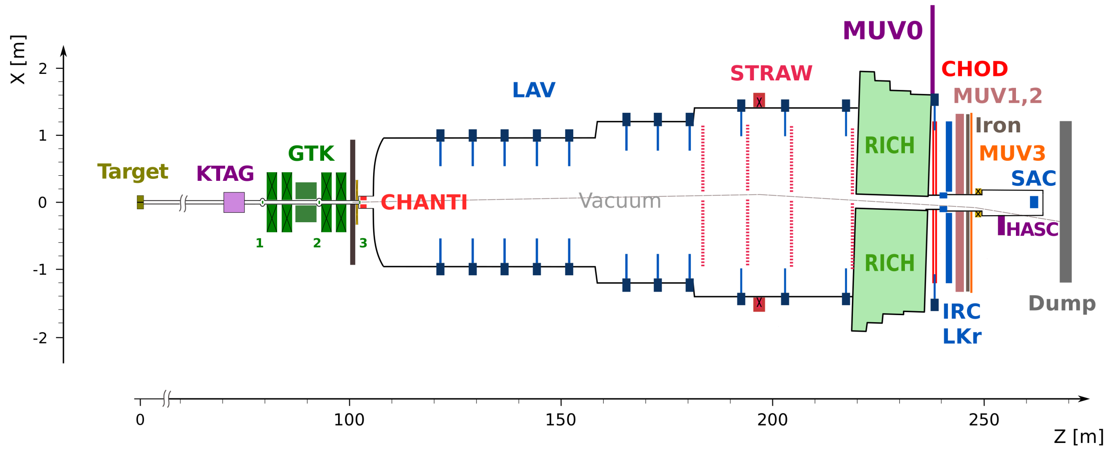

Figure 1: The schematic view of the NA62 detector layout in XZ plane.

The incoming Kaons are identified by a differential Cherenkov counter KTAG with $\sigma \sim 70$ ps time resolution and momenta are measured by a three-station silicon pixel beam-spectrometer GTK. The main spectrometer (STRAW) is located inside the vacuum tank, the first 75 m of which is used as a Fiducial Volume (FV). A Ring Image Cherenkov detector (RICH) provides a trigger time with $\sigma \sim 70$ ps time resolution and is optimized for the positively charged particles. The presence of signals in two opposite quadrants of the CHOD (Charged particle Hodoscope) is used as a multi-track trigger condition. The additional requirement of a minimum of 20 GeV energy deposited in the electromagnetic calorimeter (LKr) or at least one signal in the muon hodoscope (MUV3) is used to identify events with electrons and muons, respectively. The MT trigger lines are typically downscaled with factors of 100, for the minimum bias MT trigger, and eight for both the electron multi-track (eMT) and muons multi-track (μMT) triggers.

2. Search for $K^+ \to \pi^\pm\mu^\mp e^+$ and $\pi^0 \to \mu^-e^+$ decays

Lepton-flavour-violating (LFV) decays could provide an indication of the New Physics effects beyond the Standard Model, e.g. the processes involving $\bar{s} \to \bar{d}\mu^\pm e^\mp$ could be mediated by a leptoquark [4]. The measurements are normalized to the $K^+ \to \pi^+\pi^+\pi^-$ ($K_{3\pi}$) decay and the reconstructed invariant mass is required to be consistent with the charged kaon mass within $3\sigma_{3\pi}$, where the mass resolution $\sigma_{3\pi} = 0.9$ MeV/c^2. The particle identification criteria are based on the presence/absence of an associated signal in MUV3 and the E/p ratio for each track. The control and signal regions are defined in the invariant-mass spectra $m_{\pi\mu e}$ close to the charged kaon mass (Figure 2 shows the signal region 490 – 498 MeV/c^2 surrounded by 12 MeV/c^2 wide control regions). The effective number of K^+ decays in the FV is $N_K = (1.33 \pm 0.02) \times 10^{12}$ collected with three MT trigger lines.

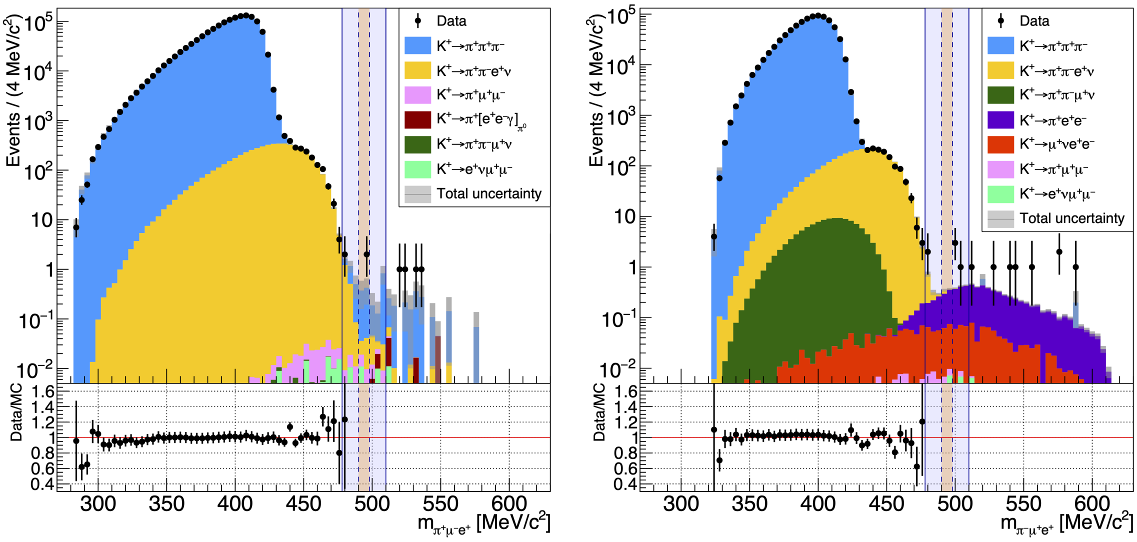

Figure 2: The reconstructed mass spectra for the $\pi^+\mu^-e^+$ (left) and $\pi^-\mu^+e^+$ (right) selections. Signal and control regions are marked with beige and light blue colours respectively. The lower panels shows the ratios between reconstructed data and simulation predictions.

The main sources of the background are either misidentification or $\pi^\pm \to l^\pm\nu_l$ decays in flight. They are studied with the simulation and dedicated control regions separately unmasked to validate the predictions [5]. The number of the predicted background and observed events in the signal regions (SR), as well as the upper limit on the branching ratios (at 90% CL), are summarized in Table 1.

	$K^+ \to \pi^-\mu^+e^+$	$K^+ \to \pi^+\mu^-e^+$	$\pi^0 \to \mu^-e^+$
Acceptance $\times 10^2$	4.90 ± 0.02	6.21 ± 0.02	3.11 ± 0.02
$\mathcal{B}_{SES} \times 10^{11}$	1.82 ± 0.08	1.44 ± 0.05	13.9 ± 0.9
Predicted in SR	1.07 ± 0.20	0.92 ± 0.34	0.23 ± 0.15
Observed in SR	0	2	0
$\mathcal{B}$ UL @ 90% CL [$\times 10^{-11}$]	4.2	6.6	32

Table 1: Search for $K^+ \to \pi^\pm\mu^\mp e^+$ and $\pi^0 \to \mu^-e^+$ decays using Run1 data.

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3. Search for $K^+ \to \pi^- l^+ l^+$ and $K^+ \to \pi^0 \pi^- e^+ e^+$ decays

The observation of lepton-number-violating (LNV) decays could be a strong evidence for the Majorana nature of the neutrinos [6], [7]. The search for the $K^+ \to \pi^- l^+ l^+$ decays is performed with normalization to the flavour-changing-neutral-current decays $K^+ \to \pi^+ l^+ l^-$ ($\mathcal{B} \sim 10^{-7}$) that are similar in topology. These will be designated as «SM decays». The mass distribution for the SM decay ($K^+ \to \pi^+ e^+ e^-$) and the LNV decay ($K^+ \to \pi^- e^+ e^+$) are presented in Figure 3. For the SM selections 11041 candidates are observed in the signal region and zero candidates for the LNV selections with the expected background 0.43 ± 0.09. The upper limit is $\mathcal{B}(K^+ \to \pi^- e^+ e^+) < 5.3 \times 10^{-11}$ [8]. The search for the $K^+ \to \pi^- \mu^+ \mu^+$ decay, based on the 2017 data, is published in [9].

The first search for the decay $K^+ \to \pi^- \pi^0 e^+ e^+$ is performed using the same dataset. The reconstructed mass spectra $m(\pi^- \pi^0 e^+ e^+)$ with expected background of 0.044 ± 0.020 events and zero candidates in the signal region are presented in Figure 4. The upper limit at 90% CL is set: $\mathcal{B}(K^+ \to \pi^- \pi^0 e^+ e^+) < 8.5 \times 10^{-10}$ [8].

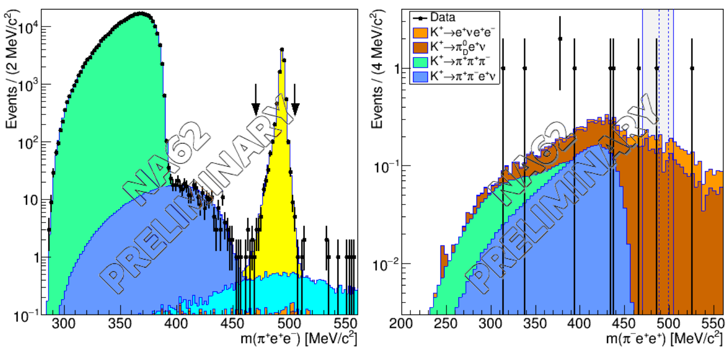

Figure 3: The reconstructed mass(πee) spectra for the data and MC samples for the SM (left) and the LNV (right) selections.

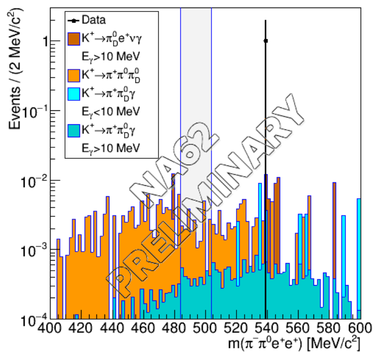

Figure 4: The reconstructed mass($\pi^- \pi^0 e^+ e^+$) spectra.

4. Summary

The NA62 experiment allows for a study of a large number of charged kaon decays. The search for various LNV and LFV decays is performed using the data taken with multi-track trigger conditions in Run1 (2016-2018). The established branching fraction upper limits at 90% CL are summarized in the Table 2. The NA62 experiment resumed data-taking in 2021 with few modifications applied during the planned SPS shutdown [10] and is approved to continue running until the next long-shutdown (LS3).

Decay mode	Previous $\mathcal{B}$ UL	NA62 2017 data	NA62 Run1 data
$K^+ \to \pi^-\mu^+\mu^+$	8.6×10^{-11} [11] (NA48/2)	4.2×10^{-11} [9]	—
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10} [12] (E865)	2.2×10^{-10} [9]	5.3×10^{-11} [8]
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10} [12] (E865)	—	4.2×10^{-11} [5]
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10} [12] (E865)	—	6.6×10^{-11} [5]
$K^+ \to \pi^+\mu^+e^-$	2.1×10^{-11} [13] (E865)	—	Not yet competitive
$K^+ \to \pi^-\pi^0e^+e^+$	—	—	8.5×10^{-10} [8]
$\pi^0 \to \mu^-e^+$	3.4×10^{-9} [12] (E865)	—	3.2×10^{-10} [5]
$\pi^0 \to \mu^\pm e^\mp$	3.6×10^{-10} [14] (KTeV)	—	Not yet competitive

Table 2: The summary of the $\mathcal{B}$ upper limits established by the NA62 for the LNV and LFV decays with the pair of leptons in the final state.

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