PROCEEDINGS OF SCIENCE

Searches for lepton flavor and lepton number violating K^+ decays at the NA62 experiment

Viacheslav Duk[a,1,*]

[a] *INFN Perugia,*
Via A. Pascoli, Perugia, Italy

E-mail: Viacheslav.Duk@cern.ch

Searches for lepton flavor and lepton number violating decays have been performed at the NA62 experiment based on the analysis of the data collected in 2016–2018. New upper limits have been set on the branching ratio of several decay modes: $K^+ \to \pi^+\mu^-e^+$, $K^+ \to \pi^-\mu^+e^+$, $K^+ \to \pi^-l^+l^+(l = e, \mu)$ and $K^+ \to \mu^-\nu e^+e^+$. A search for the decay $K^+ \to \pi^-\pi^0e^+e^+$ was made for the first time.

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[1] For the NA62 collaboration
[*] Speaker

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1. Introduction

Within the framework of the Standard Model (SM), Lepton Number (LN) and Lepton Flavor (LF) are conserved and considered as accidental symmetries. Many extensions of the SM allow for LN and LF violating processes (LNV and LFV, respectively) mediated by new particles, e.g. Majorana neutrinos, leptoquarks, Z' bosons.

The large sample of kaon decays collected by NA62 in 2016–2018 allows various searches for LFV and LNV decays. In this paper, the most recent results from LFV/LNV searches in K^+ decays with three secondary charged particles in the final state are presented. For all decay modes, the blind analysis technique is used.

2. NA62 experiment

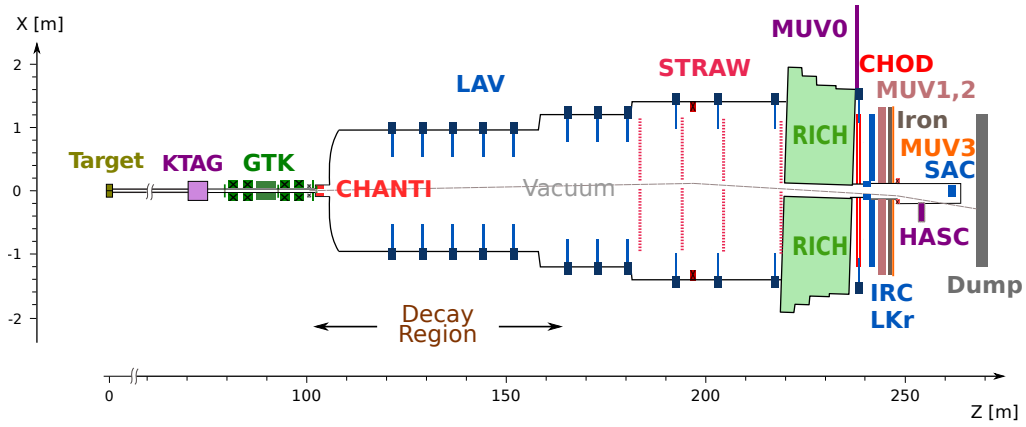

Figure 1: NA62 experimental setup.

NA62 is a fixed target experiment situated at the CERN SPS accelerator. Primary protons with 400 GeV/c momentum impinge on a beryllium target producing secondary particles. A 100 m long beam line collimates, focuses and transports charged particles of (75.0±0.8) GeV/c momentum to the decay volume. The kaon fraction in the secondary beam is 6%.

The experimental setup is shown in Fig. 1. Beam kaons are identified and timestamped by the KTAG, a differential Cherenkov detector placed on the beam and filled with nitrogen. The Gigatracker (GTK) detector, made of three silicon pixel stations, timestamps beam particles of all types and measures their momenta. The CHANTI detector, located after the GTK, vetoes beam interactions with the material in the last GTK station.

The momenta of charged particles from kaon decays are measured by the spectrometer made of four straw chambers and a dipole magnet. A 17 m long RICH detector filled with neon at atmospheric pressure is used to identify π^+, μ^+, e^+ and, together with a scintillator hodoscope (CHOD), measures the downstream track time. Hadronic calorimeters (MUV1 and MUV2) and a fast scintillator muon veto (MUV3) aid in separating π^+ from μ^+. A system of photon veto detectors (12 LAV stations, LKr, IRC, SAC) is designed to reject extra electromagnetic activity, covering angles up to 50 mrad. A detailed description of the setup can be found in [1].

The experiment started to take data in 2016. The 2016–2018 period is referred to as Run 1 in the following.

3. $K^+ \to \pi\mu e$ decays

The Run 1 data are used for this analysis. The signal rates are normalized to the $K^+ \to \pi^+\pi^+\pi^-$ decay. As a byproduct, a search for the $\pi^0 \to \mu e$ from the $K^+ \to \pi^+\pi^0, \pi^0 \to \mu e$ decay chain is performed. The main backgrounds are from the misidentification of particles and decays of pions in flight. The $(\pi\mu e)$ invariant mass distributions are shown in Fig. 2.

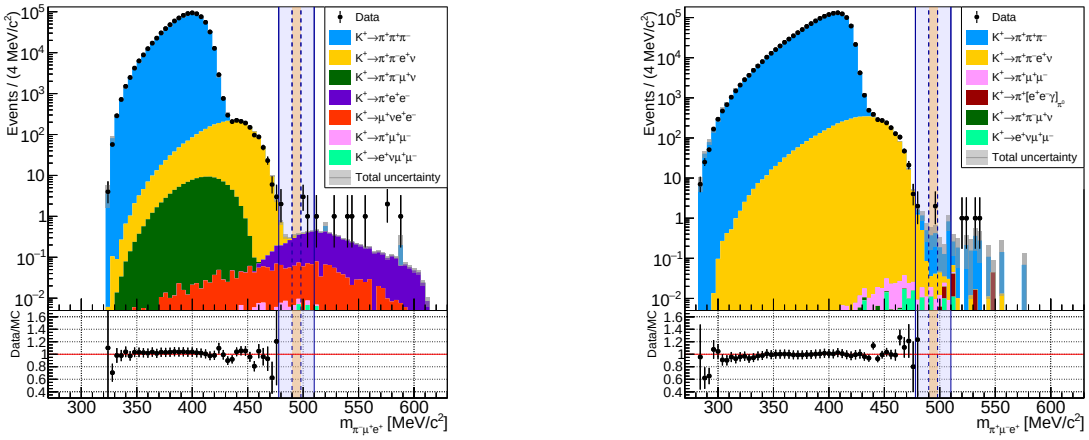

Figure 2: Reconstructed spectra for the data and simulated backgrounds. Left: $m_{\pi\mu e}$ for the $K^+ \to \pi^-\mu^+e^+$ selection. Right: $m_{\pi\mu e}$ for the $K^+ \to \pi^+\mu^-e^+$ selection. The shaded vertical band indicates the region blinded during the analysis.

The results are published in [2] and summarized in Table 1. An improvement in the upper limit of the branching ratio (BR) by a factor of order 10 has been achieved compared to previous results.

	$K^+ \to \pi^-\mu^+e^+$	$K^+ \to \pi^+\mu^-e^+$	$\pi^0 \to \mu^-e^+$
Acceptance [%]	4.90	6.21	3.11
SES	1.82×10^{-11}	1.44×10^{-11}	13.9×10^{-11}
Expected bkg	1.07(20)	0.92(34)	0.23(15)
$N_{observed}$	0	2	0
UL(BR) @90% CL	4.2×10^{-11}	6.6×10^{-11}	3.2×10^{-11}
Previous UL(BR)	5.0×10^{-10}	5.2×10^{-10}	3.4×10^{-9}

Table 1: Summary of the LFV/LNV searches in $K^+ \to \pi\mu e$ decays. The expected background and the observed number of events are related to the signal region.

4. $K^+ \to \pi^-l^+l^+$ decays

For the $K^+ \to \pi^-\mu^+\mu^+$ ($K^+ \to \pi^-e^+e^+$) mode, the partial (whole) Run 1 data are analyzed and the decay $K^+ \to \pi^+\mu^+\mu^-$ ($K^+ \to \pi^+e^+e^-$) is used for the normalization. The invariant mass distributions for the signal and normalization are shown in Fig. 3 and 4.

The results are summarized in Table 2 and the details can be found in [3, 4].

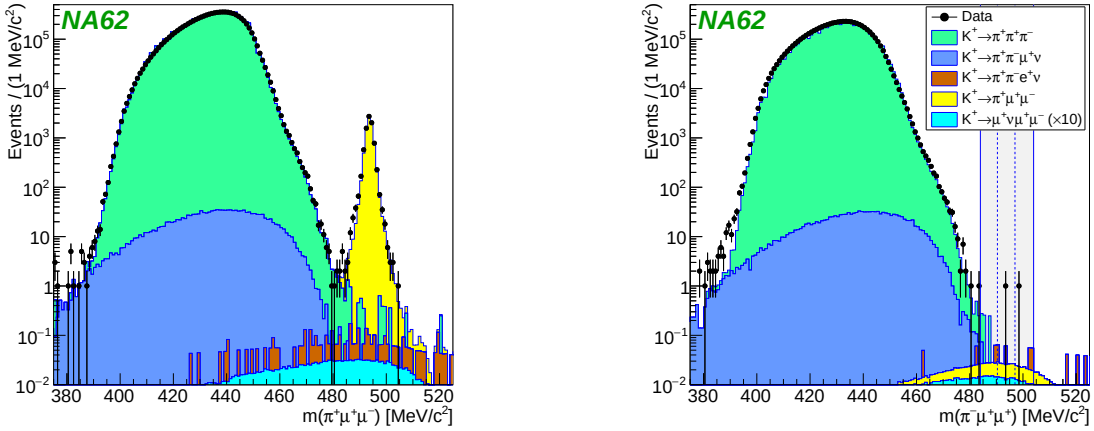

Figure 3: Reconstructed spectra for the data and simulated backgrounds. Left: $m_{\pi\mu\mu}$ for the $K^+ \to \pi^+\mu^+\mu^-$ selection. Right: $m_{\pi\mu\mu}$ for the $K^+ \to \pi^-\mu^+\mu^+$ selection. The shaded vertical band indicates the region blinded during the analysis.

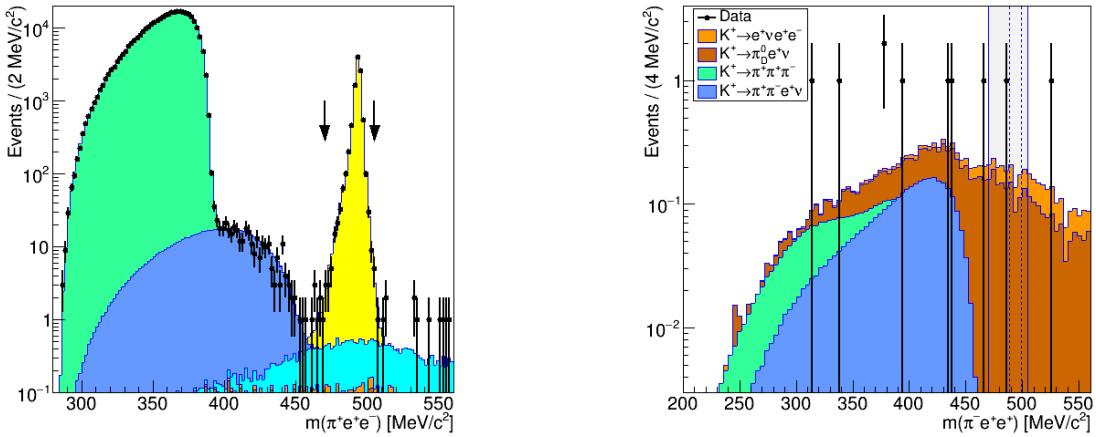

Figure 4: Reconstructed spectra for the data and simulated backgrounds. Left: $m_{\pi ee}$ for the $K^+ \to \pi^+e^+e^-$ selection. Right: $m_{\pi ee}$ for the $K^+ \to \pi^-e^+e^+$ selection. The shaded vertical band indicates the region blinded during the analysis.

5. $K^+ \to \pi^-\pi^0e^+e^+$ and $K^+ \to \mu^-\nu e^+e^+$ decays

The first search for the $K^+ \to \pi^-\pi^0e^+e^+$ decay has recently been published by NA62 [4]. Another brand new result is the upper limit on the BR of the $K^+ \to \mu^-\nu e^+e^+$ decay that has been improved by a factor of 250 [5]. Both searches use the whole Run 1 data and the $K^+ \to \pi^+e^+e^-$ decay for the normalization. The signal regions are shown in Fig. 5 and the results are summarized in Table. 3.

6. Conclusions

A wide program searching for LFV and LNV decays has been performed at the NA62 experiment. The analysis of the data collected in 2016–2018 improved the limits on the branching ratio

	$K^+ \to \pi^- \mu^+ \mu^+$	$K^+ \to \pi^- e^+ e^+$
Acceptance [%]	9.81	4.23
SES	1.28×10^{-11}	2.40×10^{-11}
Expected bkg	0.91(41)	0.43(9)
$N_{observed}$	1	0
UL(BR) @90% CL	4.2×10^{-11}	5.3×10^{-11}
Previous UL(BR)	8.6×10^{-11}	6.4×10^{-10}

Table 2: Summary of the LFV/LNV searches in $K^+ \to \pi^- l^+ l^+$ decays. The expected background and the observed number of events are related to the signal region.

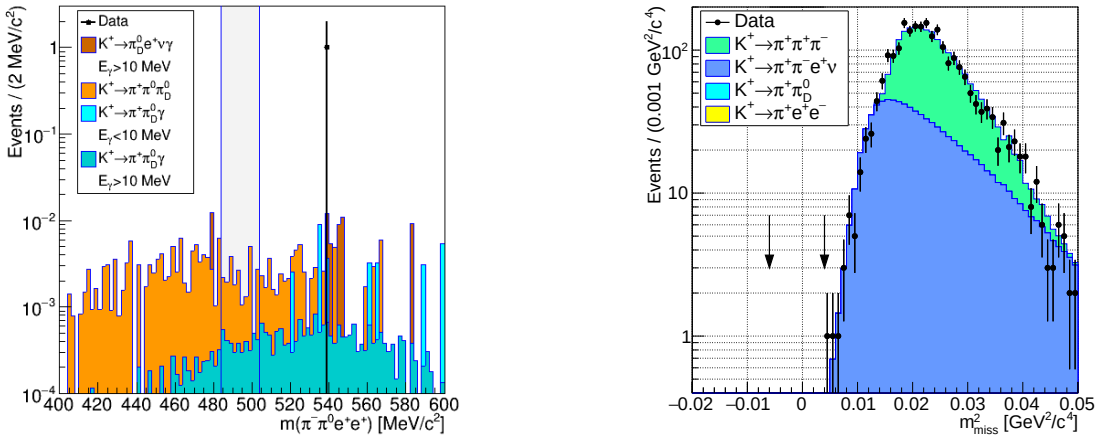

Figure 5: Reconstructed spectra for the data and simulated backgrounds. Left: $m_{\pi\pi ee}$ for the $K^+ \to \pi^-\pi^0 e^+ e^+$ selection. Right: missing mass squared $m^2_{miss} = (P_K - P_\mu - P_{e1} - P_{e2})^2$ for the $K^+ \to \mu^- \nu e^+ e^+$ selection. The shaded vertical band indicates the region blinded during the analysis.

	$K^+ \to \pi^-\pi^0 e^+ e^+$	$K^+ \to \mu^- \nu e^+ e^+$
Acceptance [%]	0.27	1.44
SES	3.8×10^{-10}	3.5×10^{-11}
Expected bkg	0.044(20)	0.26(4)
$N_{observed}$	0	0
UL(BR) @90% CL	8.5×10^{-10}	8.1×10^{-11}
Previous UL(BR)	first search	2.1×10^{-8}

Table 3: Summary of the LFV/LNV searches in $K^+ \to \pi^-\pi^0 e^+ e^+$ and $K^+ \to \mu^- \nu e^+ e^+$ decays. The expected background and the observed number of events are related to the signal region.

for several decay modes by factors of 2 to 250. The first search for the decay $K^+ \to \pi^-\pi^0 e^+ e^+$ has been performed.

The NA62 experiment resumed data taking in 2022 and will be able to significantly improve the sensitivity to LFV/LNV decays with the upcoming data.

References

[1] The NA62 Collaboration, *JINST* **12** (2017) P05025.

[2] R. Aliberti et al, *PRL* **127** (2021) 131802.

[3] E.Cortina Gil et al, *PLB* **797** (2019) 134794.

[4] E.Cortina Gil et al, *PLB* **830** (2022) 137172.

[5] E.Cortina Gil et al, [hep-ex/2211.04818].