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Search for Heavy Neutral Lepton production in K^+ decays at NA62

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Large samples of charged kaon decays have been collected by the NA62-R$_K$ (2007) and the NA62 (2015) experiments at CERN SPS. This proceedings summarizes upper limits on heavy neutrino production measured by these experiments.

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1. Introduction

The Standard Model (SM) of particle physics [1, 2, 3] does not describe the phenomenon of neutrino oscillations [4, 5] because neutrinos are strictly massless in the SM and therefore do not oscillate. One of the extensions of the SM, capable of accommodating non-zero SM neutrino masses, is the Neutrino Minimal Standard Model [6] (νMSM). In this model, three sterile massive right-handed neutrinos are added to the SM. The lightest ($\mathscr{O}(1\mathrm{keV}/c^2)$) of the sterile neutrinos serves as a dark matter candidate, while the other two ($\mathscr{O}(1\mathrm{GeV}/c^2)$) generate SM neutrino masses via the see-saw mechanism [7]. The νMSM introduces additional CPV phases which could explain the observed baryon asymmetry of the Universe.

Due to the mixing between Heavy Neutral Leptons (HNLs) and SM neutrinos, HNLs could be produced in meson decays such as $K^+ \to l^+N$ ($l = e, \mu$). The branching fraction of the production processes $K^+ \to l^+N$ can be expressed in terms of the branching fraction of the SM $K^+ \to l^+\nu_l$ (K_{l2}) decays using kinematic factor $\rho_l(m_N)$ accounting for the helicity suppression and phase space dependence on the HNL mass m_N, and the mixing parameter $|U_{l4}|^2$:

$$\mathscr{B}(K^+ \to l^+N) = \mathscr{B}(K^+ \to l^+\nu_l) \cdot \rho_l(m_N) \cdot |U_{l4}|^2. \tag{1.1}$$

This proceedings describes two analyses performed at the NA62 experiment at CERN SPS. The analysis of the NA62-R$_\mathrm{K}$ data aimed to observe HNL production in $K^+ \to \mu^+N$ decays in 2007 data [8]. The second analysis was carried out on 2015 dataset, searching for HNL production in both electron ($K^+ \to e^+N$) and muon ($K^+ \to \mu^+N$) channels [9]. Results presented in this proceedings have been previously reported in [10].

2. Experimental Setup and Data Taking Conditions

2.1 NA62-R$_\mathrm{K}$ Detector Setup

The NA62-R$_\mathrm{K}$ detector setup was similar to the one used in the preceding NA48/2 experiment [11, 12] with several improvements and modifications. The NA62-R$_\mathrm{K}$ beam with the momentum of (74.0 ± 1.4) GeV/c was produced from the primary 400 GeV/c SPS protons. The possibility to use either separate K^+ or K^- beams or simultaneous and collinear K^+ and K^- beams was introduced as a part of the upgrade from the NA48/2 experiment to the NA62-R$_\mathrm{K}$ experiment.

The NA62-R$_\mathrm{K}$ beam was steered into a 114 m long evacuated cylindrical decay region. The downstream part of the vacuum tank was sealed from a helium tank at atmospheric pressure, in which a magnetic spectrometer consisting of four drift chambers (DCHs) and a dipole magnet were housed. The spectrometer was followed by a hodoscope (HOD) used in the online trigger system and as the offline time reference for the charged particles. A Liquid Krypton electromagnetic calorimeter (LKr) was placed downstream of the HOD detector. The LKr was followed by a muon detector (MUV) placed behind a 80 cm thick iron wall. HNL search on 2007 data sample was done only on the K^+ sample.

2.2 NA62 Detector Setup

The NA62 is the most recent kaon experiment at CERN SPS with the purpose of a precise measurement of $\mathscr{B}(K^+ \to \pi^+\nu\bar{\nu})$. Compared to its predecessors, it has a significantly improved

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detector design, shown in Fig. 1. The main improvements are the KTAG system used for positive

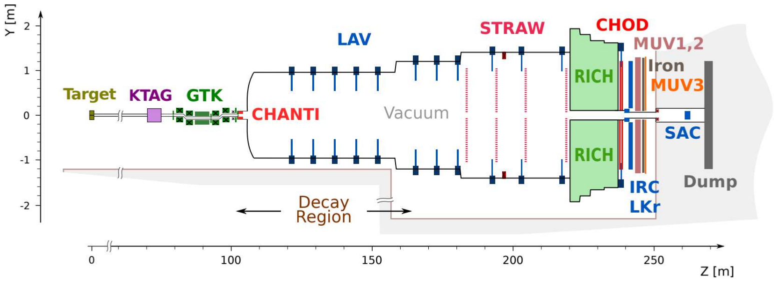

Figure 1: The NA62 detector layout.

identification of K^+ in the beam (75.0 ± 1.0 GeV/c, $\sim 6\%$ K^+) with respect to other beam particles (mainly protons and pions) and the Gigatracker (GTK, not available in 2015) detector designed for precise beam momentum measurement. Other subdetectors involve magnetic spectrometer STRAW consisting of four chambers of drift tubes operating in vacuum, a system of photon vetoes LAV, LKr, IRC and SAC, a RICH detector and a muon veto system MUV. For detailed description of the NA62 detector, see [13].

3. Event selections and HNL searches

Since the HNL searches performed at the NA62-R$_{\mathrm{K}}$ (2007 data) and NA62 (2015 data) used similar approaches, they will both be described side-by-side in this section.

3.1 Event Selections

The search for HNL produced in $K^+ \to \mu^+ N$ decays in 2007 data is performed on the sample obtained at ~ 10 times lower beam intensity compared to the preceding NA48/2 experiment in order to suppress accidental background and ensure high minimum bias trigger efficiency. The analysis requires one well reconstructed positive track identified as a muon using MUV hits.

The 2015 data analysis is performed on the minimum bias sample recorded during five days at $\sim 1\%$ nominal NA62 beam intensity and searches for both the $K^+ \to e^+ N$ and $K^+ \to \mu^+ N$ decays. Electrons are identified using E/p cut and information from the RICH subdetector, where E is the LKr cluster energy and p is the downstream track momentum. Muon identification involves E/p cut and information from the MUV system. Several background contributions are suppressed using the LAV, SAC, IRC and CHANTI vetoes and by the positive identification of the decaying kaon in the KTAG.

3.2 Selected Samples and Heavy Neutrino Signal Searches

The variable scanned for HNL signal peaks is the missing mass $m_{\mathrm{miss}} = \sqrt{(P_K - P_l)^2}$ ($l = e, \mu$), where P_K and P_l are kaon (nominal) and lepton four-momenta respectively. The regions scanned for peaks are $m_{\mathrm{miss}} \in (300, 375)$ MeV/c^2 (2007 analysis), $m_{\mathrm{miss}} \in (170, 448)$ MeV/c^2 (2015 $K^+ \to e^+ N$ analysis) and $m_{\mathrm{miss}} \in (250, 373)$ MeV/c^2 (2015 $K^+ \to \mu^+ N$ analysis). The step in the mass scan is chosen to be 1 MeV/c^2 and the half-width of the signal window is proportional to the HNL

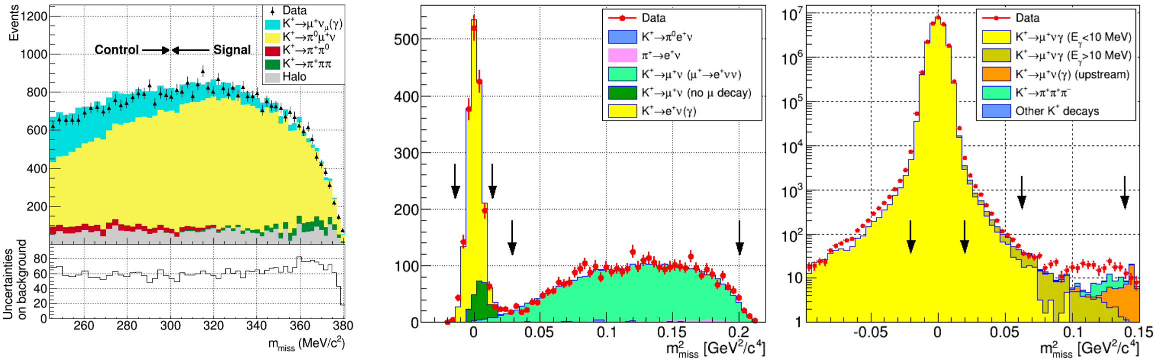

Figure 2: Missing mass distribution of the selected $K_{\mu 2}$ events and MC background estimates together with their errors for 2007 analysis (left), missing mass squared spectrum of the events passing K_{e2} selection from 2015 analysis (centre) and missing mass squared spectrum of the events passing $K_{\mu 2}$ selection from 2015 analysis (right). The arrows around the peaks at zero indicate K_{l2} event candidates used for normalization, while the other pairs of arrows mark regions scanned for HNLs.

mass resolution σ_l evaluated using MC simulations. Missing mass (squared) plots obtained from 2007 and 2015 data are shown in Fig. 2. Total number of kaon decays, evaluated using the SM signal regions for K_{l2} decays and the signal acceptance obtained from MC, are measured to be: $N_K = (5.977 \pm 0.015) \times 10^7$ (2007 data), $N_K^e = (3.00 \pm 0.11) \times 10^8$ (2015 data, $K^+ \to e^+\nu_e$) and $N_K^\mu = (1.06 \pm 0.02) \times 10^8$ (2015 data, $K^+ \to \mu^+\nu_\mu$). Factor three difference between N_K^e and N_K^μ in 2015 data originates from trigger downscaling.

No statistically significant HNL signal is observed and therefore only ULs at 90% CL on the number of signal events $N_{\rm sig}$ are determined for both analyses using the Rolke-López method [14]. From the ULs on $N_{\rm sig}$, ULs on the branching fractions of the $K^+ \to l^+N$ decays are computed (see Fig. 3) using the HNL mass dependent acceptances and the numbers of kaon decays N_K and N_K^l mentioned above.

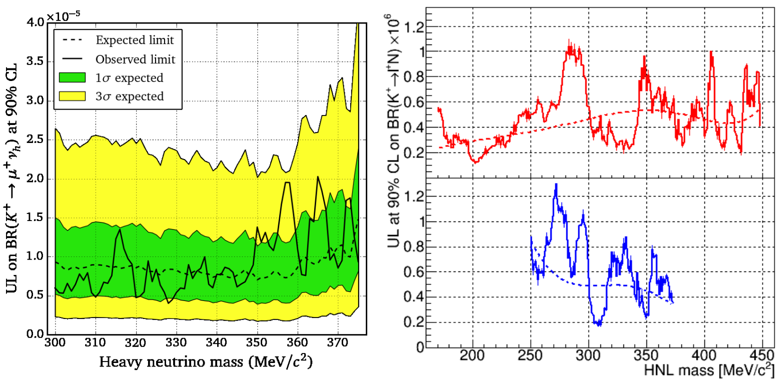

Figure 3: Left: ULs at 90% CL on $\mathscr{B}(K^+ \to \mu^+N)$ from 2007 analysis. Right: ULs at 90% CL on $\mathscr{B}(K^+ \to e^+N)$ from 2015 analysis (top) and ULs at 90% CL on $\mathscr{B}(K^+ \to \mu^+N)$ from 2015 analysis (bottom).

Upper limits on the $\mathscr{B}(K^+ \to l^+N)$ are used together with Eq. (1.1) to determine ULs on the mixing parameters $|U_{l4}|^2$. The ULs on $|U_{\mu 4}|^2$ and $|U_{e4}|^2$ obtained from the NA62-R$_{\rm K}$ and NA62 are shown in Fig. 4 and, in certain HNL mass regions, improve the previously established limits.

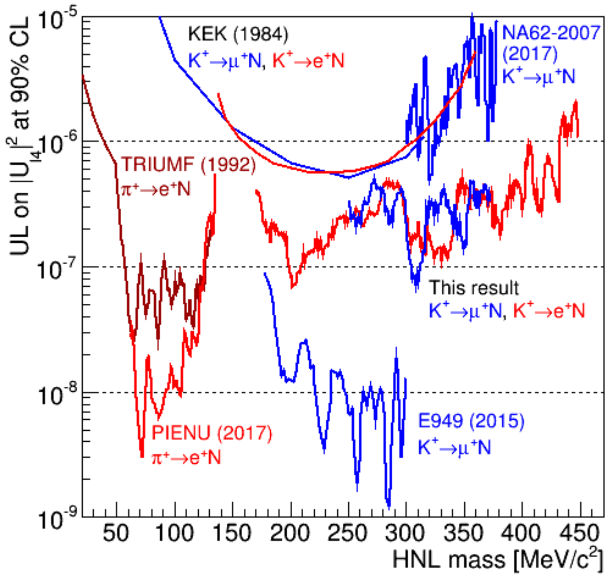

Figure 4: ULs at 90% CL on $|U_{\mu 4}|^2$ and $|U_{e4}|^2$.

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