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New limits on Heavy Neutrino from NA62

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Abstract. The NA62 experiment at CERN collected a large sample of charged kaon decays in flight with a minimum bias trigger in 2007. Upper limits on the rate of the charged kaon decay into a muon and a heavy neutral lepton (HNL) obtained from this data are reported for a range of HNL masses. The NA62 experiment has collected further data in 2015 with a completely new and improved detector. New limits on heavy neutrinos from kaon decays into electron and HNL will be presented.

1. Introduction

One of the possible Standard Model (SM) extensions that allow to accommodate non-zero neutrino masses to describe neutrino oscillations is the Neutrino Minimal Standard Model (ν MSM) [1]. The ν MSM introduces three additional neutrino mass states at 10 keV/c² and GeV/c² scales that mix with SM neutrinos. Heavy neutrinos with masses up to 493 GeV/c² and 388 GeV/c² could be produced in $K \rightarrow e\nu_e$ and $K \rightarrow \mu\nu_\mu$ decays respectively. A narrow peak in the missing mass spectra of the K_{l2} candidates would be a signature of heavy neutrino produced in $K^+ \rightarrow l^+\nu_l$.

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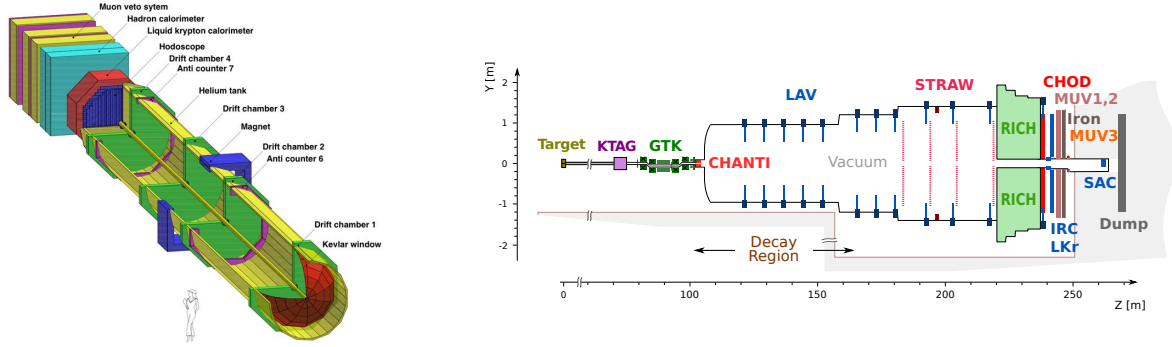


Figure 1. Schematic view of the NA62 experimental layout in 2007 (left) and 2015 (right).

Possible heavy neutrino production in $K^+ \rightarrow l^+ N$ decay is determined by decay to SM neutrino $K^+ \rightarrow l^+ \nu_l$, mixing matrix element $|U_{l4}|^2$ and $\rho_l(m_N)$ —kinematic enhancement factor that depends on heavy neutrino mass [2]:

$$\mathcal{B}(K^+ \rightarrow l^+ N) = \mathcal{B}(K^+ \rightarrow l^+ \nu) \cdot \rho_l(m_N) \cdot |U_{l4}|^2 \quad (1)$$

Previous searches of possible heavy neutrino production were performed with stopped kaon decays [3], [4]. The upper limits (UL) on mixing matrix element was set on level of 10^{-6} for heavy neutrino masses from 70 to 330 MeV/ c^2 and on the level of 10^{-8} for heavy neutrino masses from 175 to 300 MeV/ c^2 .

This proceedings summarizes results of two searches: analysis of the $K_{\mu 2}$ decay using the data collected in 2007 [5] and a preliminary result of the $K_{e 2}$ decay analysis using the data collected during NA62 2015 pilot run.

2. The NA62 experiment at CERN

The NA62 experiment is the successor to the NA48 series of kaon decay in-flight experiments. The experiment is located at CERN North Area High Intensity Facility and operates with 75 GeV/ c hadron beam (with 6% kaons) produced on the beryllium target by primary 400 GeV/ c protons extracted from CERN SPS.

2.1. The NA62 detector in 2007

During the 2007-08 run (NA62- R_K phase) the main purpose of the experiment was to measure the ratio $R_K = \Gamma(K^\pm \rightarrow e^\pm \nu) / \Gamma(K^\pm \rightarrow \mu^\pm \nu)$ [6]. The detector was based on the beam line and apparatus of the previous NA48/2 experiment (figure 1 left). The detailed description of the detector and beam line could be found in Ref. [7]. The hadron beam with 6% kaons enters a 114 m long decay volume (fiducial volume) with the vacuum inside. The secondary charged particles produced by kaon decays were registered by the spectrometer with momentum resolution $\sigma/p = 0.48\% \oplus 0.009\% \cdot p$ that consists of a dipole magnet and four drift chambers and was housed in a helium filled tank. The fast trigger signal was produced by the hodoscope CHOD that consists of two planes of scintillation bars. The electromagnetic liquid krypton calorimeter LKr with energy resolution $\sigma_E/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$ and $\sigma_{x,y} = 0.42\text{cm}/\sqrt{E} \oplus 0.06\text{cm}$ spatial resolution provides high granularity in the transverse plane. Muon veto system MUV located at the end of the detector was used for the muon identification. The beam intensity was reduced compared to NA48/2 by a factor of 10 to provide high efficiency operation with minimum bias trigger conditions.

2.2. The NA62 detector in 2015

The main goal of the NA62 experiment is to measure branching ratio of ultra rare decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ with 10% accuracy. The experiment operates with high intensity hadron beam with total particle rate of 750 MHz, of which about 6% is from K^+ . The detailed description of the NA62 detector and beam line can be found in Ref. [8]. The schematic view of the experimental setup is shown in figure 1 (right). There are significant improvements with respect to 2007 setup that include the precise measurement of the beam kaon time and momenta by the KTAG (differential Cherenkov detector) and GTK. The drift chambers from the NA48/2 experiment were replaced with four stations of straw tubes that are operating in the vacuum. Hermetic photon veto system (LAV, LKr, IRC and SAC). New detectors for particle identification: a RICH detector and muon veto system consist of fast muon hodoscope MUV3 and two hadron calorimeters MUV1 and MUV2.

3. Search for heavy neutrinos in K_{l2} decays

A signature for the possible heavy neutrino production in K_{l2} decay is a narrow spike in the missing mass $m_{miss} = \sqrt{(p_K - p_l)^2}$ spectrum, where p_K and p_l are the kaon and secondary lepton 4-momentum respectively. The average beam kaon momentum was measured during the data taking using fully reconstructed $K^+ \rightarrow \pi^+ \pi^+ \pi^-$ decay.

The analyses are based on single-track events. With an assumption that mixing matrix element $|U_{l4}|^2 < 10^{-4}$ and that heavy neutrino decays only to SM particles, the mean free path of heavy neutrino produced in NA62 is greater than 10 km and their decays in-flight could be neglected.

A search for heavy neutrinos production in kaon decays performed using two data samples:

- $K_{\mu 2}$ data sample with 5.977×10^7 kaon decays in fiducial volume collected in 2007 using a minimum bias single track topology with positively charged muon in the final state.
- $K_{e 2}$ data sample with 3.01×10^8 kaon decays in fiducial volume recorded during 5 days of operation in NA62 2015 pilot run. The beam intensity varies from 0.4% to 1.3% of the nominal 45 MHz K^+ rate. Trigger conditions require a beam particle to be identified as a K^+ , single positively charged secondary track and anti-coincidence with a signal from muon hodoscope (MUV3).

3.1. Event selection

Both analyses require single positively charged tracks. Vertex position reconstructed as a point of a closest distance of approach of the track to the K^+ beam axis reconstructed from $K^+ \rightarrow \pi^+ \pi^+ \pi^-$ decay.

In $K_{\mu 2}$ data sample analysis muons are positively identified by MUV signals associated with the track in time and space. Events with clusters in the LKr that are not associated with the track are rejected. The number of background events from the muon halo evaluated with a control data sample, and from kaon decays, evaluated with simulation.

In $K_{e 2}$ data sample analysis, electrons are identified using $0.9 < E/p < 1.15$ criteria and identification algorithm based on the RICH hit pattern. Events with hits in any other photon veto detectors or with clusters not associated with the track are rejected. The background in each mass hypothesis is evaluated from side bands of the data m_{miss} distribution.

The missing mass spectrum of selected K_{l2} candidates from both data and simulation are presented in figure 2.

3.2. New limits on Heavy Neutrino production

The search for the possible heavy neutrino production with $K^+ \rightarrow l^+ N$ decay performed for different heavy neutrino masses. A signal region for the $K_{\mu 2}$ data sample selected in

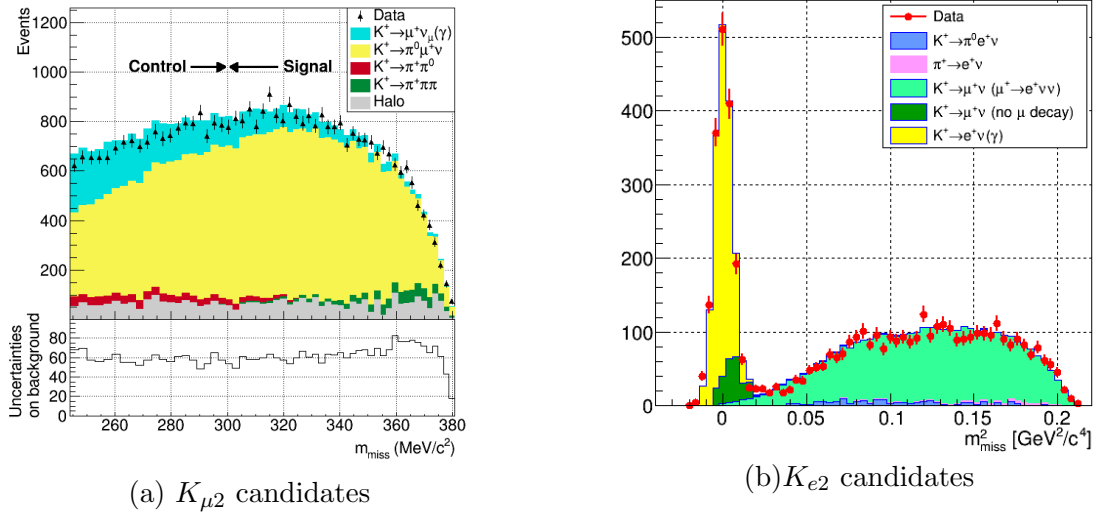


Figure 2. Missing mass spectrum distribution of $K_{\mu 2}$ (a) and $K_{e 2}$ (b) candidates and background estimation from MC.

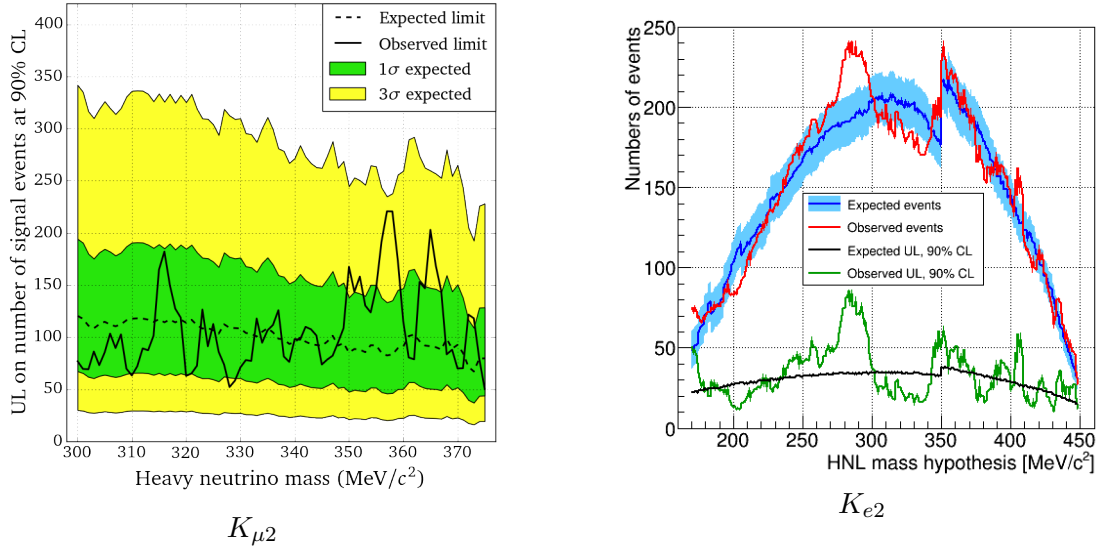


Figure 3. Observed and expected number of events passing selection criteria of $K_{\mu 2}$ (left) and $K_{e 2}$ (right) events as a function of heavy neutrino mass.

$300 < m_{miss} < 375 \text{ MeV}/c^2$ while the region $m_{miss} < 300 \text{ MeV}/c^2$ used for the control purpose.

For the $K_{e 2}$ data sample a signal region selected in $170 < m_{miss} < 448 \text{ MeV}/c^2$. The analyses performed with $1 \text{ MeV}/c^2$ step in the signal regions with an additional condition on the reconstructed mass to be within $\pm \sigma_h^l$ window of the assumed heavy neutrino mass, where σ_h^l depends on heavy neutrino mass resolution obtained from simulation. The statistical analysis is performed using Rolke-Lopez method [9] to define 90% confidence intervals for the number reconstructed events with $K^+ \rightarrow l^+ N$ decays. The upper limits on the signal events, the expected and observed limits at 90% CL are presented in figure 3 as a function of heavy neutrino (HNL) mass.

The upper limits (ULs) on mixing parameter $|U_{l4}|^2$ for each heavy neutrino mass hypotheses

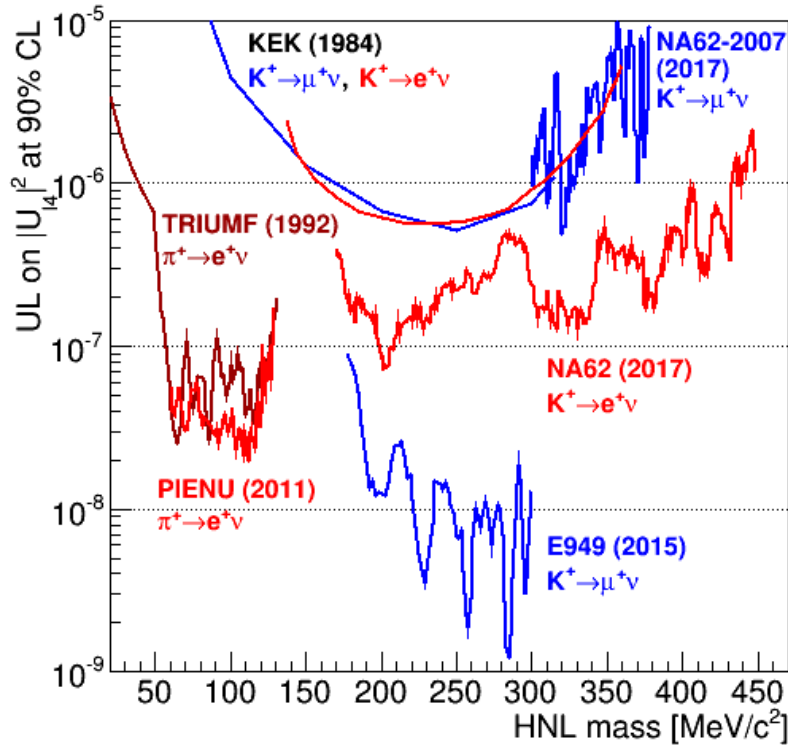


Figure 4. Upper Limit on $|U_{l4}|^2$ at 90% CL from the present NA62 analyses and comparison with the limits using π^+ and K^+ decays from other experiments.

calculated and presented in figure 4 with a comparison to other analyses of heavy neutrinos searched performed in π and K decays.

The new NA62 results improves the existing limits for both $|U_{\mu 4}|^2$ and $|U_{e 4}|^2$ in the analyzed signal regions.

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