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Search for $K^+ \to \pi^+ \nu \bar{\nu}$ at CERN: first NA62 results

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The decay $K^+ \to \pi^+ \nu \bar{\nu}$, with a very precisely predicted branching ratio of less than 10^{-10}, is one of the best candidates to reveal indirect effects of new physics at the highest mass scales. The NA62 experiment at CERN SPS is designed to measure the branching ratio of the $K^+ \to \pi^+ \nu \bar{\nu}$ with a decay-in-flight technique, novel for this channel. The statistics of the first sample collected with the full detector, in 2016, allows to reach the Standard Model sensitivity for $K^+ \to \pi^+ \nu \bar{\nu}$, entering the domain of 10^{-10} single event sensitivity and showing the proof of principle of the experiment. The preliminary result from the 2016 data set is presented.

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1. The $K^+ \to \pi^+ \nu\bar{\nu}$ decay in the Standard Model

The $K^+ \to \pi^+ \nu\bar{\nu}$ decay is a flavour changing neutral current process, highly suppressed due to quadratic GIM mechanism and to CKM suppression. The dominant contribution comes from the short-distance physics of the top quark loop, with a small charm quark contribution and negligible long-distance corrections. This makes the $K^+ \to \pi^+ \nu\bar{\nu}$ decay very clean theoretically and sensitive to physics beyond the Standard Model (SM), probing the highest mass scales among the rare meson decays [1, 2, 3, 4, 5, 6]. The SM prediction for its branching ratio is [7, 8]

$$\mathscr{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}.$$

The uncertainty on the prediction is dominated by the errors of the external inputs. The experimental result [9]

$$\mathscr{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11},$$

was obtained by the BNL E949 collaboration using kaons decaying at rest.

2. NA62 beam and detector

The NA62 detector is shown in Figure 1. The 400 GeV/c primary SPS proton beam impinges on a beryllium target producing a secondary hadron beam which, after being focussed and collimated by the beam optics, has a 6% kaon component and a momentum of (75.0±0.8) GeV/c. A differential Cherenkov detector (KTAG) filled with N_2 and placed on the beam line provides identification and precise timing of the incoming kaons. It is followed by a beam spectrometer (GTK), made of three silicon pixel stations of 6×3 cm^2 surface, exposed to the full 750 MHz beam rate, which measures the time and the 3-momentum of the beam particles before entering the evacuated fiducial decay region. Downstream of the fiducial decay region, a magnetic spectrometer (STRAW), which consists of two pairs of straw chambers on either side of a dipole magnet, measures the momentum of the charged K^+ decay products. A 17 m long RICH counter filled with neon gas is used to separate π^+, μ^+ and e^+. The time of the charged decay products is measured

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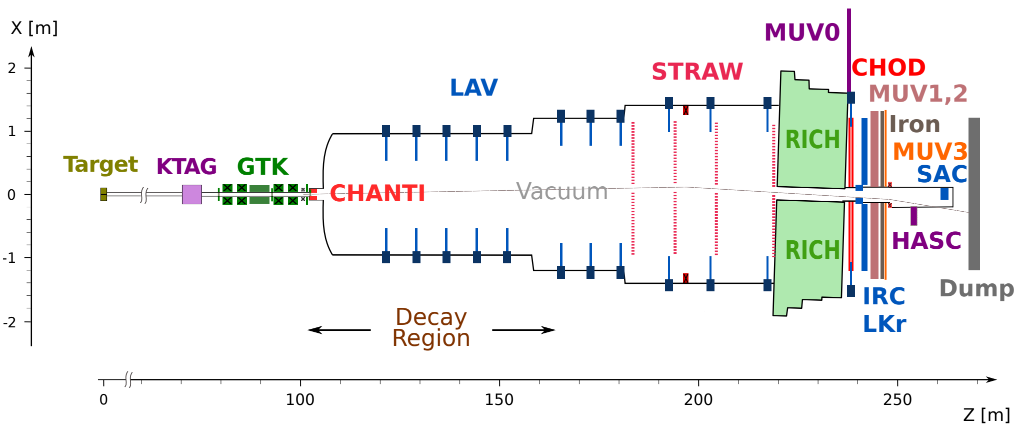

Figure 1: Schematic layout of the NA62 experiment in the xz plane

both with the RICH and with an array of scintillators (CHOD) located further downstream. Two hadronic calorimeters (MUV1 and MUV2) and a fast scintillator array (MUV3) provide further π/μ separation. A set of photons vetoes (LAVs, LKr, IRC, SAC) hermetically cover angles up to 50 mrad to reject extra electromagnetic activity. A detailed description of the detector and its performances in 2015 can be found in Ref. [10].

3. The $K^+ \to \pi^+ \nu\bar{\nu}$ selection

The present analysis is based on the 2016 data set, corresponding to a number of kaon decays in the fiducial decay region $N_K = 1.21(2) \times 10^{11}$. The $K^+ \to \pi^+ \nu\bar{\nu}$ signature consists of one track identified as a kaon in the initial state and one identified as a pion in the final state, with two missing neutrinos. The main kinematic variable is $m^2_{miss} \equiv (p_K - p_{\pi^+})^2$, where p_K and p_{π^+} are the 4-momenta of the K^+ and π^+ respectively. The analysis is performed in two kinematic regions: Region I (R1) between the $K^+ \to \mu^+ \nu_\mu$ ($K_{\mu\nu}$) and $K^+ \to \pi^+ \pi^0$ ($K_{\pi\pi}$) contributions and Region II (R2) between $K_{\pi\pi}$ and $K^+ \to \pi^+\pi^+\pi^-$ ($K_{\pi\pi\pi}$) contributions. Events with single track topology are selected using the STRAW, CHOD and RICH detectors. The downstream track is associated to an in-time kaon track, reconstructed using the KTAG and GTK detectors. The kaon decay vertex, obtained at the intersection point of the GTK and STRAW tracks, is required to be within a 50 m fiducial region beginning 10 m downstream of the last GTK station (GTK3). Figure 2-left shows the distribution at this stage of the selection of the m^2_{miss} variable. Pion identification is achieved by the calorimeters and the RICH counter, providing 10^8 muon suppression for 64% π^+ efficiency. Events passing the π^+ identification criteria are mainly $K_{\pi\pi}$ decays, which are further suppressed by rejecting in-time extra activities in the electromagnetic calorimeters LKr, LAVs, SAC, IRC, resulting in a π^0 suppression of 3×10^{-8}. The $K^+ \to \pi^+ \nu\bar{\nu}$ acceptance after the full selection is $A_{\pi\nu\nu} = 4\%$, divided between R1 (1%) and R2 (3%). The single event sensitivity for a SM $K^+ \to \pi^+ \nu\bar{\nu}$ decay is $SES = (3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \times 10^{-10}$. The quoted systematic uncertainty is dominated by the error on the random veto losses induced by the π^0 rejection procedure (0.17×10^{-10}). The total number of expected background events is reported in Table 1, together with the number of expected signal events.

Table 1: Expected number of signal and background events in R1 and R2 after the $K^+ \to \pi^+ \nu\bar{\nu}$ selection is applied on the 2016 data set.

Process	Expected events in R1+R2
$K^+ \to \pi^+ \nu\bar{\nu}$ (SM)	$0.267 \pm 0.001_{stat} \pm 0.029_{syst} \pm 0.032_{ext}$
$K^+ \to \pi^+ \pi^0 (\gamma)$ IB	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+ \nu (\gamma)$ IB	$0.020 \pm 0.003_{stat} \pm 0.003_{syst}$
$K^+ \to \pi^+ \pi^- e^+ \nu$	$0.018^{+0.024}_{-0.017}\vert_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^+ \pi^+ \pi^-$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
Upstream Background	$0.050^{+0.090}_{-0.030}\vert_{stat}$
Total Background	$0.15 \pm 0.09_{stat} \pm 0.01_{syst}$

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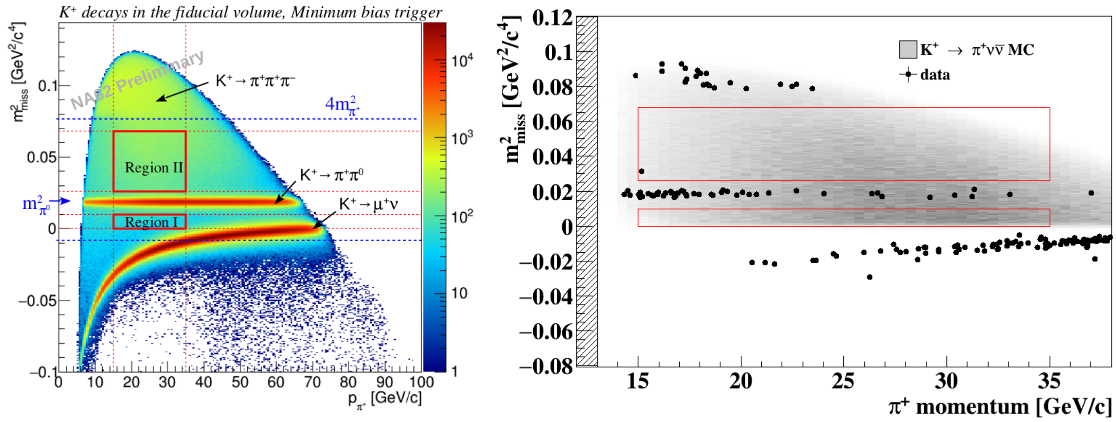

Figure 2: m^2_{miss} distribution as a function of track momentum: for events with one-track topology, selected on minimum bias data (left); for data (dots) and MC (grey area) after the full $K^+ \to \pi^+ \nu \bar{\nu}$ selection, except for the cuts on m^2_{miss} and P_{π^+} (right). The two signal regions are shown (red boxes).

4. Results

One $K^+ \to \pi^+ \nu \bar{\nu}$ candidate is found in R2 after unblinding the signal regions (Figure 2-right). Given such observation, the upper limit on $\mathscr{B}(K^+ \to \pi^+ \nu \bar{\nu})$ obtained using the CL$_s$ method [11] is

$$\mathscr{B}(K^+ \to \pi^+ \nu \bar{\nu}) < 14 \times 10^{-10} \text{ @ } 95\% \text{ CL},$$

with an expected limit of $\mathscr{B}(K^+ \to \pi^+ \nu \bar{\nu}) < 10 \times 10^{-10}$ @ 95% CL. A measurement of the branching ratio at 68% CL is also quoted: $\mathscr{B}(K^+ \to \pi^+ \nu \bar{\nu}) = 2.8^{+4.4}_{-2.3} \times 10^{-10}$ @ 68% CL. The obtained result is consistent with both the SM prediction and the previous measurements. The present analysis demonstrates that the NA62 decay-in-flight technique to study the $K^+ \to \pi^+ \nu \bar{\nu}$ decay works. Considering the statistics collected in 2017 and the one expected in 2018, about 20 SM $K^+ \to \pi^+ \nu \bar{\nu}$ events are foreseen with the full NA62 data set. Both hardware and analysis improvements are foreseen to reduce the background and improve the signal efficiency.

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