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Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at CERN

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Abstract
The NA62 experiment at CERN SPS was designed to measure the $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ with a decay-in-flight technique. NA62 took data in 2016, 2017 and 2018. Statistics collected in 2016 allowed NA62 to reach the Standard Model sensitivity and to show the proof of principle of the experiment. The preliminary result from the 2016 data set is presented.

Keywords Particle physics · Flavour physics · Kaon physics

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1 Introduction

$K^+ \to \pi^+ \nu\bar{\nu}$ is a one-loop flavour-changing neutral current (FCNC) process with hadronic contributions under control thanks to semi-leptonic kaon decay rates and isospin symmetry. The theoretical prediction is quite accurate [1, 2]

$$BR\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = (0.84 \pm 0.10) \times 10^{-10} \tag{1}$$

while the experimental situation is based on few events collected by the BNL E787/E949 experiments [3] using a kaon decay-at-rest technique

$$BR\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = \left(17.3^{+11.5}_{-10.5}\right) \times 10^{-11} \tag{2}$$

The FCNC nature of the process makes it an ideal laboratory to look for new physics which could alter the predictions of the Standard Model (SM) [5–10].

2 NA62 experiment

The NA62 Experiment at CERN is aimed at a 10% precision measurement of the $BR\left(K^+ \to \pi^+ \nu\bar{\nu}\right)$ using a kaon decay-in-flight technique. A primary 400 GeV/c momentum proton beam impinges on a beryllium target, producing a secondary beam which is selected in momentum (75 GeV/c) and composed by protons (24%), π^+ (70%) and K^+ (6%). The momentum of each secondary beam particle is measured by a silicon pixel detector (GTK) and K^+ are identified by a Cherenkov detector (KTAG). A vacuum decay region comprises photon veto detectors (LAV) and a magnetic spectrometer made by 4 stations of straw chambers (STRAW) and a dipole magnet. The vacuum region is followed by a RICH detector, to identify π^+ coming from K^+ decays, a scintillator hodoscope (CHOD), an electromagnetic (EM) calorimeter (LKR) and muon veto detectors (MUV). Small angle EM calorimeters (IRC and SAC) improve the photon veto capabilities, a scintillator detector (CHANTI) helps to reject inelastic interactions in the GTK region. A schematic view of NA62 can be seen in Fig. 1 and a detailed description can be found in [4].

3 Event selection

A signal candidate is selected by matching a K^+ in the hadron beam with a π^+ from its decay. The main kinematic variable is the missing mass m_{miss}, given by the difference of the K^+ and π^+ four-momenta. The main backgrounds have peculiar m_{miss} distributions, which define two signal regions. $K^+ \to \mu^+\nu$ would have an almost zero m^2_{miss} (i.e. the ν mass) but with the μ^+ wrongly identified as a π^+, the m^2_{miss} becomes negatively distributed. $K^+ \to \pi^+\pi^0$, where two γs from π^0 decay have been lost, has a m_{miss} peaked at the π^0 mass. Finally $K^+ \to \pi^+\pi^+\pi^-$, where 2 $\pi^\pm$ have been lost, has a m_{miss} at least twice as big as the $\pi^\pm$ mass. The signal regions are defined by $0 < m^2_{miss} < m^2_{\pi^0}$ (Region 1) and by $m^2_{\pi^0} < m^2_{miss} < 4m^2_\pi$ (Region 2); the two regions are further reduced to take into account the m^2_{miss} resolution.

The data set collected during 2016 corresponds to $(1.21 \pm 0.02) \times 10^{11}$ kaon decays, estimated by $K^+ \to \pi^+\pi^0$ events used as normalization. Taking into account

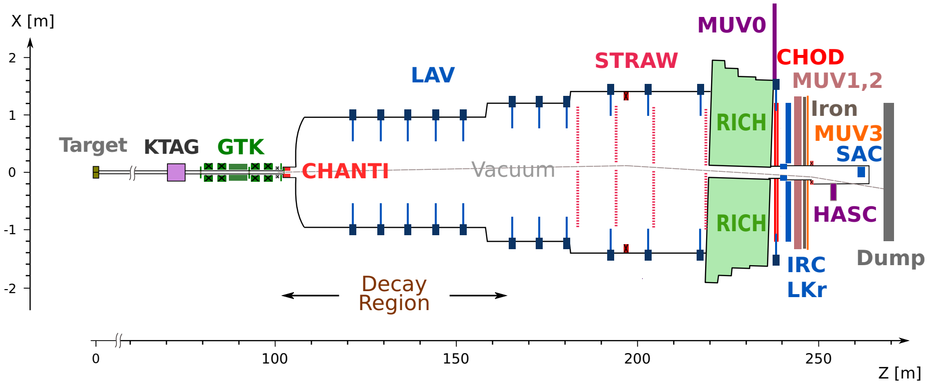

Fig. 1 Layout of the NA62 experiment

the signal acceptance (4.0 ± 0.1)%, the trigger efficiency (87 ± 2)% and random veto loss probability (76 ± 4)%, the expected number of identified signal events is $(0.267 \pm 0.001(stat) \pm 0.020(syst) \pm 0.032(ext))$ based on SM calculations which uncertainties is the quoted external error.

4 Background estimation and result

The background is made by all the charged kaon decays and by beam interactions. The $K^+ \to \pi^+\pi^0$ background is estimated collecting a downscaled data sample with a minimum bias trigger and fully reconstructing the decay (identifying two γs from π^0 decay) and assuming the reconstructed kinematics tails to be independent from the γs veto capability of the experiment. After all the $\pi^+\nu\bar{\nu}$ selection but m_{miss}, those events found in the $\pi^+\pi^0$ m_{miss} region (i.e. between Region 1 and Region 2) are used to extrapolate the number of background events in the signal regions: 0.064 events are expected. In a similar way the $K^+ \to \mu^+\nu$ background is estimated: a control data sample with an identified muon is selected and the kinematics tails are evaluated; in the $\pi^+\nu\bar{\nu}$ selected events, but for m_{miss}, those events in the $\mu^+\nu$ region (i.e. with a negative m_{miss}) are used to predict the background events in the signal regions, 0.020 events. A similar approach is used for the $K^+ \to \pi^+\pi^+\pi^-$ decay with a predicted background smaller by an order of magnitude with respect to the other channels. The decay $K^+ \to \pi^+\pi^-e^+\nu$ (K_{e4}) is not kinematically constrained, is quite rare (preventing the possibility to prepare a reasonable control sample) and is estimated by a MonteCarlo to bring 0.018 events in the signal regions. Finally, inelastic interactions or early kaon decays in the GTK region can mimic the signal: from a control sample it is estimated a total contribution of 0.050 events in the signal regions.

In total a background of $0.15 \pm 0.09(stat) \pm 0.01(syst)$ events is estimated.

After all the selection, one signal candidate event is found in the 2016 data sample, shown in Fig. 2. This corresponds to an upper limit of

$$BR\left(K^+ \to \pi^+\nu\bar{\nu}\right) < 14 \times 10^{-10} \; at \; 95\% \; CL \tag{3}$$

taking into account the background and the systematic uncertainties.

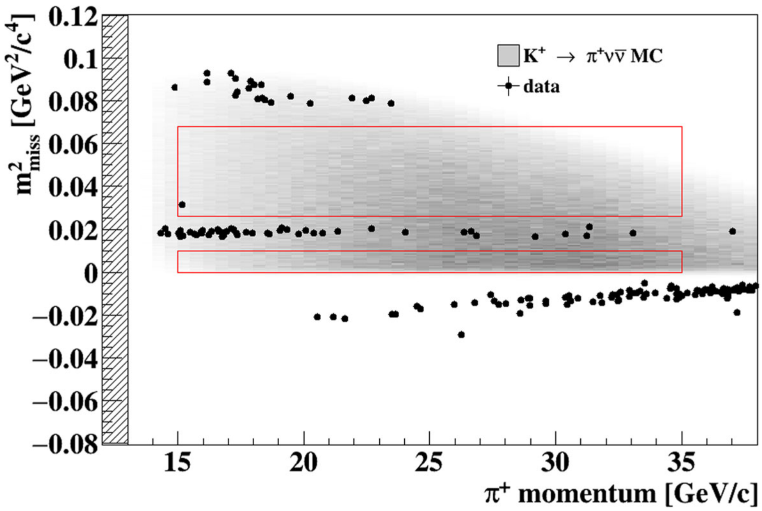

Fig. 2 Missing mass versus pion momentum after the selection. The red boxes are the signal region, dots are 2016 data events, the shaded area is the signal MonteCarlo. A signal candidate is visible in the upper signal region (Region 2 in the text)

5 Conclusions

In this paper the first measurement of the CERN NA62 experiment, based on data collected in 2016, is presented. With one signal candidate and an estimated background of 0.15 events, a preliminary upper limit of $BR\left(K^+ \to \pi^+\nu\bar{\nu}\right) < 14 \times 10^{-10}$ at 95% CL is achieved. The NA62 experiment took data in 2017 and 2018 with a 20-fold improvement in statistics with respect to 2016.

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