Measurement of $K^+ \to \pi^+\nu\overline{\nu}$ at NA62 experiment

Spasimir Balev
Scuola Normale Superiore di Pisa
56126 Pisa, ITALY

1 Introduction

The future program of the experiment NA62 at CERN SPS is currently in advanced stage of development. The main goal of the experiment is to measure the branching ratio of the very rare $K^+ \to \pi^+\nu\overline{\nu}$ decay, by detecting approximately 100 events with 10% background. In this paper is described the motivation of the measurement, the strategy of the experiment, the sources of background and the expected level of their suppression, the main properties of the beam line and necessary detectors.

2 Motivation

The $K^+ \to \pi^+\nu\overline{\nu}$ and $K_L \to \pi^0\nu\overline{\nu}$ decays are exceptionally clean modes, dominated by short distance dynamics due to power-like GIM mechanism, and therefore are excellent probes in flavour physics. At the quark level the process $d \to s\nu\nu$ (see Fig. 1) is realized by combination of Z_0 penguin and double W exchange. The leading SM contribution to the matrix element is generated by top quark loops and can be computed with negligible theoretical uncertainty. In case of $K^+ \to \pi^+\nu\overline{\nu}$ decay there is a small contribution from charm quark, while the contribution from up quark is negligible in both decay modes. The hadronic matrix element can be extracted from the well measured $K \to \pi e\nu$ decays rates with negligible theoretical uncertainty. The current estimations of the branching ratios for the the $K \to \pi\nu\overline{\nu}$ decays within the SM are $BR(K^+ \to \pi^+\nu\overline{\nu}) = (8.22 \pm 0.84) \cdot 10^{-11}$ and $BR(K_L \to \pi^0\nu\overline{\nu}) = (2.76 \pm 0.40) \cdot 10^{-11}$ [1].

Measurement of the branching ratios of both $K^+ \to \pi^+\nu\overline{\nu}$ and $K_L \to \pi^0\nu\overline{\nu}$ decay modes leads to determination of V_{td} element in CKM matrix, i.e. of the Wolfenstein parameters (ρ, η) that define the unitarity triangle (see Fig. 2), independently of the results from B-physics.

The strong suppression of $K \to \pi\nu\overline{\nu}$ decays within SM follows from the absence of tree-level contributions and the hard GIM mechanism. However, this also leads to high sensitivity to possible new-physics effects. Since the cleanness of these decays

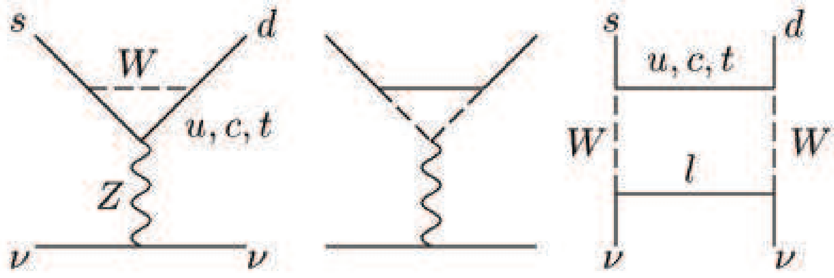


Figure 1: Diagrams of $d \to s\nu\overline{\nu}$ process.

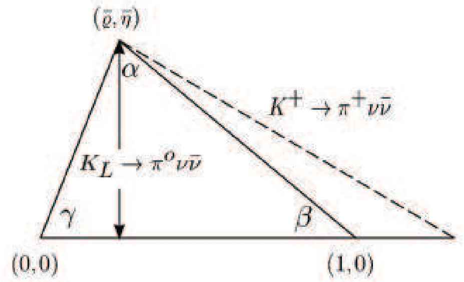


Figure 2: Connection between the branching ratios of $K \to \pi\nu\overline{\nu}$ decays and the unitarity triangle.

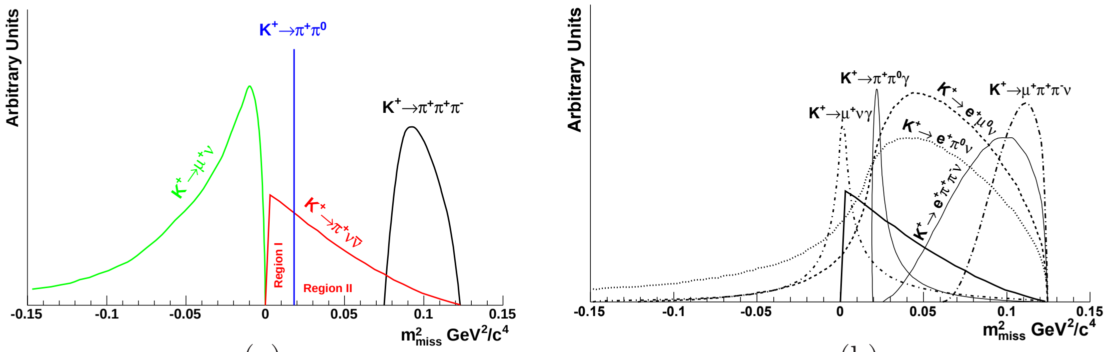
modes remains valid in all realistic extensions of SM, a precise measurement of their branching ratios provide sensitive test of the flavour structure of any model beyond SM. Evidence of new physics can be seen in $K \to \pi\nu\overline{\nu}$ decays even without significant signals in B-decays or without particles within LHC reach [2].

Only three $K^+ \to \pi^+\nu\overline{\nu}$ events were discovered by BNL E949 Collaboration. The measured value is compatible with SM prediction: $(1.47^{1.30}_{-0.89}) \cdot 10^{-10}$ [3].

The NA62 experiment [4] will use kaon decays in-flight technique, based on the NA48 apparatus and infrastructure, and the same CERN-SPS beam line which produced the kaon beam for all NA48 experiments. The experiment was presented at CERN SPS Committee in September 2005 and in December 2005 the R&D was endorsed by the CERN Research Board. Currently the experiment is in advanced stage of R&D and construction [5] with the data taking expected to begin in 2011.

3 Backgrounds

The experimental signature of the studied $K^+ \to \pi^+\nu\overline{\nu}$ decays is a single reconstructed track in the detector downstream the decay volume in time coincidence with



(a) (b)

Figure 3: Kinematically constrained (a) and kinematically not constrained (b) backgrounds to $K^+ \to \pi^+\nu\overline{\nu}$ decays.

a kaon measured by the upstream beam tracker. The kinematics of a one-track event can be fully described by the variable $m^2_{miss} = (P_K - P_\pi)^2$, where P_K and P_π are the four-momenta of the kaon and pion, respectively. Two categories of backgrounds can be considered (see Fig. 3):

- **Kinematically constrained background.** The decays in this category correspond to $\sim$95% of the total K^+ branching fraction. The $K^+ \to \pi^+\pi^0$ decay splits the kinematical region of the signal in two parts, called region I and region II. $K^+ \to \mu^+\nu$ and $K^+ \to \pi\pi\pi$ decays sit on the opposite sides of these regions where cuts must be applied as well. Rejection factor larger than 10^{12} can be achieved only if efficient photon rejection and particle identification complements the kinematical rejection.

- **Kinematically not constrained background.** The rejection of such background profits from relatively small branching fractions. However, photon veto system and particle identification are the only experimental tools available to reduce such a background.

The expected level of background is summarized in Tab. 1. The signal acceptance is found to be 14.4% (3.5% in region I and 10.9% in region II). With a flux of about $4.8 \cdot 10^{12}$ kaon per year of data taking, the expected number of signal events is 55 events/year.

4 The Experimental set-up

The layout of the experimental apparatus is presented in Fig. 4.

The K^+ beam will be produced on a beryllium target from SPS protons with momentum 400 GeV/c and intensity $3.3 \cdot 10^{12}$ protons per pulse. The nominal momentum of the K^+ beam will be $P_K = 75$ GeV/c with $\Delta P_K/P_K = 1.2\%$. The expected fraction of K^+ in the beam is 6.6%. A tungsten radiator 1 X_0 thick will be placed on the beam in the first achromat in order to absorb the positron component of the beam.

After the first achromat a differential Cerenkov counter (CEDAR) existing at CERN, will be used after its upgrade for new experimental conditions for kaon tagging, in order to keep the beam background under control.

The beam spectrometer (Gigatracker) will be placed in the second achromat station. It consists of thin silicon micro-pixel detectors for redundant momentum measurement of the incoming beam with 200 ps time resolution, necessary to provide a tight coincidence between incoming kaon and outgoing pion. The Gigatracker will work in rough conditions – near GHz rate of passing particles – hence the name.

A set of ring anti-counters (CHANTI) will be placed after the last Gigatracker station to form a "guard ring" and a large one around the beginning of the decay volume, in order to veto charged particles coming from the collimator.

The decay volume, contained in a vacuum tank, will be surrounded by a set of ring-shaped anti-counters, providing full coverage for photons originating from decay region with angles as large as 48 mrad. Lead-scintillator fibers and lead-scintillator tiles design of this system is now under the study. A lead-glass prototype will be tested in 2008 run of the NA62 experiment.

A magnetic spectrometer, operating in vacuum, will be used to measure the momentum of the out-going pion. The spectrometer is designed with 4 straw chambers with 4 coordinate views each. Chambers should introduce small material contribution (0.5% X_0 per chamber) and have a good spatial resolution (130 μm per view). 36 μm mylar straw tubes with about 10 mm in diameter welded by ultrasound machine and cowered with gold inside will be used for these reasons. This spectrometer will

Decay mode	Level of background
$K^+ \to \pi^+\pi^0$	4.3%
$K^+ \to \mu^+\nu$	2.2%
$K^+ \to \pi^+\pi^-e^+\nu$	$\sim$3.0%
Other 3-tracks decays	$\sim$ 1.5%
$K^+ \to \pi^+\pi^0\gamma$	$\sim$ 2.0%
$K^+ \to \mu^+\nu\gamma$	$\sim$ 0.7%
$K^+ \to e^+(\mu^+)\nu\pi^0$ and others	negligible
Total background	$\sim$ 13.7%

Table 1: Background levels from various K^+ decay modes.

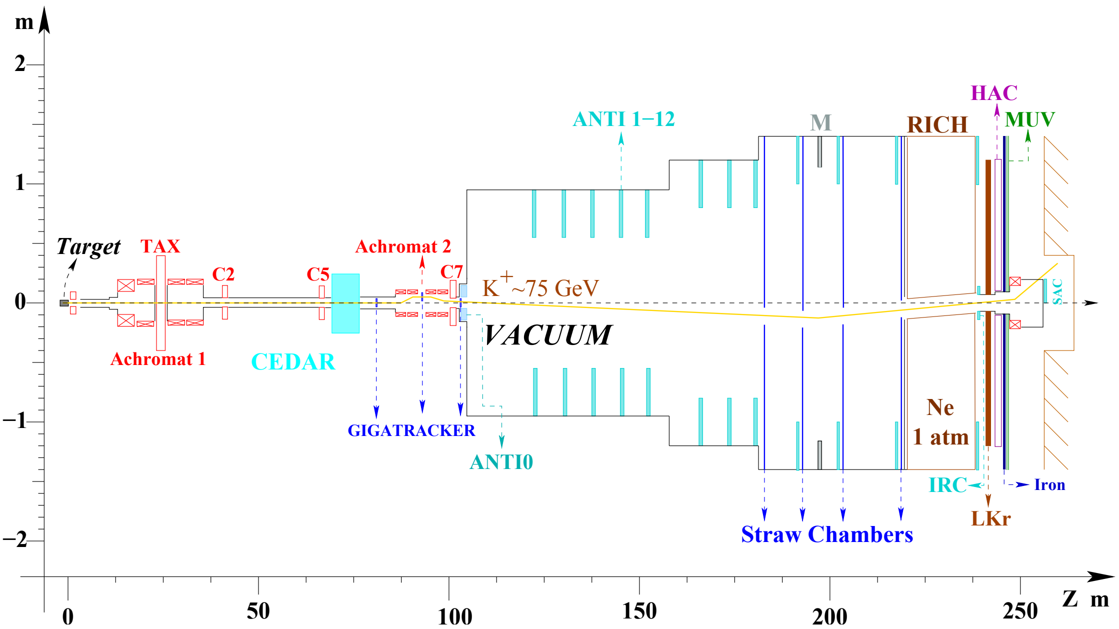


Figure 4: Layout of NA62 experimental apparatus.

be used as well as a veto for high energy negative pion from K_{e4} decays. The R&D program has been started in 2006, a full length and reduced-size prototype has been constructed, integrated and tested in the NA62 set-up during the 2007 run at CERN. The test continues during the 2008 run of the experiment.

After the magnetic spectrometer a gas Ring Imaging Cerenkov counter (RICH) will be placed, providing muon/pion separation and suppression factor smaller than 10^{-2} in the momentum interval (15–35) GeV/c. The detector will be used also for precise measurement of the pion crossing time with resolution $\sim$100 ps, sending signals to the trigger system. In addition RICH will provide redundant measurement of velocity of the charged particles. The detector consists of 18 m long tube with a diameter of 2.8 m, filled with Neon at atmospheric pressure. The Cerenkov radiation will be collected by two mirrors with 17 m of focal length. A full-length prototype 60 cm in diameter has been integrated in the NA62 set-up and tested during the 2007 NA62 run at CERN.

The Liquid Krypton Calorimeter (LKR), built for the NA48 experiment, will be used as part of the photon veto system in the forward region. During test run in 2006 it was shown that inefficiency below 10^{-5} can be reached. A program of consolidation and update of the readout electronics of the LKr is under way.

For muon identification with very small inefficiency will be used a hadron calorimeter and muon detector, placed just after LKR. The photon veto system is completed by the Intermediate Ring Calorimeter (IRC), placed at the entrance of LKR, and Small Angle Calorimeter (SAC) at the very end of the detector system, after the muon deflecting magnet, both covering the angular regions around and in the beam. SAC prototype was tested during 2006 and upper limit on its inefficiency was found to be $6.4 \cdot 10^{-5}$.

The trigger system of NA62 experiment will be at two levels. The first one (L0) is hardware trigger, which will decrease the events rate from ∼10 MHz to ∼1 MHz, employing signals from RICH, photon veto system and the muon detector. The second level (L1/2) is software and its aim is to decrease the rate of the events to kHz level.

5 Conclusions

The experiment NA62 is proposed to search for new physics by measuring $K^+ \to \pi^+\nu\overline{\nu}$ branching ratio with 10% accuracy. It is expected that in 2 years of data taking the experiment will collect ∼100 decays of this mode. Other physical opportunities, like search for lepton flavour violation processes and new low mass particles, as well as tests of lepton universality, are part of the experimental program. The R&D program of the experiment is well advanced and many of the detectors are in prototyping or construction phase.

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