The $K^+ \to \pi^+\nu\overline{\nu}$ experiment at CERN

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Abstract. The P–326 proposal for an experiment to measure the very rare kaon decay $K^+ \to \pi^+\nu\overline{\nu}$ branching ratio at the CERN SPS is described. The proposed experiment will collect about 80 $K^+ \to \pi^+\nu\overline{\nu}$ events with a 10% background in two years, leading to a 10% measurement of the CKM parameter $|V_{td}|$.

1. Introduction

The $K^+ \to \pi^+\nu\overline{\nu}$ decay, together with $K_L \to \pi^0\nu\overline{\nu}$, is a decisive test of Standard Model (SM) sensitive to new physics, both in MVF and non–MVF scenarios [1, 2, 3]. It is a FCNC process (through box and purely electroweak penguin diagrams) dominated by short distance dynamics which amplitude is governed by one single semileptonic operator. The hadronic matrix element can be parameterized in terms of the $K^+ \to \pi^0 e^+\nu$ branching ratio, well known experimentally, reducing to $\sim$ 5% the theoretical uncertainty [4] on the computed branching ratio $(8.0 \pm 1.1) \cdot 10^{-11}$.

The existing measurement of the $K^+ \to \pi^+\nu\overline{\nu}$ branching ratio, based on 3 $K^+ \to \pi^+\nu\overline{\nu}$ events [5], is compatible with SM within errors: a 10% accuracy measurement is required in order to provide a significative test of the new scenarios.

2. The P–326 proposal

The goal of the experiment is to collect about 80 $K^+ \to \pi^+\nu\overline{\nu}$ events in two years of data taking with a 10% background contamination: this can be achieved with a 10% signal acceptance using a decay in flight technique and a beam line able to provide $\sim 10^{13}$ kaon decays. The new experiment [6] will be based on the NA48 apparatus at CERN, using the same CERN–SPS beam line which produced the kaon beam for the NA48 experiment. R&D program has started in 2006 and data taking should start in year 2010.

2.1. The beam

A K^+ beam with a central momentum of 75 GeV/c and 1.1% RMS momentum bite is produced by a 400 GeV/c intense proton beam from the SPS impinging on a Be target. The main components are an achromat system made of four dipole magnets and a momentum selecting slit to allow the selection of a narrow momentum, and a second achromat where the Gigatracker is installed. The average rate in the Gigatracker is $\sim$ 800 MHz, while the one seen by the dectector is $\sim$ 11 MHz due to kaon decays and accidentals coming from the beam line. The beam is positron free and composed by 6% of K^+. Assuming 100 days of data taking at 60% efficiency, $5 \cdot 10^{12} K^+$ decays/year are expected in a 60 m long decay region.

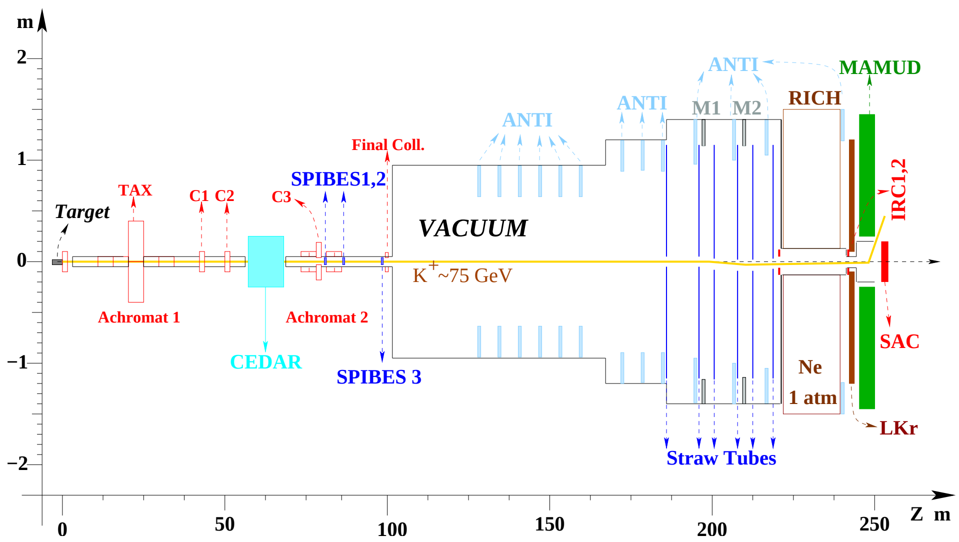

Figure 1. Layout of the experiment

2.2. The detector

The layout of the experiment is shown in figure 1. The detector consists of:

- The tracking system composed by the Gigatracker and the pion spectrometer. The Gigatracker (beam spectrometer) consists of three silicon pixel stations across the second achromat, made up by $300 \times 300 \mu m^2$ pixels each. At least 200 ps time resolution per station is needed to provide a suitable tag of the kaon track. The pion spectrometer consists of two magnets and six chambers with four double layers of straw tubes each (0.1% X_0 per view) placed in vacuum to reduce multiple scattering. It will provide redundant momentum measurement and will act as veto for charged particles.
- The particle ID system consists of a CEDAR detector to tag the K^+ in the unseparated charged beam and a RICH to separate the decay products. The CEDAR is a differential Cerenkov counter available at CERN and upgraded to be adapted to the new beam conditions. A 18 m long RICH located after the spectrometer and filled with Ne at atmospheric pressure is used for the pion identification. It is crossed by a 11 cm radius beam pipe while two tilted mirors at the end reflect the Cerenkov light toward an array of about 2000 PMTs placed in the focal plane. The RICH will provide timing information for downstream tracks with a required time resolution of 100 ps.
- The veto system identifies photons produced in kaon decays using an hermetic combination of calorimeters covering up to 50 mrad. At large angle (10–50 mrad) ring shaped calorimeters in vacuum should provide photon detection down to 50 MeV with an inefficiency of 10^{-4}. Two options are under study consisting of lead–scintillator fibers or lead–scintillator tiles. At medium angle (1–10 mrad) the existing NA48 liquid krypton electromagnetic calorimeter (LKr) [7] with upgraded electronics will be used. An inefficiency lower than 10^{-5} for photon energies above 10 GeV/c has been measured on $K^+ \to \pi^+\pi^0$ events collected by NA48/2 in 2004. The inefficiency for energies between 2 and 10 GeV/c is under study using data collected during the 2006 test run performed at the SPS with bremsstrahlung photons produced by electrons passing through the NA48/2 apparatus. At small angle (below 10 mrad) only photons with energy above 10 GeV/c illuminate the detector and a shashlyk technology will be used providing 10^{-5} inefficiency.

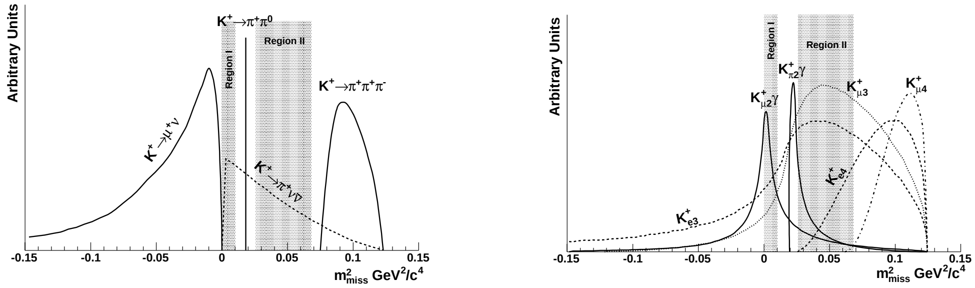

Figure 2. Squared missing mass for 75 GeV/c K^+ decays. The signal regions are compared to the kinematically (left) and not kinematically (right) constrained backgrounds.

The R&D program for the detectors is started in 2006 and continues in 2007 with prototypes integrated in the NA62 set–up and tested during the 2007 NA62 run at CERN.

3. Background rejection and sensitivity

The experimental signature of a $K^+ \to \pi^+\nu\overline{\nu}$ decay consists of only one positive track reconstructed downstream. The beam and pion spectrometers allow a precise reconstruction of the kinematics, measuring the squared missing mass defined as $m^2_{miss} = (P_K - P_\pi)^2$ under the hypotesis that the final charged particle is a pion. The m^2_{miss} allows a kinematical separation between signal and 92% of total background: as shown in figure 2 (left), the backgrounds with largest branching ratios due to $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu_\mu$ decays define two signal regions ($0 < m^2_{miss} < 0.01 GeV^2/c^4$ and $0.026 < m^2_{miss} < 0.068 GeV^2/c^4$) where background enters only because of non gaussian tails in the squared missing mass resolution. The remaining 8% background shown in figure 2 (right) is not kinematically constraint and its rejection must rely on the veto system. A 10^{-13} background rejection factor is needed. The detector components give redundancy both in kimematics reconstruction and particle identification allowing background estimation directly from the data.

Preliminary sensitivity studies on the signal acceptance have been performed using Geant3, Geant4 and Fluka based simulations. A total acceptance of 17% is obtained, showing that the goal of a 10% signal acceptance is achievable when taking into account additional losses occurring in real data taking. Considering the main background sources, a simple counting of signal and background events in the signal regions shows that a S/B ~10 is nearly achivable.

4. Conclusions

An experiment to search for new physics using $K^+ \to \pi^+\nu\overline{\nu}$ decays at the CERN SPS has been proposed. A 10^{-12} sensitivity per event can be reached using existing infrastructures and detectors. The detector requires a sophisticated technology: the general design is mostly defined and an intense R&D program is started. The beam will provide a K^+ flux ~100 times higher than NA48/2 addressing many other physics opportunities.

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