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

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Abstract. The P326 proposal of a new experiment NA62 aiming to perform precise measurement of the very rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$ branching ratio at CERN is described. About 80 $K^+ \to \pi^+\nu\bar{\nu}$ events with 10% of background is planned to obtain in two years of data taking. The status of the project, current status of R&D and future plans of the experiment are discussed.

1 Introduction

The $K^+ \to \pi^+\nu\bar{\nu}$ decay is a flavor changing neutral current process, computable with very small theoretical uncertainty of about 5% [1]. The hadronic matrix element can be parameterized in terms of the branching ratio of the well measured $K^+ \to \pi^0 e\nu$ decay [2] using isospin symmetry. The computed value is $(8.0 \pm 1.1) \times 10^{-11}$, where the error is dominated by the uncertainty in the knowledge of the CKM matrix elements. Such an extreme theoretical clarity, unique in K and B physics, makes this decay (together with $K_L \to \pi^0\nu\bar{\nu}$) extremely sensitive to new physics (see for example [3, 4]).

Only 3 $K^+ \to \pi^+\nu\bar{\nu}$ events have been observed by BNL-E949 experiment [5], that gives a central value of the branching ratio higher than the SM expectation. But $\sim 10\%$ accuracy measurement of the branching ratio is required to provide a significative test of new physics contributions. This is the goal of the proposed NA48/3 (or NA62) experiment at CERN-SPS [6]. The aim of the experiment is to collect about 80 $K^+ \to \pi^+\nu\bar{\nu}$ events with the background level of 10%.

2 Proposal of the future experiment

The NA62 experiment will use kaon decays in-flight technique, based on the NA48 apparatus and the same CERN-SPS beam line which produced the kaon beam for all NA48 experiments. The R&D program for this experiment, started in 2006, is continuing in 2007. The data taking should start in 2011.

The layout of the experiment is shown in fig.1. The goal of the experiment can be reached by having 10% signal acceptance and by using a beam line able to provide the order of 10^{13} kaon decays.

To study $K^+ \to \pi^+\nu\bar{\nu}$ decay it is necessary to reconstruct one positive pion track in the downstream detector. If a beam and a pion tracking detectors provide a precise reconstruction of the decay kinematics, the missing mass allows a kinematical separation between the signal and more than 90% of the total background (fig.2); only non-gaussian tails from $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu_\mu$

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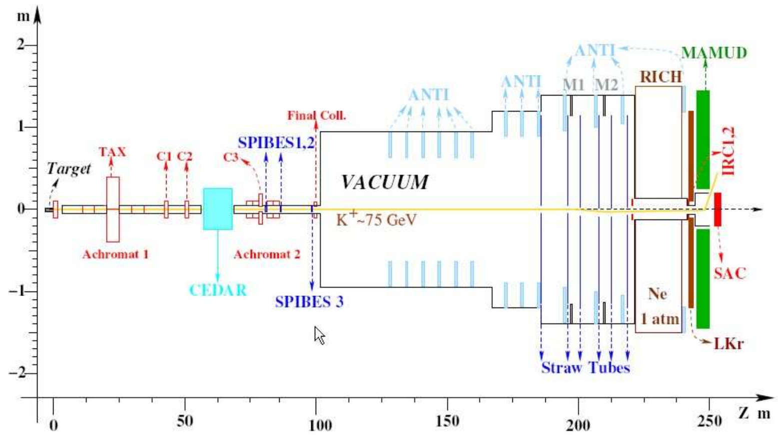

Figure 1: Layout of the experiment

in the squared missing mass resolution will present in the defined signal region. But the kinematics only cannot provide background rejection factor of 10^{13}. So, different veto (photon and muon) and particle identification (CEDAR and RICH) systems are included into experimental set-up to fulfill these needs. Moreover, the detector can provide redundancy both for kinematics reconstruction and particle identification allowing to estimate background directly from the data.

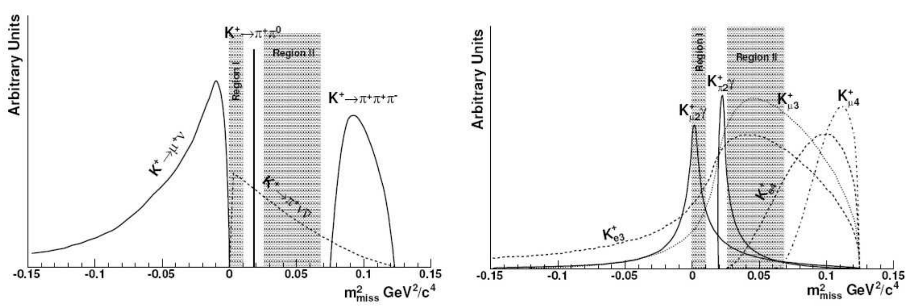

Figure 2: Squared missing mass for kaon decays

2.1 The beam line

A 400 GeV/c proton beam from the SPS, impinging a Be target, produces a secondary charged beam. 100 m long beam line selects 75 GeV/c momentum beam with 1.1% RMS momentum bite and an average rate of about 800 MHz integrated over an area of 14 cm^2. The beam contains 6% of K^+. The average rate seen by the downstream detectors integrated on their surface is ∼11 MHz. The described beam line provides 5×10^{12} K^+ decays, assuming 60 m decay region and 100 days of run at efficiency of 60%, which is a very realistic estimation based on the decennial NA48 experience at the SPS.

2.2 The experimental set-up and R&D current status

The experimental set-up consists of:

- *Beam (Gigatracker) and pion (magnetic) spectrometers.* The first one consists of three silicon pixel stations across the second achromat of the beam line, produced by 300×300 μm^2 pixel each. The time resolution of 200 ps is provided by 0.13 microns technology of silicon detector production. The magnetic spectrometer is designed with 6 (or 4) straw chambers with 4 coordinate views each. Chambers should work in vacuum, introduce small material contribution (0.5% X_0 per chamber) and have a good spatial resolution (130 microns 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 be used as a veto as well 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.

- *Differential Cherenkov counter CEDAR and RICH.* CEDAR [7], differential Cerenkov counter existing at CERN, will be used after its upgrade for new experimental conditions for kaon tagging to keep the beam background under control. The 18 m long RICH located after magnetic spectrometer and filled with Ne at atmospheric pressure aimed for particle identification and pion momentum measurement. It will contain about 2000 PMTs in the focal plane and has to reach a time resolution of 100 ps to provide time information for downstream tracks. A full-length prototype 60 cm in diameter and 96 PMTs has been integrated in the NA62 set-up and tested during the 2007 NA62 run at CERN.

- *Large angle (for 10–50 mrad), medium angle (for 1–10 mrad) and small angle (for <1 mrad) veto calorimeters.* Photon detection down to 50 MeV with an inefficiency of 10^{-4} should be provided by large angle ring-shaped calorimeter working in vacuum. Lead-scintillator fibers and lead-scintillator tiles design of this calorimeter is now under the study. The existing liquid krypton calorimeter (LKr) [8] is planned to use as a medium angle veto with an inefficiency lower than 10^{-5}. The 2006 test at SPS electron beam has confirmed the 10^{-5} inefficiency for photon energies above 10 GeV. A program of consolidation and update of the readout electronics of the LKr is under way. For small angle calorimeter "shashlyk" technology will be used to reach 10^{-5}

inefficiency for photon energies above 10 GeV. A prototype has been built and tested with electrons on the NA48 beam line in 2006.

3 Performances

Simulation has been done for preliminary analysis. The total acceptance is found to be about 17%, showing that the target of 10% of signal acceptance is safely achievable even taking into account additional losses occurring in a real data taking. RICH usage constrains the accepted pion tracks in the momentum range of 15–35 GeV/c. The high limit on this cut is an important loss of the signal acceptance, but it assures that events like $K^+ \rightarrow \pi^+\pi^0$ deposit at least 40 GeV of electromagnetic energy, making their rejection easier.

Many sources of background have been considered and simple calculations of signal and background events in the signal regions indicates that the 10% background level is nearly achievable.

4 Conclusion

A study of the extremely rare $K^+ \rightarrow \pi^+\nu\bar{\nu}$ decays is an unique instrument for searching for the new physics. The NA62 experiment at CERN-SPS proposes to follow this road by collecting about 80 events of this decay. The overall experimental design requires a sophisticated technology for which an intense R&D program has been started. Actually designed experiment is able to reach a 10^{12} sensitivity per event employing existing infrastructures and detectors.

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