The NA62 Experiment at CERN

G. Ruggiero[a]

[a]Scuola Normale Superiore,
P.zza dei Cavalieri 7, Pisa, Italy

The NA62 experiment to measure the branching ratio of the very rare kaon decay $K^+ \to \pi^+ \nu\bar{\nu}$ at the CERN SPS is described. The proposed experiment aims to collect some 100 $K^+ \to \pi^+ \nu\bar{\nu}$ events with a 10% of background. The status and the future perspectives for the experiment are discussed.

1. Introduction

Among the many rare FCNC K and B decays, the rare decays $K \to \pi\nu\bar{\nu}$ play a key role in search for new physics through underlying mechanisms of flavour mixing. The SM branching ratio can be computed to an exceptionally high degree of precision and the prediction for the $K^+ \to \pi^+ \nu\bar{\nu}$ channel is $(8.5 \pm 0.7) \times 10^{-11}$ [1]. The error comes mainly from the experimental uncertainty on the CKM matrix elements, while the irreducible theoretical uncertainty amounts to less than 2%. The extreme theoretical cleanness of these decays remain also in new physics scenarios like Minimal Flavour Violation (MFV) [2] or non-MFV models [3] and even not large deviations from the SM value (for example around 20%) can be considered clear signals of new physics.

The decay $K^+ \to \pi^+ \nu\bar{\nu}$ has been observed by the stopping kaon experiments E787 and E949 at the Brookhaven National Laboratory and the corresponding measured branching ratio is $1.73^{+1.15}_{-1.05} \times 10^{-10}$ [4]. However only a measurement of the branching ratio with at least 10% accuracy can be a significant test of new physics. This is the main goal of the NA62 experiment at CERN-SPS [5,6]. It aims to collect some 100 $K^+ \to \pi^+ \nu\bar{\nu}$ events in about two years of data taking, keeping a background contamination around 10%.

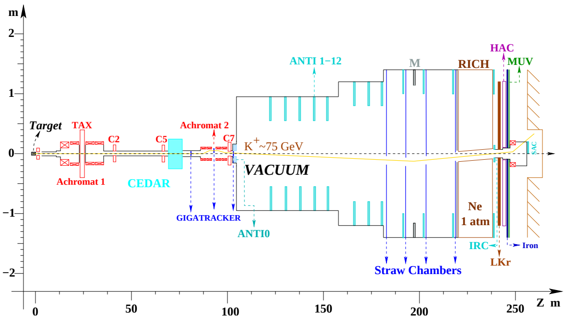

Figure 1. Layout of the experiment.

2. The NA62 Experiment

Figure 1 shows the layout of the NA62 experiment. The requirement of 100 events needs to 10% signal acceptance and at least to 10^{13} K^+ decays. The required signal to background ratio demands a background suppression factor of at least 10^{13}. A high energy kaon beam and a decay-in-flight technique are the principles of the experiment.

The experiment will be housed in the CERN North Area High Intensity Facility (NAHIF) where the NA48 [7] was located and it will use the same SPS extraction line and target of NA48. A new high acceptance beam line will deliver a 50 times more intense secondary hadron beam of positive charge of 75 GeV/c momentum (±1%), corresponding to an average rate of about 800 MHz integrated over an area of 14 cm^2. The beam is positron free and is composed by 6% of K^+. A system of subdetectors placed about 170 m downstream to the target provides the detection of the K^+ decay products. The average integrated rate on the detectors downstream is about 11 MHz, mainly due to the kaon decays and accidental muons. This beam line provides 5×10^{12} K^+ decays, assuming 60 m decay region and 100 days of run at 60% of efficiency, which is a very realistic estimate based on the decennial NA48 experience at the SPS.

The key points of NA62 are: an accurate kinematic reconstruction to disentangle the signal; a precise timing to associate the π^+ with its K^+ parent; a system of efficient vetoes to reject events with γ and μ; a particle identification system to identify the kaons in the charged beam and to distinguish π^+ from μ^+ and e^+ in the final state.

The R&D of the experiment, started in 2007, will finish at the end of 2010. The construction of the apparatus is already started in 2010 and the beginning of the data taking is foreseen in 2012-2013.

3. Kinematic Rejection

The kinematics of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay allows the signal definition. The main variable in use is the squared missing mass, m^2_{miss}, defined as the square of the difference of the 4-momenta of the K^+ and of the track downstream in the π^+ hypothesis. This variable separates the signal from more than 90% of the background coming from other K^+ decays (Figure 2). The $K^+ \rightarrow \pi^+ \pi^0$ peak divides two regions of m^2_{miss} containing a minimal amount of background. Non signal events enter here from decays with kinematic thresholds because of kinematic resolution effects (e.g. $K^+ \rightarrow \pi^+ \pi^0$, $K^+ \rightarrow \mu^+ \nu_\mu$), or from decays without kinematic thresholds, as the radiative ones. Against the first source of background low mass and high precision detectors placed in vacuum are mandatory for tracking. The very high rate in the beam detector requires also to associate the incoming K^+ to the downstream π^+ by means of tight spatial and time coincidences.

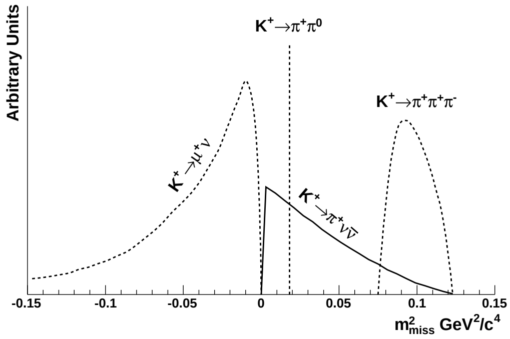

Figure 2. Squared missing mass of main K^+ decays.

The beam tracker itself and a RICH downstream provide the timing of the experiment. Notably the beam tracker must reconstruct the tracks with at least 200 ps time resolution.

The designed beam spectrometer (Gigatracker) consists of 3 Si pixel stations matching the beam size. A Si sensor 200 μm thick and a readout chip 100 μm thick bump bonded on the sensor form one pixel. Tests in laboratory on chip prototypes showed a time resolution capability of the chip itself in agreement with the requested one.

Four chambers made by straw tubes and placed in the same vacuum of the decay region form the downstream pion spectrometer. Four planes of tubes oriented along the x, y and $\pm 45°$ directions form each chamber. They provide the measurement of the coordinates of the impact point of the tracks. Regions free of tubes in each plane create an octagonal hole around the beam axis in the chambers where the beam of undecayed particles passes through. The same NA48 dipole magnet, placed after the second chamber, allows the momentum analysis. The chambers are displaced in the bending plane according to the 75 GeV/c positive beam path, mainly to veto additional high momentum charged particles. Full-length plane prototypes operating in vacuum have been tested at CERN using hadron beams in 2007, 2009 and 2010. The tests showed that the single coordinate can be reconstruction with a resolution better than 100 μm.

A Geant4 Monte Carlo simulation of the detectors described above predicted a resolution on K^+ momentum of about 0.2%, on K^+ direction of about 15 μrad, on π^+ momentum of about $0.33\% \oplus 0,007\% \times P_{track}$ (GeV/c) and on π^+ direction between 15 and 45 μrad, depending on the momentum. The expected kinematic rejection power against $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu_\mu$ decays is of about 10^4 and 10^5, respectively.

4. Vetoes

An additional rejection factor, largely independent from the kinematics, may come from γ and μ detection. Notably the $K^+ \to \pi^+\pi^0$ suppression drove the design of the photon veto system, giving a requirement of about 10^{-8} inefficiency for π^0 rejection.

The detectors designed for this goal are: a system of calorimeters (LAV) covering the angle region between 8.5 and 50 mrad; an electromagnetic calorimeter between 1 and 8.5 mrad and small angle calorimeters covering the region below 1 mrad. The key points to fulfill the experimental goal are: a cut at 35 GeV/c on the maximum π^+ momentum at analysis level to deal with π^0 of at least 40 GeV/c; a detection inefficiency below 10^{-5} for γ's in the 1-8.5 mrad region above 10 GeV and, anyhow, within 10^{-3} down to 1 GeV.

The electromagnetic liquid Kripton calorimeter of NA48 (LKr) will be reused to veto γ's in the 1-8.5 mrad region. Measurements using $K^+ \to \pi^+\pi^0$ selected on NA48 data have demonstrated the capability of the LKr to reach the required veto performance.

Twelve rings surrounding the NA62 decay and detector regions and placed in vacuum form the LAV system. The positions of the rings along the experiment guarantee the required angular coverage. The lead glass counters from the electromagnetic calorimeter of the LEP experiment OPAL [8] are the building blocks of the rings. They guarantee a level of inefficiency around 10^{-4} down to 0.5 GeV photons, as measured in test beams performed at the Dafne Beam Test facility in Frascati, using positrons. The first ring has been mounted and successfully tested at CERN on the hadron beam line in 2009. The data showed a sub-nanosecond time resolution, an essential requirement for a veto.

The muon detection system will make use of an upgraded version of the hadronic calorimeter of NA48 and of a plane of fast pad-scintillators placed at the end of the apparatus after an iron wall. Monte Carlo simulations predicted an inefficiency of muon detection around 10^{-5}, achievable by exploiting the electromagnetic and hadronic shower separation capability of the hadronic calorimeter together with the LKr detector.

5. Particle Identification

The kinematic rejection and the muon veto alone are still unable to provide enough suppression of backgrounds like $K^+ \to \mu^+\nu_\mu(\gamma)$. An identification device for the K^+ decay products, different from the calorimeters, must provide the missing 10^2 factor in the rejection of this background.

A RICH has been designed to fulfill such a goal: it should separate π^+ from μ^+ with inefficiency below 1%. It must also provide the timing of the event with a resolution below 100 ps and it should be used as a trigger for 1-track events. A vessel 17 m long placed after the pion spectrometer and filled with Ne at atmospheric pressure forms the detector. The vessel has a cylindrical shape around a 17 cm diameter beam tube used to let the undecayed particles to pass through in vacuum. A mosaic of mirrors at the end, having 17 m focal length, reflects the Cerenkov light towards two arrays of about 1000 phototubes each, placed on both the sides of the vessel at the entrance window. Hamamatsu phototubes of 1.8 cm diameter guarantee a quantum efficiency and time performances which fit the requirements.

A full length prototype of 50 cm diameter equipped with 96 phototubes has been tested at CERN on a 200 GeV hadron beam in 2007. About 17 optical photons per event were collected and the time resolution of a track was measured around 70 ps [9]. The same prototype equipped with 400 phototubes was tested at the SPS in 2009 on an hadron beam with momentum between 20 and 70 GeV/c. During this test a system formed by HPTDC's [10] mounted on one TELL1 board [11] was used for data acquisition. This apparatus has been developed by the NA62 collaboration itself in the framework of the NA62 trigger and DAQ R&D project [6]. The data showed that a π^+/μ^+ separation with the requested purity can be reached in the 15-35 GeV/c momentum range [12].

A particle identification detector on the beam line is also mandatory against accidentals. Dangerous accidental events come from the interactions of the beam particles mainly just before entering in the decay region (e.g. interactions with the last station of the Gigatracker or with the residual gas in the vacuum). Since 94% of the particles are protons and π^+, a Cerenkov Threshold Counter (CEDAR) placed on the beam line, which positively recognizes the kaons, allows the rejection of the most part of the accidentals. The CEDAR is an existing detector built at CERN in 70's [13] and a program of refurbishing both the radiating material and the detection part already started within the NA62 collaboration.

5.1. Sensitivity

A preliminary analysis has been done using Geant3 [14], Geant4 and Fluka [16] based simulations. The total acceptance is about 14.4%, showing that the target of 10% of signal acceptance is safely achievable even taking into account additional losses occurring in a real data taking. The use of the RICH constrains the accepted pion tracks within the $(15, 35)$ GeV/c momentum range. The higher cut is an important loss of signal acceptance, but assures that events like $K^+ \to \pi^+\pi^0$ deposit at least 40 GeV of electromagnetic energy, making their rejection easier.

Many sources of background have been considered and just a simple counting of signal and background events in the signal regions indicates that the 10% background appears to be within reach.

6. Conclusions

The ultra-rare $K \to \pi\nu\nu$ decay is a unique environment where to search for new physics. The NA62 experiment at CERN-SPS proposes to follow this road by collecting $O(100)$ events of the $K^+ \to \pi^+\nu\bar{\nu}$ decay. The experiment has been approved and funded. After three years of successful R&D program, the NA62 experiment is now under construction.

REFERENCES

1. J. Brod and M. Gorbahn, Phys. Rev. D 78 034006 (2008)
2. G. Isidori, F. Mescia, P. Paradisi, C. Smith, S. Trine, HEP-PH 0604074. JHEP 0608, 064 (2006).
3. M. Blanke, A.J. Buras, A. Poschenrieder, S. Recksiegel, C. Tarantino, S. Uhlig and A. Weiler, HEP-PH 0610298. JHEP 0701, 066 (2007).
4. A. V. Artamonov et al. [BNL-E949 Collaboration], Phys. Rev. D 79, 092004 (2009)
5. G. Anelli et al., CERN-SPSC-2005-013, SPSC-P-326.
6. NA62 Collaboration, CERN-SPSC-2007-035, SPSC-M-760.
7. V. Fanti et al. [NA48 Collaboration], Nucl. Instrum. Meth. A 574, 433 (2007).
8. K. Ahmet et al. [OPAL Collaboration], Nucl. Instrum. Meth. A 305, 275 (1991).
9. G. Anzivino et al., Nucl. Instrum. Meth. A 593, 314 (2008).
10. , J. Christiansen, "HPTDC High Performance Time to Digital Converter", CERN, Geneva, 2004, Version 2.2 for HPTDC version 1.3.
11. G. Haefeli, A. Bay, A. Gong, H. Gong, M. Muecke, N. Neufeld and O. Schneider, Nucl. Instrum. Meth. A 560, 494 (2006).
12. B. Angelucci et al., Nucl. Instrum. Meth. A 621, 205 (2010).
13. C. Bovet, et al., The CEDAR Counters for Particle Identification in the SPS Secondary Beams, CERN Report: CERN 82-13 (1982).
14. CERN Program Library Long Writeup, W5013 (1993).
15. J. Allison et al., IEEE Trans. Nucl. Sci. 53, 270 (2006). IETNA,53,270.
16. A. Ferrari, P.R. Sala, A. Fasso and J. Ranft, CERN-2005-010.