A detector for the measurement of the ultrarare decay $K^+ \to \pi^+\nu\bar{\nu}$: NA62 at the CERN SPS

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The NA62 experiment, which aims to measure the branching ratio of the very rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$ at the CERN SPS, will be described. The proposed experiment aims to collect $\sim$ 100 $K^+ \to \pi^+\nu\bar{\nu}$ events with a 10% of background. The experimental technique, the detectors and the perspectives for the experiment will be discussed.

1. Introduction

The Standard Model (SM) branching ratio can be computed to an exceptionally high degree of precision: the $O(G_F^2)$ electroweak amplitudes exhibit a power-like GIM mechanism; the top-quark loops largely dominate the matrix element; the sub-leading charm-quark contributions have been computed at NNLO [1]; the hadronic matrix element can be extracted from the branching ratio of the $K^+ \to \pi^0 e^+ \nu$ decay, well known experimentally [2]. The SM prediction for the $K^+ \to \pi^+\nu\bar{\nu}$ channel is $(7.81 \pm 0.80) \times 10^{-11}$ [3]. The error comes mainly form the uncertainty on the CKM parameters, the irreducible theoretical uncertainty amounts to $\sim$ 2%. The extreme theoretical cleanness of these decays remains also in new physics scenarios like Minimal Flavour Violation (MFV) [4] and even not large deviation from the SM value (for example ∼20%) can be considered as an evidence 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 measured branching ratio is $1.73^{+1.15}_{-1.05} \times 10^{-10}$ [5]. 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 [6,7] which aims to collect $O(100)$ $K^+ \to \pi^+\nu\bar{\nu}$ events in about 2 years of data taking, keeping a background contamination around 10%.

2. The NA62 experiment

The requirement of 100 events needs to 10% of signal acceptance and at least $\sim 5 \times 10^{12}$ K^+ decays. To reach the required signal over background ratio demands a background suppression of at least 10^{13}. A high energy kaon beam and a decay in-flight technique are the principles of the experiment. A high acceptance beam line will deliver a 50 times more intense secondary hadron beam with respect the old NA48 beam line. The beam particles will have a positive charge and a momentum of 75 GeV/c ($\pm 1\%$). The average rate is $\sim$800 MHz integrated over an area of 14 cm^2. The beam is positron free and is composed by $\sim$6% of K^+. The average integrated rate on the detectors downstream is $\sim$10 MHz, mainly due to the kaon decay and accidental muons.

The key points of NA62 are: a very powerful kinematical rejection; a system of efficient vetoes to reject events with γ an μ; a precise timing to associate the π^+ to the parent K^+; a particles identification system to identify the kaons among the beam particles and to distinguish π^+ from μ^+ and e^+ in the final state.

3. Kinematical rejection

The main variable in use is the squared missing mass, m^2_{miss}, defined as the difference between the kaon and the charged track 4-momenta assuming the pion mass. This variable separates the signal form more than 90% of the background coming from the main kaon decays (figure 1). The $K^+ \to \pi^+\pi^0$ peak divides 2 regions of m^2_{miss} containing a minimal amount of background.

Against this kind of background low mass and high precision detectors placed in vacuum are mandatory for tracking. A beam tracker along the beam line and a spectrometer downstream to the decay region accomplish this task. The designed beam spectrometer (Gigatracker) consists of 3 Si pixel station matching the beam size. A Si sensor 200 μm thick and a read-out chip 100 μm thick bump bonded on the sensor form one pixel, in total the 3 station have ¡$3.5\% X_0$ of material badget. Test beam on prototypes performed at CERN in 2010 showed a time resolution ¡200 ps per station. Four chambers made by straw tubes (2.1 m long and 9.6 mm mylar tubes) and placed in the same vacuum of the dacy region form the downstream pion spectrometer. They provide the measurement of the coordinates of the

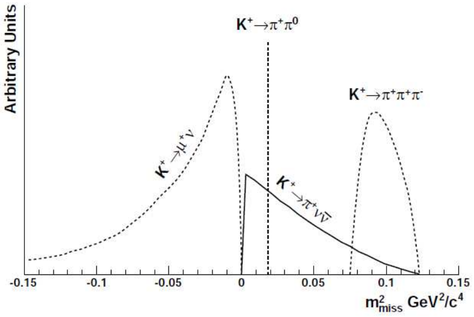

Fig. 1. Squared missing mass for the kaon decays with kinematic thresholds.

impact point of the incoming track. The same NA48 dipole magnet with a $P_{tkick} = 256MeV/c$ along the y direction, placed after the second chamber, allows the momentum analysis. 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 reconstructed with a resolution better than 100 μm.

4. Photon and charged particles vetoes

The photon veto system should guarantee a good level a good level of $K^+ \to \pi^+\pi^0$ suppression already online, in order to reduce the rate for data acquisition. The detectors designed for this goal are: a system of calorimeters (LAV) covering the angle 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*.

Twelve rings surrounding the NA62 decay and detectors regions and placed in vacuum form the LAV system. The lead glass counters of the old 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 beam performed at the BTF in Frascati. The first 2 rings have been mounted and successfully tested at CERN on the hadron beam line in 2009 and 2010. The data showed a time resolution of 700 *ps*. 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 performances, a detection inefficiency below 10^{-5} for γ's above 10 GeV and, anyhow, within 10^{-3} down to 1 GeV. The very good online time resolution, 100 ps, makes this detector essential in the trigger. In front of the LKr a small angle calorimeter (IRC) will be positioned to collect the γ's in the region below 1 $mrad$, outside the acceptance of the LKr. After all detectors in order to collect the photons inside the beam pipe another smal angle calorimeter (SAC) has been located. In order to veto the products of the interaction of the kaons in the material of the third station of the GTK, a veto detector for charged particle has been located after the last station of the GTK before the entrance of the decay region.

5. Particle identification

Since 94% of beam particles are protons and π^+, a Cherenkov Threshold Counter (CEDAR) placed on the beam line, which positively recognizes the kaons, allows the rejection of the most part of the beam accidental. The CEDAR is an existing detector built at CERN in 70's [9] and a program of refurbishing both the radiating material and the detection part (readout electronics and PMTs) already started within the NA62 collaboration. A RICH detector has been designed to separate π^+ from μ^+ with inefficiency below 1%. It also provide the timing of the event with a resolution below 100 ps and it should be used in the trigger. A vessel 17 m long placed after the track spectrometer and filled with Ne at atmospheric pressure form the detector. Tests on CERN-SPS secondary beam, performed in 2007 and 2009 [10,11], have shown an average time resolution of 70 ps and an integrated π^+/μ^+ separation of $\sim 5 \times 10^{-3}$ in a momentum range 15–35 GeV/c.The muon detection system will make use of an upgraded vertion of the old NA48 hadron calorimeter (MUV1,2), for the offline rejection of events with muons in the final state and of a plane of fast 22×22 cm^2 pad-scintillators (MUV3) placed at the end of the apparatus after an iron wall, for the trigger.

6. Trigger and data acquisition

The trigger should reduce the 10 MHz detector rate to 10 kHz in order to make the data acquisition feasible. A three-level trigger system should accomplish to this task. The Level 0 (L0) trigger is purely hardware and for his primitives consider only some detectors, the RICH, the LKr and the third station of the MUV. The Level 1 and 2 trigger are based on PC's. The detector PC's process the 1 MHz data rate which passes the L0 trigger and define more complete event information in order to build the L1 trigger decision. The filtered data are sent to a gigabit Ethernet switch and then to a PC farm which provides global event information for the ultimate trigger word (L2). The raw data are finally assembled by dedicated event-building PC's and transferred for storing on tape with a maximum speed of about 100 MB/s.

7. NA62 sensitivity

The sensitivity of the NA62 has been studied with the MC. Assuming a number of kaon decays $\sim 5 \times 10^{12}$, a signal acceptance of $\sim 10\%$ and 100% of trigger efficiency, the expected number of $K^+ \to \pi^+ \nu\bar{\nu}$ events is 45 events/year with a background contamination ¡13.5%.

8. Conclusions

The ultrarare $K^+ \to \pi^+ \nu\bar{\nu}$ is a clear physics case with high sensitivity to new physics beyond the SM. The goal of the NA62 experiment is to collect O(100) $K^+ \to \pi^+ \nu\bar{\nu}$ events in 2 years of data taking. The period 2006–2009 has been dedicated to the design and the R&D of the various NA62 detectors. The period 2010–2012 will has been allocated to the construction. At the end of 2012 a Technical run has been planned and the Physics run will be done in 2014/2015.

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