The Detector for the Kaon Rare Decays Experiment NA62 at CERN

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The NA62 experiment at CERN is aimed at a 10% measurement of $BR\left(K^+ \to \pi^+\nu\bar{\nu}\right)$. The beam line used, the detectors and the experimental strategy will be described.

1. Introduction

The $BR\,(K^+ \to \pi^+\nu\bar{\nu})$ is predicted by the theory to be $(0.85 \pm 0.07) \times 10^{-10}$ with a small error due to isospin symmetry so that a 10% measurement represents a powerful probe of possible new physics beyond the Standard Model. The NA62 experiment [1] was proposed at CERN to collect about 100 signal events with 10% background. Assuming a signal acceptance of the order of 10%, 10^{13} K^+ will be needed.

2. The beam

The existing CERN accelerator system can provide the number of K^+ decays needed for the measurement. The SPS can deliver 400 GeV/c momentum protons with the slow extraction method in pulses of 3×10^{12} protons in 4.8 s with a duty cycle of 16.8 s. The previous CERN kaon experiment NA48 [2] had a dedicated beam line and experimental cavern that will be reused for NA62. Primary protons will impinge on a beryllium target forming a secondary beam which can be selected over about 100 m to have 75 GeV/c momentum with a 1% dispersion. This secondary beam will contain about 6% of K^+ providing 4.5×10^{12} K^+ decays per year over the 60 m long fiducial volume of the experiment, fulfilling the measurement needs in two years.

Pions and protons in the beam cannot mimic a kaon decay but for beam-gas interactions. The decay volume will be evacuated at 10^{-6} mbar and K^+ will be tagged in the beam by a Cherenkov detector (CEDAR) filled with 4 bar Hydrogen. The CEDAR pressure and optical diaphragm will be tuned to select only K^+ with 45 MHz rate.

The beam particles will pass through an achromat magnetic system where three silicon pixels stations will be located to measure the particle momentum (from the diplacement with respect to a nominal momentum particle path) and direction. This detector is named Gigatracker (GTK) [3] because it will afford an instantaneous rate of 750 MHz. Each GTK station will be 60 mm wide, 27 mm high and 300 μm thick along the beam with 18000 pixels per station (the area of each pixel is 300×300 μm^2). Each GTK station corresponds to less than 0.5% radiation length. The expected performances are 0.2% momentum, 17 μrad angular and 150 ps time resolution.

Particles produced by beam interactions in the last GTK station and in the final beam collimator will be vetoed by a CHarged ANTIcounter (CHANTI) arranged in 6 stations located downstream of the GTK and made by extruded scintillator bars of triangular shape read out through WLS fibers by Silicon Photomultipliers.

3. Kinematics

The signal is composed by an incoming mother particle (the K^+) and an outgoing daughter particle (the π^+) and nothing else, all the other K^+ decay channels being background. The appropriate kinematical variable to be used is the squared missing mass given by the squared difference of K^+ and π^+ four-momenta. 92% of K^+ decays are well characterized from the point of view of m^2_{miss}, indicating two clear signal regions: between the negatively reconstructed $K^+ \rightarrow \mu^+\nu$ distribution and the $K^+ \rightarrow \pi^+\pi^0$ peak (Region I) and between this peak and the beginning of the three pions decay distribution (Region II).

The missing mass is recontructed using the GTK for the K^+ and a downstream magnetic spectrometer for the π^+. 4 chambers, each with 4 layers of straw tubes per view will be built; 4 views per chamber will be used (horizontal, vertical and ±45 degrees) with 9.6 mm diameter, 2.1 m long mylar tubes operated in vacuum. Each view corresponds to 0.1% radiation length. A track resolution of 130 μm per view was verified on a prototype built and tested in 2007. A dipole magnet with 256 MeV/c p_t kick will be placed between the second and the third chamber; a momentum resolution of $0.3\% \pm 0.007\% \times P_\pi$ is predicted, where P_π is the pion momentum in GeV/c. A 6 cm wide region per view, where undecayed beam particles will pass, will not be equipped with straws.

With the available simulation a m^2_{miss} resolution of 10^{-3} GeV^2/c^4 is expected, dominated by the K-π angle measurement. Region I will be defined as $0 < m^2_{miss} < 0.01$ GeV^2/c^4, while Region II will be $0.026 < m^2_{miss} < 0.068$ GeV^2/c^4.

4. The $K^+ \rightarrow \mu^+\nu$ background

The K^+ decay with the largest BR is $K^+ \rightarrow \mu^+\nu$. The cut on m^2_{miss}, according to the simulation, can give a suppression factor of 0.5×10^{-5}. A further 10^{-5} suppression can be achieved using the different penetrating power between pions and muons. A muon veto (MUV) will be used, composed of two modules: one is the Front Module of the old hadronic calorimeter of NA48 [2] while the other will be completely rebuilt using a sandwich of iron plates and scintillator stripes. Downstream of the two MUV modules a fast scintillator plane (MUV3) will be located to veto at the trigger level most of the 10 MHz muon rate.

A further 10^{-2} suppression will be achieved by discriminating pions from muons with a RICH detector filled with Neon at atmospheric pressure [4], selecting a momentum fiducial region between 15 and 35 GeV/c. A 17 m long, 4 m wide vessel will contain the radiator gas, with a beam pipe crossing it where the beam undecayed particles will pass. At the downstream endcap of the detector a mosaic of 20 mirrors will be located to focus the Cherenkov light 17 m upstream where 2000 single anode photomultipliers (PMT) will be placed. The PMTs will be located in two spots, on the left and on the right of the beam pipe and half of the mirrors will reflect on one PMT spot, half on the other spot to avoid the beam pipe shadow. Thanks to a test beam held in 2009 with a prototype, a muon suppression factor of 0.7% was validated, together with an event time resolution of 70 ps.

A scintillator CHarged HODoscope (CHOD) located downstream of the RICH will be used to veto inelastic interactions in the previous detector and also for triggering.

5. The $K^+ \rightarrow \pi^+\pi^0$ background

It is the second largest BR of K^+ and kinematical cuts can give, according to the simulation, a 5×10^{-5} suppression. A further 10^{-8} suppression must come from π^0 detection by vetoing at least one of the γ from π^0 decay. The γ angular acceptance is divided into three regions: between 8.5 and 50 mrad, covered by 12 rings of Large Angle Veto (LAV); between 1 and 8.5 mrad, covered by the electromagnetic calorimeter (LKR); below 1 mrad by the Inner Ring Calorimeter (IRC) and by the Small Angle Calorimeter (SAC).

The LAV [5] will be distributed along the experimental region and will be all in vacuum but the last one. They will be made of lead crystals recovered by the OPAL experiment and arranged in 12 rings of increasing diameter with 4 or 5 staggered layers of crystals per ring, with between 32 and 48 crystals per layer. The LAV system will veto γ with energy larger than 1 GeV with 10^{-5} inefficiency, degrading gradually to 10^{-4} below 1 GeV. This performances were validated in a series of test beams.

The LKR was used by the NA48 experiment [2] and it will remain in its original position. It is an homogeneous calorimeter filled with liquid krypton with longitudinal electrode ribbons forming 13000 readout cells. The LKR will veto γ with 10^{-5} inefficiency above 5 GeV, degrading gradually to 10^{-4} between 1 and 5 GeV. These results were measured using $K^+ \rightarrow \pi^+\pi^0$ collected in previous years by the NA48 experiment and by a tagged photon beam test in 2006.

The IRC is a shaslyk calorimeter shaped as a ring placed around the beam pipe and located downstream of the RICH; it is aimed at vetoing γ directed to the small angle passive area of the LKR. The SAC is also a shaslyk calorimeter placed at the very end of the experimental apparatus, downstream of all the calorimeters and muon vetoes; a dipole magnet just before the SAC will deviate charged beam particle so that only small angle γ can reach the SAC. A prototype of this calorimeter was tested in 2006.

6. Multibody decay background

Multibody kaon decays can be very dangerous. For example $K^+ \rightarrow \pi^+\pi^-e^+\nu$ can produce a π^+ which mimics the signal, a very low energy positron which can escape undetected and a high energy π^- which can remain inside the beam pipe. Defining the straight line connecting the beryllium target and the center of the LKR as the neutral beam line, the charged beam will be deviated horizontally by 1.2 mrad at the GTK position and then again by -3.6 mrad by the spectrometer dipole magnet, intersecting again the neutral beam path at the LKR position with -2.4 mrad angle. The straw chambers will be staggered with respect to the neutral beam line to veto small angle π^- up to 60 GeV/c momentum.

7. Timing and trigger

Given the high rate (750 MHz) seen by the GTK, the matching of a pion seen by the downstream spectrometer with an accidental beam particle, instead of the mother kaon, seen by the GTK is a crucial problem. Tight coincidences between the GTK track time (150 ps total resolution) with the RICH track time (100 ps) will be used to reject accidental matching. The CEDAR information (100 ps resolution) will also be used.

The trigger signal for a charged track will be provided by the RICH and the CHOD with a 10 MHz rate; muon vetoing made by the MUV3 and γ vetoing made by the LAV and the LKR will reduce the trigger rate to 1 MHz; a dedicated PC farm, partially analyzing the data, will further reduce the data transfer by a factor 40.

8. Signal acceptance and background level

The signal acceptance is expected to be 3.5% in Region I and 10.9% in Region II, according to the simulation, allowing to collect 55 signal events in one standard year of running (100 days at 50% efficiency). The total background level is predicted in the 15% range, dominated by the three decay channels described previously.

9. Conclusions

The NA62 experiment has completed a long phase of $R\&D$ and test beams in the period 2006-2009. The costruction of the final apparatus will cover mostly 2010 and 2011 with a technical run foreseen for summer 2012. The first physics run is expected for november 2012.

The NA62 experiment is a collaboration of Institutes from Bern, Birmingham, Bristol, CERN, Dubna, INFN (Ferrara, Firenze, Frascati, Napoli, Perugia, Pisa, Rome I, Rome II, Torino), Fairfax, Glasgow, IHEP Moscow, INR Protvino, Liverpool, Louvain, Mainz, Merced, San Louis Potosi, SLAC, Sofia, TRIUMF.

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