PROCEEDINGS OF SCIENCE

The NA62 experiment at CERN

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The rare decays $K^+ \to \pi^+ \nu\overline{\nu}$ are excellent processes to make tests of new physics at the highest scale complementary to LHC thanks to their theoretically cleanliness. The NA62 experiment at CERN SPS aims to collect about 100 of such events in two years of data taking, keeping the background at the level of 10%. The physics motivation, experimental technique and the status of the construction of the experiment will be presented.

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1. Introduction

The K$^+ \rightarrow \pi^+ \nu \overline{\nu}$ decay is a flavor changing neutral current process. It is very clean from the theoretical point of view: there are small contributions by hadronic matrix elements (they can be extracted from experimental observables) and long distance terms.

Its branching ratio (BR) can be calculated with very good precision in the standard model (SM). A recent calculation yields BR($K^+ \rightarrow \pi^+ \nu \overline{\nu}$) = (0.78 $\pm$ 0.08) $\times$ 10^{-10}, where the biggest uncertainties come from CKM matrix elements [1]. This decay is highly suppressed in the SM and a precise measurement of its BR represents a very sensitive test of new physics, complementary to the one accessible in LHC experiments. In addition it can be used to extract $|V_{td}|$ in a clean way and give a determination of the Unitarity Triangle independent from B physics.

The most precise measurement of the BR has been performed by the E787/E949 experiments at BNL [2]: 7 candidate events were observed in the two allowed kinematics regions, using a low energy separated K$^+$ beam and the kaon decays at rest technique. The value obtained from their analysis is BR($K^+ \rightarrow \pi^+ \nu \overline{\nu}$) = ($1.73\ ^{+1.15}{}_{-1.05}$) $\times$ 10^{-10}.

To bridge the gap between the precise theoretical prediction (few percent) and the relatively poor precision of the experimental result (about 60%), the NA62 Collaboration decided to build a challenging detector with the aim of measuring $\mathcal{O}(100)$ events of this ultra-rare decay with $\sim$10% background in two years of data taking at the CERN SPS [3, 4].

2. Experimental technique

The measurement of the $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ branching fraction is extremely complex from the experimental point of view because of the backgrounds due to the main K$^+$ decay channels and the weak signature of the signal (one π^+ track in the 3-bodies final state matched to one K$^+$ track in the beam, as can be seen in Fig. 1).

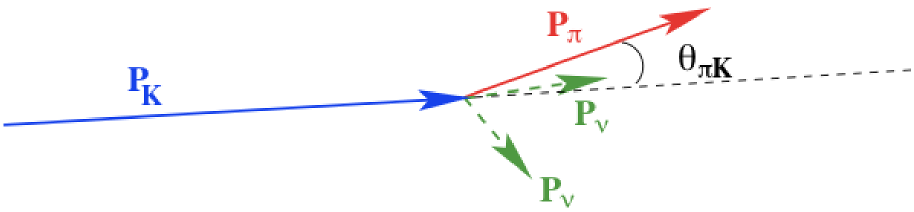

Figure 1: Schematic drawing of the relevant kinematic variables.

Three handles will be used for background reduction: kinematics, vetoing of photons and particle identification, obtained thanks to an efficient and hermetic detection system. Decay kinematics will be used for background rejection by cutting on the missing mass variable:

$$m^2_{miss} \simeq m^2_K \cdot (1 - \frac{|p_\pi|}{|p_K|}) + m^2_\pi \cdot (1 - \frac{|p_K|}{|p_\pi|}) - |p_K| \cdot |p_\pi| \cdot \theta^2_{\pi K}$$

where p_K (p_π) and m_K (m_π) are the kaon (pion) momentum and mass, respectively, and $\theta_{\pi K}$ is the angle between the two tracks.

The most probable decay final states for the K^+ are $\mu^+\nu$ (63.5%) and $\pi^+\pi^0$ (20.7%). If we include also the decays into $\pi^+\pi^-\pi^+$ (5.6%) and $\pi^+\pi^0\pi^0$ (1.8%), we can see that 92% of the background channels can be separated from the signal by kinematic cuts, as can be seen in Fig. 2. The signal regions are defined by these decays: the $\pi^+\pi^0$ splits the region in 2 parts, while the left and right borders are clearly visible from the plot.

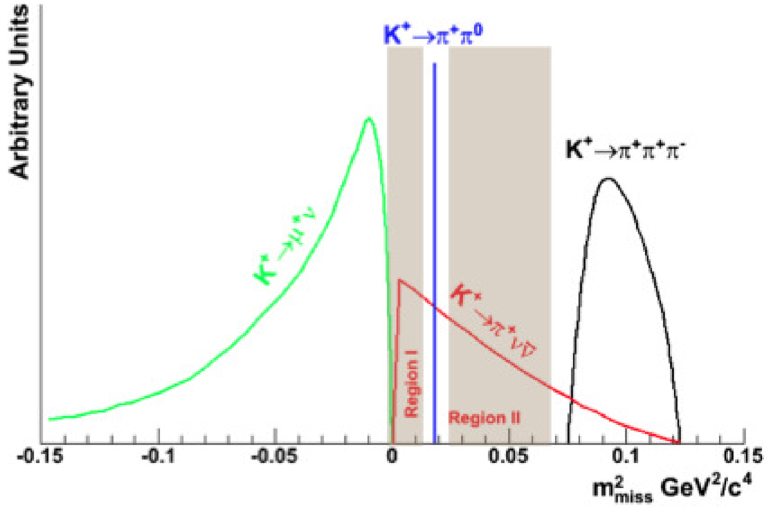

Figure 2: m^2_{miss} distribution for the signal (red curve), and the main backgrounds.

The remaining 8% decay channels cannot be separated from the signal by kinematic cuts: they represent a pollution of the signal region, as can be seen in Fig. 3.

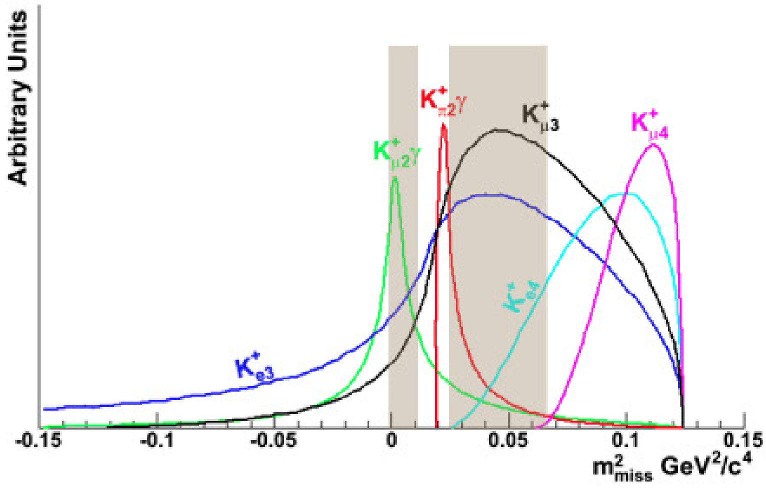

Figure 3: m^2_{miss} distribution for other backgrounds, polluting the signal region.

3. Experiment layout

A schematic drawing of the NA62 experiment layout is shown in Fig. 4. Primary protons with 400 GeV/c momentum from the CERN Super Proton Synchrotron (SPS) are directed onto a beryllium target, and a secondary beam of positively charged particles is selected in a narrow momentum band (75$\pm$0.7 GeV/c). The rate in the detectors upstream of the decay region is due to the unseparated kaon beam (mainly composed of π^+ and p: the K^+ fraction is only 6%) and amounts to about 800 MHz. Downstream detectors are subject to a total integrated rate of about 10 MHz, due to K^+ decays and halo particles. Precise timing and spatial information are required to match the upstream track with the downstream one.

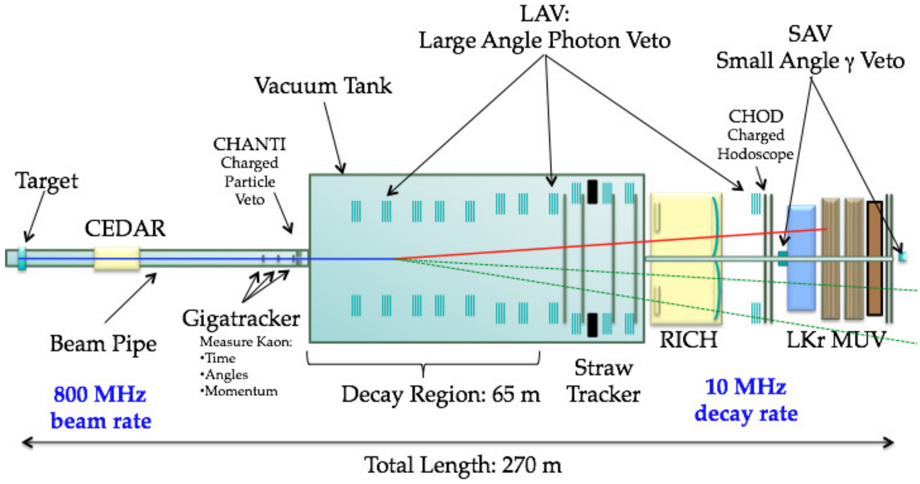

Figure 4: Schematic NA62 experiment layout.

The first detector traversed by the beam, after production and momentum selection, is the CEDAR (Cherenkov differential counter with achromatic ring focus). It's a differential counter for the positive identification of kaons with a time resolution of 100 ps and it will sustain an instantaneous rate of 50 MHz due to the kaon component in the beam (the special optics and diaphragm, shown in Fig. 5 makes it blind to other particle species). This detector is based on existing detectors at CERN [5], but features a modified mechanics and optics, plus new PMTs and electronics.

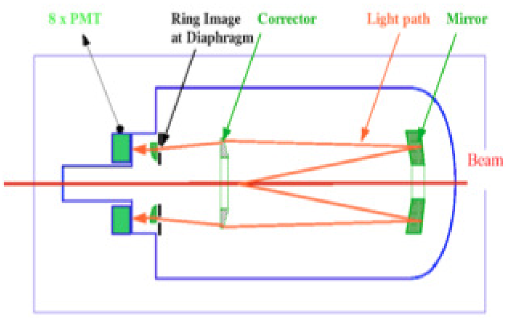

Figure 5: CEDAR optics schematic drawing.

The beam spectrometer, composed of three hybrid silicon pixel detector stations called Gigatracker [6], measures momentum, direction and time of each beam particle. The three stations are arranged in a so-called "achromat" configuration, as depicted in Fig. 6.

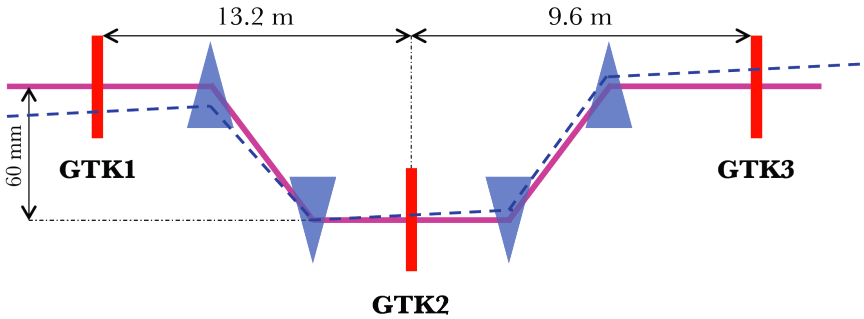

Figure 6: Schematic layout of the NA62 beam line close to the beam spectrometer. The beam is deflected by four bending magnets (blue triangles) with equal fields. The GTK stations are depicted as red rectangles.

The material in each Gigatracker (GTK) station amounts to less than 0.5% X_0 to minimize multiple scattering and hadronic interactions. For that purpose the stations are installed in vacuum and the detector and cooling thicknesses are minimized. With a pixel size of 300 μm $\times$ 300 μm and a distance of about 10 m between consecutive stations, this system features a momentum resolution of $\sim$0.2% and an angular resolution of $\sim$16 μrad in both horizontal and vertical views. The most challenging requirement on this detector is the time resolution for a single track, that should not exceed 150 ps. Prototype detectors have been tested using an infrared laser system and a high energy hadron beam: results from the test-beam show a time resolution on single hit of $\sim$175 ps using a bias of 300 V applied to the sensor.

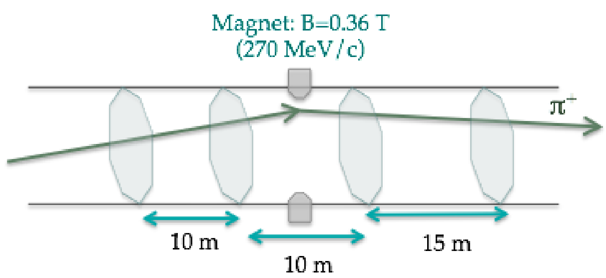

Figure 7: Schematic drawing of the downstream spectrometer, based on straw tubes installed in vacuum.

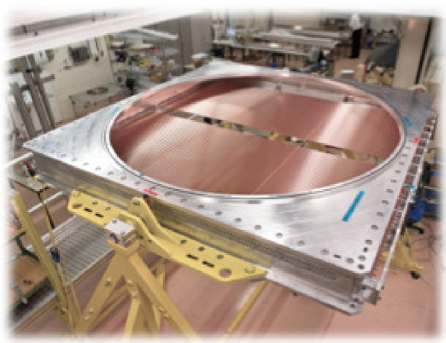

Figure 8: Picture of one straw chamber during the construction phase.

The GTK is followed by the CHANTI, an anti-coincidence detector for charged particles that surrounds the beam just before the decay region, in order to detect inelastic interactions taking place in the third GTK station. The decay region is surrounded by the Large Angle Veto (LAV) detectors [7], in order to detect photons originating from kaon decays. At the end of the decay region a large acceptance magnetic spectrometer (Fig. 7) made of 4 straw tube chambers and a dipole magnet provides the missing part of the kinematic information, measuring momentum and direction of the charged decay products [8]. Each straw chamber (Fig. 8) is characterized by a very small mass ($\sim$0.5% X_0): the material traversed by the beam is further reduced by installing the straws directly in the experiment vacuum ($\sim 10^{-6}$ mbar).

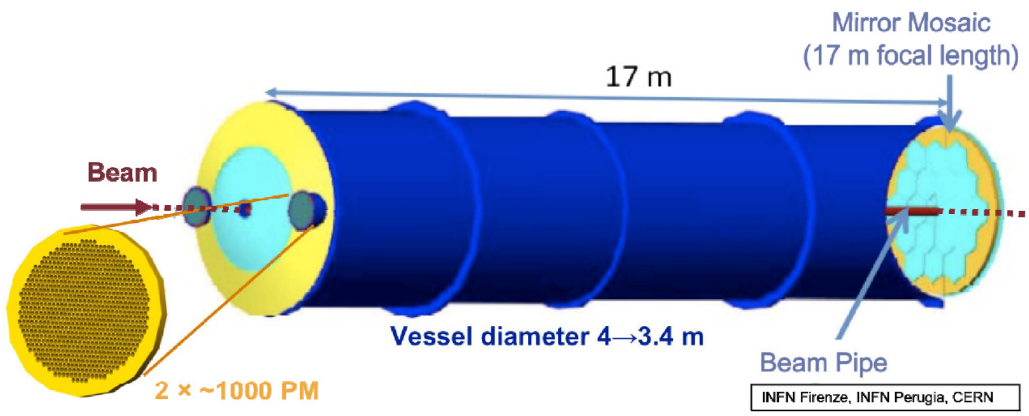

Figure 9: Schematic drawing of the NA62 RICH detector: the downstream section of the vessel is cut to show the mirrors and the beam pipe, while the upstream section shows the PMTs assembly.

Downstream of the straw tracker, a Ring Imaging CHerenkov detector (RICH) will be installed in order to separate π from μ in the momentum region between 15 and 35 GeV/c with a muon mis-identification probability lower than 10^{-2} [9]. In addition, this detector should measure the pion track time with a resolution better than 100 ps and provide a trigger signal at the lowest level (L0). The solution adopted by NA62 is a 18 m long vessel filled with Ne at atmospheric pressure ($n-1$ = 63×10^{-6}), as can be seen in Fig. 9. This solution has been validated with a test-beam of a full-length prototype, and the results show on average a time resolution of $\sim$70 ps, mis-identification probability of $\sim 5\times10^{-3}$ and an angular resolution of about 60 μrad.

A Charged HODoscope (CHOD), installed further downstream and made of scintillator material, will be used to detect possible photo-nuclear reaction in the RICH mirror plane and to back-up the RICH in the L0 trigger for charged tracks.

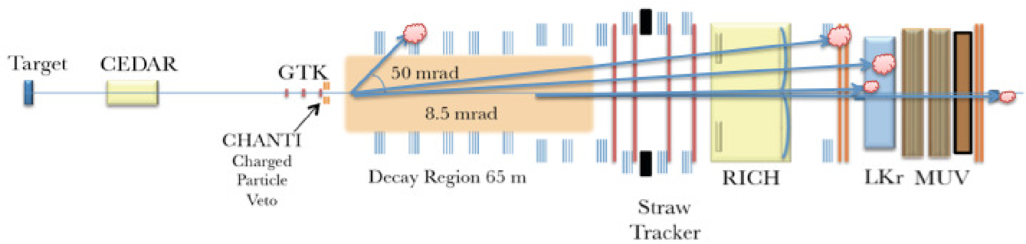

Figure 10: Possible trajectories of photons originating from kaon decays inside the decay region.

Essential for background rejection are the photon and muon veto systems. The photon veto system should provide a π^0 rejection inefficiency at the 10^{-8} level, and hermetic coverage up to 50 mrad. It is composed of 3 sub-systems, covering different angular regions, as can be seen in Fig. 10. The LAV detector system, already introduced, covers the angular region between 8.5 and

50 mrad, and is composed by 12 stations in total (of which 11 are in vacuum and 1 downstream of the RICH). A station, visible in Fig. 11 is made of 5 layers of lead-glass crystals ($\sim$20 X_0) with attached PMT from the former OPAL electromagnetic calorimeter. The region between 1 and 8.5 mrad is covered by the Liquid Kripton (LKr) electromagnetic calorimeter, while the one up to 1 mrad is instrumented with two detectors: the IRC (Intermediate Ring Calorimeter) that covers the angular region close to the inner LKr radius, and the SAC (Small Angle Calorimeter) installed behind the experimental cavern, preceded by a magnet to deflect the charged beam (Fig. 12).

Figure 11: Picture of the first produced LAV station.

The MUon Veto system is composed of 3 stations (Fig. 12), re-using part of the NA48 hadron calorimeter. The first two stations are made of 24 (MUV1) and 22 (MUV2) iron/scintillator layers, with alternating horizontal and vertical scintillator strips coupled to PMTs. The third station (MUV3), installed after a 80 cm thick iron wall, is made of scintillator tiles with direct coupling to two PMTs for the suppression of the Cerenkov component. The detector signal is used as a fast muon trigger in the L0 and the time resolution is better than 1 ns.

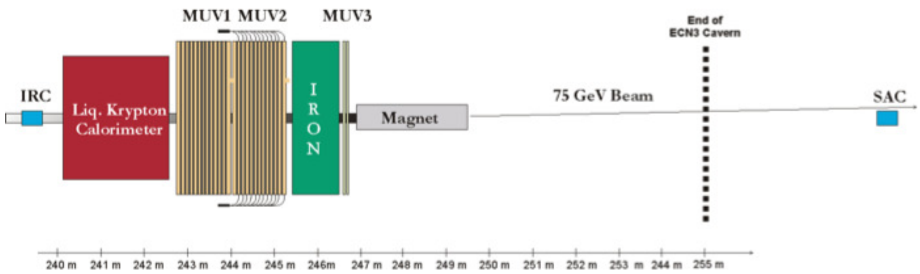

Figure 12: Schematic drawing of the most downstream part of the NA62 experiment: it includes the muon veto and the small- and medium-angle photon veto systems.

The NA62 experiment demands a highly efficient and reliable data acquisition and trigger systems. The trigger is organized in three levels. At the lowest level (L0) a hardware system takes decision based on primitives produced in the read-out boards of various sub-detectors (MUV, RICH, LAV, CHOD, LKr). The L0 system is synchronous (based on the TTC protocol), and features an input rate of about 10 MHz and $\sim$1 ms latency. The L1 is asynchronous (based on ethernet) and has approximately 1 MHz input and 100 kHz output rates (the maximum latency for this trigger level is of a few seconds). At the highest level, the L2 is a fully software system that merges information coming from different sub-detectors.

4. Conclusions

The NA62 Collaboration is building a very challenging detector to measure extremely rare kaon decays. This entails building several new detectors (GTK, STRAW, RICH, LAV, MUV, IRC, SAC, CHANTI, CHOD) and renovating two others from the former NA48 experiment. Large parts of the NA48 infrastructure will be re-used, too. The R&D is close to completion and detector construction is in advanced state. Very important tests are taking place in 2012: a Dry Run (July) for the synchronization of different sub detectors and a test of the DAQ chain, and a Technical Run (October-December) for the commissioning of the new beam-line and the data taking with a subset of the detectors installed.

The start of the data taking is planned for 2014, with the aim of measuring about one hundred $K^+ \to \pi^+ \nu\overline{\nu}$ events with $\sim$10% background in two years.

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