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Prospects for $K^+ \longrightarrow \pi^+ \nu\bar{\nu}$ observation at CERN

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The rare decays $K \longrightarrow \pi\nu\bar{\nu}$ are theoretically clean processes excellent to make tests of new physics at the highest scale complementary to LHC. The NA62 experiment at CERN SPS aims to collect of the order of 100 $K^+ \longrightarrow \pi^+\nu\bar{\nu}$ events in two years of data taking, keeping the background less than 20% of the signal. Part of the experimental apparatus has been commissioned during a technical run in 2012. The physics prospects and the status of the experiment will be reviewed.

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1. Introduction

The NA62 experiment [1, 2] is a fixed target experiment located at CERN. It uses a 800 MHz secondary charged beam produced by 400 GeV/c protons extracted from the SPS and impinging on a Be target.

Goal of the experiment is the measurement, with uncertainty less than 10%, of the Branching Ratio of the ultra-rare kaon decay $K^+ \longrightarrow \pi^+\nu\bar{\nu}$. This is predicted by the Standard Model (SM) to be $(7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$ [3]. In this expression the first error comes from the uncertainty on the CKM matrix elements, while the second one is the pure theoretical uncertainty. Because of the very small value of the Branching Ratio, the experiment has been designed to suppress the backgrounds in such a way that the ratio between signal and background is more than 5:1. It is foreseen to collect $\sim$ 100 events in two years of data taking.

2. The physics of $K^+ \longrightarrow \pi^+\nu\bar{\nu}$

In the $K^+ \longrightarrow \pi^+\nu\bar{\nu}$ decay the u quark behaves as a "spectator" in the interaction, while the s quark "decays" into the d one with the emission of the two neutrinos. This is a flavour changing neutral current process described by penguin and box diagrams, with internal loops. Because of these loops the Branching Ratio of the decay is sensitive to physics beyond the Standard Model. The prediction is free from hadronic uncertainties because the hadronic matrix elements, thanks to the isospin symmetry, can be extracted from the very well measured $\mathrm{Br}(K^+ \longrightarrow \pi^0 e^+ \nu)$. Therefore, even deviations from the SM value at the level of 20% can be considered signals of new physics. Moreover this decay can be used for a measurement of V_{td} independently from that obtained in the B mesons system.

So far the decay has been observed by the experiments E787 and E949 [4, 5] at the Brookhaven National Laboratory, measuring $\mathrm{BR}(K^+ \longrightarrow \pi^+\nu\bar{\nu}) = \left(1.73^{+1.15}_{-1.05}\right) \times 10^{-10}$.

3. Experimental technique

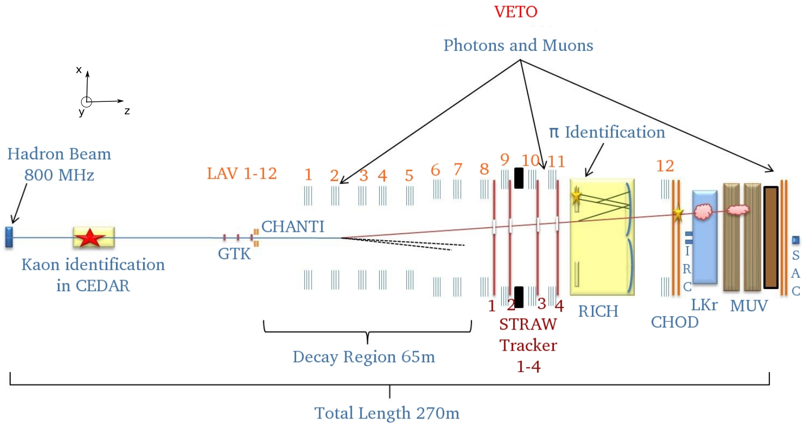

Figure 1: NA62 layout.

Figure 1 shows the layout of the experiment and will be used as reference from now on.

The SPS is able to produce high intensity beam with an high energy. For this reason a decay in flight technique is needed. High intensity beam are necessary to collect ~ 100 events in a reasonable amount of time. On the other hand high intensity beam helps in the background rejection: the 75 GeV/c beam, together with the request of a π^+ with at most 35 GeV/c, ensures the background extra particles to share at least 40 GeV/c. For example, in the case of $\sim 20\%$ branching ratio $K^+ \longrightarrow \pi^+\pi^0$ decay the π^0s has at least 40 GeV.

The signal signature is one track in the final state matched with one K^+ track in the beam. Precise kinematic reconstruction, very efficient photon veto and particle identification devices are mandatory to suppress the huge backgrounds.

4. Kinematic rejection

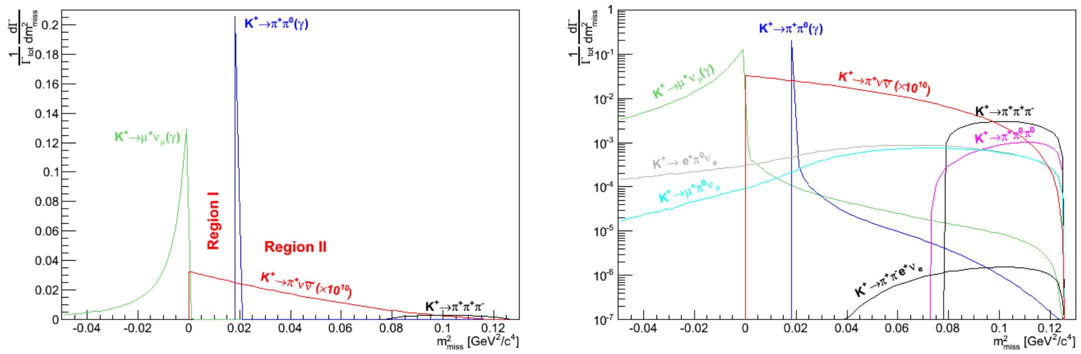

Figure 2: Square missing mass for the signal and the main backgrounds (linear scale, left) and for the next order backgrounds (logarithmic scale, right).

The variable used fot the kinamatic rejection is the square miss mass, defined as

$$m^2_{miss} = (P_K - P_\pi)^2, \tag{4.1}$$

where P_K and P_π are the four momenta of the K^+ and the π^+. The distribution of the m^2_{miss}, in the hypothesis of π^+ mass, is shown in Figure 2.

Two signal regions are defined, where a minimal background is expected, and are limited by the $K^+ \longrightarrow \pi^+\pi^0$ peak and the $K^+ \longrightarrow \pi^+\pi^+\pi^-$ threshold. The signal region contamination is due to resolution effects and radiative tails, semileptonic decays and even rare decays like $K^+ \longrightarrow \pi^+\pi^-e^+\nu$. Moreover the possibility of the beam to interact with the material along the beam line and in the residual gas in the vacuum region is a source of accidental single track background.

A tracking device mounted on the beam line (GTK) and a spectrometer located downstream the decay region (Straw spectrometer) provide the kaon and pion momenta measurements, respectively.

The beam spectrometer is composed of three hybrid silicon pixel detector stations (gigatracker stations), measuring momentum, direction and time of each beam particle. The three stations are arranged in a so-called "achromat" configuration, as depicted in Figure 3.

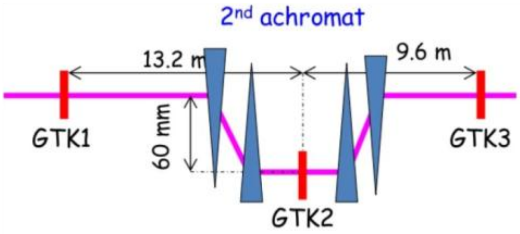

Figure 3: Four bending magnet (blue) deflect the beam. The GTK stations are shown in red.

The material in each Gigatracker (GTK) station amounts to less than 0.5% X_0, minimizing multiple scattering and hadronic interactions. The momentum resolution is expected of about 0.21%, the angular resolution of about 0.014 mrad and the time resolution of about 200 ps/station.

The downstream spectrometer is composed of four straw tube chambers (with four views, 0.1 X_0 thick each) and a magnet located between the second and the third chamber. This magnet provides a P_t kick on the incoming particles of 265 MeV/c. The spectrometer has a momentum resolution of $\frac{\Delta p_\pi}{p_\pi} \lesssim 1\%$, and angular resolution of $\Delta\theta_\pi \lesssim 66\mu$rad.

5. Photon veto system

The photon veto system consist of 12 Large Angle Veto (LAV) stations. It covers the angular range between 8.5 and 50 mrad. The design ensures that each photon crosses at least 18.6 X_0. Each station has a circular shape and is of lead glass (Schott SF57) from the former experiment OPAL [6] read with R2238 76-mm PMs.

An electromagnetic calorimeter at liquid Kripton detects photons emitted between 1 and 8.5 mrad. This detector was built and used by the NA48 experiment, but is equipped with new readout electronics. It correspond to 27 X_0 and has a remarkable time and energy resolution [7].

The very small angles photon veto is achieved by two detectors: the Inner Ring Calorimeter (IRC) and the Small Angle Calorimeter (SAC). The first detector covers the region of LKr around the beam pipe (where the LKr is inefficient), while the second is placed after the beam dump and reveals neutral particles down to 0 mrad.

6. Particle Identification

The KTAG, a differential Cherenkov counter (CEDAR), ensures kaon identification with time resolution of 100 ps.

An hadronic calorimeters (MUV) system is needed to separate pions from muons in the final state. The calorimeters are made by a sandwich of iron-scintillator with layers of scintillator strips coupled to PMs.

A pion-muon separation with 10^{-5} inefficiency can be reached using calorimeters. But this is not enough to suppress (for examples) the $K^+ \longrightarrow \mu^+ \nu_\mu$ decay: an extra 10^{-2} suppression factor is needed. A Ring Imaging CHerenkov detector (RICH) [8] has been designed with the purposes of: provide π/μ separation between 15 and 35 GeV/c, with $\lesssim 10^{-2}$ of missID probability, measure with a 100 ps time resolution the downstream charged track, providing, also, a very fast trigger.

7. Results from the 2012 Technical Run

NA62 took data in November 2012 during a technical run with a partial detector configuration [9]. Goal of the run was the commissioning of the final beam line, the analysis of the time and spatial correlation between subdetectors and estimation of their time resolution and efficiency. The beam line provided a secondary charged beam of 75 GeV/c. A selection based on the information from the electromagnetic calorimeter identified a sample of $K^+ \longrightarrow \pi^+\pi^0$ events. The events show a clear correlation in time with signals in KTAG coming from the K^+ (150 ps time resolution) and downstream detectors.

8. Conclusion

The NA62 experiment is a kaon experiment, complementary to the high-energy approach for New Physics searches and performing golden quality precision physics measurement.

In the fall of 2012 a Technical Run has been performed at CERN in the ECN3 experimental area. The analysis of the data shows that the performances of the beam line and the time resolution and the inefficiency of the detectors fit the expectations.

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