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$K^+ \to \pi^+ \nu\bar{\nu}$ at NA62

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The status of the experiment NA62 is reviewed. With its construction and commissioning completed, the experiment is now ready to tackle the measurement of $K^+ \to \pi^+ \nu\bar{\nu}$.

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1. Introduction

We know that new physics (NP) must exist but seems to be either beyond the reach of the LHC or hidden by a very special flavor structure. Since it will take a long time before a collider will surpass the LHC, any possibility to study indirectly higher energy scales is important. Rare kaon decays offer such possibility, in particular there are two decays, $K^0_L \to \pi^0 \nu \bar{\nu}$ and $K^+ \to \pi^+ \nu \bar{\nu}$ of great interest because they are not only sensitive to short distance dynamic, but also precisely predicted in the standard model (SM) and highly suppressed. The branching ratios calculated in the SM are smaller than 10^{-10} [1]. Because the current limits [2] or measurements [3] still leave a wide window of opportunity and because of the detection difficulties of such unconstrained final states, these decays represents an experimental El Dorado.

A new generation of kaon experiments, KOTO at J-PARC [4] and NA62 at CERN [5], are tackling the measurement of $K^0_L \to \pi^0 \nu \bar{\nu}$ and $K^+ \to \pi^+ \nu \bar{\nu}$ respectively. NA62 aims to perform a 10% measurement of the branching ratio or better by collecting $O(100)$ SM events.

2. NA62 In-flight technique

The $K^+ \to \pi^+ \nu \bar{\nu}$ decay has been studied so far only in stopped kaon decays. NA62 was designed and built to study the decay in-flight in order to exploit the high momentum secondary beam of the CERN SPS. In-flight decays offer the possibility of good suppression of kaon decays with photons and muons that could mimic the signal, and no interactions with the stopping target material. This requires to do the association between the decaying K^+ and the π^+ by matching the upstream and downstream tracks by means of good timing detectors ($\approx$ 100 ps): a differential Cherenkov counter (KTAG), a beam tracker (GTK) and a Ring Imaging Cherenkov counter (RICH). Hermetic photon rejection to prevent $K^+ \to \pi^+ \pi^0$ decays to mimic the signal is provided by large angle vetoes (LAV) made of lead glass, a liquid krypton calorimeter (LKr) and intermediate and small angle shashlik electro-magnetic calorimeters (IRC and SAC). Charged pions are reconstructed by hadron calorimeters (MUV1, MUV2 and HASC) while extra particles from three-pion decays and muons are vetoed by plastic scintillator hodoscopes (MUV0, CHODs, and MUV3). Very light, high rate trackers to reconstruct the K^+ and the π^+ are based on Si pixels (GTK) and straw tracker (STRAW) respectively, and are operated inside the vacuum decay tank. Full particle identification is provided by KTAG and RICH.

High energy protons (400 GeV/c) from the CERN SPS impinge on a one interaction length Be target. A secondary beam of positive polarity is selected with a momentum bite of 1 % around 75 GeV/c and transported 102 m downstream of the target where it enters a large evacuated decay tank. For a nominal pulse of 3×10^{12} protons on target, about 1.3×10^7 kaons decay usefully in the 60 m long decay region. The layout of the experiment is shown in Figure1. NA62 has been designed and built with a specific goal in mind ($K^+ \to \pi^+ \nu \bar{\nu}$) requiring high beam rate, full particle identification, hermetic coverage, very light, high rate tracking and state-of-the-art trigger and data acquisition systems. It paves the way to a broad physics program in kaon decays (lepton universality, lepton flavor violation, studies of chiral perturbation theory) and beyond (heavy neutral leptons, exotics, dark photons etc.). The experiment was commissioned in 2015 and during the 2016 SPS run first physics quality data were collected. Kinematic resolution, and muon

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and photon rejections are in line with the expectations. In the next sections the technique and the status of NA62 are briefly described.

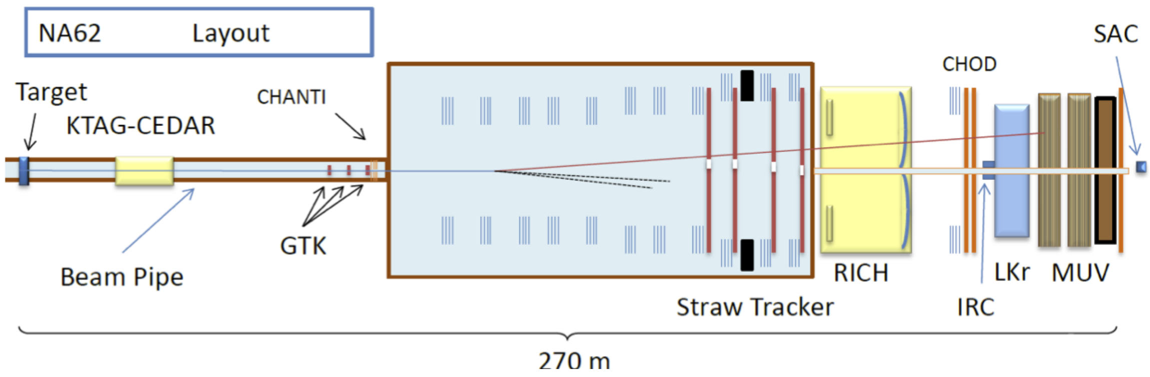

Figure 1: Schematic layout of the NA62 experiment. The drawing is not to scale.

3. Timing

One of the enabling technologies of NA62 is the gigatracker (GTK). It is a set of three stations of Si pixel detectors (pitch of 300 μm $\times$ 300 μm) with the novelty of being able to provide excellent time resolution. In this way, a high rate of tracks (up to one GHz, hence the name) can be measured in order to determine their direction and momentum. The excellent time resolution of the GTK allows one to associate the track of the kaon before it decays to the pion measured in the downstream detectors. The time resolution is essential because most of the tracks crossing the GTK have nothing to do with the interesting kaons: only 6% of the tracks are kaons (the rest being mostly pions and protons) and only 10% of the kaons decay usefully. Figure 2 are shows the time correlation between the KTAG and the GTK and the time correlation between the RICH and KTAG.

4. Particle Identification

The signal of interest is a three body decay where only one particle is measured, so it is necessary to have as much information as possible about the nature of the incoming particle and that

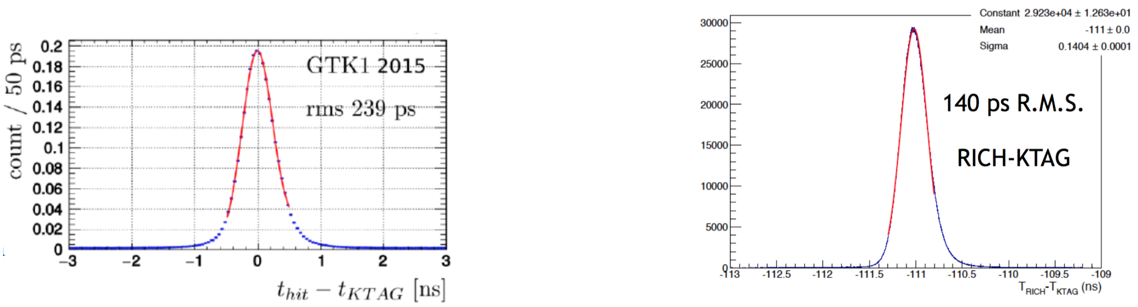

Figure 2: The left plot shows the distribution of the time difference between the GTK (one station out of three) and the KTAG. The right plot shows the time difference between the RICH and the KTAG.

of the measured decay product. For the incoming particle a differential Cherenkov counter (KTAG) works well because by adjusting suitably the pressure of the radiator (N_2 or H_2) the instrument is made sensitive to the Cherenkov photons emitted by the kaons while those emitted by the more copious pions and protons are stopped. The positive identification of the charged pion in the final state is very important because almost two thirds of all kaons decay into a single muon and a neutrino. Calorimetric separation can achieve about five order of magnitude. Kinematics separation is limited by elastic nuclear scattering and pile-up in the gigatracker, so it is essential to have the extra handle provided by the RICH.

Figure 3 shows the particle identification capability of the RICH as a function of the particle momentum measured by the STRAW magnetic spectrometer.

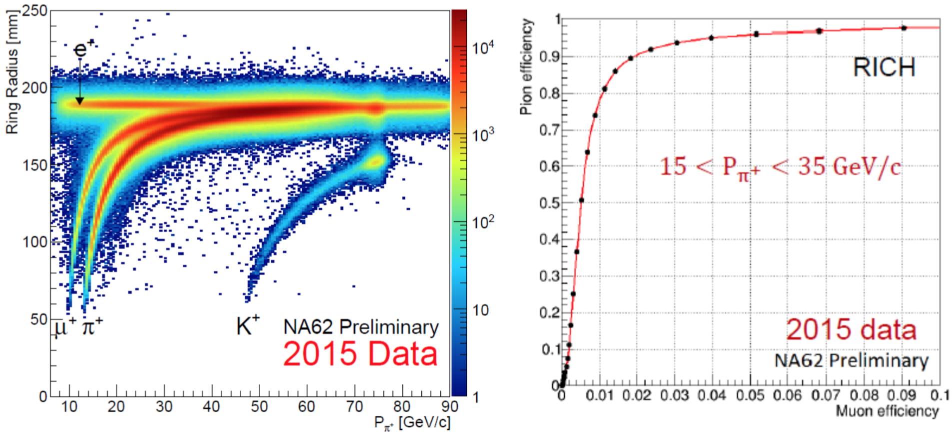

Figure 3: Left: ring radius (RICH) versus momentum (STRAW). One can appreciate the excellent π/μ separation up to high momenta. Right: a typical curve for pion versus muon efficiency.

5. Mass Resolution

Apart from vetoing extra charged particles, photons and muons, it is essential to reject kinematically the kaon decays into two and three pions. To do so one has to limit the effect of multiple scattering and elastic nuclear scattering on the trackers, especially on the last station of the GTK and the first STRAW chamber because the decay of the kaon happens in between and the effect of the scattering affects the reconstruction of the vertex and cannot be undone. For this reason the trackers have to be as thin as possible and they are housed in vacuum because not even He can be tolerated between the tracking stations. The kinematical resolution of NA62 can be appreciated in Figure 4.

6. Summary

The experiment will resume data taking until the end of the 2018 run when a second long shutdown (LS2) of the CERN accelerators will take place. A proposal to run after 2018 is expected to broaden the physics case and extend the sensitivity.

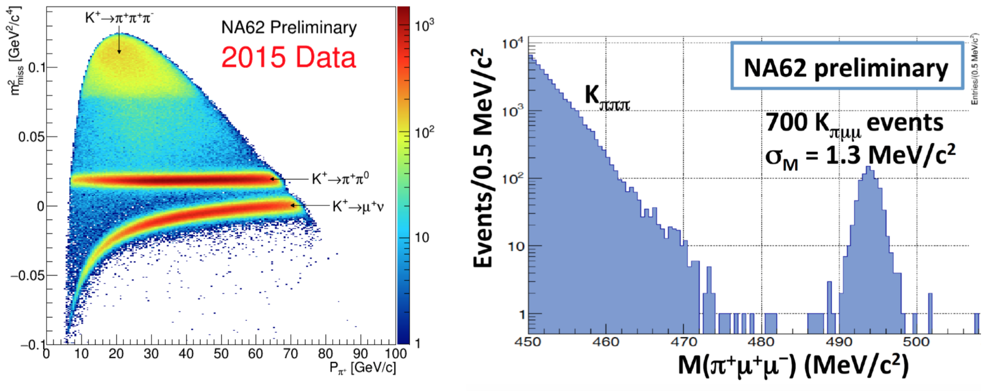

Figure 4: Left: separation by kinematics only between the $K^+ \to \pi^+\pi^0$ and $K^+\mu^+\nu$ as a function of the track momentum. The physical quantity shown is the square of the missing mass recoiling against the track assumed to be a π^+. A very sharp separation for $K^+ \to \pi^+\pi^+\pi^-$ decays can also be seen. Right: the invariant mass for $K^+ \to \pi^+\mu^+\mu^-$ candidates (branching fraction smaller than 10^{-7}) showing how good the mass resolution is in NA62.

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