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Prospects for $K^+ \to \pi^+ \nu\bar{\nu}$ observation at CERN in NA62

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Summary. — The primary goal of the NA62 experiment at CERN SPS is to measure the branching ratio (BR) of the decay $K^+ \to \pi^+ \nu\bar{\nu}$ with $\sim 10\%$ precision. The experimental method and detectors are described in the present paper. Selected results of the pilot run in 2014 are shown.

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1. – Introduction

Kaon decays remain a unique laboratory for searching for New Physics (NP) beyond the Standard Model (SM) complementary to LHC. The FCNC decays $K \to \pi\nu\bar{\nu}$ are highly suppressed within the SM and proceed through box and penguin diagrams. The SM contribution is calculated with a very good precision, thanks to well measured hadronic matrix element of the semileptonic decay $K^+ \to e^+\nu_e\pi^0$ that enters the formula for the BR. The theoretical prediction is $\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu},\ \mathrm{SM}) = (9.11 \pm 0.72) \times 10^{-11}$ [1]. Several NP models can contribute the BR of the decay at the $O(10\%)$ level [2,3].

The best (and the only) experimental result has been obtained by E787/E949 experiments with a statistics of 7 signal events using decay-at-rest technique: $\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu},\ \mathrm{exp}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$ [4].

2. – Experimental method

NA62 uses the decay-in-flight technique. The main kinematic variable used for the signal selection is the missing mass squared: $m^2_{miss} = (P_K - P_\pi)^2 = m^2_K + m^2_\pi - 2E_K E_\pi + 2|\vec{p}_K||\vec{p}_\pi|\cos\theta_{\pi K}$, where P_K and P_π are the 4-momenta of the corresponding particles, E_K, E_π, $\vec{p}_K$, $\vec{p}_\pi$ are energies and three-momenta in the laboratory frame and $\theta_{\pi K}$ is the angle between these momenta. The distribution of m^2_{miss} is shown in fig. 1.

The main background comes from the decays $K^+ \to \mu^+\nu_\mu$ (BR = 63.55%) and $K^+ \to \pi^+\pi^0$ (BR = 20.66%). The two-body kinematics of these decays defines two regions in the m^2_{miss} spectrum where the signal will not be dominated by background:

– Region I (between $K^+ \to \mu^+\nu_\mu$ and $K^+ \to \pi^+\pi^0$ peaks);

– Region II (between $K^+ \to \pi^+\pi^0$ and the region dominated by 3-body background decays $K^+ \to \pi^+\pi^+\pi^-$ and $K^+ \to \pi^+\pi^0\pi^0$).

3. – NA62 setup

Primary 400 GeV/c protons from the SPS impinging on a Be target produce a secondary hadron beam. A system of magnetic elements selects and brings to the experimental area a 750 MHz unseparated beam of 75 GeV/c momentum containing 6% of

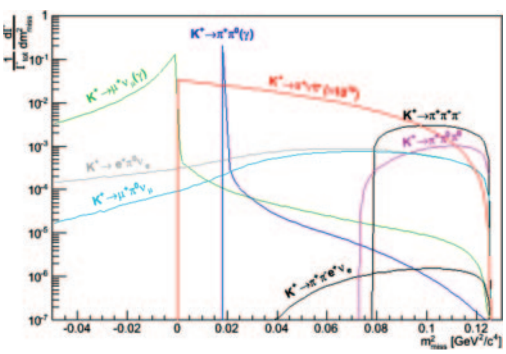

Fig. 1. – Distribution of the variable $\mathrm{m}^2_{miss} = (P_K - P_\pi)^2$ for the signal and the other kaon decay modes.

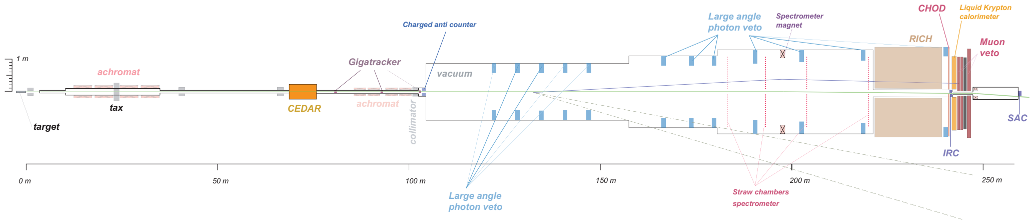

Fig. 2. – NA62 experimental setup.

kaons. To collect $O(100)$ signal events in two years of data taking with a geometrical acceptance of about 10%, the NA62 experiment needs 4.5×10^{12} kaon decays per year in the fiducial decay volume [5]. The layout of the NA62 experimental setup is shown in fig. 2 and the details can be found in [6].

4. – Signal selection

The BR measurement with 10% precision level requires controlling systematics at the percent level. The event reconstruction is based on the precise timing, kinematic cuts and redundancy requiring:

- incoming kaon: momentum, time and direction measurements in the Gigatracker spectrometer, time measurement and identification in KTAG;
- outgoing pion: momentum and direction measurements in the STRAW spectrometer, time measurement and identification in the RICH counter;
- decay reconstruction: time matching of the incoming kaon and outgoing pion, restricted decay region in vacuum, restricted pion momentum range between 15 and 35 GeV/c, leaving more than 40 GeV/c to the missing momentum;
- efficient multiple veto: against beam induced accidentals (KTAG, CHANTI), photons (LAV/SAC/IRC/LKr), muons (MUV) and multiple charged particle decays (STRAW, CHOD);
- robust and effective trigger: several levels of complexity to decrease the trigger rate from 10 MHz to 100 kHz.

5. – Kaon detection

The kaon spectrometer (Gigatracker) is composed of 3 stations and 4 achromat magnets. Each station has the size 60 mm × 30 mm and is made of 18000 silicon pixel detectors. The kaon momentum is measured with 0.2% precision, while the time resolution is ∼200 ps per station.

The kaon tagging is made by the KTAG detector. It is a Cerenkov counter filled by N_2 or H_2. The signal is read by 384 photomultipliers (PM). The kaon tagging efficiency is >95%, the time resolution is better than 100 ps.

6. – Pion detection

The momenta of secondary charged particles are measured by the STRAW spectrometer, including a spectrometer dipole magnet with $p_T = 270\,\text{MeV/c}$ and 4 straw chambers operated in vacuum. Each chamber contains 4 views (x, y, u, v) and 4 planes per view. The relative momentum resolution is $\sigma_p/p = 0.32\% \oplus 0.008\% \times p$ (GeV/c).

The RICH (Ring Imaging Cerenkov detector) consists of a 17 m long cylindrical vessel filled with Ne at atmospheric pressure. The Cerenkov light is reflected by a mosaic of 20 mirrors and detected by 2 stations of photomultipliers (PMs), 976 PMs each. The detector is aimed at μ/π separation at the level of 10^{-2} in the momentum range 15–35 GeV/c and the time measurement with a resolution better than 100 ps.

7. – Veto systems

The upstream veto CHANTI is designed to detect inelastic interactions in the GTK. It contains 6 stations of double-layer scintillator bars and provides $> 99\%$ efficiency for signal-like events with inelastic interactions.

One of the most important background to signal comes from the decay $K^+ \to \pi^+\pi^0$ with one or two photons escaping the detector. To suppress decays with $\pi^0 \to \gamma\gamma$ decays at the 10^{-8} level, a photon veto system has been developed. The photon veto includes several detectors that cover a wide angular range.

Twelve stations of Large Angle Veto (LAV) cover the angular range between 8 and 50 mrad. Stations are made of lead-glass blocks (reused from the OPAL experiment) and have an inefficiency $\sim 10^{-4}$ for photons with $E > 0.5\,\text{GeV}$.

The range between 1 and 8.5 mrad is covered by the Liquid Krypton electromagnetic calorimeter (LKr) which was used in the NA48/2 experiment. The LKr is a quasi-homogenious ionization chamber $26X_0$ deep that allows to measure the full electromagnetic shower and hence to have an extra particle identification.

Small Angle Calorimeter (SAC) and Inner Ring Calorimeter (IRC) provide an effective photon veto in the angular range <1 mrad. Both detectors have lead and scintillator plates arranged using Shashlyk configuration.

Decays with multiple charged particles in the final state are vetoed by special selections on the multiplicity in the STRAW and the charged hodoscope (CHOD). CHOD consists of two planes (vertical and horizontal) of scintillator slabs with the PM readout.

Finally, the MUon Veto is composed of 3 MUV detectors placed downstream and provides a muon rejection at the level of 10^5. The MUV1 and MUV2 are classical Fe-scintillator hadron calorimeters. The particle identification is based on the shape of hadronic showers. MUV3 is located after MUV1 and MUV2 and allows to detect non-showering muons. It is made of 80 cm iron wall and 5 cm thick scintillator tiles each read-out by two PMs in coincidence.

8. – Trigger and data acquisition system

The readout of the NA62 experiment is based on the custom-developed TEL62 board derived from the TELL1 board used in LHCb [7]. The hardware trigger is formed using the information from the RICH, MUV3, LAV and LKr. The trigger primitive rate is $\sim$10 MHz, L0 rate is $\sim$1 MHz. The software L1 trigger uses the information from individual detectors and reduces the rate to $\sim$100 kHz. After combining the information from all detectors (L2 trigger, few kHz) the events are written to disk.

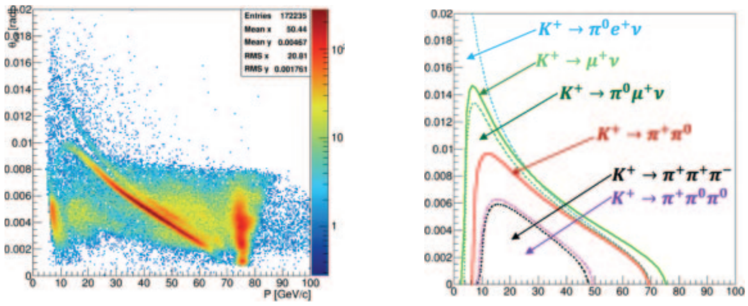

Fig. 3. – Distribution of the K-π angle *vs.* track momentum, in 2014 data (left) and as expected from simulation (right). The muon component was depleted at the trigger level.

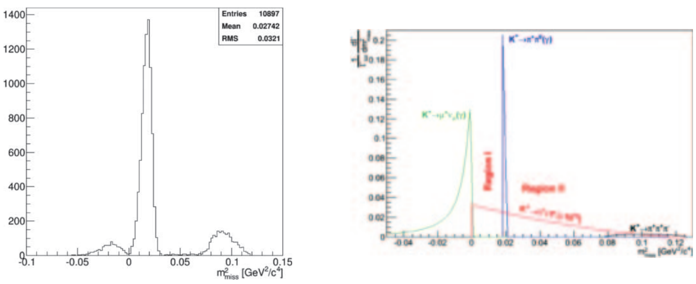

Fig. 4. – Distribution of m^2_{miss}: in 2014 data (left) and as expected from simulation (right).

9. – Commissioning run in 2014

The NA62 setup was commissioned in a ten-week run in October-December 2014. The beam was delivered at 5–20% of the nominal intensity.

Figure 3 left shows the distribution of the angle between the incoming track (the nominal mean beam direction in the absence of GTK measurement) and the secondary track from the decay measured in the STRAW spectrometer. On the right part of the figure one can see the same distribution for the main decay modes from the Monte Carlo simulations. A reasonable agreement is observed, and a scattered beam component can also be seen around 75 GeV/c.

Figure 4 shows the distribution of the main kinematic variable m^2_{miss}. The signal regions (Region I and II defined in section 2) contain known background contributions. These contributions are present because the photon rejection has not been applied and because the resolution is not yet optimal: the beam spectrometer information was not fully available and the STRAW spectrometer reconstruction was still preliminary.

10. – Conclusions

The NA62 experiment is aimed at measuring the $K^+ \to \pi^+\nu\bar{\nu}$ decay at the level of $\sim$10% by collecting $\sim$100 signal events in 2 years of data taking. In 2014 the setup was commissioned and the first data show good performance. The data taking is expected to start in 2015.

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