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

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Abstract. $K^+ \to \pi^+ \nu\bar{\nu}$ is one of the theoretically cleanest meson decay where to look for indirect effects of new physics complementary to LHC searches. The NA62 experiment at the CERN SPS is designed to measure the branching ratio of this decay with 10% precision. NA62 took data in pilot runs in 2014 and 2015 reaching the final designed beam intensity. The quality of data acquired in view of the final measurement will be presented.

1 Introduction

The NA62 experiment is located in the North Area High Intensity Facility at CERN. It is a high intensity kaon beam fixed target experiment [1]. The 3-year data-taking program at the CERN Super Proton Synchrotron (SPS) has started in 2015. The main goal of the experiment is to measure the branching ratio of the ultra-rare decay: $K^+ \to \pi^+ \nu\bar{\nu}$ with 10% accuracy. This decay is driven by Flavor Changing Neutral Current (FCNC), and the branching ratio, highly suppressed by GIM mechanism, is predicted in Standard Model with high precision (see figure 1). This makes this process very sensitive to new physics. The actual Standard Model prediction of the branching ratio is $(8.4 \pm 1.0) \times 10^{-11}$ [2]. Should the experimental value be different from the prediction, new physics contributions have to be present.

The only experimental value has been obtained combining datasets collected by Brookhaven National Laboratory (BNL) E787 and E949 experiments [3, 4]. The measured branching ratio, based on 7 events, is:

$$BR_{SM}(K^+ \to \pi^+ \nu\bar{\nu}) = (17.3^{+11.5}_{-10.5} \times 10^{-11})$$

2 NA62 Experiment

The NA62 experiment [5], sketched in figure 2, exploits the 400 GeV/c proton beam delivered by the CERN SPS. The protons impinging on a beryllium target produce a secondary hadron beam with a momentum 75 GeV/c composed of: 71% pions, 23% protons and 6% kaons. Kaons are recognized with a differential Cherenkov counter detector: the KTAG. The KTAG combines a time resolution of ~100ps and identification efficiency higher than 95%. The kaon direction momentum and time are

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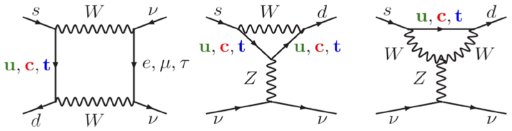

Figure 1. Flavor Changing Neutral Current (FCNC) loop processes, highly suppressed by GIM mechanism, but theoretically very clean [2].

measured by the GigaTracKer (GTK) detector. The GTK operates at ~750 MHz rate. It is composed by three stations interspersed by two pairs of dipole magnets. Each station is made of 200 μm thick silicon pixel matrix ($300\times300\mu m^2$) coupled with 100 μm thick readout chip for a total of 0.5 X_0 per station with time resolution better than 200 ps and momentum resolution 0.2%. The decay products momentum is measured by the Straw spectrometer (STRAW). This detector is composed of 4 stations made of 1792 straw tubes positioned in 4 views (X, Y, U, V). They are located in vacuum before and after a dipole magnet which produces a vertical field of 0.36 T. The momentum resolution is better than 1%. A first pion/muon separation is obtained with the RICH detector, wich is a Cherenkov detector filled with Neon at atmospheric pressure. It is designed to work in the momentum range of $15 \div 35$ GeV/c. Muon are recognised with 99% of efficiency. Time matching between primary and secondary tracks and reference time for the trigger system require RICH time resolution less than 100psec. The Charged particle HODoscope (CHOD) consisting of 128 scintillator slabs arranged in 2 planes (horizontal and vertical) measures the track crossing time with ~200 ps resolution. The photon veto system allows to reject decays with π^0 in the final state with an inefficiency better than 10^{-8}. The system covers the solid angle up to 50 mrad and it includes 4 different detectors:

- Large Angle Veto (LAV) covering the angle region $8.5 \div 50$ mrad and composed of 12 station made of lead glass blocks;
- Liquid Kripton electromagnetic calorimeter (LKr) reused from the NA48 experiment, vetoing the region $1 \div 8.5$ mrad;
- Small Angle Calorimeter (SAC) and Inner Radius Calorimeter (IRC) covering the angle region < 1 mrad.

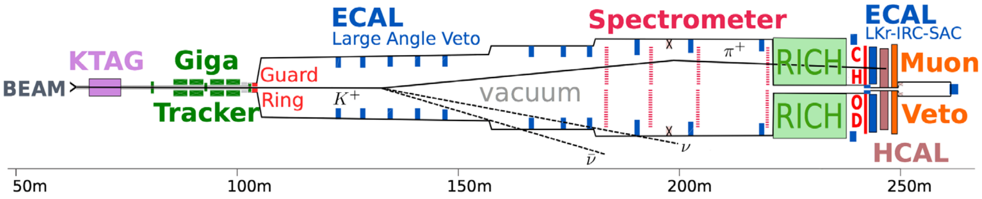

Figure 2. Scheme of the NA62 experimental setup.

Upstream, inelastic interactions and muon halo are vetoed by the CHANTI detector placed after the third station of GTK (referred as Guard Ring in figure 2).

The iron/scintillator hadronic calorimeters (HCAL) provide further pion/muon separation. Together with RICH, they guarantee a separation inefficiency of 10^{-7}. Finally the fast Muon Veto detector composed of an iron wall followed by 5 cm thick scintillators, coupled to PMTs, identifies muons. Muon Veto provides also signals for the trigger system.

In order to reduce the raw data rate, NA62 implements a multi-level trigger system consisting of a hardware L0 trigger processor, followed by a multi stage software based High-Level Trigger (HLT, L1 and L2). The purpose of the trigger system is to reduce the data rate to a manageable level, rejecting as much as possible all the main decay modes of the K^+ with a large efficiency for the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ signal. L0 logic has been implemented in hardware (FPGA), with the goal of reducing the trigger rate from 10MHz to ~1MHz. On a positive L0 decision data are transferred from the detector readout electronics to a dedicated farm of computers, which implements the HLT algorithms and other data acquisition functionality, such as the event building. L1 and L2 are software triggers expected to reduce the L0 rate from ~1MHz to ~10 kHz. The L1 algorithm aims at rejecting multi-track events, presently relying only on CHOD and LAV data fragments. A positive L1 decision issues a request to the LKr calorimeter in order to gather the full event data in the farm.

Assuming 10% signal acceptance, at least 10^{13} K^+ decays are required to reach the designed precision level. In this framework the fully functional experimental apparatus is expected to detect $\sim$ 45 events per year.

3 Analysis method

The signature of the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ signal is one track in the GTK making a vertex with a charged track identified as π^+ in the detector downstream. A key variable used to distinguish the signal from the background is the squared missing mass defined as:

$$m^2_{miss} = (p_{K^+} - p_{\pi^+})^2$$

where p_{K^+} and p_{π^+} are the four momenta of incoming kaon and outgoing pion respectively. It is possible to identify two regions in the m^2_{miss} distribution where the signal to background ratio is most favorable (see figure 3).

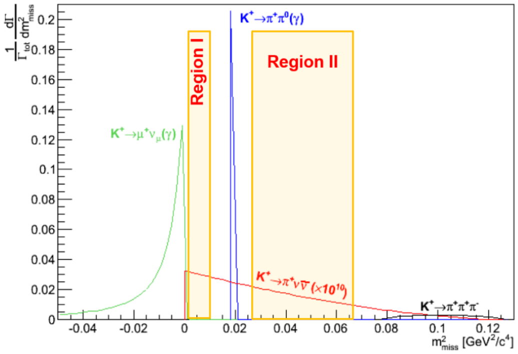

Figure 3. Theoretical m^2_{miss} distribution for signal and backgrounds from the main K^+ decay modes. In the figure the two regions where the signal/ratio is larger are highlighted.

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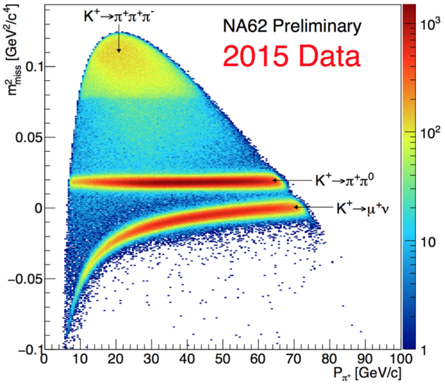

Figure 4. m^2_{miss} versus the momentum of the downstream track in single-track events confirmed by GTK and KTAG signals.

3.1 2015 data quality analysis

In this section we present some results from a study on data quality based on data collected in 2015 and relevant for the measurement of the $K^+ \to \pi^+\nu\bar{\nu}$ decay. A single outgoing track has to form a vertex with the incoming kaon, required to be in the 65m long region between the last GTK and the first straw station. A quality check on the vertex is based on the distance of closest approach (CDA) between GTK and Straw tracks. CDA has to be less than 1.5 cm. Further selection requirements to have a valid signal are:

- the track projection needs to spatially intersect an energy deposits in the calorimeters and the corresponding hit in the CHOD; and
- the associated CHOD hits have to be in time with the KTAG candidate.

The squared missing mass of tracks that satisfy all those constraints are reported in figure 4 as a function of the track momentum as measured with the spectrometer. The data shown were recorded in 2015 at around 3% of the nominal intensity.

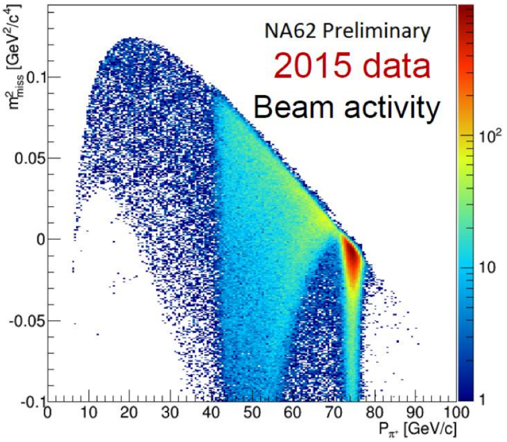

Figure 5. Plot of m^2_{miss} vs P_{π^+} momentum under π^+ mass hypothesis. The downstream track was required to be in anti-coincidence with the kaon track in KTAG.

The KTAG can also be used in anti-coincidence with a Gigatracker track in order to select single track events not related to kaons (Figure 5). This technique allows to study the background generated by the non-kaon beam. The figure 5 shows the main sources of non-kaon tracks:

- decay from beam π^+;
- elastic scattering of beam particles in the material along the beam line (KTAG and Gigatracker stations); and
- inelastic scatterings in the last GTK station are the main sources of non-kaon tracks.

3.2 Kinematic results

The resolution of the $K^+ \rightarrow \pi^+\pi^0$ squared missing mass peak is essential to reduce the tails that can span across the two signal regions. In figure 6 is shown the squared missing mass resolution as a function of momentum. The resolution measured is 1.2×10^{-3} GeV$^2/c^4$, close to the design value represented by the solid black line.

In figure 6 can also be seen that the resolution is three times larger without the GTK detector.

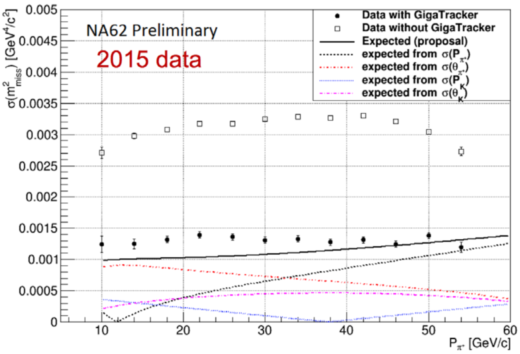

Figure 6. $\sigma(m^2_{miss})$ distribution obtained with individual kaon track measured with GTK (black points) and assuming kaon track aligned on the central beam axis (empty squares).

3.3 Particle identification

The particle identification of NA62 is designed to separate π^+ from μ^+ and e^+ in order to guarantee at least 7 orders of magnitude suppression of $K^+ \rightarrow \mu^+\nu_\mu$ in addition to the kinematic rejection.

The RICH is designed to contribute with a factor 100 to that rejection. To study the performance, $K^+ \rightarrow \mu^+\nu_\mu$ and $K^+ \rightarrow \pi^+\pi^0$ decays were selected applying the kinematic constraints, Muon Veto, and calorimetric information. The positive tracks were selected to be between 15 and 35 Gev/c. In fig 7, it is shown that remaining muon contamination of 0.01 corresponds to a pion efficiency of 80%, close to the design target. This figures are expected to be improved in 2016 run.

3.4 Photon veto

The photon veto system has to provide a suppression factor of 10^{-8} to reject π^0 from the decay: $K^+ \rightarrow \pi^+\pi^0$ ($\pi^0 \rightarrow \gamma\gamma$).

The rejection of such events is implemented by requesting at least a photon in one of the electromagnetic calorimeters, LAV, LKr, IRC or SAC. The target of a 10^8 suppression factor, is fulfilled by requiring that the photon detection has an inefficiency lower than 10^{-5} for energy greater than 10 GeV . This is true for pions that have at least 35 GeV/c momentum. Figure 8 shows the inefficiency for the detection of π^0 when only the LKr calorimeter is used, when LKr and LAV are used and when the full photon veto system is employed. The measurement of the efficiency with 2015 data results is less than 10^{-6} at 90% C.L. but it is statistically limited. New measurements are ongoing with 2016 data.

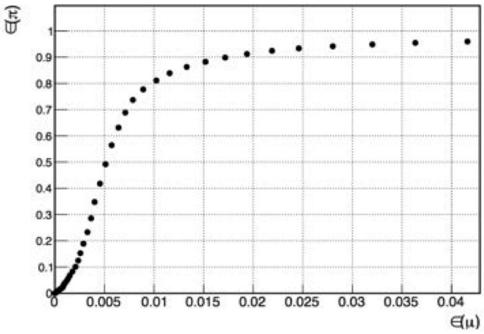

Figure 7. π^+ efficiency as a function of μ^+ remaining contamination measured by the RICH.

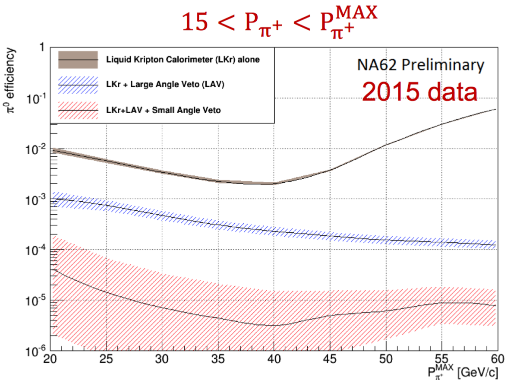

Figure 8. π^0 veto efficiency for different combinations of the calorimeters information.

4 Conclusions and Prospects

The $K^+ \to \pi^+ \nu\bar{\nu}$ branching ratio is one of the key observables to test the SM. The NA62 experiment is designed to measure its branching ratio with a 10% precision. To conclude, the data taken in 2015 shows performances close to the design sensitivity. Refined analyses are ongoing and data taking has restarted in April 2016.

References

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