PROCEEDINGS OF SCIENCE

In-flight Search for $K^+ \to \pi^+ \nu \bar{\nu}$: First NA62 Results

Augusto Ceccucci[*†]
Author affiliation
E-mail: augusto.ceccucci@cern.ch

NA62 has searched for the $K^+ \to \pi^+ \nu \bar{\nu}$ decay using a new kaon decay in-flight technique. One candidate event, compatible with the Standard Model prediction, has been observed from a sample of 1.2 $\times 10^{11}$ decays. Assuming that the event is background, an upper limit of 1.4×10^{-9} (95% CL) has been placed. Prospects for further improvements of the measurement are given.

An Alpine LHC Physics Summit (ALPS2018)
15-20 April, 2018
Obergurgl, Austria

[*]Speaker.

[†]for the NA62 Collaboration: R. Aliberti, F. Ambrosino, R. Ammendola, B. Angelucci, A. Antonelli, G. Anzivino, R. Arcidiacono, M. Barbanera, A. Biagioni, L. Bician, C. Biino, A. Bizzeti, T. Blazek, B. Bloch-Devaux, V. Bonaiuto, M. Boretto, M. Bragadireanu, D. Britton, F. Brizioli, M.B. Brunetti, D. Bryman, F. Bucci, T. Capussela, A. Ceccucci, P. Cenci, V. Cerny, C. Cerri, B. Checcucci, A. Conovaloff, P. Cooper, E. Cortina Gil, M. Corvino, F. Costantini, A. Cotta Ramusino, D. Coward, G. D'Agostini, J. Dainton, P. Dalpiaz, H. Danielsson, N. De Simone, D. Di Filippo, L. Di Lella, N. Doble, B. Dobrich, F. Duval, V. Duk, J. Engelfried, T. Enik, N. Estrada-Tristan, V. Falaleev, R. Fantechi, V. Fascianelli, L. Federici, S. Fedotov, A. Filippi, M. Fiorini, J. Fry, J. Fu, A. Fucci, L. Fulton, E. Gamberini, L. Gatignon, G. Georgiev, S. Ghinescu, A. Gianoli, M. Giorgi, S. Giudici, F. Gonnella, E. Goudzovski, C. Graham, R. Guida, E. Gushchin, F. Hahn, H. Heath, T. Husek, O. Hutanu, D. Hutchcroft, L. Iacobuzio, E. Iacopini, E. Imbergamo, B. Jenninger, K. Kampf, V. Kekelidze, S. Kholodenko, G. Khoriauli, A. Khotyantsev, A. Kleimenova, A. Korotkova, M. Koval, V. Kozhuharov, Z. Kucerova, Y. Kudenko, J. Kunze, V. Kurochka, V.Kurshetsov, G. Lanfranchi, G. Lamanna, G. Latino, P. Laycock, C. Lazzeroni, M. Lenti, G. Lehmann Miotto, E. Leonardi, P. Lichard, L. Litov, R. Lollini, D. Lomidze, A. Lonardo, P. Lubrano, M. Lupi, N. Lurkin, D. Madigozhin, I. Mannelli, G. Mannocchi, A. Mapelli, F. Marchetto, R. Marchevski, S. Martellotti, P. Massarotti, K. Massri, E. Maurice, M. Medvedeva, A. Mefodev, E. Menichetti, E. Migliore, E. Minucci, M. Mirra, M. Misheva, N. Molokanova, M. Moulson, S. Movchan, M. Napolitano, I. Neri, F. Newson, A. Norton, M. Noy, T. Numao, V. Obraztsov, A. Ostankov, S. Padolski, R. Page, V. Palladino, C. Parkinson, E. Pedreschi, M. Pepe, M. Perrin-Terrin, L. Peruzzo, P. Petrov, F. Petrucci, R. Piandani, M. Piccini, J. Pinzino, I. Polenkevich, L. Pontisso, Yu. Potrebenikov, D. Protopopescu, M. Raggi, A. Romano, P. Rubin, G. Ruggiero, V. Ryjov, A. Salamon, C. Santoni, G. Saracino, F. Sargeni, V. Semenov, A. Sergi, A. Shaikhiev, S. Shkarovskiy, D. Soldi, V. Sougonyaev, M. Sozzi, T. Spadaro, F. Spinella, A. Sturgess, J. Swallow, S. Trilov, P. Valente, B. Velghe, S. Venditti, P. Vicini, R. Volpe, M. Vormstein, H. Wahl, R. Wanke, B. Wrona, O. Yushchenko, M. Zamkovsky, A. Zinchenko.

PoS(ALPS2018)006

1. Introduction

Among the many B and K decays sensitive to high energy scales, $K^+ \to \pi^+ \nu\bar{\nu}$ stands out for the precision of the Standard Model (SM) prediction and its strong CKM [1, 2] and GIM [3] suppressions. The SM prediction [4, 5, 6] has been constantly updated and the latest appraisal reads [7]:

$$Br(K^+ \to \pi^+ \nu\bar{\nu})_{SM} = (8.39 \pm 0.30) \times 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2^\circ}\right)^{0.74}.$$

From the above formula one sees that the theoretical error, the component of the uncertainty which cannot be reduced by improving the determination of the CKM parameters, amounts to only 3.6 %. Taking typical values for V_{cb} and γ leads to the numerical prediction[1]:

$$Br(K^+ \to \pi^+ \nu\bar{\nu})_{SM} = (8.4 \pm 1.0) \times 10^{-11},$$

which is used in this paper to determine the expected number of signal events. On the experimental side, so far the decay has been studied only at rest with E787/E949 measuring [9]:

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

The striking difference between the precision of the theoretical prediction and the large experimental error has motivated the construction of a new experiment to measure the decay in-flight [10]. Extensions to the SM to which $K^+ \to \pi^+ \nu\bar{\nu}$ is sensitive include:

- Randall-Sundrum models with protective custodial symmetry [11];
- MSSM analyses [12, 13];
- simplified Z and Z' [14];
- littlest Higgs with T-Parity [15];
- LFU violation models [16].

Constraints from existing experiments which include kaon mixing, correlations with other K and B decays and limits from direct searches leave a significant window of opportunity to be explored. Here we report the first results of NA62 based on a sample of about 1.2×10^{11} decays collected in 2016 at the CERN SPS.

2. The NA62 Experiment

A cross section of the NA62 experiment is shown in Figure 1. Details about the beam and the detector can be found in [10]. The in-flight technique provides large acceptance and good suppression of the backgrounds because the interactions between the kaon decay products and the detector material are minimized. Protons from the CERN SPS are slowly extracted and hit a 40 cm

[1]Taking the latest PDG values [8] would lead to $Br(K^+ \to \pi^+ \nu\bar{\nu})_{SM} = (9.3 \pm 0.7) \times 10^{-11}$.

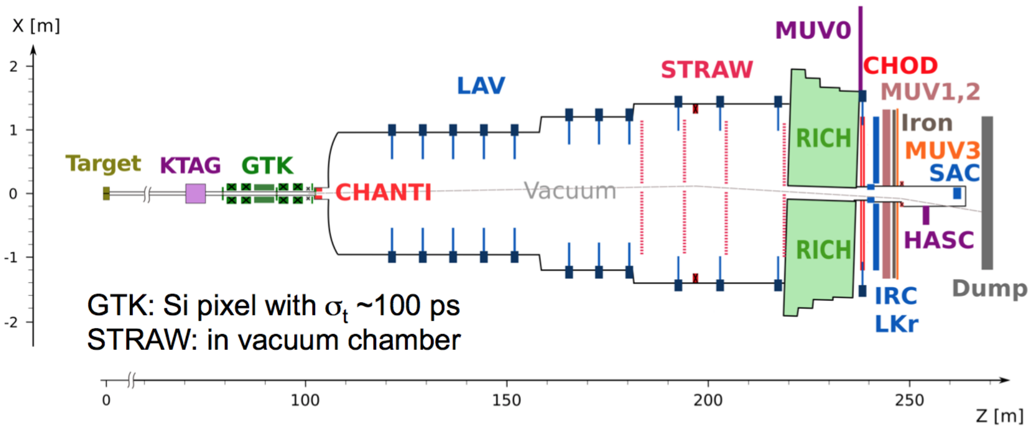

Figure 1: Horizontal cross section of the NA62 detector. The RICH is slightly off-axis with respect to the other detectors in order to take into account the kick of the dipole magnet on the undecayed beam particles.

long Be target. A secondary positively charged hadron beam of central momentum equal to 75 GeV/c and momentum bite of 1% is selected and transported 102 m downstream of the target where it enters an evacuated decay region. The momentum and direction of each beam particle is tracked by a Si pixel tracker (GTK) and the kaons (about 6% of the beam) are tagged by a differential Cherenkov counter (KTAG). The evacuated decay region is surrounded by stations of lead glass (LAV) to veto kaon decays with photons in the final state. In the forward region photons are detected by a liquid krypton calorimeter (LKr) and by other electromagnetic calorimeters covering smaller angles (IRC and SAC) with respect to the beam direction. The coverage of the acceptance is completed by a lateral muon detector (MUV0) to veto pion decaying into muons at large angles and by a hadronic sampling calorimeter (HASC) to veto charged particles from kaon decays at small angles. The direction and momentum of the π^+ originating from the kaon decay is measured by a magnetic spectrometer made of four stations of drift tubes (Straw) housed in the vacuum tank at the end of the decay region and by a dipole magnet placed between the third and the fourth Straw station. The nature of the charged particle is determined by particle identification based on a ring imaging Cherenkov counter (RICH), electromagnetic (LKr) and hadronic (MUV1 and MUV2) calorimeters. Events with large deposits of energy in the LKr or hits in the muon veto (MUV3) are rejected by the Level 0 trigger which requires a tight time coincidence between between a plastic scintillator *hodoscope* (CHOD)and the RICH. Events with hits in the CHANTI anti-counter placed downstream of the GTK are rejected in order to veto inelastic interactions occurring in the last station of the beam tracker.

3. Analysis Strategy

Events with more than one Straw track are kept only if no combination of tracks forms a vertex. In Figure 2 the squared missing mass, $m^2_{miss} = (p_K - p_\pi)^2$, is shown for the events passing the preliminary selection. Events with extra clusters in the LKr are rejected if they are found more than 10 cm away from the impact position of the π^+ on the LKr. Events with hits in either the LAV,

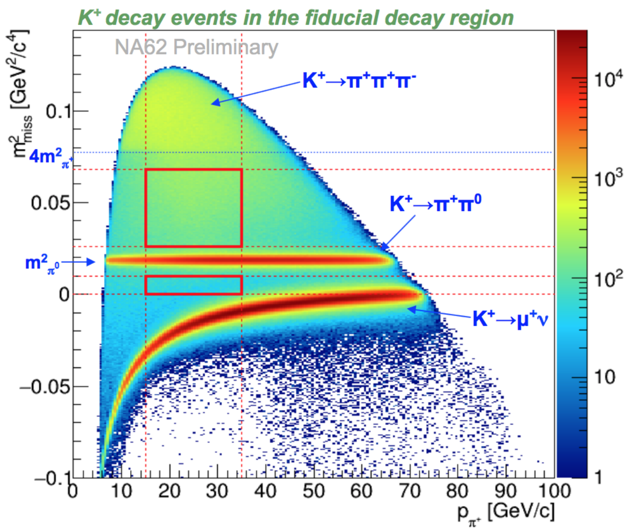

Figure 2: The scatter plot of typical kaon decays plotting the missing mass squared $m^2_{miss} = (p_K - p_\pi)^2$ as a function of the Straw track momentum under the hypothesis that the beam particle is a kaon and the track reconstructed in the Straw is a π^+. Notice the deformation of the two body kinematics for $K^+ \to \mu^+ \nu$ decays as a function of the pion momentum: this is the effect of having assigned the wrong particle hypothesis to the Straw track.

SAV, IRC or HASC in time with the π^+ are rejected. Muon candidates are rejected combining the information from the calorimeters with the RICH. Signal events are characterized by a three body kinematics, while the frequent $K^+ \to \mu^+ \nu$ and $K^+ \to \pi^+ \pi^0$ ones have a distinctive two body distribution. For the time being, simple *cut and counts* signal regions are defined using the squared missing mass recoiling against the Straw track assumed to be a π^+. This allows one to confine the search to areas which are not swamped by two body decays.

Events with Straw track momentum larger than 35 GeV/c are rejected to better suppress the $K^+ \to \pi^+ \pi^0$ decays: in this case the π^0 is geometrically bound to deposit at least 40 GeV of energy in the calorimeters where such a large amount of energy can hardly be missed. Events with Straw track momentum less than 15 GeV/c are rejected because the pion is below or too close to the Cherenkov threshold of the RICH.

The single event sensitivity (SES) is found to be $SES = (3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \times 10^{-10}$. The largest uncertainty is due to the estimation of the loss due to random veto which will be improved in the future. The signal acceptance was found to be 4%, of which about 1% in Region I (suitably defined between the $K^+ \to \mu^+ \nu$ and $K^+ \to \pi^+ \pi^0$ peaks) and 3% in Region II (defined between the $K^+ \to \pi^+ \pi^0$ peak and the area populated by $K^+ \to \pi^+ \pi^+ \pi^-$ decays). The number of expected signal and background events are given in Table 1. The inspection of the signal regions revealed one candidate event in Region II, as shown in Figure 3. The ring of the decay track as seen by the RICH is shown in Figure 4: it is beautifully consistent to be a pion.

Assuming that the event is background, a 95% CL upper limit has been placed:

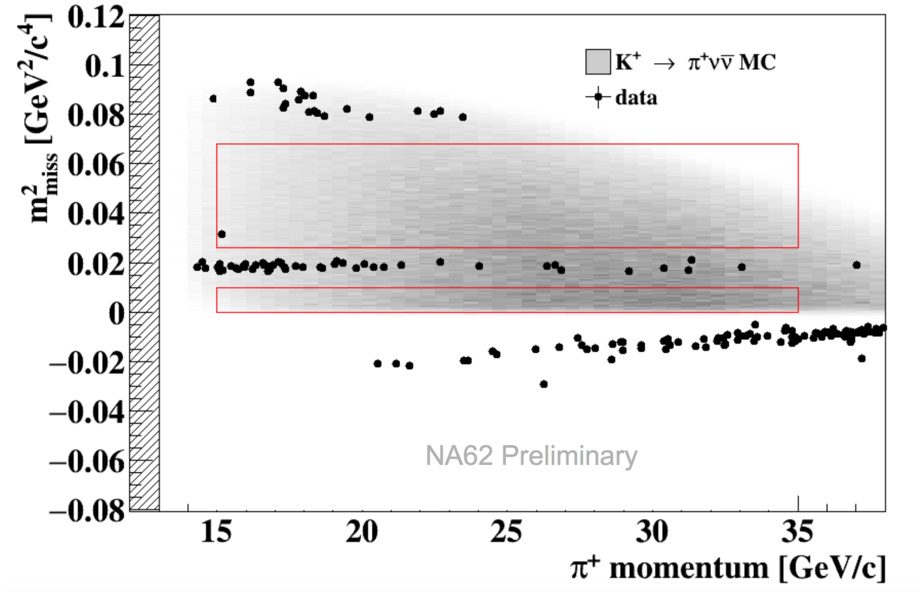

Figure 3: The data passing the analysis, the inspection of the signal boxes revealed one candidate event in Region II.

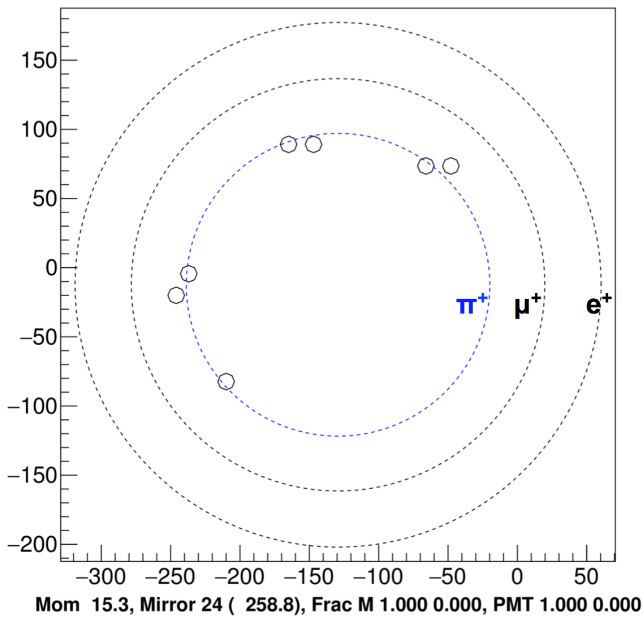

Figure 4: Display of the RICH hits for the candidate event. The rings indicate the different particle hypotheses. The candidate fits very nicely the π^+ hypothesis.

Table 1: Summary of the expected signal background expectations for the 2016 $\pi\nu\nu$ data.

Process	Expected events in signal regions
$K^+ \to \pi^+ \nu\bar{\nu}$	$0.267 \pm 0.001_{stat} \pm 0.02_{syst} \pm 0.032_{ext}$
$K^+ \to \pi^+\pi^0(\gamma)$ IB	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+\nu(\gamma)$ IB	$0.020 \pm 0.003_{stat} \pm 0.003_{syst}$
$K^+ \to \pi^+\pi^- e^+\nu$	$0.018^{+0.024}_{-0.017}\|_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^+\pi^+\pi^-$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
Upstream Background	$0.050^{+0.090}_{-0.030}\|_{stat}$
Total Background	$0.15 \pm 0.09_{stat} \pm 0.01_{syst}$

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) < 14 \times 10^{-10}.$$

For comparison, if the candidate is taken to be signal, the corresponding branching ratio (68% CL) reads:

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = 28^{+44}_{-23} \times 10^{-11}.$$

This result is not yet competitive with those obtained with the decay at rest but it shows that the new in-flight technique works. NA62 has already 20 times more statistics on tape and the analysis of the data is ongoing. Data taking is underway and will continue until the CERN Long Shutdown 2 (LS2) when the accelerator complex stops for two years of maintenance. By the end of 2018 NA62 should have accumulated about 20 SM signal events. NA62 is seeking approval to continue data taking after LS2 in order to complete the measurement with a precision of about 10%.

Acknowledgments

It is a pleasure to thank the technical and administrative staff of our collaborating institutes and to acknowledge the steadfast support of our funding agencies.

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PoS(ALPS2018)006