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Lepton flavour universality and lepton flavour conservation tests at CERN

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A precision lepton universality test by measurement of the helicity suppressed ratio of leptonic decay rates of the charged kaon with 10^5 $K^{\pm} \to e^{\pm}\nu$ decays collected by the NA62 experiment in 2007-08 is presented. The record accuracy of 0.4% constrains the parameter space of new physics models with extended Higgs sector, a fourth generation of quarks and leptons or sterile neutrinos. An improved upper limit on the rate of the lepton number violating decay $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ from the NA48/2 experiment, which probes the resonant enhancement of the rate in the presence of heavy Majorana neutrinos in the 100 MeV range, is also presented.

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1. Introduction

Charged kaons provide excellent opportunities for the lepton flavor conservation and universality studies. The two of them presented in this paper were performed during the second stage of the NA48 [1] experiment and the first (R_K - devoted) stage of its heir NA62 [2] by collecting and analyzing large samples of the $K \to \pi\mu\mu$ and $K^{\pm} \to e^{\pm}\nu$ decays. Both fixed target experiments were installed in the North Area of the CERN SPS facility it the same place and differ in beam conditions and several detector improvements.

The $K^{\pm}$ beam with a momentum of 60 and 74 GeV for NA48/2 and NA62 correspondingly entered a long (114 m) vacuumed decay volume. The detector was installed in a downstream part of this vessel. It consists of magnetic spectrometer for particle tracking, photon vetoes, liquid krypton electromagnetic calorimeter used mostly for particle identification, hodoscopes, hadron calorimeter and muon counters. The presented measurements based on data samples collected in 2007-2008 (R_K) and 2003-2004 (LFV).

2. Lepton flavour universality test

2.1 Motivation

The decays of charged pseudoscalar mesons to light leptons are suppressed by helicity conservation in the SM. The SM provides a very powerful probe for the lepton flavour universality test because the ratio of the decay widths $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ is free from uncertainties induced by meson decay constant and could be precisely estimated in the following way [3]:

$$R_K^{SM} = \left(\frac{M_e}{M_\mu}\right)^2 \left(\frac{M_K^2 - M_e^2}{M_K^2 - M_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.447 \pm 0.001) \times 10^{-5}.$$

Deviations from this value would indicate existence of physics beyond the SM (for example [4, 5, 6]). Since precision of the previous measurement [7] of R_K exceeded the uncertainty of SM estimation tens times, the R_K measurement became primary interest of the first phase of the NA62 experiment [8].

2.2 Measurement principle

The concurrent counting of K_{e2} and $K_{\mu 2}$ decays eliminates ratio $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ from systematic uncertainties related to the bean flux as well as from effects related to the setup work conditions. This is the principle used in the NA62 experiment.

The final state of each event was measured by several detectors: momentum of both charged leptons were estimated by a magnetic spectrometer installed before the LKr calorimeter, electron energy and position by LKr calorimeter. The last detector also used as a photon veto. Muon counters performed μ registration. The R_K value was calculated by using:

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \cdot \frac{A(K_{\mu 2}) f_\mu \varepsilon(K_{\mu 2})}{A(K_{e2}) f_e \varepsilon(K_{e2})} \cdot \frac{1}{f_{LKr}},$$

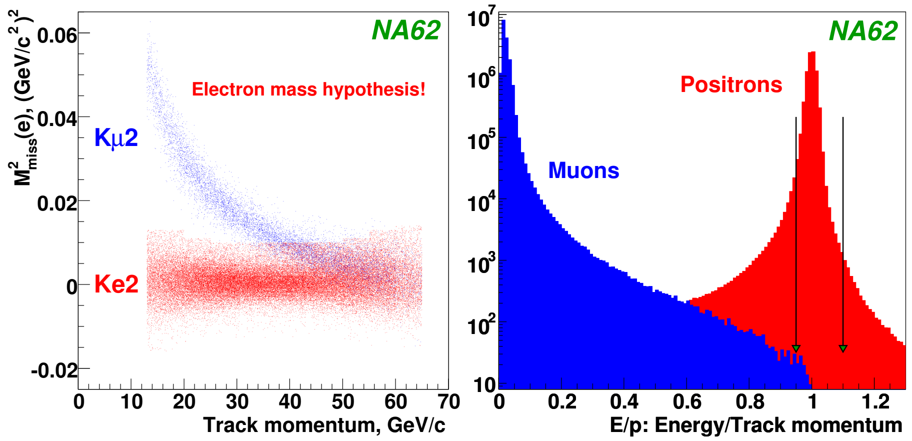

Figure 1: (left) Reconstructed squared missing mass in the electron mass hypothesis $M^2_{miss}(e)$ as a function of lepton momentum for K_{e2} and $K_{\mu 2}$ decays (data). The wrong mass assignment for the $K_{\mu 2}$ decays leads to the momentum-dependence of $M^2_{miss}(e)$. (right) E/p spectra of electrons and muons (data) measured from $K^{\pm} \to \pi^0 e^{\pm} \nu$ and $K_{\mu 2}$ decays. The electron identification criterion applied for p > 25 GeV/c is indicated with arrows.

where $N(K_{l2})$ and $N_B(K_{l2})$ are the number of selected K_{l2} and estimated background respectively; D is the $K_{\mu 2}$ trigger downscaling coefficient; $A(K_{l2})$ is the geometrical acceptance; f_l is the correspondent lepton identification efficiency; $\varepsilon(K_{l2})$ is the trigger efficiency for correspondent decay mode; f_{LKr} is the global LKr efficiency.

2.3 Reconstruction

The topology of K_{e2} and $K_{\mu 2}$ decays is similar. For both processes single charged track was measured by spectrometer and absence of additional clusters in the LKr calorimeter was checked. The kinematic principle of e/μ identification is based on missing mass reconstruction denoted as $M^2_{miss} = (P_K - P_l)^2$, where P_l is momentum reconstructed in hypothesis of muon and electron mass. The P_K value is kaon momentum reconstructed spill by spill using fully constrained $K^+ \to \pi^+\pi^+\pi^-$ decay. On fig.1 one can see effectiveness of this missing mass based separation. Ratio of reconstructed energy and momentum of charged track was used as additional selection criteria for events in kinematic region where first kind of discrimination was ineffective.

2.4 Results

Since acceptance depends of the lepton momentum data, samples were divided in 10 momentum bins and estimation of R_K was performed separately (fig.2 left). The overall data samples fit result is

$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5} = (2.488 \pm 0.010) \times 10^{-5}.$$

This result is consistent with the SM predictions and as one can see on fig. 2 (right) the uncertainty of R_K measurement was significantly improved.

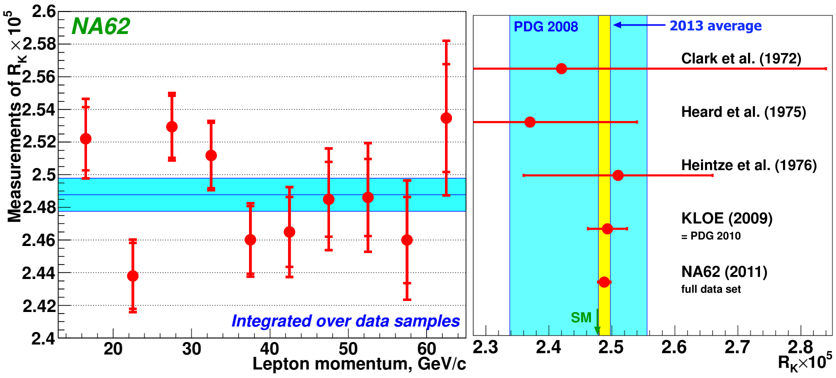

Figure 2: (left) Stability of the R_K measurement versus lepton momentum. (right) R_K world data values correspond to different measurements.

3. Lepton flavour conservation test

3.1 Motivation

The $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ decay is forbidden in the SM due to lepton number violation. At the same time there are number of models allow that these processes. For example, according to [9], the LFV process $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ could be proceed via Majorana neutrino exchange and discovering this decay could be evidence of the New Physics. The most precise measurement of this process was performed by E865 collaboration at Brookhaven [10]. Originally designed for studies the $K^{+} \to \pi^{+}\mu^{+}e^{-}$ this experiment performed several tests for LFV evidences. The collaboration reported evidence of five candidates in the signal region with background contamination of 5.3 events. An upper limit was established $BR(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}) < 3.0 \times 10^{-9}$ at 90% CL.

3.2 Measurement principle

Present analysis [11] was performed by NA48/2 collaboration using data collected in 2003-2004 for measurement the $K \to \pi\mu\mu$ process with an unprecedented statistics. The registration principle based on three charged particles tracking within the magnetic spectrometer and π/μ separation by muon veto. The $K \to \pi\mu\mu$ processes collected concurrently with the normalization channel $K \to \pi\pi\pi$. Since both processes have the same topology and masses values of π and μ are close to each other the implemented approach allowed to cancel systematic uncertainties related to inefficiencies estimations and beam description. The kaon mass resolution achieved in the measurement was $\sigma_{K\to\pi\mu\mu} = 2.5$ MeV/c^2.

The present analysis has been performed together with $K^{\pm} \to \pi^{\pm}\mu^{\pm}\mu^{\mp}$ because they had the same topology of event with the only difference in sign of the final state particles. Main background contribution related to the $K \to \pi\pi\pi$ decay due to two pions transition $\pi^{\pm} \to \mu^{\pm}\nu_{\mu}$ or the same for one with misidentification another pion as a muon.

3.3 Results

The resulting signal plots are on fig.3. 52 candidates were found in the signal region ($485MeV/c^2 <$

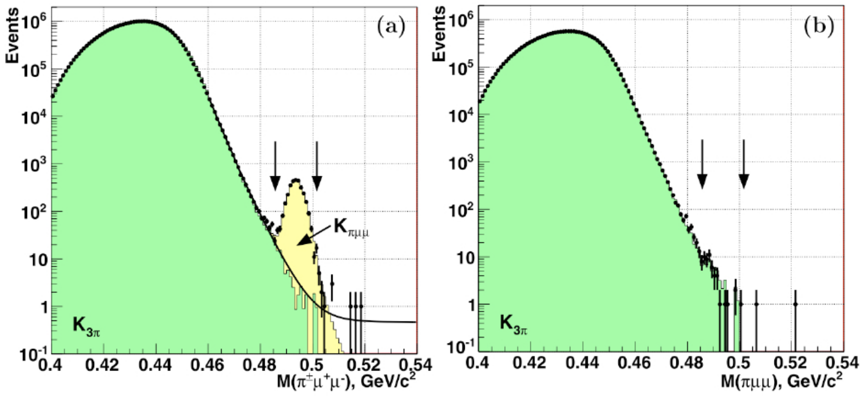

Figure 3: MC and data comparison for $K^{\pm} \to \pi^{\pm}\mu^{\pm}\mu^{\mp}$ (left) and $K^{\pm} \to \pi^{\mp}\mu^{\mp}\mu^{\pm}$ (right) studies. Green area corresponds to MC estimation of $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$ background contamination, yellow to the same of $K^{\pm} \to \pi^{\pm}\mu^{\pm}\mu^{\mp}$ process. Dots represent reconstructed data.

$M(\pi\mu\mu) < 502MeV/c^2$) while MC estimation of background gave 52.6 ± 19.8. This corresponds to a new upper limit of $BR(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}) < 1.1 \times 10^{-9}$ at 90% CL.

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