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Lepton flavour universality and lepton flavour conservation tests in kaon decays at CERN

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A precision measurement of the ratio of the rates of kaon leptonic decays $K^{\pm} \to e^{\pm}\nu$ and $K^{\pm} \to \mu^{\pm}\nu$ with the full minimum bias data sample collected with low intensity 75 GeV/c beam by the NA62 experiment at CERN in 2007-2008 is reported. The result, obtained by analyzing 150,000 reconstructed $K^{\pm} \to e^{\pm}\nu$ candidates with 11% background contamination, has a record precision of 0.4% and is in agreement with the Standard Model expectation.
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 reported. The prospects for the searches of lepton number and flavour violating decays of the charged kaon with an improved sensitivity down to 10^{-12} during the forthcoming main phase of the NA62 experiment are discussed.

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1. Introduction

The present NA62 [1] experiment and its predecessor NA48/2 [2] performed series of tests for finding new phenomena, beyond the Standard Model (SM). Two studies, aimed to test flavour conservation law and lepton flavour universality as well as prospects for future studies of forbidden decays are presented in this paper.

2. Lepton flavour universality test

2.1 Motivation

The SM provides a very clean tool for the lepton flavour universality test. The value of $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ is free from hadronic uncertainties and could be estimated including of internal bremsstrahlung (IB) radiation in the following way [3]:

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

Observing a deviation from this value would point on 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.

2.2 Measurement principle

Experimental determination of ratio $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ is free from uncertainties due to overall normalization if both processes are registered in the concurrent way. Also this approach eliminates time-dependent systematic effects related to the setup work conditions. This strategy has been applied in the NA62 experiment.
Initial state of each event of the measured processes did not register. In case of K_{e2} process energy of electron measured by the LKr electromagnetic calorimeter. Special muon counters were used for e/μ separation at downstream part of the setup. Momentum of both charged leptons were estimated by a magnetic spectrometer installed before the LKr calorimeter and muon counters.
The R_K value was calculated by using:

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

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

Reconstruction of both process is based on the same topology - one registered charged track and absence of clusters not associated to this track in the LKr calorimeter. Due to inefficiency

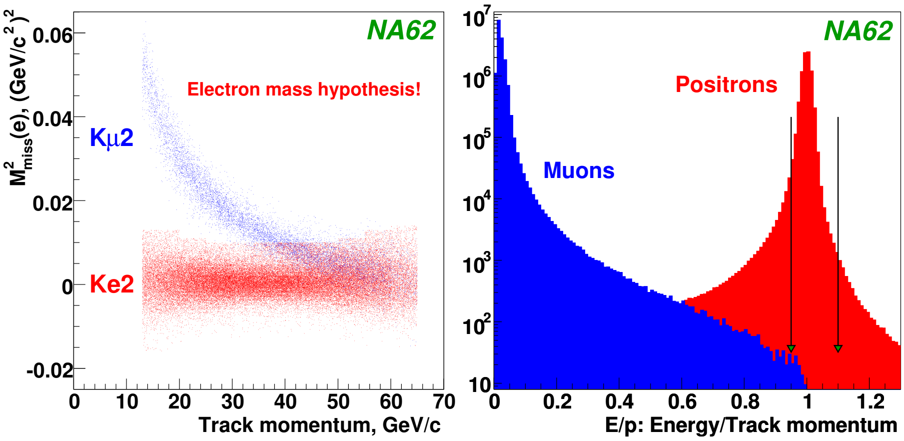

Figure 1: (left) Reconstructed squared missing mass in the electron mass hypothesis $M^2_{miss}(e)$ as a function of lepton momentum for K_{e2} and $K_{\mu 2}$ decays (data). The wrong mass assignment for the $K_{\mu 2}$ decays leads to the momentum-dependence of $M^2_{miss}(e)$. (right) E/p spectra 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.

of muon counter measurement additional kinematic cuts have been applied. On fig.1 one can see separation of K_{e2} and $K_{\mu 2}$ decays based on missing mass distribution defined as $M^2_{miss} = (P_K - P_l)^2$, where P_K is kaon momentum reconstructed spill by spill using $K^+ \to \pi^+\pi^+\pi^-$ decay and P_l is momentum reconstructed in hypothesis of muon and electron mass. Ratio of reconstructed energy and momentum of charged track used as additional selection criteria for events in kinematic region where first kind of discrimination was ineffective.

2.4 Results

To take under control the dependency of acceptance on lepton momentum and associated systematic effects, estimation of R_K has been performed in 10 momentum bins (fig.2 left). The overall data samples fit result is

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

As one can see on fig. 2 (right) uncertainty of R_K measurement significantly improved with the current result but it is far from the uncertainty of the SM prediction.

3. Lepton flavour conservation test

3.1 Motivation

There are number of models allow forbidden in the SM lepton number violation. For example, according to [8], 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 [9].

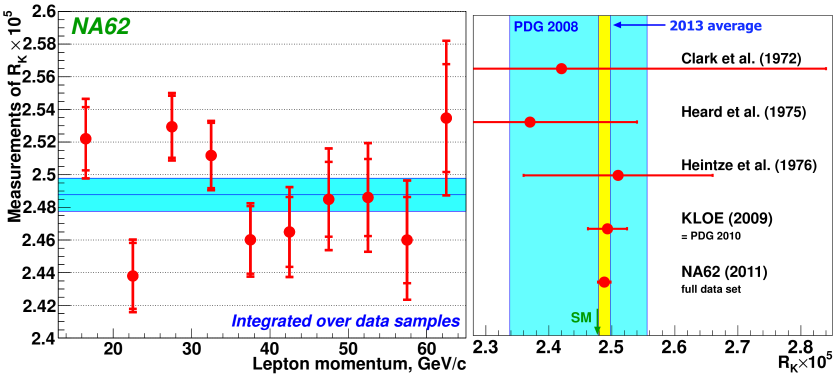

Figure 2: (left) Stability of the R_K measurement versus lepton momentum. (right) R_K world data values correspond to different measurements.

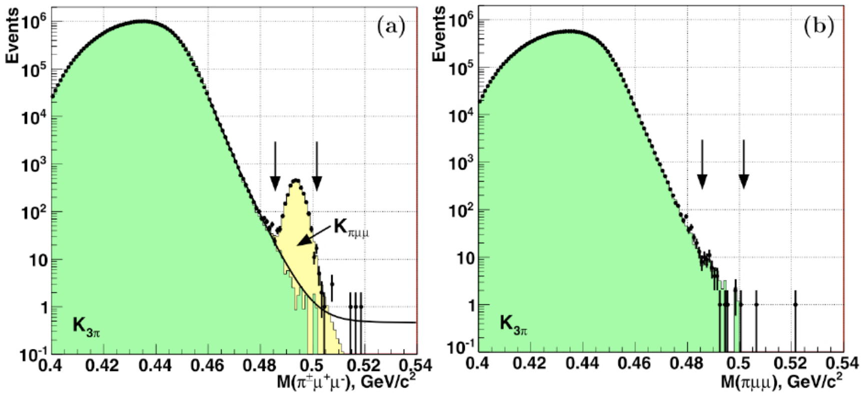

Figure 3: MC and data comparison for $K^{\pm} \to \pi^{\pm}\mu^{\pm}\mu^{\mp}$ (left) and $K^{\pm} \to \pi^{\mp}\mu^{\mp}\mu^{\pm}$ (right) studies. Green area corresponds to MC estimation of $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$ background contamination, yellow to the same of $K^{\pm} \to \pi^{\pm}\mu^{\pm}\mu^{\mp}$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

3.2 Measurement principle

Present measurement was performed by NA48/2 collaboration using data collected in 2003-2004. The setup have been used to collect $K \to \pi\mu\mu$ decays is similar to described above. Magnetic spectrometer was used for measurement of the three charged tracks and muon veto was used for muon identification. The $K \to \pi\pi\pi$ process was used for normalization.

3.3 Results

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. The resulting signal plots are on fig.3. 52 candidates were found in the signal region ($485MeV/c^2 < M(\pi\mu\mu) < 502MeV/c^2$) 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.

4. Prospects for forbidden kaon and poin decays measurements

The NA62 setup gives unique opportunities for kaon and pion studies. The initial state of reaction is under control thanks to precise position ($\sigma < 300\mu m$), momentum ($\sigma(p(K))/p(K) \sim 0.2\%$) and time ($\sigma(t) < 100ps$) measurement. The decay volume controlled by Large Angle Photo Veto (LAV) system with expected inefficiency of $\pi^0 < 10^{-8}$. Downstream part provides excellent photon measurement with LKr calorimeter ($\sigma(x) = \sigma(y) = 0.42/E(GeV) \oplus 0.06cm, \sigma(E)/E = 0.032/E(GeV) \oplus 0.09/E(GeV) \oplus 0.0042$), charged particle tracking ($\sigma(p)/p = 1.02\% \oplus 0.044\% \cdot p$), time measurement ($\sigma(t) < 100ps$), muon/pion separation (with inefficiency of 10^{-5}).
4.5×10^{12} kaon decays per year expected in the acceptance region. This also provides excellent opportunities for studies π^0 decays as product of $K^+ \to \pi^+\pi^0$ channel.
Mentioned factors make possible precision studies of the SM forbidden and ultra rare decays such as $K \to \pi\mu e$, $K \to \pi ee$, $K \to \pi\mu\mu$, $\pi^0 \to 3\gamma$, $\pi^0 \to 4\gamma$, $\pi^0 \to \mu e$ with unprecedented sensitivity.

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