Searches for lepton flavor and lepton number violation in kaon decays at CERN

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Abstract. The NA62 experiment at CERN SPS collected, during 2007 run, the world largest sample of $K^{\pm}$ leptonic decays in order to test lepton universality, by measuring the ratio:
$R_K = \Gamma(K^{\pm} \to e^{\pm}\nu)/\Gamma(K^{\pm} \to \mu^{\pm}\nu) = \Gamma(Ke2)/\Gamma(K\mu 2)$
Due to V-A structure of the charged weak current R_K is helicity suppressed in the SM therefore sensitive to non-SM effects. The final result of the analysis based on 59813 $K^{\pm} \to e^{\pm}\nu$ candidates, extracted from a sub-sample of the data set, is: $R_K = (2.487 \pm 0.013) \cdot 10^{-5}$ [1], consistent with Standard Model predictions. A test of the lepton number violation in the decay $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ by NA48/2 experiment is also reported.

Keywords: Kaons, R_K, Leptonic Kaon Decay
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NA62 EXPERIMENTAL SETUP

The first phase of the NA62 $K^+ \to \pi^+\nu\bar{\nu}$ experiment exploited the NA48/2 beam line [2] and detector setup [3] with optimizations for $Ke2$ data collection. The beam line of NA48/2 experiment was designed to deliver simultaneously K^+ and K^-, produced on a beryllium target from SPS primary protons. The beams of (74 ± 2) GeV/c, after being momentum selected and focused by magnetic elements, enter 114 m long vacuum decay volume. The momenta of the charged decay products are measured by a magnetic spectrometer consisting of four drift chambers (DCHs) and a dipole magnet. The resolution of the spectrometer is $\sigma(p)/p = 1.0\% \oplus 0.044\% p$ (p in GeV/c). A scintillator hodoscope (HOD), located after the spectrometer, produces fast trigger signals and measures the time of charged particles with an offline resolution of 150 ps. The electromagnetic energy deposit of particles is measured by a liquid krypton calorimeter (LKr) with a resolution of $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$.

MEASUREMENT OF R_K IN NA62

The ratio of kaon leptonic decay rates $R_K = \Gamma(K^{\pm} \to e^{\pm}\nu)/\Gamma(K^{\pm} \to \mu^{\pm}\nu)$, due to the cancelation of hadronic terms, is computed in the Standard Model (SM) with excellent precision :
$R_K^{SM} = (\frac{m_e}{m_\mu})^2 \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \cdot 10^{-5}$, [4]
where $\delta R_{QED} = (-3.78 \pm 0.04)\%$ is a correction due to the inner bremsstrahlung (IB) $K_{l2(\gamma)}$ process which is included by definition into R_K. Being helicity suppressed, due to V-A structure of the charged weak current, R_K is sensitive to non-SM effects. In

particular in MSSM non-vanishing e-τ mixing become possible , mediated via H^+, which can lead to order percent enhancement of R_K [5]. The present world average of $R_K = (2.493 \pm 0.025 \pm 0.019) \cdot 10^{-5}$ [6] is based on the recent measurements by KLOE collaboration [7], which pushed the precision down to $\sim 1\%$. The NA62 experiment collected data during 2007 and 2008 aiming to reach accuracy of $\sim 0.4\%$. The final result on partial data set is presented here.

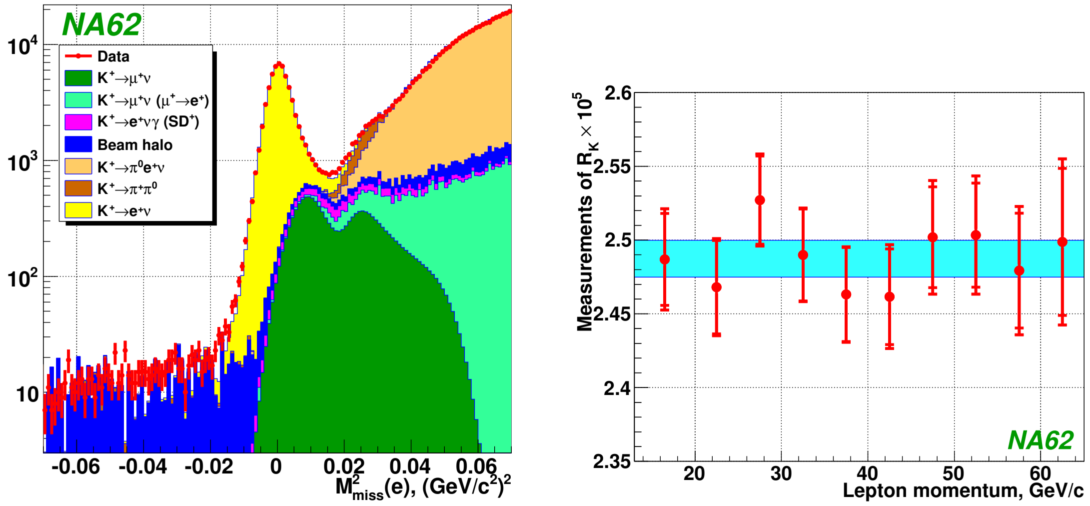
R_K data selection and analysis strategy

Due to the topological similarity of $Ke2$ and $K\mu2$ final states, large part of the selection conditions are common. The presence of a single reconstructed charged track with momentum 13 GeV/c< p <65 GeV/c, within the geometrical acceptances of DCH, LKr and HOD, and with a CDA between the charged track and the nominal kaon beam less than 1.5 cm, is required. In order to suppress the background from other kaon decays the events are rejected if a cluster in the LKr with energy larger than 2 GeV and not associated with track is found. For low track momenta, a kinematical separation between $Ke2$ and $K\mu2$ is possible, based on the reconstructed missing mass $M^2_{miss(l)} = (P_K - P_l)^2$, assuming the lepton mass to be that of an electron or a muon. NA62 is not able to directly measure the kaon four-momentum P_K in each event, nevertheless its average is monitored in each SPS spill using $K^\pm \to \pi^\pm\pi^+\pi^-$ decays. A cut $-M_1^2 < M^2_{miss}(e) < M^2{}_2$ is applied to select $Ke2$ candidates, and $-M_1^2 < M^2_{miss}(\mu) < M_2^2$ for $K\mu2$ ones, where $M^2_{1,2}$ varies for different track momenta, taking into account M_{miss} resolution. Particle identification is based on the ratio E/p of track energy deposit in the LKr (E) to its momentum measured by the spectrometer (p). Particles with 0.95 < E/p < 1.1 are identified as electrons, while particles with E/p < 0.85 as muons.

The analysis is based on counting the number of reconstructed $Ke2$ and $K\mu2$ candidates with the selection described above. Since the decays are collected simultaneously, the result does not depend on kaon flux measurement and the systematic effects due to the detector efficiency cancel to first order. To take into account the momentum dependence of signal acceptance and background level, the measurement is performed independently in bins of reconstructed lepton momentum. The ratio R_K in each bin is computed as:

$$R_K = \frac{1}{D}\frac{N(Ke2) - NB(Ke2)}{N(K\mu2) - NB(K\mu2)}\frac{f_\mu \cdot A(K\mu2) \cdot \varepsilon(K\mu2)}{f_e \cdot A(Ke2) \cdot \varepsilon(Ke2)}\frac{1}{f_{LKr}} \qquad (1)$$

where N(Kl2) are the numbers of selected Kl2 candidates (l = e,μ), NB(Kl2) are numbers of background events, f_l are the identification criteria efficiencies for electron and muon , A(Kl2) are geometrical acceptances, $\varepsilon(Kl2)$ are trigger efficiencies, f_{LKr} is the global efficiency of the LKr readout, and D=150 is the downscaling factor of the $K\mu2$ trigger. In order to compute A(Kl2), a detailed Geant3-based Monte-Carlo simulation is employed.



(a) **(b)**

FIGURE 1. (a)$M^2_{miss}(e)$ distributions for $Ke2$ and backgrounds events. (b)R_K in lepton momentum bins.

Background studies

NB(Ke2) in 1 is dominated by $K\mu 2$ events with the muon misidentified as electron, (high energetic bremsstrahlung after the magnetic spectrometer). In particular cases, the photon can take up to more than 95% of muon's energy. The probability for such process to occur is measured by sample of $K\mu 2$ with the muon passing $\sim 10X_0$ of lead before hitting the LKr. Those events have been collected during dedicated data taking periods in which a lead wall was installed in front of the LKr calorimeter in order to stop electrons. A Geant4 simulation is used to evaluate the correction to the probability for muon to give E/p>0.95. The background contribution is finally evaluated to be $(6.11 \pm 0.22)\%$. Since the incoming kaon is not tracked and the signature of Kl2 decays is a single reconstructed track, the background from beam halo is also considered. The performance of muon sweeping system results in lower background in K^+_{e2} sample ($\sim 1\%$) with respect to K^-_{e2} sample ($\sim 20\%$), therefore $\sim 90\%$ of data were collected with the K^+ beam only. Small fractions were recorded with simultaneous $K^\pm$ beams and K^- beam only. The halo background in K^+_{e2} was measured to be $(1.16 \pm 0.06)\%$ directly from data, collected when no K^+ beam was present. The total number of $Ke2$ collected candidates is 59813 with a total estimated background of $(8.71 \pm 0.24)\%$. The $M^2_{miss(e)}$ distribution for data events, red points, and simulated backgrounds are presented in Fig. 1(a).

Results and conclusions

The independent measurements of R_K in track momentum bins are shown in Fig. 1(b). The NA62 final result is $R_K = (2.487 \pm 0.011_{stat} \pm 0.007_{syst}) \cdot 10^{-5} = (2.487 \pm 0.013) \cdot 10^{-5}$[1]. This is the most precise measurement to date, it is consistent with SM expectation [4] and with KLOE measurement[7]. The precision has been improved to 0.5% to be compared to the 1% of previous PDG average. The analysis on the whole data set will allow us to reduce the uncertainty to 0.4%. This result can be used to constrain multi-Higgs [5] and fourth generation new physics scenarios. The experimental accuracy is still an order of magnitude behind the SM one, which motivates further precision measurements of R_K.

THE LEPTON NUMBER VIOLATING DECAY $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$

The decay $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$, which violates lepton number by two units, can proceed via a neutrino exchange if the neutrino is a Majorana particle, and the E865 upper limit on its rate [8] currently provides the strongest constraint on the effective Majorana neutrino mass. A new upper limit on this decay's BR has been established by NA48/2 analyzing the wrong sign events in the study of $K^\pm \to \pi^\pm \mu^\mp \mu^\pm$.

In the NA48/2 full data sample 52 wrong signs events have been observed in the signal region with an expected background, estimated from MC simulation, of $N_{WS}^{MC} = (52.6 \pm 19.8)$. A conservative estimate of the background is $52.6 - 19.8 = 32.8$ events, which translates into 32.2 signal events at 90% CL, leading to an upper limit of $BR(K^\pm \to \pi^\mp \mu^\pm \mu^\pm) < 1.1 \cdot 10^{-9}$ at 90% CL [9]. This improves by almost a factor of 3 the best previous limit [8], allowing a bound on the effective Majorana neutrino mass of <300 GeV/c^2 to be established.

SUMMARY

The NA48/2 and NA62 experiments at CERN SpS explored the field of lepton flavor and lepton number violations in the charged kaon sector. The agreement of the NA62 result $R_K = (2.487 \pm 0.013) \cdot 10^{-5}$[1] with SM expectation, strongly constrains lepton flavor violation beyond the standard model. The upper limit on lepton number violation obtained by NA48/2 experiment for the $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$ decay ($BR < 1.1 \cdot 10^{-9}$ 90% CL) is at present the best limit.

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