Kaon programme at CERN: recent results

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Searches for lepton flavour and lepton number violation in kaon decays by the NA48/2 and NA62 experiments at CERN are presented. A precision measurement of the helicity-suppressed ratio R_K of the $K^\pm \to e^\pm \nu$ and $K^\pm \to \mu^\pm \nu$ decay rates has been performed using the full data set collected by the NA62 collaboration in 2007. The data sample amounted to 145,958 reconstructed $K^\pm \to e^\pm \nu$ candidates with 11.0% background contamination. The result is $R_K = (2.488 \pm 0.010) \times 10^{-5}$, which is in agreement with the Standard Model expectation. An improved upper limit on the lepton number violating $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$ decay rate is also presented.

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Introduction

Decays of pseudoscalar mesons to light leptons ($P^{\pm} \to \ell^{\pm} \nu$, denoted $P_{\ell 2}$) are helicity suppressed in the Standard Model (SM). The specific ratios of decay rates can be computed very precisely: the SM prediction for the ratio $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ is [1]

$$R_K^{\text{SM}} = (m_e/m_\mu)^2 \left[(m_K^2 - m_e^2)/(m_K^2 - m_\mu^2) \right]^2 (1 + \delta R_{\text{QED}}) = (2.477 \pm 0.001) \times 10^{-5}, \quad (1)$$

where $\delta R_{\text{QED}} = (-3.79 \pm 0.04)\%$ is an electromagnetic correction. Within certain two Higgs doublet models (2HDM type II), R_K is sensitive to lepton flavour violating (LFV) effects via the charged Higgs boson ($H^{\pm}$) exchange [2], the dominant contribution being

$$R_K^{\text{LFV}}/R_K^{\text{SM}} \simeq 1 + (M_K/M_H)^4 (M_\tau/M_e)^2 |\Delta_R^{31}|^2 \tan^6 \beta, \quad (2)$$

where $\tan \beta$ is the ratio of the two Higgs vacuum expectation values, and $|\Delta_R^{31}|$ is the mixing parameter between the superpartners of the right-handed leptons, which can reach $\sim 10^{-3}$. This can enhance R_K by $\mathscr{O}(1\%)$ without contradicting any known experimental constraints. A precise R_K measurement based on the full data sample (~ 10 times the world sample) collected by the CERN NA62 experiment in 2007 is presented, superseding an earlier result [3] based on a partial data set.

The decay $K^{\pm} \to \pi^{\mp} \mu^{\pm} \mu^{\pm}$ violating lepton number by two units can proceed via a neutrino exchange if the neutrino is a Majorana particle [4]; it has also been studied in the context of supersymmetric models with R-parity violation [5]. The upper limit on the decay rate has been improved using a data sample collected by the CERN NA48/2 experiment in 2003–2004.

1. Search for lepton flavour violation

The measurement method is based on counting the numbers of $K_{\ell 2}$ candidates collected concurrently. The study is performed independently for 40 data samples (10 bins of lepton momentum and 4 samples with different data taking conditions) by computing the ratio R_K as:

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_{\text{B}}(K_{e2})}{N(K_{\mu 2}) - N_{\text{B}}(K_{\mu 2})} \cdot \frac{A(K_{\mu 2})}{A(K_{e2})} \cdot \frac{f_\mu \times \varepsilon(K_{\mu 2})}{f_e \times \varepsilon(K_{e2})} \cdot \frac{1}{f_{\text{LKr}}}, \quad (1.1)$$

where $N(K_{\ell 2})$ are the numbers of selected $K_{\ell 2}$ candidates ($\ell = e, \mu$), $N_{\text{B}}(K_{\ell 2})$ are the numbers of background events, $A(K_{\mu 2})/A(K_{e2})$ is the geometric acceptance correction, f_ℓ are the efficiencies of e/μ identification, $\varepsilon(K_{\ell 2})$ are the trigger efficiencies, f_{LKr} is the global efficiency of the liquid krypton (LKr) calorimeter readout (used for electron identification), and D is the downscaling factor of the $K_{\mu 2}$ trigger. A Monte Carlo simulation is used to evaluate the acceptance correction and the geometric part of the acceptances for background processes entering the computation of $N_B(K_{\ell 2})$. Particle identification, trigger and readout efficiencies and certain backgrounds are measured directly from control data samples.

A large part of the selection is common to K_{e2} and $K_{\mu 2}$ decays, with two principal differences. $K_{\ell 2}$ kinematic identification is based on the reconstructed squared missing mass assuming the track to be a positron or a muon: $M_{\text{miss}}^2(\ell) = (P_K - P_\ell)^2$, where P_K and P_ℓ ($\ell = e, \mu$) are the kaon and lepton 4-momenta (Fig. 1a). A selection condition $M_1^2 < M_{\text{miss}}^2(\ell) < M_2^2$ is applied; $M_{1,2}^2$ vary across the
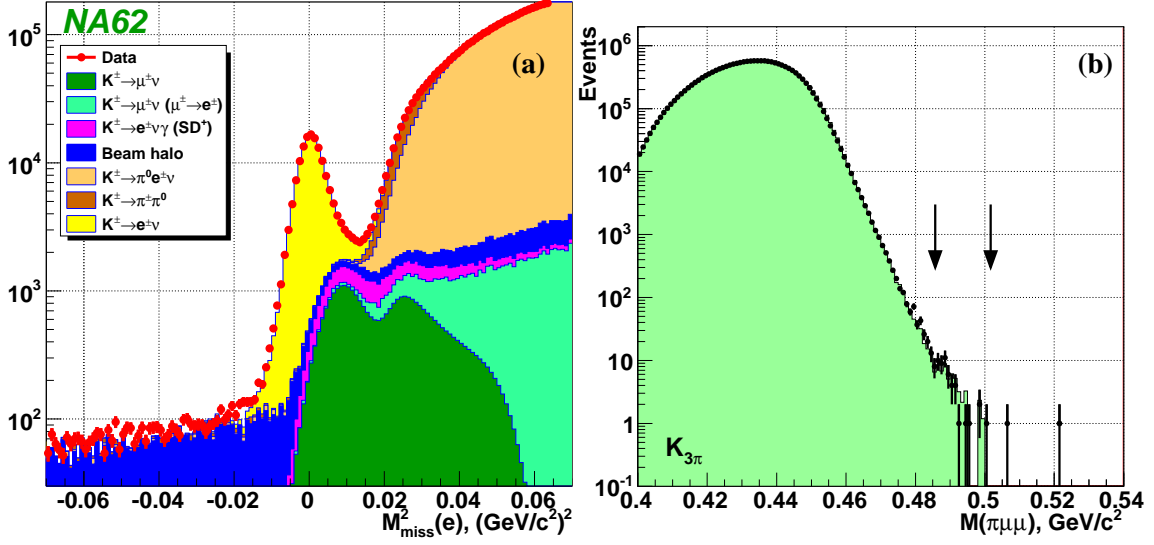
Figure 1: (a) Reconstructed squared missing mass $M_{miss}^2(e)$ distribution of the K_{e2} candidates compared with the sum of normalised estimated signal and background components. (b) Reconstructed $M(\pi^\mp\mu^\pm\mu^\pm)$ spectra: data (circles with error bars), $K^\pm \to 3\pi^\pm$ background simulation (filled area).

lepton momentum bins depending on resolution. Particle identification is based on the ratio E/p of energy deposit in the LKr calorimeter to track momentum measured by the spectrometer. Particles with $0.95 < E/p < 1.1$ ($E/p < 0.85$) are identified as positrons (muons).

The largest background to the K_{e2} decay is the $K_{\mu2}$ decay with a mis-identified muon ($E/p > 0.95$) via the 'catastrophic' bremsstrahlung process in the LKr. To reduce the corresponding uncertainty, the muon mis-identification probability $P_{\mu e}$ has been measured as a function of momentum using dedicated data samples. The numbers of selected K_{e2} and $K_{\mu2}$ candidates are 145,958 and 4.2817×10^7 (the latter pre-scaled at trigger level). Backgrounds in the K_{e2} sample integrated over lepton momentum are summarised in Table 1: they have been estimated with Monte Carlo simulations, except for the beam halo background measured directly with dedicated data samples. The contributions to the result's systematic uncertainty include the uncertainties on the backgrounds, helium purity in the spectrometer tank, acceptance correction, alignment, particle identification and trigger efficiency. The final result of the measurement, combined over the 40 independent samples taking into account correlations between the systematic errors, is

$$R_K = (2.488 \pm 0.007_{stat.} \pm 0.007_{syst.}) \times 10^{-5} = (2.488 \pm 0.010) \times 10^{-5}. \qquad (1.2)$$

This value is consistent with the Standard Model expectation, and the achieved precision dominates the world average.

2. Search for lepton number violation

The $K^\pm \to \pi^\mp\mu^\pm\mu^\pm$ decay has been searched for by reconstructing three-track vertices with no significant missing momentum from the magnetic spectrometer information. Identification of pion and muon candidates is performed on the basis of energy deposition in the LKr calorimeter

Table 1: Summary of backgrounds in the K_{e2} sample.

Source	$N_B/N(K_{e2})$	Source	$N_B/N(K_{e2})$
$K_{\mu 2}$	$(5.64 \pm 0.20)\%$	$K^\pm \to \pi^\pm \pi^0$	$(0.12 \pm 0.06)\%$
$K_{\mu 2}$ ($\mu \to e$ decay)	$(0.26 \pm 0.03)\%$	Beam halo	$(2.11 \pm 0.09)\%$
$K^\pm \to e^\pm \nu \gamma$ (SD$^+$)	$(2.60 \pm 0.11)\%$	Decays of opposite sign K	$(0.04 \pm 0.02)\%$
$K^\pm \to \pi^0 e^\pm \nu$	$(0.18 \pm 0.09)\%$	Total	$(10.95 \pm 0.27)\%$

and the the muon detector. The muon identification efficiency has been measured to be above 98% for $p > 10$ GeV/c, and above 99% for $p > 15$ GeV/c.

The invariant mass spectrum of the reconstructed $\pi^\mp \mu^\pm \mu^\pm$ candidates is presented in Fig. 1b: 52 events are observed in the signal region $|M_{\pi\mu\mu} - M_K| < 8$ MeV/c^2. The background comes from the $K_{3\pi}$ decays with subsequent $\pi^\pm \to \mu^\pm \nu$ decay, is well reproduced by Monte Carlo simulation, and has been estimated by the simulation to be (52.6 ± 19.8) events. The quoted uncertainty is systematic due to the limited precision of MC description of the high-mass region, and has been estimated from the level of agreement of data and simulation in the control mass region of (465; 485) MeV/c^2. This background estimate has been cross-checked by fitting the mass spectrum in the region between 460 and 520 MeV/c^2, excluding the signal region between 485 and 502 MeV/c^2, using the maximum likelihood estimator and assuming a Poisson probability density in each mass bin.

Conservatively assuming the expected background to be $52.6 - 19.8 = 32.8$ events to take into account its uncertainty, the upper limit for the possible signal is 32.2 events at 90% CL. The geometrical acceptance is conservatively assumed to be the smallest of those averaged over the $K^\pm \to \pi^\pm \mu^\pm \mu^\mp$ and $K_{3\pi}$ samples ($A_{\pi\mu\mu} = 15.4\%$ and $A_{3\pi} = 22.2\%$). This leads to an upper limit of BR($K^\pm \to \pi^\mp \mu^\pm \mu^\pm$) $< 1.1 \times 10^{-9}$ at 90% CL, which improves the best previous limit by almost a factor of 3. More details of the analysis are presented in [6].

3. Conclusions

The most precise measurement of lepton flavour violation parameter R_K has been performed: $R_K = (2.488 \pm 0.010) \times 10^{-5}$ is consistent with the SM expectation, and can be used to constrain multi-Higgs and fourth generation new physics scenarios. An improved upper limit of 1.1×10^{-9} for the branching fraction of the lepton number violating $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$ decay has been established.

References

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