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A precision test of lepton flavour universality in $K^+ \rightarrow l^+ \nu$ decays by NA62

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The search for New Physics (NP) beyond the Standard Model (SM) is in the focus of high energy physics today. While highest energies (LHC, Tevatron) allow to search for direct evidence, precision tests are complementary by looking for deviations from the SM in rare or forbidden processes, where the sensitivity to NP originates from virtual contributions, which can involve any particles at higher order loops. Furthermore, a very clean theoretical prediction is mandatory.

In this letter, we report a precision test of lepton universality by measuring the ratio $\mathrm{R_K}$ of leptonic decay rates $\mathrm{K}^\pm \rightarrow \mathrm{e}^+\nu$ ($\mathrm{K_{e2}}$) and $\mathrm{K}^\pm \rightarrow \mu^+\nu$ ($\mathrm{K}_{\mu 2}$). With ~150000 collected $\mathrm{K_{e2}}$ decays, the NA62 experiment has increased the corresponding world sample by an order of magnitude, aiming at measuring $\mathrm{R_K}$ with a precision better than 0.5 %, representing a precision test of $\mu - e$ lepton universality. Here, we describe the analysis based on ~40 % of the total data sample taken in 2007 using a pure K^+ beam. 59963 $\mathrm{K}^+ \rightarrow \mathrm{e}^+\nu$ candidates have been collected with (8.78 ± 0.29)% background contamination. The result $R_K = (2.486 \pm 0.013) \times 10^{-5}$ is in agreement with the Standard model prediction.

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1. Introduction

In the SM, ratios of purely leptonic decay rates of pseudoscalar mesons ($R_l = \Gamma(l^\pm \to e^\pm \nu)/\Gamma(l^\pm \to \mu^\pm \nu), l = \pi, K, B$) are predicted with excellent sub-permille accuracy due to the cancellation of hadronic uncertainties. In particular, the ratio $\mathrm{R_K} = \Gamma(\mathrm{K_{e2}})/\Gamma(\mathrm{K_{\mu 2}})$ is given as [1]

$$R_K^{SM} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_{QED}) = (2.477 \pm 0.001) \times 10^{-5}\,. \tag{1.1}$$

$\delta R_{QED} = (3.79 \pm 0.04)\,\%$ is a correction due to the inner bremsstrahlung (IB) part of the radiative $K_{l2\gamma}$ process, which, by definition, is included in $\mathrm{R_K}$, while the structure-dependent (SD) part is not. The factor $(m_e/m_\mu)^2$ accounts for the strong helicity suppression, which enhances the sensitivity to non-SM effects. Recently, it has been pointed out that, within the two Higgs doublet models, the ratio $\mathrm{R_K}$ is sensitive to lepton flavour violating effects originating at one-loop level from charged Higgs exchange [2],[3]. This can lead to an enhancement of $\mathrm{R_K}$ up to $\sim 1\%$, which is experimentally accessible. The current world average is dominated by the recent KLOE measurement $R_K = (2.493 \pm 0.031) \times 10^{-5}$ with a 1.3 % precision [4].

2. Data taking, beam and detector

For the 2007 data taking, beam setup and detector of the NA48/2 experiment were used. After passing a set of collimators, the kaon beam with a central momentum of 74.0 GeV/c and a narrow spread of 1.4 GeV/c entered a fiducial decay volume in a 114 m long cylindrical vacuum tank, which is followed by the main detector. The subdetectors relevant for the $\mathrm{K_{e2}}$ measurement are: a) A magnetic spectrometer consisting of four drift chambers (DCHs) with a central dipole magnet and four views per chamber, used to measure the momenta of charged particles. b) A plastic scintillator hodoscope (HOD) with good time resolution to provide fast trigger signals. c) The liquid krypton electromagnetic calorimeter (LKr) used for γ detection and particle identification. It's a quasi homogeneous ionization chamber, 27 radiation lengths deep, with 7 m^3 of krypton as active medium and transversally segmented into 13248 projective cells ($2 \times 2\,\mathrm{cm}^2$ each). The NA48 detector is described in detail in [5].

3. Measurement strategy and event selection

The analysis strategy is based on counting the number of reconstructed $\mathrm{K_{e2}}$ and $\mathrm{K_{\mu 2}}$ candidates collected simultaneously. As the backgrounds and acceptances strongly depend on the momentum of the charged track, the analysis is performed in bins of this variable. In each bin, the ratio $\mathrm{R_K}$ is computed as follows:

$$\mathrm{R_K} = \frac{N(\mathrm{K_{e2}}) - N_B(\mathrm{K_{e2}})}{N(\mathrm{K_{\mu 2}}) - N_B(\mathrm{K_{\mu 2}})} \cdot \frac{A(\mathrm{K_{\mu 2}}) \times f_\mu \times \varepsilon(\mathrm{K_{\mu 2}})}{A(\mathrm{K_{e2}}) \times f_e \times \varepsilon(\mathrm{K_{e2}})} \cdot \frac{1}{f_{LKr}} \cdot \frac{1}{D}\,, \tag{3.1}$$

where $N(K_{l2})$ are the numbers of selected K_{l2} candidates ($l = e, \mu$), $N_B(K_{l2})$ are the numbers of background candidates, f_l represent the particle (e/μ) ID efficiencies, $A(K_{l2})$ are the geometrical acceptances determined with MC simulations, $\varepsilon(K_{l2})$ are the trigger efficiencies, f_{LKr} is the global readout efficiency of the LKr, and D is the downscaling factor of the $\mathrm{K_{\mu 2}}$ trigger.

Due to the topological similarity of $\mathrm{K_{e2}}$ and $\mathrm{K_{\mu 2}}$ decays, a large part of the event selection is common for both channels. Their separation is achieved in two ways: a) Kinematical $\mathrm{K_{l2}}$ identification by reconstruction of the squared missing mass assuming the track to be a positron or a muon:

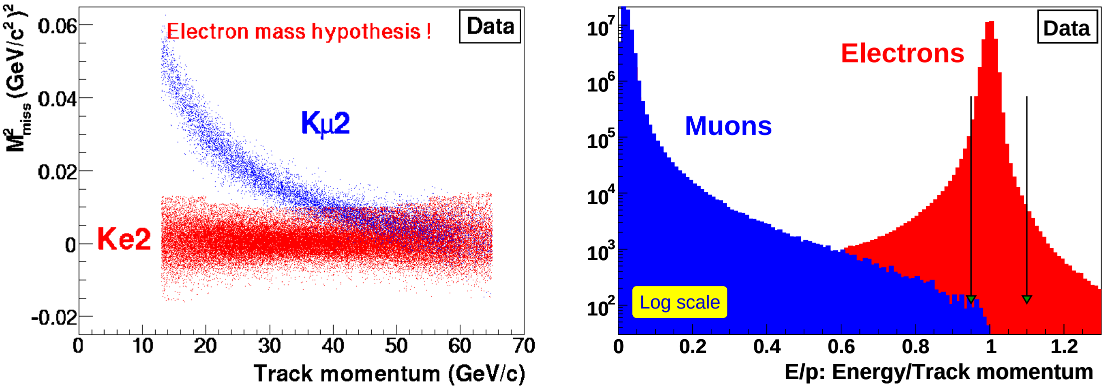


Figure 1: Variables for $K_{e2}/K_{\mu 2}$ separation. Left: Missing mass (with positron mass hypothesis) vs. track momentum for K_{e2} (red) and $K_{\mu 2}$ candidates (blue). Right: Ratio E/p for positrons and muons.

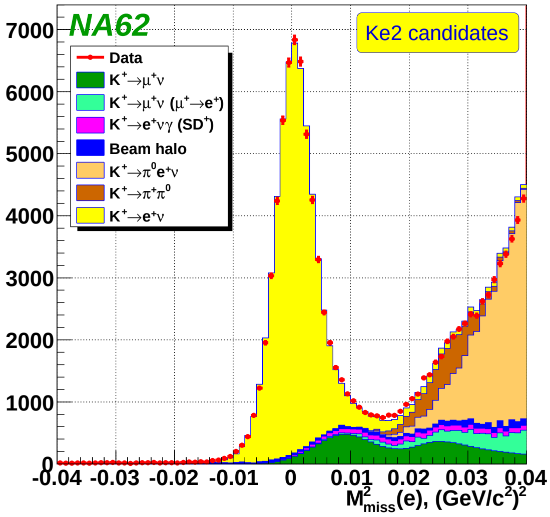
$M^2_{miss}(l) = (P_K - P_l)^2$, where $P_K, P_l \, (l = e, \mu)$ are the kaon and lepton four-momenta. However, a clear kinematical separation is possible only up to track momenta of 35 GeV/c (Fig. 1, left plot). b) Particle identification by the ratio E/p (= LKr energy deposit over track momentum), requiring $E/p < 0.85$ for muons and $0.95 < E/p < 1.10$ for positrons (Fig. 1, right plot). The particle IDs have very low inefficiencies (0.73 % for positrons, a few 10^{-5} for muons).

4. Backgrounds

$N_B(K_{e2})$ in Eq.3.1 is dominated by $K_{\mu 2}$ events with the muon depositing over 95% of its energy in the LKr by high energetic ('catastrophic') bremsstrahlung, thus faking a positron. The probability $P(\mu \to e)$ for this process (a few 10^{-6}) has been measured directly with a clean sample of muons (collected in separate periods of the 2007 data taking) passing a $\sim 9X_0$ thick lead wall before hitting the LKr. A Geant4 simulation is used to evaluate the correction to $P(\mu \to e)$ as the lead changes the process via two mechanisms: 1) muon energy loss in Pb by ionization, dominating at low momenta; 2) bremsstrahlung increasing the probability for high track momenta. The background is evaluated to be (6.10 ± 0.22)%. Other backgrounds at the percent level come from the beam halo and the structure-dependent (SD) $K_{e2\gamma}$ decay. Fig.2 shows the reconstructed squared missing mass distribution of the K_{e2} candidates compared with the sum of normalized MC signal and background components. The table on the right summarizes the identified background sources. The total background to the K_{e2} signal is (8.78 ± 0.29)%. The $K_{\mu 2}$ sample is quasi background-free. The number of K_{l2} candidates is $N(K^+ \to e^+ \nu) = 59963$ and $N(K^+ \to \mu^+ \nu) = 18.03 \times 10^6$.

5. Systematic uncertainties and result

The positron identification efficiency f_e is measured directly as a function of track momentum and its impact point at the LKr using a pure sample of positrons from K_{e3} decays. The efficiency averaged over the K_{e2} sample is (99.27 ± 0.05)%. The ratio of geometric acceptances $A(K_{\mu 2})/A(K_{e2})$ has been evaluated with a MC simulation. The assigned uncertainty is due to the limited knowledge of beam profile and divergence, and the simulation of the soft radiative photon. The trigger efficiency correction $\varepsilon(K_{e2})/\varepsilon(K_{\mu 2}) \approx 99.9$% accounts for the difference in the trigger conditions,

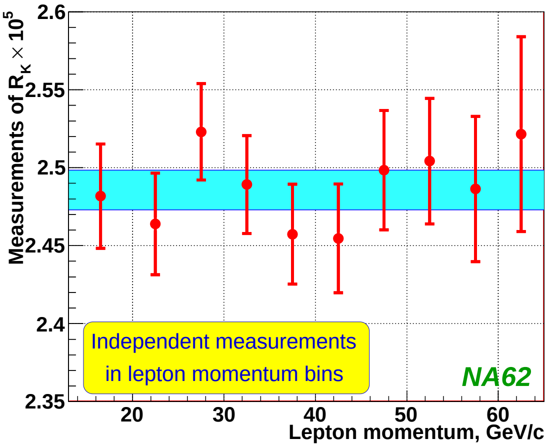


Source	B/(S+B)
$K_{\mu 2}$	$(6.10 \pm 0.22)\,\%$
$K_{\mu 2}(\mu \to e)$	$(0.27 \pm 0.04)\,\%$
$K_{e2\gamma}(SD^+)$	$(1.15 \pm 0.17)\,\%$
Beam halo	$(1.14 \pm 0.06)\,\%$
$K_{e3(D)}$	$(0.06 \pm 0.01)\,\%$
$K_{2\pi(D)}$	$(0.06 \pm 0.01)\,\%$
Total	$(8.78 \pm 0.29)\,\%$

Figure 2: Left: Reconstructed squared missing mass distribution of the K_{e2} candidates compared with the sum of normalized MC signal and background components. Right: Summary of backgrounds.

namely the requirement $E > 10$ GeV energy deposited in the LKr for K_{e2} only. The systematic uncertainties of the combined result are summarized in the table of Fig.3. The total systematic error is 0.3% relative.

The ten independent measurements of R_K in track momentum bins and the average over the bins are presented in Fig.3. The result is $R_K = (2.486 \pm 0.011_{stat} \pm 0.007_{syst}) \times 10^{-5} = (2.486 \pm 0.013) \times 10^{-5}$. This is the most precise measurement (0.5% uncertainty) to date, being consistent with the SM expectation.



Source	$\delta R_K \times 10^5$
Statistical	0.011
$K_{\mu 2}$	0.005
$K_{e2\gamma}(SD^+)$	0.004
Beam halo	0.001
Positron ID	0.001
Acceptance	0.002
DCH calibration	0.001
1TRK trigger	0.002
Total	0.013

Figure 3: Left: Measurements of R_K in momentum bins. Right: Table with summary of uncertainties.

References

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