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Test of lepton flavour universality in kaon decays at the NA62 experiment at CERN

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Summary. — A precision test of lepton flavour universality by measurement of the helicity suppressed ratio $R_K = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$ was performed by the NA62 Collaboration at CERN using a dedicated data sample collected in 2007. The result of the analysis based on 59963 $K^+ \to e^+\nu$ candidates with 8.8% background contamination is $R_K = (2.487 \pm 0.013) \times 10^{-5}$ and is consistent with the prediction of the Standard Model.

PACS 13.20.Eb – Decays of K mesons.
PACS 14.60.Cd – Electrons (including positrons).
PACS 14.60.Ef – Muons.

1. – Motivations

In the Standard Model (SM) the ratio of charged kaon leptonic decay rates $R_K = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu) = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ is predicted to excellent precision due to cancellation of hadronic uncertainties [1]:

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

where $\delta R_{\mathrm{QED}} = (-3.78 \pm 0.04)\%$ is a correction due to the inner bremsstrahlung (IB) part of the radiative decay $K^+ \to e^+\nu\gamma$(1) and the factor $(\frac{m_e^2}{m_\mu^2})$ represents the "helicity suppression" term ($\sim 10^{-5}$). The ratio R_K is sensitive to minimal supersymmetric (MSSM) and 2 Higgs doublet (2DHM) models; they predict extra contributions to the SM amplitude at the one-loop level, dominated by Lepton Flavour Violating (LFV) terms and mediated by H^+ exchange. The corresponding effect in R_K is an enhancement up to a 1% level. The current world average of $R_K = (2.493 \pm 0.031) \times 10^{-5}$ is dominated by a recent KLOE final result [2]. A new measurement of R_K based on 40% of the data sample collected by the CERN NA62 experiment in 2007 is reported here.

(*) The NA62 Collaboration.
(1) IB part is included by definition in R_K.

2. – Experimental setup and data taking

The NA62 experiment used the NA48/2 beam line (K12) and detector setup [3]. The kaon beam is produced by SPS primary protons incident on a beryllium target. Particles within a narrow momentum band of $(74 \pm 2)\,\mathrm{GeV}/c$ are selected. The fiducial decay volume is contained in a 114 m long cylindrical vacuum tank. Among the sub-detectors located downstream the decay volume, the relevant ones for the measurement are: a magnetic spectrometer, composed by four drift chambers (DCHs) and a magnet, that provides the track reconstruction; a liquid-krypton electromagnetic calorimeter (LKr) used for photon detection and particle identification; a plastic scintillator hodoscope (HOD) used for time measurement and to produce fast trigger signals. The main data sample was collected during a four months run in 2007: $\sim 4\times10^6$ SPS spills were recorded, corresponding to 300 TB of raw data. Additional data were taken in 2008 to address in detail some systematic uncertainties.

3. – Analysis strategy

The analysis strategy is based on counting the numbers of reconstructed K_{e2} and $K_{\mu 2}$ candidates collected simultaneously. Consequently, the result does not depend on kaon flux measurement and several systematic effects, such as detection efficiencies and parts of the trigger ones, cancel in the ratio. As the signal acceptance and background level are significantly dependent on lepton momentum, the R_K measurement is performed independently in 10 bins of reconstructed lepton momentum in the range from 13 to $65\,\mathrm{GeV}/c$. In each bin the ratio R_K is computed as

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

where $N(K_{l2})$ is the number of selected K_{l2} candidates $(l = e, \mu)$, $N_{\mathrm{Bkg}}(K_{l2})$ the number of background events, $A(K_{l2})$ the geometrical acceptance, f_l the particle identification efficiency, $\varepsilon(K_{l2})$ the trigger efficiency, f_{LKr} the global efficiency of the LKr readout and D is a downscaling factor used in the $K_{\mu 2}$ trigger. Acceptances are computed with a detailed Monte Carlo (MC) simulation based on Geant3. Particle identification, trigger and readout efficiencies are measured directly from data.

Due to the topological similarity of K_{e2} and $K_{\mu 2}$ events a large part of the selection criteria are common: the reconstruction of a single charged track with momentum $(13 < p < 65)\,\mathrm{GeV}/c$ and within the DCH, LKr and HOD geometrical acceptances; the reconstruction of the kaon decay vertex as the point of closest distance approach (< 1.5 cm) between the kaon axis and the upstream track extrapolation. The rejection of events with extra LKr energy deposit (< 2 GeV) not associated with the track is required to suppress the background from other kaon decays. For low track momenta K_{e2} and $K_{\mu 2}$ events are kinematically separated by reconstructing the squared missing mass (*i.e.* the neutrino mass), in the electron or muon track assumption, according to: $M^2_{\mathrm{miss}}(l) = (P_K - P_l)^2$, where P_K and P_l $(l = e, \mu)$ are the kaon and lepton four-momenta. A cut $-M_1^2 < M^2_{\mathrm{miss}}(l) < M_2^2$ is applied to select K_{l2} candidates, where M_1^2 and M_2^2 vary from 0.010 to $0.016\,(\mathrm{GeV}/c^2)^2$ for different track momenta, depending on $l = e, \mu$ and M_{miss} resolution. Lepton identification is based on the ratio E/p of the track energy deposit in the LKr to its momentum measured by the spectrometer. Tracks with $0.95 < E/p < 1.10$ ($E/p < 0.85$) are identified as electrons (muons).

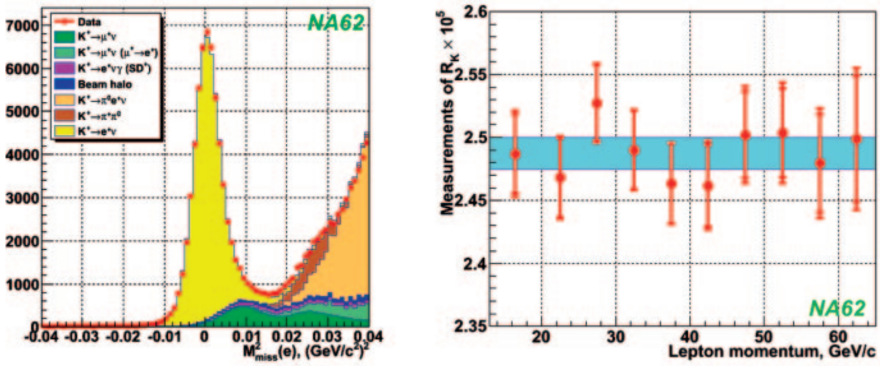

Fig. 1. – Left: $M^2_{\text{miss}}(e)$ distributions for K_{e2} and backgrounds. Right: R_K measurements in lepton momentum bins.

For lepton momenta higher than 35 GeV/c the $K_{\mu 2}$ decay with a mis-identified muon ($E/p > 0.95$) is the largest background source for K_{e2} events. The probability for a muon to be mis-identified as an electron is mainly due to a high energetic ("catastrophic") bremsstrahlung in the LKr leading to a significant energy deposit in the calorimeter. $P(\mu \to e)$ is $\sim 10^{-6}$ and was measured directly with a clean sample of muons (electron contamination $\sim 10^{-8}$) passing through a $\sim 10X_0$ thick lead (Pb) wall before hitting the LKr. A Geant4 simulation was used to correct the $P(\mu \to e)$ for the presence of Pb and the background was evaluated as $B/S = (6.11 \pm 0.22)\%$. Other sources of backgrounds and their contributions integrated over lepton momentum are: $(0.27 \pm 0.04)\%$ for $K_{\mu 2}$ (with μ decaying into e); $(1.07 \pm 0.05)\%$ for $K^+ \to e^+\nu\gamma\,(\text{SD}^+)$(2); $(1.16 \pm 0.06)\%$ for the beam halo; $(0.05 \pm 0.03)\%$ for both $K^+ \to \pi^+\pi^0$ and $K^+ \to e^+\pi^0\nu$. More details on the backgrounds above and all the systematic uncertainties involved into the R_K measurement can be found in [4]. The total background contamination is $(8.71 \pm 0.24)\%$; its uncertainty is smaller than the relative statistical uncertainty of 0.43%.

4. – Results

The $M^2_{\text{miss}}(e)$ distribution and a χ^2 fit to the measurements of R_K in the 10 lepton momentum bins are shown in fig. 1. The result based on 40% of the accumulated statistics is $R_K = (2.487 \pm 0.011_{\text{stat}} \pm 0.007_{\text{syst}}) \times 10^{-5} = (2.487 \pm 0.013) \times 10^{-5}$, consistent with the SM expectation. The analysis of the whole data set will allow to reach a relative uncertainty of 0.4%.

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(2) SD^+ refers to the structure-dependent part of the radiative decay with positive photon helicity.