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Lepton flavour violation in $K \to l\nu$ in NA62 at CERN

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Summary. — The ratio $R_K = \Gamma(K^\pm \to e^\pm\nu)/\Gamma(K^\pm \to \mu^\pm\nu)$ between the two leptonic decay rates of charged kaons is precisely predicted within the Standard Model (SM). A recent theoretical work noticed that SUSY extensions of the SM can induce mu-electron universality violation in such a way to introduce a shift of the R_K value up to few percent respect to SM one. Presently the experimental relative error of R_K, that includes also the last two recent measurements from NA48 and KLOE, is around 1.5%. During summer 2007 and summer 2008 the NA62 Collaboration performed a dedicated period of measurements at the CERN SPS in order to achieve both the statistical and systematic accuracy for a 0.5% relative error. A sample of about 140000 $K^+ \to e^+\nu$ decays has been collected. The experimental set-up and the analysis strategy will be described.

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1. – Lepton flavour violation

In the Standard Model (SM) the ratio between the two leptonic decays of charged kaons is predicted with great accuracy. Presently the best estimation of R_K gives [1]

$$R_K = \frac{\Gamma(K^\pm \to e^\pm\nu)}{\Gamma(K^\pm \to \mu^\pm\nu)} = \left(\frac{m_e^2}{m_\mu^2}\right)^2 \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \times (1+\delta R_{\mathrm{QED}}) = (2.477 \pm 0.001) \times 10^{-5}.$$

The small rate of the electronic decay respect to the muonic one is due to the helicity suppression mechanism. The $\delta R_{\mathrm{QED}} = -3.4\%$ takes into account inner bremsstrahlung processes and virtual photon processes while the structure-dependent processes are considered as background. As presented in [2] Lepton Flavour Violation (LFV) contribution can arise in Supersymmetric (SUSY) extensions of the SM. In this frame it is possible to obtain deviations up to few % respect to the SM prediction without contradicting any of the present experimental constraints. A precise measurement of R_K could, therefore, show evidence of new physics beyond the SM.

2. – Experimental status

In 2008 the Particle Data Group [3] quoted an experimental value $R_K^{2008} = (2.45 \pm 0.11) \times 10^{-5}$. The relative precision $\delta R_K/R_K = 4.5\%$ was far from any possible test with the SM prediction. This value was obtained by evaraging results from experiments performed in 1970s. In the last years two new measurements from NA48/2 [4, 5] and KLOE collaboration [6] have been available. Using these new results, the FLAVIANET working group [7] presented the result: $R_K = (2.457 \pm 0.032) \times 10^{-5}$ with the relative error $\delta R_K/R_K = 1.5\%$. The experimetal value is in agreement with the SM prediction.

3. – The NA62 experiment

The NA62 experiment at the CERN SPS intends to measure the branching ratio of the very rare decay $K^+ \to \pi^+ \nu\bar{\nu}$. Between June and October 2007 and 3 weeks in 2008 the collaboration performed a measurement campaign of 150 days, using the NA48/2 apparatus, in order to achieve a measurement of R_K with less than 0.5% accuracy. About 140000 $K^+ \to e^+\nu$ have been collected and special runs have been performed to control the possible systematic contributions at the same level of statistical error. The SPS 400 GeV/c protons impinging on a Be target produce the charged kaons beam, then the system of dipole magnets selects kaons with momentum of $75 \pm 2\,\text{GeV}/c$. Due to a greater background contribution of the beam halo present in K^- beam the collaboration has decided to run mostly with positive kaons. Concerning the detectors, they consist of:

A magnetic spectrometer composed of four drift chambers (DCHs) and a spectrometric magnet. The resolution is $\delta_p/p = 0.47\% \oplus 0.020\%p$ (GeV/c).

A plastic scintillator hodoscope (HOD) used to produce fast trigger signals. The HOD consists of a plane of vertical and a plane of horizontal strip-shaped counters, each plane consists of 64 counters arranged in four quadrants.

A liquid-krypton (LKr) electromagnetic calorimeter consists of an active volume of 7 m^3 of krypton, $27X_0$ deep, segmented transversally into 13248 cells ($2\times2\,\text{cm}^2$ each) by a system of ribbon electrodes, and with no longitudinal segmentation. The energy resolution is $\sigma_E/E = 3.2\%/\sqrt{E(\text{GeV})} \oplus 9\%E(\text{GeV}) \oplus 0.42\%$.

A beam pipe traversing the centre of the detectors allows the undecayed beam particles and the muon halo to continue their path in vacuum.

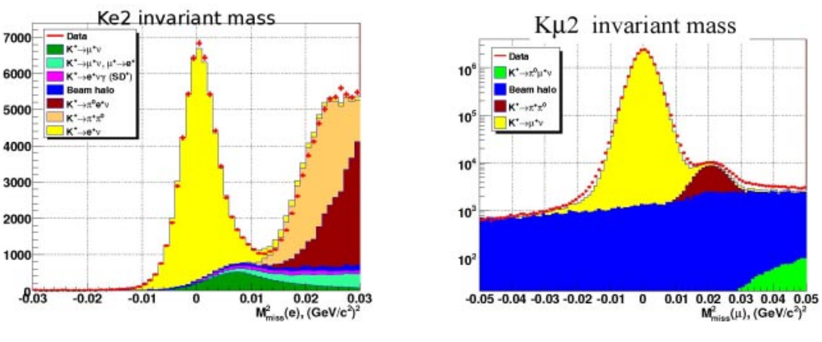

Fig. 1. – (Colour on-line) (a) Invariant mass distribution: K_{e2} data sample (dots) and signal and background channels (coloured distributions); (b) invariant mass distribution: $K_{\mu2}$ data sample (dots) and signal and background channels (coloured distributions).

TABLE I. – *Background contribution to the K_{e2} sample.*

Channel	Background contribution
$K_{\mu 2}$	$(7.38 \pm 0.20)\%$
$K_{\mu 2}(\mu \to e)$	$(1.24 \pm 0.03)\%$
$K_{e2\gamma}(SD+)$	$(7.56 \pm 0.35)\%$
Beam halo	$(1.30 \pm 0.07)\%$
K_{e3}	0.11%
$K_{2\pi}$	$(0.54 \pm 0.09)\%$
Total	12.13%

4. – The measurement strategy

The measured R_K is defined as

$$R_K = \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \frac{f_e}{f_\mu} \times \frac{A(K_{\mu 2})}{A(Ke2)} \times \frac{\epsilon(K_{\mu 2})}{\epsilon(K_{e2})} \times \frac{1}{f_{LKr}},$$

where $N(K_{l2})$ are the number of selected K_{l2} candidates $(l = e;\mu)$, $N_B(K_{l2})$ are the numbers of background events, f_l are the efficiency of e/μ identification criteria, $A(K_{l2})$ are the geometrical acceptances computed with the MC, $\epsilon(K_{l2})$ are the trigger efficiencies and f_{LKr} takes into account of readout efficiency of the electromagnetic calorimeter. Since the two leptonic decays are collected simultaneously the result is independent of the kaon flux and many of possible systematics cancel out in the ratio. R_K is evaluated as a function of the leptonic momentum, mainly to control the muon contamination in the electron sample. The selection of the two signals is based on kinematic and particle identification criteria. The two decays can be selected by requiring that the reconstructed missing mass $M^2_{\text{miss}} = (P_K - P_l)^2$, obtained from kaon and lepton 4-momenta, is compatible with zero as expected for a neutrino. Electron identification is used to select the K_{e2} candidates: $0.95 < E/p < 1.1$, where E is the energy deposited by a track in the LKr calorimeter, and p is the momentum measured by the spectrometer. Similarly, muon identification ($E/p < 0.2$) is used for the $K_{\mu 2}$ selection.

5. – Analysis status

In the left plot of fig. 1 the invariant mass of $\sim 60\,\text{k}$ K_{e2} candidates corresponding to $\sim 40\%$ of the total sample has been reported. In the plot also the MC of the signal and

TABLE II. – *Contributions to the error associated to R_K.*

Statistical	0.4%
$K_{\mu 2}$	0.25%
$K_{e2\gamma}(SD+)$	0.3%
Beam halo	0.1%
IB simulation	0.3%
Total	0.65%

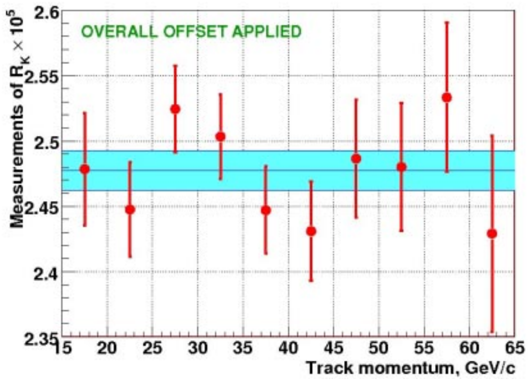

Fig. 2. – R_K as a function of track momentum.

of the various bakground has been shown. Table I shows the contribution of the main background channels to the K_{e2} sample. As can be seen, the major contribution comes from the $K_{\mu 2}$, in fact sometimes a muon can deposit all its energy in the calorimeter due to a "catastrophic bremmstrahlung" and then it can be misidentified with an electron. Special runs, with a muon beam, during the data taking have been dedicated to the measurement of the probability that a muon has an $E/p > 0.95$ and therefore misidentified as an electron. In the right plot of fig. 1 the invariant mass of $\sim 10\,\mathrm{M}$ $K_{\mu 2}$ candidates corresponding to $\sim 40\%$ of the total sample has been plotted. In the plot also the MC of the signal and of the various bakground has been reported.

In fig. 2 a preliminary result for R_K is reported as a function of leptonic momentum, to R_K an offset has been applied. As can be seen from the plot, the result is independent of the track momentum and from table II the accuracy is $\sim 0.7\%$.

6. – Conclusions

The NA62 data taking increased the World K_{e2} sample by more than an order of magnitude. The analysis of a partial data sample ($\sim 40\%$) is well advanced and gives a preliminary R_K result with ~ 0.7 of accuracy.

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