Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B (Proc. Suppl.) 187 (2009) 78–82
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
www.elsevierphysics.com

Lepton Flavor violation searches with kaons at NA62

G. Saracino on behalf of the NA62 collaboration [a]

[a]Università degli studi di Napoli Federico II, Dipartimento di Scienze Fisiche
Via Cintia 80126 Napoli Italy

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 prediction. Presently the experimental relative error of R_K, that includes also the last two recent measurements from NA48 and KLOE, is around 1.5%. A new precise measurement of R_K can be of extreme interest in order to have a more stringent test of the SM. During summer 2007 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 110000 $K^+ \to e^+\nu$ decays has been collected and special runs dedicated to the study of the main sources of systematic effects have been performed. The experimental set-up and the analysis strategy will be described.

1. Lepton Flavor Violation

In the Standard Model (SM) the R_K ratio between the two leptonic decays of charged kaons is predicted with accuracy, because of the cancelation of the common (and poorly known) hadronic contribution present in the kaons form factors. Presently the best estimation of R_K gives [1]:

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

The small rate of the electronic decay respect to the muonic one is due to the well known helicity suppression mechanism. In the R_K theoretical estimation a non negligible contribution is due to radiative $K_{l2\gamma}$ decay. The $\delta R_{QED} = -3.4\%$ takes in account inner bremsstrahlung processes and virtual photon processes while the structure dependent processes are considered as background.

Lepton Flavor Violation (LFV) possible contribution are strongly suppressed in SM and negligible. As presented in [2] LFV contribution can arise in Supersymmetric (SUSY) extensions of the SM. In this frame is possible to obtain deviations up to few % respect to 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 2006 the Particle Data Group [3] quoted an experimental value $R_K^{2006} = (2.45 \pm 0.11) \times 10^{-5}$. 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 the $NA48/2$ [4,5] and the KLOE collaborations [6] have been available. Using these new results, the FLAVIANET working group [7] presented the result: $R_K = (2.457 \pm 0.032) \times 10^{-5}$. The relative error is $\delta R_K/R_K = 1.5\%$. The experimental value is in agreement with the SM theoretical prediction. In order to obtain a more stringent test an improvement of the experimental value of R_K is needed.

3. The NA62 experiment

The NA62 experiment at the CERN laboratory in Geneve intends to measure the branching ratio of the very rare decay $K^+ \to \pi^+\nu\overline{\nu}$. The

doi:10.1016/j.nuclphysbps.2009.01.012

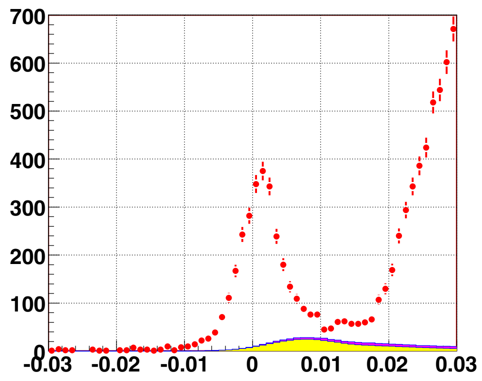

Figure 1. Missing mass squared in electron hypothesis for events passing other K_{e2} analysis cuts. Peack is shifted with respect to zero due to lack of spectrometer absolute calibration. The shaded area represents the muon background.

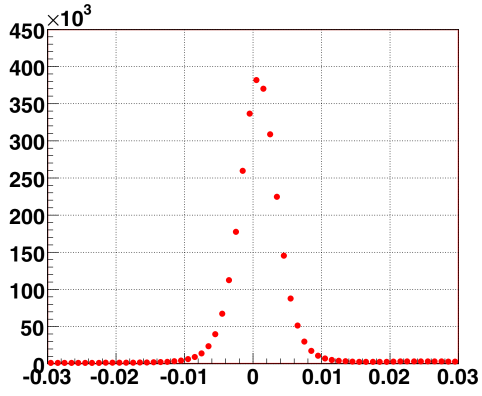

Figure 2. Missing mass squared in muon hypothesis for events passing other $K_{\mu 2}$ analysis cuts. Peack is shifted with respect to zero due to lack of spectrometer absolute calibration.

start is foreseen in the 2011, two years of data taking are needed in order to achieve a statistical sample of about 100 decays with background contamination less than 10%. Between June and October 2007 the collaboration performed a measurement campain of 120 days, using the $NA48/2$ apparatus, in order to achieve a measurement of R_K with less than 0.5% of relative error. More than 100 thousand $K^+ \rightarrow e^+\nu_e$ have been collected and special runs have been performed to control the possible systematic contributions at the same level of statistical error. The kaon beam line can provide high intensity charged kaons of both polarity. Kaons are produced by 400 GeV/c momentum protons impinging on a Be target. A system of dipole magnets selects a non separeted kaons with momentum of 75 ± 2 GeV/c. Pions contribution in the beam is about 9 times greater than kaons. Even though both the charges can be delivered at the same time, K^+ represent most of the collected sample, due to a greater background contribution of the halo present in K^- beam and the consequent decision to run mostly with positive kaons. The kaon momentum is not measured directly event by event, but the average value is obtained by $K^+ \rightarrow \pi^+\pi^+\pi^-$ decays. The measured momentum spread is $\Delta P_K^{RMS}/P_K = 2\%$.

Concerning the detectors, they consist of:

A magnetic spectrometer composed of four drift chambers (DCHs) and a spectrometric magnet (MNP33). Each chamber is composed of eight planes of sense wires arranged in four pairs of staggered planes (so called views") oriented horizontally, vertically, and along each of the two orthogonal ±45° directions. The spectrometer resolution is $\delta_p/p = 0.47\% \bigoplus 0.020\% p$ (where p is expressed in 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 comprising 64 counters arranged in four quadrants.

A liquid krypton (LKr) electromagnetic calorimeter, which is an almost homogeneous ionization chamber with an active volume of $7m^3$ of krypton, $27X_0$ deep, segmented transversally into 13,248 projective cells (2x2 cm^2 each) by a system of ribbon electrodes, and with no longitudinal segmentation. The Calorimeter energy

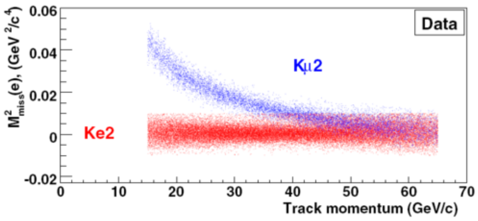

Figure 3. Missing mass squared assuming electron mass $M^2_{miss}(e)$ for the charged track vs momentum for K_{e2} and $K_{\mu2}$ decays.

resolution is $\sigma_E/E = 3.2\%/\sqrt{E} \bigoplus 9\%E + 0.42\%$ where E is expressed in GeV.

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

4. The measurement strategy

The measured R_K is defined as:

$$R_K = \frac{1}{D}\frac{N(K_{e2})-N_B(K_{e2})}{N(K_{\mu2})-N_B(K_{\mu2})}\frac{f_\mu}{f_e} \times \frac{A(\mu2)}{A(K_{e2})} \times \frac{\epsilon(K_{\mu2})}{\epsilon(K_{e2})}$$

where $N(K_{l2})$ are the numbers of selected K_{l2} candidates ($l = e; \mu$), $N_B(K_{l2})$ are the numbers of background events, f_l are efficiencies of e/μ identification criteria, $A(K_{l2})$ are the geometrical acceptances computed with MC, $\epsilon(K_{e2})$ are trigger efficiencies, and D is the downscaling factor of the $K_{\mu2}$ trigger.

All the above quantities, but the geometrical acceptances, can be evaluated from data. Since the two leptonic decays are collected simultaneously (only a trigger downscaling D = 50 is applied for the most copious $K_{\mu2}$) the result is independent from the beam flux and many of possible systematics, as trigger and detector efficiencies, cancel out in the ratio. R_K is evaluated as function of the leptonic momentum, mainly to control the muon contamination in the electron sample.

The selection of the two signal is based on kinematic and particle identification criteria. The two leptonic decays can be selected by requiring that the reconstructed missing mass $M^2_{miss} = (P_K - P_l)^2$, obtained from kaon and lepton 4-momenta, is compatible with zero within its uncertainty, as expected for a neutrino (see fig 1 and 2). Electron identification is used to select the K_{e2} candidates: $0.95 < E/p < 1.05$, where E is the energy deposited by the track in the LKr calorimeter, and p is its momentum measured by the spectrometer. Similarly, muon identification $E/p < 0.2$) is used for the $K_{\mu2}$ selection.

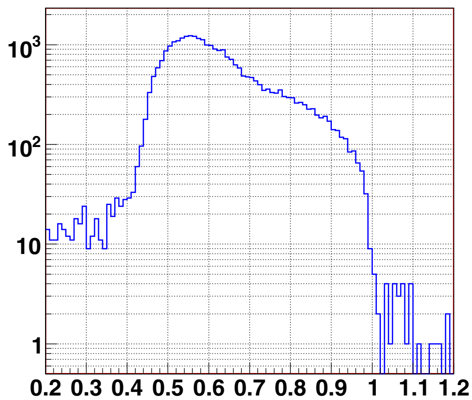

Figure 4. E/P spectrum of muons with $20GeV/c < P < 25GeV/c$). Electron identification range is between 0.95 and 1.05

The probability for a muon to fake an electron in terms of identication is a major issue for the analysis.

5. Trigger

Low bias trigger conditions have been choosen. During the first period of data taking the K_{e2} trigger was based on the coincidence of hits between the two hodoscope planes (Q1) and the release of at least 10 GeV of energy in the calorimeter E_{LKr}, the $K_{\mu2}$ trigger was based on $Q1$ condition alone, applying a downscale factor $D = 50$. In order to define a better decay fiducial volume, a

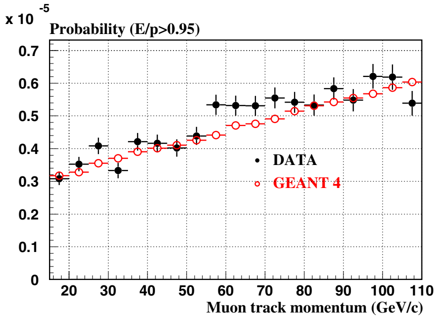

Figure 5. The measured $P(\mu \to e)$ vs track momentum.

condition on the presence of (at least) one track in the drift chamber (TRK) has been added to both the trigger conditions. In addition to these, two other (downscaled) trigger condition were used to get control sample to monitor the trigger efficiencies. The inefficiency of the Q1 trigger, expected to be at the level of 0.2% cancels out in the R_K ratio. The ineffciency of the calorimeter condition for electrons, which directly enters the result, is controlled with the $Q1/D$ sample and results to be less than 0.1% using a cut of $p > 15GeV/c$) fot the track momentun. During the last period of run the the number of K_{e2} candidates per spill reached 0.54 and the full trigger band-width of $\sim 55K$ events per 14.4 s SPS cycle was reached.

6. Systematic uncertainties

Contaminations in the K_{e2} sample: the main source of this background is due to $K_{\mu 2}$ decays when a muon is misidentified as electron. The electron-muon separation is based on kinematic and particle ID. The M^2_{miss} variable, evaluated in the electron mass hypotesis, can be applied for tracks with momentum smaller than $35GeV/c$, while for higher momenta the E/p must be applied (see fig. 3). Nevertheless a muon can release almost all the energy in the LKr (catastrofic bremsstrahlung) and therefore can be misidentified as electron ((see fig. 4). The probability $P(\mu \to e) \sim 10^{-6}$ for this misidentification was measured as function of the muon momentum, directly from data using special samples of pure muons (see fig. 5). During the first half period of data tacking, a 4.5 cm thick lead wall was inserted between the two hodoscope planes, about 1 m far from the calorimeter. The geometrical acceptance being reduced of $\sim$ 18%. The requirement that the signal in the second plane of hodoscope is compatible with a minimum ionizing particle allows to select a pure sample of muons. Energy loss in the wall is taken into account to reconstruct the effective momentum of the muon.

Other pure $K_{\mu 2}$ sample available are : 1) During the whole data taking special runs have been acquired while the hadron beam was absorbed by the beam dump ; 2) muons from $K_{\mu 2}$ decay during the standard data taking.

The background induced by the muon halo of the beam was measured to be $(1.3 \pm 0.1)\%$ using the run period with the K^+ beam dumped. The contamination can be further decreased be applying a stricter cut on the closest distance of approach between the charged track and the mean beam trajectory.

Other identified sources of background in the Ke2 sample that, however, can be reliably subtracted using MC simulation are the following:

(1) the structure dependent radiative $K_{e2\gamma}$(SD) contamination estimated by MC is $(0.7\pm0.1)\%$ for data collected without the lead wall, and $(2.8 \pm 0.4)\%$ for data collected with the lead wall.

(2)$K^+ \to \pi^0 e^+ \nu$ contamination estimated by MC is well below 1%, and only at high track momentum. The $K^+ \to \pi^+\pi^0$decay is a potential source of background, however no evidence for it was found in the 2004 test run data at 1% precision level. A possible subtraction procedure is based on kinematic rejection, and measurement of pion misidentication probability.

Backgrounds in the $K_{\mu 2}$ sample: the following sources were identified: 1) background from the muon halo, about 0.1% contamination, to be subtracted as for the K_{e2} decays; 2) $K^+ \to \pi^+\pi^0$ contamination below 0.5%, to be subtracted by MC using the measured probability of pion misidentification.

Electron identifcation efficiency: f_e and its dependence on track momentum and impact point position, can be measured with a clean sample of electrons by kinematic selection of the decays $K^{\pm} \to \pi^0 e^{\pm} \nu$ collected simultaneously with the main data sample. However the accessible kinematic region is limited to $p < 50 GeV/c$. To cover the whole analysis momentum range, a special 15h run with a broad band K_L beam was carried out. A preliminary analysis of the $K_L \to \pi^{\pm} e^{\mp} \nu$ decays from this run demonstrated that it is higher than 99% in most of the analysis momentum region (actually increasing with p). The precision of f_e measurement is expected to be better than 0.1%.

Muon identification efficiency: f_μ is momentum dependent, and lies in the range from 0.996 to 0.999 in the analysis track momentum region. It can be measured with a precision much better than 0.1% with a pure muon sample.

Geometric acceptance correction: $A(K_{\mu 2})/A(K_{e2})$ is momentum dependent, and ranges between 1.2 and 1.3 in the analysis momentum interval.

Trigger effciency correction: $\epsilon(K_{\mu 2})/\epsilon(K_{e2})$ is measured directly from data, and the expected size of the correction is as small as $\sim 0.1\%$, thanks to the low bias trigger strategy. Other known sources of systematic uncertainties include: 1) trigger afterpulses biasing the Q1 down- scaling factor D; 2) global LKr calorimeter readout inefficiency. Their contribution is of 0.1% order and can be corrected for using data

7. Conclusions

In 2007 the NA62 collaboration performed 120 days of data taking at the NA48/2 kaon beam line at CERN. About 112k K_{e2} decays were collected. The statistical precision for R_K achievable with this sample is 0.3%. The main sources of systematic errors are under control. In particular the misidentification probability $P(\mu \to e)$ for a muon to be identified as an electro can be meaured directly from data using special sample of pure muons acquired during the data taking period. Preliminary studies demonstrate that a total precision of 0.5% is within the reach.

REFERENCES

1. V. Cirigliano and I. Rosell, Two-Loop Effective Theory Analysis of $\pi(K) \to e\overline{\nu}_e[\gamma]$ Branching Ratios, Phys. Rev. Lett. 99, 231801 (2007).
2. A. Masiero, P. Paradisi and R. Petronzio, Probing new physics through $\mu - e$ universality in $K \to l\nu$ Phys. Rev. D74 (2006) 011701.
3. W.-M. Yao et al. (Particle Data Group), J. Phys. G33 (2006) 1.
4. L. Fiorini, PoS (HEP2005) 288 (2005).
5. V. Kozhuharov, PoS (KAON) 049 (2007).
6. F. Ambrosino et al., arXiv:0707.4623.
7. Flavianet Kaon Working Group, http://ific.uv.es/flavianet/.