NA48 Results

G. Ruggiero
Scuola Normale Superiore, Pisa, Italy

Measured decay rates of $K^\pm \to e^\pm\pi^0\nu_e$ and $K^\pm \to \mu^\pm\pi^0\nu_\mu$ normalized to $K^\pm \to \pi^\pm\pi^0$ are presented. These measurements are based on $K^\pm$ decays collected in a dedicated run in 2003 by the NA48/2 experiment at CERN. Using the PDG 2006 average for the $K^\pm \to \pi^\pm\pi^0$ normalization mode, the results are found to be larger than the current values given by the PDG 2006 and lead to a larger magnitude of the $|V_{us}|$ CKM element than previously accepted. When combined with the latest PDG 2006 value of $|V_{ud}|$, the result is in agreement with unitarity of the CKM matrix.
The ratio $R_K = \Gamma(K^\pm \to e^\pm\nu)/\Gamma(K^\pm \to \mu^\pm\nu)$ is calculated with very high precision within the Standard Model (SM), but corrections due to the presence of New Physics could be as high as 3%. The data obtained by the NA48/2 experiment in two years of data taking at the CERN SPS accelerator has been analyzed. The obtained result for R_K is two times more precise than the world average but is still insufficient to probe the existence of physics beyond the Standard Model. The status of the analysis of the data taken in 2007, aimed for a sub-percent precision of R_K, will be summarized.

1 Introduction

The NA48 experiment at CERN SPS is a fixed target experiment devoted to kaon physics operating since 1997. Until 2001 the experiment studied the neutral kaon decays and provided the final measurement of ϵ'/ϵ [1]. A charged kaon physics program (NA48/2) took place in 2003 and 2004: it was mainly devoted to the search for direct CP violation in the $K^\pm$ decays into three pions [2]. Beside this main topic, also semileptonic and rare charged kaon decays were studied. To this end dedicated runs with reduced intensity were taken in 2003 and 2004. The present work describes the final result of the measurement of the branching ratio of $K^\pm \to l^\pm\pi^0\nu_l$ ($l = e,\ \mu$) [3] using the 2003 data and the preliminary results of the measurement of the ratio $R_K = \Gamma(K^\pm \to e^\pm\nu_e)/\Gamma(K^\pm \to \mu^\pm\nu_\mu)$ based on the 2003 and 2004 data. The NA62 collaboration is currently carrying on the kaon physics program at CERN SPS. The first phase of this experiment aims for a sub-percent precision measurement of R_K, for which data were taken in 2007 with the NA48/2 apparatus.

2 NA48/2 Experimental Setup

The experiment used simultaneous $K^{\pm}$ beams produced by 400 GeV/c protons delivered by the SPS and impinging on a Be target with a duty cycle of 4.8 s spill over a 16.8 s accelerator period. The proton intensity on target was about 7×10^{11} proton per spill during the 2003 and 2004 normal runs. It was reduced during the special runs to allow data taking with a minimum bias trigger, while it was increased up to more than 10^{12} protons per spill during the 2007 run. A 100 m long beam line selected charged beams with 60 ± 3 GeV/c average momentum in 2003 and 2004 and 75 ± 2 GeV/c in 2007. The detector sit about 100 meter downstream to the end of the beam line and detected the products of the kaon decays happening in the evacuated region between the end of the beam line and the beginning of the detector. A detailed description of the NA48 apparatus can be found elsewhere [4]. The most relevant devices for the measurements described here were: the magnetic spectrometer, consisting of 4 drift chambers and one magnet and the high resolution liquid kripton electromagnetic calorimeter. The spectrometer worked with a reduced magnetic field in 2003 and 2004 and with full magnetic field in 2007 allowing a better momentum resolution. Other devices were the hodoscope for charged particle triggering and precise time measurement and a muon detector.

3 Measurement of the K_{l3} Branching Ratio

3.1 Theoretical aspects

The following master formula describes the branching ratio of the semileptonic charged kaon decays [5]:

$$BR(K_{l3}) = \tau_K \frac{G_F^2}{384\pi^3} m_K^5 S_{EW} |V_{us}|^2 |f_+(0)|^2 I_K^l (1 + \delta_{SU2}^K + \delta_{em}^{Kl})^2. \quad (1)$$

Here K_{l3} is a short-hand notation for $K^{\pm} \to l^{\pm}\pi^0\nu_l$ with l equal to e or μ. τ_K is the average life time of $K^{\pm}$, G_F the Fermi constant and m_K the mass of the charged kaon. S_{EW} is the short distance radiative correction, δ_{SU2}^K and δ_{em}^{Kl} are the model dependent long distance corrections due to isospin breaking in strong and electromagnetic interactions. Two form factors, $f_+(t)$ and $f_0(t)$, describe the dynamic of the semileptonic decays. Their t dependence can be approximated as:

$$f_+(t) = f_+(0)\left(1 + \lambda'_+ \frac{t}{m_{\pi^+}^2} + \lambda''_+ \frac{t^2}{m_{\pi^+}^4}\right), \quad f_0(t) = f_+(0)\left(1 + \lambda_0 \frac{t}{m_{\pi^0}^2}\right). \quad (2)$$

$f_+(0)$ is the form factor at zero momentum transfer. The parameters λ'_+, λ''_+ and λ_0 are measured [6]. I_K^l is the result over the phase space integration after factorizing out the $f_+(0)$ and depends on λ'_+, λ''_+ and λ_0, using the above approximation [5]. Finally V_{us} is the element of the CKM matrix which describes the u-s transitions.

It turns out that the measurement of the branching ratio of the charged K_{l3} decays allows a clean test of the u-s quark transitions. Moreover the ratio between the branching ratios of the K_{e3} and $K_{\mu 3}$ provides also an experimental test of the μ−e universality.

3.2 Data taking and Analysis Strategy

Because of the impossibility to measure precisely the absolute kaon flux, NA48 measured the semileptonic branching ratios normalized to $K^{\pm} \to \pi^{\pm}\pi^0$, that is the ratios $\mathcal{R}_{Kl3/K2\pi} \equiv$

$\Gamma(K_{l3})/\Gamma(K^{\pm} \to \pi^{\pm}\pi^{0})$. It is relevant that the single track topology for both the signal and the normalization channel allows a first order cancellation of the systematics.

Hits in the hodoscope compatible with a one track decay were the only input of the trigger. The trigger efficiency was measured on data to be greater than 99.8%. An offline one track selection using the spectrometer informations and a π^0 identification based on the calorimeter data, defined a sample of K_{e3}, $K_{\mu 3}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}$ decays. Extra activity in the calorimeter was allowed to select inclusively also the corresponding radiative decays. Kinematical cuts exploiting the missing energy and the decay topology separated the semileptonic from the two pions decays. The particle identification was used to distinguish the electron from the muon channel. In particular the requirement $E_{LKr}/P > 0.95$ identified an electron, where E_{LKr} is the energy released by the particle in the calorimeter and P is the particle momentum measured by the spectrometer; the cut $E_{LKr}/P < 0.8$ defined a pion. Finally, the presence of a hit in the muon detector, matching in space and time with the track, tagged a muon. The total number of selected events per decay mode was: 87×10^3 K_{e3}, 77×10^3 $K_{\mu 3}$ and 729×10^3 $K^{\pm} \to \pi^{\pm}\pi^{0}$.

The acceptance was computed using a GEANT [7] based Monte Carlo simulation. The event generation made use of the previously described parametrization for the form factors, with λ'_{+}, λ''_{+} and λ_0 taken from reference [6]. The phase space was corrected according to the Ginsberg prescription [8] to account for radiative corrections. The PHOTOS package [9] provided the generation of real bremsstrahlung photons. The acceptance varied between 7% and 14% depending on the decay mode. Different expressions of the form factors were also considered [10] and the corresponding variation of the final result quoted as systematic uncertainty. The particle identification was a source of inefficiency not canceled in the single ratio. It was measured on data and varied between 98.5% and 99.5%, depending on the particle type. The corresponding error was quoted as sytematic uncertainty. The Monte Carlo simulation pointed out a background contamination below 0.1% for K_{e2} and at the level of 0.2% and 0.3% for $K_{\mu 2}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}$, respectively.

3.3 Results

The results are:

$$\begin{aligned} \mathcal{R}_{Ke3/K2\pi} &= 0.2470 \pm 0.0009_{stat} \pm 0.0004_{syst} \\ \mathcal{R}_{K\mu 3/K2\pi} &= 0.1636 \pm 0.0006_{stat} \pm 0.0003_{syst} \\ \mathcal{R}_{K\mu 3/Ke3} &= 0.663 \pm 0.003_{stat} \pm 0.001_{syst} \end{aligned} \tag{3}$$

Analysis of these results as a function of their basic distributions shown stability.

Taking the branching ratio of $K^{\pm} \to \pi^{\pm}\pi^{0}$ from [6] the branching ratio for the semileptonic decays are:

$$\begin{aligned} BR(K_{e3}) &= 0.05168 \pm 0.00019_{stat} \pm 0.00008_{syst} \pm 0.00030_{norm} \\ BR(K_{\mu 3}) &= 0.03425 \pm 0.00013_{stat} \pm 0.00006_{syst} \pm 0.00020_{norm} \end{aligned} \tag{4}$$

The uncertainty is dominated by the error on the measurement of the branching ratio of the $K^{\pm} \to \pi^{\pm}\pi^{0}$. Both the values are significantly above the PDG 2006 values. The $BR(K_{e3})$ agrees with the BNL E865 [11] and the ISTRA+ '07 [12] measurements. Both the NA48 measurements, however, do not agree with the values measured by KLOE [13] which are in agreement with [6]. The recent KLOE measurement of the $BR(K^{\pm} \to \pi^{\pm}\pi^{0})$ [14], significantly lower than the PDG 2006 one, partially recover the difference between NA48 and KLOE.

The measurements 4 allow the extraction of V_{us}. To this end the following values were used: $S_{ew} = 1.023$ [15], $I_K^e = 0.1591$ and $I_K^{\mu} = 0.1066$ (λ'_{+}, λ''_{+} and λ_0 from [6]), $\delta^K_{SU2} = 2.31\%$, $\delta^{Ke}_{em} = 0.03\%$ and $\delta^{K\mu}_{em} = 0.2\%$ from [16,8,17], $G_F = 1.16637 \times 10^{-5}$ GeV^{-2} [18] and m_K and τ_K from [6]. The result is

$$|V_{us}| f_{+}(0) = 0.2188 \pm 0.0012 \tag{5}$$

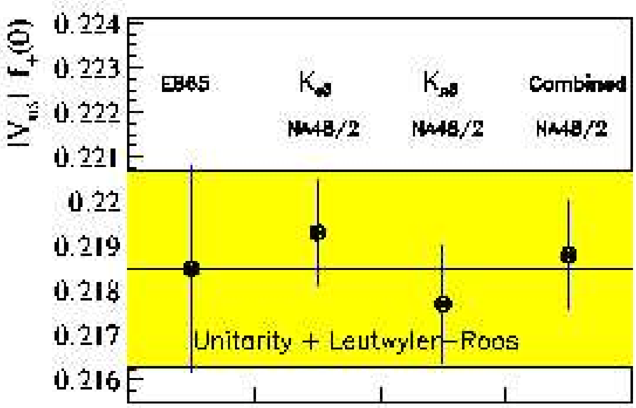


Figure 1: Comparison of the NA48 measurement of $|V_{us}|f_+(0)$ from K_{e3}, $K_{\mu3}$ and combined and the theoretical prediction computed as described in the text.

combined for K_{e3} and $K_{\mu3}$. The values obtained for the two decay modes separately are in agreement among themselves. The result is in agreement with the expected value computed using $V_{ud} = 0.9738 \pm 0.0003$ [19], $|V_{ub}| = (3.6 \pm 0.7) \times 10^{-3}$ [6], $f_+(0) = 0.961 \pm 0.008$ [5] and assuming unitarity, as shown in figure 1. The results are compatible with the unitarity of the CKM matrix. Finally the measured value of $\mathcal{R}_{K\mu3/Ke3}$ implies the μ-e universality violating quantity $g_\mu f_+^\mu(0)/g_e f_+^e(0) = 0.99 \pm 0.01$, consistent with one within the experimental errors.

4 Measurement of R_K

4.1 Theoretical aspects and experimental status

The measurement of $R_K \equiv R(K_{e2})/R(K_{\mu2})$ provides an accurate test of the lepton universality predicted in the SM. Here K_{l2} is a short-hand notation for $K^\pm \to l^\pm \nu_l$. Thanks to the cancellation in the ratio of the hadronic uncertainties, the SM predicts R_K with a sub-permille accuracy [20]:

$$R_K = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \times 10^{-5}. \quad (6)$$

Here $m_{K,e,\mu}$ are the masses of the kaon, electron and muon and δR_{QED} is the correction for virtual photon processes and inner bremsstrahlung photon emission.

The helicity suppression makes R_K sensitive to new physics. A theoretical study [21] suggests the possibility of up to some percent deviation from the SM value induced by lepton flavor violating effects, as those arising in supersymmetry extensions of SM. As a consequence a sub-percent precision measurement of R_K could probe physics beyond SM.

The PDG 2006 value, $R_K = (2.45 \pm 0.11) \times 10^{-5}$, is far from the accuracy needed. NA48 provided preliminary measurements at 2% precision using 2003 and 2004 data. More recently KLOE [22] measured this quantity with 2% level accuracy. NA62 took data for 4 months in 2007 and collected more than 10^5 K_{e2} aiming for a 0.5% precision.

4.2 Analysis Strategy

The signal signature is one track in the final state compatible with a two body kinematics. Both kinematics and particle identification discriminate between the electron and the muon channel. The requirement $E_{LKr}/P > 0.95$ identifies an electron, like in the K_{l3} analysis previously described. Once data are collected using similar triggers for the two channels, systematics cancels at zero order in the ratio. Background and particle identification efficiency, however, may affect numerator and denominator differently. Still a percent or even below measurement of R_K requires also a precise evaluation of the acceptance correction which can be as large as 10%. Since the main corrections depend on track momentum, the measurement takes advantage from an analysis in momentum bins. The background in the $K_{\mu 2}$ sample is below the percent level. On the contrary $K_{\mu 2}$ event can mimic K_{e2} in case of muons mis-identified as electrons and induce up to 10% background in the K_{e2} sample. This is a consequence of the about 10^{-6} probability of muon catastrophic energy loss in the liquid kripton calorimeter, which needs to be evaluated with percent accuracy. Muon contamination, however, depends on the kinematical discrimination power and affects K_{e2} with momentum higher than 35÷40 GeV/c, where the kinematics of the two decay modes looks similar. A more than 1% level of background from $K_{e2\gamma}$ structure dependent decays is also expected and requires a knowledge of its branching ratio with 10% accuracy. Finally an electron identification efficiency at the level of 98÷99%, requires also to be evaluated with a 10% precision. Suitable control data can accomplish for that.

4.3 Preliminary results from 2003-2004 run

The number of K_{e2} collected by NA48 in 2003 and 2004 after background subtraction was $(4670 \pm 77_{stat}{}^{+29}_{-8}(syst))$ and $(3407 \pm 63_{stat} \pm 54_{syst})$, respectively. The systematic uncertainty refers to the background subtraction procedure. In particular the muon background in the K_{e2} sample was estimated at the level of 14%, using a pure K_{e2} sample at low momentum. The results are [23,24]

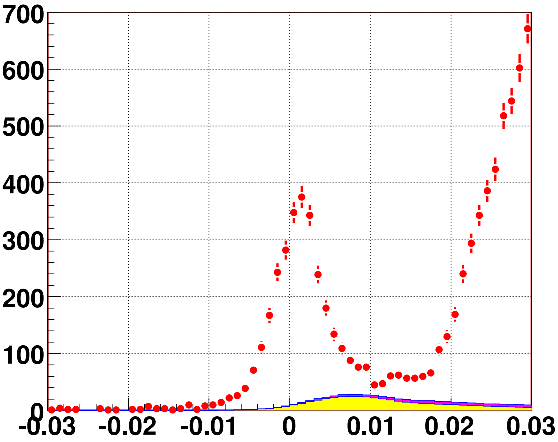
$$\begin{aligned} R_K &= (2.416 \pm 0.043 \pm 0.024) \times 10^{-5} \quad (2003) \\ R_K &= (2.455 \pm 0.045 \pm 0.041) \times 10^{-5} \quad (2004) \end{aligned} \tag{7}$$

The 2003 data suffered from kinematical requests at trigger level which induced a large trigger efficiency correction. The choice of a minimum bias trigger for $K_{\mu 2}$ and and the minimum bias plus a further requirement on the total energy in the electromagnetic calorimeter for K_{e2}, avoided that problem in 2004. The systematics of both the measurements are largely dominated by the uncertainty in the background subtraction. The other systematics are below 0.2%.

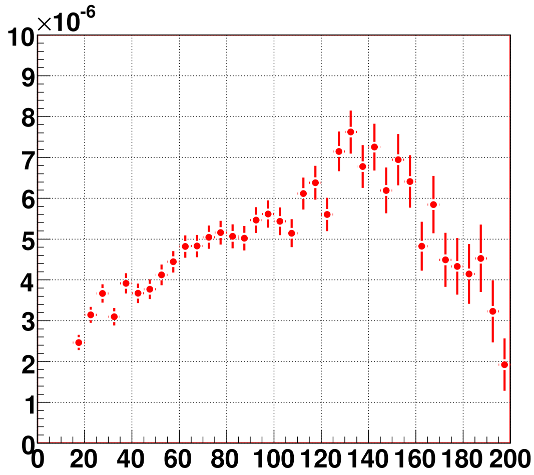
4.4 NA62 run: data collected and status of the analysis

NA62 took data in 2007. In comparison to the 2003-2004 run, the increase of the average beam momentum from 60 to 75 GeV/c and the shrink of the momentum bite from 3 to 2 GeV/c allowed a better background rejection. For the same purpose the spectrometer worked with a stronger magnetic field. The trigger was the same as in 2004. During the run an important accidental background appeared in the K^- data. For that reason only K^+ were taken for most of the period. The statistics collected matched the goal of the run: the total number of K_{e2} selected on-line was, in fact, $1,1 \times 10^5$. Figure 2 a) shows the squared invariant missing mass distribution, m^2_{miss}, for selected K_{e2}-like events, where m^2_{miss} is defined as the square of the difference between the kaon and the measured track four momenta. The number of good K_{e2} refers to the events under the peak.

Part of the data were taken with a lead bar 18.0 cm wide and 9 X_0 thick in front of the liquid kripton calorimeter to measure the probability of muon catastrophic energy loss. The presence of the bar induced about 18% loss in K_{e2} acceptance. The lead acted as a muon filter selecting a pure sample of muons without electron contamination. More precisely this bar was placed just in front of six scintillator counters of the hodoscope used to disentangle muons not interacting in lead. The normal data taking provided more than 2000 μ with momentum greater than 35 GeV/c faking an electron. Other 2000 μ of that type came from special muon runs. The preliminary result of the muon catastrophic energy loss probability as a function of momentum measured using un-calibrated data from the special runs only is shown figure 2



(a)



(b)

Figure 2: (a) m^2_{miss} in GeV^4/c^2 for K_{e2} events collected during the 2007 run. The prediction for the $K_{\mu 2}$ and the $K_{e2\gamma}$ structure depedent contamination are also shown. (b) Probability that a muon releases in the lquid kripton calorimeter more than 95% of its energy as a function of muon momentum in GeV/c.

(b). It corresponds to a $K_{\mu 2}$ contamination in the K_{e2} sample of $7.5 \pm 0.1\%$. The background level, therefore, can be controlled with the requested accuracy. Special runs with the kaon beam dumped and with K^- only were also taken to study the residual accidental background in K^+ data. Finally a measurement of the electron identification efficiency on the overall K_{e2} momentum spectrum required also special runs with K_L beam, which allow the selection of a pure sample of electron through $K_L \to e^+\pi^-\nu$ decays.

The analysis of the 2007 data is already started and preliminary results are expected soon.

References

1. A. Lai *et al*, *Eur Phys. J.* C **22**, 231 (2001),
   J.R. Batley *et al*, *Phys. Lett.* B **544**, 97 (2002).
2. J.R. Batley *et al*, *Eur. Phys. J.* C **52**, 875 (2007).
3. J.R. Batley *et al*, *Eur. Phys. J.* C **50**, 329 (2007) [Erratum-ibid. C **52**, 1021 (2007)].
4. V. Fanti *et al*, *Nucl. Instrum. Methods* A **574**, 433 (2007).
5. H. Leutwyler and M. Roos, *Z. Phys.* C **25**, 91 (1984).
6. W-M. Yao *et al* [Particle Data Group], *J. Phys. G* **33** 2006.
7. GEANT Detector Description and Simulation Tool, CERN Program Library Long Write-up W5013 1994.
8. E.S. Ginsberg, *Phys. Rev.* D **1**, 229 (1970).
9. E. Barberio and Z. Was, *Comput. Phys. Com.* **79** 1994,
   P. Golonka and Z.Was, *Eur. Phys. J.* C **45**, 97 (2006)
10. C. Gatti, *Eur. Phys. J.* C **45**, 417 (2006)
11. A. Sher *et al*, *Phys. Rev. Lett.* **91**, 261802 (2)003.
12. V.I. Romanovsky *et al*, arXiv:0704.2052.
13. F. Ambrosino *et al*, arXiv:0707.2532.
14. F. Ambrosino *et al*, arXiv:0804.4577.
15. A. Sirlin, *Nucl. Phys.* B **196**, 83 (1982)

16. V. Cirigliano *et al*, *Eur. Phys. J.* C **35**, 53 (2004),
V. Cirigliano *et al*, *Eur. Phys. J.* C **23**, 121 (2002).
17. E. Blucher *et al*, Proceedings of the CKM 2005 Workshop (WG1), UC San Diego, 15-18 March 2005.
18. A. Czarnecki, W.J. Marciano and A. Sirlin, *Phys. Rev.* D **70**, 093006 (2004).
19. W.J. Marciano, and A. Sirlin, *Phys. Rev. Lett.* **96**, 032002 (2006).
20. V. Cirigliano and I. Rosell, J. High Energy Phys. **10**, 005 (2007).
21. A. Masiero, P. Paradisi and R. Petronzio, *Phys. Rev.* D **74**, 011701 (2006).
22. F. Ambrosino *et al.*, arXiv:0707.4623.
23. L. Fiorini, PoS (HEP2005) 288 2005.
24. V. Kozhuharov, PoS (KAON) 049 2007.