Lepton universality in $K \to l\nu$ decays

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Abstract. A measurement of the ratio $R_K = \Gamma(K^\pm \to e^\pm\nu)/\Gamma(K^\pm \to \mu^\pm\nu)$ to check lepton universality has been performed by NA48 at CERN in 2003 and 2004, with an uncertainty of about 2%. Following recent theoretical studies, whereby the ratio could differ from the SM value in super-symmetric models by few percent, a dedicated run has been approved and performed at CERN in summer 2007 to reach an error of a measurement of $\approx 0.3\%$ with the collection of ≈ 120000 events.

1. Introduction

One of the cornerstones of the description of weak interaction is lepton universality, i.e. the assumption that the three families of lepton have the same properties, apart from the mass difference. The measurements of the ratios $R_\pi = \Gamma(\pi^\pm \to e^\pm\nu)/\Gamma(\pi^\pm \to \mu^\pm\nu)$ [1, 2, 3], $R_K = \Gamma(K^\pm \to e^\pm\nu)/\Gamma(K^\pm \to \mu^\pm\nu)$ [4, 5, 6] and $R_\tau = \Gamma(\tau^\pm \to e^\pm\nu_e\nu_\tau)/\Gamma(\tau^\pm \to \mu^\pm\nu_\mu\nu_\tau)$ [7, 8] confirmed the suppression of the electronic mode due to the helicity conservation. Hadronic uncertanties cancel to a large extent in the above ratios giving good theoretical predictions for them.

Within the SM, the ratio R_K is given by

$$R_K = R_{tree}(1 + \delta R_{QED}) = (\frac{m_e}{m_\mu})^2(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2})^2(1 + \delta R_{QED}) = (2.472 \pm 0.001) \cdot 10^{-5}$$

where $\delta R_{QED} = (-3.78 \pm 0.04)\%$ is an electromagnetic correction [9, 10]. A recent calculation, based on ChPT[11], gives a value of $(2.477 \pm 0.001) \cdot 10^{-5}$.

A recent theoretical study [12] suggests that lepton-flavour violation effects arising in super-symmetric extensions of the SM can induce sizeable violations of the $\mu - e$ universality, shifting R_K by a relative amount in the percent range. The current world average $R_K = (2.45 \pm 0.11) \cdot 10^{-5}$ is compatible with the SM prediction, but far from the needed level of accuracy.

The NA48 collaboration has measured the ratio R_K using data collected in 2003 and 2004. A dedicated run to achieve an accuracy of 0.5% has been approved for 2007.

2. Data taking in 2003 and 2004

During 2003 and 2004, the NA48 Collaboration was taking data with a charged kaon beam with the main purpose of testing direct CP violation by the measure of the asymmetry in the ratio of Dalitz plot slopes.

The beam line provided two simultaneous charged beams of opposite signs overlapping in space along the decay volume of the NA48 detector [13]. A momentum selection of (60 ± 3) GeV/c was performed by an achromatic system of four dipole magnets with zero total deflection. With $7 \cdot 10^{11}$ protons per pulse on the target, the positive (negative) beam flux at the entrance of the decay volume is $3.8 \cdot 10^7 (2.5 \cdot 10^7)$ particles per pulse of which 5.7%(4.9%) are $K^+(K^-)$.

During part of the running period in 2003, data for the measurement of R_K were collected using a downscaled trigger which included a cut on the missing mass computed by an online processor. However, the uncertainty on the efficiency of this cut is the dominant contribution to the systematic error.

In 2004, a dedicated 56 hours special run was performed with a very simple minimum bias trigger with the intention to minimize the contribution of the trigger efficiency to the systematic error.

In the 2003 run the trigger for the $K_{\mu 2}$ consisted of a time coincidence (called Q1) of hits in the two planes of the charged hodoscope, subsequently downscaled by a factor 50. The Q1 signal in time coincidence with an energy deposition in the LKr calorimeter of at least 10 GeV and a subsequent L2 signal from an online missing mass cut gave the trigger for the K_{e2} channel.

In the 2004 run, in order to eliminate the systematic error induced by the L2 trigger inefficiency, the L2 condition was released and the intensity of the beam was reduced to keep up with the increased rate.

2.1. Analysis

Given the similar topology of the two kinds of interesting events, the analysis cuts were kept as much as possible the same: 1 track topology, coordinate of decay vertex, geometric acceptance in the drift chambers and at the calorimeter, track momentum.

Particle identification is then done using the ratio (E/p) between the energy deposit in the calorimeter and the momuntum measured by the spectrometer: $E/p < 0.2$ for muons and $E/p > 0.95$ for electrons. Then the missing mass with the right mass hypothesis is computed and a cut on this variable is applied.

The major source of background is in the K_{e2} channel and comes from muons which lose all their energy in the LKr calorimeter, giving a value of E/p compatible with the electron hypothesis. The fraction of these muons is computed at low energies where the missing mass of such events with an electron hypothesis is different from zero and then extrapolated at high energies assuming no dependence on momentum. The accuracy of this evaluation is however limited by the statistics of the sample used.

2.2. Results

From the analysis of 2003 data, we found $4670 \pm 77_{st} {}^{+29}_{-8sy}$ events, for a value of $R_K = (2.416 \pm 0.043 \pm 0.024) \cdot 10^{-5}$. The bigger contribution to the systematic error is coming from the L2 trigger efficiency, which was limited by the size of the control sample and from a possible momentum dependence.

The 2004 analysis gave $3407 \pm 63_{st} \pm 54_{sy}$ which translates in $R_K = (2.455 \pm 0.045 \pm 0.041) \cdot 10^{-5}$.

These results are in a good agreement with the SM predictions and also with the preliminary KLOE result [14] $R_K = (2.55 \pm 0.05 \pm 0.05) \cdot 10^{-5}$, obtained with 8000 events and different systematics.

3. An high accuracy measurement in 2007

From the 2004 running experience, it was felt that a dedicated run of several months with the available intensity in the SPS could give more than 100000 K_{e2} candidates, allowing to reach an error of $\approx 0.3\%$ provided that the systematic errors could be controlled.

From the described analysis of 2004 data, the biggest systematic effect was the one due to the background in the K_{e2} channel originated by muons losing all their energy in the LKr calorimeter.

A first improvement has been the increase of the beam momentum to 75 GeV/c and the reduction of the $\Delta p/p$ to 2% to improve the resolution in the missing mass calculation. Moreover we have decided to measure the probability of a large energy deposition of muons by putting some X_0 of material in front of a part of the LKr calorimeter. In this way, all the electrons (both from K_{e2} and from muon decays) are killed and only muons reach the calorimeter and their E/p ratio is then measured. This "lead wall" consists in a bar of 4.5 cm of lead, placed in front of 6 strips of the horizontal hodoscope. The acceptance for K_{e2} decays is so reduced by 18%. Data were taken for about two months in this configuration, to accumulate statistics to measure the probability that the E/p of a muon was above 0.95. A special muon run, triggering only with those 6 strips was taken to get $\approx$ 2000 muons with $E/p > 0.95$, in addition to a similar number taken troughout the entire run.

The 2007 run started on June 20^{th} and it is expected to end at the beginning of October. Our actual estimate is to collect about 120000 K_{e2} candidates with a background of about 10%. A lot of statistics has also been collected in dedicated runs to be able to study the characteristics of the background in detail and to minimize its impact on the systematic error: indeed, in addition to the above described muon background, it has been shown that beam halo induced background should be considered seriously.

4. Conclusion

The NA48 Collaboration has measured with data collected in 2003 and 2004 the ratio R_K with a precision of $\approx$ 2%, with results in agreement with the Standard Model.

Data have been taken during the summer of 2007 to reach an error of $\approx$ 0.3%.

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