LEPTON UNIVERSALITY TEST AND THE $K^+ \to \pi^+\nu\bar{\nu}$ EXPERIMENT AT THE CERN SPS

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A measurement of the ratio $R_K = \Gamma(K^\pm \to e^\pm\nu)/\Gamma(K^\pm \to \mu^\pm\nu)$, aimed to a test of lepton universality, has been performed at CERN by the NA48/2 Experiment during 2003 and 2004. This observable is calculated with very high precision in the framework of the Standard Model (SM), but corrections due to the presence of New Physics could be as high as 3%. The measured value in the 2003-3004 data taking is two times more precise that the world average, but is still insufficient to probe the existence of physics Beyond the SM. The dedicated run for the measurement of R_K with sub-percent precision which took data in 2007 is also presented. The P-326 proposal for an experiment to measure the branching ratio of the very rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$ at the CERN SPS is briefly described. The proposed experiment aims to collect $\mathcal{O}(100)$ events with 10% background in two years data taking period. The status of the project, the R&D and future perspectives for the experiment are discussed.

1. Introduction to R_K

Lepton universality can be tested by investigating leptonic decays of light mesons, like $K^\pm \to l^\pm\nu$. These decays proceed as tree level processes within the Standard Model and R_K, defined as the ratio of K_{e2} ($K^\pm \to e^\pm\nu$) and $K_{\mu 2}$ ($K^\pm \to \mu^\pm\nu$) decay rates, can be written as:

$$R_K = \frac{\Gamma(K^\pm \to e^\pm\nu)}{\Gamma(K^\pm \to \mu^\pm\nu)} = \frac{m_e^2}{m_\mu^2}(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2})^2(1 + \delta R_K) \tag{1}$$

where δR_K represents the radiative corrections term. Theoretical uncertainties on the hadronic matrix elements cancel out in the ratio, resulting in very precise predictions (Table 1).

*On behalf of the NA62 Collaboration

Table 1. Theoretical predictions and experimental results for R_K

	$\Gamma(K_{e2})/\Gamma(K_{\mu 2})$ $[10^{-5}]$
SM prediction [1]	2.472 ± 0.001
SM prediction [2]	2.477 ± 0.001
PDG (2006)	2.45 ± 0.11
NA48/2 prelim. (2003 data) [3]	$2.416 \pm 0.043 \pm 0.024$
NA48/2 prelim. (2004 data) [4]	$2.455 \pm 0.045 \pm 0.041$
KLOE prelim. [5]	$2.55 \pm 0.05 \pm 0.05$

A recent study [6] pointed out that the value of R_K could be different in case of SUSY Lepton Flavor Violation: the difference with respect to the SM could be as high as $\pm 3\%$.

The value of R_K has been measured by three experiments in the 70s, but the precision of the combined results is still poor (4.5% error on the PDG 2006 value, as shown in Table 1). Therefore a precise measurement of R_K can probe μ-e universality and provides a stringent test of the SM.

1.1. *The NA48/2 Experiment and the measurement of R_K*

NA48/2 was primarily designed for the search of direct CP violation in $K^\pm \to \pi^\pm \pi^+ \pi^-$ and $K^\pm \to \pi^\pm \pi^0 \pi^0$ using simultaneous K^+/K^- beams with (60±3) GeV/c momentum. During part of the 2003 running period, a data sample for the measurement of R_K was collected using a downscaled trigger and a cut performed by the level 2 trigger processor on the missing mass of the decay event. During 2004, 56 hours of running with reduced beam intensity were dedicated again to the measurement of R_K, using a minimum bias trigger and eliminating the cut on the missing mass.

Event selection was based on the event topology (a good single charged track), on particle identification and on kinematics. Particle ID within the NA48/2 experiment is possible by calculating the ratio of the energy deposited in the LKr calorimeter and the momentum of the track measured by the spectrometer (E/p): electrons have E/p close to 1, while muons have typically a low E/p value (<0.2). Kinematical selection is based on the missing mass, $m^2_{miss} = (P_K - P_l)^2$, P_K and P_l being the kaon and lepton 4-momenta, respectively. The dominant background source in the

K_{e2} sample is due to $K_{\mu 2}$, which are kinematically undistinguishable at high momenta. A muon can undergo a catastrophic energy loss in LKr, with a probability of a few $\times 10^{-6}$, releasing all its energy and thus faking an electron ($E/p \sim 1$).

From the analysis of 2003 data, $(4670 \pm 77_{stat}\ {}^{+29}_{-8 syst})$ K_{e2} events were selected yielding the value shown in Table 1. The biggest contribution to the systematic error, which comes from the level 2 trigger efficiency, was removed during the 2004 run. The number of selected K_{e2} events was $(3407 \pm 63_{stat} \pm 54_{syst})$ and the biggest systematic was due to $K_{\mu 2}$ background subtraction. These results are in good agreement with SM predictions and also with the preliminary KLOE result (Table 1).

1.2. *High precision measurement of R_K by the NA62 Collaboration*

The NA62 Experiment (former NA48) was approved for a dedicated measurement of R_K in 2007 with the aim of reducing $\delta(R_K)/R_K$ below 0.5%.

During the 4 months long data taking, a new beam and spectrometer configuration was used. The kaon momentum was modified from (60 ± 3) GeV/c to the new value (75.0 ± 2.5) GeV/c and the transverse momentum kick from spectrometer magnet was increased from 120 MeV/c to 263 MeV/c, therefore improving missing mass resolution and $K_{e2}/K_{\mu 2}$ kinematic separation. The same 2004 minimum bias trigger was used and a precise measurement of $K_{\mu 2}$ background and electron misidentification probability was done directly from the data. Measurement of the probability of a large energy deposition in the LKr calorimeter by a muon was achieved during the run by putting a 9 X_0 lead bar between the hodoscope planes, in front of the calorimeter, at a cost of a loss of 18% in acceptance. Electron were stopped in the lead and we could measure the E/p distribution for muons in LKr.

In total, more than 10^5 K_{e2} events have been collected and, from preliminary studies, background contributions and other systematic effects seem well under control: a precision better than 0.5% looks reachable.

2. The $K^+ \to \pi^+ \nu\overline{\nu}$ experiment at the CERN SPS

The $K^+ \to \pi^+ \nu\overline{\nu}$ decay is flavor changing neutral current process which proceeds through box and electroweak penguin diagrams. The predicted values [7,8,9] of the branching fraction are in the order of 8×10^{-11}. The hadronic matrix element can be parametrized in terms of the $K^+ \to \pi^0 e^+ \nu$

branching ratio, well known experimentally, reducing the theoretical uncertainty to about 5% and thus making the $K^+ \to \pi^+ \nu\overline{\nu}$ decay a theoretically clean environment sensitive to new physics.

The existing measurement of the $K^+ \to \pi^+ \nu\overline{\nu}$ branching ratio, based on 3 observed events [10], is compatible with SM within errors, but a 10% accuracy measurement of the branchig ratio is required to provide a decisive test of new physics scenarios. This is the goal of the proposed NA62 experiment at CERN SPS [11], which aims to collect $\mathcal{O}(100)$ $K^+ \to \pi^+ \nu\overline{\nu}$ events in two years, keeping background contamination at the level of 10%.

Identification of a $K^+ \to \pi^+ \nu\overline{\nu}$ event is based on the reconstruction of a single positive track due to the pion in the downstream detectors, in coincidence with a kaon track in the upstream beam spectrometer. Background rejection will be achieved by kinematical selections based on the missing mass variable:

$$m^2_{miss} \sim m^2_K(1 - \frac{|p_\pi|}{|p_K|}) + m^2_\pi(1 - \frac{|p_K|}{|p_\pi|}) - |p_K| \cdot |p_\pi| \cdot \theta^2_{\pi K} \qquad (2)$$

where p_K and p_π are the K^+ and π^+ momenta, respectively, and $\theta_{\pi K}$ is the angle between the two charged tracks. Kinematical rejection will not be sufficient to suppress the background at the proposed level, therefore the use of highly efficient photon vetoes and particle identification detectors is mandatory. The proposed detector layout assures redundancy both in kinematical reconstruction and particle identication allowing background estimation directly from data.

A highly intense (800 MHz rate) 75 GeV/c positively charged particle beam will be produced by directing a 400 GeV/c primary SPS proton beam onto a Be target. The beam is positron free and is composed by 6% of K^+ (unseparated beam), which will be tagged by the existing differential Cerenkov counter called CEDAR [12]. The average rate seen by the downstream detectors is 11 MHz, due to kaon decays and accidentals coming from the beam-line.

The beam spectrometer, measuring p_K and the direction of the kaon track inside the decay volume, consists of three stations of a hybrid Si pixel detector. A time resolution of at least 200 ps per station is required to provide a suitable tag for the kaon track. The pion spectrometer, measuring p_π and the pion direction, is made by low mass straw chambers placed in vacuum, in order to reduce multiple scattering. A 18 m long RICH located after the pion spectrometer and filled with Ne at atmospheric pressure is the core of particle identication: it will identify pions with momentum greater than 15 GeV/c and will provide a time measurement of the downstream track with 100 ps time resolution. A hermetic combination of calorimeters, comprising the existing LKr calorimeter and covering up to 50 mrad, will be used to identify and veto the photons produced in kaon decays. In addition, a specific detector to veto muons tracks will be used downstream.

The NA62 Collaboration is designing an experiment able to reach 10^{12} sensitivity per event employing existing infrastructures and detectors at CERN. The overall experimental design requires sophisticated technology for which an intense R&D program has started in 2006. Data taking with the complete detector is foreseen for 2011.

Conclusions

K_{l2} decays provide a very challenging opportunity to test physics beyond the Standard Model. NA48/2 has presented two preliminary measurements of R_K, with data collected in 2003 and 2004, both compatible with SM predictions. The NA62 experiment took data in 2007 with the aim of measuring R_K with an accuracy better than 0.5%, in order to provide a stringent SM test.

The NA62 Collaboration proposed a new experiment for the measurement of Br($K^+ \to \pi^+ \nu\overline{\nu}$) with a ∼10% accuracy. The ultra-rare $K^+ \to \pi^+ \nu\overline{\nu}$ decay is a unique environment where to search for new physics. The R&D program is well advanced: during the 2007 run the Collaboration tested successfully a full length RICH counter prototype and a full length straw prototype in the actual vacuum tube.

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