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Testing LFV measuring the ratio $R_{\rm K}$ between the Branching Ratio of $\rm K^{\pm} \to e^{\pm}\nu(\gamma)$ and $\rm K^{\pm} \to \mu^{\pm}\nu(\gamma)$ in NA48/2 experiment: Measurement and Perspectives

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The measurement of the ratio $R_{\rm K} = {\rm Br}[{\rm K}^{\pm} \to {\rm e}^{\pm}\nu(\gamma)]$ / ${\rm Br}[{\rm K}^{\pm} \to \mu^{\pm}\nu(\gamma)]$ between the Branching Ratios of $\rm K^{\pm} \to e^{\pm}\nu(\gamma)$ and $\rm K \to \mu^{\pm}\nu(\gamma)$ decays is a sensitive test of lepton universality and new physics. This ratio is predicted by the Standard Model with high precision [2], while its present measurement accuracy is limited by the lack of a statistically proportionate sample of $\rm K^{\pm} \to e^{\pm}\nu(\gamma)$ decays [4] [5] [6].

The NA48/2 experiment [1], located at CERN SPS accelerator, collected two different data sets of Kaon leptonic decays. The former sample has been collected in 2003 data taking and the latter in 2004 data taking. After the description of the most relevant features of the data collected in 2003 and 2004, a preliminary result based on 2003 data set will be presented:

$$R_{\rm K} \;=\; (2.416 \pm 0.043_{\rm (stat)} \pm 0.024_{\rm (syst)}) \cdot 10^{-5}$$

Future perspectives to improve the measurement precision are also discussed.

1. Introduction

The measurement of the ratio

$$R_{\rm K} = \frac{{\rm Br}[{\rm K}^{\pm} \to {\rm e}^{\pm}\nu(\gamma)]}{{\rm Br}[{\rm K}^{\pm} \to \mu^{\pm}\nu(\gamma)]}$$

between the Branching Ratio of $\rm K^{\pm} \to e^{\pm}\nu(\gamma)$ and $\rm K \to \mu^{\pm}\nu(\gamma)$ decays is a sensitive test of lepton universality and of $V - A$ structure of the weak interactions.
This ratio is predicted by the Standard Model (SM) with high precision [2], but its measurement accuracy is limited by the lack of a statistically proportionate sample of $\rm K^{\pm} \to e^{\pm}\nu(\gamma)$ decays [4] [5] [6].
A recent theoretical study [3] shows that SUSY Lepton Flavour Violating effects could shift $R_{\rm K}$ by as much as 2-3% in either direction with respect to SM prediction. Such New Physics contributions to other similar decays[1] are much lower than the present experimental sensitivity.
NA48/2 collaboration is analysing 2 different data sets of Kaon leptonic decays: during 2003 data taking it has been collected more than 4 times the world total $\rm K^{\pm} \to e^{\pm}\nu(\gamma)$ statistics and a data sample of similar size has been collected in 2004 during a 56 hours long dedicated run. Such data sets, obtained in an experimental condition that allows an adequate control of the possible systematic effects, allow to fulfill a significant test of theoretical prediction and to do, for the first time ever, a comparison of $R_{\rm K}$ between positive and negative Kaon decays.

2. Experimental Setup

NA48/2 beam line is composed of simultaneous positive and negative beams of average momentum 60 GeV/c and momentum bite of ±3.8%.
The decay region is a 114 m long vacuum region contained in a cylindrical tank of diameter 1.9 m,

*On behalf of the NA48/2 Collaboration: Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Wien.

[1]Namely $\pi^{\pm} \to l^{\pm}\ \nu$ and $\tau^{\pm} \to l^{\pm}\ \nu\ \overline{\nu}$ $\quad l$=e,μ.

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increasing to 2.4 m in its last 48 m.
A magnetic spectrometer, separated by a Kevlar window from the vacuum region, is used to measure the momentum and flight direction of charged particles. It is equipped with four drift chambers and a dipole magnet deflecting charged particles in the horizontal direction with a kick of ~ 120 MeV/c. The momentum resolution is

$$\frac{\sigma(P)}{P} = 1.02\% \oplus [0.044 \cdot P(\mathrm{GeV})]\%.$$

The spectrometer is followed by a scintillator hodoscope providing a fast trigger for charged events and a time reference for reconstruction.
A liquid Krypton calorimeter is employed to reconstruct electron and photon energy. The active part of the calorimeter is 27 radiation lengths long and is segmented transversally in 13248 2 cm $\times$ 2 cm cells. Its energy resolution is

$$\frac{\sigma(E)}{E} = \frac{0.09}{E(\mathrm{GeV})} \oplus \frac{0.032}{\sqrt{E(\mathrm{GeV})}} \oplus 0.0042.$$

Other detectors of NA48/2 setup are a Kaon Beam spectrometer, placed ~ 65 m in front of the decay volume; a neutral hodoscope embedded in the LKr calorimeter; an hadron calorimeter; a photon veto system around the decay region and a muon veto system.

3. Data Sample

3.1. 2003 Data Sample

During 2003 run $\mathrm{K_{e2}}$ selection used a downscaled trigger requiring a signal from the scintillator hodoscope in coincidence with a signal from the LKr calorimeter compatible with an energy deposition of at least 10 GeV. A second level online processor trigger required that, in the hypothesis of a $\mathrm{K} \to \pi \mathrm{X}$ decay of Kaons with nominal momentum 60 GeV/c, the event missing mass (m_X) was below π^0 mass.
Offline events were selected requiring a track of at least 15 GeV/c crossing the beam line inside the decay region; no other in-time tracks or photons of energy > 3 GeV; a missing mass squared[2] compatible with the hypothesis of a $\mathrm{K}^\pm \to \mathrm{e}^\pm \nu$ decay ($-0.02\ \mathrm{GeV}^2/c^4 < MM(\mathrm{e})^2 < 0.02\ \mathrm{GeV}^2/c^4$) and a $0.95 < E/pc < 1.05$ ratio between the energy released in the calorimeter and the measured track momentum. The collected statistics was of 5329 $\mathrm{K_{e2}}$ candidates.
$\mathrm{K}_{\mu 2}$ selection trigger used a downscaled signal from the scintillator hodoscope. Offline selection required a track of at least 15 GeV/c crossing the beam line inside the decay region, no other in-time tracks or photons of energy > 3 GeV and a missing mass compatible with the hypothesis of a $\mathrm{K}^\pm \to \mu^\pm \nu$ decay ($-0.02\ \mathrm{GeV}^2/c^4 < MM(\mu)^2 < 0.02\ \mathrm{GeV}^2/c^4$). The number of collected $\mathrm{K}_{\mu 2}$ candidates was 619179.

3.2. 2004 Data Sample

2004 data sample has been collected during a 56 hours long special run with only minimum bias triggers and reduced beam flux. $\mathrm{K_{e2}}$ events have been triggered requiring a signal from the scintillator hodoscope in coincidence with a signal from the LKr calorimeter compatible with an energy deposition of at least 10 GeV.
Offline events were selected requiring a track of at least 15 GeV/c and less than 55 GeV/c crossing the beam line inside the decay region; no other in-time tracks or photons of energy $>$ 3 GeV; a missing mass squared compatible within 3 σ with the hypothesis of a $\mathrm{K}^\pm \to \mathrm{e}^\pm \nu$ decay ($-0.015\ \mathrm{GeV}^2/c^4 < MM(\mathrm{e})^2 < 0.015\ \mathrm{GeV}^2/c^4$) and a $0.95 < E/pc < 1.05$ ratio between the energy released in the calorimeter and the measured track momentum.
$\mathrm{K}_{\mu 2}$ selection events have been triggered using a downscaled signal from the scintillator hodoscope (downscaling factor = 50). Offline $\mathrm{K}_{\mu 2}$ selection required a track of at least 15 GeV/c crossing the beam line inside the decay region, no other in-time tracks or photons of energy $>$ 3 GeV and a missing mass compatible with the hypothesis of a $\mathrm{K}^\pm \to \mu^\pm \nu$ decay ($-0.015\ \mathrm{GeV}^2/c^4 < MM(\mu)^2 < 0.015\ \mathrm{GeV}^2/c^4$).
The statistics collected in 2004 minimum bias run was of 4115293 $\mathrm{K}_{\mu 2}$ candidates and 4933 $\mathrm{K_{e2}}$ candidates.

[2] The missing mass squared for electrons and muons tracks is defined as: $MM(l)^2 \equiv S = (P_\mathrm{K} - P_l)^2$ where l= e,μ and P_l is the 4-vector momentum of the lepton and P_K is the Kaon 4-vector momentum under the assumption of having a momentum of 60 GeV/c directed along the beam axis.

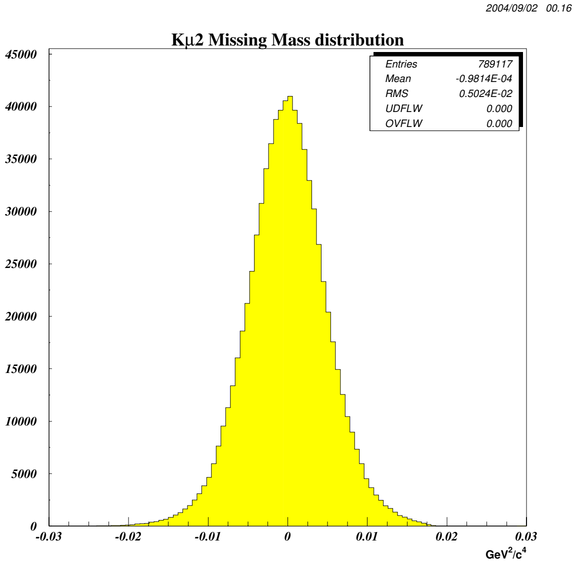

Figure 1. Distribution of the missing mass for $K_{\mu 2}$ reconstructed events. The signal is almost completely contained in 2003 signal region $-0.02\ \mathrm{GeV}^2/c^4 < MM^2(\mu) < 0.02\ \mathrm{GeV}^2/c^4$

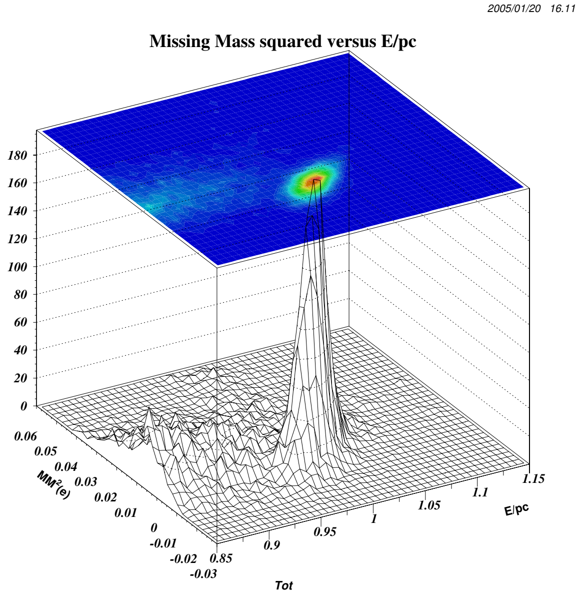

Figure 2. MM^2(e) versus E/pc distribution for K_{e2} event candidates. The bounds on lepton E/pc and MM^2(e) have been removed , allowing to explore background events distribution outside the signal region.

4. 2003 Data Analysis

Figure 1 shows the missing mass squared distribution of $K_{\mu 2}$ reconstructed events[3].
Figure 2 shows missing mass squared distribution versus E/pc of K_{e2} candidates events. Background contributions have been identified and subtracted as shown in Figure 3. The most relevant contaminations are due to $K_{\mu 2}$ events in which the muon has a high E/pc ratio; other sources of background are K_{e3} and $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ decays.

The measurement of R_K ratio allows the cancellation of acceptance and trigger effects common to K_{e2} and $K_{\mu 2}$ events. Residual corrections in the trigger selection, acceptance, accidental activity are shown in Table 1. Radiative corrections are taken into account according to [2] and [7].

[3]Background contamination at 10^{-3} level is due to $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ decays.

5. 2003 Preliminary Result

The number of collected K_{e2} events is:

$$4670 \pm 77\,(\mathrm{stat})\ ^{+29}_{-8}\,(\mathrm{syst})$$

585 of these events have been collected with a downscaling factor of 40, all others with a downscaling factor of 20. $K_{\mu 2}$ data sample has been collected with a downscaling factor of 10000.
The value of R_K ratio measurement with 2003 statistics is:

$$R_K = (2.416 \pm 0.043_{(\mathrm{stat})} \pm 0.024_{(\mathrm{syst})}) \cdot 10^{-5}$$

to be compared with the SM prediction: $(2.472 \pm 0.001) \cdot 10^{-5}$ and the present world average (PDG 2006) $(2.45 \pm 0.11) \cdot 10^{-5}$.

Table 1
Summary of corrections and uncertainties to R_K measurement. The largest statistical error comes from the uncertainty on the trigger efficiency. This is due to the limited amount of statistics, especially, in the control sample of the L1 trigger logic. The largest contributions to the systematic error come from the uncertainty on the cut acceptance and on acceptance correction due to $K_{l2\gamma}$ decays. The uncertainty due to K_{e2} background subtraction is not reported here, but taken into account in the final result.

Summary of R_K corrections		
	$\frac{\Delta R_K}{R_K}$ Correction	$\frac{\Delta R_K}{R_K}$ error
Cut Acceptance	$+1.144$	$0.007_{\text{(syst)}}$
Accidental losses	0.9976	$(\pm 2.3_{\text{(syst)}}) \cdot 10^{-3}$
Trigger Efficiency	$+1.169$	$\pm 0.008_{\text{(stat)}}$
Radiative Corrections	$+1.063$	$\pm 0.005_{\text{(syst)}}$
Total	**+1.424**	$\pm 0.008_{\text{(stat)}}$ $\pm 0.008_{\text{(syst)}}$
Downscaling factor	$2.25 \cdot 10^{-3}$	
Raw K_{e2} and $K_{\mu 2}$ ratio	$(7.54 \pm 0.09_{\text{(stat)}}\ {}^{+0.03}_{-0.01(syst)}) \cdot 10^{-3}$	
R_K Result	$(2.416 \pm 0.043_{\text{(stat)}}\ \pm 0.024_{\text{(syst)}}) \cdot 10^{-5}$	

6. Future Perspectives

New Physics effects that could contribute to R_K at the level of few percents, as shown in A. Masiero et al. paper [3], are below NA48/2 present sensitivity. Even taking into account the statistical precision attainable with 2004 data set, it is clear that both statistical and systematic errors for R_K will stay above 1%.
It has been shown [8] that during a 6 weeks long dedicated data-taking it would be possible to achieve a measurement of R_K with a statistical precision of 0.49% and a systematic precision of 0.52% (assuming a machine efficiency of 50%). Such data taking would be compatible with both LHC and CNGS proton requests for 2007.
These accuracy values have been obtained neglecting possible improvements of the setup and beam line. It would be possible to improve K_{e2} - $K_{\mu 2}$ kinematic separation increasing the spectrometer kick from 120 MeV/c to 240 MeV/c. The kinematic separation can also be improved by having a beam of particles of 75 GeV/c momentum with a momentum bite of 1.8% instead of the beam of 60 GeV/c particles and momentum bite of 3.8%, as it was the case in 2003 and 2004 data taking (see Figure 4).
A more precise measurement of R_K could be an interesting physics item for the proposed P-326 experiment [9], that could employ its Ring Imaging Cherenkov Detector (RICH) to reject $K_{\mu 2}$ background in K_{e2} signal.

7. Conclusions

The present uncertainty of R_K measurement is dominated by the statistical error:

$$R_K = (2.416 \pm 0.043_{\text{(stat)}}\ \pm 0.024_{\text{(syst)}}) \cdot 10^{-5}$$

The 2004 data set, taken during special run with a simplified trigger logic, is similar in size to 2003 data sample, but its simplified trigger logic allows a better cancellation of systematic corrections between K_{e2} and $K_{\mu 2}$ events.
Even considering both data sets, NA48/2 present sensitivity is not good enough to test precisely new physics effects that could contribute to R_K at the level of few percents. With a new 6 weeks long dedicated run it would be possible to attain a measurement of R_K with a statistical precision of 0.49% and a systematic precision of 0.52%. A more precise measurement of R_K would require a novel experimental set-up, like the one proposed by P-326 collaboration.

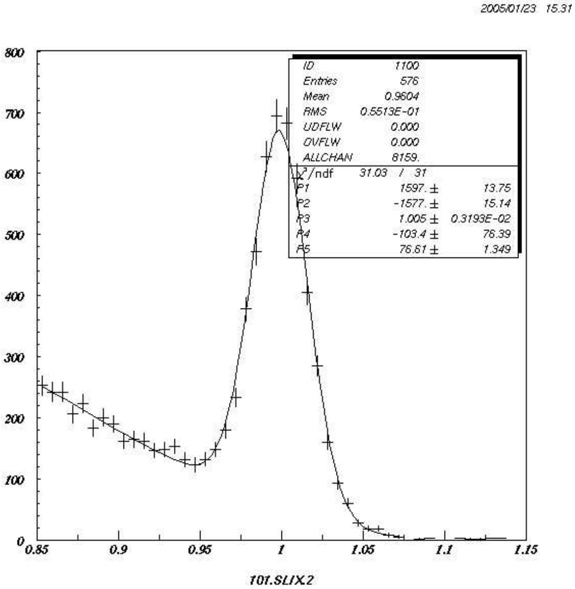

Figure 3. Fit of the E/pc distribution for signal and background events. The variable $P(3)$ indicates the point where the background distribution changes of slope (close to 1, as expected). $P(2)$ and $P(4)$ are the slopes of background events distribution. The background contamination in the signal region is 14% of the signal.

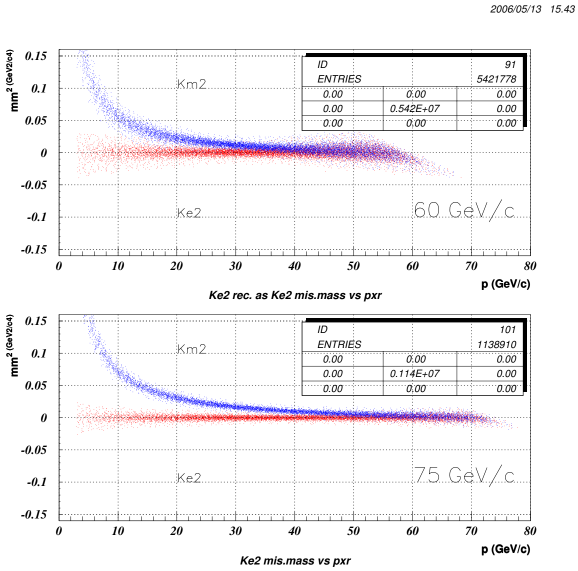

Figure 4. Kinematic separation of K_{e2} versus $K_{\mu 2}$ in the case of a spectrometer kick of 120 MeV/c and a beam of 60 GeV/c with a momentum bite of 3.8% and in the case of a spectrometer kick of 240 MeV/c and a beam of 75 GeV/c with a momentum bite of 1.8%.

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