Search for New Physics in NA62

Antonino Sergi[1]

University of Perugia and INFN

Abstract. The ratio $R_K = \frac{\Gamma(K \to e\nu_e(\gamma))}{\Gamma(K \to \mu\nu_\mu(\gamma))}$ of leptonic decay rates provides a golden probe for testing the structure of the weak interactions because it can be predicted with high accuracy within the Standard Model. The aim of the NA62 experimental programme based on the 2007 data set is a measurement of R_K reaching a new accuracy level better than 0.4% [5]. To achieve this goal, data taking strategy allowing control over the systematic effects and in particular precise background subtraction, was worked out, and a data sample of $\sim 0.16 \times 10^6$ K_{e2} candidates with just $\sim 10\%$ background was collected. The current status of the K_{l2} analysis based on the dedicated NA62 data taking is summarized. The achieved precision of background subtraction, other systematic uncertainties, and prospects of the analysis are discussed. Within the same scientific programme, NA62, in its second phase, will measure the branching ratio of the very rare kaon decay $K^+ \to \pi^+\nu\overline{\nu}$; the aim is 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

In the Standard Model of Particle Physics (SM) sub-permille accuracy is reached in the prediction of the ratios $R_P = \frac{\Gamma(P \to e\nu_e(\gamma))}{\Gamma(P \to \mu\nu_\mu(\gamma))} = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{m_P^2 - m_e^2}{m_P^2 - m_\mu^2}\right)^2 (1 + \delta R_{\text{QED}})$ of decay rates for the pseudoscalar K and π mesons. This excellent accuracy ($R_K = 2.477 \pm 0.001 \times 10^{-5}$, $R_\pi = 12.352 \pm 0.001 \times 10^{-5}$) is due to cancellations of the hadronic uncertainties[1, 2] and the precise knowledge of the electromagnetic correction δR_{QED}.

The factor $(m_e/m_\mu)^2$ accounts for helicity suppression and makes R_P very sensitive to SM extensions involving Pseudo-Scalar currents and non-universal corrections, which are expected to induce variations of R_P of the order $10^{-4} < \delta R_P/R_P < 10^{-2}$. In particular SM extensions involving Lepton Flavour Violation (LFV) are currently not ruled out by experiment.

The current world average $R_K^\pi = 2.45 \pm 0.11 \times 10^{-5}$ (PDG) dates back to three experiments performed in the 1970s, and has insufficient precision (4.5%) for stringent SM tests. A series of recent preliminary results from NA48/2 and KLOE represents a significant improvement: Combining these results with the PDG value yields a precision of 1.3%[4].

On the other hand, for what concerns the future programme, the $K^+ \to \pi^+\nu\overline{\nu}$ decay is a flavor changing neutral current process which proceeds through box and electroweak penguin diagrams. The predicted values [6, 7, 8] of the branching fraction are of 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.

---

[1] On behalf of the NA62 Collaboration

The existing measurement of the $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ branching ratio, based on 7 observed events [9], 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 [10], which aims to collect $\mathcal{O}(100)$ $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ events in two years, keeping background contamination at the level of 10%.

2. Current experimental setup

For the first phase of NA62 the experimental setup is largely based on NA48/2. The beam line K12 at CERN SPS is capable of delivering simultaneous narrow momentum band K^+ and K^- beams. A central momentum of 75 GeV/c was used during 2007 data taking. Most of the data were taken with the $K+$ beam only because the muon sweeping system is more effective in rejecting μ^+. Conversely, about 10% of the data were recorded with K^- beam only in order to measure the background induced by the beam halo via $\mu \rightarrow e$ decays. The following detectors, located downstream a vacuum decay volume ($80m$ in length), were exploited: a magnetic spectrometer composed of four drift chambers (DCHs) and a spectrometric magnet (providing a track momentum resolution of $\delta p_{[GeV/c]}/p = 0.47\% \oplus p \cdot 0.02\%$); a liquid krypton electromagnetic calorimeter (LKr) used for γ detection and particle identification; a scintillator hodoscope (HOD) used for timing measurement and to produce fast trigger signals. A minimum bias trigger configuration was employed, resulting in relatively low trigger purities, but high efficiencies for leptons with momentum $p > 10 GeV/c$. The main data sample was taken during the four months of data taking in 2007. About 4×10^6 SPS spills were recorded, corresponding to 300 TB of raw data. Additional data were collected in 2008 to address in detail some systematic uncertainties.

3. Analysis

The analysis strategy is based on counting the numbers of reconstructed K_{e2} and $K_{\mu2}$ candidates collected simultaneously, consequently the result does not rely on kaon flux measurement and several systematic effects, such as parts of the trigger and detection efficiencies, cancel in the ratio. The analysis is performed independently in bins of momentum of the charged track ($15 GeV/c < p < 65 GeV/c$), due to strong dependence of the backgrounds and acceptance on this variable. The ratio R_K is computed in each momentum bin after having subtracted the background events from the K_{e2} and $K_{\mu2}$ candidates. Correction factors are then applied in order to account for acceptances and for trigger, reconstruction and particle identification efficiencies.

Due to the topological similarity of K_{e2} and $K_{\mu2}$ decays, a large part of the selection criteria is common for both decays. This leads to cancellations of the related systematic uncertainties in R_K. Particle identification based on the ration of energy E deposited in the calorimeter and the momentum measured by the spectrometer p ($0.95 < E/p < 1.10$ for electrons, $E/p < 0.20$ for muons) and kinematic identification obtained with the measurement of the missing invariant mass ($M_{miss}^2 = (p_K - p_l)^2 < 0.01 (GeV/c)^2$ for electrons) are exploited for separating K_{e2} and $K_{\mu2}$ decays. The average momentum of the incoming kaons is measured with $K \rightarrow 3\pi$ decays and is used for K_{l2} kinematical reconstruction (M_{miss}); a narrow kaon momentum spectrum ($\Delta p_K^{rms}/p_K \sim 2\%$) is used in order to minimize the corresponding contribution to the M_{miss} resolution. After selection, 0.16×10^6 K_{e2} candidates are identified. The present analysis is based on the study of a sub-sample (40%) of the full data sample.

The study of the background is the main topic of the analysis. Detailed studies with data and MonteCarlo are performed in order to identify and measure the main sources of background. The following background contributions have been identified: (1) $K_{\mu2}$ events where the μ is mis-identified as an electron due to "catastrophic" bremsstrahlung in the LKr (the amount of background induced is $8.07 \pm 0.21\%$); (2) $K_{e2\gamma}$ events: by convention, the inner bremsstrahlung

(IB) part of the radiative $K_{l2\gamma}$ process is included into R_K, while the structure dependent (SD) $K_{l2\gamma}$ process, which can not be accurately computed, is not. Its contribution has to be measured directly and is $1.29 \pm 0.32\%$; (3) Beam muon halo with $\mu \to e$ decays: the K_{l2} decay signature consists of a single reconstructed track, thus the background in K_{l2} samples induced by the beam halo is an issue (amount of background induced is $1.23 \pm 0.07\%$). Samples of reconstructed K_{l2} candidates, of the charge not present in the beam, provide measurements of the halo background. Thus the separate K^+ and K^- beam only samples allow for cross-subtraction of the halo background with precisions much better than statistical uncertainty of the measurement; (4) minor sources of background are electrons from $K_{2\pi}$ and K_{e3} decays (contributions at the level of 0.1%).

4. Future experimental setup for measuring $K^+ \to \pi^+\nu\overline{\nu}$

For the second phase of NA62, 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 [11]. The average rate seen by the downstream detectors will be 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 identification: it will identify pions with momentum greater than 15 GeV/c and it 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.

5. Conclusions and prospects

The measurements of R_K in bins of track momentum (p) are found to be compatible and independent of p, which indicates good control over the main systematic effects. The total error is 0.6% consisting of a statistical error of 0.43% and systematic uncertainties of 0.4% mainly due to background subtraction (0.25%, 0.32% and 0.1%, respectively, due to $K_{\mu2}$, $K_{e2\gamma}$ and beam halo background). Further studies of second-order effects and minor background sources are currently underway in order to finalize the measurement of R_K with the currently considered partial 40% data sample. The total uncertainty of the partial result is $< 0.7\%$ (below the 1% level for the first time).

The whole NA62 data sample of 0.16 millions K_{e2} decay candidates, which is one order of magnitude larger than the existing world sample, allows pushing the statistical uncertainty to a level below 0.3%. Significant improvements of the $K_{\mu2}$ background and beam halo systematic uncertainties are possible thanks to the special data sets collected in 2008 and dedicated to the Ke2 systematics studies. The uncertainty due to the $K_{e2\gamma}$ (SD) background is expected to be decreased by a direct measurement of this process. The ultimate precision of the measurement is expected to reach the 0.4% level, meeting the goal declared in the proposal[10].

The NA62 programme foresees a measurement of Br($K^+ \to \pi^+\nu\overline{\nu}$) with a $\sim 10\%$ accuracy. The ultra-rare $K^+ \to \pi^+\nu\overline{\nu}$ decay is a unique environment for new physics searches. 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.

References

[1] A. Masiero, P. Paradisi and R. Petronzio, Phys. Rev. **D74** (2006) 011701.

[2] V. Cirigliano and I.Rosell, Phys. Lett. **99** (2007) 231801.

[3] C. Amsler et al. (PDG), Phys. Lett. **B667** (2008) 1.

[4] M. Antonelli et al., Nucl. Phys. B, Proc. Suppl. 181-182 (2008) 83 [arXiv:0801.1817].

[5] NA48/2 and P-326 status report, CERN-SPSC-2006-033.

[6] A. J. Buras, M. Gorbahn, U. Haisch and U. Nierste, Phys. Rev. Lett. **95**, 261805 (2005); *JHEP* **0611**, 002 (2006).

[7] G. Isidori, F. Mescia and C. Smith, Nucl. Phys. B **718**, 319 (2005).

[8] F. Mescia and C. Smith, Phys. Rev. D **76**, 034017 (2007).

[9] S. Adler *et al.* [E787/949 Collaboration], Phys. Rev. Lett. **101** 191802 (2008).

[10] G. Anelli *et al.*, CERN-SPSC-2005-013, SPSC-P-326.

[11] G. Bovet *et al.*, CERN Report: CERN 82-12 (1982).