Search for New Physics and QCD tests with Kaon decays

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Abstract. In this paper two of the most recent results from the NA62 and NA48/2 Collaborations are reviewed. The NA62-phase I experiment has been proposed to study the $\mu - e$ universality through the measurement of the ratio $R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)}$. The physics motivations and status of the analysis, based on 40% of the total data sample, are presented. The NA48/2 experiment has been designed with the main purpose of searching for direct CP violation in kaon decays. At same time, thanks to the very high statistics accumulated, extensive studies of low energy hadron dynamics have been carried out. Results on the $\pi\pi$ scattering lengths (a_0 and a_2), using two different approaches, are presented. Both experiments are installed at CERN SPS; data have been collected in 2003 and 2004 by the NA48/2 experiment and in 2007 by the NA62-phase I experiment.

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SEARCH FOR NEW PHYSICS: TEST OF $\mu - e$ UNIVERSALITY

Introduction

In the Standard Model (SM), ratios of decay rates of purely leptonic decays of light pseudoscalar mesons ($R_p = \Gamma(p^\pm \to e^\pm \nu)/\Gamma(p^\pm \to \mu^\pm \nu), p = K, \pi$) are predicted with very high accuracy, due to the cancellation of hadronic uncertainties. The ratio R_K, also denoted as $K_{e2}/K_{\mu 2}$, can be written [1]

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_{QED}) = (2.477 \pm 0.001) \cdot 10^{-5}$$

where $\delta R_{QED} = (3.78 \pm 0.04)\%$ is a correction due to the IB part of the radiative decay $K^\pm \to e^\pm \nu\gamma$. By convention the IB part is included in R_K, while the DE structure dependent part (SD) is not. The factor $\frac{m_e^2}{m_\mu^2}$ accounts for the strong helicity suppression of the K_{e2} mode, which makes the amplitude sensitive to contributions from physics beyond the SM. Recently, a theoretical study [2] pointed out that lepton-flavour violating effects arising in super-symmetric extensions of the SM can induce sizable violations of the

[1] on behalf of the NA62 Collaboration (Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, IHEP, INR, Louvain, Mainz, Merced, Napoli, Perugia, Pisa, Roma I, Roma II, San Lous Potosì, SLAC, Sofia, TRIUMF, Torino) and NA48/2 Collaboration (Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Wien).

$\mu - e$ universality, shifting R_K from the SM value by a relative amount that can be in the percent range. The precision of the PDG 2008 value [3], $R_K = (2.45 \pm 0.11) \times 10^{-5}$, has been improved by preliminary results from the NA48/2 and KLOE Collaborations. The current world average that includes the final result from KLOE [4], based on $\sim$ 13800 K_{e2} candidates, has a precision of 1.3 %, still not enough for a stringent test of the SM. In order to reduce the uncertainty, NA62 collected $\sim$ 160000 K_{e2} candidates in 2007, aiming to reach a precision on the determination of R_K of $\sim$ 0.5 %. The results presented are based on a partial sample of 40% of the total statistics.

Data analysis and background evaluation

K_{e2} and $K_{\mu 2}$ decays were collected simultaneously, making the measurement independent of the kaon flux and resulting in the cancellation of many systematic effects. MonteCarlo simulation is used only to a limited extent, for geometric acceptance correction and to evaluate the background from energetic bremsstrahlung by muons. The measurement is performed by counting the candidate events in track momentum bins:

$$R_K = \frac{N(K_{e2}) - N_{BG}(K_{e2})}{N(K_{\mu 2}) - N_{BG}(K_{\mu 2})} \cdot \frac{A(K_{\mu 2}) \cdot f_\mu \cdot \varepsilon(K_{\mu 2})}{A(K_{e2}) \cdot f_e \cdot \varepsilon(K_{e2})} \cdot \frac{1}{f_{LKr}}$$

where $N(K_{l2})$ are the numbers of selected K_{l2} candidates $(l = e, \mu)$, $N_{BG}(K_{l2})$ are the numbers of background events, f_l the particle ID efficiencies, A(K_{l2}) the geometrical acceptances and f_{LKr} the electromagnetic calorimeter (LKr) global read out efficiency. Due to the similar topology and kinematics of the K_{e2} and $K_{\mu 2}$ decays, a large part of the selection criteria is common for the two channels, leading to cancellation of systematic uncertainties in R_K. K_{e2} and $K_{\mu 2}$ are then separated using kinematical identification by reconstructing the squared missing mass (i.e. the neutrino mass) assuming the electron or the muon mass

$$M^2_{miss}(l) = (P_K - P_l)^2$$

where P_K and $P_l (l = e, \mu)$ are the kaon and lepton four-momenta. For track momenta higher than 25 GeV/c, where the kinematical separation in not possible, the E/p variable is used, requiring E/p < 0.2 for muons and 0.95 < E/p <1.10 for electrons. The $K_{\mu 2}$ sample is almost background free; the main background to the K_{e2} sample comes from muons that deposit almost all of their energy in the LKr, making a high energetic (catastrophic) bremsstrahlung. The probability for such a process, $P(\mu \to e)$, is only few 10^{-6}, however, due to the helicity suppression of the K_{e2} mode by 5 orders of magnitude, this effect turns out to be the major source of background. The probability $P(\mu \to e)$ has been measured directly from data: a lead wall $\sim 9X_0$ thick was installed in front of the calorimeter. Tracks traversing the wall and depositing > 95 % of their energy in LKr represent a sufficiently pure sample of catastrophic bremsstrahlung, with an electron contamination less than 10^{-7}. The preliminary value is $B/S = (7.4 \pm 0.2)\%$; the accuracy can be improved using the whole data sample available. Among the other sources of background, particularly important is the $K^\pm \to e^\pm \nu \gamma$ decay, which has a rate similar to the K_{e2} one. This MC estimated contribution is $B/S = (1.6 \pm 0.3)\%$; the uncertainty, due to the poor knowledge of the BR, is expected to be improved by the measurement being performed using the NA62 data.

Analysis status and prospects

From a partial sample of 40 % of the total statistics accumulated, after applying all the selection criteria, about 60k K_{e2} and 17.2 M $K_{\mu 2}$ events remain. The total B/S in the K_{e2} sample is estimated to be 12.2 %, the $K_{\mu 2}$ is almost background free; improvements for each background source are forseen. The estimated total uncertainty for this data sample is $0.6-0.7\%$, improving by a factor of 2 the present world average precision. Using the full data sample of $\sim$ 160000 K_{e2} decay candidates, the statistical uncertainty can be pushed below 0.3 % and an overall uncertainty of $\sim$ 0.5 %, as stated in the proposal, is within reach.

QCD TESTS WITH KAONS

Kaon decays are an ideal laboratory to study the low energy (below 1 GeV) regime of hadronic physics. Two different decay modes have been used in NA48/2 to measure a_0 and a_2, the S-wave $\pi\pi$ scattering lengths in Isospin states I=0 and I=2: the hadronic decay $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ ($K_{3\pi}$) and the semileptonic decay $K^{\pm} \to \pi^+\pi^-e^{\pm}\nu$ (K_{e4}). The experimental determination of a_0 and a_2 provides important constraints for Chiral Perturbation Theory (ChPT) parameters.

The main purpose of the NA48/2 experiment has been to search for direct CP violation in $K^{\pm}$ decay to three pions. The data collected in 2003-2004 provide large samples of fully reconstructed $K^{\pm} \to \pi^{\pm}\pi^+\pi^-$ and $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ decays. Here the results from a study of the final sample of $\sim 60\times 10^6$ $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ decays are reported. Thanks to the very high statistics, the excellent calorimeter energy resolution and the proper $\pi^0\pi^0$ invariant mass (M_{00}) reconstruction strategy, the M_{00} distribution of $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ events shows a cusp-like anomaly in the region around $M_{00} = 2m_+$, where m_+ is the charged pion mass. This anomaly is interpreted as an effect due mainly to the final state charge exchange scattering process $\pi^+\pi^- \to \pi^0\pi^0$ in $K^{\pm} \to \pi^{\pm}\pi^+\pi^-$ decays. The M_{00} shape distribution has been fitted using two different approaches: the Cabibbo-Isidori model [5], that includes all the one-loop and two-loops rescattering diagrams, and the Bern-Bonn model [6, 7], based on a non-relativistic field theory framework. The Bern-Bonn model with radiative corrections [7] provides presently the most complete description of rescattering effects $K \to 3\pi$ decay. The final results presented are obtained from the fits to this model:

$$(a_0 - a_2)m_+ = 0.2571 \pm 0.0048(stat) \pm 0.0025(syst) \pm 0.0014(ext)$$

$$a_2 m_+ = -0.024 \pm 0.013(stat) \pm 0.009(syst) \pm 0.002(ext)$$

We have also performed fits using the constraint between a_2 and a_0 predicted by analyticity and chiral symmetry [8], leading to the result:

$$(a_0 - a_2)m_+ = 0.2633 \pm 0.0024(stat) \pm 0.0014(syst) \pm 0.0019(ext)$$

Our results agree with the values of the $\pi\pi$ scattering lengths obtained from the measurement of the lifetime of the $\pi^+\pi^-$ atom [9], and also with theoretical calculations performed in the framework of ChPT [10, 11], which predicts $(a_0 - a_2)m_+ = 0.265 \pm 0.004$. Results on a partial sample have been published in [12]; final results with details of the analysis and of the fitting procedure can be found in [13].

The second way of evaluating the $\pi\pi$ scattering lengths is based on the form factors analysis of K_{e4} decays. The asymmetry of the dilepton system with respect to the dipion system is related to the difference δ between the s- and p-wave $\pi\pi$ scattering phases for isospin states 0 and 1 ($\delta_0^0 - \delta_1^1$). Under the assumption of isospin symmetry, the measured variation of the phase shift with the invariant mass $M_{\pi\pi}$ near threshold can be related to a_2 and a_0 using dispersion relations based on general properties like analyticity, unitarity and crossing symmetry (also known as Roy equations [14]). Numerical solutions of these relations, including experimental input data at intermediate energies, have been developed in the past years [15, 16]. Additional constraints from ChPT lead to quite precise predictions for the scattering length values ($a_0 = 0.220 \pm 0.005, a_2 = -0.0440 \pm 0.0010$) [8, 11]. Using a fit with a_2 and a_0 as free parameters, we obtain

$$a_0 = 0.2220 \pm 0.0128(stat) \pm 0.0050(syst) \pm 0.0037(theor)$$

$$a_2 = -0.0432 \pm 0.0086(stat) \pm 0.0034(syst) \pm 0.0028(theor)$$

Using the ChPT constrain, the result is

$$a_0 = 0.2206 \pm 0.0049(stat) \pm 0.0018(syst) \pm 0.0064(theor)$$

The above results are in excellent agreement with the prediction of ChPT [8, 11] and with the results obtained from the analysis of the cusp-effect in $K^\pm \to \pi^\pm\pi^0\pi^0$ decays.

The results on a partial sample from data collected in 2003 are published in [17]. A publication on the whole data sample is in preparation.

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