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# Recent results of the NA48/2 experiment

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Recent results from the NA48/2 experiment are presented. Using data collected during 2003 and 2004, branching ratios and form factors have been measured for $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$, $K^{\pm} \rightarrow \pi^{\pm}e^{+}e^{-}\gamma$ and $K^{\pm} \rightarrow \pi^{\pm}e^{+}e^{-}$. Present experimental situation in NA48/2 and future prospects in NA62 for the measurement of the ratio $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ are summarized.

## 1. Introduction

The NA48/2 experiment at CERN SPS has collected the world largest amount of charged kaon decays. During two runs in 2003 and 2004, with about 60 days of effective running each, about $18{\cdot}10^9$ events were recorded in total. The main goal of NA48/2 was the search for direct CP violation in $K^{\pm}$ decays into three pions. However, given the high statistics achieved, many other physics topics were also covered in rare and not so rare Kaon decays. In the following sections, recent results on ChPT parameters obtained by the NA48/2 collaboration will be presented together with two precision measurements of the $R_K$ ratio. Prospect for the NA62 measurement of $R_K$ will be given.

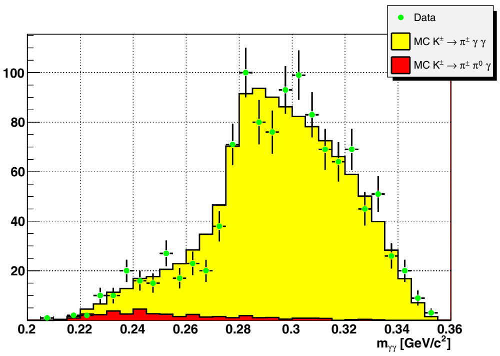


Figure 1. $M_{\gamma\gamma}$ for selected candidates (crosses), signal MC (yellow) and background (red).

## 2. NA48/2 beam line and detector

NA48/2 simultaneous $K^{+}$ and $K^{-}$ beams were produced by 400 GeV protons from the CERN SPS, impinging on a Be target. Kaons were deflected in a two stage front-end achromat to select a momentum band of $60 \pm 3$ GeV/c and then focused such that they converge at the beginning of the magnetic spectrometer. The most important detector components are the magnetic spectrometer, consisting of four drift chambers and a dipole magnet, and the quasi-homogeneous liquid Krypton calorimeter (LKr). The momentum of the charged particles and the energy of the photons are measured with a relative uncertainty of $\sim$1% at 20 GeV. A detailed description of the detector can be found in [1].

## 3. $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ decay

The contributions of the chiral lagrangian to this decay appear only at $O(p^4)$. At this order, only the $\Delta I = 1/2$ invariant amplitudes A(z) and C(z) with $z = M^2_{\gamma\gamma}/M^2_{\pi\pm}$ contribute. A(z) contains the $O(p^4)$ loop diagrams contributions and the tree level counterterms absorbed in an unknown O(1) parameter called $\hat{c}$. The value of parameter $\hat{c}$ fixes the branching ratio and the $M_{\gamma\gamma}$ spectrum shape. $O(p^6)$ studies [2] suggested that unitarity correction effects could increase the BR between 30%-40%, while vector meson exchange contributions would be negligi-


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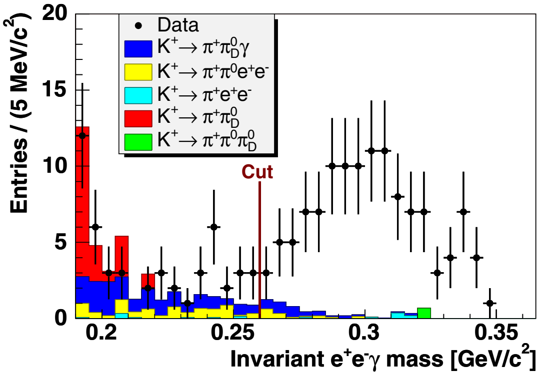


Figure 2. Invariant $ee\gamma$ mass for selected signal candidates and background expectation from MC simulation.

ble. NA48/2 has analyzed about 40% of its data sample, finding 1164 signal candidates (wrt 31 of previous E787 measurement) with 3.3% background, mainly $K^\pm \to \pi^\pm\pi^0\gamma$ . Both signal and normalization channels ($K^\pm \to \pi^\pm\pi^0$) were collected through a trigger intended to collect $K^\pm \to \pi^\pm\pi^0\pi^0$ decays, therefore suffered from a very low trigger efficiency (∼50%). The reconstructed spectrum of invariant mass in the accessible kinematic region $M_{\gamma\gamma} > 0.2 GeV/c^2$ is presented in Fig. 1, along with a MC expectation assuming ChPT O($p^6$) distribution [2] with a realistic parameter $\hat{c}$=2. The model dependent branching ratio of $K^\pm \to \pi^\pm\gamma\gamma$ has been measured using the same assumptions. The preliminary result is:

$$BR(K^\pm \to \pi^\pm\gamma\gamma) = (1.07{\pm}0.04_{sta}{\pm}0.08_{sys})\cdot 10^{-6} \quad (1)$$

A model independent BR measurement is in preparation, together with the extraction of $\hat{c}$ from a fit to $M_{\gamma\gamma}$ and BR.

## 4. The $K^\pm \to \pi^\pm e^+e^-\gamma$ decay rate

The decay $K^\pm \to \pi^\pm e^+e^-\gamma$ is similar to the decay $K^\pm \to \pi^\pm\gamma\gamma$, with one of the photons internally converting into a pair of electrons. In ChPT, the loop contribution is fixed up to the same free parameter $\hat{c}$ used in $K^\pm \to \pi^\pm\gamma\gamma$. As for $K^\pm \to \pi^\pm\gamma\gamma$ the rate is measured relatively to the $K^\pm \to \pi^\pm\pi^0_D$ channel, which has identical particle composition in the final state. Using the full NA48/2 data sample 120 $K^\pm \to \pi^\pm e^+e^-\gamma$ decay candidates (with a total background of 6.1% estimated by MC) are found in the accessible kinematic region, $M_{ee\gamma} > 0.26 GeV/c^2$. This is the first observation of this decay mode. The reconstructed spectrum of $e^+e^-\gamma$ invariant mass is presented in Fig. 2, along with MC expectations for background contributions. The model-independent partial width in the accessible kinematic region ($M_{ee\gamma} > 0.26 GeV/c^2$) is measured to be:

$$BR(M_{ee\gamma} > 0.26) = (1.19{\pm}0.12_{sta}{\pm}0.04_{sys})\cdot 10^{-8} \quad (2)$$

The ChPT parameter $\hat{c}$ assuming O($p^4$) distribution in [3] was measured to be $\hat{c} = 0.90 \pm 0.45$. The final results of the analysis have been recently published [4].

## 5. The $K^\pm \to \pi^\pm e^+e^-$ decay rate

The decay is supposed to proceed through one photon exchange, resulting in a spectrum of the $z = (M_{ee}/M_K)^2$ kinematic variable sensitive to the form factor W(z). The following parameterizations of the form factor W(z) are considered in the analysis:
1. Linear:

$$W(z) = G_F M_K^2 f_0(1 + \delta z) \quad (3)$$

with free normalization and slope ($f_0$, $\delta$).
2. Next-to-leading order ChPT:

$$W(z) = G_F M_K^2 f_0(a_+ + b_+ z) + W^{\pi\pi}(z) \quad (4)$$

with free parameters ($a_+$, $b_+$), and an explicitly calculated pion loop term $W^{\pi\pi}(z)$ [5].
3. The Dubna version of ChPT[6] parametrization involving meson form factors:

$$W(z) \equiv W(M_a, M_\rho, z) \quad (5)$$

with resonance masses ($M_a$, $M_\rho$) treated as free parameters.

The $K^\pm \to \pi^\pm e^+e^-$ rate is measured relatively to the abundant $K^\pm \to \pi^\pm\pi^0_D$ normalization channel. The final states of the signal and

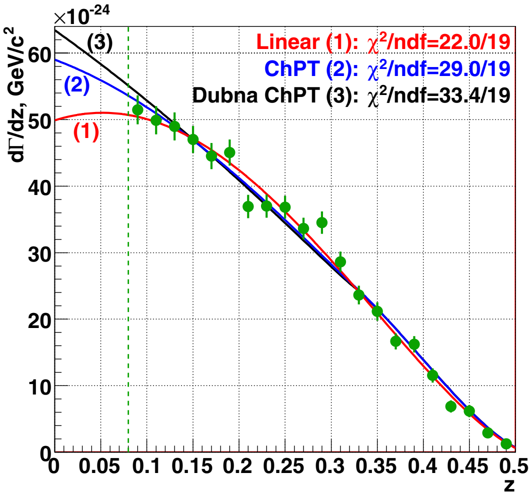


Figure 3. Computed $d\Gamma_{ee}/dz$ (background subtracted, trigger efficiencies corrected for) and the results of fits according to the considered models.

normalization channels contain identical sets of charged particles. Thus particle identification efficiencies, representing a significant source of systematic uncertainties, cancel in the first order. At the end of the selection on whole 2003 2004 data sample 7146 candidates $K^{\pm} \to \pi^{\pm} e^{+} e^{-}$ are found in the signal region, with an estimated background of 44 events (0.6%).

Table 1 shows the result of fits to the distribution of rate vs z, using the three different parametrization. All the fits are of reasonable quality, however the linear form-factor model leads to the smallest $\chi^2$ (see Fig. 3). Unfortunately the data sample is insufficient to distinguish between the models considered. The branching ratio in the full kinematic range, which is computed as the average between the two extremes corresponding to the models 1 and 3, and includes an uncertainty due to extrapolation into the inaccessible region $z < 0.08$, is:

$$BR_{MI} = (3.08 \pm 0.04_{sta} \pm 0.04_{sys} \pm 0.08_{ext} \pm 0.07_{mod}) \cdot 10^{-7} = (3.08 \pm 0.12) \cdot 10^{-7} \quad (6)$$

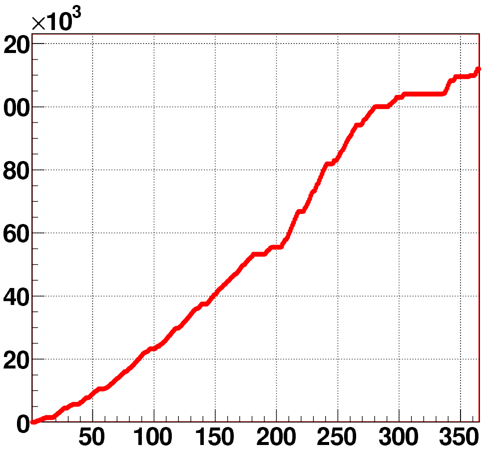


Figure 4. Cumulative distribution of the number of Ke2 candidates recorded in 2007.

Finally, a first measurement of the direct CP violating asymmetry of $K^+$ and $K^-$ decay rates in the full kinematic range was obtained by performing BR measurements separately for $K^+$ and $K^-$ and neglecting the correlated uncertainties: $\Delta(K^{\pm}_{\pi ee}) = (BR^+ - BR^-)/(BR^+ + BR^-) = (-2.1 \pm 1.5_{sta} \pm 0.3_{sys})\%$. The result is compatible to no CP violation.

## 6. The ratio $K_{e2}/K_{\mu 2}$

Despite the poor theoretical control on the meson decay constants, ratios of leptonic decay rates of pseudoscalar mesons, such as $R_K \equiv \Gamma(K_{e2})/\Gamma(K_{\mu 2})$, can be predicted with high accuracy within a given model, and have been considered as stringent tests of the V-A structure of weak interactions and of lepton universality. By convention, the definition of $R_K$ includes the inner bremsstrahlung (IB) part of the radiative $K_{l2\gamma}$ processes, while the structure dependent (SD) processes are considered as background. The SM prediction [8] is: $R_K^{SM} = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{M_K^2 - m_e^2}{M_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \cdot 10^{-5}$ where $\delta R_{QED} = -3.6\%$ is a correction due to the $K_{l2\gamma}$(IB) and virtual photon processes. A recent theoretical study [7] points

Table 1
Results of fits to the three considered models, and the model independent $BR_{MI}(z > 0.08)$.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\delta$ | = | 2.35 | ± | 0.15 stat | ± | 0.09 syst | ± | 0.00 ext | = | 2.35 | ± | 0.18 |
| $f_0$ | = | 0.532 | ± | 0.012 stat | ± | 0.008 syst | ± | 0.007 ext | = | 0.532 | ± | 0.016 |
| $BR_1 \cdot 10^7$ | = | 3.02 | ± | 0.04 stat | ± | 0.04 syst | ± | 0.08 ext | = | 3.02 | ± | 0.10 |
| a+ | = | -0.579 | ± | 0.012 stat | ± | 0.008 syst | ± | 0.007 ext | = | -0.579 | ± | 0.016 |
| b+ | = | -0.798 | ± | 0.053 stat | ± | 0.037 syst | ± | 0.017 ext | = | -0.798 | ± | 0.067 |
| $BR_2 \cdot 10^7$ | = | 3.11 | ± | 0.04 stat | ± | 0.04 syst | ± | 0.08 ext | = | 3.11 | ± | 0.10 |
| Ma/GeV | = | 0.965 | ± | 0.028 stat | ± | 0.018 syst | ± | 0.002 ext | = | 0.965 | ± | 0.033 |
| M$\rho$/GeV | = | 0.711 | ± | 0.010 stat | ± | 0.007 syst | ± | 0.002 ext | = | 0.711 | ± | 0.013 |
| $BR_3 \cdot 10^7$ | = | 3.15 | ± | 0.04 stat | ± | 0.04 syst | ± | 0.08 ext | = | 3.15 | ± | 0.10 |
| $BR_{MI} \cdot 10^7$ | = | 2.26 | ± | 0.03 stat | ± | 0.03 syst | ± | 0.06 ext | = | 2.26 | ± | 0.08 |

out that lepton flavor violating effects arising in SUSY extensions of the SM can induce sizable violations of the $\mu - e$ universality, shifting $R_K$ by a relative amount that can be as large as a few %, without contradicting any other presently known experimental constraints. The PDG 2006 world average [9] was based on experiments performed in the 1970s and in terms of precision, $\delta R_K/R_K = 4.5\%$, was far from the level allowing SM tests.

Na48/2 collected two different data sample during summer 2003 and 2004, with different trigger conditions. From those samples ~8K $K_{e2}$ candidates were selected (4670 in 2003, 3407 in 2004) leading to following preliminary results for $R_K$:

$$R_K('03) = (2.416 \pm 0.043_{sta} \pm 0.024_{sys}) \cdot 10^{-5} \quad (7)$$

$$R_K('04) = (2.455 \pm 0.045_{sta} \pm 0.041_{sys}) \cdot 10^{-5} \quad (8)$$

The main contribution to the systematic uncertainties comes from the estimate of $K_{\mu 2}$ background, due to particle misidentification, in the $K_{e2}$ sample. The above results from the NA48/2 together with recent preliminary by KLOE collaborations, lead to a world average of $R_K^{2007} = (2.433 \pm 0.036) \cdot 10^{-5}$, [10] which has a precision of $\delta R_K/R_K = 1.5\%$ not sufficient to explore SUSY enhancement of the ratio. To push the precision of the measurement below the % level, in 2007 Na62 devoted to the $K_{e2}$ physics a run which extends from the end of June to October, collecting a total number of $K_{e2}$ candidates grater than 110K. Fig. 4 shows the trend of the data collection. In order to achieve a better knowledge of the $K_{\mu 2}$ background, special runs have been taken to directly measure the muon misidentification probability.

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