Study of the rare decay $K^+ \to \pi^+\gamma\gamma$ at the NA62 experiment

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Abstract

Results of the study of a rare kaon decay $K^+ \to \pi^+\gamma\gamma$ at the NA62 experiment are presented. The model-independent branching fraction and decay spectrum are measured and compared with previous measurements and the prediction of the Chiral Perturbation Theory. Combined results of NA48/2 and NA62 data samples are also discussed.

1 Introduction

Radiative non-leptonic decays provide a good opportunity to test the predictions of the Chiral Perturbation Theory (ChPT). The differential decay rate of $K^\pm \to \pi^\pm\gamma\gamma$ process is calculated within ChPT in the next-to-leading order and can be parametrized in a following way [1]:

$$\frac{\partial\Gamma}{\partial y \partial z}(\hat{c}, y, z) = \frac{m_K}{2^9\pi^3}\left[z^2\left(|A(\hat{c}, z, y^2) + B(z)|^2 + |C(z)|^2\right) + \left(y^2 - \frac{1}{4}\lambda(1, r_\pi^2, z)\right)^2 |B(z)|^2\right]$$

where $z = m_{\gamma\gamma}^2/m_K^2$, $y = p(q_1 - q_2)/m_K^2$; p, q_1 and q_2 are kaon and photon 4-momenta.

At the lowest order of ChPT O(p^4) the main contribution comes from the loop term $A(z, \hat{c})$ including pion and kaon loop amplitudes. This term is a function of an unknown parameter $\hat{c}$ ($\hat{c}$ ∼O(1)). In the next-to-leading order ChPT O(p^6) an additional loop term $B(z)$ appears in the differential decay rate. $C(z)$ is a pole amplitude, its contribution does not exceed 5%

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[1, 2]. Another important feature of the decay is a cusp structure in the invariant $\gamma\gamma$ mass (or, in other terms, in the distribution over z) at the double pion mass. Fig. 1 illustrates ChPT predictions for several values of $\hat{c}$.

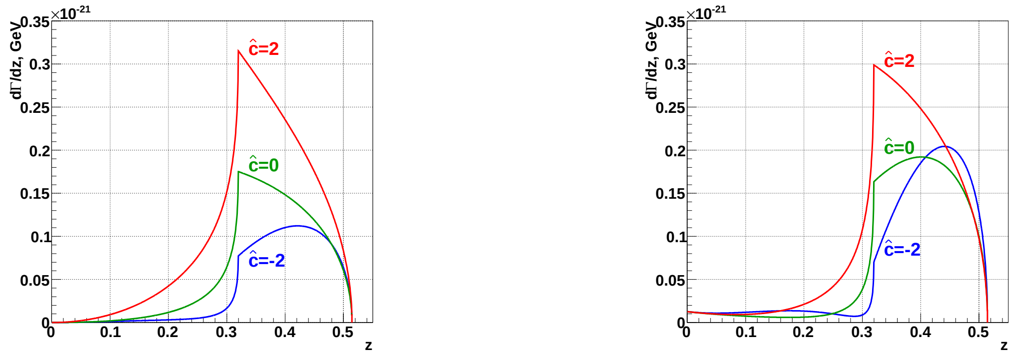

Figure 1: Differential decay rate as a function of z for ChPT O(p^4) (left) and O(p^6) (right) for different values of $\hat{c}$.

The absolute value of the branching fraction predicted by ChPT is $\sim 10^{-6}$. The first experimental measurement of the decay was done by BNL E787 experiment [3]. They selected 31 candidates in the following kinematic region: 100 MeV/c $< p_\pi <$180 MeV/c (here p_π is a pion momentum in the kaon rest frame). A significant improvement was done by NA48/2 [4] and NA62-R_K [5] experiments. These results are discussed in the paper.

2 NA62 experiment

The NA48/2 and NA62 experiments at the CERN SPS collected a large sample of charged kaon decays. The 2003-2004 Run (NA48/2) was dedicated to the search of CP violation, while in 2007-2008 (NA62) the main goal was to measure the ratio of two leptonic decay rates. Besides that, a lot of other studies were allowed, including the decay $K^+ \to \pi^+\gamma\gamma$.

At the first stage (called NA62-R_K), the NA62 experiment used the NA48/2 setup (Fig. 2) which is widely described in literature [6]. The main parts relevant for the measurement of $K^+ \to \pi^+\gamma\gamma$ decay are a magnetic spectrometer consisting of a dipole magnet and four drift chambers and a liquid krypton calorimeter. A charged hodoscope made of scintillator tiles provided a fast trigger signal.

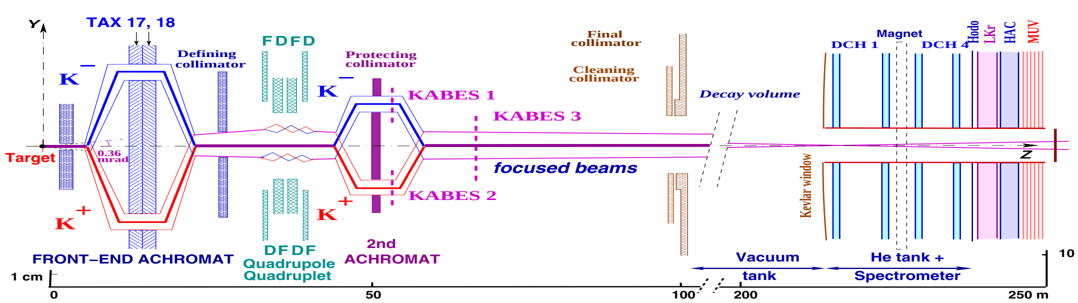

Figure 2: NA48/2 experimental setup.

The kaon beam was produced by a CERN SPS proton beam (p=400 GeV/c) impinging on a berillium target. The kaon momentum was (60.0±2.2) GeV/c in 2003-2004 (NA48/2 data) and (74.0±1.4) GeV/c in 2007-2008 (NA62-R_K).

3 Analysis of the 2007-2008 Run data

After several selections described in detail in [5] 232 candidates were chosen for the analysis with 17.4±1.1 background. Fig. 3 shows an invariant $\pi\gamma\gamma$ mass, while Fig. 4 illustrates the distribution over z. The cusp-like structure predicted by ChPT is clearly seen.

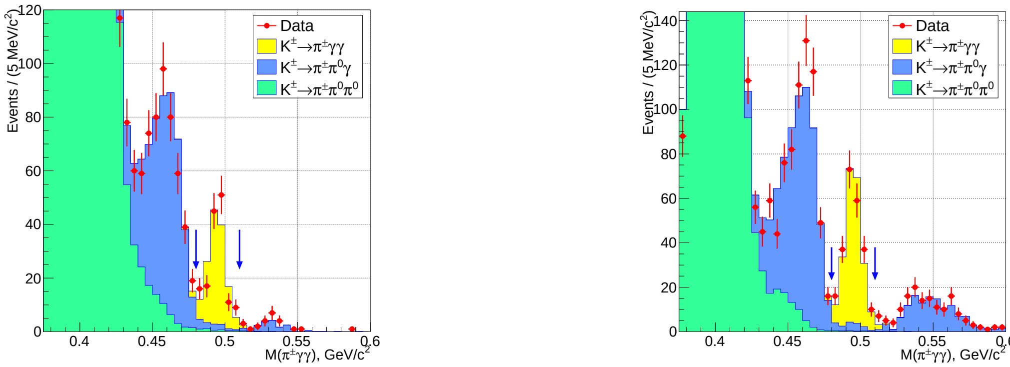

Figure 3: Distribution over $\pi\gamma\gamma$ mass. NA48/2 data are shown on the left, NA62-R$_K$ on the right. Arrows indicate a selected signal region.

For the model-independent measurement of the branching ratio (BR) the kinematic range $0.2 < z < 0.55$ was taken and divided into 8 small intervals (z-bins). The bin size was chosen so that the acceptance was model-independent within a bin. Summing up over z-bins, the following value was obtained: BR(MI) $(z > 0.2) = (1.088 \pm 0.093_{stat} \pm 0.027_{syst}) \times 10^{-6}$. The main contribution to the systematic error comes from the background estimates.

From fitting the reconstructed z-spectrum (log-likelihood method is used) the parameter $\hat{c}$ is extracted. It is evaluated within ChPT O(p^4) and O(p^6). Using the extracted value of $\hat{c}$ it is possible to calculate model-dependent BR within ChPT O(p^6) in the whole kinematical range. The results are summarized in Table 1.

4 Combined NA48/2 and NA62 results

The NA48/2 data used for the analysis contain a dedicated run in 2004 with a special trigger (at least one track in the spectrometer and at least 10 GeV energy deposited in the calorimeter) and lower intensity.

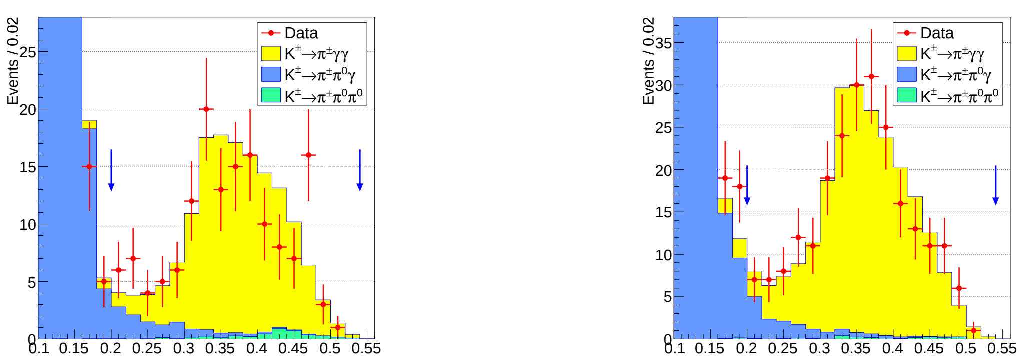

Figure 4: Distribution over $z = (m_{\gamma\gamma}/m_K)^2$ for the selected signal region. NA48/2 data are shown on the left, NA62-R$_K$ on the right. Arrows indicate a selected signal region.

The combined data are shown in Fig. 5. The obtained numbers are summarized in Table 1. To compare NA48/2+NA62 results with the values obtained by the E787 experiment, external parameters should be synchronized. The NA48/2+NA62 results recalculated with the E787 external parameters are summarized in Table 2. The results are in a good agreement, with a significant improvement in the measurement accuracy.

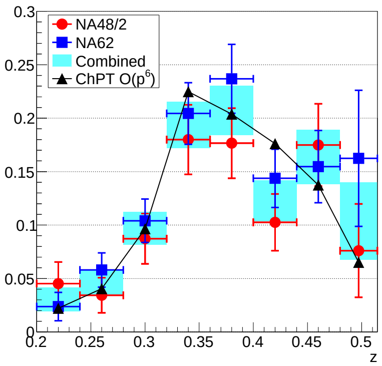

Figure 5: Model-independent BR for selected z-bins. Black points correspond to the ChPT O(p^6) prediction (differential decay rate integrated over a bin) with $\hat{c}$=1.86.

data	$\hat{c}_4$	$\hat{c}_6$	$BR_{ChPT}(\hat{c}_6) \times 10^6$	BR(MI) $\times 10^6$
NA48/2	$1.37 \pm 0.33_{stat} \pm 0.14_{syst}$	$1.41 \pm 0.38_{stat} \pm 0.11_{syst}$	$0.910 \pm 0.072_{stat} \pm 0.022_{syst}$	$0.877 \pm 0.087_{stat} \pm 0.017_{syst}$
NA62-R$_K$	$1.93 \pm 0.26_{stat} \pm 0.08_{syst}$	$2.10 \pm 0.28_{stat} \pm 0.18_{syst}$	$1.058 \pm 0.066_{stat} \pm 0.044_{syst}$	$1.088 \pm 0.093_{stat} \pm 0.027_{syst}$
Combined	$1.72 \pm 0.20_{stat} \pm 0.06_{syst}$	$1.86 \pm 0.23_{stat} \pm 0.11_{syst}$	$1.003 \pm 0.051_{stat} \pm 0.024_{syst}$	$0.965 \pm 0.061_{stat} \pm 0.014_{syst}$

Table 1: NA48/2 and NA62 results on $\hat{c}$ and BR measurement.

data	$\hat{c}_4$	$\hat{c}_6$	$BR_{ChPT}(\hat{c}_6) \times 10^6$
NA48/2+NA62	$1.60 \pm 0.20_{stat} \pm 0.06_{syst}$	$1.56 \pm 0.23_{stat} \pm 0.11_{syst}$	$1.003 \pm 0.051_{stat} \pm 0.024_{syst}$
E787	1.6 ± 0.6	1.8 ± 0.6	$1.1 \pm 0.3_{stat} \pm 0.1_{syst}$

Table 2: Comparison between NA48/2+NA62 and E787 results. NA48/2+NA62 values are recalculated using E787 external parameters.

5 Conclusions

The decay $K^+ \to \pi^+\gamma\gamma$ has been studied by NA48/2 and NA62 experiments. A cusp-like structure in the distribution over z predicted by ChPT is confirmed. The results on BR and $\hat{c}$ measurements from NA48/2 and NA62-R$_K$ are combined. The model-independent BR is measured in the range z>0.2 and found to be $(0.965 \pm 0.061_{stat} \pm 0.014_{syst}) \times 10^{-6}$. The $\hat{c}$ parameter value is extracted within ChPT O(p^4) and O(p^6). The obtained values are in agreement with previous measurements.

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