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# Study of the rare decay $K^{\pm} \longrightarrow \pi^{\pm}\gamma\gamma$

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**Abstract.** The NA62 and NA48/2 experiments at CERN collected a large sample of charged kaon decays with a low intensity beam and minimum bias trigger conditions in 2004 (NA48/2) and 2007 (NA62). This allowed measurements of a number of rare decays that are difficult to address in conventional high intensity experiments with highly selective trigger conditions. In particular, large samples of $K^{\pm} \to \pi^{\pm}\gamma\gamma$decays have been collected, allowing precision tests of the Chiral Perturbation Theory.

## 1. Introduction

The CERN kaon facility is located in the North Area (NA) extraction line of the SPS accelerator: charged kaon beams are produced, for NA48/2 in 2004 and NA62 ($R_K$ phase, more details can be found in [1]) in 2007, by 400 GeV/c protons impinging on a beryllium target. The NA48/2 experiment used two simultaneous $K^{\pm}$ beams with $(60 \pm 3)$ GeV/c momentum range, while the NA62 experiment used a modified beam line which provided $K^+$ or $K^-$ with momenta of $(74.0 \pm 1.4)$ GeV/c. For both the experiments the main subdetectors used for the analyses are: a magnetic spectrometer, composed by 4 drift chambers ($\sigma_p/p = 1.02\% \oplus 0.044\% \times p$ for NA48/2 and $\sigma_p/p = 0.48\% \oplus 0.009\% \times p$ for NA62 with $p$ in GeV/c); an hodoscope which can provide a fast trigger, $\sigma_t = 150$ ps; a Liquid

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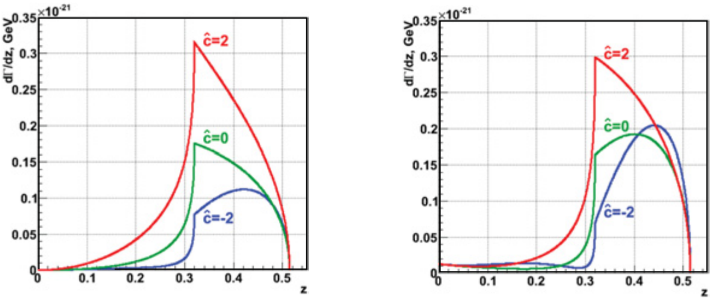



(a) $O(p^4)$.

(b) $O(p^6)$.

**Figure 1.** $z = m_{\gamma\gamma}^2/m_K^2$ spectrum for three different ĉ values at $O(p^4)$ (a) and $O(p^6)$ (b).

Krypton electromagnetic calorimeter with high granularity and quasi-homogeneous medium ($\sigma_E/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$ [E in GeV], $\sigma_x = \sigma_y = 4.2\,\text{mm}/\sqrt{E} \oplus 0.6\,\text{mm}$ (1.5 mm@10 GeV)). A detailed description of the detectors can be found in [2].

## 2. $K^\pm \to \pi^\pm\gamma\gamma$

The double differential rate for unpolarized photon, predicted by the Chiral Perturbation Theory (CHPT) [3], is:

$$\frac{d^2\Gamma}{dydz} = \frac{M_K}{2^9\pi^3}\left\{z^2\left(|A+B|^2+|C|^2\right)+\left[y^2-\frac{1}{4}\lambda(1,r_\pi^2,z)\right]^2\left(|B|^2+|D|^2\right)\right\},$$

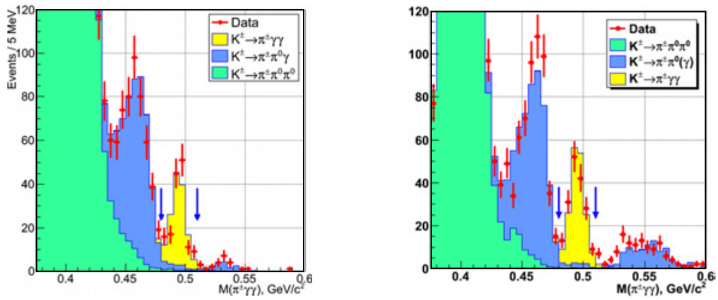
where $\lambda(a,b,c) = a^2+b^2+c^2-2(ab+bc+ca)$, $r_\pi = \frac{m_\pi}{m_K}$. $A$, $B$, $C$ and $D$ are invariant amplitudes functions of the two kinematic variables $z$ and $y$, defined as:

$$z = \frac{\left(P_{\gamma_1}+P_{\gamma_2}\right)^2}{m_K^2} = \frac{m_{\gamma\gamma}^2}{m_K^2} \quad \text{and} \quad y = \frac{P_K\cdot\left(P_{\gamma_1}-P_{\gamma_2}\right)}{m_K^2}.$$

This decay is particularly interesting because it vanishes at tree level[1] and is expected to show a "cusp-like" effect for $m_{\gamma\gamma} = 2m_{\pi^\pm}$ ($z \sim 0.32$); at $O(p^4)$ the $B$ and $D$ amplitude are still zero (they arise only at $O(p^6)$) and the rate and the spectrum are predicted to depend on $A$ and $C$. While $C$ depends only on known quantities, $A$ depends on a single $O(1)$ unknown parameter: ĉ. The $z$ spectrum dependence on ĉ at $O(p^4)$ is shown in Fig. 1a, where the predicted cusp threshold is visible. An $O(p^6)$ complete evaluation has not been performed yet, but the main contributions have been estimated: unitary corrections [4] increase the branching ratio (BR) at low ĉ values and result in a non-zero rate at $m_{\gamma\gamma} \to 0$, as shown in Fig. 1b.

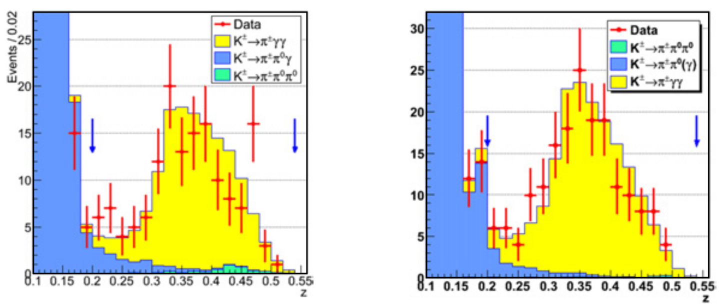
In this theoretical context the aim of NA48/2 and NA62 is to determine the ĉ value by fitting the $z$ spectrum: knowing ĉ it is possible to determine a model dependent BR. Concretely two separate analyses have been performed on the NA48/2 data sample, collected in 2004, and on the data sample collected in 2007 by NA62. In 2004 data have been collected for 3 days with a minimum bias trigger, while in 2007 the minimum bias trigger was downscaled ($D \approx 20$): in 3 months of data taking a comparable statistics with 2004 run data was collected. Final results have been obtained combining the two analyses and taking into account the correlated systematics. The invariant mass distribution, $M(\pi^\pm\gamma\gamma)$, for both 2004 and 2007 data is shown in Fig. 2, where a cut on $m_{\gamma\gamma} > 220$ MeV/c$^2$ is applied; the simulations for the

[1] At $O(p^2)$ $A$=$B$=$C$=$D$=0.




(a) 2004.    (b) 2007.

**Figure 2.** $M(\pi^{\pm}\gamma\gamma)$ spectrum for 2004 (a) and 2007 (b) data.




(a) 2004.    (a) 2007.

**Figure 3.** $z$ spectrum for 2004 (a) and 2007 (b) data.

**Table 1.** Signal candidates and main backgrounds contributions for both NA48/2 and NA62 data.

| | NA48/2 | NA62 |
|---|---|---|
| $K_{\pi\gamma\gamma}$ candidates | 149 | 175 |
| $K_{2\pi(\gamma)}$ background | $11.4 \pm 0.6$ | $11.1 \pm 1.0$ |
| $K_{3\pi}$ background | $4.1 \pm 0.4$ | $1.3 \pm 0.3$ |
| $K_{\pi\gamma\gamma}$ signal | $134 \pm 12$ | $163 \pm 13$ |

signal and the backgrounds[2] are also shown. On the other hand Fig. 3 shows the $z$ distribution for both 2004 and 2007 data; the simulations based on $O(p^6)$ calculations for signal and backgrounds are also shown. There is a visible signal region above the $K^+ \to \pi^+\pi^0$ peak, i.e. $z > 0.2$, and also indications of cusp-like behavior at $2m_\pi$. Table 1 summarizes for both 2004 (NA48/2) and 2007 (NA62) data samples the number of signal candidates and the main backgrounds contributions.

The $z$ distribution can be used to fit $\hat{c}$ using both $O(p^4)$ and $O(p^6)$ models. The results obtained using 2004 data are

$$O(p^4) : \hat{c} = 1.36 \pm 0.33_{stat} \pm 0.07_{syst} = 1.36 \pm 0.34$$
$$O(p^6) : \hat{c} = 1.67 \pm 0.39_{stat} \pm 0.09_{syst} = 1.67 \pm 0.40,$$

[2] Backgrounds are $K^{\pm} \to \pi^{\pm}\pi^0(\gamma)$ events (where the additional $\gamma$ is an accidental one) and $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ events (with a missed $\gamma$ from both the $\pi^0$'s.

while using 2007 data

$$O(p^4): \ \hat{c} = 1.71 \pm 0.29_{stat} \pm 0.06_{syst} = 1.71 \pm 0.30$$
$$O(p^6): \ \hat{c} = 2.21 \pm 0.31_{stat} \pm 0.08_{syst} = 2.21 \pm 0.32$$

and, finally, for combined analyses

$$O(p^4): \ \hat{c} = 1.56 \pm 0.22_{stat} \pm 0.07_{syst} = 1.56 \pm 0.23$$
$$O(p^6): \ \hat{c} = 2.00 \pm 0.24_{stat} \pm 0.09_{syst} = 2.00 \pm 0.26.$$

The shapes of the $z$ spectrum for $O(p^4)$ and $O(p^6)$ $\hat{c}$ values, obtained from combined analyses fit, are close one to each other and it is not possible to discriminate between the two models yet. Assuming $O(p^6)$ model, the model dependent branching ratio obtained is:

$$BR = (1.01 \pm 0.06) \times 10^{-6}$$

which is compatible with the PDG [5] value:

$$BR = (1.10 \pm 0.32) \times 10^{-6}$$

but with a factor $\sim 5$ of uncertainty improvement.

It is also possible to evaluate a model independent Branching Ratio in the signal region, $z > 0.2$, by computing partial branching fractions in 8 sufficiently small z bins, such that the acceptance is almost independent of kinematical distribution. The value obtained is

$$BR_{MI}(z > 0.2) = (0.877 \pm 0.087_{stat} \pm 0.017_{syst}) \times 10^{-6}$$

where the main systematic effect are caused by the background estimate (LKr cluster merging).

## 3. Conclusions

Combined results for $K^{\pm} \to \pi^{\pm}\gamma\gamma$decays, in 2004 and 2007 data, allow the measurement of $\hat{c}$ in both $O(p^4)$ and $O(p^6)$ frame. The model dependent $BR$ obtained is compatible with the PDG value, but with a much smaller error ($\sim$ 5 times). Moreover the model independent Branching Ratio has been presented.

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