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$K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ Studies at NA48/2 and NA62-RK Experiments at CERN

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Abstract

Final results from an analysis of about 400 $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ rare decay candidates collected by the NA48/2 and NA62-RK experiments at CERN during low intensity runs with minimum bias trigger configurations are presented. The results include a model-independent decay rate measurement and fits to Chiral Perturbation Theory (ChPT) description. The data support the ChPT prediction for a cusp in the di-photon invariant mass spectrum at the two pion threshold.

2000 MSC: 81V05, 81V15

1. Introduction

The study of $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ decay kinematic properties is a good test of the Chiral Perturbation Theory (ChPT) description of weak low energy processes. A fit of the data to the ChPT prediction[3] is presented. In addition the model-independent branching ratio is computed. The data used in this work were recorded in 2003 and 2004 by NA48/2 experiment[1] and in 2007 by the NA62-RK experiment[2]. A total of 381 $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ candidates were stored on disk. The NA48/2 and NA62-RK data sets were analysed separately but with the same software stack. The signal and the normalization events were collected using the same trigger logic, allowing to minimise systematic uncertainties.

Due to limited space the plots presented are derived from the NA62-RK data set. However NA48/2 and NA48/2 & NA62-RK combined results are presented in Table 1.

2. Experimental Setup

NA48/2 and NA62-RK experiments exploited the same detector but were running with different beam momentum, 60 GeV/c and 74 GeV/c, respectively. The unseparated hadron secondary beam was obtained from 400 GeV/c protons accelerated by the CERN SPS impinging a beryllium target.

Both experiments relied on a decay-in-flight technique. After momentum selection the particles entered an evacuated volume where about 22% (NA48/2) and 18% (NA62-RK) of the secondary beam kaons decayed.

The momenta of the charged decay products were reconstructed by a magnetic spectrometer (DCH). The energy of the released photons were measured by a liquid krypton electromagnetic calorimeter (LKr). A charged particle hodoscope placed after the spectrometer and a neutral particle hodoscope located in the LKr were used for triggering purposes. The undecayed particle traveled along the beam pipe without interacting in detectors. The DCH magnet field strength was increased for the NA62-RK experiment in order to accommodate the

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and the NA62-RK Collaboration: Birmingham, CERN. Dubna, Fairfax, Ferrara, Firenze, Frascati, Mainz, Merced, Moscow, Napoli, Perugia, Pisa, Protvino, Roma I, Roma II, Saclay, San Luis Potosi, Stanford, Sofia, Torino, TRIUMF.

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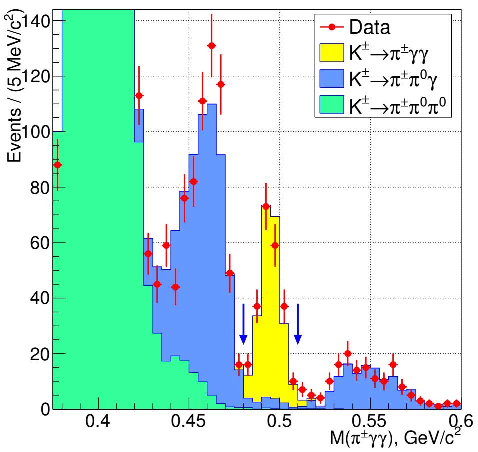

Figure 1: Invariant mass distribution of signal events. The signal region is indicated by the vertical arrows.

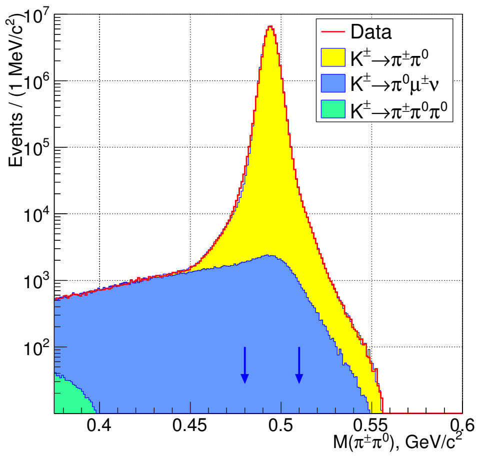

Figure 2: Invariant mass distribution of normalization events. The signal region is indicated by the vertical arrows.

beam momentum change. The resolution of the spectrometer was therefore $\sigma_p/p = (1.02 \oplus 0.044 \cdot p)\,\%$ for NA48/2 and $\sigma_p/p = (0.48 \oplus 0.009 \cdot p)\,\%$ for NA62-RK, with p in GeV/c. The energy resolution of the LKr was $\sigma_E/E = \left(3.2/\sqrt{E} \oplus 9/E \oplus 0.42\right)\%$ for both experiments, with E in GeV.

A complete description of the detector can be found in [4] and [5].

3. Experimental Method

The number of $K^\pm \to \pi^\pm\gamma\gamma$ signal events was normalized to the well known $K^\pm \to \pi^\pm\pi^0$ decay. Figures 1 and 2 show the reconstructed invariant mass distribution of the signal and of the normalization events.

Both were selected with the same minimum bias trigger chain.

The branching ratio, $\mathcal{B}$, is calculated as follows

$$\mathcal{B}\left(K_{\pi\gamma\gamma}\right) = \frac{N'_{\pi\gamma\gamma}}{N'_{2\pi}} \cdot \frac{A_{2\pi}}{A_{\pi\gamma\gamma}} \cdot \frac{\epsilon_{2\pi}}{\epsilon_{\pi\gamma\gamma}} \cdot \mathcal{B}\left(K_{2\pi}\right) \cdot \mathcal{B}\left(\pi^0_{\gamma\gamma}\right)$$

with A the acceptances determined with a Monte Carlo simulation, ϵ the tigger efficiencies and N' the numbers of events after background subtraction for signal and normalisation modes.

The main background is the radiative decay $K^\pm \to \pi^\pm\pi^0(\to \gamma\gamma)\gamma$ with the same final state as the signal after the merging of two photon clusters.

4. $K^\pm \to \pi^\pm\gamma\gamma$ Model-Independent Branching Ratio

The model-independent decay rate is obtained from partial measurements of the branching ratio in eight independent z bins above 0.2. $\mathcal{B}_j$ is computed as follows:

$$\mathcal{B}_j = \left(N_j - N_j^B\right) / \left(N_K A_j\right)$$

where N_j is the number of signal events in bin j, N_j^B is the estimated number of background events in bin j, N_K is the kaon flux measured with $K^\pm \to \pi^\pm\pi^0$ decays and A_j is the signal acceptance for bin j. The acceptance is determined using Monte Carlo. The chosen bin width is small enough to consider a constant acceptance in each individual bin.

The $z > 0.2$ bins are then summed to obtain a model-independent branching ratio. The value is reported in Table 1.

5. Chiral Perturbation Theory Parameters Fits and Model-Dependent Branching Ratio

In order to compare the data and the ChPT prediction we compute the $z = \left(m_{\gamma\gamma}/m_K\right)^2$ distribution of signal events. The obtained spectrum is presented in Figure 4.

The $K^\pm \to \pi^\pm\gamma\gamma$ differential decay rate $\frac{\partial\Gamma}{\partial y \partial z}$ can be expressed in terms of two kinematical variables (y, z) and a free parameter $\hat{c}$ as described in [3].

The predicted $\mathrm{d}\Gamma/\mathrm{d}z$ distribution as a function of the $\hat{c}$ value for $O(p^6)$ parameterization is displayed in Figure 3.

The value of all external parameters used in this analysis are given in [1, 2].

A log-likelihoof fit was performed to obtain the $\hat{c}$ value from the reconstructed z spectrum which agrees with ChPT expectations (see Figure 4). Both $O(p^4)$ and $O(p^6)$ are equally favoured by the data.

	BNL E787	CERN NA48/2	CERN NA62-RK	NA48/2 & NA62-RK
Candidates	31	149	232	
Background events	5.1 ± 3.3	15.5 ± 0.7	17.4 ± 1.1	
$\mathcal{B}_{\mathrm{MI}}\,(z > 0.2) \times 10^6$	0.6 ± 0.15 ± 0.07*	0.877 ± 0.087 ± 0.017	1.088 ± 0.093 ± 0.027	0.965 ± 0.063
$\hat{c}_4$	1.6 ± 0.6	1.37 ± 0.33 ± 0.14	1.93 ± 0.26 ± 0.08	1.72 ± 0.21
$\hat{c}_6$	1.8 ± 0.6	1.41 ± 0.38 ± 0.11	2.10 ± 0.28 ± 0.18	1.86 ± 0.25
$\mathcal{B}_6 \times 10^6$	1.1 ± 0.3 ± 0.1	0.910 ± 0.072 ± 0.022	1.058 ± 0.066 ± 0.044	1.003 ± 0.056

Table 1: Current experimental state of the art for $K^\pm \to \pi^\pm\gamma\gamma$ decay. When two uncertainties are quoted the first is statistical and the second is the estimated systematic uncertainty. For the NA48/2 & NA62-RK combination their respective statistical and systematic uncertainties are assumed to be uncorrelated. $\hat{c}_4$ and $\hat{c}_6$ refers to the value obtained by a fit of the $O(p^4)$ and $O(p^6)$ parameterization, respectively. *The BNL E797 model-independent branching ratio is computed for $0.157 < z < 0.384$.

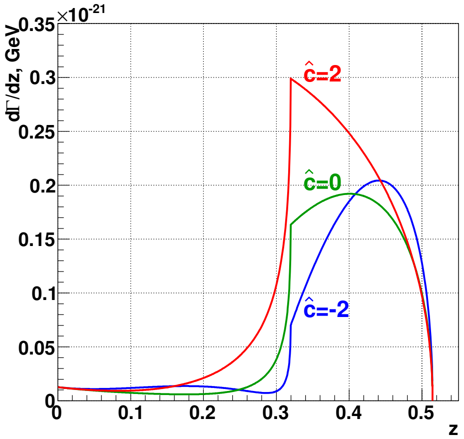

Figure 3: Next-to-leading order $O(p^6)$ expected z distribution for various values of $\hat{c}$. Notice cusp-like shape at the di-pion threshold ($z = 0.320$).

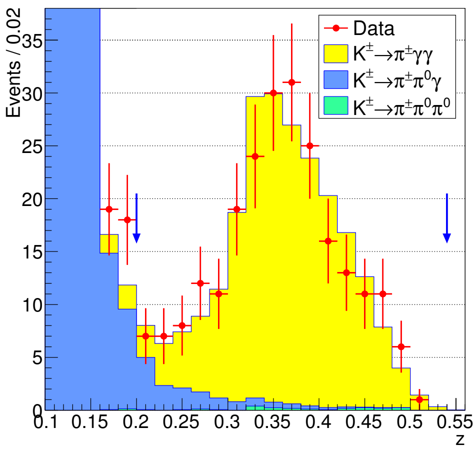

Figure 4: Reconstructed z spectrum. The estimated signal corresponds to the result of a ChPT $O(p^6)$ fit. Signal region limits are indicated with vertical arrows.

The model dependent branching ratio in the full kinematical range is obtained by integrating the ChPT $O(p^6)$ differential rate for the obtained value of $\hat{c}$.

Fits results and model-dependent total branching ratio are presented in Table 1.

6. Conclusion

Combining the NA48/2 and NA62-RK datasets the model-independent branching ratio of $K^\pm \to \pi^\pm\gamma\gamma$ was measured to be $(0.965 \pm 0.063) \times 10^{-6}$ for $z > 0.2$. The $O(p^6)$ ChPT parametrization presented in [3] describes well the data for $\hat{c}_6 = 1.86 \pm 0.25$. Furthermore the results agrees with the predicted cusp at the di-pion threshold ($z = 0.320$). Finally the model-dependent decay rate assuming a $O(p^6)$ parametrization was computed to be $(1.003 \pm 0.056) \times 10^{-6}$.

The main results are summarized in Table 1. The presented analyses are in good agreement with the previous Brookhaven E787[6] experiment. These measurements improve significantly on previous experimental knowledge of the $K^\pm \to \pi^\pm\gamma\gamma$ decay.

The upcoming NA62 run opens a new opportunity window for the study of non-leptonic kaon decays.

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