EPJ Web of Conferences **81**, 03005 (2014)
DOI: 10.1051/epjconf/20148103005

ChPT tests at NA48 and NA62

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Abstract. Final results from an analysis of about 400 $K^\pm \to \pi^\pm\gamma\gamma$ rare decay candidates collected by the NA48/2 and NA62 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.

1 Introduction

Sensitive tests for the ability of Chiral Perturbation Theory (ChPT) in describing weak low energy processes can be performed studying radiative non-leptonic decays. The $K^\pm \to \pi^\pm\gamma\gamma$ differential decay rate, in the ChPT framework, is parametrized in the following way [1] up to next-to-leading order:

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

where $z = m_{\gamma\gamma}^2/m_K^2$, $y = p(q_1 - q_2)/m_K^2$, and p, q_1, q_2 are the 4-momenta of the kaon and the two photons. The dominant contribution at lowest non-trivial order $O(p^4)$ comes from the loop term $A(z, \hat{c})$, including the pion and kaon loop amplitudes, which depends on an *a priori* unknown $O(1)$ parameter $\hat{c}$. The loop term $B(z)$ appears only at next-to-leading $O(p^6)$ order and $C(z)$ is the pole amplitude. The ChPT predictions for the decay spectra, using the $O(p^4)$ and $O(p^6)$ parametrization with different values of $\hat{c}$, are shown in Fig. 1. The $\gamma\gamma$ mass spectra show a characteristic cusp at twice the pion mass.The total branching ratio is predicted to be $BR(K^\pm \to \pi^\pm\gamma\gamma) \sim 10^{-6}$, with the pole amplitude contributing 5% or less [1, 2]. The only previous measurement of The $K^\pm \to \pi^\pm\gamma\gamma$ mode has been done by the BNL E787 experiment [3] with 31 K^+ candidates in the kinematic region of 100 MeV/c < p_π < 180 MeV/c, where p_π is the pion momentum in the kaon rest frame. The new NA48/2 [4] and NA62-R_K [5] measurements of the $K^\pm \to \pi^\pm\gamma\gamma$ decay at improved precision are reported here.

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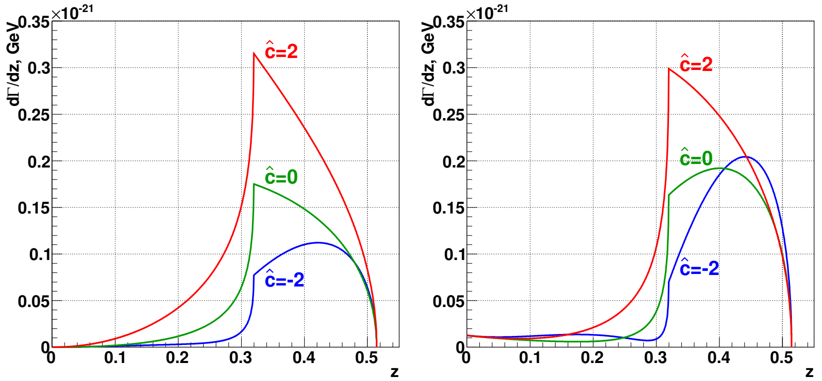

Figure 1. ChPT predictions for the differential decay rate in terms of z for $O(p^4)$ (left) and $O(p^6)$ (right) parametrizations with $\hat{c} = 2; 0; -2$.

The main components of the NA48/2 detector [6] were a magnetic spectrometer (4 drift chambers and a dipole magnet) and a liquid krypton electromagnetic calorimeter (LKr). A fast trigger signal was produced by a hodoscope (CHOD) made of plastic scintillator strips. By means of this apparatus, the NA48/2 [7] and the NA62-R_K[8] experiments, collected data from charged kaon decays in 2003-2004 and 2007 respectively. $K^\pm$ beams[1] were produced by a 400 GeV/c proton beam delivered by the CERN SPS and impinging on a beryllium target. Kaons with a momentum range of (60 ± 3) GeV/c were selected in NA48/2 and (74 ± 1) GeV/c in NA62-R_K. The NA48/2 data used for the present analysis were collected in 2004 during a dedicated run with a special trigger setup which only requires one or more tracks in the magnetic spectrometer and at least a energy deposit of 10 GeV/c in the electromagnetic calorimeter. Moreover, the intensity of the beam was lowered and the momentum spread was reduced to obtain an acceptable rate. Almost the same trigger was used during the entire NA62 2007 run (∼100 days), with an average downscale factor of ∼20.

2 Analysis strategy

3 Results

The plots in Fig. 2 show the $\pi^\pm\gamma\gamma$ invariant mass distributions compared with the MC signal and background contributions. The NA48/2 (NA62-R_K) signal sample contains 149 (232) candidates with a background contamination of 15.5 ± 0.7 (17.4 ± 1.1) events. The reconstructed z-spectra of the candidates, shown in Fig. 3, support a cusp-like shape at the two-pion mass as predicted by ChPT. In the kinematic range $z > 0.2$ we performed a model-independent measurement of the partial $K^\pm \to \pi^\pm\gamma\gamma$ branching ratio (see Fig. 4), by binning z in small intervals so that the dependence of the acceptance becomes negligible with respect to the statistical uncertainties[2]. By summing over the z bins, we obtain the model-independent branching ratio (see Fig. 4): $B_{\mathrm{MI}}(z{>}0.2) = (0.877 \pm 0.087_{\mathrm{stat}} \pm 0.017_{\mathrm{syst}}) \times 10^{-6}$ for NA48/2 and $B_{\mathrm{MI}}(z{>}0.2) = (1.088 \pm 0.093_{\mathrm{stat}} \pm 0.027_{\mathrm{syst}}) \times 10^{-6}$ for NA62-R_K. Systematics are mainly due to uncertainties of the background estimates. Using log-likelihood fits to the reconstructed z-spectra, the $\hat{c}$ parameter has been evaluated in the framework of ChPT $O(p^4)$ and $O(p^6)$ (Table 1). Moreover, by means of the $\hat{c}_6$ values in the ChPT parametrization, we could extend the BR calculation to the whole

[1] K^+ and K^- were delivered simultaneously for NA48/2, while in NA62-R_K only a K^+ beam was used.

[2] On the other hand, the y-dependence of the differential decay rate described in the ChPT framework, arises only at next-to-leading order and is anyhow very weak [1, 2].

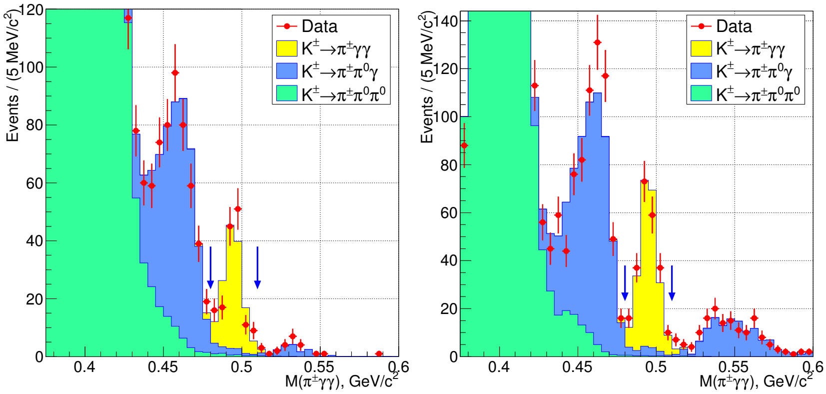

Figure 2. The $\pi^{\pm}\gamma\gamma$ invariant mass distribution in the NA48/2 (left) and NA62-R_K (right) data samples. The estimated $K^{\pm} \to \pi^{\pm}\gamma\gamma$ signal corresponds to the result of a ChPT $O(p^6)$ fit. The $K^{\pm} \to \pi^{\pm}\pi^0\gamma$ background contributes below, within and above the signal mass region through different mechanisms: photons missing the geometric acceptance (below); merging of photon LKr clusters (within); both, combined with photon conversions in the spectrometer (above). The signal region limits are indicated with vertical arrows.

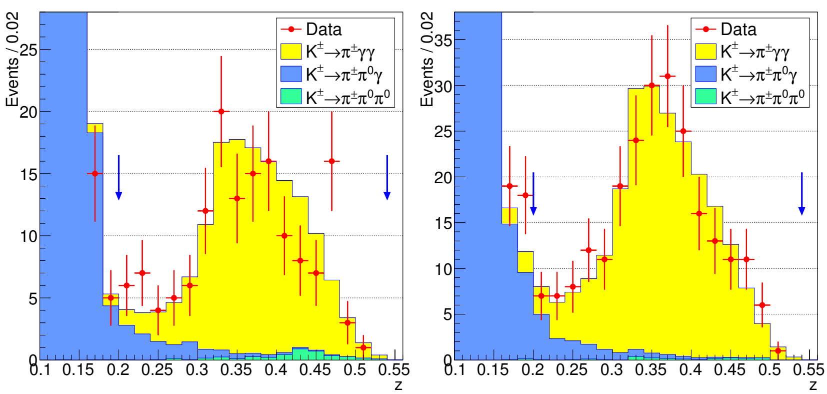

Figure 3. Reconstructed $z = (m_{\gamma\gamma}/m_K)^2$ spectrum of the $K^{\pm} \to \pi^{\pm}\gamma\gamma$ candidates in the NA48/2 (left) and NA62 (right) data, compared with the estimated contributions from the signal and the largest background $K^{\pm} \to \pi^{\pm}\pi^0\gamma$. The estimated signal is the result of a ChPT $O(p^6)$ fit. The signal region limits are indicated with vertical arrows.

physical region of the kinematic variables, obtaining model-dependent $K^{\pm} \to \pi^{\pm}\gamma\gamma$ branching ratios (shown in Table 1).

In conclusion, the combination of NA48/2 and NA62-R_K measurements of the model-independent branching ratio and the $\hat{c}$ ChPT parameter were presented here. The $\hat{c}$ parameter measured by E737 in 1997 [3] was 1.6 ± 0.6 at $O(p^4)$ and 1.8 ± 0.6 at $O(p^6)$, and the branching ratio was $(1.10 \pm 0.32) \times 10^{-6}$. The results from the NA48/2 and NA62-R_K measurement of the $K^{\pm} \to \pi^{\pm}\gamma\gamma$ decay agree with earlier data while significantly improving experimental precision (see bottom line of Table 1).

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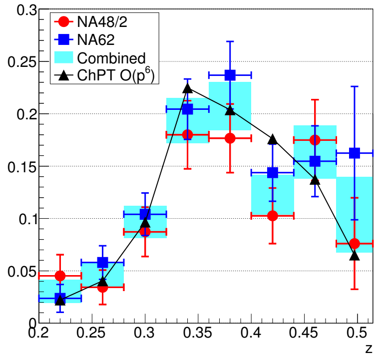

Figure 4. Measurement of the model-independent branching ratios in z bins by NA48/2 and NA62, and the combination of the two. The values of B_j computed within ChPT $O(p^6)$ formulation are obtained by integration of the ChPT differential decay rate for the central value of the combined measurement $\hat{c} = 1.86$ over the bin width.

Table 1. Results for the ChPT $\hat{c}$ parameter from fits to the z-distribution of $K^\pm \to \pi^\pm\gamma\gamma$ decays and the model-dependent branching ratios obtained using the ChPT $O(p^6)$ description.

	$\hat{c}_4$	$\hat{c}_6$	$B_{\rm ChPT}(\hat{c}_6)$
NA48/2	$1.37 \pm 0.33_{\rm stat} \pm 0.14_{\rm syst}$	$1.41 \pm 0.38_{\rm stat} \pm 0.11_{\rm syst}$	$(0.910 \pm 0.072_{\rm stat} \pm 0.022_{\rm syst}) \times 10^{-6}$
NA62-R_K	$1.93 \pm 0.26_{\rm stat} \pm 0.08_{\rm syst}$	$2.10 \pm 0.28_{\rm stat} \pm 0.18_{\rm syst}$	$(1.058 \pm 0.066_{\rm stat} \pm 0.044_{\rm syst}) \times 10^{-6}$
Combined	$1.72 \pm 0.20_{\rm stat} \pm 0.06_{\rm syst}$	$1.86 \pm 0.23_{\rm stat} \pm 0.11_{\rm syst}$	$(1.003 \pm 0.051_{\rm stat} \pm 0.024_{\rm syst}) \times 10^{-6}$

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