Standard Model predictions and new physics in rare Kaon Decays

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Rare kaon decays are historically important in flavour physics and, more generally, in the quest to establish the Standard Model with precision. For this purpose, the suitable theoretical framework to study them is chiral perturbation theory (ChPT), which describes the strong interactions at low energies.

The $\mathcal{L}_{\Delta S=1}$ weak chiral lagrangian up to NLO is written as

$$\mathcal{L}_{\Delta S=1} = \mathcal{L}^2_{\Delta S=1} + \mathcal{L}^4_{\Delta S=1} = G_8 F^4 \underbrace{\langle \lambda_6 D_\mu U^\dagger D^\mu U \rangle}_{K\to 2\pi/3\pi,\gamma\gamma} + \underbrace{G_8 F^2 \sum N_i W_i}_{K^+\to\pi^+\gamma\gamma,\ K\to\pi\pi\gamma} , \qquad (1)$$

The first term contains G_8, which is fixed by the $K \to \pi\pi$ amplitudes, while the second term represents the weak $\mathcal{O}(p^4)$ lagrangian and contains a number of counterterms N_i, which can be partially constrained through the measurement of three- and four-body kaon decays.

Radiative kaon decays are particularly interesting. Their electric amplitudes are sensitive to 5 NLO counterterms (see Table 1). They can be determined from the slope of the interference between LO and NLO amplitudes. For instance, from the study of the Dalitz plot of $K^\pm \to \pi^\pm\pi^0\gamma$ decays in the (T_c, W^2) plane one finds

$$\frac{\partial^2\Gamma}{\partial T_c^* \partial W^2} = \frac{\partial^2\Gamma_{IB}}{\partial T_c^* \partial W^2}\left[1 + \frac{m_{\pi^+}^2}{m_K} 2Re\left(\frac{E_{DE}}{eA}\right) W^2 + \frac{m_{\pi^+}^4}{m_K^2}\left(\left|\frac{E_{DE}}{eA}\right|^2 + \left|\frac{M_{DE}}{eA}\right|^2\right) W^4\right],$$

where $A = A(K^+ \to \pi^+\pi^0)$. The parameter X_E of Table 1 can be determined by measuring the term proportional to W^2.

It has been shown [1,2] that $K^\pm \to \pi^\pm\pi^0 e^+e^-$ can be combined with $K^\pm \to \pi^\pm\pi^0\gamma$ to achieve a determination of each single counterterm in Table 1. The recent experimental determinations for $K^\pm \to \pi^\pm\pi^0\gamma$ [3], $K^\pm \to \pi^\pm\pi^0 e^+e^-$ [4], $K_S \to \pi^0 e^+e^-$ [5] and $K^+ \to \pi^+\mu^+\mu^-$ [6], and further experimental improvements, for instance for $K_S \to \pi^+\pi^- e^+e^-$ [7] require more refined theoretical analyses of all these modes.

Another interesting aspects of three- and four-body rare kaon decays is that they can be used as probes of physics beyond the Standard Model. Given the rich kinematical structure of these decays, one can define observables that are very sensitive to new physics [1].

$K^\pm \to \pi^\pm \gamma^*$	$N_{14}^r - N_{15}^r$	$a_+ = -0.578 \pm 0.016$	NA48/2
$K_S \to \pi^0 \gamma^*$	$2N_{14}^r + N_{15}^r$	$a_S = (1.06^{+0.26}_{-0.21} \pm 0.07)$	NA48/1
$K^\pm \to \pi^\pm \pi^0 \gamma$	$N_{14}^r - N_{15}^r - N_{16}^r - N_{17}$	$X_E = (-24 \pm 4 \pm 4)\ \mathrm{GeV}^{-4}$	NA48/2
$K^+ \to \pi^+ \gamma\gamma$	$N_{14}^r - N_{15}^r - 2N_{18}^r$	$\hat{c} = 1.56 \pm 0.23 \pm 0.11$	NA48/2

Table 1: Weak chiral countertems and their connection to the measured slopes of different radiative decays.

Aside from the modes mentioned above, lepton flavor universality violation decays in kaon physics should be explored in more detail. For instance, an accurate measurement of the form factors in $K^\pm \to \pi^\pm e^+ e^-$ and $K^\pm \to \pi^\pm \mu^+ \mu^-$ would provide a bound on the Wilson coefficients $C_{7V}^{\mu\mu}$ and C_{7V}^{ee} [8]:

$$C_{7V}^{\mu\mu} - C_{7V}^{ee} = \alpha \frac{a_+^{\mu\mu} - a_+^{ee}}{2\pi\sqrt{2} V_{ud} V_{us}^*}. \tag{2}$$

Interestingly, this violation of nonuniversality can be related, under certain assumptions, with the anomalies observed in B-physics [8]. A deeper understanding of all these aspects related to rare kaon decays requires further experimental and theoretical analyses.

References

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