NEUTRAL KAONS AS INSTRUMENT
FOR STUDYING HEAVIER FLAVORS

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Abstract

Strangeness oscillations in decays of neutral kaons are suggested to be used as an analyzer to investigate detailed properties of heavy flavor hadrons and their decays. Here we briefly explain why, where, and to what problems this approach may be applied.

1 Introduction

History of physics provides many examples of how one studied phenomenon was used for investigating other phenomena. Here we discuss one more potential case of such a kind. Because of severe space limitations, this text can be only an extended summary of theoretical work done in the direction. For brevity reasons as well, references are given only to the basic papers published by the present author. A more complete text may be found in [1]. It contains also a longer list of references including related papers of different authors. Original papers are strongly recommended for interested readers.

Well-known for many years are strangeness oscillations in time evolution (and decays) of neutral kaons. They were applied to studies of the neutral kaons themselves to solve at least three kinds of experimental problems: 1) measurement of the tiny mass difference between two neutral kaon eigenstates, unattainable for conventional mass measurements; 2) identifying $K_L$ as the heavier eigenstate; 3) complete and unambiguous measurements of $CP$-violating parameters in various neutral kaon decays. As we will explain here, those strangeness oscillations can (and even should) be applied now to studies of heavier flavor hadrons (neutral and charged mesons, or even baryons).

2 Cascade decays

Cascade decay is a sequence of decays of both an initial state and its decay products. It consists of two or more stages which are usually considered to be quite independent of each other. However,
cascade decays producing neutral kaons may have specific properties. In particular, time distribution at their secondary stage (i.e., for the neutral kaon decay) may depend on parameters of the primary decay.

The simplest example is given by decays of charmed particles (charged mesons or baryons). An essential point here, emphasized in [2], is that Cabibbo-favored and Cabibbo-suppressed transitions together produce in such decays a coherent mixture of $K^0$ and $\bar{K}^0$. Then the neutral kaon system evolves and decays. Its decay-time distribution depends on the initial relative content of $K^0$ and $\bar{K}^0$, i.e. on properties of the primary decay.

More complicated are cascades initiated by neutral $D$ or $B$ mesons. The initial meson here, before its primary decay, develops flavor oscillations. To the decay moment it transforms into some coherent mixture of, say, $B^0$ and $\bar{B}^0$. Its content influences the neutral kaon content in the system which emerges just after the primary decay. Thus, the secondary strangeness oscillations coherently continue oscillations of the initial flavor, and we really deal with coherent double-flavor oscillations. Decay time distributions for the secondary kaons are sensitive here to both the primary decay and mixing properties of initial mesons. Moreover, time distributions of the primary and secondary decays are non-factorisable. Detailed expressions and their discussion may be found in [4, 5] for $B_d$, $B_s$ initial mesons and in [6] for $D$ mesons.

These examples demonstrate why and how the strangeness oscillations may be helpful in heavy flavor studies.

### 3 Problems for heavy flavors

In this section we briefly consider some problems in heavy flavor physics which may be solved by means of secondary kaon oscillations.

#### 3.1 Identification of meson eigenstates

Neutral $B$ or $D$ mesons, similar to kaons, evolve in time as a mixture of two eigenstates. To discriminate them one needs to use some labels. There are (at least) three possible labels, just as for kaons: 1) shorter/longer lifetime; 2) lighter/heavier mass; 3) odd/even $CP$-parity, at least approximate (definition of the approximate $CP$-parities and discussion of their possible mode-dependence see in [4, 7, 6]). To achieve complete identification of the eigenstates one should be able to relate all these labels with each other.

There seems to be no way for direct experimental connection between lifetime and mass labels (see discussion in [6]). However, it is very easy to relate lifetime with $CP$-parity. One should only compare time distributions in decays of neutral heavy flavor mesons to final states of definite (and different) $CP$-parities. The secondary kaon oscillations allow to connect $CP$-parities and masses of the heavy flavor eigenstates $1, 2, 3$, thus completing their identification. The procedure is similar to how it was done for kaons themselves, see discussion in [4, 5]. No other method for complete
identification of the heavy flavor eigenstates has been suggested till now.

3.2 Parameters of \( CP \)-violation

\( CP \)-violation in evolution of neutral \( B \) or \( D \) mesons and their decays to final states of definite \( CP \)-parities can be parametrized in a manner similar to kaons. However, it was first noticed in \([4]\), that measurements of the \( CP \)-violating parameters can be not complete: they lead to sign ambiguities if one cannot relate to each other all the eigenstate labels described in the preceding subsection. As explained in \([1]\), various sign ambiguities found later by other authors (see references in \([1]\) ) have the same underlying nature. Thus, oscillations of secondary neutral kaons, providing complete identification of heavy flavor eigenstates, at the same time eliminate ambiguities of \( CP \)-violating parameters. Note that measurements of kaon parameters \( \eta \) would also show sign ambiguities if one did not know that \( K_L \) is nearly \( CP \)-odd and heavier than \( K_S \).

\( CP \)-violation in heavy flavor decays to final states with neutral kaons has interesting specific features. It combines, in a coherent way, contributions of two sources: the heavy flavor itself and the neutral kaons. This is true both for neutral flavored mesons \([4, 6, 7]\) and for any other flavored hadrons (charged mesons or even baryons) \([2]\). Such properties may provide new possibilities for studying heavy flavor \( CP \)-violation through its “direct” comparison with known kaon violation.

3.3 Separation of flavor transitions

A characteristic feature in decays of heavy flavor hadrons, in difference with strange hadrons, is possibility of several various underlying quark decays. They generate hadron decay modes with different flavor changes. Most interesting in the present context are charmed particle decays of the types \( D \to \overline{K} \) (Cabibbo-favored) and \( D \to K \) (doubly Cabibbo-suppressed). The suppressed decays have the amplitude smallness of order 5%. Several modes of decays \( D \to K^+ \) have, nevertheless, been observed experimentally.

Decays to charged kaons allow to compare only absolute values of suppressed and favored amplitudes. The situation is different for decays to neutral kaons. Amplitudes of decays to \( \overline{K}^0 \) and \( K^0 \) appear to be coherent, since the secondary decays go to common channels. Therefore, the relative phase of the amplitudes becomes measurable as well. It may be measured by means of secondary kaon oscillations in decays of charmed charged mesons or baryons \([2]\) (detailed formulas for time distributions see in \([3]\) in the limit \( \Delta m_D, \Delta \Gamma_D \to 0 \)). In decays of neutral \( D \)-mesons the two flavor transitions may be separated from each other and from initial mixing effects by means of double-time distributions (over primary and secondary decay times) \([6]\).

Again, as for the eigenstate identification, such approach is the only one suggested till now to measure the measurable relative phase. Detailed knowledge of the suppressed amplitudes would give new valuable information about CKM-matrix and \( CP \)-violation.
4 Conclusion

The several examples given above are sufficient to confirm that the secondary kaon oscillations may, indeed, have great analyzing power for heavy flavor physics.

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References

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