Letter of Interest on Rare Charm Decays

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Abstract

Rare charm decays provide an exceptional window to test flavor-changing neutral current (FCNC) transitions in the up-quark sector, complementary to the ongoing studies in K- and B-physics. Thanks to the Glashow-Iliopoulos-Maiani (GIM) mechanism, rare charm $|\Delta c| = |\Delta u| = 1$ transitions are highly suppressed in the Standard Model (SM), such that with the current experimental sensitivities, any observation would cleanly signal new physics (NP). Besides null tests based on approximate symmetries of the SM, such as lepton universality, charged lepton-flavor conservation and CP, additional possibilities to test the SM arise from the study of angular distributions of resonant-dominated radiative and semileptonic decays. Model-independent analyses and multi-observable fits could disentangle the type of NP in terms of Wilson coefficients. In view of the current progress in the field, we plan to submit a document describing all the existing possibilities to test the up sector in rare charm decays, as well as providing an update with the most recent data available.

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Investigations of decay processes of heavy flavoured hadrons have been a primary goal with aim to test the Standard Model (SM) in flavour physics. In particular, the study of FCNC transitions, which are absent at tree level in the SM, is an excellent place to explore the quantum structure of the SM: contributions from new heavy and yet unobserved degrees of freedom could easily compete in rare processes with a suppressed SM contribution. Due to the GIM suppression of the $|\Delta c| = |\Delta u| = 1$ SM amplitudes, new physics (NP) in charm can enhance the decay rates, introduce additional sources of CP violation, or change the angular distributions of the final state particles. Depending on the process and NP couplings, precision measurements are sensitive to NP contributions at mass scales much higher than those achievable in direct production of particle collisions.

Due to the presence of non-perturbative resonant contributions, which often dominate, investigations of rare charm decays have been considered as less promising in the past, where most of the experimental effort has been focused on rare B and K decays.
However, even despite the lack of a robust effective theory framework to deal with the non-perturbative dynamics of rare charm decays, the SM symmetries lead to a very unique phenomenology and allow to define *null-test observables*. In particular, the CKM couplings and mass hierarchy of down-type quarks lead to specific features of processes sensitive to $c \to u\,\ell^+\ell^-$ transitions, which are:

- Extremely suppressed branching fractions;
- Almost vanishing CP asymmetries;
- Distinctive angular distributions sensitive to specific NP effects.

Recently, investigations of rare B decays revealed a picture of hints of physics beyond the SM in branching fractions and angular distributions that point towards a breakdown of lepton universality. If the reason underlying these anomalies is beyond the SM, the study of rare charm decays could shed some light on their origin and nature, as SM predictions lie well below the current experimental sensitivities and unfolding of effects coming from NP and their interference with SM contributions is not needed.

Recent theoretical work has suggested to test the SM in rare charm decays in:

- Searches for forbidden or rare decays of charmed hadrons in regions of phase-space where the influence of resonant contributions is minimal, see Ref. [1–3];
- Tests of lepton universality [1–4]
- Investigations of angular distributions and CP asymmetries in semi-leptonic multi-body decays of neutral and charged D mesons, as well as charmed baryons, see Refs. [1–3, 5–23];

- Measurements of branching fractions and CP asymmetries in rare radiative charm decays, see Refs. [24–30];
- Studies of charm hadron decays into di-neutrino final states, see Ref. [4].

To date, the potential of rare charm decays has hardly been exploited so far. In the future document, we will discuss the potential of the suggested topics and their prospects at experimental facilities such as LHCb [31], Belle II [32], BES III [33] and other planned experiments such as the FCC-ee [34], in the short- and midterm. A more detailed discussion on the current experimental and theoretical status of rare charm decays can be found in Ref. [35].

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