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RARE PROCESSES AND PRECISION MEASUREMENTS
RF1: Weak decays of b and c quarks
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High Precision SM Predictions for Quark Flavor Observables

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Abstract

Quark flavor physics provides the possibility to search with precision measurements for effects of new particles that are beyond the direct reach of current accelerators. For the unambiguous identification of new physics effects a profound understanding of the corresponding standard model (SM) predictions and its uncertainties is mandatory. We review several observables that are promising in this respect and where the precision of the SM prediction can be improved in the next years. We plan to submit a document describing these future possibilities in detail.

1 Introduction

The current observation of the so-called flavor anomalies is one of the hottest topics in particle physics. If these deviations turn out to be real, they will shed light to physics beyond the SM and they might help in answering questions like the origin of the matter-antimatter asymmetry in the Universe. For this programme to work highly reliable, precise SM predictions are of course crucial. We review here a list of observables where the accuracy within the SM can be improved, leading to a severe impact on our understanding of nature.

1.1 Inclusive semi-leptonic and radiative B decays

To further understand the long standing discrepancy between the exclusive and inclusive determination of the CKM elements V_{cb} and V_{ub} newly calculated corrections like the QCD correction to the Darwin term [1] can be included in the analysis, as well as higher orders in the Heavy Quark Expansion (HQE). Moreover some of the arising non-perturbative matrix elements can be related via equations of motion to e.g. matrix elements of four-quark operators. Another possibility in determining these matrix elements are sum rules and lattice simulations. A precise knowledge of the value of the b-quark mass [2] is mandatory for a relieable determination of the CKM elements. In that respect the effect of the use of different quark mass concepts for B decays can be studied. The theory tools for semi-leptonic B decays can also be used to test the convergence of the HQE in the charm sector [3], see Section 1.4.
Inclusive semileptonic FCNC decays such as $\bar{B} \to X_{(s,d)}\ell^+\ell^-$ [4] will serve as an important cross-check for the flavour anomalies currently seen in exclusive B decays, and to investigate lepton flavour universality. Inclusive radiative decays, most prominently $\bar{B} \to X_{(s,d)}\gamma$ [5], are among the standard candles in the search for new physics and in constraining the parameters spaces of BSM models.

1.2 B lifetimes and B mixing

Lifetime ratios of B mesons can be determined within the HQE. Recently a significant experimental discrepancy in the analysis of the decay $B_s \to J/\Psi\phi$ was arising between the determinations of Γ_s from ATLAS [6] and CMS [7] and LHCb [8, 9]. It would be interesting to study the sensitivity of future $e^+ - e^-$ colliders for these measurements with Monte Carlo generators like WHIZARD [10]. In theory an important contribution to the lifetime ratio comes from so-called spectator effects. The corresponding bag parameter that parameterise the non-perturbative part of the spectator effects have so far only been calculated with HQET sum rules [11]. An inclusion of strange quark mass effects as well as a lattice calculation of these parameter would be highly desirable. Moreover it was found that the previously neglected Darwin term in theory predictions can lead to sizeable effects [12, 13]. Here again a precise future determination of the non-perturbative matrix element of the Darwin operator is necessary, maybe via sum rules or lattice. Similar

Bag parameter are arising in B meson mixing, which is supposed to be very sensitive to new physics effects. These mixing parameter have so far been determined by lattice simulations [14, 15] and with HQET sum rules [11, 16]. Both in lattice as within the sum rule approach the precision can be further improved, see e.g. [17]. A precise knowledge of the SM value of B mixing can also have dramatic impact [18] on BSM models that try to explain the B anomalies [19].

1.3 Exclusive decays of heavy mesons

Exclusive decays of heavy meson can be described within the QCD factorization approach [20], which was recently extended to NNLO accuracy [21]. Here some significant discrepancies were found between experiment and theory in decay channels where QCD factorisation is supposed to work best [22]. This might be an indication for BSM effects in non-leptonic tree-level decays [23]. Further studies in that direction would be very desirable as well as the construction of BSM models that will lead to such new effects. Factorisation can also be extended to more than two-hadron final states [24,25]. Nonlocal hadronic effects beyond factorisation [26] can be further studied and the main inputs to factorisation such as the light-cone distribution amplitudes deserve an accurate assessment [27] including the strange quark mass effects [28].

1.4 Convergence of HQE tools in the charm sector

The theoretical description of charm decays is very challenging, since the charm quark is neither really heavy nor light [29]. First studies of the large lifetime ratio $\tau(D^+)/\tau(D_0)$ within the framework of the HQE [11] look very promising, but additional observables like $\tau(D_s^+)/\tau(D_0)$ or baryon lifetimes have to be studied with the same theoretical rigour. Since there will be a huge amount of charm data from the LHC experiments, BELLE II and BESIII an improvement of our theoretical understanding in the charm sector is very important. This holds in particular for CP violation in charm, where methods like the ones used in [30] should be further extended and for charm mixing where some new ideas for an explanation of the experimental value within the HQE approach were presented in [31]. Such studies will also shed some light on the potential size of quark hadron duality violations within the HQE.

Our suggested programme has considerable overlap with the one suggested by the RBC-UKQCD collaboration [32], but many of our theoretical methods have completely different systematic uncertainties.

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