Quark Flavour Physics

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1. Introduction

The physics of quark flavours, their family structure, mass spectrum, mixing angles and weak interaction properties, belongs to the sector of the Standard Model that is least understood on a fundamental level.

In order to achieve progress, it is mandatory to test in great detail the Standard Model predictions for weak decays of hadrons, for rare processes in particular, and to look for hints of New Physics. After the very successful era of experimentation at the B-meson factories (BaBar (SLAC) and Belle (KEK)) this field is going to remain very active in the years to come. In the near future the LHC at CERN, in particular the dedicated LHCb experiment, will explore new territory. Beyond the LHC, high-luminosity B factories (SuperB, SuperKEKB) as well as LHC upgrade options continue to provide excellent prospects.

Within this context research in our group is currently focussed on the theory of rare and hadronic decay processes of B mesons, CP violating observables and their phenomenological interpretation. An important challenge in this effort is posed by the effects of strong interactions, which need to be sufficiently well understood to derive the underlying weak-interaction properties of quarks from the observed decays of hadrons. The theory of hadronic B decays makes use of the factorization of amplitudes in QCD [1], which holds for a large class of exclusive B decays in the heavy-quark limit.

2. Recent Work

An international effort to investigate the status and potential of B, D and K decays before the LHC start-up, with a particular emphasis on the interplay between indirect flavour-physics probes of New Physics and direct collider searches, resulted in the publication of [2]. This report summarizes the outcome of a series of workshops at CERN. With the LHC it will be possible to probe New Physics (NP) up to energy scales almost one order of magnitude larger than it has been possible with present accelerators. While direct detection of new particles will be the main avenue to establish the presence of NP at the LHC, indirect searches will provide indispensable complementary information, since most probably it will not be possible to measure the full spectrum of new particles and their couplings through direct production. In particular, precision measurements and computations in the realm of flavour physics are expected to play a key role in constraining the unknown parameters of the Lagrangian of any NP model emerging from direct searches at the LHC.

A short review of theoretical methods for B physics at hadron colliders was given in [3]. The main emphasis was on the theory of two-body hadronic B decays, which provide a rich field of investigation in particular for the Tevatron and the LHC. The subject holds both interesting theoretical challenges as well as many opportunities for flavour studies and New Physics tests. The current status and recent developments were briefly summarized.

A detailed study of two-body decays of B mesons into longitudinally polarized light vector mesons at next-to-leading order in QCD was presented in [4]. This included explicit expressions in QCD factorization for all 34 transitions of a heavy-light B meson into a pair of longitudinal vector mesons ρ, ω, ϕ, K^* within the Standard Model. Decay rates and CP asymmetries were discussed and compared with available data. The fact that QCD penguins are systematically smaller for vector mesons in comparison to pseudoscalars in the final state, was exploited in the investigation of several methods to achieve high-precision determinations of CKM parameters and New Physics tests. Among other applications a new method was proposed to use V-spin symmetry (the approximate invariance of strong interactions under the exchange of u and s quarks) and data on $\bar{B}_d \to \bar{K}_L^{*0} K_L^{*0}$ to constrain the penguin contribution in $\bar{B}_d \to \rho_L^+ \rho_L^-$. This should lead to an independent and very precise determination of the CKM unitarity triangle.

An interesting conceptual question of QCD dynamics in rare B-meson decays was addressed in [5]. The integrated branching fraction of the process $B \to X_s l^+ l^-$ is dominated by resonance background from narrow charmonium states, such as $B \to X_s \psi \to X_s l^+ l^-$, which exceeds the non-resonant charm-loop contribution by two orders of magnitude. The origin of this fact was discussed in view of the general expectation of quark-hadron duality. The situation in $B \to X_s l^+ l^-$ was then contrasted with charm-penguin amplitudes in two-body hadronic B decays of the type $B \to \pi\pi$, for which it was demonstrated that resonance effects and the potentially non-perturbative $c\bar{c}$ threshold region do not invalidate the standard picture of QCD factorization. This holds irrespective of whether the charm quark is treated as a light or a heavy quark.

In view of future B-meson factories operating with very high luminosity, which aim at a gain in statistics by almost a factor of 100 with respect to the first generation of B factories, the study of precision observables receives additional motivation. Examples are provided by the decays $B \to K l^+ l^-$ or $B \to K \nu \bar{\nu}$, which are very promising theoretically [6].

References

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