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. On the other hand, the observed flavour parameters are of crucial significance for understanding very basic properties of matter. Examples reach from the stability of the proton, due to the down-quark mass exceeding the up-quark mass, to the violation of CP symmetry, which introduces a fundamental difference between matter and antimatter with implications for cosmology.

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. At present substantial experimental progress is being made, especially by the B-meson factories at SLAC, USA, and KEK, Japan. Within this context research in our group is currently focussed on the theory of rare decay processes of B and K 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. Many of the methods used, for examples those related to the heavy-quark limit for B decays, are not only important for that goal, but constitute interesting applications of QCD in their own right.

2. Hadronic B Decays

Processes such as $B \to \pi\pi$, πK play a central role in studying flavour physics and CP violation. In order to extract weak interaction parameters, the effects of QCD have to be isolated in a systematic way. Such an approach, which allows us to compute decay amplitudes of the type $B \to \pi\pi$ in the heavy-quark limit ($m_b \ll \Lambda_{QCD}$), has been proposed in [1]. An application of this method to the phenomenology of $B \to PV$, where P (V) is a light pseudoscalar (vector) meson, was given in [2].

A novel way to make use of CP violation measurements in $B \to \pi^+\pi^-$, in conjunction with CP violation in $B \to \psi K_S$, has been suggested in [3]. Here weak phases can be constrained with only very mild assumptions on hadronic dynamics, which are well justified in the heavy-quark limit.

Scenarios of New Physics that could induce deviations from Standard Model expectations for CP violation in channels such as $B \to \psi K_S$ and $B \to \phi K_S$ were discussed in [4]. The study is motivated by possible hints of such deviations in the data and makes predictions for additional measurements that could point to the correct pattern of New Physics.

3. CP Violation in Semileptonic B Decays

CP violation originating in the phenomenon of particle-antiparticle mixing with neutral B mesons ($B_d - \bar{B}_d$ or $B_s - \bar{B}_s$) can be measured using semileptonic B decays. The relevant parameter $a = \mathrm{Im}(\Gamma_{12}/M_{12})$ is suppressed in the Standard Model, but can be computed reliably. A future measurement exceeding those expectations would signal new dynamics in the flavour sector. In [5] the quantity a was computed at next-to-leading order in QCD within an operator product expansion in $1/m_b$. It could be shown that the hadronic uncertainties are indeed rather small after the higher-order QCD corrections are included.

4. $b \to s$ Transitions Beyond the Standard Model

The rare b-quark transitions $b \to s\gamma$, $b \to sg$, $b \to sl^+l^-$ ($l = e,\, \mu$) and $B_s \to \mu^+\mu^-$ offer promising opportunities to search for new flavour interactions. In [6] the impact of non-standard scalar and pseudoscalar interactions on these processes was investigated independently of specific models of the New Physics. Correlations between the various decay modes were emphasized and relevant bounds on the non-standard interactions could be derived based on recent data.

5. Rare Kaon Decays

Decays of kaons can offer important additional insight into flavour dynamics, complementing the results from B-meson physics. A process that has long been recognized as an interesting probe of CP violation is the rare decay $K_L \to \pi^0 e^+ e^-$. However, the presence of both direct and indirect CP violation in this decay, as well as a CP conserving component complicates any theoretical analysis of this channel. Crucial input helping to disentangle these effects comes from measurments of the related channels $K_L \to \pi^0\gamma\gamma$ and $K_S \to \pi^0 e^+ e^-$. Experiment NA48 at CERN has recently performed improved measurments of the former decay and has achieved a first measurement of the latter. Incorporating these improvements, a detailed theoretical re-analysis of $K_L \to \pi^0 e^+ e^-$ has been presented in [7].

References

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