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# Loop-induced rare decays of $B_s^0$ mesons

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A case is made for study of loop-induced rare decays of $B_s^0$ mesons as a test of the standard model and its extensions. A large amount of theoretical work on rare decays of $B_u^+$ and $B_d^0$ mesons can be directly translated into predictions for rare decays of $B_s^0$ mesons. The particular decay $B_s^0 \to \phi\gamma$ is emphasized as a potentially clean example of a radiative penguin process.

There is, to date, not a great deal of theoretical literature concerning $B_s^0$ mesons. Most has been with respect to the prospects of observing mixing[1–6] in the $B_s^0$ system, though some also deals with decay modes,[7–10] production,[11] and lifetimes.[12–14]

In recent years, however, there has been considerable interest in penguin decays of $B$ mesons and the general loop-induced $b \to sX$ transition, where $X$ is, for example, a Higgs boson, a photon, a gluon, or a lepton pair. Though none have yet been observed, all these processes may take place within the framework of the three-generation standard model. Many authors have calculated expected branching ratios for $B_u^+$ and $B_d^0$ mesons into $K^*\gamma$, $K^{(*)}l^+l^-$ in a variety of models. These processes are, in general, sensitive to physics at energy scales not directly accessible by current experimental techniques, and depend on the top-quark mass, and on details of the Higgs sector of the standard model and possible extensions thereof ranging from supersymmetry to a fourth generation and others. (For a good summary see Ref. 15.) Some experimental limits on these decays are already available.[16,17] There exists some controversy over the theoretical predictions as the issue is complicated by QCD corrections and uncertainty about how quark-level processes will manifest in specific final states. We do not address these issues here, but rather point out that many of these calculations may immediately be applied to the $B_s^0$ system where, as we shall argue, the situation may be experimentally cleaner.

We confine attention in this paper to $B_s^0$ mesons produced from the $\Upsilon(5S)$ resonance produced at $e^+e^-$ storage rings such as the Cornell Electron Storage Ring (CESR). These are expected to be produced in an analogous fashion to the production of $B_d^0\bar{B}_d^0$ and $B_u^+B_u^-$ pairs from the $\Upsilon(4S)$, together with $B_u^{*+}$ and $B_d^{*0}$ and possibly $B_s^{*0}$ mesons. The relative production rates of these $B$ mesons is unknown, and while they have been estimated,[11] they are still subject to great uncertainty. We note here that considerations to follow on the decays of $B_s^0$ mesons may also be applied to $B_s^{*0}$ mesons which decay via $B_s^{*0} \to B_s^0\gamma$.

The $B_s^0$ meson differs from the $B_d^0$ meson only in the replacement of a down quark by a strange quark. To the degree that $SU(3)_f$ is a good symmetry we expect that $b \to sX$ processes should proceed at similar rates for $B_s^0$ and $B_d^0$ mesons. [Because of the uncertainties in theoretical calculations both of penguin decays and of $B_s^0$ production from the $\Upsilon(5S)$, there seems little point in considering details, and we will approximate freely.] The point of interest is, however, that the final hadronic states will differ markedly. In analogy to $B_d^0 \to KX$, one expects the decays $B_s^0 \to \eta X$ and $B_s^0 \to \eta' X$. (References in this paper to a specific charged state are to be interpreted as also implying the charge-conjugate state.) Unfortunately, the strange pseudoscalar mesons decay predominantly into final states containing photons or $\pi^0$'s (which then decay into photons) and are thus rather difficult to study cleanly in experimental situations. The situation with $B_d^0 \to K^*X$ is rather more optimistic. From $B_d^0 \to K^*(892)X$ we have the analogous decay $B_s^0 \to \phi X$. It is this latter case which is of primary interest in this paper, particularly in the decay $B_s^0 \to \phi\gamma$. It is to this decay that we now turn our attention.

Let us compare the experimental prospects for the observation of these decays. While for the decay $B \to K^*\gamma$ it has often been stated in the literature that there is a clean signature in the form of a monoenergetic photon, this is not actually the case. $B_d^0$ and $B_u^+$ mesons are not produced at rest from the $\Upsilon(4S)$ and the resultant Doppler shift, combined with the generally poor energy resolution possible for detecting such photons, results in a rather broad distribution in the measured photon energies. The current practice[16,17] of looking for $K^*\gamma$ combinations with $\chi^2$ from the beam energy less than some specified value is equally applicable to the decay chain

$$\Upsilon(5S) \to B_s^0\bar{B}_s^0,\ B_s^0 \to \phi\gamma ,$$

independent of the boost with which the $B_s^0$ mesons are produced, whether they are directly from the $\Upsilon(5S)$, or from $B_s^{*0}$ decays. Consider now the branching ratios[18] of $K^{*0}(892)$ and $\phi$ into the experimentally cleanest channels:

$$B(K^{*0}(892) \to K^+\pi^-) \approx \tfrac{2}{3} ,$$

$$B(\phi \to K^+K^-) \approx \tfrac{1}{2} .$$

Note also that the full width[18] of $\phi$ ($\Gamma = 4.41$ MeV) is over 11 times smaller than that of the $K^*(892)$ ($\Gamma = 51.3$ MeV). The absolute production rate of $K$ mesons in the neighborhood of the $\Upsilon(4S)$ is about 5 times less than that of pions. Thus we estimate the background for the decay $B_s^0 \to \phi\gamma$ to be about 55 times lower than that for $B_d^0 \to K^{*0}\gamma$ while the detection efficiency, due to choice of final state, is smaller by a factor of only about 0.75. In practice, the relative background estimate will be somewhat less than 55 due to difficulties in identifying pions and kaons at the relevant momenta. In spite of this, it is clear that the decay $B_s^0 \to \phi\gamma$ is an experimentally promising one.

Similar arguments may be made with respect to decays such as $B_s^0 \to \phi H$ and $B_s^0 \to \phi l^+ l^-$. Depending on the number of $\Upsilon(5S)$ decays that can be obtained, the rate of production of $B_s^0$ mesons from the $\Upsilon(5S)$, the correctness of the assumption that the decay rates for the two $B_s^0 \to \phi X$ and $B_d^0 \to K^* X$ are approximately equal, and the overall background present, it may well be that radiative decays of $B_s^0$ mesons will prove a useful field of study.

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