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The Study of Radiative D_s Decays

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The study of weak radiative decays of charmed mesons is still in its developing stage. In the Standard Model (SM), the physics of charm mesons is not generally expected to have New Physics (NP) discovery potential. The weak decays of D mesons are difficult to investigate due to significant final-state interactions. However, decays mediated by $c \to u\gamma$ transitions can be affected by potential contributions coming from the non-minimal supersymmetry, which is an NP scenario. The ratio of branching fractions for radiative D^0 decays could be violated already in the SM framework, while a similar ratio for D_s^+ radiative decays offers much better prospects for NP. We present herein a sensitivity study of the radiative charm decays $D_s^+ \to \rho^+\gamma$ and $D_s^+ \to K^{*+}\gamma$ with data collected by the Belle experiment.

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1. Introduction

In the Standard Model (SM), the physics of charmed mesons faces certain challenges compared to strange and beauty mesons because the CP asymmetries and D^0 - $\bar{D}^0$ oscillations are small. Further, the weak decays of D mesons are difficult to investigate due to significant final-state interactions. However, it has been pointed out that the oscillations and $c \to u\gamma$ decays might have some contributions coming from the non-minimal supersymmetry (an NP scenario). Therefore, one can search for NP using $c \to u\gamma$ transitions. It was suggested that the NP would result in a deviation from the ratio of branching fractions [1]:

$$R_{\rho/\omega} \equiv \frac{\Gamma(D^0 \to \rho^0/\omega\gamma)}{\Gamma(D^0 \to \bar{K}^{*0}\gamma)} = \frac{\tan^2\theta_c}{2}, \tag{1}$$

where θ_c is the Cabibbo angle. In order to find the best mode to study $c \to u\gamma$ transitions, the ratios between various Cabibbo-suppressed and Cabibbo-allowed radiative decays of charmed mesons are calculated within the SM. It has been noticed that Eq. (1) could be violated already in the SM framework because of a large, unknown correction, while a similar ratio for D_s^+ radiative decays

$$R_K \equiv \frac{\Gamma(D_s^+ \to K^{*+}\gamma)}{\Gamma(D_s^+ \to \rho^+\gamma)} = \tan^2\theta_c, \tag{2}$$

offers a much better probe for an NP signal, as the latter is less sensitive to the SM correction [2]. Radiative D_s decays, such as $D_s^+ \to K^{*+}\gamma$ and $D_s^+ \to \rho^+\gamma$, have not yet been observed. The theoretical analysis of the $D \to V\gamma$ transitions was done using a model that combines heavy quark effective theory with the chiral Lagrangian approach and includes flavor symmetry breaking [3]. In addition to the s-channel annihilation and t-channel W exchange diagrams, there is a long-distance penguin-like $c \to u\gamma$ contribution in the Cabibbo-suppressed modes. Its magnitude was determined by the size of symmetry breaking, which was calculated with a vector dominance approach. Although smaller in magnitude, the penguin-like contribution would lead to sizable effects in case of cancellations among the other contributions to the amplitude. Thus, it may invalidate the suggested tests for NP effects in these decays.

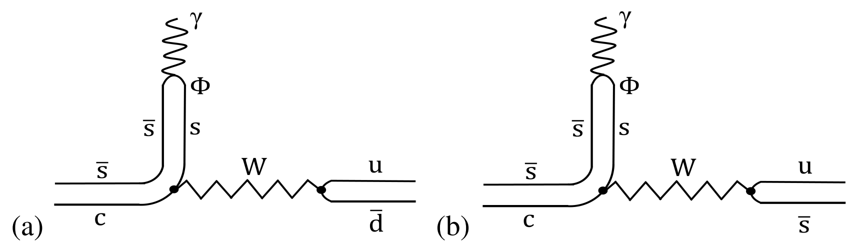

Figure 1: Feynman diagram of (a) $D_s^+ \to \rho^+\gamma$ and (b) $D_s^+ \to K^{*+}\gamma$ decay modes.

Figure 1 shows the Feynman diagram of (a) $D_s^+ \to \rho^+\gamma$ and (b) $D_s^+ \to K^{*+}\gamma$ decay modes [4]. This model predicts a range of values for the branching fractions for the various $D \to V\gamma$ modes, as listed in Table 1. We present herein the first experimental study of these radiative charm-meson decays.

Table 1: Summary of the expected value of the branching fraction.

Decay mode	Branching fraction
$D_s^+ \to \rho^+\gamma$ [3]	(3-5) $\times 10^{-4}$
$D_s^+ \to K^{*+}\gamma$ [3]	(2.1-3.2) $\times 10^{-5}$

2. KEKB and Belle

The Belle detector was located at an interaction point of the KEKB asymmetric-energy e^+e^- collider [5]. It was a large-solid-angle magnetic spectrometer comprising six subdetectors, namely silicon vertex detector, central drift chamber, aerogel Cherenkov counter, time-of-flight counter, CsI(Tl) crystal electromagnetic calorimeter, and K_L^0 and muon detector.

3. Sample Selection

We optimize the selection of signal candidates using simulated samples generated with the EvtGen [6] and Geant packages [7]. We reconstruct D_s^+ from $D_s^+ \to \rho^+\gamma$ and $D_s^+ \to K^{*+}\gamma$, where $\rho^+ \to \pi^+\pi^0$ and $K^{*+} \to K_S^0\pi^+$. These studies are based on MC samples corresponding to an integrated luminosity of 711 fb^{-1}. The branching fraction for these modes is assumed as per Table 1. The kinematic variable that distinguishes signal from background is the difference between the reconstructed mass of D_s^{*+} and D_s^+: ΔM $\equiv$ M (D_s^{*+}) - M (D_s^+). To reduce combinatorial background, we retain only those candidates that meet the following criterion: $0.08 < \Delta M < 0.20$ GeV/c^2. A π^0 veto is implemented to suppress the huge background coming from π^0 decays. We perform a dedicated background MC study in which the continuum background is found to be dominant. We employ multivariate analysis (MVA) based on the FastBDT package [8] to get rid of uds background, i.e., $e^+e^- \to u\bar{u}, d\bar{d}, s\bar{s}$. After requiring the MVA output to be greater than 0.4 (0.5) for the $D_s^+ \to \rho^+\gamma$ ($D_s^+ \to K^{*+}\gamma$) decay mode, we find a rejection of 65% (76%) of uds background at the cost of 10% (24%) of signal loss. The reconstruction efficiency is 0.5% (3.1%) for $D_s^+ \to \rho^+\gamma$ ($D_s^+ \to K^{*+}\gamma$). For $D_s^+ \to \rho^+\gamma$ decay mode, the peaking background mostly comes from $D_s^+ \to \rho^+\eta$, while for $D_s^+ \to K^{*+}\gamma$, it is mostly from $D^0 \to K_S^0\pi^0$ and $D^0 \to K_S^0\eta$ decay modes.

4. Control Sample Study

We use the peaking backgrounds $D_s^+ \to \rho^+[\eta \to \gamma\gamma]$, $D^{*0} \to [D^0 \to K_S^0\eta]\gamma$ and $D^{*0} \to [D^0 \to K_S^0\pi^0]\gamma$, as our control sample to validate the signal extraction procedure and to calibrate possible differences in the signal resolution between data and simulation. Figure 2 shows the unbinned maximum-likelihood fit performed on ΔM for (a) $D_s^+ \to \rho^+\eta$, (b) $D^0 \to K_S^0\pi^0$, and (c) $D^0 \to K_S^0\eta$ decay modes using MC samples corresponding to an integrated luminosity of 711 fb^{-1}.

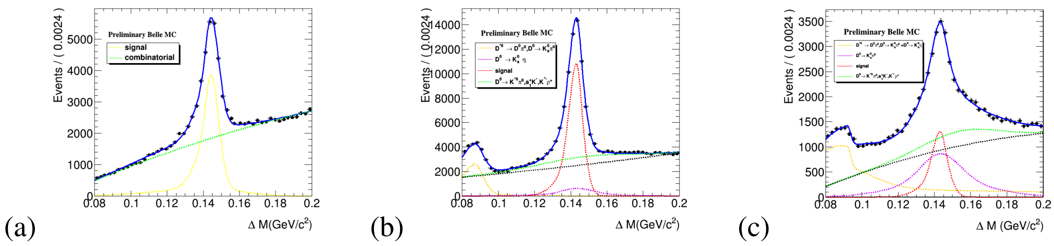

Figure 2: Fitted distribution of ΔM for (a) $D_s^+ \to \rho^+\eta$, (b) $D^0 \to K_S^0\pi^0$, and (c) $D^0 \to K_S^0\eta$ decay modes.

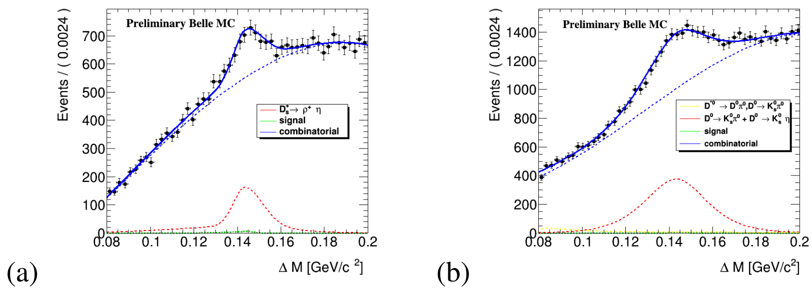

Figure 3: Fitted distribution of ΔM for (a) $D_s^+ \to \rho^+\gamma$ and (b) $D_s^+ \to K^{*+}\gamma$ decay modes.

5. Signal Extraction

We have performed unbinned maximum-likelihood fit on ΔM for both (a) $D_s^+ \to \rho^+\gamma$ and (b) $D_s^+ \to K^{*+}\gamma$ decay modes, as shown in Figure 3. For the $D_s^+ \to \rho^+\gamma$ case, the signal is modeled with the sum of two bifurcated Gaussian functions with a common mean. The peaking background is modeled with the sum of two bifurcated Gaussian functions, combinatorial background with a third-order Chebyshev polynomial. For the $D_s^+ \to K^{*+}\gamma$ mode, the signal is modeled with the sum of two bifurcated Gaussian functions. The peaking backgrounds are modeled with the sum of a Gaussian and a bifurcated Gaussian function. The combinatorial background is modeled with a third-order Chebyshev polynomial. All the signal and peaking background parameters are fixed except for the Chebyshev polynomial.

6. Preliminary Results and Outlook

We are expecting 300-400 (20-30) events for $D_s^+ \to \rho^+\gamma$ ($D_s^+ \to K^{*+}\gamma$) decay modes, assuming a branching fraction of 10^{-4}(10^{-5}), with a data sample corresponding to an integrated luminosity of 921 fb^{-1}.

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