PROCEEDINGS OF SCIENCE

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 also difficult to investigate due to the strong final-state interactions related to QCD. $c \to u\gamma$ decays can be affected by some contributions coming from the non-minimal supersymmetry, which is a NP scenario. $R_{\rho/\omega}$ could be violated already in the SM framework, while a similar relation for D_s^+ radiative decays offers a much better test for $c \to u\gamma$. Here, we present 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 II experiment.

16th International Conference on Heavy Quarks and Leptons - HQL2023
November 28 to December 2, 2023
Mumbai, India

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1. Introduction

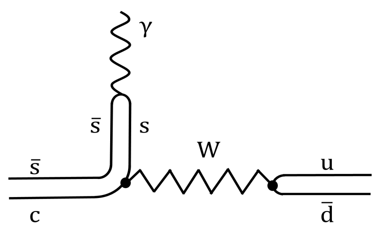
In the Standard Model (SM), the physics of charmed mesons is not generally expected to have New Physics (NP) discovery potential because of the relevant CKM matrix [1] elements V_{cs} and V_{cd} are well known and the CP asymmetries and D^0 - $\bar{D}^0$ oscillations are small. Further, the weak decays of D mesons are difficult to investigate due to the strong final-state interactions related to QCD. 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 (the 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 $R_{\rho/\omega}$ [2].

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

In order to find the best mode to test $c \to u\gamma$ decay, the ratios between various Cabibbo-suppressed and Cabibbo-allowed radiative decays of charmed mesons are calculated as predicted by the SM. It has been noticed that equation 1 could be violated already in the SM framework because of a large, unknown correction within the SM, while a similar relation for D_s^+ radiative decays offers a much better test to search for a signal of NP, as this ratio is less sensitive to the SM parameters [3].

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

Radiative D_s decays, such as $D_s^+ \to K^{*+}\ \gamma$ and $D_s^+ \to \rho^+\ \gamma$, have not been observed yet. The theoretical analysis of the $D \to V\gamma$ transitions was done using a model that combines heavy quark effective theory and the chiral Lagrangian approach and includes symmetry breaking [4]. In addition to the s-channel annihilation and t-channel W exchange, there is a long-distance penguin-like $c \to u\gamma$ contribution in the Cabibbo-suppressed modes. Its magnitude is 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 suggested tests beyond the SM effects in these decays. Figure 1 shows the Feynman diagram of $c \to u\gamma$ transition [5]. This



(a)

Figure 1: Feynman diagram

model predicts a range of values for the branching ratios predicted for the various $D \to V\gamma$ modes, as shown in table 1. Here, we present the first experimental study of these modes.

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

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

2. Sample Selection

The selection of signal candidates is optimized using simulated samples that have been generated with the EvtGen [6] and Geant packages [7]. We have reconstructed D_s^+ from $D_s^+ \to \rho^+\gamma$ and $D_s^+ \to K^{*+}\gamma$, where $\rho^+ \to \pi^+\pi^0$ and $K^{*+} \to K_s^0\pi^+$, respectively. The kinematic variable that distinguishes the signal from the background is ΔM, where ΔM is the difference between the reconstructed mass of D_s^{*+} and D_s^+ (ΔM ≡ M (D_s^{*+}) - M (D_s^+)). To reduce the combinatorial background, we keep only those candidates that satisfy the criteria: 0.08 GeV/c^2 < ΔM < 0.20 GeV/c^2. π^0 veto has been implemented to get rid of the huge background coming from π^0 decays. We have performed background MC study in which the continuum background is found to be dominant. We employ multivariate analysis (MVA) using the FastBDT package to get rid of uds background, processes such as $e^+e^- \to u\bar{u}, d\bar{d}, s\bar{s}$. After applying a cut greater than 0.4 (0.5) on MVA for $D_s^+ \to \rho^+\gamma$ ($D_s^+ \to K^{*+}\gamma$) decay mode, there is a rejection of 65% (76%) of uds background at the cost of 10%(24%) of signal loss, respectively. The reconstruction efficiency is found to be 0.5% (3.1%) for $D_s^+ \to \rho^+\gamma$ ($D_s^+ \to K^{*+}\gamma$), respectively. For ${D_s}^+ \to \rho^+\gamma$ decay mode, peaking background is mostly coming from the ${D_s}^+ \to \rho^+\eta$, and for ${D_s}^+ \to K^{*+}\gamma$, mostly coming from the $D^0 \to K^0\pi^0$ and $D^0 \to K^0\eta$ decay modes, respectively.

3. Control Sample Study

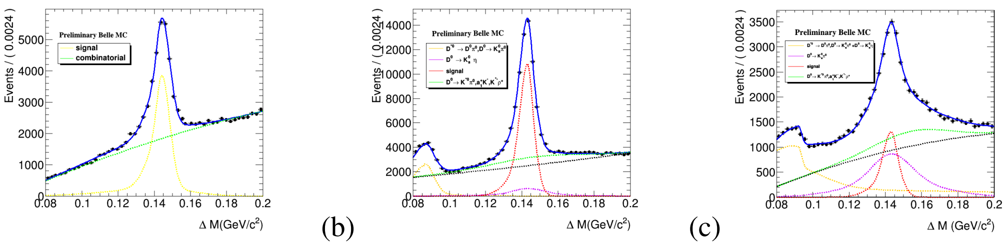
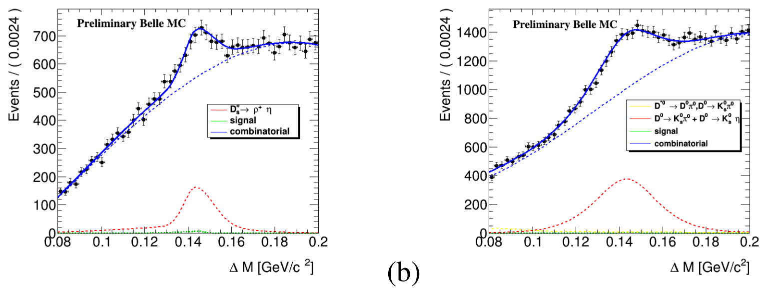


Figure 2: Fitted distribution of ΔM for (a) $D_s^+ \to \rho^+\eta$, (b) $D^0 \to K_s^0\pi^0$ and (c) $D^0 \to K_s^0\eta$ decay modes, respectively.

We utilize 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 verify the signal extraction procedure and to calibrate possible discrepancies in the signal resolution between data and simulation. Figure 2 shows the 1D unbinned maximum likelihood fit on ΔM for (a) $D_s^+ \to \rho^+\eta$ and (b) $D^0 \to K_s^0\pi^0$ and (c) $D^0 \to K_s^0\eta$ decay modes, respectively.

4. Signal Extraction



(a) (b)

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

We have performed 1D unbinned maximum likelihood fit on ΔM for (a) $D_s^+ \to \rho^+\gamma$ and (b) ${D_s}^+ \to K^{*+}\gamma$ decay modes, respectively shown in Figure 3. For $D_s^+ \to \rho^+\gamma$ case, the signal is modeled with the sum of two bifurcated Gaussian with a common mean. The peaking background is modeled with the sum of two bifurcated Gaussian, combinatorial background with third-order Chebyshev Polynomial. For ${D_s}^+ \to K^{*+}\gamma$ mode, the signal is modeled with the sum of two bifurcated Gaussian. The peaking backgrounds are modeled with the sum of a Gaussian and a bifurcated Gaussian. The combinatorial background is modeled with third-order Chebyshev Polynomial. All the signal and peaking background parameters are fixed except the Chebyshev Polynomial.

5. 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 using 10^{-4}(10^{-5}) branching fraction corresponding to an integrated luminosity of 921 fb^{-1}.

References

[1] M. Kobayashi and T. Maskawa, *CP-Violation in the Renormalizable Theory of Weak Interaction*, *Progress of Theoretical Physics* **49** (1973) 652.

[2] I.I. Bigi, *Weak decays of charm hadrons: The next lesson on qcd – and possibly more!*, 1993.

[3] B. Bajc *et al.*, *$c \to u\gamma$ in cabibbo suppressed d meson radiative weak decays*, *Phys. Rev. D* **54** (1996) 5883.

[4] S. Fajfer and P. Singer, *Long distance $c \to u\gamma$ effects in weak radiative decays of d mesons*, *Phys. Rev. D* **56** (1997) 4302.

[5] S. Fajfer *et al.*, *Long distance contributions in $d \to v\gamma$ decays*, *Eur. Phys. J. C* **6** (1999) 471.

[6] D.J. Lange, *The EvtGen particle decay simulation package*, *Nucl. Instrum. Meth. A* **462** (2001) 152.

[7] R. Brun *et al.*, *GEANT3*, *CERN-DD-EE-84-1* (1987) .