Search for the Decay $\bar{B}^0 \to D^{*0}\gamma$

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We report results of a search for the rare radiative decay $\bar{B}^0 \to D^{*0}\gamma$. Using 9.66×10^6 $B\bar{B}$ meson pairs collected with the CLEO detector at the Cornell Electron Storage Ring, we set an upper limit on the branching ratio for this decay of 5.0×10^{-5} at 90% C.L. This provides evidence that the anomalous enhancement is absent in W-exchange processes and that weak radiative B decays are dominated by the short-distance $b \to s\gamma$ mechanism in the standard model.

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In recent years exclusive [1] and inclusive [2] $b \to s\gamma$ transitions were discovered by CLEO. These observations confirmed the existence of effective flavor changing neutral current processes in the standard model (SM) and stirred significant theoretical interest by opening new avenues to search for new physical phenomena [3].

One of the essential ingredients of the inclusive $b \to s\gamma$ measurement by CLEO was the assumption that flavor annihilation and W-exchange radiative transitions, represented by decays such as $\bar{B}^0 \to D^{*0}\gamma$, are strongly suppressed. If this were not so, these decays could represent a serious experimental background to the inclusive photon spectrum used to deduce the $b \to s\gamma$ rate. The primary goal of the study presented in this Letter is to establish experimentally whether W-exchange (flavor annihilation) processes are indeed strongly suppressed in B decays.

We search for the decay $\bar{B}^0 \to D^{*0}\gamma$ (and its charge conjugate state). In the SM framework this decay proceeds via W exchange between b and $\bar{d}$ quarks (Fig. 1). Naively, this transition is suppressed by helicity effects and quantum chromodynamic (QCD) color corrections to the weak vertex. Two theoretical mechanisms to overcome this suppression have been proposed in the past. One mechanism has to do with the emission of gluons from the initial state quark [4], while the other [5] assumes a large $q\bar{q}g$ (or color octet) component in the B meson wave function. Whether either mechanism could significantly enhance the rate is debatable [6]. Theoretical estimates which take gluon emission into account predict a $\bar{B}^0 \to D^{*0}\gamma$ branching fraction of the order of 10^{-6} [6–8]. Though the numerical estimates of the rate for the color octet hypothesis are not yet available, it is expected that the rate could be enhanced by a factor of approximately 10 which is a typical color suppression factor. So far the presence of a possible enhancement in the decay $\bar{B}^0 \to D^{*0}\gamma$ has not been tested experimentally.

On the other hand, if QCD suppression is present in the decay $\bar{B}^0 \to D^{*0}\gamma$, eventually we would like to measure the strength of this suppression. Theoretical predictions for the studied decay have large uncertainties; therefore a precise knowledge of the branching fraction would allow the QCD radiative corrections to be quantified more reliably. Knowledge of these corrections becomes increasingly important as theorists suggest new ways to constrain the SM parameters using hadronic B decays. This makes the decay $\bar{B}^0 \to D^{*0}\gamma$ an interesting process to study even if QCD suppression is present.

The data analyzed in this study were collected at the Cornell Electron Storage Ring (CESR) with the CLEO detector. The results are based on 9.66×10^6 $B\bar{B}$ meson pairs, corresponding to an integrated e^+e^- luminosity of 9.2 fb^{-1} collected at the $\Upsilon(4S)$ energy of 10.58 GeV. To optimize most of our selection criteria, we also employed 4.6 fb^{-1} of $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) annihilation data ("continuum") collected approximately 60 MeV below the $\Upsilon(4S)$ energy. Our data sample was recorded with two configurations of the CLEO detector. The first third of the data were recorded with the CLEO II detector [9] which consisted of three cylindrical drift chambers placed in an axial solenoidal magnetic field of 1.5 T, a CsI(Tl)-crystal electromagnetic calorimeter, a time-of-flight plastic scintillator system, and a muon system (proportional counters embedded at various depths in the steel absorber). Two-thirds of the data were taken with the CLEO II.V configuration of the detector where the innermost drift chamber was replaced by a silicon vertex detector [10] and the argon-ethane gas of the main drift chamber was changed to a helium-propane mixture. This upgrade led to improved resolutions in momentum and specific ionization energy loss (dE/dx). The response of the detector is modeled with a GEANT-based [11] Monte Carlo simulation program. The data and simulated samples are processed by the same event reconstruction program. Whenever possible the efficiencies are either calibrated or corrected for the difference between simulated and actual detector responses using direct measurements from independent data.

We search for $\bar{B}^0 \to D^{*0}\gamma$ candidates among events where a photon with energy greater than 1.5 GeV is accompanied by a fully reconstructed D^{*0} meson. This

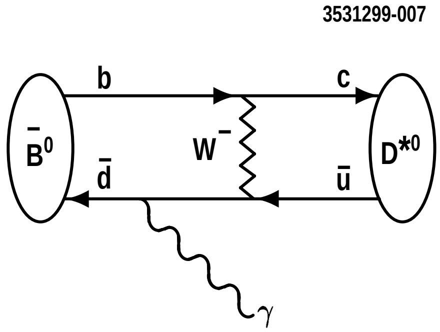

FIG. 1. One of lowest order Feynman diagrams for the decay $\bar{B}^0 \to D^{*0}\gamma$ in the standard model.

choice is due to two factors. In $\Upsilon(4S)$ decays B mesons are produced with momenta ≈ 300 MeV$/c$ so that the energy spectrum of the signal photon is not monochromatic. Further, making a tighter energy requirement on the signal photon candidate would introduce a bias in the background estimate procedure because of strong correlation between the photon energy and background shape in the signal region for continuum events. The D^{*0} mesons are reconstructed in their decays to $D^0\pi^0$ and $D^0\gamma$ with the D^0 mesons decaying to $K^-\pi^+$, $K^-\pi^+\pi^0$, or $K^-\pi^+\pi^-\pi^+$. These reconstructed channels comprise 25% of the product branching fraction for the D^{*0} and D^0 decays. Multiple entries are assigned a weight inversely proportional to the number of candidates identified in the event. As we apply selection criteria, the reweighting is performed appropriately. The average number of candidates per event before and after event selection are 10 and 1.1, respectively.

Efficient track and photon quality requirements have been designed to minimize systematic uncertainties. This includes selecting only those photons that are detected in the region of the calorimeter where the resolutions are well modeled. Kaon candidates are required to have measured dE/dx within ± 2.5 standard deviations (σ) of the expected energy loss. Pairs of photons combined to form the π^0 candidates are required to have masses within -3.5σ and $+2.5\sigma$ ($\sigma \approx 6$ MeV$/c^2$) of the π^0 mass [12]. To improve mass resolution for parent particles, the π^0 candidates are kinematically fit to this mass. To suppress combinatorial background, soft photons from the $D^{*0} \to D^0\gamma$ decays are required to have energies above 200 MeV. This selection is 50% efficient. The invariant mass of the D^0 candidates is required to be within $\pm 2.5\sigma$ ($\sigma \approx 8.0$ MeV$/c^2$), $\pm 2.0\sigma$ ($\sigma \approx 15.0$ MeV$/c^2$), and $\pm 1.5\sigma$ ($\sigma \approx 7.5$ MeV$/c^2$) of the D^0 mass of 1.8646 GeV$/c^2$ in final states with one, two, and three pions, respectively. The $D^{*0} - D^0$ mass difference δM is required to be within $\pm 2.0\sigma$ of 142.1 MeV$/c^2$ [12] ($\sigma \approx 1.0$ and 5.0 MeV$/c^2$ for the π^0 and γ decays of the D^{*0}, respectively). To select $D^0 \to K^-\pi^+\pi^0$ candidates we require the $K^-\pi^0$ and $\pi^+\pi^0$ invariant masses to be consistent with the resonant substructure of the D^0 decays [12]. Continuum data were used to optimize these criteria to suppress combinatorial backgrounds.

The major sources of background are photons from initial state radiation and from π^0 decays both from continuum and $B\bar{B}$ events. To suppress the real π^0 background and to reduce the cross feed between the π^0 and γ reconstruction channels of the D^{*0}, we apply a π^0 veto to the photons from both the D^{*0} decay and the $\bar{B}^0$ decay. This is done by rejecting photons that, when combined with another photon candidate, form π^0 candidates within -4.5σ and $+3.5\sigma$ of the π^0 mass. To suppress the remaining continuum background, we use a Fisher discriminant technique [13]. This discriminant is a linear combination of three angles and nine event shape variables. The first angle is between the $\bar{B}^0$ candidate momentum and the e^+e^- collision ("beam") axis. The second is the angle between the beam axis and the direction of the $\bar{B}^0$ candidate thrust axis. The third is the angle between the thrust axis of the $\bar{B}^0$ candidate and the thrust axis of the rest of the event. The nine event shape variables are the amount of energy detected in 10° cones around the direction of the signal photon from the $\bar{B}^0$ decay. The Fisher discriminant coefficients are optimized to maximize the separation between continuum events that are jetlike and $B\bar{B}$ events that are spherical in shape at the $\Upsilon(4S)$ energy. This important selection criterion is optimized for each reconstruction channel separately using a combination of continuum data and simulated signal events, and has an efficiency between 40% and 70% depending on the reconstruction channel.

We define the signal region in the two-dimensional plane of the beam-constrained B mass $M(B) = \sqrt{E_{\text{beam}}^2 - p(B)^2}$ and the energy difference $\Delta E = E(B) - E_{\text{beam}}$, where E_{beam} is the beam energy, $p(B)$ is the momentum of the $\bar{B}^0$ candidate, and $E(B)$ is its detected energy. The signal region is defined by $M(B) > 5.275$ GeV$/c^2$ and $|\Delta E| \le 100$ MeV. The $M(B)$ requirement is 1.5σ below the actual $\bar{B}^0$ mass [12] ($\sigma \approx 2.8$ MeV$/c^2$). These criteria are optimized to suppress the cross feed from B decays to higher-multiplicity final states. The signal region selection is 78% efficient.

The optimization of selection criteria has been performed using only continuum data and a sample of $B\bar{B}$ Monte Carlo events. After applying all criteria, there were no candidates in the signal region for the $\Upsilon(4S)$ data. Projections onto the ΔE and $M(B)$ variables are shown in Fig. 2. On average we expect 0.5 continuum background events in the signal region. We estimate this number from continuum data by relaxing the event selection requirements. The contribution from the decay $\bar{B}^0 \to D^{*0}\pi^0$ in the signal region is less than 0.9 events assuming $\mathcal{B}(\bar{B}^0 \to D^{*0}\pi^0) < 4.4 \times 10^{-4}$ at 90% C.L. [14]. The theoretical predictions for this branching fraction are of the order of 10^{-4} [15,16]. The contribution from all other known B decays in the signal region is negligible. Six data events in the ΔE sideband are consistent with Monte Carlo expectations for the cross feed from the decay $B^+ \to D^{*0}\rho^+$. This decay can produce $\bar{B}^0 \to D^{*0}\gamma$ candidates with $\Delta E < -m_\pi$ when the π^0 decays asymmetrically and is emitted along the ρ^+ direction.

To derive the upper limit we combine all six reconstruction channels. Efficiencies are weighted, taking into account the branching fractions for the D^{*0} and D^0 decays. The overall reconstruction efficiency is 2.3%, where the major contributions are due to the exclusive reconstruction approach (30%), the track and photon quality requirements (65%), the δM requirement (30%), and the Fisher discriminant technique (58%). To estimate the upper limit, we conservatively reduce reconstruction efficiency by its

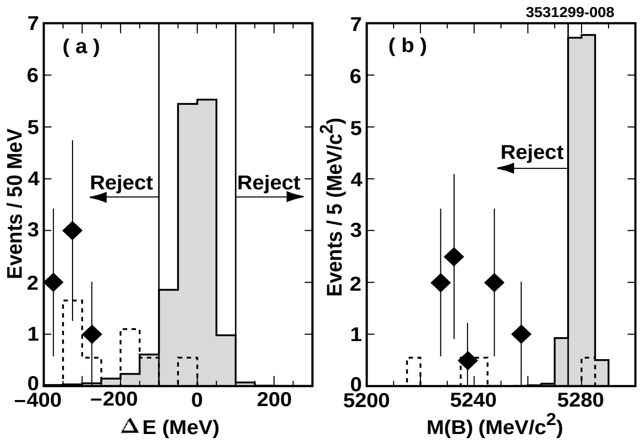

FIG. 2. (a) ΔE and (b) $M(B)$ projections of the signal region. Points show the $\Upsilon(4S)$ data; solid and dashed histograms show the predictions of the signal and $B\bar{B}$ simulations, respectively. The prediction of the $B\bar{B}$ simulation is normalized to the statistics of our data sample according to the B branching fractions [12]. Simulated signal events are shown assuming that $\mathcal{B}(\bar{B}^0 \to D^{*0}\gamma) \approx 30 \times 10^{-5}$. The nonzero simulated $B\bar{B}$ contribution in the signal region is due to the decay $\bar{B}^0 \to D^{*0}\pi^0$ assuming $\mathcal{B}(\bar{B}^0 \to D^{*0}\pi^0) = 1.0 \times 10^{-4}$. Multiple candidates are weighted as described in the text.

systematic error (18%). The largest contributions to this error are due to the uncertainties in the track and photon reconstruction efficiencies (11%), the D^0 branching fractions (9%), Fisher discriminant (6%), and the efficiencies of the requirements on the reconstructed masses of the D^0 (5%) and $\bar{B}^0$ (5%) candidates. To estimate the upper limit we assume $\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0) = \mathcal{B}(\Upsilon(4S) \to B^+B^-) = 0.5$. The upper limit on the number of detected signal events is 2.3 at 90% C.L. according to the prescription given in [17] and corresponds to an upper limit on the branching fraction for the decay $\bar{B}^0 \to D^{*0}\gamma$ of 5.0×10^{-5} at 90% C.L.

We performed the first search for the decay $\bar{B}^0 \to D^{*0}\gamma$ and set an upper limit on its branching fraction of 5.0×10^{-5} at 90% C.L. Our nonobservation is consistent with the absence of anomalous enhancements that could have overcome short-distance color suppression in the studied process. We confirm theoretical predictions that weak radiative B decays are dominated by the short-distance $b \to s\gamma$ mechanism. Finally, our results should be useful for studies of radiative and color-suppressed processes with heavy quarks at future high statistics B physics experiments. At these facilities the decay $\bar{B}^0 \to D^{*0}\gamma$ should be utilized to verify if the short-distance QCD radiative corrections are under firm theoretical control and, possibly, to search for new physical phenomena.

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