# First Search for the Flavor Changing Neutral Current Decay $D^0 \to \gamma\gamma$

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Using 13.8 $\text{fb}^{-1}$ of data collected at or just below the $\Upsilon(4S)$ with the CLEO detector, we report the result of a search for the flavor changing neutral current process $D^0 \to \gamma\gamma$. We observe no significant signal for this decay mode and determine 90% confidence level upper limits on the branching fractions $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0) < 0.033$ and $\mathcal{B}(D^0 \to \gamma\gamma) < 2.9 \times 10^{-5}$.

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In the standard model (SM), flavor changing neutral current (FCNC) processes are forbidden at the tree level but can occur at higher loop level. Therefore, they provide a good opportunity to probe new physics beyond the SM, especially those processes where very small SM signals are expected. The experimental studies of FCNC processes for charm have lagged behind those of the other flavors. The decay $D^0 \to \gamma\gamma$ is a FCNC process which has not been measured. The branching fraction for $D^0 \to \gamma\gamma$ expected from SM physics is about $10^{-8}$ or less [1,2], but gluino exchange in supersymmetric models with reasonable parameters can enhance the SM rate by as much as 2 orders of magnitude [3].

In this Letter, we present results of the first search for the FCNC process $D^0 \to \gamma\gamma$. The data were collected with two configurations (CLEO II [4] and CLEO II.V [5]) of the CLEO detector at the Cornell Electron Storage Ring (CESR). They consist of 13.8 $\text{fb}^{-1}$ taken at or just below the $\Upsilon(4S)$ where $c\bar{c}$ or other accessible quark pairs are produced with the $D^0$ candidates produced in the hadronization of $c\bar{c}$ pairs. The final states of the decays under study are reconstructed by combining detected photons or neutral pions with charged pions. The detector elements most important for the results presented here are the tracking system, which consists of several concentric detectors operating inside a 1.5 T superconducting solenoid, and the high-resolution electromagnetic calorimeter, consisting of 7800 CsI(Tl) crystals. For CLEO II, the tracking system consists of a 6-layer straw tube chamber, a 10-layer precision drift chamber, and a 51-layer main drift chamber. The main drift chamber also provides a measurement of the specific ionization loss, $dE/dx$, used for particle identification. For CLEO II.V the straw tube chamber was replaced by a 3-layer, double-sided silicon vertex detector, and the gas in the main drift chamber was changed from an argon-ethane to a helium-propane mixture.

Because of the small expected branching fraction, the mass resolution for two-photon final state, and the huge combinatoric backgrounds from random photons, it is extremely difficult to find a $D^0$ mass peak in $\gamma\gamma$ invariant mass if searching directly for $D^0 \to \gamma\gamma$. However, the situation is very different if we require the $D^0$ to be produced from the decay $D^{*+} \to D^0\pi^+$. The energy release $Q$ of candidates for the decay $D^{*+} \to D^0\pi^+$ is given by $Q/c^2 \equiv M(D^{*+}) - M(D^0) - M_{\pi^+}$. In this expression, $M(D^{*+})$ and $M(D^0)$ are the invariant masses of the $D^{*+}$ and $D^0$ candidates, respectively, and $M_{\pi^+}$ is the $\pi^+$ mass [6]. There exists an excellent calibration mode, $D^{*+} \to D^0\pi^+$ where $D^0 \to \pi^0\pi^0$. This calibration mode and the signal mode have similar final state particles so many common systematic errors will cancel. The branching fraction of $D^0 \to \pi^0\pi^0$ was measured to be $\mathcal{B}(D^0 \to \pi^0\pi^0) = (8.4 \pm 2.2) \times 10^{-4}$ [6,7]. The CLEO resolution in $Q$ is better than 1 MeV and does not differ significantly between the two $D^0$ decay modes. The analysis strategy to search for $D^0 \to \gamma\gamma$ is to use $D^{*+} \to D^0\pi^+$ where $D^0 \to \gamma\gamma$ and $D^0 \to \pi^0\pi^0$, and calculate the ratio, $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0)$. Charge-conjugate modes are implied throughout this Letter.

Candidates for $D^0$ meson decays are reconstructed by combining two detected photons or neutral pions. The invariant mass of the two photons or neutral pions is required to be within 2.5 standard deviations ($\sigma$) of the known $D^0$ mass [6]. The photon candidates are required to pass quality cuts and not to be associated with charged tracks. To form $\pi^0$ candidates, pairs of photon candidates with invariant mass within $3\sigma$ of the $\pi^0$ mass $M_{\pi^0}$ [6] are fitted kinematically with the mass constrained to $M_{\pi^0}$. To reduce combinatoric backgrounds, each $\pi^0$ or photon candidate in the $D^0 \to \pi^0\pi^0$ or $\gamma\gamma$ candidate is required to have momentum greater than 0.55 GeV$/c$. Furthermore, each $D^0$ candidate is required to have momentum greater than 2.2 GeV$/c$. These requirements come from an optimization that minimizes the statistical error of the branching fraction $D^{*+} \to D^0\pi^+$ where $D^0 \to \pi^0\pi^0$.

A $\pi^+$ is then combined with the $D^0$ candidate to form a $D^{*+}$ candidate. The $\pi^+$ candidate must be a well-reconstructed track originating from a cylinder of radius 3 mm and half-length 5 cm centered at the $e^+e^-$ interaction point. The minimum momentum requirement on the $D^0$ candidate of 2.2 GeV$/c$ corresponds to a lower limit on the $\pi^+$ momentum of approximately 100 MeV$/c$. The $dE/dx$ information for the $\pi^+$ candidate, if it exists and is reliable, is required to be within $3\sigma$ of its expected value. The two energetic photons, one from each $\pi^0$ in $D^0 \to \pi^0\pi^0$ decay, can form fake $D^0 \to \gamma\gamma$ candidate. To limit cross-feed from $D^0 \to \pi^0\pi^0$, a photon candidate in $D^0 \to \gamma\gamma$ is rejected if $M(\gamma\gamma)$ is within $3\sigma$ of $M_{\pi^0}$ when combined with any other photon in the event ($\pi^0$ veto).

To estimate the detection efficiencies and backgrounds, we generate $D^{*+} \to D^0\pi^+$ with $D^0 \to \gamma\gamma$ and $D^0 \to \pi^0\pi^0$, together with generic Monte Carlo events ($u\bar{u}$, $d\bar{d}$, $s\bar{s}$, and $c\bar{c}$) produced near the $\Upsilon(4S)$, and simulate the CLEO detector response with GEANT [8]. Simulated events for the CLEO II and CLEO II.V configurations are processed in the same manner as the data. With the above event selection, multiple candidates per event are rare (less than 1%). From Monte Carlo simulations, the cross-feed contribution from $D^0 \to \pi^0\pi^0$ to $D^0 \to \gamma\gamma$ in the signal region of the $Q$ distribution is about one event (or about four events without the $\pi^0$ veto). Other cross-feed contributions from possible $D^0 \to \eta\eta$, $\eta X$ decays are negligible.

Figure 1 shows the $Q$ distributions for $D^{*+} \to D^0\pi^+$ candidates where $D^0 \to \pi^0\pi^0$ and $D^0 \to \gamma\gamma$. The circles with error bars are CLEO data which are fit using a binned likelihood fit to a Gaussian function with expected mean and width determined from signal Monte Carlo simulation, on top of a threshold background function. For $D^{*+} \to D^0\pi^+$ where $D^0 \to \pi^0\pi^0$, $N(\pi^0\pi^0) = 628.0 \pm 31.8$ signal events are observed. The signal and background levels found in the data are in good agreement with those obtained from Monte Carlo simulations. For $D^{*+} \to D^0\pi^+$ where $D^0 \to \gamma\gamma$, no significant enhancement is observed in the signal region. The signal yield from the fit is $N(\gamma\gamma) = 19.2 \pm 9.3$ events.

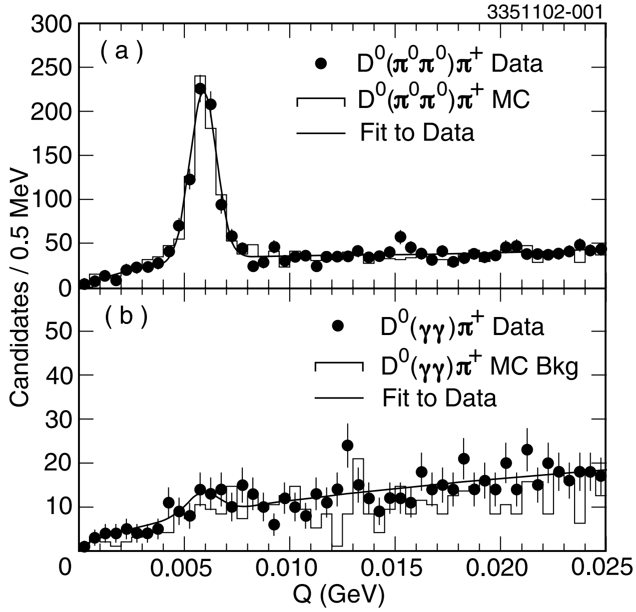


FIG. 1. The $Q$ distributions for $D^{*+} \to D^0\pi^+$ where $D^0 \to \pi^0\pi^0$ (a) and $D^0 \to \gamma\gamma$ (b). The circles are from data and the solid curves are the fit to the data. The histograms are from the normalized Monte Carlo expectations.

From Monte Carlo simulations, the relative efficiency for $D^0 \to \gamma\gamma$ and $D^0 \to \pi^0\pi^0$ is determined to be $\epsilon(\gamma\gamma)/\epsilon(\pi^0\pi^0) = 1.58 \pm 0.05$. The systematic uncertainties come from event selection, signal yield from data and Monte Carlo simulation, and are listed in Table I. The other common systematic uncertainties for $D^{*+} \to D^0\pi^+$ cancel in measuring $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0) = [N(\gamma\gamma)/N(\pi^0\pi^0)]/[\epsilon(\gamma\gamma)/\epsilon(\pi^0\pi^0)] = 0.0194 \pm 0.0094$. Combining the signal yields, relative selection efficiency and systematic uncertainties in $D^{*+} \to D^0\pi^+$ where $D^0 \to \pi^0\pi^0$ and $D^0 \to \gamma\gamma$, we then obtain a 90% confidence level (C.L.) upper limit by the following method. We consider only the physical region of the ratio $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0)$ assuming that the shape of the likelihood is Gaussian with an unknown mean, but whose standard deviation is determined by the statistical and systematic errors added in quadrature. We then determine the 90% C.L. upper limit to be the mean of the Gaussian, 90% of whose probability lies above the observed ratio. We set an upper limit: $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0) < 0.033$ at the 90% C.L. Using $\mathcal{B}(D^0 \to \pi^0\pi^0) = (8.4 \pm 2.2) \times 10^{-4}$ [6,7], we similarly set an upper limit: at the 90% C.L.

TABLE I. Summary of systematic error sources and their contribution in measuring the ratio $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0)$.

| Systematic error source | Error (%) |
|---|---|
| $\pi^0$ finding efficiency | $5.0/\pi^0$ |
| $\gamma$ finding efficiency | $3.0/\gamma$ |
| Fit yield | 3.0 |
| $D^0$ selection | 2.0 |
| MC statistics | 2.0 |
| Hadronic event selection | 1.0 |
| Total for $D^0 \to \gamma\gamma$ | 7.3 |
| Total for $D^0 \to \pi^0\pi^0$ | 10.9 |
| Total for $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0)$ | 13.1 |

In summary, we report the result of a search for the FCNC process of $D^0 \to \gamma\gamma$. We observe no significant signal for this decay mode and determine the first 90% C.L. upper limits on the following branching fractions: $\mathcal{B}(D^0 \to \gamma\gamma)/\mathcal{B}(D^0 \to \pi^0\pi^0) < 0.033$ and $\mathcal{B}(D^0 \to \gamma\gamma) < 2.9 \times 10^{-5}$. This result is an order of magnitude above the theoretical prediction of Ref. [3].

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