CLEO CONF 97-12

Search for Color-Suppressed B Hadronic Decays Processes with CLEO

CLEO Collaboration

Abstract

Using 3.1 fb^{-1} of data accumulated at the $\Upsilon(4S)$ by the CLEO-II detector, corresponding to 3.3 million $B\bar{B}$ pairs, we have searched for the color-suppressed B hadronic decay processes: $\bar{B}^0 \to D^0(D^{*0})\mathrm{X}^0$, where X^0 is a light neutral meson such as π^0, ρ^0, η, $\eta^{'}$ or ω. The D^{*0} mesons are reconstructed in $D^{*0} \to D^0\pi^0$ and the D^0 mesons in $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$. No obvious signal is observed. We set 90% C.L. upper limits on these modes, varying from 1.2 $\times 10^{-4}$ for $\bar{B}^0 \to D^0\pi^0$ to 1.7 $\times 10^{-3}$ for $\bar{B}^0 \to D^{*0}\eta^{'}$.

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I. INTRODUCTION

The B hadronic decays $\bar{B}^0 \to D^0(D^{*0})X^0$, where X^0 is a light neutral meson such as π^0, ρ^0, η, η' or ω, have not yet been observed. These decays proceed via the internal spectator diagram shown in Fig. 1.

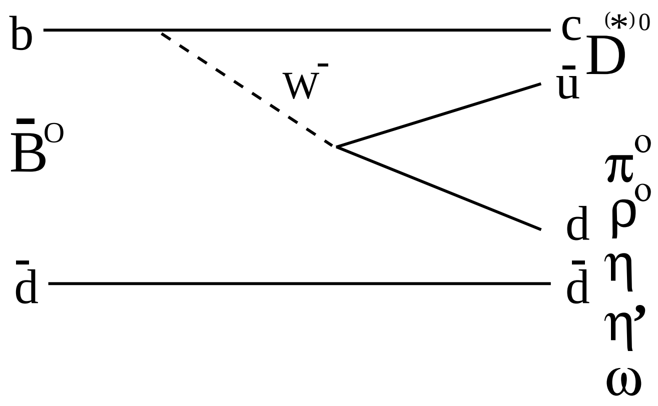

Figure 1: Internal spectator diagram of B hadronic decays $\bar{B}^0 \to D^0(D^{*0})X^0$.

The internal spectator decays are expected to be suppressed relative to the decays via external spectator diagrams, since the colors of the quarks from the virtual W must match the colors of the c quark and the accompanying spectator antiquark. Therefore these decays are refered to as color-suppressed decays, while decays via external spectator diagrams are refered to as color-favored decays. Measurements of these color-suppressed decays provide a test of factorization [1] and useful information on the scale of strong final-state interaction in the B meson system.

Previous CLEO papers [2] reported upper limits on the Color-suppressed B hadronic decays. We report new results using the full CLEO-II data set and an improved analysis method.

II. DATA SAMPLE

The data used in this analysis were produced in e^+e^- annihilations at the Cornell Electron Storage Ring (CESR) and collected with the CLEO II detector. The detector is described in detail elsewhere [3]. The intergrated luminosity is 3.1 fb^{-1} at the $\Upsilon(4s)$ resonance, which corresponds to about 3.3 $\times\ 10^6$ $B\bar{B}$ pairs, and 1.6 fb^{-1} at energies just below $B\bar{B}$ threshold (henceforth referred to as the continuum).

There are two key variables for full reconstruction of B mesons at CLEO, which make use of the fact that the B energy is the same as the beam energy. One is the beam-constrained mass, $M_B \equiv \sqrt{E_{beam}^2 - P_{observed}^2}$. The other one is the difference between the reconstructed energy and the beam energy, $\Delta E \equiv E_{observed} - E_{beam}$. M_B is narrower than the reconstructed mass since the beam energy is well-known. The ΔE variable is sensitive to missing or extra particles in the B decay, as well as particle species. For fully-reconstructed B meson decays, the M_B distribution peaks at 5.28 GeV with resolution around 2.7 MeV, and ΔE peaks at 0.0 GeV with a resolution ranging from 18 to 50 MeV, depending on the B and D^0 decay modes.

III. BACKGROUND STUDY

In this paper, we search for the color-suppressed B hadronic decay modes

$$\bar{B}^0 \to D^0\pi^0, D^0\rho^0, D^0\eta, D^0\eta', D^0\omega$$
$$\bar{B}^0 \to D^{*0}\pi^0, D^{*0}\rho^0, D^{*0}\eta, D^{*0}\eta', D^{*0}\omega$$

where $D^{*0} \to D^0\pi^0$ and $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$. There are backgrounds from continuum and $B\bar{B}$ events. Backgrounds from continuum can be controlled using event-shape variables which are described later, and monitored well using the 1.6 fb^{-1} continuum data set. The backgrounds from $B\bar{B}$ events are dominated by feedthrough from color-favored two-body hadronic decays of the type:

$$B^- \to D^0\pi^-(\rho^-, a_1^-),\ B^- \to D^{*0}\pi^-(\rho^-, a_1^-)$$
$$\bar{B}^0 \to D^+\pi^-(\rho^-, a_1^-),\ \bar{B}^0 \to D^{*+}\pi^-(\rho^-, a_1^-)$$

The branching ratios of these color-favored B meson decay modes were measured quite precisely in previous CLEO papers [2]. In most cases a real, energetic D^0 or D^{*0} from the 2-body color-favored decays is combined with a fake light meson. The backgrounds from these color-favored processes can have structure in the M_B and ΔE distributions, depending on which color-suppressed mode is being analyzed.

For decay modes involving η or η', combinatoric background is the dominating source. Therefore, backgrounds for these color-suppressed processes have no peaking structure in the M_B and ΔE distributions.

For the color-supressed mode $\bar{B}^0 \to D^0\pi^0$, the dominant background is from color-favored B meson decay $B^- \to D^0\rho^-$ where $\rho^- \to \pi^-\pi^0$. The π^0 from the ρ^- is combined with the real D^0 to form the background event. Since the ρ^- is produced in a helicity zero state it's decay products have a cosine squared distribution along the ρ^- flight direction. When the π^- from ρ^- decay is boosted backward in the ρ^- rest frame, the momentum spectrum of this π^- is very soft, and the π^0 from the ρ^- decay carries most of the momentum of the ρ^-. These background events peak in M_B around 5.28 GeV since the missing π^- from the ρ^- decay is very soft and does not contribute much to the beam-constrained mass calculation. However, ΔE for these background events differs from zero by more than one pion mass, due to the missing π^- from the ρ^- decay. For $\bar{B}^0 \to D^0(D^{*0})\pi^0$, color-favored backgrounds and color-suppressed signals are much better seperated in ΔE.

For $\bar{B}^0 \to D^0\rho^0$ and $\bar{B}^0 \to D^0\omega$, there are color-favored B meson decays that give exactly the same final state particles as our color-favored signals do. Neither misidentification nor missing or extra particles are needed for some color-favored decays to fake our signal. Therefore, the M_B distribution from these physics background peaks at 5.28 GeV while its ΔE distribution peaks at 0.0 GeV, exactly like the color-suppressed signal.

For example, $\bar{B}^0 \to D^0\rho^0$, where $\rho^0 \to \pi^+\pi^-$, is one of the color-suppressed signals we seek. $\bar{B}^0 \to D^{*+}\pi^-$ where $D^{*+} \to D^0\pi^+$ is a color-favored process that gives exactly the same final state particles as our color-suppressed signal process does. As long as the mass formed by the energetic π^- from B decay and the soft π^+ from D^{*+} decay falls into the wide ρ^0 mass window, this color-favored background can be misinterpretted as a color-suppressed signal. Similarly, color-favored decay process $\bar{B}^0 \to D^{*+}\rho^-$ where $D^{*+} \to D^0\pi^+$ gives the same final state particles as color-suppressed signal $\bar{B}^0 \to D^0\omega$ where $\omega \to \pi^+\pi^-\pi^0$. We will discuss in detail the selection cuts used to tightly controll these backgrounds.

For $\bar{B}^0 \to D^{*0}\mathrm{X}^0$, there is no corresponding color-favored B meson decay that fakes our signal like $\bar{B}^0 \to D^{*+}\pi^-$ fakes $\bar{B}^0 \to D^0\rho^0$. Also the background level from color-favored B meson decays is very low for $\bar{B}^0 \to D^{*0}\mathrm{X}^0$ decay processes, thanks to the good resolution on $D^{*0} - D^0$ mass difference.

Since signal and background are in general much better seperated in ΔE than in M_B, instead of cutting on ΔE variable and fitting M_B, we cut on M_B and fit ΔE distribution for the signal yield.

IV. EVENT SELECTION

Hadronic events are selected by requiring at least three charged tracks, a total detected energy of at least 0.15 $E_{c.m}$, and a primary vertex within 7.5 cm in the beam direction. To suppress continuum background, we require that the ratio of second to zeroth Fox-Wolfram moments R_2 determined using charged tracks and unmatched neutral showers be less than 0.3 (0.5 for clean decay modes involving η or $\eta^{'}$) [4]. To further reduce continuum background, we then require that the cosine of the angle between the sphericity axis of the B meson candidate and the sphericity axis of the remainder of the event satisfies $|\cos(\theta_{sphericity})| < 0.8$ (0.9 for decay modes involving η or $\eta^{'}$). For a jet-like continuum event, the absolute value of this angle is small, while for a $B\bar{B}$ event, the two axes are almost uncorrelated.

Using the 1.6 fb^{-1} continuum data set. we found the continuum background level to be very low for all color-suppressed modes. No peaking structure in the ΔE distributions is observed.

Selection of D^0 and D^{*0} decays

Standard track quality requirements are imposed. D^0 candidates are reconstructed in decay modes $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$. π^0 candidates are formed by combining two showers whose invariant mass is within 2.5σ of the π^0 mass (where henceforth σ denotes the r.m.s. resolution). For the charged kaon candidate, we require 2σ consistency of dE/dx. For pion candidate, 3σ consistency is required. To form $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^0$, kaon and pion momenta are required to be at least 250 MeV. For $D^0 \to K^-\pi^+\pi^+\pi^-$, the minimum momentum requirement is reduced to 200 MeV. There is an additional Dalitz weight requirement for $D^0 \to K^-\pi^+\pi^0$ decay mode to further suppress the combinatoric backgrounds. The invariant mass of D^0 candidates is required to be within 2.0σ of the nominal D^0 mass.

D^{*0} candidates are reconstructed using decay mode $D^{*0} \to D^0\pi^0$. We form D^{*0} candidates by D^0 candidates using above selection, then require that the $D^{*0} - D^0$ mass difference be within 2.5σ of the measured value [5].

Selection of the light neutral meson $\mathbf{X}^0$

Almost all the discrimination power against color-favored physics backgrounds come from selection cuts on X^0. We make full use of mass, momentum, decay angle and other kinematic variables of X^0 to suppress backgrounds while keeping signal efficiency as high as possible.

π^0 candidates in $\bar{B}^0 \to D^0(D^{*0})\pi^0$ decays are formed by combining two showers whose invariant mass is within 2.5σ of the π^0 mass. Due to the hard spectrum of two-body B meson decay, π^0 from $\bar{B}^0 \to D^0\pi^0$ decay is very energetic. We further require the momentum of the π^0 candidate to range from 2.1 GeV to 2.5 GeV. Similar momentum requirements are imposed to the other light neutral meson X^0.

For $\bar{B}^0 \to D^0\rho^0$ decays, there are color-favored physics backgrounds from $\bar{B}^0 \to D^{*+}\pi^-$ that give exactly the same final state particles. $B^- \to D^0\rho^-$ can also fake our color-suppressed signal by substituting the soft π^0 from ρ^- decay by a soft π^+ from the other B meson. For these physics backgrounds, there exists a correlation between the D^0 and the fast π^- from the fake ρ^0. To suppress these physics backgrounds, we require that the D^0 candidate to be associated with a fast π^+ from the ρ^0 candidate. There is still contribution from color-favored physics backgrounds even after this requirement. As a D^0 decay has a certain chance of being misidentified as a $\bar{D}^0$ decay. For the D^0's from our signal process, together with the dE/dx and D^0 mass requirements, this misidentification rate is determined to be less than 20%. Therefore the contribution from color-favored physics background is negligible. Since the ρ^0 from $\bar{B}^0 \to D^0\rho^0$ decay is longitudinally polarized, we also cut on the ρ^0

decay angle (the angle between the direction of the pion in the ρ^0 rest frame and the direction of the ρ^0 in the lab frame) to reduce combinatoric backgrounds.

Candidate η and η' mesons are reconstructed in their $\eta \to \gamma\gamma$ and $\eta' \to \eta\pi^+\pi^-$ decay modes. The absolute value of the η decay angle is required to be less than 0.85 to remove asymmetric decays and the raw $\gamma\gamma$ invariant mass of each η candidate must be within 30 MeV of the nominal η mass. dE/dx consistency is also required for charged pion candidates that form $\eta' \to \eta\pi^+\pi^-$. η' candidates are required to be within 30 MeV of the nominal η' mass.

ω mesons are reconstructed in the decay mode $\omega \to \pi^+\pi^-\pi^0$. Charged and neutral pions are required to have momenta greater than 250 MeV, to reject soft pions from D^{*0} or D^{*+} decays. ω candidates are also required to be within 30 MeV of the nominal ω mass.

Signal selection efficiencies for all the color-suppressed decay modes are shown in Table 1.

Table 1: Selection efficiencies of all color-suppressed modes, together with upper limits on yields and branching ratios, both at 90% C.L. The three efficiencies of each $\bar{B}^0 \to D^0(D^{*0})X^0$ correspond to the three $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$ modes.

Decay Mode	Selection Efficiency	Yield	Branching Ratio
$\bar{B}^0 \to D^0\pi^0$	26.1, 7.8, 12.5%	< 12	$< 1.2 \times 10^{-4}$
$\bar{B}^0 \to D^{*0}\pi^0$	14.1, 3.7, 5.4%	< 14	$< 4.4 \times 10^{-4}$
$\bar{B}^0 \to D^0\rho^0$	8.4, 2.6, 3.9%	< 13	$< 4.0 \times 10^{-4}$
$\bar{B}^0 \to D^{*0}\rho^0$	4.0, 1.0, 1.5%	< 5	$< 6.0 \times 10^{-4}$
$\bar{B}^0 \to D^0\eta$	24.5, 7.0, 11.4%	< 5	$< 1.4 \times 10^{-4}$
$\bar{B}^0 \to D^{*0}\eta$	10.5, 3.4, 4.9%	< 2.3	$< 2.5 \times 10^{-4}$
$\bar{B}^0 \to D^0\eta'$	13.4, 3.6, 5.9%	< 8	$< 1.0 \times 10^{-3}$
$\bar{B}^0 \to D^{*0}\eta'$	5.9, 1.7, 2.5%	< 3.9	$< 1.7 \times 10^{-3}$
$\bar{B}^0 \to D^0\omega$	12.4, 2.8, 3.2%	< 17	$< 5.6 \times 10^{-4}$
$\bar{B}^0 \to D^{*0}\omega$	4.8, 0.9, 1.3%	< 6	$< 8.0 \times 10^{-4}$

V. RESULTS

ΔE distributions of all the color-suppressed signal processes after all selection cuts are shown in Fig. $2-6$.

The ΔE distribution of each color-suppressed mode is fit with a Gaussian and background shape function which is obtained using 17×10^6 $\mathrm{B\bar{B}}$ MC events plus a continuum component. The mean value and width of Gaussian distribution are fixed and the values are determined from signal Monte Carlo. We use various color-favored decay modes $B^- \to D^0\pi^-$, $B^- \to D^0\rho^-$, $B^- \to D^{*0}\pi^-$, $B^- \to D^{*0}\rho^-$, $\bar{B}^0 \to D^+\pi^-$, $\bar{B}^0 \to D^+\rho^-$ to show that the ΔE resolutions in data and MC agree well. Possible differences between data and MC in ΔE distribution are considered and included in the yield error.

Various ΔE background shape functions have been used to fit for the signal yield. Our results are found to be insensitive to different background shapes, as long as they describe the ΔE distribution reasonably well. For each signal process with different D^0 decay mode, the yield for each D^0 submode is obtained seperately, since the ΔE resolutions are different for different. These yields are added independently to get the total yield.

Selection efficiencies of all signal modes, together with upper limits on yields and branching rations, both at 90% C.L. are shown in Table 1. Particle Data Group values for D^0, D^{*0}, η, $\eta^{'}$ and ω branching ratios are used in the upper limits calculation [5]. Among all the decay modes, the upper limit for $\bar{B}^0 \to D^0\pi^0$ mode is the lowest at 1.2 $\times 10^{-4}$. All the upper limits on branching ratios are still higher than theoretical predictions [6, 7]. Compared with factorization and QCD based calculations, no dramatic enhancement of color-suppressed B hadronic decay branching ratios is observed, indicating there is no sign of large scale final-state interaction in these B meson decay modes.

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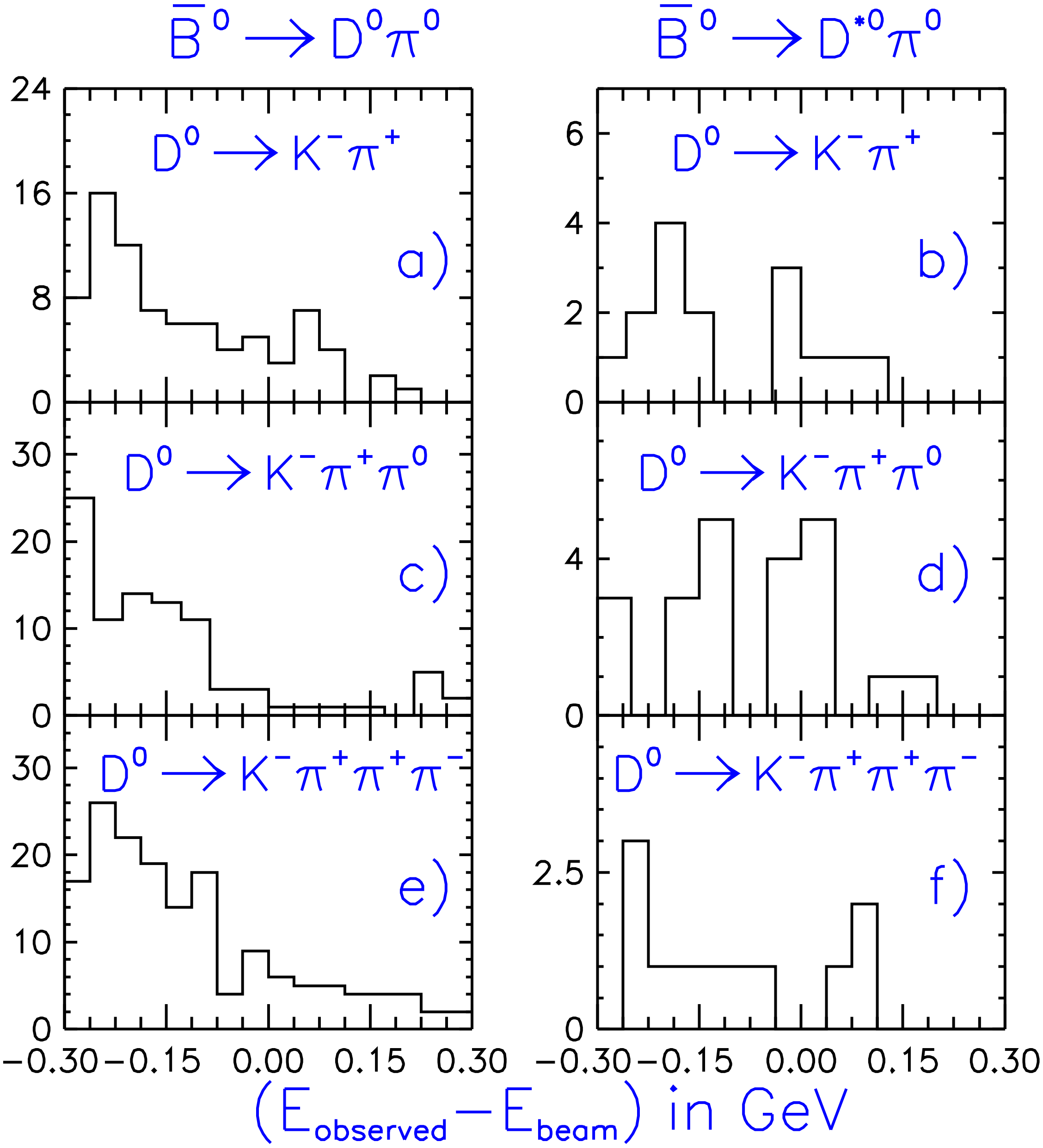

Figure 2: ΔE distributions of $\bar{B}^0 \to D^0\pi^0$ and $\bar{B}^0 \to D^{*0}\pi^0$ decay modes.

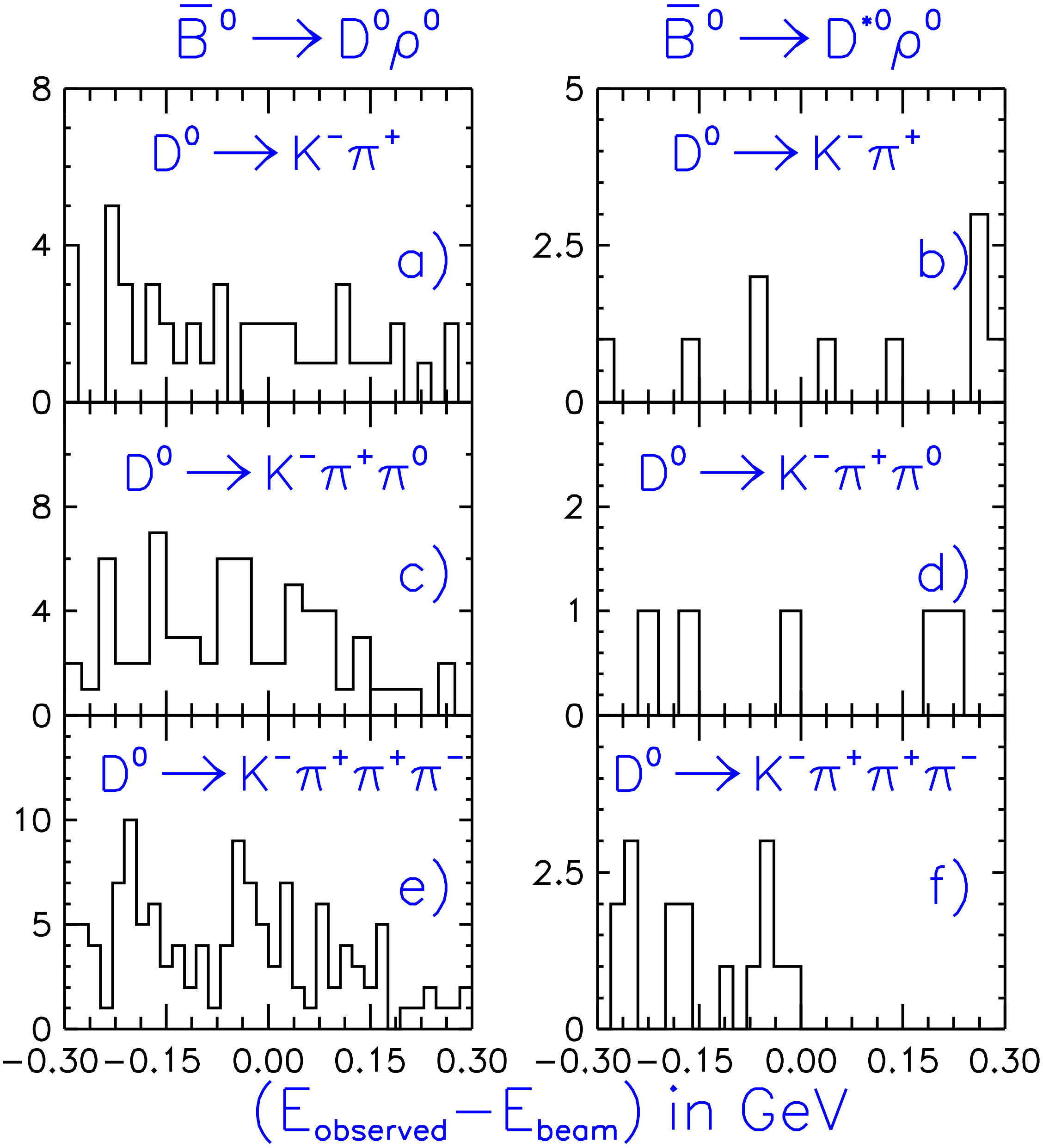

Figure 3: ΔE distributions of $\bar{B}^0 \rightarrow D^0\rho^0$ and $\bar{B}^0 \rightarrow D^{*0}\rho^0$ decay modes.

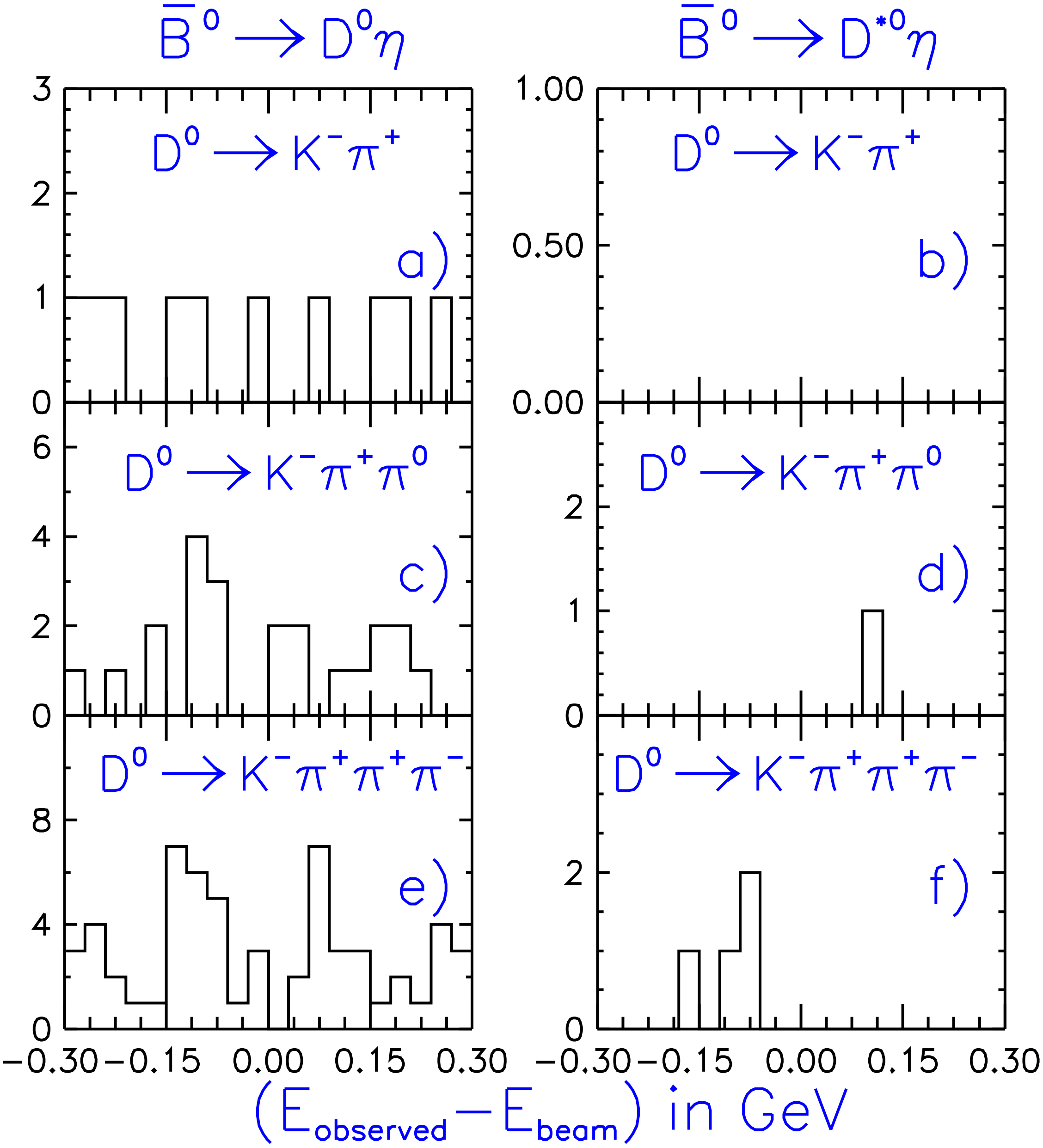

Figure 4: ΔE distributions of $\bar{B}^0 \to D^0\eta$ and $\bar{B}^0 \to D^{*0}\eta$ decay modes.

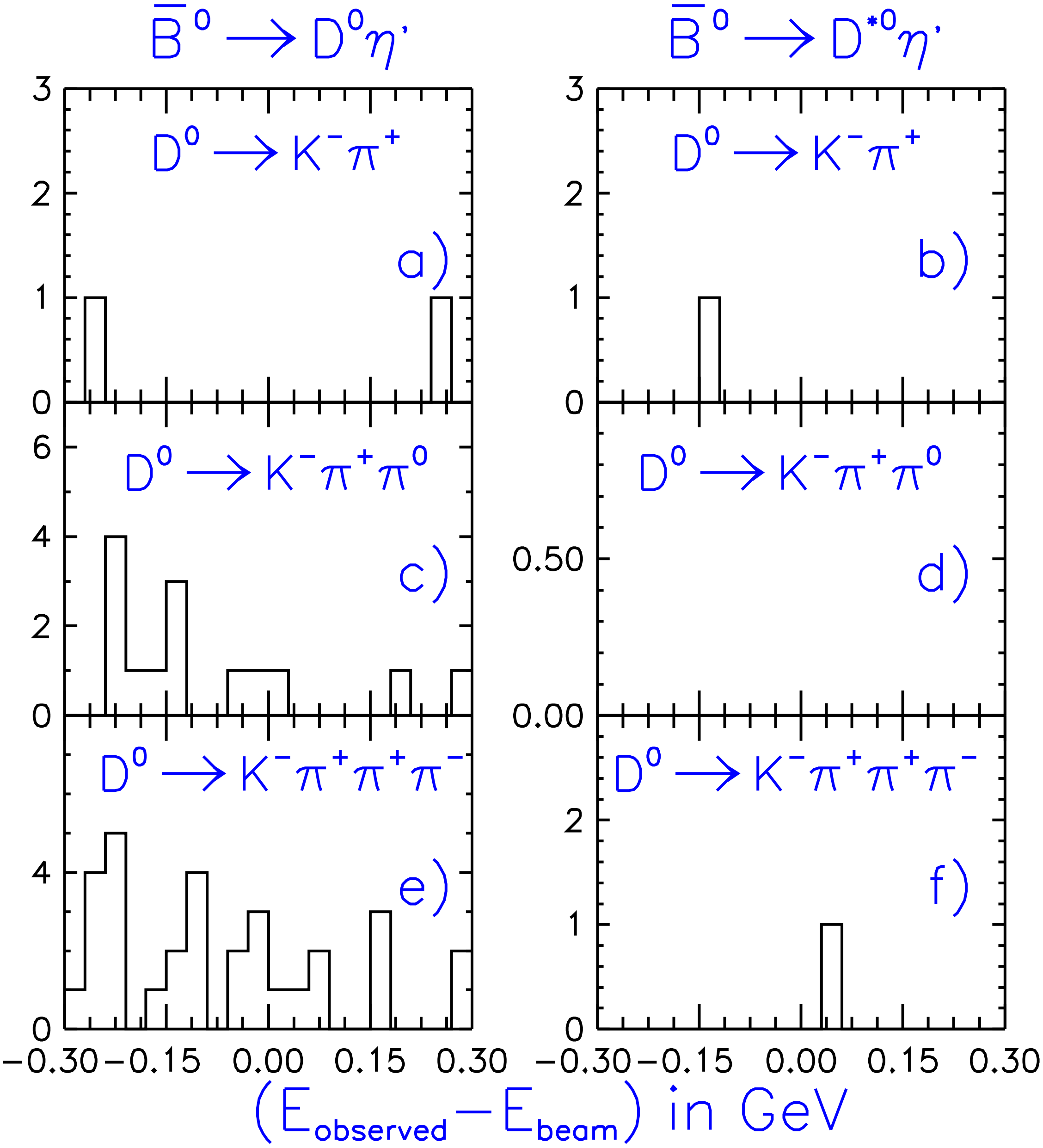

Figure 5: ΔE distributions of $\bar{B}^0 \to D^0\eta'$ and $\bar{B}^0 \to D^{*0}\eta'$ decay modes.

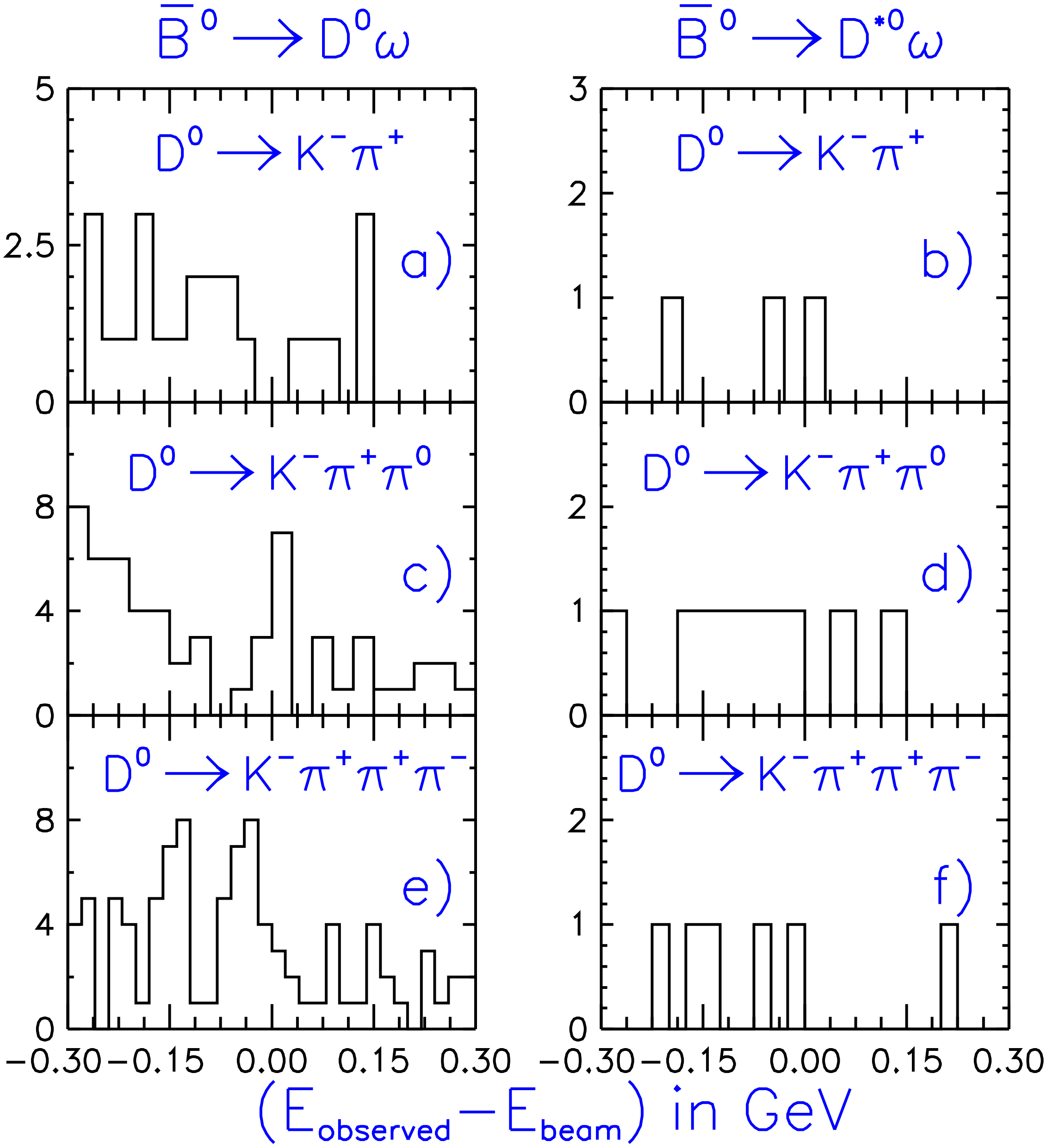

Figure 6: ΔE distributions of $\bar{B}^0 \to D^0\omega$ and $\bar{B}^0 \to D^{*0}\omega$ decay modes.