CLEO CONF 97-28
EPS97 384

# Search For the Decay $B \to D_{s1}^{+}(2536)X$

CLEO Collaboration

(August 13, 1997)

## Abstract

We have searched for the decay $B \to D_{s1}^{+}(2536)X$. The upper limit to the inclusive branching fraction is measured to be $\mathcal{B}(B \to D_{s1}^{+}X) < 0.95\%$ at the 90% confidence level. This limit is small compared with the total expected $B \to \bar{D}^{(*)}D^{(*)}KX$ rate. Assuming factorization, the $D_{s1}^{+}$ decay constant is constrained to be $f_{D_{s1}^{+}} < 114$ MeV at the 90% confidence level, at least 2.5 times smaller than that of $D_s^{+}$.

C. P. Jessop,[1] K. Lingel,[1] H. Marsiske,[1] M. L. Perl,[1] D. Ugolini,[1] R. Wang,[1] X. Zhou,[1] T. E. Coan,[2] V. Fadeyev,[2] I. Korolkov,[2] Y. Maravin,[2] I. Narsky,[2] V. Shelkov,[2] J. Staeck,[2] R. Stroynowski,[2] I. Volobouev,[2] J. Ye,[2] M. Artuso,[3] A. Efimov,[3] M. Goldberg,[3] D. He,[3] S. Kopp,[3] G. C. Moneti,[3] R. Mountain,[3] S. Schuh,[3] T. Skwarnicki,[3] S. Stone,[3] G. Viehhauser,[3] X. Xing,[3] J. Bartelt,[4] S. E. Csorna,[4] V. Jain,[4,*] K. W. McLean,[4] S. Marka,[4] R. Godang,[5] K. Kinoshita,[5] I. C. Lai,[5] P. Pomianowski,[5] S. Schrenk,[5] G. Bonvicini,[6] D. Cinabro,[6] R. Greene,[6] L. P. Perera,[6] G. J. Zhou,[6] B. Barish,[7] M. Chadha,[7] S. Chan,[7] G. Eigen,[7] J. S. Miller,[7] C. O'Grady,[7] M. Schmidtler,[7] J. Urheim,[7] A. J. Weinstein,[7] F. Würthwein,[7] D. W. Bliss,[8] G. Masek,[8] H. P. Paar,[8] S. Prell,[8] M. Sivertz,[8] V. Sharma,[8] D. M. Asner,[9] J. Gronberg,[9] T. S. Hill,[9] D. J. Lange,[9] S. Menary,[9] R. J. Morrison,[9] H. N. Nelson,[9] T. K. Nelson,[9] C. Qiao,[9] J. D. Richman,[9] D. Roberts,[9] A. Ryd,[9] M. S. Witherell,[9] R. Balest,[10] B. H. Behrens,[10] W. T. Ford,[10] H. Park,[10] J. Roy,[10] J. G. Smith,[10] J. P. Alexander,[11] C. Bebek,[11] B. E. Berger,[11] K. Berkelman,[11] K. Bloom,[11] D. G. Cassel,[11] H. A. Cho,[11] D. S. Crowcroft,[11] M. Dickson,[11] P. S. Drell,[11] K. M. Ecklund,[11] R. Ehrlich,[11] A. D. Foland,[11] P. Gaidarev,[11] R. S. Galik,[11] L. Gibbons,[11] B. Gittelman,[11] S. W. Gray,[11] D. L. Hartill,[11] B. K. Heltsley,[11] P. I. Hopman,[11] J. Kandaswamy,[11] P. C. Kim,[11] D. L. Kreinick,[11] T. Lee,[11] Y. Liu,[11] G. S. Ludwig,[11] N. B. Mistry,[11] C. R. Ng,[11] E. Nordberg,[11] M. Ogg,[11,†] J. R. Patterson,[11] D. Peterson,[11] D. Riley,[11] A. Soffer,[11] B. Valant-Spaight,[11] C. Ward,[11] M. Athanas,[12] P. Avery,[12] C. D. Jones,[12] M. Lohner,[12] C. Prescott,[12] J. Yelton,[12] J. Zheng,[12] G. Brandenburg,[13] R. A. Briere,[13] A. Ershov,[13] Y. S. Gao,[13] D. Y.-J. Kim,[13] R. Wilson,[13] H. Yamamoto,[13] T. E. Browder,[14] Y. Li,[14] J. L. Rodriguez,[14] T. Bergfeld,[15] B. I. Eisenstein,[15] J. Ernst,[15] G. E. Gladding,[15] G. D. Gollin,[15] R. M. Hans,[15] E. Johnson,[15] I. Karliner,[15] M. A. Marsh,[15] M. Palmer,[15] M. Selen,[15] J. J. Thaler,[15] K. W. Edwards,[16] A. Bellerive,[17] R. Janicek,[17] D. B. MacFarlane,[17] P. M. Patel,[17] A. J. Sadoff,[18] R. Ammar,[19] P. Baringer,[19] A. Bean,[19] D. Besson,[19] D. Coppage,[19] C. Darling,[19] R. Davis,[19] N. Hancock,[19] S. Kotov,[19] I. Kravchenko,[19] N. Kwak,[19] S. Anderson,[20] Y. Kubota,[20] S. J. Lee,[20] J. J. O'Neill,[20] S. Patton,[20] R. Poling,[20] T. Riehle,[20] V. Savinov,[20] A. Smith,[20] M. S. Alam,[21] S. B. Athar,[21] Z. Ling,[21] A. H. Mahmood,[21] H. Severini,[21] S. Timm,[21] F. Wappler,[21] A. Anastassov,[22] J. E. Duboscq,[22] D. Fujino,[22,‡] K. K. Gan,[22] T. Hart,[22] K. Honscheid,[22] H. Kagan,[22] R. Kass,[22] J. Lee,[22] M. B. Spencer,[22] M. Sung,[22] A. Undrus,[22,§] R. Wanke,[22] A. Wolf,[22] M. M. Zoeller,[22] B. Nemati,[23] S. J. Richichi,[23] W. R. Ross,[23] P. Skubic,[23] M. Bishai,[24] J. Fast,[24] J. W. Hinson,[24] N. Menon,[24] D. H. Miller,[24] E. I. Shibata,[24] I. P. J. Shipsey,[24] M. Yurko,[24] S. Glenn,[25] S. D. Johnson,[25] Y. Kwon,[25,**] S. Roberts,[25] and E. H. Thorndike[25]

---

*Permanent address: Brookhaven National Laboratory, Upton, NY 11973.

†Permanent address: University of Texas, Austin TX 78712

‡Permanent address: Lawrence Livermore National Laboratory, Livermore, CA 94551.

§Permanent address: BINP, RU-630090 Novosibirsk, Russia.

**Permanent address: Yonsei University, Seoul 120-749, Korea.

[1]Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309
[2]Southern Methodist University, Dallas, Texas 75275
[3]Syracuse University, Syracuse, New York 13244
[4]Vanderbilt University, Nashville, Tennessee 37235
[5]Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061
[6]Wayne State University, Detroit, Michigan 48202
[7]California Institute of Technology, Pasadena, California 91125
[8]University of California, San Diego, La Jolla, California 92093
[9]University of California, Santa Barbara, California 93106
[10]University of Colorado, Boulder, Colorado 80309-0390
[11]Cornell University, Ithaca, New York 14853
[12]University of Florida, Gainesville, Florida 32611
[13]Harvard University, Cambridge, Massachusetts 02138
[14]University of Hawaii at Manoa, Honolulu, Hawaii 96822
[15]University of Illinois, Champaign-Urbana, Illinois 61801
[16]Carleton University, Ottawa, Ontario, Canada K1S 5B6
and the Institute of Particle Physics, Canada
[17]McGill University, Montréal, Québec, Canada H3A 2T8
and the Institute of Particle Physics, Canada
[18]Ithaca College, Ithaca, New York 14850
[19]University of Kansas, Lawrence, Kansas 66045
[20]University of Minnesota, Minneapolis, Minnesota 55455
[21]State University of New York at Albany, Albany, New York 12222
[22]Ohio State University, Columbus, Ohio 43210
[23]University of Oklahoma, Norman, Oklahoma 73019
[24]Purdue University, West Lafayette, Indiana 47907
[25]University of Rochester, Rochester, New York 14627

## INTRODUCTION

One of the outstanding issues in $B$ meson physics is the semileptonic branching fraction puzzle. Experimentally $\mathcal{B}(B \to X\ell\nu)$ is measured to be $(10.43 \pm 0.24)\%$ [1], whereas theoretical calculations have difficulties accommodating a branching fraction below $\sim 12.5\%$ [2]. One way to reduce the theoretical expectations is through a two-fold enhancement in the assumed $\bar{b} \to \bar{c}c\bar{s}$ rate [3], which is estimated to be $\sim 15\%$ from the measured inclusive rates for $B \to D_s^+ X$ and $B \to \psi X$.

Recently, Buchella *et al.* [4] and Blok *et al.* [5] have suggested that a significant fraction of the $\bar{b} \to \bar{c}c\bar{s}$ transition hadronizes into $B \to \bar{D}DKX$. This is supported by CLEO's [6] observation of wrong-sign $D$ mesons from $B$ decays, $\mathcal{B}(B \to DX) = (7.9 \pm 2.2)\%$, where the $D$ comes from the virtual $W^+ \to c\bar{s}$. The LEP experiments [7] have also observed sizeable $B \to D^{(*)}\bar{D}^{(*)}X$ decay rates. Exclusive $B$ decays involving wrong-sign $D$ mesons can result from (1) resonant $B \to \bar{D}^{(*)}D_s^{**}$ decays, where the $W^+ \to c\bar{s}$ hadronizes to an excited $D_s^+$ meson that decays into $DKX$; and (2) non-resonant $B \to \bar{D}^{(*)}D^{(*)}K$ decays. This paper explores one possibility in the first case, namely, the decays $B \to D_{s1}^+(2536)X$ where $D_{s1}^+$ is the narrow P-wave $D_s^+$ meson with $J^P = 1^+$. The "upper-vertex" production of $D_{s1}^+$ from $W^+ \to c\bar{s}$ hadronization is shown in Figure 1(a). In addition, $D_{s1}^+$ mesons can be produced from "lower-vertex" decays $b \to c\bar{u}d$ with the creation of an $s\bar{s}$ quark pair, as shown in Figure 1(b). This produces right-sign $D$ mesons; however, the decay is expected to be suppressed. Throughout this paper charge conjugate states are implied.

Continuum $D_{s1}^+$ production has been thoroughly studied [1]. The $D_{s1}^+$ is just above the $D^*K$ mass threshold and decays dominantly into $D^{*0}K^+$ and $D^{*+}\bar{K}^0$. Other possible decay channels are negligible: $D_s^{(*)+}\pi^0$ due to isospin conservation, $D_s^{(*)+}\pi^+\pi^-$ due to OZI suppression [8], $DK$ or $D_s^+\pi^0$ due to angular momentum and parity conservation, and $D_s^{(*)+}\gamma$ due to the small radiative decay rate.

## DATA SAMPLE AND EVENT SELECTION

The data used in this analysis were selected from hadronic events collected by the CLEO II detector at the Cornell Electron Storage Ring (CESR). The CLEO II detector [9] is a large solenoidal detector with 67 tracking layers and a CsI electromagnetic calorimeter that provides efficient $\pi^0$ reconstruction. The data consist of an integrated luminosity of 3.11 fb$^{-1}$ at the $\Upsilon(4S)$ resonance, corresponding to $3.3 \times 10^6$ $B\bar{B}$ events. To evaluate non-$B\bar{B}$ backgrounds we also collected 1.61 fb$^{-1}$ of "continuum" data 60 MeV below the $\Upsilon(4S)$ resonance.

The inclusive $B \to D_{s1}^+ X$ decay is studied by reconstructing the decay channels $D_{s1}^+ \to D^{*0}K^+$ and $D^{*+}K_S^0$ using the decay modes $D^{*0} \to D^0\pi^0$ and $D^{*+} \to D^0\pi^+$. The $D^0$ is reconstructed using the decay modes $D^0 \to K^-\pi^+$ and $K^-\pi^+\pi^0$. Hadronic events are required to satisfy the ratio of Fox-Wolfram moments [10] $R_2 = H_2/H_0 < 0.3$ to reduce the background from continuum events.

Charged tracks, except pions from $K_S^0$ decays, are required to be consistent with coming from the primary interaction point. Charged kaon and pion candidates are identified using specific ionization ($dE/dx$) and, when available, time-of-flight (TOF) information. For kaon identification, we consider the relative probability for a charged track to be a kaon, $\mathcal{R}_K =$

$\mathcal{P}_K/(\mathcal{P}_\pi + \mathcal{P}_K + \mathcal{P}_p)$, where $\mathcal{P}$ is the $\chi^2$ probability for a given particle hypothesis. The requirement on $\mathcal{R}_K$ depends on the decay mode of interest. Pion candidates are identified by requiring the $dE/dx$ and, when available, TOF information to be within 3 standard deviations ($\sigma$) of that expected for pions. We select $K^0_S$ candidates through the decay to $\pi^+\pi^-$ by requiring a decay vertex displaced from the primary interaction point and a $K^0_S$ invariant mass within 10 MeV/c$^2$ of its nominal value. We reconstruct $\pi^0$ candidates through the decay to $\gamma\gamma$ by requiring candidates to have an invariant mass within 2.5 standard deviations ($\sigma \approx 5$ MeV/c$^2$) of the nominal $\pi^0$ mass.

The $K^-\pi^+$ and $K^-\pi^+\pi^0$ combinations are required to have a kaon identification of $\mathcal{R}_K > 0.5$ and 0.7, respectively, and an invariant mass within 15 and 25 MeV/c$^2$ ($\sim 2\sigma$) of the nominal $D^0$ mass, respectively. In addition, we select regions of the $D^0 \to K^-\pi^+\pi^0$ Dalitz plot to take advantage of the known resonant substructure [11]. For the $D^+_{s1} \to D^{*0}K^+$ mode, the Dalitz cut reduces the signal efficiency by 40% and the background by 80%. We relax the Dalitz cut for the $D^{*+}K^0_S$ mode since the combinatoric background is substantially lower.

The $D^{*+} \to D^0\pi^+$ candidates are required to have a mass difference $M(D^0\pi^+) - M(D^0)$ within 1.5 MeV/c$^2$ ($\sim 2\sigma$) of the nominal value of 145.4 MeV/c$^2$, where $M(X)$ is the reconstructed invariant mass of $X$. Similarly, the $D^{*0} \to D^0\pi^0$ candidates are required to have a mass difference $M(D^0\pi^0) - M(D^0)$ within 1.5 MeV/c$^2$ ($\sim 2\sigma$) of the nominal value of 142.1 MeV/c$^2$. To form $D^+_{s1}$ candidates charged kaons are combined with $D^{*0}$ candidates and $K^0_S$'s are combined with $D^{*+}$ candidates. Since the primary kaons from $D^+_{s1} \to D^{*0}K^+$ decays have low momentum, we can impose a stringent $\mathcal{R}_K > 0.9$ requirement on the $K^+$ with negligible loss of efficiency. The $D^+_{s1}$ candidates is required to have a scaled momentum $x_p = p_{D^+_{s1}}/\sqrt{E^2_{beam} - M^2_{D^+_{s1}}} < 0.45$, which is the kinematic limit for $B \to D^+_{s1}X$ decays. (We have ignored the negligible contributions from $b \to u$ decays.) Upper-vertex $D^+_{s1}$ production results in a maximum $x_p$ of 0.35, and this requirement is imposed when determining the $D^+_{s1}$ decay constant. The $D^+_{s1}$ decay channels with $\pi^0$'s in the final state often have multiple $D^+_{s1}$ candidates per event. We select the candidate with the highest $\chi^2$ probability of being a $D^+_{s1}$, which is derived from the invariant masses of the reconstructed $\pi^0$, $D^0$ and $D^*$ mesons.

## RAW YIELDS

The $D^+_{s1}$ signal is identified using the $D^*K$ mass difference, $\Delta M_1 = M(D^{*0}K^+) - M(D^{*0}) - M_{K^+}$ and $\Delta M_2 = M(D^{*+}K^0_S) - M(D^{*+}) - M_{K^0_S}$, where $M_{K^+}$ and $M_{K^0_S}$ are PDG masses. The $D^*K$ mass difference signal has a resolution that is two to four times smaller than the corresponding signal in the reconstructed $D^*K$ invariant mass distribution. The $\Delta M_1$ and $\Delta M_2$ distributions are shown in Figure 2, where the $D^0 \to K^-\pi^+$ and $K^-\pi^+\pi^0$ modes have been added together. The data is fit with a Gaussian signal and a threshold background function. The Gaussian width is fixed to that expected from a GEANT-based Monte Carlo (MC) simulation [12] ($\sigma = 2.4 - 3.6$ MeV/c$^2$, depending on the mode) and the mean is fixed to the measured $D^+_{s1}$ mass difference from continuum data ($\Delta M_1 \approx 35$ MeV/c$^2$ and $\Delta M_2 \approx 27$ MeV/c$^2$.) We observe $42 \pm 14$ signal events in the $D^{*0}K^+$ mode and $9 \pm 6$ events in the $D^{*+}K^0_S$ mode.

However, when the $D^{*0}K^+$ candidates are further subdivided into the $D^0 \to K^-\pi^+$ and

$K^-\pi^+\pi^0$ decay channels there is a marked disparity in $D_{s1}^+$ yields. As shown in Figure 3, we observe $10 \pm 8$ signal events in the $\Delta M_1$ distribution for the $D^0 \to K^-\pi^+$ channel and $33 \pm 12$ $D_{s1}^+$ signal events for the $D^0 \to K^-\pi^+\pi^0$ channel. After accounting for branching fractions and efficiencies, discussed below, this results in a $2.2\sigma$ discrepancy in the $D^{*0}K^+$ rates between the two $D^0$ modes. We cannot rule out the fact that background sources may be contributing a false $D_{s1}^+$ signal in the $D^0 \to K^-\pi^+\pi^0$ channel, but not in the $D^0 \to K^-\pi^+$ channel. However, no such mechanism has been uncovered. To be conservative, we choose to quote only an upper limit for the decay $B \to D_{s1}^+ X$.

Since the $D_{s1}^+$ reconstruction efficiency increases rapidly with $x_p$ and the $D_{s1}^+$ momentum distribution from $B$ decays is not known, we compute the inclusive $B \to D_{s1}^+ X$ branching fraction by dividing the data into four equal regions of $x_p$ from 0.05 to 0.45 and summing the efficiency corrected yields. The $D_{s1}^+ \to D^{*0}K^+$ and $D^{*+}\bar{K}^0$ branching fractions are equal according to isospin, and their ratio has been measured to be within 30% of unity [13]. We measure the branching fraction $B \to D_{s1}^+ X$ to be $(0.78 \pm 0.21)\%$ from the $D^{*0}K^+$ mode and $(0.29 \pm 0.36)\%$ from the $D^{*+}K_S^0$ mode, where the error is statistical only. The two measurements are statistically consistent. The $x_p$ distribution for $D_{s1}^+$ from $B$ decays is shown in Figure 4.

## CROSS-CHECKS

Several cross-checks, as shown in Figure 5, were performed to corroborate the validity of the $D_{s1}^+$ signal. The scaled continuum background after satisfying all selection cuts is negligible, and there is no excess in the $\Delta M_1$ signal region ($3 \pm 5$ events). The uncertainty in the continuum $D_{s1}^+$ contribution is included in the systematic error. There is also no evidence of peaking in the $\Delta M_1$ signal region for wrong-sign $D^{*0}K^-$ combinations ($0 \pm 9$ events), $D^0$ mass sidebands ($5 \pm 5$ events), and $D^{*0}$ mass sidebands ($-4 \pm 6$ events).

We have also searched for the $D^0$ signal from $D_{s1}^+ \to D^{*0}K^+$ candidates in the $\Delta M_1$ signal region, $|\Delta M_1 - 35\ \mathrm{MeV/c^2}| < 10\ \mathrm{MeV/c^2}$, by relaxing the $D^0$ mass cut and histogramming the invariant mass of all $K^-\pi^+$ and $K^-\pi^+\pi^0$ combinations that satisfy the remaining selection criteria. In events with multiple candidates per $D^0$ decay mode we select the candidate with the highest $\chi^2$ probability, which is derived from the reconstructed $\pi^0$ and $D_{s1}^+$ masses. We observe $100 \pm 15$ $D^0$ events. However, there are also real $D^0$'s in the random $D^{*0}K^+$ combinations under the $D_{s1}^+$ peak; after a $\Delta M_1$ sideband subtraction the $D^0$ invariant mass spectrum yields $44 \pm 18$ events (See Figure 6(a)). This is consistent with our $D_{s1}^+ \to D^{*0}K^+$ yield in Figure 2.

Similarly, we have studied the $D^{*0}$ signal from $D_{s1}^+ \to D^{*0}K^+$ candidates in the $\Delta M_1$ signal region. We observe $59 \pm 15$ $D^0$ events. As in the $D^0$ case there are also real $D^{*0}$'s in the random $D^{*0}K^+$ combinations under the $D_{s1}^+$ peak. After a $\Delta M_1$ sideband subtraction the $D^{*0}$ mass difference spectrum yields $25 \pm 18$ events (See Figure 6(b)), consistent with our $D_{s1}^+ \to D^{*0}K^+$ yield.

Finally, we have studied the $D_{s1}^+$ production from continuum $e^+e^- \to c\bar{c}$ events. The selection criteria is similar to that used to find $D_{s1}^+$ from $B$ decays, but since continuum charm production has a hard fragmentation, we require $x_p > 0.5$. In addition, we remove the $R_2 < 0.3$ cut, relax the charged kaon identification to $\mathcal{R}_K > 0.1$, and remove the

Dalitz cut for $D^0 \to K^-\pi^+\pi^0$. The mass difference distribution for $D^{*0}K^+$ and $D^{*+}K^0_S$ combinations are shown in Figure 7, where the $D^0 \to K^-\pi^+$ and $K^-\pi^+\pi^0$ modes have been added together. We extract the $D^+_{s1}$ signal by fitting the data with a Gaussian signal and a threshold background function. The Gaussian width is fixed to the value predicted by Monte Carlo (2.1 MeV/c$^2$), and the mean is allowed to float. We observe $222 \pm 19$ events in the $D^+_{s1} \to D^{*0}K^+$ mode with a mass difference of $35.0 \pm 0.2$ MeV/c$^2$ (statistical error only), and $101 \pm 11$ events in the $D^+_{s1} \to D^{*+}K^0_S$ mode with a mass difference of $27.5 \pm 0.3$ MeV/c$^2$. The results are consistent with the previous CLEO analysis [13].

## SYSTEMATIC ERRORS AND FINAL RESULTS

There are several sources of systematic error. We assign a systematic error of 16% to account for the $2.2\sigma$ discrepancy between the $D^{*0}K^+$ rates for the $D^0 \to K^-\pi^+$ and $K^-\pi^+\pi^0$ modes. This accomodates different methods of computing the weighted average of the $B \to D^+_{s1}X$ branching fraction from the four separate decay chains. Uncertainties due to reconstruction efficiencies include 1.5% per charged track, 5% per $\pi^0$, 5% for slow pions from $D^*$, and 5% for $K^0_S$. We also include systematic errors of 7% for MC statistics, 5% for kaon identification and the Dalitz decay cut, 4% for uncertainties in the yield for $x_p < 0.05$, and 8% for uncertainties in the continuum $D^+_{s1}$ contribution that passes our selection criteria. The total systematic error is 24%.

Averaging the $D^{*0}K^+$ and $D^{*+}K^0_S$ modes together, we obtain $\mathcal{B}(B \to D^+_{s1}X) = (0.64 \pm 0.19 \pm 0.15)\%$. Since the $D^+_{s1}$ signal is observed largely in only one decay mode $D^+_{s1} \to D^{*0}K^+$ with $D^0 \to K^-\pi^+\pi^0$, and since there is a large discrepancy between this mode and the corresponding mode involving $D^0 \to K^-\pi^+$, we instead prefer to quote an upper limit on the branching fraction to be $\mathcal{B} < 0.95\%$ at the 90% C.L. [14] This decay rate limit is small relative to the total rate expected for $B \to \bar{D}^{(*)}D^{(*)}KX$ of about $(7.9 \pm 2.2)\%$ from the wrong-sign $D$ meson yield in $B$ decays [6]. This is not surprising considering the $c\bar{s}$ system has appreciable phase space beyond the $D^+_{s1}$ mass [4]. Also, CLEO's [15] recent observation of exclusive $B \to \bar{D}^{(*)}D^{(*)}K$ decays shows that the $D^{(*)}K$ invariant mass distribution lies mostly above the $D^+_{s1}$ mass.

## $D^+_{s1}$ DECAY CONSTANT

Measurement of the $B \to D^+_{s1}X$ decay rate also provides an estimate of the $D^+_{s1}$ decay constant, $f_{D^+_{s1}}$, assuming that the $D^+_{s1}$ comes dominantly from upper-vertex decays. The inclusive decay rate for $B$ mesons into ground state or excited $D^+_s$ mesons can be calculated assuming factorization [16].

$$\Gamma(B \to D_s X) = \frac{G_F^2 |V_{cb}V_{cs}|^2}{16\pi} M_b^3 a_1^2 f_{D_s}^2 I(x,y)$$

where $a_1$ is the BSW [17] parameter for the effective charged current, and $I(x,y)$ is a kinematic factor with $x = M^2_{D_s}/M^2_b$ and $y = M^2_c/M^2_b$. For scalar or pseudoscalar $D_s$ mesons,

$I(x,y) = \sqrt{(1-x-y)^2-4xy}(1-x-2y-xy+y^2)$, and for vector or axial-vector $D_s$ mesons, $I(x,y) = \sqrt{(1-x-y)^2-4xy}(1+x-x^2-2y+xy+y^2)$.

We have tightened the $x_p$ requirement to $x_p < 0.35$ since this is the kinematic limit for upper-vertex $B \to D_{s1}^+ \bar{D} X$ decays. The production of ground state and excited $D_s^+$ mesons from lower-vertex decays such as $\bar{B} \to D_{s1}^+ \bar{K} X$ is expected to be suppressed. This is certainly true for $B \to D_s^+ X$ decays where the fraction of $D_s^+$ produced at the lower-vertex is measured to be $0.172 \pm 0.079 \pm 0.026$ [18]. Moreover, there is no evidence of $D_{s1}^+$ production in the region $x_p = 0.35 - 0.45$ where lower-vertex production is likely to occur (see Figure 4.)

With the assumption $f_{D_s^+} = f_{D_s^{*+}}$ we can extract $f_{D_{s1}^+}$ from the ratio of inclusive rates,

$$\frac{\mathcal{B}(B \to D_{s1}^+ X)}{\mathcal{B}(B \to D_s^+ X)} = \frac{\Gamma(B \to D_{s1}^+ X)}{\Gamma(B \to D_s^+ X) + \Gamma(B \to D_s^{*+} X)} \approx 0.5 \left( \frac{f_{D_{s1}^+}}{f_{D_s^+}} \right)^2$$

Many systematic errors cancel in the ratio. Since the factorization hypothesis must fail for $D_{s1}^+$ produced at low $x_p$ and since roughly half the $B \to D_{s1}^+ X$ rate occurs at $x_p < 0.15$, we take $(75 \pm 25)\%$ of the measured $B \to D_{s1}^+ X$ branching fraction when computing the $D_{s1}^+$ decay constant from the above equation. From our upper limit on $B \to D_{s1}^+ X$ and CLEO's [19] measurement of $\mathcal{B}(B \to D_s^+ X) = (12.11 \pm 0.39 \pm 0.88 \pm 1.38)\%$, we derive $f_{D_{s1}^+}/f_{D_s^+} < 0.37$ at the 90% C.L. The central value is $f_{D_{s1}^+}/f_{D_s^+} = 0.29 \pm 0.06 \pm 0.06$, where the first error is due to the total error in the inclusive $B \to D_s^+ X$ and $B \to D_{s1}^+ X$ branching fractions, and the second is the uncertainty in the non-factorizable and lower-vertex contributions to the $B \to D_{s1}^+ X$ decay rate. Using the measured value of $f_{D_s^+} = 280 \pm 40$ MeV [19] gives $f_{D_{s1}^+} = 81 \pm 26$ MeV which corresponds to an upper limit of $f_{D_{s1}^+} < 114$ MeV. This limit accomodates the prediction of $f_{D_{s1}^+} = 87 \pm 19$ MeV by Veseli and Dunietz [20].

## CONCLUSIONS

In summary, we have searched for $B$ mesons decaying into the P-wave $D_{s1}^+(2536)$ meson. The upper limit of $\mathcal{B}(B \to D_{s1}^+ X) < 0.95\%$ at the 90% C.L. accounts for only a fraction of the total wrong-sign $B \to DX$ rate. Assuming factorization, the decay constant $f_{D_{s1}^+}$ is at least a factor of 2.5 times smaller than the decay constant for the pseudoscalar $D_s^+$.

## ACKNOWLEDGEMENTS

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. J.P.A., J.R.P., and I.P.J.S. thank the NYI program of the NSF, M.S. thanks the PFF program of the NSF, G.E. thanks the Heisenberg Foundation, K.K.G., M.S., H.N.N., T.S., and H.Y. thank the OJI program of DOE, J.R.P., K.H., M.S. and V.S. thank the A.P. Sloan Foundation, R.W. thanks the Alexander von Humboldt Stiftung, and M.S. thanks Research Corporation for support. This work was supported by the National Science Foundation, the U.S. Department of Energy, and the Natural Sciences and Engineering Research Council of Canada.

# REFERENCES


[1] Particle Data Group, R.M. Barnett *et al.*, Phys. Rev. D **54**, 1 (1996).
[2] I. Bigi, B. Blok, M. Shifman and A. Vainshtein, Phys. Lett. B **323**, 408 (1994).
[3] A.F. Falk, M.B. Wise, and I. Dunietz, Phys. Rev. D **51**, 1183 (1995); E. Bagan, P. Ball, V.M. Braun, and P. Gosdzinsky, Phys. Lett. B **324**, 362 (1995); M.B. Voloshin, Phys. Rev. D **51**, 3948 (1995).
[4] G. Buchalla, I. Dunietz, and H. Yamamoto, Phys. Lett. B **364**, 188 (1995).
[5] B. Blok, M. Shifman, and N. Uraltsev, preprint CERN-TH/96-252.
[6] CLEO Collaboration, S. Glenn *et al.*, CLEO-CONF 97-27, contributing paper EPS97-383.
[7] DELPHI Collaboration, ICHEP96 (Warsaw), contributed paper PA01-108; ALEPH Collaboration, ICHEP96 (Warsaw), contributed paper PA05-060.
[8] S. Okubo, Phys. Lett. B **5**, 165 (1963); G. Zweig, CERN Report 8419/TH412 (1964); I. Iizuka, Prog. Theor. Phys. Suppl. **37**, 21 (1966).
[9] CLEO Collaboration, Y. Kubota *et al.*, Nucl. Inst. and Meth. **A320**, 66 (1992).
[10] G. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).
[11] E691 Collaboration, J.C. Anjos *et al.*, Phys. Rev. D **48**, 56 (1993).
[12] R. Brun *et al.*, GEANT 3.15, CERN DD/EE/84-1.
[13] CLEO Collaboration, J. Alexander *et al.*, Phys. Lett. B **303**, 377 (1993).
[14] The 90% upper limit is derived, assuming Gaussian statistics, by adding 1.28 times the total error to the central value.
[15] CLEO Collaboration, M. Bishai *et al.*, CLEO-CONF 97-26, contributing paper EPS97-337.
[16] Private communication with Hitoshi Yamamoto.
[17] M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C **29**, 637 (1985).
[18] CLEO Collaboration, X. Fu *et al.*, CLEO CONF-95-11, EPS0169, submitted paper to the International Europhysics Conference on High Energy Physics, Brussels, Belgium, 1995.
[19] CLEO Collaboration, D. Gibaut *et al.*, Phys. Rev. D **53**, 4734 (1996).
[20] S. Veseli and I. Dunietz, Phys. Rev. D **54**, 6803 (1996).

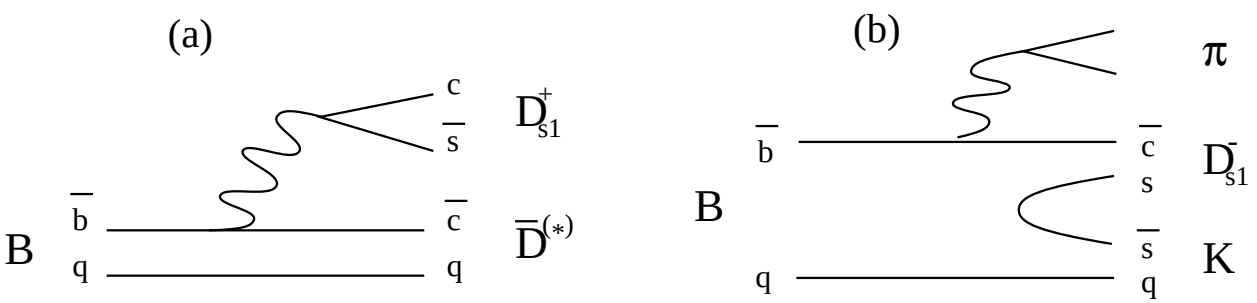


FIG. 1. Feynman diagrams for $B \to D_{s1}^{+} X$ decays from (a) upper vertex and (b) lower vertex $D_{s1}^{+}$ production.

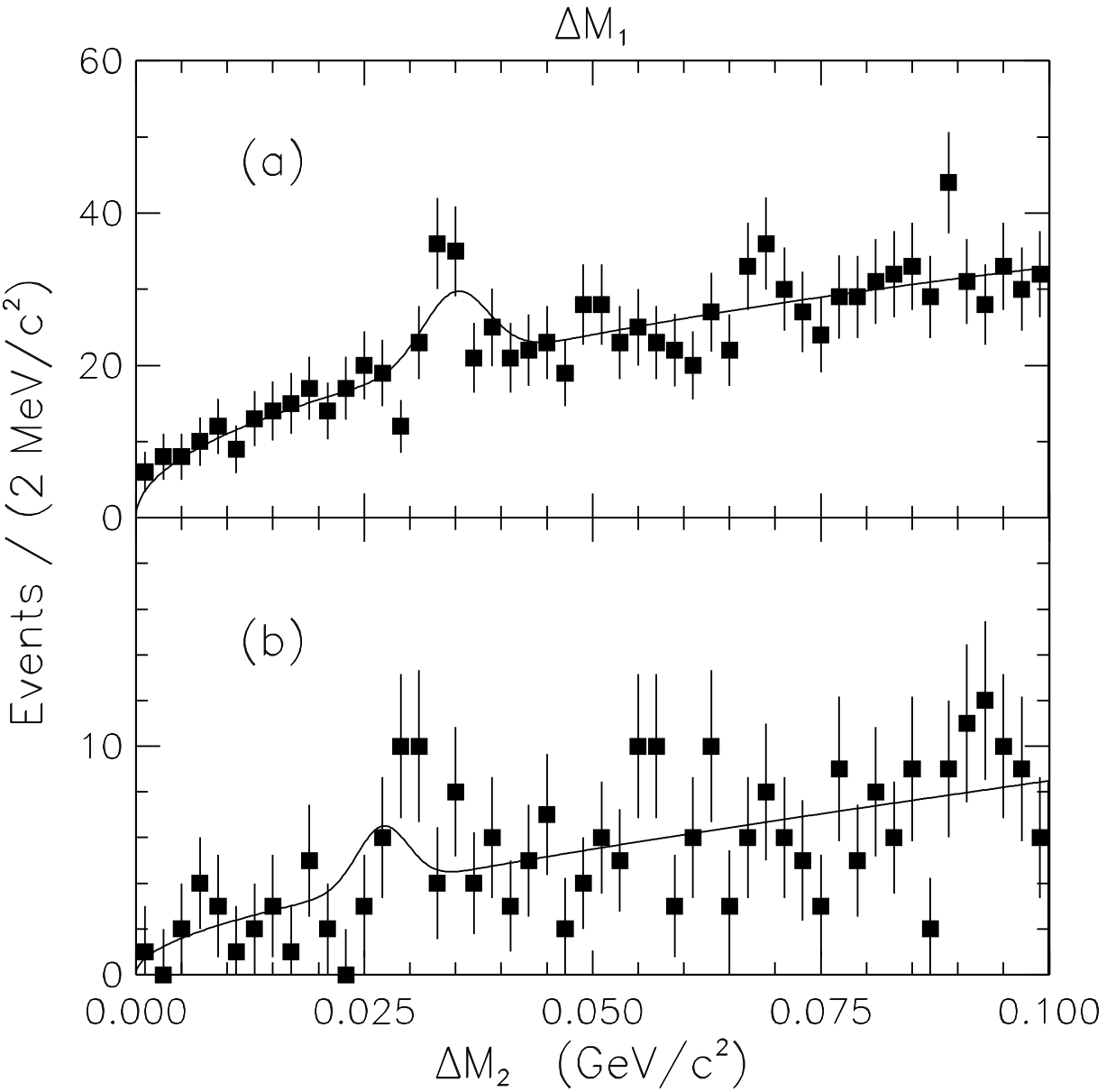


FIG. 2. The mass difference distribution for (a) $D^{*0}K^+$ and (b) $D^{*+}K^0_S$ candidates from $B$ meson decays.

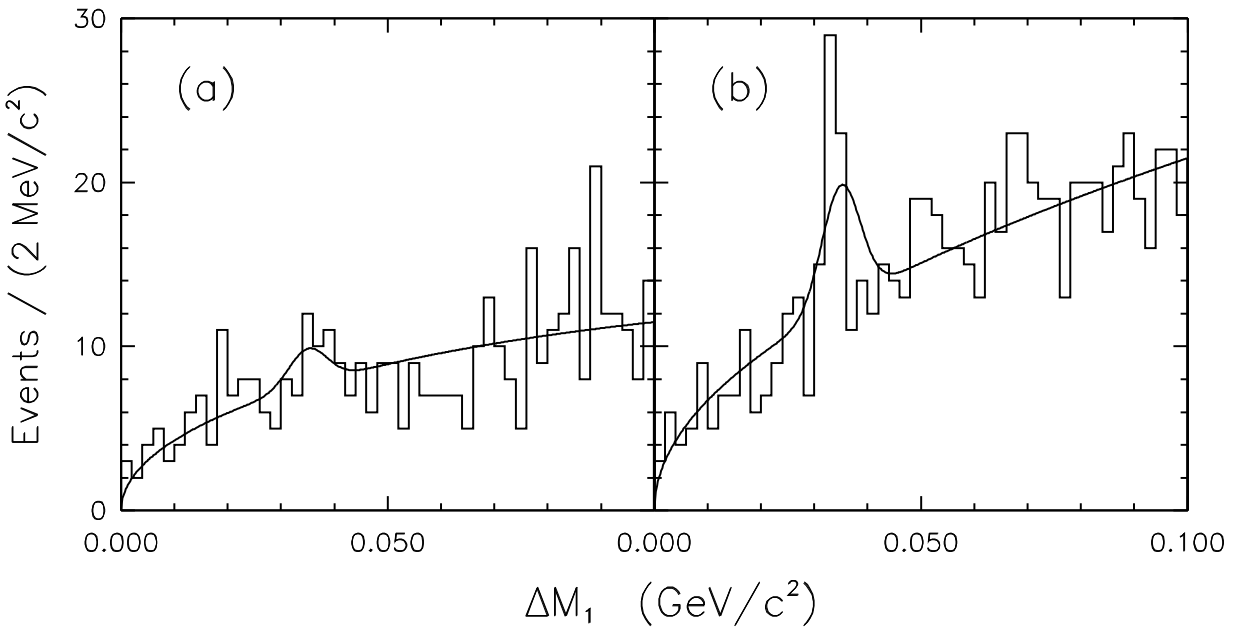


FIG. 3. The $\Delta M_1$ mass difference distribution for $D^{*0}K^+$ candidates from the (a) $D^0 \to K^-\pi^+$ and (b) $D^0 \to K^-\pi^+\pi^0$ decay channels.

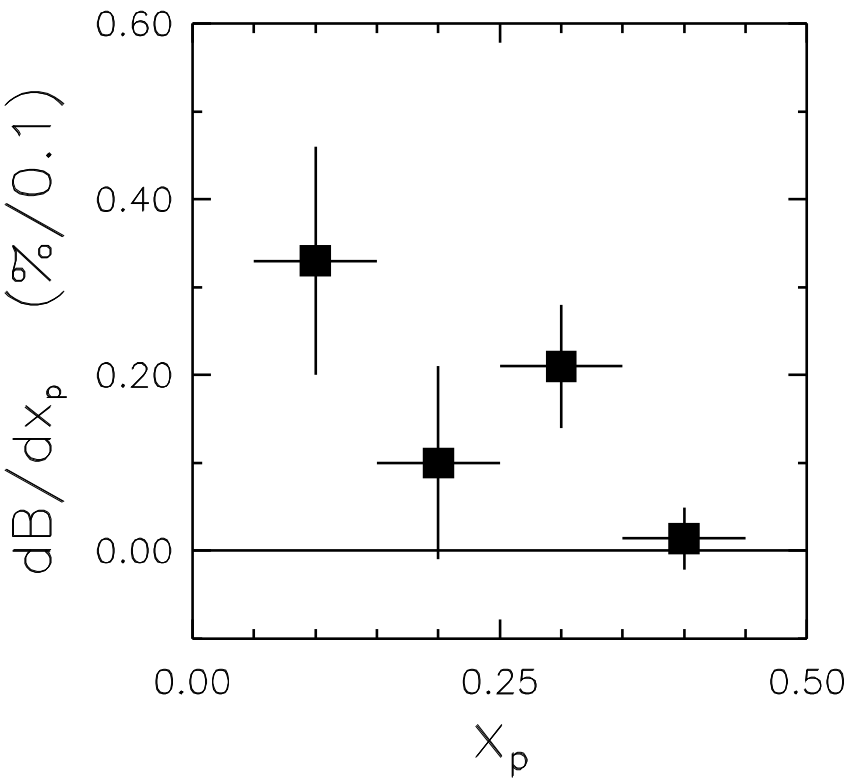


FIG. 4. The efficiency corrected yield of $B \to D_{s1}^{+} X$ as a function of the $D_{s1}^{+}$ scaled momentum $x_p$. The kinematic limit from $B \to D_{s1}^{+} X$ and $B \to D_{s1}^{+} \bar{D} X$ decays is $x_p < 0.45$ and $x_p < 0.35$, respectively. The kinematic limit from upper-vertex and lower-vertex $B \to D_{s1}^{+} X$ decays is $x_p < 0.35$ and $x_p < 0.45$, respectively.

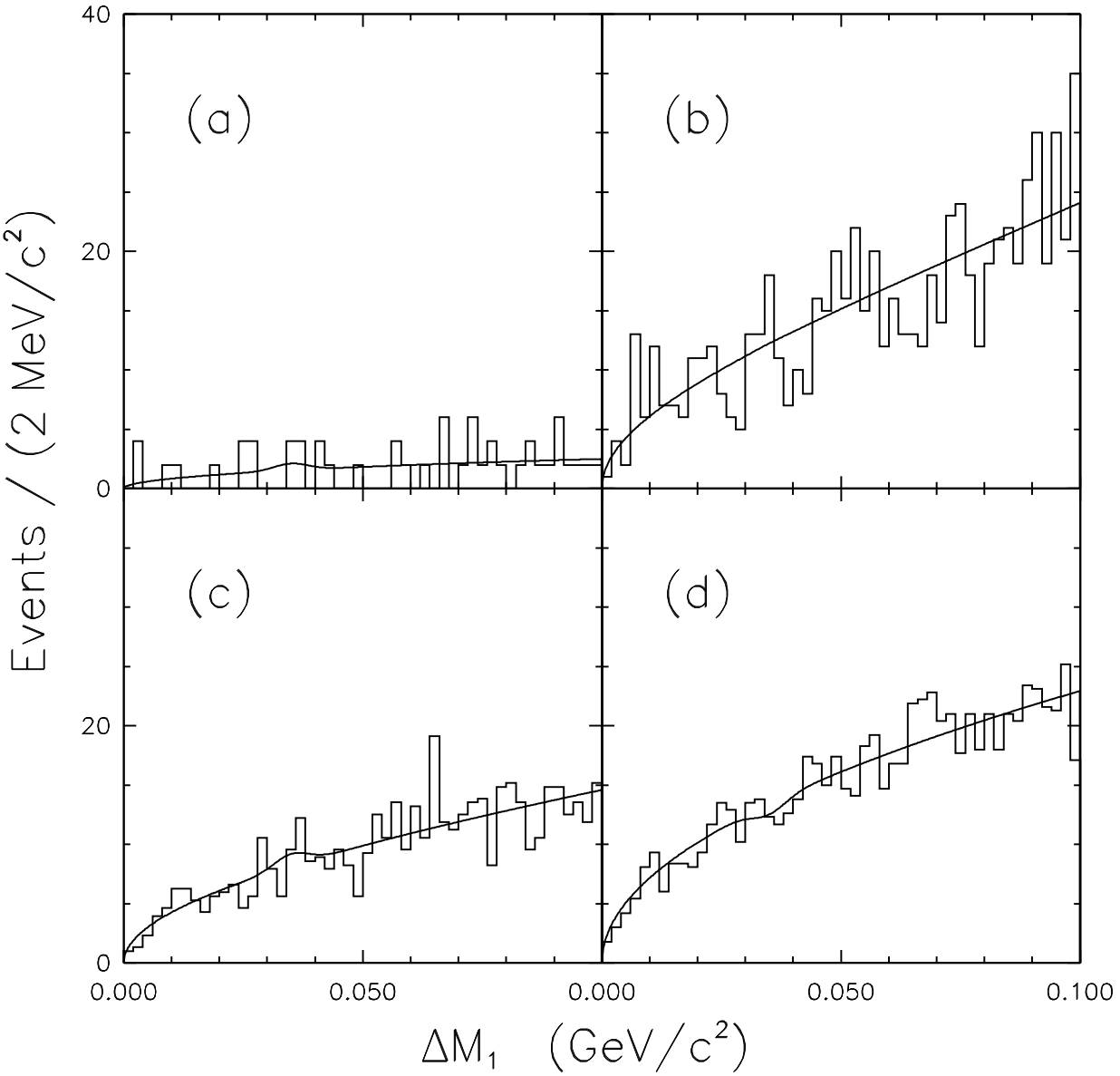


FIG. 5. The normalized $D^{*0}K^+$ mass difference distributions from (a) continuum events, (b) $D^{*0}K^-$ wrong-sign combinations, (c) $D^0$ mass sidebands, and (d) $D^{*0}$ mass sidebands.

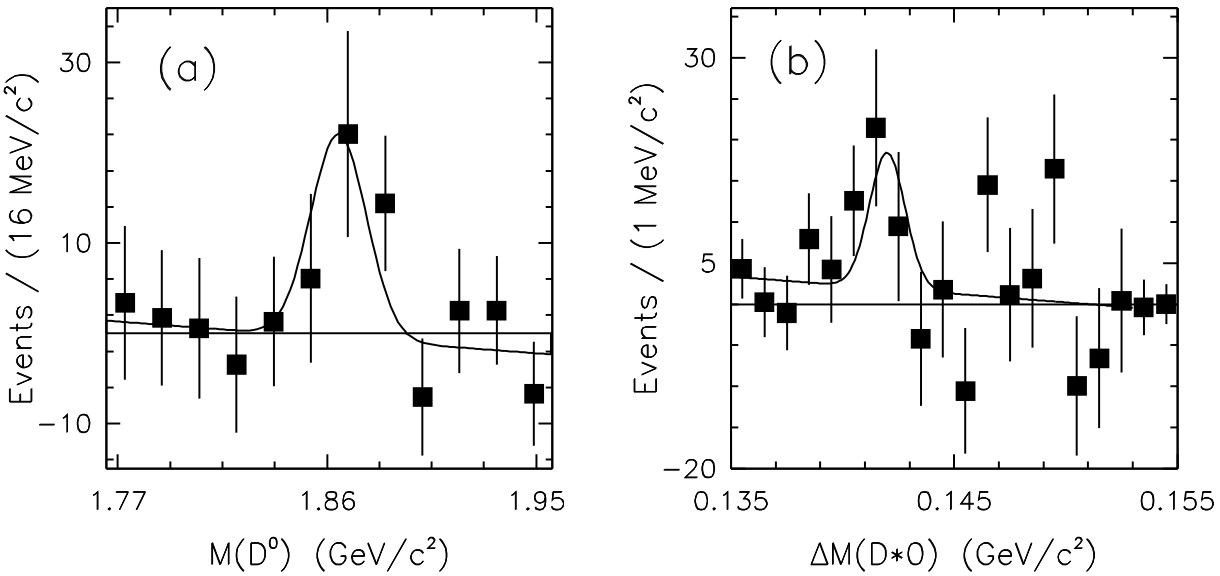


FIG. 6. (a) The invariant mass distribution for $K^-\pi^+$ and $K^-\pi^+\pi^0$ combinations from $D^{*0}K^+$ candidates in the $\Delta M_1$ signal region, after sideband subtraction. (b) The $D^{*0}$ mass difference distribution from $D^{*0}K^+$ candidates in the $\Delta M_1$ signal region, after sideband subtraction.

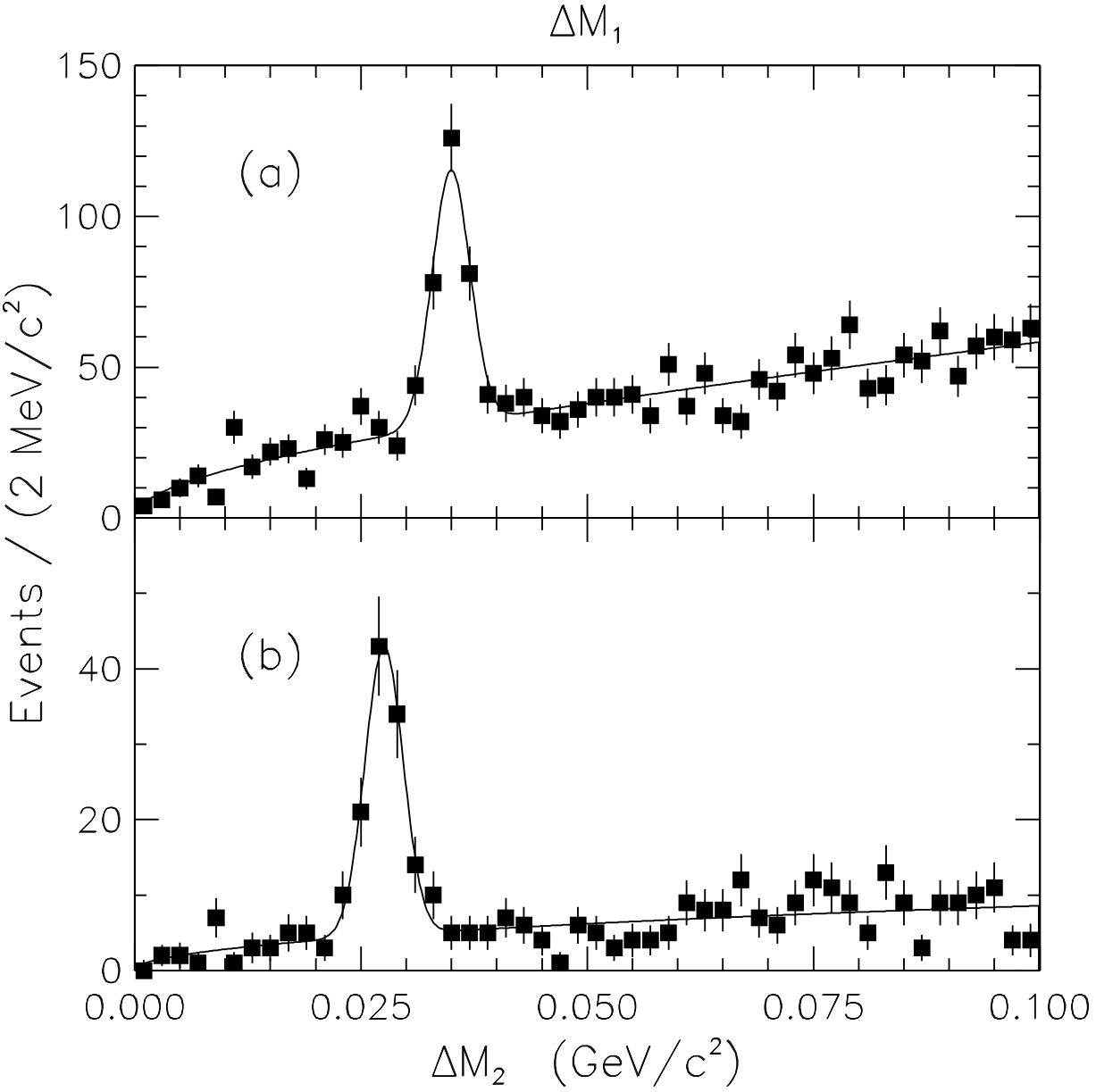


FIG. 7. The mass difference distribution for (a) $D^{*0}K^+$ and (b) $D^{*+}K^0_S$ candidates from continuum $e^+e^- \to c\bar{c}$ events.