

## Observation of Decays $B^0 \rightarrow D_s^{(*)+} \pi^-$ and $B^0 \rightarrow D_s^{(*)-} K^+$

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We report the observation of decays  $B^0 \rightarrow D_s^{(*)+} \pi^-$  and  $B^0 \rightarrow D_s^{(*)-} K^+$  in a sample of  $230 \times 10^6$   $\Upsilon(4S) \rightarrow B\bar{B}$  events recorded with the *BABAR* detector at the SLAC PEP-II asymmetric-energy  $e^+e^-$  storage ring. We measure the branching fractions  $\mathcal{B}(B^0 \rightarrow D_s^+ \pi^-) = (1.3 \pm 0.3(\text{stat}) \pm 0.2(\text{syst})) \times 10^{-5}$ ,  $\mathcal{B}(B^0 \rightarrow D_s^- K^+) = (2.5 \pm 0.4(\text{stat}) \pm 0.4(\text{syst})) \times 10^{-5}$ ,  $\mathcal{B}(B^0 \rightarrow D_s^{*+} \pi^-) = (2.8 \pm 0.6(\text{stat}) \pm 0.5(\text{syst})) \times 10^{-5}$ , and  $\mathcal{B}(B^0 \rightarrow D_s^{*-} K^+) = (2.0 \pm 0.5(\text{stat}) \pm 0.4(\text{syst})) \times 10^{-5}$ . The significances of the measurements to differ from zero are 5, 9, 6, and 5 standard deviations, respectively. This is the first observation of  $B^0 \rightarrow D_s^+ \pi^-$ ,  $B^0 \rightarrow D_s^{*+} \pi^-$ , and  $B^0 \rightarrow D_s^{*-} K^+$  decays.

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Within the Cabibbo-Kobayashi-Maskawa (CKM) model of quark-flavor mixing [1],  $CP$  violation manifests itself as a nonzero area of the unitarity triangle [2]. One of the important experimental tests of the model is the determination of the angle  $\gamma = \arg(-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*)$  of the unitarity triangle. A measurement of  $\sin(2\beta + \gamma)$  can be obtained from the study of the time dependence of the  $B^0$ ,  $\bar{B}^0 \rightarrow D^{(*)-} \pi^+$  [3] decay rates, and specifically of the interference between the CKM-favored  $B^0$  decay amplitude and CKM-suppressed  $\bar{B}^0$  amplitude [4]. The first measurements of the  $CP$  asymmetry in decays  $B^0 \rightarrow D^{(*)\mp} \pi^\pm$  have recently been published [5].

The measurement of  $\sin(2\beta + \gamma)$  in  $B^0 \rightarrow D^{(*)\mp} \pi^\pm$  decays requires knowledge of the ratios of the decay amplitudes,  $r(D^{(*)}\pi) = |A(B^0 \rightarrow D^{(*)+} \pi^-)/A(B^0 \rightarrow D^{(*)-} \pi^+)|$ . The  $CP$ -violating observables in  $B^0 \rightarrow D^{(*)\mp} \pi^\pm$  decays are proportional to  $r(D^{(*)}\pi)$  [4,5]. However, direct measurement of the branching fractions  $\mathcal{B}(B^0 \rightarrow D^{(*)+} \pi^-)$  is not possible with the currently available data sample due to the presence of the overwhelming background from  $\bar{B}^0 \rightarrow D^{(*)+} \pi^-$ . However, assuming  $SU(3)$  flavor symmetry,  $r(D^{(*)}\pi)$  can be related to the branching fraction (BF) of the decay  $B^0 \rightarrow D_s^{(*)+} \pi^-$  [4]:

$$r(D^{(*)}\pi) = \tan\theta_c \frac{f_{D^{(*)}}}{f_{D_s^{(*)}}} \sqrt{\frac{\mathcal{B}(B^0 \rightarrow D_s^{(*)+} \pi^-)}{\mathcal{B}(B^0 \rightarrow D^{(*)-} \pi^+)}} \quad (1)$$

where  $\theta_c$  is the Cabibbo angle,  $f_{D^{(*)}}$  and  $f_{D_s^{(*)}}$  are  $D^{(*)}$  and  $D_s^{(*)}$  decay constants [6]. Other  $SU(3)$ -breaking effects are believed to affect  $r(D^{(*)}\pi)$  by less than 30% [5].

Since  $B^0 \rightarrow D_s^{(*)+} \pi^-$  has four different quark flavors in the final state, only a single amplitude contributes to the decay [Fig. 1(c)]. On the other hand, there are two diagrams contributing to  $B^0 \rightarrow D^{(*)-} \pi^+$  and  $B^0 \rightarrow D^{(*)+} \pi^-$ : tree amplitudes [Figs. 1(a) and 1(b)] and color-suppressed direct  $W$ -exchange amplitudes [Figs. 1(d) and 1(e)]. The latter are assumed to be negligibly small in Eq. (1). The decays  $B^0 \rightarrow D_s^{(*)-} K^+$  [Fig. 1(f)] probe the size of the  $W$ -exchange amplitudes relative to the dominant processes  $B^0 \rightarrow D^{(*)-} \pi^+$ . The rate of  $B^0 \rightarrow D_s^{(*)-} K^+$  decays could be enhanced by final state rescattering [7], in addition to the  $W$ -exchange amplitude. The relative rates of  $B^0 \rightarrow D_s^{(*)-} K^{(*)+}$  decays could shed light on the decay dynamics,

including relative contributions of short- and long-distance effects [8].

The branching fractions  $\mathcal{B}(B^0 \rightarrow D_s^+ \pi^-)$  and  $\mathcal{B}(B^0 \rightarrow D_s^- K^+)$  have been measured previously by the *BABAR* [9] and Belle [10] collaborations, but the decays  $B^0 \rightarrow D_s^{*+} \pi^-$  and  $B^0 \rightarrow D_s^{*-} K^+$  have never been observed. In this Letter we present new measurements of the decays  $B^0 \rightarrow D_s^{(*)+} \pi^-$  and  $B^0 \rightarrow D_s^{(*)-} K^+$ . The analysis uses a sample of  $230 \times 10^6$   $\Upsilon(4S)$  decays into  $B\bar{B}$  pairs collected with the *BABAR* detector at the SLAC PEP-II asymmetric-energy  $B$  factory [11].

Since the *BABAR* detector is described in detail elsewhere [12], only the components that are crucial to this analysis are summarized here. Charged-particle tracking is provided by a five-layer double-sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH). Ionization energy loss ( $dE/dx$ ) in the DCH and SVT and Cherenkov radiation detected in a ring-imaging device are used for charged-particle identification. Photons are identified and measured using the electromagnetic calorimeter (EMC), which is comprised of 6580 thallium-doped CsI crystals. These systems are mounted inside a 1.5 T solenoidal superconducting magnet. We use the GEANT4 [13] software to simulate interactions of particles traversing the *BABAR* detector, taking into account the varying detector conditions and beam backgrounds.

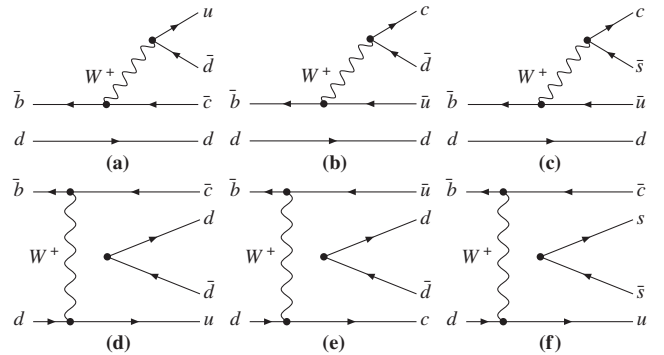


FIG. 1. Dominant Feynman diagrams for (a) CKM-favored decay  $B^0 \rightarrow D^{(*)-} \pi^+$ , (b) doubly CKM-suppressed decay  $B^0 \rightarrow D^{(*)+} \pi^-$ , and (c) the  $SU(3)$  flavor symmetry related decays  $B^0 \rightarrow D_s^{(*)+} \pi^-$ ; (d) the color-suppressed  $W$ -exchange contributions to  $B^0 \rightarrow D^{(*)-} \pi^+$ , (e)  $B^0 \rightarrow D^{(*)+} \pi^-$ , and (f) decay  $B^0 \rightarrow D_s^{(*)-} K^+$ .

Candidates for  $D_s^+$  mesons are reconstructed in the modes  $D_s^+ \rightarrow \phi \pi^+$ ,  $K_S^0 K^+$ , and  $\bar{K}^{*0} K^+$ , with  $\phi \rightarrow K^+ K^-$ ,  $K_S^0 \rightarrow \pi^+ \pi^-$ , and  $\bar{K}^{*0} \rightarrow K^- \pi^+$ . The  $K_S^0$  candidates are formed from two oppositely charged tracks, and their momenta are required to make an angle  $|\theta_{\text{flight}}| < 11^\circ$  with the line connecting their vertex and  $e^+ e^-$  interaction point (IP). All other tracks are required to originate from the IP, whose average position and size are determined hourly using two-prong and hadronic events. In order to reject background from  $D^+ \rightarrow K_S^0 \pi^+$  or  $\bar{K}^{*0} \pi^+$ , the  $K^+$  candidate in the reconstruction of  $D_s^+ \rightarrow K_S^0 K^+$  or  $\bar{K}^{*0} K^+$  is required to satisfy positive kaon identification criteria with an efficiency of 85% and 5% pion misidentification probability. The same selection is used to identify kaon daughters of the  $B$  mesons in decays  $B^0 \rightarrow D_s^{(*)-} K^+$ . In all other cases, kaons are not positively identified, but instead candidates passing pion selection are rejected. Such ‘‘pion veto’’ has an efficiency of 95% for kaons and 20% for pions. Pion daughters of  $B$  mesons in the decays  $B^0 \rightarrow D_s^{(*)+} \pi^-$  are required to be positively identified. Decay products of  $\phi$ ,  $\bar{K}^{*0}$ ,  $K_S^0$ ,  $D_s^+$ , and  $B^0$  candidates are constrained to originate from a single vertex.

We reconstruct  $D_s^{*+}$  candidates in the mode  $D_s^{*+} \rightarrow D_s^+ \gamma$  by combining  $D_s^+$  and photon candidates. Photon candidates are required to be consistent with an electromagnetic shower in the EMC, and have an energy greater than 100 MeV in the laboratory frame. When forming a  $D_s^{*+}$ , the  $D_s^+$  candidate is required to have invariant mass within 10 MeV/ $c^2$  of the nominal value [14].

After an initial preselection, we identify signal candidates using a likelihood ratio  $R_L = \mathcal{L}_{\text{sig}} / (\mathcal{L}_{\text{sig}} + \mathcal{L}_{\text{bkg}})$ , where  $\mathcal{L}_{\text{sig}} = \prod_i \mathcal{P}_{\text{sig}}(x_i)$  is the multivariate likelihood for signal events and  $\mathcal{L}_{\text{bkg}} = \prod_i \mathcal{P}_{\text{bkg}}(x_i)$  is the likelihood for background events. The ratio  $R_L$  has a maximum at  $R_L = 1$  for signal events, and at  $R_L = 0$  for background originating from continuum events. It also discriminates well against generic  $B$  decays without a real  $D_s^+$  meson in the final state. The likelihoods  $\mathcal{L}_{\text{sig}}$  and  $\mathcal{L}_{\text{bkg}}$  are computed as products of the probability density functions (PDFs)  $\mathcal{P}_{\text{sig}}(x_i)$  and  $\mathcal{P}_{\text{bkg}}(x_i)$  for a number of selection variables  $x_i$ : invariant masses of the  $\phi$ ,  $\bar{K}^{*0}$  and  $K_S^0$  candidates,  $\chi^2$  confidence level of the vertex fit for the  $B^0$  and  $D_s^+$  mesons, the helicity angles of the  $\phi$ ,  $\bar{K}^{*0}$ , and  $D_s^{*+}$  meson decays, the mass difference  $\Delta m(D_s^{*+}) = m(D_s^{*+}) - m(D_s^+)$ , the polar angle  $\theta_B$  of the  $B$  candidate momentum vector with respect to the beam axis in the  $e^+ e^-$  center-of-mass (c.m.) frame, the angle  $\theta_T$  between the thrust axis of the  $B$  candidate and the thrust axis of all other particles in the event in c.m. frame, and event topology variable  $\mathcal{F}$ , discussed below. We have determined the correlations among these variables to be negligibly small. The helicity angle  $\theta_H$  is defined as the angle between one of the decay products of a vector meson and the flight direction of its parent particle, in the meson’s rest frame. Polarization of

the vector mesons in the signal decays causes  $\cos^2 \theta_H$  ( $\phi$  and  $\bar{K}^{*0}$ ) or  $\sin^2 \theta_H$  ( $D_s^{*+}$ ) distributions, while the random background combinations tend to produce a more uniform distribution in  $\cos \theta_H$ .

Variables  $\cos \theta_B$ ,  $\cos \theta_T$ , and  $\mathcal{F}$  discriminate between spherically-symmetric  $B\bar{B}$  events and jetty continuum background.  $B\bar{B}$  pairs form a nearly uniform  $|\cos \theta_T|$  distribution, while  $|\cos \theta_T|$  distribution for the continuum peaks at 1. A linear (Fisher) discriminant  $\mathcal{F}$  is derived from the values of sphericity and thrust for the event, and the two Legendre moments  $L_0$  and  $L_2$  of the energy flow around the  $B$ -candidate thrust axis [15]. Finally, the polar angle  $\theta_B$  is distributed as  $\sin^2 \theta_B$  for real  $B$  decays, while being nearly flat in  $\cos \theta_B$  for the continuum.

We select  $B^0 \rightarrow D_s^+ \pi^-$  and  $B^0 \rightarrow D_s^- K^+$  candidates that satisfy  $R_L > 0.75$ , and accept  $B^0 \rightarrow D_s^{*+} \pi^-$  and  $B^0 \rightarrow D_s^{*-} K^+$  candidates with  $R_L > 0.8$ . We measure the relative efficiency  $\varepsilon_{R_L}$  of the  $R_L$  selection in a copious data sample of decays  $B^0 \rightarrow D^- \pi^+$  ( $D^- \rightarrow K^+ \pi^- \pi^-$ ,  $K_S^0 \pi^-$ ) and  $B^+ \rightarrow \bar{D}^{*0} \pi^+$  ( $\bar{D}^{*0} \rightarrow \bar{D}^0 \gamma$ ,  $D^0 \rightarrow K^- \pi^+$ ) in which the kinematics is similar to that of our signal events, and find that it is consistent with Monte Carlo estimates  $\varepsilon_{R_L} \approx 70\%$ . The fraction of continuum background events passing the selection varies between 2% and 15%, depending on the mode.

We identify the signal using the invariant mass  $m(D_s)$  of  $D_s$  candidates and two kinematic variables  $m_{\text{ES}}$  and  $\Delta E$ . The first is the beam-energy-substituted mass  $m_{\text{ES}} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2 / E_i^2 - \mathbf{p}_B^2}$ , where  $\sqrt{s}$  is the total c.m. energy,  $(E_i, \mathbf{p}_i)$  is the four-momentum of the initial  $e^+ e^-$  system and  $\mathbf{p}_B$  is the  $B^0$  candidate momentum, both measured in the laboratory frame. The second variable is  $\Delta E = E_B^* - \sqrt{s}/2$ , where  $E_B^*$  is the  $B^0$  candidate energy in the c.m. frame. For signal events, the  $m_{\text{ES}}$  distribution is Gaussian centered at the  $B$  meson mass with a resolution of about 2.5 MeV/ $c^2$ , and the  $\Delta E$  distribution has a maximum near zero with a resolution of about 17 MeV. The invariant mass  $m(D_s)$  has a resolution of (5–6) MeV/ $c^2$ , depending on the  $D_s^+$  decay mode. We define a fit region  $5.2 < m_{\text{ES}} < 5.3$  GeV/ $c^2$ ,  $|\Delta E| < 36$  MeV, and  $|m(D_s) - m(D_s)_{\text{PDG}}| < 50$  MeV/ $c^2$  for  $B^0 \rightarrow D_s^+ \pi^-$  and  $B^0 \rightarrow D_s^- K^+$  candidates, where  $m(D_s)_{\text{PDG}}$  is the world average  $D_s$  mass [14]. For  $B^0 \rightarrow D_s^{*+} \pi^-$  and  $B^0 \rightarrow D_s^{*-} K^+$ , we require  $|m(D_s) - m(D_s)_{\text{PDG}}| < 10$  MeV/ $c^2$ .

Less than 20% of the selected events in the  $B^0 \rightarrow D_s^{*+} \pi^-$  and  $B^0 \rightarrow D_s^{*-} K^+$  channels and less than 4% in  $B^0 \rightarrow D_s^+ \pi^-$  and  $B^0 \rightarrow D_s^- K^+$  channels contain two or more candidates that satisfy the criteria listed above. In such events we select a single  $B^0$  candidate based on an event  $\chi^2$  formed with  $m(D_s)$  (both  $D_s^+$  and  $D_s^{*+}$  modes) and  $\Delta m(D_s^{*+})$  ( $D_s^{*+}$  modes) and their average uncertainties, and the  $\Delta E$  variable. Such selection does not bias background distributions significantly.

Four classes of background contribute to the fit region. First is the *combinatorial background*, in which a true or

fake  $D_s^{(*)}$  candidate is combined with a randomly-selected pion or kaon. Second,  $B$  meson decays such as  $\bar{B}^0 \rightarrow D^{(*)+} \pi^-$ ,  $\rho^-$  with  $D^+ \rightarrow K_S^0 \pi^+$  or  $\bar{K}^{*0} \pi^+$  can constitute a background for the  $B^0 \rightarrow D_s^{(*)+} \pi^-$  modes if the pion in the  $D$  decay is misidentified as a kaon (*reflection background*). The reflection background has nearly the same  $m_{ES}$  distribution as the signal but different distributions in  $\Delta E$  and  $m(D_s)$ . The corresponding backgrounds for the  $B^0 \rightarrow D_s^- K^+$  mode ( $B^0 \rightarrow D^- K^{(*)+}$ ) are negligible. Third, rare  $B$  decays into the same final state, such as  $B^0 \rightarrow \bar{K}^{(*)0} K^+ \pi^-$  or  $\bar{K}^{(*)0} K^+ K^-$  (*charmless background*), have the same  $m_{ES}$  and  $\Delta E$  distributions as the  $B^0 \rightarrow D_s^+ \pi^-$  or  $B^0 \rightarrow D_s^- K^+$  signal, but are nearly flat in  $m(D_s)$ . The charmless background is significant in  $B^0 \rightarrow D_s^+ \pi^-$  and  $B^0 \rightarrow D_s^- K^+$  decays, but is negligible for  $B^0 \rightarrow D_s^{*+} \pi^-$  and  $B^0 \rightarrow D_s^{*-} K^+$ . Finally, *crossfeed background* from misidentification of  $\bar{B}^0 \rightarrow D_s^{(*)-} \pi^+$  events as  $B^0 \rightarrow D_s^{(*)-} K^+$  signal, and vice versa, needs to be taken into account.

We perform a two-dimensional unbinned extended maximum-likelihood fit to the  $m_{ES}$  and  $m(D_s)$  distributions to extract  $\mathcal{B}(B^0 \rightarrow D_s^+ \pi^-)$  and  $\mathcal{B}(B^0 \rightarrow D_s^- K^+)$  and constrain the contributions from charmless background modes. Charmless backgrounds are negligible for  $B^0 \rightarrow D_s^{*+} \pi^-$  and  $B^0 \rightarrow D_s^{*-} K^+$ , and we determine the BFs of these decays with a one-dimensional fit to the  $m_{ES}$  distribution. For each  $B$  decay, we simultaneously fit distributions in three  $D_s^+$  decay modes, constraining the signal BFs to a common value. The likelihood function contains the contributions of the signal and the four background components discussed above. The combinatorial background is described in  $m_{ES}$  by a threshold function [16],  $dN/dx \propto x \sqrt{1 - 2x^2/s} \exp[-\xi(1 - 2x^2/s)]$ . In  $m(D_s)$ , the combinatorial background is well described by a combination of a first-order polynomial (fake  $D_s^+$  candidates) and a Gaussian with (5–6) MeV/ $c^2$  resolution (true  $D_s^+$  candidates). The charmless background is parameterized by the signal Gaussian shape in  $m_{ES}$  and a first-order polynomial in  $m(D_s)$ .

For  $B^0 \rightarrow D_s^+ \pi^-$  and  $B^0 \rightarrow D_s^- K^+$  decays, the fit determines 14 free parameters: the shape of the combinatorial background  $\xi$  (1 parameter for all  $D_s^+$  modes), the slope of the combinatorial and charmless backgrounds in  $m(D_s)$  (3 parameters), the fraction of true  $D_s^+$  candidates in combinatorial background (3), the number of combinatorial background events (3), the number of charmless events (3), and the BF of the signal mode (1). The signal yields for each  $D_s^+$  mode are expressed as  $N_{sigi} = N_{B\bar{B}} \mathcal{B}_{sig} \mathcal{B}_i \varepsilon_i$ , where  $N_{B\bar{B}} = 230 \times 10^6$ ,  $\mathcal{B}_i$  is the  $D_s^+$  BF for the mode,  $\varepsilon_i$  is the reconstruction efficiency, and  $\mathcal{B}_{sig}$  is the BF (fit parameter) for the decay. For the  $B^0 \rightarrow D_s^{*+} \pi^-$  and  $B^0 \rightarrow D_s^{*-} K^+$  decays, 5 free parameters are determined by the fit:  $\xi$  (1 parameter for all  $D_s^+$  modes), the number of combinatorial background events (3), and the BF of the signal

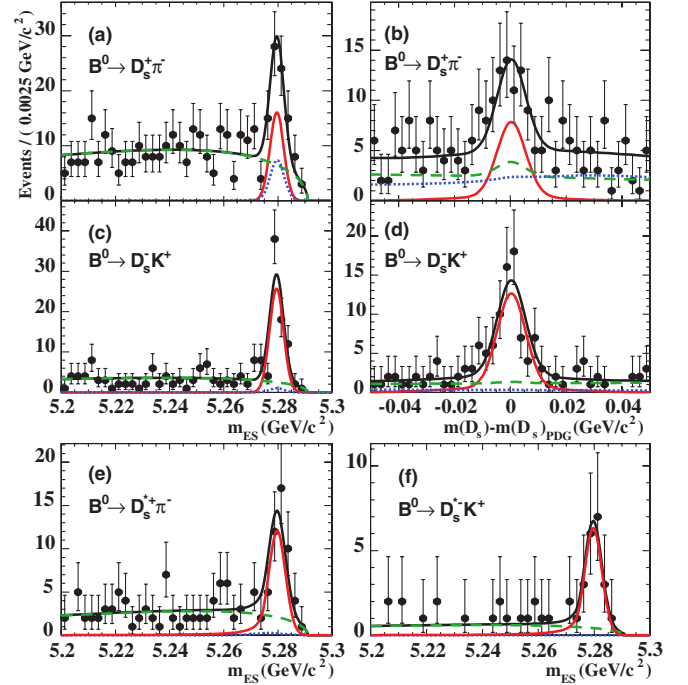


FIG. 2 (color online). (a),(c),(e),(f)  $m_{ES}$  projection of the fit with  $|m(D_s^+) - m(D_s^+)_{PDG}| < 10$  MeV/ $c^2$  and (b),(d)  $m(D_s)$  projection with  $5.275 < m_{ES} < 5.285$  GeV for (a),(b)  $B^0 \rightarrow D_s^+ \pi^-$ , (c),(d)  $B^0 \rightarrow D_s^- K^+$ , (e)  $B^0 \rightarrow D_s^{*+} \pi^-$ , and (f)  $B^0 \rightarrow D_s^{*-} K^+$ . Bins with zero events are omitted for clarity. The black solid curve corresponds to the full PDF from the combined fit to all  $D_s^+$  decay modes. Individual contributions are shown as solid red lines (signal PDF), green dashed lines (combinatorial background), and blue dotted lines (sum of reflection, charmless, and crossfeed backgrounds) curves.

mode (1). The signal efficiency  $\varepsilon_i$  varies between 6.7% and 29.3%, depending on the mode. The BFs of the channels contributing to the reflection background are fixed in the fit to the current world average values [14], and the BFs of the crossfeed backgrounds are determined by iterating the fits over each  $B$  decay mode. The fit samples contain 1305 events for  $B^0 \rightarrow D_s^+ \pi^-$ , 132 for  $B^0 \rightarrow D_s^- \pi^-$ , 539 for  $B^0 \rightarrow D_s^- K^+$ , and 41 events for  $B^0 \rightarrow D_s^{*-} K^+$  mode. The results of the fits are shown in Fig. 2 and summarized in Table I.

Systematic errors are dominated by 13% relative uncertainty for  $\mathcal{B}(D_s^+ \rightarrow \phi \pi^+)$  [17]. The relative BF uncertainties for  $\mathcal{B}(D_s^+ \rightarrow \bar{K}^{*0} K^+)/\mathcal{B}(D_s^+ \rightarrow \phi \pi^+)$  and  $\mathcal{B}(D_s^+ \rightarrow K_S^0 K^+)/\mathcal{B}(D_s^+ \rightarrow \phi \pi^+)$  contribute 5%–7%, depending on the decay channel. Uncertainties in the selection efficiency are estimated to be 3% for  $D_s^+$  modes and 7% for  $D_s^{*+}$  modes. The uncertainties in the reflection and crossfeed backgrounds are below 1% for all decay channels. Other systematic errors include the uncertainties in tracking (5%), photon (3%), and  $K_S^0$  reconstruction (0.2%–0.5%), charged-kaon identification (1%) efficiencies, and variations of the PDF shapes between data and

TABLE I. The results of the fit for the branching ratios. Shown are the probability ( $P_{\text{bkg}}$ ) of the data being consistent with the background in the absence of signal, and the measured branching fraction  $\mathcal{B}$ . The first uncertainty is statistical, and the second is systematic.

$B$ mode	$P_{\text{bkg}}$	$\mathcal{B}(10^{-5})$	$\mathcal{B} \times \mathcal{B}(D_s^+ \rightarrow \phi\pi^+)(10^{-6})$
$B^0 \rightarrow D_s^+ \pi^-$	$3 \times 10^{-6}$	$1.3 \pm 0.3 \pm 0.2$	$0.63 \pm 0.15 \pm 0.05$
$B^0 \rightarrow D_s^{*+} \pi^-$	$3 \times 10^{-8}$	$2.8 \pm 0.6 \pm 0.5$	$1.32 \pm 0.27 \pm 0.15$
$B^0 \rightarrow D_s^- K^+$	$3 \times 10^{-19}$	$2.5 \pm 0.4 \pm 0.4$	$1.21 \pm 0.17 \pm 0.11$
$B^0 \rightarrow D_s^{*-} K^+$	$2 \times 10^{-5}$	$2.0 \pm 0.5 \pm 0.4$	$0.97 \pm 0.24 \pm 0.12$

Monte Carlo calculations ([1%–5%], depending on decay mode).

The ratio  $P_{\text{bkg}} = \mathcal{L}_0/\mathcal{L}_{\text{max}}$ , where  $\mathcal{L}_{\text{max}}$  is the maximum-likelihood value, and  $\mathcal{L}_0$  is the likelihood for a fit with the signal contribution set to zero, describes the probability of the background to fluctuate to the observed number of events. The values  $P_{\text{bkg}}$  in Table I include all systematic uncertainties, which are assumed to be Gaussian-distributed. They correspond to the significance of signal observation of 5 ( $B^0 \rightarrow D_s^+ \pi^-$ ), 6 ( $B^0 \rightarrow D_s^{*+} \pi^-$ ), 9 ( $B^0 \rightarrow D_s^- K^+$ ), and 5 ( $B^0 \rightarrow D_s^{*-} K^+$ ) standard deviations. This is the first observation of  $B^0 \rightarrow D_s^+ \pi^-$ ,  $B^0 \rightarrow D_s^{*+} \pi^-$ , and  $B^0 \rightarrow D_s^{*-} K^+$  decays.

Assuming the SU(3) relation, Eq. (1), we determine  $r(D\pi) = (1.29 \pm 0.15(\text{stat}) \pm 0.13(\text{syst})) \times 10^{-2}$ , and  $r(D^*\pi) = (1.87 \pm 0.19(\text{stat}) \pm 0.19(\text{syst})) \times 10^{-2}$ , which implies small  $CP$  asymmetries in  $B^0 \rightarrow D^{(*)\mp} \pi^\pm$  decays. The branching fractions for  $B^0 \rightarrow D_s^{(*)-} K^+$  are small compared to the dominant decays  $B^0 \rightarrow D^{(*)-} \pi^+$ , implying relatively insignificant contributions from the color-suppressed  $W$ -exchange diagrams. These results supersede our previously published measurements [9].

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