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Branching fractions and CP asymmetries in B decays through $b \to c$ processes at Belle

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We report results of the branching fractions for a number of charm B decays including $\bar{\mathrm{B}}^0 \to \mathrm{D}^{*+}\pi^-$, $\bar{\mathrm{B}}^0 \to \mathrm{D}^{*+}\mathrm{K}^-$, $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\pi^-$ and $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\mathrm{K}^-$ all measured using 772×10^6 B-meson pairs recorded by the Belle experiment at the KEKB asymmetric-energy e^+e^- collider. The measurements provide a precise test of QCD factorisation. We also report preliminary results for the branching fraction $\mathcal{B}(\mathrm{B}^+ \to \mathrm{D}_s^{*+}(\eta, \mathrm{K}_\mathrm{S}^0)/\mathrm{D}^+(\eta, \mathrm{K}_\mathrm{S}^0))$ and the time-dependent CP asymmetry in $\mathrm{B} \to \eta_\mathrm{c}\mathrm{K}_\mathrm{S}^0$. The latter measurement provides information on $\sin 2\phi_1$.

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1. Introduction

The study of hadronic B decays to charm has an important role to play in the determination of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1, 2], Charge Parity (CP) violation parameters and in searches of new physics beyond the Standard Model. Despite the small branching fractions involved, two-body modes such as $\mathrm{B} \to \mathrm{D}\pi$ and $\mathrm{B} \to \mathrm{D}^*\pi$ can still be studied in relatively clean samples. These four-quark-flavor decays are ideal for analysing QCD factorization methods due to the absence of any penguin or annihilation processes. Finally, these modes must also be precisely measured as they are a significant background for CKM parameter measurements.

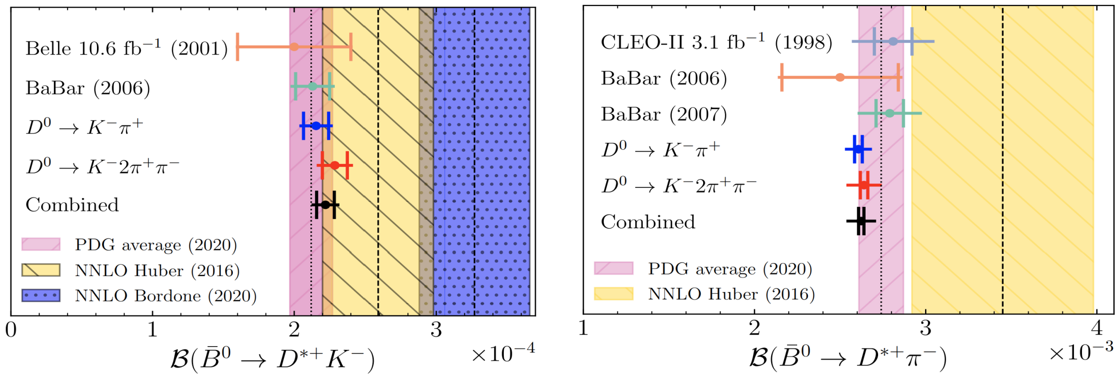
The Belle experiment is one of several scientific projects undertaken by the High Energy Accelerator Research Organization (KEK) located in Tsukuba, Japan. The KEKB accelerator is an asymmetric $\mathrm{e}^+\,\mathrm{e}^-$ collider carrying 8.0 GeV electrons and 3.5 GeV positrons. The beams collide with a centre of mass (c.m.) energy of $\sqrt{s}$ =10.58 GeV which is just above the $\Upsilon(4S)$ resonance, and will therefore produce B mesons in large quantities. During its lifetime, the Belle experiment attained a peak luminosity of $2.1 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ and collected in total $711\,\mathrm{fb}^{-1}$ of 772×10^6 B pairs. The full Belle data set was used for each of the analyses reported here.

2. Measurement of the branching fractions of $\bar{\mathrm{B}}^0 \to \mathrm{D}^{*+}\pi^-$ and $\bar{\mathrm{B}}^0 \to \mathrm{D}^{*+}\mathrm{K}^-$ decays and their ratio

The fit results and comparisons with theoretical predictions and previous measurements are shown in Fig. 1. for the branching fraction, and Fig. 2 for their ratio. The results are $\mathcal{B}(\bar{\mathrm{B}}^0 \to \mathrm{D}^{*+}\pi^-) = (2.62 \pm 0.02 \pm 0.09) \times 10^{-3}$, $\mathcal{B}(\bar{\mathrm{B}}^0 \to \mathrm{D}^{*+}\mathrm{K}^-) = (2.22 \pm 0.06 \pm 0.08) \times 10^{-4}$ and $\mathcal{R}_{K/\pi} = (8.41 \pm 0.24 \pm 0.13) \times 10^{-2}$ where the first uncertainty is statistical and the second is systematic. Comparisons to theoretical predictions from Huber et al. [3] find deviations of 1.7σ, 0.9σ and 2.7σ respectively. The $\bar{\mathrm{B}}^0 \to \mathrm{D}^{*+}\mathrm{K}^-$ branching fraction is also compared to the prediction from Bordone et al. [4] at Next-to-Next-to-Leading-Order (NNLO) and is found to deviate by 2.6σ. The branching fractions are consistent with previous experimental measurements, whereas the ratio is in tension with results from BaBar [6] and LHCb [10]. The statistical and systematic uncertainties are improved, both due to better understanding of the detector and access to the larger dataset. These results have been used as the basis for further QCD factorization tests detailed in Ref. [11].

3. Measurement of the branching fractions of $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\pi^-$ and $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\mathrm{K}^-$ decays and their ratio

The signal-enhanced fit projections for the data are shown in Fig. 3. The results are $\mathcal{B}(\bar{\mathrm{B}}^0 \to \mathrm{D}^+\pi^-) = (2.48 \pm 0.01 \pm 0.09 \pm 0.04) \times 10^{-3}$, $\mathcal{B}(\bar{\mathrm{B}}^0 \to \mathrm{D}^+\mathrm{K}^-) = (2.03 \pm 0.05 \pm 0.07 \pm 0.03) \times 10^{-4}$ and $R^D = 0.0819 \pm 0.0020 \pm 0.0023$. The first uncertainty is statistical and the second is systematic. The third uncertainty in the measurements of the branching fraction is related to the branching fraction of the $\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+$ decay. The $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\mathrm{K}^-$ decay branching fraction is calculated by multiplying the R^D value from the fit by the calculated $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\pi^-$ branching fraction. The $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\mathrm{h}^-(\mathrm{h}= \mathrm{K}/\pi)$ branching fraction and R^D results are consistent with the world average values [16] to within their uncertainties. The individual branching fractions of $\bar{\mathrm{B}}^0 \to \mathrm{D}^+\pi^-$ and



(a) **(b)**

Figure 1: Branching fraction measurement comparisons using the full data sample and the data subsamples with previous measurements from (a) Belle [13] and BaBar [6], and (b) BaBar [7, 8] and CLEO-II [15]. Uncertainties are given by the inner and outer error bars, where the inner is purely statistical while the outer is the sum in quadrature of both statistical and systematic uncertainties. The theoretical predictions are taken from [3, 4].

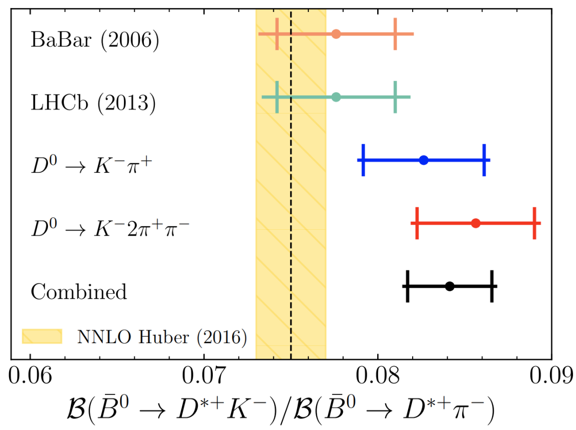
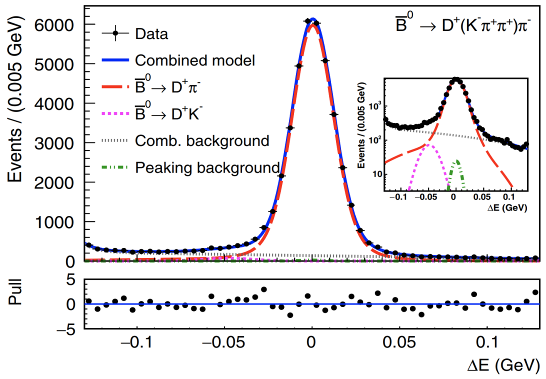


Figure 2: Branching fraction ratio measurements using the full data sample and the data subsamples with previous measurements from BaBar [6], LHCb [10]. Uncertainties are given by the inner and outer error bars, where the inner is purely statistical while the outer is sum in quadrature of both statistical and systematic uncertainties.

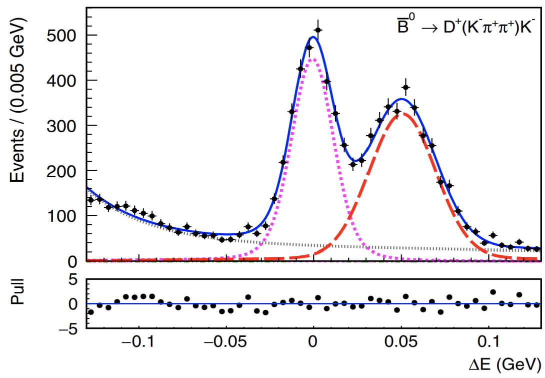
$\mathrm{\bar{B}}^0 \to \mathrm{D^+K^-}$ are in tension with the theoretical predictions of Refs. [3, 4], however, their ratio agrees to within uncertainties.

4. Measurement of the branching fractions of $\mathbf{B^+ \to D^+(K^0_S/\eta)}$ and $\mathbf{B^+ \to D_s^{*+}(K^0_S/\eta)}$ decays

The fit projections to ΔE distributions are shown for each decay mode in Fig. 4 which can also be found in Ref. [12]. The expected yield for signal events is 0. In the absence of any significant statistics we calculate an upper limit for the branching fraction using the frequentist method and an ensemble of 2000 pseudo-experiments. The confidence limit is calculated as the



(a)



(b)

Figure 3: ΔE distributions for $\bar{B}^0 \to D^+h^-$ candidates obtained from the (a) pion-enriched $\bar{B}^0 \to D^+\pi^-$ and (b) kaon-enriched $\bar{B}^0 \to D^+K^-$ data samples. The projections of the combined fit and individual components of a simultaneous unbinned maximum-likelihood fit are overlaid. The distributions of pulls between the fit and the data points is also shown.

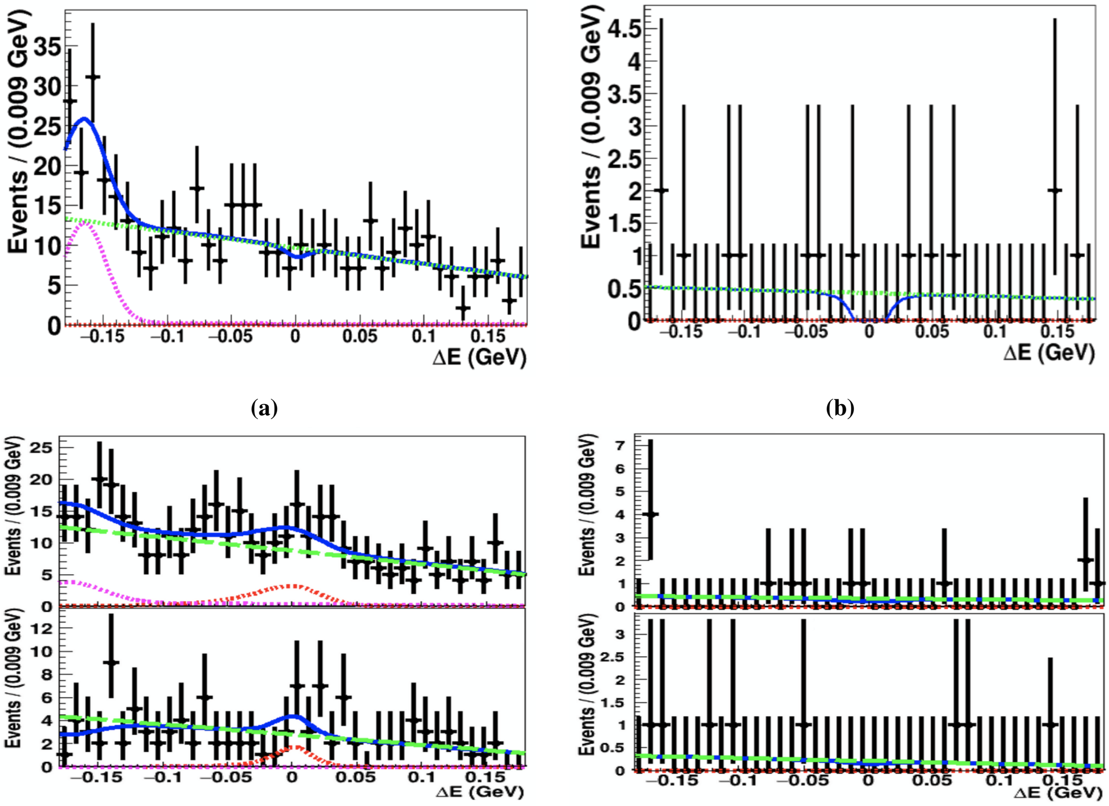
percentage of pseudo-experiments with a fitted yield greater than the expected signal yield in data. The preliminary results are $\mathcal{B}(B^+ \to D_s^{*+}K_S^0) < 0.6 \times 10^{-5}$, $\mathcal{B}(B^+ \to D_s^{*+}\eta) < 1.7 \times 10^{-5}$, $\mathcal{B}(B^+ \to D^+K_S^0) < 0.2 \times 10^{-5}$ and $\mathcal{B}(B^+ \to D^+\eta) < 1.2 \times 10^{-5}$ all at the 90% confidence level. These results are the most accurate so far and provide an upper limit ~ 20 times tighter than previous results [5, 14].

5. Measurement of the branching fraction and CP-violating parameters of $B^0 \to \eta_c K_S^0$

Fit projections in ΔE, $M(K_S^0K^+\pi^-)$ and the proper time difference Δt in the signal-enhanced region are shown in Fig. 5. We obtain preliminary results for the branching fraction $\mathcal{B}(B^0 \to \eta_c(K_S^0K^+\pi^-)K_S^0) = (9.8 \pm 0.6 \pm 0.4 \pm 2.3_{\text{int}}) \times 10^{-6}$, and the CP-violation parameters $\mathcal{S} = 0.59 \pm 0.17 \pm 0.07$ and $\mathcal{A} = 0.16 \pm 0.12 \pm 0.06$. The first error is statistical and the second is systematic. For the branching fraction, the last error accounts for signal and non-resonant peaking background interference. These results are consistent with previous results from BaBar [9].

6. Summary

We report on several recent analyses of B to charm hadronic decays at Belle performed on the full Belle data set corresponding to 711 fb^{-1} of integrated luminosity collected at the $\Upsilon(4S)$ resonance. We present measurements of the branching fractions of $\bar{B}^0 \to D^{*+}h^-(h = K/\pi)$, $\bar{B}^0 \to D^+h^-(h = K/\pi)$ and $B^0 \to \eta_c K_S^0$. We also find upper limits for the branching fractions of $B^+ \to D^+(K_S^0/\eta)$ and $B^+ \to D_s^{*+}(K_S^0/\eta)$. Finally, we present preliminary results of the CP-violating parameters for $B^0 \to \eta_c K_S^0$.



(a) **(b)**

(c) **(d)**

Figure 4: Fits of ΔE distributions in data for modes (a) $\mathrm{B}^+ \to \mathrm{D}^+\mathrm{K}^0_\mathrm{S}$, (b) $\mathrm{B}^+ \to \mathrm{D}^{*+}_\mathrm{s}\mathrm{K}^0_\mathrm{S}$, (c, top) $\mathrm{B}^+ \to \mathrm{D}^+\eta(\gamma\gamma)$, (c, bottom) $\mathrm{B}^+ \to \mathrm{D}^+\eta(\pi^-\pi^+\pi^0)$, (d, top) $\mathrm{B}^+ \to \mathrm{D}^{*+}_\mathrm{s}\eta(\gamma\gamma)$, (d, bottom) $\mathrm{B}^+ \to \mathrm{D}^{*+}_\mathrm{s}\eta(\pi^-\pi^+\pi^0)$. The data points with error bars are measurements in data, the curves are the various PDF components: the solid (blue) fitted total PDF, the dotted (red) signal PDF, the dotted (magenta) for peaking background on the lower side of the ΔE and the dotted (green) for the combinatorial background mainly from $q\bar{q}$ events.

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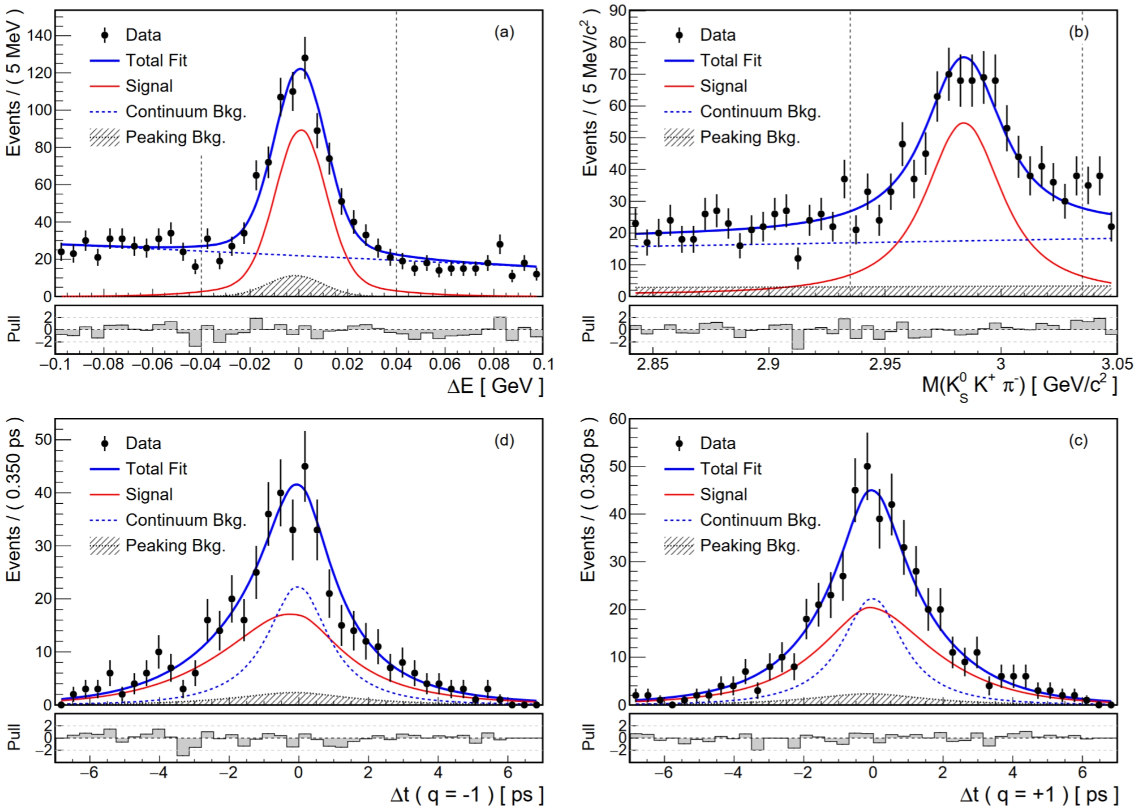

Figure 5: Projections in ΔE (a), $M(\mathrm{K}^0_\mathrm{S}\mathrm{K}^+\pi^-)$ (b) and proper time difference Δt for B^0 (c) and $\bar{\mathrm{B}}^0$-tagged (d) events in the signal-enhanced region. Curves show the fit model and its components, points represent the data. SVD1 and SVD2 experiment data and model are combined. Continuum background component includes non-peaking $\mathrm{B}\overline{\mathrm{B}}$ background.

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