Angles from B Decays with Charm: Summary of Working Group 5 of the CKM Workshop 2006

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We summarize the results presented in Working Group 5 (WG5) of the CKM 2006 Workshop in Nagoya. The charge of WG5 was to discuss the measurements of unitarity triangle angles $\beta = \phi_1$ and $\gamma = \phi_3$ from B-meson decays containing charm quark(s) in the final states.

I. INTRODUCTION

The focus of Working Group 5 at the CKM 2006 Workshop were the measurements of $\beta = \phi_1$ and $\gamma = \phi_3$ angles in the standard unitarity triangle of the Cabibbo–Kobayashi–Maskawa (CKM) matrix [1, 2] that are obtained from B decays into final state mesons with valence c quark(s). The discussion summary of the previous edition in this workshop series can be found in [3].

II. MEASUREMENTS OF β IN B DECAYS WITH CHARMONIUM.

B^0-meson decays originating from $b \to c\bar{c}s$ quark-level transitions are the key channels to measure the B^0_d–$\bar{B}^0_d$ mixing phase [4]. In the CKM picture of CP violation this phase equals $2\beta = \phi_1$, with

$$\beta = \mathrm{Arg}\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \qquad (1)$$

one of the angles in the standard unitarity triangle. A particularly clean measurement of β is provided by the time dependent CP asymmetry in the "golden" channel $B^0 \to J/\psi K_S$. Here the theory error, i.e. the difference between $\sin(2\beta)$ and the coefficient of $\sin(\Delta m t)$, $\Delta S_{J/\psi K_S}$, is small because it is given by a doubly Cabibbo-suppressed ratio of penguin to tree amplitudes [5]. Neglecting this correction leads to small "penguin pollution" of extracted $\sin(2\beta)$.

In view of the steadily increasing accuracy at the e^+e^- B factories and the quickly approaching start of the LHC, a closer look at the size of penguin pollution in $B^0 \to J/\psi K_S$ was taken as part of our Working Group discussions. The conclusion of an analysis performed several years ago [6] was that these corrections are extremely small, of the order of less than a per mil of the observed value, although a precise calculation is not possible. The analysis was extended recently by the authors of [7] using a formalism that combines the QCD-improved factorization and the perturbative QCD approaches. The penguin pollution $\Delta S_{J/\psi K_S}$ and the direct CP asymmetry $A_{J/\psi K_S}$ were calculated at leading power in $1/m_b$ and at next-to-leading order in α_s. Both quantities were found to be at the 10^{-3} level [8].

A different avenue to deal with these corrections was chosen by the authors of [9, 10]: employing the SU(3) flavour symmetry of strong interactions and further plausible dynamical assumptions, the data from $B^0 \to J/\psi\pi^0$ channel, where penguin-to-tree ratio is not CKM suppressed, are used to estimate $\Delta S_{J/\psi K_S}$. A fit to the current data gives $\Delta S_{J/\psi K_S} = 0.000 \pm 0.012$. This estimate of $\Delta S_{J/\psi K_S}$ is an order of magnitude larger than the alternative ones discussed above, and is comparable to the present experimental systematic error. Note, however, that the quoted error reflects also the size of experimental errors on observables in $B^0 \to J/\psi\pi^0$ decay and does not necessarily reflect the size of penguin pollution. In

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this sense the quoted bound on penguin pollution is a conservative one. At the LHC, the penguin pollution in B^0_d ! J= K_S can be controlled using the B^0_s ! J= K_S channel and the U-spin symmetry [11] as sketched below.

The above estimates of penguin pollution are especially interesting in light of a rather small recent experimental sin(2) value, which leads to some tension in the CKM ts. Following a recent paper [12] the implications for the allowed region in the space of the general New Physics (NP) parameters for B^0_d{B^0_d mixing were discussed [13]. In this analysis, the \true" value of is xed by and $jV_{ub}j$ extracted from tree-level processes, which are assumed not to be a ected by NP. Comparison with the value of extracted from B^0_d ! J= K_S then gives a constraint on a NP phase $^{NP}_d$ in B^0_d{B^0_d mixing. The result depends sensitively on $jV_{ub}j$, where the inclusive and exclusive determinations give $^{NP}_d j_{incl}$ = (11:0 4:3) and $^{NP}_d j_{excl}$ = (3:4 7:9) , respectively. Similar effects were also found in Refs. [14], and should be closely monitored in the future.

On the experimental side, the B-factory experiments BaBar and Belle have analyzed datasets of 384 and 535 10^6 BB pairs, respectively. The preliminary BaBar result is given as an average over several cc K_S/K_L channels [15]: sin 2 = 0:710 0:034 0:019 and j j = 0:932 0:026 0:017 (Fig. 2). Belle reported the result using only the J= K^0 modes [16]: sin 2 $_1$ = 0:642 0:031 0:017 and A = 0:018 0:021 0:014 with A = C = (1 j j^2)=(1 + j j^2) (Fig. 1). It should be noticed that nal states with di erent (cc) resonances can have di erent S corrections. At present these are expected to be smaller than experimental errors. With increasing experimental accuracy, however, averaging the CP asymmetry measurements from di erent modes may become problematic. Experimentally, the predicted uncertainty on S and C from the B-factories at 2 ab ^{1} will still be dominated by statistics while the systematic component of the error originates mainly from the knowledge of the vertexing algorithm performance.

A. Measurements of and cos2

Several methods based on the decays into resonant or multi-body nal states are being used to resolve the discrete ambiguity in the determination of from measured sin 2 . A theoretical review of determinations from B decays involving charm nal states was presented by A. Datta [17]: the b ! ccs transitions B ! J= $K^{( )}$, B ! $D^{( )}D^{( )}K_S$, the b ! ccd transition B ! $D^{( )}D^{( )}$ and the b ! cud transition B ! $D^{( )}h^0$.

The decay B ! J= K^0 ! J= K_S ^{0} is a VV decay. The corresponding time-dependent angular distribution allows a measurement of both sin 2 and cos2 [18]. The sign ambiguity can be resolved by using the interference between the K S-wave and P-wave amplitudes in the K (892) region and assuming small strong interactions between J= and K . The result of such an analysis

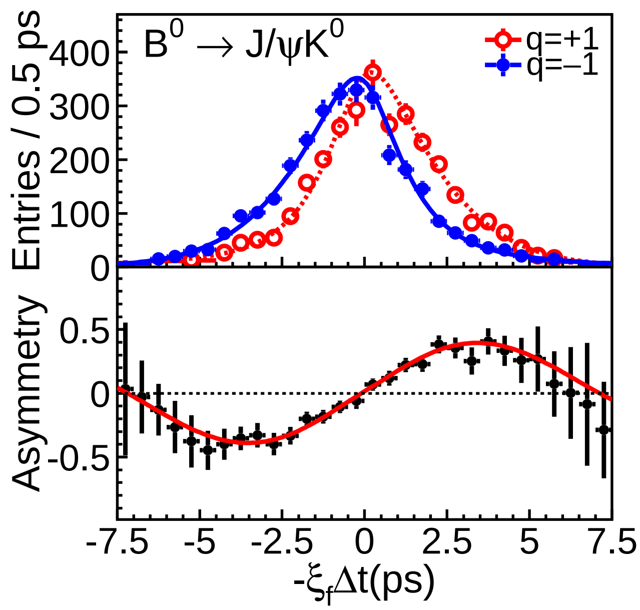

FIG. 1: Background subtracted t distributions and asymmetry for events with good tags for J= K^0 modes in the Belle analysis. In the asymmetry plot, solid curve shows the t result.

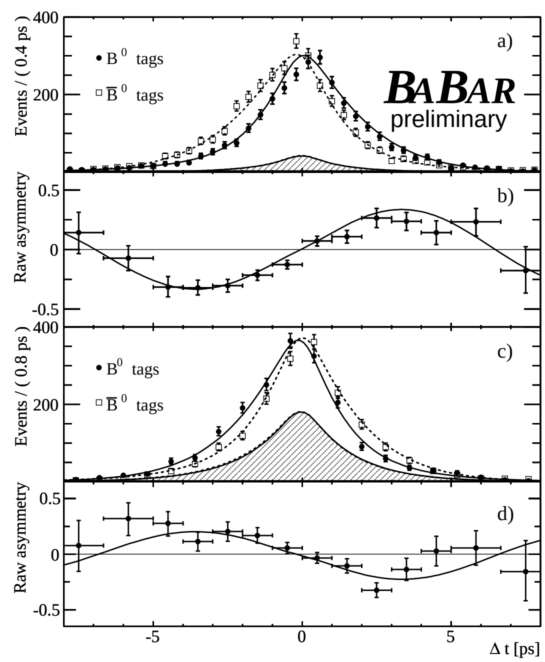

FIG. 2: a) Number of CP-odd candidates (J= K_S, (2S)K_S, $_{c1}K_S$, and $_cK_S$) in the signal region with a B^0 tag (N_{B^0}) and with a B^0 tag (N_{barB^0}), and b) the raw asymmetry (N_{B^0} N_{B^0})=(N_{B^0} + N_{B^0}), as functions of t. Figures c) and d) are the corresponding distributions for the CP-even mode J= K_L. The solid (dashed) curves represent the t projections in t for B^0 (B^0) tags. The shaded regions represent the estimated background contributions.

yields a positive value for $\cos 2\beta$ [19].

The $B(t) \to D^{*+}D^{*-}K_S$ decay can have both non-resonant and resonant contributions making it sensitive to $\cos 2\beta$ [20]. Using the theoretical calculation for the sign of the hadronic coefficient in front of $\cos 2\beta$ [20], $\cos 2\beta$ is preferred to be positive at the 94% confidence level [21].

The tree level $b \to c\bar{u}d$ decay $B(t) \to Dh^0$ ($h^0 = \pi^0, \eta, \omega, \ldots$) with $D \to K_S\pi^+\pi^-$ uses the variation of the strong phase over the final phase space to obtain β without discrete ambiguities [22]. The sensitivity to the phase comes from the interference of different resonance decays that either come from B^0 directly or from a prior oscillation through $\bar{B}^0$. Results of such analyses are available from both BaBar and Belle [15, 23].

In order to obtain β from $B(t) \to D^{(*)}D^{(*)}$, one needs further information to deal with the penguin effects. This can be provided by the U-spin-related $B_s \to D_s^{(*)}D_s^{(*)}$ modes [11, 24] or by using SU(3)-related $B \to D^{(*)}D_s^{(*)}$ decays and dynamical assumptions [25]. The BaBar measurements of CP observables in $B(t) \to D^{(*)+}D^{(*)-}$ were presented [23], while a new Belle measurement of $B(t) \to D^+D^-$ was reported [26]. There is a slight disagreement between the two experiments on the size of the direct CP asymmetry in $B(t) \to D^+D^-$. While Belle obtains $C_{D^+D^-} = -0.91 \pm 0.23 \pm 0.06$, BaBar quotes $C_{D^+D^-} = 0.11 \pm 0.35 \pm 0.06$. In the Standard Model (SM), a small direct CP asymmetry is expected based on an estimate using a combination of naive factorization and an arbitrarily large strong phase due to the final-state interactions [27]. In Ref. [24], a detailed analysis of the allowed region in observable space for CP violation in $B_d^0 \to D^+D^-$ was performed in view of the new B-factory measurements, together with an estimate of the relevant hadronic penguin parameters and observables. The questions of the most promising strategies for the extraction of CP-violating phases, about the interplay with other measurements of CP violation and regarding NP search were also addressed.

B. CPT/T violation in mixing.

BaBar has presented experimental results on CP and CPT violation in mixing [28]. Allowing for CPT violation, the general parametrization of B^0–$\bar{B}^0$ mixing is

$$
\begin{aligned}
|B_L\rangle &= p\sqrt{1-z}\,|B^0\rangle + q\sqrt{1+z}\,|\bar{B}^0\rangle, \\
|B_H\rangle &= p\sqrt{1+z}\,|B^0\rangle - q\sqrt{1-z}\,|\bar{B}^0\rangle, \qquad (2)
\end{aligned}
$$

with z denoting a complex parameter that is zero if CPT is conserved. On the other hand, CP violation in mixing is found, if $|q/p| \neq 1$ (while CP violation in the interference of mixing and decay is possible if $\arg(q/p) \neq 0$).

In the SM, $|q/p|$ is close to 1,

$$\frac{q}{p} \approx 1 - \frac{1}{2}\,\mathrm{Im}\,\frac{\Gamma_{12}}{M_{12}}, \qquad (3)$$

where $\langle B^0|H_{eff}|\bar{B}^0\rangle = M_{12} - i\Gamma_{12}/2$. The CP-violating quantity $\mathrm{Im}(\Gamma_{12}/M_{12})$ is suppressed by an additional factor $(m_c^2 - m_u^2)/m_b^2 \approx 0.1$ relative to $|\Gamma_{12}/M_{12}|$, giving $|\mathrm{Im}(\Gamma_{12}/M_{12})| < 10^{-3}$ in the SM [29, 30].

The CP- and CPT-violating parameters are determined from time-dependent fits to B^0–$\bar{B}^0$ pair events in two complementary approaches. In the first approach, two high-momentum leptons are demanded in order to select inclusive semileptonic B^0 decays. In the second approach, one of the B mesons is partially reconstructed in the semileptonic $D^{*-}l^+\nu_l$ channel (only the lepton and the soft pion from $D^{*-} \to \bar{D}^0\pi^-$ decay are reconstructed), while for the flavour of the other B a leptonic tag is used.

No evidence of CP or CPT violation is found in mixing with either of the two methods. The first method gives

$$
\begin{aligned}
|q/p| - 1 &= (-0.8 \pm 2.7_{(stat.)} \pm 1.9_{(syst.)}) \times 10^{-3}, \\
\mathrm{Im}\,z &= (-13.9 \pm 7.3_{(stat.)} \pm 3.2_{(syst.)}) \times 10^{-3}, \\
\Delta\Gamma \times \mathrm{Re}\,z &= (-7.1 \pm 3.9_{(stat.)} \pm 2.0_{(syst.)}) \times 10^{-3}\,\mathrm{ps}^{-1},
\end{aligned}
$$

where z was taken to be time independent. The preliminary result from the second method is:

$$|q/p| - 1 = (6.5 \pm 3.4_{(stat.)} \pm 2.0_{(syst.)}) \times 10^{-3}. \qquad (4)$$

Both results are compatible with the SM expectations and with previously published BaBar results [31, 32]. As first pointed out by Kostelecky [33], taking the CPT-violating parameter z to be constant in time is not very natural. Since CPT violation in the quantum field theory implies Lorentz violation one can expect $z \propto \beta^\mu a_\mu$, where β^μ is the decaying B-meson four-velocity and a_μ a constant four-vector describing Lorentz violation. Because of the Earth's rotation the product of the two vectors is time dependent $z = z_0 + z_1\cos(\Omega\hat{t} + \phi)$, with Ω the Earth's rotation frequency, $\hat{t}$ the sidereal time, while z_0 and z_1 are constants. BaBar analysis accounting for this time dependence gives results for $\mathrm{Im}\,z_1$ and $\Delta\Gamma\,\mathrm{Re}\,z_1$ consistent with zero at 2.2σ as shown in Fig. 3.

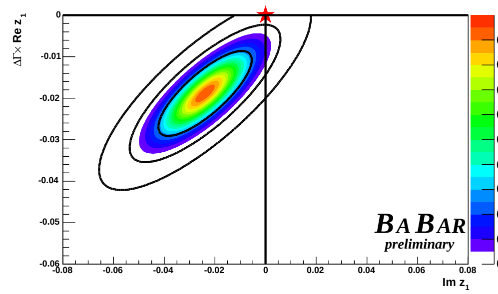

FIG. 3: Allowed regions for the CPT-violating parameters $\mathrm{Im}\,z_1$ and $\Delta\Gamma\,\mathrm{Re}\,z_1$ at various confidence levels. The red star represents the SM expectation and the solid black ellipses correspond to 1, 2 and 3σ significances.

III. MEASUREMENTS OF

The extraction of from $B \to (f)_D K$ decays uses the interference between $\bar{b} \to \bar{c}u\bar{s}$ and $\bar{b} \to \bar{u}c\bar{s}$ transitions. The interference is nonzero when the final state f is accessible to both D and $\bar{D}$ mesons. The theoretical uncertainty is completely negligible as there are no penguin contributions.

Several methods were proposed that differ in the choices for the final states f: CP eigenstate (GLW method [34]), doubly Cabbibo suppressed (ADS method [35]), and a combination of these two methods using a D Dalitz analysis (GGSZ method [36]).

The feasibility of the measurement crucially depends on the size of r_B, the ratio of the B decay amplitudes involved ($r_B = |A(B^+ \to \bar{D}K^+)|/|A(B^+ \to DK^+)|$). The value of r_B is given by the ratio of the CKM matrix elements $|V_{ub}V_{cs}|/|V_{cb}V_{us}|$ and the colour suppression factor, and is estimated to be in the range 0.1–0.2 [37]. For different D decays, the B system parameters are common, which means that the combination of different D channels can help more than just adding more statistics [38].

The shift due to D–$\bar{D}$ mixing is estimated to be less than one degree for doubly Cabibbo-suppressed decays and much smaller in other cases, and can eventually be included in the determination. The effect due to CP violation in the neutral D sector is negligible in the SM and at most at the 10^{-2} order if one considers NP in the charm sector [39].

Results from the two B-factories Belle/KEKB and BaBar/PEPII are available. The Belle collaboration uses a data sample that consists of 386 $10^6 B\bar{B}$ pairs [40]. The decay chains $B^+ \to DK^+$, $B^+ \to D^* K^+$ with $D^* \to D\pi^0$ and $B^+ \to DK^{*+}$ with $K^{*+} \to K_S^0\pi^+$ are selected for the analysis. The analysis of the BaBar collaboration [41] is based on 347 $10^6 B\bar{B}$ pairs. The reconstructed final states are $B^+ \to DK^+$ and $B^+ \to D^* K^+$ with two D^* channels: $D^* \to D\pi^0$ and $D^* \to D$.[1] The neutral D meson is reconstructed in the $K_S^0\pi^+\pi^-$ final state in all cases. The number of reconstructed signal events in the Belle's data are 331 23, 81 11 and 54 8 for the $B^+ \to DK^+$, $B^+ \to D^* K^+$ and $B^+ \to DK^{*+}$ channels, respectively. BaBar finds 398 23, 97 13 and 93 12 signal events in the $B^+ \to DK^+$, $B^+ \to D^*[D\pi^0]K^+$ and $B^+ \to D^*[D]K^+$ channels respectively.

The $D^0 \to K_S^0\pi^+\pi^-$ decay amplitude $f(m_+^2, m_-^2)$ ($m_\pm^2 = m^2(K_S^0\pi^\pm)$) is determined independently from a large sample of flavor-tagged $D^{*-} \to \bar{D}^0\pi^-$, $\bar{D}^0 \to K_S^0\pi^+\pi^-$ decays produced in continuum $e^+e^- \to q\bar{q}$ annihilation. The amplitude f is parametrized as a coherent sum of two-body decay amplitudes plus a non-resonant decay amplitude,

$$f(m_+^2, m_-^2) = \sum_{j=1}^{N} a_j e^{i\,j} A_j(m_+^2, m_-^2) + b e^{i}, \quad (5)$$

where the sum is over the resonances present in $K_S^0\pi^+\pi^-$, $A_j(m_+^2, m_-^2)$ is the corresponding Breit-Wigner form, a_j and $_j$ are respectively the amplitude and phase of the matrix element for a decay through j-th resonance, while b and are the amplitude and phase of the non-resonant component. The total phase and amplitude are arbitrary. To be consistent with the CLEO analysis [43], the K_S^0 mode is chosen to have unit amplitude and zero phase.

For Belle, a set of 18 two-body amplitudes is used. These include five Cabibbo-allowed amplitudes: $K^*(892)^+$, $K^*(1410)^+$, $K_0^*(1430)^+$, $K_2^*(1430)^+$ and $K^*(1680)^+$, their doubly Cabibbo-suppressed partners, and eight channels with a K_S^0 and a resonance: , !, $f_0(980)$, $f_2(1270)$, $f_0(1370)$, (1450), $_1$ and $_2$. The Breit–Wigner masses and widths of the scalars $_1$ and $_2$ are left unconstrained, while the parameters of the other resonances are taken to be the same as in the CLEO analysis [43]. The parameters of the resonances obtained in the fit are as follows: $M_{1} = 519$ 6 MeV/c^2, $_{1} = 454$ 12 MeV/c^2, $M_{2} = 1050$ 8 MeV/c^2 and $_{2} = 101$ 7 MeV/c^2 (the errors are statistical only). In the BaBar case, a similar model is used with 16 two-body decay amplitudes and phases. In particular, a model based on a fit to scattering data (K-matrix [44]) is used to parametrize alternatively the S-wave component and it is used to estimate the model systematic uncertainty. The agreement between the data and the fit result is satisfactory for the purpose of measuring and the discrepancy is taken into account in the model uncertainty.

Once $f(m_+^2, m_-^2)$ is determined, a fit to B data allows the determination of r_B, and $_B$, where $_B = \arg[A(B^+ \to \bar{D}K^+)/A(B^+ \to DK^+)]$. Analysis of CP violation is performed by means of an unbinned maximum likelihood fit with the B^+ and B^- samples fitted separately using Cartesian parameters $x = r_B \cos(_B)$ and $y = r_B \sin(_B)$. The fit is performed by minimizing the negative likelihood function of n events

$$-2\log L = -2\sum_{i=1}^{n} \log p(m_{+,i}^2, m_{-,i}^2; \Delta E_i, M_{bc,i}); \quad (6)$$

with the Dalitz plot density p represented as

$$\begin{aligned} p(m_+^2, m_-^2; \Delta E, M_{bc}) = \\ |f(m_+^2, m_-^2) + (x + iy) f(m_-^2, m_+^2)|^2 \quad (7) \\ F_{sig}(\Delta E, M_{bc}) + F_{bck}(m_+^2, m_-^2; \Delta E, M_{bc}). \end{aligned}$$

The signal distribution F_{sig} is a function of two kinematic variables, ΔE and M_{bc}, F_{bck} is the distribution

[1] The previous BaBar [42] publication includes also the $B^+ \to DK^{*+}$ channel but this mode is not included in the recent update.

of the background, and $= (m_+^2; m_-^2)$ is the total e ciency. The background density function F_{bck} is determined from analysis of sideband events in data and with MC generated events.

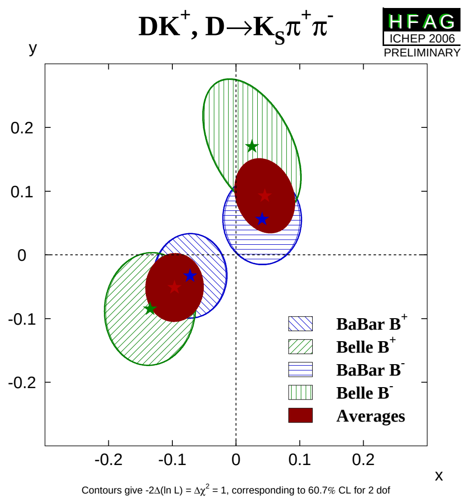

FIG. 4: Results of signal ts with free parameters $x = r\cos(+ _B)$ and $y = r\sin(+ _B)$ for $B \to DK$ from the BaBar and Belle latest publications [45]. The contours indicate one standard deviation.

Figure 4 shows the results of the separate B^+ and B data ts for $B \to DK$ mode in the x{y plane for the BaBar and Belle collaborations. Con dence intervals were then calculated using a frequentist technique (the so-called Neyman procedure in the BaBar case, the uni ed approach of Feldman and Cousins [46] in the Belle case). The central values for the parameters $, r_B$ and for the combined t (using the $(x ; y)$ obtained for all modes) with their one-standard-deviation intervals are presented in Tab. I for the BaBar and Belle analysis.

The uncertainties in the model used to parametrize the $D^0 \to K_S^0 {}^+$ decay amplitude lead to an associated systematic error in the t result. These uncertainties arise from the fact that there is no unique choice for the set of quasi-2-body channels in the decay, as well as from the various possible parameterizations of certain components, such as the non-resonant amplitude. To evaluate this uncertainty several alternative models have been used to t the data.

Despite similar statistical errors obtained for $(x ; y)$ in the two experiments, the resulting error is much smaller in Belle's analysis. Since the uncertainty on scales roughly as $1/r_B$, the di erence is explained by noticing that the BaBar $(x ; y)$ measurements favor values of r_B smaller than the Belle results.

At present the amplitude in the Dalitz plot analysis is described as a sum of Breit{Wigner-like resonances (5). This approach is valid for narrow well-spaced resonances but fails to describe broad resonances, in particular the scalar ones. In addition, interferences between overlapping resonances may not be well accounted for within the Breit{Wigner model, which in turn can have an impact on the determination of the CKM parameter . The K-matrix approach appears as a possible alternative that correctly implements unitarity of S matrix in 2-body scattering also for overlapping resonances. Its extension to 3-body decays is delicate with incomplete analytic structure from unitarity constraints. Nevertheless, a K-matrix approach extended to 3-body decays would provide an alternative to the current model (sum of Breit{Wigner-like resonances) and help to assess the model error more precisely [48].

The error due to the resonance model can be avoided by using the model-independent measurement proposed in [36]. In this approach, the Dalitz plot is partitioned in bins symmetric with respect to the $^+$ axis. Counting the number of events in such bins from entangled D decay samples, in addition to the already utilized avour-tagged D decay samples, can determine the strong phase variation over the Dalitz plot. For this the data of a -charm factory is needed. Useful samples consist of $(3770) \to D^0\overline{D}^0$ events where one of the D mesons decays into a CP eigenstate (such as K^+K or $K_S^0 \to$), while the D meson going in the opposite direction decays into $K_S^0 {}^+$. Using also a similar sample where both mesons from the (3770) decay into the $K^0 {}^+$ state provides enough information to measure all the needed hadronic parameters in D decay up to one overall discrete ambiguity (this can be resolved using a Breit-Wigner model). CLEO-c showed that with the current integrated luminosity of 280 pb^{-1} at the (3770) resonance, these samples are already available.

With the luminosity of 750 pb^{-1}, that CLEO-c should get at the end of its operation, the samples will be respectively about 1000 and 2000 events. Using these two samples with a binned analysis and assuming $r_B = 0.1$, a 4° precision on $_3$ could be obtained [49, 50]. An unbinned implementation of the model independent approach was presented by A. Poluektov [50].

Channels with bigger r_B 0.3 0.4, such as $B^0 \to D^0K^0$, have been proposed. An analysis of this channel exploits the b-quark avour tag provided by the sign of the charged kaon in the K^0 decay [47].

IV. MEASUREMENTS OF sin(2 +)

A B^0 meson can decay into $D^{( )} {}^+$ nal state either directly through a Cabibbo-favoured transition (proportional to V_{cb}) or can rst oscillate into a B^0 and then decay via a doubly Cabibbo-suppressed transition (proportional to V_{ub}). The interference of the two contributions generates the observables S in the time-dependent CP asymmetries that are equal to $2r^{( )}\sin(2 +)$ [51, 52], where $re^i = A(B^0 \to D {}^+)/A(B^0 \to D {}^+)$. Unfortunately this ratio is very small, O(0.02), and one furthermore needs to have knowledge of the relative strong phase in order to be able to extract the weak phases. To

TABLE I: Results of the combination of $B^+ \, ! \, DK^+$, $B^+ \, ! \, D \, K^+$, and $B^+ \, ! \, DK \, ^+$ modes for BaBar and Belle analyses. The rst error is statistical, the second is systematic and the third one is the model error. In the case of BaBar, one standard deviation constraint is given for the r_B values.

Parameter	BaBar	Belle
	(92 41 11 12)	$(53^{+15}_{18}$ 3 9)
r_B^{DK}	$< 0{:}140$	$0{:}159^{+0{:}054}_{0{:}050}$ 0:012 0:049
$^{DK}_{B}$	(118 63 19 36)	$(146^{+19}_{20}$ 3 23)
$r_B^{D\,K}$	0:017 0:203	$0{:}175^{+0{:}108}_{0{:}099}$ 0:013 0:049
$^{D\,K}_{B}$	(62 59 18 10)	$(302^{+34}_{35}$ 6 23)
r_B^{DK}		$0{:}564^{+0{:}216}_{0{:}155}$ 0:041 0:084
$^{DK}_{B}$		$(243^{+20}_{23}$ 3 49)

do so one either needs to measure the observables with $O(r^2)$ precision or use external input on r.

BaBar and Belle have performed time-dependent analyses with full and partial reconstruction techniques (for the $D \quad ^+$ channel, see Fig. 5) [53, 54], giving

$$a^D \quad = 2r \sin 2 \; + \quad \cos \quad = \quad 0{:}037 \quad 0{:}011; \qquad (8)$$

with an error that is still dominated by the statistical component.

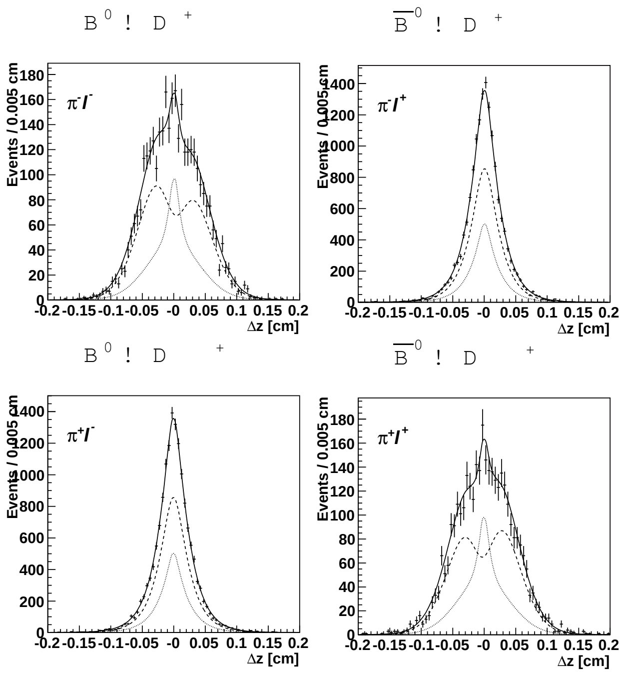

FIG. 5: t distributions for the partial reconstruction sample from Belle experiment. Curves are the t results for the signal, background, and their sum.

Estimate of r in $B^0 \, ! \, D \quad ^+$ from the $B^0 \, ! \, D_s \quad ^+$ decay using SU(3) symmetry was presented by M. Baak [55]. The potential breaking of underlying assumptions can come from several sources: non-factorizable contributions, nal state interactions, or missing diagrams in calculation – e.g. W-exchange. Nevertheless a global t to several observables can constrain such e ects, which leaves hopes that such measurement can be included in the Unitarity Triangle global ts [55].

Interesting ideas on how to extract sin(2 +) from multi-body decays have been discussed. In particular, a time-dependent Dalitz analysis of the $B^0 \, ! \, D \, K^0 \, ^+$ decay can separate V_{cb} and V_{ub} contributions (visible through K and D resonances respectively) and therefore be sensitive to the weak phase. Unfortunately, given the level of background only with 10 ab ^{1} of integrated luminosity one can aim at a 10% error [56].

V. AND AT HADRON COLLIDERS.

An overview of various determinations using B_s decays into charmed nal states was given by R. Fleischer [57]. For the decays that have both tree and penguin amplitudes, the U-spin symmetry is used to obtain the information on the penguin-to-tree ratio. In the U-spin based methods only the SU(3) avour symmetry is used, while in other uses of SU(3), for instance in diagrammatic approaches, further dynamical assumptions such as neglecting annihilation-like amplitudes are commonly used. The U-spin symmetry o ers also a powerful tool for the analysis of the $B_d \, ! \, D^{(\,)}$, $B_s \, ! \, D_s^{(\,)} K$ system [52].

The hadronic matrix elements of the $B_s \, ! \; J= \, K_S$ and $B_d \, ! \; J= \, K_S$ decays are related through the U-spin symmetry [11]. The penguin and tree amplitudes in $B_s \, ! \; J= \, K_S$ are multiplied by the combinations of CKM elements of similar size, $V_{cb}V_{cd}$ and $V_{ub}V_{ud}$ respectively. In $B_d \, ! \; J= \, K_S$, on the other hand, the tree is relatively $1= \, ^2$ enhanced compared to the penguin. This hierarchy allows for the determination of penguin pollution on sin 2 determination for both decays simultaneously, up to the SU(3)-breaking e ects, thereby complementing the discussion given in Section II. This type of analysis can also be used to determine the hadronic penguin e ects in the extraction of the B_s^0–$\overline{B}_s^0$ mixing phase $_s^{SM}$ 2 from the B_s ! J= channel [58] by relating it to the B_d ! J= ^{0} decay [59].

Another interesting U-spin-related system is given by the B_s ! $D_s^+ D_s$ and B_d ! $D^+ D$ decays [11, 24]. Here we may take the penguin e ects into account in the determination of the B_d^0{B_d^0 and B_s^0{B_s^0 mixing phases $_d$ and $_s$, respectively. As was noted in Ref. [60], the analysis of the $B_{d(s)}$! $D_{d(s)}^+ D_{d(s)}$ decays can also straightforwardly be applied to the $B_{d(s)}$! $K^0 K^0$ system. Following these lines, the penguin e ects in the determination of sin $_s$ from the b ! s penguin decay B_s^0 ! $K^0 K^0$ can be included through its B_d^0 ! $K^0 K^0$ partner [61] (here B_s^0 ! $K^0 K^0$ and B_d^0 ! $K^0 K^0$ take the rôles of B_s^0 ! $D_s^+ D_s$ and B_d^0 ! $D^+ D$, respectively); this is also the case for the corresponding $B_{d(s)}$! $K^0 K^0$ decays [59, 62].

The theoretically cleanest determinations of the mixing phases $_s$ and are o ered by the pure tree decays B_s ! D $K_{S(L)}$ and B_d ! D ^{0};D ^{0};:::, respectively [63]. The weak phase , on the other hand, can be obtained from pure tree colour-allowed S = 1 decays B_s ! $D_s K$ [64] and/or from the pure tree colour-suppressed S = 1 B_s ! D $^{(0)}$, B_s ! D , ... and B_d ! D $K_{S(L)}$ decays. Since these are tree decays there is no penguin pollution. There is enough experimental information to extract all the hadronic parameters because many di erent D decays can be used for the same B decay process. Each additional D decay mode brings in one additional parameter, the strong phase between D and D decay, while also bringing in two additional observables, the corresponding branching ratio and the CP asymmetry.

The study of B ! $D^0 K$ decay by CDF, where the D^0 is reconstructed in avor (K $^+$) or CP-even (K K^+; $^+$) eigenstates was reported [65], with the measurement of the ratio R = BR(B ! D^0_{flav}K)=BR(B ! D^0_{flav}), which is one of the inputs in the GLW method for determination [34], quoting the value 0:065 0:007 0:004 [66].

CDF observed for the rst time the B_s^0 ! $D_s^+ D_s$ channel and reported the measurement of the ratio R = BR(B_s ! $D_s^+ D_s$)=BR(B^0 ! $D_s^+ D$)= 1:67 0:41(stat) 0:12(syst) 0:24(f_s=f_d) 0:39(Br) [67]. Performing a run on the (5S) resonance, also the Belle collaboration has recently obtained an upper bound of 6:7% (90% C.L.) for this branching ratio [68]. Moreover, the D0 collaboration has performed a rst analysis of the combined B_s ! $D_s^{(\ )} D_s^{(\ )}$ branching ratio, with the result of BR(B_s ! $D_s^{(\ )} D_s^{(\ )}$) = $(3{:}9^{+1:9+1:6}_{\ 1:7\ 1:5})$% [69]. For a recent analysis using these Tevatron results to control the penguin e ects in B_d^0 ! $D^+ D$ see Ref. [24].

The LHCb sensitivity for the extraction of was simulated for B ! DK tree-level decays [70]. A combination of the GLW and ADS methods with the avour D ! K and D ! K decays leads to a statistical error on in the range 5{12 for r_B 0:08 with 2 fb ^{1} data. The use of B ! D ^{0}K that are more challenging at LHCb is also under study. The statistical precision on from neutral B decays has been estimated to be in the range 7{10 for 2 fb ^{1} of LHCb data, while a Dalitz analysis in B ! (K_S $^+$)$_D$ K is estimated to lead to a statistical error on of about 8 . An impact of the four-body D decay, B ! ($K^+ K$ $^+$)$_D$ K was also simulated, with estimated accuracy 14 . All in all the estimated precision on from a combination of these modes is expected to be at 5 for 2 fb ^{1}, which is comparable to the indirect determination of using CKM ts.

VI. CONCLUSIONS

In the next two years, the $e^+ e$ B-factories will reach a total integrated luminosity of about 2 ab ^{1} and CDF/D0 of several fb ^{1}. The measurement of the angle will be performed in several channels with no limitation due to systematics uncertainty and with a theory error under control. The current world average error on is around 20 [71, 72]. A more precise measurement will be challenging, especially since the sensitivity depends critically on the real value of r_B for the various channels that need to be combined. Thanks to the quickly approaching start of the LHC and its dedicated B-decay experiment LHCb, we will soon get full access to the rich physics potential of the B_s-meson system, and will also enter a new era for the precision measurements of . In the more distant future, an upgrade of LHCb and a super B-factory (or a super avour factory) could bring the measurements to their ultimate precisions.

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