Introduction

The first meeting of the International Review Committee appointed by INFN to review the Super$B$ project resulted in several detailed questions concerning the physics capability of Super$B$ being posed. The Super$B$ CDR discussed the physics objectives of the enterprise in some depth; these additional questions were thus meant to elucidate particular areas of interest to the committee members.

In order to prepare a coherent response, the proponents convened the Sixth Super$B$ Workshop at the IFIC in Valencia, Spain from January 7-15, 2008. Organizational details and the presentations made at the workshop can be accessed at https://agenda.infn.it/conferenceDisplay.py?confId=308. The workshop was organized into several working groups. This document comprises the reports from these groups.

The motivation for undertaking a new generation of e^+e^- experiments is, of course, to measure effects of New Physics on the decays of heavy quarks and leptons. A detailed picture of the observed pattern of such effects will be crucial to gaining an understanding of any New Physics found at the LHC. As detailed herein, much of the study of the capability of the LHC to distinguish between, for example, models of supersymmetry breaking have emphasized information accessible at high p_{T}. Many of the existing constraints on models of New Physics, however, come from flavor physics. Improving limits and teasing out new effects in the flavor sector will be just as important in constraining models after New Physics has been found as it has been in the construction of viable candidate models in the years before LHC operation.

In confronting New Physics effects on the weak decays of b, c quarks and τ leptons, however, it is crucial to have the appropriate experimental sensitivity. The experiment must measure *CP* asymmetries, rare branching fractions and interesting kinematic distributions to sufficient precision to make manifest the expected effects of New Physics, or to place constraining limits. There is a strong consensus in the community that doing so requires a data sample corresponding to an integrated luminosity of 50 to 100 ab^{-1}. There is also a consensus that a reasonable benchmark for obtaining such a data sample is of the order of five years of running. Meeting both these constraints requires a collider luminosity of 10^{36} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ or more. It is these boundary conditions that set the luminosity of Super$B$.

Reaching this luminosity with a conventional collider design extrapolated from PEP-II or KEKB is difficult; beam currents and thus power consumption are very high, and the resulting detector backgrounds are formidable. The crabbed waist design of Super$B$ provides an elegant solution to the problem; Super$B$ can reach unprecedented luminosity with beam currents and power consumption comparable to those at PEP-II . The test of the crabbed waist concept, presently underway at Frascati, is proceeding very well. More remains to be done, but it has already been demonstrated that beam sizes at collision can be reduced and luminosity thereby increased, with no sacrifice in specific luminosity. A brief report on the crabbed waist experiments is in preparation.

The different peak luminosities of Super$B$ and SuperKEKB result in quite different physics capabilities. Aside from higher luminosity at much lower power consumption, Super$B$ also offers a polarized electron beam and is capable of running at lower center-of-mass energies, both of which significantly increase the physics reach of the project. The rest of this section is devoted to a succinct comparison between the physics capabilities of Super$B$ and SuperKEKB. Any such comparison is perforce difficult, especially when provided by the proponents of one of the proposed projects. To improve the precision of the comparison, let us list a few of the salient characteristics of the two collider projects as proposed

- Super$B$ has an initial luminosity of 10^{36} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and can therefore integrate 15 ab^{-1} in a Snowmass Year of 10^7 seconds. SuperKEKB, as embodied in the KEK Roadmap, will have a luminosity of 2×10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and can thus integrate approximately 2 ab^{-1} in the 200 days of running specified, assuming the same overall efficiency.

- Super$B$ has a proposed upgrade path that can raise the peak luminosity to 2.5×10^{36} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. SuperKEKB has the potential of reaching 8×10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ by 2027, but this substantial upgrade is not included in the KEK Roadmap.

- The power consumption of Super$B$ is 17 MW. The power consumption of SuperKEKB, which uses much higher beam currents to produce smaller luminosity, is much higher. We can find no documentation on the SuperKEKB power consumption at 2×10^{35}, but the consumption at 4×10^{35} is quoted as 60 MW for RF alone.

- These higher currents produce very difficult detector backgrounds at SuperKEKB. While adequate solutions have apparently been found for luminosities in the 10^{35} regime, systems that can accommodate the rates at higher luminosities and are sufficiently radiation-hard have not been developed. With the crabbed waist design at Super$B$ currents are comparable to those at PEP-II and backgrounds are a much less difficult issue. There are luminosity-associated backgrounds as well as current-associated backgrounds; these are currently under detailed study.

- It appears that τ physics will assume great importance as a probe of physics beyond the Standard Model. Super$B$ includes in the baseline design an 85% longitudinally polarized electron beam and spin rotators to facilitate the production of polarized τ pairs. This polarization is the key to the study of the structure of lepton-flavor-violating couplings in τ decay, as well as the search for a τ EDM, or for *CP* violation in τ decay. SuperKEKB does not incorporate a polarized beam.

- The recent observation of large $D^0\overline{D}^0$ mixing raises the exciting possibility of finding *CP* violation in charm decay, which would almost certainly indicate physics beyond the Standard Model. Super$B$ can attack this problem in a comprehensive manner, with high luminosity data sample in the $\Upsilon(4S)$ region and at the $\psi(3770)$ resonance, as the collider is designed to run at lower center-of-mass energies, at reduced luminosity. With very short duration low energy runs, a data sample an order of magnitude greater than that of the final BES-III sample can readily be obtained. SuperKEKB cannot run at low energies.

With these machine parameters and characteristics in mind, we will now compare the physics capabilities of Super$B$ and SuperKEKB in several specific areas:

B Physics

B physics remains a primary objective of Super$B$. With *BABAR* and Belle having clearly established the ability of the CKM phase to account for *CP*-violating asymmetries in tree-level $b \to c\bar{c}s$ decays, the focus shifts to the study of very rare processes. With a SUSY mass scale below 1 TeV, New Physics effects in *CP*-violating asymmetries, in branching fractions and kinematic distributions of penguin-dominated decays and in leptonic decays can indeed be seen, in the five-year Super$B$ data sample. It is highly unlikely that these effects can be studied with the SuperKEKB sample.

Table I shows a quantitative comparison of the two proposals for some of the important observables that will be measured at Super$B$, including all the so-called "golden processes" of Table II (see the following section). We list below some additional comments on the entries of Table I

TABLE I: Comparison of current experimental sensitivities with those expected at the upgraded KEKB (10 ab^{-1}) and at Super$B$ (75 ab^{-1}). Only a small selection of observables are shown. Quoted sensitivities are relative uncertainties if given as a percentage, and absolute uncertainties otherwise. An "X" means that the quantity is not measured at this integrated luminosity. For more details, see text and Refs. [1, 2, 3].

Mode	Sensitivity		
	Current	10 ab^{-1}	75 ab^{-1}
$\mathcal{B}(B \to X_s\gamma)$	7%	5%	3%
$A_{CP}(B \to X_s\gamma)$	0.037	0.01	0.004–0.005
$\mathcal{B}(B^+ \to \tau^+\nu)$	30%	10%	3–4%
$\mathcal{B}(B^+ \to \mu^+\nu)$	X	20%	5–6%
$\mathcal{B}(B \to X_s l^+l^-)$	23%	15%	4–6%
$A_{\mathrm{FB}}(B \to X_s l^+l^-)_{s_0}$	X	30%	4–6%
$\mathcal{B}(B \to K\nu\overline{\nu})$	X	X	16–20%
$S(K^0_S\pi^0\gamma)$	0.24	0.08	0.02–0.03

- The measurements of $\mathcal{B}(B \to X_s\gamma)$ and $\mathcal{B}(B^+ \to \ell^+\nu)$ are particularly important in minimal flavor violation scenarios. It is crucial to be able to search for small deviations from the Standard Model value. Therefore the improvement is sensitivity provided by Super$B$ is highly significant (see Figure 5).

- The statistics of the upgraded KEKB is not sufficient to take advantage of the theoretical cleanliness of several inclusive observables, such as the zero-crossing of the forward-backward asymmetry in $b \to s\ell^+\ell^-$. Results with 10 ab^{-1} would not match the precision from the exclusive mode $B \to K^*\mu^+\mu^-$, which will be measured by LHCb. Furthermore, these exclusive channel measurements will be limited by hadronic uncertainties. Super$B$ can provide a much more precise and theoretically clean measurement using inclusive modes.

- Several interesting rare decay modes, such as $B \to K\nu\bar{\nu}$, cannot be observed with the statistics of the upgraded KEKB, unless dramatic and unexpected New Physics enhancements are present. Preliminary studies are underway on several other channels in this category, such as $B \to \gamma\gamma$ and $B \to$ invisible decays which are sensitive to New Physics models with extra-dimensions.

- Another area for comparison is the phenomenological analysis within the MSSM with generic mass insertion discussed in the Super$B$ CDR. Fig. 1 shows how well the $(\delta_{13})_{LL}$ can be reconstructed at Super$B$ and with the KEKB upgrade. Improvements in lattice QCD performance, as discussed in the Appendix of the CDR, are assumed in both cases. The remarkable difference in sensitivity stems mainly from the different performance in measuring the CKM parameters $\bar{\rho}$ and $\bar{\eta}$.

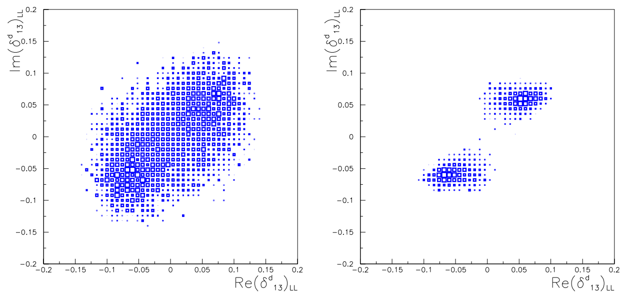

FIG. 1: Determination of the SUSY mass-insertion parameter $(\delta_{13})_{LL}$ at the upgraded KEKB (left) and Super$B$ (right).

Charm Physics

The influence of New Physics on the charm sector is often overlooked. Constraints on flavor-changing neutral currents from new physics in the up quark sector are much weaker than in the down quark sector. Thus high sensitivity studies of rare charm decays offer the possibility of isolating New Physics effects in $D^0\overline{D}^0$ mixing, in *CP* violation and in rare decay branching fractions.

The recent observation of substantial $D^0\overline{D}^0$ mixing raises the very exciting possibility of measuring *CP* violation in charm decays. Many of the most sensitive measurements remain statistics limited even with Super$B$ - size data samples, providing a substantial motivation for gathering a sample many times that possible with the KEKB upgrade.

In several specific cases, *CP* violation in mixing can be studied more precisely by taking advantage of the clean environment provided by exclusive $D^0\overline{D}^0$ production at the $\psi(3770)$ resonance. We have therefore included in the Super$B$ design the unique capability of running at this center-of mass-energy. Long data-taking runs are not required; a run of two months duration at the $\psi(3770)$ would yield a data sample an order of magnitude larger than the total BES-III sample at that energy.

Tau Physics

It is not unlikely that the most exciting results on New Physics in the flavor sector at Super$B$ will be found in τ decays. With 75 ab^{-1} Super$B$ can cover a significant portion of the parameter space of most New Physics scenarios predictions for lepton flavor violation (LFV) in tau decays.

The sensitivity in radiative processes such as $\mathcal{B}(\tau \to \mu\gamma)$ (2×10^{-9}) and in $\mathcal{B}(\tau \to \mu\mu\mu)$ decays (2×10^{-10}) gives Super$B$ a real chance to observe these LFV decays. These measurements are complementary to searches for $\mu \to e\gamma$ decay. In fact, the ratio $\mathcal{B}(\tau \to \mu\gamma)/\mathcal{B}(\mu \to e\gamma)$ is an important diagnostic of SUSY-breaking scenarios. If LFV decays such us $\tau \to \mu\gamma$ and $\tau \to \mu\mu\mu$ are found, the polarized electron beam of Super$B$ provides us with a means of determining the helicity structure of the LFV coupling, a most exciting prospect. The polarized beam also provides a novel additional handle on backgrounds to these rare processes.

The longitudinally polarized high energy ring electron beam, which is a unique feature of Super$B$, is also the key to searching for *CP* violation in tau production or decay. An asymmetry in production would signal a τ EDM, with a sensitivity of $\sim 10^{-19}$ $e$cm, while an unexpected *CP*-violating asymmetry in decay would be a clear signature of New Physics.

The polarized beam and the ability to procure a data sample of sufficient size to find lepton flavor-violating events, as opposed to setting limits on LFV processes are unique to Super$B$.

Spectroscopy

One of the most surprising results of the past decade has been the plethora of new states with no ready quark model explanation by the B Factories and the Tevatron. These states clearly indicate the existence of exotic combinations of quarks and gluons into hybrids, molecules or tetraquarks.

These studies, which promise to greatly enhance our understanding of the non-perturbative regime of QCD, are at an early stage. Many new states have been found. These may be combinations involving light quarks or charmed quarks, but only in the case of the $X(3872)$ have there been observations of more than a single decay channel. It is crucial to increase the available statistics by of the order of one hundred-fold in order to facilitate searches for additional decay modes. In the case of $X(3872)$ state, for example, it is particularly critical to observe both decays to charmonium and to D or D_s^+ pairs, the latter having very small branching fractions. It is also important to provide enhanced sensitivity to search for additional states, such as the neutral partners of the $Z(4430)$.

Bottomonium studies are quite challenging, since the expected but not yet observed states are often broad and have many decay channels, thus requiring a large data sample. Leptonic decays of bottomonium states also provide, through lepton universality tests, a unique window on New Physics.

Data samples adequate for these studies, which in some cases require dedicated runs of relatively short duration, in both the 4 and 10 GeV regions, are obtainable only at Super$B$.

[1] M. Bona *et al.*, arXiv:0709.0451 [hep-ex].
[2] T. Browder, M. Ciuchini, T. Gershon, M. Hazumi, T. Hurth, Y. Okada and A. Stocchi, JHEP **0802** (2008) 110 [arXiv:0710.3799 [hep-ph]].
[3] T. E. Browder, T. Gershon, D. Pirjol, A. Soni and J. Zupan, arXiv:0802.3201 [hep-ph].

Charm Physics

New Physics, in general, generates flavor-changing neutral currents (FCNC). Those could be much less suppressed in the up-type than the down-type quark sectors. Among the up-type quarks, only charm allows the *full* range of probes for FCNC, and thus New Physics, in oscillation phenomena, in particular those involving *CP* violation. The Standard Model makes nontrivial predictions for *CP* violation in charm transitions: *direct CP* violation should occur only in Cabibbo-suppressed modes at an observable level $\sim \mathcal{O}(10^{-3})$.

The recent evidence for $D^0\overline{D}^0$ oscillations – with x_D, $y_D \simeq 0.005$–0.01 – does not prove the presence of New Physics. However it greatly widens the stage on which *CP* violation can appear as a manifestation of New Physics. Within the Standard Model, time dependent *CP* asymmetries could reach the 10^{-5} [10^{-4}] level in Cabibbo-allowed and once [doubly]-suppressed modes, whereas New Physics could enhance these asymmetries by almost three orders of magnitude. A search for New Physics should then aim at sensitivity levels of $\mathcal{O}(10^{-3})$ or better and $\mathcal{O}(10^{-2})$ or better in Cabibbo-allowed or once-suppressed nonleptonic channels and in doubly Cabibbo-suppressed or wrong-sign semileptonic modes, respectively. Signals for New Physics might actually be clearer in D than in B decays: for while *conventional* New Physics scenarios tend to create larger effects in the latter than the former, those signals must also contend with a much larger Standard Model "background" in the latter than the former.

These searches can be done at the $\Upsilon(4S)$ using D^* tagging and tracking of the D production and decay vertices. Relatively short runs in the charm threshold region can provide unique and important information on strong phases needed for a proper interpretation of results obtained in $\Upsilon(4S)$ runs. They might reveal significantly enhanced effects that can be seen only in $e^+e^- \to D^0\overline{D}^0$ exclusive production.

1. New Physics in charm decays: mainly *CP* violation

The landscape

New Physics in general generates flavor changing neutral currents (FCNC). The Standard Model had to be crafted carefully to suppress them in the strangeness sector down to the observed level. Those FCNC could actually be much less suppressed in the up-type than the down-type quark sectors. Among the up-type quarks, only charm allows the *full* range of probes for FCNC, and thus, New Physics in oscillation phenomena, in particular those involving *CP* violation: (i) Top quarks decay before they can hadronize; without top hadrons T^0 oscillations cannot occur. Furthermore the sheer size of phase space in top decays greatly reduces the coherence between different amplitudes needed to make direct *CP* violation observable. (ii) Hadrons built with u and $\bar{u}$ quarks, like the π^0 and η, are their own antiparticle; thus there can be no $\pi^0 - \pi^0$ etc. oscillations as a matter of principle. They also decay very rapidly. In addition, they possess so few decay channels that *CPT* invariance largely rules out *CP* asymmetries in their decays.

Strong evidence for $D^0\overline{D}^0$ oscillations has been recently found [1]. The most recent averages for the mixing parameters are

$$x_D \equiv \frac{\Delta M_D}{\bar{\Gamma}_D} = 0.0097^{+0.0027}_{-0.0029} \,, \qquad (8)$$

$$y_D \equiv \frac{\Delta \Gamma_D}{2\bar{\Gamma}_D} = 0.0078^{+0.0018}_{-0.0019} \,. \qquad (9)$$

According to our present understanding – or lack thereof – these quantities could be produced by Standard Model dynamics, yet x_D could still harbour substantial contributions from New Physics. It will require a theoretical breakthrough to resolve this ambiguity in the interpretation of the data.

We will be on much firmer ground in interpreting *CP* asymmetries. For on one hand, $D^0\overline{D}^0$ oscillations greatly widen the stage on which *CP* violation can appear as a manifestation of New Physics; on the other hand, the Standard Model makes nontrivial predictions for *CP* violation in charm transitions. In CKM dynamics there is a weak phase in $\Delta C = 1$ transitions entering (in the Wolfenstein representation) through V_{cs}, yet it is highly diluted:

$$V_{cs} \simeq 1 - \frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 \simeq 0.97 - 6 \cdot 10^{-4} i \,. \qquad (10)$$

Furthermore two different, yet coherent, amplitudes must contribute to the same channel to produce a direct *CP* asymmetry. Within the Standard Model this can happen at an observable level only in Cabibbo-suppressed modes – even in these channels, *CP* asymmetries can be no more than $\mathcal{O}(10^{-3})$. This means that any observation of direct *CP* violation in Cabibbo-allowed or doubly-suppressed channel establishes the intervention of New Physics. The only exception to this general rule is provided by modes like $D^{\pm} \to K_S\pi^{\pm}$, where one becomes sensitive to (i) the interference between $D^+ \to \bar{K}^0\pi^+$ and $D^+ \to K^0\pi^+$ and (ii) the slight *CP* impurity in the K_S state. The latter effect dominates, inducing a *CP* asymmetry of $3.3 \cdot 10^{-3}$.

With x_D, $y_D \sim 0.005 - 0.01$ the possibilities for *CP* asymmetries proliferate. In addition to the aforementioned direct *CP* violation one can encounter *time dependent CP* asymmetries. The latter can be induced by *CP* violation in $\Delta C = 2$ dynamics, or even by CP-conserving contributions to the latter that can make the weak phase in a $\Delta C = 1$ amplitude observable. In both cases an educated Standard Model guess points to time-dependent CP asymmetries of order $10^{-3} \sim x_D \sim 10^{-5}$.

The menu

There are three classes of CP asymmetries:

1. Direct CP violation can lead to a difference in the rates for $D \to f$ and $\bar{D} \to \bar{f}$:

$$|A_f| \equiv |A(D \to f)| \neq |\bar{A}_{\bar{f}}| \equiv |A(\bar{D} \to \bar{f})| \ . \tag{11}$$

   Strong phase shifts due to final state interactions, are required to produce such asymmetries in partial widths. Since charm decays proceed in an environment populated by many resonances, this requirement will not, in general, represent a limiting factor; it might make, however, the interpretation of signals a more complex task.

2. Indirect CP violation – *i.e.*, that which occurs only in $\Delta C = 2$ transitions. One measure for it is provided by

$$|q/p| \sim 1 + \frac{\Delta\Gamma_D}{\Delta M_D} \sin\phi_{\rm weak} \neq 1 \ . \tag{12}$$

   The same educated Standard Model guess mentioned above points to $|1 - |q/p|| \sim \text{several} \times 10^{-4}$. One should note here that the factor $\Delta\Gamma_D/\Delta M_D$ apparently is close to unity and thus provides no suppression to this observable, unlike the case of B^0 mesons. Thus one has practically undiluted access to a weak phase due to the intervention of New Physics in $D^0\overline{D}^0$ oscillations. As discussed below, such an asymmetry can be searched for cleanly in semileptonic decays of neutral D mesons. While we already know the ratio of wrong-sign leptons is small, their CP asymmetry could conceivably be as large as several percent! While the rate of wrong-sign leptons oscillates with time, the CP asymmetry does not.

3. CP violation in the interference between mixing and decay: In qualitative analogy to $B_d \to J/\psi K^0_S$, a time-dependent CP asymmetry can arise due to an interference between an oscillation and decay amplitude:

$$\phi_f = \arg\left(\frac{q}{p}\frac{\bar{A}_{\bar{f}}}{A_f}\right) \neq 0 \ . \tag{13}$$

   A CP asymmetry generated by $\phi_f \neq 0$ is also proportional to $\sin\Delta M_D t \simeq x_D(t/\tau_D)$ and thus effectively bounded by x_D; *i.e.*, the present lack of a signal for a time-dependent CP asymmetry in $D^0 \to K^+K^-$ on about the 1% level is not telling at all, in view of $x_D \leq 1\%$. Yet any improvement in experimental sensitivity could reveal a genuine signal.

Searching for CP violation in charm decays is not a "wild goose chase". We know that baryogenesis requires the presence of CP-violating New Physics. Signals for such New Physics might actually be clearer in D than in B decays: for while *conventional* New Physics scenarios tend to create larger effects in the latter than the former, those signals would also have to contend with a much larger Standard Model "background" in the latter than the former; *i.e.*, the theoretical "signal-to-noise" ratio could be better in charm decays.

The required searches can be undertaken very profitably in runs at the $\Upsilon(4S)$ by tagging the D^0 flavor at production time using $D^{*+} \to D^0\pi^+$ decays and reconstructing the proper decay time and its error. This is done by tracking the D production and decay vertices with constraints provided by the position and size of the tight e^+e^- interaction region. Relatively short runs in the charm threshold region, *e.g.*, $\psi(3770)$, can provide unique and important information on strong phases needed for a proper interpretation of results obtained in $\Upsilon(4S)$ runs. In the latter D^0 flavor tagging exploits the quantum correlations at $\psi(3770)$; the poor proper time resolution (about the D^0 lifetime) will make time-dependent measurements challenging.

In summary: Comprehensive and precise studies of CP invariance in charm decays provide sensitive probes for the presence of New Physics.

- 'Comprehensive' means that one analyses non-leptonic as well as semileptonic channels on all Cabibbo levels in as many modes as possible; *i.e.*, including final states containing neutrals.

- 'Precise' means that one achieves sensitivity levels of 10^{-3} or better.

Charm decays provide another highly promising avenue towards finding CP violation, namely in final state distributions, rather than in partial widths considered so far. This issue will be addressed separately below.

Side remarks on rare decays

The obvious motivation for measuring the branching fractions for $D^+/D_s^+ \to \mu^+\nu$, $\tau^+\nu$ decays is to extract the decay constants f_D and f_{D_s} in order to compare them with lattice QCD calculations and, hopefully, to validate these calculations with high accuracy. A more ambitious goal is to probe for contributions from a charged Higgs field, as an indication of New Physics.

The mode $D^0 \rightarrow \mu^+\mu^-$ arises within the Standard Model mainly through a two photon intermediate state – $D^0 \rightarrow \gamma^*\gamma^* \rightarrow \mu^+\mu^-$ – and can reach the 10^{-12} level. With the present experimental upper bound of 1.3×10^{-6} there is a search window for New Physics of six orders of magnitude. Multi-Higgs models or SUSY models with R parity breaking could conceivably induce a signal in a range as "large" as few$\times 10^{-8}$ and 10^{-6}, respectively.

Channels such as $D \rightarrow \gamma h$, l^+l^-h, $l^+l^-h_1h_2$, with h denoting a hadron, receive relatively sizable contributions within the Standard Model from long distance dynamics. Thus a search for New Physics contributions are not very promising there, unless one can measure precisely the lepton spectra in the final states.

One can probe a rather exotic variant of New Physics by searching for two-body modes $D^+ \rightarrow K^+/\pi^+ f$; the charge neutral f denotes a 'familon', which could arise as the Nambu-Goldstone boson resulting from the spontaneous breakdown of a global family symmetry. It has been searched for in K^+ and B^+ decays, but apparently not yet in D^+ decays.

2. $D^0\overline{D}^0$ mixing at $\Upsilon(4S)$ and $\psi(3770)$ energies

The parameters describing charm mixing can be measured in time-dependent studies of D mesons or with time-integrated observables of D mesons produced coherently near charm threshold.

The time-dependent $D^0\overline{D}^0$ mixing formalism and a summary of recent experimental results can be found in Ref. [2]. Many different charm decay modes can be used to search for charm mixing.

- The appearance of "wrong-sign" kaons in semileptonic decays would provide direct evidence for $D^0\overline{D}^0$ oscillations (or another process of beyond Standard Model origin).

- The most precise limits are obtained by exploiting the time-dependence of D decays produced in e^+e^- collision near 10 GeV.

  – The wrong-sign hadronic decay $D^0 \rightarrow K^+\pi^-$ is sensitive to linear combinations of the mass and lifetime differences, denoted x'^2 and y'. The relation of these parameters to x_D and y_D is controlled by a strong phase difference $\delta_{K\pi}$.

  – Direct measurements of x_D and y_D independent of unknown strong interaction phases can also be made using time-dependent studies of amplitudes present in multi-body decays of the D^0, for example, $D^0 \rightarrow K^0_S\pi^+\pi^-$.

  – Direct evidence of y_D can also appear through lifetime differences between decays to CP eigenstates. The measured quantity in this case y_{CP}, is equivalent to y_D in the absence of CP violation.

- Another approach is to study quantum correlations near charm threshold [3] in $e^+e^- \rightarrow D^0\overline{D}^0(\pi^0)$ and $e^+e^- \rightarrow D^0\overline{D}^0\gamma(\pi^0)$ decays, which yield C-odd and C-even $D^0\overline{D}^0$ pairs, respectively. Taken together, the time-integrated decay rate to semileptonic, $K\pi$, and CP eigenstates provide sensitivity to x_D, y_D, and $\cos\delta_{K\pi}$.

Several recent results provide evidence that charm mixing is at the upper end of the range of Standard Model predictions.

BABAR [4] and CDF [5] find evidence for oscillations in $D^0 \rightarrow K^+\pi^-$, with 3.9σ (ΔLog$\mathcal{L}$) and 3.8σ (Bayesian), respectively. The most precise measurement is from Belle which excludes $x'^2 = y' = 0$ at 2.1σ [6] (Feldman-Cousins).

Belle [7] and *BABAR* [8] see 3.2σ and 3σ effects, respectively, for y_{CP} in $D^0 \rightarrow K^+K^-$. The most precise measurement of y_D is in $D^0 \rightarrow K^0_S\pi^+\pi^-$ from Belle [9] and is only 1.2σ significant. From the same analysis, Belle also reports a 2.4σ significant result for x_D. The current situation would greatly benefit from more precise knowledge of the strong phase difference δ; this would allow one to unfold x_D and y_D from the $D^0 \rightarrow K^+\pi^-$ measurements of x'^2 and y', and directly compare them to the $D^0 \rightarrow K^0_S\pi^+\pi^-$ results.

All mixing measurements can be combined to obtain world average (WA) values for x and y. The Heavy Flavor Averaging Group (HFAG) has done such a combination [10, 11]. The resulting 1σ-5σ contours are shown in Fig. 10 and Fig. 11. The fits exclude the no-mixing point ($x = y = 0$) at 6.7σ for both the no CP violation scenario and the case allowing for CP violation. One-dimensional likelihood functions for parameters are obtained by allowing, for any value of the parameter, all other fit parameters to take their preferred values. The resulting likelihood functions give central values, 68.3% C.L. intervals, and 95% C.L. intervals as listed in Table IV.

From the results of the HFAG averaging, we can conclude the following:

- The experimental data consistently indicates that D^0 mesons undergo mixing. The effect is presumably dominated by long-distance processes, and unless $|x| \gg |y|$, it may be difficult to identify New Physics from mixing alone.

- Since y_{CP} is positive, the CP-even state is shorter-lived, as in the K^0-$\overline{K}^0$ system. However, since x appears to be positive, the CP-even state is heavier, unlike in the K^0-$\overline{K}^0$ system.

- There is no evidence yet for CP violation in the D^0-$\overline{D}^0$ system.

TABLE IV: HFAG Charm Mixing Averages.

Fit	Parameter	HFAG Average	95% C.L. Interval
CPV	$x(\%)$	$0.97^{+0.27}_{-0.29}$	(0.39:1.48)
	$y(\%)$	$0.78^{+0.18}_{-0.19}$	(0.41:1.13)
	$R_D(\%)$	0.335 ± 0.009	(0.316:0.353)
	$\delta_{K\pi}(^\circ)$	$21.9^{+11.5}_{-12.5}$	(-6.3:44.6)
	$\delta_{K\pi\pi^0}(^\circ)$	$32.4^{+25.1}_{-25.8}$	(-20.3:82.7)
	$A_D(\%)$	-2.2 ± 2.5	(-7.10:2.67)
	$\|q/p\|$	$0.86^{+0.18}_{-0.15}$	(0.59:1.23)
	$\phi(^\circ)$	$-9.6^{+8.3}_{-9.5}$	(-30.3:6.5)

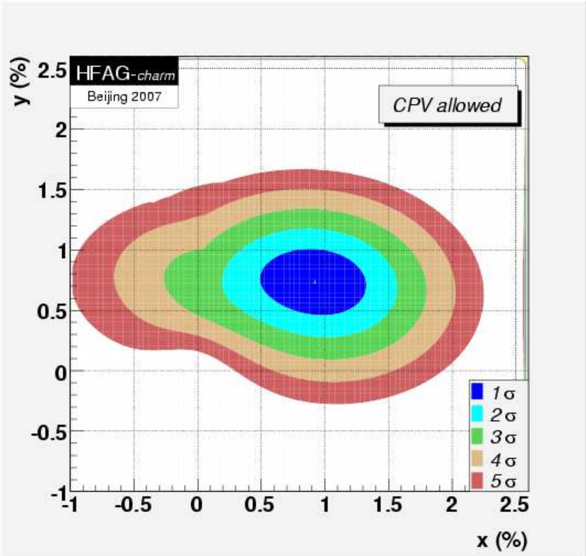

FIG. 10: Two-dimensional 1σ-5σ contours for (x, y), obtained from a global fit to the measured observables for x, y, $|q/p|$, Arg(q/p), $\delta_{K\pi}$, $\delta_{K\pi\pi^0}$, and R_D from measurements of $D^0 \to K^+\ell\nu$, $D^0 \to h^+h^-$, $D^0 \to K^+\pi^-$, $D^0 \to K^+\pi^-\pi^0$, $D^0 \to K^+\pi^-\pi^+\pi^-$, and $D^0 \to K^0_S\pi^+\pi^-$ decays, and double-tagged branching fractions measured at the $\psi(3770)$ resonance (from HFAG [12]).

The interpretation of the new results in terms of New Physics is inconclusive. It is not yet clear whether the effect is caused by $x_D \neq 0$ or $y_D \neq 0$ or both, although the latter is favored, as shown in Table IV. Furthermore, there is no single 5σ observation of charm mixing nor is one anticipated from the current B Factories. This situation will be remedied by results anticipated from Super$B$. Table V shows the sensitivity to mixing in $D^0 \to K^+\pi^-$, K^+K^-, and $K^0_S\pi^+\pi^-$ channels from the $\Upsilon(4S)$ data is in excess of 5σ if the lifetime and mass differences in the D^0 system lie at the upper end of the range of Standard Model predictions.

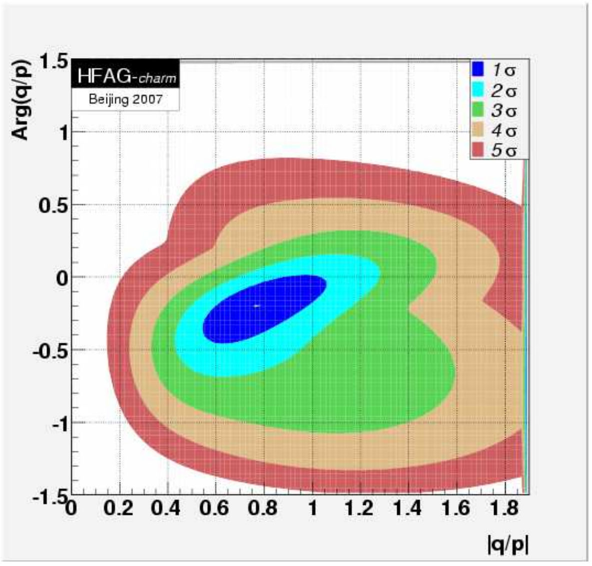

FIG. 11: Two-dimensional 1σ-5σ contours for $(|q/p|$, Arg$(q/p))$, obtained from a global fit to the measured observables for x, y, $|q/p|$, Arg(q/p), $\delta_{K\pi}$, $\delta_{K\pi\pi^0}$, and R_D from measurements of $D^0 \to K^+\ell\nu$, $D^0 \to h^+h^-$, $D^0 \to K^+\pi^-$, $D^0 \to K^+\pi^-\pi^0$, $D^0 \to K^+\pi^-\pi^+\pi^-$, and $D^0 \to K^0_S\pi^+\pi^-$ decays, and double-tagged branching fractions measured at the $\psi(3770)$ resonance (from HFAG [12]).

Table V also shows the sensitivity to mixing from two months of running at charm threshold. The sensitivity to the mixing parameters is comparable to five years at $\Upsilon(4S)$, with different sources of systematic uncertainties. The $\psi(3770)$ data provides unique sensitivity to $\cos\delta_{K\pi}$. Although $\cos\delta_{K\pi}$ can be determined from a global fit to $\Upsilon(4S)$ results, the direct measurement from $\psi(3770)$ data allow y' and x'^2 determined from $D^0 \to K^+\pi^-$ to contribute to the precision determination of x and y.

Although the D mesons from $\psi(3770)$ decay are produced nearly at rest in the center-of-mass frame, the asymmetric e^+e^- collisions make time-dependent mixing analyses possible. However, since the production rate of charm during threshold running and $\Upsilon(4S)$ running is comparable, the statistical power of the time-dependent analyses near threshold is small.

A serious limitation in the interpretation of charm oscillations in terms of New Physics is the theoretical uncertainty on the Standard Model prediction. However, the recent evidence for oscillations opens the window to searches for CP asymmetries that do provide unequivocal New Physics signals. The sensitivity to these New Physics signals is shown in Fig. 12.

TABLE V: Approximate expected precision (σ) on the measured quantities using methods described in the text for the integrated luminosity of 75 ab^{-1} at Super$B$ at 10 GeV and 300 fb^{-1} ($\sim$ two months) running at charm threshold.

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\lvert q/p\rvert$	3×10^{-2}	
	ϕ	2°	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2)\times10^{-5}$
	y		$(1-2)\times10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

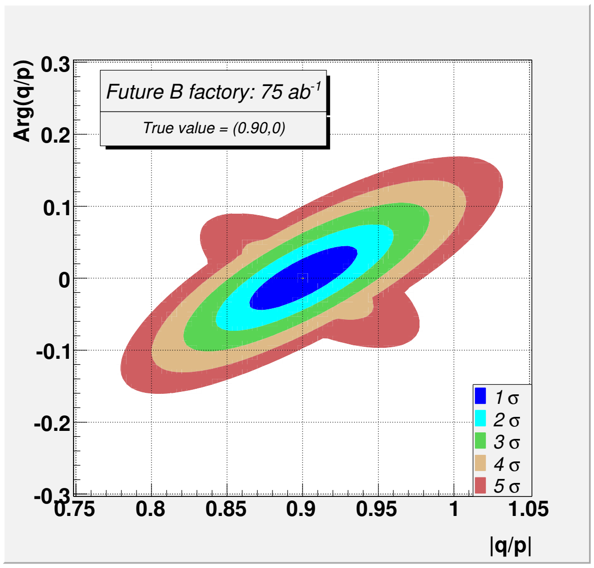

FIG. 12: Projected two-dimensional 1σ-5σ contours with 75 ab^{-1} for ($|q/p|$, Arg(q/p)), obtained from a global fit to the observables for x, y, $|q/p|$, Arg(q/p), $\delta_{K\pi}$, $\delta_{K\pi\pi^0}$, and R_D from the sensitivity estimates in Table V. A "true value" of $|q/p| = 0.90$, Arg$(q/p) = 0$ is assumed.

3. *CP* violation

Direct *CP* violation

Searches for *CP* violation in $\Delta C = 1$ transitions can be performed by measuring asymmetries in the partial widths or in final state distributions.

Golden modes are the Cabibbo-suppressed decays $D^0 \to h^+h^-$, $h = K, \pi$, and the doubly Cabibbo-suppressed decay $D^0 \to K^+\pi^-$. These studies can be performed either time-integrated or by analyzing the time dependence of the D^0 and $\overline{D}^0$ decay rates, although in both cases time-integrated asymmetries are measured. Data at the $\Upsilon(4S)$ provides the largest data sample with excellent purities (as large as $\sim$ 99%). The contamination from $B\overline{B}$ decays can be virtually eliminated by imposing a 2.5 GeV/c cut on the D momentum in the center-of-mass frame, which preserves more than 85% of signal events.

The most precise analysis to date [13] compares time-integrated $D^0 \to h^+h^-$ and $\overline{D}^0 \to h^+h^-$ rates, $a^{hh}_{CP} = [N_{D^0} - N_{\overline{D}^0}]/[N_{D^0} + N_{\overline{D}^0}]$, where N_{D^0} ($N_{\overline{D}^0}$) is the number of D^0 ($\overline{D}^0$) mesons decaying into h^+h^- final state. In this construction, all *CP* violation contributions, direct and indirect are present. Direct *CP* violation in one or both modes would be signaled by a non-vanishing difference between the asymmetries for $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$, $a^{KK}_{CP} \neq a^{\pi\pi}_{CP}$. There are two main experimental challenges in these measurements. Firstly, the experimental asymmetry in D^0 flavor tagging. This asymmetry is measured by determining the relative detection efficiency for soft pions in data, using the Cabibbo-allowed decay $D^0 \to K^-\pi^-$ with (tagged) and without (non-tagged) soft-pion flavor tagging, as a function of the pion-momentum and the polar angle in the lab frame. For the azimuthal dependence, an integrated scale factor is sufficient, since charm production is uniform in azimuth. Since the reconstructed modes are *CP*-even, this is the only detector asymmetry. Secondly, the forward-backward (FB) asymmetry in $c\bar{c}$ production at $\Upsilon(4S)$, a consequence of the γ/Z^0 interference and higher order QED corrections (both at the percent level at this energy), coupled with the asymmetric acceptance of the detector, which produces a difference in the number of reconstructed D^0 and $\bar{D}^0$ events. This effect is directly measured by determining the number of D^0 and $\overline{D}^0$ events (after soft pion asymmetry correction) as a function of $\cos\theta^{CM}_D$ and decomposing these events into even (representing the *CP* asymmetry and independent of $|\cos\theta^{CM}_D|$) and odd (representing the FB production asymmetry) parts. The associated systematic uncertainties are therefore not a limiting factor, and are mostly statistical in nature. Other potential sources of uncertainty are highly suppressed because the final states are reconstructed identically for D^0 and $\bar{D}^0$. With a Super$B$ data sample of 75 ab^{-1}, sensitivities at 3×10^{-4} and 4×10^{-4} level, for a^{KK}_{CP} and $a^{\pi\pi}_{CP}$ respectively, are foreseen.

A time-dependent D-mixing analysis of DCS (wrong sign) $D^0 \to K^+\pi^-$ and $\overline{D}^0 \to K^-\pi^+$ decays can be used to separate the contributions of DCS decays from $D^0\overline{D}^0$ mixing, separately for D^0 and $\overline{D}^0$. A direct *CP* asymmetry can then be constructed from the difference of DCS D^0 and $\overline{D}^0$ decays, $A_D = (R_{D^0} - R_{\overline{D}^0})/(R_{D^0} + R_{\overline{D}^0})$, where $R_{D^0}(R_{\overline{D}^0})$ is the D^0 ($\overline{D}^0$) DCS rate. The main experimental difficulties in this analysis are accurate proper time reconstruction and calibration, together with asymmetry in the D^0 flavor tagging and the modeling of the differences between K^+ and K^- absorption in the detector. At Super$B$, the much smaller luminous region and the significantly enhanced vertexing capabilities provide proper time significances at the 10σ level (3-4 times better than in *BABAR* [14], with decay length resolution of about 80 μm, $\sim 3\sigma$), significantly reducing the systematic uncertainties associated with the modeling of the long decay time component and possible biases. Systematic uncertainties related to the asymmetry in the soft-pion tagging can be keep under control using a similar procedure to that outlined above. Corrections due to the FB production asymmetry and kaon hadronic interactions can be performed relying mainly on data, through untagged $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$ decays measured as a function of $\cos\theta_D^{CM}$. Scaling the statistical uncertainty from the *BABAR* analysis to 75 ab^{-1} we obtain a sensitivity on A_D of 4×10^{-3}. To reach or improve this sensitivity level, systematic uncertainties, currently 15×10^{-3}, will have to be reduced by a factor of five or better, which is feasible since the uncertainty of the systematic corrections scale with the size of the data sample.

For asymmetries in final state distributions, the simplest way is to compare *CP* conjugate Dalitz plots for 3-body decays. Different regions of the Dalitz plot may exhibit *CP* asymmetries of varying signs that largely cancel out when one integrates over the entire phase space, therefore subdomains of the Dalitz plot could contain significantly larger *CP* asymmetries than the whole phase space. Since understanding the dynamics is not an easy goal to achieve, one could try up to four strategies, three of which are model-independent. First, quantify differences between the D^0 and $\overline{D}^0$ Dalitz plots in two dimensions. Secondly, look for differences in the angular moments of D^0 and $\overline{D}^0$ intensity distributions. Thirdly, in a model-dependent approach, look for *CP* asymmetries in the amplitudes describing intermediate states in the D^0 and $\overline{D}^0$ decays. Finally, look for the phase-space integrated asymmetry. Asymmetries in the D^0 flavor assignment and FB production asymmetries only affect the last method, and can be kept under control, as discussed above. From the pioneering *BABAR* analysis using $D^0 \to \pi^-\pi^+\pi^0$ and $D^0 \to K^-K^+\pi^0$ [15], sensitivities at 3×10^{-4} and 9×10^{-4} level, respectively, are anticipated.

For more complex final states other probes have to be employed. A golden example is discussed below.

Indirect *CP* violation at the $\Upsilon(4S)$ and $\psi(3770)$

CP violation in mixing can be investigated from the data taken at the $\Upsilon(4S)$ and at the $\psi(3770)$ resonances in semi-leptonic transitions. In both cases one measures an asymmetry from events in which the D^0 or $\bar{D}^0$, previously flavor tagged, has oscillated (signaled as a wrong sign decay),

$$a_{SL} = \frac{N^{--}(t) - N^{++}(t)}{N^{--}(t) + N^{++}(t)} = \frac{|q|^4 - |p|^4}{|q|^4 + |p|^4}\ , \qquad (14)$$

where N^{--} (N^{--}) represents the number of $D^0 \to \ell^-\nu X$ ($\overline{D}^0 \to \ell^+\nu X$) decays when the other D meson was tagged as D^0 ($\overline{D}^0$) at production time. Data at the $\psi(3770)$ benefit from a very clean environment with almost no background. Several decay channels can be exclusively reconstructed to increase the asymmetry sensitivity. Considering the D^0 and $\bar{D}^0$ both decaying into $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K^-e^+\nu$, $K^-\mu^+\nu$, $K^{*-}e^+\nu$, $K^{*-}\mu^+\nu$, $K^{*-}e^+\nu$, $\pi^-e^+\nu$, $\pi^-\mu^+\nu$, K^-K^+ and $\pi^-\pi^+$, and using recent results for the $D^0\overline{D}^0$ mixing parameters x and y [1], a sensitivity to *CP* violation of 2.5% in one month of running at threshold is expected. The quantum correlation ensures that the same-sign combinations can only be due to mixing; thus hadronic modes can be treated like the semileptonic decays (no DCS contribution). Control of systematic uncertainties is expected at the percent level, dominated by channels with π^0 and ν particles [16, 17]. Missing mass techniques with full reconstruction of $\psi(3770) \to D\bar{D}$ events, omitting one of the product particles, can be used to evaluate the accuracy in the reconstruction. Large control samples of decay channels with unequivocal particle content like $D^0 \to K^0_s\pi^+\pi^-$ and $D^+ \to K^-\pi^+\pi^+$ will reduce the uncertainty on PID efficiencies. Other sources of systematic uncertainties will also benefit from the precise measurement of the beam energy and improved detector performance.

At the $\Upsilon(4S)$, the soft pion coming from D^* decays ($D^{*+} \to D^0\pi^+$) can be used to tag the flavor of the D^0. The measurement of wrong sign leptons in semileptonic decays then provides a clear signature of a mixed event. Data are taken from the continuum. Background events from B decays can be reduced by imposing a 2.5 GeV/c cut on the D momentum. With this method, the statistical sensitivity in the decay asymmetries would reach the 1% level in one year of data taking. Systematic uncertainties are foreseen to arise from the control of backgrounds and PID management (mainly lepton identification), which will benefit from the vertex capabilities to suppress the background and large control samples to study the PID.

*CP*V in the interference of mixing and decay

CP violation in the interplay of $\Delta C = 1, 2$ dynamics can be searched for through time-dependent analyses of $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays. *CP* violation and $D^0\overline{D}^0$ mixing alter the decay time distribution of D^0 and $\overline{D}^0$ mesons that decay into final states of specific *CP*, and a time-dependent analysis of the tagged D^0

and $\overline{D}^0$ intensities allows a measurement of the ϕ_f. To a good approximation, these decay time distributions can be treated as exponential, with effective lifetimes $\tau^+_{hh}$and τ^-_{hh}.

The effective lifetimes can be combined into the quantities y_{CP} and ΔY:

$$y_{CP} = \frac{\tau_{K\pi}}{\langle\tau_{hh}\rangle} - 1 \ , \quad \Delta Y = \frac{\tau_{K\pi}}{\langle\tau_{hh}\rangle} A_\tau \ ,$$

where $\langle\tau_{hh}\rangle = (\tau^+_{hh} + \tau^-_{hh})/2$ and $A_\tau = (\tau^+_{hh} - \tau^-_{hh})/(\tau^+_{hh} + \tau^-_{hh})$. The golden mode is $D^0 \to K^+K^-$, since the combinatorial background is $\sim 10\times$ smaller than in the $\pi^+\pi^-$ channel, and the selected sample is $\sim 2\times$ larger. $D^0 \to K^0_S\phi$ instead has a large ($\sim$ 10%) contribution from S wave, so it is better analyzed using the Dalitz plot technique (see Sec. 4).

The Super$B$ sensitivity to y_{CP} and ΔY in the KK and $\pi\pi$ modes can be extrapolated from the current *BABAR* analysis [13], assuming that the systematic errors can be kept under control. Provided that *CP* violation in mixing is small, the sensitivity to the *CP*-violating phase is dominated by the first term in the expression for y_{CP} and ΔY.

$$2y_{CP} = (|q/p| + |p/q|)y\cos\phi - (|q/p| - |p/q|)x\sin\phi,$$
$$2\Delta Y = (|q/p| - |p/q|)y\cos\phi - (|q/p| + |p/q|)x\sin\phi,$$

therefore we can estimate the sensitivity as $\delta(\cos\phi) \simeq \delta(y_{CP})/y \simeq 3\times10^{-4}/y$, $\delta(\sin\phi) \simeq \delta(\Delta Y)/x \simeq 3\times10^{-4}/x$.

Most of the systematic errors affecting the signal cancel in the lifetime ratio. The errors associated with the background are unrelated between D^0 and $\overline{D}^0$ and do not cancel; however they do improve with statistics. In addition, the superior resolution of the vertex detector will further reduce the systematic errors associated with the position measurement. We therefore expect that the systematic errors can be kept under control.

One underlying assumption in the recent *BABAR* analysis [13] is that the resolution bias is the same for all the channels ($K\pi$, KK, $\pi\pi$) and does not depend on the polar angle θ. This could introduce a bias in the measurements, because of the different polar angle acceptance in the various channels. With a higher statistics sample, however, this systematic effect can be overcome by splitting the sample into polar angle (or other variable) intervals. The production asymmetry is not important with *BABAR* statistics, but could become significant at sensitivities of the order of few $\times10^{-4}$. However this can be handled using control samples, such as the untagged D^0, which have about 5 times more events (assuming D^0 and D^* have the same asymmetry), as discussed in Sec. 3.

T odd correlations

All *CP* asymmetries observed so far have surfaced in partial widths – with one notable exception: the forward-backward asymmetry $\langle A\rangle$ in the $\pi^+\pi^-$ and e^+e^- planes in $K_L \to \pi^+\pi^-e^+e^-$. $\langle A\rangle \simeq 14\%$ had been predicted – and confirmed by experiment – as being driven by the indirect *CP* impurity $|\eta_{+-}| \simeq 0.23\%$. The reason for this magnification by two orders of magnitude is well understood: $\langle A\rangle$ is induced by the interference between a *CP*-violating and a *CP*-conserving amplitude, both of which are suppressed, albeit for different reasons. This explains why the enhancement of the *CP* asymmetry comes at the expense of the branching ratio, which is about $3\cdot10^{-7}$; *i.e.*, one has traded branching fraction for the size of the asymmetry.

It is possible that a similar effect and enhancement occurs in the analogous mode $D_L \to K^+K^-\mu^+\mu^-$, where D_L denotes the "long-lived" neutral D meson. This mode can be studied uniquely at Super$B$ operating at the $\psi(3770)$ by *CP*-tagging the other neutral D meson produced as a "short-lived" D_S:

$$e^+e^- \to \gamma^* \to D^0\overline{D}^0 \to [K^+K^-]_D D_L \qquad (15)$$

There is a more general lesson from the $K^0_L \to \pi^+\pi^-e^+e^-$ example, namely that *CP* violation could surface in an enhanced fashion in multi-body final states. This could turn an apparent vice in charm decays – the preponderance of multi-body final states – into a virtue. This issue will be addressed in detail in Sec. 4.

These considerations also apply to four-body modes, although less experience with such studies has been accumulated so far. Some intriguing pilot studies have been performed on a comparison of $D^0 \to f$ and $\overline{D}^0 \to f$, $f = K^+K^-\pi^+\pi^-$ channels. Denoting by ϕ the angle between the $\pi^+\pi^-$ and K^+K^- planes, one has

$$\frac{d\Gamma}{d\phi}(D^0 \to f) = \Gamma_1\cos^2\phi + \Gamma_2\sin^2\phi + \Gamma_3\cos\phi\sin\phi \ , \quad (16)$$

$$\frac{d\Gamma}{d\phi}(\overline{D}^0 \to f) = \overline{\Gamma}_1\cos^2\phi + \overline{\Gamma}_2\sin^2\phi - \overline{\Gamma}_3\cos\phi\sin\phi \ . \quad (17)$$

Upon integrating over ϕ, the Γ_3 and $\overline{\Gamma}_3$ terms cancel; $(\Gamma_1, \Gamma_2) \neq (\overline{\Gamma}_1, \overline{\Gamma}_2)$ thus represents a *CP* asymmetry in the partial widths. The Γ_3 and $\overline{\Gamma}_3$ terms can be projected out by integrating over two quadrants:

$$\langle A\rangle = \frac{\int_0^{\pi/2} d\phi\frac{d\Gamma}{d\phi} - \int_{\pi/2}^{\pi} d\phi\frac{d\Gamma}{d\phi}}{\int_0^{\pi} d\phi\frac{d\Gamma}{d\phi}} = \frac{2\Gamma_3}{\pi(\Gamma_1+\Gamma_2)} \ , \quad (18)$$

$$\langle\overline{A}\rangle = \frac{\int_0^{\pi/2} d\phi\frac{d\overline{\Gamma}}{d\phi} - \int_{\pi/2}^{\pi} d\phi\frac{d\overline{\Gamma}}{d\phi}}{\int_0^{\pi} d\phi\frac{d\overline{\Gamma}}{d\phi}} = \frac{2\overline{\Gamma}_3}{\pi(\overline{\Gamma}_1+\overline{\Gamma}_2)} \ . \quad (19)$$

While Γ_3 and $\overline{\Gamma}_3$ represent T-odd moments, they do not necessarily signal T violation, since they could be induced by strong final state interactions. Yet

$$\Gamma_3 \neq \overline{\Gamma}_3 \implies CP \text{ violation.} \tag{20}$$

Such an analysis is theoretically clean, since the dependence on the angle ϕ is specifically predicted, which in turn allows cross checks to control experimental systematics.

Alternatively, one can define another T-odd correlation among the pion and kaon momenta, namely $C_T \equiv \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$ for D^0 and $\overline{C}_T \equiv \vec{p}_{K^-} \cdot (\vec{p}_{\pi^-} \times \vec{p}_{\pi^+})$ for $\overline{D}^0$. Similar to the previous case one has: $C_T \neq -\overline{C}_T \implies$ *CP* violation. One can then construct T-odd moments

$$A_T = \frac{\Gamma(C_T > 0) - \Gamma(C_T < 0)}{\Gamma(C_T > 0) + \Gamma(C_T < 0)} , \tag{21}$$

$$\overline{A}_T = \frac{\Gamma(\overline{C}_T > 0) - \Gamma(\overline{C}_T < 0)}{\Gamma(\overline{C}_T > 0) + \Gamma(\overline{C}_T < 0)} , \tag{22}$$

and therefore

$$A_{\not{T}} = \frac{1}{2}(A_T - \overline{A}_T) \neq 0 \implies CP \text{ violation.} \tag{23}$$

A preliminary study based on 380 fb^{-1} of *BABAR* data suggests a sensitivity of 5.3×10^{-3} in $A_{\not{T}}$ that would extrapolate to 4×10^{-4} for 75 ab^{-1}. With such a sample one can analyze even time slices of $A_{\not{T}}$. These are very promising sensitivities.

Similar *CP* studies can be performed for other four-body modes, and one can also compare Y_L^0 moments and even full amplitude analyses.

Charm baryon decays

Charm baryons decays are sensitive only to direct *CP* violation. Longitudinally polarized beams – motivated mainly by *CP* studies in τ production and decays – provide an intriguing handle for *CP* studies in charm baryon decays, since charm baryons would be produced with a net longitudinal polarization that would allow the formation of novel *CP*-odd correlations with the momenta of the particles in the final state. The control of the sign of longitudinal polarization provides an excellent handle on systematics.

4. Mixing and *CP*V in 3-body decays

A Dalitz plot analysis of $D^0 \to K_S^0\pi^+\pi^-$ events provides a golden method for studying mixing and *CP* violation in mixing/decay/interference. If Dalitz plot model systematics can be kept under control, direct *CP*-violation can also be investigated. Present *BABAR* data [18] show that at the $\Upsilon(4S)$, signal events from the decay chain $D^{*+} \to D^0\pi^+$ with $D^0 \to K_S^0\pi^+\pi^-$ can be selected at a rate close to 1000/fb^{-1} with a purity of 97.0%, and a mistag probability of 0.1%. K_S^0 are reconstructed in the $\pi^+\pi^-$ final state; a requirement that the K_S^0 proper time be $\leq 8\tau_S$ allows us to reduce K_L^0 contamination to a level of 10^{-5}. Reconstructing the $D^0 \to K_S^0\pi^+\pi^-$ decay vertex, the D^0 proper time (τ_D) can be measured with an average error of ± 0.2 ps in *BABAR* and ± 0.1 ps at Super$B$, to be compared with the D^0 lifetime of 0.4 ps.

We use the invariant mass of $K\pi$ pairs: $m_+^2 = m^2(K_S^0, \pi^+)$ and $m_-^2 = m^2(K_S^0, \pi^-)$, and we define the following Dalitz plot amplitudes (f_D) and probabilities (p_D), which also depend on t:

$$p_D(m_+^2, m_-^2, t) \equiv |f_D(m_+^2, m_-^2, t)|^2 \quad D^0\text{tag} \tag{24}$$

$$\overline{p}_D(m_+^2, m_-^2, t) \equiv |\overline{f}_D(m_+^2, m_-^2, t)|^2 \quad \overline{D}^0\text{tag} \tag{25}$$

The signatures for interesting processes are the following ones:

- Mixing without *CP* violation

$$p_D(m_+^2, m_-^2, t) = \overline{p}_D(m_-^2, m_+^2, t) \quad \forall\, t \quad \text{but} \tag{26}$$

$$p_D(m_+^2, m_-^2, 0) \neq p_D(m_+^2, m_-^2, t) \tag{27}$$

- *CP* violation in mixing

$$p_D(m_+^2, m_-^2, 0) = \overline{p}_D(m_-^2, m_+^2, 0) \quad \text{and} \tag{28}$$

$$p_D(m_+^2, m_-^2, t) \neq \overline{p}_D(m_-^2, m_+^2, t) \tag{29}$$

- Direct *CP* violation

$$p_D(m_+^2, m_-^2, 0) \neq \overline{p}_D(m_-^2, m_+^2, 0) \tag{30}$$

and the quantities, to be measured, that enter in the previous Dalitz plot distribution functions, are: x, y (mixing parameters), $|q/p|$ or $\epsilon = \frac{1-|q/p|}{1+|q/p|}$ and $\phi = \arg(\frac{q\bar{A}_f}{pA_f})$ (*CP*-violation parameters).

x, y, ϵ and ϕ can be extracted in a Dalitz model-dependent analysis with the isobar or K-matrix approach, using global fits. Examples are described in references [18, 19]. For the model-dependent approach, we conservatively estimate the Super$B$ sensitivity at 75 ab^{-1} by extrapolating from the current analyses. Statistical errors can be scaled with the square root of luminosity. The result exceeds the desired goal of 10^{-3}, a level not reachable by BES-III. The second source is from systematic errors due to the experiment. They are mainly due to background parametrization, efficiency variation over the Dalitz plot, experimental resolution biases on Dalitz plot variables, decay time parametrization, and mistag fractions. Background parametrization is checked with sidebands (according to the Monte Carlo, the background does not peak in the D^0 mass signal region), and scales with statistics. Efficiency variation studied with Monte Carlo events scales with the Monte Carlo statistics. Biases on Dalitz plot variable mass resolution are negligible. Decay time parametrization improves with the size of the data sample and due to the time resolution at Super$B$. Mistag fractions can be checked with other final D states; their contribution is negligible. It is thus plausible that the errors arising from experimental sources can be scale with statistics as well, but we prefer to be conservative, and evaluate these systematic errors using an additional safety factor of two. These errors are shown in Table VI; we can see that they are smaller than the statistical errors.

TABLE VI: Current Belle errors with 0.54 ab^{-1} on relevant mixing and *CP* violation parameters.

Par.	Stat.	Exp. Syst.	Model Syst.	Total
x (10^{-4})	30.0	8.0	12.0	33.3
y (10^{-4})	24.0	10.0	7.0	26.9
ϵ (10^{-4})	15.0	2.5	4.0	15.7
ϕ (deg)	17.0	4.0	3.0	17.7

TABLE VII: Super$B$ errors with 75 ab^{-1} on relevant mixing and *CP* violation parameters.

Par.	Stat.	Exp. Syst.	Model Syst.	Total
x (10^{-4})	2.5	1.4	4.0	4.9
y (10^{-4})	2.0	1.7	2.3	3.5
ϵ (10^{-4})	1.3	0.4	1.3	1.9
ϕ (deg)	1.4	0.7	1.0	1.9

The last, but not the least important, source of systematic errors, is the model used, typically isobar or K-matrix models or a partial-wave analysis. Uncertainties arise from radius parameters, masses and widths of the resonances, and the choice of resonances included in the fit. Recent results from CLEO and Belle [9, 19] have, however, demonstrated that the mixing and *CP* violation parameters are not very sensitive to Dalitz model variations. The sensitivity to models will be checked using two model independent approaches:

- With a very large data sample, a partial-wave analysis is capable to determine the amplitude and phase variation over the phase space directly from data.
- Data collected at charm threshold will make the $D^0\overline{D}^0$ relative phase accessible [20].

Even if it is extremely difficult to make predictions on the Dalitz model systematics at Super$B$, it is reasonable to assume that these will be substantially reduced with respect to the present errors from Belle [9]. By comparing the CLEO analysis based on 9.0 fb^{-1} with the Belle analysis based on 540 fb^{-1}, we realize an improvement of the Dalitz model systematic error of more than a factor of four on average. This improvement is mainly due to the fact that the larger statistics data sample allows a better determination of the Dalitz model parameters. Contemplating a factor of three improvement for the model error at Super$B$ seems conservative, since it does not take into account the benefits of partial-wave analysis, and the use of data collected at charm threshold. Sensitivity predictions for mixing and *CP* violation parameters at Super$B$ are shown in Table VII.

[1] Heavy Flavor Averaging Group (E. Barberio *et al.*), [arXiv:hep-ex/0603003]. Updates and plots: http://www.slac.stanford.edu/xorg/hfag.

[2] D. M. Asner, to appear in the Review of Particle Physics.

[3] D. M. Asner and W. M. Sun, Phys. Rev. D **73**, 034024 (2006) [arXiv:hep-ph/0507238].

[4] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. Lett. **98**, 211802 (2007) [arXiv:hep-ex/0703020].

[5] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **100**, 121802 (2008) [arXiv:0712.1567 [hep-ex]].

[6] L. M. Zhang *et al.* [Belle Collaboration], Phys. Rev. Lett. **96**, 151801 (2006) [arXiv:hep-ex/0601029].

[7] M. Staric *et al.* [Belle Collaboration], Phys. Rev. Lett. **98**, 211803 (2007) [arXiv:hep-ex/0703036].

[8] B. Aubert *et al.* [*BABAR* Collaboration], arXiv:0712.2249 [hep-ex] - submitted to Phys. Rev. D.

[9] K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **99**, 131803 (2007) [arXiv:0704.1000 [hep-ex]].

[10] A. J. Schwartz, *Proceedings of 5th Flavor Physics and CP Violation Conference (FPCP 2007), Bled, Slovenia, 12-16 May 2007, pp 024* [arXiv:0708.4225 [hep-ex]].

[11] A. J. Schwartz, *Proceedings of the BES-Belle-CLEO-BABAR Workshop on Charm Physics, IHEP, Beijing, 26-27 November 2007.* [arXiv:0803.0082 [hep-ex]].

[12] Heavy Flavor Averaging Group (HFAG)-charm subgroup http://www.slac.stanford.edu/xorg/hfag/charm/.

[13] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. Lett. **100**, 061803 (2008) [arXiv:0709.2715 [hep-ex]].

[14] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. Lett. **98**, 211802 (2007) [arXiv:hep-ex/0703020].

[15] B. Aubert *et al.* [*BABAR* Collaboration], submitted to Phys. Rev. Lett. [arXiv:0802.4035].

[16] Q. He *et al.* [CLEO Collaboration], Phys. Rev. Lett. **95**, 121801 (2005), Erratum-ibid. **96**, 199903 (2006) [arXiv:hep-ex/0504003].

[17] T. E. Coan *et al.* (CLEO Collaboration) Phys. Rev. Lett. **95**, 181802 (2005) [arXiv:hep-ex/0506052].

[18] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. Lett. **95**, 121802 (2005) [arXiv:hep-ex/0504039].

[19] D. M. Asner *et al.* [CLEO Collaboration], Phys. Rev. D **72**, 012001 (2005) [arXiv:hep-ex/0503045].

[20] E. White and Q. He [CLEO Collaboration], arXiv:0711.2285 [hep-ex].