Sharpening the physics case for charm physics at SuperB

New Physics in general generates flavour 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 SM makes nontrivial predictions for CP violation in charm transitions: *direct* CP violation should occur only in Cabibbo suppressed modes on an observable level $\sim \mathcal{O}(10^{-3})$.

The recent evidence for $D^0 - \overline{\ast}D^0$ oscillations – with x_D, $y_D \simeq 0.005 \div 0.01$ – does not prove the presence of New Physics. However it greatly widens the stage, on which CP violation can appear and establish itself as a manifestation of New Physics. Within the SM time dependent CP asymmetries might reach the 10^{-5} $[10^{-4}]$ level in Cabibbo allowed and once [doubly] suppressed modes, whereas New Physics could enhance them 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 would also have to contend with a much larger SM 'background' in the latter than the former.

The required searches can be undertaken very profitably in runs 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 $e^+e^- \to D^0\overline{\ast}D^0$ running.

I. SEARCHING FOR NEW PHYSICS IN CHARM DECAYS – MAINLY CP VIOLATION

A. The landscape

New Physics in general generates flavour changing neutral currents (FCNC). The SM 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 it is only charm that 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, and 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 $\overline{\ast}u$ 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 $D^0 - \overline{\ast}D^0$ oscillations has been recently found pointing to [1]

$$x_D \equiv \frac{\Delta M_D}{\overline{\ast}\Gamma_D} = 0.0081 \pm 0.0033 \; , \qquad (1)$$

$$y_D \equiv \frac{\Delta \Gamma_D}{2\overline{\ast}\Gamma_D} = 0.0031 \pm 0.0028 \; . \qquad (2)$$

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

One will be on much firmer ground in interpreting CP asymmetries. For on one hand $D^0 - \overline{\ast}D^0$ oscillations greatly widen the stage, on which CP violation can appear and establish itself as a manifestation of New Physics; on the other hand the SM makes very nontrivial predictions for CP violation on 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 a highly diluted one:

$$V_{cs} \simeq 1 - \frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 \simeq 0.97 - 6 \cdot 10^{-4} i \; . \qquad (3)$$

Furthermore one needs two different, yet coherent amplitudes contribute to the same channel to obtain a direct CP asymmetry. Within the SM this can happen only in Cabibbo suppressed modes on an observable level, namely no more than $\mathcal{O}(10^{-3})$. That means that any observation of a 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 $D^+ \to \overline{\ast}K^0\pi^+$ 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, $y_D \sim 0.005 \div 0.01$ 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 an $\Delta C = 1$ amplitude observable. In both cases an educated SM guess points to time dependent CP asymmetries of order $10^{-3}x_D \sim 10^{-5}$.

B. 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 $\overline{*}D \to \overline{*}f$:

$$|A_f| \equiv |A(D \to f)| \neq |\overline{*}A_{\overline{*}f}| \equiv |A(\overline{*}D \to \overline{*}f)| \ . \quad (4)$$

   Such asymmetries in partial widths require strong phase shifts due to final state interactions. Since charm decays proceed in an environment populated by many resonances, this requirement will hardly represent a limiting factor in general; it might make the interpretation of signals a more complex task though.

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

$$|q/p| \sim 1 + \frac{\Delta\Gamma_D}{\Delta M_D}\sin\phi_{\rm weak} \neq 1 \ . \quad (5)$$

   The same educated SM guess mentioned before points to $|1-|q/p|| \sim$ 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 in 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 later 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. In qualitative analogy to $B_d \to \psi K_S$ a time dependent CP asymmetry can arise due to an interference between an oscillation and decay amplitude:

$$\phi_f = \arg\left(\frac{q}{p}\frac{\overline{A}_{\overline{f}}}{A_f}\right) \neq 0 \ . \quad (6)$$

   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'. For 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 SM 'background' in the latter than the former; i.e., the theoretical 'signal-to-noise' ratio might be better in charm decays.

The required searches can be undertaken very profitably in runs at the $\Upsilon(4S)$ tagging the D^0 flavor at production time using $D^{*+} \to D^0\pi^+$ decays and reconstructing the proper decay time and its error tracking the D production and decay vertices with contraints 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 $\psi(3770)$, while 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 nonleptonic as well as semileptonic channels on all Cabibbo levels in as many modes as possible; i.e., also in final states containing neutrals.

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

C. Side remarks on rare decays

The obvious motivation for measuring $D^+/D_s^+ \to \mu^+\nu$, $\tau^+\nu$ is to extract the decay constants f_D and f_{D_s} to compare them with the findings of lattice QCD and hopefully validate the latter's findings with high accuracy. A more ambitious goal is to probe for contributions from a charged Higgs field.

The mode $D^0 \to \mu^+\mu^-$ arises within the SM mainly through a two photon intermediate state – $D^0 \to$ "$\gamma\gamma$" $\to \mu^+\mu^-$ – and can reach the 10^{-12} level. With the present experimental upper bound of $1.3 \cdot 10^{-6}$ 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}.

Channels like $D \to \gamma h$, l^+l^-h, $l^+l^-h_1h_2$ with h denoting a hadron receive relatively sizable contributions within the SM from long distance dynamics, making a search for New Physics contributions not very promising there, at least 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 $D^+ \to K^+/\pi^+ f$; 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 never in D^+ decays.

II. D^0 $\overline{D}^0$ MIXING RUNNING AT $\Upsilon(4S)$ AND $\psi(3770)$ ENERGIES

(In progress)

III. CP VIOLATION

A. Direct CP violation

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

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

The most precise analysis to date [2] compares time integrated $D^0 \to h^+h^-$ and $\overline{D}^0 \to h^+h^-$ rates, $a_{CP}^{hh} = [N_{D^0} - N_{\overline{D}^0}]/[N_{D^0} + N_{\overline{D}^0}]$, 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. The presence of 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 $D^0 \to \pi^+\pi^-$, $a_{CP}^{KK} \neq a_{CP}^{\pi\pi}$. Two are the main experimental challenges of these measurements. Firstly, the experimental asymmetry in the D^0 flavor tagging. To correct for this asymmetry it is measured 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 magnitude abd polar angle in the lab frame. For the azimuth dependence an integrated scale factor is enough, since charm production is azimuthally uniform. Since the reconstructed modes are CP-even, this in the only detector asymmetry. Secondly, the forward-backward (FB) asymmetry in $c\overline{*}c$ production at $\Upsilon(4S)$, consequence of the γ/Z^0 interference and higher order QED corrections (both at percent level at this energy), coupled with the asymmetric acceptance of the detector, which produces a difference in the numbers of reconstructed D^0 and $\overline{*}D^0$ 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 $\cos\theta_D^{CM}$ and decomposing these into an even (that represents the CP asymmetry and should be independent of $|\cos\theta_D^{CM}|$) and odd (that represents the FB production asymmetry) parts. The associated systematic uncertainties are therefore not a limiting factor and have mostly an statistical nature. Other potential sources are highly suppressed because the final states are reconstructed identically for D^0 and $\overline{*}D^0$. With a SuperB luminosity of 75 ab^{-1}, sensitivities at 3×10^{-4} and 4×10^{-4} level, for a_{CP}^{KK} and $a_{CP}^{\pi\pi}$ respectively, are foreseen.

The 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 from 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 the 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 SuperB, the much smaller luminous region and the significantly enhanced vertexing capabilities, will provide proper time significances at 10σ level (3-4 times better than in BaBar [3], with decay length resolution of about 80 μm, $\sim 3\sigma$), significantly helping in reducing the systematic uncertainties associated to the modelling 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 sensitivie level, systematic uncertainties, currently 15×10^{-3}, will have to be reduced by a factor 5 or better, something feasible taking into accout that systematic corrections rely mainly on data.

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 whole 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 achive, 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 asignment and FB production asymetries only affect the last method, and can be kept under control as previously discussed. From the pionnering Babar analysis using $D^0 \to \pi^-\pi^+\pi^0$ and $D^0 \to K^-K^+\pi^0$ [4], 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 discussed in Sec. III D.

B. Indirect CP violation at $\Upsilon(4S)$ 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 $\overline{*}D^0$, previously flavour tagged, has oscillated (signaled as a wrong sign decay),

$$a_{SL} = \frac{N^{--}(t) - N^{++}(t)}{N^{--}(t) + N^{++}(t)} = \frac{|q|^4 - |p|^4}{|q|^4 + |p|^4} \ , \qquad (7)$$

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 $\psi(3770)$ largely benefits from a very clean environment with almost no background. Several decay channels can be exclusively reconstructed and combined to increase the assymetry sensitivity. Considering the D^0 and $\overline{*}D^0$ 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], it is expected a sensitivity to CP violation of 2.5% in one month of running at threshold. The quantum correlation insures that the same sign combinations can only be due to mixing, and hadronic modes can be treated like the semileptonic decays (no DCS contribution). Control on systematic uncertainties are expected likewise at the percent level, dominated by channels with π^0 and ν particles [5, 6]. Missing mass techniques with fully reconstruction of $\psi(3770) \to D\overline{*}D$ 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 beneficit 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 flavour of the D^0. The measurement of wrong sign leptons in semileptonic decays gives then a clear signature of a mixed event. Data are taken from the continuum. Background events from B decays can be reduced imposing a 2.5 GeV/c cut on the D momentum. With this method the statistical sensitivity in the decay asymetries would reach the 1% level in one year of data taking. Systematic uncertainties are foreseen to come from the background control 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.

C. CP violation in interference between 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 alters 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. IV).

The sensitivity to y_{CP} and ΔY with the SuperB in the KK and $\pi\pi$ sample can be extrapolated from the current BaBar analysis [2], assuming that the systematic errors can be kept under control. Provided that the CP violation in mixing is small we can extract the sensitivity to the CP violating phase as $\delta(\cos\phi) \simeq \delta(y_{CP})/y \simeq 3 \times 10^{-4}/y$, $\delta(\sin\phi) \simeq \delta(\Delta Y)/x \simeq 3 \times 10^{-4}/x$.

Most of the systematic errors affecting the signal cancel in the lifetime ratio. The errors associated to the background are instead unrelated between D^0 and $\overline{D}^0$ and don't cancel, however these improve with the statistics. In the Babar systematic studies the main remaining one is the cut on the error on the proper time which is related to the fraction of outliers for which $\sim 2/3$ is statistical and $\sim 1/3$ is systematic.Another underlying assumption is that the resolution bias is the same for all the channels ($K\pi$, KK, $\pi\pi$) and its 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. However with a higher statistics this systematic effect can be overcome by splitting the sample into polar angle (or other variable) intervals. The production asymmetry is important with the BaBar statistics while this could become significant at sensitivities of the order of few $\times 10^{-4}$, however this can be handled using control samples such as the untagged D^0 which has about 5 times more events (assuming D^0 and D^* have the same asymmetry), as discussed in Sec. III A.

The total systematic error on the BaBar analysis is presently 17×10^{-4}. We estimate the total error with the SuperB sample by adding in quadrature the statistical and systematic errors (rescaled appropriately for the luminosity) with an estimate for the irreducible part of the systematic error. The sensitivity as a function of the luminosity is shown in Fig 1.

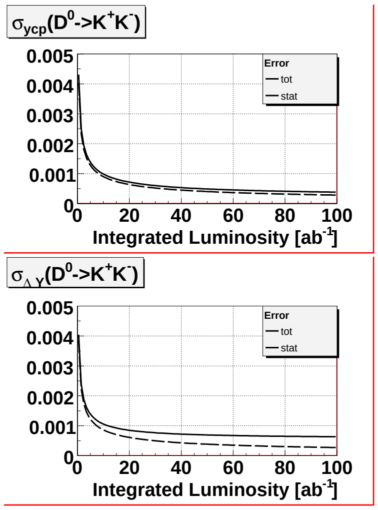

FIG. 1: Total and statistical error on y_{cp} (top) and ΔY (left) extracted from $D^0 \to K^+K^-$ as a function of the integrated luminosity.

D. T odd correlations

All CP asymmetries observed so far have surfaced in partial widths – with one notable exception, namely 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 understand: $\langle A \rangle$ 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 $3 \cdot 10^{-7}$; i.e., one has traded in branching ratio 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 could be studied uniquely at SuperB operating at the $\psi(3770)$ by CP tagging the other neutral D meson produced as a D_S:

$$e^+e^- \to \gamma^* \to D^0\overline{D}^0 \to [K^+K^-]_D D_L \tag{8}$$

There is a more general lesson from the $K_L \to \pi^+\pi^-e^+e^-$ 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. IV.

These considerations apply also 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

$$\frac{d\Gamma}{d\phi}(D^0 \to f) = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi\ , \tag{9}$$

$$\frac{d\Gamma}{d\phi}(\overline{D}^0 \to f) = \overline{\Gamma}_1 \cos^2\phi + \overline{\Gamma}_2 \sin^2\phi - \overline{\Gamma}_3 \cos\phi \sin\phi\ . \tag{10}$$

Upon integrating over ϕ the Γ_3 and $\overline{\Gamma}_3$ terms out. $(\Gamma_1, \Gamma_2) \neq (\overline{\Gamma}_1, \overline{\Gamma}_2)$ 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:

$$\langle A \rangle = \frac{\int_0^{\pi/2} d\phi \frac{d\Gamma}{d\phi} - \int_{\pi/2}^{\pi} d\phi \frac{d\Gamma}{d\phi}}{\int_0^{\pi} d\phi \frac{d\Gamma}{d\phi}} = \frac{2\Gamma_3}{\pi(\Gamma_1 + \Gamma_2)}\ , \tag{11}$$

$$\langle \overline{A} \rangle = \frac{\int_0^{\pi/2} d\phi \frac{d\overline{\Gamma}}{d\phi} - \int_{\pi/2}^{\pi} d\phi \frac{d\overline{\Gamma}}{d\phi}}{\int_0^{\pi} d\phi \frac{d\overline{\Gamma}}{d\phi}} = \frac{2\overline{\Gamma}_3}{\pi(\overline{\Gamma}_1 + \overline{\Gamma}_2)}\ . \tag{12}$$

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

$$\Gamma_3 \neq \overline{\Gamma}_3 \implies \text{CP violation.} \tag{13}$$

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

$$A_T = \frac{\Gamma(C_T > 0) - \Gamma(C_T > 0)}{\Gamma(C_T > 0) + \Gamma(C_T > 0)}\,, \tag{14}$$

$$\overline{A}_T = \frac{\Gamma(\overline{C}_T > 0) - \Gamma(\overline{C}_T > 0)}{\Gamma(\overline{C}_T > 0) + \Gamma(\overline{C}_T > 0)}\,, \tag{15}$$

and therefore

$$A_{\not{T}} = \frac{1}{2}(A_T - \overline{A}_T) \neq 0 \implies \text{CP violation.} \tag{16}$$

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 $4 \cdot 10^{-4}$ 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.

E. Charm baryon decays

Charm baryons are of course sensitive only to direct CP violation. Yet if longitudinally polarized beams were available – motivated by CP studies in τ production and decays – they would provide an intriguing handle for CP studies in charm baryon decays. For charm baryons would be produced with a net longitudinal polarization that would allow to form novel CP odd correlations with the momenta of the particles in the final state. Since the polarization could be controlled, one would have a new handle to deal with systematics.

IV. MIXING AND CP VIOLATION IN 3-BODY DECAYS

A golden method for the mixing and *CP*-violation in mixing/decay/interference is the Dalitz analysis of $D^0 \to K_S^0\pi^+\pi^-$ events. If Dalitz model systematics could be kept under control, direct *CP*-violation could be investigated too. Present *BABAR* data [7] show that at $\Upsilon(4S)$, 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 $1000/\,\mathrm{fb}^{-1}$ with a purity of 97.0% and a mistag probability of 0.1%. K_S^0 are reconstructed in $\pi^+\pi^-$ final state, an upper cut on K_S^0 proper time ($\leq 8\tau_S$) ensure us to push K_L^0 contamination at a level of 10^{-5} level. 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 a SuperB, to be compared with 0.4 ps, the D^0 lifetime.

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, for us, also depend on t:

$$p_D(m_+^2, m_-^2, t) \equiv |f_D(m_+^2, m_-^2, t)|^2 \quad D^0 \text{ tag} \tag{17}$$

$$\overline{p}_D(m_+^2, m_-^2, t) \equiv |\overline{f}_D(m_+^2, m_-^2, t)|^2 \quad \overline{D}^0 \text{ tag} \tag{18}$$

The signatures for interesting processes are the following ones:

- Mixing without *CP*-violation

$$p_D(m_+^2, m_-^2, t) = \overline{p}_D(m_-^2, m_+^2, t) \quad \forall t \quad \text{but} \tag{19}$$

$$p_D(m_+^2, m_-^2, 0) \neq p_D(m_+^2, m_-^2, t) \tag{20}$$

- *CP*-violation in mixing

$$p_D(m_+^2, m_-^2, 0) = \overline{p}_D(m_-^2, m_+^2, 0) \quad \text{and} \tag{21}$$

$$p_D(m_+^2, m_-^2, t) \neq \overline{p}_D(m_-^2, m_+^2, t) \tag{22}$$

- Direct *CP*-violation

$$p_D(m_+^2, m_-^2, 0) \neq \overline{p}_D(m_-^2, m_+^2, 0) \tag{23}$$

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 $\phi = \arg(\frac{q\overline{*}A_f}{pA_f})$ (*CP*-violation parameters).

x, y,ϵ and ϕ can be extracted in a Dalitz model dependent analysis with the isobar or K-matrix approach, making global fits. Examples are described in references [7, 8]. For the model dependent approach, we estimate the SuperB sensitivity (at 75 ab^{-1}), extrapolating in conservative way the present data. Statistical errors can be scaled with the square root of luminosity. We get a result which is much better than the desired goal of 10^{-3}, not reachable by BESIII. The second source is from systematicc errors due to the experiment. They are mainly due t background paremeterization, efficiency variation through the Dalitz plot, experimental resolution biases on Dalitz plot variables, decay time parameterization, and mistag fractions. Background paramterization is checked with sidebands (according to the Monte Carlo the background does not have any bump in the D^0 mass signal region), and it scales with statistics. Efficiency variation is studied with Monte Carlo events and it scales with the Monte Carlo statistics. Biases on Dalitz plot variable mass resolution are negligible. Decay time paramterization improves with data and the time resolution will be immproved at the SuperB. Mistag fractions can be checked with other final D states and their contribution is negligible. There is the chance that these errors from experimental source could be reduced scaling to statistics, too, but we prefer to be conservative and avalute them putting a safety factor of two. They are reported in Table I, and we can see that they are less than the statistical ones.

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 I: Belle present errors on 0.54 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

TABLE II: SuperB errors on 75 ab^{-1} on relevant mixing and *CP*-violation parameters.

The last, but not least, source of systematic errors, is due to the decay models: the isobar, K-matrix, partial-waves ones. Uncertaities come from radius paramters, masses and widths of the resonances, the choice of resonances included in the fit. Recent results from CLEO and Belle [8, 9] have demonstrated that the mixing and *CP*-violation parameters are not very sensitive to Dalitz model variations. Dalitz model will be checked using two model independent approaches:

- with 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 accessible the D^0-$\overline{D}^0$ relative phase [10].

Even if it is extremely difficult to make predictions on the Dalitz model systematics at SuperB it is reasonable to assume that it will be reduced with respect to the present one from Belle [9] by a sizeble factor. By comparing the Cleo analysis based on 9.0 fb^{-1} with Belle one based on 540 fb^{-1} we realize an improvement of the Dalitz model systematic error better than a factor 4 on average. This improvement is mainly due to the fact that the larger statistic data sample allows a better determination of the Dalitz model parameters. Considering a factor 3 improvement for the model error at SuperB seems conservative since it is not taking into account the benefits of partial-wave analysis and of data collected at charm threshold. Sensitivity predictions for mixing and *CP*-violation parameters at SuperB are reported in Table II.

---

[1] Heavy Flavor Averaging Group (E. Barbeiro *et al*), [arXiv:hep-ex/0603003]. Updates and plots: http://www.slac.stanford.edu/xorg/hfag/
[2] B. Aubert *et al.* [BABAR Collaboration], Submitted to Phys. Rev. Lett. [arXiv:0709.2715].
[3] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **98**, 211802 (2007) [arXiv:hep-ex/0703020].
[4] B. Aubert *et al.* [BABAR Collaboration], To be submitted to Phys. Rev. Lett. [arXiv:xxxx.xxxx].
[5] Q. He *et al.* [CLEO Collaboration], Phys. Rev. Lett. **95**, 121801 (2005), Erratum-ibid. **96**, 199903 (2006) [arXiv:hep-ex/0504003].
[6] T. E. Coan *et al.* (CLEO Collaboration) Phys. Rev. Lett. **95**, 181802 (2005) [arXiv:hep-ex/0506052].
[7] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **95**, 121802 (2005) [arXiv:hep-ex/0504039].
[8] D. M. Asner *et al.* [CLEO Collaboration], Phys. Rev. D **72**, 012001 (2005) [arXiv:hep-ex/0503045].
[9] K. Abe *et al.* [BELLE Collaboration], Phys. Rev. Lett. **99**, 131803 (2007) [arXiv:0704.1000 [hep-ex]].
[10] E. White and Q. He [CLEO Collaboration], arXiv:0711.2285 [hep-ex].