Super$B$
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Abstract

Super$B$ is a high luminosity e^+e^- collider that will be able to indirectly probe new physics at energy scales far beyond the reach of any man made accelerator planned or in existence. Just as detailed understanding of the Standard Model of particle physics was developed from stringent constraints imposed by flavour changing processes between quarks, the detailed structure of any new physics is severely constrained by flavour processes as a result of either the Standard Model or any new physics effects. In order to elucidate this strucutre it is necessary to perform a number of complementary studies of a set of golden channels. With these measurements in hand, the pattern of deviations from the Standard Model behaviour can be used as a test of the structure of new physics. If new physics is found at the LHC, then the many golden measurements from Super$B$ will help decode the subtle nature of the new physics. However if no new particles are found at the LHC, Super$B$ will be able to search for new physics at energy scales up to $10 - 100$TeV. In either scenario, flavour physics measurements that can be made at Super$B$ play a pivotal role in understanding the nature of physics beyond the Standard Model. A strategy for using the interplay between measurements to understand physics beyond the Standard Model is discussed in detail in this document.

This report details the Physics case of the Super$B$ Project, updating the work detailed in both the Super$B$ Conceptual Design Report in 2007 and the Proceedings of Super$B$ Workshop VI in Valencia in 2008.

Contents

Introduction (from CDR)

The search for evidence of physics beyond the Standard Model will be the main objective of elementary particle physics in the coming decade. The LHC at CERN will soon commence a search for the Higgs boson, the missing building block of the Standard Model. It will also begin an intensive search for New Physics beyond the Standard Model, a search motivated by the expectation that a new scale is expected make an appearance at energies around 1 TeV, which will be accessible to the LHC.

The production and observation of new particles is not, however, the only way to look for New Physics. New particles can reveal themselves through virtual effects in decays of Standard Model particles such as B and D mesons and τ leptons. Since quantum effects typically become smaller as the mass of the virtual particles increases, high-precision measurements are required to have an extended mass reach. In some instances, in fact, high-precision measurements of heavy flavour decays allow us to probe New Physics energy scales inaccessible at present and next-generation colliders.

Flavour physics is fertile ground for indirect New Physics searches for several reasons. Flavour Changing Neutral Currents (FCNC), neutral meson-antimeson mixing and *CP* violation occur only at the loop level in the Standard Model and are therefore potentially subject to $\mathcal{O}(1)$ New Physics virtual corrections. In addition, quark flavour violation in the Standard Model is governed by the weak interaction and suppressed by the small Cabibbo-Kobayashi-Maskawa (CKM) mixing angles. These features are not necessarily shared by New Physics, which could, therefore, produce very large effects in particular cases. Indeed, the inclusion in the Standard Model of generic New Physics flavour-violating terms with natural $\mathcal{O}(1)$ couplings is known to violate present experimental constraints unless the New Physics scale is pushed up to 10–100 TeV, depending on the flavour sector. The difference between the New Physics scale emerging from flavour physics and that suggested by Higgs physics could be a problem for model builders, but it clearly indicates that flavour physics has either the potential to push the explored New Physics scale in the 100 TeV region or, if the New Physics scale is indeed close to 1 TeV, that the flavour structure of New Physics is non-trivial and the experimental determination of the flavour-violating couplings is particularly interesting.

On quite general grounds, indirect New Physics searches in flavour-changing processes explore a parameter space including the New Physics scale and the New Physics flavour- and *CP*-violating couplings. In specific models, these are related to fundamental parameters, such as the masses and couplings of new particles. In particular, an observable New Physics effect could be generated by small New Physics scales and/or large couplings. Conversely, small effects in the flavour sector could be due to large New Physics scales and/or small couplings. The question of whether or not New Physics is flavour-blind is therefore crucial; if so, New Physics searches in flavour physics would be unfeasible. Fortunately, the concept of Minimal Flavour Violation (MFV) provides a negative answer: even if New Physics did not contain new sources of flavour and *CP* violation, the flavour-violating couplings present in the Standard Model are enough to produce a new phenomenology that makes flavour processes sensitive to the presence of new particles. In other words, MFV puts a lower bound on the flavour effects generated by New Physics at a given mass scale, a sort of "worst case" scenario for the flavour-violating couplings. Thus the MFV concept is extremely useful to exclude New Physics flavour-blindness and to assess the "minimum" performance of flavour physics in searching for New Physics, keeping in mind that larger effects are quite possible and easily produced in many scenarios beyond MFV.

The effectiveness of flavour physics in constraining New Physics has already been demonstrated by the B Factories, whose superb performance in measuring the parameters of the CKM matrix, together with new results from the Tevatron on B_s physics, already allow interesting bounds on New Physics. A few discrepancies exist in the current data, although several measurements alone do not approach 10% accuracy. One lesson from the B Factories is that precision is crucial in these kind of studies, as are redundant measurements of the same underlying quantity. In Fig. 1 we show the regions on the $\overline{\rho}$-$\overline{\eta}$ plane selected by different constraints assuming the current measurement precision, and that expected at Super$B$. With the precision reached at Super$B$, the current discrepancies would clearly indicate the presence of New Physics in the flavour sector!

In light of these considerations, it is clear that a Super Flavour Factory can provide unique evidence for New Physics in the heavy flavour sector by searching for virtual effects that induce deviations from Standard Model predictions at the percent level, and for processes that are highly suppressed, or even forbidden, in the Standard Model, but can be enhanced by New Physics. Two features of the Super Flavour Factory are appealing from an experimental point of view: the possibility of measuring dozens of New Physics-

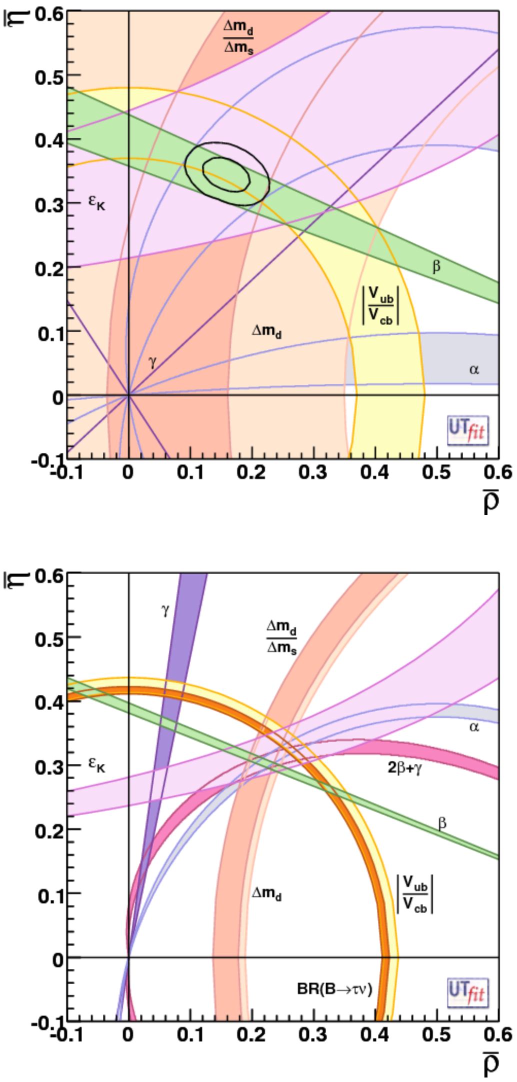

FIG. 1: Regions corresponding to 95% probability for $\bar{\rho}$ and $\bar{\eta}$ selected by different constraints, assuming present central values with present errors (left) or with errors expected at Super*B* (right).

sensitive observables with unprecedented precision, thanks to the high luminosity and the very clean experimental environment; and the ability to change the center-of-mass energy to produce well-defined particle-antiparticle pairs of B^+, B_d, B_s, D^0, D^+, D_s mesons and τ leptons, exploiting the quantum-coherence inherent in production via resonances e^+e^- annihilation.

Physics at Super*B* could begin around 2015. An obvious question is then how the Super Flavour Factory physics program fits into the program of particle physics early in the next decade? Several scenarios are conceivable, but the most pertinent is whether the LHC will have produced non-standard (possibly flavoured) particles with masses below 1 to 2 TeV or not.

If New Physics has been found elsewhere, the importance of flavour physics studies becomes twofold: not only could the open window on much larger scales extend the New Physics mass spectrum found at the LHC, but a detailed study of the flavour- and *CP*-violating couplings of newly discovered particles could be carried out even in the unfavourable MFV case, taking advantage of the crucial information on the New Physics scale provided by the LHC. Although LHCb, ATLAS or CMS could be the first to observe flavour-related effects in new particle production or decay, only with the Super Flavour Factory would we be able to perform a systematic analysis of their flavour- and *CP*-violating couplings in processes involving the second and third generations of quarks and leptons. These studies have a unique capability to reconstruct the New Physics Lagrangian from the observed phenomenology. A typical example is supersymmetry (SUSY): most of the couplings appearing in the soft SUSY-breaking sector of the Lagrangian could be measured at the Super Flavour Factory. In this scenario, high p_T and flavour physics observations would both be required to understand the nature of New Physics.

If physics beyond the Standard Model is not found at the LHC, indirect searches in flavour-changing processes become of the utmost importance to probe New Physics scales in the 10–100 TeV region. After all, the 1 TeV New Physics scale naturally required in order to stabilize the Fermi scale could be somewhat higher, without invalidating the concept of naturalness. Yet an acceptable upward shift of the New Physics scale would put LHC out of the game, and leave the task of discovering New Physics to indirect searches. A Super Flavour Factory would be able to probe the interesting mass range, giving naturalness a second chance before discarding it in favour of more exotic explanations of the Fermi scale. Unfortunately, given the presence of the unknown flavour couplings, there is no guarantee that the virtual effects of a new particle with a mass of 100 TeV are observable even at the Super Flavour Factory Still, values of the New Physics scale in the 10–100 TeV range can be naturally reached in most New Physics models, including, for example, the Minimal Supersymmetric Standard Model, and even models with MFV are sensitive to scales larger than 1 TeV in the large $\tan\beta$ regime. Notice that LHCb and the Super Flavour Factory, which find their strengths in measuring different decay processes, are complementary in the effort to observe New Physics effects from large scales.

In any case, regardless of whether or not New Physics has already been found, it is crucial to exploit the full richness of the phenomenology accessible at the Super Flavour Factory in order to increase the chances of observing New Physics flavour effects and to study the New Physics flavour structure.

Another anticipated result related to Super Flavour Factory physics is the search for lepton flavour violation (LFV) in the decay $\mu \to e\gamma$ by the MEG collaboration. Indeed, searches for LFV in the transitions between the second and third generations, the golden mode being $\tau \to \mu\gamma$, are a centerpiece of the Super Flavour Factory physics program. The observation of $\tau \to \mu\gamma$ with a branching ratio around 10^{-9}, an unmistakable signal of New Physics, is accessible at Super$B$. Super$B$ will probe values of $\mathcal{B}(\tau \to \mu\gamma)$ an order of magnitude smaller than previous experiments; this is the range predicted by most New Physics models. For example, within Grand-Unified models, MEG and Super$B$ sensitivities are such that the pattern of LFV observations (and non-observation) can identify the dominant source of LFV and distinguish whether it is governed by the CKM or the PNMS matrix. Other topics in τ physics can be studied at the Super Flavour Factory as well, in particular, the precise determination of τ production and decay properties, including *CP*-violating observables, such as the T-odd triple products which benefit from the polarized τ leptons that Super$B$ can produce with a polarized electron beam.

New Physics searches with B_d and B^+ decays proceed along the lines already begun at the B Factories. The full set of B Factory measurements can be addressed, improving the accuracy of several observables, *e.g.* CKM angles, $b \to s$ penguin transitions, $B(B^+ \to \tau^+\nu_\tau)$, etc. down to $\mathcal{O}(1\%)$. Additional New Physics-sensitive measurements such as the *CP* asymmetry in $B \to X_s\gamma$ or the forward-backward asymmetry in $B \to X_s l^+ l^-$ become possible with the Super$B$ dataset. Any of these measurements could show a clear deviation from the Standard Model or be used to feed more sophisticated New Physics analyses. Notice that, in this sector, the overlap with the LHCb physics program is rather limited and the Super Flavour Factory performance is, typically, superior.

It is worth noting that while some New Physics analyses depend only on measured quantities, others require theoretical information on hadronic parameters. The only approach that can, in principle, achieve the required theoretical accuracy is lattice QCD, where the limiting factor is likely to be uncontrolled systematic uncertainties. From this point of view, it is reassuring that lattice simulations have already begun to go beyond the quenched approximation. Extrapolations based on computing power foreseen in 2015, taking into account different sources of systematics (chiral extrapolation, heavy mass extrapolation, continuum limit, finite-size effects, etc.), indicate that an accuracy of $\mathcal{O}(1\%)$ is achievable on the hadronic parameters of interest for the Super Flavour Factory physics program, even without considering progress in theory and in algorithms, which are likely to occur, but difficult to anticipate.

The case of B_s studies is somewhat different. The high oscillation frequency makes it impossible to perform fully time-dependent measurements at Super$B$. In addition, most of the interesting observables, such as the phase ϕ_{B_s} of the B_s mixing amplitude or $B(B_s \to \mu^+\mu^-)$, will have been measured with high precision by LHCb (and possibly by Belle running at the $\Upsilon(5S)$) before Super$B$ begins. Nevertheless, a short run at the $\Upsilon(5S)$ would suffice to accurately measure New Physics-sensitive quantities, such as the semileptonic *CP* asymmetry a^s_{sl}, which cannot be observed at hadronic colliders. It is interesting to note that, thanks to the quantum coherence of the $B_s\overline{B}_s$ pairs and the (limited) time sensitivity achievable at Super$B$, it would be possible to measure *CP* violating phases through terms in the time-dependent decay rates that depend on $\Delta\Gamma_s$. That is, the same quantities that can be extracted from the full time-dependent analysis can still be determined. Using this method and the full Super$B$ statistics, it should be possible not only to measure ϕ_{B_s} with an accuracy competitive with LHCb, but also to access other CKM angles with B_s decays. A similar consideration applies to $B_s \to \mu^+\mu^-$, where, with the full statistics, one could hope to probe the Standard Model value of this branching ratio. However, gains in B_s physics would be paid for with statistics potentially available for B_d/B^+ physics. It is not clear at this point whether this would be worthwhile in the first few years of operation of Super$B$. Nevertheless, it seems prudent to maintain this unique capability.

Finally, it is important to note that a large numbers of charmed particles are produced at the Super$B$ while running on the Υ resonances; this sample would be 10^4 times the statistics of existing charm factories and would still be much larger than samples at future dedicated facilities. It is clear that the next generation physics program of a charm factory could be carried out at Super$B$. Some studies, for instance those related to the calibration of lattice QCD, could benefit from a short run at the $D\overline{D}$ threshold. Others, such as mixing studies based on quantum coherence, can only be done at threshold. In any case, a run of 1 to 2 months at threshold would produce a $D\overline{D}$ sample ten times larger than that available at the conclusion of running at the new charm factories. With these statistics, interesting New Physics-related measurements in the D sector become possible, in particular *CP* violation in D decay and improved measurements of $D\overline{D}$ oscillation parameters.

Introduction (VALENCIA)

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 $p_{\rm T}$. 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 it is crucial to have the appropriate experimental sensitivity. The experiment must measure *CP* asymmetries in very rare decays, 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, yielding 15 ab^{-1}/Snowmass Year of 1.5×10^7 seconds. It is these boundary conditions that set the luminosity of Super$B$.

Reaching this luminosity with a collider design extrapolated from PEP-II or KEKB, such as SuperKEKB, is difficult; beam currents and thus power consumption are very high, and the resulting detector backgrounds are formidable. The low emittance, 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 . A test of the crabbed waist concept is underway at Frascati; it is proceeding very well, producing impressive increases in the specific luminosity at DAΦNE. More remains to be done, but the results are very encouraging.

It is important that results with sensitivity to New Physics be obtained in a timely way, engendering a "conversation" with the LHC experiments. Super$B$ can confidently be expected to produce a very large data sample before the end of the next decade. The more gradual SuperKEKB approach to achieving high peak luminosity cannot produce comparable data samples until close to the end of the following decade [2].

τ physics will likely 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.

The following is a brief resumé of the capabilities of Super$B$. In some instances, comparisons are made between physics results that can be obtained with the five year, 75 ab^{-1} Super$B$ sample and a 10 ab^{-1} sample such as could perhaps be obtained in the first five years of running of SuperKEKB. More detailed discussions will be found in the ensuing sections.

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.

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

- 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

TABLE I: Comparison of current experimental sensitivities with a 10 ab^{-1} sample and the five year Super$B$ 75 ab^{-1} sample. 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. [3, 4, 9].

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%
$\mathcal{B}(B \to K\nu\bar{\nu})$	X	X	16–20%
$S(K^0_S\pi^0\gamma)$	0.24	0.08	0.02–0.03

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.

- A 10 ab^{-1} sample is not sufficiently large 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 10 ab^{-1}, 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. 2 shows how well the $(\delta_{13})_{LL}$ can be reconstructed at Super$B$ with 10 ab^{-1}. Improvements in lattice QCD performance, 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 $\bar{\eta}$.

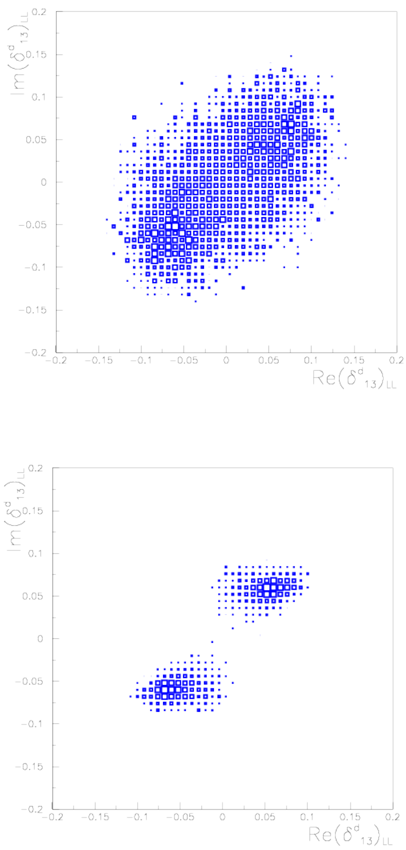

FIG. 2: Determination of the SUSY mass-insertion parameter $(\delta_{13})_{LL}$ with a 10 ab^{-1} sample (top) and with Super$B$ (bottom).

Charm Physics

At a Super-Flavour Factory one can analyze the weak decays of all charm hadrons in a comprehensive and detailed way with high experimental sensitivities. The main focus is on searching for manifestations of NP. The best opportunities are in probing CP invariance in nonleptonic as well as semileptonic transitions and to a lesser degree in rare decays. While even NP is unlikely to generate large effects, the 'background' from SM dynamics is in many cases truly minute. Thus the very fact of observing a CP asymmetry in many cases is tantamount to establish the intervention of NP – in marked contrast to the challenge one faces in B decays.

A dual 'sea change' concerning charm studies has been brought about in the last two years: on the experimental side it was caused by the observation of $D^0 - \bar{D}^0$ oscillations; it has in turn prompted theorists to analyze the impact of *non*-ad-hoc models of

NP, namely ones motivated by considerations *outside* of flavour dynamics.

A Super-flavour factory operating at the $\Upsilon(4S)$ resonance will yield 'en passant' huge sets of high quality charm data on charm, including searches for time dependent CP asymmetries. A unique and highly desirable feature of the design proposed here is that it would allow complementary running at the charm threshold. Furthermore one can rely on Initial State Radiation (ISR) to generate charm production at threshold during $\Upsilon(4S)$ operations; for the anticipated huge luminosities of a Super-Flavour Factory should lead to large statistics even for ISR processes with their intrinsic 'penalty' on rate.

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 $\mathcal{B}(\tau \rightarrow \mu\gamma)$ (2×10^{-9}) and in $\mathcal{B}(\tau \rightarrow \mu\mu\mu)$ decays (2×10^{-10}) gives Super$B$ a real chance to observe these LFV decays. These measurements are complementary to searches for $\mu \rightarrow e\gamma$ decay. In fact, the ratio $\mathcal{B}(\tau \rightarrow \mu\gamma)/\mathcal{B}(\mu \rightarrow e\gamma)$ is an important diagnostic of SUSY-breaking scenarios. If LFV decays such us $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow \mu\mu\mu$ 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] Y. Ohnishi, SuperKEKB Meeting, Atami, Izu, Japan, January 24-26, 2008. See also K. Kinoshita, BEACH 2008, Columbia, SC, June 23-28, 2008.
[3] T. Browder, M. Ciuchini, T. Gershon, M. Hazumi, T. Hurth, Y. Okada and A. Stocchi, JHEP **0802** (2008) 110 [arXiv:0710.3799 [hep-ph]].
[4] T. E. Browder, T. Gershon, D. Pirjol, A. Soni and J. Zupan, arXiv:0802.3201 [hep-ph].

1. B Physics at the Υ(4S)

A. New Physics in *CP* violation

1. ΔS measurements

It is possible to use time-dependent CP (TDCP) asymmetry measurements to search for signs of new physics (NP) in the form of heavy particles contributing to loop topologies and additional contributions from NP for tree level processes (See [1, 2]). In order for such a search to have a reasonable chance of seeing new physics one has to study a mode, or set of modes, that are loop (or penguin) dominated. The golden channels for this type of measurement fall into the category of penguin dominated TDCP measurements of $b \to s$ and $b \to d$ transitions and tree level $b \to c\bar{c}s$ transitions. These measurement can trigger the observation of new physics if the value of $S^f = \sin 2\beta_{\text{eff}}$ measured in one of these decays deviates significantly from that measured in the tree dominated $c\bar{c}s$ decays like $J/\psi K^0$ ($S = \sin 2\beta$), or from that predicted by the Standard Model (S^{SM}). The current level of such deviations $\Delta S^{tree} = S^{SM} - S$ and $\Delta S^{penguin} = S^f - S_{SM}$ from the theoretically clean penguin (tree) modes are 2.7σ (2.1σ) from the SM prediction [1, 2], and the deviation $\Delta S^f = S^f - S$ is small using current data. Such tantalizing hints of a deviation beckons us to study this area further in order to see of these deviations are indications of new physics, or if these effects are merely statistical fluctuations.

The interpretation of the precise data on the TDCP asymmetries in terms of the CKM parameters requires a reasonable control over the hadronic matrix elements. In particular, the ratio of the penguin versus the tree contribution has to be known from the theoretical side in order to turn the measurements of CP asymmetries into a test of the standard model.

Explicitly, the typical amplitude for a non-leptonic two-body decay can be written as:

$$A(B^0 \to f) = \mathcal{A}\left[1 + r_f\, e^{i\delta_f}\, e^{i\theta_f}\right], \qquad (1)$$

where usually $\mathcal{A}$ is the tree amplitude and r_f denotes the modulus of the penguin-over-tree ratio, which has a strong phase θ_f. The weak phase δ_f is in the cases at hand the CKM angle γ, while the modulus of the CKM factors is absorbed into r_f. The observables C^f and S^f can be expressed as:

$$C^f = -2r_f \sin\theta_f \sin\delta_f, \qquad (2)$$

$$S^f = \sin\phi + 2r_f \cos\theta_f \sin(\phi + \delta_f) + r_f^2 \sin(\phi + 2\delta_f), \qquad (3)$$

where ϕ is the mixing phase stemming from the $\Delta B = 2$ interaction.

The key issue in the theoretical understanding of CP asymmetries is the ratio r_f, which for the "gold-plated modes" is heavily CKM suppressed. However, at the precision of a Super Flavour Factory even a small r_f will be observable and hence relevant for the analysis.

There are basically three ways to assess the ratio r_f. From the purely theoretical side one may try to compute r_f either in the parton model, i.e. by calculating the relevant matrix elements in terms of quarks an gluons [3, 4] or in terms of hadronic intermediate states, making use of data for the resulting matrix elements [5]. The third possibility is to rely completely on data, making use of approximate symmetry relations between matrix elements [6–9].

Typically the partonic calculation yields a quite small ratio r_f, reflecting mainly the presence of the perturbative loop factor $1/(16\pi^2)$. On this basis the typical deviations $\Delta S^f = S^f - \sin\phi$ are of the order of 10^{-4} [4]. The calculations based on hadronic intermediate states yield larger results, however still at a level, which is currently unobservable, $\Delta S^f \sim 10^{-3} \cdots 10^{-2}$ [5].

Based on data there are indications that r_f in fact can be sizable [6]. As an example, based on the data of $B \to J/\psi\pi^0$ one extracts values for r_f which can be as large as 0.8, yielding shifts as large as $\Delta S^f \sim -7\%$ [7]. In fact the data on $B \to J/\psi\pi^0$ indicate a negative shift, which would soften the currently existing tension between $\sin 2\beta$ and V_{ub}.

Table II summarizes the state of current measurements [10], theoretical uncertainties [11–19] on the standard model interpretation of any deviation. The new physics discovery potential deviations required at a Super*B* factory to observe new physics are also shown. Where appropriate, reducible systematic uncertainties, and data driven bounds on the SM uncertainties have been scaled by luminosity from current measurements in making these extrapolations.

The golden $b \to s$ penguin modes for this new physics search are $B^0 \to \eta' K^0$ and $B^0 \to K^0_S K^0_S K^0_S$. Some theoretical work is required to better understand the standard model pollution in $B^0 \to f_0^0 K^0_S$ and $B^0 \to \phi K^0_S \pi^0$. Long distance contributions were neglected when computing the SM uncertainty for $f_0^0 K^0_S$, whereas $B^0 \to \phi K^0_S \pi^0$ is expected to be theoretically clean. If the SM uncertainty can be computed with comparable precision to the golden modes, both $f_0^0 K^0_S$ and $\phi K^0_S \pi^0$ would be as precise as the other golden modes mentioned. The golden $b \to d$ process is $B^0 \to J/\psi\pi^0$.

One can see from the table that it is possible to discover new physics if there is a deviation of 0.01 from SM expectations of sin2β as measured in tree decays. It is possible to observe a deviation of 5σ or more of about 0.1 in $\sin 2\beta_{\text{eff}}$ from $b \to s$ transitions in the golden modes. A similar level of precision can also be reached using the golden $b \to d$ modes.

2. The $A_{K\pi}$ puzzle

The phenomenon of direct *CP* violation is an intriguing one, however the use of measurements in comprehending the SM or new physics rests on our understanding of strong phase differences that are difficult

TABLE II: Current experimental precision [10], and that expected at a Super$B$ experiment with 75 ab^{-1} of data. The 5σ discovery limit deviations at 75 ab^{-1} are also listed. The first entry in the table corresponds to the tree level calibration mode, and the next two sections of the table refer to $b \to s$ and $b \to d$ transitions. A long dash '−'denotes that there is no theoretical uncertainty computed yet for a given mode, thus the corresponding 3 and 5σ deviations are best case scenarios.

Mode	Current Precision			Predicted Precision (75 ab^{-1})			Discovery Potential	
	Stat.	Syst.	Th.	Stat.	Syst.	Th.	3σ	5σ
$J/\psi K_S^0$	0.022	0.010	< 0.01	0.002	0.005	< 0.001	0.02	0.03
$\eta' K_S^0$	0.08	0.02	0.014	0.006	0.005	0.014	0.05	0.08
$\phi K_S^0 \pi^0$	0.28	0.01	–	0.020	0.010	–	0.07	0.11
$f_0 K_S^0$	0.18	0.04	0.02	0.012	0.003	0.02	0.07	0.12
$K_S^0 K_S^0 K_S^0$	0.19	0.03	0.013	0.015	0.020	0.013	0.08	0.14
ϕK_S^0	0.26	0.03	0.02	0.020	0.010	0.005	0.09	0.14
$\pi^0 K_S^0$	0.20	0.03	0.025	0.015	0.015	0.025	0.10	0.16
ωK_S^0	0.28	0.02	0.035	0.020	0.005	0.035	0.12	0.21
$K^+ K^- K_S^0$	0.08	0.03	0.05	0.006	0.005	0.05	0.15	0.26
$\pi^0 \pi^0 K_S^0$	0.71	0.08	–	0.038	0.045	–	0.18	0.30
ρK_S^0	0.28	0.07	0.14	0.020	0.017	0.14	0.41	0.61
$J/\psi \pi^0$	0.21	0.04	–	0.016	0.005	–	0.05	0.08
$D^{*+} D^{*-}$	0.16	0.03	–	0.012	0.017	–	0.06	0.11
$D^+ D^-$	0.36	0.05	–	0.027	0.008	–	0.09	0.14

to calculate directly. Data driven methods can be used to constrain the strong phase differences, and in doing so one has the possibility to use direct *CP* violation measurements as a tool to test the SM and probe for new physics.

One conundrum that has been perplexing the community for several years is the so called $K\pi$ puzzle. In the SM the difference $\Delta A_{K\pi}$ between the direct *CP* asymmetry in $B_z \to K^\pm \pi^\mp$ and $B^\pm \to K^\pm \pi^0$ is expected to be small and positive. The world average of this quantity turns out to be -0.148 ± 0.028, which is clearly different from expectations [20, 21]. It has been noted that the difference observed here could be a sign of new physics, however the question of weather a more detailed understanding of the hadronic dynamics of these decays would resolve the discrepancy remained a possibility. Super$B$ will be able to perform a precision measurement of the direct *CP* asymmetries in these modes, an in turn will be capable of doing a precision measurement of $\Delta A_{K\pi}$.

B. Mixing and *CP* Violation in Mixing

The measurement of the mixing frequency Δm_d at Super$B$ is of interest as this physics parameter will come to be a significant systematic uncertainty in many of the time-dependent *CP* asymmetry studies and other new physics searches. The current precision on this parameter is dominated by early measurements of the B-Factories, so there is the potential to improve knowledge of this parameter sufficiently so that it no longer plays an important role in error evaluation of other more important observables. It is anticipated that one will be able to measure Δm_d with a precision of better than ± 0.006 at Super$B$ and will be systematically limited. This level of precision is comparable with the current PDG average value [22].

With the discoveries of *CP* violation in decay and indirect *CP* violation at the B-Factories, it is natural to continue to search for *CP* violation in mixing. The test for this phenomenon is a part of generic time-dependent *CP* violation measurements where one searches for $|\lambda| = q/p \neq 0$, where q/p. The cosine coefficient measured at the same time as the ΔS parameters discussed previously are related to $|\lambda|$, and the Charmonium decays are a good place to search for CP violation in mixing where Super$B$ will be able to achieve a precision on $C = (1 - |\lambda|^2)/(1 + |\lambda|^2)$ of 0.005 with $J/\psi K^0$. It is possible to perform a precision measurement of $|q/p|$ using di-lepton events with a precision of a few per mille as discussed in Section 1 D.

C. New Physics in mixing

It is possible to search for signs of new physics in mixing in a model independent way. This is done, starting from a tree level determination of the apex of the unitarity triangle $(\overline{\rho}, \overline{\eta})$, and searching for any perturbation from the SM solution using a generic parameterization of new physics with an amplitude and phase, in addition to the SM contribution. The ratio of new physics and standard model amplitudes can be parameterized simply in terms of an amplitude ratio C_d and phase difference ϕ_{B_d}:

$$C_d e^{2i\phi_{B_d}} = \frac{\langle B_d|\mathcal{H}_{eff}^{NP+SM}|\overline{B}_d\rangle}{\langle B_d|\mathcal{H}_{eff}^{SM}|\overline{B}_d\rangle} = \frac{A_d^{SM}e^{2i\phi_d^{SM}} + A_d^{NP}e^{2i(\phi_d^{SM}+\phi_d^{NP})}}{A_d^{SM}e^{2i\phi_d^{SM}}}$$

where the SM phase for B_d mixing $\phi_d^{SM} = \beta$. The corresponding constraints on the new physics phase and amplitude ratios are given in Fig. 3. Current data is consistent with small values of the amplitude for new physics, and a large new physics phase. Using data from Super*B* we would be able to make a precision search for new physics in B_d mixing.

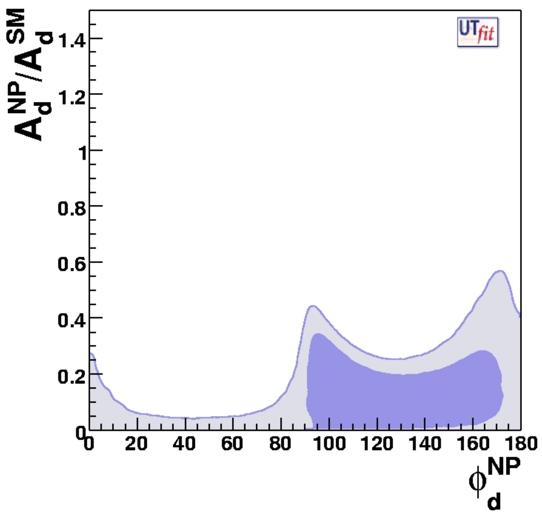

FIG. 3: Constraints on possible new physics amplitude and phase contributions to B_d mixing [23]. **TO COMPLETE ...**Add a second plot with what one would expect at Super*B* precision.

D. Tests of *CPT*

The combined symmetry of C, P, and T otherwise written as *CPT* is conserved in locally gauge invariant quantum field theory. The role of *CPT* in our understanding of physics is described in more detail in Refs. [24–27] and an observation of *CPT* violation would be a sign of new physics. *CPT* violation could be manifest in neutral meson mixing, so a Super Flavour Factory is well suited to test this symmetry. The textbook description of neutral meson mixing in terms of the complex parameters p and q can be extended to allow for possible *CPT* violation. On doing so the heavy and light mass eigenstates of the B_z meson $B_{\rm H}$ and $B_{\rm L}$ become

$$|B_{\rm L,H}\rangle = p\sqrt{1\mp z}|B_z\rangle \pm q\sqrt{1\pm z}|\overline{B}^0\rangle,$$

where B_z and $\overline{B}^0$ are the strong eigenstates of the neutral B meson. The *CPT* conserving solution is recovered when $z = 0$ and if *CP* and *CPT* are conserved in mixing then $|q|^2 + |p|^2 = 1$.

There are two types of *CPT* test that have been performed at the current B-factories. The more powerful of these methods is the analysis of di-lepton events where both B mesons in an event decay into an $X^{\mp}\ell^{\pm}\nu$ final state. Di-lepton events can be categorized by lepton charge into three types: $++$, $+-$ and $--$ where the numbers of such events N^{++}, N^{+-} and N^{--} are related to $\Delta\Gamma$ and z as a function of Δt as described in Ref. [28]. Using these distributions one can construct two asymmetries: the first is a T/CP asymmetry:

$$\mathcal{A}_{T/CP} = \frac{P(\overline{B}^0\to B_z) - P(B_z\to\overline{B}^0)}{P(\overline{B}^0\to B_z) + P(B_z\to\overline{B}^0)} = \frac{N^{++} - N^{--}}{N^{++} - N^{--}} = \frac{1-\left|\frac{q}{p}\right|^4}{1+\left|\frac{q}{p}\right|^4},$$

and the second is a *CPT* asymmetry:

$$\mathcal{A}_{CPT}(\Delta t) = \frac{N^{+-}(\Delta t>0) - N^{+-}(\Delta t<0)}{N^{+-}(\Delta t>0) + N^{+-}(\Delta t<0)} \simeq 2\frac{{\rm Im}z\sin(\Delta m_d\Delta t) - {\rm Re}z\sinh\left(\frac{\Delta\Gamma\Delta t}{2}\right)}{\cosh\left(\frac{\Delta\Gamma\Delta t}{2}\right) + \cos(\Delta m_d\Delta t)},$$

where $\mathcal{A}_{CPT}(\Delta t)$ is sensitive to $\Delta\Gamma\times{\rm Re}z$. In the SM $\mathcal{A}_{T/CP}\sim 10^{-3}$ and $\mathcal{A}_{CPT} = 0$ [29, 30]. *BABAR* measures [31]:

$$\left|\frac{q}{p}\right| - 1 = (-0.8\pm 2.7({\rm stat})\pm 1.9({\rm syst}))\times 10^{-3},$$
$${\rm Im}z = (-13.9\pm 7.3({\rm stat})\pm 3.2({\rm syst}))\times 10^{-3},$$
$$\Delta\Gamma\times{\rm Re}z = (-7.1\pm 3.9({\rm stat})\pm 2.0({\rm syst}))\times 10^{-3},$$

which is compatible with no *CP* violation in $B_z - \overline{B}^0$ mixing and *CPT* conservation. It is possible to study variations as a function of sidereal time, where 1 sidereal day is approximately 0.99727 solar days [32] where z depends on the four momentum of the B candidate. *BABAR* re-analyzed their data to and find that it is consistent with $z = 0$ at 2.8 standard deviations [28].

With data from the first few years of operation at Super$B$ it would be possible to perform a more precise test of CPT than performed by the current experiments and on doing so continue the search for CPT violation. These measurements would become limited by systematic uncertainties after the first few years of running at Super$B$. The precision on CPT violating observables that could be reached with Super$B$ is:

$$\sigma(\mathrm{Im})z = 0.6 \times 10^{-3},$$
$$\sigma(\Delta\Gamma \times \mathrm{Re}z) = 0.3 \times 10^{-3},$$

However with such a measurement it would be possible to test if the 2.8σ hint for CPT violation were a real effect or the result of a statistical fluctuation.

E. $|V_{ub}|$

F. $|V_{cb}|$

G. Rare B decays

$b \to \tau\nu$ Specifically mention the current limits from the Tevatron, expectations from the LHC with 30 and 100 fb^{-1}, and compare these with the current B-factories, and SuperB expectations

H. Semi-leptonic B decays

I. Radiative B decays

J. Phenomenology

1. New Physics

2. Precision CKM

By the time Super$B$ starts to take data it is expected that the knowledge of the CKM matrix parameters (sides and angles) will be dominated by a combination of measurements from the B-factories and LHCb. These will include measurements of β and γ with a precision of the order of 1°, and a measurement of α with a precision of $5-6°$. LHCb will not be able to improve upon the existing measurements of $|V_{ub}|$ and $|V_{cb}|$, which have uncertainties of 8% and 4%, respectively. SuperB will be able to perform precision measurements of the angles of the unitarity triangle as well as $|V_{ub}|$ and $|V_{cb}|$. The anticipated precision attainable for these observables is given in Table III. Together this set of information will play a vital role in defining a model-independent determination of quark mixing in the Standard Model, thus providing a precision test of the CKM anzatz. Precision knowledge of the CKM matrix itself facilitates several new physics search opportunities available to Super$B$ and other experiments.

TABLE III: The expected precision on CKM observables from Super$B$. The third column indicates if the measurement is theoretically clean, or dominated by theory uncertainties.

CKM observable	Precision (75 ab^{-1})	Theory uncertainty
β ($c\bar{c}s$)	0.1°	clean
α	$1-2°$	dominant
γ	$1-2°$	clean
$\lvert V_{cb}\rvert$ (inclusive)	0.5%	dominant
$\lvert V_{cb}\rvert$ (exclusive)	1.0%	dominant
$\lvert V_{ub}\rvert$ (inclusive)	2.0%	dominant
$\lvert V_{ub}\rvert$ (exclusive)	3.0%	dominant

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2. B Physics at the Υ(5S)

Measurement of CKM- and New Physics-related quantities in the B_s sector is a natural extension of the traditional B Factory program. In some cases, studies of B_s mesons allow the extraction of the same fundamental quantities accessible at a B Factory operating at the Υ(4S) resonance, but with reduced theoretical uncertainty. Experiments running at hadronic machines are expected to be the main source of B_s-related measurements. In particular, in the near future, the increased dataset of the Tevatron experiments and the start of the LHCb, ATLAS, and CMS programs will surely yield important new results.

It is also worth noting, however, that despite the rapid $B_s\overline{B}_s$ oscillation frequency, it is also feasible to carry out B_s studies in the very clean environment of e^+e^- annihilation machines by running at the $\Upsilon(5S)$ resonance, where it is possible to perform measurements involving neutral particles (*e.g.*, π^0, η and η' mesons, radiative photons, *etc.*) CLEO [1–3] and Belle [4, 5] have had short runs at the $\Upsilon(5S)$, measuring the main features of this resonance. The results clearly indicate the potential for an e^+e^- machine to contribute to this area of B physics, and have inspired the work in this section, and elsewhere [6–8]. Note that, in contrast to much of the remainder of this chapter, there are no experimental analyses for many of the measurements of interest, and therefore our studies are based on Monte Carlo simulations.

A detailed study of the physics capability of Super$B$ at the $\Upsilon(5S)$ can be found in the Conceptual Design Report [9]. The main conclusions of that study are summarized here.

The production of B_s mesons at the $\Upsilon(5S)$ allows comprehensive studies of the decay rates of the B_s with a completeness and accuracy comparable to that currently available for B_d and B_u mesons, thereby improving our understanding of B physics and helping to reduce the theoretical uncertainties related to New Physics-sensitive B_d quantities. Moreover, B_s physics provides additional methods and observables to probe New Physics effects in $b \to s$ transitions. In the following, we concentrate on this second point, providing examples of some of the highlight measurements that could be performed by Super$B$ operating at the $\Upsilon(5S)$ resonance.

The $\Upsilon(5S)$ resonance is a $J^{PC} = 1^{--}$ state of a $b\bar{b}$ quark pair with an invariant mass of $m_{\Upsilon(5S)} = (10.865 \pm 0.008)$ GeV/c^2 [10–12]. The cross section $\sigma(e^+e^- \to \Upsilon(5S))$ is $0.301 \pm 0.002 \pm 0.039$ nb [13], which is about three times smaller than $\sigma(e^+e^- \to \Upsilon(4S))$. Unlike the $\Upsilon(4S)$ state, this resonance is sufficiently massive to decay into several B meson states: vector-vector ($B^*\bar{B}^*$), pseudoscalar-vector ($B\bar{B}^*$), and pseudoscalar-pseudoscalar (BB) combinations of charged B mesons, as well as neutral B_d and B_s mesons, as well as into $B^{(*)}\bar{B}^{(*)}\pi$ states. The B pair production rates at the $\Upsilon(5S)$ resonance are summarized in Ref. [9]. As with reconstructing B decays at the $\Upsilon(4S)$, one can use the precisely determined initial state kinematics to compute the usual discriminating variables $m_{\rm ES}$ and ΔE. There is a small complication that the different B pairs produced occupy slightly different regions in the $m_{\rm ES} - \Delta E$ plane and this can be used to study fine details of the decay properties of these B mesons. With the small beam energy spread of Super$B$, the resolution of $m_{\rm ES}$ will be comparable to the current B Factories, resulting in almost negligible crossover between $B_s\overline{B}_s$ and $B\overline{B}\pi$ states.

3. *Measurement of B_s Mixing Parameters*

In analogy with the B_d system, the absolute value and the phase of the $B_s\overline{B}_s$ mixing amplitude can be used to test for the presence of New Physics in $\Delta B = 2$ $b \to s$ transitions. These measurements can be made at hadronic colliders [14]. The recent measurement of Δm_s [15–17] provides the first milestone in this physics program. Similar tests for New Physics effects can be made by measuring quantities such as $\Delta\Gamma_s$ and the CP asymmetry in semileptonic decays $A^s_{\rm SL}$. These observables can be measured using the large statistics, and high reconstruction efficiency available in the clean environment of Super$B$. It is not necessary to resolve B_s oscillations to make these measurements.

In a generic New Physics scenario, the effect of $\Delta B = 2$ New Physics contributions can be parameterized in terms of an amplitude and phase, C_{B_s} and

ϕ_{B_s}, (in analogy with Section 1 C). In the absence of New Physics effects, $C_{B_s} = 1$ and $\phi_{B_s} = 0$. The measured values of Δm_s and $\sin 2\beta_s$ are related to Standard Model quantities through the relations :

$$\Delta m_s^{\rm exp} = C_{B_s} \cdot \Delta m_s^{\rm SM}, \quad (4)$$
$$\sin 2\beta_s^{\rm exp} = \sin(2\beta_s^{\rm SM} + 2\phi_{B_s})\,. \quad (5)$$

The semileptonic *CP* asymmetry [18] and the value of $\Delta\Gamma_s/\Gamma_s$ [19] are sensitive to New Physics contributions to the $\Delta B = 2$ effective Hamiltonian, and can be expressed in terms of the parameters C_{B_s} and ϕ_{B_s}.

Different experimental methods have been proposed to extract the lifetime difference $\Delta\Gamma_s$ [20]. For instance, $\Delta\Gamma_s$ can be obtained from the angular distribution of untagged $B_s \to J/\psi\phi$ decays. This angular analysis allows separation of the *CP* odd and *CP* even components of the final state, which have a distinct time evolution, given by different combinations of the two exponential factors $e^{-\Gamma_{L,H}t}$. This allows the extraction of the two parameters $\Gamma_{L,H}$ or, equivalently, Γ_s and $\Delta\Gamma_s$. The weak phase of the mixing amplitude, β_s, also appears in this parameterization, and a constraint on this phase can be extracted along with the other two parameters (see Eq. 7 below). Measurements of $\Delta\Gamma_s$ and β_s have been performed by CDF [21] and DØ [22]. With a few ab^{-1} of data at the $\Upsilon(5S)$ Super*B* will be able to improve upon the current experimental precision, and provide a useful second measurement to cross check any results from LHCb in this area.

We have also studied the performance of two different experimental techniques that can be used to to extract the semi-leptonic asymmetry $A^s_{\rm SL}$, defined as:

$$A^s_{\rm SL} = \frac{1-|q/p|^4}{1+|q/p|^4}\,. \quad (6)$$

The first technique consists of exclusively reconstructing one of the two B mesons into a self-tagging hadronic final state (such as $B_s \to D_s^{(*)}\pi$) and looking for the signature of a semi-leptonic decay (high momentum lepton) in the rest of the event. The second approach is more inclusive, using all events with two high momentum leptons. In this case, contributions from B_s and B_d decays cannot be separated, and a combined asymmetry, $A_{\rm CH}$ is measured. Results from this type of analysis are available from DØ [23]. We expect to be able to reach precisions of 0.006 and 0.004 on $A^s_{\rm SL}$ and $A_{\rm CH}$, respectively, with 1 ab^{-1} of data. These measurements quickly become systematically limited at Super*B*, however the achievable precision would be a clear improvement over the current experimental situation. The cleaner experimental environment at Super*B* suggests that this experiment is better suited at making precision measurements of the semi-leptonic asymmetries than experiments at a hadron collider. The measurement of $A^s_{\rm SL}$ (and, to a lesser extent, also to $A^d_{\rm SL}$), can be used to test the Littlest Higgs Model with T-parity as discussed in Ref. [9].

4. Time Dependent CP Asymmetries at the $\Upsilon(5S)$

Let us consider a B_s pair produced at the $\Upsilon(5S)$ resonance, through a $B_s^*\overline{B}_s^*$ state. If one of the two B_s mesons decays into a *CP* eigenstate f and the other to a flavour-tagging final state, the untagged time-dependent decay rate $R(\Delta t)$ as a function of the proper time difference Δt can be written in terms of the parameter $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$ as [19]:

$$R(\Delta t) = \mathcal{N}\frac{e^{-|\Delta t|/\tau(B_s)}}{2\tau(B_s)}\Big[\cosh(\frac{\Delta\Gamma_s \Delta t}{2}) - \frac{2\,\Re(\lambda_f)}{1+|\lambda_f|^2}\sinh(\frac{\Delta\Gamma_s\Delta t}{2})\Big]\,, \quad (7)$$

where the normalization factor $\mathcal{N}$ is fixed to $1-(\frac{\Delta\Gamma_s}{2\Gamma_s})^2$. Here we have neglected *CP* violation in mixing.

It is not possible to perform a a similar time-dependent analysis to that for the case of $B_d \to J/\psi K^0$ decays, at Super*B* as the detector would be unable to resolve the very fast B_s oscillations. However, since $\Delta\Gamma_s \neq 0$, the untagged time-dependent decay rate also allows λ_f to be probed, through the $\Re(\lambda_f)$-dependence of the coefficient of the Δt-odd $\sinh(\frac{\Delta\Gamma_s\Delta t}{2})$ term. Such an analysis has been performed by DØ [24, 25]. A "two-bin" time-dependent analysis using this approach is possible at Super*B*.

If one considers the decay $B_s \to J/\psi\phi$ decay, and for simplicity assumes that this is a pure *CP*-even eigenstate (more generally a full angular analysis can be used to isolate *CP*-even and *CP*-odd contributions), it is possible to measure the weak phase of B_s mixing $2\beta_s$. A precision of $\sim 10^\circ$ and $\sim 3^\circ$ can be achieved on β_s, with 1 ab^{-1} and 30 ab^{-1} of integrated luminosity, respectively. There is a two-fold ambiguity resulting from the sign of β_s that can produce almost twice the resolution in the measurement, when β_s has a value close to zero as in the SM. Such a measurement as this is not limited by systematics and the precision can be improved by collecting more data.

While LHCb is expected to achieve a better precision on the measurement of β_s using a tagged analysis of $B_s \to J/\psi\phi$, the strength of Super*B* lies in the ability to make measurements that are not possible in a hadronic environment, in analogy with the ΔS measurements discussed for B_d decays (Section 1 A) there are effective β_s (denoted $\beta_{s,\rm eff}$) that will form a secondary basis for new physics searches. As with the B_d case it will be necessary to compare the SM expectations of β_s, with the measurements from tree decays and with $\beta_{s,\mathrm{eff}}$ from penguin dominated rare decay. Among the interesting final states Super$B$ can study are $B_s \to J/\psi\eta$, $B_s \to J/\psi\eta'$, $B_s \to D_s^{(*)+}D_s^{(*)-}$, $B_s \to D^{(*)}K_S^0$, $B_s \to D^{(*)}\phi$, $B_s \to J/\psi K_S^0$, $B_s \to \phi\eta'$ and $B_s \to K_S^0\pi^0$. Studies on the measurement of the effective β_s using the pure $b \to s$ penguin transition $B_s \to K^0\bar{K}^0$, indicate that Super$B$ will be able to measure this phase with a precision of 11° assuming a data sample of 30 ab^{-1}.

5. *Rare Radiative B_s Decays*

It is possible to search for possible NP effects by comparing measurements of $\Delta B = 1$ $b \to s$ transitions, measurements of $|V_{td}/V_{ts}|$, and Δm_s. Super$B$ will be able to perform a precision measurement of $|V_{td}/V_{ts}|$ using the ratio $R = \mathcal{B}(B_d^0 \to \rho^0\gamma)/\mathcal{B}(B_d \to K^{*0}\gamma)$ to a precision that is expected to be ultimately limited by the presence of a power-suppressed correction term. The ratio $R_s = \mathcal{B}(B_s^0 \to K^{*0}\gamma)/\mathcal{B}(B_d^0 \to K^{*0}\gamma)$ has the advantage that there is no W exchange diagram contribution to hinder interpretation of results. Assuming that $\mathcal{B}(B_s^0 \to K^{*0}\gamma) = 1.54 \times 10^{-6}$, and taking reasonable estimates from lattice QCD for the form factor ratio ξ to extract $|V_{td}/V_{ts}|$ with a precision of a few percent with a multi- ab^{-1} sample of data. As shown in in Table V,

6. *Measurement of $B_s \to \gamma\gamma$*

In analogy with the B_d decay $b \to s\gamma$, the decay $B_s \to \gamma\gamma$ is considered a promising golden channel to search for new physics at Super$B$. The final state contains both CP-odd and CP-even components, allowing for the study of CP-violating effects with B Factory tagging techniques. The Standard Model expectation for the branching ratio is $\mathcal{B}(B_s \to \gamma\gamma) \sim (2-8)\times 10^{-7}$ [26]. New Physics effects are expected to give sizable contributions to the decay rate in certain scenarios [27, 28]. For instance, in R-parity-violating SUSY models, neutralino exchange can enhance the branching ratio up to $\mathcal{B}(B_s \to \gamma\gamma) \simeq 5 \times 10^{-6}$ [29]. On the other hand, in R-parity-conserving SUSY models, in particular in softly broken supersymmetry, $\mathcal{B}(B_s \to \gamma\gamma)$ is found to be highly correlated with $\mathcal{B}(b \to s\gamma)$ [30].

Experimentally the measurement of $B_s \to \gamma\gamma$ will be much less demanding at Super$B$ than the well established measurement of final states such as $B_d^0 \to \pi^0\pi^0$. The presence of two high-energy photons in the final state is a clear signature for the signal, particularly with a recoil technique. Both *BABAR* [31] and Belle [32] have published results of searches for $B_d^0 \to \gamma\gamma$, setting the current experiment upper limit at $\mathcal{B}(B_d \to \gamma\gamma) < 6.2 \times 10^{-7}$ which is a proof of principle that one can measure the corresponding B_s decay at Super$B$. We anticipate that it will be possible to observe 14 signal events and 20 background events in a sample of 1 ab^{-1} assuming a Standard Model branching fraction. With 30 ab^{-1}, one can achieve a statistical error of 7% and a systematic error smaller than 5% from a straight forward analysis. It would be possible to improve upon this precision using tagging information, which would also facilitate the measurement of a direct CP asymmetry in this mode.

7. *Phenomenological Implications*

The experimental measurements of $\Delta\Gamma$, A_{SL}^s, A_{CH} and CP violation parameters described in the previous sections can be used to determined the $\Delta B = 2$ New Physics contributions in the B_s sector. The knowledge of $\overline{\rho}$ and $\overline{\eta}$ is assumed to come from studies at the $\Upsilon(4S)$.

To illustrate the impact of the measurement at Super$B$ at the $\Upsilon(5S)$, we show in Fig. 4 selected regions in the ϕ_{B_s}–C_{B_s} plane (right), compared to the current situation (left). Corresponding numerical results are given in Table IV.

TABLE IV: Uncertainty of New Physics parameters ϕ_{B_s} and C_{B_s} using the experimental and theoretical information available at the time of Super$B$ and given in Tables V (30 ab^{-1}) and **??** (Lattice inputs**TO COMPLETE ...**). These uncertainties are compared to the present determination.

Parameter	Today	At Super$B$ (30 ab^{-1})
ϕ_{B_s}	$(-3 \pm 19)^\circ \cup (94 \pm 19)^\circ$	$\pm 1.9^\circ$
C_{B_s}	1.15 ± 0.36	± 0.026

It is important to note that the uncertainty on the parameter C_{B_s} is dominated by the uncertainty on f_{B_s} and bag parameters. The error on ϕ_{B_s} is not limited by systematics and theory, and can be improved to 1–2° with a longer dedicated run at the $\Upsilon(5S)$. LHCb will also measure the New Physics phase ϕ_{B_s} and is expected to achieve a comparable sensitivity with full statistics (~ 10 fb^{-1}) of $\sim 1^\circ$.

A. Summary

The results presented in this section section are summarized in Table V for two scenarios (i) a short (1 ab^{-1}) and (ii) a long (30 ab^{-1}) run at the $\Upsilon(5S)$ resonance. Collecting 1 ab^{-1} will take less

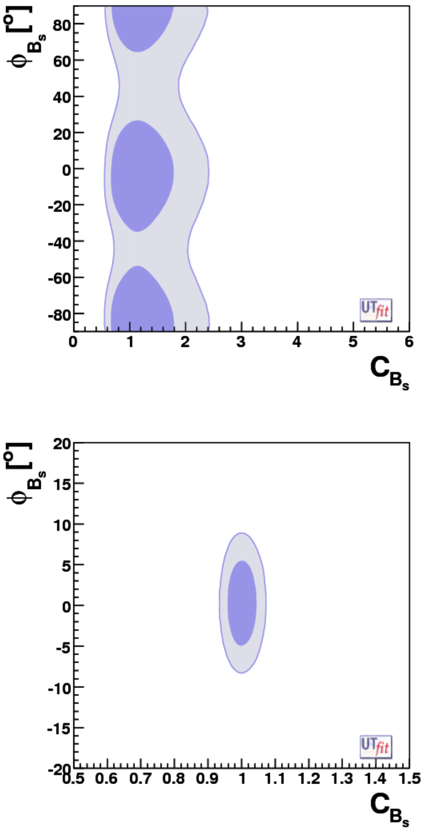

FIG. 4: Allowed regions in the C_{B_s}–ϕ_{B_s} plane given by the current data (left) and at the time of Super$B$ (right). Note that the scales for the axes are different in the two cases.

than one month at the Super$B$ design luminosity of 10^{36} cm^{-2} sec^{-1}.

While it is clear that Super$B$ cannot compete with hadronic experiments on modes such as $B_s \to \mu^+\mu^-$ and $B_s \to J/\psi\phi$, it is also evident that many important channels that are not easily accessible at hadronic experiments such as LHCb will be measurable at Super$B$. The golden channels $B_s \to \gamma\gamma$ and $B_s \to K^0\bar{K}^0$ will be measurable at Super$B$. Therefore Super$B$ will complement the results from LHCb and enrich the search for new physics in flavour decays by accumulating several ab^{-1} of data at the $\Upsilon(5S)$ resonance.

Measuring an absolute branching fraction in a hadronic environment is limited by ones determination of luminosity. So in addition to being able to study these B_s golden modes, it is anticipated that there will be befits to the field when interpreting some LHCb analyses if one can obtain precision measurements of a number of absolute branching fractions from Super$B$, especially when, as in the case of determining the long distance contribution to $B_s \to \mu^+\mu^-$ one needs to understand a decay channel with a neutral final state like $B_s \to \gamma\gamma$. In time an understanding of the full list of branching fractions are useful to strengthen LHCb programme will develop, and measurement of these will enrich both the Super$B$ and LHCb physics output.

TABLE V: Summary of the expected precision of some of the most important measurements that can be performed at Super$B$ operating at the $\Upsilon(5S)$ resonance, with an integrated luminosity of 1 ab^{-1} and 30 ab^{-1}.

Observable	1 ab^{-1}	30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
$A^s_{\rm SL}$	0.006	0.004
$A_{\rm CH}$	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8 \times 10^{-9}$
$\lvert V_{td}/V_{ts}\rvert$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s (angular analysis)	20°	8°
β_s ($J/\psi\phi$)	10°	3°
β_s ($K^0\bar{K}^0$)	24°	11°

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3. Charm Physics

The SM projects a rather dull weak phenomenology for charm transitions; yet as has been stated since the early discussions about a Tau-Charm Factory in the late 1980's, this fact can be turned to our advantage: detailed studies in particular of CP invariance in charm decays can act as (almost) zero-background searches for physics beyond the SM. While no clear signal for the intervention of NP has been uncovered yet in charm transitions, the situation has changed qualitatively in the last two years:

- $D^0 - \bar{D}^0$ oscillations have been resolved experimentally with x_D, $y_D \sim 0.5 - 1\%$.
- This breakthrough has lead to 'new thinking' among theorists. They have began to realize that scenarios of NP motivated by considerations *outside* of flavour dynamics can produce an observable footprint in charm decays; i.e., one is no longer forced to invoke the old 'stand-by' of NP scenarios, namely SUSY models with *broken R* parity, to produce observable effects in an ad-hoc fashion. There is every reason to think that this emerging renaissance of creative thinking about charm dynamics will continue and bear novel fruits.

The Super-Flavour Factory allows comprehensive charm studies in three different environments:

1. One has the large production rate of charm mesons and baryons at the $\Upsilon(4S)$ and can benefit greatly from the Lorentz boost imparted onto the charm hadrons.
2. Through ISR processes one can implement charm production at threshold in a C odd configuration. It is precisely the ultrahigh luminosity of a Super-Flavour Factory that makes this a significant rate despite its intrinsic suppression.
3. The Super-Flavour Factory design discussed here allows running at the charm threshold region, where one can make use of quantum correlations. The anticipated ultrahigh luminosity is again crucial, since high statistics can be achieved with relatively limited running.

A. On the Uniqueness of Charm

NP will in general induce flavour changing neutral currents (FCNC). The SM had to be crafted judiciously to have them greatly suppressed for strangeness; the weight of FCNC is then even more reduced for the up-type quarks u, c and t. Yet NP scenarios could exhibit a very different pattern with FCNC being significantly more relevant for up-type quarks.

Among those it is only the charm quark that allows the full range of probes for FCNC in general and for CP violation in particular [**?**]. For top quarks do not hadronize [**?**] thus eliminating the occurrence of $T^0 - \bar{T}^0$ oscillations. Neutral pions etc. cannot oscillate, since they are their own antiparticles; furthermore CPT constraints are such that they rule out most CP asymmetries.

B. $D^0 - \bar{D}^0$ Oscillations

1. *Experimental Status*

While the existence of $D^0 - \bar{D}^0$ oscillations is considered as established - $(x_D, y_D) \neq (0, 0)$ - the size of

x_D, y_D and even their relative strengths are not known with sufficient accuracy to know if *CPV* is manifest in mixing. Their accurate values will hardly shed light on their theoretical interpretation; yet having them is not merely a 'noble goal' (G. Wilkinson), but a practical one: for knowing their values with some accuracy will help validate measurements of the presumably small CP asymmetries, as discussed later.

So far, almost all the information on mixing parameters has come from decays where the final state f is accessible to either D^0 or $\overline{D}^0$. In all such decays, deviations from exponential behaviour in the number of D^0 ($\overline{D}^0$)'s, $N(\bar{N})$, at time t have been exploited. To second order in x and y,

$$\begin{aligned} N(t) &= N(0)e^{-\Gamma t} \times [1 + \frac{x^2+y^2}{4}|\lambda_f|^2(\Gamma t)^2 \\ &+ |\lambda_f|(y\cos\overline{\delta_f+\phi_f} - x\sin\overline{\delta_f+\phi_f})(\Gamma t)] \\ \bar{N}(t) &= \bar{N}(0)e^{-\Gamma t} \times [1 + \frac{x^2+y^2}{4}|\lambda_f|^{-2}(\Gamma t)^2 \\ &+ |\lambda_f|^{-1}(y\cos\overline{\delta_f-\phi_f} - x\sin\overline{\delta_f-\phi_f})(\Gamma t)] \end{aligned} \tag{8}$$

where

$$\lambda_f = \left(q\bar{\mathcal{A}}_f\right)/\left(p\mathcal{A}_f\right), \quad \phi_f = \psi_f + \phi_M, \quad \phi_m = \arg q/p.$$

The decay amplitudes $\mathcal{A}_f$ and $\bar{\mathcal{A}}_f$ describe, respectively, the processes $D^0 \to f$ and $\overline{D}^0 \to f$) with relative strong (weak) phases δ_f (ψ_f).

The strong phase δ_f is generally unknown. However, when f is a (self-conjugate) *CP*-eigenstate, it is zero. In such cases, for 3-body conjugate final states ("golden decays") it is possible to measure x_D, y_D, $|q/p|$ and ϕ_m using time-dependent Dalitz plot (TDDP) analyses.

The first and second terms in (8) correspond, respectively, to direct decay ($D^0 \to f$) [1], and to decay after mixing ($D^0 \to \overline{D}^0 \to f$). The third term, linear in t, is due to the interference between these two.

Three kinds of successful mixing parameter measurements have exploited the linear dependence of this term upon x and y (both $\ll 1$): WS decays $D^0 \to K^+\pi^-$; decays to *CP* eigen-states h^-h^+ ($h = K$ and $h = \pi$); and decays to 3-body states ($K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$ and $K^0_S K^+K^-$).

Wrong-sign (WS) semi-leptonic decays $D^0 \to X^+\ell^-\bar{\nu}_\ell$ have also been examined for mixing. Such decays can only arise from mixing ($D^0 \to \overline{D}^0$) followed by decay, so their time-dependence is described by the second term alone in Eq. (8). So the rates, $\propto (x^2+y^2)/4 \sim 5 \times 10^{-5}$, are very small and only upper limits have, so far, been found.

2. WS decays $D^0 \to K^+\pi^-$

Evidence for $D^0\overline{D}^0$ oscillations has been found by *BABAR* [**?**] and by CDF [**?**] from WS decays $D^0 \to K^+\pi^-$ by comparing their time-dependence with that for decays to the right-sign (RS) final state, $f = K^-\pi^+$. In the WS case, direct decays are doubly Cabbibo-suppressed (DCS), so $|\lambda_f| \gg 1$ and deviations from exponential are quite large. By contrast, such deviations for RS decays are negligible. Even assuming that *CP* is conserved ($\phi_m = \phi_f = 0$), the strong phase difference $\delta_{K\pi}$ between D^0 and $\overline{D}^0$ decays to $K^+\pi^-$ is virtually unknown, making it possible only to measure x'^2 and y', where x', and y' are (x_D, y_D), rotated by angle $\delta_{K\pi}$

$$\begin{aligned} x' &= x_D\cos\delta_{K\pi} + y_D\sin\delta_{K\pi} \\ y' &= y_D\cos\delta_{K\pi} - x_D\sin\delta_{K\pi} \end{aligned} \tag{9}$$

and not x and y directly.

3. Decays to CP eigenstates K^-K^+ and $\pi^-\pi^+$

Mean lifetimes, τ_{hh}, of decays to *CP*-even states $f = h^+h^-$ (where $h = \pi$ or K) are related to y_{CP}, the value of y_D if *CP* is conserved. With *CP* conservation, y_{CP} is given by

$$y_{CP} \approx \frac{\tau_{K^-\pi^+}}{\tau_{hh}} - 1, \tag{10}$$

where $\tau_{K^-\pi^+}$ is the lifetime for the mixed-*CP* state $f = K^-\pi^+$.

Measurements of y_{CP} by Belle [**?**] and *BABAR* [**? ?**] show evidence for mixing ($y_{CP} \neq 0$) at a level of at least 3σ in each case, and are in good agreement. The world average for all measurements is $1.107 \pm 0.217\%$ [**?**].

4. Decays to multi-body hadronic states

WS decays to $K^+\pi^-\pi^0$ have been studied by *BABAR* [**?**]. In these decays, the final state f is specified by its position (s_0, s_+) in the Dalitz plot (DP) representing the phase space available to the three-body system. The coordinates are, respectively, the squared invariant masses for the neutral and positively charged $K\pi$ systems. With the assumption that there is no *CPV*, and a model for the strong phase $\delta(s_0, s_+)$ over the DP due to final state interactions, allows the measurement of x'' and y'' (x_D and y_D, respectively, rotated by the unknown strong phase $\delta_{K\pi\pi}$ arising from the decay). In this case, unlike the 2-body decay to $K^+\pi^-$, the rotated x_D value is linear, not quadratic, coming from the interference term in (8).

Decays to self-conjugate, three-body states such as $K^0_S h^- h^+$ include *CP*- eigenstates, with $\delta_f = 0$. In such cases, measurement of x_D and y_D are, therefore, possible. Analyses of the $K^0_S \pi^- \pi^+$ final state carried out by Belle and *BABAR* [**?**], have each led to uncertainties in x_D and y_D of $\sim 0.3\%$, and each has a contribution from uncertainties in the assumptions made in the decay models used for the strong phase $\delta(s_0, s_+)$ of $\sim 0.03\%$.

5. *Combination of measurements and CPV*

In each case discussed, asymmetries between measurements for D^0 and $\bar{D}^0$ event samples have also been made. These provided indirect information on the *CP* mixing parameters $|q/p|$ and $\arg q/p$. In 3-body decays to self- conjugate final states, these parameters can be determined directly. Asymmetries in direct decay rates (either allowing $\mathcal{A}_{\bar{f}} \neq \bar{\mathcal{A}}_f$ or not) have also provided information on direct *CPV*. However, all these asymmetries are, so far, consistent with zero.

In all, 28 mixing observables have been measured. The Heavy Flavor Averaging Group (HFAG) has included these, with their covariances, in a χ^2 fit to obtain mixing parameter values [**?**], both allowing for *CPV* and requiring *CP* conservation. The *CPV* fit values are

$$\begin{array}{llll} x = 0.98^{+0.24}_{-0.26}\ \% & & y = (0.83 \pm 0.16)\% \\ |q/p| = 0.87^{+0.17}_{-0.15} & & \phi_M = -8.5^{+7.4}_{-7.0}\ ^\circ \\ \delta_{K\pi} = 26.4^{+9.6}_{-9.9}\ ^\circ & & \delta_{K\pi\pi} = 14.8^{+20.2}_{-22.1}\ ^\circ \end{array}$$

6. *Measurements of strong phases*

Data taken at the $\psi(3770)$ ($D\bar{D}$ threshold), allow independent determination of strong phases using the property that Dz and $\bar{D}^0$ pairs are produced coherently. For $D^0 \to K^+\pi^-$, for example, a value $\delta_{K\pi} = -130^{+38}_{-28}{}^\circ$ has been obtained by the CLEO-c collaboration [**?**]. Clearly, this is less precise than the HFAG value. More data from BES III that should improve this estimate by a factor ~ 3 - a useful additional constraint on mixing values - is forthcoming.

7. *Theoretical Interpretation*

Most authors have concluded that effects even as 'high' as $x_D \simeq 1\% \simeq y_D$ could conceivably be generated by SM dynamics alone (see, e.g., [**? ? ? ?**]). Some, however, think that x_D in particular might contain a sizable or even large contribution from NP [**?**]. Short of a breakthough in our computational powers – one that lattice QCD seems unlikely to achieve – this issue cannot be decided by theoretical means. A much more realistic way is to search for CP asymmetries in general and in particular those that involve oscillations, since CP violation cannot be generated by long distance dynamics. This strategy will be explained below.

8. *Measuring x_D and y_D at a Super-Flavour Factory*

To make progress in understanding what role (if any) new physics beyond the SM plays in the charm sector, we need to know if, and at what level, *CPV* occurs in either mixing or in decay. At present, mixing measurements are not sufficiently precise to answer either of these questions.

The current average value of x_D, appears to lie at the tantalizingly high end of SM expectations, so more precise measurements are of great interest. The current value comes largely from TDDP analyses of "golden decays" which also provide direct measurement of the *CPV* parameters. Other methods define y_D relatively well, but better knowledge of the unknown strong phase δ_f is required to improve on x_D. Measurement of δ_f comes mostly from self-consistency of the various mixing measurements with a very weak constraint from CLEO-c measurements [**?**] of coherent decays from $D\bar{D}$ threshold. With most *BABAR* and Belle data analyzed, uncertainties from TDDP analyses are large.

At Super*B*, we expect to improve on this situation in several ways. First, sample sizes at the $\Upsilon(4S)$ will be much larger, thereby improving statistical precision on all current measurements by about a factor 10. In addition, we plan to run at $D\bar{D}$ threshold which should greatly improve measurement of δ_f that will add to the precision of all but the golden decays.

For *CPV* studies, improvements in sensitivity are possible in three areas. First, the larger samples of golden decay channels will allow improvements in measurements of all mixing and *CPV* parameters (direct or otherwise). Secondly, for all channels, we can expect to measure *effective* values (x_D',y_D') for D^0 and ($\bar{x_D}'$, $\bar{y_D}'$) for $\bar{D}^0$ separately (independent of any knowledge of δ_f). Neglecting direct *CPV*, the differences

$$Delta_{xy} = \frac{x'_D - \bar{x_D}'}{x'_D} \approx \frac{y'_D - \bar{y_D}'}{y'_D} \approx \left|\frac{q}{p}\right|^2 - 1 \quad (11)$$

can be measured for each decay channel, and will be indicative of *CPV*. Since systematic uncertainties will be similar for D^0 and $\bar{D}^0$, then uncertainties in these differences will approximately scale with the square root of luminosity. If *CPV* arises from the decay amplitude, or from its interference with mixing, then these differences Δ_{xy} will depend upon decay mode.

A third metric for *CPV* could also come from measurement of the asymmetry:

$$a_{SL} = \frac{\Gamma_{\ell^-} - \bar{\Gamma}_{\ell^+}}{\Gamma_{\ell^-} + \bar{\Gamma}_{\ell^+}} = \frac{|q|^4 - |p|^4}{|q|^4 + |p|^4} \quad (12)$$

where Γ_{ℓ^-} ($\bar{\Gamma}_{\ell^+}$) are decay rates for "wrong-sign" semileptonic D ($\bar{D}$) decays. This asymmetry is difficult to measure precisely, but it can be large. For the current world average value for $|q/p|$ [?], it is in the 90% confidence range $a_{SL} \in \{+0.3, -0.75\}$. If it is not zero, then it is evidence for *CPV* in mixing.

9. Estimates for SuperB at $\Upsilon(4S)$

To estimate what might be possible with a Super$B$ experiment, we start with what has been achieved with BABAR running 475 fb^{-1} at the $\Upsilon(4S)$ and project to 75 ab^{-1}. We also estimate the additional leverage that we might gain from the expected yield from BES III, or from a BABAR-size sample from Super$B$, in either case running at the $D\bar{D}$ threshold. We do this by projecting results already obtained by CLEO-c using 818 pb^{-1}. We also speculate on possibilities for time-dependent measurements at threshold utilizing the boost unique to Super$B$.

make a fit to D-mixing results from BABAR, using a We employ a technique similar to that used by the HFAG group [?] to obtain values for x_D and y_D from the BABAR experiment. We define a χ^2 that incorporates all D-mixing measurements from BABAR, and their uncertainties (statistical and systematic) and their most important correlations. Measurements included are of (x'^2, y') from WS $D^0 \to K^+\pi^-$ decays [?], (x'', y'') from $K^+\pi^-\pi^0$ [?], y_{CP} from both tagged [?] and untagged [?] analyses of $D^0 \to h^-h^+$ decays and (x_D, y_D) from the combined $K^0_S h^-h^+$ samples [?] ($h = \pi, K$). In each case, we take results based upon the assumption of no *CPV*. We neglect information yet to come from $h^-h^+\pi^0$ and $K^0_S K^{mp\pi^\pm}$. Results are reported in Table ??. Fig. 5(a) shows the inputs to and the 65% and 90% confidence limits from this fit.

Include the table here.

In this table, we also report the projection to a 75 ab^{-1} sample from Super$B$ running at the $\Upsilon(4S)$. For this, we assumed that BABAR uncertainties will shrink in accordance with the square root of the luminosities - a reasonable assumption since major systematic uncertainties are estimated from data and simulated studies that should scale in this way. In the case of the $K^0_S h^-h^-$ mode, the systematic uncertainty arising from the decay model of $\sim 0.03\%$ is not scaled.

We have made a simulated study of the $K^0_S\pi^-\pi^+$ analysis with FastSim. In the Super$B$ geometry, we observe an improvement of a factor 2??? in the resolution of decay time measurements that arises partly from the much smaller beam spot, and partly from the smaller radius of the silicon vertex detector. This leads to an improvement in the uncertainties in x_D and y_D of a factor $\sim$ 0.80??? We include this factor in the estimates used in the estimated precision for these parameters in Table ?? and Fig ??(b).

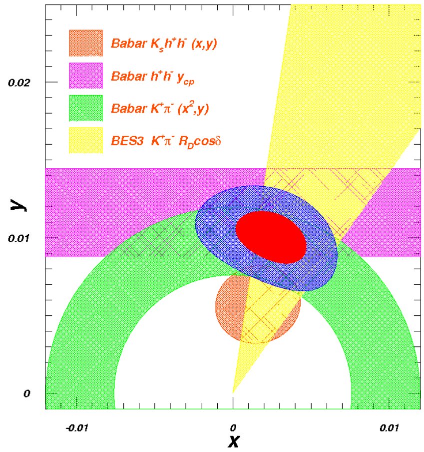

FIG. 5: Values for x_D and y_D obtained fron the various mixing measurements made by BABAR. The red contour indicates the 65% confidence region obtained from a χ^2 fit. The blue contour is the 90% region. Systematic uncertainties are added in quadrature with the statistical ones, and the major quoted correlations are included in the fit.

10. Estimated sensitivity to CPV

From Table ?? we estimate

We need Rolf's averages here to estimate $\sqrt{2} * sigma_x / x$ times a factor to remove the systematic uncertainties

Measurements of a_{SL} are possible, but are subject to large uncertainty. At the $\Upsilon(4S)$, BABAR was able to identify three events that were candidates for

In Table ??

...

11. Value of data from $D\bar{D}$ threshold

Running at $D\bar{D}$ threshold allows an independent measurement of the strong phases $\delta_{K\pi}$, $\delta_{K\pi\pi}$, etc.. for channels that we will use for mixing measurements at the $\Upsilon(4S)$. In Table **??** and Figs. **??**(c) and (d), we include results that might be expected from inclusion of such measurements of $\delta_{K\pi}$ from the $10\,\mathrm{fb}^{-1}$ threshold sample expected to come from BES III and also what we would expect from a $600\,\mathrm{fb}^{-1}$ at Super$B$. In this projection, we scale the result obtained by the CLEO-c collaboration, $\delta_{K\pi} = -130^{+38}_{-28}\,^\circ$), by the ratio of the projected luminosities (10 fb^{-1} from BES III and 600 fb^{-1} at Super$B$). As can be seen, ...

Make the fits and then summarize the effects here ...

Other reductions in uncertainties in x_D and y_D that may arise from running Super$B$ at threshold include the possibility of a model-independent assessment of the time-integrated dependence of $\delta(s_0, s_+)$ on DP coordinates. Less obvious is the possibility of making a time-dependent measurement of this variation. Estimation of these effects require a simulation that has yet to be made.

Perhaps we include the measurement of a_{SL} here ...?

C. CP Violation

1. Generalities

On the phenomenological level one differentiates between two classes of CP violation, namely *indirect* CP violation residing in $\Delta C = 2$ dynamics driving oscillations and *direct* CP violation affecting $\Delta C = 1$ decays. These two sources can produce three classes of effects [**?**]:

1. 'CP violation *in* $D^0 - \bar{D}^0$ oscillations': due to the SM's selection rules this is most cleanly expressed through a difference in the transitions to 'wrong-sign' leptons:

$$a_{SL}(D^0) \equiv \frac{\Gamma(D^0(t) \to \ell^- \bar{\nu} K^+) - \Gamma(\bar{D}^0 \to \ell^+ \nu K^-)}{\Gamma(D^0(t) \to \ell^- \bar{\nu} K^+) + \Gamma(\bar{D}^0 \to \ell^+ \nu K^-)} = \frac{|q_D|^4 - |p_D|^4}{|q_D|^4 + |p_D|^4} \ . \quad (13)$$

While the fraction of wrong-sign leptons oscillates with the time of decay, the fractional asymmetry does not. Data tell us that the production rate of 'wrong-sign' leptons in D decays is very low. Yet as illustrated below their CP asymmetry could be rather large.

It should be noted that also nonleptonic modes of neutral D mesons depend on the quantity $|q_D/p_D|$, see Eq.(15).

2. 'CP violation *involving* $D^0 - \bar{D}^0$ oscillations': it can emerge in nonleptonic final states common to D^0 and $\bar{D}^0$ decays in qualitative, though of course not quantitative analogy to $B_d \to \psi K_S$. Relevant channels are $D^0 \to K_S\phi/\eta$, $K^+K^-/\pi^+\pi^-$, $K^+\pi^-$ on the Cabibbo allowed, once and twice forbidden levels, respectively. CP asymmetries are driven by $|q_D/p_D| \neq 1$ as well as $\mathrm{Im}\frac{q_D}{p_D}\bar{\rho}(f) \neq 0$ with $\bar{\rho}(f) = T(\bar{D}^0 \to f)/T(D^0 \to f)$ denoting the ratio of decay amplitudes. Such asymmetries depend on the time of decay in a characteristic way, which can be well approximated by a linear dependence due to x_D, $y_D \ll 1$:

$$\frac{\Gamma(D^0(t) \to f) - \Gamma(\bar{D}^0(t) \to f)}{\Gamma(D^0(t) \to f) + \Gamma(\bar{D}^0(t) \to f)} \equiv S_f \frac{t}{2\bar{\tau}} \quad (14)$$

with

$$S_f = -\eta_f y_D \left(\left|\frac{q_D}{p_D}\right| - \left|\frac{p_D}{q_D}\right| \right) \cos 2\varphi + -\eta_f x_D \left(\left|\frac{q_D}{p_D}\right| + \left|\frac{p_D}{q_D}\right| \right) \sin 2\varphi \quad (15)$$

in the *absence* of *direct* CP violation. In that case one has a useful connection between the two asymmetries listed so far [**? ?**]:

$$S_f = -\eta_f \frac{x_D^2 + y_D^2}{y_D} a_{\mathrm{SL}}(D^0) \quad (16)$$

3. 'Direct CP violation' characterized by a difference in the moduli of the decay amplitudes describing CP conjugate transitions:

$$|T(D \to f)| \neq |T(\bar{D} \to \bar{f})| \ . \quad (17)$$

For two-body final states it requires the presence of two coherent amplitudes differing in both their weak as well as strong phases.

Three-body final states with their much richer dynamical structure can provides us with more detailed information about the operators driving these decays [**?**]. Accordingly they require a more involved analysis. Fortunately a great deal of experience exists on how to deal with it through Dalitz plot studies. A Super-Flavour Factory provides a particularly suitable environment, since it allows to study not only all charged particles final states like $D^\pm \to \pi^\pm\pi^+\pi^-$ but also ones with neutrals like $D^0 \to \pi^+\pi^-\pi^0$ and $D^\pm \to \pi^\pm\pi^0\pi^0$.

Comparing transitions with different charge combinations provides insight into the impact of the strong interactions. A working group of theorists and experimentalists has been formed under the name 'Les Nabis' [**?**] to refine the theoretical tools for Dalitz plot studies to a degree that the huge statistics anticipated from a Super-Flavour Factory can be exploited. While a full Dalitz plot description has to be the ultimate goal, achieving it represents a long term task. A model independent method has been proposed in Ref.[**?**] as an intermediate step at least.

2. SM Expectations

As far as *direct* CP violation in the SM is concerned, it can occur only in once Cabibbo suppressed channels, but not in Cabibbo allowed and doubly suppressed ones, where one has only a single weak amplitude. Thus any observation of a CP asymmetry in the latter establishes the intervention of NP – except for final states containing K_S mesons, where the CP odd component in the K_S wave function induces an asymmetry [**?**]. Cabibbo suppressed modes like $D^0 \to K^+K^-$, $\pi^+\pi^-$ are expected to show direct CP violation within the SM, yet only on the $\mathcal{O}(10^{-4})$ level.

While $D^0 - \bar{D}^0$ oscillations are dominated by long distance dynamics within the SM, CP violation can arise there through $|q_D/p_D| \neq 1$ through a deficit in weak universality, albeit only on less than the 10^{-3} level [**?**]. Time dependent CP asymmetries involving oscillations can arise also in the SM. Since, however, they are driven by terms of the form x_D or $y_D \times \mathrm{Im}\frac{q_D}{p_D}\bar{\rho}(f)$, they cannot exceed the 10^{-5} level.

In summary: Due to the impact of nonperturbative dynamics that are beyond firm theoretical control one cannot make accurate predictions on SM CP asymmetries in charm decays. Nevertheless one can make highly non-trivial ones, as sketched above, namely that they are at best tiny. One can*not count* on NP creating large CP asymmetries in D transitions, but its manifestations might be clearer here than in B decays; for the SM creates much smaller "backgrounds"; i.e., it induces still much smaller effects:

$$\left[\frac{\text{exp. NP signal}}{\text{SM CP "backgr."}}\right]_{\mathbf{D}} > \left[\frac{\text{exp. NP signal}}{\text{SM CP "backgr."}}\right]_{\mathbf{B}} \quad (18)$$

3. Experimental Landscape

While it is an experimental fact that no evidence for CP violation has emerged in charm transitions so far, one should not over-interpret this statement. In particular CP asymmetries involving oscillations depend on expressions of the form x_D or y_D × weak phases and with x_D and $y_D \leq 1\%$ one can hardly exceed the 1% level. To put it differently: only recently has one entered a regime where NP has a chance to induce an observable asymmetry, yet now any improvement in experimental sensitivity could reveal an effect.

...

Gentlemen, formulate the rest! Ikaros

4. Littlest Higgs Models with T Parity – A Viable Non-ad-hoc Scenario

What has changed over the last two years – and is likely to produce further 'fruits' in the future – is that theorists have developed *non*-ad-hoc scenarios for NP – i.e. ones *not* motivated by considerations of flavour dynamics – that are *not* minimal flavour violating [**? ?**].

'Little Higgs' models are motivated by the desire to 'delay the day of reckoning'; i.e., to reconcile the *non*-observation of NP effects in the electroweak parameters even on the quantum level with the possibility to discover NP quanta via their direct production in LHC collisions. A sub-class of them – Little Higgs models with T parity – are *not* minimal flavour violating in general and in particular can generate observable CP violation in charm decays [**?**]. Since they are relatively 'frugal' in introducing extra parameters, observing their quanta in high $p_\perp$ collisions would allow to significantly tighten predictions of their impact on K, D and B decays.

While these models are hard pressed to generate values for $|q_D/p_D|$ *out*side its present experimental range of $0.86^{+0.17}_{-0.15}$, they can well induce it *in*side it; i.e., they could move $|q_D/p_D|$ much further away from unity than the less than 10^{-3} amount expected for the SM. Likewise they could produce CP asymmetries in $D^0 \to K_S\phi$, K^+K^-, $\pi^+\pi^-$ up to the 1% level; i.e., much larger than the 10^{-5} SM expectation. It should also be noted that in some parts of the parameter space of these models their impact could not be identified in B decays: in particular the CP asymmetry in $B_s \to \psi\phi$ would still remain below 5% as predicted in the SM. Their strongest correlation exists with the branching ratio for the ultra-rare mode $K_L \to \pi^0\nu\bar{\nu}$ [**?**].

5. Case Studies at a Super-Flavour Factory

...

that is for you, Gentlemen! Ikaros

D. Rare Decays

E. $D^0 \to \mu^+\mu^-$, $\gamma\gamma$

$D^0 \to \mu^+\mu^-$ has the cleanest experimental signature. However its rate suffers greatly from helicity suppression and the need for weak annihilation – two effects that are basically model independent. In the SM the rate is estimated to be greatly dominated by long-distance dynamics – yet on a very tiny level [? ?]:

$$\begin{aligned} \mathrm{BR}(D^0 \to \mu^+\mu^-)_{\mathrm{SM}} &\simeq \mathrm{BR}(D^0 \to \mu^+\mu^-)_{\mathrm{LD}} \\ &\simeq 3 \cdot 10^{-5} \times \mathrm{BR}(D^0 \to \gamma\gamma)_{\mathrm{SM}} \end{aligned} \tag{19}$$

With the SM contribution to $D^0 \to \gamma\gamma$ again being dominated by long-distance forces [? ?]

$$\mathrm{BR}(D^0 \to \gamma\gamma)_{\mathrm{SM}} \simeq \mathrm{BR}(D^0 \to \gamma\gamma)_{\mathrm{LD}} \sim (1 \pm 0.5) \cdot 10^{-8} , \tag{20}$$

one infers

$$\mathrm{BR}(D^0 \to \mu^+\mu^-)_{\mathrm{SM}} \sim 3 \cdot 10^{-13} \tag{21}$$

to be compared with the present bounds

$$\mathrm{BR}(D^0 \to \mu^+\mu^-)_{exp} \leq 5.3 \cdot 10^{-7} \tag{22}$$

$$\mathrm{BR}(D^0 \to \gamma\gamma)_{exp} \leq 2.7 \cdot 10^{-5}. \tag{23}$$

The bound of Eq.(23) implies a bound of 10^{-9} in Eq.(22) – i.e., a much tighter one. In either case there is a rather wide window of opportunity for discovering NP in $D^0 \to \mu^+\mu^-$. As pointed out in [?] in several NP models there is actually a relatively tight connection between the NP contributions to $\mathrm{BR}(D^0 \to \mu^+\mu^-)$ and $\Delta M_D/\Gamma_D$.

Specifically LHT makes short-distance contributions to $D^0 \to \mu^+\mu^-$ and $D^0 \to \gamma\gamma$ that can be calculated in a straightforward way as a function of viable LHT parameters. Their size is under active study now [?]. No matter what drives $D^0 \to \gamma\gamma$ - whether it is from short or long distance dynamics – it provides a long distance contribution to $D^0 \to \mu^+\mu^-$. For a proper interpretation of these rare D decays it is thus important to search for $D^0 \to \gamma\gamma$ with as high a sensitivity as possible.

1. $D \to l^+l^-X$

There is general agreement that studying $D \to \gamma X$ etc. is very unlikely to allow establishing the presence of NP because of uncertainties due to long distance dynamics [? ?]. The same strong caveat probably applies also to $D \to l^+l^-X$ – unless a CP asymmetry is observed there, in particular in the lepton spectra.

...

Discuss this ...

F. A case for Running at the $D\bar{D}$ threshold?

Options have been considered in which Super B will run at energies below the $\Upsilon(4S)$. One of these is to run at reduced luminosity for a few months to accumulate a BABAR-size sample at the $\psi(3770)$ where, by tagging events in which one D meson is identified, the other D can be studied with very small background contamination. It has been shown, in fact, by the CLEO c collaboration in several charm studies, that such data will be competitive (or superior) to running with two or more orders higher integrated luminosity at the $\Upsilon(4S)$. Three such instances are identified that could have relevance at Super B.

1. Measurement of a_{SL}

...

2. Search for $D^0 \to \mu^+\mu^-$

...

3. Time-Dependent Measurements

...

Discuss these and any other items ...

[1] Charge-conjugate modes are implicitly included unless noted otherwise.

4. τ physics

Searching for lepton-flavor-violating (LFV) τ decays constitutes one of the most clean and powerful tools to discover and characterize NP scenarios. Although the SM when complemented with the experimentally observed neutrino-mixing phenomenology does include LFV τ decays, the rates are extremely low and experimentally unobservable, making the discovery of LFV an unambiguous signal for physics beyond the SM.

Experimental investigations on *CP* violation in τ decay and on the τ EDM and $g-2$ provide Super$B$ with additional experimentally clean tools to advance our knowledge on unexplored territories, with the ability to test some specific NP scenarios.

With an integrated luminosity of $75\,\mathrm{ab}^{-1}$, Super$B$ will be able to explore a significant portion of the parameter space of most New Physics scenarios by searching for LFV in τ decays. While the MEG experiment will search for $\mu \to e\gamma$ with great sensitivity, Super$B$ will uniquely explore transitions between the third and first or second generations, providing crucial information to determine the specific New Physics model that produces LFV. The LHC experiments are, in general, not competitive in LFV searches. Furthermore, Super$B$ includes features that make it superior to Belle II for LFV searches: a larger planned luminosity and a polarized electron beam, which is equivalent to a substantial boost in effective luminosity, and smaller beam currents, leading to smaller machine backgrounds. Super$B$ can have a 80% longitudinally polarized electron beam, which will provide means to improve the selection of LFV final states, given a specific LFV interaction, or to better determine the features of the LFV interaction, once they are found.

Experimental studies on *CP* violation in τ decay and on the τ EDM and $g-2$ are especially clean tools, because they rely on measurement of asymmetries with relatively small systematic uncertainties from the experiment. The beam polarization also improves the experimental sensitivity for τ EDM and $g-2$ determinations, by allowing measurements of the polarization of a single tau, rather than measurements of correlations between two τ leptons produced in the same events. With this technique, Super$B$ can test whether supersymmetry is a viable explanation for the present discrepancy on the muon $g-2$. Although the most plausible NP models constrained with the available experimental results predict *CP* violation in τ decay and the τ EDM in a range that is not measurable, Super$B$ can test specific models that enhance those effects to measurable levels.

A. Lepton Flavor Violation in τ decay

Predictions from New Physics models

In the following, we discuss the size of τ LFV effects on decays and correlations that are expected in supersymmetric extensions of the Standard Model and, in particular, in the so-called constrained MSSM, The flavor-conserving phenomenology of this framework is characterized by five parameters: $M_{1/2}$, M_0, A_0, $\tan\beta$, sgn μ. We will discuss a subset of the "Snowmass Points and Slopes" (SPS) [1], listed in Table VI, in this five-dimensional parameter space to illustrate the main distinctive features of the model as they relate to lepton flavor violation.

Specifying one such point is sufficient to determine the phenomenology of the model relevant for the LHC, but it is not sufficient to unambiguously compute LFV rates. The amount of flavor-violation is controlled by other parameters, which play no role in high-p_T physics. Nonetheless, specifying the flavor-conserving parameters allows us to simplify the description of LFV decays and, in particular, to establish clear correlations among different processes.

TABLE VI: Values of $M_{1/2}$, M_0, A_0, $\tan\beta$, and sign of μ for the SPS points considered in the analysis.

SPS	$M_{1/2}$ (GeV)	M_0 (GeV)	A_0 (GeV)	$\tan\beta$	μ
1 a	250	100	-100	10	> 0
1 b	400	200	0	30	> 0
2	300	1450	0	10	> 0
3	400	90	0	10	> 0
4	300	400	0	50	> 0
5	300	150	-1000	5	> 0

At all the SPS points, LFV decays are dominated by the contribution of dipole-type effective operators of the form $(\bar{l}_i\sigma_{\mu\nu}l_jF^{\mu\nu})$. Defining $\mathcal{R}^{(a)}_{(b)} = \mathcal{B}(\tau \to a)/\mathcal{B}(\tau \to b)$, The dipole dominance allows us to establish the following relations,

$$\begin{aligned}
\mathcal{R}^{(\mu ee)}_{(\mu\gamma)} &\approx 1.0\times 10^{-2} \;\to\; \mathcal{B}(\tau\to\mu e^+e^-) < 5\times 10^{-10}\\
\mathcal{R}^{(\mu\rho^0)}_{(\mu\gamma)} &\approx 2.5\times 10^{-3} \;\to\; \mathcal{B}(\tau\to\mu\rho^0) < 10^{-10}\\
\mathcal{R}^{(3\mu)}_{(\mu\gamma)} &\approx 2.2\times 10^{-3} \;\to\; \mathcal{B}(\tau\to 3\mu) < 10^{-10}\\
\mathcal{R}^{(\mu\eta)}_{(\mu\gamma)} &< 10^{-3} \;\to\; \mathcal{B}(\tau\to\mu\eta) < 5\times 10^{-11},
\end{aligned}$$

where the bounds correspond to the present limit $\mathcal{B}(\tau\to\mu\gamma) < 4.5\times 10^{-8}$. Similar relations hold for $\tau \to e$ transitions. Assuming an experimental reach at Super$B$ at the level of 10^{-9} only $\tau\to\mu\gamma$ and $\tau\to e\gamma$ decays would be within experimental reach in this list. However, it is interesting to notice that some processes as $\tau\to\mu\rho$ ($\rho\to\pi^+\pi^-$) can reach branching ratios of 10^{-10} for special values of the parameters [2]. Taking into account that these modes are cleaner from the experimental point of view, they could still be interesting processes in a Super$B$.

To estimate the overall scale of $\tau\to(\mu,e)\gamma$ rates, we must specify the value of the LFV couplings, since they are not determined by the SPS conditions. In the mass-insertion and leading-log approximation, assuming that the leading LFV couplings appear in the left-handed slepton sector, we can write

$$\frac{\mathcal{B}(l_j \to l_i \gamma)}{\mathcal{B}(l_j \to l_i \bar{\nu}_i \nu_j)} \approx \frac{\alpha^3}{G_F^2} \frac{\left| \left(m^2_{\tilde{L}} \right)_{ji} \right|^2}{M_S^8} \tan^2 \beta,$$

where, to a good approximation, $M_S^8 \simeq 0.5 M_0^2 M_{1/2}^2 \times (M_0^2 + 0.6 M_{1/2}^2)^2$. In a Grand Unified Theory (GUT) with heavy right-handed neutrinos, the off-diagonal entries of the slepton mass matrix $m^2_{\tilde{L}}$ are likely to be dominated by the flavor mixing in the (s)neutrino sector. These terms can be expressed as

$$\left(m^2_{\tilde{L}} \right)_{ji} \approx -\frac{6 M_0^2 + 2 A_0^2}{16 \pi^2} \, \delta_{ij}, \tag{24}$$

where $\delta_{ij} = \left(Y_\nu^\dagger Y_\nu \right)_{ji} \log(M_{GUT}/M_R)$ in terms of the neutrino Yukawa couplings (Y_ν), the average heavy right-handed neutrino mass (M_R) and the GUT scale ($M_{GUT} \sim 10^{15}$–10^{16} GeV). The experimental information on neutrino masses and mixings is not sufficient to fix completely the structure in the neutrino Yukawa matrix, even assuming some kind of quark-lepton unification. we can take two limiting situations that are called "CKM-like" and "PMNS-like" [3]. Taking the "PMNS-like" case and given the large phenomenological value of the 2–3 mixing in the neutrino sector (and the corresponding suppression of the 1–3 mixing) we expect $|\delta_{32}| \gg |\delta_{31}|$ hence $\mathcal{B}(\tau \to \mu\gamma) \gg \mathcal{B}(\tau \to e\gamma)$. For sufficiently heavy right-handed neutrinos, the normalization of Y_ν is such that $\mathcal{B}(\tau \to \mu\gamma)$ can reach values in the 10^{-9} range. In particular, $\mathcal{B}(\tau \to \mu\gamma) \gtrsim 10^{-9}$ if at least one heavy right-handed neutrino has a mass around or above 10^{13} GeV (in SPS 4) or 10^{14} GeV (in SPS 1a,1b,2,3,5).

A key issue that must be addressed is the role of $\mathcal{B}(\mu \to e\gamma)$ in constraining the LFV couplings and, more generally, the correlations between $\mathcal{B}(\tau \to (\mu, e)\gamma)$ and $\mathcal{B}(\mu \to e\gamma)$ in this framework. An extensive analysis of such questions has been presented in Ref. [4, 5], under the hypothesis of a hierarchical spectrum for the heavy right-handed neutrinos.

The overall structure of the $\mathcal{B}(\tau \to \mu\gamma)$ vs. $\mathcal{B}(\mu \to e\gamma)$ correlation in SPS 1a is shown in Fig. 6. As anticipated, $\mathcal{B}(\tau \to \mu\gamma) \sim 10^{-9}$ requires a heavy right-handed neutrino around or above 10^{14} GeV. This possibility is not excluded by $\mathcal{B}(\mu \to e\gamma)$ only if the 1–3 mixing in the lepton sector (the θ_{13} angle of the neutrino mixing matrix) is sufficiently small. This is a general feature, valid at all SPS points, as illustrated in Fig. 7. In Table VII we show the predictions for $\mathcal{B}(\tau \to \mu\gamma)$ and $\mathcal{B}(\tau \to \mu\mu\mu)$ corresponding to the neutrino mass parameters chosen in Fig. 7 (in particular $M_{N_3} = 10^{14}$ GeV), for the various SPS points. Note that this case contains points that are within the Super*B* sensitivity range, yet are not excluded by $\mathcal{B}(\mu \to e\gamma)$ (as illustrated in Fig. 7). It is also interesting to notice the possible correlations with other processes. For instance, in $SU(5)$ GUT models a large *CP* phase in the B_s system would imply a large $\mathcal{B}(\tau \to \mu\gamma)$ due to the unification of the squark and slepton mass matrices at $M_{\rm GUT}$ [6–9].

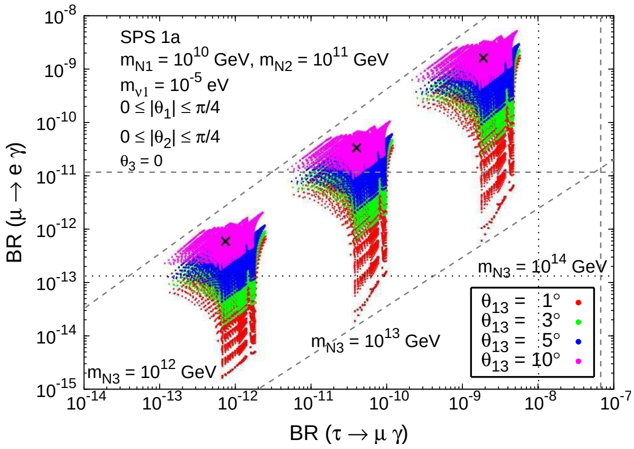

FIG. 6: $\mathcal{B}(\tau \to \mu\gamma)$ vs. $\mathcal{B}(\mu \to e\gamma)$ in SPS 1a, for three reference values of the heavy right-handed neutrino mass and several values of θ_{13}. The horizontal dashed (dotted) line denotes the present experimental bound (future sensitivity) on $\mathcal{B}(\mu \to e\gamma)$. All other relevant parameters are set to the values specified in Ref. [4].

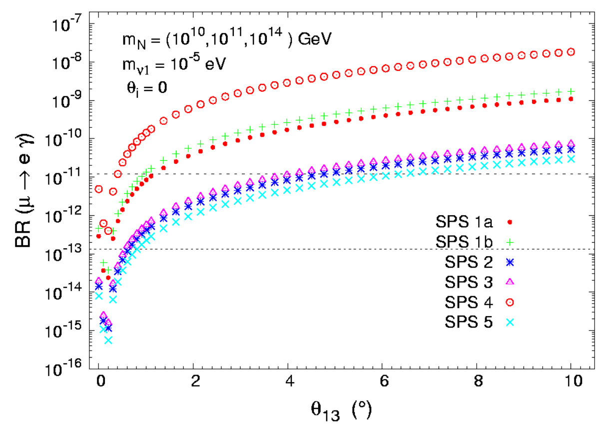

FIG. 7: $\mathcal{B}(\mu \to e\,\gamma)$ as a function of θ_{13} (in degrees) for various SPS points. The dashed (dotted) horizontal line denotes the present experimental bound (future sensitivity). All other relevant parameters are set to the values specified in Ref. [4].

Still, it is very hard to believe that the MSSM realization that nature has chosen is completely flavor blind in the soft sector while the Yukawa sector presents a highly non-trivial structure. Thus, we must explore other "flavored MSSM" realizations to be able to analyze the host of new results that will arrive from Super*B* and LHC experiments. The use of flavor sym-

TABLE VII: Predictions for $\mathcal{B}(\tau \to \mu\,\gamma)$ and $\mathcal{B}(\tau \to \mu\mu\mu)$ corresponding to the SPS points. The values of m_{N_i} and m_{ν_1} are as specified in Fig. 7 [4].

SPS	1 a	1 b	2	3	4	5
$\mathcal{B}(\tau \to \mu\gamma) \times 10^{-9}$	4.2	7.9	0.18	0.26	97	0.019
$\mathcal{B}(\tau \to \mu\mu\mu) \times 10^{-12}$	9.4	18	0.41	0.59	220	0.043

metries can explain the complicated Yukawa structures and at the same time predict a non-trivial structure in the soft-breaking terms. In these flavor models, we can have a large variety of predictions with different flavor symmetries. However, LFV processes are always the most interesting observables in these models and it is relatively easy to obtain $\mathcal{B}(\tau \to \mu\gamma) \sim 10^{-9}$ as shown in Ref. [10, 11] for an $SU(3)$ flavor symmetry. We have to emphasize here that this process can even compete in sizable regions of the parameter space with the future bound at MEG for the process $\mu \to e\gamma$.

LFV in the NUHM scenario

At large $\tan\beta$ and not too heavy Higgs masses, another class of LFV interactions is relevant, the effective coupling between a μ–τ pair and the heavy (scalar and pseudoscalar) Higgs bosons. This coupling can overcome the constraints on $\mathcal{B}(\tau \to \mu\mu\mu)$ and $\mathcal{B}(\tau \to \mu\eta)$ dictated by $\mathcal{B}(\tau \to \mu\gamma)$ in the dipole-dominance scenario. Such a configuration cannot be realized in the CMSSM, but it could be realized in the so-called NUHM SUSY scenario, which is also theoretically well-motivated and rather general. In such a framework, there are specific regions of the parameter space in which processes like $\tau \to \mu\eta$ and $\tau \to \mu f_1(980)$, $f_1(980) \to \pi^+\pi^-$ could have a branching ratio in the 10^{-9}–10^{-10} range, comparable or even slightly larger than $\mathcal{B}(\tau \to \mu\gamma)$ [2, 13, 16].

Another interesting possibility are MSSM models with R-parity violation [14]. In these models several of the bounds on R-parity violating couplings are obtained from B and τ processes and Super$B$ can improve these bounds or even discover some signal. The processes $\tau \to \mu\eta$ and $\tau \to \mu\mu\mu$ are specially interesting and can improve the present bounds by more than an order of magnitude.

Finally, in more exotic New Physics frameworks, such as Little Higgs Models with T parity (LHT) or Z' models with non-vanishing LFV couplings ($Z'\ell_i\ell_j$), the $\tau \to \mu\mu\mu$ rate could be as large as, or even larger than $\tau \to \mu\gamma$ (see *e.g.*, [15]). In this respect, an improvement of $\mathcal{B}(\tau \to \mu\mu\mu)$ at the 10^{-10} level would be interesting even with $\mathcal{B}(\tau \to \mu\gamma) \lesssim 10^{-9}$.

Super*B* experimental reach

The vast experience accumulated on the B-factories offers a reliable base for estimating the reach of Super$B$ on τ LFV searches. To a first approximation, the Super$B$ detector is expected to have performances comparable to or better than the *BABAR* for electron identification and for electromagnetic energy resolution and hermeticity. The Super$B$ project on the other hand has an improved momentum resolution, thanks to silicon layers closer to the beams, and improved muon identification.

The typical τ LFV decay search consists in counting candidate events and measuring if there is an excess against the expected background. By running a *BABAR* analysis unchanged on a larger statistical sample, all expected upper limits scale down at least as the square root of the luminosity ($\propto 1/\sqrt{\mathcal{L}}$). This extrapolation poses a lower limit for the Super$B$ reach, which will be ameliorated by detector improvements and only moderately worsened by a small expected increase of beam backgrounds. If it is possible to maintain the B-factory efficiencies while keeping the expected amount of background events of the order one, then Super$B$ will deliver upper limits that will scale down linearly with the integrated luminosity ($\propto 1/\mathcal{L}$). In first approximation, scaling approximately like $1/\mathcal{L}$ is possible for τ LFV decays into three leptons, or into a lepton and two hadrons in the final state (where the two hadrons may come through a hadron resonance). On the other hand, searches for $\tau \to \ell\gamma$ suffer higher backgrounds and tend to scale more like $\propto 1/\sqrt{\mathcal{L}}$.

BABAR τ LFV searches are optimized for the best expected upper limits, which typically corresponds to maximizing the signal efficiency while keeping the expected background events of the order one or less, when the analysis is not background dominated. Since the analysis optimization depends on the size of the analyzed sample and on the amount of expected backgrounds, one must re-optimize the B-factory analyses for the Super$B$ luminosity, especially for the low background searches. In the following, we extrapolate the *BABAR* most recent results by re-optimizing the analysis for $\tau \to \ell\ell\ell$, and assuming a conservative $1/\sqrt{\mathcal{L}}$ scaling for $\tau \to \ell\gamma$. The experimental reach is expressed in terms of "the expected 90% CL upper limit" assuming no signal, as well as in terms of a "3σ evidence branching fraction" in the presence of projected backgrounds; furthermore a minimum of 5 expected signal events is required for evidence. In the absence of signal, for large numbers of expected background events $N_{\rm bkg}$, the expected 90% CL upper limit for the number of signal events can be approximated as $N_{90}^{UL} \sim 1.28(1/2+\sqrt{1/2 + N_{\rm bkg}})$[38] whereas for small $N_{\rm bkg}$ a value for N_{90}^{UL} is obtained using the method described in [16], which gives, for $N_{\rm bkg} \sim 0$, $N_{90}^{UL} \sim 2.4$. If a signal is determined from counting events within a signal region, the 90% CL branching ratio upper limit is:

$$B_{90}^{UL} = \frac{N_{90}^{UL}}{2N_{\tau\tau}\epsilon} = \frac{N_{90}^{UL}}{2\mathcal{L}\sigma_{\tau\tau}\epsilon}\,, \qquad (25)$$

where $N_{\tau\tau} = \mathcal{L}\sigma_{\tau\tau}$ is the number of τ-pairs produced in e^+e^- collisions; $\mathcal{L}$ is the integrated luminosity, $\sigma_{\tau\tau}$=0.919 nb [17] is the τ-pair production cross section, and ϵ is the signal efficiency.

The $\tau \to \mu\gamma$ projected sensitivity is based on the most recent *BABAR* preliminary result [18]. Some Super$B$ improvements with respect to *BABAR* are taken into account:

- the smaller beam size and (to a minor extent) the improved momentum resolution will improve the invariant mass and energy resolution of the τ candidates and are expected to reduce the signal region area by 35%;
- the improved coverage for photons is expected to increase the acceptance by 20%;

Further gains are possible with a complete re-optimization of the analysis for Super$B$, but they have not yet been investigated and are neglected here. The 80% polarized electron beam influences the angular distribution of the τ decay products in a way that depends on the interaction that causes LFV. For 100% polarized tau leptons, the typical distribution of the cosine of the helicity angle is triangular (see Figure 8), and 75% of the signal could be retained while removing 50% of a presumably flat background, like the accidental combination of an ISR photon with a muon from $\tau \to \mu\nu\overline{\nu}$. However this improvement in the signal to noise ratio has a negligible effect on the expected reach of the $\tau \to \ell\gamma$ searches. For $\tau \to \mu\gamma$, we expect the final efficiency to be ~ 7.3% and the final background to be ~ 260 events. This leads to an expected 90%CL upper limit of 2.4×10^{-9} and a 3σ evidence reach of $5.4{\times}10^{-9}$. One additional benefit of beam polarization is the possibility to determine the helicity structure of the LFV coupling from the final state momenta distributions (see for instance Ref.[19] for the $\tau \to \mu\mu\mu$ process). The extrapolation of the $\tau \to e\gamma$ search receives benefits from similar improvements, and has a projected 90% CL upper limit of 3.0×10^{-9} and a 3σ evidence reach of 6.8×10^{-9}.

By re-optimizing the *BABAR* analyses for 75 fb^{-1} of data, we obtained refined projected upper limits for LFV searches for τ into three leptons [20], which lie between the $\propto 1/\mathcal{L}$ and the $\propto 1/\sqrt{\mathcal{L}}$ extrapolations (see Fig. 9). Super$B$ detector improvements are expected to have a minor impact for these channels, and they are conservatively neglected. Since after the optimization the expected backgrounds are small, also beam polarization has a minor impact (which we neglect) on the expected reach of the search. The re-optimization has been performed by using the *BABAR* data and the simulation of the *BABAR* detector. The expected 90% confidence upper limits are in the range $[2.3-8.2]\times 10^{-10}$, depending on the channel, and the 3σ evidence branching fractions are $[1.2-4.0]\times 10^{-9}$. For technical reasons, the amount of simulated data that has been used (equivalent to about twice the *BABAR* collected luminosity) permits only a crude estimate of some specific backgrounds that have exactly the same particle con-

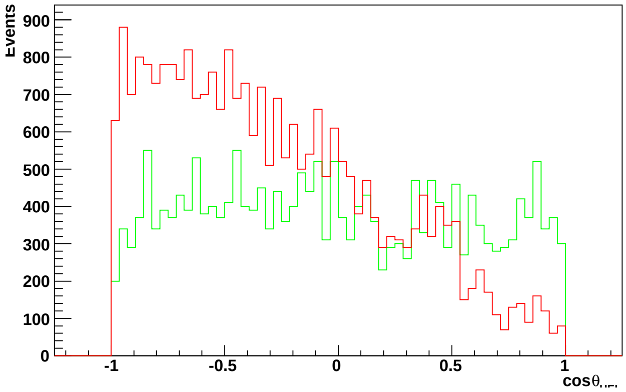

FIG. 8: Distribution of the cosine of the helicity angle of the muon from $\tau \to \mu\gamma$ decays of τ leptons produced in the forward region by annihilations of 80% polarized electrons against unpolarized positrons. The red line corresponds to LFV events generated according to most common SUSY NP models, the green (flat) line corresponds to LFV events generated with no correlation between the final state momenta and the τ polarization, which are expected to simulate accidental SM background events.

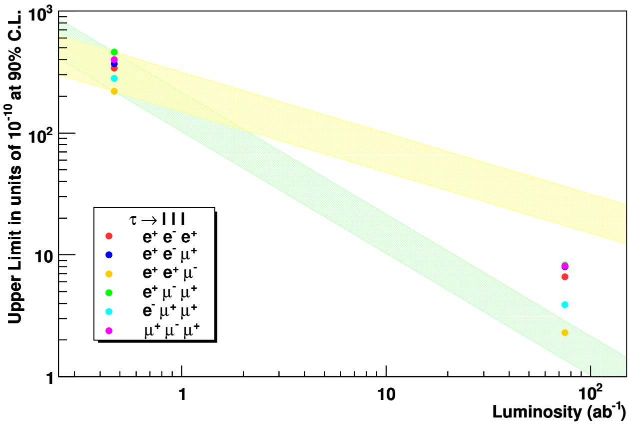

FIG. 9: Expected Super$B$ 90% CL upper limits for $\tau \to \ell\ell\ell$ LFV decays compared with the most recent *BABAR* expected upper limits. The upper and lower bands indicate the $1/\sqrt{\mathcal{L}}$ and $1/\mathcal{L}$ extrapolations, respectively.

tent of the signal as a result of rare and accidental combination of SM processes. For instance, the BABAR simulated samples only contain a few events where a $\tau \to \mu\nu\bar{\nu}$ decay combines with an e^+e^- pair from an ISR photon to accidentally match the τ mass and energy, therefore the extrapolation to the Super$B$ integrated luminosity has some uncertainty. To improve, one needs to either simulate extremely large samples of generic events, or to carefully design dedicated simulations that attempt to model very specific signal candidates.

We consider the projected results for $\tau \to \ell\ell\ell$ indicative also for hadronic lepton-flavor-violating final states containing a lepton (either a muon or electron) and a hadronic system like a pseudoscalar or vector meson (π^0, η, η', K^0_S, ω, ϕ, K^*, f_1, *etc.*) or a non-resonant system of two pions, two kaons or a pion and kaon.

The LFV searches $\tau \to \ell\pi^0$ and $\tau \to \ell\eta\,(\eta \to \gamma\gamma)$, will suffer from accidental backgrounds similar to $\tau \to \ell\gamma$ at high rates, when two hard ISR photons accidentally reconstruct to a π^0 or η mass, but the rate for two hard-photon ISR emission will be roughly 100 times lower than the rate for a signal hard photon emission and lower still when requiring a $\gamma\gamma$ mass to match that of a π^0 or η. Consequently, this is not expected to be an issue at Super$B$ luminosities.

When compared with Belle II, the Super$B$ project expects appreciably better results due to its larger luminosity and due to the availability of polarized beams.

Table VIII summarizes the sensitivities for various LFV decays.

TABLE VIII: Expected 90% CL upper limits and 3σ evidence reach on LFV decays with 75 ab^{-1} with a polarized electron beam.

Process	Expected 90% CL upper limit	3σ evidence reach
$\mathcal{B}(\tau \to \mu\,\gamma)$	2.1×10^{-9}	4.8×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	2.7×10^{-9}	6.0×10^{-9}
$\mathcal{B}(\tau \to \ell\ell\ell)$	$2.3–8.3 \times 10^{-10}$	$1.2–4.0 \times 10^{-9}$

B. *CP* Violation in τ decay

CP violation in the quark sector has been observed both in the K and in the B systems; the experimental results are, thus far, fully explained by the complex phase of the CKM matrix. On the contrary, *CP* violation in the lepton sector has yet not been observed. Within the Standard Model, *CP*-violating effects in charged-lepton decays are predicted to be vanishingly small. For instance, the *CP* asymmetry rate of $\tau^\pm \to K^\pm\pi^0\nu$ is estimated to be of order $\mathcal{O}(10^{-12})$ [21]. Evidence for *CP* violation in τ decay would therefore be a clear signal of New Physics. In one instance, the $\tau^\pm \to K_S\pi^\pm\nu$ rate asymmetry, a small *CP* asymmetry of 3.3×10^{-3} is induced by the known *CP*-violating phase of the $K^0\overline{K}^0$ mixing amplitude [22]. This asymmetry is known to 2% precision. Thus, this mode can serve as a calibration, and in addition, any deviation from the expected asymmetry would be a sign of New Physics.

Most of the known New Physics models cannot generate observable *CP*-violating effects in τ decays (see *e.g.*, [15]). The only known exceptions are R parity-violating supersymmetry [14, 23] or specific non-supersymmetric multi-Higgs models [24–26]. In such a framework, the new physics contributes at tree level and if the sfermions or charged Higgses are relatively light with sizable couplings to the light quarks, these new-physics contributions can be important. In some cases, the *CP* asymmetries of various τ-decay channels or the T-odd *CP*-violating asymmetries in the angular distribution can be enhanced up to the 10^{-1} level, without conflicting with other observables, and saturating the experimental limits obtained by CLEO [25–27]. In particular, these models have been shown to be able to produce sizable asymmetries in the decays $\tau \to K\pi\nu_\tau$ $\tau \to K\eta^{(\prime)}\nu_\tau$ and $\tau \to K\pi\pi\nu_\tau$ [23–26].

A first search for *CP* violation in τ decay has been conducted by the CLEO collaboration [27], looking for a tau-charge-dependent asymmetry of the angular distribution of the hadronic system produced in $\tau \to K_S\pi\nu$. In multi-Higgs doublet New Physics, the *CP*-violating asymmetry arises from the Higgs coupling and the interference between S wave scalar exchange and P wave vector exchange. The Cabibbo-suppressed decay mode into $K_S\pi\nu$ has a larger mass-dependent Higgs coupling; the events in the sidebands of the K_S mass distributions can thus be used to calibrate the detector response. With a data sample of $13.3\,\mathrm{fb}^{-1}$ (12.2×10^6 tau pairs), the mean of the optimal asymmetry observable is $\langle\xi\rangle = (-2.0\pm1.8)\times10^{-3}$. As the above measurement relies on detector calibration with side-band events, it is conceivable that Super$B$ with $75\,\mathrm{ab}^{-1}$ would not be limited by systematics and would therefore reach an experimental resolution $\Delta\langle\xi\rangle \approx 2.4 \times 10^{-5}$.

C. Measurement of the τ electric dipole moment

In minimal SUSY frameworks with flavor-independent *CP*-violating phases, like the constrained MSSM, lepton EDMs (d_ℓ) scale linearly with the lepton mass. As a result, the existing limits on the electron EDM generally preclude any visible effect in the τ and μ cases. In more general MSSM models, however, the strength of *CP*-violation may be different for different flavors and this simple linear scaling does not apply [10]. A very simple example is given by models where the *CP*-violation phases are associated to the third generation, in our case, to the stau trilinear coupling, A_τ [28]. In this case, τ EDM will be large and EDMs for the first two generations will be suppressed by small mixings. Unfortunately, there are also situations where the additional flavor dependence can generate a further suppression in the tau-EDM [10]. Thus, it is always necessary to measure all three lepton EDMs independently to be able to discriminate the flavor dependence of *CP* phases. Furthermore, in multi-Higgs models EDMs scale with the cube of the lepton masses [29], d_τ can thus be substantially enhanced. However, in this case the electron and muon EDMs receive sizable two-loop effects via Barr-Zee diagrams, which again scale linearly with the lepton masses. As a result, one can derive an approximate bound $d_\tau \lesssim 0.1 \times (m_\tau/m_\mu)^3(m_\mu/m_e)d_e$ which is still very strong. From the present experimental upper bound on the electron EDM, $d_e \lesssim 10^{-27} e\,\mathrm{cm}$, it follows that $d_\tau \lesssim 10^{-22} e\,\mathrm{cm}$.

The τ electric dipole moment (EDM) influences both the angular distributions and the polarization of the τ produced in e^+e^- annihilation. With a polarized beam, it is possible to construct observables from the angular distribution of the products of a single τ decay that unambiguously discriminate between the contribution due to the τ EDM and other effects [30, 31]. Recent work has provided an estimate of the Super*B* upper limit sensitivity for the real part of the τ EDM $|\mathrm{Re}\{d_\tau^\gamma\}| \leq 7.2 \times 10^{-20}\, e\,\mathrm{cm}$ with $75\,\mathrm{ab}^{-1}$ [30]. The result assumes a 100% polarized electron beam colliding with unpolarized positrons at the $\Upsilon(4S)$ peak, no uncertainty on the polarization, and perfect reconstruction of the τ decays $\tau \to \pi\nu$. Studies have been done assuming more realistic conditions:

- an electron beam with a linear polarization of $80\% \pm 1\%$;
- 80% geometric acceptance;
- track reconstruction efficiency $97.5\% \pm 0.1\%$ (similarly to what has been achieved in LEP analyses [32] and *BABAR* ISR analyses [33].

The process $e^+e^- \to \tau^+\tau^-$ is simulated with the KK generator [34] and the Tauola package for tau decay [34]; the simulation includes the complete spin correlation density matrix of the initial-state beams and the final state τ leptons. τ EDM effects are simulated by weighting the τ decay product angular distributions. The studies are not complete, and do not yet include uncertainties in reconstructing the τ direction. The preliminary indications are that the τ EDM experimental resolution is $\approx 10 \times 10^{-20} e\,\mathrm{cm}$, corresponding to an angular asymmetry of 3×10^{-5}; the uncertainties in track reconstruction give a $\approx 1 \times 10^{-20}$ systematic contribution. Asymmetries proportional to the τ EDM depend on events that go into the same detector regions but arise from τ leptons produced at different angles, minimizing the impact of efficiency uncertainties. It must be added that all the hadronic τ channels have at least theoretically the same statistical power as the $\tau \to \pi\nu$ mode in measuring the tau polarization [35], and can therefore be used to improve the experimental resolution.

A search for the τ EDM with unpolarized beams has been completed at Belle [36]. In this case, one must measure correlations of the angular distributions of both tau leptons in the same events, thereby losing in both reconstruction efficiency and statistical precision. The analysis shows the impact of inefficiency and uncertainties in the τ direction reconstruction, and also demonstrates that all τ decays, including leptonic decays with two neutrinos, provide statistically useful information for measurement of the tau EDM. With $29.5\,\mathrm{fb}^{-1}$ of data, the experimental resolution on the real and imaginary parts of the τ EDM is $[0.9-1.7] \times 10^{-17}\, e\,\mathrm{cm}$, including systematic effects. An optimistic extrapolation to Super*B* at $75\,\mathrm{ab}^{-1}$, assuming systematic effects can be reduced according to statistics, corresponds to an experimental resolution of $[17-34] \times 10^{-20}$.

D. Measurement of the τ $g-2$

The Standard Model prediction for the muon anomalous magnetic moment is not in perfect agreement with recent experimental results. In particular, $\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} \approx (3\pm1)\times10^{-9}$. Within the MSSM, this discrepancy can naturally be accommodated, provided $\tan\beta \gtrsim 10$ and $\mu > 0$.

A measurement of the τ anomalous magnetic moment could be very useful to confirm or disprove the interpretation of Δa_μ as due to New Physics contributions. The natural scaling of heavy-particle effects on lepton magnetic dipole moments, implies $\Delta a_\tau/\Delta a_\mu \sim m_\tau^2/m_\mu^2$. Thus, if we interpret the present muon discrepancy $\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} \approx (3\pm1)\times10^{-9}$ as a signal of New Physics, we should expect $\Delta a_\tau \approx 10^{-6}$.

In the supersymmetric case, such an estimate holds for all the SPS points (see Table IX) and, more generally, in the limit of almost degenerate slepton masses. If $m_{\tilde\nu_\tau}^2 << m_{\tilde\nu_\mu}^2$ (as happens, for instance, in the so-called effective-SUSY scenario), Δa_τ could be enhanced up to the 10^{-5} level.

TABLE IX: Values of Δa_μ and Δa_τ for various SPS points.

SPS	1 a	1 b	2	3	4	5
$\Delta a_\mu \times 10^{-9}$	3.1	3.2	1.6	1.4	4.8	1.1
$\Delta a_\tau \times 10^{-6}$	0.9	0.9	0.5	0.4	1.4	0.3

In a manner similar to an EDM, the τ anomalous moment (g–2) influences both the angular distribution and the polarization of the τ produced in e^+e^- annihilation. Polarized beams allow the measurement of the real part of the g–2 form factor by statistically measuring the τ polarization with the angular distributions of its decay products. Bernabéu *et al.* [37] estimate that Super$B$ with $75\,\text{ab}^{-1}$ will measure the real and imaginary part of the g–2 form factor at the $\Upsilon(4S)$ with a resolution in the range $[0.75 - 1.7] \times 10^{-6}$. Two measurements of the real part of $g-2$ are proposed, one fitting the polar angle distribution of the τ leptons, and one based on the measurement of the τ transverse and longitudinal polarization from the angular distribution of its decay products. All events with τ leptons decaying either in $\pi\nu$ or $\rho\nu$ are considered, but no detector effects are accounted for. For the τ polarization measurements, electron beams with perfectly known 100% polarization are assumed. Studies simulating more realistic experimental conditions are ongoing. While the polar angle distribution measurement will conceivably suffer from uncertainties in the τ direction reconstruction, the preliminary results on the τ EDM measurement, mentioned above, indicate that asymmetries measuring the τ polarization are least affected by reconstruction systematics. Transposing the preliminary results obtained with simulations for the τ EDM to the real part of the $g-2$ form factor, one can estimate that $a_\mu = (g-2)/2$ can be measured with a statistical error of 2.4×10^{-6}, with systematic effects from reconstruction uncertainties one order of magnitude lower.

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satisfies the relation

$$90\% \approx \int_{-\infty}^{\mu+1.28\sigma} G(\mu,\sigma),$$

where $G(\mu,\sigma)$ is a Gaussian with mean μ and variance σ^2. For order 100 expected background events, the formula approximates toy Monte Carlo simulations within better than 5%.

5. Electroweak neutral current measurements

The combination of high luminosity and polarised electrons at Super*B* provides a unique opportunity to measure a number of electroweak neutral current parameters with precisions comparable to those obtained at SLC and LEP but at a Q^2 of $(10.58\ \text{GeV})^2$. The cross-sections for $e^+e^- \to \mu^+\mu^-$, as for the other final-state fermions, are sensitive to the beam polarisation almost entirely through $Z-\gamma$ interference. Although the asymmetries are small, the Super*B* sample size will be sufficiently large to yield very interesting physics. This physics program includes precision $\sin^2\theta_W$ measurements with $\mu^+\mu^-$, $\tau^+\tau^-$ and $c\bar{c}$ events as well as measurements of the neutral current vector coupling of the b. Such measurements are sensitive to a Z' and can probe neutral current universality at high precision.

With polarisation, Super*B* will make a relatively straightforward measurement of the left-right asymmetry of $e^+e^- \to \mu^+\mu^-$ in a manner identical to that performed by the SLC collaboration [1, 2] which operated at the Z-pole. SLC measured $\sin^2\theta_W = 0.23098 \pm 0.00026$ where the error includes a systematic uncertainty component of ± 0.00013 dominated by the polarisation uncertainty of 0.5%. The ZFITTER software has been used to estimate the level of sensitivity that might reached at Super*B* where the left-right asymmetry is be approximately -0.0005. A $e^+e^- \to \mu^+\mu^-(\gamma)$ selection using *BABAR* data had an efficiency selection efficiency of 53% for a 99.6% purity. Such a selection will provide a sample of 46 billion μ-pair events at Super*B* for an integrated luminosity of 75 ab^{-1}. Assuming 80% polarisation can be achieved, the statistical error on the left-right asymmetry will be approximately 5×10^{-6} which corresponds to a relative error of $\mathcal{O}(1\%)$. If the polarimeter systematic errors can be kept below this level, the uncertainty on $\sin^2\theta_W$ will be ~ 0.0002, which is competitive with the SLC measurement but at a much lower Q^2. Similar measurements can be made with $e^+e^- \to \tau^+\tau^-(\gamma)$ and with charm, although one would expect the statistical errors to be larger owing to a lower selection efficiency. Nonetheless, those measurements will provide the most stringent tests of neutral current universality.

These precision measurements are sensitive to the same new physics scenerios, such as a Z', being probed by the QWeak experiment at the Jefferson Laboratory, which will measure $\sin^2\theta_W$ to approximately 0.3% at $Q^2 = (0.16\,\text{GeV})^2$. Figure 10 shows the current and planned measurements of $\sin^2\theta_W$.

As Super*B* will be running on the $\Upsilon(4S)$, the left-right asymmetry for B-mesons will be senstive to the product of the electon neutral current axial coupling and b-quark neutral current vector coupling g_V^b, as described in a proposal for measuring the g_V^s at a ϕ-factory [4]. With one billion reconstructed $B\bar{B}$ events from $\Upsilon(4S)$ decays with an 80% polarised beam, Super*B* will provide a measurement of g_V^b that is competitive with the measurement from LEP and SLC, $g_V^b = -0.3220 \pm 0.0077$[2] but at a lower Q^2. In addition to probing new physics, this measurement will shed light on the long-standing 3σ difference between the measurements of $\sin^2\theta_W$ obtained from the forward-backward asymmetry of b-quarks and those obtained using leptons.

We note that other asymmetry measurements at Super*B*, such as the forward-backward left-right asymmetry can provide additional information about neutral current couplings.

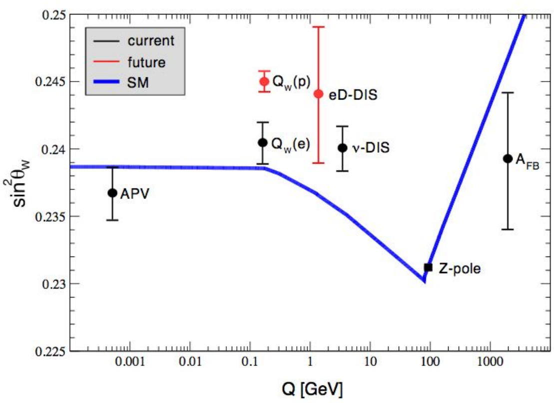

FIG. 10: Summary of experiments that have measured or are proposing to measure $\sin^2\theta_W$ as compiled in [3]. The standard model running of $\sin^2\theta_W$ is overlayed on the data points. Super*B* will provide a point at $Q = 10.58$ GeV with an error comparable to that of the measurement at the Z-pole.

[1] K. Abe *et al.* [SLD Collaboration], Phys. Rev. Lett. **73** (1994) 25 [arXiv:hep-ex/9404001].

[2] [ALEPH, DELPHI, L3, OPAL, SLC Collaborations, and the LEP EW Working Group], Phys. Rept. **427**, 257 (2006) [arXiv:hep-ex/0509008].
[3] Experimental proposal for JLab E02-020 (QWeak), `http://qweak.jlab.org/DocDB/0007/000703/005/Qweak_Update_final2.pdf`; W. T. H. Van Oers [Qweak Collaboration], Nucl. Phys. A **790** (2007) 81.
[4] J. Bernabeu, F. J. Botella and O. Vives, Nucl. Phys. B **472** (1996) 659 [arXiv:hep-ph/9512424].

6. Spectroscopy

A. Introduction

Although the Standard Model is well-established, QCD, the fundamental theory of strong interactions, provides a quantitative comprehension only of phenomena at very high energy scales, where perturbation theory is effective due to asymptotic freedom. The description of hadron dynamics below the QCD dimensional transmutation scale is therefore far from being under full theoretical control.

Systems that include heavy quark-antiquark pairs (quarkonia) are a unique and, in fact, ideal laboratory for probing both the high energy regimes of QCD, where an expansion in terms of the coupling constant is possible, and the low energy regimes, where nonperturbative effects dominate. For this reason, quarkonia have been studied for decades in great detail. The detailed level of understanding of the quarkonia mass spectra is such that a particle mimicking quarkonium properties, but not fitting any quarkonium level, is most likely to be considered to be of a different nature.

In particular, in the past few years the B Factories and the Tevatron have provided evidence for states that do not admit the conventional mesonic interpretation and that instead could be made of a larger number of constituents. While this possibility has been considered since the beginning of the quark model [1], the actual identification of such states would represent a major revolution in our understanding of elementary particles. It would also imply the existence of a large number of additional states that have not yet been observed.

Finally, the study of the strong bound states could be of relevance to understanding the Higgs boson, if it turns out to be itself a bound state, as predicted by several technicolor models (with or without extra dimensions) [2].

The most likely possible states beyond the mesons and the baryons are:

- **hybrids:** bound states of a quark-antiquark pair and a number of constituent gluons. The lowest-lying state is expected to have quantum numbers $J^{PC} = 0^{+-}$. Since a quarkonium state cannot have these quantum numbers (see below), this a unique signature for hybrids. An additional signature is the preference for a hybrid to decay into quarkonium and a state that can be produced by the excited gluons (*e.g.*, $\pi^+\pi^-$ pairs); see *e.g.*, Ref. [3].

- **molecules:** bound states of two mesons, usually represented as $[Q\bar{q}][q'\bar{Q}]$, where Q is the heavy quark. The system would be stable if the binding energy were to set the mass of the states below the sum of the two meson masses. While this could be the case for when $Q = b$, this does not apply for $Q = c$, the case for which most of the current experimental data exist. In this case, the two mesons can be bound by pion exchange. This means that only states decaying strongly into pions can bind with other mesons (*e.g.*, there could be D^*D states), but that the bound state could decay into its constituents [4].

- **tetraquarks:** a bound quark pair, neutralizing its color with a bound antiquark pair, usually represented as $[Qq][\bar{q}'\bar{Q}]$. A full nonet of states is predicted for each spin-parity, *i.e.*, a large number of states are expected. There is no need for these states to be close to any threshold [5].

In addition, before the panorama of states is fully clarified, there is always the lurking possibility that some of the observed states are misinterpretations of threshold effects: a given amplitude might be enhanced when new hadronic final states become energetically possible, even in the absence of resonances.

While there are now several good experimental candidates for unconventional states, the overall picture is not complete and needs confirmation, as well as discrimination between the alternative explanations. A much larger dataset than is currently available is needed, at several energies, to pursue this program; this capability is uniquely within the reach of Super$B$.

B. Light Mesons

The problem of the interpretation of the light scalar mesons, namely f_0, a_0, κ, σ, is one of the oldest problems in hadron physics [6]. For many years the question about the existence of the σ meson as a real resonance in $\pi\pi$ scattering has been debated [7]; only recently has a thorough analysis of $\pi\pi$ scattering amplitudes shown that the $\sigma(500)$ and $\kappa(800)$ can be considered as proper resonances [8].

Reconsideration of the σ was triggered by the E791 analysis of $D \to 3\pi$ data [9]; a number of papers have commented on those results, *e.g.*, Ref. [10]. The role of the scalar mesons in several exclusive B decays could be rather relevant: for example, in the perspective of a high precision measurement of the α angle at the SuperB factory, the hadronic contributions, like the one of the isoscalar σ in $B \to \rho\pi$, must be properly controlled [11]. Also several studies on light and heavy scalar mesons could be performed analyzing the Dalitz plots of exclusive decays like $B \to KKK$ and $B \to K\pi\pi$. In this respect, having sufficient statistics to clearly assess the presence of a scalar $\kappa(800)$ resonance, would certainly be a major result for hadron spectroscopy.

Beyond the “taxonomic” interest in the classification of scalar mesons, the idea that these mesons could play a key role in our understanding of aspects of non-perturbative QCD has been raised several times; see for example Ref. [12].

In what follows we would like to underscore the latter point by observing that:

- Light scalar mesons are most likely the lightest particles with an *exotic* structure, *i.e.*, they cannot be classified as $q\bar{q}$ mesons.
- Their dynamics is tightly connected with instanton physics. Recent discussions have shown that instanton effects make possible a consistent model for the description of light scalar meson dynamics, under the hypothesis that these particles are diquark-antidiquark mesons.

Therefore, new modes of aggregation of quark matter could be established by the experimental/theoretical investigation of these particles, further expanding the role of instantons in hadron physics.

The idea of four-quark mesons dates back to the pioneering papers by Jaffe [13], while the discussion of exotic mesons and hadrons in terms of diquarks was introduced in Ref. [14] and then extended in Ref. [15] to the scalar meson sector.

We will assume that the scalar mesons below 1 GeV are indeed bound states of a spin 0 diquark and an anti-diquark (we will often call this a tetraquark). A spin 0 diquark field is a color antitriplet $\mathfrak{q} = qq$ bound state (same color of an antiquark).

As in a standard $q\bar{q}$ meson, the color is neutralized between a diquark and an antidiquark $\mathfrak{q}^\alpha \bar{\mathfrak{q}}_\alpha$. Since a spin zero diquark is in a $\bar{\mathbf{3}}$-flavor representation because of Fermi statistics, flavor nonets of $\mathfrak{q}\bar{\mathfrak{q}}$ states are allowed, the so called ‘crypto-exotic’ multiplets. We believe that the sub-GeV scalar mesons most likely represent the lowest tetraquark nonet.

The $\mathfrak{q}\bar{\mathfrak{q}}$ model of light-scalars is very effective at explaining the most striking feature of these particles, namely their inverted pattern, with respect to that of ordinary $q\bar{q}$ mesons, in the mass-versus-I_3 diagram [13], as shown in Fig. 11.

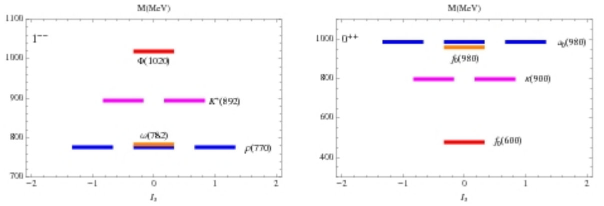

FIG. 11: Vector mesons ($q\bar{q}$ states) and the sub-GeV scalar mesons in the $I_3 - m$ plane.

Such a pattern cannot be explained in a $q\bar{q}$ model where, for example, the $f_0(980)$ would be an $s\bar{s}$ state [10] while the $I = 1$, $a_0(980)$, would be a $u\bar{u} + d\bar{d}$ state. If this were the case, the degeneracy of the two particles would be rather unnatural.

Besides a correct description of the mass-I_3 pattern, the tetraquark model offers the possibility of explaining the decay rates of scalars at a level never reached by standard $q\bar{q}$ descriptions. The effective decay Lagrangian into two pseudoscalar mesons, *e.g.*, $\sigma \to \pi\pi$, is written as:

$$\mathcal{L}_1 = c_1 S^i_j \epsilon^{jtu} \epsilon_{irs} \partial_\mu \Pi^r_t \partial^\mu \Pi^s_u, \qquad (26)$$

where i, j are the flavor labels of $\mathfrak{q}^i$ and $\bar{\mathfrak{q}}^j$, while r, s, t, u are the flavor labels of the quarks $\bar{q}^t, \bar{q}^u$ and q^r, q^s. c_1 is an effective coupling and S, Π are the scalar and pseudoscalar matrices of meson fields. Observe for example how $\pi^+\pi^-$ are produced by a $[ud][\bar{u}\bar{d}]$ tetraquark by setting the right flavor indices in (26).

This Lagrangian describes the quark exchange amplitude for the quarks to tunnel out of their diquark shells in S to form ordinary pseudoscalar mesons Π [15]. The antisymmetrization in the flavor indices of quarks ($\bar{\mathbf{3}}-$flavor representation) is guaranteed by the ϵ tensors.

Such a mechanism is the straightforward alternative to the most natural color string breaking $\mathfrak{q} \sim\sim q\bar{q} \sim\sim \bar{\mathfrak{q}} \to B\bar{B}$, *i.e.*, a baryon-anti-baryon decay, which happens to be phase-space forbidden to sub-GeV scalar mesons. For a discussion about baryonia see [16].

The problem with eq. (26) is simply that it is not able to describe the observed decay $f_0 \to \pi\pi$, since $f_0 \sim [qs][\bar{q}\bar{s}]$, with $q = u, d$. To form a $\pi^+\pi^-$ pair of mesons in the final state one should require to: *i*) break the diquarks binding to annihilate the s and the $\bar{s}$ quarks *ii*) create from the vacuum a $q\bar{q}$ pair. Alternatively one could annihilate the diquark and the antidiquark directly into a $q\bar{q}$ pair via a six-fermion interaction, not paying the prize of breaking the diquark shells, and hadronize the two light quarks produced into two pions via a quark pair creation. This possibility is provided by six-fermion, instanton induced low energy vertices [17]. Such vertices contain a term of the form $\mathcal{I} = \sum_{i,j} \bar{\mathfrak{q}}_i \mathfrak{q}_j \bar{q}_j q_i$, i, j being flavor indices and $\mathfrak{q}_{i\alpha} = \epsilon_{ijk}\epsilon_{\alpha\beta\gamma}\bar{q}_C^{j\beta}\gamma_5 q^{k\gamma}$ being a spin zero diquark.

Alternatively, one can go through a mixing between the two isoscalars f_0 and σ. However, as discussed in [17], such mixing is expected to be too small, $< 5°$, to account for the structure of the inverted mass pattern (a precise determination of the κ mass would be crucial to fix this point).

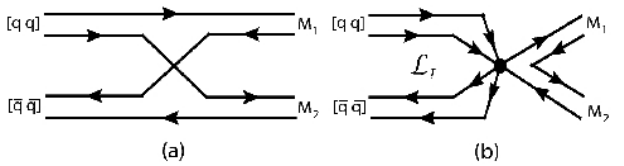

FIG. 12: Decay of a tetraquark scalar meson S in two $q\bar{q}$ mesons $M_1 M_2$: (a) quark rearrangement (b) instanton-induced process.

Thus in addition to the quark-exchange diagrams, described at the effective theory level by the Lagrangian of Eq. (26), (see Fig. 12 (a)), we a have six-fermion microscopic interaction of the form $\mathcal{I}$ (see Fig. 12 (b) [18]) which contributes to the following effective lagrangian term

$$\mathcal{L}_2 = c_2 \text{Tr}(\mathbf{S}(\partial\mathbf{\Pi})^2) \qquad (27)$$

(roughly, introduce a $\bar{q}_k q_k$ in $\mathcal{I}$ and call $S^i_j \sim \bar{\mathfrak{q}}_j \mathfrak{q}^i$, $\Pi^i_j \sim \bar{q}_j q^i$ respectively). c_2 is an effective coupling expected to be rather smaller than c_1 in (26). Observe that this term is also contained in (26) which actually corresponds to the combination $2\text{Tr}(\mathbf{S}(\partial\mathbf{\Pi})^2) - \text{Tr}\mathbf{S}\text{Tr}(\partial\mathbf{\Pi})^2$, barring the contribution from the singlet pseudoscalar. The latter term could be described by an 'annihilation' diagram at the meson level.

If on the other hand we assume that the lowest scalar nonet is made up of standard $\bar{q}q$ mesons, there are no diquarks around, and we expect the instanton contributions to enter only in operators of the kind $\text{Tr}\mathbf{S}\text{Tr}(\partial\mathbf{\Pi})^2$. Thus the decay lagrangians to be used to fit data in the $4q$ and $2q$ hypotheses are

$$\mathcal{L}^{(4q)} = \mathcal{L}_1(c_1) + \mathcal{L}_2(c_2)$$
$$\mathcal{L}^{(2q)} = \mathcal{L}_1(c'_2) + \mathcal{L}_2(c'_1)$$

with evident notation. It is expected $|c_1^{(\prime)}| \gg |c_2^{(\prime)}|$.

With such a description of the dynamics one can determine numerical results for the decay amplitudes as reported in the following Table (four-quark fit $|c_1| \simeq 0.02, |c_2| \simeq 0.002$). Such a good description of decays is possible *only* if the assumption is made that sub-GeV light scalars are diquark-antidiquark mesons (see Table X). In the $q\bar{q}$ hypothesis, the agreement of $a_0 \to \pi^0\eta$ with data appears very poor.

TABLE X: Numerical results, amplitudes in GeV. Second and third columns: results obtained with a decay Lagrangian including or not including instanton effects, respectively (Labels I and no-I mean that we add or do not add the instanton contribution.). No $f_0 - \sigma$ mixing is assumed in this table. Fourth column: best fit, see text, with instanton effects included. Fifth column: predictions for a $q\bar{q}$ picture of the light scalars. The $\eta - \eta'$ singlet-octet mixing angle assumed: $\phi_{PS} = -22°$ [19]. Data for σ and κ decays are from [8], the reported amplitudes correspond to: $\Gamma_{\text{tot}}(\sigma) = 272 \pm 6$, $\Gamma_{\text{tot}}(\kappa) = 557 \pm 24$.

Proc.	$\mathcal{A}_{\text{th}}([qq][\bar{q}\bar{q}])$			$\mathcal{A}_{\text{th}}(q\bar{q})$	$\mathcal{A}_{\text{expt}}$
	I	no-I	best fit	I	
$\sigma(\pi^+\pi^-)$	input	input	1.7	input	2.27(0.03)
$\kappa^+(K^0\pi^+)$	5.0	5.5	3.6	4.4	5.2(0.1)
$f_0(\pi^+\pi^-)$	input	**0**	1.6	input	1.4(0.6)
$f_0(K^+K^-)$	4.8	4.5	3.8	4.4	3.8(1.1)
$a_0(\pi^0\eta)$	4.5	5.4	3.0	8.9	2.8(0.1)
$a_0(K^+K^-)$	3.4	3.7	2.4	3.0	2.16(0.04)

A relative of the lowest lying scalar mesons may have been found very recently by *BABAR*: the $Y(2175)$, a particle first observed in the decay $Y \to \phi f_0(980)$ [20]. For a discussion see [21]

C. Charmonium

In the past few years the B Factories have observed several states with clear $c\bar{c}$ content, which do not behave like standard mesons, and that are therefore an indication of new spectroscopy.

The $X(3872)$ was the first state found not to easily fit into charmonium spectroscopy. It was initially observed decaying into $J/\psi\pi^+\pi^-$ with a mass just beyond the open charm threshold [22]. The $\pi^+\pi^-$ invariant mass distribution, the observation of the $X \to J/\psi\gamma$ and the full angular analysis by CDF [23] and Belle [24], along with the evidence for the $X \to \psi(2S)\gamma$ decay found by *BABAR* [25], favor the assignment of $J^{PC} = 1^{++}$ for this state, and of $X \to J/\psi\rho$ as its dominant decay. There are several indications that this is not a (pure) charmonium state: the mass assignment does not match any prediction of long-verified potential models (see Fig. 13); the dominant decay would be isospin-violating; and the state is narrow (less than a few MeV), despite its mass lying above threshold for the production of two charmed mesons. At the same time the relative rates to $\psi(2S)\gamma$ and $J/\psi\gamma$ are more easily explained in terms of conventional charmonium decays. The closeness to the $D^0 D^{*0}$ threshold suggests also the hypothesis that it may be a molecule composed of these two mesons or a threshold effect.

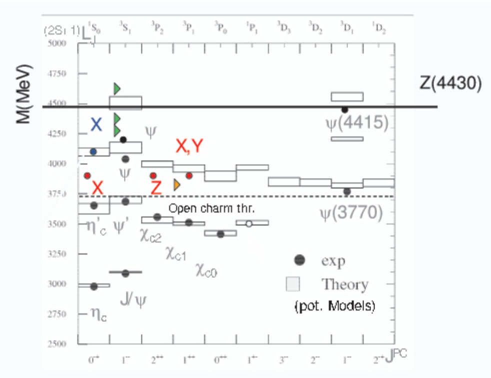

FIG. 13: Measured masses of the newly observed states, positioned in the spectroscopy according to their most likely quantum numbers. The charged state ($Z(4430)$) clearly has no C quantum number.

Another aspect of interest is the measurement of the mass of the $X(3872)$ in the $D^{*0}D^0$ decay mode [26, 27], which could differ from the value measured in the $J/\psi\pi\pi$ decay. The mass difference and the difference in the lineshape in the two modes could help in discriminating between the many models [28, 29]. If the mass difference is confirmed, it is possible that there are indeed two different states, one decaying to $D^{*0}D^0$ and the other decaying to $J/\psi\pi\pi$: the di-quarks with a heavy meson are effectively flavor-triplets, and diquark pairs would show the same nonet structure as ordinary mesons, so that it would be natural to expect two states with $S = I_3 = 0$ very close in mass [5] .

A data sample of $\mathcal{O}(50\,ab^{-1})$ would yield several (3÷11) thousands fully reconstructed $B \to X(3872)K$ decays in each of the above-mentioned modes. This would allow a detailed study of the $X(3872)$ decay dynamics and lineshape, crucial to enlighten possible evidences for non-$q\bar{q}$ composition.

The B Factories have also found a number of new states with $J^{PC} = 1^{--}$ by looking for events where the initial state radiation brings the e^+e^- center-of-mass energy down to the particle's mass. It was expected that above the open charm threshold all states would be seen in $R = \sigma_{had}/\sigma_{\mu\mu}$ scans. When the high luminosity at B Factories allowed to study exclusive final states containing a J/ψ or a $\psi(2S)$, at least three new unusual particles have been discovered: the $Y(4260)$ decaying to $J/\psi\pi^+\pi^-$ [30], the $Y(4350)$ [31] and the $Y(4660)$ [32] decaying to $\psi(2S)\pi^+\pi^-$.

The $\pi^+\pi^-$ invariant mass is a critical observable in discerning the nature of these particles, which are unlikely to belong to charmonium since there are already other 1^{--} known charmonium states, their masses are above the open-charm threshold, yet they are relatively narrow and are not observed to decay into two charmed mesons (the most stringent limit being [33] $\mathcal{B}(Y(4260) \to D\bar{D})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) < 1.0$ at 90% CL). Another puzzling feature of these states is the ratio of the partial widths $\Gamma(J/\psi\pi^+\pi^-)/\Gamma(\psi(2S)\pi^+\pi^-)$, that is small for the $Y(4260)$ and large for the $Y(4350)$ and $Y(4260)$. The current statistics does not allow to measure these ratios.

Figure 14 shows the dipion invariant mass spectra for all regions in which new resonances have been observed. Only the $Y(4660)$ seems to show a well-defined intermediate state (most likely an f_0), while others have a more complex structure.

The $Y(4260)$ is currently considered a good hybrid candidate, while the $Y(4350)$ and $Y(4660)$ are good candidates for $[cd][\bar{c}\bar{d}]$ and $[cs][\bar{c}\bar{s}]$ tetraquarks, respectively. The latter would prefer to decay to f_0, while the mass difference is consistent with the hypothesis that the two belong to the same nonet.

A run at 50 ab^{-1} of integrated luminosity, yielding samples of 30 k $Y(4260) \to J/\psi\pi^+\pi^-$ and $\approx 3\ k$ events each for $Y(4350), Y(4660) \to \psi(2S)\pi^+\pi^-$, would allow a detailed study of the lineshape, a measurement of $\Gamma(J/\psi\pi^+\pi^-)/\Gamma(\psi(2S)\pi^+\pi^-)$, and a study of the $\pi^+\pi^-$ invariant mass spectra, as well as of the angular distributions. Furthermore it will be possible to search for other exclusive decays to charmonia such as $J/\psi\eta/\pi^0$,$\psi(2S)\eta/\pi^0$,$\chi_{cJ}\pi^+\pi^-$, $\gamma J/\psi$, $\gamma\psi(2S)$

The turning point in the query for states beyond charmonium has been the observation by the Belle Collaboration of a charged state decaying into $\psi(2S)\pi^\pm$ [34, 35] soon followed by two more charged states, the $Z_1^+(4050)$ and the $Z_2^+(4430)$, decaying to $\chi_{c1}\pi^+$[36]. Figure 15 shows the fit to the $\psi(2S)\pi$ invariant mass distribution in $B \to \psi(2S)\pi K$ decays, returning a mass $M = 4433 \pm 4(\text{stat.}) \pm 2(\text{syst.})$ MeV/c^2 and a width $\Gamma = 44^{+18}_{-13}(\text{stat.})^{+30}_{-13}(\text{syst.})$ MeV.

Such states must contain a c and a $\bar{c}$, but according to their charge they must also contain at least an u and a $\bar{d}$. The only possibilities for explaining these state are the tetraquark or the molecule composition, or the presence of some threshold effects. The latter two options are viable for the $Z^+(4430)$ due to the closeness of the D_1D^* threshold.

The analysis is highly complicated by the presence of K^* resonances in the $B \to (c\bar{c})\pi^+K$ final state and by the $c\bar{c}$ polarization. The analysis of the full *BABAR* data sample did not confirm nor exclude the observation of the $Z^+(4430)$ [37]. No result has yet been presented on the search for the $Z_1^+(4050)$ and $Z_2^+(4430)$.

It is critical to confirm the existence of these states, and if confirmed to find the corresponding neutral states and/or to observe them in other decay modes. With an integrated luminosity of 50 ab^{-1} we can expect to collect samples of 100 k to 1.5 M fully re-

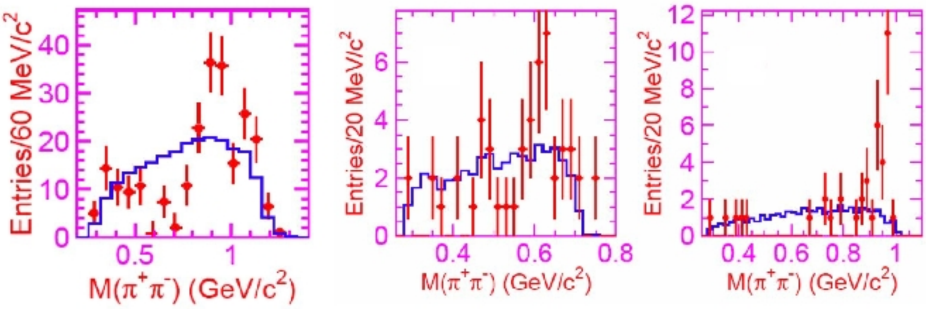

FIG. 14: Di-pion invariant mass distribution in $Y(4260) \to J/\psi\pi^+\pi^-$ (left), $Y(4350) \to \psi(2S)\pi^+\pi^-$ (center), and $Y(4660) \to \psi(2S)\pi^+\pi^-$ (right) decays.

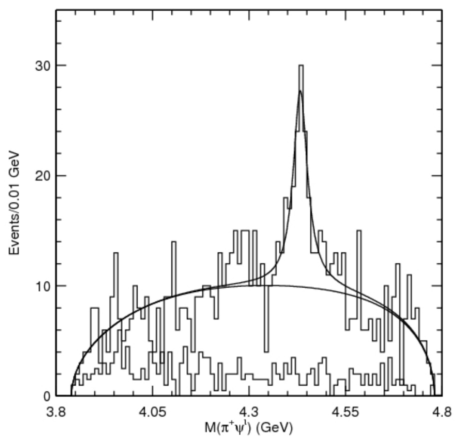

FIG. 15: The $\psi(2S)\pi$ invariant mass distribution in $B \to \psi(2S)\pi K$ decays.

constructed $B \to J/\psi\pi^+K$, $B \to \psi(2S)\pi^+K$ and $B \to \chi_{cJ}\pi^+K$ events that will allow to establish unambiguously the existence of these states and to determine their properties.

In summary, there are several reasons why a run at fifty to one hundred times the existing integrated luminosity is decisive to convert these hints into a solid picture:

- all the new states, apart from the $X(3872)$, have been observed in only a single decay channel, with significance that are barely above 5σ. A hundredfold increase in statistics would allow searches in several other modes. In particular, it is important to observe both the decay to charmonium and to D-meson pairs and/or D_s meson pairs. Since the branching fractions of observable final states for the D and especially for the D_s mesons are particularly small, current experiments do not have the sensitivity to observe all the decays.

- most models predict several other states, such as the neutral partners of the $Z(4430)$ and the nonet partners, for instance $[cd][\bar{c}\bar{s}]$ candidates decaying into a charmonium state and a kaon, at a significantly lower rate (see *e.g.*, Ref. [38]) than the observed modes. Furthermore , several of these states decay into particles (in particular neutral pions and kaons) that have a low detection efficiency.

In order to achieve high luminosities the event rate and the machine backgrounds will increase significantly. It is therefore important to estimate the impact of the changes in the detector and of this background on the search potentiality. As a first step it has been tested with a fast simulation of the $e^+e^- \to Y(4260)\gamma_{ISR}, Y(4260) \to J/\psi\pi\pi$ signal that the detector changes do not affect significantly the efficiency. A more comprehensive study is on the way.

D. Bottomonium

In comparison to charmonium, our knowledge of bottomonium below flavor threshold is far from complete: in particular, as shown in Fig. 16, almost all the spectrum of spin singlet states (parabottomonia) is still *terra incognita*. Moreover, in the bottomonium system, four narrow D wave states are expected in the region around 10.16 GeV, and their study [39], started by CLEO-III, is currently under way in this generation of B-factories. In total, the current generation of

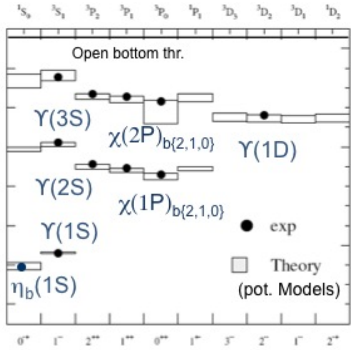

FIG. 16: Measured masses of the bottomonia, positioned in the spectroscopy according to their most likely quantum numbers.

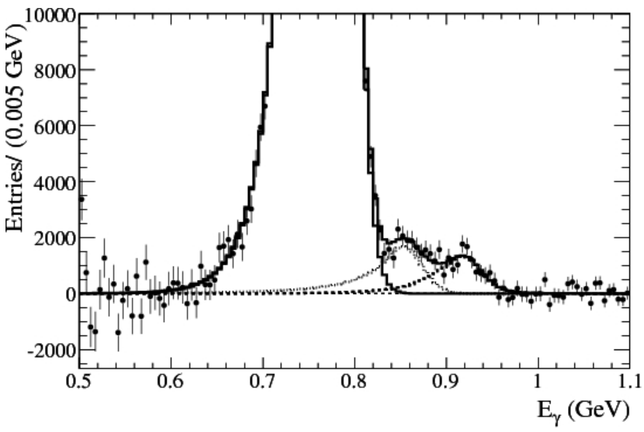

FIG. 17: The inclusive photon spectrum at 3S from BABAR, after continuum subtraction: the peaks from $\chi_{b1,2} \to \Upsilon(1S)$, ISR production of $\Upsilon(1S)$ and $\Upsilon(3S) \to \eta_b$ are visible, left to right in the plot.

B-factories have integrated (1.2,2.6,1.3)*10^8 Υ(1,2,3S) decays on resonance peak, as shown in tableXI.

TABLE XI: $\Upsilon(nS, n \neq 4)$ datasets after year 2000 at B-factories.

Expt.	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(5-6S)$
CLEO	20M	9M	6M	0.5 fb^{-1}
BELLE	98M	160M	11M	133 fb^{-1}
BABAR	-	100M	122M	3.3 fb^{-1}

Moreover, up to 133 fb^{-1} were accumulated in the Υ(5S) region, and have started yielding interesting results about transitions to narrow states through the open beauty threshold, defying naïve expectations. The analysis of such data is in progress and will probably lead to new discoveries in the near future, but it is clear that ten to hundred times the statistics are needed to find all the pieces of the bottomonium puzzle.

1. *Regular bottomonium*

Only recently, the ground state η_b(1S) has been discovered by Babar [40, 41], as shown in Fig.17, but all other parabottomonia are still missing and surely two of them will hardly be within reach of the current generation of B-factories. Besides the hyperfine splitting, other η_b decay properties can be predicted with relatively small errors in the NRQCD approximation and deserve experimental verification: the total width and the partial width to two photons.

The total width of η_b should be measurable by BaBar and Belle, at least as an upper limit, from the inclusive photon spectra of hindered transitions. A precise measurement (i.e. better than 10% error) of the η_b total width requires much higher statistics, which will be available only at super-B factories. Given the large photon background in the low energy part of the spectrum (i.e. below 100 MeV), the experimentalists are challenged to detect all the η_b decay products on one or more specific channels and try the exclusive reconstruction. At present date, only few exclusive decay modes have been observed by CLEO [43], with significances above 5σ, for the χ_b states, which can be reached from Υ(2,3S) peaks via transitions which have branching ratios at 10% level. As ratios for direct M1 transitions to η_b are expected in the 10^{-4} range, at least two decades more statistics are probably needed.

In long term perspective, the most important measurement to perform is the two-photon width, as theory predictions on the ratio $\Gamma_{\gamma\gamma}(\eta_b)/\Gamma_{l+l-}(\Upsilon)$ are quite insensitive to the renormalization scale [42], and yield $\Gamma_{\gamma\gamma}(\eta_b) = 0.66 \pm 0.09$ keV. If $\Gamma_{tot}(\eta_b) < 10$ MeV this would imply a branching ratio at the level of 10^{-4}, and a cross section $\sigma(\Upsilon(2,3S) \to \gamma\eta_b \to \gamma\gamma\gamma) \sim 0.2$ fb, which is by far smaller than the cross section for the continuum process $\sigma(e^+e^- \to \gamma_{ISR} \to \gamma\gamma\gamma)$. The ISR background can actually be avoided by running on 3S peak and using the dipion pair to tag the 2S decay, and then select exclusive $\pi\pi\gamma\gamma\gamma$ events, from the process $\Upsilon(3S) \to \pi\pi\Upsilon(2S) \to \pi\pi\gamma\eta_b(1S)$. In this case, experimentalists are challenged to maximize the efficiency on detection and tracking of low momentum dipion pairs.

The discovery of one or more exclusive decay modes of η_b(1S) will also be useful for the search of the analogous direct M1 transitions between vector and pseudoscalar 2S and 3S excitations. For the time being, the current record sample of $\Upsilon(3S)$ decays can allow

BaBar to discover the η_b(2S) in the inclusive photon spectrum, and the $h_b(1P)$ either via the cascade process $\Upsilon(3S) \to \pi^0 h_b(1P) \to \pi^0\gamma\eta_b(1S)$, as done by CLEO to find the $h_c(1P)$ state in the charmonium system, or via $\Upsilon(3S) \to \pi\pi h_b(1P) \to \pi\pi\gamma\eta_b(1S)$, as suggested in ref. [44, 45].

Most likely, the states h_b(2P) and η_b(3S) will need super-B factories to be discovered. If η_b(3S) detection should depend crucially on exclusive reconstruction of some decay channel, but it is almost surely reachable from the Υ(3S), it is not yet clear which transition will allow us to reach h_b(2P): as the expected mass difference $M(\Upsilon(3S)) - M(h_b(2P)) < M(\pi^0)$, detection of $h_b(2P)$ cannot benefit from running on narrow bottomonia.

The recent discovery of unexpectedly large widths for the transitions $\Upsilon(4S) \to \eta\Upsilon(1S)$[46] and Υ(5S)$\to \pi\pi\Upsilon(1S)$[47] may suggest that hadronic transitions to other narrow bottomonia can open new pathways to these states, e.g. Υ(5S)$\to \eta h_b$(2P). In the next paragraph, we will further elaborate on the large physics potential of runs above $B_s\bar{B}_s$ threshold, also for hadron spectroscopy.

2. *Exotic bottomonium*

(BaBar and Belle scans and future scan perspectives)

Exotic states with two bottom quarks, analogous to those with two charm quarks, could also exist. In this respect, bottomonium spectroscopy is a very good testbench for speculations advanced to explain the charmonium states. On the other side, searching for new bottomonium states is more challenging, since they tend to be broader and there are more possible decay channels. This explains why there are still eight unobserved states with masses below open bottomonium threshold.

Among the known states, there is already one with unusual behavior: there has been a recent observation [47] of an anomalous enhancement, by two orders of magnitude, of the rate of $\Upsilon(5S)$ decays to the $\Upsilon(1S)$ or a $\Upsilon(2S)$ and two pions. This indicates that either the $\Upsilon(5S)$ itself or a state very close by in mass has a decay mechanism that enhances the amplitudes for these processes.

In order to understand whether the exotic state coincides with the $\Upsilon(5S)$) or not, a high luminosity (at least 20 fb^{-1} per point to have a 10% error) scan of the resonance region is needed.

In any case, the presence of two decay channels to other bottomonium states excludes the possibility of this state being a molecular aggregate, but all other models are possible, and would predict a large variety of not yet observed states.

As an example, one can estimate possible resonant states with the tetraquark model, by assuming that the masses of states with two b quarks can be obtained from one with two c quarks by adding the mass difference between the $\Upsilon(1S)$) and the J/ψ. Under this assumption, which works approximately for the known bottomonium states, we could expect three nonets that could be produced by the $\Upsilon(3S)$ and decaying into $\Upsilon(1S)$ and pions. Assuming that the production and decay rates of these new states are comparable to the charmonium states, and assuming a data sample of $\Upsilon(3S)$ events comparable in size to the current $\Upsilon(4S)$ sample is needed to clarify the picture, we would need about 10^9 $\Upsilon(3S)$ mesons, corresponding to an integrated luminosity of 0.3 ab^{-1}.

As already mentioned, searching for bottomonium-like states would require higher statistics than the corresponding charmonium ones; this therefore represents an even stronger case for Super$B$.

E. Interplay with other experiments

SuperB is not the only next generation experiment capable of investigating heavy quark spectroscopy.

The LHCb experiment is starting to investigate its potentialities in the field. The complementarity of these studies with SuperB are evident, considering the present interplay between B-Factories and the Tevatron: the larger number of mesons produced allows detailed studies of the decay modes with final states made of charged particles. All other modes are best investigated by e^+e^- machines.

The only other next generation experiment at a e^+e^- machine is BES-III, but their current plan is to run below the energies of interest, at the $\psi(3770)$ [48], where they expect to collect 5 fb^{-1} per year. Even if a plan to run at the energies of the exotic states were developed, given the lower luminosity the complementarity of SuperB and BES-III would be the same as the B-Factories and CLEO-c.

A separate mention is deserved by the PANDA experiment at FAIR [49], a proton-antiproton collider which could produce the exotic resonances at threshold (i.e. $e^+e^- \to X, Y$). This innovative production mechanism allows for copious production without the hindrance of fragmentation products. Considering the expected characteristics of the antiproton beam and an integrated luminosity of 2 fb^{-1} per year, running at the J/ψ mass would yield 3.5 10^9 J/ψ mesons per year. Considering that $\Gamma_{ee}[Y(4260)] * \mathcal{B}(Y(4260) \to p\bar{p}) < 0.05\Gamma_{ee}[J/\psi] * \mathcal{B}(J/\psi \to p\bar{p})$@90% C.L. [50] and assuming $\Gamma_{ee}[Y(4260)] = \Gamma_{ee}[J/\psi]$, we could expect as much as 30K $Y(4260) \to J/\psi\pi\pi$ with a J/ψ decaying leptonically per year. Besides the large uncertainty on the assumption, this estimate can be compared with the 60K events in the same decay chain approximately produced in a year of SuperB via ISR. The complementarity of the two experiments is guaranteed by the fact that the final states that can be studied by the two experiments are different and that the PANDA experiment can more easily access the narrow states while SuperB can study in detail larger states if the production mechanism is favourable. Furthermore, in case the center-of-mass-energy of SuperB is changed to the $Y(4260)$ mass, assuming a factor 10 loss in luminosity with respect to running at the $\Upsilon(4S)$, the number of events produced in the decay chain used as example would raise to 700K per year: a few weeks scan would then be equivalent to the PANDA dataset. Finally, PANDA can only reach center-of-mass energies as high as 5 GeV and therefore has no access to bottomonium spectroscopy.

7. Direct Searches

Bottomonium decays also allow direct searches for physics beyond the Standard Model in regions of the parameters space that have not been reached by LEP [51]: the possibility of a rather light non-standard Higgs boson has not been ruled out in several scenarios beyond the Standard Model [52–54], due to the fact that a new scalar may be uncharged under the gauge symmetries, similar to a sterile neutrino in the fermion case. These studies indicate that its mass could be less than twice the b mass, placing it within the reach of Super$B$. Moreover, the LHC might not be able to unravel a signal from a light Higgs boson whose mass is below $B\bar{B}$ threshold, since it will be difficult for the soft decay products to pass the LHC triggers. Dark matter may also be light, evading LEP searches if it does not couple strongly to the Z^0 [55–57, 59]. Finally, the new field of Dark Forces(see Sec. 7 C) predicts low interacting light particles that couple mostly to photons that can therefore be produced at a Flavour Factory and that would require a large luminosity.

Super$B$ will be required in most of these cases to precisely determine its masses and couplings, and will play an important discovery role.

A. Light Higgs

A Higgs h with $M_h < M_\Upsilon$ can be produced in $\Upsilon(nS)$ decays via the Wilczek mechanism [60] with a branching ratio, at leading-order, $\frac{\Gamma(\Upsilon(nS)\to\gamma h)}{\Gamma(\Upsilon(nS)\to\mu\mu)} = \frac{\sqrt{2}G_F m_b^2}{\alpha\pi M_{\Upsilon(nS)}} E_\gamma X_d^2$ where X_d is a model-dependent quantity containing the coupling of the Higgs to bottom quarks, m_b is the bottom quark mass, α and G_F are the electroweak parameters, and E_γ is the photon energy.

From a theoretical viewpoint, the existence of a light pseudoscalar Higgs is not unexpected in many extensions of the SM. As an example, the Next-to-Minimal Supersymmetric Standard Model (NMSSM) has a gauge singlet added to the MSSM two-doublet Higgs sector [61] leading to seven physical Higgs bosons, five of them neutral, including two pseudoscalars. In the limit of either slightly broken R or Peccei-Quinn (PQ) symmetries, the lightest CP-odd Higgs boson (denoted by A_1) can be much lighter than the other Higgs bosons, providing unique signatures at a (Super) B factory as shown below.

The A_1 coupling to down-type fermions turns out to be proportional to $X_d = \cos\theta_A \tan\beta$, where $\tan\beta$ denotes the ratio of the vevs of the up- and down-type Higgs bosons and θ_A is the mixing angle of the singlet and non-singlet components that constitute the physical A_1 state [62]. If $\cos\theta_A \sim 0.1 - 0.5$, present LEP and B physics bounds can be simultaneously satisfied [63], while a light Higgs could still show up in Υ radiative decays into tauonic pairs: $\Upsilon(nS) \to \gamma A_1(\to \tau^+\tau^-)\ ;\quad n = 1, 2, 3$.

As this light Higgs acquires its couplings to Standard Model fermions via mixing with the Standard Model Higgs, it therefore couples to mass, and will decay to the heaviest available Standard Model fermion. In the region $M_{A_1} > 2M_\tau$, there are two measurements which have sensitivity: lepton universality of Υ decays, and searches for a monochromatic photon peak in tauonic Υ decays.

The measurement of lepton universality compares the branching ratios of Υ to e^+e^-, $\mu^+\mu^-$ and $\tau^+\tau^-$ [64, 65], which should all be identical in the Standard Model, besides space-phase differences. This inclusive measurement is relevant especially when the monochromatic photon signal is buried under backgrounds. Under reasonable sets of the NMSSM parameters that satisfy all current LEP and B physics bounds, it has been shown [54, 66] that A_1 bosons with masses between 9-10.5 GeV can give sizeable deviations from SM if $5 \lesssim tan(\beta) \lesssim 20$.

Unfortunately recent measurements of these branching fractions are systematics limited and hardly any dramatic improvement (e.g. below 1% accuracy) is expected by SuperB. Alternatively, in the search for monochromatic photons [53] the first relevant decay mode is $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$ first, followed by $\Upsilon(1S) \to \gamma\tau^+\tau^-$, which has only a 4.5% branching fraction, but has low background. The second decay mode is $\Upsilon(3S) \to \gamma\tau^+\tau^-$, which suffers from much worse backgrounds from $e^+e^- \to \tau^+\tau^-\gamma$ events, but

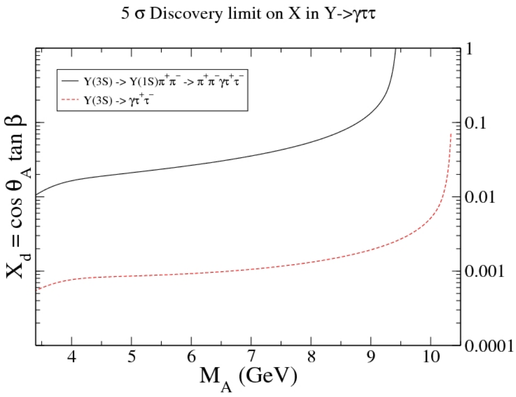

FIG. 18: Five σ discovery potential of Super$B$ with $\Upsilon(3S)$ data, in the mode $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S) \to \pi^+\pi^-\tau^+\tau^-\gamma$ (solid black) and $\Upsilon(3S) \to \tau^+\tau^-\gamma$ (dashed red). An integrated luminosity of 1 ab^{-1} was assumed.

also has a rate that is more than a factor of ten higher. The corresponding exclusion plots expected at SuperB are in Fig. 18.

Let us finally point out another possible signal for detection of a light CP-odd Higgs boson related to bottomonium spectroscopy. As studied in [68], significant A_1-$\eta_b(nS)$ mixing should sizeably alter the hyperfine splitting $M(\Upsilon(nS)) - M(\eta_b(nS))$ as compared to SM expectations. This kind of search has a great advantage with respect to the radiative decays of Upsilon resonances since it is free of those theoretical uncertainties coming from QCD and relativistic corrections plaguing the Wilczek formula. Moreover, from an experimental point of view, the mixing could spoil a simple-minded search for narrow peaks in the photon spectrum while the measurement of hyperfine splittings would still yield unexpected results hinting at the existence of a light pseudoscalar Higgs [68].

B. Invisible decays and Dark Matter

Finally, if Dark Matter is lighter than 5 GeV, it will require a Super B Factory to determine its properties. Generally, in this mass region one needs two particles, the dark matter particle χ, and a boson that couples it to the Standard Model U . The most promising searches are in invisible and radiative decays of the Υ, which can be measured in the mode $\Upsilon(3S) \to \pi^+\pi^- invisible$, which is sensitive to a vector U [57]. The current best sensitivity to this process has been achieved by the BaBar Experiment [58]; however, this result is still an order of magnitude above the Standard Model prediction. The sensitivity is limited by the amount of background that needs to be subtracted, primarily due to undetected leptons from $\Upsilon(1S) \to \ell^+\ell^-$ in the final state. Studies of this background suggest that the only way to further improve the measurement to the level of the Standard Model is to employ both far-backward and far-forward tagging into the design of the detector. Achieving a $3-5\sigma$ sensitivity to the Standard Model will require active background tagging down to 5-10 degrees above the beam-line in both the forward and backward directions.

The second most promising signature is radiative decays $\Upsilon(1S) \to \gamma + invisible$. This is probably the most favored mode theoretically, and is sensitive to a scalar or pseudoscalar U. The mediator coupling the Standard Model particles to final state χ's can be a pseudoscalar Higgs, $U = A_1$, which can be naturally light, and would appear in this mode [38]. In such models the Dark Matter can be naturally be a bino-like neutralino. Extended detector coverage in the forward and backward directions is important to reducing the radiative QED backgrounds which dominate this final state.

It is expected that improving detector coverage with active coverage for tagging low-angle or missing-particle backgrounds will also improve the sensitivity in flagship measurements of Super-B, including $B \to K\nu\bar{\nu}$ and $B \to \ell\nu$.

C. Dark Forces

Recent cosmic ray measurements of the electron and positron flux from ATIC[70], FERMI[71], and PAMELA[72] have spectra which are not well described by galactic cosmic ray models such as GALPROP[73]. For instance, PAMELA shows an increase in the positron/electron fraction with increasing energy. No corresponding increase in the antiproton spectrum is observed. There have been two main approaches attempting to explain these features: astrophysical sources (particularly from undetected, nearby pulsars)[74] and annihilating or decaying dark matter.

Arkani-Hamed *et al.*[75] and Pospelov *et al.*[76] have introduced a class of theories containing a new "dark force" and a light, hidden sector. In this model, the ATIC and PAMELA signals are due to dark matter particles with mass $\sim 400-800\,\mathrm{GeV}/c^2$ annihilating into the gauge boson force carrier with mass $\sim 1\,\mathrm{GeV}/c^2$, dubbed the A', which subsequently decays to Standard Model particles. If the A' mass is below twice the proton mass, decays to $p\bar{p}$ are kinematically forbidden allowing only decays to states like e^+e^-, $\mu^+\mu^-$, and $\pi\pi$. If the dark force is non-Abelian, this theory can also accommodate the 511 keV signal found by the INTEGRAL satellite [77] and the DAMA modulation data [78].

The dark sector couples to the Standard Model through kinetic mixing with the photon (hence we call the A' the "dark photon") with a mixing strength ϵ. The current limits on ϵ from various experiments are shown on Figure 19. Low-energy, high luminosity e^+e^- experiments like the B-Factories are in excellent position to probe these theories, as pointed out in papers by Batell *et al.* [79] and Essig *et al.* [80]. Broadly speaking, there are three categories for dark force searches at SuperB: direct production, rare B-decays, and rare decays of other mesons.

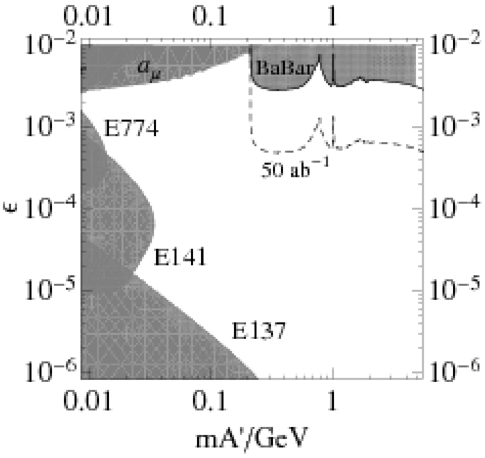

FIG. 19: Shaded: The current constraints on the kinetic mixing parameter ϵ as a function of dark photon mass. Dashed line: the expected constraint from SuperB with $50ab^{-1}$ of data.

The most general searches for dark forces are in direct e^+e^- production. The primary model independent signature is $e^+e^- \rightarrow \gamma A' \rightarrow \gamma l^+l^-$. While these channels are the cleanest theoretically, they suffer from large irreducable QED backgrounds. Searches for narrow resonances in $e^+e^- \rightarrow \gamma\mu\mu$ and $e^+e^- \rightarrow \gamma\tau\tau$ have been carried out by CLEO[81] and BaBar[82]. The limit on ϵ obtained from the BaBar $e^+e^- \rightarrow \gamma\mu\mu$ analysis using $32fb^{-1}$ is shown on Figure 19. With the increased luminosity, SuperB should be sensitive to values of ϵ down to 5×10^{-4}. Since the gauge symmetry of the dark sector is by constuction broken, there is also at least one "dark Higgs" (h') in the model. Therefore there can also be interactions like $e^+e^- \rightarrow A\prime h' \rightarrow 3(l^+l^-)$. While this channel is suppressed with respect to $e^+e^- \rightarrow \gamma A'$, the final state of 6-leptons (with possibly all three pairs giving a narrow resonance) should be much cleaner with a small irreducible QED background. There are a number of other, more model dependent searches we can do at SuperB. For instance, if the dark force is non-Abelian there can be final states with 4-,8-, or even 12- or more leptons with many pairs forming a narrow resonance. While these final states are harder to use to extract ϵ limits, any evidence of a narrow resonance in them would be evidence for new physics.

Searches can also be performed in very rare decays of the B-meson. Generally speaking, and decay involving a photon can be used to search for a dark photon. We can search in the l^+l^- mass spectrum in modes such as $B \rightarrow Kl^+l^-$ for a narrow resonance, although there will be a large background from the normal SM process. In addition, loop dominated modes such as $B^0 \rightarrow l^+l^-l^+l^-$ or $B \rightarrow Kl^+l^-l^+l^-$ can enhanced by a "Higgs'-strahlung' from the top quark in the loop[83]. If these modes are observed, We can look in the di-lepton mass spectrum for a resonance.

Finally, we can search for dark forces in rare meson decays [84]. The SuperB experiment will not be just a B-meson factory, it will also produce huge samples of other mesons such as π^0, η, K, ϕ, and $J\psi$. For instance, there are roughly $10^10\pi^0/ab^-1$ and $10^9\eta/ab^-1$ produced which can be used to search for the channel $\pi^0/\eta \rightarrow \gamma A' \rightarrow \gamma l^+l^-$. Searching the huge meson samples for rare decays such as these should give limits on ϵ that are competitive to other measurements.

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8. Role of Lattice QCD

This section describes the role of lattice QCD in the physics case of SuperB.

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9. Interplay between measurements

	AC	RVV2	AKM	δLL	FBMSSM
$D^0 - \bar{D}^0$	★★★	★	★	★	★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★

TABLE XII: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY models [1]. ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

A. Constraints on new physics

Numerous studies of flavour and CP-violating observables in New Physics models have been performed over the past years. In what follows we give a brief summary of the results obtained within the MSSM with various realisations of flavour, in the Standard Model with a 4th generation of quarks and leptons (SM4), in Randall-Sundrum models with bulk fields, both with the SM bulk gauge group (minimal RS) and with a protective custodial symmetry (RSc), and in the Littlest Higgs model with T-parity (LHT model). Clearly our focus lies on those observables that can be measured at a SuperB factory with high precision and thus provide a powerful tool to discriminate among various scenarios.

B. MSSM flavour models

An extensive analysis of flavour and CP-violating effects in various MSSM flavour models has been presented in [1]. A brief summary of the results can be found in Table XII, which indicates the possible size of effects in various B physics observables, in $D^0 - \bar{D}^0$ mixing and in the $\tau \to \mu\gamma$ decay. Finding for instance large NP effects in the latter decay or in the CP asymmetry $S_{\phi K_S}$ would rule out the AKM model [2] while favouring the other models analysed. Similarly observing significant CP-violating effects in $D - \bar{D}$ mixing would disfavour all models analysed except the AC [3] model [4].

Interestingly, even the flavour blind MSSM (FBMSSM) analysed in [5] can account for large effects in various B physics observables. Of particular interest in this case are CP-violating observables like $A_{\rm CP}^{b\to s\gamma}$ and $S_{\phi K_S}$ which, due to the minimal flavour structure of the model, are highly correlated with electric dipole moments (EDMs). In Fig. 20 we show $A_{\rm CP}^{b\to s\gamma}$ as a function of $S_{\phi K_S}$. Due to the strong correlation between these two asymmetries, the aim to address the present tension in $S_{\phi K_S}$ unambiguously predicts large NP effects in the CP asymmetry in $b\to s\gamma$, which even changes sign with respect to the SM prediction.

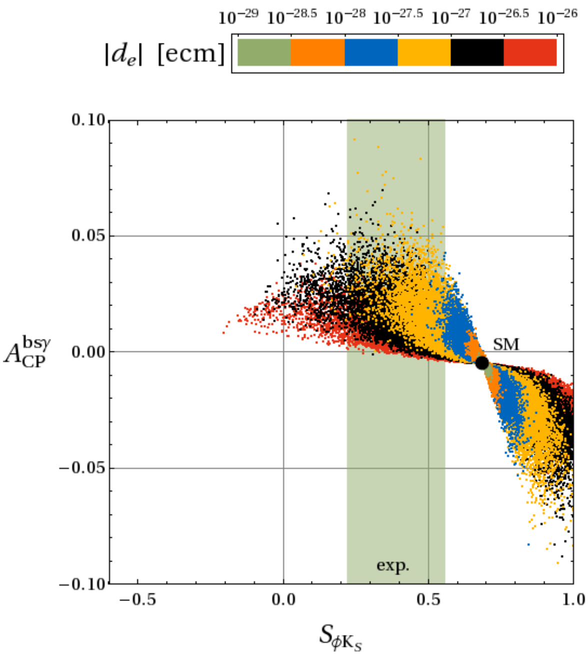

FIG. 20: Correlation between the CP asymmetries $A_{\rm CP}^{b\to s\gamma}$ and $S_{\phi K_S}$ in the FBMSSM [5]. The various colours indicate the predicted lower bound on the electron EDM.

C. Fourth generation of quarks and leptons

Recently the implications on flavour physics observables of extending the SM by a fourth generation of quarks and leptons (SM4) have received a lot of attention, see e. g. [6, 7]. The guidelines of how to extract the new parameters of the CKM4 matrix from future data has been presented in [7] and will not be repeated here. Instead we show in Figs. 21 and 22 the CP asymmetries $S_{\phi K_S}$ and $A_{\rm CP}^{b\to s\gamma}$, respectively, as functions of $S_{\psi\phi}$. In both cases a strong correlation can be observed. Therefore, if the present deviation from the SM prediction in $S_{\psi\phi}$ will be confirmed by future more accurate data, the SM4 unambiguously predicts large effects in $S_{\phi K_S}$ and $A_{\rm CP}^{b\to s\gamma}$. Together with the possible direct observation of a 4th generation at the LHC, these effects can be used to tighten the allowed SM4 parameter space.

D. Minimal and custodially extended RS models

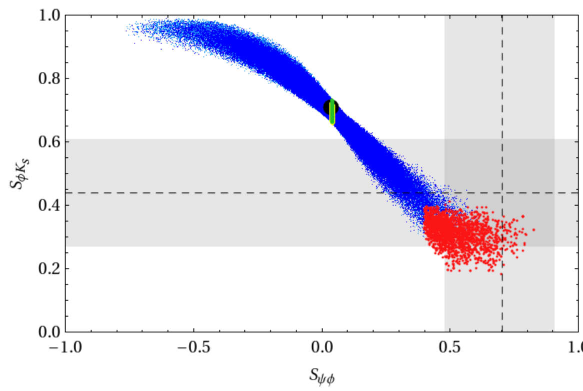

FIG. 21: Correlation between the CP asymmetries $S_{\phi K_S}$ and $S_{\psi\phi}$ in the SM4 [7].

A theoretically particularly appealing approach to the SM flavour puzzle is given by Randall-Sundrum models with bulk fermions [8]. In this scenario the observed hierarchies in quark masses and CKM mixings are naturally obtained from the different localisation of fermions along the 5D bulk. Implications for low energy flavour violating observables have been studied extensively in the literature, see e. g. [9–11].

Interestingly the observed pattern of effects depends crucially on the realisation of the model. In the minimal scenario with only the SM gauge group in the bulk, the NP contributions to rare decays are dominantly left-handed. Consequently large effects could be expected in both B and K decays [9–11]. As an example Fig. 23 shows the correlation between $Br(B_s\to\mu^+\mu^-)$ and $Br(B\to X_s\nu\bar\nu)$ in the minimal RS model. The latter branching ratio can reach values larger than 10^{-4}, which necessarily coincide with large NP effects also in the former channel.

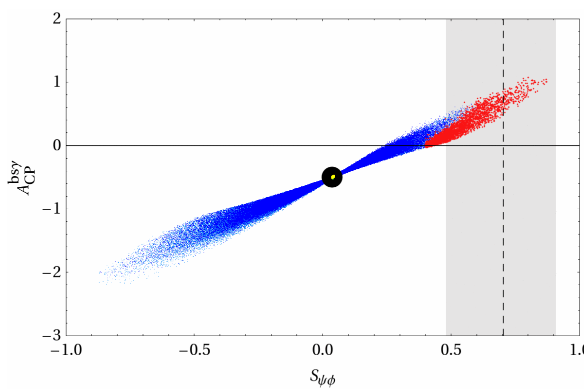

FIG. 22: Correlation between the CP asymmetries $A_{\rm CP}^{b\to s\gamma}$ and $S_{\psi\phi}$ in the SM4 [7].

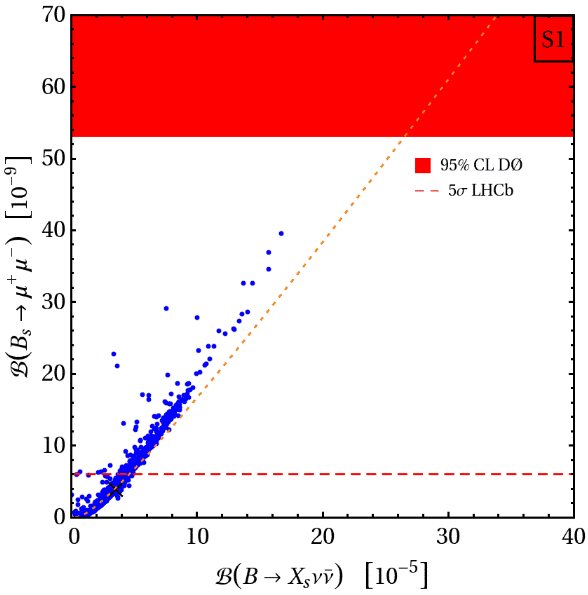

FIG. 23: Correlation between the branching ratios for $B_s \to \mu^+\mu^-$ and $B \to X_s\nu\bar{\nu}$ in the minimal RS model [11].

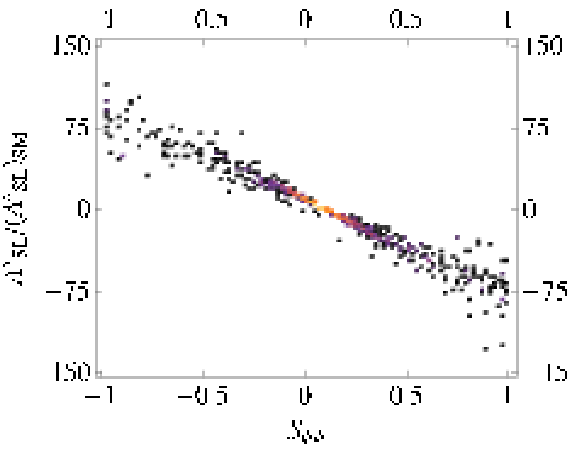

FIG. 24: Correlation between the CP asymmetries $A^s_{\rm SL}$ and $S_{\psi\phi}$ in the RSc model [10].

The situation is completely different in case of a custodially extended bulk gauge symmetry [10]. Due to the suppression of left-handed flavour changing Z couplings, rare decays in this case are dominated by right-handed currents. Consequently, while large NP effects can appear in the kaon sector, the effects in rare B decays are predicted to be small and therefore difficult to disentangle from the SM. The situation is however different in the $\Delta F = 2$ sector, where a large new phase in $B_s - \bar{B}_s$ mixing can be generated (see Fig. 24).

E. Littlest Higgs model with T-parity

The detailed FCNC studies in the Littlest Higgs model with T-parity (LHT) performed in 2006–2007 [12] have recently been updated [13] in light of an additional LHT contribution to the Z penguin pointed out in [14] and of new input from experiments and lattice calculations. While the additional contribution affected the size of some of the possible effects, the main conclusions from [12] remained intact:

- Large NP effects are possible in CP asymmetries related to $B_s - \bar{B}_s$ mixing and in rare K decays.
- The effects in rare B decays are small and therefore difficult to measure.
- Large effects can be expected in LFV μ and τ decays, as summarised in Table XIII.
- Ratios of LFV branching ratios turn out to be very different from the MSSM predictions and can therefore serve as a clean tool to distinguish between these two models (see Table XIV).

decay	$f = 1000$ GeV	$f = 500$ GeV	SuperB sensitivity
$\tau \to e\gamma$	$8 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
$\tau \to \mu\gamma$	$8 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
$\tau^- \to e^-e^+e^-$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-10}$
$\tau^- \to \mu^-\mu^+\mu^-$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-10}$
$\tau^- \to e^-\mu^+\mu^-$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	
$\tau^- \to \mu^-e^+e^-$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	
$\tau^- \to \mu^-e^+\mu^-$	$6 \cdot 10^{-14}$	$1 \cdot 10^{-13}$	
$\tau^- \to e^-\mu^+e^-$	$6 \cdot 10^{-14}$	$1 \cdot 10^{-13}$	
$\tau \to \mu\pi$	$4 \cdot 10^{-10}$	$5 \cdot 10^{-8}$	
$\tau \to e\pi$	$4 \cdot 10^{-10}$	$5 \cdot 10^{-8}$	
$\tau \to \mu\eta$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$4 \cdot 10^{-10}$
$\tau \to e\eta$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$6 \cdot 10^{-10}$
$\tau \to \mu\eta'$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	
$\tau \to e\eta'$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	

TABLE XIII: Maximal values on LFV τ decay branching ratios in the LHT model, for two different values of the scale f, after imposing the constraints on $\mu \to e\gamma$ and $\mu^- \to e^-e^+e^-$ [13].

A detailed study of $D^0 - \bar{D}^0$ mixing in the LHT model has been performed in [17]. While in case of the CP-consering observables x and y a possible NP contribution is difficult to disentangle due to the poor knowledge of the SM long-distance contributions, an observation of CP violation in the D system would be an unabmiguous sign of NP. Fig. 25 shows the correlation between the semileptonic CP-asymmetry $a_{\rm SL}$ and the asymmetry in $D \to K_S\phi$ decays. We observe that

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.4$	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.4$	$\sim 2\cdot 10^{-3}$	$0.06\ldots0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.3$	$\sim 2\cdot 10^{-3}$	$0.02\ldots0.04$
$\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.3$	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$0.8\ldots2.0$	~ 5	$0.3\ldots0.5$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau^-\to \mu^-e^+e^-)}$	$0.7\ldots1.6$	~ 0.2	$5\ldots10$

TABLE XIV: Comparison of various ratios of branching ratios in the LHT model ($f = 1$ TeV) [13] and in the MSSM without [15] and with [16] significant Higgs contributions.

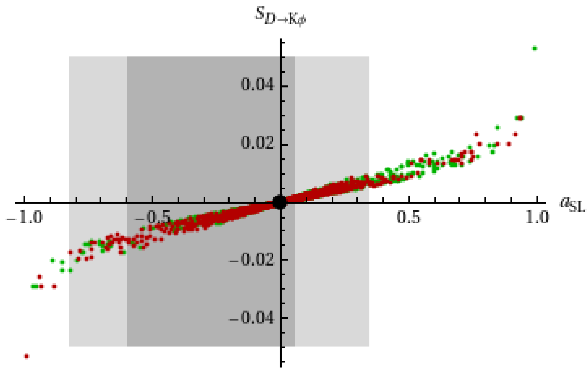

FIG. 25: Correlation between the CP asymmetries a_{SL} and $S_{K_S\phi}$ in the LHT model [17].

in both obsrvables LHT physics can lead to spectacular deviations from the tiny SM prediction. A deviation from the correlation in Fig. 25 would be a clear sign of direct CP violation in the $D\to K_S\phi$ channel.

old text to be revised

This section sumarizes the interplay between measurements, and how these can be put together in a clear way in order to reject or support generic NP hypotheses. Where appropriate we should update our models and approaches.

Part of the interplay will naturally be linked to the searches performed at Super$B$ and how these can be used to go beyond the search reach of the LHC and other experiments.

Theoretical limitations coming from hadronic uncertainties or lattice improvements would also be described here, unless a more detailed treatment is found to be more relevant for a particular section prior to this end-game section.

- For example, consider the constraints on charged higgs mass vs $\tan\beta$ from (e.g.) the Haisch conf proceedings, and add to this the ATLAS predictions so that we know that we can extract more information than the LHC. (See Fig. 26).
- Likewise for the δ_{ij} parameters vs gluino mass plots (See Fig. 27).
- Also include the A^0 mass vs $\tan\beta$ plot from the valencia document (See Fig. 28).
- Is there an equivalent plot we can make for θ_{13} vs MEG and SuperB τ LFV limits? Based on Herro et al. or some 'generic' models.

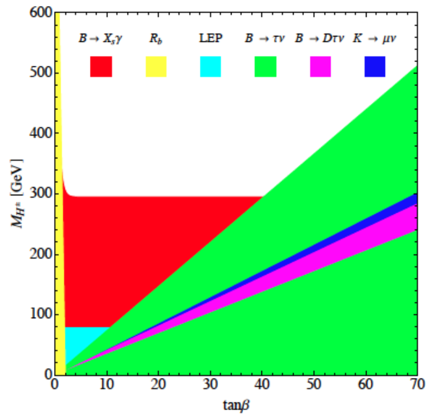

FIG. 26: Direct and indirect bounds on the constraint on m_{H^+} in Type II 2HDM as a function of $\tan\beta$. This plot is taken from U. Haisch arXiv:0805.2141. We should (i) update the plot with predictions using SuperB with $75ab^{-1}$, and overlay on this the constraints obtained from ATLAS via direct searches (see arXiv:0901.0512) for comparison. Alternatively include a now ($1.5ab^{-1}$) plot in addition to the $75ab^{-1}$ so that the reader will understand when ATLAS will be able to say something new in this area.

The other important aspect of this section is to develop a golden matrix that goes beyond the B-decays measurements presented in Valencia. Include charm, spectroscopy, $\tau\to\mu\gamma$, and $\tau\to 3\ell$ (See Table XV).

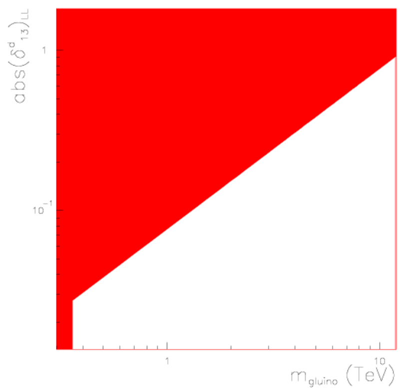

FIG. 27: Direct and indirect bounds on the gluino mass vs. $\delta^d_{13,(LL)}$ from LEP, and those expected from SuperB and the LHC. This plot needs to have the direct constraints added to it with three regions of interest described: i) the direct search region where SuperB also sees something: Large coupling (ii) the direct search region where SuperB does not see something: Small coupling, and (iii) the region where neither experiment sees anything. The font's on these plots should be made so that they are readable...

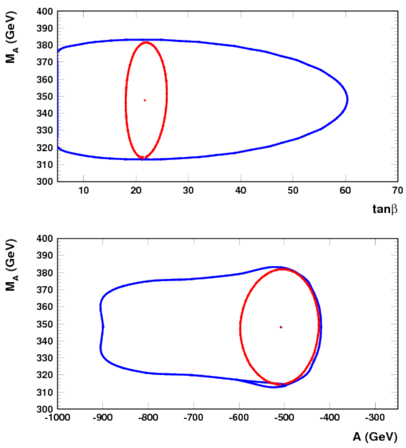

FIG. 28: The red (clear) contour corresponds to the LHC scenario that includes the low-energy and electroweak constraints, while the blue (darker) contour makes the same assumptions about the assumed LHC discoveries, but does not include any external constraints.

F. Precision CKM constraints.

- show the precision obtained on the CKM picture, as a test of the CKM anzatz, and relate this to the new physics goals of SuperB and how this is part of the interplay picture.
- Also refer to the $K \to \pi\nu\bar{\nu}$ error budget being dominated by CKM. If we improve CKM, we open up new ways to look for new physics (See Fig. 29).

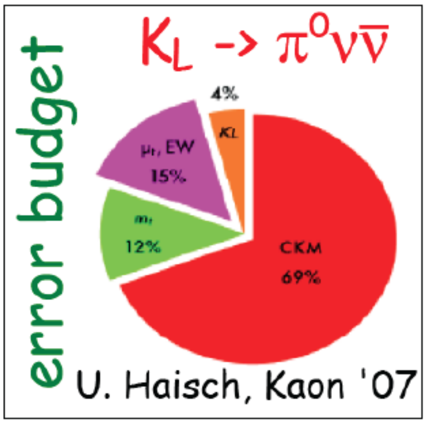

FIG. 29: The error budget on $K^+ \to \pi^+\nu\bar{\nu}$. The error budget on $K^0 \to \pi^0\nu\bar{\nu}$.

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10. Conclusions

Super*B* is a next generation high luminosity e^+e^- collider that will accumulate a data sample of $75ab^{-1}$ with five years of nominal data taking. This experiment could start running as early as 2015, by which time the LHC will have accumulated a significant sam-

TABLE XV: The golden matrix of observables versus new physics scenarios. L denotes a large effect, M denotes a measurable effect, and CKM denotes a measurement that also requires precision determination of the CKM matrix.

	H^+ high $\tan\beta$	MFV	Non-MFV	NP Z-penguins	Right-handed currents	LTH	SUSY
$\mathcal{B}(B \to X_s\gamma)$		L	M		M		
$\mathcal{A}_{CP}(B \to X_s\gamma)$			L		M		
$\mathcal{B}(B \to \tau\nu)$	L-CKM						
$\mathcal{B}(B \to X_s\ell\ell)$			M	M	M		
$\mathcal{B}(B \to K\nu\overline{\nu})$			M	L			
$S_{K_S\pi^0\gamma}$					L		
The angle β (ΔS)			L-CKM		L		
$B_s \to \gamma\gamma$							L
$D^0 \to \mu^+\mu^-$						L	L
Mixing in $D^0 \to K^+K^-, K^+\pi^-, K_S\pi^+\pi^-$						L	L
direct CPV in $D^0 \to K^+K^-\pi^+\pi^-, D^+ \to K_S\pi^+$						L	L
$\tau \to \mu\gamma$							L
$\tau \to \mu\mu\mu$						L	

ple of data, and would be reporting the results of searches for or direct measurements of new physics. Those results are limited in that they measure only flavour diagonal processes. In order to fully understand the nature of new physics, one also has to measure the off-diagonal terms, in analogy to the CKM and PMNS mixing matrices. The new physics capability of the Super$B$ experiment is completely complementary to the direct searches that are now underway at the LHC. There are many measurements that could provide an unequivocal signal for new physics, and with hind-sight it would be possible to decode the more subtle nature of new physics by comparing the results of many measurements against theoretical predictions. The interplay between measurements made at Super$B$ and those possible at other experiments is discussed in detail in Section 9 where a strategy for elucidating the nature of new physics is outlined. This strategy is only feasible through a combination of direct and indirect searches, where most of the latter are only possible at a Super Flavour Factory like Super$B$.

The new physics sensitive measurements possible at Super$B$ are discussed in detail throughout this paper. Some of the golden channels that we aim to measure are discussed in the following summary. In terms of Higgs physics, one can combine information from rare B decays in order to precisely measure $\tan\beta$ or the coupling A in CMSSM. In addition to learning about the couplings and structure of the Higgs sector beyond the Standard Model, one can indirectly search for charged Higgs particles to a level that exceeds the LHC search capabilities by a factor of $3-5$ over the full range of $\tan\beta$. CP violation parameters in B and D decays are also sensitive probes of Higgs and SUSY particles, and these will be studied to the fullest extent possible.

Again, using rare B decays measured at Super$B$ it is possible to probe the structure of SUSY. For example, two thirds of the MSSM parameters are flavour couplings, and with rare decay measurements from a Super Flavour Factory it would be possible measure the real and imaginary parts of a number of flavour couplings of SUSY models to a few percent.

In should be noted that exclusive decays of the rare processes $b \to s\ell\ell$ and $b \to s\gamma$ will be measured with high statistics at LHCb. At Super$B$ however one can also perform both inclusive and exclusive measurements of these decays. Inclusive decays provide important additional constraints as the theoretical uncertainties on the exclusive processes are much larger than the inclusive ones. These sets of measurements at Super$B$ will be limited by theoretical uncertainties as discussed in Section 1.

Super$B$ has by far the greatest sensitivity for studies of Lepton Flavour Violating τ decays and will be able to search down to branching fractions of the level of 2×10^{-10}. SUSY GUT models, using constraints from the current B_s mixing and phase measurements from the Tevatron predict that such τ LFV channels could exist with branching fractions of a few 10^{-8}. In addition to LFV studies in τ decays, Super$B$ will search for LFV in di-lepton decays of light mesons. Such decays are sensitive to light Higgs or Dark Matter particles that would be difficult or impossible to detect in high energy machines. Similarly, the detailed study of the decays of light mesons could elucidate, or exclude large parts of the parameter space for the dark sector which is commonly referred to as 'Dark Forces' in the literature.

There are a number of deviations from the Standard Model at the level of $2-3\sigma$ at the existing B-factories. If any of these were a manifestation of new physics, the increased precision obtainable at Super$B$ would be able to convert these hints into discoveries of new physics. One such deviation is that of a CPT test using di-lepton decays of B mesons. A precision test of CPT could be performed at SuperB which in turn could probe new physics near the plank scale for some quantum gravity scenarios. The current discrepancy between measurement at the Standard Model is at the level of 2.7σ.

If no new physics were found at the LHC, then experimentalists would have to re-consider the SUSY flavour problem, which is driven by rare decay measurements in the flavour sector. These measurements already point to a new physics scale of 10-100 TeV. Using the clean environment at Super$B$ particle physicists would be able to indirectly probe this energy range in order to elucidate the new physics.

Likewise, if the LHC fails to find the Standard Model Higgs, it would be possible to combine information from Super$B$ with measurements of $g-2$, and Ω_{CDM} to improve the indirect constrains on the Higgs mass in CMSSM. The currently preferred mass for the Higgs from this method is compatible with the results of precision electroweak fits.

In addition to the aforementioned new physics search capabilities, Super$B$ will be able to perform precision tests of the Standard Model, which in turn could reduce theoretical uncertainties sufficiently to pave the way for additional new physics searches. One highlight of the Standard Model measurements is the possibility to perform a precision measurement of $\sin^2\theta_{\rm W}$. Charm mixing has been firmly established in recent years, and a detailed study of possible CP violation effects in charm would be performed at Super$B$. These would include the study of quantum-correlated $D^0\overline{D}^0$ decays, which would give access to additional experimental observables beyond those studied in charm decays at the $\Upsilon(4S)$. Any large manifestation of CP violation in charm would be a clear indication of new physics. In addition to the aforementioned studies, data from Super$B$ could be used to measure a number of benchmark parameters, such as meson masses and decay constants, which in turn could be used to further validate Lattice QCD and hone our understanding of theory.

In summary the Super$B$ experiment would be able to perform precision measurements of a wide array of new physics sensitive and Standard Model observables. By interpreting the resulting pattern of measurements and deviations from the Standard Model this experiment would be able to elucidate details of the nature of new physics to energy scales up to 100 TeV. This broad physics programme is complementary to the direct search programme at the LHC.