Super$B$
Progress Reports

The Physics

December 31, 2009

Abstract

This report details the progress made in by the Super$B$ Project in the area of the Physics case since the publication of the Super$B$ Conceptual Design Report in 2007 and the Proceedings of Super$B$ Workshop VI in Valencia in 2008.

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-sensitive observables with unprecedented precision, thanks to the high luminosity and the very clean ex-

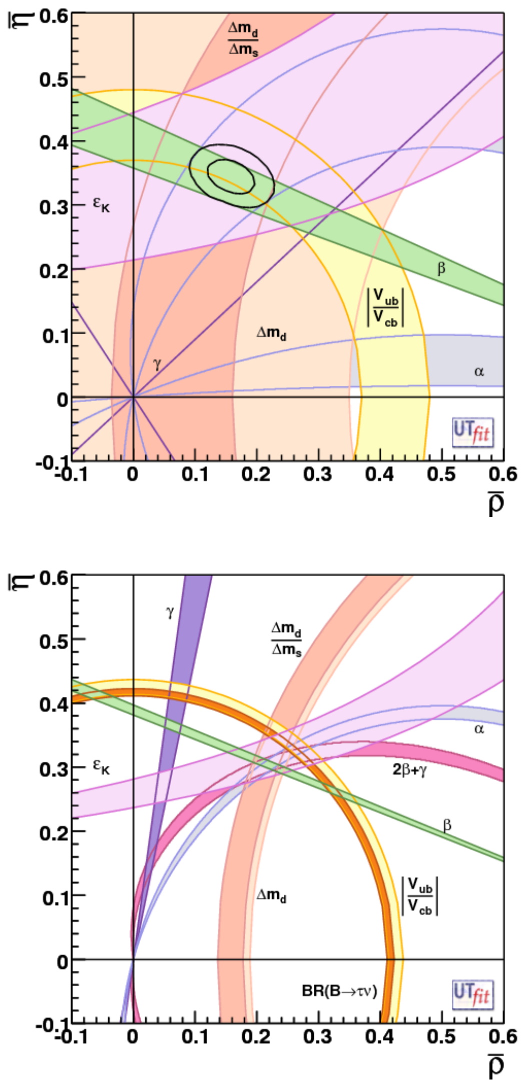

FIG. 1: Regions corresponding to 95% probability for $\overline{\rho}$ and $\overline{\eta}$ selected by different constraints, assuming present central values with present errors (left) or with errors expected at Super$B$ (right).

perimental 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} $\text{cm}^{-2}\text{s}^{-1}$ or more, yielding 15 ab^{-1}/Snowmass Year of $1.5{\times}10^7$ 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 to be able to search for small deviations from the

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. [1, 3, 4].

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%
$A_{\rm FB}(B \to X_s l^+l^-)_{s_0}$	X	30%	4–6%
$\mathcal{B}(B \to K\nu\overline{\nu})$	X	X	16–20%
$S(K^0_S\pi^0\gamma)$	0.24	0.08	0.02–0.03

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 $\bar{\eta}$.

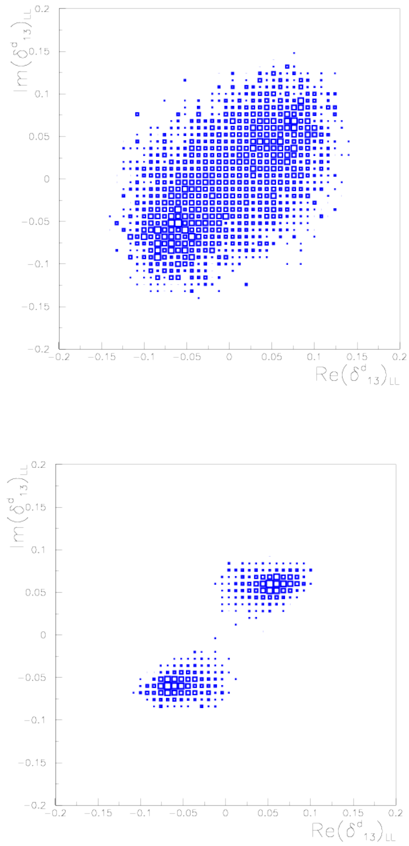

FIG. 2: Determination of the SUSY mass-insertion parameter $(\delta_{13})_{LL}$ with a 10 ab^{-1} sample (top) and with Super$B$ (bottom).

Charm Physics

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

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

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

An upgraded KEKB is not capable of running at this reduced energy.

Tau Physics

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

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

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

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

Spectroscopy

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

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

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

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

[1] M. Bona *et al.*, arXiv:0709.0451 [hep-ex].
[2] 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].

B Physics at the $\Upsilon(4S)$

This section should be 10-20 pages long+B_s section

This section sumarizes the B physics programme and what it can achieve. It should be stand alone and focus on the physics goals in the following order of priority: new physics reach (noting where this exceeds LHC where appropraite), unique and important Standard Model test. Finally it may be appropriate to consider mentioning a number of precision SM tests that would also be done as calibration channels.

Each sub-section should succinctly describe the necessary physics case, and at the end there should be a short summary giving the highlights (one or two short paragraphs) for people who might be browsing through looking for specific information on our B-physics goals.

Also the sub-sections are not necessarily ranked in order of importance.

A. New Physics in *CP* violation

B. New Physics in mixing

C. $|V_{ub}|$

D. $|V_{cb}|$

E. 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

F. Semi-leptonic B decays

G. Radiative B decays

H. 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 X and Y%, 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 II. 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 II: 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 ($75\,\text{ab}^{-1}$)	Theory uncertainty
β ($c\bar{c}s$)	0.2°	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

B Physics at the $\Upsilon(5\text{S})$

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 $\Upsilon(4\text{S})$ 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 [? ? ?] and Belle [? ?] 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 [? ? ?]. 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.

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 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, having an invariant mass of $m_{\Upsilon(5S)} = (10.865 \pm 0.008)$ GeV/c^2 [? ? ?]. The cross section of $\Upsilon(5S)$ production in e^+e^- collisions is $\sigma(e^+e^- \rightarrow \Upsilon(5S)) = 0.301 \pm 0.002 \pm 0.039$ nb [?], which corresponds to about one third of the $\Upsilon(4S)$ one. 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. Tab. III shows the current experimental status of B pair production rates, along with the values used in the study presented in this section.

TABLE III: Υ(5S) decay branching ratios as measured by CLEO [?] and Belle [?]. The last column shows the values used throughout this section.

Υ(5S) Decay Modes	CLEO	Belle	This Study
$B_s^{(*)}\bar{B}_s^{(*)}$ (%)	26^{+7}_{-4}	21^{+6}_{-3}	26
$(B_s^*\bar{B}_s^*)/(B_s^{(*)}\bar{B}_s^{(*)})$	–	$0.94^{+0.06}_{-0.09}$	0.94
$(B_s^*\bar{B}_s + B_s\bar{B}_s^*)/(B_s^{(*)}\bar{B}_s^{(*)})$	–	–	0.03
$(B_s\bar{B}_s)/(B_s^{(*)}\bar{B}_s^{(*)})$	–	–	0.03
$B_d^*\bar{B}_d^*$ (%)	$43.6 \pm 8.3 \pm 7.2$	–	44
$B_d\bar{B}_d^* + B_d^*\bar{B}_d$ (%)	$14.3 \pm 5.3 \pm 2.7$	–	7
$B_d\bar{B}_d$ (%)	< 13.8	–	7
$B_d\bar{B}_d^{(*)}\pi + B_d^{(*)}\bar{B}_d\pi$ (%)	< 19.7	–	16
$B_d\bar{B}_d\pi\pi$ (%)	< 8.9	–	-

The multiplicity of possible final states implies different momenta for the produced $B\overline{B}$ pairs and affects the reconstruction methods. In particular, the distribution of the usual discriminating variables $m_{\rm ES}$ and ΔE is different depending on the final state, as shown in Fig 3. This feature is extremely helpful in isolating the different final states in the $(m_{\rm ES}, \Delta E)$ plane. 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. We have taken this small effect into account in our simulations.

3. *Measurement of B_s Mixing Parameters*

The absolute value and the phase of the $B_s\overline{B}_s$ mixing amplitude can be used to test for the presence of

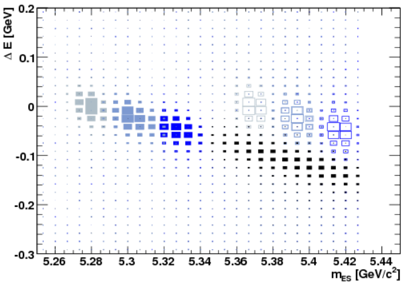

FIG. 3: Distribution of ΔE *vs.* $m_{\rm ES}$ for a sample of simulated $B_{d,s}$ mesons produced at the $\Upsilon(5S)$ resonance and decaying into $J/\psi\,\phi$ final states. Events coming from $B_q^{(*)}B_q^{(*)}$ $(q = d, s)$ are all generated with the same relative rate. We use full boxes for $q = d$ and empty boxes for $q = s$. The colour scale identifies VV, VP and PP events (from the darker to the lighter). Events from $B_dB_d\pi$ events are also shown (black boxes).

New Physics in $\Delta B = 2$ $b \rightarrow s$ transitions. These measurements can be made at hadronic colliders [?]. The recent measurement of Δm_s [? ? ?] provides the first milestone in this physics program. These studies exploit the high Lorentz boost $\beta\gamma$ of B_s mesons produced at high energy hadronic colliders; the rapid B_s oscillations can be resolved, with current vertex detector spatial resolution ($\sim 100\,\mu$m), only with a large boost.

Similar tests for New Physics effects can be made by measuring quantities such as $\Delta\Gamma_s$ and the CP asymmetry in semileptonic decays $A^s_{\rm SL}$, which can be done at Super$B$, taking advantage of the large statistics, high efficiency of lepton reconstruction, and low backgrounds. These measurements do not require the B_s oscillations to be resolved.

In a generic New Physics scenario, the effect of $\Delta B = 2$ New Physics contributions can be parameterized in terms of two quantities, C_{B_s} and ϕ_{B_s}, given by the relation (see also Section ??):

$$C_{B_s}\, e^{2i\phi_{B_s}} = \frac{\langle B_s|H_{\rm eff}^{\rm full}|\overline{B}_s\rangle}{\langle B_s|H_{\rm eff}^{\rm SM}|\overline{B}_s\rangle}\,. \qquad (1)$$

In the absence of New Physics effects, $C_{B_s} = 1$ and $\phi_{B_s} = 0$, by definition. The measured values of Δm_s and $\sin 2\beta_s$ (discussed in Section 0 H 3) are related to Standard Model quantities through the relations :

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

The semileptonic CP asymmetry [?] and the value of $\Delta\Gamma_s/\Gamma_s$ [?] 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 $\Delta\Gamma_s$ [?]. 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 parametrization, and a constraint on this phase can be extracted along with the other two parameters (see Eq. 5 below). Measurements of $\Delta\Gamma_s$ have been performed by CDF [**?**] and DØ [**?**]; DØ also obtains a constraint on β_s. We have performed a simulation based on toy Monte Carlo experiments to evaluate the sensitivity of this measurement at Super$B$. An example of the evolution of the precision on $\Delta\Gamma_s$ as a function of the integrated luminosity is shown in Fig. 4. We see that with a few ab^{-1} of data accumulated at the $\Upsilon(5S)$ it will be possible to improve upon the current experimental precision. Clearly, LHCb also has the potential to improve this measurement.

We have also studied the performance of two different experimental techniques that can be used to to extract the semileptonic asymmetry $A^s_{\rm SL}$, defined as (see also Section **??**):

$$A^s_{\rm SL} = \frac{\mathcal{B}(B_s \to \overline{B}_s \to D_s^{(*)-} l^+\nu_l) - \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+} l^-\nu_l)}{\mathcal{B}(B_s \to \overline{B}_s \to D_s^{(*)-} l^+\nu_l) + \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+} l^-\nu_l)} = \frac{1-|q/p|^4}{1+|q/p|^4}\,.$$

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 semileptonic 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 [**?**]. Fig. 4 shows the statistical errors we expect on $A^s_{\rm SL}$ and $A_{\rm CH}$. Notice that, in both cases, the error becomes systematics dominated after a relatively small period of data taking. Nonetheless, a clear improvement on the current experimental situation is possible. Since measurements in a hadronic environment generally suffer from larger systematic effects; Super$B$ appears better-suited to obtain precise measurements of the semileptonic asymmetries.

It is interesting to mention that in the Littlest Higgs Model with T-parity introduced in Section **??** one finds large and correlated corrections to the *CP* asymmetries $S_{J/\psi\phi}$ and $A^s_{\rm SL}$ (and, to a lesser extent, also to $A^d_{\rm SL}$), as shown in Fig. 5). Note that all these *CP* asymmetries, in contrast to many other flavour observables, are not sensitive to the UV completion of the model and, thus allow for more reliable theoretical predictions.

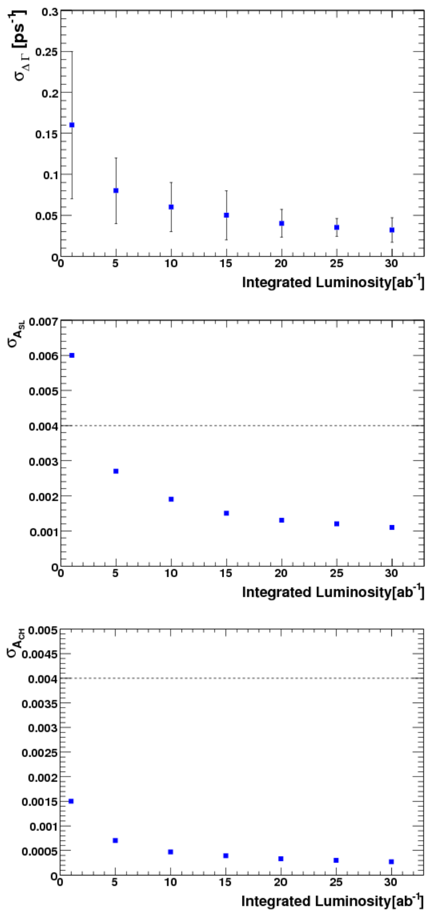

FIG. 4: Trend of the error on $\Delta\Gamma_s$, $A_{\rm SL}$ and $A_{\rm CH}$ as a function of the integrated luminosity. The error bars show the *rms* of the error distribution in the toy Monte Carlo experiments. The dashed line in the last two plots represents the systematic error on the current measurements at the $\Upsilon(4S)$ resonance, shown for comparison.

4. *Time Dependent* ***CP*** *Asymmetries at the* $\boldsymbol{\Upsilon(5S)}$

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 decay rates as a function of the proper time difference Δt can be written in

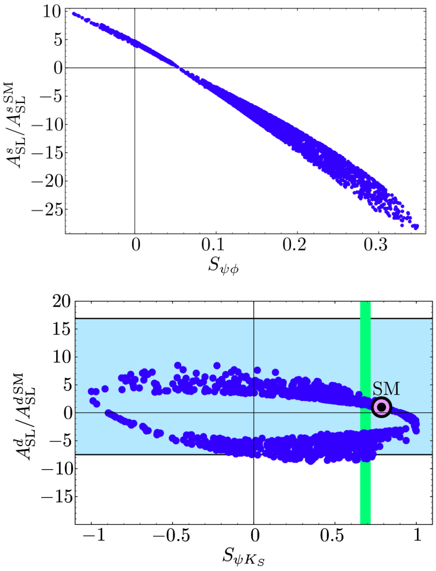

FIG. 5: Left (right) plot shows the correlation between $A^s_{\rm SL}$ ($A^d_{\rm SL}$) and $S_{J/\psi\phi}$ ($S_{J/\psi K_S}$) computed in the Littlest Higgs Model with T-parity (see text). The shaded areas represent the present experimental constraints.

terms of the parameter $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$ as [?]:

$$\begin{aligned}\Gamma_{\bar{B}_s\to f}(\Delta t) &= \mathcal{N}\frac{e^{-|\Delta t|/\tau(B_s)}}{4\tau(B_s)}\Big[\cosh(\tfrac{\Delta\Gamma_s\Delta t}{2}) + \\ &\tfrac{2\,\Im(\lambda_f)}{1+|\lambda_f|^2}\sin(\Delta m_s\Delta t) - \tfrac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos(\Delta m_s\Delta t) - \tfrac{2\,\Re(\lambda_f)}{1+|\lambda_f|^2}\sinh(\tfrac{\Delta\Gamma_s\Delta t}{2})\Big]\\ \Gamma_{B_s\to f}(\Delta t) &= \mathcal{N}\frac{e^{-|\Delta t|/\tau(B_s)}}{4\tau(B_s)}\Big[\cosh(\tfrac{\Delta\Gamma_s\Delta t}{2}) - \\ &\tfrac{2\,\Im(\lambda_f)}{1+|\lambda_f|^2}\sin(\Delta m_s\Delta t) + \tfrac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos(\Delta m_s\Delta t) - \tfrac{2\,\Re(\lambda_f)}{1+|\lambda_f|^2}\sinh(\tfrac{\Delta\Gamma_s\Delta t}{2})\Big]\end{aligned} \quad (4)$$

giving an *untagged* time-dependent decay rate of

$$\Gamma_{\bar{B}_s\to f}(\Delta t)+\Gamma_{B_s\to f}(\Delta t) = \mathcal{N}\frac{e^{-|\Delta t|/\tau(B_s)}}{2\tau(B_s)}\Big[\cosh(\frac{\Delta\Gamma_s\Delta t}{2}) - \frac{2\,\Re(\lambda_f)}{1+|\lambda_f|^2}\sinh(\frac{\Delta\Gamma_s\Delta t}{2})\Big] \quad (5)$$

With the requirement $\int_{-\infty}^{+\infty}\Gamma_{\bar{B}_s\to f}(\Delta t) + \Gamma_{B_s\to f}(\Delta t)d(\Delta t) = 1$, the normalization factor $\mathcal{N}$ is fixed to $1-(\frac{\Delta\Gamma_s}{2\Gamma_s})^2$. In this formulation, we have neglected effects due to *CP* violation in mixing.

We have investigated the possibility of performing a similar time-dependent analysis to that for the case of $B_d \to J/\psi K^0$ decays, despite the very fast B_s oscillations. We performed a toy simulation to find the sensitivity to the time dependent *CP* asymmetry in the decay $B_s \to J/\psi\phi$, and found that in order to measure the *CP* violation parameters it would be necessary to achieve a resolution $\sigma(\Delta t) < 0.11$ ps, which does not appear to be possible – improvements coming from new technology, together with the possibility of adding a layer of silicon detectors close to the beam pipe (see Section **??**), can only reduce the resolution $\sigma(\Delta t)$ to ~ 0.4 ps with a Lorentz boost of $\beta\gamma \sim 0.3$.

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 [? ?]. We have explored the possibility of taking advantage of this, using a "two-bin" time-dependent analysis. We have carried out toy simulations in which we perform a simultaneous fit to extract the yields in four categories (for different signs of Δt and tag flavour). These yields can then be used to constrain λ_f.

For instance, considering the $B_s \to J/\psi\phi$ decay, and assuming, for simplicity, that it is a pure *CP*-even eigenstate (in the general case, an angular analysis can be used to isolate *CP*-even and *CP*-odd contributions), this technique can be used to extract a constraint on the weak phase of the mixing $2\beta_s$. A precision on β_s of $\sim 10^\circ$ and $\sim 3^\circ$ can be achieved, with 1 ab^{-1} and 30 ab^{-1} of integrated luminosity, respectively. Anyway, a two-fold ambiguity between β_s and $-\beta_s$ can produce a (almost) two-times larger resolution in the total pdf, when the value of β_s is close to zero (as it should be in the SM). On the other side, this measurement is not limited by systematics, and the precision can be readily improved by collecting more data.

While the precision that can be achieved in the $B_s \to J/\psi\phi$ channel is not fully competitive with that possible at LHCb, where a tagged analysis can be done, the success of this technique opens the possibility of using several other channels, not accessible at hadronic machines, that are sensitive to the weak phase of the B_s mixing amplitude. Among the many interesting final states Super*B* could study are $B_s \to J/\psi\eta$, $B_s \to J/\psi\eta'$, $B_s \to D_s^{(*)+}D_s^{(*)-}$, $B_s \to D^{(*)}K^0_S$, $B_s \to D^{(*)}\phi$, $B_s \to J/\psi K^0_S$, $B_s \to \phi\eta'$ and $B_s \to K^0_S\pi^0$. We have performed a study on the particularly interesting channel $B_s \to K^0\bar{K}^0$, which is a pure $b \to s$ penguin transition, complementary to those that can be studied in B_d decays (see Section **??**). With 30 ab^{-1} accumulated at the $\Upsilon(5S)$, we can reach an error on β_s of 11°.

5. *Rare Leptonic B_s Decays*

In the Standard Model $\mathcal{B}(B_s \to \mu^+\mu^-) = (3.35 \pm 0.32)\times 10^{-9}$ [? ?]; this decay is chirally suppressed, and proceeds in the Standard Model through loop diagrams, which makes it particularly sensitive to New Physics contributions [? ? ? ? ? ? ? ? ? ?]. A combined analysis of B and K rare decays [?] has recently studied this decay in the context of MFV models with one Higgs doublet or two Higgs doublets at small $\tan\beta$, finding $\mathcal{B}(B_s \to \mu\mu) < 7.42\times 10^{-9}$ at 95% probability: this decay rate requires large $\tan\beta$ to receive significant New Physics contributions in MFV models.

Indeed, in a very large $\tan\beta$ scenario, Yukawa couplings contribute, resulting in a sizable enhancement of the decay rate [? ? ?]. The current experimental limit is $\mathcal{B}(B_s \to \mu^+\mu^-) < 1.0\times10^{-7}$ at 90% confidence level [? ?].

We have estimated the Super$B$ sensitivity to the branching ratio for this decay. The numbers of expected events (6 signal events and 960 background events in 30 ab^{-1}) suggest that Super$B$ would not be competitive for this measurement; indeed, this is one of the primary motivations of the LHC B physics program.

6. *Rare Radiative* B_s *Decays*

An independent measurement of $|V_{td}/V_{ts}|$, to be compared with the information coming from the Δm_s measurement, can be provided by $\Delta B = 1$ $b \to s$ transitions, which can be sensitive to New Physics in a different way than Δm_s.

Such a test is provided by the ratio $R = \mathcal{B}(B_d^0 \to \rho^0\gamma)/\mathcal{B}(B_d \to K^{*0}\gamma)$ (see Section ??), which allows a measurement of $|V_{td}/V_{ts}|$, with an uncertainty that is expected to be ultimately limited by the presence of the power-suppressed correction term ΔR in Eq. ??. In particular, a significant contribution is expected to come from the W-exchange diagram, which contributes to $B_d^0 \to \rho^0\gamma$ but not to $B_d^0 \to K^{*0}\gamma$. This contribution is of order $\Lambda_{\rm QCD}/m_b$ and is CKM suppressed in the Standard Model. Beyond the Standard Model, however, the CKM suppression may no longer be present. It is therefore interesting to look for a similar observable that is not affected by the presence of the W-exchange term, to be sure that no hadronic uncertainty is introduced going from the Standard Model to New Physics scenarios. There is such an observable: the ratio $R_s = \mathcal{B}(B_s^0 \to K^{*0}\gamma)/\mathcal{B}(B_d^0 \to K^{*0}\gamma)$. These two decays are not affected by W-exchange and ΔR is expected to be small even in the presence of New Physics. The ratio R_s is given again by Eq. ?? where ΔR, and the isospin, kinematic and form factor terms are appropriately replaced.

We have performed toy simulations to estimate our sensitivity, with an assumption of $\mathcal{B}(B_s^0 \to K^{*0}\gamma) = 1.54\times10^{-6}$. The results have been combined with the lattice QCD prediction for the form factor ratio ξ to extract the corresponding determination of $|V_{td}/V_{ts}|$. The error on this determination is fully dominated by the experimental statistical error, even assuming the present error on ξ. Thus the ratio of R_s can be thought of as a golden method for a clean determination of the ratio $|V_{td}/V_{ts}|$ from radiative B decays. As shown in in Table V, $|V_{td}/V_{ts}|$ can be measured to a precision of a few percent with a multi-ab^{-1} data sample accumulated by Super$B$ at the $\Upsilon(5S)$.

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

For several years, $b \to s\gamma$ has been considered the golden mode to probe New Physics in the flavour sector. Indeed, branching ratios and *CP* asymmetries of $b \to s\gamma$ provide significant constraints on the mass insertion parameters of the mass matrix (see Sections ?? and ??). It is important to look for other channels of this type that can play a similar rôle. An interesting candidate is the decay $B_s \to \gamma\gamma$. 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 $\mathcal{B}(B_s \to \gamma\gamma) \sim (2-8)\times10^{-7}$ [?]. New Physics effects are expected to give sizable contributions to the decay rate in certain scenarios [? ?]. For instance, in R-parity-violating SUSY models, neutralino exchange can enhance the branching ratio up to $\mathcal{B}(B_s \to \gamma\gamma) \simeq 5\times10^{-6}$ [?]. 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 $\mathcal{B}(b \to s\gamma)$ [?].

From the experimental point of view, the exclusive measurement of $B_s \to \gamma\gamma$ is very similar to other measurements already performed at B Factories (such as $B_d^0 \to \pi^0\pi^0$). The presence of two high-energetic photons presents a clear signature for signal events, particularly with a recoil technique. Both BABAR [?] and Belle [?] have published results of searches for $B_d^0 \to \gamma\gamma$, setting the current experiment upper limit at $\mathcal{B}(B_d \to \gamma\gamma) < 6.2\times10^{-7}$. These results are encouraging for the study of $B_s \to \gamma\gamma$ at Super$B$, though they show that considerable effort will be necessary to control systematic uncertainties. The limiting systematic is knowledge of the efficiency for photon reconstruction, which can be reduced with dedicated studies on control samples with similar photon energy range.

A dedicated simulation shows that we expect 14 signal events and 20 background events in a sample of 1 ab^{-1}, indicating that the decay could be observed if it has the Standard Model branching fraction. With 30 ab^{-1}, one can achieve a statistical error of 7% and a systematic error smaller than 5%. Using tagging information, direct CP asymmetry can also be measured with good accuracy, as already done at the B factories for neutral decays.

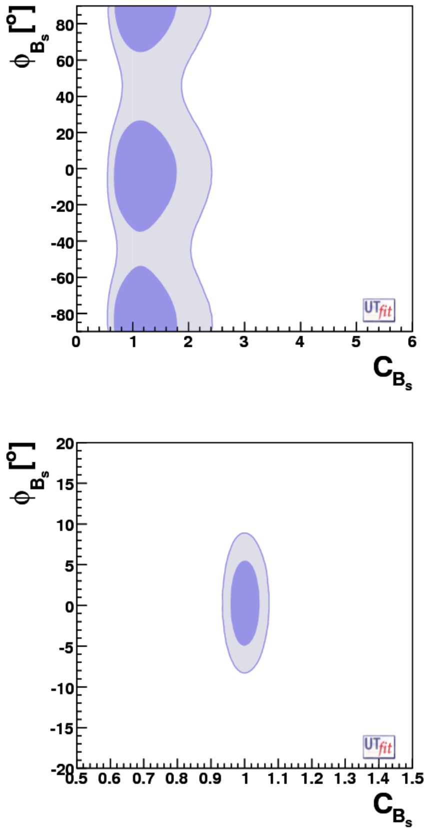

FIG. 6: Allowed regions in the C_{B_s}–ϕ_{B_s} plane given by the current data (left) and at the time of Super$B$ (right). Note that the scales for the axes are different in the two cases.

8. *Phenomenological Implications*

The experimental measurements of $\Delta\Gamma$, $A^s_{\rm SL}$, $A_{\rm CH}$ 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 $\bar{\rho}$ and $\bar{\eta}$ 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. 6 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.

It is important to note that the uncertainty on the parameter C_{B_s} is largely dominated by the uncertainty on the related hadronic quantity, namely 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 $\Upsilon(5S)$.

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 **??**. 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

LHCb will also measure the New Physics phase ϕ_{B_s}. With the final available statistics (~ 10 fb^{-1}), the uncertainty on ϕ_{B_s} is estimated to be less than 1°.

I. Summary

Discuss the $\Upsilon(4S)$ physics interest.

The results presented in the rest of this section section are summarized in Table V for the case of either a short (1 ab^{-1}) or a long (30 ab^{-1}) run at the $\Upsilon(5S)$. Collecting 1 ab^{-1} takes less than one month at a design peak luminosity of 10^{36} cm^{-2} sec^{-1}.

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	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
$A^s_{\rm SL}$	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 from $J/\psi\phi$	10°	3°
β_s from $B_s \to K^0\bar{K}^0$	24°	11°

It is fortunate for experiments in the hadronic environment that many of the most interesting B_s decay channels contain dileptons in the final state. 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 clear that many important channels that are not easily accessible at hadronic experiments such as LHCb, among them $B_s \to \gamma\gamma$ and $B_s \to K^0\bar{K}^0$. Therefore, Super$B$ will complement the results from

LHCb, and enrich its own physics program, by accumulating several ab^{-1} at the $\Upsilon(5S)$.

Charm Physics

This section should be 5-10 pages long

This section should identify the most important areas of charm physics that can be addressed by SuperB. In particular it is worth noting any CPV tests, rare or semi-leptonic decays that can augement new physcis seraches that will justify the experiment. In addition to the case for charm physics taken at the $\Upsilon(4S)$, one should also keep in mind that the threshold running needs to have a solid physics case. If this is not ready in time for the interim document, we need to have a clear and realistic plan of what can be done to justify the additional costs and disruption to other data taking by going to charm threshold.

In particular when talking about new physics constraints it is important to stress anything that could potentially give a reach beyond that of the LHC¿

J. Charm mixing

K. *CP* violation in charm decays

L. Rare charm decays

M. Phenomenology

τ and polarisation physics

This section should be 5-10 pages long

This section sumarizes the programme and what it can achieve. It should be stand alone and focus on the physics goals in the following order of priority: new physics reach (noting where this exceeds LHC where appropraite), unique and important Standard Model test. Finally it may be appropriate to consider mentioning a number of precision SM tests that would also be done as calibration channels.

Polarization is an issue. The physics case for including polarisation in the machine design needs to be justified in order to offset the additional cost to the project, and the added complexity of operation of the machine. This section should clearly address these issues as best it can given the timescale. Note that in the longer term: for the case for polarisation needs to be fully justified before the end of the TDR writing period.

N. Lepton Flavour Violation in τ decay

For $\tau \to 3\ell$ Specifically mention the current limits from the B-factories and expectations from the LHC. Compare these with SuperB expectations.

O. *CP* Violation in τ decay

P. Measurement of the τ electric dipole moment

Q. Measurement of the τ $g-2$

R. Phenomenology

Spectroscopy and Exotics

This section should be 5-10 pages long

This section sumarizes the programme and what it can achieve. It should be stand alone and focus on the physics goals in the following order of priority: new physics reach (noting where this exceeds LHC where appropraite), unique and important Standard Model test. Finally it may be appropriate to consider mentioning a number of precision SM tests that would also be done as calibration channels.

S. Invisible decays and Dark Matter searches

T. Di-lepton decays and tests of Lepton Universality

U. Light Higgs searches

V. Other spectroscopy measurements

W. Phenomenology

Role of Lattice QCD

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

Interplay between measurements

X. Constraints on new physics

This section should be 5-10 pages long

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. 7).
- Likewise for the δ_{ij} parameters vs gluino mass plots (See Fig. 8).
- Also include the A^0 mass vs $\tan\beta$ plot from the valencia document (See Fig. 9).
- 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.

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 VI).

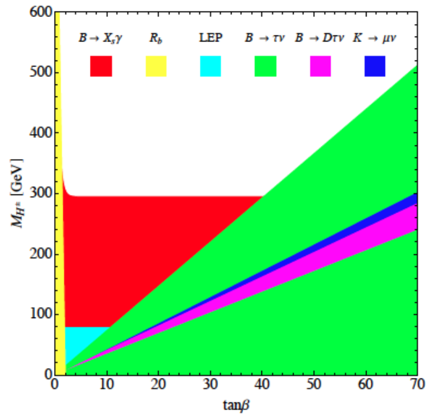

FIG. 7: Direct and indirect bounds on the constraint on m_{H^+} in Type II 2HDM as a function of $\tan\beta$. This plot is taken from U. Haisch arXiv:0805.2141. We should (i) update the plot with predictions using SuperB with $75ab^{-1}$, and overlay on this the constraints obtained from ATLAS via direct 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.

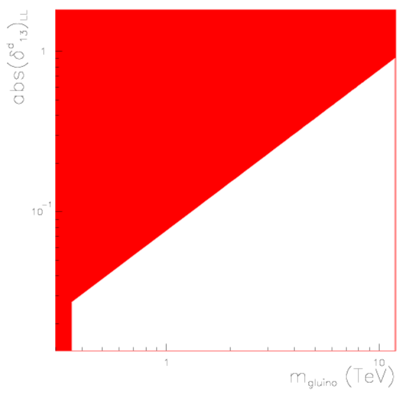

FIG. 8: Direct and indirect bounds on the gluino mass vs. $\delta^d_{13,(LL)}$ from LEP, and those expected from SuperB and the LHC. This plot needs to have the direct constraints added to it with three regions of interest described: i) the direct search region where SuperB also sees something: Large 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...

Y. 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 $K \to \pi\nu\overline{\nu}$ error budget being dominated by CKM. If we improve CKM, we

TABLE VI: 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 β	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		
$\tau \to \mu\gamma$							L
$\tau \to \mu\mu\mu$						L	

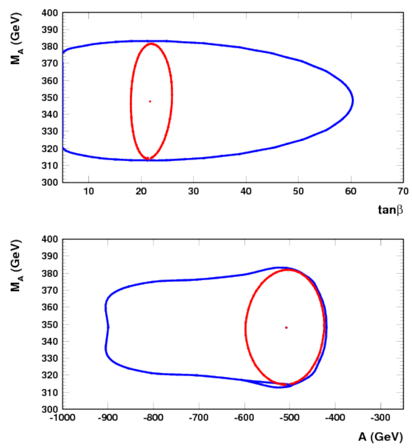

FIG. 9: The red (clear) contour corresponds to the LHC scenario that includes the low-energy and electroweak constraints, while the blue (darker) contour makes the same assumptions about the assumed LHC discoveries, but does not include any external constraints.

open up new ways to look for new physics (See Fig. 10).

Conclusion

This section should be between 1 and 2 pages.

The conclusion provides a brief recap of the physics goals of Super$B$ and how these will benefit the field of high energy physics.

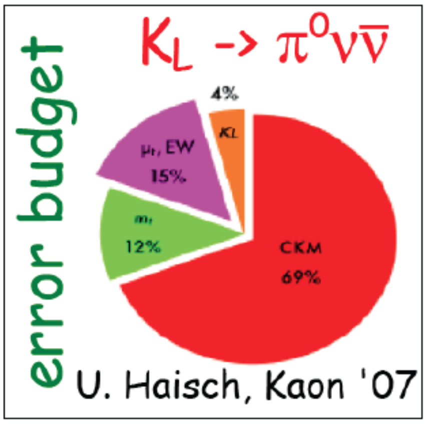

FIG. 10: The error budget on $K^+ \to \pi^+\nu\bar{\nu}$. The error budget on $K^0 \to \pi^0\nu\bar{\nu}$.