

The impact of Super B on flavour physics

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Abstract

This report provides a succinct summary of the physics programme of Super B , and describes that potential in the context of experiments making measurements in flavour physics over the next 10 to 20 years. Detailed comparisons are made with Belle II and LHCb, the other B physics experiments that will run in this decade. Super B will play a crucial role in defining the landscape of flavour physics over the next 20 years.

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1. Introduction

SuperB is an approved high luminosity e^+e^- collider intended to search for indirect and some direct signs of new physics (NP) at low energy, while at the same time, enabling precision tests of the Standard Model (SM). This experiment will be built at a new laboratory on the Tor Vergata campus near Rome, Italy named after Nicola Cabibbo. The project has been described in a Conceptual Design Report [1], and more recently by a set of three white papers on the accelerator [2], detector [3], and physics programme [4].

The main focus of the physics programme rests in the study of so-called *Golden Modes*, these are decay channels that provide access to measurements of theoretically clean observables that can provide both stringent constraints on models of NP, and precision tests of the SM. A number of ancillary measurements that remain important include those with observables that may not be theoretically clean, and those that can be used to provide stringent constraints on the SM but are not sensitive to NP. The remainder of this section introduces SuperB before discussing the golden modes for SuperB, precision CKM measurement modes, and an outline of the rest of this report.

A. SuperB in a nutshell

SuperB will accumulate 75 ab^{-1} of data over a period of five years of nominal data taking at the $\Upsilon(4S)$. In addition to operating at the centre of mass energy of the $\Upsilon(4S)$, this experiment will also run at other energies ranging from charm threshold, at the $\psi(3770)$, to the $\Upsilon(5S)$. SuperB will be constructed and commissioned with an engineering run by the end of 2016, and nominal data taking expected to commence in 2017. Thus the physics potential of SuperB discussed here is expected to re-define the flavour physics landscape by 2021.

B. Golden modes for SuperB

In the indirect search for NP using flavour-changing processes, there are two necessary ingredients (i) a decay channel that can be experimentally studied to a sufficient precision to identify a deviation from the SM, and (ii) sufficient theoretical understanding of the SM calculation to validate that any inconsistency between theory and data is a real NP effect, as opposed to uncontrolled or underestimated theoretical uncertainties. However, high sensitivity to NP also means that a decay channel allows for significant deviations from the SM within NP models. We will analyse this aspect by using a variety of presently popular NP benchmark models in Section 3 B. Direct searches, such as those for a light Higgs boson or Dark Matter candidates, are more straightforward, where discovery of a new particle that doesn't match any SM expectation would be a clean indication of NP.

Based on this premise, we list the Golden channels/observables relevant for SuperB in the following.

τ Physics

- Lepton flavour violation in tau decays: $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow 3\ell$ as specific examples of the experimental reach.

$B_{u,d}$ Physics

- $B^+ \rightarrow \tau^+\nu$ and $B^+ \rightarrow \mu^+\nu$
- $B^+ \rightarrow K^{(*)+}\nu\bar{\nu}$
- $b \rightarrow s\gamma$
- $b \rightarrow s\ell\ell$
- ΔS measurements, in particular $B^0 \rightarrow \eta' K_s^0$, and S in $B \rightarrow K_s^0 \pi^0 \gamma$.

B_s Physics

- Semi-leptonic CP asymmetry A_{SL}^s .
- $B_s \rightarrow \gamma\gamma$.

Charm Physics

- mixing parameters and CP violation.

Other Physics

- Precision measurement of $\sin^2 \theta_W$ at $\sqrt{s} = 10.58 \text{ GeV}/c^2$.
- Direct searches for non-standard light Higgs bosons, Dark Matter and Dark Forces

Each of these groups of golden measurements is described briefly in the following text.

τ Physics Since Lepton Flavor Violation (LFV) is severely suppressed in the SM, LFV τ decays are especially clean and unambiguous experimental probes for NP effects. SuperB can experimentally access τ LFV decay rates over 100 times smaller than BABAR for the most clean channels (e.g. $\tau \rightarrow 3\ell$), and over 10 times smaller for other modes such as $\tau \rightarrow \ell\gamma$ that have irreducible backgrounds. In all cases, the SuperB polarised electron beam provides additional advantages to determine the properties of the LFV interaction from the polarization-dependent angular distribution of the τ decay products, and to improve the selection for specific NP models. This gives SuperB a distinct advantage over other experiments.

The electron beam polarization provides SuperB with even more significant advantages for measuring CP violation in τ decay and for measuring the fundamental τ properties corresponding to the $g-2$ and EDM form factors from the angular distribution of the τ decay products. In all three cases SuperB will extend considerably the present experimental physics reach, providing sensitivity to some specific NP models and a first statistically significant measurement of the τ $g-2$ form factor.

This document concentrates only on the $\tau \rightarrow \ell\gamma$ and $\tau \rightarrow 3\ell$ channels as specific examples to illustrate the physics reach of SuperB in this area, but one should not forget that SuperB will provide the same advantages to extend the experimental reach for all other τ LFV modes, some of which can be most sensitive to specific NP models.

$B_{u,d}$ Physics The main goals of the B Physics programme at SuperB cover observables measured using the decays of B_u and B_d mesons, and, with a smaller collected data sample, of B_s mesons. NP is expected to affect the predictions computed in the SM framework for many observables. Some of the theoretically cleanest observables are related to final states with ν 's or many neutral particles, and these can only be studied in an e^+e^- environment, where SuperB will have the largest data sample available. Modes of particular interest include $B \rightarrow \ell\nu$, which can be used to constrain charged Higgs particles, and $B \rightarrow K^{(*)}\nu\bar{\nu}$, which is highly sensitive to Z penguin and other electroweak penguin effects. The $b \rightarrow s\gamma$ and $b \rightarrow s\ell\ell$ transitions can be measured inclusively and exclusively at SuperB. In contrast it is only possible to exclusively reconstruct these modes in a hadronic environment. Golden observables at SuperB include the various kinematical and angular distributions, as well as CP and isospin asymmetries. For the branching ratios, it is important to perform both inclusive and exclusive measurements to ensure that results obtained from theoretical interpretation of the data are in agreement, and similarly it is important to measure both electron and muon final states in $b \rightarrow s\ell\ell$ in order to constrain all of the available NP sensitive observables.

The focus on time-dependent CP violation measurements is twofold, (i) constraining NP in loop (penguin) and tree processes and (ii) performing precision CKM constraints. Most of the B_d decays of interest can only be measured in an e^+e^- environment: SuperB will measure CP asymmetries in a wide variety of hadronic $b \rightarrow s$ penguin modes, especially in the most precisely determined penguin channel $B^0 \rightarrow \eta' K^0$. Moreover, SuperB will measure the photon polarisation via the mixing-induced asymmetry in the $B^0 \rightarrow K_s^0 \pi^0 \gamma$ mode. Other important channels of this kind are decays such as $B \rightarrow J/\psi \pi^0$, which is needed to constrain the theoretical uncertainties on the tree level $b \rightarrow c\bar{c}s$ β measurement. Furthermore, final states with K_L^0 mesons provide useful cross checks of the K_s^0 decays (with opposite CP eigenvalues). It would be challenging to try and reconstruct these important $B_{u,d}$ modes in a hadronic environment: at LHCb the reconstruction efficiencies are reduced for final states containing several neutral particles and for analyses where the B decay vertex must be determined from a K_s^0 meson. However, LHCb can perform complementary measurements using B_s decay modes such as $B_s \rightarrow J/\psi \phi$, $B_s \rightarrow \phi\gamma$ and $B_s \rightarrow \phi\phi$, as discussed below in Section 2 C.

B_s Physics An expected data sample of approximately 1 ab^{-1} collected at the $\Upsilon(5S)$ resonance will provide a large sample of B_s decays. This sample will allow comprehensive studies of the decay rates of the B_s that are comparable in precision to the currently available results for $B_{u,d}$ mesons. Additionally, two important contributions to B_s physics that can be made by SuperB are a precision measurement of the semi-leptonic

asymmetry A_{SL}^s , which is complementary to the measurement of β_s for searching for NP in B_s mixing, and a measurement of $B_s \rightarrow \gamma\gamma$.

Hadron experiments are able to measure A_{SL}^s , however the ultimate precision attainable will be limited by knowledge of systematic uncertainties related to charge asymmetries in the data. In order to overcome this limitation, it is currently preferred that one measures an asymmetry difference $\Delta A^{s,d} = A_{SL}^s - A_{SL}^d$ [5]. The measurement of A_{SL}^s in an e^+e^- environment will be useful as this will be subject to a different set of systematic uncertainties that will ultimately limit the precision, however it is expected that one can measure A_{SL}^s directly without having to resort to an asymmetry difference in order to overcome the lack of knowledge of charge asymmetry in data.

In general the decay $B_s \rightarrow \gamma\gamma$ can be affected in a similar way to $B_{u,d} \rightarrow X\gamma$ by the presence of NP (for example see [6]), making this an important channel to measure. In some models however the B_s and $B_{u,d}$ decays are uncorrelated and in those cases the B_s channel may have better sensitivity [7, 8] to NP.

Charm Physics The main goals of charm physics currently are to perform precision measurements of mixing in the charm system, and to search for possible CP violation in the up-quark sector. A distinct advantage that one has at SuperB in this area is that in addition to large samples of relatively clean events accumulated at the $\Upsilon(4S)$, one can utilise data collected at the $\psi(3770)$, in particular to constrain strong phases and Dalitz models required for charm mixing measurements and the determination of the Unitarity triangle angle γ using the standard GGSZ method, to reduce model uncertainties. Data collected at the $\psi(3770)$ provide an almost pure “ D meson beam” that can be used to perform precision measurements that can be used to reduce systematic uncertainties for measurements made at the $\Upsilon(4S)$ or in a hadronic environment. In some cases, results from such a run can compete with results from the $\Upsilon(4S)$ data reported here. Therefore, depending on the run schedule, some results could become available at a similar level of precision earlier in the SuperB cycle. Time-dependent CP asymmetry studies in D decays have recently been proposed in Ref. [9], and studies are in progress to understand the potential of such measurements at SuperB.

Other Physics A precise measurement of the left-right asymmetries of $e^+e^- \rightarrow \ell^+\ell^-$, $b\bar{b}$ can be performed at SuperB thanks to the polarized electron beam. This allows for a determination of $\sin^2\theta_W$ at the $\Upsilon(4S)$ with precision comparable to the LEP/SLC measurement at the Z pole, which is of interest for two particular reasons (i) a measurement at the $\Upsilon(4S)$ is theoretically cleaner than one at the Z (no b fragmentation uncertainties), and (ii) there is no measurement at this particular energy which is in a region where $\sin^2\theta_W$ is changing rapidly. This result can be fed into precision electroweak fits along with existing and other planned measurements. The JLab experiment QWeak [10] will improve the precision of the $\sin^2\theta_W$ at a lower \sqrt{s} than SuperB, and there is a proposed experiment called MESA, at Mainz, to perform a measurement at an even smaller energy scale.

The previously mentioned golden channels and observables are focused on observation of NP effects through indirect means. In addition to SM spectroscopy, SuperB can also search for light dark matter, light Higgs particles that could exist in multi-Higgs scenarios beyond the SM, and to also search for evidence of Dark Forces.

C. Precision CKM measurement modes

In addition to the aforementioned Golden modes, there is a list of precision measurements that can be used to determine the CKM parameters at the percent level and to test the SM by checking the compatibility of experimental results. Current data indicate a number of inconsistencies at the level of $2-3\sigma$ in these constraints which deserve to be further investigated. Yet, even if no NP signal will emerge from these measurements, a precise determination of the CKM parameters is a crucial ingredient to improve the SM prediction, and hence the NP sensitivity, of several flavour observables.

The precision CKM measurements include

- $|V_{ub}|$ (inclusive and exclusive measurements)
- $|V_{cb}|$ (inclusive and exclusive measurements)
- α from $b \rightarrow u\bar{u}d$ transitions
- β from $b \rightarrow c\bar{c}s$ transitions
- γ from $B \rightarrow DK$ transitions

Data collected at or just above the $\psi(3770)$ resonance can be used to measure $|V_{cd}|$ and $|V_{cs}|$, and one can perform a precision measurement of $|V_{us}|$ using τ decays. Super B is the only experiment that can complete this set of measurements in order to perform direct and indirect precision tests of the CKM mechanism.

D. Other measurements

There is a vast potential to perform other measurements that are not classified as either a *golden mode* or a *precision CKM measurement mode*. These include hundreds of possible measurements of B , D , τ , Υ , and $\psi(3770)$ decays as well as studies of ISR processes and both conventional and exotic spectroscopy not listed above. A partial description of these possibilities is listed in Refs. [1, 4, 11], and will be discussed in the context of the result of existing experiments in the forthcoming Physics of the B Factories book currently in preparation [12]. Super B will integrate 150 (75) times the data of BABAR and Belle enabling a significant improvement in precision of these other measurements. This area of the programme will not be discussed further here.

E. The remainder of this document

The remainder of this document includes a brief summary of flavour physics experiments related to the Super B programme (Section 2). These include the flavour physics experiments Belle II and LHCb that have some measurements in common with Super B , plus those flavour experiments that provide complementary information, or for which Super B measurements themselves will be useful.

Section 3 summarises the experimental reach of Super B based on the physics studies that have been previously described in Refs. [1, 4, 11]. Where appropriate, these measurements are compared with the expectations of other experiments. Section 3 also revisits the issue of interplay between measurements to highlight the complementarity of different searches for NP in the context of the time-scale of the first five years of data taking. Finally Section 4 provides a succinct summary of the physics programme for Super B in the context of the experimental landscape circa 2021.

2. Other experiments

One purpose of this report is to put Super B in the context of current and next-generation flavour experiments. Indeed, one should not forget that there are other important flavour experiments that can be of interest when interpreting results from Super B . Some of the measurements of these other experiments provide complementary constraints on new physics that could have an impact on the Super B physics programme, and in return some of the measurements possible at Super B will feed back into the physics programme of those other experiments.

There are two other experiments that will focus on B physics in this decade: Belle II, currently under construction at KEK in Tsukuba, Japan, and LHCb, currently operating at CERN in Geneva. Additionally, there are several flavour physics experiments that are relevant for the physics programme of Super B in terms of providing complementary constraints on new physics, and in terms of requiring input from Super B measurements. These other experiments are BES III, COMET, KLOE 2, KOTO, MEG, Mu2e, and NA62. A planned upgrade of LHCb may start taking data shortly after Super B , but take longer to complete its physics programme. An estimate of the relative time scales for data taking for these experiments are shown in Figure 1.

The remainder of this section describes the relationship between Super B and these other experiments in the context of the global picture of constraining new physics.

A. Belle II

The Belle II experiment, an e^+e^- experiment running at the $\Upsilon(4S)$, has many similarities with Super B , and there is a large overlap in their respective physics programmes. There are several important differences between these two Super Flavour Factories:

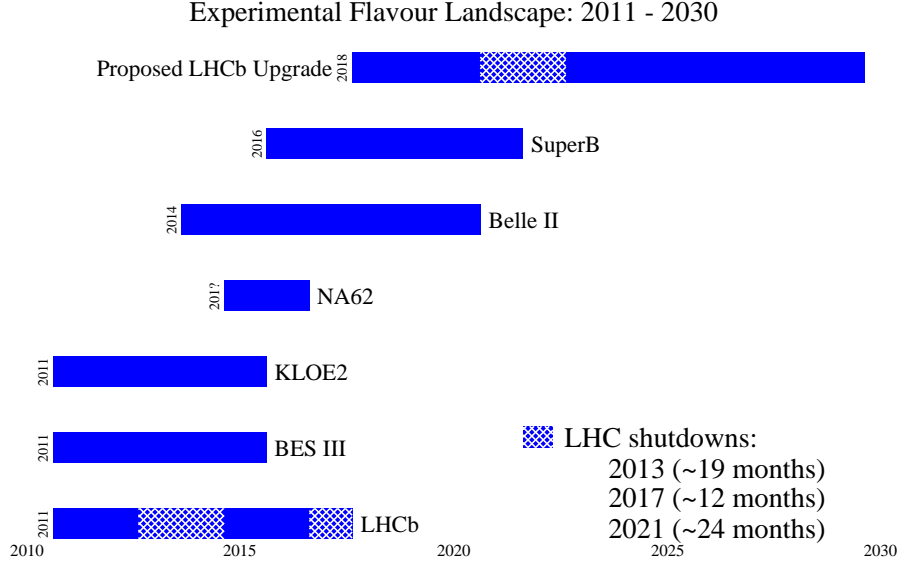


FIG. 1: Time scales of data taking anticipated for existing, approved, and proposed flavour physics experiments discussed in this document. One can see that LHCb, BES III and NA62 will have completed their currently defined run programmes prior to the SuperB and Belle II. Any upgrade of LHCb would achieve final results sometime after the Super Flavour Factories will have achieved their goals.

- On the time-scale that SuperB will accumulate 75 ab^{-1} , it is expected that Belle II will be able to integrate 50 ab^{-1} at the $\Upsilon(4S)$. One would then expect that SuperB will outperform Belle II in terms of precision by about 20% in general for measurements that are not limited by systematic uncertainties. Where measurements will be limited by systematic uncertainties, the expectation of the ultimate precision reached depends on assumptions that have entered into extrapolations, and differences between experiments should be interpreted as a possible range of the ultimate precision attainable.
- SuperB can run at energies below the $\Upsilon(2S)$, and will run at both the $\Upsilon(1S)$ and $\psi(3770)$. This provides SuperB with a significantly broader physics programme through the direct searches for light scalar mesons (Higgs and Dark Matter), tests of lepton universality, searches for Dark Forces, and so on. Measurements at charm threshold will feed back into the B physics programme of all flavour experiments: for example reducing model uncertainties in the measurement of the Unitarity triangle angle γ , and improving the precision of charm mixing measurements. Other charm threshold measurements will also enable lattice QCD to be tested more precisely in a regime where calculations are better understood. This will impact upon the corresponding work in B decays.
- The electron beam at SuperB will be polarised to at least 80% for running at the $\Upsilon(4S)$. The polarized electron beam provides SuperB with the ability to perform precision electroweak studies in an energy regime free from hadronic uncertainties related to b fragmentation that otherwise limit the interpretation of SLC/LEP measurements, and also provides an additional kinematic variable to support background fighting techniques in rare and Lepton Flavour Violating (LFV) τ decay studies. The benefits of polarisation for τ LFV are model dependent.

More details on the Belle II experiment and physics programme can be found in Ref. [13].

B. BES III

The physics programme of BES III, an e^+e^- experiment running at charm threshold, will overlap significantly with the SuperB measurements made at charm threshold. The anticipated data sample to be accumulated at the $\psi(3770)$ by BES III is 10 fb^{-1} by the middle of the this decade [14]. In comparison, SuperB expects to be

able to accumulate 500 fb^{-1} with several months of running¹. Thus SuperB will be able to make significant improvements on the precision of measurements made by BES III: in general SuperB results will have statistical uncertainties reduced by a factor of seven for all observables where these experimental programmes overlap. As SuperB will take data after BES III we expect that there will be a natural evolution in the understanding of flavour physics at charm threshold from one experiment to the other. More details on the BES III experiment and physics programme can be found in Ref. [15].

C. LHCb (and planned upgrade)

Although LHCb is a B physics experiment, the starkly different running environment of a hadronic machine dictates a physics programme that has only moderate overlap with the SuperB programme. LHCb benefits from a high b cross section and all types of B -hadrons are produced in the pp collisions, including a large number of B_s mesons. The most striking outcome of any comparison between SuperB and LHCb is that the strengths of the two experiments are largely complementary. For example, the large boost of the B hadrons produced at LHC allows for studies of the oscillations and mixing-induced CP violation of B_s mesons, while most of the measurements that constitute the primary physics motivation for SuperB cannot be performed in the hadronic environment with its higher backgrounds and trigger difficulties (as previously mentioned in Section 1 B).

Clearly, there is some uncertainty as to when one can expect results with full integrated luminosity from LHCb and LHCb upgrade. Presently, the following shutdowns at CERN are planned over the next decade [16]

- 2013 – 2014: A 15-19 month shutdown (duration not yet decided) for upgrades to the LHC, where test-beams, the PS and SPS are expected to be unavailable during the shutdown as manpower will be redirected to LHC upgrade work.
- 2017: A shutdown of some length (to be confirmed) for the ATLAS and CMS experiments to install pixel detector upgrades.
- 2021: Likely date to commence a shutdown for a future luminosity upgrade to the LHC. The length of this shutdown is unknown, by it is probably between 18 and 24 months.

Based on the Chamonix Conference presentations in January 2011 and LHCb upgrade LOI [17, 18], we expect that LHCb will accumulate 5 fb^{-1} by the end of its data taking life², and that the LHCb upgrade accumulate 50 fb^{-1} . The experiment will be able to collect a maximum of 5 fb^{-1} of data per year starting in 2018 [18], so 10 years of running will be required to reach the goal of 50 fb^{-1} . There will also be expected shutdowns of LHC for upgrades of the accelerator and other experiments (as indicated above), but the timing and duration of those shutdowns has not yet been determined. In any case, a *possible* time line for an upgraded LHCb, and several other flavour experiments, is given in Figure 1. Despite the uncertainty in mapping out the time scales, we think it is fairly safe to state that by and large the results from LHCb will precede those of SuperB, which in turn will produce its results well in advance of the conclusion of an upgraded LHCb experiment. While the majority of the main motivational measurements made by these experiments are distinct, there will be synergy in cross-calibration of the few modes that are in common. In addition, any potential upgrade of LHCb will benefit from the measurements made at SuperB. More details on the LHCb experiment and physics programme can be found in Ref. [19].

The following assumes an integrated luminosity of 5 fb^{-1} , achieved by 2017.

B_s^0 physics: The LHCb programme in this area is largely complementary to that of SuperB. Any NP discovery in the B_s sector at LHCb would naturally motivate complementary searches for NP at SuperB, and vice versa. Golden B_s observables at LHCb include

$B_s^0 \rightarrow \mu^+ \mu^-$: CDF has recently produced a preliminary result of $BR(B_s \rightarrow \mu^+ \mu^-) = (1.8_{-0.9}^{+1.1}) \times 10^{-9}$ (with a corresponding upper limit of $< 4 \times 10^{-8}$ at 95% C.L.) [20], while LHCb and CMS have now produced a combined LHC result where the branching ratio is limited to be $< 1.5 \times 10^{-8}$ (95% C.L.) [21]. The

¹ It is likely the SuperB threshold run will take place after the machine has been optimised for $\Upsilon(4S)$ operation. This would be a few years into the data taking life of SuperB.

² LHCb is limited to a maximum integrated luminosity recorded of 1 fb^{-1} per year, integrating 5 fb^{-1} by 2017, instead of the $2 \text{ fb}^{-1}/\text{yr}$ originally expected.

SM expectation for this channel is 3.6×10^{-9} , and has about a 10% theoretical uncertainty. It is expected that LHCb with 5 fb^{-1} of data will reach a precision of 30% on the branching ratio of this mode assuming a SM rate [18]. NP can appear in loops for this decay, which is of relevance when one considers the interplay between this observable and those from SuperB.

$2\beta_s$ from $B_s^0 \rightarrow J/\psi\phi$: The current precision on this observable from the Tevatron is ~ 0.35 , and LHCb has recently presented a result with a precision of ± 0.19 . It is expected that LHCb will be able to measure this quantity to a precision of 0.019 with 5 fb^{-1} , where theoretical uncertainties are of the order of 0.003 [18].

$B_s \rightarrow \phi\gamma$: LHCb can measure the time-dependent CP asymmetry in this channel which is sensitive to the presence of new right-handed currents. A precision of 0.07 on S is expected [18].

The measurement of γ : This is a precision CKM measurement that is useful for over constraining the CKM mechanism. LHCb should have measured γ to a precision of 4° by the time SuperB starts taking data. SuperB will reach an ultimate precision of $\sim 1^\circ$ on γ for any given channel.

$\sin(2\beta)$ from $J/\psi K_s^0$: This is a precision CKM measurement that is useful for over constraining the CKM mechanism. The B Factories have measured β to a precision of 0.8° , and it is expected that LHCb will reduce this uncertainty to 0.5° . SuperB will be able to improve on this and measure β with a precision of 0.1° .

$B \rightarrow K^{(*)}\mu\mu$: LHCb is expected to accumulate approximately 8,000 events in the channel $B^0 \rightarrow K^{*0}\mu^+\mu^-$ [22]. This large data sample will allow precise measurements of the lepton forward-backward asymmetry, and other angular observables sensitive to the presence of NP (for example see [23, 24]). LHCb will have significantly lower efficiency for the $B^0 \rightarrow K^{*0}e^+e^-$ channel and will accumulate perhaps 400 events [25, 26]. SuperB will select a larger sample of $B \rightarrow K^*\mu^+\mu^-$ decays ($\sim 10,000 - 15,000$) and will accumulate a roughly equal number of $B \rightarrow K^*e^+e^-$ decays, plus a large sample of fully inclusive $B \rightarrow X_s\ell^+\ell^-$. We further comment on $b \rightarrow s\ell^+\ell^-$ physics in Section 3.

Lepton Flavour Violation: Preliminary studies show that LFV searches by LHCb will at best match existing limits from BABAR and Belle [27–29].

Charm mixing: In Ref. [4] it was concluded that, with 75 ab^{-1} at the $\Upsilon(4S)$, SuperB could allow measurements of x and y with a precision of a few parts in 10^{-4} . $D^0\bar{D}^0$ asymmetries in these parameters would allow estimation of the complex CPV parameter q/p with uncertainties $\sim 1\%$ and $\sim 1.5^\circ$, in magnitude and phase, respectively³. Measurements of $|q/p|$ in a broad mix of individual channels with a precision of a few percent are expected that could reveal whether CPV comes from direct or indirect sources.

The most precise results are expected to come from time-dependent Dalitz plot (TDDP) analyses of decays of D^0 to self-conjugate final states ($K_s^0\pi^+\pi^-$, $K_s^0K^+K^-$, etc.)⁴ and, for y_{CP} , from lifetime measurements for decays to CP eigenstates (K^+K^- , $\pi^+\pi^-$, etc.).

Statistical uncertainties in x , y , y_{CP} , $|q/p|$ and $\arg\{q/p\}$, scaled by the appropriate projected event yields, are reported in Table I for SuperB, LHCb and Belle II. These are normalized to BABAR and Belle II measurements. For LHCb, we project 5 fb^{-1} yields from a 37 pb^{-1} exposure that has $1.2 \times 10^5 D^0 \rightarrow K^+K^-$ and $15.4 \times 10^3 D^0 \rightarrow K_s^0\pi^+\pi^-$ events [30, 31], each flavour-tagged by the sign of the pion from D^* decay. We assume that, for the last 4 fb^{-1} , the LHC energy doubles and that this doubles the production cross sections. For the $K_s^0\pi^+\pi^-$ mode we further assume that a factor 2 in improved trigger efficiency is achieved.

³ The observables are the magnitude and phase of $\lambda_f = \frac{q}{p} \frac{\bar{A}_f}{A_f}$ where $A_f(\bar{A}_f)$ are the amplitudes for decays of $D^0(\bar{D}^0) \rightarrow f$. All data have, so far, been analyzed in terms of models (or measurements) for $A_f(\bar{A}_f)$ with specific hypotheses for the phase of $\frac{\bar{A}_f}{A_f}$. In this sense, the magnitude and phase of $\frac{q}{p}$ have been regarded by the HFAG as observables, though they do, of course, depend on the models used for each decay mode f .

⁴ The precision from the TDDP analyses is systematically limited by knowledge of the proper decay amplitude model to use to describe the Dalitz plot populations. Strong phase measurements made at charm threshold should substantially reduce this limitation for LHCb, SuperB and Belle II. A 500 fb^{-1} charm threshold run could reduce this limitation, and a time-dependent analysis of mixing could add further, independent information on mixing and CPV . Estimates in Table I assume this uncertainty can be ignored.

Additional precision gained from the LHCb upgrade The following assumes an upgrade with an integrated luminosity of 50 fb^{-1} , starting to take data in 2018. It is assumed that the full integrated luminosity could be achieved as early as 2030, although this depends on the performance and upgrade schedule of the LHC over the coming decade. Final measurements from the LHCb upgrade are expected to appear some years after the SuperB ones.

B_s^0 physics: The LHCb upgrade programme may be influenced by discoveries or constraints imposed by measurements made at SuperB and Belle II as well as the measurement of A_{SL}^s . In addition, basic exclusive B_s^0 branching ratios will have been measured by the Super Flavour Factories running at $\Upsilon(5S)$ with a high precision, which will help this CERN experiment interpret its ratios of branching ratios as absolute quantities. As far as B_s golden modes are concerned, an upgrade of LHCb would be able to significantly improve the precision of $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)$ from about 30% to about 8%, of $2\beta_s$ from 0.019 to 0.006, and of $S(B_s \rightarrow \phi\gamma)$ from 0.07 to 0.02 [18].

The measurement of γ : The ultimate precision of this Unitarity triangle angle for both the LHCb upgrade and SuperB are comparable at the level of $\sim 1^\circ$ for any given channel. The measurement of the strong phase as a function of the position in the Dalitz plot in $D \rightarrow K_s^0 h^+ h^-$ decays that is an integral part of the GGSZ method to measure γ is an input from SuperB to the LHCb upgrade programme.

$\sin(2\beta)$ from $J/\psi K_s^0$: The LHCb upgrade is expected to reach a precision of 0.2° on β . This will provide a useful crosscheck of the result from SuperB, the latter is expected to have a precision of 0.1° .

$B \rightarrow K^{(*)} \mu \mu$: An upgraded LHCb experiment will select a very large sample, perhaps 100,000 events [26], of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ decays and will be able to do a full angular analysis for this channel with high precision. Hence, the precision on quantities measured using this particular channel will surpass that of the previously measured ones at SuperB. The $B^0 \rightarrow K^{*0} e^+ e^-$ channel will have perhaps one-tenth of the statistics and will be somewhat smaller than the SuperB data sample for this channel. However, reconstruction of $B \rightarrow X_s \ell^+ \ell^-$ in a fully inclusive way will not be part of the LHCb upgrade program. See Section 3 for further comments on this channel.

Lepton Flavour Violation: Preliminary studies show that LFV searches by the LHCb upgrade will not be competitive with SuperB [27–29]. Anticipated limits from the LHCb upgrade will be up to an order of magnitude less stringent than SuperB or Belle II.

Charm mixing: For the LHCb upgrade, we simply take the anticipated factor 10 increase in integrated luminosity at face value and assume it will result in a reduction factor $\sqrt{10}$ in uncertainties reported at the 5 fb^{-1} level. We realize that things may not be that simple in practice since event pile up and tracking problems at the higher luminosities may exist.

More details on the LHCb experiment can be found in Refs. [18, 19], and more information on the proposed LHCb upgrade can be found in Ref. [18].

D. NA62

The primary goal of NA62 is a measurement of the branching ratio of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ from a data sample containing 100 signal events. The result of this challenging measurement is sensitive to NP in the transition between the second and the first generation. In the SM it can be used to place a constraint on the CKM parameters, via a theoretically clean bound on the value of (ρ, η) , the apex position of the unitarity triangle. This additional input can be combined with the many different direct and indirect constraints that will be made at SuperB in order to search for NP corrections which could appear in the determination of the unitarity triangle. This experiment anticipates taking data for two years (~ 100 days of running assuming a SM branching ratio) in order to accumulate 100 $\pi^+ \nu \bar{\nu}$ events, and this measurement should be completed before SuperB commences. The result will provide information from the kaon sector to constrain models of minimal flavour violation, that will complement some of the measurements that SuperB will make. In addition to the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ mode, there are a number of other interesting measurements that NA62 will make, including a precision measurement of R_K , the ratio of $K_{e2}/K_{\mu2}$ decays, where $K_{\ell2} = K^\pm \rightarrow \ell^\pm \nu$. Most of the detectors should be commissioned for this experiment during a technical run in September 2012. Following this, data taking will commence as soon as the

LHC injector chain is available following the 2013/2014 stop⁵. More details on the NA62 experiment can be found in Ref. [32], and a recent overview of the physics can be found in Ref. [33].

E. KOTO

The primary goal of the KOTO E14 experiment is the measurement of $\text{BR}(K_L^0 \rightarrow \pi^0 \nu \bar{\nu})$. This decay is theoretically cleaner than the corresponding charged mode. The branching ratio of $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ is proportional to the Wolfenstein parameter η , and measures the height of the unitarity triangle. The initial aim of KOTO is to observe this decay, which assuming a SM rate will correspond to 3 signal events, using data collected during 2012 [34].

F. KLOE 2

The KLOE 2 experiment at LNF Frascati is another dedicated kaon experiment that will make a number of important flavour physics measurements. Some of the goals of this experiment include testing lepton universality by measuring R_K , and making precision tests of CPT in the neutral kaon system. In addition, this experiment will be able to make precision tests of the SM. There are a number of light meson searches for Dark Forces that can be done at KLOE 2, these complement the corresponding exotic spectroscopy studies planned at SuperB. More information about the diverse KLOE 2 physics programme can be found in Refs. [35]. KLOE 2 plans to run until the autumn of 2015, and we expect this programme to be completed well before SuperB acquires its full data sample.

G. MEG, COMET and Mu2e

The main goal of the MEG, COMET and Mu2e experiments is the search for LFV in the $\mu \rightarrow e$ transition. In the case of MEG, the search is for charged LFV via $\mu \rightarrow e \gamma$. The experiment is taking data and reported recently $\text{BR}(\mu \rightarrow e \gamma) < 2.4 \times 10^{-12}$ at 90% CL [36]. In a few years, MEG is expected to reach its design sensitivity of 10^{-13} . COMET and Mu2e are proposed experiments aiming to search for $\mu \rightarrow e$ conversion in nuclear material in a time frame that is comparable to the SuperB one. SINDRUM II currently holds the record for the most precise limit, $R_{\mu e} < 7 \cdot 10^{-12}$ (90% CL), using gold nuclei [37]. Mu2e is designed to achieve a 90% CL upper limit sensitivity of $R_{\mu e} < 6 \times 10^{-17}$ [38], similarly to COMET [39].

The relationship between muon LFV and the τ LFV searches at SuperB is model dependent. Most NP models have a large number of free parameters, whose determination requires measurements of both types of LFV. The degree of correlation between muon and τ LFV that is predicted in most analyzed and published NP scenarios depends on the practical choice to study only minimal models where most free parameters are unified, or subjected to symmetries or hierarchies that are not experimentally constrained, yet are simple, elegant or mimic experimental patterns in other physics sectors. Therefore, in the general case it remains essential to experimentally constrain both the muon and τ LFV rates.

SUSY models typically predict $\tau \rightarrow \mu \gamma \gg \mu \rightarrow e \gamma \gg R_{\mu e}$, with scale factors in the range from 10^{-1} to 10^{-4} [40–42]. In most SUSY models, the muon LFV is suppressed if the mixing between the first and third generation neutrinos is small or zero, i.e. when θ_{13} is small [43], while the τ LFV is unaffected. Global fits give $\theta_{13} < 5.4^\circ$ at 90% CL [44], however recent data suggest that θ_{13} might be around the above limit or higher [45]. In other models like Little Higgs with T -parity, the above rates are either similar or even have an inverted hierarchy [46]. Most published references predict that COMET and Mu2e are more sensitive than MEG to NP effects, and MEG is more sensitive than SuperB. But even in these minimal NP frameworks SuperB measurements often remain complementary and essential to validate the models and measure their parameters.

⁵ It is anticipated that the time-scale for this will be less than the full shutdown period for the LHC.

3. Experimental Reach

The experimental reach of Super B is considered in two ways, firstly the precision on observables as discussed in Section 3 A for a number of benchmark processes. Secondly it is important to understand how to combine the measurements in order to constrain models of new physics and the SM. This is discussed in Section 3 B. Unless otherwise stated the anticipated precisions for Super B come from Ref. [4], those from Belle II come from Ref. [13], and those for LHCb and the LHCb upgrade come from Ref. [18].

A. Sensitivity Comparison

The sensitivity to observables computed from the Super B Golden Modes is shown in Table I. In all cases the quoted precisions are based on the use of the anticipated full experimental data sets: 75 ab^{-1} for Super B ($+500 \text{ fb}^{-1}$ at charm threshold and 1 ab^{-1} at the $\Upsilon(5S)$), 50 ab^{-1} for Belle II, 10 fb^{-1} at charm threshold for BES III, 5 fb^{-1} for LHCb, and 50 fb^{-1} for the proposed LHCb upgrade. The experiments are listed in chronological order from left to right, depending on when the full integrated luminosity will be reached.

It is evident from the Table that many Golden Modes will only be measured at Super B and Belle II. For those channels, Super B measurements will generally have smaller statistical uncertainties than Belle II measurements. For measurements whose total uncertainty dominated by statistics, then, Super B measurements will provide somewhat greater sensitivity than Belle II. However, many results will be limited by systematic effects, in which cases we would expect comparable overall precision for Super B and Belle II. This issue highlights an important point for observables that will be systematically limited at Super B and Belle II: quoted sensitivities will depend strongly on any assumptions made when estimating the systematic uncertainty. In such cases the quoted sensitivities should be interpreted as a possible range for the ultimate sensitivity attainable. A selection of golden modes for other flavour experiments is given in Table II (this table excludes entries corresponding to Super B golden modes).

While Table I gives an idea of the relative capabilities of the different flavour experiments, it is necessarily simple for certain measurements. In particular, the measurements made in the $b \rightarrow s\ell^+\ell^-$ sector are too numerous and complex to describe well in table format. Both exclusive modes (e.g. $B \rightarrow K^{(*)}\ell^+\ell^-$) and inclusive modes ($B \rightarrow X_s\ell^+\ell^-$) are of interest in searching for NP, indeed the theoretical uncertainties associated with the inclusive modes are likely to be smaller than those of the exclusive modes [4], thus increasing the sensitivity to NP using inclusive measurements. Furthermore, final states with both muons and electrons are interesting to measure separately. For each specific channel, then, there are several observables that one can measure: branching ratios, direct CP asymmetries, isospin asymmetries and the ratio of the rate of the muon channel to the rate of the electron channel. Additionally, there are observables that depend on the angular distributions in $B \rightarrow K^*\ell^+\ell^-$ and $B \rightarrow X_s\ell^+\ell^-$: the forward backward lepton asymmetry, the K^* polarization fraction and other asymmetries, such as $A_T^{(2)}$ and related variables [54], all of which are sensitive to NP.

LHCb (and its possible upgrade) will make its greatest contribution in the exclusive mode $B^0 \rightarrow K^{*0}\mu^+\mu^-$, for which it will accumulate high statistics, as reported in Table I. Super B will perform complementary measurements by accumulating large samples of the related modes $B^+ \rightarrow K^{*+}\mu^+\mu^-$ and $B^0 \rightarrow K^{*0}e^+e^-$, which will permit the study of several quantities that are sensitive to NP, such as the e -to- μ ratio, R_{K^*} . Super B , in contrast to LHCb, will fully explore the $b \rightarrow s\ell^+\ell^-$ sector, with measurements of all relevant observables with high statistics in all channels, including the inclusive modes. Estimates of the reach of Super B for many of these observables can be found in [4]. Belle II will make similar measurements, with generally somewhat lower statistics.

The precisions of observables computed from the CKM measurement modes are shown in Table III. Regarding the three angles of the Unitarity Triangle, one can see that the most precise measurements of α will come from Super B and Belle II, and that for the angles β and γ it is possible to obtain results of comparable precision from Super B , Belle II and the LHCb upgrade. The current experimental situation with regard to $|V_{ub}|$ and $|V_{cb}|$ is that inclusive and exclusive measurements are not in good agreement. The additional data available at Super B will allow a precision comparison of these quantities. It should be noted that for the time-dependent CP analyses performed by *BABAR*, one typically (i) includes more final states, and (ii) performs a more sophisticated analysis in order to obtain a smaller uncertainty than the corresponding Belle results. The main difference between the extrapolations for Super B and Belle II is that the latter has larger *irreducible* systematic uncertainties based on experience with the silicon vertex detector capabilities from Belle. It is reasonable to presume that Belle

TABLE I: Experimental sensitivities for SuperB Golden Modes. Where appropriate, the sensitivity for other experiments is also indicated. The current state of the art is also shown (usually an average of BABAR and Belle results). Entries marked with (est.) for Belle II are estimated from the SuperB results, scaling by the difference in integrated luminosity.

Observable/mode	Current now	LHCb (2017) 5 fb ⁻¹	SuperB (2021) 75 ab ⁻¹	Belle II (2021) 50 ab ⁻¹	LHCb upgrade (10 years of running) 50 fb ⁻¹	theory now
τ Decays						
$\tau \rightarrow \mu\gamma$ ($\times 10^{-9}$)	< 44		< 2.4	< 5.0		
$\tau \rightarrow e\gamma$ ($\times 10^{-9}$)	< 33		< 3.0	< 3.7 (est.)		
$\tau \rightarrow \ell\ell\ell$ ($\times 10^{-10}$)	< 150 – 270	< 244 ^a	< 2.3 – 8.2	< 10	< 24 ^b	
$B_{u,d}$ Decays						
BR($B \rightarrow \tau\nu$) ($\times 10^{-4}$)	1.64 ± 0.34		0.05	0.04		1.1 ± 0.2
BR($B \rightarrow \mu\nu$) ($\times 10^{-6}$)	< 1.0		0.02	0.03		0.47 ± 0.08
BR($B \rightarrow K^{*+}\nu\bar{\nu}$) ($\times 10^{-6}$)	< 80		1.1	2.0		6.8 ± 1.1
BR($B \rightarrow K^+\nu\bar{\nu}$) ($\times 10^{-6}$)	< 160		0.7	1.6		3.6 ± 0.5
BR($B \rightarrow X_s\gamma$) ($\times 10^{-4}$)	3.55 ± 0.26		0.11	0.13	0.23	3.15 ± 0.23
$ACP(B \rightarrow X_{(s+d)}\gamma)$	0.060 ± 0.060		0.02	0.02		$\sim 10^{-6}$
$B \rightarrow K^*\mu^+\mu^-$ (events)	250 ^c	8000	10-15k ^d	7-10k	100,000	-
BR($B \rightarrow K^*\mu^+\mu^-$) ($\times 10^{-6}$)	1.15 ± 0.16		0.06	0.07		1.19 ± 0.39
$B \rightarrow K^*e^+e^-$ (events)	165	400	10-15k	7-10k	5,000	-
BR($B \rightarrow K^*e^+e^-$) ($\times 10^{-6}$)	1.09 ± 0.17		0.05	0.07		1.19 ± 0.39
$AFB(B \rightarrow K^*\ell^+\ell^-)$	0.27 ± 0.14^e	^f	0.040	0.03		-0.089 ± 0.020
$B \rightarrow X_s\ell^+\ell^-$ (events)	280		8,600	7,000		-
BR($B \rightarrow X_s\ell^+\ell^-$) ($\times 10^{-6}$) ^g	3.66 ± 0.77^h		0.08	0.10		1.59 ± 0.11
S in $B \rightarrow K_S^0\pi^0\gamma$	-0.15 ± 0.20		0.03	0.03		-0.1 to 0.1
S in $B \rightarrow \eta'K^0$	0.59 ± 0.07		0.01	0.02		± 0.015
S in $B \rightarrow \phi K^0$	0.56 ± 0.17	0.15	0.02	0.03	0.03	± 0.02
B_s^0 Decays						
BR($B_s^0 \rightarrow \gamma\gamma$) ($\times 10^{-6}$)	< 8.7		0.3	0.2 – 0.3		0.4 – 1.0
A_{SL}^s ($\times 10^{-3}$)	-7.87 ± 1.96^i	^j	4.	5. (est.)		0.02 ± 0.01
D Decays						
x	$(0.63 \pm 0.20)\%$	0.06%	0.02%	0.04%	0.02%	$\sim 10^{-2}^k$
y	$(0.75 \pm 0.12)\%$	0.03%	0.01%	0.03%	0.01%	$\sim 10^{-2}$ (see above).
y_{CP}	$(1.11 \pm 0.22)\%$	0.02%	0.03%	0.05%	0.01%	$\sim 10^{-2}$ (see above).
$ q/p $	$(0.91 \pm 0.17)\%$	8.5%	2.7%	3.0%	3%	$\sim 10^{-3}$ (see above).
$\arg\{q/p\}$ ($^\circ$)	-10.2 ± 9.2	4.4	1.4	1.4	2.0	$\sim 10^{-3}$ (see above).
Other processes Decays						
$\sin^2\theta_W$ at $\sqrt{s} = 10.58 \text{ GeV}/c^2$			0.0002	^l		clean

^aBased on extrapolation of the results presented in [47] for 2 fb⁻¹ to 5 fb⁻¹.

^bExtrapolation from LHCb assuming no background.

^cThe separate yields for $B \rightarrow K^*\ell^+\ell^-$ in muon and electron channels are not published for all experiments. We assume an equal number of selected events in the two channels for SuperB and Belle II.

^dThe ranges presented represent results of independent extrapolations of BABAR and Belle data.

^eFor $0 < q^2 < 4.3 \text{ GeV}^2$, although we include the BABAR measurement made in the q^2 range 0-6.25 GeV².

^fPlease see discussion of $b \rightarrow s\ell^+\ell^-$ in text.

^gFor low- q^2 region, 1-6 GeV².

^hCurrent measurement is over full q^2 -range.

ⁱThe semileptonic asymmetry A_{SL}^b for a mixture of all beauty hadron decays is shown. The D0 measurement [48] is not yet confirmed by other experiments.

^jMonte Carlo studies have been performed for LHCb [5]. While statistically competitive it should be noted that systematic uncertainties will be important, and can be controlled better by measuring differences of the asymmetry in B_s and B_d decays.

^kSM theoretical estimates for charm mixing parameters are difficult due to the predominance of long range effects. It is generally accepted that x and y in the 1% range, compatible with current experimental measurements, can be accommodated and that CPV asymmetries are likely to be $\sim 10^{-3}$. See [49–53] and earlier references for more details.

^lThe Belle II experiment can be used to measure axial vector couplings related to $\sin^2\theta_W$, but is unable to perform a stand-alone measurement of the weak mixing angle.

TABLE II: Some of the golden modes to be measured at facilities other than SuperB.

Observable	Current value	Experiment	Precision
$\text{BR}(B_s \rightarrow \mu\mu) (\times 10^{-9})$	$< 11^a$	LHCb	± 1
		LHCb upgrade	± 0.3
$2\beta_s$ from $B_s^0 \rightarrow J/\psi\phi$ (rad)	0.13 ± 0.19^b	LHCb	0.019
		LHCb upgrade	0.006
S in $B_s \rightarrow \phi\gamma$		LHCb	0.07
		LHCb upgrade	0.02
$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ (% BR measurement)	7 events	NA62	100 events (10%)
$K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$		KOTO	3 events (observe)
$\text{BR}(\mu \rightarrow e\gamma) (\times 10^{-13})$	< 280	MEG	< 1
$R_{\mu e}$	$< 7 \times 10^{-12}$	COMET/Mu2E	$< 6 \times 10^{-17}$

^aCombined LHC limit, CMS-PAS-BPH-11-019; LHCb-CONF-2011-047; CERN-LHCb-CONF-2011-047.

^bThere is a second solution at $2\beta_s \sim -3.2$, See G. Raven's contribution to Lepton Photon 2011. It will be possible to resolve this ambiguity in the near future.

II will perform better than expected with the proposed pixel detector for the innermost layer and a five layer double-sided SVT akin to the SuperB design. For these reasons we believe the Belle II predictions to be slightly underestimating their capability. It is clear from this table, that state of the art for this set of observables, as defined by SuperB and Belle II circa the end of 2021, will not be surpassed by any additional input from an LHCb upgrade. Including results from the LHCb upgrade will have only marginal impact and may improve the precision of the world averages of β and γ measurements by 30% when those results become available once the full LHCb upgrade data sample has been analyzed. Only SuperB and Belle II will be able to measure the angle α with precision.

In summary, it is clear that SuperB has the best expected sensitivities (in some cases, together with Belle II) for virtually all the golden and precision CKM channels that it aims to measure. In terms of performing direct and indirect constraints on the SM, only SuperB will be able to measure a complete set of constraints in each of these categories in order to push our current 10% determination of the CKM mechanism, down to the 1% level using angles. The stated improvements on $|V_{ub}|$ and $|V_{cb}|$ include a reasonable level of progress for the precision of Lattice QCD inputs. While Belle II will match sensitivities of SuperB in some measurements, SuperB will be able to make additional measurements owing to its charm threshold program and beam polarisation. In time the LHCb upgrade should be able to improve constraints on $B^0 \rightarrow K^{*0}\mu^+\mu^-$ and in the charm mixing parameter y_{CP} .

B. Interplay between observables

The interplay between measurements of golden modes discussed in this document and a sample of NP models is highlighted by the golden matrix of Table IV. The pattern of deviations from the SM (★★★= large, ★★= medium, ★= observable, but small) and their correlations can be used to identify the structure of the NP Lagrangian.

An example of this can be seen with regard to the interpretation of LFV τ decays: in models where the LFV amplitude is dominated by the electric dipole operator, the ratio of the rates of $\tau \rightarrow 3\ell$ and $\tau \rightarrow \mu\gamma$ is governed by the electromagnetic coupling α_e . In other models, this ratio could become of order one, a very favourable situation for SuperB which could observe the decay $\tau \rightarrow 3\ell$ only. In such a case, many models, including the MSSM, would be ruled out. The Littlest Higgs model with T parity (LHT) is an example of a model which could produce large ratios of the rates of $\tau \rightarrow 3\ell$ and $\tau \rightarrow \mu\gamma$. Figure 2 (from Ref. [46]) illustrates the correlation between these two golden observables in the context of the LHT model with a symmetry breaking scale $f = 500$ GeV.

Flavor changing neutral current processes can provide evidence for NP. For example one can compare the results of experimental measurements in $B \rightarrow K^{(*)}\nu\bar{\nu}$ decays with the SM expectation to elucidate information on models with right handed currents. Figure 3 shows the constraint on the model-independent parameters (ϵ, η) , defined in Ref. [60]. The SM expectation for these parameters is (1, 0). The polarisation measurement in the K^* mode starts to become important once datasets of 75 ab^{-1} have been achieved. Other observables that

TABLE III: Experimental sensitivities for SuperB precision CKM measurement modes. Where appropriate, the sensitivity for other experiments is also indicated. The current state of the art is also shown, with α and γ taken from UTFit [55], and the remainder of the observables taken from HFAG. Entries marked with (est.) for Belle II are estimated from the SuperB results, scaling by the difference in integrated luminosity. In order to control theoretical uncertainties on the charmonium β measurement, one has to be able to measure $B_d \rightarrow J/\psi\pi^0$ or $B_s \rightarrow J/\psi K_S^0$. The precision for the former has been determined for SuperB integrated luminosities, however while LHCb will be able to measure the latter, the precision on this control channel is not yet known, and is indicated by a ‘?’.

Observable/mode	Current now	LHCb (2017)	SuperB (2021)	Belle II (2021)	LHCb upgrade (10 years of running)	theory now
		5 fb^{-1}	75 ab^{-1}	50 ab^{-1}	50 fb^{-1}	
α from $u\bar{u}d$	6.1°	$5^\circ{}^a$	1°	1°	b	$1 - 2^\circ$
β from $c\bar{c}s$ (S)	0.8° (0.020)	0.5° (0.008)	0.1° (0.002)	0.3° (0.007)	0.2° (0.003)	clean
S from $B_d \rightarrow J/\psi\pi^0$	0.21		0.014	0.021 (est.)		clean
S from $B_s \rightarrow J/\psi K_S^0$?			?	clean
γ from $B \rightarrow DK$	11°	$\sim 4^\circ$	1°	1.5°	0.9°	clean
$ V_{cb} $ (inclusive) %	1.7		0.5%	0.6 (est.)		dominant
$ V_{cb} $ (exclusive) %	2.2		1.0%	1.2 (est.)		dominant
$ V_{ub} $ (inclusive) %	4.4		2.0%	3.0		dominant
$ V_{ub} $ (exclusive) %	7.0		3.0%	5.0		dominant

^aThis estimate is based on the study in Ref. [56], combined with the expectation that the $B \rightarrow \pi\pi\pi$ approach will be systematics limited at this level [57]. Ignoring systematic errors one may reach a precision of 3° with 10 fb^{-1} of data.

^bIt is not clear how well any LHCb upgrade might be able to measure this angle, however it is unlikely to be competitive with SuperB.

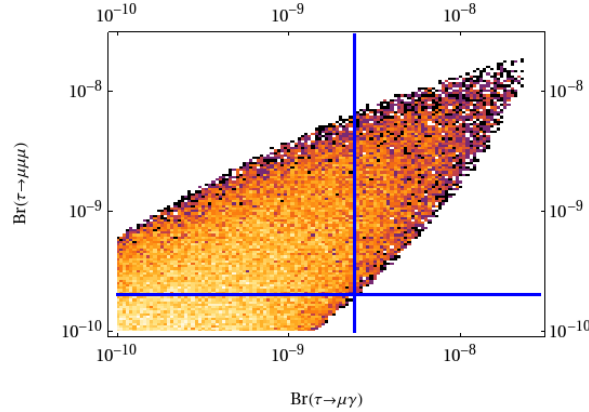


FIG. 2: Correlation between $\text{Br}(\tau \rightarrow \mu\gamma)$ and $\text{Br}(\tau \rightarrow \mu\mu\mu)$ in the LHT for the symmetry breaking scale $f = 500 \text{ GeV}$. The solid lines indicate expected SuperB sensitivities.

can be used to test for right handed currents include the time-dependent CP asymmetry parameters measured in $B^0 \rightarrow K_S^0 \pi^0 \gamma$, a mode which is only accessible in an e^+e^- environment.

The set of inclusive observables encompassing $b \rightarrow s\gamma$ and $b \rightarrow s\ell\ell$ transitions can be used to constrain the MSSM with generic soft SUSY-breaking terms. These measurements are essentially constraints on off-diagonal entries of the squark mixing matrices as functions of the average SUSY mass. Figure 4 shows the constraints that can be achieved on the real and imaginary parts of the mass insertion parameter $(\delta_{23}^d)_{LR}$ for a SUSY scale 1 TeV (top plot) and the region of mass insertions and SUSY masses where a deviation from the SM larger than 3σ can be observed at SuperB (bottom plot). SUSY searches at the LHC are starting to rule out the parameter space for low energy scales $\sim 1 \text{ TeV}$, and it is possible that by the time SuperB starts running, there will be no evidence for new physics. In this case combinations of flavour observables, such as those described here, can provide a window to probe to energies beyond the reach of the LHC. For mass insertions ~ 0.1 the energy scale probed by SuperB is 10 TeV, and for larger values the scale increases. Direct searches for SUSY at the LHC

TABLE IV: Golden matrix of observables/modes that can be measured at SuperB. The size of the NP effect in a given model/scenario is indicated by the number of stars: $\star\star\star$, $\star\star$, \star . The more stars the larger the effect. Additional notes: CKM indicates precision CKM required. Lattice QCD improvements are required at the predicted level (See CDR/White paper for details). A question mark indicates that the channel has not been studied yet. The information here is taken from previous work done within SuperB and from Refs. [46, 58, 59] where details on specific models can be found.

Observable/mode	charged Higgs high $\tan\beta$	MFV NP low $\tan\beta$	non-MFV NP 2-3 sector	NP in Z penguins	Right-handed currents	LHT	SUSY				
							AC	RVV2	AKM	δLL	FBMSSM
$\tau \rightarrow \mu\gamma$ $\tau \rightarrow \ell\ell\ell$						$\star\star\star$	$\star\star\star$	\star	$\star\star\star$	$\star\star\star$	$\star\star\star$?
$B \rightarrow \tau\nu, \mu\nu$ $B \rightarrow K^{(*)+}\nu\bar{\nu}$ S in $B \rightarrow K_S^0\pi^0\gamma$ S in other penguin modes $AC P(B \rightarrow X_s\gamma)$ $BR(B \rightarrow X_s\gamma)$ $BR(B \rightarrow X_s\ell\ell)$ $B \rightarrow K^{(*)}\ell\ell$ (FB Asym)	$\star\star\star$ (CKM)		\star $\star\star$ $\star\star\star$ (CKM) $\star\star\star$ $\star\star$ $\star\star$ $\star\star$	$\star\star\star$	$\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star$ \star \star		$\star\star\star$ $\star\star\star$ $\star\star\star$ \star \star \star \star	\star $\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star\star$	$\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star\star$ $\star\star\star$	$\star\star\star$ $\star\star\star$	

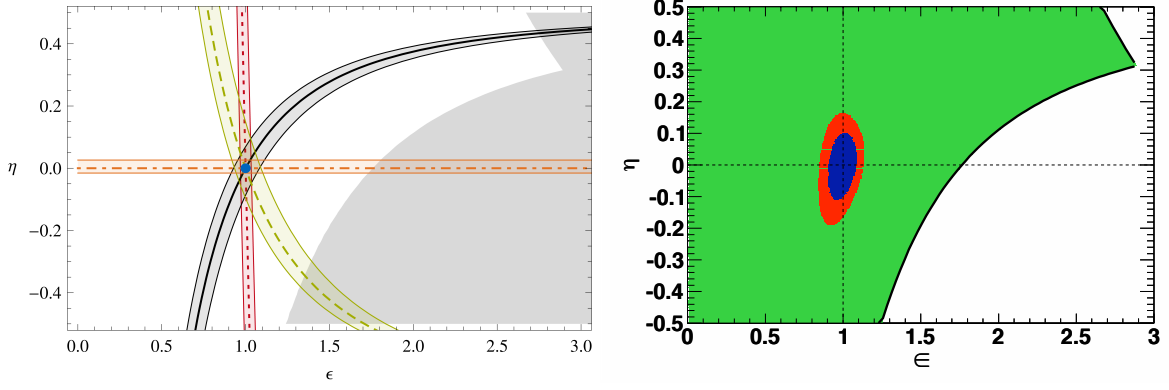


FIG. 3: The constraint on the (ϵ, η) plane obtained from $B^0 \rightarrow K^{*0} \nu \bar{\nu}$ decays. The parameters are defined in Ref. [60] (top figure taken from this reference). The top plot shows the dependence of ϵ and η on the measurable quantities. The horizontal band corresponds to the constraint from a polarisation measurement in $B \rightarrow K^{*} \nu \bar{\nu}$, and the band increasing (decreasing) from left to right corresponds to $B \rightarrow K \nu \bar{\nu}$ ($B \rightarrow K^{*} \nu \bar{\nu}$). The vertical constraint comes from the inclusive measurement of $B \rightarrow X_s \nu \bar{\nu}$. The error bands shown in this plot are theoretical. The oval contours of the bottom plot show the expected experimental constraint using measurements of the branching ratios of $B \rightarrow K^{(*)} \nu \bar{\nu}$ and the angular analysis of $B^0 \rightarrow K^{*0} \nu \bar{\nu}$ with 75 ab^{-1} at SuperB. The green region represents the constraint based on current experimental limits.

place the energy scale above $\sim 1 \text{ TeV}$. As a result we expect mass insertions to give visible effects for magnitudes greater than 0.01.

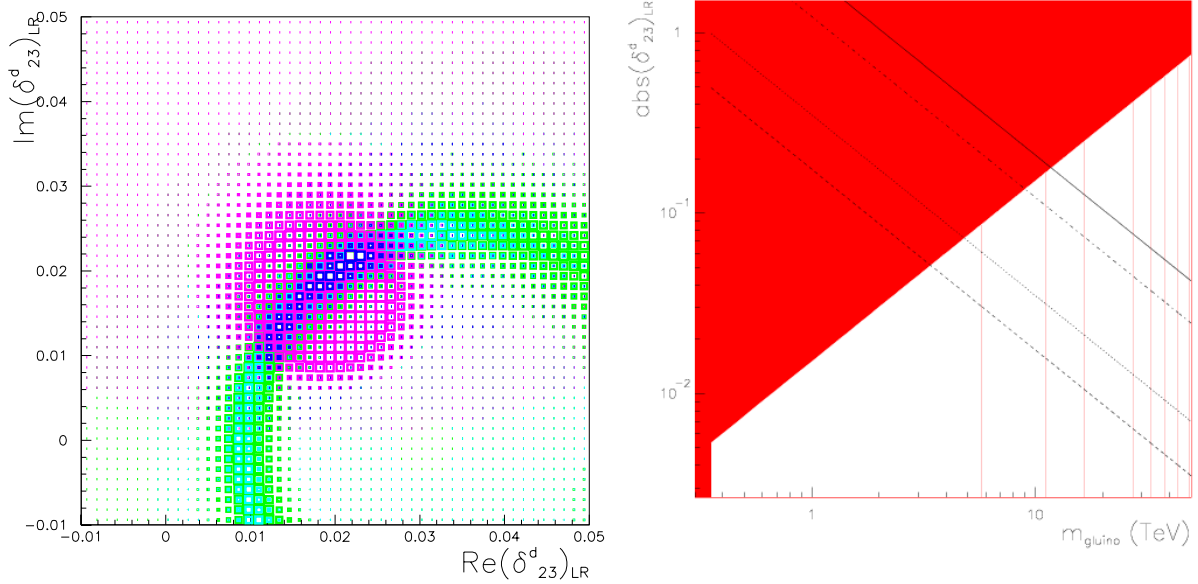


FIG. 4: Top plot: extraction of $(\delta_{23}^d)_{LR}$ from the measurements of $a_{CP}(B_d \rightarrow X_s \gamma)$ (magenta), $BR(B_d \rightarrow X_s \gamma)$ (green) and $BR(B_d \rightarrow X_s \ell^+ \ell^-)$ (cyan) with the errors expected at next-generation flavor experiments. Central values are generated using $(\delta_{23}^d)_{LR} = 0.028 e^{i\pi/4}$ and squark and gluino masses at 1 TeV. Bottom plot: region of the parameter space where a non-vanishing $(\delta_{23}^d)_{LR}$ can be extracted with at least 3σ significance (in red).

It is also possible to constrain the mass of a charged Higgs boson in Two-Higgs Doublet Models Type II (2HDM-II) at SuperB. The constraint one obtains from the measurement of $B \rightarrow \ell \nu$ decays on the mass of a H^+ boson as a function of $\tan \beta$ is given in Figure 5. Similar constraints can be obtained for the MSSM. One can see that the excluded region obtained from the SuperB measurements is far greater than that obtained from

direct searches at the LHC, assuming a data sample of 30 fb^{-1} of data collected at a centre of mass energy of 14 TeV by ATLAS. In the MSSM, stronger bounds on the same plane could be obtained from $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ measured at LHCb depending on the value of other SUSY parameters.

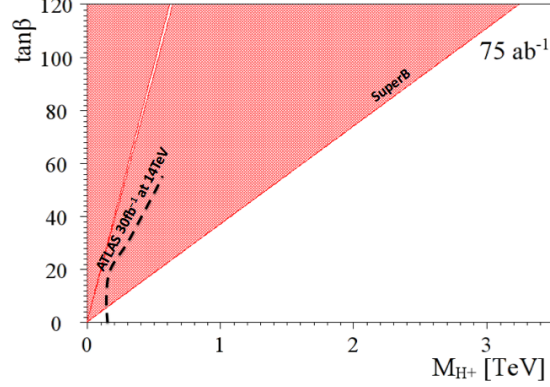


FIG. 5: The constraint on the mass of a charged Higgs boson as a function of $\tan\beta$ in a 2HDM-II (95% C.L.). The constraint anticipated from the LHC with 30 fb^{-1} of data collected at a centre of mass energy of 14 TeV is also shown for comparison. The SuperB constraint is dominated by $B \rightarrow \tau\nu$ up to luminosities $\sim 30 \text{ ab}^{-1}$, and the $B \rightarrow \mu\nu$ contribution dominates above this. The ATLAS constraint is taken from arXiv:0901.0512.

Finally in the context of precision tests of the CKM matrix, SuperB would be able to reduce the constraints on the ρ, η plane to the level illustrated by Figure 6. The central values assumed correspond to the current measurements. If one extrapolates to the precision attained with 75 ab^{-1} of data from SuperB, a percent level test of CKM could be performed, and if we assume for the sake of illustration that the central values would stay at today's values, then we would obtain a clear NP signal.

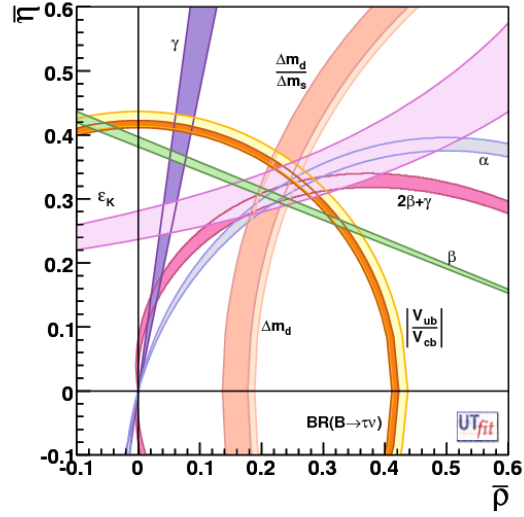


FIG. 6: Constraints on the $(\bar{\rho}, \bar{\eta})$ plane using measurements from SuperB. This is the dream scenario, where existing central values are extrapolated to sensitivities expected from SuperB with 75 ab^{-1} and one can see that the constraints are not consistent with the CKM scenario. This highlights the importance of performing a precision CKM test with SuperB.

4. Summary

The high energy physics community has a strong programme of existing and planned flavour physics experiments. These experiments complement each other well, and if one combines all of the results, then one will be able to restrict the parameter space and viable classes of NP. The flavour landscape when the first physics results from SuperB are available in 2017 will have been defined by the B Factories (*BABAR* and Belle), as well as BES III, LHCb, and the kaon experiments. The two Super Flavour Factories, SuperB and Belle II, will dominate the redefinition of this landscape between 2017 and 2021 as they will collect two orders of magnitude more data than their predecessors. This redefinition will have many significant contributions from SuperB, which will collect more data than Belle II and has the benefit of two unique features: polarised electrons and the ability to collect data near charm threshold. The LHCb upgrade will improve upon the results from LHCb, integrating 50 fb^{-1} by the end of its lifetime. Each of these areas has unique potential to teach us something new about nature.

In order to maximize our understanding of new physics, one has to measure as many golden channels as possible, and determine the correlations of any deviations from SM expectations that would arise from NP. *A priori*, one can not predict the model to pursue, and thus we arrive at a golden matrix of observables vs. viable NP scenarios. The measurement of these observables would contribute to the long-term program of identifying and reconstructing the NP Lagrangian. To this end, a key ingredient could come from direct searches at the LHC, in case new particles are found before the start of SuperB. Yet, even if no new particle is unearthed, measurements from SuperB could still be sensitive to scales larger than that achievable at the LHC. Some of the indirect constraints that will be made at the Super Flavour Factories extend the search capabilities beyond the LHC, for example in the case of a charged Higgs boson, where current experimental bounds from *BABAR* and Belle are equivalent to those expected from ATLAS with 30 fb^{-1} of data at 14 TeV collision energies. The golden matrix is shown in Table IV, with expected numerical precisions indicated in Tables I and II for the SuperB and a selection golden modes from other experiments, respectively.

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