Status of the Super$B$ project

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Super$B$ is a next generation asymmetric e^+e^- flavor factory with a baseline luminosity of 10^{36} cm^{-2} s^{-1}, almost two orders of magnitude larger than the peak luminosity of the existing B-factories. The physics motivation is presented and the conceptual design of the detector is briefly described.

1. The Super$B$ project

Super$B$ is a proposed next-generation asymmetric e^+e^- flavor factory designed to run at a baseline luminosity of 10^{36} cm^{-2} s^{-1}, between 50 and 80 times the peak luminosity reached by earlier B-factories KEKB and PEP-II. The machine is foreseen to operate mainly at the $\Upsilon(4S)$ center-of-mass (CM) energy with the possibility of running in the energy range between the $\Psi(3770)$ and $\Upsilon(5S)$ resonances.

The LHC has recently started a decade long programme whose main goal is the search for the Standard Model (SM) Higgs particle and for direct signals of new physics (NP), which are expected to lie around the 1 TeV energy scale. If NP phenomena are observed, data from very sensitive heavy flavor experiments are needed to better understand their nature. Determining the flavor structure of the NP involved requires the information on rare b, c and τ decays that a very high luminosity asymmetric flavor factory can provide. On the other hand, if evidence of NP is not found at the energy frontier experiments, then the measurement of those processes at Super$B$ would provide another way to explore mass scales up to 10 TeV or more, well beyond the direct reach of the LHC.

The NP sensitive observables that Super$B$ can measure are to a large extent complementary to those accessible at LHCb, the flavor physics experiment at CERN. Typically, rare decays with one or more neutrinos or photons in the final states are unique to an e^+e^- collider where the environment is much cleaner.

2. Physics program

A selection of measurements that are part of the Super$B$ physics program is briefly discussed. The reader is referred to refs. [1,2] for an extensive discussion of the physics reach of the experiment.

2.1. Rare B decays

One of the strengths of the physics program of Super$B$ is the large number of decays where the SM uncertainty is small and which can display a measurable deviation from the SM in one or more NP scenarios. A large fraction of these 'golden' channels are rare B decays where NP particles enter the leading loops.

As an example we consider the decays $B \to l\nu$ with $l = \tau, \mu$, whose rates can be strongly affected by a charged Higgs in a scenario with large $\tan\beta$. For example, in the two Higgs doublet model (2HDM-II) the effect of the charged Higgs is a rescaling of the SM branching fraction by a factor $(1 - \tan^2\beta\, M_B^2/M_{H^+}^2)^2$, where M_{H^+} is the mass of the Higgs boson [1]. Fig. 1 compares the exclusion regions in the $M_{H^+} - \tan\beta$ plane from measurements of $\mathcal{B}(B \to l\nu)$ based on 2ab^{-1} and 75ab^{-1}, assuming that the central value is centered at the SM prediction. In scenarios with large $\tan\beta$ Super$B$ can push the lower bound on M_{H^+} from the hundreds of GeV up to the TeV region.

*On behalf of the Super$B$ collaboration.

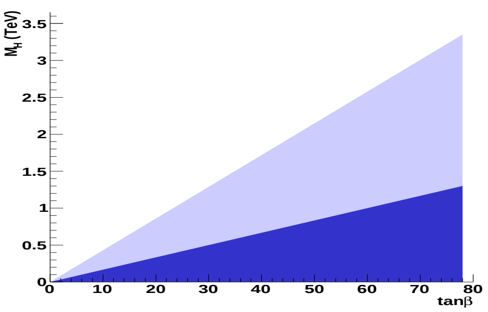

Figure 1. Exclusion regions at 95% CL in the $M_{H^\pm} - \tan\beta$ plane for the 2HDM-II, with 2 ab^{-1} (dark area) and 75 ab^{-1} (dark+light area).

2.2. Time-dependent CP asymmetry in penguin-dominated modes

New Physics can be probed in mixing-induced CP violation of processes dominated by $b \to s$ penguin loops. In the SM $\sin 2\beta$ can be measured from the time dependent CP asymmetry of these decays up to small corrections $\Delta S \equiv \sin 2\beta|_{b\to s} - \sin 2\beta$. The interest lies in the fact that NP particles in the loops can cause measurable deviations from the SM prediction. The potential of this approach depends on both the experimental uncertainty on $\sin 2\beta|_{b\to s}$ for the individual channels and the accuracy of the SM prediction for ΔS. The decays $\eta' K^0$, ϕK^0 and $K_S K_S K_S$ are expected to have the smallest theoretical uncertainty of ΔS [3].

At present no significant deviations from the SM predictions have been observed. When extrapolated to a data sample of 75 ab^{-1}, the experimental errors on ΔS are expected to lie in the range 0.01-0.03, close to the current theory precisions of the cleanest modes. Therefore, at a super$B$ factory these processes will be sensitive probes of NP. LHCb is expected to have limited capability for this class of channels [3].

2.3. Precise measurement of the Cabibbo-Kobayashi-Maskawa matrix

Super$B$ can dramatically improve our knowledge of the Cabibbo-Kobayashi-Maskawa (CKM) matrix thanks to the possibility of performing a wide range of measurements which constrain its elements. The uncertainty on the CKM parameters obtained from the SM fit using the available experimental and theoretical information are expected to decrease by a factor 10 at Super$B$ compared to today [1]. A precise knowledge of the CKM matrix is important per se, but it is also a powerful tool to spot inconsistencies in the SM and evidence of NP. Several measurements used for the determination of $\bar\rho, \bar\eta$ can in fact be affected by the presence of NP, revealing itself as an inconsistency in the $\bar\rho - \bar\eta$ plane.

2.4. τ and charm physics

Super$B$ is able to explore a significant portion of the parameter space in many NP scenarios by searching lepton flavor violatin (LFV) in transitions between the third and first or second lepton generations, complementing studies in the muon sector such as the search for $\mu \to e\gamma$. Compared to the potential of the current B-factories considered together, Super$B$ with 75ab^{-1} can improve the sensitivity by a factor ranging between 7 and 50 depending on the backround conditions of the channel analyzed. Moreover, since the baseline machine design incorporates the polarization of the electron beam (up to 85%), the resulting τ polarization can be exploited either to further improve the background-signal separation or to better determine the features of the LFV interaction once it is observed. Other sensitive probes of NP include tests of lepton flavor universality and the search of CP violation in τ decays.

Super$B$ can operate as a charm factory at the CM energy of both the $\Upsilon(4S)$ and the $\Psi(3770)$, where the quantum correlations in the coherent production of $D^0\bar{D}^0$ can be exploited [2]. The recent observation of the $D^0 - \bar{D}^0$ mixing opens a unique window to the search of CP violation in the charm sector, whose observation would provide a strong hint of physics beyond the SM. The program also includes the search of CP violation in time-independent measurements and the study of rare and forbidden charm decays, as well as precise measurements of CKM matrix parameters [1,2].

2.5. Correlation of flavor observables

Correlations among NP effects in different flavor observables can be exploited to characterize or invalidate models beyond the SM. For example, in ref. [4] the authors consider a flavor blind supersymmetric scenario where the CKM matrix is the only source of flavor violation, but new CP violating phases are present. This model implies definite correlations among observables such as $A_{CP}(b \to s\gamma)$, $S_{\phi(\eta')K_S}$ and the electron and neutron electric dipole moments (EDM). Figure 2 shows $A_{CP}(b \to s\gamma)$ vs $S_{\phi K_S}$ resulting from the scan over the relevant SUSY parameters space[2]. The various colored bands show the attained values of the electron EDM. Though the current measurements of $A_{CP}(b \to s\gamma)$ and $S_{\phi K_S}$ are consistent with the SM prediction, the errors expected with 75 ab^{-1} ($\sigma = 0.004$ and $\sigma = 0.02$, respectively [1]) make the correlated analysis of these observables a powerful tool to probe or falsify the flavor blind scenario.

The case just discussed exemplify a general concept. In ref. [5] it is shown how the characteristic patterns of correlations among a number of flavor observables allow to distinguish between several different SUSY and non-SUSY scenarios. A brief summary of the results is shown in table 1, which indicates the possible size of the effects in a set of observables that can be measured with unprecedented precision at a super flavor factory. Finding for instance large NP effects in the $\tau \to \mu\gamma$ and in the CP asymmetry $A_{CP}(b \to s\gamma)$ would favor the δLL and FBMSSM models and rule out the other models analyzed. Similarly, observing significant effects in $D - \bar{D}$ mixing would disfavor all models analyzed except the AC and LHT models[3].

3. Accelerator concept and detector

To reach the required luminosity of 10^{36} cm^{-2}s^{-1} Super$B$ exploits a new collision

[2]See [4] for all the assumptions used.
[3]See [5] and references therein for details.

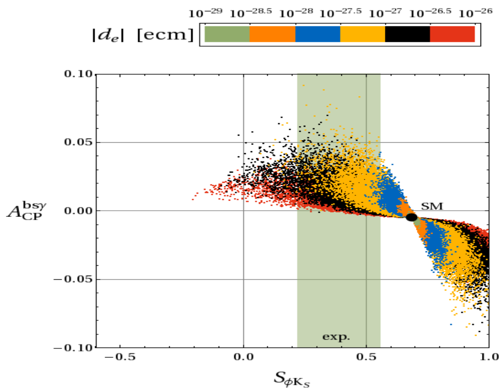

Figure 2. $A_{CP}(b \to s\gamma)$ vs $S_{\phi K_S}$ [4]. The grey band corresponds to the current experimental bound on $S_{\phi K_S}$ at the 68% C.L.

scheme which is based on a small collision area, very small β_y^* at the interaction point, large Piwinsky angle and the crab waist scheme [1,6]. This novel approach has several advantages, most notably the fact that the very large increase in luminosity is achieved with beam currents and wall plug power similar to those reached at PEP-II and KEKB. In the current layout the accelerator consists of 4.2 GeV/6.7 GeV positron/electron beams, corresponding to a CM boost $\beta\gamma \sim 0.24$ in the lab frame (it was $\beta\gamma = 0.56$ in BaBar).

The Super$B$ detector concept is based on the BaBar design [7] with some modifications required to deal with the reduced boost and higher event rates. With the current machine design a number of components of the SLAC B-factory can be reused, resulting in a significant reduction of costs. These include parts of the PEP-II accelerator complex, the BaBar super-conducting solenoid, the CsI(Tl) crystals of the barrel electromagnetic calorimeter (EMC) and the quartz bars of the Cherenkov particle identification system (DIRC).

In the remainder of this section a brief description of the baseline detector under development is provided, focussing on those aspects

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

Table 1
"DNA" of flavor physics effects for some interesting observables in a selection of SUSY and non-SUSY models [5]. ★★★ indicates large effects, ★★ visible but small effects and ★ negligible effects.

where Super$B$ differs significantly from BaBar [8].

The tracking system is composed of a silicon vertex detector (SVT) surrounded by the drift chamber (DCH). To retain the Δt resolution achieved in BaBar for time-dependent CP violation measurements, the reduced Super$B$ boost is compensated by improving the vertex resolution with the addition of an inner SVT layer at about 1.5 cm from the interaction point. The current baseline configuration for the innermost layer is based on the striplets technology (options based on hybrid pixels and CMOS monolithic active pixels are also being developed), while the outer layers are based of microstrip silicon sensors. The BaBar drift chamber is replaced by a new one. Anticipated improvements include a lighter, carbon-fiber mechanical structure and faster readout electronics. The hadron particle identification system is placed just outside the DCH and will make use of the radiator quartz bars of the BaBar DIRC, with the old PMTs replaced by fast pixelated PMTs and the imaging region reduced in size to control the background rates. The EMC can reuse the barrel portion of the BaBar EMC (5760 CsI(Tl) crystals) because estimated rates and radiation levels indicate that this system will continue to function in the Super$B$ environment. In contrast, the CsI(Tl) crystals of the forward endcap will be replaced with LYSO crystals, which are suitable for their excellent radiation hardness, fast decay time, small Molière radius and relatively high light yield. The outermost detector system is the Instrumented Flux Return for the detection of muons and neutral hadrons. The Resistive Plate Chambers and Limited Streamer Tubes used in BaBar will be replaced by faster extruded scintillator bars, and the amount and distribution of the absorber (iron or brass) will be optimized.

Two additional systems are being considered to possibly improve the performance of the detector: a forward particle identification device placed between the DCH and the forward endcap EMC, and a backward EMC calorimeter [8].

The Technical Design Report of the project is in preparation.

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