

The Physics Potential of SuperB

Fergus F. Wilson¹ on behalf of the SuperB Collaboration
STFC Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, UK

SuperB is a major new European e^+e^- collider facility to be built in Italy that will provide a precise study of the structure of New Physics beyond the Standard Model at energy scales above the LHC as well as a comprehensive program of Standard Model physics. In this article, I review the physics opportunities, the status of the accelerator and detector studies, and the future plans.

1 Introduction

The new SuperB facility will investigate the consequences for flavour physics of any discoveries at the LHC and search for New Physics (NP) signatures at energy scales that exceed the direct search capabilities of the LHC. A super-flavour factory will also be able to improve the precision and sensitivity of the previous generation of flavour factories by factors of five to ten. The sides and angles of the Unitarity Triangle will be determined to an accuracy of $\sim 1\%$. Limits on Lepton Flavour Violation (LFV) in τ decays will be improved by two orders of magnitude. It will become feasible to search for CP violation (CPV) in charm mixing. Extensive searches for new states in bottomium and charmonium spectroscopy will be achieved. New precision measurements of electroweak properties, such as the running of the weak mixing angle $\sin^2 \theta_W$ with energy, should become possible.

Flavour physics is an ideal tool for indirect searches for NP. Both mixing and CPV in B and D mesons occur at the loop level in the Standard Model (SM) and therefore can be subject to NP corrections. New virtual particles occurring in the loops or tree diagrams can also change the predicted branching fractions or angular distributions of rare decays. Current experimental limits indicate NP with trivial flavour couplings has a scale in the 10-100 TeV range, which is much higher than the 1 TeV scale suggested by SM Higgs physics. This means that either the NP scale can not be seen in direct searches at the LHC or the NP scale is close to 1 TeV and therefore the flavour structure of the NP must be very complex. In either case, indirect searches provide a way of understanding the new phenomena in great detail.

SuperB is an asymmetric e^+e^- collider with a 1.3 km circumference. The design calls for 6.7 GeV positrons colliding with 4.18 GeV electrons at a centre of mass energy $\sqrt{s} =$

¹Fergus.Wilson@stfc.ac.uk

10.58 GeV. The boost $\beta\gamma = 0.238$ is approximately half the value used at *BABAR* [1]. The electron beam can be 60%-80% polarized. The design luminosity is $10^{36} \text{ cm}^{-2}\text{s}^{-1}$ and data taking is expected to start in the latter part of this decade with a delivered integrated luminosity of 75 ab^{-1} over five years. It should be possible to exceed the baseline luminosity specification, leading to the prospect of collecting $20\text{-}40 \text{ ab}^{-1}$ per year in later years.

In the following sections, I discuss the physics potential of some of the key measurements to be made at the Super*B* factory with an integrated luminosity of 75 ab^{-1} . In addition, there is a comprehensive program for B_s at the $Y(5S)$ resonance, bottomium and charmonium spectroscopy, ISR physics, g-2 hadronic contributions, and two-photon interactions, to name just a few.

2 Physics Potential

Both *BABAR* and Belle [2] have successfully measured the CKM Unitarity Triangle angles α , β and γ [3]. Although there are discrepancies in some measurements, overall everything is consistent to a few sigma. Increasing the statistics will show if these tensions are real and possible signs of NP. It will be possible to measure the angles α and γ to $1 - 2\%$, and β to 0.1% . $|V_{cb}|$ and $|V_{ub}|$ can be measured to 1% and 2% accuracy, respectively, in both inclusive and exclusive semileptonic decays. The production of copious amounts of charm decays could lead to the measurement of the charm Unitarity Triangle parameters. Figure 1 shows the $\bar{\rho}\text{-}\bar{\eta}$ plane with current and predicted experimental measurements, assuming the current measurements maintain their central values.

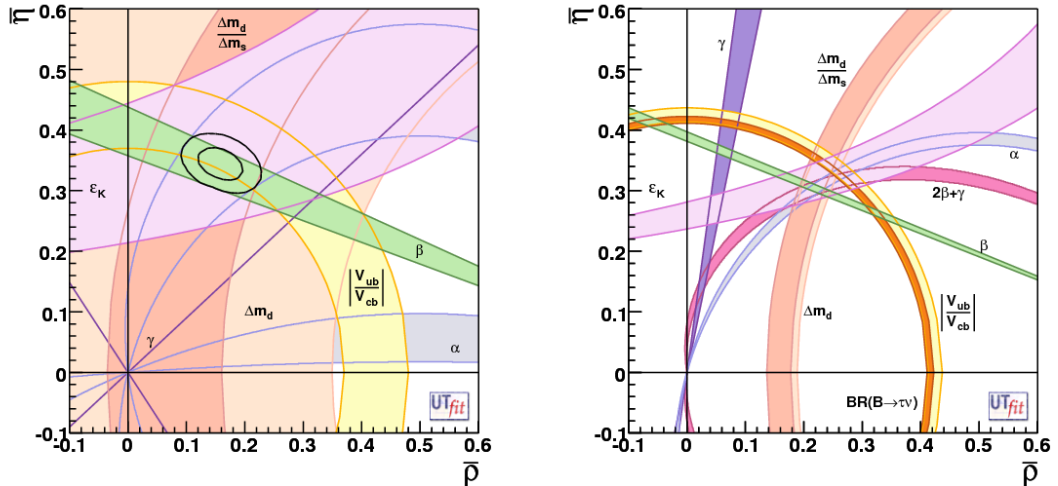


Figure 1: Regions corresponding to 95% probability for $\bar{\rho}$ and $\bar{\eta}$ with current measurements (left) and with Super*B* precision assuming the current central values (right).

	H^+ high $\tan\beta$	MFV	non-MFV	NP Z-penguins	Right-hand currents	LTH	SUSY models				
							AC	RVV2	AKM	δLL	FBMSSM
$\mathcal{B}(\tau \rightarrow \mu\gamma)$							L	L	M	L	L
$\mathcal{B}(\tau \rightarrow \mu\mu\mu)$						L					
$\mathcal{B}(B \rightarrow \tau\nu, \mu\nu)$	L-CKM										
$\mathcal{B}(B \rightarrow K^{(*)}\nu\bar{\nu})$			M	L			M	M	M	M	M
$S_{K_s^0\pi^0\gamma}$					L						
Angle β (ΔS)			L-CKM		L		L	M	M	L	L
$A_{CP}(B \rightarrow X_s\gamma)$			L		M		M	M	M	L	L
$\mathcal{B}(B \rightarrow X_s\gamma)$		L	M		M						
$\mathcal{B}(B \rightarrow X_s ll)$			M	M	M						
$A_{FB}(B \rightarrow K^{(*)}ll)$							M	M	M	L	L
Charm mixing							L	M	M	M	M
CPV in Charm	L									L	

Table 1: The golden matrix of observables versus a sample of NP scenarios. MFV is a representative Minimal Flavour Violation model; LTH is a Littlest Higgs Model with T Parity. A number of explicit SUSY models are included [6]. L denotes a large effect, M a measurable effect and L-CKM indicates a measurement that requires precise measurement of the CKM matrix. ΔS is the difference in the angle β between $b \rightarrow s$ penguin-dominated transitions and $b \rightarrow c\bar{c}s$ decays.

SuperB will make precision measurements of a series of “Golden Modes”. The SM predictions for these modes are well calculated and they can be cleanly measured experimentally. NP scenarios can be differentiated by comparing the measured values with NP predictions. Table 1 shows just some of the key measurements and a sample of NP models.

In 2-Higgs-doublet (2HDM-II) and MSSM models, the decay $B \rightarrow \tau\nu$ is sensitive to the presence of a charged Higgs H^- replacing the SM W^- . SuperB will be able to exclude masses up to $\sim 2 - 3$ TeV for values of $\tan\beta$ up to 80. The region of charged Higgs mass versus $\tan\beta$ that can be excluded is shown in Figure 2 for both the 2HDM-II and MSSM models. This includes the current 20% uncertainty from f_b and V_{ub} that can be expected to be much reduced in the future.

SuperB can access the off-diagonal elements of generic squark mass matrices in the MSSM model using the mass insertion approximation. These can not be seen by the LHC general purpose detectors. As an example, SuperB is sensitive to non-zero values of the matrix element $(\delta_{23}^d)_{LL,LR}$ for gluino masses in the 1-10 TeV range through decays such as $b \rightarrow s\gamma$ and $b \rightarrow sl^+l^-$ (Figure 3).

An almost equal number of $\tau^+\tau^-$ pairs are produced as $B\bar{B}$ pairs at the $Y(4S)$ resonance. Current experimental 90% confidence level upper limits on τ LFV are in the $10^{-8} - 10^{-7}$ range, depending on the decay. In the very clean environment of SuperB, upper limits on τ LFV can be achieved down to a level of 2×10^{-10} for $\tau \rightarrow \mu\mu\mu$ and SuperB can measure the upper limits in ~ 50 other τ decay modes. Background-free modes should scale with the luminosity while other modes will scale with $\sqrt{\mathcal{L}}$ or better, thanks to re-optimized analysis techniques. In $\tau \rightarrow \mu\gamma$ for example, LFV is predicted at the level $10^{-10} - 10^{-7}$ depending

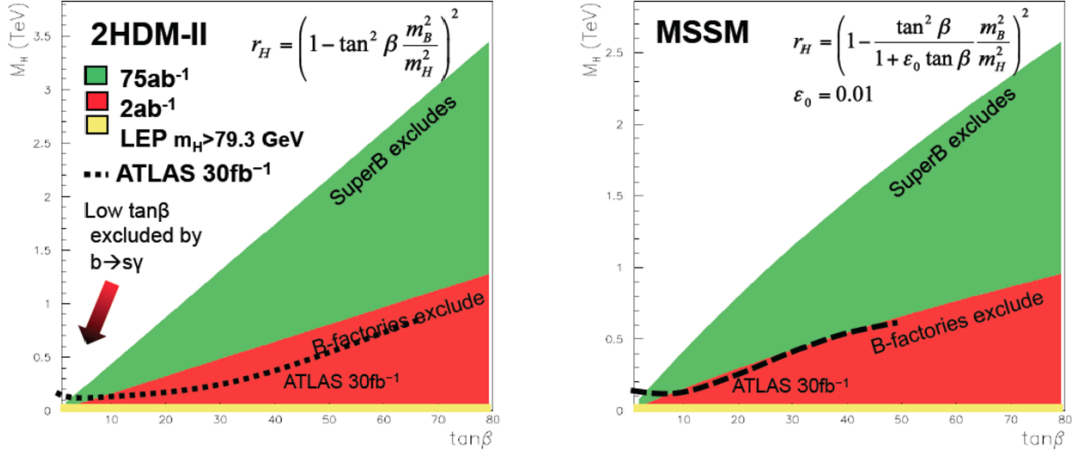


Figure 2: The mass of the charged Higgs versus $\tan \beta$ from $B \rightarrow \tau \nu$ decays for a 2HDM-II (left) and MSSM (right) model. The dark (red) region is excluded assuming the $BABAR$ and Belle datasets are combined and the light (green) region shows the exclusion potential of SuperB.

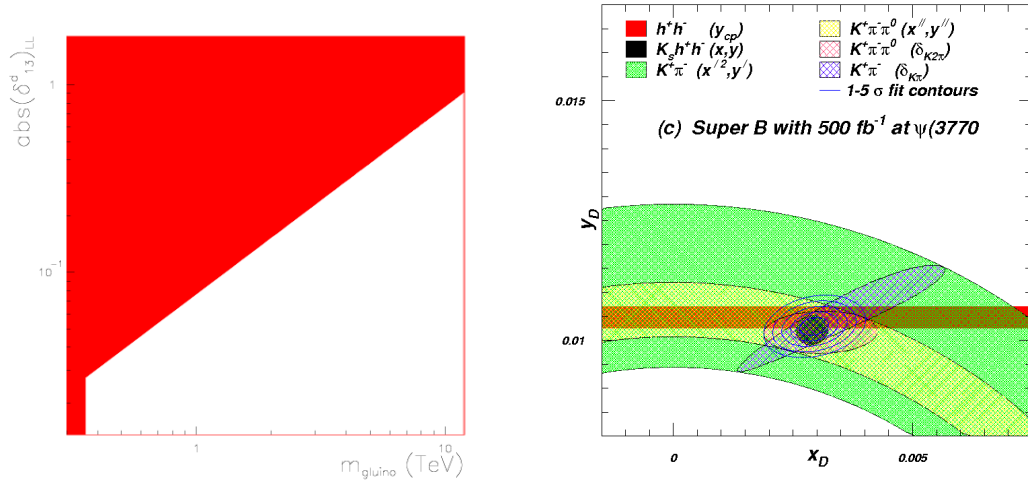


Figure 3: Left: The shaded (red) region shows where a measurement can be made (defined as a 3σ significance) of the matrix element $(\delta_{23}^d)_{LL,LR}$ as a function of gluino mass in an MSSM model from measurements involving a $b \rightarrow s$ transition. Right: the expected precision on charm mixing parameters from combining BES-III and SuperB $\psi(3770)$ and $Y(4S)$ data.

on the NP model. SU(5) SUSY GUT models predict $\tau \rightarrow \mu \gamma$ branching fractions between 10^{-7} and 10^{-9} depending on the NP phase, so the majority of the parameter space is within

the expected SuperB sensitivity of 2×10^{-9} .

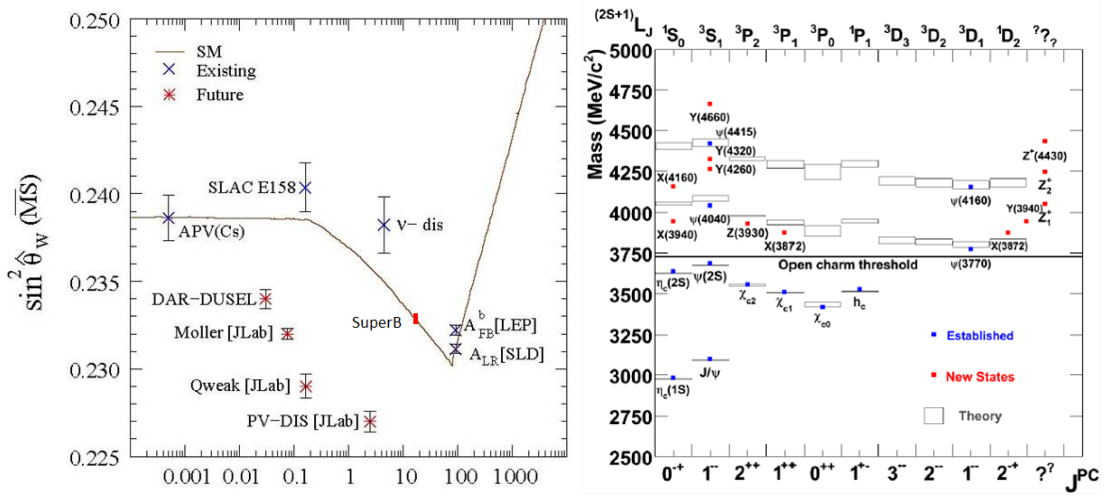


Figure 4: Left: Measurements of $\sin^2 \theta_w$ as a function of energy (GeV). The size of the bar at an energy ~ 10.6 GeV representing the SuperB measurement is approximately the same size as the error. Right: Measured masses of newly observed states positioned according to their most likely quantum numbers.

CPV in charm decays is expected to be very low in the SM ($< 1\%$) so its detection would be a clear indicator of NP. Current values for the mixing parameters x and y from HFAG [3] fits give $(0.63 \pm 0.20)\%$ and $(0.75 \pm 0.12)\%$, respectively, allowing for CPV [4]. At SuperB, the errors should reduce to 0.07% and 0.02%, respectively. If the results are combined with expected results from BES-III and a dedicated SuperB 500 fb^{-1} run (~ 4 months running) at the $D \bar{D}$ threshold, the BES-III/CLEO-c physics programme can be repeated leading to a further reduction in these errors to 0.02% and 0.01%, respectively. This is shown in the right-hand plot of Figure 3.

If a polarised electron beam is available, many of the upper limits on τ LFV modes can be improved by an additional factor of two. The polarisation also allows for the search for τ EDM at a level of $2 \times 10^{-19} e \text{ cm}$ and measurement of the τ anomalous magnetic moment $\Delta\alpha_\tau$ with an error of 10^{-6} . The value of $\sin^2 \theta_w$ can be measured with an accuracy $\pm 1.8 \times 10^{-4}$ at $Q = 10.58 \text{ GeV}$ and so help understand the discrepancy in the measurements from LEP, SLD and NuTeV [5]. This is shown in the left-hand plot of Figure 4 where the size of the bar at $Q = 10.58 \text{ GeV}$ represents the expected error on the SuperB measurement. It may even be possible to measure $\sin^2 \theta_w$ at the $\psi(3770)$ mass if polarisation can be achieved.

The B-Factories and the Tevatron have discovered heavy bound states that do not fit into the conventional meson interpretation. However, apart from some exceptions like the $X(3872)$, they have only been observed in a single decay channel with a significance only just above 5σ . The right-hand plot of Figure 4 shows some of the newly discovered states. Possible

explanations include hybrids, molecules, tetraquarks and threshold effects. SuperB's ability to run at the $Y(nS)$ resonances and charm threshold provides a unique opportunity for testing low- and high-energy QCD predictions. Predicting the expected rates for poorly measured resonances is of course hard and work is on-going to improve the extrapolations. The $B \rightarrow X(3872)K$ decays should produce $\sim 2k - 10k$ events in each of their main decay channels. $Y(4260) \rightarrow J/\psi \pi^+ \pi^-$ will have $\sim 45k$ events, while $\sim 4.5k$ events can be expected for both $Y(4350)$ and $Y(4660)$ decaying to $\psi(2S)\pi^+ \pi^-$. It should be possible to confirm the existence of the $Z_1^+(4050)$, $Z^+(4430)$ and $Z_2^+(4430)$ as SuperB will collect between $150k - 2M$ events of the relevant fully reconstructed final states $J/\psi \pi^+ K$, $\psi(2S)\pi^+ K$, and $\chi_{cJ}\pi^+ K$.

3 Status of the project

The physics potential [6], and the detector [7] and accelerator [8] plans have been extensively documented. The accelerator parameters are close to final for operating in the $\psi(3770)$ to $Y(5S)$ energy range and the accelerator will reuse large parts of the SLAC PEP-II hardware. The campus of Tor Vergata University, Rome, was chosen as the site at the end of May 2011. Data taking should begin five to six years after construction begins.

References

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