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Super$B$

Fergus WILSON*
STFC Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, UK
E-mail: Fergus.Wilson@stfc.ac.uk

Super$B$ is a major new European e^+e^- collider facility to be built in Italy. The measurements that can be made will allow for the precise study of the structure of New Physics beyond the Standard Model at energy scales above the LHC. In this article, I review the physics opportunities, the status of the accelerator and detector studies, and the future plans.

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*Speaker.

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1. Introduction

A super-flavour factory will 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. New precision measurements of electroweak properties, such as the running of the weak mixing angle $\sin^2\theta_W$ with energy, should become possible. But the primary goal will be the search for New Physics (NP) signatures at energy scales that exceed the direct search capabilities of the LHC.

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. We are therefore presented with a scenario in which 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.

Super*B* 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 $\sqrt{s} = 10.58$ GeV. The boost $\beta\gamma = 0.238$ is approximately half the value used at *BABAR* [1] to keep the power consumption low (< 20 MW). The design luminosity is $10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ 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. Confidence is high that the baseline luminosity specification can be exceeded, leading to the prospect of collecting 20-40 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 $\Upsilon(5S)$ resonance, Majorana neutrino searches through $B^+/D^+ \to X^- l^+ l^+$ decays [2], bottomium and charmonium spectroscopy, exotic resonances, and two-photon interactions, to name just a few.

2. Physics Potential

Both *BABAR* and Belle [3] have successfully measured the CKM Unitarity Triangle angles α, β and γ [4]. 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. Figure 1a shows the $\overline{\rho}$-$\overline{\eta}$ plane with current experimental measurements and Figure 1b shows what the $\overline{\rho}$-$\overline{\eta}$ plane will look like with Super*B* statistics, assuming the current measurements maintain their central values.

PoS(BEAUTY 2011)056

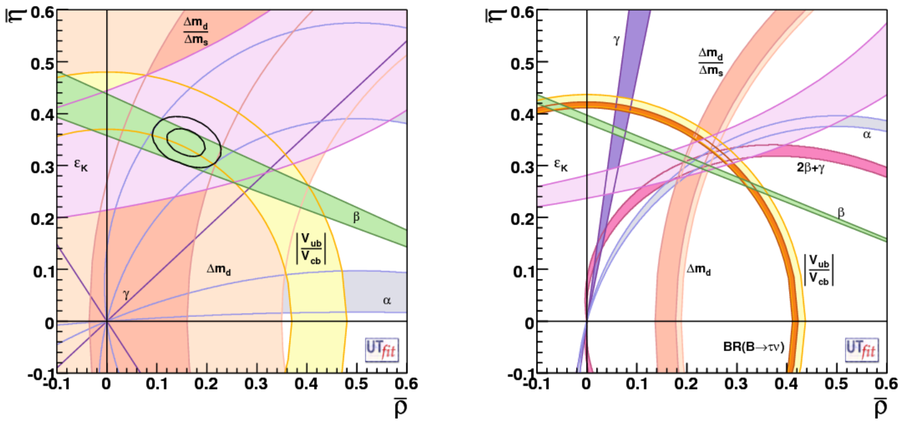

Figure 1: Regions corresponding to 95% probability for $\bar{\rho}$ and $\bar{\eta}$ with current measurements (left) and with Super*B* precision assuming the current central values (right).

	H^+ high tanβ	MFV	non-MFV	NP Z-penguins	Right-hand currents	LTH	SUSY
$\mathscr{B}(B \to X_s\gamma)$		L	M		M		
$A_{CP}(B \to X_s\gamma)$			L		M		
$\mathscr{B}(B \to \tau\nu)$	L-CKM						
$\mathscr{B}(B \to X_s ll)$			M	M	M		
$\mathscr{B}(B \to K\nu\overline{\nu})$			M	L			
$S_{K_S^0\pi^0\gamma}$					L		
Angle β (ΔS)			L-CKM		L		
$\mathscr{B}(\tau \to \mu\gamma)$							L
$\mathscr{B}(\tau \to \mu\mu\mu)$						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. 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 $b \to s$ penguin-dominated transitions and $b \to c\bar{c}s$ decays.

In parallel with improved determination of the Unitarity Triangle, Super*B* 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 $B \to \tau\nu$ is sensitive to the presence of a charged Higgs H^- replacing the SM W^-. The region of charged Higgs mass versus tanβ that can be excluded is shown in Figure 2. This includes a 20% uncertainty from f_b and $V_{\rm ub}$ that can be expected to be much reduced in the future.

Super*B* can access the off-diagonal elements of generic squark mass matrices in the MSSM

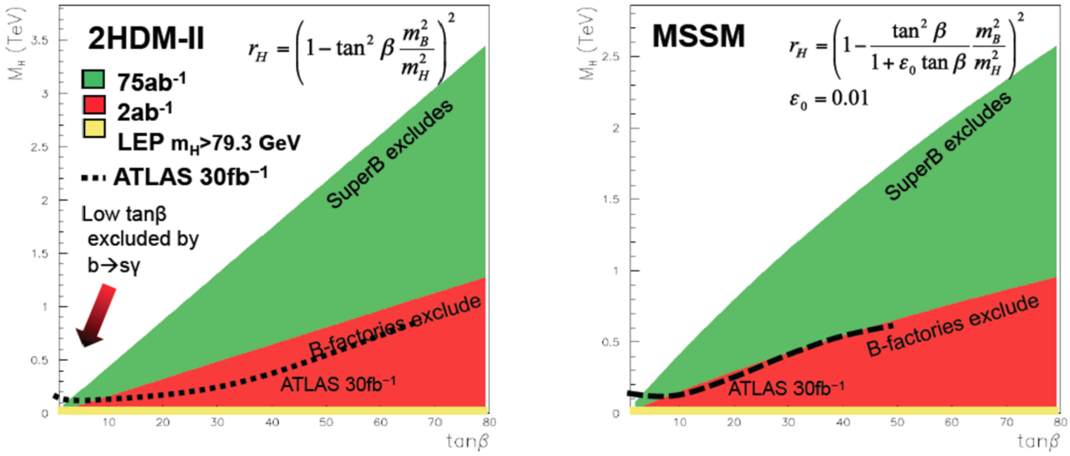

Figure 2: The mass of the charged Higgs versus $\tan\beta$ from $B \to \tau\nu$ decays for a 2HDM-II (left) and MSSM (right) model. The dark (red) region is excluded assuming the BABAR and Belle datasets are combined and the light (green) region shows the exclusion potential of Super*B*.

model using the mass insertion approximation. These can not be seen by the LHC general purpose detectors. Considering decays like $b \to s\gamma$ and $b \to sl^+l^-$, the dark (red) region in Figure 3 shows the region sensitive to non-zero values of the absolute value of the matrix element $(\delta^d_{23})_{LL,LR}$ as a function of the gluino mass. SUSY mass scales in the range 1-10 TeV can be measured.

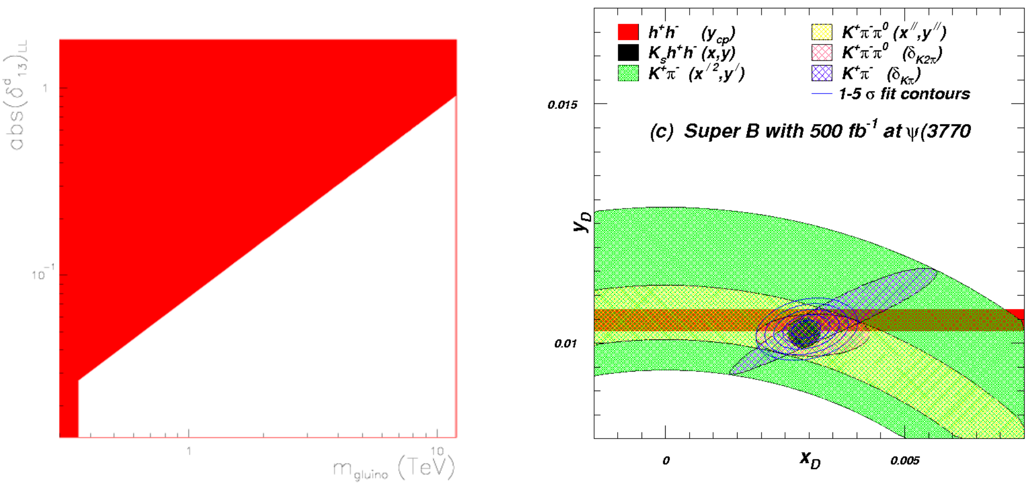

Figure 3: Left: The shaded (red) region shows where a measurement can be made (defined as a 3σ significance) of the matrix element $(\delta^d_{23})_{LL,LR}$ as a function of gluino mass in an MSSM model from measurements involving a $b \to s$ transition. Right: the expected precision on charm mixing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

An almost equal number of $\tau^+\tau^-$ pairs are produced as $B\bar{B}$ pairs at the $\Upsilon(4S)$ 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 Super*B*, upper limits on τ LFV can be achieved down to a level of 2×10^{-10} for $\tau\to\mu\mu\mu$. This is illustrated in Figure 4, which compares current *BABAR* and Belle measurements [5] with some predictions for Super*B*. Background-free modes should scale with the luminosity while other modes will scale with $\sqrt{\mathscr{L}}$ or better, thanks to re-optimized analysis techniques. In $\tau\to\mu\gamma$ for example, LFV is predicted at the level 10^{-10} – 10^{-7} depending on the NP model. Figure 5 shows the predicted branching fraction $\mathscr{B}(\tau\to\mu\gamma)$ in an SU(5) SUSY GUT model as a function of the NP phase. The expected Super*B* sensitivity of 2×10^{-9} covers the majority of the parameter space. These τ measurements are complementary to the measurement of θ_{13} in ν experiments and LFV in $\mu\to e\gamma$.

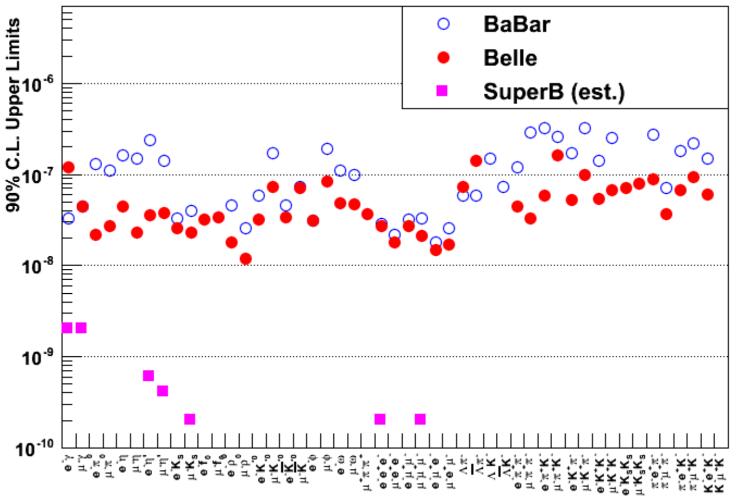

Figure 4: Current 90% confidence limits on branching fractions for τ LFV decays from *BABAR* and Belle compared to predictions for Super*B*. The majority of the modes will be measurable at Super*B*.

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 [4] fits give $(0.63\pm0.20)\%$ and $(0.75\pm0.12)\%$, allowing for CPV [4]. At Super*B*, 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 Super*B* 500 fb^{-1} run ($\sim$ 4 months) 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 $2\times10^{-19}e\,$cm and measurement of $\Delta\alpha_\tau$ with an error of 10^{-6}. The value of $\sin^2\theta_w$ can be measured with an accuracy $\pm1.8\times10^{-4}$ at $Q=10.58\,$GeV and so help understand the discrepancy in the measurements from LEP, SLD and NuTev [6]. This is shown in right-hand plot of Figure 5 where the size of the bar represents the expected error on the Super*B* measurement.

3. Status of the project

The physics potential [7], and the detector [8] and accelerator [9] plans have been extensively

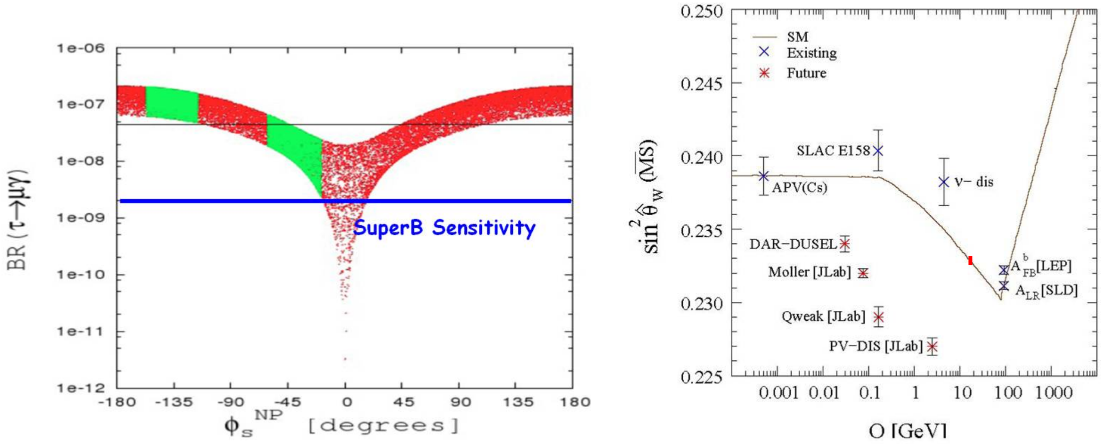

Figure 5: Left: $\mathscr{B}(B \to \mu\gamma)$ in an SU(5) SUSY GUT model as a function of parameter space and NP phase. Right: Measurements of $\sin^2\theta_w$ as a function of energy. The size of the bar at an energy $\sim 10.6\,\mathrm{GeV}$ representing the Super*B* measurement is approximately the same size as the error.

documented. The detector will reuse a large part of the *BABAR* detector. Major upgrades and options include the vertex detector, the tracking chamber, forward and rear calorimetry, and enhanced particle identification. The DAQ, readout and reconstruction will need to be redesigned to cope with a logging data rate of 1.9 Gbytes/s. The accelerator parameters are close to final for operating in the $\psi(3770)$ to $\Upsilon(5S)$ energy range and the accelerator will reuse large parts of the SLAC PEP-II hardware. Work is progressing towards the detector TDR and the first collaboration meeting will be held May 2011. Data taking should begin five to six years after construction begins.

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