EPJ Web of Conferences **28**, 04006 (2012)
DOI: 10.1051/epjconf/20122804006

The complementarity of Super*B* with the LHC

Adrian Bevan[1,a]

School of Physics and Astronomy, Queen Mary University of London, London, E1 4NS, UK.

Abstract. The complementarity between results anticipated from Super*B* with those from the LHC experiments is discussed here. Super*B* can contribute to searches for new physics using indirect constraints via precision tests of the standard model. In addition to the indirect constraints, there are a number of direct searches that can be performed at low energy. There is a well motivated programme of measurements to make at Super*B*, the results of which will add to our understanding of possible scenarios of physics beyond the standard model.

1 Introduction

The Super*B* project is described in detail in Refs [1–4]. This is a high luminosity e^+e^- experiment designed to study both quark and charged lepton flavour transitions with vast numbers of $B_{u,d,s}$, D and τ decays, as well as perform precision tests of the standard model of particle physics (SM). A few of the measurements possible at Super*B* can be performed at the LHC, however the real strength of the physics programme rests in the observables that are unique to these facilities. These proceedings concentrate on some observables accessible to Super*B* and in particular measurements of these complement the knowledge being attained at the LHC. This discussion is broken down into issues pertaining to the new physics (NP) energy scale, followed by forbidden and rare processes, CP violation and mixing, and precision electroweak constraints. A more detailed discussion of the Super*B* physics programme can be found in Refs [3,4]. It is anticipated that Super*B* will be taking data by 2017.

As discussed in section 2, one may learn something about the energy scale of any underlying NP from such measurements, should this not already be ascertained from LHC results by the time data taking commences. If the NP energy scale is defined by results from the LHC before the Super Flavor Factories take data, one can start to constrain couplings within the underlying theory. Otherwise deviations from the SM may give some indication of an upper bound on the NP scale and hence the ideal integrated luminosity required to observe NP at the SLHC. Forbidden and rare decays within the SM constitute a set of powerful quantum interferometers for NP searches. In the case of forbidden processes (section 3) one tests for null results, while in the case of rare decays (section 4) one searches for deviations from SM expectations resulting from interference effects. Studies of such decays are cleaner in an e^+e^- environment than a hadronic one, and in many cases provide complementary information to direct or indirect searches at the LHC. An advantage of studying decays in a clean environment is that in addition to all charged hadronic final states, that are often subject to non-trivial model uncertainties, one can measure processes that are theoretically clean. Such probes for NP provide a robust set of redundant measurements that can be used to disentangle the nature of any underlying NP that may be manifest (see the interplay discussions in Refs [3,4]). While mixing and CP violation phenomena have been extensively studied in neutral kaon and B meson systems at previous generations of experiments, there has been relatively little work done in the charm sector. Similarly only a few CP violation measurements have been made in τ decays. Super*B* will be able to probe these effects in B, D and τ decays as discussed in section 5. Finally Super*B*'s potential for precision electroweak physics is highlighted.

[a] e-mail: `a.j.bevan@qmul.ac.uk`

2 The new physics energy scale

Naturalness arguments have led theorists to postulate that new heavy particles must exist at the electroweak symmetry breaking scale, with masses of $\leq 1TeV$. Recent results from the LHC have failed to uncover any sign of such new particles, and it is expected that searches will reach the TeV scale soon. One should recall that the interpretation of these direct searches for NP are done in a model dependent way, for example using the so-called constrained minimal SUSY scenario (CMSSM) or some other simplified model. Nonetheless experimental results from the LHC place lower bounds on the masses of postulated new particles. If one considers, for example, generic MSSM in the mass-insertion hypothesis [5,6], there are well in excess of 100 parameters that need to be considered as opposed to just five used for CMSSM searches. Most of these parameters are complex couplings in the flavour sector that are often ignored in phenomenological studies. The reason why phenomenologists do not consider generic studies of the full parameter space is the result of practical issues, i.e. numerical considerations and resources. The well known curse of dimensionality [7] is an issue affecting analysis where the number of samples in a given dimension n ($\sim$ 1000 or larger) raised to the power of the number of dimensions m ($>$ 100). Hence the total number of samples required for a complete study is $n^m > 10^{300}$ which clearly places a practical limit on phenomenological analysis.

We can consider the implications of indirect constraints on NP attainable through the study of low energy effects, where for example historically the large value of Δm_d measured by the ARGUS experiment contradicted popular belief that the top quark was light (a few tens of GeV), and the result of that story was the discovery of a heavy top quark with mass $\sim$ 170 GeV, just where indirect constraints had predicted it would be. Today there are no large deviations from loop dominated flavour changing processes that point to a TeV scale NP and this needs to be understood. Either there is NP at a TeV, in which case we need to discover this at the LHC and subsequently understand why flavour has not revealed its presence indirectly as was often the case in the past, or there is no NP at that scale and we need to revert to indirect searches using lower energy probes at various experiments.

An example of this is illustrated in the following: Complex couplings present in MSSM in the mass-insertion hypothesis can be constrained using a number of rare decays, for example inclusive measurements of $b \to s\gamma$ and $b \to s\ell\ell$. While existing measurements do not place significant constraints on couplings, with data from Super*B* one will be able to measure the magnitude and phase of some of these couplings, and simultaneously place an upper bound on the mass of new particles. Hence if the LHC discovers a $\tilde{g}$ in the near future, the inclusive B decays mentioned here can be used to determine a coupling constant of the model. If however there is no imminent discovery from CERN, then results from Super*B* could also be used to infer an upper limit on the mass scale to complement direct bounds from the LHC. In turn this information can be used to determine how much data one would require from the SLHC in order to make a direct discovery of a $\tilde{g}$ in this model. This is a single example of the so-called interplay problem linking results from particle physics and cosmological studies in the context of elucidating the structure of some higher theory. Further discussion on this issue can be found in [3,4] and references therein.

3 Forbidden processes

While it is well known that quarks and neutrinos mix, and that this phenomenon of weak interactions has profound impact on the manifest nature of the universe, as yet there is no direct evidence to support the hypothesis that charged leptons may change type. However the fact that neutrinos mix means that lepton number conservation is violated in nature. A natural consequence of this is to expect that one may ultimately learn that lepton number is also violated in charged decays, this is usually referred to as lepton flavour violation (LFV). Given three generations of charged lepton, there are three couplings associated with charged LFV relating to (i) $\mu \to e$ (ii) $\tau \to \mu$, and (iii) $\tau \to e$ transition probabilities. This area of physics is highly model dependent, and so it is imperative that one searches for processes related to all three of these couplings in order to determine both the magnitude and hierarchy of any possible effects. The MEG experiment at PSI is searching for transitions of the first type via $\mu \to e\gamma$ [8] and is expected to reach an ultimate sensitivity of $\sim 10^{-13}$. The COMET and Mu2E experiments aim to study $\mu \to e$ transitions via conversion in material. Super$B$ will be able to search for a wide range of complementary LFV signatures to constrain couplings related to $\tau \to \mu$ and $\tau \to e$ transitions. A unique feature of Super$B$ is a polarised electron beam, which in turn allows one to reconstruct the polarisation of the decaying taus. Using this information one can suppress SM background in searches for $\tau \to \mu\gamma$ decays, as well as probe the chiral structure of any NP encountered.

In many models one transition will dominate over the others, highlighting the relevance of searching for both μ and τ charged LFV processes. Understanding of the full set of transitions is ultimately required in order to establish a theory of charged LFV. The manifest phenomena can also be correlated with the neutrino sector, and with quark flavour changing processes e.g. see Ref. [3], and references therein. In specific models the level of LFV manifest in the τ sector can be related to CP violation and mixing in the B_s sector, highlighting the importance of a global (quark and lepton) flavour analysis.

4 Rare decays

There are a number of interesting rare decays of B and D mesons that may be affected by NP and can be studied at Super$B$. Rare charm decays often (but not always) have theoretical uncertainties arising from long distance contributions that may make interpretation of the data challenging. Nonetheless they can be used to probe dynamics of various NP scenarios. The golden rare decay channels for Super$B$ include inclusive $b \to s\gamma$ and $b \to s\ell\ell$ decays as discussed in Section 2, which can only be measured in a clean e^+e^- environment. In addition to these one can constrain the charged Higgs mass using a combination of $B \to \tau\nu$ and $B \to \mu\nu$. This will complement the direct searches and increase the energy range probed to the multi-TeV level ahead of the SLHC. One can study the Z-penguin operator sector of the SM using $B \to K\nu\bar{\nu}$ decays, and in doing so, cleanly search for NP that may manifest itself here (for example Z' and new heavy scalar particles).

The LHCb experiment will be able to study $B \to K^{(*)}\mu^+\mu^-$, and is expected to accumulate of the order of 8,000 events in $5fb^{-1}$ of data. Super$B$ is expected to accumulate between 10,000 and 15,000 events in both the di-muon and di-electron final states (as well as making measurements of the corresponding inclusive modes). The combination of all four of these measurements is required in order to disentangle the full set of possible NP models that can affect these processes. Furthermore, by measuring all final states, one has the opportunity to understand if NP is present, or if one is witnessing a statistical fluctuation.

One can also study B_s rare decays using data from $\Upsilon(5S)$ running, such as $B_s \to \gamma\gamma$, which can be enhanced by SUSY and 2HDM. The correlation between observed enhancements in B_s rare decays, with the corresponding B_d processes such as $b \to (s,d)\gamma$ can be used to distinguish between models. Detailed discussions of the rare decay programme at Super$B$ can be found in Refs [3,4].

5 CP violation and mixing

Super$B$ will be able to study CP violation in B, D and τ decays. Expectations for the precision attainable for both time-dependent and time-integrated measurements in B^0 and $B^\pm$ decays at Super$B$ are well understood, based on a decade of groundwork laid by the BABAR and Belle experiments, and can be found in Ref. [3]. One may think that the previous decade of measurements would have negated the interest in this area, however it has recently been pointed out that the golden mode ($J/\psi K^0_S$) measurement of $\sin 2\beta$ is $\sim 3\sigma$ from the SM value [9]. Not only that, but one can search for NP via $b \to c$ tree, as well as $b \to d$ and $b \to s$ loop transitions.

Knowledge of charm meson mixing is relatively recent, and as a result the next generation of experiments is expected to make significant progress not only in studying mixing, but also searching for possible CP violation effects. The channel that dominates our knowledge of mixing is $D \to K_S h^+h^-$, which requires input from measurements at charm threshold, $\psi(3770)$. This vital input is a map of the strong phase difference as a function of position in the $K_S h^+h^-$ Dalitz plot. This strong phase map is also an input into the programme to measure the unitarity triangle angle γ. Recently it was remarked that one can perform time-dependent CP asymmetry measurements in charm decays in analogy with the approach taken by the B factories, and that such time-dependent measurements may provide a new way to directly measure the mixing phase [10]. Following this presentation LHCb showed results on a non-zero asymmetry difference between $D \to \pi^+\pi^-$ and $D \to K^+K^-$ decays [11]. That measurement does not use all of the available information and it is hoped that LHCb will adopt the methodology proposed for Super*B* in the future in order to disentangle direct and indirect CP asymmetries. Understanding if one has observed NP or not will require inputs from a number of different channels, including all neutral final states, motivating the need for results from Super*B*.

Searches for signs of CP violation in tau lepton decays have been largely neglected thus far. A recent measurement from *BABAR* shows a 3σ deviation from SM expectations in $\tau \to K_S\pi^0\nu$ decays [12], where as the corresponding Belle result (using a different approach) is compatible with expectations [13]. Super*B* will be able to perform precision tests of CP violation in the τ sector to compliment work done with *B* and *D* mesons.

6 Precision electroweak constraints

One of the inputs to precision electroweak fits used to predict the SM Higgs mass is the measurement of $\sin^2\theta_W$ from LEP/SLC. The $e^+e^- \to b\overline{b}$ contribution to this result is affected by hadronization uncertainties that limit the power of the experimental measurement at the Z pole. It is possible to measure $\sin^2\theta_W$ using the full set of e^+e^- to di-fermion transitions at the $\Upsilon(4S)$ energy where one expects to achieve the same precision on $\sin^2\theta_W$ as obtained for $e^+e^- \to b\overline{b}$ with the LEP/SLC combination. Once the Higgs mass has been measured, $\sin^2\theta_W$ becomes a sensitive probe for NP [14].

7 Summary

The broad physics programme of Super*B* will be able to provide a number of constraints on NP to complement the direct searches and other measurements being performed at the LHC. If the LHC doesn't find direct evidence of NP before Super*B* has accumulated a significant fraction of its data set, then it should be possible to infer upper bounds on the NP energy scale. With regard to flavour measurements, Super*B* and LHCb complement each other as one experiment excels at measurements of inclusive final states, states with many neutral particles (π^0, γ, ν), and states with electrons in that would otherwise be difficult to trigger on in a hadronic environment. Whereas the other provides precision constraints on final states with sufficient charged tracks to efficiently trigger on the event. Combining results of results from Super*B* with other flavour experiments will enable theorists to understand the structure of the NP Lagrangian.

References

1. M. E. Biagini et al., arXiv:1009.6178.
2. E. Grauges et al., arXiv:1007.4241.
3. B. O'Leary et al., arXiv:1008.1541.
4. B. Meadows et al., arXiv:1109.5028.
5. L. Hall, A. Kostelecky and S. Raby, Nucl. Phys. **B267** 415 (1986).
6. M. Ciuchini, E. Franco, A. Masiero and L. Silvestrini, Phys. Rev. D **67** (2003) 075016 [Erratum-ibid. D **68** (2003) 079901].
7. R. Bellman, Adaptive Control Processes: A guided tour, (OUP, 1961).
8. J. Adam *et al.* [MEG Collaboration], Phys. Rev. Lett. **107** (2011) 171801.
9. E. Lunghi and A. Soni, JHEP **0709** (2007) 053.
10. A. J. Bevan, G. Inguglia and B. Meadows, Phys. Rev. D **84** (2011) 114009.
11. R. Aaij *et al.* [LHCb Collaboration], arXiv:1112.0938 [hep-ex].
12. J. P. Lees *et al.* [BABAR Collaboration], arXiv:1109.1527 [hep-ex].
13. M. Bischofberger *et al.* [The Belle Collaboration], Phys. Rev. Lett. **107** (2011) 131801.
14. Mike Roney, Private communication.