Version 0.0.1
January 14, 2008

Report from Working Group on B Physics

Marco Ciuchini*,[1] Tim Gershon†,[2] Achille Stocchi‡,[3,4] and **and others**

[1] *INFN, sezione di Roma Tre, I-00146 Rome, Italy*
[2] *Department of Physics, University of Warwick, UK*
[3] *Laboratoire de l'Accelerateur Lineaire IN2P3-CNRS, France*
[4] *University de Paris-Sud, BP34, F-91898 Orsay cedex, France*

Abstract

In this note we summarise the activity of the working group on B physics at the scientific retreat, "SuperB Workshop VI: New Physics at the Super Flavour Factory Super$B$." This consists of two main parts. The first is a description of work done since the writing of the CDR, including work done during the retreat itself, and plans for further work to sharpen the physics case of Super$B$. The second part is an attempt to answer prototype questions, similar to those expected from the International Review Committee.

* ciuchini@roma3.infn.it
† T.J.Gershon@warwick.ac.uk
‡ stocchi@lal.in2p3.fr

DRAFT version 0.0.1 January 14, 2008

I. INTRODUCTION

In this note we summarise the activity of the working group on B physics at the scientific retreat, "SuperB Workshop VI: New Physics at the Super Flavour Factory Super$B$," held January 7-15$^{\text{th}}$, 2008 at IFIC in Valencia. This consists of two main parts. The first is a description of work done since the writing of the CDR [1], including work done during the retreat itself, and plans for further work to sharpen the physics case of Super$B$. The second part is an attempt to answer prototype questions, similar to those expected from the International Review Committee. We concentrate on B physics at the $\Upsilon(4S)$, since we do not think that there is too much to add to the previous studies of the potential for B_s physics at the $\Upsilon(5S)$ [2].

II. WORK DONE

- Progress since the CDR - work on several important channels —Vub— - new scheme from PG and collaborators (ask him to make a short summary) will also ask others (MN) for opinions on whether 2% is possible maybe even below 2% is possible? K(*)tautau (not in CDR) - could be interesting for current B factories! $\mathcal{B}(b \to s\gamma)$ - maybe possible to get down to 3%? TH & IB

- Models - CDR discussed mainly MSSM and LHT models - Some work on ED and nMSSM discussed in this meeting

- Detector simulation - hermiticity (effects on signal efficiencies and backgrounds) - KL detection particularly important for several analyses

- Some possibilities to improve analyses

III. ANSWERS TO PROTOTYPE IRC QUESTIONS

Since we do not yet have an official list of questions from the International Review Committee, we discuss below some topics that are relevant to issues that we consider likely to be mentioned in questions. Note that these points are not independent, and that matters discussed in one subsection are often relevant also to others.

A. Comparison between Super$B$ and the KEKB upgrade

First of all, we must emphasise that the KEKB upgrade plan (to a peak instantaneous luminosity of 2×10^{35}) cannot be called a Super Flavour Factory. That title must be reserved for a machine that can accumulate the data samples necessary for a precision study of flavour in the LHC era. We expect that our colleagues who are the proponents of the KEKB upgrade, who have for many years been promoting an upgrade to a higher luminosity, will agree on this.

Secondly, we recall that a comparison must take into account not only the available statistics (luminosity), but that the low backgrounds and improved hermiticity (largely due to the smaller beam energy asymmetry) of Super$B$ provide a significant enhancement for many analyses (especially recoil analyses) that are crucial to the physics case of Super$B$.

DRAFT version 0.0.1 January 14, 2008

include Marco's plot from IRC meeting here

Due to the high power consumption, there is a question over how many months per year KEKB can afford to run. However, we understand that the estimated total integrated luminosity should be taken to be 10 ab^{-1}. We do not currently have an estimate of sensitivity with that data sample from the KEKB upgrade proponents, and therefore we must rely on our own estimates. We also note that 2×10^{35} is a kind of maximum for KEKB, whereas 10^{36} is a kind of baseline for Super$B$.

We can do a quantitative analysis to compare the two proposals, and this will be prepared. Indeed, for some specific examples, this has already been done. The figure below shows a comparison of the exclusion plot in the $m(H^+)$–$\tan\beta$ plane coming from a measurement of $\mathcal{B}(B \to \tau\nu)$ with the different data samples (assuming that the result is consistent with the SM). Note that this plot was specifically requested by the IRC during the meeting in November. Another plot that will be prepared is the MSSM exclusion plot for various different luminosities (but with naive scaling of sensitivities). A comparison of the sensitivities to NP at the ("worst case") mSUGRA snowmass point (see below) may also be interesting. However, we believe that a qualitative comparison of the physics reach may be more useful.

The most obvious channel to demonstrate a dramatic improvement in the physics reach of Super$B$ compared to the KEKB upgrade is for lepton flavour violating τ decays (*eg.* $\tau \to \mu\gamma$), but there are also several in B physics. Examples include

- $B \to K\nu\bar{\nu}$
  discussed in details in the talk of F. Renga
- $B \to$ invisible
  in the SM, $B \to \nu\bar{\nu}\gamma$ has a branching fraction of $\mathcal{O}(10^{-9})$ ($\mathcal{B}(B \to \nu\bar{\nu})$ being negligibly small); NP from *eg.* models with extra-dimensions and light dark matter permit $\mathcal{B}$ up to 10^{-5}; the current limit is $\mathcal{O}(10^{-4})$ – we will ask groups working on models with extra-dimensions to take look at this channel
- $B \to l\nu$
  discussed in the talks of A. Bevan and S. Robertson. Note that $B \to \mu\nu$ is experimentally cleaner and will eventually overtake $B \to \tau\nu$ (which will become systematics limited) in terms of sensitivity to small NP effects. Furthermore, this channel allows a NP-sensitive universality check from the ratio $\mathcal{B}(B \to \tau\nu)/\mathcal{B}(B \to \mu\nu)$.
- $\mathcal{B}(b \to s\gamma)$
  though this is likely systematics and/or theory limited
- $\mathcal{B}(b \to sl^+l^-)$
  possibly theory limited
- zero crossing in the inclusive $b \to sl^+l^-$ forward-backward asymmetry
- we are also alert to other possibilities, including other rare channels which are not necessarily discussed in the CDR. We do not want to make an excessively long list, but there are plenty of things to think about, *eg.* $B \to \gamma\gamma$, $B \to$ 4leptons, ... Even $B_d \to \mu\mu$ could possibly be observed with data samples in excess of 100 ab^{-1}.

DRAFT version 0.0.1 January 14, 2008

B. Discovery potential of Super$B$

As was discussed in the CDR [1], we consider the discovery potential of Super$B$ in two scenarios, that differ in terms of the results from the LHC.

- LHC discovers new particles
  In this case the unique and essential role of Super$B$ is to measure the flavour structure of the NP. In that sense, measurements from Super$B$ that are consistent with the SM would be equally valuable to those that show significant deviations – in either case this would provide information about the NP flavour structure that cannot be provided by other experiments. Of course, it is human nature to find the possibility of seeing NP effects – *ie.* deviations from the SM predictions – more attractive. As seen in the discussion on benchmark points below, this is likely to be the case even in the "worst case scenario". However, we emphasise that measurement of the NP flavour couplings must be considered the primary discovery goal of Super$B$, and that only in the case that results from both LHC and Super$B$ are available can the NP Lagrangian be reconstructed.

- There is no NP discovery at LHC
  If this occurs, the goal of Super$B$ would be to discover deviations in flavour observables. Such an effect would, in this scenario, be the first NP discovery! The absense of knowledge about the NP scale from LHC would make it impossible to reconstruct the NP Lagrangian, but a NP discovery at Super$B$ would provide a solid indication that the NP scale not too far above the LHC reach.

C. Golden processes

A golden channel is any channel that is very well known in the SM. This includes "null tests" (observables that are zero (at least approximately) in the SM) but also other channels with clean predictions. This puts emphasis on inclusive modes much more than exclusive decays. While there are probably specific channels that can be selected in charm and in τ physics, in B physics there are so many golden channels that selecting one or two risks missing the point. The rationale for building Super$B$ based on the NP-sensitivity of any individual channel can certainly be challenged – it is due to the enormous range of golden channels that Super$B$ has unsurpassed sensitivity. Nonetheless, since we are obliged, we can select some channels for which Super$B$ has unique potential.

[We have not yet completely decided which channels though. Some suggestions include $B \to \mu\nu$, fully inclusive $b \to sll$. Suggestions that have been ruled out: any hadronic decay, including $B \to \phi K^0$.]

D. Benchmarks

Work has begun to assess the NP sensitivity of Super$B$ in several benchmark scenarios. This was presented by F. Ronga, making use of tools developed with collaborators including G. Isidori and P. Paride [3]. A study has been done using the Snowmass point SPS1a, which uses the mSUGRA model with parameters [4]

$$\text{SPS1}a: \quad m_0 = 100\text{GeV}, \quad m_{1/2} = 250\text{GeV}, \quad A_0 = -100\text{GeV}, \quad \tan\beta = 10, \quad \mu > 0.$$

DRAFT version 0.0.1 January 14, 2008

$\mathcal{R}(b \to s\gamma)$	=	1.063±0.022
$\mathcal{R}(\Delta m_s)$	=	1.0582±0.0007
$\mathcal{R}(B \to \tau\nu)$	=	0.970±0.007
$\mathcal{R}(B \to X_s l^+ l^-)$	=	0.910±0.003
$\mathcal{R}(\Delta m_s/\Delta m_d)$	=	0.99988±0.00005
$\mathcal{B}(B_s \to \mu^+\mu^-)/10^{-9}$	=	2.736±0.066
$\mathcal{B}(B_d \to \mu^+\mu^-)/10^{-10}$	=	1.580±0.038

TABLE I: Expected values of flavour observables based on expected measurements from LHC in the SPS1a benchmark scenario. Quantities denoted $\mathcal{R}$ are the ratios to the SM values (uncertainties on the SM expectations are not included).

Note that this point is extremely good for LHC - the pattern of sparticle masses allows them all to be measured with reasonably good accuracy. By contrast, the high squark masses and the low value of $\tan\beta$ suppress effects on flavour observables (recall that mSUGRA is a realisation of minimal flavour violation).

The predictions for several flavour observables are shown in Table I. A clear pattern of deviations from SM is predicted, but all are too small to be observed (again, remember that this is really the "worst case scenario"). However, even here Super$B$ could see 1-2 σ deviations in $\mathcal{R}(B \to \tau\nu)$, $\mathcal{R}(b \to s\gamma)$ and $\mathcal{R}(B \to X_s l^+ l^-)$, though this does depend to some extent of improvements in theory. Furthermore, we stress once again that LHC measurements alone could not establish that the model behind their measurements is mSUGRA, and that in order to do so, Super$B$ would be needed to confirm that the NP flavour coupling are small as predicted.

We are planning to develop this work in two ways. First, we would like to add more observables to those in Table I. For example, the list should include $b \to s\nu\bar{\nu}$, the zero crossing point of $b \to sll$ (in a MFV model there is no point to add CP violating observables, which will all be consistent with the SM. We would also like to extend the study to other benchmark points with larger efects in the flavour sector. This can include other Snowmass points, for example SPS4 and SPS5, which correspond to mSUGRA with large $\tan\beta$ and mSUGRA with a relatively light stop respectively:

$$\text{SPS4}: \quad m_0 = 400\text{GeV}, \quad m_{1/2} = 300\text{GeV}, \quad A_0 = 0, \quad \tan\beta = 50, \quad \mu > 0,$$

$$\text{SPS5}: \quad m_0 = 150\text{GeV}, \quad m_{1/2} = 300\text{GeV}, \quad A_0 = -1000, \quad \tan\beta = 5, \quad \mu > 0.$$

These points are expected to result in observable effects at Super$B$, despite being MFV. However, we must also include some non-MFV points, *ie.* add some flavour structure. This should, however, be done in a way that restricts the NP to a reasonable number of parameters. Examples of how this can be achieved were shown in a talk by T. Shindou [5]. This work highlights the importance of correlations between flavour observables to distinguish NP models. Another interesting aspect is the use of models which link to the lepton sector (we also plan to discuss with the authors of [6]).

- also work that links to tau LFV from Herrero and collaborators (should discuss with them and ask them to contribute)

DRAFT version 0.0.1 January 14, 2008

1. On minimal flavour violation

To be changed

[1] M. Bona *et al.*, arXiv:0709.0451 [hep-ex].
[2] E. Baracchini *et al.*, JHEP **0708** (2007) 005 [arXiv:hep-ph/0703258].
[3] O. Buchmueller *et al.*, Phys. Lett. B **657** (2007) 87 [arXiv:0707.3447 [hep-ph]].
[4] B. C. Allanach *et al.*, arXiv:hep-ph/0202233.
[5] T. Goto, Y. Okada, T. Shindou and M. Tanaka, arXiv:0711.2935 [hep-ph].
[6] S. Antusch, E. Arganda, M. J. Herrero and A. M. Teixeira, JHEP **0611** (2006) 090 [arXiv:hep-ph/0607263].

DRAFT version 0.0.1 January 14, 2008