First Report
of the International Review Committee[1] (IRC)
for the Super*B* Project

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Introduction and Context

The quest for a deeper understanding of the physics of the Universe, and therefore for the physics which underpins the Standard Model (SM), is at the heart of contemporary particle physics. The role of quark and lepton flavour in this new physics will be a cornerstone in our understanding.

The present status of the Super*B* project is delineated in its Conceptual Design Report [1] (CDR) and in subsequent developments. It is driven by the necessity for precision measurements of rare decay phenomena as manifestations of quark and lepton flavour physics. It exploits the sensitivity of these decay rates and decay parameters to the manifestation of any new physics in the form of new contributions to flavour-changing decay amplitudes over a wide range of energy scale.

The Super*B* project addresses this challenge by means of an electron-positron (e^+e^-) collider, with asymmetric beam energies, and with two orders of magnitude more luminosity, 10^{36} cm^{-1} s^{-1}, than hitherto. It is thus a very ambitious project which makes possible a new level, both in sensitivity and in precision, of inclusive e^+e^- annihilation measurements of flavour production. It anticipates by the latter half of the next decade the exhaustion of present, and presently foreseen, e^+e^- experimental facilities (PEP2 now @ luminosity 10^{34} cm^{-1} s^{-1}, and SuperKEKB in ~2016 @ luminosity 2×10^{35} cm^{-1} s^{-1}), together with the completion of the first 10 fb^{-1} data-taking of the LHC*b* experiment at CERN.

The Super*B* specification would, if realised on its presently proposed schedule, provide a step-change of between a factor 5 and 10 increase in luminosity over its immediate e^+e^- predecessor, presently foreseen to be SuperKEK*B*, in the second half of the next decade. The possibility on this timescale of an upgrade, SuperLHC*b*, of LHC*b* at CERN to an experiment with an horizon of 100 fb^{-1}, operating alongside Super*B*, would then complete the scope of this next generation of flavour physics experiments, as it does now in the present generation.

The Super*B* CDR therefore anticipates an aggressive timescale for its realisation. It does so now, having just demonstrated first evidence of the feasibility of an innovative scheme for interaction region luminosity, the "crab waist" technique, in the

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[1] Rolf Heuer (DESY) attended the first two meetings of the committee in 2007.

[2] Tatsuya Nakada joined the IRP at the third meeting in April 2008 bringing represention of restricted ECFA to the IRP's deliberations.

DAΦNE storage ring [2]. This scheme, if feasible at the higher energy, higher current, and much smaller emittance of Super*B*, reduces substantially the required stored beam currents, and thereby the power consumption, of the machine.

This first report by the IRC follows three meetings with the Super*B* collaboration, in July and November 2007, and in April 2008. Its purpose is to mark the achievement of a conceptual design, and to assess the progress this conceptual design makes towards a technical design.

2. Physics

The physics impact of a Super*B* is based on its initial luminosity of 10^{36} cm^{-1} s^{-1} integrating to 75 ab^{-1} over a plausible first experimental cycle of 5 years. This resulting step change in statistical sensitivity, together with an experiment based on substantial experience at the present generation of *B*-factories, enables a broad range of measurements of decay rates and branching ratios to be made with hitherto unprecedented precision. Without Super*B*, many of these measurements would otherwise be impossible.

The scope of measurements which are possible with a "75 ab^{-1} Super*B*" is substantial. It is already well demonstrated in the Conceptual Design Report [1] (CDR) and in subsequent work reported in the proceedings of Workshop VI in Valencia [3]. It continues to develop. It includes *b* and *c*-quark physics, τ-physics and lepton flavour violation (LFV). It also includes a "non-perturbative" dimension in the form of spectroscopic measurements of resonant phenomena which aims to expose new states of light quarks or *c*-quarks. These states may be the manifestation of exotic combinations of quarks and gluons in "molecules", "tetraquarks", and "hybrids", the observation of any of which has a very direct bearing on progress in hadronic physics, and thus on the development of quantum chromodynamics (QCD).

Some examples, which so far stand out, follow.

It will be a major challenge to understand a physics landscape at the Terascale or multi-Terascale set by supersymmetry (SUSY) if SUSY is to be the basis of the new physics. It is clear that "75 ab^{-1}" sensitivity in the *B*-sector will make it possible to make measurements with unprecedented accuracy of the CKM $\bar{\rho}$ and $\bar{\eta}$ parameters (anticipating foreseeable improvements in lattice QCD calculations), and to explore their consequences in SUSY parameter space. The resulting few % (< 10%) precision in for example measurements of "golden" *b*-decay modes will enable unique discrimination over an important range of possibilities. Following a discovery, in a constrained MSSM (CMSSM), it will be possible to complement other measurements by focusing at Super*B* on a determination of the four SUSY parameters in such a scenario. From a more general, phenomenological, perspective, Super*B* measurements will have unique sensitivity to soft, SUSY-breaking, terms, making it possible to discriminate between various low-energy manifestations of supergravity-based theory. Measurements of leptonic decays ($B \to \tau\upsilon$) with such "75 ab^{-1}" sensitivity cover a large region of the m(H^+)-tan β plane. Thus, in these and in many other ways, Super*B* measurements are very likely to have a unique impact on important and fundamental questions in a "SUSY physics era", such as:

- Is the observed SUSY manifestation due to supergravity, to gauge mediation, to anomaly mediation, or to some other mechanism?
- Is one concerned with a minimal SUSY extension of the SM (MSSM) or a non-minimal one?

Following first observation of possible $D\overline{D}$ oscillation, it has recently been realised that at luminosity 10^{36} cm^{-1} s^{-1} precision measurements of charm production are possible which may well be sensitive to new physics, and thereby which may provide a new probe of it. For example, with D*-tagging the level of precision which can be anticipated, with in many cases relatively short data-taking periods, could enable sensitivity to time dependence (oscillation) at the 10^{-3} level.

LFV at Super*B* is focused on measurements in the heaviest lepton flavour generation, namely measurements of τ–decays. It has unchallengeable sensitivity to *CP*-violation, electric dipole moment, and *g*-2 in τ–physics. Its precision also of course contributes substantially to tests of lepton universality. The possibility of 85% electron polarisation is essential in this physics, both for background suppression where it is an experimental issue, and for physics sensitivity, in some cases being crucial to the feasibility of the measurement (which itself is anyway unique to Super*B*). Overall, the combination of proposed luminosity with polarisation in Super*B* will enable LFV physics to impact on for example SUSY physics at a similar level as does *B*-physics.

The above examples of course assume a particular, new, physics context (SUSY), which may, or may not, have been discovered by “energy-frontier” measurements at the LHC. They illustrate how measurements at Super*B* will have major impact on establishing the nature and properties of new Terascale physics whatever it may be, and how these measurements will be essential for a full understanding of it. However, LHC measurements are of course limited by kinematic reach and by the mass scale of new physics. In cases where new physics involves non-minimal flavour violation, resulting in new contributions to FCNC decay amplitudes which decrease only slowly with mass scale, measurement at a “75 ab^{-1}” physics at Super*B* thus amounts to “energy-frontier” discovery with a sensitivity for new physics extending up to a mass scale about 10 TeV.

In short, the step change in luminosity which amounts to a data sample of 75 ab^{-1}, which Super*B* brings, makes possible measurements that are crucial to our comprehension of the physics which is explains the Standard Model. In some cases, for example if dynamic issues are at a multi-TeV energy scale, measurements at Super*B* may provide the only window on this physics.

It is therefore clear to the IRC that the present effort to continue the investigations of the physics potential of a Super*B* should continue. Already a remarkable profile of possibilities is apparent. It is likely that many more will emerge from this continuation which will further underpin what is a fascinating horizon for Terascale, and multi-Terascale, physics at a “75 ab^{-1}” asymmetric e^+e^- collider, as well as for a swathe of results of importance for hadronic physics and chromodynamics which also come with it.

3. Experiment

The Super*B* CDR includes a comprehensive and advanced evaluation of the concept for an experiment. This arises in large part because of the decade of experience of flavour factory physics at *BABAR* and BELLE. Further, it leads to a substantial reduction in construction costs by taking advantage wherever possible of detector components presently operating in the *BABAR* experiment. It is thus very important to recognise the advantages, not least in cost savings and obviously also in experience with detector function, in preserving carefully the detectors from *BABAR* which are appropriate for Super*B* data-taking.

There are issues which arise because of the huge luminosity at Super*B* and the need to improve detector performance in the face of the experimental challenge of precision measurements. R&D is already underway where appropriate, and, given the timescale foreseen by the Super*B* collaboration, it is important to maintain, and where possible to accelerate, this work to a conclusion, so as to enable the appropriate decisions for the experiment to be taken in a timely fashion.

Of particular importance in an experiment such as Super*B* is the machine-detector interface, especially so in view of the innovative approach combining "crab waist" with small bunch dimension which is proposed. Many issues are already being addressed. Many are still emerging as a result of emerging physics opportunities. An example is the need for longitudinal electron polarisation particularly in LFV. There is therefore a commensurate need to address how a measurement of this polarisation can be made with the necessary accuracy, and to evaluate and include in experimental design the implications of the delivery to the experiment of polarisation along with adequate luminosity.

4. Machine

The Super*B* CDR includes the combination of numerous novel concepts, mostly adapted from design studies of linear-colliders and from operational experience with *B*-factories and synchrotron light sources. The luminosity design goal is exciting, ambitious and challenging.

The step change of two orders of magnitude in luminosity required for Super*B* physics is achieved by pushing many machine parameters *simultaneously* beyond (by factors, and sometimes by orders of magnitude) the maximum levels of performance achieved to date. The successful operation of the machine relies thus on what are presently cutting-edge techniques in accelerator physics, almost all of which are applied so as to work beyond their limit determined by either or both of present understanding and present experience. This is a demanding scenario, not least because it leaves no contingency whatsoever when trying to achieve and to maintain machine operation at design specification.

The Super*B* design primarily relies on validation by means of simulation, with the recent, and noteworthy, exception of experimental evidence for luminosity increase using the innovative crab-waist tests at DAΦNE. The simulation work is clearly at a stage where it should be expanded in scope and context so as to include all relevant accelerator physics, e.g. emittance and emittance-tuning including beam-beam effects, Intra Beam Scattering (IBS), and time-dependent phenomena that occur due to heating and to varying beam currents. Further, the procedure of trickle injection from a higher emittance injector should be simulated with realistic injection magnets and protection collimators for the experiment. The importance of such inclusive simulation is critical in view of the dependence of the machine operation simultaneously on a number of cutting-edge applications of machine physics and technology, and the likelihood of many unforeseen correlations between these applications.

It is also important to stress that the construction of the machine attempts to minimise costs by taking as much advantage as possible of components from PEP2. Given the proposed timescale, and given the need for substantial further design simulation and R&D before the final overall design specification is completed, it is important therefore to reassert the necessity to procure and protect all components from PEP2 which could possibly be of use for Super*B* until such time as this is for sure not the case.

The importance of taking forward the design of the Super*B* machine expeditiously requires a growing investment in the accelerator physics and engineering R&D work. This growth in both scope and volume of in-depth evaluation requires the oversight of an expert Machine Advisory Committee (MAC).

5. Conclusion

We recommend strongly that work towards the realisation of a Super*B*, taken to be an asymmetric e^+e^- collider with luminosity at least 10^{36} cm^{-2} s^{-1}, continues.

The Super*B* concept is at an important stage. The significance of the physics programme at such a machine continues to be developed, increasing in both scope and importance. It motivates an even more concerted effort to meet many technical challenges, in particular concerned with the design of storage rings which meet the physics specification.

So far there has been no “showstopper”; rather there has emerged a number of innovative and noteworthy developments at the cutting-edge of contemporary technique in accelerator physics and of detector technology. There still remains the possibility of insurmountable technical challenges, in particular in establishing the physics of machine performance which, in some aspects, address fundamental issues of accelerator physics. Beginning as soon as possible, these challenges must be addressed if progress is to continue with the aim of realising Super*B* on the proposed time schedule. To this end, it is now both timely and highly appropriate that a Machine Advisory Committee be established to oversee progress in the many critical issues faced in the design of the Super*B* asymmetric collider.

It is clear from the above that it is essential at this time to ensure appropriate conservation and preservation of detector and machine components from PEP2 and *BaBar* which could be incorporated into Super*B*.

References

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[3] Draft of Proceedings of Super*B* Workshop VI on New Physics at the Super Flavor Factory, supplied to the IRC, April 29/30 2008.