Letter of Intent
for
KEK Super B Factory

Part I: Physics

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Executive Summary

The grand challenge of elementary particle physics is to identify the fundamental elements of Nature and uncover the ultimate theory of their creation, interactions and annihilation. To this end, all elementary particles and the forces between them should be described in a unified picture. Such unification naturally requires a deep understanding of physical laws at a very high-energy scale; for instance the unification of electroweak and strong forces is expected to occur at around 10^{16} GeV, which is often called the GUT scale.

It is unlikely that the GUT scale will be realized at any accelerator-based experiment even in the distant future. However, there are a few very promising ways to promote our grand challenge. One such approach is to elucidate the nature of quantum loop effects by producing as many particles as possible. This provides the rationale to pursue the luminosity frontier.

There is no doubt that past experiments at the luminosity (or intensity) frontier of the age have yielded epoch-making results. This good tradition has been followed by Belle and BaBar, experiments at energy-asymmetric e^+e^- B factories KEKB and PEPII, which have observed CP violation in the neutral B meson system. The result is in good agreement with the constraints from the Kobayashi-Maskawa (KM) model of CP violation. We are now confident that the KM phase is the dominant source of CP violation. In 2003 the KEKB collider achieved its design luminosity of $1{\times}10^{34}$ cm^{-2}s^{-1}. The Belle experiment will accumulate an integrated luminosity of 500 fb^{-1} within a few years. This will suffice to determine the Unitarity Triangle with a precision of $\mathcal{O}(10)\%$. Various other quantities in B meson decays will also become accessible. In particular, the first observation of direct CP violation in charmless B decays is anticipated.

Over the past thirty years, the success of the Standard Model, which incorporates the KM mechanism, has become increasingly firm. This strongly indicates that the Standard Model is *the* effective low-energy description of Nature. Yet there are several reasons to believe that physics beyond the Standard Model should exist. One of the most outstanding problems is the quadratically divergent radiative correction to the Higgs mass, which requires a fine tuning of the bare Higgs mass unless the cutoff scale is $\mathcal{O}(1)$ TeV. This suggests that the new physics lies at the energy scale of $\mathcal{O}(1)$ TeV. There is a good chance that LHC will discover new elementary particles such as supersymmetric (SUSY) particles. With this vision in mind, we raise an important question "what should be a role of the luminosity frontier in the LHC era ?"

To answer the question, we note that the flavor sector of the Standard Model is quite successful in spite of the problem in the Higgs sector. This is connected to the observation that Flavor-Changing-Neutral-Currents (FCNCs) are highly suppressed. Indeed, if one considers a general new physics model without any mechanism to suppress FCNC processes, present experimental results on B physics imply that the new physics energy scale should be larger than $\mathcal{O}(10^3)$ TeV. This apparent mismatch is called *the new physics flavor problem.* To overcome the problem, any new physics at the TeV scale should have a mechanism to suppress FCNC processes, which often results in a distinctive flavor structure at low energy. Therefore, the indispensable roles of the luminosity frontier are to observe deviations from the Standard Model in flavor physics, and more importantly, to distinguish between different new physics models by a close examination of the flavor structure. Comprehensive studies of B meson decays in the clean e^+e^- environment provide the ideal solution for this purpose, which is not possible at LHC nor even at the future linear collider.

These provide the primary motivation for SuperKEKB, a major upgrade of KEKB. Its design luminosity is 5×10^{35} cm^{-2}s^{-1}, which is 50 times as large as the peak luminosity achieved by KEKB. Various FCNC processes, such as the radiative decay $b \to s\gamma$, the semileptonic decay $b \to sl^+l^-$, and the hadronic decays $b \to s\bar{q}q$ and $b \to d\bar{q}q$, can be studied with unprecedented precision. All of these processes are suppressed in the Standard Model by the GIM mechanism, and therefore the effect of new physics is relatively enhanced. New observables that are currently out of reach will also become accessible. In addition to B meson decays, FCNC processes in τ and charm decays will also be studied at SuperKEKB.

The Belle detector will be upgraded to take full advantage of the high luminosity of SuperKEKB. In spite of harsh beam backgrounds, the detector performance will be at least as good as the present Belle detector and improvements in several aspects are envisaged. Table 1 summarizes the physics reach at SuperKEKB. As a reference, measurements expected at LHCb are also listed. One of the big advantages of SuperKEKB is the capability to reconstruct rare decays that have γ's, π^0's, K_L^0's or neutrinos in the final states. There are several key observables in Table 1 that require this capability. Also important are time-dependent CP asymmetry measurements using only a K_S^0 and a constraint from the interaction point to determine the B decay vertices. Examples include $B^0 \to K^{*0}(\to K_S^0\pi^0)\gamma$, $\pi^0 K_S^0$ and $K_S^0 K_S^0 K_S^0$. These fundamental measurements cannot be carried out at hadron colliders.

Figure 1(a) shows a comparison between time-dependent CP asymmetries in $B^0 \to J/\psi K_S^0$, which is dominated by the $b \to c\bar{c}s$ tree process, and $B^0 \to \phi K_S^0$, which is governed by the $b \to s\bar{s}s$ FCNC (penguin) process. It demonstrates how well a possible new CP-violating phase can be measured. Such a new source of CP violation may revolutionize the understanding of the origin of the matter-dominated Universe, which is one of the major unresolved issues in cosmology. Figure 1(b) shows correlations between time-dependent CP asymmetries in $B^0 \to K^{*0}\gamma$ and $B^0 \to \phi K_S^0$ decays in two representative new physics models with different SUSY breaking scenarios; the SU(5) SUSY GUT with right-handed neutrinos and the minimal supergravity model. The two can be clearly distinguished. This demonstrates that SuperKEKB is sensitive to a quantum phase even at the GUT scale. Note that these two models may have rather similar mass spectra. It will therefore be very difficult to distinguish one from the other at LHC. If SUSY particles are discovered at LHC, the origin of SUSY breaking will become one of the primary themes in elementary particle physics. SuperKEKB will play a leading role in such studies.

We emphasize that the example above is just one of several useful correlations that can be measured only at SuperKEKB. The true value of SuperKEKB is a capability to observe the pattern as a whole, which allows us to differentiate a variety of new physics scenarios. It is so to speak "*DNA identification of new physics*", in that each measurement does not yield a basic physical parameter of the new physics but provides an essential piece of the overall flavor structure. This strategy works better when we accumulate more data. Thus the target annual integrated luminosity of 5 ab^{-1} is not a luxury but necessity, and stable long-term operation of SuperKEKB is necessary to meet the requirements.

Determination of the Unitarity Triangle will also be pushed forward and will be incorporated in the global pattern mentioned above. This can be done at SuperKEKB using redundant measurements of all three angles and all three sides of the Unitarity Triangle. In particular, ϕ_2 measurements and V_{ub} measurements require the reconstruction of π^0 mesons and neutrinos and

Observable	SuperKEKB		LHCb
	(5 ab^{-1})	(50 ab^{-1})	(0.002ab^{-1})
$\Delta\mathcal{S}_{\phi K^0_S}$	0.079	0.031	0.2
$\Delta\mathcal{S}_{K^+K^-K^0_S}$	0.056	0.026	
$\Delta\mathcal{S}_{\eta' K^0_S}$	0.049	0.024	×
$\Delta\mathcal{S}_{K^0_S K^0_S K^0_S}$	0.14	0.04	×
$\Delta\mathcal{S}_{\pi^0 K^0_S}$	0.10	0.03	×
$\sin 2\chi$ ($B_s \to J/\psi\phi$)	×	×	0.058
$\mathcal{S}_{K^{*0}\gamma}$	0.14	0.04	×
$\mathcal{B}(B \to X_s\gamma)$	5%	5%	×
$A_{CP}(B \to X_s\gamma)$	0.011	5×10^{-3}	×
C_9 from $A_{FB}(B \to K^*\ell^+\ell^-)$	32%	10%	
C_{10} from $A_{FB}(B \to K^*\ell^+\ell^-)$	44%	14%	
$\mathcal{B}(B_s \to \mu^+\mu^-)$	×	×	4σ (3 years)
$\mathcal{B}(B^+ \to K^+\nu\nu)$		5.1σ	×
$\mathcal{B}(B^+ \to D\tau\nu)$	8%	2.5%	×
$\mathcal{B}(B^0 \to D\tau\nu)$	3.5σ	9%	×
$\sin 2\phi_1$	0.019	0.014	0.022
ϕ_2 ($\pi\pi$ isospin)	3.9°	1.2°	×
ϕ_2 ($\rho\pi$)	2.9°	0.9°	×
ϕ_3 ($DK^{(*)}$)	4°	1.2°	8°
ϕ_3 ($B_s \to KK$)	×	×	5°
ϕ_3 ($B_s \to D_sK$)	×	×	14°
$\lvert V_{ub}\rvert$ (inclusive)	5.8%	4.4%	×
$\mathcal{B}(\tau \to \mu\gamma)$	$< 1.8 \times 10^{-8}$		

Table 1: Summary of the physics reach at SuperKEKB. Expected errors for the key observables are listed for an integrated luminosity of 5 ab^{-1}, which corresponds to one year of operation, and with 50 ab^{-1}. $\Delta\mathcal{S}_f$ is defined by $\Delta\mathcal{S}_f \equiv (-\xi_f)\mathcal{S}_f - \mathcal{S}_{J/\psi K^0_S}$, where ξ_f is the CP eigenvalue of the final state f. For comparison, expected sensitivities at LHCb with one year of operation are also listed if available. The × marks indicate measurements that are very difficult or impossible.

are thus unique to a Super B-Factory. An inconsistency among these measurements implies new physics. Figure 2 shows the expected constraints at 50 ab^{-1}. An ultimate precision of $\mathcal{O}(1)\%$ will be obtained at SuperKEKB.

We thus conclude that the physics case at SuperKEKB is compelling. It will be the place to elucidate *the new physics flavor problem* in the LHC era. The physics program at SuperKEKB is not only complementary to the next-generation energy frontier programme, but is an essential element of the grand challenge in elementary particle physics.

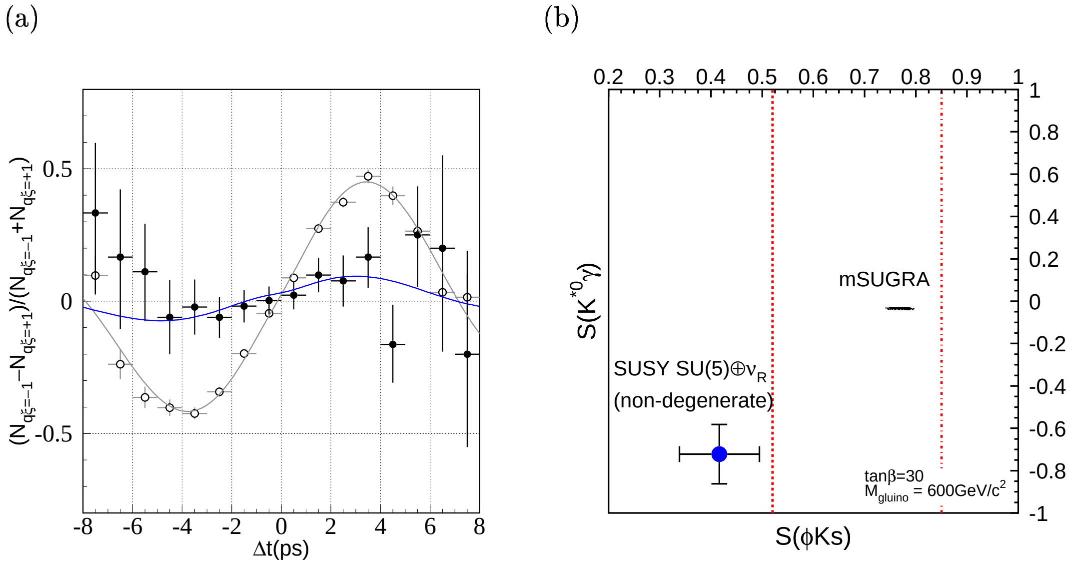

Figure 1: (a) Time-dependent CP asymmetries in $B^0 \to \phi K_S^0$ and $B^0 \to J/\psi K_S^0$ decays expected with one year of operation at SuperKEKB (5 ab^{-1}). The world average values (as of August 2003) for the modes governed by the $b \to s$ transition are used as the input values of $\mathcal{S}_{\phi K_S^0} = +0.24$ and $\mathcal{A}_{\phi K_S^0} = +0.07$. (b) A correlation between time-dependent CP asymmetries in $B^0 \to K^{*0}\gamma$ and $B^0 \to \phi K_S^0$. The dots show the range in the minimal supergravity model (mSUGRA). The circle corresponds to a possible point of supersymmetric SU(5) GUT model with right-handed neutrinos. Error bars associated with the circle indicate expected errors with one year of operation at SuperKEKB. The present experimental bound of $\mathcal{S}_{\phi K_S^0} < +0.52$ ($\mathcal{S}_{\phi K_S^0} < +0.85$) at the 2σ (3σ) level is also shown by the dashed (dot-dashed) vertical line.

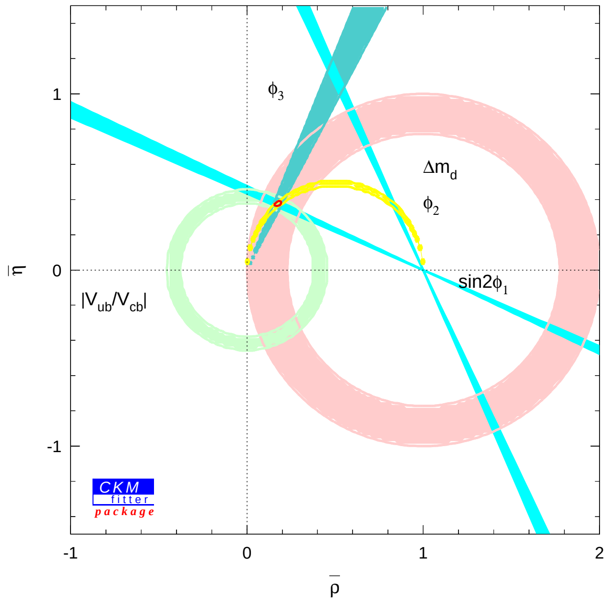

Figure 2: Constraints on the CKM unitarity triangle at 50 ab^{-1}.