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 creations, interactions and annihilations. To this end, all the elementary particles and the forces among them should be described in a unified picture. Such unification naturally requires 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^{15} GeV, which is often called the GUT scale.

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

It is no doubt that past experiments at a luminosify (or intensity) frontier of the age had yielded epoch-making results. The 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 has achieved its design luminosity of 1×10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. It is foreseen that 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, 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 machanism, has become increasingly firmer. This strongly indicates that the Standard Model is *the* effctive 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 large radiative correction on the Higgs mass, which suggests that the new physics lies in the energy scale of $\mathcal{O}(1)$ TeV. There will be a good chance that LHC will discover new elementary particles such as SUSY particles. With this vision in mind, an important question is "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 fact that observed Flavor-Changing-Neutral-Currents (FCNCs) are highly suppressed. Indeed, if one considers a general new physics model without any mechanism to suppress FCNCs, 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 the FCNC processes, which often results in a distinctive flavor structure at low energy. Therefore important roles of the luminosity frontier are

- to observe deviations from the Standard Model in the flavor physics, and
- to distinguish between different new physics models.

These provide the primary motivation of 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 $b \to s\gamma$, semileptonic decay $b \to sl^+l^-$, and hadronic decays $b \to sq\bar{q}$ and $b \to dq\bar{q}$, can be studied with unprecedented precisions. 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 will be envisaged. Table 1 summarizes physics reach at SuperKEKB. As a reference, measurements expected at LHCb are also listed. One of the big advantages of SuperKEKB is a capability of reconstructing rare decays that have γ, π^0 or neutrinos in the final states. There are several key observables that require such particles as listed in Table 1. 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 $B^0 \to K^{*0}\gamma$, $\pi^0 K_S^0$ and $K_S^0 K_S^0 K_S^0$. These important measurements can not 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 have a large impact on Baryogenesis. Figure 1(b) shows correlations between time-dependent CP asymmetries in $B^0 \to K^{*0}\gamma$ and $B^0 \to \phi K_S^0$. Two SUSY breacking scenarios are considered for the study. It is seen that they can be clearly distinguished. Note that these two models have rather similar mass spectra. Therefore it will be very difficult to distinguish one from the other at LHC.

Determination of the Unitarity Triangle will also be pushed forward. At SuperKEKB, it can be done using measurements of all three angles and 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 are thus unique at SuperKEKB. Some inconsistency among these measurements implies the signature of new physics. Figure 2 shows expected constraints at 50 ab^{-1}. The ultimate precsion of $\mathcal{O}(1)\%$ will be obtained at SuperKEKB.

With all these considerations, we conclude that the physics case at SuperKEKB is quite compelling. It will serve as the central place to elucidate the new physics flavor problem in the LHC era.

Observable	SuperKEKB		LHCb
	($5\ \mathrm{ab}^{-1}$)	($50\ \mathrm{ab}^{-1}$)	($0.002\mathrm{ab}^{-1}$)
$\Delta\mathcal{S}_{\phi K^0_S}$	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%	×
$\mathcal{B}(B_s \to \mu^+\mu^-)$	×	×	○
$\mathcal{B}(B^+ \to K^+\nu\nu)$		5.1σ	×
$\mathcal{B}(B^+ \to D\tau\nu)$	12.7σ	40.3σ	×
$\mathcal{B}(B^0 \to D\tau\nu)$	3.5σ	11.0σ	×
$\sin 2\phi_1$	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 ($DK^{(*)}$)	5°		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%	×
$\mathcal{B}(\tau \to \mu\gamma)$	$< 1.8 \times 10^{-8}$		
$\mathcal{B}(\tau \to \mu/e\eta)$	$< 1 \times 10^{-8}$		
$\mathcal{B}(\tau \to \ell\ell\ell)$	$< 1 \times 10^{-8}$		

Table 1: Summary of physics reach at SuperKEKB.

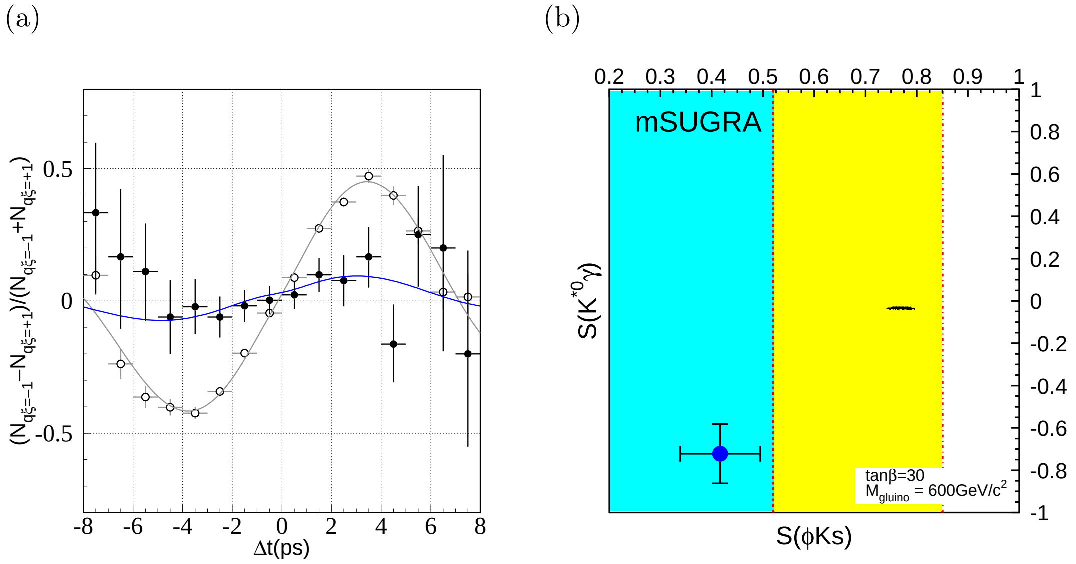

Figure 1: (a) Time-dependent CP asymmetries in $B^0 \to \phi K_S^0$ and $B^0 \to J/\psi K_S^0$ decays expected with one year operation of SuperKEKB (5 ab^{-1}). (b) A correlation between time-dependent CP asymmetries in $B^0 \to K^{*0}\gamma$ and $B^0 \to \phi K_S^0$. Scatter plots show a range of minimal supergravity model (mSUGRA). The circle corresponds to a SUSY SU(5) model with right-handed neutrinos. Error bars associated with the circle indicate expected errors with one year operation of SuperKEKB. A present experimental bound at 2σ (3σ) level is also shown by the dashed (dot-dashed) vertical line.

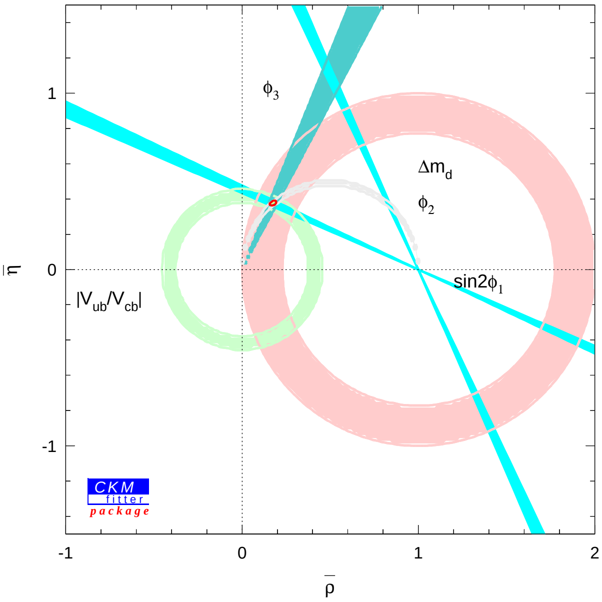

Figure 2: Constraints on the CKM unitarity triangle at 50 ab^{-1}.