Future B-Factories

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This paper presents the scientific motivations for future Super Flavor Factories. An update on the status of the projects of High Luminosity B-factories *SuperB* and *SuperKEKB* is presented, together with the approval process.

1 Introduction

The experiments *BABAR* and *Belle* at the e^+e^- asymmetric colliding beam machines *PEPII* and *KEKB*, have run for about a decade with a remarkable success, contributing to the elucidation of the Cabibbo-Kobayashi-Maskawa (CKM) paradigma [1] of flavor physics in the framework of the Standard Model of fundamental interactions (SM) that has been one of the most tested theories of all time. Nonetheless the SM can not explain many physical observations and crucial questions are still left unanswered as how can we explain the still unobserved original antimatter in the Universe or the nature of dark matter, whose existence can be inferred from the cosmological observations. The beautiful results on neutrinos from SuperKamiokande [2] Are now suggesting that NP is at hand and Lepton Flavor Violation(LFV) would be one of the most clear signals of it. There are two complimentary ways to search for new physics effect in elementary interaction. A *direct* way is pursued presently at LHC, where the energy available for the interaction is the largest available at present, and new particles not predicted by the SM are searched for. The other way to search for NP is by looking at the *indirect* effects of NP in interference processes (as CP-Violation in quark sectors) and rare or forbidden decays (like lepton flavor violation processes in μ and τ decays).

It is a general opinion that a new experimental exploration beyond SM is needed to discover New Physics (NP). Higher luminosity B factories can help today to improve precision in the CKM measurements looking for little small discrepancies from SM predictions. A crucial question today is: how precision measurements at low energy in flavor sector can help in discovering New Physics (NP) Beyond the Standard Model (BSM) in the era of LHC [3]. The answer to this very legitimate question can be given by focusing the attention on a few specific points showing the clear complementarity between high luminosity flavor factory potential and the energy frontier colliding beam machines.

1. Flavor precision measurements are sensitive to NP through:
    - measurement of symmetries due to interference effects in known processes
    - measurement of decay rates for very rare or SM forbidden modes.
2. NP effects are governed by :

- NP scale Λ
- effective coupling reflecting on different intensity (coupling effect) or different patterns (from symmetries).

3. The aim of Future Factories is to collect between 5 and 10 $\times 10^{10}$ b $\bar{b}$, c $\bar{c}$, $\tau^+\tau^-$ pair thanks to an integrated luminosity between 50 and 100 ab^{-1}. Clear signals of NP from:
   - Lepton Flavor Violation in τ decay
   - Discovery of CP violation in charm decay.

If the NP scale Λ is found at LHC, the future flavor factories will study the flavor structure of NP, contributing to the determination of couplings Flavor Violating (FV) and CP violating of NP. If instead the NP scale Λ is not found at LHC, indirect signals of NP could be looked for at Super Flavor Factories and linked to NP models. Regions in parameter space can be constrained with NP(Λ) sensitivity higher than TeV up to order of tens or even hundreds of TeV. In what follows a very quick summary of the flavor physics results and the perspective for dedicated experiments with single beam for experiments at colliding beam super flavor factories are presented. The Super Flavor machine, the Detector and the experimental tools are strongly correlated to make possible hitting the target of NP.

2 Present Status

The physics of quark b has been the most studied topics in the past few years with two B-factories operating in USA and in Japan, it was in actual fact the main motivation for the construction of $PEPII$ and $KEKB$. The contribution to b physics has come from $BABAR$ and $Belle$ that have recorded more than almost 1.5 ab^{-1} at the $\Upsilon(4S)$ resonance, and from CDF and D0 experiments with the study of B_S system at Tevatron. B-factories made measurement of almost all elements involving third generation quarks of the CKM matrix, strictly constraining the space parameters for NP insertions in the weak sector. Many different measurements were made, even beyond the original goals, spanning from precision measurements of CKM elements, spectroscopy of unexpected states, and measurements of rare decays which constrained MSSM models such as $B \to \tau\nu$ decays.

With further increase of statistics, the sensitivity to new physics will become higher, and the new measurement of CKM unitarity triangle could in principle lead to inconsistencies with SM, which can not be observed with the present result. In Fig. 2 we show the achievable sensitivity to the unitarity triangle using the statistics expected at Super-Flavor factories.

3 B-τ-Charm Perspectives

The search for new physics through the use of very high luminosity machines, leading to high sensitivities for rare processes is complimentary with the choice of pursuing new physics by opening new energy thresholds, as done at LHC. Understanding the NP flavor structure during LHC operations by means of Super Flavor Factories is described in various papers (see for example *SuperB* CDR [4] and *Belle* Physics document [5] and [6]) . In what follows the sensitivities for Super-Flavor factories will be shown considering samples consisting of integrated luminosities $\geq 75\text{ab}^{-1}$, corresponding to 5 years run of an e^+e^- asymmetric machine running

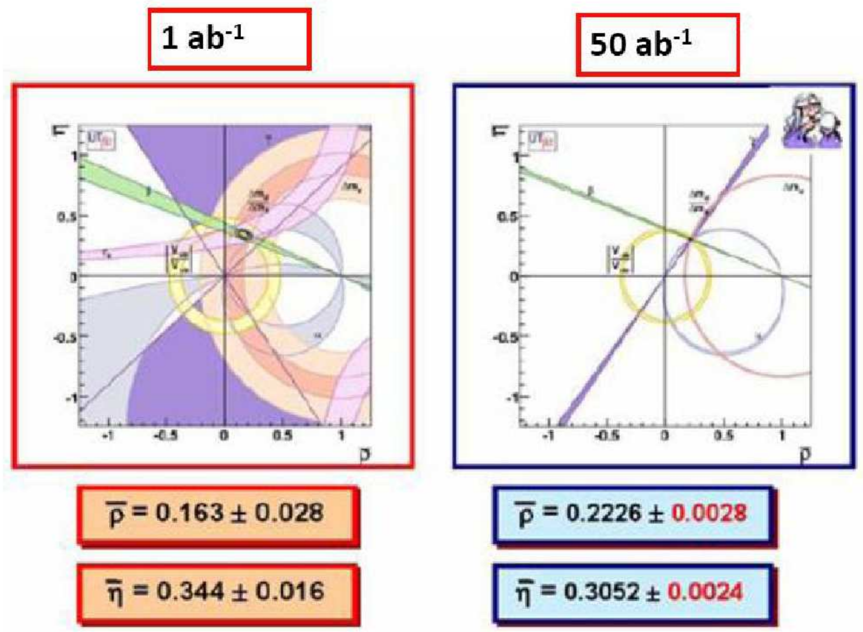

Figure 1: Present results on unitarity triangle measurement (on the left) and predicted results achievable with 50 ab^{-1} statistics (on the right)as from a general fit by UTfit group [1]

with a peak luminosity of $10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Only a small selection of observables for the above integrated luminosity are shown here, a more detailed description is in [11].

3.1 B physics

Super-Flavor facilities will produce the largest samples of B mesons available, improving the sensitivities for many of the rare processes already studied at B-factories, and would provide novel measurement for channels presently beyond experimental reach. Many searches for small deviations, a brief references about the reaches for a foreseeable *SuperB* factory are reported in table 1.

For the channel $b \to s\ell^+\ell^-$ Super-B can use inclusive modes, therefore it can provide a precise and theoretically clean measurement, not affected by systematics coming from the hadronic correction affecting the study of exclusive channels as $B \to K^*\ell^+\ell^-$.

Such channels are also accessible with high statistics at LHC. Nonetheless several interesting rare decay modes, such as $B \to K\nu\bar{\nu}$, can only be observed with high integrated luminosity $\geq 75\ ab^{-1}$, and need a clean environment not compatible with LHC backgrounds. Other channels can also be accessible as $B \to \gamma\gamma$ and $B \to \nu\bar{\nu}$ decays which are sensitive to New Physics models with extra-dimensions. The sensitivity in the high luminosity Super Flavor Factory *SuperB* can be seen in fig. 2, where by reducing the statistical error, which is the main contributor to the experimental error, the Standard Model can be severely challenged.

In addition to CKM measurements $Super-B$-factories would be able to measure CP viola-

Table 1: Super-B **Some channels sensitive to new physics.**

Parameter	Baseline	Upgrade
B($B \to X_s\gamma$)	7%	3%
$A_{CP}(B \to X_s\gamma$)	0.037	0.004-0.005
$B(B^+ \to \tau^+\nu)$	30%	$3-4\%$
$B(B^+ \to \mu^+\nu)$	No	5-6 %
B($B \to X_s l^+ l^-$)	23%	4-6%
A_{FB} $(B \to X_s l^+ l^-)_{s_0 xing}$	No	4-6%
B($B \to K\nu\bar{\nu}$)	No	16-20%
$S_{CP}(B \to K_S\pi^0\gamma\nu\bar{\nu}$)	0.24	0.02-0.03

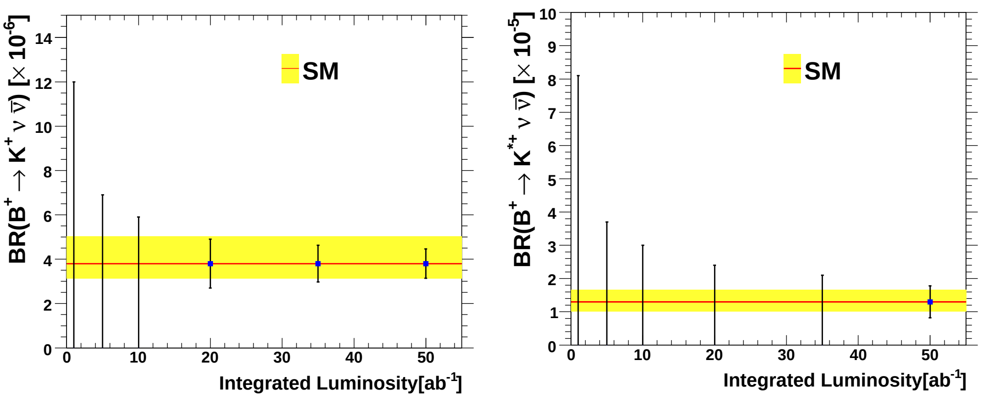

Figure 2: Test the mechanism of direct CP violation is based on the presence of a weak phase ϕ that shows opposite sign in the decay of B^0 $\bar{B}^0$ and a strong phase δ that doesn't change sign.

tion asymmetries in branching fractions and in B meson leptonic decays for a SUSY mass scale below 1 TeV, that would be complimentary with direct observations at LHC. The sensitivity needed to study the SUSY structure for such low energies would be reached after five years of data taking at new machines allowing to extend the sensitivity for SUSY well beyond the TeV scale, allowing to see NP contribution coming from a 10-TeV-scale SUSY, which would not be discovered by LHC.

3.2 tau physics

The τ physics will assume great importance to probe new physics beyond Standard Model. The τ-sector, with the use larger integrated luminosities available at *SuperB* and *SuperKEKB*, will provide precise measurement of both direct effects, via LFV processes, and indirect effects, visible in g-2 [7] and electric dipole moment (EDM) of τ [8].

The use of polarized beams, as in the baseline design of *SuperB*, would help reducing backgrounds to $\tau \to \mu\gamma$ decay, which is expected to be the most sensible to new physics, in fact polarized beams would allow to reduce backgrounds coming from $e^+e^- \to \mu\mu\gamma$ processes. The sensitivities achieved after few years of data taking with *SuperB* would be as high as 2×10^{-9} for $\tau \to \mu\gamma$ and 2×10^{-10} for $\tau \to \mu\mu\mu$ [9]. Due to the lack of polarization option *SuperKEKB* the angular distribution of muons coming from $\tau \to \mu\gamma$ can not be used to reject backgrounds leading to sensitivities worse by a factor of 2.5.

The other hint for New Physics come from g-2 measurement : at present muon g-2 is measured to be $\Delta a_\mu = a_\mu^{SM} - a_\mu^{exp} = (3 \pm 1) \times 10^{-9}$ and any effect on τ's would at least scale with the ratio between the tau and muon mass, making the effect within reach of future flavor factories *SuperB* and *SuperKEKB*. The two machine have different design , only *SuperB* will have a high polarized beam ($\geq$ 80%) and the capability of running at charm threshold. The polarization and an integrated luminosity $\geq 75ab^{-1}$ will allow to investigate the magnetic structure of τ , combining the measurements of total cross section angular distribution and Forward-Backward asymmetry with a sensitivities up to 0.6×10^{-6} [7], equivalent to the sensitivity for muons in g-2 experiments.

3.3 Charm physics

Major improvements are foreseen in the charm sector as well.The recent observation of large $D^0\bar{D}^0$ mixing [10] raises the exciting possibility of finding CP violation in charm decay, which would be a major hint for physics beyond the Standard Model. Future flavor factories *SuperB* and *SuperKEKB* will be able to make comprehensive studies in the charm-sector, taking data with high luminosity 10^{36} at the Υ(4S) resonance. *SuperB* could also take data at a lower center-of-mass energy corresponding to $\psi\prime$ (3770) resonance, still with a remarkable high luminosity 10^{35} , that is the same design luminosity of the future $Super\ \tau - charm$ that is planned at Novosibirsk.

Both future B-Factories show common distinctive features useful to study rare processes in the charm sector. The experimental environment is very clean, both at production threshold, where the backgrounds contribution are small with respect to great rate of production of D mesons, and at Υ(4S) energy, where D's can be efficiently tagged through $D^\star \to D\pi^\pm$ decay, which make possible also a flavor tag on the produced D. On the other side, D production at $\Psi\prime$ would allow a coherent production of $D^0\bar{D}^0$ pairs, opening novel ways to measure CPV processes and allowing the measurement of the phase related to CPV in the up sector. While running at threshold offer lower background and access to the measurement of both direct and indirect CPV, it comes at the expense of statistics, and although having larger cross section (by a factor 3) suffers from lower luminosities. In Figure 3 present and future precision for CPV parameters are shown.

3.4 Summary of the physics goals

The expected precision of some of the most important measurements that can be performed at Super Flavor Factories are contained and compared in

fully comprehensive tables where the reach of the B Factories at 2 ab^{-1} and at 75 ab^{-1} are reported in the above quoted *SuperB* CDR [4].

The physics program for the future Flavor Factories can be summarized:

1. Increase by O(10) the precision of *BABAR* and *Belle* in Flavor sector

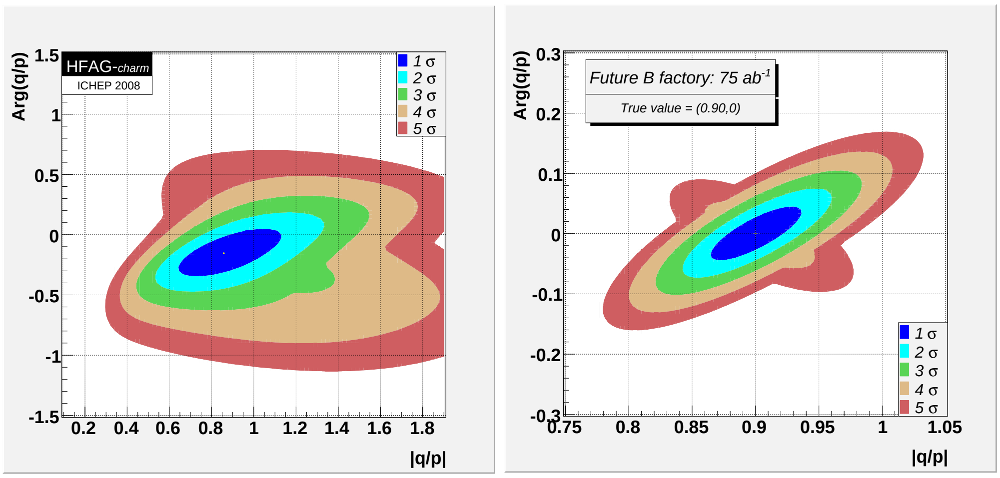

Figure 3: Two dimensional contours Charm mixing and CP violation as a function of $\frac{q}{p}$ a strong phase δ that doesn't change sign, at present (left) and after 5 years of datataking from one of the Super Flavor Factories under design.

2. Challenge CKM in $(\rho.\eta)$ plane at 1% level.

3. Explore CP violation in charm sector

   - CP violation in $D^0\overline{D}^0$ mixing at $\Upsilon(4s)$and at chatm threshold (3770 MeV)
   - Explore the measurement of violating phase

4. τ Physics (LFV), also with the addition of beam polarization:

   - Reduce the irreducible background in LFV channel $\tau \to \mu\gamma$.
   - Explore T Violation.
   - Search for magnetic structure of τ .

5. Explore New Spectroscopy in a clean environment with extremely high statistics.

All these goals can be achieved by a machine with a peak luminosity of $10^{36}cm^2s^{-1}$ in 5 years run at $\Upsilon(4s)$, with one polarized beam and possibility to operate at charm threshold for a few months and with a peak luminosity of $10^{35}cm^2s^{-1}$.

4 e^+e^- colliders

The present status of e^+e^- factories shows $KEKB$ in Tsukuba as the only B-Factory running after the shut down of $PEPII$, the Φ-Factories $Da\Phi ne$ in Frascati ready for restart after the upgrades and $VEPP2000$ in Novosibirsk and the tau-charm-Factory $BEPCII$ in Beijing. The luminosity needed to accomplish the challenging Physics program of the future B-factories is $10^{36}\text{cm}^{-2}s^{-1}$. The luminosity $\mathcal{L}$ of a collider is given by the superposition integral:

$$\mathcal{L} = f_c \int d^3\vec{\mathbf{x}}\; dt\; \rho_1(\vec{\mathbf{x}}, t)\rho_2(\vec{\mathbf{x}}, t) \cdot 2c \tag{1}$$

where f_c is the bunch collision frequency, $\rho_i(\vec{\mathbf{x}}, t)$ are the local spatial densities of particles in a bunch of the the beam i at the position $\vec{\mathbf{x}}$ at time t and c is the speed of light. The luminosity is readily maximized by increasing f_c and the local spatial densities ρ.

The upper limit on f_c is set by the available number of stable buckets in the ring and by the minimum distance d between two adjacent bunches necessary to impede parasitic collisions, in this respect a quick separation of the low and high energy beams is necessary to reduce d. The *BABAR* approach was to implement an head on collision scheme and to exploit the energy asymetry and a pair of Halbach dipoles placed at ±20cm from the IP to separate the HER from the LER before the occurence of parasitic collisions. KEKB renounced to the advantages of an head on collision scheme in favour of a crossing angle one. The advantage of this approach is that the beam lines separates in the straight drift section between the IP and the first vertical focusing quadrupole of the final doublet. The disadvantage of this aproach is that the superposition of the head of a colliding beam with the tail of the opposite one is not optimal so that the luminosity is reduced. As a mater of fact the general formula (1) can be expressed in a closed form assuming gaussian bunches and neglecting the bunch length by

$$\mathcal{L} \sim f_c \frac{N_1\, N_2}{4\pi\; \sigma_y \sigma_x} \frac{1}{\sqrt{1 + \varphi^2_{\mathbf{Piwi.}}}} \tag{2}$$

where σ_y,σ_x and σ_z are respectively the RMS vertical, radial and longitudinal bunch length, and N_i is the total number of particles contained in a bunch of the beam i. The finite crossing angle effect on the luminosity is contained in the Piwinsky angle factor $\varphi_{\mathbf{Piwi.}}$ defined as

$$\varphi_{\mathbf{Piwi.}} = \frac{\sigma_z\; \tan \chi/2}{\sigma_x} \tag{3}$$

where χ is the full crossing angle. The *SuperB* path to reach $10^{36}\text{cm}^{-2}s^{-1}$ is the "large Piwinsky angle with crab waist collisions" scheme. The first key ingredient is to increase the Piwinsky factor by reducing σ_x. Doing that almost all the advantages of the short bunches collision scheme are kept without the burden of the actual bunch shortening. The most important effect of this choice is that the length of the bunch overlap region is reduced to σ_x/χ so that the vertical beta function at the collision point can be reduced to

$$\beta^\star_y \sim \frac{\sigma_x}{\chi} \sim 300\mu\text{m} \ll \sigma_z \sim 6\text{mm}$$

thus allowing the vertical beam size to be reduced to 40 nm, moreover the vertical tune shift is reduced and the vertical synchrobetatron resonances are suppressed [13] However, a large Piwinski angle itself introduces new beam-beam resonances that may strongly limit the maximum achievable luminosity. The second key ingredient, that is the "crab waist transform" [14], reduces the strenght of the betatron and synchrobetatron resonances increasing the beam beam limit. This concept was successfully tested in collisions at DaΦne [15].

SuperKEKB original path to high luminosity was to increase the beam current by a factor 4(2) for the LER(HER) and to push the beam beam tune shift parameter by the short bunches

(σ_z 3mm) "crab crossing" collision scheme. The main issues of this configuration are the wall-plug power needed to store such high current beams, the detector background component that scales with the currents and the head tail fast instability that limit the luminosity attainable with this scheme to $5 \cdot 10^{35}\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$

To overcome these problems the SuperKEKB collaboration proposed a new approach 'called 'nano beam italian scheme" based on low emittance lattice (like *SuperB*), crab crossing collisions with traveling focus whose parameters are presented, together with the *SuperB* ones, in table 2.

Table 2: Machine parameters for *SuperB* and superKEKB

Parameter	units	*SuperB*	superKEKB
Energy (HER/LER)	GeV	4/7	3.5/8
Luminosity	$10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.0	0.8
Beam Current (HER/LER)	A	2.7/2.7	3.8/2.2
$\mathrm{N}_{bunches}$	1740	2230	
ε_y (LER/HER)	pm	7/4	34/11
ε_x (LER/HER)	nm	2.8/1.6	2.8/2
β_y (LER/HER)	μm	210/370	210/370
β_x (LER/HER)	cm	3.5/2.0	4.4/2.5
σ_z	mm	5	5
Crossing angle χ	mrad	60	60
RF power (AC line)	MW	26	¿ 50
beam beam hor. tune shift (LER/HER)	%	0.4/0.13	8.1 /8.1
beam beam ver. tune shift (LER/HER)	%	9.4/9.5	9.0 /8.7

For a complete view of the e^+e^- colliders including future machines see Fig. 4.

5 Basics of Detectors

For both future B-Factories *SuperB* and *SuperKEKB* the communities of experimenters are planning the reuse of large part of the existing apparatus of *BABAR* and *Belle*. The detectors for both colliders will be asymmetric reflecting the asymmetry of machines needed for boosting the center of mass (typically the $\Upsilon(4s)$ to determine the decay time of B^0 and $\overline{B}^0$ allowing the measurement of their time decay asymmetry. Detectors have to be as hermetic as possible and their main requirements are:

- Good measurement of decay vertices by means of precise multilayer Silicon Vertex Detector.
- A central tracking chamber almost transparent for a good direction and p_T in an intense magnetic field.
- A Cherenkov particle identifier, to identify distinguish pions, kaons and protons in a quite wide range with high efficiency.

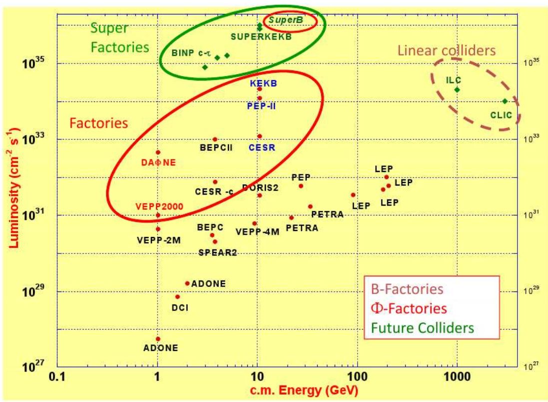

Figure 4: e^+e^- colliders

- An electromagnetic calorimeter with high energy resolution for soft photons and a good identification of electrons.
- a good detector for muon and neutral hadrons

They should be upgraded version of *BABAR* and *Belle*.

5.1 the *SuperB* detector

The baseline of the apparatus that is under study for *SuperB* is largely based on the reuse of *BABAR* detector as presented in details in the *SuperB* Conceptual Design Report (CDR) [4] It reuses the:

- Fused Silica bars of the internal reflecting Cherenkov Detector (DIRC) that has shown high efficiency in kaon identification.
- Mechanical support of DIRC and drift chamber(DCH) .
- The barrel of the electromagnetic calorimeter (EMC), the mechanical structure and the scintillating crystals of CsI(Tl).
- The magnet with the Superconducting coil and the magnetic flux return (that needs some redesign).

Some elements of *BABAR* have aged and therefore their replacement would be needed. Others require moderate improvements to cope with the high luminosity environment, a factor (100 higher the in *BABAR*), with a reduced the center of mass boost at $\Upsilon(4s)$: $\beta\gamma = 2.83$ as from the energy choice of *SuperB*, where the positron energy is 4 GeV and electron energy is 7

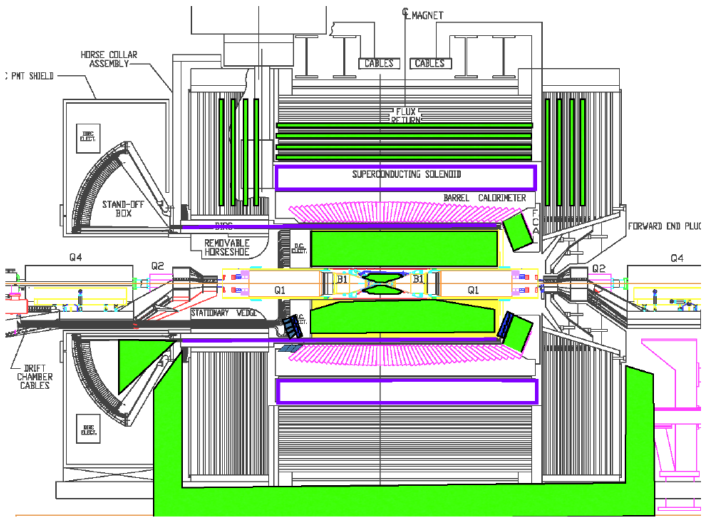

Figure 5: The *SuperB* Detector . In green are the detector component to be rebuilt in the baseline and in the optimal design

GeV (4×7 GeV)[1]. , and the high DAQ rates and with the expected very high darta acquisition (DAQ) rate.Then within respect to *BABAR* are considered the following changes:

- A small (≤ 1.2 cm radius) beam pipe technology.
- A new very thin 6 layer Silicon Vertex Tracker. *The optimal choice should be a thin pixel first layer L0 and double sided detectors in the remaining 5 layers.*
- A new DCH with a carbon fiber mechanical structure, with modified gas mixture and cell size.
- About DIRC an optimized Photon detection for fused silica bars.
- The possible addition of a forward PID system (TOF in Baseline option)
- A rebuilt Forward EMC , made with crystals of LYSO and an additional Backward EMC endcap mainly for vetoing.
- The instrumented flux return for muon and neutral hadron detection based in *BABAR* on Limited Streamer Tubes and RPC's would be changed to the extruded plastic scintillator bars.
- The electronics, the trigger and DAQ will be updated to cope with real event rate 100 times higher than in *BABAR*.
- Computing upgrade is needed for a massive data volume similar to the LHC experiments.

[1]In *PEPII* the beam energies were 3.11 and 9.0 GeV with a $\beta\gamma$ of 0.556 and in *KEKB* 3.5 and 8.0 GeV with $\beta\gamma = 0.42$

Fig. 5.1 shows the side view of the *SuperB* detector where the half above the beam is the baseline choice with small changes from the *BABAR* design, where instead in the lower part improving options are clearly visible as the shaped DCH, the additional FOrward PID and Backward EMC.

5.2 *Belle* Detector

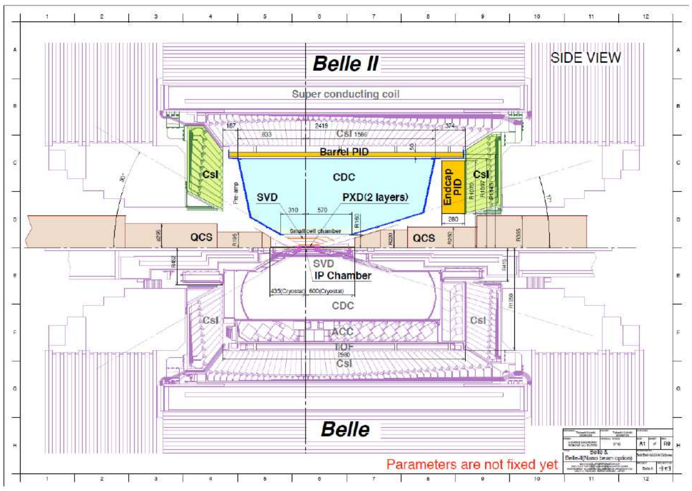

Figure 6: In the upper part of the figure the apparatus *BelleII* modified for running at *SuperKEKB* is shown. It has to be compared with the *Belle* apparatus in the lower part of the figure.

In a very similar way for the *SuperKEKB* project the Fig. 5.2 shows the evolution from the *Belle* apparatus to the expected *BelleII*. Of course some problems are common to the two machines and therefore the solutions are quite similar.

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Discussion

Benny Ward (Baylor University: Are yoy saying that the Super KEK-B factory cannot do polarisation, or that they have chosen not to do polarization - I could not understand what you were saying.
Peter Chrisan Lublijana : I just have a comment. In fact for super keke b there is no principla reason to have polarisation, but we have not considered it up to now - it costs money and manpower.
Vera Lüth, SLAC: I think one thing we probably should have added to your table is that there is now an operating tau-charm factory in Beijung.
Toru Iijima: Do you think that you can achive the target luminosity with polarisation?
Mauro Savrie (University of Ferrara, INFN): You didn't make any coments on the possible time schedule of the two machines. Could you comment on that please?
Helena Abramowich (Tel Aviv University): I am hesitating to ask this question, but what warrants the need for two B-factory machines at this stage?
Benni Ward (Baylor University): What are the cost of these two machines?