The Future of Super Flavor Factories

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Abstract. The status of the flavor physics is presented: the experimental achievements, the outstanding success of the CKM picture within the Standard Model and the flavor experiments presently running and in preparation. From now on the exploration beyond the Standard Model needs a global approach where single measurements coming from individual ad hoc experiments and a more wide set of results expected from multipurpose detectors running at the future Flavor Factories could add value complementary to the direct investigation at LHC. The perspective of the Flavor Factories of next generation, that are expected to be built and running within the next decade, is discussed, with a focus on the technical specific aspects of each individual project.

1. Introduction
The Standard Model of fundamental interactions (SM) has been one of the most tested theories of all time. Past decades have been marked by the great success of Standard Model confirmed by the measurements on Electroweak sector at hadron and $e^+e^-$ machines, such as the LEP results, the discovery of top quark, the measurements on CP Violation, coming from the recent Kaons experiments at Cern and Fermilab and from the present B Factories KEKB and PEPII. 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 the cosmological observations. It is a general opinion that a new experimental exploration beyond SM is needed to discover New Physics (NP). The beautiful results on neutrinos from SuperKamiokande are now suggesting that NP is at hand and Lepton Flavor Violation 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 (LFV) processes in $\mu$ and $\tau$ decays).

The complementarity between the two approaches can be expected and based on the fact that NP processes are mainly governed by two parameters, the NP energy scale $\Lambda$ and the effective coupling $C$, which can have different intensities and different patterns, described by the NP flavor sector. Super Flavor factories, producing $7 - 9 \times 10^{10}$ pairs of B and D mesons and of $\tau$ leptons, will be able to provide hints for NP both if LHC will have evidence for NP or not. If new physics is found at the $\Lambda$ scale at LHC, such an high statistics would provide precision...
measurement of the flavor structure of NP, CPV phases and FV processes, along with obtaining possible hints for heavier states not observed at LHC. If LHC would not manage to observe NP(Λ), super flavor factories will be able to look for indirect signals of NP in rare processes, and constrain phase space of NP(Λ) models up to the order of several tens, or even an hundred of TeV.

In what follows the present status of flavor physics and the perspectives 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

CP-Violation in the Kaon sector has been investigated for the last forty years, since the first famous Brookhaven experiment of 1964 , discovering CP Violating, with the measurement of $B(K_L \rightarrow \pi^+\pi^-) = (1.076 \pm 0.08) \times 10^{-3}$ [1]. Direct CPV measurement was established in 1999 both at CERN and FNAL[2], with the measurement of the double ratio: $\Gamma(K_L \rightarrow \pi^0\pi^0)\Gamma(K_S \rightarrow \pi^+\pi^-)/\Gamma(K_S \rightarrow \pi^0\pi^0)\Gamma(K_L \rightarrow \pi^+\pi^-) \sim 1 - 6\text{Re}(\epsilon'/\varepsilon)$, which was measured to be $\text{Re}(\epsilon'/\varepsilon) = (1.66 \pm 0.26) \times 10^{-3}$, when SM predicted a value of 0. So after forty years of searches in the Kaon sector, new measurements are needed to shed more light to possible NP insertion in $\text{Re}(\epsilon'/\varepsilon)$, which can be done with dedicated experiments.

Along with the Kaon system, also the D meson system is particularly interesting for looking for new physics, being the only system in the up-sector where mixing has been observed, by both BaBar and Belle experiments[3]. In both experiments [4], the measurements are incompatible with no-mixing at 9.8σ, which is a clear sign of mixing in the D-system. On the other hand no evidence for CPV, which would be a clear sign of physics beyond the SM, has been observed, as shown in figure 2.

B-physics, on the other hand, has been one of the most studied topics in the past few years with two B-factories, BaBar and Belle, recording almost 1.5 ab$^{-1}$ at the $\Upsilon(4S)$ resonance, and the study of $B_S$ systems at Tevatron. B-factories made measurement of almost all elements involving third generation quarks of the Cabibbo-Kobayashi-Maskawa 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 figure 2 we show the achievable sensitivity to the unitarity triangle using the statistics expected at Super-Flavor factories.

3. Future Kaon Experiments

One of the most sensitive channels to NP in the Kaon sector is $K \to \pi \ell \bar{\ell}$. This channel is particularly promising since there is only one hadronic current present, and the $K - \pi$ matrix is well known, and the long distance effects are strongly suppressed due to the presence of only one hadronic current. From the theoretical standpoint the SM predictions are clean, with only 3-5% dependence on the theoretical parameters for $K \to \pi \nu \bar{\nu}$ channels, where the lack of knowledge of neutrino masses affect the predictions. In table 1 the present results and SM predictions are reported for all the four channels.

Many experiments are taking data or are being designed to search for the $K_L \to \pi^0 \nu \bar{\nu}$ decay. This decay is the least affected by theoretical uncertainties, with parametrization errors accounting only to 1% relative error on the SM BF prediction. The main experimental problems arise from the impossibility to fully reconstruct the parent particle, due to the missing momentum carried by the neutrinos. No kinematic constraint can be used either with no charged particles present in the final state. A crucial part in this kind of experiments is the veto on charged particles which prevents contamination from other common $K_L$ decays.

Two different approaches were followed in designing dedicated experiment for $K_L \to \pi^0 \nu \bar{\nu}$:

- using a low energy beam for $K_L$ production: even if the beam emission is expected to be large, but $K_L$ time of flight can be used for kinematics, and dedicated sub detectors will be used for $\gamma$-tracking [8];
- using high energy $K_L$: in this case the beam is pencil-like, making it possible to constrain the photon to be coming from a rather narrow region, enabling a strict kinematics constrain.

Figure 2. Present results on unitarity triangle measurement (on the left) and predicted results achievable for 75 $ab^{-1}$ statistics (on the right).
Table 1. SM predictions, present limit and result for $K \rightarrow \pi \ell \bar{\ell}$ decays. Processes involved in the decay are reported along with the direct CPV ($CPV_{dir}$) contributions to the channels under study.

| Channel | SM prediction | Present Limit | Notes and observed events |
|---------|---------------|---------------|---------------------------|
| $K_L \rightarrow \pi^0 e^+ e^-$ | $10^{-11}$ | $< 2.8 \cdot 10^{-10}$ | CPC + CPV |
| $K_L \rightarrow \pi^0 \mu^+ \mu^-$ | $CPV_{dir} 3 \cdot 10^{-12}$ | FNAL KTeV [5] | 3 events (2.05 bkg) |
| $K_L \rightarrow \pi^0 \mu^+ \mu^-$ | $10^{-11}$ | $< 3.8 \cdot 10^{-10}$ | CPC + CPV |
| $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ | $CPV_{dir} 1 \cdot 10^{-12}$ | FNAL KTeV [5] | 2 events (0.87 bkg) |
| $K_L \rightarrow \pi^0 \nu \bar{\nu}$ | $5\%$ parametrization | BNL E787+E949 [6] | 3 events (2.05 bkg) |
| $K_L \rightarrow \pi^0 \nu \bar{\nu}$ | $2\%$ parametrization | KEK E391a [7] | Direct CPV |

The veto capabilities are excellent, and only high $p_t$ events are recorded [9]. With E17 being in commissioning at J-Park we are expecting $\sim 100$ signal event before 2012.

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ has already been measured, but the statistical significance is not enough to allow an observation claim. Further studies are needed in order to shed more light on E787 and E949 measurements. A new experiment, NA62 [10], is being designed in order to provide new and better measurement. The design is different from previous experiments, with the use of a non separated 75 GeV/c $K$ beam, decaying in flight. The sensitivity is not limited by the beam flux and it is designed to have a higher acceptance with respect to E787 and E949, with an improvement of about 14%, the expected number of events is of $O(100)$ in two years of data taking with a signal to background ratio of $S/B \sim 10$. In 2012 it will be possible to reduce errors to the point that NP would be significantly distinguishable from SM predictions.

4. Lepton Flavor Violation Dedicated experiments
Observation of Lepton Flavor Violating (LFV) processes is one of the clearest sign of direct effects of physics beyond SM. Although SM predicts LFV through neutrino mixing and W boson loops, the expected BF for such processes is well beyond experimental reach, for experiments both present and expected in the foreseeable future, with predicted rates $< O(10^{-40})$ in $\tau$ sector [11], and similar rates in the $\mu$-sector. On the other hand many NP models predict rates large enough to be within the present experimental reach, with expected BF larger than $O(10^{-8})$ in $\tau$-sector and $O(10^{-12})$ in $\mu$-sector [12].

In the past decade many experiments looked for LFV decays, with dedicated experiments, such as MEGA and Sindrum, looking for $\mu \rightarrow e\gamma$ and $\mu \rightarrow eee$ decays. The results and future perspectives for LFV in $\mu$-sector are shown in figure 4.

SUPERSYMMETRIC SO(5) models predict rather large rates for $\mu \rightarrow e\gamma$ decays, with rates up to $10^{-14} - 10^{-13}$, and SO(10) supersymmetric models predict rates even larger with $BF(\mu \rightarrow e\gamma)_{SO(10)}/BF(\mu \rightarrow e\gamma)_{SO(5)} \sim 100$. MEGA sensitivity fell just below the ones needed to observe SO(5) and SO(10) supersymmetries, and a new experiment was designed to fill the gap.

At the moment MEG experiment, the ideal successor of MEGA experiment, is taking data, dedicating all its effort towards the observation of $\mu \rightarrow e\gamma$ decays. The goal of the experiment is to measure the decay $\mu \rightarrow e\gamma$ produced by muons arrested inside a stopping target. The signature of such an event is given by a track produced by the electron and a single photon, since this is a two body decay both electron and photon are monochromatic, being the center
of mass frame the same as the laboratory frame, since the muons decay at rest, we expect $E_{\gamma} = E_e = 58\text{MeV}$.

The detector consists of two main subdetectors: a liquid Xe electromagnetic calorimeter and a solenoidal drift chamber and spectrometer for electron measurement. The liquid Xe has been the scintillator of choice for the photon detector since it is a fast detector, along with having a good light yield ($\sim 0.8\ NaI$). The calorimeter short radiation lenght (2.7 cm) made it possible to reduce the volume of the detector, and the calibration of the subdetector is done with a 1 MeV Cockroft-W alton generator, which consents an online diagnostic of the calorimeter response. The drift chambers are immersed in a non-uniform solenoidal field, making it possible to make precise measurement of the electrons momenta, while the magnetic gradient sweeps the particle away, preventing high occupancies in the drift chamber that would hinder the sub-detector performances. To ensure the proper coincidence between the photon and the electron, scintillation counters were added in the drift chamber region to ensure precise timing measurement for electron timing. The sensitivity achievable by MEG experiment is expected to be $10^{-13}$ [13].

Another possible approach, employed by the m2e collaboration, is by looking at muon conversion in muonic atoms obtained by binding the stopped muons and the atoms present in the stopping target. This kind of atoms have a small lifetime, being $\sim 10^{-16}$, and there are three main processes leading to their decay: muon capture $\mu A \rightarrow \nu_{\mu} A'$, muon decay $\mu A \rightarrow e\nu_e\nu_\mu A$, and muon conversion $\mu A \rightarrow eA'$. In conversions the outgoing electron is the only revealed particle, and since the electrons are monochromatic a good tracking detector would provide a unique way to remove most background sources. A setup such as the m2e proposed one would consent high rates since, unlike in MEG experiment, no coincidence is required. The limiting factor on the operating rate of the experiment is constituted by the muonic atom lifetime, limiting the muon beam pulses to a frequency of $\sim 1\ MHz$. The goal for mu2e experiments (shown in figure 3 is to measure muon conversion or put an upper limit for the process as low as $\Gamma(\mu A \rightarrow eA')/\Gamma(\mu A \rightarrow e\nu_e\nu_\mu A) < 10^{-16}$, after studying a sample of $10^{18}$ muons, produced.

![Figure 3. History of charged lepton flavor violation searches in muon decays. The MEG and Mu2e sensitivity goals are shown (source: F. Cervelli).](image-url)
Figure 4. Layout of m2e experiment as proposed in [14].

Table 2. 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%    |
| $A_{FB}(B \to X_s l^+ l^-)_{sq,xing}$ | 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 |

in two years by the FNAL muon beam [14].

5. B-τ-Charm Factories 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. The experimentation at a Super Flavor Factory (see [16] and [17]) would then be really useful to understand the NP flavor structure even during LHC operations. In the following sensitivities for Super-Flavor factories will be shown considering samples consisting of integrated luminosities $\geq 75ab^{-1}$, corresponding to an $e^+e^-$ asymmetric machine running for 5 years with a peak luminosity of $10^{36}cm^{-2}s^{-1}$. Only a small selection of observables are shown, see for details [15].

5.1. 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 2.

For the channel $b \to s l^+ l^-$ 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
\[ a b^{-1}, \text{ and need a clean environment not compatible with LHC backgrounds. Other channels can also be accessible as } B \rightarrow \gamma \gamma \text{ and } B \rightarrow \nu \bar{\nu} \text{ 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 5, where by reducing the statistical error, which is the main contributor to the experimental error, the Standard Model can be severely challenged. In figure 6 the potentiality of SuperB is presented in the hypothesis that LHC discovers New Physics, it is clear from the two figure how the two facilities would be complimentary, largely reducing the parameter space for all NP models.}

After a decade where BaBar and BELLE have clearly established CKM to account for CP violating asymmetries in tree-level starting with \( b \rightarrow (\bar{c}\bar{c}s)b \) decays, the goal future \( B \)-factories will be the study of very rare processes. The SuperB-factory would be able to measure CP violation asymmetries in branching fractions and in \( B \) meson leptonic decays with SUSY mass scale below 1 TeV, which 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 SuperB. On the other hand such large samples of \( B \)-mesons would consent 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.

A comprehensive reference for future \( B \)-factories is represented by SuperB CDR (2007) and more recently in the proceeding of the VI SuperB Workshop held in Valencia (Spain) in January 2008 [17]. The CDR [16] contains most of the \( B \) physics studies including the discussion of phenomenological analysis within the MSSM with generic mass insertion.

Figures 7 shows how well the \((\delta_{13})_{LL}\) can be reconstructed at SuperB with an integrated luminosity 75 \( ab^{-1} \) versus a lower luminosity of 10 \( ab^{-1} \). Since \((\delta_{13})_{LL}\) is strongly dependent on theoretical expectations, improvements in lattice QCD performance, are assumed in both cases. The main difference between the two plots is due to great precision achievable in the measurement of the CKM parameters \( \rho \) and \( \eta \) with high luminosity.
Figure 6. Constraints on New Physics parameters in the case of SuperSimmetry is discovered by LHC in blue (dark), and constraints from LHC plus SuperB in red (clear).

The benchmarks for flavor physics need the specification of New Physics flavor structure. An evaluation of sensitivity is made for flavor observable measurable at SuperB within the mSUGRA models at the SPS1a, SPS4 and SPS5 benchmark points defined for the LHC in [18]. The purpose of this evaluation is to express the deviation from the SM predictions of those observables in MFV scenario where LHC can reconstruct a large part of the SUSY spectrum. The measurement which will be likely to be affected in the MFV model are specified, for each SPS point in Table 3.

5.2. Charm physics

Major improvements are foreseen in the charm sector as well. The recent observation of large $D^0\bar{D}^0$ mixing 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 will be able to make comprehensive studies in the charm-sector, taking high luminosity data sample on the $\Upsilon(4S)$ resonance, like SuperB and SuperKEKB facilities, but also taking data in the of $\psi'$ (3770) resonance, where the future Novosibirsk facility is expected to operate, SuperB will be able to run at $\psi'$ energy, featuring a collider designed to run at lower center-of-mass energies at reduced luminosity $10^{35}$. 

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Figure 7. Determination of the SUSY mass-insertion parameter $\delta_{13}^{LL}$ with 10 $ab^{-1}$ (left) and with 75 $ab^{-1}$ (right).

Table 3. Snowmass points definition. The quantities $M_{1/2}$, $M_0$, $A_0$ are expressed in GeV.

|   | SPS | $M_{1/2}$ | $M_0$ | $A_0$ | $\tan \beta$ | $\mu$ |
|---|-----|-----------|-------|-------|--------------|------|
| 1 | a   | 250       | 100   | -100  | 10           | >0   |
|   | b   | 400       | 200   | 0     | 30           | >0   |
| 2 |     | 300       | 1450  | 0     | 10           | >0   |
| 3 |     | 400       | 90    | 0     | 10           | >0   |
| 4 |     | 300       | 400   | 0     | 50           | >0   |
| 5 |     | 300       | 150   | -1000 | 5            | >0   |

All Super Flavor 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 $\Upsilon(4S)$ energy, where $D$’s can be efficiently tagged through $D^* \rightarrow D\pi^\pm$ decay, which make possible also a flavor tag on the produced $D$. On the other side, $D$ production at $\Psi$ 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 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 (a factor 10). A problem that can be addressed only by SuperB running at lower energies, but not by Novosibirsk machine, is the measurement of time-dependent CPV. Time dependent measurement can be done at 4 GeV threshold only by an asymmetric machine, which is not the case of the Novosibirsk project. In time-dependent measurement the vertexing detector should be able to achieve precisions of the order of few tens of microns, this is possible only at SuperB, where the beam spot is known with nm precision as will be discussed in section 6.2. In figure 8 present and future precision for CPV parameters are shown.
5.3. τ physics

The τ physics will assume great importance to probe new physics beyond Standard Mode. The τ-sector, with the use larger integrated luminosities available at SuperB and SuperKEKB facilities, will provide precise measurement of both direct effects, via LFV processes, and indirect effects, visible in $g - 2$ and electron dipole moment (EDM) of τ’s.

The use of polarized beams, as expected at SuperB, would help reducing backgrounds in $\tau \rightarrow \mu \gamma$ decay, which is expected to be the most sensible to new physics, in fact polarized beams would allow to reduce backgrounds coming from $e^+e^- \rightarrow \mu\mu\gamma$ processes. The sensitivities achieved after few years of data taking at SuperB would be as high as $2 \times 10^{-9}$ for $\tau \rightarrow \mu\gamma$ and $2 \times 10^{-10}$ for $\tau \rightarrow \mu\mu\mu$ [19]. Due to the lack of polarization option SuperKEKB the angular distribution of muons coming from $\tau \rightarrow \mu\gamma$ can not be used to reject backgrounds leading to sensitivities worse by a factor of 2.5, as shown in figure 9.

The other hint for New Physics come from $g - 2$ measurement: at present muon $g - 2$ is measured to be $\Delta a_\mu = a_\mu^M - a_\mu^{exp} = (3 \pm 1) \times 10^{-9}$ 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 will be able, assuming an integrated luminosity of $75 ab^{-1}$, to measure $g - 2$ in all τ decay channels combining the results to obtain sensitivities of up to $0.6 \times 10^{-6}$, however the lack of polarization option make SuperKEKB less sensitive to this processes.

6. Future flavor machines

High luminosity in colliding beam machines can be achieved by acting on the parameters contributing to the well known luminosity formula:

$$L = f_{coll} \frac{N^+N^-}{4\pi\sigma_x\sigma_y} R_l$$

(1)

where $f_{coll}$ is the collision frequency, $N^+$ and $N^-$ are the number of particles per beam, $\sigma_x$ and $\sigma_y$ are the rms horizontal and vertical beam sizes and $R_l$ is a reduction factor accounting for the geometrical and hourglass effects.
Traditionally the high luminosity is based on short bunches, on low betatron functions at IP, on low beam emittance, and in increasing the beam currents. This way has been chosen in the present project for KEKB upgrade where the main feature is a large increase in operating currents: 9.4 Amps in Low Energy Ring (LER) and 4.1 Amps in the High Energy Ring (HER) [20].

Short bunch length allows the decrease of the vertical beam size $y^*$ at the IP, reducing the “hourglass” effect which hinders to reach higher luminosities. The SuperB strategy for $L \geq 10^{36}$ is based instead on a new idea for beam-beam collisions, “Crab waist” (CW) scheme as described in [21].

6.1. SuperKEKB: rising currents to rise luminosity
SuperKEKB approach to achieve higher luminosity is to rise currents present in their beam lines up to 4.1 A in the HER and 9.2 in the LER. This is done by shortening the bunch length, and increasing the number of bunches. This choice comes at the rise of power consumption due to higher synchrotron radiation losses, however the small bunch size allows to reduce beam disruption and the goal for the machine is to reach luminosities as high as $8 \times 10^{35}$, the integrated luminosity goal is recording $50 \text{ ab}^{-1}$ before 2020.

The SuperBelle detector is affected by the increase in the beam currents, in fact the increase of beam current make beam background worse. Present simulation shown that the inner detectors would expect a background increase of about 20 times mostly due to beam gas effects coming from HER and LER. The detector design should then be robust and able to handle high rates and high occupancies especially in the inner tracker systems. The layout of the new machine and the IR position is shown in figure 11.

6.2. The large crossing angle and the “Crab waist” concept
The “Crab waist” (CW) scheme combines several potentially advantageous concepts. The CW principle has been tested at LNF, Frascati, where is being applied to the daΦne-Φ Factory luminosity upgrade.

The first feature is represented by the large Piwinski angle at the IP, this angle is defined, in the case of beam crossing angle $\theta$, as:
Figure 10. Expected integrated luminosity for SuperKEKB (source: M. Yamauchi).

Figure 11. Layout of SuperKEKB, and interaction region position (source: M. Yamauchi).
\[
\Phi = \tan \left( \frac{\theta}{2} \right) \frac{\sigma_x}{\sigma_y} \approx \frac{\theta}{2} \frac{\sigma_x}{\sigma_y}
\]

and the luminosity can then be expressed as a function of the tune shift \( \xi : L \propto \frac{N \xi_y}{\beta_y} \) where \( \beta_y \) is the vertical beta function.

Tune shifts \( \xi_x \) and \( \xi_y \) scale in the following way:

\[
\xi_y \propto \frac{N \sqrt{\beta_y}}{\sigma_x \sqrt{1 + \phi^2}} \approx \frac{2N \sqrt{\beta_y}}{\sigma_x \theta} \quad (3)
\]

and

\[
\xi_x \propto \frac{N \sqrt{\beta_y}}{\sigma_x^2 (1 + \phi^2)} \approx \frac{4N}{(\sigma_x \theta)^2} \quad (4)
\]

\( \sigma_x \) being the horizontal rms bunch size, \( \sigma_z \) the rms bunch length, \( N \) the number of particles per bunch. Here we consider the case of flat beams, small horizontal crossing angle \( \ll 1 \) and large \( \Phi \gg 1 \).

In the “Crabwaist” scheme \( \Phi \gg 1 \) is obtained by decreasing the horizontal beam size and increasing the crossing angle. In this way, both luminosity and horizontal tune shift increase, and the overlap area of colliding bunches is decreasing proportionally to \( \sigma_x \). So, if the vertical beta function \( \beta_y \) is made comparable to the overlap area size:

\[
\beta_y \approx \frac{\sigma_x}{\theta} \ll \sigma_z \quad (5)
\]

then:

- beam size at IP can be very small, Luminosity is therefore high as from Eq: \( (1) \)
- vertical tune shift can be low to acceptable levels.
- and there is a suppression of instabilities due to synchrobetatron resonances [23], which would make the beam easily handled.

With Crab Waist the length of beam is not crucial for the luminosity gain, and a machine operating with CW scheme does not need particularly short bunches for the luminosity gain. High Order Modes causing excessive heating in the beam pipe can be reduced, together with coherent synchrotron radiation due to short bunches. With reduced heating and reduced radiation the power needed to operate SuperB factory would be lower than the quantity needed without a CW scheme, and kept to reasonable levels. The CW transformation is expected to solve the problems arising from the the choice of large Piwinski angle, which, while beneficial to the luminosity, introduces new beam-beam resonances and may strongly limit the maximum tune shifts achievable (see for example in [24]). As an example of how the CW transformation works, figure 12 shows the focusing effect in the bunch crossing.

The CW transformation acts on the \( y \)-plane as described by the following formula:

\[
y \rightarrow y - \frac{\chi xy'}{\tan(2\theta)}
\]

where \( \chi \) is the crab coefficient (of the order of one), \( x(y) \) is the particle horizontal (vertical) coordinate, \( y' \) is the vertical slope.

During the test at daΦne facility the luminosity presented a linear behavior as a function of the product of currents present in the beams, as expected. Specific luminosity was found to be higher than during the past best runs of daΦne (see figure 14). The maximum measured peak luminosity was of the order of \( 2 \times 10^{32} \), using 800 mA of electrons and 600 mA of positrons. The
Figure 12. Sketch of the large Pivinski angle and crab waist scheme for SuperB. Top: CW transformation OFF. Bottom: CW transformation ON. In red is the LEB, in blue the HEB. For clarity sake the crossing angle has been reduced in the picture by a factor 4 to enhance in a qualitative way the CW transformation effect.

Figure 13. The top figure is the display of Synchrotron Light Monitor (SLM) taken in the Main daΦne Control Room during the tests. The bump is corresponding to the status of Crab Sextupoles OFF, when the beam size, due to instabilities and resonances, grows up. The lower part of the figure shows the effect of CW on luminosity as seen in the online display. The test shown an increase of a factor $\sim 2$ with respect to the previous records, achieved with about half of the current circulating in the beams. The power consumption, thanks to the reduction of beam current was reduced by a factor $\sim 4$. Such a reduction is expected to be scaleable up to $\Upsilon(4S)$ energies, making the design of a Super Flavor factory with high luminosity and lower power consumption possible.
6.3. daΦne upgrade and the “Crab Waist” test

At the end of 2007 in Frascati an upgrade program has been started. aiming to a luminosity increase of daΦne, with a substantial reduction of electric power consumption and a reduced background in the detectors. The beam crossing region of daΦne has been modified and magnetic sextupoles for the bunch phase rotation of “Crab waist” have been installed. One of the main,

Figure 14. “Crab Waist” effect. From top left luminosity vs product of beam currents to top right: specific luminosity vs time (it is constant!). In the center plot: beam currents vs time (electron in blue and positron in red). In the bottom plot tune shifts vs bunch current are shown.

Figure 15. On the left is the plot of the expected grow of peak luminosity after the start up of the machine, marked as year 0, that is expected before 2015. The right plot shows instead the expected integrated luminosity as a function of time In 5 years most of the planned physics program should be completed.
still preliminary results of this test, without entering in a detailed description, that can be found for example in [22]. The effects of CW in reducing the beam disruption ad the to the reduction and in the increase of luminosity is clearly visible in figure 13. The vertical beam size at the collision is pushed down to 3.5µm and the luminosity grows when CW sextupoles are active, on the contrary when crab sextuples are switched OFF the luminosity drops down by a factor ≈ 2

6.4. Novosibirsk Project for charm-factory
The $\tau$-charm factory will be using a large Piwinsky angle solution, and will adopt many solutions similar to the one chose for SuperB factory. The main features for the future machine based in Novosibirsk, figure 16, are the polarized electron beams with expected polarization of up to 80% longitudinal polarization, and a variable energy with a possible range going from $J/\Psi$ threshold to charmed baryon production threshold. No symmetry is needed for this machine and the energy is accurately measured by observing compton scattering between beams, making it an important facility to study CP violation processes in the charm sector, even if it has lower luminosities compared to the two Super B factories by almost a factor 10.

7. Conclusions
The design of SuperB is strengthened by the results of the test of LNF for DaΦne upgrade. The parameters that are expected to allow the construction of the Super Flavor Factory with polarization for $\tau$ physics, are being finalized, making the facility able to run as asymmetric factory at charm threshold (4.0 GeV) for the study of CP violation with time dependent analysis analogous to the BaBar and Belle extraction of $\sin(2\beta)$.

The SuperB machine is expected to produce physics before the mid of next decade, integrated luminosity is to grow fast as shown in figure 15.

With the design of SuperB and SuperKEKB projects the future of flavor physics is bright as in the last decade, and as the new project will become operational the flavor structure of NP will be investigated while the scale of those interaction will be looked for at LHC.

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