The BELLE II project

Boris A. Shwartz[1]
Budker Institute of Nuclear Physics of SB RAS
Lavrentiev av., 11, 630090 Novosibirsk, Russia

This talk describes the SuperKEKB/Belle II project with a brief survey of other flavor factories projects.

1 Introduction

In the last ten years a lot of physics results came from two B-factories – KEKB [1] and PEP-II [2]. Experiments had been conducted at these B-factories with the Belle [3] (KEKB) and BaBar [4] (PEP-II) detectors in the energy range of the Υ meson family. Both detectors are forward/backward asymmetric detectors with high vertex resolution, magnetic spectrometry, excellent calorimetry and sophisticated particle identification ability. Integrated luminosity collected by both detectors exceeded 1500 fb^{-1}. Now both B-factories completed operation. At present one new super B-factory is under construction, another one is at the beginning stage and the Super-C-tau project is at the R&D stage in Novosibirsk. This report concentrates on the SuperKEKB/Belle II project with a brief survey of other projects.

At the end of June 2010, the Belle detector completed its operation after 10 years of experiments and collection of more than 1000 fb^{-1} of integrated luminosity at the KEKB asymmetric-energy e^+e^- collider. The world highest luminosity of the collider, $2.1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, as well as high quality and performance of the Belle detector provided a basis to obtain numerous results in several fields of particle physics. Although the most known Belle achievements concern the CP symmetry violation in the quark sector, very important results were also obtained in the heavy quarkonium spectroscopy, tau lepton decays and two-photon physics.

Motivated by the success of the KEKB/Belle experiment, the new advanced project, KEKB II/Belle II, was accepted. The KEKB II luminosity will exceed the previous one by about 40 times. In many aspects, Belle II will have considerably better performance than Belle. This upgrade will open exciting possibilities in a search and study of new physics phenomena in the heavy quarkonia, lepton flavour violation in tau decays as well as in other particle physics fields.

[1]shwartz@inp.nsk.su

2 Main results from previous B-factories and physics at 50 ab^{-1}

The main goal of the previous generation of B-factories was a study of the CP symmetry violation in B meson decays. This goal was achieved successfully. In 2001, the presence of CP violation in the B meson system was established by the Belle and BaBar collaborations [5] which observed time-dependent asymmetry in the decay process $B^0 \to J/\Psi K_S^0$. Later the CP violation including direct CP violation was observed in many other decay modes. In general, in these experiments Standard Model (SM) was confirmed with the Kobayashi-Maskawa mechanism of CP violation.

In case of CP asymmetry the time dependence of the decay probability is expressed as:

$$p(\Delta t) = \frac{e^{|\Delta t|/\tau_{B_0}}}{4\tau_{B_0}}\{1 \pm [S_{f_{CP}} \sin(\Delta m_d \Delta t) + A_{f_{CP}} \cos(\Delta m_d \Delta t)]\}, \tag{1}$$

where $S_{f_{CP}} = -\xi_{f_{CP}} \sin(2\phi_1)$ – corresponds to indirect CP violation; $A_{f_{CP}}$ – direct CP violation; $\xi_{f_{CP}}$ is CP eigenvalue of the state. The preliminary result of Belle on the CP asymmetry based on the 711 fb^{-1} sample (772M BB pairs) is [6]: $S = 0.668 \pm 0.023 \pm 0.013$ (syst.), $A = 0.007 \pm 0.016 \pm 0.013$ (syst.). The measured asymmetry in $B^0 \to J/\Psi K_S^0$ decays is shown in Fig. 1. In experiments at the super B-factories the accuracy of $\sin(2\varphi_1)$ will be improved by more than twice.

Direct CP violation was also observed at B-factories in $B^0 \to \pi^+\pi^-$ and $B^0 \to K^+\pi^-$ decays. The angle ϕ_2 has been measured with $B^0 \to \pi\pi$, $\rho\pi$ and $\rho\rho$ systems using isospin symmetries. The angle ϕ_3 has also been measured through the processes $B \to D(^*)K(^*)$ and the evidence of direct CP violation in $B \to DK$ decays was obtained.

Magnitudes of the CKM matrix elements have been measured by the Belle and BaBar much more precisely than before. At 50 ab^{-1}, which should be reached with new generation of B-factories, uncertainties in the ϕ_2 and ϕ_3 angles will be improved to about 1.5°. The $\overline{\rho}$ and $\overline{\eta}$ parameters of the unitarity triangle will be determined with 6-8 times better accuracy than now.

Another very important goal of the experiments at B factories is a search for the New Physics, i.e. phenomena which are not described by the SM.

The value of time-dependent CP violation (TDCPV) measured in the decay $B^0 \to \phi K_S$ determines $\sin 2\phi_1$. Now the difference of this value measured in the $B^0 \to \phi K_S$ and in the $B \to J/\psi K_S$ modes is $\Delta S \equiv \sin 2\phi_1^{\phi K_S} - \sin 2\phi_1^{J/\psi K^0} = 0.22 \pm 0.17$, while the SM prediction is about 0.03. A confirmation of this difference would be a serious indication of a New Physics. With the Belle II detector the accuracy of this quantity can be better than the SM theoretical prediction.

In the SM the CP violation in the b quark radiative decays is suppressed. For example the decay time-dependent CP asymmetry in the $B^0 \to K_S\pi^0\gamma$ decay is estimated to be $S \approx -2(m_s/m_b)\sin 2\phi_1 \approx -0.04$. On the other hand, in L-R symmetric models, the asymmetry

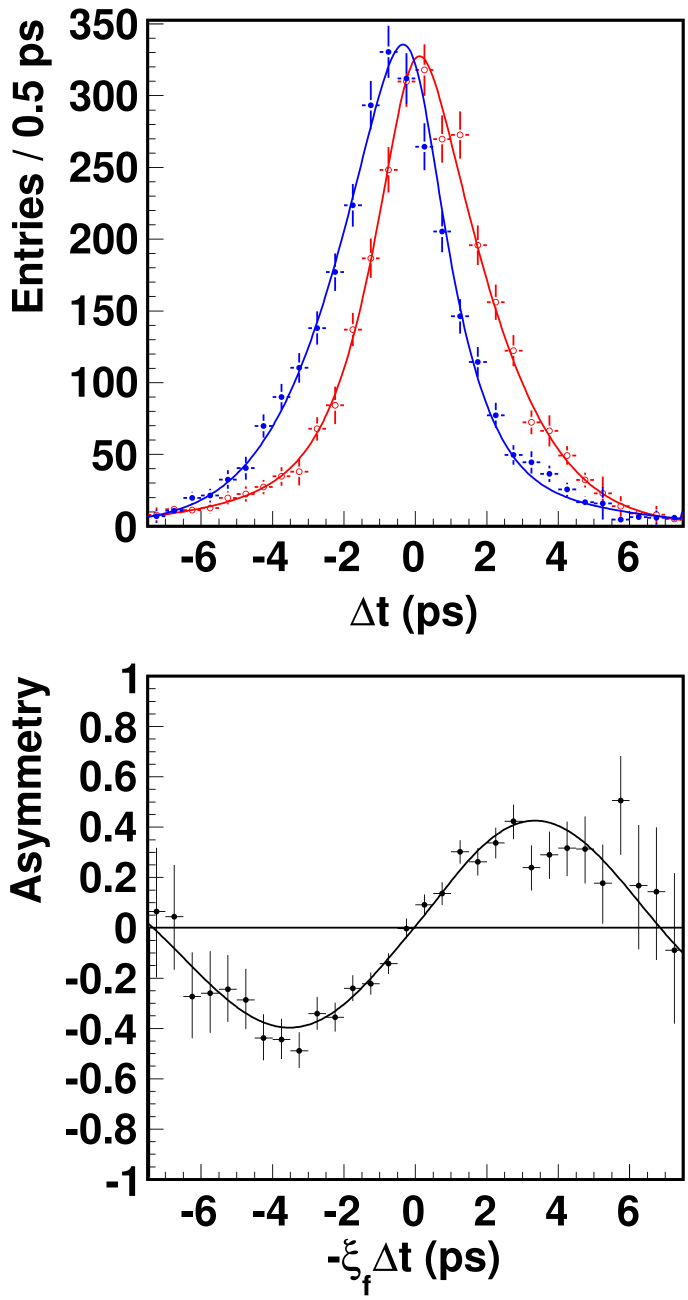

Figure 1: The measured asymmetry in $B^0 \to J/\Psi K_S^0$ decays.

can be as large as $S \approx 0.67 \cos 2\phi_1 \approx 0.5$. The expected accuracy of $S(K_S \pi^0 \gamma)$ with 50 ab^{-1} will reach the SM value and thus cover the whole range of NP predictions.

The process sensitive to the new physics with charged Higgs boson is a decay $B^+ \to \tau^+ \nu_\tau$. The branching ratio of this decay was measured by Belle with 657$\cdot 10^6$ $B\overline{B}$ events is [8]:

$$B(B^+ \to \tau^+ \nu) = (1.54^{+0.38}_{-0.37}(stat.)^{+0.29}_{-0.31}(syst.)) \times 10^{-4}.$$

BaBar result on this value based on 468$\cdot 10^6$ $B\overline{B}$ events [9] is:

$$B(B^+ \to \tau^+ \nu) = (1.7 \pm 0.8(stat.) \pm 0.2(syst.)) \times 10^{-4}.$$

The averaging performed by HFAG results in the value $(1.64 \pm 0.39) \times 10^{-4}$ which is higher than the SM prediction based on the CKM fit $(0.763^{+0.114}_{-0.061}) \times 10^{-4}$.

Excellent performance of the electromagnetic calorimeter is crucial for the this measurement. The Belle II calorimeter maintains this performance even with more severe backgrounds expected at SuperKEKB. With much higher statistics this will provide an improvement of the accuracy of the ratio Γ/Γ_{SM} to about 0.08 including uncertainties from theory (on V_{ub} and f_B), while a purely experimental uncertainty will reach 0.04.

Charged lepton flavour violation (LFV) would be a very clear manifestation of the new physics since in the Standard Model the lepton flavour violation decays are extremely rare. For example, $Br(\tau \to l\gamma) \sim 10^{-54}$ and $Br(\tau \to 3leptons) \sim 10^{-14}$. At Belle and BaBar 44 different LFV modes were searched for. The most stringent limit is $B(\tau \to \mu^+ e^- e^-) < 1.5 \times 10^{-8}$ [7]. The sensitivity for different modes is limited by background suppression or statistics. In general, the improvement in upper limits on the LFV decays achieved by studies at the B-factories is ~ 100 compared to CLEO.

With 50 ab^{-1} of integrated luminosity the sensitivity to the considered processes will be: for $\tau \to l\gamma$ – $Br \sim O(10^{-8-9})$; for $\tau \to lll, l + meson$ – $Br \sim O(10^{-9-10})$, which reaches the range of predictions in some NP models.

A lot of results were obtained by Belle and BaBar on the hadron spectroscopy. The latest example from the bottomonium family is the observation of the h_b mesons as well as the new unexpected Z_b states. Details can be found in the report of A.Kuzmin at this conference [10].

Earlier, several new states (XYZ states) were found in the charm sector. The detailed report about these results was presented at this conference by S.Eidelman [11].

In the last years a lot of new data on the spectroscopy of light hadrons were obtained at the B- and ϕ-factories, at the BaBar, Belle and KLOE detectors, using initial state radiation (ISR) processes [13]. The status report of this research is given by E.Solodov at this conference [12]. With 50 times high statistics expected at superB-factories the amount and accuracy of physics results provided by this approach will be drastically widen. These results will be competitive and complementary to the data from conventional low energy e$^+$e$^-$ colliders.

3 SuperKEKB and Belle II

The SuperKEKB collider will be the upgraded KEKB using the same tunnel and some elements of the previous B-factory. The new project is based on the so called ”Nano-Beam” scheme, first proposed in [14]. The main features of this project are the following:

- reuse of the KEKB components as much as possible;
- to keep the present cells in HER.
- replacement of the dipole magnets in LER, reusing other main magnets in the LER arcs.
- no option for polarization is considered at present.

The fundamental parameters of the new collider are listed in Table 1

	KEKB (achieved)	SuperKEKB
Energy, GeV (e^+/e^-)	3.5/8.0	4.0/7.0
Beam current, A	1.64/1.19	3.6/2.6
Vertical β function at IP, mm	5.9/5.9	0.27/0.30
Beam-beam parameter, ξ_y	0.129/0.090	0.09/0.081
Luminosity, $10^{34}\text{cm}^{-2}\text{s}^{-1}$	2.11	80

Table 1: Comparison of the main parameters of SuperKEKB and previous KEKB colliders

SuperKEKB/Belle II project is approved and the commissioning of the collider is planned to the second half of 2014 FY. The goal is to collect the integrated luminosity of 50 ab^{-1} by the end of 2021.

The Belle II detector project is described in the Technical Design Report [15]. Demands on the detector are defined first of all by the rates from various physics processes at the luminosity of $8 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ as listed in Table 2.

The schematic view of the Belle II detector (top half) in comparison to the previous Belle detector (bottom half) is presented in Fig. 2.

Vertex detection at the Belle II detector will be implemented via the Pixel Detector (PXD) and Silicon Vertex Detector (SVD). The PXD is based on DEPFET technology which allows to produce very thin (down to 50 μm) sensors. Two layers of PXD with the pixel size of 50×75 μm will be arranged around the interaction region.

The SVD consists of four layers of double-sided silicon strip detectors (DSSD). To increase radial coverage the slanted sensors are used in the forward region. The rectangular and wedge shape DSSDs with the strip pitch from 160/50 μm to 240/75 μm are used in SVD. The configuration of PXD and SVD in comparison with the Belle detector is presented in

Physics process	Cross section, nb	Rate, Hz
$\Upsilon(4S) \to B\overline{B}$	1.2	960
Continuum $e^+e^- \to$hadrons	2.8	2200
$e^+e^- \to \mu^+\mu^-$	0.8	640
$e^+e^- \to \tau^+\tau^-$	0.8	640
Bhabha ($\theta_{lab} > 17^\circ$)	44	350*
$e^+e^- \to \gamma\gamma$ ($\theta_{lab} > 17^\circ$)	2.4	19*
2γ-processes, ($\theta_{lab} > 17^\circ, p_t > 0.1\text{GeV}/c$)	80	15000
Total	130	20000

Table 2: Total cross section and trigger rates with $L = 8 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ from various physics processes at $\Upsilon(4S)$.
(*) - rate is prescaled by a factor of 1/100.

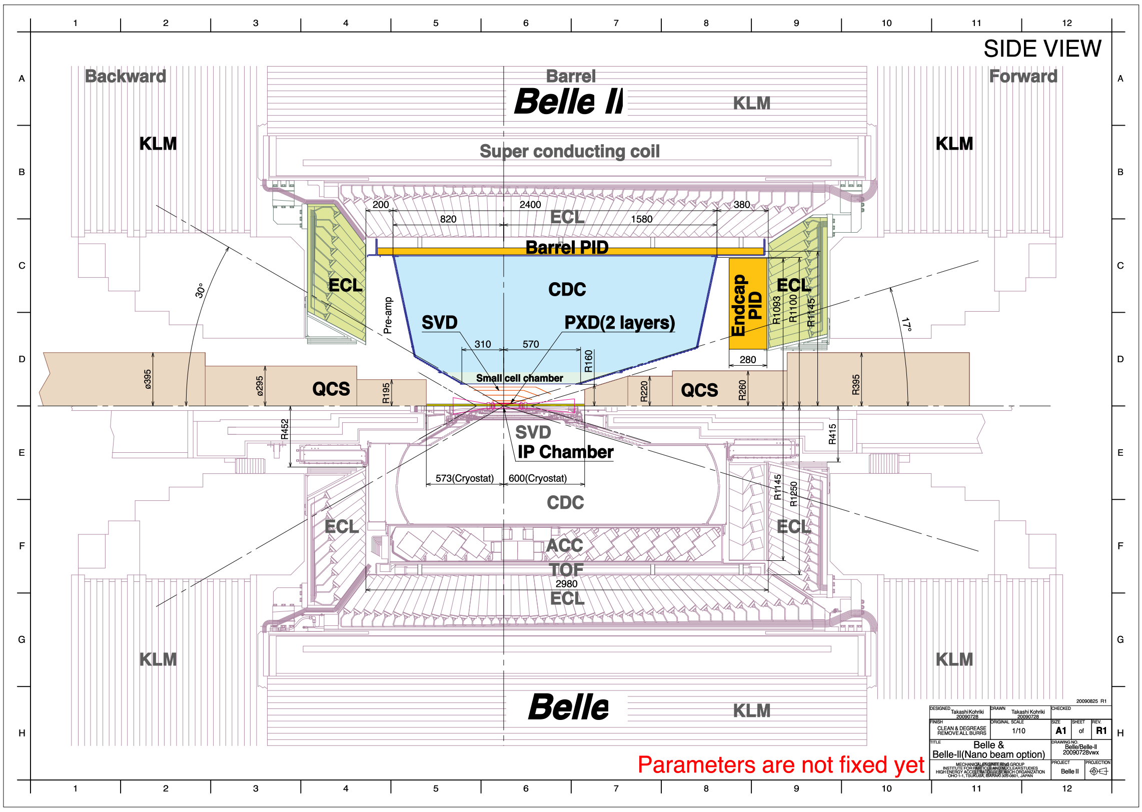

Figure 2: Schematic view of the Belle II detector (top half) in comparison to the previous Belle detector (bottom half).

	Belle II	Belle
Beam Pipe r, mm	10	15
DEPFET		
Layer 1 r, mm	14	
Layer 2 r, mm	22	
DSSD		
Layer 3 r, mm	38	20
Layer 4 r, mm	80	43.5
Layer 5 r, mm	115	70
Layer 6 r, mm	140	88

Table 3: SVD configuration.

Table 3. The PXD and SVD together should provide impact parameter resolution of about 20 μm.

The central drift chamber (CDC) of the Belle II detector is intended for three basic functions: track reconstruction and its precise momentum measurement; a measurement of the ionization losses of the charged particles for the identification purposes; a generation of the signals for the trigger system. The Belle II CDC follows the global structure of its predecessor in the Belle detector, for the material of the major parts, the superlayer wire configuration, the cell structure, the wire material and the gas mixture.

The radii of inner and outer cylinders changed from 77 to 160 mm and from 880 to 1130 mm, respectively. The number of layers increases slightly, from 50 to 56 while the number of the sense wires changed from 8400 to 14336. The momentum resolution of Belle II with CDC and SVD is:

$$\sigma_{p_t}/p_t = 0.1\% \cdot p_t[\mathrm{GeV/c}] \oplus 0.3\%/\beta.$$

The expected dE/dx resolution is about 5%.

The particle identification system in the barrel part of the Belle II detector is based on the time-of-propagation (TOP) counters [16]. The basic idea is to detect simultaneously the direction and arrival time of the Cherenkov photons propagating in the quartz radiator. Photons are detected by the Hamamatsu 16 channel MCP-PMTs which have excellent timing and gain performance. This system will provide a good pion-kaon separation in the momentum range up to 3.5 GeV/c.

Identification of charged particles in the forward endcap region will be performed by the proximity-focusing aerogel ring-imaging Cherenkov detector (ARICH). Cherenkov photons emitted in the 2 cm thick aerogel radiator with the refraction index $n \approx 1.05$ pass 20 cm expansion gap and are detected by the array of position sensitive hybrid avalanche photodetectors (HAPD). This system allows to obtain 99% of kaon identification efficiency at 1% of pion misidentification for particles with 4 GeV/c momentum.

The first priority of the electromagnetic crystal calorimeter (ECL) upgrade is the calorimeter electronics modification following the general strategy of the Belle upgrade. The main idea is to shorten the shaping time and to use a pipe-line readout with waveform analysis. A radical way to improve the characteristics of ECL is a replacement of the slow CsI(Tl) in the endcap part where the background rate is extremely high. The baseline for such an option is to use pure CsI crystals instead crystals doped by Tl. The light readout is made with vacuum photopenthodes. The existing mechanical structure is kept. This option has been developing for the last five years and is now well prepared for construction.

A superconducting solenoid providing a magnetic field of 1.5 T as well as an iron yoke will be reused from the Belle detector.

At Belle the KL&Muon detector consisted of the glass-electrode resistive plate chambers (RPC). The upgrade plan implies keeping the RPC system in the barrel part of the Belle II and replacement of the endcap parts to the system based on the plastic scintillators. The endcap KL&Muon detectors consist of the polisterene scintillator bars with implemented WLS fibers for light collection. To detect the reemitted light delivered by fibers, MPPCs of 1.3×1.3 mm area will be used.

The trigger system of the Belle II detector should satisfy the following requirements:

- high efficiency for hadronic events;
- maximum average trigger rate of 30 kHz;
- fixed latency of about 5 μs;
- timing precision of less than 10 ns;
- minimum two-event separation of 200 ns;
- trigger configuration that is flexible and robust.

To meet these requirements, the Belle triggering scheme with new technologies was adopted.

The data acquisition (DAQ) system of the Belle II detector has to cope with a high data flow which will reach 600 MB/sec at full luminosity. The system transfers the data from the front-end electronics through several steps of data processing, and finally to the storage system. The main components of the data flow are the unified data link called the Belle2Link, the common readout platform called COPPER, the event builder system, and the high level trigger (HLT) system.

The detector front-end boards with digitizers are placed near or inside the detector structure and the digitized signals are transferred into COPPER systems through long optical fibers using the Belle2Link. A simple data reduction is performed on each front-end electronics board or on the receiver module of COPPER, while the data formatting and module-level event building is done on COPPER using the on-board CPU. The further event building and reduction are done on the readout PCs and the event builder, and finally processed by the HLT farms for the software event selection.

4 SuperB in Italy

Another project of the SuperB-factory, SuperB, was developed to be constructed in Italy [17]. SuperB is a two-ring, asymmetric-energy ($E^- = 4.18$ GeV, $E^+ = 6.7$ GeV) collider with:

- large Piwinski angle and "crab waist" (LPA & CW) collision scheme;
- ultralow emittance lattices;
- an option of the longitudinally polarized electron beam is possible;
- target luminosity of $10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at the $\Upsilon(4S)$;
- possibility to run at τ/charm threshold with $L = 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

The circumference of the rings is 1258 m, the number of bunches will be from 978 to 1956 for different modes providing the electron (positron) current from 1.9(1.5) to 4.0(3.1) A.

This collider was designed taking into account the following criteria:

- minimizing building costs;
- minimizing running costs;
- reuse of some PEP-II B-Factory hardware (magnets, RF).

The SuperB detector is based on the BaBar detector experience and some elements [18]. The detector contains the silicon vertex tracker based on the silicon pixel and silicon strip detectors, drift chamber, modified DIRK system for particle identification. The barrel calorimeter and superconducting solenoid of the BaBar detector will be used in the new project. Forward and backward regions are still under discussions and study. Two crystal options are studied for forward endcap calorimeter: LYSO or pure CsI crystals.

5 BINP Super-Tau-charm factory project

A Super $c-\tau$-factory (CTF) is a symmetric electron-positron collider operating in the range of center-of-mass (c.m.) energies from 2 to 5 GeV with a high luminosity of about $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [19]. The main goal of experiments at CTF is a study of the processes with c quarks and τ leptons in the final state using data samples that are 3-4 orders of magnitude higher than available today.

The following most important tasks should be listed:

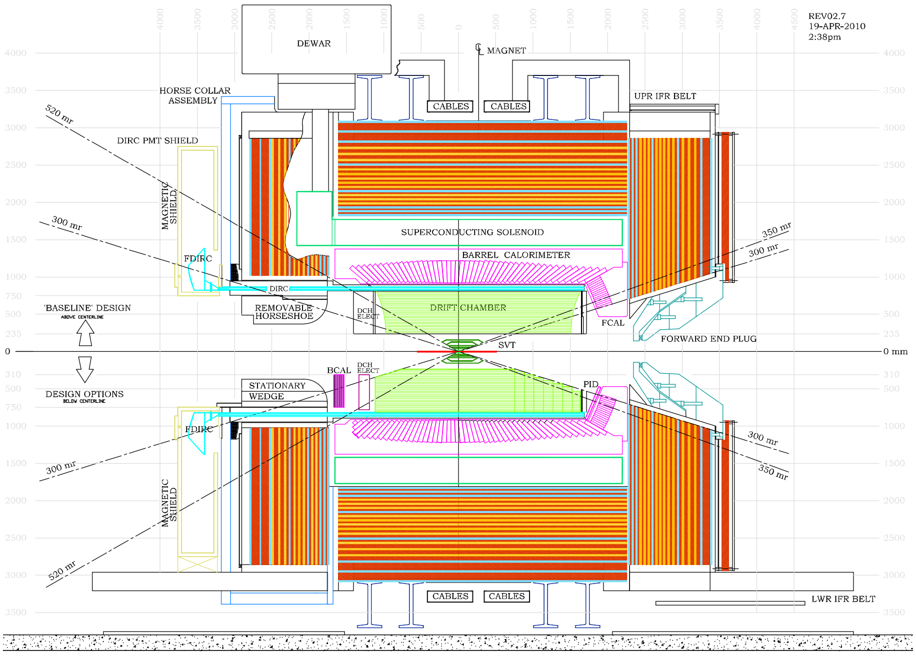

Figure 3: Schematic view of the SuperB detector.

- Precise charm physics:
  - Precise measurement of the charm hadron parameters which are crucial for the high-precision CKM matrix (strong phases, f_D, f_{D_s}, form factors).
  - Study of D^0 mixing, search for CPV in mixing, strong phases for ϕ_3 measurements at SuperB and LHC using C-tau-factory as a unique source of coherent $D^0/\overline{D}^0$ states.
- High-precision τ-lepton physics with polarized beams:
  - Tests of the charged lepton universality, study of the Lorentz structure of τ-decays.
  - Search for CP and T violation in τ-decays.
  - Search for LFV decays ($\tau \to \mu\gamma$).
  - Search for second class currents (using kinematical constraints at threshold).
- High-statistics hadron spectroscopy and search for exotics:
  - Precise charmonium spectroscopy.
  - Spectroscopy of the highly excited charmonium states (complementary to Bottomonium).

– Light hadron spectroscopy in charmonium decays.

The collider of this project implies two rings with a Crab Waist collision scheme and single interaction point with sub-millimeter β_y at IP. The beam energy of each ring is from 1.0 to 2.5 GeV. To keep damping parameters in the whole energy range to optimize the luminosity, four superconducting wigglers are included. A possibility of experiments with the longitudinally polarized electrons in the whole energy range is provided by a special source of polarized electrons and five siberian snakes in the ring. The collider will be equipped by an on-line energy monitoring system based on back Compton scattering of the laser photons which provides an accuracy of $5 \div 10 \cdot 10^{-5}$.

The detector for the BINP C-tau-factory should have ultimate hermeticity; ability of $e/\mu/\pi/K$ separation up to 2 GeV/c; good momentum resolution for charged particles; high efficiency to low p_T tracks, excellent energy resolution of electromagnetic calorimeter including high efficiency to low energy (∼20 MeV) photons. The detector design is now under development.

6 Conclusion

The last decade demonstrated the fruitfulness and efficiency of the flavor "factories" in particle physics. The huge amount of results was obtained at the B-factories, but many new questions arose and the broad field of research will be opened by the superB-factories. It is clear that the superB-factories will produce the information complementary to the LHC. At present, the superKEKB/Belle II project is under construction and other B- and c-tau-factories projects are at a design stage. We can hope for new exciting results in the next decade.

Acknowledgments

I would like to thank organisers for the kind invitation to this impressive Conference as well as for their help and hospitality in Munich. My participation in this Conference was supported by the grant RFBR 11-02-08128.

References

[1] S. Kurokawa *et al.*, Nucl. Instr. and Meth., **A499**, 1 (2003).

[2] PEP-II Conceptual Design Report, SLAC-372, LBL-PUB-5303, CALT-68-1715, UCRL-ID-106426, UC-IIRPA-91-01 (1991).

[3] A. Abashian *et al.*, Nucl. Instr. and Meth., **A479**, 117 (2002).

[4] B. Aubert *et al.*, Nucl. Instr. and Meth., **A479**, 1 (2002).

[5] A. Abashian *et al.*, (Belle Collaboration), Phys. Rev. Lett. **86**, 2509 (2001);
B. Aubert *et al.*, (BABAR Collaboration), Phys. Rev. Lett. **86**, 2515 (2001).

[6] A.Poluektov, Recent EW results from Belle, talk given at Morion EW conference, 2011.

[7] Y. Miyazaki *et al.*, Phys. Lett. B **660** 154 (2008).

[8] K. Hara *et al.*(Belle Collaboration), Phys. Rev. **D82**, 071101 (2010).

[9] B. Aubert *et al.*(BABAR Collaboration), Phys. Rev. **D81**, 051101(2010).

[10] A.Kuzmin, Bottomonium results at Belle, talk at this conference.

[11] S.Eidelman, Status of X, Y, Z states, talk at this conference.

[12] E.Solodov, Recent results on hadrons via Initial State radiation at BABAR, talk at this conference.

[13] V.N. Baier, V.A.Khoze, Sov. Phys. JETP **21** 1145 (1965);
S. Binner, H.J. Kuhn, K. Melnikov, Phys. Lett.B **459** 279 (1999);
M.Benayoun *et al.*, Mod. Phys. Lett. A **14** 2605 (1999).

[14] P. Raimondi, Talk, given at the 2d SuperB workshop, Frascati, http://www.lnf.infn.it/conference/superb06/talks/raimondi1.ppt, 2006.

[15] T. Abe *et al.*, Belle II technical design report, KEK Report 2010-1 (2010).

[16] K. Inami *et al.*, Nucl. Instr. and Meth. **A595**, 96 (2008).

[17] M.E. Biagini *et al.*, http://arxiv.org/abs/1009.6178, 2010;
M. Biagini, talk at XVII SuperB Workshop and Kick-off Meeting, Elba, May 29-June 1, 2011.

[18] E. Grauges *et al.*, INFN/AE 10/4, LAL 10-115, SLAC-R-954, arXiv:1007.4241v1 (2010).

[19] E. Levichev, The project of a Tau-Charm factory with crab waist in Novosibirsk, Phys. Part. Nucl. Lett., **5**, 554(2008);
A. Blinov *et al.*, The Project of Tau-charm factory with crab waist in Novosibirsk. ICFA Beam Dyn. Newslett., **48**, 268 (2009).