

## Super KEKB and Belle II: Status of the KEK Super B Factory

---

**Zdeněk Doležal**\*†

*Charles University in Prague, Faculty of Mathematics and Physics,*

*V Holesovickach 2, Prague, The Czech Republic CZ180 00*

*E-mail: [Zdenek.Dolezal@mff.cuni.cz](mailto:Zdenek.Dolezal@mff.cuni.cz)*

The Belle detector at the KEKB electron-positron collider has collected approximately 800 million  $\Upsilon(4S)$  events in its decade of operation. The KEKB group has proposed Super-KEKB, an upgrade of KEKB to increase the luminosity by two orders of magnitude during a three-year shutdown, with an ultimate goal of  $8 \times 10^{35} \text{cm}^{-2} \text{s}^{-1}$  luminosity.

To exploit the increased luminosity, an upgrade of the Belle detector has been proposed. A new international collaboration Belle-II, is being formed, with a broader participation of European institutes. Super-KEKB and Belle-II were officially placed on the KEK 5-year Roadmap in early 2008. The paper presents physics motivation, basic methods of the accelerator upgrade, as well as key improvements of the detector. More details are given on the DEPFET pixel detector that will be completely built in Europe.

*European Physical Society Europhysics Conference on High Energy Physics, EPS-HEP 2009,*

*July 16 - 22 2009*

*Krakow, Poland*

---

\*Speaker.

†For the Belle II collaboration

## 1. Introduction

Studying phenomena with heavy flavour involved played a crucial role in forming Standard Model (SM). Past decade brought exciting discoveries and new measurements namely at the processes with B-mesons produced. These experiments were carried out at two B-factories (PEP III at SLAC and KEKB at KEK) where asymmetric beams of  $e^+e^-$  collide at the  $\Upsilon$  resonance which predominantly decays to  $B\bar{B}$ .

The detectors built at the B-factories registered an enormous number of 1.5 billion  $B\bar{B}$  pairs. BaBar at PEP III (stopped in 2008) collected  $553 \text{ fb}^{-1}$  integrated luminosity, while Belle at KEK is still in operation and has accumulated  $950 \text{ fb}^{-1}$  until July 2009.

A few examples of the scientific highlights of these factories are

- discovery of CP violation in B system
- measurement of CKM matrix elements
- observation of new charmonium and charmonium-like states
- discovery of  $D^0$  mixing
- many probes of New Physics

## 2. Physics Potential of the Super B factory

Despite the success of the current B-factories many questions yet remain to be answered. Many of the existing measurements have statistical uncertainties higher than their systematics. More statistics would bring a substantial improvement in the accuracy. The most prominent are the parameters of CKM matrix, especially its complex phase, related to the angles of the CKM unitarity triangle. Better determination of  $\phi_2 = \alpha$  would be possible: it is strongly constrained by the  $B^0 \rightarrow \rho^0 \rho^0$ ,  $B^0 \rightarrow \pi^0 \pi^0$  and  $B^0 \rightarrow \rho^0 \pi^0$  decay channels. With  $5 \text{ ab}^{-1}$   $\phi_2$  can be measured with an uncertainty of 2 degrees. The value of  $\sin 2\phi_1 = \sin 2\beta$  can be achieved with a precision of 1% with  $5 \text{ ab}^{-1}$ . Here theory uncertainty is also 1%. Third angle  $\phi_3 = \gamma$  can be measured at least with 5 degree error with  $5 \text{ ab}^{-1}$ .

Precise determination of CKM matrix would yield an important input for SM as well as for New Physics theories. With this precision any discrepancy with the KM scheme will provide insight into NP.

This is not the only way NP can be observed. Many of the studied channels are penguin processes, highly suppressed in the Standard Model. Also CP violation in these processes should be small. Analysis of current Belle and BaBar data show several hints of discrepancies between SM and measured quantities. With statistics increased by two orders of magnitude statistically significant effects could be established.

Let us recall a well known fact from the kaon era: discrepancies between theory and experiment can be a very powerful probe to much higher energy scale. Within the Minimal Flavour Violation scenario, for example, the current limits on the NP contribution to FCNC translate into the mass scale of NP above 100 GeV. Super B factory with the greatly enhanced sensitivity will push this limit by an order of magnitude higher.

These were only a few ideas about physics potential of the upgraded KEKB. More details can be found at [1, 2].

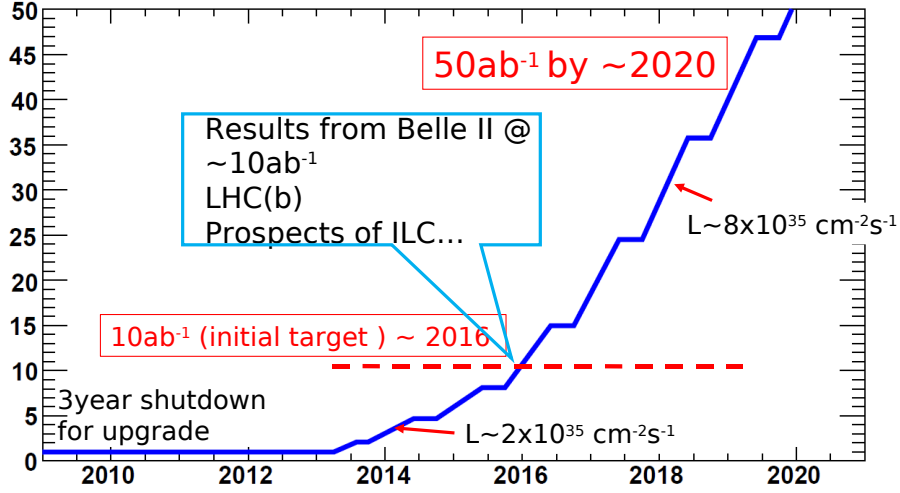


Figure 1: SuperKEKB luminosity prospects

### 3. Accelerator Upgrade

The project of Super-B factory in Japan is based on the upgrade of existing KEKB collider. It is an asymmetric machine using beam of electrons of 8 GeV and positrons of 3.5 GeV. The collider operates since 1999 at the High Energy Accelerator Research Organization KEK in Tsukuba. Its parameters have been constantly improved throughout past decade and now the machine operates in an excellent mode, delivering the highest luminosity in the world  $\mathcal{L}_{\max} = 2.1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ . This has been possible by a crab cavity, installed in 2007, and by other improvements.

However the upgrade plans are much more ambitious (see Fig. 1). After the 3-year shutdown and obvious learning curve the upgraded collider should finally reach  $8 \times 10^{35} \text{cm}^{-2}\text{s}^{-1}$  – 40 times higher than today. This will allow to collect an integrated luminosity of  $50 \text{ab}^{-1}$  by 2020.

How can these values be achieved? Luminosity can be expressed in a following form:

$$\mathcal{L} = \frac{\gamma_{\pm}}{2er_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right) \frac{I_{\pm} \xi_{\pm} R_L}{\beta_y^* R_y} \quad (3.1)$$

Here  $\gamma_{\pm}$  are relativistic factors of electron and positron beam,  $r_e$  is the classical electron radius,  $\sigma_x^*$  and  $\sigma_y^*$  are beam dimensions at the interaction point (IP) in horizontal and vertical directions.  $I_{\pm}$  are the currents of both beams,  $\xi_{\pm y}$  is the beam-beam parameter,  $\beta_y^*$  is the vertical  $\beta$  function at the IP and  $(R_L/R_y)$  is a luminosity reduction factor (or tune shift) which reflects crossing at the finite (non-zero) angle.

To increase luminosity two options have been studied at KEK. One, called *high-current option* requires increase of stored beam current from 1.7/1.4 A to 9.4/4.1 A. At the same time the beam-beam parameter has to be increased from 0.1 to 0.3 or more. Recent simulations and tests show, that this option will not deliver the luminosity expected. Therefore, a work on the second option, called *nano-beam* has started. This is based on the idea of P. Raimondi from Frascati [3] and assumes drastic squeezing the beam size at the IP. This means lowering  $\beta_y^*$  from current value of 6 mm down to 0.27/0.42 mm and also slight increase of currents to 3.6/2.6 A. The comparison of preliminary parameters for both options as well as for the current machine is shown in Table 1.

Parameter	KEKB		SuperKEKB	
	design	achieved	high-current	nano-beam
$\beta_y^*$ [mm]	10/10	5.9/5.9	3/6	0.27/0.42
$\sigma_y^*$ [ $\mu\text{m}$ ]	1.9	1.1	0.85/0.73	0.084/0.072
$\xi_{\pm y}$	0.052	0.101/0.096	0.3/0.51	0.088/0.09
$I_{\pm}$ [A]	2.6/1.1	1.62/1.15	9.4/4.1	3.6/2.6
$L$ [ $10^{34}\text{cm}^{-2}\text{s}^{-1}$ ]	1	2.1	53	80

**Table 1:** Machine parameters for various options (preliminary). For the notation see text

#### 4. Detector Upgrade

The increase of the luminosity will inevitably bring higher occupancy and radiation doses. To cope with them an upgrade of Belle detector is planned. Large number of the detector components will be reused, but many others have to be replaced to prevent compromising the detector performance.

The upgrade of Belle is pursued by a new collaboration called Belle II [4]. This collaboration consisting of around 45 institutes is represented by a spokesperson P. Križan from Ljubljana and the Institute and Executive Boards. The regular collaboration meetings are open and new collaborators are welcome.

Vertex detector, built from the double-sided silicon strip sensors will be replaced by 2 layers of pixels based on DEPFET technology (see next section). They will be followed by four layers of double-sided silicon strip sensors (DSSD). To cope with high occupancy the strips will be read out by fast APV25 chips, designed for the CMS experiment at the LHC. The outer radius of silicon will extend to 14 cm.

A new drift chamber with higher granularity and  $\text{He}/\text{C}_2\text{H}_6$  is under design to measure tracks and  $dE/dx$ .

The key requirement for detectors at Super B factories is an ability to separate kaons from pions. This will be provided by Time-of-Propagation counter in the barrel region and proximity focusing Cherenkov ring imaging counter with aerogel radiators in the endcap. TOP will measure the time that the internally reflected light travels down the quartz bar and one spatial coordinate along the bar.

The main concern for the electromagnetic calorimeter (ECL) is the background increase. Hence the readout electronics will be replaced by a new version equipped with pipeline and waveform sampling. CsI(Tl) crystals in the barrel will remain the same, but pure CsI will be used in the endcap.

The muon system of Belle based on resistive plate chambers will probably remain unchanged in the barrel region. The harsh background conditions in the endcap region will force us to use a scintillator based solution, with the light detected by the Geiger mode APDs.

A new readout system is under design. The main challenge is to handle large data volumes from the pixel detector.

Individual detector components are prototyped and technology choices will be made in the first half of 2010. The detailed description of the detector upgrade can be found in [5].

## 5. DEPFET pixel vertex detector

The most challenging experimental requirement is the detection of the decay point of the short-living B-mesons, relying on high-performance vertex detector. Therefore two inner layers of Belle II vertex detector will use DEPFET pixels.

The DEPLETED Field Effect Transistor structure, provides detection and amplification properties jointly. A MOS or junction field effect transistor is integrated onto a detector substrate. By means of sideways depletion, appropriate bulk, source and drain potentials, and an additional deep-implantation, a potential minimum for electrons is created right underneath the transistor channel. This can be regarded as an internal transistor gate. A particle entering the detector creates electron-hole pairs in the fully depleted silicon substrate. While the holes drift to the rear contact of the detector, the electrons are collected and stored in the internal gate. The signal charge leads to a change in the potential of the internal gate, resulting in a modulation of the channel transistor current. After readout, the signal charges are cleared out of the internal gate. A low noise is obtained because of the small capacitance of the internal gate. Since all charge generated in the fully depleted bulk is collected, the device provides a high signal as well. Both together yield a very large S/N ratio. The DEPFET pixel detectors have been developed for vertex detection at the ILC for many years and have now received high level of maturity [7]. Several beam tests have shown that pixels of  $24 \times 38 \mu\text{m}^2$  pitch achieve intrinsic resolution below  $2 \mu\text{m}$ .

For the Belle II vertex detector the use of very thin ( $50 \mu\text{m}$ ) detectors is planned with the pitch around  $38 \times 50 \mu\text{m}^2$ . The detector geometry is still under discussion, but preliminary radii of the two layers are 1.3 and 2.2 cm. Simulations show, that use of pixels brings a factor of 3 improvement in an impact parameter resolution when compared to originally proposed DSSD. It is expected that the vertex detector will be delivered by the DEPFET collaboration centered in Europe (Czech Republic, Germany, Poland, Spain).

## 6. Conclusions

As shown in the previous sections, exciting physics experiment is under preparation at KEK. Both accelerator and detector upgrade proposals are well under way. An open international collaboration has been created.

## References

- [1] T.E. Browder et al., *On the Physics Case of a Super Flavour Factory*, [hep-ph/0710.3799].
- [2] T.E. Browder et al., *New Physics at a Super Flavor Factory*, [hep-ph/0802.3201].
- [3] C. Milardi et al., *Crab waist collision at DAFNE*, ICFA Beam Dyn. Newslett. 48:23-33, 2009.
- [4] Belle II WWW pages, <http://superb.kek.jp/>
- [5] I. Adachi et al., *sBelle Design Study Report*, [hep-ph/0810.4084].
- [6] J. Kemmer and G. Lutz, *New Semiconductor Detector Concepts*, Nucl. Inst. and Meth. in Phys. Res. A253(1987)365–377.
- [7] J.J. Velthuis et al., *DEPFET, a monolithic active pixel sensor for the ILC*, Nucl. Inst. and Meth. in Phys. Res. A579(2007)685–689.