STATUS AND PROSPECTS OF THE BELLE II EXPERIMENT

L. Santelj (for the Belle II collaboration)
High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

The Belle II experiment at the SuperKEKB e^+e^- collider will start its operation in 2018, with the goal of collecting 50 ab^{-1} of data. This will allow for high precision measurements in the quark flavor sector, opening a window into physics at the energies beyond achievable at the high energy frontier experiments. We present the recent status of the SuperKEKB and the Belle II detector construction, along with some physics prospects.

1 Introduction

The results of B factory experiments, Belle and BaBar, have confirmed the Standard Model (SM) picture of the quark flavor sector and the complex phase of the CKM matrix as the main source of the CP violation. However, at the current level of experimental precision, in most flavor-changing neutral-current processes the new physics (NP) contributions at the level of $\sim 20\%$ compared to the SM are still allowed. In order to further constrain the NP models, or potentially discover NP contributions, a significantly larger amount of data is needed. For this purpose the Belle experiment and the KEKB collider are being upgraded to the Belle II and SuperKEKB, a 2nd generation B factory, which will enable to collect 50 times larger data sample of B decays than available from the B factories.

2 SuperKEKB

The SuperKEKB is an asymmetric energy e^+e^- collider, a successor of the KEKB [1]. It will mostly operate at the energy of the $\Upsilon(4S)$ resonance, which decays into a pair of B mesons ($B\bar{B}$). Due to asymmetric energies of the e^+ (4 GeV) and e^- (7 GeV) beams, the B meson pair is produced with the known Lorentz boost, allowing measurements of lifetimes, mixing parameters, and time-dependent CP violation. The design luminosity of SuperKEKB is 8×10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, about 40 times larger that of KEKB. In order to achieve such a high luminosity, majority of KEKB components needed to be upgraded or replaced, with the guiding idea being to squeeze the beam vertical beta function at the interaction point (IP) down to 1/20 that of KEKB and to increase the beam currents for a factor of 2 (while keeping the same beam-beam parameter). To avoid the degradation of luminosity due to the hourglass effect, which results from squeezing the beta function far below the bunch length, a so-called *nano-beam scheme* of colliding narrow beams with a large crossing angle is adopted. The crossing angle at SuperKEKB is increased to 83 mrad (from 22 mrad at KEKB), which requires the new final-focusing quadrupole magnets to be located much nearer to the IP than at KEKB.

By the beginning of 2016 most of the accelerator main components were installed and in February the first turns and successful storage of beams in both, electron and positron, rings were achieved. The installation and tuning of a new positron damping ring is underway and finally the new super-conducting final-focusing magnets will be installed early next year.

3 The Belle II detector

Due to the much increased event rate and radiation background levels at the SuperKEKB, and in order to take advantage of newly available technologies, an upgrade of the Belle detector is also necessary. As a more detailed description of the Belle II detector can be found elsewhere [2], only a brief description and a current status of the detector main sub-systems is given here.

Closest to the IP is the vertexing detector. A new detector, consisting of two pixelated DEPFET (Depleted P-channel Field Effect Transistor) and four Double Sided Silicon Detector layers, will be installed. The excellent spatial resolution of first two layers and the reduced beampipe radius (1 cm), which allows the first layer to be placed only 1.4 cm from the IP, will greatly improve the vertex position resolution. The comparison of the Belle and expected Belle II vertex resolution is shown in Figure 1. In addition, the efficiency for K_S^0 vertex reconstruction will increase, due to the larger volume of the vertexing detector.

The tracking system, the Central Drift Chamber (CDC), which starts just outside the vertexing detectors is also newly built. It has smaller drift cells and extends to the larger radius than in Belle. Its construction has been completed and the cosmic ray test is ongoing.

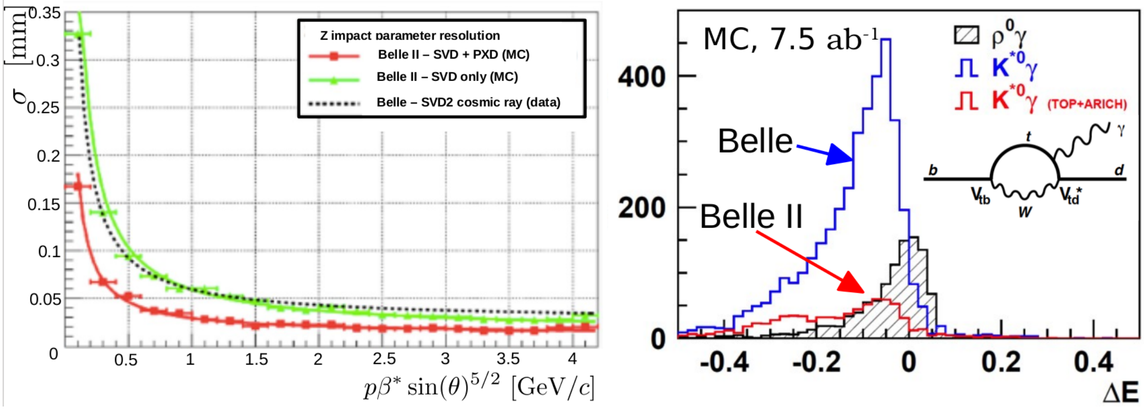

Figure 1 – Left: The Belle II expected resolution of vertex z position. The red line is for tracks with at least one hit in the first two layers, the green line is for tracks with no such hits, and the black dashed line is for the Belle detector. Right: Comparison of the amount of background from $B^0 \to K^{*0}\gamma$ decay to the reconstructed $B^0 \to \rho^0\gamma$ decay at the Belle and Belle II (simulated data).

The particle identification system of the Belle II will consist of two novel systems: the Time of Propagation (TOP) counter in the barrel region and the Aerogel Ring Imaging Cherenkov (ARICH) counter in the forward end-cap region. These two systems will replace Belle's Cherenkov threshold counter (ACC), with the main goal of improving the π/K discrimination. This is of great importance not only for the reconstruction of decay modes (Figure 1, right) but also for the efficiency of flavor tagging algorithms. Very recently the installation of all 16 TOP modules was completed. The ARICH, which is to be installed in the autumn, is being assembled.

On the outer side of PID detectors is the electromagnetic calorimeter (ECL), which reuses CsI(Tl) crystals from Belle, but the readout electronics is newly developed to cope with higher backgrounds. The outermost is K_L^0 and μ detector (KLM). Its endcaps now consist fully of scintillator strips instrumented with silicon photomultipliers and in the barrel part the inner two layers of RPCs were replaced by scintillator strips.

4 Physics prospects of Belle II

The very rich physics program of the Belle II covers measurements of $B^{0,\pm}$ and $B_S^{(*)}$ decays, charm physics, τ lepton physics and hadron spectroscopy. Large variety of measurements will provide a way to observe many potential manifestations of NP, either by over-constraining the flavor sector of the SM, searches for the processes not allowed in the SM (like LFV τ decays), or direct searches for NP at light (MeV-GeV) scales.

Due to the very different environments of e^+e^- and hadron collisions, the physics program of Belle II is largely complementary (and in some cases competitive) to the B physics experiments at hadron colliders, namely LHCb. Some strong points of Belle II are:

- The low background e^+e^- environment allows for high efficiency reconstruction of final states with photons from B, π^0, η, η', etc decays. Neutral K_L^0 are also efficiently reconstructed.
- As the initial state is fully known ($B\bar{B}$), the full reconstruction of one of B mesons in a hadronic or semileptonic state allows for reconstruction of the other B in the final states with neutrinos. In addition, this enables measurements of inclusive decays such as $B^0 \to X_s l^+ l^-, X_s\gamma$.
- As the B mesons of a pair are in an entangled state, the flavor of one can be inferred from the decay products of the other with very high efficiency.
- In addition of producing large sample of B decays, at B factory also D mesons and τ leptons are produced in copious amouts.

While the LHCb will dominate measurements with all charged final states (due to very large samples of $B_{(s)}$ decays), the Belle II will dominate final states with neutrinos or multiple photons. The physics program of the Belle II is in more detail described in reference [3], and a list of projected sensitivities to various flavor observables can be found in reference [4]. Below we list a few selected examples of projected sensitivity at Belle II.

4.1 CP violation in $b \to sss$ penguin decays

Comparing the time-dependent CP asymmetry parameters of penguin dominated $b \to sss$ decays (e.g. $B^0 \to \phi K_S^0, B^0 \to \eta' K_S^0$) with the tree dominated $b \to c\bar{c}s$ decays ($B^0 \to J/\psi K_S^0$) is one of gold-plated observables in search for the new CP violating phases. In the SM the difference of these parameters is expected to vanish within small corrections (as $\mathcal{S}_{b\to c} = \sin 2\phi_1 \simeq \mathcal{S}_{b\to s}$). However, NP can contribute in the loops of $b \to sss$ decays and induce deviations. At the level of current experimental uncertainties no such deviations are observed, but as most of the measurements are statistically limited a significantly larger data sample of the Belle II will take the sensitivity to the new level (see Figure 2 left).

4.2 $B \to D^{(*)}\tau\nu$

The large mass of τ lepton makes the $B \to D^{(*)}\tau\nu$ decay kinematically suppressed compared to the ordinary semileptonic B decays (with e or μ), but at the same time also sensitive to the possible charged Higgs contributions. At the moment there is a large discrepancy of about 4σ between the $B \to D^{(*)}\tau\nu$ decay rates as measured by Belle, BaBar and LHCb, and the SM prediction. As can be seen from the middle plot of Figure 2, the Belle II is expected to reduce the measured uncertainties of $R(D^{(*)})$ by factor of ~ 5, down to the level of current theory precision.

4.3 $B \to K^{(*)}\nu\nu$

The rare $B \to K^{(*)}\nu\nu$ decays are one of the theoretically cleanest FCNC processes, and as such provide an important test of the SM. In addition, they are very interesting in the view of recent *LHCb anomalies* in exclusive $b \to sl^+l^-$ decays. Provided that the rates of these decays are at the level as predicted by the SM, the Belle II should be able to reach the level of $B \to K^*\nu\nu$ (Figure 2 right), while the current constraints are an order of magnitude above it.

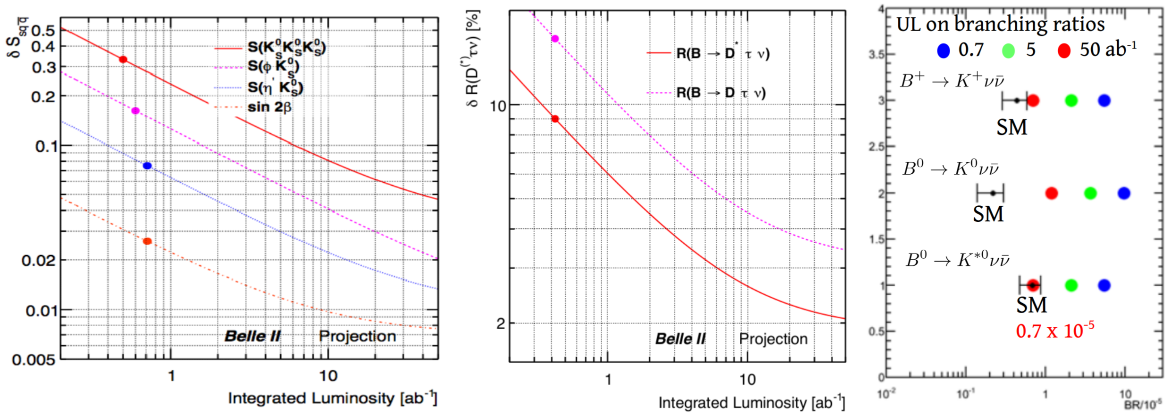

Figure 2 – Left: Projected sensitivity of the Belle II measurements of time-dependent CP violation parameters in $b \to s$ penguin dominated B decays. Middle: Projected sensitivity of the $R(B \to D^{(*)}\tau\nu)$ measurements. Right: Projected sensitivity of measurements of $B \to K^{(*)}\nu\nu$ branching fractions.

5 Schedule and Summary

The Belle II experiment, as the next generation B factory, will in the next few years become a new major player at the precision frontier of NP searches. As mentioned, the first beams have just circulated around the SuperKEKB tunnel and the accelerator commissioning is ongoing. At this point a simple commissioning detector (BEAST II) is placed around the interaction region to measure and understand the background levels. The Belle II (without the vertexing detector) will be moved to the beam line at the end of 2016, and collision tuning of accelerator and data taking will start in late 2017. Finally, the installation of vertexing detector and the full physics runs are planned for the second half of 2018. From then on, Belle II plans to collect ~ 10 ab^{-1} of data per year, reaching its goal of ~ 50 ab^{-1} by 2024.

The amount of collected data will significantly exceed the data available from the B factories already at the very early stages of the Belle II operation, so stay tuned for loads of new physics (which is just around the corner).

References

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