Searches for New Physics at the Belle II Experiment

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The Belle II experiment at the SuperKEKB collider is an upgrade of the Belle / KEKB experiment. It will start physics data taking from 2018 and with $\sim 40$ times luminosity, its goal is to accumulate $50 \text{ ab}^{-1}$ of $e^+e^-$ collision data. The physics programs have a wide range of areas for new physics, such as more constraints on CKM Unitarity Triangle, searching for charged Higgs, direct CPV, Lepton Flavour Violation and dark matter. In this monograph, we will review the current status of Belle II and SuperKEKB construction and introduce the main physics opportunities at this facility.

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1 Introduction

B factory is an $e^+e^-$ collider which runs at the $\Upsilon(4S)$ resonance energy to produce B meson pairs. The major B factories are Belle running at KEKB and BaBar running at PEP-II. They have totally collected 1.5$ab^{-1}$ of $e^+e^-$ collision data. With that data sample, they’ve reached fruitful physics achievements in a wide range of areas, such as the CKM angle measurement, $|V_{cb}|$ and $V_{ub}$ measurement, semileptonic and leptonic B decays, rare B decays, $\tau$ physics, $D^0$ mixing and CPV, B physics at the $\Upsilon(5S)$, two-photon physics and new resonances.

Belle II experiment at SuperKEKB collider is an upgrade of Belle to search for New Physics, which is physics beyond the Standard Model (SM), by plan to take 50$ab^{-1}$ $e^+e^-$ collision data. The SuperKEKB asymmetric electron positron collider can provide a clean environment for producing B meson pairs via $\Upsilon(4S)$ resonance decay. Its designed luminosity is $8 \times 10^{35} cm^{-2}s^{-1}$, which is about 40 times larger than the KEKB collider. The 50 $ab^{-1}$ overall integrated luminosity corresponds to 55 billion of $B\bar{B}$ pairs, 47 billion of $\tau^+\tau^-$ pairs and 65 billion $c\bar{c}$ states.

In this article, we will introduce the Belle II / SuperKEKB experiment, the opportunities for new physics on it, and the current status and future plan of the experiment.

2 Belle II / SuperKEKB

For achieving the 40 times luminosity compared with KEKB, many parts of the accelerator are upgraded. The most important part is the beam size. The beam bunches are significant squeezed to obtain the so-called nano-beam. The beam energies will be changed slightly to have a less boosted center-of-mass system.

Most subdetectors of Belle will be upgraded accordingly for Belle II apparatus, as shown in Figure 1. This includes the newly designed vertex detection system (PXD and SVD), a drift chamber with longer arms and smaller cells, a completely new PID system which consists of TOP detector at the barrel and ARICH detector in the forward end, the electro-magnetic calorimeter (ECL) with upgraded crystals and electronics, and upgraded $K_L-\mu$ detection system (KLM). The trigger system, DAQ, and software systems are also upgraded accordingly. With the high radiation intensity comes with the high luminosity, the Belle II detector has to be capable of handling higher beam related backgrounds.

3 Opportunities for New Physics on Belle II

With much larger data set, there are lots of opportunities for New Physics searches on Belle II.
3.1 Constraining the CKM UT

With higher integrated luminosity, the precision of CKM Unitarity Triangle (UT) parameters could be significantly improved, as shown in Figure 2.

![Figure 2: Comparison of the current precision of CKM UT (left) and the predicted precision with the 50 $\text{ab}^{-1}$ data collected with Belle II (right).](image)

3.2 $b \to s\gamma$ Decays

In Standard Model (SM), the decay $b \to s\gamma$ is suppressed. The CP asymmetry for $B^0 \to K_S\pi^0\gamma$ is predicted as about 0.04. With the precision predicted with the large data set from Belle II, it is possible to distinguish between different SUSY models by measuring the asymmetry \cite{1}, as shown in Figure 3.
3.3 Charged Higgs: $B^+ \rightarrow \tau^+ \nu$ and $B \rightarrow D^{(*)}\tau\nu$

The decays $B^+ \rightarrow \tau^+ \nu$ [2] and $B \rightarrow D^{(*)}\tau\nu$ are very sensitive to a charged Higgs. In some NP models, charged Higgs can be exchanged in addition to the W boson. The branching fractions of these decays could be enhanced, and this can be checked by using the large data sample from Belle II.

3.4 Direct CPV: $B \rightarrow K\pi$

Standard Model predicts the CP asymmetry difference $A_{CP}$ between $B^0 \rightarrow K^+\pi^-$ and $B^+ \rightarrow K^+\pi^0$ should be zero, but the measurement of the $K\pi$ channels shows that $A_{CP}$ is not zero [3].

The independent sum rule predicts that [4]:

$$A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+} \frac{B(B^+ \rightarrow K^0\pi^+\tau_B^0)}{B(B^0 \rightarrow K^+\pi^-\tau_{B^+})} = A_{CP}^{K^+\pi^0} \frac{2B(B^+ \rightarrow K^+\pi^0\tau_{B^0})}{B(B^0 \rightarrow K^+\pi^-\tau_{B^+})} + A_{CP}^{K^0\pi^0} \frac{2B(B^0 \rightarrow K^0\pi^0)}{B(B^0 \rightarrow K^+\pi^-)}.$$  

With data set from Belle II, the measurement precision will allow us to compare the $A_{CP}$ predicted by this equation and the measured $A_{CP}$ to check whether there is New Physics.

3.5 $\tau$ Lepton Flavour Violation

The Lepton Flavour Violation decays are highly depressed by SM, in a branching fraction as $10^{-25}$, but they could be enhanced by some New Physics scenarios. The red dots in Figure 4 shows the sensitivity for some LFV decays in Belle II [5]. The branching fraction of the decays is within the capability of the experiment.
3.6 Dark Sector

It’s possible to search dark matter in accelerator. One possibility is the dark photon $A'$. Its mass is predicted in the range of MeV to GeV. There’re two ways to detect dark photon: probing leptonically decaying dark photons through mixing, or probing sub-GeV dark matter in invisible decays. The upper limits for dark photon measurement for different experiments are shown in Figure 5. With much higher integrated luminosity, Belle II has an advantage to search dark photon $A'$.

![Figure 4: The $\tau$ Lepton Flavour Violation measurement sensitivity by Belle II and other experiments.](image)

![Figure 5: The upper limit for dark photon measurement for different experiments.](image)

4 Status and Schedule

The SuperKEKB accelerator is now at the final stage of construction and the upgrade of the Belle II detector is on going. There are three phases in commission and operation of Belle II. In phase 1 at the early 2016, the commissioning of various components will start without rolling-in the detector. In phase 2 for middle 2017, Belle II detector will be partly commissioned to take test physics data without the vertex detector. Finally, in phase 3, the Belle II detector with full apparatus is going to take physics data, which is expected at the end of 2018. By 2024, the full data sample of $50 \text{ ab}^{-1}$ will be taken.

5 Summary

B factories like Belle and BaBar have proved to be excellent for flavour physics. As an upgrade, the Belle II / SuperKEKB experiment could play an important role in the searching for New Physics. With the much larger data set, Belle II has a rich physics program, which makes it possible to study the channels with missing energy
and neutral particles in the final states. Now the accelerator and detector are under
collection, and the physics data taking will start at the end of 2018.

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