PROCEEDINGS OF SCIENCE

The Belle II experiment Status and Prospects

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The Belle II experiment at the SuperKEKB energy-asymmetric e^+e^- collider is a substantial upgrade of the B factory facility at the Japanese KEK laboratory. The design luminosity of the machine is $8 \times 10^{35}\,\mathrm{cm^{-2}s^{-1}}$ and the Belle II experiment aims to record $50\,\mathrm{ab^{-1}}$ of data, a factor of 50 more than its predecessor. With this data set, Belle II will be able to measure the Cabibbo-Kobayashi-Maskawa (CKM) matrix, the matrix elements and their phases, with unprecedented precision and explore flavor physics with B and charmed mesons, and τ leptons. Belle II has also a unique capability to search for low mass dark matter and low mass mediators. From February to July 2018, the machine has completed a commissioning run, achieved a peak luminosity of $5.5 \times 10^{33}\,\mathrm{cm^{-2}s^{-1}}$, and Belle II has recorded a data sample of about $0.5\,\mathrm{fb^{-1}}$. Regular operations, with full detector, have started in March 2019. Here, we reported the status of the Belle II detector, the results from the early data, and the prospects for the study of rare decays, in the quest of uncovering New Physics.

The 21st international workshop on neutrinos from accelerators (NuFact2019)
August 26 - August 31, 2019
Daegu, Korea

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1. Introduction

The decay of B meson can improve the knowledge of the topic such as the mixing, the rare decays and the CP violation, even the New Physics beyond the SM. The experiments with high yield of $B\bar{B}$ are designed as "B factory", which is also produce a mass of $D\bar{D}$ meson pairs and $\tau\bar{\tau}$ lepton pairs.

The Belle experiment [1] and the BaBar experiment [2] operated from 1999 to late of 2000s, and both of them are designed as first generation of B factories which produced a plenty of B meson pairs at electron-positron accelerator. In 2001, time-dependent CP violation (tCPV) of B meson decay is found by both experiments. Later, the direct CPV was found at $B^0 \to K\pi$ decays in 2004.

There are still some following problems left in the B factory experiments: 1. New CPV phases in quark sector. 2. Multiple Higgs bosons. 3. Flavor-changing neutral current beyond the SM. 4. Lepton flavor violation beyond the SM. To solve the above problems, an experiment with much higher luminosity than first generation B factory are needed. The SuperKEKB accelerator[3] and the Belle II experiment[4] have potential to explore the above problem in floavor physics with target of recording data of 50 ab^{-1}.

2. SuperKEKB and Belle II

The SuperKEKB accelerators consists of two storange ring: The electron (positron) accelerator operating at energy of 7.007 GeV (4.0 GeV) which is called as high energy ring (low energy ring), or "HER" ("LER"). The SuperKEKB shrinks the vertical beam size (σ_y) to tens of nanometer at the collision point, which is called as "nano-beam". The currents of each beam are only twice than ones of KEKB. As a result, a designed instantaneous luminosity is $8.0 \times 10^{35}\ cm^{-2}s^{-1}$, which is about 40 times than one of KEKB accelerator.

The Belle II detector is the successor of the Belle detector, and the track efficiency and particle identification are largely improved by the several updates of the subdetectors.

2.1 Commissioning runs

On the road to high luminosity, SuperKEKB and Belle II have the commissioning schedule which ensures the stability of beam operation and the enduribility of subdetector under radiation damage. Phase 1 operated from Feb. to June, 2016, and this is the first SuperKEKB beam operation without the Belle II detector. The BEAST detectors were installed to monitor beam background neart interaction point. Phase 2 operated from April to July, 2018 with the most part of Belle II detector (without VXD) and the QCS magnet. The beam collisions are firstly operated at phase 2, and data of integrated luminosity 0.5 fb^{-1} are recorded.

Phase 3 operates from March, 2019 to Feb. 2019 with the full Belle II detector, as one layer of the PXD detector and the SVD detector are installed in the end of 2018. The collision of SuperKEKB started from the end of March, 2019 and the full Belle II detectors have recorded the collision data of 6.49 fb^{-1} until June, 2019. As the beta function value is shrinked to 2 mm, the peak luminosity has reached $1.2 \times 10^{34}\ cm^{-2}s^{-1}$. The main target of this commisioning run are the increasing the luminosity under a steady beam condition, and the recorded data have validated the beam steability and the detector performance. The validations are as following: 1. Fig.1 shows

$\sigma_{68}(\Delta d_0)$ distributions of two-particles evets. The differences (Δd_0) of measured parameter d_0 of the two trackers distribute within $14.2\pm0.1\,\mu$m at 68% confidence level in data, and this is known as the resolution of the impact parameter by PXD, SVD and CDC subdetectors. So, the alighment and the calibration of beam and inner detectors are proven well. 2. Separation of Kaon/pion by the TOP detector is proven by the decay of $D^{*+} \to D^0[K^-\pi^+]\pi^+$ data. If the likelihood ratio $R_{K/\pi} = \frac{L_K}{L_K+L_\pi}$ is set to be 0.6, the pion mis-identification fraction is ~ 0.10. 3. The B^0-$\bar{B}^0$ mixing is measured by decay mode of $B^0 \to D^{*-}l^+\nu$. The unmixing fraction is observed to have an oscillation in time Δt. This observation proves the ability of precise measurement for vertex of B decays, so the it validated the ability to measure the time-dependent CP violation.

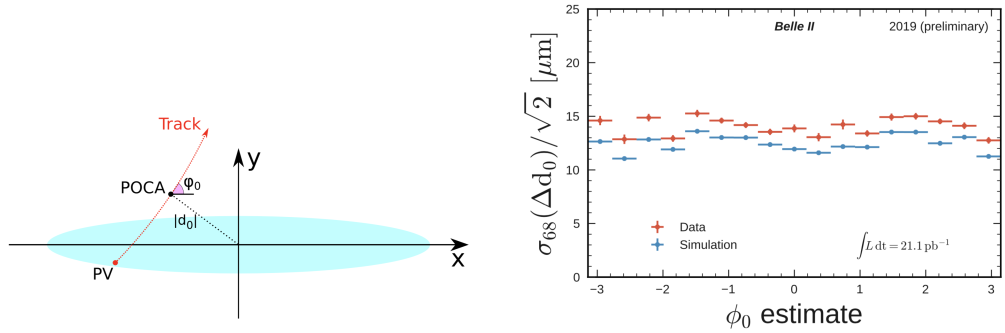

Figure 1: Left figure shows the coordinate system on x-y plane. For a track from primary vertex (PV), the transverse impact parameter (d_0) is the signed distance between the point of cloest approach (POCA) and the z axis, and φ_0 is the azimuthal angle of the track momentum at the POCA. Right figure shows the 68% interval $\sigma_{68}(\Delta d_0)/\sqrt{2}$ of differences Δd_0 of tranverse impact parameters for two tracks. The two tracks t_1, and t_2 at two-track event are produced back-to back in CM, and the tranverse impact parameters, $d_0(t_1)$ and $d_0(t_2)$ have opposite sign. A difference $\Delta d_0 \equiv d_0(t_1)+d_0(t_2)$ dividev by $\sqrt{2}$ is an estimation of d_0 resolution.

3. Physics Prospects

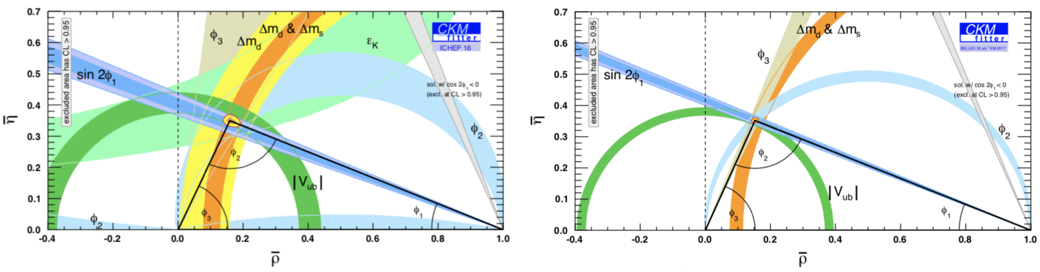

Figure 2: Left figure is the CKM Unitary Trangle fit today by CKMfitter group. Right figure is the CKM UT fit which is extrapolated to the $50\,\text{ab}^{-1}$ luminosity for an SM-like scenario from [5].

Belle II have covered the following physical topics: semi-leptonic and leptonic B decays, radiative and electroweak penguin B decays, time dependent CP violation in B decays, measurement of the CKM UT angle φ_3, hadronic B decays, Charm physics, quarkonium, tau and low multiplicity physics, dark sector, and beyond the SM and global fit analyses. The details of the physics can be read at "The Belle II Physics Book"[5]. In this talk, we only talked about some selected topics. Fig.2 shows the CKM unitary triangle global fit for today and the future if Belle II has reached integrated luminosity of $50\,\text{ab}^{-1}$. Belle II will measure parameters of UT triangle precisely by observing a plenty of B meson decays. For example, the branching ratio of $B^+ \to \tau^+\nu_\tau$ decay relates to value of $|V_{\mu b}|$. As the Belle II has developed an new analysis tool which is called "Full Event Interpreter", an decay with multiple missing masses such as $B^+ \to \tau^+\nu_\tau$ can be reconstructed well with lower background contamination. Another example is $B^0 \to \pi^0\pi^0$ decay, as the direct CP asymmetry A_{CP} is the function of φ_2. Belle II has ability to detect π^0 with lower momentum than LHCb. The precise measurement of φ_2 from the mode is expected at Belle II.

4. Rediscoveries of early Belle II data

At comminisioning run, Belle II has re-discovered particles and some B meson decays modes to validate its performance using data of integrated luminosity of few fb^{-1}.

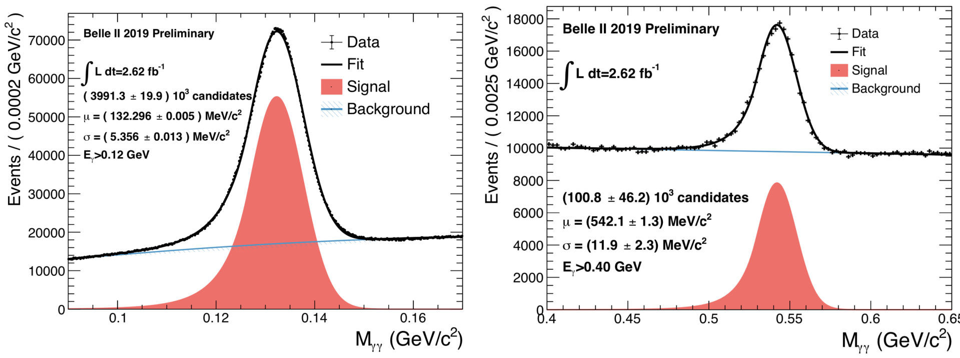

Figure 3: Invariant mass spectrum of $\gamma\gamma$ at phase 3 data. Left plot shows a clear peak at π^0 mass value. The colored peak is a fitted result of π^0 signal, which is a Crystak Ball function. Right plot shows a clear peak at η mass value. The signal is also fitted with a Crystal Ball function.

In Fig.3 , we can see that a clear peak of π^0 (left) and a clear peak of η(right) are at the $\gamma\gamma$ invariant mass spectrum. This shows an ability of γ-ray detection of the ECL detector. In addition, other particles such as J/ψ, Λ^0 and D^0 are re-discovered by combinations of charged particles at invariant mass spectrum.

Fig.4 shows the B mesons reconstructed from $B^{0/\pm} \to D^{0(*)} + h^{0/\pm}$, where h is π or ρ,and $D^{0(*)}$ is reconstructed from K^0_S, $K^\pm$, $\pi^\pm$. There is a clear peak at $\Delta E = 0.0$ GeV and $M_{bc} = 5.28\ \text{GeV/c}^2$, so the B mesons can be reconstructed from neutrals and charged particles efficiently.

5. Conclusion

SuperKEKB and Belle II are on the road of achieving high luminosity, and commisioning run of collision started from 2018. At the phase 3 run, the beam operation increase its luminosity by shrinking the beta function value steadily. The collected data of phase 3 proved the good performance of the SuperKEKB beam and the Belle II detector. Belle II confirmed rediscoveries of some particles and B mesons from data of integrated luminosity of few fb^{-1}. Belle II aim the precise measurement of CKM UT parameters and search for new physics beyond the SM in near future.

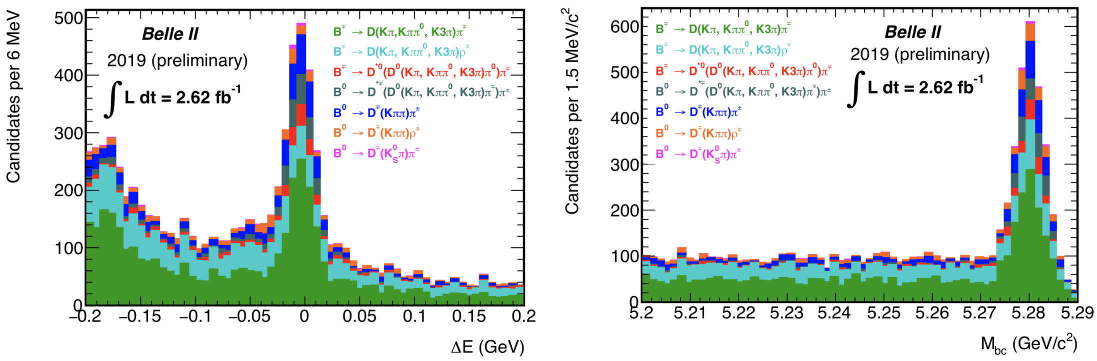

Figure 4: Distribution of ΔE (left) and M_{bc}(right) for all $B^{0/\pm} \to D^{0(*)} + h^{0/\pm}$ candidates in collision data.

References

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