Status and prospects of Belle II at SuperKEKB

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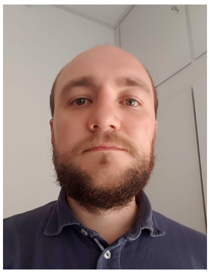

The Belle II experiment at SuperKEKB accelerator has started collecting the first data from e^+e^- collisions. The dataset collected this year will be used for detector studies that will be coupled with physics analyses, such as searches for the dark photon. In 2019, Belle II commissioning will enter the final phase and detector will start data taking with gradually increasing instantaneous luminosity. In this talk, we review some of the key Belle II features and analysis techniques together with their applications. Using the Full Event Interpretation algorithm, by 2021 Belle II will be able to improve world average measurement of $\mathcal{R}(D^{(*)})$ by a factor of 2. Around the same time, high sensitivity to time-dependent CP Violation measurements will allow to improve $b \to qqs$ results by a factor of 2. Belle II has an ambitious programme in τ physics, aiming to move down the upper limit of the rate of Charged Lepton Flavour Violating τ decays by an order of magnitude. Belle II has an unique reach for many heavy quarkonia measurements, such as energy scans of e^+e^- collisions at energies above open flavour limit that will reveal the structure of heavy bottomonium-like resonances.

1 Belle II experiment at SuperKEKB

The Belle II experiment [1] is a 4π detector collecting data in e^+e^- collisions produced by the SuperKEKB accelerator located in Tsukuba, Japan. While the SuperKEKB accelerator utilizes the tunnels of its predecessor, the KEKB accelerator, and will reuse some of KEKBs components, it is a new machine otherwise, designed to operate with double the beam current. Focusing magnets of the SuperKEKB will ensure a beam width of ~ 50 nm at the point of bunch crossing, which is 20 times smaller than that of KEKB. Higher beam current and more compact interaction region will allow for instantaneous luminosity of $8.0 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$, 40 times higher than KEKB.

Belle II inherits the design of the Belle detector with major improvements in all of the subsystems. The Belle II interaction point is surrounded by the vertex detector that will provide precise measurements of charged-particle production vertices with a resolution that improves upon that of Belle by a factor of two. The vertex detector is surrounded by the central drift chamber (CDC), which is used for the track reconstruction. The aerogel Cherenkov counters and time-of-propagation counters, in conjunction with the CDC, provide particle identification.

The technology used in Belle II is expected to improve significantly π and K separation. Electromagnetic showers are detected by an array of CsI(Tl) crystals located inside the solenoid coil. The outermost layer of the detector is composed of 14 iron layers alternating with scintillators and serves for K_L and μ detection.

SuperKEKB and Belle II are in the Phase II of commissioning now. The detector is currently recording collisions at $\Upsilon(4S)$ energy and low instantaneous luminosity with the BEAST II detector installed in place of the vertex detector. BEAST II contains a slice of the vertex detector and radiation monitors used in beam background studies [2]. Alongside tuning of the detector and accelerator, Belle II will collect 20fb^{-1} of data. Later this year, BEAST II will be replaced by the vertex detector and Belle II will start Phase III of data taking in 2019.

2 Physics at Phase II

The Belle II hardware trigger (L1 trigger) consists of orthogonal trigger lines (no comma) that generate trigger decisions based on outputs from different subdetector-systems. These lines trigger on a variety of elementary signatures, in particular on high-energy clusters in ECL and back-to-back muon tracks. In Phase III, the outputs of the L1 will be processed by the high-level trigger (HLT) that will be tuned for B-physics. During the Phase II, the lower instantaneous luminosity allows for operations without HLT, that means that a large number of low-multiplicity events will be recorded which will open the path for physically-significant and unique measurements.

2.1 Dark Photon

Cosmological observations suggest the existence of dark matter (DM) [3], but this is yet to be directly observed in laboratories. One of the minimal DM scenario implies that the portal to the DM sector, the dark photon, can be produced directly in e^+e^- collisions together with an initial state radiation photon. Such a process will have very clean signature in the detector single photon in the detector and recoil mass distribution for this process will peak on the mass of the dark photon. The main backgrounds of this measurement are $e^+e^-(\gamma)$ and $\gamma\gamma(\gamma)$ with all particles but a single γ escape the detection. These backgrounds can be constrained by a thorough study of ECL blind spots, which will be an important part of the detector commissioning. Search for the single photon at the Phase II will allow reducing the current upper limit on the dark photons strength of kinetic mixing [4] for dark photons below 1 GeV/c^2 by a factor of two.

3 Physics at Phase III: some of the key techniques, features and measurements

3.1 Full event interpretation and $\mathcal{R}(D^{(*)})$

Belle II is expected to gather 50ab^{-1} of data in e^+e^- collisions by 2025. This dataset will be used for a plethora of measurements covering a vast variety of phenomena, from precise measurements of CKM parameters to direct searches of beyond the Standard Model objects [5]. One of the unique features of the Belle II experiment (with respect to the existing collider experiments) is a possibility of full event interpretation. At Belle II, B-mesons are produced in pairs during the decay of the $\Upsilon(4S)$. If one of the B-mesons ("tag meson) decays to the fully-reconstructible final state, and another ("signal meson) decays to the final state with missing energy, it is possible to constrain the lost momentum using known 4-momentum of initial state and reconstructed 4-momenta:

$$p_{miss} = (p_{beam} - p_{tag} - p_{signal}). \quad (1)$$

Full event interpretation is crucial for analyses of B decays with neutrinos in the final state. The most intriguing analyses of this kind are the measurements of $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ variables defined as

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}l\nu_l)}, \ l = e, \ \mu \quad (2)$$

since their current values show 4σ tension with their SM predictions. Signal ($B \to D^{(*)}\tau\nu_\tau$), normalisation ($B \to D^{(*)}l\nu_l$) and background decay candidates populate different areas in the signal lepton momentum versus invariant mass of the missed energy (squared 4-vector of the missed momentum) phase space. Using a two-dimensional fit of this plane, Belle II will reach current world average precision with only 5ab^{-1} of data.

3.2 Time dependent CP violation measurements

Another strong side of B-factories are measurements of the time dependent CP violation in B^0 decays. Here, the tag meson decaying to the flavour eigenstate is partially reconstructed to define a decay vertex. The signal meson is fully reconstructed and the decay time information Δt is obtained from the known boost and the distance between the two vertices along the z-axis. Reduced boost of the Belle II experiment with respect to its predecessor is compensated by increased vertex resolution, yielding a 20% better Δt resolution.

Amplitude of time-dependent CP asymmetry in $b \to ccs$ decays gives direct input to measurements of the CKM angle ϕ_1, but it is also interesting to measure corrections to the amplitude in penguin-dominated $b \to qqs$, $(q = u, d, s)$ decays. $B \to \eta' K^0$ is a particularly promising channel of this kind since it is has among the strictest QCD predictions $\Delta S^{QCDF} = 0.01 \pm 0.01$ [6] that are far more precise than results of the current measurements $\Delta S^{Data} = -0.05 \pm 0.06$ [7]. Signal decay candidate in this analyses is reconstructed from several final states, most of them containing multiple neutral particles. Due to the low track multiplicity in the event, Belle II can effectively handle such cases (compared to hadron machine experiments). This, together with the good sensitivity to the time-dependent CP violation phenomena, will allow Belle II measurement of ΔS in $B \to \eta' K^0$ decays with 5ab^{-1} to be twice as precise as the current world average.

3.3 τ at Belle II

Belle II is not only a B-factory, but also a τ factory: e^+e^- collisions produce almost equal amounts of prompt $\tau^+\tau^-$ and $b\bar{b}$ pairs, so by the end of data taking Belle II is expected to have recorded 45 billion of $e^+e^- \to \tau^+\tau^-$ events. This dataset will be sufficient to put many world-best constraints on branching fractions of charged lepton flavour violating decays. Belle II will be able to put an upper limit of $Br(\tau \to \mu\gamma)$ to 10^{-9}, testing several non-SM scenarios by way of this [8, 9].

3.4 Out of the resonance

Most of the time Belle II will collect data from e^+e^- collisions at $\Upsilon(4S)$ energy, but a few percent of the dataset will be collected away from the $4S$ resonance, in its vicinity. Energy scans above $b\bar{b}$ threshold will allow to perform production cross-section measurements for $h_b(nP)\pi\pi$, $\Upsilon(nS)\pi\pi$ and $B^{(*)}_{(s)}\bar{B}^{(*)}_{(s)}$ final states. These cross-sections are crucial to understand the inner structure of bottomonium-like hadrons.

4 Conclusion

At 0:38 am (GMT+09:00), April 26, 2018, Belle II has recorded and reconstructed the first hadronic event in e^+e^- collisions (see Figure 1). The data taking with low luminosity will

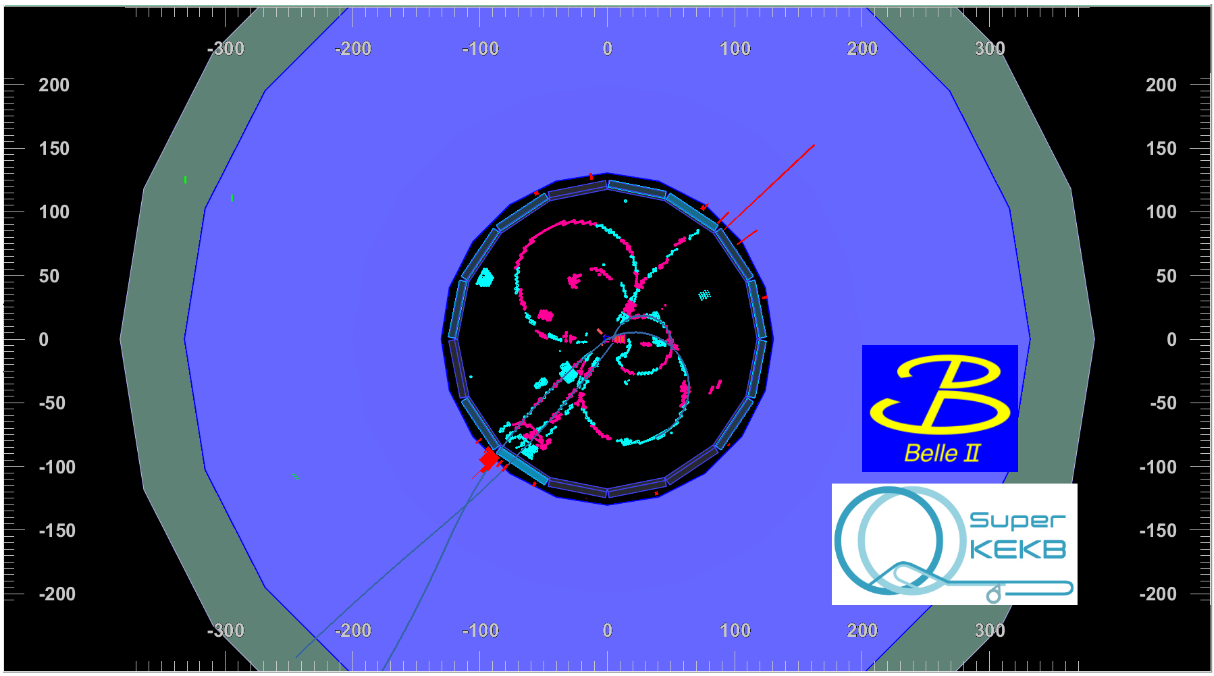

Figure 1 – Event display of the first hadronic event recorded and reconstructed at Belle II

continue until June 2018 and the collected data will be used for beam background studies, detector calibration and an early physics program. The data taking will resume in 2019 with gradual increase of the instantaneous luminosity and by 2025, Belle II is expected to collect 50ab^{-}1 of data in e^+e^- collisions. This dataset will allow for addressing many of the hottest topics in flavour physics and perform a set of unique searches beyond the Standard Model.

References

1. T. Abe *et al., arXiv:1011.0352.*
2. *P.M.Lewis et al., arXiv:1802.01366.*
3. *P.A.R.Ade et al. (Planck Collaboration), Astron. Astrophys.* **594**, *A13 (2016).*
4. *J.P.Lees on behalf of the BaBar Collaboration,* Phys. Rev. Lett. **119**, *131804 (2017).*
5. *E. Kou, P. Urquijo, The Belle II collaboration, and The B2TiP theory community, In preparation.*
6. *M. Beneke,Phys. Lett.* **B620**, *143150 (2005).*
7. *Y. Amhis et al. (HFLAV),Eur.Phys.J.* **C7712**, *895 (2017).*
8. *G. Cveti, C. Dib, C. S. Kim, and J. D. Kim,*Phys. Rev. *D* **66**, *034008 (2002).*
9. *C. Yue, Y. Zhang, L. Liu,Phys.Lett.* **B547**, *252-256 (2002).*