Status and prospects of Belle II at SuperKEKB

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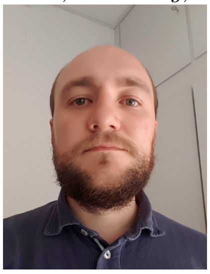

Belle II experiment at SuperKEKB accelerator started to collect the first data from e^+e^- collisions. The dataset collected this year will be used for detector studies that will be coupled with the physics analyses, such as searches for the Dark Photon. In 2019, Belle II commissioning will enter the 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, Belle II will be able to improve world average measurement of $\mathcal{R}(D^{(*)})$ by the factor of 2 by 2021. By the same time, high sensitivity to Time-Dependent CP Violation measurements will allow to improve $b \to qqs$ results twice. 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 the order of magnitude. Belle II has 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

Belle II experiment [1] is a 4π detector collecting data in e^+e^- collisions produced by SuperKEKB accelerator located in Tsukuba, Japan. While SuperKEKB machine is built in tunnels of KEKB accelerator and reuse some of the KEKB's components, it is mostly new machine designed to operate with the factor of 2 higher beam current. Focusing magnets of the SuperKEKB will ensure ~ 50 nm beam width 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 $8.0 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-2}$, 40 times higher than KEKB.

Belle II inherits design of the Belle detector with major improvements in all of the subsystems. Belle II interaction point is surrounded by the silicon vertex detector that will provide precise measurement of charged-particles trajectories near their production space-point with twice better resolution than at Belle. The vertex detector is surrounded by the central drift chamber used for reconstruction and identification of charged particles. The drift chamber is complemented by aerogel Cherenkov counters and time-of-propagation counters. 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 outter-most layer of the detector is composed from 14 iron layers altering with scincillators and serves for K_L and μ detection.

SuperKEKB and Belle II are in the Phase II of commissioning now. Detector is recording collisions at $\Upsilon 4(S)$ energy and low instantaneous luminosity with the BEAST II detector installed in place of the vertex detector. BEAST II contains slice of the vertex detector and radiation monitors used in beam background studies [2]. Alongside with 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

Belle II hardware trigger (L1 trigger) consists of orthogonal trigger lines, that generate trigger decision basing on outputs from the different subsystems. These lines trigger on variety of elementary signatures, in particular on high-energy clusters in ECL and back-to-back muon tracks. In Phase III, 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 high number of low-multiplicity events will be recorded which opens the path for the physically-significant and unique measurements.

2.1 Dark Photon

Existence of the Dark Matter (DM) is implied by the cosmological observations [3], but not yet confirmed in laboratories. Some of the minimal DM scenarios imply it can be produced directly in e^+e^- collisions together with an initial state radiation photon. Such process will have very clean signature in the detector - single photon in the detector - and distribution of recoil mass of the photon will peak on the mass of the Dark Boson. The main backgrounds of this measurement are $e^+e^-(\gamma)$ and $\gamma\gamma(\gamma)$ with all particles but single γ escape the detection. These backgrounds can be constrained by thorough study of ECL blind spots, that is important part of the detector commissioning. Search for the single photon at the Phase II will allow to reducing twice the current upper limit on the Dark Photon's strength of kinetic mixing [4] for dark photons below 1 GeV/c^2.

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 measuremtns covering wast variety of phenomena, from preciese measuremetns fo CKM parameters to direct searches of beyond the Standard Model objects [5]. One the unique features of Belle II experiment (with respect to the existing collider experiments) is an possibility of the full event interpretation. At Belle II, B-mesons are produced in pairs during the decay of the $\Upsilon 4(S)$. 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 the missing energy, it is possible to constraint the lost momentum using known 4-momentum of initial state and reconstructed 4-momentums as

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

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 R(D) and R(D*) variables defined as

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

since their current values show 4σ tension with the SM predictions. Signal ($B \to D(D*)\tau\nu_\tau$), normalisation ($B \to D(D*)l\nu_l$) 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 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, tag meson decaying to the flavour eigenstate is partially reconstructed to define decay vertex. Signal meson is fully reconstructed and decay time information Δt is obtained from the known boost and distance between the two vertices along the z-axis. Reduced boost of the Belle II experiment with respect to its ancestor is compensated by increased vertex resolution, yielding in 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 particularly promising channels 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 candidates in this analyses are reconstructed from several final states, most of them containing multiple neutral particles. Due the low track multiplicity in the event, Belle II can effectively handle such cases (comparing 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 more precise than the current world average.

3.3 τ at Belle II

Belle II is not only 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 expecting to have recorded 45 billions of $e^+e^- \to \tau^+\tau^-$ events. This dataset will be sufficient to put many world-best constraints on branchings of charged lepton flavour violating decays. Such, Belle II will be able to put upper limit of $Br(\tau \to \mu\gamma)$ to 10^{-9}, testing by this several non-SM scenarios [8, 9].

3.4 Out of the resonance

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

4 Conclusion

At 0:38am (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 continue until the June 2018 and collected data will be used for the beam background studies, detector calibration and an early physics program. The data taking will be resumed 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 to address many hottest topics in flavour physics and perform a set of unique searches beyond the Standard Model.

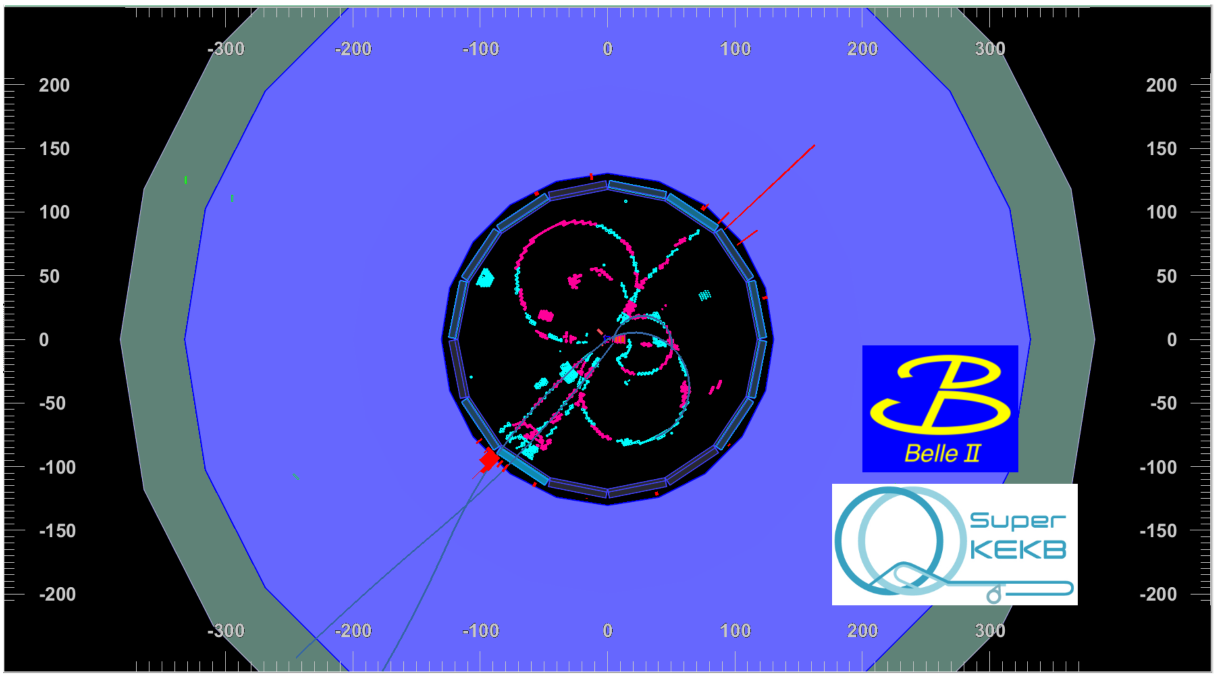

Figure 1 – Event display of the first hadroinc event recorded and reconstructed at Belle II

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