PROCEEDINGS OF SCIENCE

Recent results from the Belle II experiment

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Belle II is a flavor physics experiment at the SuperKEKB e^+e^- collider. It has accumulated 380 fb^{-1} of data as of May 2022, and has obtained several results with the world's best precision or sensitivity. Recent results mainly with 190 fb^{-1} of data are presented.

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1. Introduction

Belle II [1] is a flavor physics experiment at KEK with the SuperKEKB asymmetric e^+e^- collider (4 GeV on 7 GeV) [2], aiming at collecting an integrated luminosity of 50 ab^{-1}. As of May 2022, SuperKEKB achieved the world's highest luminosity of 4.1×10^{34} cm^{2}s^{-1}, and Belle II accumulated 380 fb^{-1} of data. Recent results from Belle II are reported below[1]

2. Lifetime Measurements

While SuperKEKB is operated at an energy of $\Upsilon(4S)$ to produce B mesons, it also produces many charm hadrons; hence Belle II is a good place to study charm hadrons. Belle II has better vertex resolution than Belle and BaBar, because the vertex detector of Belle II is located at a closer position to the interaction point (IP), which benefits the lifetime measurement. Belle II measures the lifetime of D^0 and D^+ using 72 fb^{-1} of data [3], and that of Λ_c^+ with 207 fb^{-1} of data [4].

The D^0, D^+ and Λ_c^+ candidates are reconstructed with the decay chains of $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$, $D^{*+} \to D^+(\to K^-\pi^+\pi^+)\pi^0$ and $\Lambda_c^+ \to pK^-\pi^+$. The lifetime is determined from a fit to the decay time t calculated by $t = m(\vec{L} \cdot \vec{p})/|\vec{p}|^2$, where m, $\vec{L}$ and $\vec{p}$ are the mass, momentum, displacement of the decay point from the IP of D^0, D^+ or Λ_c^+. Figure 1 shows the decay time distribution for Λ_c^+. The lifetimes are obtained to be $\tau(D^0) = 410.5 \pm 1.1 \pm 0.8$ fs, $\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1$ fs and $\tau(\Lambda_c^+) = 203.20 \pm 0.89 \pm 0.77$ fs. These are the most precise measurements to date.

Measurement of the mixing frequency Δm and lifetime of B^0 is also done using 190 fb^{-1} data. The decay time difference Δt of the two B mesons produced in pair is calculated from the decay vertices. The hadronic decay $B^0 \to D^{(*)0-}h^+$ ($h = \pi, K$) is used for the signal B, while the other B is used for the flavor tagging. Figure 2 shows the Δt distribution and asymmetry. We obtain $\tau(B^0) = 1.49 \pm 0.013 \pm 0.008$ ps and $\Delta m = 0.516 \pm 0.008 \pm 0.005$ ps^{-1}. The result has similar uncertainty as Belle [5] and BaBar [6], and will be further improved by including semileptonic B decays $B \to D^*\ell\nu$ ($\ell = e, \mu$) for the signal B.

3. Measurements on $\phi_3(= \gamma)$

The CKM unitarity triangle angle $\phi_3(= \gamma)$ can be measured using the interference between the tree $b \to c\bar{u}s$ and $b \to u\bar{c}s$ processes. Therefore, ϕ_3 becomes a reference of the Standard Model, and the precise measurement of ϕ_3 is necessary in the study of New Physics contribution in the CKM fit.

Measurement of ϕ_3 with $B^- \to D(K_S^0h^+h^-)h^-$ is performed with 711 fb^{-1} and 128 fb^{-1} data by Belle and Belle II [7]. The analysis uses a model-independent binned Dalitz plot technique, and the strong-phase parameters of the D decay are taken as external inputs. We obtain $\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ$, where the third uncertainty is due to external inputs. The improvement from the previous Belle result [8] comes not only from the larger data set but also from the addition of $D \to K_S^0K^+K^-$ decays and the improvement of K_S^0 selection and background suppression. The

[1]Charge conjugate modes are implied unless explicitly stated. First and second uncertainties are statistical and systematic.

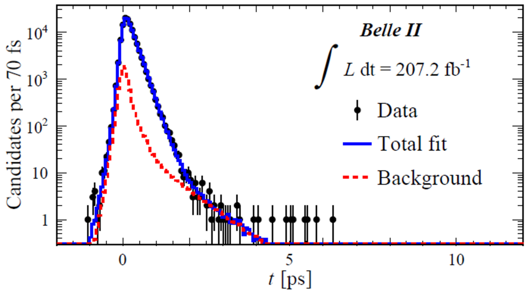

Figure 1: Decay time distributin of Λ_c^+

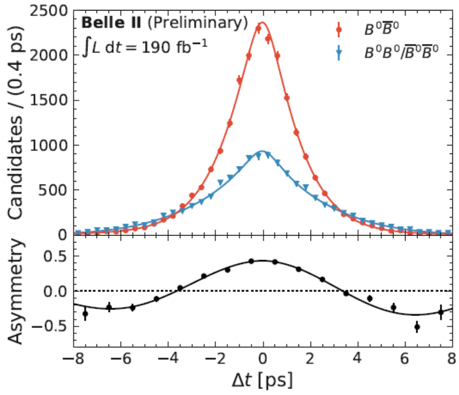

Figure 2: Δt and asymmetry distribution in the $B^0\bar{B}^0$ system.

uncertainty of this measurement is expected to be reduced to 3° with 10 ab^{-1} data by adding more D final states [9].

4. Semileptonic B Decays

Studies of semi-leptonic B decays $B \to \pi e\nu$ [10] and $B^0 \to D^*\ell\nu$ are performed with 190 fb^{-1} data. In both analyses, one of the two B mesons is reconstructed with more than 10000 hadronic decays with "Full Event Interpretation" technique [11]. The tagging efficiency is around 0.5% for B^+, which is much higher than the conventional tagging algorithms.

For $B \to \pi e\nu$, the signal is extracted from the fit to the square of the missing mass, $M^2_{\rm miss}$, in 3 bins of q^2 (= $m^2_{e\nu}$). Figure 3 shows an example of the $M^2_{\rm miss}$ distribution. We obtain $\mathcal{B}(B^0 \to \pi^- e^+\nu) = (1.43\pm0.27\pm0.07)\times10^{-4}$ and $\mathcal{B}(B^+ \to \pi^0 e^+\nu) = (8.33\pm1.67\pm0.55)\times10^{-5}$, from which $|V_{ub}|$ is extracted to be $(3.88 \pm 0.45) \times 10^{-3}$. For $B^0 \to D^*\ell\nu$, the signal is extracted by applying the selection $-0.5 < M^2_{\rm miss} < 0.5$ GeV^2. Figure 4 shows the $M^2_{\rm miss}$ distribution for $B^0 \to D^{*-}\mu^+\nu_\mu$. From the fit to the differential branching fraction as a function of $w = (m_B^2 + m_{D^*}^2 - q^2)/(2m_B m_{D^*})$, $|V_{cb}|$ is estimated to be $(37.9 \pm 2.7) \times 10^{-3}$. These results are consistent with PDG [12], but are still statistically limited. More precise measurements are expected with the larger dataset.

5. Study of Dark Sector

Despite of the intensive studies through various experiments, the nature of the Dark Matter is still unknown. Dark matters with the $O(10-1000)$ GeV mass has been intensively searched based on the WIMP hypothis, but no hint has been seen so far. The possibility of the dark matter in sub-GeV region gathers attention. Belle II is an ideal place to study it, and a few results have been reported with initial data of Belle II. One of them is a search for the dark Higgstrahlung process.

This search has been done using 8.34 fb^{-1} of data [13]. The process in search is $e^+e^- \to A'(\to \mu^+\mu^-)h'$ assuming the next-to-minimal dark photon model. Here, A' is the dark photon, which couples to the SM photon via kinetic mixing parameter ϵ, and h' is the dark Higgs boson.

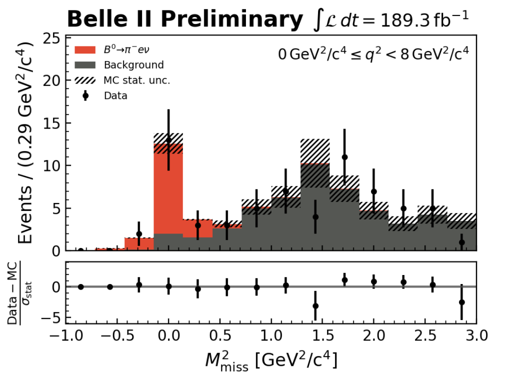

Figure 3: M^2_{miss} for $B^0 \to pi^- e^+ \nu_e$ with $0 < q^2 < 8$ GeV.

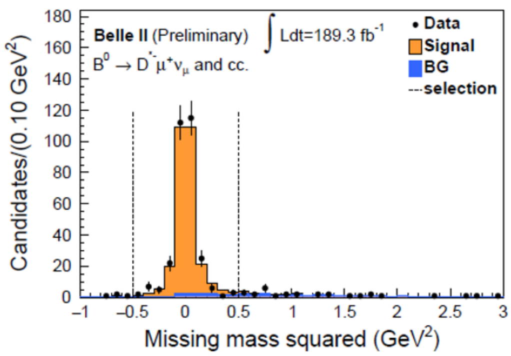

Figure 4: M^2_{miss} for $B^0 \to D^{*-}\mu^+\nu_\mu$.

We consider the scenario with $M_{h'} < M_{A'}$, where $M_{h'}$ ($M_{A'}$) is the h' (A') mass. In this scenario, h' becomes long-lived and thus invisible. The final state of this process is $\mu^+\mu^-$ from A' only, and the recoil mass corresponds to $M_{h'}$. The search of the signal is done in 9003 partially overlapping search windows in the dimuon and recoil masses.

Figure 5 shows the 90% CL upper limit on the cross section of $e^+e^- \to A'h'$ as a function of $M_{A'}$ and $M_{h'}$ masses. This can be translated to the limit on $\epsilon^2 \times \alpha_D$, where α_D is the coupling of A' to h', as shown in Fig. 6. Limit is set in the region $1.65 < M_{A'} < 10.5$ GeV and $M_{h'} < M_{A'}$, which was not explored previously.

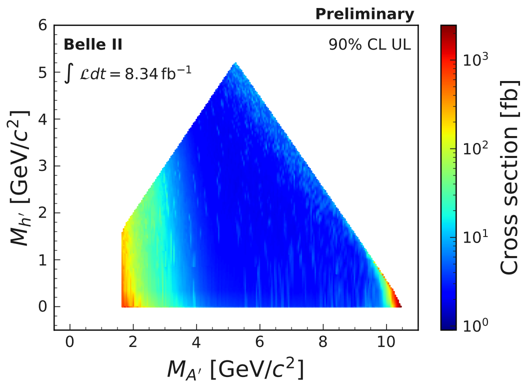

Figure 5: 90% CL upper limit on the cross section of $e^+e^- \to A'h'$ as a function of $M_{A'}$ and $M_{h'}$.

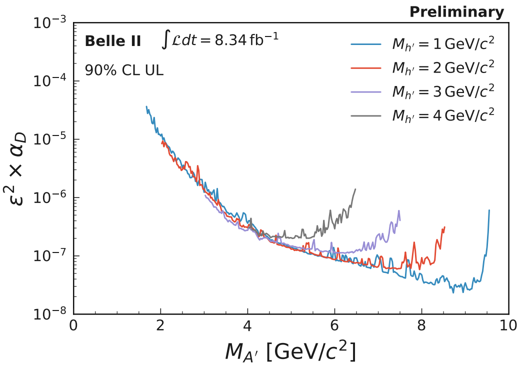

Figure 6: 90% CL upper limit on $\epsilon \times \alpha_D$ as a function of $M_{A'}$.

6. Conclusion

Although the accumulated integrated luminosity is still smaller than Belle and BaBar, Belle II has obtained several results with the world's best precision or sensitivity. There are results that show the potential of Belle II, and only a part of them are covered here. More results from Belle II are expected to come in near future.

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