The *Belle II* Experiment

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Abstract. The *Belle II* experiment will analyze the products of the e^+e^- collisions at the center-of-mass energy corresponding to the mass of the $\Upsilon(4S)$ produced at the high-luminosity B-Factory SuperKEKB. The experiment will collect 50 ab^{-1}, allowing to probe the Standard Model at a never-reached level, and to put very stringent constraints in the space of parameters of many New Physics models. I report here the expected precision that *Belle II* will reach with the full dataset on a selection of observables in the charm and B physics sectors.

1. Introduction

The most important result achieved by the B-Factories BELLE and *BABAR* was the confirmation of the CKM mechanism as the one responsible for CP violation (CPV) in the Standard Model (SM), which earned Kobayashi and Maskawa the Nobel prize in 2008. This measurement was only one of those performed with the 1.5 ab^{-1} of data that they collected together. Most of the measurements have confirmed the SM predictions, other measurements are in tension with the predicted value, but the size of the disagreement is not large enough to open to a particular New Physics (NP) scenario. Moreover, there are a certain number of observations that are not well accommodated in the SM, e.g. the size of the asymmetry between matter and antimatter. In order to find an explanation for these observations, a significantly larger data sample is needed. *Belle II* sits on the intensity frontier path to NP, with its data it will be possible to search for NP beyond the TeV scale.

2. The High-Luminosity B-Factory SuperKEKB and The Detector *Belle II*

In order to increase the data sample by almost two orders of magnitude, a new accelerator concept is needed. SuperKEKB is an upgrade of the KEKB accelerator, based on the nano-beam scheme [1], and it is designed to reach the highest luminosity ever reached of 8×10^{35}cm^{-2}s^{-1}. Some of the new beam features will have a direct impact on the physics analyses. The size of the beams on the transverse plane at the interaction point will be reduced by a factor 20 with respect to KEKB. The luminous region is used as a constraint in the decay and therefore physics analyses will benefit from this reduction. The center-of-mass boost is reduced by roughly a factor two with respect to the previous B-Factories, increasing the detector hermiticity, that is crucial in missing-energy analyses. The consequent reduction of the vertices separation (Δz) deteriorates the resolution of the Δt[2] that is recovered by a completely new vertex detector. Finally, the factor 40 higher instantaneous luminosity will imply higher background rates (and consequently

[1] for the *Belle II* Collaboration.
[2] the difference of decaying time of two particles, e.g.: B and $\bar{B}$, or mother and daughter particles.

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higher detector occupancy, radiation damage, fake hits) and higher event rate (demanding very high DAQ and computing performances).

The *Belle II* detector is a general purpose detector and it is described in detail elsewhere [2]. The tracking system is composed by a 6-layer silicon Vertex Detector (VXD) and the Central Drift Chamber. The particle identification is performed by the AEROGEL Cherenkov ring imaging and the time-of-flight sub-detectors. The K_L^0 and muon detector is installed outside the electromagnetic calorimeter. The detector has been developed in order to reach similar or better performances that the former BELLE one. Improvements are expected, in particular in the interaction point and secondary vertex resolution and in K_S^0 and π^0 reconstruction.

3. Expectations on B Physics

The B-Factories are perfect environments to study B physics: in the e^+e^- collision a boosted $Y(4S)$ is produced and immediately decays in a couple of entangled B mesons. Depending on the signal signature, the *other* B (the tag-side B) is fully or inclusively reconstructed. The full reconstruction is used with weak signal signatures (e.g. two neutrinos in the final state), and it is cleaner but less efficient than the inclusive reconstruction. A reconstructed B meson sample with high-efficiency flavour/charge tagging is available for the analyses. With the full reconstruction tool missing-energy analyses are straightforward.

3.1. The Unitary Triangle and CP Violating Phases

One of the great achievements of the B-Factories is the measurement of the angles and sides of the Unitary Triangle (UT). *Belle II* will continue improving the constraints on the UT. In particular, the expected precisions with the full statistics on the three angles α/ϕ_2, β/ϕ_1, γ/ϕ_3 are 1°, $0.4^\circ, 1.5^\circ$, respectively. Improvements on the sides measurements are also expected: between 1.2% and 1.4% for $|V_{cb}|$ and 2.4% and 3% for $|V_{ub}|$.

The size of CPV in the SM is orders of magnitude smaller that the one needed to explain the asymmetry between matter and antimatter. One of the missions of *Belle II* will be to search for new CP violating phases. One place to look for additional CP violating phases are B^0 decays through penguin processes in ϕK_S^0, $\eta' K_S^0$ and $K_S^0 K_S^0 K_S^0$. The expected sensitivity on the parameter S[3] as a function of the integrated luminosity is shown in Figure 1. The expected

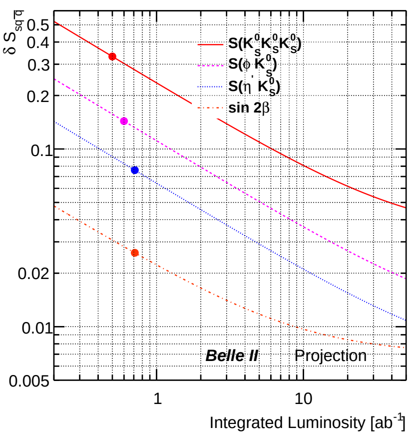

Figure 1. Expected error on the parameter S as a function of the integrated luminosity for different final states.

[3] the equivalent of $\sin 2\beta/\sin 2\phi_1$.

precision with the full dataset should be good enough to distinguish different theory models [3].

3.2. Right-Handed Currents and Rare B decays

In certain New Physics scenarios, helicity-suppressed amplitudes (e.g. $b \to s\gamma_R$) can be enhanced. The sensitive observable is represented by the parameter S mentioned above. Analysing the full dataset *Belle II* should be able to either exclude or confirm this enhancement. For example, the experimental precision on S for the $K^0_S\pi^0\gamma$ final state is expected to be around 0.035, while certain theory models predict a value of 0.5 [3].

Rare decays as $B \to h^{(*)}\nu\nu$, with $h = K, \pi$ are very clean from the theoretical point of view, and this makes them golden places where to look for New Physics contributions. Standard Model expectations on the branching ratio for channels with pion in the final state are orders of magnitude below the expected upper limit reachable with the full *Belle II* statistics (around 10^{-5}) and therefore any significant signal would be a sign of NP. The SM branching ratios for channels with kaons in the final states are higher, e.g. *Belle II* should be able to measure the branching ratio of the decay $B \to K^{*0}\nu\nu$ with an error of 30% with the full dataset.

3.3. Charged Higgs

The 2-Higgs doublet model can be tested in $B^+ \to \tau^+\nu$ and $B^0 \to D^{(*)-}\tau^+\nu$ decays. In the case of the $\tau^+\nu$ final state, the analysis consists in fully reconstructing the tag-side B, and then measure the branching ratio of the signal channel. This measurement put constraints in the $(\tan\beta, m_{H^\pm})$ space, and with the 50ab^{-1} of *Belle II*, the allowed region will considerably shrink. In the $D^{(*)}\tau\nu$ case, the observable is a ratio of branching ratios:

$$R = \frac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}\ell\nu)} \quad (1)$$

The current measurements of R are in tension with the SM showing an excess of around 3σ. *Belle II* will be able to confirm the excess already with 5 ab^{-1}. The expected precision with the full dataset is expected to be 2% (3.5%) for the $D^*\tau\nu$ ($D^*\tau\nu$) final state.

4. Charm Physics Expectations

B-Factories are excellent places to study charm physics since the production of charm is at the same level as the production of bottom. The analyses techniques are quite different since there is not a coherent production of $D^0 - \bar{D}^0$: flavour tagging is done selecting D^0 from D^{*+} decays and there is no access to relative strong phases. As for B physics, time-dependent analysis are possible, as well as D meson full reconstruction for neutrinos and inclusive analyses.

4.1. Mixing and Indirect CPV

One of the most interesting things in charm is the study of mixing and CP violation. The reason for this is that the possible new physics must couple to up-type quarks, opposed to what should happens for all the other mixing systems. This means that the information on NP that lies in the charm sector is complementary to what we can find in the B and kaon systems.

Belle II will be essential in the direct measurement of the mixing parameters x and y through the time-dependent analysis on the Dalitz Plot of the $D^0 \to K^0_S\pi^+\pi^-$ decays. The sensitivity on the mixing parameters should reach the level of 0.05% for y and 0.08% for x. In this analysis the CP violating parameters $|q/p|$ and $\phi = \arg(q/p)$ will also be directly measured. This analysis will be limited by the systematic error associated to the modelling of the decays on the Dalitz Plot.

In Figure 2 the expected allowed region for the mixing and CP violating parameters after the combination of all measurements including the expectations for *Belle II* full dataset results by the Heavy Flavour Average Group. The allowed regions are much smaller than the current ones, attesting the significant contribution of *Belle II* to the charm sector.

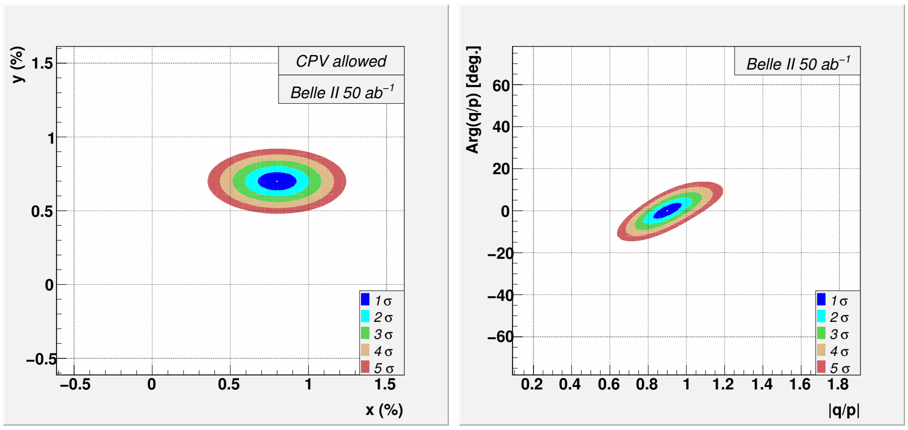

Figure 2. Expected allowed regions for the mixing (left) and the CP violating (right) parameters with *Belle II* full statistics. The central values are $(x, y) = (0.8, 0.7)$ and $(|q/p|, \phi|) = (0.9, 0)$.

4.2. Time-Integrated CPV

The search for CP violation in charm decays will be also performed in the measurement of the A^f_{CP} asymmetries defined as:

$$A^f_{CP} = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})} \tag{2}$$

The most important contribution of *Belle II* will be on channels with neutrals in the final state such as $D^0 \to K^0_S\pi^0, \pi^0\pi^0, K^0_S\eta$ and $D^+ \to \pi^+\pi^0$. The expected sensitivity will reach 0.03% (for the $K^0_S\pi^0$ final state).According some models [4] direct CPV in radiative decays ($D^0 \to \phi\gamma, \rho\gamma$) can be enhanced above 1%, corresponding to the level of the expected experimental sensitivity. It would therefore be possible to measure it with *Belle II* full dataset.

5. Conclusions

Flavour physics will continue to play a fundamental role in the process of understanding Nature in the next decade. The *Belle II* physics program is very rich, it can open a many NP scenarios. The complementarity with LHCb physics is established, both experiments are needed in case something unexpected will be found. Moreover, the existence of observables with comparable precision will be an important check for both experiments. The construction of the accelerator is expected to be completed by mid 2015, while *Belle II* construction is ongoing. We expect the first physics run in 2017, with the full dataset of 50 ab^{-1} collected in the next 6 years.

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