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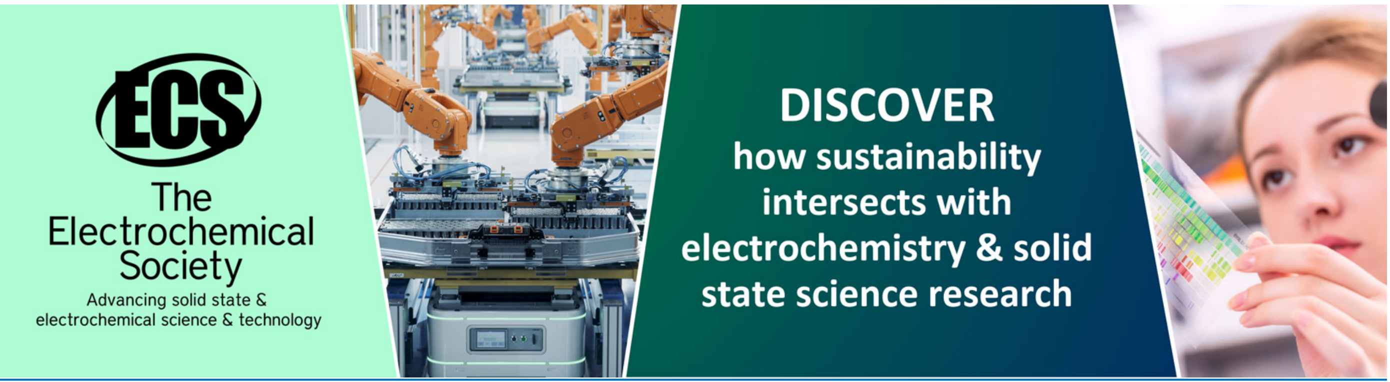

Prospects for measurement of $R(D)$ and $R(D^*)$ in Belle II.

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Abstract. The ratios $R(D) = \mathcal{B}(\bar{B} \to D\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B} \to D\ell^-\bar{\nu}_\ell)$ and $R(D^*) = \mathcal{B}(\bar{B} \to D^*\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B} \to D^*\ell^-\bar{\nu}_\ell)$, measured by the Babar, Belle and LHCb experiments, show a 3.9σ deviation with respect to the Standard Model Prediction. If it is confirmed, it would be a clear evidence for Physics Beyond the SM. Here we present a description of the Belle II experiments, and the plans to measure the ratios mentioned.

1. Introduction

The Babar and Belle experiments, known as B factories, collected more than 1.5 ab^{-1} of e^+e^- collisions, mainly at $\Upsilon(4S)$ resonance. These samples allowed to discover CP violation on B mesons, and to confirm to high precision the Cabbibo-Kobayashi-Maskawa mechanism for quark mixing in the Standard Model. However, besides the success of the SM, there is room to New Physics, as the $R(D)$ and $R(D^*)$ anomalies show. Semileptonic decays are an excellent tool to look for evidence of New Physics beyond the Standard Model (NP). In particular, lepton universality tests can help to probe the SM predictions. In the SM, the Branching fractions $\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)$ and $\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)$ are different only due to the mass of the charged lepton involved. Figure 1 show the tree level diagram of the possible decays. Assuming leptonic universality, the theoretical prediction for the ratios $R(D)$ and $R(D^*)$ [3, 4], are given by

$$R(D) = \frac{\mathcal{B}(\bar{B}\to D\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}\to D\mu^-\bar{\nu}_\mu)} = 0.299 \pm 0.011, \quad (1)$$

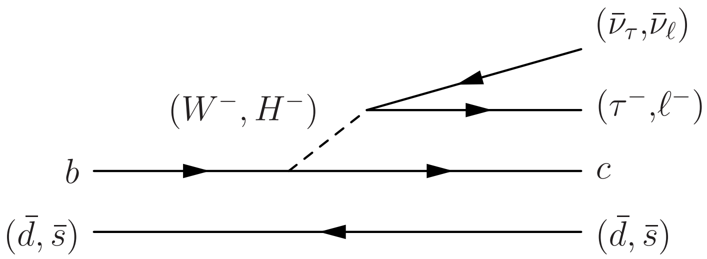

Figure 1. Tree level Feynman diagram showing the possible scenarios for the decays $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ and $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$.

Table 1. Summary of experimental measurements of semitauonic B decays [5].

Experiment	Tag method	τ mode	$R(D)$	$R(D^*)$	ρ
Belle 07	inclusive	$e\nu\nu$, $\pi\nu$	0.38 ± 0.11	0.34 ± 0.08	–
Belle 10	inclusive	$\ell\nu\nu$, $\pi\nu$			
BaBar 12	hadronic	$\ell\nu\nu$	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$	-0.27
Belle 15	hadronic	$\ell\nu\nu$	$0.375 \pm 0.064 \pm 0.026$	$0.293 \pm 0.038 \pm 0.015$	-0.32
Belle 16	semileptonic	$\ell\nu\nu$	–	$0.302 \pm 0.030 \pm 0.011$	–
Belle 17	hadronic	$\pi\nu$, $\rho\nu$	–	$0.270 \pm 0.035 \pm 0.027$	–
LHCb 16	–	$\ell\nu\nu$	–	$0.336 \pm 0.027 \pm 0.030$	–
HFAG	–	–	$0.407 \pm 0.039 \pm 0.024$	$0.304 \pm 0.013 \pm 0.007$	-0.20
SM	–	–	0.300 ± 0.008	0.252 ± 0.003	–

$$R(D^*) = \frac{\mathcal{B}(\bar{B}\to D^*\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}\to D^*\mu^-\bar{\nu}_\mu)} = 0.252 \pm 0.003. \quad (2)$$

However, the current experimental measurements shown a 3.9σ deviation from the SM prediction. We show in the figure the different measurements from BaBar, Belle and LHCb. A new measurement from a Belle II experiment, could help to resolve or confirm this discrepancy.

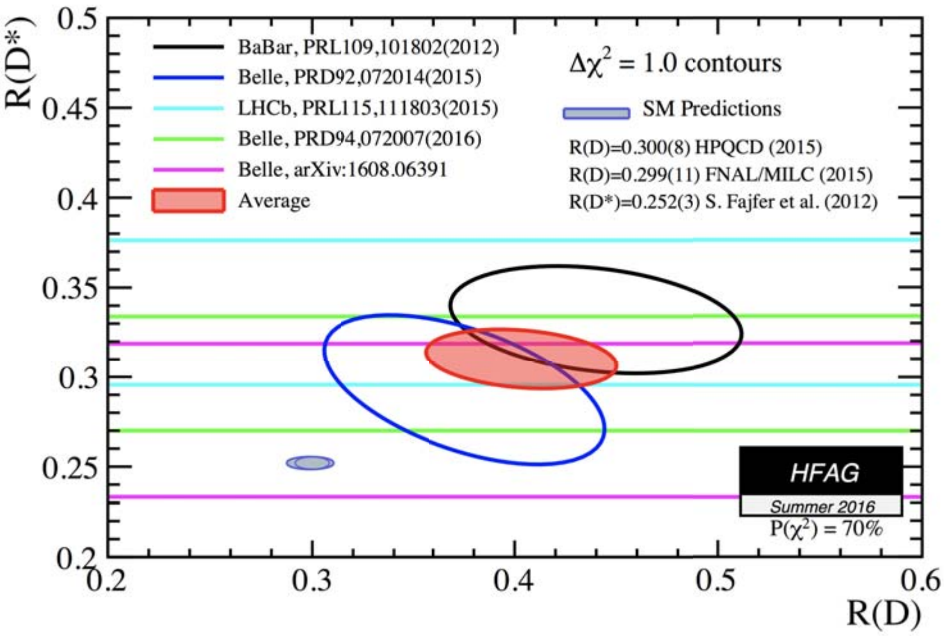

Figure 2. Measured values and SM prediction of $R(D)$ and $R(D^*)$

2. Belle II and SuperKEKB

The Belle II experiment is being built at SuperKEKB factory, in Tsukuba, Japan [6, 7]. It is expected to start taking data at the beginning of 2018, and to collect 50ab^{-1} of integrated luminosity by year 2024. The LHCb experiment is currently running, providing excellent results, and it will be continuing doing so for the coming years, creating a healthy competition with Belle

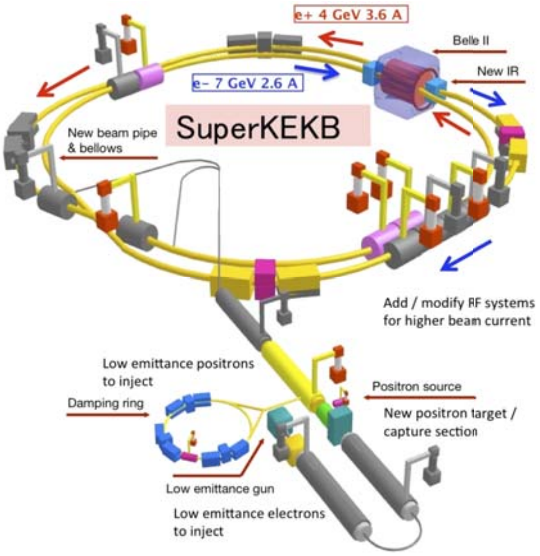

Figure 3. The SUperKEKB accelerator.

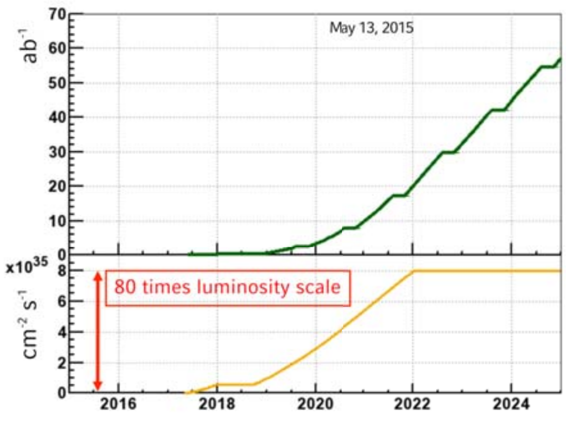

Figure 4. Instantaneous and integrated luminosity projections for SuperKEKB.

II. However, the Belle II experiment is a solid-angle detector working on a clean environment of electron-positron collisions allowing the possibility of the full reconstruction of final states, taking into account the kinematical constraints. These features give the capability of studying in great detail decays such as $\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)$, where the neutrino energy is missed. Below we list some of the characteristics of SuperKEKB and the Belle II detector.

- SuperKEKB is an asymmetric energy beam collider, which provides a boost to the $\Upsilon(4S)$ system with respect to the laboratory reference frame. This boost will be $\beta\gamma = 0.28$ (4.0 GeV for positrons, and 7.5 GeV for electrons).
- The beryllium beam pipe has a 1.0 cm radius, this allows to have a close interaction point with the first layer of the silicon detector layer, at 1.3 cm.
- The new vertex detector is comprised of two devices, the silicon Pixel Detector (PXD) and 36 Silicon Vertex Detector (SVD), with altogether six layers around a 10mm radius Be beam pipe. The first layers at $r = 14$mm and $r = 22$mm will use pixelated sensors of the DEPFET type. The remaining four layers at radii of 38mm, 80mm, 115mm, and 140mm will be equipped 40 with double-sided silicon strip sensors.
- A large Central Drift Chamber (CDC) with thousands of wires, will allow very good resolution at track reconstruction and dE/dx measurement.
- Two Chreenkov detectors, the time of propagation detector (TOP) and the aerogel ring-imaging Cherenkov detector (ARICH) in the endcap, will provide particle identification (PID), allowing very good separation of kaons and pions.
- The Electromagnetic calorimeter (ECL) is located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. The ECL uses Thallium activated Cesium Iodide CsI(Tl) crystals in the barrel region, and pure CsI crystals for the endcaps regions. It is equipped with faster readout electronics with respect to the Belle experiment, in order to manage larger amount of background events.
- Outside the solenoid coil, there is an iron flux-return instrumented to detect K_L^0 mesons and to identify muons (KLM). The KLM consists mainly of Resistive Plate Chambers (RPC) in

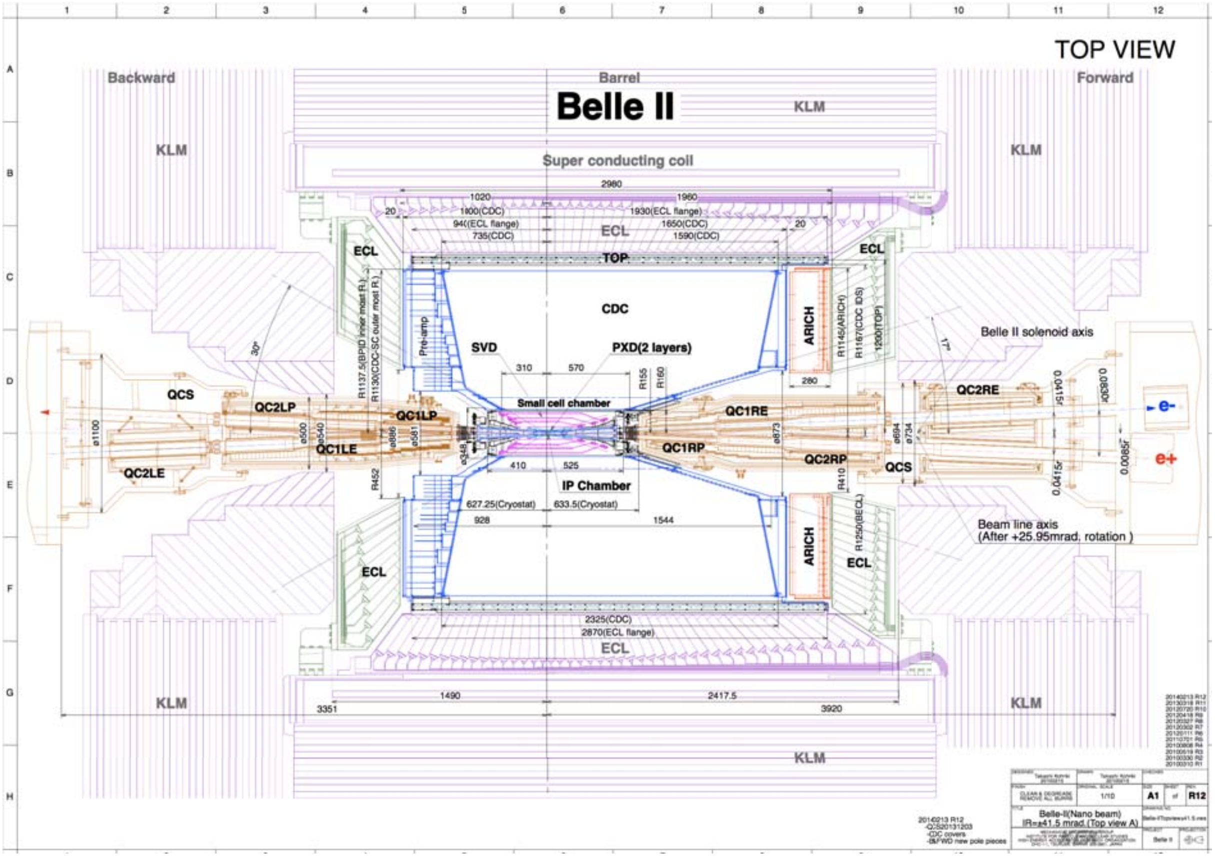

Figure 5. Belle II top view.

the barrel regions, and scintillators in the endcaps regions. K_L^0 mesons shower hadronically in the absorptive iron plates, and can be detected in the KLM active detectors.

3. The method for the measurement.

The strategy of the $R(D^{(*)})$ measurement is to take a ratio of the yields of the $B \to D^{(*)}\tau\nu_\tau$ and the $B \to D^{(*)}\ell\nu_\ell$ events. Three different methods can be used un a $B-$factory experiment: hadronic tag, semileptonic tag, and untagged. The Full Event Interpretation functionality in Belle II Software [8], allows to perform physics analysis taking into account the Missing Energy from neutrinos.

In the hadronic tag analysis the most important variables to separate signal events are related to the missing momentum such as the extra energy on ECL, E_{extra}, and the missing mass squared, M^2_{miss},

$$M^2_{miss} = (p_{e^+e^-} - p_{B_{sig}} - p_{B_{comp}})^2. \qquad (3)$$

The missing mass squared is used to separate $B \to D^{(*)}\tau\nu_\tau$ signals from $B \to D^{(*)}\ell\nu_\ell$. The $B \to D^{(*)}\tau\nu_\tau$ are distributed in the higher missing squared mass, and then a multivariate analysis can be used to separate signal events from background processes. One of the advantages of this analysis is the capability of the τ polarization, $P_\tau(D^*)$, measurement using kinematics of the two-body τ decays. $P_\tau(D^*)$ is measured using the distribution of $\cos\theta_{hel}$, which is the cosine of the angle between the momentum of the τ-daughter meson and the direction opposite the momentum of the $\tau\nu_\tau$ system.

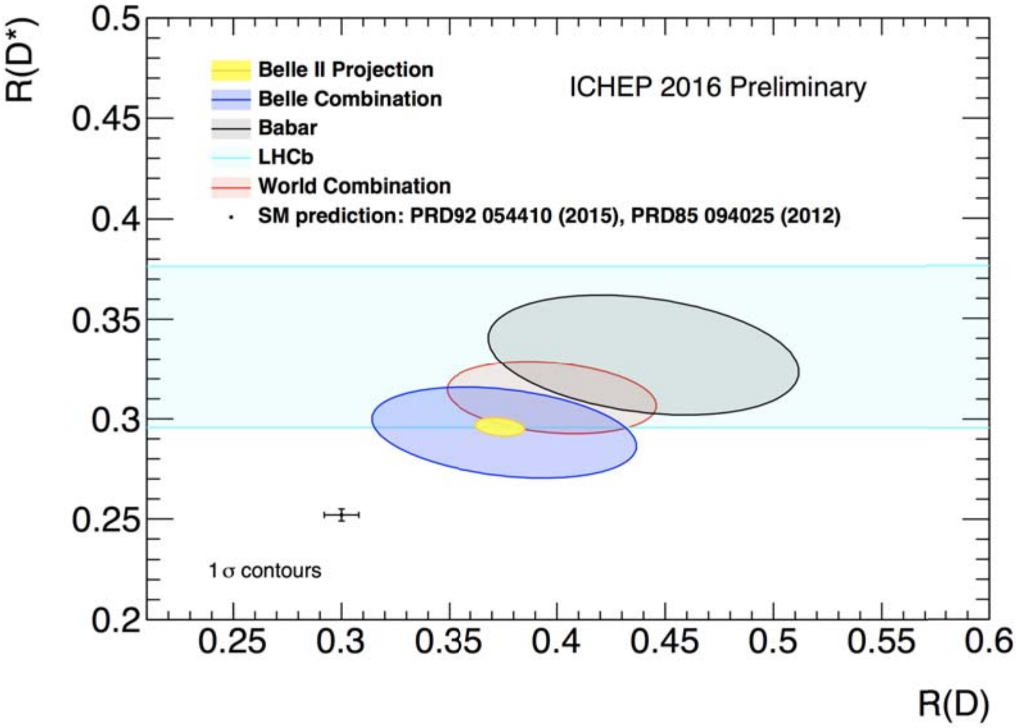

Figure 6. Expected Belle II constraints on the $R(D)$ vs $R(D^*)$ plane, compared to existing experimental constraints from Belle.

For the analysis with semileptonic tagging, the energy deposited in the calorimeter is used to separate $B \to D^*\tau\nu_\tau$ and $B \to D^*\ell\nu_\ell$ from other background, and a multivariate analysis using the angles between the original B meson and the D meson and the lepton can be used to discriminate between $B \to D^*\tau\nu_\tau$ and $B \to D^*\ell\nu_\ell$ events.

In the untagged method, the most important variable to extract signal candidates is the beam-constrained mass of the accompanying B-meson. In this analysis the products of the signal decay firstly are selected and the rest of the event is used to build various shape or topological parameters that discriminate B-meson decays from other hadronic modes. The signal efficiency of the untagged method can be higher than in other methods.

4. Belle II projections

Based on the existing results from Belle and expected improvements at Belle II, the Belle II precisions in the $R(D^{(*)})$ and $P_\tau(D^*)$ measurements are estimated and shown in Table 2 [9]. In Figure 6, the expected precisions at Belle II are compared to the current results and the SM expectations. The $R(D^{(*)})$ precision will be comparable to the current theoretical uncertainty in the SM expectations.

5. Final Remarks

Belle II is ready to collect the legacy of the first generation of B-factories and to continue on the path set by them. Its main purpose will be searching for NP signatures at the intensity frontier. Solving or measuring a confirmation the $R(D^{(*)})$ anomalies, will help to probe the SM to a high degree of precision.

Table 2. Expected precision on $R(D^{(*)})$ and $P_{\tau}(D^*)$ at Belle II. The first and the second values are the expected statistical and the systematic errors, respectively. These expectations arevshown as the relative (absolute) values for $R(D^{(*)})(P_{\tau}(D^*))$.

	5 ab^{-1}	50 ab^{-1}
$R(D)$	$(6.0 \pm 3.9)\%$	$(2.0 \pm 2.5)\%$
$R(D^*)$	$(3.0 \pm 2.5)\%$	$(1.0 \pm 2.0)\%$
$P_{\tau}(D^*)$	0.18 ± 0.08	0.06 ± 0.04

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References

[1] Elisa Guido. Belle II physics prospects. *PoS*, FPCP2017:036, 2017.
[2] J Bennett. Belle ii physics prospects, status and schedule. *Journal of Physics: Conference Series*, 770(1):012044, 2016.
[3] Dante Bigi and Paolo Gambino. Revisiting $B \to D\ell\nu$. *Phys. Rev.*, D94(9):094008, 2016.
[4] Florian U. Bernlochner, Zoltan Ligeti, Michele Papucci, and Dean J. Robinson. Combined analysis of semileptonic B decays to D and D^*: $R(D^{(*)})$, $|V_{cb}|$, and new physics. *Phys. Rev.*, D95(11):115008, 2017.
[5] HFAG Collaboration. Average of r(d) and r(d*) for fpcp 2017, 2017.
[6] James Kahn (on behalf of the Belle II collaboration). The belle ii experiment. *CERN Proceedings*, 1(0):45, 2017.
[7] Ivan Heredia de la Cruz. The Belle II experiment: fundamental physics at the flavor frontier. *J. Phys. Conf. Ser.*, 761(1):012017, 2016.
[8] Thomas Keck. The Full Event Interpretation for Belle II. Master's thesis, KIT, Karlsruhe, 2014-11.
[9] Gianluca Inguglia. Studies of dark sector & B decays involving τ at Belle and Belle II. *PoS*, ICHEP2016:131, 2016.