Hadronic B decays at Belle and Belle II

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Abstract. The Belle and Belle II B-factories have collectively gathered an extensive 1.1 ab^{-1} dataset of e^+e^- collisions at the $\Upsilon(4S)$ resonance, resulting in the production of numerous $B\bar{B}$ pairs. This allows for precise measurements of hadronic B decays, essential to test Quantum Chromodynamics (QCD) and refine theoretical models. This also helps improve simulation accuracy. We present results for the B to hadronic decays such as $B^- \to D^0\rho^-$, $B \to DK^*K_{(s)}^{(*)(0)}$ and the first Belle and Belle II combined ϕ_3 measurement.

Keywords: Hadronic, CKM, Belle II

1 Introduction

Hadronic B decays make up about 75% of all B meson decays, yet nearly half remain unmeasured. To estimate the unmeasured decays, Belle II [1] relies on the PYTHIA [2] fragmentation model, which doesn't accurately represent B decays. Belle II also offers a unique opportunity to study decays involving missing energy through a B-tagging technique. Here, one of the two B mesons produced in a collision is fully reconstructed. Hadronic B-tagging provides high precision in determining the B meson's momentum and direction. Belle II uses a specialized algorithm for this called Full Event Interpretation (FEI) [3], which employs machine learning classifiers trained on Belle II's Monte Carlo (MC) simulations. However, mismatches between the simulation and accurate data can affect the FEI's efficiency, reducing its performance and limiting the experiment's potential. By making more measurements of hadronic B decays, we can improve the FEI's efficiency and background rejection, leading to better B meson studies and a deeper understanding of B decay models.

2 $B^- \to D^0\rho^-$

$B^- \to D^0\rho^-$(with charge conjugation implied) is crucial in hadronic tagging for Belle II. However, the tagging efficiency for this decay is hindered by a significant discrepancy between data and Monte Carlo (MC) simulations, highlighting the need of re-evaluation. An effort is being made to improve the measurement using 362 fb^{-1} of data in Belle II [4]. To extract the signal, an unbinned maximum

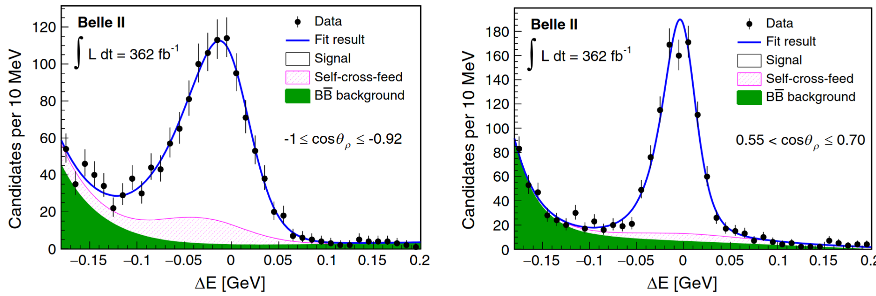

Fig. 1. Fitted ΔE distribution for the lowest(left) and highest(right) $cos\theta_\rho$ interval

likelihood fit to the ΔE (difference between expected and observed B meson energy) distribution 1 is performed. The major challenge is the contribution from the non-resonant $B^- \to D\pi^-\pi^0$ as the ΔE distribution is indistinguishable from that of $B^- \to D^-\rho$. This is addressed by fitting ΔE in nine bins of the cosine of ρ helicity angle ($cos\theta_\rho$). The background-subtracted $cos\theta_\rho$ distribution is shown in Fig**??**. A (1.9±1.8)% fraction of $B^- \to D\pi^-\pi^0$ contribution is found in $B^- \to D^-\rho$ decays. The background-subtracted $\pi^-\pi^0$ invariant mass distribution is shown in Fig**??**, overlaid with the simulated data using the fractions of $B^- \to D\pi^-\pi^0$ and $B^- \to D\rho^-$ decays resulting from the fit.

The simulation matches the data distribution well. The BF measured is $(0.939 \pm 0.021(stat) \pm 0.050(syst))\%$, which is, to date, the most precise measurement.

3 $B \to D^*KK_{(s)}^{(*)0}$ and $B \to DD_s$

$B \to D^*KK_{(s)}^{(*)0}$ decays make up a few percent of the overall hadronic branching fraction. But only a few of these decays are well measured. Since these decays serve as inputs for simulations and tagging techniques, they must be well-measured.

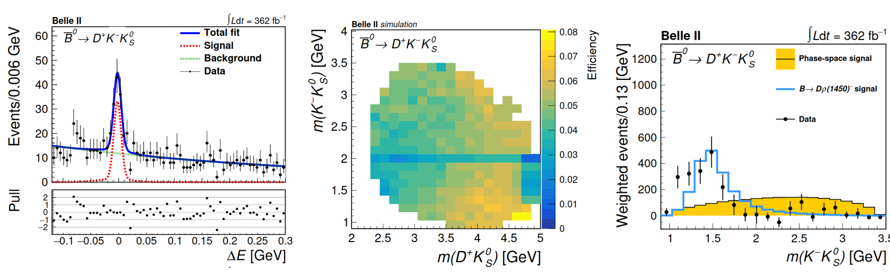

Fig. 2. ΔE(left), Dalitz(middle) and $m(KK_S^0)$(right) distribution of $\bar{B}^0 \to D^+K^-K_S^0$

These decays proceed via a tree-level diagram with external W emission, but there is also the possibility of $B \to DX^-(\to KK^-)$, with an intermediate resonance X^-. This study reports a more precise measurement of eight $B \to DK^-K$ absolute branching fractions and observation of the three unobserved $B \to DK^-K^0_S$ channels using a data sample of 362fb^{-1} collected at Belle II [5]. The intermediate states are also studied by Dalitz analysis, and more precise

Channel	Yield	Average ε	$\mathcal{B}$ $[10^{-4}]$	Stat. significance $[\sigma]$
$B^- \to D^0K^-K^0_S$	209 ± 17	0.098	$1.82 \pm 0.16 \pm 0.08$	> 10
$\overline{B}^0 \to D^+K^-K^0_S$	105 ± 14	0.048	$0.82 \pm 0.12 \pm 0.05$	10
$B^- \to D^{*0}K^-K^0_S$	51 ± 9	0.044	$1.47 \pm 0.27 \pm 0.10$	8
$\overline{B}^0 \to D^{*+}K^-K^0_S$	36 ± 7	0.046	$0.91 \pm 0.19 \pm 0.05$	9
$B^- \to D^0K^-K^{*0}$	325 ± 19	0.043	$7.19 \pm 0.45 \pm 0.33$	> 10
$\overline{B}^0 \to D^+K^-K^{*0}$	385 ± 22	0.021	$7.56 \pm 0.45 \pm 0.38$	> 10
$B^- \to D^{*0}K^-K^{*0}$	160 ± 15	0.019	$11.93 \pm 1.14 \pm 0.93$	> 10
$\overline{B}^0 \to D^{*+}K^-K^{*0}$	193 ± 14	0.020	$13.12 \pm 1.21 \pm 0.71$	> 10
$B^- \to D^0D^-_s$	144 ± 12 / 153 ± 13	0.09 / 0.04	$95 \pm 6 \pm 5$	> 10 / > 10
$\overline{B}^0 \to D^+D^-_s$	145 ± 12 / 159 ± 13	0.05 / 0.02	$89 \pm 5 \pm 5$	> 10 / > 10
$B^- \to D^{*0}D^-_s$	30 ± 6 / 29 ± 7	0.04 / 0.02	$65 \pm 10 \pm 6$	7 / 8
$\overline{B}^0 \to D^{*+}D^-_s$	43 ± 7 / 37 ± 7	0.04 / 0.02	$83 \pm 10 \pm 6$	> 10 / > 10

Fig. 3. branching fraction results and significance of all the decay channels studied

BFs for four $B \to DD_s$ are obtained. The signal yields are extracted using likelihood fits to the unbinned ΔE distribution. The BF is obtained by the efficiency-corrected integral of the $m(KK^-), m(DK)$ distribution for the three body decays. The ΔE, Dalitz plot and $M(KK^0_S)$ distributions for one of the first observed decay $\bar{B}^0 \to D^+K^-K^0_S$ is shown in Fig2. The table with all the measured BFs and their significance is shown in Fig3

4 ϕ_3 measurement with Belle + Belle II data

The CKM angle $\phi_3(\gamma)$, defined as $\phi_3 = arg(V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$ can be measured directly by exploiting the interference between tree-level quark-transition amplitudes that involve $\bar{b} \to \bar{u}c\bar{s}$ and $\bar{b} \to \bar{c}u\bar{s}$. Assuming contribution from only the standard model, the measurement of ϕ_3 provides a good test against indirect determinations from global unitarity fits. Here, ϕ_3 is measured using results from samples of up to 711 fb^{-1} from the Belle experiment and up to 362 fb^{-1} from the Belle II [6]. experiment. This study combines results from analyses of $B^+ \to DK^+$, $B^+ \to D\pi^+$, and $B^+ \to D^*K^+$ decays, where D is an admixture of D^0 and $\bar{D}^0$ mesons. Several methods and different final states are used in the study to obtain ϕ_3. Fig4 shows the 1-CL distribution as a function of ϕ_3. The ϕ_3 measured is $(75.2 \pm 7.6)^\circ$, which agrees with the current world average.

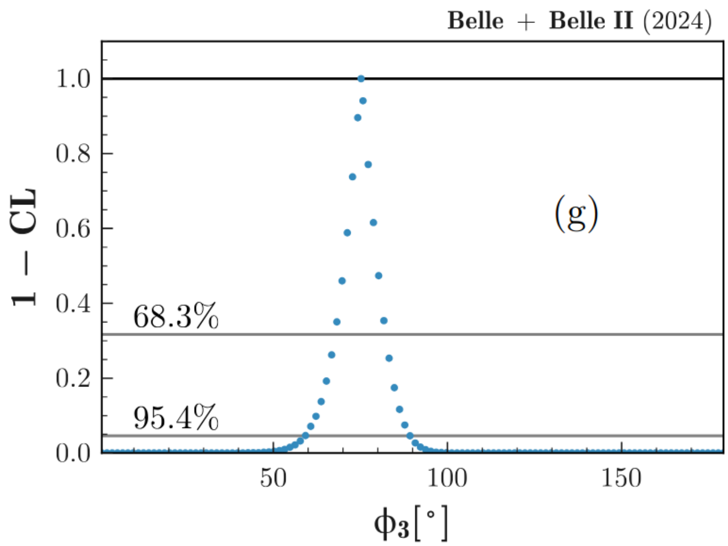

Fig. 4. 1-CL distributions as functions of ϕ_3

5 Conclusion

We discuss precise measurements of hadronic B decays in the Belle and Belle II experiment. The decays $B^- \to D\rho^-$ and $B \to DD_s$ are measured more precisely. There are new observations for $B \to DKK_S^0$. We also present the first combined Belle+Belle II result on ϕ_3, which is in agreement with the world average.

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