



Studies of the semileptonic $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ and $B^- \rightarrow D^0 \ell^- \bar{\nu}_\ell$ decay processes with 34.6 fb^{-1} of Belle II data

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248 Abstract

249 We report measurements of the $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ and $B^- \rightarrow D^0 \ell^- \bar{\nu}_\ell$ processes using 34.6 fb^{-1} of
250 collision events recorded by the Belle II experiment at the SuperKEKB asymmetric-energy e^+e^-
251 collider. For the $B^- \rightarrow D^0 \ell^- \bar{\nu}_\ell$ channel, we present first studies that isolate this decay from other
252 semileptonic processes and backgrounds. We report a measurement of the $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ branch-
253 ing fraction and obtain $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell) = (4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\pi_s})\%$, in agreement
254 with the world average. Here the uncertainties are statistical, systematic, and related to slow pion
255 reconstruction, respectively. The systematic uncertainties are limited by the statistics of auxiliary
256 measurements and will improve in the future. We also report differential branching fractions in
257 five bins of the hadronic recoil parameter w for $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$, unfolded to account for resolution
258 and efficiency effects.

259 **1. INTRODUCTION**

260 Precision measurements of the decays of $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ and $B^- \rightarrow D^0\ell^-\bar{\nu}_\ell$ ($\ell = e$ or μ)
261 play an important role in the determination of the magnitude of the Cabibbo-Kobayashi-
262 Maskawa matrix element $|V_{cb}|$ and are probes for the understanding of the hadronic dy-
263 namics of B meson decays. These processes also constitute a source of background for
264 measurements of charmless semileptonic decays and their understanding is important to
265 study $\bar{B}^0 \rightarrow D^{(*)+}\tau^-\bar{\nu}_\tau$. This motivates measurements of their branching fractions and
266 kinematic distributions at Belle II. The most precise measurements of $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell)$
267 and $\mathcal{B}(B^- \rightarrow D^0\ell^-\bar{\nu}_\ell)$ were obtained by the *BABAR* [1, 2] and Belle [3] collaborations. Since
268 March 2019, the Belle II experiment has been collecting e^+e^- collision events with the full
269 detector and in this conference note studies, using an integrated luminosity of 34.6 fb^{-1} , are
270 reported.

271 **2. THE BELLE II DETECTOR AND DATA SAMPLE**

272 The Belle II detector [4, 5] operates at the SuperKEKB asymmetric-energy electron-
273 positron collider [6], located at the KEK laboratory in Tsukuba, Japan. The detector con-
274 sists of several nested detector subsystems arranged around the beam pipe in a cylindrical
275 geometry. The innermost subsystem is the vertex detector, which includes two layers of sili-
276 con pixel detectors and four outer layers of silicon strip detectors. Currently, the second pixel
277 layer is installed in only a small part of the solid angle, while the remaining vertex detector
278 layers are fully installed. Most of the tracking volume consists of a helium and ethane-based
279 small-cell drift chamber. Outside the drift chamber, a Cherenkov-light imaging and time-
280 of-propagation detector provides charged-particle identification in the barrel region. In the
281 forward endcap, this function is provided by a proximity-focusing, ring-imaging Cherenkov
282 detector with an aerogel radiator. Further out is an electromagnetic calorimeter, consisting
283 of a barrel and two endcap sections made of CsI(Tl) crystals. A uniform 1.5 T magnetic
284 field is provided by a superconducting solenoid situated outside the calorimeter. Multiple
285 layers of scintillators and resistive plate chambers, located between the magnetic flux-return
286 iron plates, constitute the K_L and muon identification system.

287 The data used in this analysis were collected in 2019 and 2020 at a center-of-mass (CM)
288 energy of 10.58 GeV, corresponding to the mass of the $\Upsilon(4S)$ resonance. The energies of
289 the electron and positron beams are 7 GeV and 4 GeV, respectively, resulting in a boost of
290 $\beta\gamma = 0.28$ of the CM frame relative to the lab frame. The number of B meson pairs in
291 the analyzed collision events has been counted using event-shape variables and has been
292 determined to be $N_{B\bar{B}} = (37.7 \pm 0.6) \times 10^6$.

293 Simulated Monte Carlo (MC) samples of signal events, with the subsequent decays
294 $D^{*+} \rightarrow D^0\pi^+$ (for $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$) and $D^0 \rightarrow K^-\pi^+$ (for both processes), are used to
295 obtain the reconstruction efficiencies and signal kinematic distributions. These events were
296 generated with EvtGen [7]. Samples of background events are used to obtain kinematic
297 distributions of the background. These include a sample of $e^+e^- \rightarrow B\bar{B}$ with generic B
298 meson decays, generated with EvtGen, and corresponding to an integrated luminosity of
299 100 fb^{-1} and 200 fb^{-1} for the $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ and $B^- \rightarrow D^0\ell^-\bar{\nu}_\ell$ analyses, respectively.
300 Sample of continuum $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s, c$) is simulated with KKMC [8] interfaced with

301 PYTHIA [9]. All recorded collisions and simulated events were analyzed in the basf2 [10]
 302 framework and a summary of the track reconstruction algorithms can be found in Ref. [11].

303 3. EVENT SELECTION

304 We reconstruct candidate events for both final states by reconstructing the $D^0 \rightarrow K^- \pi^+$
 305 decay and for $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ the $D^{*+} \rightarrow D^0 \pi_s^+$ cascade. Here, π_s indicates the soft pion
 306 originating from the D^{*+} decay. Reconstruction of the charge-conjugate decays is implied.

307 Signal candidate reconstruction begins with the selection of charged-particle tracks. The
 308 distance of closest approach between each track and the interaction point is required to be
 309 less than 2 cm along the z direction (parallel to the beams) and less than 0.5 cm in the trans-
 310 verse $r - \phi$ plane and must have a CM frame momentum in the range $p_\ell^* \in [1.2, 2.4]$ GeV/ c .
 311 The lepton candidate must also satisfy lepton-identification (lepton-ID) criteria based on
 312 information from all available detectors. A dedicated algorithm identifies photons from
 313 bremsstrahlung processes and corrects the momentum of reconstructed electron candidates
 314 if such can be identified. Given the high purity of the $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ decay chain, applica-
 315 tion of kaon or pion identification criteria is deemed unnecessary and is thus not performed.
 316 For the $B^- \rightarrow D^0 \ell^- \bar{\nu}_l$ decay we apply loose kaon and pion identification criteria to increase
 317 the purity of the selected events.

318 3.1. $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ Reconstruction

319 From the $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ selection, a vertex fit is applied to the D^0 candidate, constraining
 320 its $K^- \pi^+$ daughter tracks to originate from a common point. The invariant mass of the D^0
 321 candidate is required to satisfy $m_{K\pi} \in [1.85, 1.88]$ GeV/ c^2 after the fit. The $D^{*+} \rightarrow D^0 \pi_s^+$
 322 candidate decay is also subjected to a vertex fit, after which the mass difference between
 323 the D^* and D^0 candidates is required to satisfy $\Delta m \in [0.144, 0.148]$ GeV/ c^2 . Continuum
 324 background is suppressed by requiring the momentum of the D^* candidate in the CM frame
 325 to be less than 2.5 GeV/ c . Further continuum suppression is achieved by requiring $R_2 < 0.3$,
 326 where R_2 is the ratio of the second and zeroth Fox-Wolfram moments [12], calculated using
 327 all the tracks and photon candidates in the event. After applying all the selection criteria
 328 above, multiple $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ candidates are found in only about 2% of the events. For all
 329 candidates, we perform a vertex fit for the decay $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ and in events with multiple
 330 candidates per event, we select the candidate with the smallest value of the vertex-fit χ^2 .
 331 The signal efficiency after all selection criteria is $\epsilon = (21.3 \pm 2.2)\%$ for $\bar{B}^0 \rightarrow D^{*+} e^- \bar{\nu}_e$
 332 and $\epsilon = (21.8 \pm 2.2)\%$ for $\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu$. These values are obtained from signal MC
 333 with lepton-ID efficiency corrections obtained from data-MC comparisons of reconstructed
 334 $J/\psi \rightarrow \ell^+ \ell^-$, $e^+ e^- \rightarrow \ell^+ \ell^-$ and $e^+ e^- \rightarrow e^+ e^- \ell^+ \ell^-$ decays. The quoted uncertainties are
 335 dominated by the uncertainties on the slow pion reconstruction efficiency. This uncertainty
 336 was estimated by studying slow pions from $B \rightarrow D^* \pi$ and $B \rightarrow D^* \rho$ decays, and will be
 337 reduced in the future.

338 **3.2. $B^- \rightarrow D^0 \ell^- \bar{\nu}_l$ Reconstruction**

339 To reduce the sizeable background of $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ and $B^- \rightarrow D^{*0} \ell^- \bar{\nu}_l$ decays in
 340 the reconstructed $B^- \rightarrow D^0 \ell^- \bar{\nu}_l$ candidates, an active veto is applied. This is done by
 341 combining charged and neutral soft pion candidates and photons to explicitly reconstruct
 342 the $D^{*+} \rightarrow D^0 \pi_s^+$, $D^{*0} \rightarrow D^0 \pi^0$ and $D^{*0} \rightarrow D^0 \gamma$ decay cascades. Candidates us-
 343 ing charged or neutral slow pions or photons are vetoed if a combination is found with
 344 $\Delta m \in [0.144, 0.148]$ GeV/ c^2 or $\Delta m \in [0.141, 0.145]$ GeV/ c^2 , respectively. To further control
 345 these backgrounds, a multivariate classifier in the form of a deep neural network is trained.
 346 Its input layer consists of the four-momenta of the final state particles, and variables char-
 347 acterizing cluster properties in the electromagnetic calorimeter. The latter can be used to
 348 identify further neutral soft pions and photons from $D^{*0} \rightarrow D^0 \pi^0$ and $D^{*0} \rightarrow D^0 \gamma$ decays,
 349 which were missed in the explicit reconstruction. The most important distinguishing input
 350 feature to veto $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ events are the D^0 and lepton momenta. Finally, we demand
 351 that the invariant mass of the $D^0 \ell$ system is smaller than 3.15 GeV/ c^2 and the momentum of
 352 the candidate lepton in the laboratory frame is below 3 GeV/ c . No best candidate selection
 353 is carried out and all candidate events are analyzed.

354 **4. SIGNAL AND BACKGROUND SEPARATION**

355 For each candidate, we calculate the angle between the $Y = D^{*+} \ell$ or $Y = D^0 \ell$ system
 356 and the B meson in the center-of-mass frame of the collision. It can be calculated using the
 357 reconstructed momenta and energies via

$$\cos \theta_{BY} = \frac{2 E_B^* E_Y^* - m_B^2 - m_Y^2}{2 |p_B^*| |p_Y^*|}, \quad (1)$$

358 where E_Y^* , $|p_Y^*|$, and m_Y are the CM energy, momentum, and invariant mass of the $D^{*+} \ell$ or
 359 $D^0 \ell$ system, m_B is the nominal B mass [13], and E_B^* , $|p_B^*|$ are the CM energy and momentum
 360 of the B ; the CM is inferred from the beam four-momenta. For correctly reconstructed
 361 $B^- \rightarrow D^0 \ell^- \bar{\nu}_l$ and $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ candidates with perfect detector resolution and correct
 362 values of E_B^* and p_B^* , the value of $\cos \theta_{BY}$ ranges between the geometric range of $[-1, 1]$. Due
 363 to the finite beam-energy spread, final-state radiation, and detector resolution, the $\cos \theta_{BY}$
 364 distributions of signal events is smeared beyond the geometric range, but retains an excellent
 365 sensitivity to separate signal from background processes.

366 **4.1. Signal Yield Determination**

367 We determine the $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_l$ and $B^- \rightarrow D^0 \ell^- \bar{\nu}_l$ signal event yields by carrying out a
 368 binned maximum-likelihood fit to the $\cos \theta_{BY}$ distribution. The probability density functions
 369 (PDFs) used in this fit are determined from simulated samples. We apply momentum-
 370 and polar-angle-dependent corrections to the lepton-identification efficiencies of leptons and
 371 hadrons. For leptons, corrections of the order of a few percent are obtained from $J/\psi \rightarrow$
 372 $\ell^+ \ell^-$ ($\ell = e, \mu$) decays. Corrections for hadrons misidentified as leptons are obtained from
 373 samples of reconstructed $K_S \rightarrow \pi^+ \pi^-$ decays. The $B^- \rightarrow D^0 \ell^- \bar{\nu}_l$ fit uses four components,

374 for signal, D^* background from $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ and $B^- \rightarrow D^{*0}\ell^-\bar{\nu}_l$, background from other
 375 $B\bar{B}$ processes, and continuum processes. The $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ fit uses three components for
 376 signal, background from B mesons, and continuum processes.

377 Figure 1 shows the fitted $\cos\theta_{BY}$ distributions for $B^- \rightarrow D^0\ell^-\bar{\nu}_l$ and $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$.
 378 The fitted distribution describe the measured spectra well. The selected $B^- \rightarrow D^0\ell^-\bar{\nu}_l$
 379 candidates have a sizeable contamination from $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ processes, but the signal can
 380 be clearly isolated. In total, we find 6186 ± 234 and 5800 ± 231 $B^- \rightarrow D^0\ell^-\bar{\nu}_l$ candidates in
 381 the electron and muon channels, respectively. The $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ channel is much cleaner,
 382 in contrast, and in total we fit 9583 ± 134 and 9860 ± 132 signal events.

383 4.2. Branching Fraction determination for $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$

For $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ we determine the measured branching fraction of the measured signal yields N_s using

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l) = \frac{N_s}{\epsilon \times N_{B^0} \times \mathcal{B}(D^{*+} \rightarrow D^0\pi^+) \times \mathcal{B}(D^0 \rightarrow K^-\pi^+)}, \quad (2)$$

where ϵ is the product of the signal reconstruction efficiency and acceptance, and N_{B^0} is the number of B^0 mesons in the data sample, further discussed in Section 5. We determine

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}e^-\bar{\nu}_e) = (4.59 \pm 0.06_{\text{stat}} \pm 0.48_{\text{syst}}) \%, \quad (3)$$

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\mu^-\bar{\nu}_\mu) = (4.62 \pm 0.06_{\text{stat}} \pm 0.49_{\text{syst}}) \%. \quad (4)$$

Both branching fractions are below, but compatible with, the current world average of $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l) = (5.05 \pm 0.14) \%$ from Ref. [14] within 0.9 and 0.8 standard deviations, respectively. The first uncertainty is from statistics and the second from systematic uncertainties, further discussed in Section 5. The combined branching fraction is

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l) = (4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\pi_s}) \%, \quad (5)$$

where we single out the dominant uncertainty from the slow pion efficiency. The combined branching fraction is obtained by a variance weighted average of Eqs. 3 and 4, taking into account the systematic correlations. The ratio of the electron and muon branching fraction is sensitive to lepton-flavor violating processes predicted in theories extending the Standard Model [15]. We find for the ratio

$$R_{e\mu} = \frac{\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}e^-\bar{\nu}_e)}{\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\mu^-\bar{\nu}_\mu)} = 0.99 \pm 0.03, \quad (6)$$

384 which is compatible with the Standard Model expectation of near unity.

385 4.3. Reconstruction of the hadronic recoil parameter w for $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$

For $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ we reconstruct the hadronic recoil parameter w , defined as

$$w = \frac{m_B^2 - m_{D^{*+}}^2 - q^2}{2m_B m_{D^{*+}}} = v_B \cdot v_{D^{*+}}. \quad (7)$$

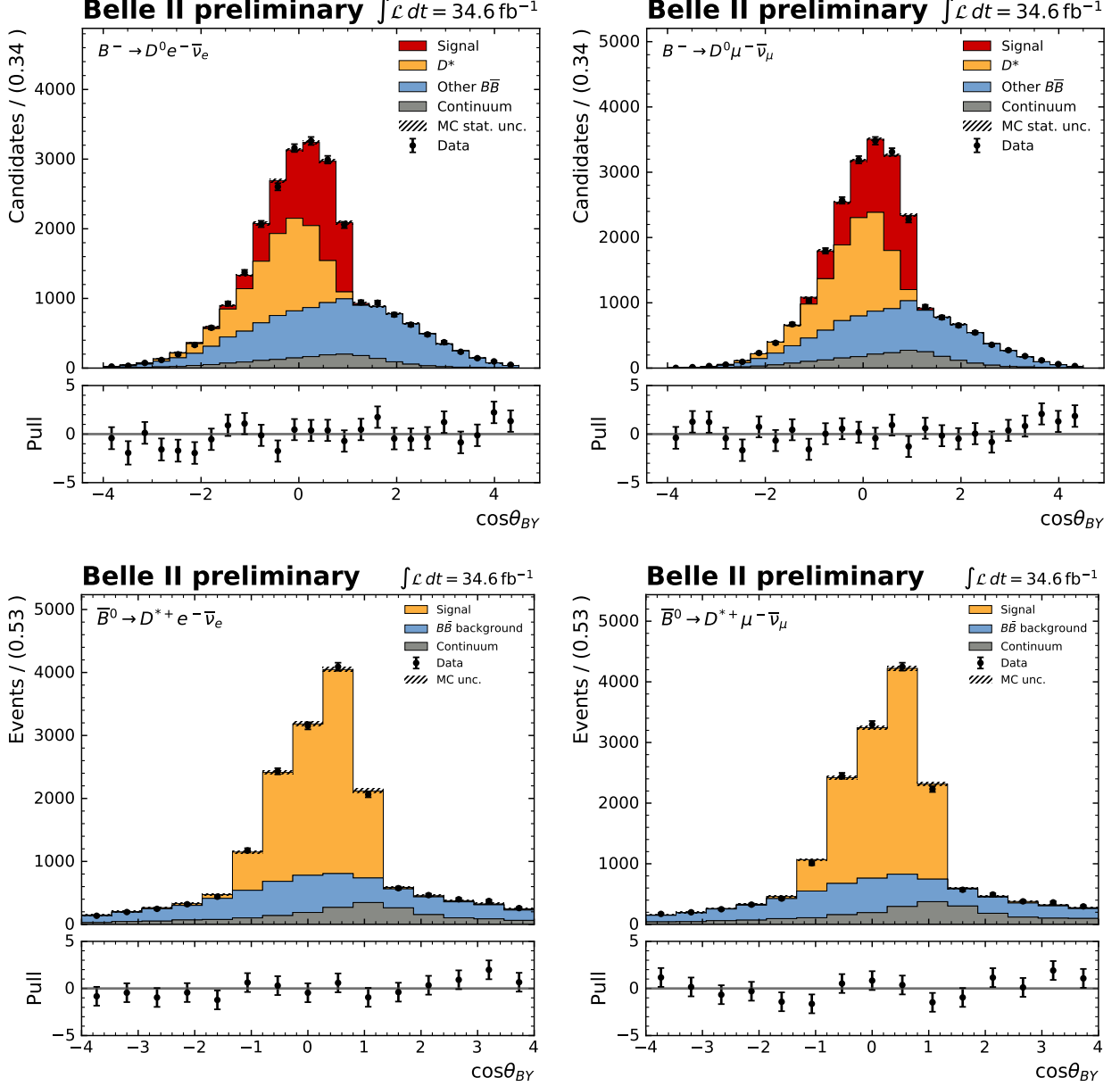


FIG. 1. The fitted $\cos\theta_{BY}$ distributions for the selected electron (left) and muon (right) candidates are shown. The top row displaying $B^- \rightarrow D^0 \ell^- \bar{\nu}_\ell$ and the bottom row shows the results for $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$.

386 Here $q^2 = (p_B - p_{D^{*+}})^2$ denotes the four-momentum transfer square of the B^- to the D^{*+} -
387 meson system. Further, v_B and $v_{D^{*+}}$ denote the four-velocities of the B^- and D^{*+} -mesons,
388 respectively. Measurements of the partial branching fraction in bins of w are sensitive to the
389 non-perturbative dynamics of the $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ decay and a key step to determine $|V_{cb}|$
390 from $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ and $B^- \rightarrow D^0 \ell^- \bar{\nu}_\ell$ decays.

391 In order to reconstruct w , the true direction of the signal B meson needs to be estimated.
392 This is done by exploiting that the magnitude of the B meson momentum vector in the CM

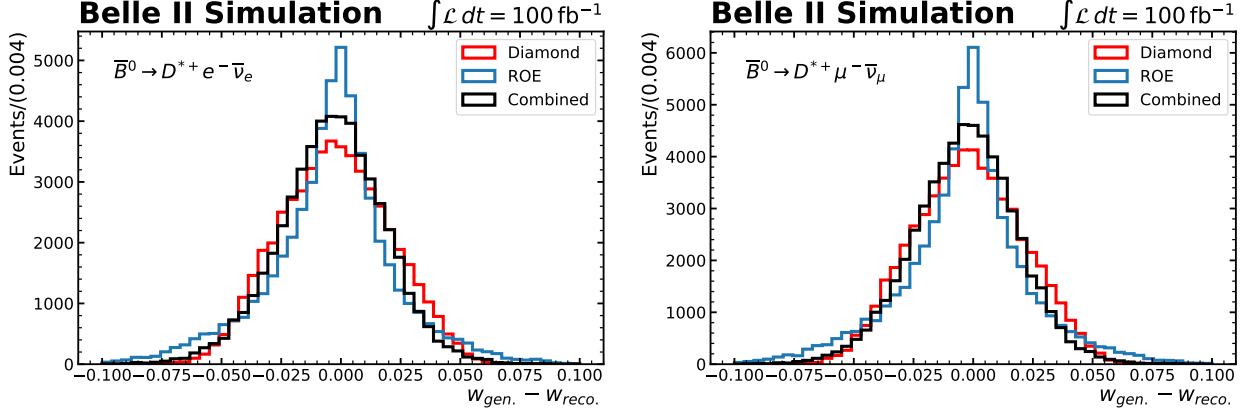


FIG. 2. The residual of the generated and reconstructed w values, after the final reconstruction and for the electron (left) and muon (right) channel, are shown. The three compared methods are: diamond frame (red), ROE (blue), and the used combined approach. For more details, see text.

393 is determined by the beam energy and its known mass. The momentum direction of the
 394 B meson is constrained to lie on a cone around the momentum direction of the combined
 395 $D^{*+}\ell$ system. We combine the diamond frame reconstruction detailed in Ref. [16] with the
 396 estimated direction of the B meson, as constrained by the remaining tracks and neutral
 397 clusters not used in the $D^{*+}\ell$ reconstruction (called the rest of event or ROE). This is done
 398 by modifying the diamond frame weights: cone directions opposite to the ROE retain a
 399 higher weight, whereas cone directions more parallel to the ROE are weighted down. This is
 400 implemented using weights $\frac{1}{2}(1 - \hat{p}_{\text{ROE}} \cdot \hat{p}_{\text{cone}})$, with \hat{p} denoting the normalized momentum
 401 vectors of the ROE or a cone direction. We reconstruct five bins of w with bin widths larger
 402 than the expected resolution of about 0.02. A comparison of the reconstruction resolution,
 403 comparing the reconstruction performance using the diamond frame, the estimated direction
 404 from the rest-of-the-event (ROE), or the used combined approach, is shown in Figure 2. We
 405 choose four bins with equal bin widths of 0.1 between 1 and 1.4, and one bin ranging from 1.4
 406 to $w_{\text{max}} = (m_B^2 + m_{D^{*+}}^2)/(2m_B m_{D^{*+}}) = 1.504$. In each reconstructed w bin, we determine
 407 the number of signal events by fitting $\cos\theta_{BY}$. The post-fit distribution of the measured w
 408 spectra for the electron and muon final states are shown in Figure 3. In Figures 4 and 5,
 409 the fitted $\cos\theta_{BY}$ distribution of each bin are shown.

410 4.4. Unfolding of the hadronic recoil parameter w for $\bar{B}^0 \rightarrow D^{*+}\ell^{-}\bar{\nu}_\ell$

In order to confront the measured w distributions with predictions for the decay rate, effects from resolution and efficiencies have to be reverted. This is done by constructing a χ^2 function of the form

$$\chi^2 = (\mathbf{N}_s - \bar{\mathbf{N}}_s \times \mathcal{M}) C_{\text{exp}}^{-1} (\mathbf{N}_s - \bar{\mathbf{N}}_s \times \mathcal{M}) . \quad (8)$$

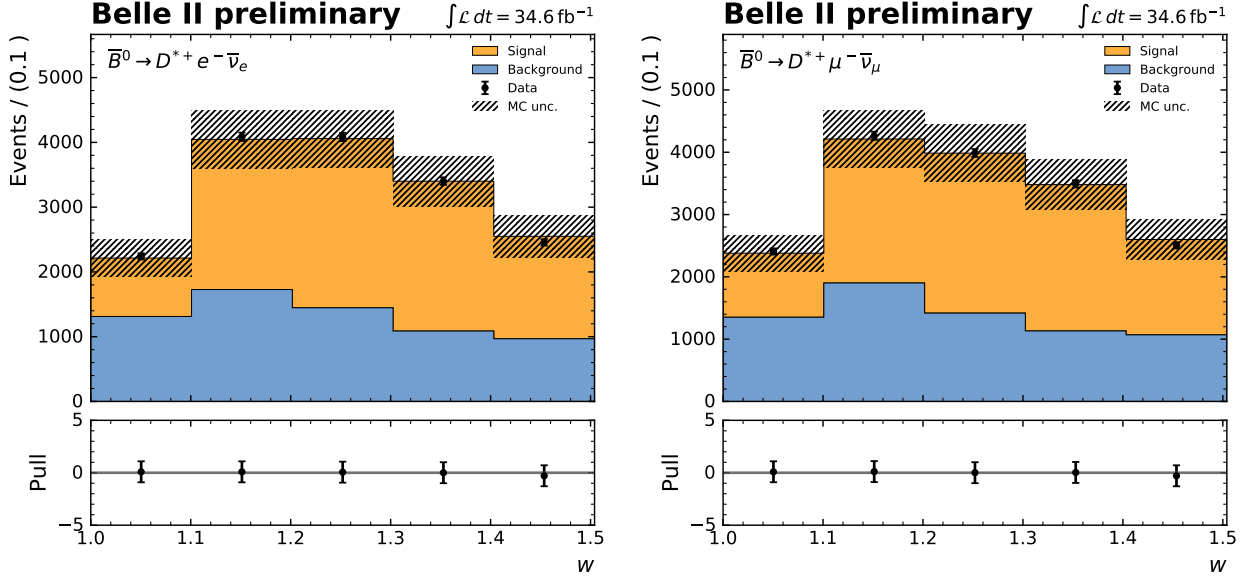


FIG. 3. The fitted w distribution for electron (left) and muon (right) $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ candidates are shown, after fitting $\cos \theta_{BY}$ in each bin. The background can be described adequately as can be seen by the near zero pulls in each bin.

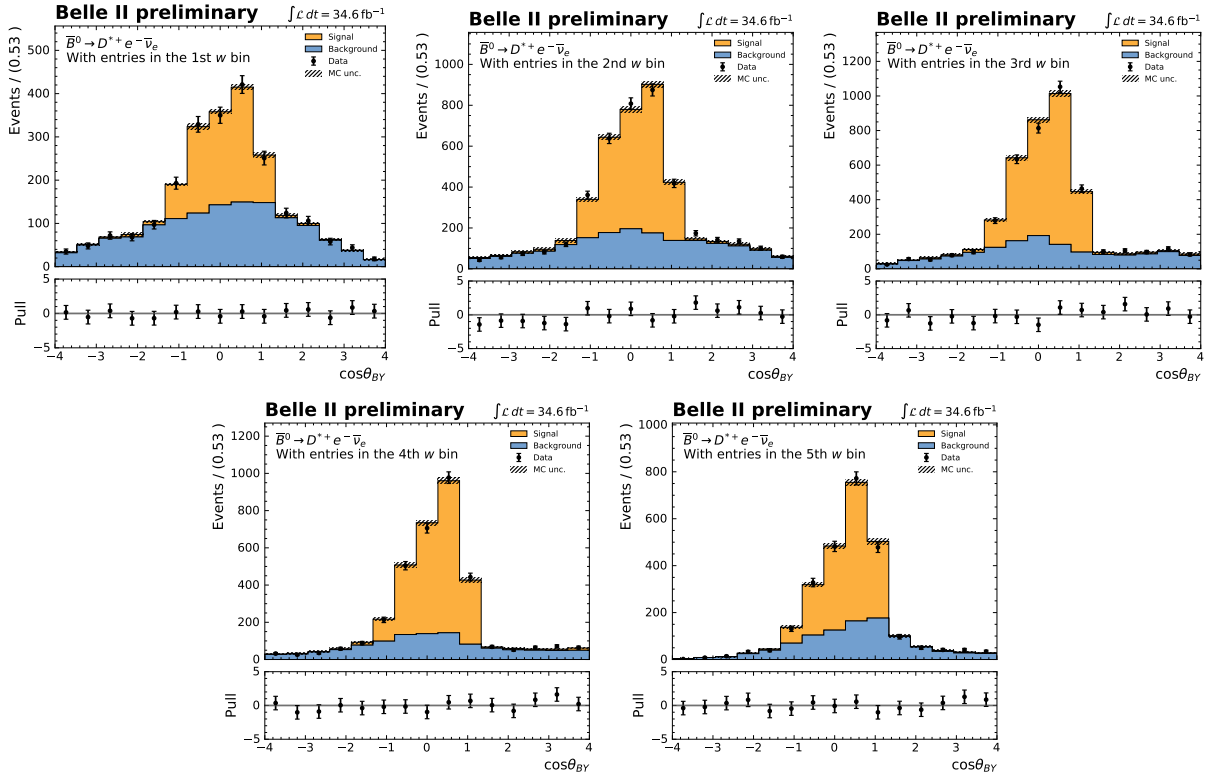


FIG. 4. The fitted $\cos \theta_{BY}$ distributions of all w bins of $\bar{B}^0 \rightarrow D^{*+} e^- \bar{\nu}_e$ for the electron final state are shown.

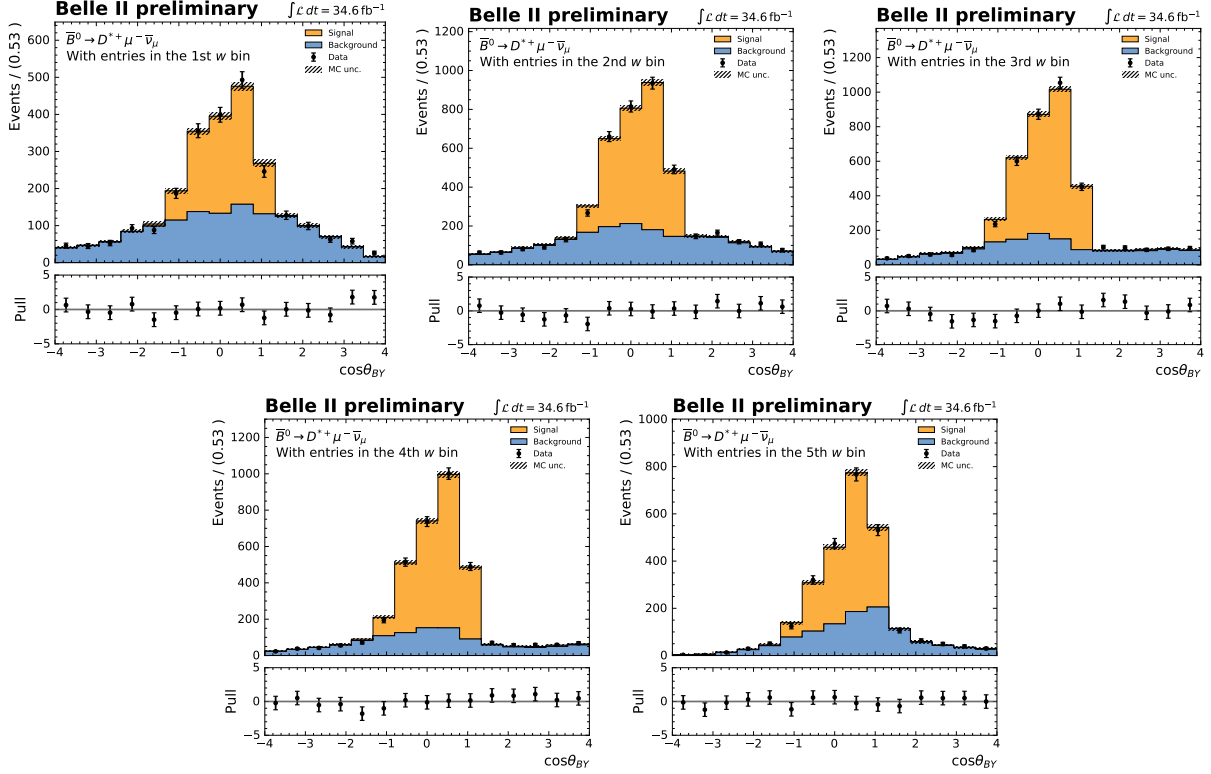


FIG. 5. The fitted $\cos\theta_{BY}$ distributions of all w bins of $\bar{B}^0 \rightarrow D^{*+}\mu^-\bar{\nu}_\mu$ for the muon final state are shown.

Here, C_{exp} denotes the experimental covariance of the measurement. The migration matrix \mathcal{M} denotes the conditional probabilities

$$\mathcal{M}_{ij} = \mathcal{P}(\text{measured value in bin } i | \text{true value in bin } j), \quad (9)$$

mapping the reconstructed signal yields \mathbf{N}_s , expressed as a vector of the bins, into their unfolded values $\bar{\mathbf{N}}_s$. The unfolded yields are converted into partial decay rates using

$$\Delta\Gamma_i = \frac{\bar{N}_{si} \times \tau_{B^0}}{\epsilon_i \times N_{B^0} \times \mathcal{B}(D^{*+} \rightarrow D^0\pi^+) \times \mathcal{B}(D^0 \rightarrow K^-\pi^+)}, \quad (10)$$

411 with $\tau_{B^0} = (1.519 \pm 0.004)$ ps the B^0 meson lifetime. Further, ϵ_i denotes the reconstruction
 412 efficiency and acceptance of signal events with true values of w in bin i . The resulting un-
 413 folded distributions are shown in Figure 6 and compared to the BGL form factor parameters
 414 of Ref. [17, 18].

415 5. SYSTEMATIC UNCERTAINTIES

416 The relative systematic uncertainties affecting the $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ branching fraction
 417 measurement are listed in Table I. We assume no correlation among the individual sources

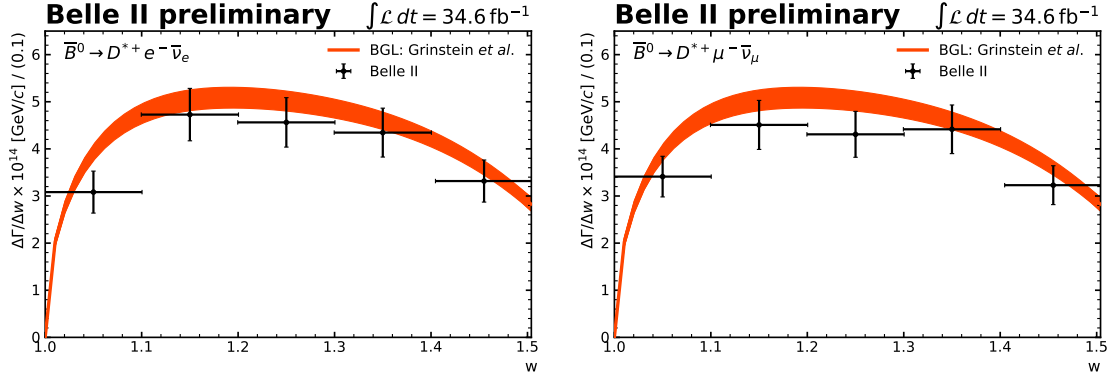


FIG. 6. The measured partial decay rates for electrons and muons are compared to the BGL form factor parameters of Ref. [17, 18].

Source	Relative uncertainty (%)	
	$\bar{B}^0 \rightarrow D^{*+} e^- \bar{\nu}_e$	$\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu$
PDF shape uncertainties	0.7	0.6
$\mathcal{B}(\bar{B} \rightarrow D^{**} \ell \bar{\nu})$	0.1	< 0.1
Lepton-ID	0.4	1.9
MC statistics, efficiency	< 0.1	< 0.1
Tracking of K, π, ℓ	2.4	2.4
Tracking of π_s	9.9	9.9
N_{B^0}	2.0	2.0
Charm branching fractions	1.1	1.1
$\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$ Form Factors	1.1	1.1
Total	10.5	10.7

TABLE I. Summary of the relative systematic uncertainties for the measurements of $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell)$. The first two uncertainties impact the extracted signal yield, while the others impact the other factors of Eq. (2).

418 of uncertainty and sum them in quadrature to obtain the total systematic uncertainty. The
 419 methods used for obtaining these uncertainties are detailed below.

420 The lepton-identification corrections are measured with statistical uncertainties that arise
 421 from the limited size of the control samples, as well as systematic uncertainties. We produce
 422 500 sets of correction values sampled from Gaussian distributions that reflect these uncer-
 423 tainties, accounting for systematic correlations. Each set of corrections is used to estimate
 424 the uncertainty on the efficiencies and on the $\cos\theta_{BY}$ distributions.

425 The impact of the finite sizes of the MC samples is directly incorporated into the fit
 426 procedure via nuisance parameters.

427 The semileptonic decays $\bar{B} \rightarrow D^{**} \ell \bar{\nu}$, where D^{**} indicates an excited charm meson heavier

428 than the D^* , have a similar particle content to that of signal decays. As a result, the fit may
 429 be biased if the branching fractions of $\bar{B} \rightarrow D^{**}\ell\bar{\nu}$ are incorrect in the generic MC sample.
 430 To estimate the systematic uncertainty, we obtain the $B\bar{B}$ PDF from the MC after varying
 431 the branching fractions for these decays by $\pm 25\%$, which is twice the relative uncertainty
 432 on $\mathcal{B}(\bar{B} \rightarrow D^0\pi^+\ell^-\bar{\nu})$. The resulting change in the signal yield is taken as the systematic
 433 uncertainty.

434 The tracking efficiency uncertainty for the lepton, kaon, and pion is 0.91% per track.
 435 This is obtained by comparing $R_{2/3}$ for $e^+e^- \rightarrow \tau^+\tau^-$ events in data and MC, where $R_{2/3}$ is
 436 the fraction of 3-prong τ decays in which only two hadron tracks are found. The uncertainty
 437 on the soft pion tracking efficiency is determined by the study of $B \rightarrow D^*\pi$ and $B \rightarrow D^*\rho$
 438 decays and estimated to be 9.9%.

439 To obtain the number of B^0 mesons in the sample, we use the relation

$$N_{B^0} = 2 \times N_{B\bar{B}} \times (1 + f_{+0})^{-1} . \quad (11)$$

440 Here $f_{+0} = \mathcal{B}(\Upsilon(4S) \rightarrow B^+ B^-) / \mathcal{B}(\Upsilon(4S) \rightarrow B^0 \bar{B}^0) = 1.058 \pm 0.024$ [14]. The number of
 441 B meson pairs in the analyzed data set is determined to be $N_{B\bar{B}} = (37.7 \pm 0.6) \times 10^6$.

442 The uncertainties of the selection efficiencies on the used form factors used to simulate
 443 $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ are taken from Ref. [17, 18] and varied within their uncertainties.

444 Lastly, we account for the impact of the uncertainties in the charm branching fractions,
 445 $\mathcal{B}(D^{*+} \rightarrow D^0\pi^+) = (67.7 \pm 0.5)\%$ and $\mathcal{B}(D^0 \rightarrow K^-\pi^+) = (3.950 \pm 0.031)\%$ [13], on the
 446 signal branching fraction.

447 6. SUMMARY AND CONCLUSIONS

We present measurements of the semileptonic $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ and $B^- \rightarrow D^0\ell^-\bar{\nu}_l$ processes using 34.6 fb^{-1} of recorded collision events of Belle II data. We demonstrate the capability to reconstruct and separate $B^- \rightarrow D^0\ell^-\bar{\nu}_l$ candidates from the large backgrounds from $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ and other processes. In addition, we measure the $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ branching fraction and obtain a value of

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l) = (4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\pi_s})\% , \quad (12)$$

448 lower, but in good agreement with, the current world average. The largest systematic uncer-
 449 tainty stems from the knowledge of the slow pion reconstruction efficiency. This uncertainty
 450 will improve with the statistics of the control samples that will become soon available. In
 451 addition, we demonstrate the capability to reconstruct the hadronic recoil parameter w
 452 and present unfolded partial decay rates. Such measurements in both $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_l$ and
 453 $B^- \rightarrow D^0\ell^-\bar{\nu}_l$ are crucial for future precision measurements of $|V_{cb}|$ in these channels by
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