$B \to \overline{D}^{**} \ell^+ \nu_\ell$ decays experimental status @Belle

Frank Meier

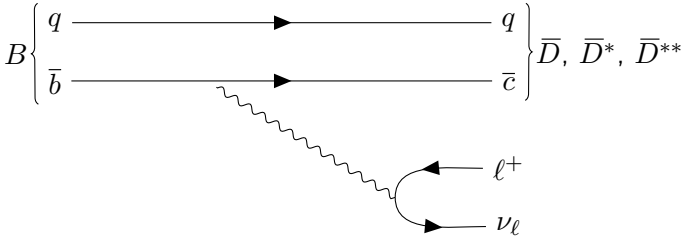
Open LHCb Workshop on semileptonic exclusive $b \to c$ decays
12 - 14 April 2023

Duke UNIVERSITY

Research supported by
U.S. DEPARTMENT OF ENERGY | Office of Science

Introduction

- deviation between inclusive and exclusive determinations of $|V_{cb}|$
- gap of $\sim$1.75% between inclusive and exclusive branching fraction measurements of $B \to X_c \ell \nu_\ell$
- persistent 3σ deviation between SM expectation and experimental results for $R(D^{(*)})$



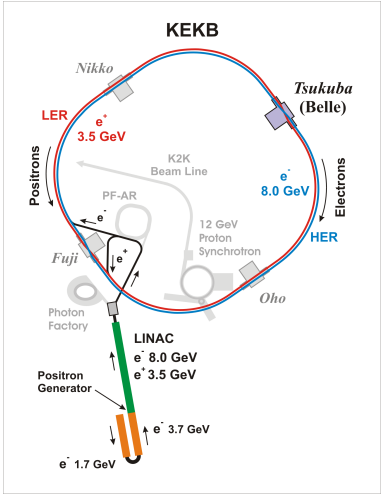
- $B \to \overline{D} \ell^+ \nu_\ell$ and $B \to \overline{D}^* \ell^+ \nu_\ell$ known at 3 - 4% level
- $B \to \overline{D} \pi \ell^+ \nu_\ell$ and $B \to \overline{D}^* \pi \ell^+ \nu_\ell$ only known at 7 - 9% / 12 - 14% level for charged / neutral modes
- $B \to \overline{D}^{(*)} \pi \ell^+ \nu_\ell$ and $B \to \overline{D}^{(*)} \pi^+ \pi^- \ell^+ \nu_\ell$ important background contributions in $R(D^{(*)})$ measurements
  - reduce uncertainty on absolute branching fraction
  - study intermediate states, especially for $D\pi\pi$ final state

Overview of $B \to \overline{D}^{**} \ell^+ \nu_\ell$ status

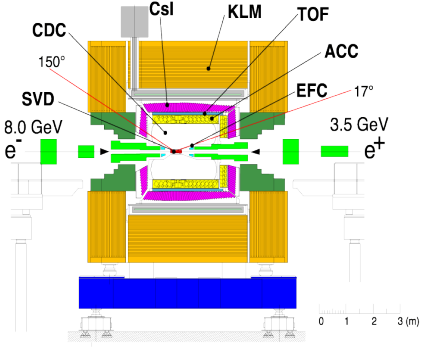
Decay mode	BaBar (PRL 116, 041801 (2016))	Belle (PRD 98, 012005 (2018))
$B^0 \to \overline{D}^0 \pi^- \ell^+ \nu_\ell$	$(0.43 \pm 0.08 \pm 0.03)\%$	$(0.405 \pm 0.036 \pm 0.041)\%$
$B^+ \to D^- \pi^+ \ell^+ \nu_\ell$	$(0.42 \pm 0.06 \pm 0.03)\%$	$(0.455 \pm 0.027 \pm 0.039)\%$
$B^0 \to \overline{D}^{*0} \pi^- \ell^+ \nu_\ell$	$(0.48 \pm 0.08 \pm 0.04)\%$	$(0.646 \pm 0.053 \pm 0.052)\%$
$B^+ \to D^{*-} \pi^+ \ell^+ \nu_\ell$	$(0.59 \pm 0.05 \pm 0.04)\%$	$(0.603 \pm 0.043 \pm 0.038)\%$
$B^0 \to D^- \pi^+ \pi^- \ell^+ \nu_\ell$	$(0.127 \pm 0.039 \pm 0.026 \pm 0.007)\%$	-
$B^+ \to \overline{D}^0 \pi^+ \pi^- \ell^+ \nu_\ell$	$(0.161 \pm 0.030 \pm 0.018 \pm 0.008)\%$	-
$B^0 \to D^{*-} \pi^+ \pi^- \ell^+ \nu_\ell$	$(0.138 \pm 0.039 \pm 0.030 \pm 0.003)\%$	-
$B^+ \to \overline{D}^{*0} \pi^+ \pi^- \ell^+ \nu_\ell$	$(0.080 \pm 0.040 \pm 0.023 \pm 0.003)\%$	-

- D^{**} is orbitally excited ($L = 1$) charmed meson not far from threshold
- two doublets of states with light-quark total angular momenta of $j_q = \frac{1}{2}$ and $j_q = \frac{3}{2}$
- spin-0 state D_0^* only decays to $D\pi$, spin-1 states D_1 and D_1' only into $D^*\pi$
- spin-2 state D_2^* can decay both into $D\pi$ and $D^*\pi$
- $j_q = \frac{3}{2}$ states (D_1 and D_2^*) have significant D-wave component $\Rightarrow$ narrow width of $\sim$20 MeV
- $j_q = \frac{1}{2}$ states (D_0^* and D_1') decay mainly via S-wave $\Rightarrow$ broad width of few 100 MeV

Experimental Setup



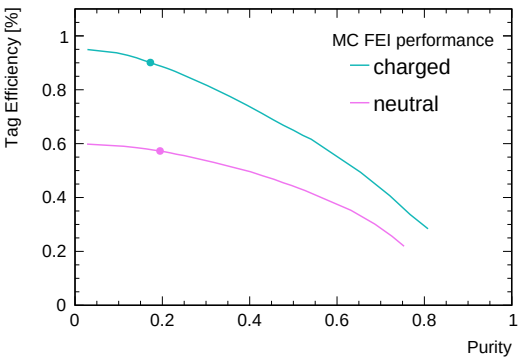
- asymmetric collision of e^+e^-
- center-of-mass energy mostly at $\Upsilon(4S)$ resonance
- $\Upsilon(4S) \to B^+B^-$ ($\sim$51.5%), $\Upsilon(4S) \to B^0\overline{B}^0$ ($\sim$48.5%)
- Belle collected $\sim$772M $B\overline{B}$ pairs over the course of 10 years

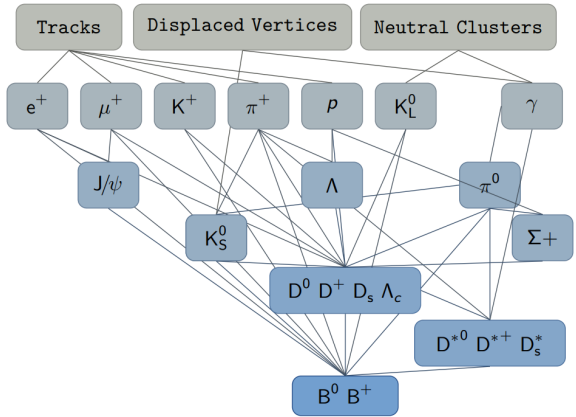


Full Event Interpretation

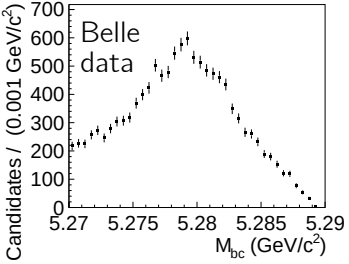
Comput. Softw. Big Sci. 3 (2019)

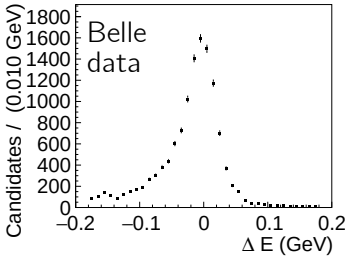
- fully reconstruct one of the B mesons (tag-side) in many exclusive modes
- hadronic and semileptonic version:
  trade-off between efficiency and purity
- train BDT for each stage
  $\Rightarrow$ signal probability

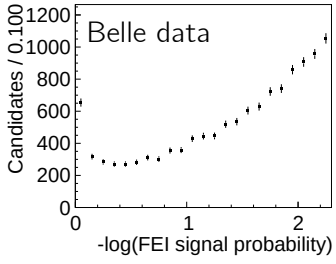




Distributions of tag-side B meson candidates







$$M_{\text{bc}} = \sqrt{(E_{\text{c.m.}}/c^2)^2 - \left(\vec{P}_{B_{\text{tag}}}/c\right)^2} \qquad \Delta E = E_{B_{\text{tag}}} - E_{\text{c.m.}}$$

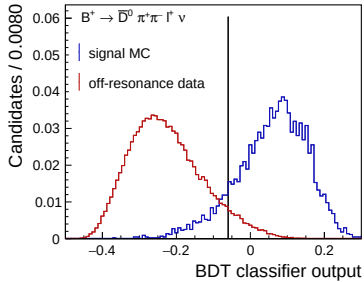
- $E_{\text{c.m.}}$: half of the center-of-mass (c.m.) energy of the beams
- $\vec{P}_{B_{\text{tag}}}$ and $E_{B_{\text{tag}}}$: momentum and energy of the B_{tag} meson in the c.m. frame

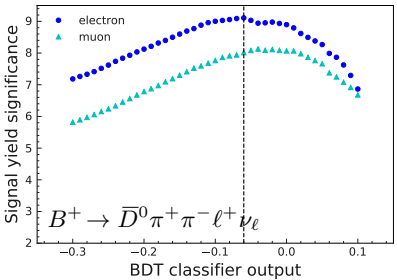
Analysis in a nut shell

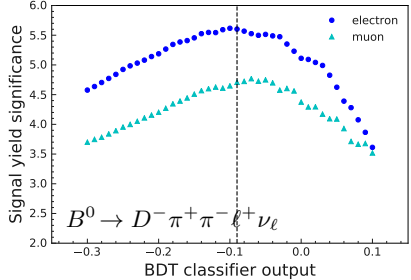
- convert data from Belle to Belle II format using B2BII Comput. Softw. Big Sci. 2 (2018)
- run hadronic Full Event Interpretation with dedicated Belle training
  - B_{tag} selection: $|\Delta E| < 180$ MeV, $M_{\text{bc}} > 5.27$ GeV/c^2, signal probability > 0.005
- final state particle selection ($e^{\pm}$, $\mu^{\pm}$, $K^{\pm}$, $\pi^{\pm}$, π^0, and K^0_S)
- reconstruct D from final state particles and D^* by adding slow pion
  - 10 D^0 final states: $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K^0_S\pi^+\pi^-$, K^+K^-, $K^0_S\pi^0$, $K^0_S\pi^+\pi^-\pi^0$, $\pi^+\pi^-$, $K^-\pi^+\pi^-\pi^+\pi^0$, and $\pi^+\pi^-\pi^0$
  - 9 D^+ final states: $K^0_S\pi^+$, $K^0_S\pi^+\pi^-\pi^+$, $K^-\pi^+\pi^+$, $K^-K^+\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K^0_S\pi^+\pi^0$, $K^0_SK^+$, $\pi^+\pi^0$, and $\pi^+\pi^-\pi^+$
- combine $D^{(*)}$ with 0, 1, and 2 bachelor pions + 1 lepton to form 24 different B_{sig} modes
- reconstruct $\Upsilon(4S)$ from B_{tag} + B_{sig} (B^+B^-, $B^0\overline{B}^0$, B^0B^0)
- check that there are no additional tracks in the rest of the event
- best $\Upsilon(4S)$ candidate selection based on tag-side signal probability and preference of D^* over D modes
- measure branching fractions of $B \to \overline{D}^{(*)}\pi\ell^+\nu_\ell$ and $B \to \overline{D}\pi^+\pi^-\ell^+\nu_\ell$ relative to $B \to \overline{D}^*\ell^+\nu_\ell$

BDT to suppress continuum background in $D\pi\pi$ modes

- training samples:
  - background: off-resonance data
  - signal: $B^+ \to \overline{D}{}_1^0 \ell^+ \nu_\ell$ with $\overline{D}{}_1^0 \to \overline{D}{}^0 \pi^+ \pi^-$
    $B^0 \to D_1^- \ell^+ \nu_\ell$ with $D_1^- \to D^- \pi^+ \pi^-$
- 25 training variables describing tag-side quantities, event shape, and rest of the event, like unaccounted energy in the ECL or Fox-Wolfram moments
- scan BDT output classifier to find optimal relative signal significance

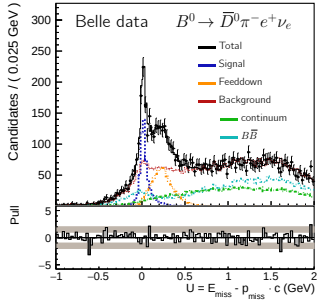






Fit model

- fit dimension: $U = E_{\text{miss}} - p_{\text{miss}} \cdot c$ with $E_{\text{miss}} = E_{e^+e^-} - E_{\text{tag}} - E_{D^{**}} - E_l$
  - better sensitivity than fitting missing mass squared $M_\nu^2 = E_{\text{miss}}^2/c^4 - p_{\text{miss}}^2/c^2$
- simultaneous fit in 16 categories split by B flavor mode (B^0 vs B^+), the D mode (D^0/D^+ vs D^{*0}/D^{*+}), the number of pion daughters ($D\pi$ vs $D\pi\pi$), and the lepton mode (e vs μ)
- fit components:
  - signal (from MC)
  - feeddown: π^0 missed in reconstruction of $D^* \to D\pi^0$
  - off-resonance data to describe continuum events
  - $B\overline{B}$ background
  - $B \to \overline{D}^{**}\ell^+\nu_\ell$ background
- PDF constructed as histograms with 120 bins in range -1 - 2 GeV
  - MC weighted to correct known data-MC differences in PID, tracking efficiency, π^0 and K_S^0 efficiency, charm branching fractions, and tagging mode composition



Signal fit model

- $B^+ \to D^- \pi^+ \ell^+ \nu_\ell$: 62% via $\overline{D}_0^{*0}$ and 38% via $\overline{D}_2^{*0}$
- $B^0 \to \overline{D}^0 \pi^- \ell^+ \nu_\ell$: 71% via D_0^{*-} and 29% via D_2^{*-}
- $B^+ \to D^{*-} \pi^+ \ell^+ \nu_\ell$: 45% via $\overline{D}_1^0$, 40% via $\overline{D}_1^{\prime 0}$, and 15% via $\overline{D}_2^{*0}$
- $B \to \overline{D}^{(*)} \pi \ell^+ \nu_\ell$ templates above convolved with Gaussian of floating mean and width
- $B^0 \to \overline{D}^{*0} \pi^- \ell^+ \nu_\ell$: 42.5% via D_1^-, 47% via $D_1^{\prime -}$, and 10.5% via D_2^{*-}
- $B \to \overline{D} \pi^+ \pi^- \ell^+ \nu_\ell$: decay via D_1
- $B \to \overline{D}^* \pi^+ \pi^- \ell^+ \nu_\ell$
  - decay via D_1'
  - template constructed with only 30 bins in -0.5 - 1 GeV

$B \to \overline{D}^{**} \ell^+ \nu_\ell$ background model

- combination of 14 different MC sample
  - $B^+ \to \overline{D}^{**0} \ell^+ \nu_\ell$ with $\overline{D}^{**0} \in (\overline{D}_0^{*0}, \overline{D}_1^0, \overline{D}_1'^0, \overline{D}_2^{*0})$
  - $B^+ \to \overline{D}_1^0 \ell^+ \nu_\ell$ with $\overline{D}_1^0 \to \overline{D}^0 \pi^+ \pi^-$
  - $B^+ \to \overline{D}^0 \pi^+ \pi^- \ell^+ \nu_\ell$
  - $B^+ \to \overline{D}^{*0} \pi^+ \pi^- \ell^+ \nu_\ell$
  - $B^0 \to D^{**-} \ell^+ \nu_\ell$ with $D^{**-} \in (D_0^{*-}, D_1^-, D_1'^-, D_2^{*-})$
  - $B^0 \to D_1^- \ell^+ \nu_\ell$ with $D_1^- \to D^- \pi^+ \pi^-$
  - $B^0 \to D^- \pi^+ \pi^- \ell^+ \nu_\ell$
  - $B^0 \to D^{*-} \pi^+ \pi^- \ell^+ \nu_\ell$
- events of these samples are background if
  - signal candidates are misreconstructed
  - final state particles are swapped between B_{sig} and B_{tag} candidates
  - $D^{**} \to D^{(*)} \pi^0$
- signal-to-background (crossfeed) efficiency ratio fixed to MC value
- background yield related to signal component within simultaneous fit

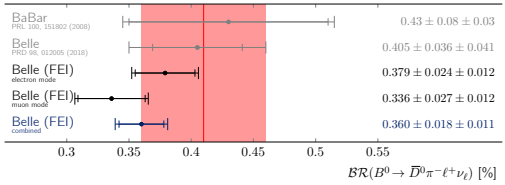
Relative systematic uncertainties

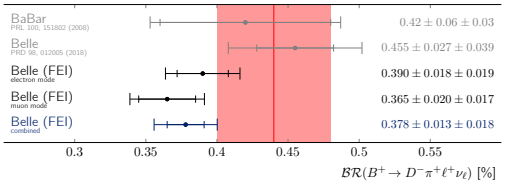
- many systematic uncertainties reduced because of partial cancellation in ratio with normalization mode
- systematic uncertainties from lepton PID (0.1 - 0.6%), tracking (0.3 - 0.7%), π^0 efficiency (0.1 - 0.4%) low
- hadron PID cancels well for B^0, but not so well for B^+ modes (up to 3.6%)
- systematic uncertainties due to finite MC statistics
  - shape uncertainties small for $D^{(*)}\pi$ modes (0.7 - 1.1%), but largest systematic for $D^{(*)}\pi\pi$ modes (4.5 - 17.1%)
  - signal efficiency uncertainty 0.5 - 0.7% for $D^{(*)}\pi$ modes, but up to 8% for $B^0 \to D^{*-}\pi^+\pi^-\ell^+\nu_\ell$
- sizable systematic uncertainty of 3.9 - 5.5% for difference between BDT signal efficiency in data and MC
- uncertainty on branching fraction of normalization mode $\Rightarrow$ systematic of 2.4% (B^0) and 3.9% (B^+)
- uncertainty on branching fraction of charm modes 0.9 - 1.4%
- uncertainty on D^{**} composition of signal model (and related signal efficiency) 0.8 - 1.1%

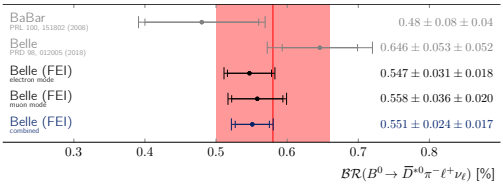
Total systematic uncertainties in %

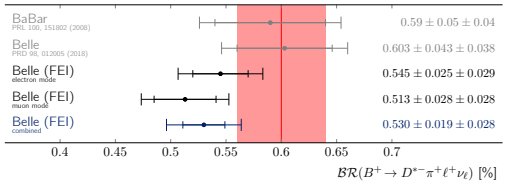
	$D\pi\ell\nu_\ell$	$D^*\pi\ell\nu_\ell$	$D\pi\pi\ell\nu_\ell$	$D^*\pi\pi\ell\nu_\ell$
B^0	3.1	3.2	9.2	20.0
B^+	4.7	5.3	8.3	12.8

Branching fraction results for $B \to \overline{D}^{(*)}\pi\ell^+\nu_\ell$ modes



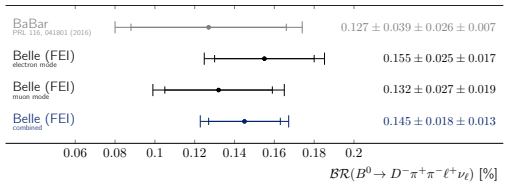


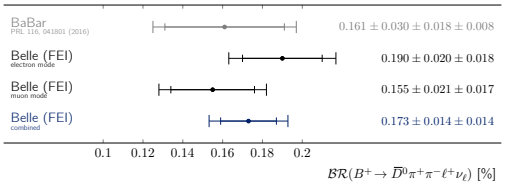


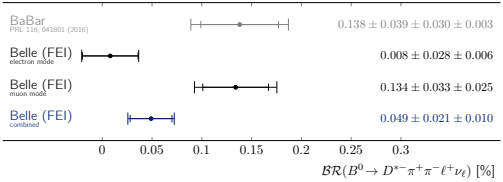


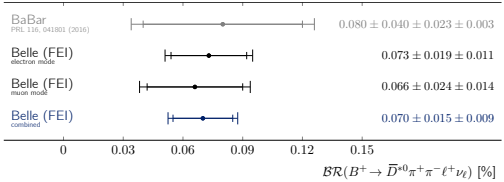
- all results compatible with previous world averages, but slightly lower
- most precise measurements to date

Branching fraction results for $D\pi\pi$ modes







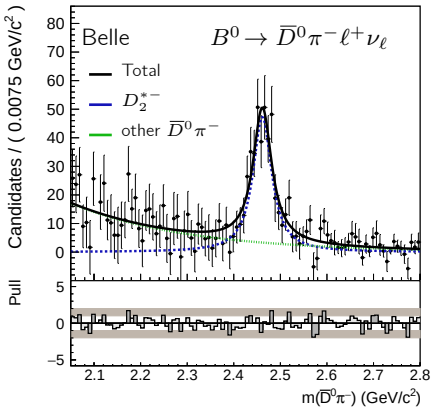


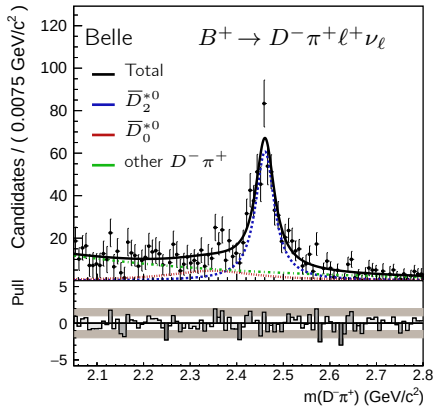
- most precise determinations of these branching fractions to date (except for $B^0 \to D^{*-} \pi^+ \pi^- \ell^+ \nu_\ell$)
- values compatible with previous world averages

Extraction of exclusive $B \to \overline{D}^{**}\ell^+\nu_\ell$ branching fractions

- determine D^{**} composition (D_0^*, D_1, D_1', D_2^*)
- based on previous fit to $U = E_{\text{miss}} - p_{\text{miss}} \cdot c$ distribution calculate signal weights
  - use implementation of "Custom Orthogonal Weight functions (COWs) for event classification" paper (NIMA 1040, 167270 (2022))
  - checked that correlations between discriminating and control variable are small (<5%)
- fit $m(D\pi)$, $m(D^*\pi) - m(D^*)$, and m($D\pi\pi$) distributions
- PDF: Breit-Wigner functions convolved with Gaussian of width 3.4 MeV/c^2

Fit of weighted m($D\pi$) distribution





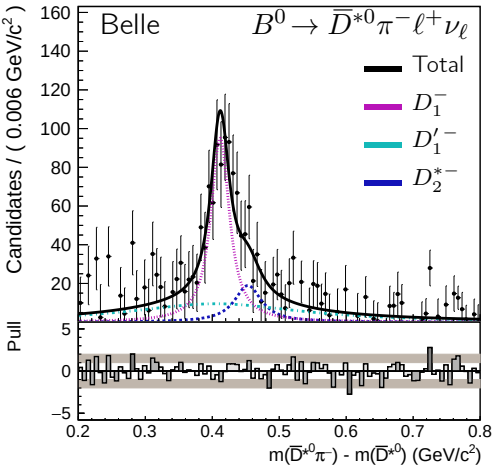
- peak position and width of D^{**} resonances floating in fit but constrained with Gaussian to PDG values
- model contains additional exponential function

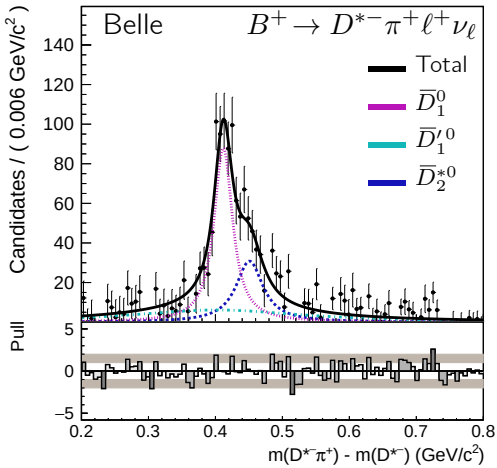
Numerical results of exclusive D^{**} branching fractions

	yield	branching fraction [%]	PDG [%]
$B^0 \to D_0^{*-}\ell^+\nu_\ell$ with $D_0^{*-} \to \overline{D}^0\pi^-$	-	<0.044 at 90% CL	0.30 ± 0.12
$B^0 \to D_2^{*-}\ell^+\nu_\ell$ with $D_2^{*-} \to \overline{D}^0\pi^-$	457±45	$0.157 \pm 0.015\,(\text{stat}) \pm 0.005\,(\text{syst})$	0.121 ± 0.033
other $B^0 \to \overline{D}^0\pi^-\ell^+\nu_\ell$	547±45	-	
$B^+ \to \overline{D}_0^{*0}\ell^+\nu_\ell$ with $\overline{D}_0^{*0} \to D^-\pi^+$	180±72	$0.054 \pm 0.022\,(\text{stat}) \pm 0.005\,(\text{syst})$	0.25 ± 0.05
$B^+ \to \overline{D}_2^{*0}\ell^+\nu_\ell$ with $\overline{D}_2^{*0} \to D^-\pi^+$	590±39	$0.163 \pm 0.011\,(\text{stat}) \pm 0.008\,(\text{syst})$	0.153 ± 0.016
other $B^+ \to D^-\pi^+\ell^+\nu_\ell$	520±70	-	

- systematic uncertainty contains contribution from precision of PDG world averages (fixing peak position and width vs floating them)
- decays via D_2^* compatible with PDG but more precise
- no decay via D_0^{*-} found
- decay via $\overline{D}_0^{*0}$ smaller than PDG and less precise
- sum of $\overline{D}_0^{*0}$ yield and undefined / nonresonant yield in same ballpark as PDG value for $\overline{D}_0^{*0}$

Fit of weighted m($D^*\pi$) distribution





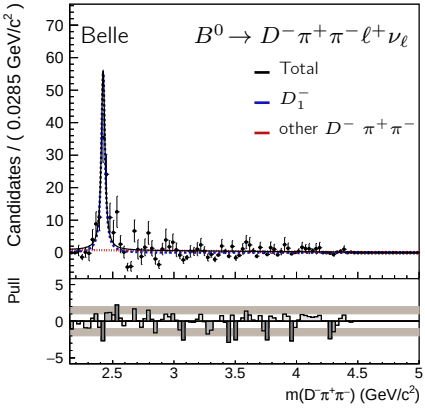
- shape parameters of D_1 and D_2^* constrained and of D_1' fixed to PDG world averages

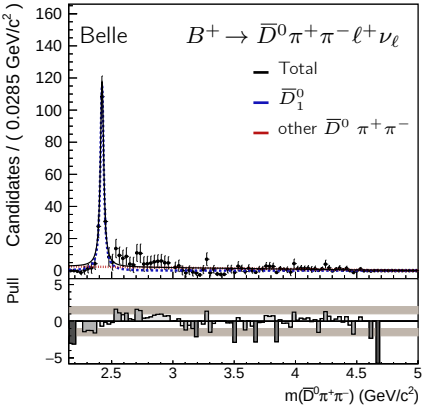
Numerical results of exclusive D^{**} branching fractions

	yield	branching fraction [%]	PDG [%]
$B^0 \to D_1^- \ell^+ \nu_\ell$ with $D_1^- \to \overline{D}^{*0}\pi^-$	866 ± 142	$0.306 \pm 0.050\,(\text{stat}) \pm 0.029\,(\text{syst})$	0.280 ± 0.028
$B^0 \to D_1'^- \ell^+ \nu_\ell$ with $D_1'^- \to \overline{D}^{*0}\pi^-$	523 ± 173	$0.206 \pm 0.068\,(\text{stat}) \pm 0.025\,(\text{syst})$	0.31 ± 0.09
$B^0 \to D_2^{*-} \ell^+ \nu_\ell$ with $D_2^{*-} \to \overline{D}^{*0}\pi^-$	145 ± 114	$0.051 \pm 0.040\,(\text{stat}) \pm 0.010\,(\text{syst})$	0.068 ± 0.012
$B^+ \to \overline{D}_1^0 \ell^+ \nu_\ell$ with $\overline{D}_1^0 \to D^{*-}\pi^+$	698 ± 65	$0.249 \pm 0.023\,(\text{stat}) \pm 0.015\,(\text{syst})$	0.303 ± 0.020
$B^+ \to \overline{D}_1'^0 \ell^+ \nu_\ell$ with $\overline{D}_1'^0 \to D^{*-}\pi^+$	353 ± 93	$0.138 \pm 0.036\,(\text{stat}) \pm 0.009\,(\text{syst})$	0.27 ± 0.06
$B^+ \to \overline{D}_2^{*0} \ell^+ \nu_\ell$ with $\overline{D}_2^{*0} \to D^{*-}\pi^+$	382 ± 74	$0.137 \pm 0.026\,(\text{stat}) \pm 0.009\,(\text{syst})$	0.101 ± 0.024

- decays via D_1 and D_2^* compatible with PDG but less precise
- branching fractions of D_1' modes lower than PDG and with similar precision

Fit of weighted m($D\pi\pi$) distribution





- initially fitted with single Gaussian + first-order polynomial (all shape parameters floating)
- fitted peak position and width compatible with D_1 resonance
  $\Rightarrow$ interpret Gaussian component as $B \to \overline{D}_1\ell^+\nu_\ell$ with $D_1 \to D\pi^+\pi^-$
- final model Breit-Wigner function convolved with Gaussian (shape parameters constrained to PDG values)

Fit results of m($D\pi\pi$) fit

- 103 ± 13 $D_1 \to D\pi^+\pi^-$ candidates found for B^0 mode and 197 ± 20 candidates for B^+ mode
- statistical significance of D_1 components 17.3 and 25.1
- remaining signal events (42 ± 13 / 131 ± 20) either nonresonant decay process or decay via very broad resonance (D_0^* or D_1')

$$\mathcal{B}(B^0 \to D_1^- \ell^+ \nu_\ell) \times \mathcal{B}(D_1^- \to D^- \pi^+ \pi^-) = (0.102 \pm 0.013\,(\text{stat}) \pm 0.009\,(\text{syst}))\%$$
$$\mathcal{B}(B^+ \to \overline{D}_1^0 \ell^+ \nu_\ell) \times \mathcal{B}(\overline{D}_1^0 \to \overline{D}^0 \pi^+ \pi^-) = (0.105 \pm 0.011\,(\text{stat}) \pm 0.009\,(\text{syst}))\%$$

- first observation of these decay modes

Conclusion

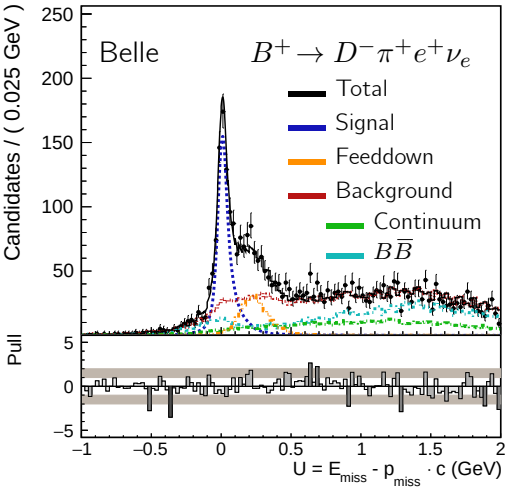
- world's best measurements of $B \to \overline{D}^{**} \ell^+ \nu_\ell$ branching fractions
- improvement of at least factor 2 over any other measurement, mainly thanks to new tagging algorithm
- all results of combined branching fractions compatible with previous world averages
- statistical uncertainties dominate for B^0 modes, for B^+ modes statistical and systematic uncertainties of similar size

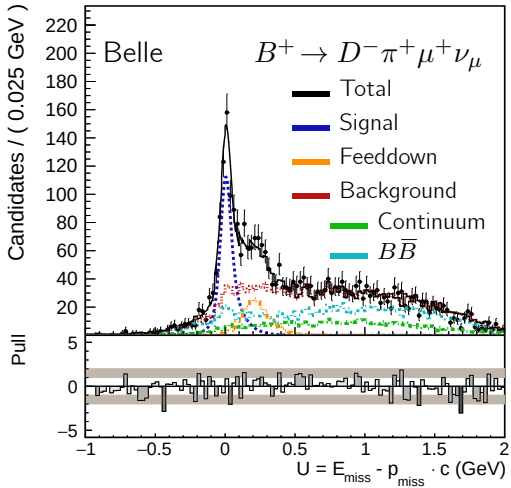
$$\mathcal{B}(B^0 \to \overline{D}^0 \pi^- \ell^+ \nu_\ell) = 0.360 \pm 0.018\,(\text{stat}) \pm 0.011\,(\text{syst})\%$$
$$\mathcal{B}(B^+ \to D^- \pi^+ \ell^+ \nu_\ell) = 0.378 \pm 0.013\,(\text{stat}) \pm 0.018\,(\text{syst})\%$$
$$\mathcal{B}(B^0 \to \overline{D}^{*0} \pi^- \ell^+ \nu_\ell) = 0.551 \pm 0.024\,(\text{stat}) \pm 0.017\,(\text{syst})\%$$
$$\mathcal{B}(B^+ \to D^{*-} \pi^+ \ell^+ \nu_\ell) = 0.530 \pm 0.019\,(\text{stat}) \pm 0.028\,(\text{syst})\%$$
$$\mathcal{B}(B^0 \to D^- \pi^+ \pi^- \ell^+ \nu_\ell) = 0.145 \pm 0.018\,(\text{stat}) \pm 0.013\,(\text{syst})\%$$
$$\mathcal{B}(B^+ \to \overline{D}^0 \pi^+ \pi^- \ell^+ \nu_\ell) = 0.173 \pm 0.014\,(\text{stat}) \pm 0.014\,(\text{syst})\%$$
$$\mathcal{B}(B^0 \to D^{*-} \pi^+ \pi^- \ell^+ \nu_\ell) = 0.049 \pm 0.021\,(\text{stat}) \pm 0.010\,(\text{syst})\%$$
$$\mathcal{B}(B^+ \to \overline{D}^{*0} \pi^+ \pi^- \ell^+ \nu_\ell) = 0.070 \pm 0.015\,(\text{stat}) \pm 0.009\,(\text{syst})\%$$

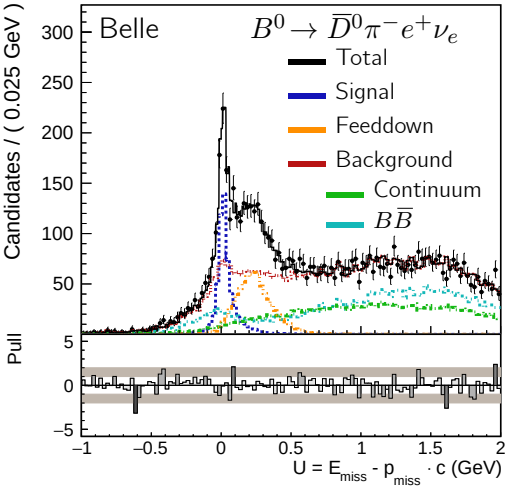
- first observation of $B \to \overline{D}_1 \ell^+ \nu_\ell$ with $D_1 \to D\pi^+\pi^-$
- paper available at arXiv:2211.09833 and accepted for publication by PRD

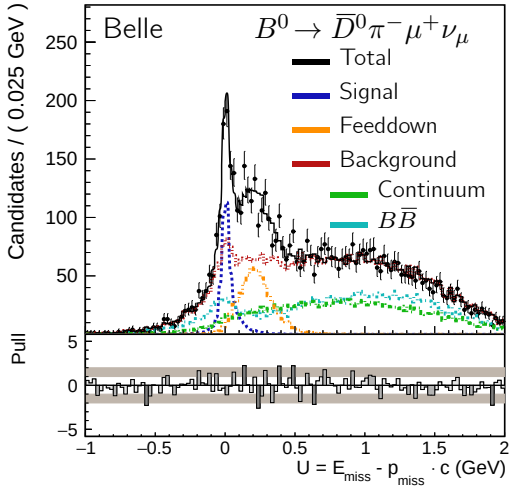
Backup

$B^+ \to D^- \pi^+ \ell^+ \nu_\ell$

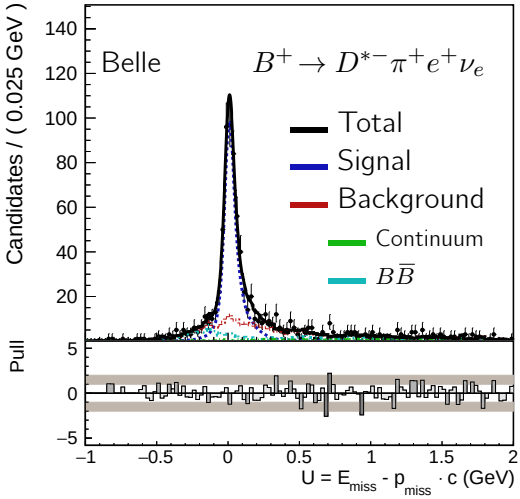


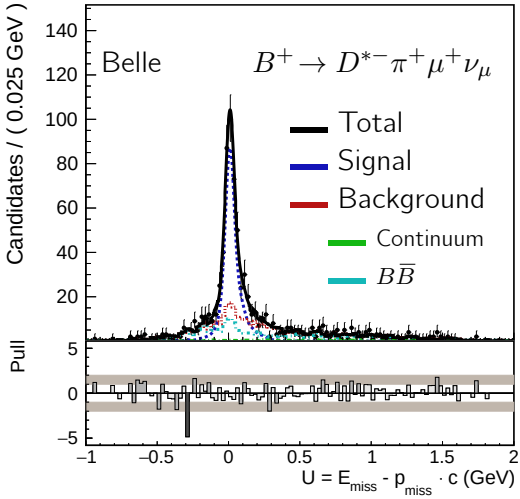


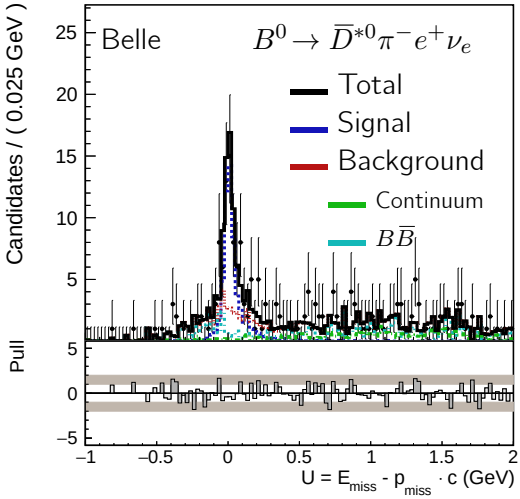

Belle
$B^0 \to \overline{D}^0 \pi^- e^+ \nu_e$
Total
Signal
Feeddown
Background
Continuum
$B\overline{B}$
Candidates / (0.025 GeV)
Pull
U = E_miss - p_miss · c (GeV)

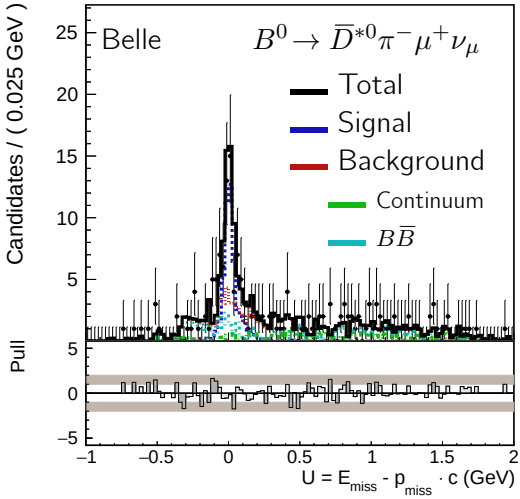

Belle
$B^0 \to \overline{D}^0 \pi^- \mu^+ \nu_\mu$
Total
Signal
Feeddown
Background
Continuum
$B\overline{B}$
Candidates / (0.025 GeV)
Pull
U = E_miss - p_miss · c (GeV)

$B^+ \to D^{*-}\pi^+\ell^+\nu_\ell$



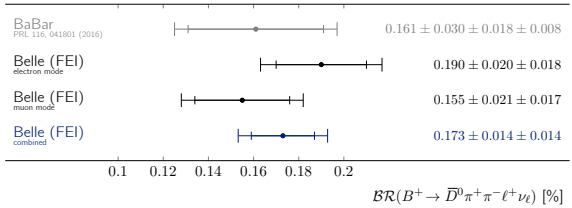


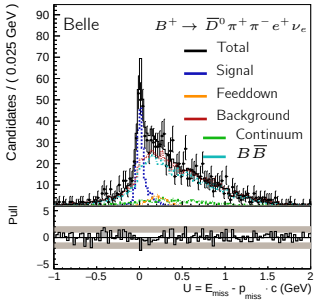

Belle
$B^0 \to \overline{D}^{*0}\pi^- e^+\nu_e$
Total
Signal
Background
Continuum
$B\overline{B}$
Candidates / (0.025 GeV)
Pull
U = E_miss - p_miss · c (GeV)

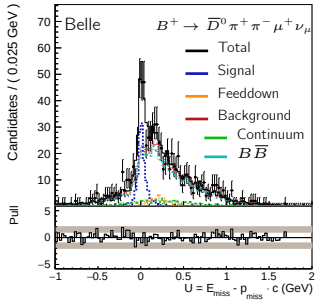

Belle
$B^0 \to \overline{D}^{*0}\pi^- \mu^+\nu_\mu$
Total
Signal
Background
Continuum
$B\overline{B}$
Candidates / (0.025 GeV)
Pull
U = E_miss - p_miss · c (GeV)

Results for $B^+ \to \overline{D}^0 \pi^+ \pi^- \ell^+ \nu_\ell$

- $N_{\text{sig}}(B^+ \to \overline{D}^0 \pi^+ \pi^- e^+ \nu_e) = 196 \pm 20$
- $N_{\text{sig}}(B^+ \to \overline{D}^0 \pi^+ \pi^- \mu^+ \nu_\mu) = 132 \pm 18$
- BaBar found 171 ± 30 $B^+ \to \overline{D}^0 \pi^+ \pi^- \ell^+ \nu_\ell$



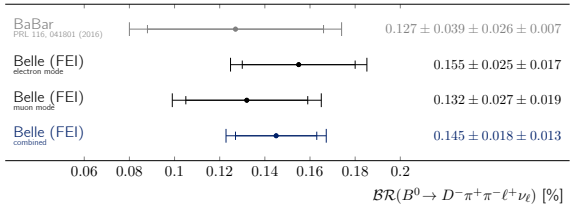


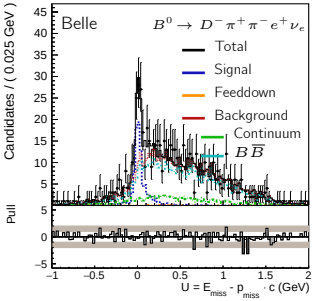


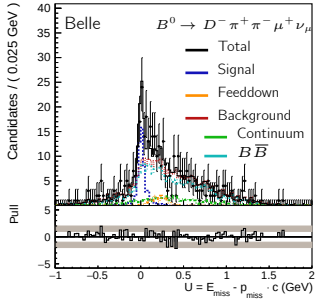
- good agreement of combined value with BaBar measurement
- statistical uncertainty reduced by factor 2

Results for $B^0 \to D^- \pi^+ \pi^- \ell^+ \nu_\ell$

- $N_{\text{sig}}(B^0 \to D^- \pi^+ \pi^- e^+ \nu_e) = 88 \pm 14$
- $N_{\text{sig}}(B^0 \to D^- \pi^+ \pi^- \mu^+ \nu_\mu) = 58 \pm 12$
- BaBar found 56 ± 17 $B^0 \to D^- \pi^+ \pi^- \ell^+ \nu_\ell$

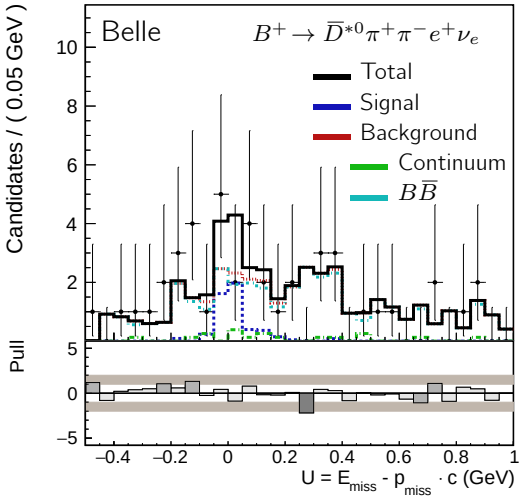


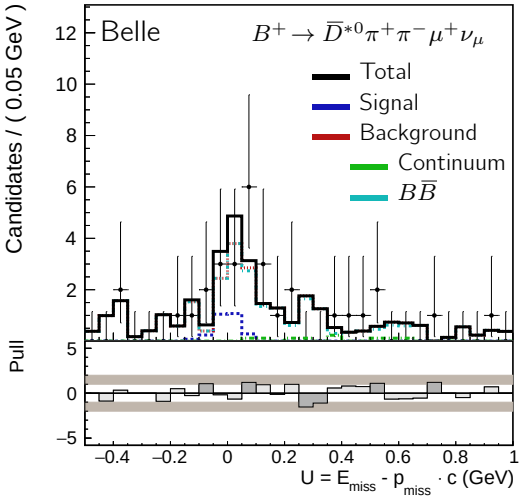




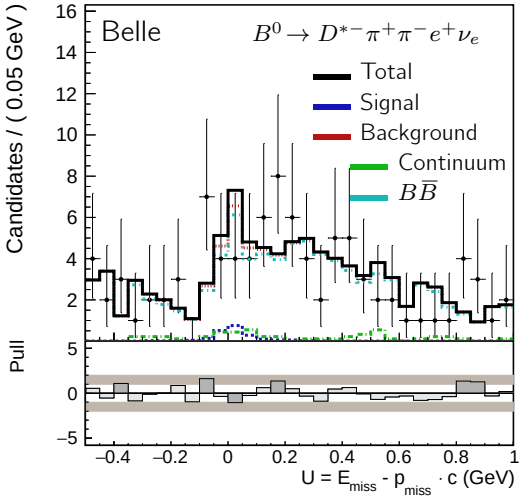
- total branching fraction compatible with BaBar value
- statistical uncertainty again reduced by factor 2

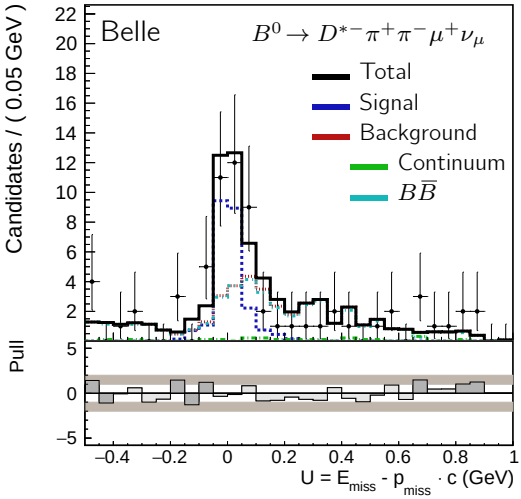
Fit of $B^+ \to \overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$





Results for $B^0 \to D^{*-}\pi^+\pi^-\ell^+\nu_\ell$





Relative systematic uncertainties of $B \to \overline{D}^{(*)}\pi\ell^+\nu_\ell$ (in %)

	$B^0 \to \overline{D}^0\pi^-\ell^+\nu_\ell$	$B^+ \to D^-\pi^+\ell^+\nu_\ell$	$B^0 \to \overline{D}^{*0}\pi^-\ell^+\nu_\ell$	$B^+ \to D^{*-}\pi^+\ell^+\nu_\ell$
MC statistics: fit model	1.1	0.7	1.1	0.7
MC statistics: efficiency	0.6	0.5	0.7	0.7
Charm branching ratios	1.0	1.4	1.1	1.2
Signal D^{**} composition	0.8	0.8	0.9	1.1
Lepton PID	0.1	0.1	0.1	0.1
Charged hadron PID	0.3	1.5	0.2	2.0
Tracking efficiency	0.3	0.6	0.6	0.6
π^0 efficiency	0.1	0.4	0.3	0.2
$B \to \overline{D}^*\ell^+\nu_\ell$/ $B \to \overline{D}^{**}\ell^+\nu_\ell$ form factors	0.5	0.4	0.3	0.5
sum	1.9	2.6	2.1	3.5
$\mathcal{B}$ ($B \to \overline{D}^*\ell^+\nu_\ell$)	2.4	3.9	2.4	3.9
sum incl. $\mathcal{B}$ ($B \to \overline{D}^*\ell^+\nu_\ell$)	3.1	4.7	3.2	5.3

Relative systematic uncertainties of $B \to \overline{D}^{(*)}\pi^+\pi^-\ell^+\nu_\ell$ (in %)

	$B^0 \to D^-\pi^+\pi^-\ell^+\nu_\ell$	$B^+ \to \overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$	$B^0 \to D^{*-}\pi^+\pi^-\ell^+\nu_\ell$	$B^+ \to \overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$
MC statistics: fit model	7.0	4.5	17.1	10.6
MC statistics: efficiency	2.4	1.8	8.1	3.7
Charm branching ratios	1.4	0.9	1.0	0.9
BDT	3.9	4.0	5.5	4.2
Lepton PID	0.3	0.3	0.6	0.4
Charged hadron PID	2.4	3.6	1.6	1.6
Tracking efficiency	0.5	0.7	0.6	0.7
π^0 efficiency	0.4	0.2	0.4	0.3
$B \to \overline{D}^*\ell^+\nu_\ell$ form factors	0.1	0.1	0.1	0.1
sum	8.9	7.3	19.8	12.2
$\mathcal{B}$ $(B \to \overline{D}^*\ell^+\nu_\ell)$	2.4	3.9	2.4	3.9
sum incl. $\mathcal{B}$ $(B \to \overline{D}^*\ell^+\nu_\ell)$	9.2	8.3	20.0	12.8