New results on semileptonic *B* meson decays from the Belle experiment

T08: Flavour Physics and CP Violation

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Content

Recent Belle results on semileptonic *b* → *u* decays:

inclusive | exclusive

- Measurement of **partial** branching fractions of inclusive $B \to X_u \ell^+ \nu$ decays with hadronic tagging [PRD 104 , 012008 (2021)]
- Measurement of **differential** branching fractions of inclusive $B \to X_u \ell^+ \nu$ decays [preliminary]
- Measurement of the branching fraction of the decay $B^+ \to \pi^+ \pi^- \ell^+ \nu$ in fully reconstructed evernts at Belle [PRD 103, 112001(2021)]
- Measurement of the branching fractions of the $B^+ \to \eta \ell^+ \nu$ and $B^+ \to \eta' \ell^+ \nu$ decays with signal-side only reconstruction in the full q^2 range [arXiv:2104.13354, preliminary]

Content

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inclusive | exclusive

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First measurement

- Measurement of **differential** branching fractions of inclusive **$B \to X_u \ell^+ \nu$** decays [preliminary]
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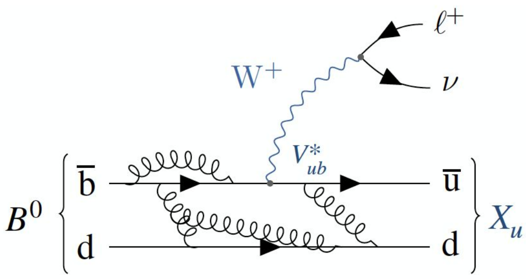
$\Delta\mathcal{B}(B \to X_u \ell^+ \nu)$ and $|V_{ub}^{\text{incl.}}|$

[PRD 104 , 012008 (2021)]

Introduction



- **$|V_{ub}|$ puzzle:**

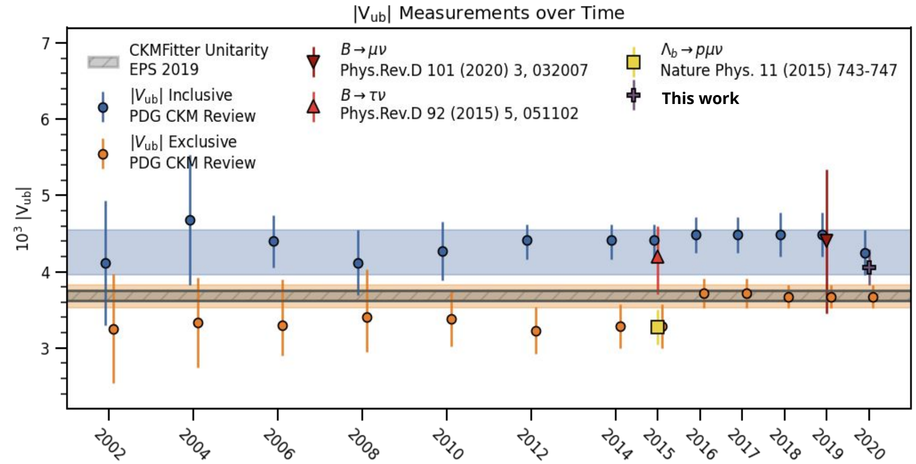
HFLAV

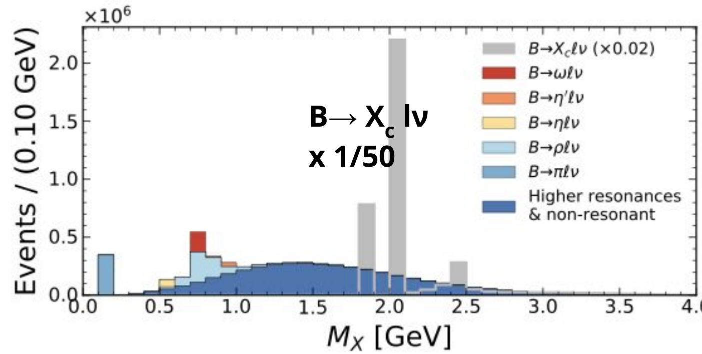
3σ

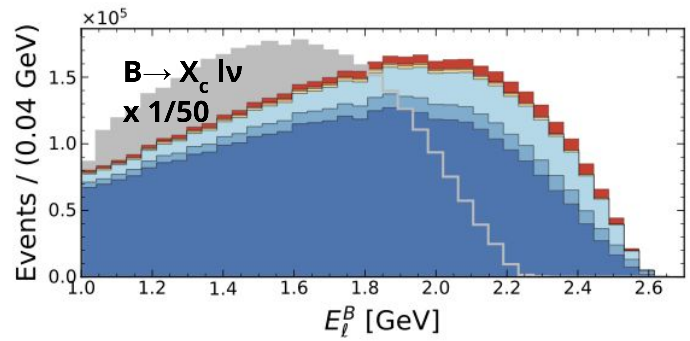
$$|V_{ub}^{\text{excl.}}| = (3.67 \pm 0.09 \pm 0.12) \times 10^{-3},$$
$$|V_{ub}^{\text{incl.}}| = \left(4.32 \pm 0.12^{+0.12}_{-0.13}\right) \times 10^{-3}.$$

- Measurements challenging due to **$B \to X_c l\nu$**

Clear **separation** only **possible** in certain **kinematic regions**, e.g. **lepton endpoint** or **low M_X**

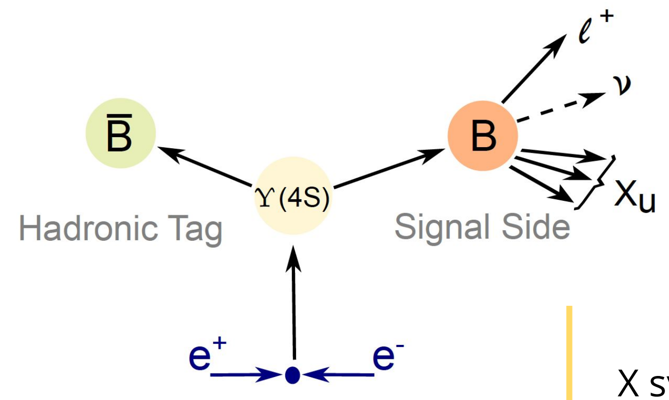






Reconstruction Strategy

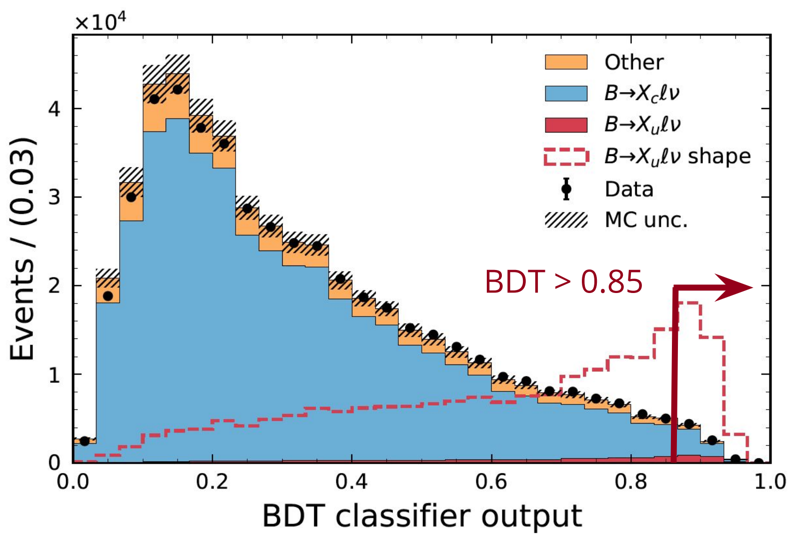
- Using **full Belle dataset of 711 fb^{-1}**
- **Hadronic tagging** with Neural Networks (ca. **0.2-0.3% efficiency**)
- Use **machine learning (BDT)** to suppress backgrounds with 11 trainning features, e.g. MM^2, $\#K^\pm$, $\#K_s$, etc.



X system properties

Can fully assign each final state particle to either the tag or signal side

→ Allows to reconstruct X system



Reconstructed kinematic variables

- Hadronic system *X*:

$$p_X = \sum_i\left(\sqrt{m_\pi^2 + |\mathbf{p_i}|^2}, \mathbf{p_i}\right) + \sum_i(E_i, \mathbf{k_i})$$

- Missing mass squared:

$$MM^2 = \left(P_{\Upsilon(4S)} - P_{\text{tag}} - P_X - P_\ell\right)^2$$

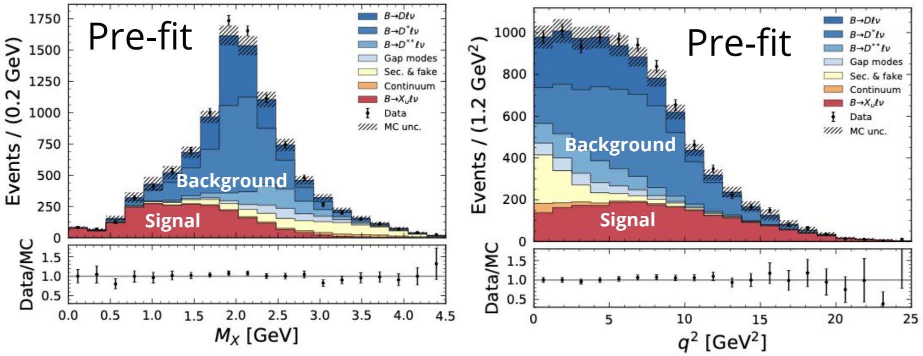
- Leptonic system:

$$q^2 = (P_B - P_X)^2 = (P_l + P_\nu)^2$$

Result

- Extract signal using binned likelihood in **3 phase space (PS) regions**
  - $E_\ell^B > 1$ GeV (covers 86% of available signal PS)
  - $E_\ell^B > 1$ GeV, $M_X < 1.7$ GeV (56%)
  - $E_\ell^B > 1$ GeV, $M_X < 1.7$ GeV, $q^2 > 8$ GeV^2 (31%)

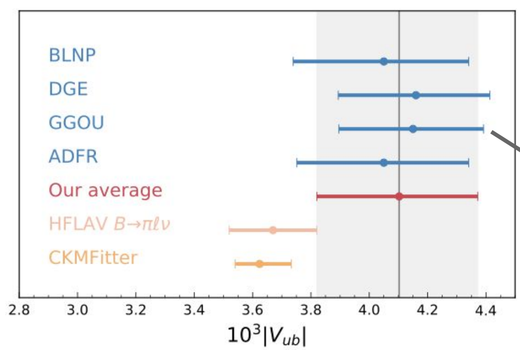
  → Fit either E_ℓ^B, M_X, q^2 or 2D (M_X:q^2)



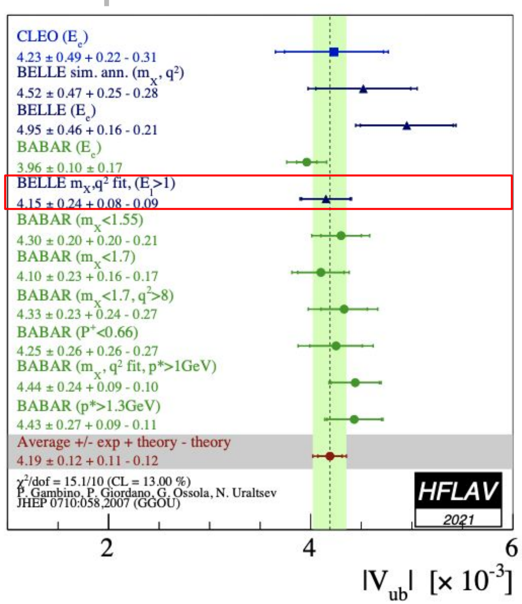
- Signal yields further corrected for efficiency & acceptance in various PS regions
- Convert partial BF in $E_\ell^B > 1$ GeV of 2D fit result to $|V_{ub}|$; based on **four** calculaitons of the decay rate

$\Delta\mathcal{B}(B \to X_u \ell^+ \nu;\ E_\ell^B > 1\ \text{GeV}) =$
$(1.59 \pm 0.07_{stat} \pm 0.16_{sys}) \times 10^{-3}$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell^+ \nu_\ell)}{\tau_B \cdot \Delta\Gamma(B \to X_u \ell^+ \nu_\ell)}}$$



Comparions based on GGOU



Our average:

$|V_{ub}| = (4.10 \pm 0.09_{stat} \pm 0.22_{sys} \pm 0.15_{theo}) \times 10^{-3}$

Value is compatible with excl. and CKM expectation within 1.3σ and 1.6σ

Differential $\Delta\mathcal{B}(B \to X_u \ell^+ \nu)$

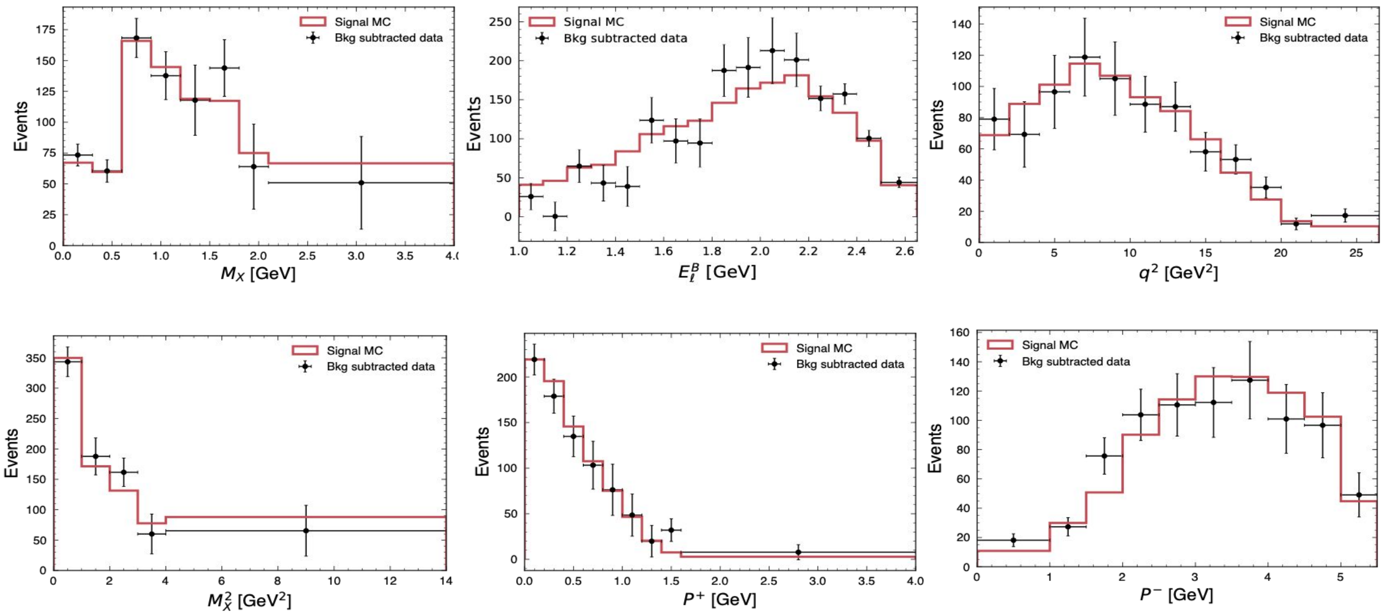
Kinematic Variables

- We measure the following 6 kinematic variables in the phase space of $E_l^B > 1$ GeV:

q^2, E_l^B, M_X, M_X^2, P_+, P_- (light-cone momenta: $P_\pm = E_X \mp |p_X|$)

- Selection and reconstruction inherited from the partial BR measurement presented previously.
- Additional selections on **$|E_{miss} - P_{miss}| < 0.1$ GeV** and reconstructed **$M_X < 2.4$ GeV** to improve resolution and reduce background shape uncertainty
- Background subtraction done via **M_X fit;** subtracted spectra are shown as below

Preliminary

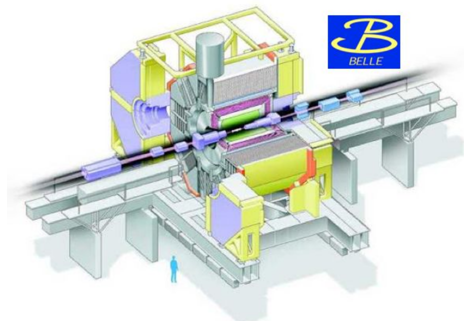


- Full bkg-sub. uncertainties are propagated

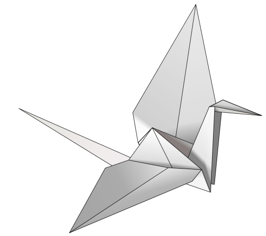
- Overlaid histograms: signal hybrid X_u (& normalised to fitted signal yields) .

Unfolding

X: **true distribution**

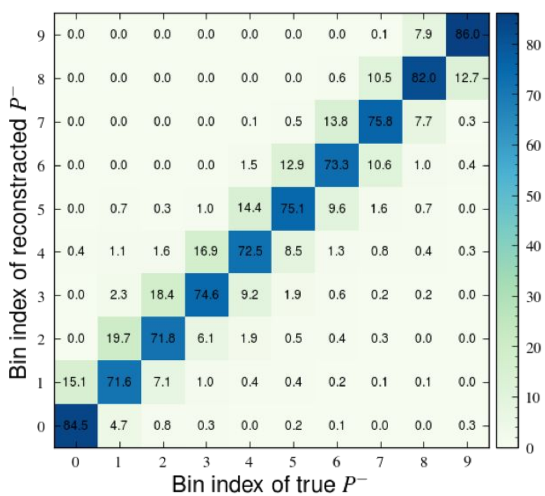


***M*: detector response**



***Y*: measured distribution**

- The detector response is represented by a migration matrix ***M***
- *M*(*i*, *j*) indicates the probability (%) to observe an event in bin *i* if it had a generator-level value in bin *j*



$$MX = Y$$

Direct solution for X is

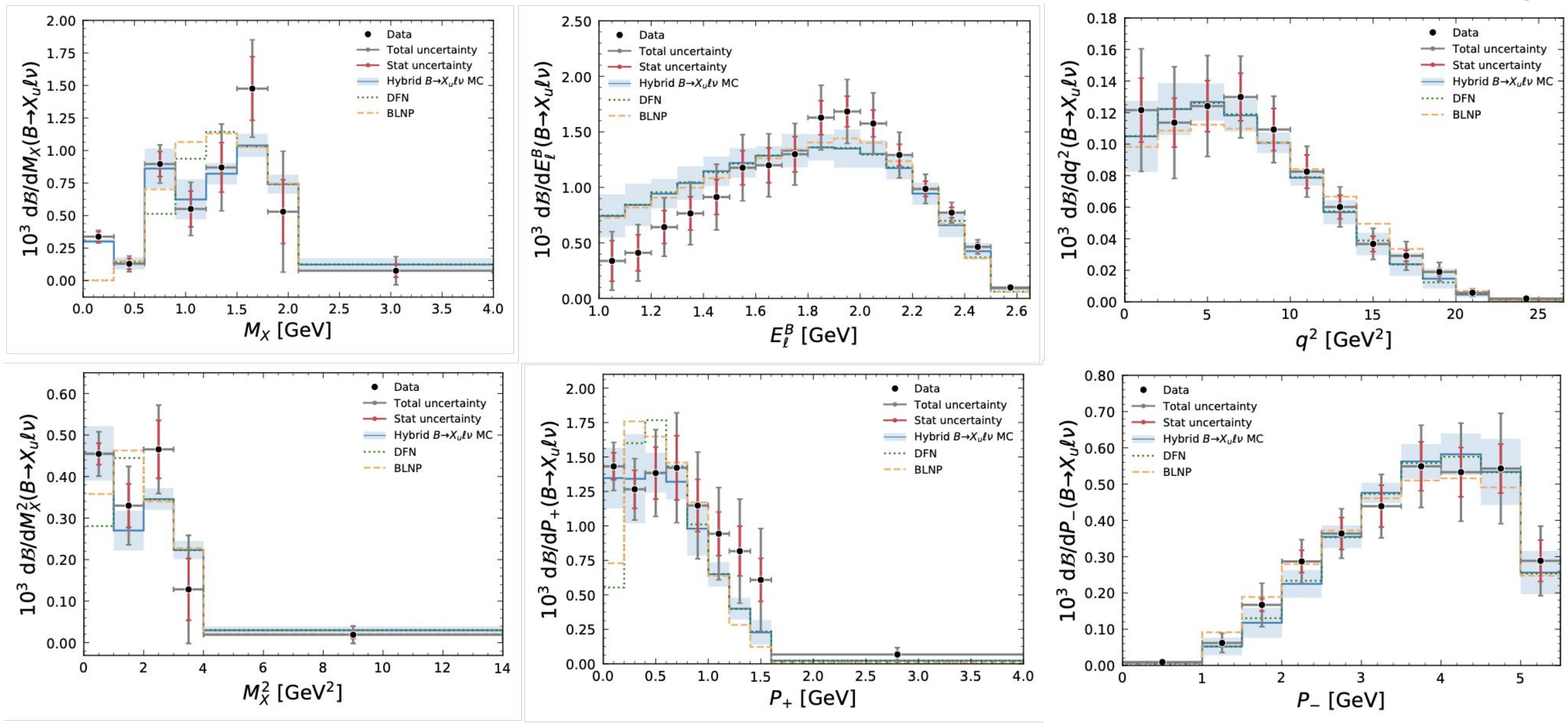
$$X = M^{-1}Y$$

- One regularization method: **Singular-Value-Decomposition (SVD)** [NIMA 372:469(1996)] is used
- Dedicated validations and toy tests have been carried out; minimal dependence on m_b and precise X_u modelling

Preliminary Result

- Convert unfolded yield to $\Delta\mathcal{B}$ in each bin considering reconstruction efficiency & acceptance
- Measured differential braching fractions (E_l^B > 1 GeV) shown as below
- All MC shapes are normalised to 1.59 x 10^{-3} [1]
- Necessary input for future model-independent determinations of $|V_{ub}|$ (e.g. NNVub, SIMBA)

Preliminary

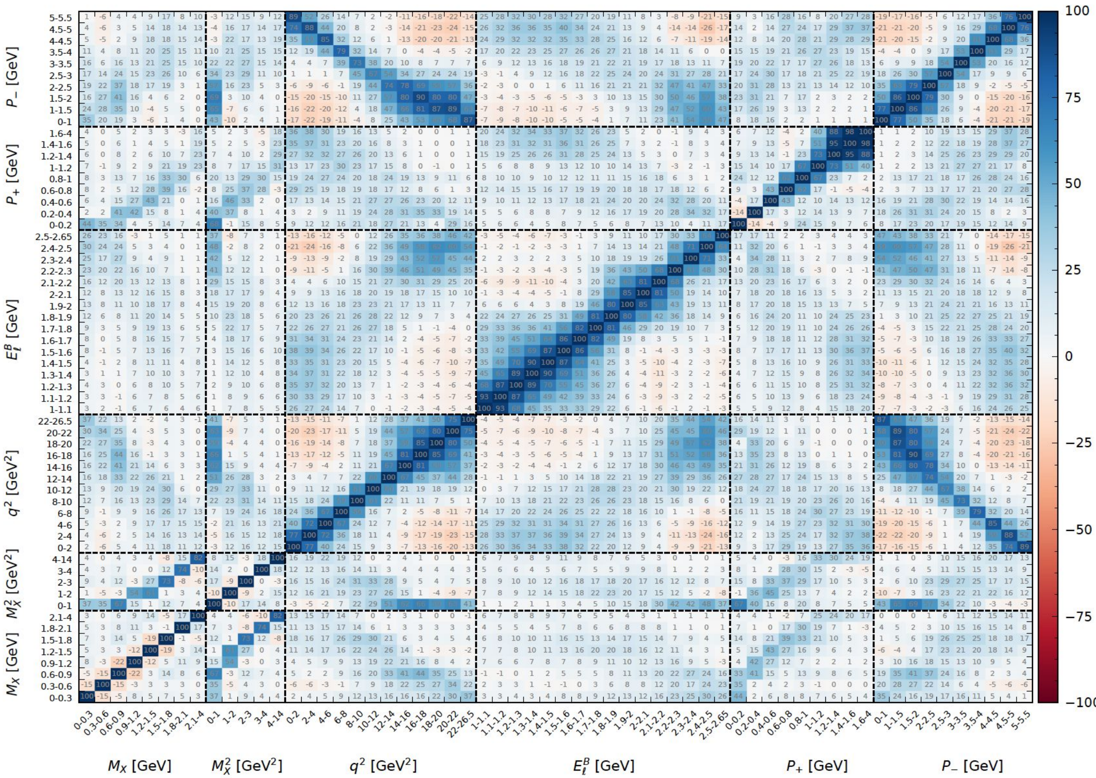


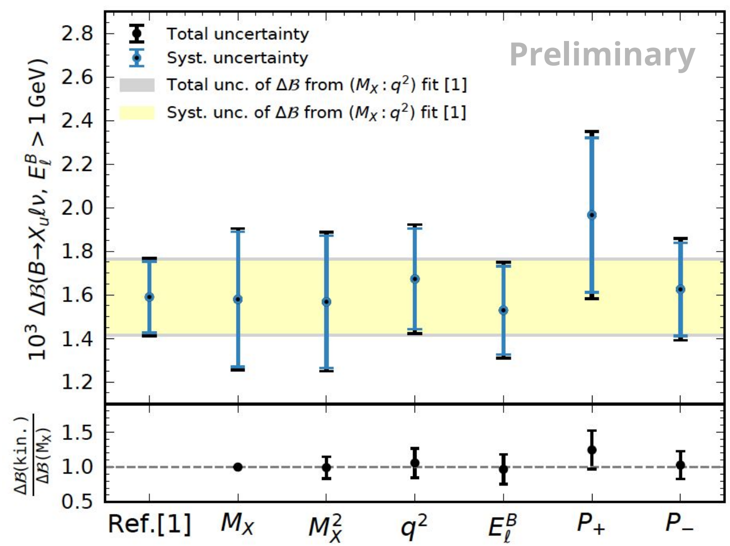
[1] Belle, PRD 104 , 012008 (2021)

Compatibility Check

- Full correlations of differential $\Delta\mathcal{B}$ are extracted
- Summed $\Delta\mathcal{B}$ agree well with $(1.59 \pm 0.07 \pm 0.16)\times10^{-3}$ from $(M_X{:}q^2)$ fit result of [1]

Full experimental correlations (stat. + syst.)





$\mathcal{B}(B^{+} \rightarrow \pi^{+}\pi^{-}\ell^{+}\nu)$

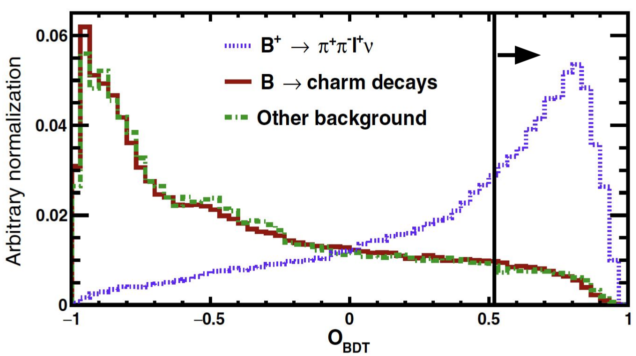
[PRD 103, 112001(2021)]

Event Selection

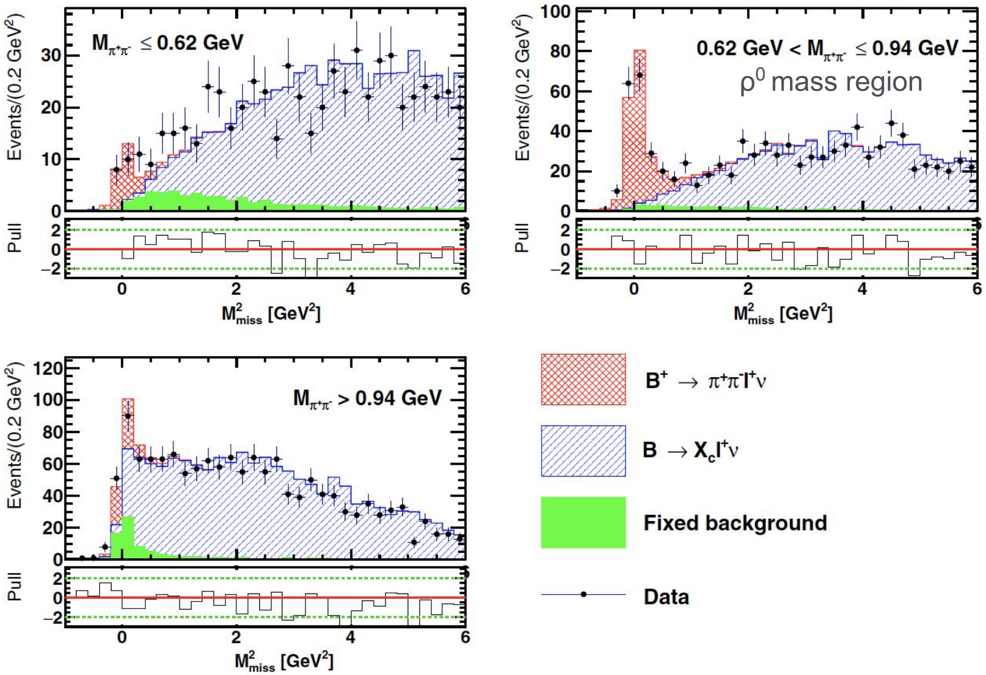
- Use full Belle dataset & hadronic tagging with Neural Networks
- Charged B_{tag} selected to reconstruct the missing momentum

$$P_{\rm miss} = P_{\Upsilon(4S)} - P_{B^{\pm}_{\rm tag}} - P_{\ell^{\mp}} - P_{\pi^{+}} - P_{\pi^{-}}$$

- Background suppressed by a BDT trained on 6 features e.g. ΔE_{sig}, θ_{miss} etc.
- Signal yield extracted by fitting M^2_{miss} in bins of $\mathbf{M_{\pi\pi}}$ and $\mathbf{q^2}$ wtih 3 configurations: 1D of each, and 2D



Projection of 1D($M_{\pi\pi}$) fit result



Result

- First measurement of full ($\pi^+\pi^-$) spectrum: resonant & nonresonant contributions
- Branching fraction derived with 3 configurations
- Systematic uncertainties dominates error budget leading source is signal modelling
- Observe excess when comparing to $\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu) = [18.3 \pm 1.0_{stat} \pm 1.0_{sys}] \times 10^{-5}$

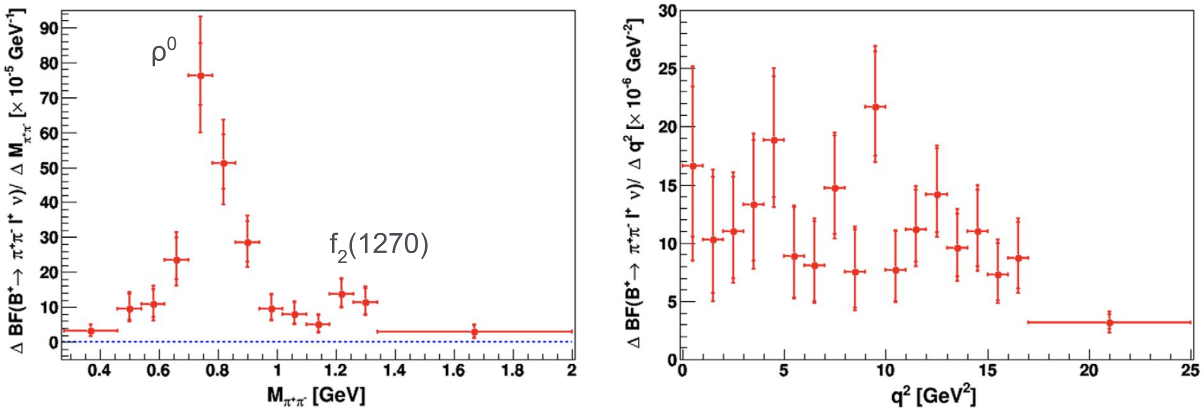
with same Belle dataset [PRD 88,032005(2013)]

$$\mathcal{B}(B^+ \to \pi^+\pi^-\ell^+\nu_\ell)[1D(M_{\pi\pi})] = [22.3^{+2.0}_{-1.8}(\text{stat}) \pm 4.0(\text{syst})] \times 10^{-5}$$

$$\mathcal{B}(B^+ \to \pi^+\pi^-\ell^+\nu_\ell)[1D(q^2)] = [22.7^{+1.9}_{-1.6}(\text{stat}) \pm 3.5(\text{syst})] \times 10^{-5}$$

$$\mathcal{B}(B^+ \to \pi^+\pi^-\ell^+\nu_\ell)[2D] = [23.0^{+2.0}_{-1.8}(\text{stat}) \pm 3.0(\text{syst})] \times 10^{-5}$$

Partial banching fractions with 1D($M_{\pi\pi}$) and 1D(q^2) config.



$\mathcal{B}(B^+ \to \eta^{(\prime)} \ell^+ \nu)$

[arXiv:2104.13354]

Preliminary Result

- Using full Belle dataset
- Background suppression is based on $|\cos(\theta^*_{B\eta(')\ell+})|<1$ and two BDTs (B$\bar{B}$ bkg, continuum bkg)
- Signal yield extracted by a binned ML fit in beam-const. mass and energy difference
- Statistical uncertainty is dominating error budget

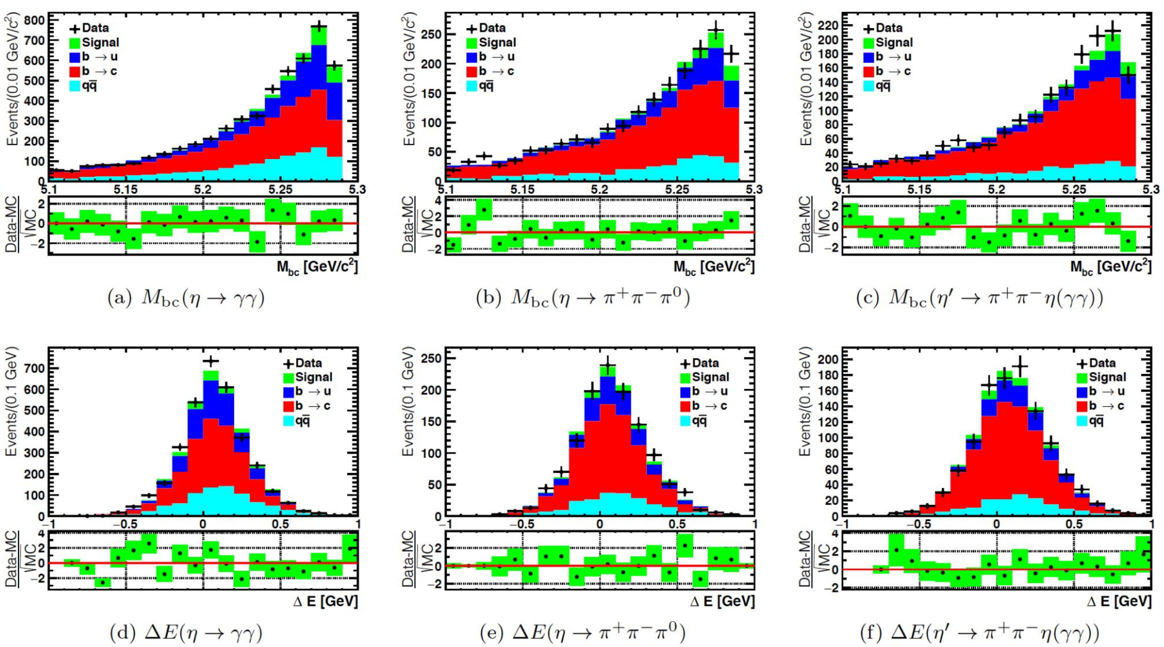
$$\cos(\theta^\star_{B\ell\eta^{(\prime)}}) = \frac{2E^\star_B E^\star_{\ell\eta^{(\prime)}} - m_B^2 c^4 - m^2_{\ell\eta^{(\prime)}} c^4}{2|\vec{p}^\star_B||\vec{p}^\star_{\ell\eta^{(\prime)}}|c^2}$$

$$M_{\rm bc} = \sqrt{E^{\star 2}_{\rm beam}/c^4 - \vec{p}^{\star 2}_B/c^2}$$

$$\Delta E = E^\star_B - E^\star_{\rm beam}$$

Preliminary

Post-fit projections



(a) $M_{\rm bc}(\eta \to \gamma\gamma)$ (b) $M_{\rm bc}(\eta \to \pi^+\pi^-\pi^0)$ (c) $M_{\rm bc}(\eta' \to \pi^+\pi^-\eta(\gamma\gamma))$

(d) $\Delta E(\eta \to \gamma\gamma)$ (e) $\Delta E(\eta \to \pi^+\pi^-\pi^0)$ (f) $\Delta E(\eta' \to \pi^+\pi^-\eta(\gamma\gamma))$

$\mathcal{B}(B^+ \to \eta\ell^+\nu)$ = $(2.83 \pm 0.55_{stat} \pm 0.34_{sys}) \times 10^{-5}$

$\mathcal{B}(B^+ \to \eta'\ell^+\nu)$ = $(2.79 \pm 1.29_{stat} \pm 0.30_{sys}) \times 10^{-5}$

Summary

- Several semileptonic B decays measured by Belle recently
  - Discrepancy btw. exclusive & **inclusive** $|V_{ub}|$ is reduced by the recent partial BF measurement of $B \to X_u \ell^+ \nu$; **differential spectra** were measured for the **first time**
  - **First** measurement of $B^+ \to \pi^+\pi^-\ell^+\nu$ mass spectrum, q^2 distribution and branching fraction; potential new channel for exclusive $|V_{ub}|$
  - New measurement of $B^+ \to \eta^{(\prime)}\ell^+\nu$
- Beyond these important results, the accumulated knowledge on MC modelling, analysis techniques, etc. will be beneficial for future measurements by e.g. Belle II or LHCb

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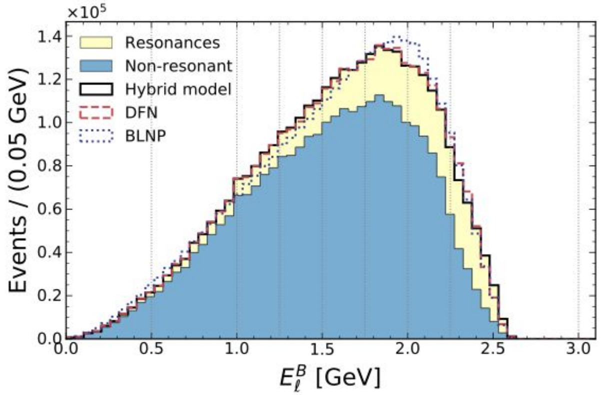
Backup

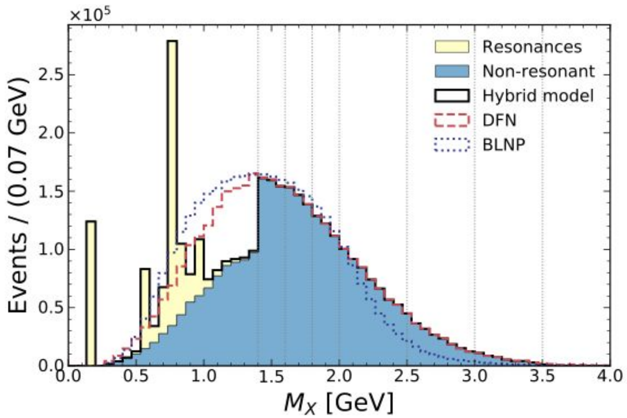
$\Delta\mathcal{B}(B \to X_u \ell^+ \nu)$ and $|V_{ub}^{\text{incl.}}|$

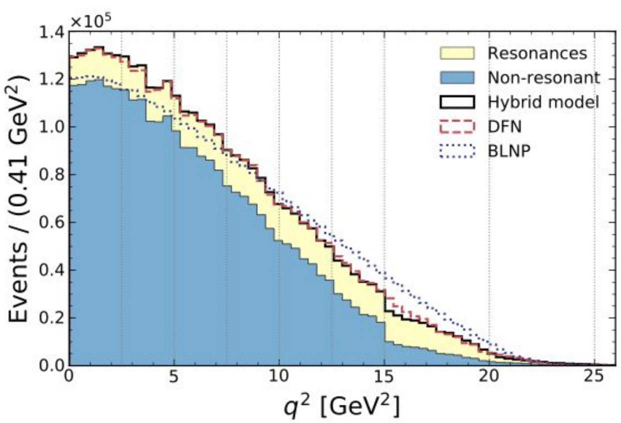
[PRD 104 , 012008 (2021)]

Hybrid modelling of $B \rightarrow X_u l \nu$

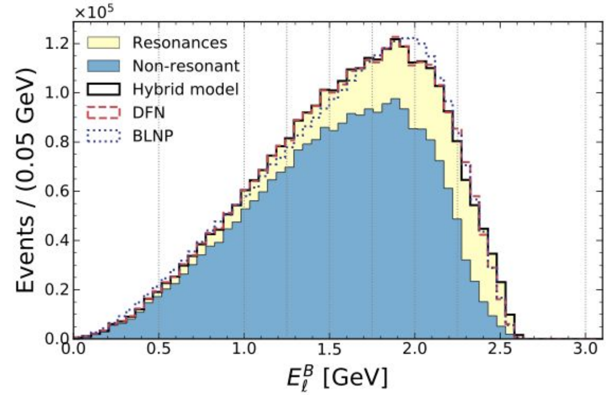
$B^{\pm}$

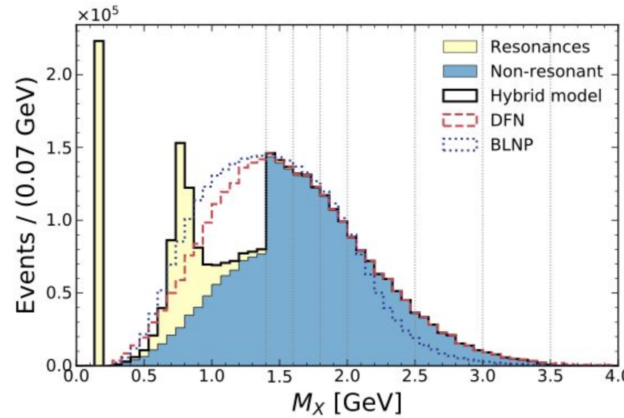


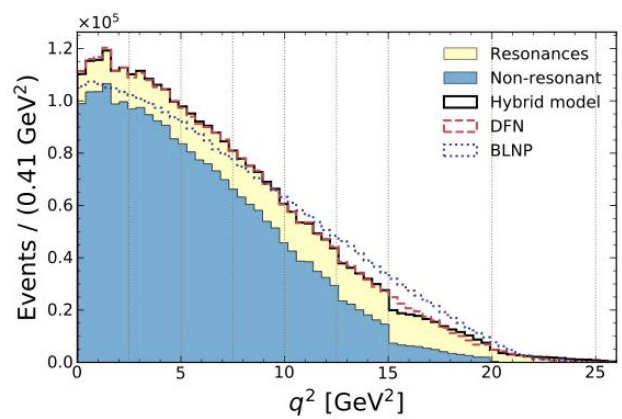




B^0







Details on Theory Rates

The theory rates $\Delta\Gamma(B \to X_u \ell^+ \nu_\ell)$ from various theory calculations are listed. The rates are in units of ps^{-1}.

Phase-space region	BLNP [51]	DGE [52, 53]	GGOU [54]	ADFR [55, 56]
$M_X < 1.7\,\mathrm{GeV}$	$45.2^{+5.4}_{-4.6}$	$42.3^{+5.8}_{-3.8}$	$43.7^{+3.9}_{-3.2}$	$52.3^{+5.4}_{-4.7}$
$M_X < 1.7\,\mathrm{GeV},\ q^2 > 8\,\mathrm{GeV}^2$	$23.4^{+3.4}_{-2.6}$	$24.3^{+2.6}_{-1.9}$	$23.3^{+3.2}_{-2.4}$	$31.1^{+3.0}_{-2.6}$
$p_\ell > 1\,\mathrm{GeV}$	$61.5^{+6.4}_{-5.1}$	$58.2^{+3.6}_{-3.0}$	$58.5^{+2.7}_{-2.3}$	$61.5^{+5.8}_{-5.1}$

- **BLNP**: The prediction of Bosch, Lange, Neubert and Paz (short BLNP) of Ref. [51] provides a prediction at NLO accuracy and incorporate all known corrections. Predictions are interpolated between the shape-function dominated region (endpoint of the lepton spectrum, small hadronic mass) to the region of phase space, that can be described via teh operator product expansion (OPE). As input we use $m_b^{\mathrm{SF}} = 4.58 \pm 0.03\,\mathrm{GeV}$ and $\mu_\pi^{2\,\mathrm{SF}} = 0.20^{+0.09}_{-0.10}\,\mathrm{GeV}^2$.

- **DGE**: The dressed gluon approximation (short DGE) from Andersen and Gardi [52, 53] makes predictions avoiding the direct use of shape functions, but produces predictions for hadronic observables using the on-shell b-quark mass. The calculation is carried out in the $\overline{\mathrm{MS}}$ scheme and we use $m_b(\overline{\mathrm{MS}}) = 4.19 \pm 0.04\,\mathrm{GeV}$.

- **GGOU**: The prediction from Gambino, Giordano, Ossola and Uraltsev [54] (short GGOU) incorporate all known perturbative and non-perturbative effects up to the order $\mathcal{O}(\alpha_s^2\,\beta_0)$ and $\mathcal{O}(1/m_b^3)$, respectively. The shape function dependence is incorporated by parametrizing its effects in each structure function with a single light-cone function. The calculation is carried out in the kinetic scheme and we use as inputs $m_b^{\mathrm{kin}} = 4.55 \pm 0.02$ GeV and $\mu_\pi^{2\,\mathrm{kin}} = 0.46 \pm 0.08\,\mathrm{GeV}^2$.

- **ADFR**: The calculation of Aglietti, Di Lodovico, Ferrera, and Ricciardi [55, 56] makes use of the ratio of $B \to X_u \ell^+ \nu_\ell$ to $B \to X_c \ell^+ \nu_\ell$ rates and soft-gluon resummation at NNLO and an effective QCD coupling approach. The calculation uses the $\overline{\mathrm{MS}}$ scheme and we use $m_b(\overline{\mathrm{MS}}) = 4.19 \pm 0.04\,\mathrm{GeV}$.

References cited in
[1] Belle, PRD 104 , 012008 (2021)

Systematics on Partial BR

TABLE IV. The relative uncertainty on the extracted $B \to X_u \ell^+ \nu_\ell$ partial branching fractions are shown. For definitions of additive and multiplicative errors, see text.

	Relative uncertainties (%)				
Phase-space region	$M_X < 1.7$ GeV, $E_\ell^B > 1$ GeV	$M_X < 1.7$ GeV, $E_\ell^B > 1$ GeV	$M_X < 1.7$ GeV, $q^2 > 8$ GeV^2, $E_\ell^B > 1$ GeV	$E_\ell^B > 1$ GeV	$E_\ell^B > 1$ GeV
Fit variable(s)	(M_X fit)	(E_ℓ^B fit)	(q^2 fit)	(E_ℓ^B fit)	(M_X:q^2 fit)
Additive uncertainties					
$B \to X_u \ell^+ \nu_\ell$ modeling					
$B \to \pi \ell^+ \nu_\ell$ FFs	0.1	0.7	1.4	0.6	0.4
$B \to \rho \ell^+ \nu_\ell$ FFs	0.2	1.9	4.3	1.9	0.7
$B \to \omega \ell^+ \nu_\ell$ FFs	0.5	3.2	5.2	3.1	0.8
$B \to \eta \ell^+ \nu_\ell$ FFs	0.1	1.6	3.0	1.6	0.3
$B \to \eta' \ell^+ \nu_\ell$ FFs	0.1	1.6	3.0	1.6	1.6
$\mathcal{B}(B \to \pi \ell^+ \nu_\ell)$	0.2	0.1	0.2	0.1	0.2
$\mathcal{B}(B \to \rho \ell^+ \nu_\ell)$	0.3	0.7	0.8	0.5	0.4
$\mathcal{B}(B \to \omega \ell^+ \nu_\ell)$	<0.1	0.1	0.8	0.1	0.1
$\mathcal{B}(B \to \eta \ell^+ \nu_\ell)$	<0.1	0.1	<0.1	0.1	<0.1
$\mathcal{B}(B \to \eta' \ell^+ \nu_\ell)$	<0.1	<0.1	0.1	0.1	<0.1
$\mathcal{B}(B \to X_u \ell^+ \nu)$	0.7	2.0	2.1	2.1	2.1
DFN parameters	2.3	3.5	1.1	3.5	5.0
Hybrid model	2.7	8.7	4.6	8.7	3.1
$B \to X_c \ell^+ \nu_\ell$ modeling					
$B \to D \ell^+ \nu_\ell$ FFs	0.1	0.1	0.9	0.1	<0.1
$B \to D^* \ell^+ \nu_\ell$ FFs	1.4	1.2	3.0	1.3	1.1
$B \to D^{**} \ell^+ \nu_\ell$ FFs	0.4	0.5	0.3	0.5	0.4
$\mathcal{B}(B \to D \ell^+ \nu_\ell)$	0.1	<0.1	0.2	<0.1	0.2
$\mathcal{B}(B \to D^* \ell^+ \nu_\ell)$	<0.1	<0.1	0.3	<0.1	0.2
$\mathcal{B}(B \to D^{**} \ell^+ \nu_\ell)$	0.6	0.1	0.3	0.1	0.5
Gap modeling	1.1	0.1	0.3	0.1	1.0
MC statistics	1.3	1.6	3.8	1.7	1.6
Tracking efficiency	0.3	...	0.8	...	0.4
$\mathcal{L}_{\ell \mathrm{ID}}$ shape	1.0	0.5	1.3	0.6	1.2
$\mathcal{L}_{K/\pi \mathrm{ID}}$ shape	1.2	-	1.3	-	1.0
$D \to X \ell \nu_\ell$	0.1	0.1	0.1	0.1	0.1
π_s efficiency	<0.1	...	0.1	...	0.1
Multiplicative uncertainties					
$B \to X_u \ell^+ \nu_\ell$ modeling					
$B \to \pi \ell^+ \nu_\ell$ FFs	0.2	0.2	1.9	0.2	0.2
$B \to \rho \ell^+ \nu_\ell$ FFs	0.7	0.8	3.7	0.8	0.6
$B \to \omega \ell^+ \nu_\ell$ FFs	1.3	1.6	6.1	1.6	1.1
$B \to \eta \ell^+ \nu_\ell$ FFs	0.3	0.3	1.8	0.3	0.2
$B \to \eta' \ell^+ \nu_\ell$ FFs	0.2	0.3	1.8	0.3	0.2
$\mathcal{B}(B \to \pi \ell^+ \nu_\ell)$	0.3	0.4	0.4	0.4	0.3
$\mathcal{B}(B \to \rho \ell^+ \nu_\ell)$	0.4	0.6	0.6	0.6	0.4
$\mathcal{B}(B \to \omega \ell^+ \nu_\ell)$	<0.1	<0.1	0.1	<0.1	<0.1
$\mathcal{B}(B \to \eta \ell^+ \nu_\ell)$	0.1	0.1	<0.1	0.1	<0.1
$\mathcal{B}(B \to \eta' \ell^+ \nu_\ell)$	0.1	0.1	0.1	0.1	0.1
$\mathcal{B}(B \to X_u \ell^+ \nu)$	3.0	3.2	2.9	4.8	3.8
DFN parameters	2.5	2.5	2.7	6.8	3.6
Hybrid model	0.2	0.8	1.4	4.7	2.8
π^+ multiplicity	1.7	2.5	2.3	3.1	1.7
γ_s ($s\bar{s}$ fragmentation)	0.5	0.8	1.1	1.1	0.8
$\mathcal{L}_{\ell \mathrm{ID}}$ efficiency	1.5	1.6	1.6	1.6	1.5
$\mathcal{L}_{K/\pi \mathrm{ID}}$ efficiency	0.7	0.6	0.6	0.6	0.7
$N_{B\bar{B}}$	1.3	1.3	1.3	1.3	1.3
Tracking efficiency	0.8	0.3	0.8	0.3	0.9
Tagging calibration	3.6	3.6	3.6	3.6	3.6
Total systematic uncertainty	7.8	12.6	14.6	15.4	10.4

Shape uncertainties

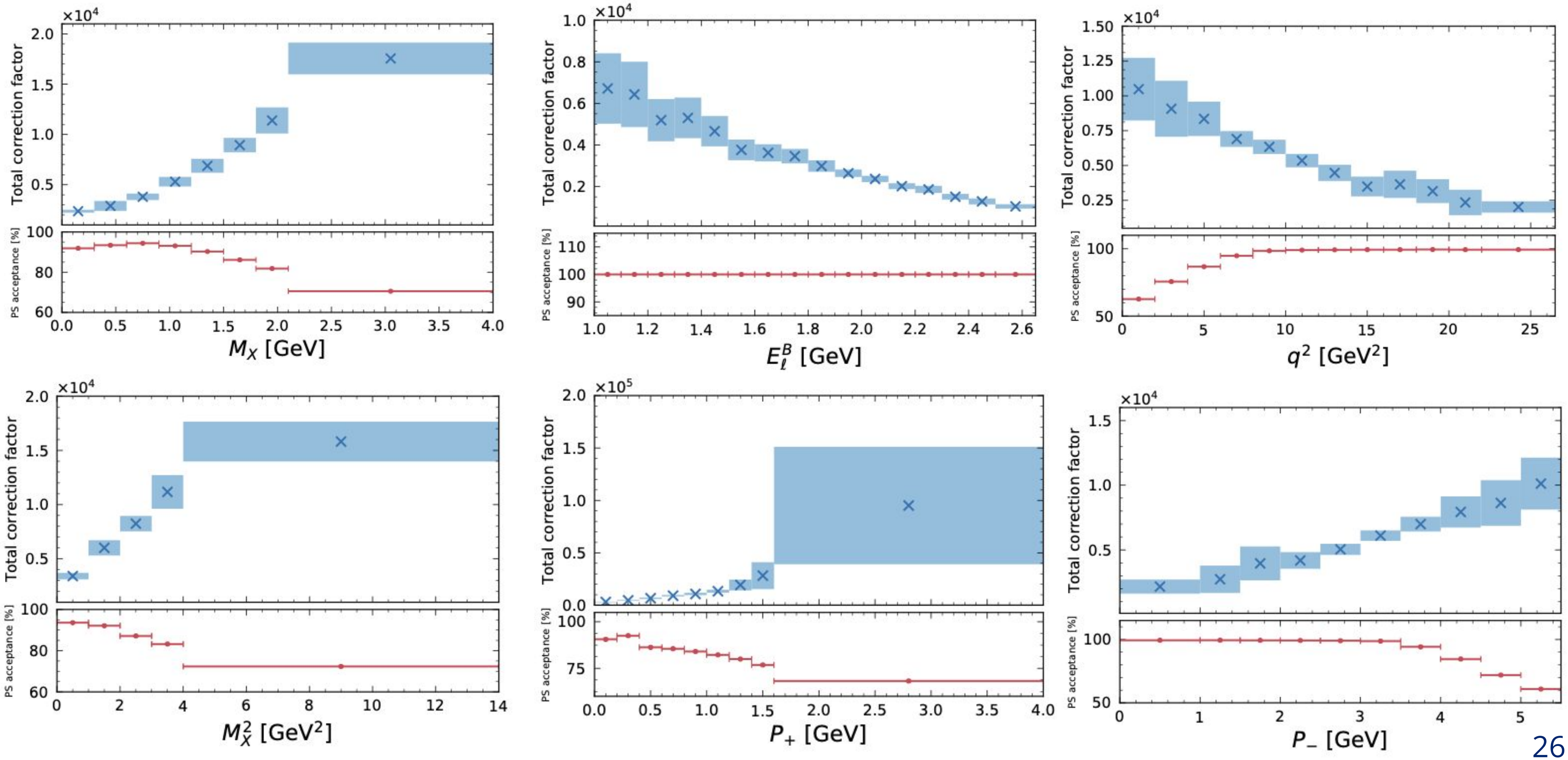
Effect on normalization

Differential $\Delta\mathcal{B}(B \rightarrow X_u \ell^+ \nu)$

Efficiency & Acceptance Correction

$$\epsilon^{i}_{\Delta\mathscr{B}(\text{PS})} = \frac{N^{\text{PS}}_{\text{gen,i}}}{N^{\text{tot}}_{\text{gen,i}}} \Big/ \epsilon^{i}_{\text{tag}} \cdot \epsilon^{i}_{\text{sel}} = \frac{N^{\text{sel}}_{\text{true,i}}}{N^{\text{tot}}_{\text{gen,i}}}$$

Preliminary



Relative Uncertainty for M_X

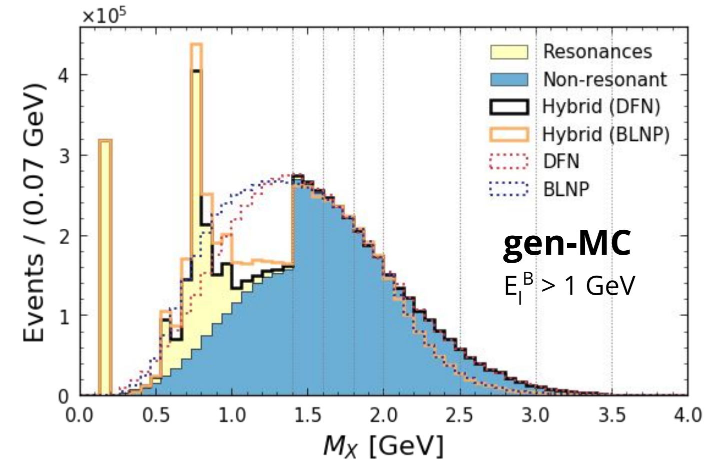
Preliminary

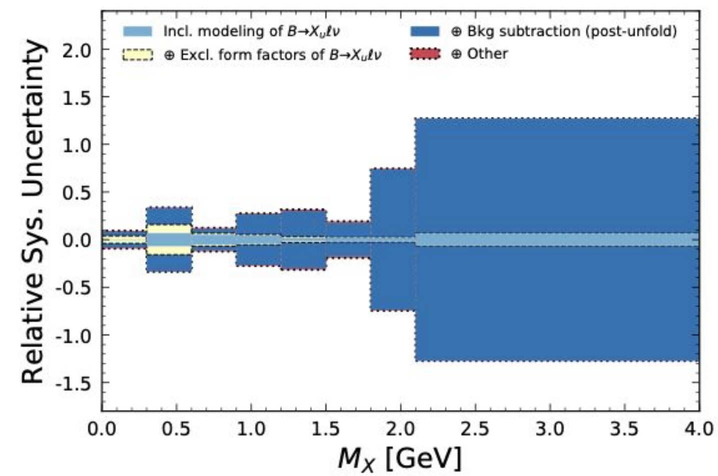
Relative uncertainty (%):

M_X [GeV]	0-0.3	0.3-0.6	0.6-0.9	0.9-1.2	1.2-1.5	1.5-1.8	1.8-2.1	2.1-4.0
Tracking efficiency	0.55	0.56	0.82	0.86	0.95	1.05	1.15	1.19
Tagging calibration	3.69	3.69	3.65	3.64	3.64	3.57	3.79	3.66
Slow pion efficiency	0.00	0.07	0.04	0.05	0.04	0.04	0.06	0.04
K_s^0	0.04	0.05	0.04	0.02	0.04	0.03	0.02	0.05
eID	0.72	0.83	0.74	0.69	0.73	0.74	0.94	1.22
μID	1.59	1.25	1.34	1.29	1.44	1.35	1.09	0.70
K/π ID	0.39	0.67	0.68	0.74	0.81	1.02	1.27	1.24
$\mathcal{B}(B \to X_u \ell \nu)$	0.18	0.44	0.07	0.59	0.82	0.69	0.73	0.46
$\mathcal{B}(B \to \pi \ell \nu)$	0.42	0.45	0.45	0.14	0.05	0.04	0.05	0.05
$\mathcal{B}(B \to \rho \ell \nu)$	0.42	1.00	0.61	0.56	0.33	0.16	0.22	0.15
$\mathcal{B}(B \to \omega \ell \nu)$	0.42	0.39	0.65	0.12	0.11	0.06	0.11	0.10
$\mathcal{B}(B \to \eta \ell \nu)$	0.41	1.16	0.46	0.11	0.06	0.03	0.03	0.14
$\mathcal{B}(B \to \eta' \ell \nu)$	0.42	0.39	0.46	0.24	0.30	0.03	0.14	0.11
$B \to \pi \ell \nu$ FF	0.98	3.08	1.52	0.53	1.05	0.37	0.36	0.38
$B \to \rho \ell \nu$ FF	2.77	8.54	3.96	2.94	1.65	0.59	0.83	0.89
$B \to \omega \ell \nu$ FF	2.40	9.71	1.10	0.90	1.41	0.70	0.65	1.32
$B \to \eta \ell \nu$ FF	0.71	3.58	0.09	0.09	0.51	0.28	0.27	0.07
$B \to \eta' \ell \nu$ FF	0.69	3.65	0.16	0.27	0.48	0.29	0.32	0.15
Hybrid model	0.21	5.86	5.08	4.01	0.50	1.97	2.02	6.13
DFN parameters	0.18	3.66	1.01	1.38	1.64	0.87	0.50	1.35
γ_s	0.47	4.17	2.36	3.98	3.08	4.10	9.31	3.60
π^+ multiplicity modeling	0.57	0.42	0.45	4.15	7.98	4.78	3.98	2.34
$N_{B\bar{B}}$	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Background subtraction	5.97	26.93	8.23	25.15	29.65	16.80	73.36	126.64
MC stat. (migration matrix)	4.04	11.22	3.54	6.85	4.30	4.71	6.85	8.22
Total syst. uncertainty	9.36	33.77	12.32	27.56	31.62	19.21	74.55	127.23
Total stat. uncertainty	11.11	32.64	10.77	24.99	21.88	16.54	46.24	66.76
Total uncertainty	14.53	46.97	16.36	37.20	38.45	25.35	87.73	143.68

The generator-level MC illustrates the hybrid model of excl. and incl. components.

(providing some hints on sys., but keep in mind: the systematics is a combined effect of three parts....)



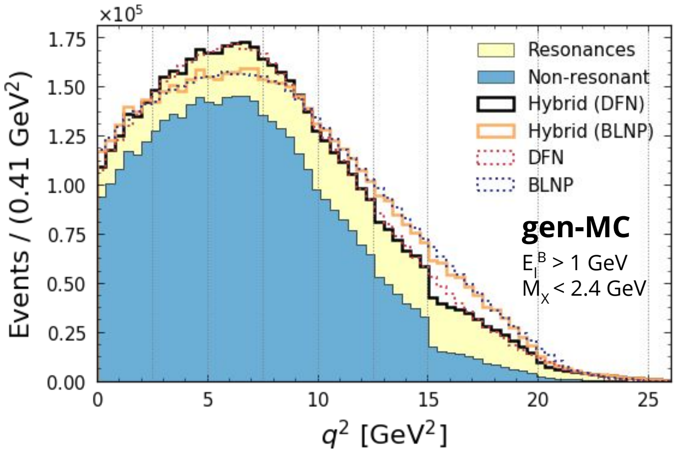


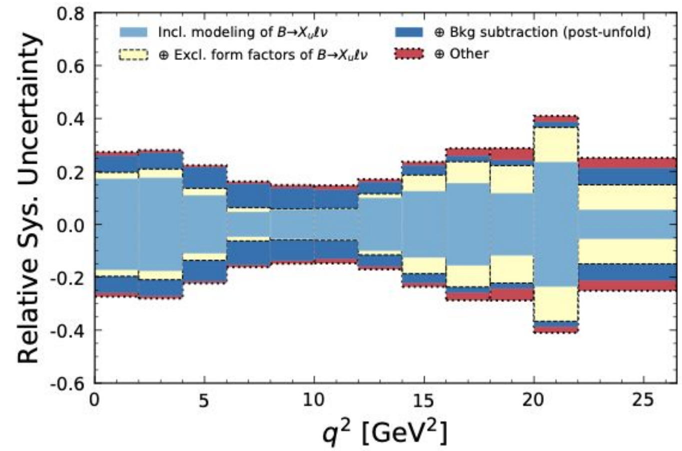
Relative Uncertainty for q^2

Preliminary

Relative uncertainty (%):

q^2 [GeV]	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-26.5
Tracking efficiency	0.93	0.95	0.94	0.90	0.89	0.87	0.82	0.75	0.72	0.67	0.55	0.57
Tagging calibration	3.58	3.69	3.71	3.69	3.65	3.63	3.63	3.64	3.64	3.73	3.86	3.76
Slow pion efficiency	0.02	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.06	0.09	0.07
K_s^0	0.03	0.03	0.04	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.04	0.04
eID	0.79	0.77	0.77	0.75	0.74	0.66	0.69	0.83	0.87	0.83	0.82	0.79
μID	1.39	1.26	1.24	1.32	1.34	1.46	1.45	1.39	1.33	1.52	1.64	1.47
K/π ID	0.85	0.96	0.93	0.83	0.79	0.77	0.70	0.65	0.53	0.35	0.20	0.22
$\mathcal{B}(B \to X_u \ell \nu)$	1.26	1.01	0.75	0.54	0.42	0.01	0.56	1.06	2.01	1.47	0.64	0.45
$\mathcal{B}(B \to \pi \ell \nu)$	1.21	0.95	0.77	0.59	0.27	0.36	1.25	2.93	5.10	6.53	5.64	5.65
$\mathcal{B}(B \to \rho \ell \nu)$	1.14	0.96	0.89	0.64	0.39	0.59	1.37	3.06	5.13	6.55	5.62	5.64
$\mathcal{B}(B \to \omega \ell \nu)$	1.13	0.92	0.74	0.52	0.21	0.32	1.23	2.92	5.09	6.53	5.62	5.61
$\mathcal{B}(B \to \eta \ell \nu)$	1.14	0.93	0.74	0.54	0.26	0.35	1.23	2.91	5.09	6.53	5.62	5.61
$\mathcal{B}(B \to \eta' \ell \nu)$	1.13	0.94	0.74	0.53	0.22	0.33	1.23	2.92	5.08	6.53	5.62	5.61
$B \to \pi \ell \nu$ FF	2.60	3.00	2.38	1.25	0.38	0.83	2.12	4.39	3.83	2.07	5.51	2.63
$B \to \rho \ell \nu$ FF	5.05	5.44	4.29	2.36	1.29	1.18	2.46	7.53	10.45	7.01	15.88	8.74
$B \to \omega \ell \nu$ FF	6.69	8.65	5.85	2.92	1.07	1.19	4.27	9.92	13.29	16.85	20.29	9.44
$B \to \eta \ell \nu$ FF	2.35	2.53	1.67	0.85	0.34	0.35	1.41	2.76	2.80	2.76	6.99	3.00
$B \to \eta' \ell \nu$ FF	2.42	2.62	1.74	0.92	0.38	0.39	1.34	2.78	3.20	2.90	6.53	3.30
Hybrid model	16.17	16.41	9.91	2.71	3.62	4.69	9.82	12.48	15.53	11.75	23.34	5.45
DFN parameters	6.01	6.43	4.78	3.86	4.12	3.19	2.03	1.44	1.10	1.01	3.26	1.01
γ_s	6.28	4.39	1.39	1.41	1.52	3.14	0.43	0.07	1.98	1.99	0.47	1.09
π^+ multiplicity	2.74	3.08	2.85	2.18	3.18	4.00	3.09	0.10	0.14	0.07	1.41	0.42
$N_{B\bar{B}}$	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Background subtraction	16.66	16.89	16.52	13.79	12.22	11.30	10.67	11.54	9.77	9.14	10.18	12.96
MC stat. (migration matrix)	2.94	3.15	2.37	2.29	2.56	2.87	2.69	3.62	3.40	3.81	7.33	7.81
Total syst. uncertainty	27.32	28.03	22.28	16.20	14.86	14.73	17.05	23.60	28.71	28.79	40.98	25.11
Total stat. uncertainty	16.71	13.67	13.05	11.61	12.26	12.87	12.45	13.30	11.96	12.12	15.69	19.97
Total uncertainty	32.02	31.19	25.82	19.93	19.26	19.56	21.11	27.09	31.10	31.23	43.88	32.08





$\mathcal{B}(B^+ \to \pi^+\pi^-\ell^+\nu)$

[PRD 103, 112001(2021)]

Yields and Relative Uncertainty

TABLE VI. Signal yields (Y^i_{signal}), signal reconstruction efficiency (ϵ^i), and partial branching fractions ($\Delta\mathcal{B}^i$) for each bin i in the 1D(q^2) configuration with the bin number convention defined according to Table II. The first quoted uncertainty is statistical, and the second is systematic.

Bin	Y^i_{signal}	$\epsilon^i[10^{-4}]$	$\Delta\mathcal{B}^i[10^{-5}]$
1	$16.5^{+6.8}_{-6.1}$	6.27 ± 0.19	$1.66^{+0.68}_{-0.61} \pm 0.53$
2	$11.4^{+6.0}_{-5.1}$	6.97 ± 0.22	$1.03^{+0.54}_{-0.46} \pm 0.25$
3	$13.0^{+5.6}_{-4.7}$	7.45 ± 0.25	$1.10^{+0.47}_{-0.40} \pm 0.20$
4	$16.0^{+6.6}_{-5.8}$	7.56 ± 0.27	$1.33^{+0.55}_{-0.48} \pm 0.26$
5	$24.3^{+7.1}_{-6.3}$	8.13 ± 0.31	$1.88^{+0.55}_{-0.49} \pm 0.29$
6	$12.2^{+5.7}_{-4.9}$	8.60 ± 0.35	$0.89^{+0.42}_{-0.36} \pm 0.10$
7	$10.8^{+5.1}_{-4.1}$	8.43 ± 0.38	$0.81^{+0.38}_{-0.31} \pm 0.13$
8	$21.4^{+6.5}_{-5.7}$	9.17 ± 0.44	$1.47^{+0.45}_{-0.39} \pm 0.17$
9	$9.6^{+4.7}_{-3.9}$	8.03 ± 0.45	$0.75^{+0.37}_{-0.31} \pm 0.13$
10	$30.8^{+6.7}_{-6.0}$	8.96 ± 0.53	$2.17^{+0.47}_{-0.42} \pm 0.23$
11	$11.6^{+5.0}_{-4.1}$	9.52 ± 0.60	$0.77^{+0.33}_{-0.27} \pm 0.09$
12	$16.3^{+4.9}_{-4.1}$	9.14 ± 0.66	$1.12^{+0.34}_{-0.28} \pm 0.14$
13	$19.4^{+5.3}_{-4.5}$	8.62 ± 0.72	$1.42^{+0.39}_{-0.33} \pm 0.17$
14	$15.4^{+4.7}_{-4.0}$	10.1 ± 0.88	$0.96^{+0.29}_{-0.25} \pm 0.15$
15	$15.1^{+4.9}_{-4.1}$	8.65 ± 0.93	$1.10^{+0.36}_{-0.30} \pm 0.17$
16	$10.8^{+4.0}_{-3.2}$	9.31 ± 1.12	$0.73^{+0.27}_{-0.22} \pm 0.12$
17	$12.3^{+4.4}_{-3.7}$	8.94 ± 1.28	$0.87^{+0.31}_{-0.26} \pm 0.15$
18	$32.3^{+6.8}_{-6.1}$	7.85 ± 0.88	$2.59^{+0.55}_{-0.49} \pm 0.47$

TABLE XI. Relative systematic uncertainties in percent for the fits in q^2 bins. The bin-number convention is defined in Table II.

Source	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12	Bin 13	Bin 14	Bin 15	Bin 16	Bin 17	Bin 18
FF $B \to D^{(*)}\ell\nu$	1.19	0.85	0.40	0.40	0.20	0.45	0.56	0.71	1.08	0.20	1.07	0.10	0.04	0.07	0.05	0.02	0.15	0.03
FF $B \to D^{**}\ell\nu$	1.93	2.36	1.27	1.84	1.05	1.09	1.12	0.73	0.72	0.29	0.66	0.10	0.07	0.20	0.15	0.21	0.22	0.08
Shapes $B \to X_u\ell\nu$	0.20	0.36	0.42	0.33	0.23	0.32	0.25	0.26	0.11	0.08	0.21	0.22	0.37	0.35	1.32	1.30	0.40	1.89
$\mathcal{B}(B \to D^{(*)}\ell\nu)$	1.92	3.10	2.05	2.35	1.41	2.63	1.17	1.11	1.79	0.24	0.91	0.06	0.04	0.08	0.09	0.05	0.24	0.07
$\mathcal{B}(B \to D^{**}\ell\nu)$	0.66	0.78	0.42	0.61	0.31	0.37	0.39	0.22	0.18	0.08	0.17	0.02	0.02	0.04	0.05	0.02	0.08	0.02
$\mathcal{B}(B \to X_u\ell\nu)$	0.68	0.71	0.15	1.07	0.83	0.67	0.66	0.53	0.53	0.42	1.85	1.06	1.37	1.20	3.81	2.30	0.95	1.88
Continuum	1.70	0.93	0.34	0.43	0.13	0.45	0.32	0.41	0.54	0.02	0.19	0.03	0.28	0.07	0.01	0.27	0.40	0.14
Rare	7.44	1.47	0.73	0.97	0.60	0.30	0.31	0.46	1.09	0.34	0.44	0.29	0.30	0.20	0.39	0.01	0.25	0.16
Sec. Leptons	0.29	0.14	0.16	0.20	0.01	0.32	0.03	0.01	0.11	0.02	0.00	0.01	0.00	0.01	0.00	0.01	0.07	0.03
Fake leptons	2.56	1.05	0.20	0.17	0.11	0.15	0.04	0.23	0.09	0.04	0.20	0.02	0.16	0.01	0.40	0.08	0.55	0.27
ℓID	1.99	2.03	2.08	2.02	2.04	1.98	1.96	1.91	1.85	1.87	1.82	1.83	1.74	1.83	1.83	1.89	1.89	1.89
πID	1.23	1.21	1.19	1.17	1.15	1.12	1.11	1.07	1.06	1.03	0.97	0.96	0.93	0.84	0.81	0.81	0.81	0.68
FSR	0.19	0.50	0.06	0.58	0.05	0.06	1.05	0.65	2.11	0.03	0.36	0.43	0.24	0.46	0.73	0.92	0.35	0.35
Signal model	29.8	23.0	16.6	18.2	13.7	8.79	13.7	8.76	14.1	6.24	5.44	8.15	5.69	10.9	4.44	8.21	4.88	10.2
Nom. Eff. Stats.	3.03	3.16	3.36	3.57	3.81	4.07	4.51	4.80	5.60	5.92	6.30	7.22	8.35	8.68	10.8	12.0	14.3	11.2
Fit procedure	0.27	1.79	1.46	2.09	0.99	1.27	2.43	1.18	2.36	1.08	3.67	0.68	1.29	1.00	2.50	2.53	1.44	1.19
BDT selection	2.31	1.88	1.55	2.22	1.00	1.65	0.88	2.19	1.08	0.76	1.07	0.64	0.21	0.32	0.74	0.21	0.32	2.15
No. $B\bar{B}$ pairs	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
$\mathcal{B}(\Upsilon(4S) \to B^+B^-)$	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	2.17	3.17	4.17	5.17	6.17
Tracking efficiency	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Tagging efficiency	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20
Nonresonant $B \to X_u\ell\nu$	0.42	1.75	1.54	1.25	0.82	1.64	0.93	1.87	5.21	2.60	2.59	3.07	4.12	5.19	6.62	4.63	4.07	5.26
Total	31.7	24.5	18.1	19.9	15.4	11.7	15.7	11.8	17.4	10.5	11.1	12.5	12.2	15.9	15.5	17.0	17.3	18.3

$\mathcal{B}(B^+ \to \eta^{(\prime)} \ell^+ \nu)$

[arXiv:2104.13354]

Relative Uncertainty in %

Preliminary

Source	$\eta(\gamma\gamma)$	$\eta(\pi^+\pi^-\pi^0)$	η'
Statistical	22	39	46
Combined Systematic	11	14	11
$\mathcal{B}\left(B^{\pm} \to X_{Bkg}\right)$	2.4	1.7	1.3
$\mathcal{B}\left(\eta^{(\prime)} \to X\right)$	0.51	1.2	1.7
$B \to D^{(*,**)}\ell^+\nu_\ell$ form factor	0.82	1.1	1.3
$B \to \eta^{(\prime)}\ell^+\nu_\ell$ form factor	3.0	2.9	0.14
$B \to \omega\ell^+\nu_\ell$ form factor	0.81	2.1	2
$\overline{b} \to \overline{u}\ell^+\nu_\ell$ shape	0.39	0.15	0.21
Background with K_L^0	3.5	8.6	3.8
Continuum	0.2	0.62	0.63
$N_{B\overline{B}}$	1.4	1.4	1.4
$\mathcal{B}\left(\Upsilon(4S) \to B^+B^-\right)$	1.2	1.2	1.2
$\overline{b} \to \overline{u}\ell^+\nu_\ell$ yield	4.1	5.2	4.4
Monte Carlo	0.86	1.3	2.3
Charged tracks	0.35	1.1	1.1
γ detection	4.0	2.5	4.0
Electron ID	1.6	1.6	1.5
Muon ID	2.1	2.1	2
First $\pi^{\pm}$ PID	0	0.97	1.1
Second $\pi^{\pm}$ PID	0	1.3	2.2
Misidentified Leptons	4.3	5.5	2.3
Control Mode	5.0	5.0	5.0