European Physical Society Conference on High Energy Physics
Palais Du Pharo – Marseille

Measurements of semileptonic and leptonic B decays at Belle and Belle II

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Motivations of (Semi)leptonic B decays

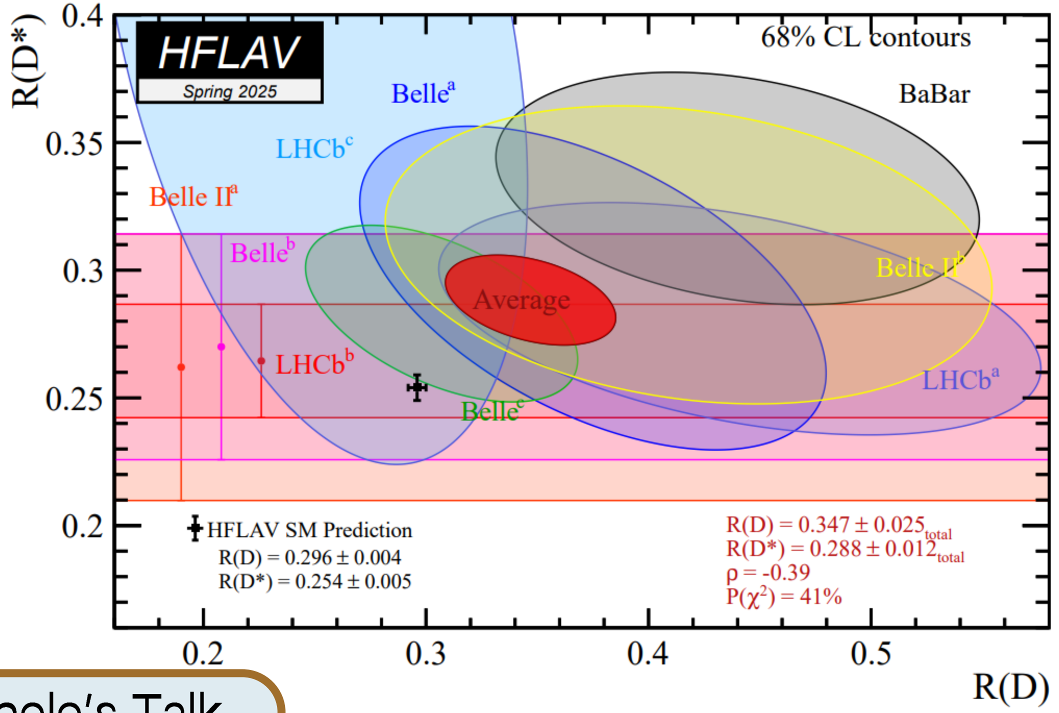
Lepton-Flavor Universality tests | SM Precision Measurements | Electroweak Penguins

- In the Standard Model (SM), the W boson couples equally to $\tau, \mu, e \rightarrow$ Lepton-Flavor Universality (LFU)
- Semileptonic B decays are sensitive to new physics beyond SM
- Ratio measurements provide stringent LFU tests: branching fractions, angular asymmetry, etc.
  - ✓ Normalization ($|V_{xb}|$) cancels
  - ✓ Part of theoretical, experimental uncertainties cancels

$$R(H_{\tau/\ell}) = \frac{B(B \rightarrow H\tau\nu)}{B(B \rightarrow H\ell\nu)}$$

$$H = D^{(*)}, X, \pi, \ ...$$

$$\ell = e, \mu$$



Tension of $R\left(D^{(*)}_{\tau/\ell}\right)$ with SM ~3σ

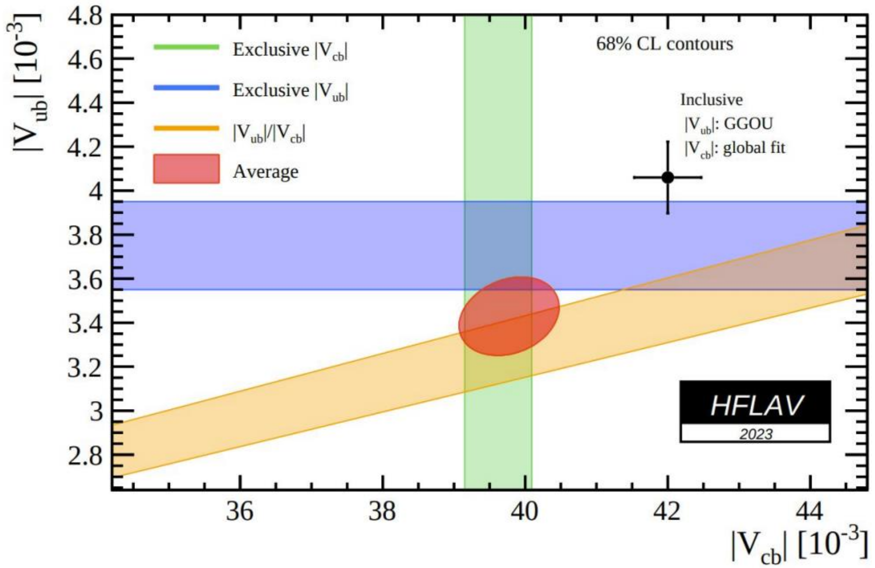
Covered by Michele's Talk

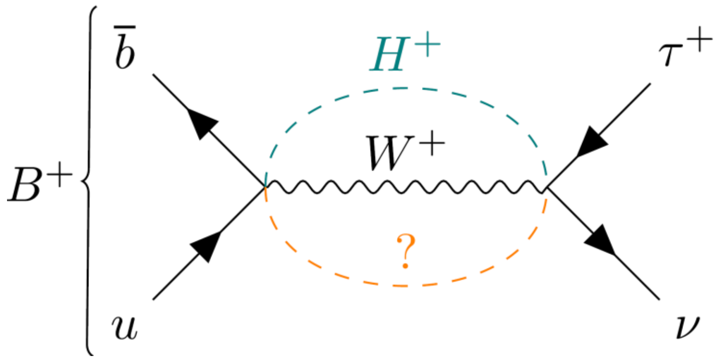
Motivations of (Semi)leptonic B decays

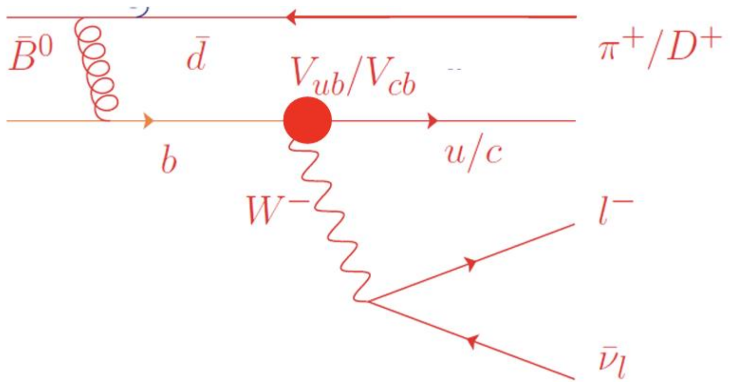
Lepton–Flavor Universality tests | **SM Precision Measurements** | Electroweak Penguins

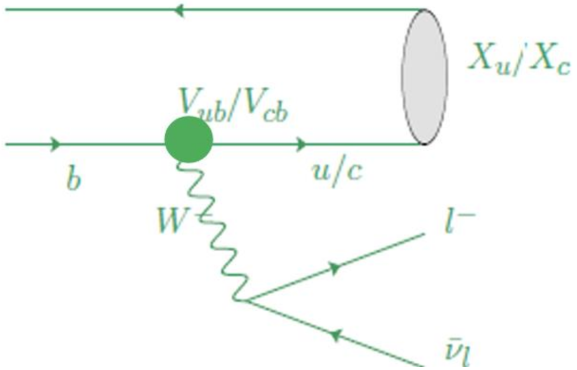
- $|V_{ub}|$ and $|V_{cb}|$ important to **constrain** CKM Unitarity
- **Precisely** measured with semileptonic B decays

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$







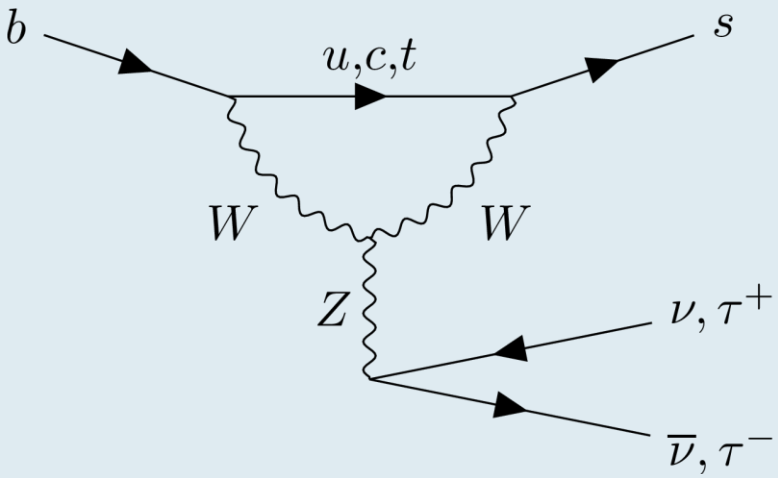


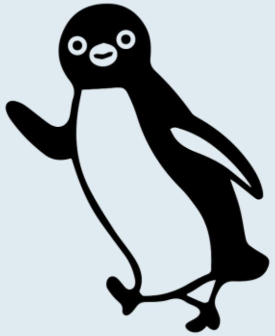
Motivations of (Semi)leptonic B decays

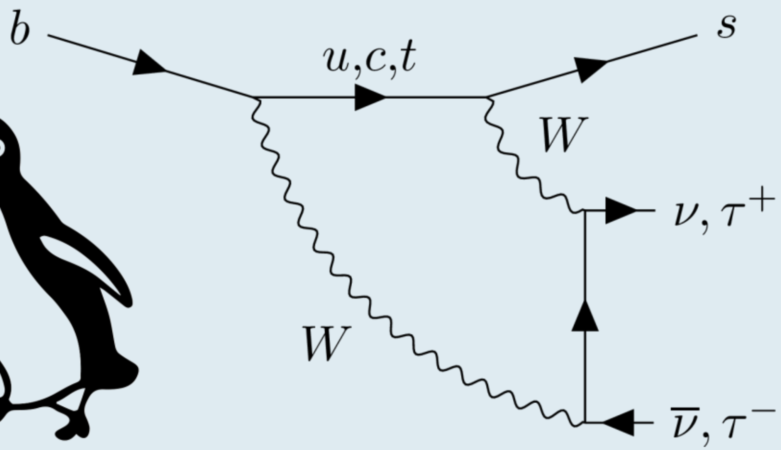
Lepton–Flavor Universality tests | SM Precision Measurements | **Electroweak Penguins**

- Flavor–changing neutral currents are not possible at tree level in the **Standard Model (SM)**
- Branching fractions predicted in the range 10^{-7}–10^{-4} with 5–30% uncertainties (dominated by soft QCD effects).
- Highly sensitive to potential **non–SM contributions.**

Covered by Valerio's Talk





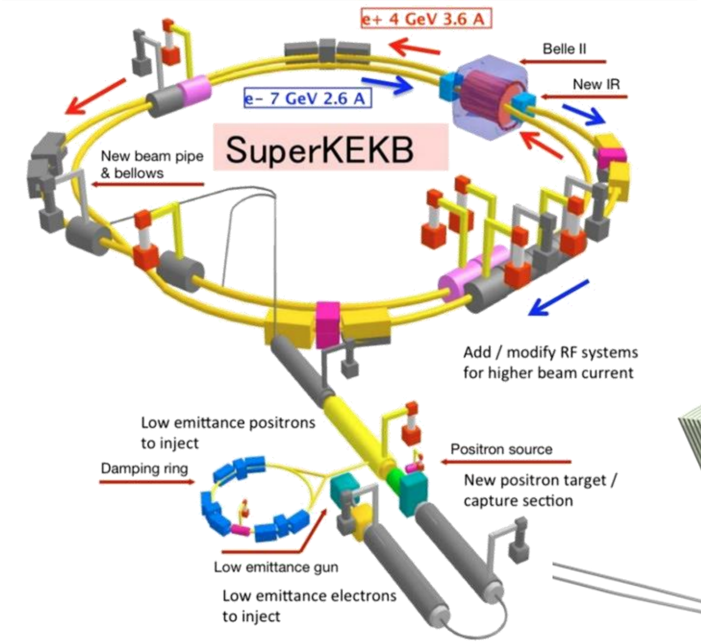


Standard Model Feynman diagram of Penguins with missing energy

The Belle (II) experiment

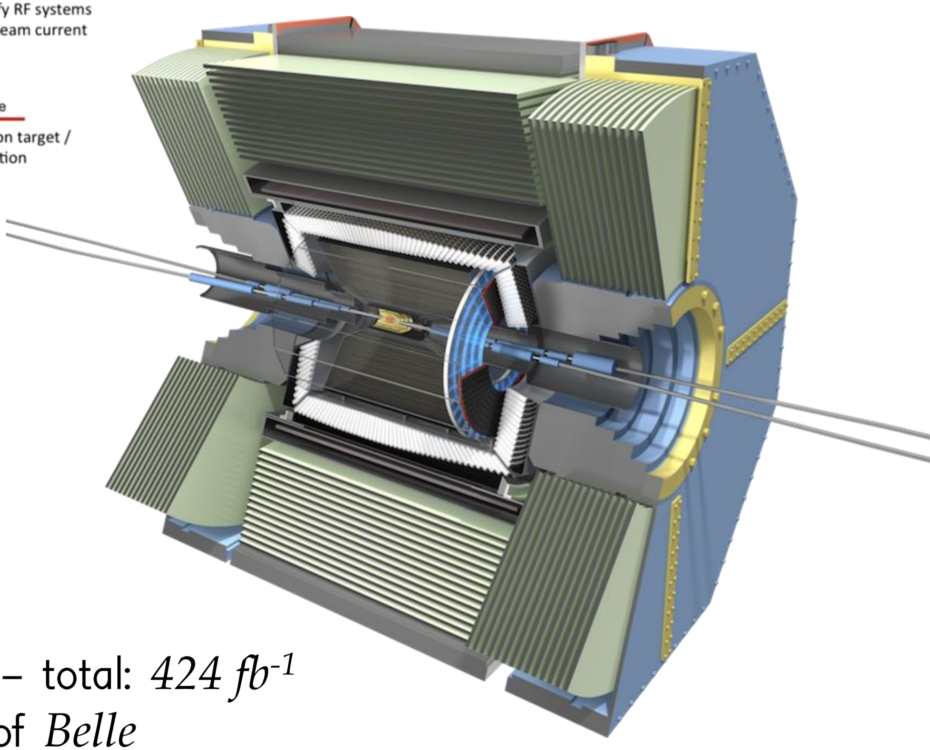
SuperKEKB

- e^+e^- collider with energies *4 GeV* and *7 GeV* operating around $\Upsilon(4S)$ resonance.
- Achieved world-record peak (December 2024) Luminosity of $L = 5.1 \times 10^{34} cm^{-2} s^{-1}$



Belle II

- Nearly $\boldsymbol{4\pi}$ detector coverage
- Tracking, PID and photon reconstruction capabilities
- **Similar performance** for electrons and muons
- Well-suited to measure decays with **missing energy**, $\boldsymbol{\pi^0}$ in the final state, **inclusive** measurement
- From 2019 – 2024, ***500 fb**$^{-1}$* of data was collected.



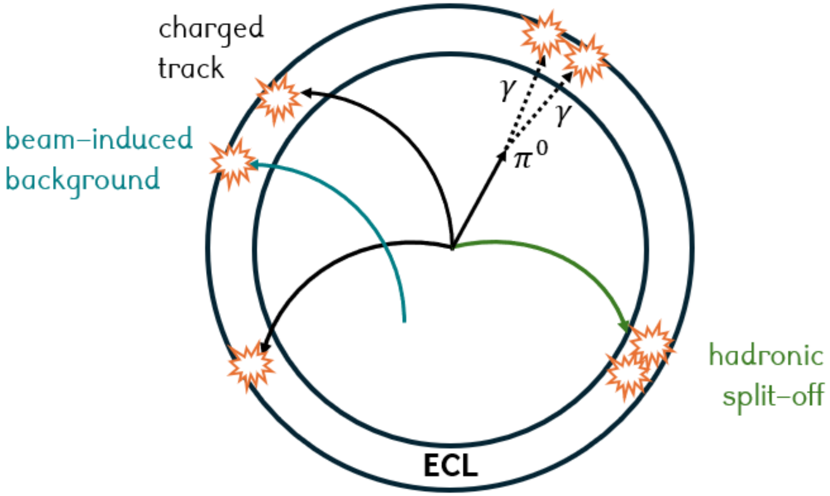
RUN1: Data at $\Upsilon(4S)$: *365 fb*$^{-1}$, about $\mathbf{4 \times 10^8}$ $\boldsymbol{B\overline{B}}$ – total: *424 fb*$^{-1}$
Statistics similar to *BaBar* and about half of *Belle*

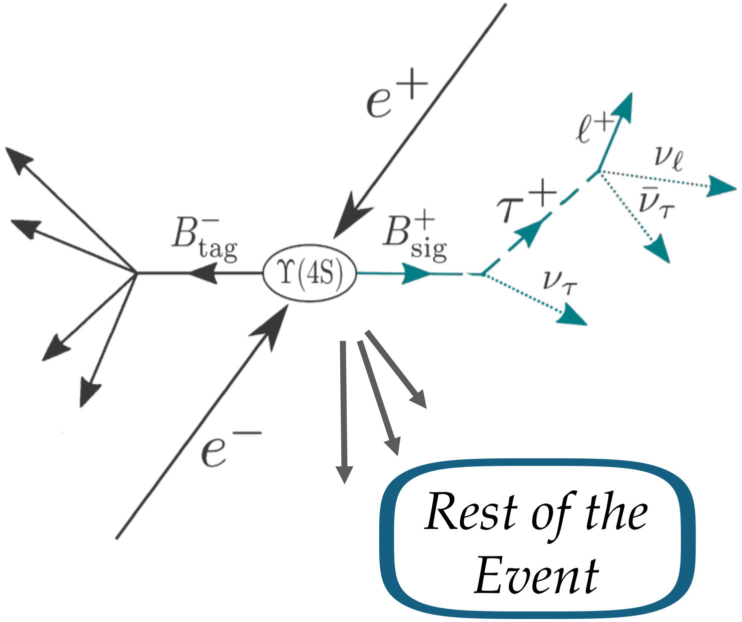
$B \to \tau\nu$ with hadronic tag

Event Reconstruction

One B meson is fully reconstructed using a multivariate algorithm, Full Event Interpretation (FEI) with Hadronic Tagging.

1. $\mathcal{O}_{FEI}$
2. $\Delta E = E_B^* - \sqrt{s}/2$
3. $M_{bc}c^2 = \sqrt{s/4 - (p_B^* c)^2}$



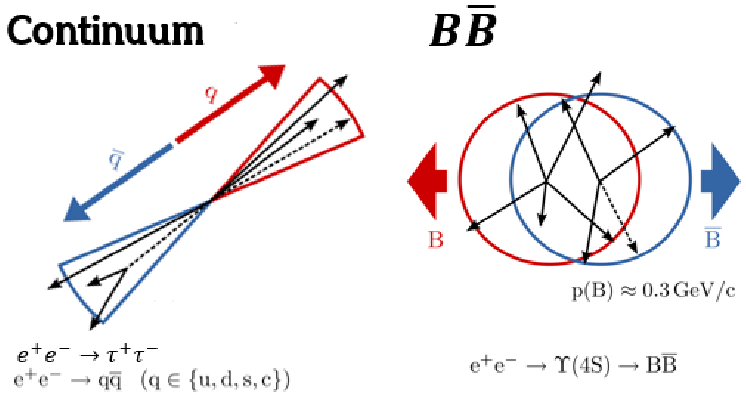


Rest of the Event:
It is crucial to reject fake photons in the ECL from background
Sum of all the cleaned clusters energy → $\boldsymbol{E_{ECL}^{extra}}$.
Missing Quantities:
We build the missing part of each event using also the information of the Rest of Event:

$$p_{miss} = p_{beams} - p_{B_{tag}} - p_{track} - p_{ROE}$$

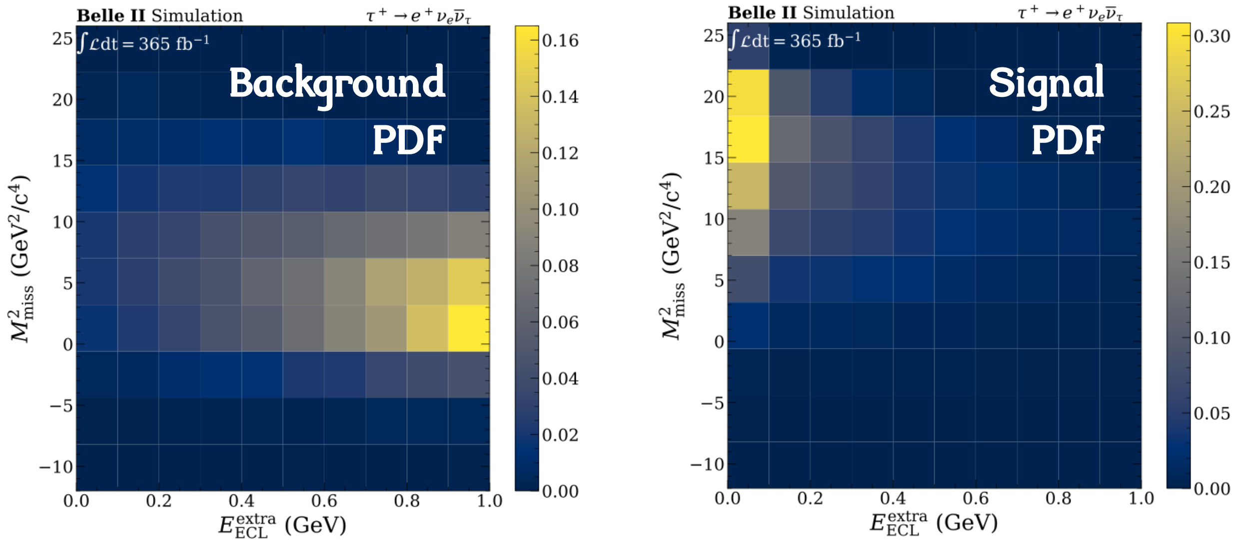
*We will use the **Extra ECL Energy** and the **missing mass squared** to extract the signal yield*

Signal Selection Strategy



Continuum Suppression

MVA: 2 BDTs trained, one for leptonic and one for hadronic τ^+ decays.
Features = only variables not correlated with our fit variables.
Plots in the backup.



Signal Enhancement

The selection optimization is done performing **maximum likelihood fits** M^2_{miss} *vs* E^{extra}_{ECL} on simulation *PDFs*.

Other important variable to enhance the signal:

- **Momentum of the π/ρ (higher than the background)**

Validation via control samples

Main Sample	*Continuum*	$B\bar{B}$	*Sig.* $\tau \to \ell\nu\nu$	*Sig.* $\tau \to h\nu$
Control Sample	Off-resonance Data	Extra Tracks	$B \to D^*\ell\nu$	Double Tag

Result

Submitted to PRD: *arXiv:2502.04885*

Branching Fraction Extraction

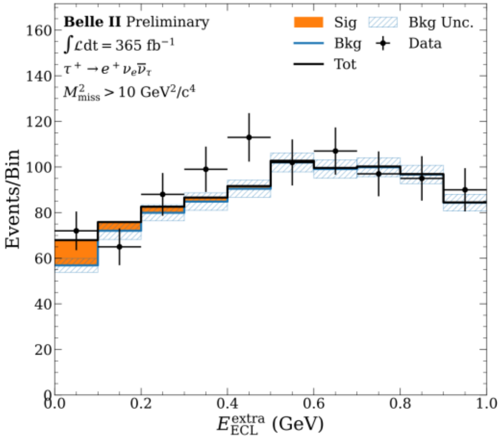
3.0σ with respect to background-only hypothesis.

Main Systematics: MC Statistics (13%), Fit Variables PDF (5.5%), PDG Branching Fraction (4.1%)

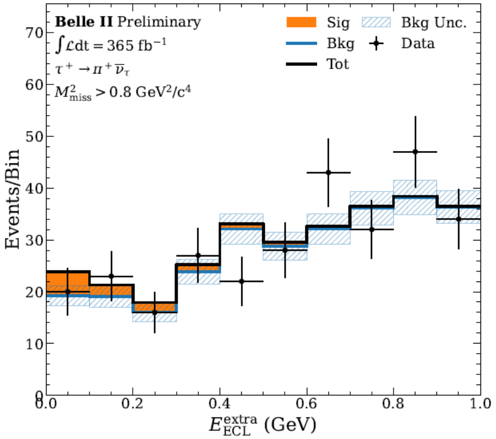
Assuming the SM, and using $f_B = 190.0 \pm 1.3$ MeV from Lattice QCD:

$$|V_{ub}| = \left(4.41^{+0.74}_{-0.89}\right) \times 10^{-3}$$

$\tau \to e\nu\nu$

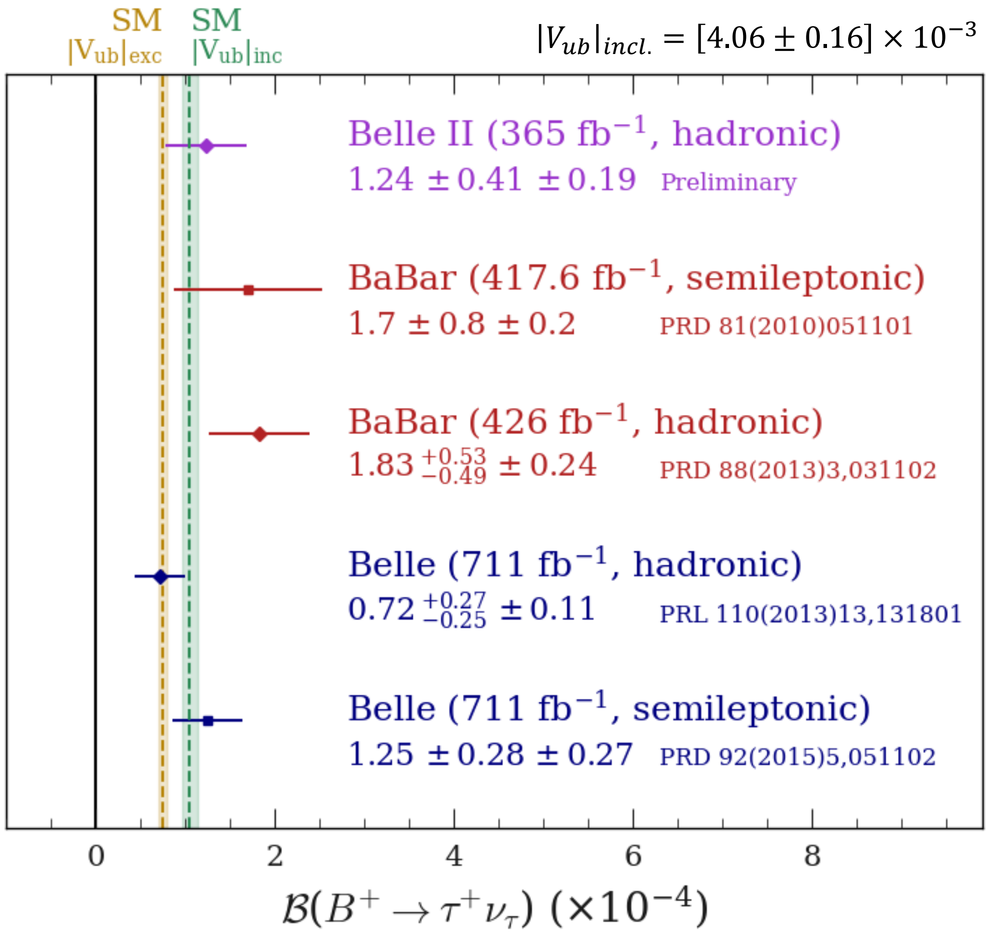


$\tau \to \pi\nu$



$|V_{ub}|_{excl.} = [3.43 \pm 0.12] \times 10^{-3}$

$|V_{ub}|_{incl.} = [4.06 \pm 0.16] \times 10^{-3}$



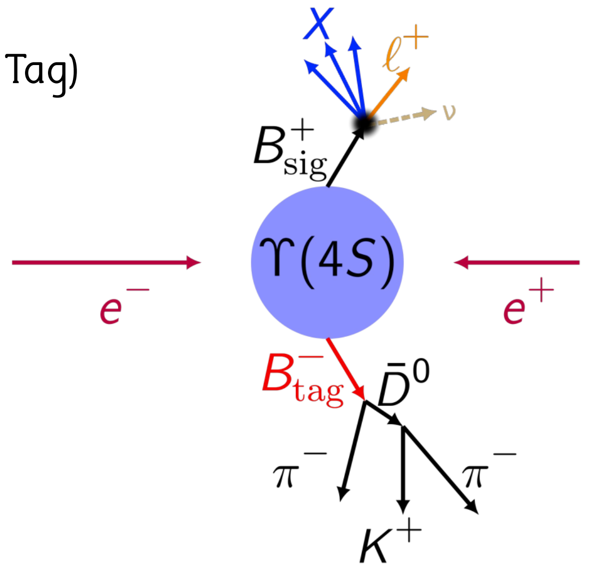
$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.24 \pm 0.41(\text{stat.}) \pm 0.19(\text{syst.})) \times 10^{-4}$$

$|V_{ub}|$ from inclusive $B \to X_u \ell \nu$ decays

New at EPS25

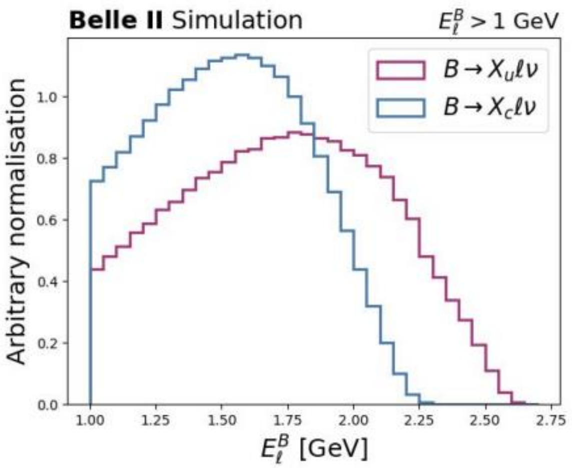
Dataset Reconstruction

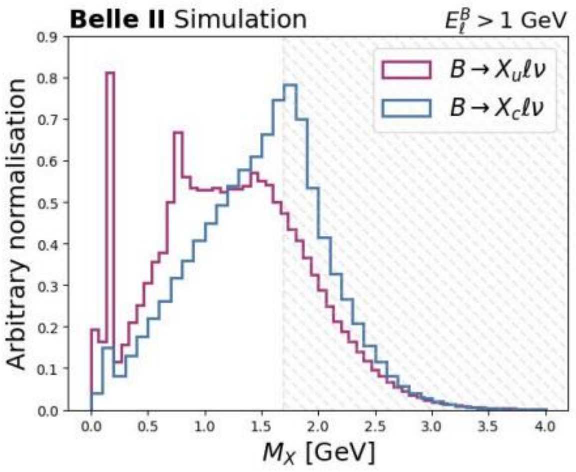
- B_{tag} reconstructed in hadronic decay channels (Had. Tag)
- Reconstructed lepton (electron or muon)
- Neutrino characterised as missing energy
- **Hadronic system X** characterised from rest-of-event
- **3 main kinematical variables** to suppress $X_c\ell\nu$:
  1. $E_\ell(B)$: lepton energy (in B_{sig} rest-frame)
  2. M_X : mass of hadronic system
  3. Q^2 : momentum transferred

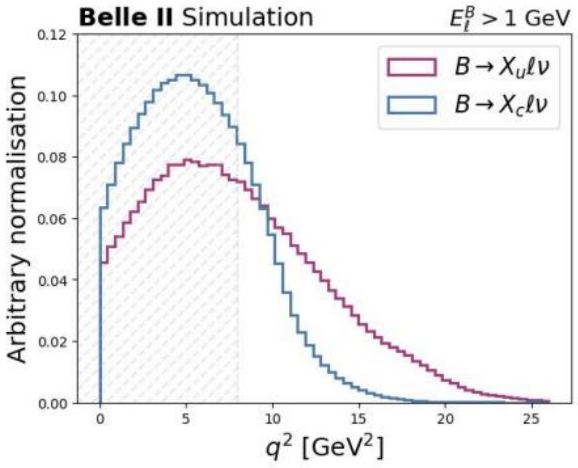


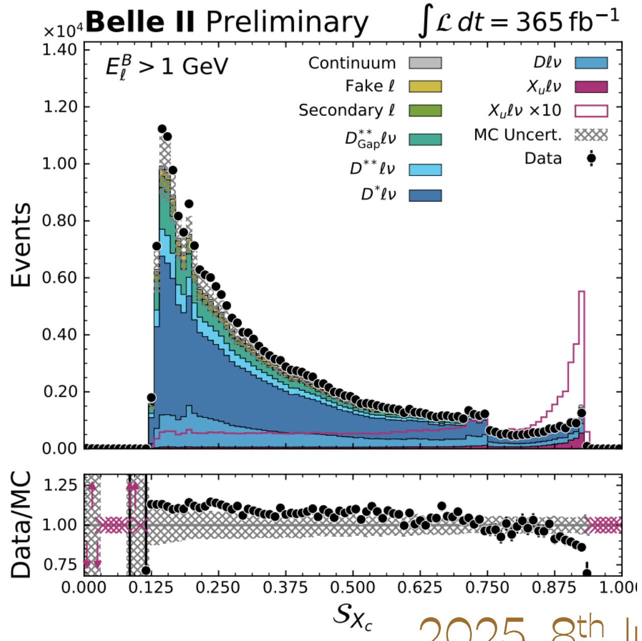
Background Suppression

- **Continuum** suppression via a NN using Event Geometry variables
- $X_c\ell\nu$ suppression via a NN using the kinematics of $B\to X_c\ell\nu$ decays and low-momentum π properties to reject $B\to D^*\ell\nu$ decays.



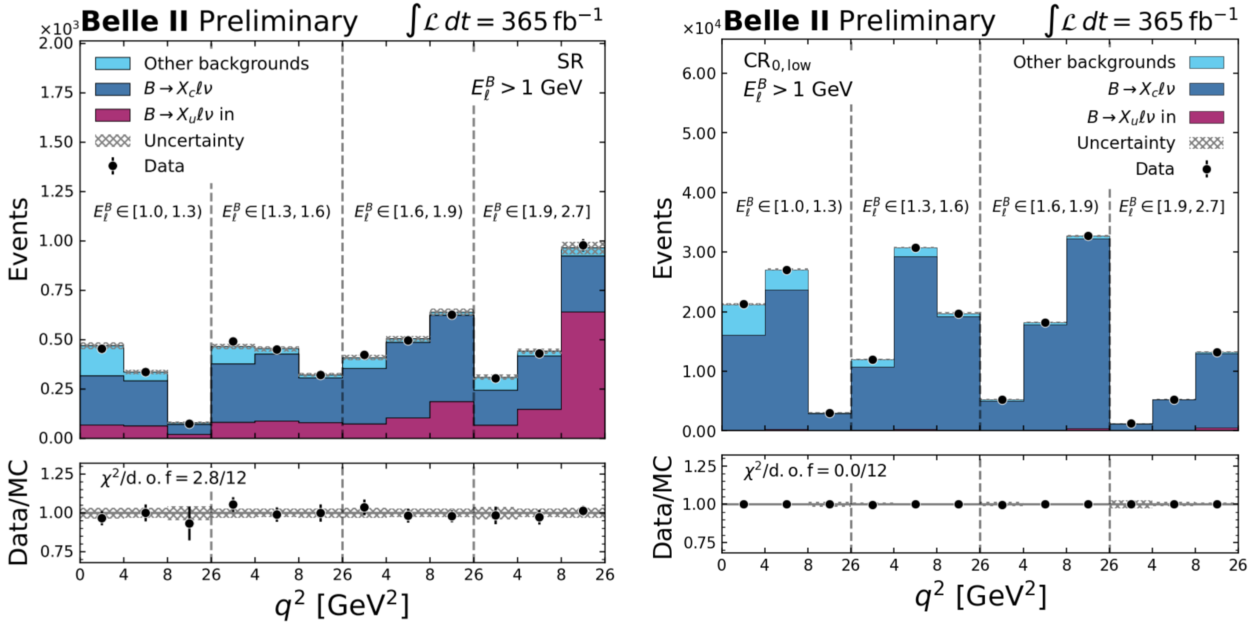






Signal Extraction Strategy

- **Binned template fit** with *pyhf*, *cabinetry*
  - Constrained source-wise nuisance parameters
  - Parameter of interest (POI): signal strength
- *3 templates*:
  1. $X_u\ell\nu$ **template**: signal events that pass the considered phase-space cuts on reconstruction and generator level
  2. Main background: $B \to X_c\ell\nu$
  3. Other backgrounds (**fake/secondary leptons + continuum**)
- Simultaneous Fit with the control sample, to correct the shape of the $X_c\ell\nu$ background



3 Different Fits in the 3 different phase spaces to extract the signal strength, and then determine V_{ub}

Phase Space	Fit Variables
$E_\ell^B > 1\ GeV$	$E_\ell^B : q^2$
$E_\ell^B > 1\ GeV$ $M_X < 1.7\ GeV$	$E_\ell^B : q^2$
$E_\ell^B > 1\ GeV$ $M_X < 1.7\ GeV$ $q^2 > 8\ GeV^2$	E_ℓ^B

Result

New at EPS25

BLNP: Phys. Rev. D **72**, 073006
DGE: JHEP 01, 097 (2006)
GGOU: JHEP 10, 058 (2007)

The broadest phase-space region, where inclusive $B \to X_u \ell \nu$ theoretical predictions are most reliable, is defined by a selection $E_\ell\,(B) > 1$ GeV.

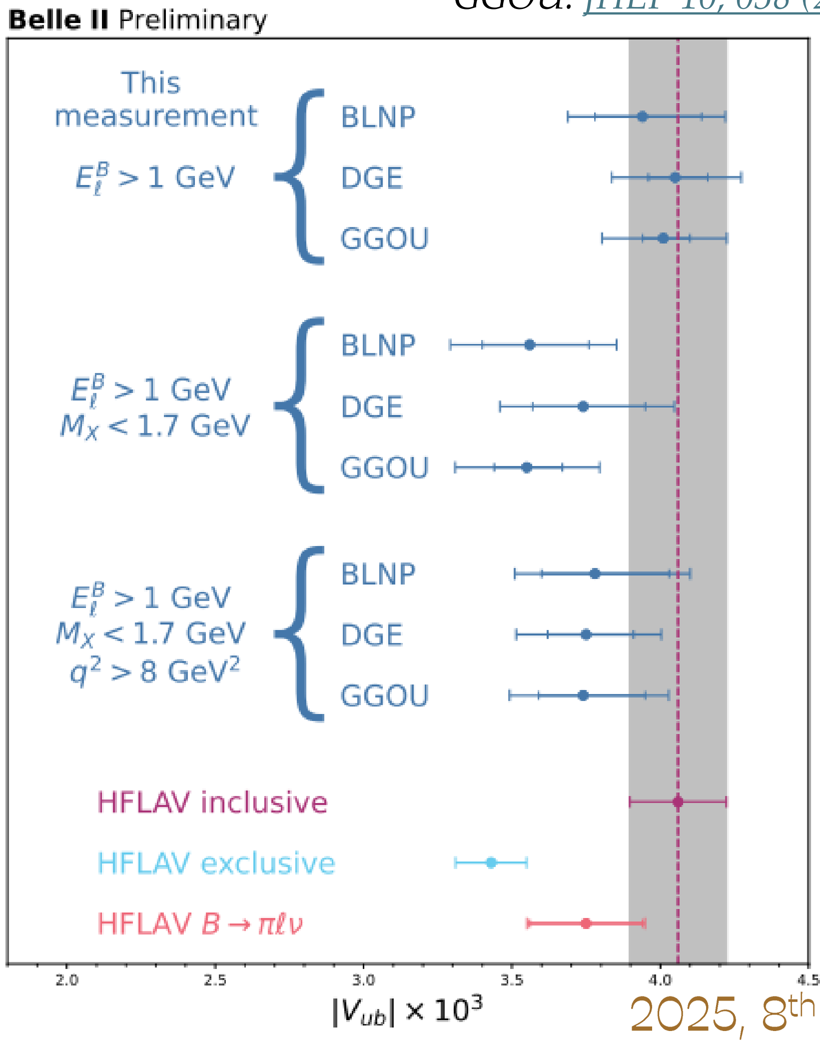
$$\Delta\mathcal{B}(B \to X_u \ell \nu) = (1.54 \pm 0.08 \pm 0.12) \times 10^{-3}$$

The obtained value of $|V_{ub}|$ using a partial decay rate predicted by the **GGOU framework** is

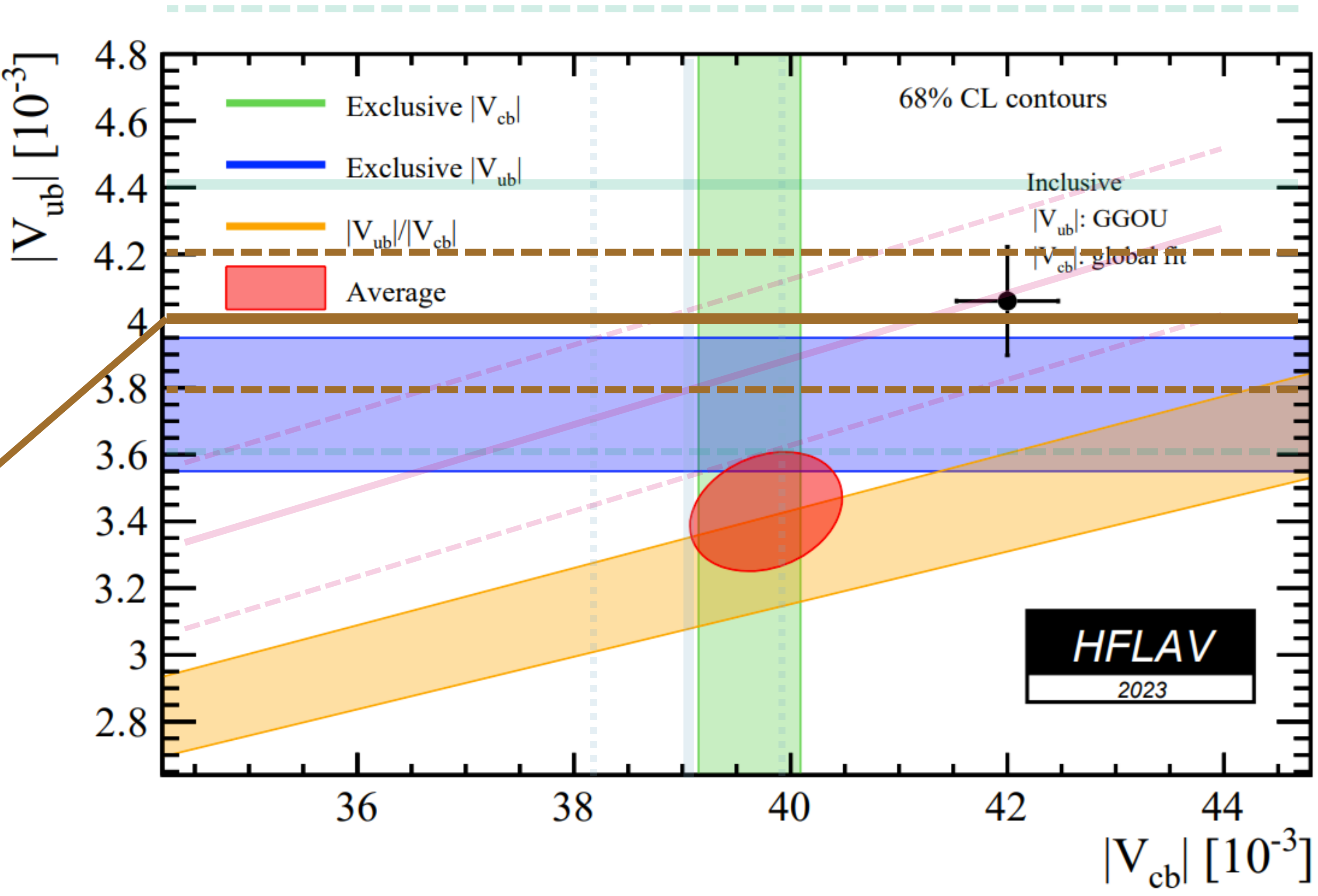
$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\tau_B \Delta\Gamma(B \to X_u \ell \nu)}}$$

$$|V_{ub}| = (4.01 \pm 0.11 \pm 0.16^{+0.09}_{-0.07}) \times 10^{-3}$$

- **Compatible** with the average value obtained from measurements using $B \to \pi \ell \nu$ decays within uncertainties
- **Exceeds** the HFLAV exclusive average
- Measurement is **competitive** with other measurements



First Hints of the future picture



$V_{ub}\,(B \to X\ell\nu)$

$|V_{ub}|/|V_{cb}|$ *from inclusive* $B \to X\ell\nu$ *decays*

Dataset Reconstruction

Dataset and Tagging: Belle dataset of $711\ fb^{-1}$
Apply improved Belle II hadronic tagging algorithm

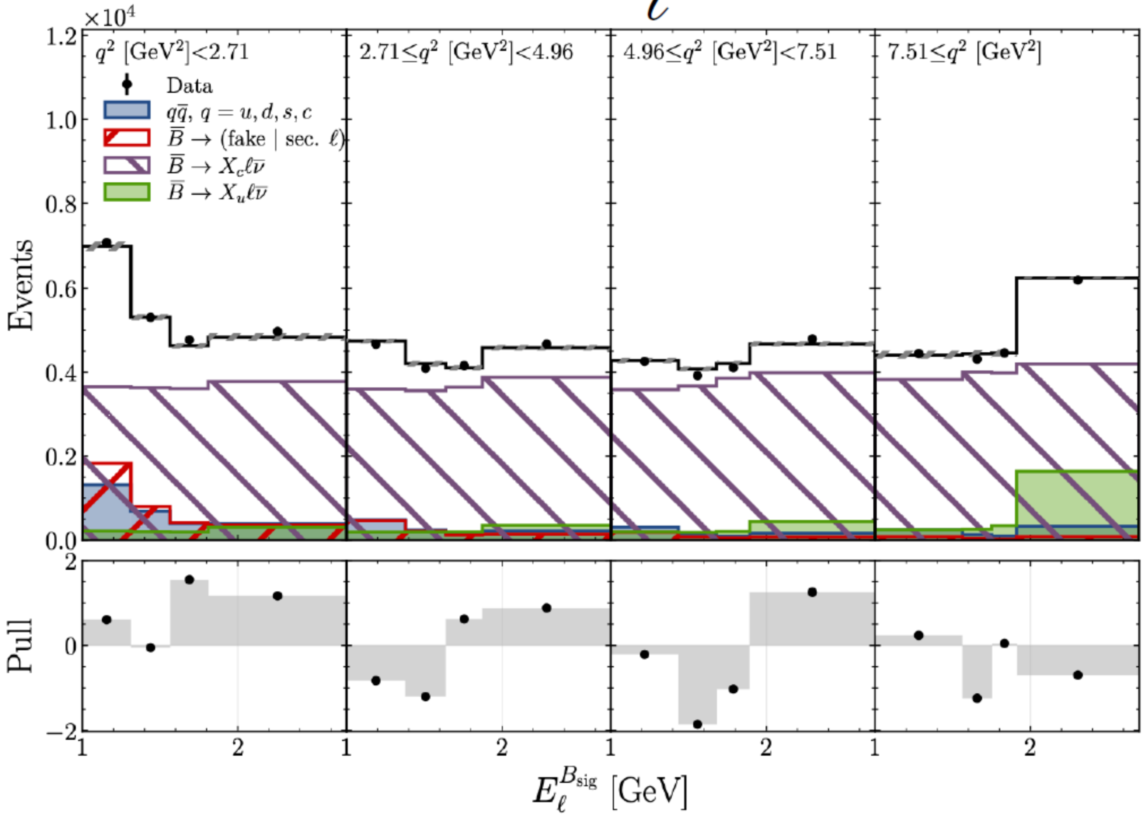
- K^+ or K_S reconstruction to tag a $b \to c$ decay
  - $N(K) > 0$ signal depleted sample for $X_c \ell \nu$ decays
  - $N(K) = 0$ signal enhanced sample to extract signal yields

- Inclusive D^* reconstruction to veto $b \to c$
  - Reconstructing **soft pion** and **high** M^2_{miss}

- *1D* **fit** to E_ℓ in u–depleted sample to get $N^{Xc\ell\nu}$

- *2D* **fit** *to* $E_\ell \times q^2$ in u–enhanced sample to get $N^{Xu\ell\nu}$

E_ℓ



Result

[Phys. Rev. D 111, 092016]

- Unfold $B \to X_u \ell \nu$ & $B \to X_c \ell \nu$ yields
- Take ratio and correct for efficiency to form differential ratios

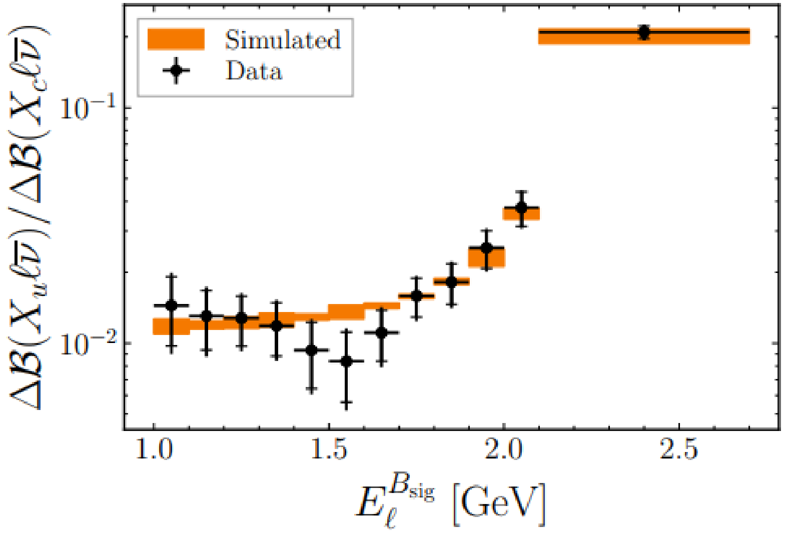
$$\frac{|V_{ub}|}{|V_{cb}|} = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell\nu)\Delta\Gamma(B \to X_c \ell\nu)}{\Delta\mathcal{B}(B \to X_c \ell\nu)\Delta\Gamma(B \to X_u \ell\nu)}}$$

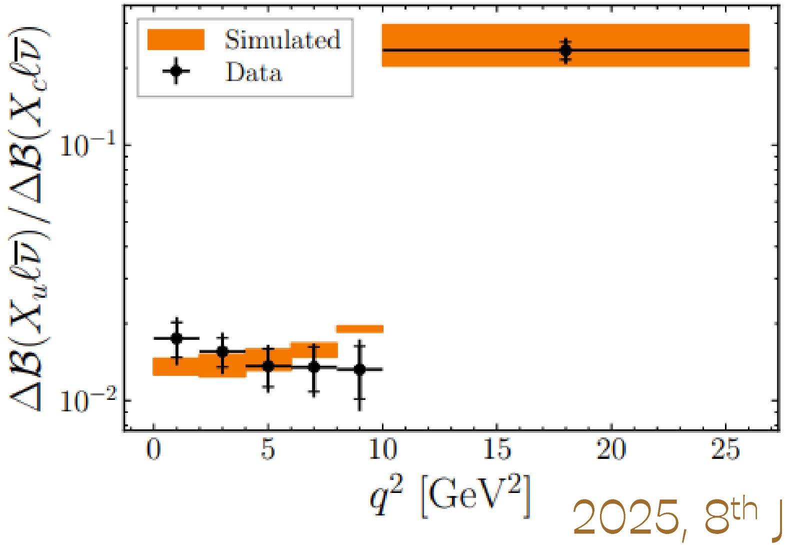
Theory decay rates:
$\Delta\Gamma^{\mathrm{GGOU}}(B \to X_u \ell \nu) = 58.5^{+2.7}_{-2.3}\ \mathrm{ps}^{-1}$
$\Delta\Gamma^{\mathrm{BLNP}}(B \to X_u \ell \nu) = 61.5^{+6.4}_{-5.1}\ \mathrm{ps}^{-1}$
$\Delta\Gamma^{\mathrm{Kin}}(B \to X_c \ell \nu) = 29.7 \pm 1.2\ \mathrm{ps}^{-1}$

$|V_{ub}|/|V_{cb}|$ with partial Branching Fraction:

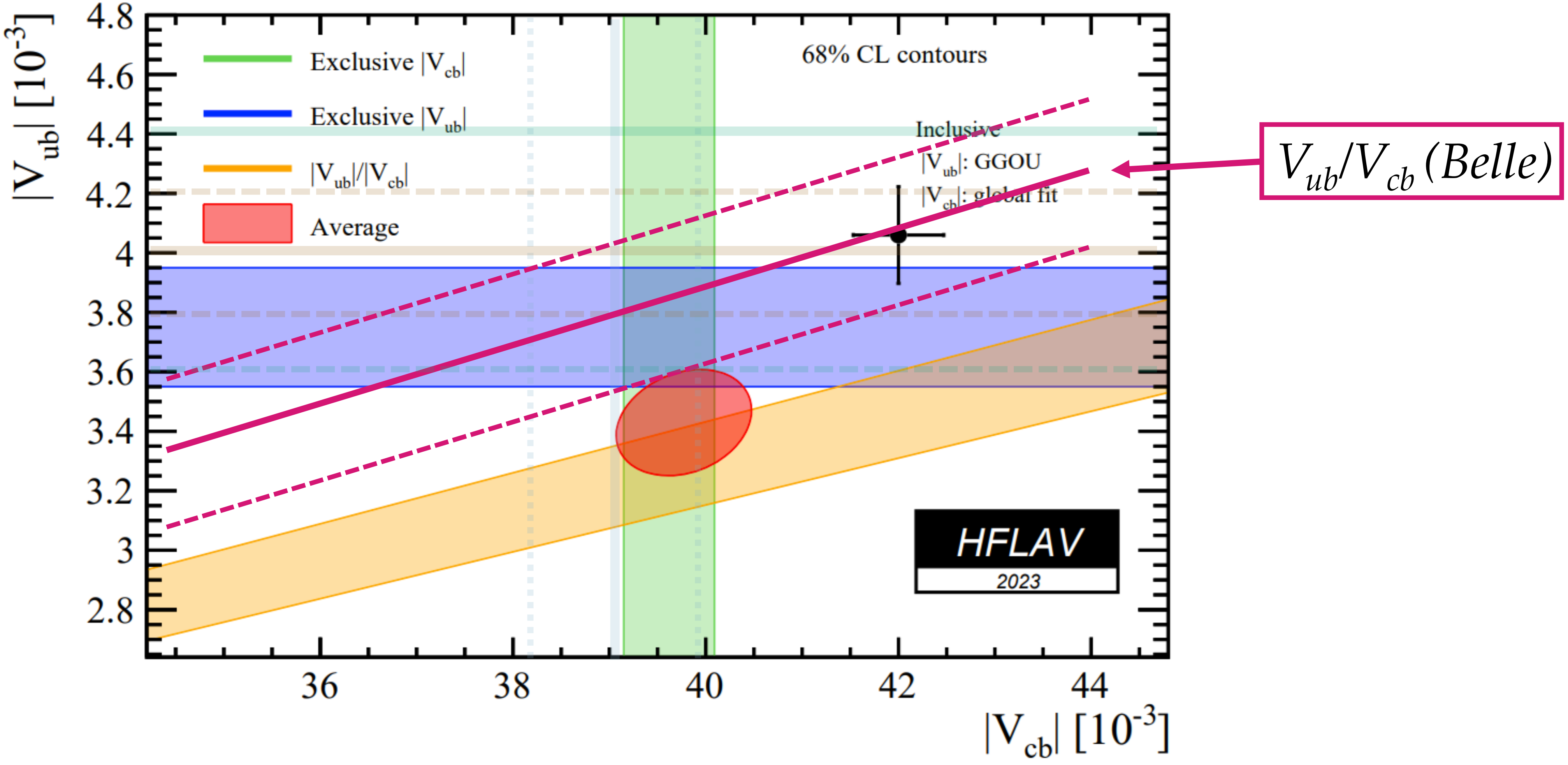
$$\frac{|V_{ub}|}{|V_{cb}|}^{\mathrm{BLNP}} = \left(9.81 \pm 0.42_{\mathrm{stat.}} \pm 0.38_{\mathrm{syst.}} \pm 0.51_{\Delta\Gamma(B\to X_u\ell\nu)} \pm 0.20_{\Delta\Gamma(B\to X_c\ell\nu)}\right) \times 10^{-2}$$

$$\frac{|V_{ub}|}{|V_{cb}|}^{\mathrm{GGOU}} = \left(10.06 \pm 0.43_{\mathrm{stat.}} \pm 0.39_{\mathrm{syst.}} \pm 0.23_{\Delta\Gamma(B\to X_u\ell\nu)} \pm 0.20_{\Delta\Gamma(B\to X_c\ell\nu)}\right) \times 10^{-2}$$





First Hints of the future picture

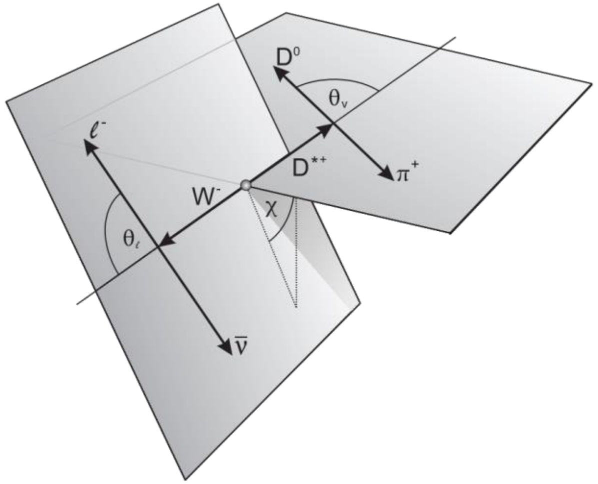


$|V_{cb}|$ *from* $B \to D\ell\nu$

Introduction

Analysis Workflow

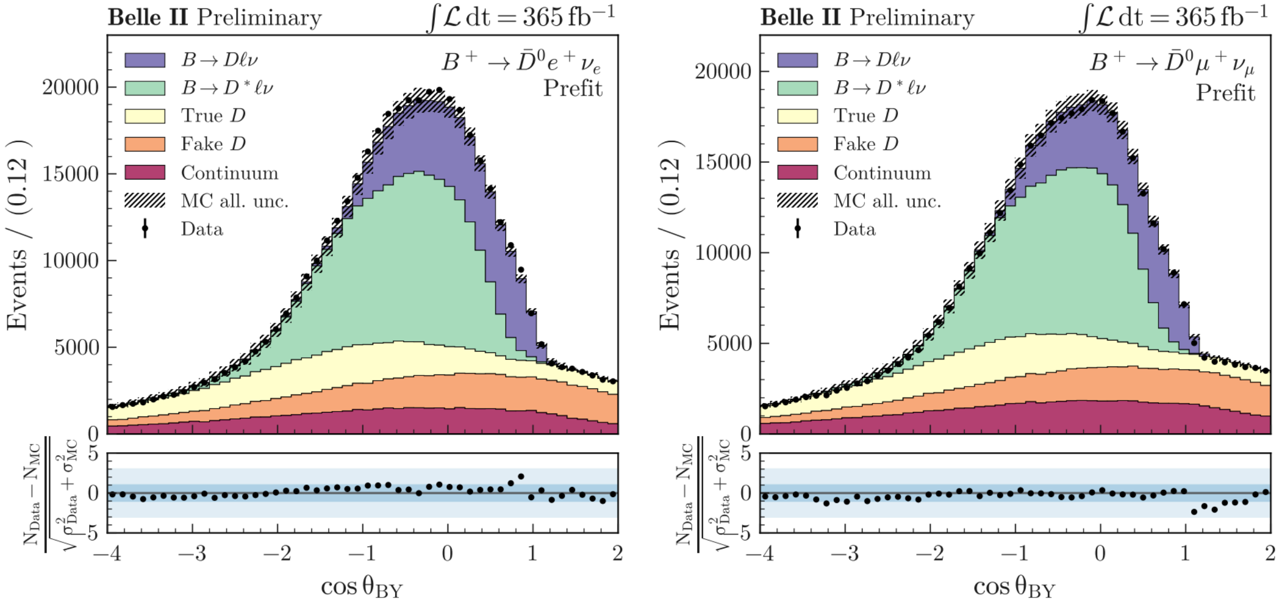
- Candidate $B \to D\ell\nu$ are formed from $\ell(e, \mu)$ and a D $(D \to K\pi, D \to K\pi\pi)$
- Exploit *isospin symmetry* to analyze B^0 and B^+ decays simultaneously and reduce experimental uncertainties.
- *Signal variable* using available kinematic constant



$$\cos\theta_{BY} = \frac{2\,E_{\text{Beam}}E_Y - m_B^2 - m_Y^2}{2|\vec{p}_B||\vec{p}_Y|}$$

$Y = D\ell$

$$w = \frac{m_B^2 + m_D^2 - q^2}{2m_B m_D}$$



- **Backgrounds**
  - $B \to D^*\ell\nu$
  - Continuum events $e^+e^- \to q\bar{q}$

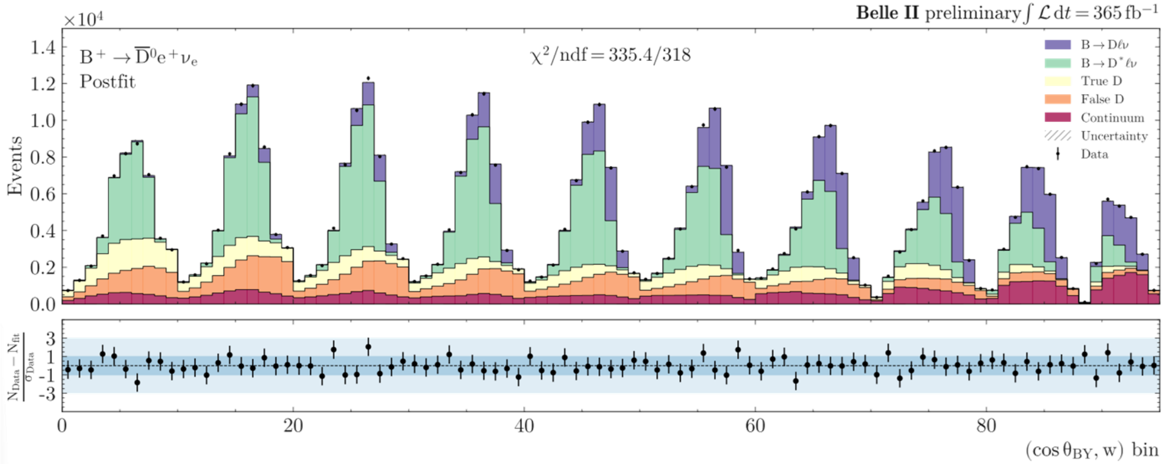
Result

Submitted to PRD: ***arXiv:2506.15256***

Signal Extraction

The branching fractions of each of the two modes were measured with a fit on $cos\theta_{BY}$ in bins of w.

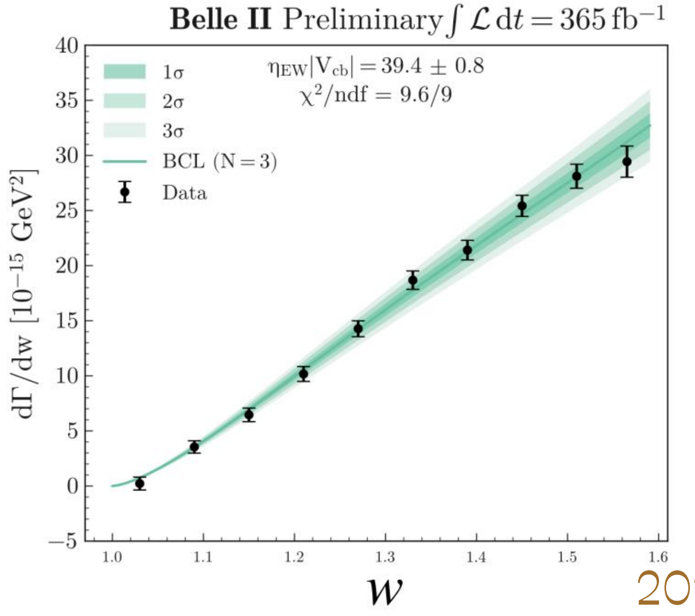
$$\mathcal{B}(B^0 \to D^- \ell^+ \nu_\ell) = (2.06 \pm 0.05\,(\text{stat.}) \pm 0.10\,(\text{sys.}))\%$$
$$\mathcal{B}(B^+ \to \bar{D}^0 \ell^+ \nu_\ell) = (2.31 \pm 0.04\,(\text{stat.}) \pm 0.09\,(\text{sys.}))\%$$



$|V_{cb}|$ extraction

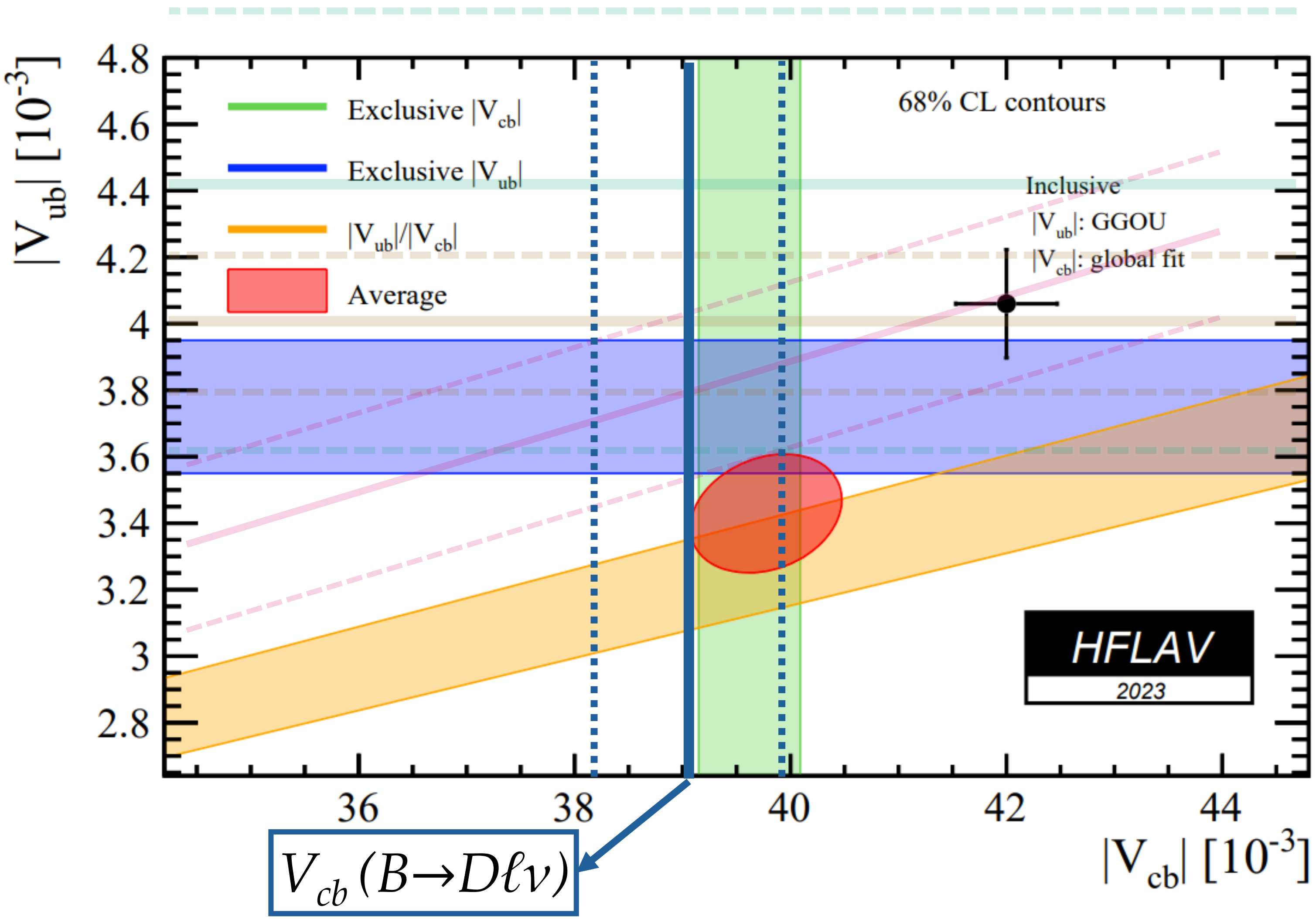
Fit differential decay rates using *Bourrely-Caprini-Lellouch (BCL) [PhysRevD.82.099902]* parameterization of form factor

$$|V_{cb}|_{\text{BCL}} = (39.2 \pm 0.4\,(\text{stat.}) \pm 0.6\,(\text{sys.}) \pm 0.5\,(\text{th.})) \times 10^{-3}$$



Most precise measurement to date using $B \to D\ell\nu$ decays

First Hints of the future picture



Conclusions

Semileptonic and ***Leptonic B*** decays provide key tests of the Standard Model and are sensitive to New Physics.

We presented in this talk:

- New measurement of $B \to \tau\nu$ with hadronic tagging.
- **Improved extraction of $|V_{ub}|$ from $B \to X_u \ell \nu$ decays.**

New at EPS

- $|V_{ub}|/|V_{cb}|$ from inclusive $B \to X \ell \nu$ decays
- Precise determination of $|V_{cb}|$ from $B \to D \ell \nu$ decays.

Stay tuned for more exciting results from Belle II people!

That's all!

Thanks for the attention

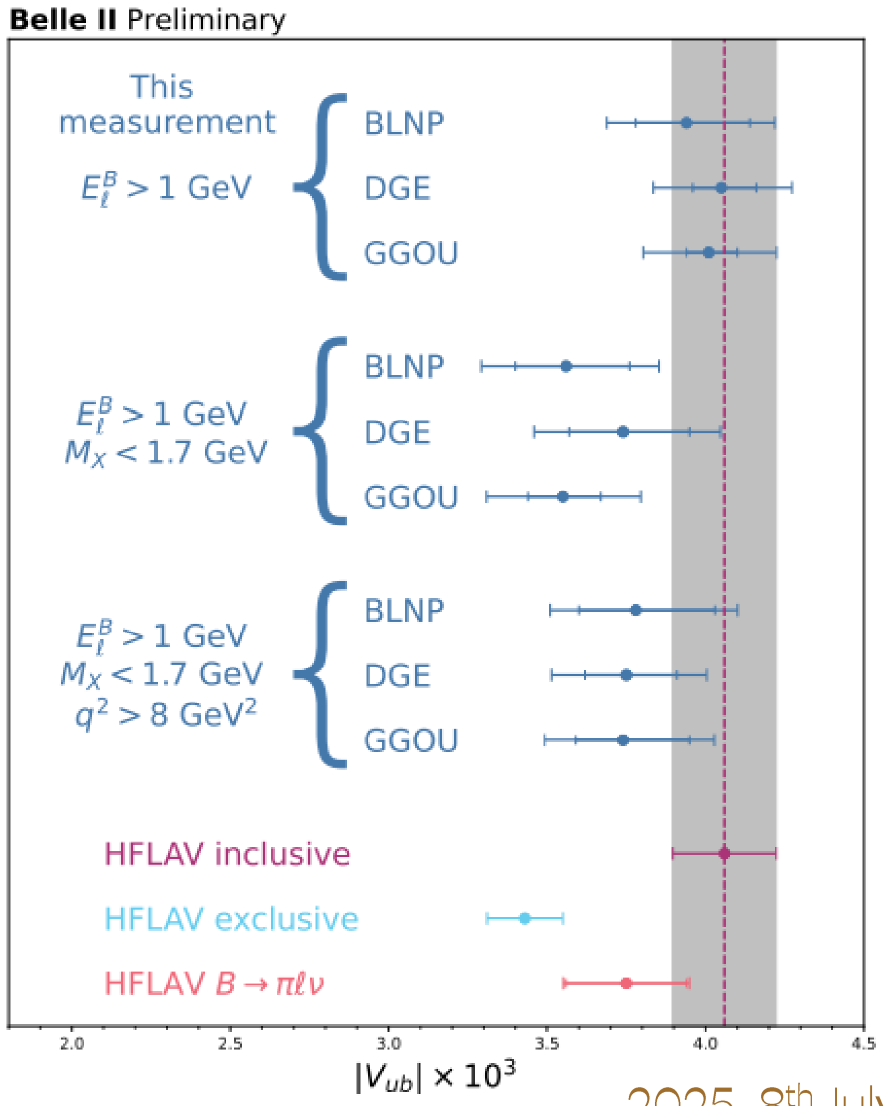
Backup

$|V_{ub}|$ *from inclusive* $B \to X_u \ell \nu$ *decays*

New at EPS25

Discussion about $|V_{ub}|$

- Our measurement agrees with inclusive $|V_{ub}|$ average but finds slightly lower values
- Our nominal value agrees with $|V_{ub}|$ from $B \rightarrow \pi l v$ HFLAV average
- Our nominal value disagrees with exclusive $|V_{ub}|$ average
  - The $|V_{ub}|/|V_{cb}|$ ratios from LHCb pull down the exclusive average
- New information to include in averages
  - This measurement
  - Measurement from exclusive $B \rightarrow \rho/\omega\, l\, v$
  - Measurement of inclusive $|V_{ub}|/|V_{cb}|$ ratio
- It will be interesting to see how the picture evolves in the next few years



Branching Fractions

- Branching fractions taken from HFLAV
  - The inclusive B ⟶ Xu l v BF is taken separately for B+/B0 from the PDG
- $B \to X_c \ell v$ computed assuming isospin symmetry
- The inclusive $B \to X_c \ell v$ Branching Fraction doesn't match the sum of exclusive ones
- The gap is filled with $B \to D^* \eta \ell v$ decays

	$\mathcal{B}$ (%)	
Decay mode	B^+	B^0
Incl. $B \to X_u \ell \nu$	0.192 ± 0.024	0.176 ± 0.022
$B \to \pi \ell \nu$	0.0078 ± 0.0003	0.0150 ± 0.0006
$B \to \rho \ell \nu$	0.0158 ± 0.0011	0.0294 ± 0.0021
$B \to \omega \ell \nu$	0.0119 ± 0.0009	-
$B \to \eta \ell \nu$	0.0035 ± 0.0004	-
$B \to \eta' \ell \nu$	0.0024 ± 0.0007	-
Incl. $B \to X_c \ell \nu$	11.05 ± 0.16	10.27 ± 0.15
$B \to D \ell \nu$	2.27 ± 0.06	2.11 ± 0.05
$B \to D^* \ell \nu$	5.27 ± 0.12	4.90 ± 0.11
$B \to D^1 \ell \nu$	0.64 ± 0.10	0.59 ± 0.10
$B \to D_0^* \ell \nu$	0.13 ± 0.19	0.12 ± 0.18
$B \to D_1' \ell \nu$	0.28 ± 0.04	0.26 ± 0.04
$B \to D_2^* \ell \nu$	0.32 ± 0.03	0.30 ± 0.03
$B \to D_s K \ell \nu$	0.03 ± 0.01	-
$B \to D_s^* K \ell \nu$	0.03 ± 0.02	-
$B \to D \eta \ell \nu$	0.90 ± 0.90	0.86 ± 0.86
$B \to D^* \eta \ell \nu$	0.90 ± 0.90	0.86 ± 0.86
$B \to D \pi \pi \ell \nu$	0.07 ± 0.09	0.07 ± 0.08
$B \to D^* \pi \pi \ell \nu$	0.22 ± 0.10	0.20 ± 0.10

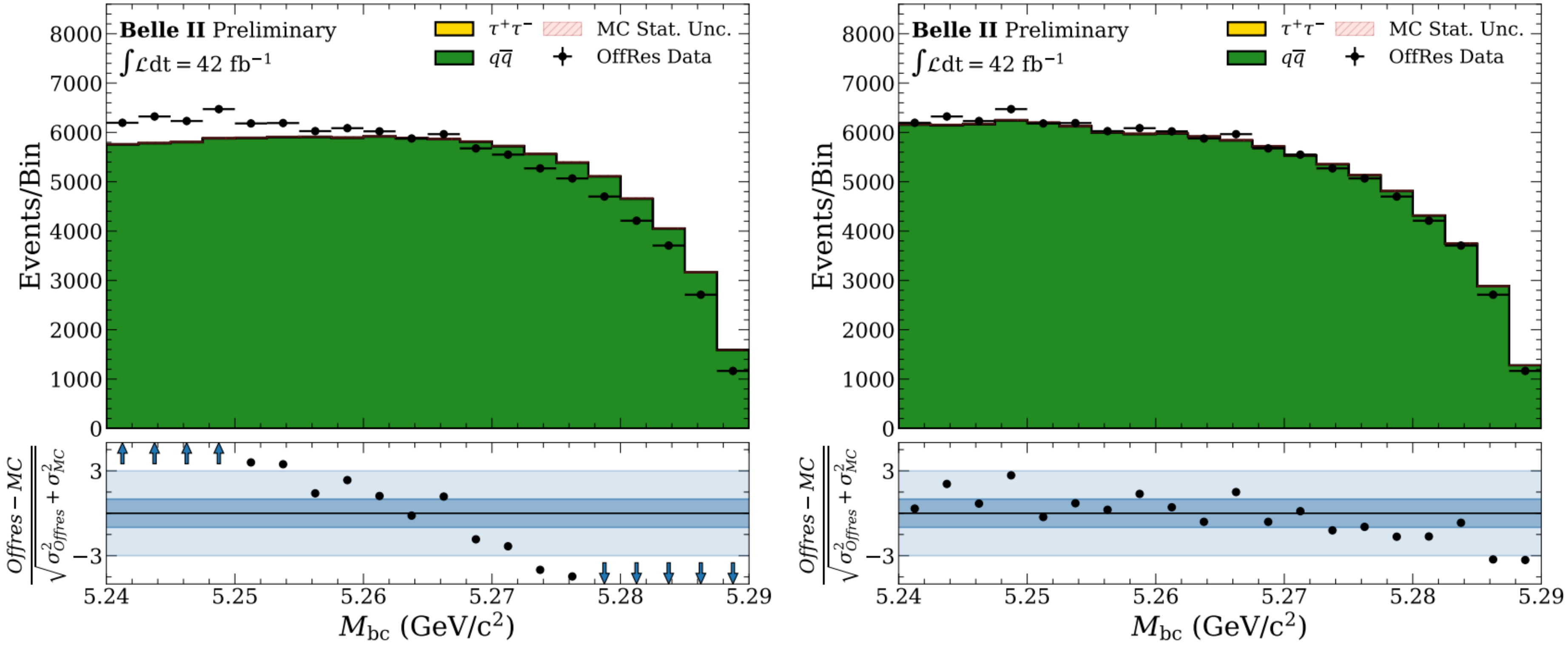
Systematics Budget

Uncertainty source	Relative uncertainty (%) Fit 1	Fit 2	Fit 3
DFN parameters	4.4	4.5	5.7
DFN $\to$ BLNP	0.2	0.8	1.3
γ_S	1.7	2.1	2.1
$B \to \pi \ell \nu$ form factors	0.3	0.3	0.3
$B \to \rho \ell \nu$ form factors	0.3	0.3	0.2
$B \to \omega \ell \nu$ form factors	0.1	0.1	0.1
$B \to \eta/\eta' \ell \nu$ form factors	< 0.1	< 0.1	< 0.1
$B^{\pm} \to X_u \ell \nu$ branching fractions	0.9	0.6	0.5
$B^0 \to X_u \ell \nu$ branching fractions	0.6	0.5	0.5
$B \to D^{**}_{\text{Broad}}$ form factors	0.5	0.1	0.2
$B \to D^{**}_{\text{Narrow}}$ form factors	0.1	< 0.1	< 0.1
$B \to D/D^* \ell \nu$ form factors	< 0.1	< 0.1	< 0.1
$B^{\pm} \to X_c \ell \nu$ branching fractions	0.7	0.5	0.2
$B^0 \to X_c \ell \nu$ branching fractions	0.6	0.2	0.1
D decay branching fractions	0.1	0.3	0.1
SR $X_c \ell \nu$ normalisation	1.6	3.5	3.4
CR $X_c \ell \nu$ normalisation	1.0	1.1	0.4
Other backgrounds normalisation	0.3	N/A	N/A
X_u fragmentation	0.3	4.4	3.9
$N_{\Upsilon(4S)}$	1.4	1.4	1.4
FEI	1.3	1.3	1.4
π_s	0.4	0.2	0.3
ℓ identification	0.7	0.7	0.6
$f^{\pm/00}$	0.6	0.7	0.6
Continuum calibration	0.2	0.2	0.2
Tracking	0.3	0.3	0.3
K^0_S efficiency	0.1	0.1	< 0.1
$K^{\pm}$ ID	< 0.1	< 0.1	< 0.1
Simulated data statistics	1.1	1.1	0.8
Fit bias	2.6	2.3	1.8
Composition uncertainty	1.3	5.7	0.2
$B \to X_c \ell \nu$ overestimation correction	2.6	0.4	1.3
Total systematic	7.8	10.5	9.7
Statistical	5.4	5.6	4.5
Total	9.5	11.9	10.7

$B \to \tau \nu$ with hadronic tag

Continuum reweighting BDT

We enhance MC simulation accuracy by adjusting events using multivariate analysis (MVA) to identify and correct data–MC differences. We use a Fast Boosted Decision Tree (FBDT) classifier for reweighting. Calibration involves 200/fb of continuum MC events and all off-resonance data (42/fb).



FastBDT: A speed-optimized and cache-friendly implementation of stochastic gradient-boosted decision trees for multivariate classification

$$\Delta E_{off} = \left(\frac{E_{on}}{E_{off}}\right) E_B^* - \frac{E_{on}}{2}$$

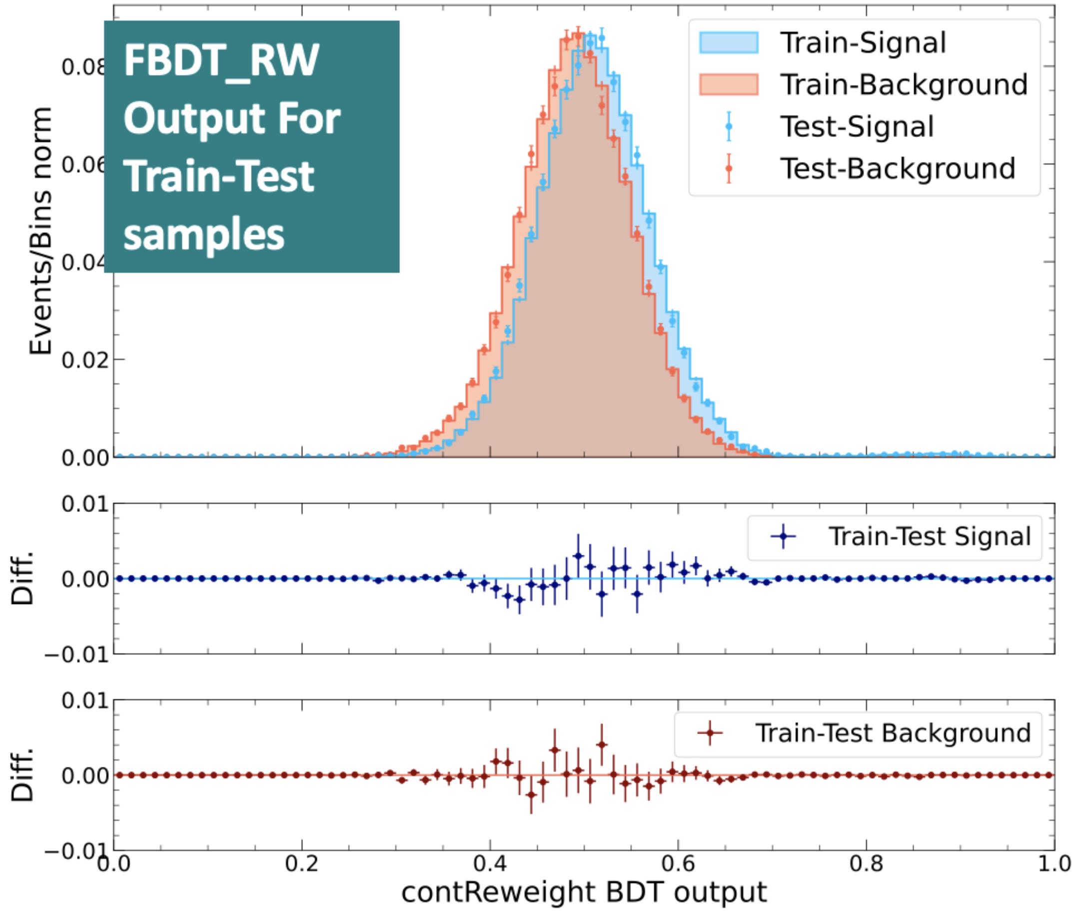
$$M_{bc,off} = \sqrt{\frac{E_{on}^2}{4} - \frac{E_{on}^2}{E_{off}^2} p_B^{*2}}$$

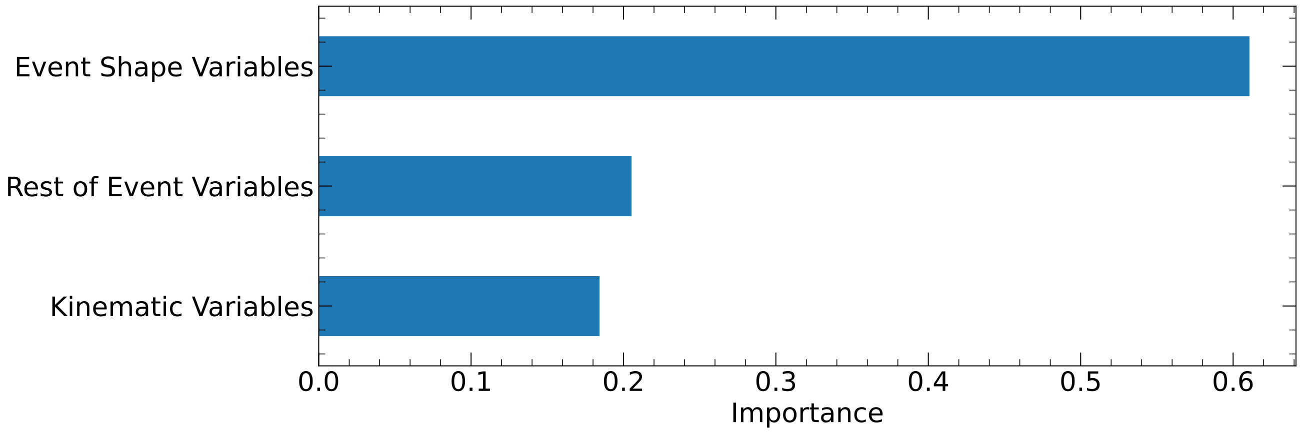
Variables distributions before and after the correction

Continuum reweighting BDT

We train a FastBDT using **Off-Res data as "Signal"** and **MC continuum as "Background" to correct the MC shape to Off-Res data.**

- 1.3M events, Train/Test sample 80%/20%





The discriminator output is transformed in an event-by-event weight to correct MC shape:

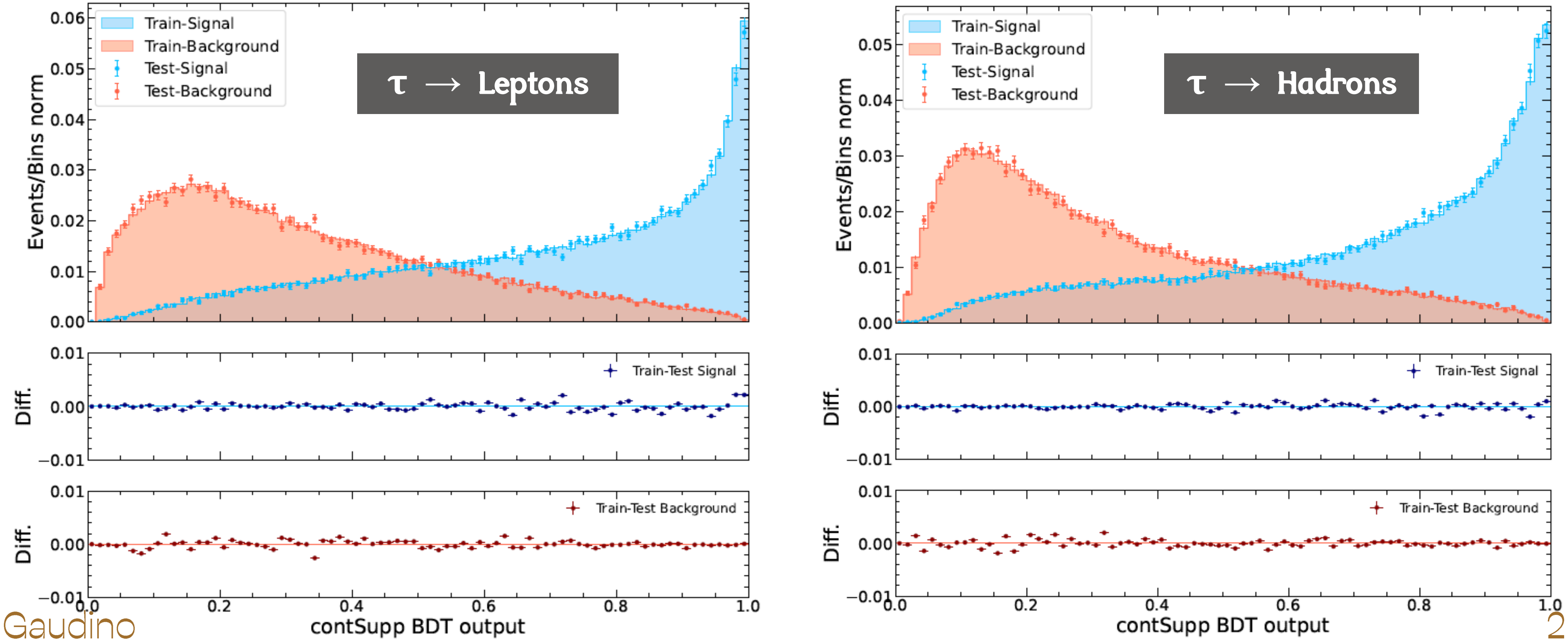
$$w_i = \frac{\mathcal{O}_{CR,i}}{1 - \mathcal{O}_{CR,i}}$$

Continuum reweighting BDT

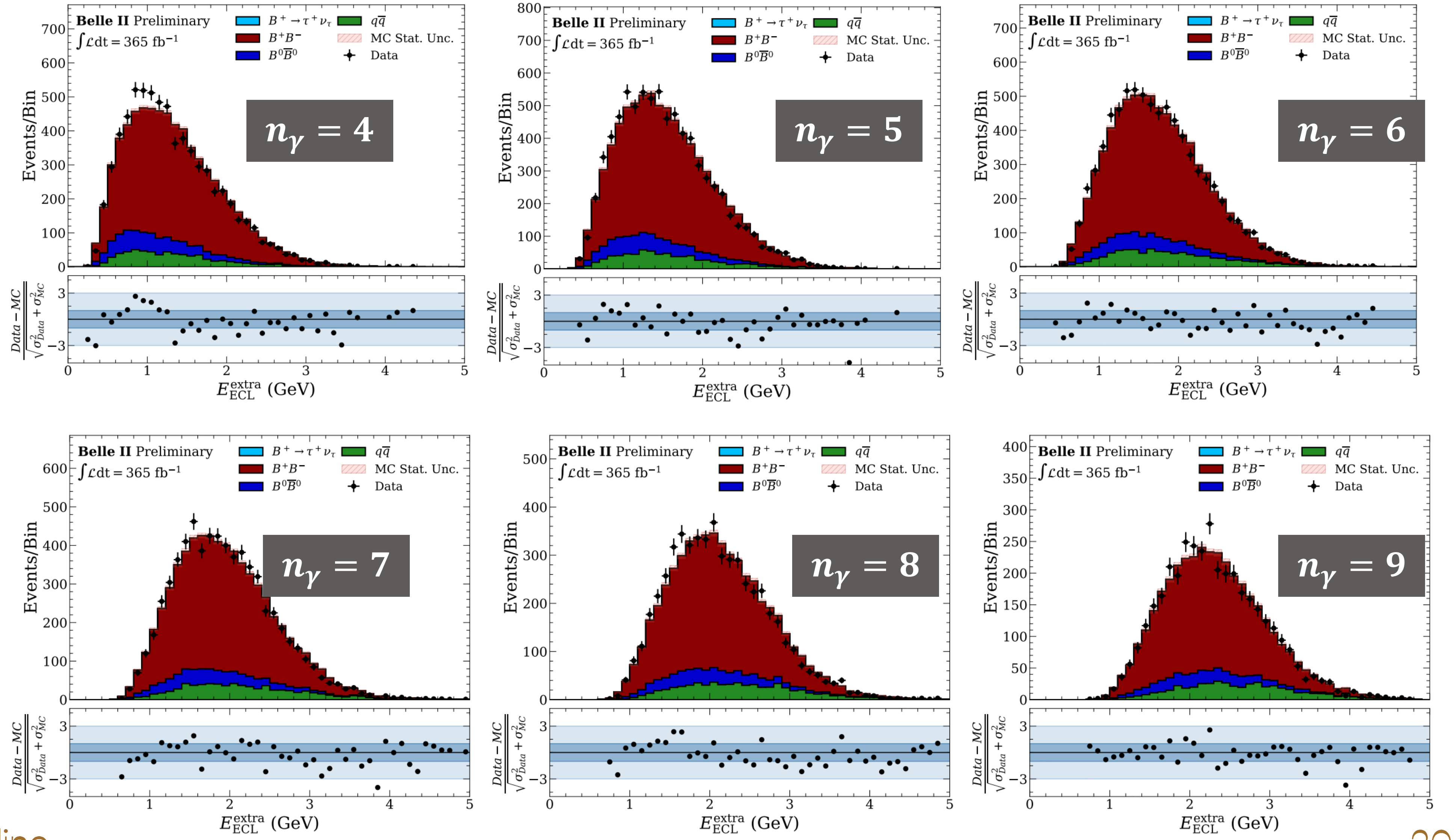
To suppress continuum, we train **2 FastBDT**, one for Leptons and one for Hadrons, using **MC continuum as "Signal"** and **MC $B\bar{B}$ as "Background"**.

In the training, the weights from continuum reweighting are used.

- 300K events, Train/Test sample 80%/20%
- Signal/Background events ratio = 1
- Features = only variables with good Data/MC agreement and less correlated with our fit variables.



Study of Extra Clusters



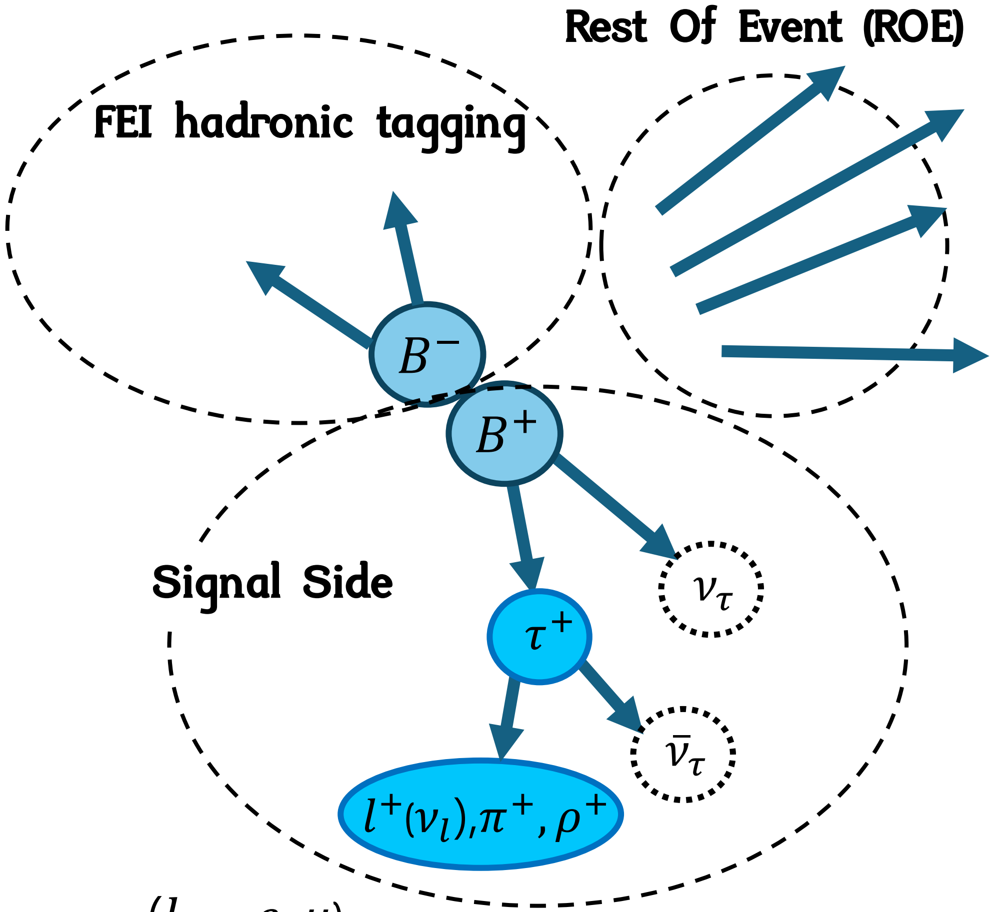
Giovanni Gaudino

2025, 8th July

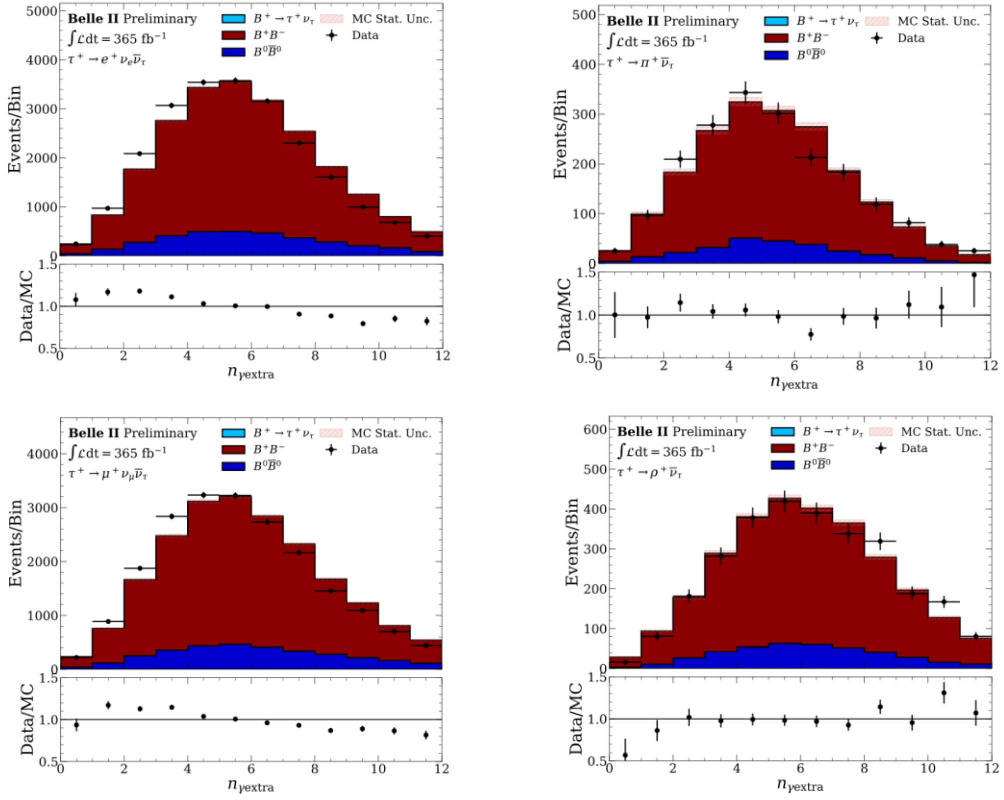
Extra Tracks Control Sample

For the main channel, we require no charged tracks in the ROE.
In this control samples, $N_{ROE\ Tracks} > 1$ → **same background composition but no signal events.**

We apply same reconstruction and selection as for the main analysis.

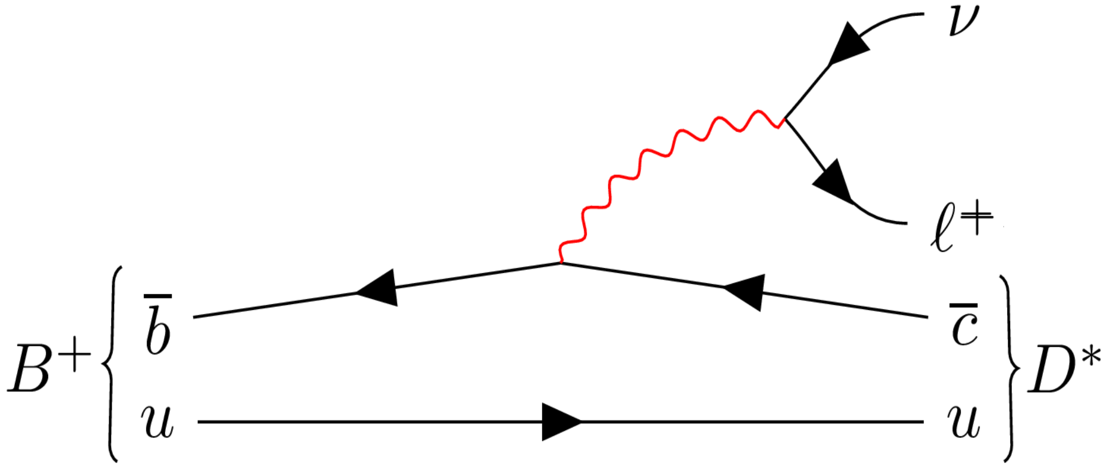


$(l = e, \mu)$



$B \to D^* \ell \nu$ control sample

In this control sample we have is one lepton and the D^{*0} is fully reconstructed through hadronic decays. $\to$ **E_{ECL}^{extra} peaks at 0.**



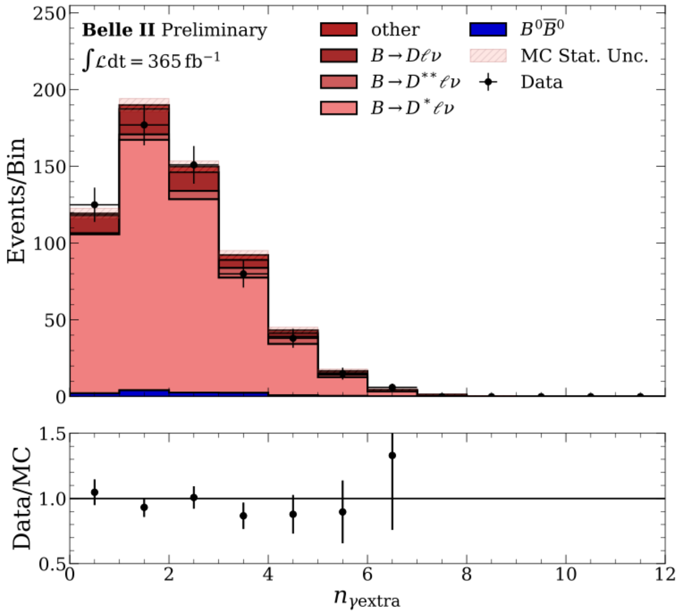
D^* decays

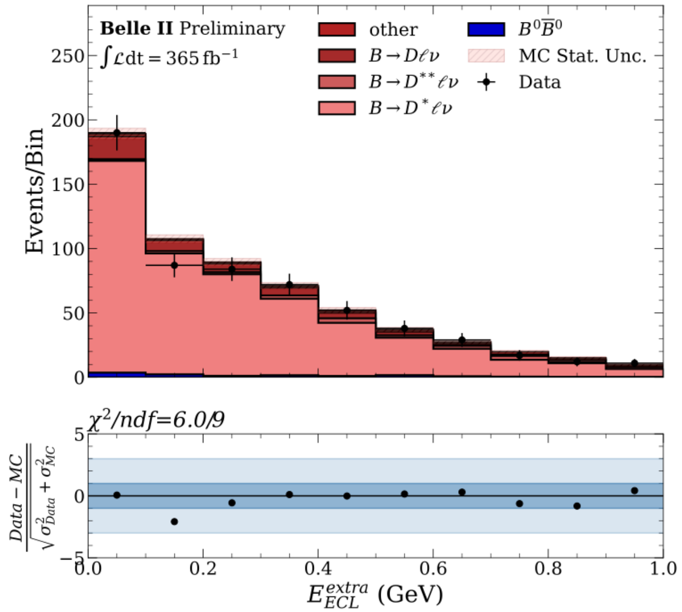
- $D^* \to D\gamma$
- $D^* \to D\pi^0$

D decays

- $D \to K\pi$
- $D \to K\pi\pi\pi$
- $D \to K_S\pi\pi$

We apply same reconstruction and selection as for the main analysis.



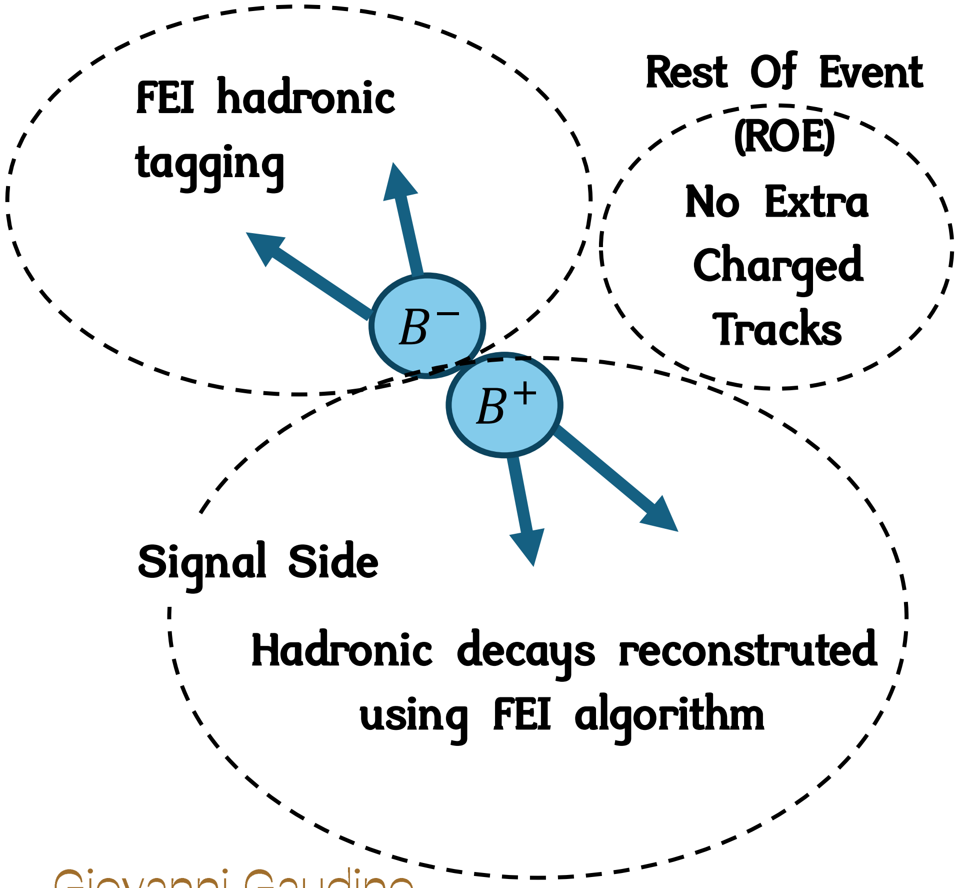


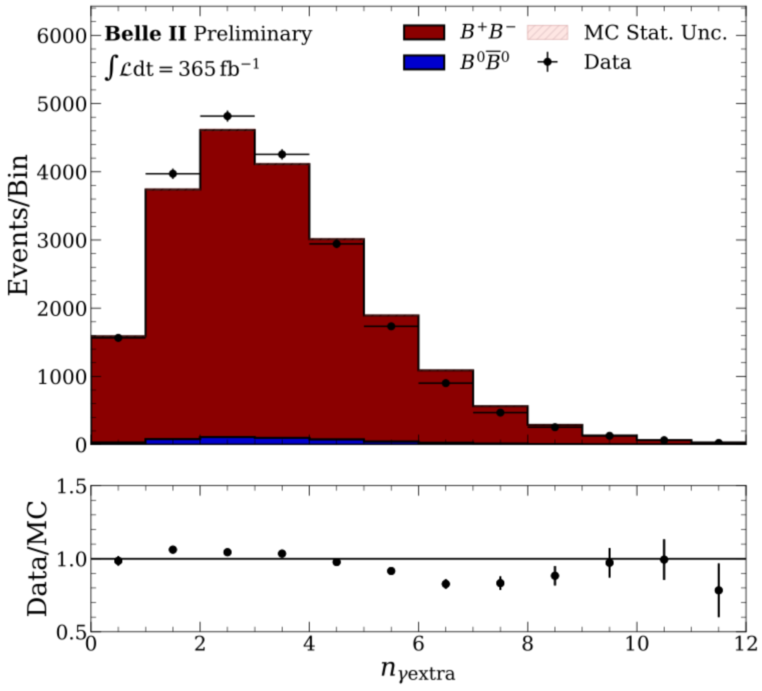
We also check the agreement of signal selection efficiency in data and MC and find a **Data/MC ratio equal to 0.96 ± 0.04 $\to$ no further efficiency correction is applied.**

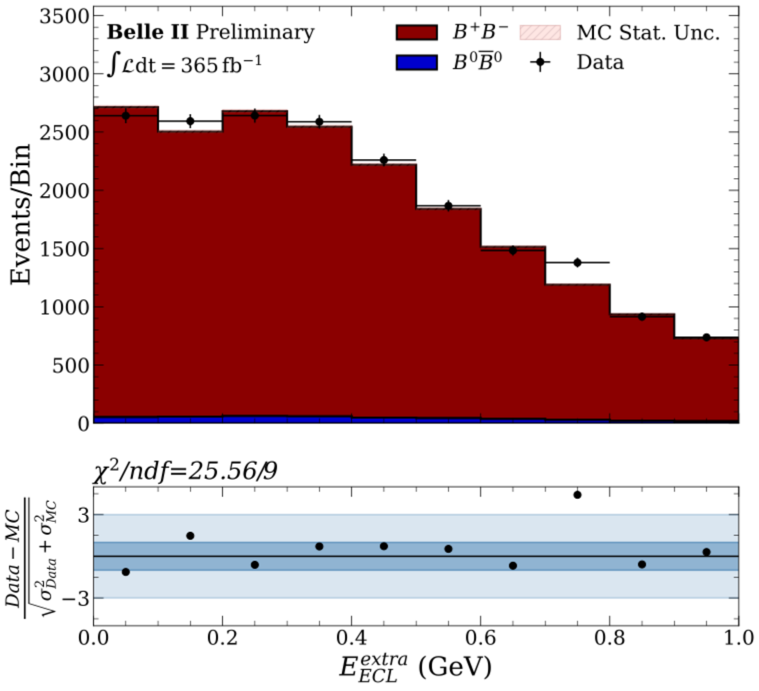
Double Tag Control Sample

We reconstruct the **two B candidates using the hadronic tagging FEI alogritm**.
As for the haronic signal channel, the decay is fully reconstructed.

We apply same reconstruction and selection as for the main analysis.







Systematics Budget

Source	Syst.
Simulation statistics	13.3%
Fit variables PDF corrections	5.5%
Decays branching fractions in MC	4.1%
Tag B^- reconstruction efficiency	2.2%
Continuum reweighting	1.9%
π^0 reconstruction efficiency	0.9%
Continuum normalization	0.7%
Particle identification	0.6%
Number of produced $\Upsilon(4S)$	1.5%
Fraction of B^+B^- pairs	2.1%
Tracking efficiency	0.2%
Total	15.5%

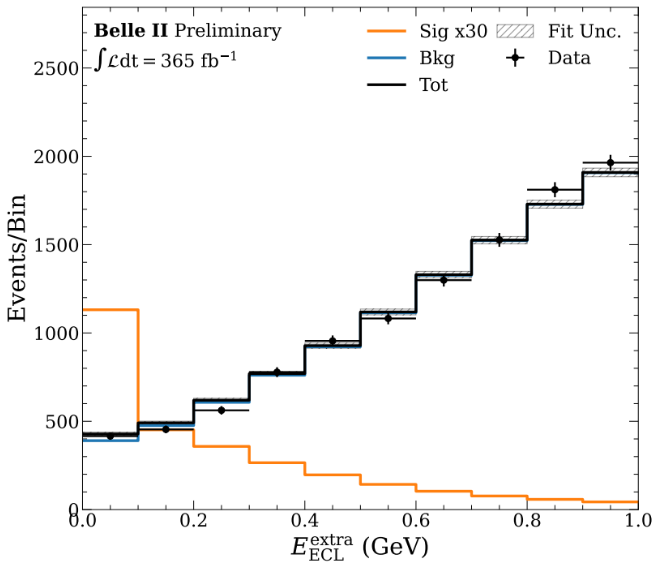
Simulation statistics → It is expected to reduce using more simulations.

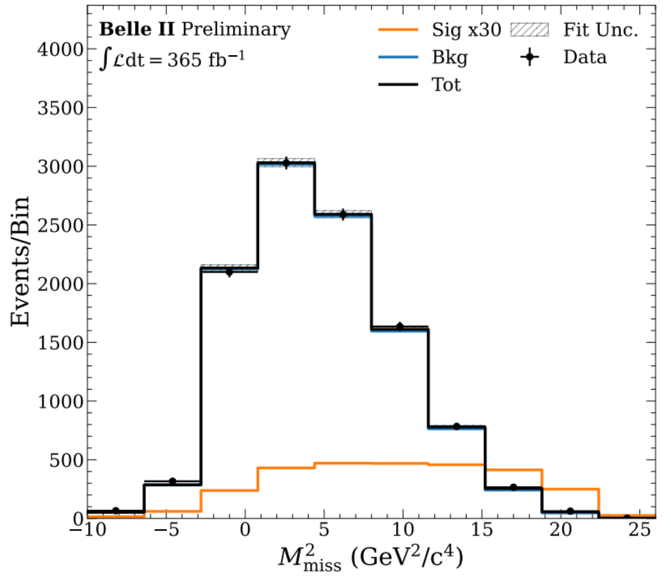
Fit variables PDF corrections → It is expected to reduce with increasing luminosity and better modeling of ECL photons in MC simulations.

The effect of each source on the final result is estimated by fluctuating the assumptions several times and propagating the effect on the PDF shapes, generating in this way a set of alternative PDFs.

Fraction of B^+B^- pairs → When uncertainties do not affect the signal yields, they are propagated directly to the BR.

After Fit Plots





	$\epsilon(10^{-4})$	$\epsilon(10^{-4})$ Belle
e^+	7.3	3.0
μ^+	7.6	3.1
π^+	3.4	1.8
ρ^+	3.1	3.4

Each ϵ_k includes the τ^+ branching fractions and cross-feed as predicted by MC and calibrated on control samples.

Five free parameters: four background yields and one common branching fraction.

E_{ECL}^{extra} and M^2_{miss} 2D PDFs from the MC calibrated on the control samples.

$$n_{s,k} = 2n_{\Upsilon(4S)} \cdot f^{+-} \cdot \epsilon_k \cdot B(B^+ \to \tau^+ \nu_\tau)$$