$B \to D^{(*)}\tau\nu$ and $b \to s$ penguin anomalies at Belle and Belle II

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for Belle and Belle II collaborations

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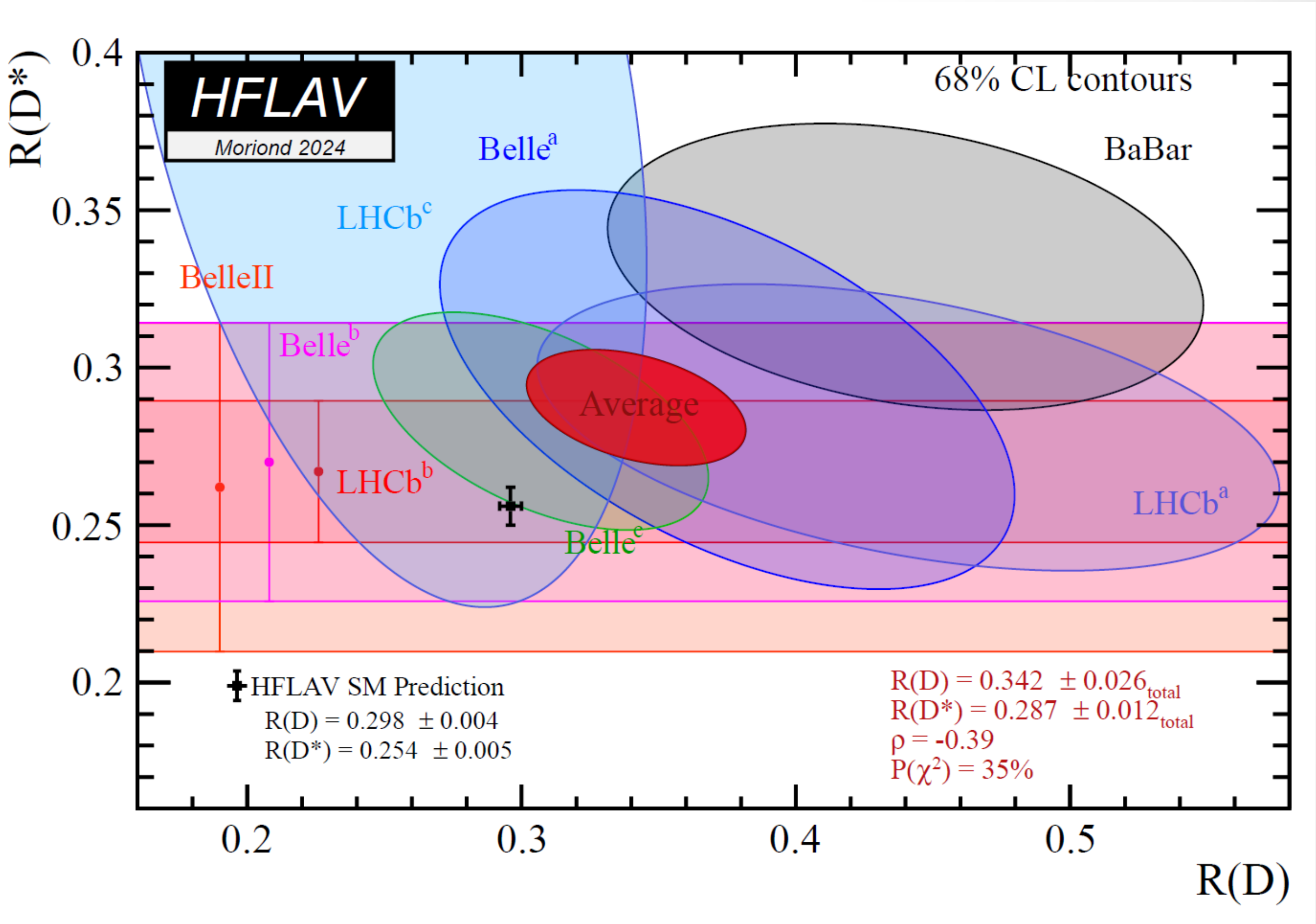
Lepton Flavor Universality Anomaly in $B \to D^{(*)}\tau\nu$ Decays

- $R\left(D^{(*)}\right) = \frac{\mathcal{B}(B\to D^{(*)}\tau\overline{\nu})}{\mathcal{B}(B\to D^{(*)}\ell\overline{\nu})}$ $\quad \ell = e, \mu$
- Measurements so far show deviation from the SM expectation
  - $R(D) \sim 1.6\sigma$
  - $R(D*) \sim 2.5\sigma$
  - <u>**Combined ~ 3.3σ**</u>

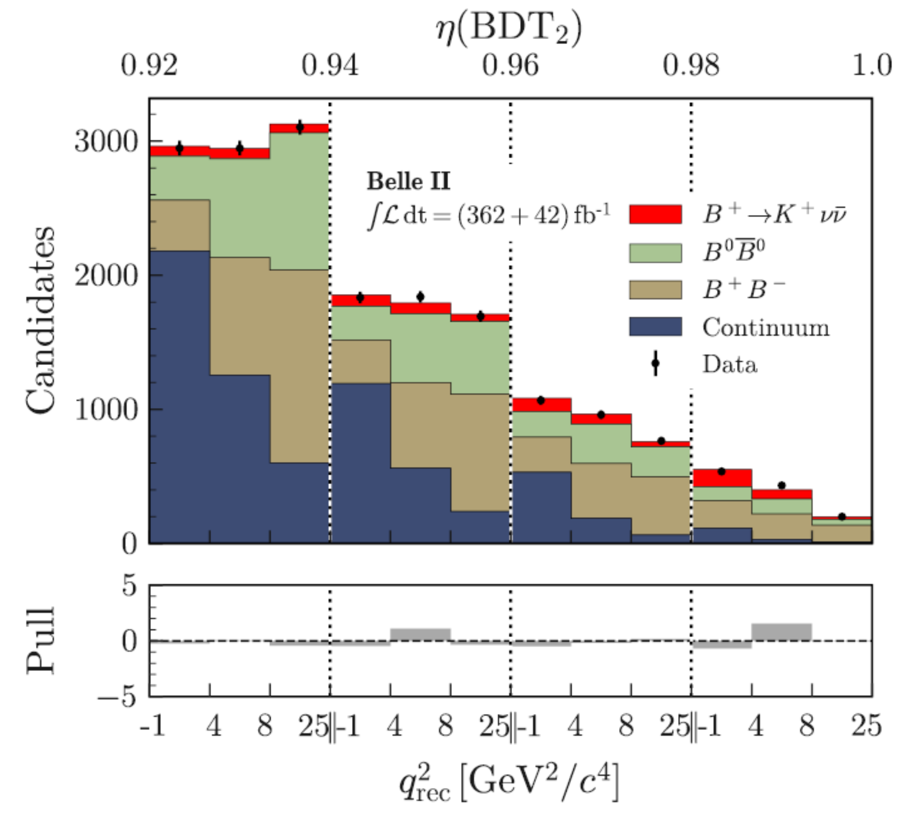


Evidence for $B \to K\nu\bar{\nu}$ Decays at Belle II

[Phys. Rev. D **109**, 112006]

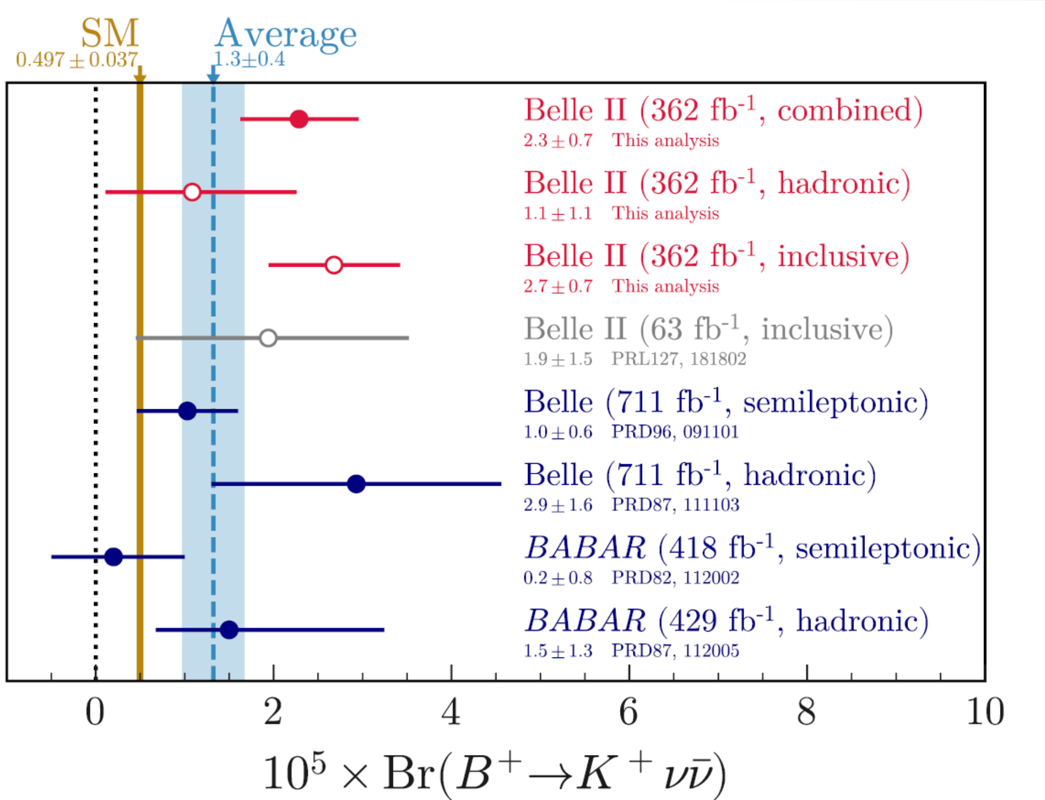
- Signal **evidence of 3.5σ significance** by inclusive + hadronic tag

Inclusive tag



Inclusive tag :	$[2.7 \pm 0.5(\mathrm{stat}) \pm 0.5(\mathrm{syst})] \times 10^{-5}$
Hadronic Tag	$[1.1^{+0.9}_{-0.8}(\mathrm{stat})^{+0.8}_{-0.5}(\mathrm{syst})] \times 10^{-5}$
Combined	$(2.3 \pm 0.7) \times 10^{-5}$
SM expectation:	4.97×10^{-6}

2.7σ deviation



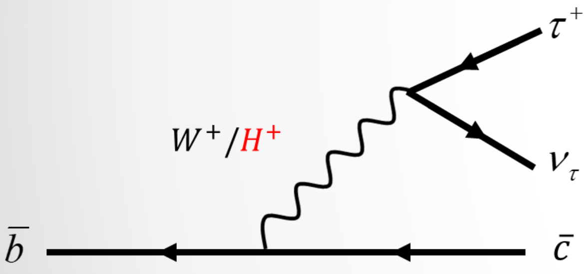
Possible New Physics in $B \to D^{(*)}\tau\nu$ and $b \to s$ Penguin

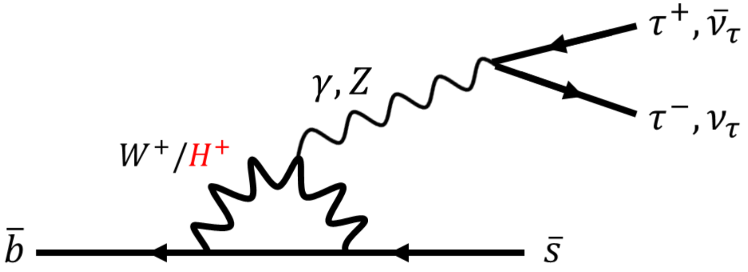
- Deviations from the SM may indicate

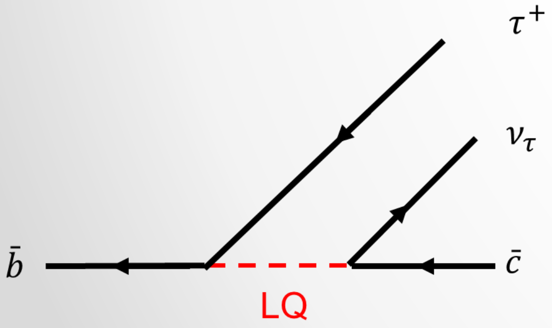
<u>New Physics (NP) effects in B decays with tau flavor</u>.
  - Charged Higgs
  - Leptoquark
  - …

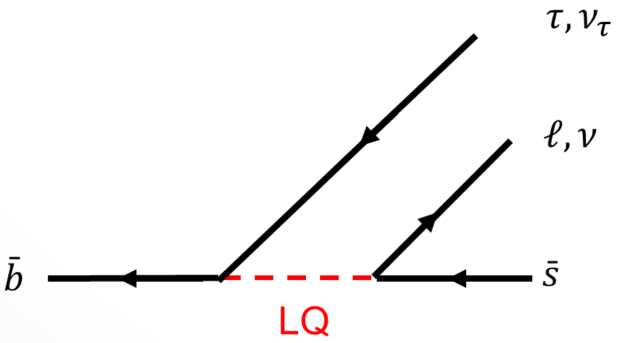
$B^0 \to D^{(*)-}\tau^+\nu$

$B^0 \to X_s\nu\bar{\nu}, K^{*0}\tau\tau, K^{(*)0}\tau\ell$

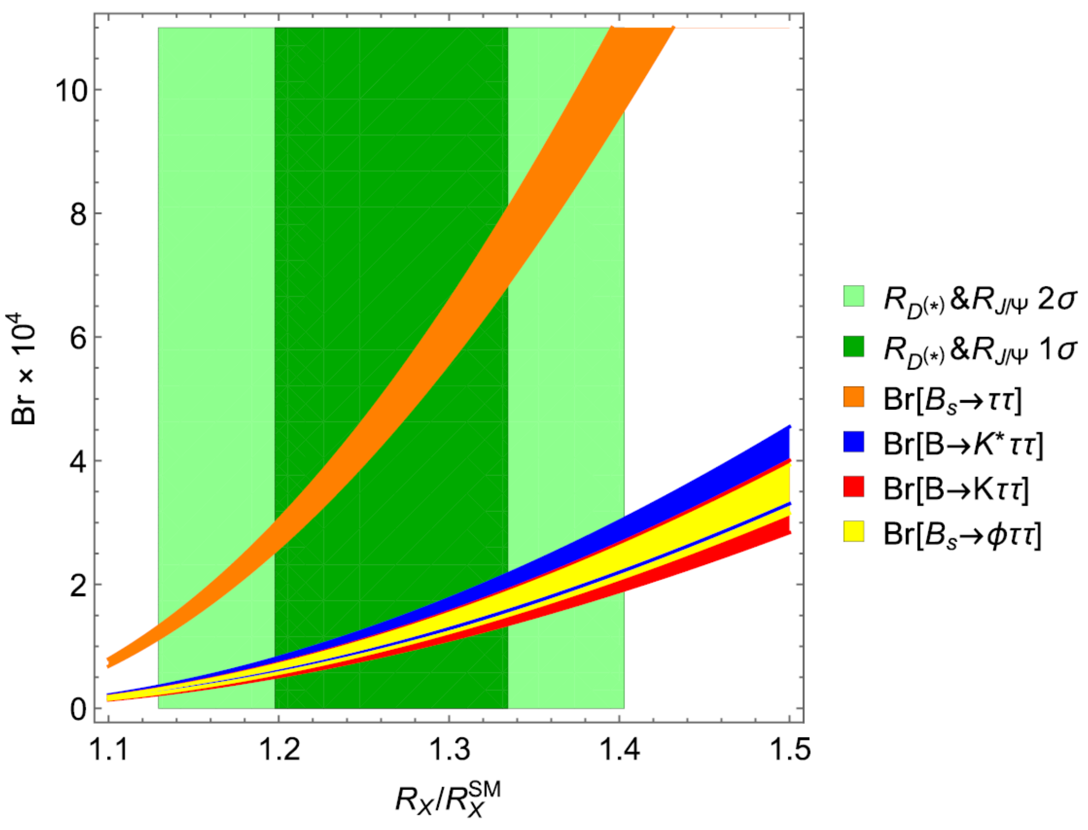








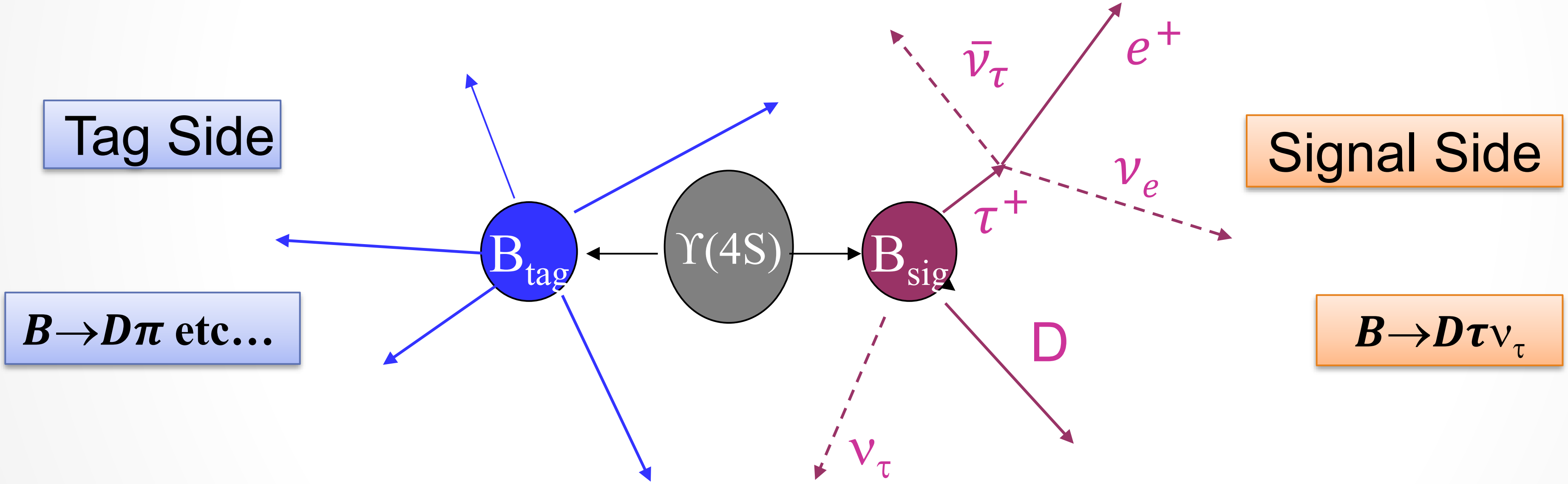
Possible NP enhancement of $\mathcal{B}(b \to s\tau^+\tau^-)$ as a function of R(X)
[B. Capdevila et al., PRL120, 181802(2018)]



B Decay Analyses with Missing at B-factory

- **Difficulty due to the neutrino(s)** in the signal decay

→ Utilize the B factory specific feature : **Tagging one of the $B\bar{B}$ pair in the event**



Reconstruct and remove B_{tag} from the event
→ Search for the signal decay in the remaining particles

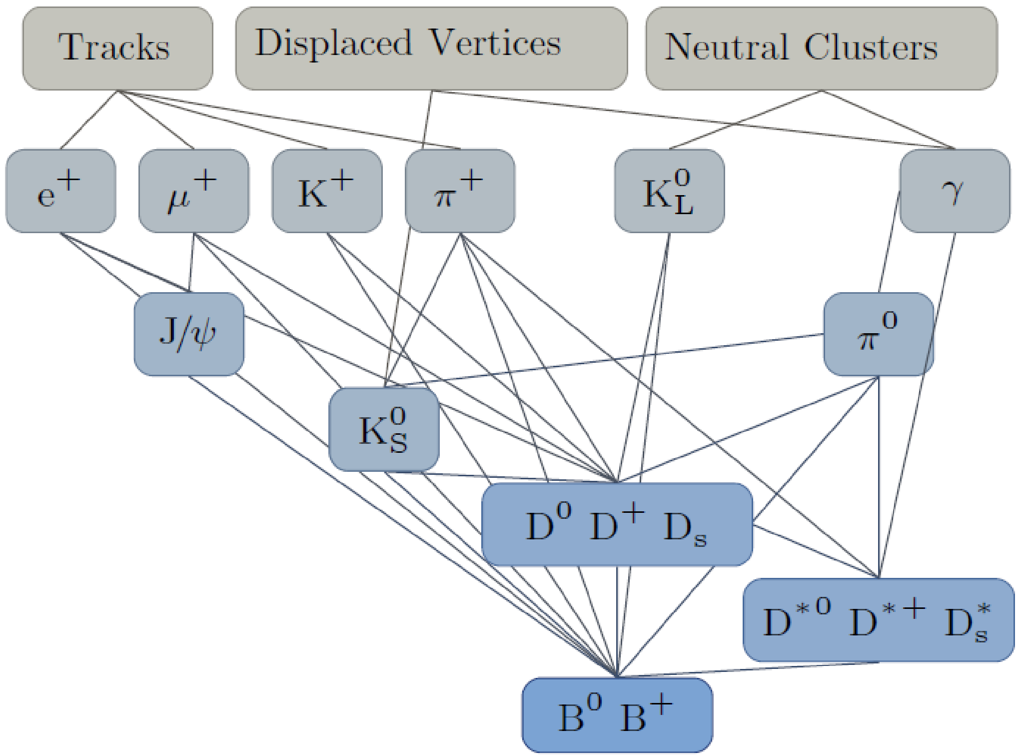
B_{tag}: Full Event Interpretation (FEI)

[Computing and Software for Big Science 3, 6 (2019)]

- Reconstruct > 100 intermediate decays
  → $O(10{,}000)$ decay chains

- Multivariate classifier for signal probability
  → $\boldsymbol{O_{FEI} = 0 \sim 1}$ **for BG ~ Sig**
  - Cut on O_{FEI} : Optimize eff. vs purity in each analysis
  - Additionally kinematical cuts are performed
    - B_{tag} invariant mass for hadronic decays
    - Missing ~ neutrino for semileptonic decays

- **Hadronic** and **Semleptonic** Tagging
  - **Hadronic ~ 0.5 % eff.**
  - **Semileptonic ~ 1 % eff.** (eff. depends on O_{FEI} cut)



Recent Belle,BelleII Results

- $B^0 \to D^{(*)}\tau\nu$ R(D(*)) with **Semileptonic Tag** at **Belle II**
  arXiv:2504.11220, accepted by PRD
- $B^0 \to K^{*0}\tau\tau$ with **Hadronic Tag** at **Belle II**
  arXiv:2504.10042, submitted to PRL
- $B^0 \to K_S^0\tau\ell$ and $B^0 \to K^{*0}\tau\ell$ with **Hadronic Tag** at **Belle** + **Belle II**
  arXiv:2412.16470 ($K_S^0\tau\ell$), accepted by PRL
  arXiv:2505.08418 ($K^{*0}\tau\ell$), accepted by JHEP
- $B^0 \to X_s\nu\bar{\nu}$ with **Hadronic Tag** at **Belle II**
- **Reinterpretation of the $B^+ \to K^+\nu\bar{\nu}$ Belle II Result**
  arXiv:2507.12393, submitted to PRD

Analyzed data
Belle : 711fb^{-1}
BelleII : 365fb^{-1}

$B^0 \to D^{(*)}\tau\nu$ with Semileptonic Tag at Belle II

[arXiv:2504.11220] accepted by PRD

- First $R(D^{(*)})$ BelleII measurement using semileptonic B tagging
- 365fb^{-1} Belle II data
- Semileptonic FEI Tag, neutral B_{tag}
    - Charged B_{tag} is left for future study (require precise slow π^0 understanding)
- Leptonic tau decays: $\tau \to e\bar{\nu}_e\nu_\tau$, $\mu\bar{\nu}_\mu\nu_\tau$
- Fit signal B→D(*)τv and normalization B→D(*)lv simultaneously
  → obtain R(D*) and R(D)

$B^0 \to D^{(*)}\tau\nu$ Signal Separation

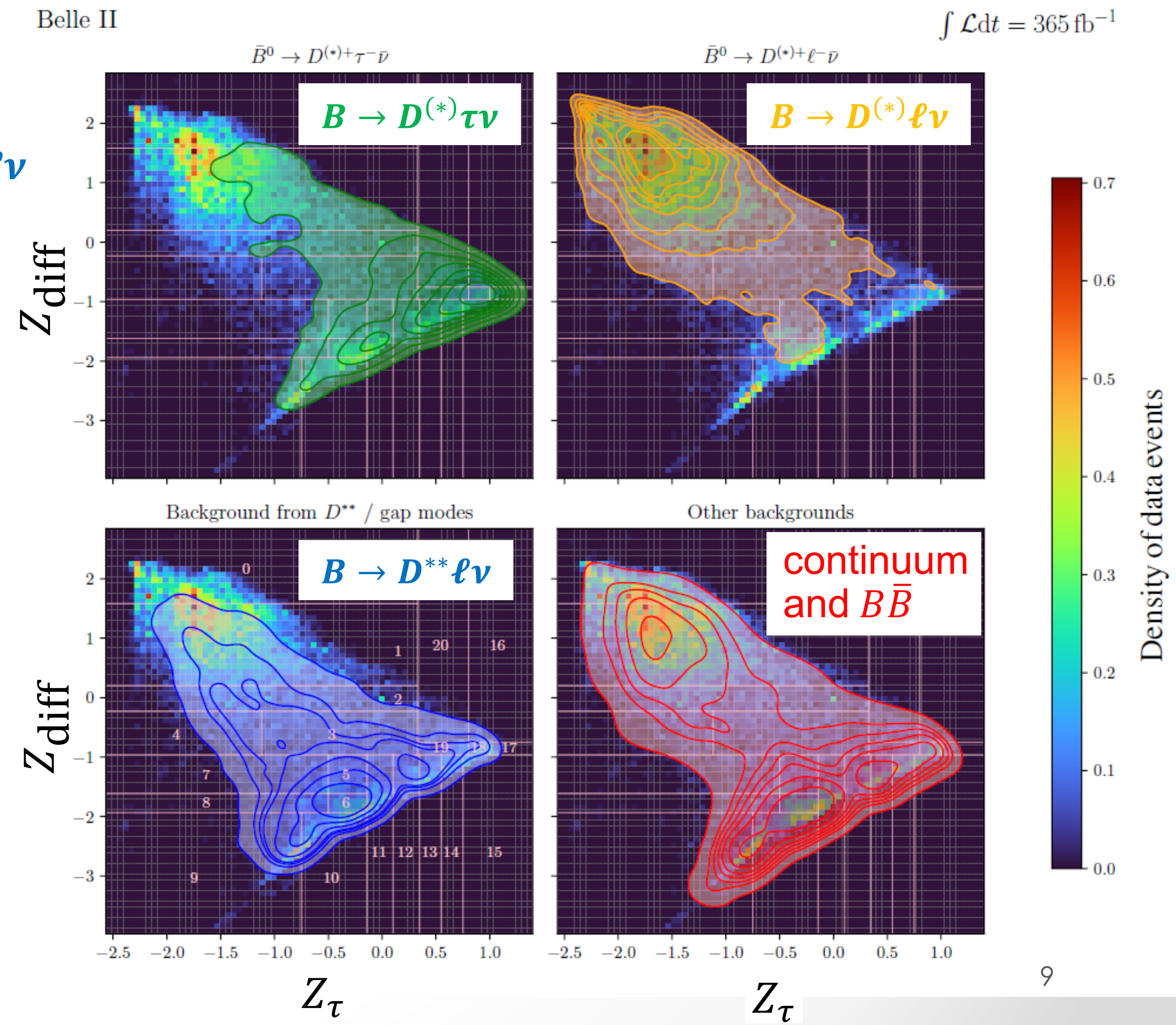
BDT used to separate events

- Semitauonic signal events : $B \to D^{(*)}\tau\nu$
- Semileptonic events $B \to D^{(*)}\ell\nu$ and $B \to D^{**}\ell\nu$
- Background events: continuum and $B\bar{B}$

- Trained on 5 input variables
  - 2 specific decay angle correlations to semileptonic decays
  - Extra energy in the calorimeter
  - Signal side D and lepton momentum

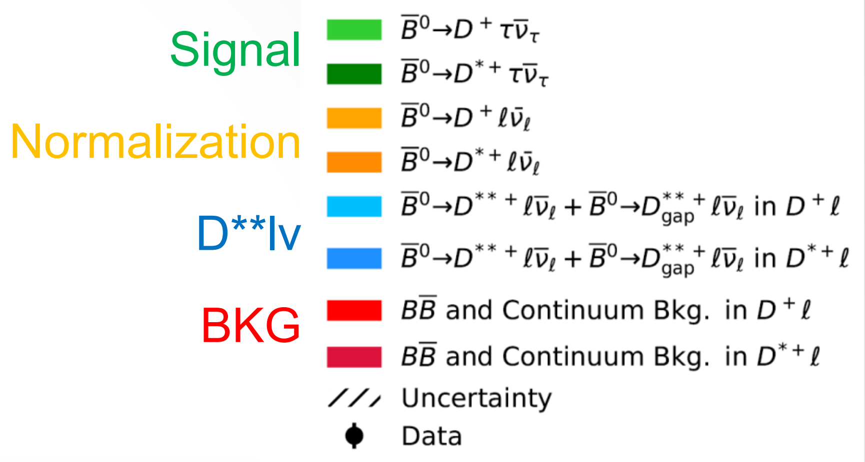
- Output for each event: $Z_\tau, Z_\ell, Z_{\text{bkg}}$

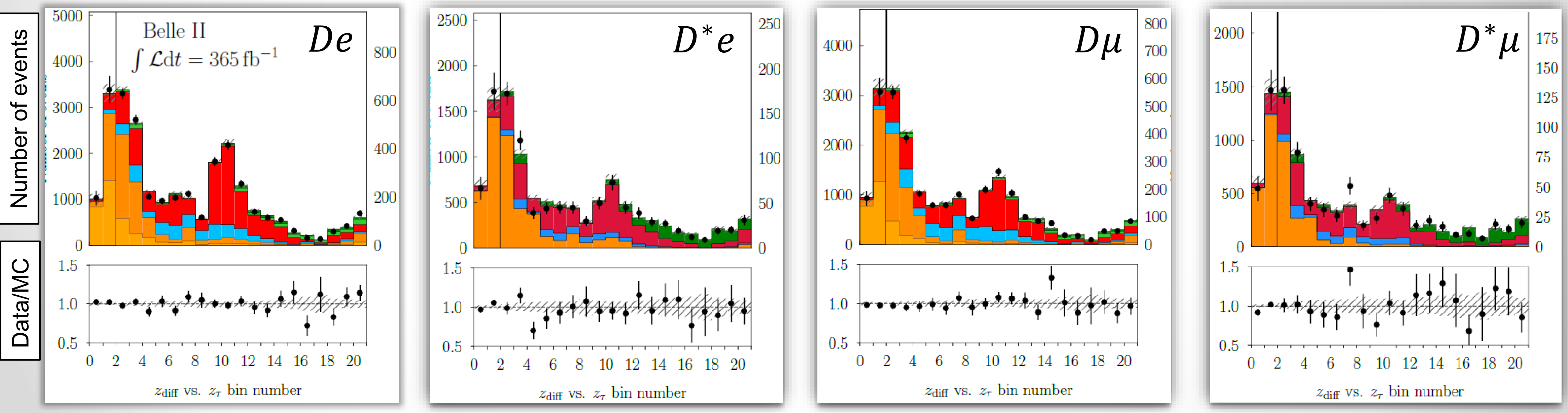
→ Use $Z_\tau, Z_{\text{diff}} \equiv Z_\ell - Z_{\text{bkg}}$ for the signal extraction



$B^0 \to D^{(*)}\tau\nu$ Signal Extraction Fit

- Fit is performed over 4 channels :$De, D^*e, D\mu, D^*\mu$
- 2D binned likelihood fits to Z_τ and Z_{diff} → projected to 1D
  - X=0,1 → large normalization events → left axis
  - Larger X → semitauonic signals → right axis
- 10 fit parameters : 2 signal, 2 normalization, 6 background



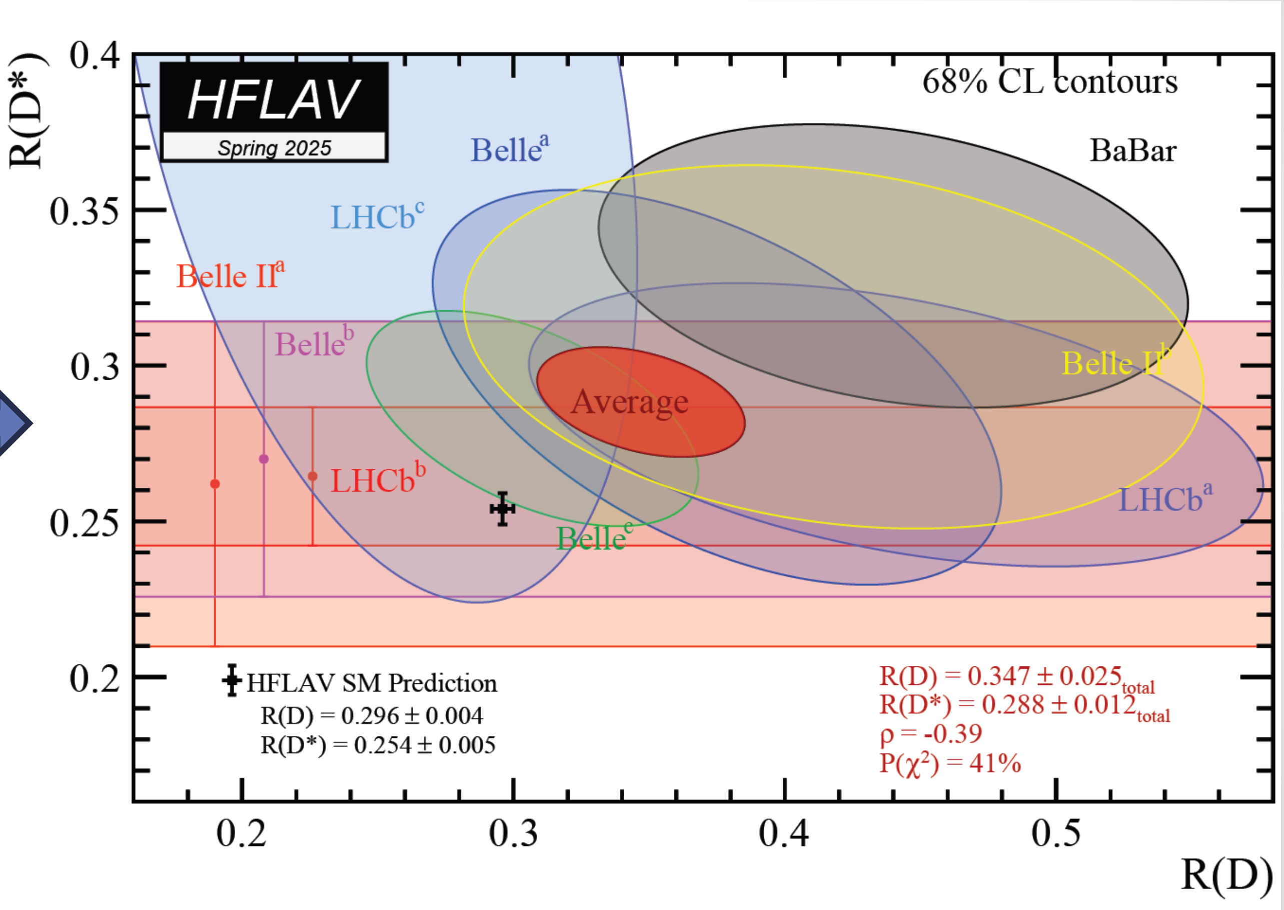


$B^0 \to D^{(*)}\tau\nu$ $R(D^{(*)})$ Results

First Belle II R(D$^{(*)}$) Results with semileptonic tag

$$\mathcal{R}(D^+) = 0.418 \pm 0.074(\text{stat}) \pm 0.051(\text{syst})$$
$$\mathcal{R}(D^{*+}) = 0.306 \pm 0.034(\text{stat}) \pm 0.018(\text{syst})$$

The tension between the R(D$^{(*)}$) measurements and the SM increases from 3.3σ to 3.8σ.



Also measured semi-electric to semi-muonic ratio

$$\mathcal{R}(D^+_{e/\mu}) = 1.07 \pm 0.05(\text{stat}) \pm 0.02(\text{syst})$$
$$\mathcal{R}(D^{*+}_{e/\mu}) = 1.08 \pm 0.04(\text{stat}) \pm 0.02(\text{syst})$$

consistent with 1 in 1.2 and1.6 σ

$B^0 \to K^{*0}\tau\tau$ with Hadronic Tag at Belle II

[arXiv:2504.10042], submitted to PRL

- b→s penguin and box diagrams
- SM Prediction (0.98±0.10) x 10^{-7}

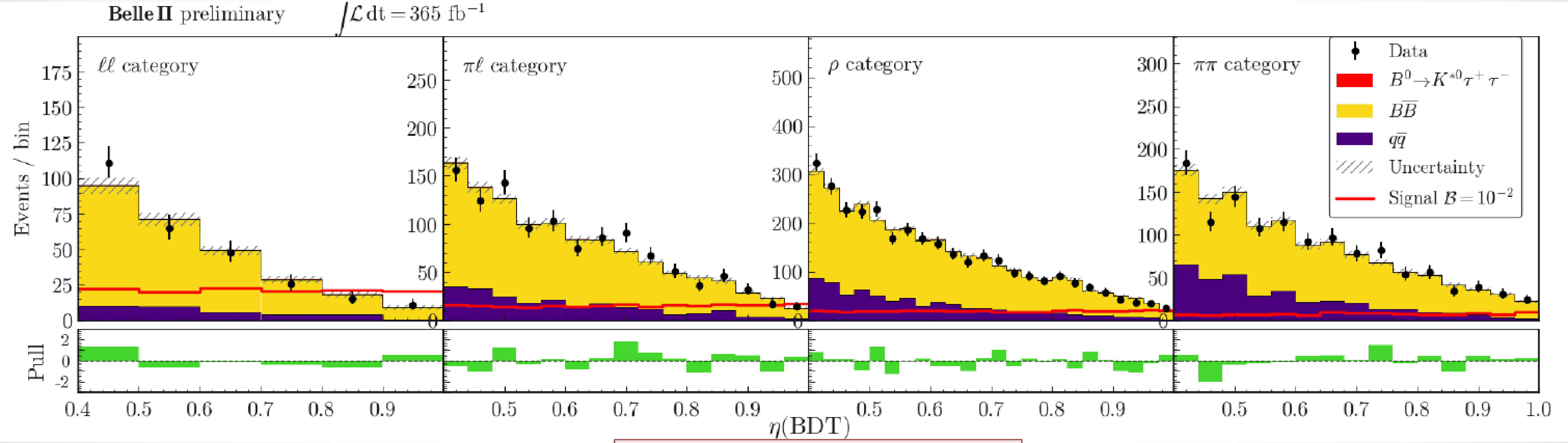
[J. L. Hewett, Phys. Rev. D 53, 4964 (1996), B. Capdevila et al., Phys. Rev. Lett. 120, 181802 (2018)]

- 365fb^{-1} Belle II data
- Hadronic FEI Tag
- One prong tau decays: $\tau \to e\bar{\nu}_e\nu_\tau\ ,\ \mu\bar{\nu}_\mu\nu_\tau\ ,\ \pi\nu_\tau\ ,\ \rho\nu_\tau(\rho \to \pi\pi^0)$
- $K^{*0} \to K^+\pi^-$
- Previous result: Belle 711fb^{-1} $\mathcal{B}(B^0 \to K^{*0}\tau\tau) < 3.1 \times 10^{-3}$ (90% $C.L.$)

[Phys. Rev. D **108**, L011102 (2023)]

$B^0 \to K^{*0}\tau\tau$ Result

- Fit BDT Output to extract signals
  - Event shape variables
  - q^2, kinematics of K* and τ candidates
  - Missing energy and momentum, extra energy in calorimeter
- Calibration by control samples such as off-resonance data, B→K*J/ψ events
- Separate events in 4 categories depending $\tau\tau$ daughters
  - $\ell\ell$, $\pi\ell$, ρ + anything, $\pi\pi$



No significant signal → set upper limit (90% C.L.)

$$\mathcal{B}(B^0 \to K^{*0}\tau\tau) < 1.8 \times 10^{-3}$$

Most stringent upper limit, with **factor 2 improved sensitivity** compared to the previous Belle analysis (thanks to FEI and BDT selections)

$B^0 \to K_S^0 \tau \ell$ and $B^0 \to K^{*0} \tau \ell$ with Hadronic Tag at Belle + Belle II

[arXiv:2412.16470 ($K^0 \tau \ell$)], accepted by PRL
[arXiv:2505.08418 ($K^{*0} \tau \ell$)], accepted by JHEP

- b→s lepton flavor violation
- Combine Belle and BelleII Data
  - 711fb^{-1} Belle
  - 365fb^{-1} Belle II
- Hadronic FEI Tag
- Tau candidate: require one charged track
  - For $K_S^0 \tau \ell$, e, μ, π, ρ(→ππ^0) for one prong τ decays
  - For $K^{*0} \tau \ell$, no explicit particle ID required
- $K_S^0 \to \pi^+ \pi^-$, $K^{*0} \to K^+ \pi^-$

- Previously published results:
  - BaBar $B^+ \to K^+ \tau \ell$ upper limits at [1.5, 4.5] x 10^{-5} [PRD 86, 012004 (2012)]
  - Belle $B^+ \to K^+ \tau \ell$
    most stringent upper limit for $B^+ \to K^+ \tau^+ \mu^-$ at 6×10^{-6} [PRL130, 261802 (2023)]
  - LHCb $B^+ \to K^{*0} \tau \mu$ upper limits at [0.8,1.0] x 10^{-5} [JHEP 06 2023 143]

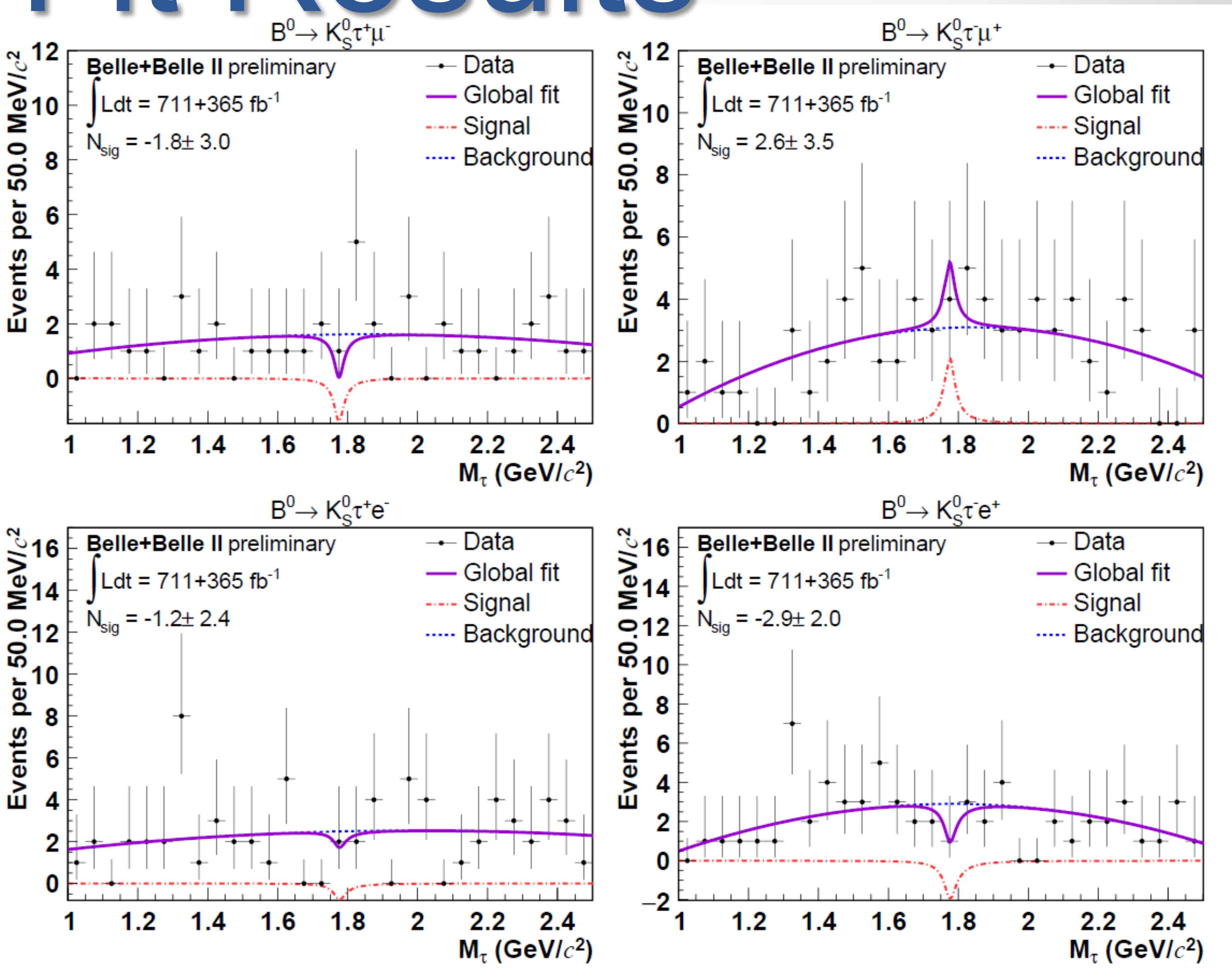
(LHCb reported (preliminary) world best upper limit of $B^0 \to K^{*0} \tau e$ at Moriond 2025 [arXiv:2506.15347])

$B^0 \to K_S^0 \tau \ell$ Fit Results

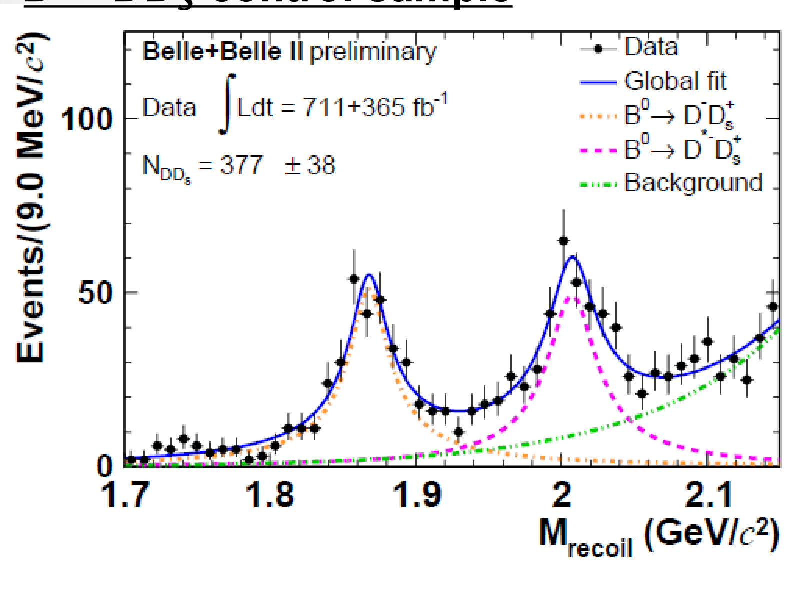
- Signal is exracted by fit to the recoiling τ mass

$$M_\tau^2 = (E_{e^+e^-} - p_\ell - p_{K_S^0} - p_{B_{tag}})^2$$

- Calibration by recoiling D mass in $B \to DD_S$ control sample



$B \to DD_S$ control sample



No significant signal → set upper limits (90% C.L.)

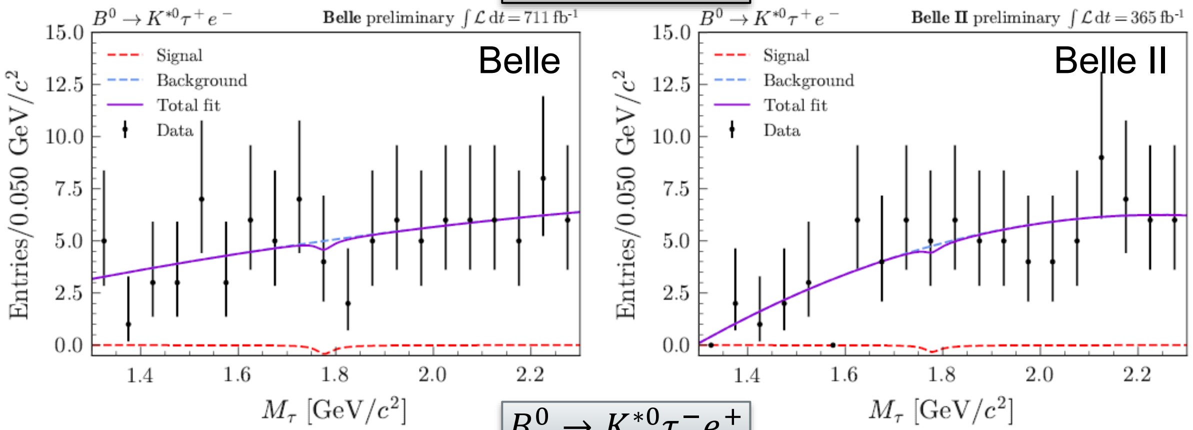
$$\mathcal{B}(B^0 \to K_S^0 \tau^+ \mu^-) < 1.1 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K_S^0 \tau^- \mu^+) < 3.6 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K_S^0 \tau^+ e^-) < 1.5 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K_S^0 \tau^- e^+) < 0.8 \times 10^{-5}$$

First in $B^0 \to K_S \tau l$
Best limit for b→sτe

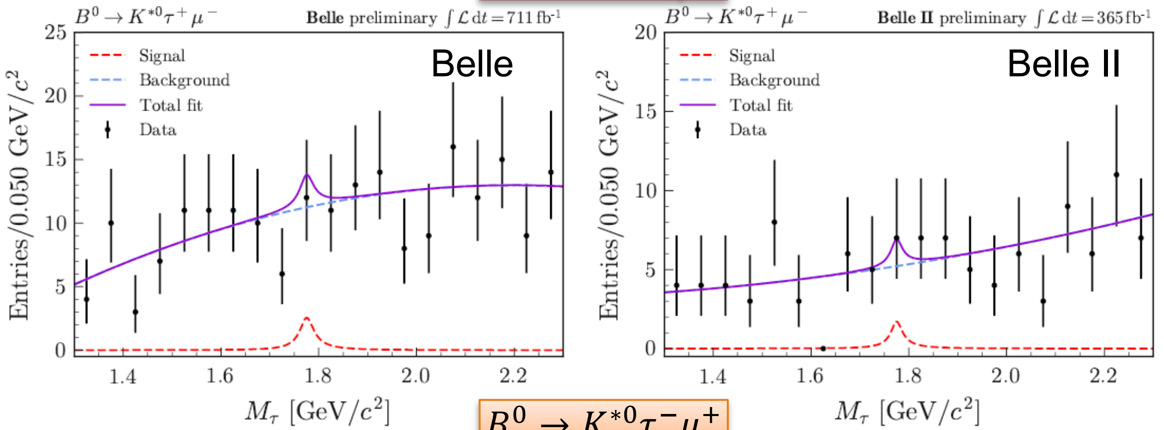
$B^0 \to K^{*0}\tau\ell$ Fit Results

- Simultaneous fit of Belle and Belle II data

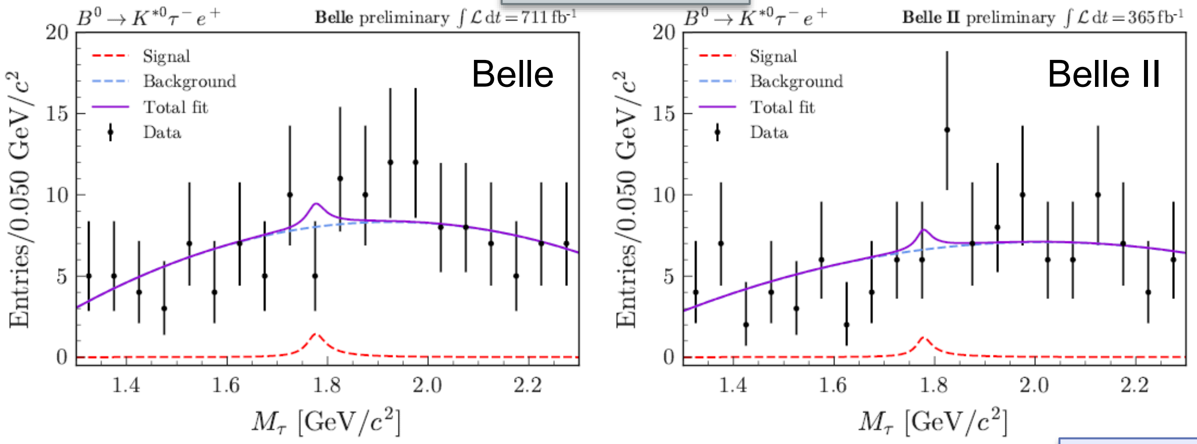
$B^0 \to K^{*0}\tau^+e^-$



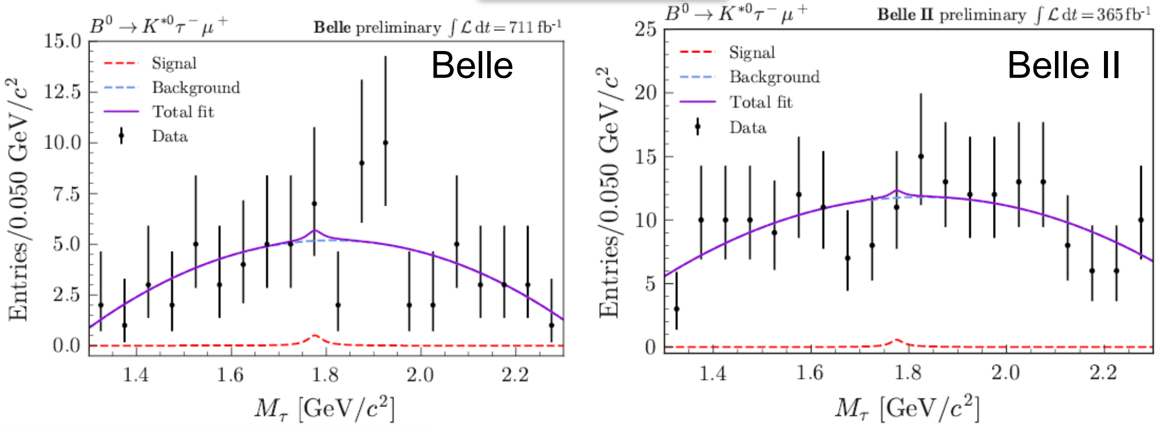
$B^0 \to K^{*0}\tau^+\mu^-$



$B^0 \to K^{*0}\tau^-e^+$



$B^0 \to K^{*0}\tau^-\mu^+$



No significant signal → set upper limits (90% C.L.)

$$\mathcal{B}\left(B^0 \to K^{*0}\tau^+e^-\right) < 2.9 \times 10^{-5}$$
$$\mathcal{B}\left(B^0 \to K^{*0}\tau^-e^+\right) < 6.4 \times 10^{-5}$$
$$\mathcal{B}\left(B^0 \to K^{*0}\tau^+\mu^-\right) < 4.2 \times 10^{-5}$$
$$\mathcal{B}\left(B^0 \to K^{*0}\tau^-\mu^+\right) < 5.6 \times 10^{-5}$$

First at B-factory in $B^0 \to K^{*0}\tau\ell$

Search for $B^0 \to X_s\, \nu\bar{\nu}$ with Hadronic Tag at Belle II

- Inclusive b→s decays → Sensitive to the different NP parameters [T. Felkl et al., JHEP 12, 118 (2021)]
- SM Prediction $(2.9 \pm 0.3) \times 10^{-5}$ [A. J. Buras et al., JHEP 02, 184 (2015)]
- Previous result: ALEPH, $\mathcal{B}(b \to s\nu\bar{\nu}) < 6.4 \times 10^{-4}$ $(90\%\ C.L.)$ [Eur. Phys. J. C 19, 213 (2001)]
- $365\,\mathrm{fb}^{-1}$ Belle II data
- Hadronic FEI Tag

$B^0 \to X_s \nu\bar{\nu}$ Results

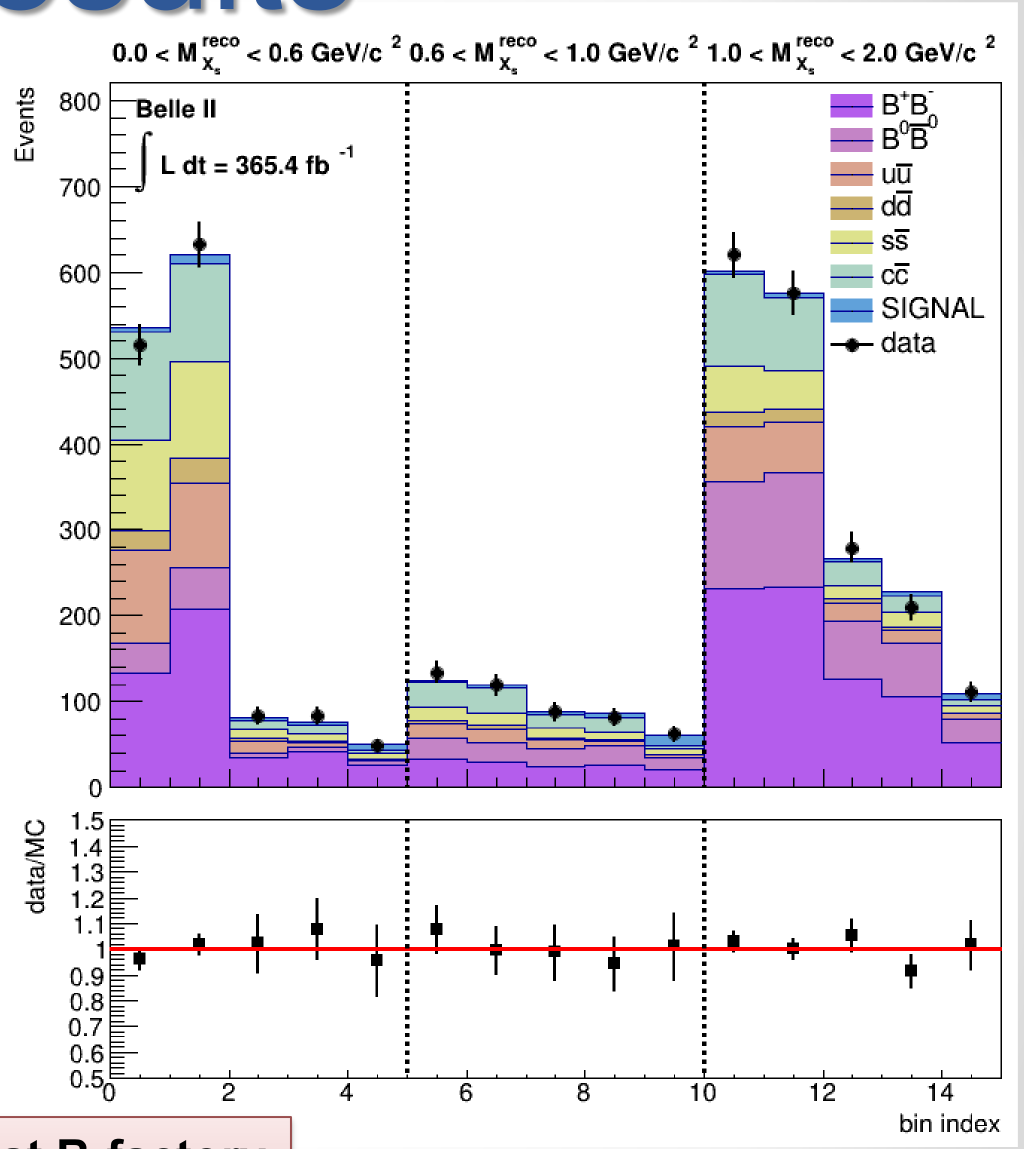
- X_S reconstructed in 30 decay modes:
  K, Kπ, K2π, K3π, K4π, 3K, 3Kπ
  covers 93% of the inclusive modes
- Requires no remaining particles
- Background suppression by BDT
- Fit the BDT output in 3 M_{X_S} regions

no significant signal → set upper limits (90% C.L.)

$$\mathcal{B}(B^0 \to X_S\nu\bar{\nu}) < \begin{cases} 2.5 \times 10^{-5} & (0.0 < M_{X_S} < 0.6\ \mathrm{GeV}/c^2) \\ 1.0 \times 10^{-4} & (0.6 < M_{X_S} < 1.0\ \mathrm{GeV}/c^2) \\ 3.5 \times 10^{-4} & (1.0\ \mathrm{GeV}/c^2 < M_{X_S}) \end{cases}$$

For entire M_{X_S} region

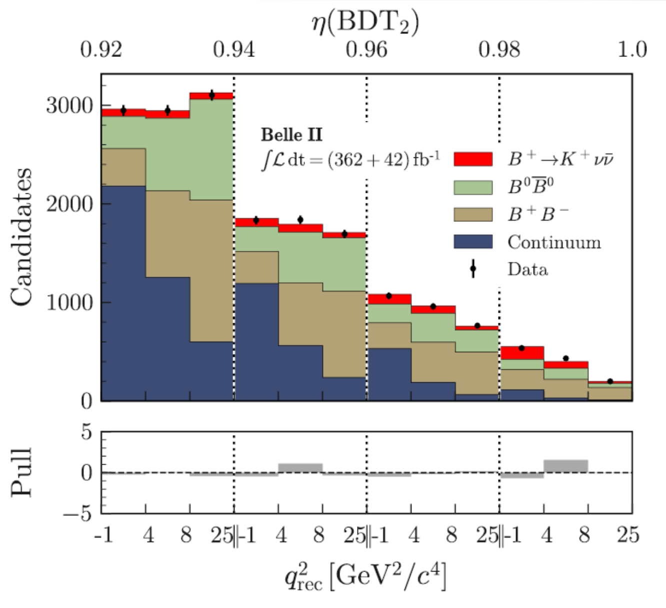
$$\mathcal{B}(B^0 \to X_S\nu\bar{\nu}) < 3.6 \times 10^{-4}$$



World best limit and first at B-factory
Compatible with the hadronic tagged contribution to Belle II $B^+ \to K^+\nu\bar{\nu}$

Reinterpretation of $B^+ \to K^+\nu\bar{\nu}$

[arXiv:2507.12393], submitted to PRD



Belle II Inclusive + Hadronic Tag Analysis Result

$$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = [2.3 \pm 0.5(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})] \times 10^{-5}$$

3.5σ above the bkg-only hypothesis
2.7σ above the SM prediction

SM shape is assumed → How to interpret it in the new physics models?

Reinterpretation with model-agnostic likelihoods

based on [L. Gärtner et al., Eur. Phys. J. C 84, 693 (2024)]

- Number density for SM: $n_0(x) = L \int \varepsilon(x|q^2)\sigma_0(q^2)dq^2 \to \sum_{q^2 bins} n_{0,q^2}(x)$,

$$\begin{cases} x = \text{fitting variable} \\ \varepsilon = \text{efficiency} \\ \sigma_0 = \text{cross section density} \\ L = \text{luminosity} \end{cases}$$

← Model dependent

- Number density for alternative model: $n_1(x) = \sum_{q^2 bins} n_{0,q^2}(x)\, w(q^2)$, $w(q^2) = \sigma_1(q^2)/\sigma_0(q^2)$

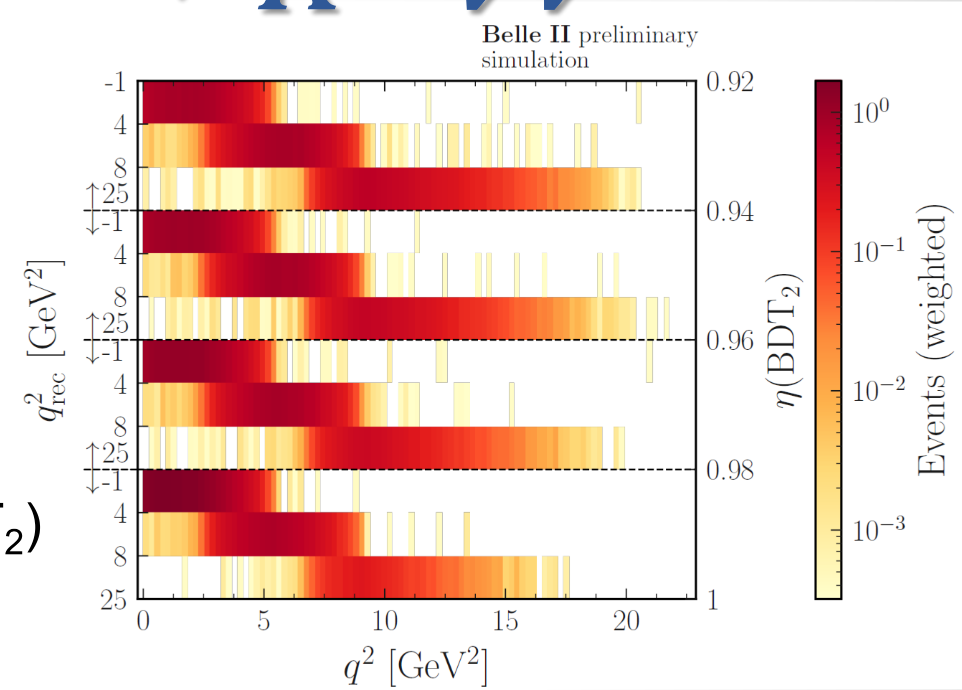
Application to $B^+ \to K^+ \nu\bar{\nu}$

<u>**Number density for the alternative model:**</u>

$$n_1(x) = \sum_{q^2 bins} n_{0,q^2}(x)\, w(q^2)$$
$$w(q^2) = \sigma_1(q^2)/\sigma_0(q^2)$$

- $n_{0,q^2}(x)$: calculated for the SM

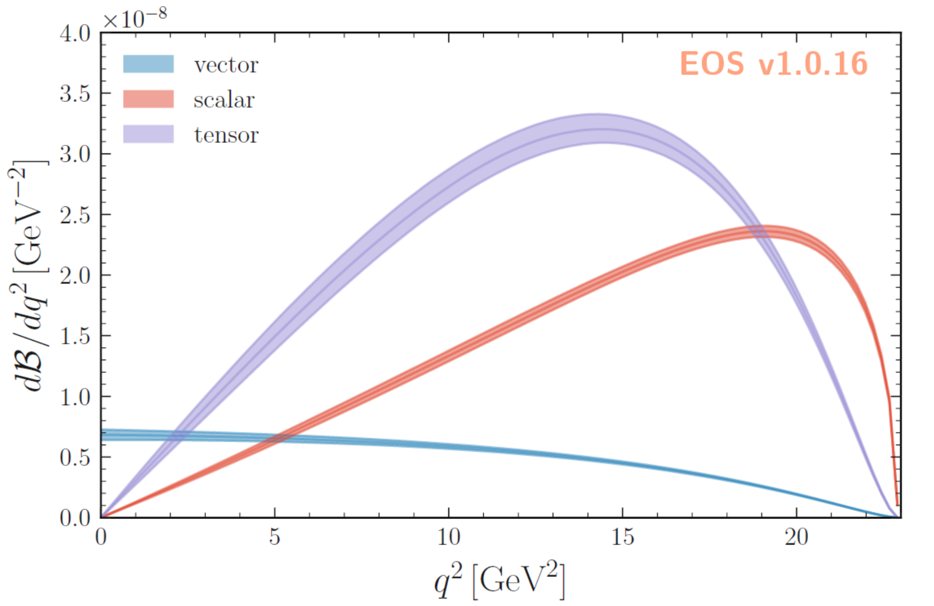
a map for q² → histogram bins of reconstructed q² and η(BDT₂)



- Weight $w(q^2)$ calculated for the NP model

Differential cross section calculated with Weak Effective Theory (WET) including vector, scalar and tensor contributions

(SM: C_{VL} only)



$$\frac{d\mathcal{B}}{dq^2} = \alpha(q^2)|C_{VL} + C_{VR}|^2 + \beta(q^2)|C_{SL} + C_{SR}|^2 + \gamma(q^2)|C_{TL}|^2$$

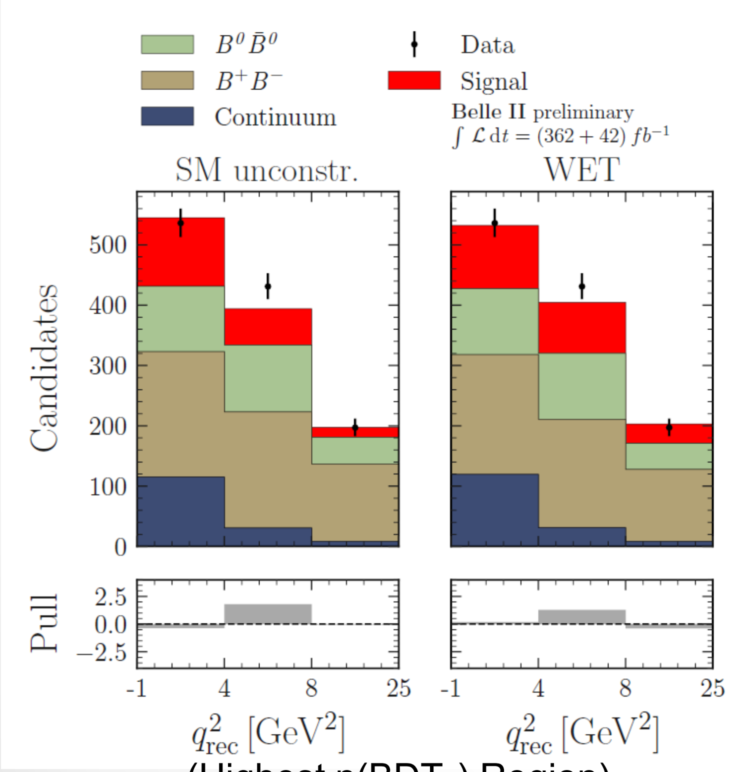
NP Interpretation of $B^+ \to K^+ \nu \bar{\nu}$

- Fit with the reweighted number density

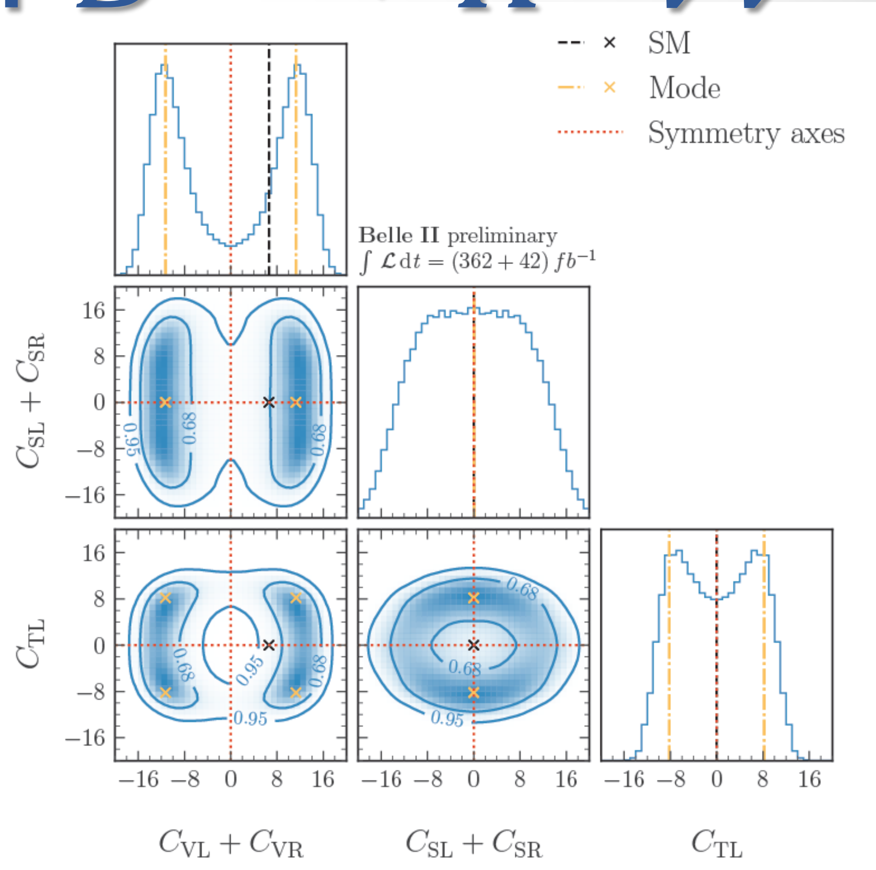
  Three parameters of interest (taken as real) :

$$C_{VL} + C_{VR} \,,\ C_{SL} + C_{SR} \,,\ C_{TL}$$

- 3.3σ significance v.s. bkg only



(Highest η(BDT_2) Region)



Vector + Tensor solution is preferred

Parameters	Mode	68% HDI	95% HDI
$\lvert C_{VL} + C_{VR}\rvert$	11.3	[7.82, 14.6]	[1.86, 16.2]
$\lvert C_{SL} + C_{SR}\rvert$	0.00	[0.00, 9.58]	[0.00, 15.4]
$\lvert C_{TL}\rvert$	8.21	[2.29, 9.62]	[0.00, 11.2]

The necessary information for reinterpretation with any NP model will also be published on HEPData.

Summary

- Anomaly in R(D*) and R(D) and large $B \to K\nu\bar{\nu}$ signal

→ Correlated NP may be in $B \to D^{(*)}\tau\nu$ and $b \to s$ penguin decays

New results from Belle+BelleII with analyses with the improved sensitivity are reported.

- Tension in $R(D^{(*)})$ increased to 3.8 σ by adding the BelleII semileptonic tag results
- Searches for b→s penguin decays with τ and ν
  - Best upper limit of $B^0 \to K^*\tau\tau$
  - First search of $B^0 \to K_S^0\tau\ell$
  - First search at B-factories of $B^0 \to K^{*0}\tau\ell$
  - Best upper limit of $B^0 \to X_S\nu\bar{\nu}$

- Reinterpretation of $B^+ \to K^+\nu\bar{\nu}$ with New Physics by WET calculation is performed
  - Vector + Tensor solution is preferred.
  - The tools for further reinterpretation with other any NP possibilities will be provided.

More results will come with increasing Belle II data

$B^0 \to D^{(*)}\tau\nu$ $R(D^{(*)})$ Syst. Errors

- Multiplicatives are small

→ cancel by taking Ratio

- MC sample size is the largest source
- B→$D^{**}\ell\nu$ understanding (written as "Gap B")

and the semileptonic/tauonic form factors are the next largest

TABLE I. Systematic uncertainties on $\mathcal{R}(D^+)$ and $\mathcal{R}(D^{*+})$ ranked by the magnitude of the uncertainty on $\mathcal{R}(D^+)$. The percentage values in brackets indicate the relative uncertainty.

Systematic Uncertainty	$\Delta\mathcal{R}(D^+)$	$\Delta\mathcal{R}(D^{*+})$
Additive		
MC sample size	0.033 (8.0%)	0.014 (4.7%)
Gap $\mathcal{B}$	0.027 (6.4%)	0.001 (0.1%)
LID efficiency (μ)	0.022 (5.1%)	0.001 (0.1%)
Fake rates (e)	0.012 (2.9%)	0.003 (0.9%)
$\pi^\pm$ from $D^* \to D\pi$	0.003 (0.7%)	0.001 (0.1%)
Continuum fraction	0.002 (0.6%)	0.001 (0.2%)
$\overline{B} \to D^{(*)}\ell\bar{\nu}_\ell$ / $\tau\bar{\nu}_\tau$ FFs	0.002 (0.5%)	0.002 (0.7%)
Gap FFs	0.002 (0.5%)	0.001 (0.2%)
$\mathcal{B}(\overline{B} \to D^{**}\ell\bar{\nu}_\ell)$	0.002 (0.5%)	0.001 (0.1%)
$\overline{B} \to D^{**}\ell\bar{\nu}_\ell$ FFs	0.001 (0.3%)	0.001 (0.2%)
BDT modeling	0.001 (0.3%)	0.001 (0.2%)
LID efficiency (e)	0.001 (0.1%)	0.001 (0.2%)
Fake rates (μ)	0.001 (0.1%)	0.001 (0.1%)
Total Additive Uncertainty	0.050 (12%)	0.015 (4.8%)
Multiplicative		
$\overline{B} \to D^{(*)}\ell\bar{\nu}_\ell$ / $\tau\bar{\nu}_\tau$ FFs	0.009 (2.1%)	0.011 (3.5%)
MC sample size	0.007 (1.7%)	0.004 (1.2%)
LID efficiency (e)	0.001 (0.2%)	0.001 (0.2%)
$\mathcal{B}(\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau)$	0.001 (0.2%)	0.001 (0.2%)
LID efficiency (μ)	0.001 (0.1%)	0.001 (0.1%)
Tracking efficiency	0.001 (0.1%)	0.001 (0.1%)
$\pi^\pm$ from $D^* \to D\pi$	– (–)	0.001 (0.2%)
Total Multiplicative Uncertainty	0.012 (2.8%)	0.011 (3.7%)
Total Syst. Uncertainty	0.051 (12%)	0.018 (6.2%)
Total Stat. Uncertainty	0.074 (18%)	0.034 (11%)
Total Uncertainty	0.090 (22%)	0.039 (13%)

$B^0 \to K^{*0}\tau\tau$ Efficiency and Syst. Errors

Signal efficiencies and expected background yields

Signal category	$\varepsilon \times 10^5$	$B\overline{B}$	$q\bar{q}$
$\ell\ell$	4.0	275	39
$\pi\ell$	7.6	1058	230
ρ	15.5	3279	845
$\pi\pi$	4.0	1077	424

Systematic errors

Source	Impact on $\mathcal{B} \times 10^{-3}$
$B \to D^{**}\ell/\tau\nu$ branching fractions	0.29
Simulated sample size	0.27
$q\bar{q}$ normalization	0.18
ROE cluster multiplicity	0.17
π and K ID	0.14
B decay branching fraction	0.11
Combinatorial $B\overline{B}$ normalization	0.09
Signal and peaking $B^0\overline{B}^0$ normalization	0.07
Lepton ID	0.04
π^0 efficiency	0.03
f_{00}	0.01
$N_{\Upsilon(4S)}$	0.01
$D \to K_L^0$ decays	0.01
Signal form factors	0.01
Luminosity	< 0.01
Total systematics	0.52
Statistics	0.86

$B^0 \to K_S^0 \tau \ell$ Efficiency and Syst. Errors

TABLE I. Efficiencies (ϵ), signal yields ($N_{\rm sig}$) of the data fit, central value of the branching fractions and the observed $\mathcal{B}^{\rm UL}$ at 90% CL. The first uncertainty of the central value is statistical and the second is systematic.

			$\mathcal{B}(10^{-5})$	
Channels	$\epsilon(10^{-4})$	$N_{\rm sig}$	Central value	UL
$B^0 \to K_S^0 \tau^+ \mu^-$	1.7	-1.8 ± 3.0	$-1.0 \pm 1.6 \pm 0.2$	1.1
$B^0 \to K_S^0 \tau^- \mu^+$	2.1	2.6 ± 3.5	$1.1 \pm 1.6 \pm 0.3$	3.6
$B^0 \to K_S^0 \tau^+ e^-$	2.0	-1.2 ± 2.4	$-0.5 \pm 1.1 \pm 0.1$	1.5
$B^0 \to K_S^0 \tau^- e^+$	2.1	-2.9 ± 2.0	$-1.2 \pm 0.9 \pm 0.3$	0.8

Systematic errors

- BDT selections 16-18 %
- Signal PDF 15%
- B_{tag} efficiency 4%
- Fitting procedure 0.8-1.6%
- K_S reconstruction 1.1%
- PID 0.3-1.0%
- π^0 reconstruction 1.3%
- Requirement of no additional π^0 1.0 %
- $N_{B\bar{B}}$ 1.1%
- $f_{+-/00}$ 1.5%
- $\mathcal{B}$ of K_S, τ, ρ, π^0 0.7%

$B \to D_S\ D^-$ sample (applies to BDT selections and Signal PDF)

$B^0 \to K^{*0}\tau\ell$ Efficiency and Syst. Errors

B flavor and ℓ charge relations

$OS\ell :\ B^0 \to K^{*0}\tau^+\ell^-$

$SS\ell :\ B^0 \to K^{*0}\tau^-\ell^+$

Signal efficiencies

	OSe	SSe	$OS\mu$	$SS\mu$
Belle	0.046	0.038	0.052	0.024
Belle II	0.075	0.056	0.060	0.051

Systematic errors

Source	Belle				Belle II			
	OSe	SSe	$OS\mu$	$SS\mu$	OSe	SSe	$OS\mu$	$SS\mu$
FEI efficiency [%]	4.9	4.9	4.9	4.9	6.2	6.1	6.1	6.2
Lepton ID efficiency [%]	2.0	2.4	2.2	2.2	0.7	1.1	0.7	0.6
Hadron ID efficiency [%]	1.9	2.0	1.9	2.0	3.7	3.7	3.6	3.7
BDT efficiency [%]	27	21	18	23	29	31	34	31
Tracking efficiency [%]	1.4				1.1			
Total efficiency [%]	27.6	21.8	18.9	23.7	29.8	31.8	34.7	31.7
Signal PDF μ [%]	0.1				0.2			
Signal PDF λ [%]	21				59			
$N_{\Upsilon(4S)}$ [%]	1.4				1.6			
f^{00} [%]	0.8							
Background PDF ($\times 10^{-5}$)	0.11	0.28	0.09	0.02	0.11	0.28	0.09	0.02
Total impact on UL ($\times 10^{-5}$)	0.3	0.9	0.4	0.5	0.3	0.9	0.4	0.5

$B^0 \to X_s \nu\bar{\nu}$ Efficiency and Syst. Errors

Explicit 30 Decay modes

	$B^0\bar{B}^0$			$B^\pm$		
K	K_S^0			$K^\pm$		
$K\pi$	$K^\pm\pi^\mp$	$K_S^0\pi^0$		$K^\pm\pi^0$	$K_S^0\pi^\pm$	
$K2\pi$	$K^\pm\pi^\mp\pi^0$	$K_S^0\pi^\pm\pi^\mp$	$K_S^0\pi^0\pi^0$	$K^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^0$	$K^\pm\pi^0\pi^0$
$K3\pi$	$K^\pm\pi^\mp\pi^\pm\pi^\mp$	$K_S^0\pi^\pm\pi^\mp\pi^0$	$K^\pm\pi^\mp\pi^0\pi^0$	$K^\pm\pi^\mp\pi^\pm\pi^0$	$K_S^0\pi^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^0\pi^0$
$K4\pi$	$K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^0$	$K_S^0\pi^\pm\pi^\mp\pi^\pm\pi^\mp$	$K_S^0\pi^\pm\pi^\mp\pi^0\pi^0$	$K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^\pm$	$K_S^0\pi^\pm\pi^\mp\pi^\pm\pi^0$	$K^\pm\pi^\mp\pi^\pm\pi^0\pi^0$
$3K$	$K^\pm K^\mp K_S^0$			$K^\pm K^\mp K^\pm$		
$3K\pi$	$K^\pm K^\mp K^\pm\pi^\mp$	$K^\pm K^\mp K_S^0\pi^0$		$K^\pm K^\mp K^\pm\pi^0$	$K_S^0 K^\pm K^\mp\pi^\pm$	

Branching fractions and efficiencies

			$\mathcal{B}$ $[10^{-5}]$		
M_{X_s} $[\mathrm{GeV}/c^2]$	ϵ	N_{sig}	Central value	$\mathrm{UL_{obs}}$	$\mathrm{UL_{exp}}$
$[0, 0.6]$	0.25%	10^{+18+18}_{-17-16}	$0.5^{+0.9+0.9}_{-0.8-0.8}$	2.5	2.4
$[0.6, 1.0]$	0.11%	36^{+27+31}_{-25-26}	$3.8^{+2.8+3.2}_{-2.6-2.7}$	10.0	7.2
$[1.0, M_{X_s}^{\max})$	0.06%	33^{+44+64}_{-42-53}	$7.2^{+9.6+13.9}_{-9.2-11.6}$	35.3	28.3
Full range	0.11%	80^{+61+93}_{-59-79}	$11.5^{+8.9+13.5}_{-8.5-11.4}$	35.6	27.9

Systematic errors

Source	Uncertainty $[10^{-5}]$
MC statistics	$^{+7.0}_{-5.9}$
Background normalization	$^{+6.2}_{-6.1}$
Branching ratio of major B meson decay	$^{+2.9}_{-2.1}$
Fragmentation	$^{+2.7}_{-1.8}$
Photon multiplicity correction	$^{+2.5}_{-1.8}$
$\mathcal{O}$ selection efficiency	$^{+3.3}_{-0.9}$
Non-resonant $X_s\nu\bar{\nu}$ generation point	$^{+3.3}_{-0.7}$
Other subdominant contributions	$^{+3.7}_{-2.7}$
Total systematic uncertainty	$^{+13.5}_{-11.4}$