$b \to s\ell^+\ell^-(\ell = e, \mu, \tau)$ and $b \to s\nu\bar{\nu}$ at Belle and Belle II

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on behalf of the Belle & Belle II collaborations

Moriond 2026 @ La Thuile, Italy - Mar 16, 2026

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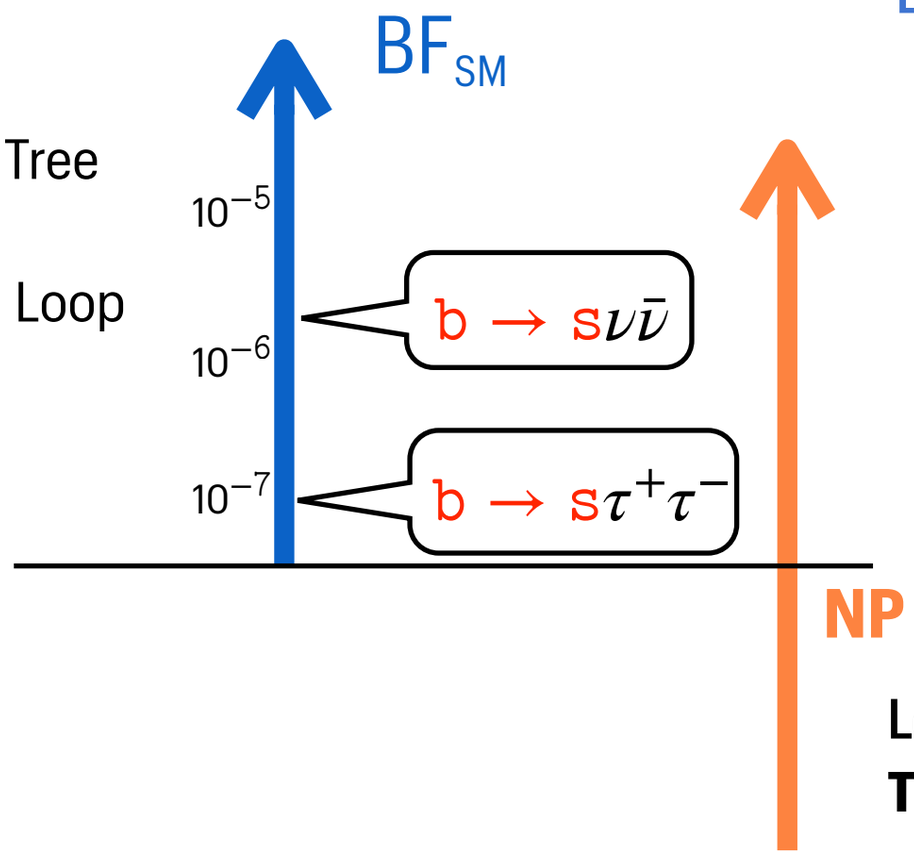
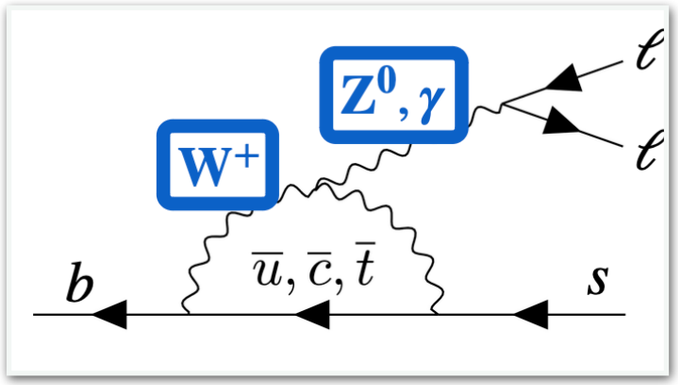
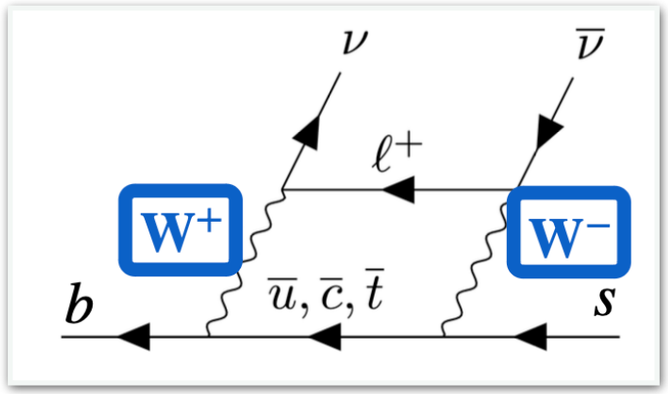
Electroweak Penguin @ B factory

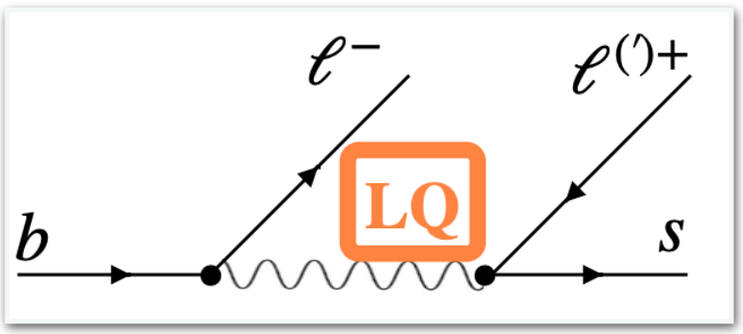


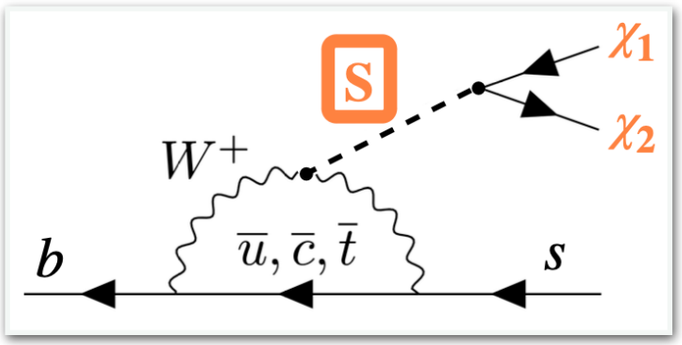
Flavor changing neutral currents **FCNC** occur at **loop level** in the **SM**
Low branching fractions (BF) due to CKM and GIM suppression





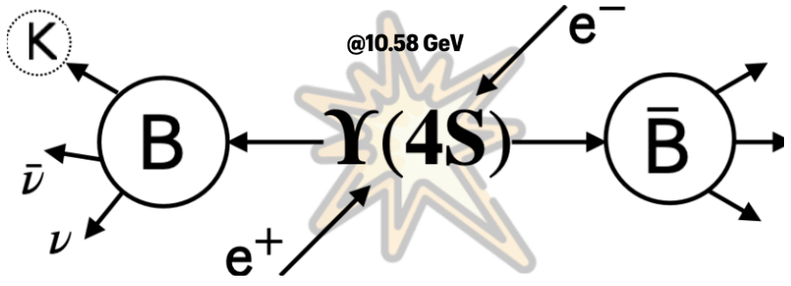
Look for enhancements in FCNC and LFV due to **NP** contributions
Third generation coupling



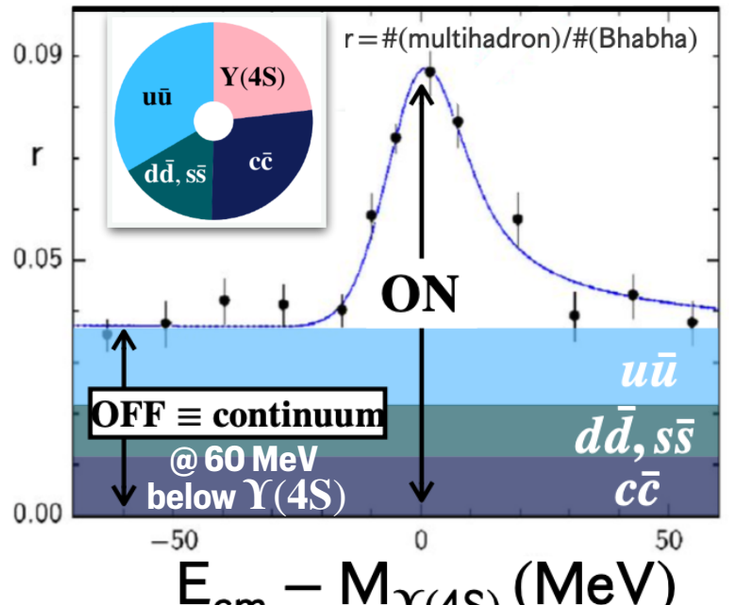


Final states with third-generation leptons are connected to many scenarios explaining the ‘anomalies’
↦ Missing energy!

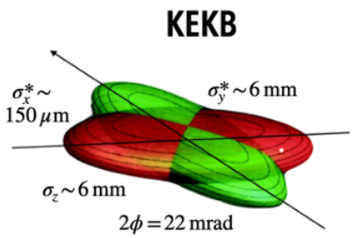
B factory—e^+e^- collision at $\Upsilon(4S)$

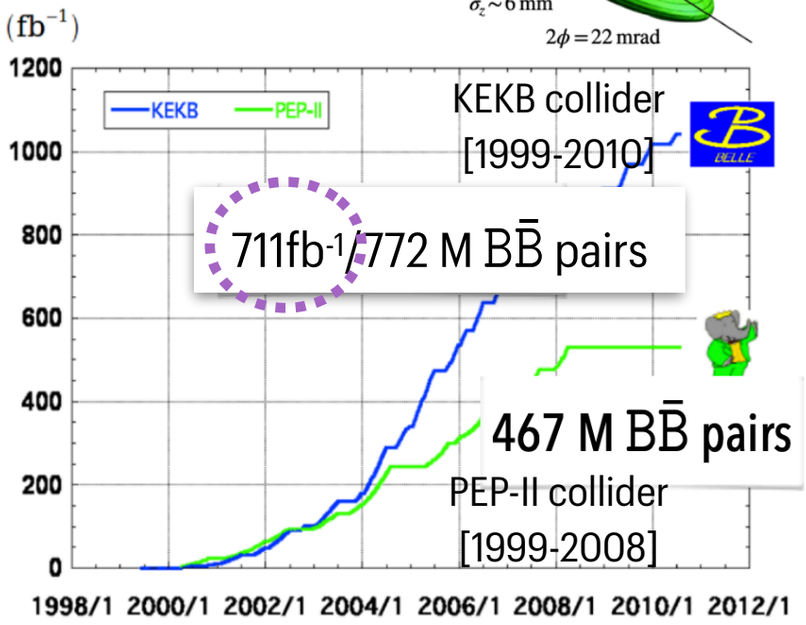


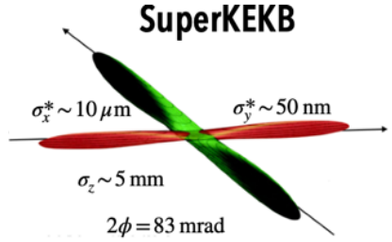
- e^+e^- constrained kinematics and **no other particles** at threshold
- Relatively low-$q\bar{q}$ background → calibrate by off-resonance data
- Good hermeticity → fully reconstruct events with invisible particles

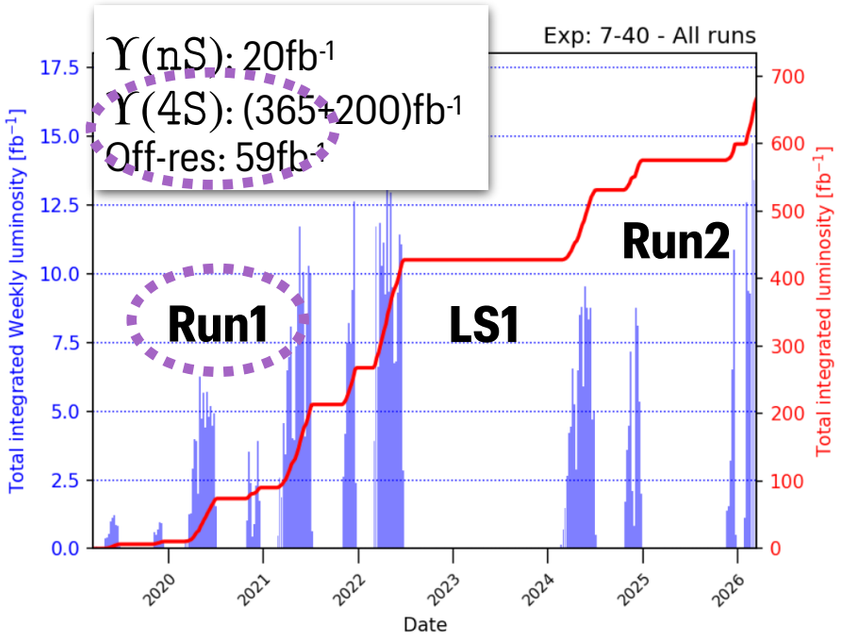


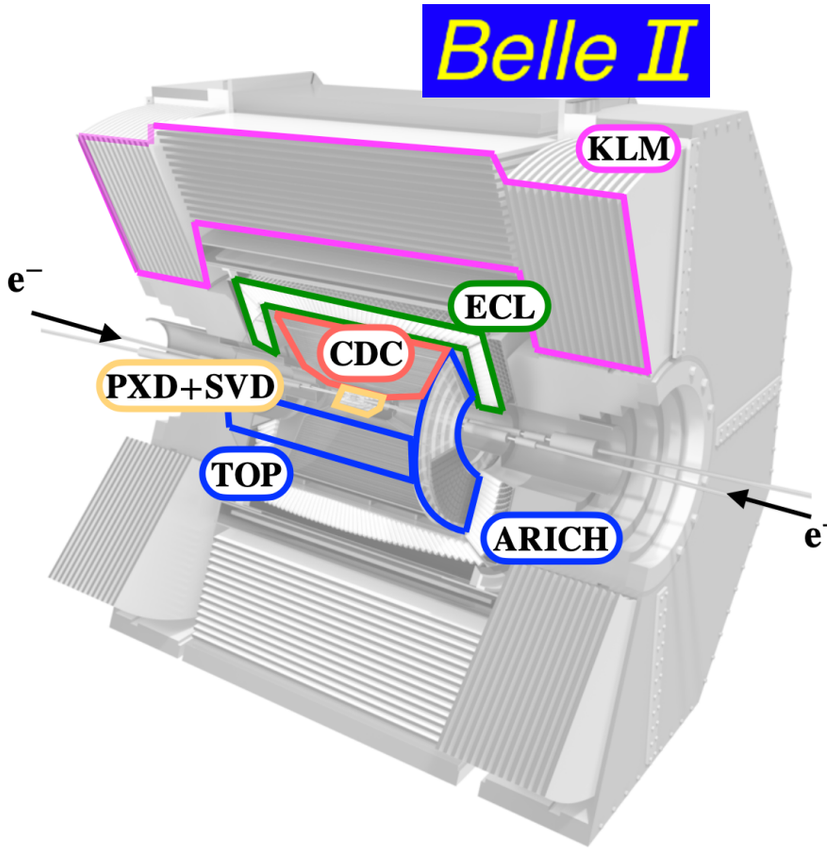
1st generation B factory ⇢ **nanobeam** scheme ⇢ 2nd generation B factory





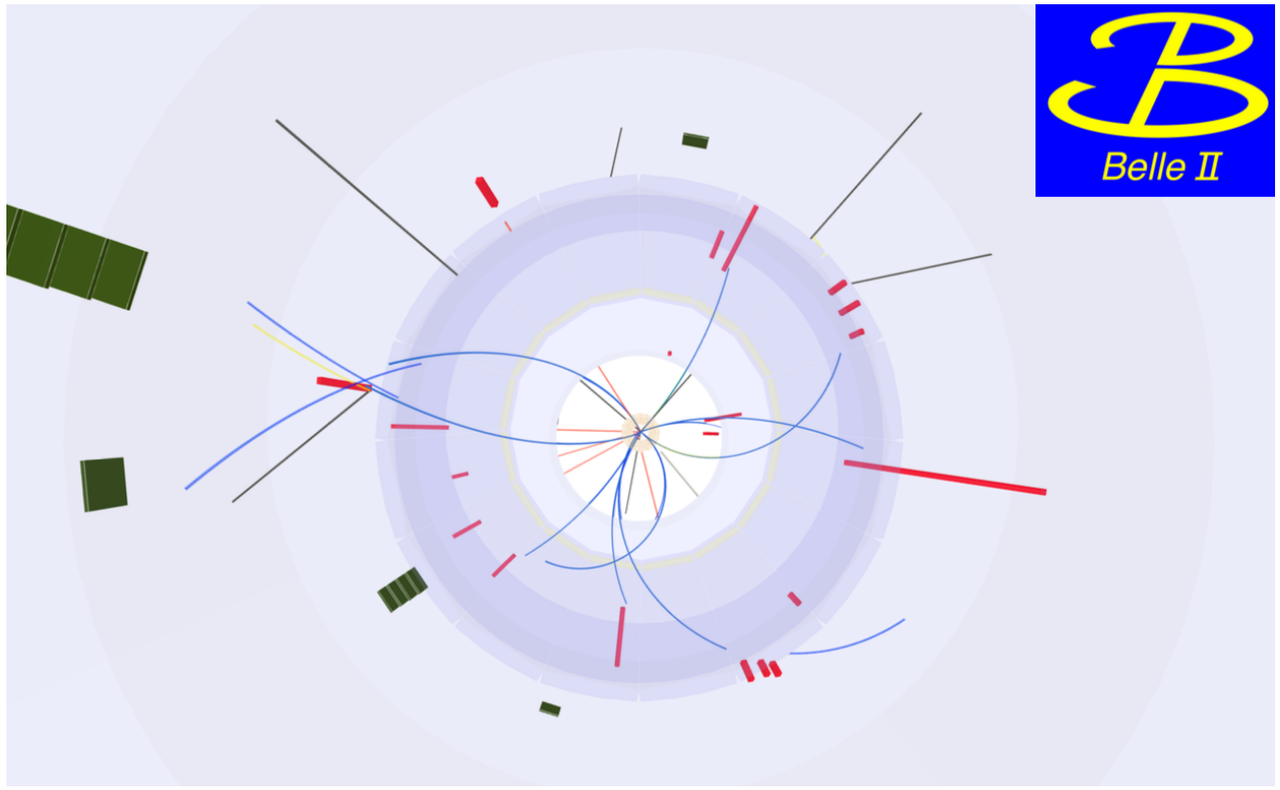






Today's results are based on: Belle + Belle II run 1

Reconstruction



Clean environment

But low *b*-cross section $\sigma(e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}) \approx 1$ nb wrt $\sigma(pp \rightarrow b\bar{b}X)$ at LHC ≈ O(100 μb)

Need high performance from all sub-detectors and optimised analysis strategies

Reconstruction —B_{tag}

Inclusive Tag

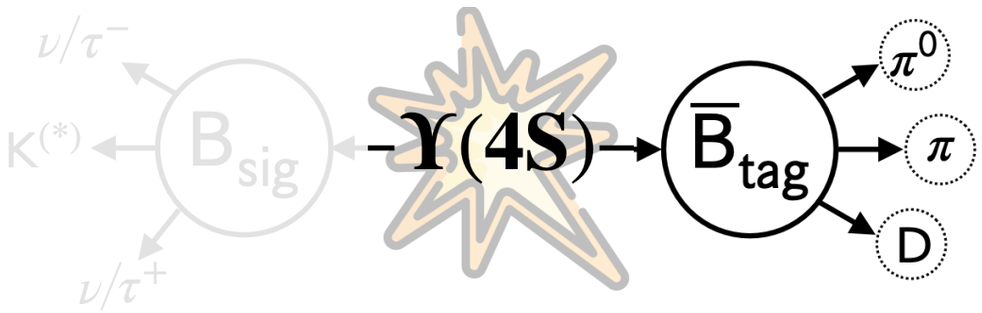
$\epsilon = \mathcal{O}(10)\%$

Efficiency

Purity

Using inclusive properties of B_{tag} to suppress background by exploiting distinct signal features with machine learning

Reconstruction —B_{tag}



Inclusive Tag

$\epsilon = \mathcal{O}(10)\%$

Using inclusive properties of B_{tag} to suppress background by exploiting distinct signal features with machine learning

Efficiency

Purity

Exclusive Tag

$\epsilon = \mathcal{O}(1\text{-}0.1)\%$

Semileptonic tag $D^{(*)}\ell\nu(\pi)$

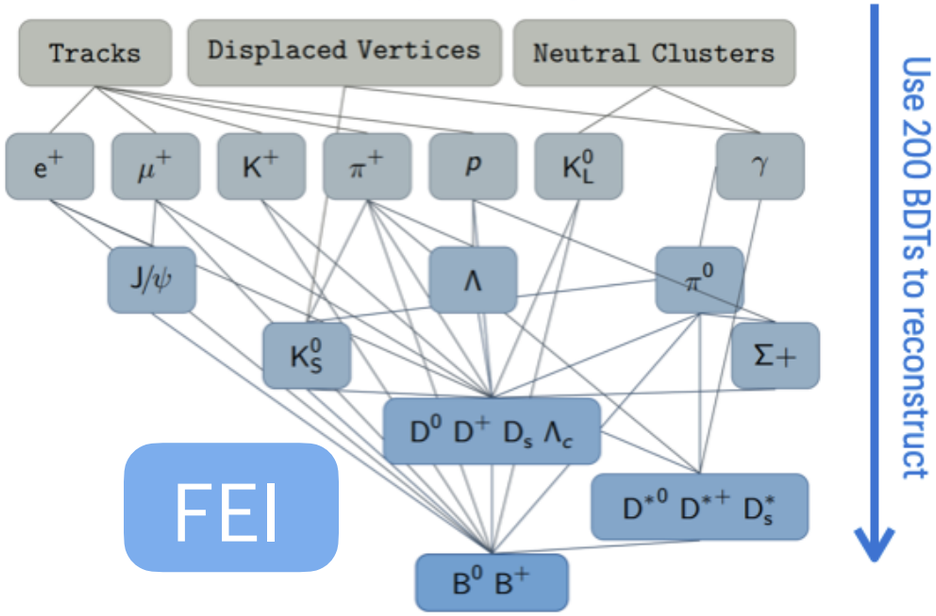
Hadronic tag $D^{(*)}n\pi$, $J/\psi K^{(*)}$,$D^{(*)}D_s^{(*)}$....

Knowledge of B_{tag}

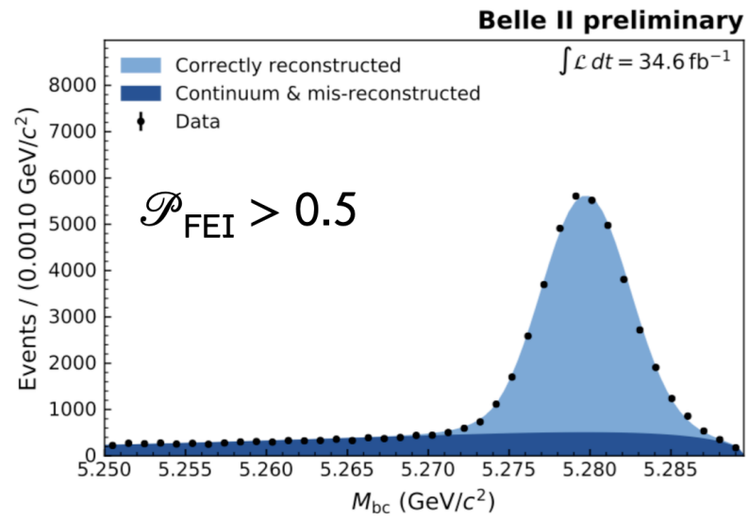
The quality of the *B*-candidate

→ BDT output $\mathscr{P}_{FEI}$

Comput Softw Big Sci 3, 6 (2019)



Use 200 BDTs to reconstruct



$$M_{bc} = \sqrt{(E^*_{beam}/c^2)^2 - (p^*_B/c)^2}$$

$b \to s\ell^+\ell^-(\ell = e, \mu, \tau)$

Focus on $b \to s\tau\tau$

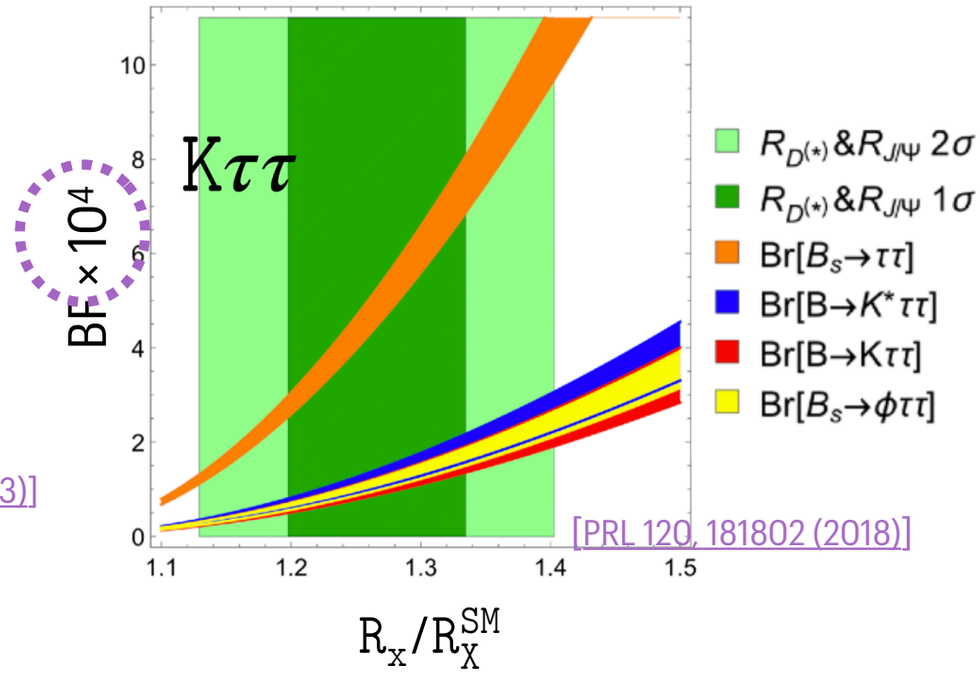
- Belle II can provide distinctive information on $b \to see$ and $b \to s\mu\mu$ using samples more than five times larger than those currently available. [2207.06307]
  - Interesting result on inclusive $B \to X_s \ell\ell, \ell = e, \mu$ and first R_{Xs} measurement will be presented by Zihan

FCNC $b \to s\tau\tau$ involving 3rd generation leptons

$$\mathcal{B}_{SM}(B \to K\tau^+\tau^-) = \sim 10^{-7}$$

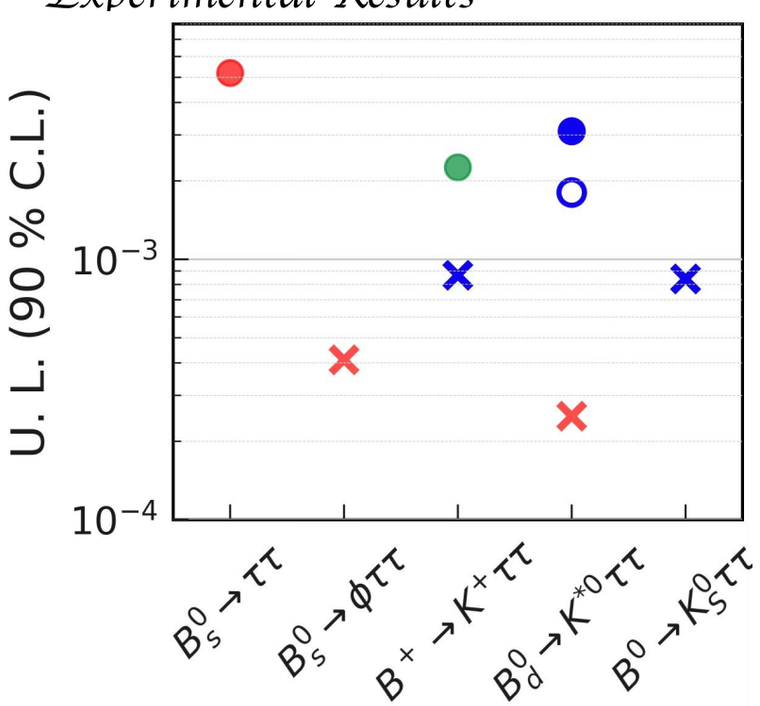
- NP models that accommodate $b \to c\tau\nu$ anomalies predict an **enhancement of $\mathcal{O}(10^2 - 10^3)$**
- Recent $B^+ \to K^+\nu\bar{\nu}$ excess, combined with $R_{D(*)}$ constraints, suggest LFUV in τ's [PLB 848, 138411 (2023)]

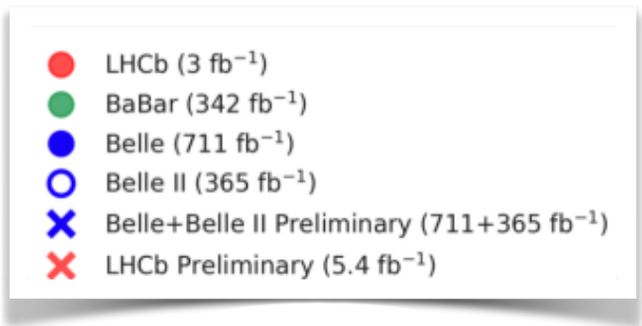
$$\frac{\mathcal{B}(B \to K^{(*)}\tau\tau)}{\mathcal{B}(B \to K^{(*)}\tau\tau)^{SM}} \in [15, 49]$$



[PRL 120, 181802 (2018)]

Experimental Results





[PRL 118 251802(2017)]
[PRL 118 031802(2017)]
[PRD 108 L011102(2023)]
[PRL 135 151801(2025)]
CKM 2025
[2510.13716]

Three results use **hadronic tagging:**

$$B^0 \to K^{*0}\tau^+\tau^-$$
$$B^+ \to K^+\tau^+\tau^-$$
$$B^0 \to K_S^0\tau^+\tau^- \quad \text{NEW!}$$

Focus on $b \to s\tau\tau$

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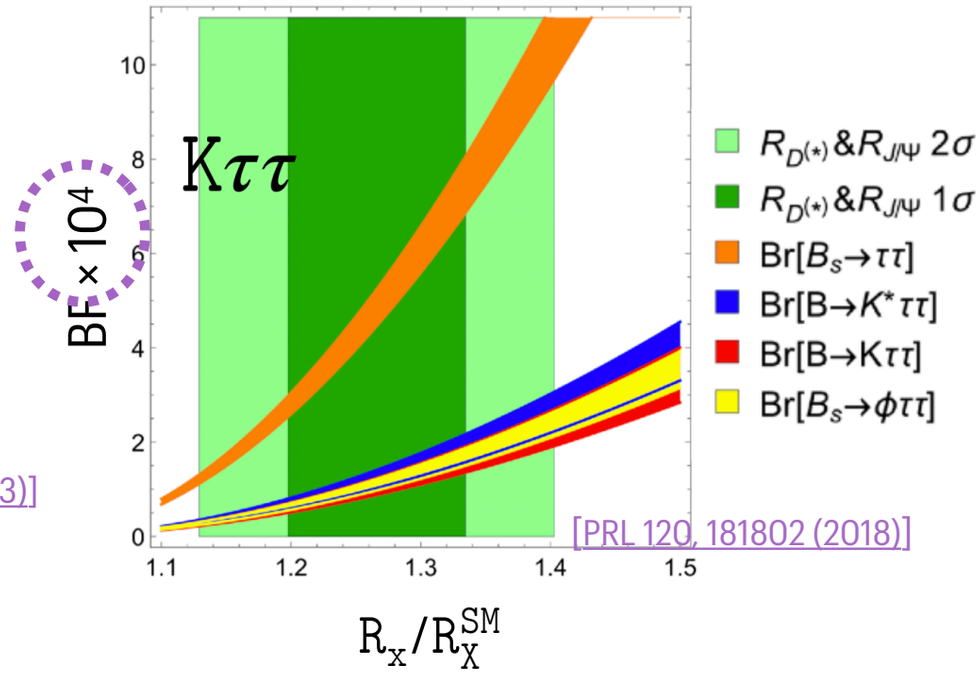
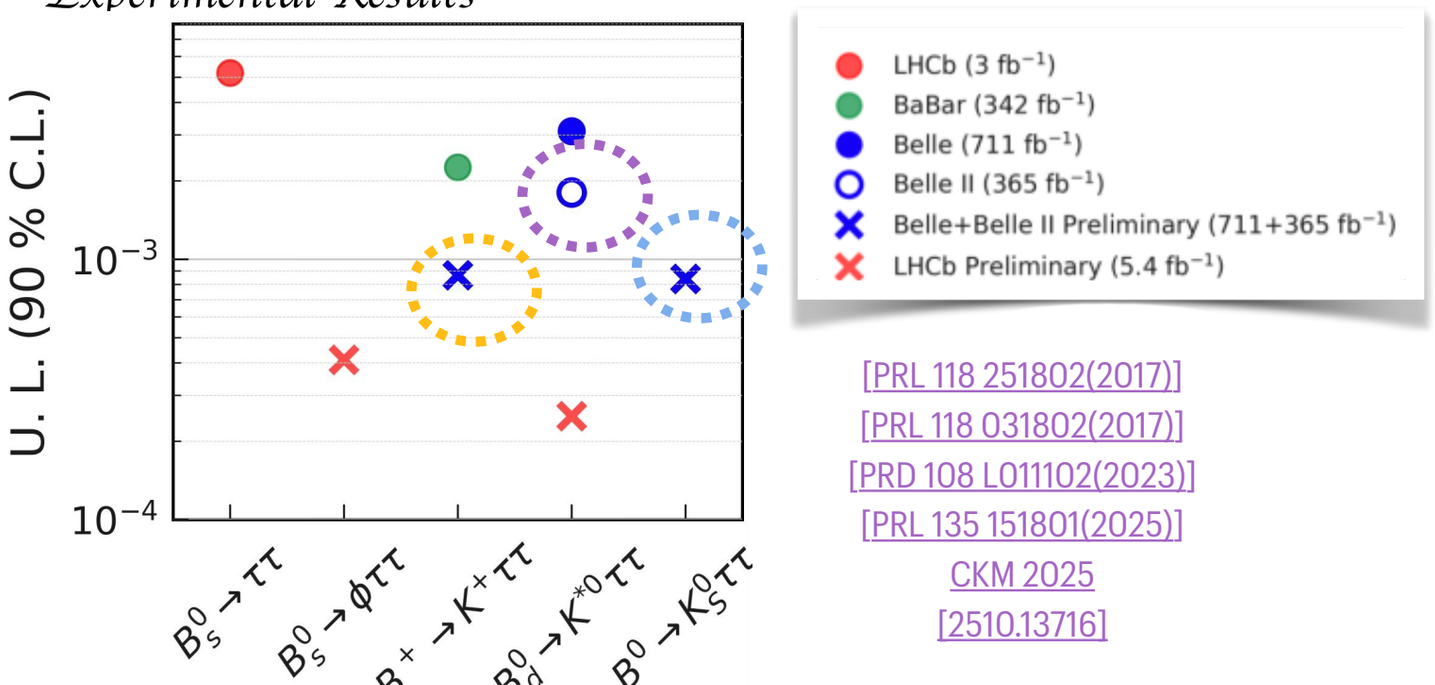


[PRL 120, 181802 (2018)]

Experimental Results



[PRL 118 251802(2017)]
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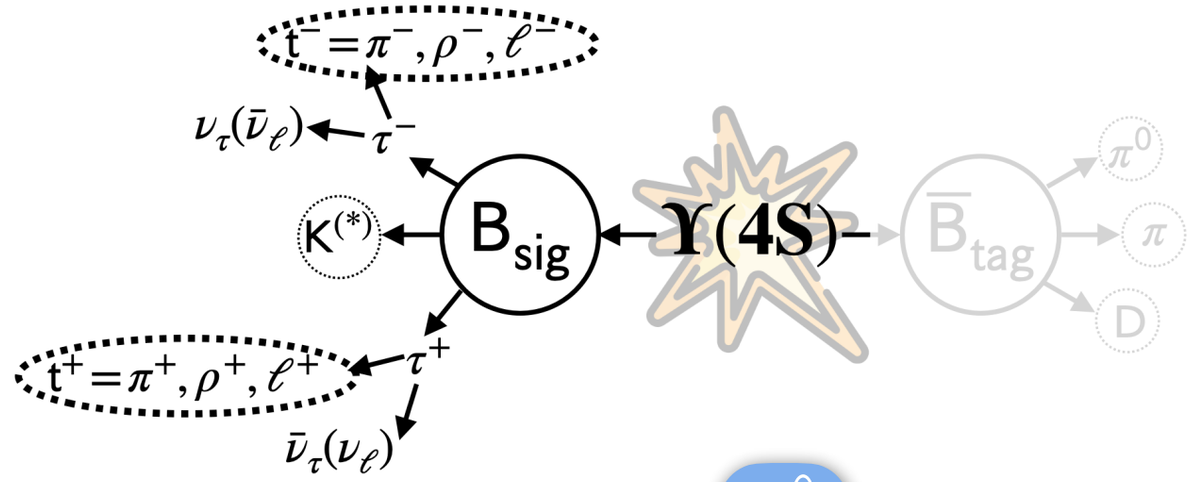
Three results use **hadronic tagging:**

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

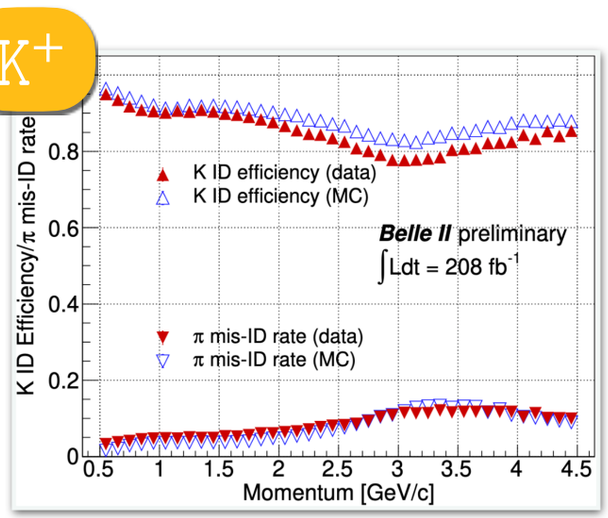
$B^+ \to K^+\tau^+\tau^-$

$B^0 \to K_S^0\tau^+\tau^-$ NEW!

Reconstruction —B_{sig}



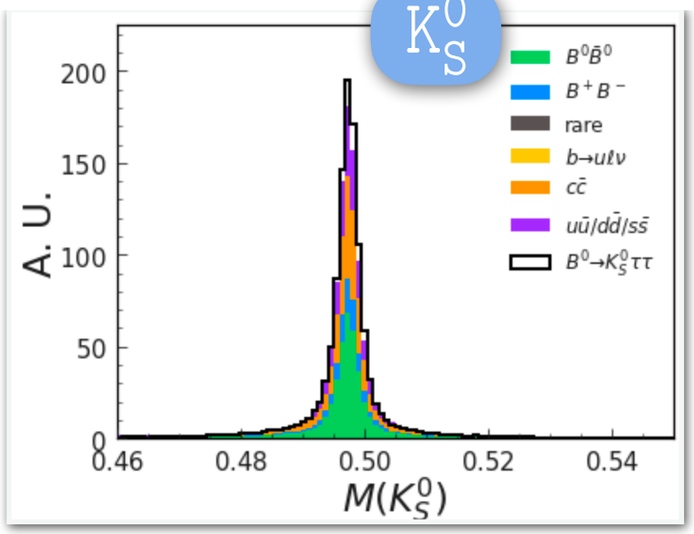
K^+



$\varepsilon \sim 90\,\%$ @ $\pi \to K \sim 6\,\%$

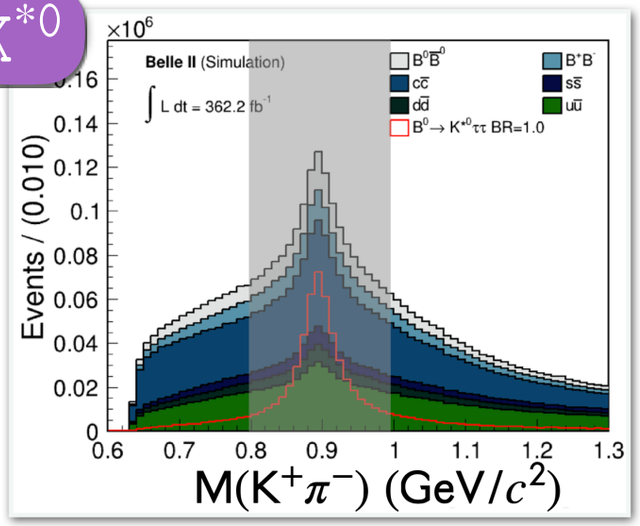
With likelihood based selector
(NN-based in the future)

K^0_S



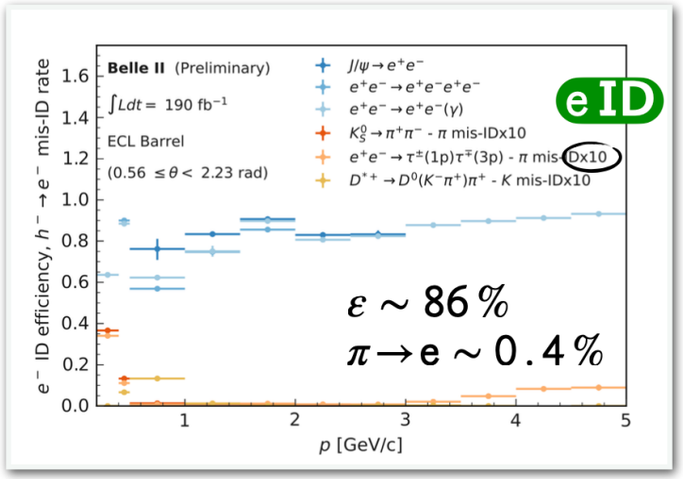
$K^0_S \to \pi^+\pi^-$ with vertex & mass &
momentum-binned, decay length selection
(>98% purity)

K^{*0}

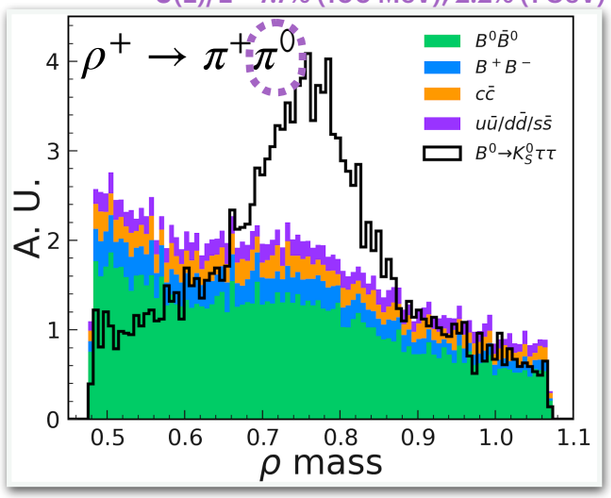


Focus on resonant only

- τ **prong recontruction:**
  - leptonic decays K^+
  - 1-prong decays → leptonic and hadronic final states are treated separately K^{*0} K^0_S



Photon efficiency > 90% (p > 1.5 GeV/c)
σ(E)/E = 7.7% (100 MeV), 2.2% (1 GeV)



Search for $B^0 \to K^{*0}\tau^+\tau^-$ and $B^0 \to K^0_S\tau^+\tau^-$

BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

Similar strategy

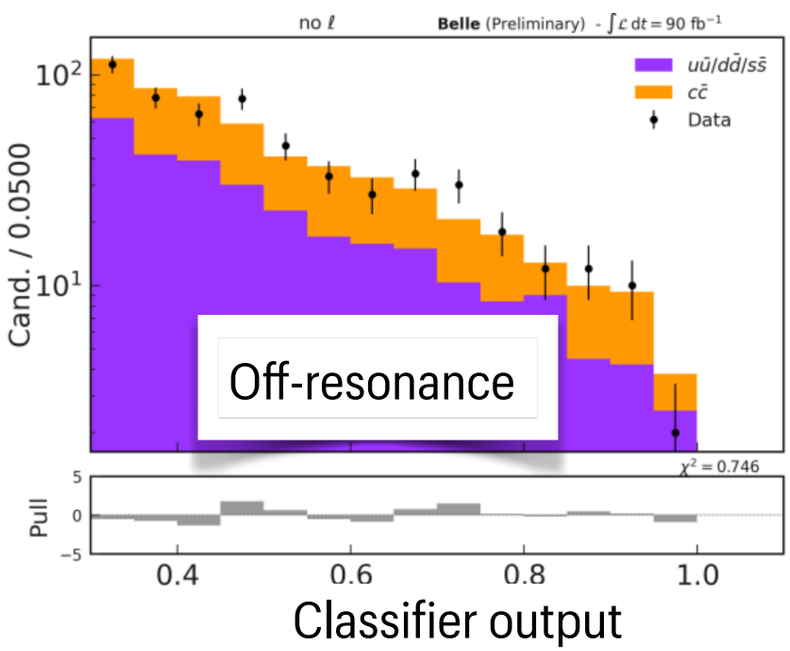
K^{*0} K^0_S

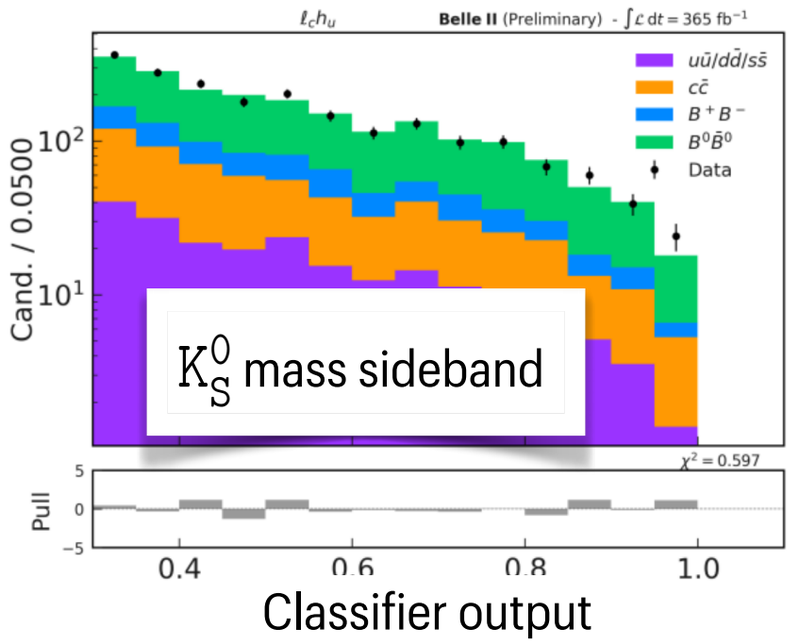
- Hadronic B-tagging with **Belle II** and **Belle+Belle II data**
- Consider hadronic and leptonic τ decays
- Most discriminative variables combined in BDTs; transformed outputs used to extract signals
- **Validated with multiple control samples**:

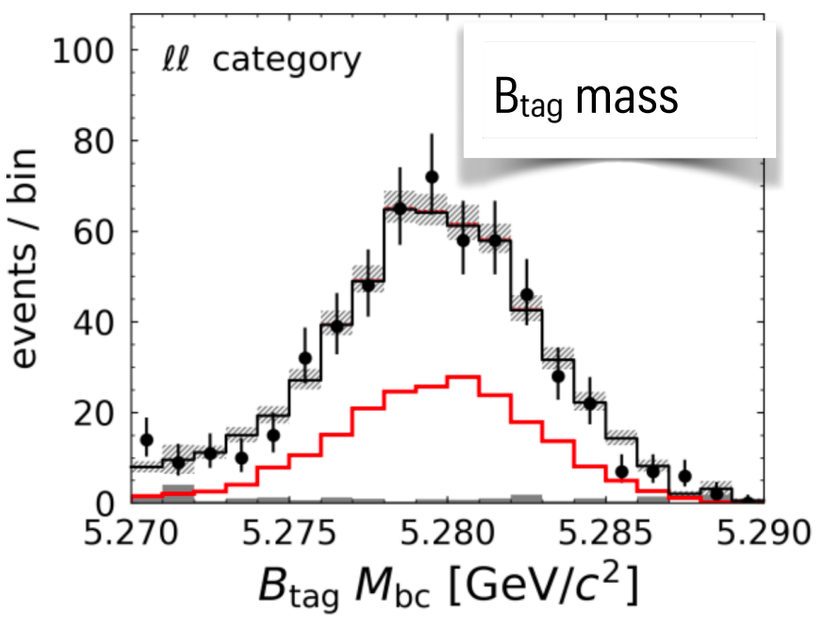
K^{*0}
- **Background:** off-resonance, sample with B_{sig} and B_{tag} having same flavor; **signal**: $B^0 \to K^{*0}J/\psi$

K^0_S
- **Background:** off-resonance, B_{tag} mass, K^0_S mass+quality & B_{tag} mass sidebands: **signal**: $D^- \to K^0_S\pi^-/\rho^-$ veto

90 / 43 fb^{-1} for Belle and Belle II run1 data







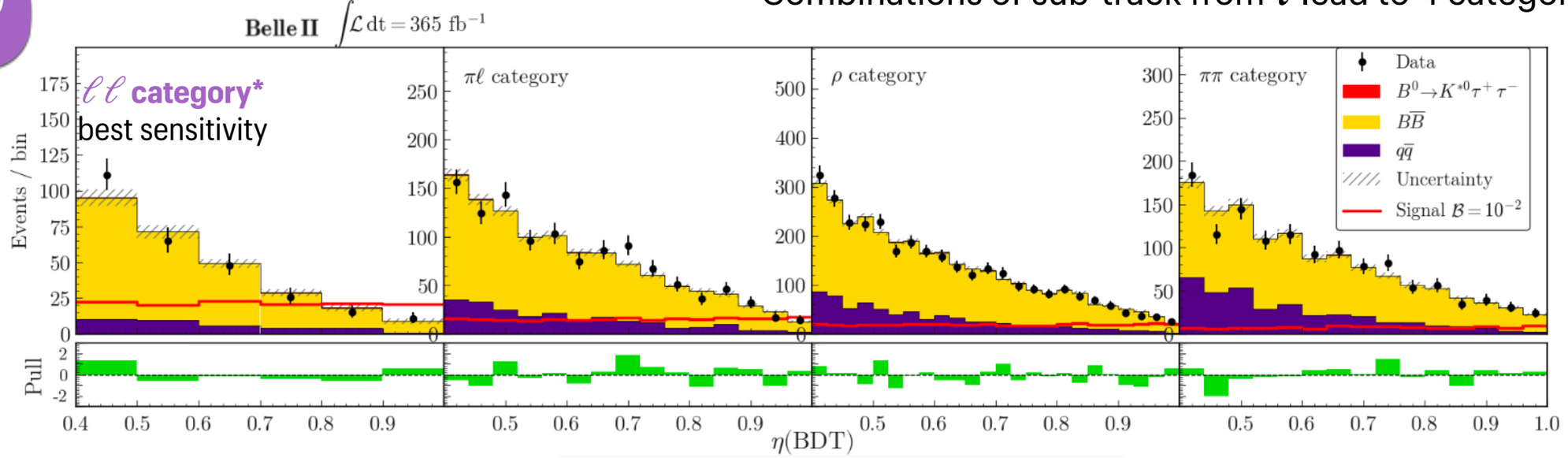
Result for $B^0 \to K^{*0}\tau^+\tau^-$ and $B^0 \to K^0_S\tau^+\tau^-$

BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

[PRL 135 151801(2025)]

K^{*0}

Combinations of sub-track from τ lead to 4 categories



$\mathcal{B}^{UL} < 1.8 \times 10^{-3}$ at 90% CL

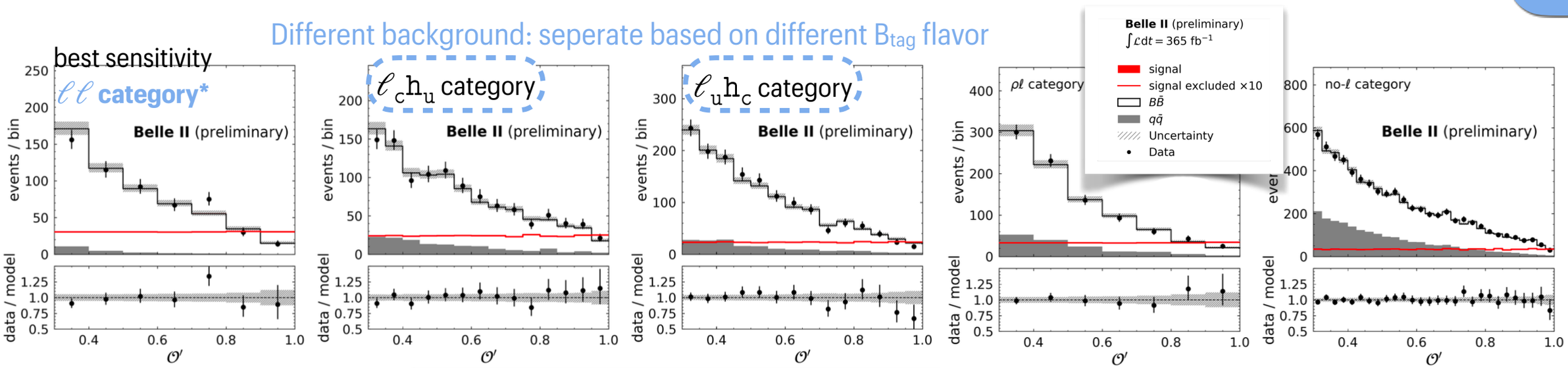
Twice better with only half sample wrt Belle! Better tagging + more categories + BDT classifer...

K^0_S

Preliminary, paper in preparation

10 possible combination group in 5 orthogonal categories

Different background: seperate based on different B_{tag} flavor



Combined $\mathcal{B}^{UL} < 8.4 \times 10^{-4}$ at 90% CL

First search on this channel!

Search for $B^+ \to K^+\tau^+\tau^-$

Preliminary, paper in preparation

BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

Strategy

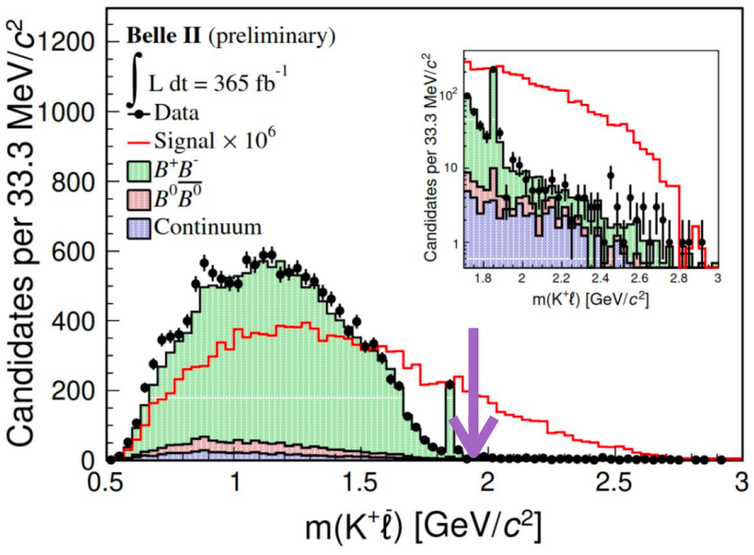
- Hadronic B-tagging & combine Belle and Belle II data
- On Signal-side, consider only **leptonic τ decays**: $\tau \to e\nu\bar{\nu}, \tau \to \mu\nu\bar{\nu}$
- **Cut-based** approach to suppress backgrounds (D mass threshold, ℓ momentum, M^2_{miss})
- **Signal extraction:** Poisson-event counts from optimized E_{ECL} - total energy of extra-photons in EM calorimeter (ECL)
  - validated by sideband samples

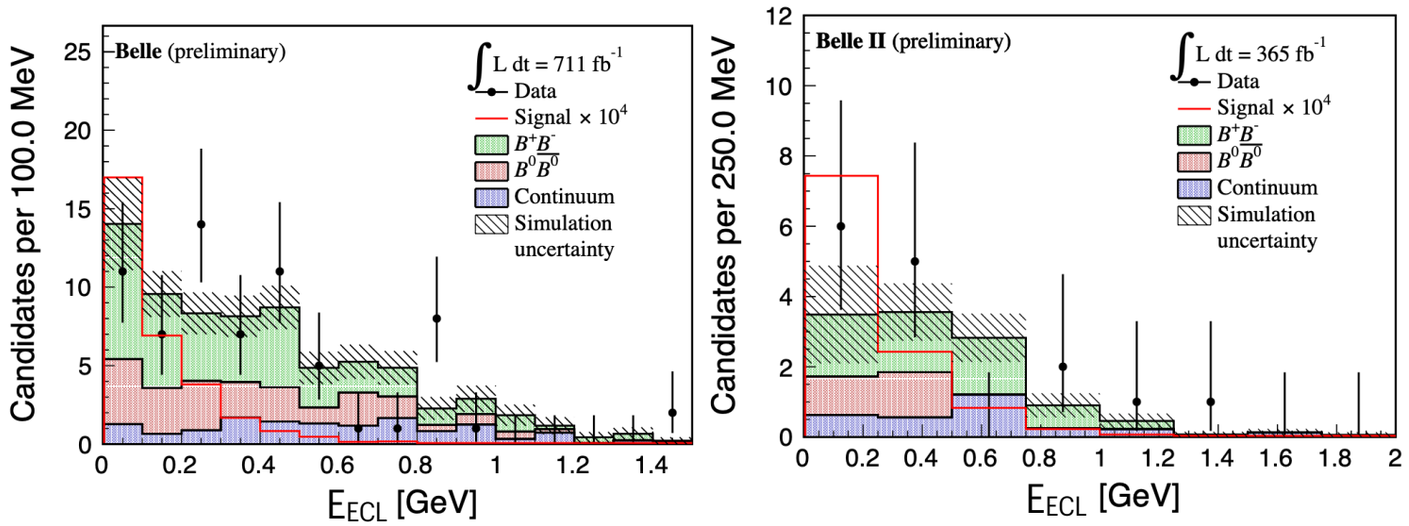
Results

D mass threshold cut:

$m(K\ell) > 1.9\ GeV/c^2$

Reject dominant $D \to K\ell\nu$ background





	Belle	Belle II
N_{bkg}	$14.1 \pm 1.6 \pm 1.9$	$3.5 \pm 0.7 \pm 0.9$
N_{obs}	11	6
$\mathcal{B}(B^+ \to K^+\tau^+\tau^-) \times 10^4$	$-2.7^{+3.2}_{-2.6} \pm 2.2$	$5.1^{+5.6}_{-4.3} \pm 2.5$
Obs. (exp.) limit (10^{-3})	0.4 (0.7)	1.6 (0.9)

Most stringent limit on this channel!

$\mathcal{B}^{UL} < 8.7 \times 10^{-4}$ at 90% confidence level

$b \to s\nu\bar{\nu}$

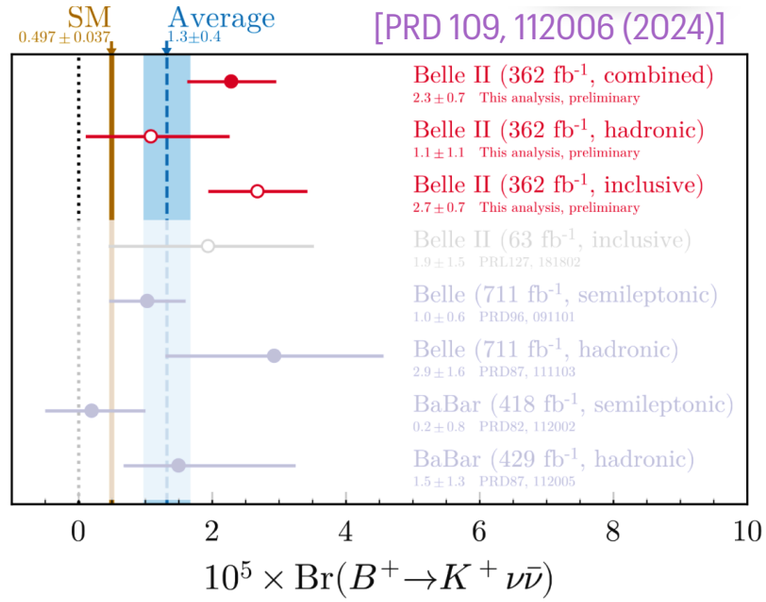
$B^+ \to K^+ \nu\bar{\nu}$ reinterpretation

[PRD 112, 092016 (2025)]

Belle II
365 fb^{-1}

Belle II showed **first evidence** of decays using hadronic and inclusive B-tagging with **2.7σ deviation from SM**

$(2.3 \pm 0.7) \times 10^{-5}$ **(combined)**
$(1.1^{+1.2}_{-1.0}) \times 10^{-5}$ **(hadronic)**
$(2.7 \pm 0.7) \times 10^{-5}$ **(inclusive)**

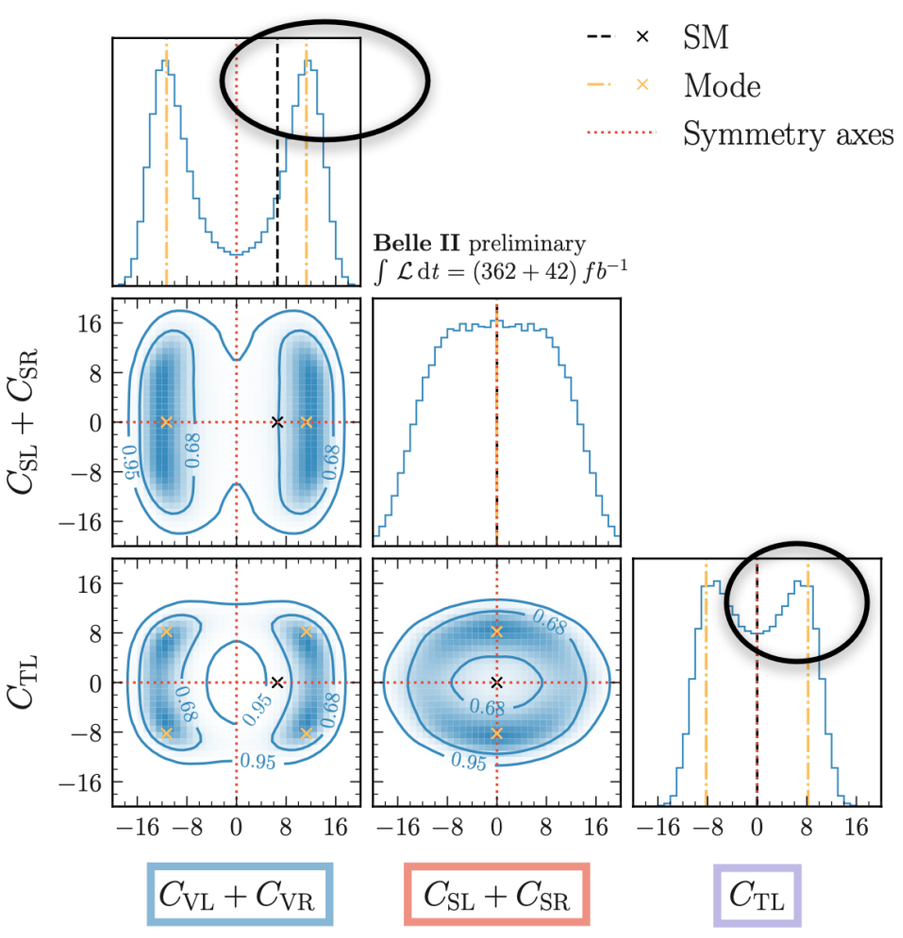


- Reinterpretation method can be applied to test alternative models σ_1 [EPJ 84(2024)693]
- Given the **null number density n_0** (e.g. SM) obtain **alternative n_1** via reweighting

$$n(x) = \mathscr{L} \int \varepsilon(x \mid q^2)\sigma(q^2)dq^2$$

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

$$x \equiv q^2_{rec} \times \eta(BDT_2)$$



Weak **E**ffective **T**heory (**WET**)

$$\frac{d\mathcal{B}}{dq^2} = 3\tau_B \left(\frac{4G_F}{\sqrt{2}}\frac{\alpha}{2\pi}\right)^2 |V_{ts}^* V_{tb}|^2 \frac{\sqrt{\lambda_{BK}}q^2}{(4\pi)^3 M_B^3} \left[\frac{\lambda_{BK}}{24q^2}|f_+(q^2)|^2 |C_{VL} + C_{VR}|^2 + \frac{(M_B^2 - M_K^2)^2}{8(m_b - m_s)^2}|f_0(q^2)|^2 |C_{SL} + C_{SR}|^2 + \frac{2\lambda_{BK}}{3(M_B + M_K)^2}|f_T(q^2)|^2 |C_{TL}|^2\right]$$

- Prefer larger vector and non-zero tensor contributions compared to SM
- $(|C_{VL} + C_{VR}|, |C_{SL} + C_{SR}|, |C_{TL}|) = (11.3, 0, 8.2)$

Method and data to reinterpret the results with alternative models are available for external users on HEPData

First $B \to X_s \nu\bar{\nu}$ search

2511.10980, accepted by PRL

Belle II
365 fb^{-1}

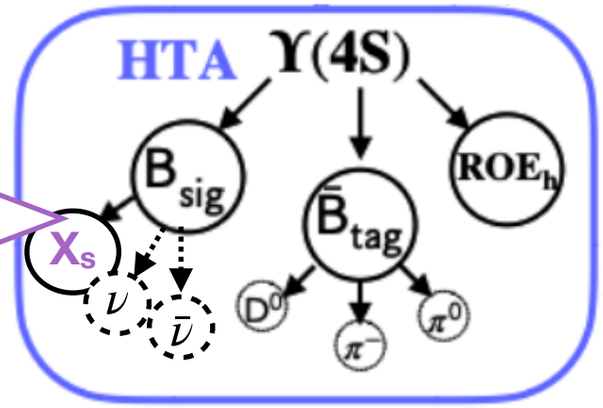
Motivation

- $\mathcal{B}_{SM}(B \to X_s \nu\bar{\nu}) = [(3.35\text{-}3.62) \pm 0.11] \times 10^{-5}$ [2512.19138]
  - Theoretically clean and sensitive to several possible sources of NP and complementary to the exclusive K(*) searches [JHEP12(2021)118]
  - Similar measurement from ALEPH $\mathcal{B}_{UL}(b \to s\nu\bar{\nu}) < 6.4 \times 10^{-4}$ [EPJC 19,2130227(2001)]
- **Only possible at e^+e^- experiments**

First use of sum-of-exclusive to study final states with $\nu\bar{\nu}$

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

Knπ, n=0,1,2,3,4
3K, 3Kπ



Rest **O**f **E**vent:
γ, π^+, π^0 ...

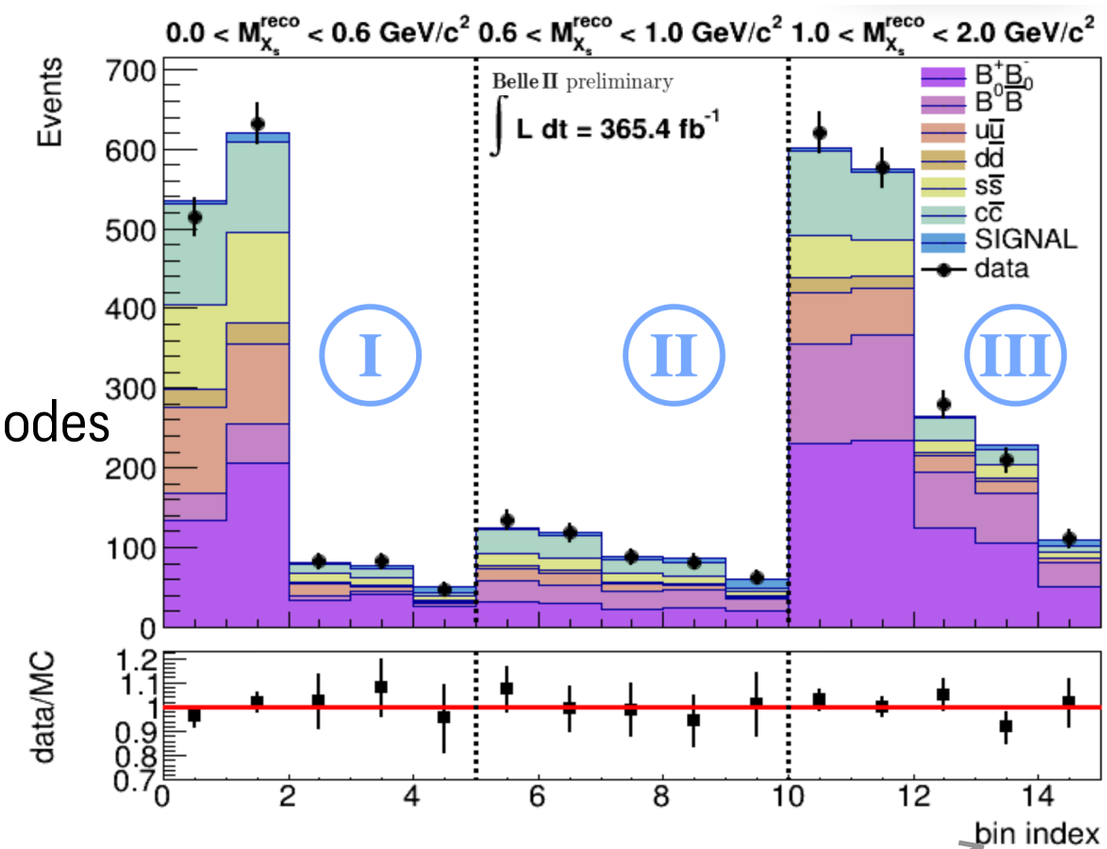
Strategy

- **Hadronic B-tagging**
- **Multiple samples used to calibrate simulations and obtain systematic uncertainties**
  - $B \to X_s J/\psi(\to \mu^+\mu^-)$ for the BDT efficiency
  - Off-resonance samples for $q\bar{q} = u, d, c, s$ backgrounds
  - BDT output $\mathcal{O}$ and Mbc sidebands for syst. uncertainty of $B\bar{B}$ background normalization
  - ...

First $B \to X_s \nu\bar{\nu}$ search: Result

2511.10980, accepted by PRL

Belle II
365 fb^{-1}



Signal Extraction

- 2D signal region $\mathcal{O} \times M_{X_s}^{reco}$ plane mapped into a 1D index
- Regions I, II, III are enhanced in K, K*(892) and $(K n\pi)_{\text{non-res}}$ modes

*Compatible with hadronically-tagged Belle II

	M_{X_s} [GeV/c^2]	ϵ	N_{sig}	$\mathcal{B}$ [10^{-5}] Central value	UL$_{\text{obs}}$	UL$_{\text{exp}}$
*	$[0, 0.6]$	0.26%	10^{+18+18}_{-17-16}	$0.5^{+0.9+0.9}_{-0.8-0.8}$	2.5	2.4
	$[0.6, 1.0]$	0.12%	37^{+27+31}_{-25-26}	$3.8^{+2.8+3.3}_{-2.6-2.7}$	10.1	7.3
	$[1.0, m_B]$	0.06%	33^{+44+63}_{-42-53}	$7.3^{+9.6+13.8}_{-9.2-11.5}$	35.1	27.9

Combined UL

$$\mathcal{B}(B \to X_s \nu\bar{\nu}) = \left[11.6^{+8.9}_{-8.6}(\text{stat})^{+13.5}_{-11.3}(\text{syst})\right] \times 10^{-5}$$

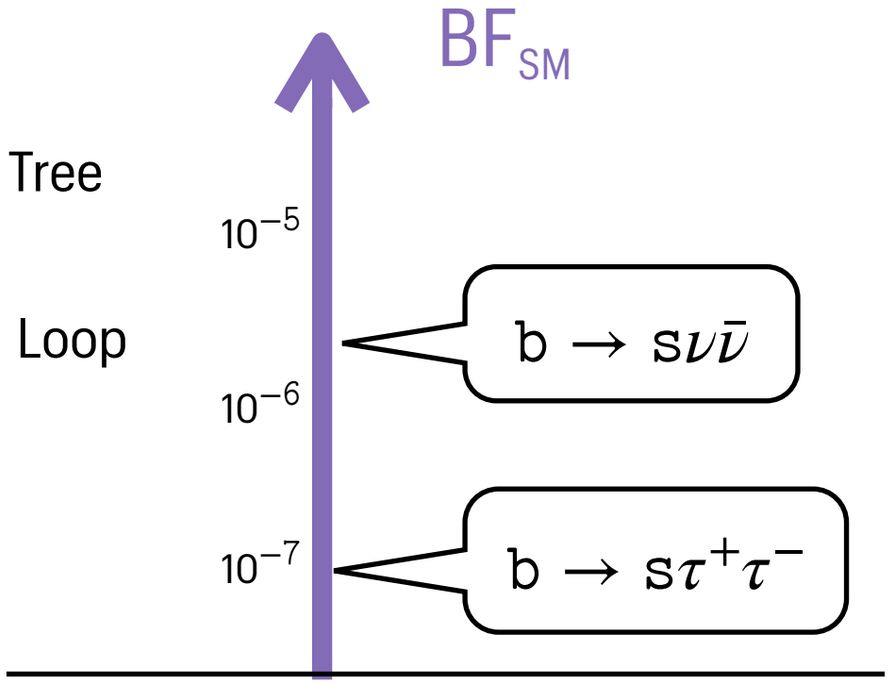
$$\mathcal{B}(B \to X_s \nu\bar{\nu}) < 3.6 \times 10^{-4} @ 90\,\%\,\text{CL}$$

First/Most stringent UL on the inclusive rate

Summary

BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

(Belle+)Belle II producing world-leading results

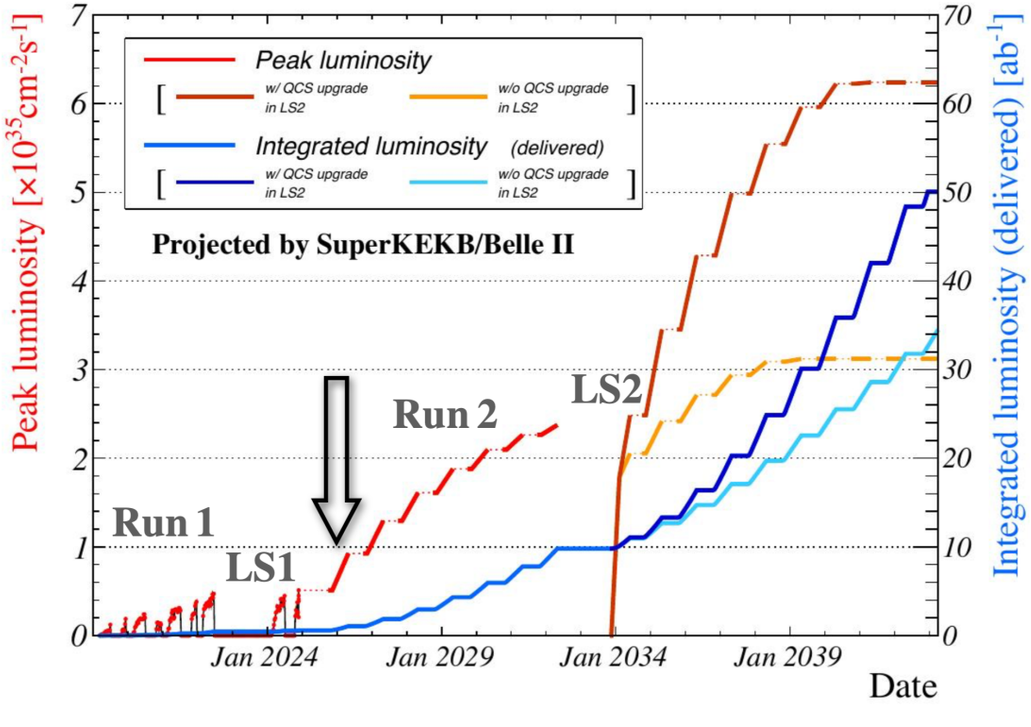


Using hadronic B-tagging, we have..

- Most stringent limit on $B^+ \to K^+\tau^+\tau^-$ decay
- First search and upper limit on $B^0 \to K^0_S\tau^+\tau^-$ decay
- Upper limit on $B^0 \to K^{*0}\tau^+\tau^-$ decay

Additional tagging methods (inclusive and semileptonic tagging) are under investigation to improve efficiency.

- Inclusive+hadronic tagging combined $B^+ \to K^+\nu\bar{\nu}$ result shows 2.7σ tension wrt SM. A model-agnostic likelihood reinterpretation within WET sets constraints on Wilson coefficients.
- Most stringent $B \to X_s\nu\bar{\nu}$ limit using hadronic B-tagging



More results on these transitions will come soon!

Thank you for you attention

Backup

Uncertainty for $B \to X_s \nu\bar{\nu}$

BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

Although result is statistically limited, a careful assessment of the systematic uncertainties is performed.

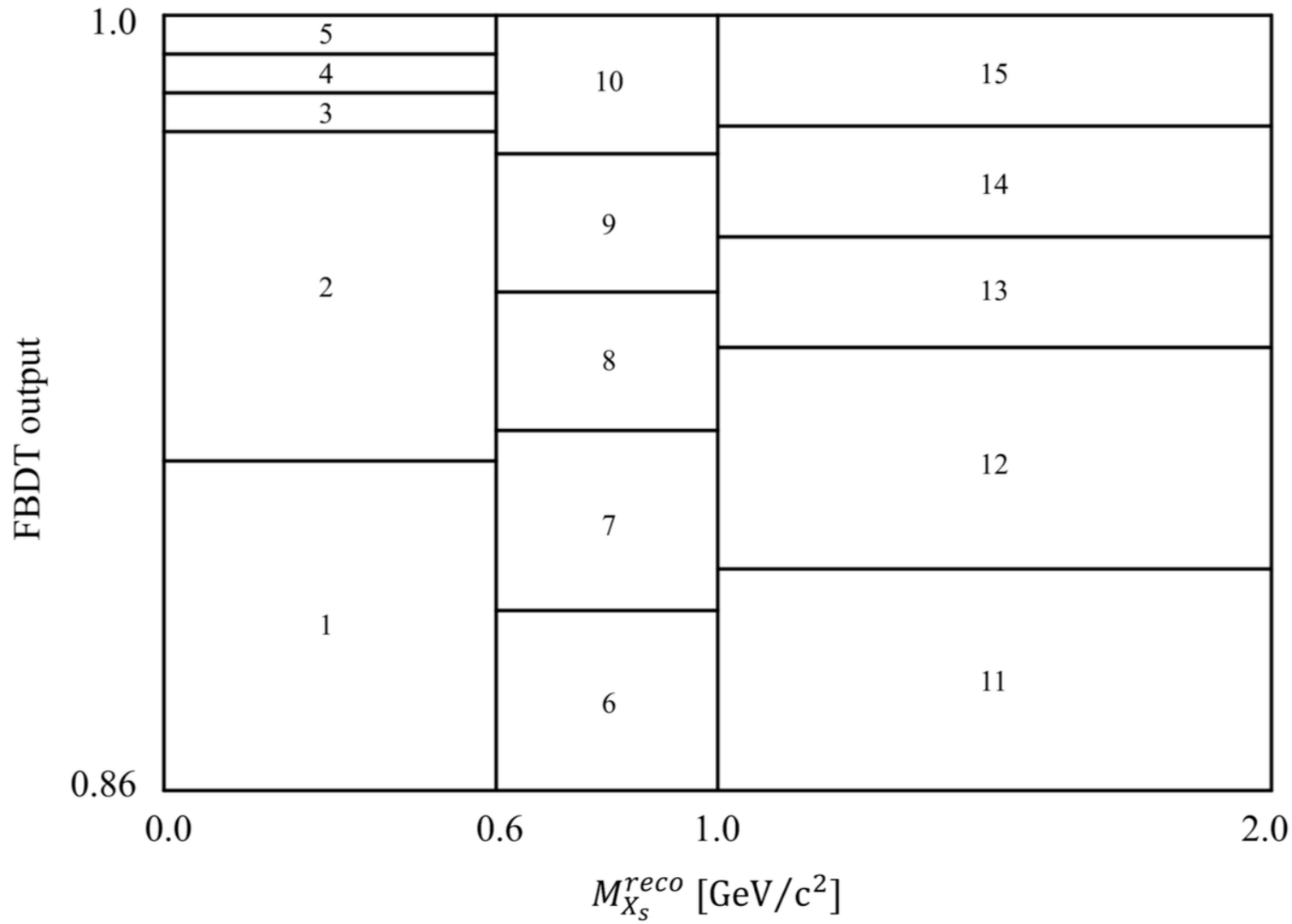
Dominant contributions from:

- Limited **MC statistic**
- **Background normalization**

Source	Impact on $\sigma_{\mathcal{B}}$ $[10^{-5}]$
Simulated-sample size	6.0
Background normalization	5.7
Branching fractions of major B-decays	2.3
Non-resonant $X_s\nu\bar{\nu}$ generation range	2.1
$\mathcal{O}_{\mathrm{BDT}}$ selection efficiency	2.0
Photon multiplicity correction	1.8
$q\bar{q}$ background efficiency	1.8
Other subdominant contributions	3.0
Total systematic sources	11.7

$B \to X_s \nu\bar{\nu}$ Search

Belle II
365 fb^{-1}



Uncertainty for $B^0 \to K^0_S \tau^+ \tau^-$

BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

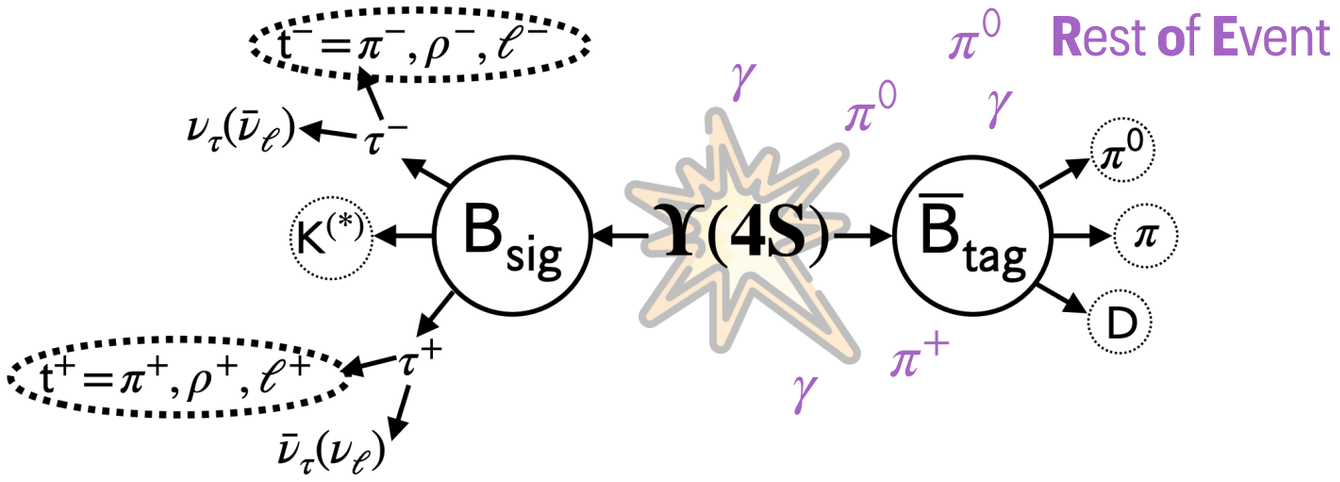
Although result is statistically limited, a careful assessment of the systematic uncertainties is performed.

Dominant contributions from:

- Limited **MC statistic**
- $B\bar{B}$ **background** knowledge
  - Identify ~ 70 leading modes
  - For measured modes, correct their branching ratio according to latest PDG values and propogate uncertainty
  - For unmeasured modes, a 100% uncertainty is considered.

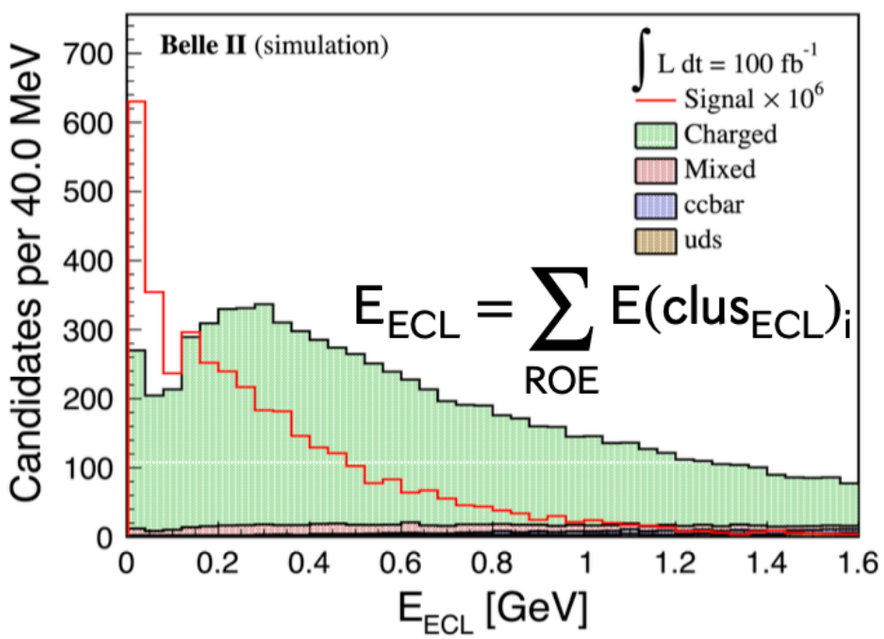
Source	**Uncertainty type, parameters**	$\sigma_{\mathcal{B}}(10^{-3})$
MC statistics	Uncorrelated shape, 140	0.18
Leading B-decay branching fractions	Correlated shape, 30	0.11
B-tagging efficiency	Correlated shape, 2	0.06
Combinatorial B^0_{tag} normalization	Correlated shape, 10	0.05
$D \to K^0_L$ modeling	Correlated shape, 2	0.05
Lepton ID	Correlated shape, 6	0.03
Signal efficiency uncertainty	Normalization, 2	0.03
f_{00}	Correlated shape, 1	0.02
π^0 efficiency	Correlated shape, 2	0.02
$q\bar{q}$ normalization	Normalization, 4	0.02
Signal model	Correlated shape, 1	0.02
K^0_S efficiency	Correlated shape, 2	<0.01
Number of $\Upsilon(4S)$	Normalization, 2	<0.01
Luminosity uncertainty	Normalization, 2	<0.01
Tracking efficiency	Correlated Shape, 2	<0.01
Leading τ-decay branching fractions	Correlated shape, 10	<0.01
χ_d	Correlated shape, 1	<0.01
Total		**0.23**

Rest of Event



In the hadronic B tag analyses, events with neutral-mesons (π^0, K^0_S) are usually rejected.

The total energy of the extra-photons (ECL clusters) is one of the most discriminating variables



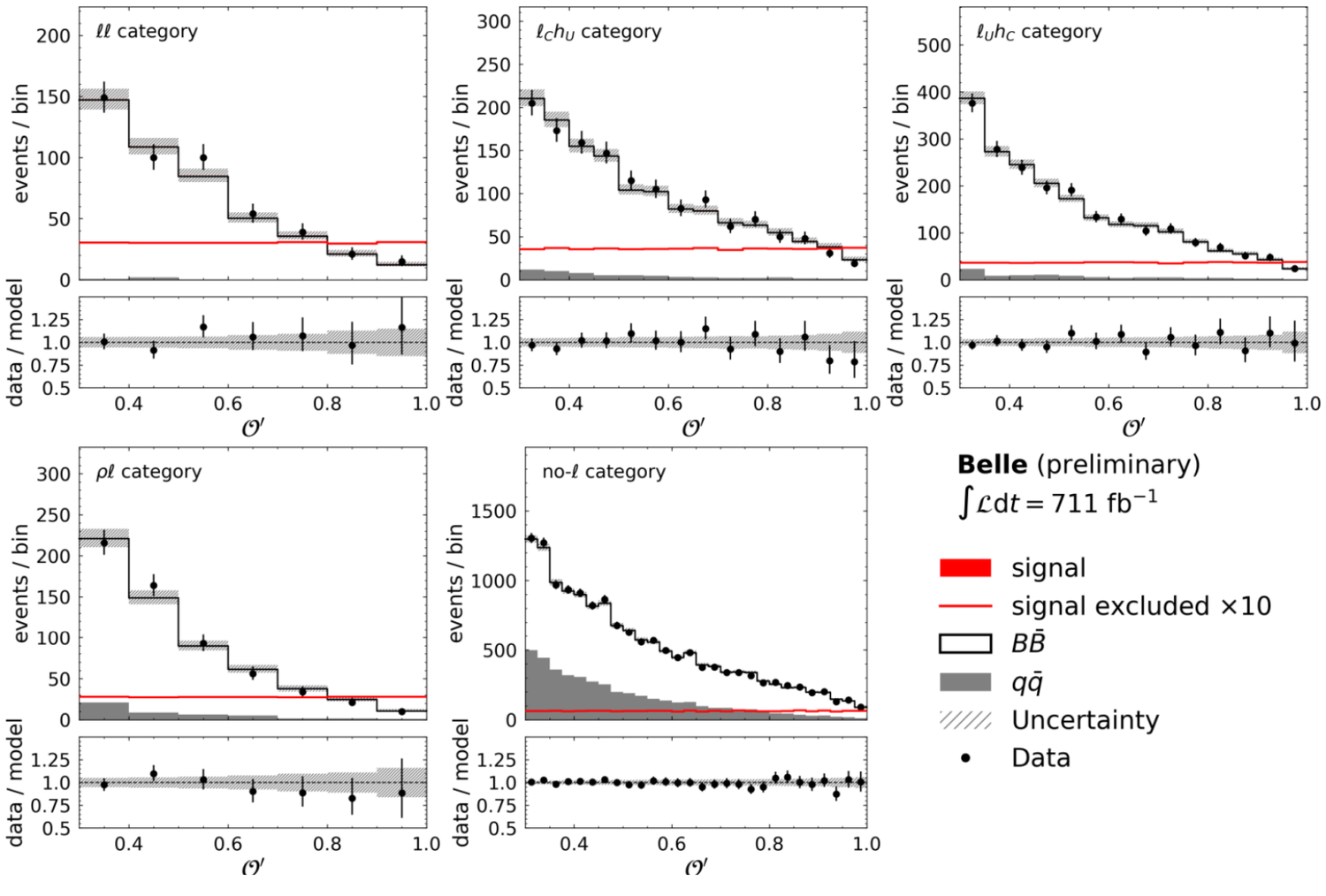
- No extra activity in ECL expected for signal events
  - Tails due to mis-reconstructed and ECL energy resolution
- Background has larger ECL deposits
  - Events at ~0 to energy threshold adopted in the extra-photon selection
- Used for
  - Background suppression in BDT K^{*0} K^0_S
  - Signal extraction K^+

Fits in $B^0 \to K^0_S \tau\tau$ (Belle)

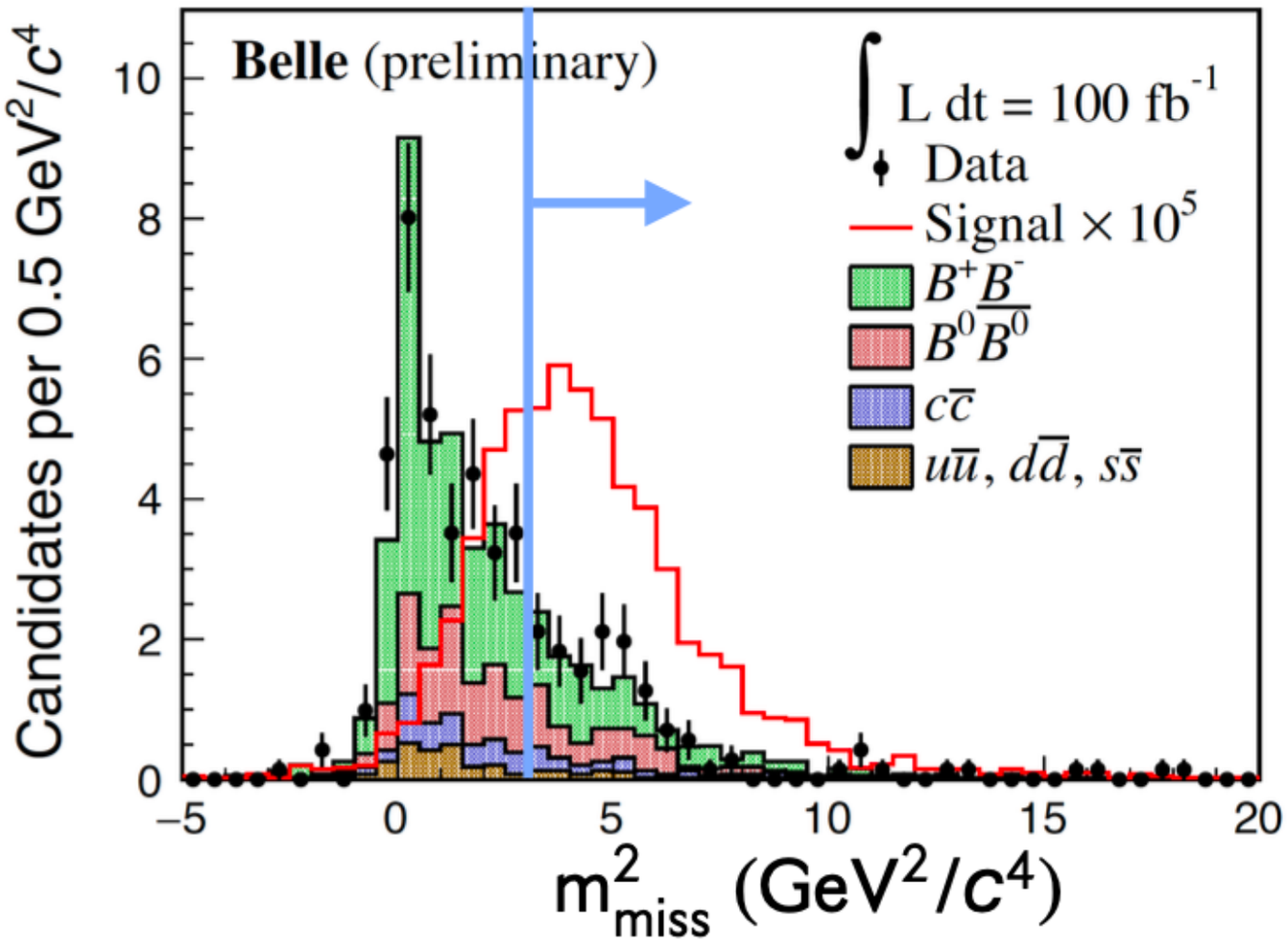
μ	μ
e	μ
e	e
μ	ρ
e	ρ
μ	h
e	h
ρ	ρ
ρ	h
h	h

• ll • ρl • $l_u h_c$ • $l_c h_u$ • $l0$

For each reconstructed category a BDT is trained for the **background suppression.**



Other cuts in $B^+ \to K^+\tau\tau$



$$m^2_{\text{miss}} = p^2_{\text{miss}} = \begin{pmatrix} E^*_{\text{miss}} \\ \boldsymbol{p}^*_{\text{miss}} \end{pmatrix}^2$$

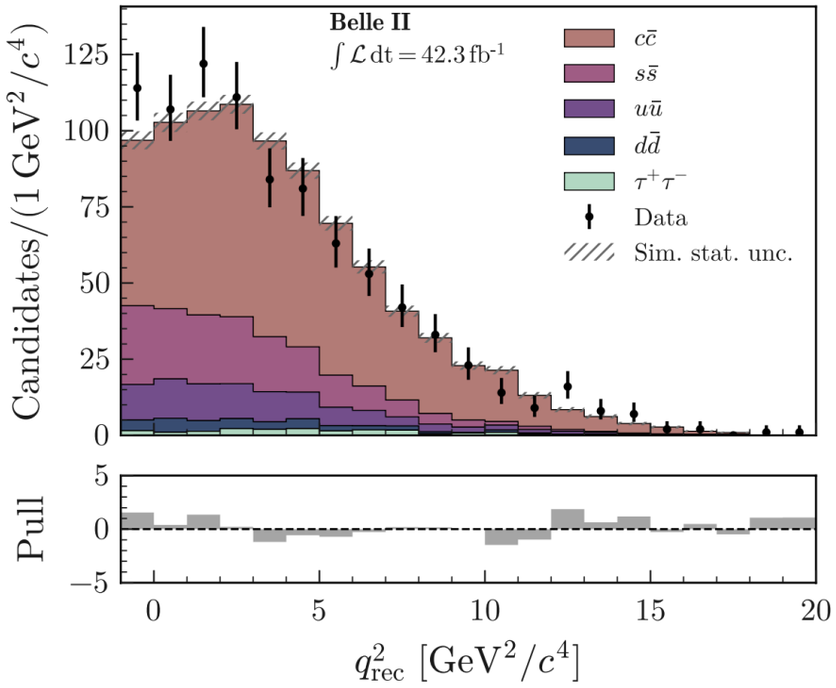
$$p_{\text{miss}} = p_{e^+e^-} - p_{B_{\text{sig}}} - p_{B_{\text{tag}}}$$

Search for $B^+ \to K^+\nu\bar{\nu}$: Strategy

Focus on Inclusive Tag: **Two consecutive classifiers** with signal kaon, event shape and ROE information

Final observables: q^2_{rec} in different second classifier (BDT) bins

$$q^2_{rec} = s/(4c^4) + M^2_K - \sqrt{s}E^*_K/c$$



Signal efficiency validation with $B^+ \to J/\psi K^+$ sample, remove J/ψ and correct K^+ kinematics to match $K^+\nu\bar{\nu}$ (1.00±0.03)

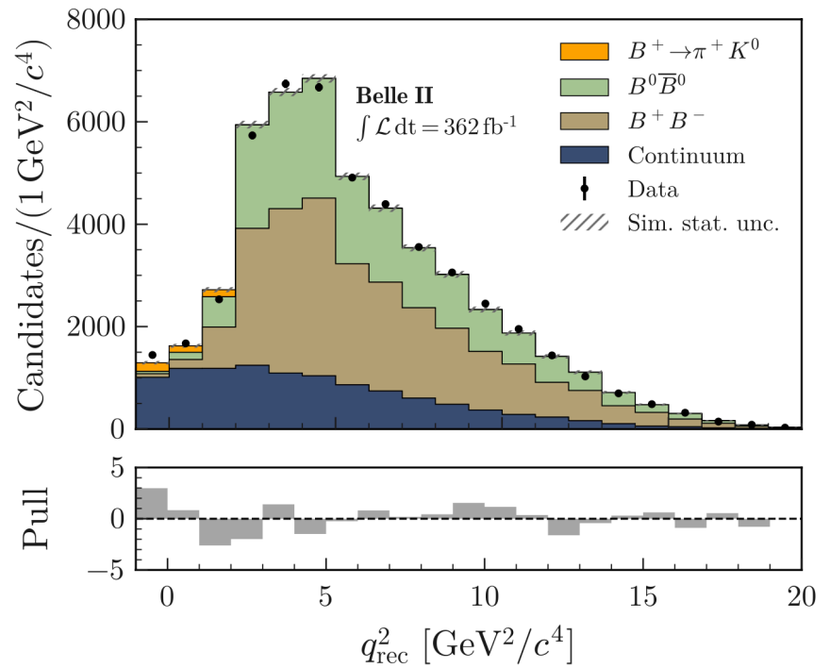
Background validation:

- $q\bar{q}$ background: Off-resonance data to correct for data/MC differences in normalisation and shape
- Undetected K^0_L in EM calorimeter can mimic neutrinos
  - K^0_L detection efficiency: $e^+e^- \to \gamma\phi(K^0_S K^0_L)$
  - $B \to K^+ D^{(*)}(K^0_L X)$: corrected using pion-enriched sample
  - $B^+ \to K^+ K^0_L K^0_L$ events: Model with BaBar [PRD85, 112010(2021)]
    $B^+ \to K^+ K^0_S K^0_S$ measurement as input

Closure validation measuring:

$$\mathcal{B}(B^+ \to \pi^+ K^0) = (2.5 \pm 0.5) \times 10^{-5}$$

Compatible with PDG $(2.38 \pm 0.08) \times 10^{-5}$



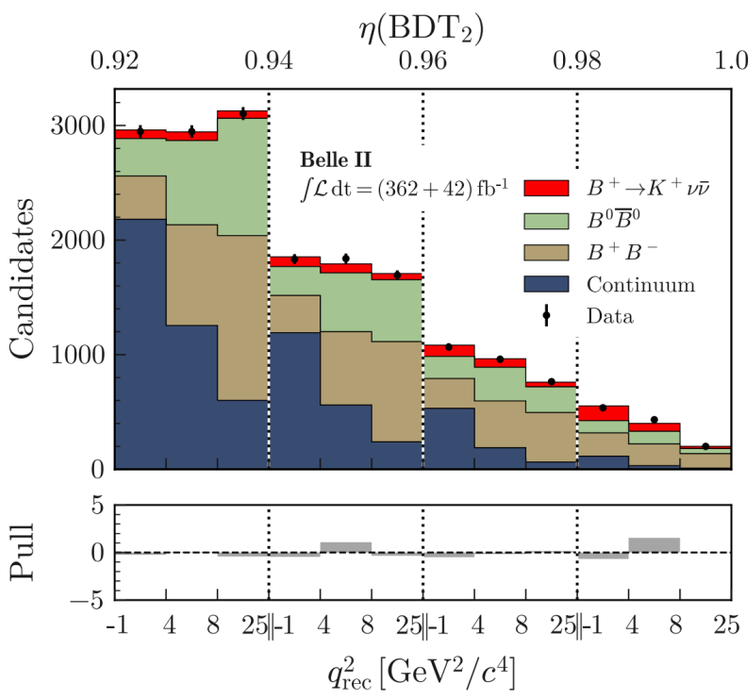
Evidence for $B^+ \to K^+\nu\bar{\nu}$: Results

Consistent within 1.2σ

Inclusive Tag $\mathcal{B} = (2.7 \pm 0.5 \pm 0.5) \times 10^{-5}$

3.5σ significance

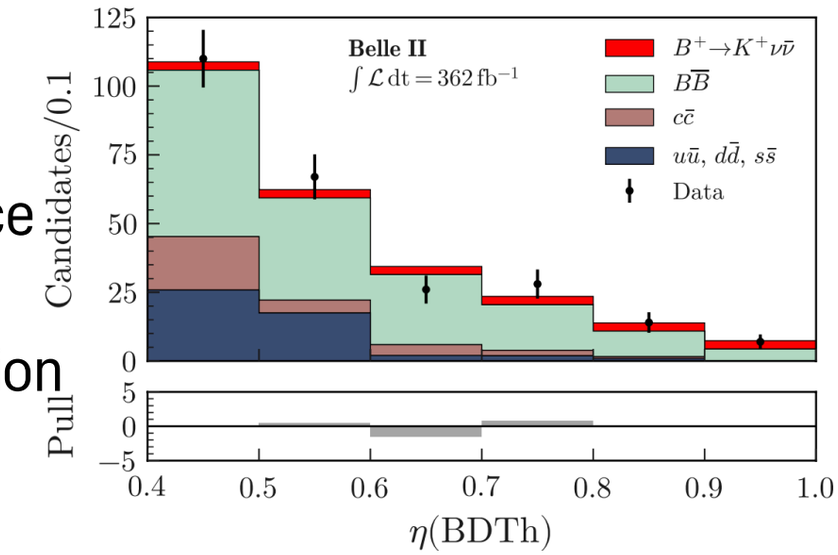
2.9σ deviation from SM



Hadronic Tag $\mathcal{B} = (1.1\ ^{+0.9}_{-0.8}\ ^{+0.8}_{-0.5}) \times 10^{-5}$

1.1σ significance

0.6σ deviation from SM



Combination $\mathcal{B} = (2.3\ \pm 0.5\ ^{+0.5}_{-0.5}) \times 10^{-5}$

3.5σ significance

2.7σ deviation from SM

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