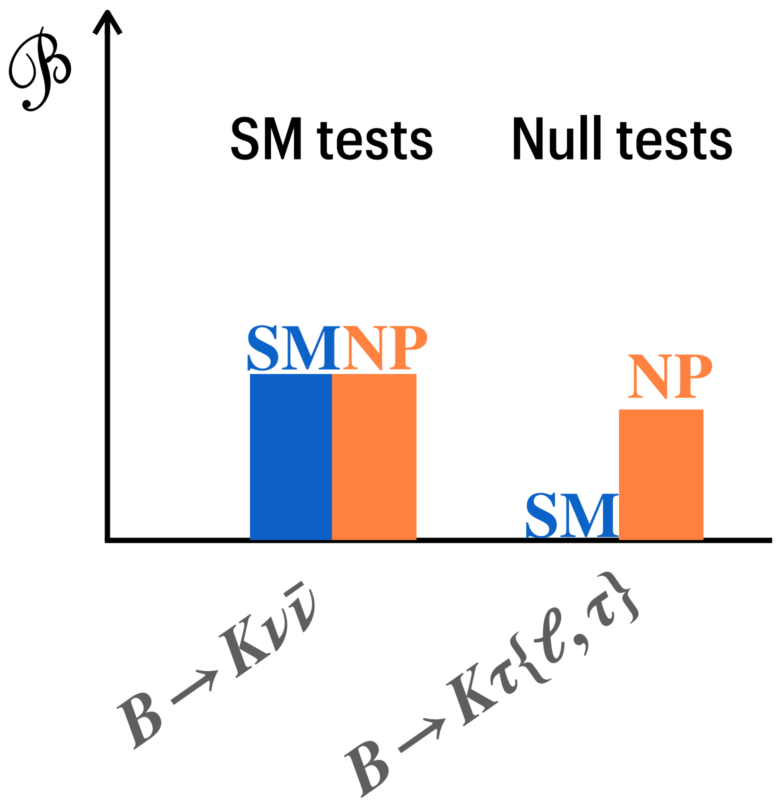
Missing Energy EWP decays at Belle II

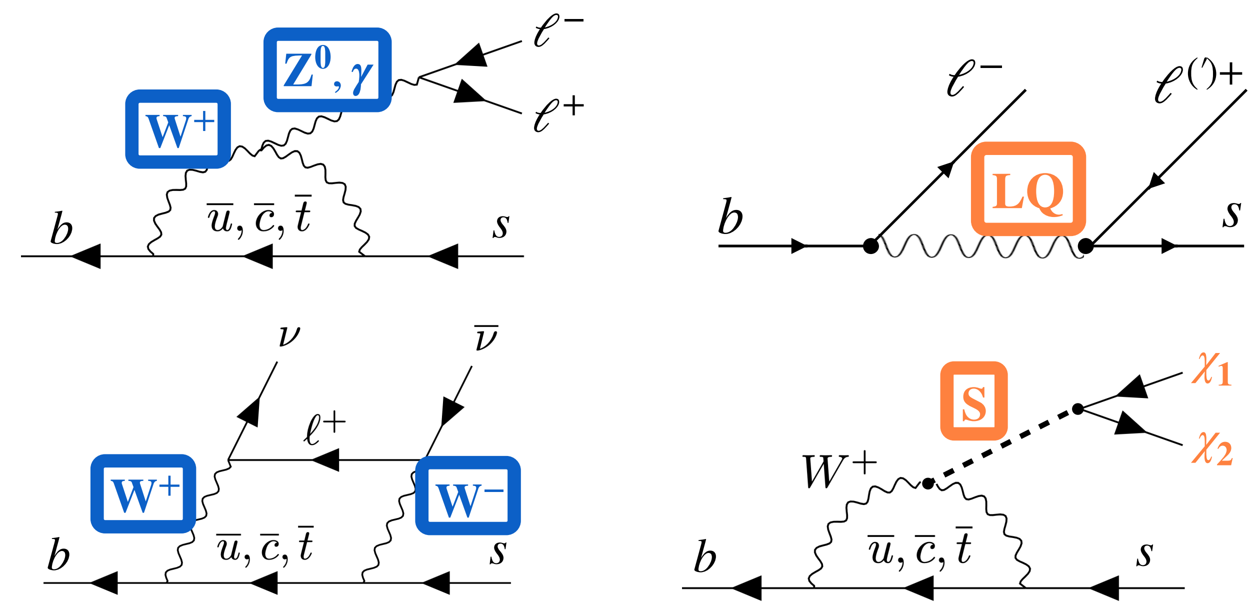
Gaetano de Marino*,
on behalf of the Belle II Collaboration
2025 BELLE II PHYSICS WEEK
Tsukuba, KEK

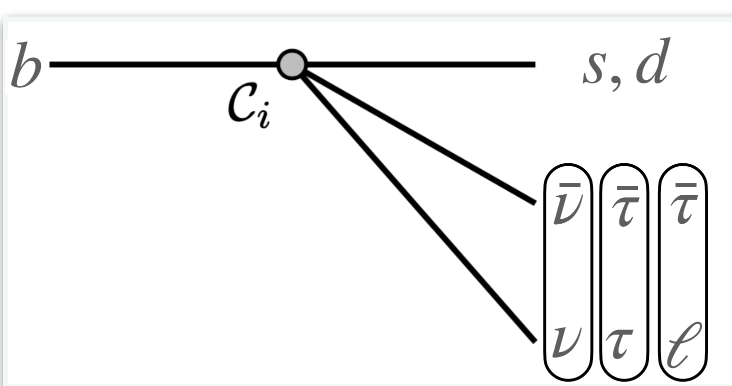
*gaetano.demarino@ijs.si

THE BEAUTY IN THE RARE



- FCNC: suppressed in the SM, good probes of NP
- Anomalies ⇔ Final states with $\tau, \nu_{(\tau)}$ ⇔ missing energy



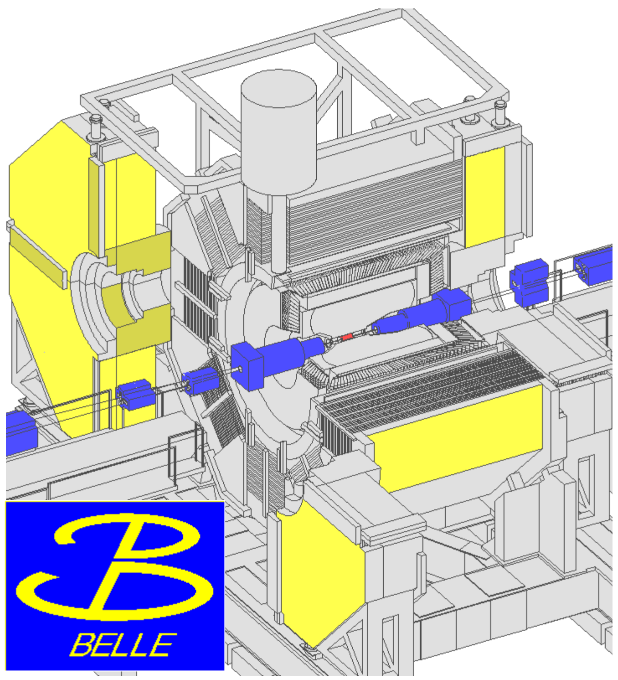


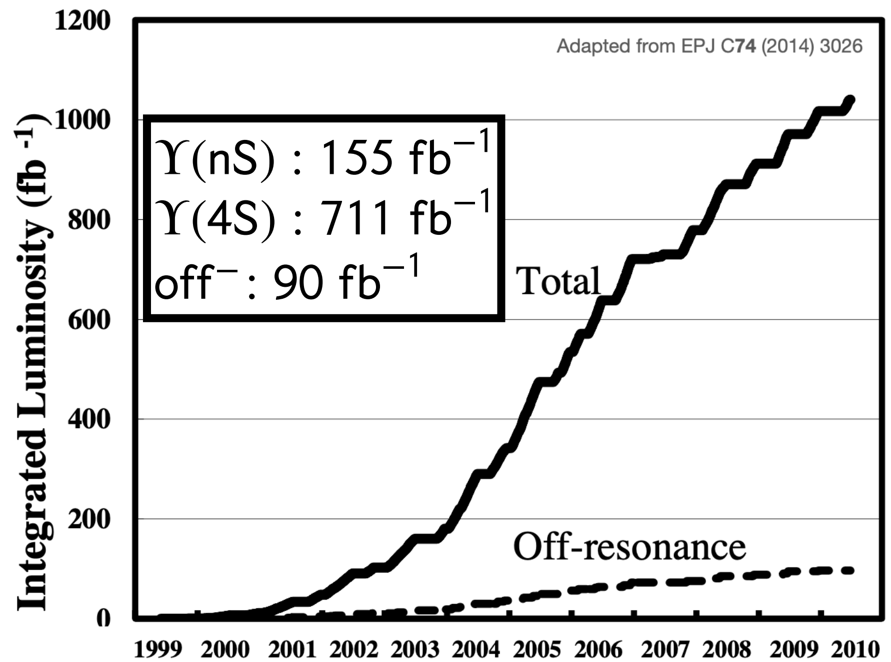
Looking for

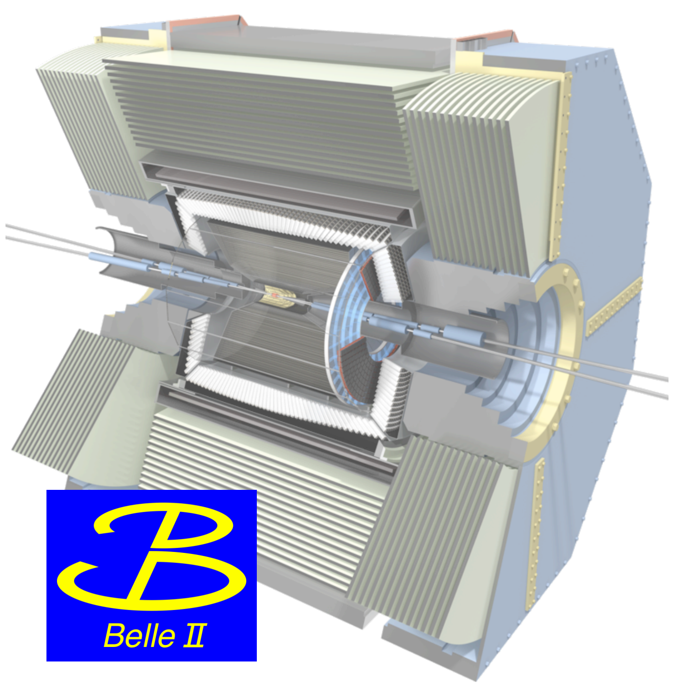
- Alterations of SM couplings $\mathbf{C_9^{eff} = C_9^{SM} + C_9^{NP}}$
- Additional operators $\mathcal{O}_{9,10}^{\prime\ell\ell}$ $\mathcal{O}_{R}^{\nu_i\nu_j}$ $\mathcal{O}_{S(P)}^{\ell_1\ell_2} = \frac{e^2}{16\pi^2}[\bar{s}\mathcal{P}_R b][\bar{\ell}_1(\gamma_5)\ell_2]$

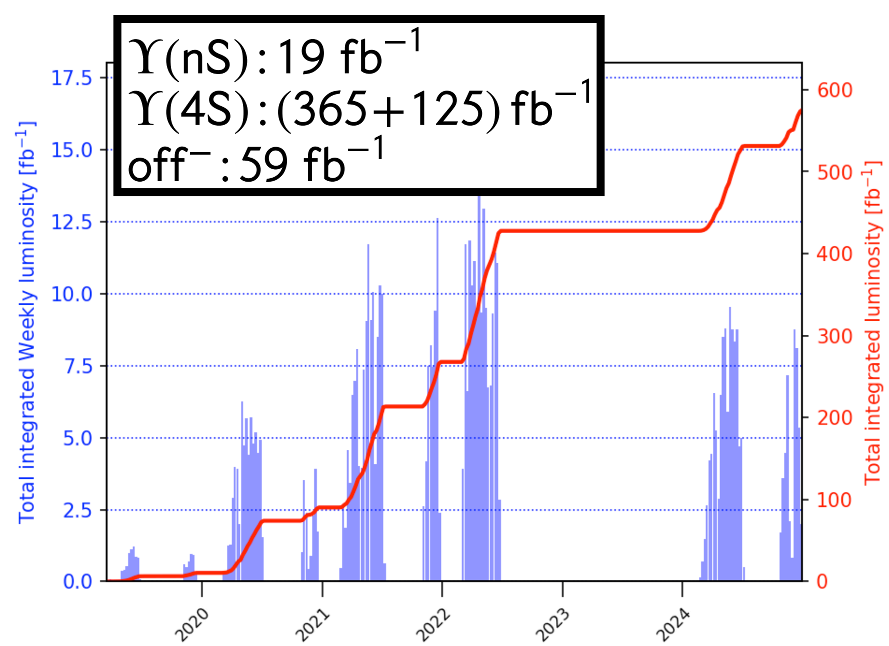
☞ More details on Wednesday (Elisa)

B-FACTORIES, BELLE (II)









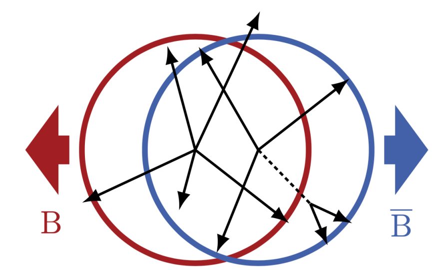
1. Threshold $B\overline{B}$ production

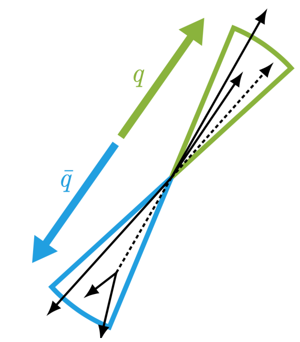
→ Two B's and nothing else

2. Relatively low $q\bar{q}$-background

→ Can be calibrated in OFF-res. data

→ Suppressed with shape info

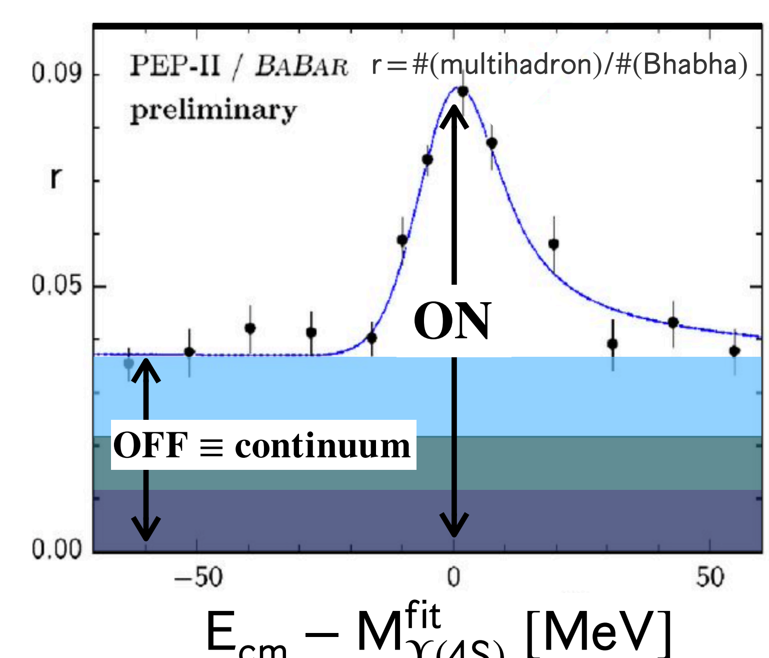




3. Known initial kinematics

+ almost-4π detector coverage

→ reconstruct final states with ν's

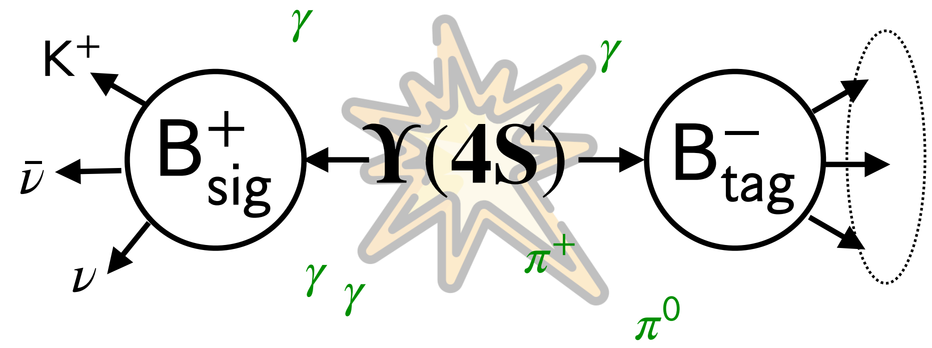


B-TAGGING FOR MISSING ENERGY

INCLUSIVE

$\mathcal{O}(10-100\%)$ @ $\leq 1\ \%$ purity

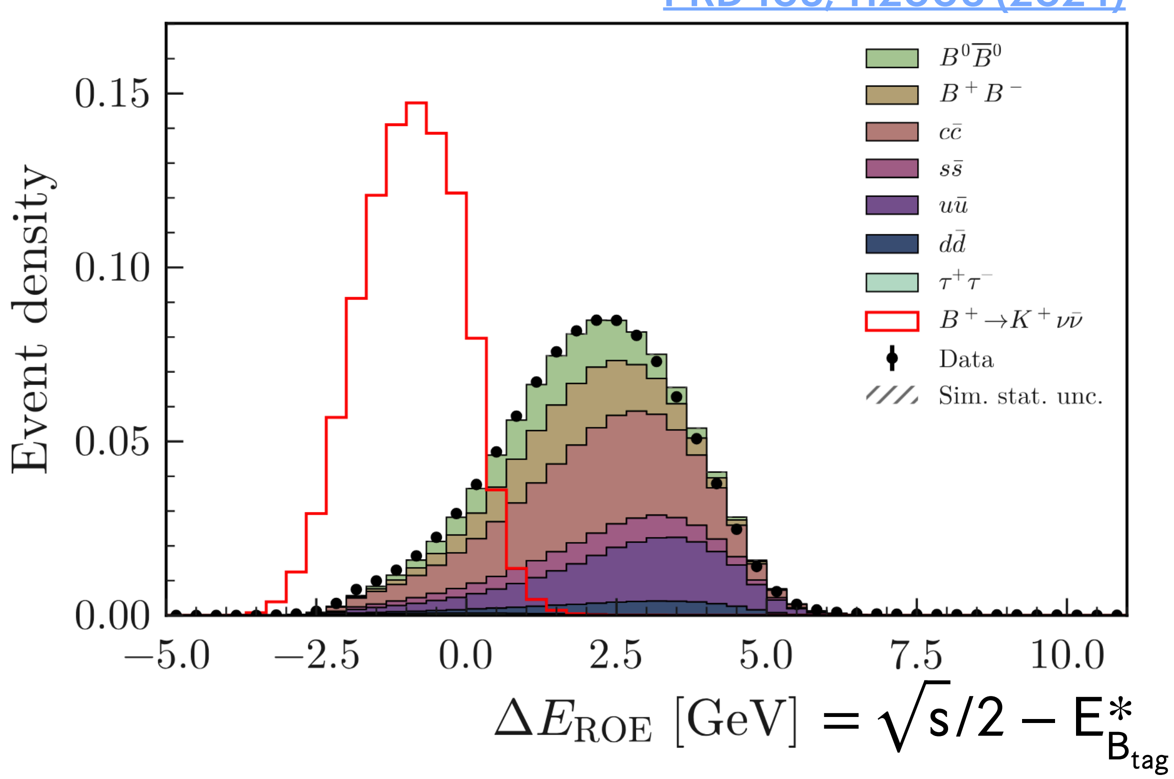
ITA



Used for

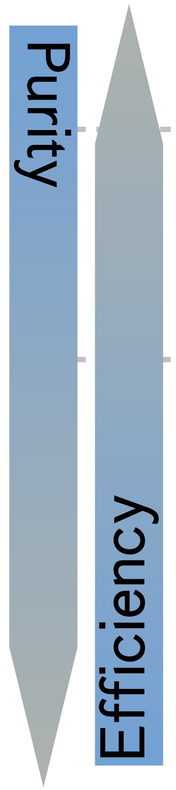
- Background filtering
- Partial kinematic info

PRD 109, 112006 (2024)



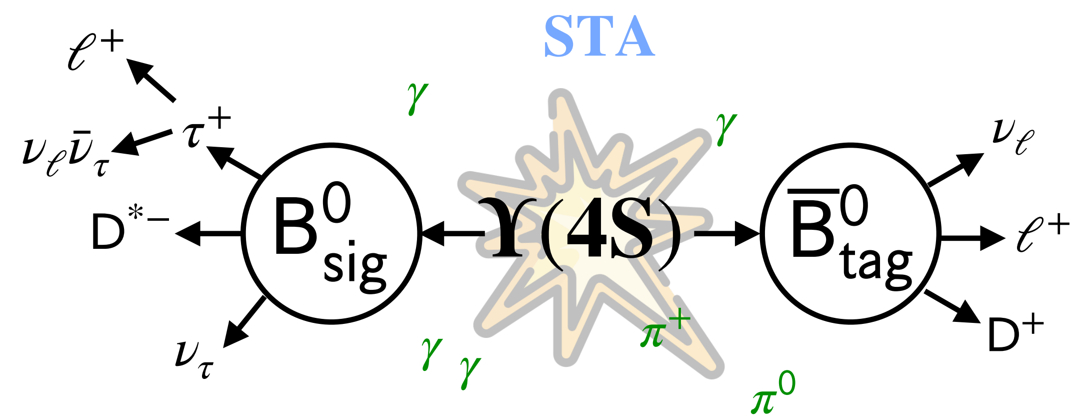
- Can maximise sensitivity for decays with specific signatures (e.g. one signal track)
- Uses global properties of the Rest Of Event ($\equiv B_{tag}$ + spurious objects)
  - kinematics, topology, final state composition

B-TAGGING FOR MISSING ENERGY



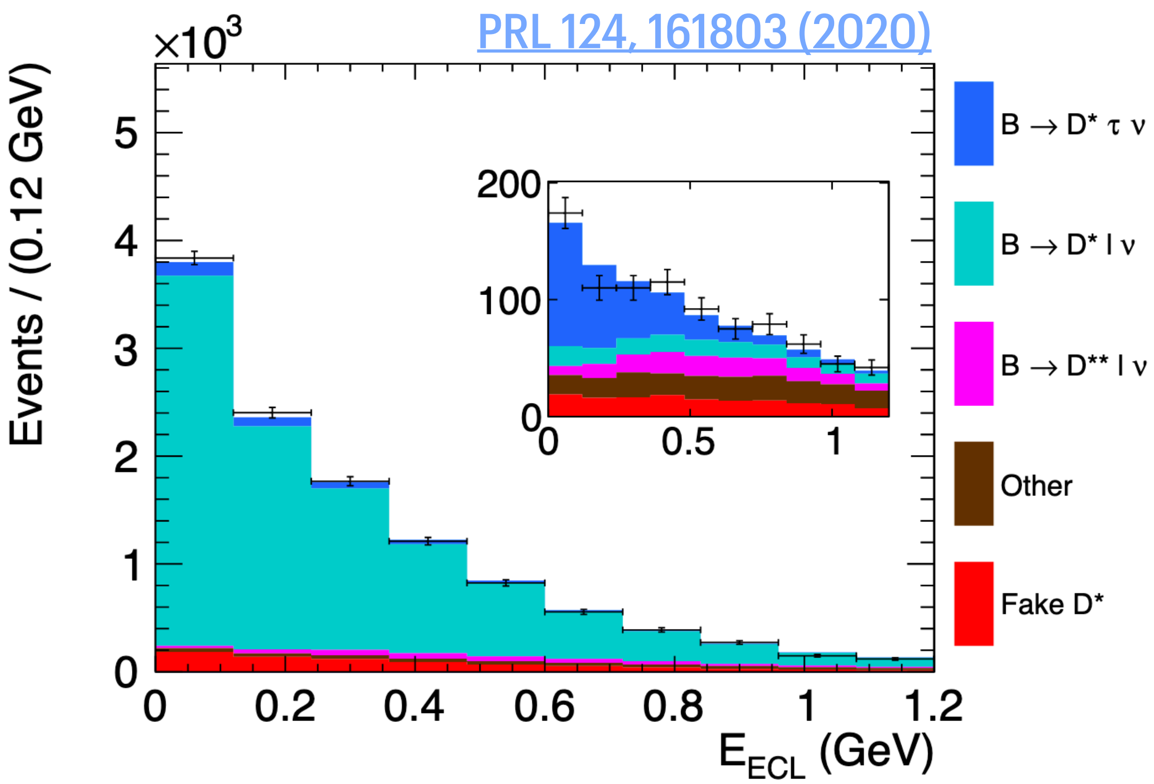
INCLUSIVE — $\mathcal{O}(10 - 100\%)$ @ $\leq 1\,\%$ purity

EXCLUSIVE SEMILEPTONIC — $\mathcal{O}(2.0\%)$ @ $5\,\%$ purity



Used for

- Background filtering
- Partial kinematic info
- Flavour info



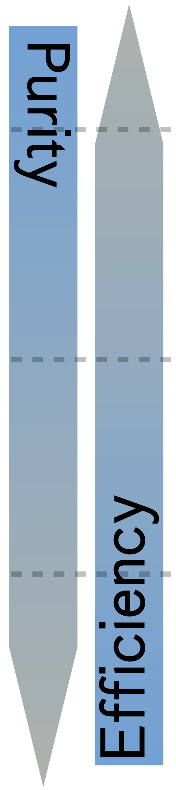
$\mathbf{E_{ECL}}$ → Sum of the energy deposits in the calorimeter that cannot be associated with the reconstructed daughters of the B_{tag} or the B_{sig}

Signal events → $\mathbf{E_{ECL}} \sim 0$

Background events → Additional neutral clusters from unreconstructed particles

☞ Talk tomorrow (Karim)

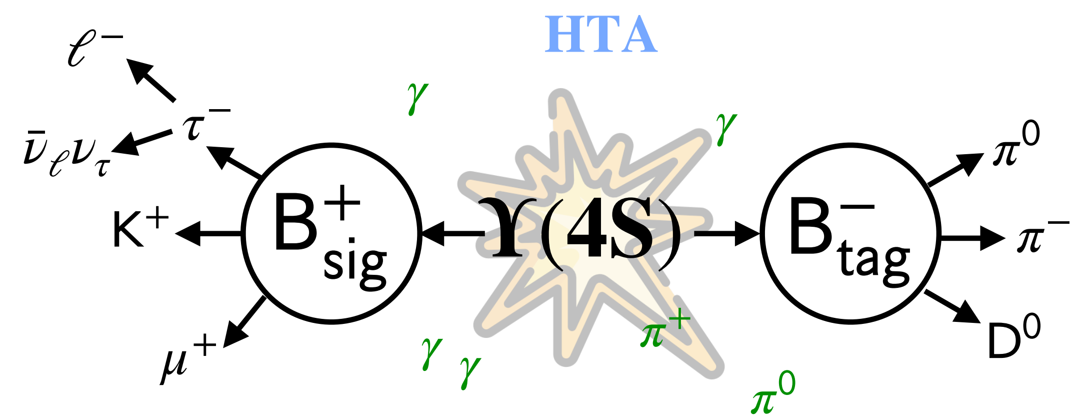
B-TAGGING FOR MISSING ENERGY

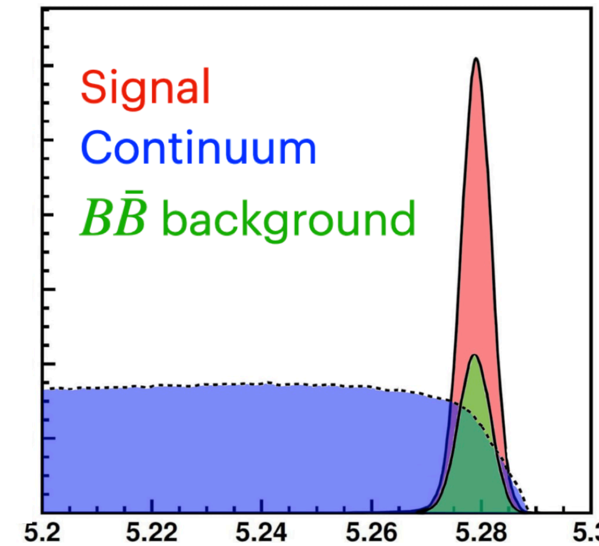


INCLUSIVE — $\mathcal{O}(10-100\%)$ @ $\leq 1\,\%$ purity

EXCLUSIVE SEMILEPTONIC — $\mathcal{O}(2.0\%)$ @ $5\,\%$ purity

EXCLUSIVE HADRONIC — $\mathcal{O}(0.5\%)$ @ $10\,\%$ purity



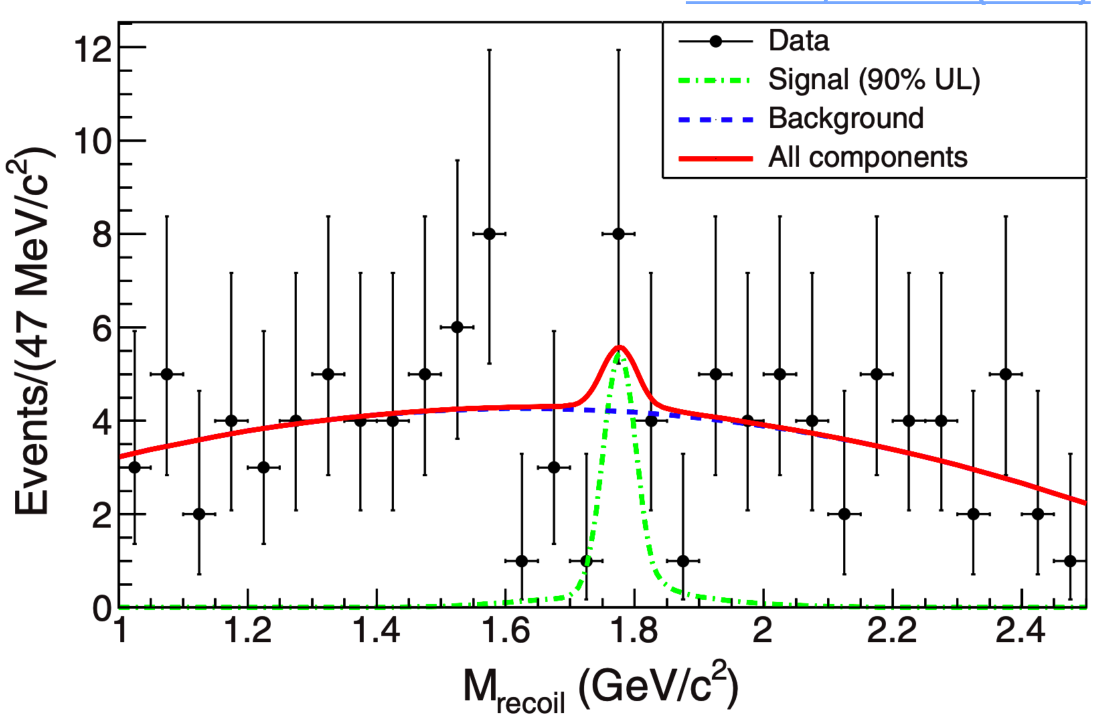


M_{bc} (GeV/c²) $= \sqrt{s/4 - p^{*2}_{B_{tag}}}$

Used for

- Background filtering
- Flavour info
- Full kinematic info

PRL 130, 181803 (2023)



The reconstruction of the B_{tag} allows to know the 3-momentum of the B_{tag} on an event-by-event basis with excellent resolution

$$M_{recoil} = \left[m_B^2 + m_{K\ell}^2 - 2(E^*_{beam}E^*_{K\ell} + |\vec{p}^*_{B_{tag}}||\vec{p}^*_{K\ell}|\cos\theta)\right]^{1/2}$$

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

$B \to K^{(*)}\nu\bar{\nu}$ SEARCH

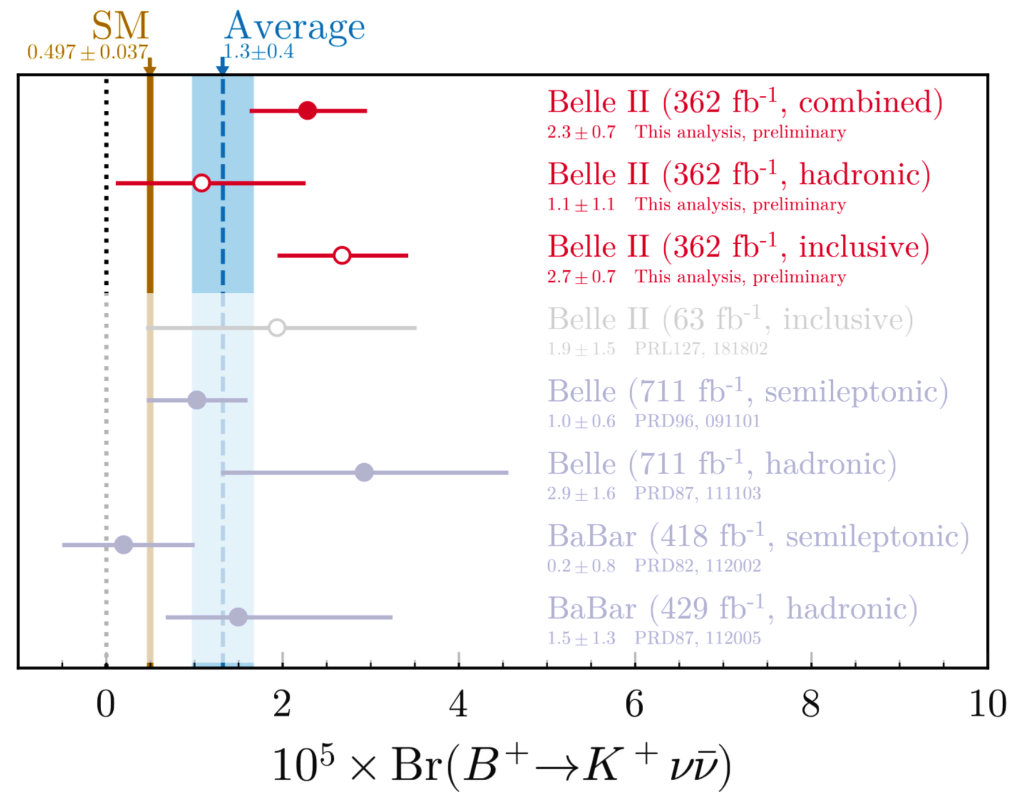
3.5 σ from background-only hypothesis

2.7 σ from SM-exp

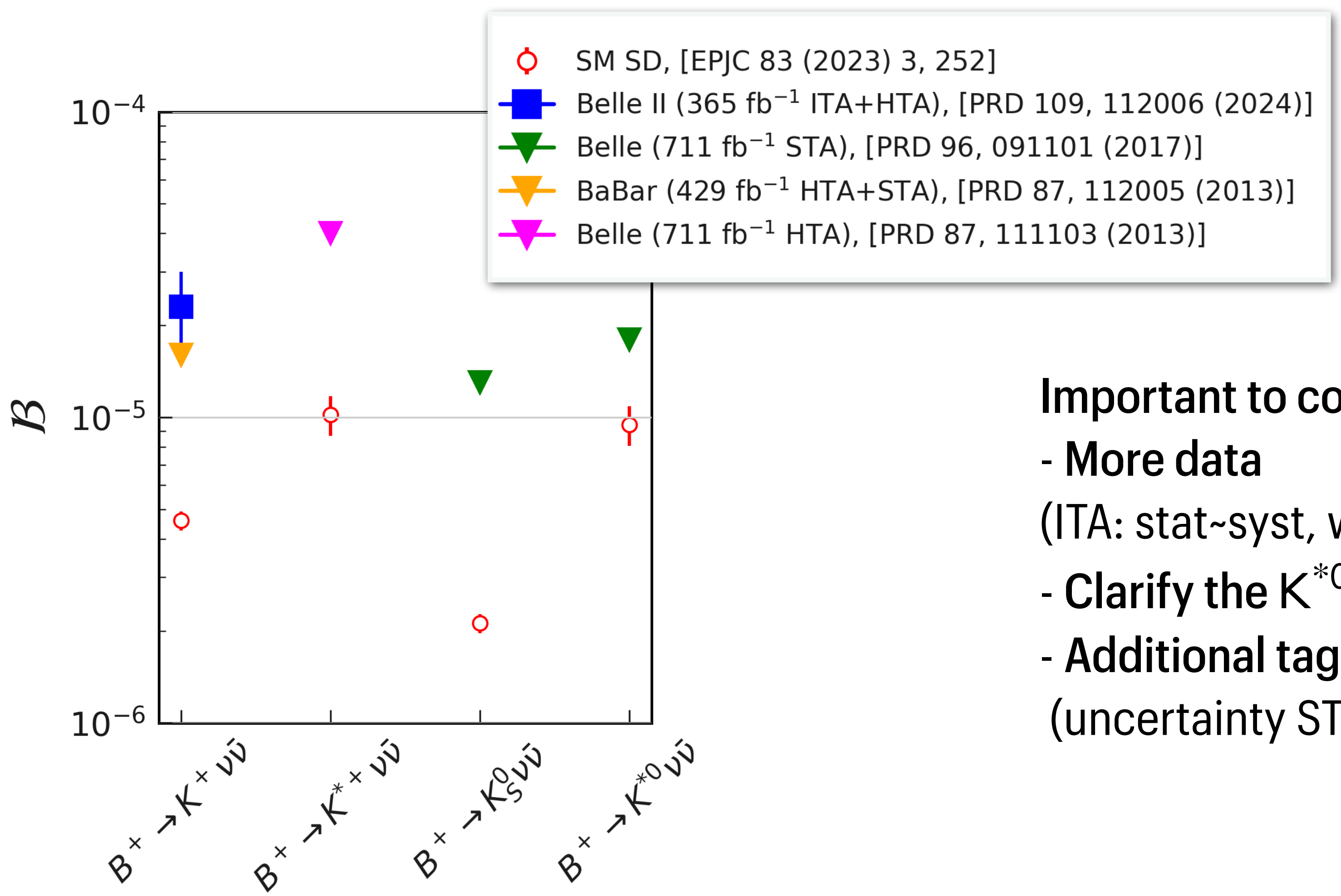
$(2.3 \pm 0.7) \times 10^{-5}$ **(combined)**

$(1.1^{+1.2}_{-1.0}) \times 10^{-5}$ **(hadronic)**

$(2.7 \pm 0.7) \times 10^{-5}$ **(inclusive)**



- Belle II showed the **first evidence of $B^+ \to K^+\nu\bar{\nu}$ decays** using hadronic and inclusive B-tagged samples [PRD 109, 112006 (2024)]



Important to corroborate the 2023 result

- More data

(ITA: stat~syst, with some syst being statistical in nature)

- Clarify the $K^{*0}\nu\bar{\nu}$

- Additional tagging approaches

(uncertainty STA~ITA)

☞ **Talks on Wednesday (Olcyr, Martin, Michael)**

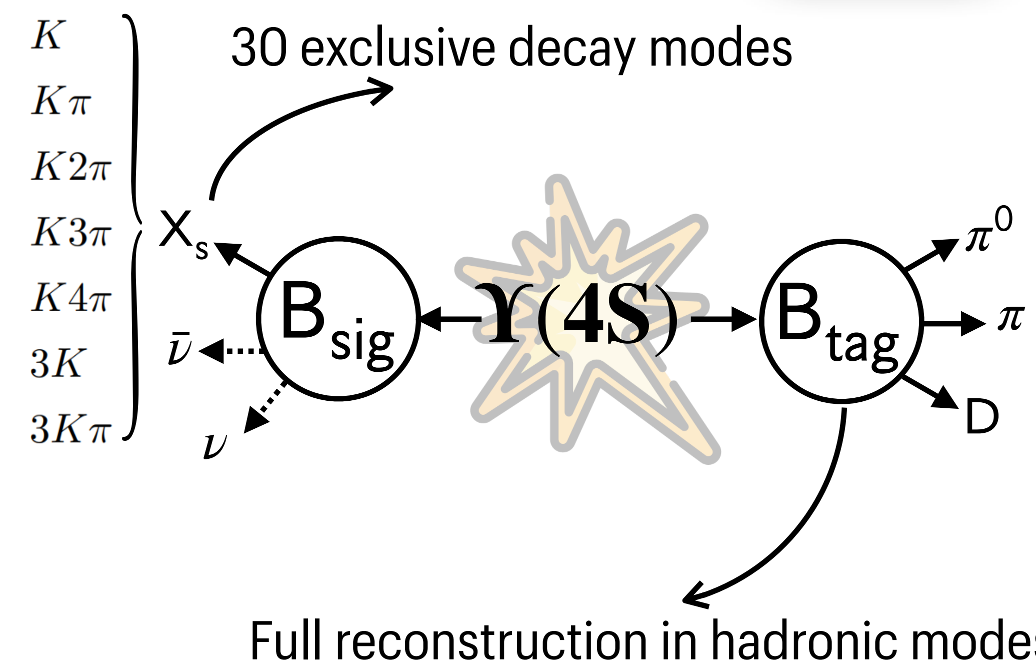
$B \to X_s \nu\bar{\nu}$ SEARCH

With sum-of-exclusive method

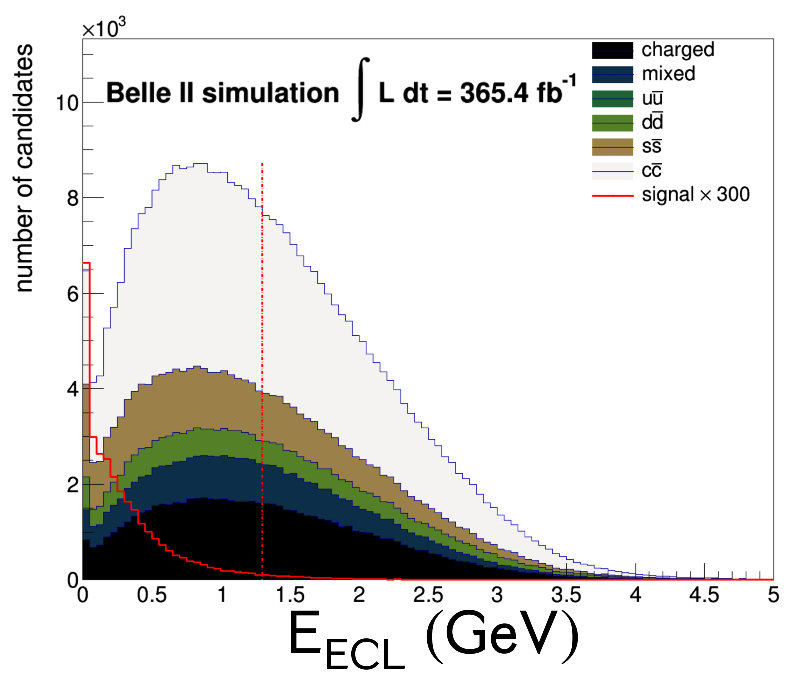
Preliminary, paper in preparation

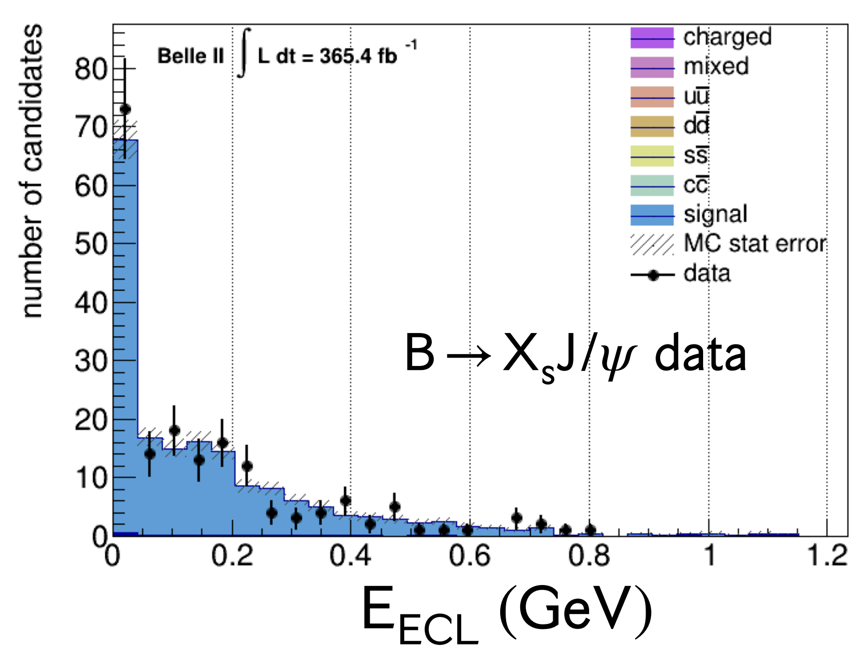
Belle II 365 fb^{-1}

- $\mathscr{B}_{SM}(B \to X_s \nu\bar{\nu}) = (2.9 \pm 0.3) \times 10^{-5}$ [1]
  - **Theoretically clean and complementary to exclusive searches)** [2]
- Only measurement from ALEPH $\mathscr{B}_{UL} < 6.4 \times 10^{-4}$ [3]
- **Only possible at e⁺e⁻ experiments**



- Multivariate analysis (BDT) for background suppression ↦ output $\mathscr{O}$
- Calibrate simulations and obtain systematic uncertainties with
  - **Off-resonance data** ↦ $q\bar{q}$ (q = u, d, s, c) backgrounds
  - $B \to X_s J/\psi(\to \mu^+\mu^-)$ ↦ BDT efficiency and feature validation
  - **$\mathscr{O}$ and M_{bc} sidebands** ↦ $B\bar{B}$ background normalisation (syst. unc.)





[1] JHEP02(2015)184
[2] JHEP12(2021)118
[3] EPJC 19,2130227(2001)

Preliminary, paper in preparation

Belle II 365 fb^{-1}

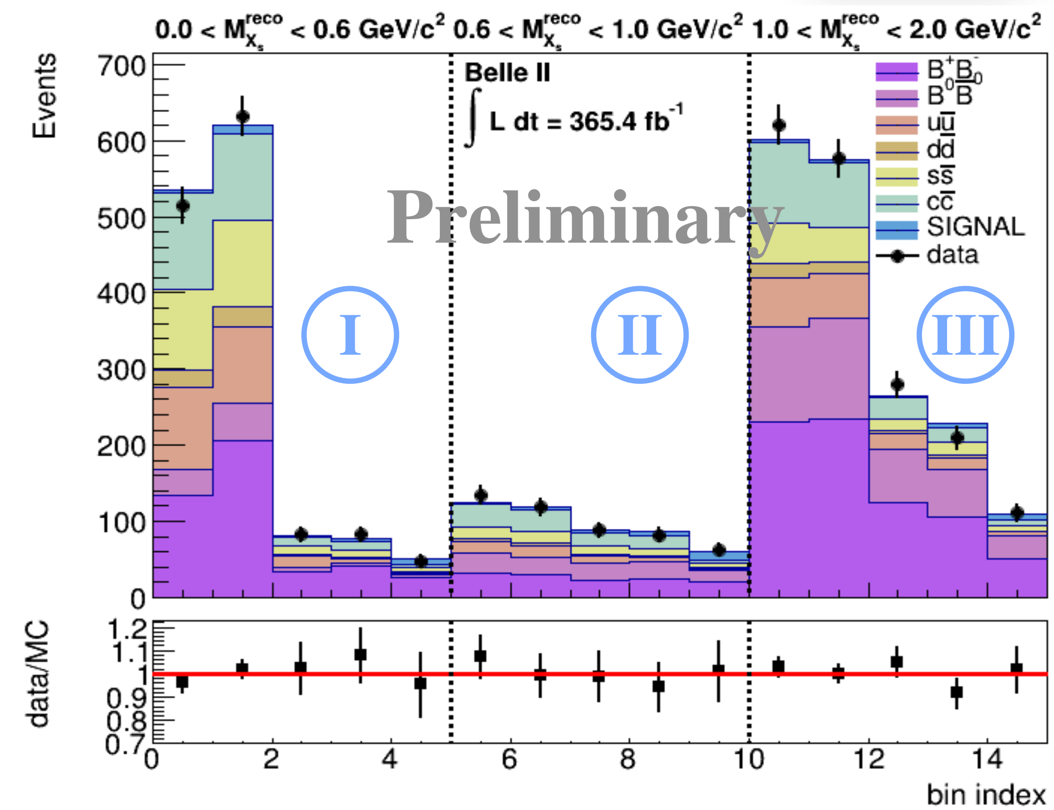
$B \to X_s \nu\bar{\nu}$ SEARCH

With sum-of-exclusive method

2D signal region $\mathcal{O} \times M^{reco}_{X_s}$ plane mapped into a 1D index

Regions I, II, III are enhanced in K, $K^*(892)$ and $(Kn\pi)$ modes

$M^{reco}_{X_s}$ to M_{X_s} (true) for the signal extraction



M_{X_s} [GeV/c^2]	ϵ	N_{sig}	$\mathcal{B}$ [10^{-5}] Central value	UL_{obs}	UL_{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

*Compatible with the hadronically-tagged Belle II $B^+ \to K^+ \nu\bar{\nu}$

Combined

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

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

Most stringent UL on the inclusive rate

- Finite size of the MC samples used for the templates
- ±20% background normalisation from M_{bc} and $\mathcal{O}$ sidebands
- Uncertainties on B_{sig} decay modes
- Non-resonant M_{X_s} threshold (set at 1.1 GeV/c^2)

☞ Talk on Wednesday (Jack)

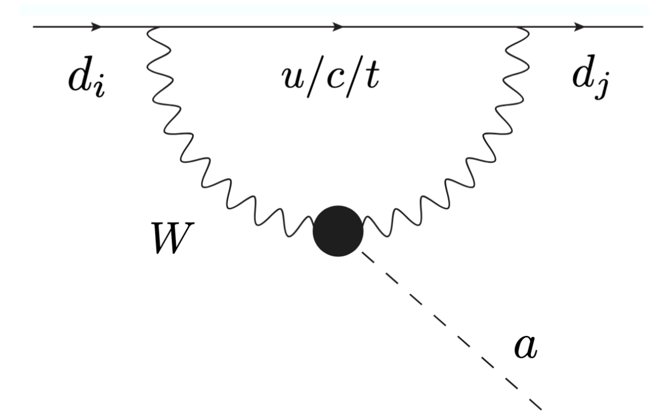
$B^+ \to K^+ X(\to \text{invisible})$

Preliminary, paper in preparation

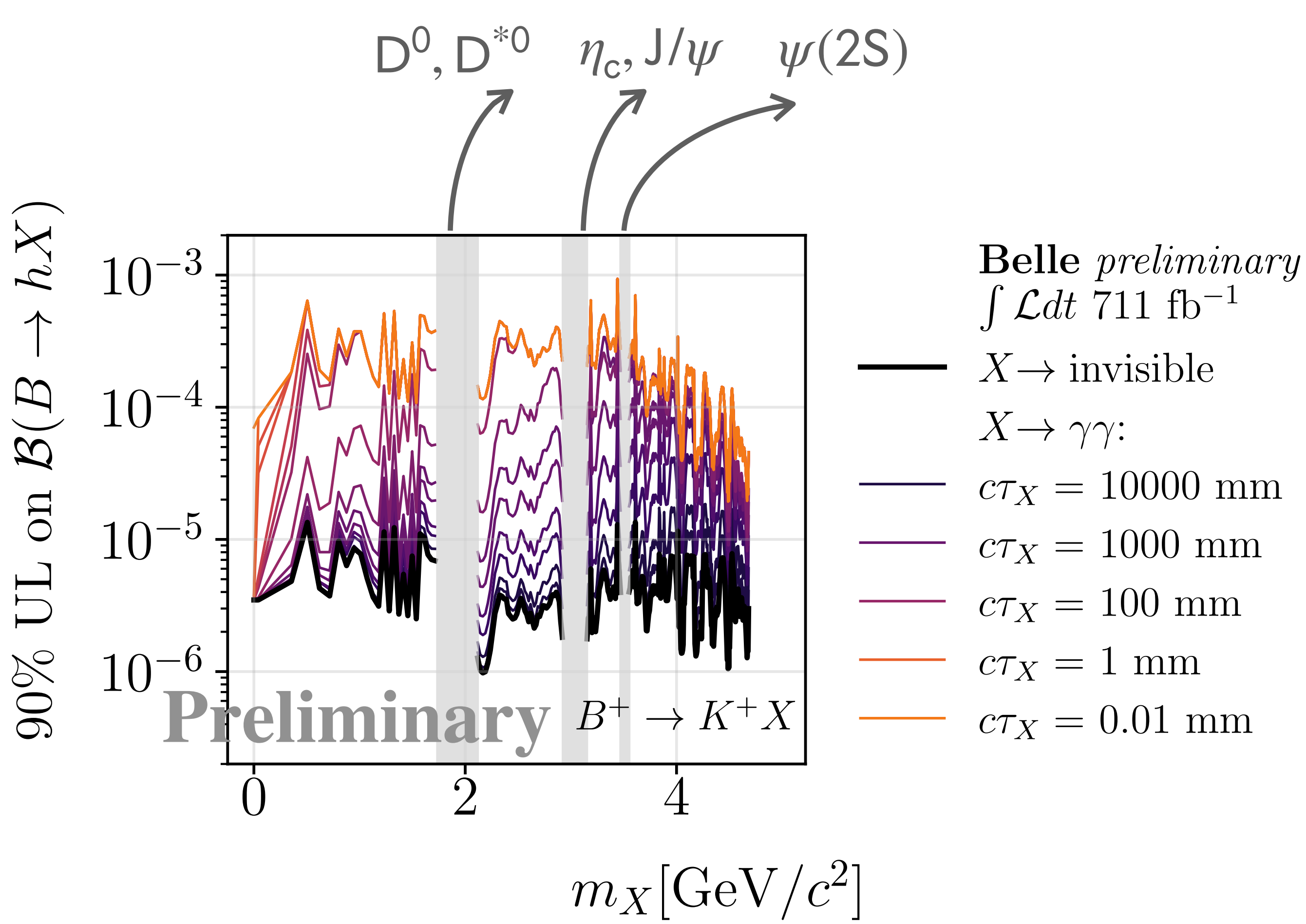
BELLE 711 fb^{-1}

- **Search for $B^+ \to \{\pi^+, K^+, D_s^+, p\}X$ and $B^0 \to D^0 X$**

  X invisible because
  - it decays outside of detector ($X \to \gamma\gamma$)
  - it decays to dark sector ($X \to \chi\chi$)
- **Optimised for the two-body** decay kinematics
- **B_{tag} in hadronic decay modes**
- Signal extracted from the fits to the **momentum of the hadron in the signal B rest frame**
- Narrow SM resonances are vetoed
- **Limits reinterpreted to several model couplings**



PRL118,111802

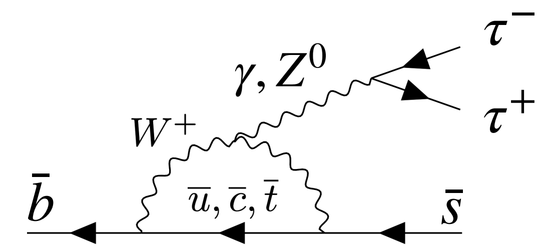


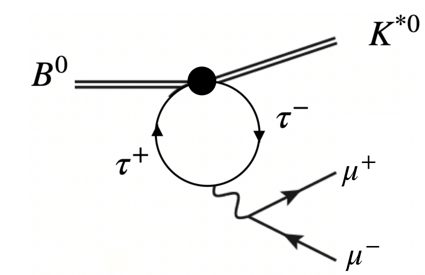
☞ Talk on Wednesday (Patrick)

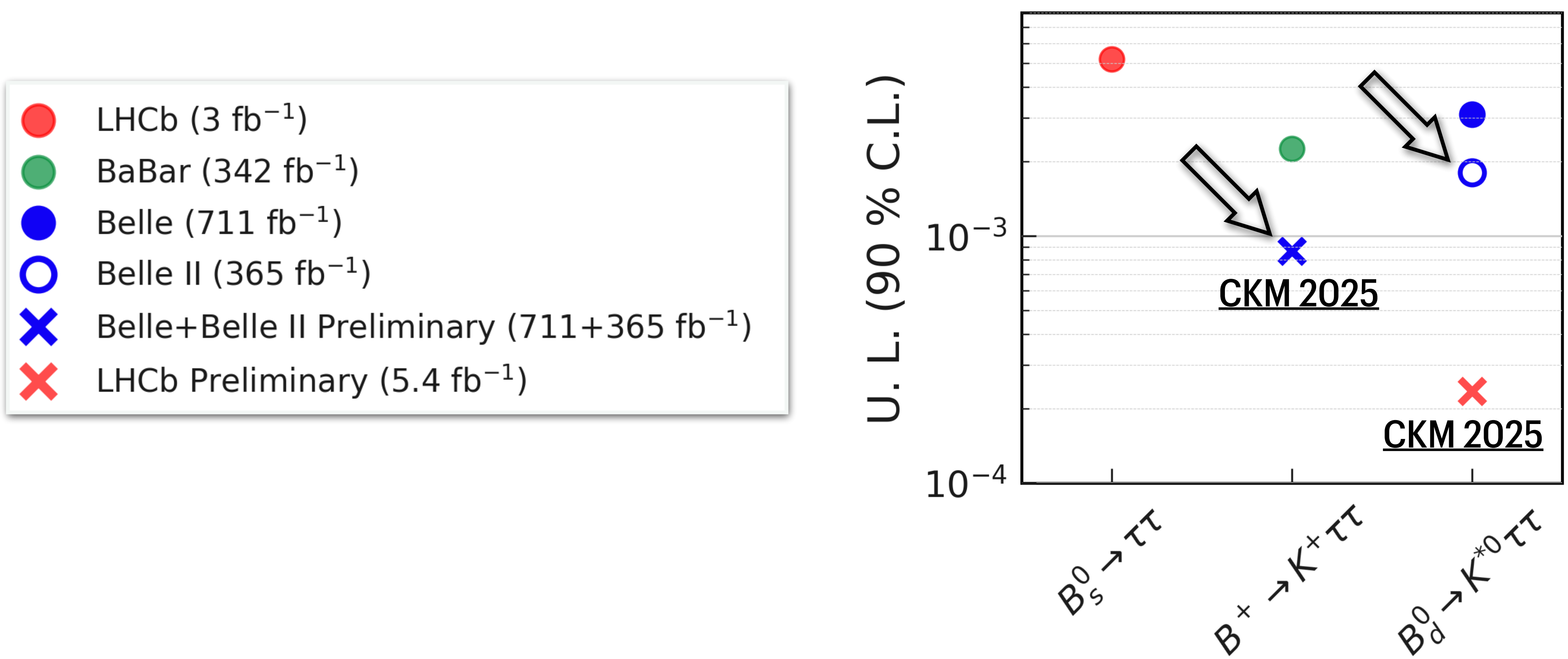
$b \to s\tau\bar{\tau}$

EXPERIMENTAL STATUS

- $\mathscr{B}_{\rm SM} \sim \mathcal{O}(10^{-7})$ PRD 107, 014511 (2023)
- **Before 2025, very few experimental results and upper limits ~ $\mathcal{O}(10^{-3})$**
- **Pre-CKM 2025**
  - Belle II $B^0 \to K^{*0}\tau\tau$ result improved Belle's (×2) [2504.10042 PRL accepted]
  - Indirect measurement on $\mathscr{C}_9^{\tau\tau}$ from LHCb in $B^0 \to K^{*0}\mu\mu$
- **CKM 2025:**
  - First $B^+ \to K^+\tau\tau$ (Belle and Belle II) result UL@90%CL = 8.7×10^{-4}
  - First direct search at LHCb $B^0 \to K^{*0}\tau\tau$ result UL@90%CL ~ 2.4×10^{-4}
- **Limits for $B \to P\tau\tau$ and $B \to V\tau\tau$ provide complementary information in constraining NP** ☞ Next talk (Claudia)



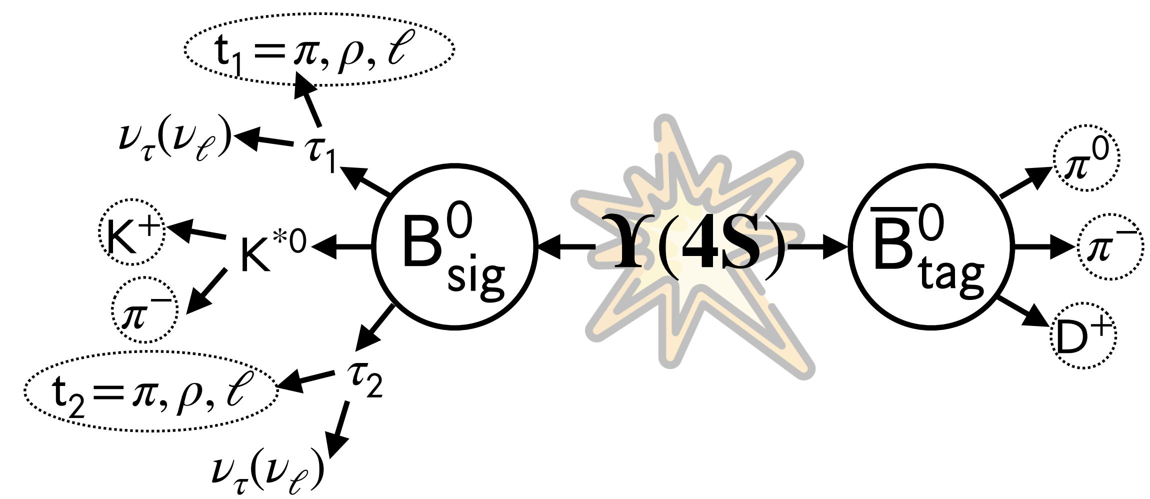




$B^0 \to K^{*0}\tau\bar{\tau}$ SEARCH

2504.10042, PRL accepted
HEPData

Belle II
365 fb^{-1}

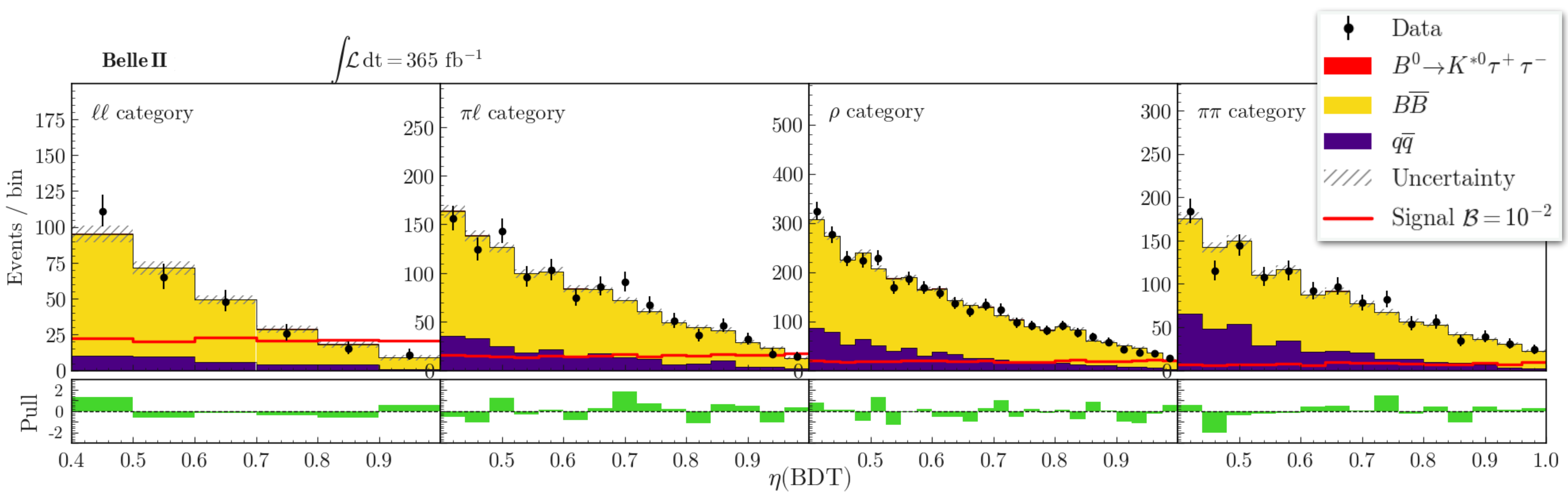


Strategy

- Hadronic B-tagging
- Multivariate analysis based on missing energy, residual energy in calorimeter, q^2, K^{*0} properties, ...
- Calibration and validation:
  - off-resonance sample
  - same-flavor B^0B^0 sample
  - $B^0 \to K^{*0} J/\psi(\mu\mu)$
- **Simultaneous fit to BDT output in four $\tau\tau$ categories: $\ell\ell$, $\ell\pi$, $\pi\pi$, ρX**

$\mathcal{B}(B^0 \to K^{*0}\tau\tau) = [-0.15 \pm 0.86\,(\text{stat}) \pm 0.52\,(\text{syst})] \times 10^{-3}$

$\mathcal{B}(B^0 \to K^{*0}\tau\tau) < 1.8 \times 10^{-3}$ (90 % CL)



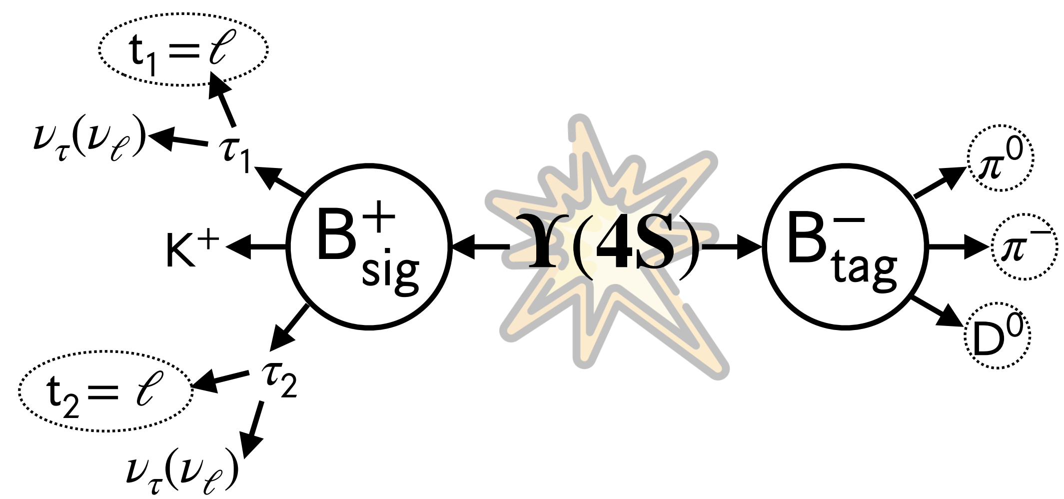
$B^+ \to K^+\tau\bar{\tau}$ SEARCH

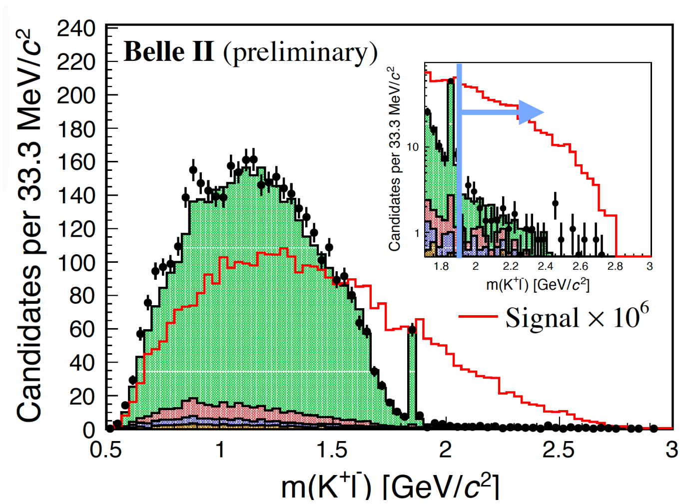
Preliminary, paper in preparation

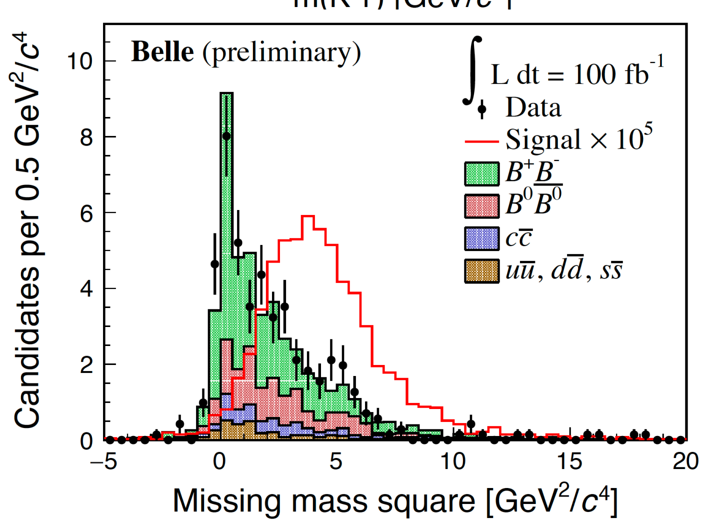
BELLE 711 fb^{-1} Belle II 365 fb^{-1}

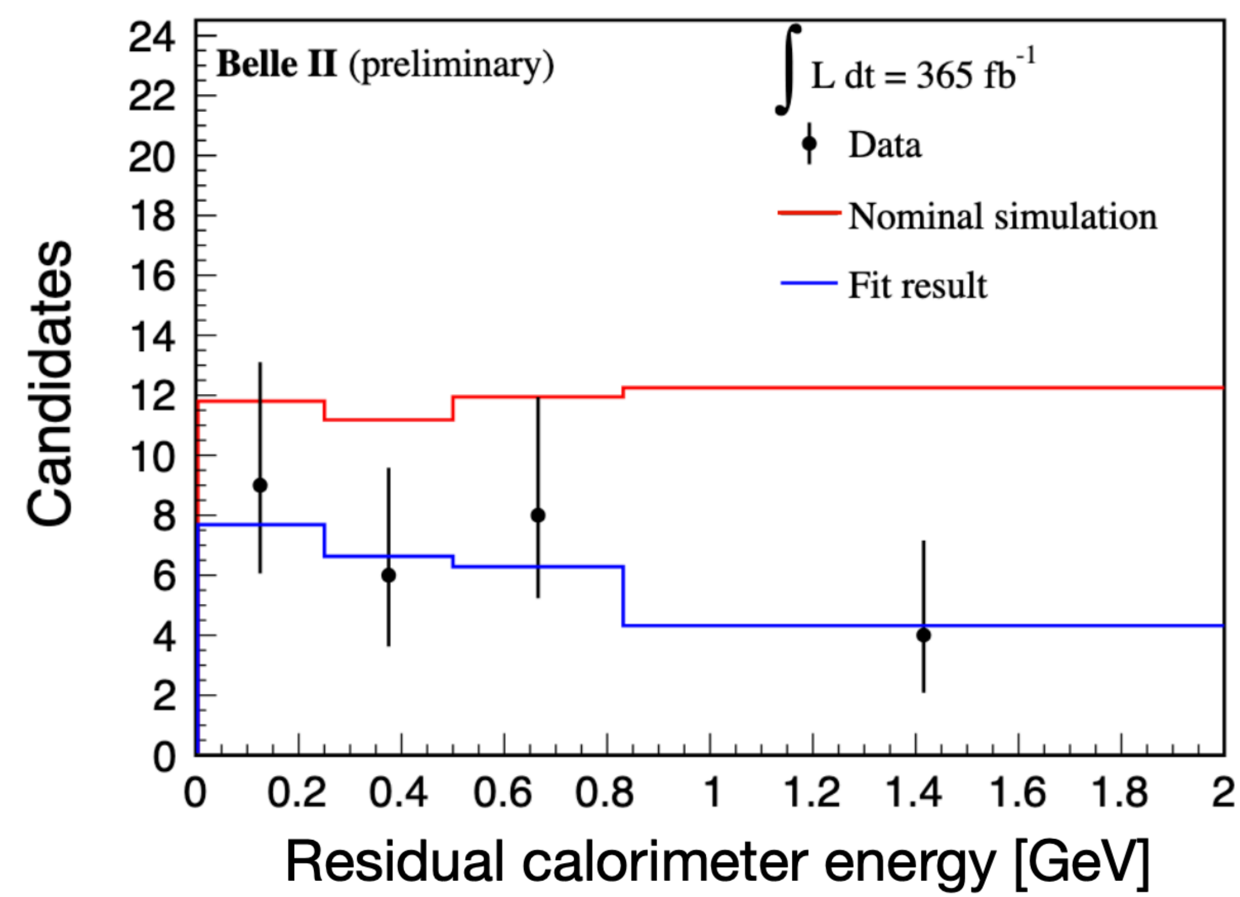
Strategy

- Hadronic B-tagging
- Focus on **leptonic τ decays** and background-depleted region above D-mass, **m(K⁺ℓ⁻) > 1.9 GeV**
- Optimise selection on **lepton momentum, missing mass and signal window of E_{ECL}**
- E_{ECL} shape validation in side bands. **Residual mismodeling cured by fitting the simulation to match data in the control samples and extrapolating it into the signal region**









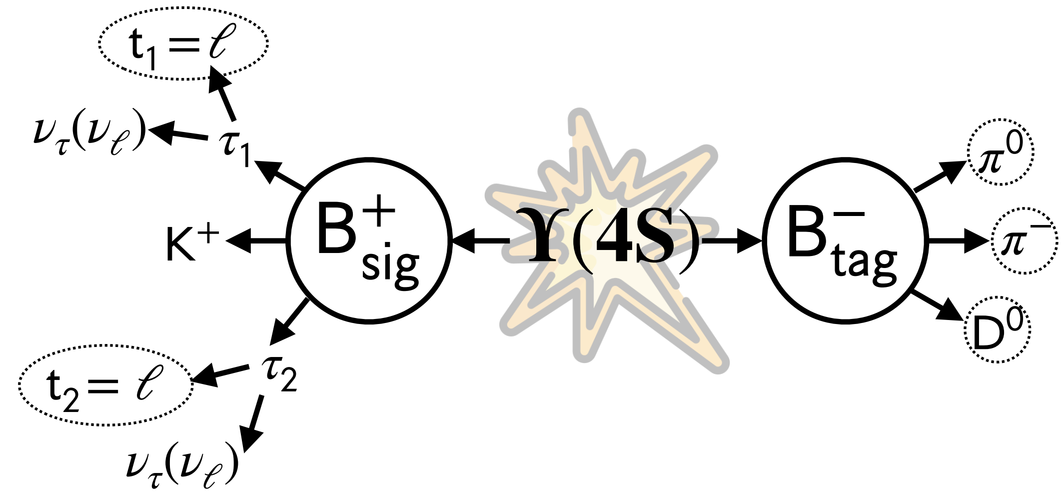
$B^+ \to K^+\tau\bar{\tau}$ SEARCH

Preliminary, paper in preparation

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

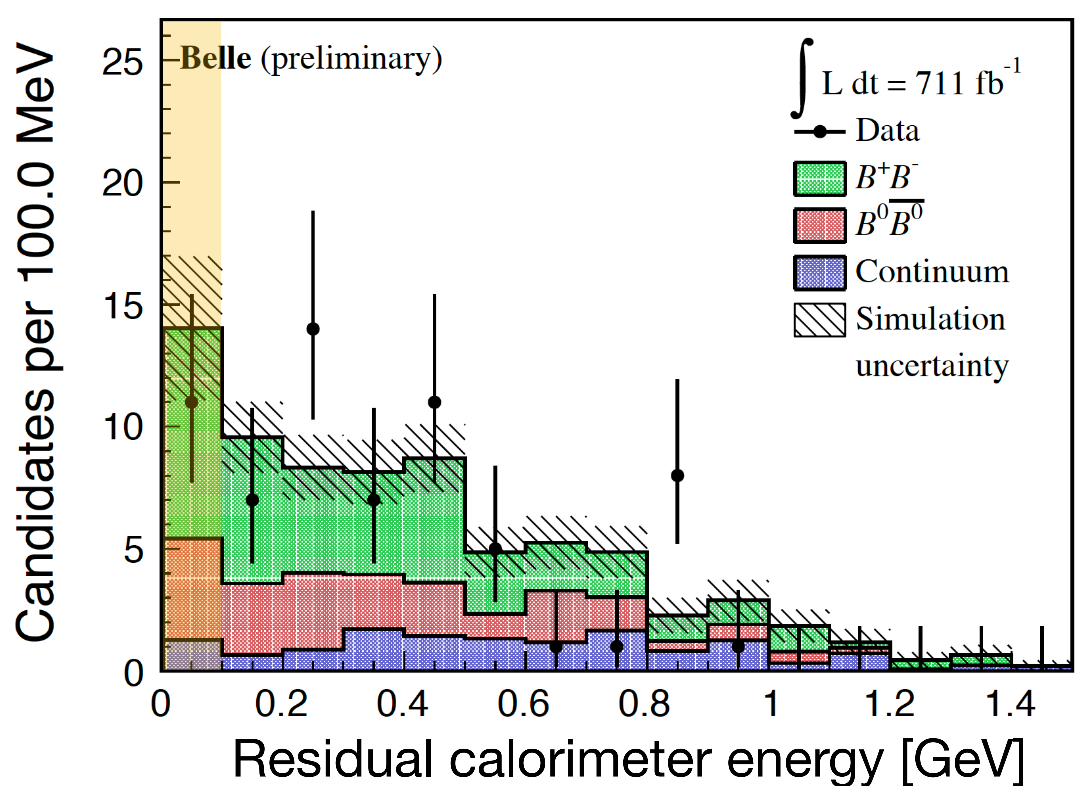
Strategy

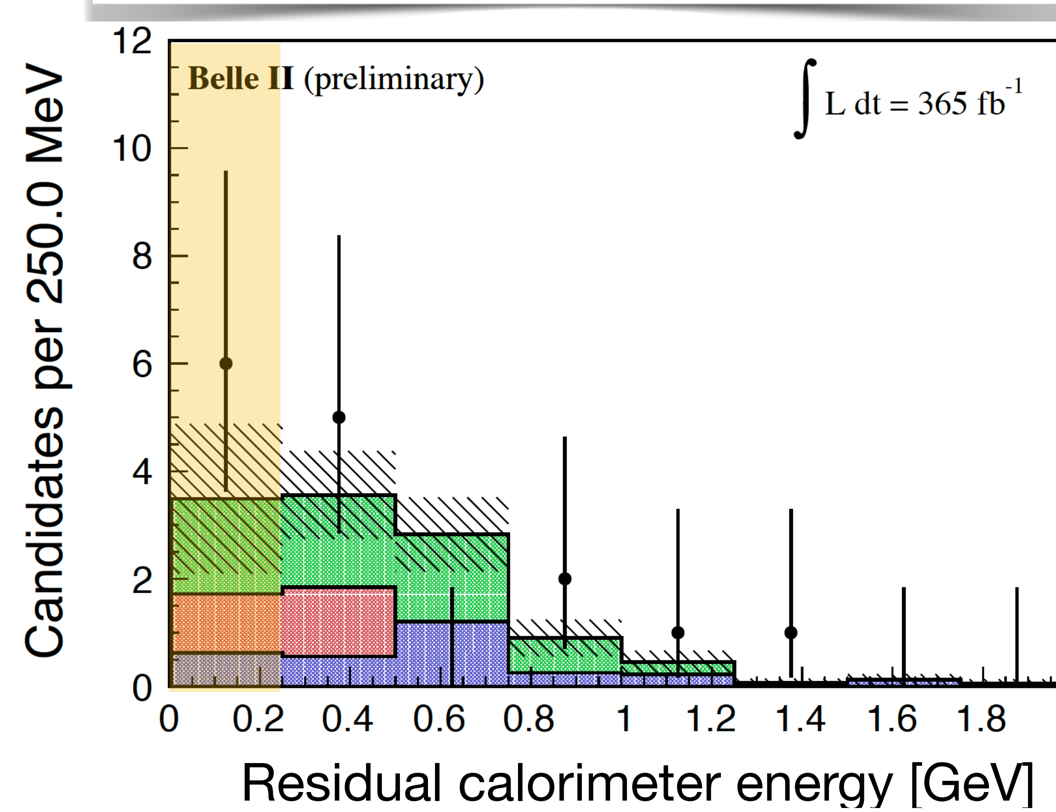
- Hadronic B-tagging
- Focus on **leptonic τ decays** and background-depleted region above D-mass, **m($K^+\ell^-$) > 1.9 GeV**
- Optimise selection on **lepton momentum, missing mass and signal window of E_{ECL}**
- E_{ECL} shape validation in side bands. **Residual mismodeling cured by fitting the simulation to match data in the control samples and extrapolating it into the signal region**



$\mathcal{B}(B^+ \to K^+\tau\tau) = [3.13^{\pm 3.70}_{\pm 3.30}] \times 10^{-4}$

$\mathcal{B}(B^+ \to K^+\tau\tau) < 8.7 \times 10^{-4}$ **(90 % CL)**



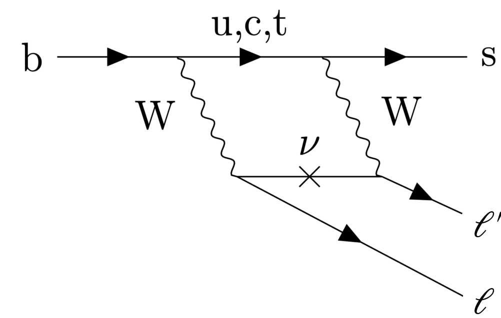


Combined fit to Belle and Belle II samples

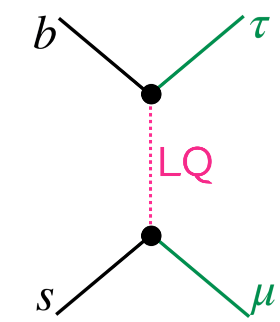
$b \to s \tau \bar{\ell}$

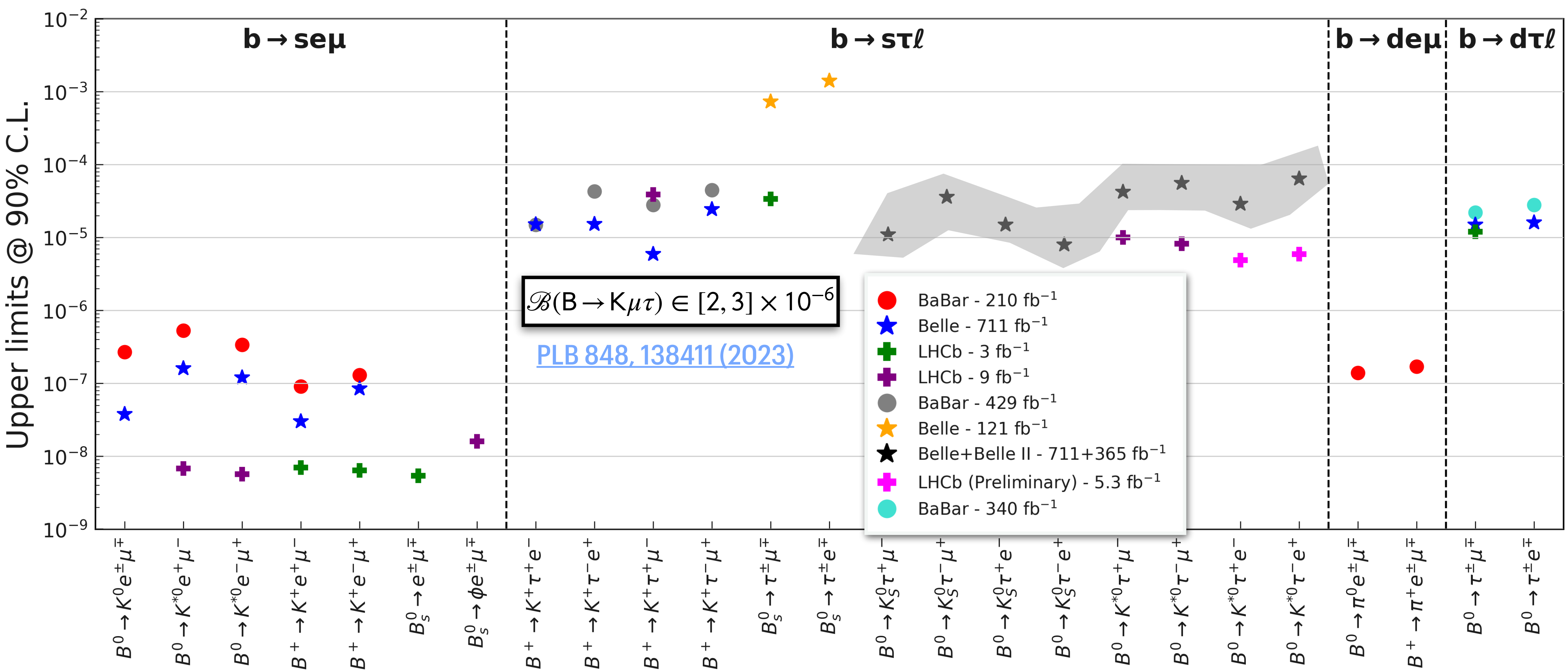
CHARGED LEPTON FLAVOR VIOLATION IN B DECAYS

- Can occur in the SM via ν mixing but highly suppressed ($\propto m_\nu^2/m_W^2$)



- NP models explaining B-related tensions can lead to sizeable LFV but must obey the constraints from other flavor observables [1602.00881, 1606.00524, 1611.06676, 1806.05689, 2103.16558, 2206.09717, ...]





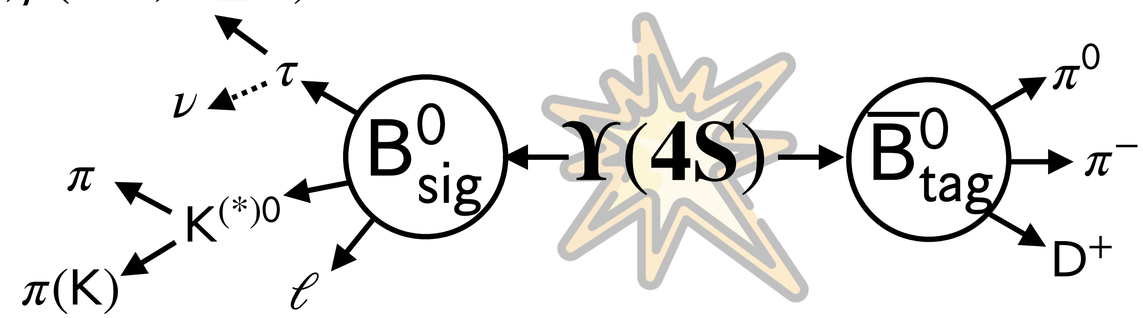
$B^0 \to K^{(*)0}\tau\ell$ SEARCHES

K^{*0}: JHEP08(2025)184
K^0_S: PRL 135 (2025) 4, 041801

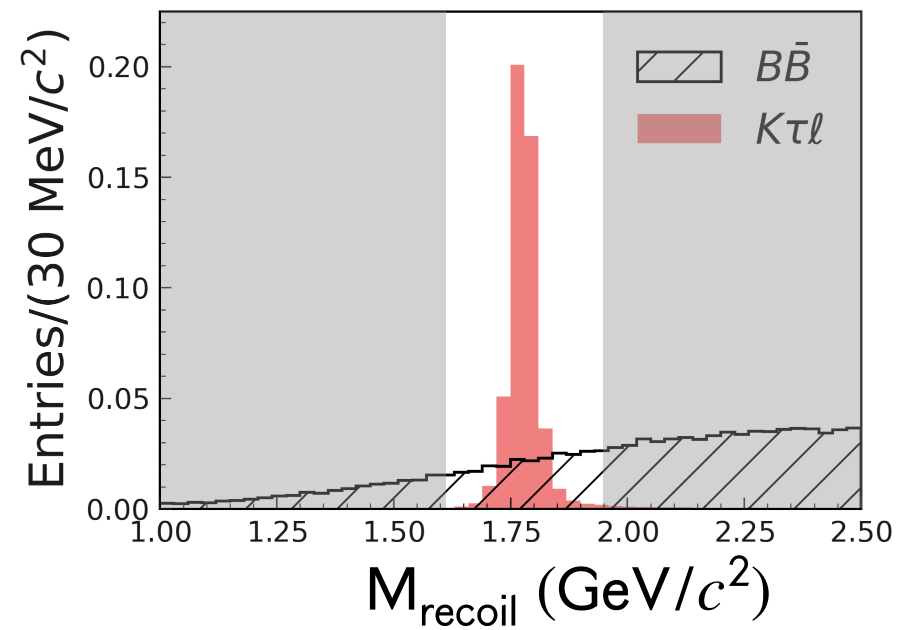
BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

- K^0 and K^{*0} probe **different NP mediators**
- Similar analysis strategy for the two modes
  1. Hadronic B-tagging and Belle+Belle II datasets
     ↦ Signal extraction from fit to the recoil mass
     Excellent resolution for signal
     No peaking backgrounds, even for irreducible contributions like $B^0 \to D_s^-(\tau^-\bar{\nu})K^{(*)0}\ell^+\nu$

$t_\tau = \ell\nu\bar{\nu}, \pi, \rho(n\pi^\pm, n \leq 3)$



$$M^2_{recoil} = (p_{e^+e^-} - p_\ell - p_K - p_{B_{tag}})^2$$
$$= M^2_{K\ell} + m^2_B - 2(E_{K\ell}\sqrt{s}/2 + \vec{p}_{B_{tag}} \cdot \vec{p}_{B_{K\ell}})$$



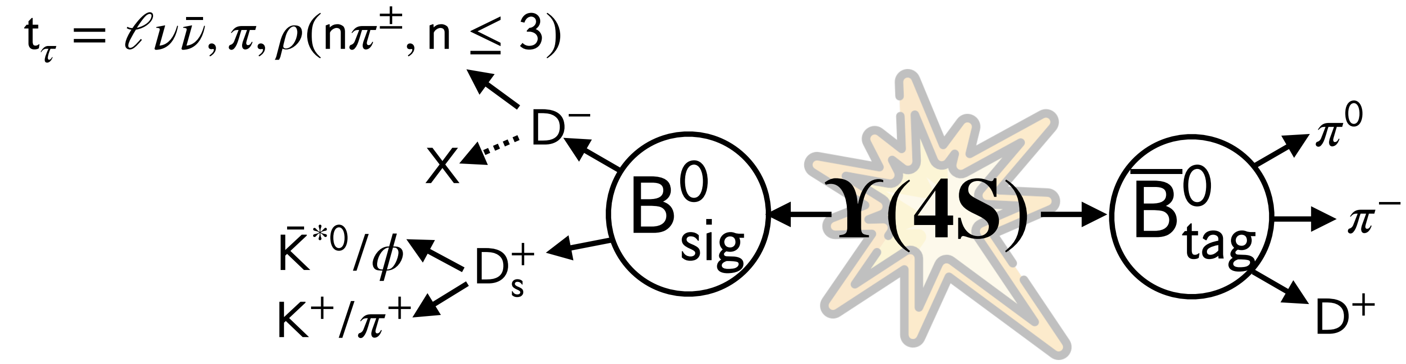
$B^0 \to K^{(*)0}\tau\ell$ SEARCHES

K^{*0}: JHEP08(2025)184
K_S^0: PRL 135 (2025) 4, 041801

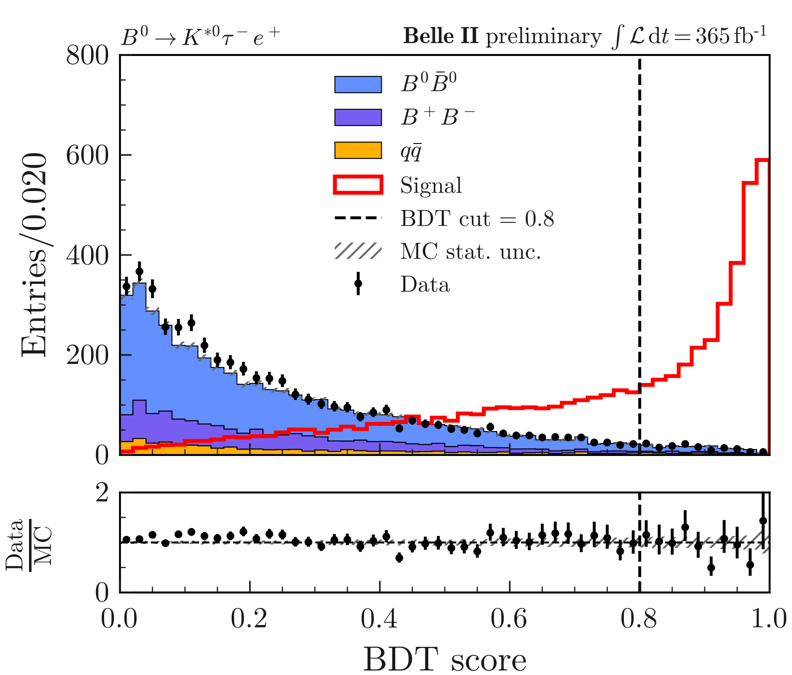
BELLE 711 fb^{-1} | Belle II 365 fb^{-1}

- K^0 and K^{*0} probe **different NP mediators**
- Similar analysis strategy for the two modes

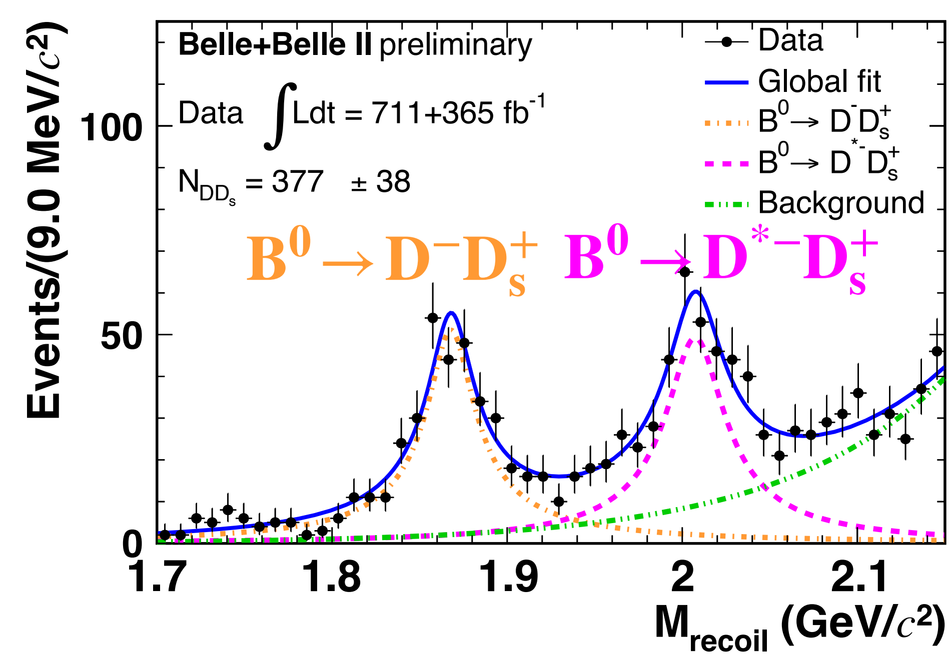
1. **Hadronic B-tagging and Belle+Belle II datasets**
   ↦ Signal extraction from fit to the recoil mass
   Excellent resolution for signal
   No peaking backgrounds, even for irreducible contributions
   like $B^0 \to D_s^-(\tau^-\bar{\nu})K^{(*)0}\ell^+\nu$



2. **Background suppression with BDT**
   ↦ Optimisation performed for each final state and separately for Belle and Belle II
   ↦ Agreement checked in M_{recoil} sidebands



3. **Calibration with $B^0 \to D_s^+(\to K_S K^+/\phi\pi^+)D^{(*)-}$**
   - Signal PDF
   - BDT output efficiency



$B^0 \to K^{(*)0}\tau\ell$ SEARCHES

K^{*0}: JHEP08(2025)184
K^0_S: PRL 135 (2025) 4, 041801

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

- K^0 and K^{*0} probe **different NP mediators**
- Main differences

  - $\mathbf{K^0_S}$:

  τ decays are exclusively reconstructed in their ℓ, π, ρ modes

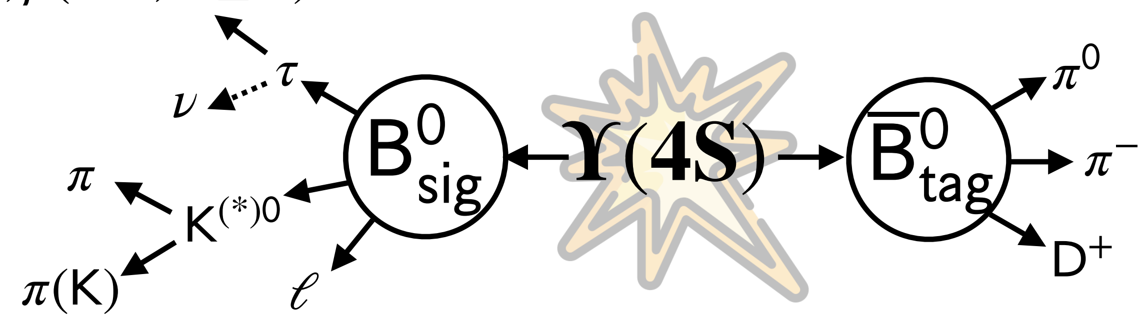
  Belle and Belle II samples are fitted together

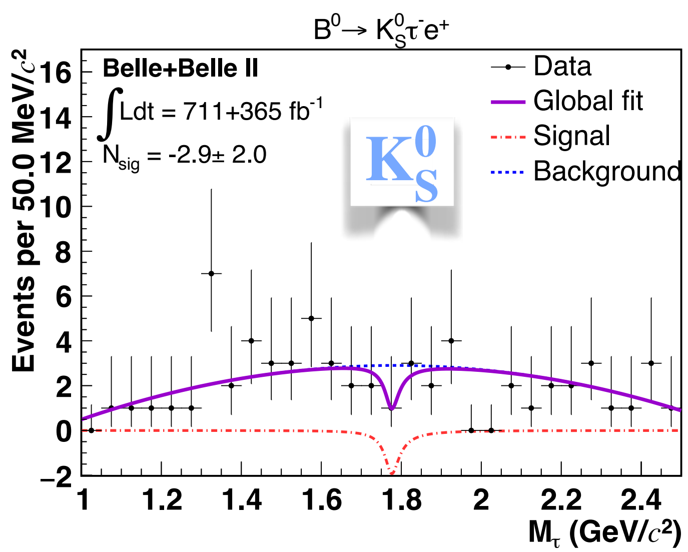
  - $\mathbf{K^{*0}}$:

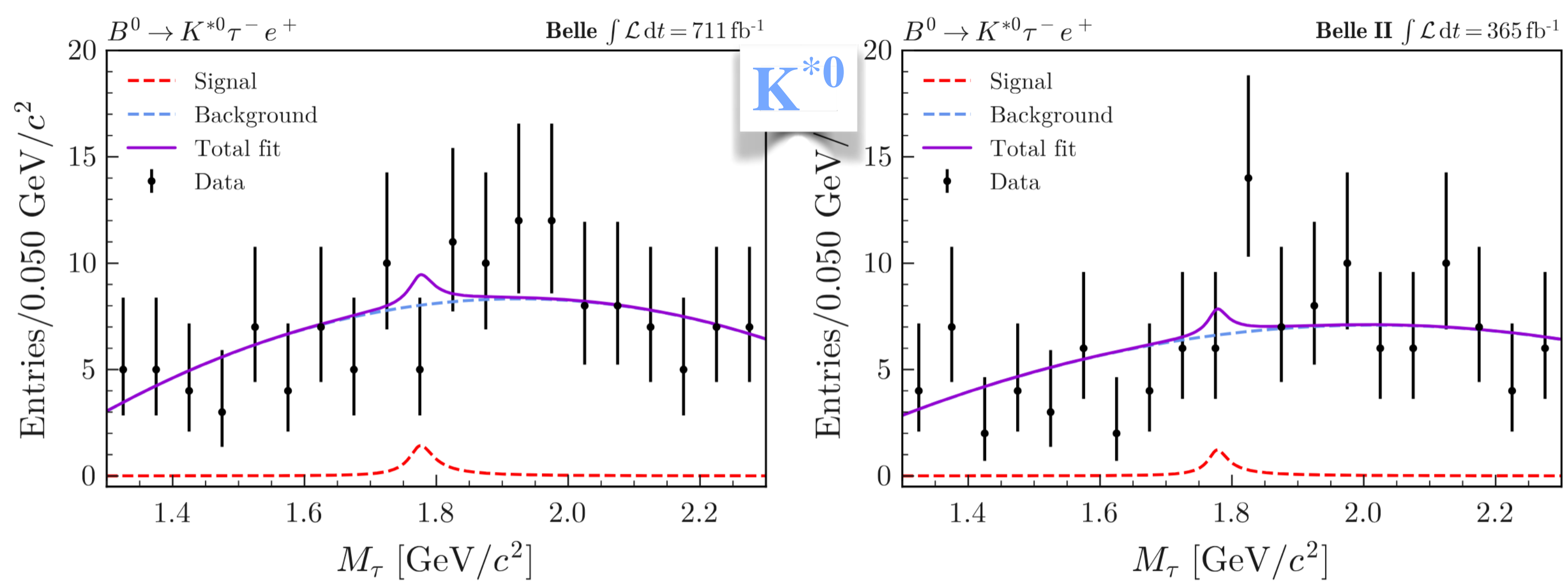
  τ decays are inclusively reconstructed in their 1,3-prong modes

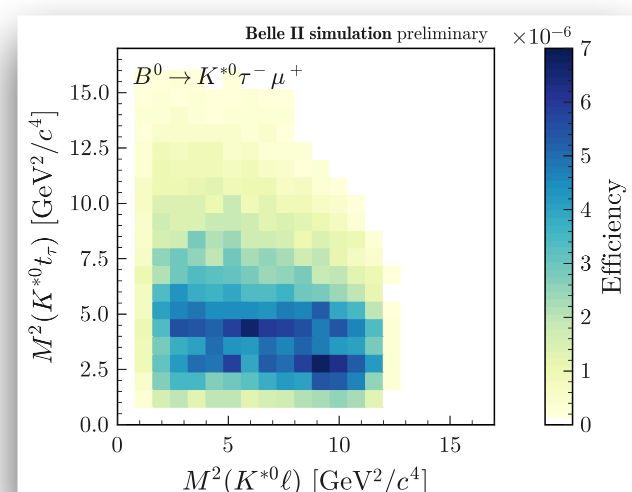
  Belle and Belle II samples are fitted simultaneously

$t_\tau = \ell\nu\bar{\nu}, \pi, \rho(n\pi^\pm, n \leq 3)$









Selection efficiency as a function of dof (q^2,...) for the phase space model allow to reinterpret the results in specific BSM models

$\Delta\mathscr{C}_9^{\tau\ell} = -\Delta\mathscr{C}_{10}^{\tau\ell} \neq 0, \quad \Delta\mathscr{C}_S^{\tau\ell} \neq 0$ HEPData

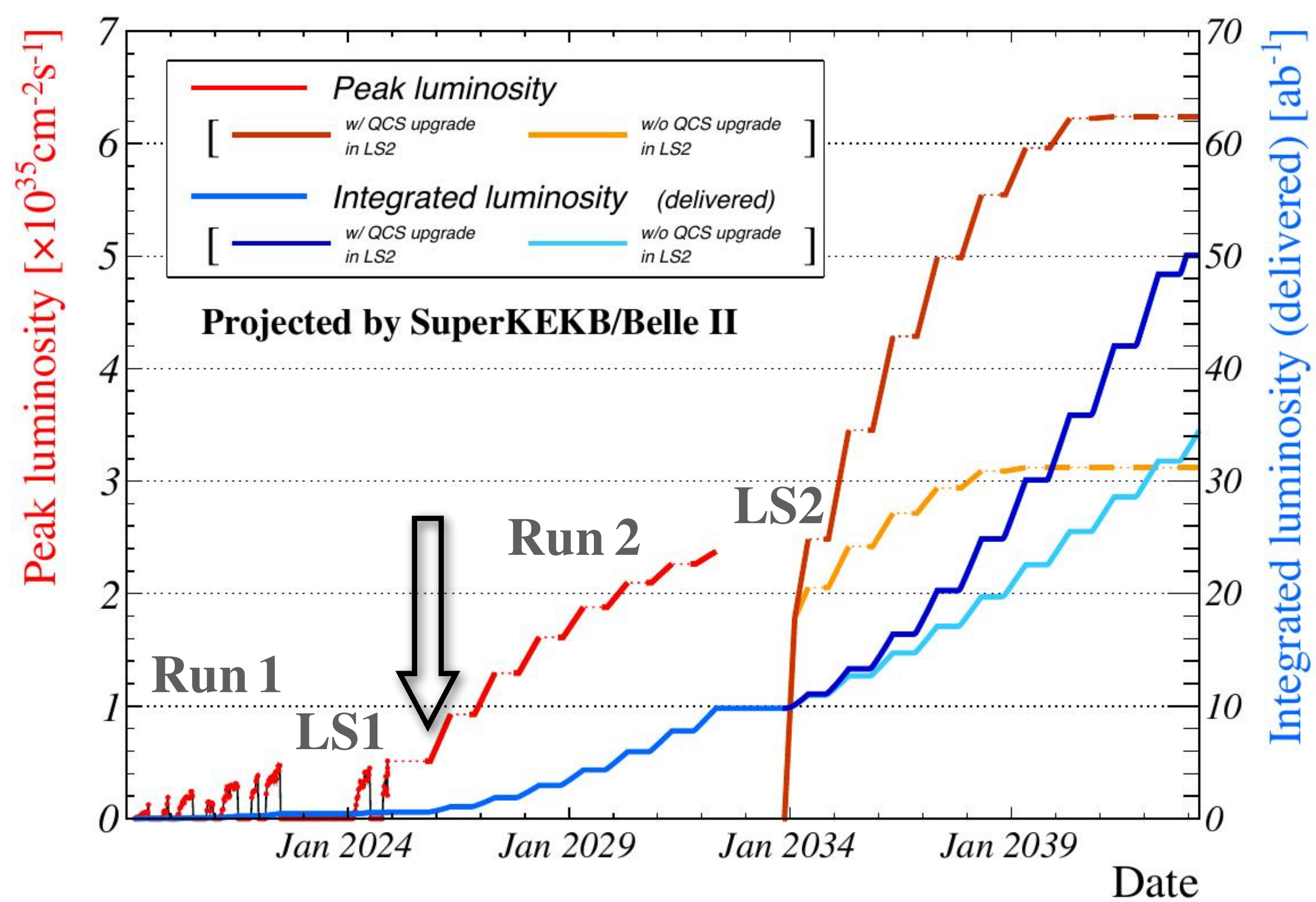
CONCLUSION&OUTLOOK

- **EW and LFV *B* decays allow to test SM and probe NP**
- **Many (Belle+)Belle II recent results, most world-leading**
- **While analysing more data and waiting for next data-taking period, working on the tools to improve sensitivity**
  - tagging approaches/new constraints
  - better control on systematics
  - new modes, b→ d, ...

  reinterpret results

☞ **Talk right next (Lorenz)!**

Thank you for your attention



A model-agnostic likelihood for the reinterpretation of the $B^+ \to K^+ \nu\bar{\nu}$ measurement at Belle II

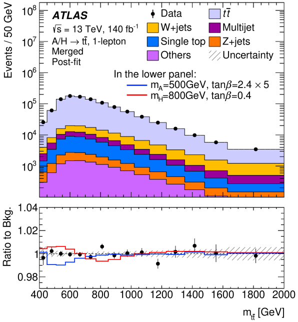
Lorenz Gärtner[1] on behalf of the Belle II Collaboration

[1] *LMU Munich*

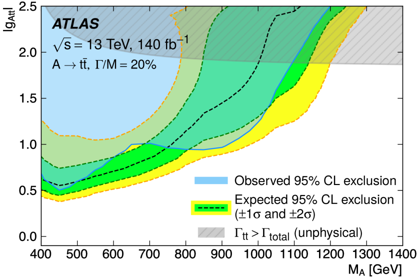
October 6, 2025

New theory, new analysis?

Measurements
How much signal do we find?



(Re)interpretations
What can we learn about theory?

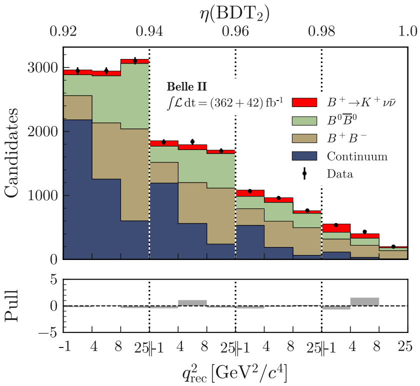


ATLAS-EXOT-2020-25

Belle II has reported

"Evidence for $B^+ \to K^+\nu\bar{\nu}$ decays"

PRD 109.112006



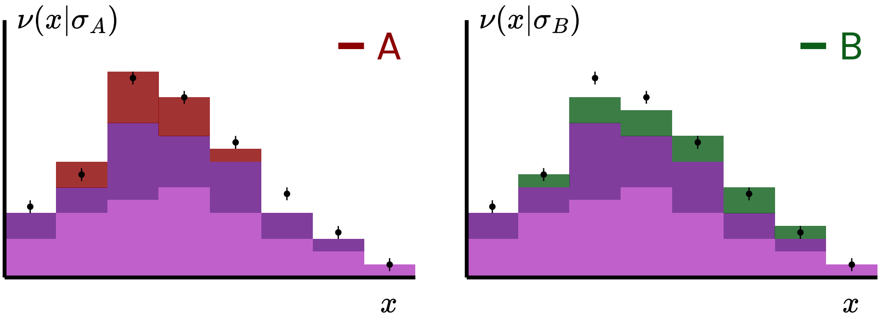
➜ 2.7 σ excess w.r.t. SM

Based on $p(n|\mathrm{SM})$

Implications for $p(n|\mathrm{NP})$?

Signal templates for new physics

$$p(n|\text{model A}) \neq p(n|\text{model B})$$



redist

A reinterpretation framework focussed on **distributability**, **speed** and **simplicity**

EPJC 84, 693 (2024)

github.com/lorenzennio/redist

Reinterpretation through reweighting

Template likelihood

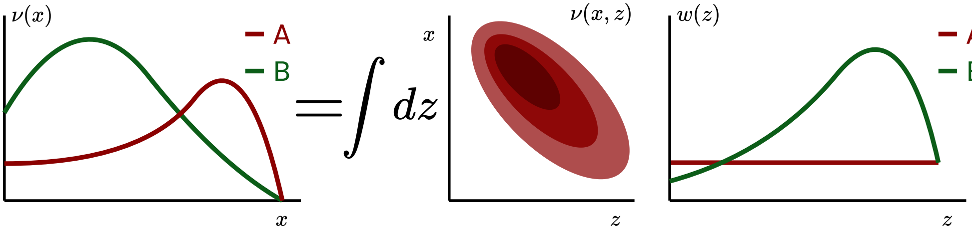
$$p(n|\nu) = \prod_{\text{bin } b} \text{Pois}(n_b|\nu_b) \qquad \nu_b = \sum_{\text{sample } s} \nu_{bs}$$

Reinterpretation through reweighting

Template likelihood

$$p(n|\nu) = \prod_{\text{bin } b} \text{Pois}(n_b|\nu_b) \qquad \nu_b = \sum_{\text{sample } s} \nu_{bs}$$

New signal templates with **joint number density $\boldsymbol{\nu(x,z)}$**



$w(z) = \sigma_B(z)/\sigma_A(z)$ – ratio of predictions
z – kinematic d.o.f., x – reconstruction variable(s)

Constraining $b \to s\nu\nu$
Weak Effective Theory (WET) Wilson coefficients*

arXiv:2507.12393

Does it work? 🤔
Yes! Proof on concept: EPJC 84, 693 (2024)

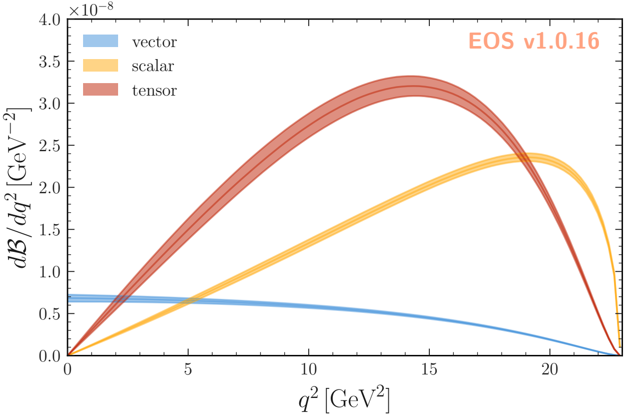
*See Wolfgang Altmannshofer's and David Marzocca's talks.

$b \to s\nu\nu$ WET decay kinematics

WET = low energy EFT including NP above the electroweak scale

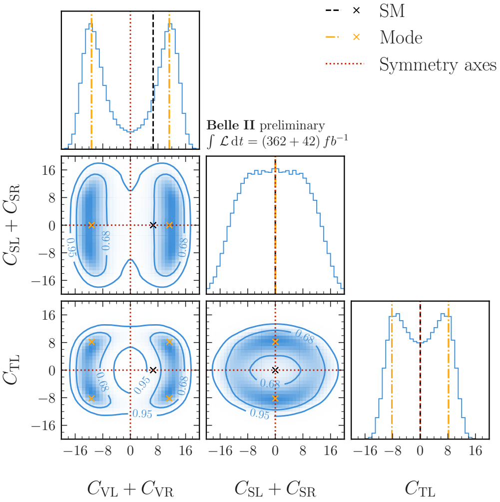
$$\frac{d\mathcal{B}}{dq^2} = \alpha(q^2)\,\left|C_{\mathrm{VL}} + C_{\mathrm{VR}}\right|^2 + \beta(q^2)\,\left|C_{\mathrm{SL}} + C_{\mathrm{SR}}\right|^2 + \gamma(q^2)\,\left|C_{\mathrm{TL}}\right|^2$$

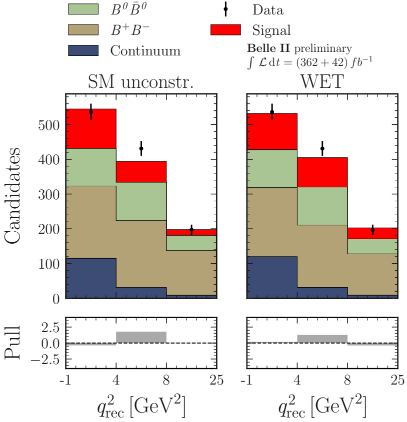
SM contains only *vector* contribution.



arXiv:2111.04327

WET marginal posterior



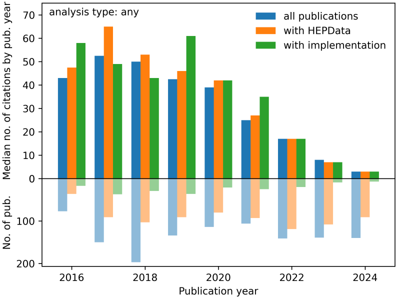


First ever direct constraints on $b \to s\nu\bar{\nu}$ WET Wilson coefficients 🥳

HEPData

Repository for publication-related High-Energy Physics data

- Data tables, likelihoods, ...
- 10.6k publications
- >4 million page views / year
- 43 Belle, 9 Belle II entries
- $B^+ \to K^+ \nu\bar{\nu}$ entry (coming soon): likelihood & joint number densities



HistFactory **Search for $B^0 \to K^{*0}\tau^+\tau^-$ decays at the Belle II experiment**

The Belle-II collaboration Adachi, I. ; Adamczyk, K. ; Aggarwal, L. ; *et al.*

ATLAS View Data

ALICE View Data

CMS View Data

LHCb View Data

Main takeaways

- Public likelihoods & reinterpretability increase analyses' impact!
- Created a **publishable, reinterpretable likelihood** for $B^+ \to K^+ \nu\bar{\nu}$
  - **Bias-free BSM inference**, reproducibility, combinations, ...
  - On HEPData soon!
  - Precedent case for future Belle II analyses.
- **First ever** direct constraints on $b \to s\nu\bar{\nu}$ WET Wilson coefficients.

EPJC 84, 693 (2024)
arXiv:2507.12393

Approaches to reinterpretation

Simulation based reinterpretation

- Produce and analyse new MC samples for each point in theory space

🔥 Resource-heavy

Simplified model reinterpretation

- Assume that efficiencies are unaffected by kinematic shape changes

⚠️ Potentially biased results

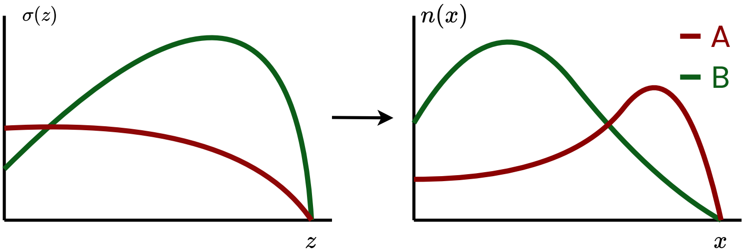
arXiv:2109.04981 [hep-ph]

Is accurate reinterpretation without new MC samples possible?

♻️ **Yes, we can reweight samples or even histograms directly!**

Templates from kinematic predictions

$$n(x|\sigma) = \int dz\, L\, \varepsilon(x|z)\, \sigma(z) = \int dz\, n_\sigma(x,z)$$



$z(= q^2)$ – kinematic d.o.f.

x – reconstruction / fitting variable(s)

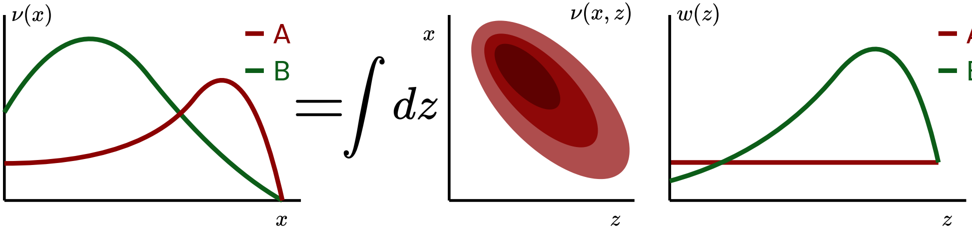
L – luminosity

$\varepsilon(x|z)$ – conditional efficiency

$n_\sigma(x,z)$ – joint number density

Reweight to new model

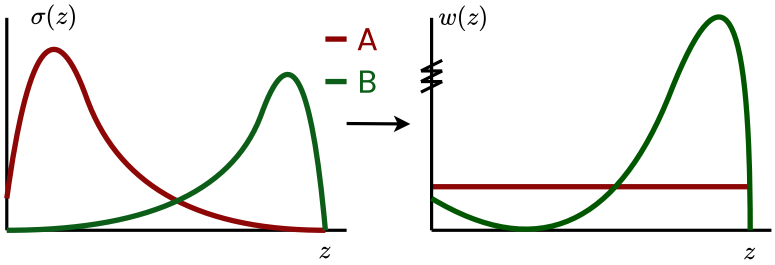
$$n(x|B) = \int dz\, L\, \varepsilon(x|z)\, \sigma_B(z) = \int dz\, L\, \varepsilon(x|z)\, \sigma_A(z) \frac{\sigma_B(z)}{\sigma_A(z)} = \int dz\, \underbrace{n_A(x,z)}_{\text{main object}}\, w(z).$$



$p(x|n_A, \theta)$ = model-agnostic likelihood

Method limitations

Substantial model changes ➜ large weights



Minimal requirement:

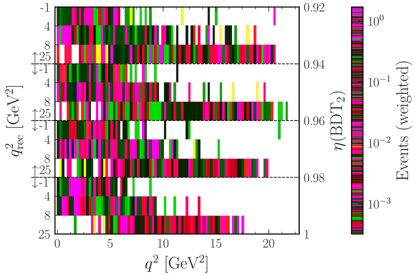
$$\mathrm{supp}(\sigma_B) \in \mathrm{supp}(\sigma_A)$$

Always possible to compare only in $\mathrm{supp}(\sigma_A)$

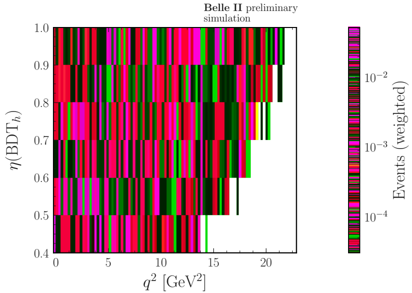
Joint number densities

Main object for reinterpretation, $n(x, z)$ ➜ **Essential for publication.**

ITA (plot for publication)



HTA



Kinematic binning: $q^2 = [-1, (0, 22.885, 100)]$ GeV^2

Weak Effective Theory for $B \to K\nu\bar{\nu}$

The effective Lagrangian is

$$\mathcal{L}^{WET} = \sum_{X=L,R} C_{\mathrm{VX}}\,\mathcal{O}_{\mathrm{VX}} + \sum_{X=L,R} C_{\mathrm{SX}}\,\mathcal{O}_{\mathrm{SX}} + C_{\mathrm{TL}}\,\mathcal{O}_{\mathrm{TL}} + \text{h.c.}$$

The $d = 6$ contributing operators in and beyond the SM are given by

$$\mathcal{O}_{\mathrm{VL}} = \left(\overline{\nu_L}\gamma_\mu\nu_L\right)\left(\overline{s_L}\gamma^\mu b_L\right) \qquad \mathcal{O}_{\mathrm{VR}} = \left(\overline{\nu_L}\gamma_\mu\nu_L\right)\left(\overline{s_R}\gamma^\mu b_R\right)$$

$$\mathcal{O}_{\mathrm{SL}} = \left(\overline{\nu_L^c}\nu_L\right)\left(\overline{s_R}b_L\right) \qquad \mathcal{O}_{\mathrm{SR}} = \left(\overline{\nu_L^c}\nu_L\right)\left(\overline{s_L}b_R\right)$$

$$\mathcal{O}_{\mathrm{TL}} = \left(\overline{\nu_L^c}\sigma_{\mu\nu}\nu_L\right)\left(\overline{s_R}\sigma^{\mu\nu}b_L\right)$$

arXiv:2111.04327

WET decay kinematics

$$\frac{d\mathcal{B}(B \to K \nu \bar{\nu})}{dq^2} = \frac{3 G_F^2 \alpha^2 \tau_B}{32 \pi^5 m_B^3} \left| V_{ts}^* V_{tb} \right|^2 \sqrt{\lambda_{BK}} q^2 \left[\frac{\lambda_{BK}}{24 q^2} \left| f_+(q^2) \right|^2 \left| C_{\mathrm{VL}} + C_{\mathrm{VR}} \right|^2 + \frac{\left(m_B^2 - m_K^2\right)^2}{8 \left(m_b - m_s\right)^2} \left| f_0(q^2) \right|^2 \left| C_{\mathrm{SL}} + C_{\mathrm{SR}} \right|^2 + \frac{2 \lambda_{BK}}{3 \left(m_B + m_K\right)^2} \left| f_T(q^2) \right|^2 \left| C_{\mathrm{TL}} \right|^2 \right]$$

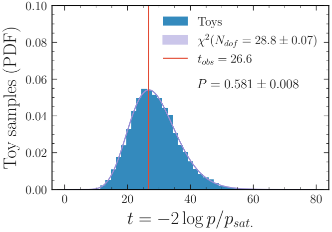
for $J^P = 0^-$ kaon states.
Note $q^2 \neq q^2_{rec}$.

arXiv:2111.04327

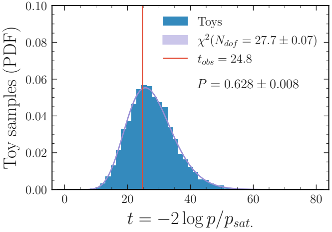
Goodness of fit

$$P_{\text{gof}} = \int_{t_{obs}}^{\infty} dt \, p(t, \quad t = -2 \ln \frac{p(n, a \mid \hat{\eta}, \hat{\chi})}{p_{\text{sat}}(n, a \mid \bar{\chi})},$$

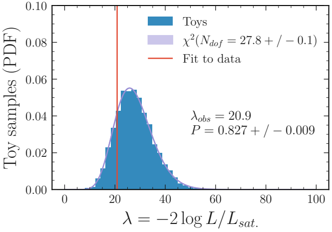
SM



WET



$B^+ \to K^+ X$

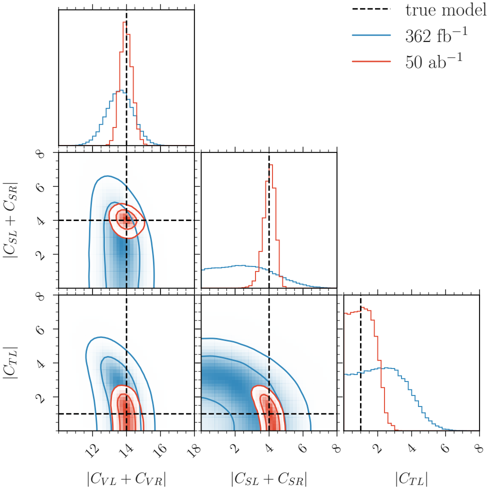


Validation through closure testing

- Build simple statistical model on MC data
- Inject new physics in MC data
- Infer a posterior in the Wilson coefficients

$$p(\theta|x) \propto p(x|\theta)p(\theta)$$

EPJC 84, 693 (2024)

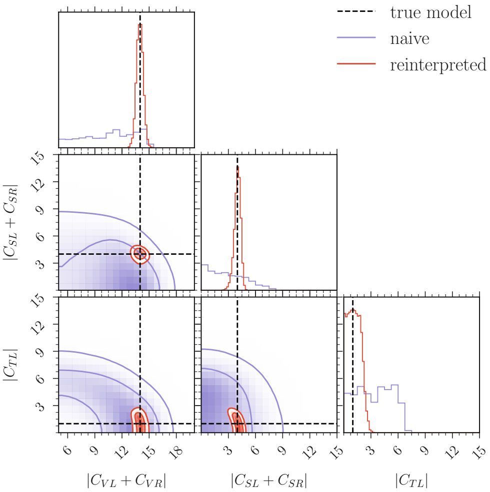


Necessity of reinterpretation

- Infer Wilson coefficients only from
$$\mathcal{B}(\{C_i\})/\mathcal{B}_{SM}$$
- Ignore effect of kinematic shape changes

➜ **No constraining power!**

EPJC 84, 693 (2024)



Prior sensitivity WET

Alternative priors

$$p\left(\eta_i\right) = \begin{cases} \mathcal{N}(\eta_i|\mu = C_i^{\mathrm{SM}}, \sigma = 20) & \eta_i \geq 0 \\ 0 & \eta_i < 0 \end{cases} \quad (1)$$

$$p\left(\eta_i\right) \propto \begin{cases} \eta_i & \eta_i \leq 30 \\ 0 & \eta_i > 30 \end{cases} \quad (2)$$

Uniform priors

Parameters	Mode	68% HDI	95% HDI
$\lvert C_{\mathrm{VL}} + C_{\mathrm{VR}}\rvert$	11.3	[7.82, 14.6]	[1.86, 16.2]
$\lvert C_{\mathrm{SL}} + C_{\mathrm{SR}}\rvert$	0.00	[0.00, 9.53]	[0.00, 15.4]
$\lvert C_{\mathrm{TL}}\rvert$	8.21	[2.29, 9.62]	[0.00, 11.2]

Alternative priors

Priors	Parameters	Mode	68% HDI	95% HDI
(1)	$\lvert C_{\mathrm{VL}} + C_{\mathrm{VR}}\rvert$	11.4	[7.97, 14.6]	[2.21, 16.4]
	$\lvert C_{\mathrm{SL}} + C_{\mathrm{SR}}\rvert$	0.00	[0.00, 9.16]	[0.00, 14.7]
	$\lvert C_{\mathrm{TL}}\rvert$	7.69	[1.54, 8.75]	[0.00, 11.0]
(2)	$\lvert C_{\mathrm{VL}} + C_{\mathrm{VR}}\rvert$	11.6	[8.21, 14.0]	[4.17, 16.0]
	$\lvert C_{\mathrm{SL}} + C_{\mathrm{SR}}\rvert$	8.93	[4.56, 12.6]	[1.27, 15.6]
	$\lvert C_{\mathrm{TL}}\rvert$	7.17	[3.89, 9.59]	[1.41, 11.7]

A comparative scale

Naive reinterpretation

For each Wilson coefficient

$$\mu_{SM}\mathcal{B}_{SM} = \int dq^2 \frac{d\mathcal{B}_{WET}}{dq^2}$$

$$|C_{\mathrm{VL}} + C_{\mathrm{VR}}| = 14.2^{+1.9}_{-2.2}$$

$$|C_{\mathrm{SL}} + C_{\mathrm{SR}}| = 8.38^{+1.12}_{-1.30}$$

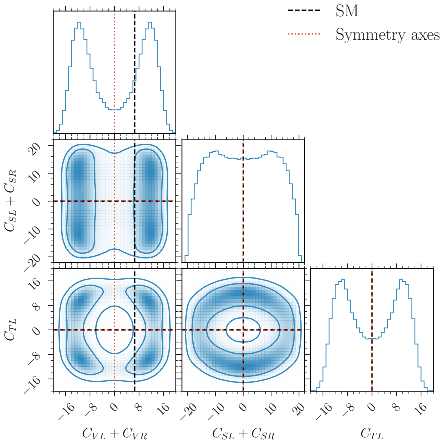
$$|C_{\mathrm{TL}}| = 6.93^{+0.93}_{-1.08}$$

Our results

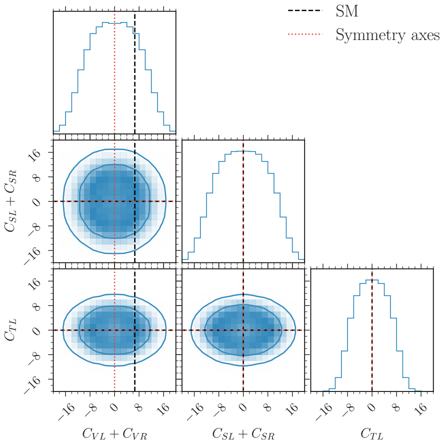
Parameters	Mode	68% HDI
$\lvert C_{\mathrm{VL}} + C_{\mathrm{VR}}\rvert$	11.3	[7.82, 14.6]
$\lvert C_{\mathrm{SL}} + C_{\mathrm{SR}}\rvert$	0.00	[0.00, 9.53]
$\lvert C_{\mathrm{TL}}\rvert$	8.21	[2.29, 9.62]

WET marginal posteriors (individual)

ITA



HTA



HistFactory model

Likelihood function for observed event counts n is

$$L(n, a|\eta, \chi) = \underbrace{\prod_{c \in \text{channels}} \prod_{b \in \text{bins}} \text{Pois}\left(n_{cb}|\nu_{cb}(\eta, \chi)\right)}_{\text{multiple channels}} \underbrace{\prod_{\chi \in \boldsymbol{\chi}} c_{\chi}\left(a_{\chi}|\chi\right)}_{\text{constraint terms}}$$

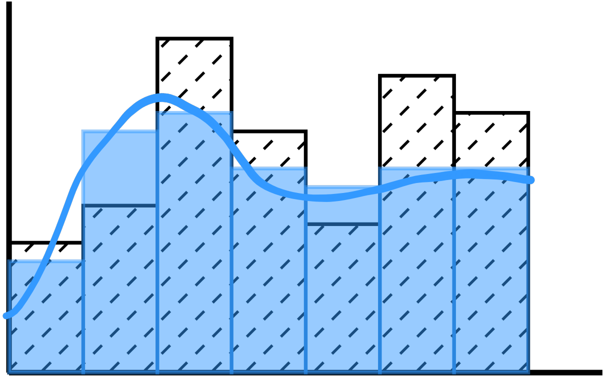
Expected number of events per channel per bin are

$$\nu_{cb}(\eta, \chi) = \sum_{s \in \text{samples}} \underbrace{\prod_{\kappa \in \boldsymbol{\kappa}} \kappa_{scb}(\eta, \chi)}_{\text{multiplicative modifiers}} \left(\nu_{scb}^{0}(\eta, \chi) + \underbrace{\sum_{\Delta \in \boldsymbol{\Delta}} \Delta_{scb}(\eta, \chi)}_{\text{additive modifiers}}\right).$$

Modifiers and constraints

Description	Modification	Constraint Term c_χ	Input
Uncorrelated Shape	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \mathrm{Pois}\left(r_b = \sigma_b^{-2} \middle\| \rho_b = \sigma_b^{-2}\gamma_b\right)$	σ_b
Correlated Shape	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\| \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\left(a = 0 \middle\| \alpha, \sigma = 1\right)$	$\Delta_{scb,\alpha=\pm 1}$
Normalisation Unc.	$\kappa_{scb}(\alpha) = g_p\left(\alpha \middle\| \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\left(a = 0 \middle\| \alpha, \sigma = 1\right)$	$\kappa_{scb,\alpha=\pm 1}$
MC Stat. Uncertainty	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \mathrm{Gaus}\left(a_{\gamma_b} = 1 \middle\| \gamma_b, \delta_b\right)$	$\delta_b^2 = \sum_s \delta_{sb}^2$
Luminosity	$\kappa_{scb}(\lambda) = \lambda$	$\mathrm{Gaus}\left(l = \lambda_0 \middle\| \lambda, \sigma_\lambda\right)$	$\lambda_0, \sigma_\lambda$
Normalisation	$\kappa_{scb}(\mu_b) = \mu_b$		
Data-driven Shape	$\kappa_{scb}(\gamma_b) = \gamma_b$		

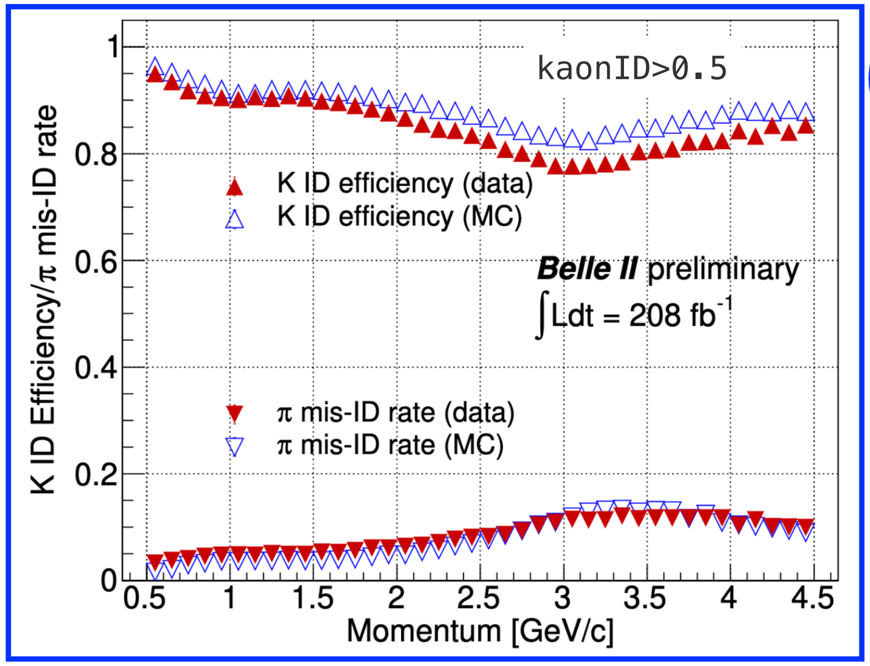
Custom modifiers



SUPPORTING MATERIAL

Belle II TDR, arXiv: 1011.0352

KEY BELLE II PERFORMANCE

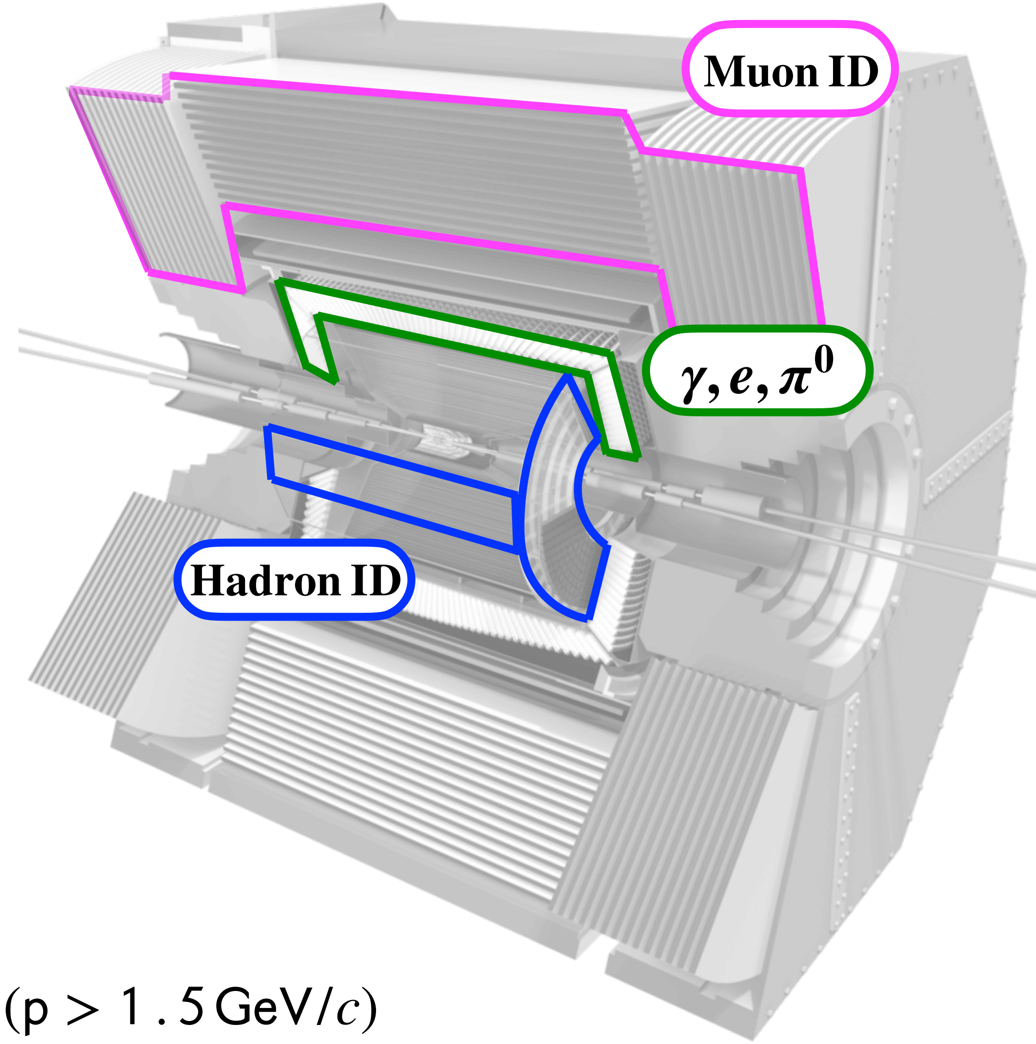


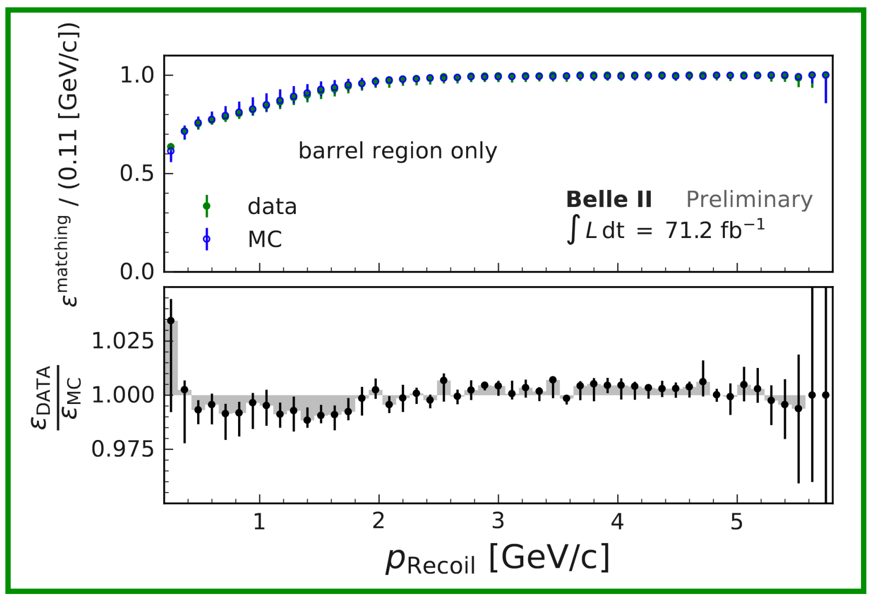
K ID

$\varepsilon \sim 90\,\%$

$\pi \to K \sim 6\,\%$

Good kaon identification in full momentum range

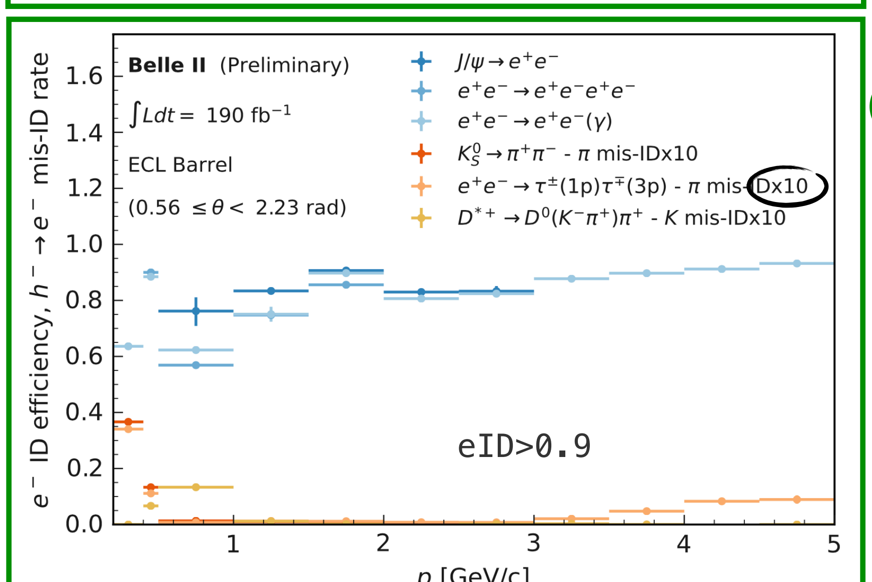




γ, π^0

High photon efficiency $\varepsilon > 90\,\%$ ($p > 1.5\,\mathrm{GeV}/c$)

Belle-like resolution on π^0 mass



e ID

$\varepsilon \sim 86\,\%$

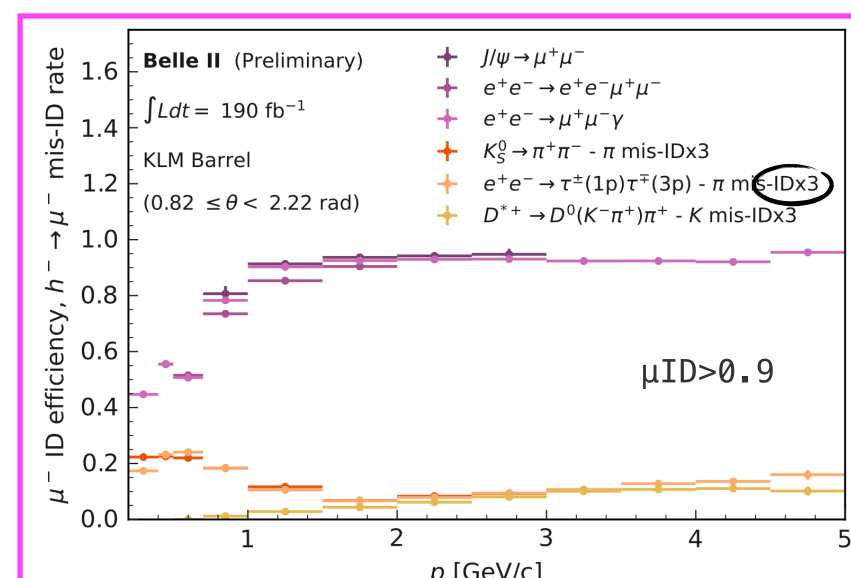
$\pi \to e \sim 0.4\,\%$

μ ID

$\varepsilon \sim 90\,\%$

$\pi \to \mu \sim 7\,\%$

Good lepton ID and similar $e - \mu$ performance

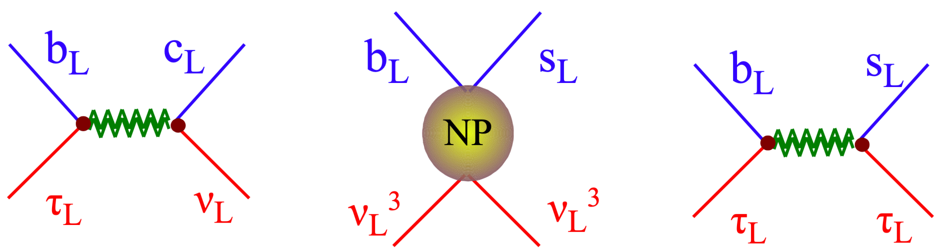


$B \to K\tau\bar{\tau}$ MOTIVATION

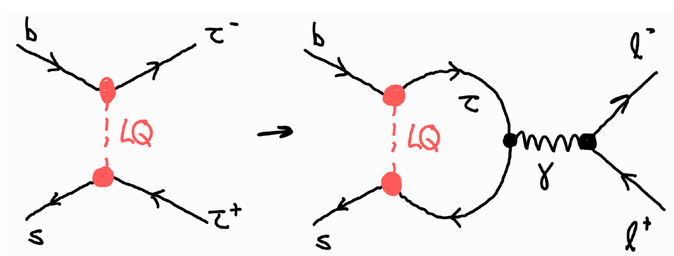
- $\mathscr{B}_{SM}(B^0 \to K^0\tau^+\tau^-)\,|_{q^2 \in (4m_\tau^2, q^2_{max})} = 0.78 \times 10^{-7}$ [1]
- **Correlation with $R_{D^{(*)}}$ [2] → Large enhancements to SM BF $\mathscr{O}(10^2 - 10^3)$ [3]**
- **$B^+ \to K^+\nu\bar{\nu}$ excess, combined with R_{K^*} constraints, suggest LFUV in τ's [4,5]**

$$C_9^{\tau\tau} = C_{10}^{\tau\tau} \sim -\frac{2\pi}{\alpha}\frac{V_{cb}}{V_{tb}V_{ts}^*}\left(\sqrt{\frac{R_{D^{(*)}}}{R_{D^{(*)}}^{SM}}} - 1\right)$$

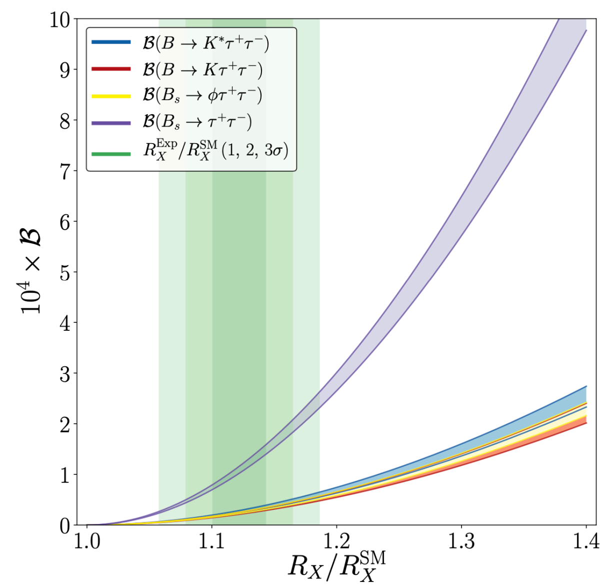
$$\frac{\mathscr{B}(B \to K^*\tau\tau)}{\mathscr{B}(B \to K^*\tau\tau)^{SM}} \in [16, 48]$$

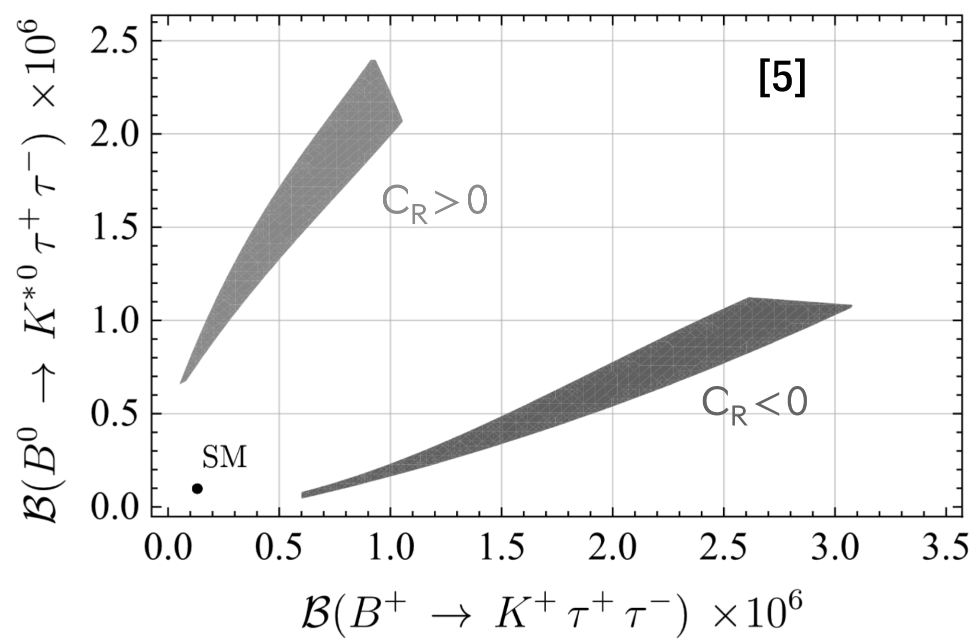


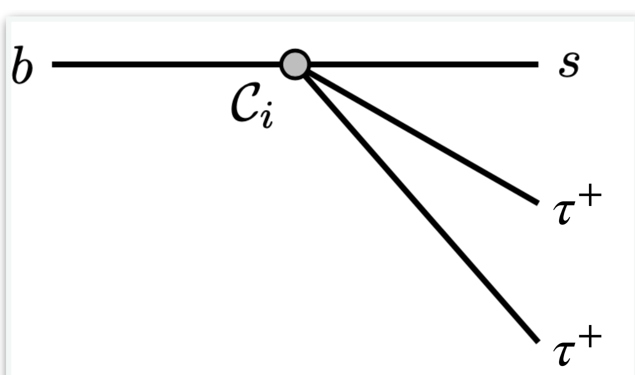
G. Isidori, KMI2025



W. Altmannshofer, Anomalies Vienna 2025







$$\mathscr{O}_{9(10)}^{\tau\tau} = \frac{e^2}{16\pi^2}[\bar{s}\gamma_\mu \mathscr{P}_L b][\bar{\tau}\gamma^\mu(\gamma_5)\tau]$$

$$\mathscr{L}_{eff} = \frac{4G_F}{\sqrt{2}}\lambda_t \sum_i \left(C_i(\mu) \;\; \mathscr{O}_i(\mu) \right)$$

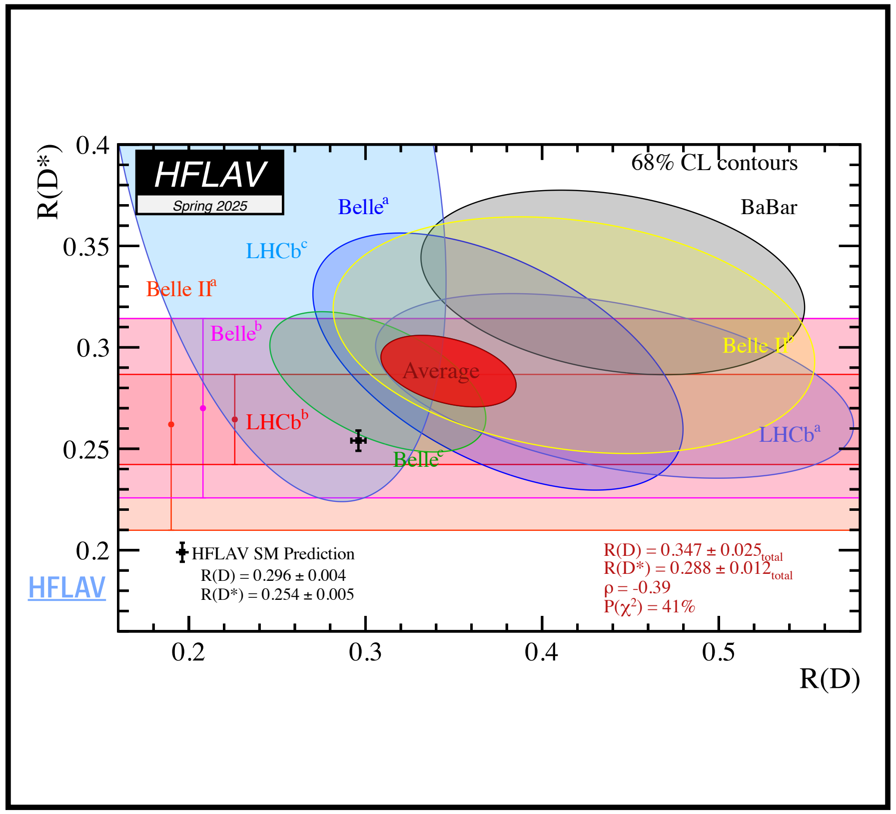
$$C_i^{\tau\tau} = C_i^{\tau\tau}|_{SM} + C_i^{\tau\tau}|_{NP}$$

[1] PRD 107, 014511 (2023) [2] PRL 120, 181802 (2018) [3] PRD 105,113007 (2022) [4] PLB 848, 138411 (2023) [5] 2309.00075

WHY B-DECAYS

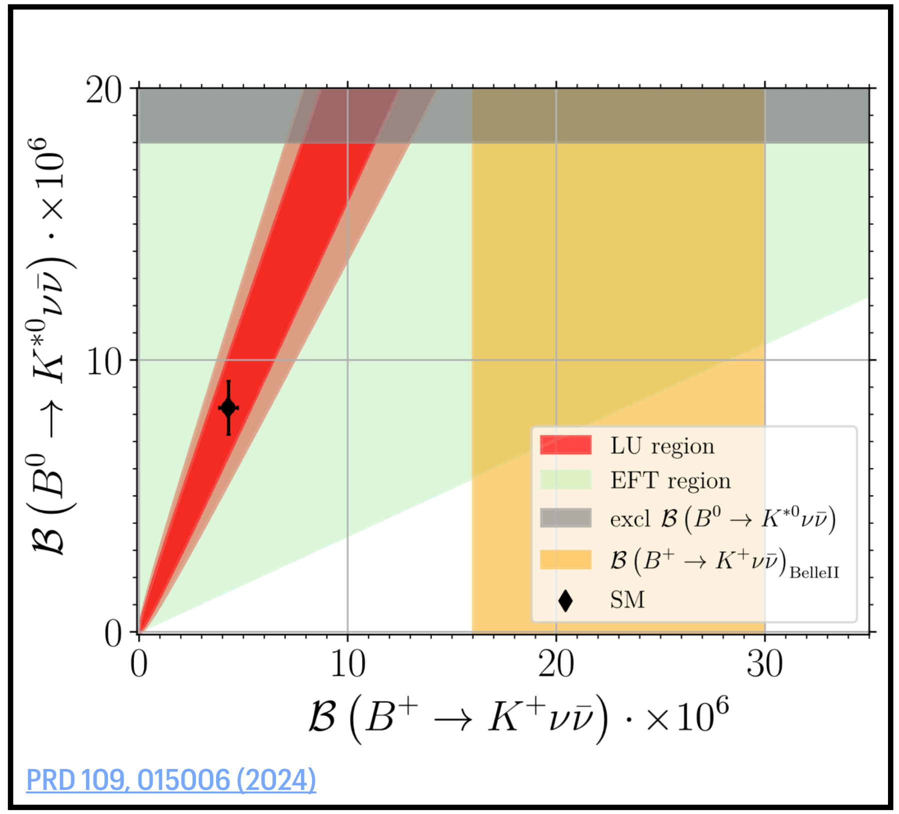
Tensions in *b*-transitions

$b \to c\tau\nu$



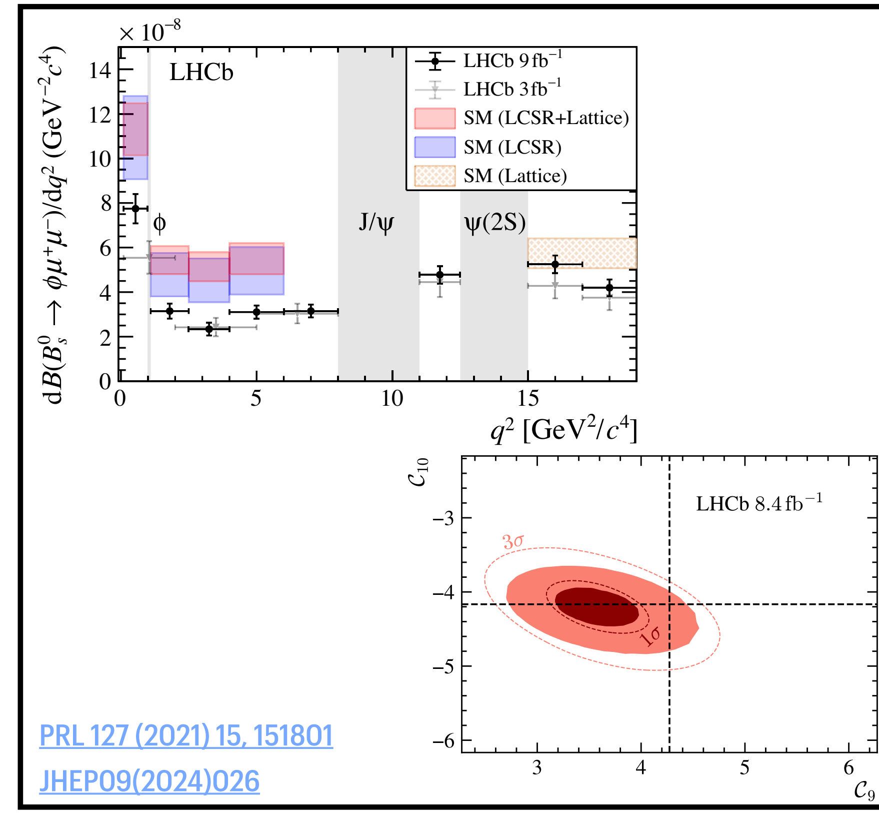
HFLAV

$b \to s\nu\nu$



PRD 109, 015006 (2024)

$b \to s\mu\mu$



PRL 127 (2021) 15, 151801
JHEP09(2024)026

3.8σ for R(D)-R(D*)

$$R(D^{(*)}) = \frac{\mathscr{B}(B \to D^{(*)}\tau\nu)}{\mathscr{B}(B \to D^{(*)}\ell\nu)}$$

See Boyang's talk later today

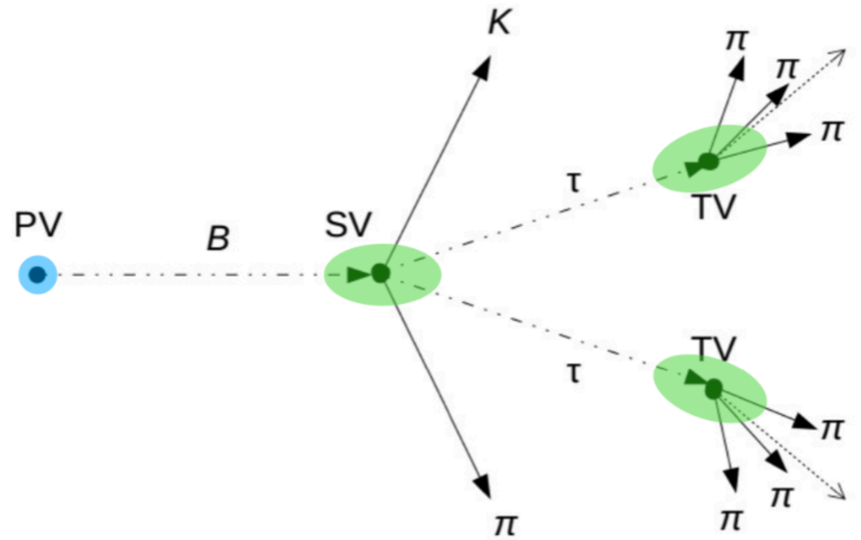
$$\frac{\mathscr{B}(B^+ \to K^+\nu\nu)}{\mathscr{B}_{SM}(B^+ \to K^+\nu\nu)} = 5.4 \pm 1.5 \ (2.7\sigma)$$

$1\text{-}3\sigma$ in branching ratios/ angular observables

Is there a joint explanation?

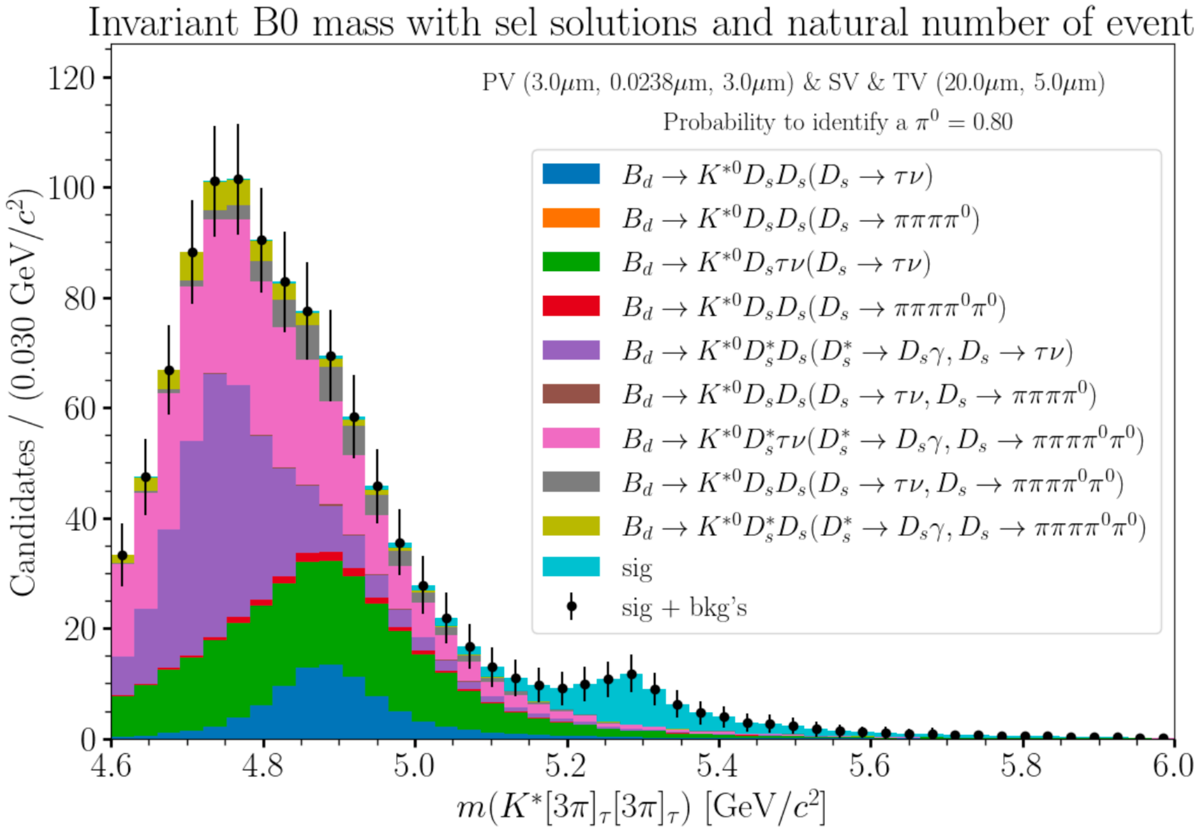
WHY B-DECAYS

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



https://indico.global/event/11057/contributions/131852/

Tristan Miralles et al.



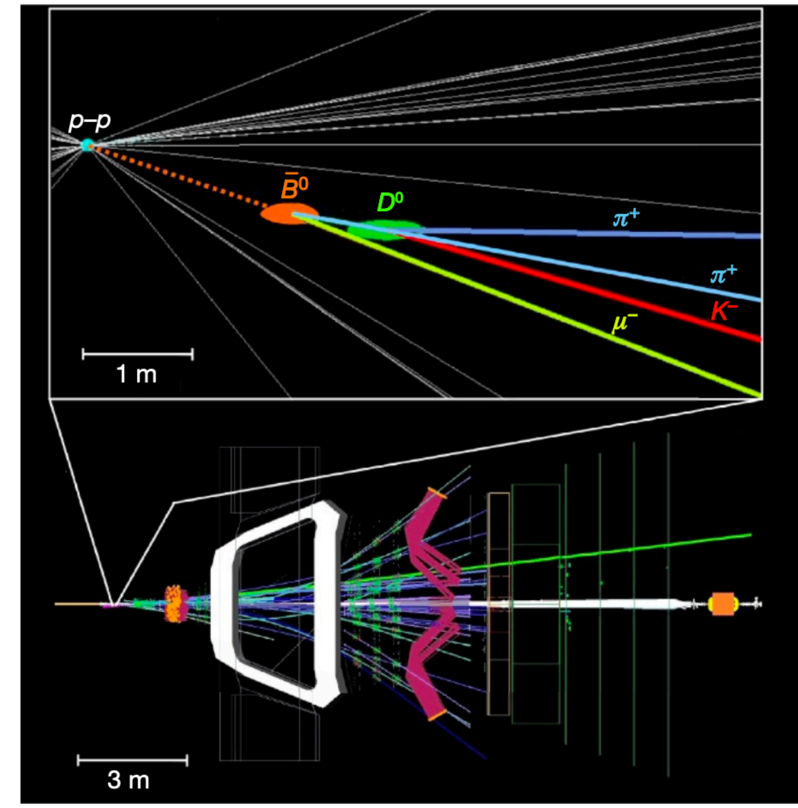
- Event kinematics fully reconstructable (with 4-fold ambiguity)
- Expect 3σ significance with nominal IDEA detector
  - Extensive detector study: strong dependence on vertex resolution and material budget

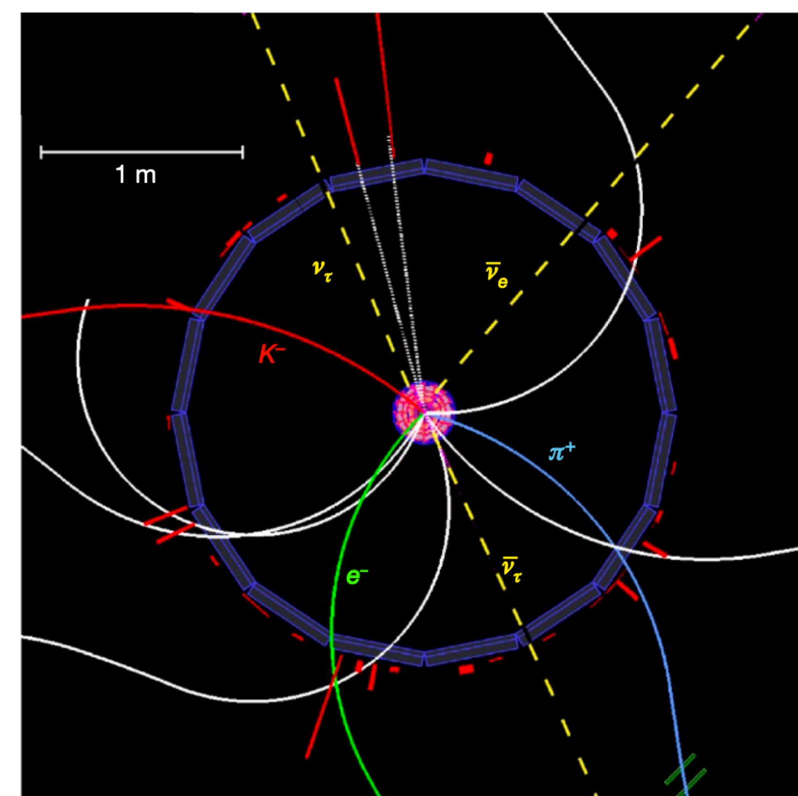
BELLE II AND LHC*b*

Better with muons/charged particles that can be vertexed
Richer *b*-hadron program
high backgrounds / high σ_b

Properties	LHC*b*	Belle II
σ_b	$\mathcal{O}(100\mu b)$	~ 1 nb
$\int \mathscr{L}dt$ (fb^{-1})	$18 \rightarrow 300$	$(1+)0.6 \rightarrow 30$-50
Background level	~ 60 mb	~ 4 nb
Typical efficiency	Low	High
π^0, K^0_S efficiency	Low	High
Initial state	Not well known	Well known
Decay-time resolution	Excellent	Good
Collision spot size	Large	Tiny
Heavy bottoms hadrons	$B_{u,d,s,c}$, $b-$baryons	$B_{u,d(,s)}$
B-flavour tagging capability	$\sim 5\%$	$\sim 35\%$
τ physics capability	Limited	Excellent

Better with γ and ν
Higher tagging efficiency
Low backgrounds / low σ_b





SYST K+

- Dominant systematic uncertainties in terms of BF ($\times 10^{-3}$):
  - poor knowledge of semileptonic $B \to D^{**}$ decays: 0.29
  - limited simulated sample size: 0.27

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
$D \to K_L$ decays	0.01
Signal form factors	0.01
Luminosity	< 0.01
Total systematics	0.52
Statistics	0.86

RESULTS K+

$$\text{BF} = \frac{N_{\text{obs}} - N_{\text{exp}}}{2\epsilon f^{+-} N_{B\bar{B}}}$$

Belle

Observed events (N_{obs}) $= 11^{+3.66}_{-2.99}$

Expected background (N_{exp}) $= 14.05 \pm 2.45$

Signal efficiency (ϵ) $= (1.40 \pm 0.16) \times 10^{-5}$

$f^{+-} = 0.5113^{+0.0073}_{-0.0108}$

$N_{B\bar{B}}$: $(772 \pm 11) \times 10^6$

$\text{BF} = (-2.76^{+3.31}_{-2.70} \pm 2.24) \times 10^{-4}$

Belle II

Observed events (N_{obs}) $= 6^{+2.80}_{-2.13}$

Expected background (N_{exp}) $= 3.48 \pm 1.17$

Signal efficiency (ϵ) $= (1.26 \pm 0.18) \times 10^{-5}$

$f^{+-} = 0.5113^{+0.0073}_{-0.0108}$

$N_{B\bar{B}}$: $(387 \pm 6) \times 10^6$

$\text{BF} = (5.05^{+5.62}_{-4.27} \pm 2.46) \times 10^{-4}$

SYST K*0

A. Additive:
1. Expected background yield

B. Multiplicative:
1. FEI scale factor: 0.76 ± 0.08 (0.75 ± 0.09)
2. Simulated sample-size: statistical uncertainty of the signal efficiency due to limited size of the generated signal simulation.
3. PID correction
4. π^0 veto efficiency: 1.03 ± 0.02 (1.03 ± 0.03)
5. Tracking efficiency: 0.35% (0.27%) per track
6. Signal decay model: uncertainty due to generated model dependence
7. f^{+-}: $0.511^{+0.007}_{-0.011}$ from HFLAV, taken its uncertainty as systematics
8. $N_{B\bar{B}}$: $772 \pm 11 (387 \pm 6) \times 10^6$, taken its uncertainty as systematics

Sources	Impact on BF (Belle)	Impact on BF (Belle II)
Expected bkg yield	±2.5 events	±1.2 events
FEI scale factor	10.1%	12.6%
Simulated sample size	3.3%	3.5%
PID correction	1.0%	1.6%
pi0 veto	1.9%	2.9%
Tracking efficiency	1.1%	0.8%
Signal decay model	3.5%	4.3%
f+-	$^{+1.4}_{-2.1}$ %	$^{+1.4}_{-2.1}$ %
Number of BBbar pairs	1.4%	1.6%

SYST X_S

Source	Impact on $\sigma_{\mathcal{B}}$ $[10^{-5}]$
MC statistics	6.4
Background normalization	6.1
Branching ratio of major B meson decay	2.5
Non-resonant $X_s \nu \bar{\nu}$ generation point	2.3
$\mathcal{O}$ selection efficiency	2.3
Photon multiplicity correction	2.2
$q\bar{q}$ background efficiency	1.9
Other subdominant contributions	3.2
Total systematic sources	12.4

$B_s \to \tau\tau$ and $B \to K^{(*)}\tau\tau$

- **Extremely difficult measurement** — *Tera-Z machine* such as FCC-ee needed! [Kamenik et al. '17]

Exp. limits (90%CL.):

$$\mathcal{B}(B_s \to \tau\tau) < 6.8 \times 10^{-3}$$ [LHCb. '17]

$$\mathcal{B}(B^+ \to K^+\tau\tau) < 2.25 \times 10^{-3}$$ [BaBar. '16]

$$\mathcal{B}(B^0 \to K^{0*}\tau\tau) < 1.8 \times 10^{-3}$$ [Belle-II. '25]

vs.

SM predictions:

$$\mathcal{B}_{\rm SM} \approx 10^{-7}$$

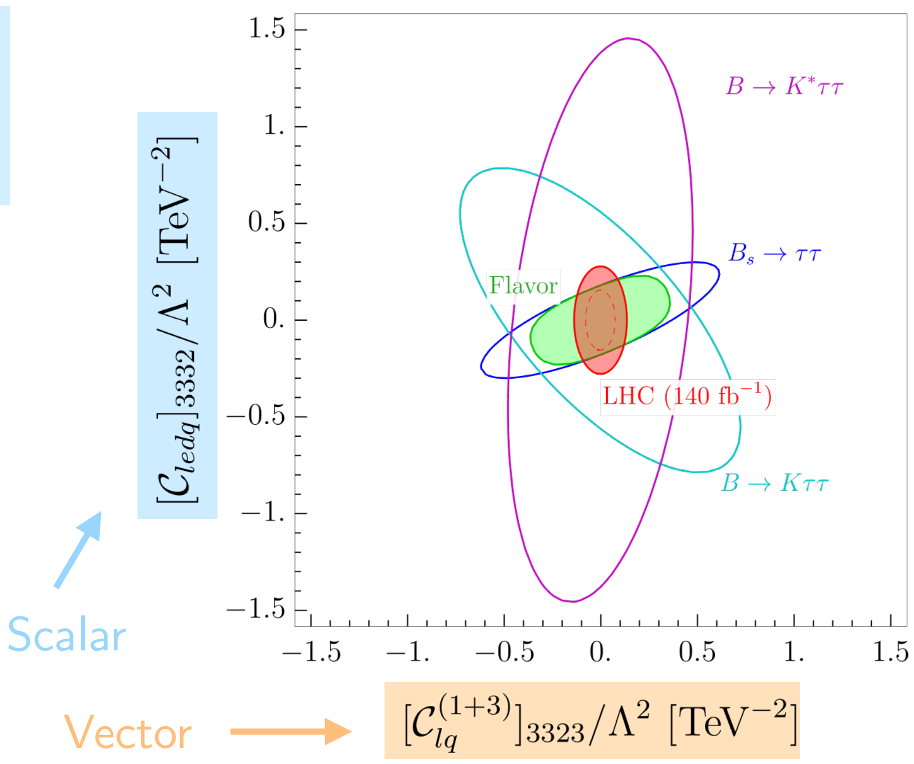
see e.g. [Capdevilla et al. '17]

Effectively, "null tests" for NP effects given the current exp. sensitivity — $\approx \times 10^4$ *above the SM values.*

Current reach: $\dfrac{|\mathcal{C}_{bs\tau\tau}|}{\Lambda^2} \lesssim (1.3\ \text{TeV})^{-2}$

Complementarity to $pp \to \tau\tau$ at the **LHC!**

see e.g. [Faroughy et al. '16], [Allwicher et al. (**OS**), 22]



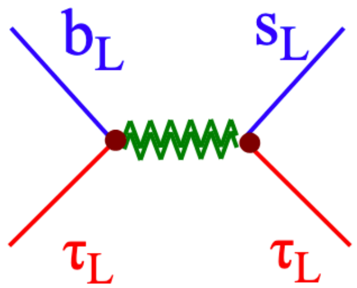
G. Isidori – The Flavor of New Physics *KMI2025, Nagoya – 6th March 2025*

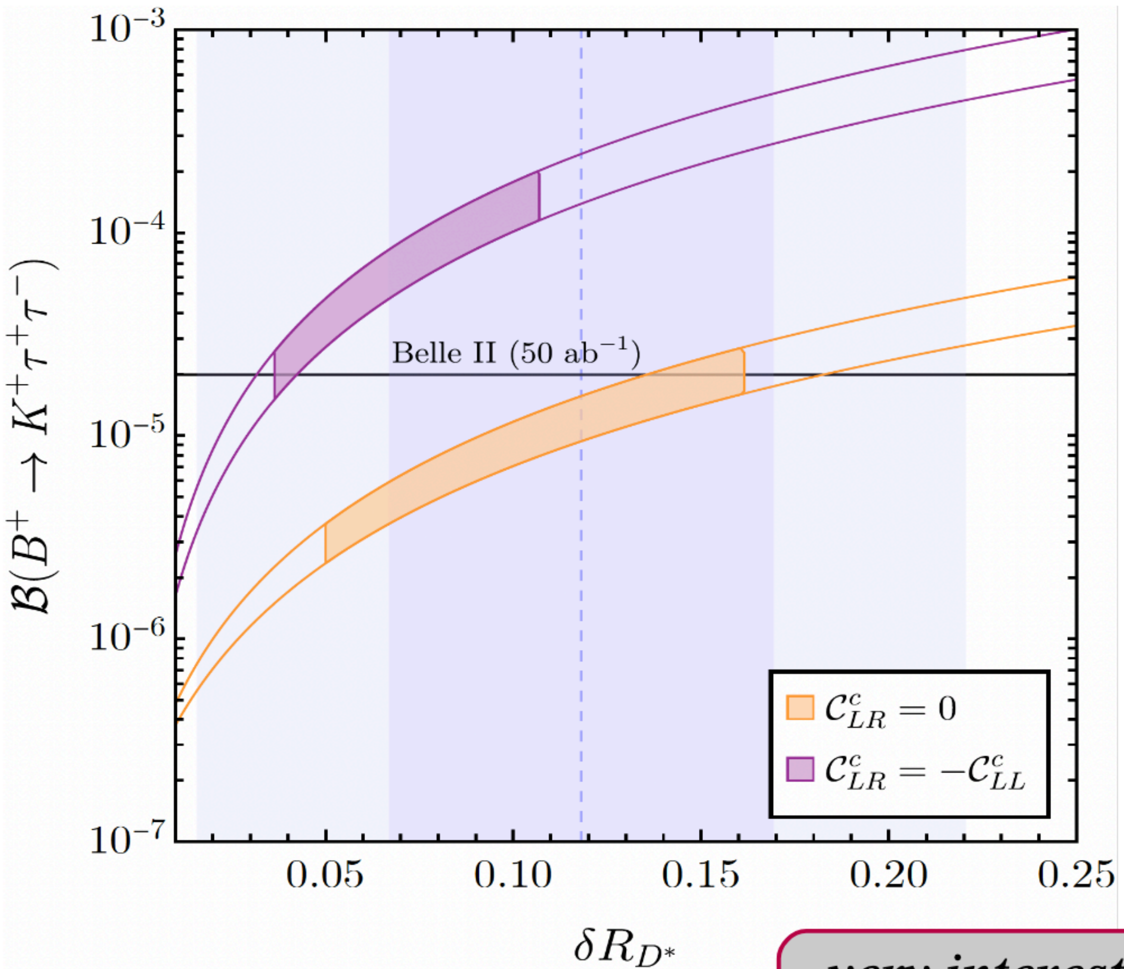
▶ *A brief look to current data & future prospects*

The idea of flavor non-universal interactions – with a 1st layer of new physics already at the TeV scale – has several interesting implications for various low-energy measurements (*with different degree of model-dependence*)

E.g.: III) Potential large enhancement of b→sττ rates

b→sνν rates are affected at the LQ exchange already at the tree-level (contrary b→sνν) and involve only 3rd gen. leptons → possible huge effect compared to SM





very interesting for Belle-II (4)