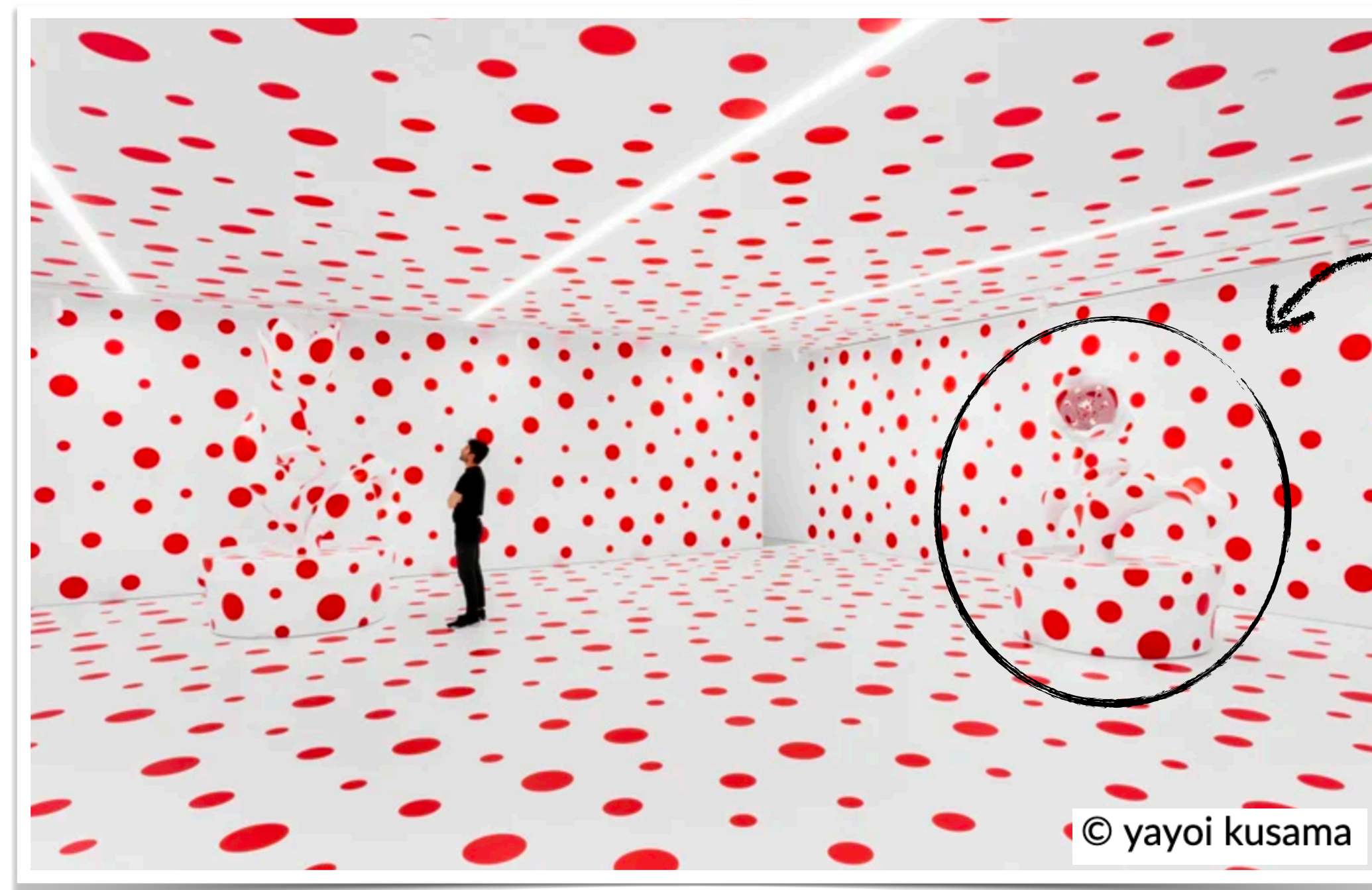


EWP B decays with missing energy: status and future potential of Belle II analyses

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Belle II Physics week
October 8th, 2025
KEK



Search
carefully!

Preface

- Exhaustive overview of the results in Gaetano and Lorenz's talk
- I will discuss the conventional steps of EWP B decays with missing energy (EWP+missE), with some emphasis on systematic uncertainties
- I will highlight the commonalities and distinctive features of the various works, selected based on personal basis.
- I will mainly focus on tagged analyses, inclusive method discussed in detailed by Sasha yesterday

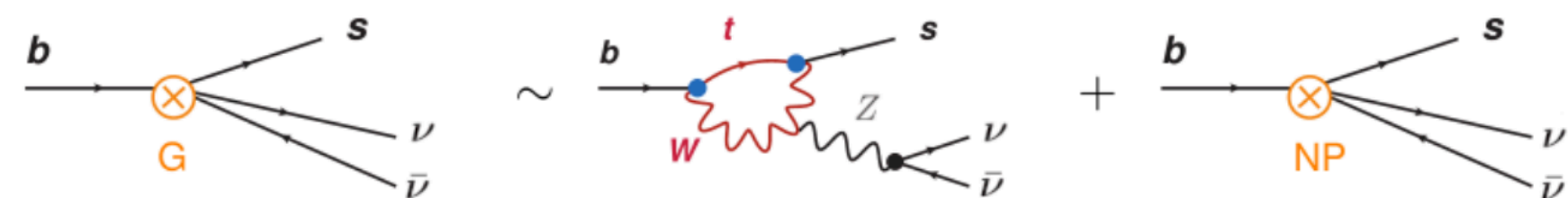
Introduction



Theoretical motivations

EWP B decays with missing energy (EWP+missE) as probe for new Physics

W. Altmannshofer



$$G \sim \frac{1}{16\pi^2} \frac{g^4}{m_W^2} \frac{m_t^2}{m_W^2} V_{tb} V_{ts}^* + \frac{C_{NP}}{\Lambda_{NP}^2}$$

measure
precisely

calculate precisely
the SM contribution

get information on
NP coupling and scale

$$\mathcal{L}_{\text{SMEFT}}^{(d=6)} = \sum_i \frac{C_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)}[\psi_{\text{SM}}]$$

*in general violate all the
accidental symmetries and
properties of the SM*

We can expect large effects in rare or forbidden processes!

Precision tests of forbidden or suppressed processes in the SM
are powerful probes of physics **Beyond the Standard Model.**

>> **Flavour Physics !** <<

$$\frac{\delta C}{C_{\text{SM}}} \sim \frac{C}{\lambda_{\text{SM}}} \frac{v^2}{\Lambda^2} < 10\% \quad \xrightarrow{\text{for } c=1} \quad \Lambda > \frac{v}{\sqrt{\lambda_{\text{SM}} \sqrt{10\%}}} \sim \frac{0.8}{\sqrt{\lambda_{\text{SM}}}} \text{ TeV}$$

Measuring this precisely puts strong constraints on the EFT combination c/Λ^2 ,
the **better the smallest λ_{SM}** is.

Exp

- Very **large statistics**
- Small **backgrounds and systematics**

TH

- Good control over the SM prediction:
 - **SM inputs** (CKM matrix elements)
 - **QCD matrix elements** (form factors)
 - control over the possible **long-distance contributions**

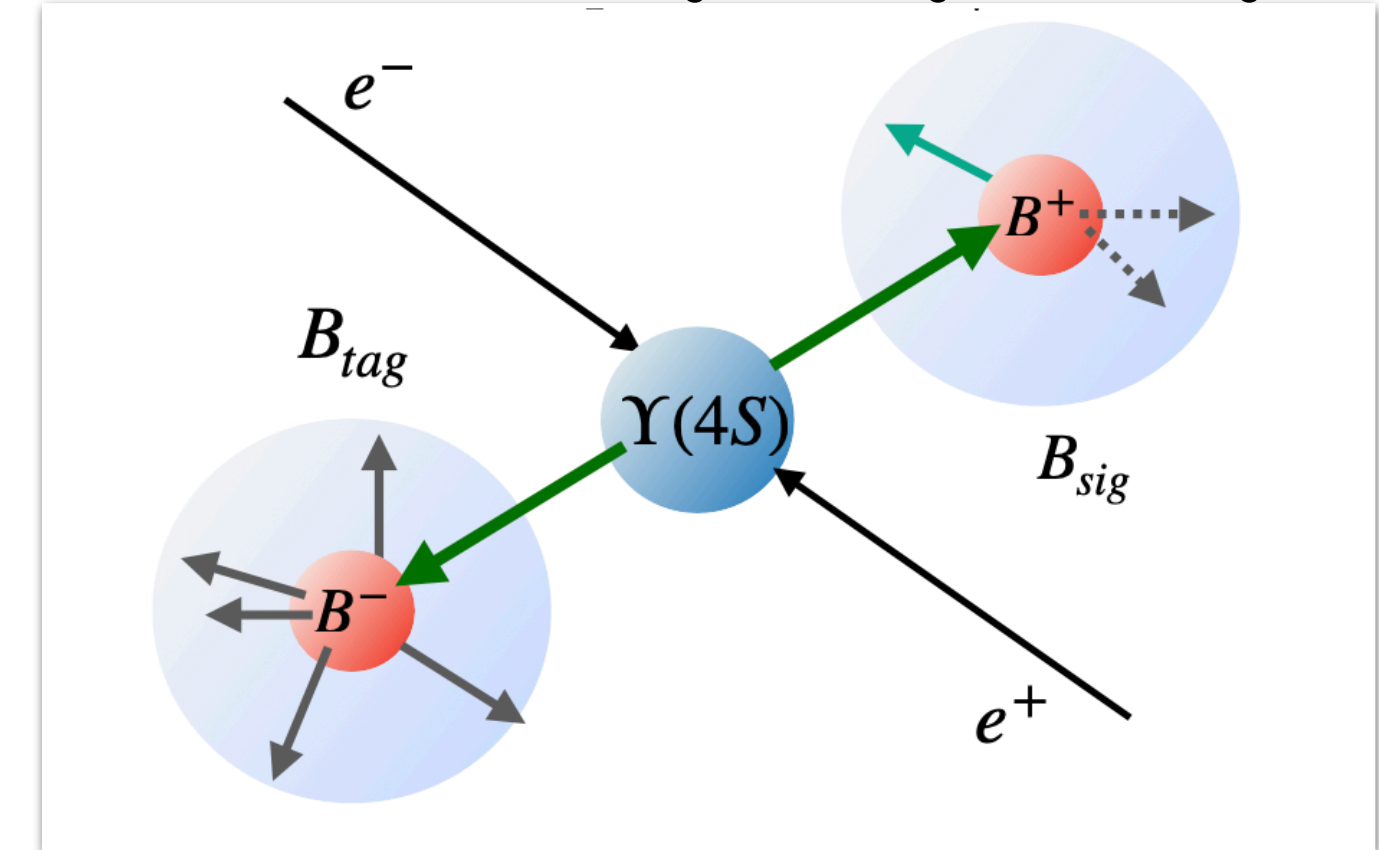
In rarity lies power

D. Marzocca

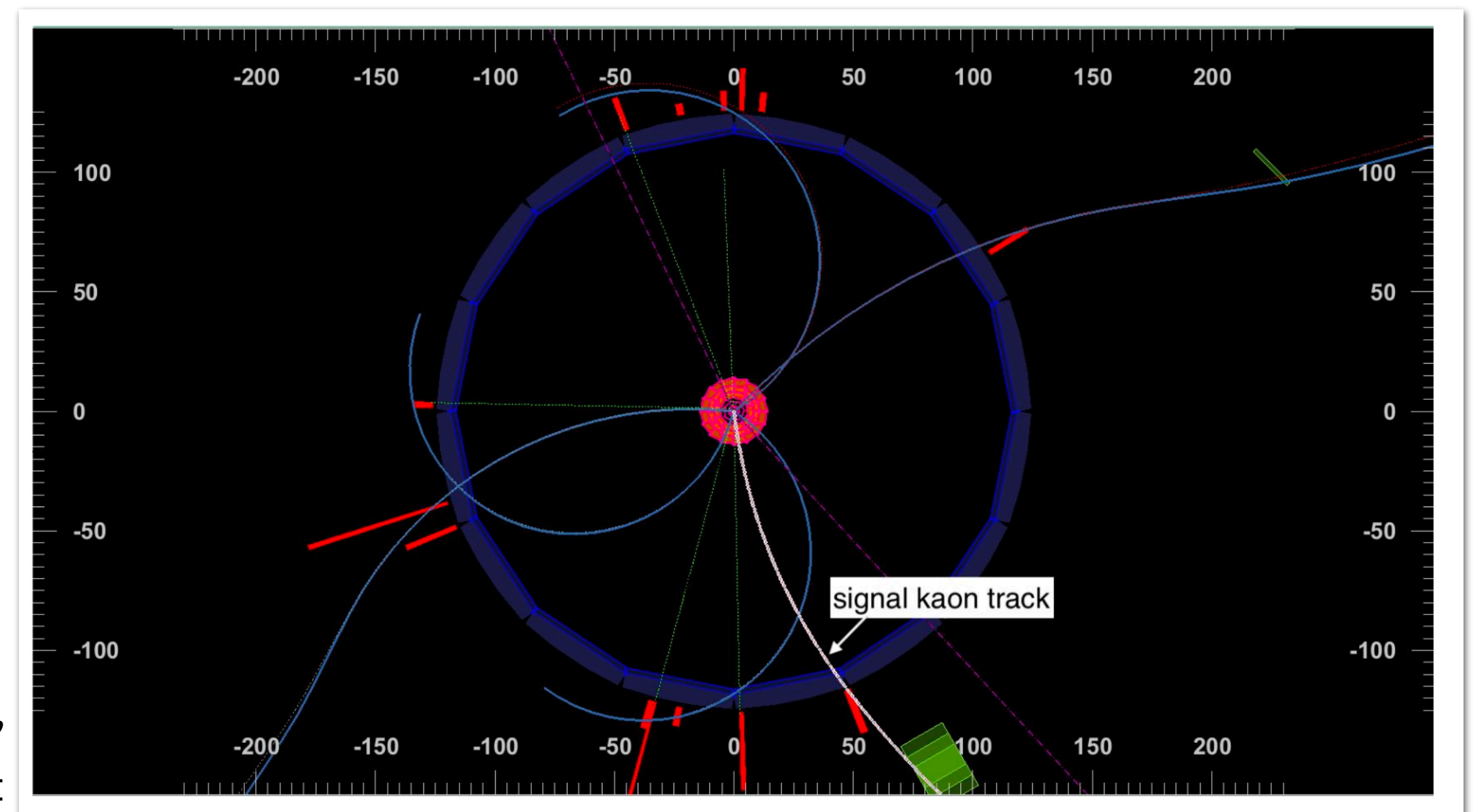
EWP+missE searches @ Belle II (I)

- **Belle II** is well suited to study missing energy modes:
 - **constrained kinematics** and **detector hermeticity** - good missing momentum reconstruction
 - low average multiplicity - neutral reconstruction
- **Experimental challenges:**
 - low (or zero) branching fraction with large background
 - apart from $b \rightarrow s \tau \ell$ case, signal is non-peaking: multiple undetected neutrinos, no narrow signal structure

$$E_{\text{Miss}} = E_{\text{beam}} - E_{B_{\text{tag}}} - E_{B_{\text{sig}}, \text{visible daughters}}$$

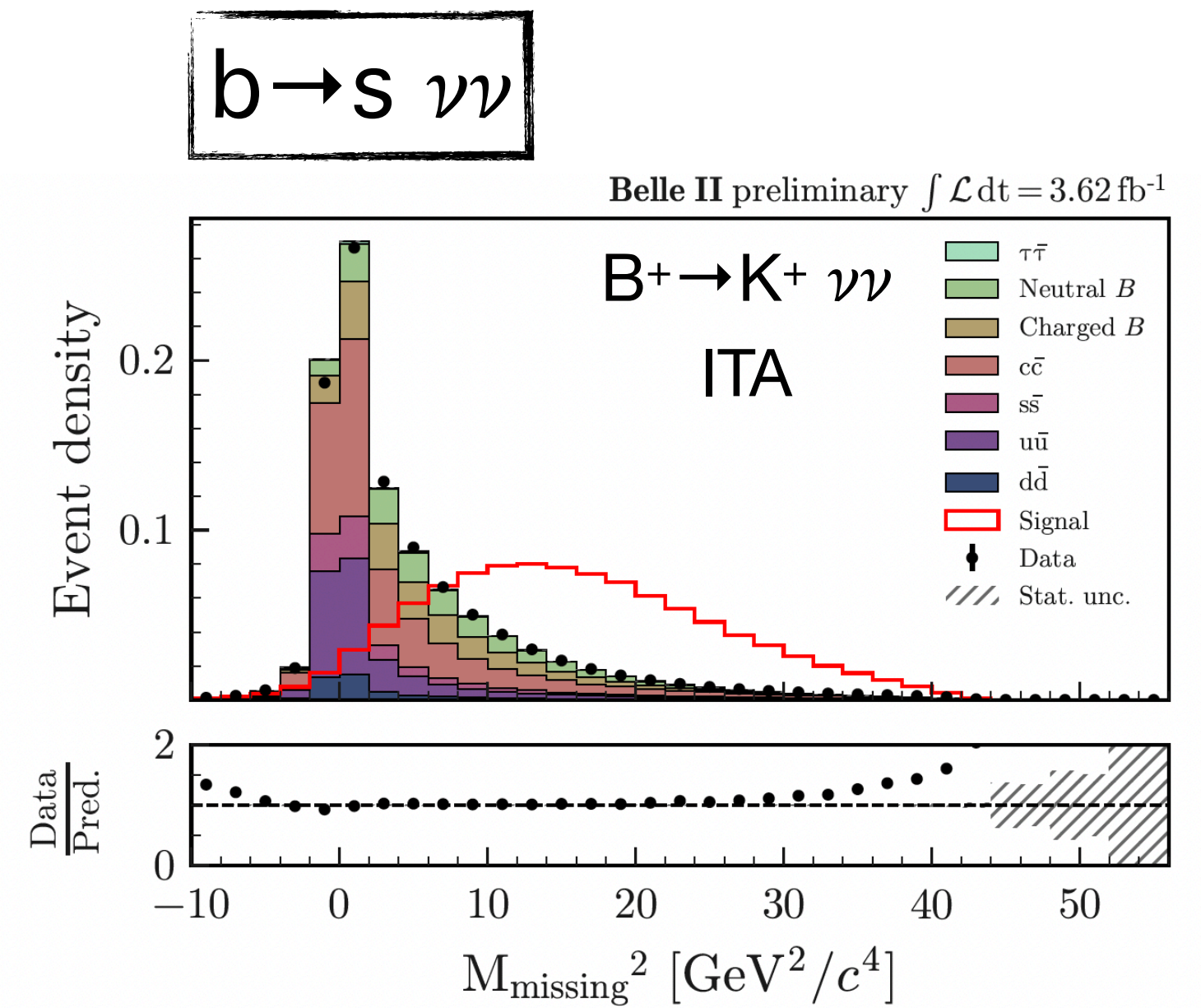
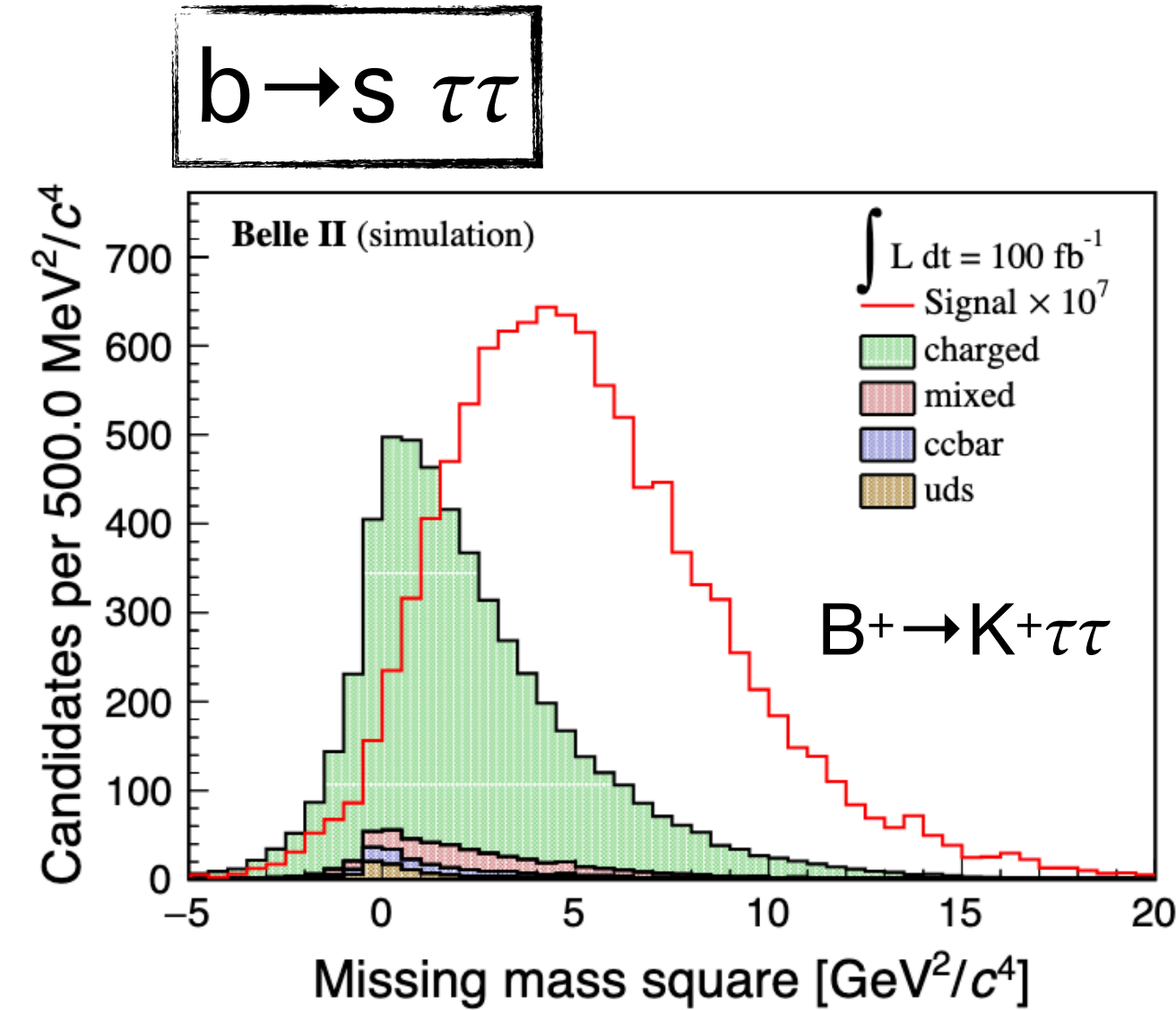
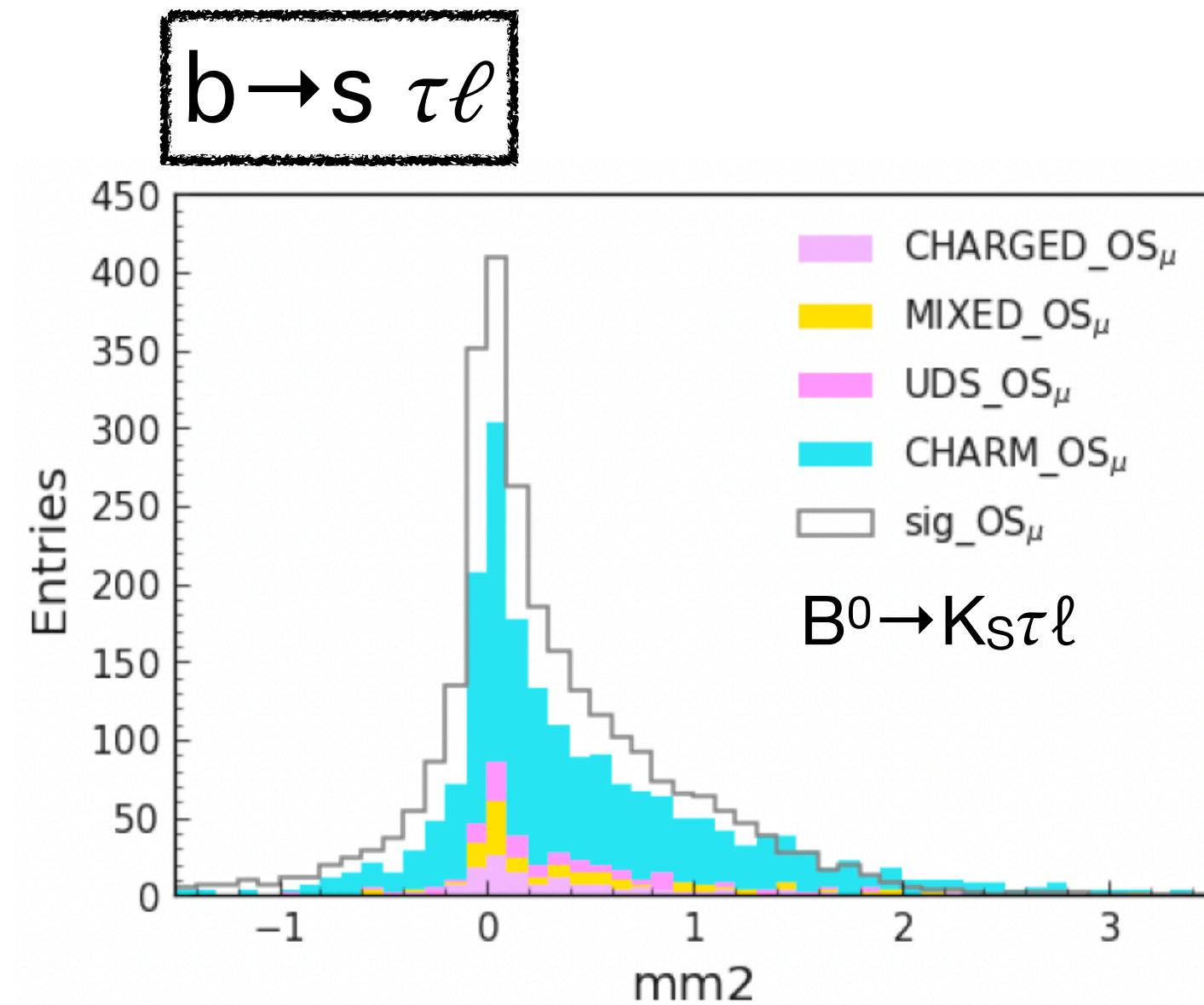


simulated $B^+ \rightarrow K^+ \nu \nu$ event



EWP+missE searches @ Belle II (I)

Three main categories of EWP+missE modes studies @ Belle II :



Produced missing energy

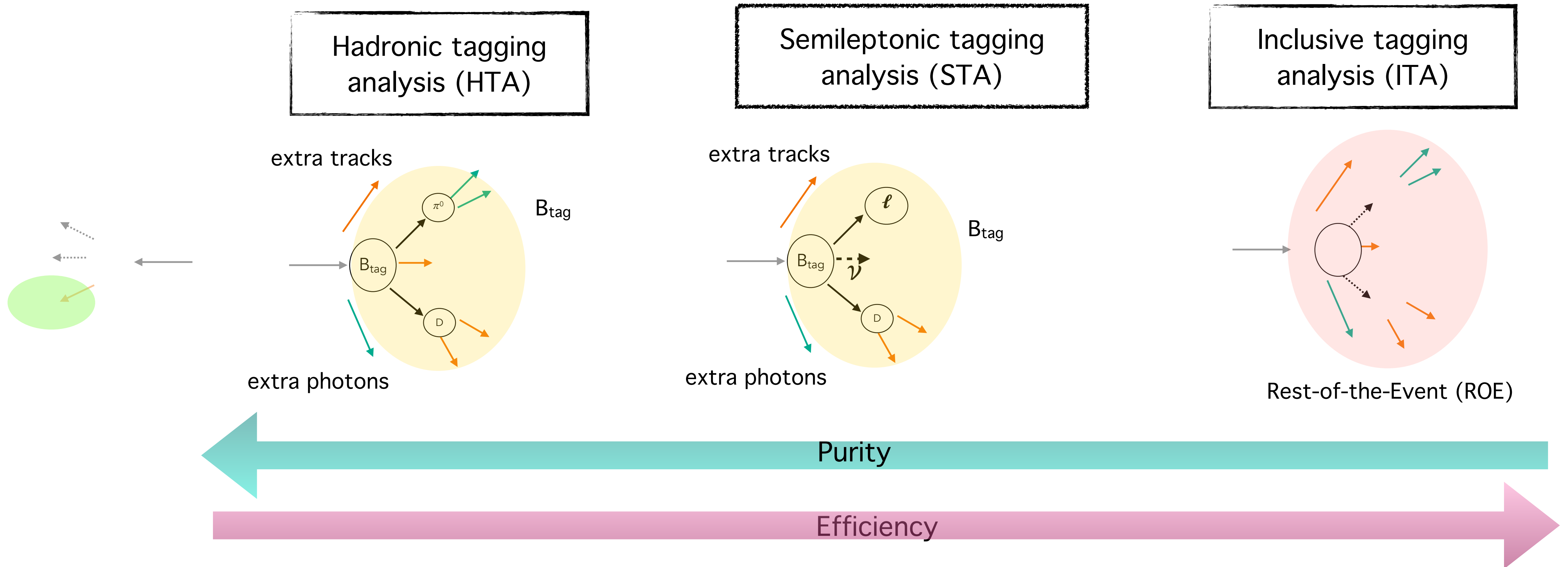
SM branching ratio

0

$O(10^{-7})$

$O(10^{-5})$

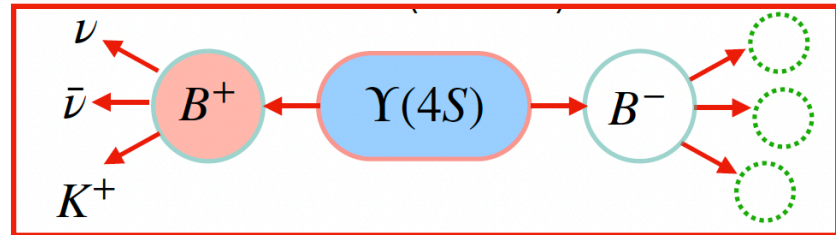
Tagging techniques



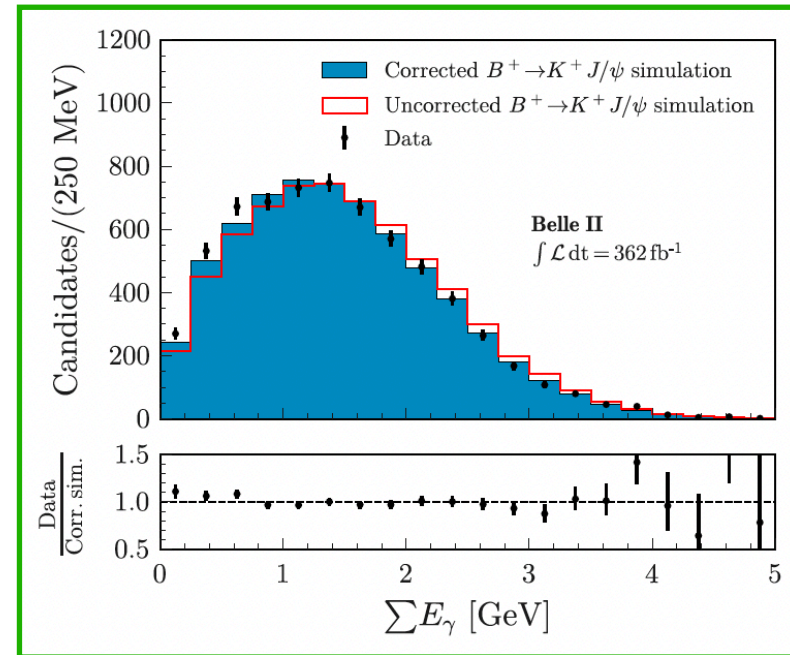
- So far, most of the analyses have been performed using **HAD Full Event Interpretation (FEI)**
- First **STA** results to come next year
- When applicable, **ITA** has proved to be **more sensitive than HTA**

Typical analysis flow

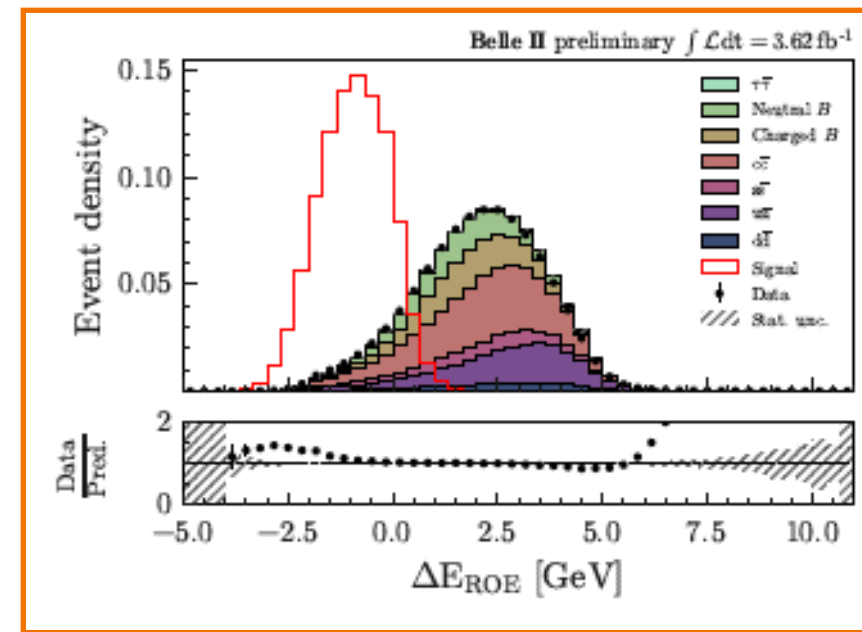
Reconstruction and basic selection



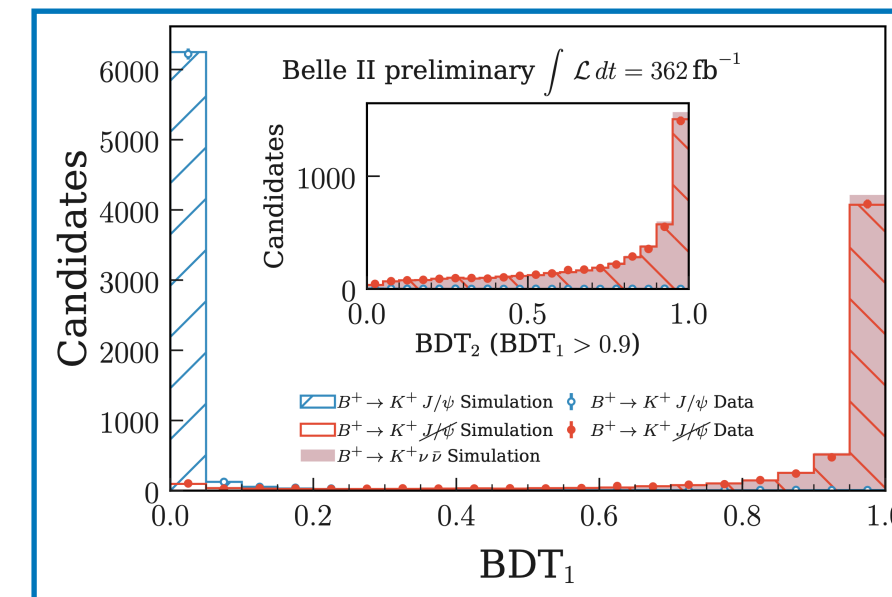
Data-MC corrections



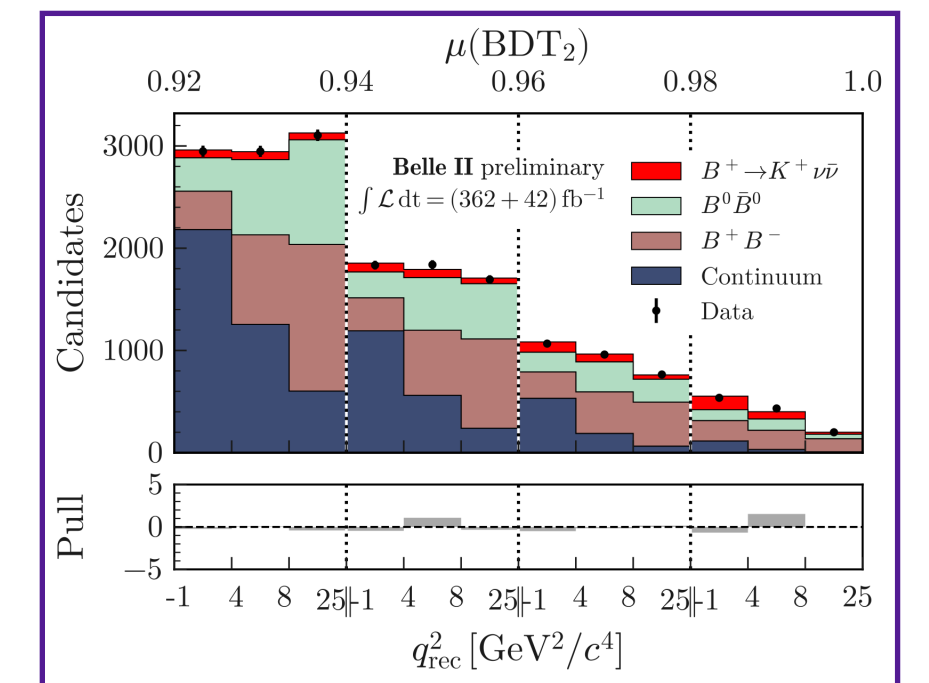
Background suppression



Validation



Signal extraction and Statistical interpretation



Branching Fraction as main measurable

In the SM, EWP+missE modes are **rare or forbidden**.

The main measurable is the **branching fraction**, on which we usually set upper limits:

$$\mathcal{B} = \frac{N_{sig}}{N_{B\bar{B}} \cdot \epsilon_{sig}}$$

- N_{sig} : from sample-composition fit or cut-and-count
- ϵ_{sig} : from signal MC
- $N_{B\bar{B}}$: from external inputs (f_{+-}/f_{00} and $\mathcal{R}(4S)$ counting)

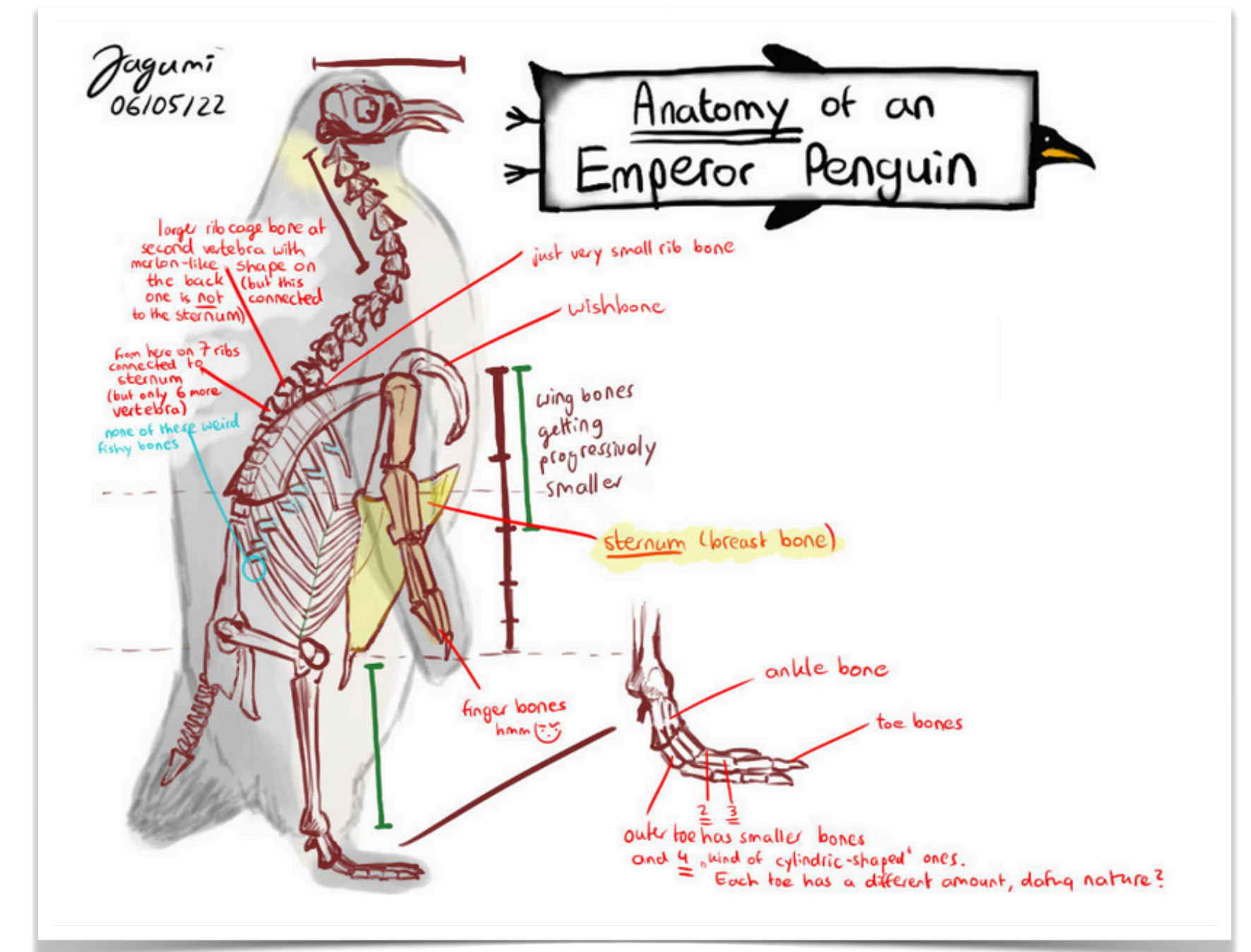
Both N_{sig} and ϵ_{sig} 's estimates require **corrections** to account for data/simulation discrepancies and bring the dominant **systematic uncertainties**

Uncertainty balance

- The **balance between statistical and systematic uncertainty** depends on signal extraction strategy and working point (= background contamination), same examples:

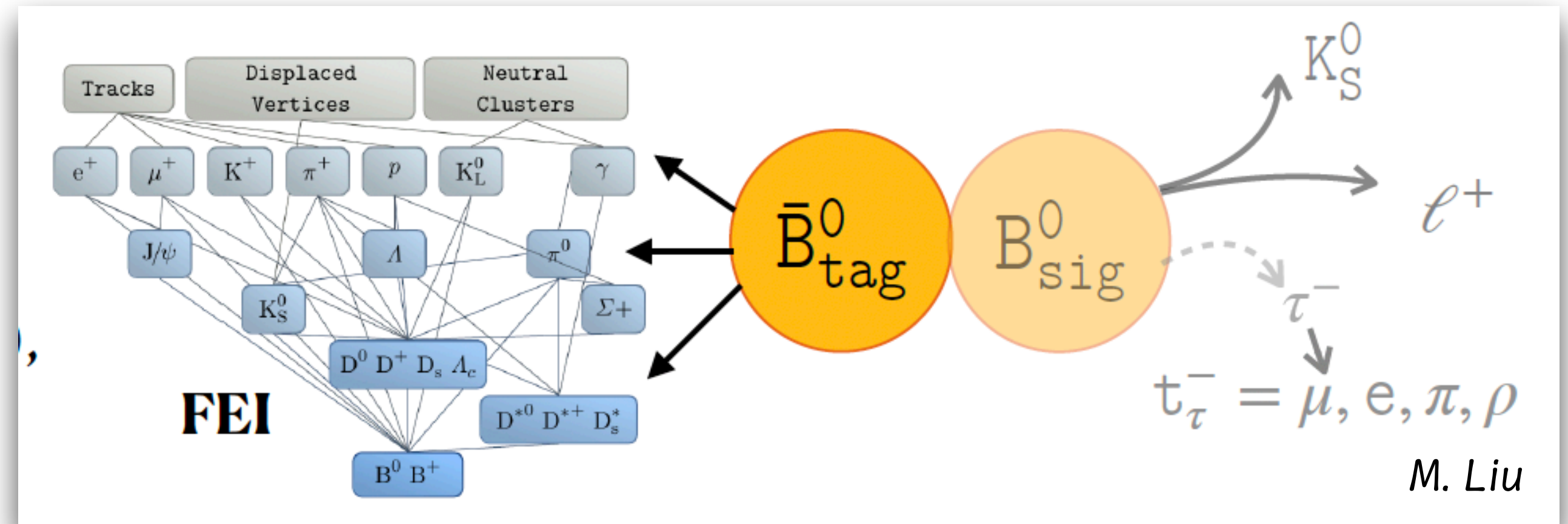
Analysis	Signal extraction strategy	Typical dominant syst. unc.	BF uncertainty balance	Measured BF uncertainty	Sample
$B^+ \rightarrow K^+ \gamma \gamma$ ITA	Binned fit	Knowledge of background normalization, limited size of simulated sample, syst for specific backgrounds/neutral energy corrections	Stat = Syst	$\pm 0.7 \times 10^{-5}$	
$B^+ \rightarrow K^+ \gamma \gamma$ HTA			Stat dominates but syst approaching	$\pm 1.1 \times 10^{-5}$	
$B^0 \rightarrow K^{*0} \tau \tau$ HTA				$\pm 1.0 \times 10^{-3}$	
$B^+ \rightarrow K^+ \tau \tau$ HTA	Cut-and-count	Knowledge of background normalization	Stat dominates but syst approaching	$^{+3.7}_{-3.3} \times 10^{-4}$	
$B^0 \rightarrow K^{*0} \tau \ell$ HTA	Unbinned fit	Knowledge of signal efficiency and signal PDF parameters	Negligible systematic uncertainty	$\sim \pm (1.5-2.8) \times 10^{-5}$	

Analysis dissection



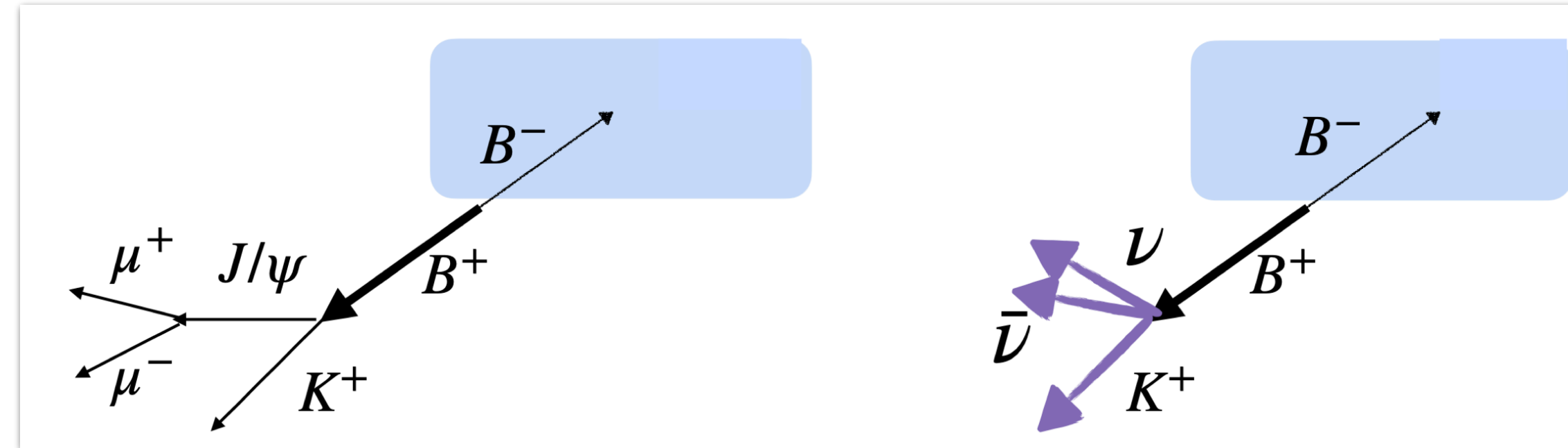
B_{tag} reconstruction and efficiency calibration from FEI

- B_{tag} reconstructed using “FEI” (see Karim’s [talk](#) for more details)



- Goodness of B_{tag} is quantified by the “FEI” signal probability
- Different $\mathcal{P}_{\text{FEI}}$ working points recommended:
 - for HTA: $>10^{-2}$, $>10^{-3}$ (most used)
- The choice is analysis dependent: @ analysis design stage, it’s worth checking different values
- **Corrections** are given on a B_{tag} mode-dependent basis, with uncertainty of the order of 5% (usually, negligible impact on BF systematic error balance)

Alternative FEI calibration: signal embedding (I)

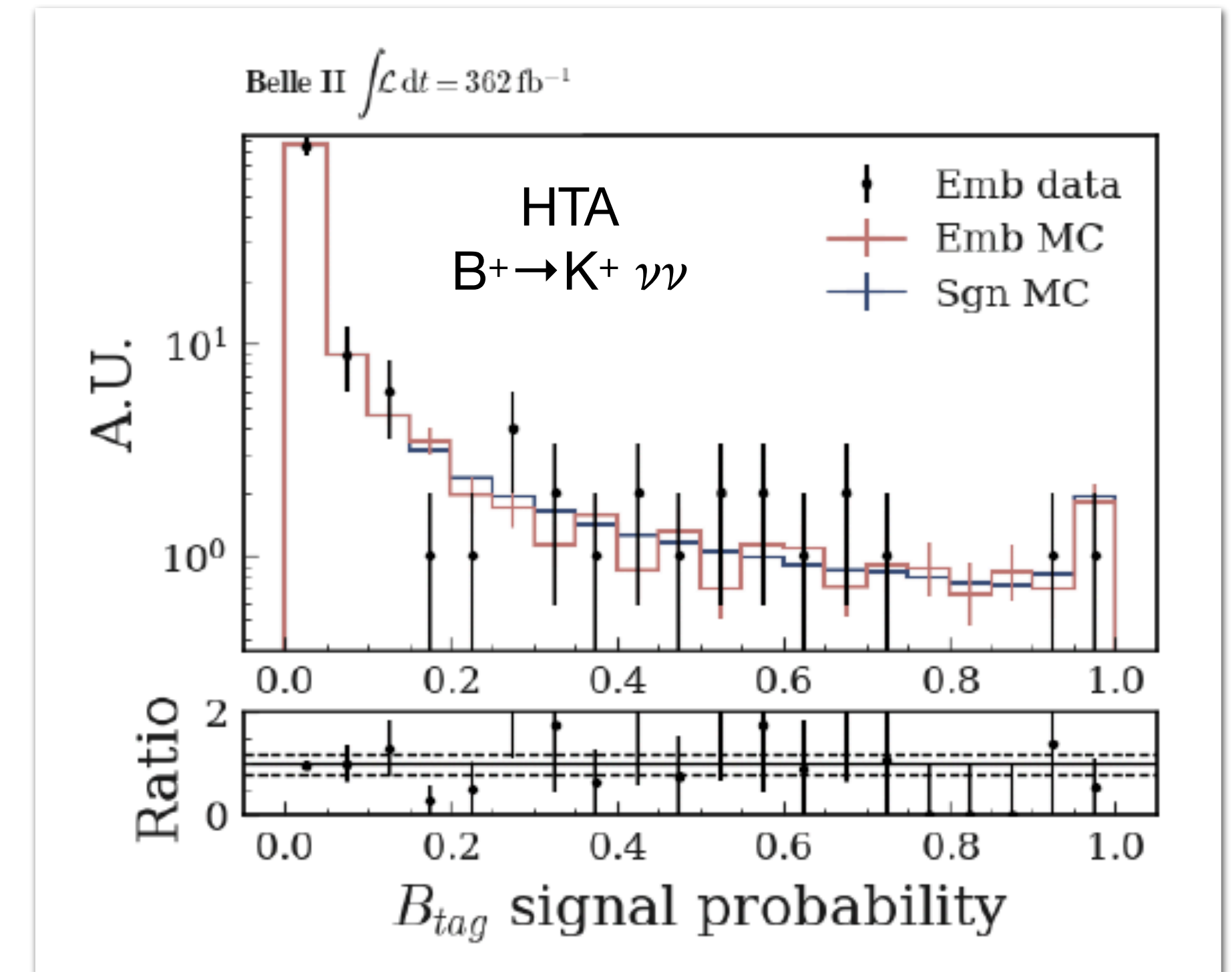


Alternative FEI calibration technique: [signal embedding](#) (now official [basf2 tool](#))

- Reconstruct $B \rightarrow J/\psi(\mu\mu)K^{(*)}$ events (large branching ratio, experimentally very clean)
- Remove $J/\psi(\mu\mu)K^{(*)}$ from reconstructed objects and replace with a signal B candidate from simulated signal events (both in data and MC)
- ROE (or B_{tag} +extra particles) is untouched

Alternative FEI calibration: signal embedding (II)

- Before using it:
 - check that the **embedded sample is a good control sample** for the signal (*always do that when you choose a sideband*)
 - check Data/MC agreement for selection variable
- Data/MC efficiency ratio used as tag efficiency correction
 - usually consistent with official FEI corrections
- CONTRA: low statistics
- PRO: analysis-specific control sample, **can be use to validate signal extraction variable and full signal efficiency** (and assign **systematic uncertainty** → has an impact)
 - this method is indeed used also in **ITA** for full **signal efficiency validation**



B_{sig} reconstruction: strange mesons

- Also signal side reconstruction can be done **exclusively** or **inclusively** (or in-between)
 - semi-exclusive reconstruction performed in $B \rightarrow X_s \nu \nu$ search
- **Strange meson** reconstruction (K , K_s , K^{*0}), starts from tracks+PID requirements as per performance group recommendation (more on Bianca, Eldar and Ale's talks tomorrow)

$B^+ \rightarrow K^+ \tau \tau$

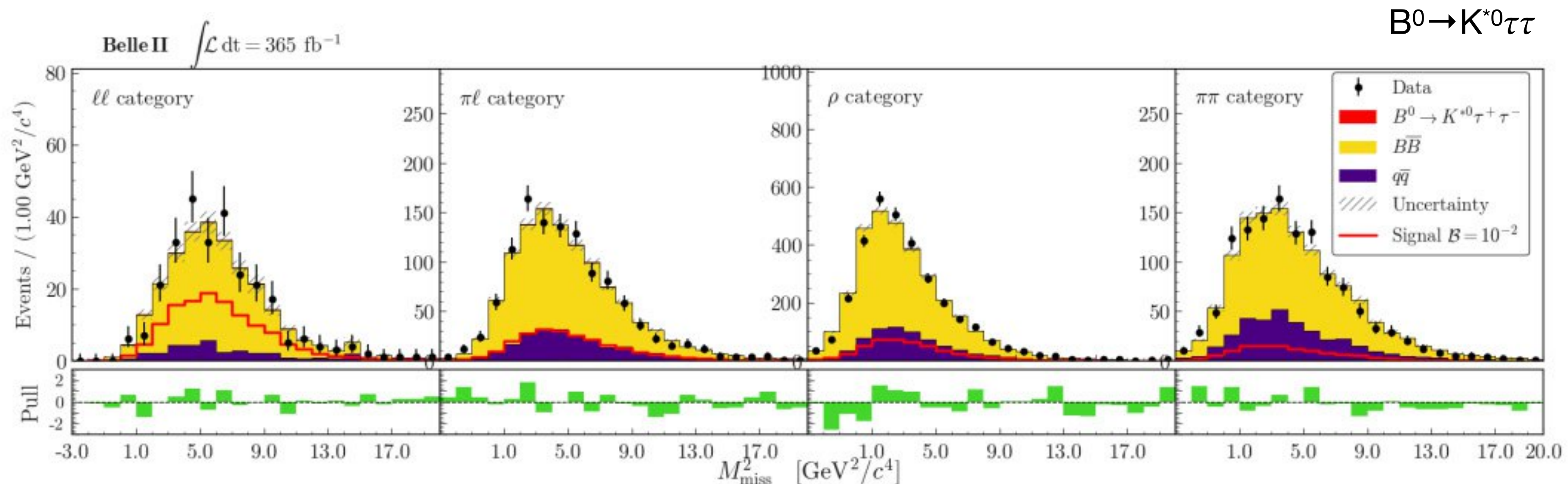
- Usually, **multiple PID working points are tested** and the associated systematic uncertainty is sub-dominant or negligible

118 from the ACC, CDC, and TOF for Belle. For Belle II, information from all subdetectors
119 except the PXD and SVD is used, resulting in a kaon identification efficiency of 85% (88%
120 for Belle) for a pion fake rate of 5% (8% for Belle) and a pion identification efficiency of
121 90% (91% for Belle) for a kaon fake rate of 7% (6% for Belle) at the particle identification
122 working points $\mathcal{P}_K, \mathcal{P}_\pi > 0.6$. For Belle, electrons are identified using the information from
123 the ECL, CDC and ACC, and information from the KLM only is used for muon identifi-
124 cation. Using the likelihood ratio requirement $\mathcal{P}_e(\mathcal{P}_\mu) > 0.9$, the lepton identification has
125 an efficiency of 92% (89%) and a pion fake rate of 0.3% (1.4%) for electrons (muons with
126 momentum larger than 0.6 GeV/c). For Belle II, the electron identification uses a boosted-
127 decision-tree (BDT) classifier trained with information from all sub-detectors except the
128 PXD and SVD and the muon identification uses information from all sub-detectors except
129 the PXD and SVD. At the particle identification working point $\mathcal{P}_e(\mathcal{P}_\mu) > 0.9$, the electron
130 (muon) identification has an efficiency of 86% (89%) and a pion mis-identification rate of
131 0.4% (7%).

B_{sig} reconstruction: leptons (I)

In most of the analyses, τ is reconstructed exclusively:

- $\tau \rightarrow \ell$, $\ell = e, \mu$ always included
- in some cases, π and ρ modes are also considered

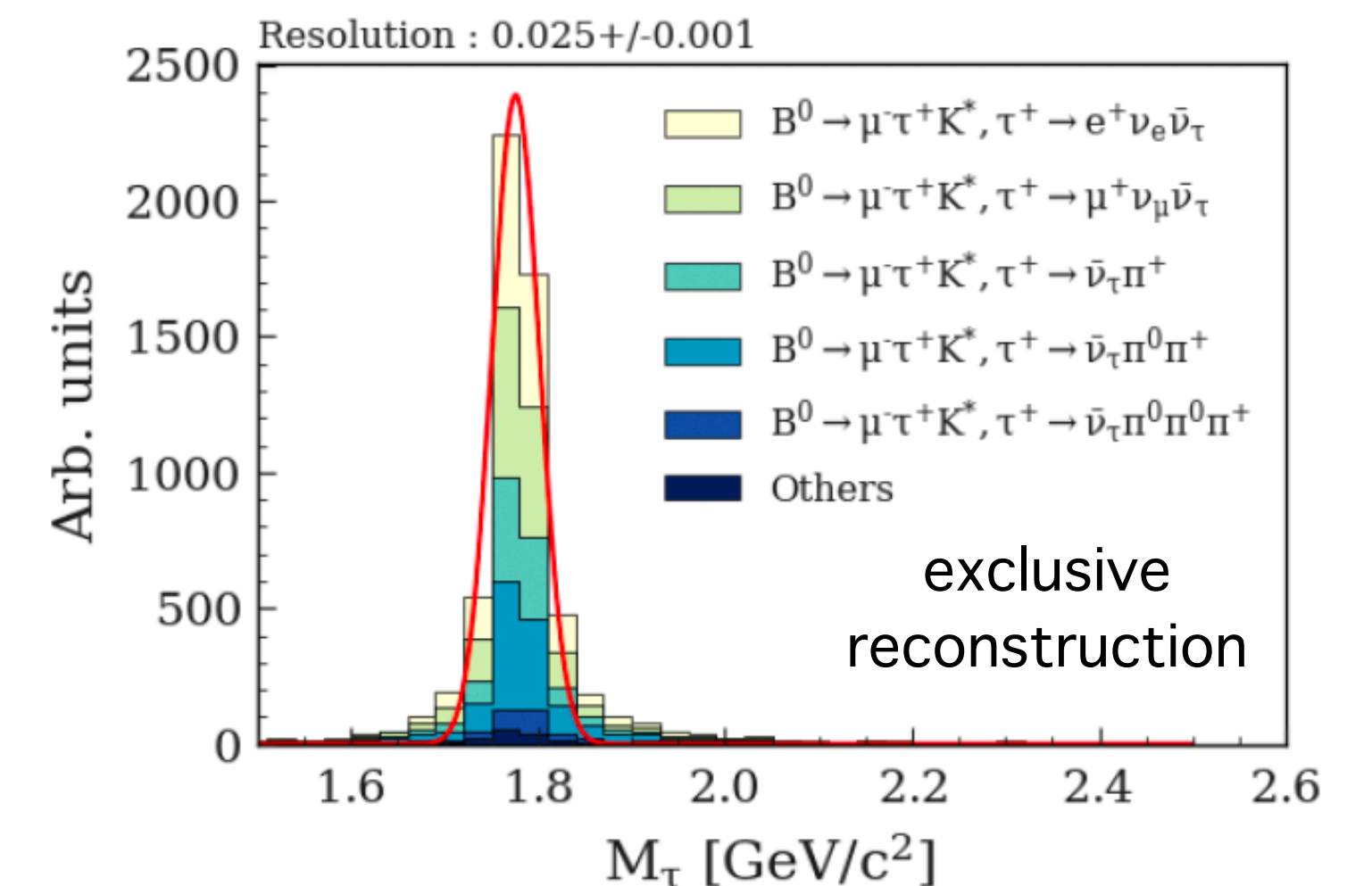
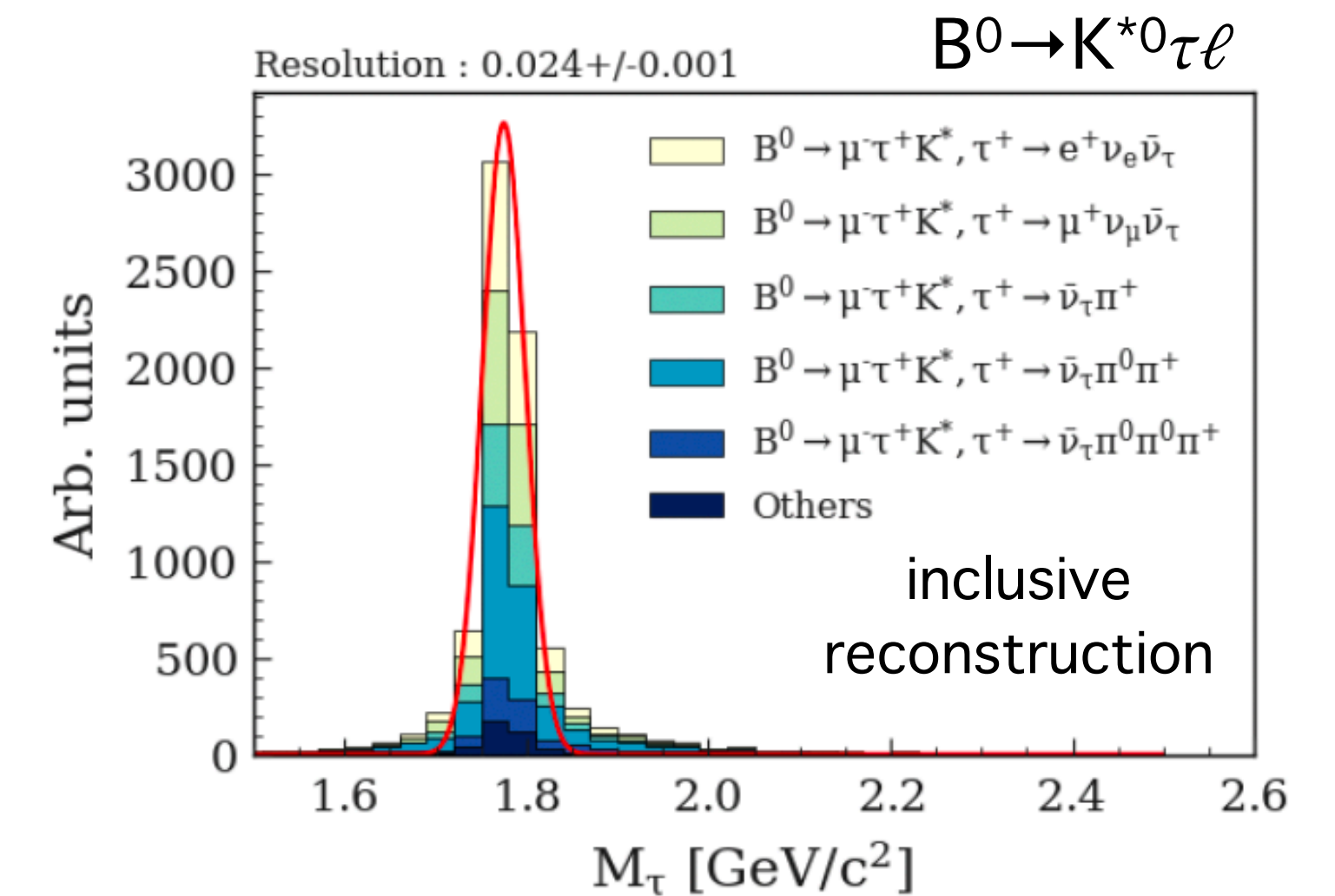


Even if channel with hadrons are less pure than leptonic modes, ~35% reduction on $B^0 \rightarrow K^{*0} \tau \tau$ BF uncertainty when adding them (analysis dependent)

B_{sig} reconstruction: leptons (II)

In $B \rightarrow K^{*0} \tau \ell$ search, τ is reconstructed with an **inclusive technique**:

- $\tau \rightarrow$ 1-prong track without particle ID, allow for up to 2 extra-tracks to includes also $\tau \rightarrow$ 3-prong decays
- comparison with exclusive reconstruction performed:
 - **slightly higher efficiency** in inclusive approach
 - τ invariant mass resolution **essentially unchanged**

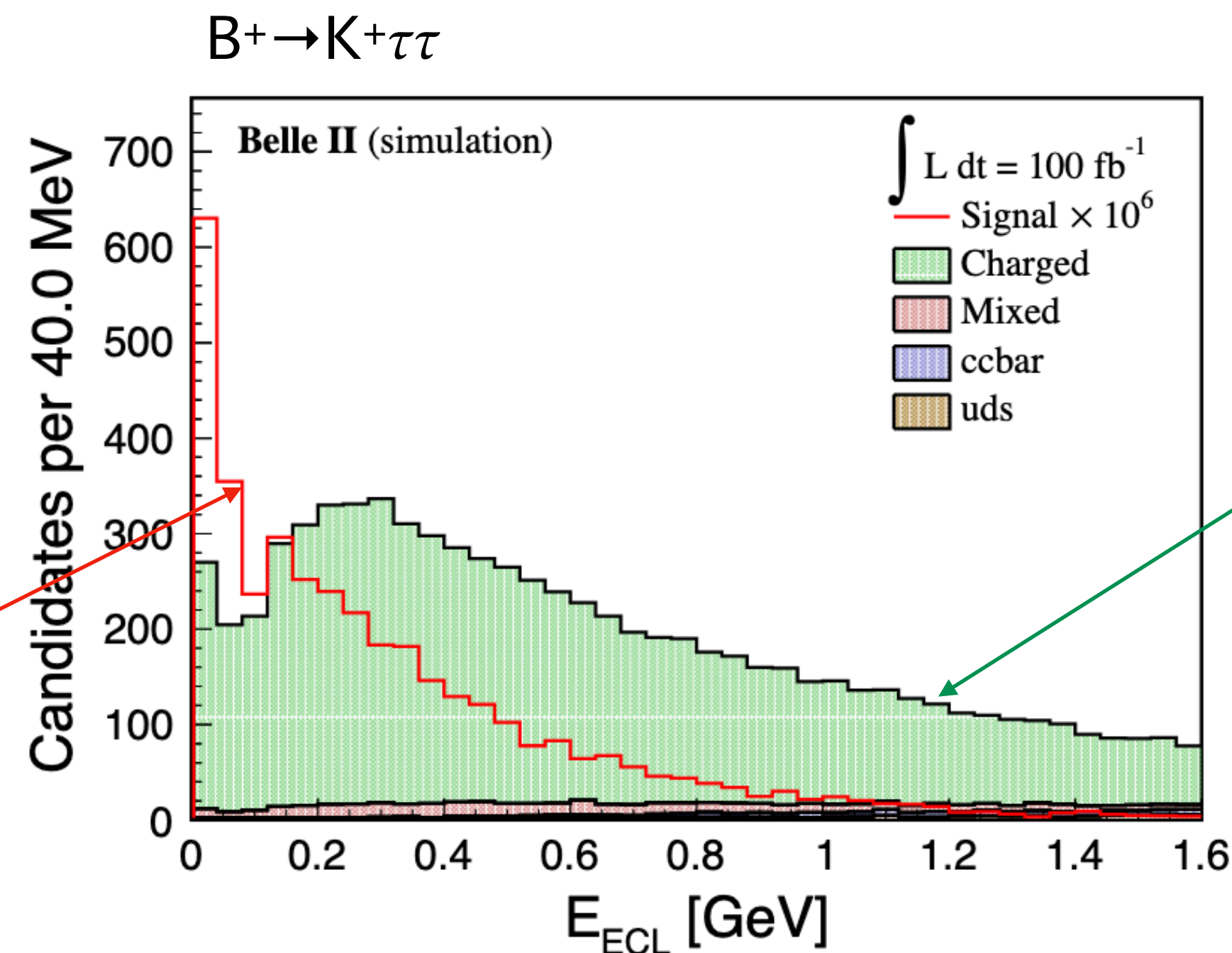


Treatment of extra-particles

- In tagged analyses, events with **extra-tracks** or **neutral extra-mesons** such as π^0 or K_s are usually rejected
- **Extra-photons total energy** is one of the most discriminating variables in missing energy analyses

$$E_{\text{ECL}} = \sum_{\text{extra-}\gamma} E_i$$

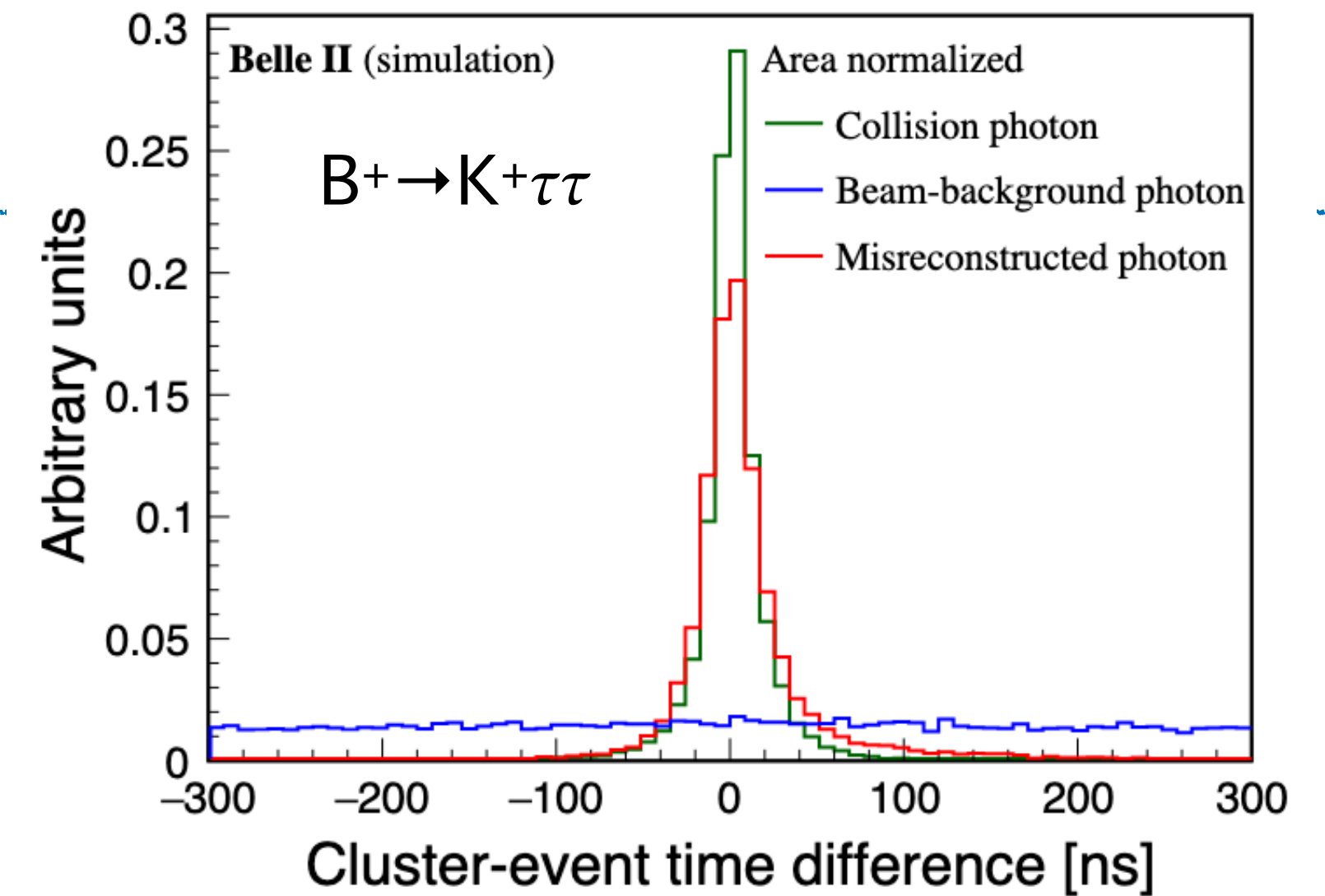
Ideally, for correctly reconstructed signal events, no extra activity in the calorimeter is expected. Tails in the signal distribution are due to mis-reconstruction effects and ECL energy resolution.



Larger ECL deposits are expected from background events. Peak at zero due to energy threshold adopted in extra photon selection

E_{ECL} calibration

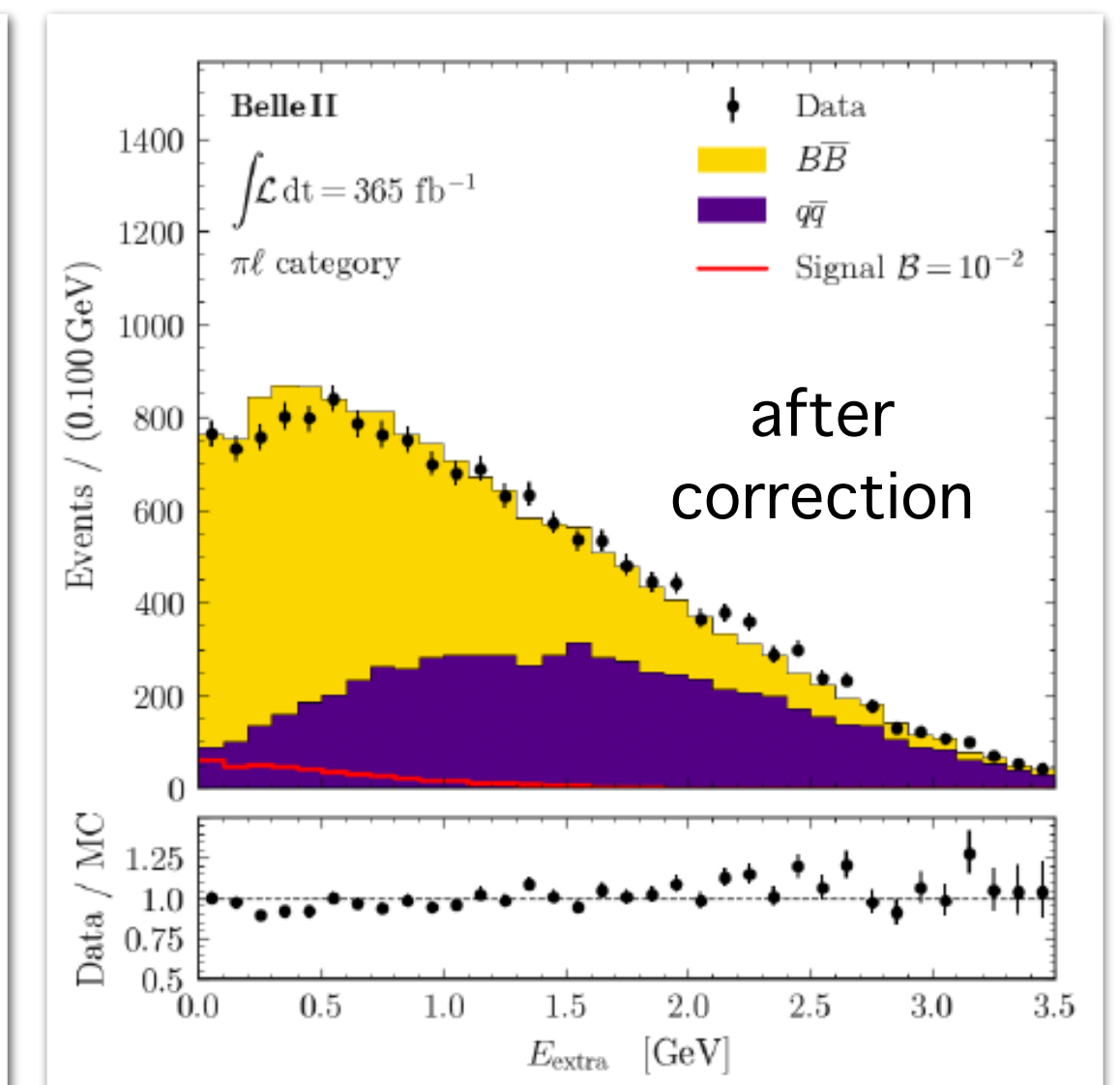
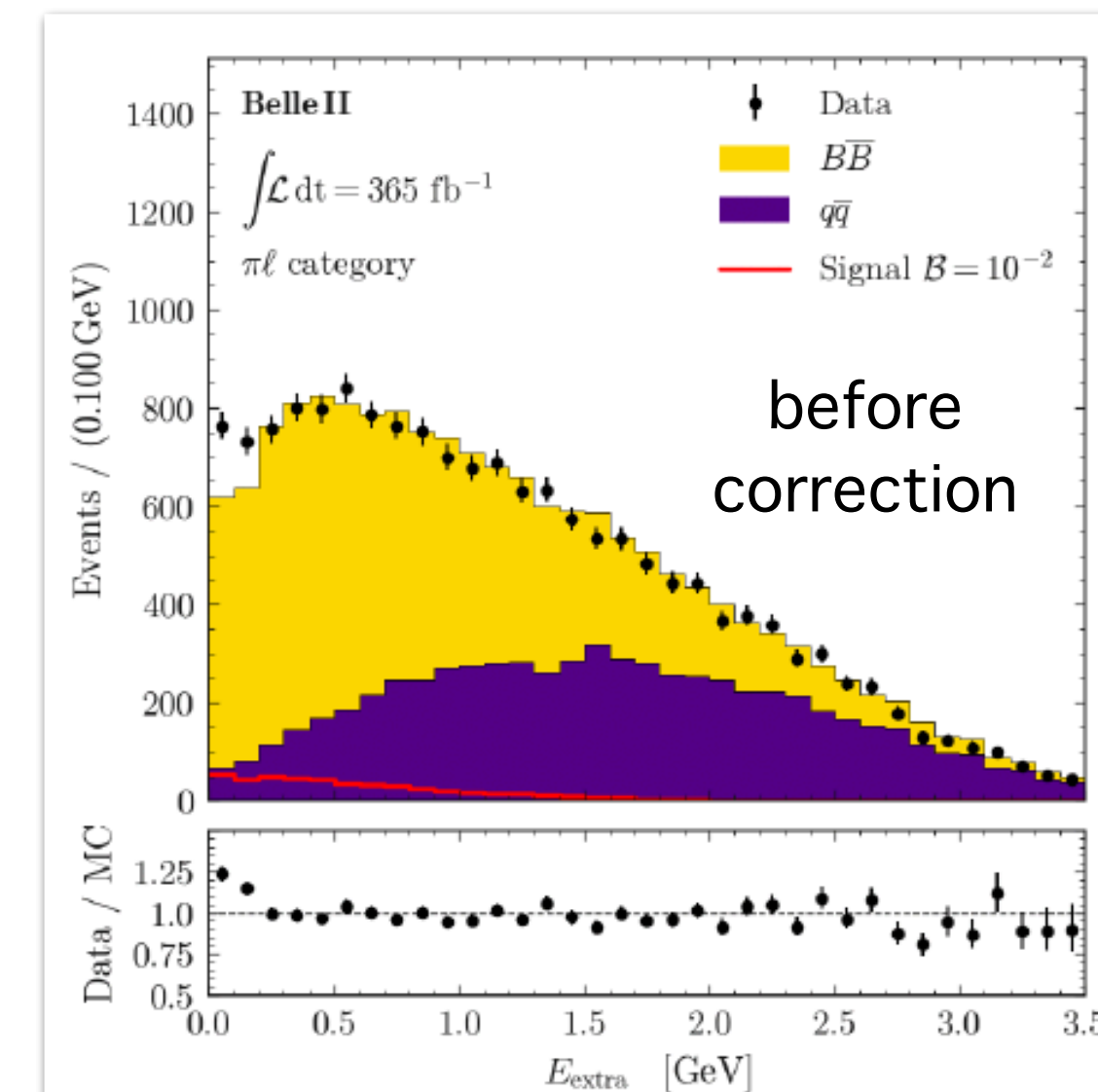
- Extra-photons originates from **real photons**, **beam backgrounds**, **ECL clusters from tracks** for which cluster-track mating failed



- Data/MC agreement in E_{ECL} depends on the extra-photon selection and on the MC campaign. Ad hoc **correction** may be needed:

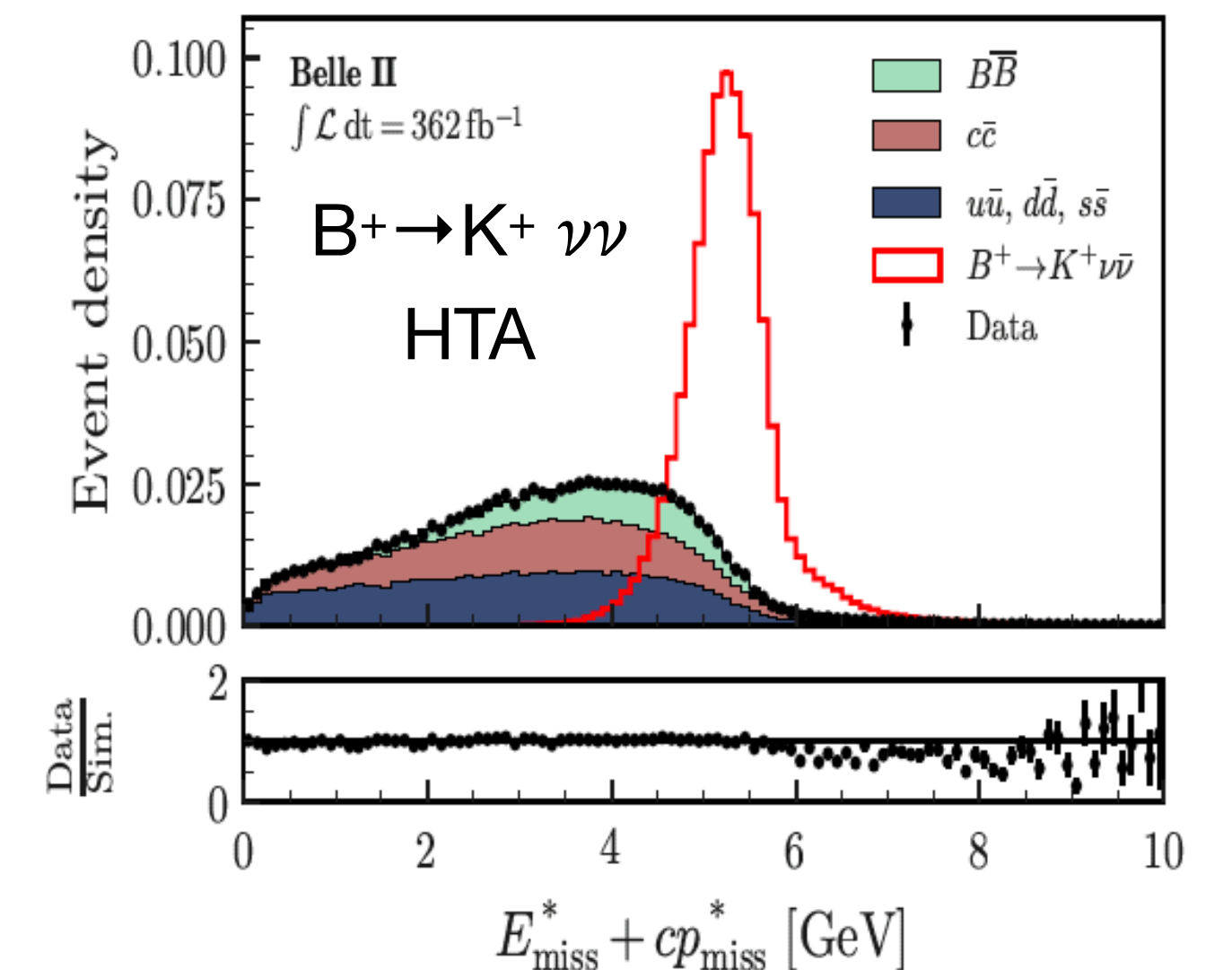
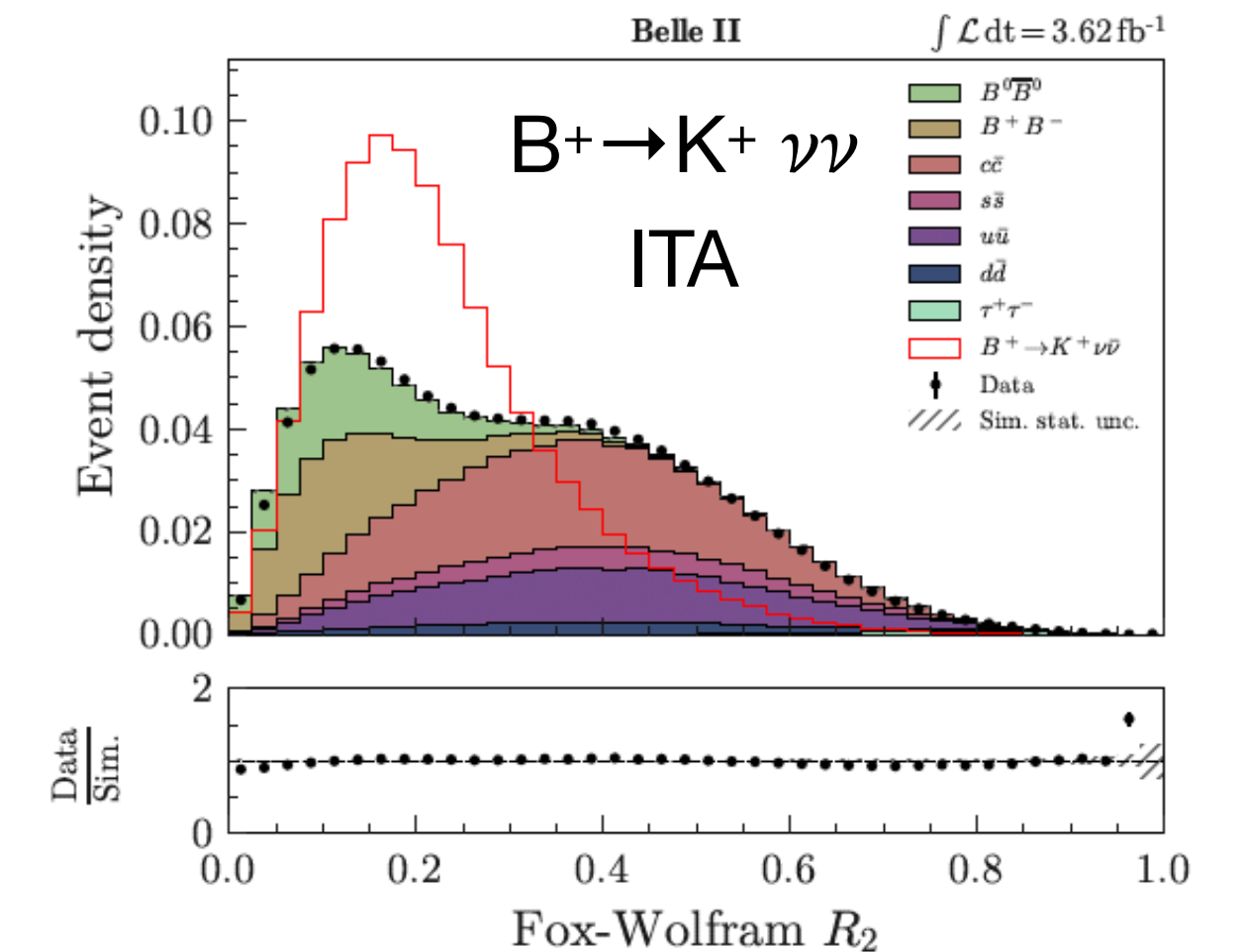
Event-by-event correction based on photon multiplicity distribution in some sideband and apply to E_{ECL} in the single region.

Remaining discrepancy $\leftrightarrow$ systematic uncertainty (has an impact)



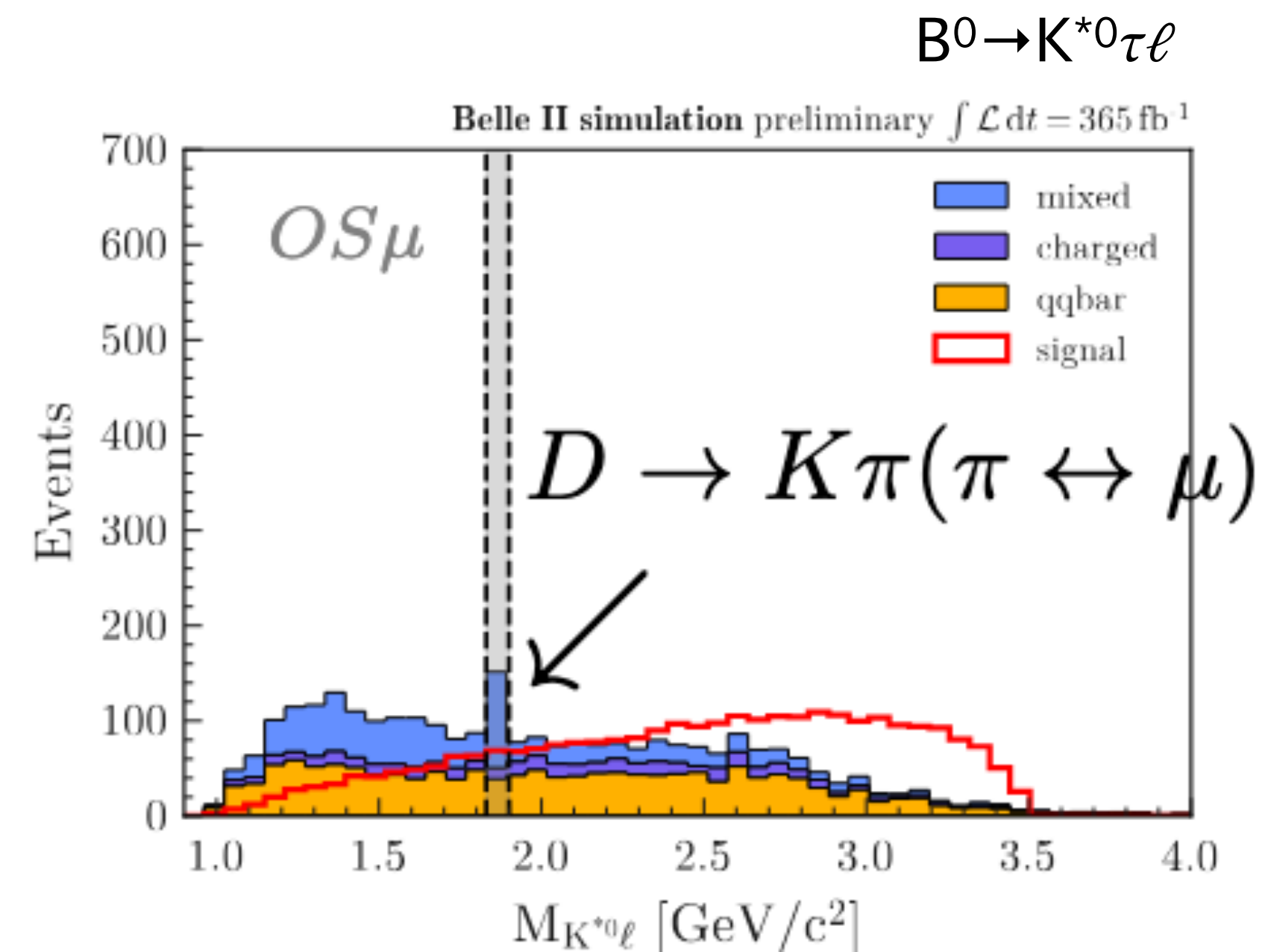
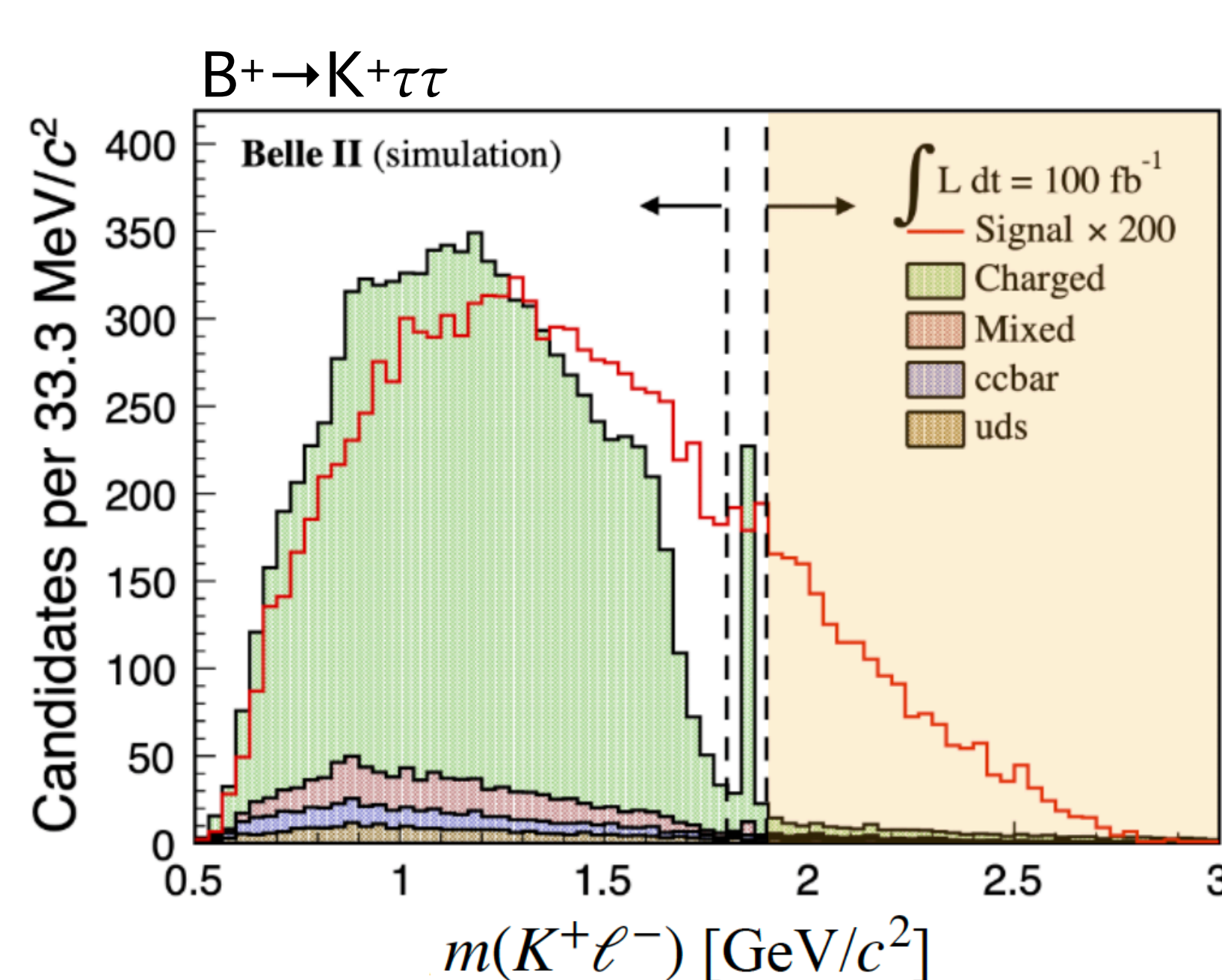
Strategies for background suppression

- After signal side reconstruction and requirements on ROE/extra-particles, the **final background suppression** stage is implemented
- Identify **discriminant** and **well-described** variables
 - E_{ECL} , P_{miss} , kinematic properties of signal side particles
 - Variables targeting specific backgrounds (see next slide)
 - Event shape variables to suppress continuum background
- Combined in a **multivariate tool** or used in a **cut-and-count** analysis.



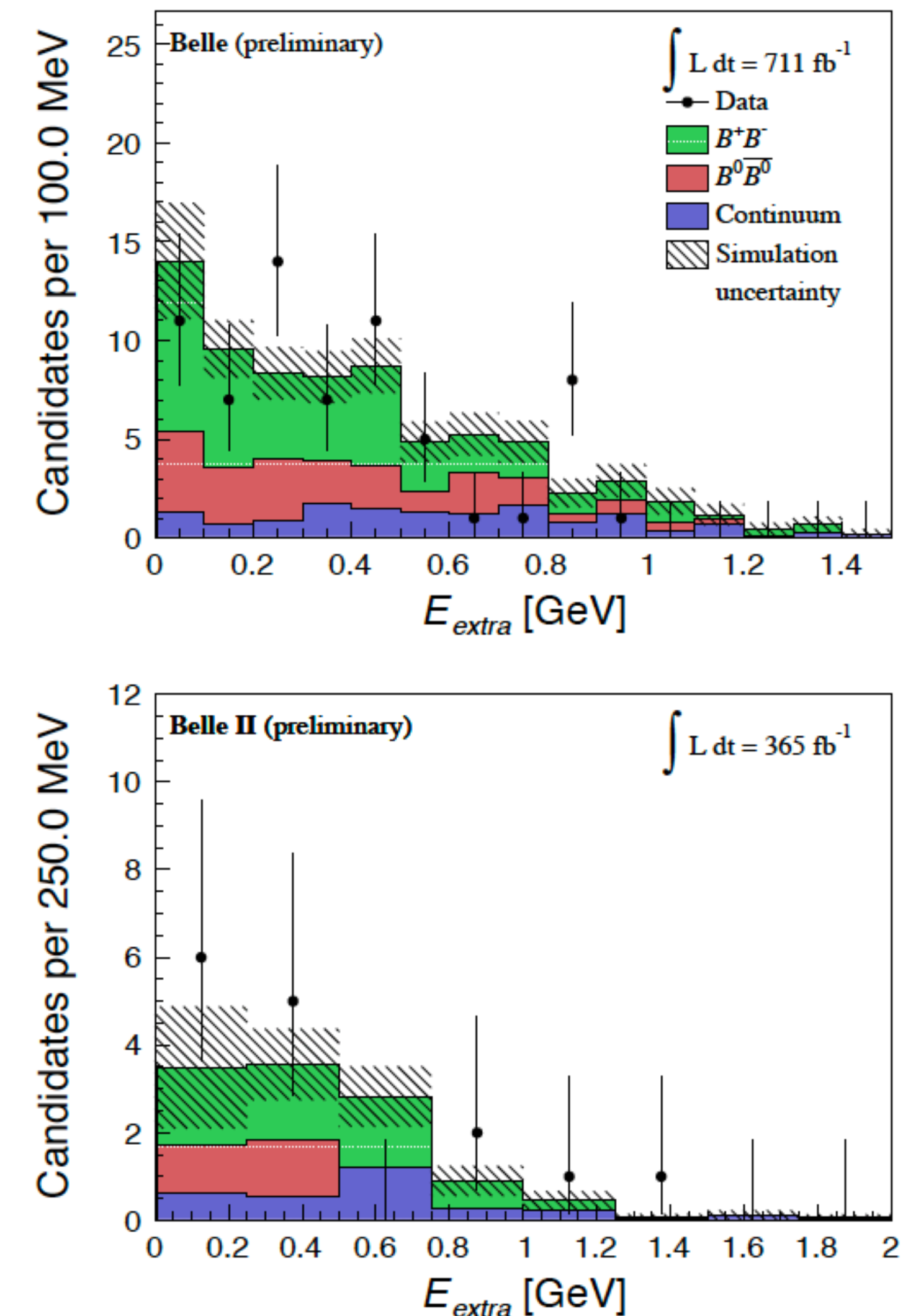
A remark on dominant common backgrounds

- Dominant backgrounds are usually from **semileptonic B decays** in which the **signal $K^{(*)}$** actually come from a **$D^{(*)}$**
- The **invariant mass** of the signal $K^{(*)}$ and another track in the event (e.g. a signal side lepton in $b \rightarrow s \tau \ell / \tau \tau$) can be used to reject background



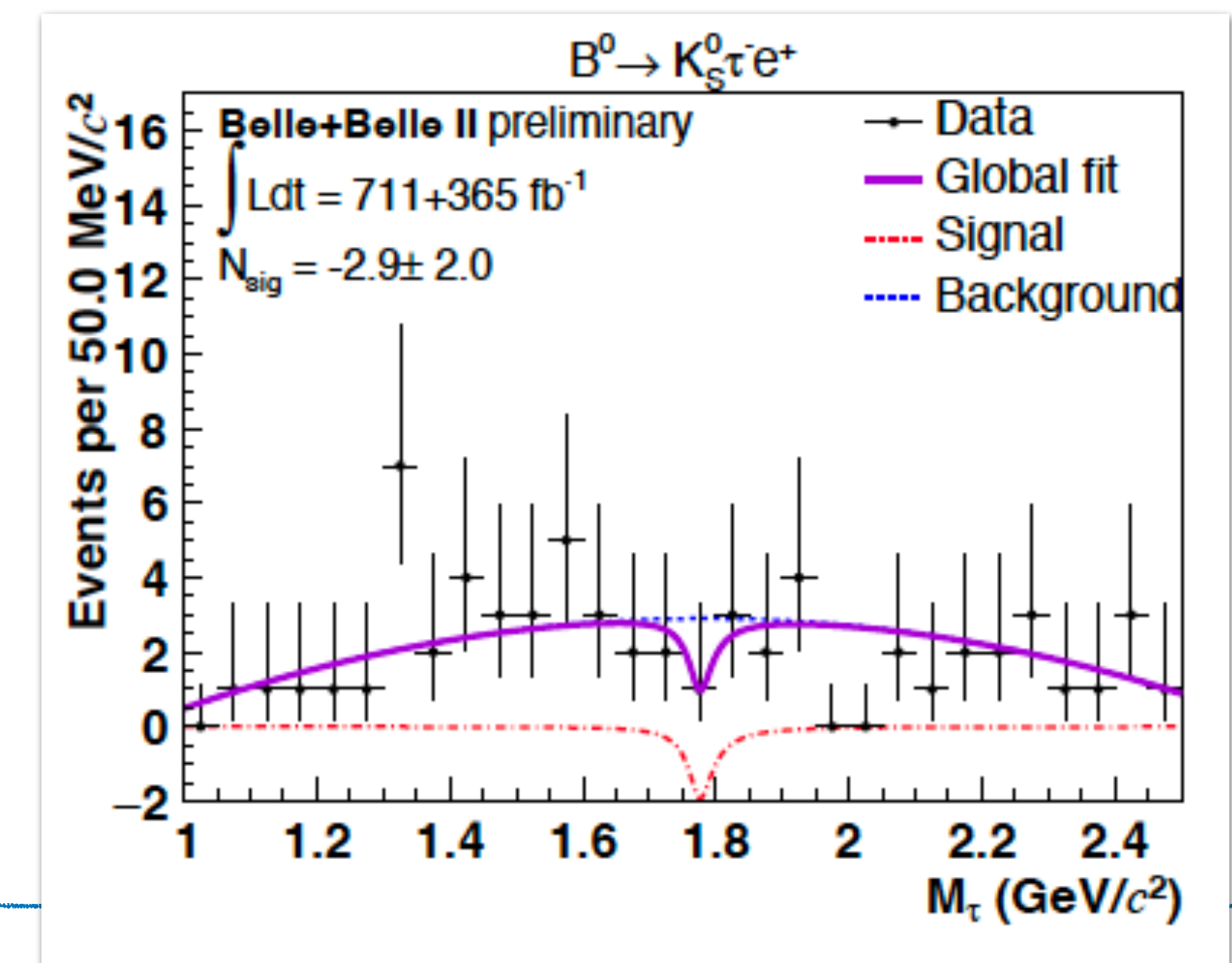
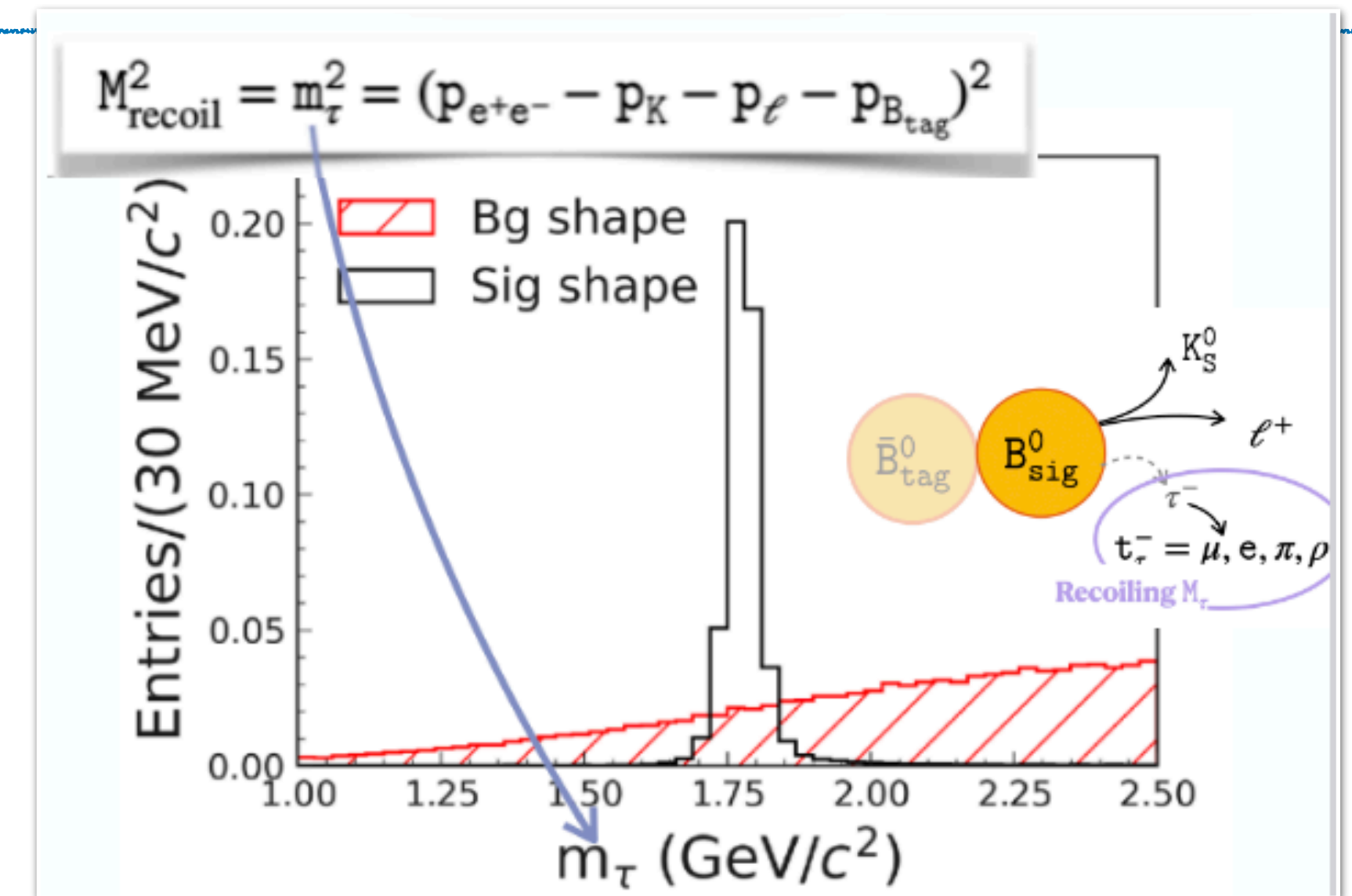
An example of cut-and-count analysis: $B^+ \rightarrow K^+ \tau \tau$

- τ reconstructed in leptonic modes
- $m(K\ell)$ cut to reject most of the background
- Final signal region defined by M^2_{miss} , τ daughter momentum and E_{ECL}
- Use E_{ECL} , B_{tag} , M_{BC} and q^2 sidebands to correct background estimate
- Dominant systematic uncertainty from background and FEI corrections



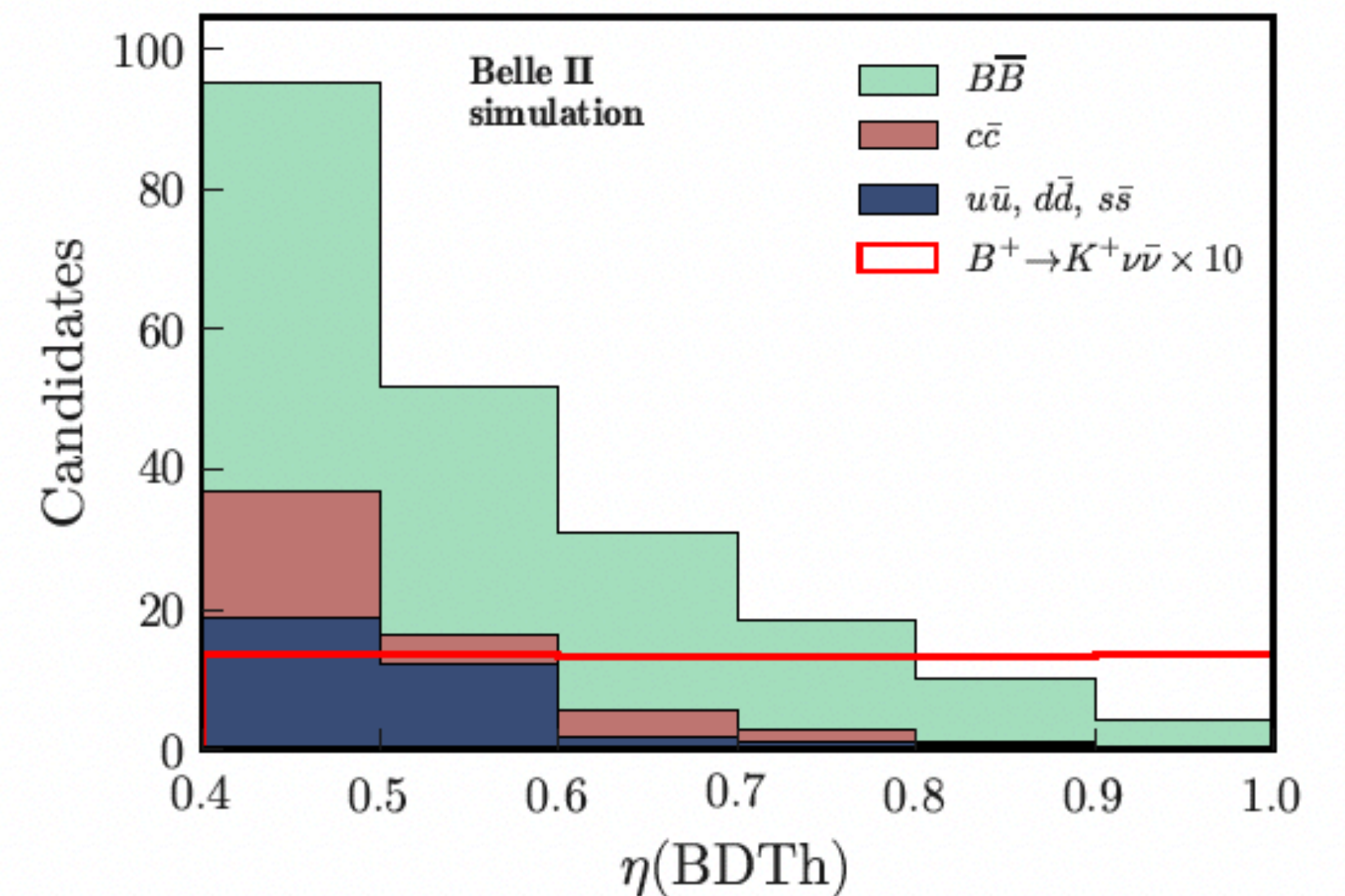
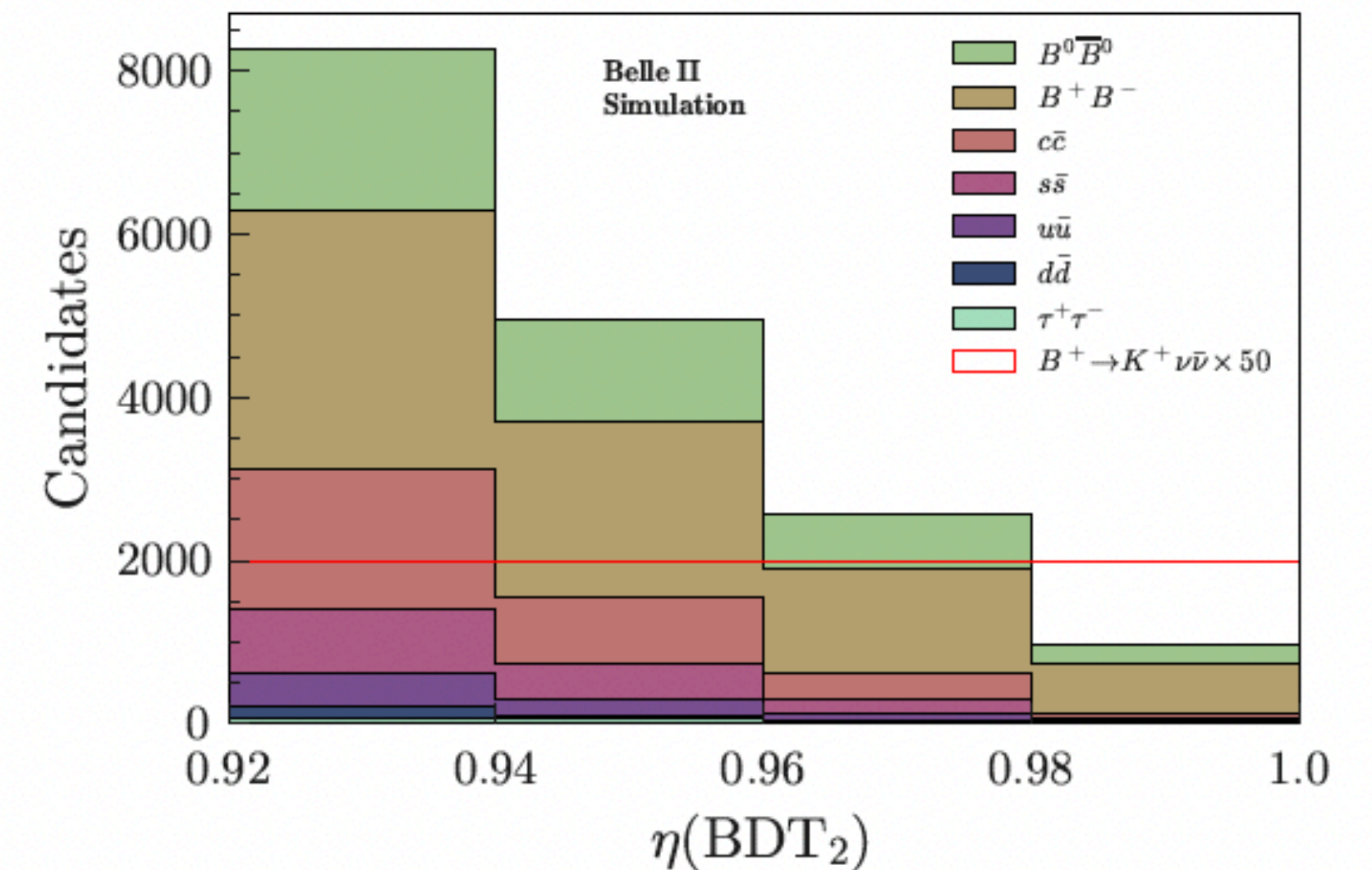
An example of unbinned fit analysis: $B^0 \rightarrow K_S \tau \ell$

- Discriminant variables combined in a **BDT**
- In this case, we have a variable which is **peaky** for the signal: m_τ
- Used as **signal extraction variable**
- Dominant systematics from calibration of BDT cut **efficiency** and **signal PDF** parameterisation



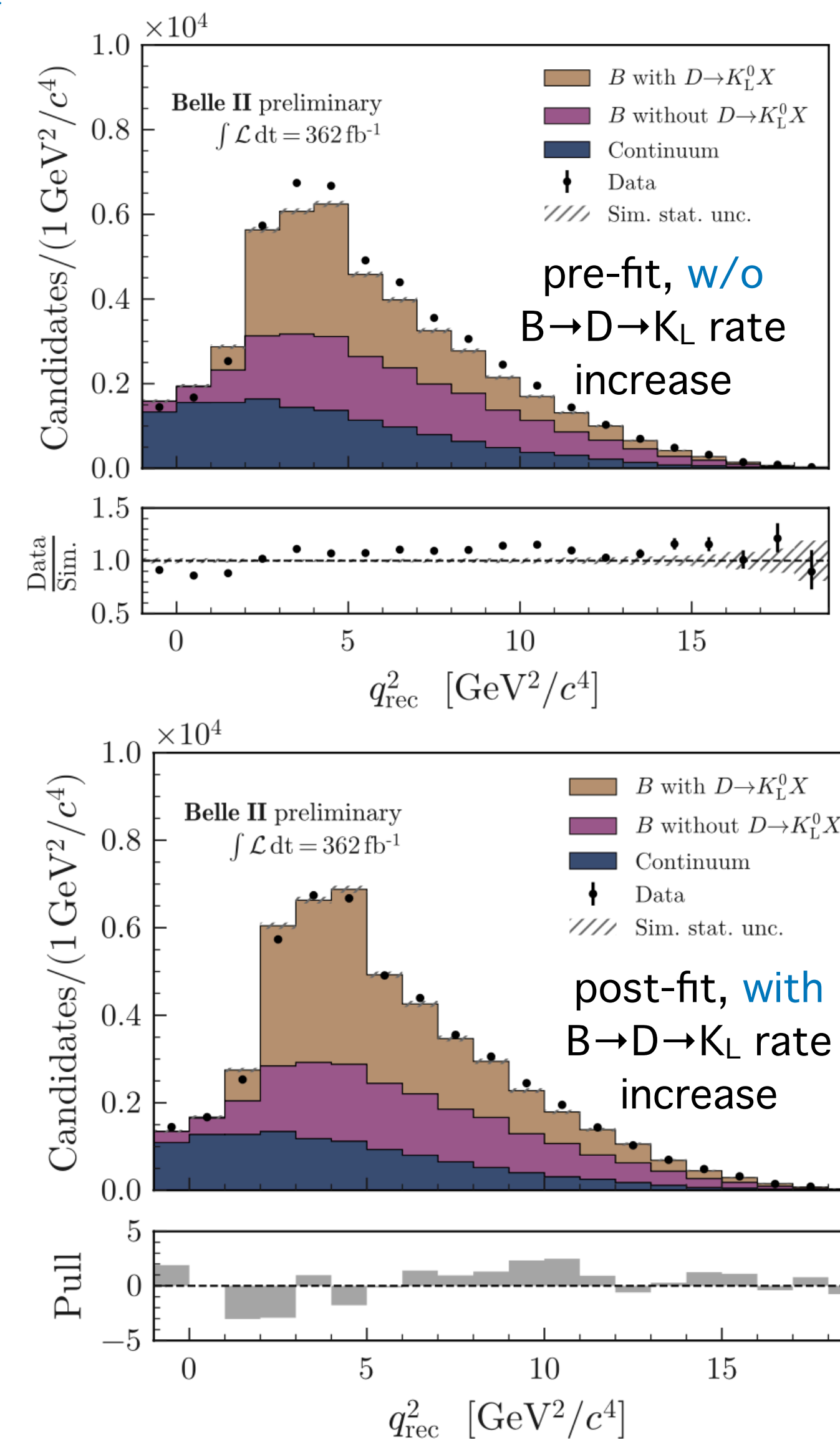
Examples of binned fit analyses: $B^+ \rightarrow K^+ \nu \bar{\nu}$ (I)

- Final background suppression via **BDT**, also used as **signal extraction variable**
- **HTA**: control samples used to correct the qq and generic BB normalisation before the BDT training; data/MC validation repeated in the signal region to assign systematic uncertainty
- **ITA**: data/MC comparison in off-resonance data is used to background normalization systematics
- In both cases, corrections for **specific backgrounds** are applied before the classifier training



Example of specific background study in $B^+ \rightarrow K^+ \nu \nu$

- Study **pion-enriched control sample** ($B^+ \rightarrow \pi^+ X$ instead of $B^+ \rightarrow K^+ X$)
- Observed data excess in q^2_{rec} distribution above D threshold
- Excess fixed by increasing **$B \rightarrow D \rightarrow K_L$ component** by +30%
 - derived from 3-component fit to q^2_{rec}
- Procedure successfully validated on electron- and muon-enriched control samples
- 10% systematic uncertainties to cover differences in scaling factor from the different sidebands



Systematic Uncertainties for $B^+ \rightarrow K^+ \nu \nu$

ITA

Source	Impact on σ_μ
1 Normalization of $B\bar{B}$ background	0.90
Normalization of continuum background	0.10
Leading B -decay branching fractions	0.22
3 Branching fraction for $B^+ \rightarrow K^+ K_L^0 K_L^0$	0.49
p-wave component for $B^+ \rightarrow K^+ K_S^0 K_L^0$	0.02
4 Branching fraction for $B \rightarrow D^{**}$	0.42
Branching fraction for $B^+ \rightarrow K^+ n \bar{n}$	0.20
Branching fraction for $D \rightarrow K_L^0 X$	0.14
Continuum-background modeling, BDT_c	0.01
Integrated luminosity	<0.01
Number of $B\bar{B}$	0.02
Off-resonance sample normalization	0.05
Track-finding efficiency	0.20
Signal-kaon PID	0.07
Photon energy	0.08
Hadronic energy	0.37
K_L^0 efficiency in ECL	0.22
Signal SM form-factors	0.02
Global signal efficiency	0.03
2 Simulated-sample size	0.52

HTA

Source	Impact on σ_μ
1 Normalization of $B\bar{B}$ background	0.91
4 Normalization of continuum background	0.58
Leading B -decay branching fractions	0.10
Branching fraction for $B^+ \rightarrow K^+ K_L^0 K_L^0$	0.20
Branching fraction for $B \rightarrow D^{**}$	<0.01
Branching fraction for $B^+ \rightarrow K^+ n \bar{n}$	0.05
Branching fraction for $D \rightarrow K_L^0 X$	0.03
Continuum-background modeling, BDT_c	0.29
Number of $B\bar{B}$	0.07
Track finding efficiency	0.01
Signal-kaon PID	<0.01
2 Extra-photon multiplicity	0.61
K_L^0 efficiency	0.31
Signal SM form-factors	0.06
Signal efficiency	0.42
3 Simulated-sample size	0.60

Pre box-opening consistency checks

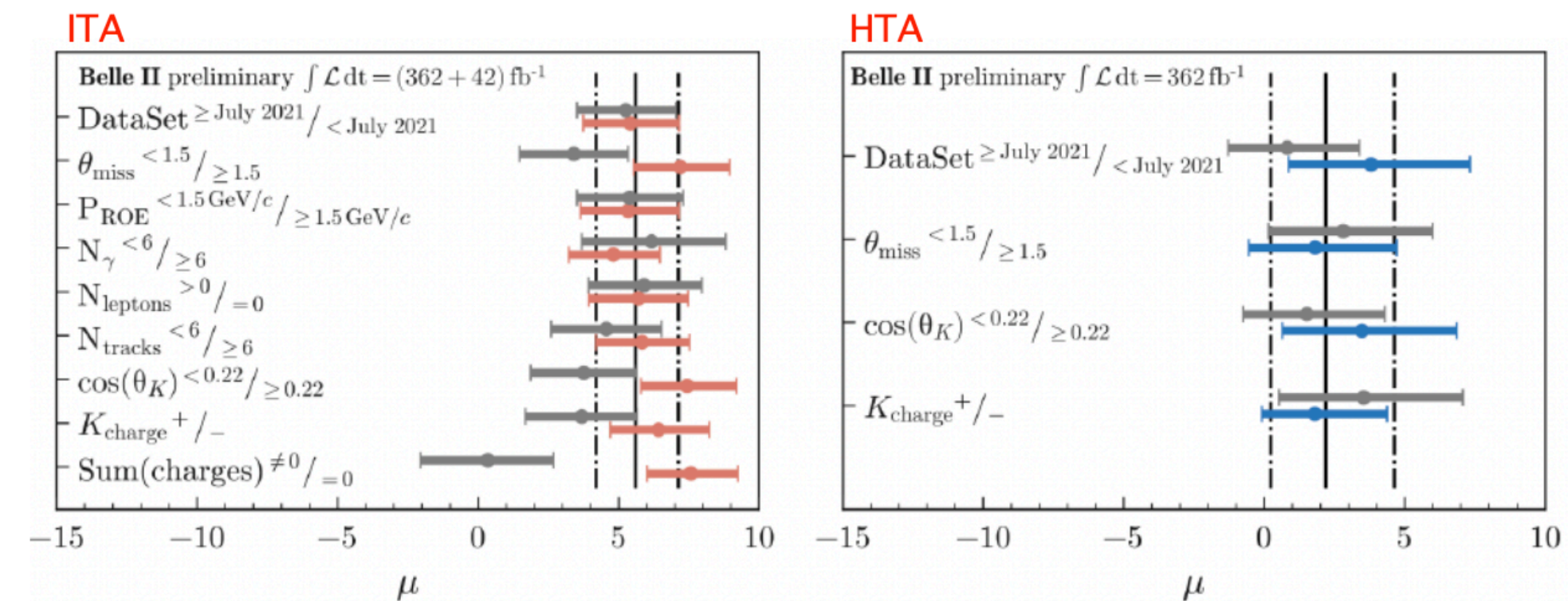
Once the analysis is frozen, before looking the full signal region, perform test on portions of the dataset or on control samples to see that you get what you expect

- 1) Fit to the **same-flavor** data → BR, p-value, pulls
- 2) **Partial fit**
 - a) signal region restricted to the lowest sensitive BDT bins with all signal categories → BR, p-value, pulls
- 3) Blind fit on **half-split proc vs prompt**, where only the uncertainty and the μ differences between the two samples are compared
- 4) **Full fit** to the signal region **keeping all results blinded** except pulls of nuisances
- 5) **Partial fit**
 - b) signal region restricted to $\pi\pi$ category → BR, p-value, pulls

$$B^0 \rightarrow K^{*0} \tau \tau$$

$$B^+ \rightarrow K^+ \nu \nu$$

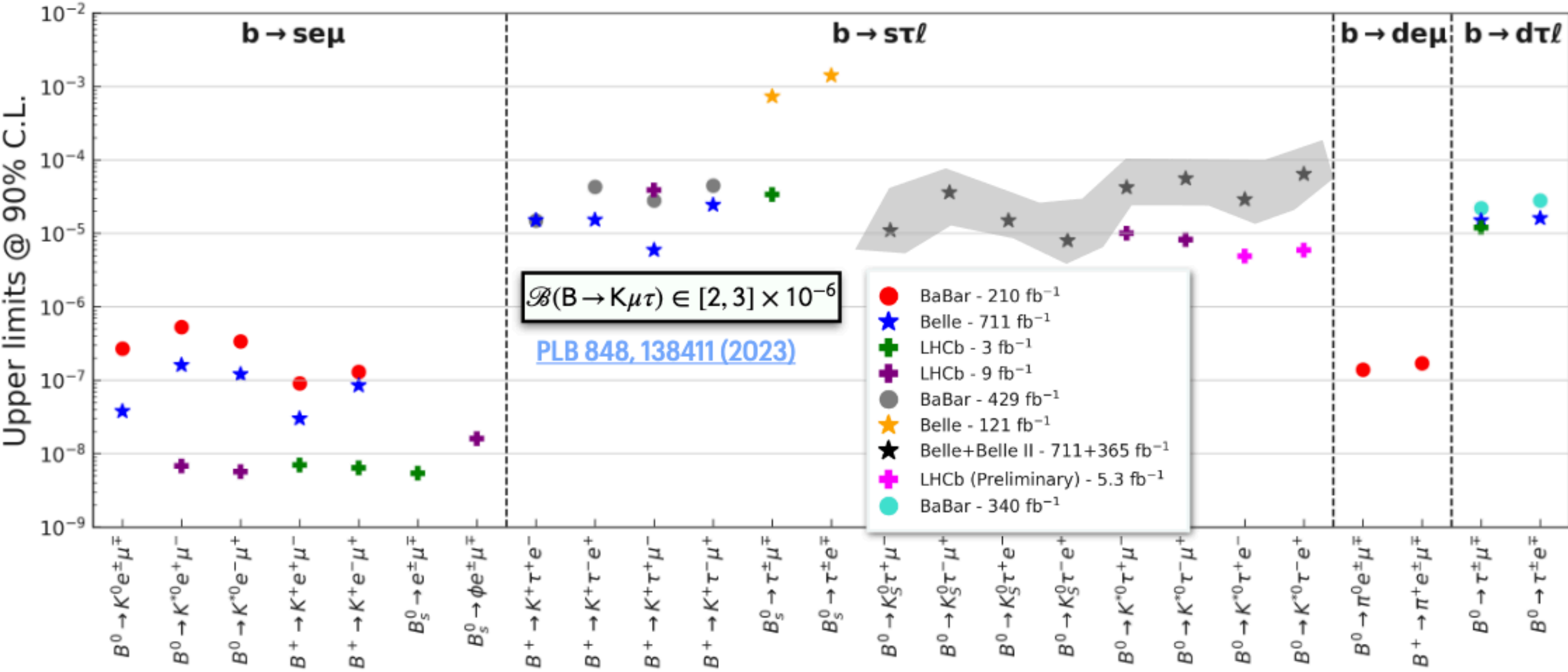
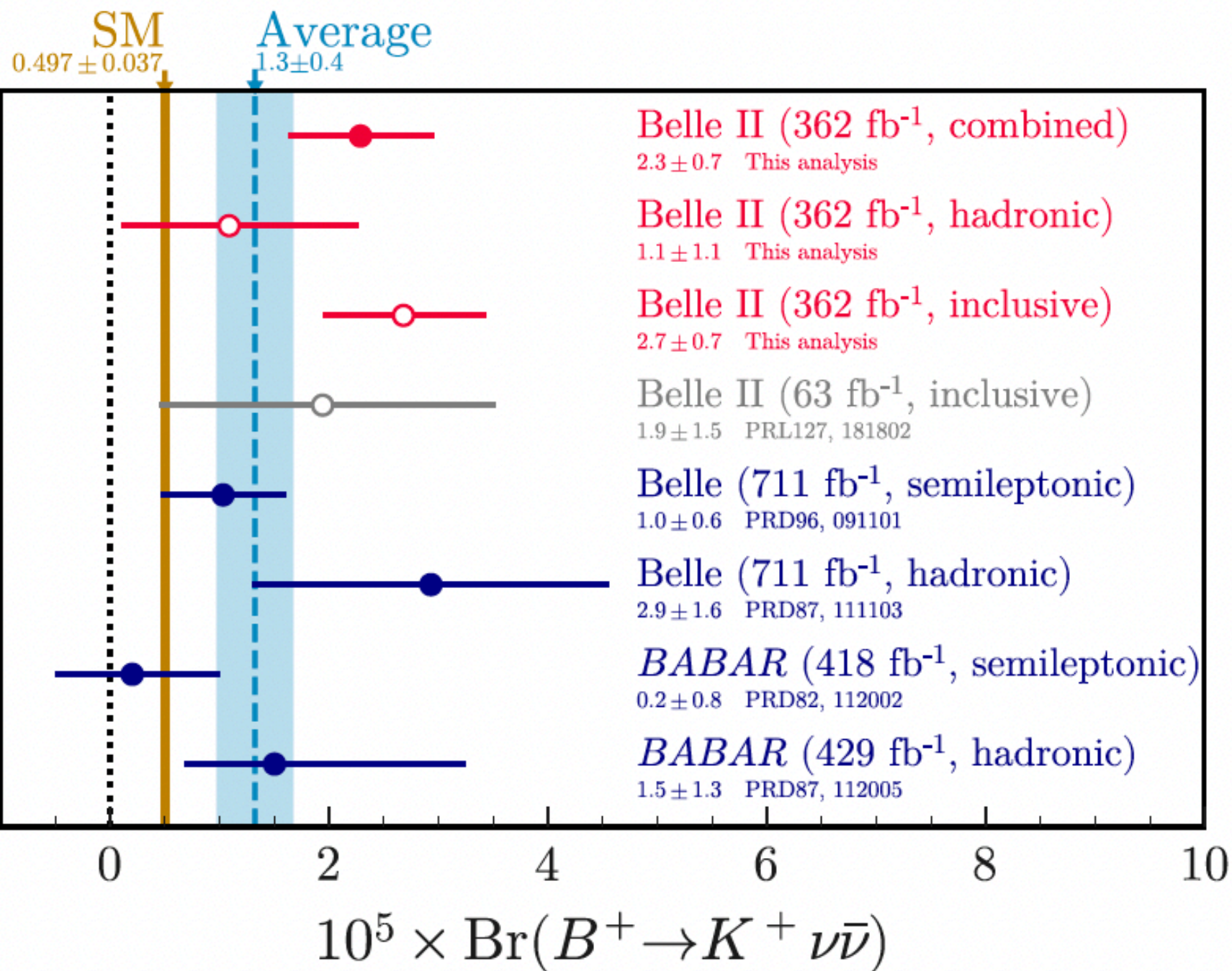
Divide data sample into pairs of statistically independent datasets, according to various features



Good stability for all splittings for both analyses

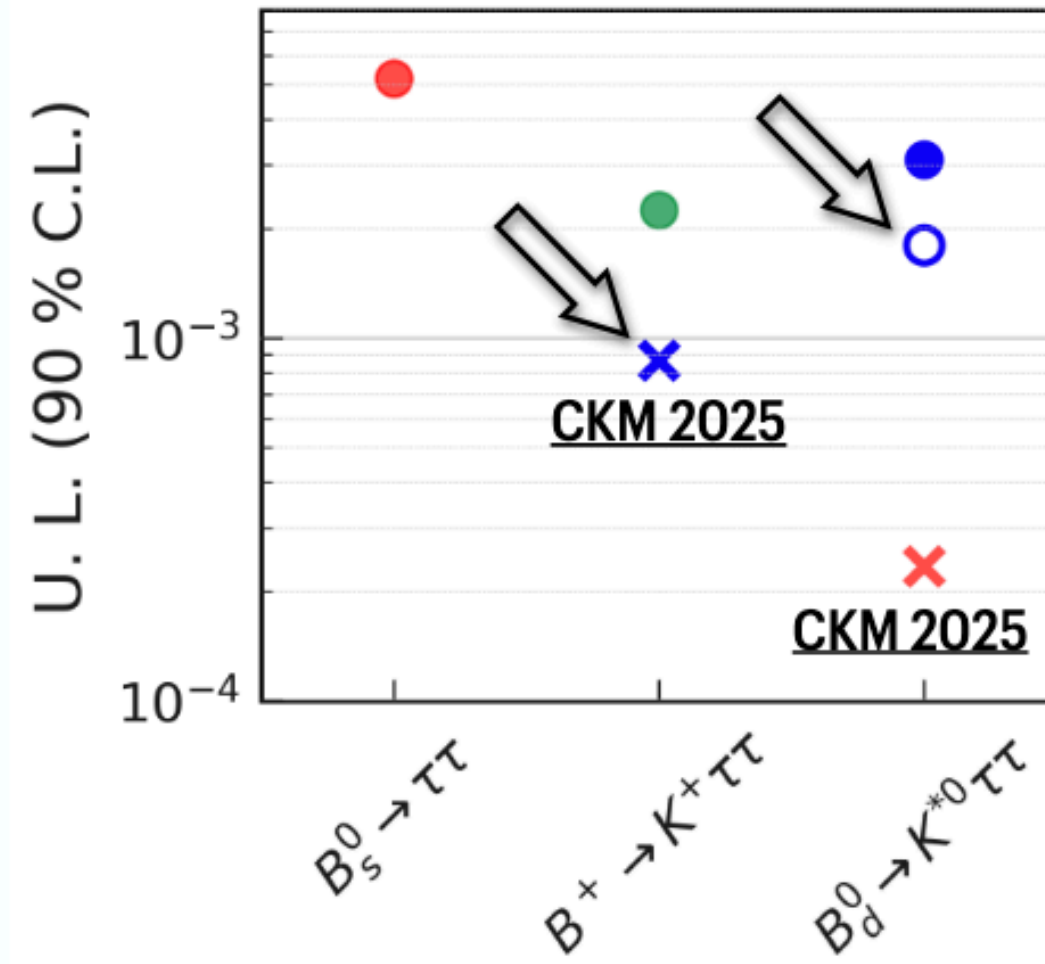
- Excellent agreement when splitting ITA sample according to **lepton multiplicity** (probing “semileptonic tag” vs “hadronic tag”)
- Tension in “**Sum(charges)**” for ITA consistent with statistical fluctuation

Gran-summary



$B \rightarrow X_s \nu \nu$

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



What's next

Improve sensitivity with Belle II data

- $b \rightarrow s\gamma\gamma$: unique to Belle II, corroborate evidence improving precision with
 - ITA with additional $K^{(*)}$ channels
 - additional tagging techniques (STA to improve precision, HTA to study q^2 spectrum with better resolution)
 - use of Run2 dataset (and what will come next)
- $b \rightarrow s\tau\tau$:
 - most stringent limit from $B^0 \rightarrow K^{*0}\tau\tau$ LHCb measurement (Abhijit's talk)
 - many handles to improve Belle II $B^+ \rightarrow K^+\tau\tau$ measurement: additional τ channels, semileptonic and inclusive tag, further optimisation of analysis strategy when adding less pure modes
- $b \rightarrow d$ effort also started

Future perspective in systematics

We foreseen improvements on systematics related to:

- background normalisations → generally, **statistical in origin**
- specific **background modelling**
- **detectors performances** (improvements in particle reconstruction and identification algorithms, usage of MCrd)
- **simulated sample size** → larger MC samples can be produced in a smart way (save to disk only skimmed events)

Source	Impact on σ_μ
Normalization of $B\bar{B}$ background	0.90
Normalization of continuum background	0.10
Leading B -decay branching fractions	0.22
Branching fraction for $B^+ \rightarrow K^+ K_L^0 K_L^0$	0.49
p-wave component for $B^+ \rightarrow K^+ K_S^0 K_L^0$	0.02
Branching fraction for $B \rightarrow D^{**}$	0.42
Branching fraction for $B^+ \rightarrow K^+ n \bar{n}$	0.20
Branching fraction for $D \rightarrow K_L^0 X$	0.14
Continuum-background modeling, BDT _c	0.01
Integrated luminosity	<0.01
Number of $B\bar{B}$	0.02
Off-resonance sample normalization	0.05
Track-finding efficiency	0.20
Signal-kaon PID	0.07
Photon energy	0.08
Hadronic energy	0.37
K_L^0 efficiency in ECL	0.22
Signal SM form-factors	0.02
Global signal efficiency	0.03
Simulated-sample size	0.52

Summary

- EWP+missE are excellent probe for New Physics
- Analysis are challenging, background validation is a key point
- Systematics starts to be important for all analyses, handles to improve them
- A lot of work ahead for Belle II to continue producing world-leading results
 - combination of tagging technique
 - improvements in reconstruction, MC modelling, and analysis technique are within reach



Extra slides

References

	Analysis	Journal reference
$b \rightarrow s \gamma \gamma$	$B^+ \rightarrow K^+ \gamma \gamma$ [doc] $B \rightarrow X_s \gamma \gamma$ [doc]	<u>PRD 109 (2024) 11, 112006</u> , to be submitted to PRL
$b \rightarrow s \tau \tau$	$B^+ \rightarrow K^+ \tau \tau$ [doc] $B^0 \rightarrow K^{*0} \tau \tau$ [doc]	to be submitted to PRL, <u>PRL 135 (2025), 151801</u>
$b \rightarrow s \tau \ell$	$B^0 \rightarrow K_S \tau \ell$ [doc] $B^0 \rightarrow K^{*0} \tau \ell$ [doc]	<u>PRL 135 (2025) 4, 041801</u> <u>JHEP 08 (2025) 184</u>

$B^+ \rightarrow K^+ \nu \nu$ ITA

Source	Correction	Uncertainty type, parameters	Uncertainty size	Impact on σ_μ
Normalization of $B\bar{B}$ background		Global, 2	50%	0.90
Normalization of continuum background		Global, 5	50%	0.10
Leading B -decay branching fractions		Shape, 6	$O(1\%)$	0.22
Branching fraction for $B^+ \rightarrow K^+ K_L^0 K_L^0$	q^2 dependent $O(100\%)$	Shape, 1	20%	0.49
p-wave component for $B^+ \rightarrow K^+ K_S^0 K_L^0$	q^2 dependent $O(100\%)$	Shape, 1	30%	0.02
Branching fraction for $B \rightarrow D^{**}$		Shape, 1	50%	0.42
Branching fraction for $B^+ \rightarrow K^+ n \bar{n}$	q^2 dependent $O(100\%)$	Shape, 1	100%	0.20
Branching fraction for $D \rightarrow K_L^0 X$	+30%	Shape, 1	10%	0.14
Continuum-background modeling, BDT _c	Multivariate $O(10\%)$	Shape, 1	100% of correction	0.01
Integrated luminosity		Global, 1	1%	<0.01
Number of $B\bar{B}$		Global, 1	1.5%	0.02
Off-resonance sample normalization		Global, 1	5%	0.05
Track-finding efficiency		Shape, 1	0.3%	0.20
Signal-kaon PID	p, θ dependent $O(10\text{--}100\%)$	Shape, 7	$O(1\%)$	0.07
Photon energy		Shape, 1	0.5%	0.08
Hadronic energy	−10%	Shape, 1	10%	0.37
K_L^0 efficiency in ECL	−17%	Shape, 1	8.5%	0.22
Signal SM form-factors	q^2 dependent $O(1\%)$	Shape, 3	$O(1\%)$	0.02
Global signal efficiency		Global, 1	3%	0.03
Simulated-sample size		Shape, 156	$O(1\%)$	0.52

$B^+ \rightarrow K^+ \nu \nu$ HTA

Source	Correction	Uncertainty type, parameters	Uncertainty size	Impact on σ_μ
Normalization of $B\bar{B}$ background		Global, 1	30%	0.91
Normalization of continuum background		Global, 2	50%	0.58
Leading B -decay branching fractions		Shape, 3	$O(1\%)$	0.10
Branching fraction for $B^+ \rightarrow K^+ K_L^0 K_L^0$	q^2 dependent $O(100\%)$	Shape, 1	20%	0.20
Branching fraction for $B \rightarrow D^{**}$		Shape, 1	50%	<0.01
Branching fraction for $B^+ \rightarrow K^+ n \bar{n}$	q^2 dependent $O(100\%)$	Shape, 1	100%	0.05
Branching fraction for $D \rightarrow K_L^0 X$	+30%	Shape, 1	10%	0.03
Continuum-background modeling, BDT _c	Multivariate $O(10\%)$	Shape, 1	100% of correction	0.29
Number of $B\bar{B}$		Global, 1	1.5%	0.07
Track finding efficiency		Global, 1	0.3%	0.01
Signal-kaon PID	p, θ dependent $O(10\text{--}100\%)$	Shape, 3	$O(1\%)$	<0.01
Extra-photon multiplicity	$n_{\gamma\text{extra}}$ dependent $O(20\%)$	Shape, 1	$O(20\%)$	0.61
K_L^0 efficiency		Shape, 1	17%	0.31
Signal SM form-factors	q^2 dependent $O(1\%)$	Shape, 3	$O(1\%)$	0.06
Signal efficiency		Shape, 6	16%	0.42
Simulated-sample size		Shape, 18	$O(1\%)$	0.60

$B \rightarrow X_s \nu \nu$

Source	Impact on σ_B [10^{-5}]
Simulated-sample size	6.0
Background normalization	5.7
Branching ratio of major B meson decay	2.3
Non-resonant $X_s \nu \bar{\nu}$ generation point	2.1
$\mathcal{O}_{\text{BDT}}$ 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

$B^0 \rightarrow K^{*0} \tau \tau$

Source	Impact on $\mathcal{B} \times 10^{-3}$
$B \rightarrow D^{**} \ell / \tau \nu$ 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 $B \bar{B}$ normalization	0.09
Signal and peaking $B^0 \bar{B}^0$ normalization	0.07
Lepton ID	0.04
π^0 efficiency	0.03
f_{00}	0.01
$N_{\Upsilon(4S)}$	0.01
$D \rightarrow K_L^0$ decays	0.01
Signal form factors	0.01
Luminosity	<0.01
Total systematics	0.52
Statistics	0.86

Signal category	$\varepsilon \times 10^5$	$B \bar{B}$	$q \bar{q}$
$\ell \ell$	4.0 ± 0.6	275	39
$\pi \ell$	7.6 ± 1.1	1058	230
ρ	15.5 ± 2.2	3279	845
$\pi \pi$	4.0 ± 0.6	1077	424

$$B^+ \rightarrow K^+ \tau \tau$$

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%

$$B^0 \rightarrow K_S \tau \ell$$

Source (%)	$K_S^0 \tau^+ \mu^-$	$K_S^0 \tau^- \mu^+$	$K_S^0 \tau^+ e^-$	$K_S^0 \tau^- e^+$
BDT selection	17.1	17.5	16.6	19.2
Signal PDF	15.7	15.7	15.7	15.7
B_{tag} calibration	3.7	3.7	3.7	3.7
Lepton identification	0.3	0.3	0.5	0.5
τ daughter reconstruction	5.3	6.5	6.1	6.4
Linearity	1.6	1.4	0.8	1.4
Number of $B\bar{B}$ pairs	1.1	1.1	1.1	1.1
f_{+-}/f_{00}	2.3	2.3	2.3	2.3
K_S^0 , τ , ρ , π^0 branching fractions	0.7	0.7	0.7	0.7
Total	24	24	23	25

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

$$B^0 \rightarrow K^{*0} \tau \ell$$

Source	Belle	Belle II
FEI efficiency	4.9%(<i>OSe</i>), 4.9%(<i>SSe</i>), 4.9%(<i>OSμ</i>), 4.9%(<i>SSμ</i>)	6.2%(<i>OSe</i>), 6.1%(<i>SSe</i>), 6.1%(<i>OSμ</i>), 6.2%(<i>SSμ</i>)
Lepton ID efficiency	2.0%(<i>OSe</i>), 2.4%(<i>SSe</i>), 2.2%(<i>OSμ</i>), 2.2%(<i>SSμ</i>)	0.7%(<i>OSe</i>), 1.1%(<i>SSe</i>), 0.7%(<i>OSμ</i>), 0.6%(<i>SSμ</i>)
Hadron ID efficiency	1.9%(<i>OSe</i>), 2.0%(<i>SSe</i>), 1.9%(<i>OSμ</i>), 2.0%(<i>SSμ</i>)	3.7%(<i>OSe</i>), 3.7%(<i>SSe</i>), 3.6%(<i>OSμ</i>), 3.7%(<i>SSμ</i>)
BDT efficiency	27%(<i>OSe</i>), 21%(<i>SSe</i>), 18%(<i>OSμ</i>), 23%(<i>SSμ</i>)	29%(<i>OSe</i>), 31%(<i>SSe</i>), 34%(<i>OSμ</i>), 31%(<i>SSμ</i>)
Tracking efficiency	1.4%	1.1%
Total efficiency	27.6%(<i>OSe</i>), 21.8%(<i>SSe</i>), 18.9%(<i>OSμ</i>), 23.7%(<i>SSμ</i>)	29.8%(<i>OSe</i>), 31.8%(<i>SSe</i>), 34.7%(<i>OSμ</i>), 31.7%(<i>SSμ</i>)
Signal mean μ	0.1%	0.2%
Signal width λ	21%	59%
Background shape exp ($\times 10^{-5}$)	0.1(<i>OSe</i>), 0.1(<i>SSe</i>), 0.1(<i>OSμ</i>), 0.6(<i>SSμ</i>)	
Background shape obs ($\times 10^{-5}$)	0.1(<i>OSe</i>), 0.3(<i>SSe</i>), 0.1(<i>OSμ</i>), 0.1(<i>SSμ</i>)	
$B\bar{B}$ pairs	1.4%	1.6%
f^{00}		0.8%
$Br(K^{*0} \rightarrow K^+ \pi^-)$		< 0.05%
MC statistics		< 0.0005%

Decay	$\mathcal{B}^{\text{fit}} \ (\times 10^{-5})$	$\mathcal{B}_{\text{obs(exp)}}^{\text{UL}} \ (\times 10^{-5})$
<i>OSe</i> : $B^0 \rightarrow K^{*0} \tau^+ e^-$	-0.24 ± 1.46	2.9 (2.8)
<i>SSe</i> : $B^0 \rightarrow K^{*0} \tau^- e^+$	1.17 ± 2.77	6.4 (4.4)
<i>OSμ</i> : $B^0 \rightarrow K^{*0} \tau^+ \mu^-$	1.07 ± 1.80	4.2 (3.0)
<i>SSμ</i> : $B^0 \rightarrow K^{*0} \tau^- \mu^+$	0.48 ± 2.61	5.6 (5.5)

		<i>OSe</i>	<i>SSe</i>	<i>OSμ</i>	<i>SSμ</i>
Belle	N_{sig}	-0.6 ± 3.3	2.2 ± 5.2	2.8 ± 4.7	0.6 ± 3.2
	N_{bkg}	99.5 ± 10.4	140.0 ± 12.7	207.4 ± 15.0	76.4 ± 9.3
Belle II	N_{sig}	-0.5 ± 2.8	1.7 ± 3.9	1.6 ± 2.7	0.6 ± 3.3
	N_{bkg}	86.5 ± 9.8	120.1 ± 11.8	109.1 ± 10.9	198.4 ± 14.5

$B \rightarrow X_s \nu \nu$

- A special case: $B \rightarrow X_s \nu \nu$ with $X_s =$ sum-of-exclusive modes
- 30 modes, ~93% of entire X_s sample based on Belle II MC (PYTHIA8)

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

- Signal model: exclusive $B \rightarrow K \nu \nu$ and $B \rightarrow K^* \nu \nu$ + and $B \rightarrow X_s \nu \nu$ for $M_{X_s} > 1.1$ GeV/c² (systematic on endpoint variation, mid-importance)
 - Fermi motion model, assuming Gaussian b-quark momentum distribution.
 - Final-state hadrons fragmentation simulated via Pythia8 and corrected using $B \rightarrow X_s \gamma$ study (negligible associated systematics)