# Status and prospects for rare B decays at Belle II

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on behalf of the Belle II collaboration

Second Italian Workshop on
the Physics at High Intensity
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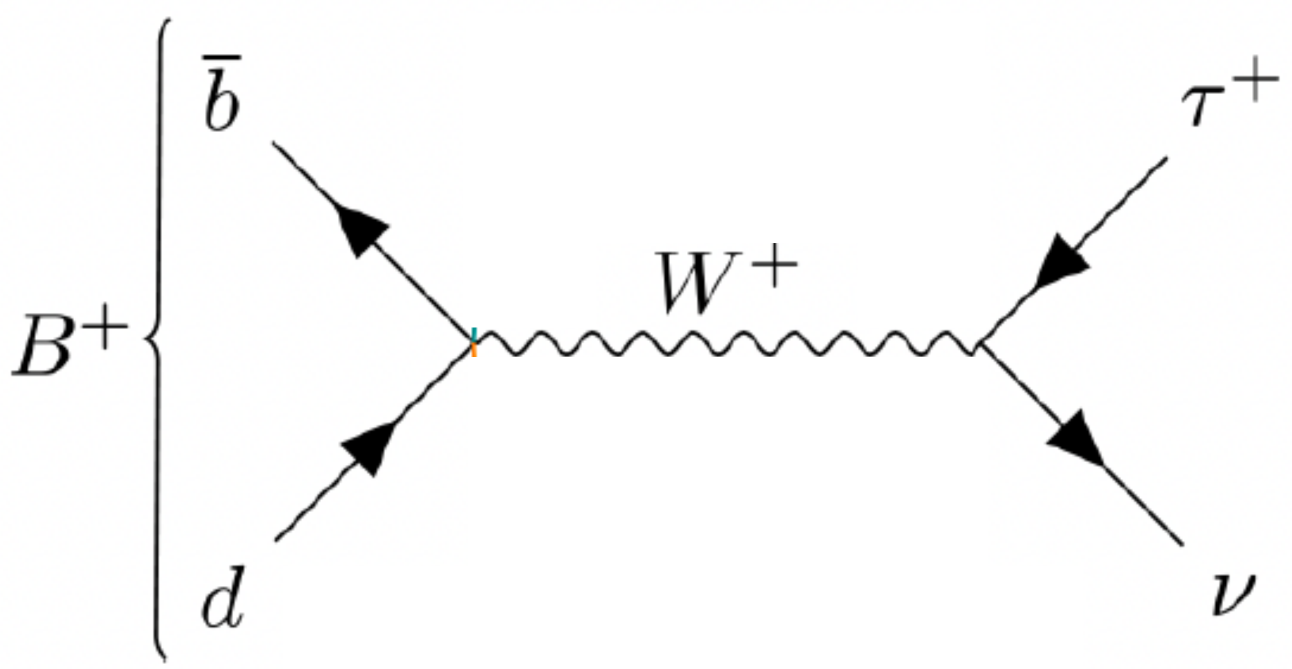
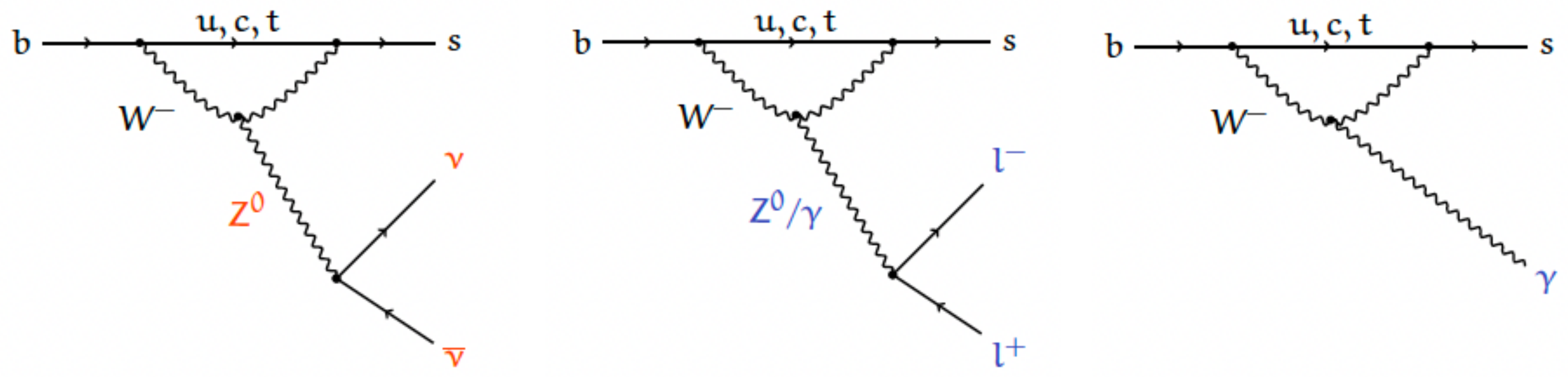
# Rare B decays and new physics searches

Purely leptonic B decays and b→s(/d) transitions are suppressed in the Standard Model (SM)




Purely leptonic B decays:

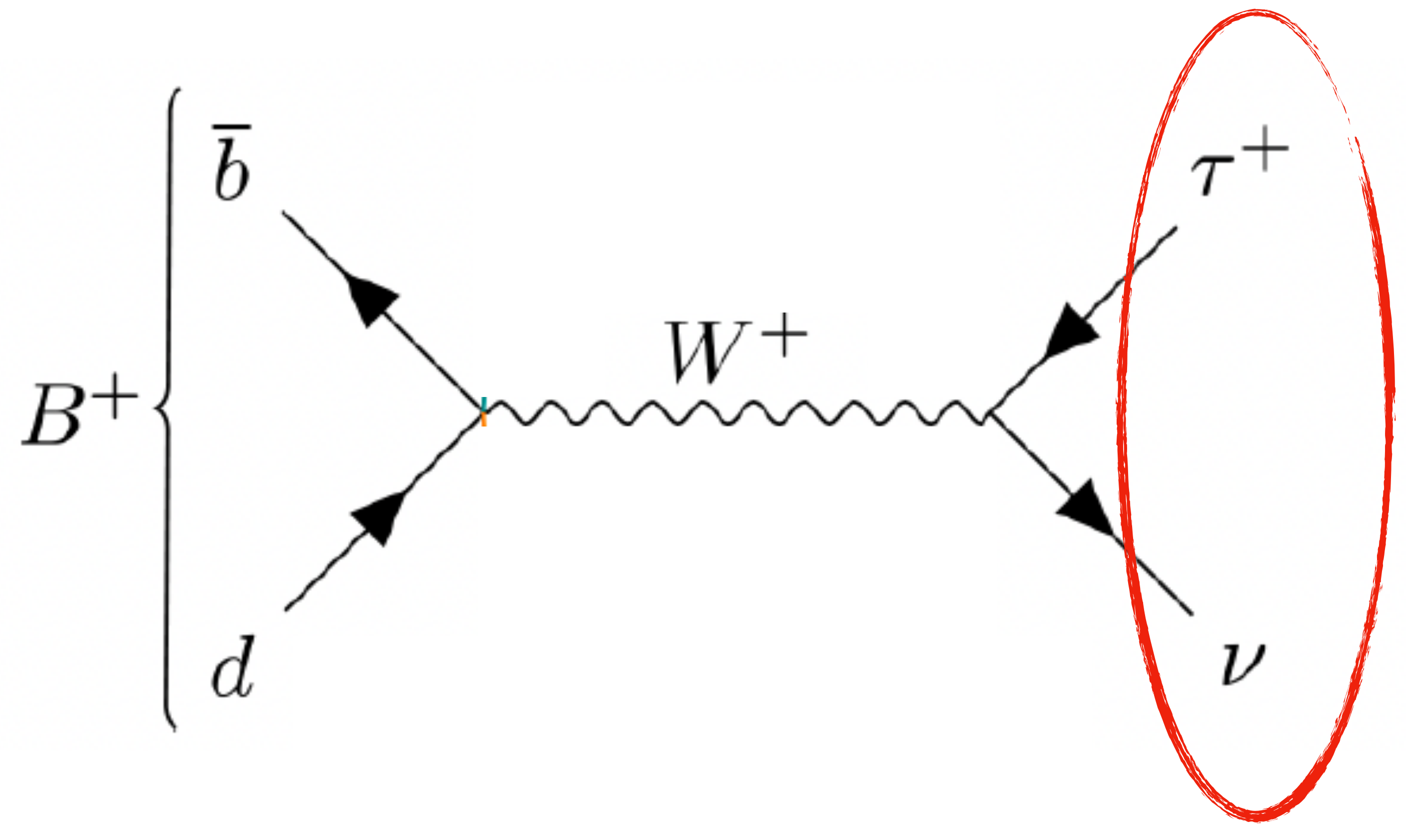
- suppressed by CKM matrix-element $|V_{ub}|$ and helicity factor $\propto m^2_\ell$
- $\mathcal{B}(B\to\tau\nu)_{SM} \sim 10^{-4}$ (15%-20% uncertainty)

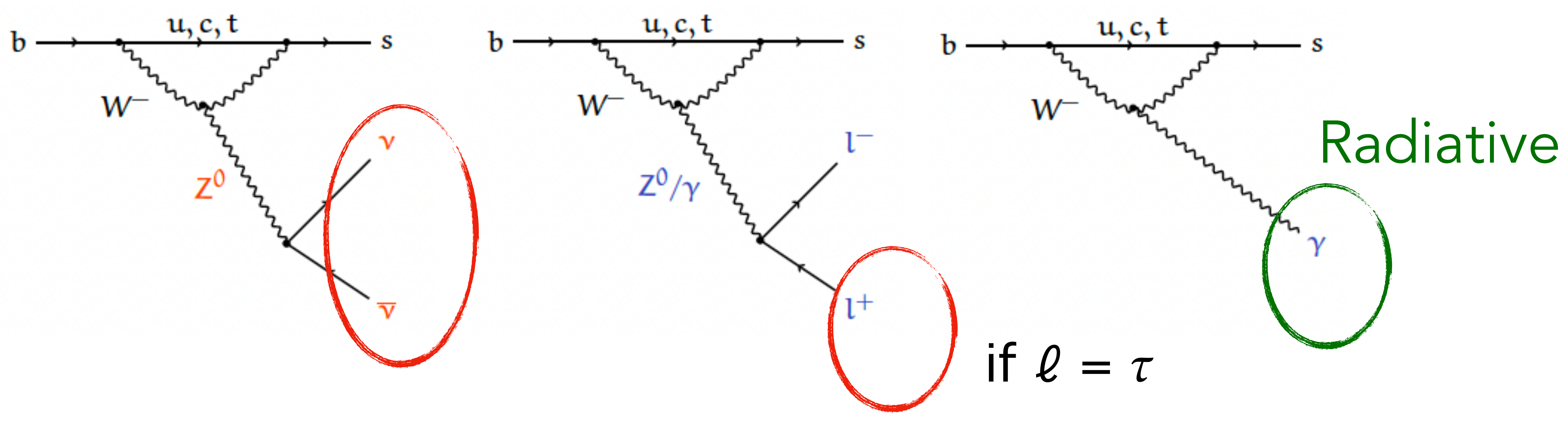
Electroweak and radiative penguin modes:

- FCNC prohibited at tree level
- SM branching fraction $\in [10^{-4}, 10^{-7}]$, ~10-30% uncertainties
- more accurate precision on angular observables, asymmetries, and ratios

Deviation from SM foreseen in New Physics (NP) scenarios, e.g. new mediators, new sources of missing energy for $b\to s\nu\bar{\nu}$

# Rare B decays and new physics searches

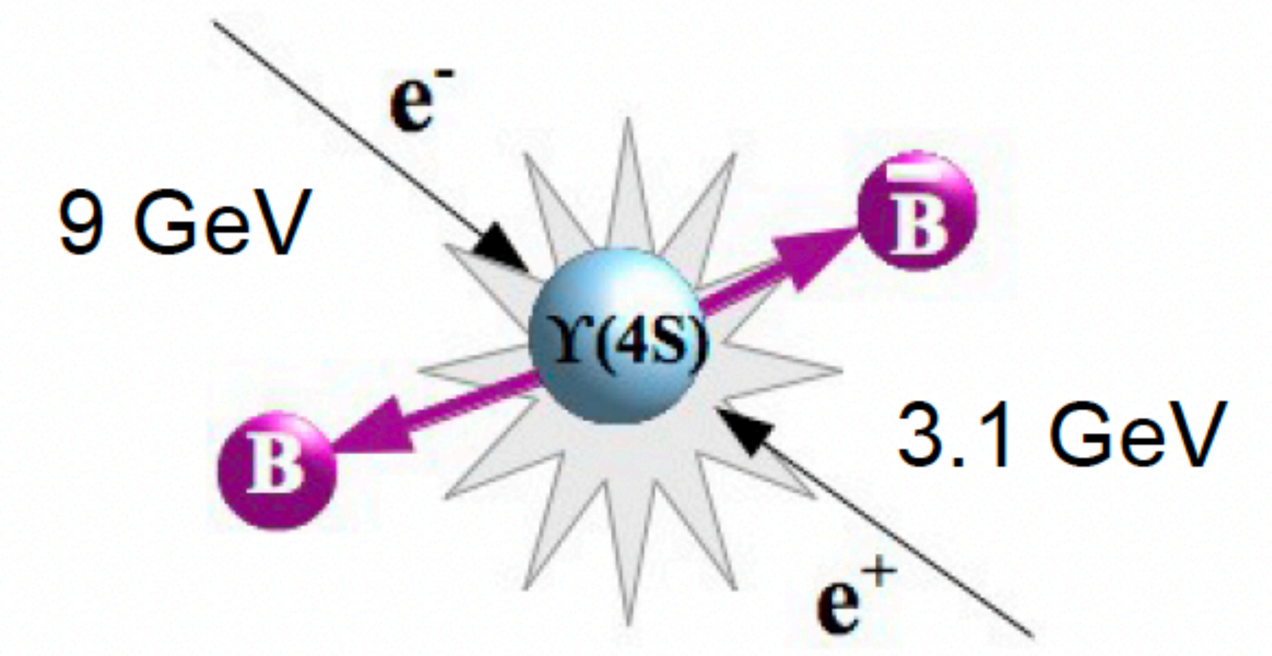


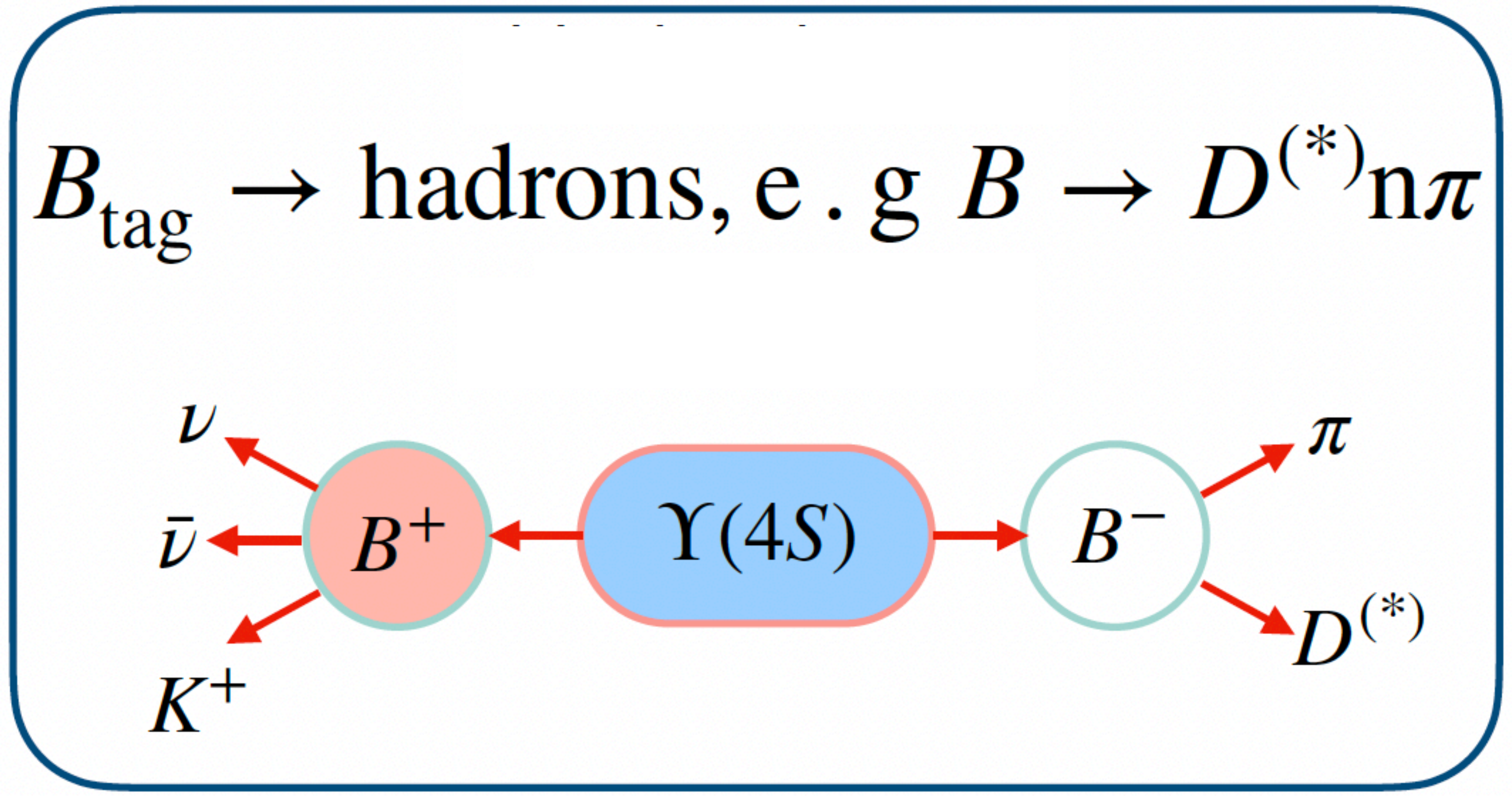

Missing energy modes

# Experimental challenges (I)

- Missing energy modes: challenging due to un-reconstructed neutrinos
- Exploit knowledge of the initial energy to measure missing energy
- Different tagging methods are feasible, e.g. $B^+ \to K^+ \nu\bar{\nu}$

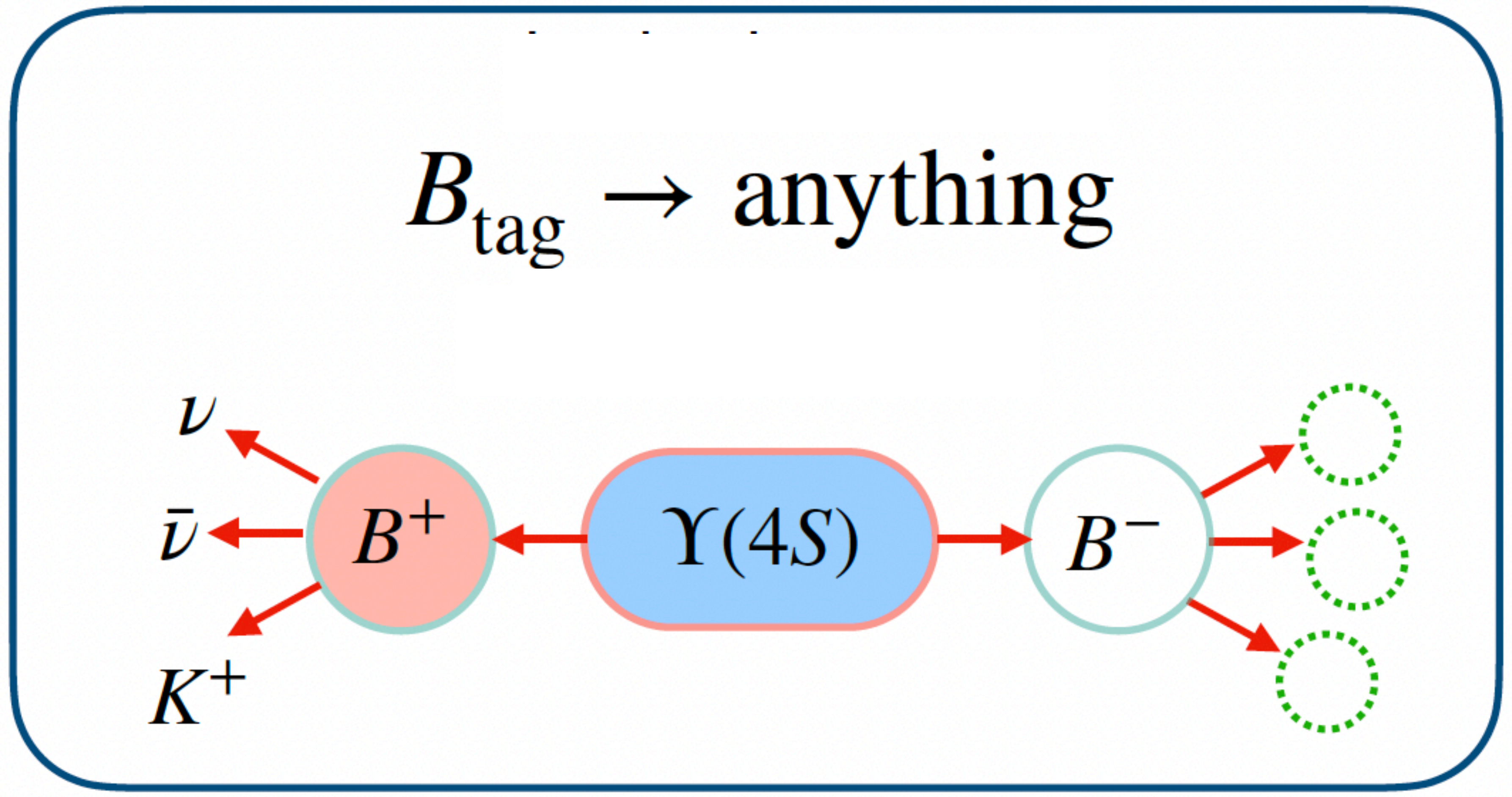



Maximise purity : hadronic tag analyses




Machine-learning based reconstruction algorithm
[Comp.Soft.BigSci. 3, 6 (2019)]: $\varepsilon_{tag} \sim O(1\%)$

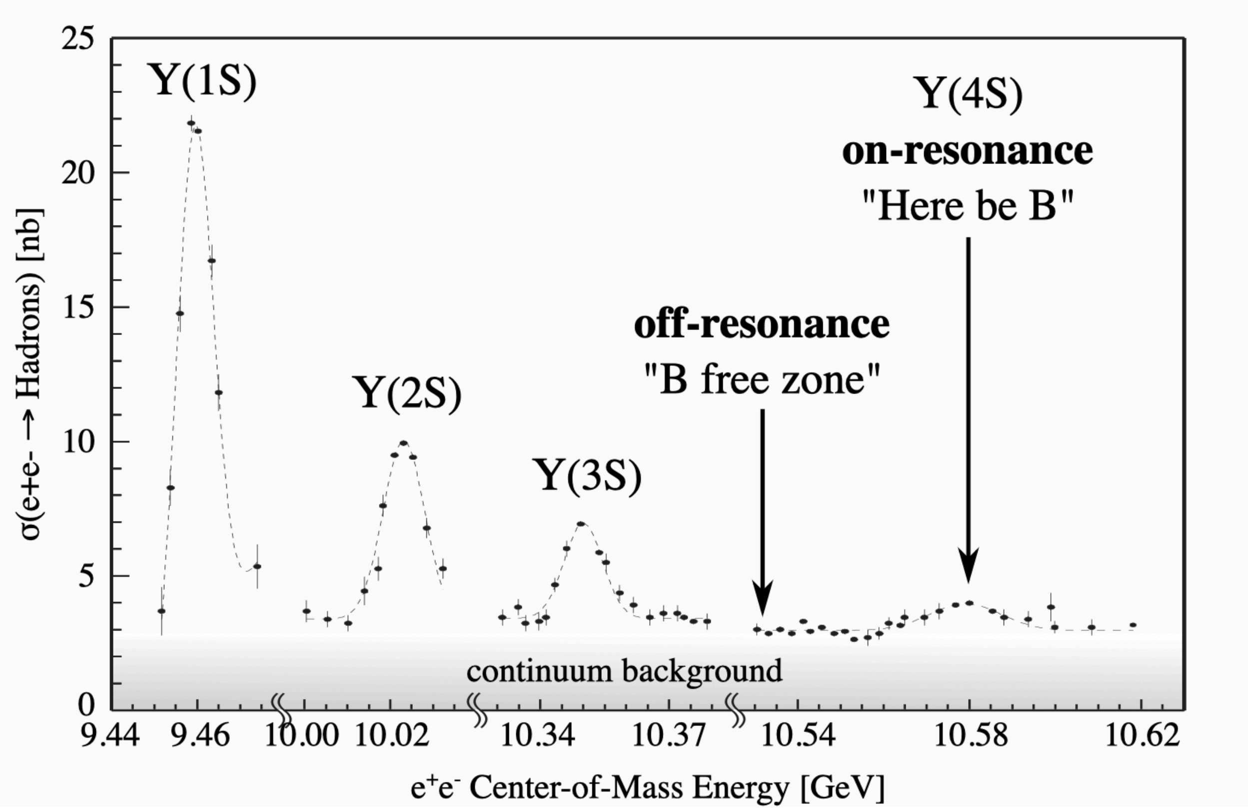
Maximise efficiency : inclusive tag analyses



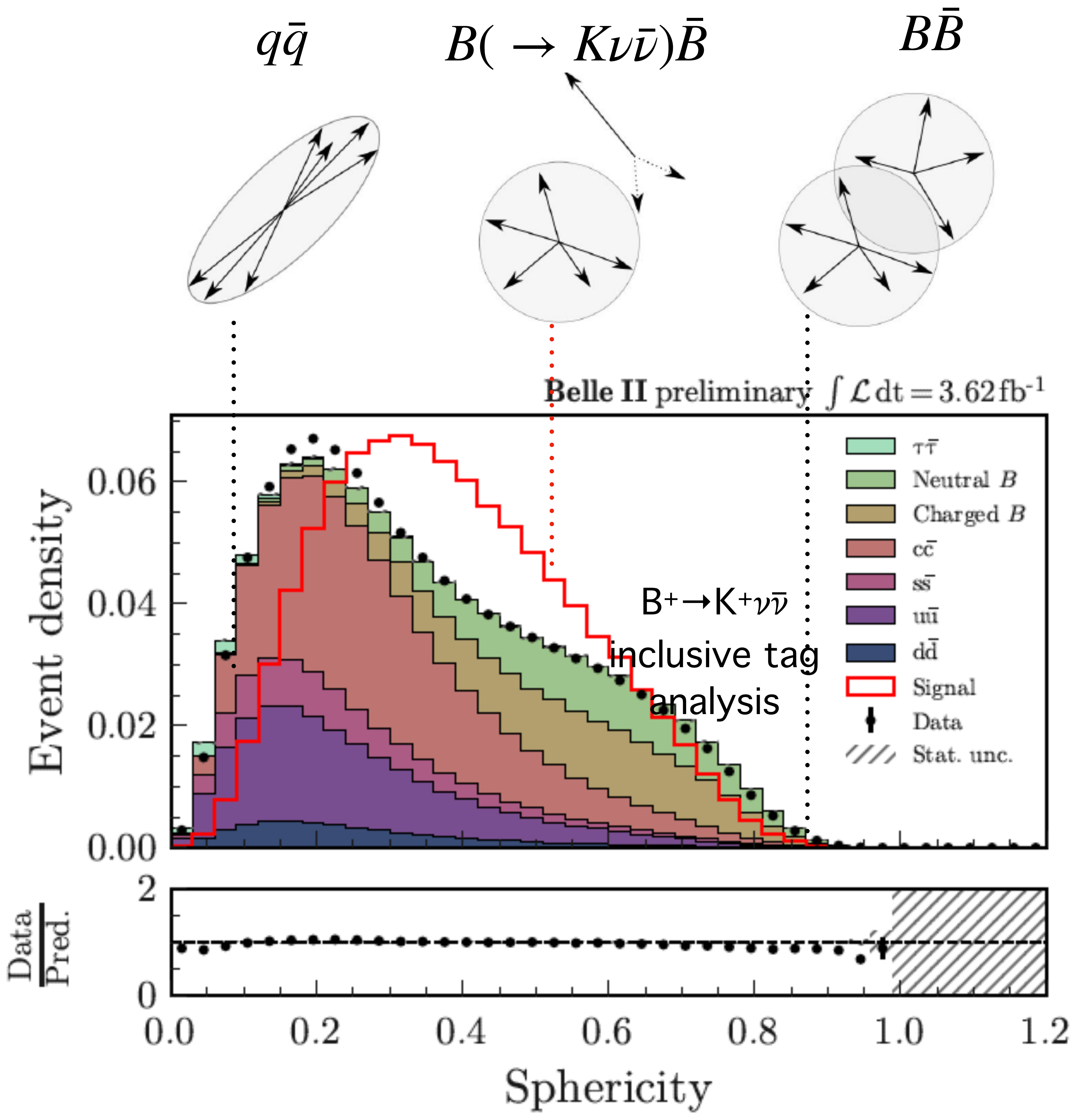

No explicit tag reconstruction:
$\varepsilon_{tag} \sim 100\%$

# Experimental challenges (II)

- Contamination from $e^+e^- \to q\bar{q}$ ("continuum") events
  - modelling validated by using data taken 60 MeV below the $\Upsilon(4S)$ resonance




  - exploit "event-shape" variables
  - for background suppression, usually combine them in multivariate tools



# Radiative B decays

# Inclusive $B \to X_s \gamma$

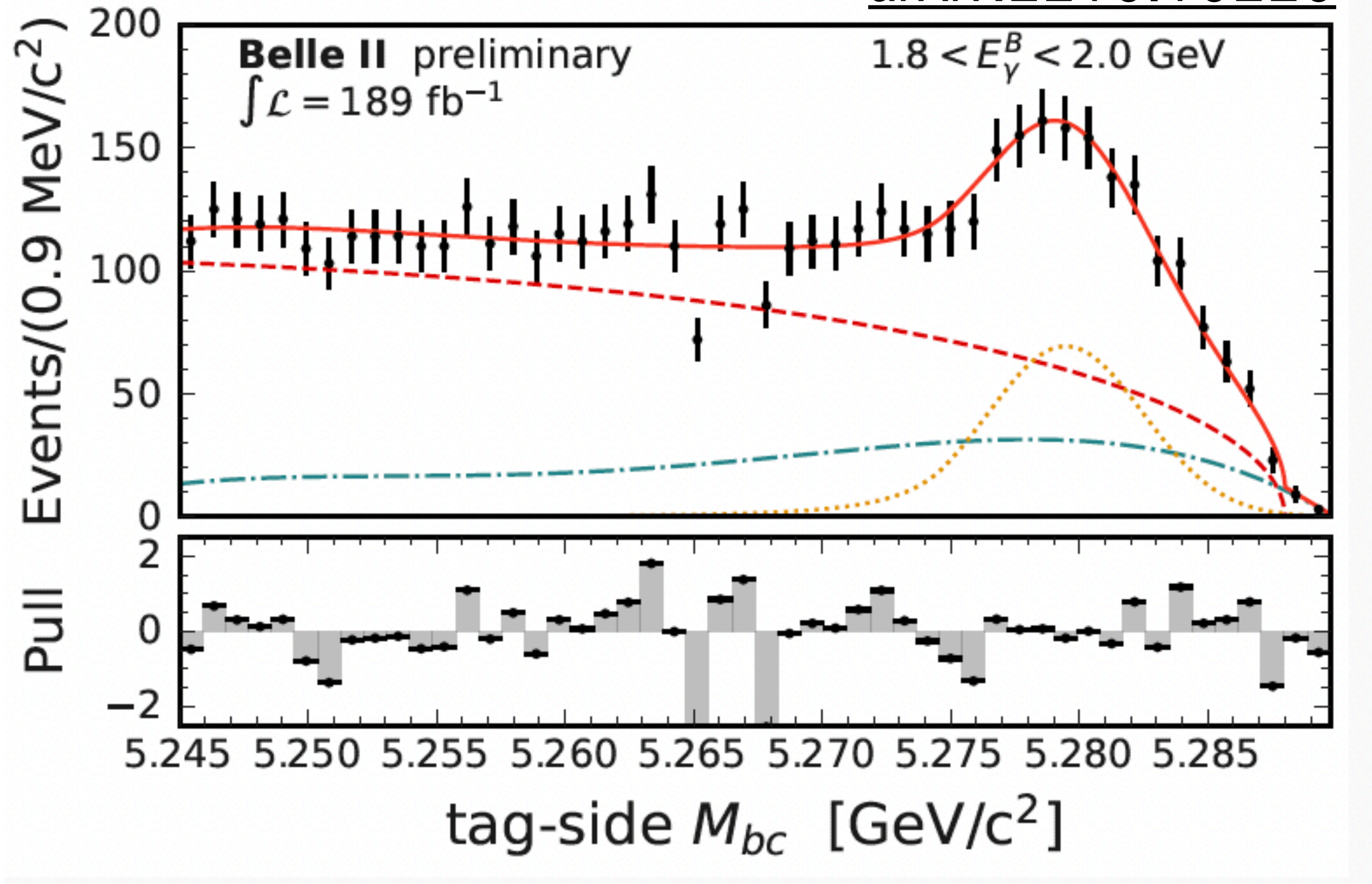
- Sensitive to new physics [JHEP11(2012)036], $E_\gamma$ spectrum allows to determine $m_b$ and other non-perturbative parameters [PRL 127, 102001]
- Reconstruct a High energy photon in the recoil of a hadronic $B_{tag}$
  - fully inclusive $X_s$ reconstruction: avoid hadronic uncertainties
- Background yield from fit to $B_{tag}$ kinematic distribution, in $E_\gamma^B$ bins; subtracted from data to obtain the signal spectrum
- Partial branching fractions in $E_\gamma^B$ bins

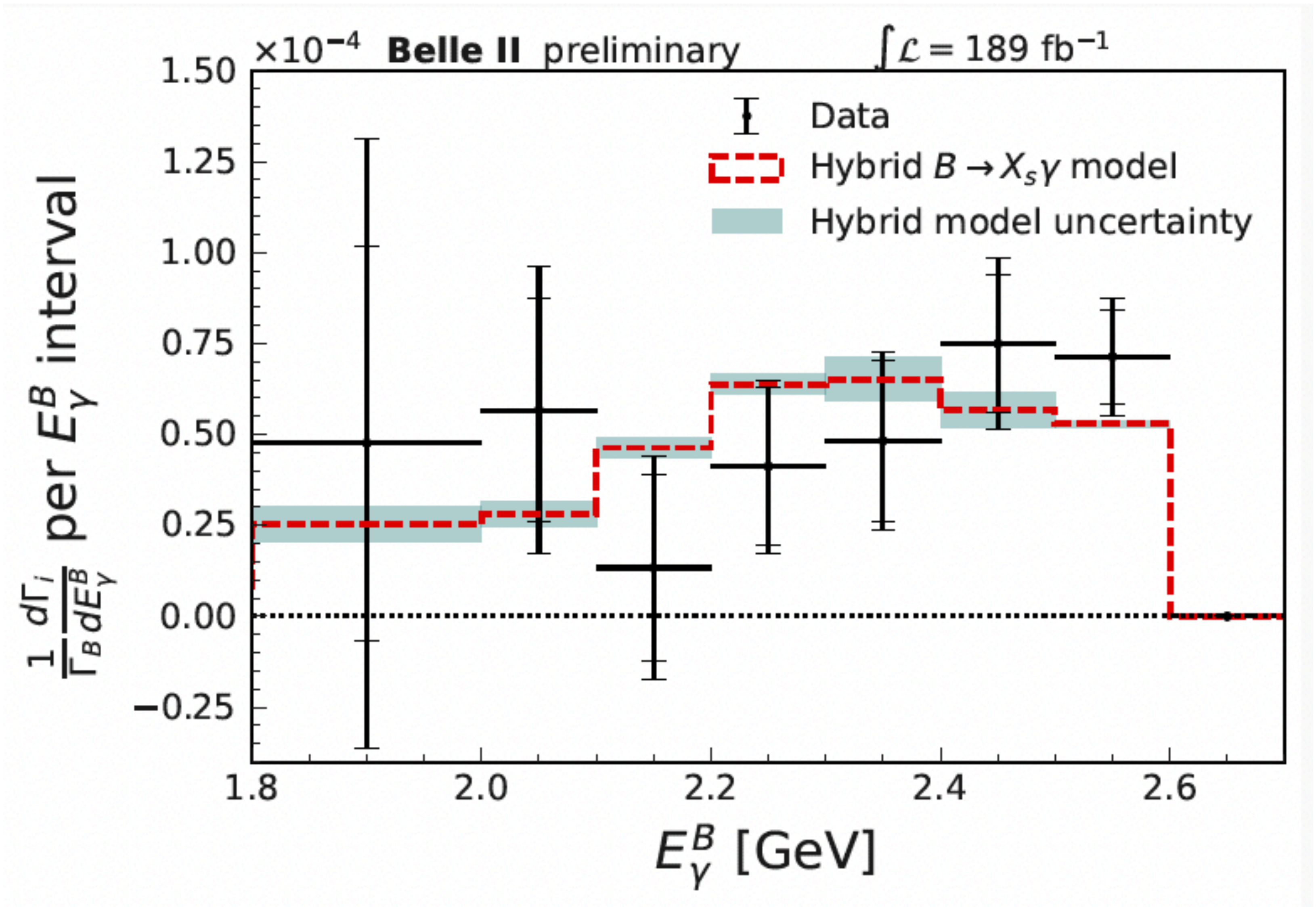
| $E_\gamma^B$ threshold [GeV] | $\mathcal{B}(B \to X_s\gamma)$ $[10^{-4}]$ |
|---|---|
| 1.8 | $3.54 \pm 0.78$ (stat.) $\pm 0.83$ (syst.) |
| 2.0 | $3.06 \pm 0.56$ (stat.) $\pm 0.47$ (syst.) |
| 2.1 | $2.49 \pm 0.46$ (stat.) $\pm 0.35$ (syst.) |

Better (similar) statistical (systematic ) precision wrt BaBar [PRD 77 (2008) 051103] on similar statistics

- Perspectives:
  - for hadronic tagged analysis, ≳10 $ab^{-1}$ to reach theoretical precision (~5%)
  - additional measurements with semileptonic and inclusive tag also feasible at Belle II

arXiv:2210.10220



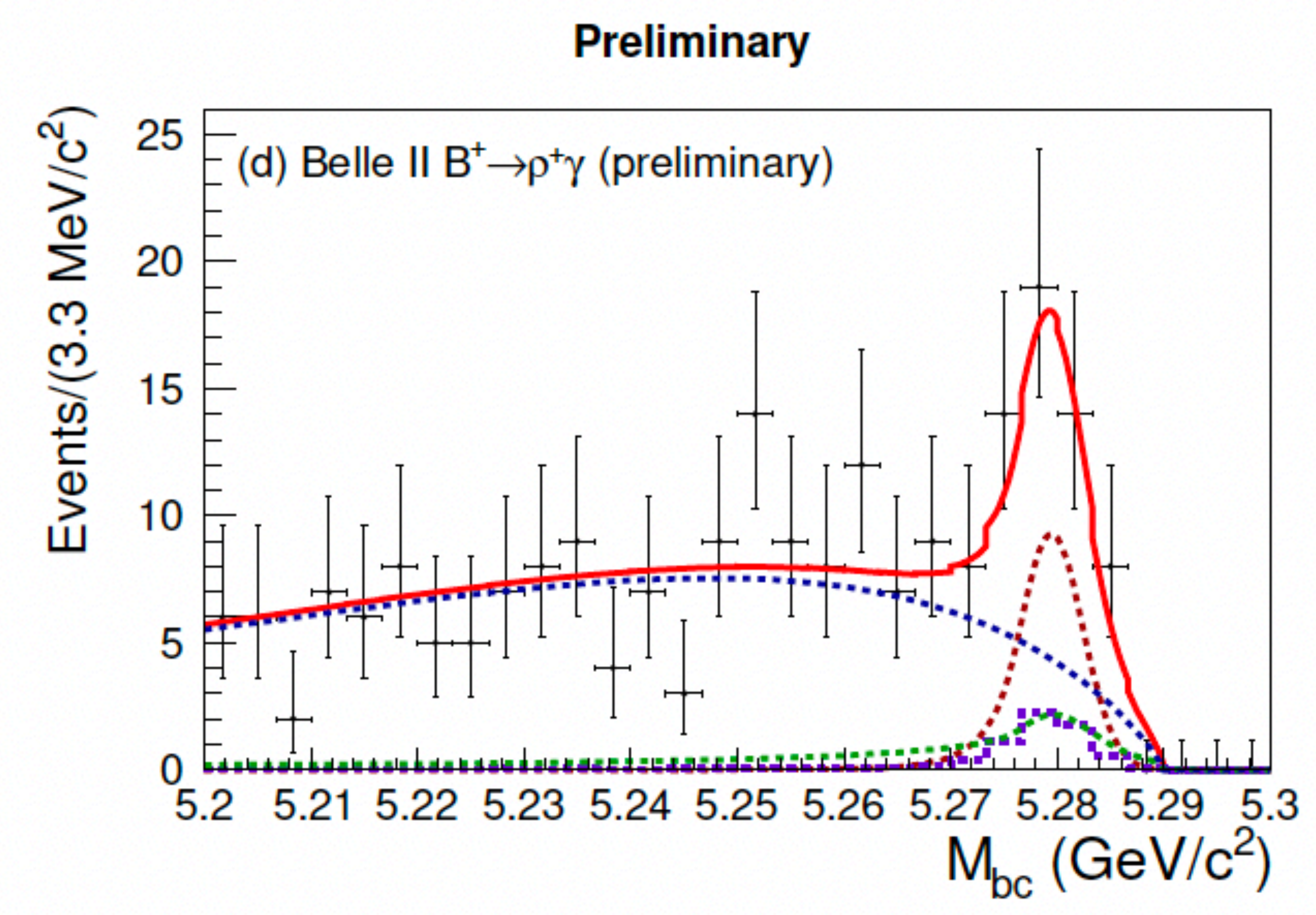

$E_\gamma^B$ = photon energy in the signal B rest frame

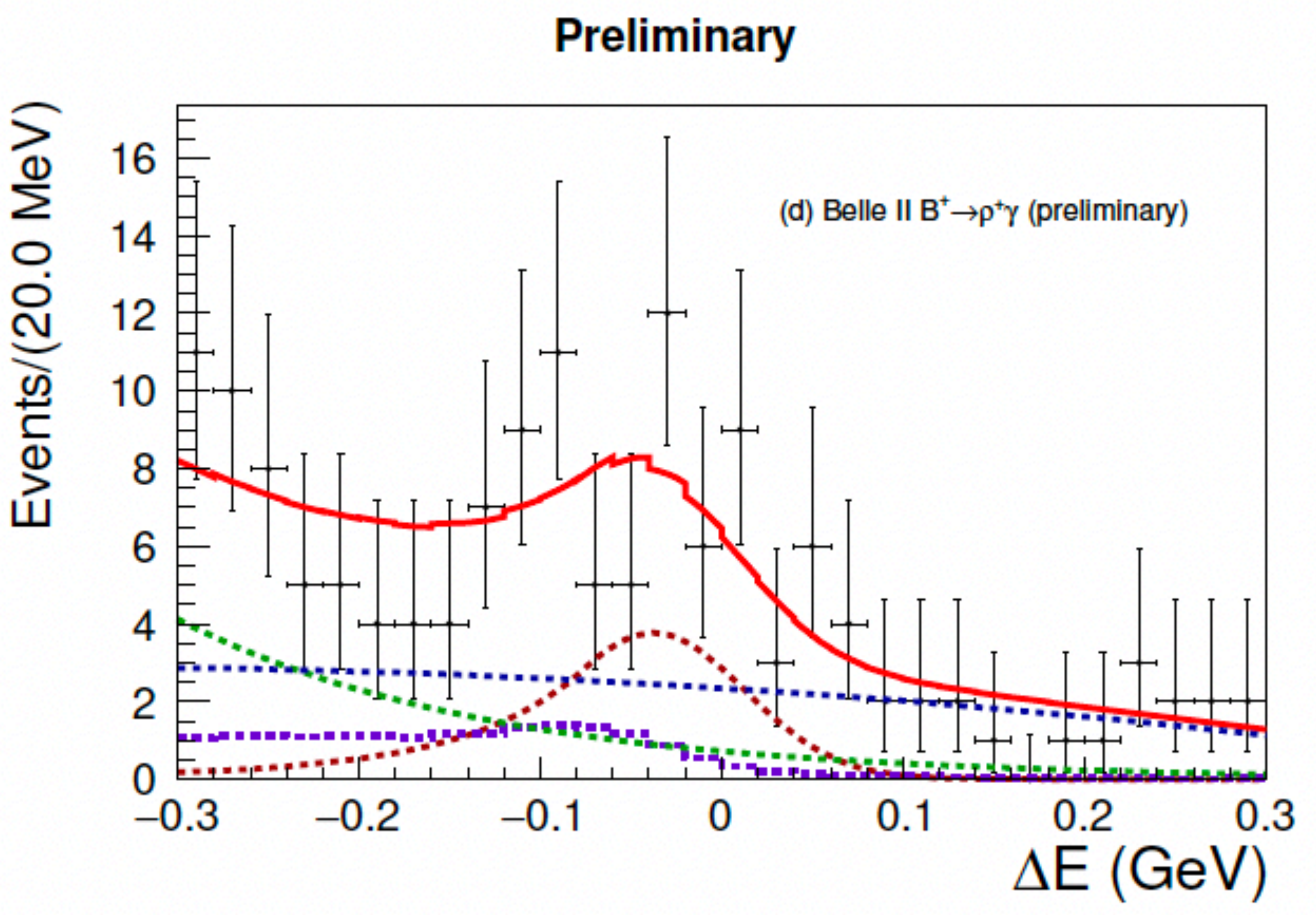
# B→ργ

- Probing NP in b→dγ transitions using Belle+Belle II (711+362 $fb^{-1}$) dataset
- Extract signal yield from a simultaneous fit to di-pion mass, ργ mass with $B$ energy replaced by beam energy, difference between expected and observed $B$ energy
  - Results:

$$\mathcal{B}\left(B^{+} \to \rho^{+}\gamma\right) = \left(12.9^{+2.0+1.3}_{-1.9-1.2}\right) \times 10^{-7},$$
$$\mathcal{B}\left(B^{0} \to \rho^{0}\gamma\right) = \left(7.5^{+1.3+1.0}_{-1.3-0.8}\right) \times 10^{-7},$$
$$A_{\rm CP}\left(B^{+} \to \rho^{+}\gamma\right) = \left(-8.4^{+15.2+1.3}_{-15.3-1.4}\right) \%,$$
$$A_{\rm I}\left(B \to \rho\gamma\right) = \left(11.0^{+11.2+7.1+3.8}_{-11.7-6.3-3.9}\right) \%,$$

Most precise measurement to date
Isospin asymmetry consistent with zero
(~2 σ level departure from null-asymmetry reported in previous Belle analysis [PRL 101, 111801 (2008) 411] on 600 $fb^{-1}$)



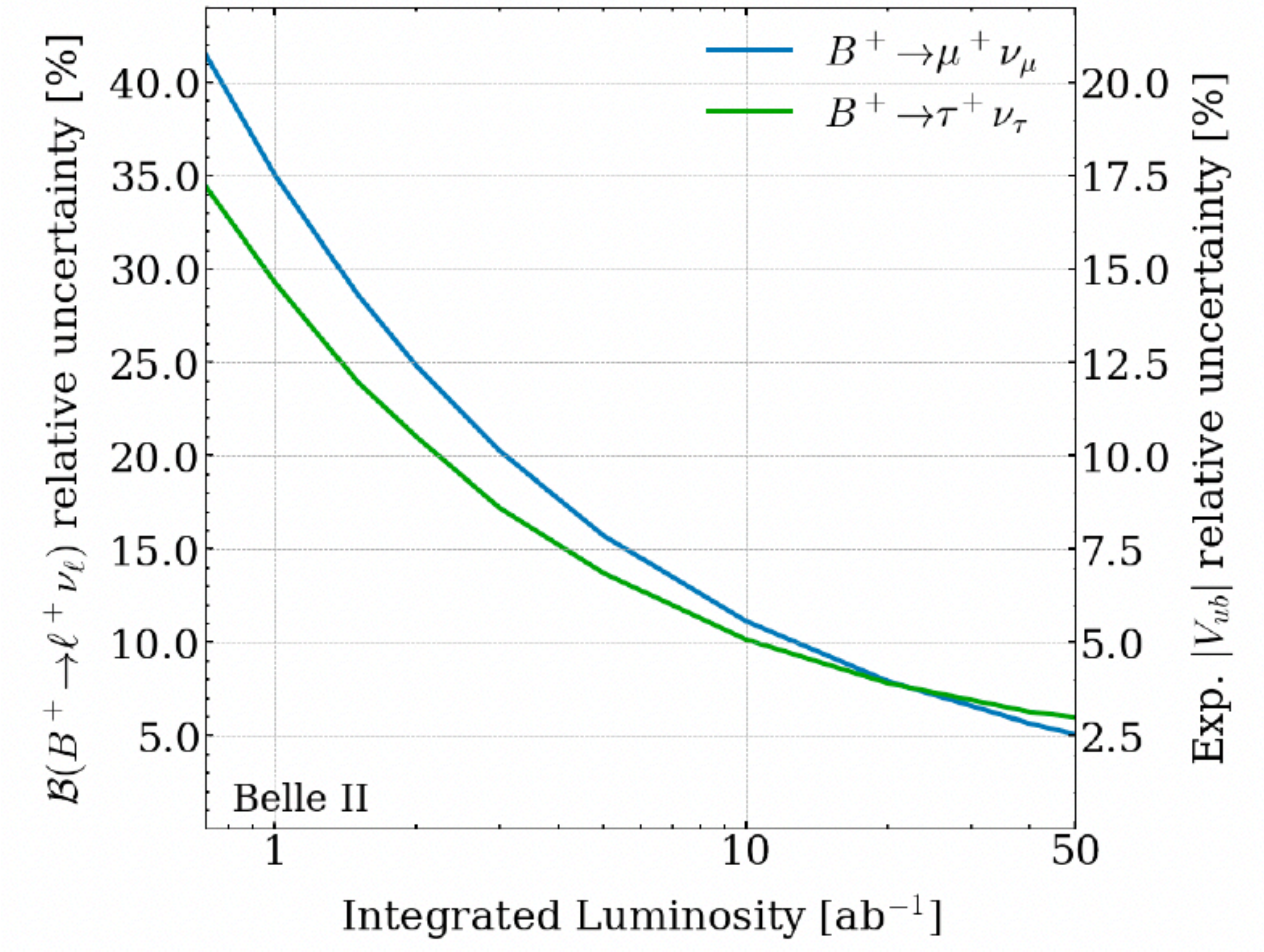



# Missing energy modes

# $B \to \tau\nu$

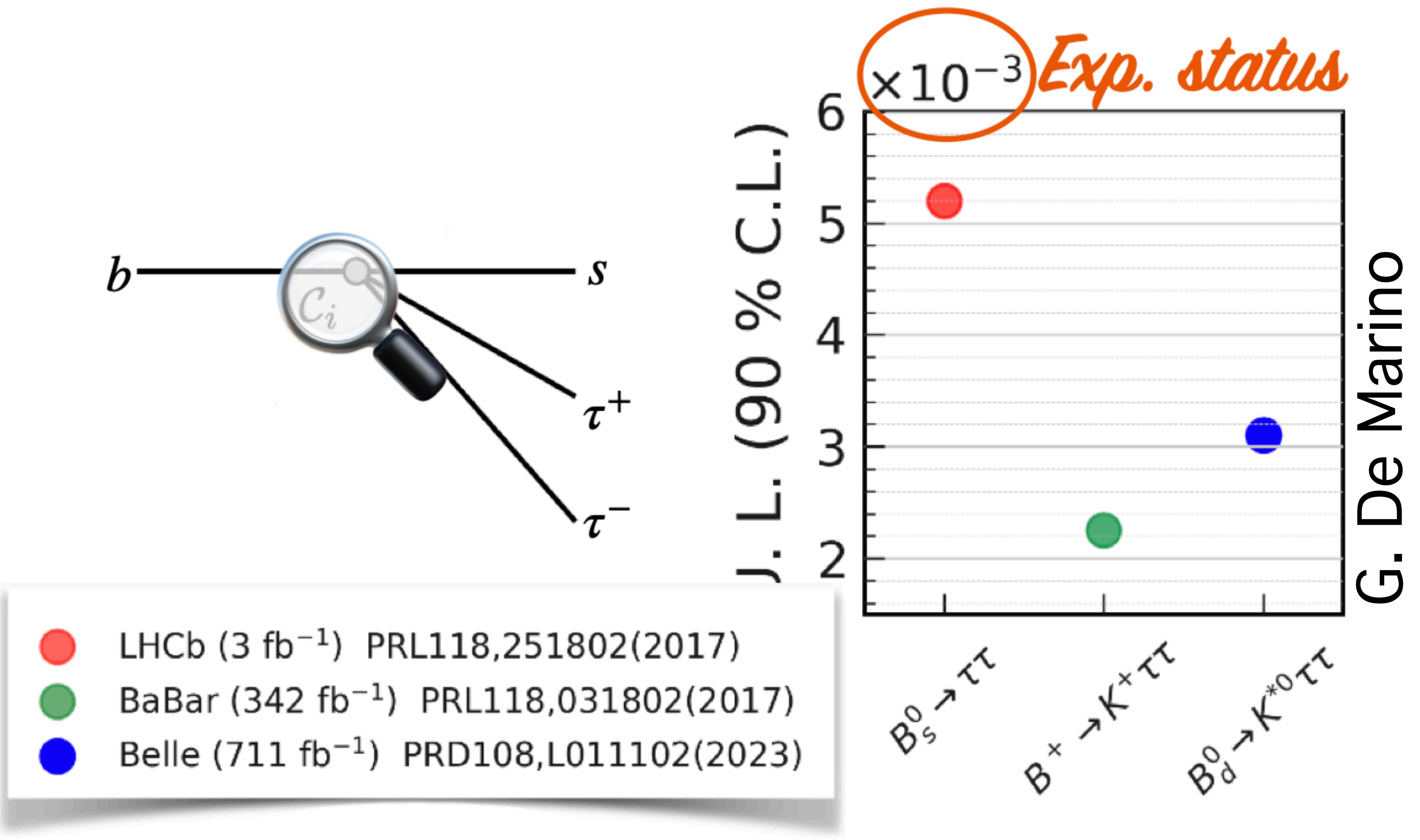
- Probe for non-SM effects at tree level and provide complementary measurement of $|V_{ub}|$ wrt semileptonic $b \to u\ell\nu$ final states
  - SM BF expectation: $\mathcal{B}(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left[1 - \frac{m_\tau^2}{m_B^2}\right]^2 f_B^2 |V_{ub}|^2 \tau_{B^+}$
  - ~ $10^{-4}$, with 15%-20% uncertainty (depending on $f_B$ and $V_{ub}$ values)
- Experimental status
  - tagged analysis from Belle and BaBar, stat limited
  - BF average: $(1.09 \pm 0.24) \times 10^{-4}$ (PDG)
- Perspectives (hadronic-tagged analysis):
  - ultimately limited by by knowledge of KL veto efficiency, $B_{tag}$ efficiency, peaking backgrounds
  - can benefit from semileptonic and inclusive tagging approach

arXiv:1011.0352



# b→sττ searches

- Motivation: SM BF at $10^{-7}$ level (~10% uncertainty), Enhancements foreseen in NP models scenarios explaining R(D(*)) or recent B→Kνν excess
- Experimental status: first result from Belle on $K^{*0}$ mode published in 2023, no result on $K^{+}$ mode with full Belle statistics
- Perspectives:




arXiv:1011.0352

| | $\mathcal{B}(B^0 \to K^{*0}\tau\tau)$ (had tag) | |
|---|---|---|
| ab$^{-1}$ | "Baseline" scenario | "Improved" scenario |
| 1 | $< 3.2 \times 10^{-3}$ | $< 1.2 \times 10^{-3}$ |
| 5 | $< 2.0 \times 10^{-3}$ | $< 6.8 \times 10^{-4}$ |
| 10 | $< 1.8 \times 10^{-3}$ | $< 6.5 \times 10^{-4}$ |
| 50 | $< 1.6 \times 10^{-3}$ | $< 5.3 \times 10^{-4}$ |

- "baseline": Belle analysis as starting point + increasing statistics
- "improved": 50% increase in signal efficiency for the same background level
- further improvements by using semileptonic tag and charged mode

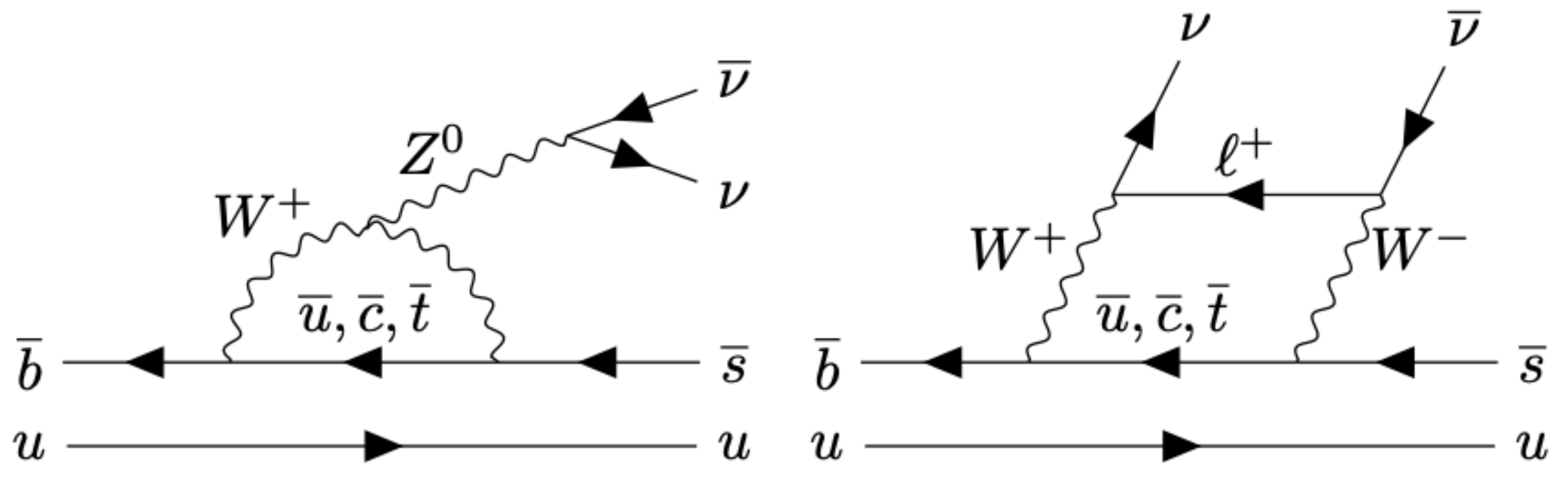
- Belle II will provide updates with improved methods also on b→sτℓ transitions

# Missing energy modes: $B^+ \to K^+ \nu\bar{\nu}$

# Motivation and experimental status

Theory:

- b→s transition prohibited at tree level in the SM
  - branching fraction: $(5.6 \pm 0.4) \times 10^{-6}$ [PRD 107, 119903 (2023)]
- Can receive contribution from NP
  - new mediators, new invisible particles in the final state

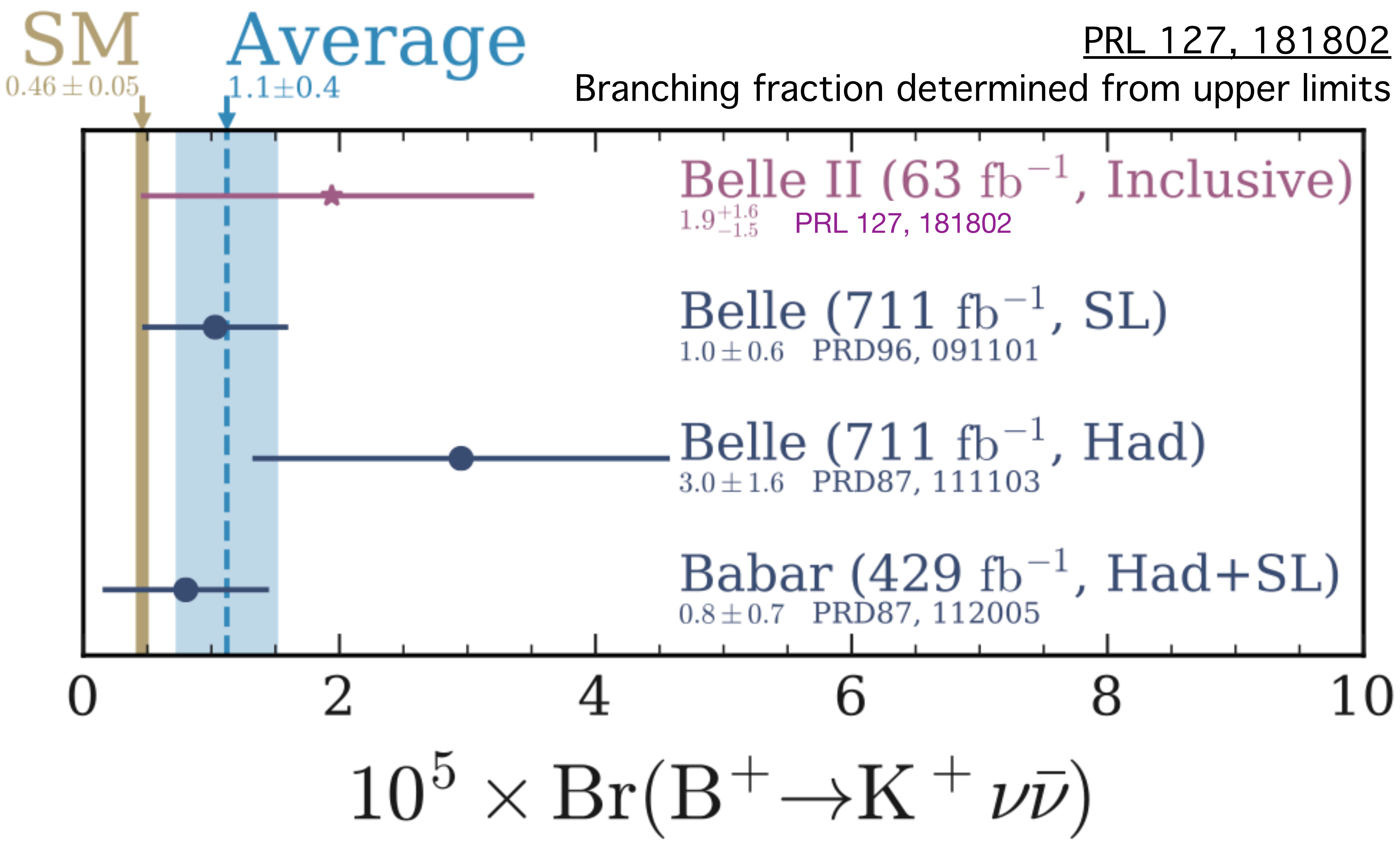



Experiment:

- Challenges:
  - low branching fraction with large background
  - no peak – two neutrinos leads to no good kinematic constraint
- Signal not observed from previous measurements

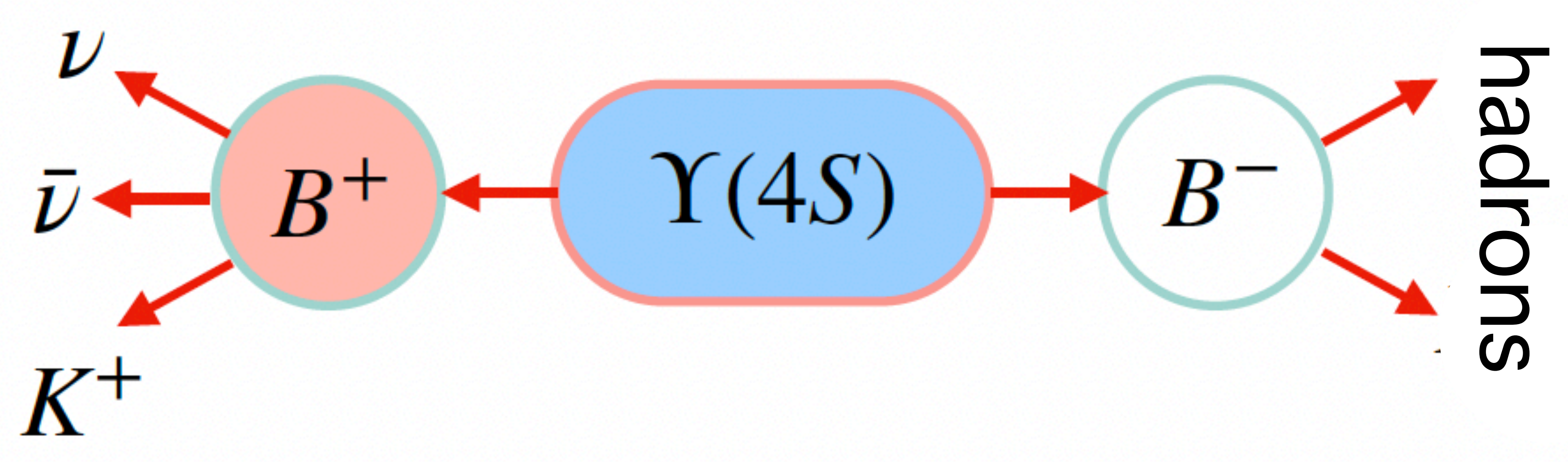
PRL 127, 181802

Branching fraction determined from upper limits

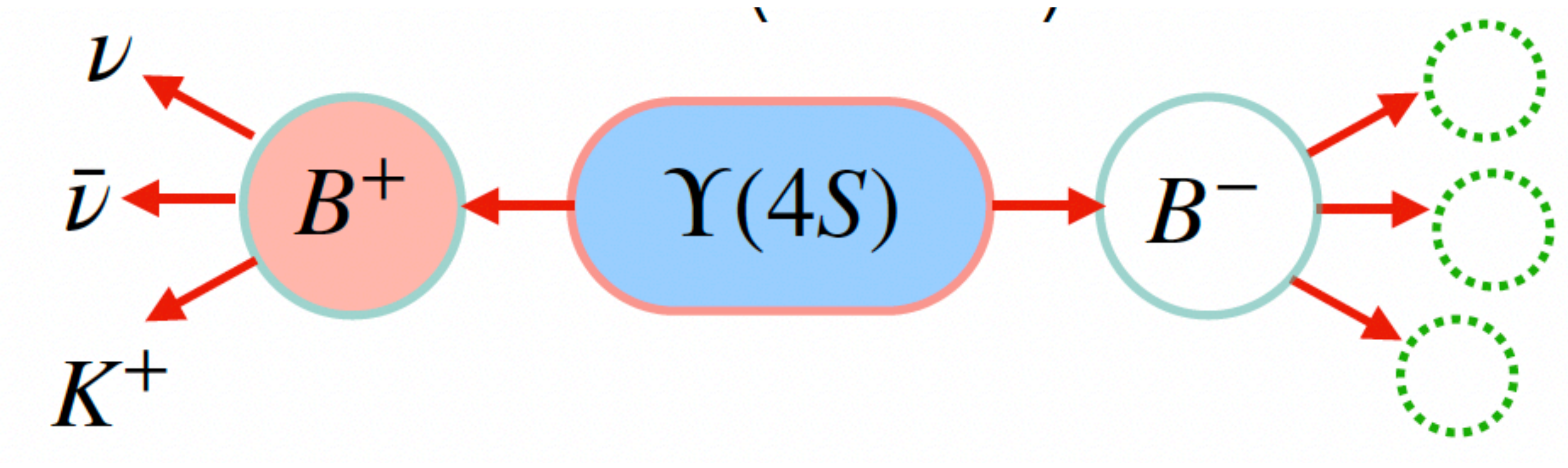


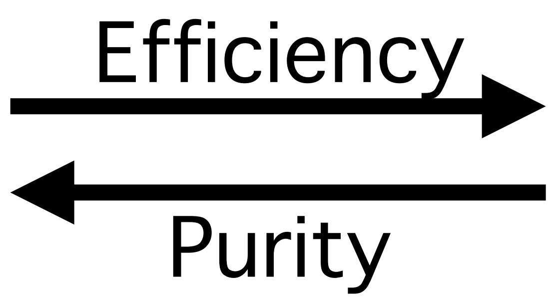
# Updated search for $B^+ \to K^+ \nu\bar{\nu}$ on full Belle II dataset (362 fb$^{-1}$)

Hadronic Tag analysis (HTA)
more conventional




Inclusive Tag analysis (ITA):
more sensitive

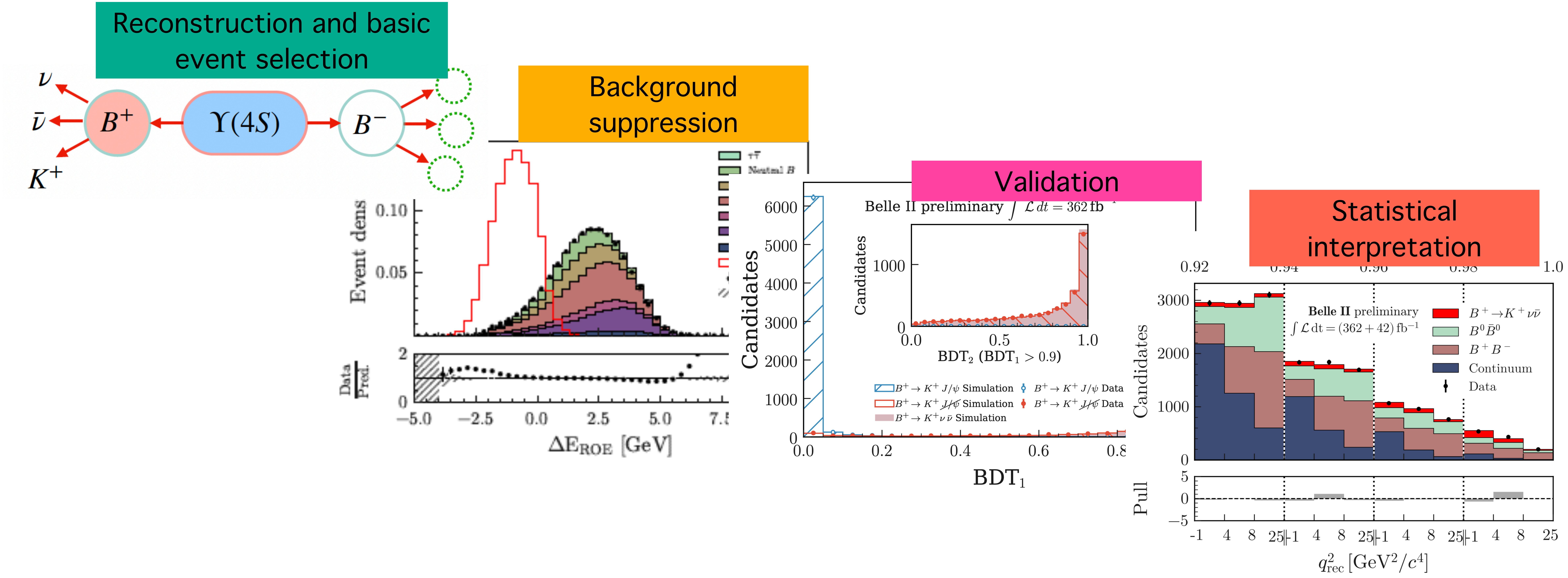



ITA is the main analysis, the driver for the final precision

Almost statistical independent samples

# Analysis flow in a nutshell




Except for the tagging method, ITA and HTA are kept as similar as possible in all steps

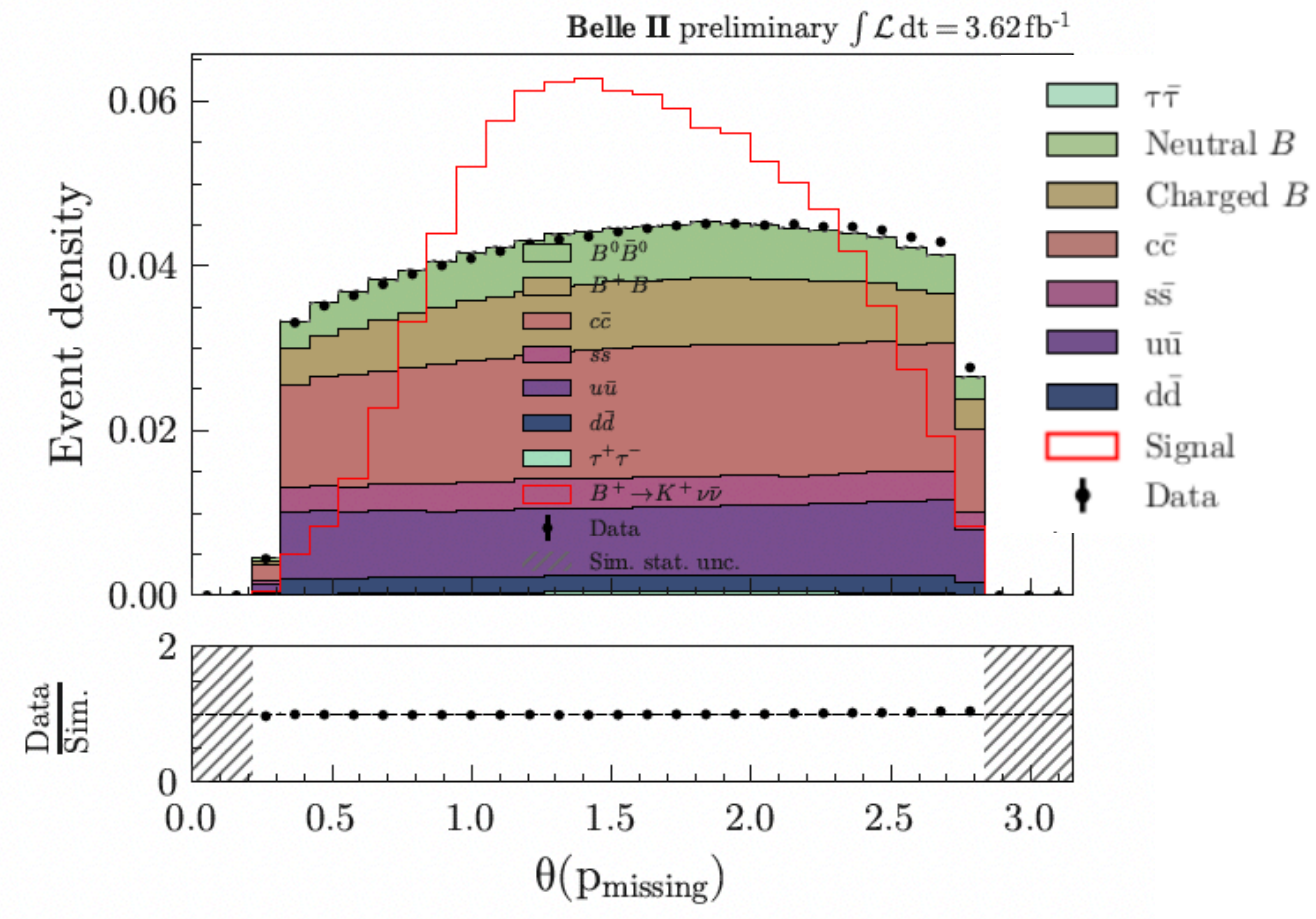
In what follows details of the ITA will be given, highlighting relevant differences of HTA

# Signal kaon reconstruction and basic event selection

- Signal kaon reconstruction:
  - identified charged kaon; K-ID efficiency ~ 68%, 1.2% K/$\pi$ mis-ID rate
  - In ITA, best signal Kaon chosen according to smallest mass squared of the neutrino pair ($q^2_{rec}$):

$$q^2_{\rm rec} = s/(4c^4) + M_K^2 - \sqrt{s}E_K^*/c^4$$

- Require missing energy to be in the central part of the detector




polar angle associated to missing momentum vector

# Background suppression and signal extraction strategy

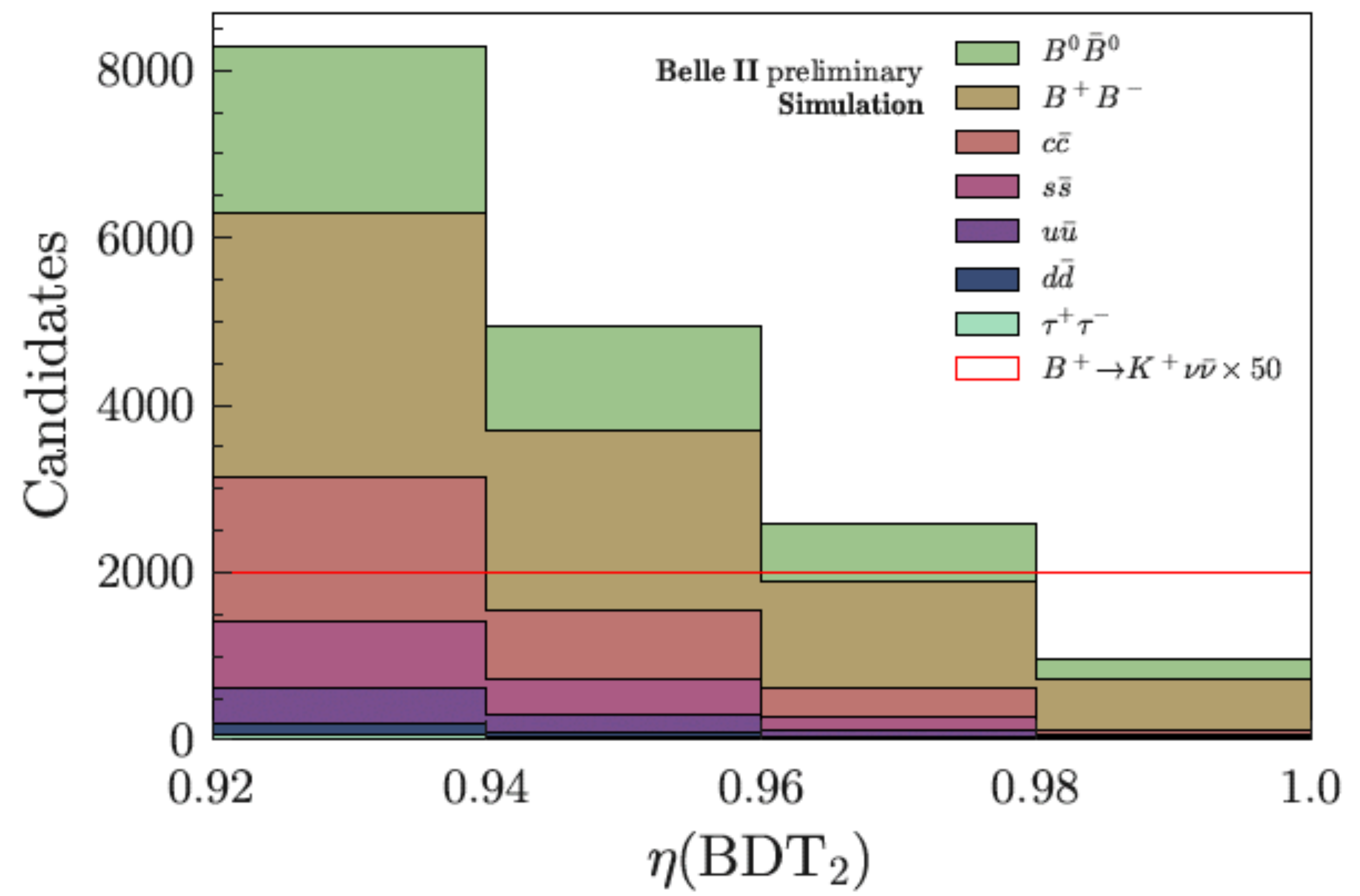
Background suppression:

- Use “event-shape”, kinematics, vertexing, missing energy information
- two successive BDTs (BDT1 and BDT2) in ITA, one single BDT in HTA

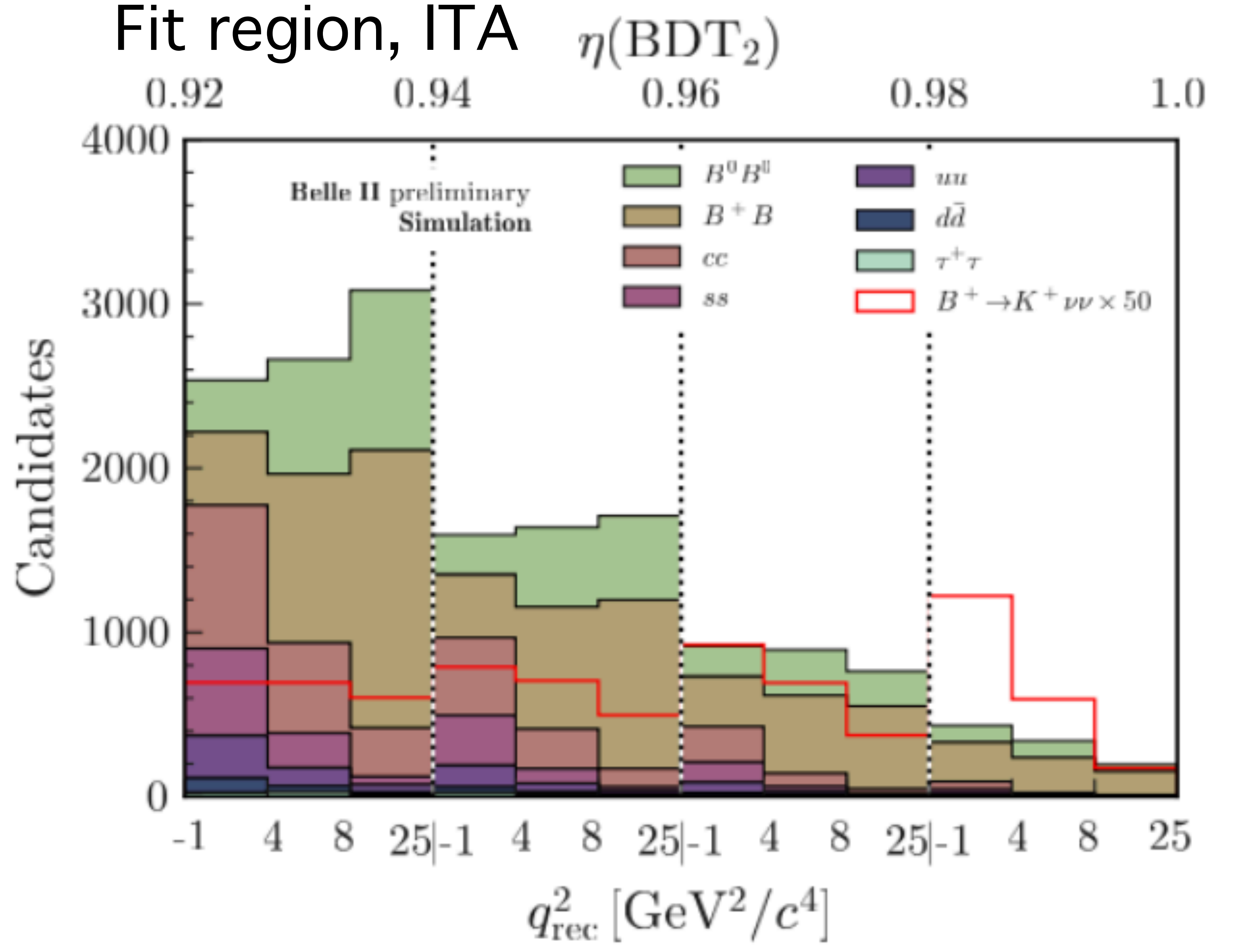
Signal extraction:

- Measure signal strength $\mu$ = $B_{measured}$/ $B_{SM,short\text{-}distance}$ with $B_{SM,short\text{-}distance} = 4.97 \times 10^{-6}$, by fitting classifier output and $q^2_{rec}$ (ITA only)

Signal region, ITA



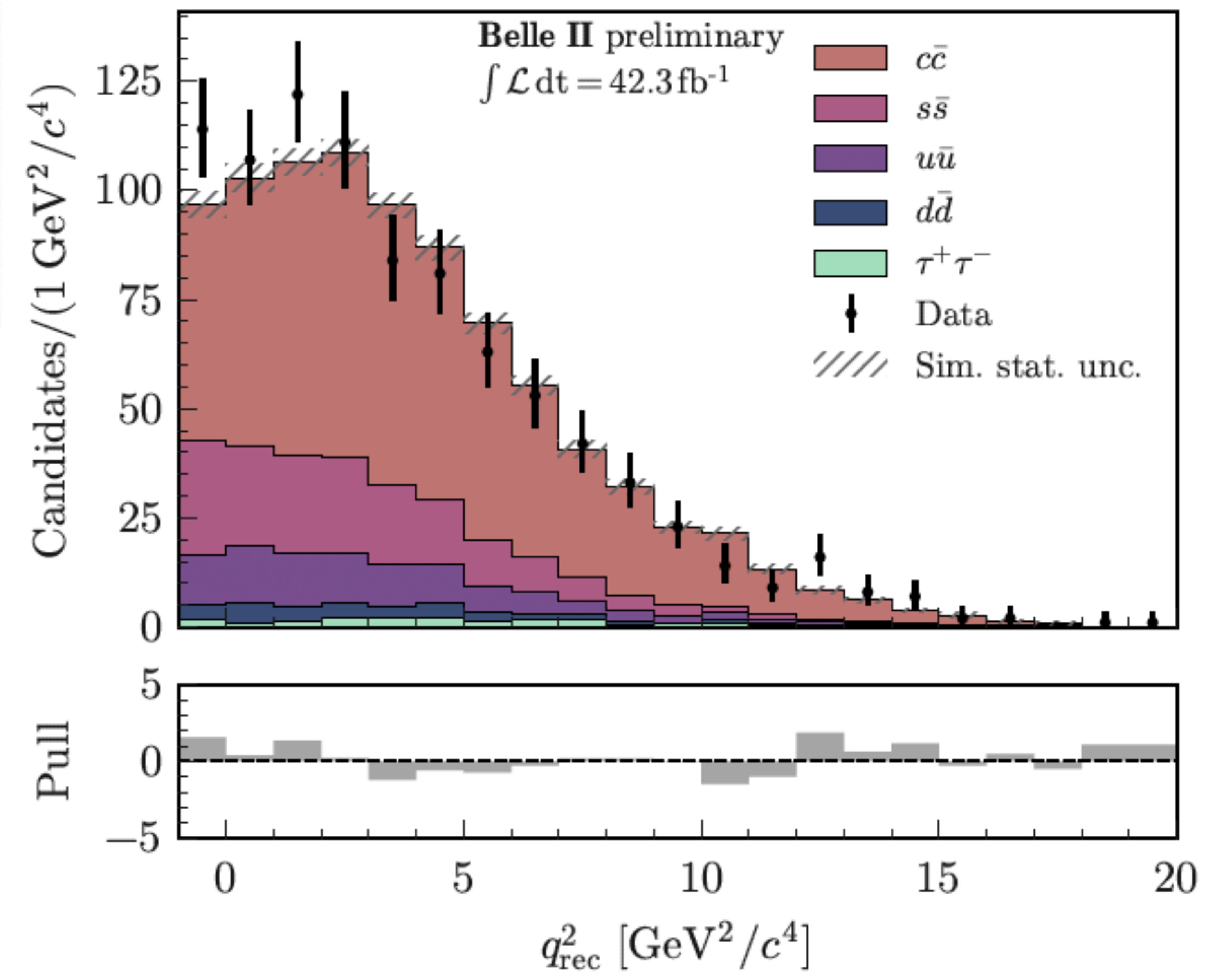

Fit region, ITA



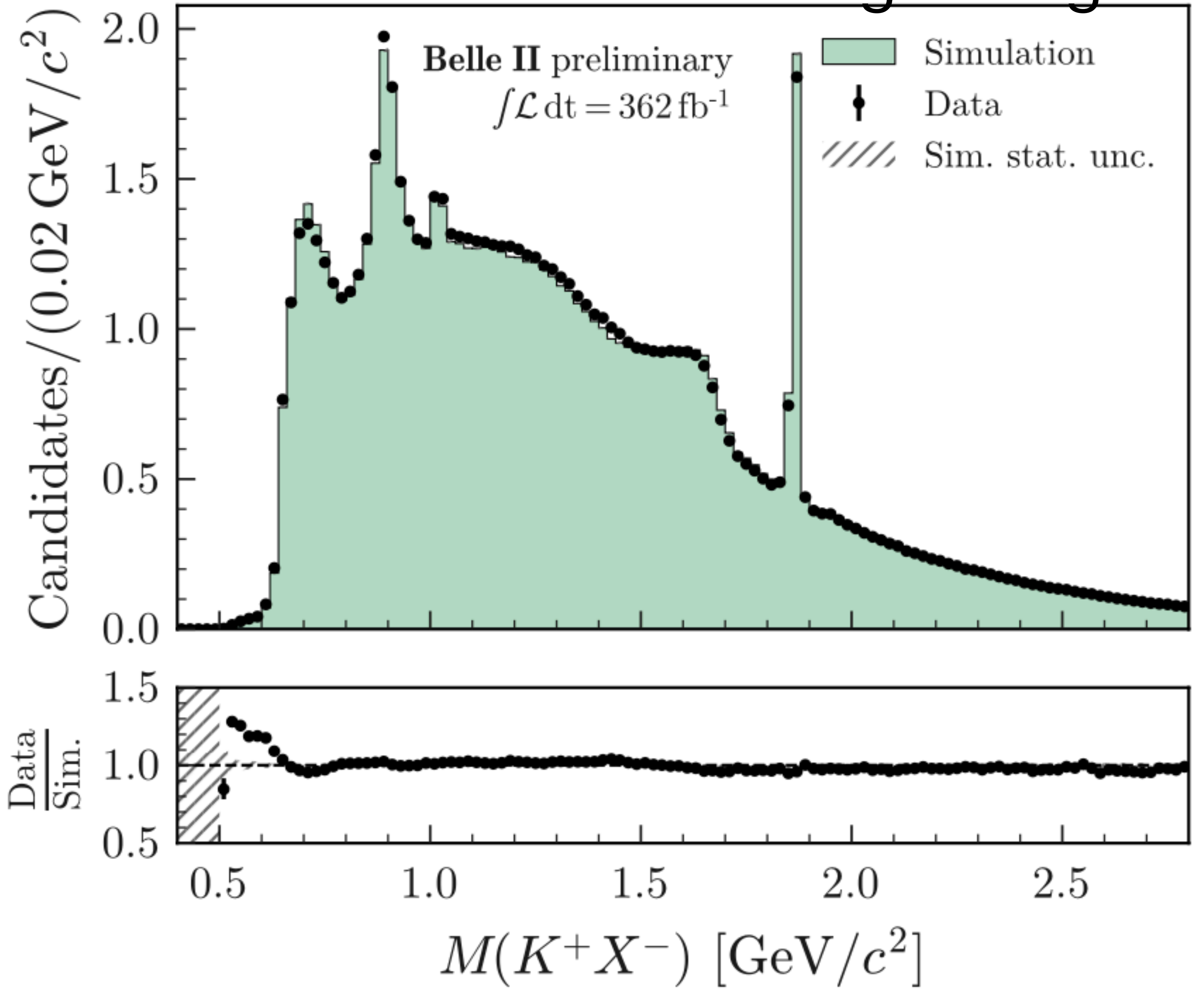
# Background validation (I)

- qq contamination: check modelling using off-resonance data
  - 40% difference in data/MC normalisation
  - correct for shape and normalization differences

- Semileptonic $B \to D^{(*)}(\to KX)\ell\nu$ decays
  - resonances well reproduced in simulation
  - dedicated systematic uncertainties on decay branching fractions, enlarged for $B \to D^{**}\ell\nu$ decays

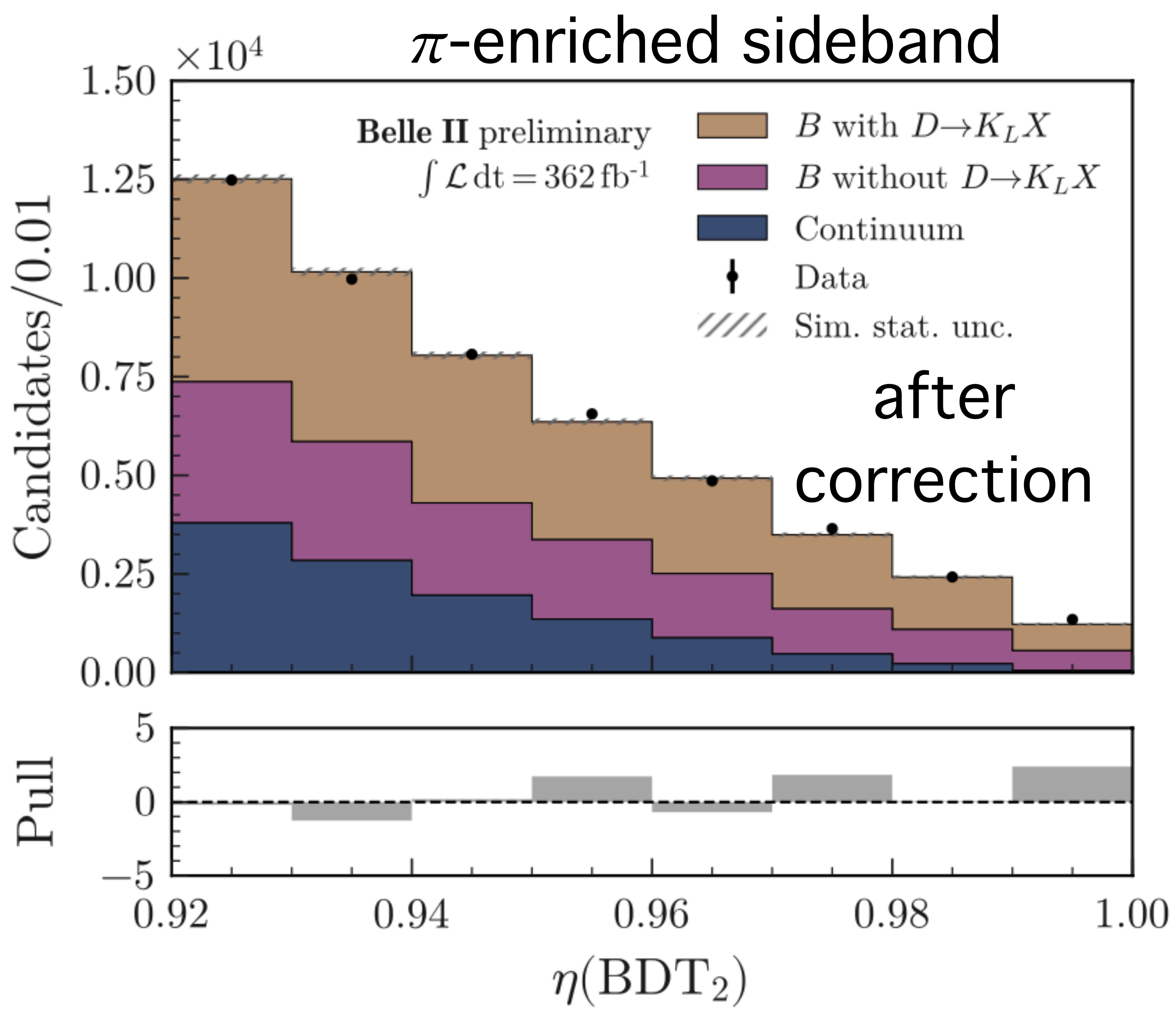



events in BDT1 signal region

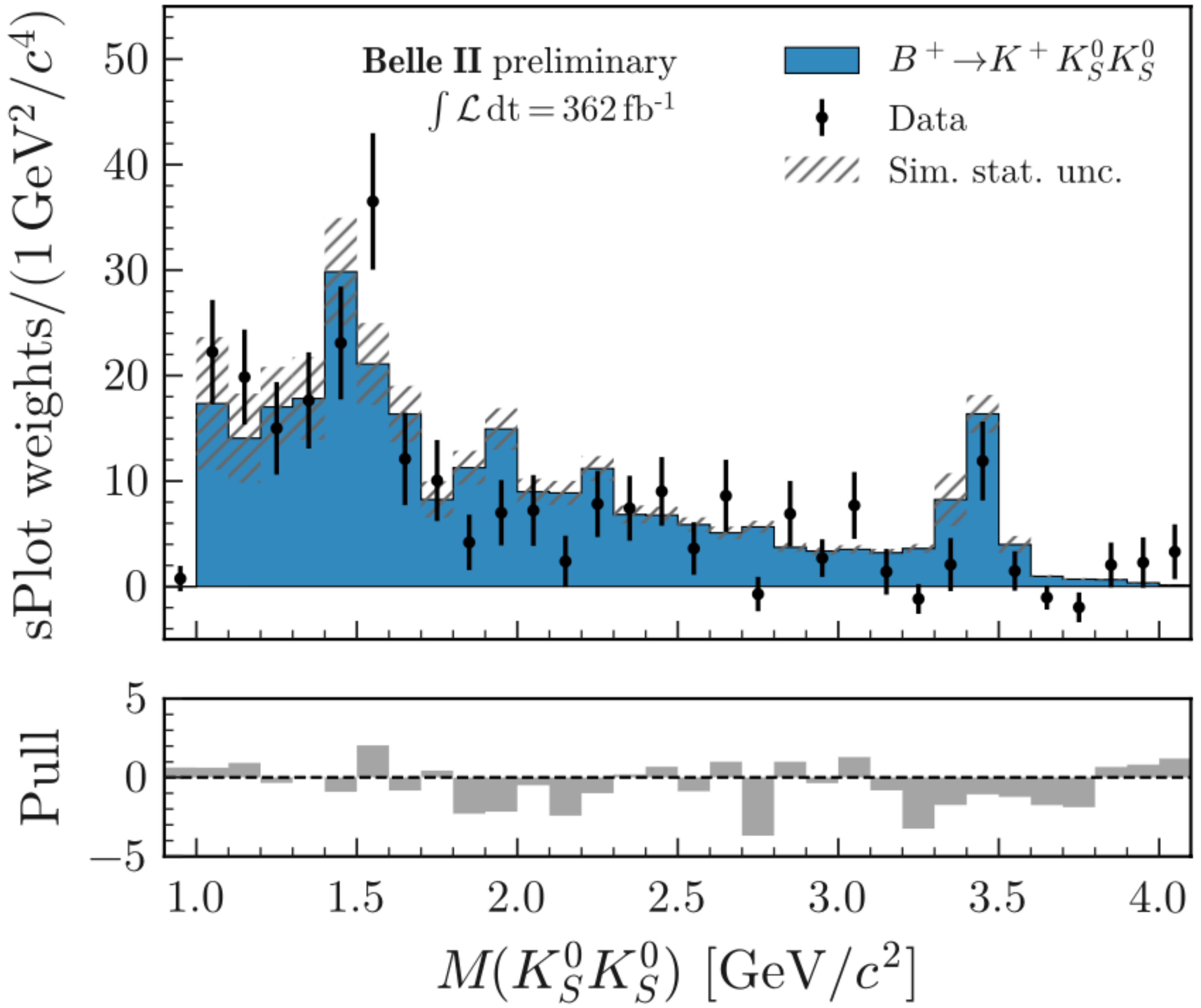


# Background validation (II)

- Hadronic $B \to D^{(*)}K^+$ decays: validated by studying pion and lepton-enriched sidebands
  - $q^2_{rec}$ fit to validate size of $B \to X_c(\to K_L + X)$, data favours 1.3x scaling-up

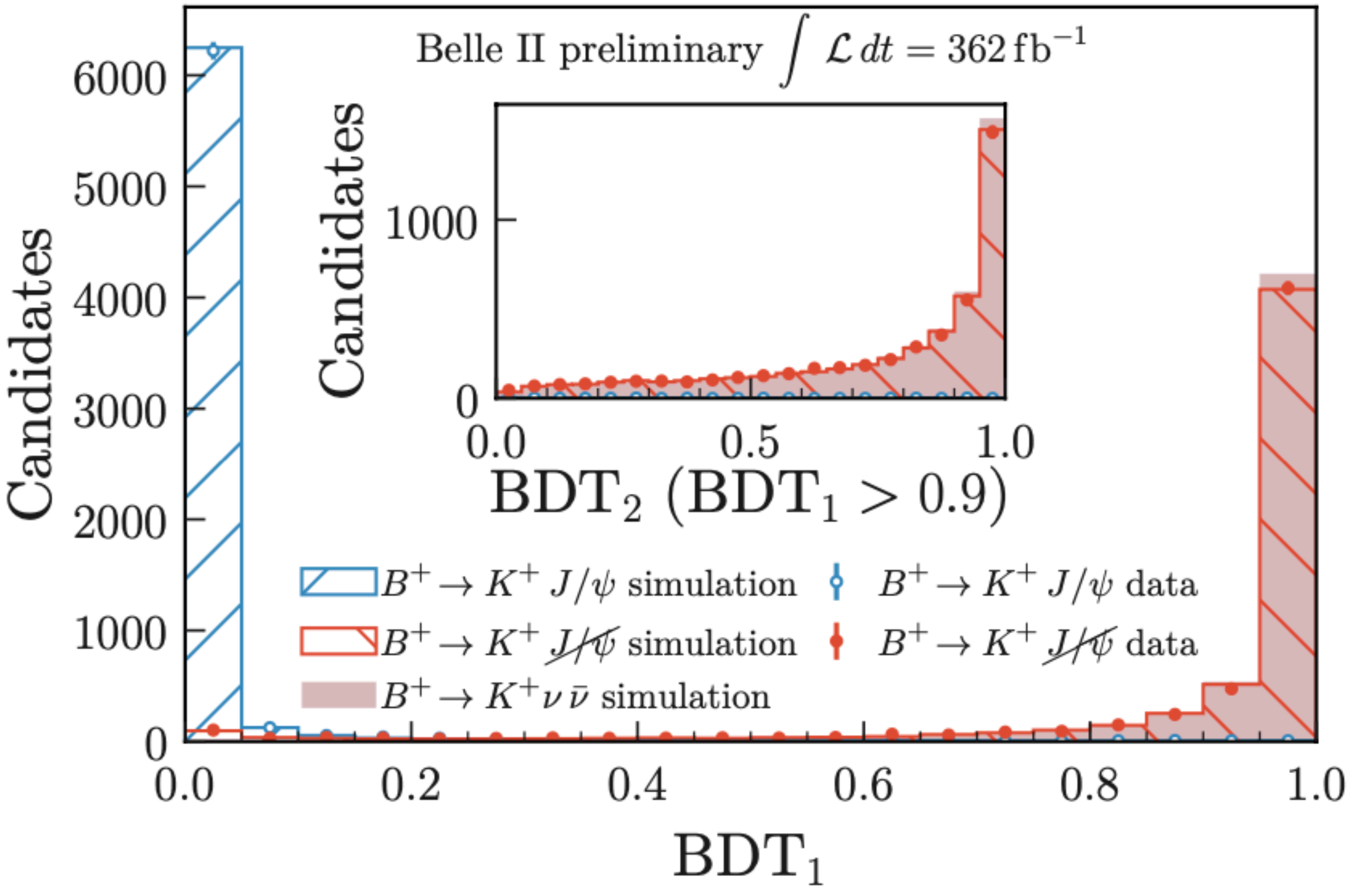



- $B^+ \to K^+ K_L K_L$ : $O(10^{-5})$ branching ratio, $K_L$ escaping electromagnetic calorimeter mimic missing neutrinos
  - model according to BaBar analysis [PRD 85, 112010 (2012)] and validate using $B^+ \to K^+ K_S K_S$



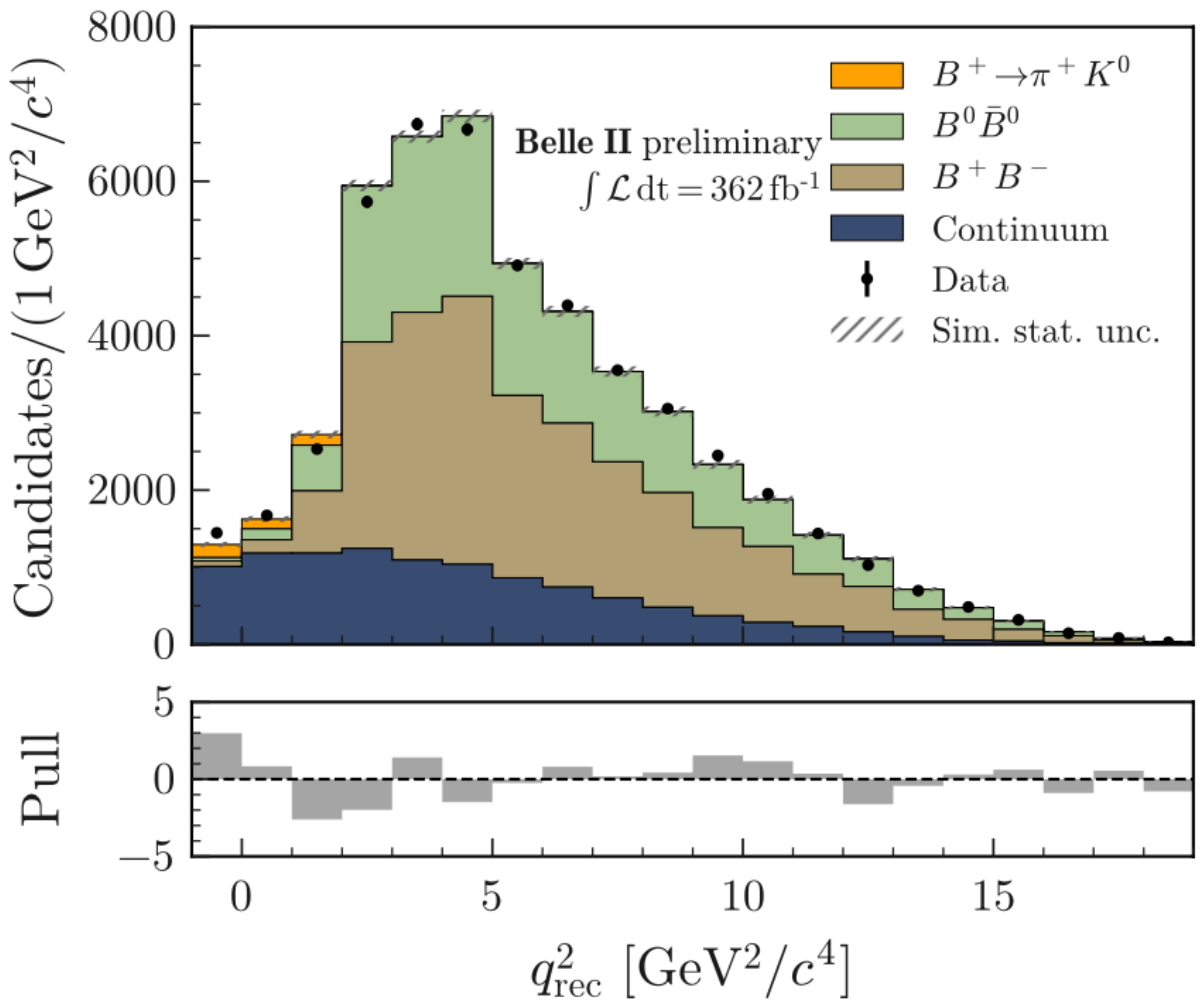
# Signal efficiency Validation


- Use $B^+ \to J/\psi(\mu\mu)K^+$ control channel
  - "embedding" procedure: remove muons from reconstructed objects to mimic neutrinos and replace $K^+$ kinematics from simulated signal events to match signal topology (both in data and MC)
- Data/MC efficiency ratio: $1.00 \pm 0.03$ → good agreement
- 3% is included as signal shape systematic uncertainty



# Closure test: measuring a known and rare mode

- Measure $B^+ \to \pi^+ K^0$ branching fraction by minimally adapting inclusive analysis strategy, e.g.
  - request pion-ID instead of K-ID
  - different $q^2_{rec}$ bins to increase sensitivity




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

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

# Systematics

| Source | Uncertainty size | Impact on $\sigma_\mu$ |
|---|---|---|
| Normalization of $B\bar{B}$ background | 50% | 0.88 |
| Normalization of continuum background | 50% | 0.10 |
| Leading $B$-decay branching fractions | $O(1\%)$ | 0.22 |
| Branching fraction for $B^+ \to K^+ K^0_L K^0_L$ | 20% | 0.49 |
| p-wave component for $B^+ \to K^+ K^0_S K^0_L$ | 30% | 0.02 |
| Branching fraction for $B \to D^{**}$ | 50% | 0.42 |
| Branching fraction for $B^+ \to n\bar{n}K^+$ | 100% | 0.20 |
| Branching fraction for $D \to K^0_L X$ | 10% | 0.14 |
| Continuum-background modeling, BDT$_c$ | 100% of correction | 0.01 |
| Integrated luminosity | 1% | $< 0.01$ |
| Number of $B\bar{B}$ | 1.5% | 0.02 |
| Off-resonance sample normalization | 5% | 0.05 |
| Track-finding efficiency | 0.3% | 0.20 |
| Signal-kaon PID | $O(1\%)$ | 0.07 |
| Photon energy | 0.5% | 0.08 |
| Hadronic energy | 10% | 0.36 |
| $K^0_L$ efficiency in ECL | 8% | 0.21 |
| Signal SM form-factors | $O(1\%)$ | 0.02 |
| Global signal efficiency | 3% | 0.03 |
| Simulated-sample size | $O(1\%)$ | 0.52 |

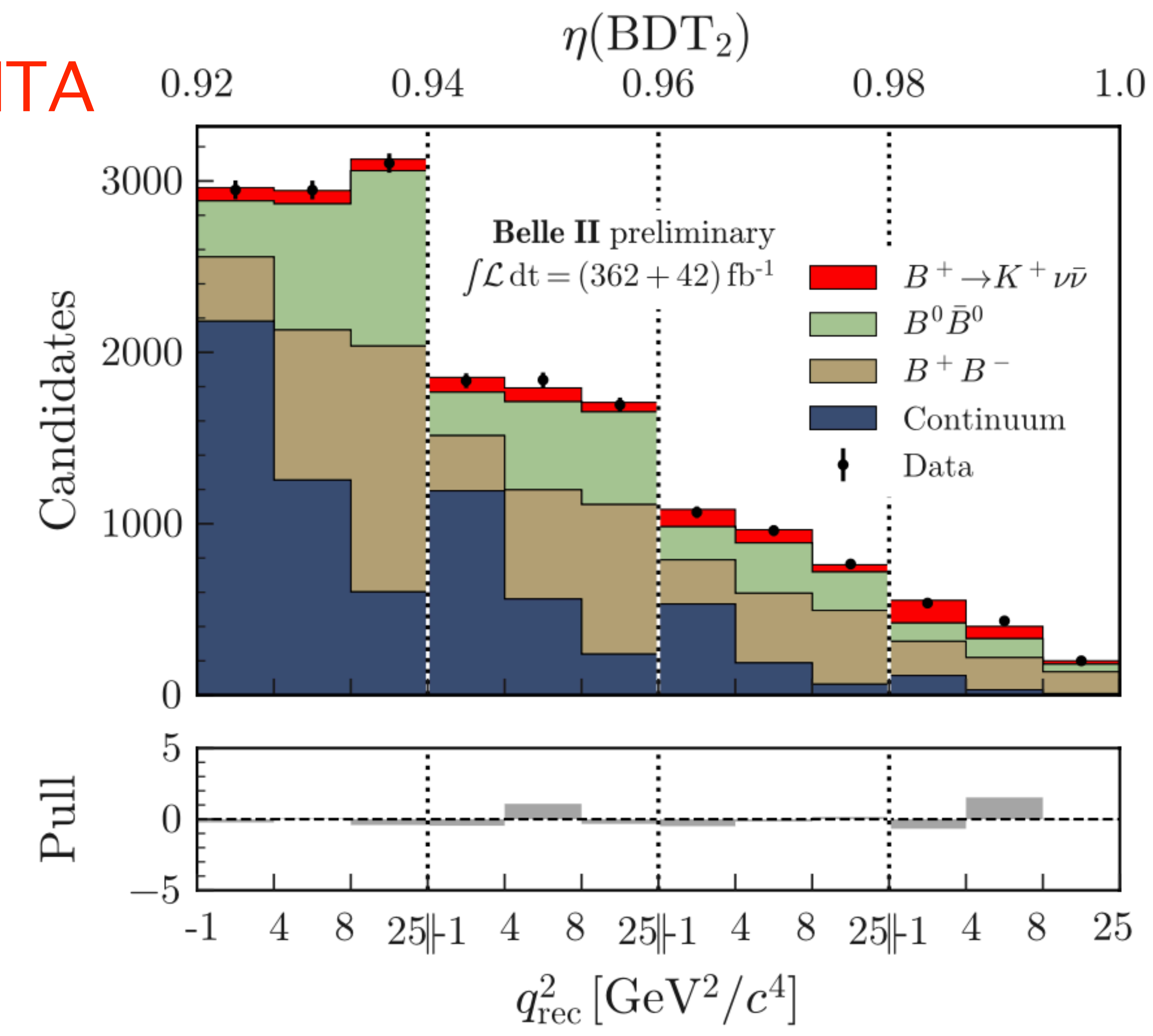
spoiler: statistical uncertainty =1.1

- Dominant sources of systematic uncertainties for ITA :
  - $B\bar{B}$ background normalisation
  - Limited size of simulation sample for the fit model
  - knowledge of $B^+ \to K^+ K_L K_L$ decay rate and modelling of $B^+ \to D^{**}\ell\nu$ decays
- In HTA, dominant sources are background normalisation, simulation sample size, and systematic on mis-modelling of extra-photon multiplicity.

$\mu$ = $B_{measured}/B_{SM,short\text{-}distance}$
with $B_{SM,short\text{-}distance}$ = $4.97 \times 10^{-6}$

# Results

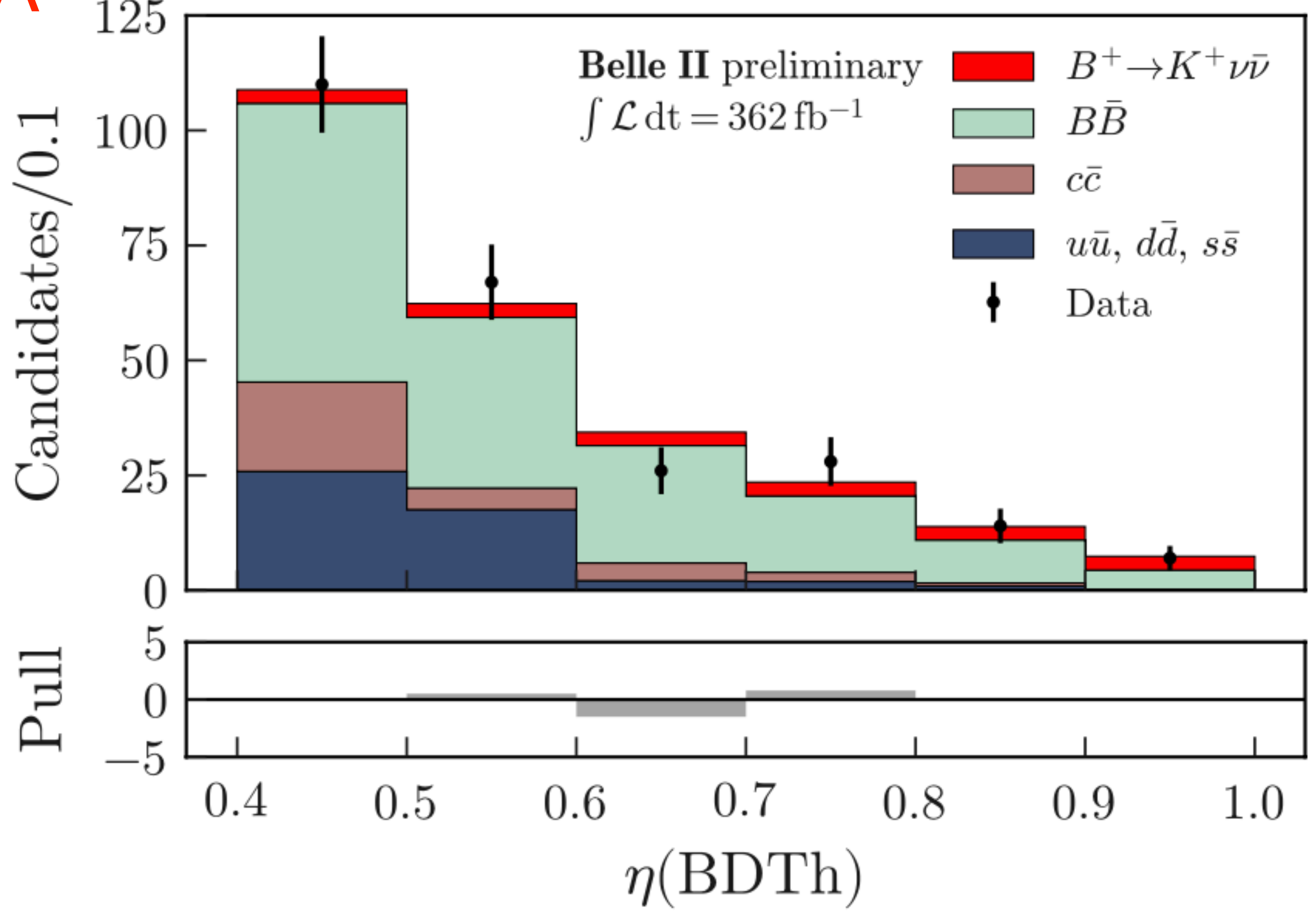
ITA




$$\mu = 5.6 \pm 1.1(\mathrm{stat})^{+1.1}_{-0.9}(\mathrm{syst})$$

3.6σ significance wrt background-only hypothesis,
3.0σ deviation from SM

HTA




$$\mu = 2.2 \pm 2.3(\mathrm{stat})^{+1.6}_{-0.7}(\mathrm{syst})$$

1.1σ significance wrt background-only hypothesis,
0.6σ deviation from SM

Compatibility between data and fit result from pseudo-experiments: 47% (61%) for ITA (HTA)

# Results

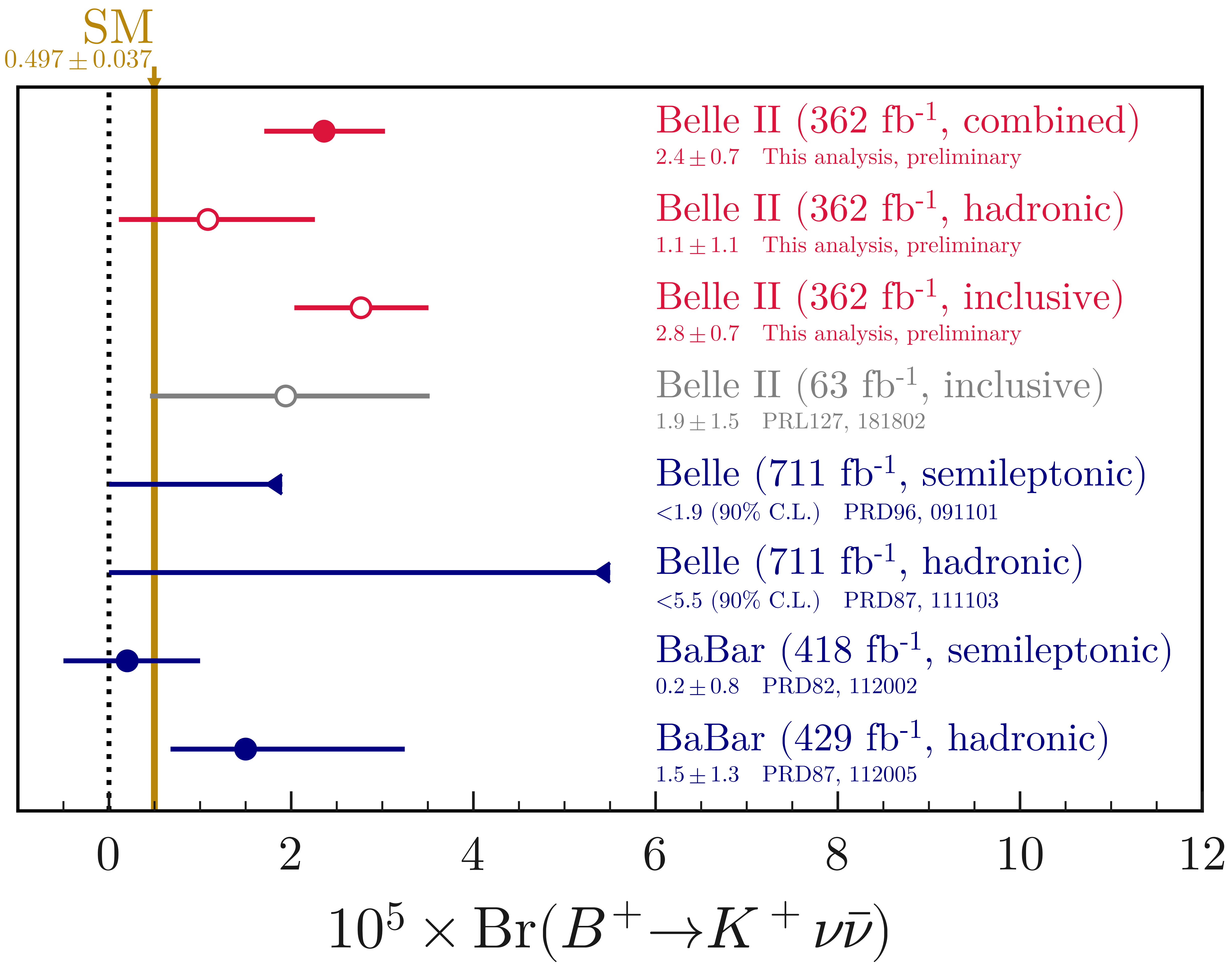
Combination: $\mu = 4.7 \pm 1.0(\text{stat}) \pm 0.9(\text{syst})$

$$\mathcal{B}(B^+ \to K^+ \nu \bar{\nu}) = [2.4 \pm 0.5(\text{stat})^{+0.5}_{-0.4}(\text{syst})] \times 10^{-5}$$

- significance wrt null hypothesis: $3.6\sigma$
- significance wrt SM: $2.8\sigma$

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

# Comparison with previous measurements




- ITA result:
  - in agreement with previous hadronic-tag and inclusive measurements
  - 2.4σ tension with BaBar semileptonic-tag analysis
  - comparable precision wrt previous best measurements
- HTA result:
  - in agreement with all previous measurements
  - most precise result with hadronic tag method
- Overall good compatibility: p-value ~ 30%

# Conclusions

- Belle II can probe NP by studying pure leptonic B decays and $b \to s$ transitions
  - results shown for inclusive and exclusive radiative decays on partial Belle II dataset or full BelleII+Belle sample
  - prospects for B decay modes with $\tau$ in the final states
  - first evidence for $B^+ \to K^+ \nu\bar{\nu}$ with Belle II data
- Ongoing analysis on topics touched today with full Belle II (+ Belle) dataset
- Data taking to resume early in 2024

# Extra-slides

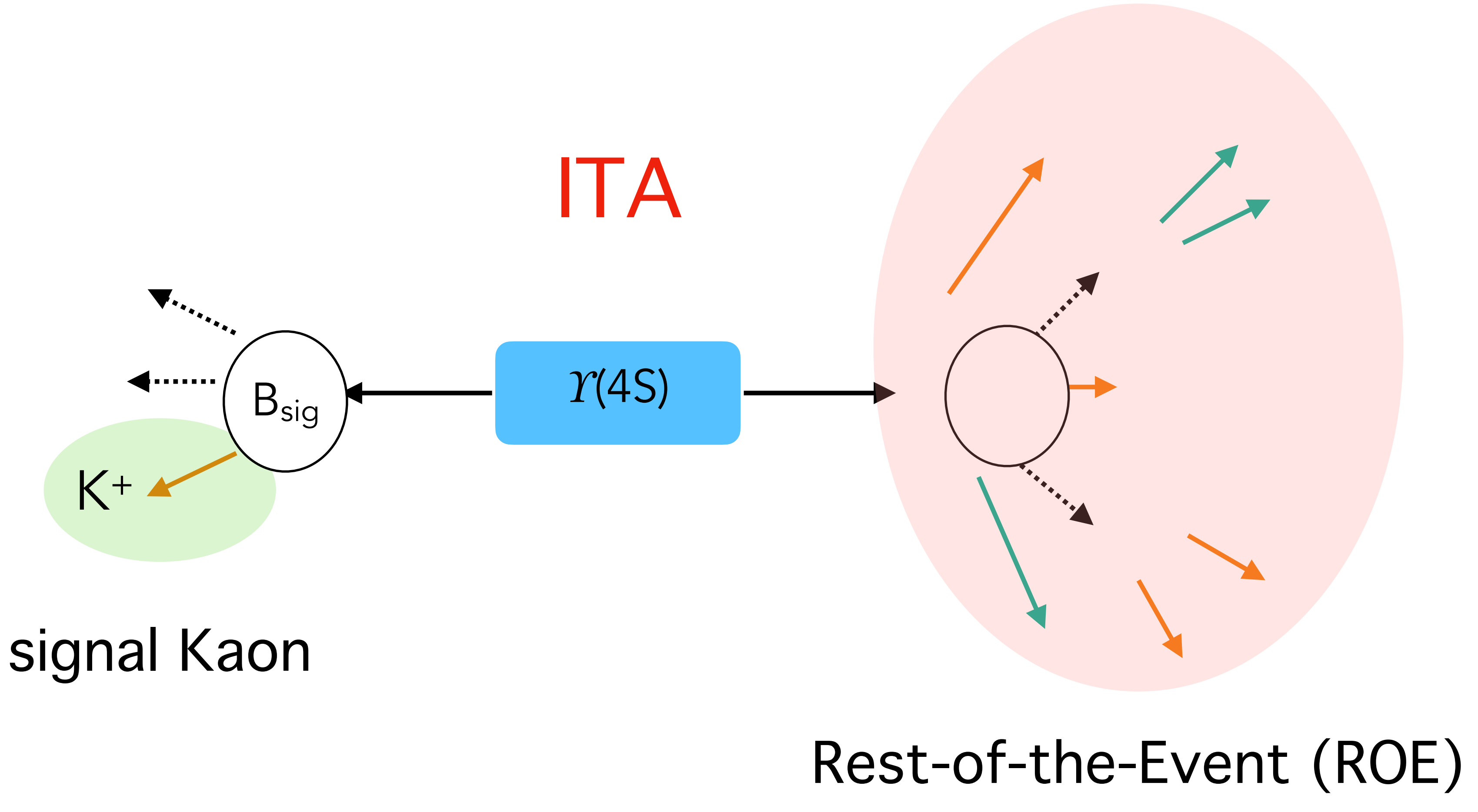
# Reconstruction and basic event selection (I)

## ITA

- No explicit tag reconstruction: $\varepsilon \sim 100\%$
- Signal candidate: identified charged kaon
  - K-ID efficiency ~ 68%, 1.2% $K/\pi$ mis-ID rate
- Best signal Kaon chosen according to smallest $q^2_{rec}$:

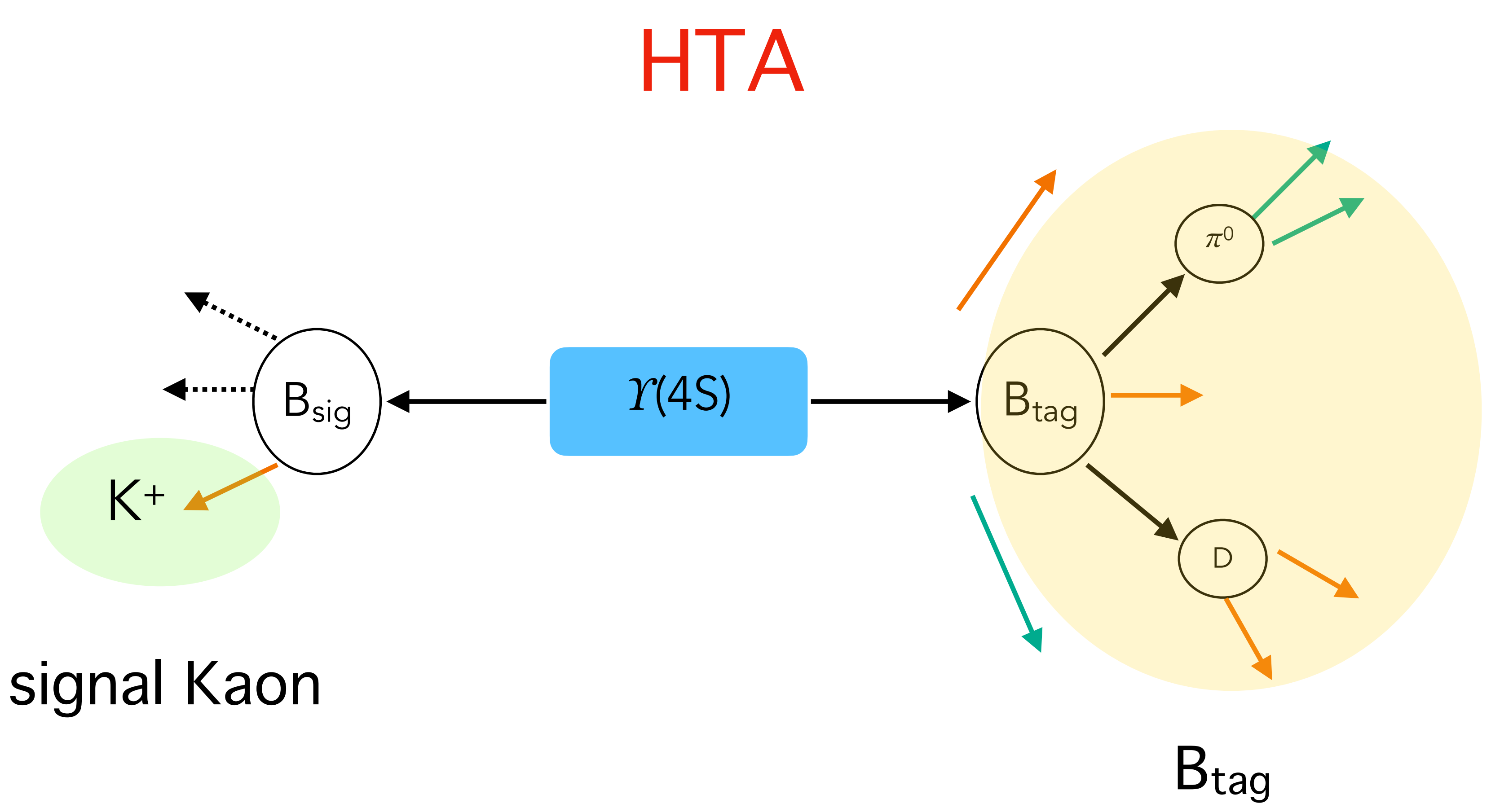
$$q^2_{\rm rec} = s/(4c^4) + M_K^2 - \sqrt{s}E_K^*/c^4$$

  - pick true K 96% of the times
  - no bias in the procedure, x-checked by selecting best kaon at random



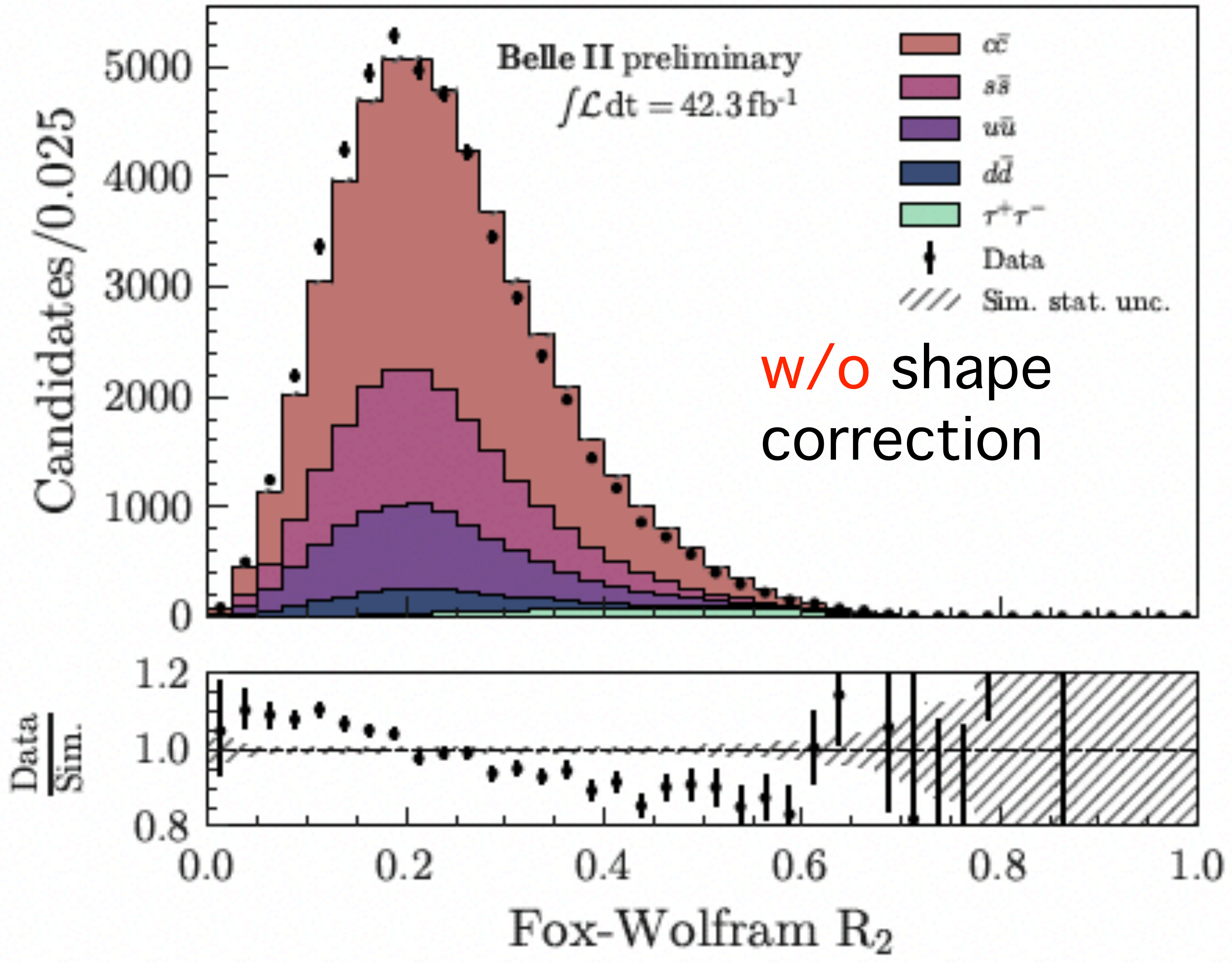

## HTA

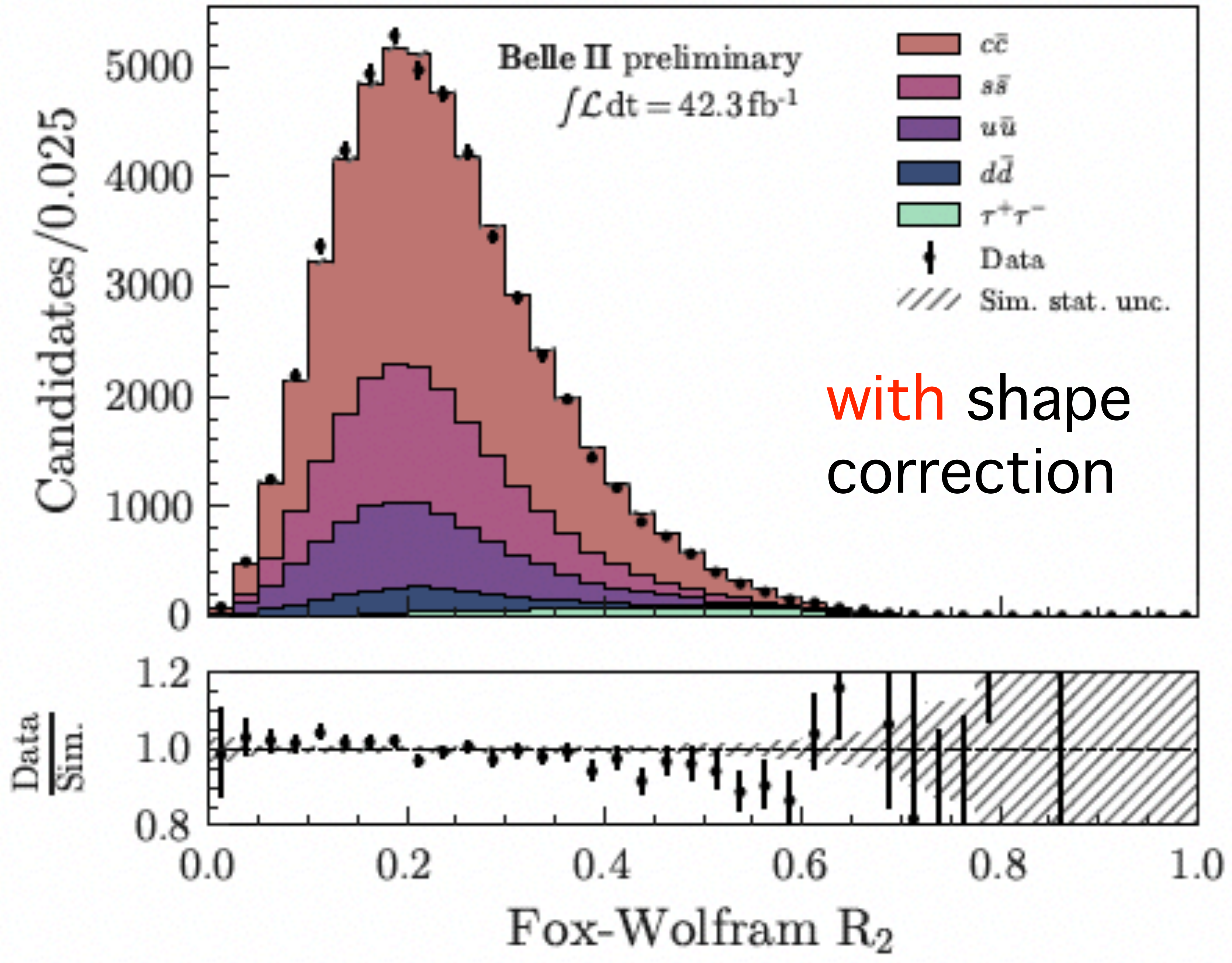
- Hadronic tag reconstruction, as in $R(X\tau/\ell)$
- same signal kaon reconstruction but $q^2_{rec}$ requirement (lower candidate multiplicity thanks to $B_{tag}$ reconstruction)



# q$\bar{q}$ background studies

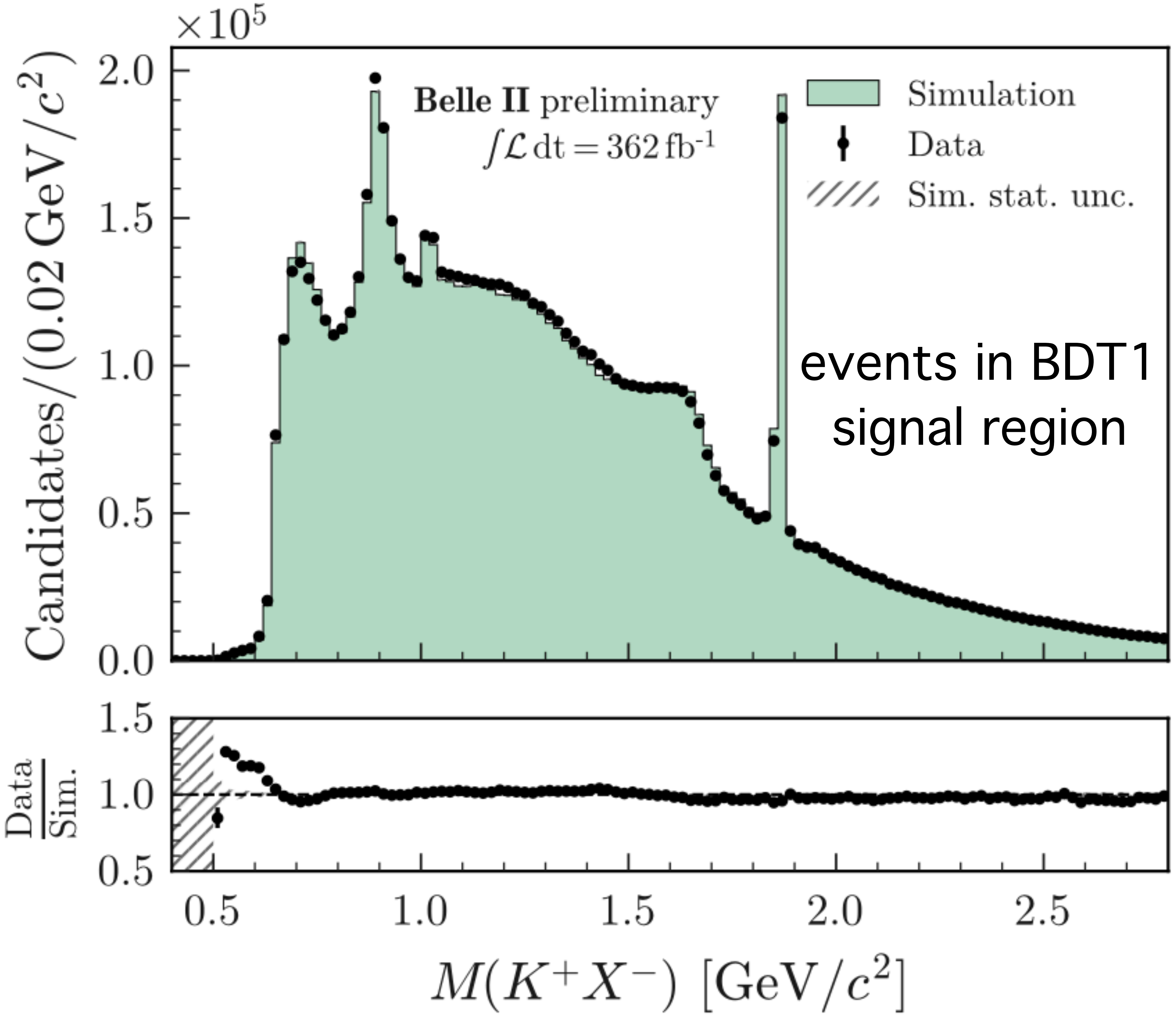
- ~ 40% of background events in signal region from q$\bar{q}$ events
- KKMC generator used to generate q$\bar{q}$ pairs, PYTHIA simulate hadronization, and EVTGEN for decay modelling
- Check modelling by comparing off-resonance data and q$\bar{q}$ simulation
  - 40% difference in data/MC normalisation (used as systematic uncertainty)
  - shape corrected by event-by-event data-drive corrections [J. Phys.: Conf. Ser. 368 012028]



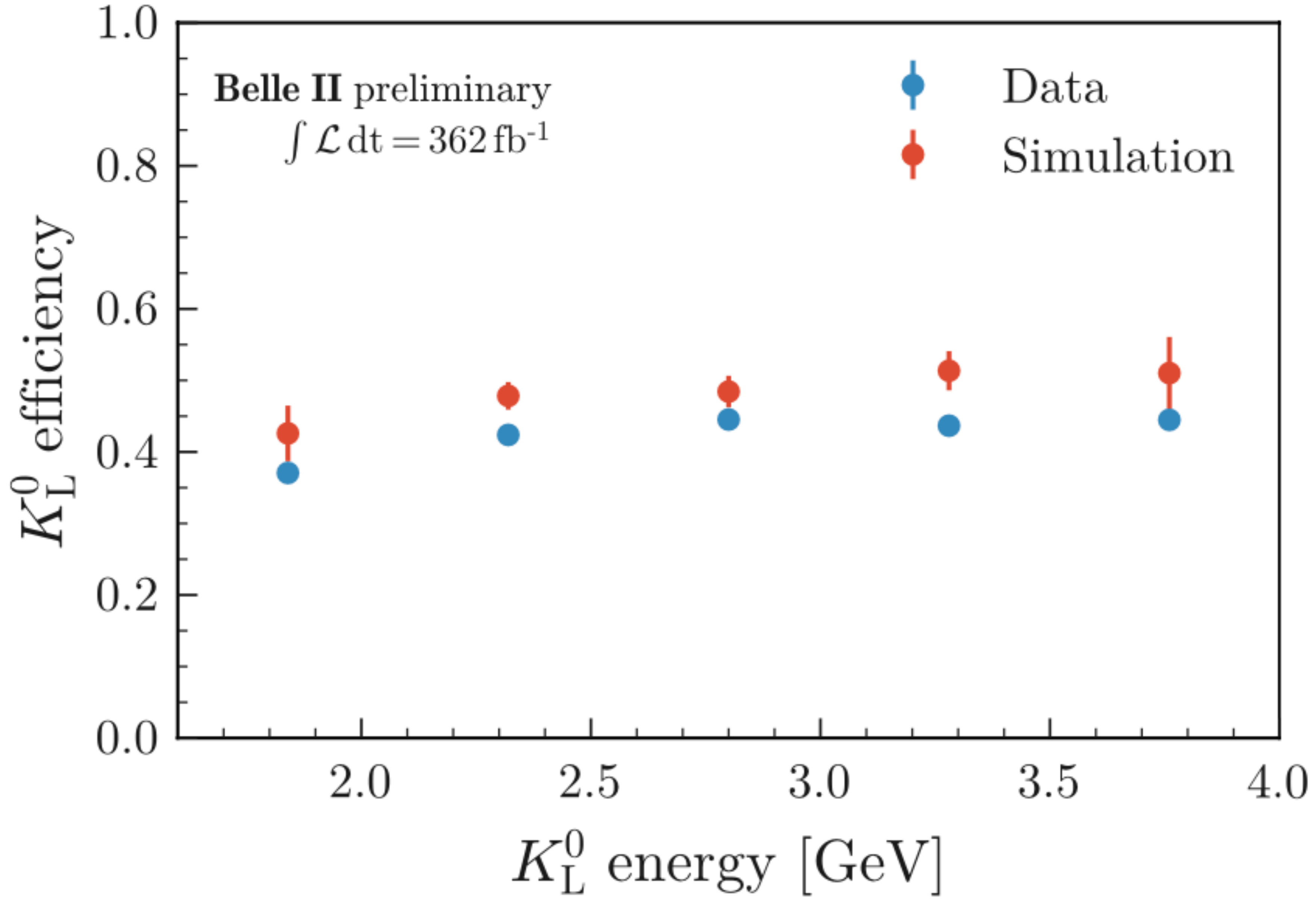
# Semileptonic B→D$^{(*)}$(→K$^+$X)$\ell\nu$ decays

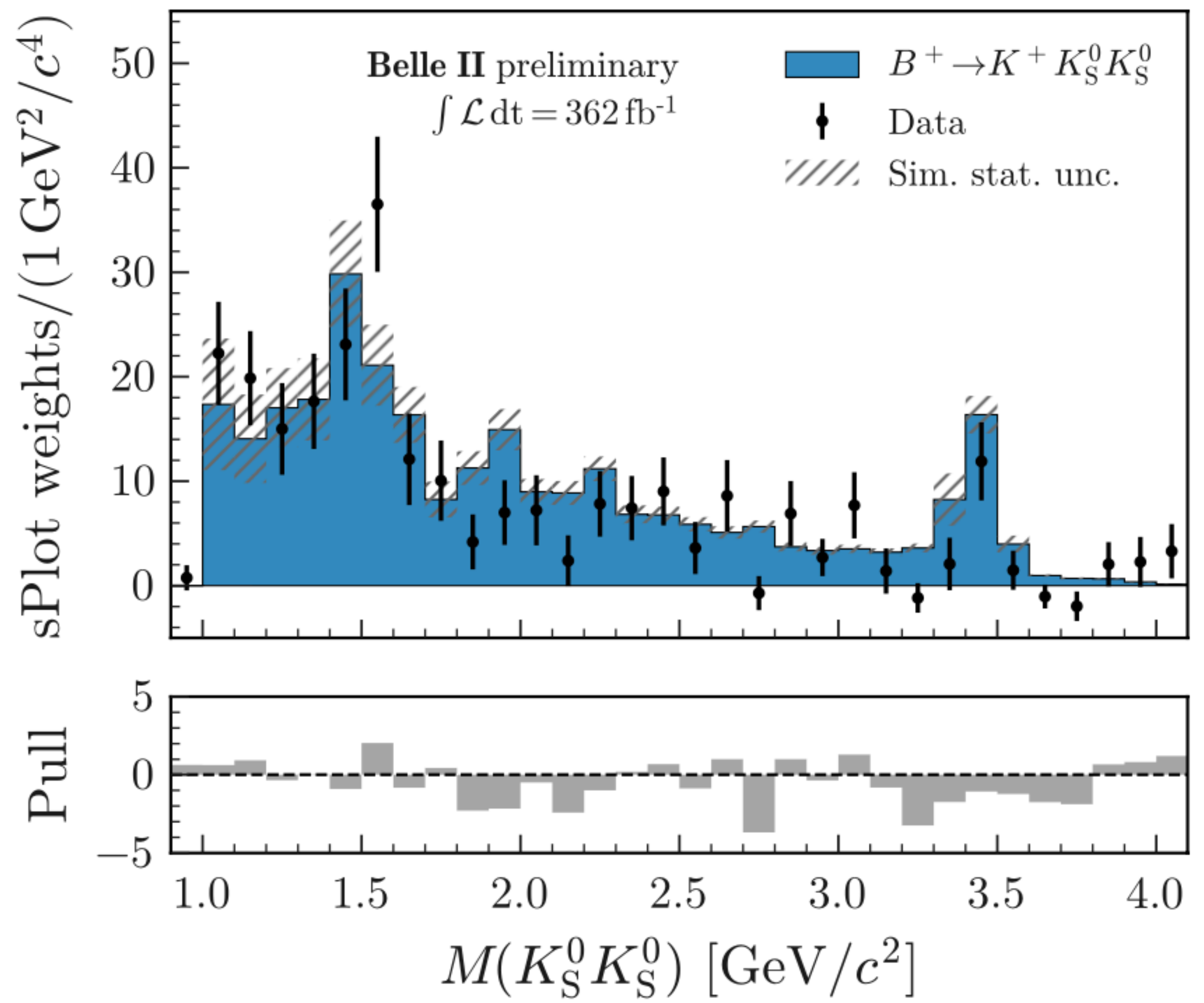
- Semileptonic B decays generally well modelled in EVTGEN, modes with D** less well known
- Inspect invariant mass of signal K and any other track in the ROE
  - also used at background suppression stage
- Resonances well reproduced in simulation
- Dedicated systematic uncertainties on decay branching fractions, enlarged for B→D**$\ell\nu$ decays
  - impact of uncertainties on form factors found to be negligible



# $B^+ \to K^+ K_L K_L$

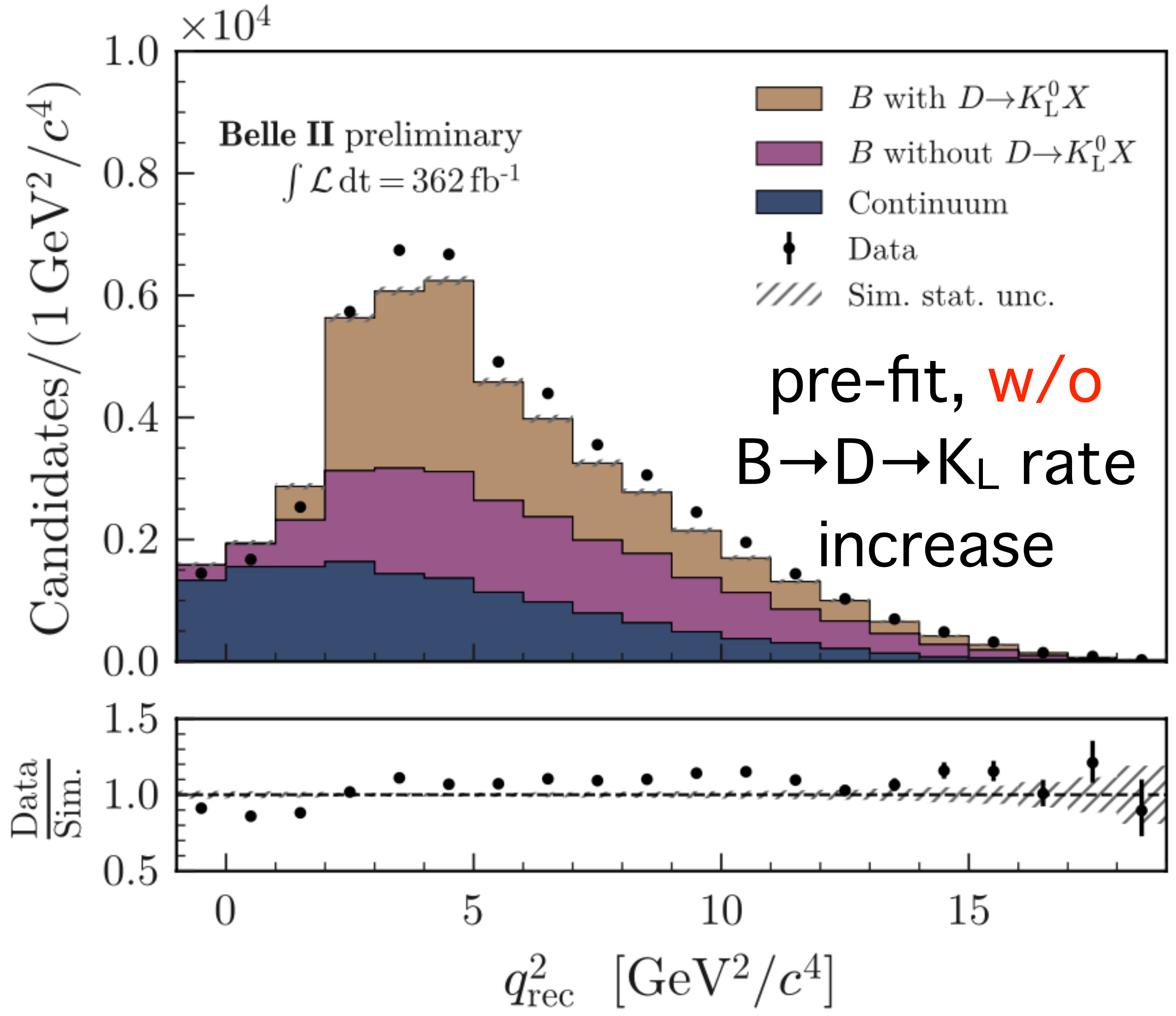
- Most signal-like background:
  - $O(10^{-5})$ branching ratio, $K_L$ escaping electromagnetic calorimeter mimic missing neutrinos
- Study $K_L$ detection efficiency in the calorimeter from $e^+e^- \to \gamma\varphi(\to K_L K_S)$ control sample: correct for 17% inefficiency in data wrt simulation in the whole $K_L$ energy range
- Model $B^+ \to K^+ K_L K_L$ according to BaBar analysis [PRD 85, 112010 (2012)]
- Validate the modelling on $B^+ \to K^+ K_S K_S$
- Similar study for $B^+ \to K^+ nn$, smaller contamination wrt $B^+ \to K^+ K_L K_L$ mode

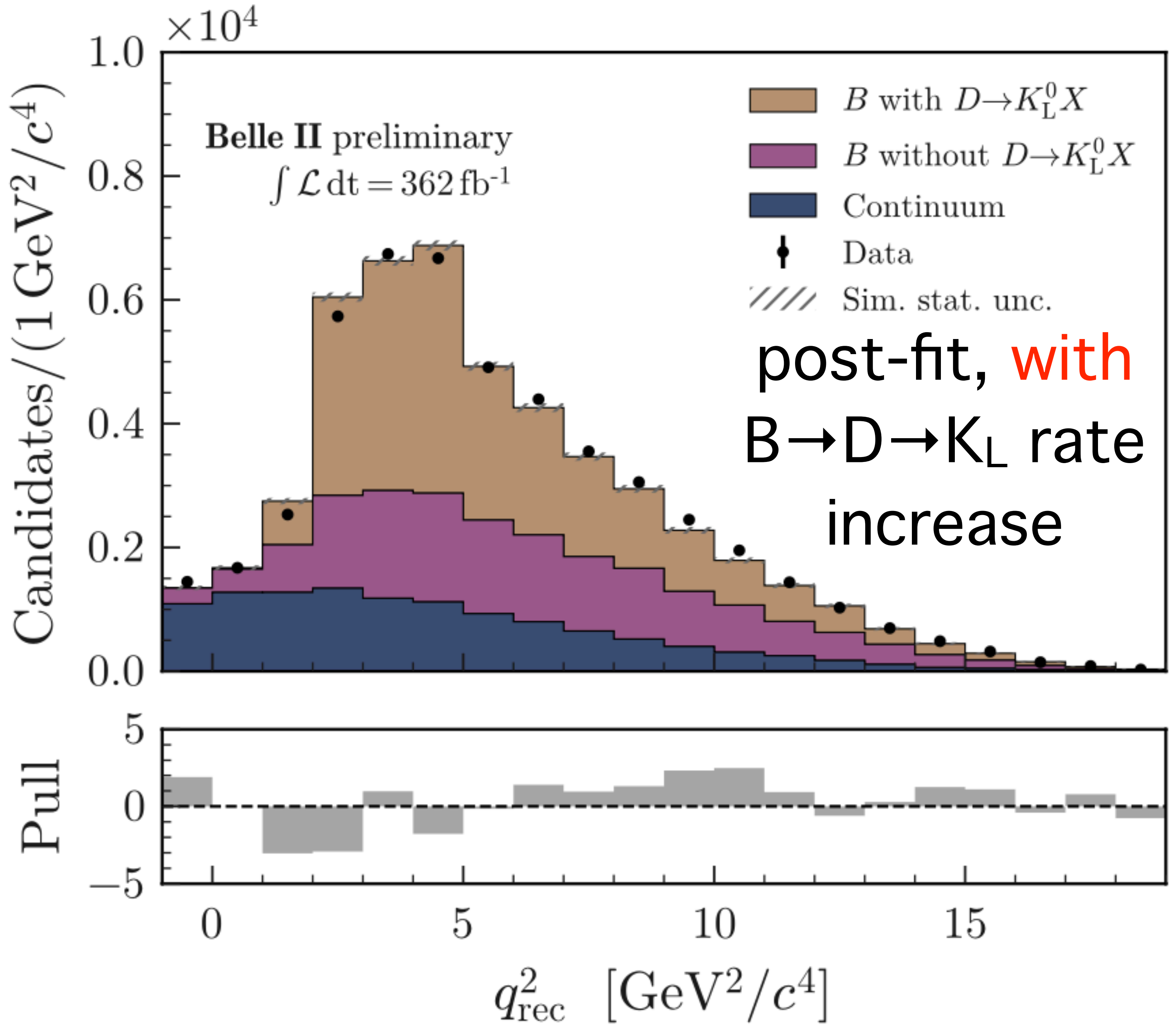


# Hadronic $B \to D^{(*)}K^+$ decays (I)

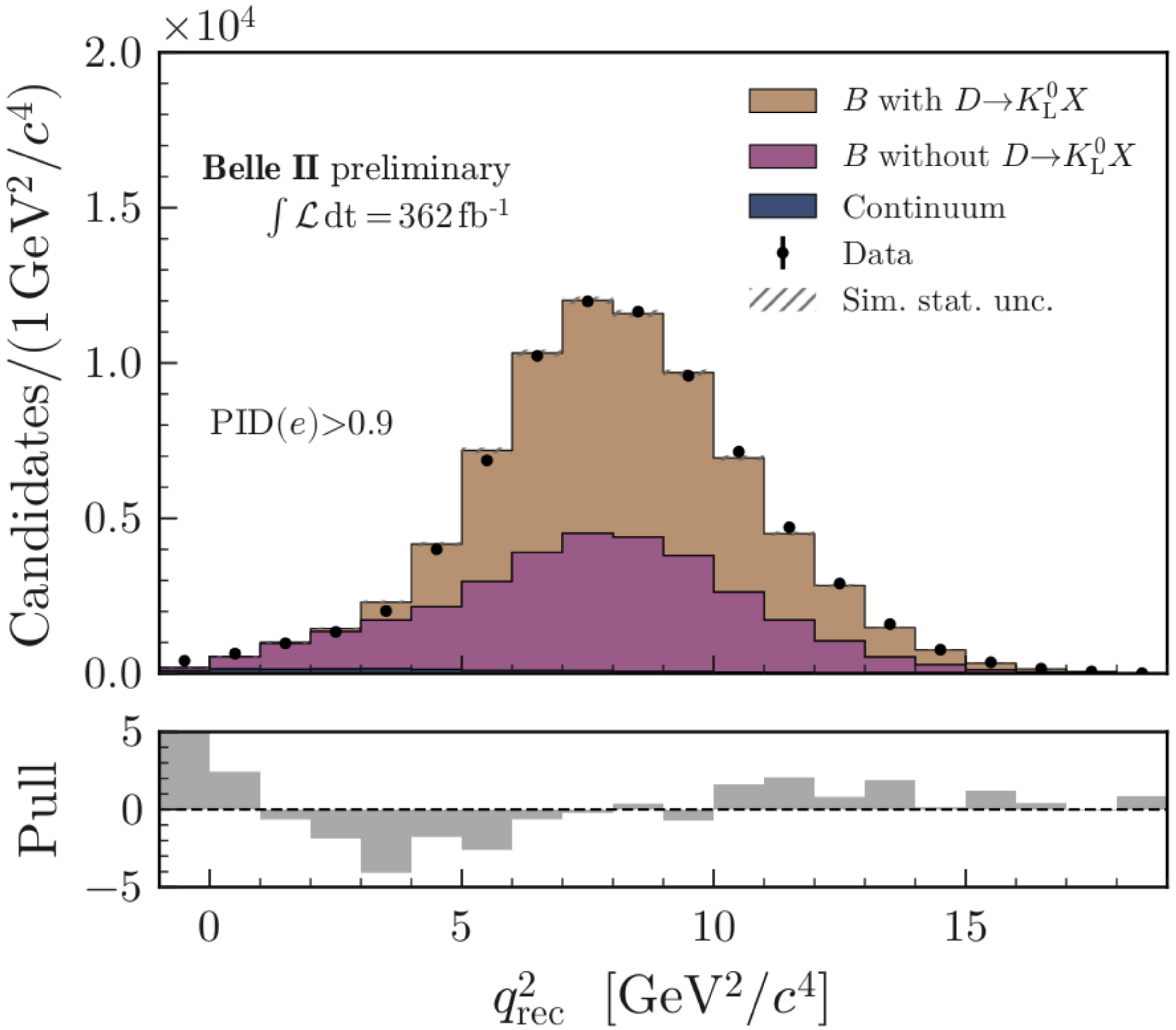
- Study pion-enriched control sample ($B^+ \to \pi^+ X$)
- Observed data excess in $q^2_{rec}$ distribution above D threshold
  - $D^0 \to K^0/\overline{K}^0 X$ and $D^0 \to K^0 \overline{K}^0 X$ simulated by EVTGEN have significant uncertainties
- Excess fixed by increasing $B \to D \to K_L$ component 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

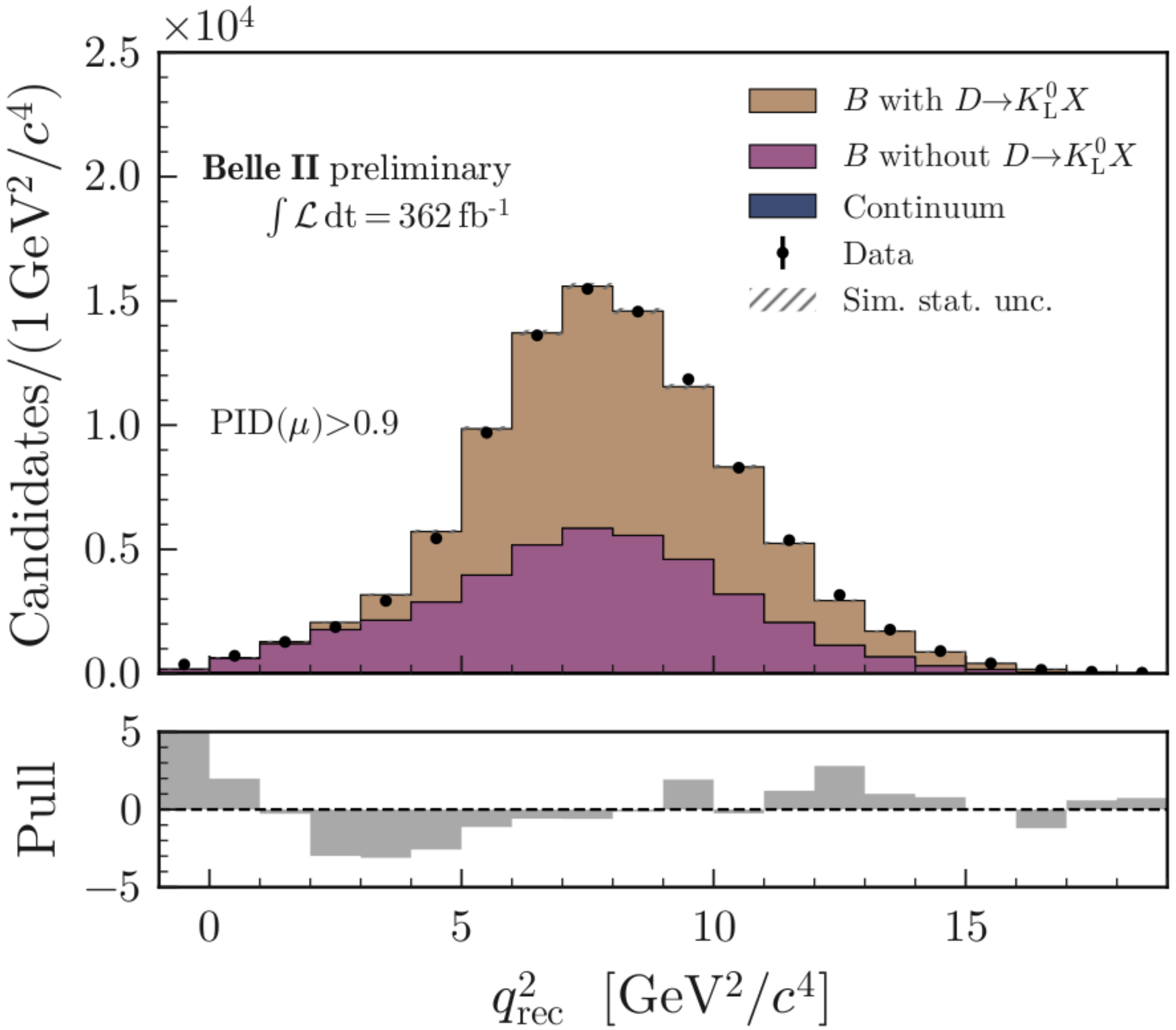


# Hadronic B→D(*)K+ decays

- Result of 3-component $q^2_{rec}$ fit to estimate scaling of B→D→$K_L$ component in electron- and muon-enriched control sample to validate the procedure establish from the pion-enriched control sample study

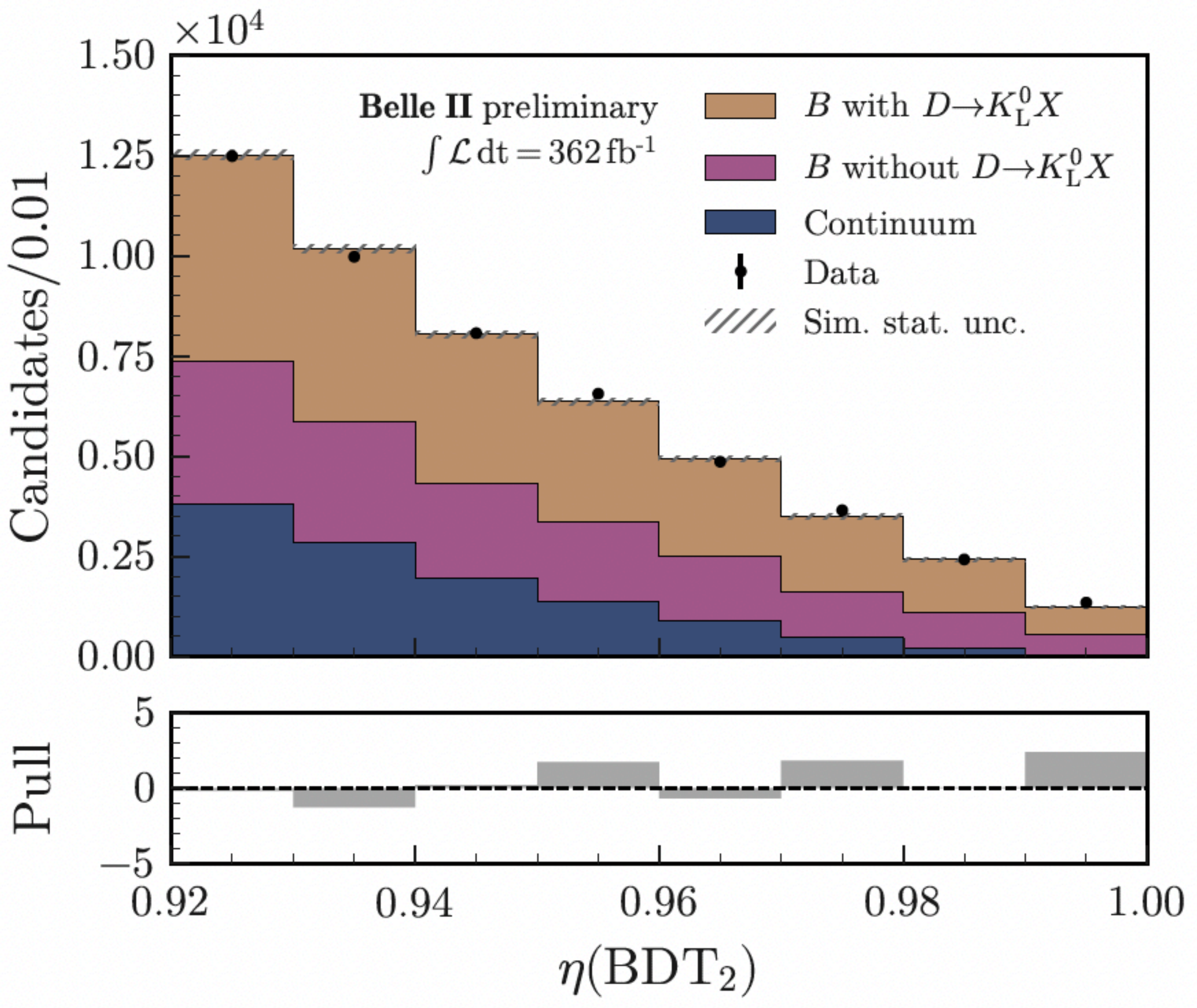


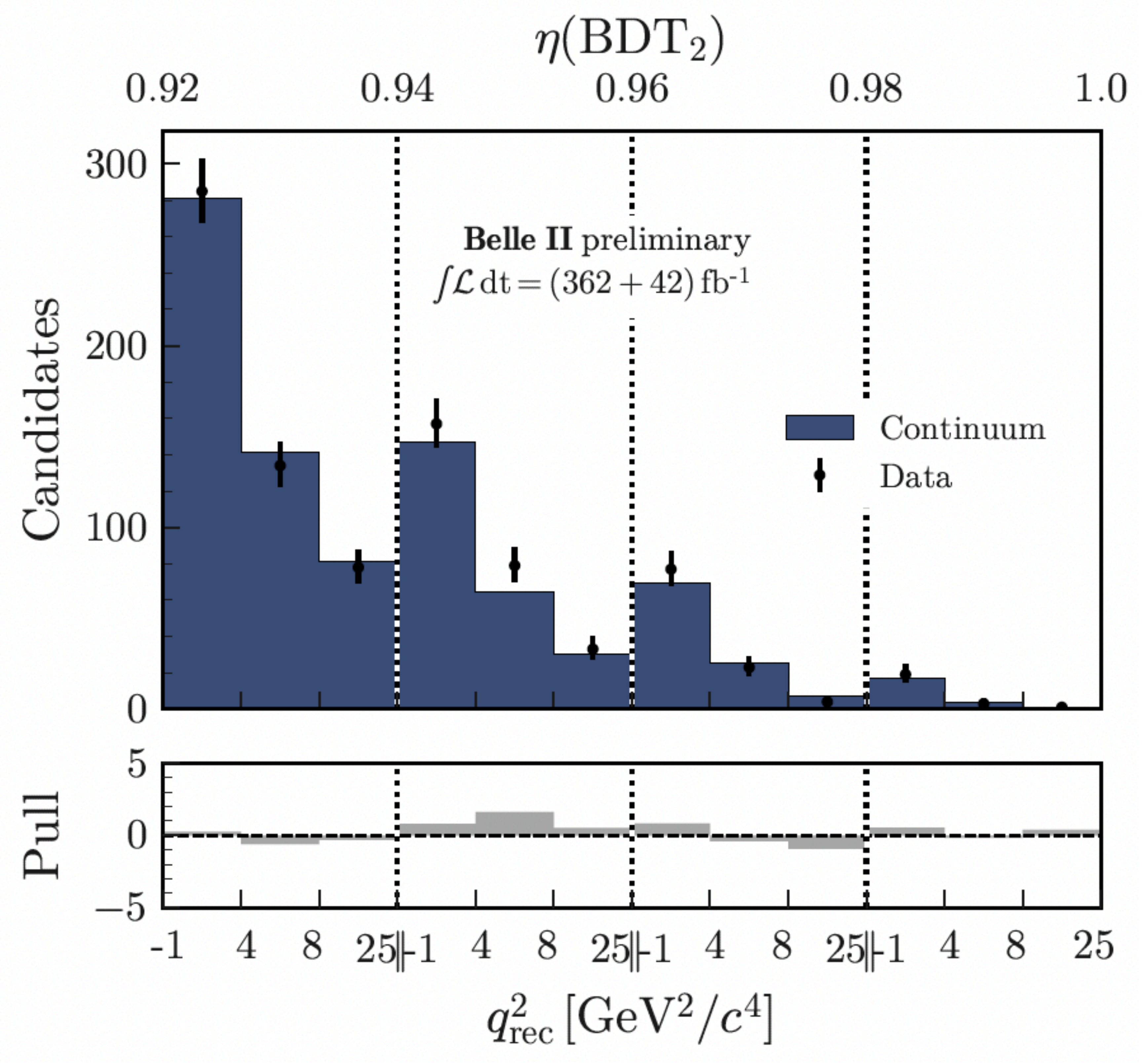

The scaling factors found in the three sidebands are within 10% → considered a systematic uncertainty

# Hadronic B→D(*)K+ decays (II)

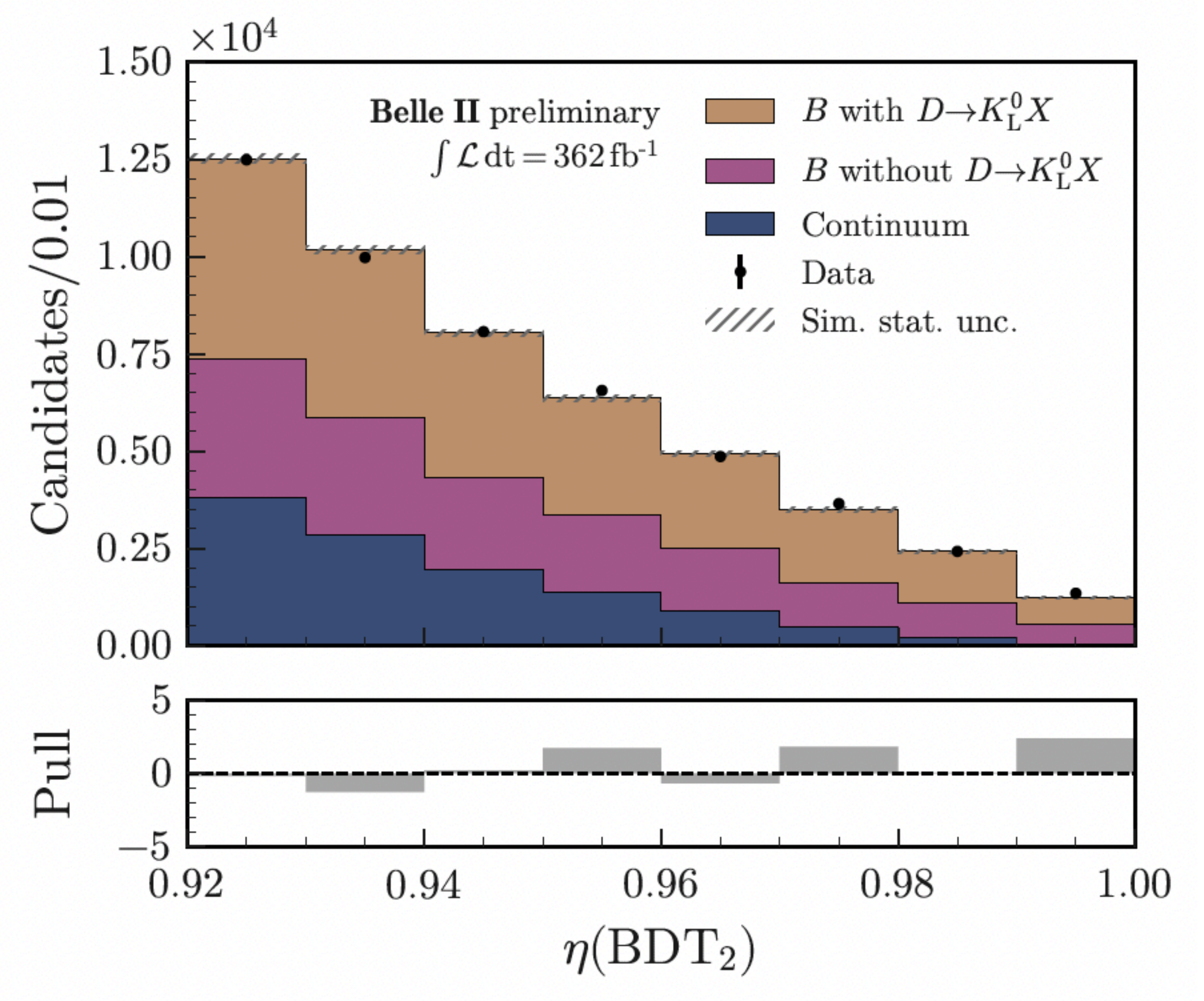
Classifier output for pion-enriched sample well reproduced when incorporating B→D→$K_L$ scale factor



# BDT2 output in control samples




off-resonance data
simultaneously fitted with on-resonance data
in the signal strength extraction fit

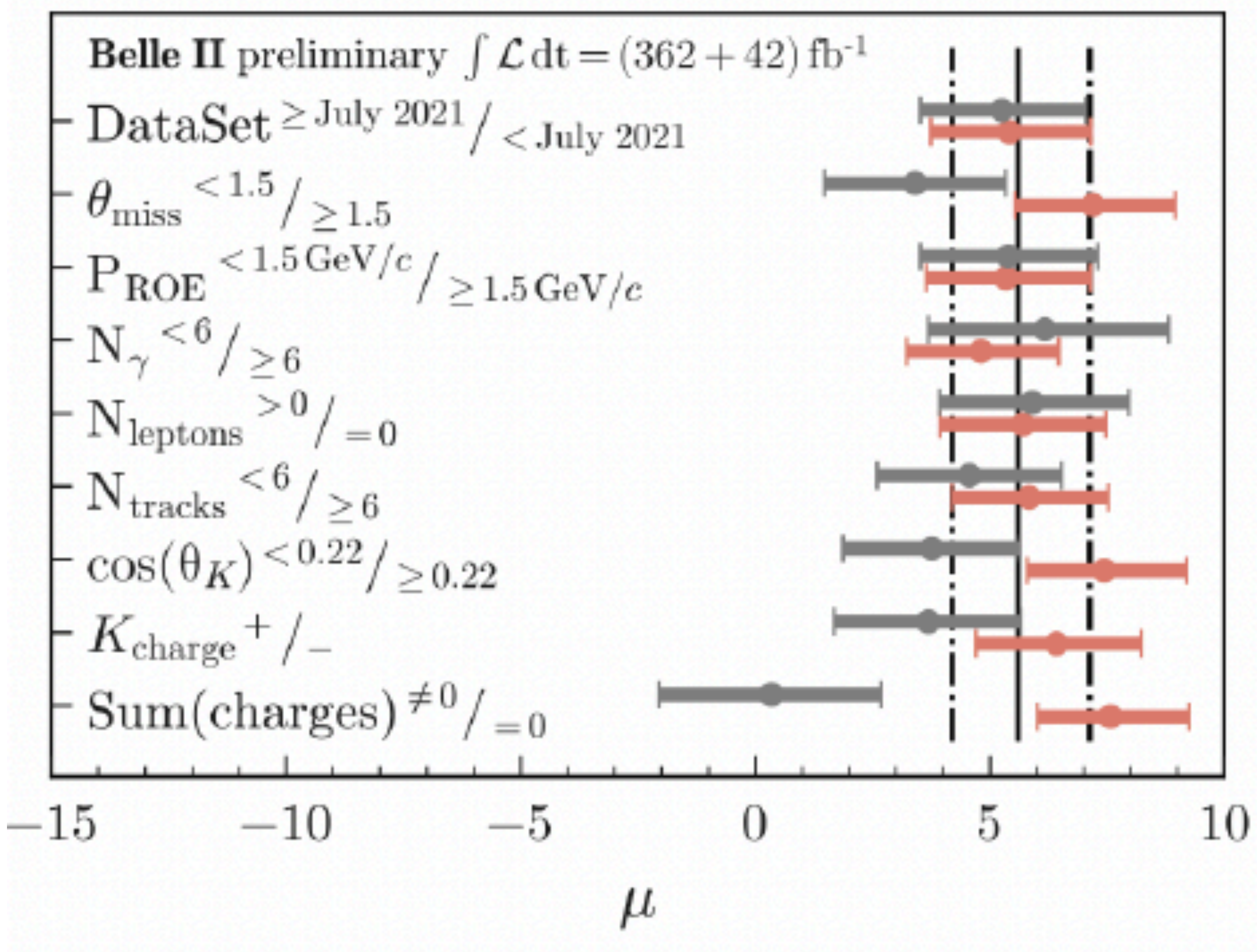



classifier output for the pion-enriched sample

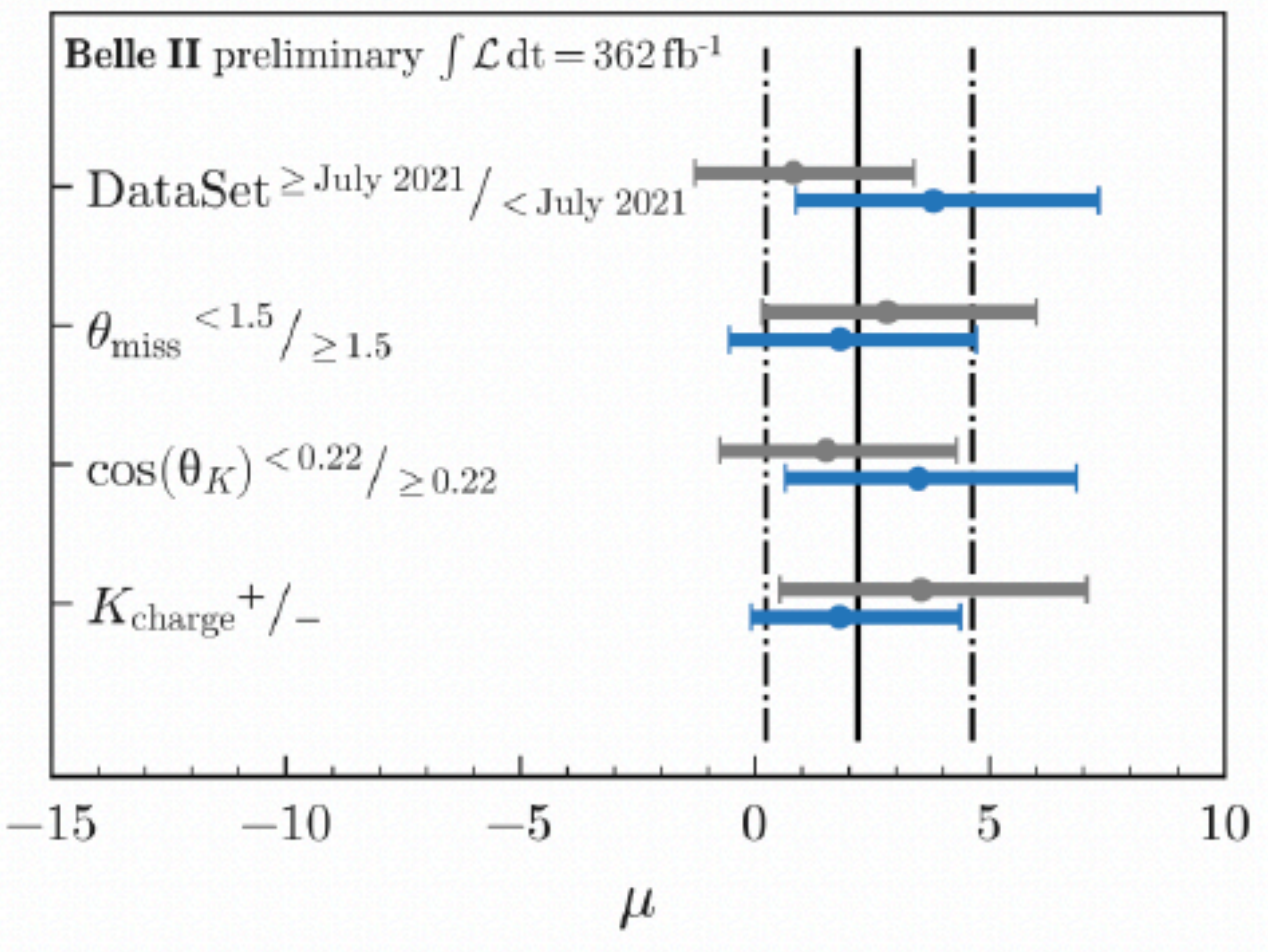
# Consistency checks: one example

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

ITA




HTA

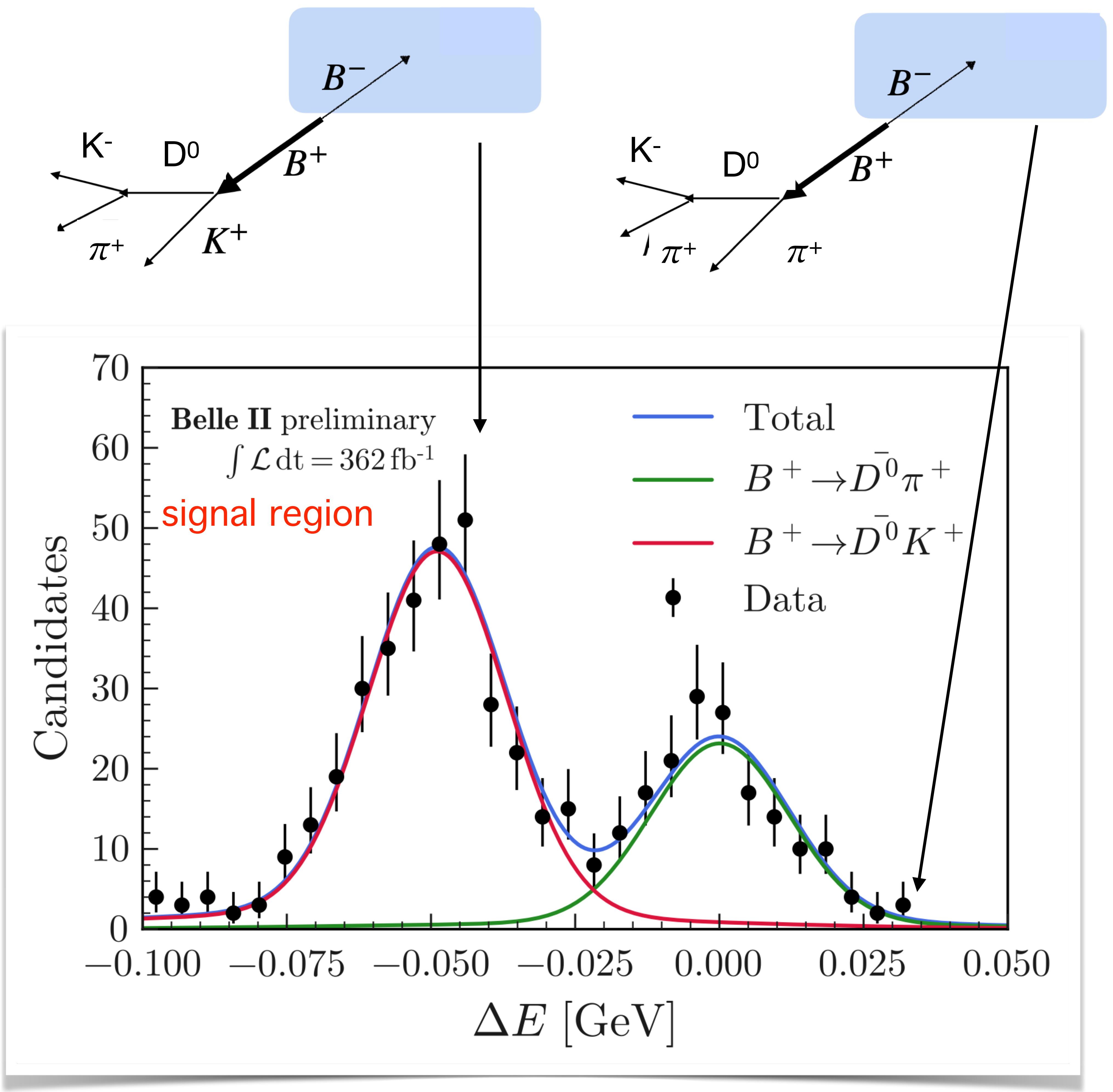



Good stability for all splittings for both analyses

- 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

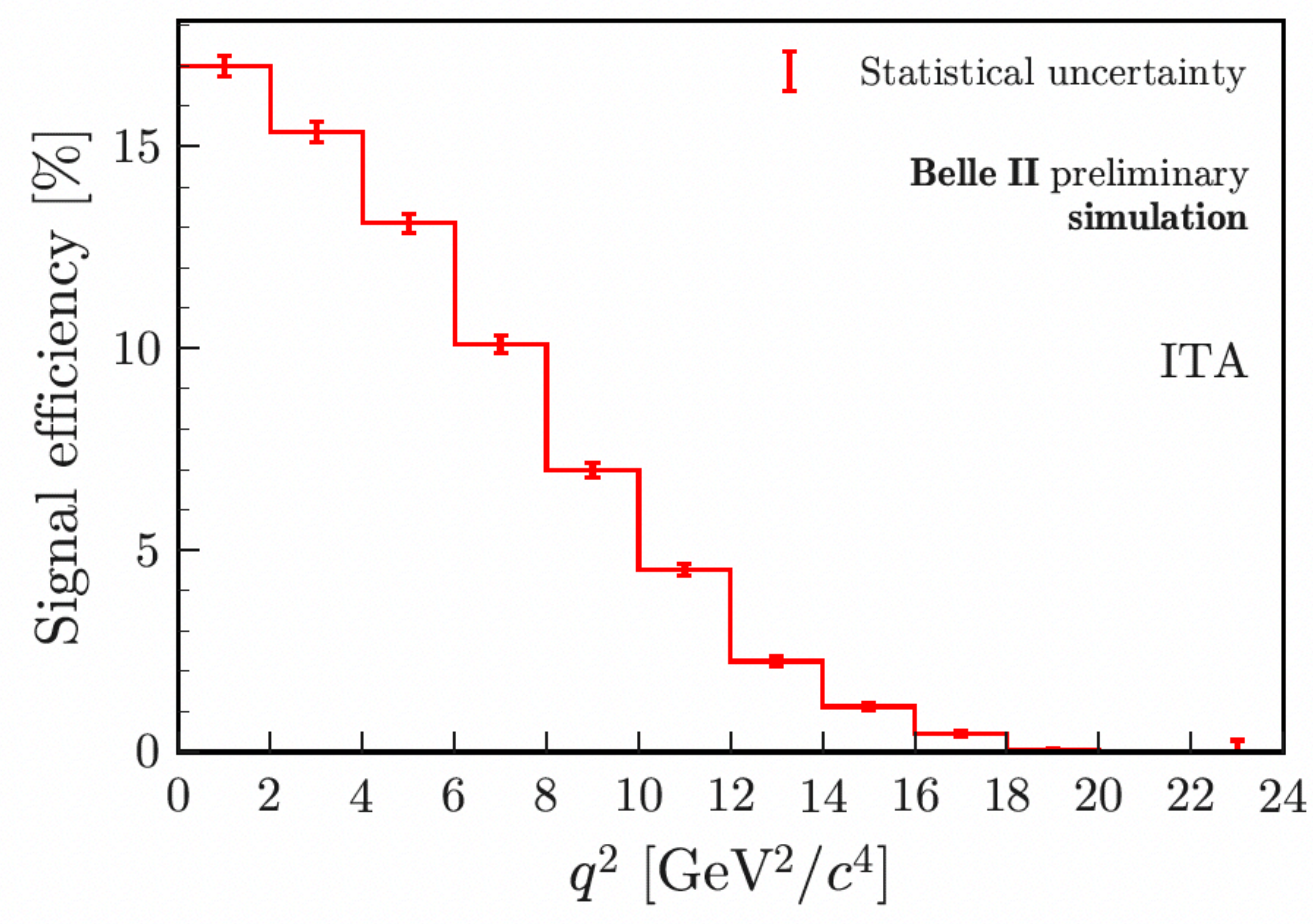
# Kaon ID requirement validation

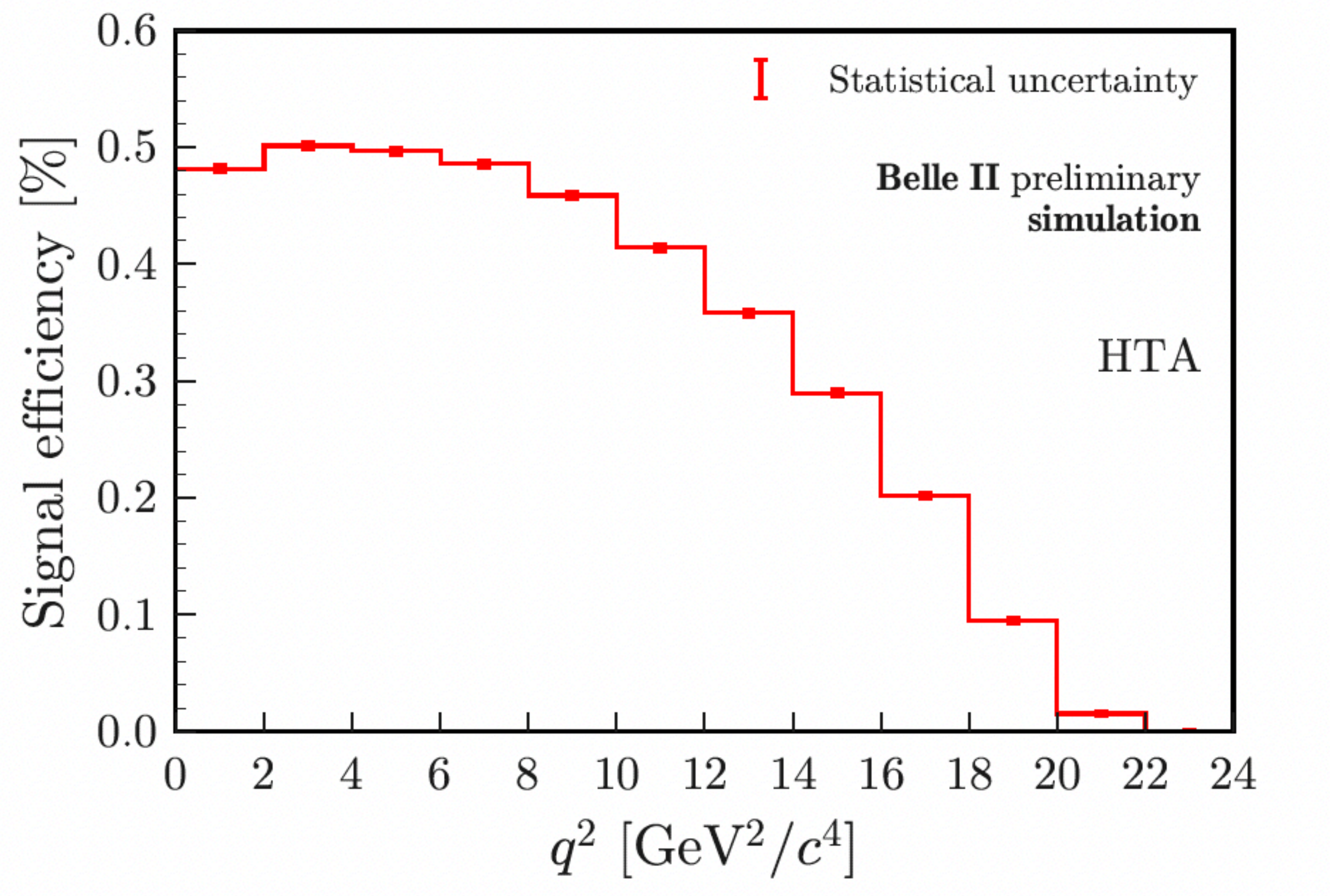
- K-ID efficiency and K→$\pi$ mis-ID rate from high statistics $D^{*+} \to \pi D^0(\to K\pi)$
- Analysis-specific validation using B→D(K$\pi$)h (h = K, $\pi$)
  - remove D daughters to mimic signal topology and apply nominal selection
- Data/MC ratio of relative abundance of B→DK and B→D$\pi$ from ΔE fit: 1.03±0.09




ΔE = difference between measured and expected energy

# Signal efficiencies as a function of $q^2$



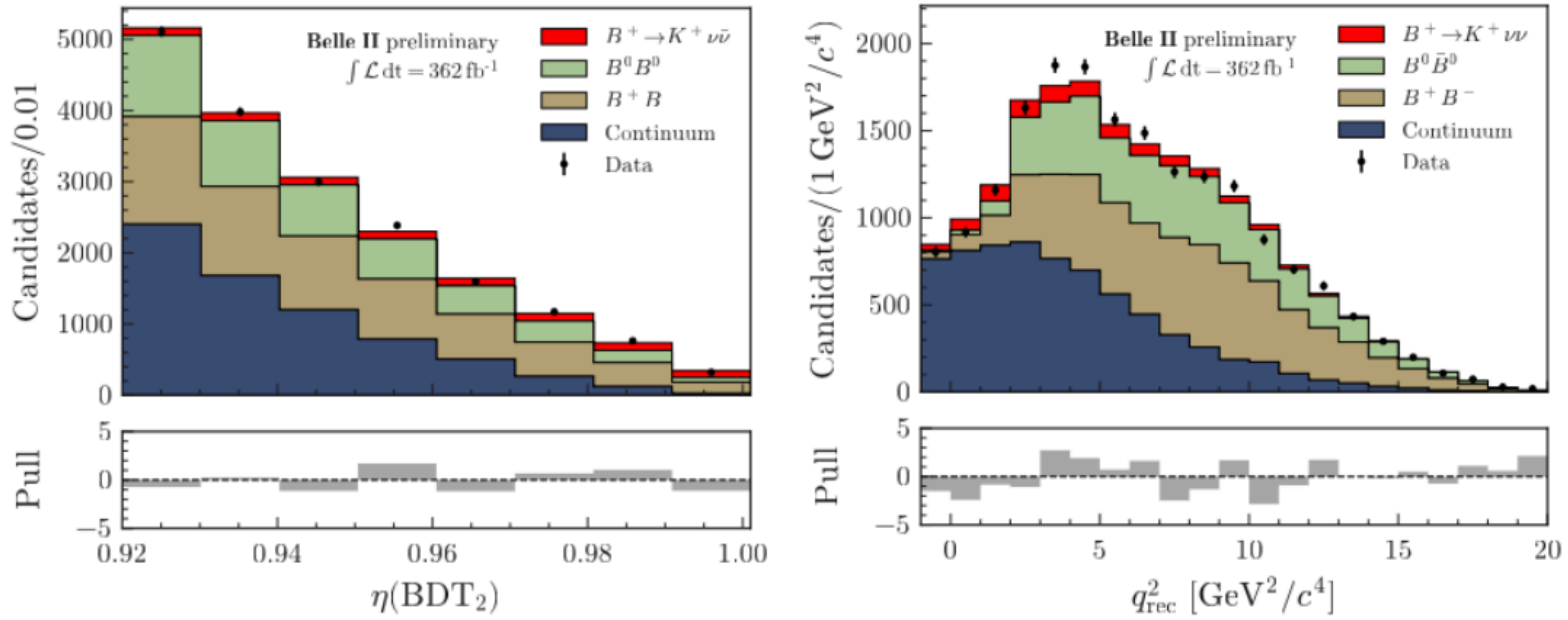

- Efficiencies in the signal regions ad a function of the generated $q^2$
- Much lower efficiency in HTA w.r.t. ITA, but smaller variation in $q^2$

# Systematic uncertainties for HTA analysis

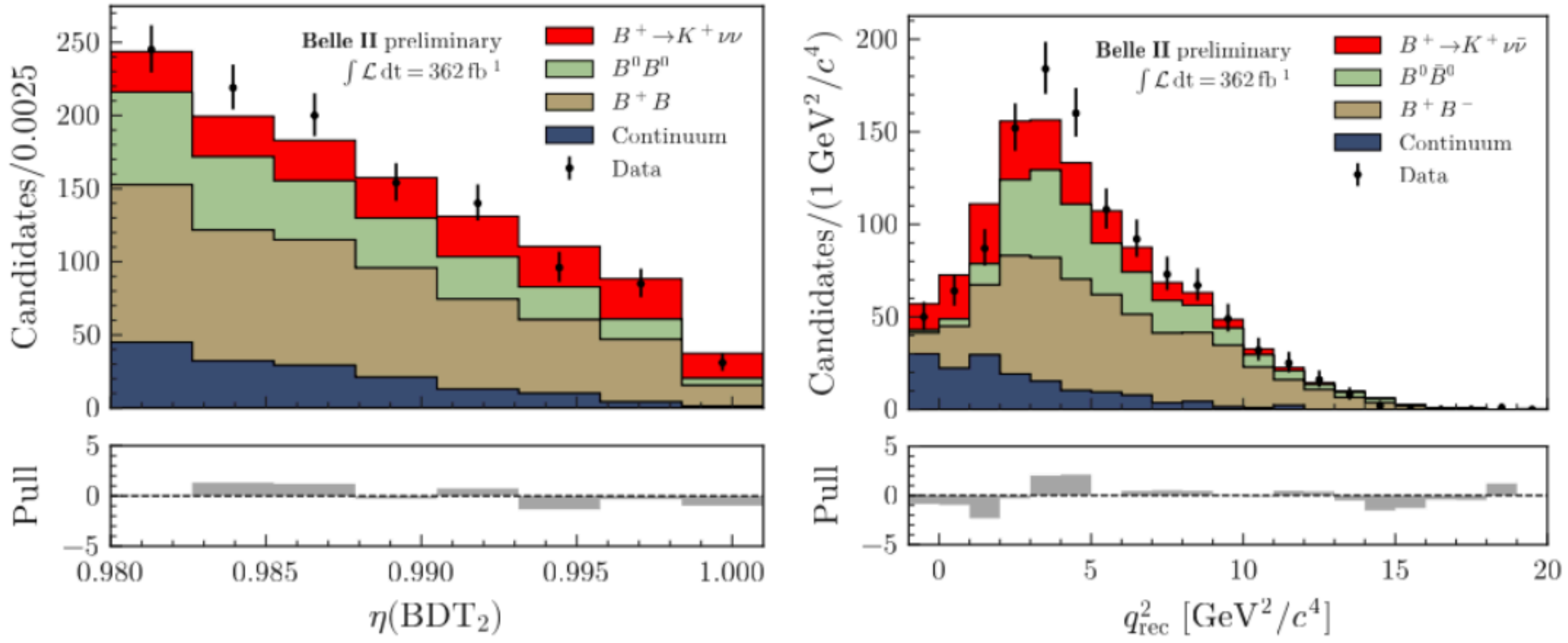
| Source | Uncertainty size | Impact on $\sigma_\mu$ | |
|---|---|---|---|
| Normalization of $B\overline{B}$ background | 30% | 0.91 | 1. |
| Normalization of continuum background | 50% | 0.58 | |
| Leading $B$-decay branching fractions | $O(1\%)$ | 0.10 | |
| Branching fraction for $B^+ \to K^+ K^0_L K^0_L$ | 20% | 0.20 | |
| Branching fraction for $B \to D^{**}$ | 50% | $< 0.01$ | |
| Branching fraction for $B^+ \to K^+ n\bar{n}$ | 100% | 0.05 | |
| Branching fraction for $D \to K^0_L X$ | 10% | 0.03 | |
| Continuum-background modeling, $\mathrm{BDT_c}$ | 100% of correction | 0.29 | |
| Number of $B\bar{B}$ | 1.5% | 0.07 | |
| Track finding efficiency | 0.3% | 0.01 | |
| Signal-kaon PID | $O(1\%)$ | $< 0.01$ | |
| Extra-photon multiplicity | $O(20\%)$ | 0.61 | 2. |
| $K^0_L$ efficiency | 17% | 0.31 | |
| Signal SM form-factors | $O(1\%)$ | 0.06 | |
| Signal efficiency | 16% | 0.42 | 3. |
| Simulated-sample size | $O(1\%)$ | 0.60 | |

# Post fit distributions (ITA)

## Signal region: η(BDT2) > 0.92



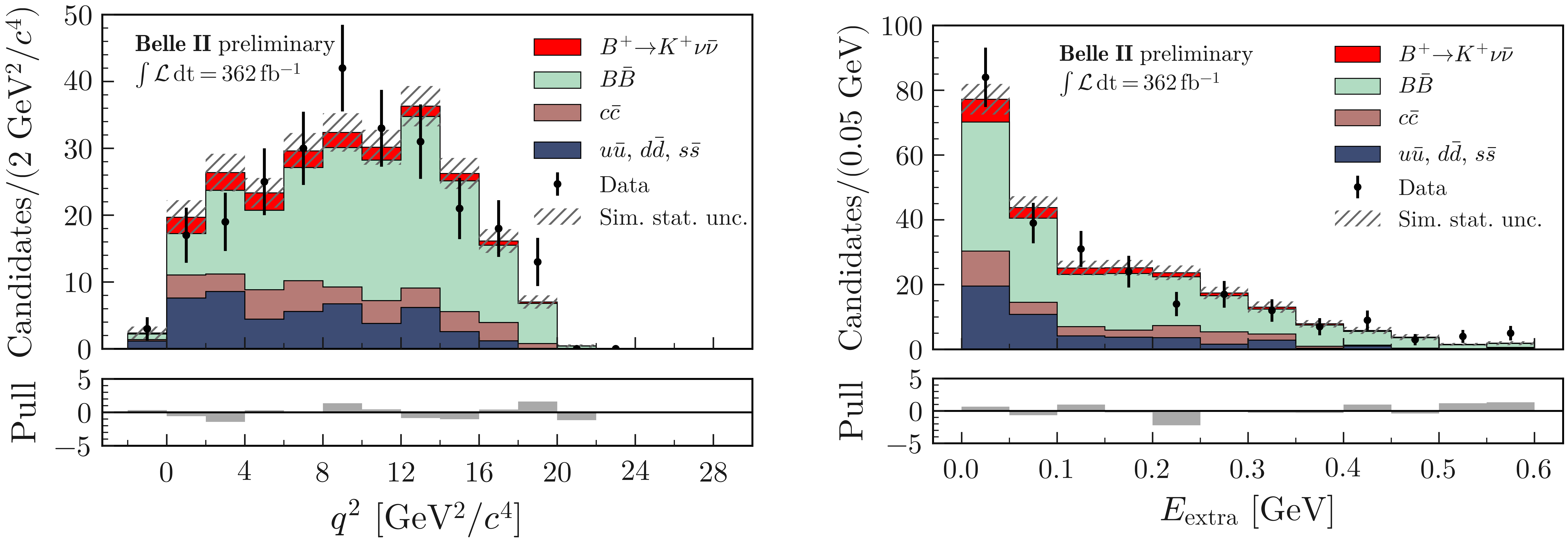

## Most sensitive region: η(BDT2) > 0.98




- Good description of classifier output
- Some difference in $q^2_{rec}$: not conclusive due to coarse binning choice, dictated from experimental resolution

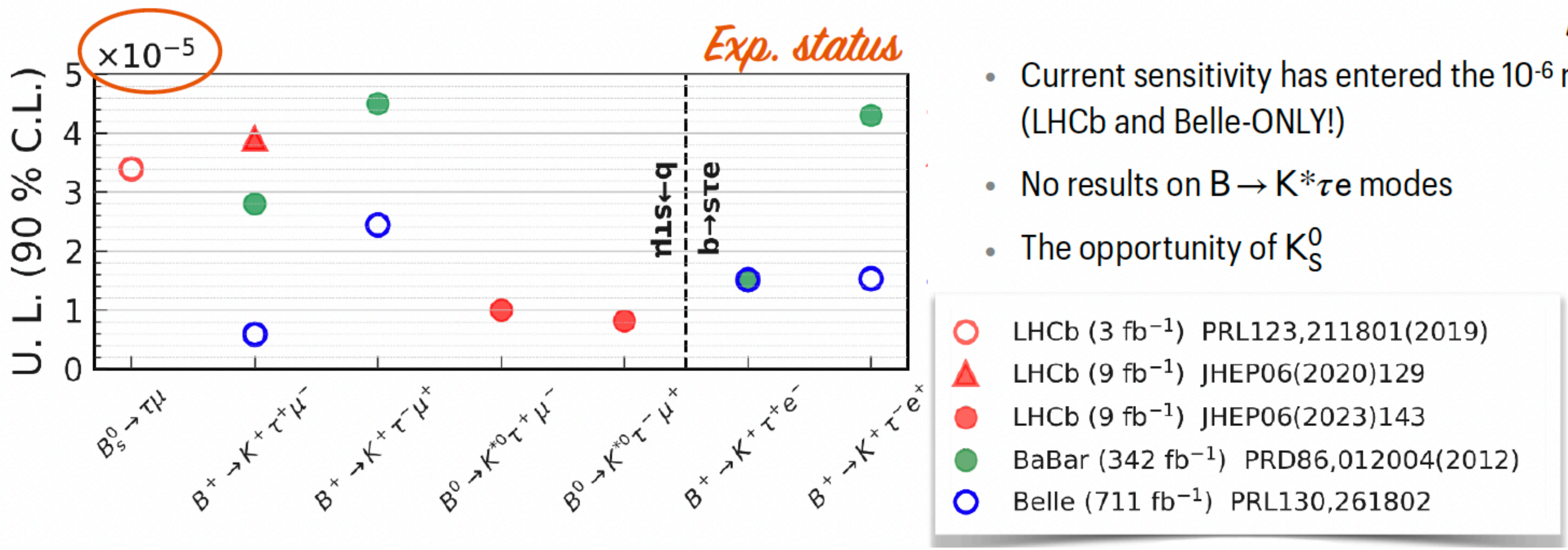
# Post fit distributions (HTA)

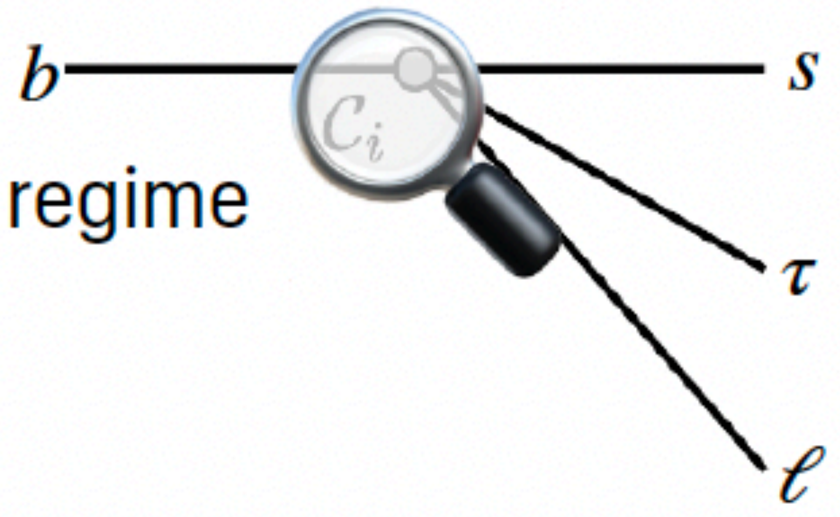
Signal region: η(BDTH) > 0.6




Good description of $q^2$ and extra neutral energy in the calorimeter (most discriminant variable)

# $b\to s\tau\ell$




- Current sensitivity has entered the $10^{-6}$ regime (LHCb and Belle-ONLY!)
- No results on $B\to K^*\tau e$ modes
- The opportunity of $K_S^0$

# $b \to s\gamma$ (I)

$B \to X_s\gamma$:

- ~ 5% theoretical unit. on BF, for $E\gamma$>1.4 GeV
- Dominant systematics from knowledge of residual background
- "baseline" = Belle II performances, "improved" = improved $\pi^0$ veto modeling

arXiv:2210.10220

TABLE I: Results of the partial branching fraction measurements. The right-hand part of the table shows the main contributions to the systematic uncertainty. Signal efficiency and background modelling uncertainties are correlated (see Sections 9.2 and 9.3).

| $E_\gamma^B$ [GeV ] | $\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma^B}(10^{-4})$ | Statistical | Systematic | Fit procedure | Signal efficiency | Background modelling | Other |
|---|---|---|---|---|---|---|---|
| 1.8 – 2.0 | 0.48 | 0.54 | 0.64 | 0.42 | 0.03 | 0.49 | 0.09 |
| 2.0 – 2.1 | 0.57 | 0.31 | 0.25 | 0.17 | 0.06 | 0.17 | 0.07 |
| 2.1 – 2.2 | 0.13 | 0.26 | 0.16 | 0.13 | 0.01 | 0.11 | 0.01 |
| 2.2 – 2.3 | 0.41 | 0.22 | 0.10 | 0.07 | 0.05 | 0.04 | 0.02 |
| 2.3 – 2.4 | 0.48 | 0.22 | 0.10 | 0.06 | 0.06 | 0.02 | 0.05 |
| 2.4 – 2.5 | 0.75 | 0.19 | 0.14 | 0.04 | 0.09 | 0.02 | 0.09 |
| 2.5 – 2.6 | 0.71 | 0.13 | 0.10 | 0.02 | 0.09 | 0.00 | 0.04 |

arXiv:1011.0352

Table 5: Projected fractional uncertainties of the $B \to X_s\gamma$ branching fraction measurement for various $E_\gamma^B$ thresholds. The systematic uncertainty is presented for a baseline scenario when the remaining background is known to the 10% level, and an improved scenario, when the background is known to the 5% level.

| Lower $E_\gamma^B$ threshold | Statistical uncertainty | | | | Baseline (improved) |
|---|---|---|---|---|---|
| | 1 $ab^{-1}$ | 5 $ab^{-1}$ | 10 $ab^{-1}$ | 50 $ab^{-1}$ | syst. uncertainty |
| 1.4 GeV | 10.7% | 6.4% | 4.7% | 2.2% | 10.3% (5.2%) |
| 1.6 GeV | 9.9% | 6.1% | 4.5% | 2.1% | 8.5% (4.2%) |
| 1.8 GeV | 9.3% | 5.7% | 4.2% | 2.0% | 6.5% (3.2%) |
| 2.0 GeV | 8.3% | 5.1% | 3.8% | 1.7% | 3.7% (1.8%) |

# b→s$\gamma$ (II)

B→$\rho\gamma$ systematics uncertainties

Belle II Preliminary

| Source | $\mathcal{B}_{\rho^+\gamma} \times 10^8$ | $\mathcal{B}_{\rho^0\gamma} \times 10^8$ | $A_I$ | $A_{CP}$ |
|---|---|---|---|---|
| Reconstruction eff. | 4.1 | 1.2 | 1.4% | 0.5% |
| Selection eff. | 8.8 | 3.3 | 4.0% | 0.6% |
| Fixed PDF parameters | 1.1 | 2.6 | 1.8% | 0.2% |
| Signal shape | 4.6 | 3.0 | 3.1% | 0.5% |
| Histogram PDF | 0.8 | 1.5 | 1.1% | 0.6% |
| $K^*\gamma$ yield | 3.4 | 5.4 | 3.2% | 0.1% |
| $B\overline{B}$ peaking yield | 2.2 | 0.8 | 0.9% | 0.2% |
| $A_{CP}$ of peaking background | 0.1 | 0.0 | 0.1% | 1.0% |
| Number of $B\overline{B}$ | 1.7 | 1.4 | 0.3% | 0.1% |
| Other parameters | 3.9 | 3.5 | 3.9% | 0.0% |
| Total | 12.4 | 8.6 | 7.6% | 1.5% |

B→K*$\gamma$ projections

arXiv:1011.0352

Table 6: Projected statistical and systematic (absolute) uncertainties of relevant observables from $B \to K^*\gamma$ decays.

| Observable | 1 ab$^{-1}$ | 5 ab$^{-1}$ | 10 ab$^{-1}$ | 50 ab$^{-1}$ | Systematic uncertainty |
|---|---|---|---|---|---|
| $\Delta_{0+}(B \to K^*\gamma)$ | 1.3% | 0.6% | 0.4% | 0.2% | 1.2% |
| $A_{CP}(B^0 \to K^{*0}\gamma)$ | 1.4% | 0.6% | 0.5% | 0.2% | 0.2% |
| $A_{CP}(B^+ \to K^{*+}\gamma)$ | 1.9% | 0.9% | 0.6% | 0.3% | 0.2% |
| $\Delta A_{CP}(B \to K^*\gamma)$ | 2.4% | 1.1% | 0.7% | 0.3% | 0.3% |