RECENT BELLE II RESULTS ON ELECTRO WEAK PENGUINS

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on behalf of the Belle II collaboration

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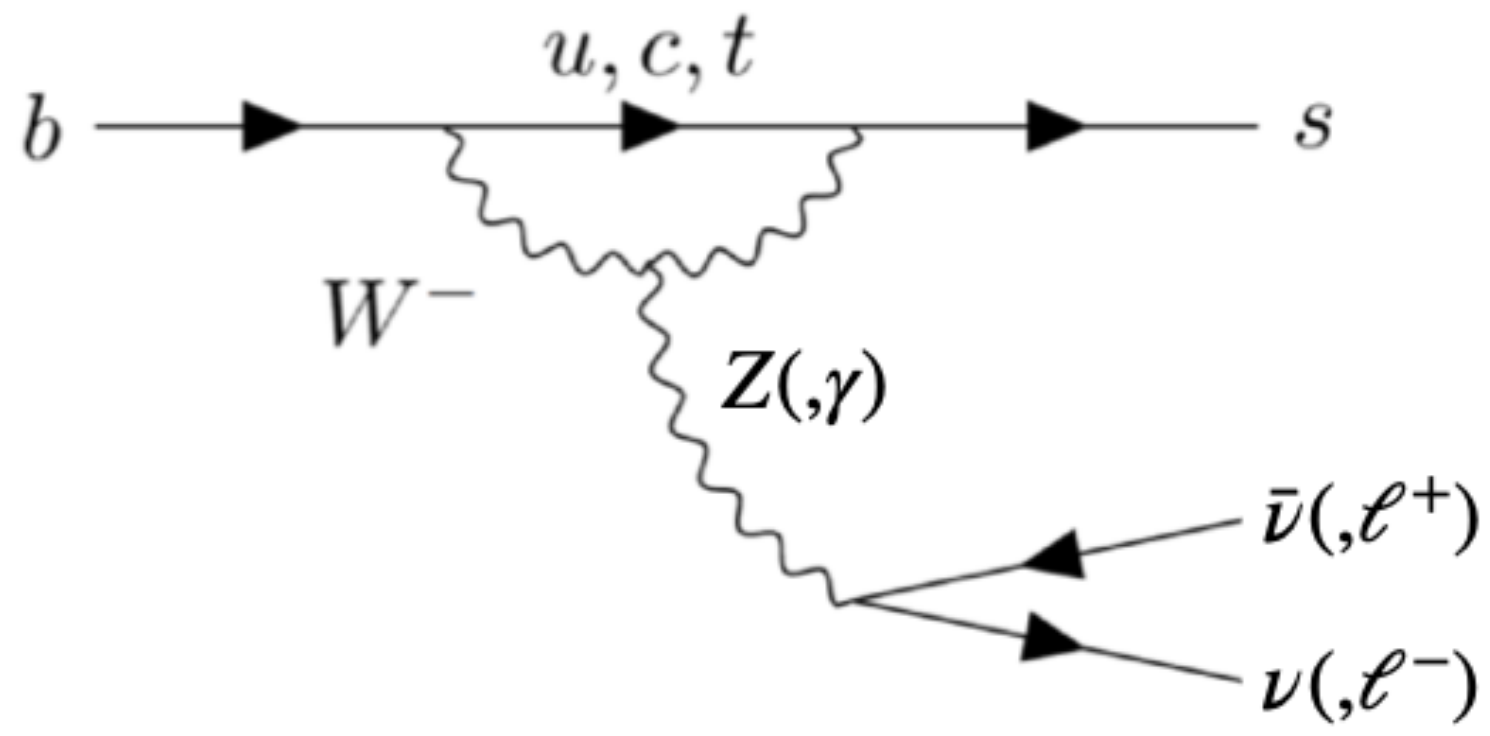
Electroweak and radiative penguins

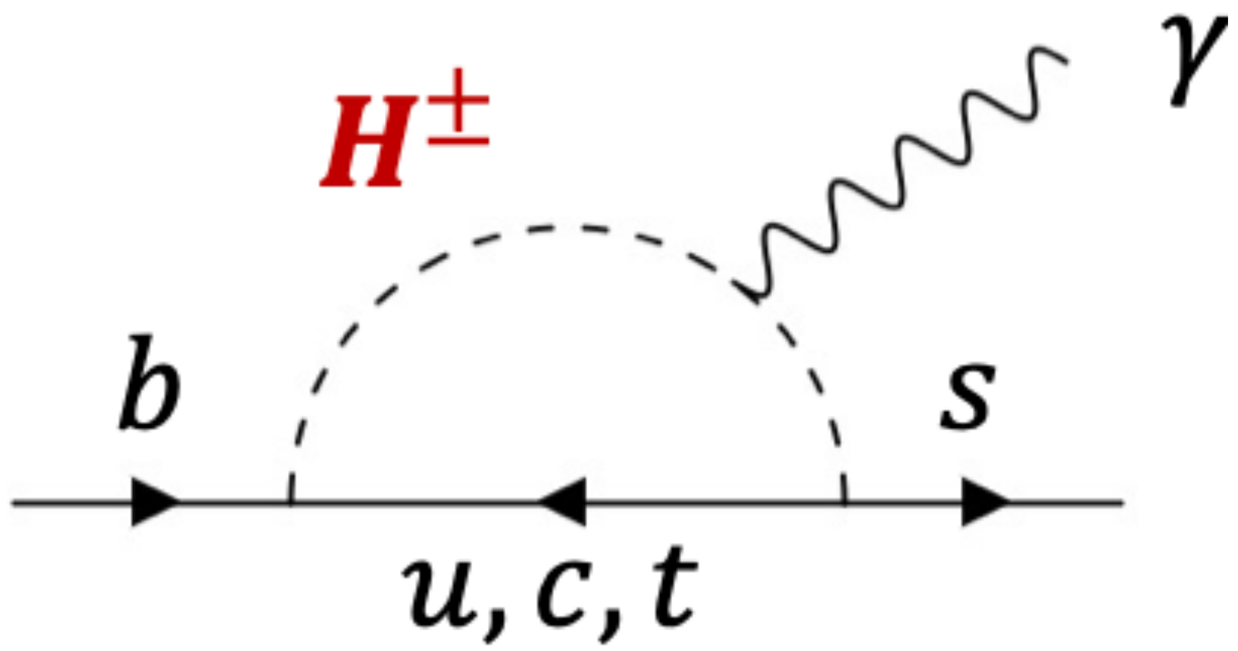
$b \to s$ transitions: flavor-changing neutral current
not possible at tree level in the standard model (SM)

- Predictions for branching fractions ~10^{-7}—10^{-4}, with 5—30% uncertainties (dominated by soft QCD effects)
- Precise predictions for angular observables, asymmetries, and ratios



Highly sensitive to potential new physics (NP) contribution

- Mediators in loops or new tree level diagrams
- Sources of missing energy (e.g. $b \to s + \mathrm{DM}$)
- Can modify rates, asymmetries, and angular distributions

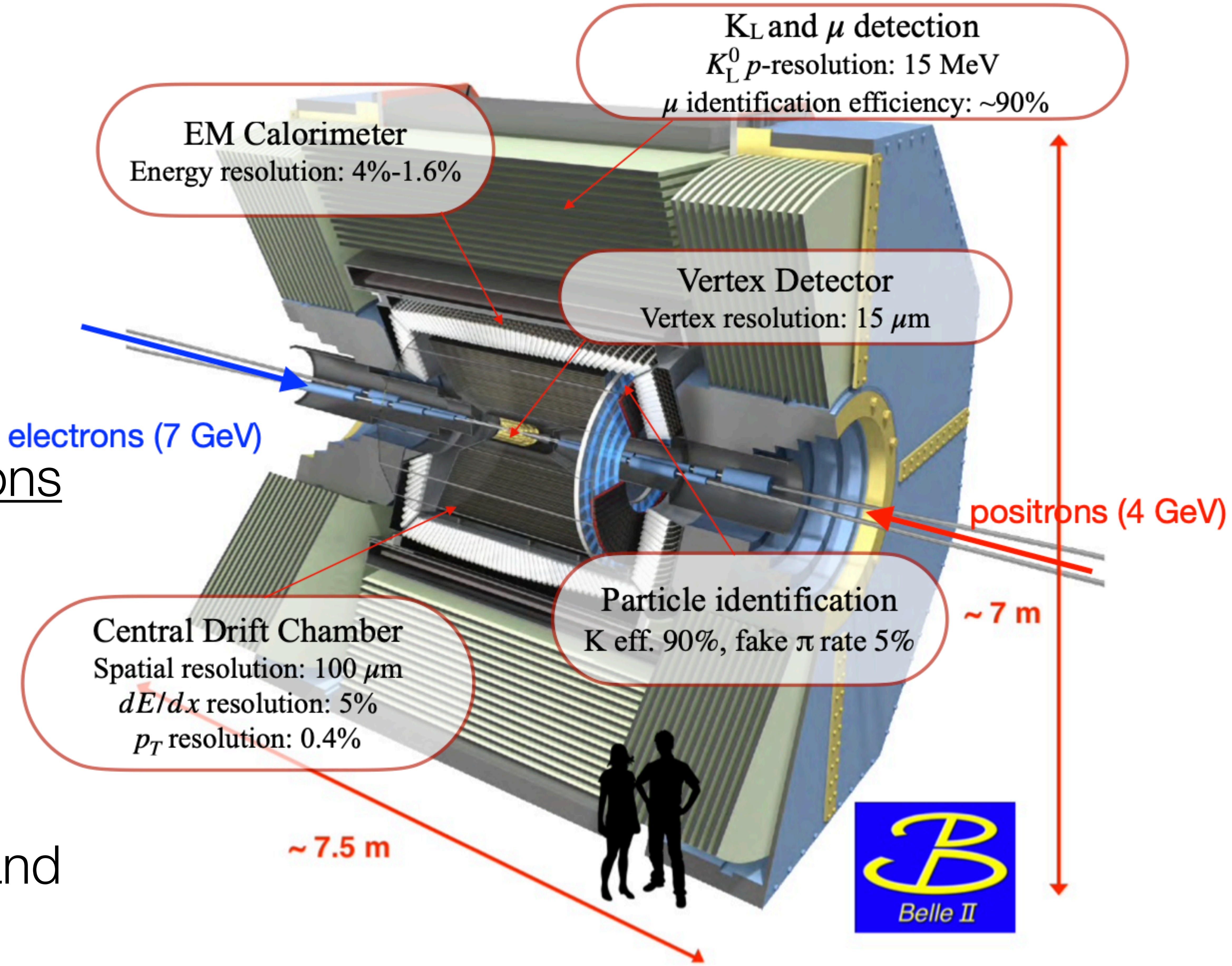


=> Plenty of opportunities to probe the SM and explore the NP

Belle II @ SuperKEKB

Energy-asymmetric e^+e^- collisions at 10.58 GeV corresponding to the $\Upsilon(4S)$-resonance mass

- $B\overline{B}$ at threshold production: low background
- Collide point-like particles and nearly 4π coverage: reconstruct final states with neutrinos or inclusively
- Flavor universal: similar performance for electrons and muons



Belle II in 2019-2022:

☑ world-record luminosity by SuperKEKB: 4.7×10^{34} cm^{-2}s^{-1}

☑ collected 424 fb^{-1} of data

☑ now starting one year stop for vertex detector completion and improved beampipe

Today's results from 63 fb^{-1} and 190 fb^{-1}

Reconstruction techniques

A typical $B\bar{B}$ event generates ~10 tracks and ~10 photons

Challenge: measurements of inclusive decays or decays including neutrinos suffer from missing kinematic info

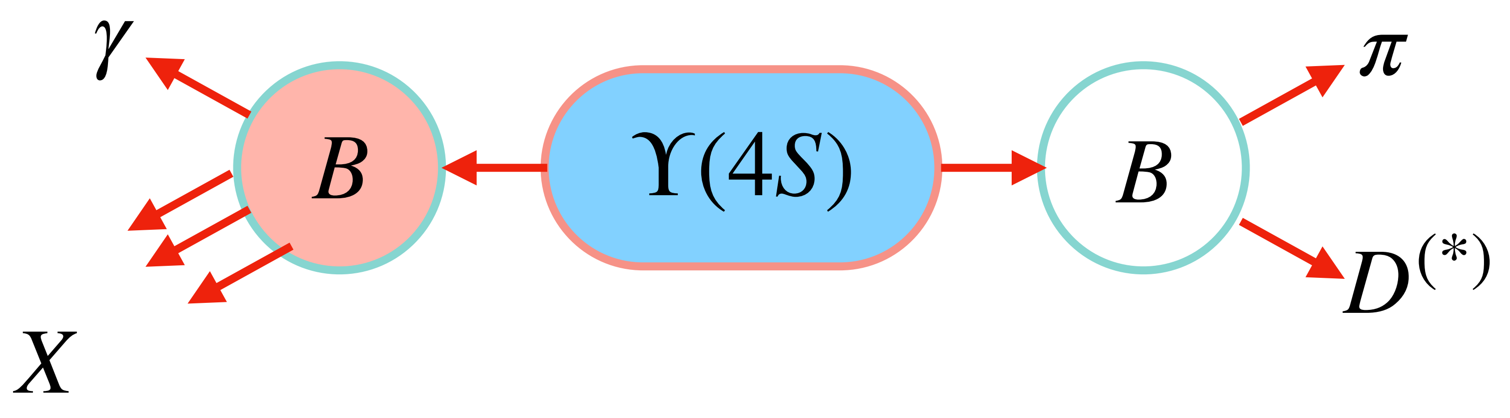
For example, $B \to K^{(*)}\nu\bar{\nu}$, fully-inclusive $B \to X_s\gamma$

- Information from partner B (tag) provides insight about signal B
- Methods specific to B-factory experiments

Hadronic tag

$$B_{\rm tag} \to \text{hadrons, e.g. } B \to D^{(*)} n\pi$$

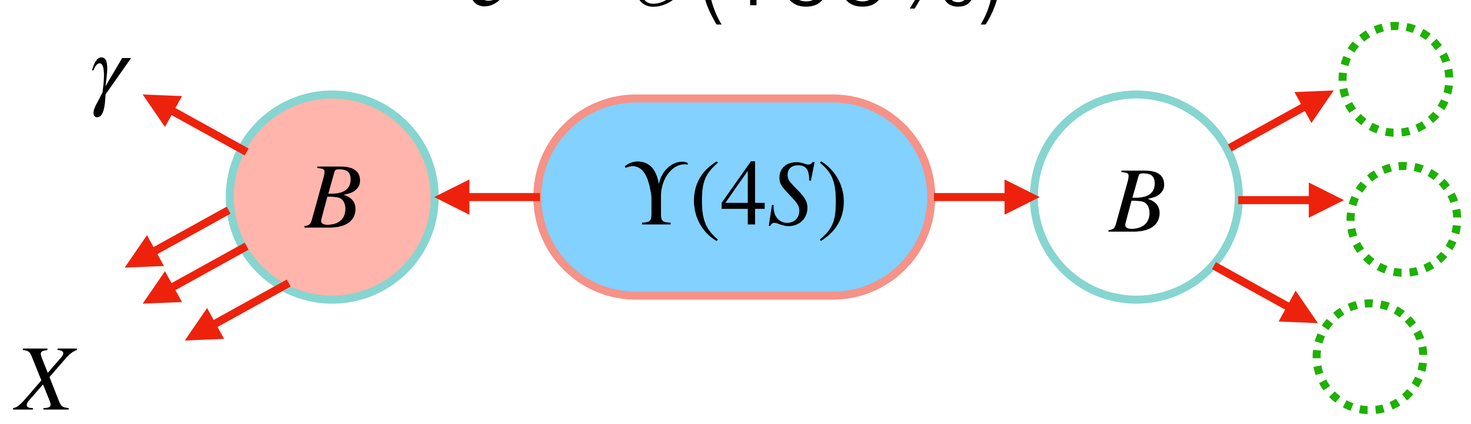
$$\epsilon = \mathcal{O}(0.1\%)$$



Inclusive tag

$$B_{\rm tag} \to \text{anything}$$

$$\epsilon = \mathcal{O}(100\%)$$



← Purities of the tagged samples, available physics observables

Tagging efficiencies, achievable yields →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Electroweak penguins and friends neighbourhood
1. $B \to K^* \ell \ell$
2. $B \to J/\psi K$
3. $B \to K \nu \bar{\nu}$
Radiative decays district
4. $B \to X_s \gamma$

Electroweak penguins and friends neighbourhood

Preparing for $R(K^{(*)})$ (I)

Belle II can provide independent check of $R(K^{(*)})$ anomalies with few ab^{-1}

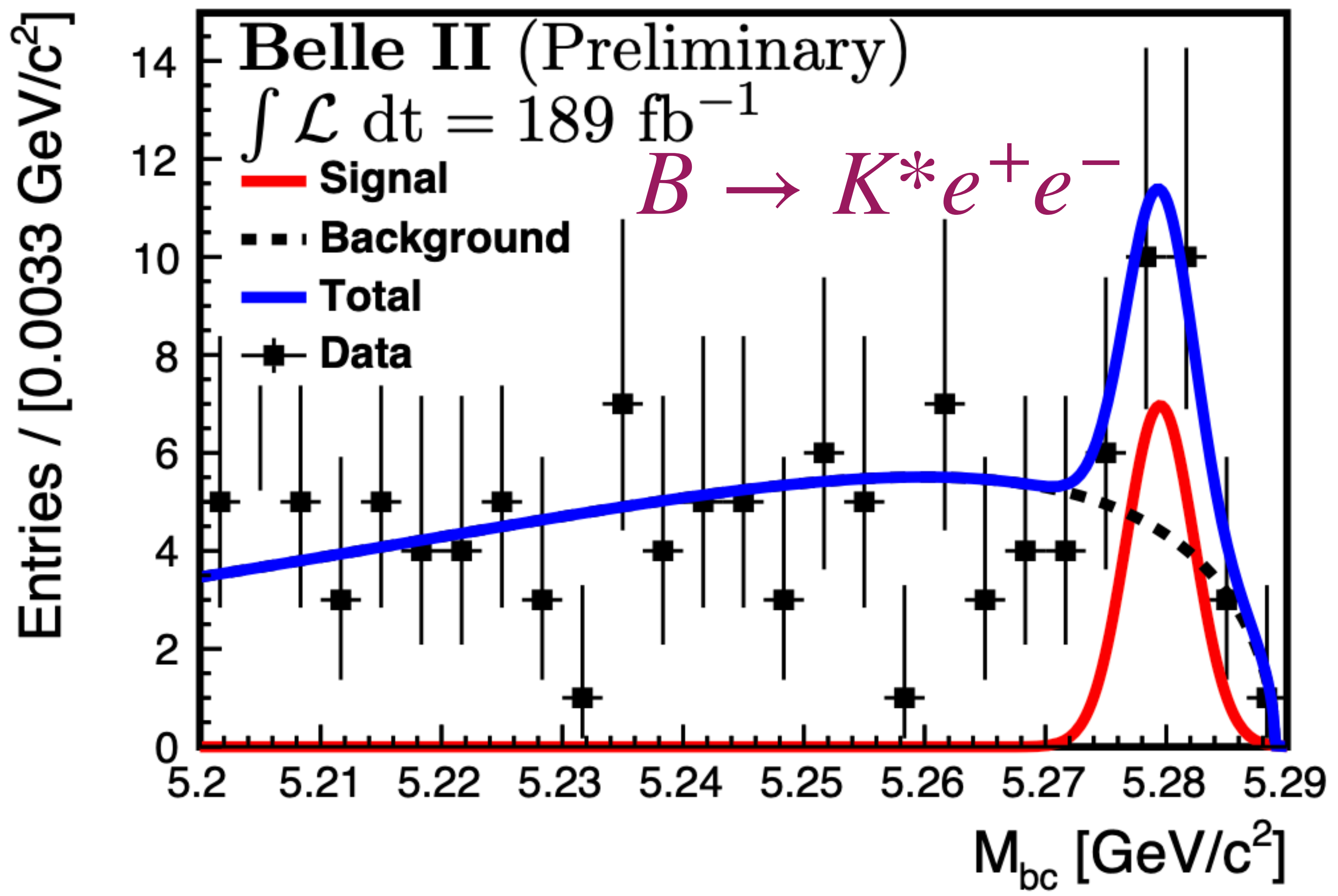
Belle II search for $B \to K^*(892) l^+ l^-$ ($l = e, \mu$) with 189 fb^{-1}

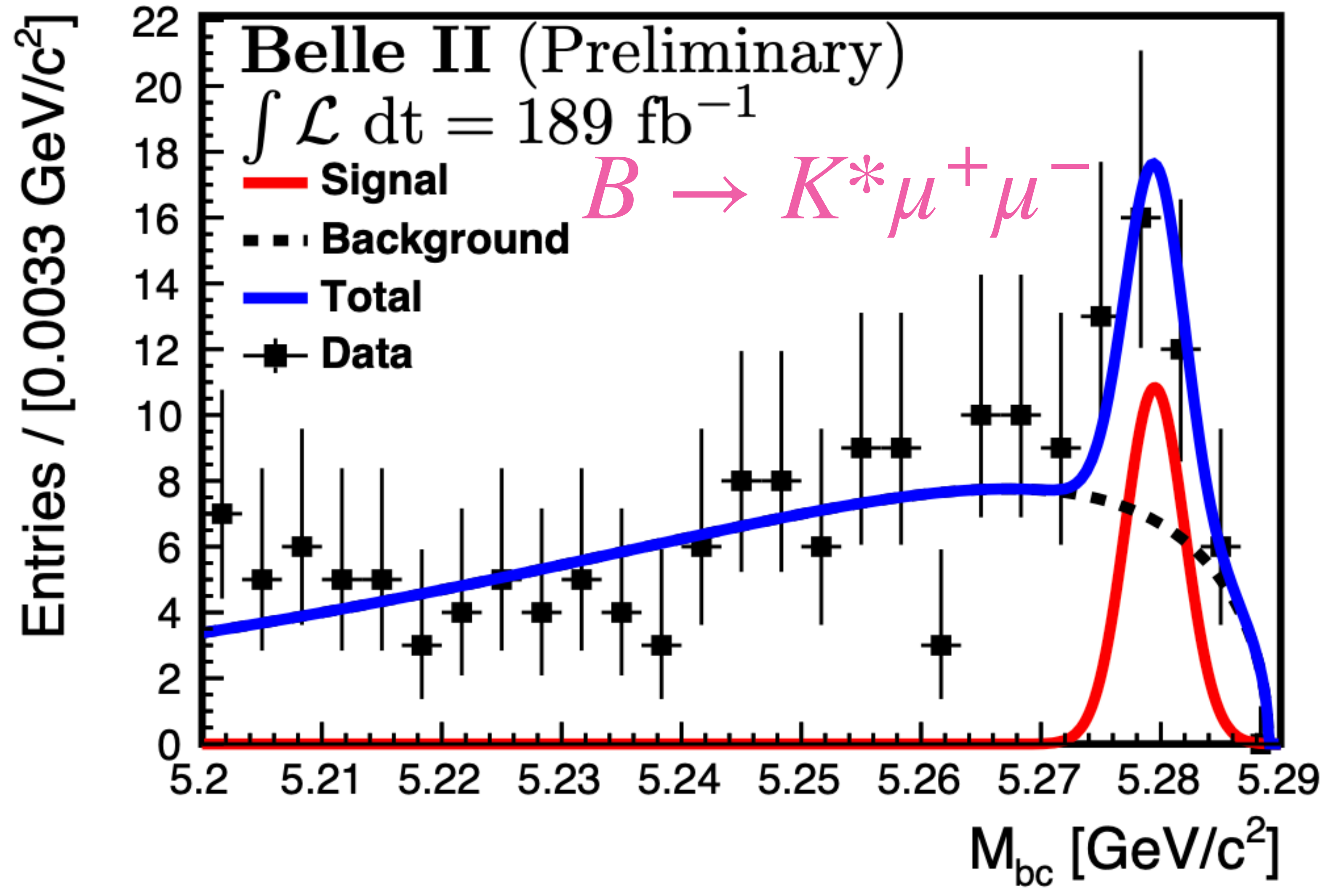
Challenge: limited by sample size

- Reconstruct $K^* \to K^+\pi^-$, $K^+\pi^0$, $K^0_S\pi^+$ + 2 same-flavor leptons
- Background suppression: charm veto (e.g $J/\psi \to ll$), BDT to suppress candidates from $e^+e^- \to q\bar{q}$ and other $e^+e^- \to B\bar{B}$
- Signal yield extracted from the fit of $M_{bc} = \sqrt{E^2_{beam} - p^{*2}_B}$ and $\Delta E = E^*_B - E_{beam}$

Decay	Belle II (10^{-6})	PDG (10^{-6})
$B \to K^* e^+ e^-$	$1.42 \pm 0.48 \pm 0.09$	1.19 ± 0.20
$B \to K^* \mu^+ \mu^-$	$1.19 \pm 0.31^{+0.08}_{-0.07}$	1.06 ± 0.09

Precision for e and μ channels in same ballpark, ~25—30%





Preparing for $R(K^{(*)})$ (II)

NEW!

Belle II measurement of $B \to J/\psi K$ decays with 189 fb^{-1}

Not an EW penguin process but a control channel for $B \to K l^+ l^-$

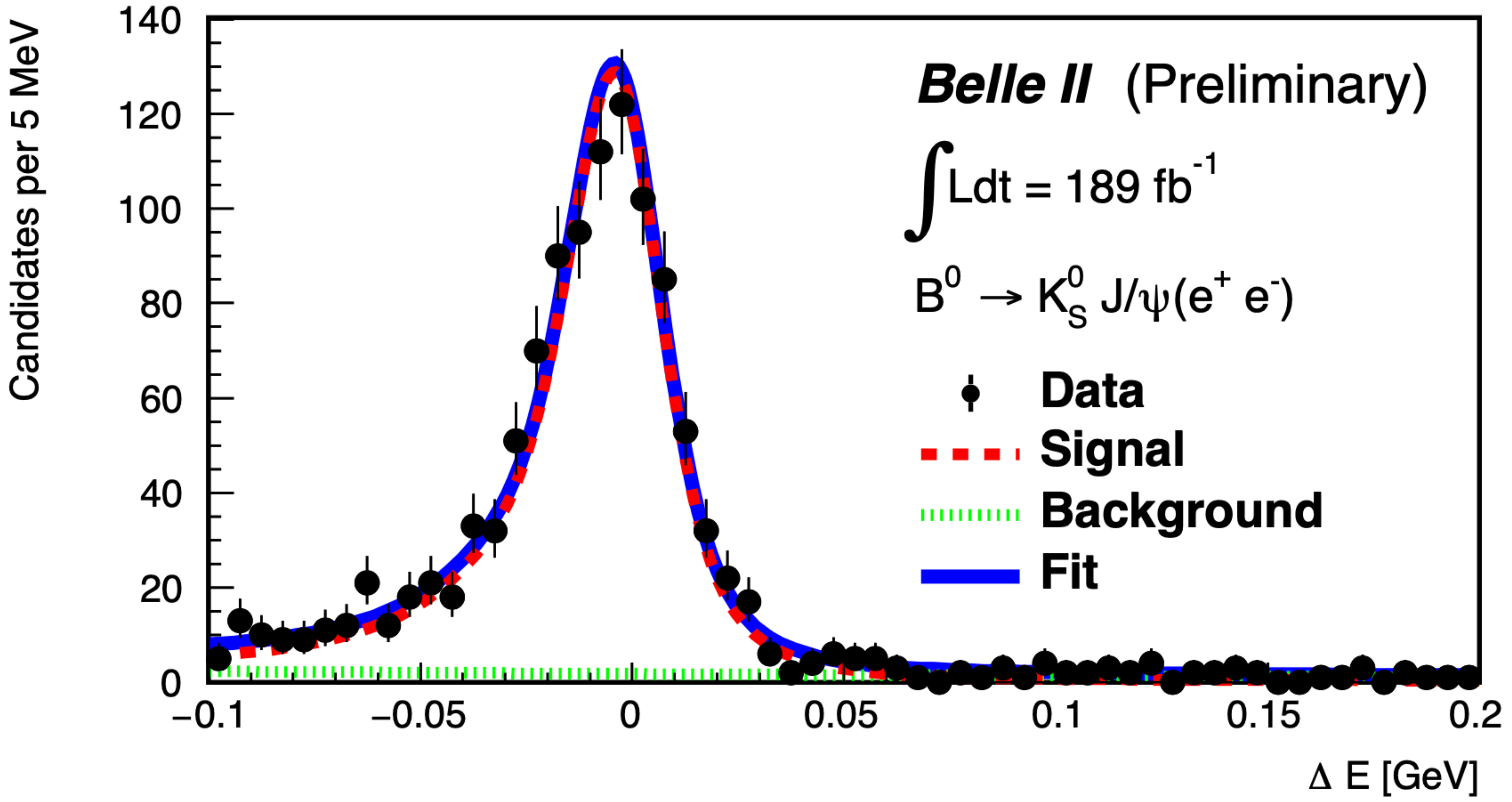
=> Validate R_K measurement, lepton identification

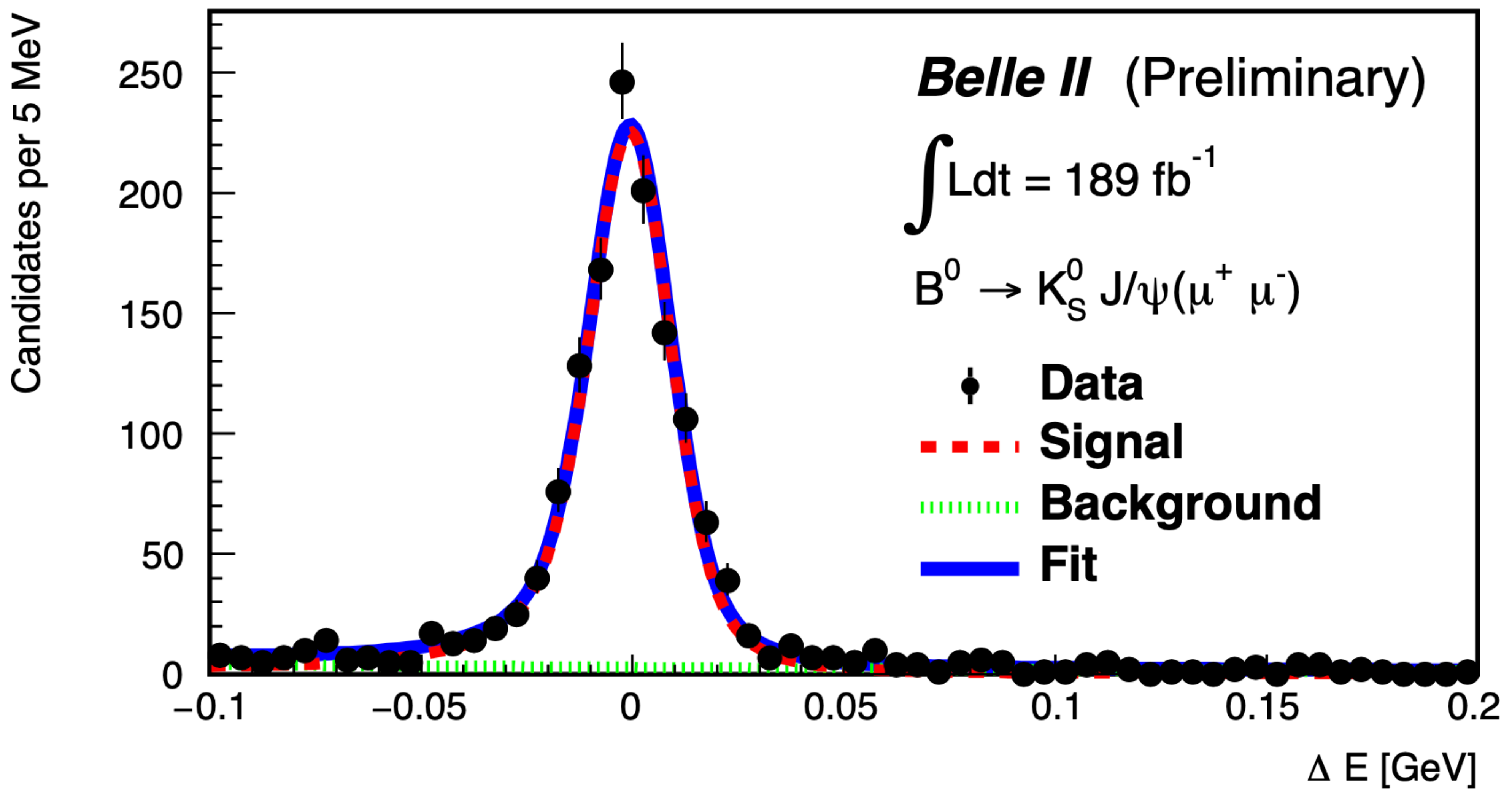
- Reconstruct $B^+ \to K^+ J/\psi$ and $B^0 \to K^0_S J/\psi$ decays ($J/\psi \to e^+e^-$, $\mu^+\mu^-$)
- Signal yield extracted from the fit of M_{bc} and ΔE

$$R_K(J/\psi) = \frac{\mathcal{B}(B \to KJ/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B \to KJ/\psi(\to e^+e^-))}$$

Observable	Belle II	Belle (2021)
$R_{K^+}(J/\psi)$	$1.009 \pm 0.022 \pm 0.008$	$0.994 \pm 0.011 \pm 0.010$
$R_{K^0_S}(J/\psi)$	$1.042 \pm 0.042 \pm 0.008$	$0.993 \pm 0.015 \pm 0.010$

Lepton identification systematic uncertainty improved wrt Belle



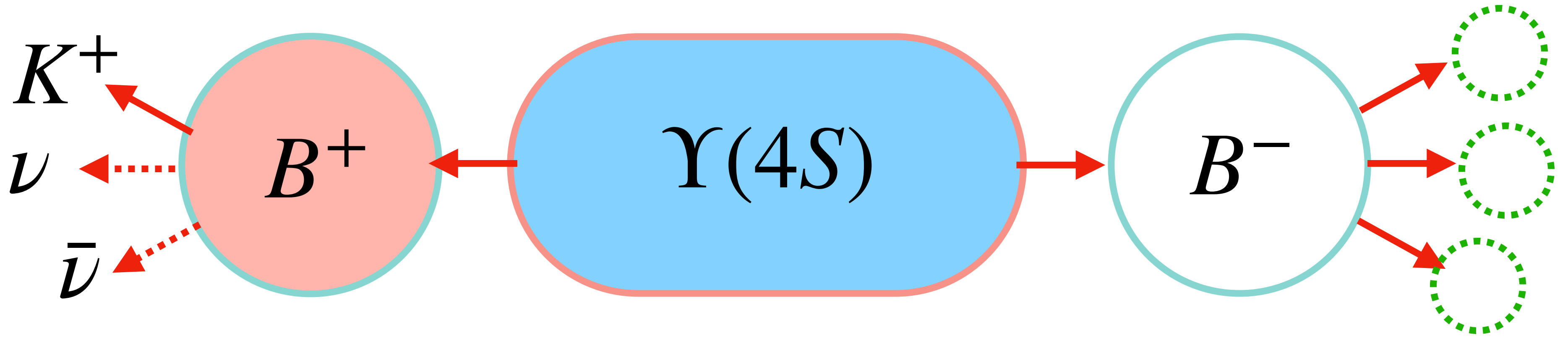


PRL 127, 181802

Search for $B^+ \to K^+\nu\bar{\nu}$ (I)

SM probe complementary to explain $b\to sll$ anomalies (e.g PRD98.05503, PRD102.015023)

Reliable prediction (no amplitudes with virtual photon)
$BF_{SM}(B^+\to K^+\nu\bar{\nu}) = (4.6\pm0.5)\times10^{-6}$ [arxiv:1606.00916]



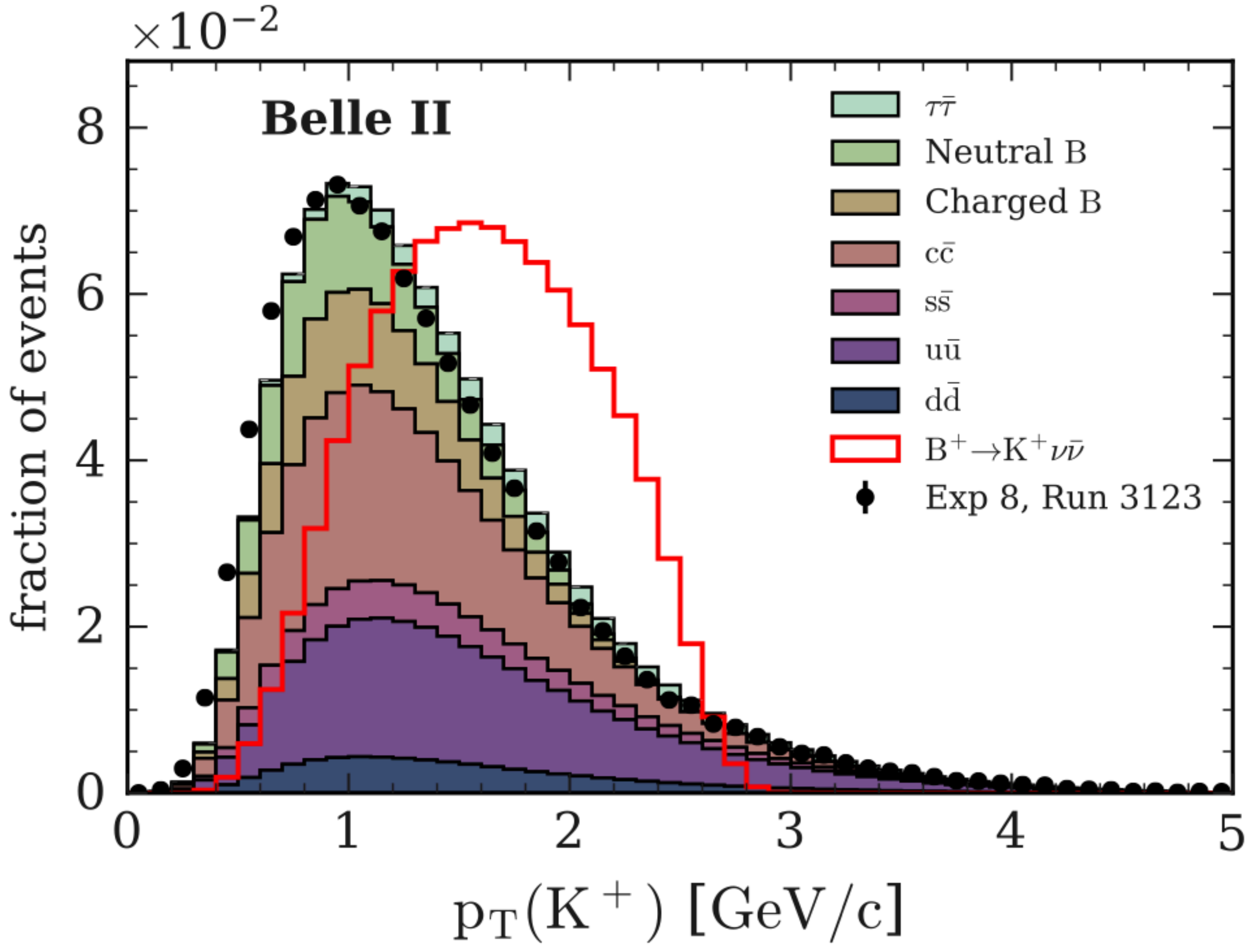
=> Unique to Belle II

Challenge: two neutrinos in the final state and limited sample size

Use inclusive approach to search for $B^+\to K^+\nu\bar{\nu}$ in 63 fb^{-1}

Signal kaon = candidate - track with the highest p_T

- Associate all remaining tracks and clusters to other B in the event
- Use 2 consequent BDTs based on kinematics, event-topology, tagged B, and vertexing variables, to suppress background



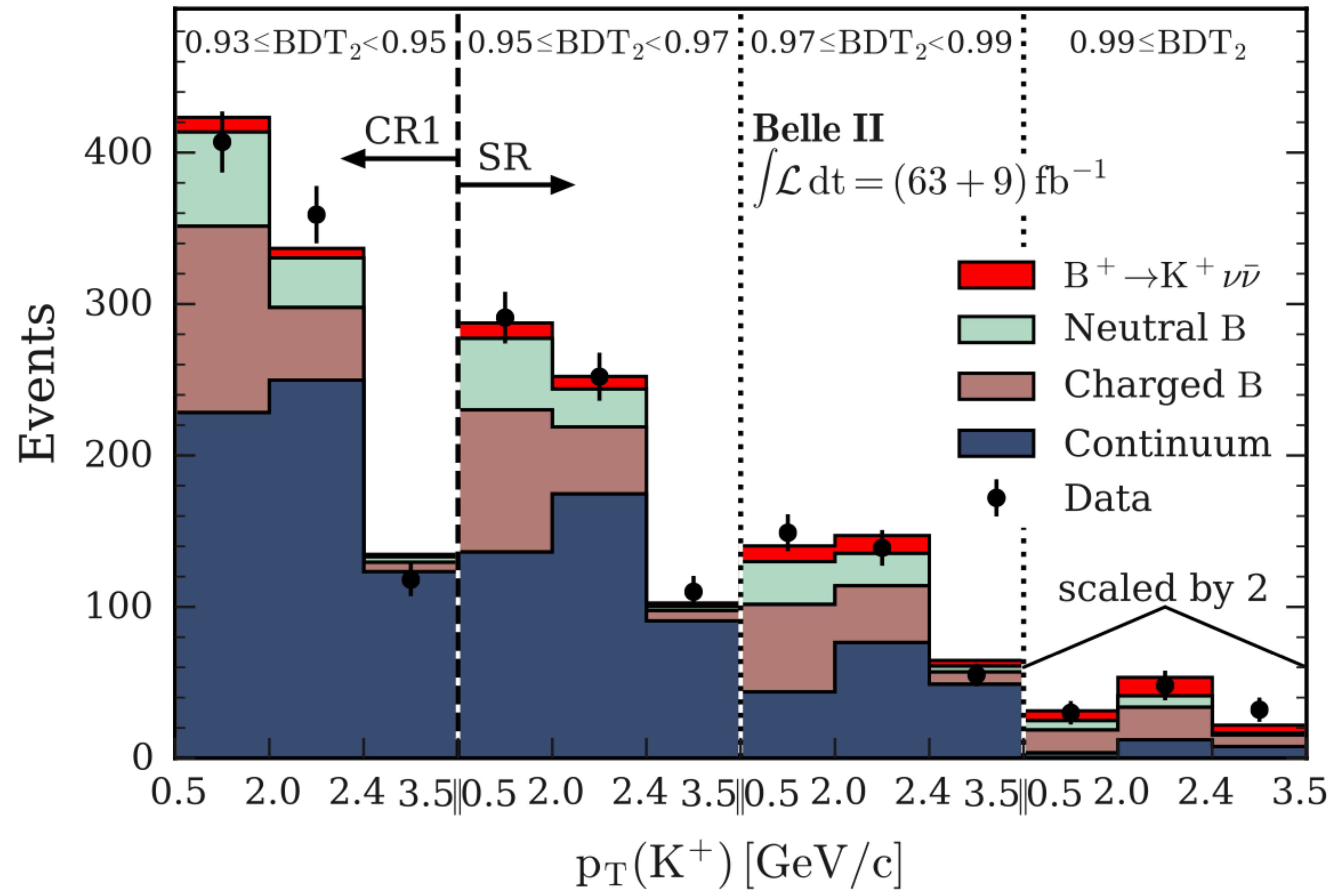
Search for $B^+ \to K^+\nu\bar{\nu}$ (II)

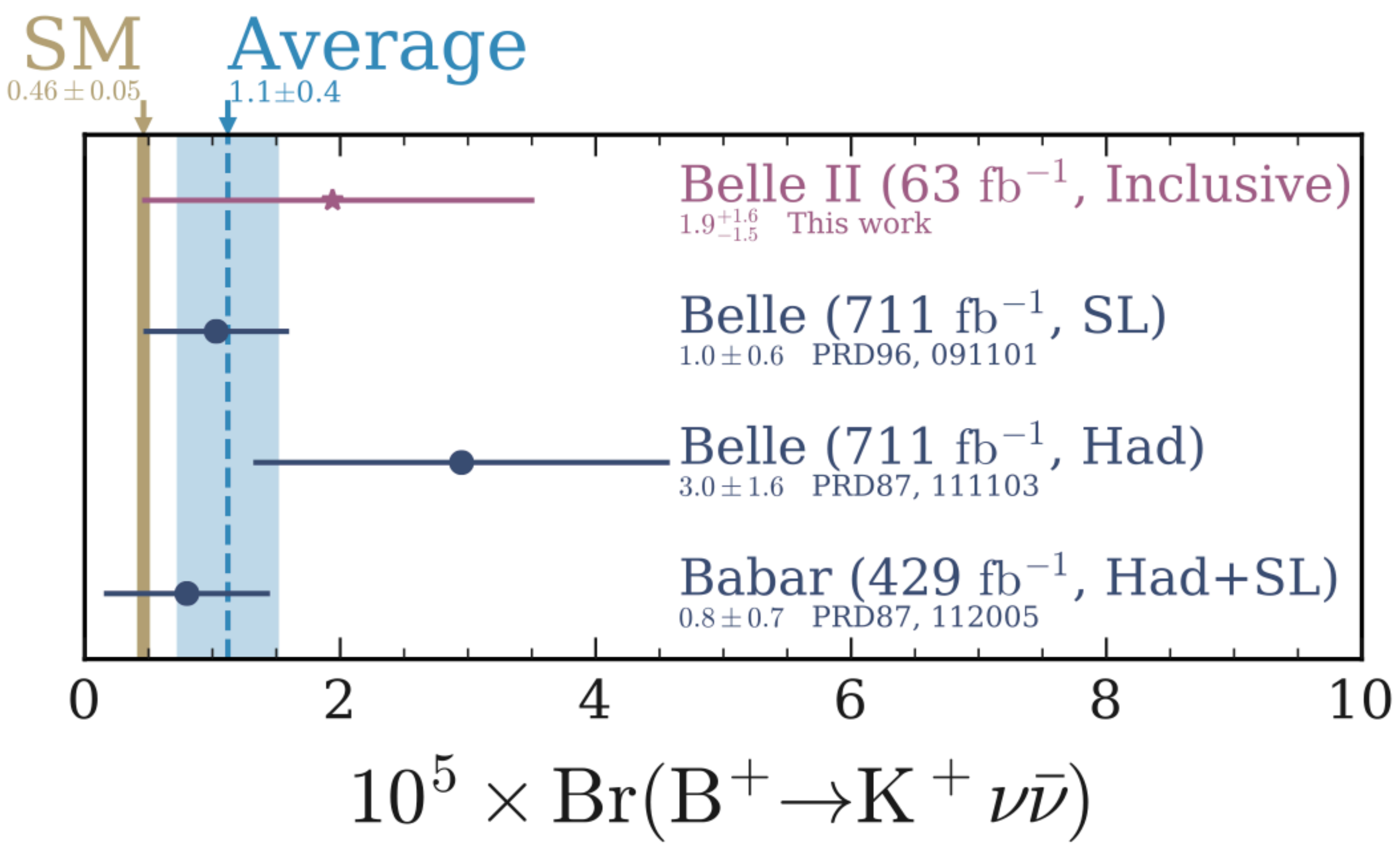
Signal from maximum likelihood fit in bins of $p_T(K^+)$ and BDT output

- Branching fraction $BF(B^+ \to K^+\nu\bar{\nu}) = (1.9^{+1.6}_{-1.5}) \times 10^{-5}$
- Corresponding upper limit @ 90% CL $BF(B^+ \to K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}$

Signal strength comparable with the SM at 1σ and with background only hypothesis at 1.3σ

Inclusive method offers 20%—350% sensitivity improvement over previous approaches





Radiative decays district

NEW!

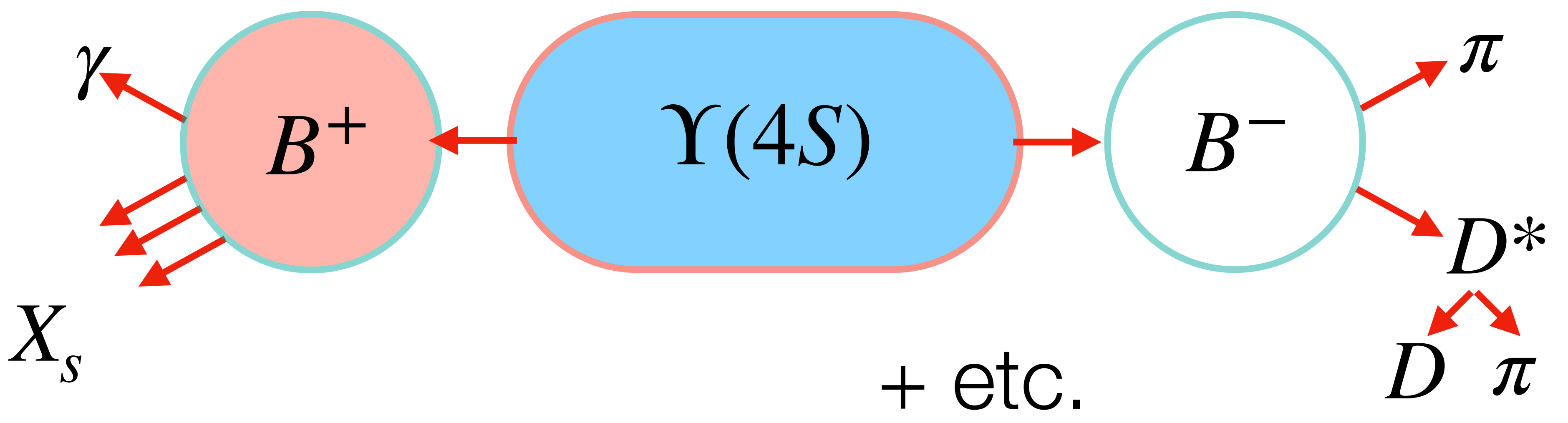
Inclusive BF($B \to X_s\gamma$) (I)

$b \to s\gamma$ has higher rates and is sensitive differently to NP wrt $b \to sll$

Inclusive **Exclusive**

← Experimental challenge

Theory challenge →



E_γ^B - photon energy in the B_{sig} rest frame

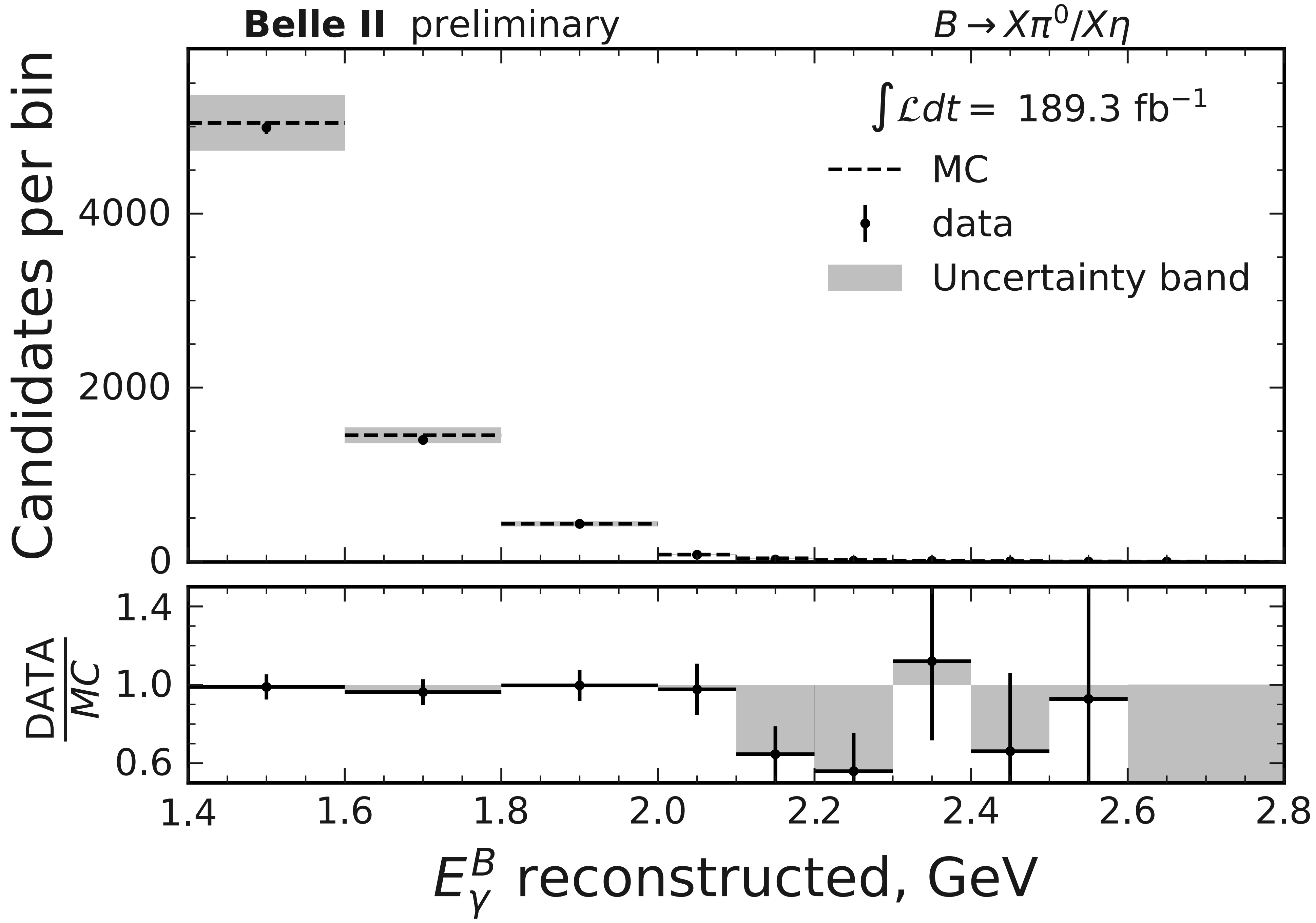
Study of inclusive $B \to X_s\gamma$ decay. In addition to NP searches extract:

- some SM parameters, e.g. mass of b-quark [RevModPhys88.035008]
- shape function describing the motion of b-quark inside B [PRL127.102001]

Today: BF($B \to X_s\gamma$) and photon spectrum with hadronic tag in 189 fb^{-1}

Challenge: suppress and subtract background contributions

- Reconstruct tag side using multitude of hadronic channels
- Reconstruct signal photon candidate with highest E_γ^B ($E_\gamma^B > 1.4$ GeV)
- Veto photons coming from π^0 and η decays



Inclusive BF($B \to X_s\gamma$) (II)

NEW!

- Suppress $e^+e^- \to q\bar{q}$ background by combining event-topology, B_{tag} kinematics, and vertexing variables in a BDT.
- Determine number of well-reconstructed B_{tag} mesons in data and simulation* by fitting the M_{bc} distribution in bins of E_γ^B.
  *$B \to X_s\gamma$ is excluded from simulation
- From E_γ^B distributions obtained in data subtract those in simulation

=> Obtain number of $B \to X_s\gamma$ decays.

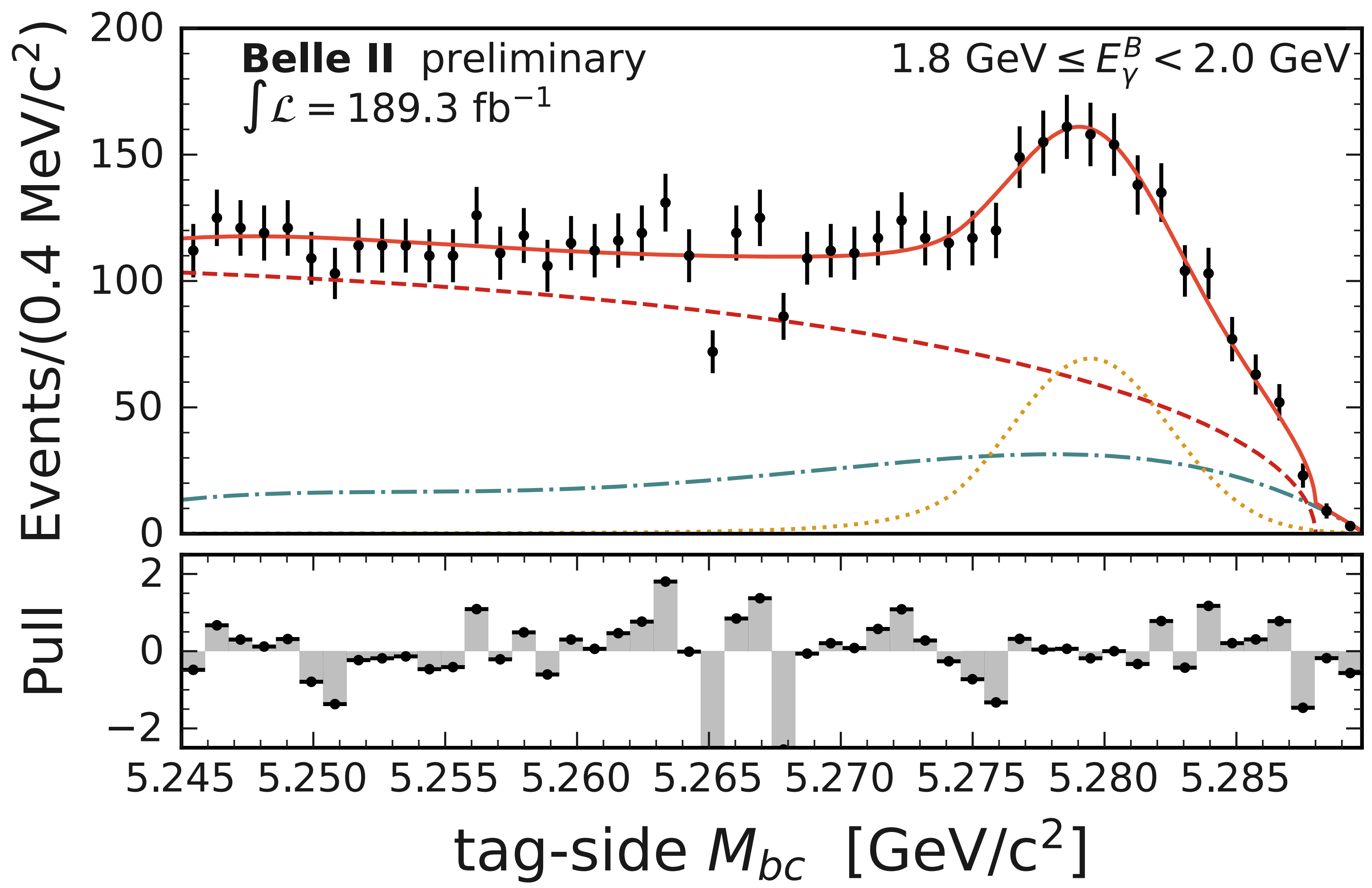
- Calculate partial branching fractions in bins of E_γ^B

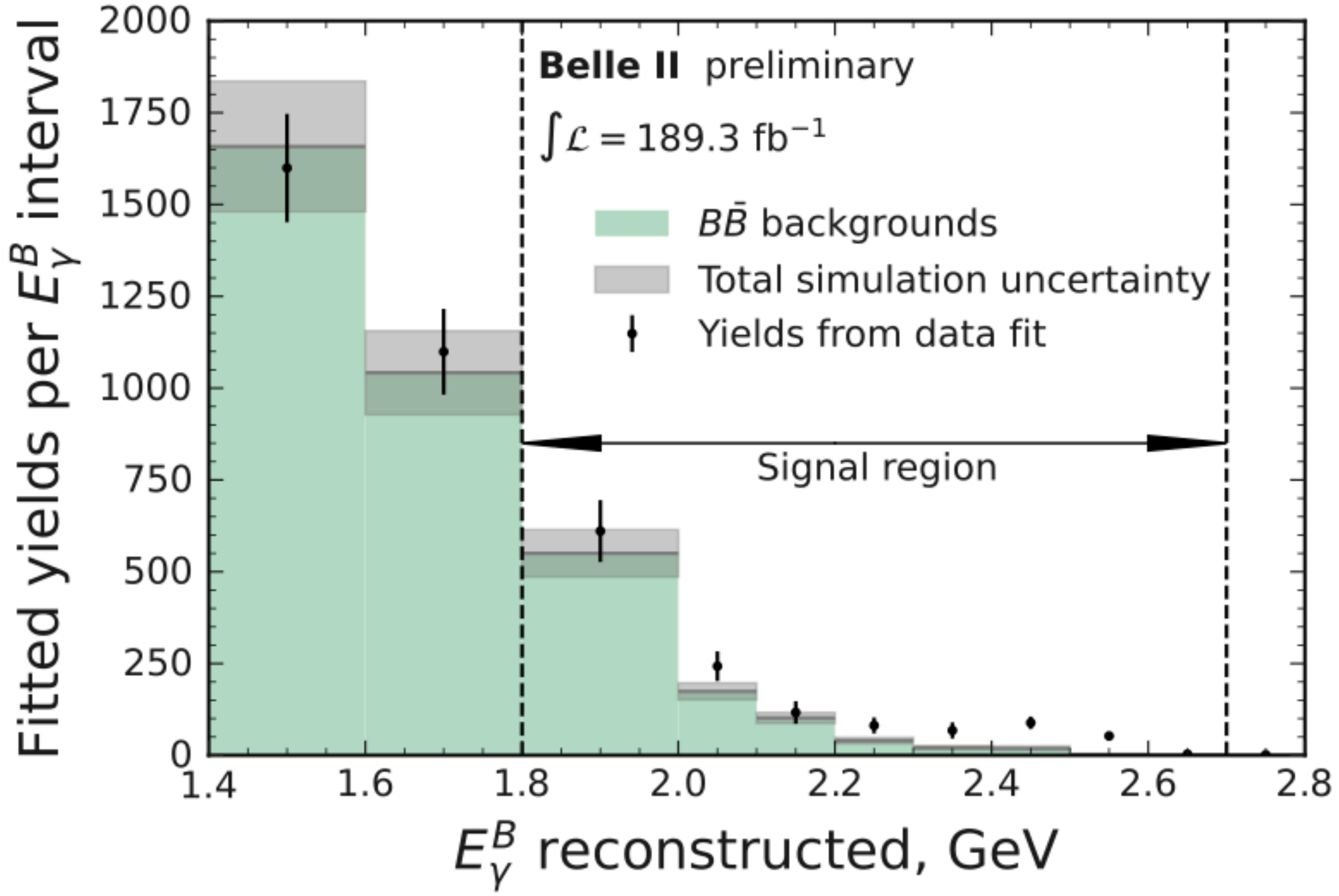
$$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma} = \frac{\mathcal{U}_i \cdot (N_i^{\text{DATA}} - N_i^{\text{BKG, MC}} - N_i^{B\to X_d\gamma})}{\varepsilon_i \cdot N_B}$$

N_i^{DATA} ($N_i^{\text{BKG,MC}}$) - number of events in data (simulation)

$\mathcal{U}_i$ - unfolding factor $\quad$ $N_i^{B\to X_d\gamma}$ - number of $B \to X_d\gamma$ events

ε_i - signal efficiency $\quad$ N_B - number of $B\bar{B}$ pairs



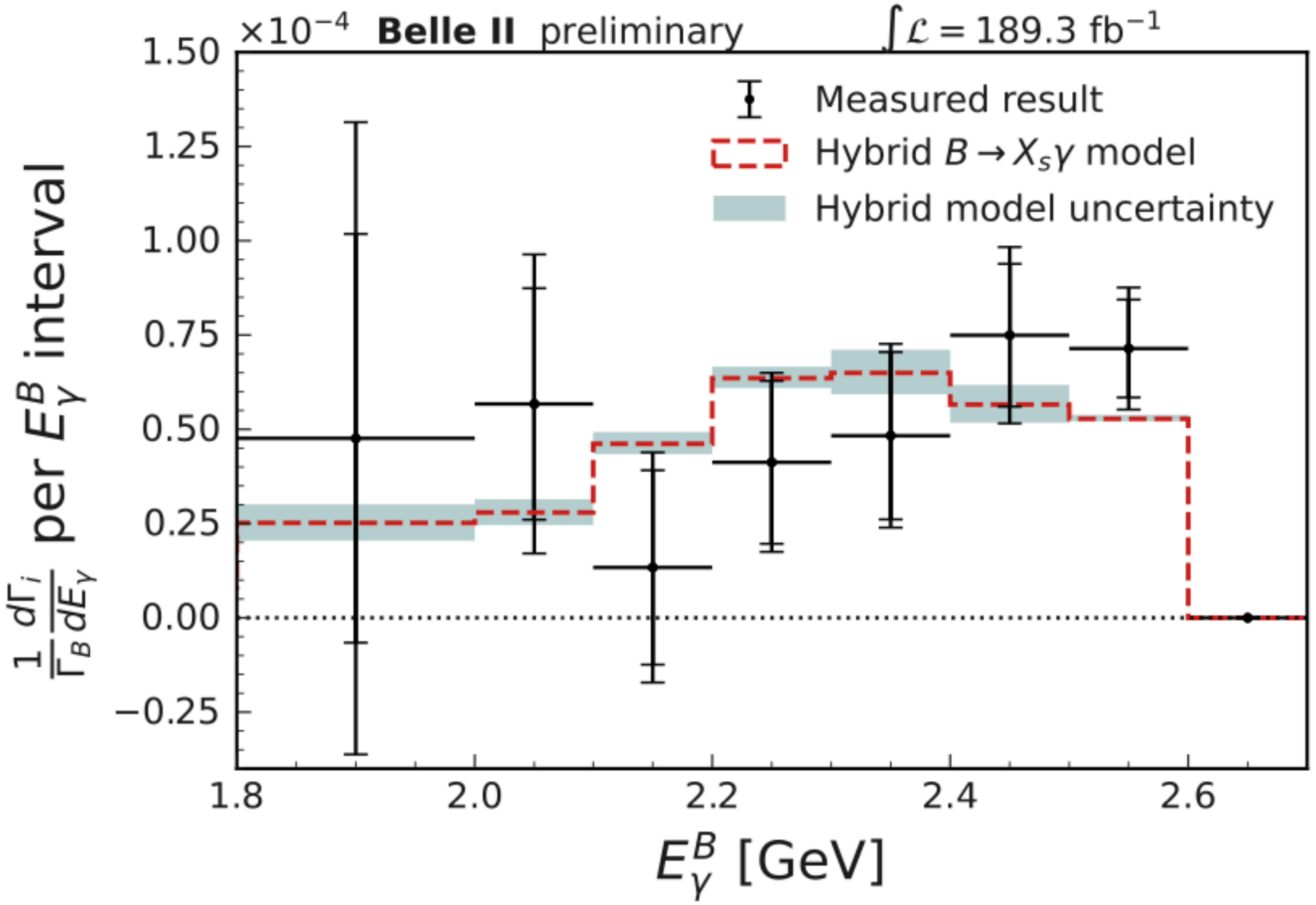


NEW!

Inclusive BF($B \to X_s\gamma$) (III)

- Integrate results for various E_γ^B thresholds

E_γ^B threshold, GeV	$\mathcal{B}(B \to X_s\gamma)(10^{-4})$
1.8	3.54 ± 0.78 (stat.) ± 0.83 (syst.)
2.0	3.06 ± 0.56 (stat.) ± 0.47 (syst.)



- Largest systematic effects due to simulation mismodelings and bkg normalization data-simulation discrepancy.
- BaBar hadron tag result for $E_\gamma^B > 1.9$ GeV (210 fb^{-1}): $(3.66 \pm 0.85 \pm 0.60)\times10^{-4}$ [PRD77.051103]
- SM prediction for $E_\gamma^B > 1.6$ GeV: $(3.40 \pm 0.17)\times10^{-4}$ [JHEP06(2020)175]

Competitive with the BaBar hadronic tag measurement

Summary

- $b \to s$ transitions offer powerful probe of the SM and physics beyond
- $b \to s$ studies are essential portion of the Belle II physics program
  - unique access to radiative and missing energy modes

- Measurements with 63 fb^{-1} and 190 fb^{-1} presented:
  - $B \to K^{*} ll$ branching fraction;
  - NEW! Branching fraction, isospin asymmetry, and $R_K(J/\psi)$ of $B \to J/\psi K$ decays;
  - $B \to K \nu \bar{\nu}$ branching fraction;
  - $B \to K^{*} \gamma$ branching fraction;
  - NEW! Partial branching fractions of $B \to X_s \gamma$ decay with hadronic tag approach.

Belle II is on track to carry out independent and/or unique searches of NP indications in EW and Rad penguins

Backup

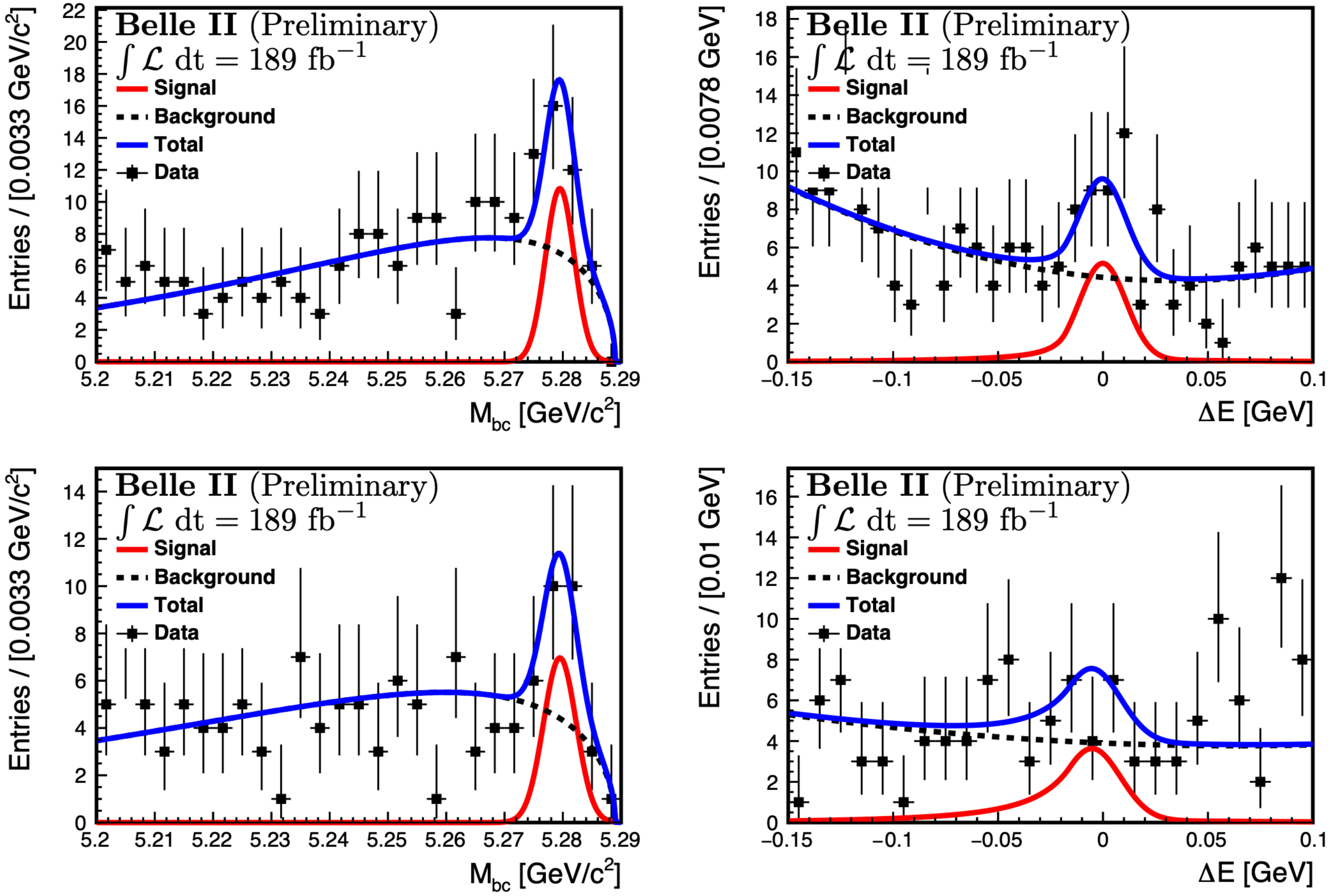
arXiv:2206.05946

Measurement of BF($B \to K^*\ell\ell$)

$$M_{bc} = \sqrt{E_{beam}^2 - \overrightarrow{p}_B^{*2}} \qquad \Delta E = E_B^* - E_{beam}$$

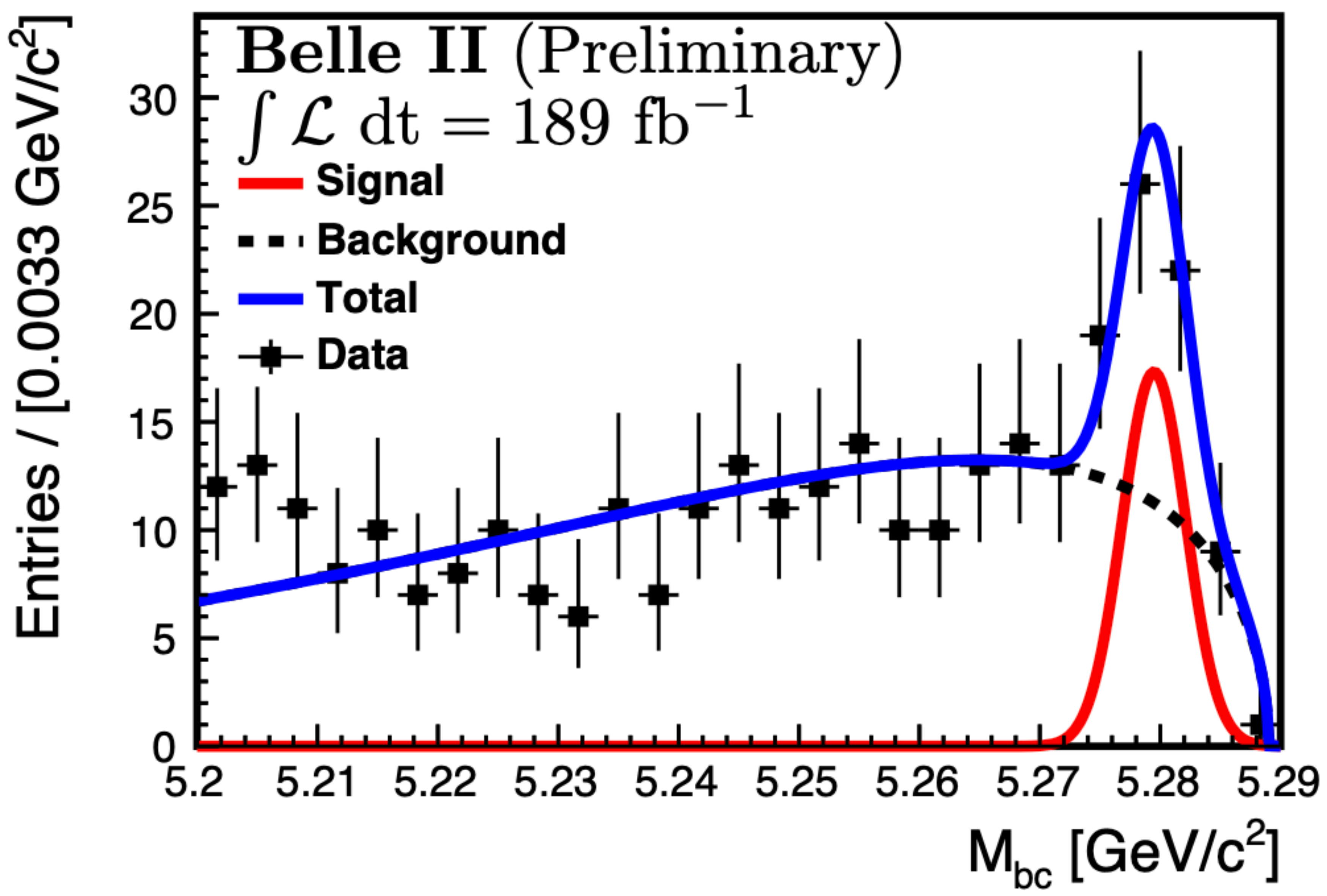
$B \to K^*\mu^+\mu^-$

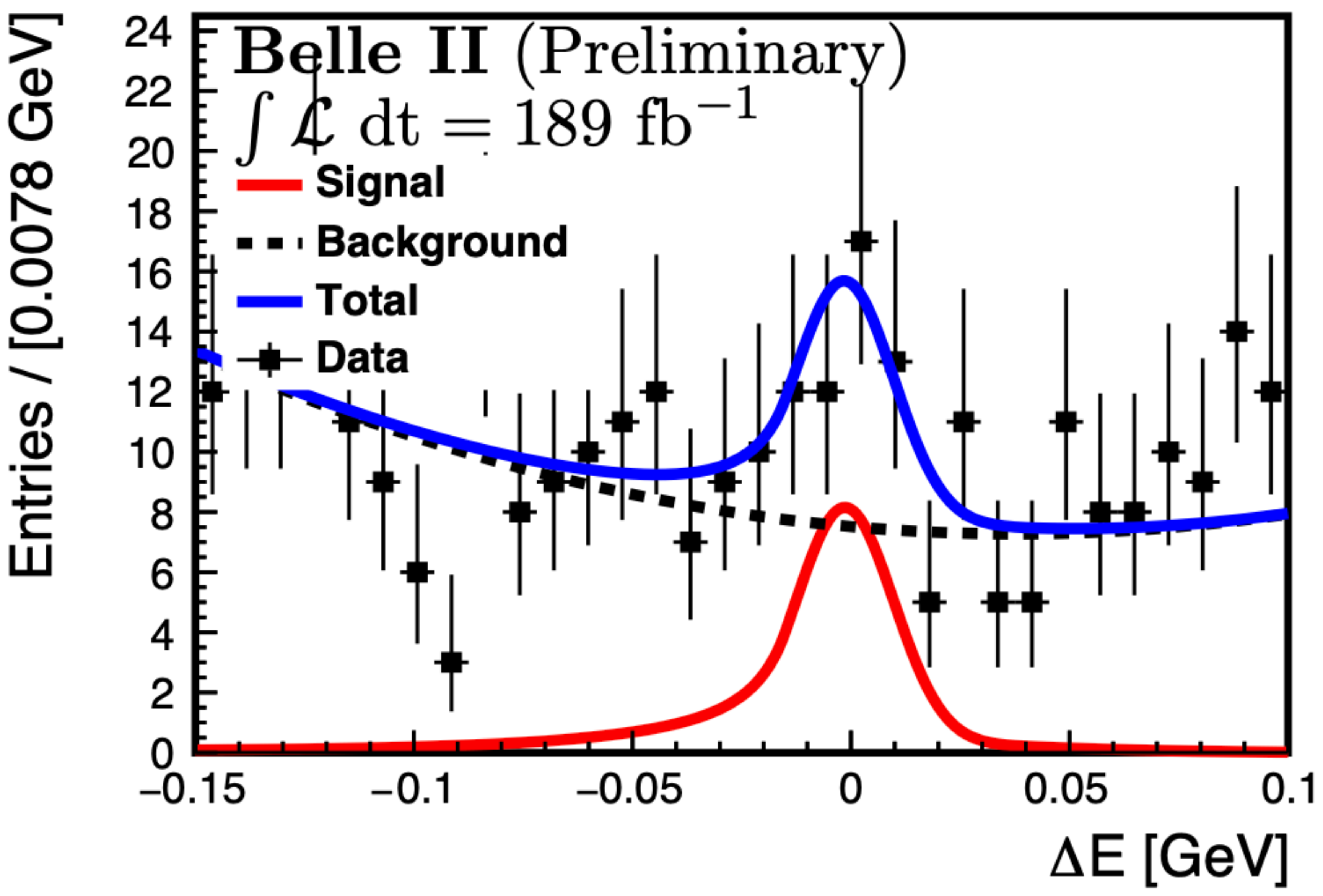
$B \to K^*e^+e^-$



Measurement of BF($B \to K^*\ell\ell$)

$B \to K^*\ell^+\ell^-$





Measurement of $B \to J/\psi K$ decays

Branching fraction

Decay	Belle II (10^{-5})	PDG (10^{-5})
$B^+ \to K^+ J/\psi(\to e^+e^-)$	$6.00 \pm 0.10 \pm 0.19$	6.09 ± 0.12
$B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$	$6.06 \pm 0.09 \pm 0.19$	6.08 ± 0.12
$B^0 \to K^0_S J/\psi(\to e^+e^-)$	$2.67 \pm 0.08 \pm 0.12$	2.66 ± 0.10
$B^0 \to K^0_S J/\psi(\to \mu^+\mu^-)$	$2.78 \pm 0.08 \pm 0.12$	2.65 ± 0.10

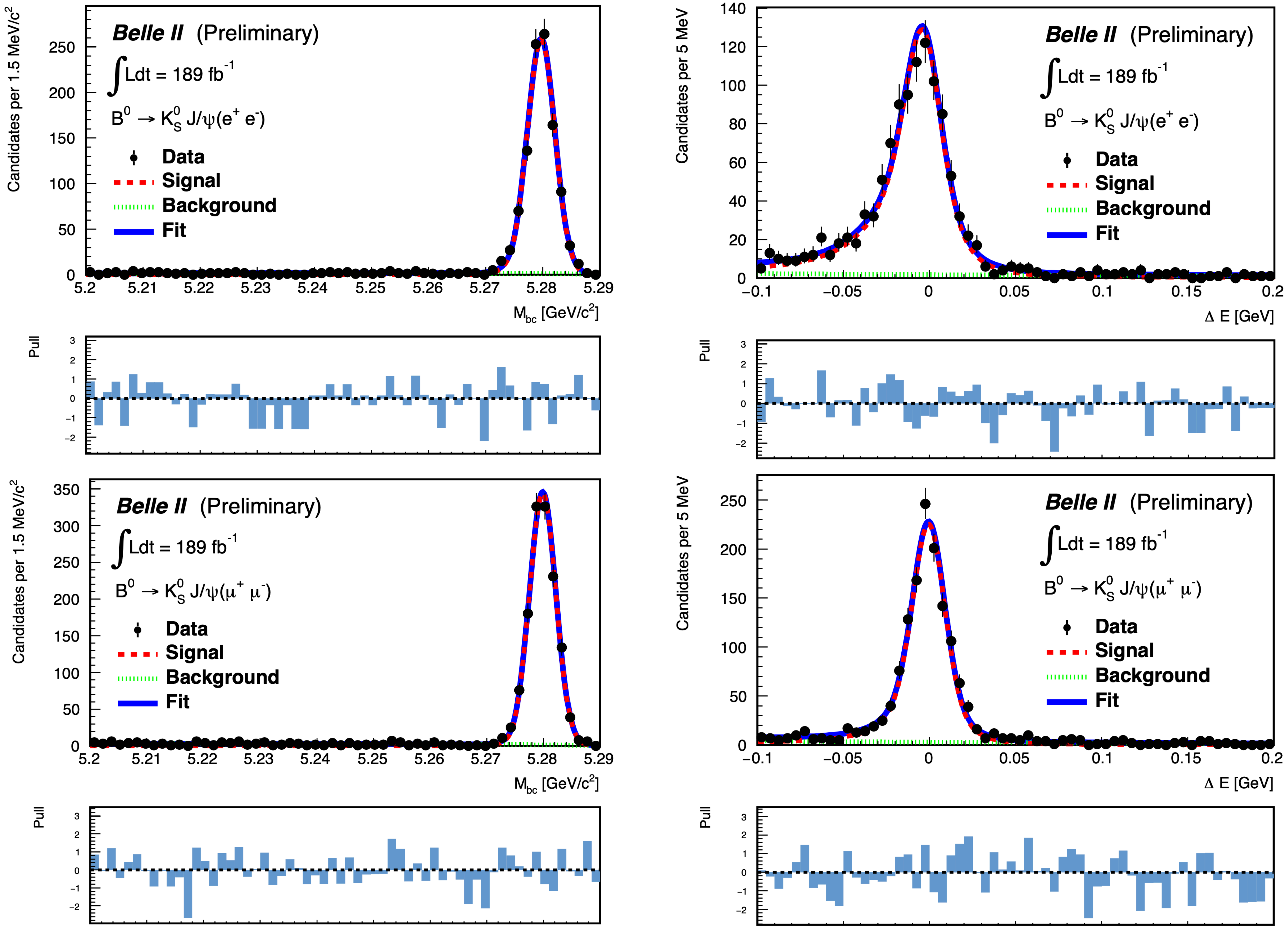
$$R_K(J/\psi) = \frac{\mathcal{B}(B \to KJ/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B \to KJ/\psi(\to e^+e^-))}$$

Observable	Belle II	Belle (2021)
$R_{K^+}(J/\psi)$	$1.009 \pm 0.022 \pm 0.008$	$0.994 \pm 0.011 \pm 0.010$
$R_{K^0_S}(J/\psi)$	$1.042 \pm 0.042 \pm 0.008$	$0.993 \pm 0.015 \pm 0.010$

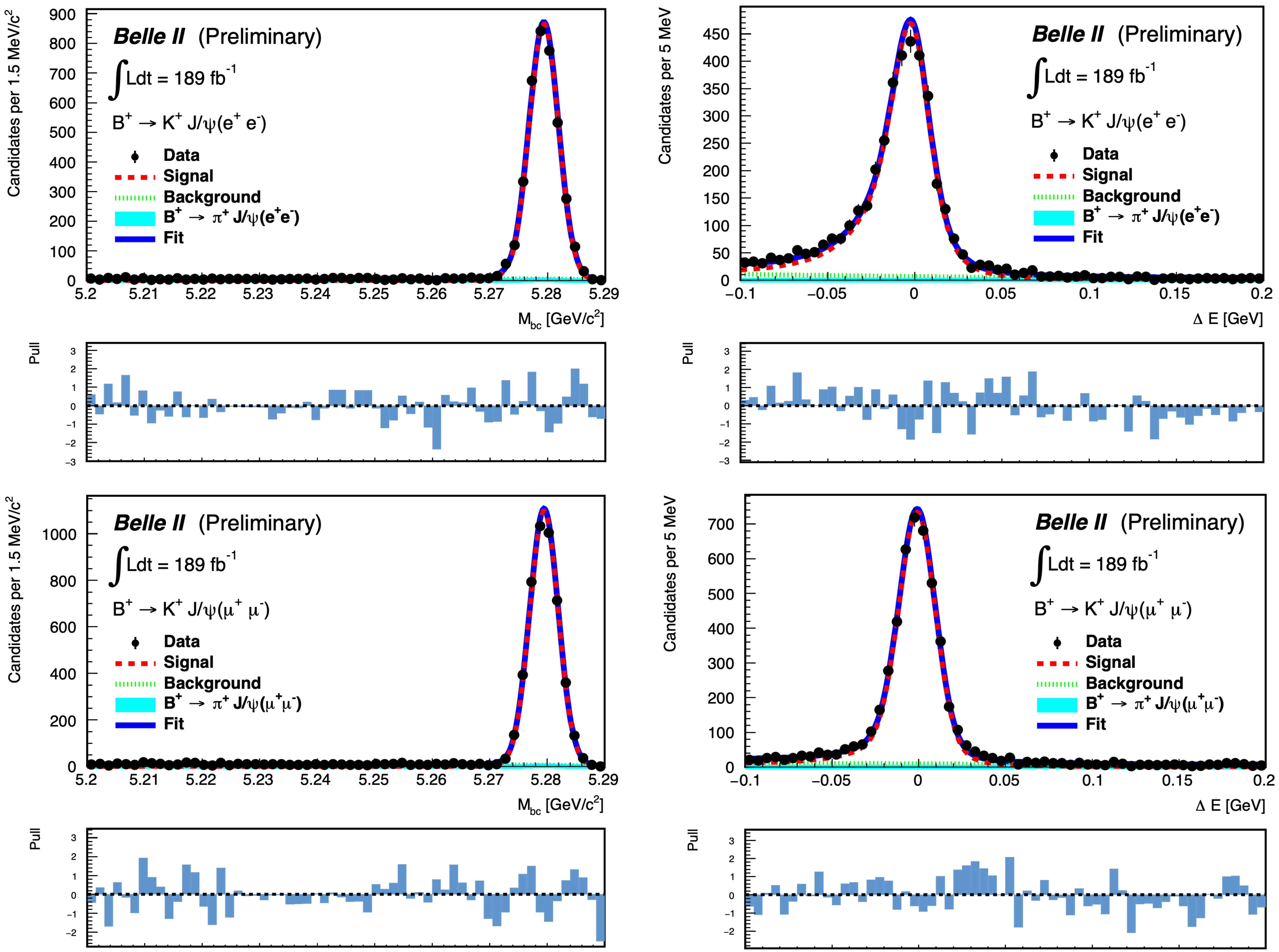
$$A_I = \frac{(\tau_{B^+}/\tau_{B^0})(f^{\pm}/f^{00})(n_{sig}/\epsilon)\,|_{K^0_S J/\psi(\ell\ell)} - (n_{sig}/\epsilon)\,|_{K^+ J/\psi(\ell\ell)}}{(\tau_{B^+}/\tau_{B^0})(f^{\pm}/f^{00})(n_{sig}/\epsilon)\,|_{K^0_S J/\psi(\ell\ell)} + (n_{sig}/\epsilon)\,|_{K^+ J/\psi(\ell\ell)}}$$

Observable	Belle II	Belle (2021)
$A_I(J/\psi \to e^+e^-)$	$-0.022 \pm 0.016 \pm 0.030$	$-0.002 \pm 0.007 \pm 0.024$
$A_I(J/\psi \to \mu^+\mu^-)$	$-0.006 \pm 0.015 \pm 0.030$	

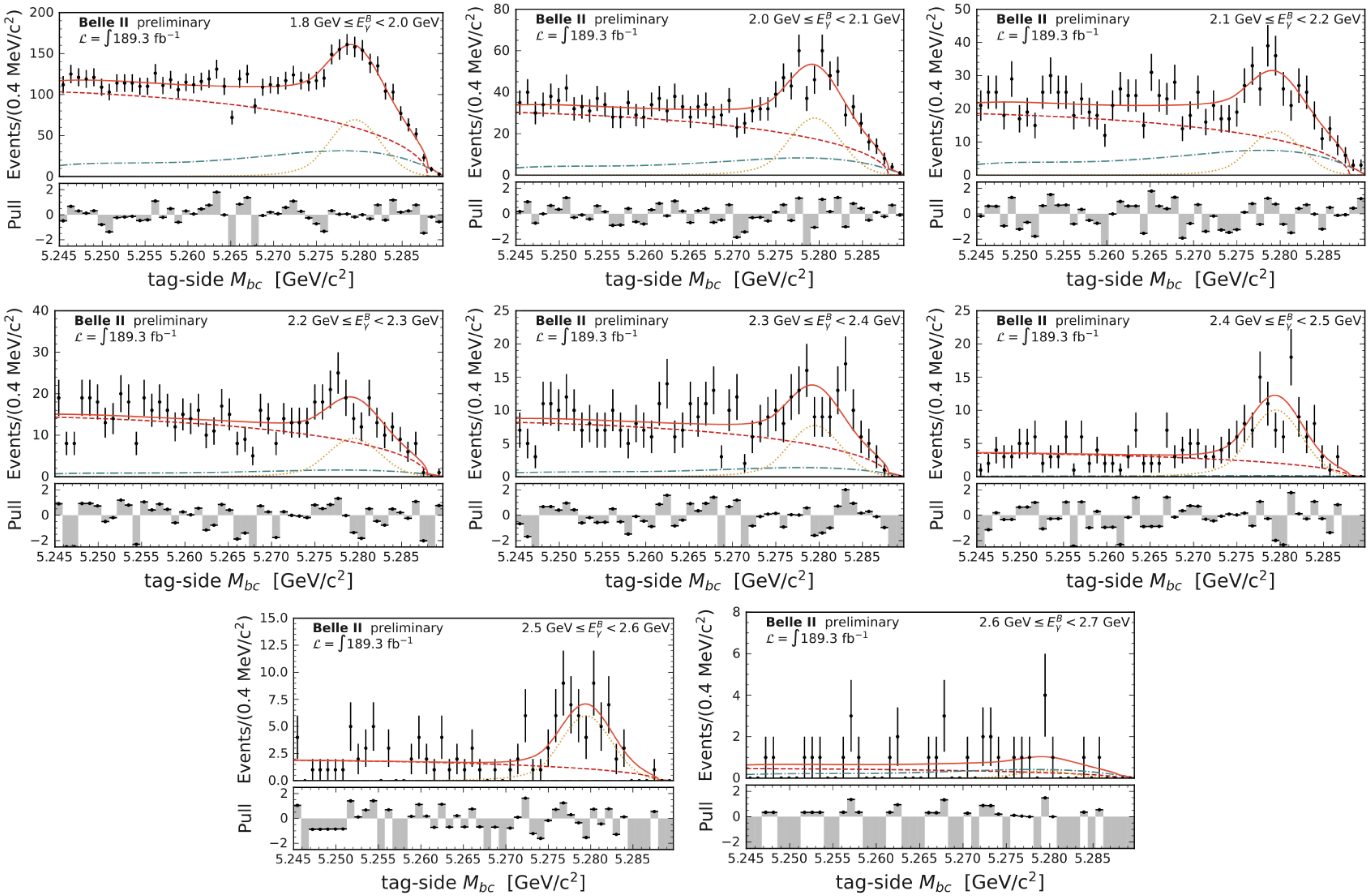
Measurement of $B \to J/\psi K$ decays



Measurement of $B \to J/\psi K$ decays



Inclusive BF($B \to X_s\gamma$)



Inclusive BF($B \to X_s\gamma$)

TABLE I: Partial branching fraction measurement results and uncertainties. Note that signal efficiency and background modelling uncertainties are correlated (see Sections 7.2 and 7.3).

E_γ^B [GeV]	$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma}(10^{-4})$	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