



東京大学  
THE UNIVERSITY OF TOKYO



# Measurement of inclusive $B \rightarrow X_s \ell^+ \ell^-$ branching fractions at Belle II

Zihan Wang

on behalf of the Belle II collaboration

60<sup>th</sup> Rencontres de Moriond 2026: Electroweak Interactions & Unified Theories

La Thuile, Italy

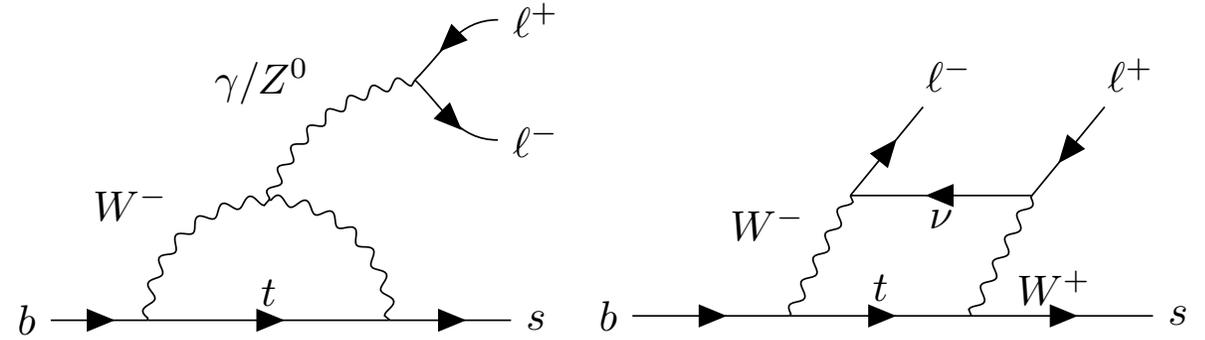
2026.03.16



# Motivation

$b \rightarrow s \ell^+ \ell^-$  transition  $\ell = e \text{ or } \mu$

- Flavor Changing Neutral Current (FCNC)
- Suppressed in the SM, sensitive to small contributions from new physics

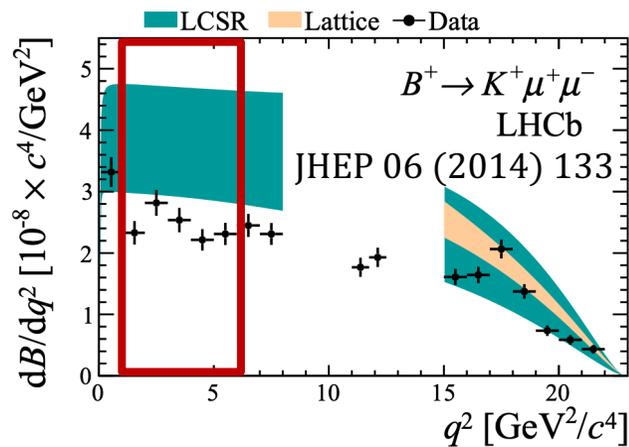


## Anomalies in exclusive measurements

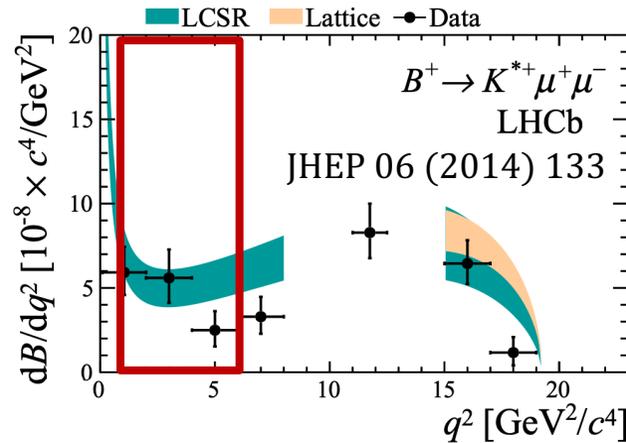
$$\mathcal{B}^{\text{SM}}(B \rightarrow X_s \ell^+ \ell^-) = 4.2 \times 10^{-6} \quad [\text{Nucl.Phys.B Proc.Suppl. 117 (2003) 624}]$$

$$\mathbf{q} = \mathbf{p}_{\ell^+} + \mathbf{p}_{\ell^-}$$

- Observed lower  $\mathcal{B}(B \rightarrow K^{(*)} \mu \mu)$  than SM prediction in low- $q^2$  region [1, 6] [ $\text{GeV}^2/c^4$ ]
- However, large theoretical uncertainties ( $\sim 20\%$ ) prevent a clear claim of discovery of physics beyond the SM
  - Large uncertainties from  $B \rightarrow K$  form factor calculation



2026/03/16

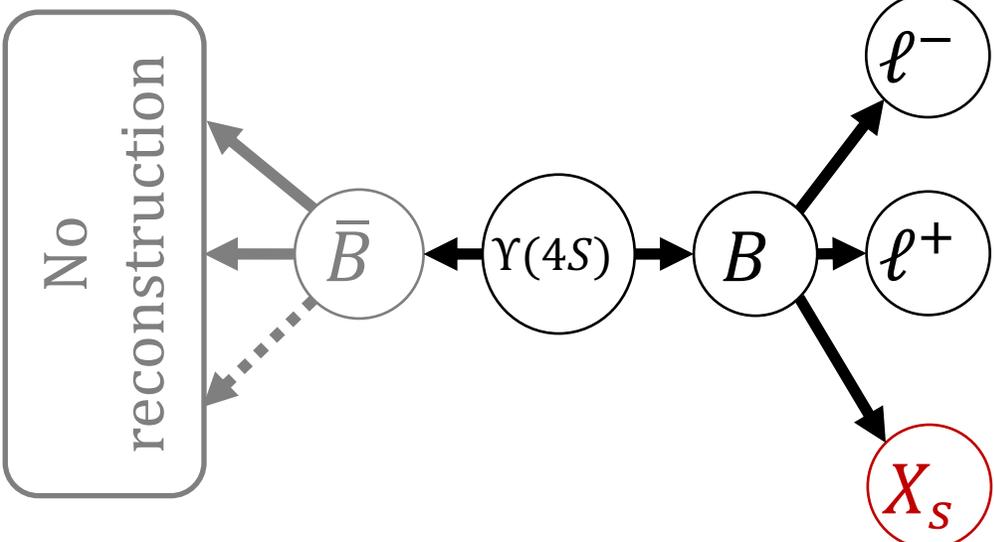


Zihan Wang

Motivates inclusive  $B \rightarrow X_s \ell \ell$  measurement whose SM prediction is less uncertain (7%)

$$X_s = \{K, K^*, K\pi, K\eta, K\rho, 3K, \dots\}$$

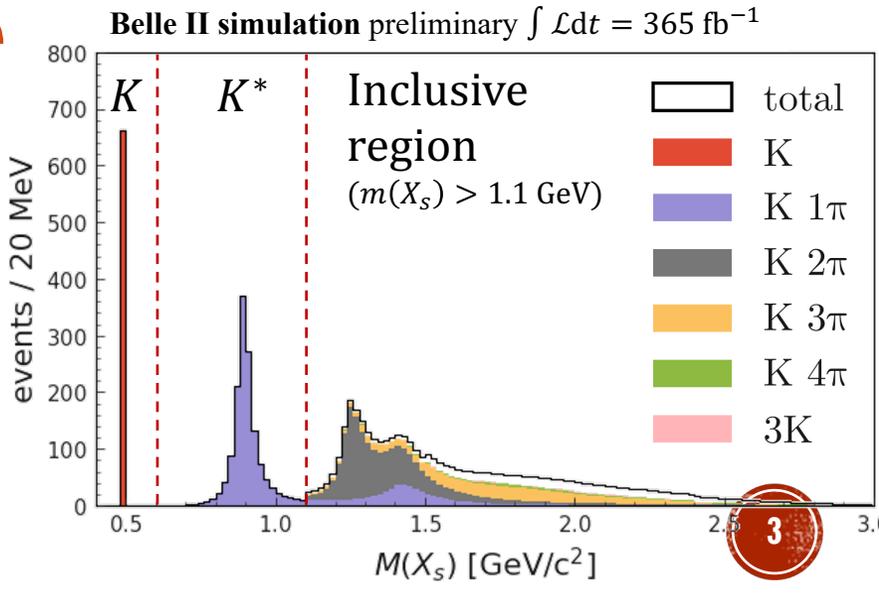
# Analysis strategy



- Use 2019-2022 Belle II data ( $365 \text{ fb}^{-1}$ )
- Sum-of-exclusive:**  $X_S$  reconstructed from 20 hadronic modes in  $m_{X_S} < 1.8 \text{ GeV}/c^2$  region
  - Visible events ratio is  $\sim 71\%$  including  $K_L^0$  events
- $$\mathcal{B}(B \rightarrow X_S \ell^+ \ell^-) = \frac{N_{\text{sig}}}{\varepsilon \cdot f_{\text{visi}} \cdot 2N_{B\bar{B}}}$$

Efficiency of reconstructed modes: by simulation  
 Visible fraction: by Pythia (Lund String model)

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

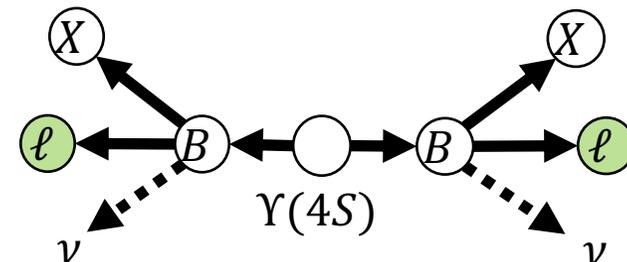
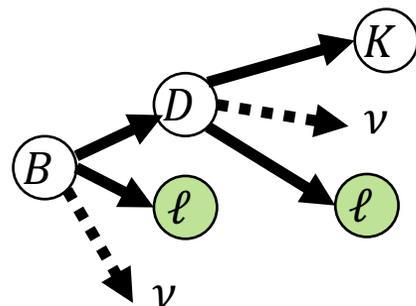


# Selection & background rejection

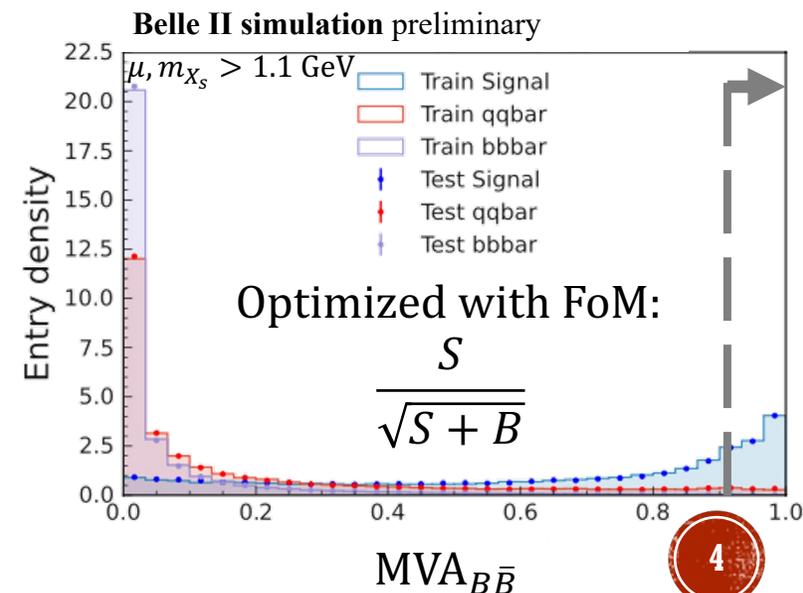
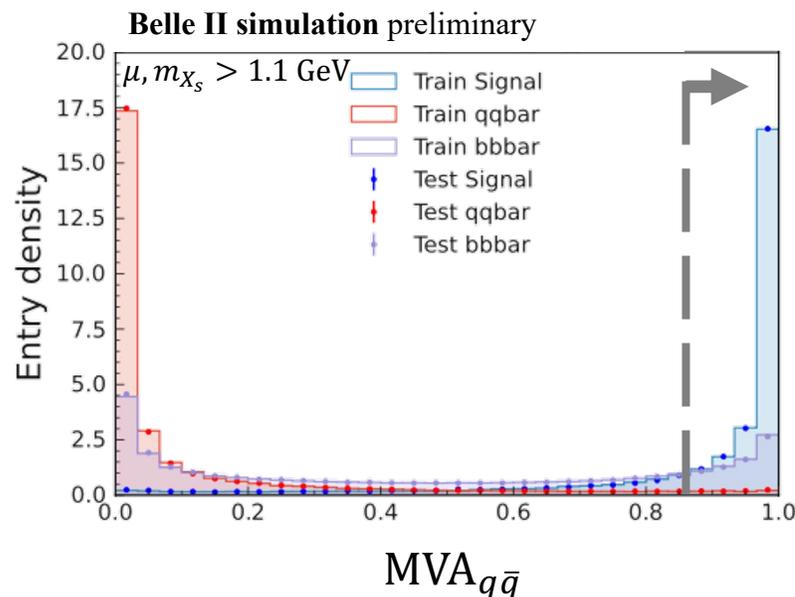
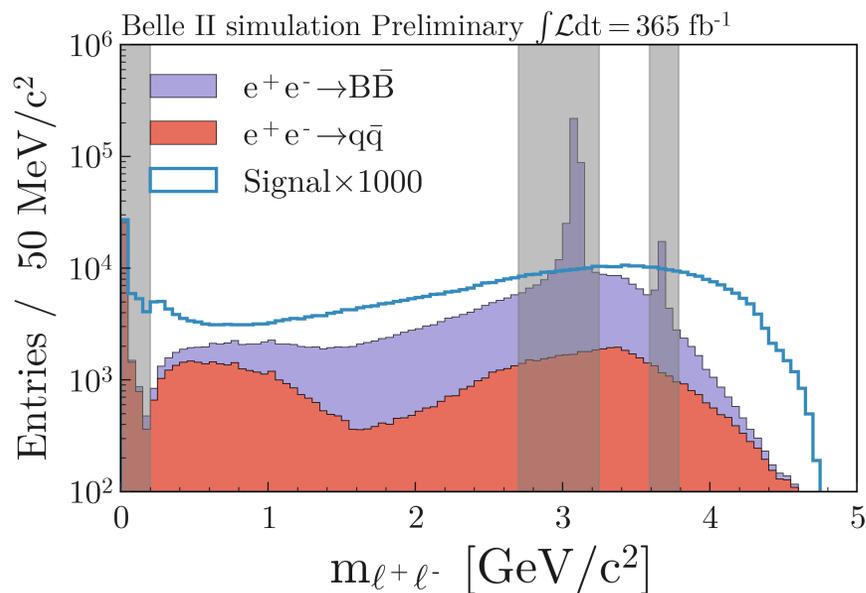
- **Cut-based selections** on  $m_{\ell^+\ell^-}$  vetoing charmonium processes  $B \rightarrow X_S J/\psi(\psi(2S))$  and gamma conversions  $\gamma \rightarrow e^+e^-$

- **Dominant backgrounds:**

- **Semi-leptonic events** ( $B\bar{B}$  events, rate  $\approx O(10^3)$  of signal)
- **Continuum events** ( $\sigma_{ee \rightarrow q\bar{q}}/\sigma_{ee \rightarrow B\bar{B}} \approx 3.4$ )



- **MVA-based selection** with 8 classifiers: lepton flavor ( $e$  or  $\mu$ ),  $X_S$  mass (above or below 1.1 GeV), background type ( $q\bar{q}$  or  $B\bar{B}$ ). Use missing energy, event shape information, etc.



# Signal modeling improvement

- Signal modeling influences reconstruction efficiency greatly
- The largest systematic uncertainties in precedent analysis

**Exclusive region  $m_{X_s} < 1.1 \text{ GeV}/c^2$ :**

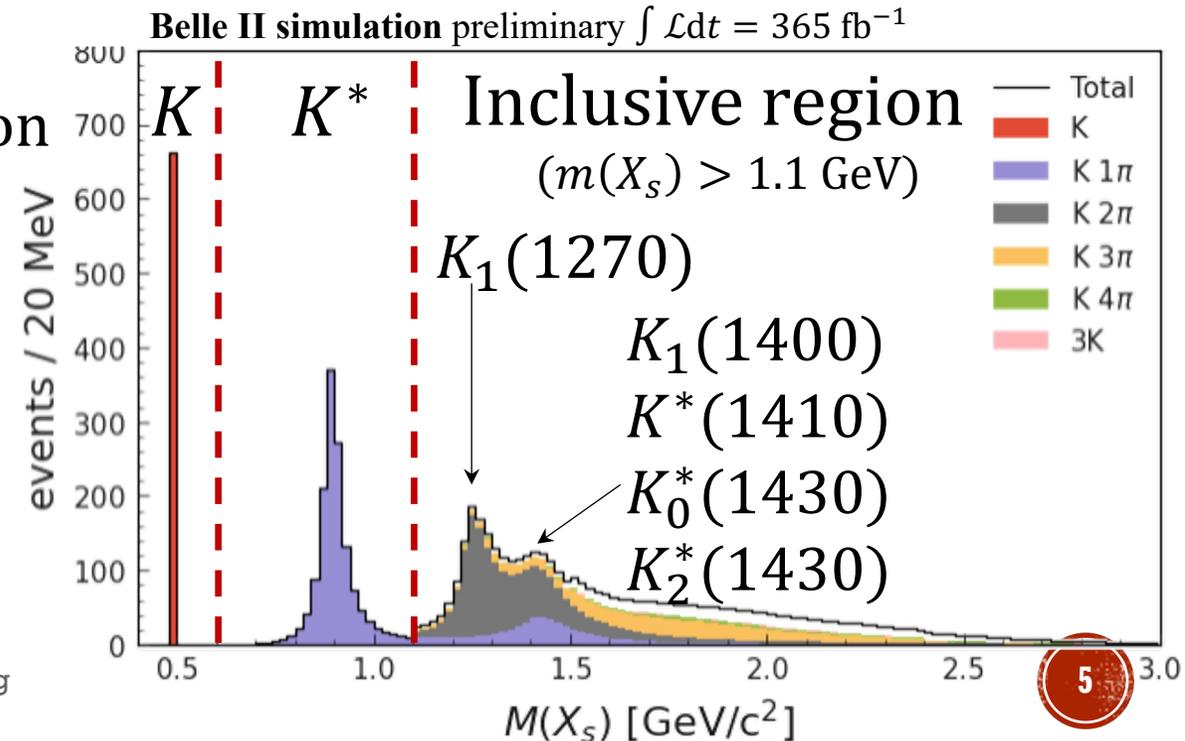
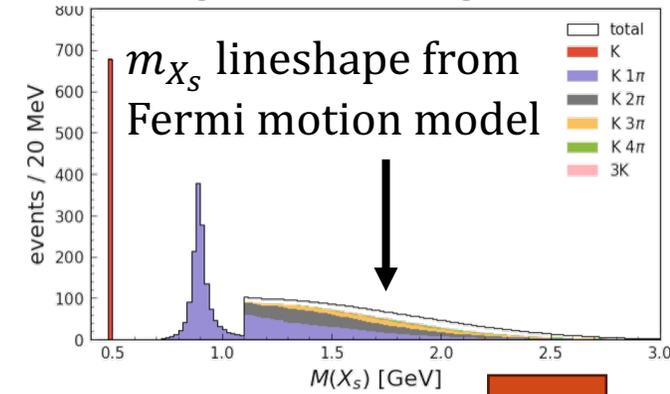
- Latest world average values as  $\mathcal{B}(B \rightarrow K^{(*)} \ell^+ \ell^-)$  input

**Inclusive region  $m_{X_s} > 1.1 \text{ GeV}/c^2$ :**

- Data driven way for fragmentation correction
  - $B \rightarrow X_s \gamma$  and  $B \rightarrow X_s J/\psi$  measurements
- Introduce high mass resonant structures

**Systematic uncertainty suppressed  
 to **1/3** of Belle, **1/2** of Babar  
 in  $1 < q^2 < 6 \text{ GeV}^2/c^4$  region**

Signal modeling in Belle



# Signal extraction & results

New for Moriond EW!

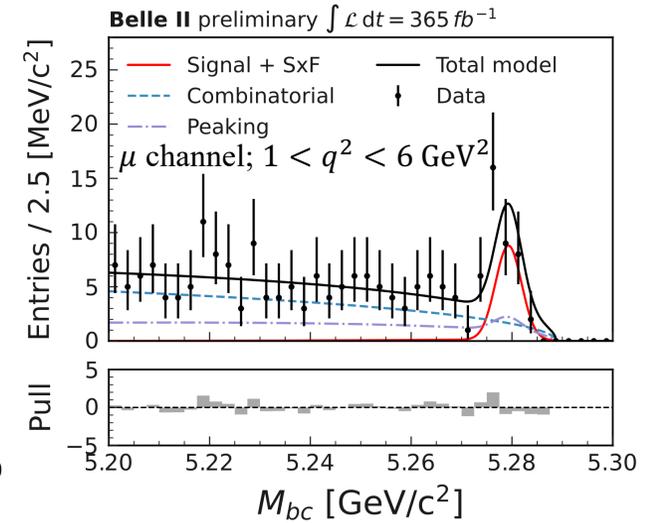
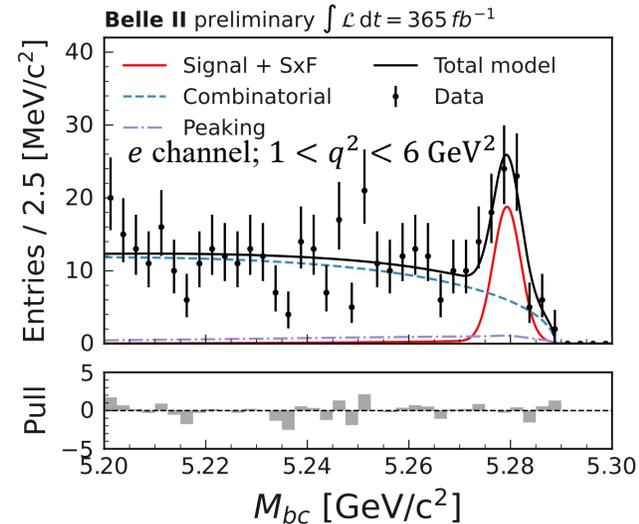
- Fit to  $M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$  spectrum for yield extraction
- Peaking background by mis-identified leptons estimated in data-driven way
- Branching fraction in  $1 < q^2 < 6 \text{ GeV}^2/c^4$  region:

$$\mathcal{B}(B \rightarrow X_s e^+ e^-) = (1.60 \pm 0.33_{-0.11}^{+0.15}) \times 10^{-6}$$

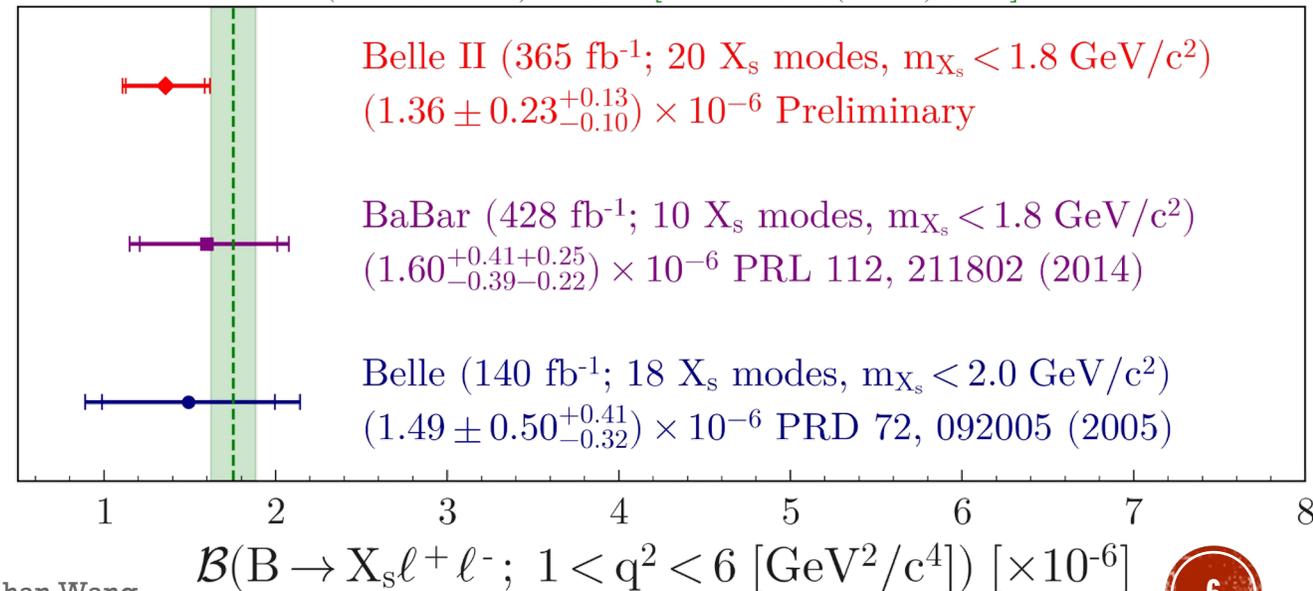
$$\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-) = (1.13 \pm 0.33_{-0.08}^{+0.11}) \times 10^{-6}$$

$$\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-) = (1.36 \pm 0.23_{-0.10}^{+0.13}) \times 10^{-6}$$

- 2 times better sensitivity
- Consistent with SM predictions
- More results in backup!
  - Differential and integrated branching fractions
  - First measurement of  $R(X_s) = \frac{\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-)}{\mathcal{B}(B \rightarrow X_s e^+ e^-)}$

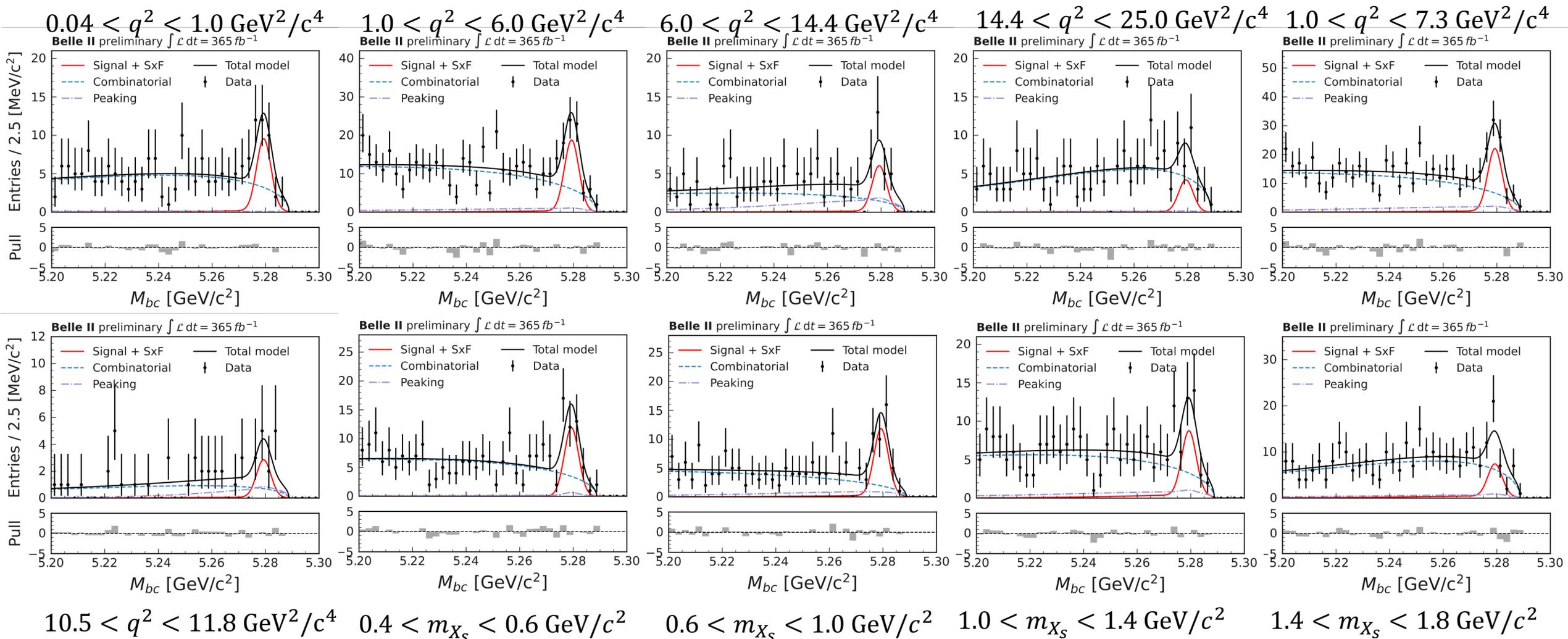


SM =  $(1.76 \pm 0.13) \times 10^{-6}$  [JHEP 10 (2020) 088]



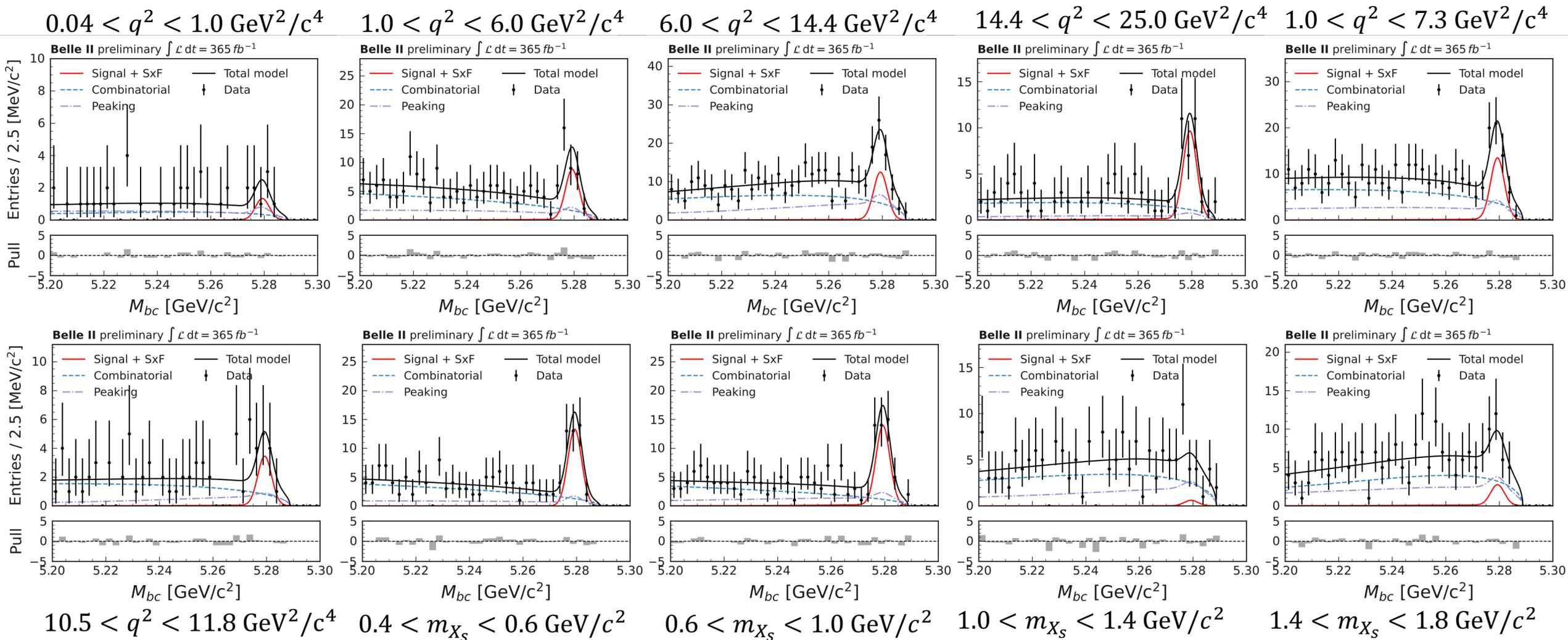
# BACK UP

# Fitting projections in di-electron channel



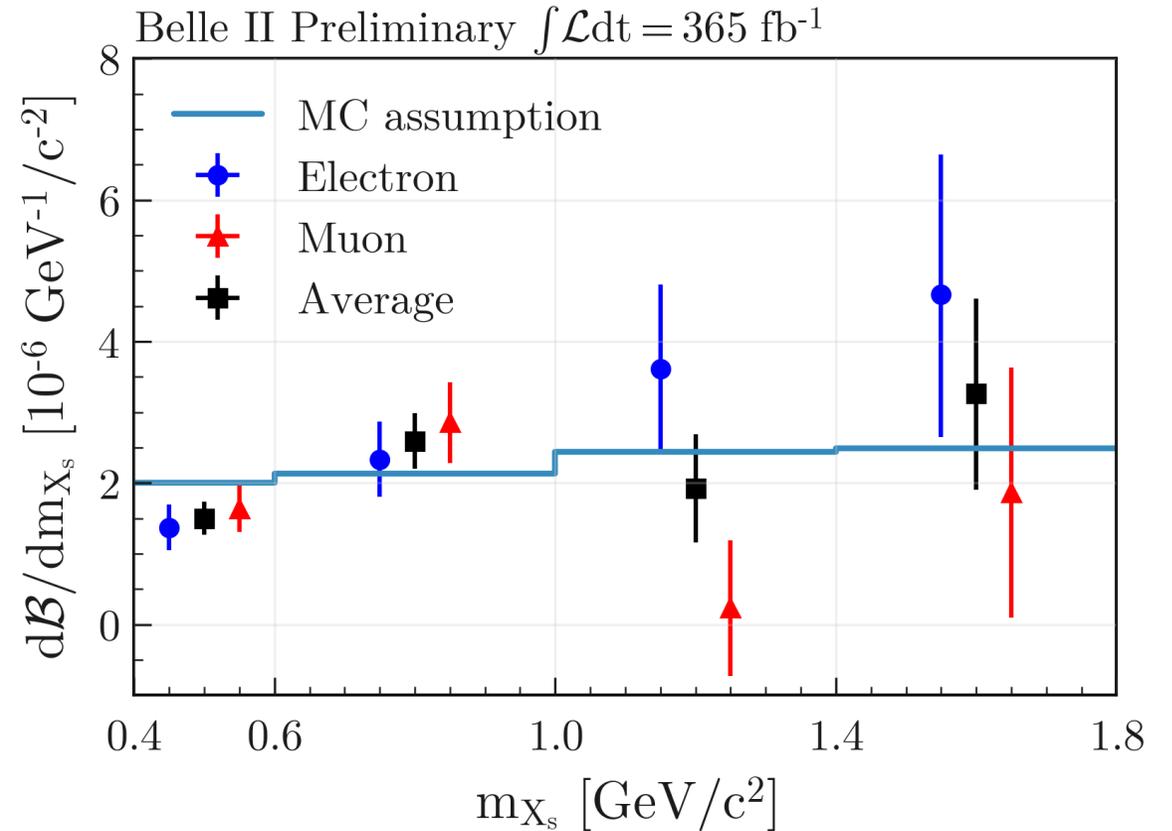
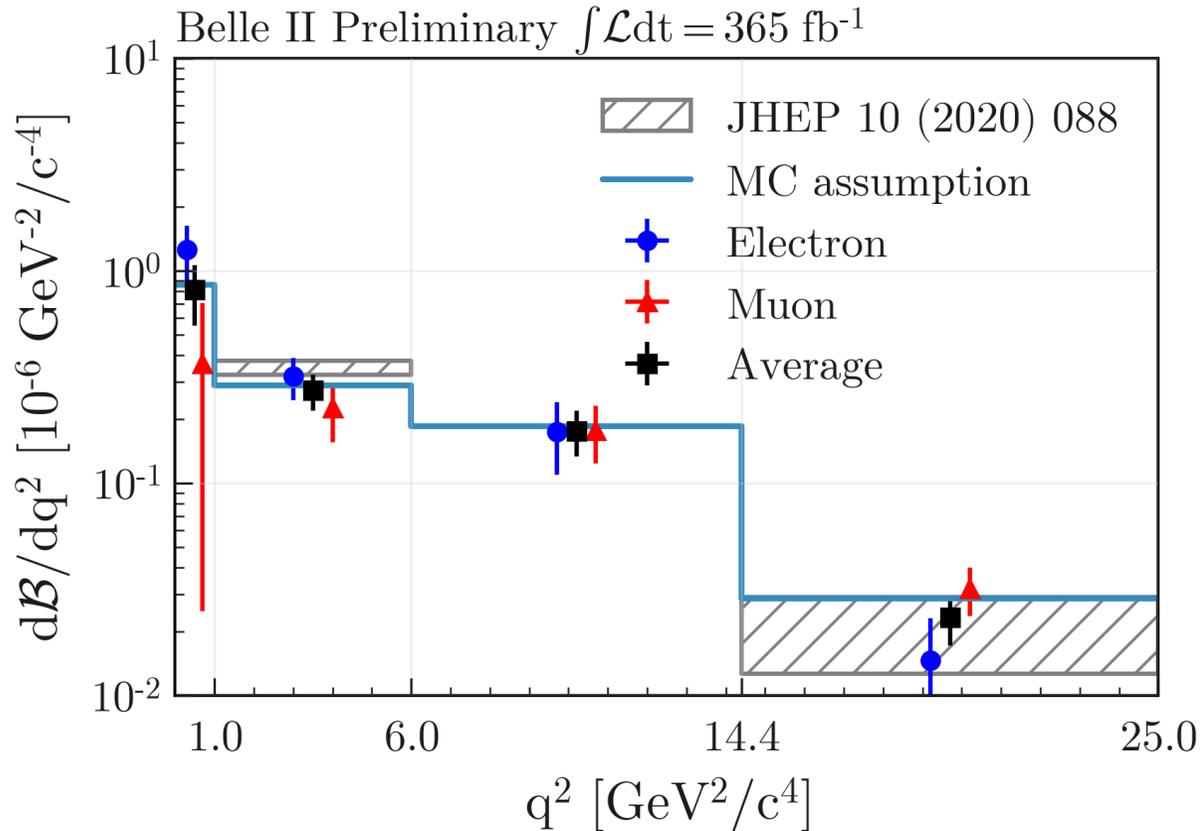
■ Total signal yield:  $100.4 \pm 14.3$

# Fitting projections in di-muon channel



■ Total signal yield:  $81.1 \pm 12.9$

# Differential Branching fractions



- Good consistency with MC expectations and SM predictions (gray shadow)
  - Total branching fraction from SM used for MC

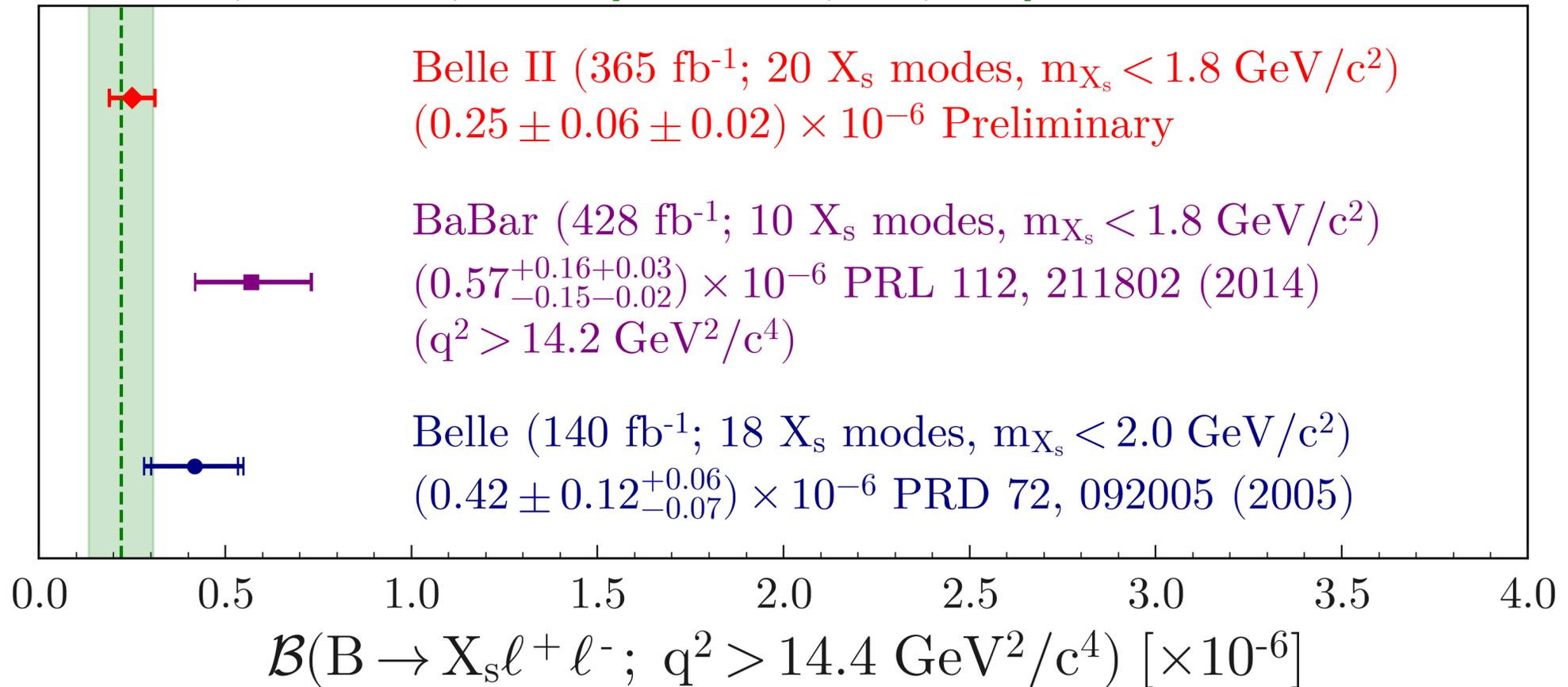
# Differential branching fractions

Table II: Measured differential branching fractions (in the unit of  $10^{-6}$ ) in different kinematic bins. The first and second uncertainties are statistical and systematic, respectively.  $\varepsilon(m_{X_s} < 1.8 \text{ GeV}/c^2)$  is the fraction of  $m_{X_s} < 1.8 \text{ GeV}/c^2$  events in reconstructed modes. The visible ratio  $f_{\text{visi}}$  is the proportion of reconstructed modes in the total  $X_s$  rate.

Bin name	Bin definition	$\mathcal{B}(B \rightarrow X_s e^+ e^-)$	$\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-)$	$\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-)$	$\varepsilon(m_{X_s} < 1.8 \text{ GeV}/c^2)$	$f_{\text{visi}}$
$q_1^2$	$0.04 < q^2 < 1.0$ [ $\text{GeV}^2/c^4$ ]	$1.26 \pm 0.36_{-0.10}^{+0.14}$	$0.37 \pm 0.33 \pm 0.07$	$0.81 \pm 0.24_{-0.07}^{+0.09}$	$0.71 \pm 0.02$	$0.76_{-0.06}^{+0.02}$
$q_2^2$	$1.0 < q^2 < 6.0$ [ $\text{GeV}^2/c^4$ ]	$1.60 \pm 0.33_{-0.11}^{+0.15}$	$1.13 \pm 0.33_{-0.08}^{+0.11}$	$1.36 \pm 0.23_{-0.10}^{+0.13}$	$0.79 \pm 0.01$	$0.80_{-0.05}^{+0.02}$
$q_3^2$	$6.0 < q^2 < 14.4$ [ $\text{GeV}^2/c^4$ ]	$1.47 \pm 0.53_{-0.11}^{+0.12}$	$1.49 \pm 0.43_{-0.11}^{+0.12}$	$1.48 \pm 0.34_{-0.10}^{+0.12}$	$0.93 \pm 0.01$	$0.90_{-0.04}^{+0.01}$
$q_4^2$	$14.4 < q^2 < 25.0$ [ $\text{GeV}^2/c^4$ ]	$0.15 \pm 0.09_{-0.01}^{+0.02}$	$0.34 \pm 0.08_{-0.02}^{+0.03}$	$0.25 \pm 0.06 \pm 0.02$	1.00	$0.98_{-0.01}^{+0.00}$
$q_5^2$	$1.0 < q^2 < 7.3$ [ $\text{GeV}^2/c^4$ ]	$1.88 \pm 0.33_{-0.13}^{+0.18}$	$1.56 \pm 0.39_{-0.11}^{+0.15}$	$1.72 \pm 0.25_{-0.12}^{+0.16}$	$0.80 \pm 0.01$	$0.81_{-0.05}^{+0.02}$
$q_6^2$	$10.5 < q^2 < 11.8$ $\text{GeV}^2/c^4$	$0.22 \pm 0.12 \pm 0.03$	$0.21 \pm 0.10 \pm 0.02$	$0.21 \pm 0.08 \pm 0.02$	$0.99 \pm 0.01$	$0.92_{-0.04}^{+0.01}$
$m_1$	$0.4 < m_{X_s} < 0.6$ [ $\text{GeV}/c^2$ ]	$0.27 \pm 0.06 \pm 0.01$	$0.33 \pm 0.06 \pm 0.01$	$0.30 \pm 0.05 \pm 0.01$	—	1.00
$m_2$	$0.6 < m_{X_s} < 1.0$ [ $\text{GeV}/c^2$ ]	$0.93 \pm 0.21 \pm 0.04$	$1.14 \pm 0.22 \pm 0.05$	$1.04 \pm 0.15 \pm 0.04$	—	1.00
$m_3$	$1.0 < m_{X_s} < 1.4$ [ $\text{GeV}/c^2$ ]	$1.44 \pm 0.45_{-0.15}^{+0.14}$	$0.09 \pm 0.38 \pm 0.07$	$0.77 \pm 0.30_{-0.09}^{+0.08}$	—	$0.91_{-0.06}^{+0.00}$
$m_4$	$1.4 < m_{X_s} < 1.8$ [ $\text{GeV}/c^2$ ]	$1.87 \pm 0.77_{-0.20}^{+0.25}$	$0.75 \pm 0.70_{-0.08}^{+0.10}$	$1.31 \pm 0.52_{-0.13}^{+0.17}$	—	$0.81_{-0.08}^{+0.03}$

# Differential branching fractions

SM =  $(0.22 \pm 0.09) \times 10^{-6}$  [JHEP 10 (2020) 088]



# Total Branching fractions and $R(X_s)$

- Inclusive branching fraction requiring both  $m_{\ell^+\ell^-} > 0.2$  GeV and  $m_{X_s} < 1.8$  GeV by summing  $m_1$  to  $m_4$  results:

$$\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-; m_{X_s} < 1.8 \text{ GeV}) = (3.42 \pm 0.62_{-0.23}^{+0.27}) \times 10^{-6}$$

- Inclusive BF by summing  $q_1^2$  to  $q_4^2$  results:

$$\mathcal{B}(B \rightarrow X_s e^+ e^-) = (4.49 \pm 0.73_{-0.31}^{+0.41}) \times 10^{-6}$$

$$\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-) = (3.33 \pm 0.64_{-0.24}^{+0.30}) \times 10^{-6}$$

$$\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-) = (3.91 \pm 0.49_{-0.26}^{+0.34}) \times 10^{-6}$$

SM:  $(4.18 \pm 0.70) \times 10^{-6}$ , consistent

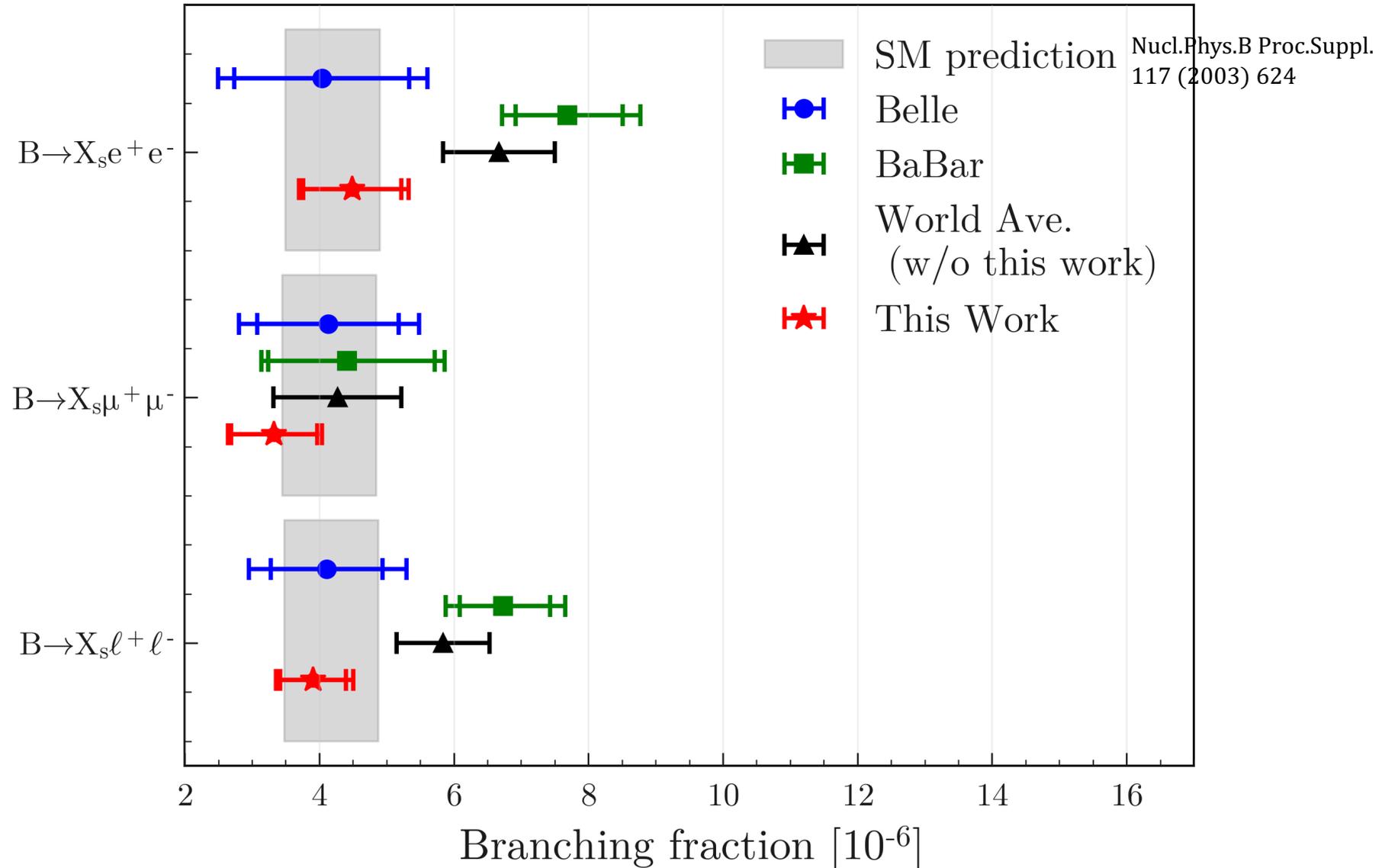
Bin name	Bin definition
$q_1^2$	$0.04 < q^2 < 1.0$ [(GeV/c) <sup>2</sup> ]
$q_2^2$	$1.0 < q^2 < 6.0$ [(GeV/c) <sup>2</sup> ]
$q_3^2$	$6.0 < q^2 < 14.4$ [(GeV/c) <sup>2</sup> ]
$q_4^2$	$14.4 < q^2 < 25.0$ [(GeV/c) <sup>2</sup> ]
$m_1(X_s)$	$0.4 < m(X_s) < 0.6$ [GeV/c <sup>2</sup> ]
$m_2(X_s)$	$0.6 < m(X_s) < 1.0$ [GeV/c <sup>2</sup> ]
$m_3(X_s)$	$1.0 < m(X_s) < 1.4$ [GeV/c <sup>2</sup> ]
$m_4(X_s)$	$1.4 < m(X_s) < 1.8$ [GeV/c <sup>2</sup> ]

- $R(X_s)$  by taking the ratio of di-muon over di-electron:

**First measurement!**  $R(X_s) = \frac{\mathcal{B}(B \rightarrow X_s \mu^+ \mu^-)}{\mathcal{B}(B \rightarrow X_s e^+ e^-)} = 0.74 \pm 0.19 \pm 0.04$

Consistent with lepton flavor universality

# Total branching fractions



# Systematic uncertainties

Table IV: Breakdown of relative systematic uncertainties (in %) for differential branching fraction, inclusive branching fraction, and  $R_{X_s}$ .  $\mathcal{B}$  and  $\mathcal{B}_{1.8}$  represents  $\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-)$  and  $\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-; m_{X_s} < 1.8 \text{ GeV}/c^2)$ , respectively.

	$q_1^2$	$q_2^2$	$q_3^2$	$q_4^2$	$q_5^2$	$q_6^2$	$m_1$	$m_2$	$m_3$	$m_4$	$\mathcal{B}$	$\mathcal{B}_{1.8}$	$R(X_s)$
Signal shape	$\pm 0.3$	$\pm 0.3$	$\pm 0.2$	$\pm 0.1$	$\pm 0.2$	$\pm 0.4$	$\pm 0.1$	$\pm 0.3$	$\pm 0.4$	$\pm 0.2$	$\pm 0.2$	$\pm 0.3$	$\pm 0.4$
Self cross-feed	$\pm 1.3$	$\pm 0.7$	$\pm 0.9$	$\pm 1.0$	$\pm 0.7$	$\pm 1.0$	$\pm 0.6$	$\pm 0.8$	$\pm 2.0$	$\pm 1.5$	$\pm 0.9$	$\pm 1.3$	$\pm 1.7$
Peaking background	$\pm 0.6$	$\pm 0.5$	$\pm 1.9$	$\pm 0.5$	$\pm 0.6$	$\pm 2.4$	$\pm 0.1$	$\pm 0.5$	$\pm 4.3$	$\pm 0.6$	$\pm 1.0$	$\pm 1.4$	$\pm 2.2$
Fiting bias	$\pm 3.7$	$\pm 0.0$	$\pm 0.1$	$\pm 3.4$	$\pm 0.0$	$\pm 6.3$	$\pm 0.0$	$\pm 1.7$	$\pm 0.1$	$\pm 3.0$	$\pm 1.0$	$\pm 1.7$	$\pm 2.2$
$\mathcal{B}(B \rightarrow K \ell^+ \ell^-)$	$\pm 1.2$	$\pm 2.8$	$\pm 2.9$	$\pm 3.8$	$\pm 2.8$	$\pm 2.9$	—	—	$\pm 0.0$	$\pm 0.0$	$\pm 2.6$	$\pm 0.0$	—
$\mathcal{B}(B \rightarrow K^* \ell^+ \ell^-)$	$\pm 1.7$	$\pm 1.4$	$\pm 1.8$	$\pm 1.9$	$\pm 1.4$	$\pm 2.0$	—	—	$\pm 1.0$	$\pm 0.2$	$\pm 1.6$	$\pm 0.3$	—
Kaon resonances	$\pm 2.7$	$\pm 3.4$	$\pm 3.7$	$\pm 1.2$	$\pm 3.4$	$\pm 4.3$	—	—	$\pm 3.8$	$\pm 4.8$	$\pm 3.2$	$\pm 2.7$	—
Fragmentation	+2.3 -3.1	+1.2 -1.7	+0.8 -1.2	+0.0 -0.1	+1.1 -1.6	+0.6 -0.9	—	—	+3.8 -5.5	+4.2 -5.9	+1.2 -1.7	+2.5 -3.5	—
Fermi motion	$\pm 0.8$	+0.3 -0.5	+0.3 -0.2	+0.1 -0.0	+0.3 -0.5	+0.2 -0.1	—	—	+1.7 -2.0	+0.7 -0.8	$\pm 0.4$	+0.6 -0.8	—
$b$ quark mass	+0.1 -0.0	$\pm 0.0$	—	—	$\pm 0.1$	$\pm 0.2$	$\pm 0.0$	$\pm 0.1$	—				
$s$ quark mass	+0.1 -0.0	$\pm 0.0$	—	—	+0.4 -0.0	+0.0 -0.1	$\pm 0.0$	+0.1 -0.0	—				
$K^* - X_s$ transition	+6.0 -3.5	+3.4 -2.6	+0.8 -1.0	+4.6 -1.4	+3.1 -2.4	+2.2 -0.8	—	—	+0.8 -6.0	$\pm 0.1$	+3.0 -2.1	+0.2 -1.4	—
Missing mode	+7.4 -3.1	+6.6 -2.5	+4.7 -1.3	+0.8 -0.1	+6.5 -2.4	+4.2 -1.0	—	—	+6.2 -0.5	+9.9 -3.4	+5.7 -2.0	+5.2 -1.4	—
Tracking	$\pm 1.1$	$\pm 1.0$	$\pm 1.0$	$\pm 0.9$	$\pm 1.0$	$\pm 1.0$	$\pm 0.7$	$\pm 1.1$	$\pm 1.2$	$\pm 1.3$	$\pm 1.0$	$\pm 1.2$	—
$K_S^0$ reconstruction	$\pm 0.7$	$\pm 0.8$	$\pm 0.6$	$\pm 0.5$	$\pm 0.7$	$\pm 0.5$	$\pm 0.7$	$\pm 0.6$	$\pm 0.5$	$\pm 0.5$	$\pm 0.7$	$\pm 0.6$	—
KaonID	$\pm 0.8$	$\pm 0.7$	$\pm 0.9$	$\pm 1.5$	$\pm 0.7$	$\pm 1.0$	$\pm 0.6$	$\pm 1.3$	$\pm 1.2$	$\pm 1.5$	$\pm 0.8$	$\pm 1.3$	—
PionID	$\pm 0.2$	$\pm 0.1$	$\pm 0.0$	$\pm 0.2$	$\pm 0.3$	$\pm 0.3$	$\pm 0.1$	$\pm 0.2$	—				
LeptonID	$\pm 0.7$	$\pm 0.7$	$\pm 0.8$	$\pm 0.5$	$\pm 0.7$	$\pm 0.7$	$\pm 0.7$	$\pm 0.7$	$\pm 0.8$	$\pm 0.7$	$\pm 0.7$	$\pm 0.7$	$\pm 1.4$
$\pi^0$ reconstruction	$\pm 0.3$	$\pm 0.1$	$\pm 0.1$	$\pm 0.0$	$\pm 0.1$	$\pm 0.1$	$\pm 0.0$	$\pm 0.1$	$\pm 0.3$	$\pm 0.4$	$\pm 0.1$	$\pm 0.2$	—
MVA	$\pm 1.7$	$\pm 1.3$	$\pm 1.2$	$\pm 1.2$	$\pm 1.3$	$\pm 1.2$	$\pm 0.9$	$\pm 1.2$	$\pm 2.9$	$\pm 2.5$	$\pm 1.4$	$\pm 2.1$	$\pm 2.7$
MC statistics	$\pm 0.7$	$\pm 0.3$	$\pm 0.4$	$\pm 0.5$	$\pm 0.3$	$\pm 0.8$	$\pm 0.3$	$\pm 0.5$	$\pm 0.8$	$\pm 0.9$	$\pm 0.5$	$\pm 0.7$	$\pm 0.9$
$B$ counting	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	$\pm 2.4$	—
Total $\sigma_{sys.}$	+11.7 -8.5	+9.4 -7.0	+7.9 -6.6	+8.1 -6.8	+9.3 -6.9	+10.5 -9.5	$\pm 3.0$	$\pm 3.9$	+10.6 -11.3	+13.0 -10.0	+8.7 -6.7	+7.9 -6.7	$\pm 4.8$
Total $\sigma_{stat.}$	$\pm 30.0$	$\pm 17.1$	$\pm 23.2$	$\pm 24.7$	$\pm 14.8$	$\pm 36.9$	$\pm 15.2$	$\pm 14.7$	$\pm 38.4$	$\pm 39.7$	$\pm 12.4$	$\pm 18.1$	$\pm 25.3$