Rare decays at LHCb

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On behalf of the LHCb collaboration

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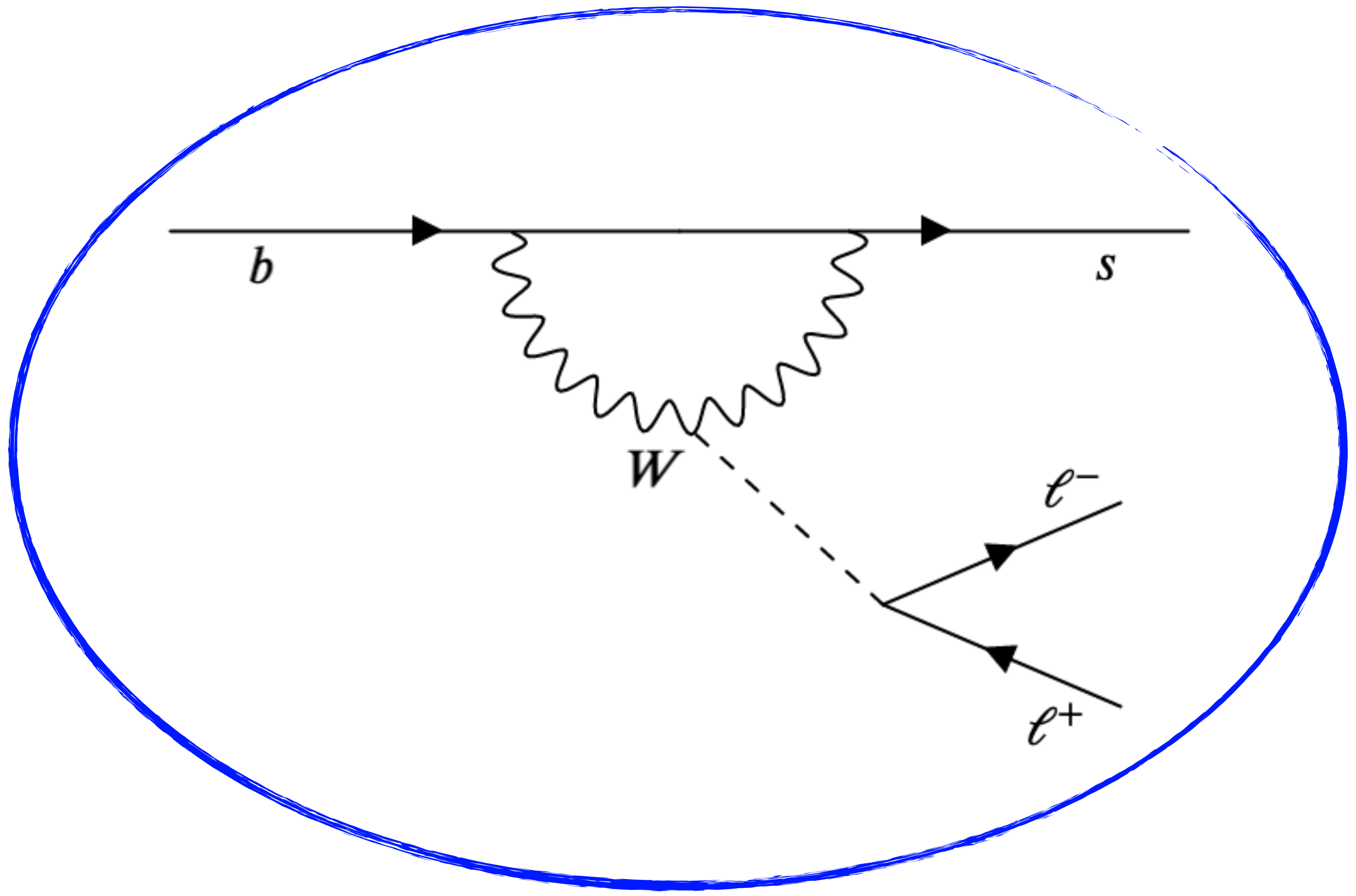
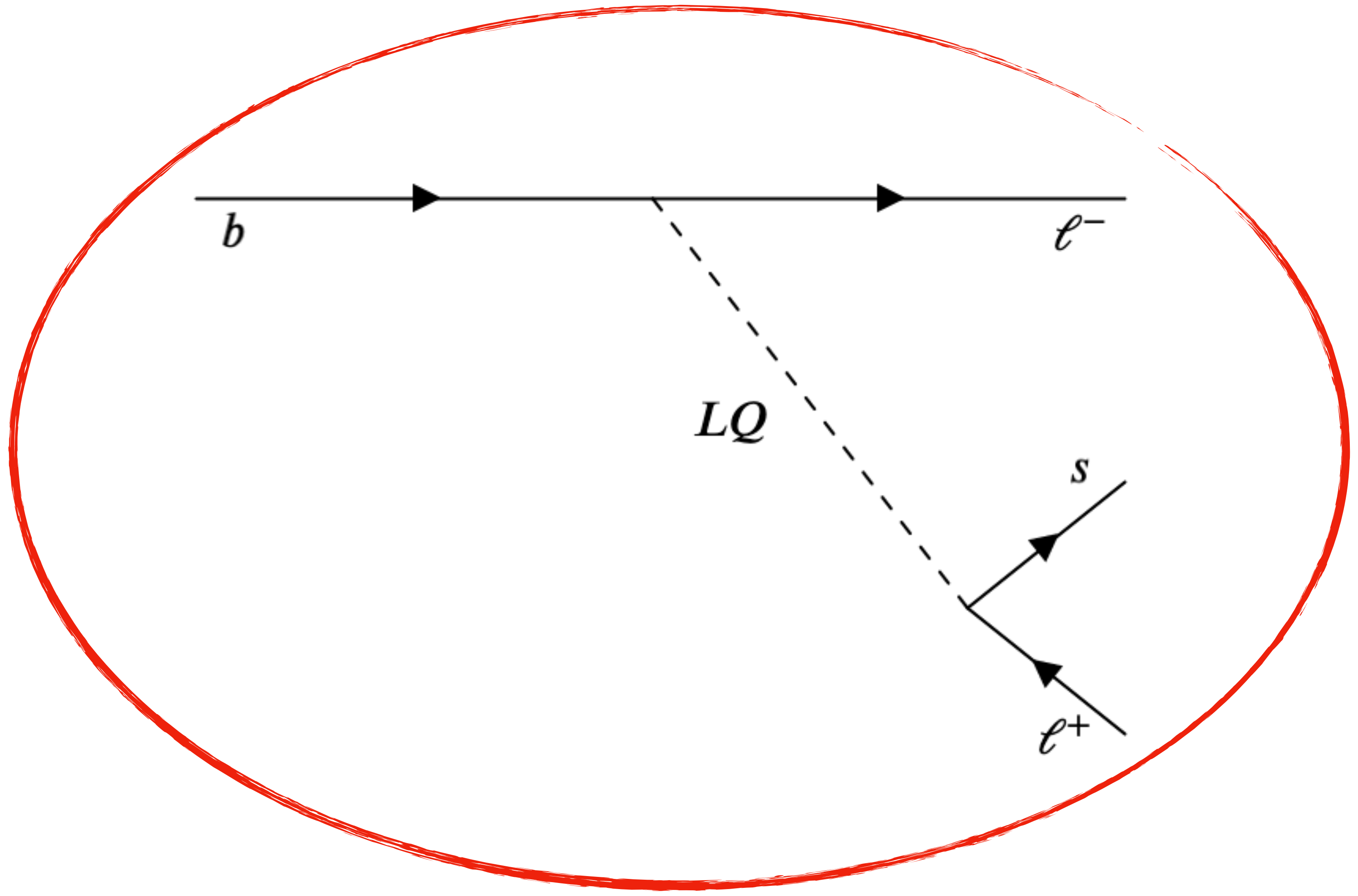
Indirect searches for New Physics with rare B decays

- The Standard Model (SM) of particle physics correctly describes a wide range of phenomena involving elementary particles…
- … but well-established experimental facts (e.g. dark matter and dark energy, matter-antimatter asymmetry, …) motivate the search for a more comprehensive theory
- **Precision measurements can probe New Physics (NP) at much higher scales** than direct searches

- Rare B meson decays offer a rich phenomenology for indirect searches
- $b \to s\, l^+ l^-$ transitions are Flavor Changing Neutral Currents (FCNC) decays: branching ratios of $\mathcal{O}(10^{-9} - 10^{-7})$
- Sensitive to the presence of new virtual particles entering the quantum loops





Effective theories for $b \to s\, l^+ l^-$ decays

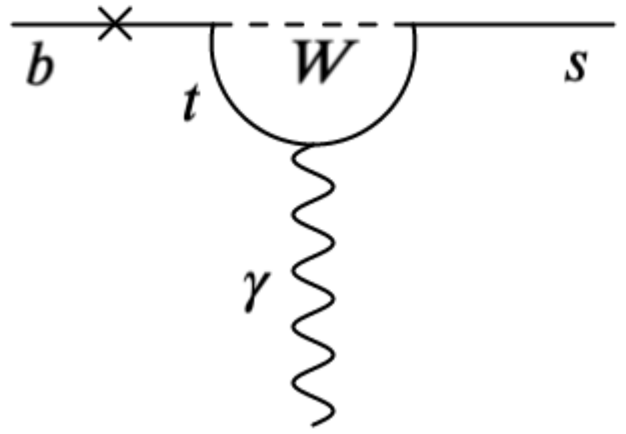
[Rev.Mod.Phys. 68 (1996) 1125-1144]

- Rare B decays described in a model-independent way with **effective hamiltonian**:
  - FCNC processes (high energy contributions) treated as point-like and encoded in Wilson coefficients $C_i(\lambda)$
  - Long-distance physics (low energy contributions) described by effective operators $Q_i(\lambda)$
  - $\lambda = m_b \sim 4\,\text{GeV}$ is the energy scale of the process

$$H_{eff}^{b\to s} = \frac{G_F}{\sqrt{2}} \sum_i V_{ib} V_{is}^* \, C_i(\lambda)\, Q_i(\lambda)$$

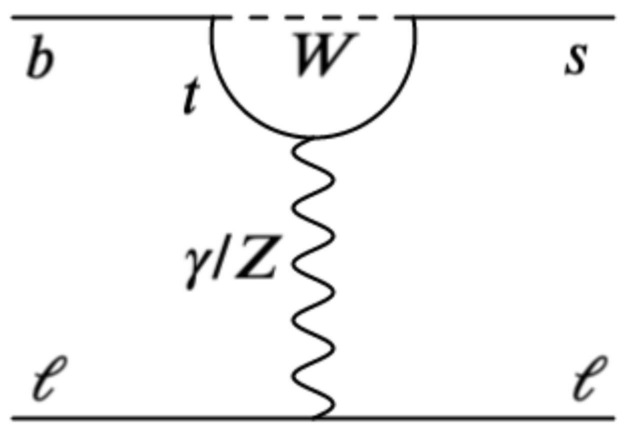
- Dominant SM contributions:

$$Q_7 = \frac{e^2}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu} \text{ (electromagnetic operator)}$$



$$Q_9 = \frac{e^2}{16\pi^2} (\bar{s}_L \gamma_\mu b_L) \sum_l (\bar{l}\gamma^\mu l) \text{ (semi-leptonic vector operator)}$$

$$Q_{10} = \frac{e^2}{16\pi^2} (\bar{s}_L \gamma_\mu b_L) \sum_l (\bar{l}\gamma^\mu \gamma^5 l) \text{ (semi-leptonic axial vector operator)}$$



- NP can modify the values of Wilson coefficients or add new ones
- A **coherent set of "anomalies"** in measurements involving $b \to s\, l^+ l^-$ processes (e.g. [JHEP 06 (2014) 133], [PRL 125 (2020) 011802], [JHEP 08 (2017) 055])
- **Exciting times!** More data needed in order to understand the nature of flavor anomalies

Outline

- In today's talk **recent developments in rare B decays at LHCb**:

1) Measurement of R_K

2) Measurement of the rare $B^0_{(s)} \to \mu^+\mu^-$ decay properties

New! 3) Branching ratio measurement of the rare $B^0_s \to \phi\,\mu^+\mu^-$ decay and first observation of the rare $B^0_s \to f_2'(1525)\,\mu^+\mu^-$

New! 4) Angular analysis of $B^0_s \to \phi\mu^+\mu^-$

5) Angular analysis of $B^+ \to K^{*+}\mu^+\mu^-$

6) Angular analysis of $B^0 \to K^{*0}e^+e^-$ at very low q^2

Measurement of R_K - Strategy

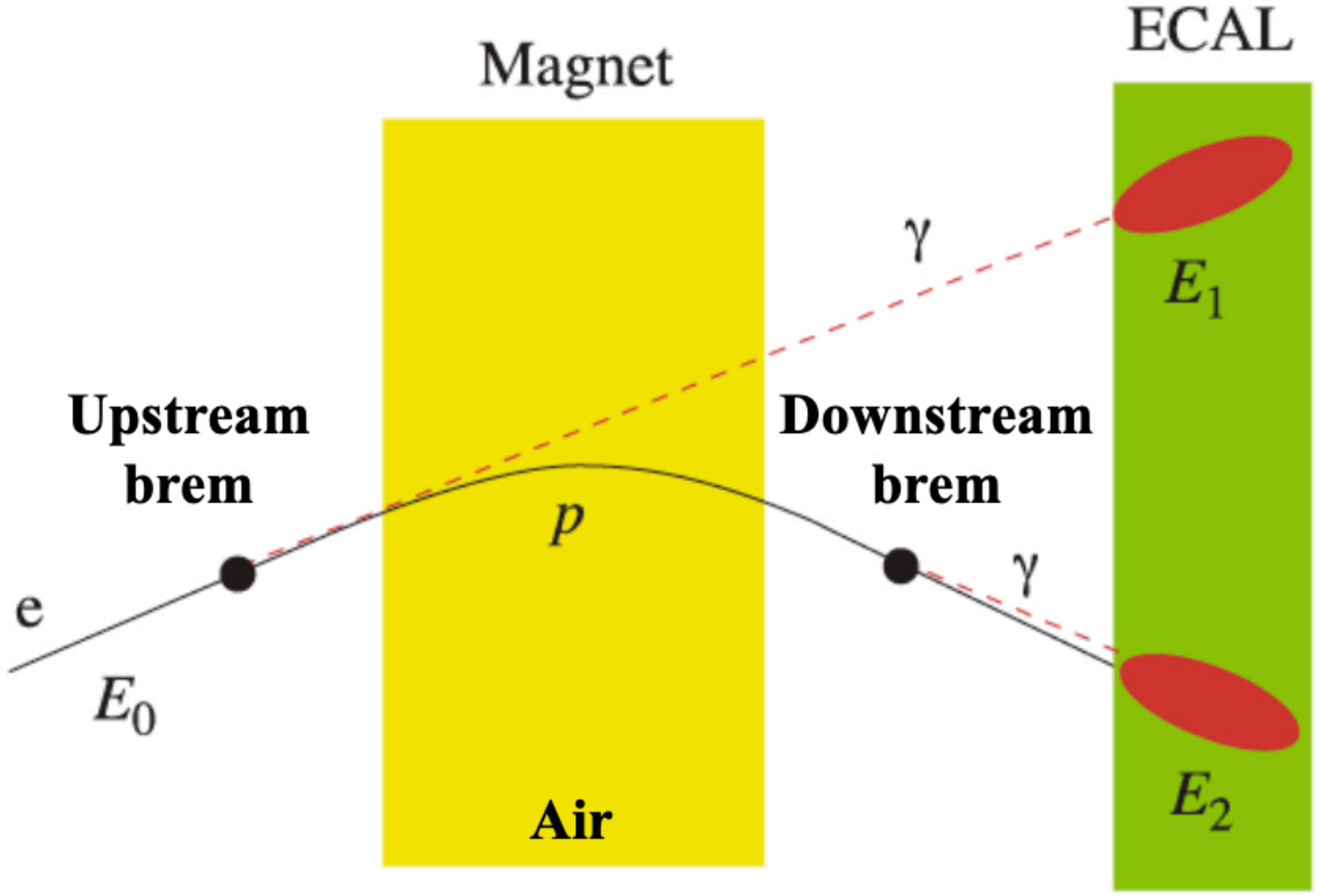
[LHCb-PAPER-2021-004]

$$R_K = \frac{\int_{1.1\,GeV^2}^{6.0\,GeV^2} \frac{d\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{dq^2} dq^2}{\int_{1.1\,GeV^2}^{6.0\,GeV^2} \frac{d\mathcal{B}(B^+ \to K^+e^+e^-)}{dq^2} dq^2}$$

q^2 = **dilepton system invariant mass**

- Measured in $q^2 \in [1.1, 6.0]\ GeV^2$ with **full LHCb dataset (9 fb^{-1})**
- SM predicts $\mathbf{R_K^{SM} \cong 1}$
  - Corrections: $\mathcal{O}(m_\mu^4/q^4) \sim 10^{-4}$ + radiative effects $\mathcal{O}(1\%)$ [JHEP 12 (2007) 040] [Eur.Phys.J. C76 (2016) 8, 440]

- Main challenge is to get **differences between muon and electron detection under control:**
  - Bremsstrahlung photon in the calorimeter emitted before the magnet are "added back"
  - Three trigger categories considered: e± from signal B, K± from signal B, rest of the event



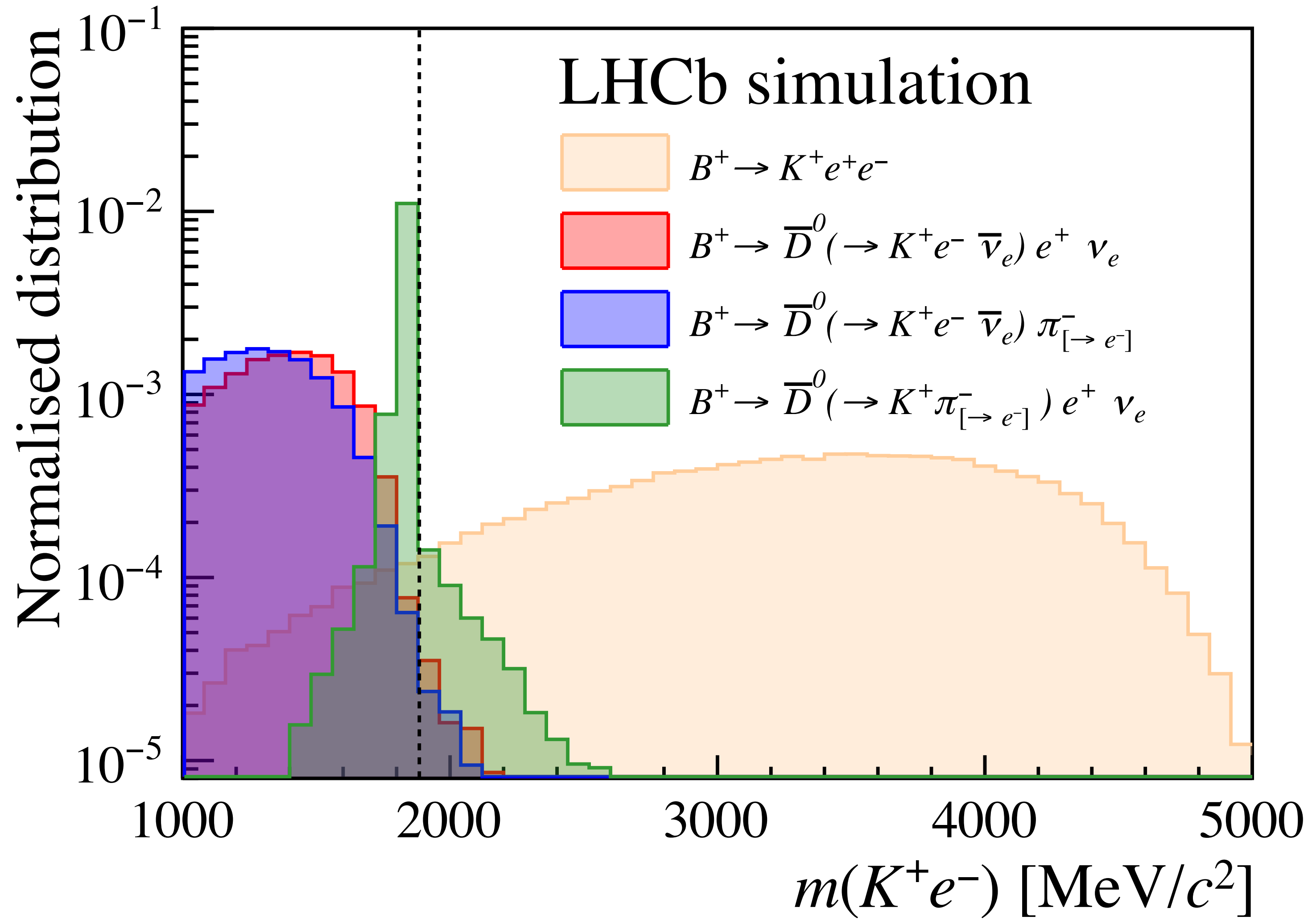
- ***R*$_K$ measured as double ratio** using the $B^+ \to J/\psi K^+$ normalization mode:

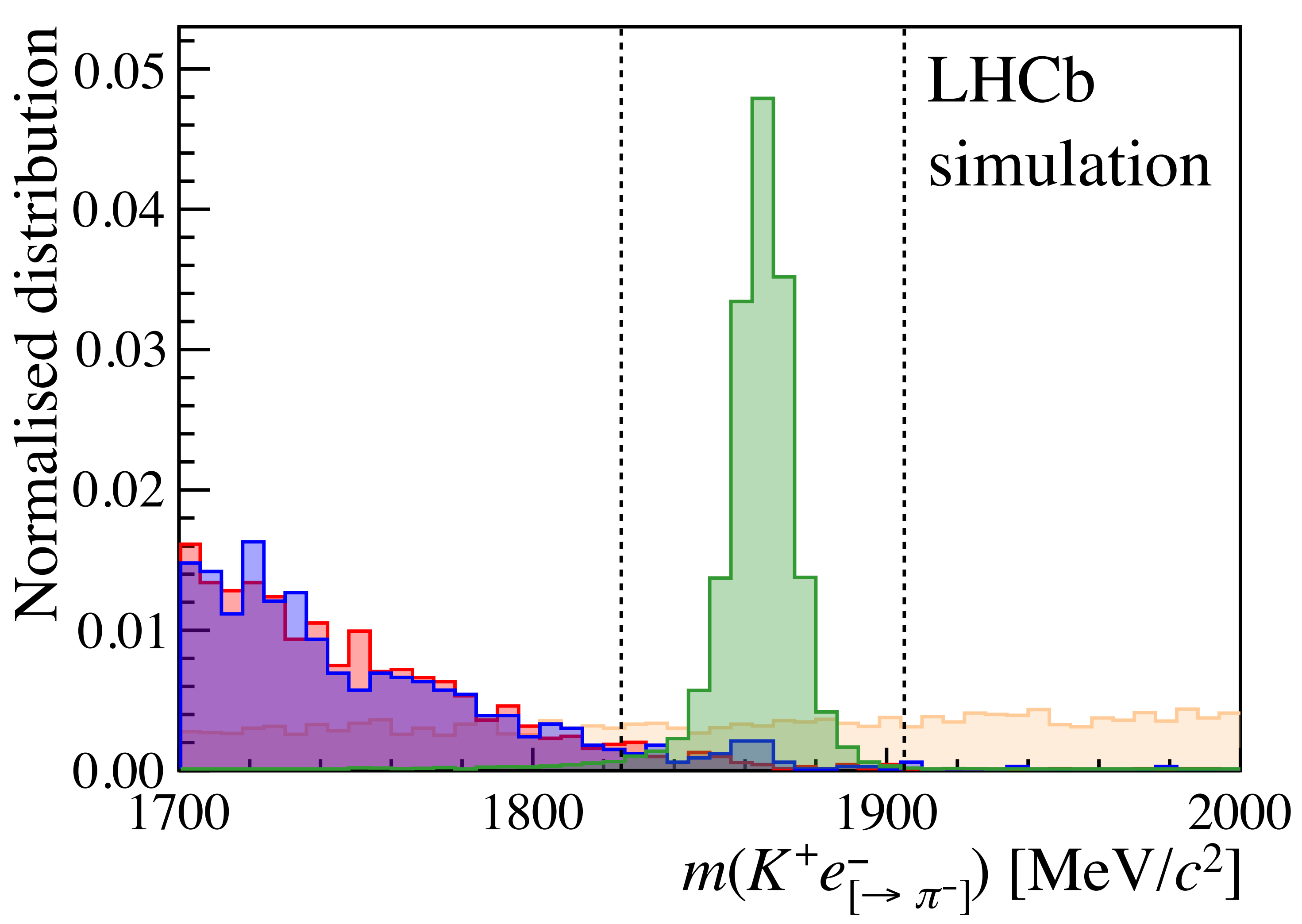
$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to J/\psi(\to \mu^+\mu^-)K^+)} \cdot \frac{\mathcal{B}(B^+ \to J/\psi(\to e^+e^-)K^+)}{\mathcal{B}(B^+ \to K^+e^+e^-)} = \frac{N^{rare}_{\mu^+\mu^-}\,\varepsilon^{norm}_{\mu^+\mu^-}}{N^{norm}_{\mu^+\mu^-}\,\varepsilon^{rare}_{\mu^+\mu^-}} \cdot \frac{N^{norm}_{e^+e^-}\,\varepsilon^{rare}_{e^+e^-}}{N^{rare}_{e^+e^-}\,\varepsilon^{norm}_{e^+e^-}}$$

- **Identical selection for rare and normalization mode**
- Yields extracted from **unbinned extended ML fit to the invariant mass**
- Selection efficiencies corrected for systematic effects

Measurement of R_K - Selection and background rejection

- Candidates are required to come from **displaced and well reconstructed vertices**
- Doubly mis-identified decays rejected with **particle-identification (PID)**, e.g. $B^+ \to K^+\pi^-\pi^+$
- Other mis-identified and partially reconstructed decays **vetoed**:
  - Cascade backgrounds $B \to H_c(\to K^+ l^- \bar{\nu}_l X)\, l^+ \nu_l Y$ reduced by imposing $m(K^+l^-) > m_{D^0}$
  - D^0 mass vetoed applying the pion mass hypothesis on electrons



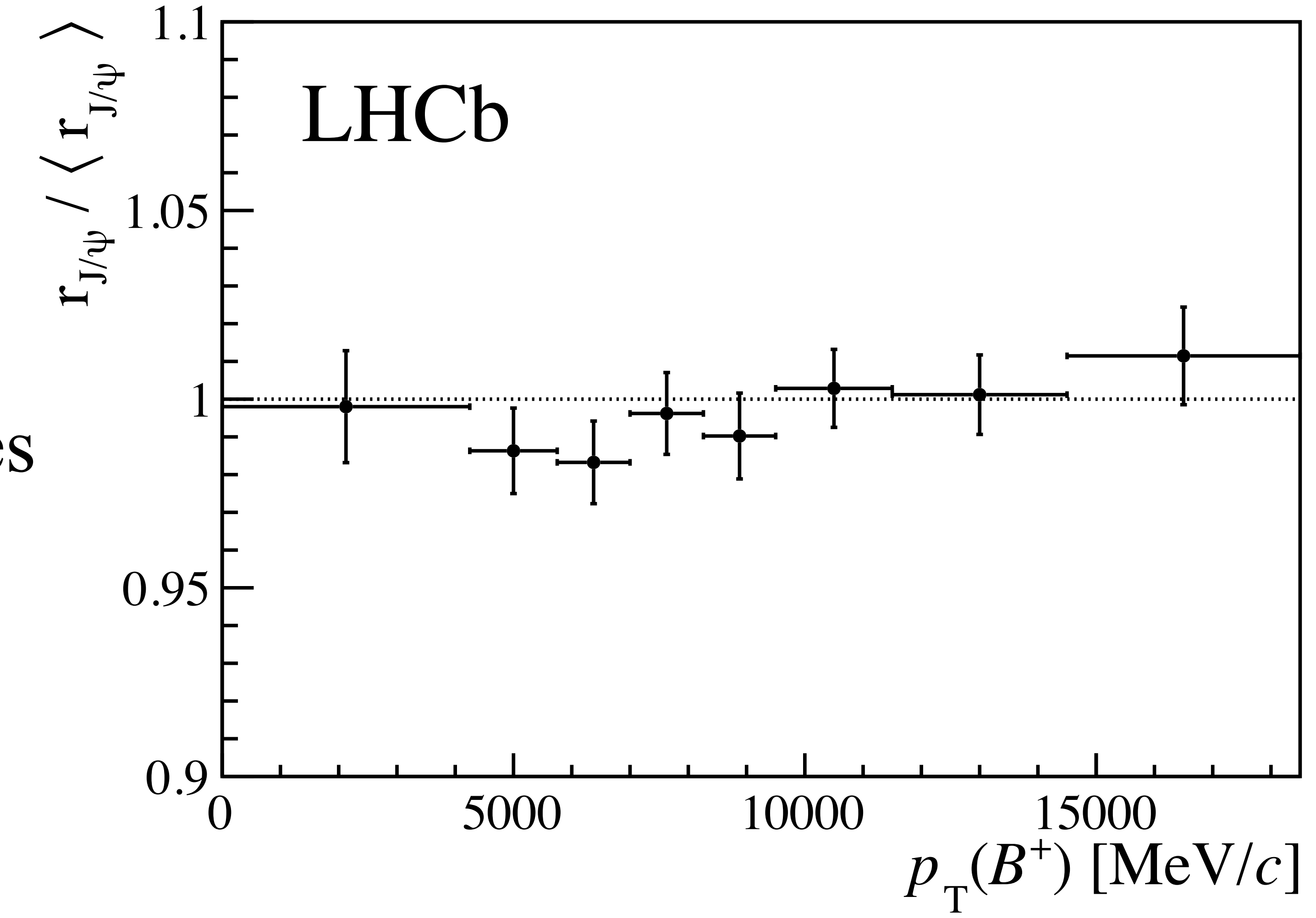


- Boosted Decision Tree (BDT) used to suppress most combinatorial background
- Main background left after selection:
  - Muon mode: combinatorial background + mis-identified $B^+ \to J/\psi\, \pi^+$ in normalization mode
  - Electron mode: combinatorial background + partially reconstructed $B^{(0,+)} \to K^+\pi^{(-,0)}e^+e^-$ and $B^{(0,+)} \to J/\psi(\to e^+e^-)\, K^+\pi^{(-,0)}$

Measurement of R_K - Cross-checks

[LHCb-PAPER-2021-004]

$$r_{J/\psi} = \frac{\mathcal{B}(B^+ \to K^+ J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+ J/\psi(\to e^+e^-))} = \frac{N^{norm}_{\mu^+\mu^-}}{\varepsilon^{norm}_{\mu^+\mu^-}} \cdot \frac{\varepsilon^{norm}_{e^+e^-}}{N^{norm}_{e^+e^-}}$$



- Stringent cross-check on the single ratio $r_{J/\psi}$
- Measurements show $\mathcal{B}(J/\psi \to \mu^+\mu^-) \simeq \mathcal{B}(J/\psi \to e^+e^-)$ with sub-percent precision [PDG]
- **It does not benefit from the double ratio cancellation** of systematic uncertainties in the efficiencies
- **Result: $\mathbf{r_{J/\psi} = 0.981 \pm 0.020}$** (uncertainty includes statistical and systematic contributions)
- Differential $r_{J/\psi}$ as a function of kinematic variables (e.g. $p_T(B^+)$) consistent with unity

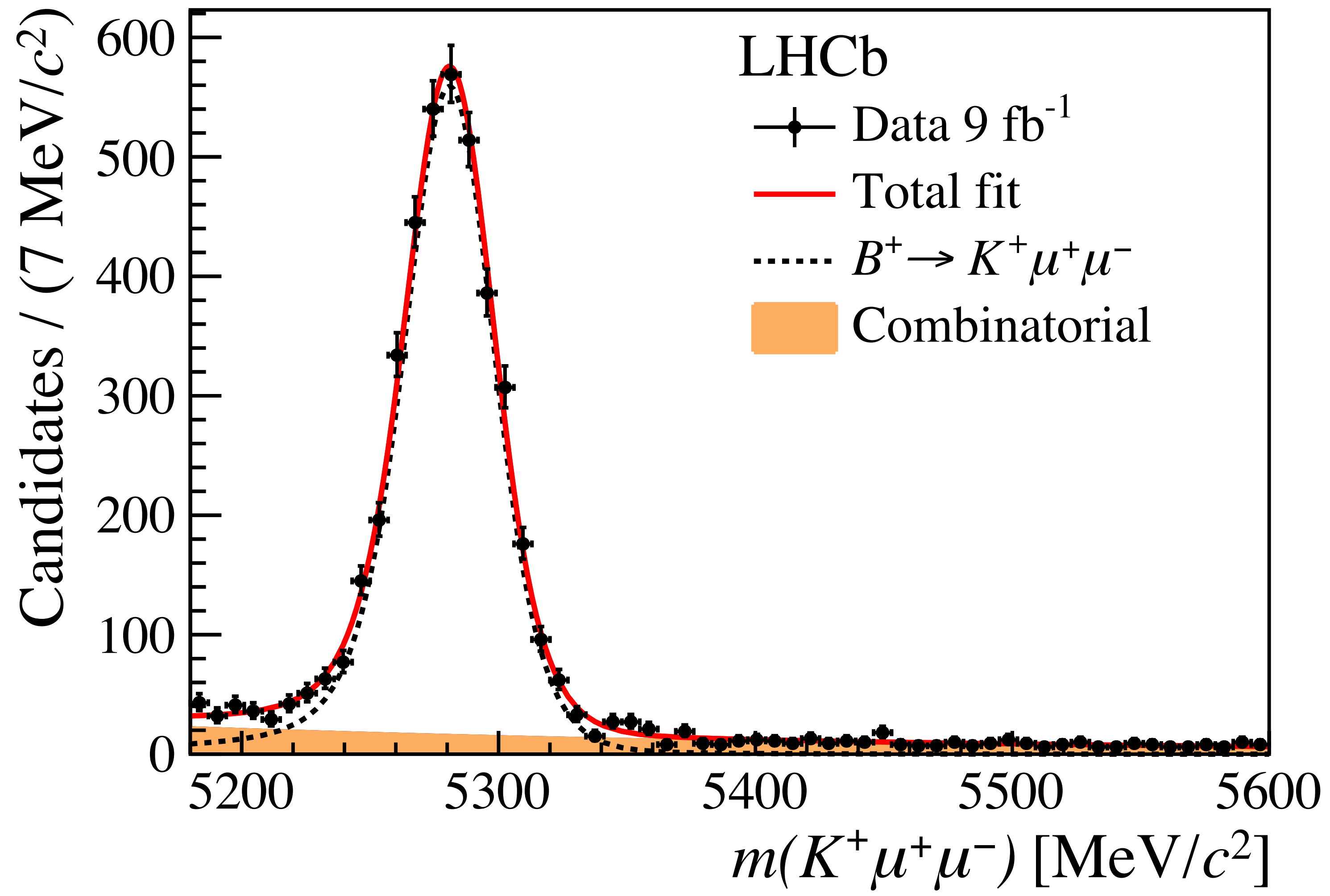
$$R_{\psi(2S)} = \frac{\mathcal{B}(B^+ \to K^+ \psi(2S)(\to \mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+ \psi(2S)(\to e^+e^-))} \cdot \frac{\mathcal{B}(B^+ \to K^+ J/\psi(\to e^+e^-))}{\mathcal{B}(B^+ \to K^+ J/\psi(\to \mu^+\mu^-))}$$

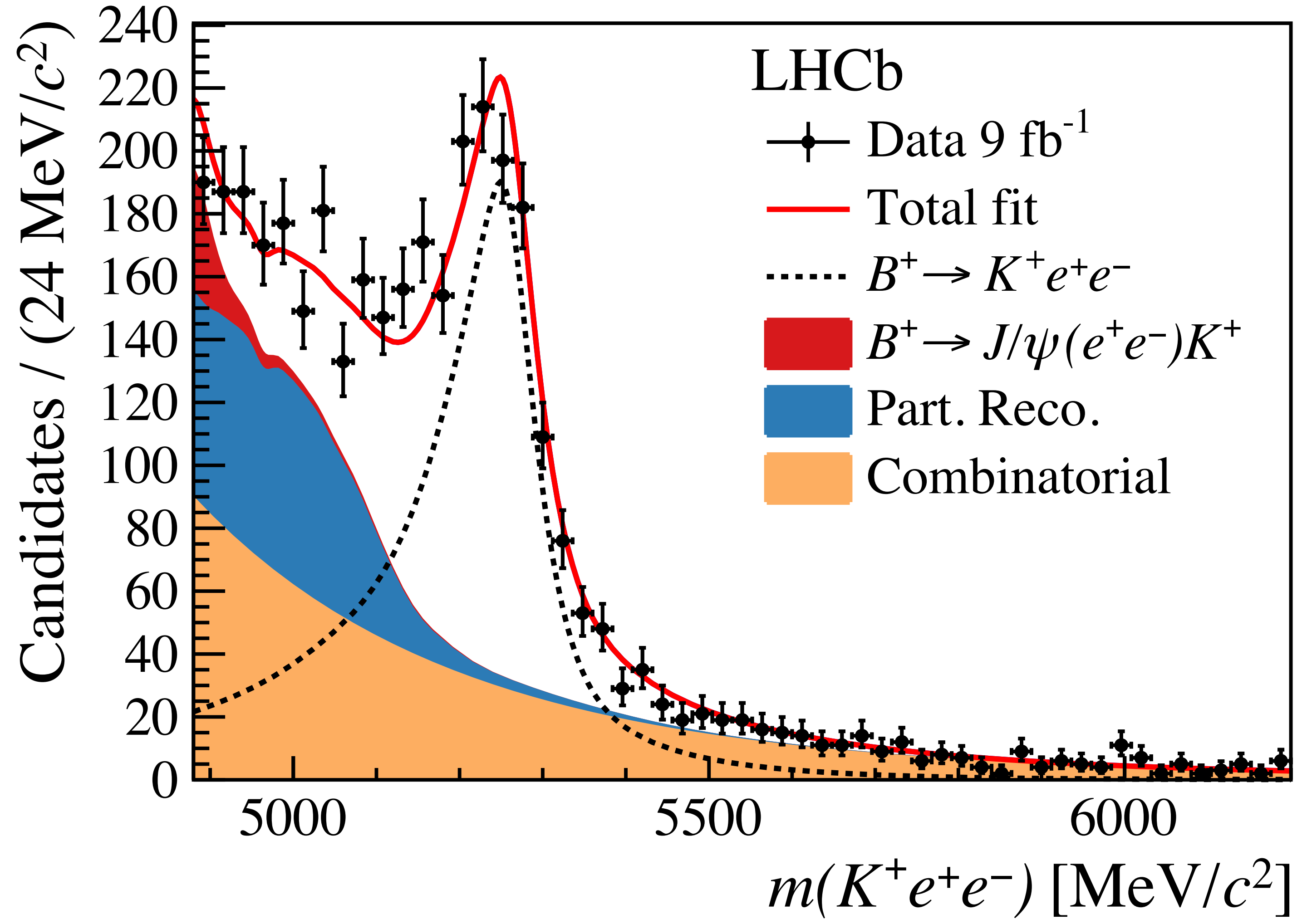
- Additional double-ratio cross-check on $R_{\psi(2S)}$, with q^2 away from J/ψ pole
- **Result: $\mathbf{R_{\psi(2S)} = 0.997 \pm 0.011}$** (uncertainty includes statistical and systematic contributions)

- Cross-checks show that **control of the efficiencies is at $\mathcal{O}(1\%)$**

Measurement of R_K - Results

- Rare modes $B^+ \to K^+ l^+ l^-$ fitted simultaneously in **3 (trigger) × 2 (data-taking runs) categories**
- R_K extracted as parameter of the simultaneous fit, normalization yields incorporated as gaussian constraints

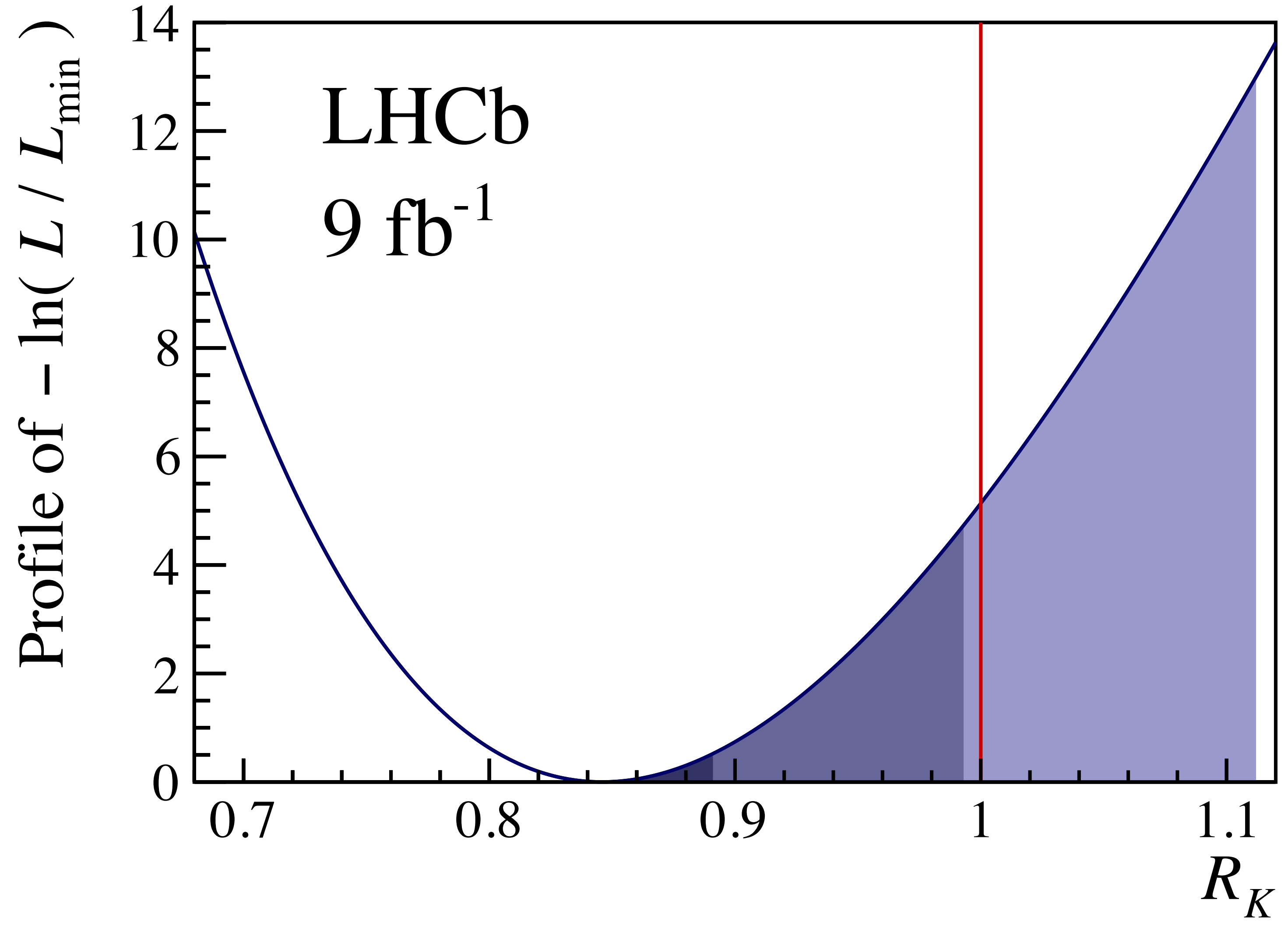




- Final result (first uncertainty is statistical, second is systematic):

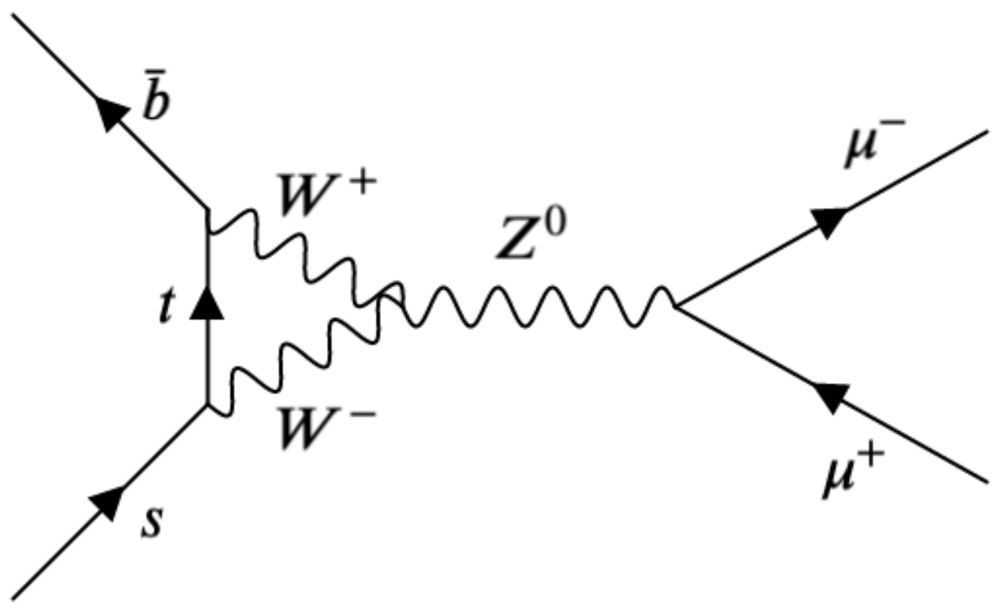
$$R_K(1.1 < q^2 < 6.0\ GeV^2) = 0.846^{+0.042}_{-0.039}{}^{+0.013}_{-0.012}$$

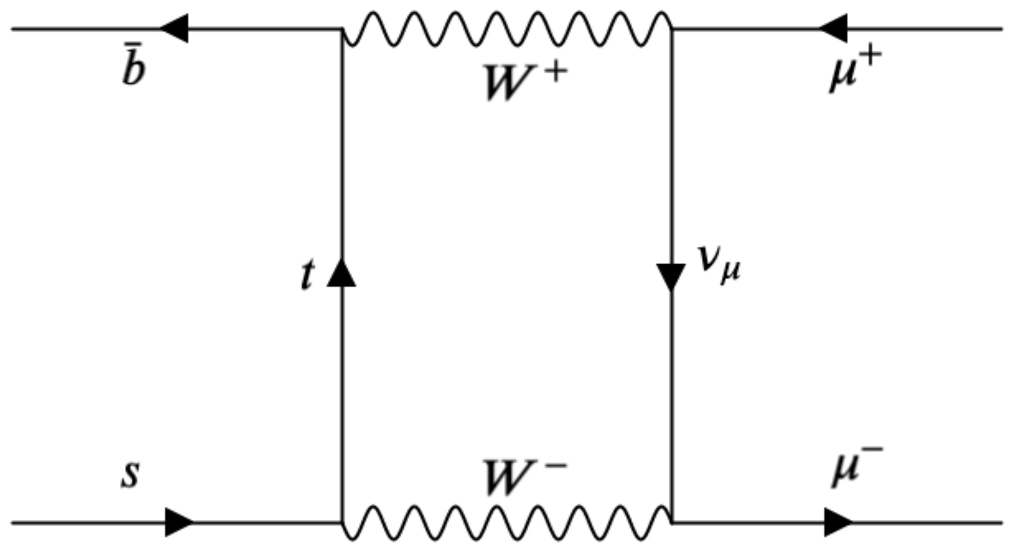
- Uncertainty statistically dominated, main systematic uncertainty ($\mathcal{O}(1\%)$) from fit model of rare electron mode
- **3.1 σ deviation with respect to the SM**: evidence for LFU violation in $B^+ \to K^+ l^+ l^-$ decays



Measurement of the rare $B^0_{(s)} \to \mu^+\mu^-$ decay properties - Introduction

- $B^0_{(s)}$ decays to two muons are FCNC and helicity suppressed





- **Very clean SM prediction** based on C_{10} and single hadronic constant

$$\mathscr{B}(B^0_s \to \mu^+\mu^-)_{SM} = (3.66 \pm 0.14) \times 10^{-9}$$

$$\mathscr{B}(B^0 \to \mu^+\mu^-)_{SM} = (1.03 \pm 0.05) \times 10^{-10}$$

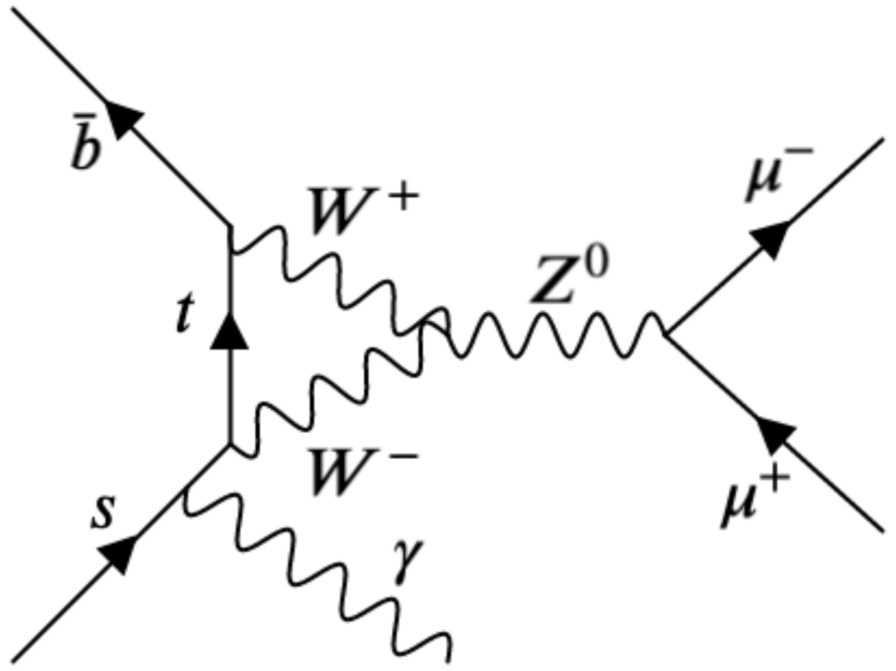
[JHEP 10 (2019) 232]

$$\tau_{B^0_s \to \mu^+\mu^-} = \frac{\tau_{B^0_s}}{1-y_s^2}\left[\frac{1+2\mathscr{A}_{\Delta\Gamma_s} y_s + y_s^2}{1+\mathscr{A}_{\Delta\Gamma_s} y_s}\right]$$

$$y_s \equiv \frac{\Delta\Gamma_s}{2\Gamma_s} \qquad \mathscr{A}_{\Delta\Gamma_s} \equiv \frac{R_H^{\mu^+\mu^-} - R_L^{\mu^+\mu^-}}{R_H^{\mu^+\mu^-} + R_L^{\mu^+\mu^-}}$$

- In the SM, only the heavy mass eigenstate contributes to effective lifetime: $\mathscr{A}^{SM}_{\Delta\Gamma_s} = +1$
- NP can modify $\mathscr{A}_{\Delta\Gamma_s}$ even if branching fractions are not modified

- Today: **results with full LHCb dataset**
    - Bonus: Search for $B^0_s \to \mu^+\mu^-\gamma$ (ISR)



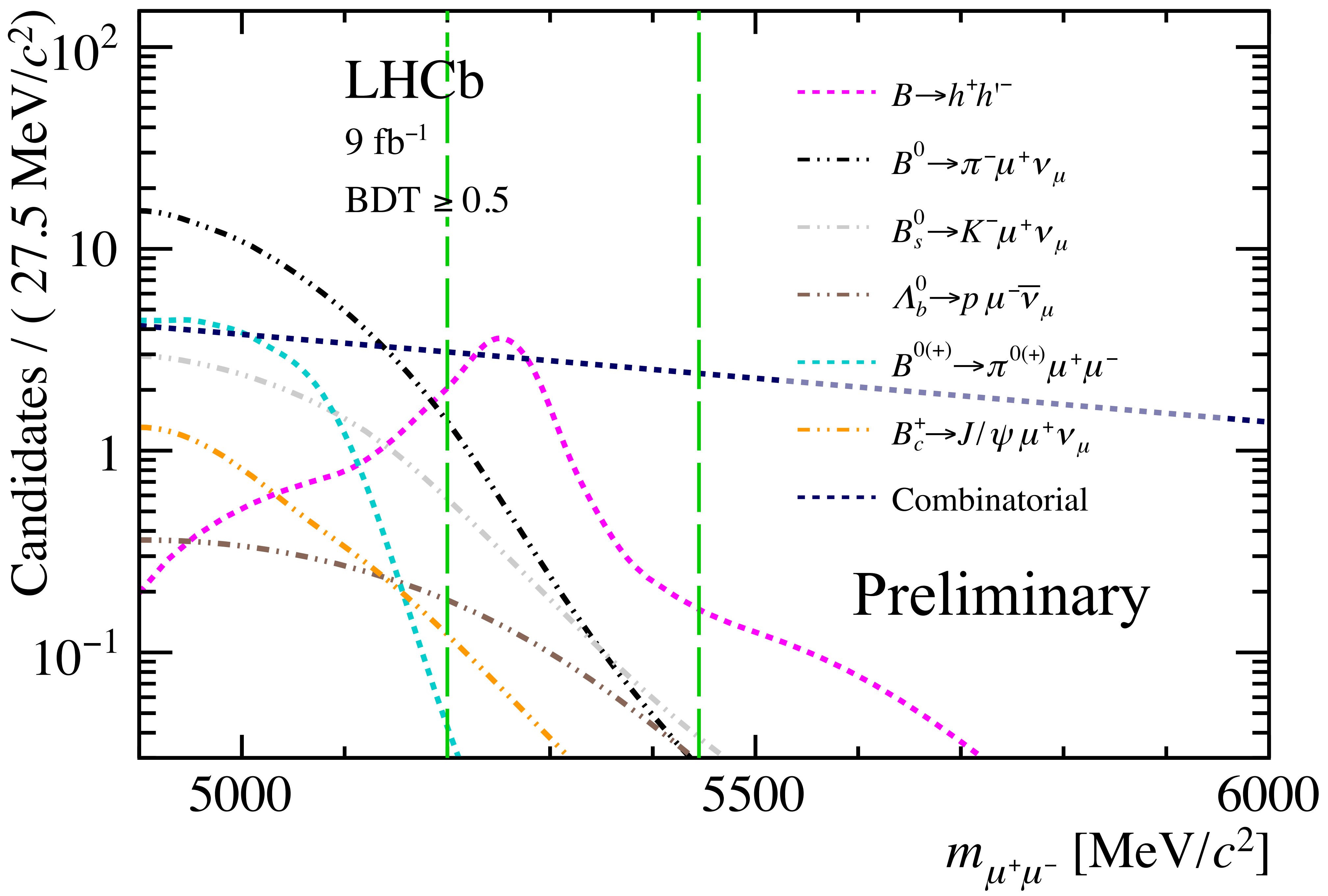
- $\mathcal{O}(10^{-10})$ in the SM

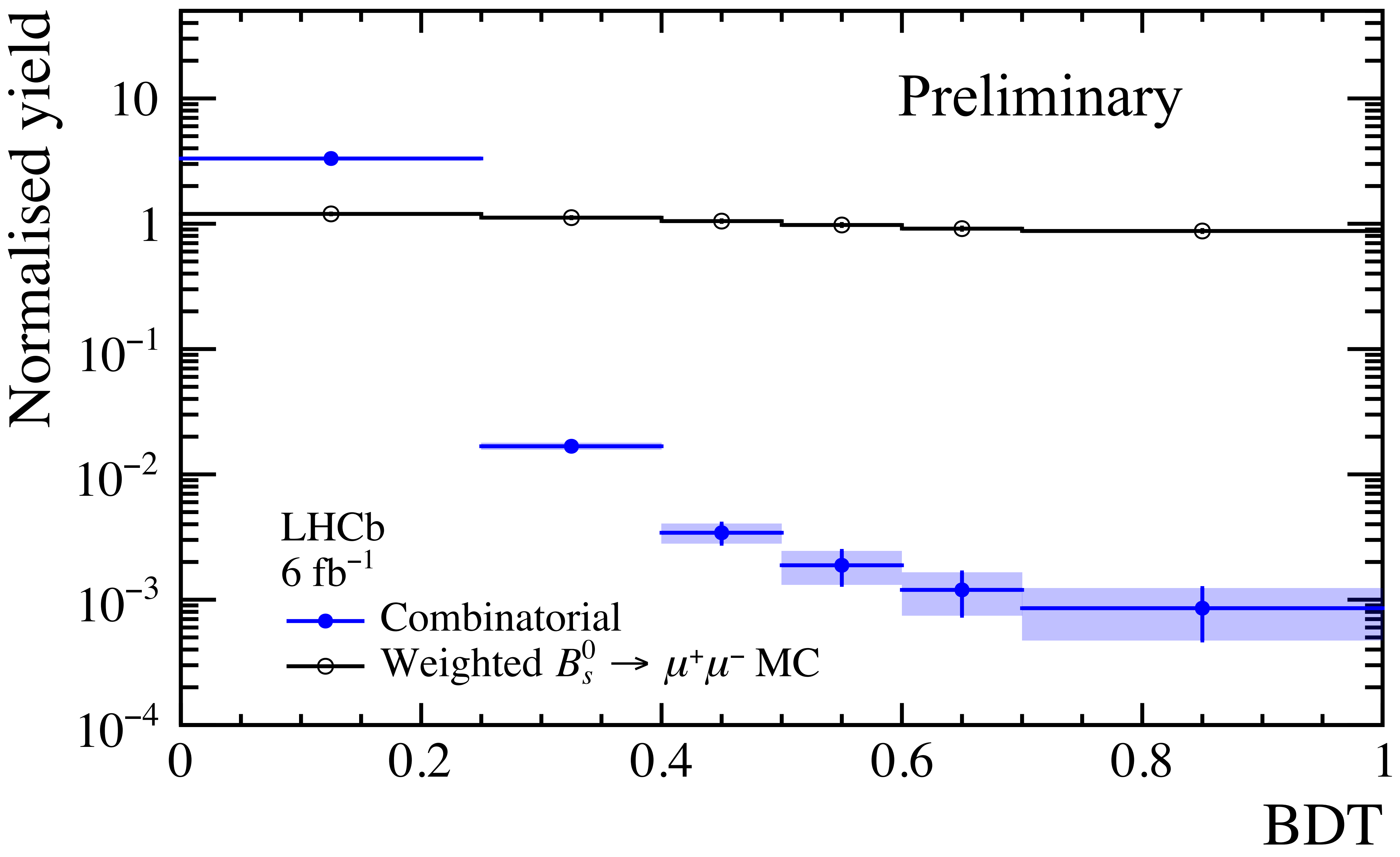
[JHEP 11 (2017) 184]

Measurement of the rare $B^0_{(s)} \to \mu^+\mu^-$ decay properties - Strategy

[LHCb-PAPER-2021-007] (in preparation)

- Two normalization channels used: $B^0 \to K^+\pi^-$ and $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$
- Strong PID cut on muons, **backgrounds left**: combinatorial, partially reconstructed semileptonic, doubly mis-identified $B^0_{(s)} \to h^+h^-$
- Simultaneous invariant mass fit over **5 (bins of BDT) × 2 (data-taking runs) categories**, first BDT bin rejected since background dominated





- Mis-identified and partially reconstructed background yields estimated with simulation and fixed in mass fit
- Combinatorial background floating component

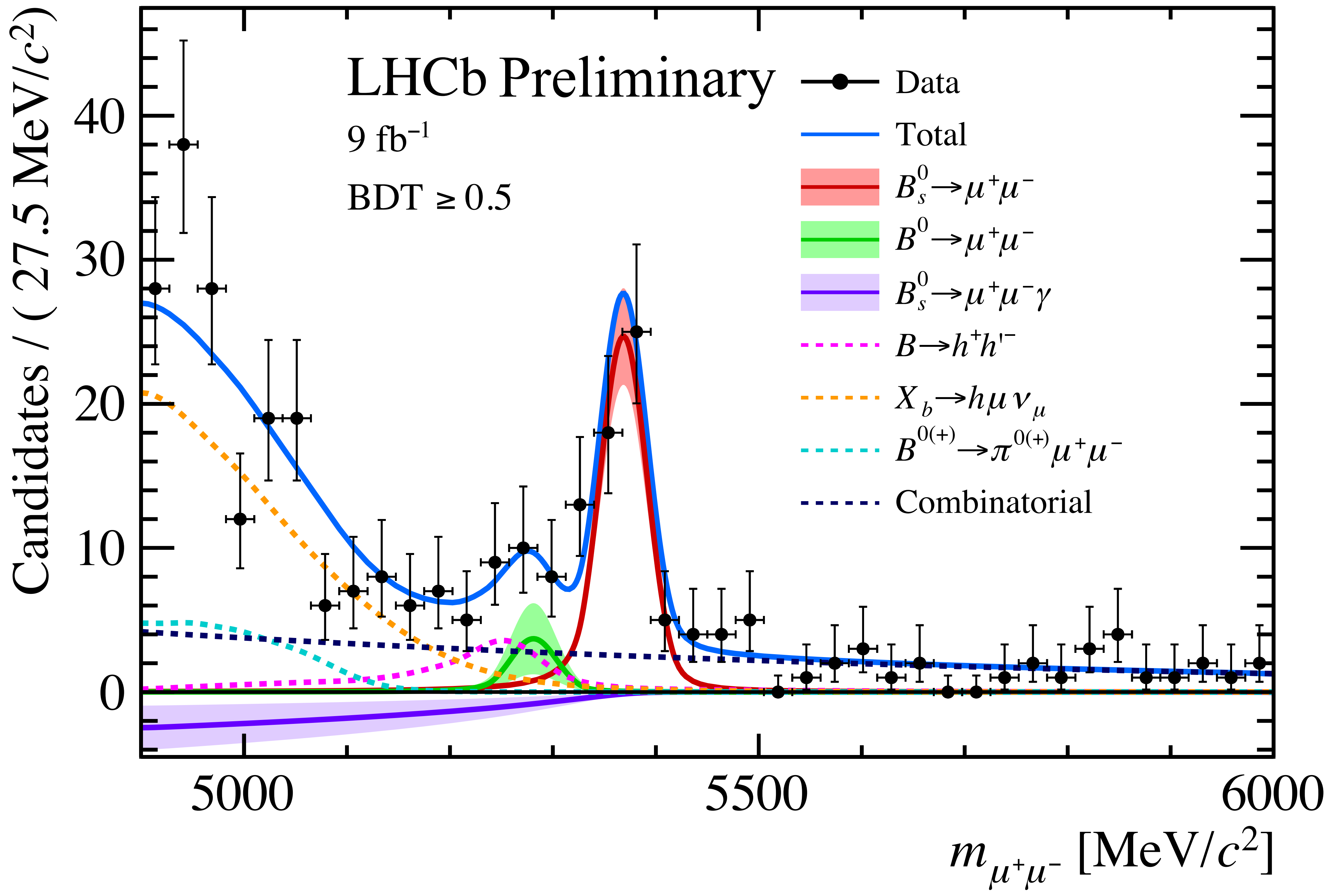
Measurement of the rare $B^0_{(s)} \to \mu^+\mu^-$ decay properties - Branching ratio

[LHCb-PAPER-2021-007] (in preparation)

- **Mass fit results** (first uncertainty statistical, second systematic):
  - $\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.09^{+0.46}_{-0.43}{}^{+0.15}_{-0.11}) \times 10^{-9}$ ($10.8\,\sigma$) in agreement with SM
  - $B^0 \to \mu^+\mu^-$ compatible with background at $1.7\,\sigma$
  - $B^0_s \to \mu^+\mu^-\gamma$ compatible with background at $1.5\,\sigma$

Preliminary

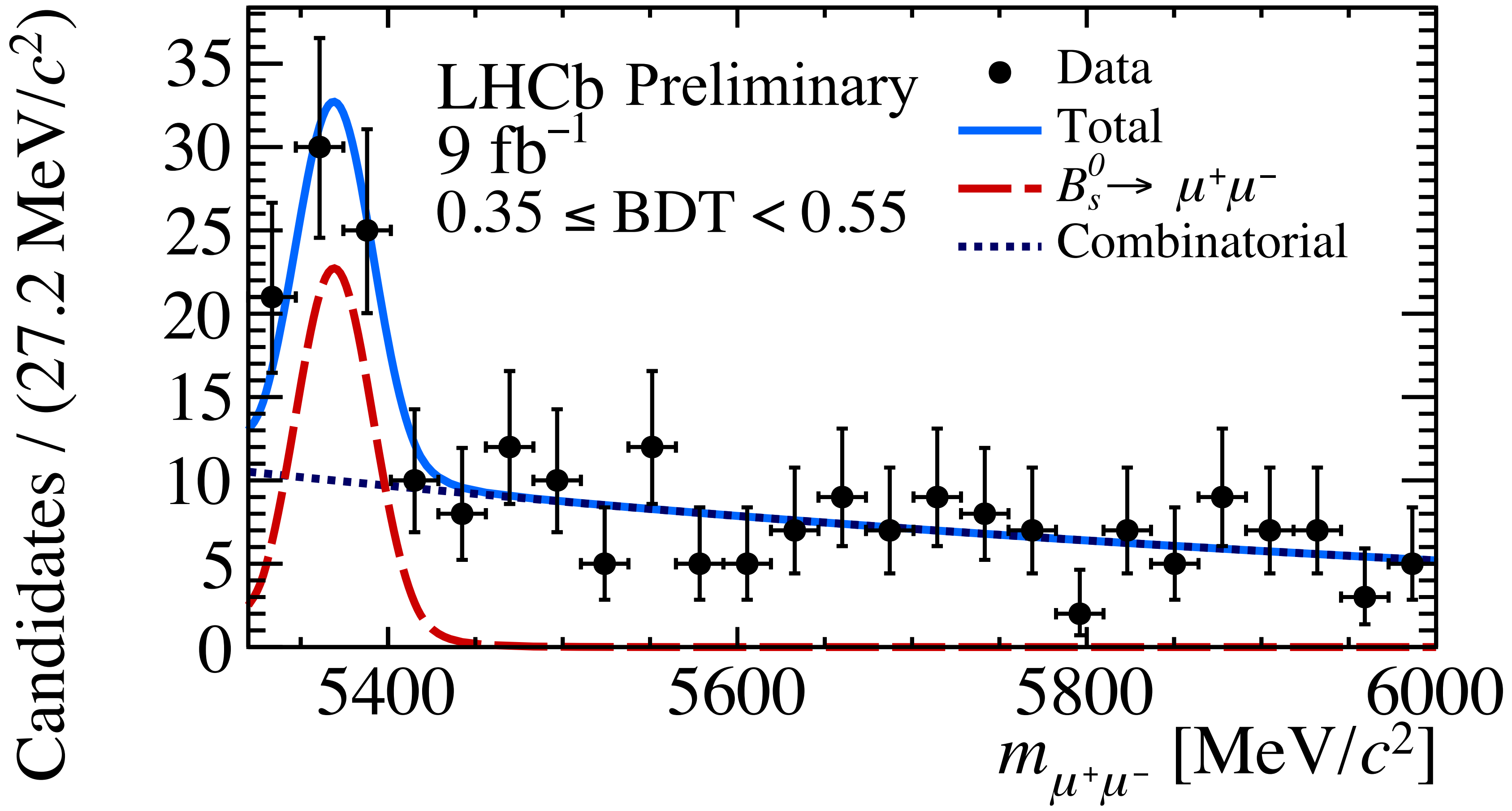
- **Limits set with CLs method:**
  - $\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}$ (95 % CL)
  - $\mathcal{B}(B^0_s \to \mu^+\mu^-\gamma)_{m_{\mu^+\mu^-} > 4.9 GeV} < 2.0 \times 10^{-9}$ (95 % CL)

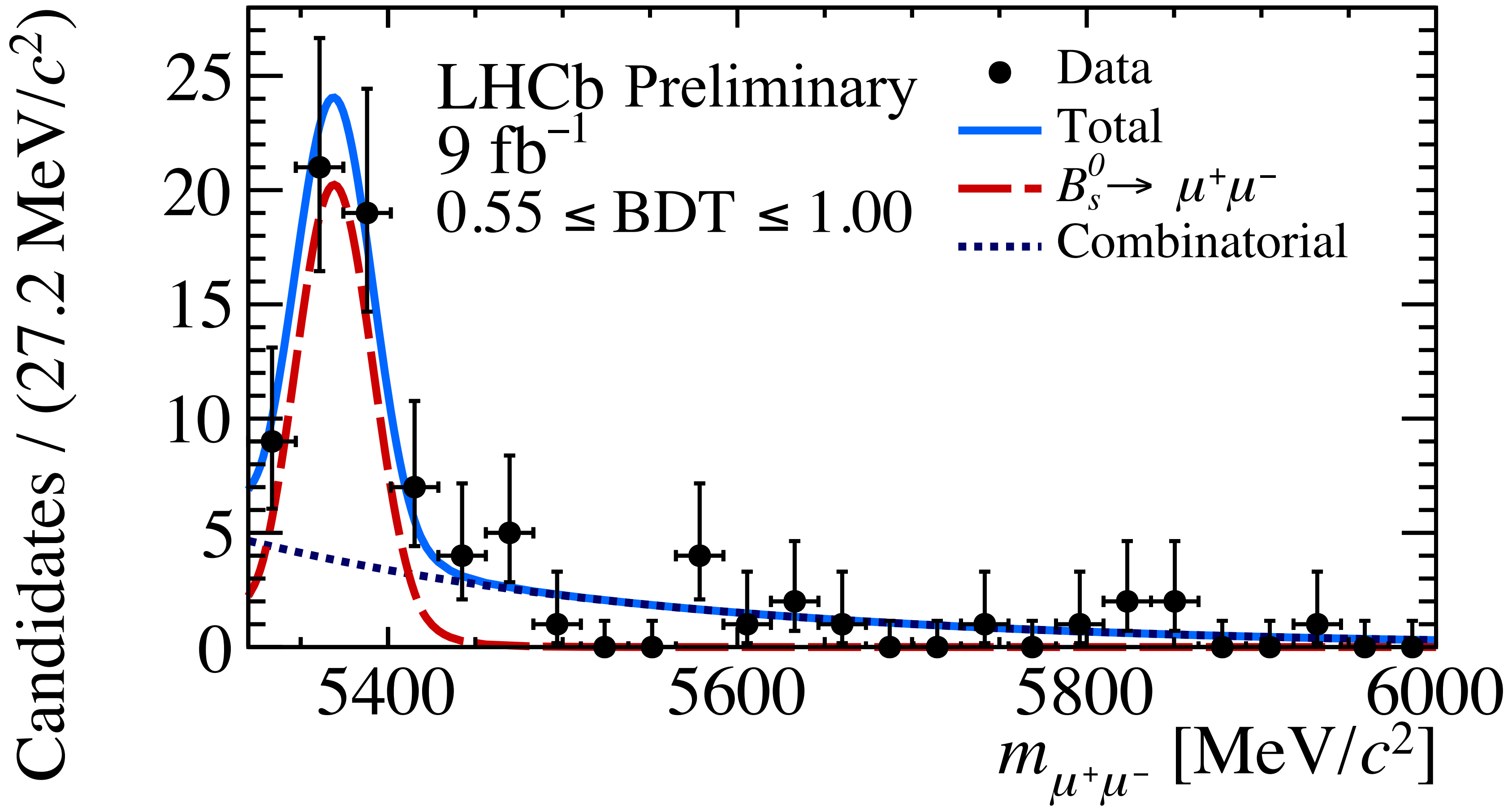


- Uncertainty statistically dominated
- Main systematic uncertainties: for $B^0_s \to \mu^+\mu^-$ fragmentation fraction ratio (~ 3%), for $B^0 \to \mu^+\mu^-$ exclusive background mass model (~ 4%)

Measurement of the rare $B^0_{(s)} \to \mu^+\mu^-$ decay properties - Effective lifetime [LHCb-PAPER-2021-007] (in preparation)

- For effective lifetime measurement, **tighter mass window chosen**: no mis-identified or partially reconstructed background
- Looser PID requirement needed
- **Mass fit performed on two BDT bins to extract sWeights** [Nucl.Instrum.Meth. A555: 356-369, 2005]



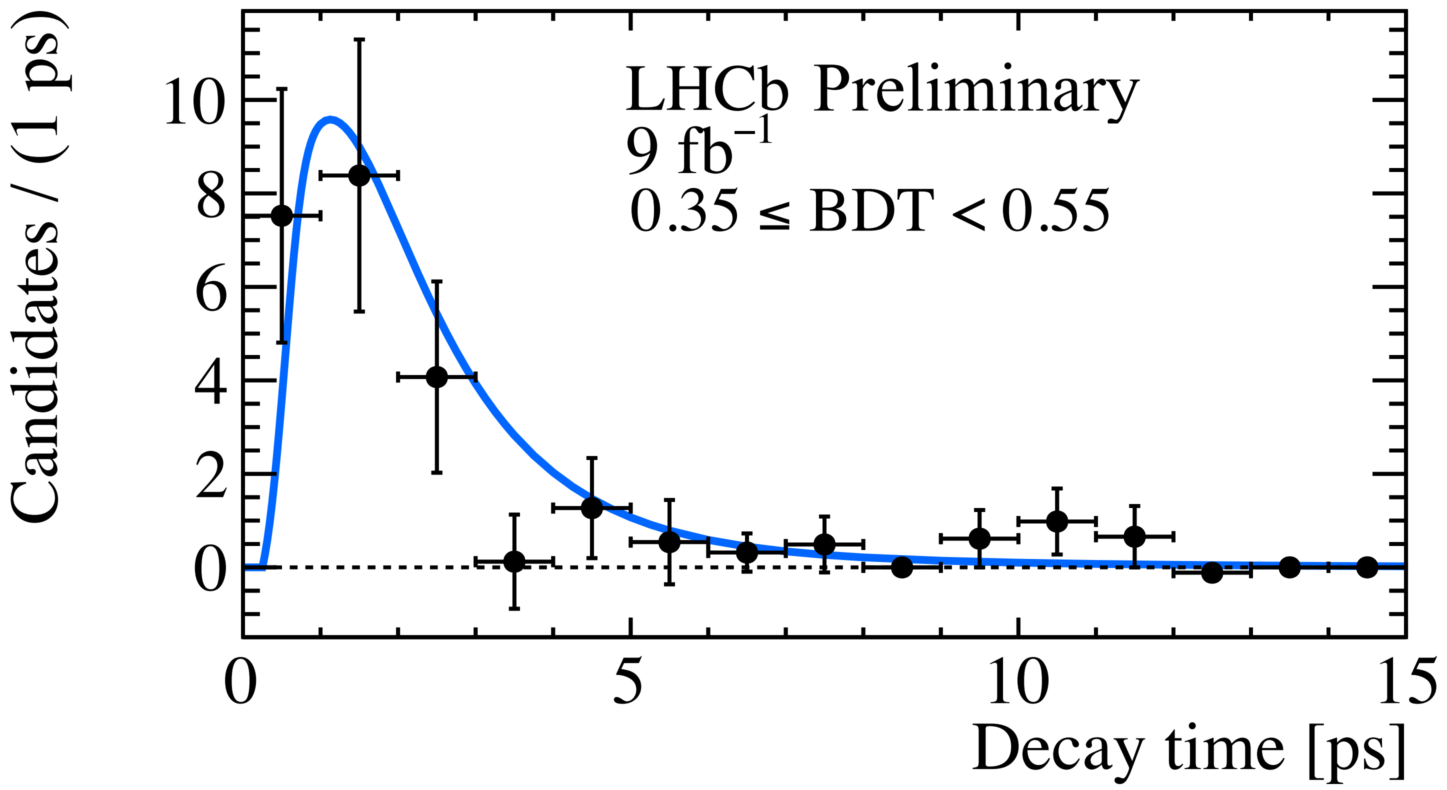


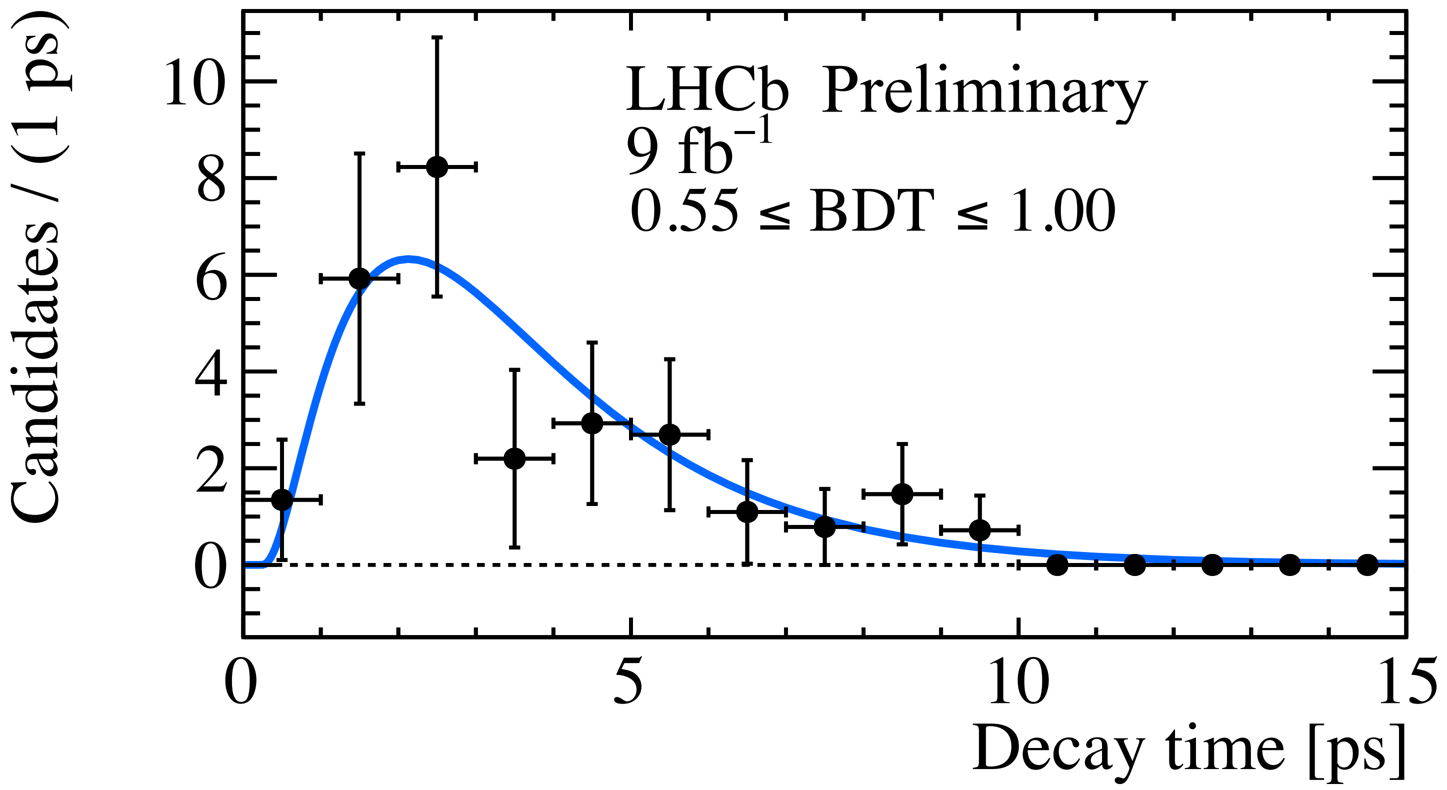
- Final fit on background-subtracted decay time distribution

$$\tau_{B^0_s \to \mu^+\mu^-} = 2.07 \pm 0.29 \pm 0.03 \text{ ps}$$

Preliminary

- First uncertainty statistical, second systematic
- Result compatible with $\mathscr{A}_{\Delta\Gamma_s} = +1$ at $1.5\,\sigma$





Branching ratio measurement of the rare $B_s^0 \to \phi \mu^+\mu^-$ decay - Strategy

New! [LHCb-PAPER-2021-014]

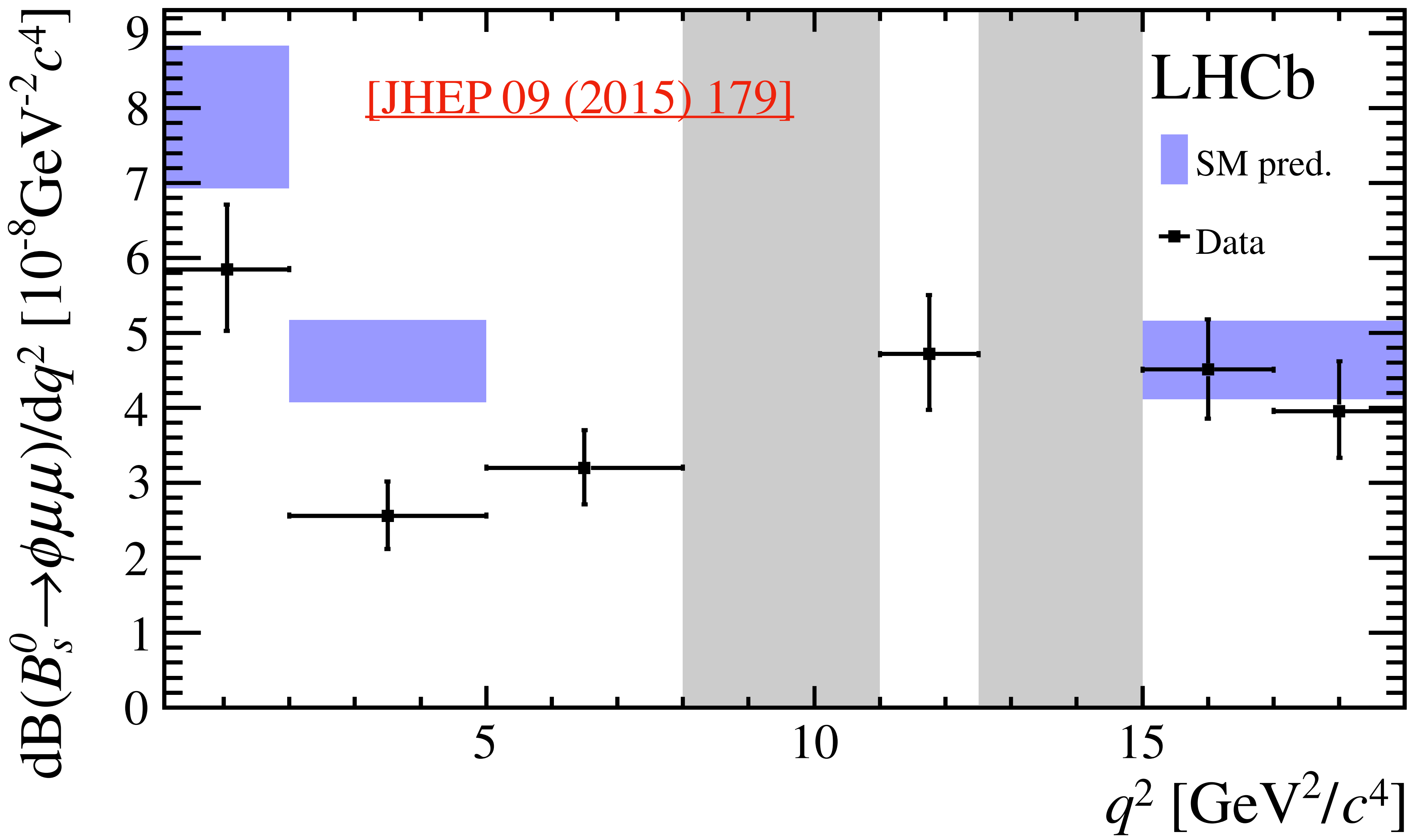
- Reconstructed through the decay $\phi \to K^+K^-$
- SM prediction in $1.1 < q^2 < 6.0\, GeV^2$:
  - $(5.37 \pm 0.66) \times 10^{-8}\, GeV^{-2}$ from Light Cone Sum Rules + Lattice QCD
  - $(4.77 \pm 1.01) \times 10^{-8}\, GeV^{-2}$ from Light Cone Sum Rules

[Eur.Phys.J. C75 (2015) 382] [JHEP 08 (2016) 098] [arXiv:1810.08132] [PoS LATTICE2014 (2015) 372] [Phys.Rev.Lett. 112 (2014) 212003]

- Differential branching fraction determined in bins of q^2 relative to the $B_s^0 \to J/\psi\,(\to \mu^+\mu^-)\,\phi$ normalization mode

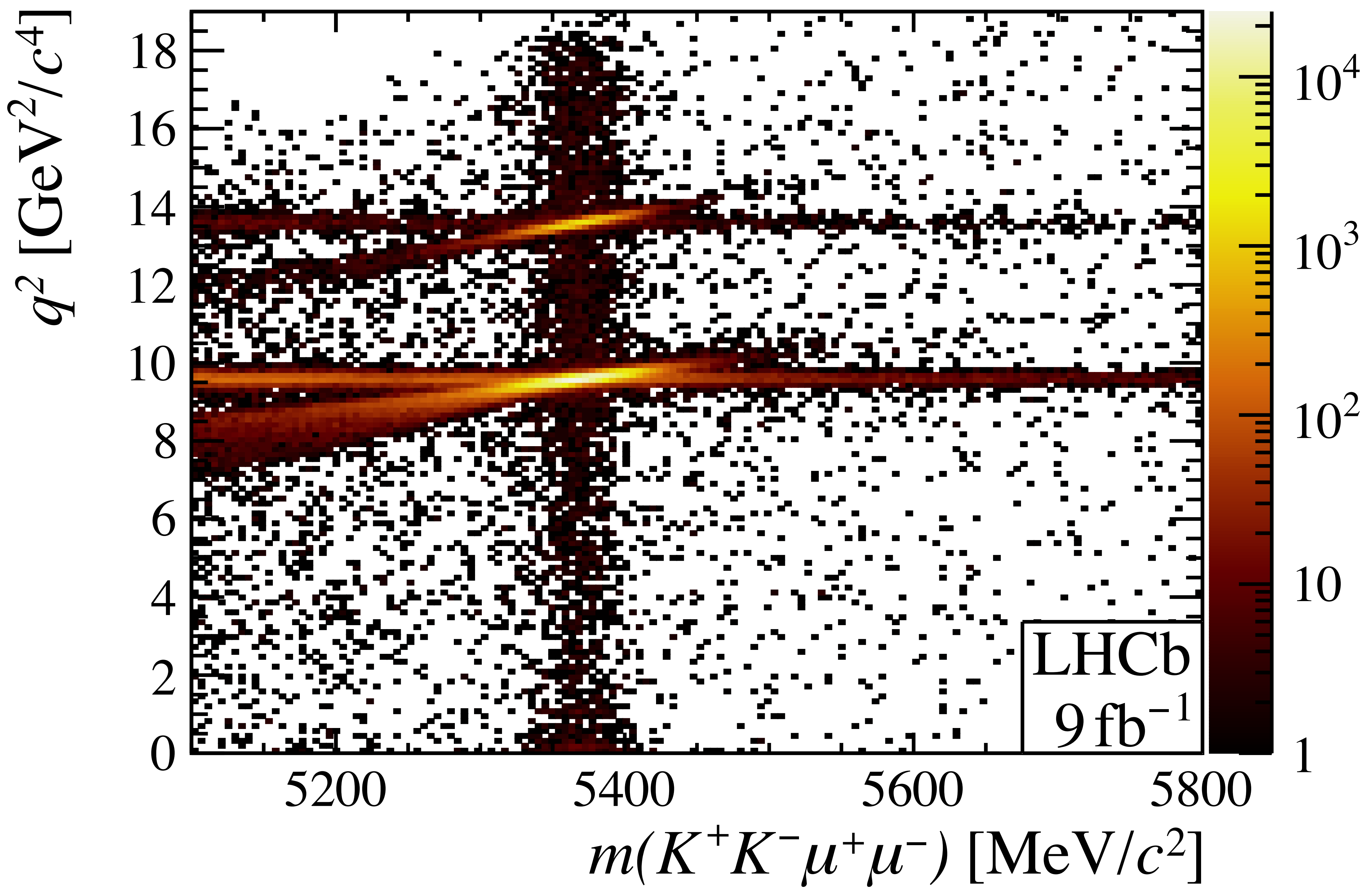
$$\frac{d\mathcal{B}(B_s^0 \to \phi\,\mu^+\mu^-)}{dq^2} = \frac{\mathcal{B}(B_s^0 \to J/\psi\,\phi) \cdot \mathcal{B}(J/\psi \to \mu^+\mu^-)}{q^2_{max} - q^2_{min}} \cdot \frac{N_{rare}}{N_{norm}} \cdot \frac{\varepsilon_{norm}}{\varepsilon_{rare}}$$

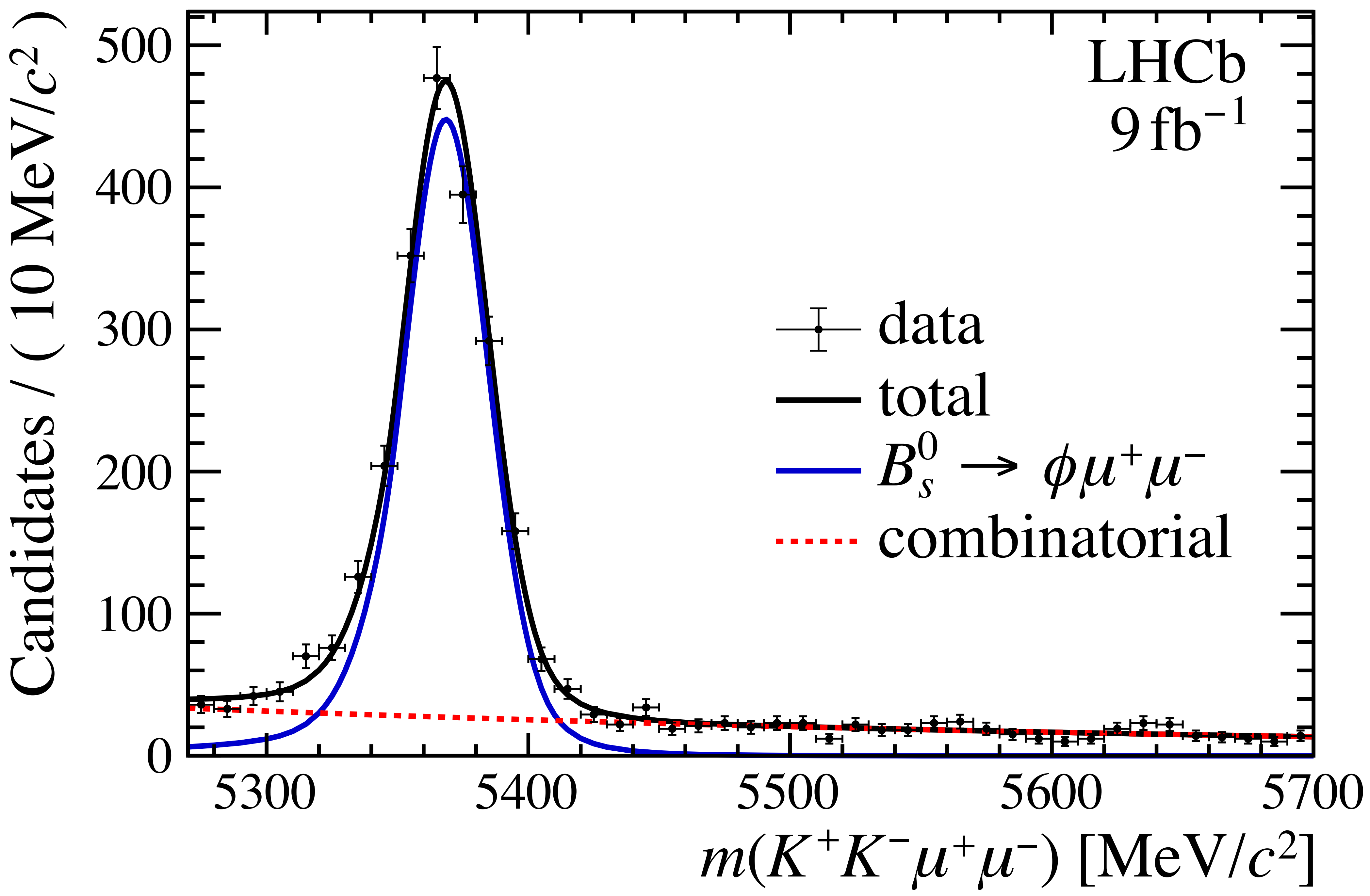
- **Previously measured by LHCb using Run 1 data (3 fb^{-1})**
- $3\,\sigma$ deviation with respect to the SM in $1.0 < q^2 < 6.0\, GeV^2$
- Today: **update with full LHCb dataset**



Branching ratio measurement of the rare $B_s^0 \to \phi \mu^+ \mu^-$ decay - Selection

- Candidates selected from **displaced and well reconstructed vertices**
- $|m(K^+K^-) - m_\phi| < 12\,MeV$
- For rare mode, vetoes on q^2 values corresponding to J/ψ, $\psi(2S)$, ϕ
- Background from mis-identified particles rejected with PID requirements
- Combinatorial background reduced with a BDT

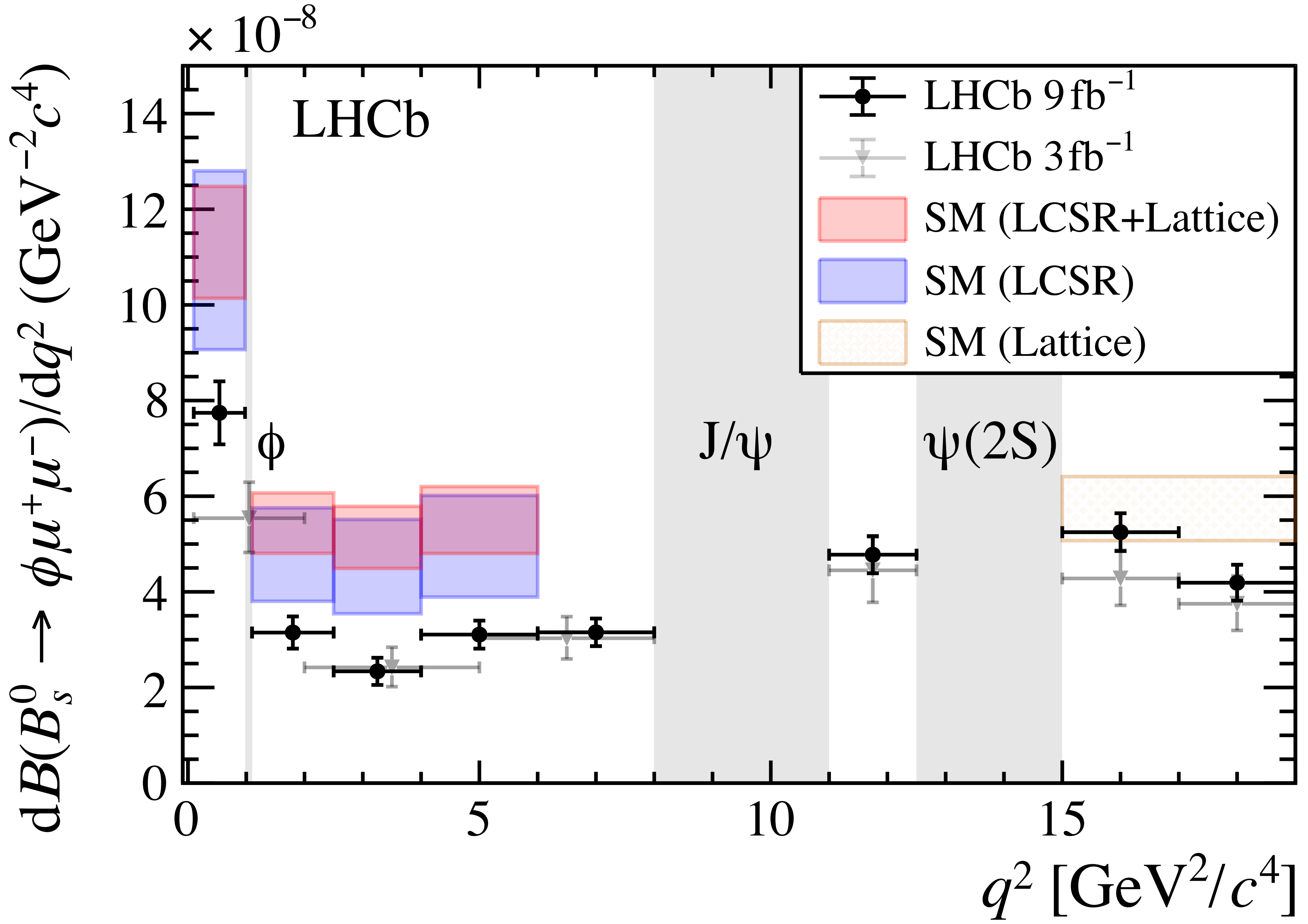




Branching ratio measurement of the rare $B_s^0 \to \phi\mu^+\mu^-$ decay - Results

New! [LHCb-PAPER-2021-014]

- Simultaneous fit over data-taking periods 2011-2012, 2015-2016, 2017-2018
- Results shown in bins of q^2 (details in the backup)
- In $1.1 < q^2 < 6.0\, GeV^2$:
  - **3.6σ deviation from LCSR + Lattice SM prediction**
  - **1.8σ deviation from LCSR SM prediction**



- Total branching ratio determined by summing up the contributions of the q^2 bins and correcting for the vetoed regions:

$$\frac{\mathscr{B}(B_s^0 \to \phi\mu^+\mu^-)}{\mathscr{B}(B_s^0 \to J/\psi\,\phi)} = (8.00 \pm 0.21 \pm 0.16 \pm 0.03) \times 10^{-4}$$

$$\mathscr{B}(B_s^0 \to \phi\mu^+\mu^-) = (8.00 \pm 0.21 \pm 0.16 \pm 0.03 \pm 0.39) \times 10^{-7}$$

- Uncertainties are statistical, systematic, from the extrapolation to the full q^2 region and on $\mathscr{B}(B_s^0 \to J/\psi\,\phi)$
- Dominating systematic uncertainties across the bins: $\mathscr{B}(B_s^0 \to J/\psi\,\phi)$ ($\mathcal{O}(11-37\%)$), model used to generate MC signal ($\mathcal{O}(4-10\%)$):
  - Assessed by varying $\Delta\Gamma_s$ and the form factors used in the generation of the events

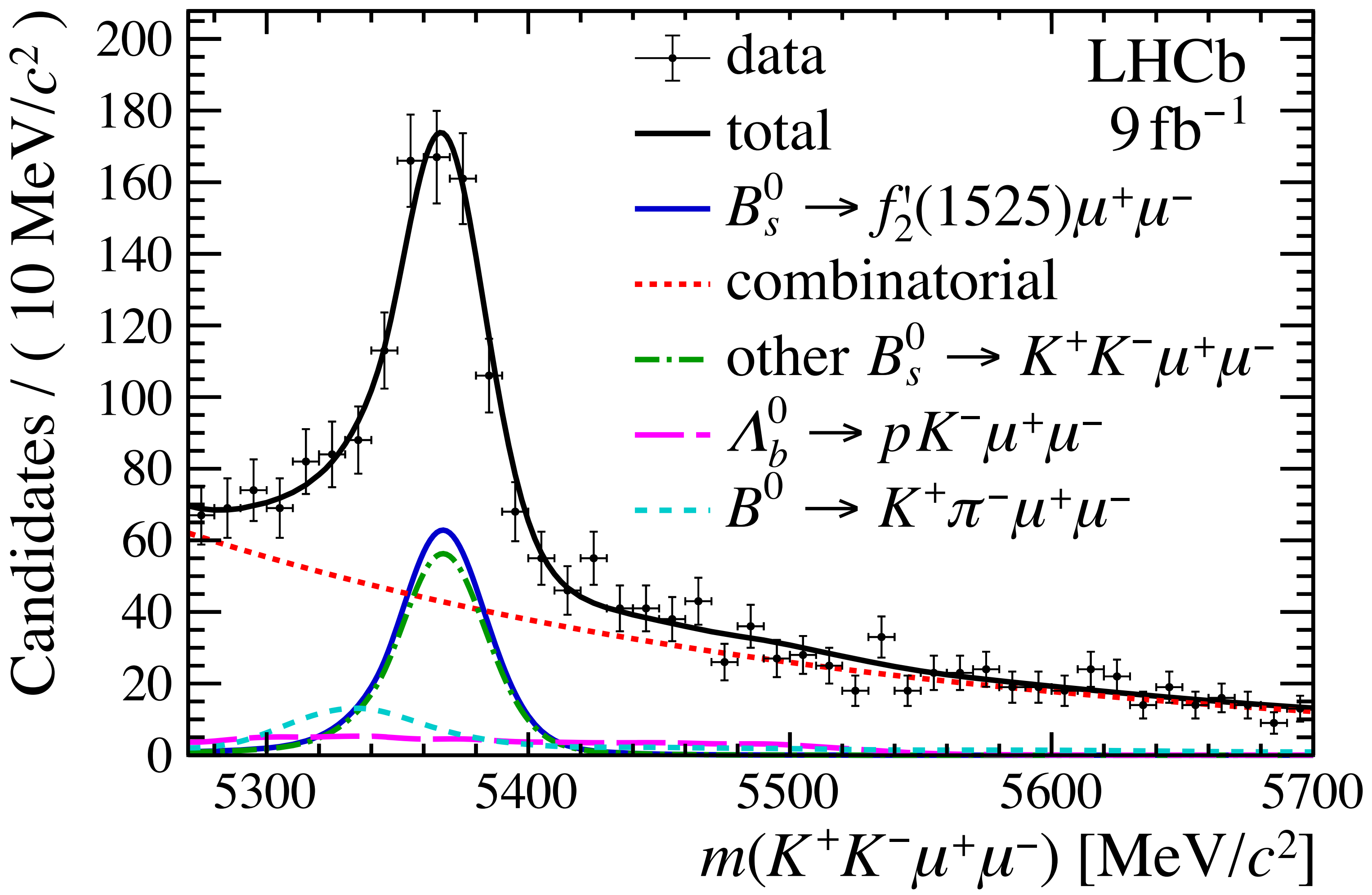
First observation of the rare $B_s^0 \to f_2'(1525)\mu^+\mu^-$

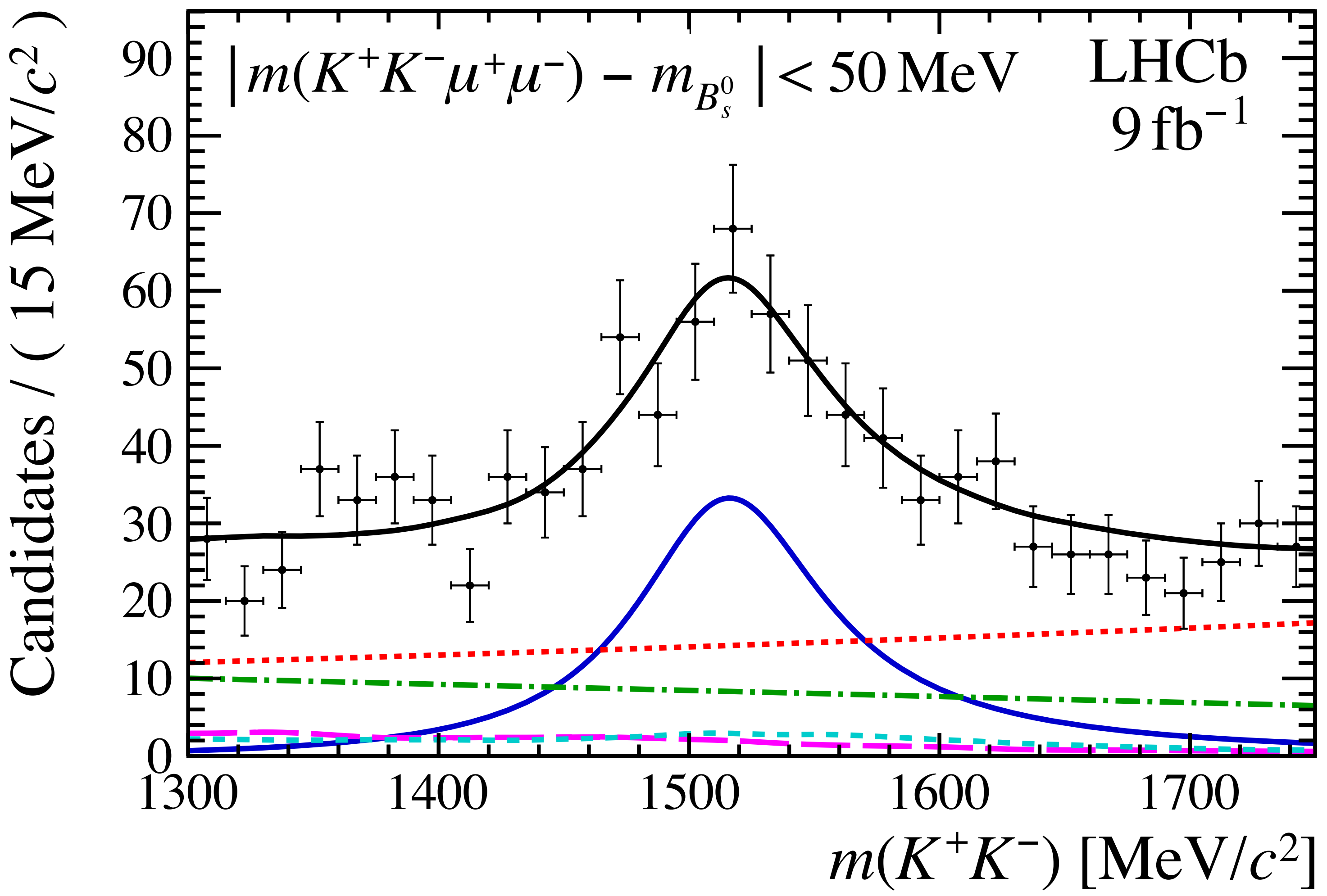
New! [LHCb-PAPER-2021-014]

- Combined q^2 region $[0.1, 0.98] \cup [1.1, 8.0] \cup [11.0, 12.5]\, GeV^2$
- $|m(K^+K^-) - m_{f_2'}| < 225\, MeV$

$$\frac{\mathcal{B}(B_s^0 \to f_2'\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = \mathcal{B}(J/\psi \to \mu^+\mu^-) \cdot \frac{\mathcal{B}(\phi \to K^+K^-)}{\mathcal{B}(f_2' \to K^+K^-)} \cdot \frac{N_{rare}}{N_{norm}} \cdot \frac{\varepsilon_{norm}}{\varepsilon_{rare}}$$

- 2D fit to B_s^0 and f_2' masses to separate signal and non-resonant contributions





$$\frac{\mathcal{B}(B_s^0 \to f_2'\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = (1.55 \pm 0.19 \pm 0.06 \pm 0.06) \times 10^{-4}$$

$$\mathcal{B}(B_s^0 \to f_2'\mu^+\mu^-) = (1.57 \pm 0.19 \pm 0.06 \pm 0.06 \pm 0.08) \times 10^{-7}$$

- Agreement with SM predictions: $(1.8^{+1.1}_{-0.7}) \times 10^{-7}$, $(2.31^{+0.69}_{-0.50}) \times 10^{-7}$, $(2.13 \pm 0.43) \times 10^{-7}$

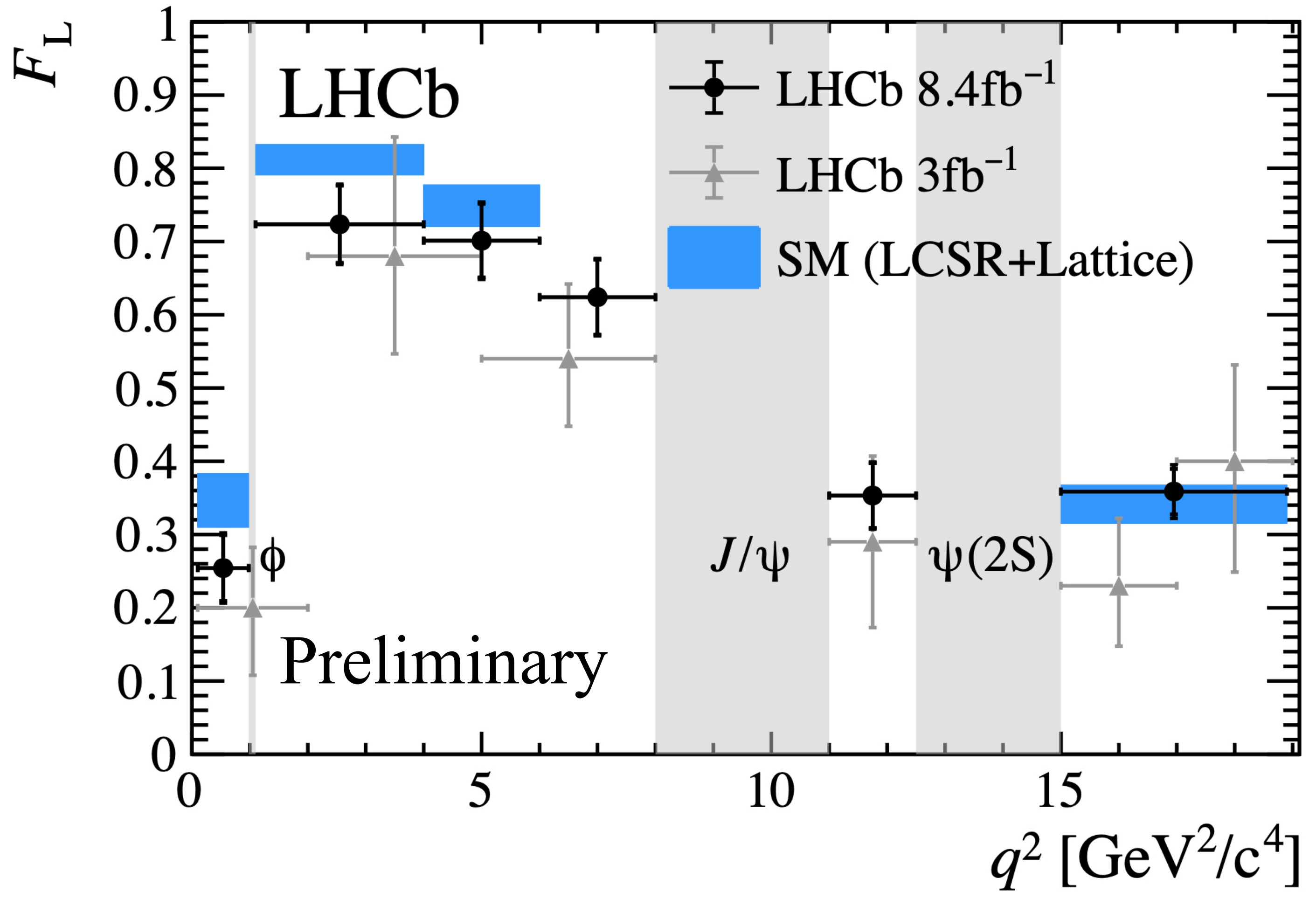
[arXiv:2009.06213] [Phys.Rev. D83 (2011) 034034] [Eur.Phys.J. C81 (2021) 30]

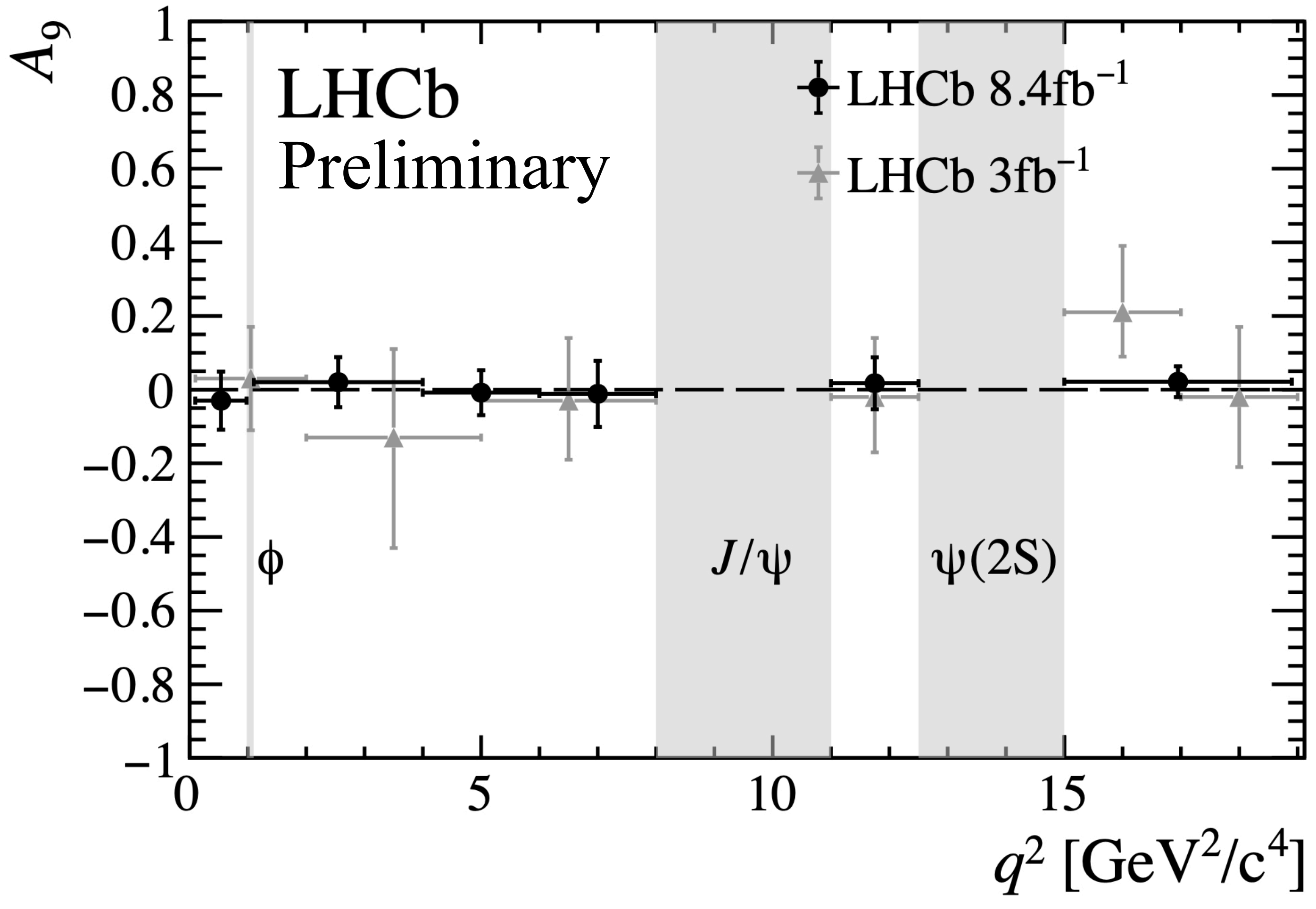
- Uncertainties are statistical, systematic, from the extrapolation to the full q^2 region and on $\mathcal{B}(B_s^0 \to J/\psi\,\phi)$
- Observed with a **statistical significance of 9 σ**
- Dominating systematic uncertainties: $\mathcal{B}(B_s^0 \to J/\psi\,\phi)$ ($\mathcal{O}(7\%)$), uncertainty on $\mathcal{B}(\phi \to K^+K^-)/\mathcal{B}(f_2' \to K^+K^-)$ ($\mathcal{O}(4\%)$)

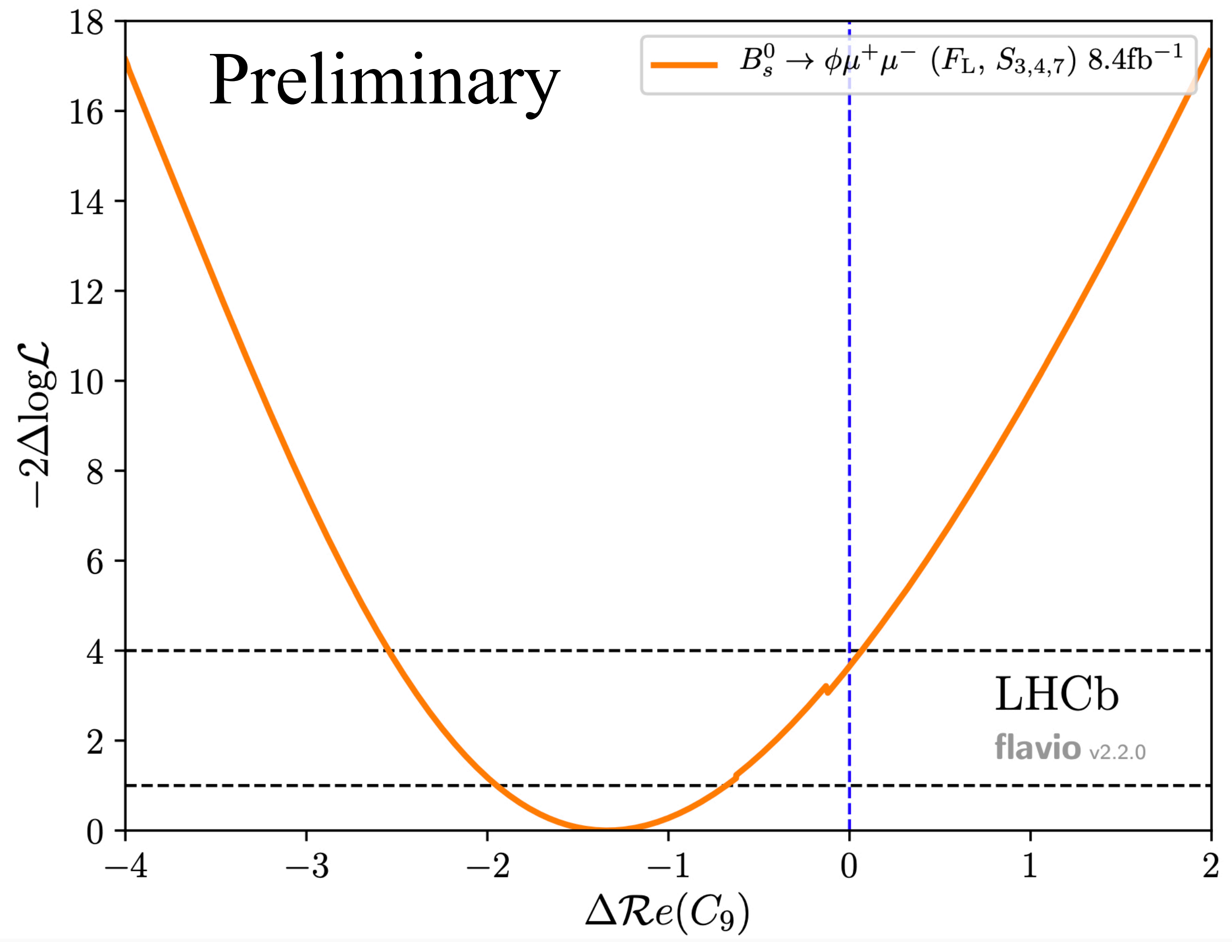
Angular analysis of $B_s^0 \to \phi\mu^+\mu^-$

New! [LHCb-PAPER-2021-022] (in preparation)

- **Update of Run 1 analysis with 8.4 fb^{-1}**
- 4D fit to B_s^0 invariant mass and three helicity angles to determine 4 CP averages and 4 CP asymmetries in bins of q^2:
  - F_L and $S_{3,4,7} + A_{FB}^{CP}$ and $A_{5,8,9}$ — $A_{8,9} \sim 0$ in SM but could be large due to NP [JHEP 07 (2008) 106]
- Fit performed simultaneously over 3 data-taking periods (2011-2012, 2016, 2017-2018)
- Event selection identical to $B_s^0 \to \phi\mu^+\mu^-$ branching ratio measurement
- Non-resonant contribution (F_s) at $1-2\,\%$, ignored in fit and taken into account in systematic uncertainty
- **Overall agreement with SM expectations** in the results, mild tensions in F_L (more in backup)
- Fit to CP averages varying $Re(C_9)$: shift of -1.3, **$1.9\,\sigma$ deviation with respect to the SM**
- Uncertainty statistically dominated, systematic uncertainties vary for angular observables and across q^2 bins



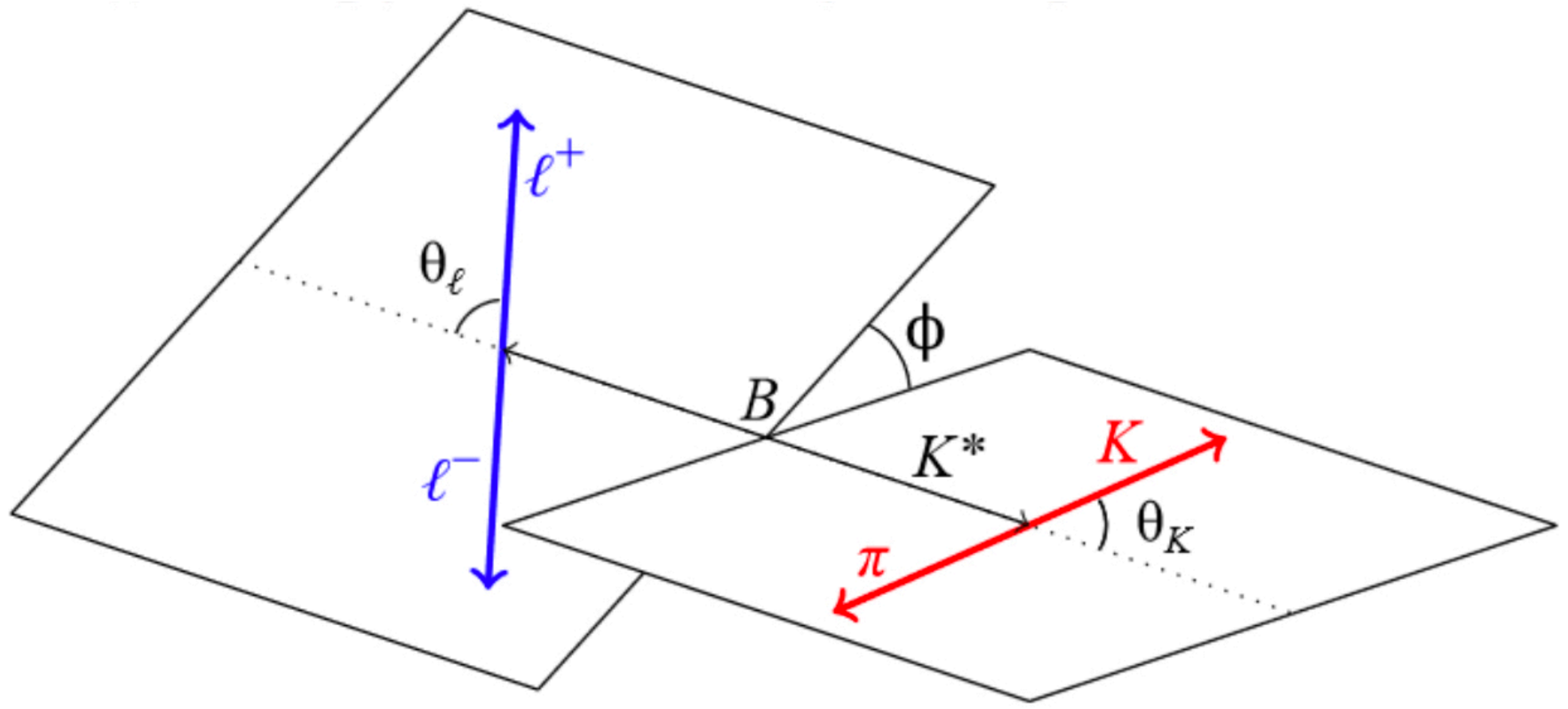




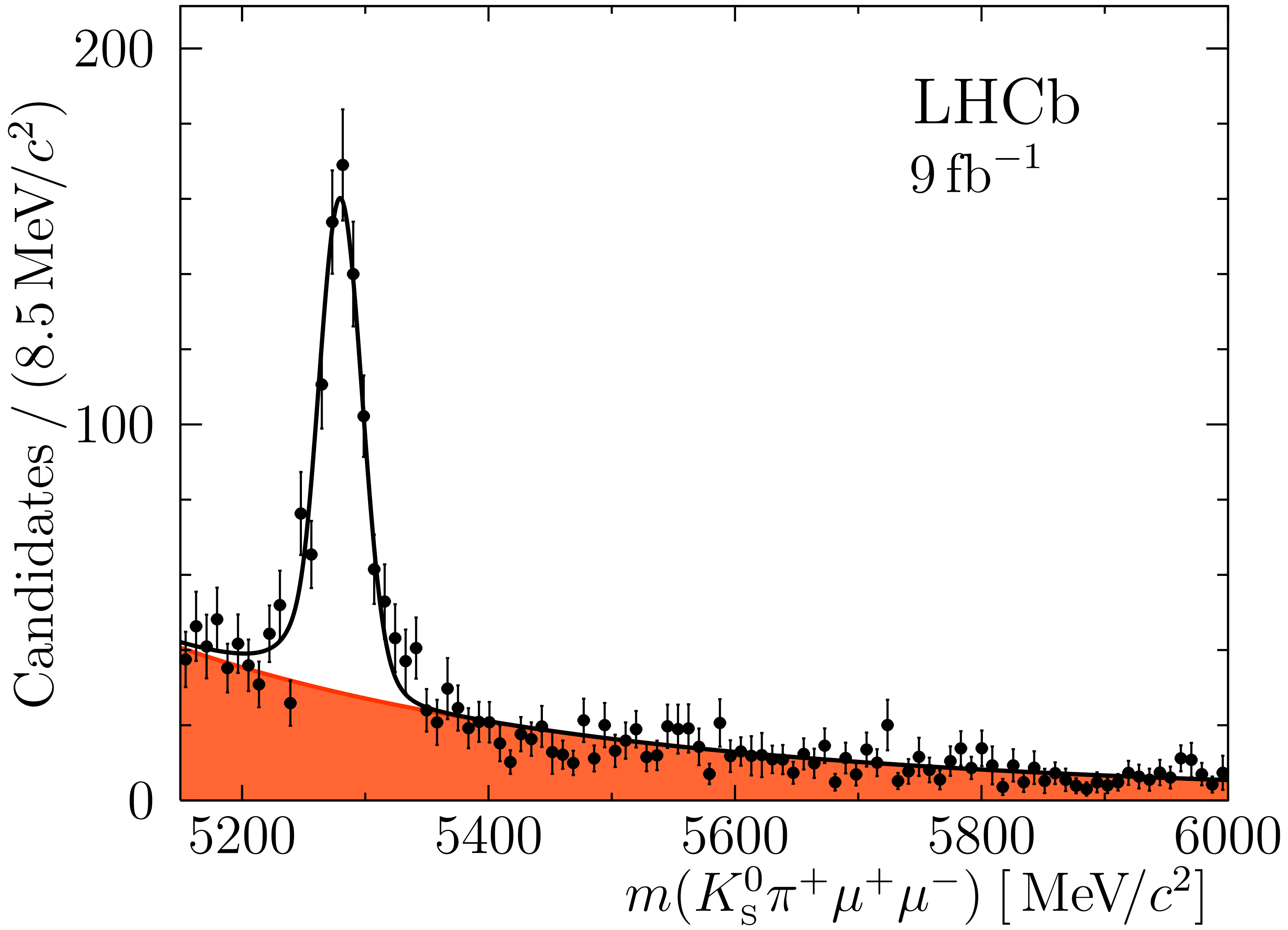
Angular analysis of $B^+ \to K^{*+}\mu^+\mu^-$ - Strategy

[Phys.Rev.Lett. 126, 161802 (2021)]

- **Full set of angular observables measured in intervals of q²** for the first time using **full LHCb dataset**
- Decay reconstructed through $K^{*+} \to K^0_S\pi^+$
  - K^0_S decays inside (long tracks) or outside (downstream tracks) the vertex detector
  - Analysis performed in 2 (data-taking runs) × 2 (long + downstream tracks) categories



- Background from mis-identified and partially reconstructed decays vetoed, e.g.:
  - $B^0 \to K^0_S\mu^+\mu^- + \pi^+$ from the rest of the event
  - $B^+ \to J/\psi(\to \mu^+\mu^-)K^{*+}$ with exchanged pions and muons
- Combinatorial background reduced with a BDT

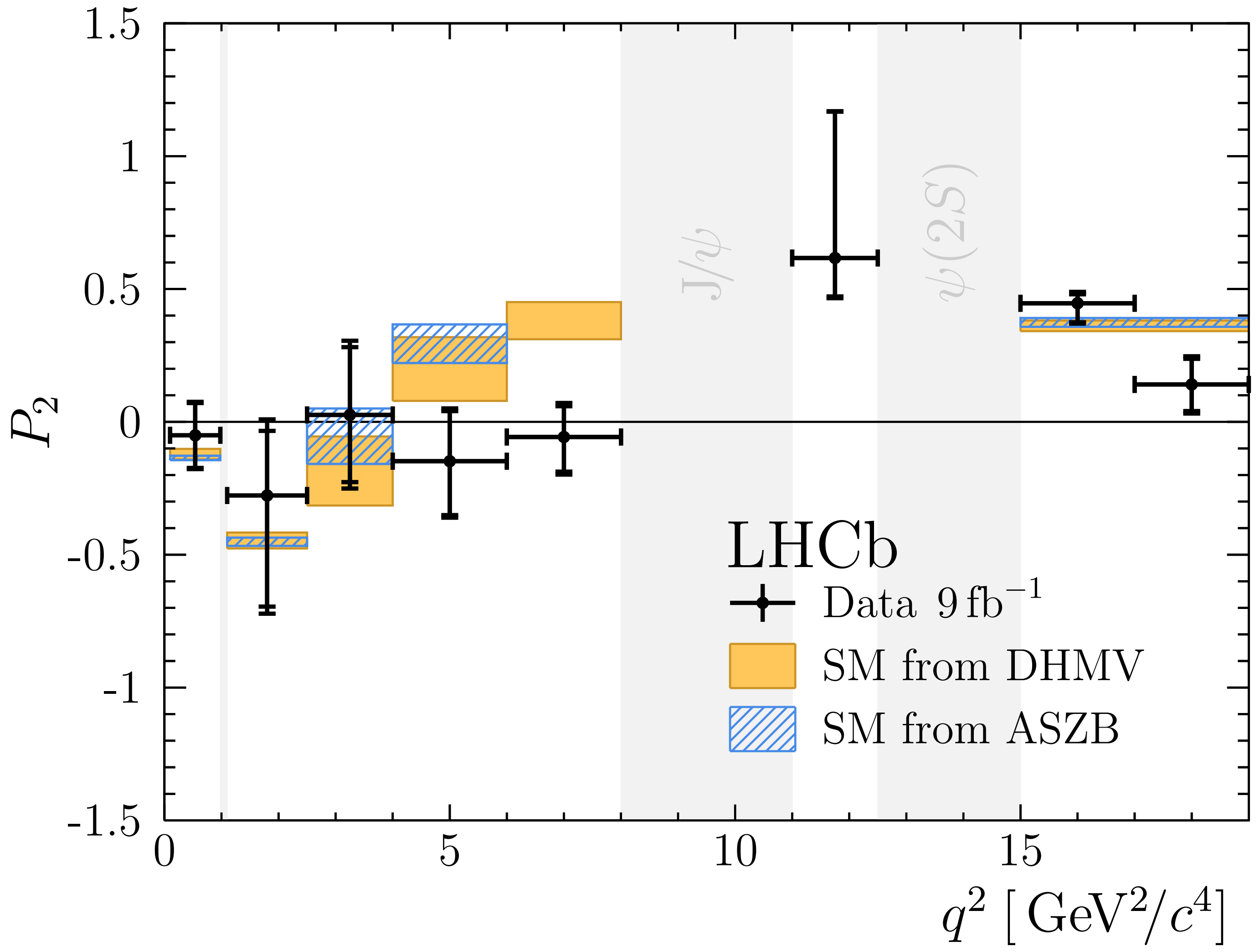


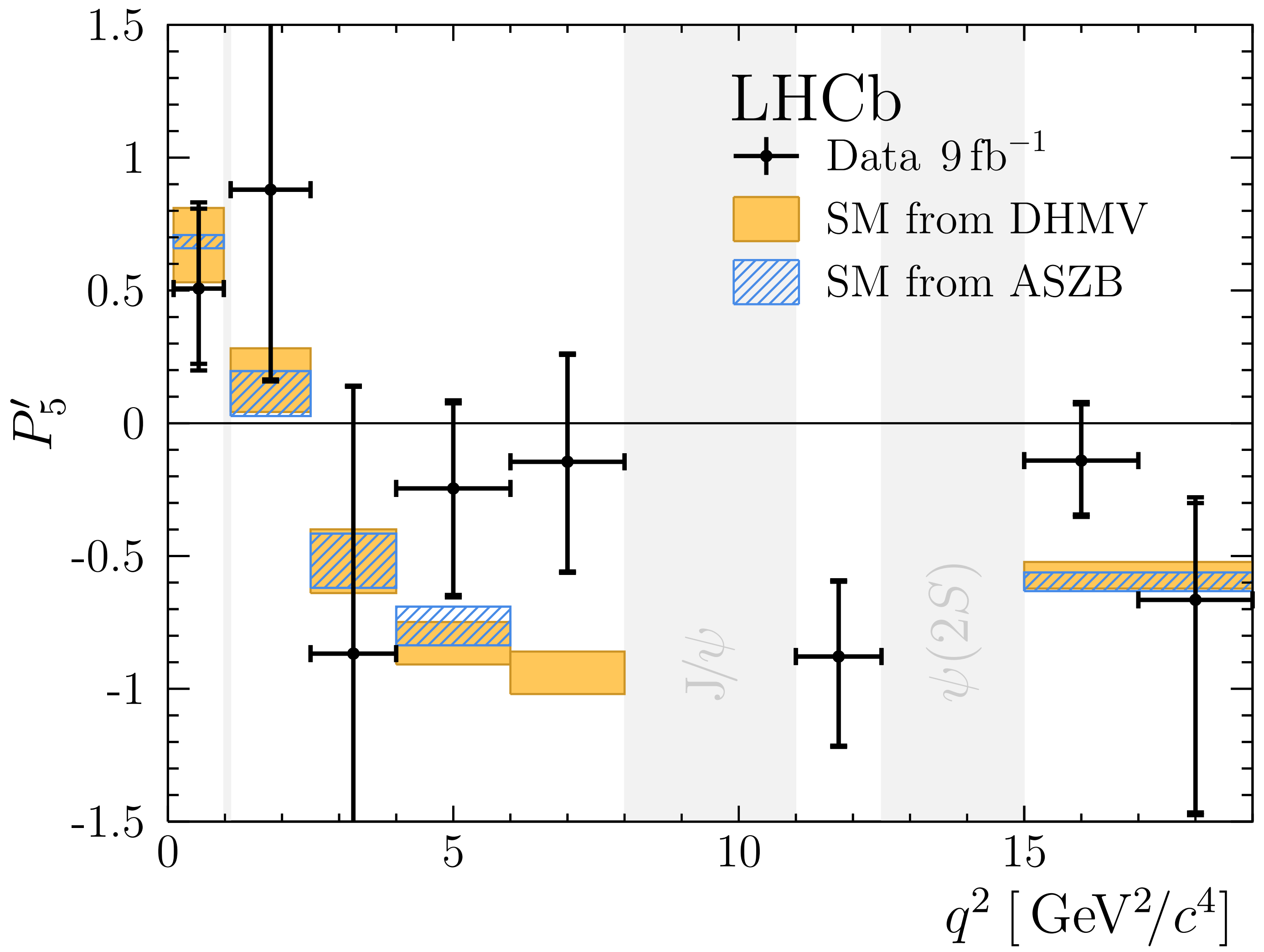
- 2D fit to B^+ and K^{*+} invariant mass to constrain non-resonant $B^+ \to K^0_S\pi^+\mu^+\mu^-$
- 4D fit to B^+ invariant mass and three helicity angles to determine 8 angular observables
  - **Two angular bases**:
    - $F_L, \; A_{FB}, \; S_{3,4,5,7,8,9}$
    - $F_L, \; P_{i=1,2,3} = \dfrac{S_{j=3,6,9}}{(1-F_L)}, \; P'_{i=4,5,6,8} = \dfrac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$

Angular analysis of $B^+ \to K^{*+}\mu^+\mu^-$ - Results

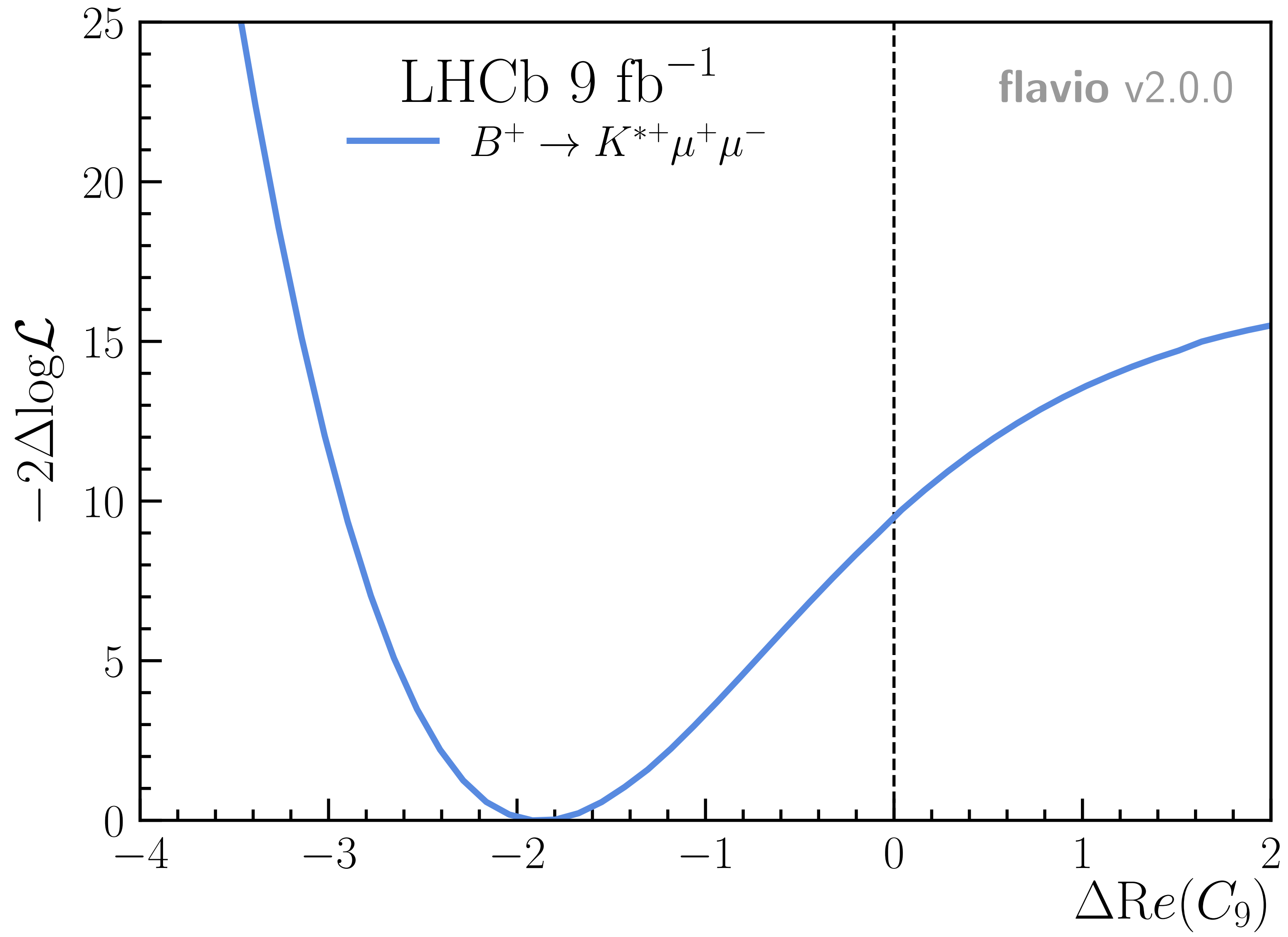
[Phys.Rev.Lett. 126, 161802 (2021)]

- **Local deviations from SM predictions** observed in P_2 and P_5' (more results in backup)





- Fit to angular observables varying $Re(C_9)$
- q^2 in intervals up to 6.0 GeV^2 + [15.0, 19.0] GeV^2 to avoid charmonium resonances
- Shift of -1.9: **3.1 σ deviation with respect to the SM**
- Uncertainty statistically dominated. Main systematic uncertainties from limited size of MC, signal fit model and acceptance parameterization



Angular analysis of $B^0 \to K^{*0}e^+e^-$ at very low q^2 - Strategy

[JHEP 12 (2020) 081]

- Angular analysis in $\mathbf{q^2 \in [0.0008, 0.2570]\ GeV^2}$, **sensitive to right-handed currents** in $b \to s\gamma\ (C_7')$
- Update of Run 1 analysis with full LHCb dataset
- Non-resonant $K\pi$ contribution neglected at $q^2 \sim 0$
- Two trigger categories: $e^\pm$ from signal B or rest of the event
- Simultaneous fit to B^0 invariant mass and three helicity angles over 2 (trigger) × 2 (data-taking runs) categories

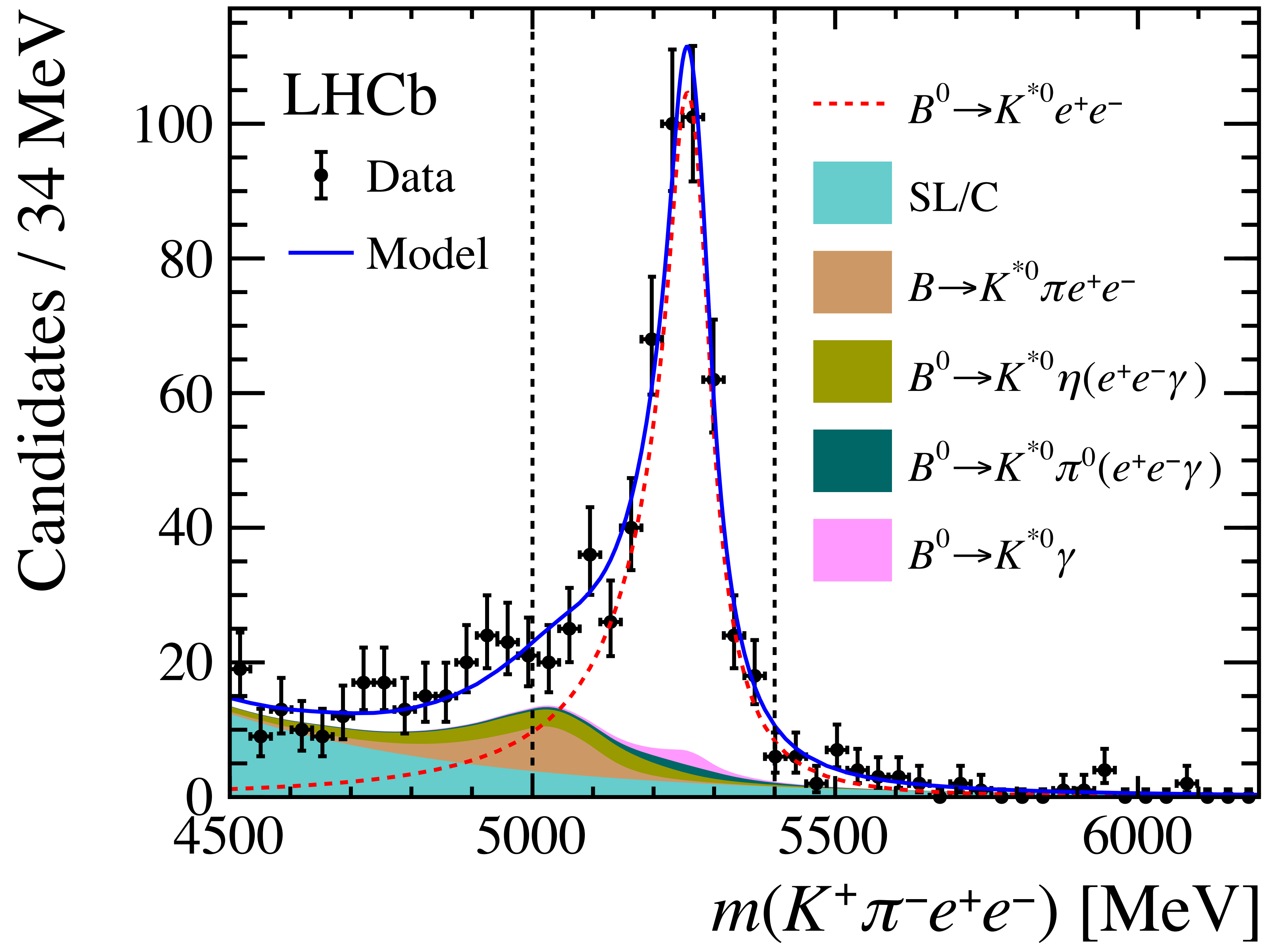
$\tan\chi \equiv |A_R/A_L|$ ratio of right- and left-handed photon amplitude

$$A_T^{(2)} = \sin(2\chi)\cos(\phi_L - \phi_R)$$

$$A_T^{Im} = \sin(2\chi)\sin(\phi_L - \phi_R)$$

~ 0 in the SM

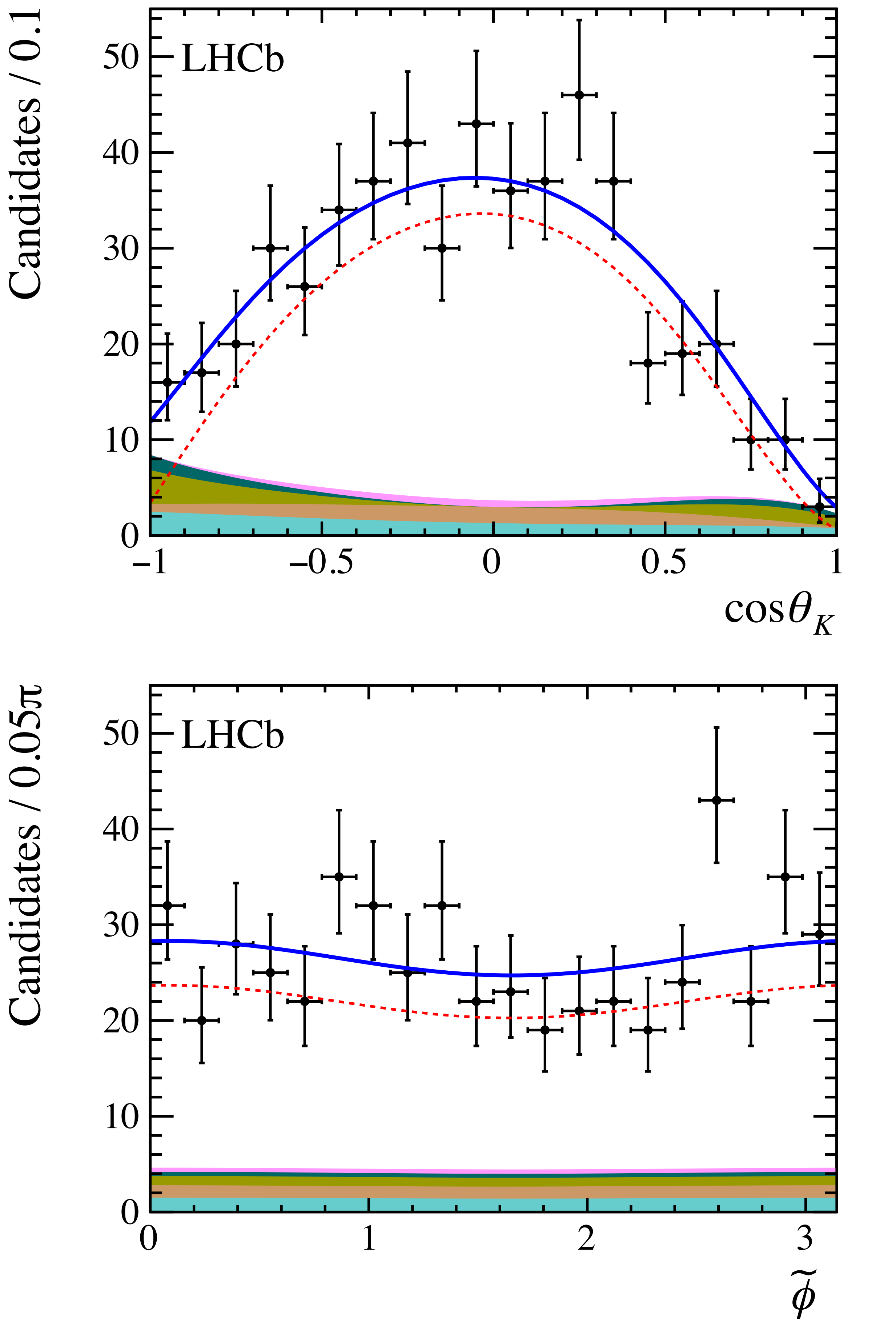
- Background from mis-identified and partially reconstructed decays vetoed
- Combinatorial background reduced with a BDT



Angular analysis of $B^0 \to K^{*0}e^+e^-$ at very low q^2 - Results

[JHEP 12 (2020) 081]

- Results compatible with SM (first uncertainty is statistical, second is systematic):



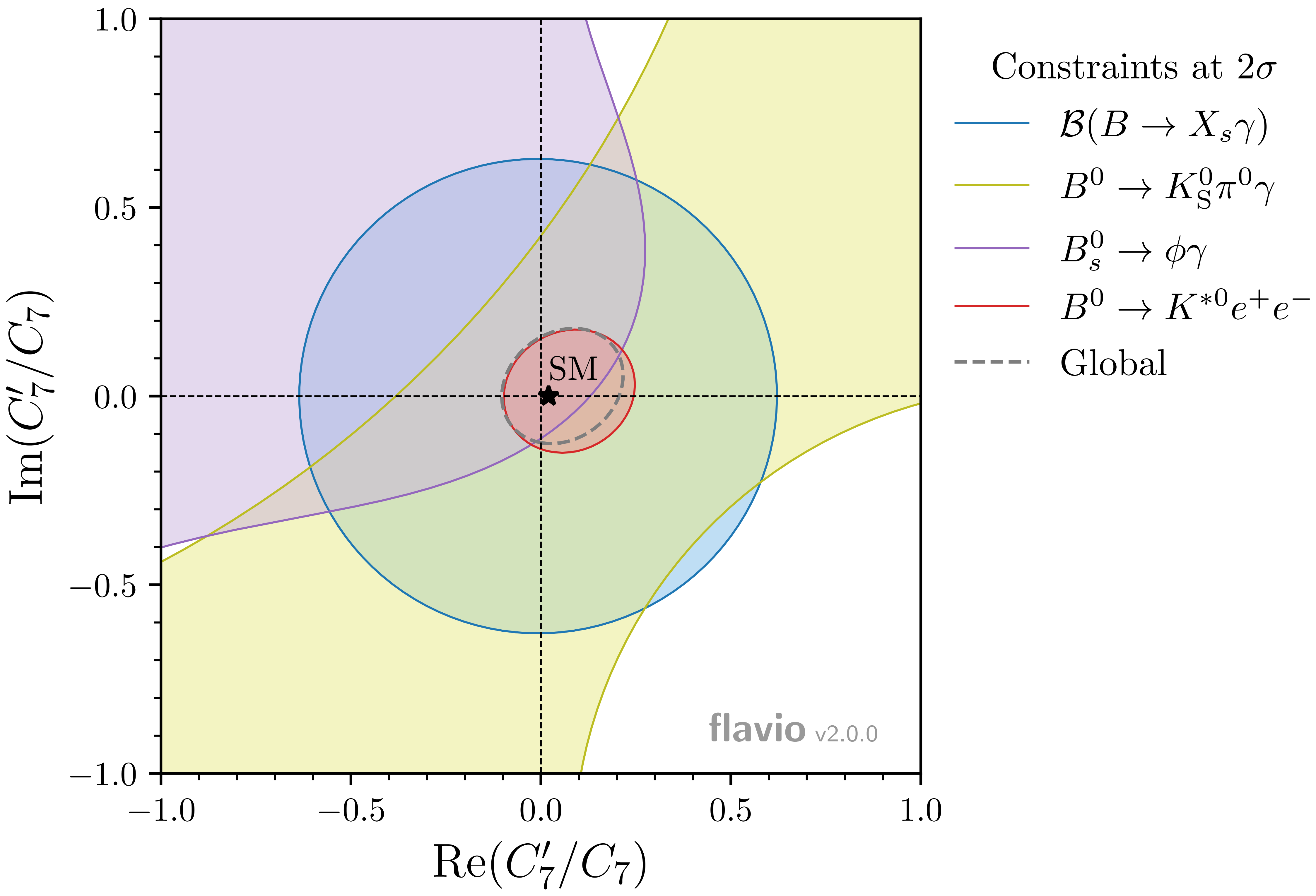
$$F_L = +0.044 \pm 0.026 \pm 0.014$$

$$A_T^{Re} = -0.06 \pm 0.08 \pm 0.02$$

$$A_T^{(2)} = +0.11 \pm 0.10 \pm 0.02$$

$$A_T^{Im} = +0.02 \pm 0.10 \pm 0.01$$

- **Strong constraint on C_7':**



- Uncertainty is statistically dominated
- Main systematic uncertainties from limited size of MC and data used to evaluate angular shapes and acceptance

Conclusions

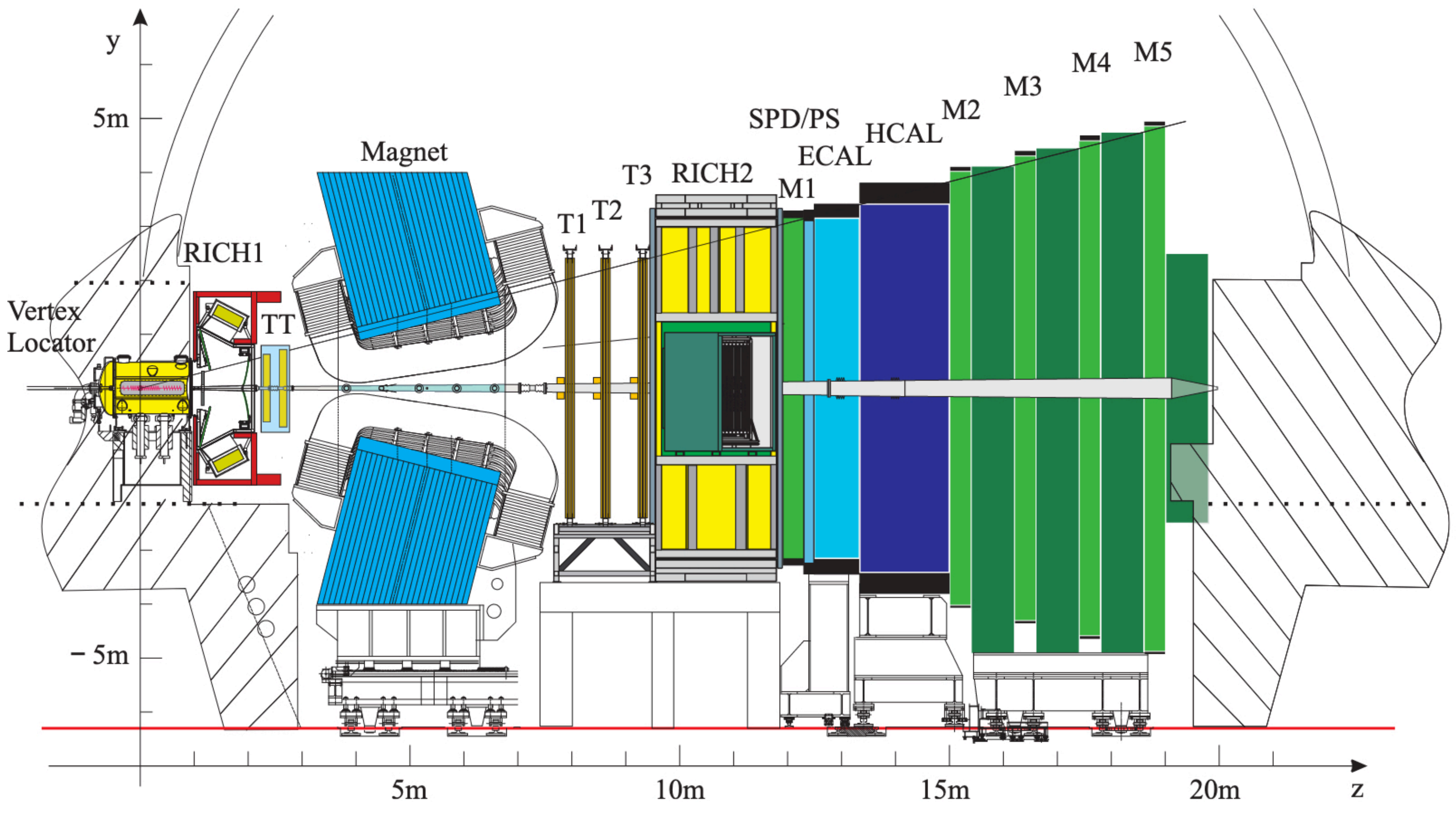
- A coherent set of anomalies arises in measurements of rare $b \to s\, l^+l^-$ processes
- Several new results in rare B decays using the full LHCb dataset:
  - Measurement of R_K shows 3.1 σ deviation with respect to the SM
  - Entering the precision regime in the measurement of properties of $B^0_{(s)} \to \mu^+\mu^-$ decays
  - Local deviations from the SM predictions in the measurement of $B^0_s \to \phi\mu^+\mu^-$ branching fraction and $B^+ \to K^{*+}\mu^+\mu^-$ angular observables
  - Overall agreement with the SM in the angular analysis of $B^0_s \to \phi\mu^+\mu^-$
  - Strong constraints on right-handed currents in $b \to s\,\gamma$ processes
- **More measurements to come!**

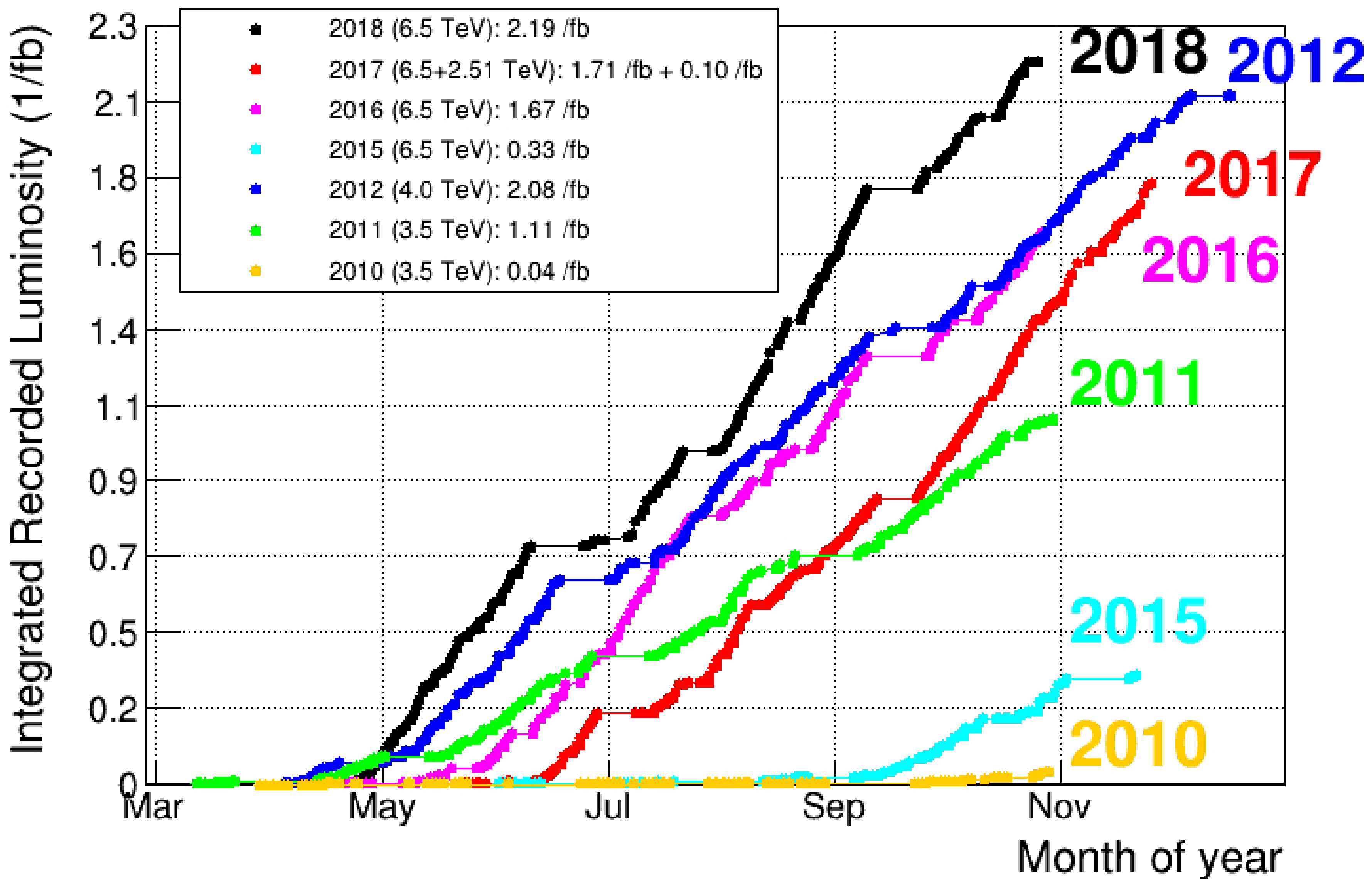
Backup

From Pinterest

The LHCb detector

[Int.J.Mod.Phys. A 30, 1530022 (2015)] [JINST 3 (2008) S08005]



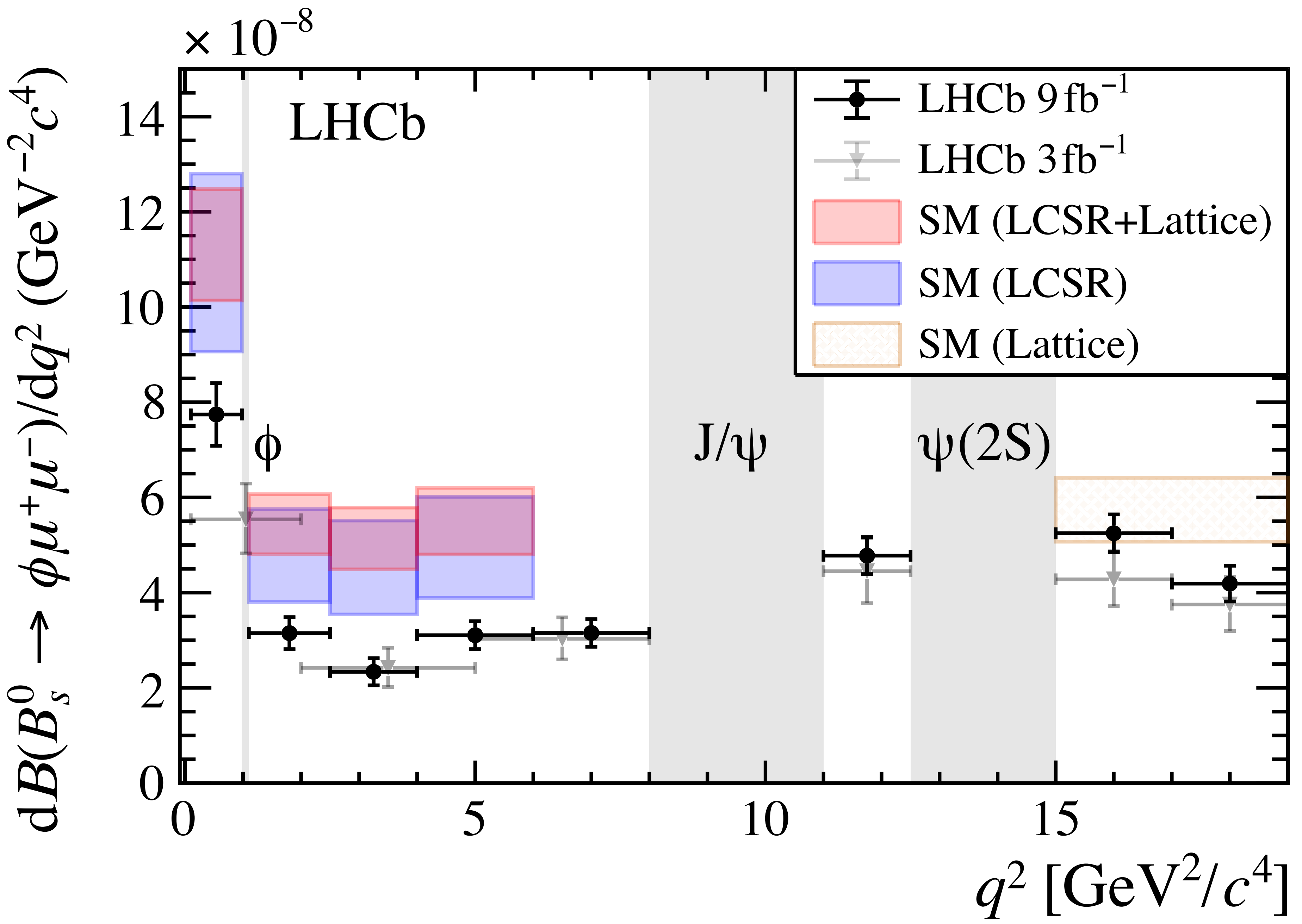


- High vertex resolution $\sigma_{IP} = 15 + 29/p_T\ \mu\text{m}$
- Low momentum muon trigger $p_T^{\mu} > 1.75$ GeV (2018)
- PID capabilities $\epsilon_{\mu} \sim 98\,\%$ with $\epsilon_{\pi\to\mu} \sim 1\,\%$
- Good momentum resolution $\sigma_p/p = 0.5 - 1.0\,\%$, $p \in [2{,}200]$ GeV

$B_s^0 \to \phi \mu^+\mu^-$ branching ratio measurement - Detailed results

New! [LHCb-PAPER-2021-014]

q^2 interval $[\mathrm{GeV}^2/c^4]$	$\mathrm{d}\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)/\mathcal{B}(B_s^0 \to J/\psi\phi)\mathrm{d}q^2$ $[10^{-5}\,\mathrm{GeV}^{-2}c^4]$	$\mathrm{d}\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)/\mathrm{d}q^2$ $[10^{-8}\,\mathrm{GeV}^{-2}c^4]$
0.1–0.98	$7.61 \pm 0.52 \pm 0.12$	$7.74 \pm 0.53 \pm 0.12 \pm 0.37$
1.1–2.5	$3.09 \pm 0.29 \pm 0.07$	$3.15 \pm 0.29 \pm 0.07 \pm 0.15$
2.5–4.0	$2.30 \pm 0.25 \pm 0.05$	$2.34 \pm 0.26 \pm 0.05 \pm 0.11$
4.0–6.0	$3.05 \pm 0.24 \pm 0.06$	$3.11 \pm 0.24 \pm 0.06 \pm 0.15$
6.0–8.0	$3.10 \pm 0.23 \pm 0.06$	$3.15 \pm 0.24 \pm 0.06 \pm 0.15$
11.0–12.5	$4.69 \pm 0.30 \pm 0.07$	$4.78 \pm 0.30 \pm 0.08 \pm 0.23$
15.0–17.0	$5.15 \pm 0.28 \pm 0.10$	$5.25 \pm 0.29 \pm 0.10 \pm 0.25$
17.0–19.0	$4.12 \pm 0.29 \pm 0.12$	$4.19 \pm 0.29 \pm 0.12 \pm 0.20$
1.1–6.0	$2.83 \pm 0.15 \pm 0.05$	$2.88 \pm 0.15 \pm 0.05 \pm 0.14$
15.0–19.0	$4.55 \pm 0.20 \pm 0.11$	$4.63 \pm 0.20 \pm 0.11 \pm 0.22$



$B_s^0 \to \phi\mu^+\mu^-$ branching ratio measurement - Systematic uncertainties

New! [LHCb-PAPER-2021-014]

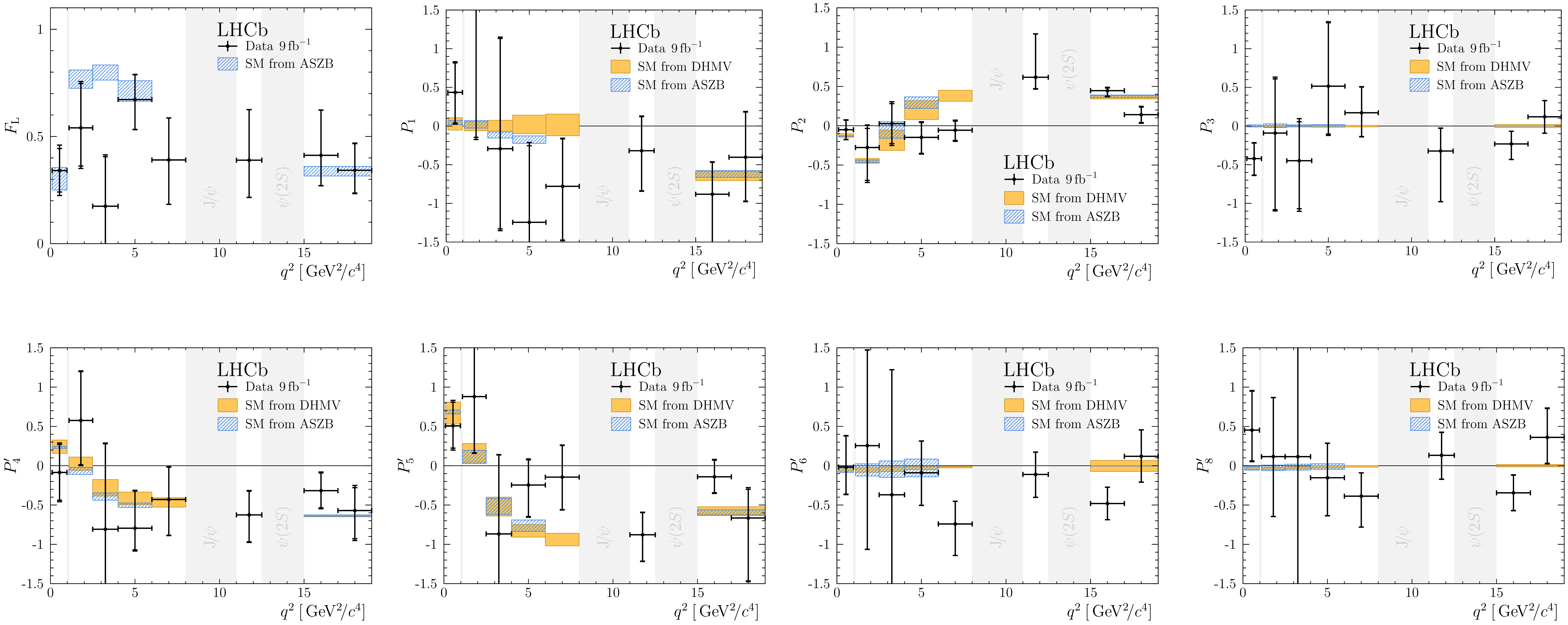
Source	$\sigma_{\text{syst.}}\left(\mathrm{d}\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)/\mathrm{d}q^2\right)$ $[10^{-8}\,\mathrm{GeV}^{-2}c^4]$	$\sigma_{\text{syst.}}\left(\mathcal{B}(B_s^0 \to f_2'\mu^+\mu^-)\right)$ $[10^{-7}]$
Physics model	0.04–0.10	0.02
Limited simulation sample	0.02–0.07	0.01
Residual background	0.01–0.04	0.01
Fit bias	0.00–0.03	< 0.01
Signal fit model	0.00–0.01	0.03
Simulation corrections	0.00–0.03	0.01
Residual mismodelling	0.00–0.02	< 0.01
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	0.01–0.04	0.01
$\mathcal{B}(\phi \to K^+K^-)/\mathcal{B}(f_2' \to K^+K^-)$	–	0.04
Quadratic sum	0.05–0.12	0.06
Normalization $\mathcal{B}(B_s^0 \to J/\psi\phi)$	0.11–0.37	0.07

$B_s^0 \to \phi\mu^+\mu^-$ angular analysis - More results

New! [LHCb-PAPER-2021-022] (in preparation)

Angular analysis of $B^+ \to K^{*+}\mu^+\mu^-$ - More results (1/2)

[Phys.Rev.Lett. 126, 161802 (2021)]



Angular analysis of $B^+ \to K^{*+}\mu^+\mu^-$ - More results (2/2)

[Phys.Rev.Lett. 126, 161802 (2021)]