



Rare decays at LHCb

Jacopo Cerasoli

► To cite this version:

Jacopo Cerasoli. Rare decays at LHCb. Lomonosov Conference on Elementary Particle Physics, Aug 2021, Moscow, Russia. hal-03376121

HAL Id: hal-03376121

<https://hal.science/hal-03376121>

Submitted on 28 Oct 2021

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Rare decays at LHCb

Jacopo Cerasoli

Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

On behalf of the LHCb collaboration

Lomonosov Conference on Elementary Particle Physics

August 22nd 2021

- **Rare B decays can probe new physics at much higher scales** than direct searches with the use of an **effective hamiltonian**:

- FCNC (**high energy contributions**) treated as point-like, encoded in Wilson coefficients $C_i(\lambda)$
- Long-distance physics (**low energy contributions**) described by effective operators $Q_i(\lambda)$

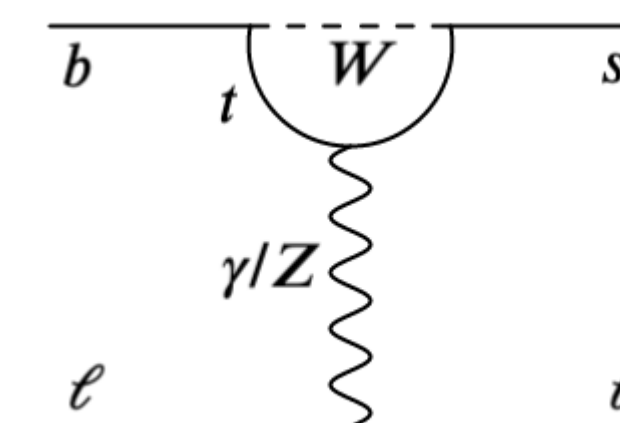
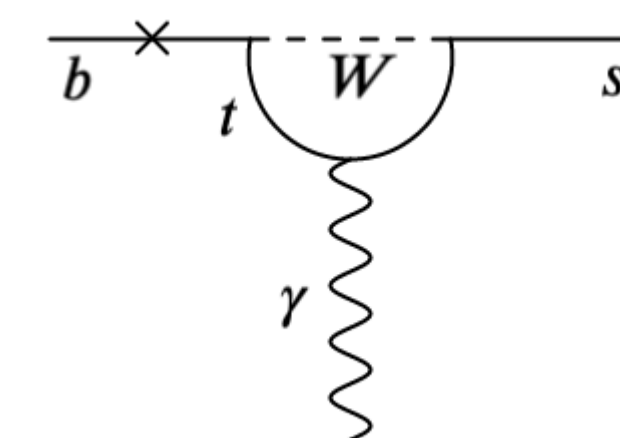
$$H_{eff}^{b \rightarrow s} = \frac{G_F}{\sqrt{2}} \sum_i V_{ib} V_{is}^* C_i(\lambda) Q_i(\lambda)$$

- 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 $b \rightarrow s l^+ l^-$ processes (e.g. [\[JHEP 06 \(2014\) 133\]](#), [\[PRL 125 \(2020\) 011802\]](#), [\[JHEP 08 \(2017\) 055\]](#))

Outline

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

1) Measurement of R_K [\[arXiv:2103.11769\]](#)

2) Measurement of the rare $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decay properties [\[LHCb-PAPER-2021-007/8\]](#)  On arXiv tomorrow!

3) Branching ratio measurement of the $B_s^0 \rightarrow \phi \mu^+ \mu^-$ decay and first observation of $B_s^0 \rightarrow f_2'(1525) \mu^+ \mu^-$ [\[arXiv:2105.14007\]](#)

4) Angular analysis of $B_s^0 \rightarrow \phi \mu^+ \mu^-$ [\[arXiv:2107.13428\]](#)

5) Measurement of photon polarization in $\Lambda_b^0 \rightarrow \Lambda \gamma$ decays [\[LHCb-PAPER-2021-030\]](#) (in preparation)

Measurement of R_K - Strategy

[arXiv:2103.11769]

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

- Measured in $q^2 \in [1.1, 6.0] \text{ GeV}^2$ with **full LHCb dataset (9 fb⁻¹)**

- SM predicts $R_K^{\text{SM}} \cong 1$

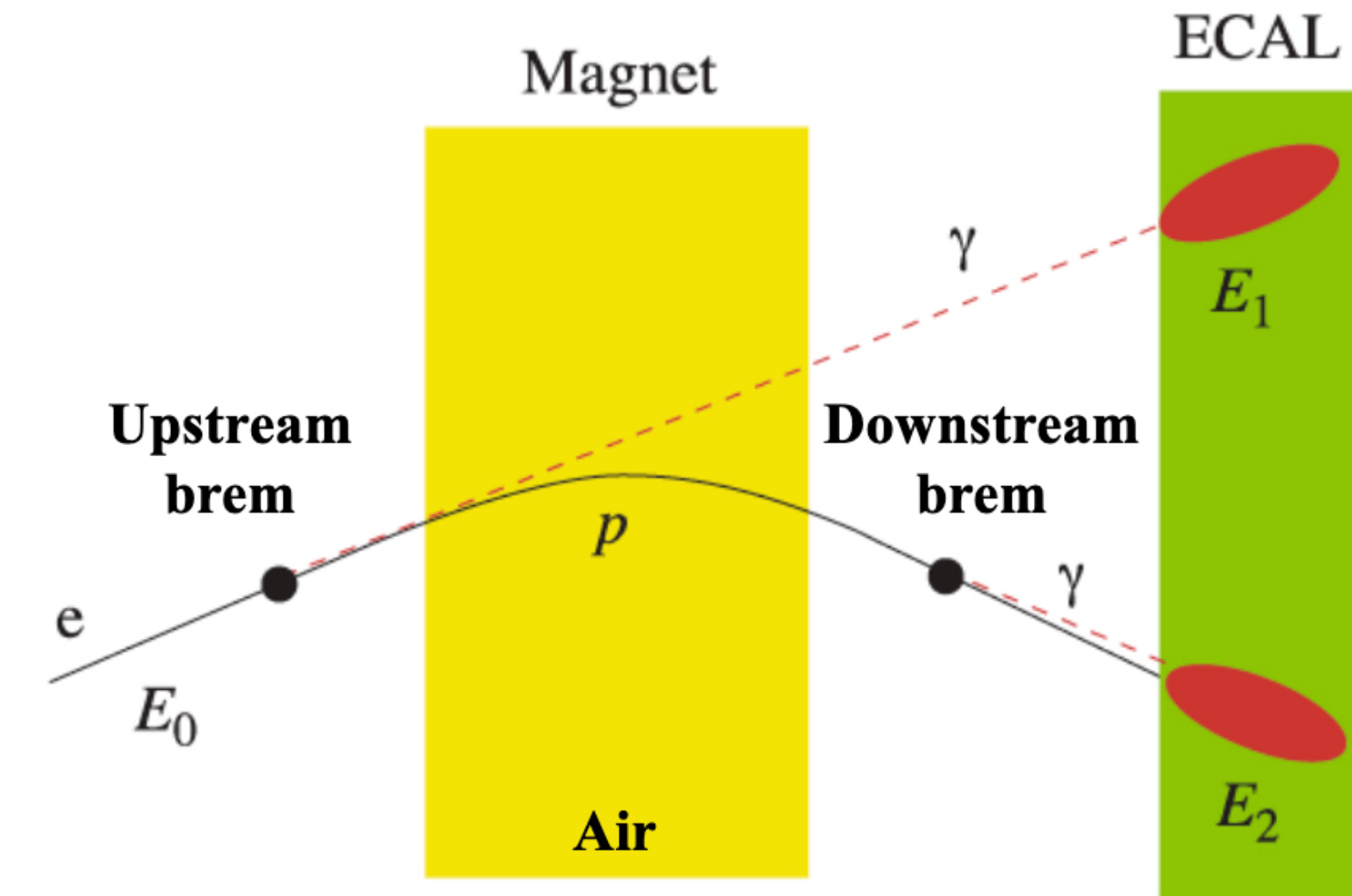
- Corrections: $\mathcal{O}(m_\mu^4/q^4) \sim 10^{-4}$ + radiative effects $\mathcal{O}(1\%)$

[JHEP 12 (2007) 040]

[Eur.Phys.J. C76 (2016) 8, 440]

q^2 = dilepton system invariant mass squared

- 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”



- R_K measured as double ratio using the $B^+ \rightarrow J/\psi K^+$ normalization mode:

$$R_K = \frac{\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \rightarrow J/\psi(\rightarrow \mu^+ \mu^-) K^+)} \cdot \frac{\mathcal{B}(B^+ \rightarrow J/\psi(\rightarrow e^+ e^-) K^+)}{\mathcal{B}(B^+ \rightarrow K^+ e^+ e^-)} = \frac{N_{\mu^+ \mu^-}^{\text{rare}} \epsilon_{\mu^+ \mu^-}^{\text{norm}}}{N_{\mu^+ \mu^-}^{\text{norm}} \epsilon_{\mu^+ \mu^-}^{\text{rare}}} \cdot \frac{N_{e^+ e^-}^{\text{norm}} \epsilon_{e^+ e^-}^{\text{rare}}}{N_{e^+ e^-}^{\text{rare}} \epsilon_{e^+ e^-}^{\text{norm}}}$$

- **Identical selection for rare and normalization modes** (more info in the backup)

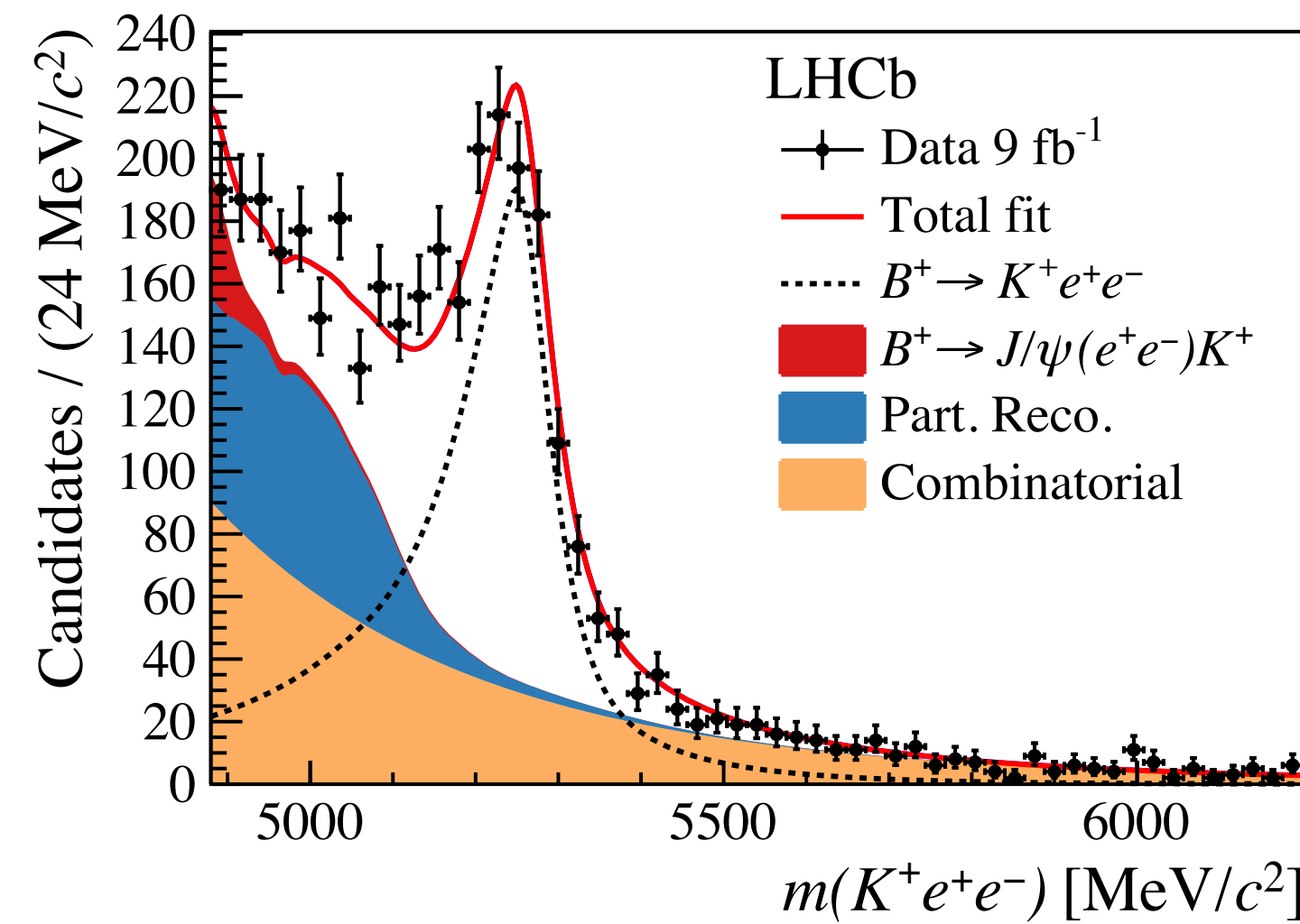
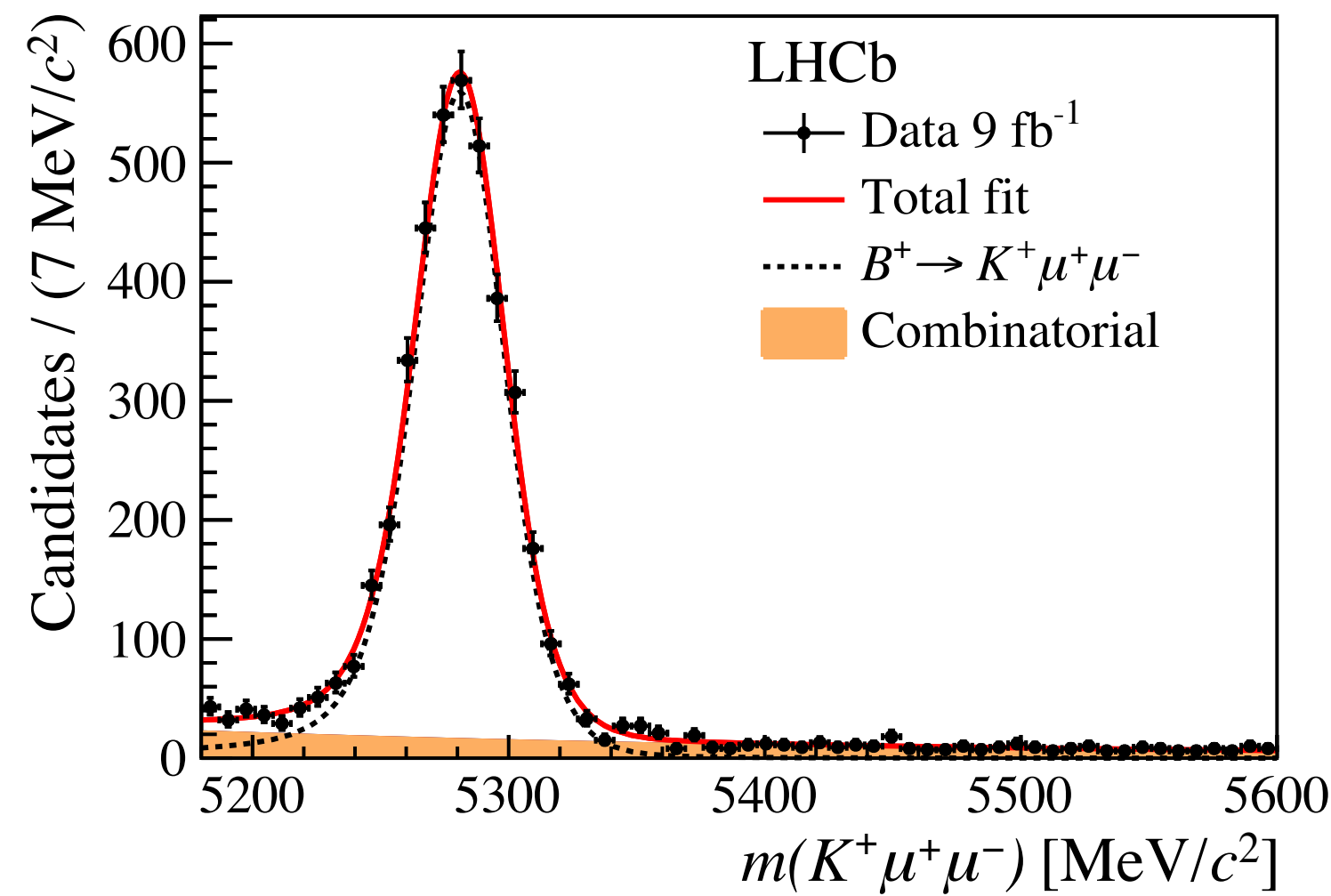
$$r_{J/\psi} = \frac{\mathcal{B}(B^+ \rightarrow K^+ J/\psi(\rightarrow \mu^+ \mu^-))}{\mathcal{B}(B^+ \rightarrow K^+ J/\psi(\rightarrow e^+ e^-))} = \frac{N_{\mu^+ \mu^-}^{norm}}{\epsilon_{\mu^+ \mu^-}^{norm}} \cdot \frac{\epsilon_{e^+ e^-}^{norm}}{N_{e^+ e^-}^{norm}}$$

- $r_{J/\psi} \simeq 1$ even in presence of NP, stringent cross-check! [\[PDG\]](#)
- **It does not benefit from the double ratio cancellation** of systematic uncertainties in the efficiencies
- **Result: $r_{J/\psi} = 0.981 \pm 0.020$** (uncertainty includes statistical and systematic contributions)

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

- Cross-check of the double-ratio with q^2 away from J/ψ pole
- **Result: $R_{\psi(2S)} = 0.997 \pm 0.011$** (uncertainty includes statistical and systematic contributions)
- Cross-checks show that **control of the efficiencies is at $\mathcal{O}(1\%)$**

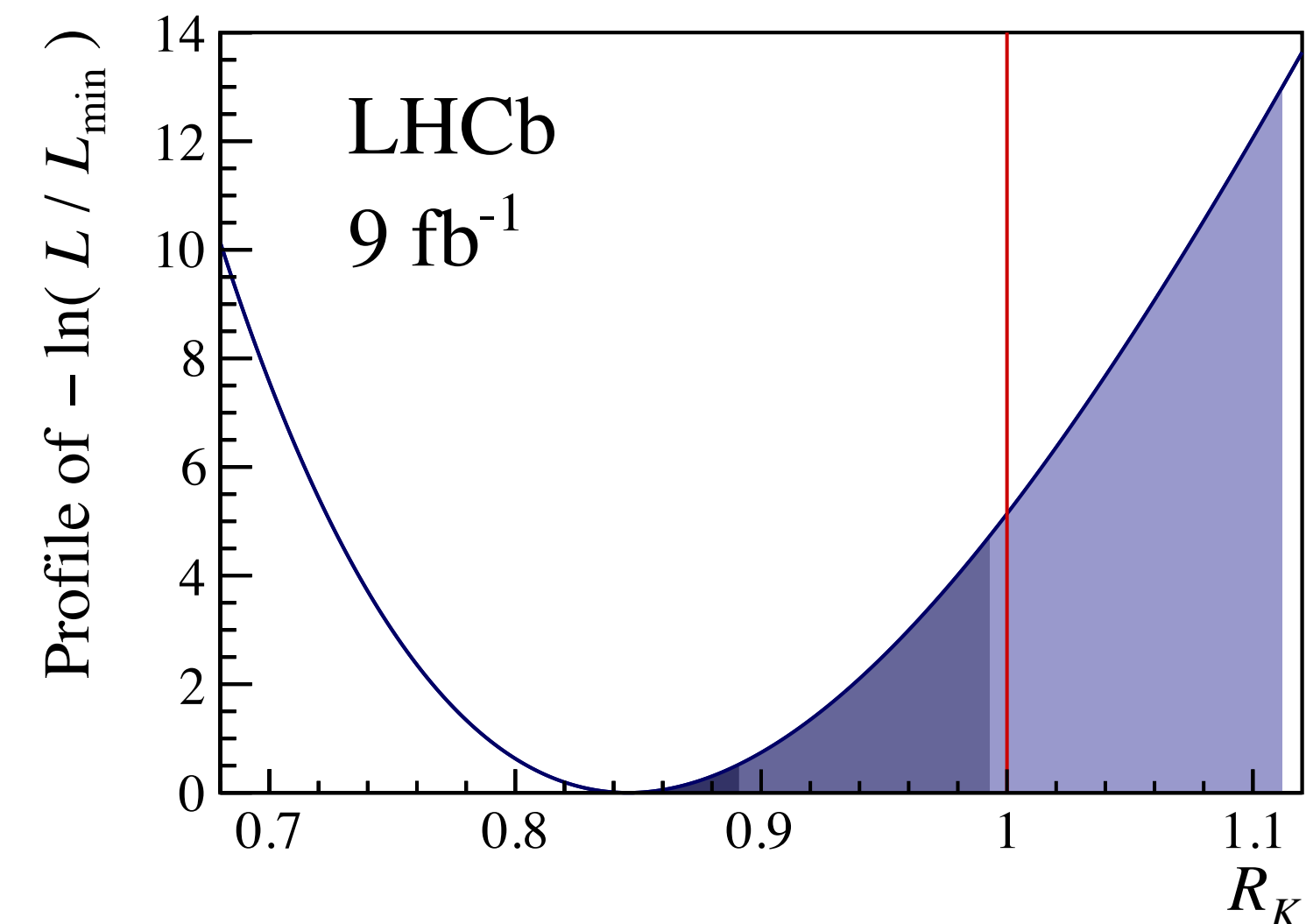
- Mass fits of the rare modes performed simultaneously in **3 (trigger) $\times$ 2 (data-taking runs) categories**
- R_K extracted as parameter of the simultaneous fit, normalization yields incorporated as gaussian constraints



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

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

- 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 $B^+ \rightarrow K^+ l^+ l^-$ decays



Measurement of the rare $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decay properties - Strategy

[LHCb-PAPER-2021-007/8]

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

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{SM} = (3.66 \pm 0.14) \times 10^{-9}$$

[JHEP 10 (2019) 232]

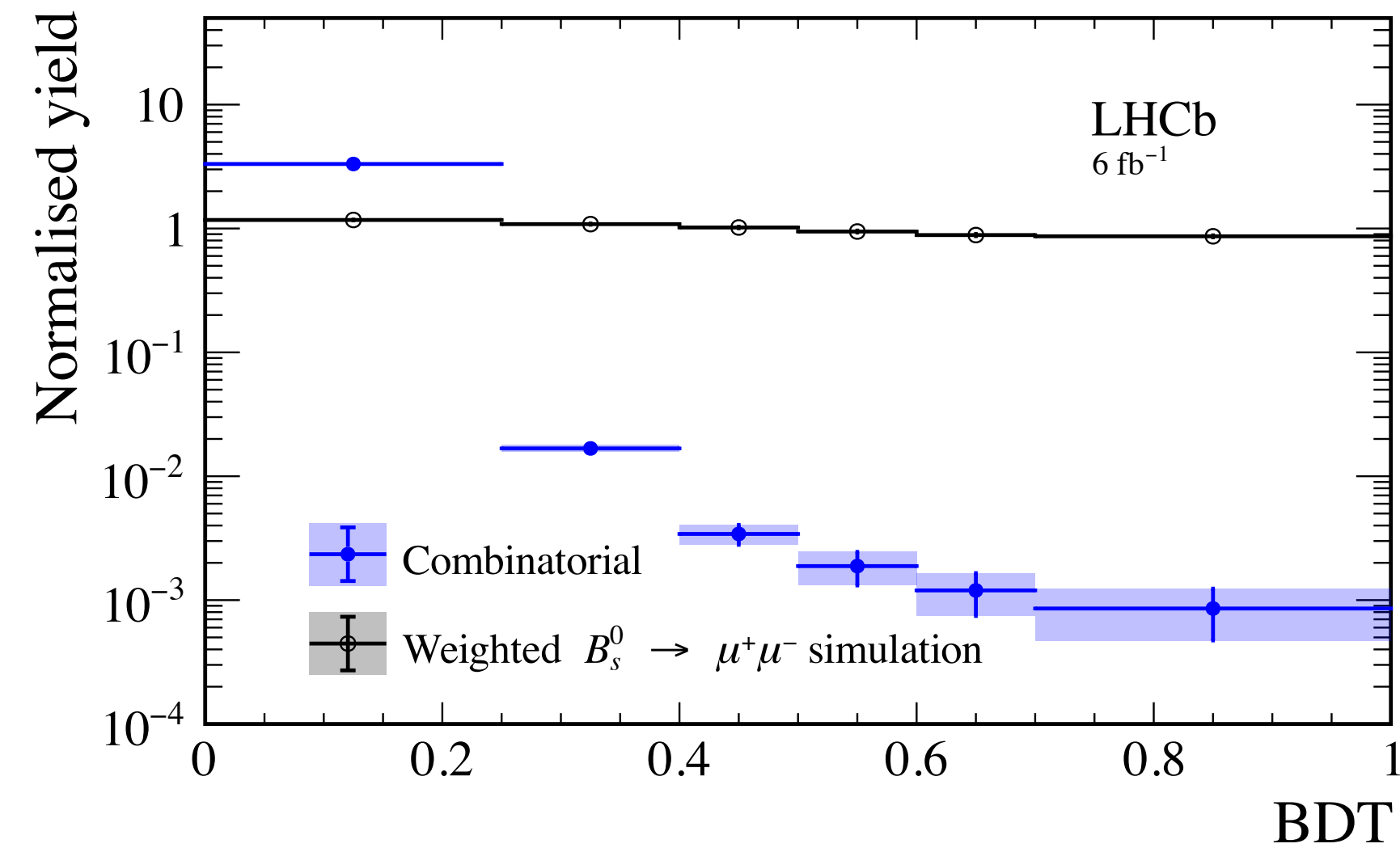
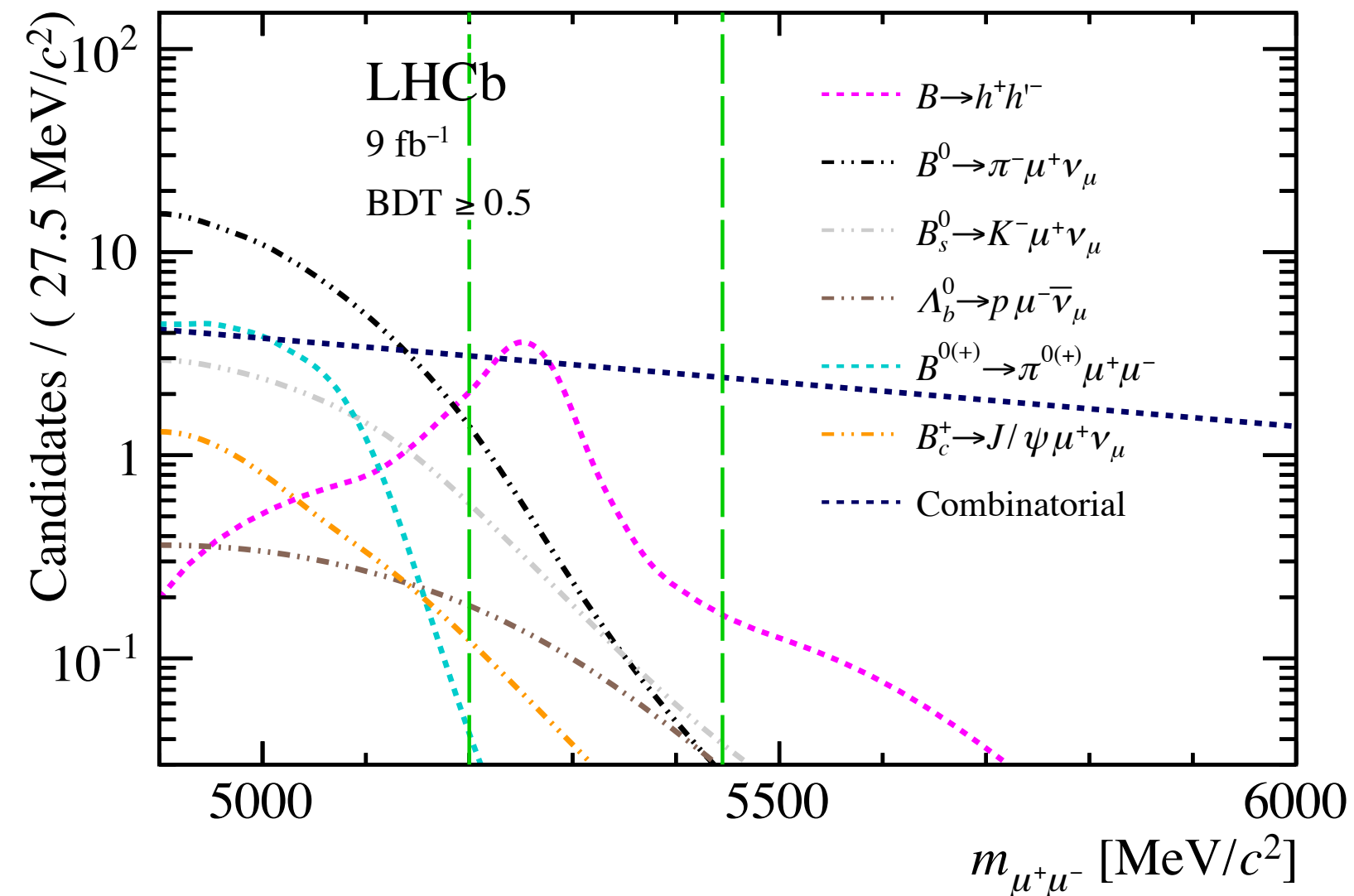
$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)_{SM} = (1.03 \pm 0.05) \times 10^{-10}$$

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^- \gamma)_{SM} \sim 10^{-10} \text{ (initial state radiation) } [JHEP 11 (2017) 184]$$

$$\tau_{B_s^0 \rightarrow \mu^+ \mu^-} = \frac{\tau_{B_s^0}}{1 - y_s^2} \left[\frac{1 + 2 \mathcal{A}_{\Delta\Gamma_s} y_s + y_s^2}{1 + \mathcal{A}_{\Delta\Gamma_s} y_s} \right]$$

$$y_s \equiv \frac{\Delta\Gamma_s}{2\Gamma_s} \quad \mathcal{A}_{\Delta\Gamma_s} \equiv \frac{R_H^{\mu^+ \mu^-} - R_L^{\mu^+ \mu^-}}{R_H^{\mu^+ \mu^-} + R_L^{\mu^+ \mu^-}} = +1 \text{ in the SM}$$

- Two normalization channels used: $B^0 \rightarrow K^+ \pi^-$ and $B^+ \rightarrow J/\psi(\rightarrow \mu^+ \mu^-) K^+$
- Strong PID cut on muons, **backgrounds left:** combinatorial, partially reconstructed semileptonic, doubly mis-identified $B_{(s)}^0 \rightarrow h^+ h^-$
- Simultaneous mass fit over **5 (BDT bins, first one rejected) $\times$ 2 (data-taking runs) categories** with **full LHCb dataset (9 fb⁻¹)**



- Mis-identified and partially reconstructed background yields estimated with simulation and fixed, combinatorial background left floating

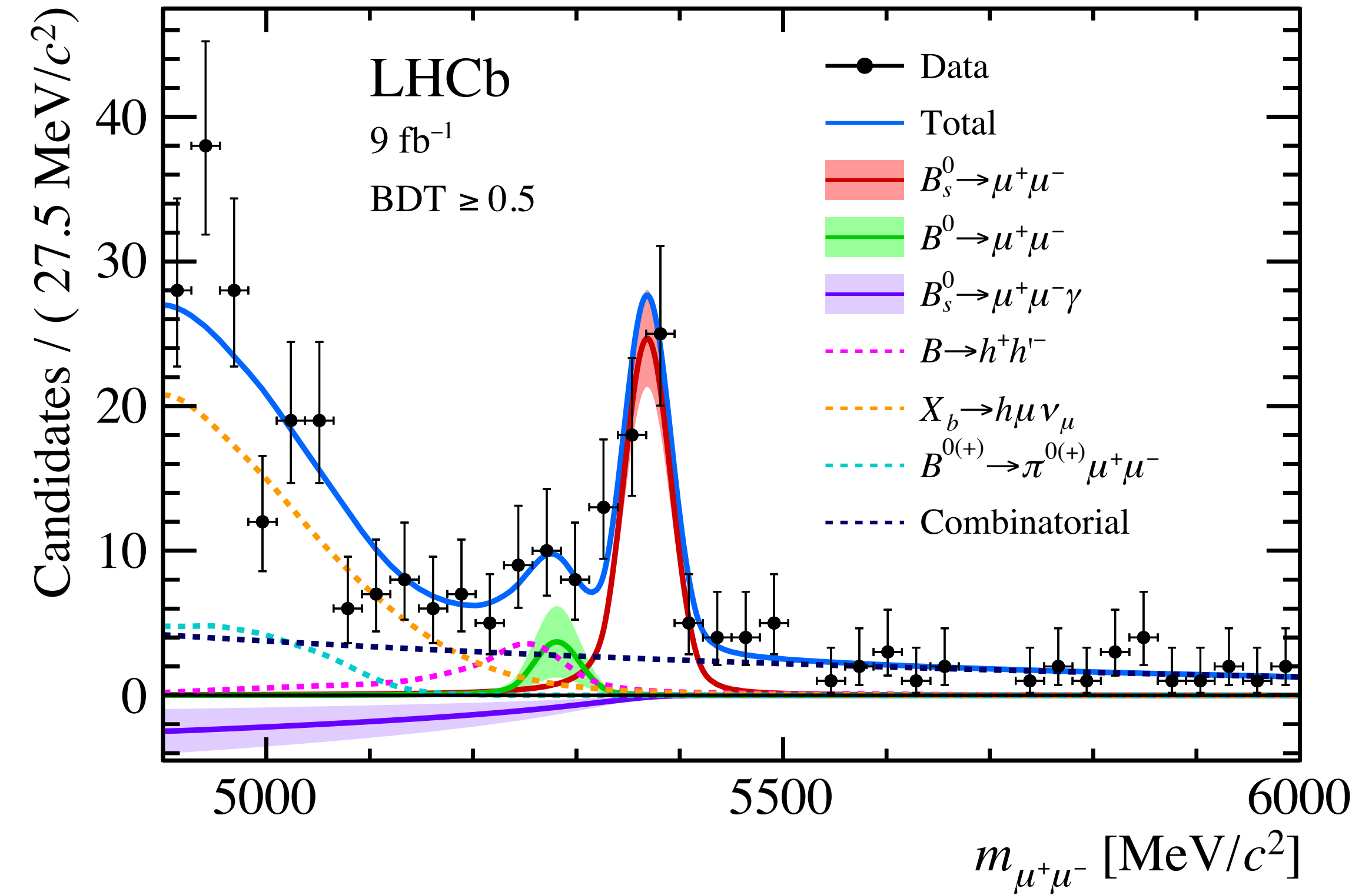
- $B_s^0 \rightarrow \mu^+\mu^-$ observed with statistical significance of 10.8σ
- $B^0 \rightarrow \mu^+\mu^-$ compatible with background hypothesis at 1.7σ
- $B_s^0 \rightarrow \mu^+\mu^-\gamma$ compatible with background hypothesis at 1.5σ

Results

- $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$ in agreement with SM
- $\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) < 2.6 \times 10^{-10}$ (95 % CL)
- $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-\gamma)_{m_{\mu^+\mu^-} > 4.9 \text{ GeV}} < 2.0 \times 10^{-9}$ (95 % CL)

- Uncertainty statistically dominated

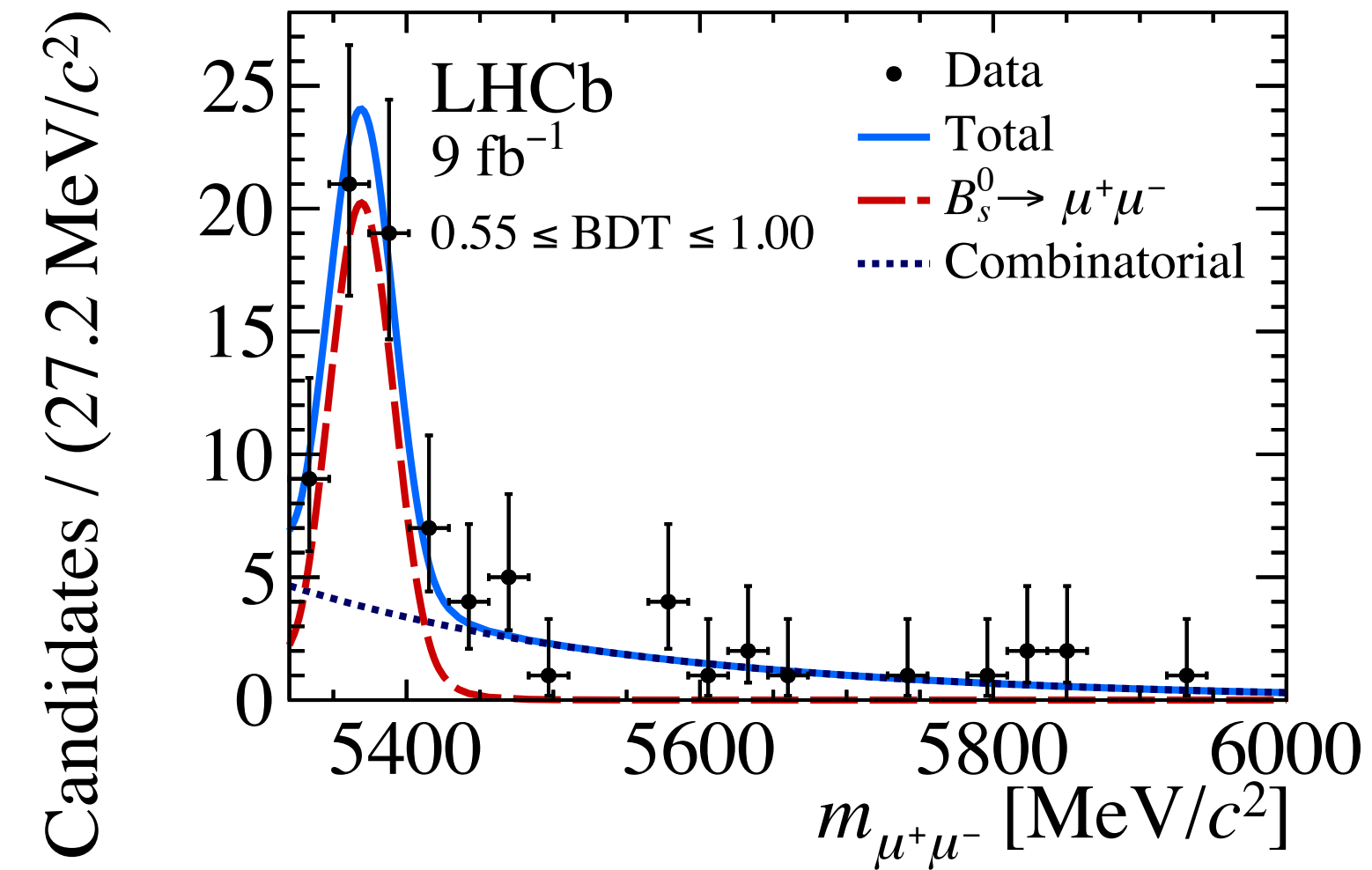
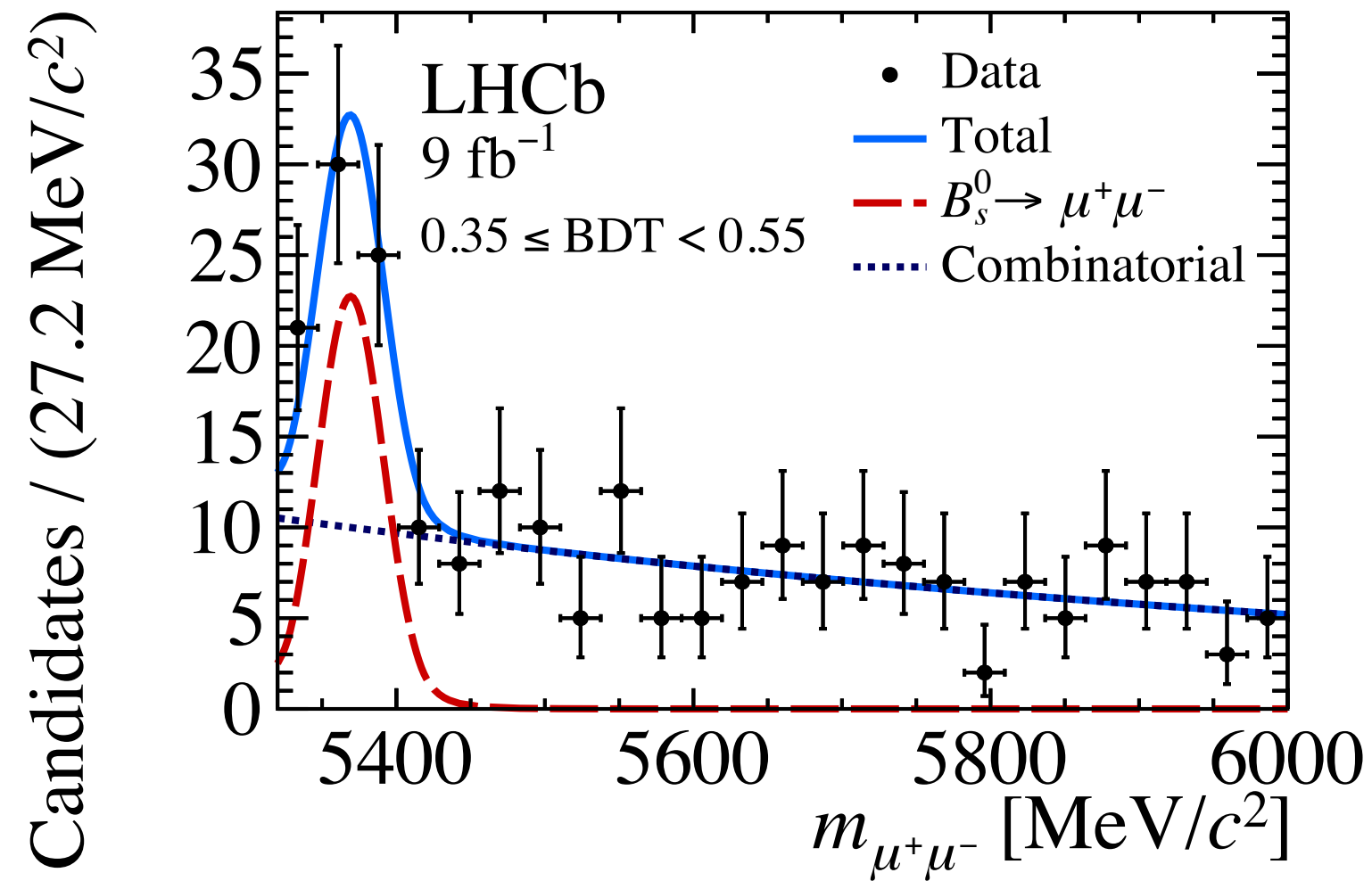
- Main systematic uncertainties: for $B_s^0 \rightarrow \mu^+\mu^-$ fragmentation fraction ratio ($\sim 3\%$), for $B^0 \rightarrow \mu^+\mu^-$ exclusive background mass model ($\sim 9\%$)



Measurement of the rare $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decay properties - Effective lifetime

[LHCb-PAPER-2021-007/8]

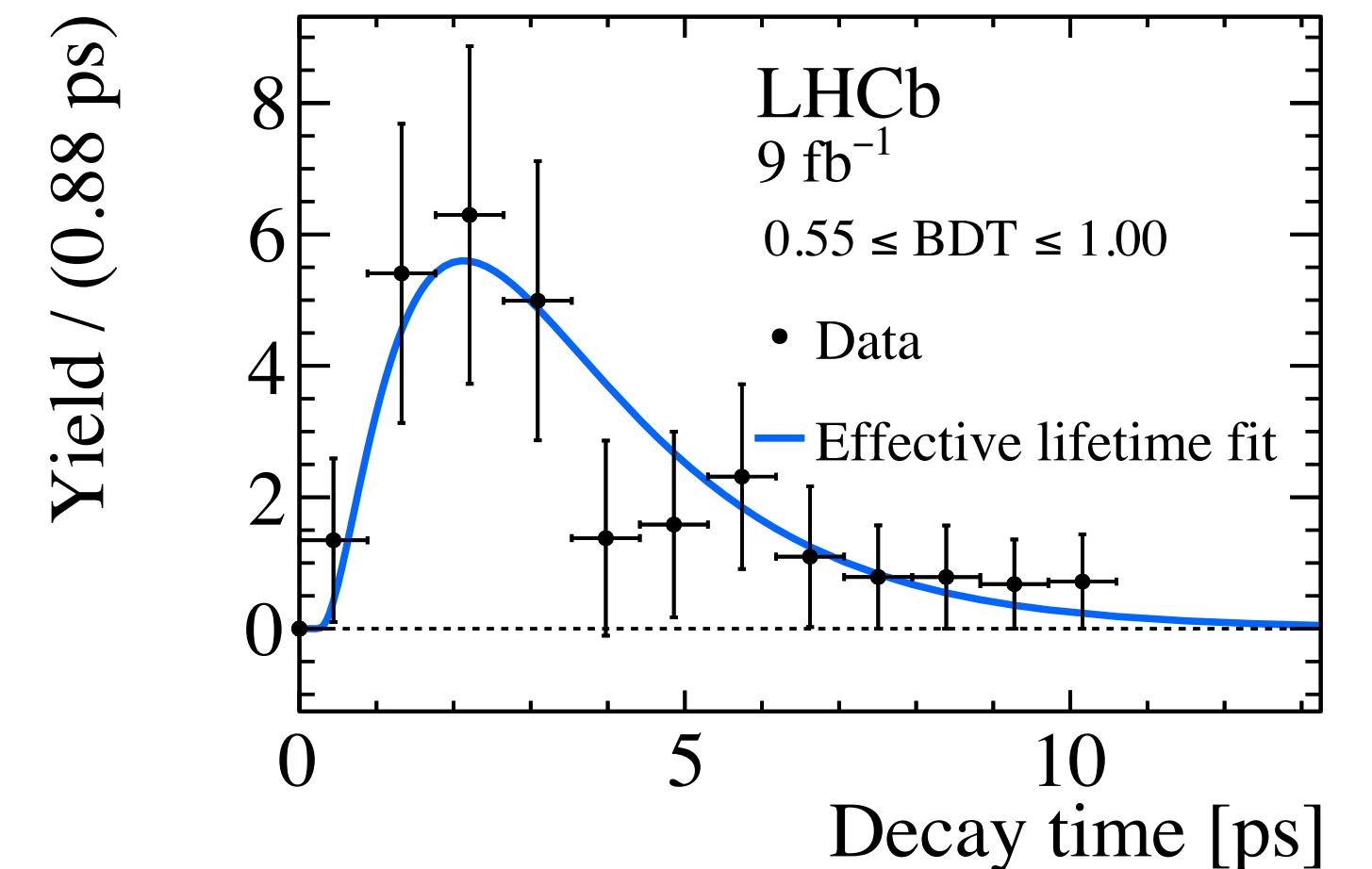
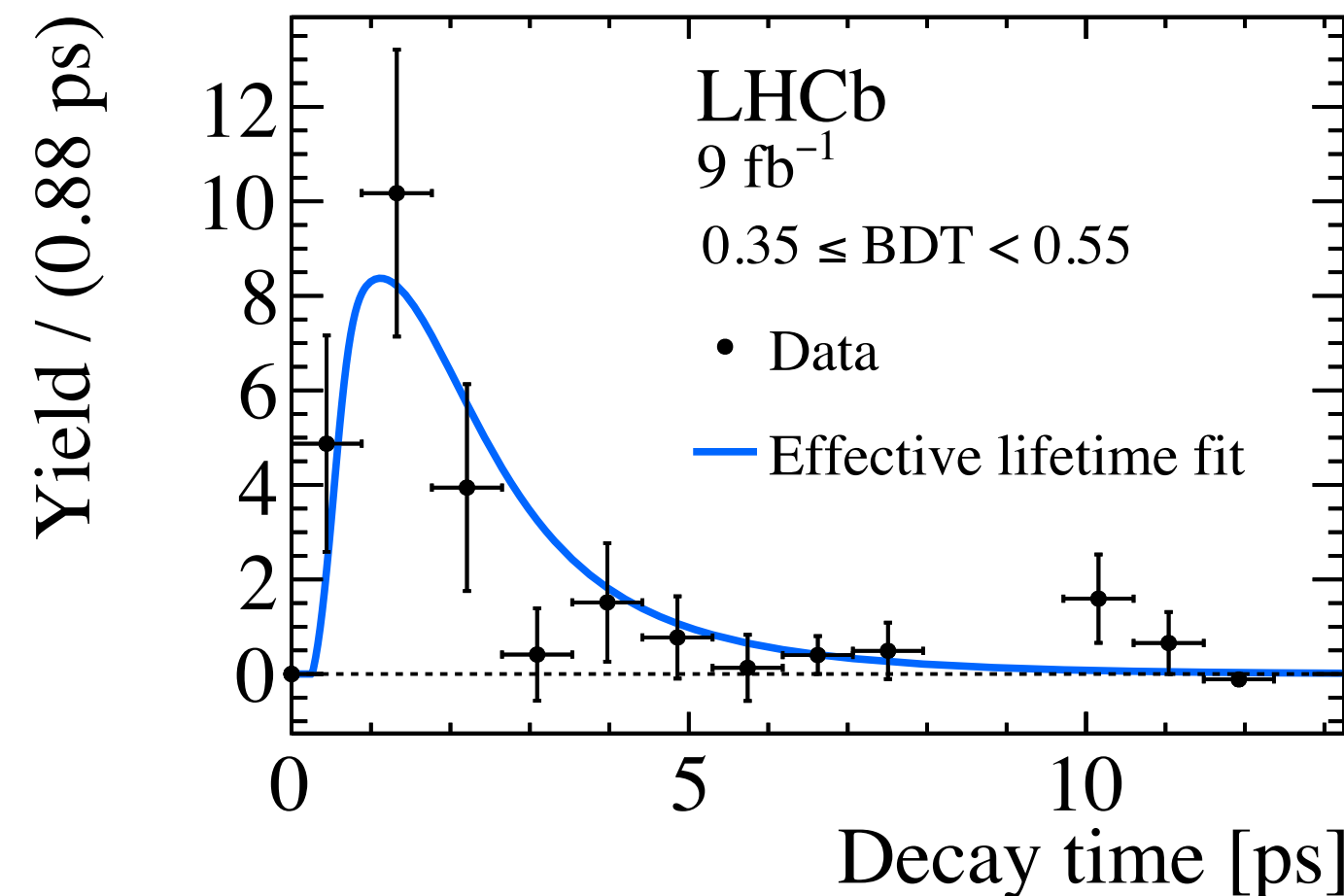
- For effective lifetime measurement, **tighter mass window chosen**: no mis-identified or partially reconstructed background
- Looser PID requirement needed
- **Background subtraction performed in two bins with sWeights** [\[Nucl.Instrum.Meth. A555: 356-369, 2005\]](#)



- Final fit on decay time distribution

$$\tau_{B_s^0 \rightarrow \mu^+\mu^-} = 2.07 \pm 0.29 \pm 0.03 \text{ ps}$$

- Result compatible with $\mathcal{A}_{\Delta\Gamma_s} = +1$ at 1.5 σ



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

[arXiv:2105.14007]

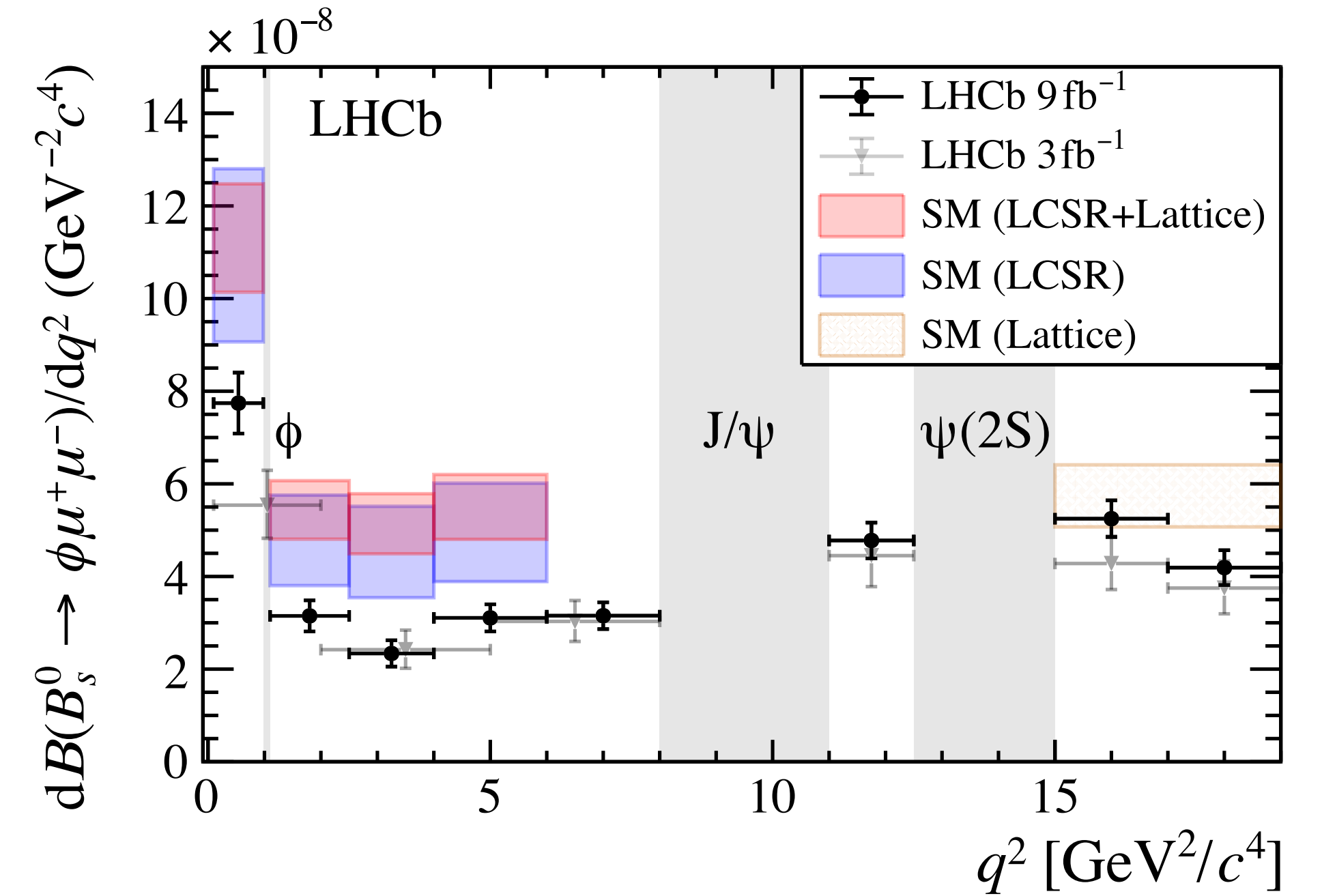
- Previously measured by LHCb using 3 fb⁻¹, update with full dataset (9 fb⁻¹)
- $|m(K^+K^-) - m_\phi| < 12 \text{ MeV}$ (more selection details in the backup)
- Normalization mode $B_s^0 \rightarrow J/\psi (\rightarrow \mu^+ \mu^-) \phi$
- In $1.1 < q^2 < 6.0 \text{ GeV}^2$ (details in the backup):

- **3.6 σ deviation from LCSR + Lattice SM prediction**

- **1.8 σ deviation from LCSR SM prediction**

[Eur.Phys.J. C75 (2015) 382] [JHEP 08 (2016) 098] [Phys.Rev.Lett. 112 (2014) 212003]

[arXiv:1810.08132] [PoS LATTICE2014 (2015) 372]



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

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

$$\mathcal{B}(B_s^0 \rightarrow \phi \mu^+ \mu^-) = (8.14 \pm 0.21 \pm 0.16 \pm 0.03 \pm 0.39) \times 10^{-7}$$

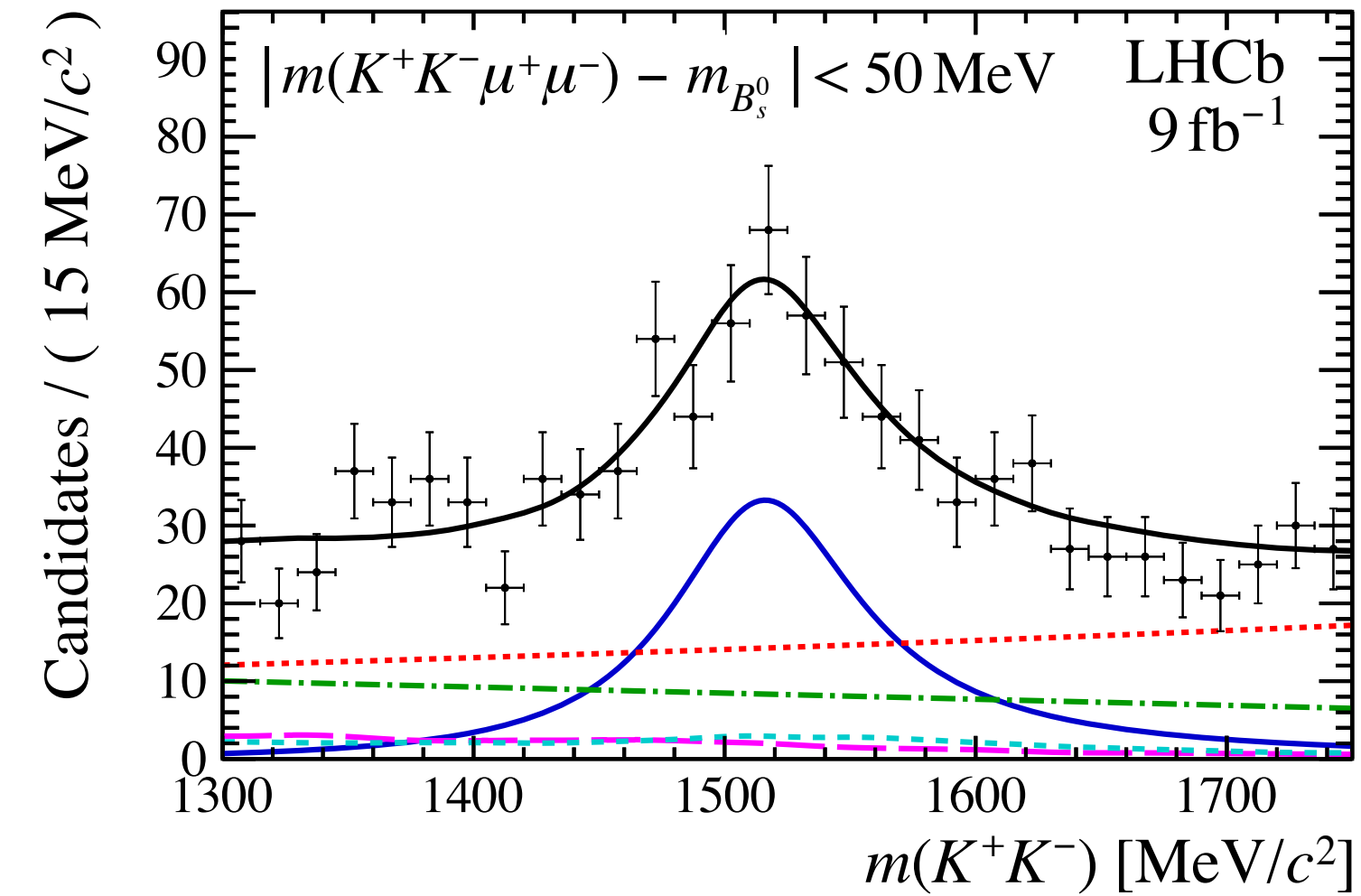
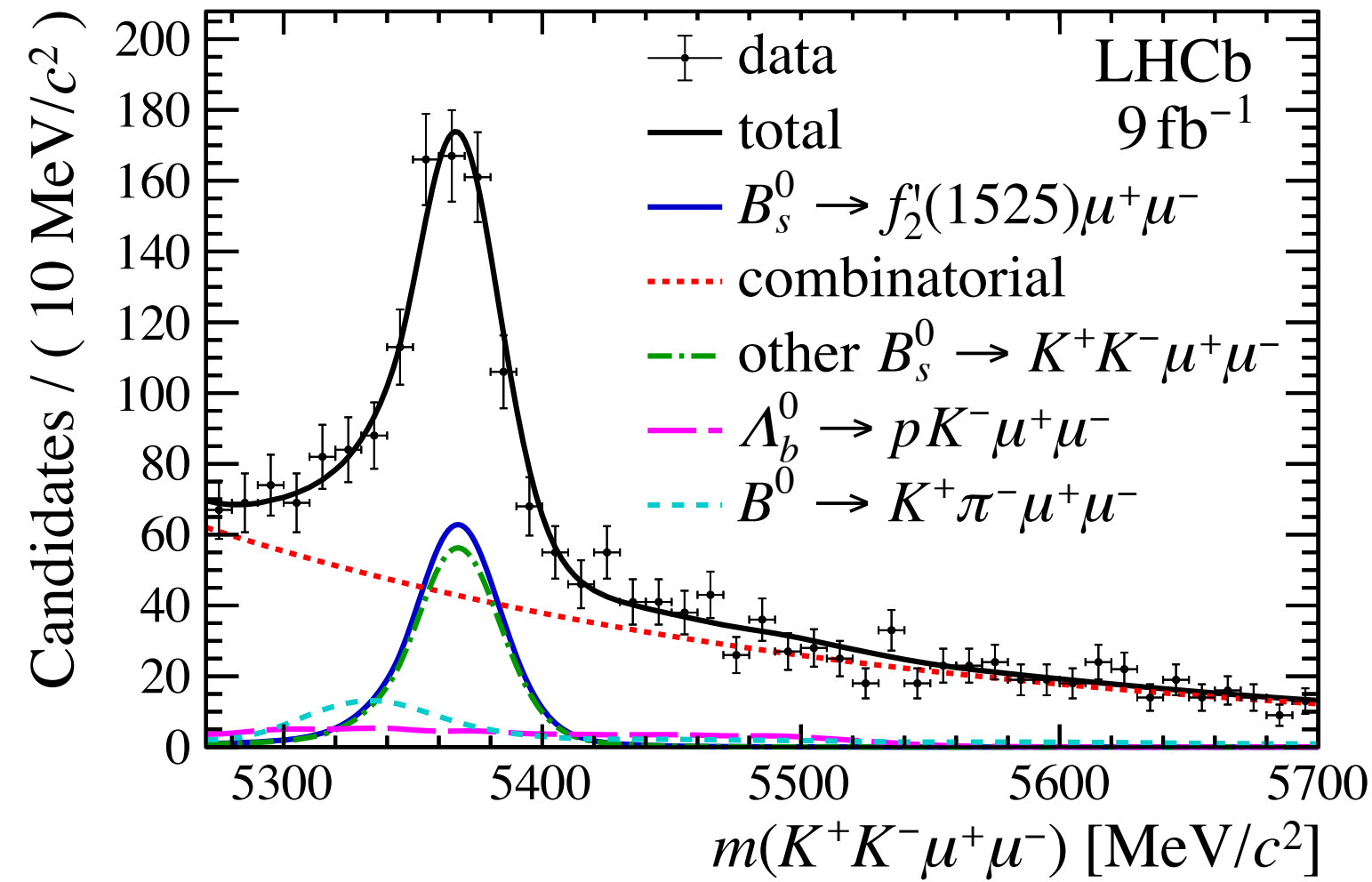
- Uncertainties are statistical, systematic, from the extrapolation to the full q^2 region and on $\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)$
- Dominating systematic uncertainties across the bins: $\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)$, model used to generate MC signal (details in backup)

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

[arXiv:2105.14007]

- Full LHCb dataset used (9 fb⁻¹), combined q^2 region $[0.1, 0.98] \cup [1.1, 8.0] \cup [11.0, 12.5] \text{ GeV}^2$
- $|m(K^+K^-) - m_{f_2'}| < 225 \text{ MeV}$
- 2D mass fit to separate signal and non-resonant contributions

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



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

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

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

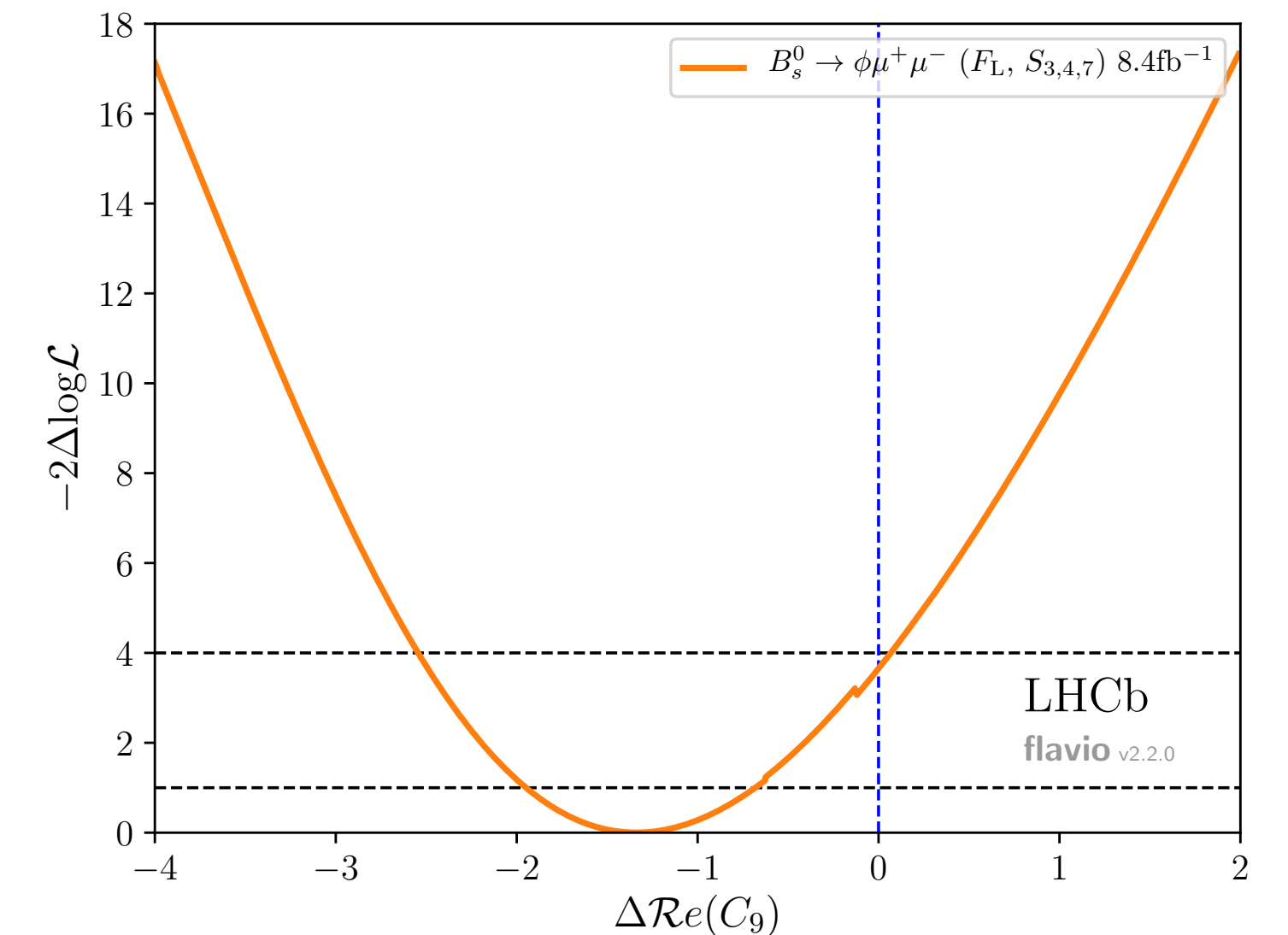
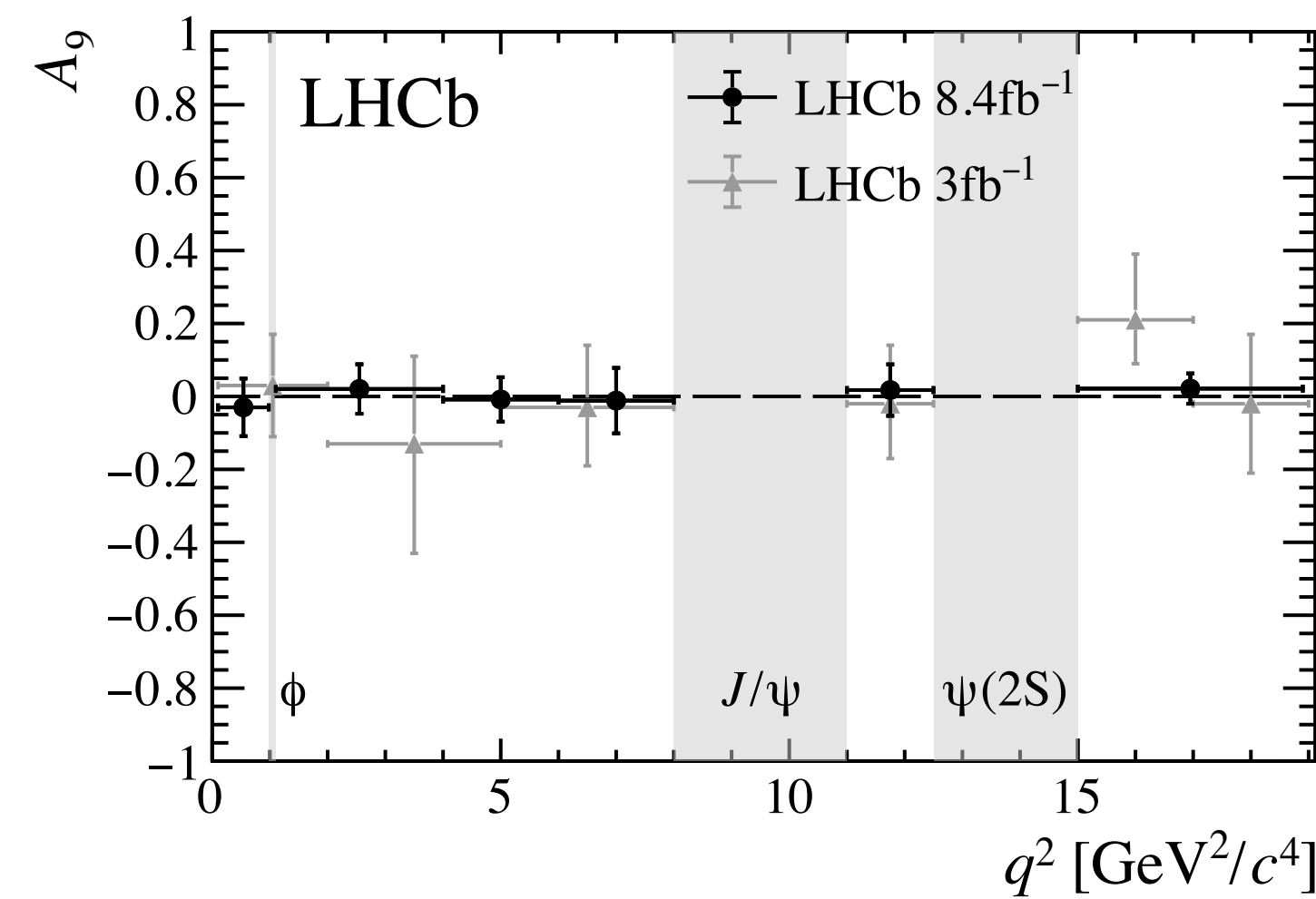
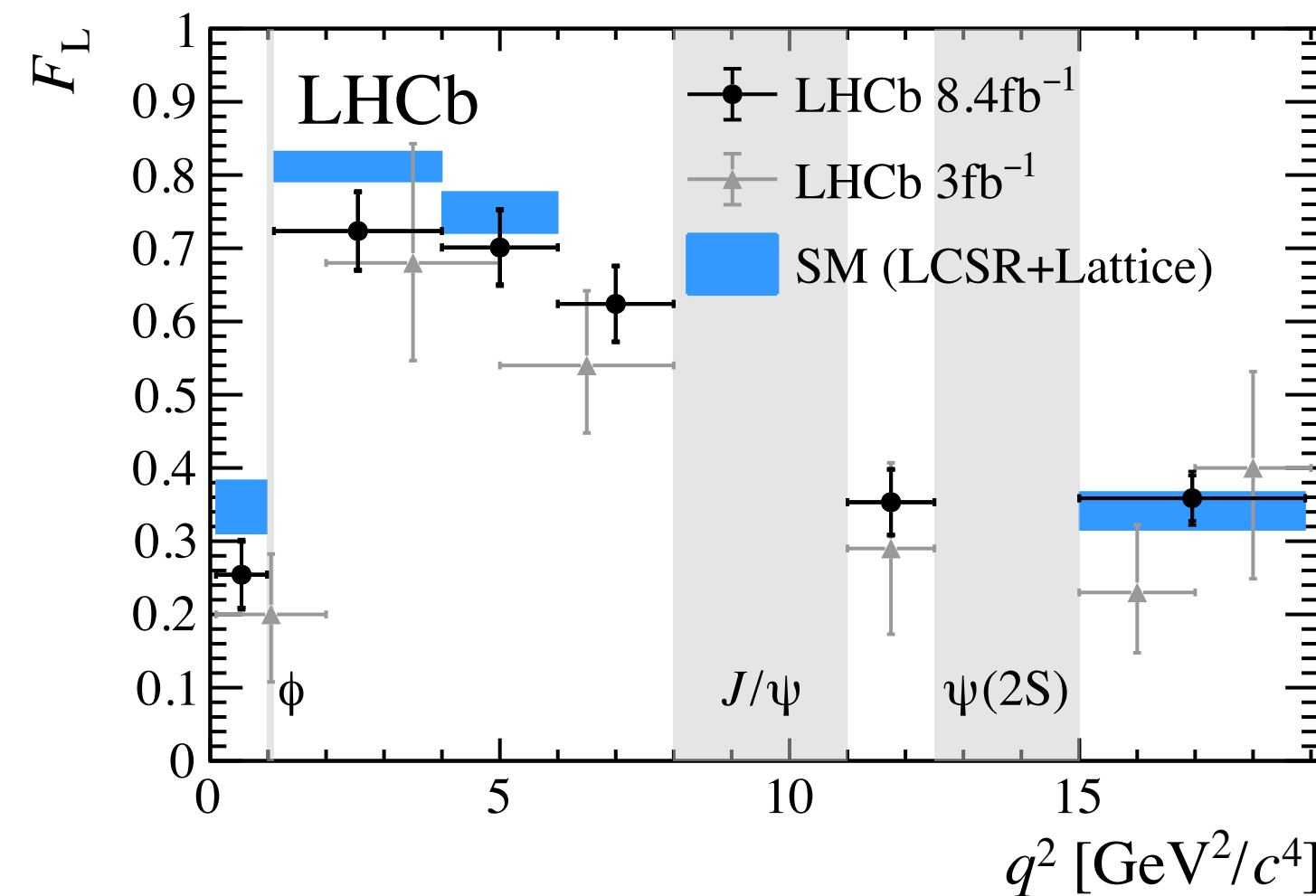
[Phys.Rev. D103 095007 (2021)] [Phys.Rev. D83 034034 (2011)] [Eur.Phys.J. C81 (2021) 30]

- Observed with a **statistical significance of 9 σ**
- Dominating systematic uncertainties: $\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)$, uncertainty on $\mathcal{B}(\phi \rightarrow K^+ K^-)/\mathcal{B}(f_2' \rightarrow K^+ K^-)$ (details in the backup)

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

[arXiv:2107.13428]

- Previously performed by LHCb using 3 fb⁻¹, update 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]
- Event selection identical to $B_s^0 \rightarrow \phi \mu^+ \mu^-$ branching ratio measurement (details in backup)
- Non-resonant contribution at 1 – 2 % , ignored in fit and taken into account in systematic uncertainty
- Results in overall agreement with SM expectations, mild tensions in F_L (more in backup)
- Fit to CP averages varying $Re(C_9)$: shift of –1.3, 1.9 σ deviation with respect to the SM
- Uncertainty statistically dominated, systematic uncertainties vary for angular observables and across q^2 bins



Photon polarization measurement in $\Lambda_b^0 \rightarrow \Lambda \gamma$ decays - Strategy

[LHCb-PAPER-2021-030]
(in preparation)

- $\Lambda_b^0 \rightarrow \Lambda \gamma$ decay is a FCNC process suppressed in the SM
- Photons from b ($\bar{b}$) decays are predominantly left-handed (right-handed)
- Angular distribution: $\Gamma(\theta_p) \propto 1 - \alpha_\gamma \alpha_\Lambda \cos \theta_p$

$$\alpha_\gamma = \frac{N_L^\gamma - N_R^\gamma}{N_L^\gamma + N_R^\gamma} = 1 + \mathcal{O}(m_s^2/m_b^2) \text{ in the SM (-1 for } \bar{b}\text{)}$$

$$\alpha_\Lambda = 0.754 \pm 0.004 \text{ (averaged over } \Lambda \text{ and } \bar{\Lambda} \text{ decays) [Nat. Phys. 15, 631–634 (2019)]}$$

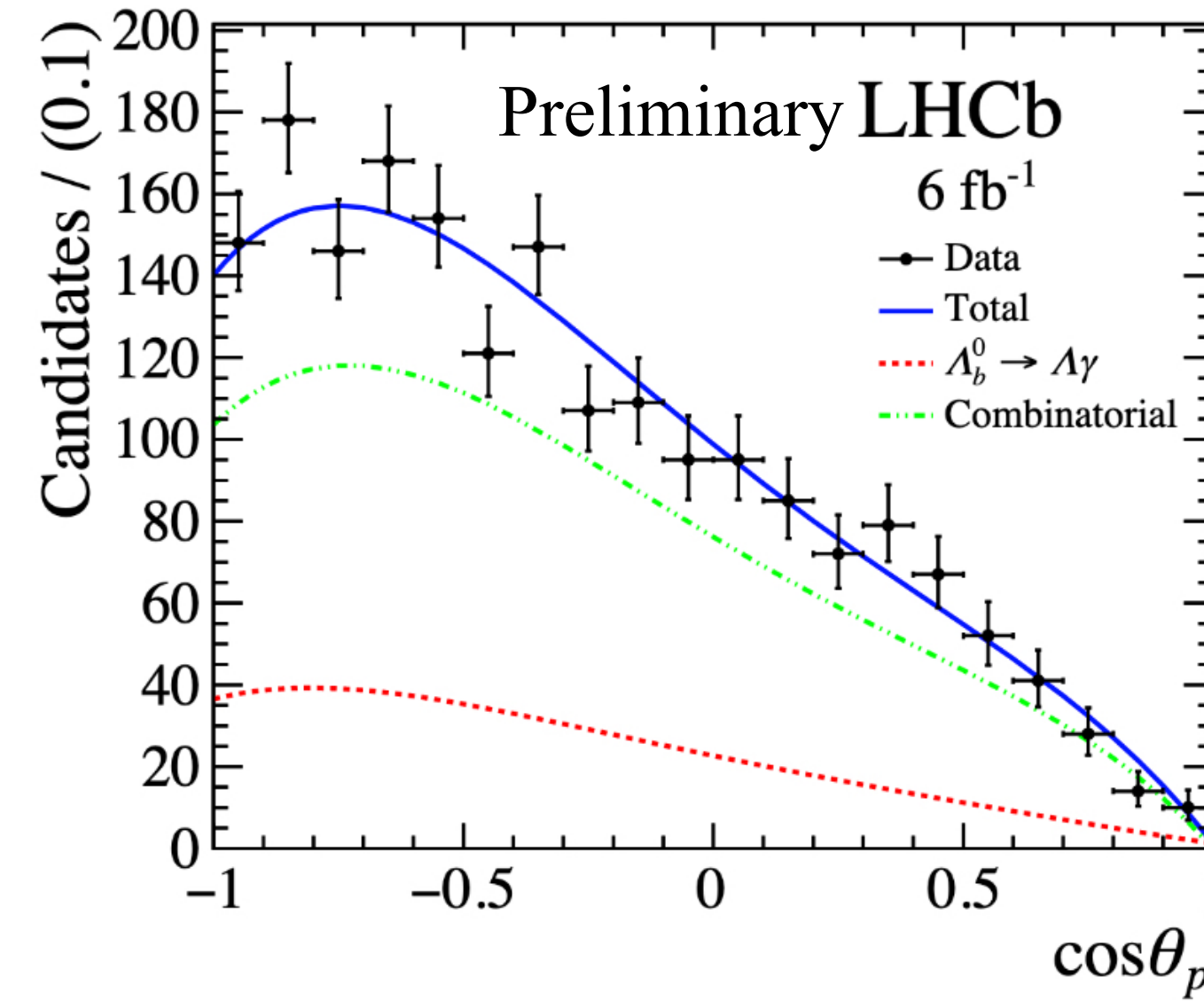
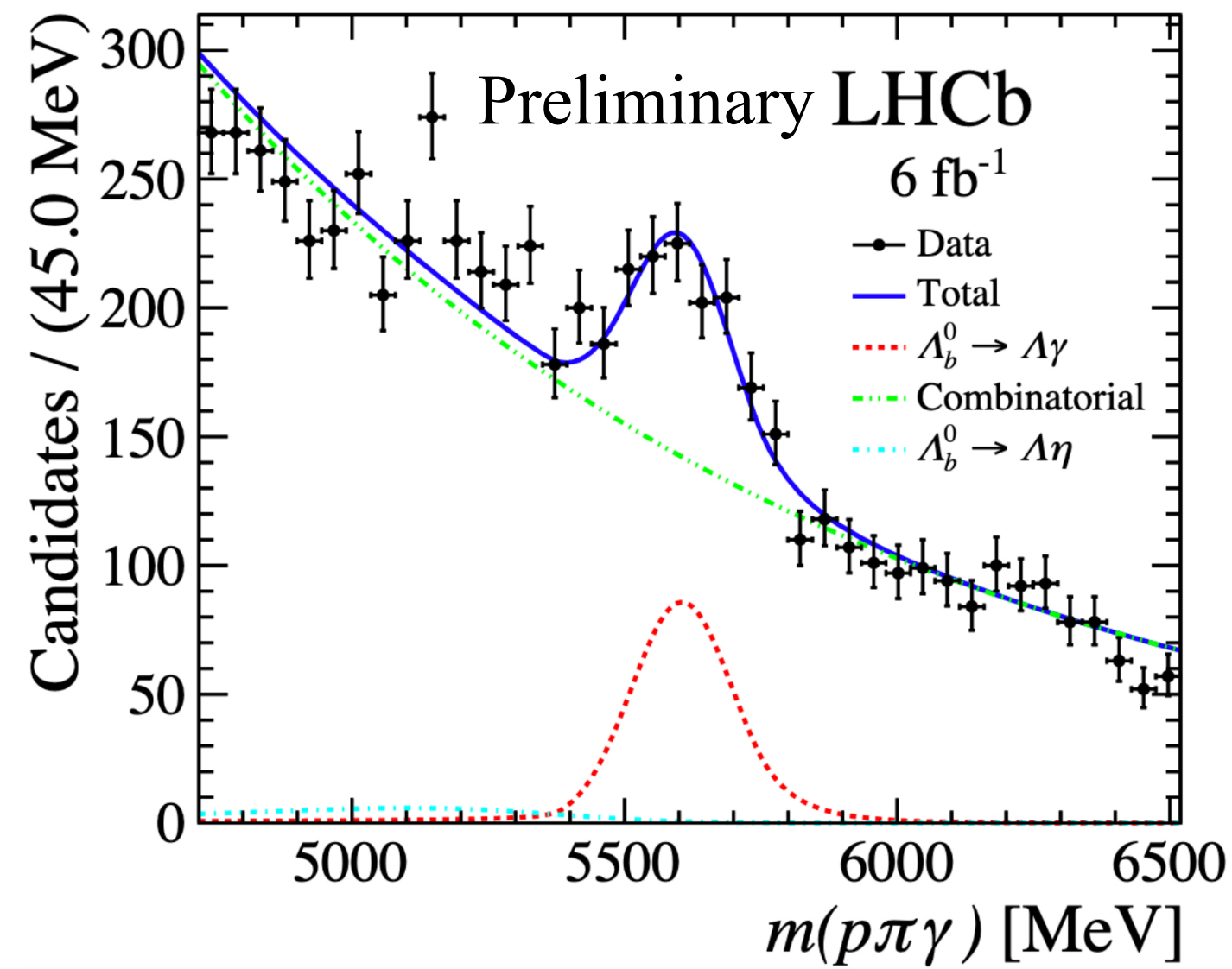
θ_p angle between the proton momentum in the Λ rest frame and the Λ momentum in the Λ_b^0 rest frame

- **Sensitive to right-handed contributions** in $b \rightarrow s \gamma$ transitions (C_7')
- **6 fb⁻¹ used**
- Background from random combination of tracks suppressed with Boosted Decision Tree
- Main background left:
 - Combination of real Λ with random photon (combinatorial)
 - $\Lambda_b^0 \rightarrow \Lambda \eta$ ($\rightarrow \gamma \gamma$) with one missing photon

Photon polarization measurement in $\Lambda_b^0 \rightarrow \Lambda \gamma$ decays - Results

[LHCb-PAPER-2021-030]
(in preparation)

- Mass fit to constrain signal to background ratio
- Fit to the $\cos \theta_p$ distribution, acceptance parametrized with fourth order polynomial



- Additionally α_γ measured separately for $\Lambda_b^0 \rightarrow \Lambda \gamma$ (α_γ^-) and $\bar{\Lambda}_b^0 \rightarrow \bar{\Lambda} \gamma$ (α_γ^+)

$$\alpha_\gamma = 0.82^{+0.17+0.04}_{-0.26-0.13}$$

$$\alpha_\gamma^- > 0.56 \text{ (0.44) at 90 \% (95 \%) CL}$$

$$\alpha_\gamma^+ = -0.56^{+0.36+0.16}_{-0.33-0.09}$$

Preliminary

- Main systematic uncertainty from the limited knowledge of the angular shape of the combinatorial background

Conclusions

- A **coherent set of anomalies** arises in measurements of rare $b \rightarrow s l^+ l^-$ processes
- Several new results in **rare B decays at LHCb**:
 - Measurement of R_K shows 3.1σ deviation with respect to the SM
 - Entering the precision regime in the measurement of properties of $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decays
 - Local deviations from the SM predictions in the measurement of $B_s^0 \rightarrow \phi \mu^+ \mu^-$ branching fraction
 - Overall agreement with the SM in the angular analysis of $B_s^0 \rightarrow \phi \mu^+ \mu^-$
 - Photon polarization measured in b -baryon decays for the first time, results in agreement with SM
- **Exciting times!** More measurements needed in order to understand the nature of flavor anomalies

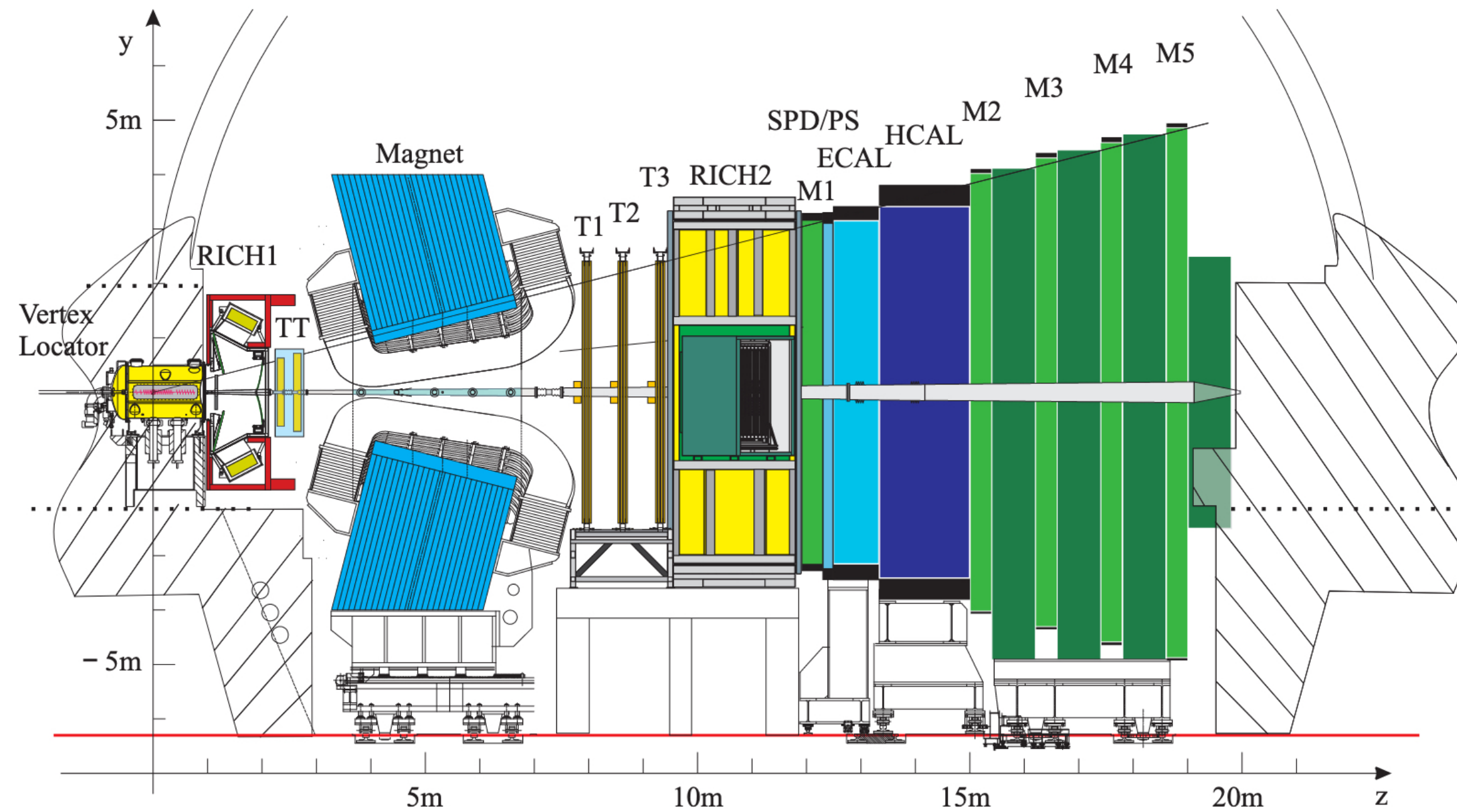
Backup



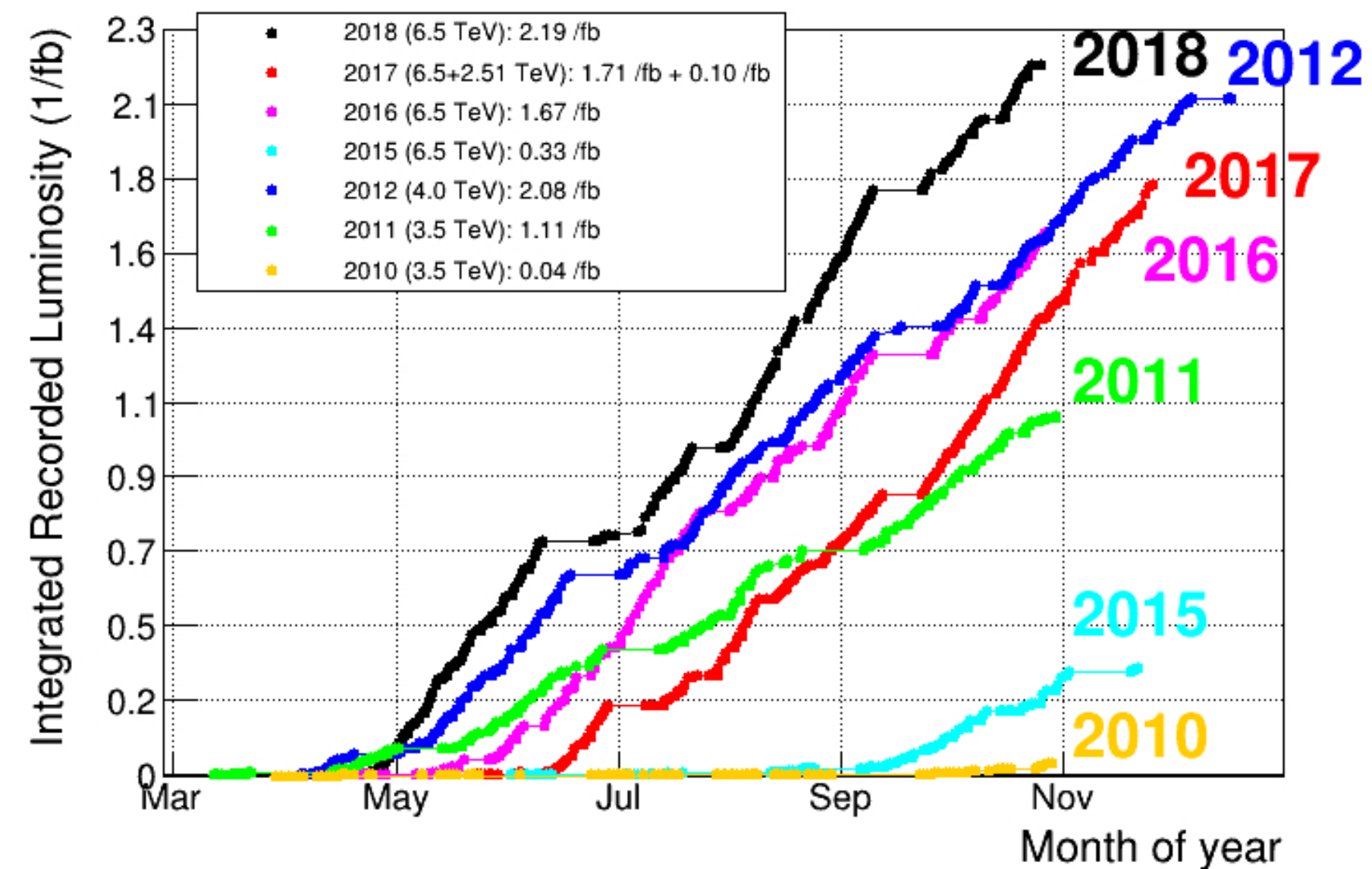
From Pinterest

The LHCb detector

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



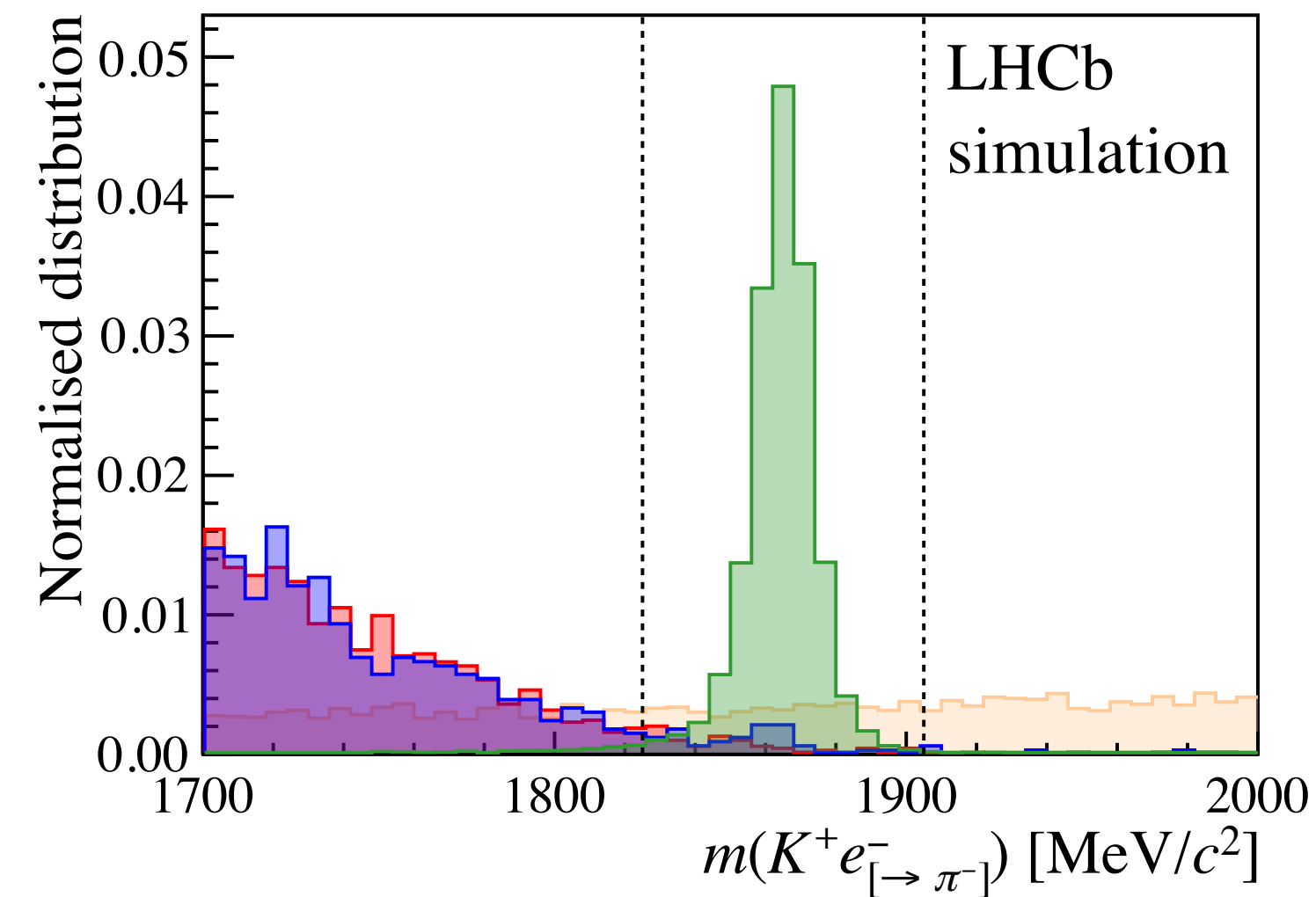
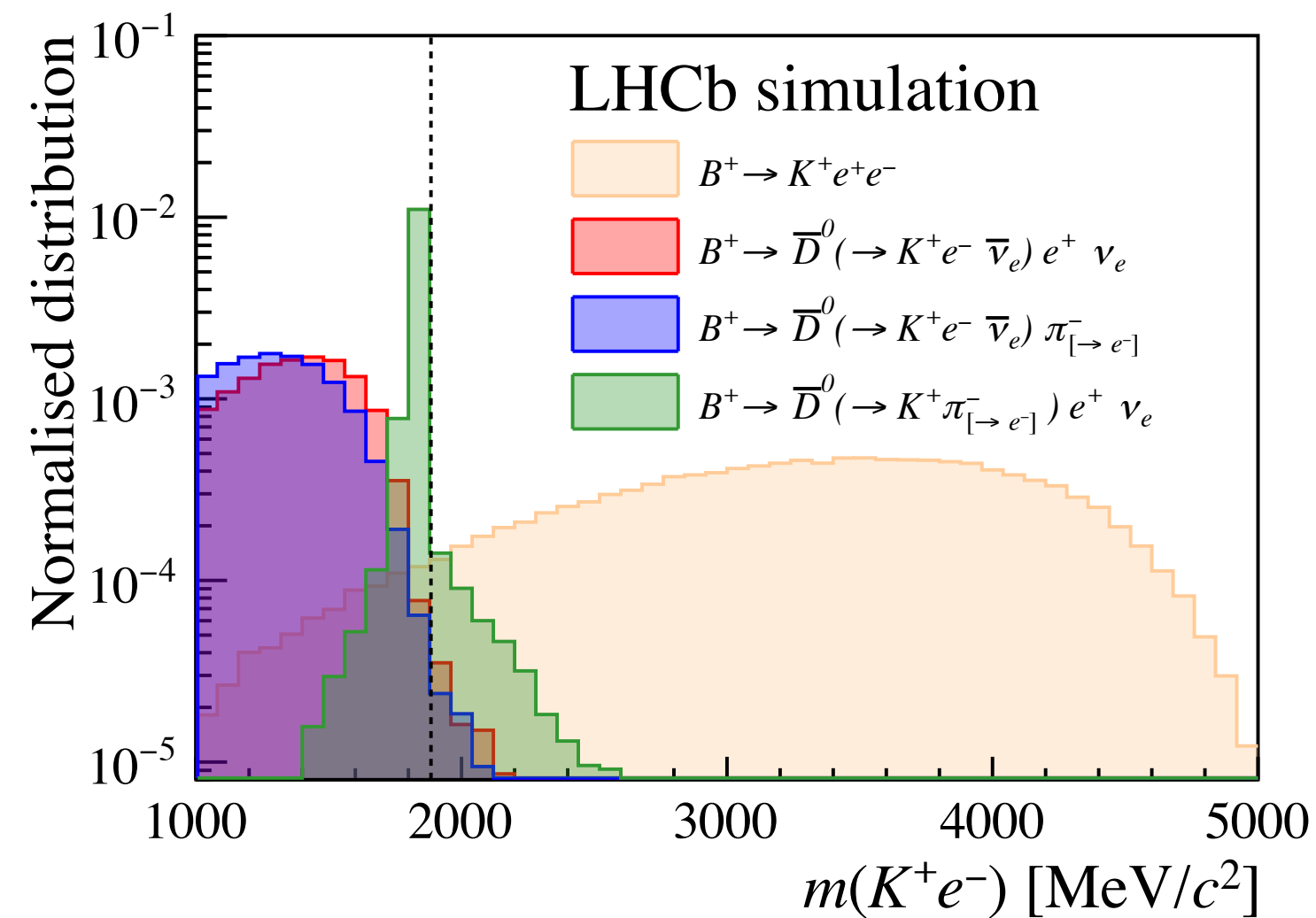
- High vertex resolution $\sigma_{IP} = 15 + 29/p_T \mu\text{m}$
- Low momentum muon trigger $p_T^\mu > 1.75 \text{ GeV}$ (2018)
- PID capabilities $\epsilon_\mu \sim 98 \%$ with $\epsilon_{\pi \rightarrow \mu} \sim 1 \%$
- Good momentum resolution $\sigma_p/p = 0.5 - 1.0 \%$, $p \in [2, 200] \text{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



Measurement of R_K - Selection and background rejection

[arXiv:2103.11769]

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

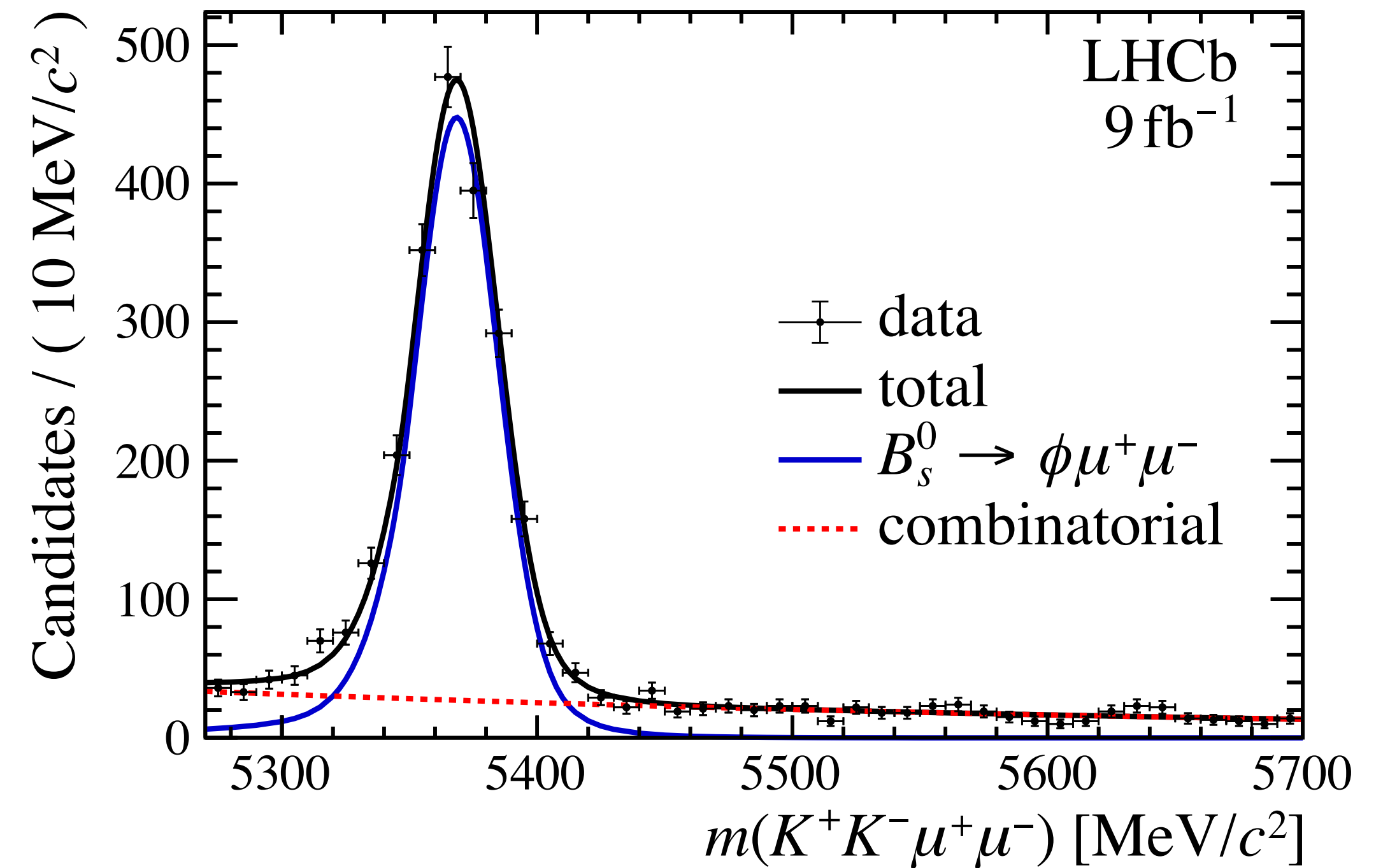
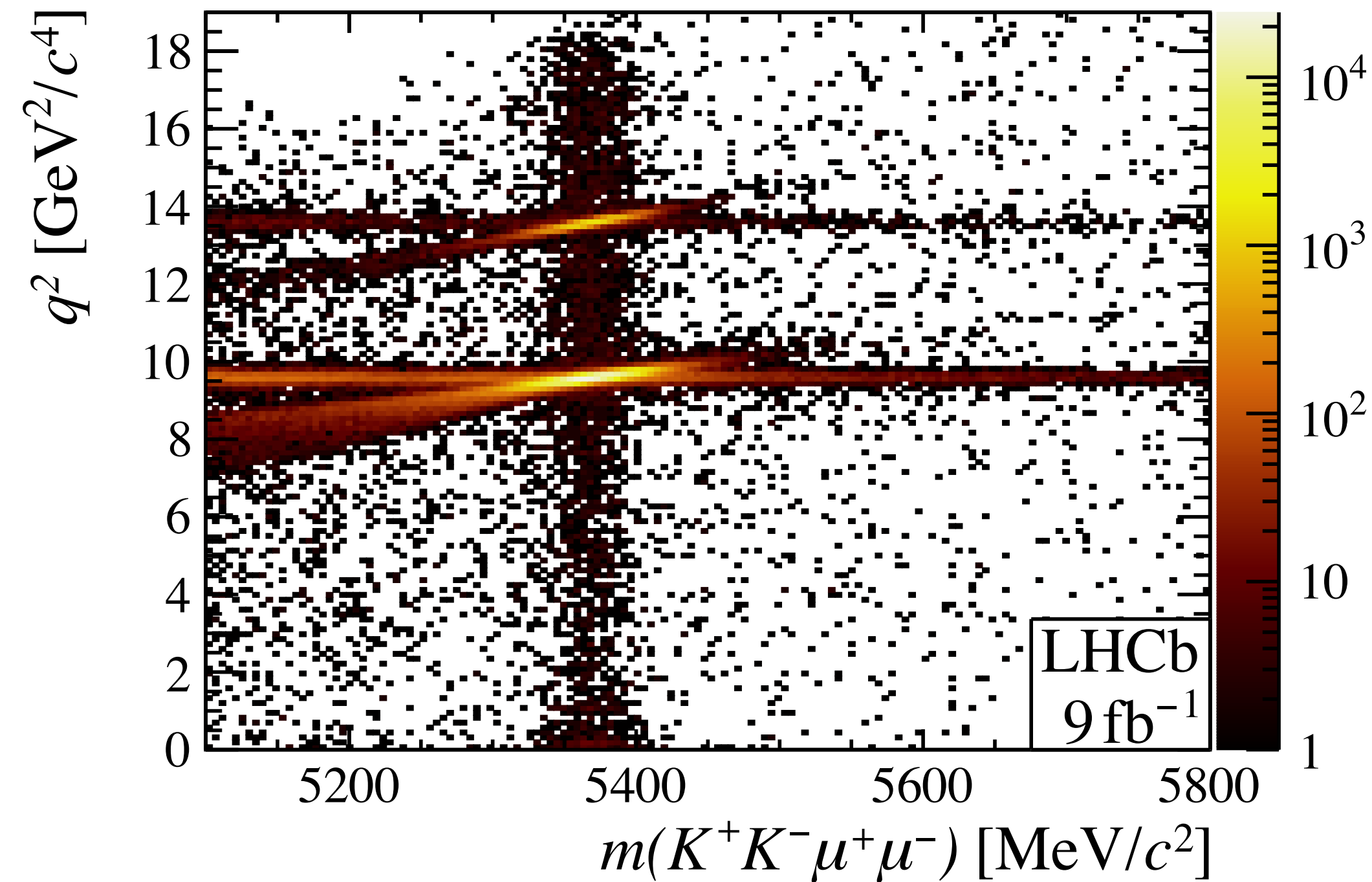


- Boosted Decision Tree (BDT) used to suppress most combinatorial background
- Main background left after selection:
 - Muon mode: combinatorial background + mis-identified $B^+ \rightarrow J/\psi \pi^+$ in normalization mode
 - Electron mode: combinatorial background + partially reconstructed $B^{(0,+)}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

$B_s^0 \rightarrow \phi \mu^+ \mu^-$ branching ratio measurement - Selection

[arXiv:2105.14007]

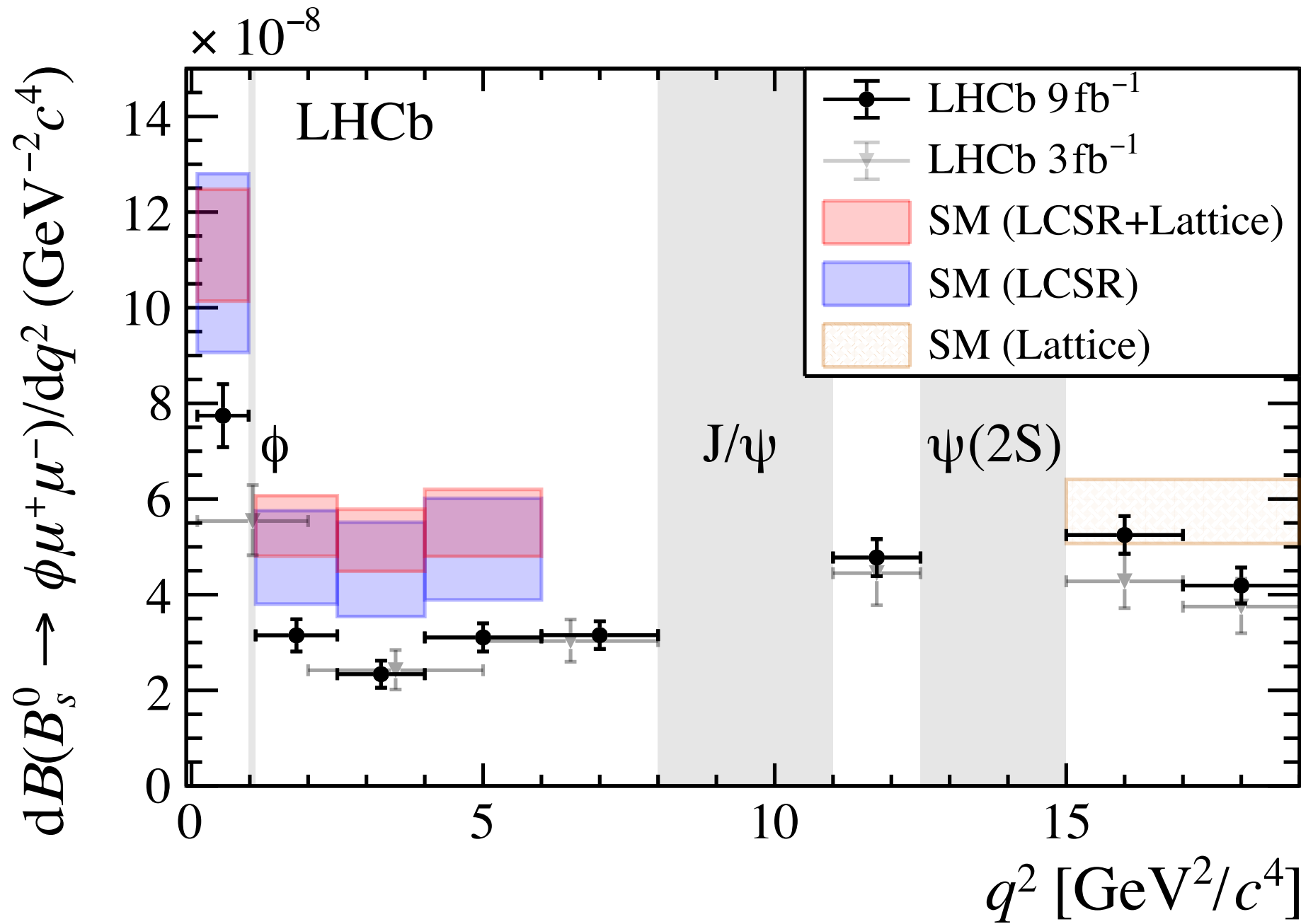
- Candidates selected from **displaced and well reconstructed vertices**
- $|m(K^+K^-) - m_\phi| < 12 \text{ MeV}$
- For rare mode, vetoes on q^2 values corresponding to J/ψ , $\psi(2S)$, ϕ
- Background from mis-identified particles rejected with PID requirements
- Combinatorial background reduced with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



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

[arXiv:2105.14007]

q^2 interval [GeV ² /c ⁴]	$\mathrm{d}\mathcal{B}(B_s^0 \rightarrow \phi \mu^+ \mu^-)/\mathcal{B}(B_s^0 \rightarrow J/\psi \phi) \mathrm{d}q^2$ [10 ⁻⁵ GeV ⁻² c ⁴]	$\mathrm{d}\mathcal{B}(B_s^0 \rightarrow \phi \mu^+ \mu^-)/\mathrm{d}q^2$ [10 ⁻⁸ 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	$4.55 \pm 0.20 \pm 0.11$	$4.63 \pm 0.20 \pm 0.11 \pm 0.22$



Source	$\sigma_{\text{syst.}}(\text{d}\mathcal{B}(B_s^0 \rightarrow \phi \mu^+ \mu^-)/\text{d}q^2)$ [$10^{-8} \text{ GeV}^{-2} c^4$]	$\sigma_{\text{syst.}}(\mathcal{B}(B_s^0 \rightarrow f_2' \mu^+ \mu^-))$ [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
$\mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)$	0.01–0.04	0.01
$\mathcal{B}(\phi \rightarrow K^+ K^-)/\mathcal{B}(f_2' \rightarrow K^+ K^-)$	–	0.04
Quadratic sum	0.05–0.12	0.06
Normalization $\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)$	0.11–0.37	0.07

- Uncertainty on model used to generate MC signal assessed by varying $\Delta\Gamma_s$ and the form factors used in the generation of the events

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

[arXiv:2107.13428]

