Radiative B hadron decays at LHCb

On behalf of LHCb collaboration

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web

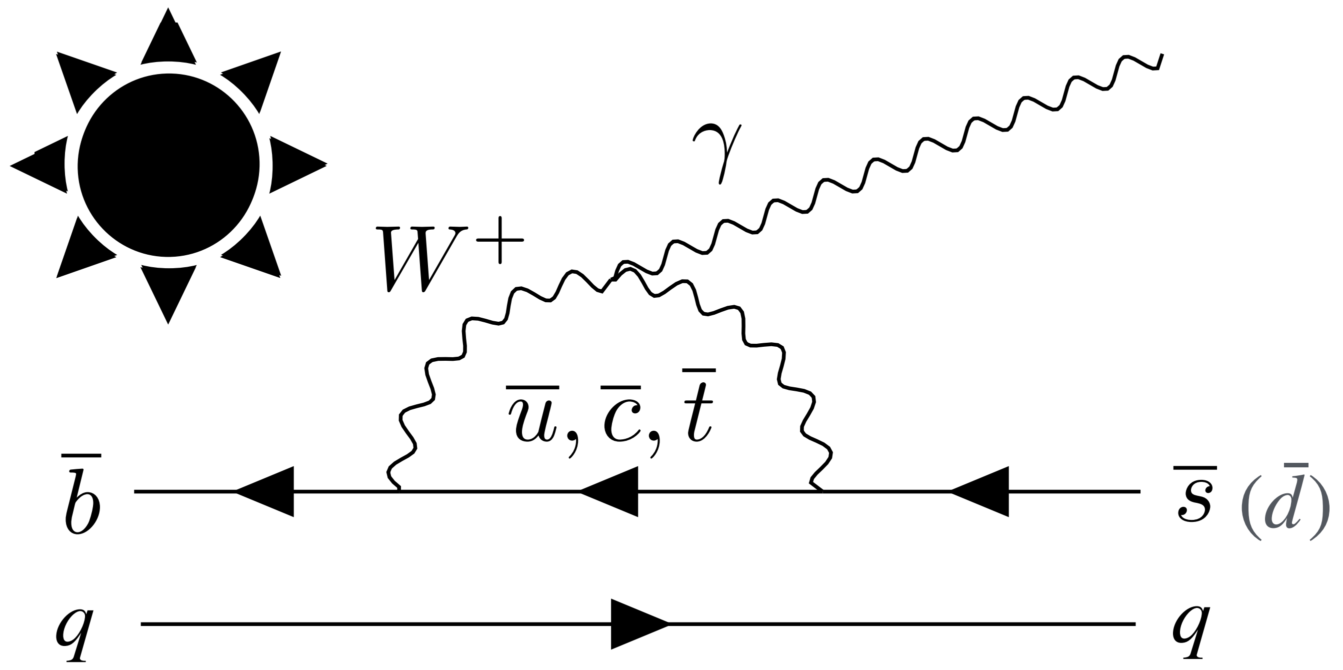
Radiative B-decays

- Flavour Changing Neutral Currents (FCNC): $b \to s(d)\gamma$
  - Proceed at loop-level → suppressed in the SM
  - Low BF's due to CKM suppression
    - Even lower for $b \to d\gamma$ transitions given $|V_{td}/V_{ts}| \sim$ 0.2

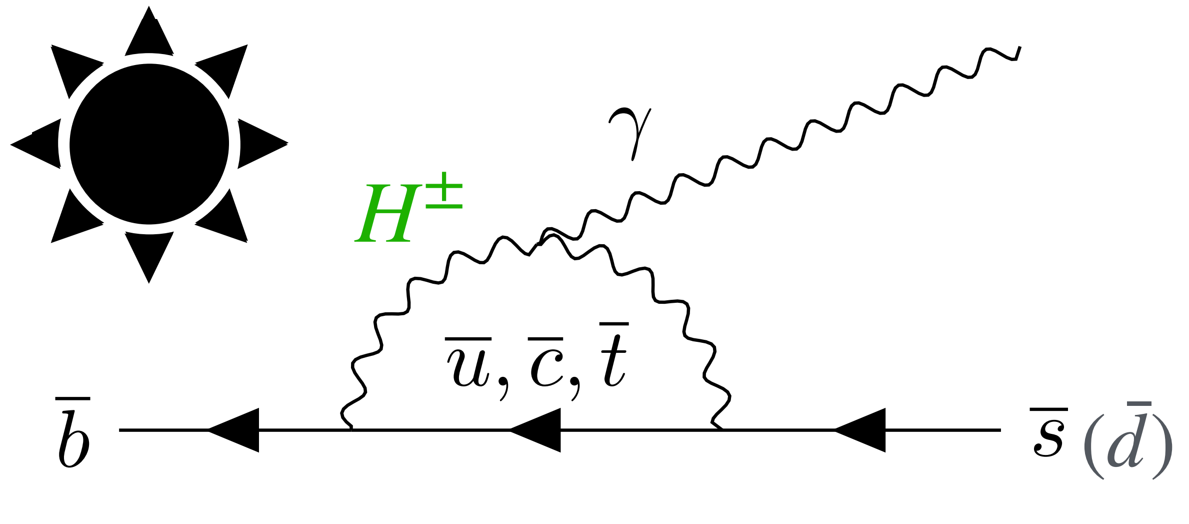
- Branching ratios (BR) ~ few 10^{-5} for $b \to s\gamma$ transitions,

  ~10^{-6} for $b \to d\gamma$ ones

- Very sensitive to NP since SM contribution is small!



radiative electroweak decays (SM)



NP (example)

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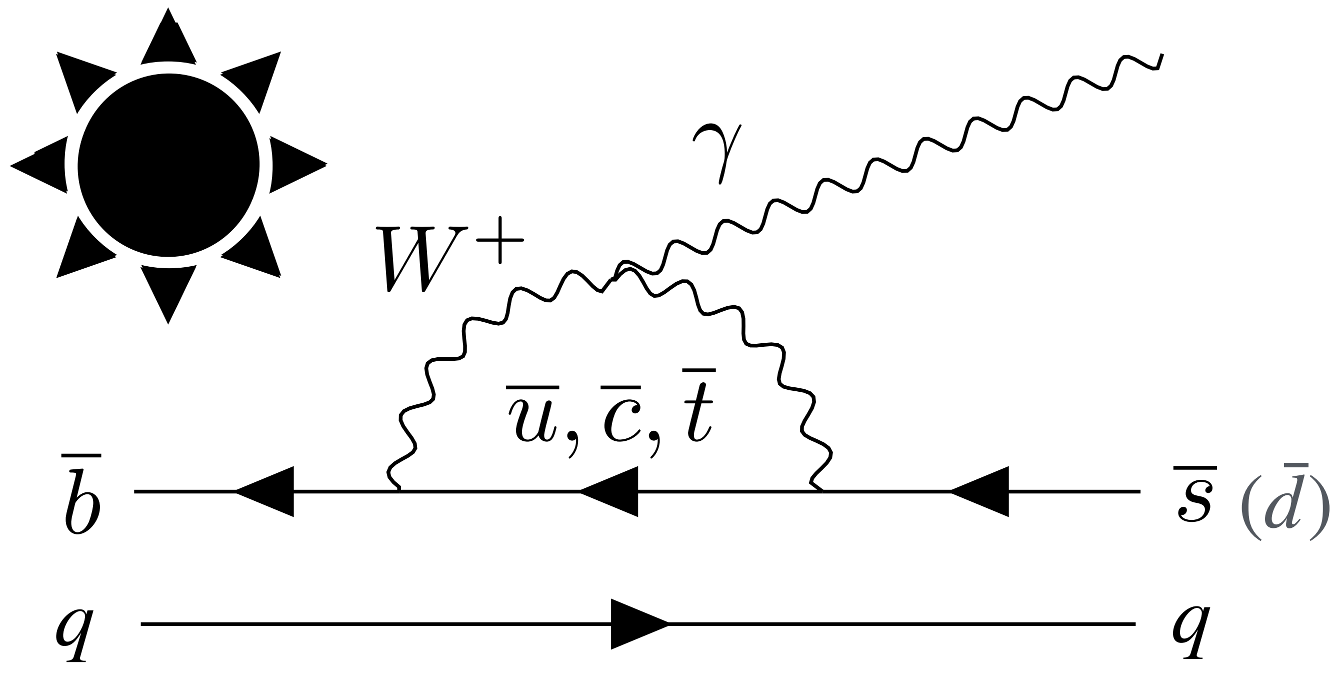


radiative electroweak decays (SM)

Effective hamiltonian described as operator product expansion, C_i being the Wilson coefficients, that encode the short-distance physics, and $\mathcal{O}_i$ the corresponding operators

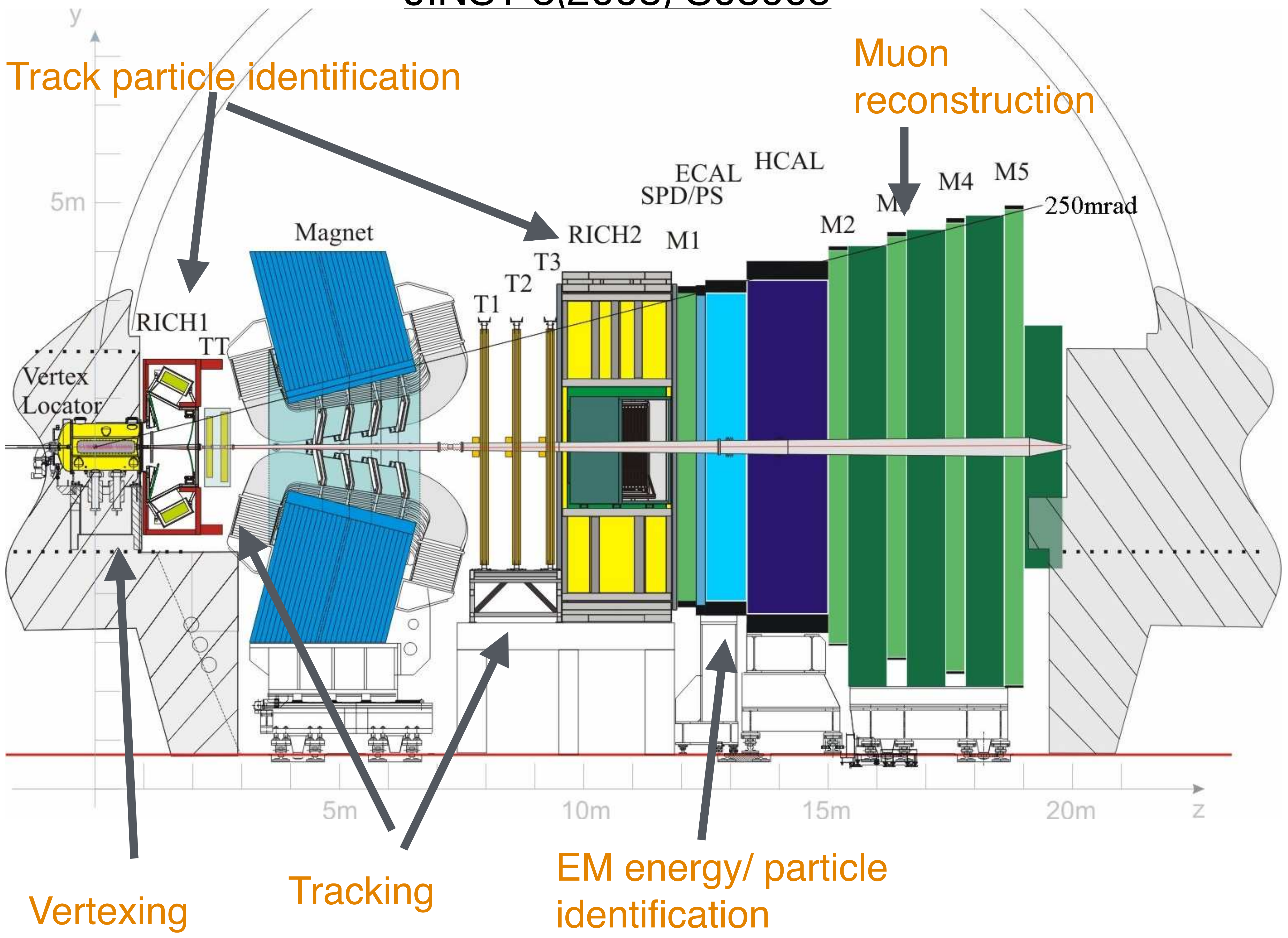
$$\mathcal{H}_{eff} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_i (\underbrace{C_i \mathcal{O}_i}_{\text{Left handed part}} + \underbrace{C_i^{'} \mathcal{O}_i^{'}}_{\text{Right handed part}})$$

$$C_i^{(')} = C_i^{SM} + C_i^{NP}$$

Coupling	Radiative $b \to s\gamma$	Leptonic $B \to \mu\mu$	Semileptonic $b \to s\ell\ell$
$\mathcal{C}_7^{(\prime)}$	✓		✓
$\mathcal{C}_9^{(\prime)}$			✓
$\mathcal{C}_{10}^{(\prime)}$		✓	✓
$\mathcal{C}_S^{(\prime)}$		✓	
$\mathcal{C}_P^{(\prime)}$		✓	

LHCb experiment

JINST 3(2008) S08005



- Designed for the study of b and c hadrons
- Forward arm spectrometer with unique coverage in pseudorapidity ($2 < \eta < 5$)
- Excellent vertex resolution
  - $\sigma_{IP} = 20\ \mu m$
- Excellent momentum resolution
  - $\Delta p/p = 0.5\% - 1.0\,\%\,(5 - 200\ GeV/c)$
- Good photon energy resolution

$$\sigma(E)/E = 1\% + 10\,\%/\sqrt{E}$$

- Efficient particle identification
  - $\epsilon(K \to K) \sim 95\,\%$ for $\epsilon(\pi \to K) \sim 5\,\%$
  - $\epsilon(e) \sim 90\,\%$ for $\epsilon(h \to e) \sim 5\,\%$
  - $\epsilon(\mu) \sim 98\,\%$ for $\epsilon(\pi \to \mu) \sim 1 - 3\,\%$

Selected results from radiative decays

$b \to d\gamma$

- Measurement of $B^0 \to \rho^0\gamma$ branching fraction [ArXiv:2507.14401]
- First evidence of the $B_s^0 \to K^-\pi^+\gamma$ decay [LHCb-PAPER-2025-056 In preparation]

★ Preliminary

$b \to s\gamma$

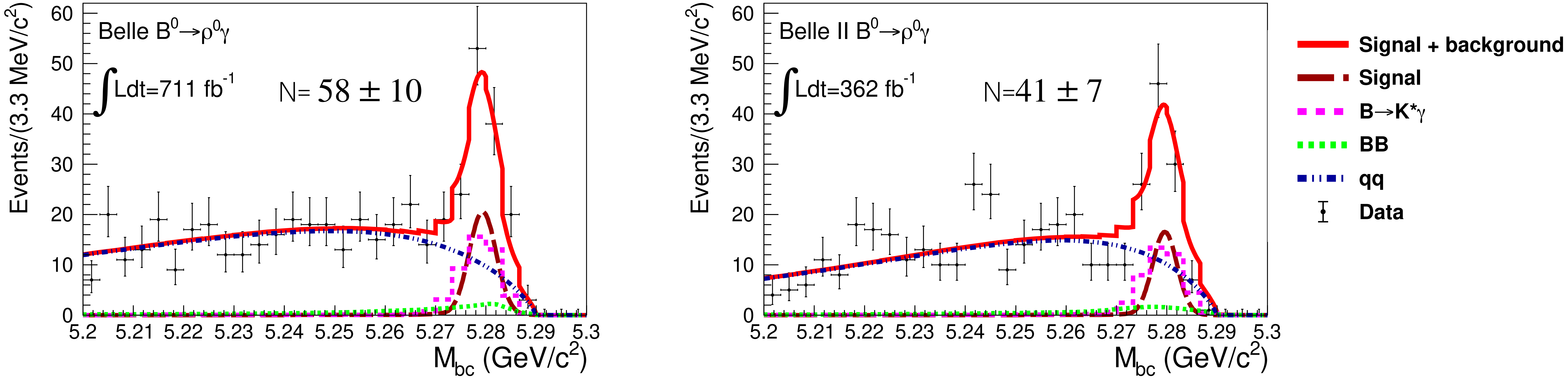
Not covered today

- Constraints on the photon polarisation in $b \to s\gamma$ transitions using $B_s^0 \to \phi e^+e^-$ decays [JHEP 03 (2025) 047]
- Amplitude analysis of the radiative decay $B_s^0 \to K^+K^-\gamma$ [JHEP 08 (2024) 093]
- Amplitude analysis of $\Lambda_b^0 \to pK^-\gamma$ decay [JHEP 06 (2024) 098]

$B^0 \to \rho^0\gamma$ branching fraction

- First observed by Belle and BaBar [PRL 101 (2008) 111801, PRD78 (2008)112001]
  - Latest PDG average, combining BaBar and Belle measurements, is $(8.6 \pm 1.5) \times 10^{-7}$ [PDG]
- Recent result combining Belle and Belle II data [PhysRevD.111.L071103]

PhysRevD.111.L071103



- Using Run 1+ 2 LHCb data (9 fb^{-1})
- First measurement associated to the $b \to d\gamma$ transitions in LHCb
  - Measurement of the ratio of the branching fractions between $B^0 \to \rho^0\gamma$ and $B^0 \to K^{*0}\gamma$
    - Provide an independent and direct constraint on the ratio of the CKM matrix elements $|V_{td}/V_{ts}|$
    - Current theoretical uncertainty dominated by the $B^0 \to \rho^0$ and $B^0 \to K^{*0}$ form factors uncertainties [JHEP 04 (2006) 046]

$B^0 \to \rho^0\gamma$ branching fraction

ArXiv:2507.14401

- Ratio of branching fraction

$$\frac{\mathcal{B}(B^0\to \rho^0\gamma)}{\mathcal{B}(B^0\to K^{*0}\gamma)} = \frac{N(B^0\to \rho^0(\pi^+\pi^-)\gamma)}{N(B^0\to K^{*0}(K^+\pi^-)\gamma)} \times \frac{\varepsilon(B^0\to K^{*0}(K^+\pi^-)\gamma)}{\varepsilon(B^0\to \rho^0(\pi^+\pi^-)\gamma)} \times \mathcal{R}_{\mathcal{B}},$$

Yields: simultaneous unbinned maximum-likelihood fit to B invariant mass

Efficiencies: simulation corrected for MC/data differences

$$\frac{\mathcal{B}(K^{*0}\to K^+\pi^-)}{\mathcal{B}(\rho^0\to\pi^+\pi^-)}$$

- Mass window selections
  - $m_{\pi\pi} \in [630{,}920]$ MeV/c², $m_{K\pi} \in [795.5{,}995.5]$ MeV/c² (related efficiencies are accounted for)
- Charm veto $m_{\pi\gamma\to\pi^0} > 2000$ MeV/c²
- Combinatorial background suppressed by a BDT which uses kinematic and isolation variables
- PID criteria (charged and neutral) optimized with respect to the specific backgrounds
- MC/data differences corrected thanks to kinematic weighting and PID calibration samples

	$B^0 \to \rho^0\gamma(\%)$
$B^0 \to K^*\gamma$	11
$B^0 \to \rho^0(\pi^+\pi^-)\pi^0$	12
$B_s^0 \to \phi(\pi^+\pi^-\pi^0)\gamma$	13
$B^0 \to K^+\pi^-\pi^0$	0.4
$B^0 \to \rho^0\eta$	0.9

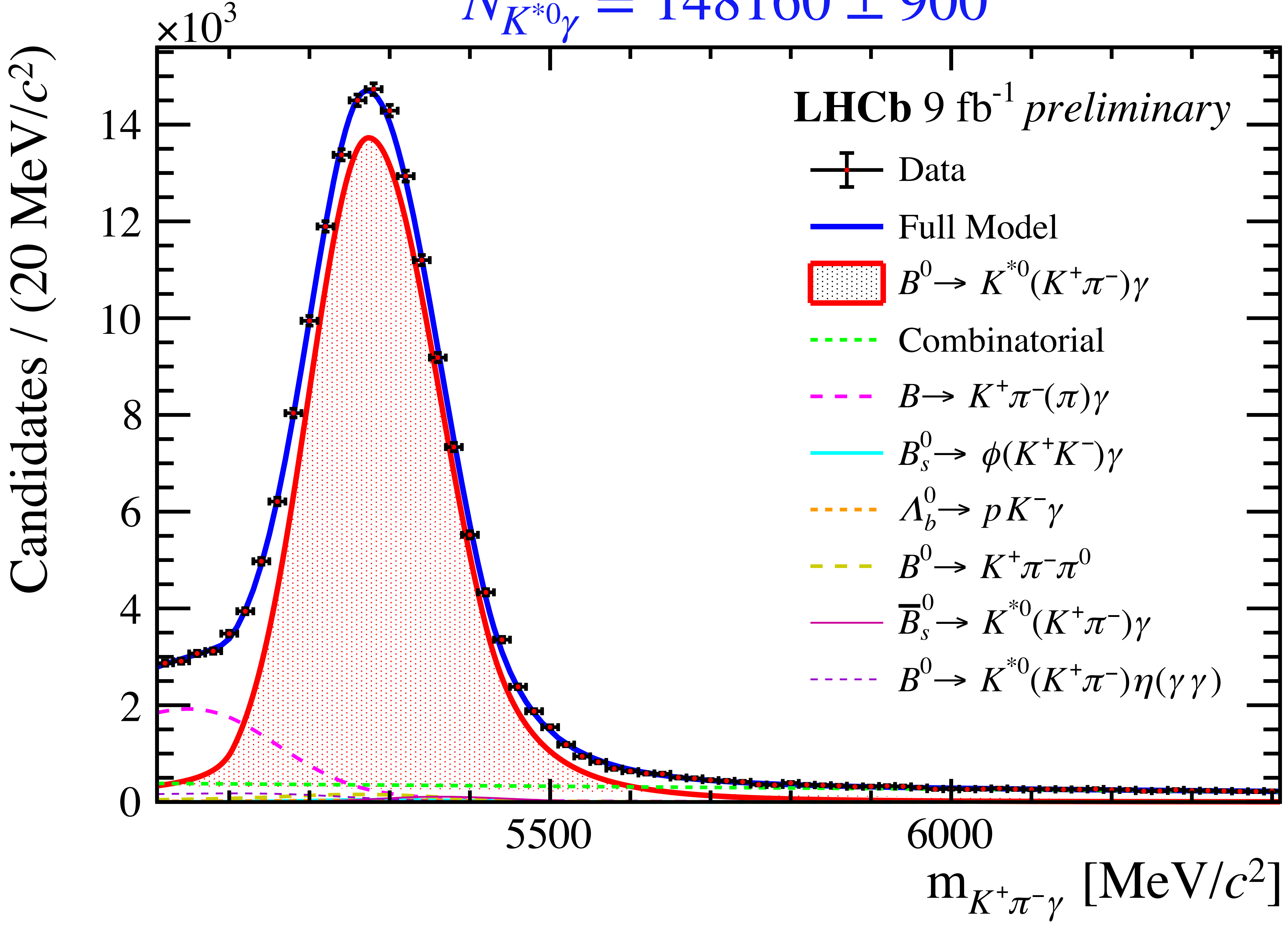
	$B^0 \to K^{*0}\gamma(\%)$
$B^0 \to K^+\pi^-\pi^0$	1.6
$B^0 \to K^*\eta$	1.6
$\bar{B}_s^0 \to K^{*0}\gamma$	0.8
$\Lambda_b^0 \to pK^-\gamma$	0.5
$B_s^0 \to \phi\gamma$	0.4

$B^0 \to \rho^0\gamma$ branching fraction

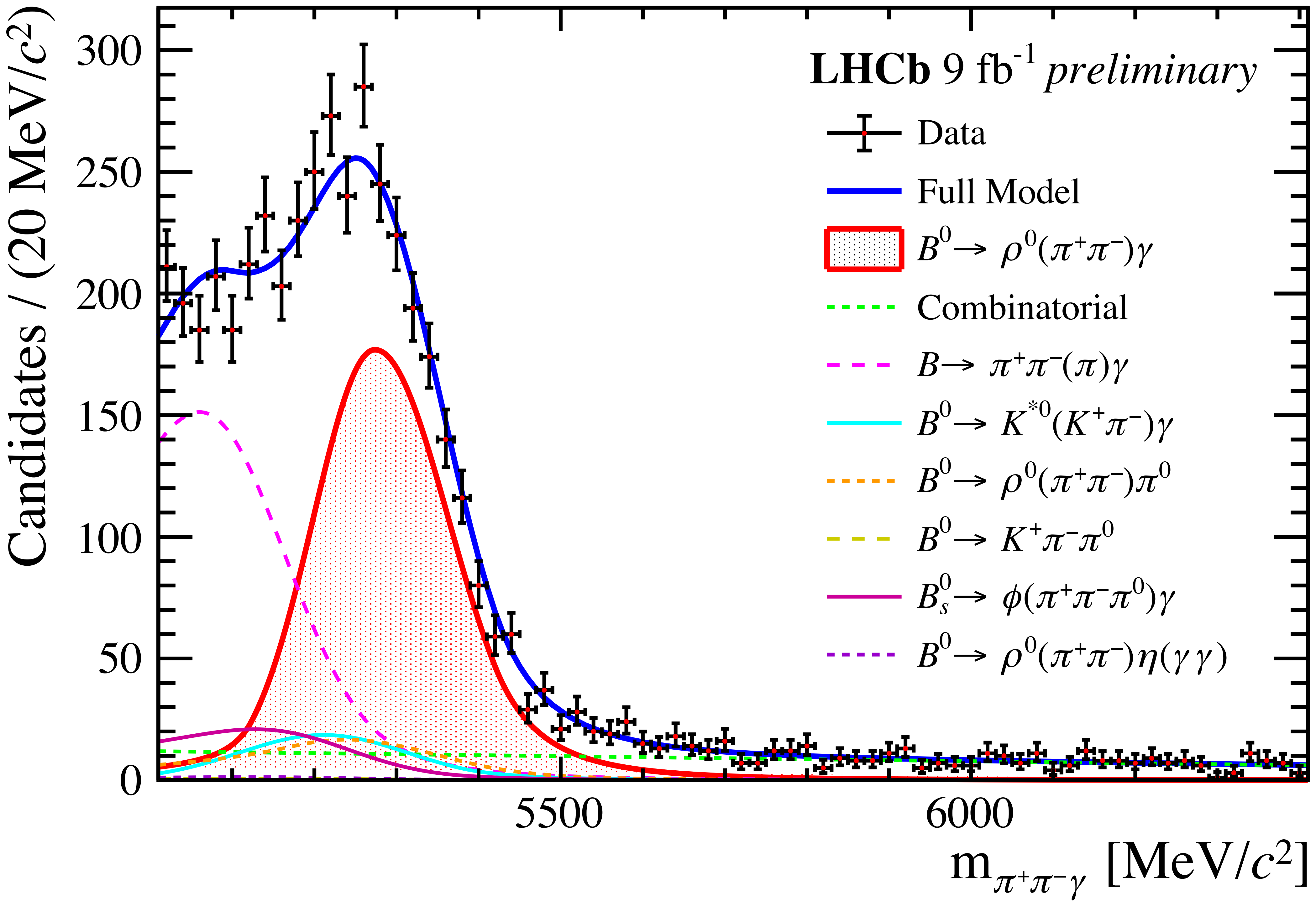
ArXiv:2507.14401

- Normalization and signal modes shared most of the signal shape parameters
- Misidentified background contributions to the $B^0 \to K^{*0}\gamma$ and $B^0 \to \rho^0\gamma$ samples are fixed as fractions of the fitted $B^0 \to K^{*0}\gamma$ yield
  - Shapes of those specific backgrounds are obtained from simulation

$N_{K^{*0}\gamma} = 148160 \pm 900$



$N_{\rho^0\gamma} = 1917 \pm 71$



$B^0 \to \rho^0\gamma$ branching fraction: Systematics

ArXiv:2507.14401

Systematics: Yield ratio

Source	Uncertainty [%]
Signal mass model	$(+0.5,\ -0.6)$
Background contributions	$(+2.0,\ -2.2)$
Background mass models	$(+1.1,\ -0.8)$
Total systematic uncertainty	$(+2.3,\ -2.4)$

Efficiency ratio:

Source	Uncertainty [%]
Simulated samples size	$(+0.8,\ -0.8)$
Kinematics corrections	$(+1.1,\ -0.2)$
Kaon/pion reconstruction	$(+0.3,\ -0.3)$
Charged PID	$(+0.7,\ -1.3)$
Neutral PID	$(+0.1,\ -0.1)$
Total systematic uncertainty	$(+1.6,\ -1.6)$

Dominated by the 25% relative uncertainty on the $B^0 \to \rho^0(\pi^+\pi^-)\pi^0$ branching fraction

$B^0 \to \rho^0\gamma$ branching fraction

ArXiv:2507.14401

- The ratio of branching fraction is measured as

$$\frac{\mathcal{B}(B^0 \to \rho^0\gamma)}{\mathcal{B}(B^0 \to K^{*0}\gamma)} = 0.0189 \pm 0.0007 \pm 0.0005,$$

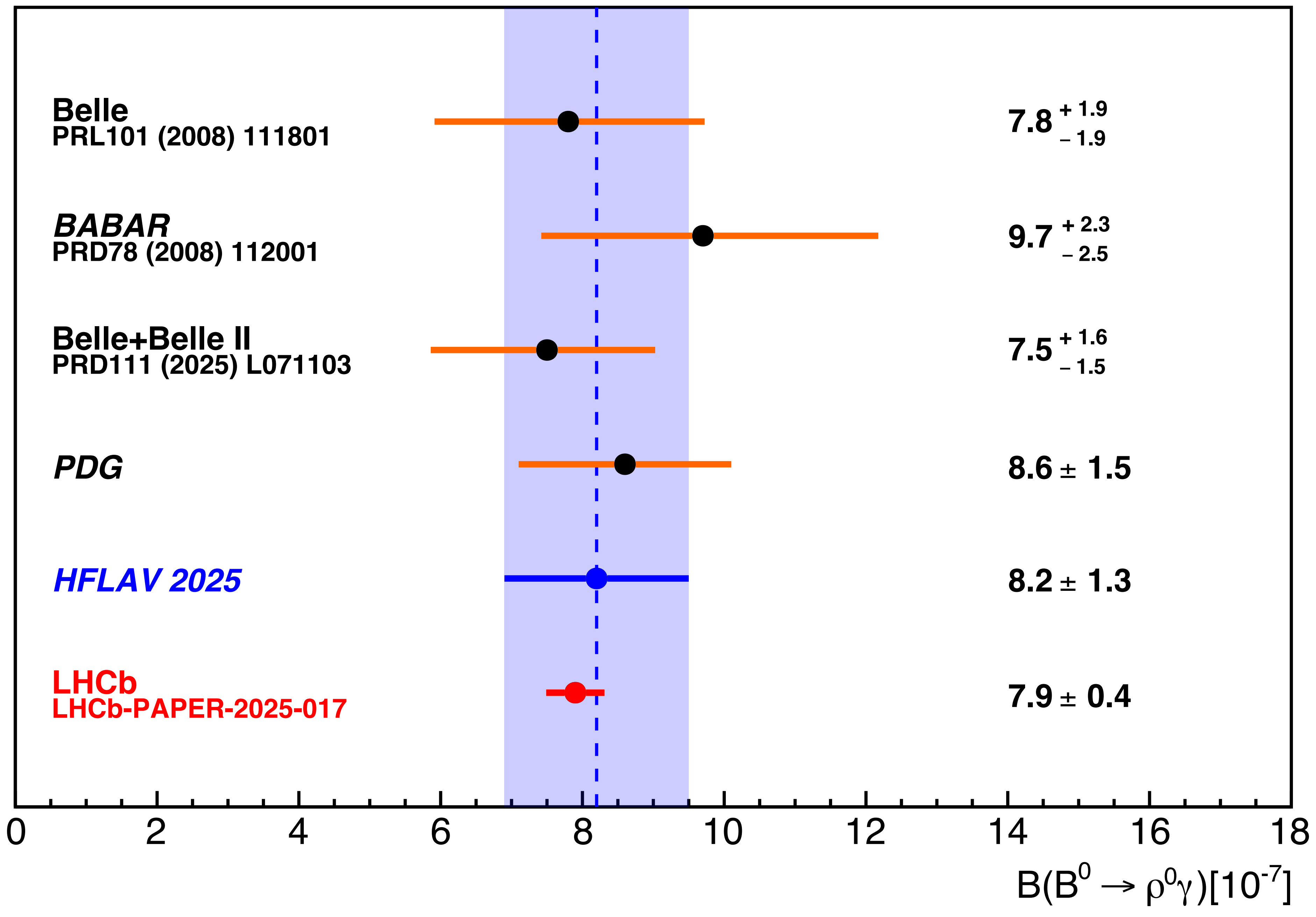
- Combining with the known $B^0 \to K^{*0}\gamma$ branching fraction from HFLAV, this gives

$$\mathcal{B}(B^0 \to \rho^0\gamma) = (7.9 \pm 0.3 \pm 0.2 \pm 0.2) \times 10^{-7},$$

The first uncertainty is statistical, the second systematic and the last one is due to the uncertainty $B^0 \to K^{*0}\gamma$ branching fraction

- Assuming $\rho^0 \to \pi^+\pi^-$ decay saturates the dipion spectrum in the $m_{\pi\pi}$ range used ($m_{\pi\pi} \in [630{,}920]$MeV/c²)

- **Most precise** measurement to date

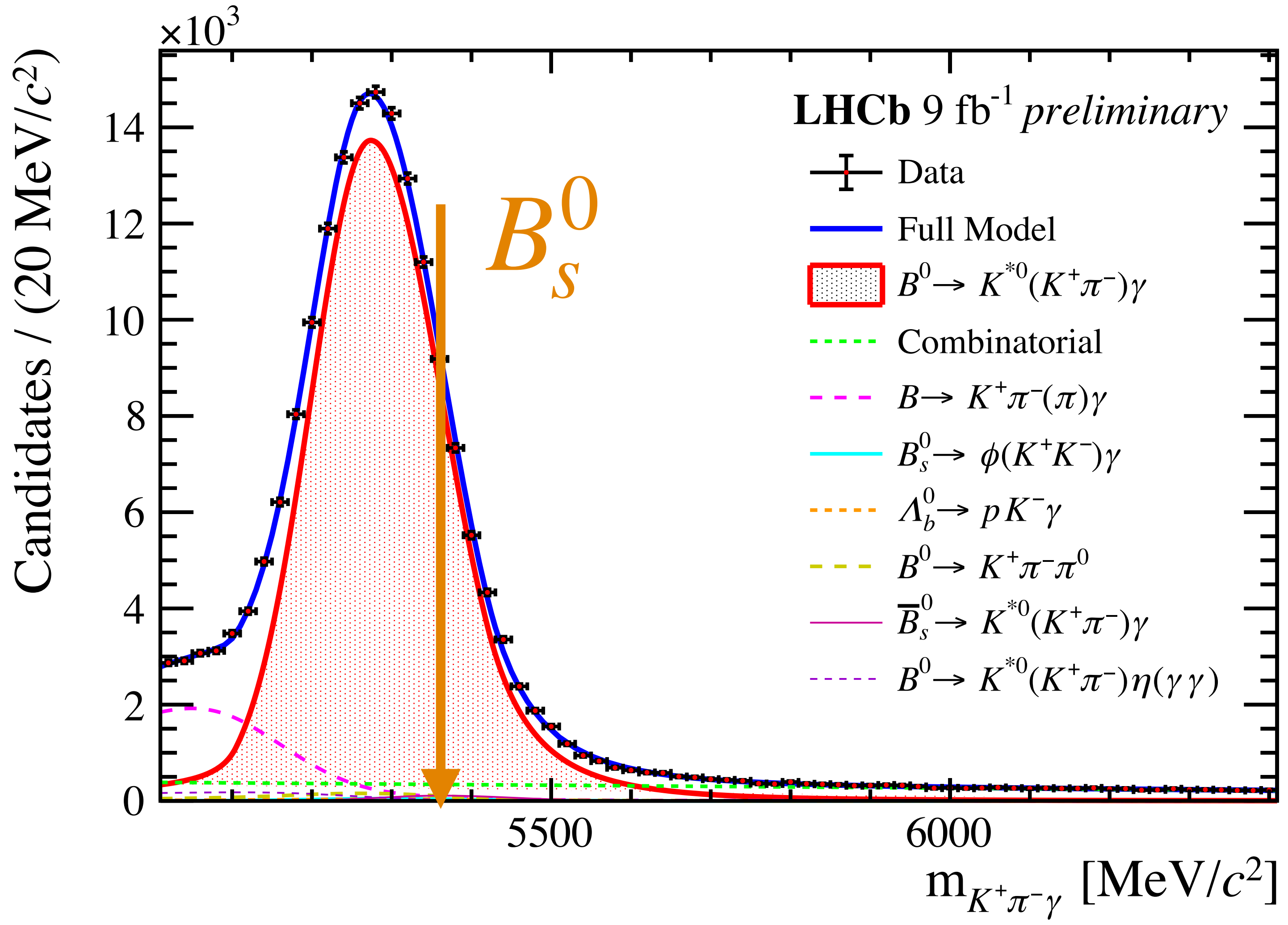


$B_s^0 \to \bar{K}^{*0}\gamma$ branching fraction

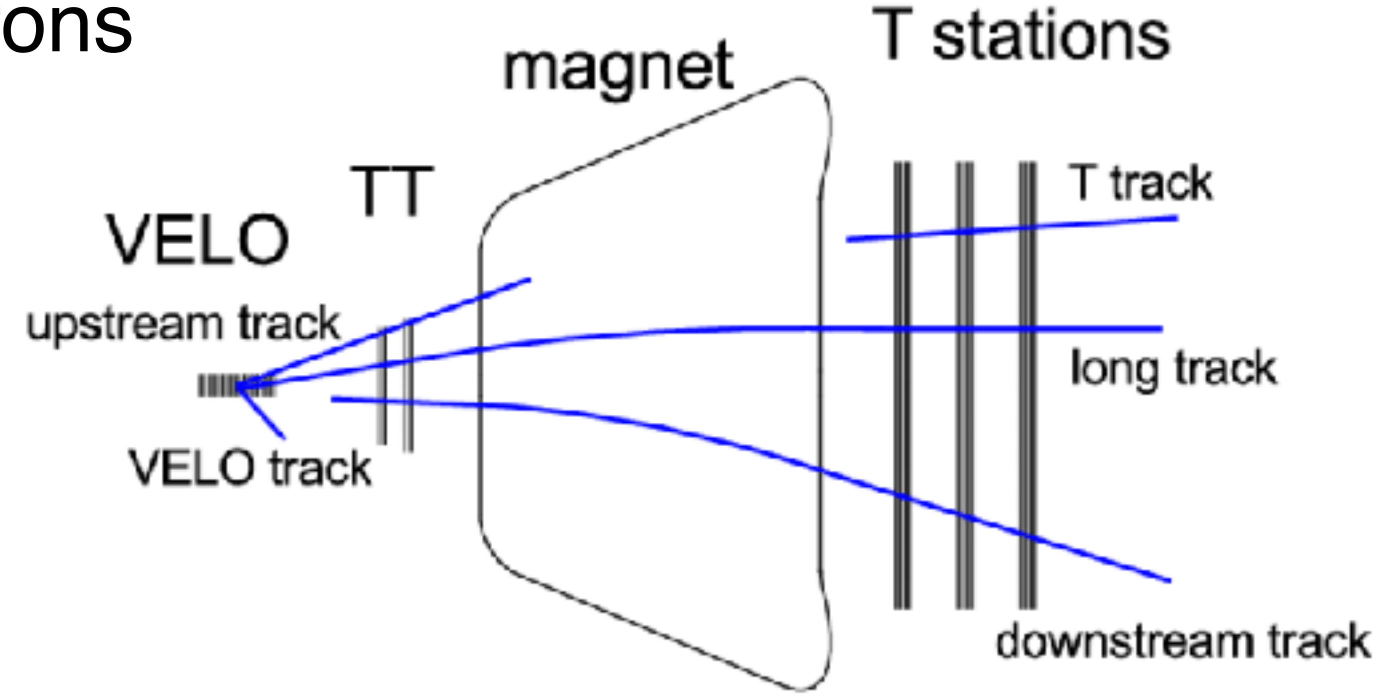
LHCb-PAPER-2025-056
In preparation

Preliminary

- First search of this decay by the LHCb with 9 fb^{-1} of Run 1+2 data
- An alternative way to measure $|V_{td}/V_{ts}|$ by measuring ratio of $\mathcal{B}(B_s^0 \to \bar{K}^{*0}\gamma)/\mathcal{B}(\bar{B}^0 \to \bar{K}^{*0}\gamma)$
- Theoretically clean because of cancellation of dominant form-factor uncertainty
- Experimentally challenging due to smaller yield and poor resolution
  - Use photon converted to e^+e^- for better resolution (3 times) [PRD 92, 112002 (2015)]
  - Resolution of invariant mass is improved by additional selection on invariant mass of downstream photon candidates and uncertainty of the invariant mass of b candidates involving long tracks



- Analysis performed in
  - Low ($796 < m(K^-\pi^+) < 996$ MeV/c^2) and high ($996 < m(K^-\pi^+) < 1800$ MeV/c^2) and long and downstream electrons



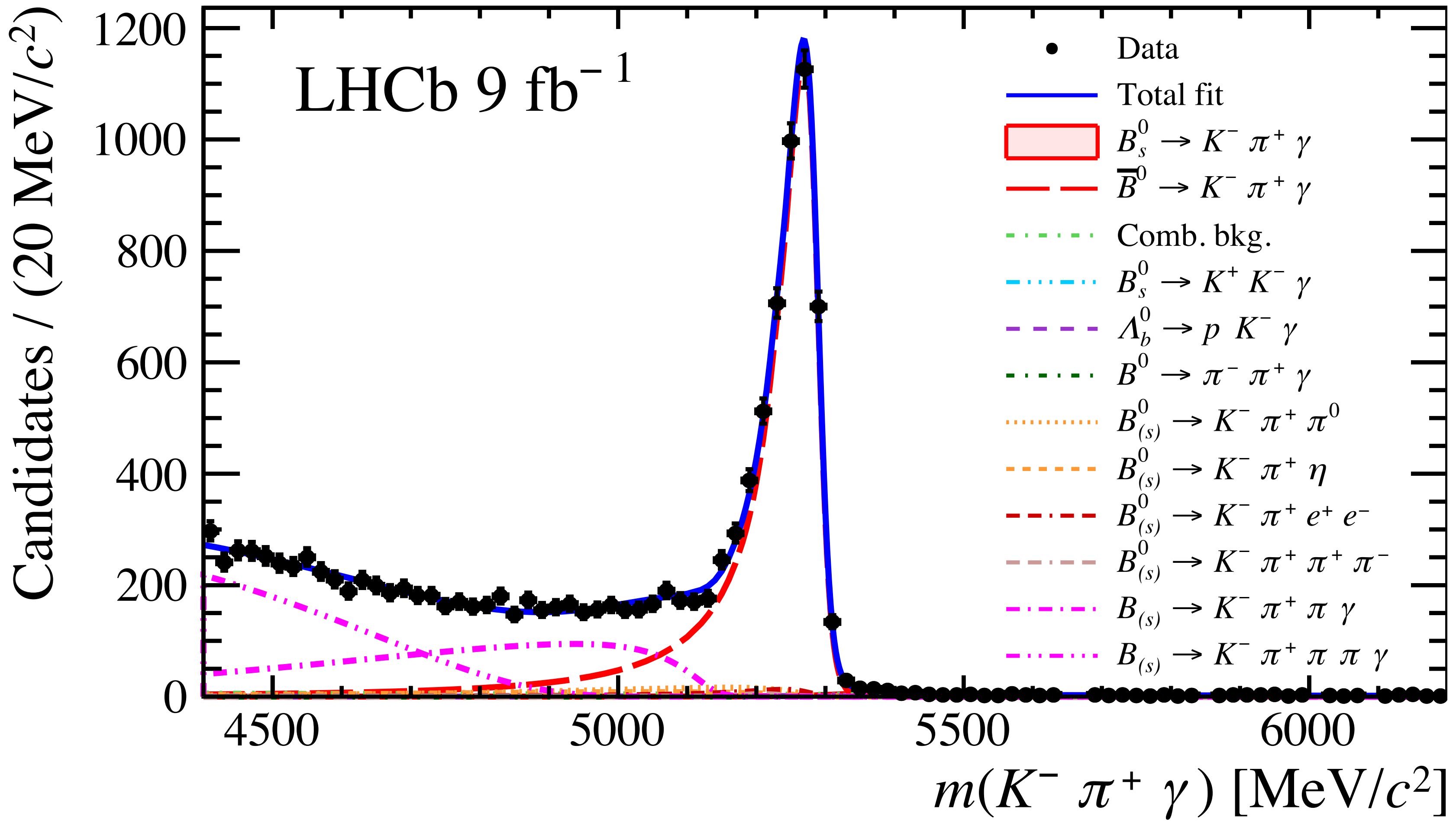
- Better resolution in downstream electrons due to less bremsstrahlung

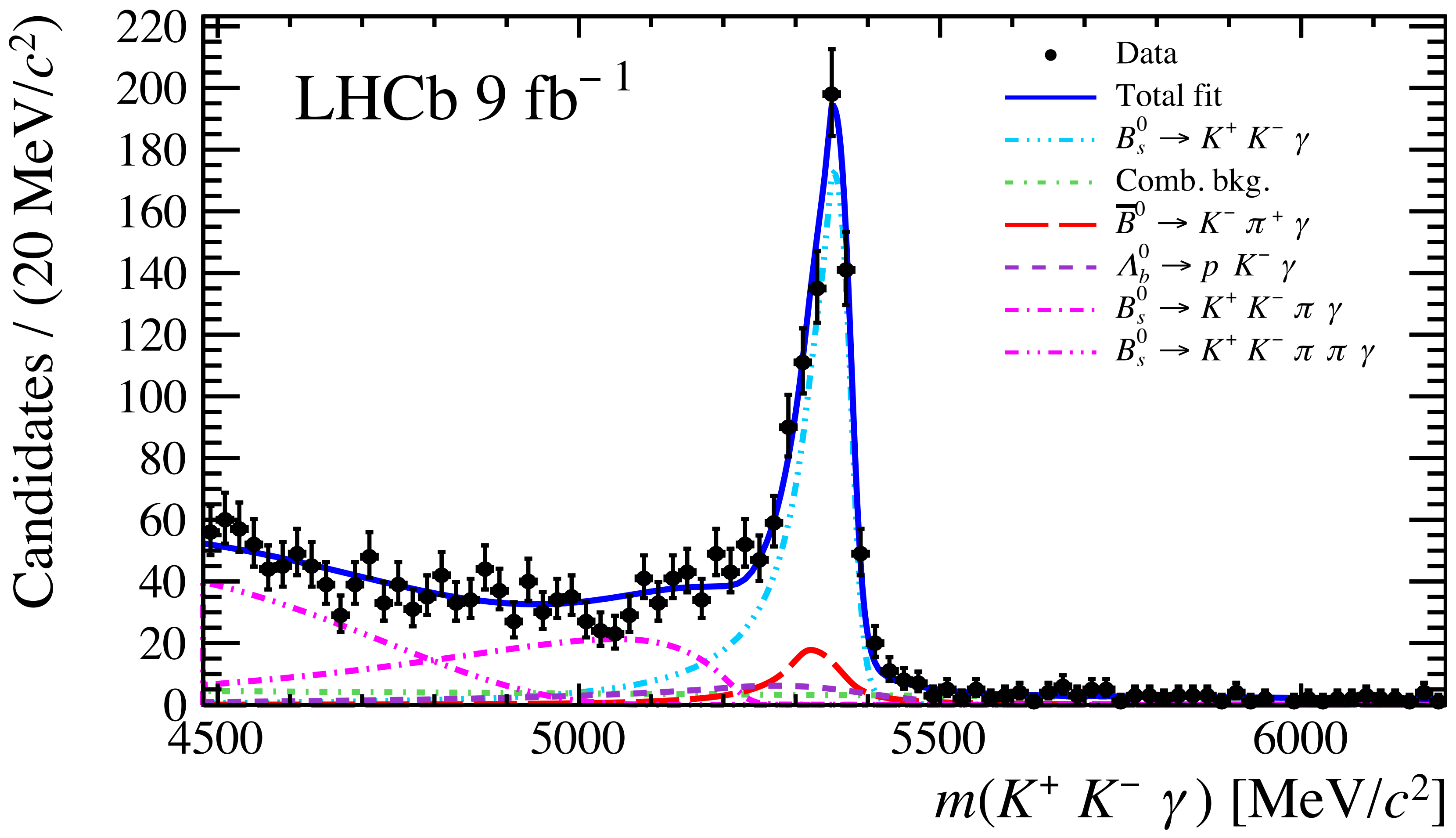
$B_s^0 \to \bar{K}^{*0}\gamma$ branching fraction

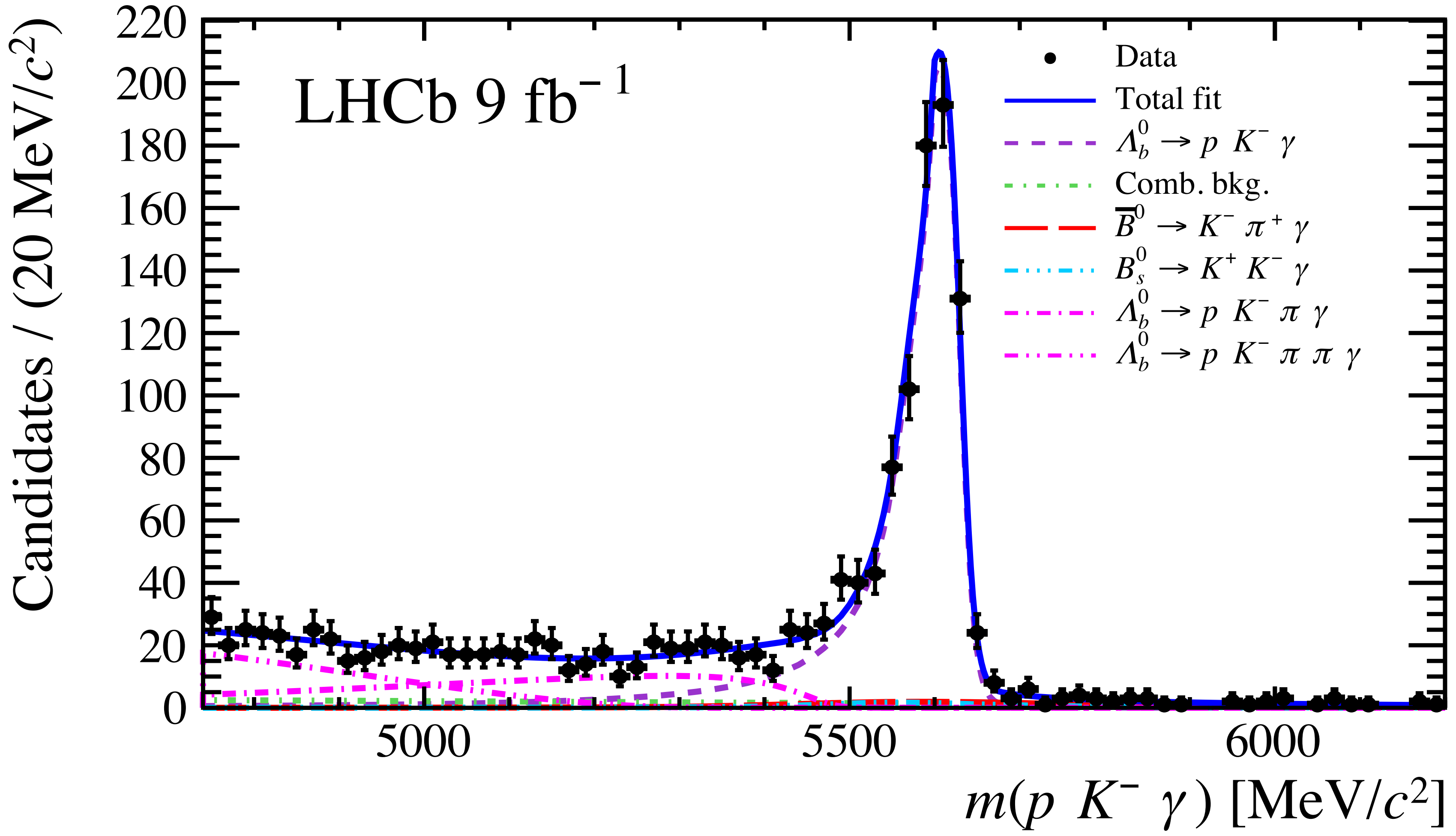
LHCb-PAPER-2025-056
In preparation

Preliminary

- Particle identification criteria and boosted decision tree are used to suppress the misidentified background and combinatorial background
- Remaining misidentified backgrounds are constrained to product of the ratio of efficiencies and observed yield in the simultaneous data fit to $m(K^-\pi^+\gamma)$, $m(K^+K^-\gamma)$ and $m(pK^-\gamma)$ decay modes







$B_s^0 \to \bar{K}^{*0}\gamma$ branching fraction

LHCb-PAPER-2025-056
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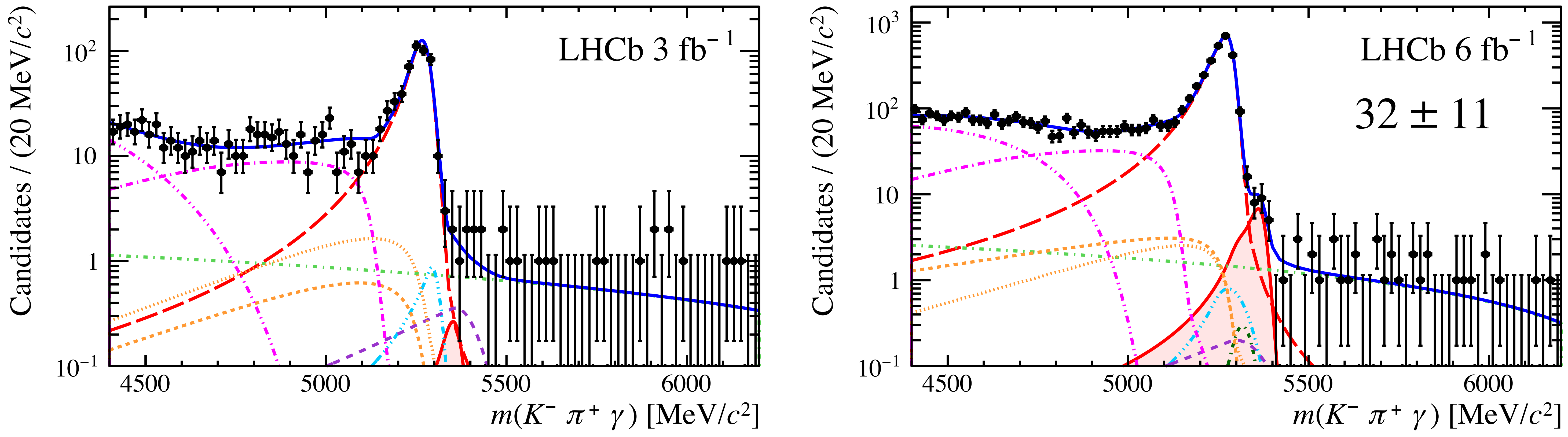
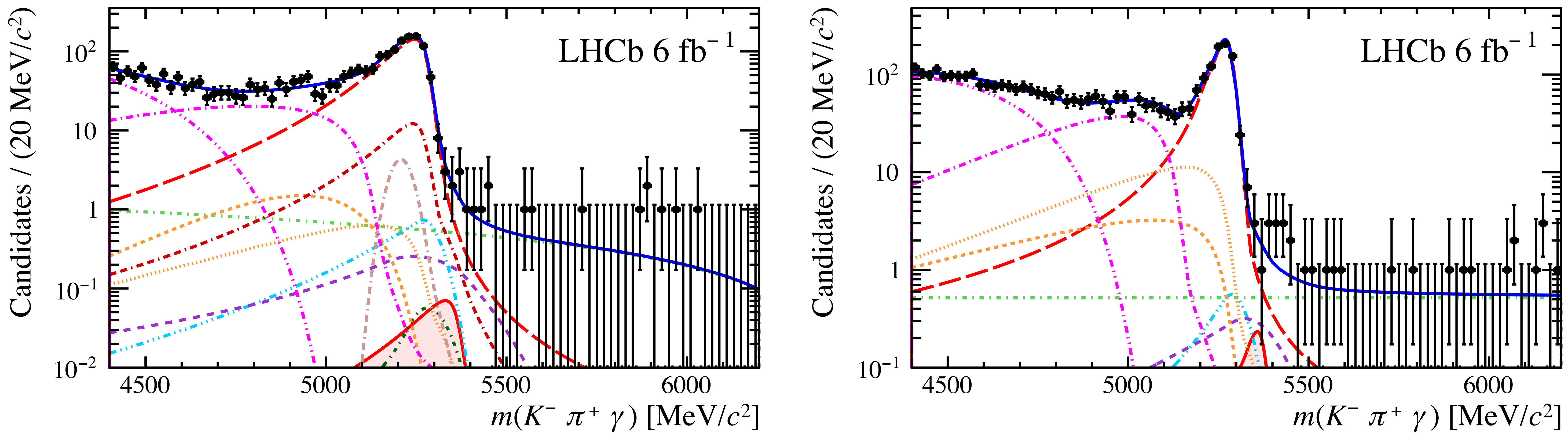


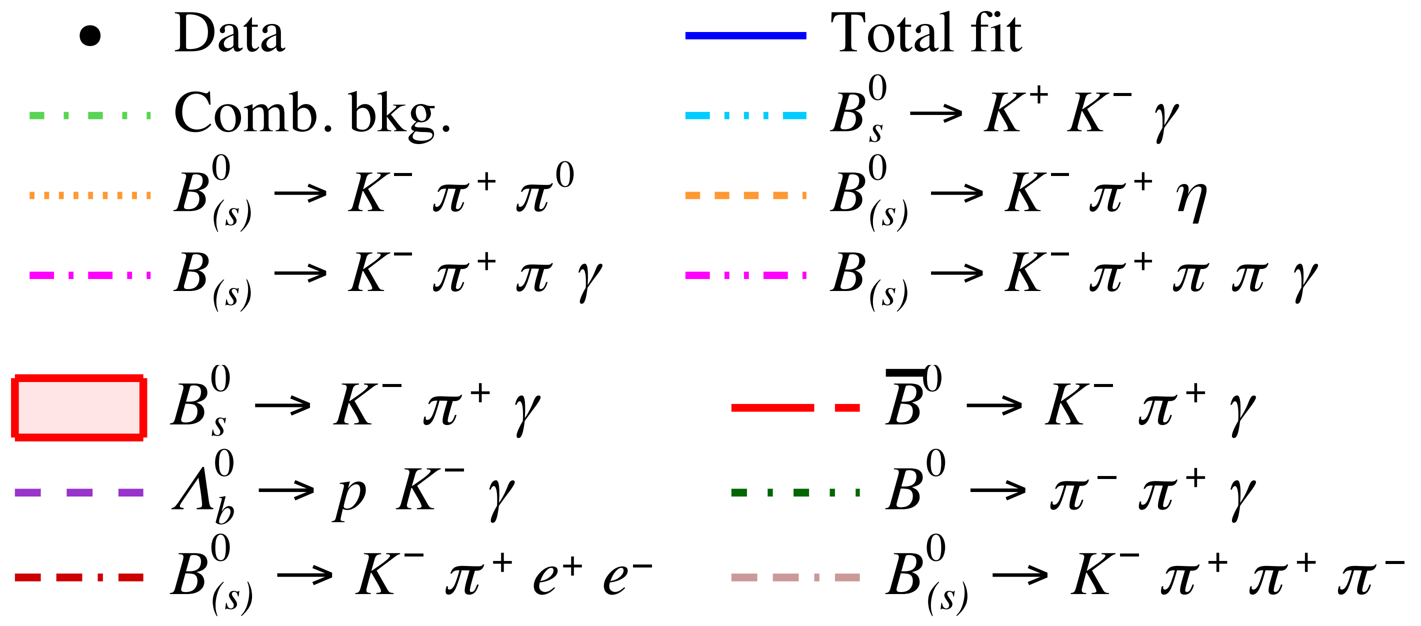
Run 1 downstream low m($K\pi$)

Run 2 downstream low m($K\pi$)



Run 2 long track high m($K\pi$)

Run 2 downstream high m($K\pi$)



- 38 ± 18 signal yields

$$\frac{\mathcal{B}(B_s^0 \to K^-\pi^+\gamma)}{\mathcal{B}(\bar{B}^0 \to K^-\pi^+\gamma)} = (0.037 \pm 0.012 \pm 0.004)$$

$796 < m(K^-\pi^+) < 996$ MeV/c^2

$$\frac{\mathcal{B}(B_s^0 \to K^-\pi^+\gamma)}{\mathcal{B}(\bar{B}^0 \to K^-\pi^+\gamma)} = (0.002 \pm 0.027 \pm 0.013)$$

$996 < m(K^-\pi^+) < 1800$ MeV/c^2

- Consistent with SM predictions

- Pseudo-experiment shows 0.03% probability that background processes can produce data less compatible with zero signal than real data
  - 3.5 standard deviation significance

Interpretation

- Using the branching fraction ratios and form factor ratios (Ball, Jones & Zwicky) for $B \to V\gamma$, $|V_{td}/V_{ts}|$ can be predicted from the global CKM fit

$$\frac{\mathcal{B}(B^0_{(s)}\to X\gamma)}{\mathcal{B}(B^0\to K^{*0}\gamma)} \propto S\xi^{-2}\left|\frac{V_{td}}{V_{ts}}\right|^2$$

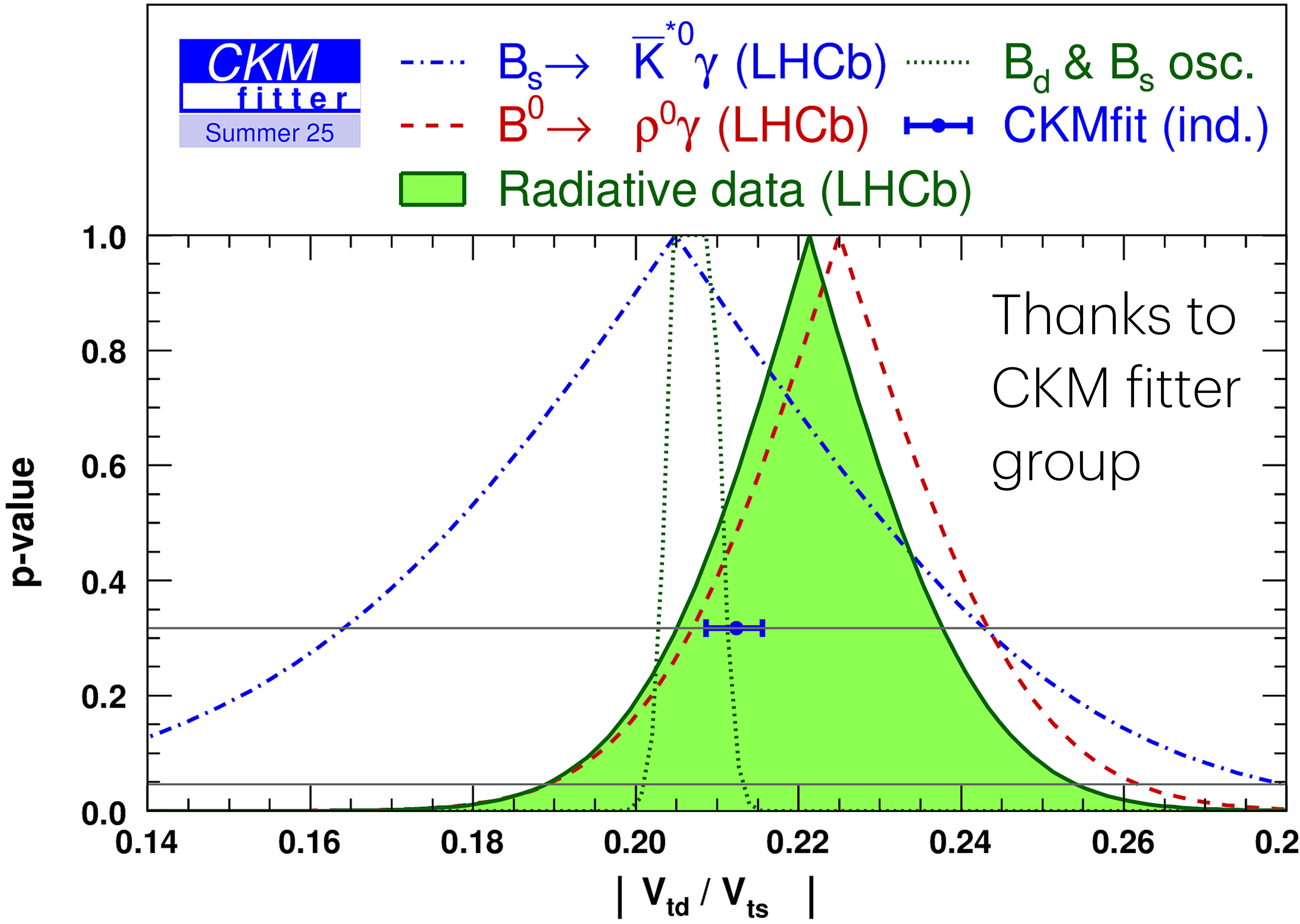
PRD 75 054004, 2007

$$\xi_\rho \equiv \frac{T_1^{B\to K^*}(0)}{T_1^{B\to\rho}(0)} = 1.17 \pm 0.09$$

$$\xi_{\bar{K}^*} \equiv \frac{T_1^{B\to K^*}(0)}{T_1^{B_s\to\bar{K}^*}(0)} = 1.09 \pm 0.09$$

$S = \frac{1}{2}$, for ρ^0

- Dominated by theoretical form factor uncertainty



Thanks to CKM fitter group

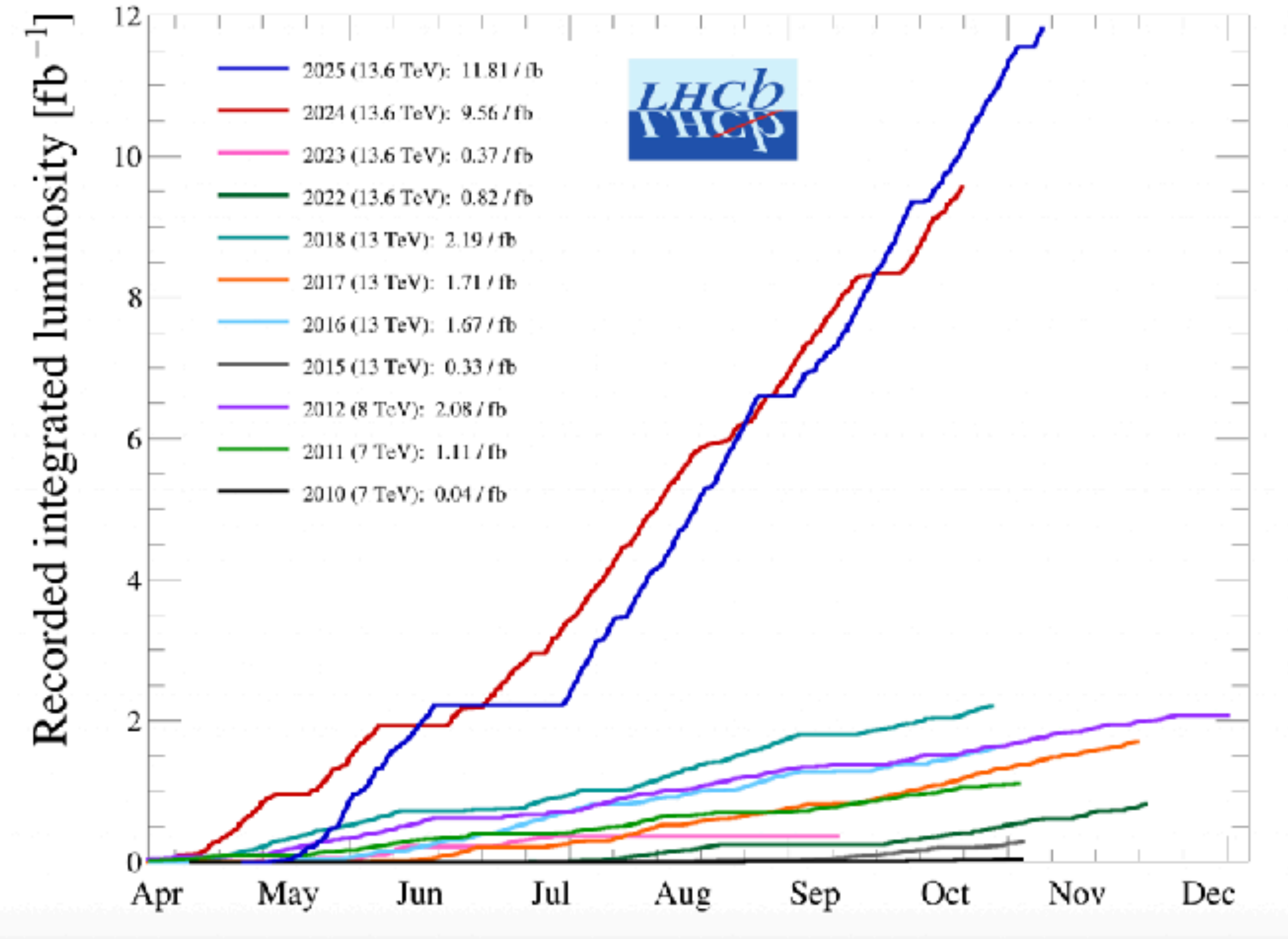
Outlook and conclusions

- Radiative decay offers a unique environment to look for BSM physics
- LHCb pushing limits towards unprecedented levels

- Today's presentation covers
  - Branching fraction measurement of $B^0 \to \rho^0\gamma$
    - Precise measurement of branching fractions
  - First evidence of the $B_s^0 \to K^-\pi^+\gamma$ decay (New) Preliminary

- Updated theoretical form factors ratio is necessary to test the SM

- Run 3 data taking is currently ongoing (until July 2026)
  - **> 9** fb^{-1} data collected in 2024 and **> 11** fb^{-1} in 2025
  - Upgraded detector and trigger system (fully software base) enhance signal efficiency
  - Open the door to new searches
    (rarer modes, use of converted photons, time dependent analyses)



Thank you for your attention!

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Backup

Systematics

Period Track $m(K^-\pi^+)$	Run 1 downstream low	Run 2 downstream low	Run 2 long low	Run 2 downstream high
$K^-\pi^+\gamma$ and $\overline{K}^*(892)^0e^+e^-$ model	0.4	1.7	3.0	1.8
$B\to K^-\pi^+\pi\gamma$ resonant structure	0.0	0.1	0.5	0.2
Misidentified-hadron model	0.4	0.2	0.5	0.9
$\overline{K}^*(892)^0\pi^+\pi^-$ model	–	–	0.0	–
Combinatorial model	0.1	0.7	1.1	0.1
External inputs	0.2	0.1	0.5	0.3
Simulation sample size	0.4	0.6	0.9	0.4
Hadron-identification corrections	1.6	0.4	0.1	0.9
Electron-identification corrections	–	–	0.1	–
Simulation corrections	0.1	1.7	1.4	0.2
Misidentified-hadron yield	0.4	0.5	1.1	1.3
Total	1.9	2.7	3.9	2.6

Wilson Coefficient

- Wilson coefficients are loosely constrained by $b \to d\gamma$ decays