Radiative B_s^0 meson decays at LHCb

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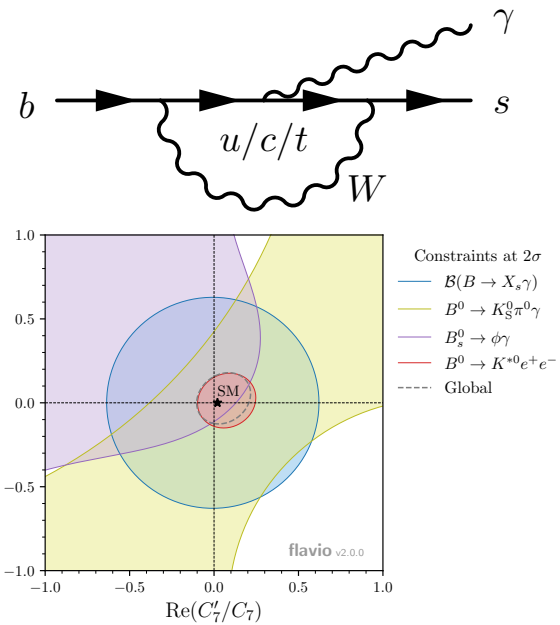
Introduction

- FCNC b decays sensitive to BSM physics with some outstanding discrepancies from SM
- Radiative decays: $\mathcal{C}_7^{(\prime)}$

+ RH-polarised photon further supressed by $m_q/m_b \rightarrow$ Particular sensitivity to new RH currents [JHEP 04 (2017) 027, PRL 79 185]



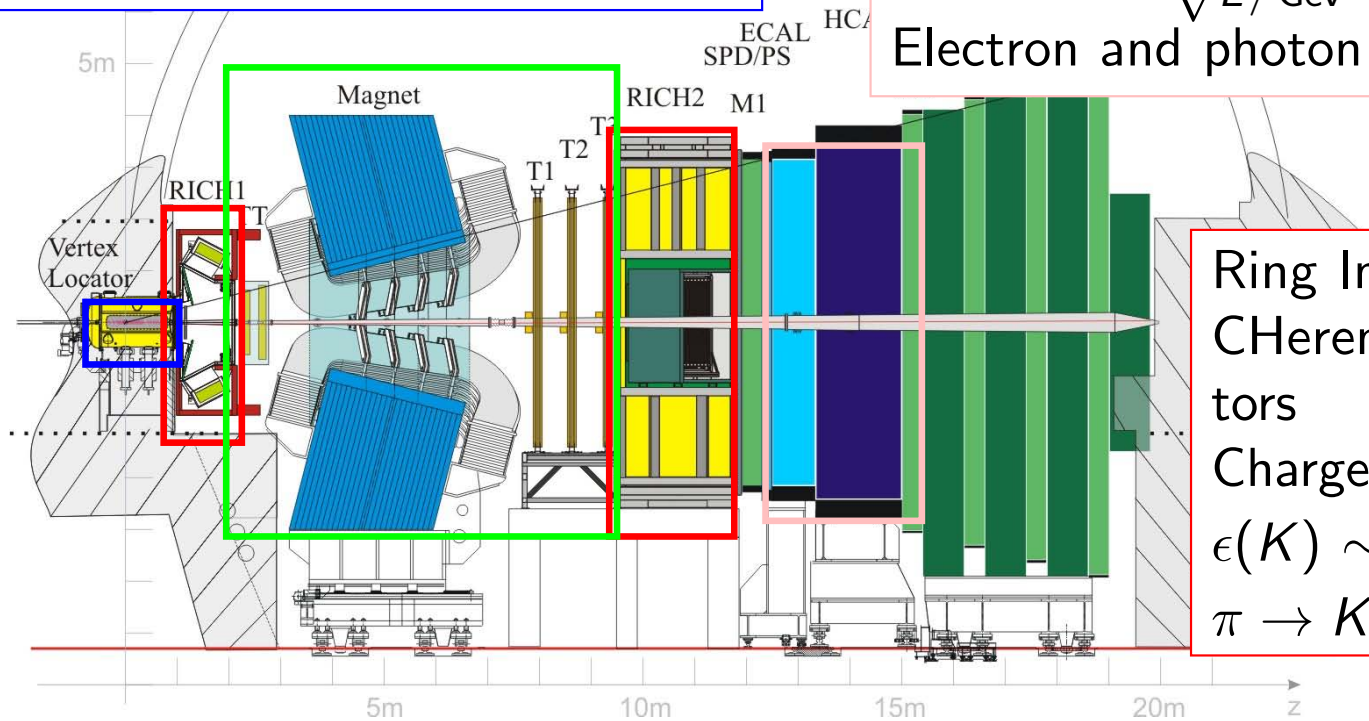
[JHEP 12 (2020) 081]

- LHCb has analysed several radiative decays of B^0, B^+, B_s^0, Λ_b^0, and Ξ_b hadrons
- This talk:
  - Search for $B_s^0 \to K\pi\gamma$ (in progress)
  - Amplitude analysis of $B_s^0 \to KK\gamma$ [JHEP 08 (2024) 093]
  - Search for $B_s^0 \to \mu\mu\gamma$ [JHEP 07 (2024) 101]

- Single-arm forward spectrometer optimised for b-hadron physics
- High $\sqrt{s} \rightarrow$ Ideal to study B_s^0 mesons

VErtex LOcator
15 µm resolution (high p_T)

Calorimeters
$\frac{\sigma_E}{E} \sim 1\% + \frac{10\%}{\sqrt{E/\text{GeV}}}$ (ECAL)
Electron and photon ID

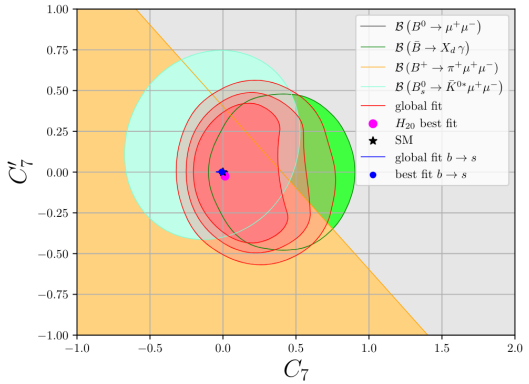


Ring Imaging CHerenkov detectors
Charged particle ID
$\epsilon(K)$ ~95% at 5%
$\pi \rightarrow K$ misID

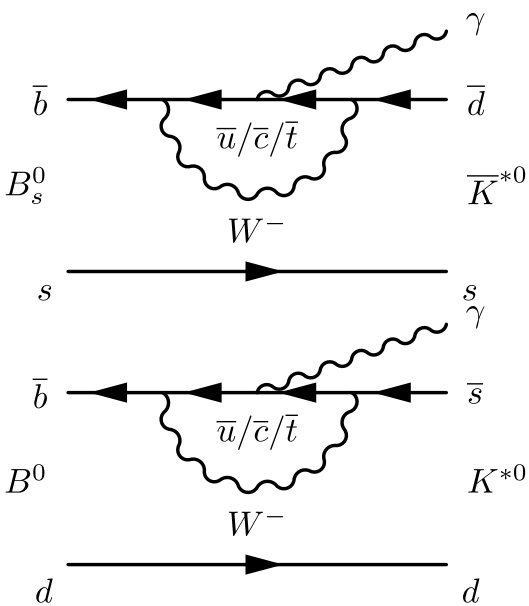
Tracking system with 4Tm magnet
Momentum resolution: $\Delta p/p \sim 0.5\%$ (low p)

Search for $B_s^0 \to K^-\pi^+\gamma$

- $b \to d$ transitions still poorly explored
- $\mathcal{B}(B_s^0 \to \overline{K}^{*0}\gamma)/\mathcal{B}(B^0 \to K^{*0}\gamma)$ related in SM to $|V_{td}/V_{ts}|$ with only small form factor uncertainty [PRD 75 054004]
- Search with $3\,\text{fb}^{-1}$ (Run 1) + $6\,\text{fb}^{-1}$ (Run 2) pp collisions, simultaneously in two windows:
  - $796 < m(K\pi) < 996\,\text{MeV}$
  - $996 < m(K\pi) < 1800\,\text{MeV}$
- Expect $N(B_s^0)/N(B^0) \sim 1\%$



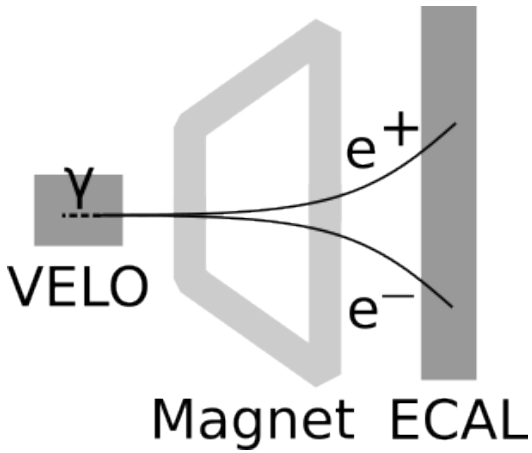
[EPJC83 5 419]



F. Bishop, M. Chefdeville (LAPP)
O. Deschamps (LPC)

Search for $B_s^0 \to K^-\pi^+\gamma$

- Resolution comparable to $m_{B_s^0} - m_{B^0} \to$ Use photons converting before magnet
  - Previously used to study radiative decays of $\chi_{(b/c)}$ mesons [JHEP 10 (2013) 115, JHEP 10 (2014) 088] and search for $B^0_{(s)} \to J/\psi\eta$ decays [PRD92 112002]
  - Lower yields

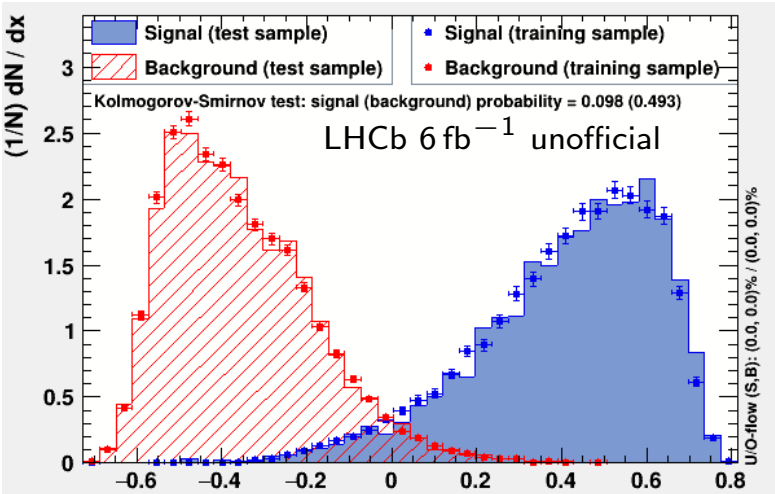


- Reconstruct as a pair of downstream (DD, no VELO) or long (LL) tracks
- Most challenging background is still $B^0 \to K^+\pi^-\gamma$ decay $\to$ essential to further improve mass resolution:
  - Only use electrons with no bremsstrahlung reconstructed
  - Selections on $m(B)$ uncertainty and $m(ee)$ to optimise $N^2_{B^0_s}/N_{B^0_s}\sqrt{N_{B^0_s} + N_{B^0}}$ in signal window

Search for $B_s^0 \to K^-\pi^+\gamma$

- RICH particle ID to reduce $\Lambda_b^0 \to pK\gamma$, $B_s^0 \to KK\gamma$
- Vetoes to remove $K\pi\pi^0$ decays with charmless and single-charm resonances
- Fake conversions: $m(ee)$, vertex quality, electron PID, VELO energy deposition

- Selection with adaptive-boosted decision tree to reduce background from random combinations of tracks ($\varepsilon_{sig} \sim 70\%$)



Search for $B_s^0 \to K^-\pi^+\gamma$

- Simultaneous fit to data in $K\pi\gamma/KK\gamma/pK\gamma$ final states to constrain hadronic misID yields
- Other backgrounds: Missing pion, missing photon (from $\pi^0/\eta \to \gamma\gamma$), combinatorial
- $5320 < m(K\pi\gamma) < 5400\,\text{MeV}$ blinded

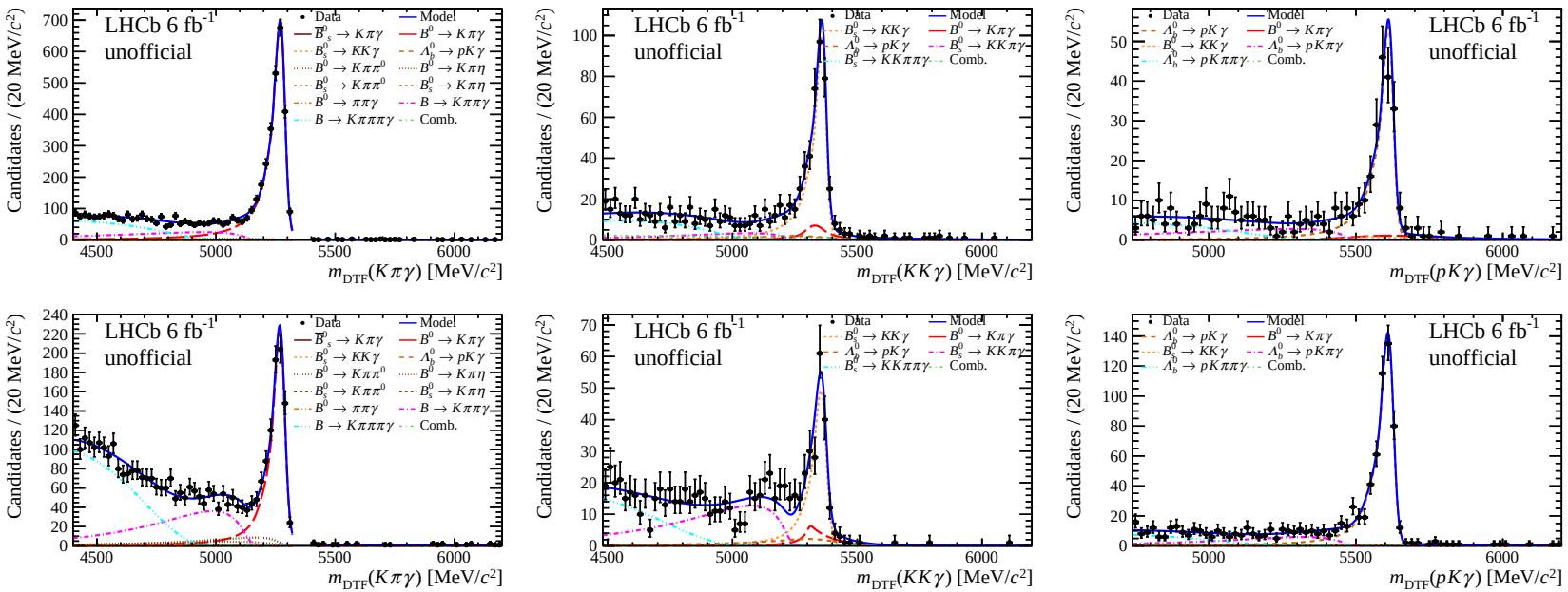


Figure 1: Invariant mass distribution of (left) $K^+\pi^-\gamma$ and (centre) $K^+K^-\gamma$, and (right) $pK^-\gamma$ candidates in the (top) low and (bottom) high $m(K\pi)$ windows in Run 2 DD data.

Search for $B_s^0 \to K^-\pi^+\gamma$

- Expect 55 signal decays in total
- Expected sensitivity $> 3\sigma$ (stat. only) assessed with pseudoexperiments generated with SM-predicted $\mathcal{B}$
  - Dominated by Run 2 DD low-$m(K\pi)$ data
- Systematic uncertainties under evaluation
- Analysis in internal review: Expect results next year!

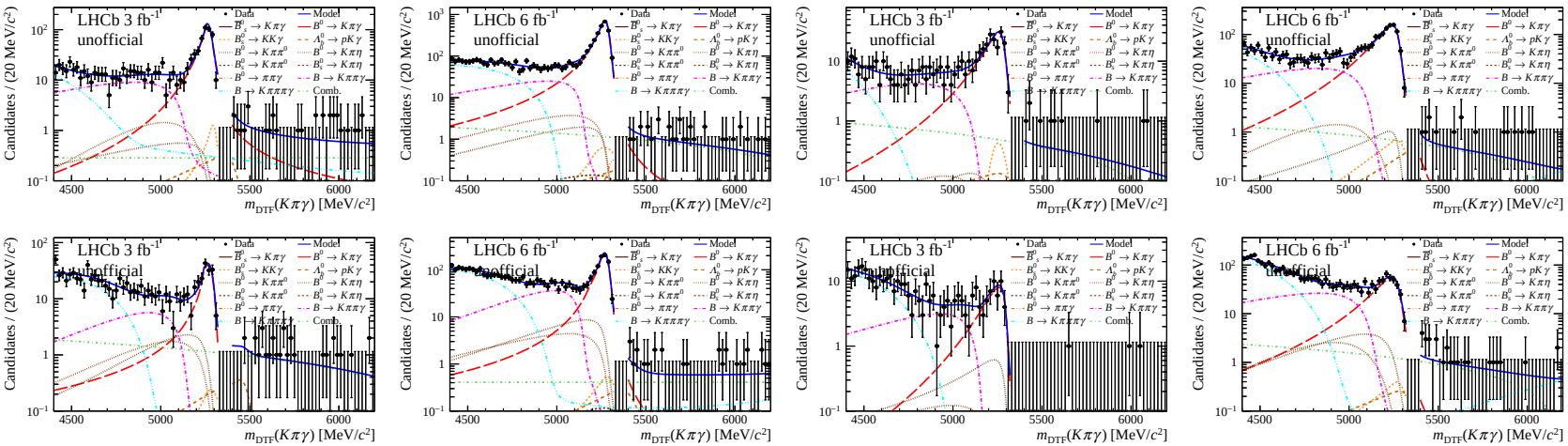
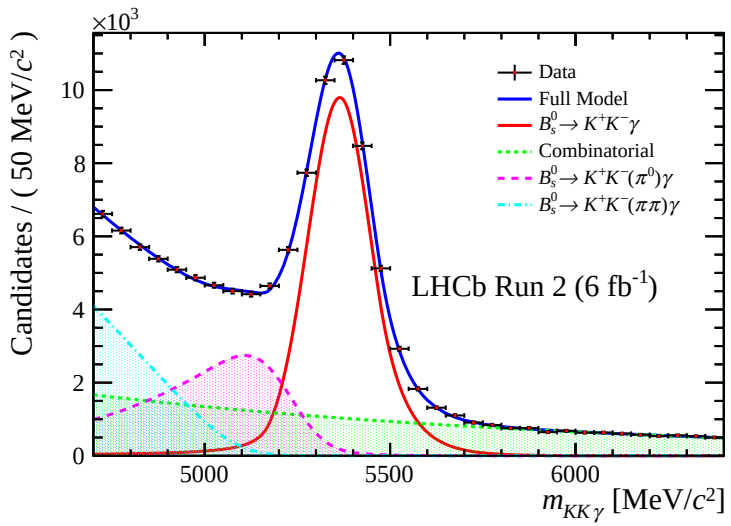


Figure 2: Invariant mass distribution of $K^+\pi^-\gamma$ candidates for (columns 1+2) DD and (columns 3+4) LL conversions in (columns 1+3) Run 1 and (columns 2+4) Run 2 data in the (top row) low and (bottom row) high mass windows.

Amplitude analysis of $B_s^0 \to KK\gamma$ JHEP 08 (2024) 093

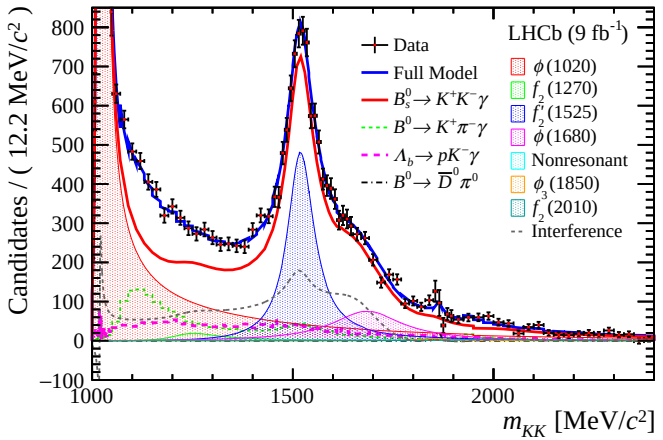
- BSM physics can impact transition dynamics
  + S-wave amplitude not allowed $\to$ clean spectrum
- Good-quality kaon pairs forming a vertex combined with an energetic photon
- Loose selection to reduce combinatorial and peaking backgrounds
- Combinatorial and missing-pion background statistically subtracted with the sPlot method
- Hadronic and π^0 misID backgrounds included in amplitude model
- $N_s = 50200 \pm 500$ $(9\,\text{fb}^{-1})$

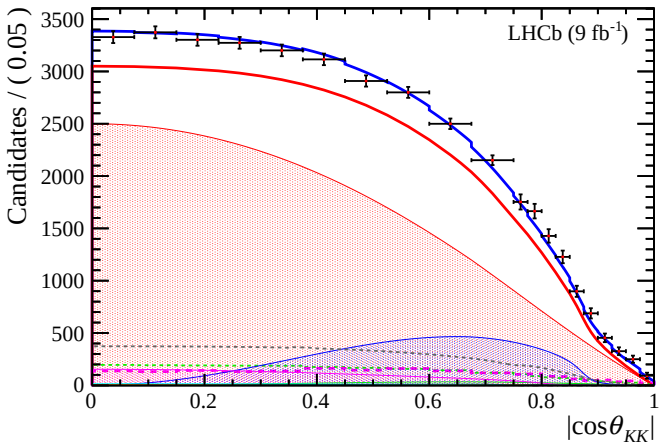
O. Deschamps, R. Lefevre, B. Quintana (LPC)



- Isobar amplitude model
- Include established mesons observed in dikaon final state that significantly improve fit quality + have significant fitted isobar coefficient
- Acceptance and resolution from simulation
- Several almost degenerate solutions; best fit:

State	Fit fraction [%]	Relative fit fraction [%]	Phase [deg.]
$\phi(1020)$	$70.3\ ^{+0.9}_{-1.0}\ ^{+1.0}_{-1.2}$	100	0 (fixed)
$f_2(1270)$	$0.8 \pm 0.3\ ^{+0.2}_{-0.3}$	$1.2\ ^{+0.4}_{-0.3}\ ^{+0.3}_{-0.5}$	$-55\ ^{+13}_{-17}\ ^{+25}_{-17}$
$f_2'(1525)$	$12.1\ ^{+0.6}_{-0.5}\ ^{+0.9}_{-0.4}$	$17.3\ ^{+0.8}_{-0.7}\ ^{+1.3}_{-0.5}$	0 (fixed)
$\phi(1680)$	$3.8\ ^{+0.6}_{-0.5} \pm 0.7$	$5.4\ ^{+0.9}_{-0.6}\ ^{+1.0}_{-1.1}$	$137\ ^{+5}_{-6} \pm 8$
$\phi_3(1850)$	$0.3\ ^{+0.2}_{-0.1}\ ^{+0.2}_{-0.1}$	$0.4\ ^{+0.3}_{-0.2}\ ^{+0.3}_{-0.2}$	$-61\ ^{+16}_{-13}\ ^{+13}_{-12}$
$f_2(2010)$	$0.4 \pm 0.2\ ^{+0.2}_{-0.1}$	$0.6\ ^{+0.3}_{-0.2}\ ^{+0.3}_{-0.2}$	$43\ ^{+30}_{-24}\ ^{+52}_{-59}$
$(KK)_{NR}$	$0.5\ ^{+0.4}_{-0.2}\ ^{+0.3}_{-0.2}$	$0.6\ ^{+0.5}_{-0.3}\ ^{+0.5}_{-0.3}$	$165\ ^{+6}_{-16} \pm 9$





*First observation of $B_s^0 \to f_2'(1525)\gamma$ *

$$\frac{\mathcal{B}(B_s^0 \to f_2'(1525)\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = (19.4^{+0.9}_{-0.8}(\text{stat.})^{+1.4}_{-0.5}(\text{syst.}) \pm 0.5(\mathcal{B}))\%$$

Largest systematic: background modelling in amplitude fit

$$\frac{\mathcal{B}(B_s^0 \to f_2(1270)\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = (0.25^{+0.09}_{-0.07}(\text{stat.})^{+0.06}_{-0.10}(\text{syst.}) \pm 0.03(\mathcal{B}))$$

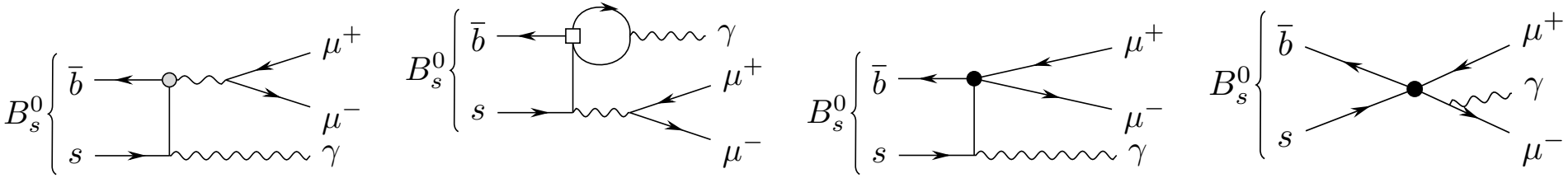
$$\frac{\mathcal{B}(B_s^0 \to (\phi(1680) \to K^+K^-)\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = (2.6^{+0.4}_{-0.3}(\text{stat.}) \pm 0.5(\text{syst.})) \times 10^{-2}$$

$$r_\phi = 1.0 \pm 0.2(\text{stat.}) \pm 0.1(\text{syst.})(\text{ GeV}/c)^{-1}$$

+ Mass/width of $\phi(1020)$ and $f_2'(1525)$ measured $\to$ Compatible with world average

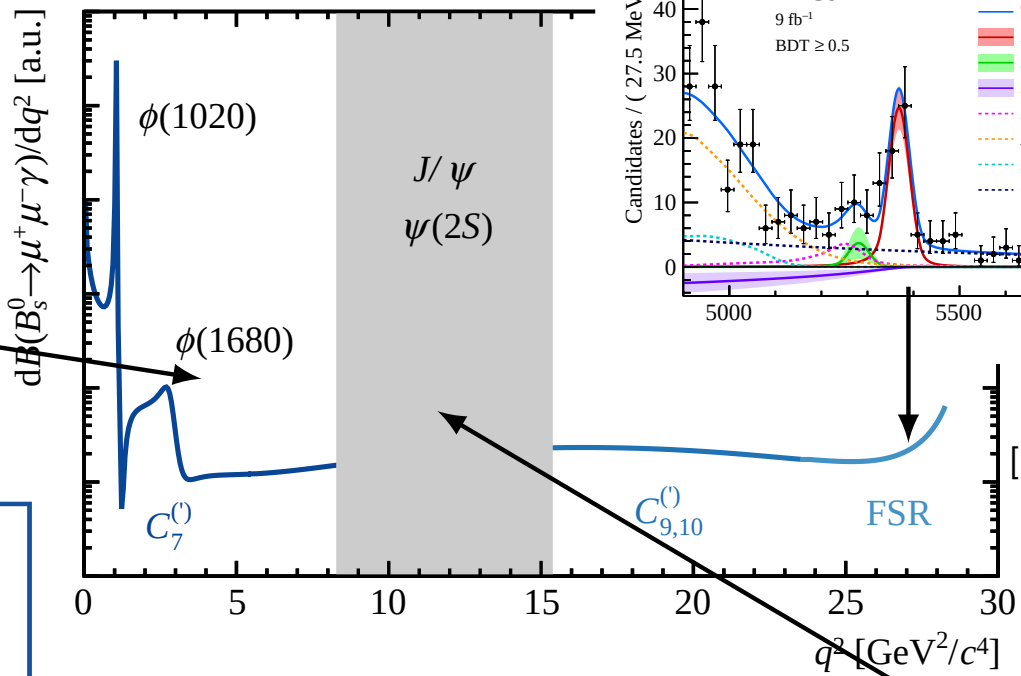
Search for $B_s^0 \to \mu\mu\gamma$

JHEP 07 (2024) 101



Sensitive to a range of FCNC operators

This analysis $5.4\,\text{fb}^{-1}$ pp collisions (2016-18)



Part-reco

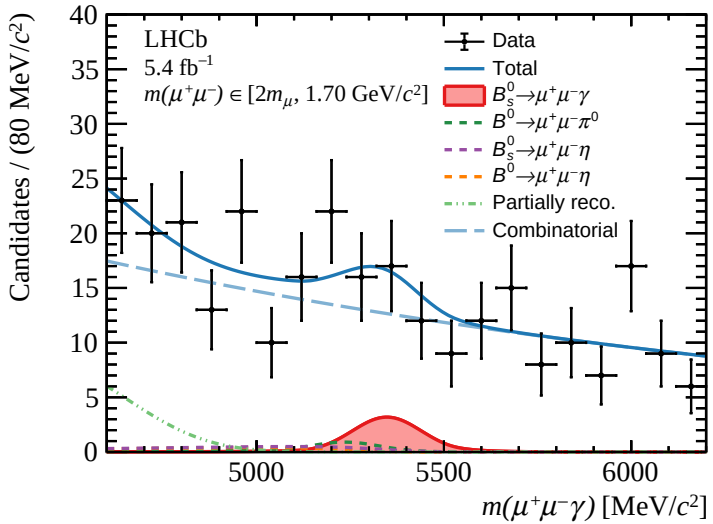
[PRD105 012010]

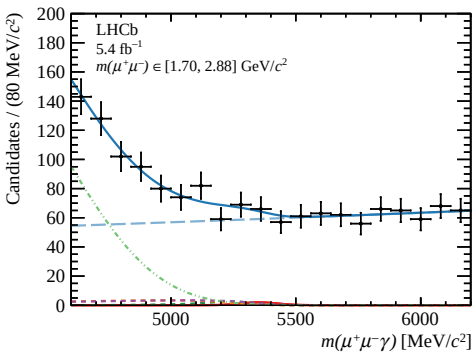
q^2 bin	I	II	III
q^2 [GeV$^2/c^4$]	$[4m_\mu^2, 2.89]$	$[2.89, 8.29]$	$[15.37, m_{B^0_s}^2]$
$m(\mu^+\mu^-)$ [GeV/c^2]	$[2m_\mu, 1.70]$	$[1.70, 2.88]$	$[3.92, m_{B^0_s}]$
$10^{10} \times \mathcal{B}(B_s^0 \to \mu^+\mu^-\gamma)$	82 ± 15	2.54 ± 0.34	9.1 ± 1.1
Fraction of $B_s^0 \to \mu^+\mu^-\gamma$	87%	2.7%	9.8%

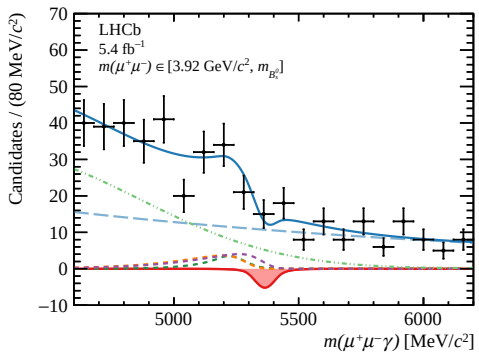
$B_s^0 \to J/\psi\gamma$ search in progress @ LHCb

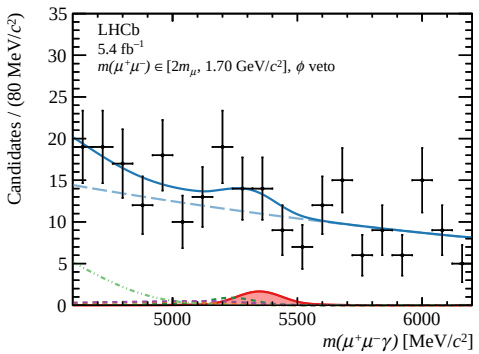
I. Bachiller, J-F. Marchand (LAPP), M. Réboud (IJCLab), J. Wang, X. Wu (Wuhan)

- Tight selection using MLP classifiers to reduce background from misidentification and combinatorics
- $B_s^0 \to \phi\gamma$ decay used to assess data-MC agreement
- No evidence of signal seen
- Branching fraction normalised to $B_s^0 \to J/\psi\eta$

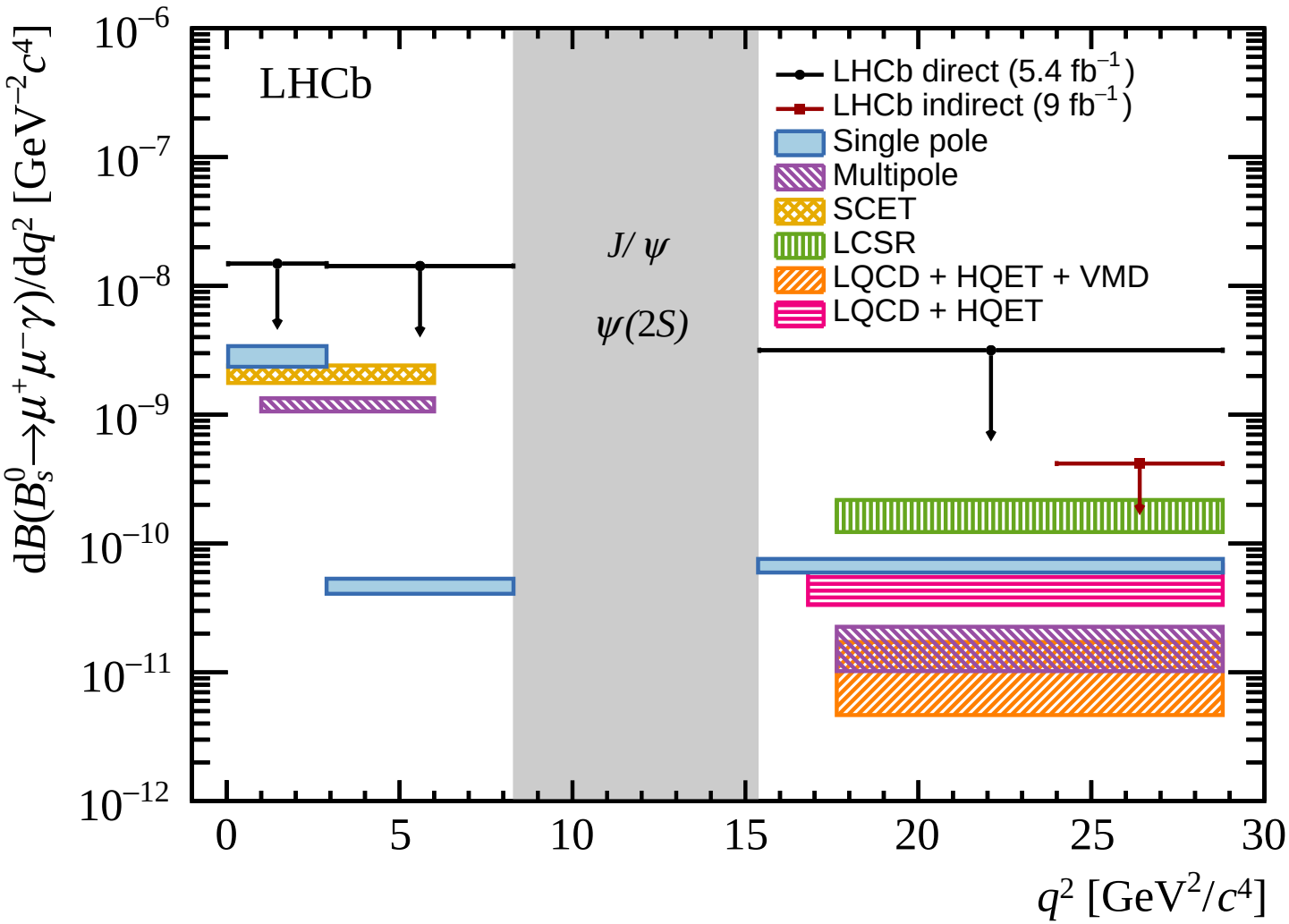








Upper limits on $\mathcal{B}$ set in each q^2 bin using CLs method



Summary

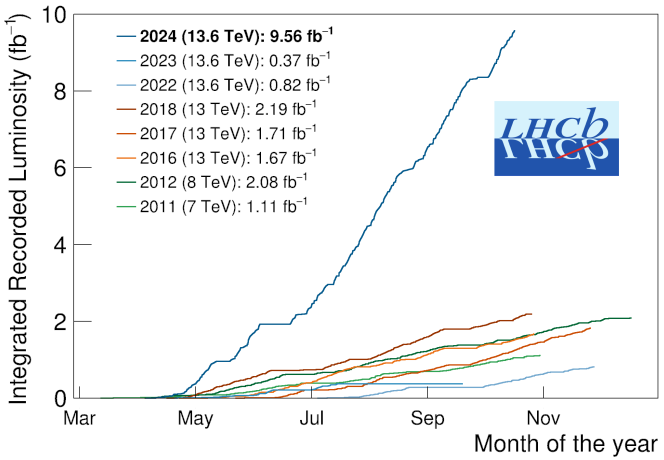
- LHCb data continues to expand our knowledge of radiative B_s^0 meson decays:
  - Search for $B_s^0 \to K\pi\gamma$ (in progress)
  - Amplitude analysis of $B_s^0 \to KK\gamma$ [JHEP 08 (2024) 093]
  - Search for $B_s^0 \to \mu\mu\gamma$ [JHEP 07 (2024) 101]

+ $\mathcal{B}$ and time-dependent CP violation of $B_s^0 \to \phi\gamma$ in progress: Recent improvements in Inclusive Flavour Tagging will significantly improve sensitivity

- In 2024 LHCb collected $9.56\,\text{fb}^{-1}$ pp collisions @ up to $2 \times 10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}$

+ $2-3\times \uparrow$ trigger efficiencies (especially for converted photons)

$\to$ Many improved results to look forward to!



https://lhcb-outreach.web.cern.ch