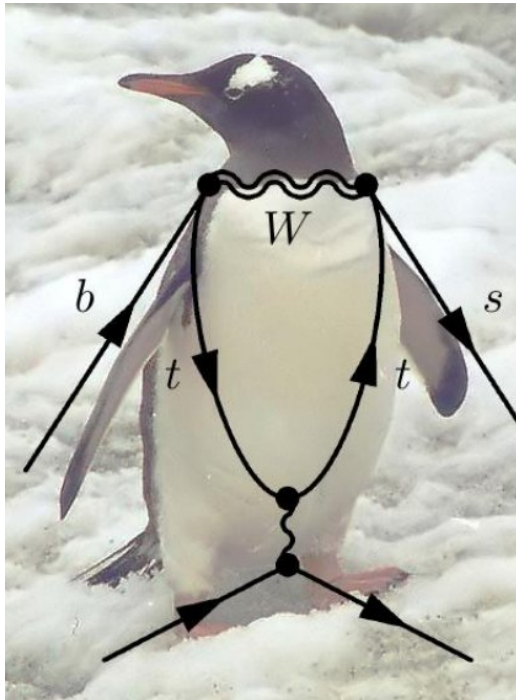


# Highlights on Recent LHCb FCNC Results



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2026/04/18



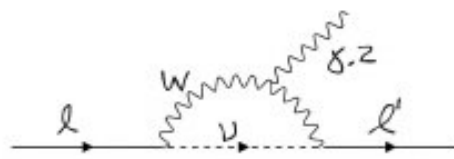
# Outline

- Introduction on (very) rare heavy hadron decays
- A heavily biased selection of recent LHCb results on
  - Rare B decays ( $b \rightarrow s\ell^+\ell^-$ ,  $b \rightarrow d\ell^+\ell^-$ ,  $\ell = e, \mu, \tau$ )
  - Rare charm decays into a pair of leptons
  - For a complete list, click [here](#)
- Prospects & summary

# Rare decays and very rare decays

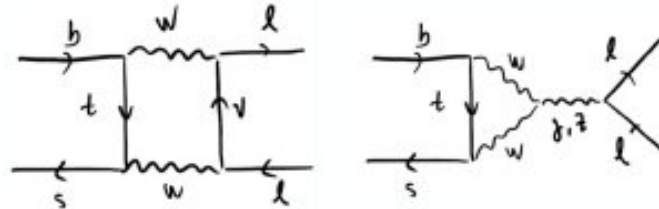
- Rare decays are processes mediated by flavor-changing neutral currents (FCNC)
- Very rare decays involve other highly suppressed processes that are usually out of reach experimentally

## NEUTRINO OSCILLATION



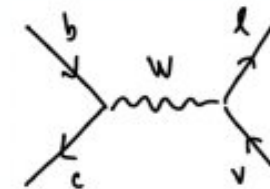
LFV

## LOOP-LEVEL

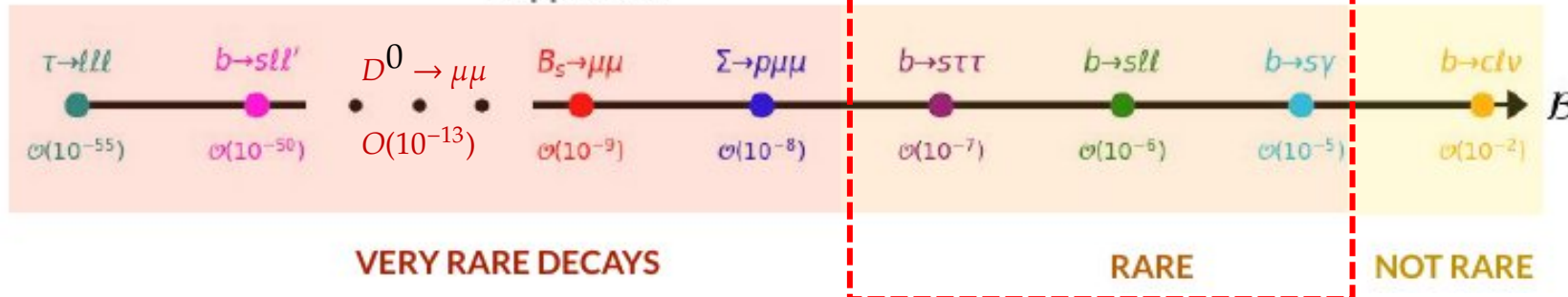


Helicity suppressed

## TREE-LEVEL



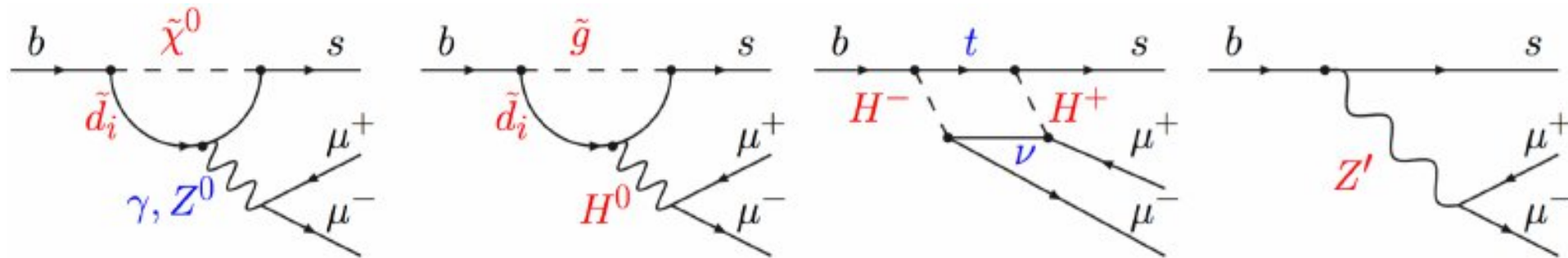
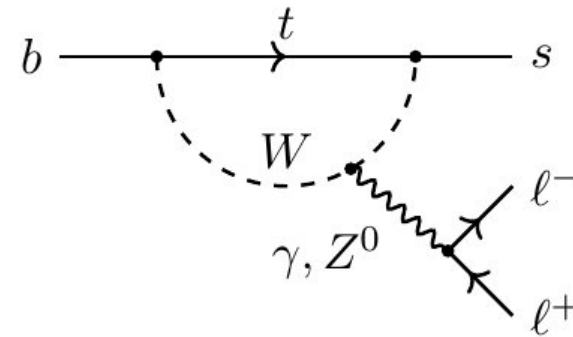
FCNC



# Rare decays as a probe for New Physics

- FCNC processes suppressed in SM
- New physics particles with energy scale up to  $O(100)$  TeV could manifest in the loops

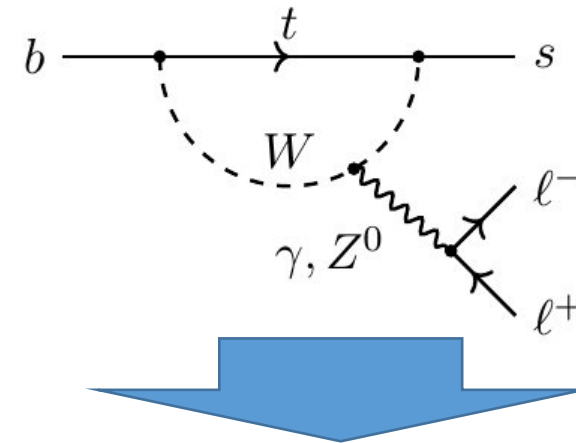
$b \rightarrow sll$  decays in the SM



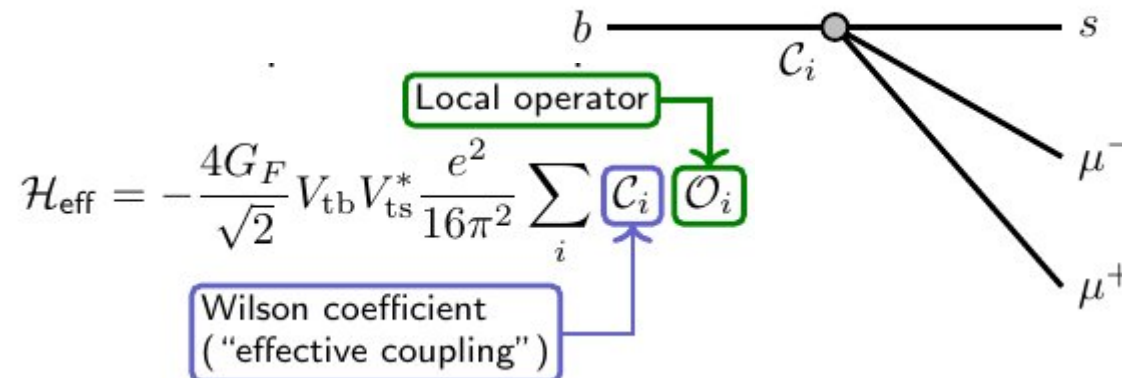
# Rare decays as a probe for New Physics

- FCNC processes suppressed in SM
- New physics particles with energy scale up to  $O(100)$  TeV could manifest in the loops
- This could cause deviation of Wilson coefficients from SM values

$b \rightarrow sll$  decays in the SM



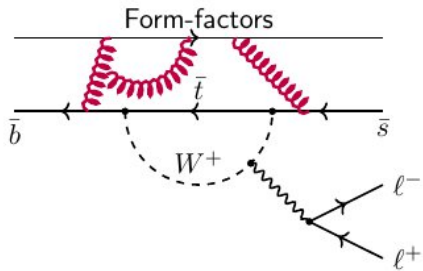
Effective description



Wilson coefficient	Operator
$\gamma$ -penguin <sup>1</sup>	$\mathcal{C}_7^{(l)}$ $\frac{e}{g^2} m_b (\bar{s} \sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}$
ew. penguin	$\mathcal{C}_9^{(l)}$ $\frac{e^2}{g^2} (\bar{s} \gamma_\mu P_{L(R)} b) (\bar{l} \gamma^\mu l)$
	$\mathcal{C}_{10}^{(l)}$ $\frac{e^2}{g^2} (\bar{s} \gamma_\mu P_{L(R)} b) (\bar{l} \gamma^\mu \gamma_5 l)$
scalar	$\mathcal{C}_S^{(l)}$ $\frac{e^2}{16\pi^2} m_b (\bar{s} P_{R(L)} b) (\bar{l} l)$
pseudoscalar	$\mathcal{C}_P^{(l)}$ $\frac{e^2}{16\pi^2} m_b (\bar{s} P_{R(L)} b) (\bar{l} \gamma_5 l)$

$b \rightarrow s\gamma$   
 $b \rightarrow sll$   
 $B_s^0 \rightarrow \mu^+ \mu^-$

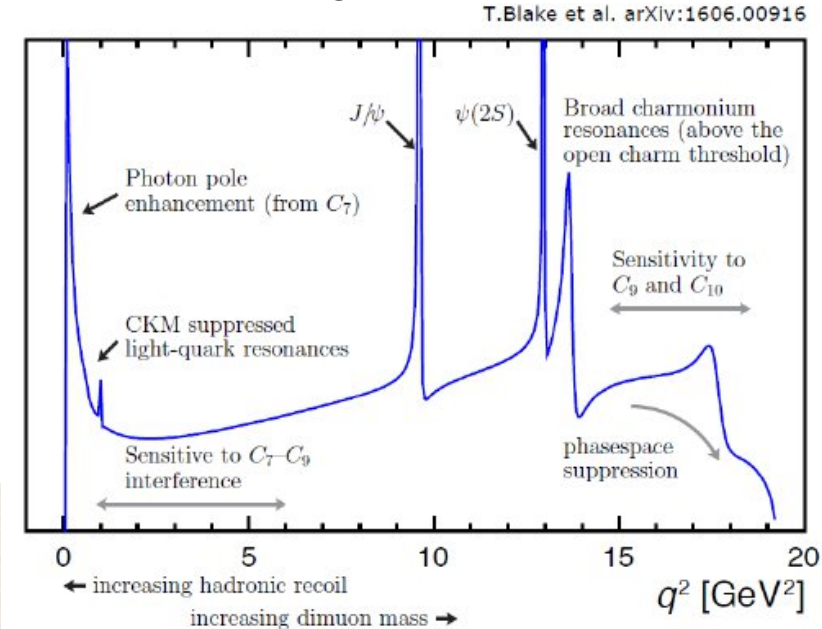
# Observables in FCNC $b \rightarrow s\ell\ell$ decays



Physics depends on  $q^2 = m_{\ell\ell}^2$  :

- Resonances (e.g.  $J/\psi$ ,  $\phi$ )
- Photon pole at low  $q^2$ :  $C_7$
- Vector or axial vector current:  $C_{9,10}$

$d\Gamma/dq^2$



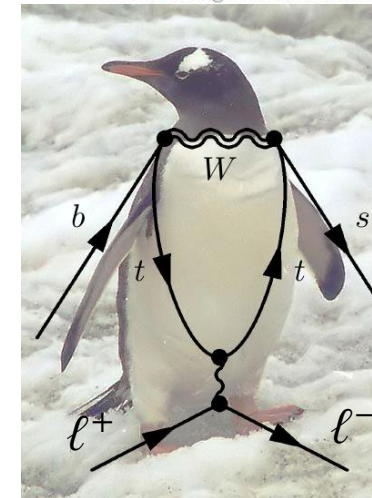
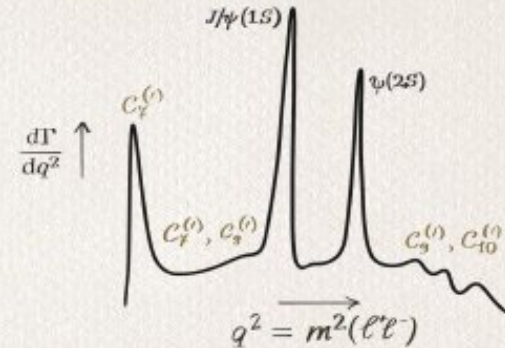
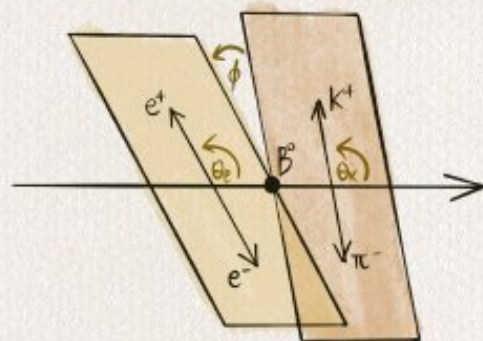
Theoretical uncertainties

Ratio of BFs  
Test of LFU

Angular Analyses

Differential branching fractions

$$R_H = \frac{\mathcal{B}(b \rightarrow s\mu\mu)}{\mathcal{B}(b \rightarrow se\bar{e})}$$

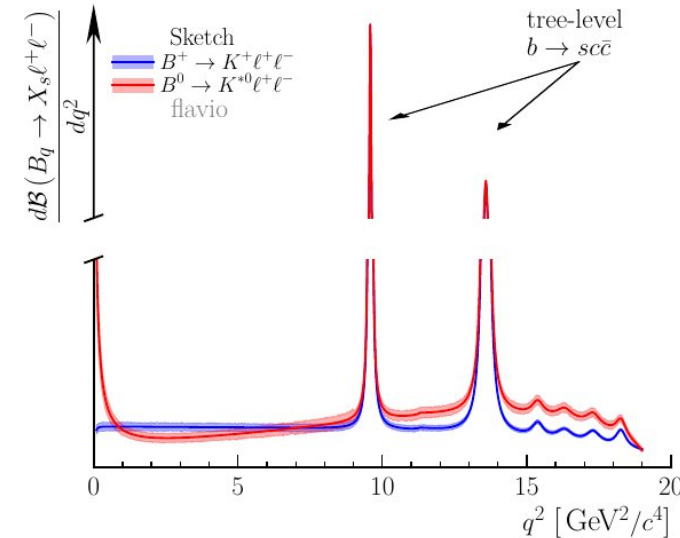
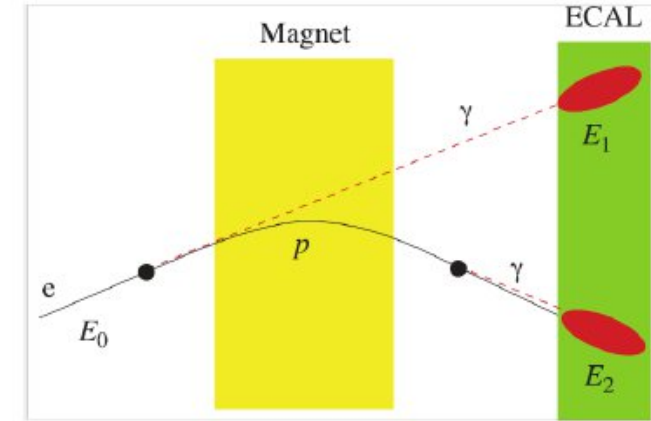
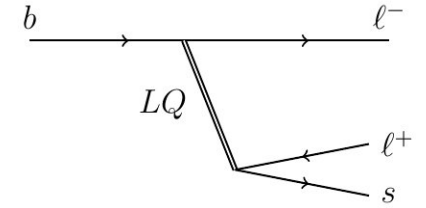


# R(K<sup>(\*)</sup>) measurements @ LHCb

- Electrons & muons behave quite differently in the LHCb detector
- Lower efficiencies & worse resolution (energy loss) for electrons
- Double-ratio of branching fractions:

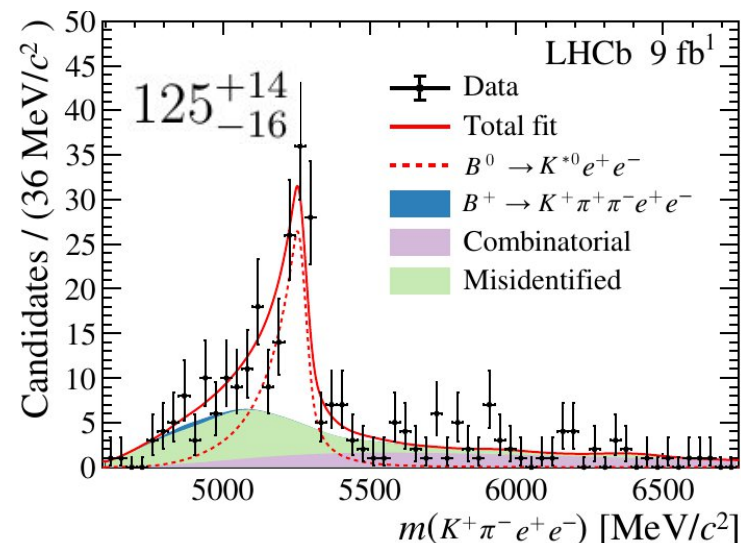
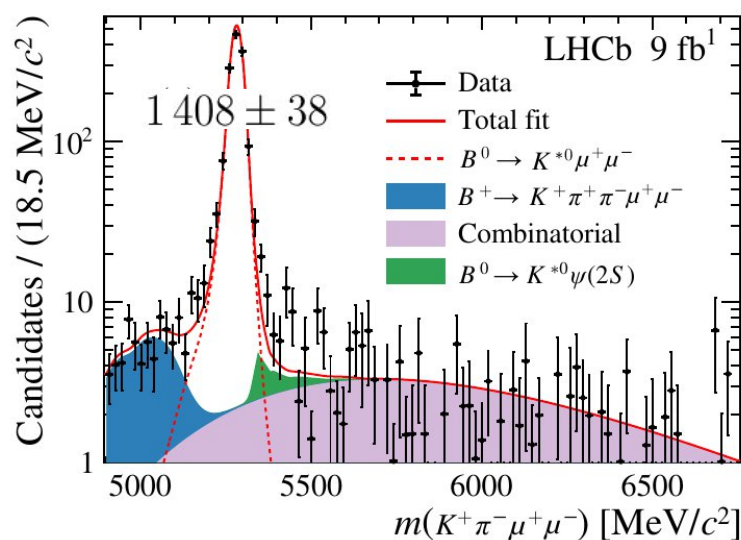
$$R_X = \frac{\mathcal{B}(B_q \rightarrow X_s \mu^+ \mu^-)}{\mathcal{B}(B_q \rightarrow X_s J/\psi(\mu^+ \mu^-))} \cdot \frac{\mathcal{B}(B_q \rightarrow X_s J/\psi(e^+ e^-))}{\mathcal{B}(B_q \rightarrow X_s e^+ e^-)}$$

- Most of systematic uncertainties cancel to 1st order
- LFU in  $J/\psi \rightarrow l^+ l^-$  well established at ‰ level [BESIII, PRD 88, 032007 (2013)]
- Validated in  $\psi(2S)$  mode



# $R(K^*)$ result at high $q^2$

- First LHCb result at high  $q^2$  region above  $\psi(2S)$  ( $q^2 > 14.0 \text{ GeV}^2$ )
- Full Runs1-2  $9 \text{ fb}^{-1}$  analysis



Most precise to date:

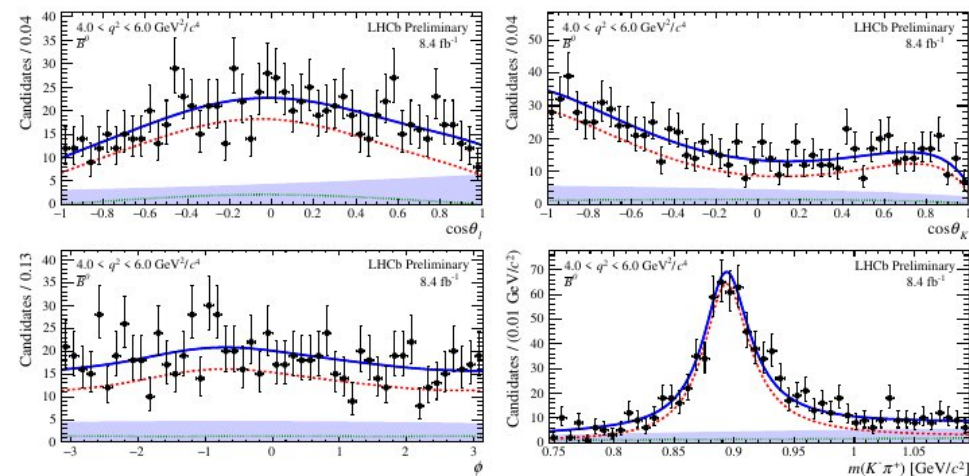
$$R_{K^{*0}} = 1.08^{+0.14}_{-0.12} (\text{stat}) \pm 0.07 (\text{syst})$$

$$R_{K^{*0}} = \frac{N/\varepsilon(B^0 \rightarrow K^{*0} \mu^+ \mu^-)}{N/\varepsilon(B^0 \rightarrow K^{*0} J/\psi (\rightarrow \mu^+ \mu^-))} \bigg/ \frac{N/\varepsilon(B^0 \rightarrow K^{*0} e^+ e^-)}{N/\varepsilon(B^0 \rightarrow K^{*0} J/\psi (\rightarrow e^+ e^-))}$$

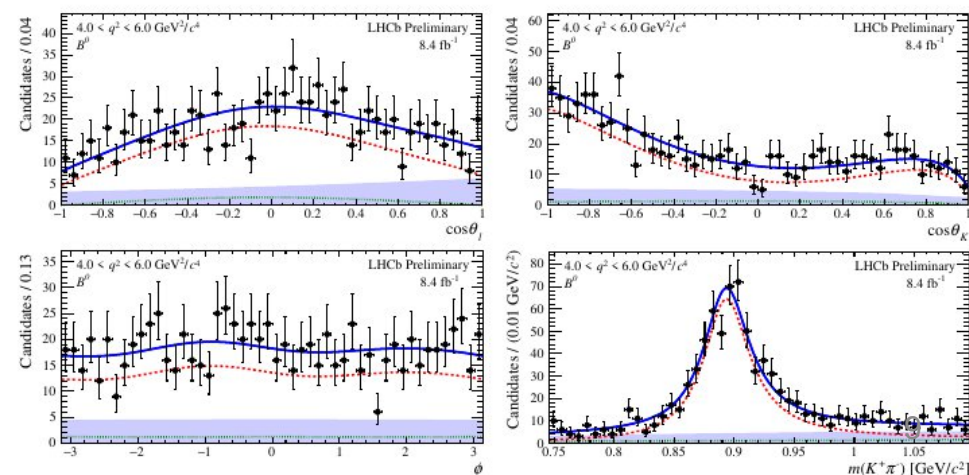
# Legacy Runs 1-2 $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ measurement

- 5D (3 decay angles,  $m_B$ ,  $m_{K\pi}$ ) unbinned ML fit in bins of  $q^2$ 
  - Improved selection, more observables (CPV, dBF)
  - Finer  $q^2$  binning  $\sim 1 \text{ GeV}^2$
  - Lepton mass accounted for
  - Full suite of S-wave and P-/S-wave interference observables
  - 2x statistics:  $\sim 12\text{k}$  signals
  - Data split into  $B^0$  and  $\bar{B}^0$ , and fit simultaneously

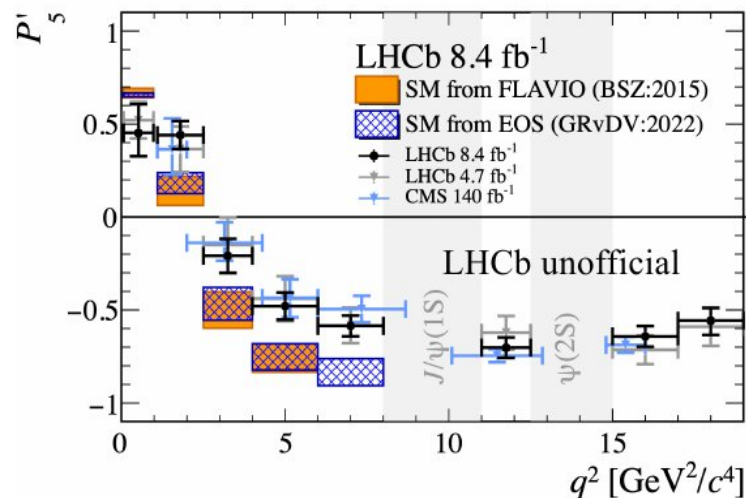
$\bar{B}^0$ :



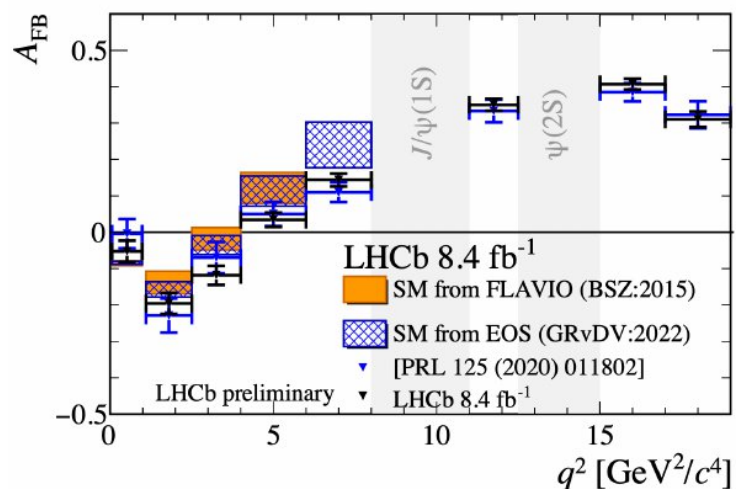
$B^0$ :



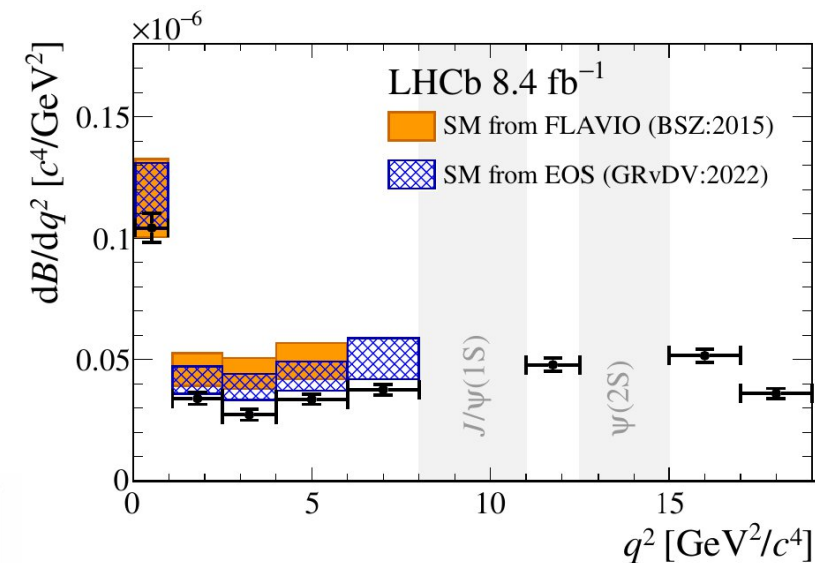
# Legacy Runs 1-2 $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ measurement



- Results in  $P'_5$  excellent agreement with both CMS and previous LHCb
- Deviations of 2.6 and 2.7  $\sigma$  in 4-6 and 6-8 GeV<sup>2</sup> bins



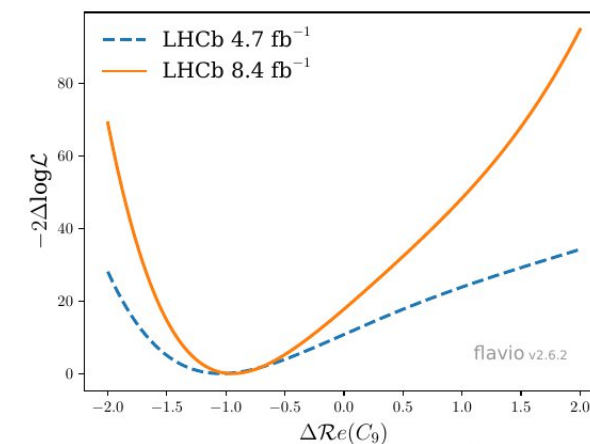
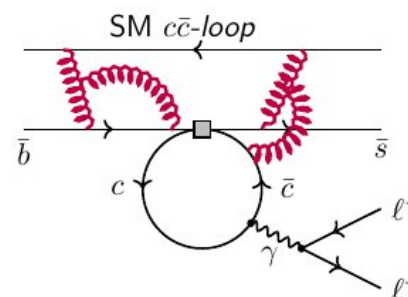
The forward-backward asymmetry,  $A_{FB}$ , also now shows marked disagreement with improved statistics



- The branching fraction is consistently below SM predictions

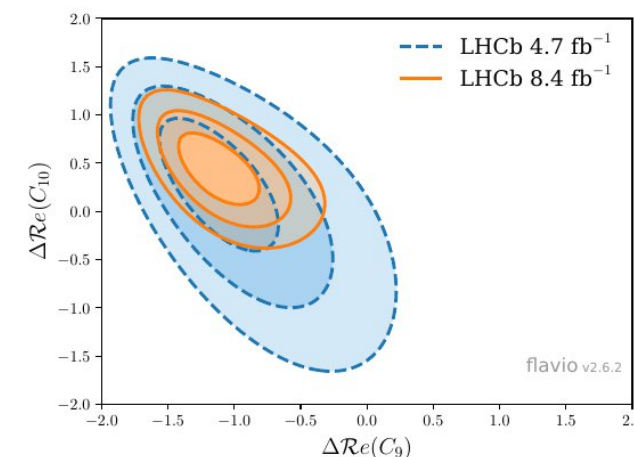
# Legacy Runs 1-2 $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ measurement

- Interpretation in terms of Wilson coefficients, by combining angular observables and BFs up to  $8 \text{ GeV}^2$
- Alternative theory packages with different approaches on (non-local) FFs, with consistent results
- Tension most pronounced in  $\text{Re}(C_9)$ , with shifts consistent across  $q^2$  bins
- NP or underestimated hadronic (charm-loop) contributions?



$$\Delta \text{Re} C_9 = -0.93^{+0.18}_{-0.16}$$

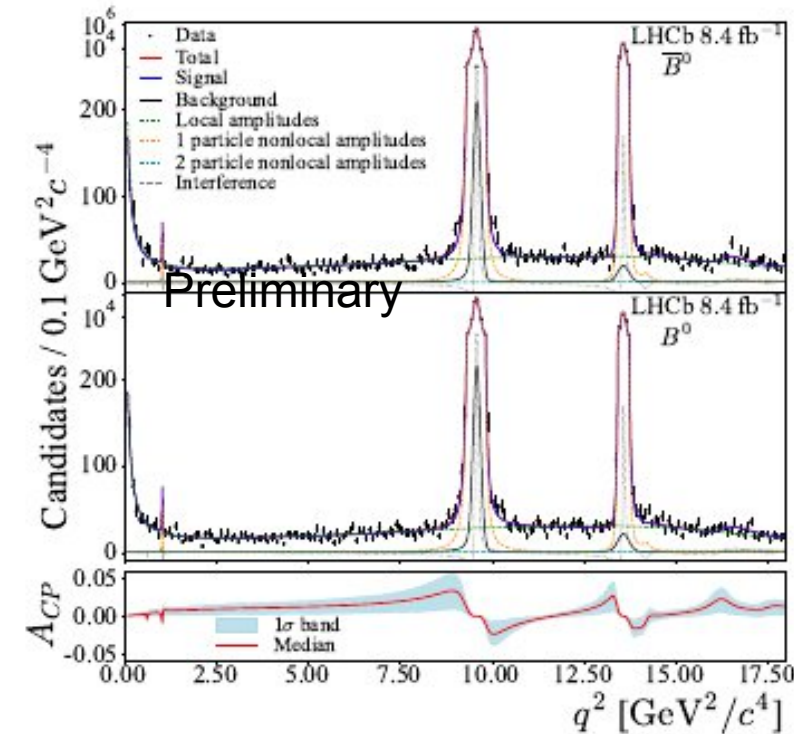
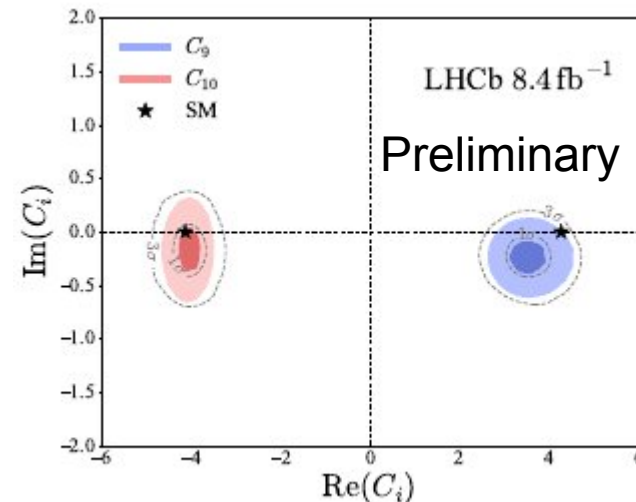
Significance  $4.1 \sigma$



# CPV of (non-)local amplitudes in $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

- Local FCNC loops versus non-local charm loops
- Using Runs1-2 8.4 fb<sup>-1</sup> data
- Unbinned angular analysis to determine complex Wilson coefficients:

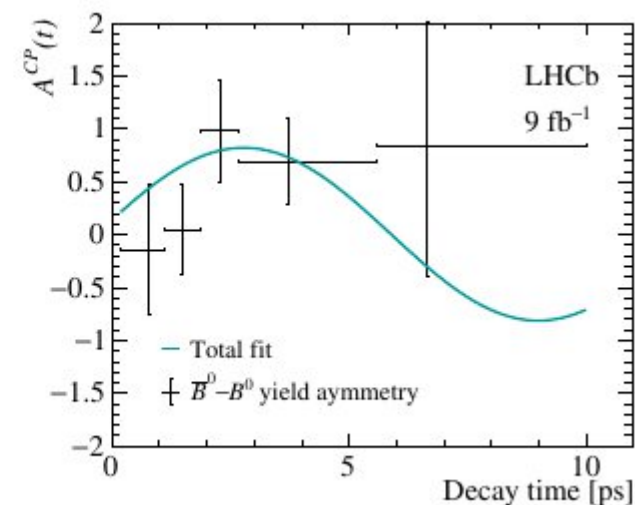
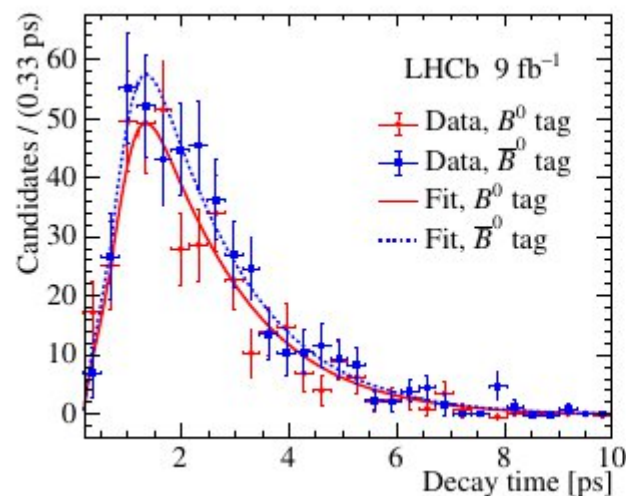
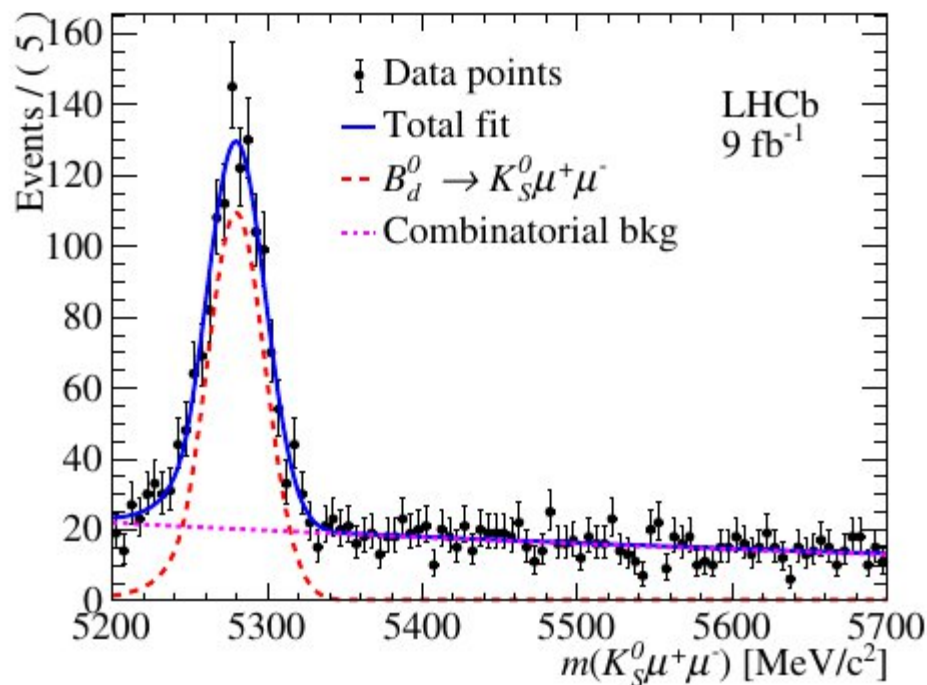
Wilson coefficient results		
$\ C_9\ $	$3.50 \pm 0.30$	$\pm 0.15$
$\ C_{10}\ $	$4.04 \pm 0.18$	$\pm 0.15$
$\delta\phi_{C_9}$	$-0.067 \pm 0.032$	$\pm 0.011$
$\delta\phi_{C_{10}}$	$0.043 \pm 0.035$	$\pm 0.010$
$\text{Re}(C_9)$	$3.50 \pm 0.30$	$\pm 0.15$
$\text{Im}(C_9)$	$-0.23 \pm 0.11$	$\pm 0.04$
$\text{Re}(C_{10})$	$-4.04 \pm 0.18$	$\pm 0.15$
$\text{Im}(C_{10})$	$-0.17 \pm 0.14$	$\pm 0.04$
$\text{Re}(C'_9)$	$0.39 \pm 0.46$	$\pm 0.21$
$\text{Re}(C'_{10})$	$-0.12 \pm 0.21$	$\pm 0.06$



**No CPV found**  
**Good agreement with SM**  
 (Non-)local amplitudes in  $B^+ \rightarrow K^+ \mu^+ \mu^-$  studied in [\[arXiv:2603.12477\]](https://arxiv.org/abs/2603.12477)

# Time-dep. CPV in $B^0 \rightarrow K_S^0 \mu^+ \mu^-$

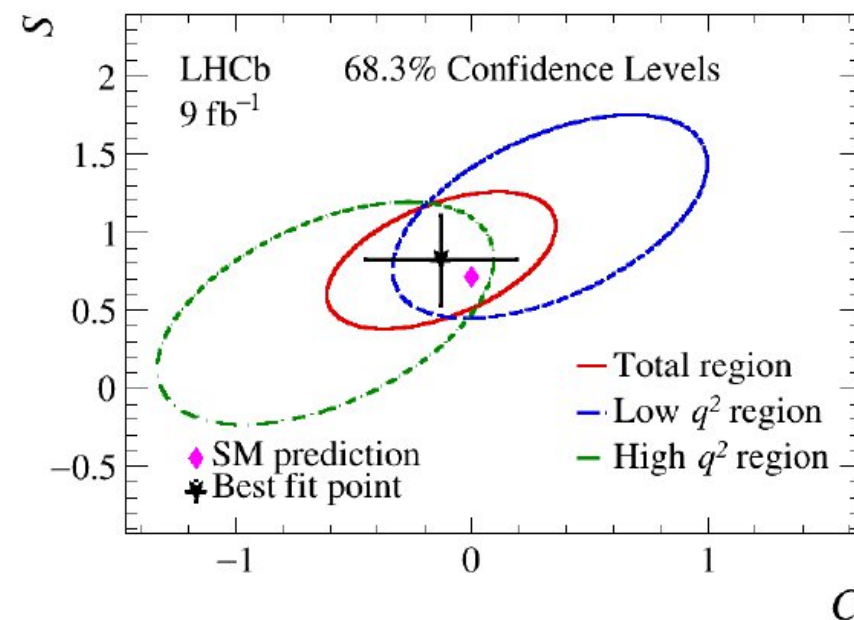
- Using full Runs1-2 data
- First time-dependent CPV measurement in  $b \rightarrow sl^+l^-$  processes
- Flavor tagged B mesons



# Time-dep. CPV in $B^0 \rightarrow K_S^0 \mu^+ \mu^-$

- Using full Runs1-2 data
- First time-dependent CPV measurement in  $b \rightarrow sl^+l^-$  processes
- Flavor tagged B mesons
- CPV parameters extracted:

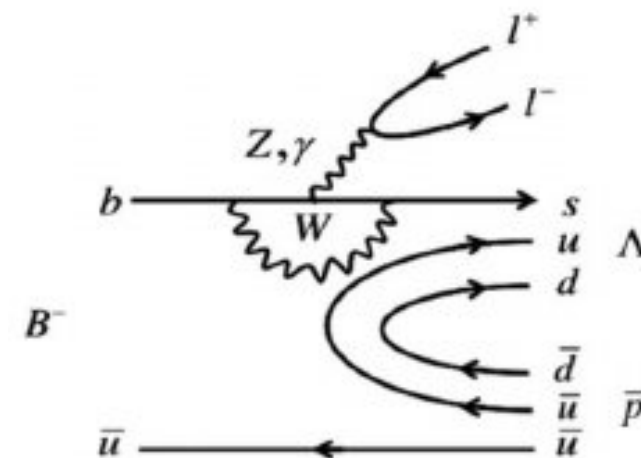
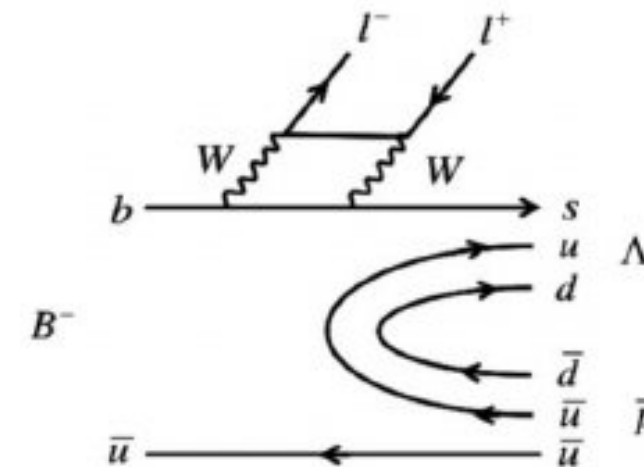
$q^2$ range [ $\text{GeV}^2/c^4$ ]	$C$	$S$
Total	$-0.13 \pm 0.32$	$+0.82 \pm 0.29$
Low: $q^2 < 8.0$	$+0.33 \pm 0.44$	$+1.10 \pm 0.43$
High: $11.0 < q^2 < 15.0$ or $q^2 > 17.5$	$-0.62 \pm 0.47$	$+0.48 \pm 0.47$



$$\mathcal{A}^{CP}(t) \equiv \frac{\Gamma(\bar{B}^0(t) \rightarrow K_S^0 \mu^+ \mu^-) - \Gamma(B^0(t) \rightarrow K_S^0 \mu^+ \mu^-)}{\Gamma(\bar{B}^0(t) \rightarrow K_S^0 \mu^+ \mu^-) + \Gamma(B^0(t) \rightarrow K_S^0 \mu^+ \mu^-)} \simeq S \sin(\Delta m_d t) - C \cos(\Delta m_d t),$$

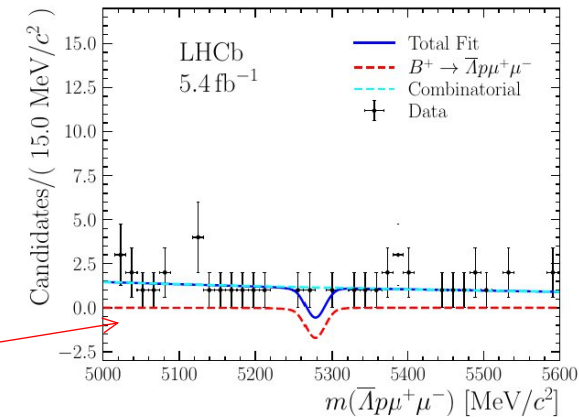
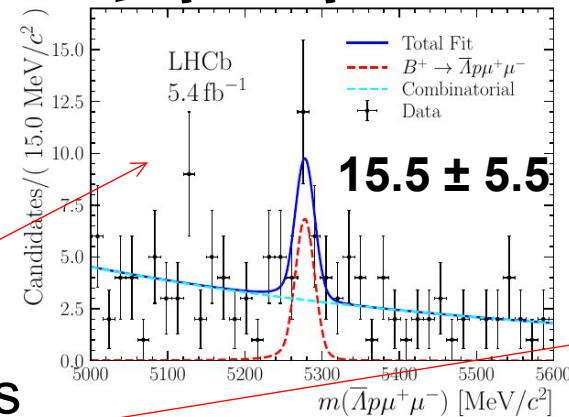
# First evidence of $B^+ \rightarrow \bar{\Lambda} p \mu^+ \mu^-$

- Mediated via  $b \rightarrow s \mu^+ \mu^-$ , baryonic final state less explored to mesonic counterparts
  - Phenomenology of hadronization
  - Rich dynamics in hadronic system
  - Clean access to exotic states such as [X\(2085\)](#)
- Threshold enhancement effects in  $\bar{\Lambda} p$  system observed in other multibody decays, e.g.  $B^+ \rightarrow \bar{\Lambda} p \pi^+ \pi^-$  [\[link\]](#) and  $B \rightarrow \bar{\Lambda} p K K$  [\[link\]](#)
- SM based BF prediction at  $\sim 1.08 \times 10^{-7}$  [\[link\]](#)
- Expecting significantly lower BF if FFs from a more recent paper [\[link\]](#) are used instead

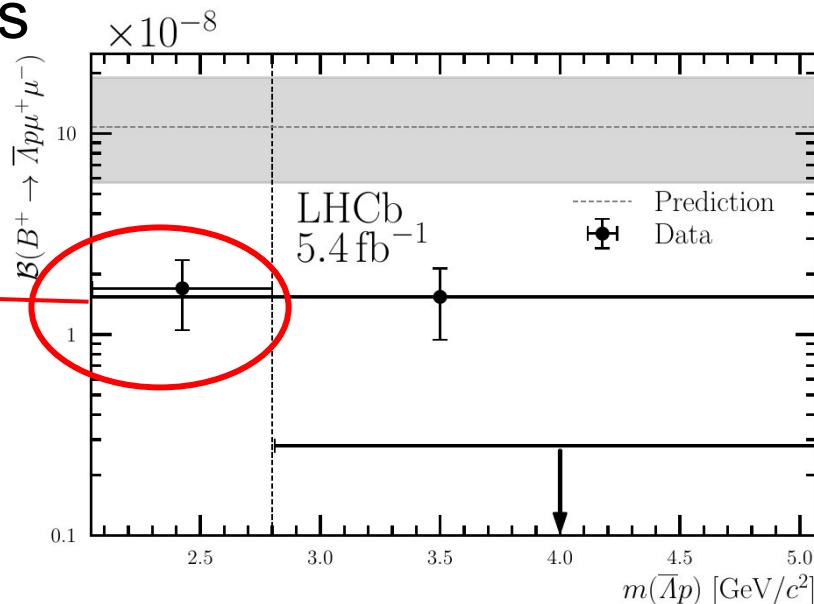


# First evidence of $B^+ \rightarrow \bar{\Lambda} p \mu^+ \mu^-$

- Using  $5.4 \text{ fb}^{-1}$  Run2 data
- Normalization channel:  $B^+ \rightarrow J/\psi \bar{\Lambda} p$ 
  - Also used for signal shape calibration & correction for data/simulation differences
- Signal searched for in low & high  $m(\bar{\Lambda} p)$  regions



Contribution of X(2085) or heavy strange mesons?



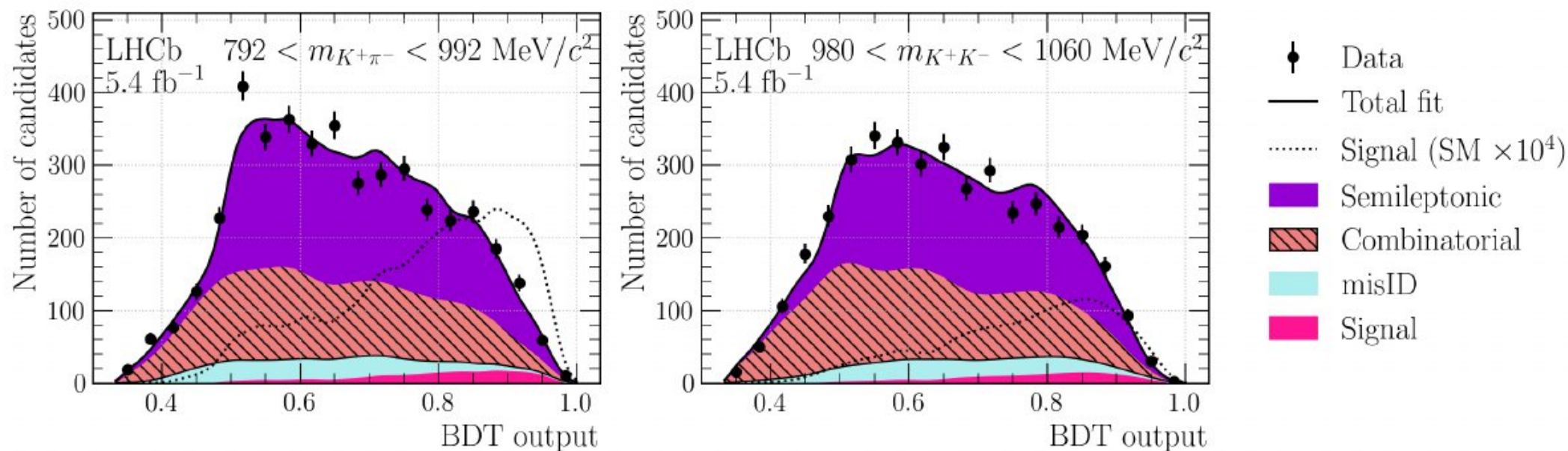
- Evidence for the decay found in the  $m(\bar{\Lambda} p) < 2.8 \text{ GeV}$  region with significance of  $3.5\sigma$
- The total branching fraction is measured:

$$\mathcal{B}(B^+ \rightarrow \bar{\Lambda} p \mu^+ \mu^-) = (1.54 \pm 0.65_{\text{stat}} \pm 0.18_{\text{syst}} \pm 0.13_{\text{ext}}) \times 10^{-8}$$

Work based on Run3 data ongoing  
Also, what about  $B^+ \rightarrow \bar{\Lambda}^* p \mu^+ \mu^-$ ?

# Search for $B^0 \rightarrow K^+ \pi^- \tau^+ \tau^-$ & $B_S^0 \rightarrow K^+ K^- \tau^+ \tau^-$

- Using Run2 5.4 fb<sup>-1</sup> data
- Reconstructing taus with muonic channel
- Decays are searched for in bins of dihadron masses



Searches in the lowest  $K\pi$  and  $KK$  bins

# Search for $B^0 \rightarrow K^+ \pi^- \tau^+ \tau^-$ & $B_s^0 \rightarrow K^+ K^- \tau^+ \tau^-$

- Using Run2 5.4 fb<sup>-1</sup> data
- Reconstructing taus with muonic channel
- Decays are searched for in bins of dihadron masses
- No signal founds, upper limits are set:

$$\mathcal{B}(B^0 \rightarrow K^{*0} \tau^+ \tau^-) < 2.8 \times 10^{-4} \text{ (} 2.5 \times 10^{-4} \text{) at 95\% (90\%) CL,}$$

One order of magnitude improvement than [BelleII](#)!

$$\mathcal{B}(B_s^0 \rightarrow \phi \tau^+ \tau^-) < 4.7 \times 10^{-4} \text{ (} 4.1 \times 10^{-4} \text{) at 95\% (90\%) CL.}$$

First search!

Upper limit on the shift  $\Delta^2$  in the  $\mathcal{C}_{9(10)}^{\tau\tau}$  Wilson coefficient at 90% and 95% CL.

Confidence level	$B^0 \rightarrow K^+ \pi^- \tau^+ \tau^-$	$B_s^0 \rightarrow K^+ K^- \tau^+ \tau^-$	$\mathcal{C}_{9(10)}^{\tau\tau} = \mathcal{C}_{9(10)}^{\text{NP}} - (+)\Delta$
90%	$2.5 \times 10^4$	$4.5 \times 10^4$	
95%	$2.9 \times 10^4$	$5.2 \times 10^4$	

# First evidence of $B^+ \rightarrow \pi^+ e^+ e^-$

- Full Runs1-2 9 fb<sup>-1</sup> analysis
- Normalized to  $B^+ \rightarrow K^+ J/\psi(\rightarrow e^+ e^-)$
- Two  $q^2$  regions: below  $J/\psi$  & above  $\psi(2S)$
- Evidence with signal significance of  $3.2\sigma$

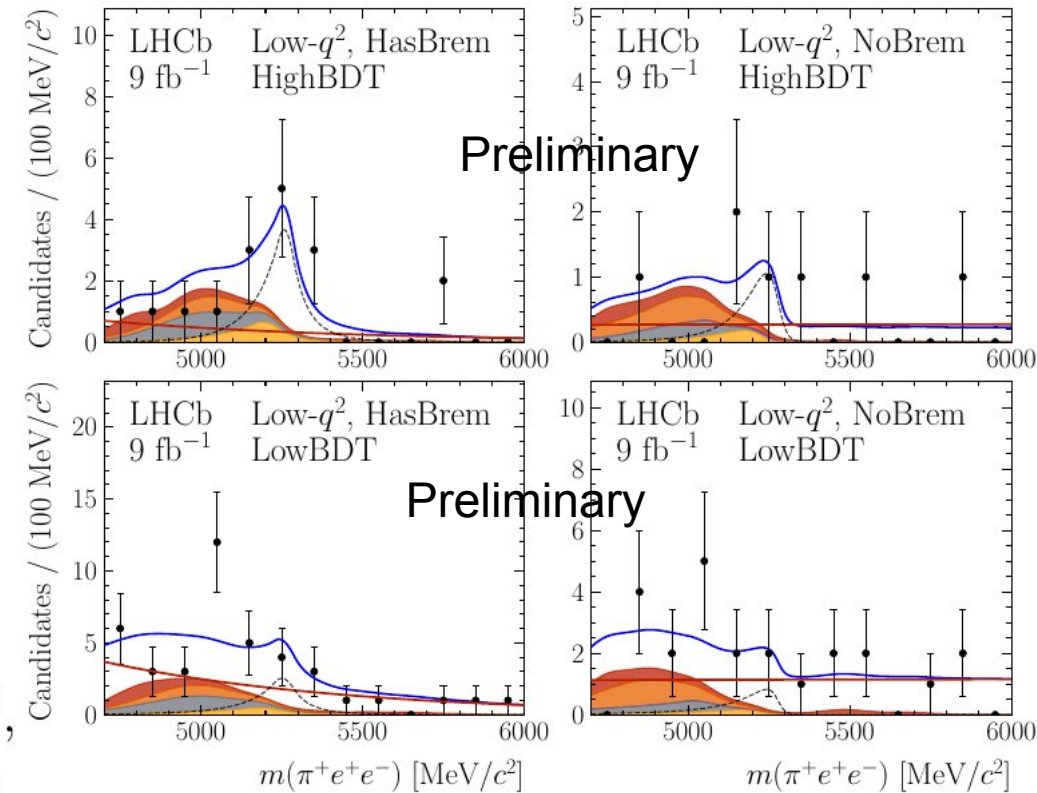
- Total BF:

$$\mathcal{B}(B^+ \rightarrow \pi^+ e^+ e^-) = (2.4^{+0.9}_{-0.8} \text{ } ^{+0.4}_{-0.2}) \times 10^{-8}$$

- Partial BFs:

$$\mathcal{B}(B^+ \rightarrow \pi^+ e^+ e^-)^{[0.045,6] \text{ GeV}^2/c^4} = (0.76^{+0.30}_{-0.27} \text{ } ^{+0.14}_{-0.08}) \times 10^{-8},$$

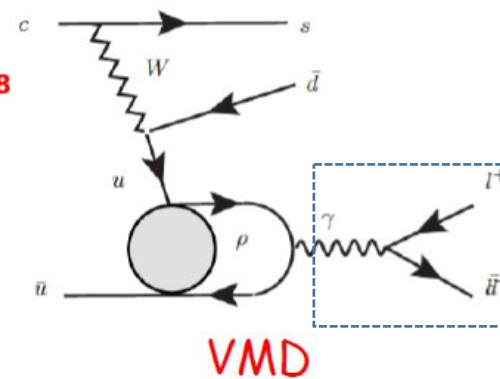
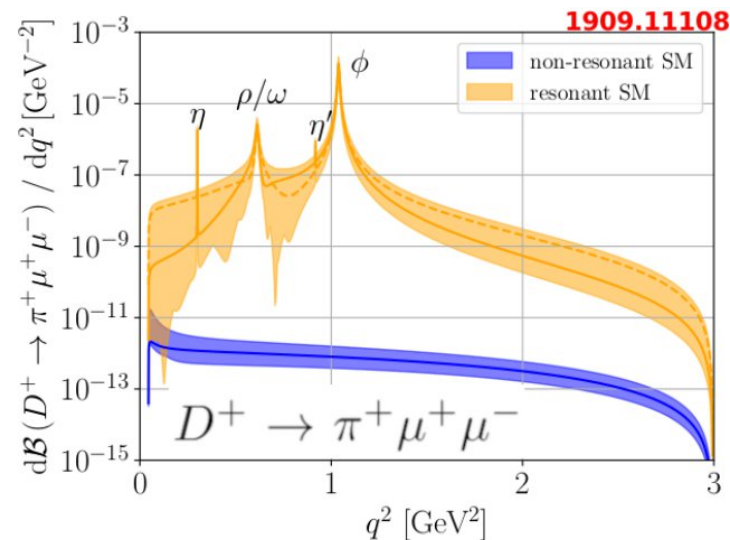
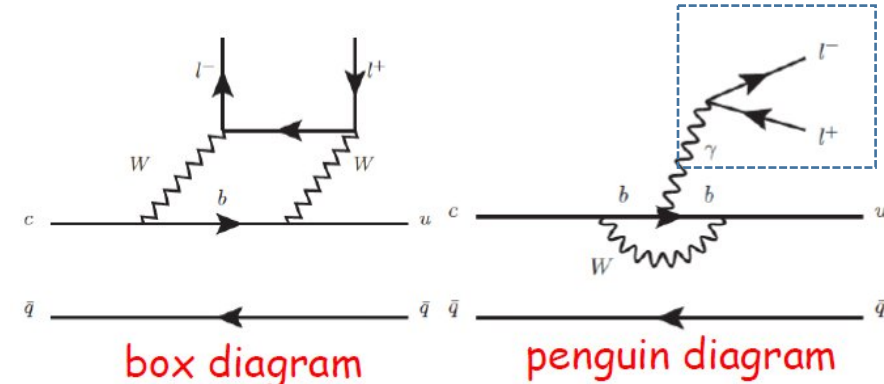
$$\mathcal{B}(B^+ \rightarrow \pi^+ e^+ e^-)^{[15,25] \text{ GeV}^2/c^4} = (0.40^{+0.52}_{-0.45} \text{ } ^{+0.24}_{-0.22}) \times 10^{-8}.$$



More LHCb results on  $b \rightarrow d\ell\ell^{(\prime)}$  showing up!

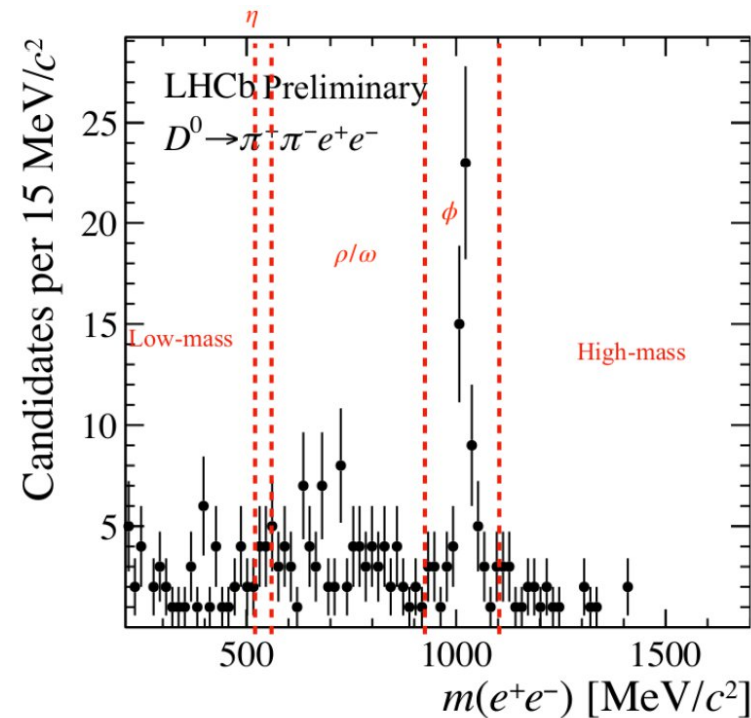
# Flavor Changing Neutral Currents in charm

- $c \rightarrow u\ell\ell$  processes forbidden at tree level in SM, only allowed in loop and box diagrams
  - Strongly suppressed due to GIM cancellation:
  - Expected SM BF  $\sim O(10^{-9})$
  - NP might manifest in the loops
- $D \rightarrow X\ell^+\ell^-$  dominated by Long-Distance contributions
  - Vector Meson Dominance (VMD)
  - BF  $\sim O(10^{-6})$  for  $D \rightarrow X\ell^+\ell^-$



# Search for $D^0 \rightarrow h^+ h^- e^+ e^-$

- Based on Run2 6 fb<sup>-1</sup> dataset
- Signals searched for in different dielectron mass regions
- Normalized to  $D^0 \rightarrow K^- \pi^+ e^+ e^-$  in resonant region

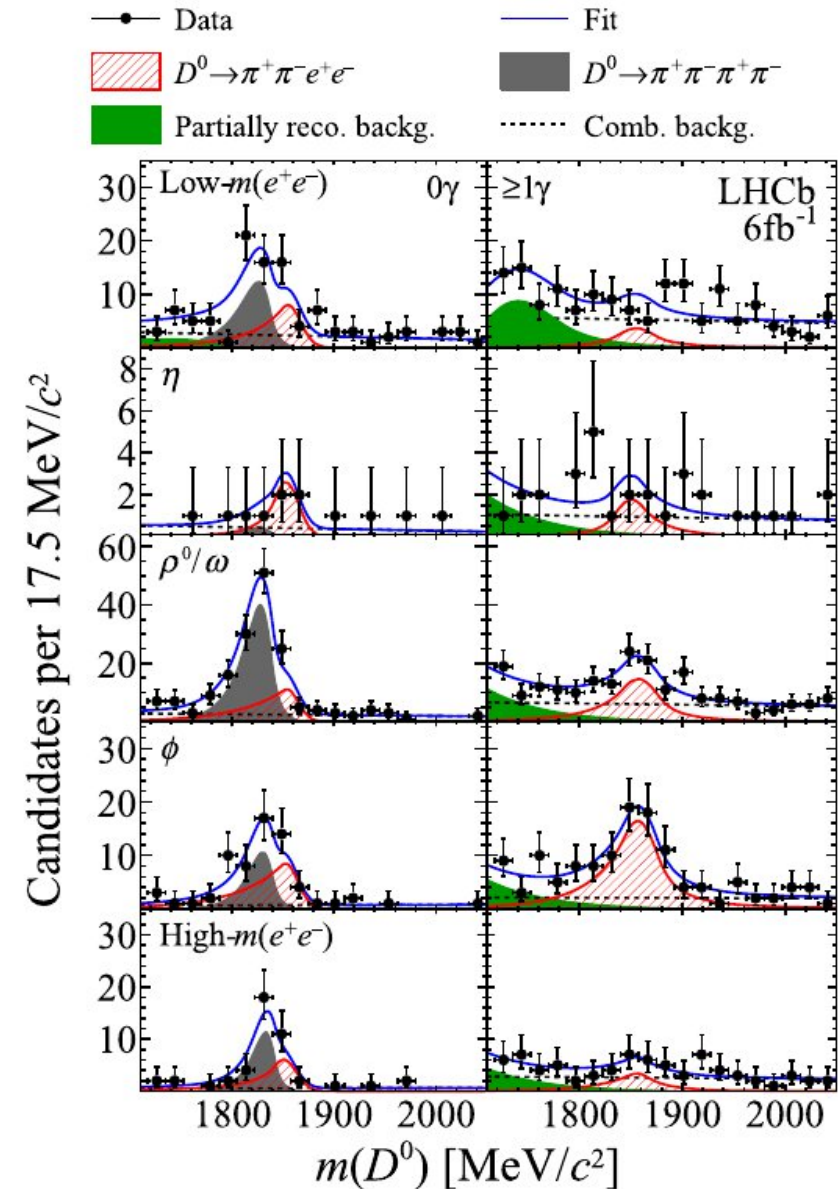


# Search for $D^0 \rightarrow \pi^+ \pi^- e^+ e^-$

- Based on Run2 6 fb<sup>-1</sup> dataset
- Signals searched for in 5 dielectron mass regions
- First observation in  $\rho/\omega$  &  $\phi$  regions

$m(e^+e^-)$ region	[MeV/c <sup>2</sup> ]	Yield	$S$
	$D^0 \rightarrow \pi^+ \pi^- e^+ e^-$		
Low mass	$2m_\mu - 525$	$37 \pm 13$	$2.8\sigma$
$\eta$	525–565	$10 \pm 7$	$1.6\sigma$
$\rho^0/\omega$	565–950	$97 \pm 21$	$5.5\sigma$
$\phi$	950–1100	$100 \pm 18$	$8.1\sigma$
High mass	$> 1100$	$30 \pm 11$	$2.9\sigma$

- Total BF:  $\mathcal{B}(D^0 \rightarrow \pi^+ \pi^- [e^+ e^-]_{m(e^+e^-) > 2m_\mu})$   
 $= (13.3 \pm 1.7 \pm 1.7 \pm 1.8) \times 10^{-7}$



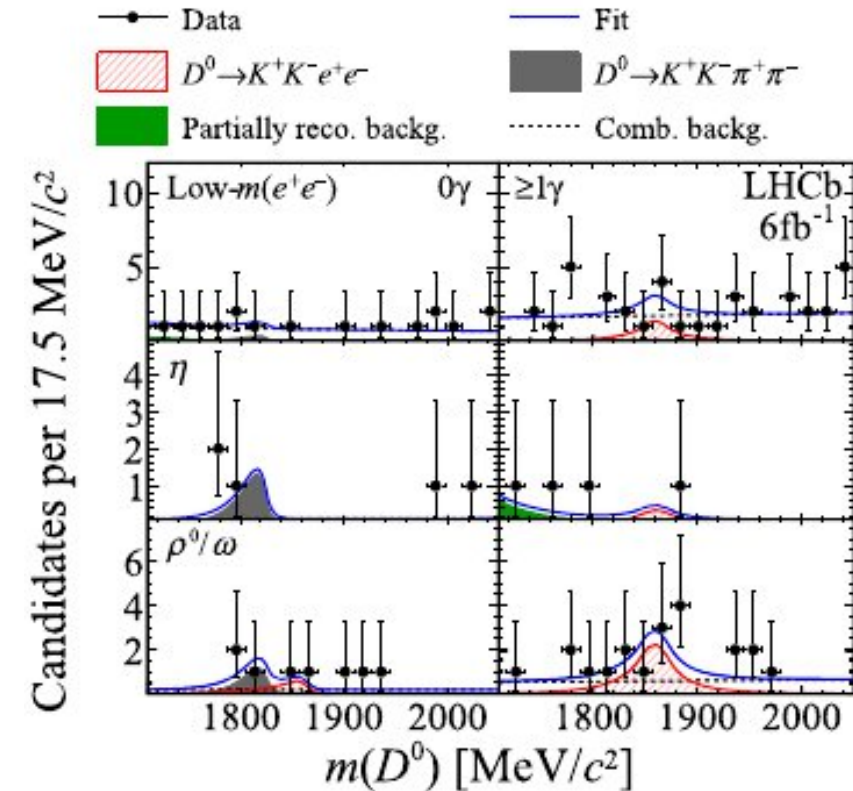
# Search for $D^0 \rightarrow K^+ K^- e^+ e^-$

- Based on Run2 6 fb<sup>-1</sup> dataset
- Signals searched for in 3 dielectron mass regions

$m(e^+e^-)$ region	[MeV/c <sup>2</sup> ]	Yield	$S$
$D^0 \rightarrow K^+ K^- e^+ e^-$			
Low mass	$2m_\mu - 525$	$4 \pm 8$	$1.2\sigma$
$\eta$	525–565	$1 \pm 2$	$1.1\sigma$
$\rho^0/\omega$	$> 565$	$12 \pm 7$	$2.2\sigma$

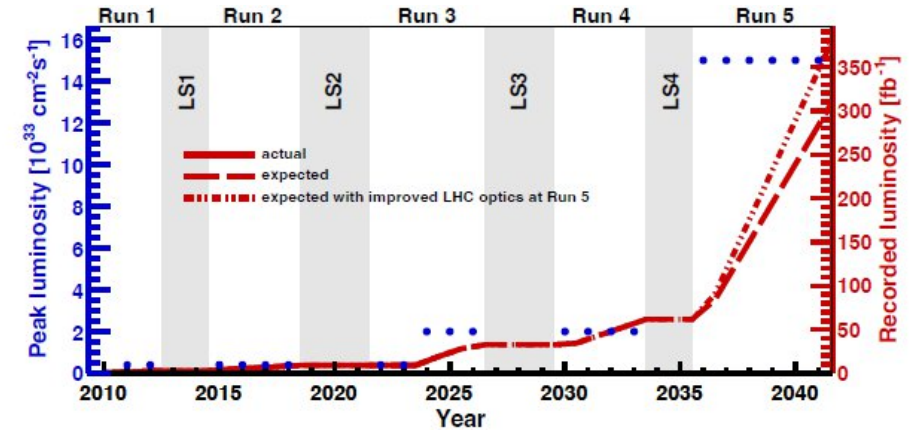
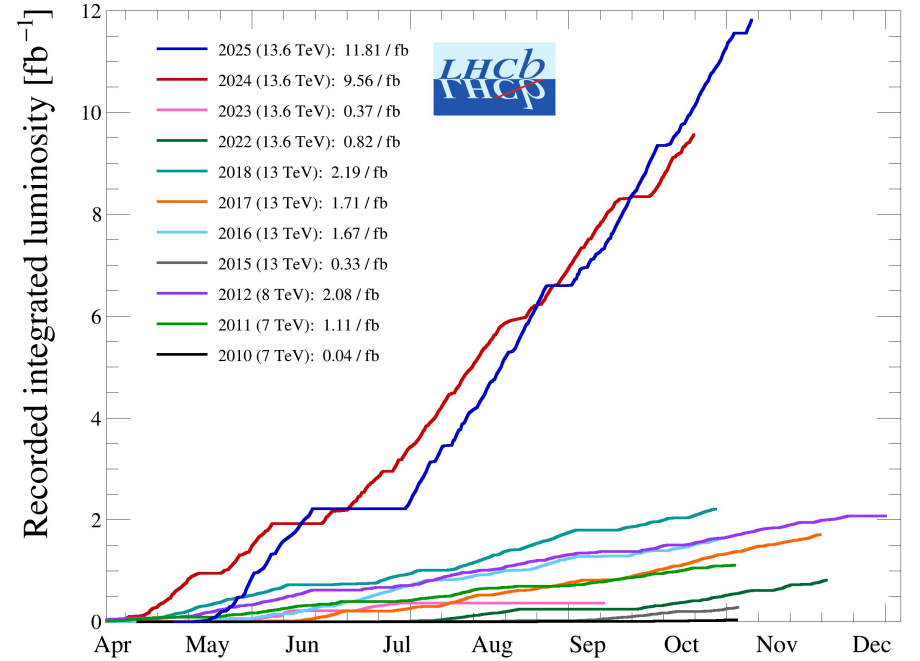
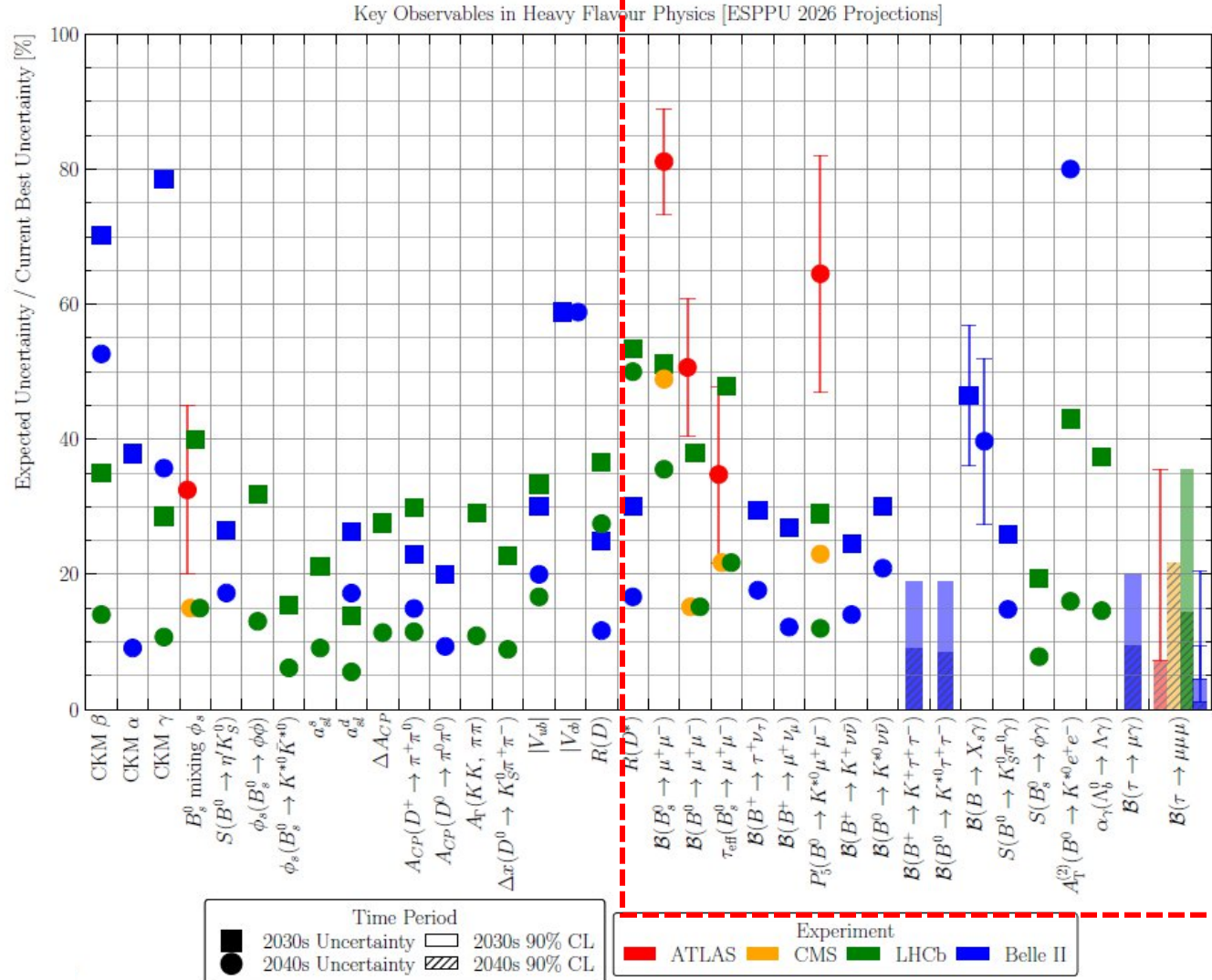
- BF upper limits of  $O(10^{-7})$  are set in different regions

Similar study performed by BELLE(II) yielding less stringent limits  
[PRD 112 (2025) L071101]



# LHCb prospects

Total recorded luminosity by year – pp



# Summary

- Rare heavy hadron decays offer unique opportunities for indirect NP searches
- LHCb as major player in the field for rare decays:
  - Entering precision era for  $B \rightarrow K^{(*)} \mu^+ \mu^-$  decays
  - New frontiers: time-dep.,  $b \rightarrow dl^+l^-$ , baryonic decays,  $b \rightarrow s\tau^+\tau^-$ , light hadrons, ...
- So far, no surprises, but tensions still persist ( $C_9$ ?)
- More results are on the way, stay tuned!
- A huge Run3 data sample available for analysis, while understanding of new LHCb detector ongoing [[arXiv:2511.16564](https://arxiv.org/abs/2511.16564)]
- And we will have Run4 and Upgrade-II!
  - $50 \text{ fb}^{-1}$  by 2033,  $> 300 \text{ fb}^{-1}$  by 2041 for LHCb