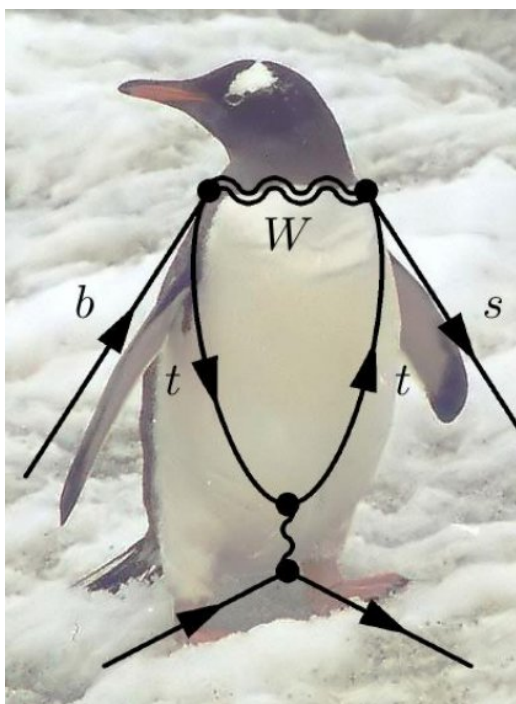
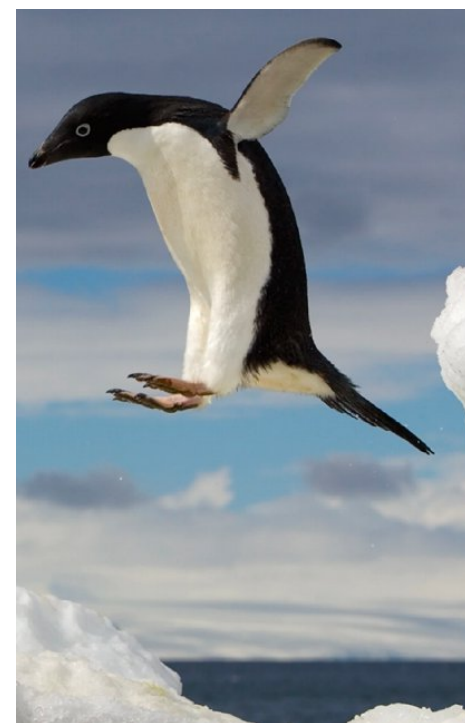


# Highlights on Recent LHCb Rare Decay Results



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Wuhan University  
2026/03/30



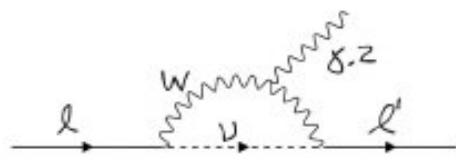
# Outline

- 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



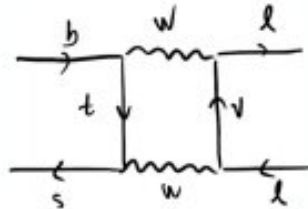
LFV

$\tau \rightarrow lll$   
 $\propto (10^{-55})$

$b \rightarrow sll'$   
 $\propto (10^{-50})$

$D^0 \rightarrow \mu\mu$   
 $O(10^{-13})$

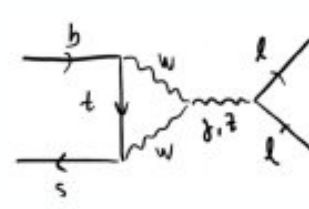
## LOOP-LEVEL



Helicity suppressed

$B_s \rightarrow \mu\mu$   
 $\propto (10^{-9})$

$\Sigma \rightarrow p\mu\mu$   
 $\propto (10^{-8})$



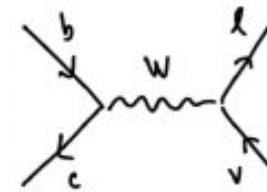
FCNC

$b \rightarrow s\tau\tau$   
 $\propto (10^{-7})$

$b \rightarrow sll$   
 $\propto (10^{-6})$

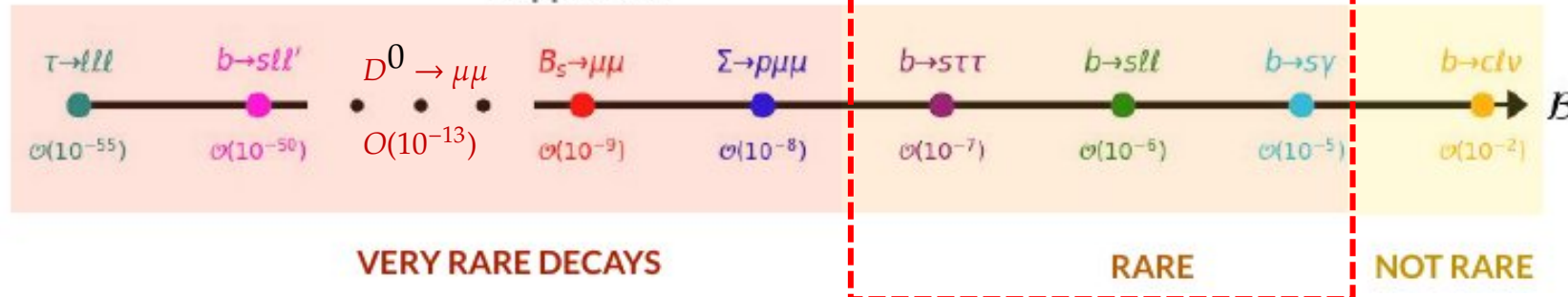
$b \rightarrow s\gamma$   
 $\propto (10^{-5})$

## TREE-LEVEL



FCCC

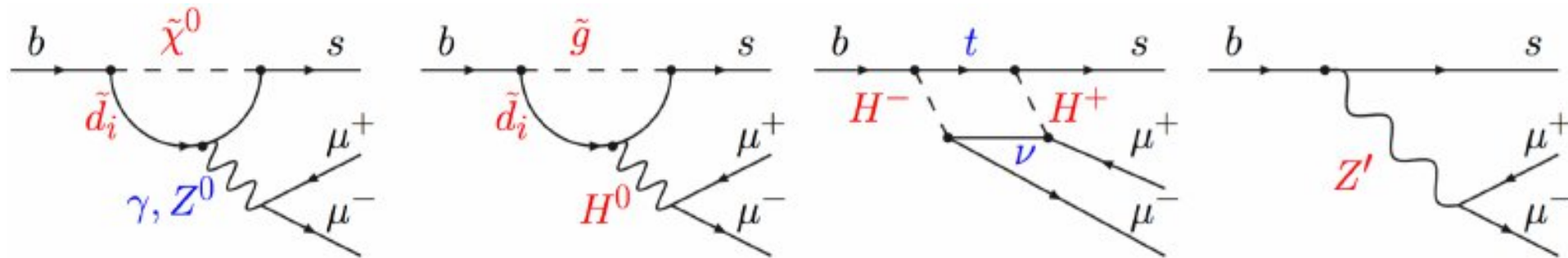
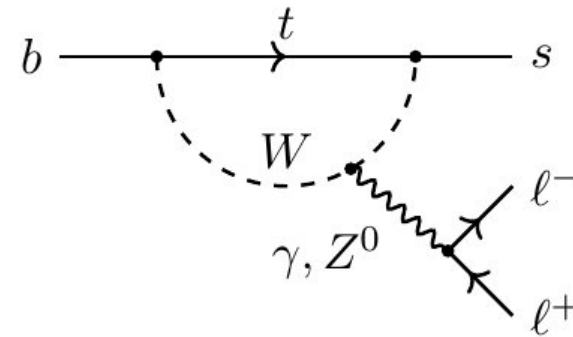
$b \rightarrow cl\nu$   
 $\propto (10^{-2})$



# 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

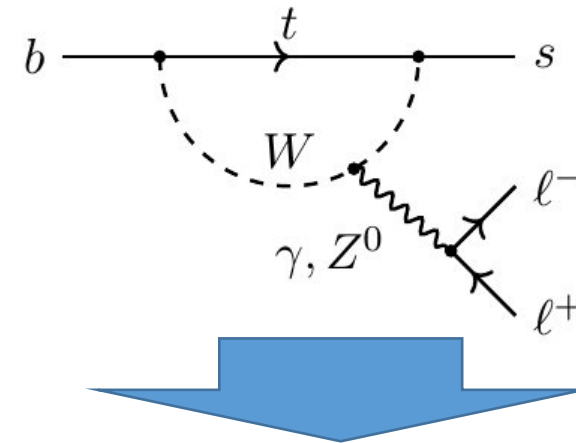
$b \rightarrow sll$  decays in the SM



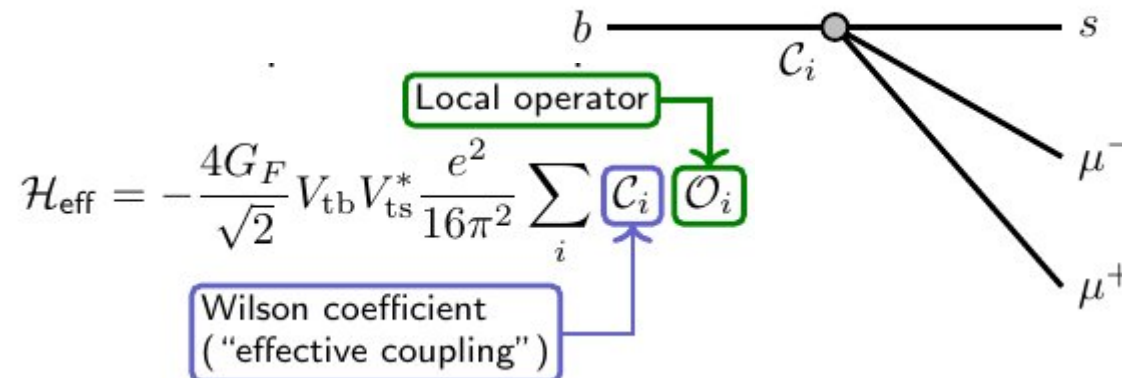
# Rare decays as a probe for New Physics

- 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

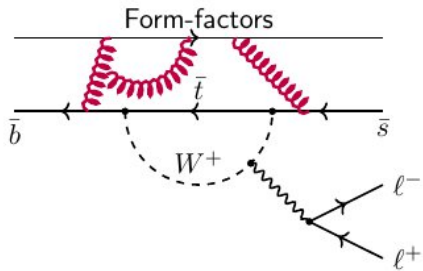


$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i C_i O_i$$

Wilson coefficient	Operator
$\gamma$ -penguin <sup>1</sup>	$C_7^{(l)} \frac{e}{g^2} m_b (\bar{s} \sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}$
ew. penguin	$C_9^{(l)} \frac{e^2}{g^2} (\bar{s} \gamma_\mu P_{L(R)} b) (\bar{l} \gamma^\mu l)$
	$C_{10}^{(l)} \frac{e^2}{g^2} (\bar{s} \gamma_\mu P_{L(R)} b) (\bar{l} \gamma^\mu \gamma_5 l)$
scalar	$C_S^{(l)} \frac{e^2}{16\pi^2} m_b (\bar{s} P_{R(L)} b) (\bar{l} l)$
pseudoscalar	$C_P^{(l)} \frac{e^2}{16\pi^2} m_b (\bar{s} P_{R(L)} b) (\bar{l} \gamma_5 l)$

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

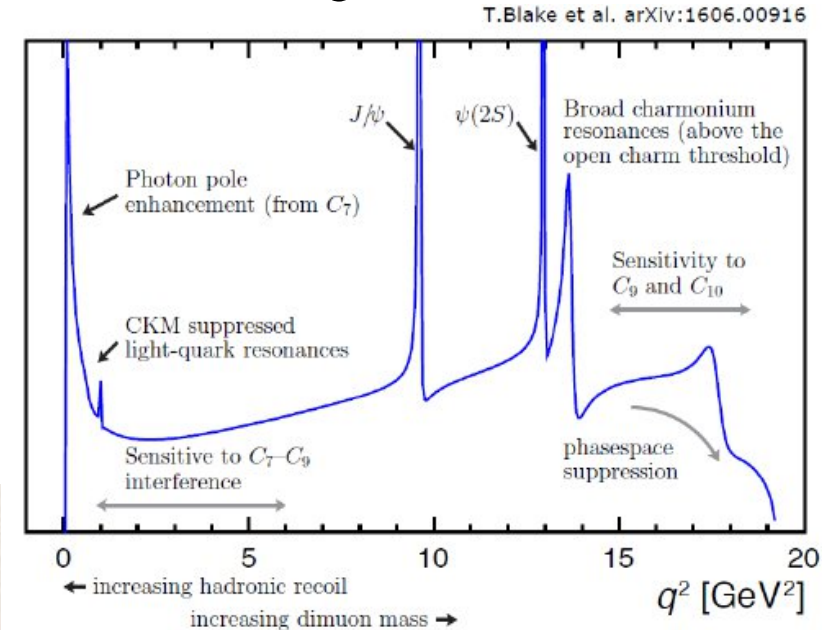
# Observables in FCNC $b \rightarrow s\ell\ell$ decays



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:  $C_{9,10}$

$d\Gamma/dq^2$



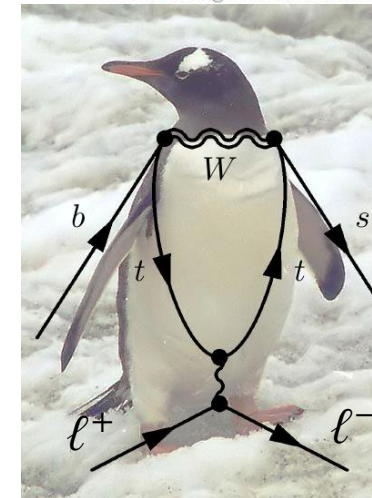
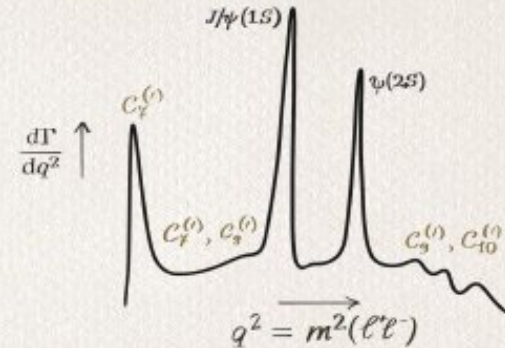
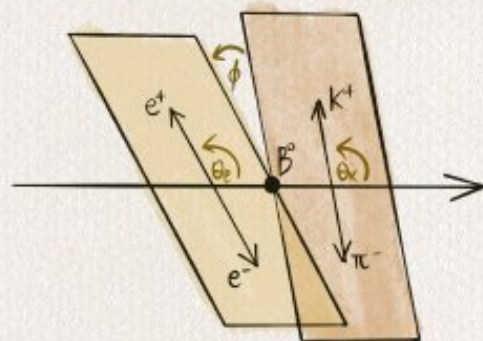
Theoretical uncertainties

Ratio of BFs  
Test of LFU

Angular Analyses

Differential branching fractions

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

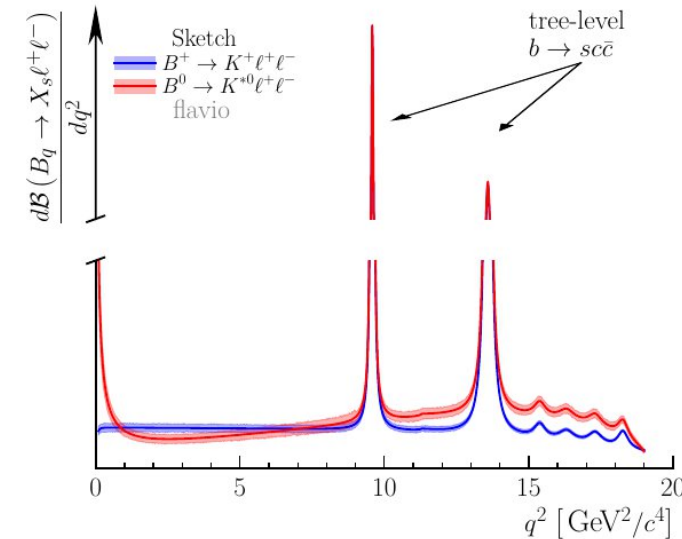
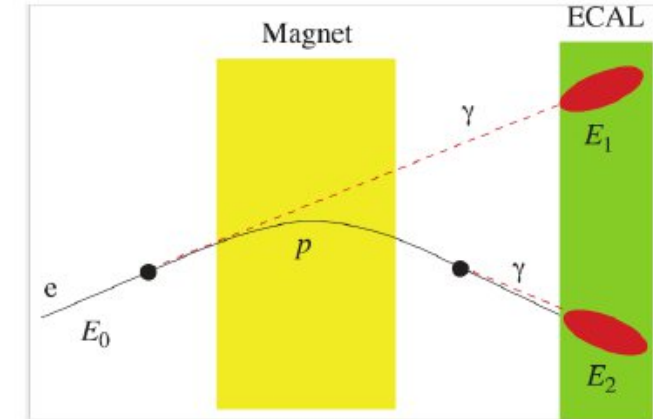
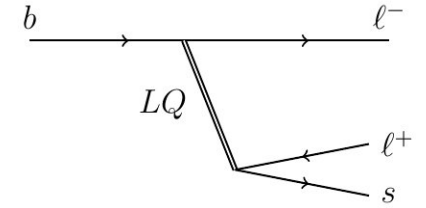


# R(K<sup>(\*)</sup>) measurements @ LHCb

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

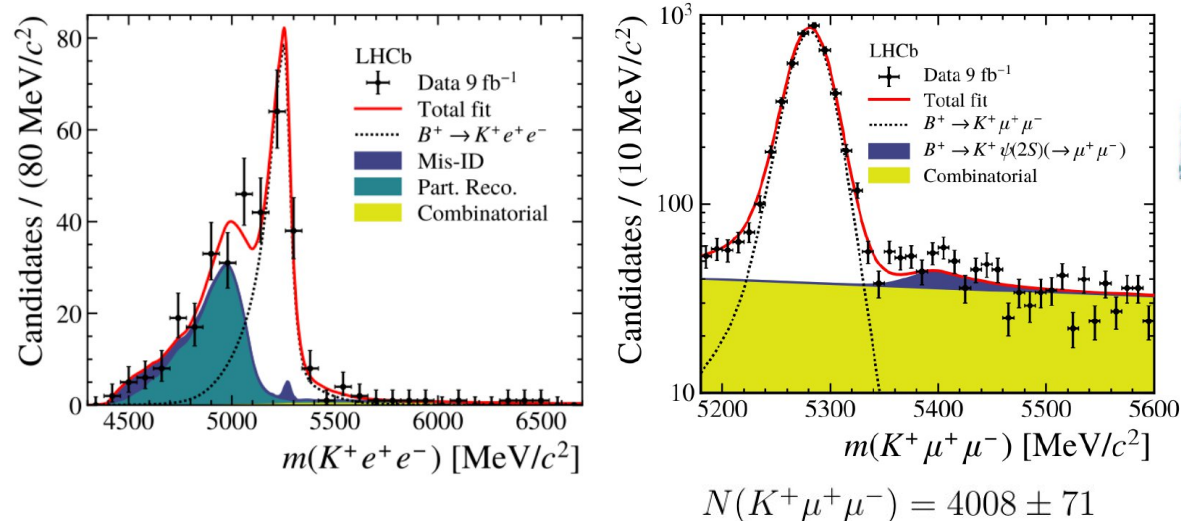
$$R_X = \frac{\mathcal{B}(B_q \rightarrow X_s \mu^+ \mu^-)}{\mathcal{B}(B_q \rightarrow X_s J/\psi(\mu^+ \mu^-))} \cdot \frac{\mathcal{B}(B_q \rightarrow X_s J/\psi(e^+ e^-))}{\mathcal{B}(B_q \rightarrow X_s e^+ e^-)}$$

- 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 $q^2$

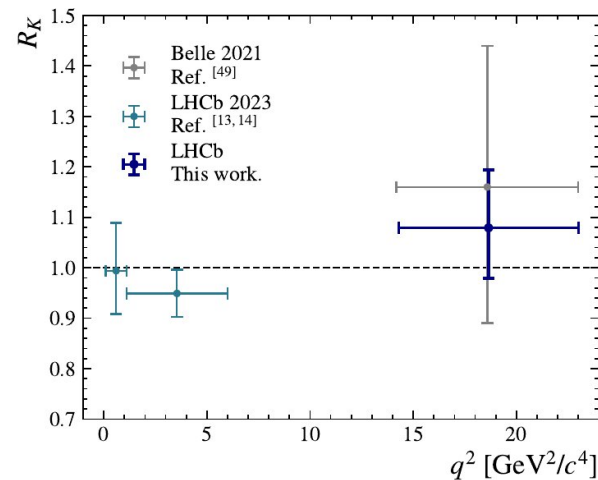
- First LHCb result at high  $q^2$  region above  $\psi(2S)$  ( $q^2 > 14.3 \text{ GeV}^2$ )
- Full Runs1-2  $9 \text{ fb}^{-1}$  analysis



Most precise to date:

$$R_K(q^2 > 14.3 \text{ GeV}^2/c^4) = 1.08^{+0.11}_{-0.09} \text{ }^{+0.04}_{-0.04}$$

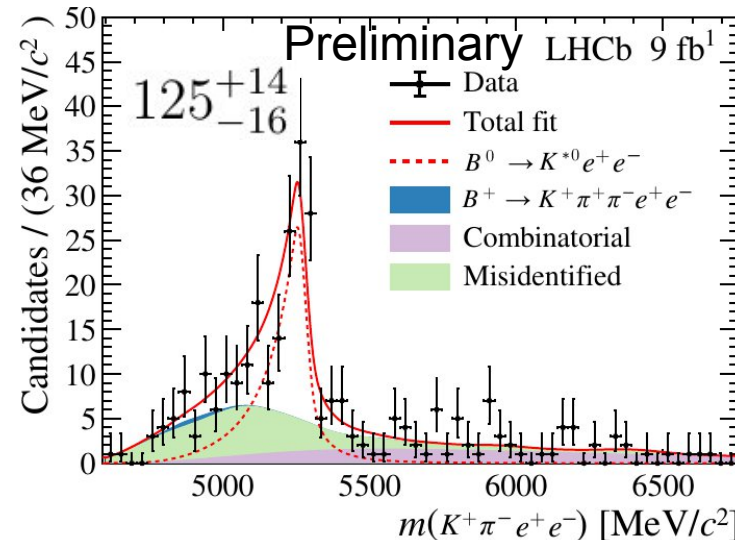
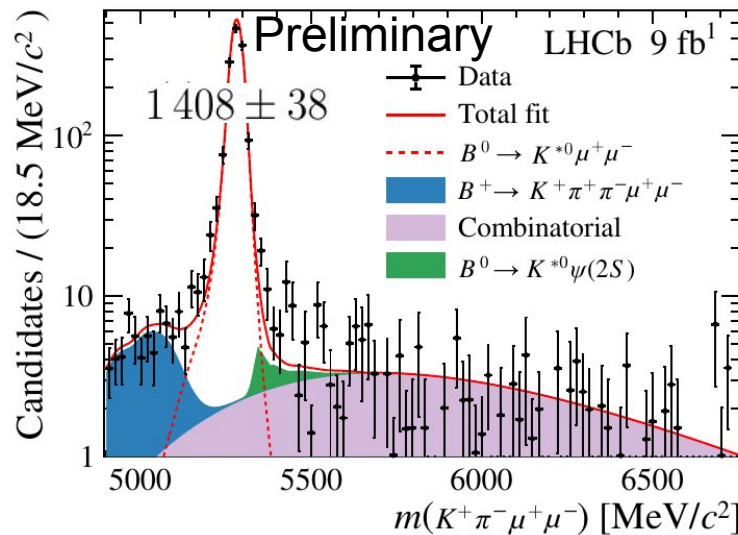
Compatible with the SM



$$R_K = \frac{N(K^+\mu^+\mu^-)}{N(K^+e^+e^-)} \cdot \frac{\epsilon(K^+e^+e^-)}{\epsilon(K^+\mu^+\mu^-)} \cdot \frac{1}{r_{J/\psi}}$$

# $R(K^*)$ 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:

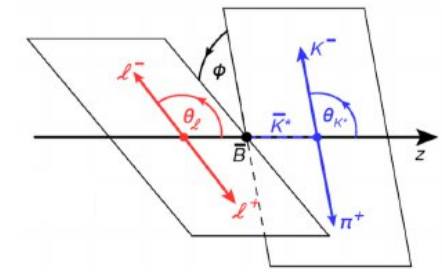
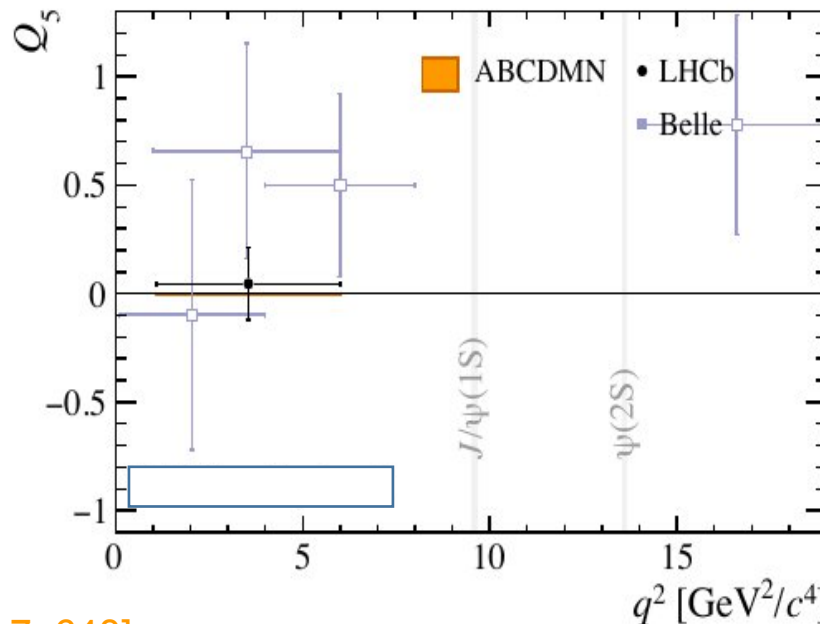
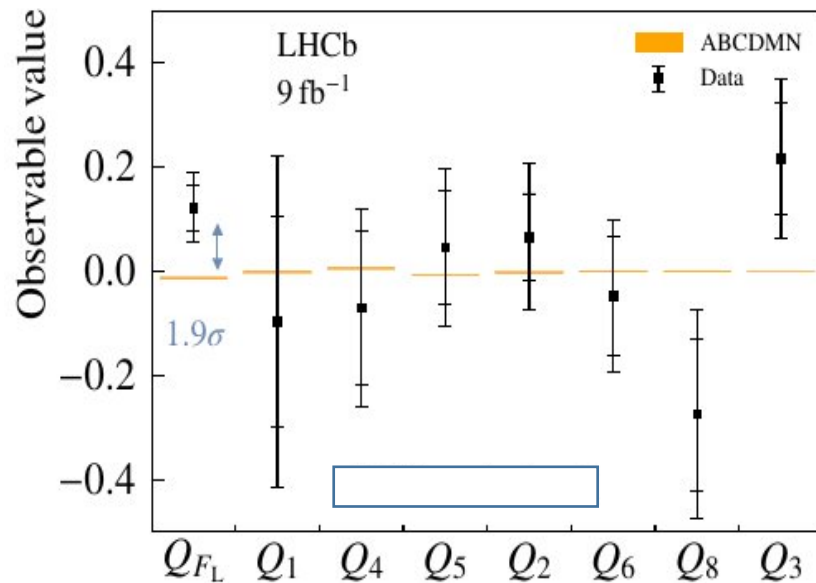
$$R_{K^{*0}} = 1.08^{+0.14}_{-0.12} (\text{stat}) \pm 0.07 (\text{syst})$$

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

# LFU in angular analysis of $B \rightarrow K^{*0} e^+ e^-$

- First angular analysis at central  $q^2$  region
- Full Runs1-2  $9 \text{ fb}^{-1}$  analysis with 5D unbinned weighted fit
- LFU quantities derived by comparing  $e^+ e^-$  to  $\mu^+ \mu^-$  results in [PRL 132 (2024) 131801]

$$Q_i = P_i^{(\mu)} - P_i^{(e)}$$

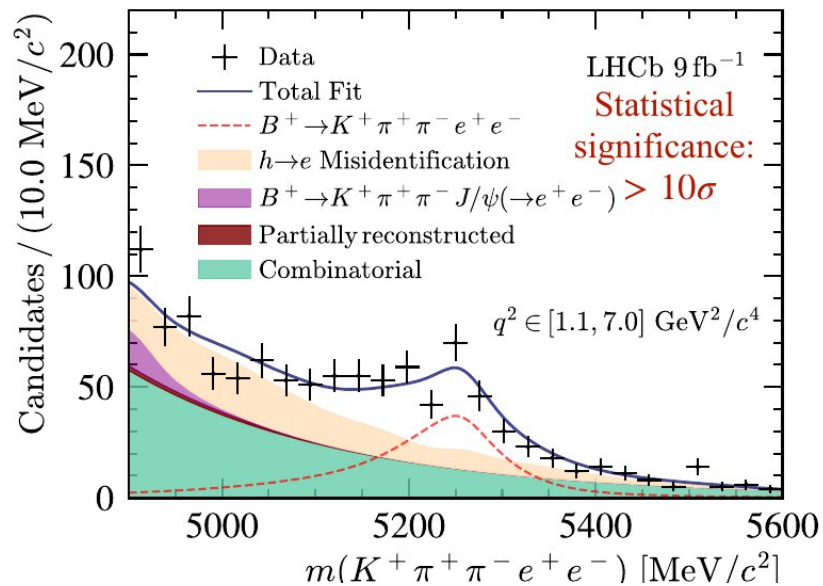


Results are all consistent with LFU conservation hypothesis

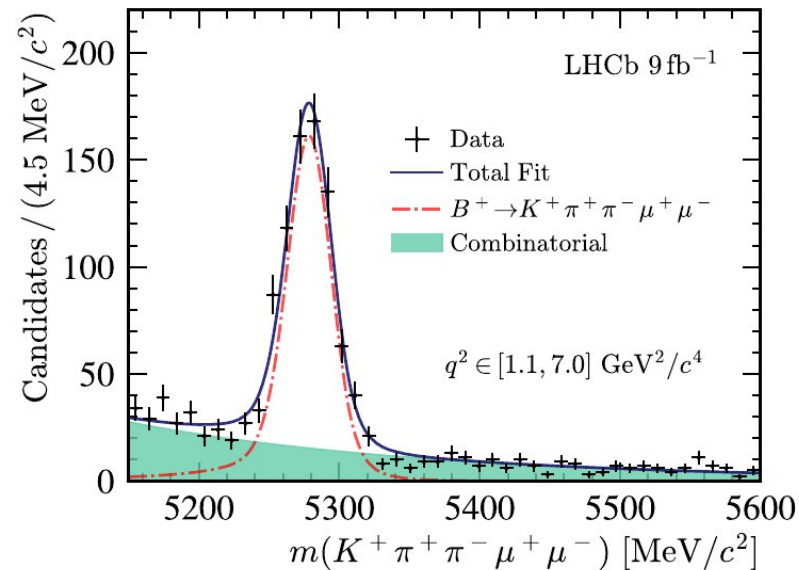
# $R(K\pi\pi)$ : LFU in $B \rightarrow K\pi\pi l^+ l^-$

- First LFU test in this channel, inclusive  $K\pi\pi$  system
- In central  $q^2$  region:  $1.0 < q^2 < 7.0 \text{ GeV}^2$
- First observation of  $B^+ \rightarrow K^+ \pi^+ \pi^- e^+ e^-$
- Cross-checks:  $r_{J/\psi} = 1.033 \pm 0.017$ ,  $R_{\psi(2S)} = 1.040 \pm 0.030$

$$R_{K\pi\pi}^{-1} \equiv \frac{\frac{\mathcal{N}}{\epsilon}(B^+ \rightarrow K^+ \pi^+ \pi^- e^+ e^-)}{\frac{\mathcal{N}}{\epsilon}[B^+ \rightarrow K^+ \pi^+ \pi^- J/\psi (\rightarrow e^+ e^-)]} \bigg/ \frac{\frac{\mathcal{N}}{\epsilon}(B^+ \rightarrow K^+ \pi^+ \pi^- \mu^+ \mu^-)}{\frac{\mathcal{N}}{\epsilon}[B^+ \rightarrow K^+ \pi^+ \pi^- J/\psi (\rightarrow \mu^+ \mu^-)]}$$



$$\mathcal{N}(B^+ \rightarrow K^+ \pi^+ \pi^- e^+ e^-) = 264 \pm 21$$



$$\mathcal{N}(B^+ \rightarrow K^+ \pi^+ \pi^- \mu^+ \mu^-) = 731 \pm 31$$

$$R_{K\pi\pi}^{-1} = 1.31_{-0.17}^{+0.18} \text{ (stat)}_{-0.09}^{+0.12} \text{ (syst)}$$

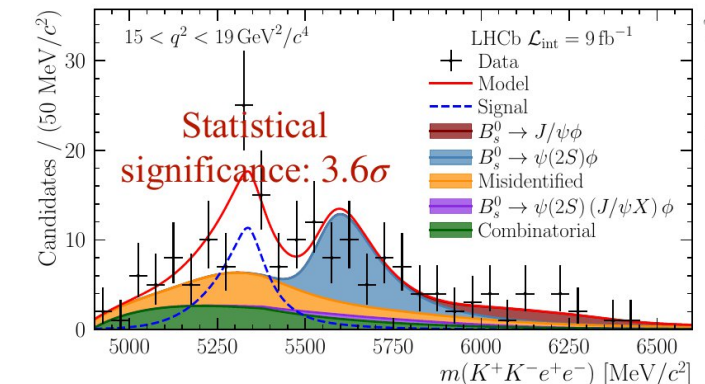
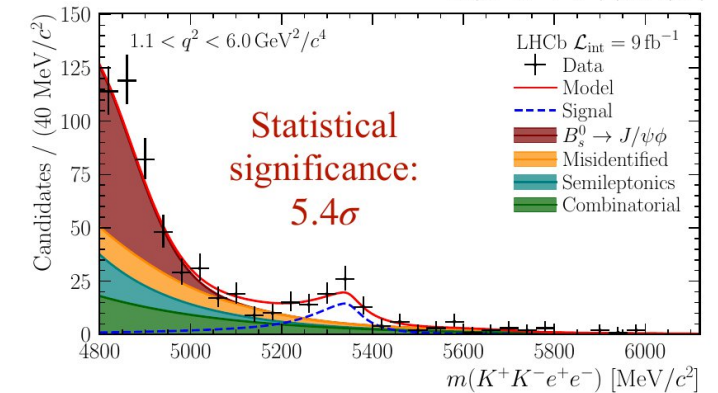
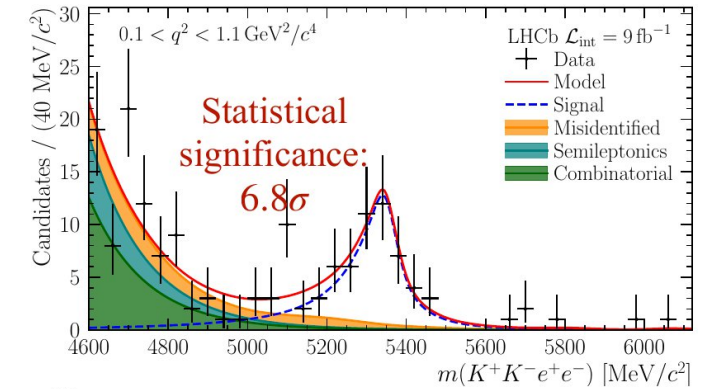
— Compatible with the SM

# $R(\phi)$ : LFU in $B_s^0 \rightarrow \phi l^+ l^-$

- First LFU test for  $B_s^0$  decays
- In three  $q^2$  regions:  $[0.1, 1.1]$ ,  $[1.1, 6.0]$ ,  $[15, 19]$   $\text{GeV}^2$
- Cross-checks:  $r_{J/\psi} = 0.997 \pm 0.013$ ,  $R_{\psi(2S)} = 1.010 \pm 0.026$
- Results in agreement with SM:

$q^2$ [ $\text{GeV}^2/c^4$ ]	$R_\phi^{-1}$
$0.1 < q^2 < 1.1$	$1.57^{+0.28}_{-0.25} \pm 0.05$
$1.1 < q^2 < 6.0$	$0.91^{+0.20}_{-0.19} \pm 0.05$
$15.0 < q^2 < 19.0$	$0.85^{+0.24}_{-0.23} \pm 0.10$

$$R_\phi = \left( \frac{\mathcal{B}(B_s^0 \rightarrow \phi \mu^+ \mu^-)}{\mathcal{B}(B_s^0 \rightarrow J/\psi(\rightarrow \mu^+ \mu^-) \phi)} \right) \bigg/ \left( \frac{\mathcal{B}(B_s^0 \rightarrow \phi e^+ e^-)}{\mathcal{B}(B_s^0 \rightarrow J/\psi(\rightarrow e^+ e^-) \phi)} \right)$$



# 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  $3.2\sigma$

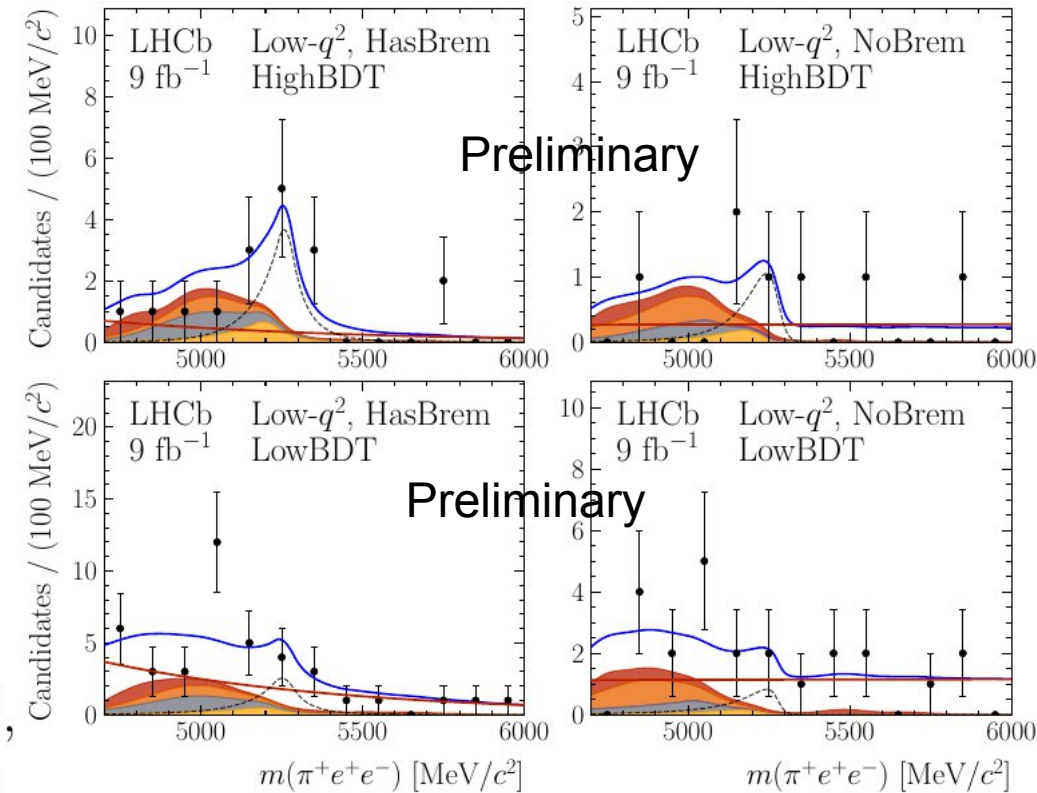
- Total BF:

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

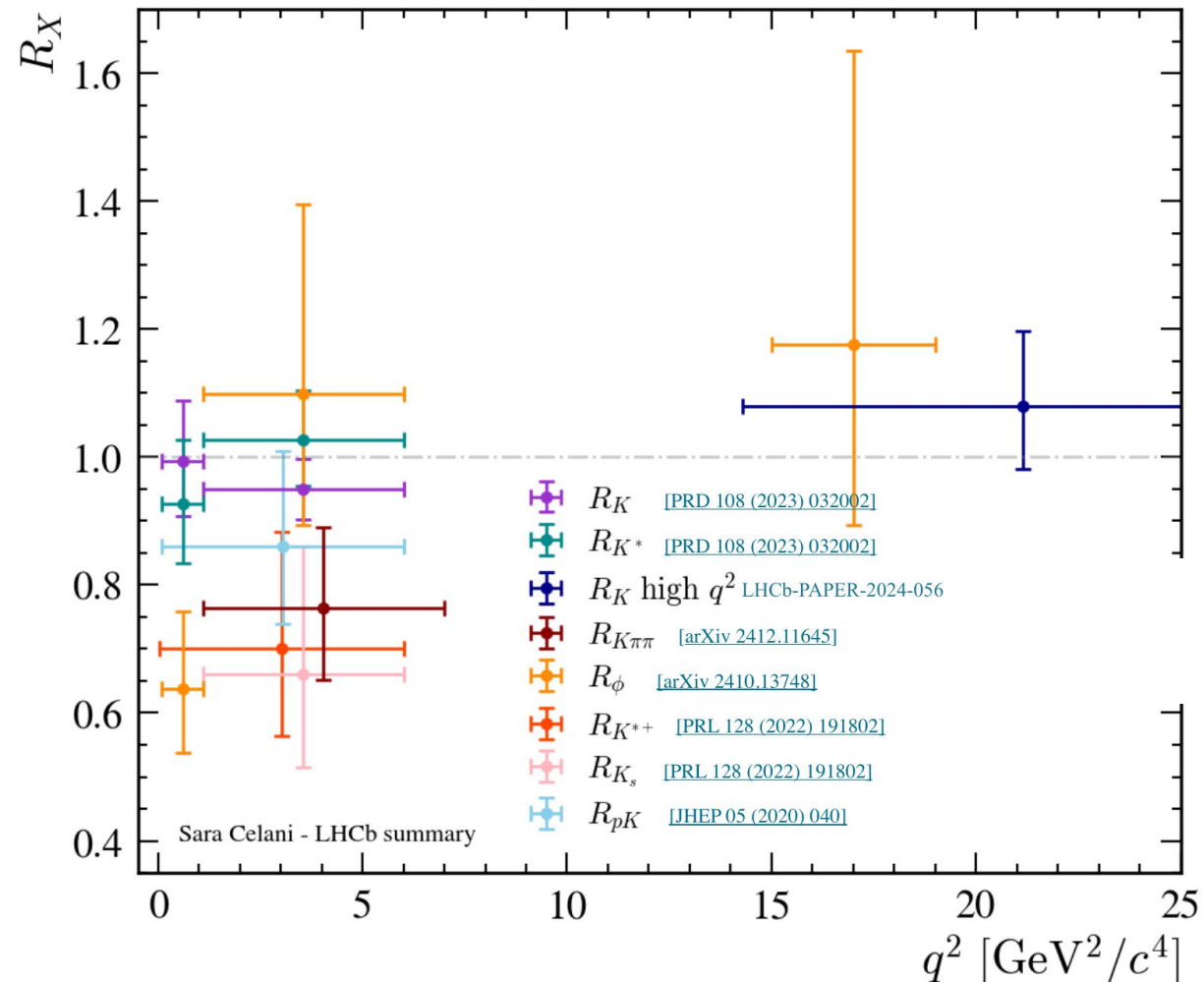
- Partial BFs:

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

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



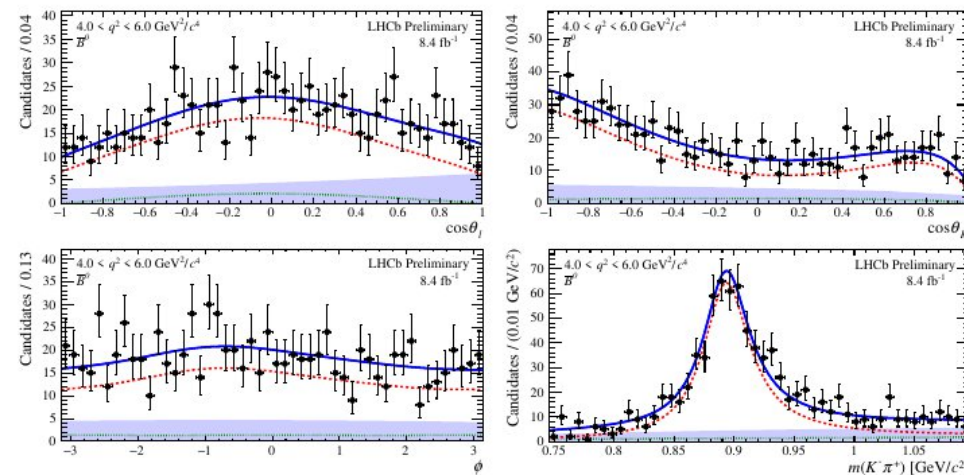
# Summary of LHCb FCNC LFU results



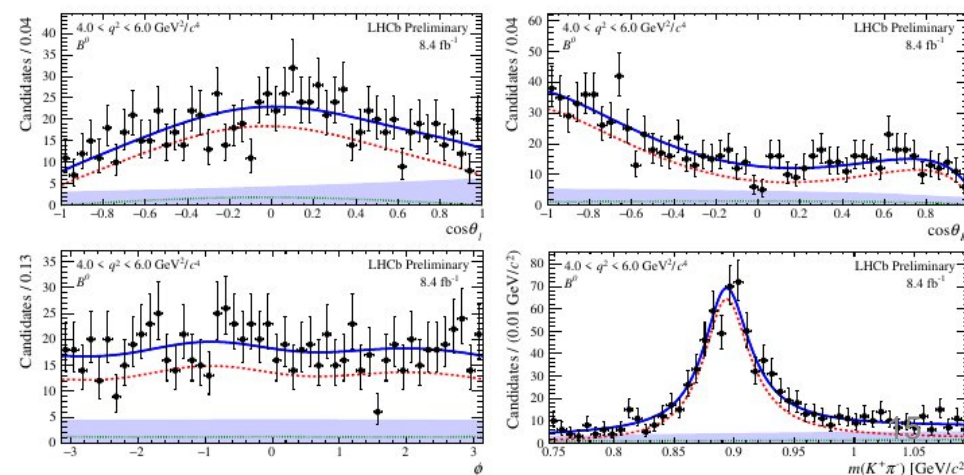
# Legacy Runs 1-2 $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ measurement

- 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

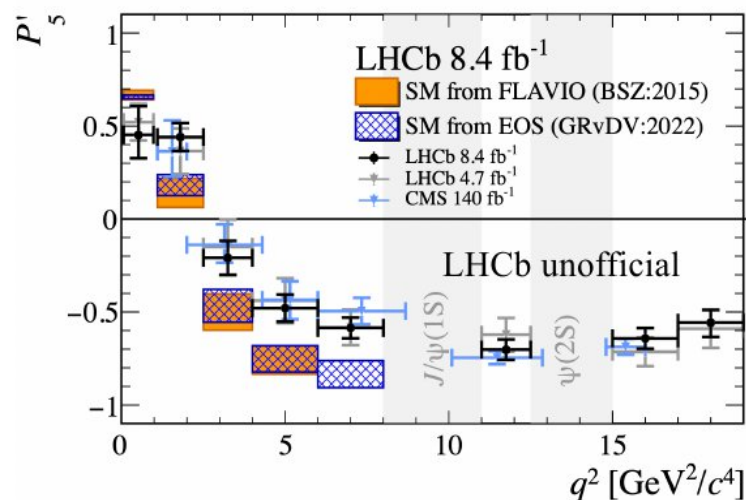
$\bar{B}^0$ :



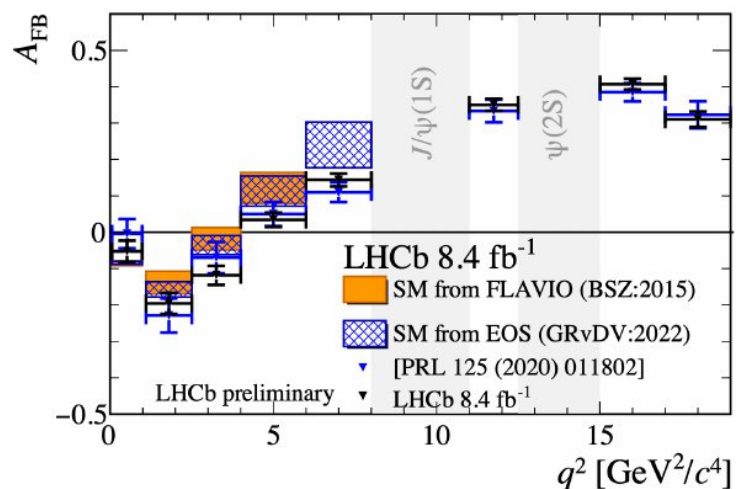
$B^0$ :



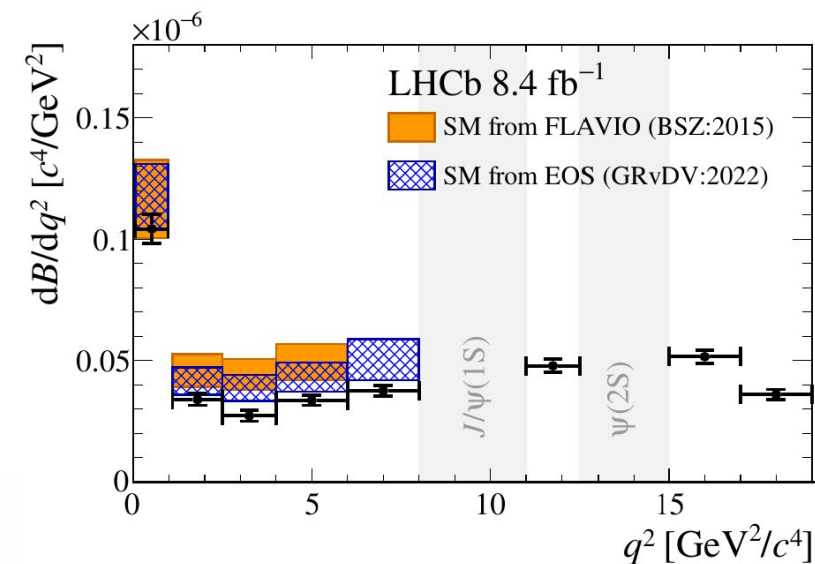
# Legacy Runs 1-2 $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ measurement



- 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



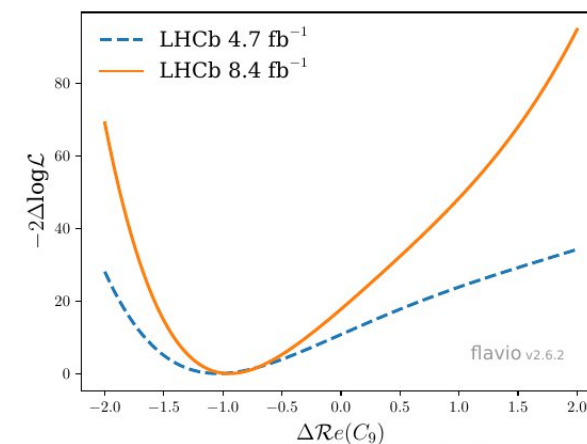
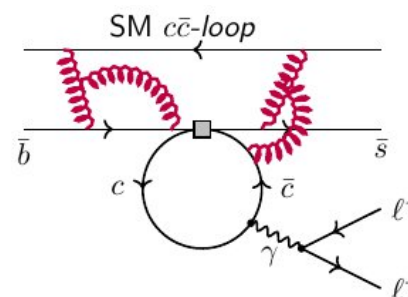
The forward-backward asymmetry,  $A_{FB}$ , also now shows marked disagreement with improved statistics



- The branching fraction is consistently below SM predictions

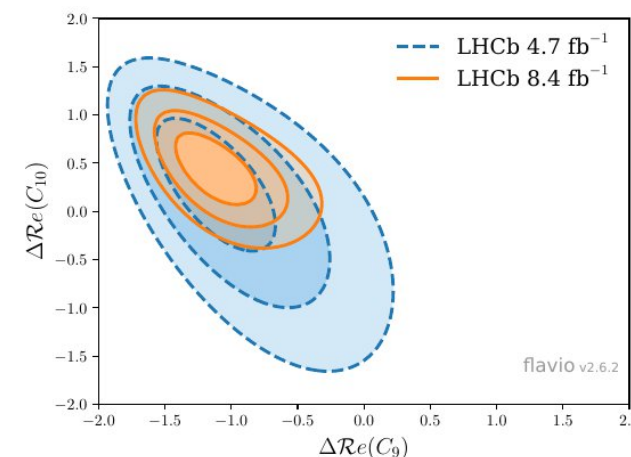
# Legacy Runs 1-2 $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ measurement

- 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?



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

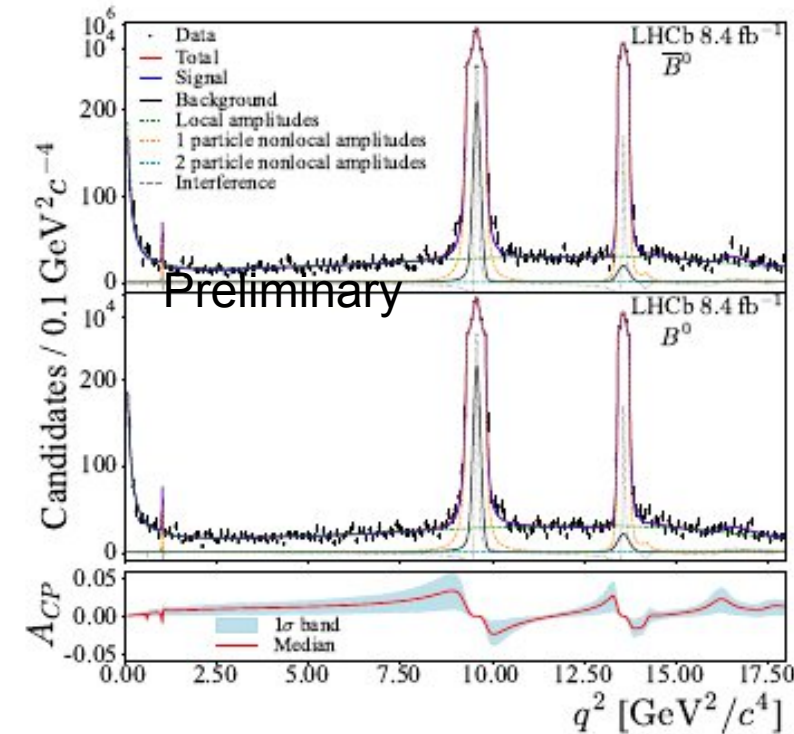
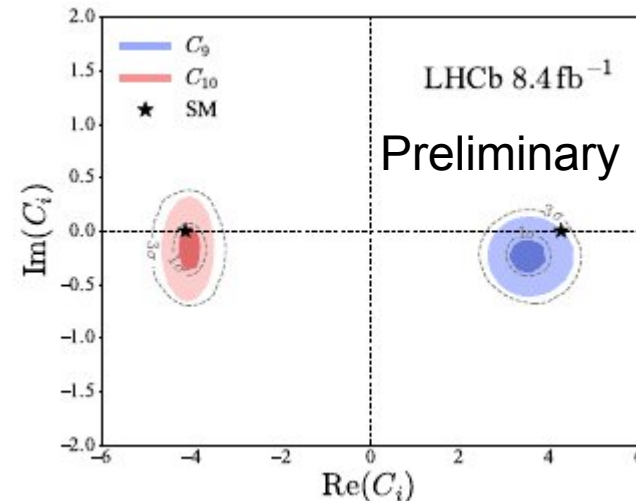
Significance  $4.1 \sigma$



# 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:

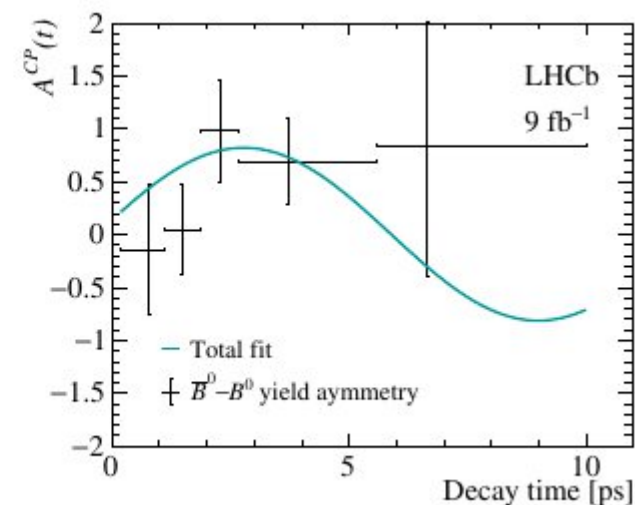
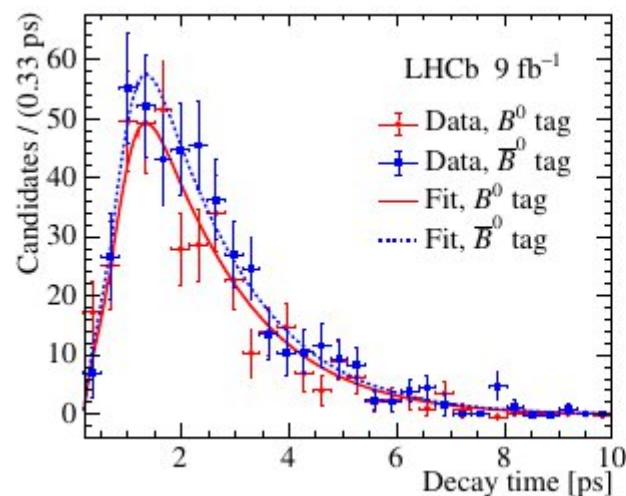
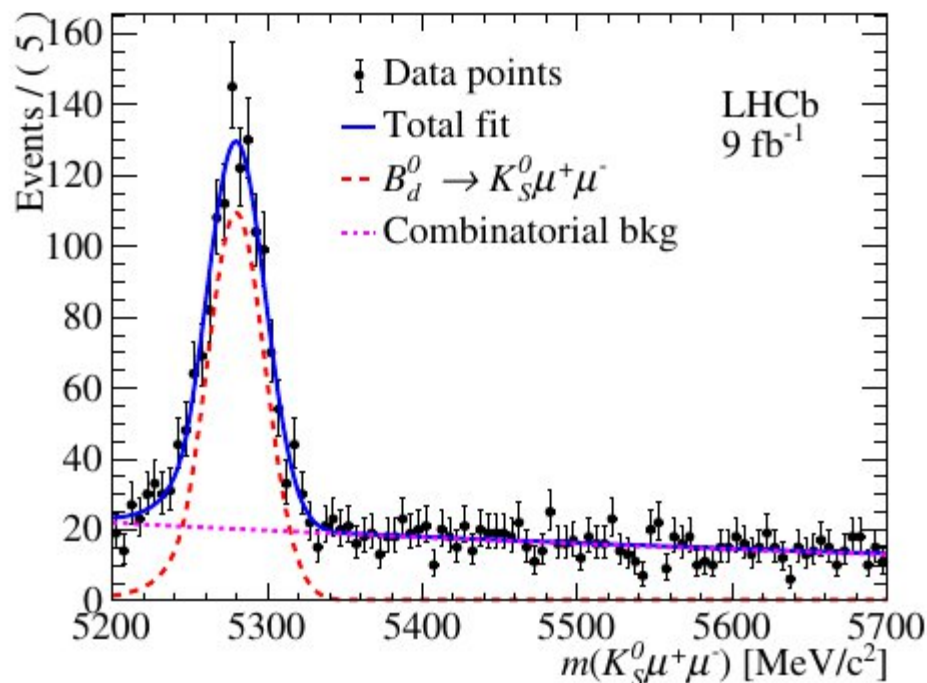
Wilson coefficient results		
$\ C_9\ $	$3.50 \pm 0.30$	$\pm 0.15$
$\ C_{10}\ $	$4.04 \pm 0.18$	$\pm 0.15$
$\delta\phi_{C_9}$	$-0.067 \pm 0.032$	$\pm 0.011$
$\delta\phi_{C_{10}}$	$0.043 \pm 0.035$	$\pm 0.010$
$\text{Re}(C_9)$	$3.50 \pm 0.30$	$\pm 0.15$
$\text{Im}(C_9)$	$-0.23 \pm 0.11$	$\pm 0.04$
$\text{Re}(C_{10})$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



**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 $B^0 \rightarrow K_S^0 \mu^+ \mu^-$

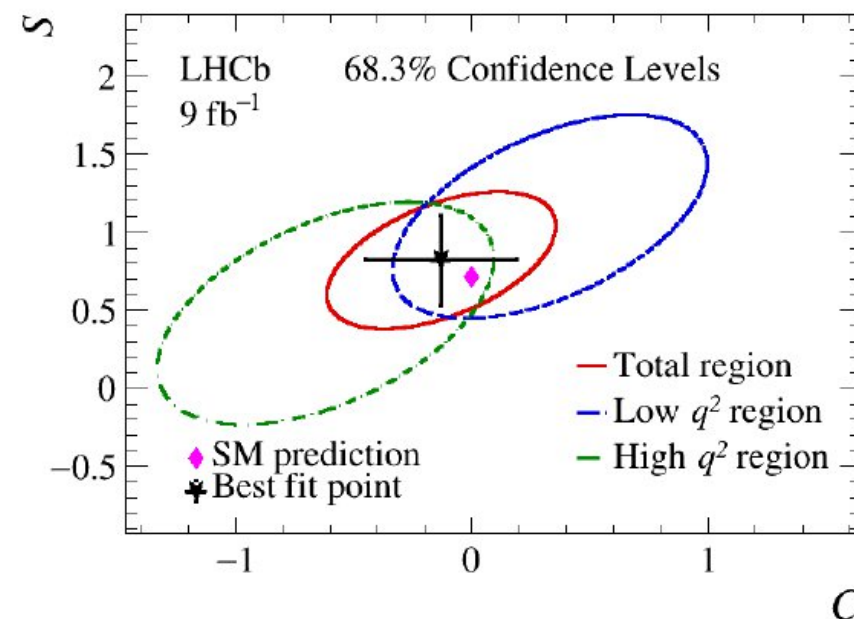
- Using full Runs1-2 data
- First time-dependent CPV measurement in  $b \rightarrow sl^+l^-$  processes
- Flavor tagged B mesons



# 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:

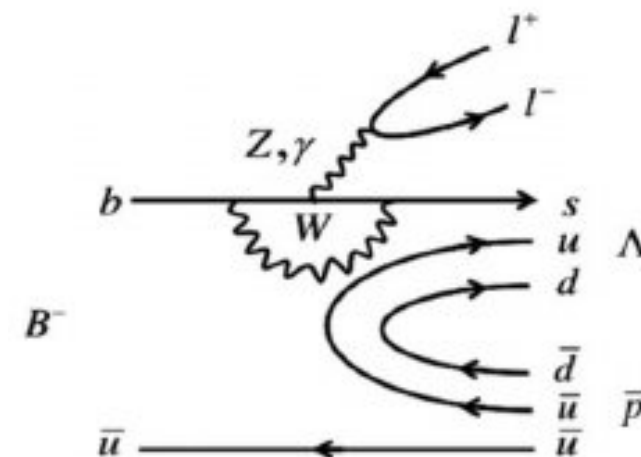
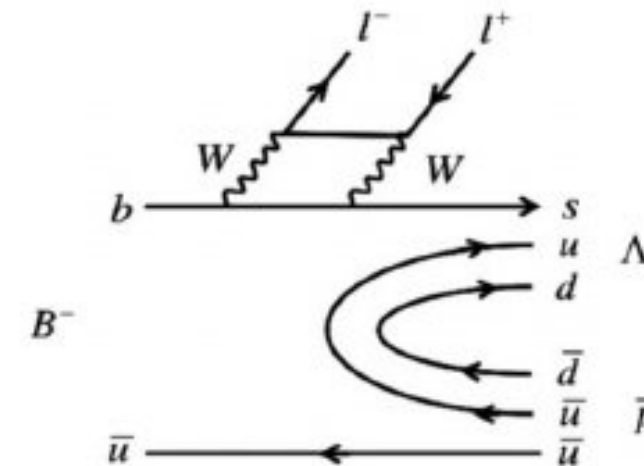
$q^2$ range [ $\text{GeV}^2/c^4$ ]	$C$	$S$
Total	$-0.13 \pm 0.32$	$+0.82 \pm 0.29$
Low: $q^2 < 8.0$	$+0.33 \pm 0.44$	$+1.10 \pm 0.43$
High: $11.0 < q^2 < 15.0$ or $q^2 > 17.5$	$-0.62 \pm 0.47$	$+0.48 \pm 0.47$



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

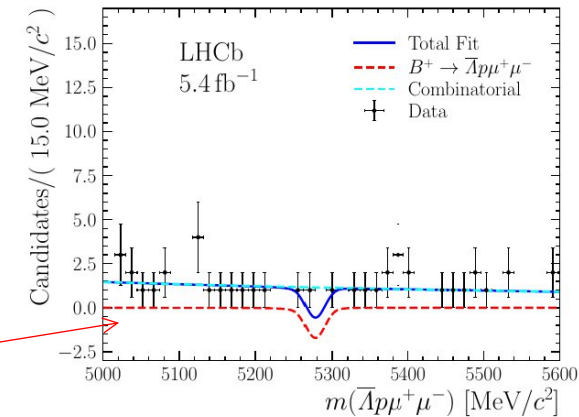
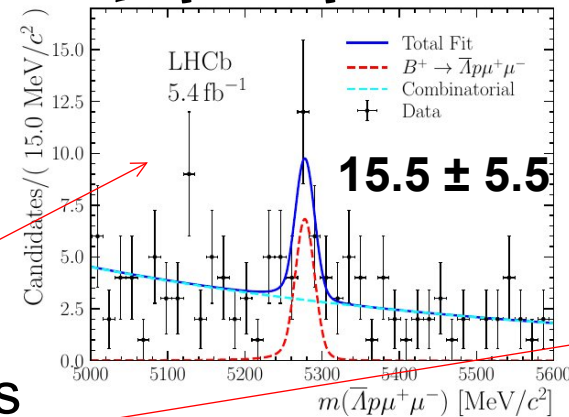
# First evidence of $B^+ \rightarrow \bar{\Lambda} p \mu^+ \mu^-$

- 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 $B^+ \rightarrow \bar{\Lambda} p \mu^+ \mu^-$

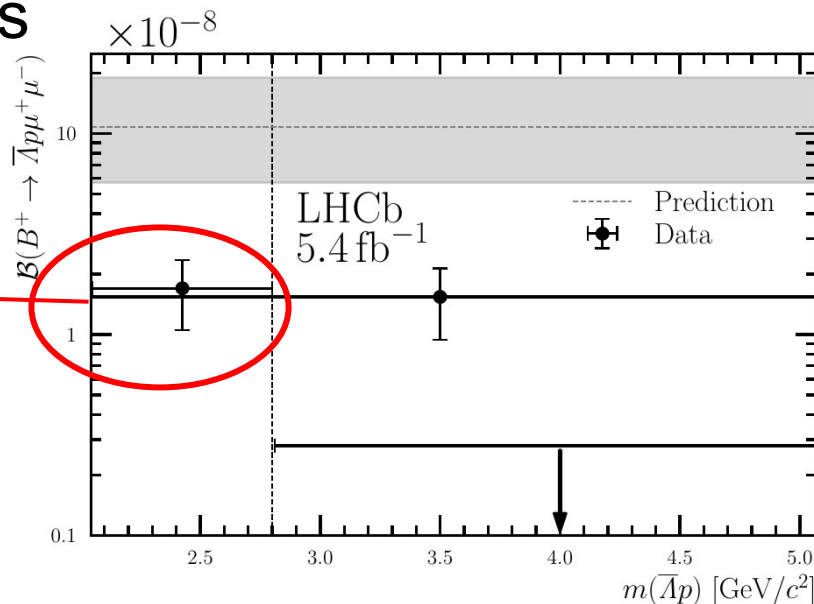
- Using  $5.4 \text{ fb}^{-1}$  Run2 data
- Normalization channel:  $B^+ \rightarrow J/\psi \bar{\Lambda} p$ 
  - Also used for signal shape calibration & correction for data/simulation differences
- Signal searched for in low & high  $m(\bar{\Lambda} p)$  regions



- 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:

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

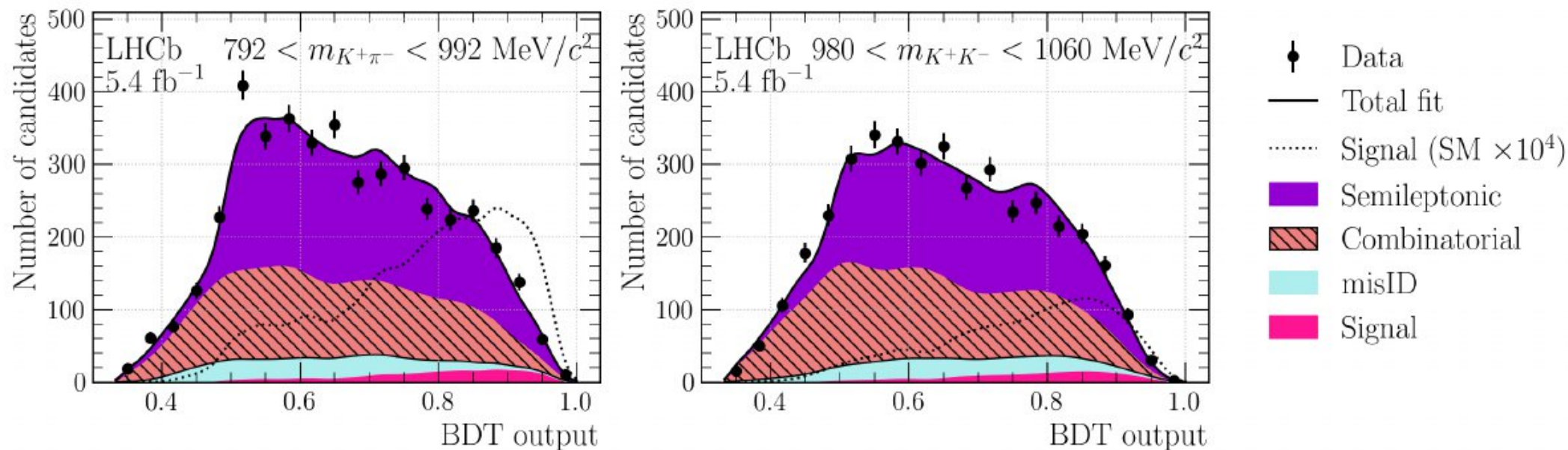
Contribution of X(2085) or heavy strange mesons?



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](#)!

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

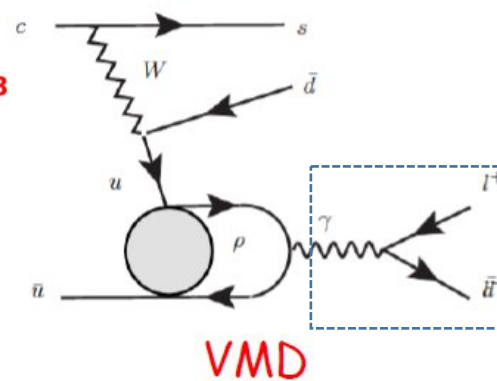
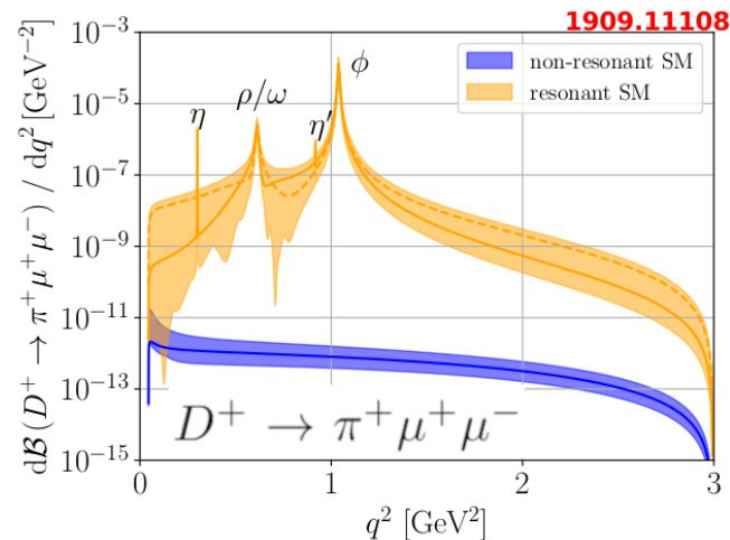
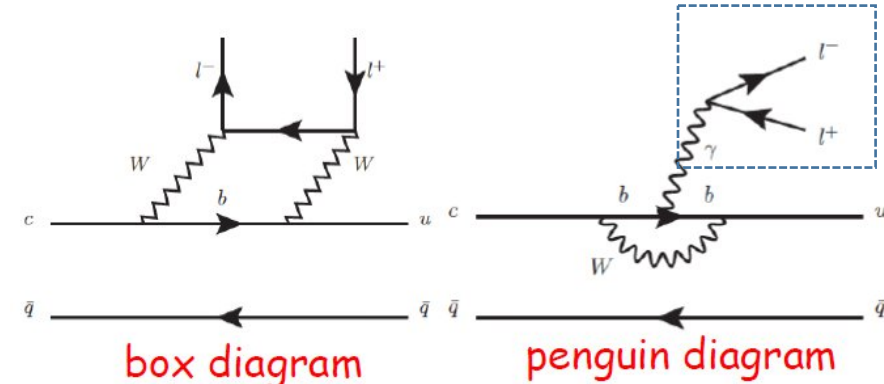
First search!

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%	$2.9 \times 10^4$	$5.2 \times 10^4$	

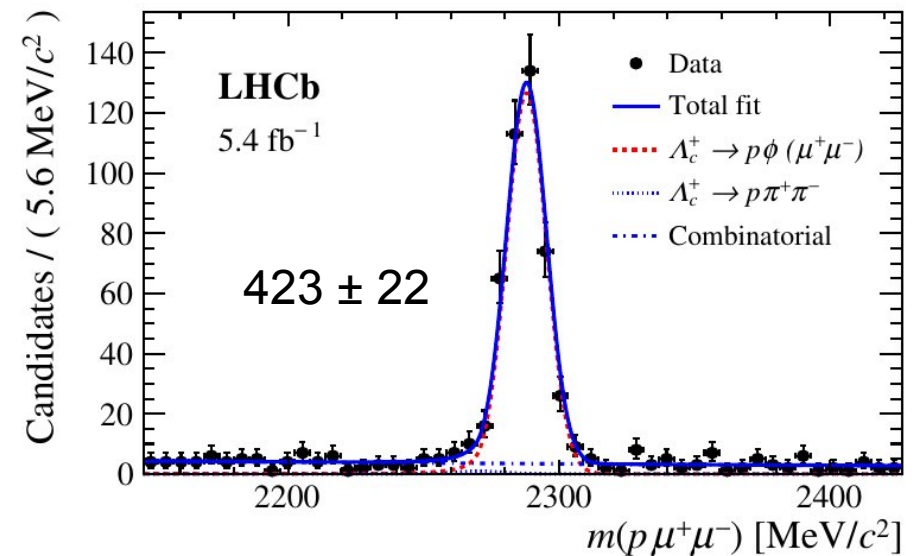
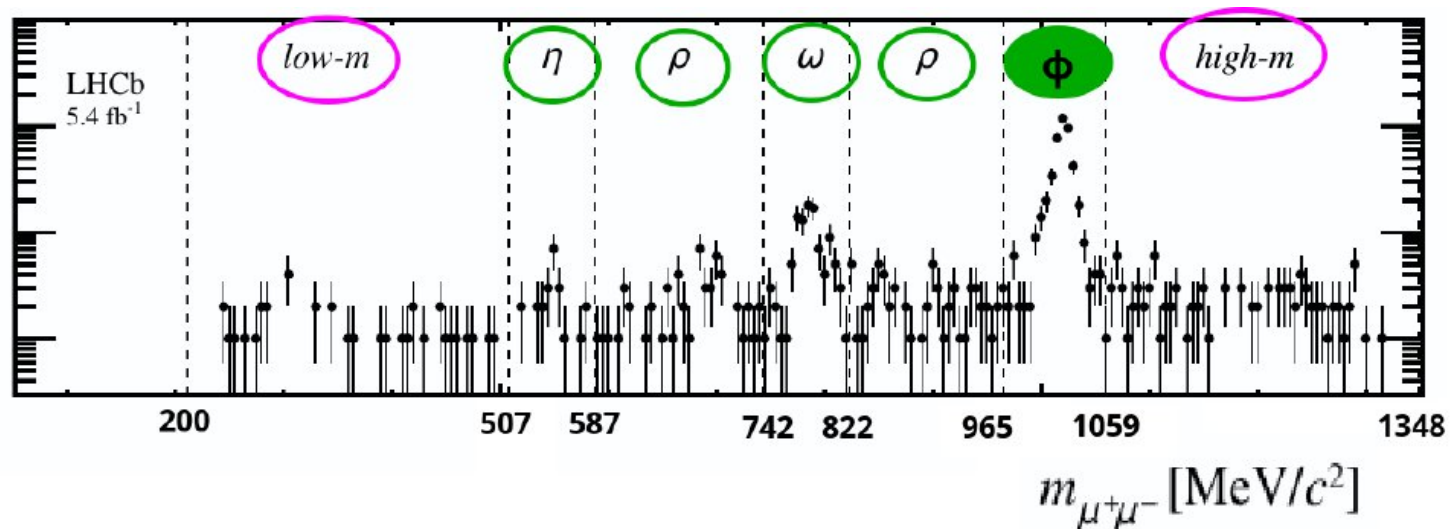
# Flavor Changing Neutral Currents in charm

- $c \rightarrow u\ell\ell$  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 $\Lambda_c^+ \rightarrow p\mu^+\mu^-$

- Based on Run2 5.4 fb<sup>-1</sup> dataset
- Signals searched for in 6 dimuon mass regions
- Normalized to  $\phi$  resonant region



# Search for $\Lambda_c^+ \rightarrow p\mu^+\mu^-$

- BFs measured in different resonant regions:

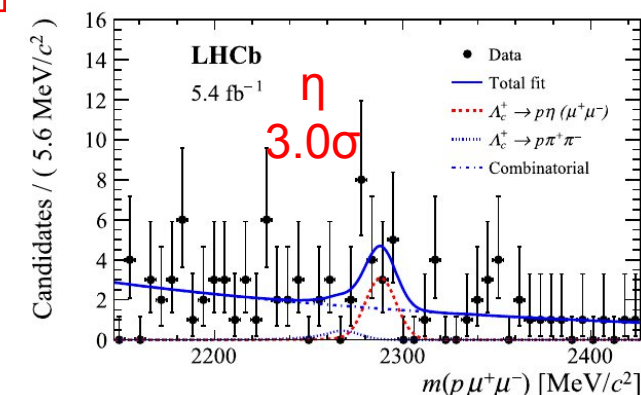
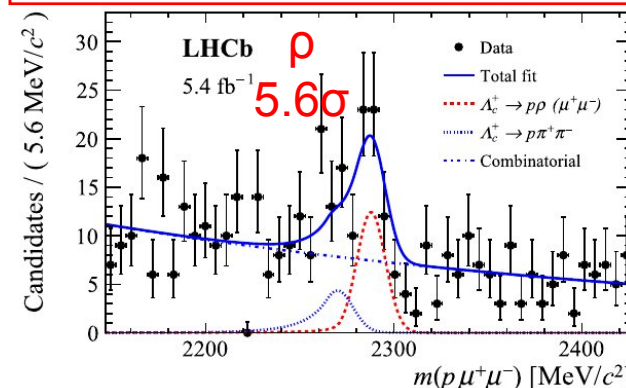
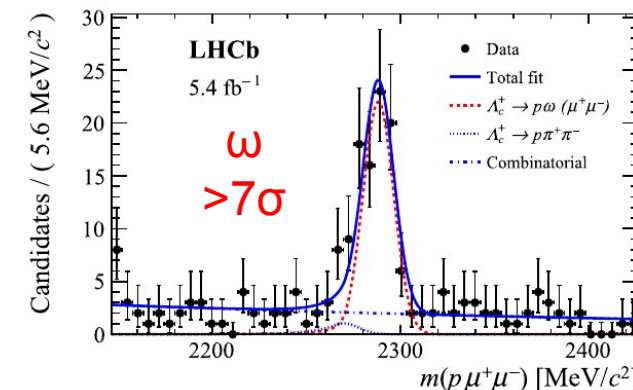
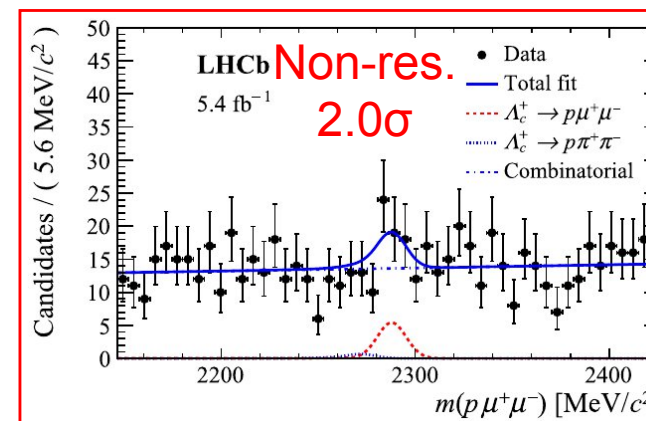
$$\mathcal{B}(\Lambda_c^+ \rightarrow p\omega) = (9.82 \pm 1.23(\text{stat}) \pm 0.73(\text{syst}) \pm 2.79(\text{ext})) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\rho) = (1.52 \pm 0.34(\text{stat}) \pm 0.14(\text{syst}) \pm 0.24(\text{ext})) \times 10^{-3}$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\eta) = (1.67 \pm 0.69(\text{stat}) \pm 0.23(\text{syst}) \pm 0.34(\text{ext})) \times 10^{-3}$$

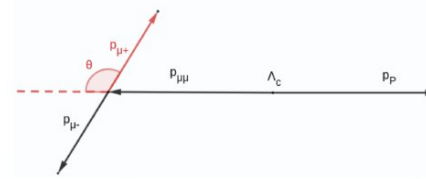
- Most stringent limit set on non-resonant BF:

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\mu^+\mu^-) < 2.9 \text{ (3.2)} \times 10^{-8} \text{ at 90\% (95\%) CL.}$$



# $\Lambda_c^+ \rightarrow p \mu^+ \mu^-$ : CPV & angular asymmetries

- Asymmetries in  $\phi$  region compatible with SM prediction and conservation of P and CP symmetry



$$A_{FB} = \frac{\Gamma(\cos \theta_\mu > 0) - \Gamma(\cos \theta_\mu < 0)}{\Gamma(\cos \theta_\mu > 0) + \Gamma(\cos \theta_\mu < 0)}$$

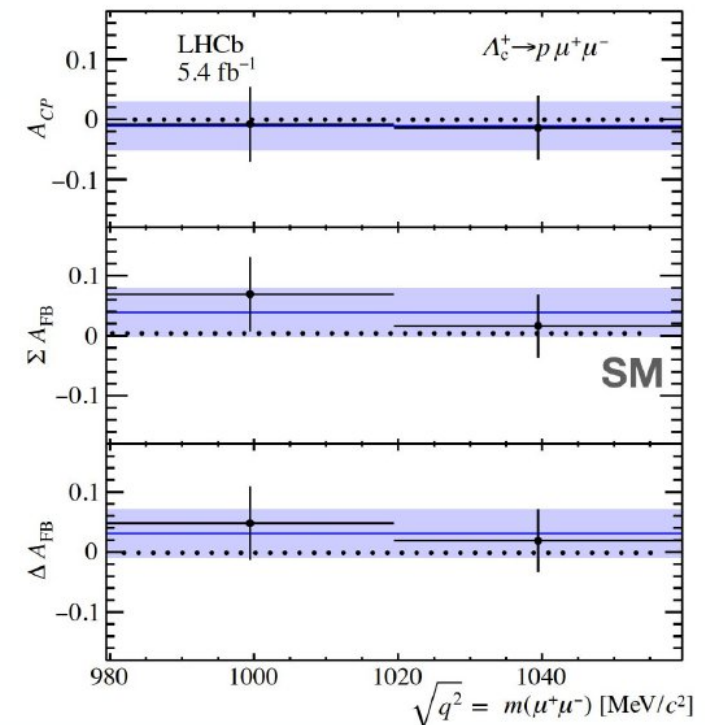
$$A_{CP} = \frac{\Gamma(\Lambda_c^+ \rightarrow p \mu^+ \mu^-) - \Gamma(\Lambda_c^- \rightarrow \bar{p} \mu^+ \mu^-)}{\Gamma(\Lambda_c^+ \rightarrow p \mu^+ \mu^-) + \Gamma(\Lambda_c^- \rightarrow \bar{p} \mu^+ \mu^-)}$$

$$\Sigma A_{FB}^{CP} \equiv 1/2 \cdot \left[ A_{FB}^{\Lambda_c^+} + A_{FB}^{\Lambda_c^-} \right]$$

$$\Delta A_{FB}^{CP} \equiv 1/2 \cdot \left[ A_{FB}^{\Lambda_c^+} - A_{FB}^{\Lambda_c^-} \right]$$

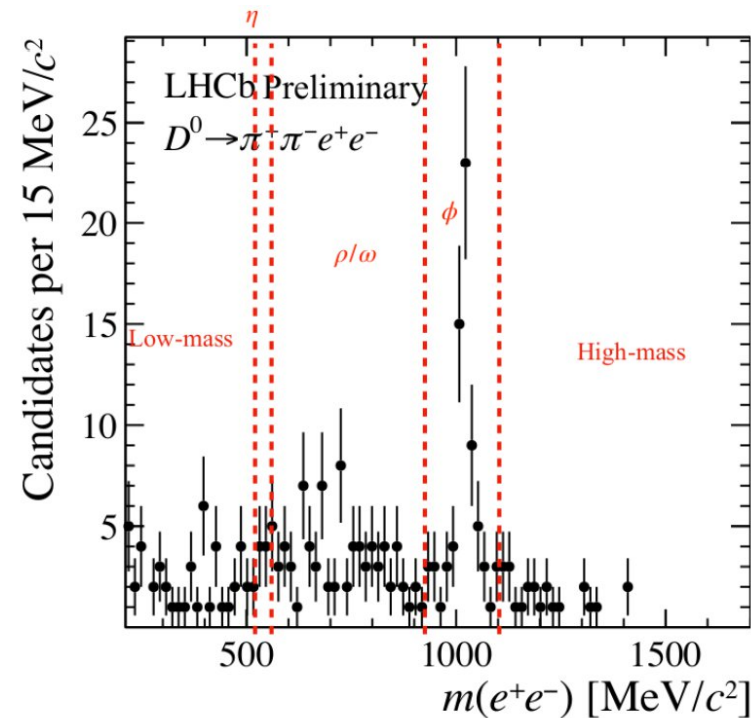
Dimuon-mass integrated

	Stat.	Sys.
$A_{CP}$	$(-1.1 \pm 4.0)$	$\pm 0.5$
$\Sigma A_{FB}$	$(3.9 \pm 4.0)$	$\pm 0.6$
$\Delta A_{FB}$	$(3.1 \pm 4.0)$	$\pm 0.4$



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

- Based on Run2 5.4 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

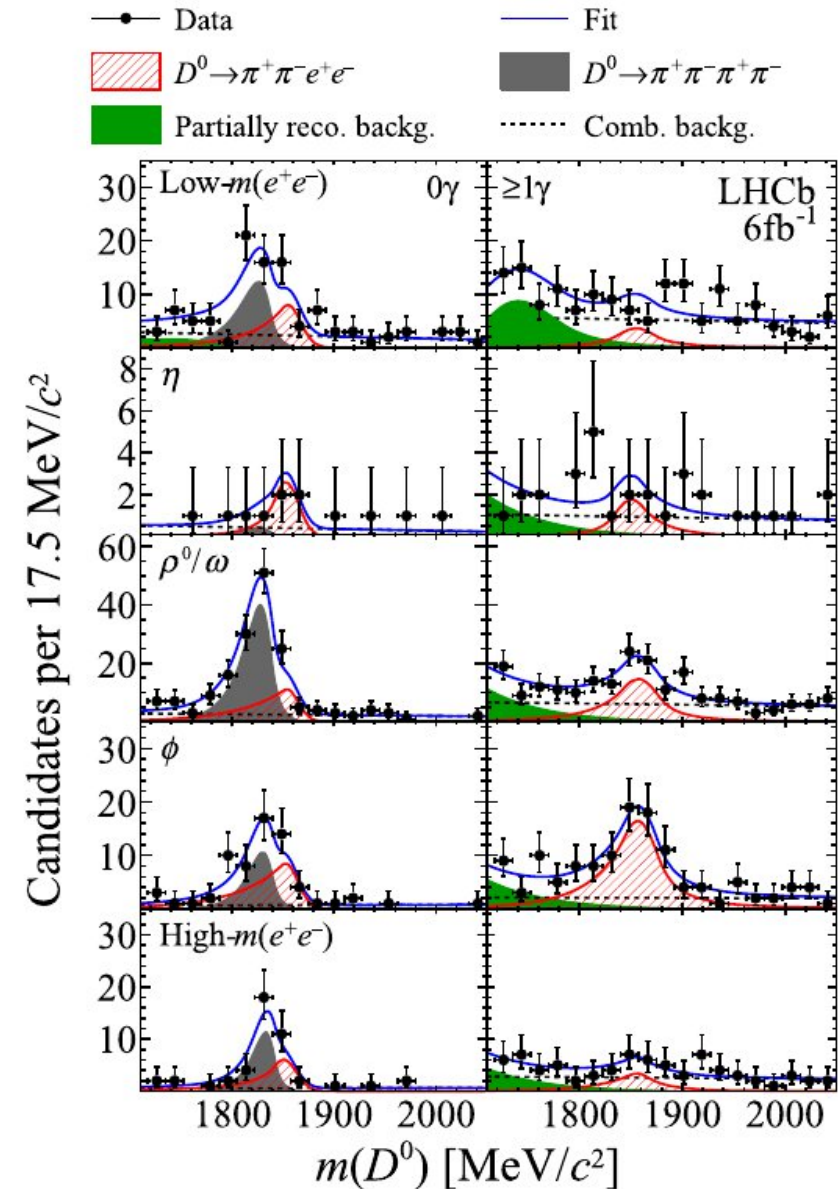


# Search for $D^0 \rightarrow \pi^+ \pi^- e^+ e^-$

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



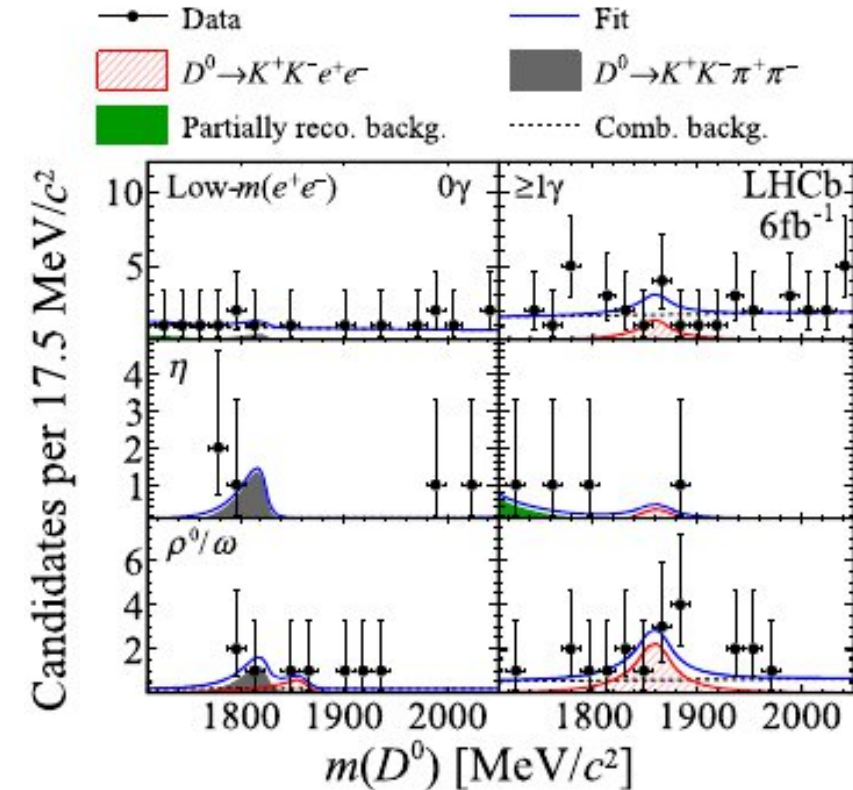
# Search for $D^0 \rightarrow K^+ K^- e^+ e^-$

- 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	$1 \pm 2$	$1.1\sigma$
$\rho^0/\omega$	$> 565$	$12 \pm 7$	$2.2\sigma$

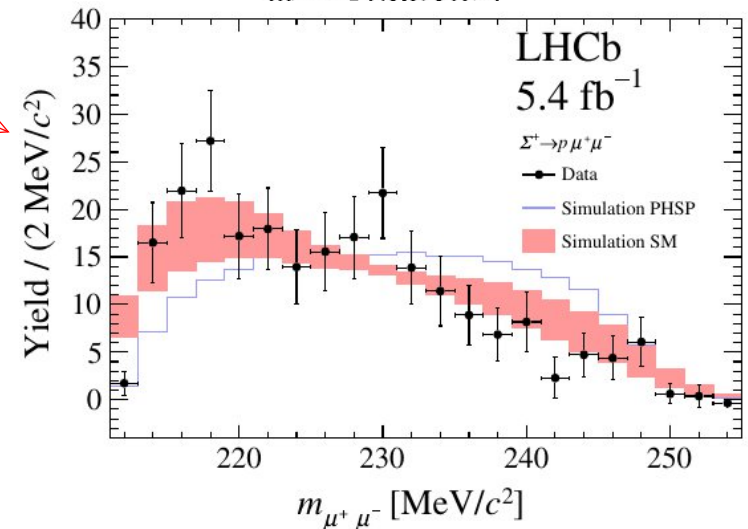
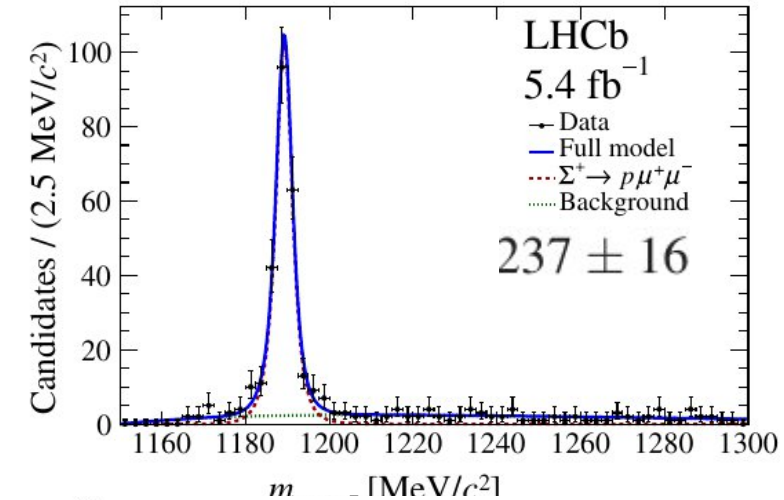
- BF upper limits of  $O(10^{-7})$  are set in different regions

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



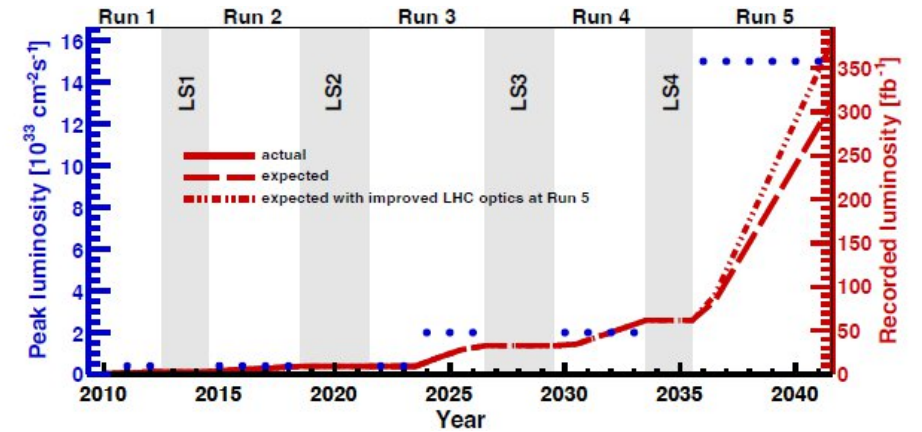
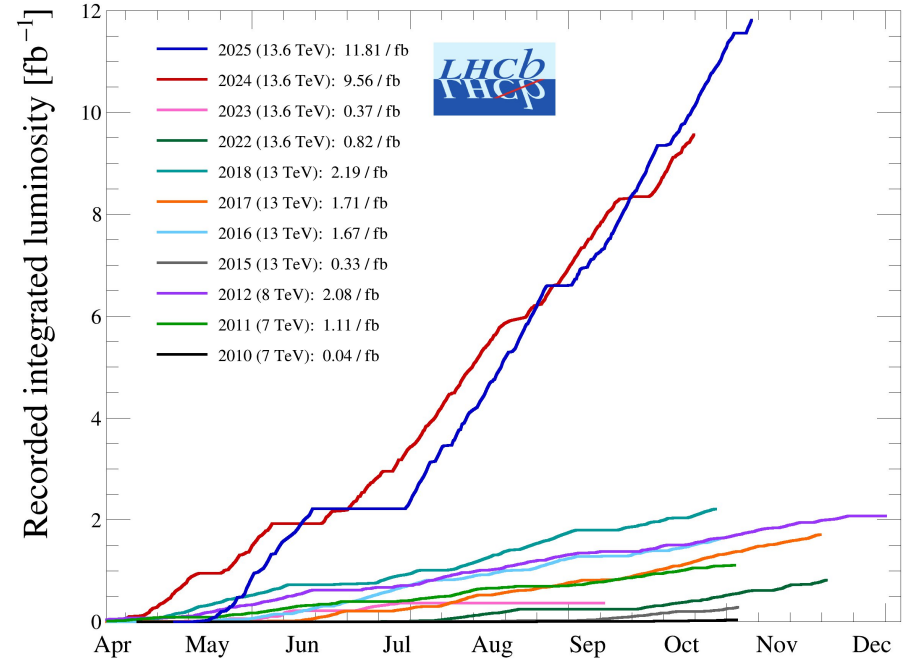
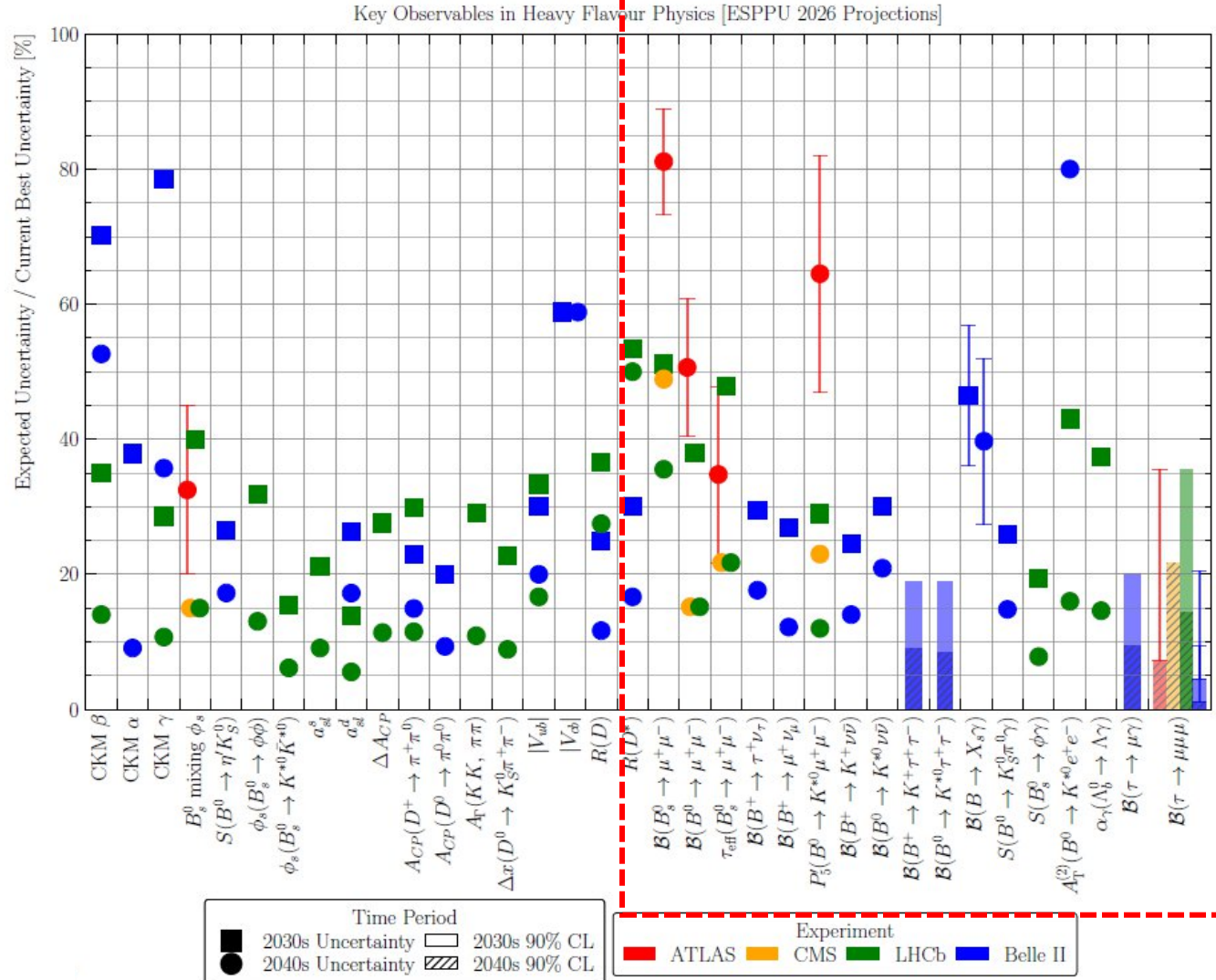
# Other rare decays: recent LHCb results

- First observation of  $\Sigma \rightarrow p\mu^+\mu^-$  [[PRL 135 \(2025\) 051801](#)]
  - $\mathcal{B}(\Sigma^+ \rightarrow p\mu^+\mu^-) = (1.08 \pm 0.17) \times 10^{-8}$
  - Rarest baryon decay ever observed
  - No structure found in the dimuon mass spectrum, compatible with SM
- Search for  $K_{S(L)}^0 \rightarrow \pi^+\pi^-\mu^+\mu^-$  [[arxiv:2511.02619](#)]
- Search for  $\eta^{(\prime)} \rightarrow (\pi^+\pi^-)\mu^+\mu^-$  [[LHCb-CONF-2025-002](#)]
- Search for  $\tau \rightarrow \mu\mu\mu$  [[arXiv:2601.20785](#)]



# 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