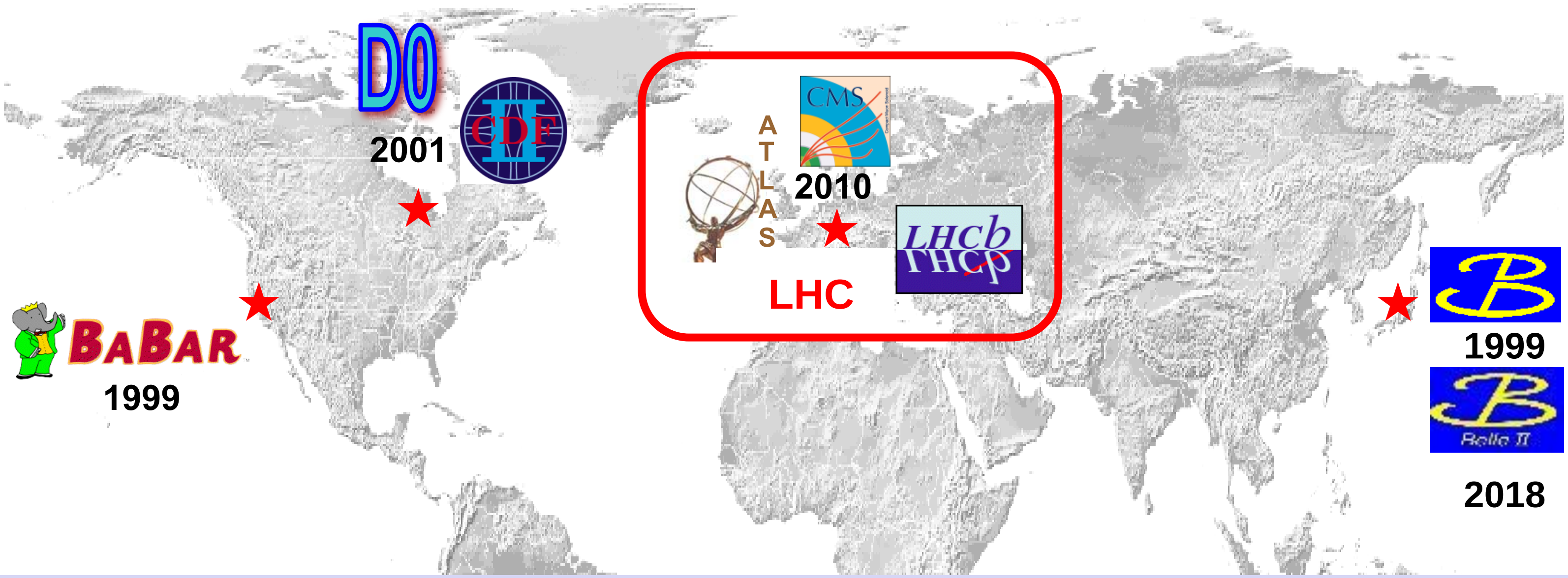


Flavour Physics @ LHC

(On behalf of LHCb, covering LHC highlights)

Yuehong Xie
Central China Normal University

SUSY2021, 23-28 August 2021

Outline

- **Flavour physics program at LHC**
- **Mixing, CP violation and CKM unitarity**
- **Rare decays and lepton flavour universality**
- **Summary and future prospects**

LHC talks on flavour physics in parallel sessions

✓ Mixing and CP violation at LHCb
Adam Davis, Flavour session, 25/08/2022

✓ Flavour anomalies at LHCb
Miriam Lucio Martinez, Flavour session, 26/08/2022

✓ ATLAS measurements of CP violation and rare decays processes with beauty mesons
Maria Smizanska, Flavour session, 27/08/2022

Flavour physics program at LHC

Role of flavour physics

- **Key open HEP questions**
  - What is the origin of matter-antimatter asymmetry in the Universe?
  - Is there physics beyond the Standard Model and what is the form?

- **Precision study of flavour and CP symmetry breaking can probe BSM physics at energy scale unaccessible directly at colliders**
  - Looking for new sources of CP violation

    Precision flavour measurements to overconstrain CKM matrix

  - Looking for new phenomena in rare or forbidden decays

    Flavour changing neutral current

    Lepton flavor universality violation

    Lepton flavor number violation

    …

LHC: heavy flavour factory

- **LHC**

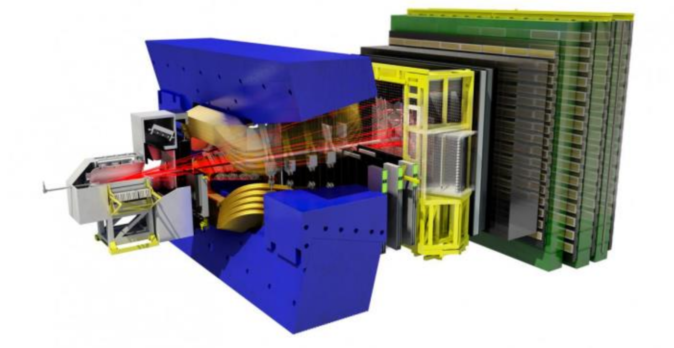
Large production cross sections:

$\sigma(b\bar{b}X) \sim 0.2\% \times \sigma_{pp}^{\text{inelas}}$, $\sigma(c\bar{c}X) \sim 4\% \times \sigma_{pp}^{\text{inelas}}$

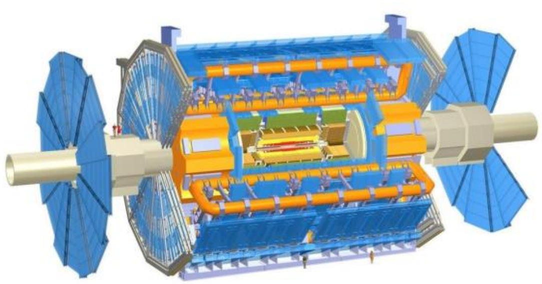
All species of b- and c-hadrons:

$B^0, B_s^0, B^+, B_c^+, \Lambda_b^0, D^0, D^+, D_s^+, \Lambda_c^+, J/\psi, \Xi_{cc}^{++}, P_c,$ ...

- **LHCb: 3(Run1)+6(Run 2) fb^{-1}**
  - ✓ Forward spectrometer $(2 < \eta < 5)$
  - ✓ Excellent vertexing, PID, tracking and flexible trigger
  - ✓ CP violation, rare decays, spectroscopy, QCD, electroweak, heavy ion, …



- **ATLAS/CMS: ~180fb^{-1}**
  - ✓ Covering $\sim 4\pi$ solid angle
  - ✓ No hadron identification
  - ✓ General purpose, B physics focusing on $\mu^+\mu^- X$ final states



Mixing, CP violation and CKM unitarity test

CKM mixing matrix

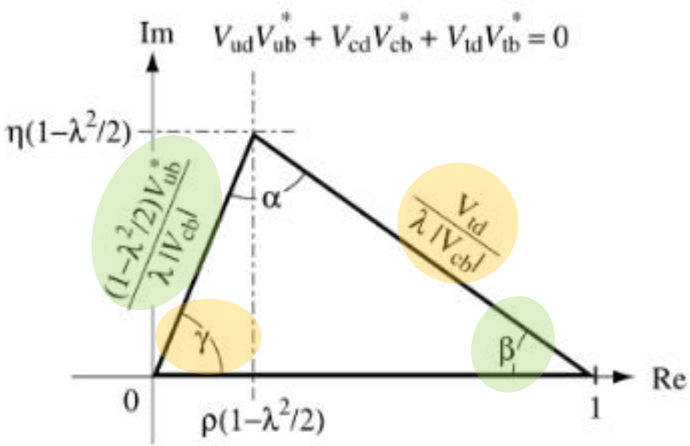
- **Origin of CPV in SM:** **nonzero CKM weak phase ($\eta \neq 0$)**

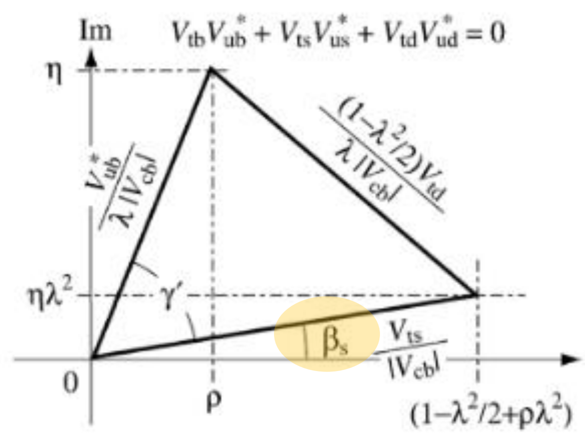
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$V_{CKM} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda - iA^2\lambda^5\eta & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\hat{\rho}-i\hat{\eta}) & -A\lambda^2 - iA\lambda^4\eta & 1 \end{pmatrix}$$

CPV in charm $|V_{td}|e^{-i\beta}$ $-|V_{ts}|e^{i\beta_s}$ $|V_{ub}|e^{-i\gamma}$

- **Test of Unitarity by measuring**
  - ✓ Angles (CP violating) and sides (CP conserving)





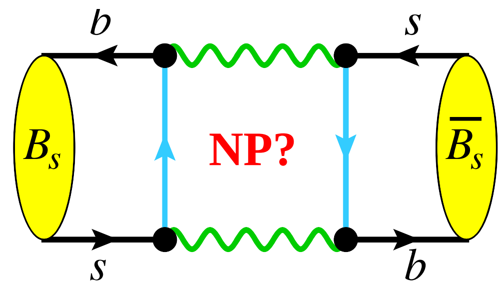
LHC dominating

B factories dominating, LHC catching up

B_s^0 mixing phase $\phi_s = -2\beta_s^{\rm eff}$

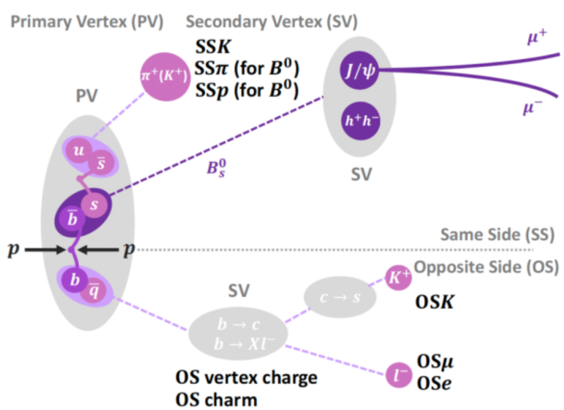
ϕ_s: sensitive to new physics in B_s^0 mixing.

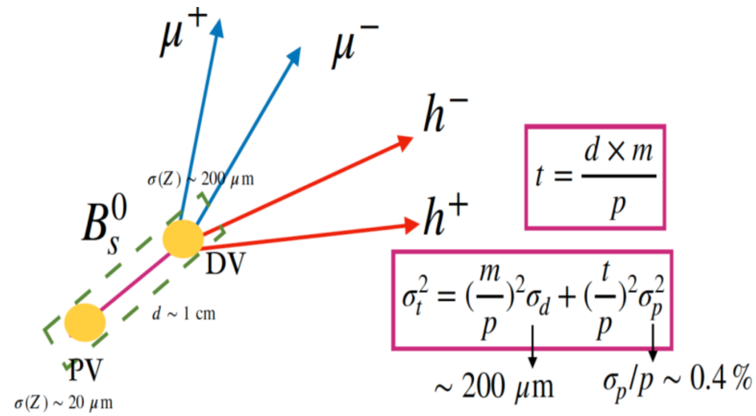
Golden channel: $B_s^0 \to J/\psi\phi(\to K^+K^-)$



$$A_{\rm CP}(t) = \frac{\Gamma_{\bar{B}_s{}^0\to f}(t) - \Gamma_{B_s{}^0\to f}(t)}{\Gamma_{\bar{B}_s{}^0\to f}(t) + \Gamma_{B_s{}^0\to f}(t)} \approx -\eta_f \sin\phi_s \sin(\Delta m_s t)$$

- Good flavor tagging & time reconstruction performance essential



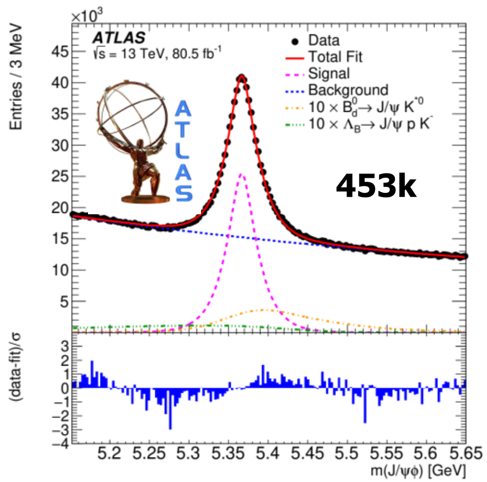


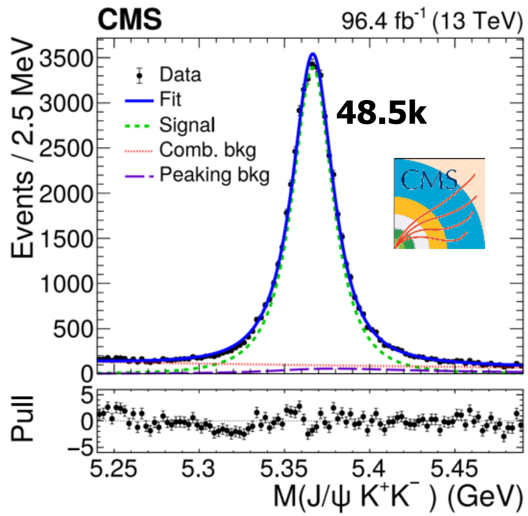
	tagging power	σ_t	features
ATLAS	1.75%	70 fs	new Inner B-Layers improve σ_t
CMS	~10%	75 fs	new DNN OS muon tagger
LHCb	4.73%	45 fs	excellent K/π separation & vertex reconstruction

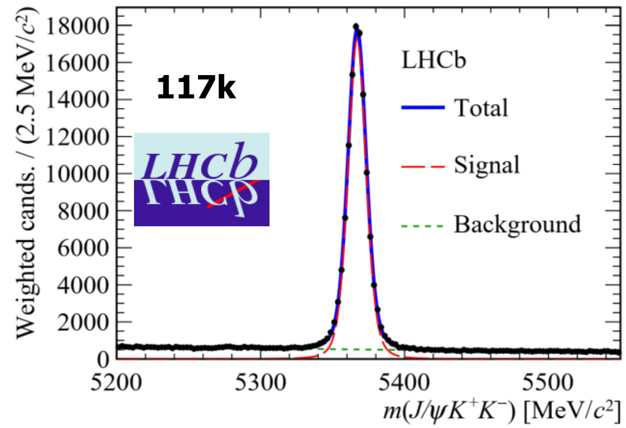
$B_s^0 \to J/\psi\phi$ analyses

LHCb, EPJC 80 (2020) 601
ATLAS, EPJC 81 (2021) 342
CMS, PLB 816 (2021) 136188

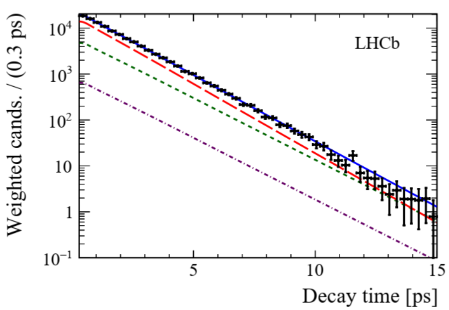
❑ Signal reconstruction & selection

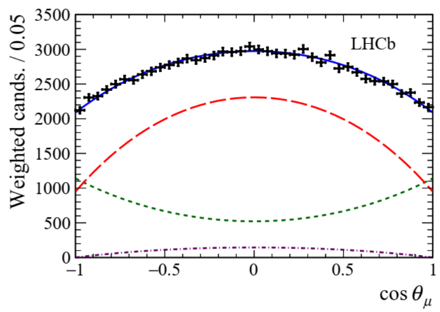


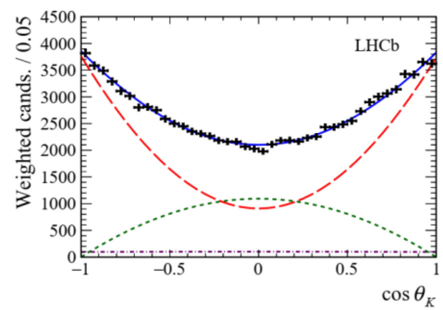


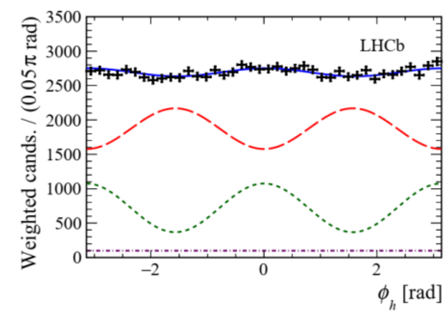


❑ Tagged 4-dimensional time-angular fit





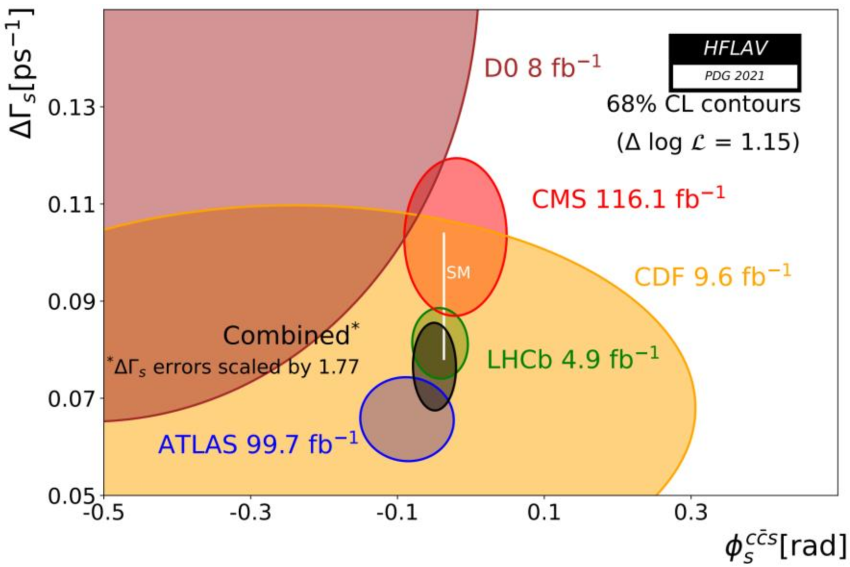




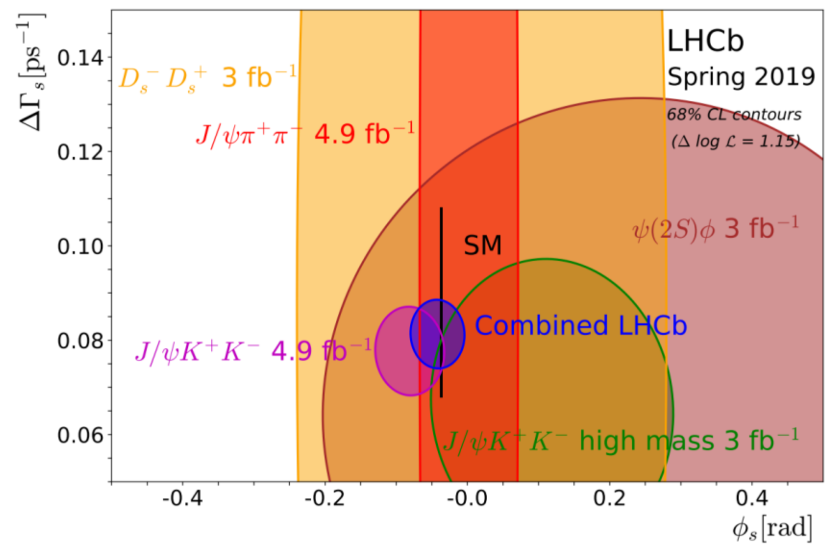
ϕ_s and $\Delta\Gamma_s$ results

ATLAS, EPJC 81 (2021) 342
CMS, PLB 816 (2021) 136188
LHCb, EPJC 80 (2020) 601

❑ World average



❑ LHCb $b \to c\bar{c}s$ combination



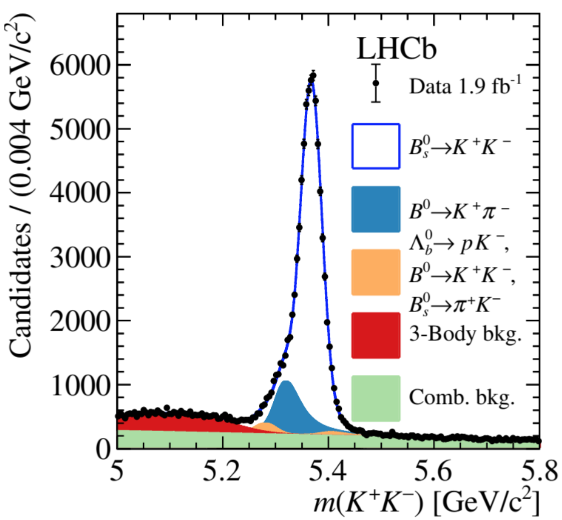
Collab.	Decay Modes	ϕ_s (mrad)	$\Delta\Gamma_s$ (ps^{-1})
ATLAS	$J/\psi K^+K^-$	-87 ± 41	0.0657 ± 0.0057
CMS	$J/\psi K^+K^-$	-21 ± 45	0.1032 ± 0.0106
LHCb	$J/\psi K^+K^-$, $J/\psi\pi^+\pi^-$, $D_s^+D_s^-$	-42 ± 25	0.0813 ± 0.0048
HFLAV	Above+CDF+D0	-50 ± 19	0.082 ± 0.005
SM prediction from CKMfitter		-37 ± 1	0.091 ± 0.013

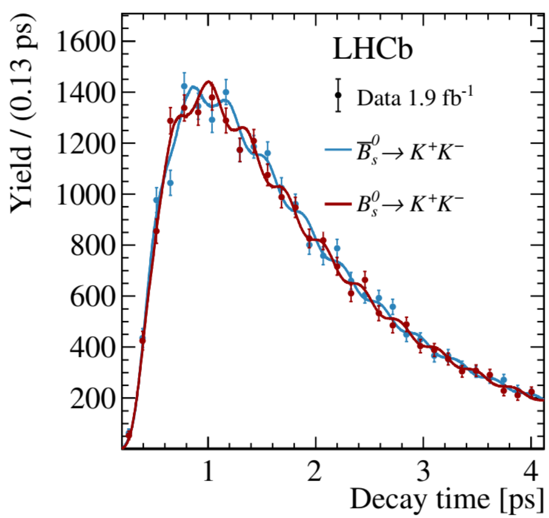
CPV in $B_s^0 \to K^+K^-$

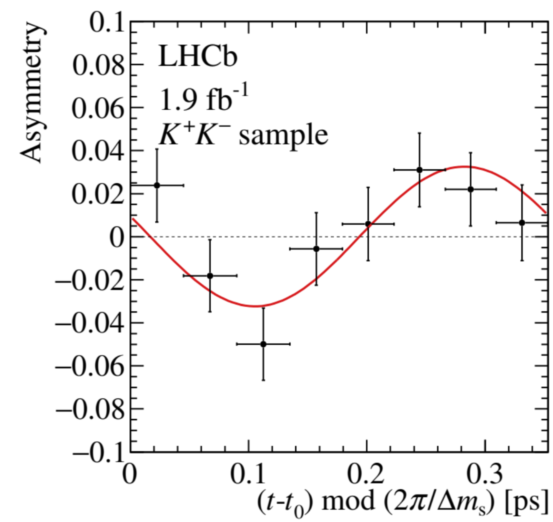
JHEP 03 (2021) 075

- Flavour-tagged time-dependent analysis with 2015+2016 data

$$A_{CP}(t) = \frac{\Gamma_{\bar{B}_s^0\to f}(t) - \Gamma_{B_s^0\to f}(t)}{\Gamma_{\bar{B}_s^0\to f}(t) + \Gamma_{B_s^0\to f}(t)} = \frac{-C_f\cos(\Delta m_s t) + S_f \sin(\Delta m_s t)}{\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)}$$







$S_{KK} = 0.123 \pm 0.034 \pm 0.015$

$C_{KK} = 0.164 \pm 0.034 \pm 0.014$

$A_{KK}^{\Delta} = -0.83 \pm 0.05 \pm 0.09$

First observation of time-dependent CP violation in B_s^0 decays!

$K\pi$ puzzle confirmed

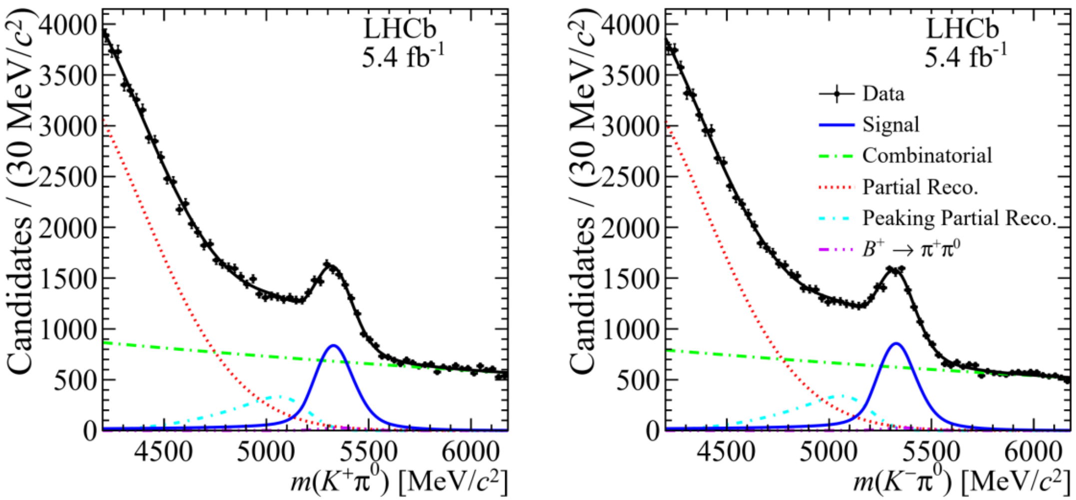
PRL 126 (2021) 091802

- **Anomaly in CP asymmetries of $B \to K\pi$ decays**

  $\Delta A_{\mathrm{CP}}(K\pi) = A_{\mathrm{CP}}(K^+\pi^0) - A_{\mathrm{CP}}(K^+\pi^-) \approx 0.124 \pm 0.021$

  $\Delta A_{\mathrm{CP}}(K\pi) \approx 0$ expected based on isospin symmetry. 5.5σ discrepancy!

- **Most precise $A_{CP}(K^+\pi^0)$ with LHCb Run2 data**

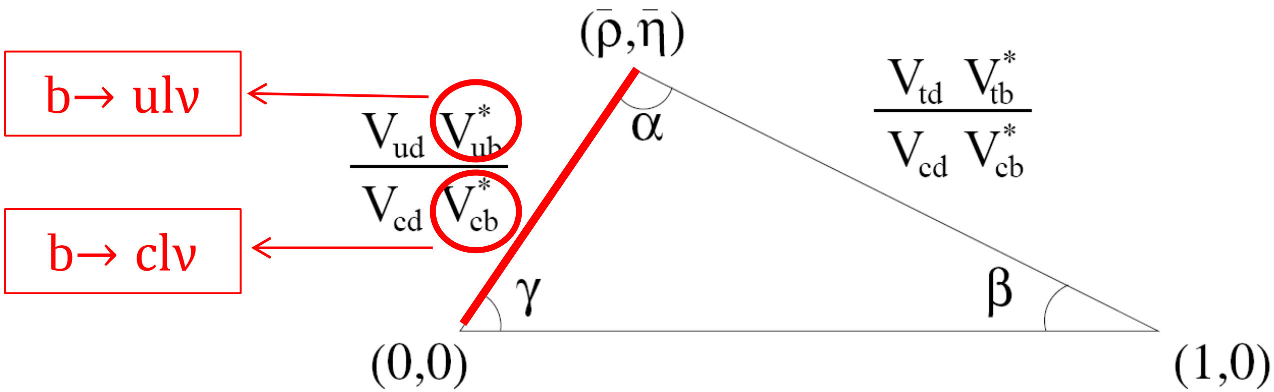


$$A_{\mathrm{CP}}(K^+\pi^0) = 0.025 \pm 0.015 \pm 0.006 \pm 0.003$$

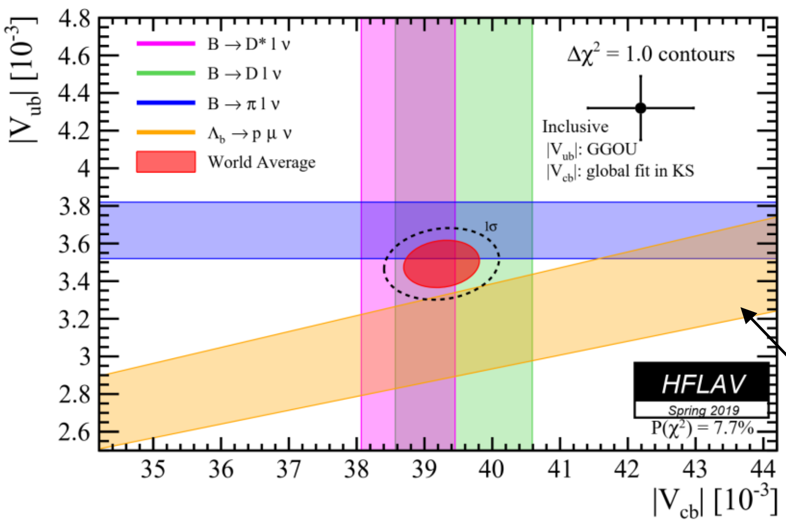
WA: $A_{\mathrm{CP}}(K^+\pi^0) = 0.040 \pm 0.021$ ⇨ $A_{\mathrm{CP}}(K^+\pi^0) = 0.031 \pm 0.013$

$\Delta A_{CP}(K\pi) = 0.115 \pm 0.014$ (8σ from zero)

V_{ub}/V_{cb} puzzle



❑ **Tension between inclusive and exclusive determinations**



- **Inclusive: high background**

  $|V_{ub}| = (4.25 \pm 0.30) \times 10^{-3}$

  $|V_{ub}/V_{cb}| = 0.102 \pm 0.007$

- **Exclusive: need LQCD inputs**

  $|V_{ub}| = (3.67 \pm 0.15) \times 10^{-3}$

  $|V_{ub}/V_{cb}| = 0.093 \pm 0.004$

- **$|V_{ub}/V_{cb}|$ in $\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu$ by LHCb**

$$\left|\frac{V_{ub}}{V_{cb}}\right| = 0.083 \pm 0.004 \pm 0.004$$

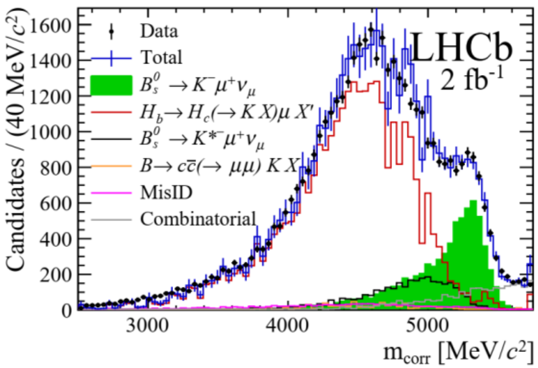
[Nature Physics 11 (2015) 743]

$\mathrm{V_{ub}/V_{cb}}$ in $B_s^0 \to K^-\mu^+\nu_\mu$

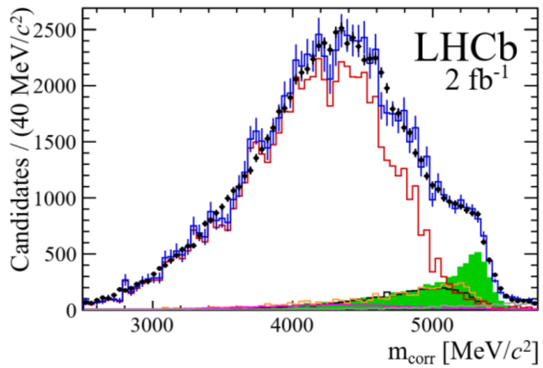
PRL 126 (2021) 081804

- Measure $\mathrm{R_{BF}} = \mathrm{BF}\left(B_s^0 \to K^-\mu^+\nu_\mu\right)/\mathrm{BF}\left(B_s^0 \to D_s^-\mu^+\nu_\mu\right)$

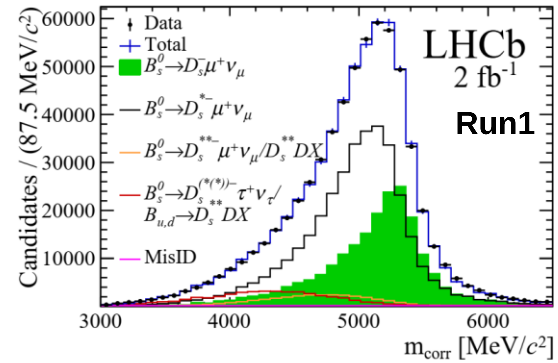
$B_s^0 \to K^-\mu^+\nu_\mu$ low q^2



$B_s^0 \to K^-\mu^+\nu_\mu$ high q^2



$B_s^0 \to D_s^-\mu^+\nu_\mu$



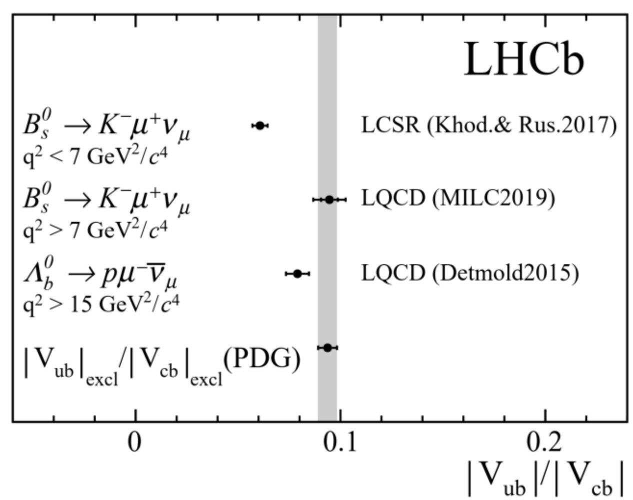
- Determine $|\mathrm{V_{ub}/V_{cb}}|$ through $\mathrm{R}_{BF} = |\mathrm{V_{ub}/V_{cb}}|^2\left(\mathrm{FF}_K/\mathrm{FF}_{D_s}\right)$

Low q^2: LCSR $\mathrm{FF}_K = 4.14 \pm 0.38\ \mathrm{ps}^{-1}$

$\left|\frac{\mathrm{V_{ub}}}{\mathrm{V_{cb}}}\right|$ (low) $= 0.061 \pm 0.004$

High q^2: LQCD $\mathrm{FF}_K = 3.32 \pm 0.46\ \mathrm{ps}^{-1}$

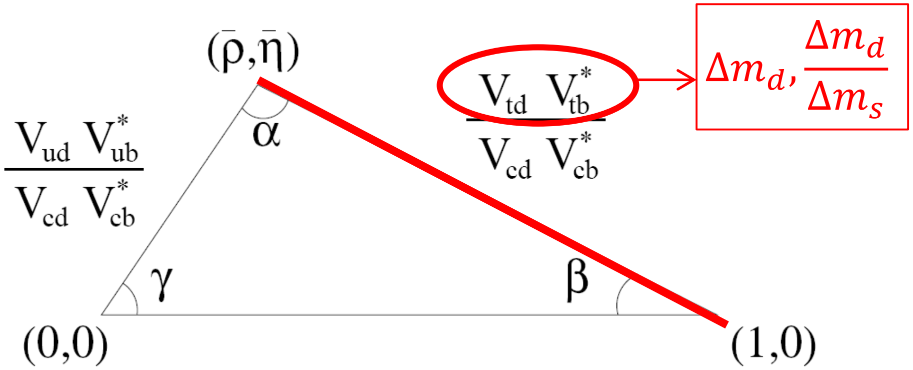
$\left|\frac{\mathrm{V_{ub}}}{\mathrm{V_{cb}}}\right|$ (high) $= 0.095 \pm 0.008$

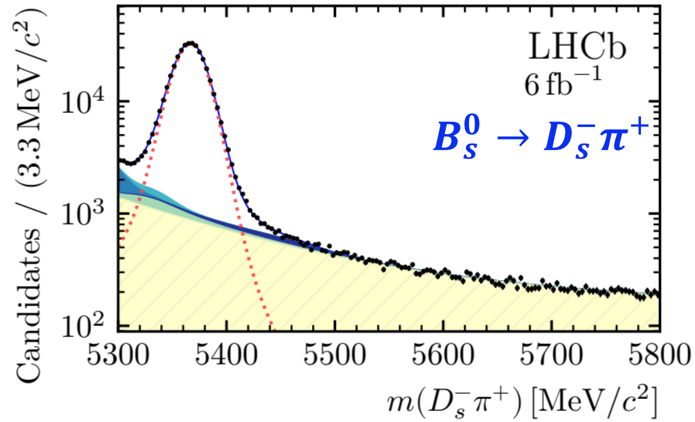


Consistent with other excl. measurements

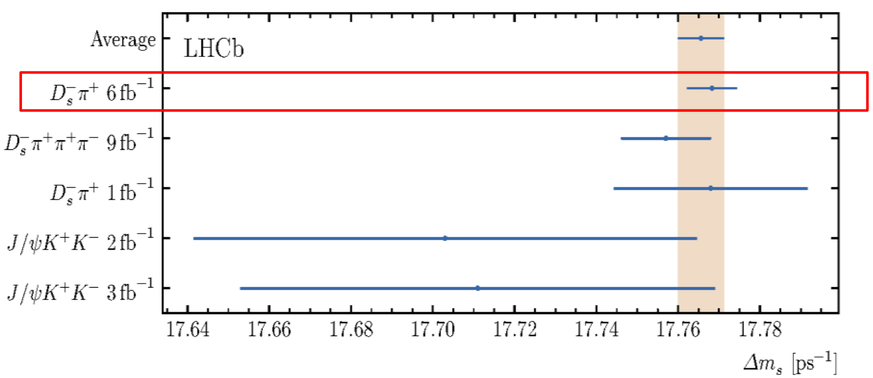
Improvement on Δm_s

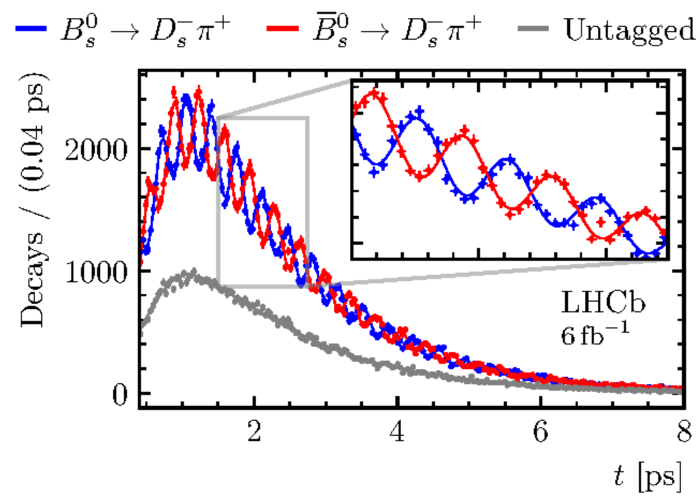
arXiv:2104.04421





- Run2 analysis of $B_s^0 \to D_s^- \pi^+$
- LHCb combination





$$\Delta m_s = 17.7656 \pm 0.0057\ \text{ps}^{-1}$$

SM prediction: $\Delta m_s = 18.4^{+0.7}_{-1.2}\ \text{ps}^{-1}$

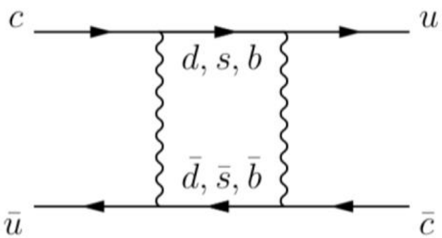
Luzio, Kirk, Lenz, JHEP 12 (2019) 009

$$P(t) \sim e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) \pm \cos(\Delta m_s t)\right]$$

Update on D^0-$\bar{D}^0$ mixing

arXiv:2106.03774

- D^0-$\bar{D}^0$ oscillation observed but mass difference poorly known

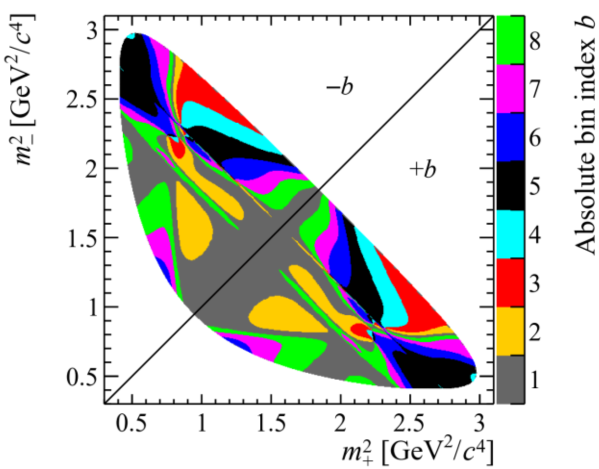


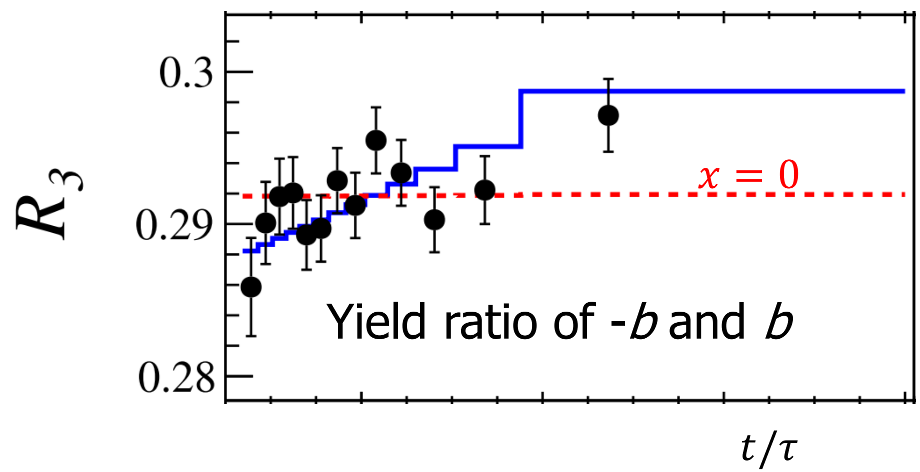
$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

$$y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} = (0.68^{+0.06}_{-0.07})\% \neq 0$$

$$x = \frac{m_1 - m_2}{\Gamma} = (0.37 \pm 0.12)\%$$

- Time-dependent Dalitz analysis of $D^0 \to K_S^0\pi^+\pi^-$ with Run 2 data





$x = (3.98^{+0.56}_{-0.54}) \times 10^{-3}$ $y = (4.6^{+1.5}_{-1.4}) \times 10^{-3}$

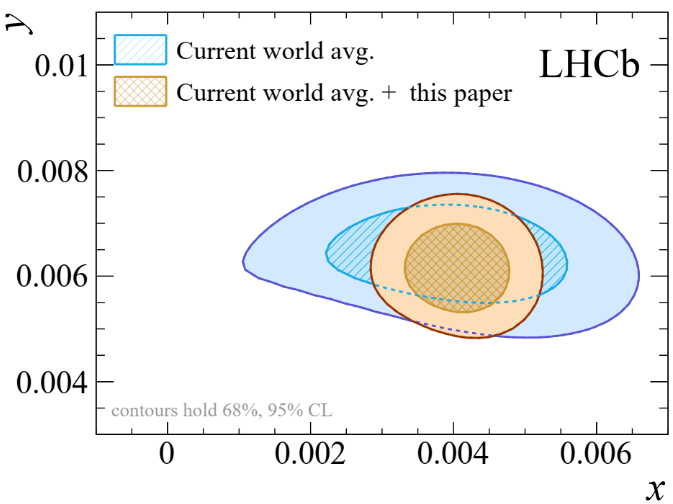
First observation of non-zero mass difference of D^0 mass eigenstates!

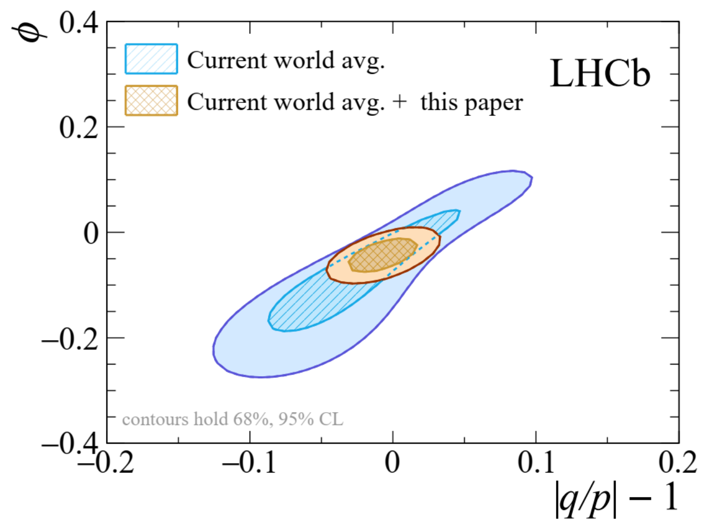
Updated D^0 parameters

arXiv:2106.03774

- Combination with $D^0 \to K^-\pi^+$ and $D^0 \to h^+h^-(h = K, \pi)$

$x\ [10^{-2}]$	$0.405\ ^{+0.049}_{-0.049}$	both non-zero
$y\ [10^{-2}]$	$0.613\ ^{+0.057}_{-0.055}$	
$\lvert q/p \rvert$	$0.993\ ^{+0.016}_{-0.016}$	consistent with CP symmetry
ϕ	$-0.042\ ^{+0.021}_{-0.022}$	



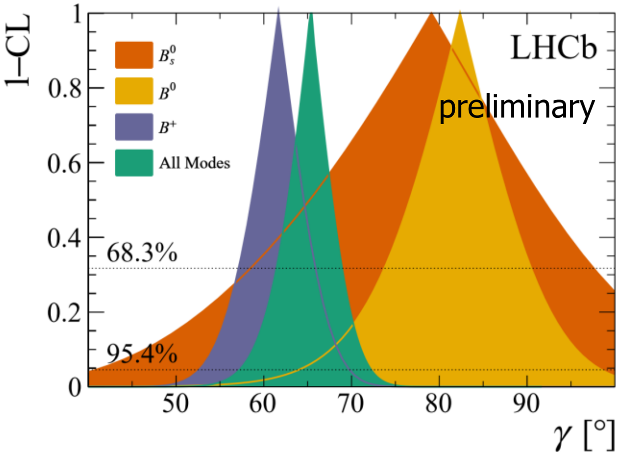


D^0 mixing and CP violation parameters improved significantly.

D^0-$\overline{D}^0$ parameters from a combination of beauty and charm measurements presented by Adam Davis in the Flavour session on 25/8

LHC: pushing the frontier

And significant improvements in γ, $\sin 2\beta$ …



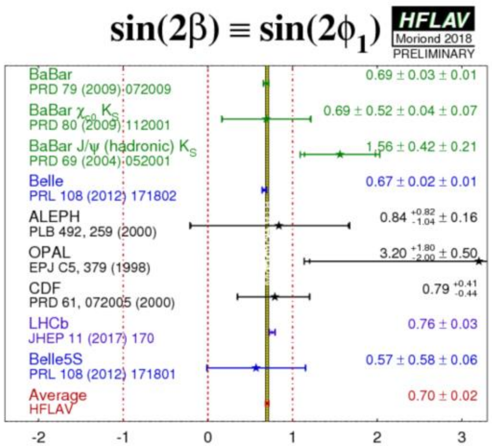
LHCb-CONF-2021-001

LHCb:

$\gamma = (65.4^{+3.8}_{-4.2})^{\circ}$

Previous WA:

$\gamma = (73.5^{+4.2}_{-5.1})^{\circ}$



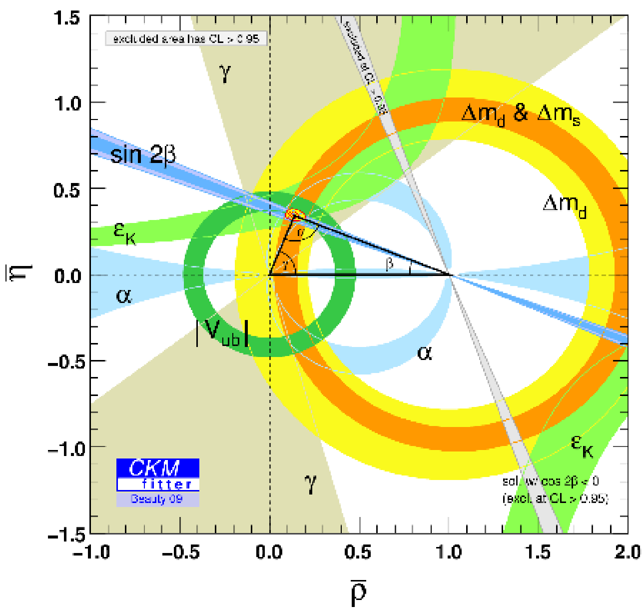
LHCb:

$\sin 2\beta = 0.76 \pm 0.03$

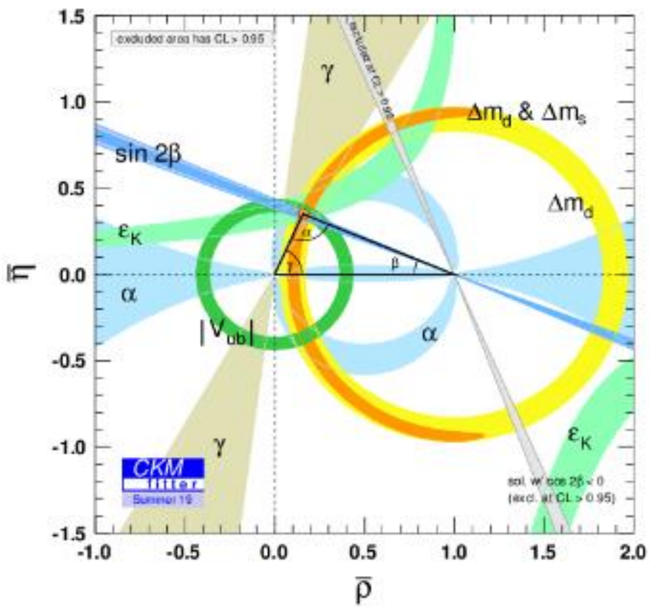
WA:

$\sin 2\beta = 0.70 \pm 0.02$

When LHC started



Current status



Rare decays

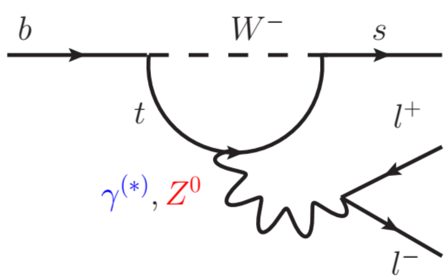
FCNC $b \to s l^+ l^-$ decays

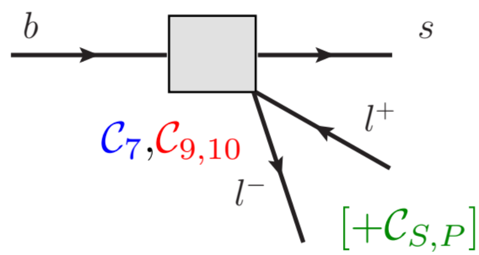
- **FCNC $b \to s l^+ l^-$ decays described by effective Hamiltonian**

$$H = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i \, O_i + \frac{K}{\Lambda_{NP}^2} O_j^{(6)}$$

New physics can affect Wilson coefficients C_i and/or add new operators O_j

- **Sensitivity to Wilson coefficients**

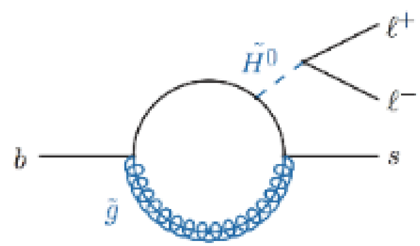


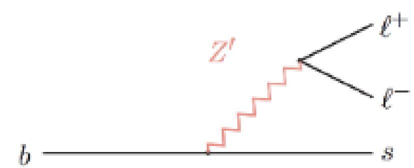


- $B^0_{(s)} \to l^+ l^-$
  $[\mathcal{C}_{10}, \mathcal{C}_S, \mathcal{C}_P]$
- $b \to s l^+ l^-$
  $[\mathcal{C}_7, \mathcal{C}_9, \mathcal{C}_{10}]$

7: photon penguin; 9,10: EW penguin; S,P: (pseudo-)scalar penguin

- **Theoretically clean probes of NP**
  - ✓ Pure leptonic decays
  - ✓ Special angular observables
  - ✓ Ratio between $e/\mu/\tau$

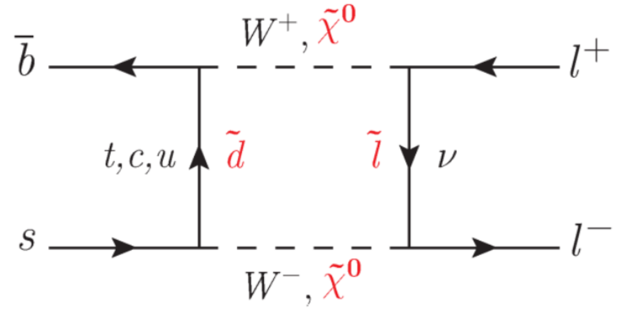




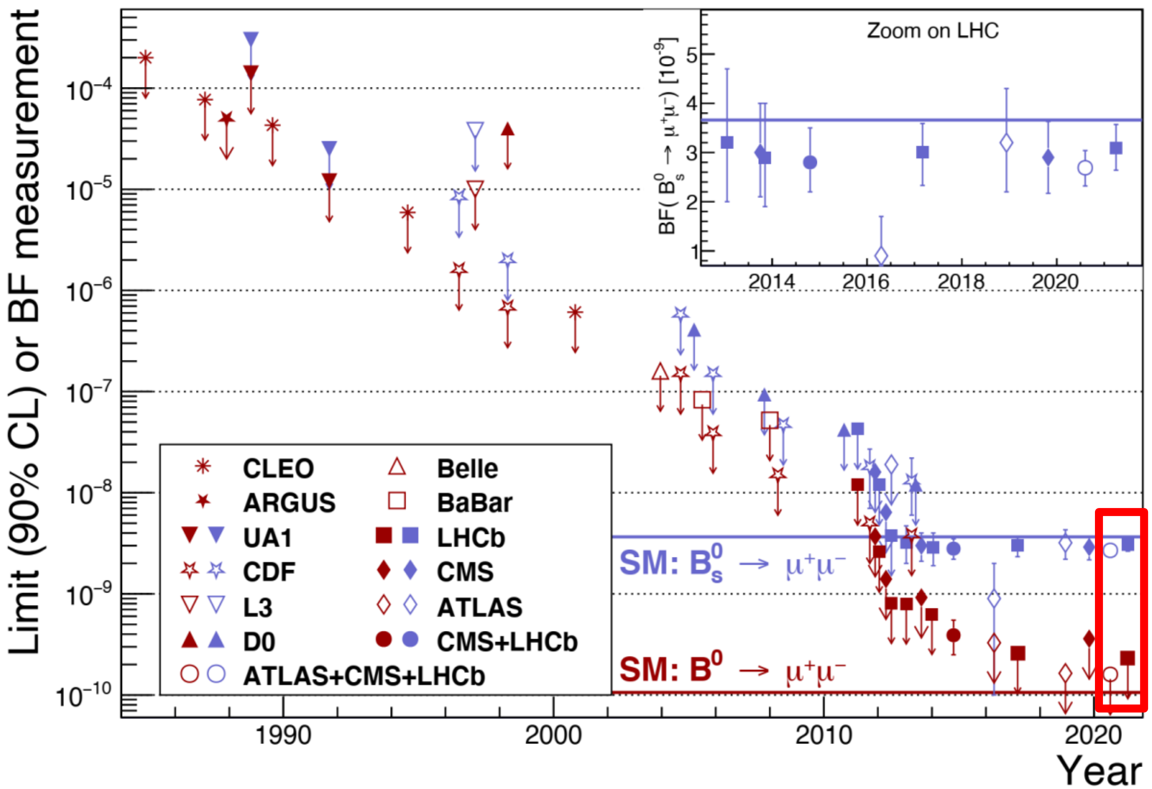
$B^0_{(s)} \to \mu^+\mu^-$

- Very rare, theoretically clean, with high sensitivity to NP Beneke, Bobeth, JHEP 10 (2019 232)

$$B^{SM}(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.14) \times 10^{-9}$$
$$B^{SM}(B^0 \to \mu^+\mu^-) = (1.03 \pm 0.05) \times 10^{-10}$$



- More than 30 years of pursuit



- LHC 2011-2016 combination
- **LHCb Run2 update**

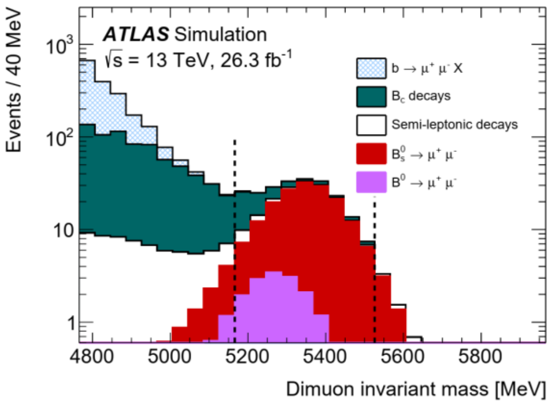
LHC combination of $B^0_{(s)} \to \mu^+\mu^-$

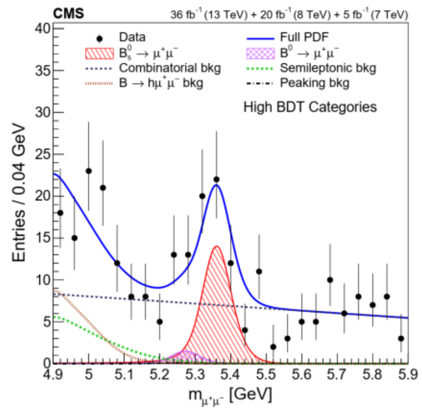
- ATLAS, CMS and LHCb results using 2011-2016 data

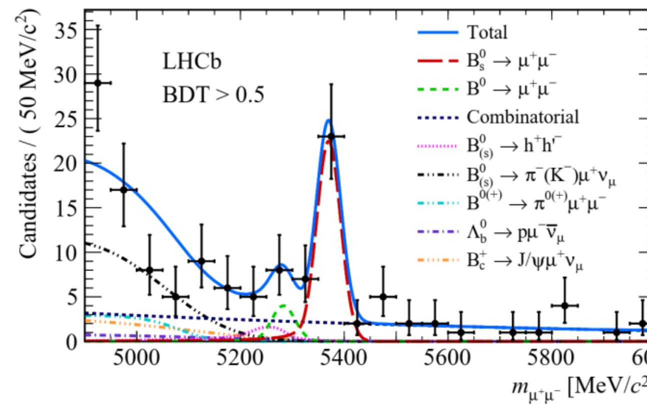
JHEP 04 (2019) 098

JHEP 04 (2020) 188

PRL 118 (2017) 191801



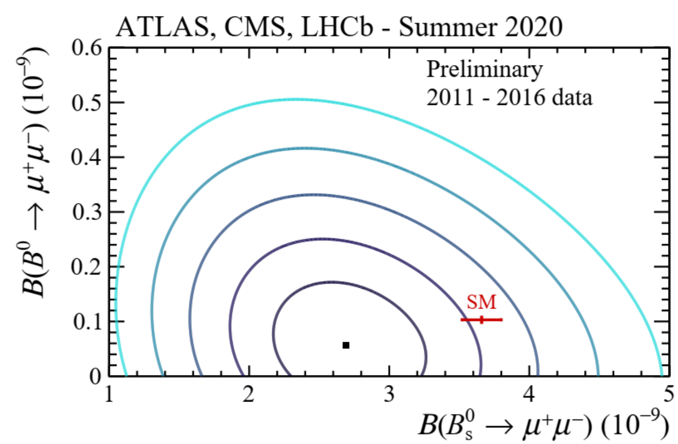




- Combination results consistent with SM at 2.1σ

LHCb-CONF-2020-002

	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$\mathcal{B}(B^0 \to \mu^+\mu^-)$
ATLAS	$(2.8^{+0.8}_{-0.7}) \times 10^{-9}$	$< 2.1 \times 10^{-10}$
CMS	$(2.9 \pm 0.7 \pm 0.2) \times 10^{-9}$	$< 3.6 \times 10^{-10}$
LHCb	$(3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$	$< 3.4 \times 10^{-10}$
Average	$(2.69^{+0.37}_{-0.35}) \times 10^{-9}$	$< 1.6 \times 10^{-9}$



Update on $B^0_{(s)} \to \mu^+\mu^-$

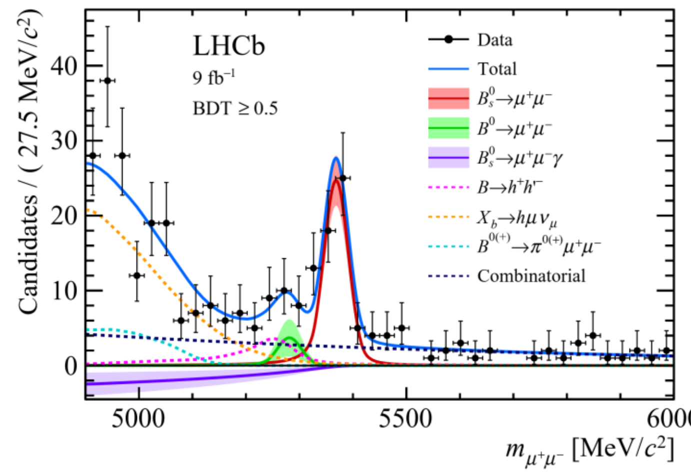
arXiv:2108.09283,
arXiv:2108.09284

❑ BF with full Run1+Run2 sample

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.09^{+0.46}_{-0.43}{}^{+0.15}_{-0.11}\right) \times 10^{-9}$$

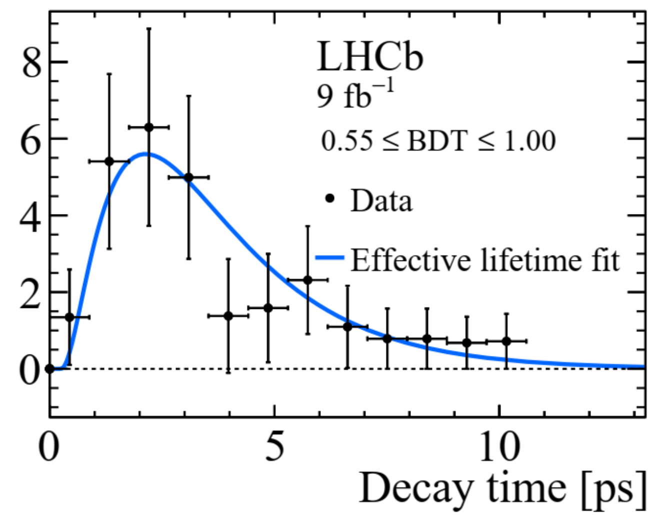
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10} \text{ @90\% CL}$$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-\gamma; m(\mu\mu) > 4.9 \text{ GeV}) < 2.0 \times 10^{-9}$$



❑ Effective lifetime

$$\tau^{\text{eff}}(B_s^0 \to \mu^+\mu^-) = 2.07 \pm 0.29 \pm 0.03 \text{ ps}$$

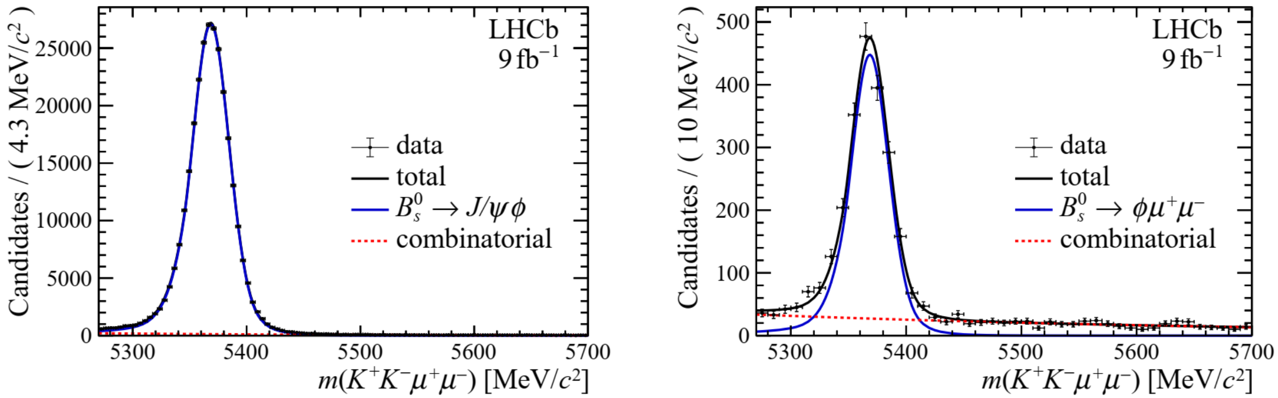


New results agree with previous results and SM predictions

$B_s^0 \to \phi\mu^+\mu^-$ BF update

arXiv: 2105.14007

- BF from Run 1+2 data, with $B_s^0 \to J/\psi\phi$ for normalization

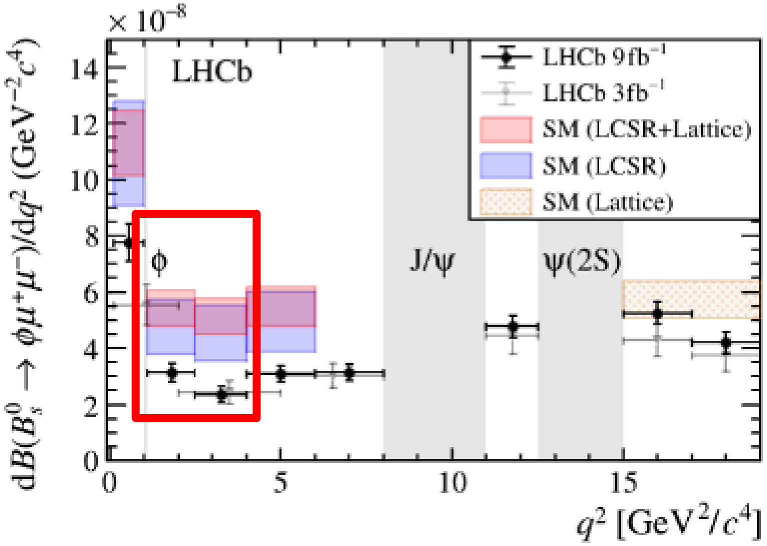


$$B(B_s^0 \to \phi\mu^+\mu^-) = (8.14 \pm 0.21 \pm 0.16 \pm 0.13 \pm 0.09 \pm 0.39) \times 10^{-7}$$

- Differential rate

$$1.1 < q^2 = m^2(\mu\mu) < 6.0\ \mathrm{GeV}^2:$$

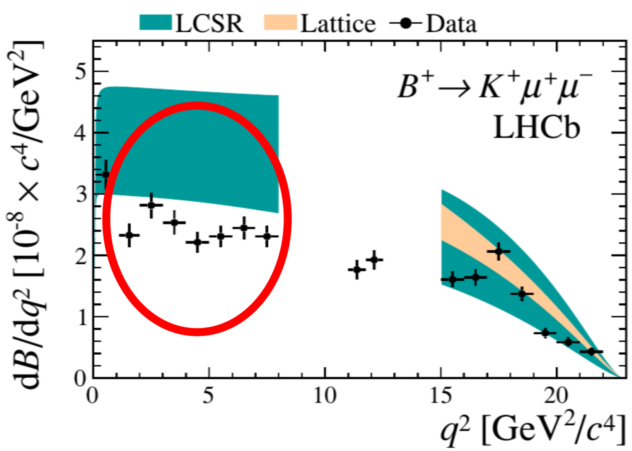
3.6σ below SM prediction based on LQCD+LCSR



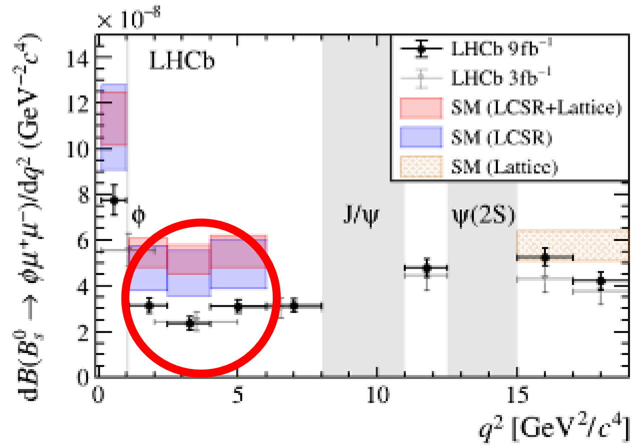
$b \to sl^+l^-$ branching fractions

- **Measured values consistently below SM predictions**
  Caveat: significant theory uncertainties from hadronic form factors

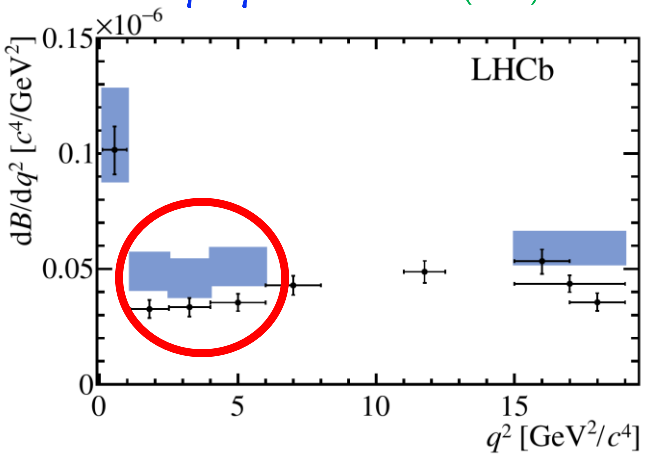
$B^+ \to K^+\mu^+\mu^-$ JHEP 06(2014)133



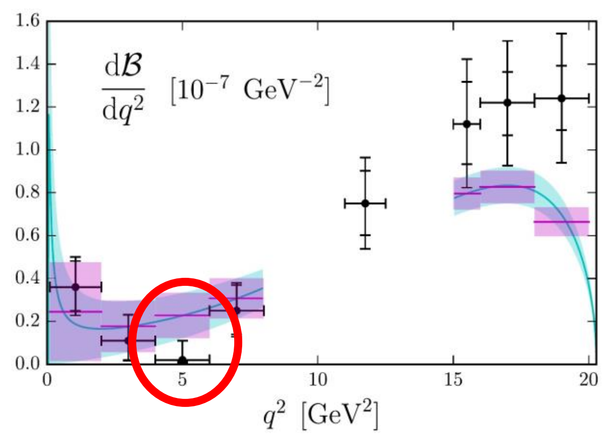
$B_s^0 \to \phi\mu^+\mu^-$ arXiv: 2105.14007



$B^0 \to K^{*0}\mu^+\mu^-$ JHEP 04(2017)142



$\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$ JHEP 06(2015)115



$B_s^0 \to \phi\mu^+\mu^-$ angular analysis

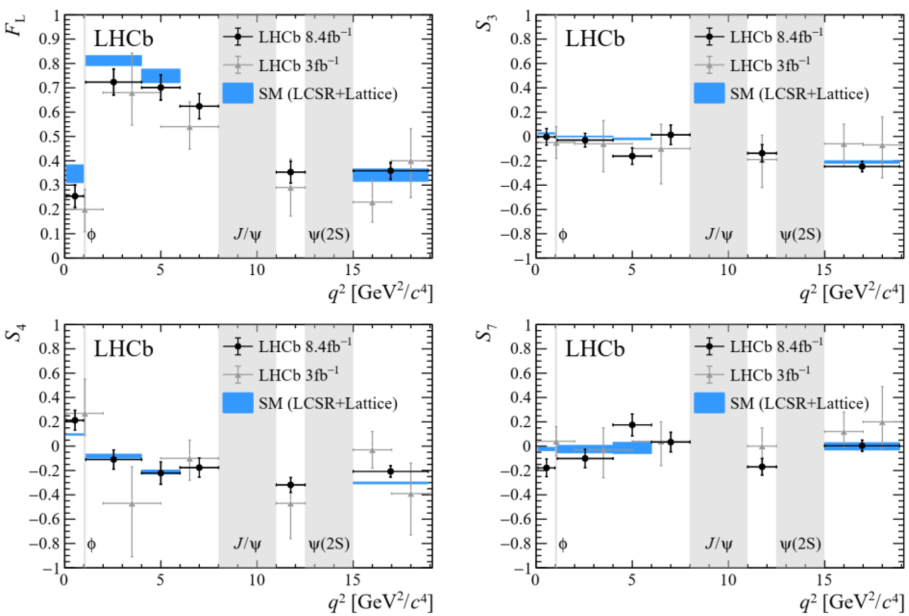
arXiv:2107.13428

- **Untagged angular observables**

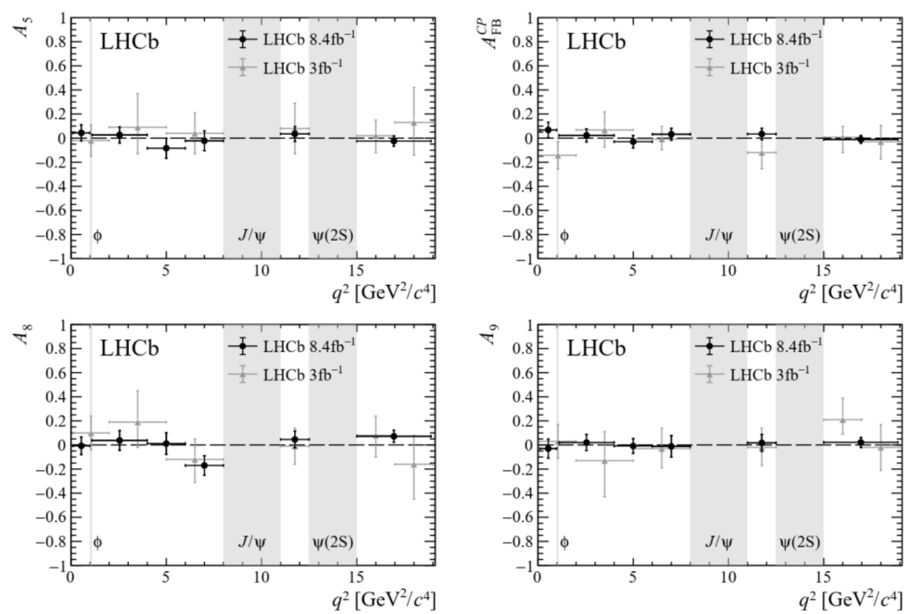
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_l\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K(1+\tfrac{1}{3}\cos 2\theta_l) + F_{\mathrm{L}}\cos^2\theta_K(1-\cos 2\theta_l) + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + A_5\sin 2\theta_K\sin\theta_l\cos\phi + \tfrac{4}{3}A_{\mathrm{FB}}^{CP}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi + A_8\sin 2\theta_K\sin 2\theta_l\sin\phi + A_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big],$$

- **Results in general consistent with SM expectations**

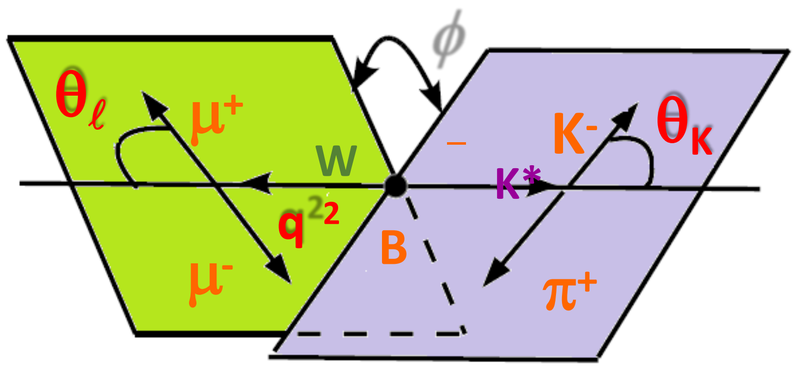
CP average: F_L, S_3, S_4, S_7



CP asymmetries: $A_{FB}^{CP}, A_5, A_8, A_9$



Angular analysis: $B^0 \to K^{*0}\mu^+\mu^-$



$$\frac{1}{\mathrm{d}(\Gamma+\bar\Gamma)/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar\Gamma)}{\mathrm{d}q^2\,\mathrm{d}\vec\Omega}\Big|_{\mathrm{P}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K$$
$$+\tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_l$$
$$-F_{\mathrm{L}}\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi$$
$$+\tfrac{4}{3}A_{\mathrm{FB}}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]$$

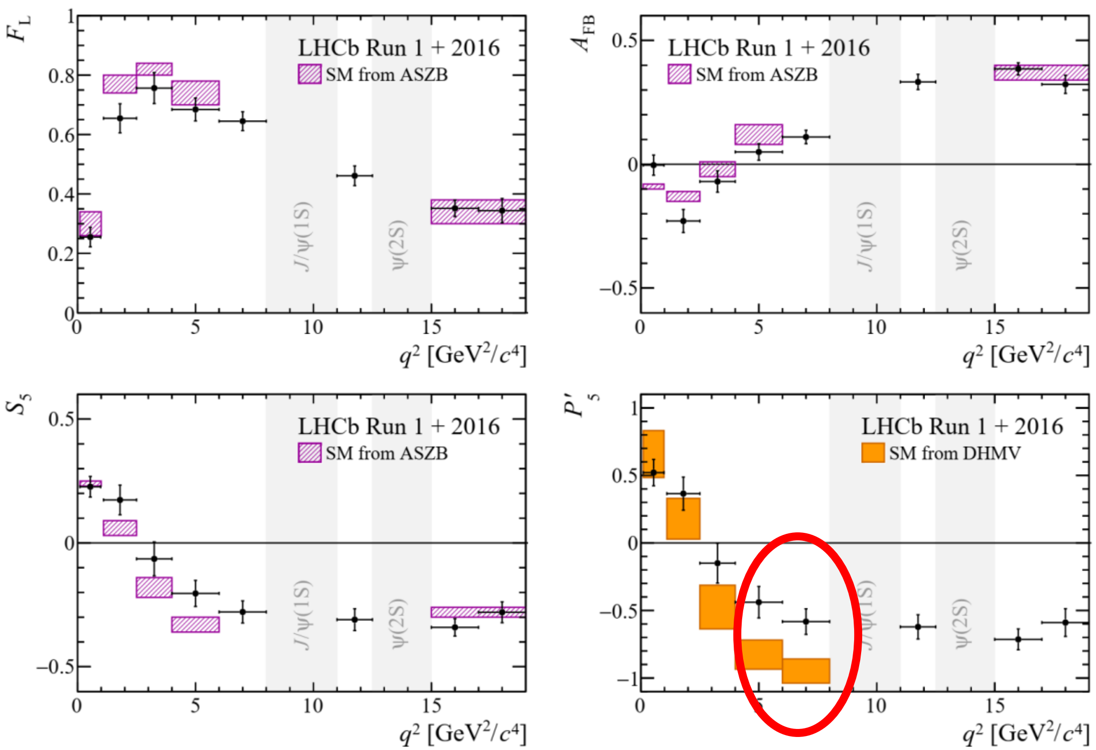
- **8 independent CP-averaged observables: F_L, A_{FB}, $S_{3,4,5,7,8,9}$**
- **Form factors cancel at leading order: $P'_i = S_i/\sqrt{F_L(1-F_L)}$**

Update on $B^0 \to K^{*0}\mu^+\mu^-$

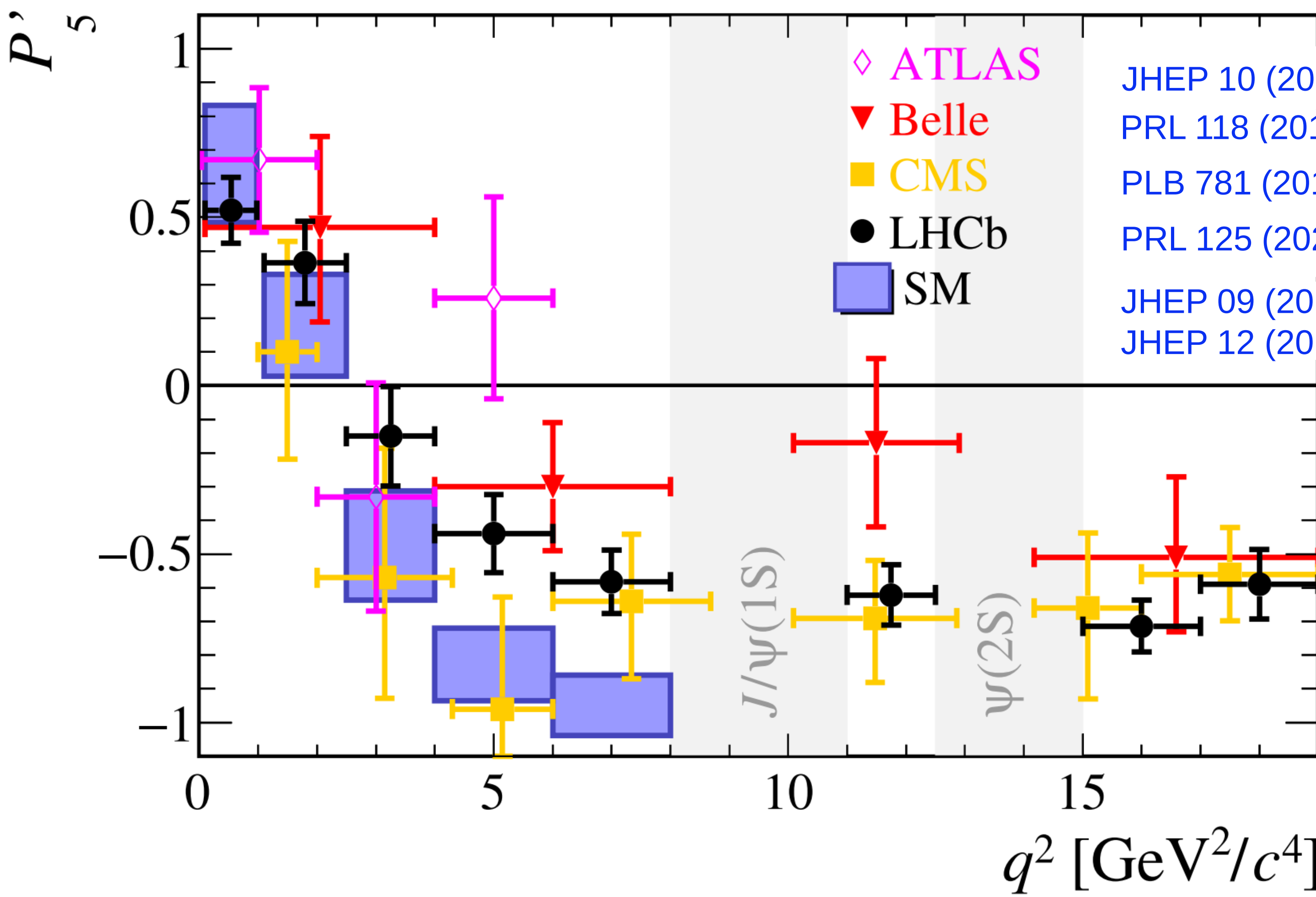
PRL 125 (2020) 011802

- Tension of P_5' with SM seen in Run 1 result persists with new data

	Run 1	Run1+2016
$4.0 < q^2 < 6.0\ \mathrm{GeV}^2$	2.8σ	2.5σ
$6.0 < q^2 < 8.0\ \mathrm{GeV}^2$	3.0σ	2.9σ



P'_5 comparison



JHEP 10 (2018) 047
PRL 118 (2017) 111801
PLB 781 (2018) 517
PRL 125 (2020) 011802
JHEP 09 (2010) 089
JHEP 12 (2014) 125

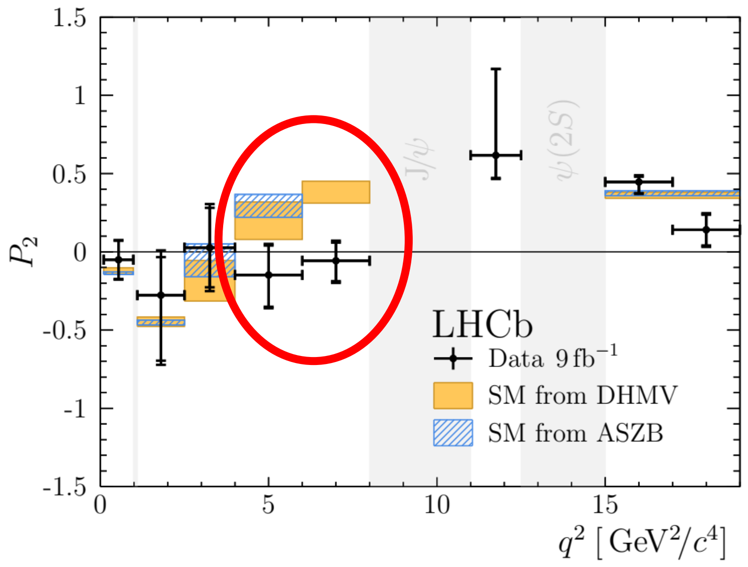
$B^+ \to K^{*+}\mu^+\mu^-$

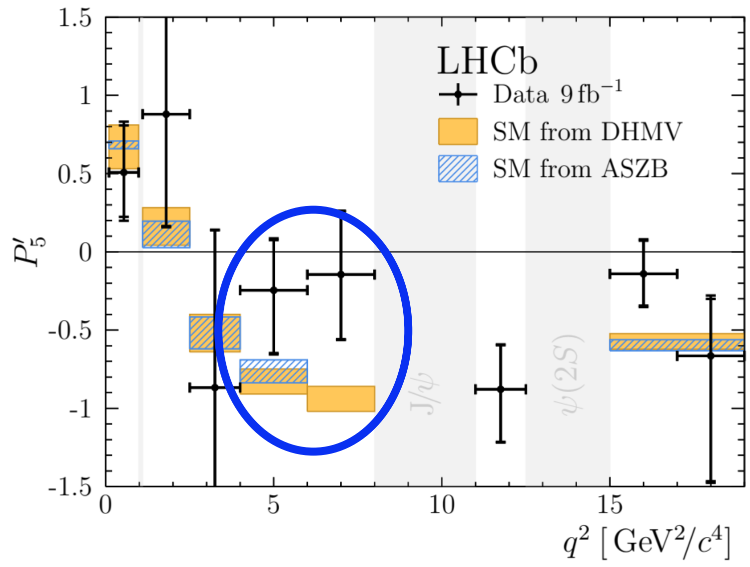
PRL 126 (2021) 161802

- **First analysis of $B^+ \to K^{*+}\mu^+\mu^-$ using full Run1+Run2 sample**

  P_5': pattern consistent with that seen in $B^0 \to K^{*0}\mu^+\mu^-$

  $P_2 = \frac{2}{3}A_{FB}/(1-F_L)$: tension of 3.0σ with SM in $6.0 < q^2 < 8.0\ \mathrm{GeV}^2$

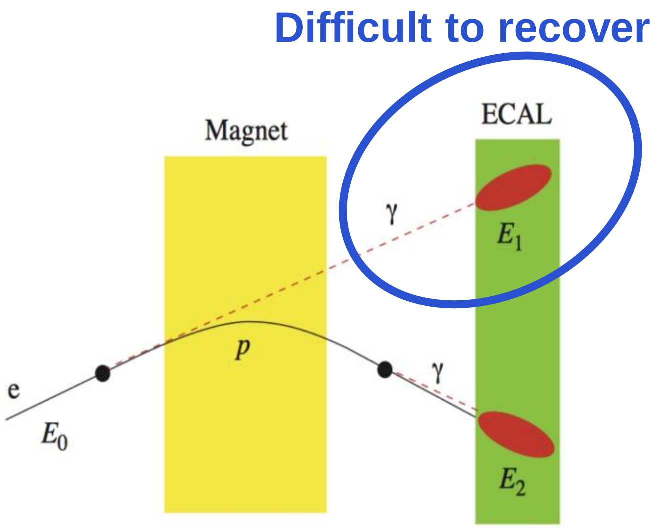




Lepton flavor universality test

$$R_{K^{(*)}} = \frac{B(B \to K^{(*)}\mu^+\mu^-)}{B(B \to K^{(*)}e^+e^-)} = \frac{B(B \to K^{(*)}\mu^+\mu^-)/B(B \to K^{(*)}J/\psi(\to \mu^+\mu^-))}{B(B \to K^{(*)}e^+e^-)/B(B \to K^{(*)}J/\psi(\to e^+e))}$$

- $R_{K^{(*)}} = 1.000 \pm 0.001$ **in the SM, with uncertainties related to form factors largely cancelled**
- **Experimental challenge: electron reconstruction**
- **Double ratio technique**



Electron Bremstrahlungs recovery

Update on R_K

- Previous result with Run1+2015+2016 sample — PRL 122 (2019) 191801

$$R_K(1.1 < q^2 < 6.0\ \mathrm{GeV}^2) = 0.846^{+0.060}_{-0.054}{}^{+0.016}_{-0.014}$$

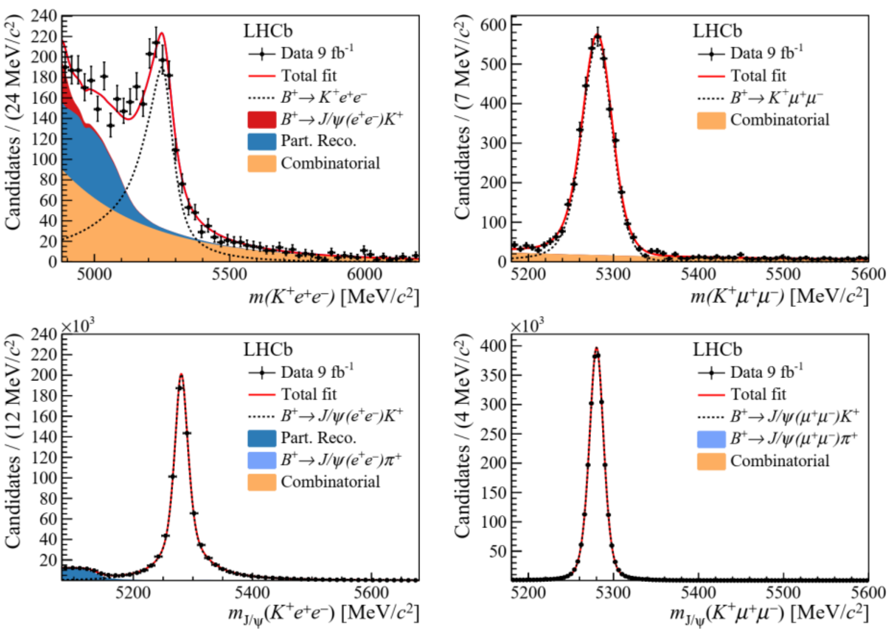
(2.5σ from SM)

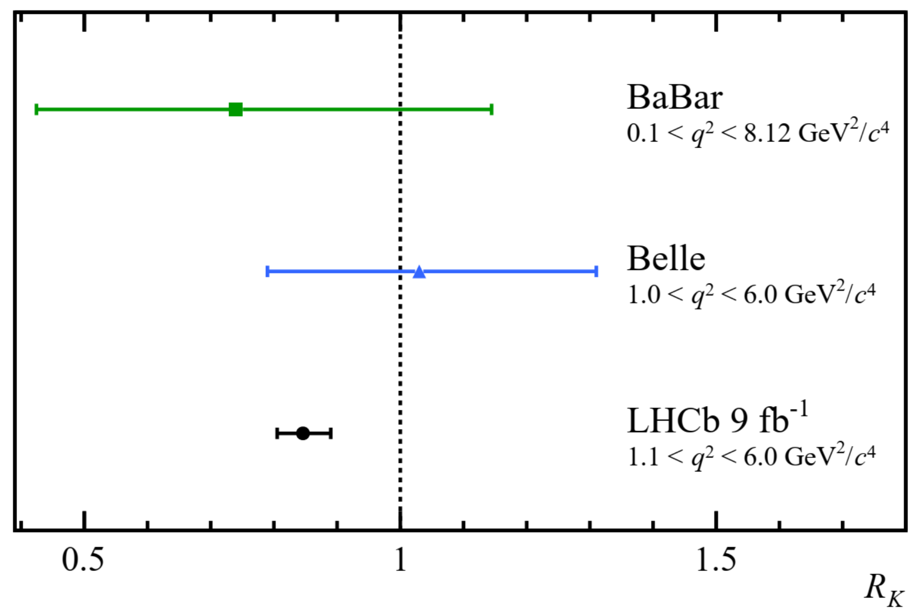
- New result with full Run1+Run2 sample

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

(3.1σ from SM)

arXiv:2105.14007





R_{pK} and R_{K^*}

- Test of LFU in $\Lambda_b^0 \to pK^- l^+ l^-$ with Run1+2016 data

$$R_{pK}(0.1 < q^2 < 6.0\ \text{GeV}^2) = 0.86^{+0.14}_{-0.11} \pm 0.05$$

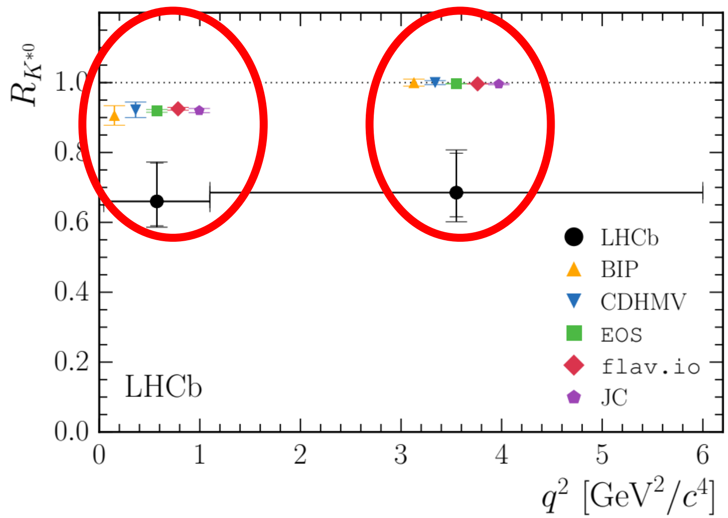
JHEP 05 (2020) 040

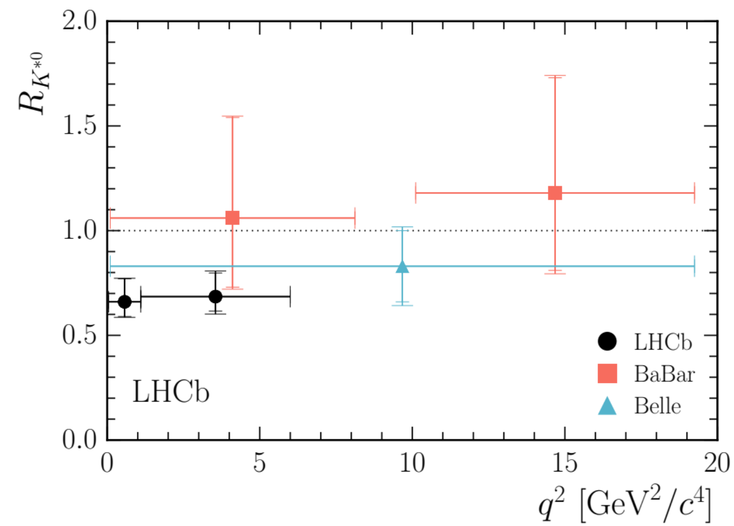
- Test of LFU in $B^0 \to K^{*0} l^+ l^-$ with Run1 data

JHEP 08 (2017) 055

$$R_{K^*}(0.045 < q^2 < 1.1\ \text{GeV}^2) = 0.66^{+0.11}_{-0.07} \pm 0.05$$ (2.1-2.3σ from SM)

$$R_{K^*}(1.1 < q^2 < 6.0\ \text{GeV}^2) = 0.69^{+0.11}_{-0.07} \pm 0.05$$ (2.4-2.5σ from SM)





Summary

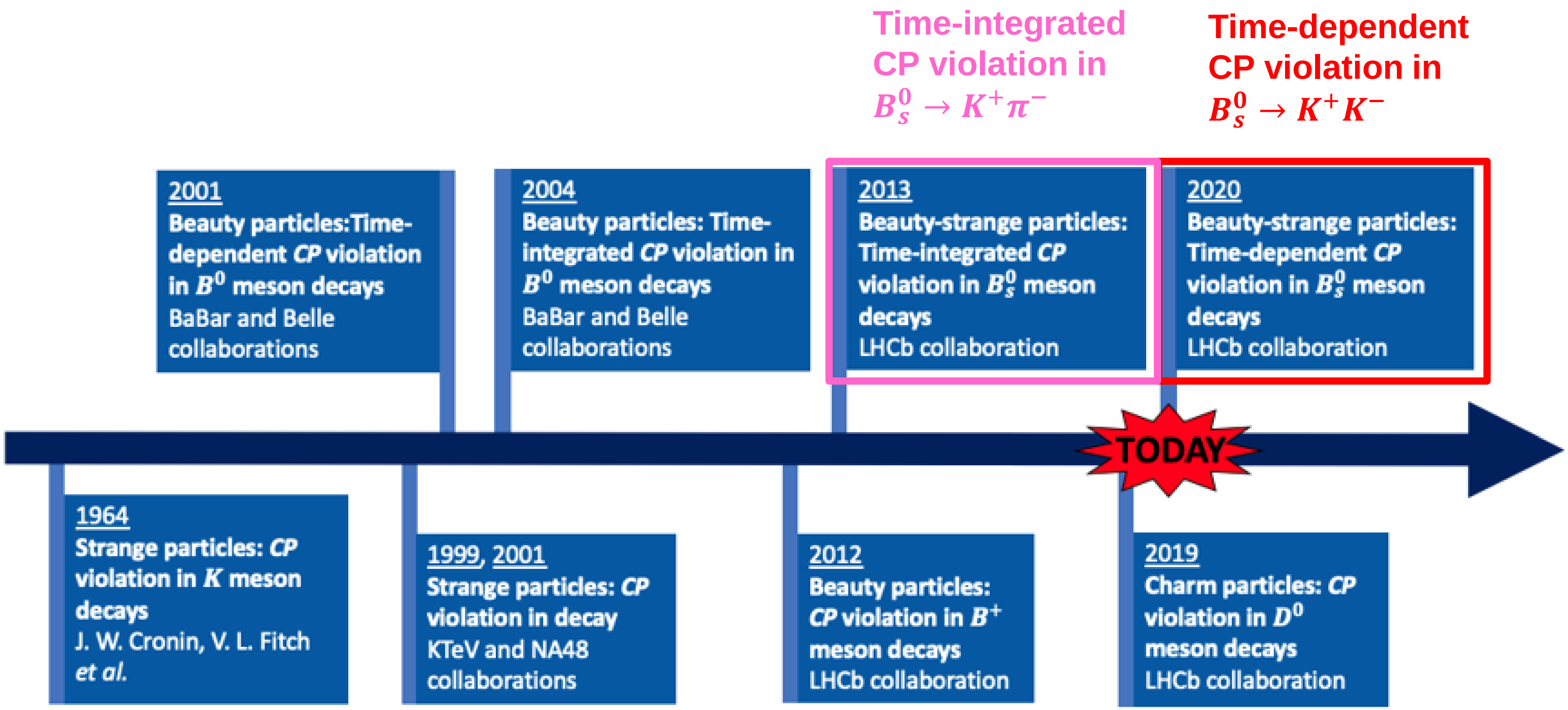
- CP violation in quark sector is measured with higher precision and broadly consistent with the CKM picture
  - Hint of leptonic CP violation at T2K experiment
- A few anomalies in $b \to s l^+ l^-$ transitions persist, **such as hints of LFUV, anomalous angular distributions**
  - Any connection with the anomaly in muon g-2?
- More results in the pipeline, and many interesting results not mentioned, **e.g. spectroscopy and production**
- Exciting opportunities expected with upgraded LHCb detector (50 fb^{-1}), its phase-2 upgrade (300 fb^{-1}), and ATLAS & CMS B physics programs at HL-LHC

Phase-II

31	32	33	34	35	36	37	39
LS4	Run 5			LS5	Run 6		
	L_{peak} $2\mathrm{x}10^{34} cm^{-2} s^{-1}$				L_{peak} $2\mathrm{x}10^{34}$		
					L_{int} ~300 fb^{-1}		

Backup slides

CP violation milestones



Search for $B^0_{(s)} \to e^+e^-$

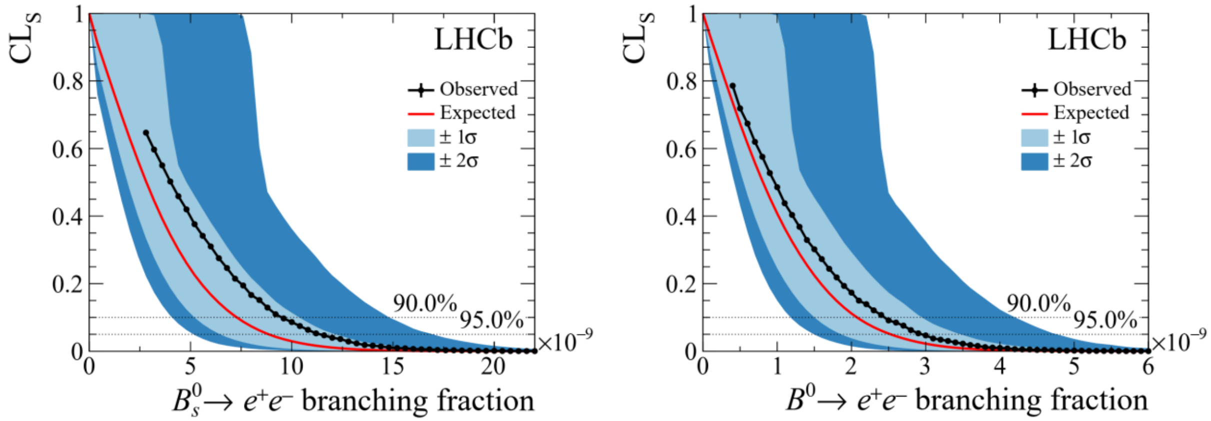
PRL 124 (2020) 211802

- **Extremely rare in the SM (helicity and CKM suppression)**

  $$\mathrm{B}(B_s^0 \to e^+e^-) = (8.60 \pm 0.36) \times 10^{-14},$$
  $$\mathrm{B}(B^0 \to e^+e^-) = (2.41 \pm 0.13) \times 10^{-15}$$

- **Could be enhanced to 10^{-8} and 10^{-10} by new physics**

- **LHCb limits @90% using 2011-2016 data**

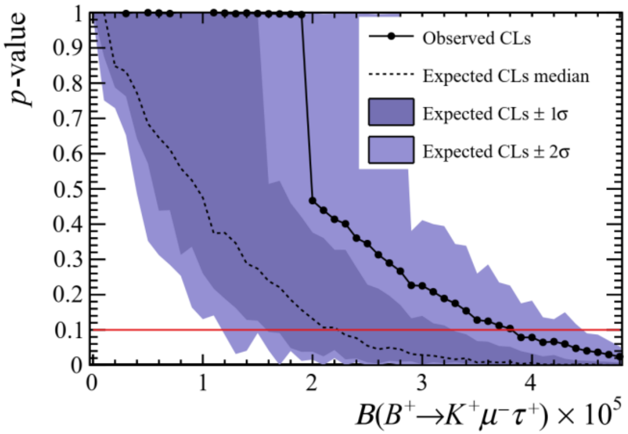


LHCb: $B(B_s^0 \to e^+e^-) < 9.4 \times 10^{-9},\ B(B^0 \to e^+e^-) < 2.5 \times 10^{-9}$

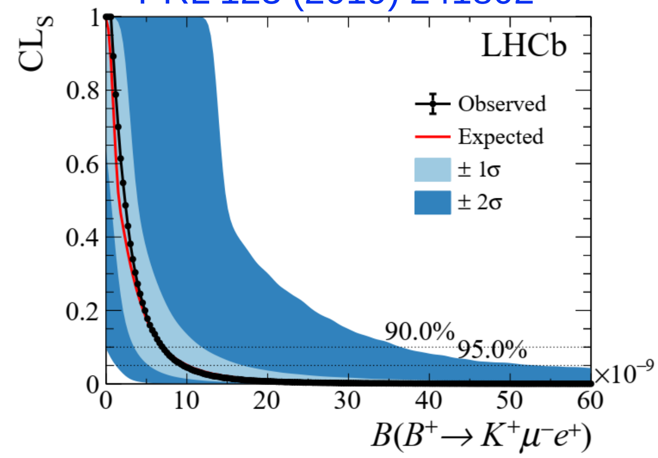
CDF: $\mathrm{B}(B_s^0 \to e^+e^-) < 2.8 \times 10^{-7},\ \mathrm{B}(B^0 \to e^+e^-) < 8.3 \times 10^{-8}$

Lepton flavour violation

JHEP 06 (2020) 129



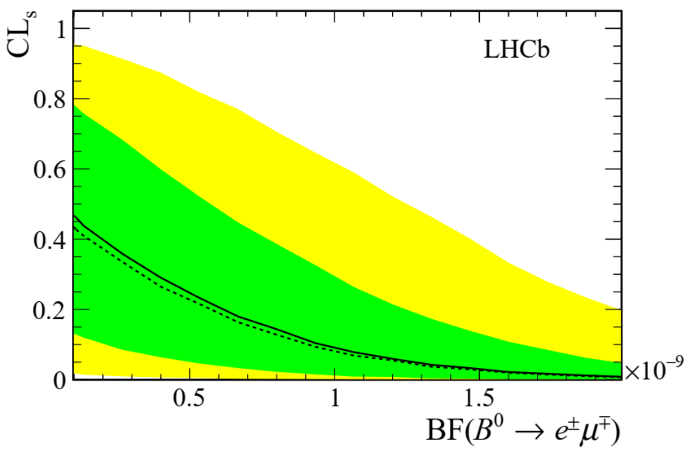
PRL 123 (2019) 241802

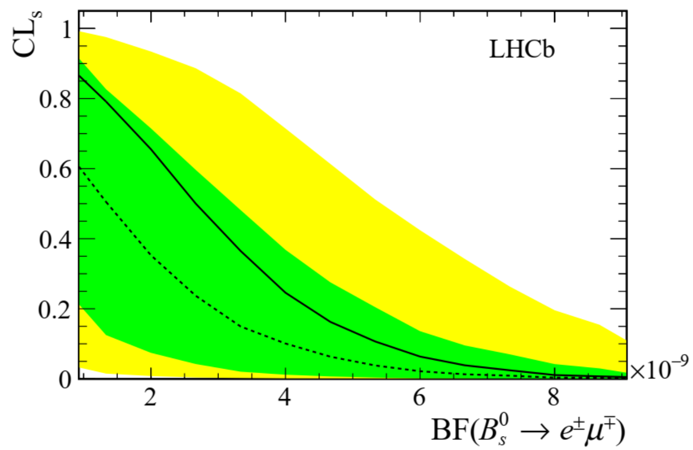


$\mathrm{B}(B^+ \to K^+\mu^+\tau^-) < 3.9 \times 10^{-5}$ @90%CL

$\mathrm{B}(B^+ \to K^+\mu^+\tau^-) < 7 \times 10^{-9}$ @70%CL

JHEP 03 (2017) 078

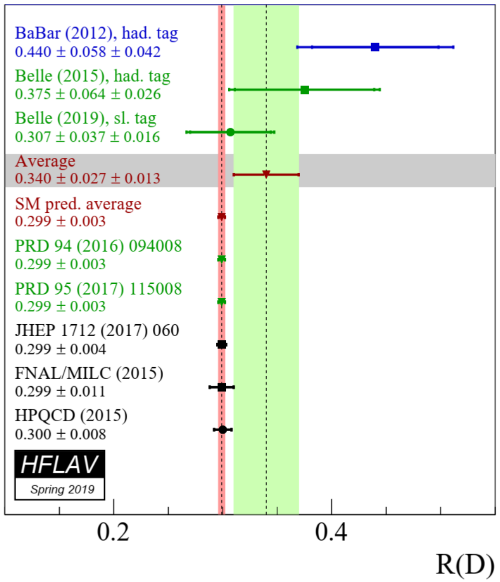


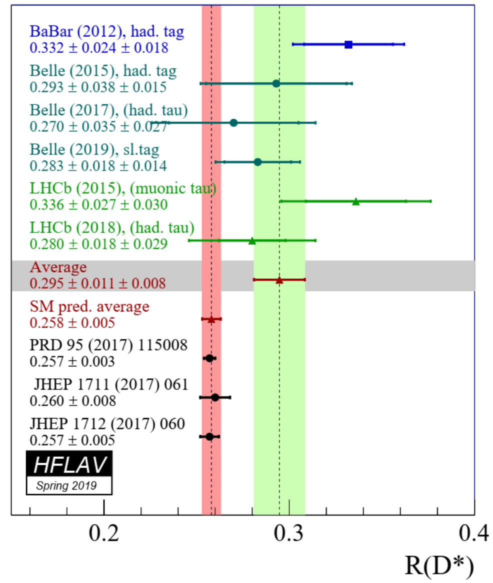


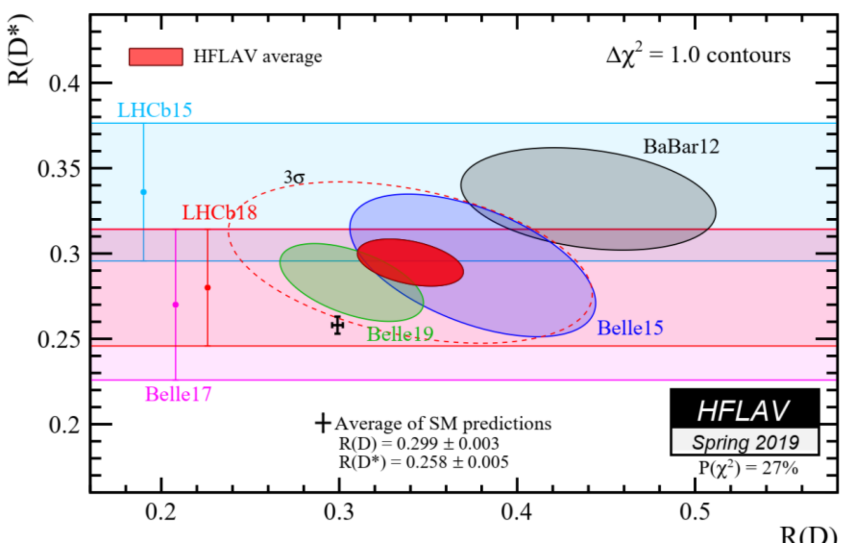
$\mathrm{B}\left(B^0 \to e^\pm\mu^\mp\right) < 3.9 \times 10^{-5}$ @90%CL

$\mathrm{B}\left(B_s^0 \to e^\pm\mu^\mp\right) < 6.0 \times 10^{-5}$ @90%CL

$$R_{D^{(*)}} = \frac{B(\bar{B}\to D^{*}\tau^{-}\bar{\nu}_{\tau})}{B(\bar{B}\to D^{*}l^{-}\bar{\nu}_{\tau})} \quad (l=\mu, e)$$







Overall tension of
3.1σ with SM